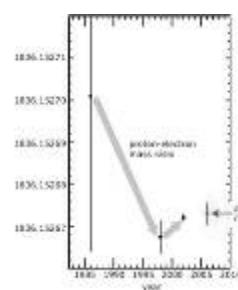
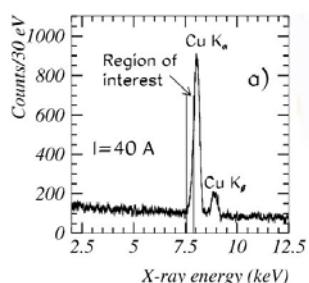


# ÖSTERREICHISCHE AKADEMIE DER WISSENSCHAFTEN

## JAHRESBERICHT 2006

### Stefan-Meyer-Institut (SMI) für subatomare Physik



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# 1 WISSENSCHAFTLICHE TÄTIGKEIT

## 1.1 Zusammenfassung des wissenschaftlichen Berichts 2006

In Jahr 2006 fanden zwei umfangreiche arbeitsintensive Strahlzeiten statt: die Messung der Röntgenlinie von pionischem Deuterium (piD) am PSI, und das erste Experiment von ASACUSA nach der Stilllegung des PS-Komplexes des CERN während des Jahres 2005. Das piD Experiment wurde erfolgreich zu Ende gebracht. Die Daten, die zusätzliche Randbedingungen für die Bestimmung der Pion-Nukleon-Streulängen liefern, werden von unseren Kollaborationspartnern in Jülich ausgewertet. Diese Strahlzeit markiert das Ende unserer Experimente mit pionischen Atomen am PSI. Die Analyse der im Jahr 2005 aufgenommenen Daten von pionischem Wassertoff findet am SMI statt und soll bis Ende 2007 abgeschlossen werden.

ASACUSA ist einer der drei Forschungsschwerpunkte des SMI. In der Strahlzeit im Jahr 2006 wurde eine erste Testmessung der Hyperfeinstruktur (HFS) von antiprotonischem Helium mit einem gepulst verstärkten cw-Laser durchgeführt. Trotz des verspäteten Starts des AD am CERN sowie dessen – im Vergleich zu früheren Jahren – schlechteren Strahleigenschaften, konnte die Messgenauigkeit bereits signifikant verbessert werden. Zusammen mit D. Bakalov aus Sofia durchgeführte Berechnungen der Sensitivität der beobachtbaren Übergänge auf das magnetische Moment  $\mu_p$  des Antiprotons zeigten, dass der bisher nur auf 0,3% genau bekannte Wert von  $\mu_p$  in einer vierwöchigen Messung im Jahr 2007 um einen Faktor 3 verbessert werden kann. Die Messung der HFS eines anderen Zustandes von antiprotonischem Helium ermöglicht eine weitere Verbesserung um einen Faktor 3 in einer zukünftigen Messung.

In derselben Strahlzeit konnte auch erstmals ein Zwei-Photonen Laserübergang beobachtet werden. Im Gegensatz zu Ein-Photonen Übergängen zeigen diese keine Dopplerverbreiterung und versprechen deshalb eine höhere Genauigkeit.

Im Jahr 2006 konnte die Auswertung früherer Daten von Kollaborationspartnern am CERN abgeschlossen werden, und ein Wert für das Massenverhältnis Antiproton zu Elektron mit einer Genauigkeit von  $3 \times 10^{-9}$  konnte in Physical Review Letters veröffentlicht werden. Daraus konnte ein Test der CPT-Symmetrie mit entsprechender Genauigkeit gewonnen werden.

Ebenfalls früher aufgenommene Daten zum Stoßverhalten von antiprotonischen Helium mit Deuterium wurden am SMI ausgewertet und in Chemical Physics Letters veröffentlicht. Die gemessenen Stoßquerschnitte können als Fallbeispiel für chemische Reaktionen bei tiefen Temperaturen betrachtet werden.

Langfristig plant die ASACUSA Kollaboration die Messung der Grundzustands-Hyperfeinaufspaltung (HFS) von Antiwasserstoff. Dies verspricht einen noch genaueren Test der CPT-Symmetrie, da die entsprechende Größe für Wasserstoff auf  $10^{-12}$  genau gemessen wurde. Fortschritte wurden bei der Entwicklung von zwei Fallen zur Bildung von Antiwasserstoff aus Antiprotonen und Positronen erzielt, so dass die Entwicklung der Nachweisapparatur – die in der Verantwortung des SMI liegt – intensiviert werden muss.

In einem der beiden anderen Forschungsschwerpunkte des SMI, dem Studium der Kaon-Nukleon-Wechselwirkung, ist das SIDDHARTA Projekt am weitesten fortgeschritten. Die neuen Röntgendetektoren (Silizium-Drift-Detektoren) werden am SMI getestet und charakterisiert, wobei das Ziel ist, während des Sommers 2007 einen Teil der Detektoren am LNF (Frascati) zu installieren und damit einen ersten Test im Strahl in diesem Herbst durchzuführen. Die Datenaufnahme von kaonischem Wasserstoff und erstmals kaonischem Deuterium ist für 2008 und 2009 geplant. Die Scientific Community erwartet gespannt die Resultate dieser Messungen.

Die Suche nach tiefgebundenen Zuständen von Kaonen in leichten Kernen, die auf eine Voraussage von Akaishi und Yamazaki zurückgeht, wird zuerst mit Proton-Proton-Stößen am FOPI-Experiment an der GSI Darmstadt untersucht werden. Die am SMI durchgeführte Analyse eines früheren Experiments mit Proton-Deuterium-Stößen ergab, dass Proton-Proton-Stöße bessere Möglichkeiten bieten, das einfachste Kaon-Cluster  $K^-pp$  nachzuweisen. Im Moment wird ein Experimentiervorschlag an die GSI vorbereitet, wobei es sich herausstellte, dass ein zusätzlicher Vorwärtsdetektor in FOPI installiert werden muss.

Längerfristig beteiligt sich das SMI in einem Experiment an J-PARC in Japan zur Messung des 3d-2p Röntgenübergangs in kaonischem  ${}^3He$ , und dem AMADEUS Projekt am LNF, welches ursprünglich von SMI zusammen mit der Gruppe von C. Guaraldo vom LNF vorgeschlagen wurde. AMADEUS wird den leicht veränderten KLOE-Detektor, sowie den bereits für SIDDHARTA erwarteten Luminositätsupgrade des DAΦNE  $e^+e^-$  Colliders des LNF nützen. Erstmals sollen total inklusive Messungen (d.h. sowohl die Bildung als auch der Zerfall) an in Gastargets niederer Dichte gestoppten Kaon-Cluster durchgeführt werden.

VIP, ein kleineres Projekt des SMI, untersucht die mögliche Verletzung des Pauli-Prinzips. Hierzu wird versucht, charakteristische Röntgenstrahlen von Kupfer zu beobachten, deren Energie durch die Anwesenheit eines dritten Elektrons im Grundzustand verschoben wäre. Während ersten Testmessungen am LNF konnte der frühere Grenzwert bereits um zwei Größenordnungen verbessert werden. Dies wurde in Physics Letters B veröffentlicht. Das Experiment wurde zwischenzeitlich im Laboratori Nazionale di Gran Sasso aufgebaut, um Untergrund durch die kosmische Höhenstrahlung zu verringern. Es wird dort für etwa zwei Jahre betrieben werden, so dass eine weitere substantielle Verbesserung des Resultats erwartet werden kann.

Der dritte Forschungsschwerpunkt des SMI bezieht sich auf Experimente mit Antiprotonen an der geplanten FAIR Anlage in Darmstadt. Hierzu werden ein Cluster Jet Target sowie neuartige Photodetektoren für Cerenkovzähler als Teil von EU FP6 Projekten am SMI entwickelt. Neue Anträge für Designstudien im 7. Rahmenprogramm werden für FLAIR – wobei SMI die Rolle des Koordinators übernimmt – und das AIC Projekt vorbereitet.

## 1.2 Summary of scientific report 2006

In 2006 two long beam times took place, which needed substantial manpower: the measurement of the X-rays of pionic deuterium (piD) at PSI, and the first ASACUSA beam time at CERN-AD after the shutdown of the CERN PS complex in 2005. The piD beam time was successfully executed. The data, which will give additional constraints for the extraction of the pion-nucleon scattering length, will be analyzed by our collaboration partners in Jülich. This beam time marks the end of our involvement in pionic atom experiments at PSI. The analysis of the pionic hydrogen data taken in 2005 is still going on at SMI and will be finished during 2007.

ASACUSA is one of three main scientific programs of SMI. In the beam time 2006 a first test measurement of the hyperfine structure (HFS) of antiprotonic helium was done with a new pulse-amplified laser system. In spite of the late start and weak performance of the AD – compared to previous years – a substantial improvement of the accuracy over an earlier measurement could be achieved. Recent theoretical investigations together with D. Bakalov (Sofia) of the sensitivity of the observable transitions in antiprotonic helium on the magnetic moment  $\mu_p$  of the antiproton show that an improvement of  $\mu_p$  by a factor 3 over the currently known value (accuracy 0.3%) will be possible in four weeks of beam time planned for 2007. By measuring the HFS of another state of antiprotonic helium, a further improvement of a factor 3 will be possible in a future run.

During the same beam time, a first signal of a two-photon transition in antiprotonic helium was observed. Other than the single-photon transitions used so far, two-photon transitions are not susceptible to the Doppler effect and thus promise higher resolution.

In 2006, the analysis of laser spectroscopy data taken in 2004 was finished by collaborators at CERN and a first determination of the antiproton-to-electron mass ratio with an error of  $3 \times 10^{-9}$  was published in Physical Review Letters, in agreement with the corresponding value of the proton. Thus, a CPT test on the equality of the antiproton charge and mass of similar precision was obtained.

Data taken earlier on the collisional interaction of antiprotonic helium with deuterium admixtures, which can be used as a case study of chemical reactions at low temperatures, were analyzed at SMI and published in Chemical Physics Letters.

The long-term program of ASACUSA consists of a measurement of the hyperfine structure of antihydrogen, which promises a test of CPT of even higher precision as the HFS of hydrogen is known to a precision of  $10^{-12}$ . Progress has been achieved in the two optional trap setups to form antihydrogen from antiprotons and positrons, and the development of a spectrometer line to measure the antihydrogen HFS – which is the task of SMI – will be intensified in 2007.

Within one of the two other medium term research programs of SMI, the study of the Kaon-Nucleon-Interaction, SIDDHARTA is the most advanced. The test and characterization of silicon drift detectors is going on at SMI, with the goal to install a first subset of the full experimental setup at LNF Frascati during summer 2007 and to start a first beam test in this fall. Data taking is foreseen in 2008 and maybe 2009 on kaonic hydrogen and, for the first time, on kaonic deuterium. Both results are eagerly awaited by the scientific community.

The search for deeply bound kaonic states in light nuclei following the prediction by Akaishi and Yamazaki will first be studied with proton-proton collision in the FOPI experiment at GSI. A test experiment using a proton-deuterium reaction was analyzed at SMI and it was concluded, that proton-proton interactions will offer a better chance to detect the simplest kaonic cluster K-pp. Currently a proposal to GSI is prepared, and it became clear, that an additional forward detector has to be installed inside FOPI.

As long-term projects, SMI is participating in an experiment at J-PARC (Japan) to measure the 3d-2p X-ray transition in kaonic  $^3\text{He}$ , and the AMADEUS project at LNF Frascati which was ini-

tially proposed jointly by SMI and the LNF group around Carlo Guaraldo. AMADEUS makes use of the slightly modified KLOE detector and an increase of the luminosity of the DAΦNE e<sup>+</sup>e<sup>-</sup> collider at LNF, which is already expected to be available for SIDDHARTA. AMADEUS wants to measure – for the first time in a totally inclusive measurement – both the formation and decay of kaonic clusters by stopping kaons in low density gas targets.

Among the smaller projects of SMI is the test of the violation of the Pauli principle (VIP) by trying to observe characteristic X-rays from copper targets, which would be shifted in energy due to the presence of a third electron in the 1s state. During first tests in the laboratory at LNF already the previous limit could be improved by two orders of magnitude, which was published in Physics Letters B. The experiment is now installed in Laboratori Nazionali di Gran Sasso to reduce the background from cosmic rays and will run for the next two years, expecting a further substantial improvement.

The third main scientific program of SMI relates to antiprotons at the planned FAIR facility in Darmstadt. The development of a cluster jet target for PANDA as well as developments of novel APD detectors for Cerenkov counters are going on as a part of the EU FP6 project I3 Hadron Physics. New design study applications in FP7 are currently being prepared for FLAIR – where SMI will be a coordinator – and AIC.

## 1.3 Scientific report 2006

The research activity of our institute is divided into three main research topics and their sub-projects. In the following a brief and concise overview is given. A chart of the scientific program for the years 2006 – 2012 can be found on the next page (Fig. 1).

### ➤ FS1\_A: Kaon-Nucleon Interaction: Kaonic atoms and kaonic nuclei

- FS1\_b\_A: Kaonic hydrogen and deuterium: SIDDHARTA
  - FS1\_b\_b: SIDDHARTA: Joint Research Activity 10 in I3 Hadron Physics
- FS1\_c: Deeply bound kaonic nuclei with FOPI at GSI
- FS1\_d: AMADEUS at DAΦNE2
- FS1\_e: Deeply bound kaonic nuclei K-ppn and K-pnn: Experiment E549 at KEK
- FS1\_f: Kaonic helium X-rays: Experiment E570 at KEK
- FS1\_g: Study of kaon-nucleon interaction @ J-PARC
- FS1\_h Theoretical Studies of Low Energy QCD, Investigated with Exotic Atoms

### ➤ FS2\_A: Matter - antimatter symmetry: ASACUSA @ CERN

- FS2\_b: Hyperfine structure of antiprotonic helium
- FS2\_c: Precision laser spectroscopy of antiprotonic helium
- FS2\_d: Measurement of the ground-state hyperfine structure of antihydrogen

### ➤ FS3\_A: Antiprotons at FAIR

- FS3\_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research
- FS3\_c\_A: PANDA: Proton Antiproton Annihilations at Darmstadt
  - FS3\_c\_b: Internal target system for PANDA: Joint Research Activity 7 in I3 Hadron Physics
  - FS3\_c\_c: Cherenkov Imaging Detectors (DIRACSecondary beams)
  - FS3\_c\_d: Development and tests of novel matrix avalanche photo detectors for PANDA
- FS3\_d: Antiproton Ion Collider

### ➤ Sonstige Forschungsprojekte

- Pion-Nucleon Interaction
- Röntgenspektroskopie an der VERA – Beschleunigeranlage (PIXE)
- SUNS - Spallation Ultra Cold Neutron Source at PSI, Source Development
- VIP @ Gran Sasso (Violation of the Pauli Exclusion Principle Experiment)



### 1.3.1 FS1\_A: Kaon-Nucleon Interaction: Kaonic atoms and kaonic nuclei

One of the outstanding fundamental problems in hadron physics today is the question of the origin of the large hadron masses made up of light quarks. The current mass of the up and down quarks is two orders of magnitude smaller than a typical hadron mass of about 1 GeV. This extraordinary phenomenon is proposed to originate from spontaneous breaking of chiral symmetry of massless quarks in strong interaction physics<sup>1</sup>. It results in a ground state - the vacuum state - with a finite expectation value of quark-antiquark pairs, the chiral quark condensate<sup>2</sup>. The hadrons are considered to be quasi-particle excitations of this chiral condensate.

Since long time it is known that the antikaon-nucleon ( $\bar{K}$ -N) interaction around threshold is dominated by the  $\Lambda(1405)$  baryon resonance located 27 MeV below the  $K^-p$  threshold, which can be interpreted as a  $K^-p$  bound state. The  $\bar{K}$ -N amplitude, calculated by a coupled channel approach in the resonance regime<sup>3,4</sup>, shows in the real part of the isospin  $I=0$ ,  $K^-p$  amplitude a dispersive behaviour, being strongly attractive below the resonance and repulsive above it (Fig. 2). The latter is experimentally reflected by the  $\bar{K}$ -N scattering cross section<sup>5</sup>, the X-ray results from kaonic hydrogen experiments  $KpX$ <sup>6</sup> at KEK and recently DEAR<sup>7</sup> at LNF-INFN, which show repulsive shifts.

Precision X-ray spectroscopy on kaonic hydrogen to study the chiral symmetry breaking scenario in the strangeness sector will be continued with SIDDHARTA investigating the  $K^-p$  and, for the first time,  $K^-d$  s-wave interaction at threshold.

Another way to gain information how the hadron mass is generated will be the study how the hadron mass changes in a nuclear medium. The mass shift of a meson in a nuclear medium gives an evidence of the partial restoration of spontaneous chiral symmetry breaking in QCD. A new way of in-medium hadron mass spectroscopy has started with a series of experiments at GSI, which observed deeply bound pionic 1s and 2p states in Pb and Sn nuclei<sup>8</sup>.

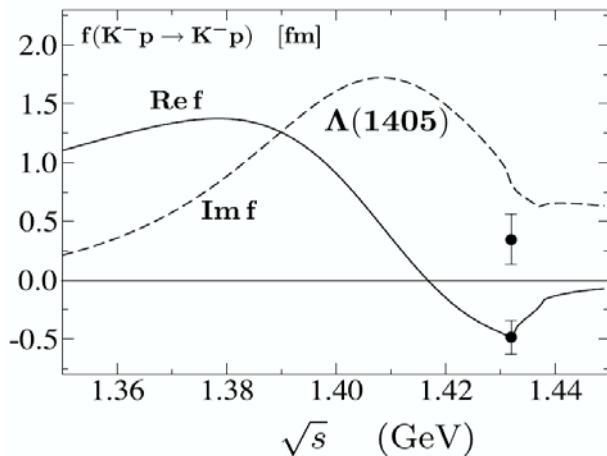


Fig. 2: Real and imaginary parts of the  $K^-p$  forward elastic scattering amplitude calculated in the Chiral  $SU(3)$  Coupled Channels approach. Real and imaginary parts of the scattering length deduced from the DEAR kaonic hydrogen measurements are also shown, with  $\sqrt{s}$  as being the invariant  $K^-N$  center-of-mass energy.

SIDDHARTA investigating the  $K^-p$  and, for the first time,  $K^-d$  s-wave interaction at threshold.

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<sup>1</sup> Y. Nambu and G. Jona-Lasinio, Phys. Rev. 122 (1961) 345.

<sup>2</sup> U. Vogl and W. Weise, Prog. Part. Nucl. Phys. 27 (1991) 195.

<sup>3</sup> N. Kaiser, P. B. Siegel and W. Weise, Nucl. Phys. A594 (1995) 325

<sup>4</sup> N. Kaiser, T. Waas and W. Weise, Nucl. Phys. A612 (1997) 297.

<sup>5</sup> A. D. Martin, Nucl. Phys. B179 (1981) 33.

<sup>6</sup> M. Iwasaki *et al.*, Phys. Rev. Lett. 78 (1997) 3067.

<sup>7</sup> G. Beer *et al.*, Phys. Rev. Lett. 94 (2005) 212302.

<sup>8</sup> P. Kienle, T. Yamazaki, Progress in Particle and Nuclear Physics 52 (2004) 85.

Recently, exotic nuclear systems involving a  $\bar{K}$  ( $K^-$  or  $\bar{K}^0$ ) as a constituent have been investigated theoretically<sup>9,10</sup> based on phenomenological constructed  $\bar{K}$ - $N$  interactions, which reproduce low energy  $\bar{K}$ - $N$  scattering data<sup>5</sup>, kaonic hydrogen atom data (KpX<sup>6</sup> and DEAR<sup>7</sup>) and the binding energy and decay width of  $\Lambda(1405)$ . These interactions, which are consistent with the prediction based on a chiral SU(3) effective Lagrangian as well as the recent experimental indication on decreased in-medium  $K^-$ -mass from sub-threshold nuclear reactions, are characterized by a strongly attractive I=0 part, causing drastic shrinkage of  $\bar{K}$ -bound nuclei and increasing the binding energies in proton-rich nuclei. The predicted  $\bar{K}$ -bound states have high average nucleon densities, several times the normal nuclear density, with large binding energies.

These clusters would represent indeed the ideal condition to investigate how the spontaneous and explicit symmetry breaking pattern of low-energy QCD changes in a dense nuclear medium.

Very recently, double  $K^-$ -systems  $ppK^-K^-$  and  $p\bar{p}nK^-K^-$  have also been predicted to be high-density systems<sup>11</sup>. Such compact nuclear systems, which can be called " $\bar{K}$ -clusters", may be beyond the scope of the present theoretical treatment based on hadronic structure and interactions, as they are likely to be in a new phase of nuclear matter. "Antikaon mediated bound nuclear systems", with quarks, anti-quarks and gluons as constituents are microscopic building blocks of kaon condensed matter<sup>12</sup> or represent colour superconducting systems with high di-quark content (Fig. 3). Of course, information whether kaon condensation can occur in nuclear matter will have direct applications in astrophysics (neutron stars, strange stars).

The SMI will participate in the search for antikaon-mediated bound nuclear systems with different experimental studies:

- The precision studies of kaonic hydrogen and kaonic deuterium with SIDDHARTA will set new constraints in the description of  $\Lambda(1405)$ .
- The KEK experiment PS-E570 will measure the 2p shift and width of kaonic helium, induced by strong interaction, with high precision (in the order of  $\sim$  eV). This will help to clarify the existence of deeply bound kaon nuclear systems.
- With FOPI at GSI a search of deeply bound nuclear clusters, like  $K^-pp$ , will be performed, using proton induced reactions and heavy ion collisions.
- To study the formation of antikaon-mediated bound nuclear systems in full detail the AMADEUS project has been started. An LOI was submitted to LNF - INFN.

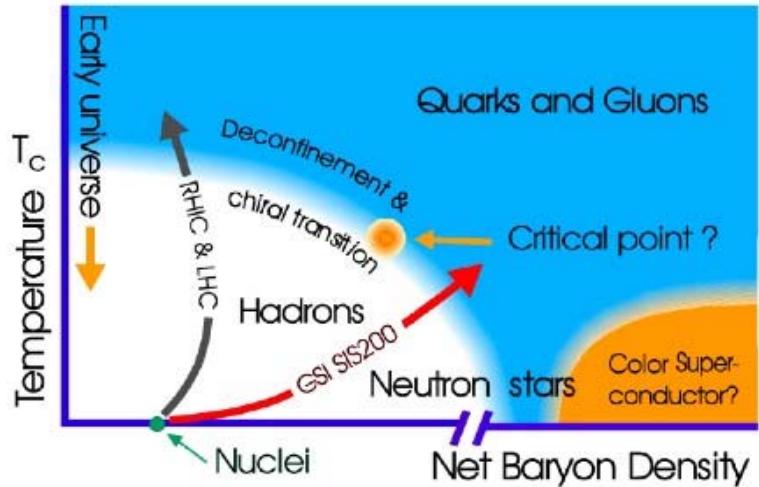


Fig. 3: Phase diagram of nuclear matter.

<sup>9</sup> Y. Akaishi and T. Yamazaki, Phys. Rev. C 65 (2002) 044005.

<sup>10</sup> T. Yamazaki and Y. Akaishi, Phys. Lett. B 535 (2002) 70.

<sup>11</sup> T. Yamazaki, A. Doté and Y. Akaishi, Phys. Lett. B 587 (2004) 167.

<sup>12</sup> G.E. Brown, C.H. Lee, M. Rho and V. Thorsson, Nucl. Phys. A567 (1994) 937.

## Outlook

In the first half of 2007 the SIDDHARTA setup has to be prepared for installation at DAΦNE in summer 2007. First test beam might be available at the end of 2007.

In parallel to the work for SIDDHARTA there will be test beam time at GSI to develop a forward detector system for FOPI, which is essential for the upcoming program to search for deeply bound K<sub>pp</sub> clusters.

For AMADEUS design studies of an inner tracker system are foreseen, together with the detector group at LNFrascati.

In addition, an LOI (title: An ultra-light inner tracker system for precision measurements on high intensity/luminosity low and medium energy beams) will be worked out, to show our interest to participate in the next EU program FP7.

### PERSONEN:

Name	Funktion	Funktion: Zeitraum
Dr. Paul Bühler	Projektleitung	01.01.2006 bis 31.12.2013
Dipl.-Ing. Dr. Michael Cagnelli	Projektmitarbeit	01.01.1997 bis 31.12.2013
Dr. Tomoichi Ishiwatari	Projektmitarbeit	01.04.2002 bis 31.12.2013
Prof. Dr. Paul Kienle	Projektmitarbeit	01.03.2002 bis 31.12.2013
Dipl.-Ing. Dr. Johann Marton	Projektmitarbeit	01.01.1997 bis 31.12.2013
Philipp Schmid	Projektmitarbeit	01.06.2005 bis 31.12.2006
Dr. Ken Suzuki	Projektmitarbeit	01.12.2006 bis 30.11.2012
Univ.-Prof. Dr. Eberhard Widmann	Projektmitarbeit	01.11.2004 bis 31.12.2013
Dr. Johann Zmeskal	Projektleitung	01.01.1997 bis 31.12.2013

### PUBLIKATIONEN:

Curceanu, C.; Rusertski, A.; Widmann, E. (2006) Exotic atoms cast light on fundamental questions. CERN Courier, Bd. 46 (9), S. 32-34. [Widmann, E. (KoautorIn)]
Kienle, P. (15.06.2006) Probing the structure of nuclei bound by antikaons. (International Workshop Exotic hadronic atoms, deeply bound kaonic nuclear states and antihydrogen: present results, future challenges) In Reihe: Mini-proceedings of: International Workshop Exotic hadronic atoms, deeply bound kaonic nuclear states and antihydrogen: present results, future challenges. [Kienle, P. (HauptautorIn)]

### VORTRAG/POSTERPRÄSENTATION:

Kienle, Paul (03.04.2006) Experimental Studies of Antikaon Mediated Nuclear Bound States. Vortrag: ISHIP 2006, Frankfurt/ Main/GERMANY. [Kienle, Paul]
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Kienle, Paul (04.12.2006) Experimental Studies of Chiral Symmetry Restoration in a Nuclear Medium, Probed by S-Wave Pion Dynamics. Vortrag: Yukawa International Seminar 2006, New Frontiers in QCD, Kyoto/JAPAN. [Kienle, Paul]
Kienle, Paul (12.06.2006) Deeply Bound Kaonic Nuclear States. Vortrag: MESON 2006, Kra-

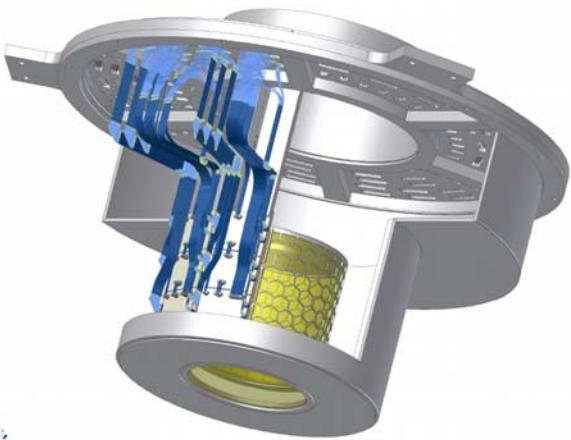
kau/POLAND. [Kienle, Paul]

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Widmann, Eberhard (06.11.2006) Studying fundamental symmetries and interactions with exotic atoms. Vortrag: Seminar zur starken Wechselwirkung (TU München), München/GERMANY. [Widmann, Eberhard]

Widmann, Eberhard (12.10.2006) Studying fundamental interactions and symmetries with exotic atoms. Vortrag: Seminar physics department (Uppsala University), Uppsala /SWEDEN. [Widmann, Eberhard]

### 1.3.1.1 FS1\_b\_A: Kaonic hydrogen and deuterium: SIDDHARTA



*Fig. 4: The SIDDHARTA target SDD detector arrangement is sketched.*

the strong interaction shift and width of the L-state of kaonic  ${}^4\text{He}$  and of kaonic  ${}^3\text{He}$  will be measured.

The SIDDHARTA setup was designed at SMI during 2005 and first half of 2006 and guided by the successful design strategy of the DEAR setup (the DEAR setup was designed and built at SMI<sup>13</sup>). The design of the mounting and shielding structure for the SIDDHARTA vacuum chamber was done together with the LNF workshop and will be built completely at LNF under supervision of SMI.

The larger pieces of the vacuum chamber will be machined and welded at LNF, because the dimension of the chamber exceeds the size of work pieces, which could be done in our mechanical workshop. All smaller, but quite delicate items will be machined at SMI: like vacuum feed-through, kaon entrance window, the cooling lines for the target cell as well as for the SDDs. The construction phase started in the second half of 2006 and will be finished in spring 2007.

A first prototype of the cryogenic target cell was developed and built at SMI in the second half of 2006 (Fig. 5). The light weight cell is made only from selected materials: pure aluminium and Kapton, and was successfully tested at a temperature of 25 K filled with helium gas at a pressure of 0.3 MPa. A rupture test at room temperature yields a burst pressure of 0.5 MPa, fulfilling the safety margin of 1.5.

To achieve the required energy resolution of the X-ray detector system, the SDD-chips have to be cooled to  $\sim 170$  K and the preamplifier electronics has to be closely mounted at the backside of the SDD-chip. Two  $3 \text{ cm}^2$  SDD-chips are mounted in an aluminum case with

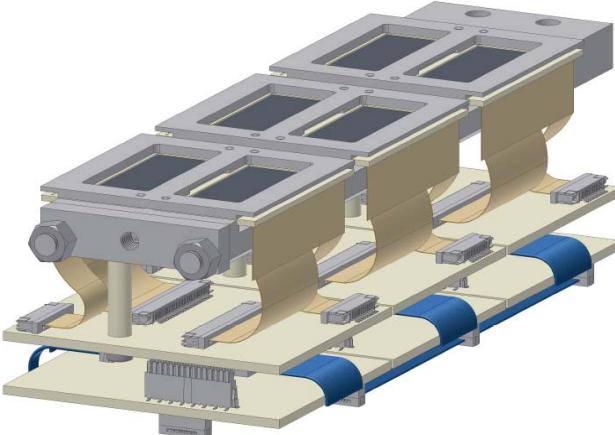
The goal of SIDDHARTA (Silicon Drift Detector for Hadronic Atom Research by Timing Applications) is to perform precision measurements of the shift and width of kaonic atoms at the percent level. Therefore, a detector with good energy resolution ( $\text{FWHM} \sim 150$  eV at 6 keV) and in addition with good timing capability (better than  $1\mu\text{s}$ ) is essential. This new developed detector is currently in the assembling phase (see also FS1\_b\_b).

The first part of the SIDDHARTA program, a precision measurement of kaonic hydrogen, is a continuation of DEAR, but will improve the precision of the DEAR data at least by a factor of 10. The second part includes the first measurement of kaonic deuterium. In addition



*Fig. 5: Prototype cryogenic target cell made of  $75 \mu\text{m}$  Kapton, within a pure aluminum grid.*

<sup>13</sup> Zmeskal, Proceedings EXA05, Editors A. Hirtl, J. Marton, E. Widmann, J. Zmeskal, Austrian Academy of Science Press, Vienna 2005, p. 139



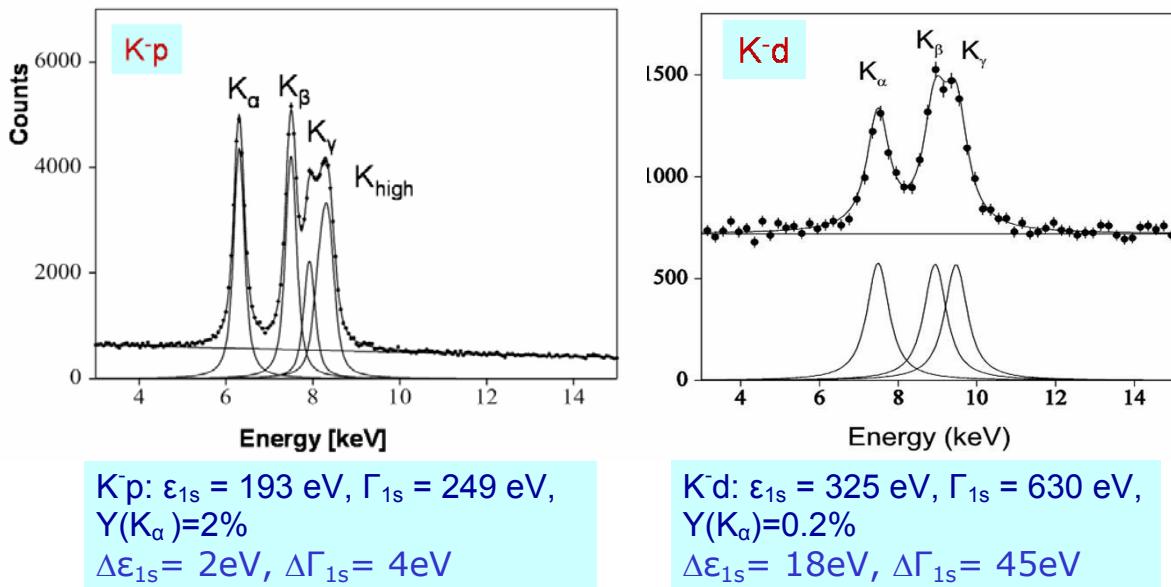
*Fig. 6: Sub-unit of SDD cooling and mounting device with pre-amplifier boards.*

Analyze the element content of the materials in use with a sensitivity for detecting Fe impurities in the order of ppm. All the materials used for the construction of the SDD mounting devices and the target cell body were analyzed during 2006. The iron content of the mechanical components was always less than 50 ppm, as required by the experiment. It should be mentioned that also the ceramic frame of the SDD-chip was carefully studied and the ceramic material with the lowest iron content was chosen.

### Outlook

For the first half of 2007 the assembling and testing of the vacuum chamber is foreseen, as well as cooling and rupture tests of the target cell.

The installation of the whole setup at DAΦNE is planned for summer 2007, with final tests at our laboratory at LNF. A first test beam, with a reduced number of SDDs, is scheduled for end of 2007. Study of the background situation might be possible during this beam time, which is given to the machine crew to tune and optimize the beam to achieve the luminosity goal of a few times  $10^{32} \text{ cm}^{-2}\text{s}^{-1}$ .



*Fig. 7: Simulation of kaonic hydrogen X-rays for an integrated luminosity of  $5 \text{ fb}^{-1}$ .*

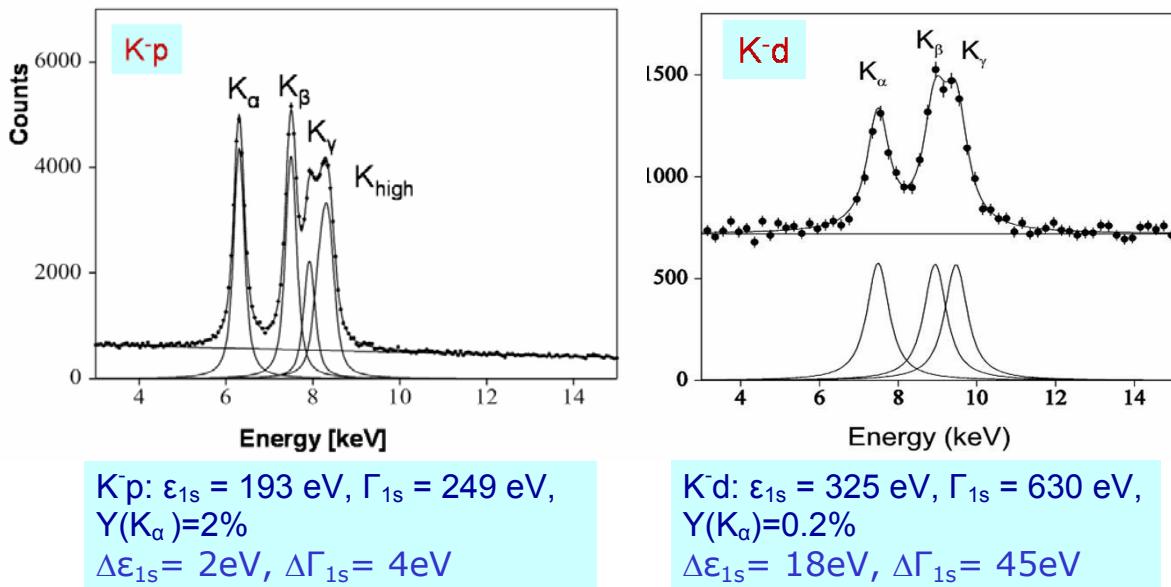
three aluminum cases connected to build up a sub-unit (Fig. 6). Finally, twelve of these sub-units will be arranged around the target cell, with an active detector area of  $216 \text{ cm}^2$  (Fig. 4).

For a careful analysis of the material used for this setup, especially for the target cell, the SDD mounting and the structure material close to the SDD-chip, a PIXE (Proton Induced X-ray Emission) apparatus at VERA (Vienna Environmental Research Accelerator, University of Vienna, Institut für Isotopenforschung und Kernphysik) has been developed. We were able to analyze the element content of the materials in use with a sensitivity for detecting Fe impurities in the order of ppm. All the materials used for the construction of the SDD mounting devices and the target cell body were analyzed during 2006. The iron content of the mechanical components was always less than 50 ppm, as required by the experiment. It should be mentioned that also the ceramic frame of the SDD-chip was carefully studied and the ceramic material with the lowest iron content was chosen.

### Outlook

For the first half of 2007 the assembling and testing of the vacuum chamber is foreseen, as well as cooling and rupture tests of the target cell.

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*Fig. 7: Simulation of kaonic hydrogen X-rays for an integrated luminosity of  $5 \text{ fb}^{-1}$ .*

With an average luminosity of  $10^{32} \text{ cm}^{-2}\text{s}^{-1}$  in about 60 days of beam time more than 50000 kaonic hydrogen K $\alpha$  events will be collected - enough to fulfill the goal of a percent level measurement.

For the deuterium case a Monte Carlo simulation<sup>14</sup> shows that a kaonic deuterium measurement becomes feasible. The following assumptions, coming from theory, were used in the simulation: shift = - 325 eV, width = 630 eV, X-ray yield = 0.2% (a factor ten less than in hydrogen). The result is that in 60 days more than 5000 kaonic K $\alpha$  events could be collected.

#### PERSONEN:

Name	Funktion	Funktion: Zeitraum
Dr. Paul Bühler	Projektmitarbeit	01.01.2006 bis 31.12.2012
Dipl.-Ing. Dr. Michael Cargnelli	Projektmitarbeit	01.01.2004 bis 31.12.2009
Dr. Tomoichi Ishiwatari	Projektmitarbeit	01.01.2004 bis 31.12.2009
Prof. Dr. Paul Kienle	Projektmitarbeit	01.01.2004 bis 31.12.2009
Dipl.-Ing. Dr. Johann Marton	Projektleitung	01.01.2004 bis 31.12.2009
Dr. Ken Suzuki	Projektmitarbeit	01.12.2006 bis 31.12.2012
Univ.-Prof. Dr. Eberhard Widmann	Projektmitarbeit	01.01.2004 bis 31.12.2009
Dr. Johann Zmeskal	Projektleitung, Projektmitarbeit	01.01.2004 bis 31.12.2009

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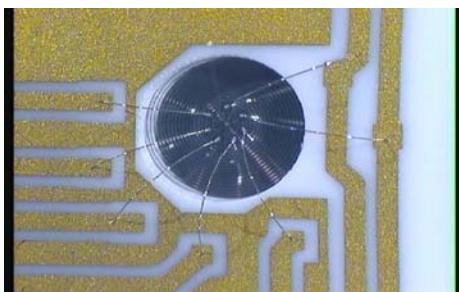
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Cargnelli, M.; Ishiwatari, T.; Kienle, P.; Marton, J.; Widmann, E. et al. [...] (15.06.2006) Kaonic Hydrogen Experiment. (International Workshop Exotic hadronic atoms, deeply bound kaonic nuclear states and antihydrogen: present results, future challenges) In Reihe: Mini-procedings of: International Workshop Exotic hadronic atoms, deeply bound kaonic nuclear states and antihydrogen: present results, future challenges. [Cargnelli, M. (KoautorIn); Ishiwatari, T. (KoautorIn); Kienle, P. (KoautorIn); Marton, J. (HauptautorIn); Widmann, E. (KoautorIn); Zmeskal, J. (KoautorIn)]
Marton, Johann (11.07.2006) Experimental studies on kaonic atoms at DAFNE: Recent results and perspectives. (PARTICLES AND NUCLEI: Seventeenth International Conference on Particles and Nuclei) In Reihe: American Institute of Physics Conference Proceedings - Volume 842: American Institute of Physics, S. 256-258. [Marton, J. (HauptautorIn)]
Marton, Johann (15.06.2006) Exotic Atom Research Using Large Area Silicon Drift Detectors. (International Symposium On Detector Development For Particle, Astroparticle And Synchrotron Radiation Experiments (SNIC 2006). [Marton, J. (HauptautorIn)]

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### 1.3.1.2 FS1\_b\_b: SIDDHARTA: Joint Research Activity 10 in I3 Hadron Physics



*Fig. 8: A picture of the SDD backside done during optical inspection, the wires bonded on the ceramic board and SDD-chip are clearly visible.*

Very good energy resolution (in the order of 135 eV at 6 keV) and good timing resolution (about 500 ns FWHM) are the main features of Silicon Drift Detectors (SDDs)<sup>15</sup>. But, up to now no large area devices were available (available sizes up to 10 mm<sup>2</sup>, first prototypes with an active area of 30 mm<sup>2</sup>). Therefore, the SIDDHARTA (Silicon Drift Detector for Hadronic Atom Research by Timing Applications) collaboration was formed to develop large area SDD devices within the 6<sup>th</sup>-framework program of the EU (I3-Hadron Physics). The goal is to build SDD-chips with total active area of 300 mm<sup>2</sup>, consisting of 3 individual elements on one chip. Finally, a detector system with a total active area of more than 200 cm<sup>2</sup> is envisioned. This unique detector system will be used to perform precision measurements of kaonic atoms at the percent level.

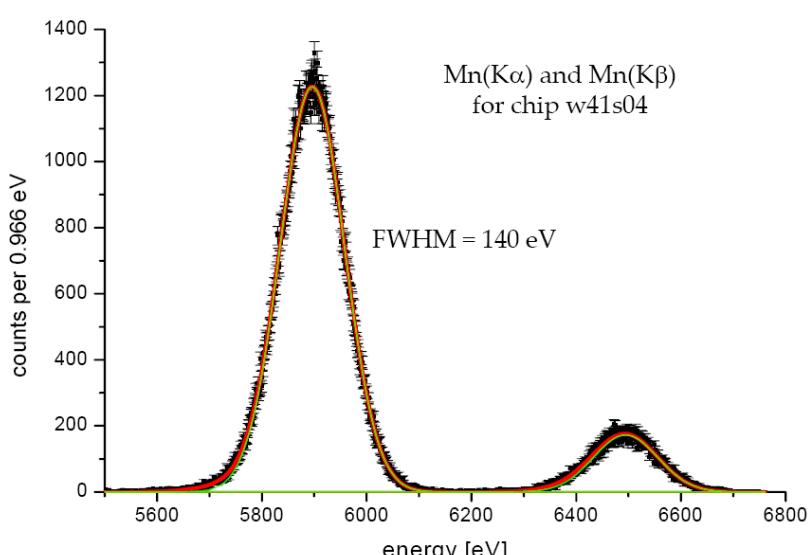
The X-ray timing signal from the kaonic atom transition of interest can be used together with the time signal of the back-to-back K<sup>+</sup>K<sup>-</sup> pair to set up a triple coincidence. With this coincidence method it will be possible to suppress the continuous background as well as fluorescence X-rays by almost three orders of magnitude, compared with the background in the DEAR experiment.

The SDD-chips were produced at the MPI-Halbleiterlabor, München. After a test series of 8 SDD-chips to evaluate the gluing and bonding technique, in the first half of 2006 the first 10 SDD-chips were mounted in ceramic holders and bonded under the supervision of SMI at the Fraunhofer Institut (IZM-Berlin).

These chips were successfully tested in Vienna - first an optical inspection of all delivered chips took place, then the electrical characteristic of each chip was determined and compared with the MPI data. Finally spectroscopic measurements were performed, showing very good energy resolution of about 140 eV at 6 keV.

To make use of the good performance of SDDs a new pre-amplifier chip (source follower configuration) is under development at Politecnico Milano, to achieve better rate and long-term stability. Tests in the second half of 2006 have shown promising results.

After having successfully tested 10 SDD-chips we started in the second half of 2006 the assembly



*Fig. 9: A typical spectrum taken during the spectroscopic measurement using a Fe-55 radioactive source.*

<sup>15</sup>J. Kemmer, G. Lutz, Nucl. Instr. and Meth. A 253 (1987) 365

of the 70 SDD-chips, foreseen to be used in SIDDHARTA. Until end of 2006, 25 chips were mounted, bonded and finally electrically characterized at SMI. The spectroscopic test measurements are running.

## Outlook

Preparing the SDD ceramic holders for mounting and bonding of the SDDs will be continued as well as electronic and spectroscopic test measurements of the finished SDD devices. The goal is to finish the test measurements of all 70 chips within spring 2007. Long-term measurements are going on in parallel with a set of 4 chips at SMI and at LNF.

A test at the BTF (beam test facility) at LNF is planned for end of March 2007. The installation of 6 SDD-chip at the DAFNE machine is foreseen for the second half of 2007 and first beam, but only for machine development, is expected in November 2007. In this period debugging of the SDD system and background measurements might be possible.

### PERSONEN:

Name	Funktion	Funktion: Zeitraum
Dr. Paul Bühler	Projektmitarbeit	01.01.2004 bis 31.12.2007
Dipl.-Ing. Dr. Michael Cargnelli	Projektmitarbeit	01.01.2004 bis 31.12.2007
Dr. Tomoichi Ishiwatari	Projektmitarbeit	01.01.2004 bis 31.12.2007
Dipl.-Ing. Dr. Johann Marton	Projektleitung	01.01.2004 bis 31.12.2007
Univ.-Prof. Dr. Eberhard Widmann	Projektmitarbeit	01.01.2004 bis 31.12.2007
Dr. Johann Zmeskal	Projektmitarbeit	01.01.2004 bis 31.12.2007

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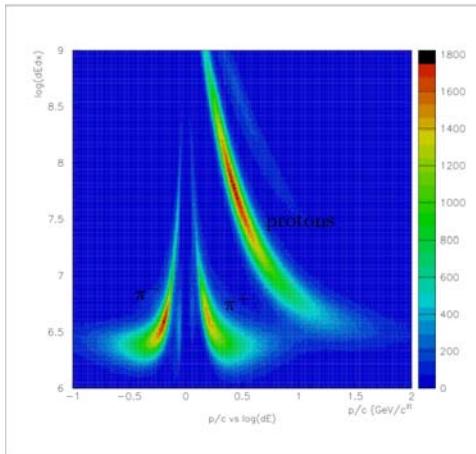
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### 1.3.1.3 FS1\_c: Deeply bound kaonic nuclei with FOPI at GSI

In 2005 two different experiments - Al+Al and p+D<sub>2</sub> - were carried out with the FOPI (FOur PI) detector at GSI to study the production of antikaon-mediated bound nuclear states, so called kaonic clusters.

In the period under review (2006) much progress has been made with the analysis of the acquired data and studies have been performed in preparation of follow-up experiments.



**Fig. 10:**  $dE/dx$  versus momentum as measured with the FOPI central drift chamber (CDC) in the proton experiment.

self as a peak in the invariant mass spectrum of the decay products ( $\pi^-$  and two protons) at approximately 2.3 GeV/c<sup>2</sup>.

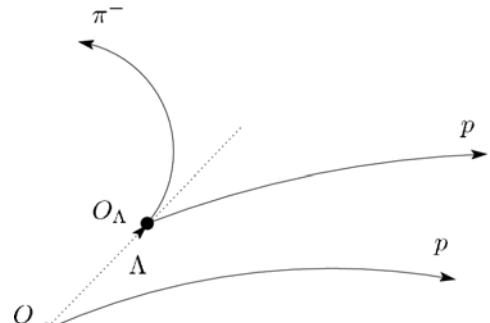
The method relies on a proper identification of the charged particles and selection of the particles to combine for the invariant mass calculation. Combinations of particles which do not originate from the K<sup>-</sup>pp decay lead to combinatorial background which can dominate the invariant mass spectrum. Therefore, it needs to be reduced by application of specific selection criteria.

With FOPI the pion and proton identification is achieved with momentum and dEdx measurements with the CDC and the Helitron. The CDC is the central drift chamber and covers the angular range from approximately 30 to 90 degrees. The Helitron covers the forward direction between 7 and 30 degrees. Fig. 10 shows the dE/dx versus momentum distribution measured in the CDC. The distributions of protons and pions in this parameter plane are well separated, allowing a proper particle identification.

Whereas the Al+Al data are being analyzed at GSI, SMI together with collaboration members from the TU Munich are responsible for analyzing the data from the proton experiment.

With the limited statistics obtained for the proton induced reactions it was not possible to verify or rule out the existence of kaonic clusters. However, the data was used to test data analysis concepts and allowed to identify possibilities for improvement of the experimental setup for follow-up experiments.

With FOPI kaonic clusters can be detected by invariant mass analysis of the charged decay products. E.g. the most fundamental kaonic cluster K<sup>-</sup>pp decays into a  $\Lambda$ -hyperon and a proton and the  $\Lambda$  further decays into a  $\pi^-$  and a proton. The existence of a K<sup>-</sup>pp would manifest it-



**Fig. 11:** Decay pattern of the K-pp. K-pp decays at O into a  $\Lambda$  and a proton. The  $\Lambda$  travels a finite distance before it decays at  $O_\Lambda$  into a  $\pi^-$  and a proton.

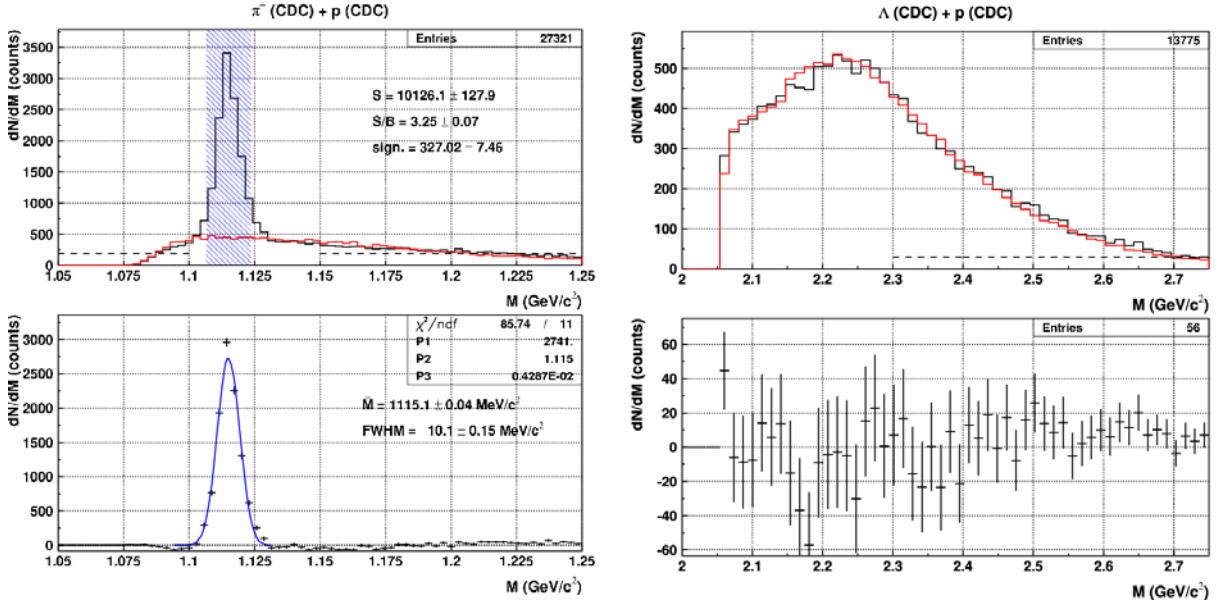


Fig. 12: The left panels show  $\pi$ -proton and the right panels  $\Lambda$ -proton invariant mass spectra. In the upper panels the black line represents the same-event combinations, whereas the red line shows the mixed-event background estimate. The lower panels show the spectra corrected for the combinatorial background. With the available small statistics no indication of  $K\text{-}pp$  is found in the invariant mass spectra (right panels).

In order to select the particles to combine for invariant mass analysis a criterion is used which is based on the spatial topology of the tracks of the  $K\text{-}pp$  decay products. This topology is depicted in Fig. 11. The  $K\text{-}pp$  decays promptly at the location of the main vertex  $O$ , emitting a  $\Lambda$  and a proton. The  $\Lambda$ -hyperon has a mean path of 7 cm. Therefore it has a good chance to first move away from the main vertex location before it decays at  $O_\Lambda$  into a pion and a proton.

For selection of the potential decay products of the  $\Lambda$  it is required that the tracks of the pion and proton have an intersection point which is well separated from the main vertex and that the reconstructed  $\Lambda$ -momentum vector is aligned with the connecting line between  $O$  and  $O_\Lambda$ . Such selected hyperons are then combined with protons, the tracks of which are required to pass through the main vertex.

This strategy substantially reduces the combinatorial background but can not fully eliminate it. For estimation of the remaining combinatorial background a so called event-mixing method is applied. Tracks from different events are combined as if they were from the same event. The left part of Fig. 12 shows the invariant mass distribution of  $\pi^-$ -proton combinations measured in the CDC. The black line in the upper panel represents the same-event combinations and the red line shows the combinatorial background from the event-mixing method. In the lower panel the background subtracted  $\Lambda$ -signal is shown.

The invariant mass spectrum of the combination of these  $\Lambda$ s with protons unfortunately reveals no indication for the existence of a bound nuclear state (see right part of Fig. 12). However, with the actually available number of  $21 \cdot 10^6$  events only very few clusters (in the order of 20) are expected to be formed. In view of the combinatorial background, this is much too few to be visible in the

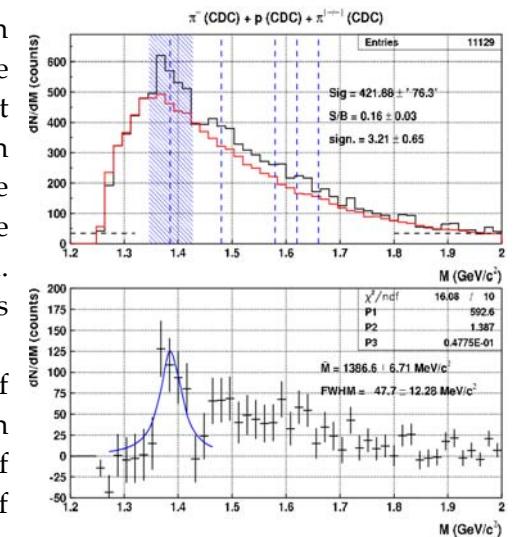


Fig. 13:  $\Lambda\text{-}\pi$  invariant mass spectrum with a peak at the  $\Sigma^*(1385)$  mass.

invariant mass spectrum.

$\Sigma^*(1385)$  is a hyperon which has a very similar decay pattern as the  $K^- pp$ . It decays into a  $\Lambda$  and pion and is therefore suited to test the data analysis concepts. Fig. 13 shows the invariant mass spectrum of  $\Lambda$ -pion combinations measured with the CDC. In this case the signal at the nominal mass of 1385 MeV/c is clearly visible demonstrating the applicability of the method for identification of  $K^- pp$ .

One of the crucial points in this method is the spatial resolution with which the main and secondary vertices can be determined. Whereas in the CDC range the tracks can be extrapolated with sufficient accuracy to the target region, this is not possible for the angular region covered by the Helitron. Due to this fact the combinatorial background in this region can not be efficiently suppressed, which severely limits the sensitivity of the measurement in forward direction.

However, data and simulations suggest that in the proton experiment a large fraction of the particles fly in forward direction. Therefore to enhance the detection efficiency for kaonic clusters in proton-induced reactions the tracking capabilities of the existing experimental setup has to be improved.

In preparation for follow-up experiments, we have therefore started to work out concepts for an additional detector system which will supplement the existing FOPI detectors and enhance the tracking capabilities in forward direction.

## Outlook

We finished an evaluation of the data obtained from the first proton test beamtime carried out at GSI in 2005, and based on the result we worked on further optimization of the experimental condition for our goal, namely to perform a reliable experimental test of the existence of  $K^- pp$ , which is the most fundamental kaonic nuclear system of such kind, examine the whole theoretical scenario of deeply bound kaonic nuclei.

We chose the  $p + p \rightarrow K^+ + X$  reaction at  $T_p = 3.5$  GeV. From exclusive measurement of that reaction, the signal of the  $K^- pp$  can be obtained from 1) missing mass spectroscopy with  $K^+$  measurement and 2) invariant mass spectroscopy of X from its decay product.

For the missing mass spectroscopy, a clear identification of charged kaon of momentum range up to 1 GeV/c is crucial. Separation of kaon from pion and proton with energy loss and momentum information becomes very difficult above 500 MeV/c due to minimum ionizing nature.

FOPI has accomplished a development of Resistive Plate Chambers (RPC) and replaced the existing Barrel detector (time-of-flight barrel made of scintillation counters). Thanks to the excellent timing resolution of the RPC ( $\sigma_t \approx 80$  ps), charged kaon emitted at angles  $\theta > 25^\circ$  can be safely distinguished from pion and proton up to 1 GeV/c, provided we have a start counter with timing resolution of  $\sigma_t \approx 120$  ps. For the invariant mass spectroscopy, the signal of the  $K^- pp$  is detected through the decay branch,  $K^- pp \rightarrow \Lambda + p \rightarrow [p + \pi^-] + p$  where no neutral particle is involved in the final state. For this three final state particles invariant mass reconstruction, a good vertex information in addition to a good momentum resolution in a forward sector ( $\theta < 25^\circ$ ) is required in order first to select clean  $\Lambda$  signal and then to suppress the combinatorial background. Upon the request above, we need an inner tracking detector which fulfills position resolution of  $\Delta_{xy} \approx 1$  mm, good timing resolution ( $\sigma_t \approx 120$  ps) and trigger capability under the magnetic field of 0.6 T.

We are presently working on development of scintillating fiber hodoscope detector (SciFi) with APD readout right behind the target inside CDC and a double sided silicon strip detector system for the first phase (2007 – 2008). We plan short beamtimes in March and April for the test of the detector, and more if needed.

We have also started R&D work on a novel Time-Projection Chamber with GEM readout together with members of the PANDA collaboration, to be used from 2009 on.

#### PERSONEN:

Name	Funktion	Funktion: Zeitraum
Dr. Paul Bühler	Projektleitung, Projektmitarbeit	01.09.2004 bis 31.12.2009
Dipl.-Ing. Dr. Michael Cagnelli	Projektmitarbeit	01.09.2004 bis 31.12.2009
Prof. Dr. Paul Kienle	Projektmitarbeit	01.09.2004 bis 31.12.2009
Dipl.-Ing. Dr. Johann Marton	Projektmitarbeit	01.09.2004 bis 31.12.2009
Philipp Schmid	Projektmitarbeit	01.06.2005 bis 30.09.2006
Dr. Ken Suzuki	Projektmitarbeit	01.12.2006 bis 30.11.2012
Univ.-Prof. Dr. Eberhard Widmann	Projektmitarbeit	01.11.2004 bis 31.12.2009
Dr. Johann Zmeskal	Projektmitarbeit	01.09.2004 bis 31.12.2009

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Bühler, P.; Cagnelli, M.; Kienle, P.; Marton, J.; Widmann, E. et al. [...] (15.06.2006) Search for ppK- in p+d-reaction with FOPI. (International Workshop Exotic hadronic atoms, deeply bound kaonic nuclear states and antihydrogen: present results, future challenges). [Bühler, P. (HauptautorIn); Cagnelli, M. (KoautorIn); Kienle, P. (KoautorIn); Marton, J. (KoautorIn); Widmann, E. (KoautorIn); Zmeskal, J. (KoautorIn)]

#### VORTRAG/POSTERPRÄSENTATION:

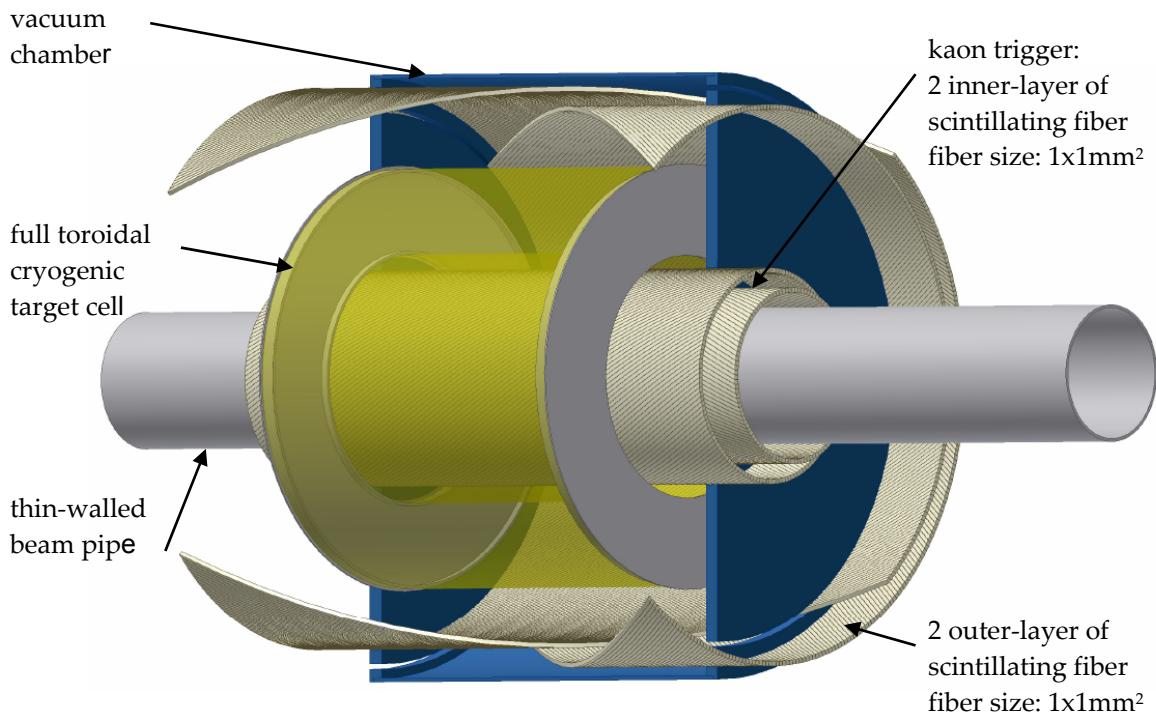
Bühler, Paul (15.09.2006) Particle reconstruction in the p+X experiment using CDC and Helitron/Plawa . Vortrag: FOPI collaboration meeting, Warschau/POLAND. [Bühler, Paul]
Bühler, Paul (17.10.2006) p+X @ FOPI - status. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Bühler, Paul]
Bühler, Paul (22.06.2006) Search for ppK- in p+d-reaction with FOPI . Vortrag: International Workshop Exotic hadronic atoms, deeply bound kaonic nuclear states and antihydrogen: present results, future challenges (ECT*), Trento/ITALY. [Bühler, Paul]
Bühler, Paul (27.04.2006) The search for kaonic nuclear clusters - a status report. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Bühler, Paul]
Cagnelli, Michael (07.08.2006) Data from p (3.5GeV) + plastic at FOPI (Oct. 2005). Vortrag: Work-meeting "Study of kaonic nuclear clusters at FOPI" (TU München), München/GERMANY. [Cagnelli, Michael]
Cagnelli, Michael (07.08.2006) Simulation of K-cluster at FOPI. Vortrag: Meeting "Study of kaonic nuclear clusters at FOPI" (TU München), München/GERMANY. [Cagnelli, Michael]
Cagnelli, Michael (17.10.2006) Simulations for pp2KX. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Cagnelli, Michael]
Schmid, Philipp (18.09.2006) Experimental search for deeply bound kaonic states. Vortrag: ÖPG-FAKT Tagung 2006 (Österreichische Physikalische Gesellschaft), Maria Lankowitz/AUSTRIA. [Schmid, Philipp]

Suzuki, Ken (20.10.2006) Simulation on the  $p + p \rightarrow K+ + K-pp$  reaction with FOPI in Search for the kaonic nuclear cluster  $K-pp$ . Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Suzuki, Ken]

Zmeskal, Johann (17.10.2006) Search for antikaon-mediated bound nuclear clusters with FOPI, AMADEUS and P15. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Zmeskal, Johann]

Zmeskal, Johann (18.09.2006) Search for antikaon-mediated bound nuclear clusters with FOPI and AMADEUS. Vortrag: Seminar TU München, München/GERMANY. [Zmeskal, Johann]

### 1.3.1.4 FS1\_d: AMADEUS at DAΦNE2



*Fig. 14: A possible layout of AMADEUS within KLOE.*

The change of the hadron masses and hadron interactions in the nuclear medium and the structure of cold dense hadronic matter are hot topics of hadron physics today. These important, yet unsolved, problems will be the research field of AMADEUS (Antikaonic Matter At DAFNE: Experiments with Unravelling Spectroscopy)<sup>16</sup>.

AMADEUS will search for antikaon-mediated deeply bound nuclear states, which could represent, indeed, the ideal conditions for investigating the way in which the spontaneous and explicit chiral symmetry breaking pattern of low-energy QCD occurs in the nuclear environment.

The hypothesis of the possible existence of deeply bound kaonic nuclear states was already formulated in 1986 by Wycech<sup>17</sup> but is only a few years old in the structured form of a phenomenological model formulated by Akaishi and Yamazaki<sup>18</sup>. The existence of such a deeply bound system is presently matter of lively discussions among theoreticians and experimentalists.

First experimental indications have been produced at KEK<sup>19, 20, 21</sup>, LNF<sup>22</sup>, GSI<sup>23</sup> and BNL<sup>24</sup>. Lately, one data set of the KEK experiment E471 was withdrawn, because the succeeding experi-

<sup>16</sup> AMADEUS LOI, www.lnf.infn.it (Nuclear Physics – SIDDHARTA).

<sup>17</sup> S. Wycech, Nucl. Phys. A450 (1986) 399c.

<sup>18</sup> Y. Akaishi and T. Yamazaki, Phys. Rev. C 65 (2002) 044005.

<sup>19</sup> T. Suzuki et al., Phys. Lett. B 597 (2004) 263.

<sup>20</sup> M. Iwasaki et al., arXiv: nucl-ex/0310018.

<sup>21</sup> M. Iwasaki (KEK PS-E471 Collaboration), Proceedings EXA05, Editors A. Hirtl, J. Marton, E. Widmann, J. Zmeskal, Austrian Academy of Science Press, Vienna 2005, p.191.

<sup>22</sup> M. Agnello et al., Phys. Rev. Lett. 94 (2005) 212303.

<sup>23</sup> N. Hermann (FOPI Collaboration), Proceedings EXA05, Editors A. Hirtl, J. Marton, E. Widmann, J. Zmeskal, Austrian Academy of Science Press, Vienna 2005, p.61.

ment E549 could not confirm, with even higher statistics, the observed peak in E471, which was previously interpreted as an antikaon-mediated deeply bound nuclear state.

The new proposal, AMADEUS at DAΦNE, will perform, for the first time, a systematic and complete spectroscopic study, by measuring all particles in the formation and in the decay process.

Moreover, AMADEUS aims to perform other types of measurements as: elastic and inelastic kaon interactions on various nuclei, obtaining important information for a better understanding of the underlying processes.

In 2006 the AMADEUS LOI was presented to the LNF Scientific Committee as well as to INFN. The AMADEUS collaboration was encouraged to go on and to present a proposal.

A first design study of the AMADEUS setup within KLOE<sup>25</sup> was performed under the leadership of SMI. A solution which is presently under study is to use a toroidal target placed around the beam pipe at the interaction region. A scintillator (or scintillating fiber) detector is placed around the pipe just in front of the target. This detector is essential, delivering an optimal trigger condition by making use of the back-to-back topology of the kaons produced from the  $\Phi$ -decay.

The AMADEUS collaboration considers as well as the KLOE collaboration the implementation of an inner tracker. A common used inner tracker is currently under study. Even more general, an application for an FP7 project is under discussion, to develop a light weight inner tracker for high luminosity/intensity beams.

The KLOE drift chamber is filled with a helium isobutane mixture, which could act as an active target where deeply bound kaonic clusters will be formed. Monte Carlo simulations performed at LNF and SMI have shown that a few thousand clusters might have been formed within the KLOE drift chamber. A K-cluster analysis group was formed, consisting of members from KLOE and AMADEUS (only from LNF and SMI). This work was started mid 2006.

## Outlook

At SMI studies of the AMADEUS interaction region are continued, which will include beam pipe, kaon monitor and cryogenic toroidal target cell. In addition a prototype of a kaon monitor made of a scintillating fiber array with Geiger-mode APD readout is planned in preparation for the proposal. This work is also of great interest for FOPI, where we plan to build a forward detector, which might be a scintillating fiber X-Y-array.

More work is necessary for the design studies of an inner-tracker system. Two devices are currently under study: a TPC (time projection chamber) with GEM (gas electron multiplication) readout and a set of 4 - 5 radial GEM detectors. A part of this work should lead to an application at FP7 (the call is expected for end of 2007).

The analysis of the KLOE data to look for antikaon-mediated deeply bound nuclear clusters is going on.

## PERSONEN:

Name	Funktion	Funktion: Zeitraum
Dr. Paul Bühler	Projektmitarbeit	01.01.2006 bis 31.12.2012
Dipl.-Ing. Dr. Michael Cagnelli	Projektmitarbeit	22.08.2005 bis 31.12.2012
Dr. Tomoichi Ishiwatari	Projektmitarbeit	22.08.2005 bis 31.12.2012
Prof. Dr. Paul Kienle	Projektmitarbeit	22.08.2008 bis 31.12.2012

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<sup>24</sup> T. Kishimoto et al., Nucl. Phys. A 754 (2005) 383c.

<sup>25</sup> KLOE: A General Purpose Detector for DAFNE, The KLOE Collaboration, LNF-92/019 (IR).

Name	Funktion	Funktion: Zeitraum
Dipl.-Ing. Dr. Johann Marton	Projektmitarbeit	22.08.2005 bis 31.12.2012
Dr. Ken Suzuki	Projektmitarbeit	01.12.2006 bis 30.11.2012
Univ.-Prof. Dr. Eberhard Widmann	Projektmitarbeit	22.08.2005 bis 31.12.2012
Dr. Johann Zmeskal	Projektleitung	22.08.2005 bis 31.12.2012

#### PUBLIKATIONEN:

Cargnelli, M.; Curceanu, C.; Faber, M.; Guaraldo, C.; Hirtl, A. et al. [...] (01.03.2006) Letter of Intent: Study of deeply bound kaonic nuclear states at DAΦNE2. [Bühler, P. (KoautorIn); Cargnelli, M. (KoautorIn); Hirtl, A. (KoautorIn); Ishiwatari, T. (KoautorIn); Kienle, P. (KoautorIn); Marton, J. (KoautorIn); Widmann, E. (KoautorIn); Zmeskal, J. (KoautorIn)]
Bühler, P.; Cargnelli, M.; Kienle, P.; Marton, J.; Widmann, E. et al. [...] (15.06.2006) AMADEUS at DAFNE 2. (International Workshop Exotic hadronic atoms, deeply bound kaonic nuclear states and antihydrogen: present results, future challenges). [Cargnelli, M. (KoautorIn); Ishiwatari, T. (KoautorIn); Kienle, P. (KoautorIn); Marton, J. (KoautorIn); Widmann, E. (KoautorIn); Zmeskal, J. (HauptautorIn)]

#### VORTRAG/POSTERPRÄSENTATION:

Cargnelli, Michael (27.04.2006) AMADEUS - Study of deeply bound kaonic nuclear states at DAFNE2 . Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Cargnelli, Michael]
Kienle, Paul (11.10.2006) The AMADEUS Project. Vortrag: IX International Conference on Hyper-nuclear and Strange Particle Physics, Mainz/GERMANY. [Kienle, Paul]
Zmeskal, Johann (12.06.2006) Search for kaonic nuclei at DAFNE 2: the AMADEUS project. Vortrag: 9th International Workshop on Meson Production, Properties and Interaction - MESON 06, Krakow/POLAND. [Zmeskal, Johann]
Zmeskal, Johann (17.10.2006) Search for antikaon-mediated bound nuclear clusters with FOPI, AMADEUS and P15. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Zmeskal, Johann]
Zmeskal, Johann (18.09.2006) Search for antikaon-mediated bound nuclear clusters with FOPI and AMADEUS. Vortrag: Seminar TU München, München/GERMANY. [Zmeskal, Johann]
Zmeskal, Johann (23.06.2006) AMADEUS at DAFNE 2. Vortrag: International Workshop: Exotic hadronic atoms, deeply bound kaonic nuclear states and antihydrogen: present results, future challenges (ECT*), Trento/ITALY. [Zmeskal, Johann]

### 1.3.1.5 FS1\_e: Deeply bound kaonic nuclei K-ppn and K-pnn: Experiment E549 at KEK

Akaishi and Yamazaki predicted strongly bound kaonic nuclear states with narrow width<sup>26</sup>. In the E549 and E570 experiments, data of the  ${}^4\text{He}(\text{stopped K}, \text{N})$  reactions with N being a proton or a neutron were accumulated to increase the statistics obtained by the previous experiment (E471), with upgrades of the detector systems<sup>27, 28</sup>. Compared to E471, about 20 times of statistics for the proton inclusive data and 5 times for the neutron data were accumulated. The time resolution was improved from 300 to 120 ps for the proton data, and from 300 to 200 ps for the neutron data.

The narrow ( $\sim 20$  MeV) peak identified as the  $S^0(3115)$  state in Ref<sup>29</sup> was not reproduced in both the inclusive  ${}^4\text{He}(\text{stopped K}, \text{p})$  and semi-inclusive  ${}^4\text{He}(\text{stopped K}, \text{p}X^\pm)$  reaction channels<sup>28</sup>, where  $X^\pm$  denotes one of the decay charged particles. Detailed comparison of the experimental data and simulations showed that the narrow peak structure previously reported as the  $S^0(3115)$  state was caused by an analysis procedure which used an approximation function for the slewing correction of the time-of-flight measurement. With a slewing correction function taking into account higher-order terms, it was found that the peak reported in<sup>29</sup> has a much larger width, if it exists at all. The upper limit of the probability for the  $S^0$  state to have a narrow width ( $< 20$  MeV) was found to be only  $10^{-4}$ .

For the neutron spectra obtained by the  ${}^4\text{He}(\text{stopped K}, \text{n})$  reaction, an indication for a peak-like structure named later  $S^+(3140)$  was reported previously<sup>30</sup>, although it was never published. A recent analysis including the E549 and E570 data shows that in contradiction to the previous result, no significant narrow peak structure can be seen in the spectra (see Fig. 15)<sup>27</sup>.

The RIKEN group is now analyzing the proton and neutron data assuming a wider peak than was theoretically predicted. The determination of the background components, which is important to find a wide peak, has been performed with detail studies of the hyperon-decay channels. In particular, data analysis based on the invariant mass, which is similar to the analysis performed by FINUDA, could be helped to understand our spectra.

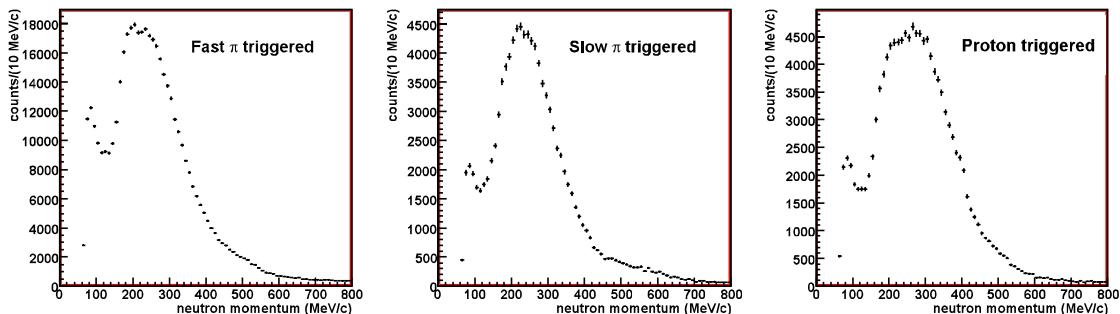


Fig. 15: The neutron momentum spectra: triggered with fast pions (left), with slow pions (middle), with protons (right).

<sup>26</sup> Y. Akaishi and T. Yamazaki, Phys. Rec. C 65 (2002) 04405.

<sup>27</sup> H. Yim *et al.*, Proc. of HYP06, Mainz 2006.

<sup>28</sup> M. Iwasaki *et al.*, Proc. of HYP06, Mainz 2006.

<sup>29</sup> T. Suzuki *et al.*, Phys. Lett. B 597 (2004) 263.

<sup>30</sup> M. Iwasaki *et al.*, nucl-ex/0310018 (2004).

PERSONEN:

Name	Funktion	Funktion: Zeitraum
Dr. Tomoichi Ishiwatari	Projektmitarbeit	01.11.2004 bis 31.12.2006
Prof. Dr. Paul Kienle	Projektmitarbeit	01.11.2004 bis 31.12.2006
Univ.-Prof. Dr. Eberhard Widmann	Projektleitung, Projektmitarbeit	01.11.2004 bis 31.12.2006

PUBLIKATIONEN:

Sato, M.; Ishiwatari, T.; Widmann, E. (11.07.2006) Experimental study of strange tribaryons in the  ${}^4\text{He}(\text{K}^-, \text{p})$  reaction. (PARTICLES AND NUCLEI: Seventeenth International Conference on Particles and Nuclei) In Reihe: AIP Conference Proceedings - Volume 842: American Institute of Physics, S. 480-482. [Ishiwatari, T. (KoautorIn); Widmann, E. (KoautorIn)]

### 1.3.1.6 FS1\_f: Kaonic helium X-rays: Experiment E570 at KEK

There is a long-standing problem in the energy level of the kaonic  ${}^4\text{He}$  2p state. A large repulsive shift (about -40 eV) of the kaonic  ${}^4\text{He}$  2p state was measured by three experimental groups<sup>31</sup> in the 1970's and 80's, while a very small shift (< 1 eV) was obtained by the optical models<sup>32,33</sup> calculated from the kaonic atom X-ray data with  $Z>2$ . This significant disagreement (a difference of over 5 standard deviations) between the experimental results and the theoretical calculations is known as the "kaonic helium puzzle."

More than 30 years ago, a formation of kaon-nucleus bound states has been predicted<sup>34</sup>. Recently, Akaishi and Yamazaki predicted the formation of a narrow width of the deeply bound kaonic states, taking into account the available kaonic X-rays data including  $Z=1$ , and 2, as well as the data from scattering experiments<sup>35</sup>. The experimental search for these states has been performed at KEK, LNF, and BNL<sup>36</sup>.

Apart from the direct measurements of the deeply bound kaonic states, the accurate determination of the energy and width of the kaonic  ${}^4\text{He}$  X-rays is quite important for:

- Solving of the kaonic helium puzzle (the large repulsive shift).
- Determination of the accurate theory (the optical potential model or the deeply-bound theory).
- Further improvement of studies in the field of the low-energy physics in the strangeness sector.

In the KEK PS E570 experiment<sup>37</sup>, the energy shift and width of the kaonic He L X-rays were measured, using a new technique for the X-ray spectroscopy. Due to our experience with the development of silicon drift detectors (SDDs) for SIDDHARTA, SMI proposed to install 8 SDDs as X-ray detectors. The measurement was performed in October and December 2005 at the KEK K5 beam line. The X-ray events from the kaonic atoms were selected using the data of the drift chambers as well as the SDD timing. The kaonic X-rays were measured with high energy resolution (about 180 eV FWHM at 6.5 keV), and a good time resolution (about 430 ns FWHM)<sup>37</sup>.

The in-beam energy calibration of the SDDs was performed using the Ti and Ni X-ray lines. The X-ray energy of the calibration lines was carefully studied. Since these X-rays were induced by the pion component of the kaon beam ( $\pi : K = 200 : 1$ ), there might be an energy shift due to the existence of satellite lines (X-ray transitions with different electron configurations)<sup>38</sup>.

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<sup>31</sup> C.E. Wiegand *et al.*, Phys. Rev. Lett. 27(1971) 1410; C.J. Batty *et al.*, Nucl. Phys. A 326 (1979) 455; S. Baird *et al.*, Nucl. Phys. A 392(1983) 297.

<sup>32</sup> C. J. Batty *et al.*, Nucl. Phys. A 326 (1979) 455.

<sup>33</sup> Y. Akaishi, Proc. of International Conference on Exotic Atoms and Related Topics (EXA05), Vienna, Austria, 2005.

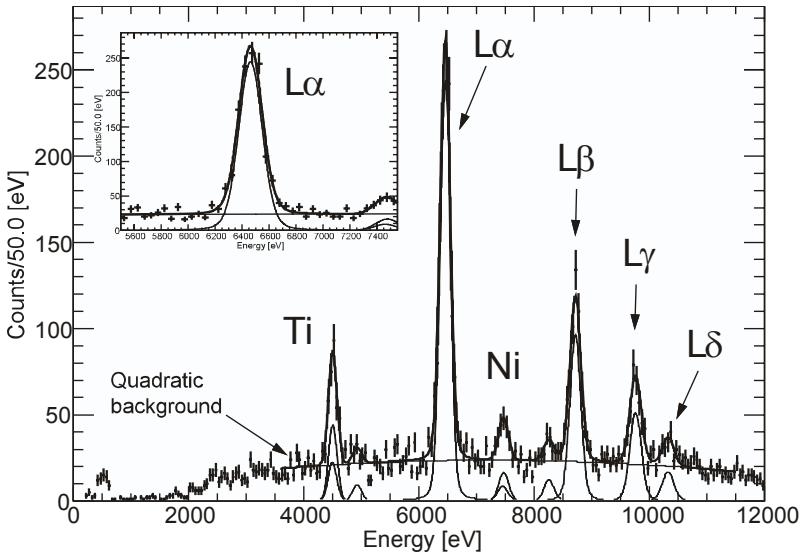
<sup>34</sup> R. Seki, Phys. Rev. C5(1972) 1996; J. H. Koch *et al.*, Phys. Rev. C5(1972) 381.

<sup>35</sup> Y. Akaishi and T. Yamazaki, Phys. Rev. C 65 (2002) 04405.

<sup>36</sup> T. Suzuki *et al.*, Phys. Lett. B 597 (2004) 263; M. Agnello *et al.*, Phys. Rev. Lett. 94 (2005) 212303; T. Kishimoto *et al.*, Nucl. Phys. A 754 (2005) 383.

<sup>37</sup> R. S. Hayano *et al.*, Proc. of "IX International Conference on Hypernuclear and Strange Particle Physics" (HYP2006), Mainz, 2006.

<sup>38</sup> Y. Cauchois *et al.*, Wavelengths of X-ray Emission Lines and Absorption Edges, Pergamon Press, Oxford, 1978.



**Fig. 16:** Energy spectra of kaonic helium after selecting data of drift chamber and timing between the kaon events and the X-ray events. The data are taken in the October 2005 run. Four lines of the kaonic He L transitions are clearly seen.

data taking, an  $^{55}\text{Fe}$  source was also installed to see an X-ray line with the well known energy. To check the energy shift, the X-ray lines induced by gamma-rays were also measured with a  $^{57}\text{Co}$  source. It is found that there is no significant energy shift due to induced pions. This measurement proved that the effects of the satellite peaks were negligible for our energy calibration.

The high-energy tails caused by the pile-up events were rejected using the flash-ADC data. Since these data stored the signal pulse shapes, we can select only events which cause no pile-up. The analysis is in progress.

The kaonic X-rays pass through liquid He. In this case, there is a significant effect of the incoherent (Compton) scattering in the target material, which causes X-ray energy loss, and creates a low-energy tail on the peaks. The estimation of the Compton tail is now in progress by Monte Carlo simulations.

Fig. 16 shows the energy spectra taken in the October run. The kaonic helium L-series lines ( $\text{L}\alpha$ ,  $\text{L}\beta$ ,  $\text{L}\gamma$  and  $\text{L}\delta$ ) are clearly observed. The energy of the kaonic helium X-rays were determined with a statistical accuracy of 2 eV. The determination of the final values for the shift and width is still in progress, but the present results show that the shift is definitely much smaller than -40 eV, and most likely less than  $\pm 10$  eV<sup>37</sup>. This means that the results of the three previous experiments were disproved.

## Outlook

Although the energy shift is found to be small, much accurate determination of the shift and width is very important to check whether the Akaishi-Yamazaki theory or the optical models are correct. The optical models can predict only an energy shift of less than 1 eV and a small width, while the Akaishi-Yamazaki theory can predict larger shifts and widths, which depend on the potential depth<sup>33</sup>. In particular, if we find a finite natural width in our results, this indicates that the optical potential is not correct.

The measurements of the kaonic  $^3\text{He}$  are also important. According to the Akaishi-Yamazaki theory, the energy shifts and widths of the kaonic  $^3\text{He}$  and  $^4\text{He}$  are very sensitive to the potential depths. Because the deeply-bound states are related to these potential depths, accurate measure-

The theoretical calculation of the energy shift due to the satellite lines induced by (high-energy) pions is not known, because a relativistic calculation is needed, while calculations of the satellite lines are usually by low-energy protons or light ions, which are performed with nonrelativistic approximation.

The effects of the energy shifts caused by the satellite peaks were measured with a pion beam at the PSI  $\pi\text{M}1$  beam channel in 2006. As targets, thin Cu, Ti and Ni foils were used. During the

ments of both the kaonic  ${}^3\text{He}$  and  ${}^4\text{He}$  are very important. As a next step, the measurements of kaonic  ${}^3\text{He}$  (and  ${}^4\text{He}$ ) X-ray lines are planned at LNF (Italy) and J-PARC (Japan).

#### PERSONEN:

Name	Funktion	Funktion: Zeitraum
Dipl.-Ing. Dr. Michael Cagnelli	Projektmitarbeit	01.10.2004 bis 31.12.2006
Dr. Tomoichi Ishiwatari	Projektmitarbeit	01.10.2004 bis 31.12.2006
Dr. Bertalan Juhasz	Projektmitarbeit	01.09.2006 bis 31.12.2006
Dipl.-Ing. Dr. Johann Marton	Projektmitarbeit	01.10.2004 bis 31.12.2006
Philipp Schmid	Projektmitarbeit	01.06.2005 bis 31.12.2006
Univ.-Prof. Dr. Eberhard Widmann	Projektleitung	01.11.2004 bis 31.12.2006
Dr. Johann Zmeskal	Projektmitarbeit	01.10.2004 bis 31.12.2006

#### PUBLIKATIONEN:

Okada, S.; Cagnelli, M.; Ishiwatari, T.; Juhaesz, B.; Kienle, P. et al. [...] (17.11.2006) Precise measurement of kaonic helium 3d  $\rightarrow$  2p x-rays. (Conference on the Intersections of Particle and Nuclear Physics) In Reihe: AIP Conference Proceedings - Volume 870: American Institute of Physics, S. 493-495. [Cagnelli, M. (KoautorIn); Ishiwatari, T. (KoautorIn); Juhasz, B. (KoautorIn); Kienle, P. (KoautorIn); Marton, J. (KoautorIn); Schmid, P. (KoautorIn); Widmann, E. (KoautorIn); Zmeskal, J. (KoautorIn)]

#### VORTRAG/POSTERPRÄSENTATION:

Ishiwatari, T. (28.09.2006) Status report for E570. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik)/AUSTRIA. [Ishiwatari, Tomoichi]
Ishiwatari, Tomoichi (10.05.2006) Precision spectroscopy of Kaonic Helium 3d->2p X-rays. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Ishiwatari, Tomoichi]

### 1.3.1.7 FS1\_g: Study of the Kaon-Nucleon interaction @ J-PARC

J-PARC (Japan Proton Accelerator Research Complex) is a facility currently under construction as a joint venture of KEK and JAEA (Japan Atomic Energy Agency) in Tokai-mura, Ibaraki, Japan. Using a 50 GeV high-intensity proton synchrotron, secondary kaon beams of the highest intensity ever reached will become available from spring 2009.

Proposals for the first experiments at J-PARC were submitted and evaluated in 2006. SMI joined two proposals, which were both approved:

E15: A search for deeply-bound kaonic nuclear states by in-flight  ${}^3\text{He}(K^-, n)$  reaction.

E17: Precision spectroscopy of Kaonic Helium  $3\text{d} \rightarrow 2\text{p}$  X-rays.

Both experiments can be regarded as successors of the KEK experiments E471/549 and E570 in

which we have already been involved. E15 will search for the simplest K-cluster  $K^-pp$  by in-flight ( $K^-, n$ ) reactions. In-flight reactions have the advantage that the two-nucleon absorption of kaons, which is the largest background in experiments with stopped kaons, is strongly reduced. In addition to a missing-mass measurement as done so far, E15 will also allow invariant mass spectroscopy by detecting all charged particles originating from the decay of the K-cluster by using a cylindrical drift chamber in a solenoid magnet. This feature will be required from all



Fig. 17: Magnets of the 50 GeV protons synchrotron during installation in August 2006.

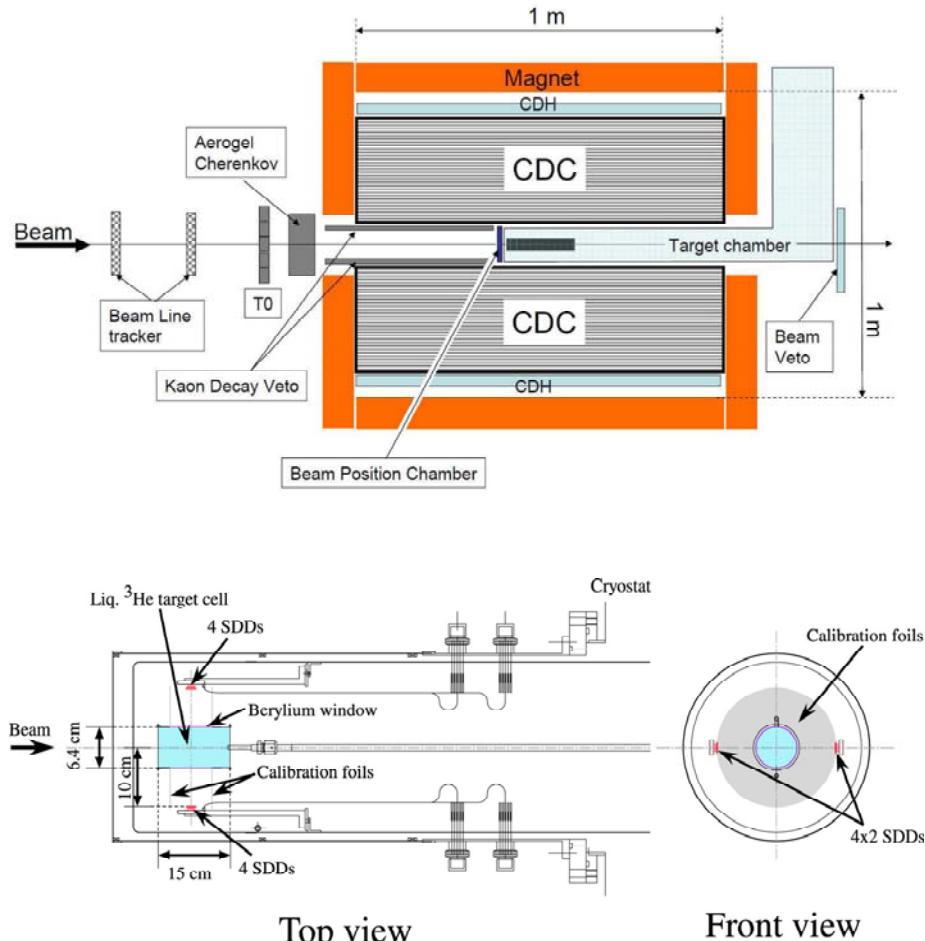


Fig. 18: Schematic setup of experiment E15 (top). View of the target and X-ray detectors for E17 (bottom).

next-generation experiments searching for deeply bound kaonic states. The experiment is already completely funded in Japan and construction is under way with the goal to be ready for the first beam from J-PARC in spring 2009.

E17 proposes to essentially perform the same measurement of 3d-2p X-ray transitions in  ${}^3\text{He}$  as E570 did it for  ${}^4\text{He}$ . The comparison of kaonic  ${}^3\text{He}$  and  ${}^4\text{He}$  will provide crucial information on the isospin-dependent kaon -nucleus strong interaction at the low energy limit, and will provide decisive data to understand the basis of the Akaishi-Yamazaki prediction of deeply-bound kaonic nuclei (see section on E570). E17 will make use of the liquid  ${}^3\text{He}$ -target, which is being constructed for E15, with some modifications to put SDD X-ray detectors close to it. As extensive experience was gained in operating SDDs in a high-intensity hadron beam, the experiment will be rather straightforward. SMI will participate – as before in E570 – by providing new SDD detectors in clusters as developed for SIDDHARTA having less dead areas to increase the solid angle.

## Outlook

Both experiments are expected to start data taking in spring 2009. E17 can finish with 1-4 weeks of data taking depending on the initial performance of the accelerator, while E15 will require 8 weeks of full phase-1 beam intensity.

### PERSONEN:

Name	Funktion	Funktion: Zeitraum
Dr. Paul Bühler	Projektmitarbeit	01.01.2006 bis 31.12.2012
Dipl.-Ing. Dr. Michael Cagnelli	Projektmitarbeit	01.01.2006 bis 31.12.2012
Dr. Tomoichi Ishiwatari	Projektmitarbeit	01.01.2006 bis 31.12.2012
Prof. Dr. Paul Kienle	Projektmitarbeit	01.01.2006 bis 31.12.2012
Dipl.-Ing. Dr. Johann Marton	Projektleitung, Projektmitarbeit	01.01.2006 bis 31.12.2012
Dr. Ken Suzuki	Projektmitarbeit	01.12.2006 bis 30.11.2012
Univ.-Prof. Dr. Eberhard Widmann	Projektmitarbeit	01.01.2006 bis 31.12.2012
Dr. Johann Zmeskal	Projektmitarbeit	01.01.2006 bis 31.12.2012

### PUBLIKATIONEN:

Buehler, P.; Cagnelli, M.; Hirtl, A.; Ishiwatari, T.; Kienle, P. et al. [...] (15.06.2006) Technical proposal to J-PARC: A search for deeply-bound kaonic nuclear states by-in-flight  ${}^3\text{He}(K^-, n)$  reaction. [Bühler, P. (KoautorIn); Cagnelli, M. (KoautorIn); Hirtl, A. (KoautorIn); Ishiwatari, T. (KoautorIn); Kienle, P. (KoautorIn); Marton, J. (KoautorIn); Widmann, E. (KoautorIn); Zmeskal, J. (KoautorIn)]

Buehler, P.; Cagnelli, M.; Hirtl, A.; Ishiwatari, T.; Kienle, P. et al. [...] (15.06.2006) Technical proposal to J-PARC: Precision spectroscopy of Kaonic Helium 3 3d  $\otimes$  2p X-rays. [Bühler, P. (KoautorIn); Cagnelli, M. (KoautorIn); Hirtl, A. (KoautorIn); Ishiwatari, T. (KoautorIn); Marton, J. (KoautorIn); Widmann, E. (KoautorIn); Zmeskal, J. (KoautorIn)]

### **1.3.1.8 FS1\_h: Theoretical Studies of Low Energy QCD, Investigated with Exotic Atoms**

In 2006 the collaboration with theoreticians of the Atomic Institute of TU Vienna was continued. Theoretical work was done on the development of theoretical models concerning the scientific case of kaonic atoms nuclear clusters which is in lively debate now<sup>39,40</sup> since a clear experimental verification is missing. Our institute will participate in new challenging experimental studies on this topic in experiments (AMADEUS@LNF, FOPI@GSI).

An important issue is the extraction of the isoscalar and isovector pion-nucleon scattering lengths. Given the unprecedented values of our PSI experiment on the strong interaction shift and width the correction terms are still an open question. Especially the correction concerning the strong interaction shift is large<sup>41</sup>. Results of theoretical studies<sup>42</sup> were published in 2006.

#### **Outlook**

Together with T.E.O. Ericson the extension of the theoretical work on theoretical treatment of our pionic hydrogen data was already discussed in February 2007 and will be continued.

#### **PERSONEN:**

Name	Funktion	Funktion: Zeitraum
Prof. Dr. Paul Kienle	Projektmitarbeit	01.01.2003 bis 31.12.2008
Dipl.-Ing. Dr. Johann Marton	Projektleitung	01.01.2003 bis 31.12.2008
Univ.-Prof. Dr. Eberhard Widmann	Projektmitarbeit	01.11.2004 bis 31.12.2008

#### **PUBLIKATIONEN:**

Ericson, T.E.O.; Ivanov, A. (2006) Dispersive e.m. corrections to pi N scattering lengths. Physics Letters B, Bd. 634 (1), S. 39-47. [Ivanov, A. (KoautorIn)]
Ericson, T. E. O.; Ivanov, A (11.07.2006) Dispersive e.m. corrections to pi N scattering at threshold. (PARTICLES AND NUCLEI: Seventeenth International Conference on Particles and Nuclei) In Reihe: AIP Conference Proceedings - Volume 842: American Institute of Physics, S. 525-527. [Ivanov, A. (KoautorIn)]
Ivanov, A.; Marton, J. (15.06.2006) Phenomenological quantum field theoretic model of Kaonic Nuclear Clusters K-pp, K-pnn and so on. (International Workshop Exotic hadronic atoms, deeply bound kaonic nuclear states and antihydrogen: present results, future challenges). [Ivanov, A. (HauptautorIn); Marton, J. (KoautorIn)]

#### **VORTRAG/POSTERPRÄSENTATION:**

Ivanov, A. (11.09.2006) Phenomenological model of Kaonic Nuclear Clusters K-pp, K -pnn and so
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<sup>39</sup> T. Yamazaki, Proc. EXA05, Austrian Academy of Sciences Press,  
Eds. A.Hirtl, J. Marton, E. Widmann, J. Zmeskal (2005) 23

<sup>40</sup> W. Weise, Proc. ECT\* Workshop, arXiv:hep-ph/0610201 v1 (2006) p.39

<sup>41</sup> J. Gasser et al., Eur. Phys. J. C 26, 13–34 (2002)

<sup>42</sup> T. Ericson and A. Ivanov, Phys. Lett. (2006)

on. Vortrag: Symposium QCD: Facts and Prospects, Oberwölz, Steiermark/AUSTRIA. [Ivanov, Andrei]

Ivanov, Andrei (21.06.2006) Phenomenological quantum field theoretic model of Kaonic Nuclear Clusters K-pp, K-pnn and so on. Vortrag: International Workshop Exotic hadronic atoms, deeply bound kaonic nuclear states and antihydrogen: present results, future challenges (ECT\*), Trento/ITALY. [Ivanov, Andrei]

### 1.3.2 FS2\_A: Matter - antimatter symmetry: ASACUSA @ CERN

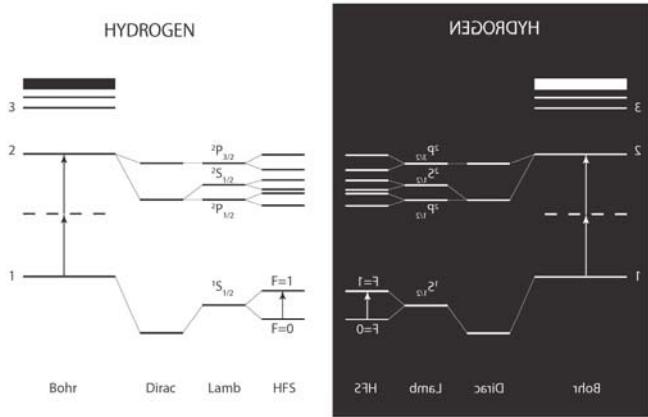


Fig. 19: Energy levels of hydrogen and antihydrogen.

metry) as well as the accuracy of state-of-the-art three-body QED calculations via the precision laser and microwave spectroscopy of atoms containing antiprotons.

Antihydrogen, the simplest antimatter atom consisting of a positron and an antiproton, is a promising tool for testing CPT symmetry because the CPT conjugate system, hydrogen, has been measured to precision of  $\sim 10^{-14}$  for the 1S-2S two-photon laser transition and  $\sim 10^{-12}$  for the ground-state hyperfine structure.

Antiprotonic helium is a neutral three-body system consisting of a helium nucleus, an antiproton, and an electron (see Fig. 20). The energy levels of the antiproton have been measured by precision laser spectroscopy to an accuracy of about  $10^{-8}$ . Each level ( $n, L$ ) is split into a quadruplet due to the magnetic interaction of the electron spin, the antiproton angular momentum and the antiproton spin.

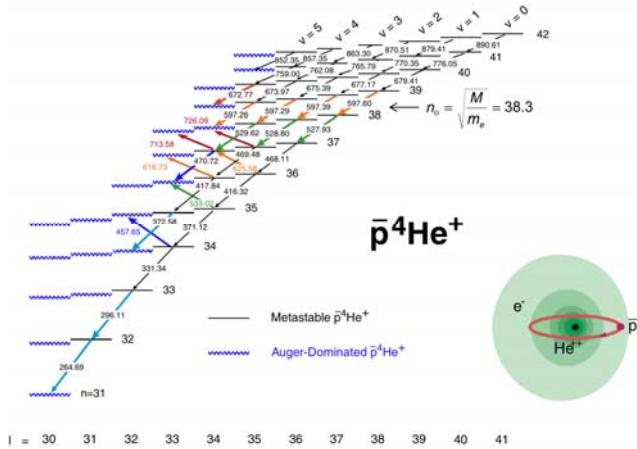


Fig. 20: Level diagram of antiprotonic helium.

This is the second main scientific program at SMI. Our institute has become a full member of ASACUSA and a Memorandum of Understanding has been signed between the Academy of Sciences, the other member institutes, and CERN. Within the ASACUSA program, SMI is involved in the precision spectroscopy of antiprotonic helium and the development of a spectrometer beam line for the measurement of the ground-state hyperfine splitting of antihydrogen. These experiments investigate the matter/antimatter symmetry (CPT symmetry)

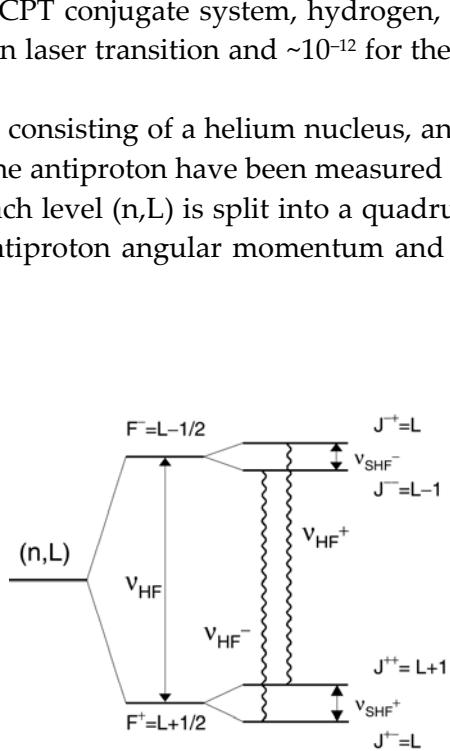


Fig. 21: Hyperfine structure of antiprotonic  ${}^4\text{He}$ .

PERSONEN:

Name	Funktion	Funktion: Zeitraum	
Dr. Bertalan Juhasz	Projektmitarbeit	01.07.2005 31.12.2012	bis
Chloe Malbrunot	Projektmitarbeit	01.07.2006 30.06.2007	bis
Dipl.-Ing. Dr. Johann Marton	Projektmitarbeit	01.11.2004 31.12.2012	bis
B. Sc. with 1st degree honours Thomas Pask	Projektmitarbeit	01.07.2005 31.12.2012	bis
Dr. Ken Suzuki	Projektmitarbeit	01.12.2006 30.11.2012	bis
Univ.-Prof. Dr. Eberhard Widmann	Projektleitung, Projektmitarbeit	01.11.2004 31.12.2012	bis
Dr. Johann Zmeskal	Projektmitarbeit	01.11.2004 31.12.2012	bis

PUBLIKATIONEN:

Curceanu, C.; Rusetski, A.; Widmann, E. (2006) Exotic atoms cast light on fundamental questions. CERN Courier, Bd. 46 (9), S. 32-34. [Widmann, E. (KoautorIn)]

VORTRAG/POSTERPRÄSENTATION:

Marton, Johann (20.07.2006) Testing Matter/Antimatter Symmetry with Antiprotonic Atoms and Antihydrogen. Posterpräsentation: International Conference on Atomic Physics ICAP 2006, Innsbruck/AUSTRIA. [Marton, Johann]

Juhasz, Bertalan (06.10.2006) ASACUSA: Testing the CPT symmetry with antiprotons. Vortrag: ECFA meeting, Debrecen/HUNGARY. [Juhasz, Bertalan]

Widmann, Eberhard (03.02.2006) Physics with low-energy antiprotons – from AD to FLAIR. Vortrag: XLIV International Winter Meeting on Nuclear Physics , Bormio /ITALY. [Widmann, Eberhard]

Widmann, Eberhard (05.04.2006) Fundamental tests with trapped antiprotons part 1. Vortrag: Trapped charged particles for fundamental interactions, WE Heraeus Winter School, Hirschgägg/AUSTRIA. [Widmann, Eberhard]

Widmann, Eberhard (05.04.2006) Fundamental tests with trapped antiprotons part 2. Vortrag: Trapped charged particles for fundamental interactions, WE Heraeus Winter School, Hirschgägg/AUSTRIA. [Widmann, Eberhard]

Widmann, Eberhard (06.11.2006) Studying fundamental symmetries and interactions with exotic atoms. Vortrag: Seminar zur starken Wechselwirkung (TU München), München/GERMANY. [Widmann, Eberhard]

Widmann, Eberhard (07.04.2006) Fundamental tests with trapped antiprotons part 3. Vortrag: Trapped charged particles for fundamental interactions, WE Heraeus Winter School, Hirschgägg/AUSTRIA. [Widmann, Eberhard]

Widmann, Eberhard (07.04.2006) Fundamental tests with trapped antiprotons part 4. Vortrag:

Trapped charged particles for fundamental interactions, WE Heraeus Winter School, Hirschegg/AUSTRIA. [Widmann, Eberhard]

Widmann, Eberhard (12.10.2006) Studying fundamental interactions and symmetries with exotic atoms. Vortrag: Seminar physics department (Uppsala University), Uppsala /SWEDEN. [Widmann, Eberhard]

Widmann, Eberhard (14.09.2006) Physics with low-energy antiprotons Part 1. Vortrag: 6th Euro-school on Exotic Beams, ECT\* Trento, Trento/ITALY. [Widmann, Eberhard]

Widmann, Eberhard (14.09.2006) Physics with low-energy antiprotons Part 2. Vortrag: 6th Euro-school on Exotic Beams, ECT\* Trento, Trento/ITALY. [Widmann, Eberhard]

Widmann, Eberhard (15.09.2006) Physics with low-energy antiprotons Part 3. Vortrag: 6th Euro-school on Exotic Beams, ECT\* Trento, Trento/ITALY. [Widmann, Eberhard]

Widmann, Eberhard (27.03.2006) Current and future experiments with low-energy ANTIPROTONS. Vortrag: Seminar Inst. f. theoret. Physik TU Wien, Wien/AUSTRIA. [Widmann, Eberhard]

Widmann, Eberhard (30.03.2006) Present and future of exotic atom research with antiprotons. Vortrag: Symposium (MPI Heidelberg), Heidelberg/GERMANY. [Widmann, Eberhard]

### 1.3.2.1 FS2\_b: Hyperfine structure of antiprotonic helium

The hyperfine structure of antiprotonic helium is investigated by a laser-microwave-laser method, where a first laser pulse is used to depopulate one of the hyperfine (HF) doublets (e.g. F<sup>-</sup> in Fig. 21), a microwave pulse to transfer population from F<sup>-</sup> to F<sup>+</sup>, and a second laser pulse to detect the population change caused by the microwave pulse. During the 3 weeks of beam time allotted to this experiment in 2006, it was shown that an improved determination of the hyperfine splitting of  $\bar{p}^4\text{He}^+$  is possible and a systematic study was commenced. This systematic study included density dependent laser spectroscopy scans, collision parameter studies and preliminary microwave scans.

The laser scans demonstrated a distinct improvement to the achievable population asymmetry of the system. Fig. 22 shows the difference between the results of 2001 (left) and 2006 (right). The comparison between these two diagrams illustrates the increased stability and narrower bandwidth of the new pulse amplified cw laser system. The clear separation of the two hyperfine doublets is essential for a good signal to noise ratio.

Collisions between atoms cause broadening, damping and relaxation effects to the state that is being measured. Currently these various collision parameters are theoretically estimated to an accuracy of only orders of magnitude. The improvement to the laser system removes the previous 150 ns limit on the separation between the two laser pulses and, therefore, the microwave pulse length. This has allowed a time evolution study, both with and without the microwave, to experimentally determine the collision parameters as a function of target density more accurately. With further analysis these results will be publishable.

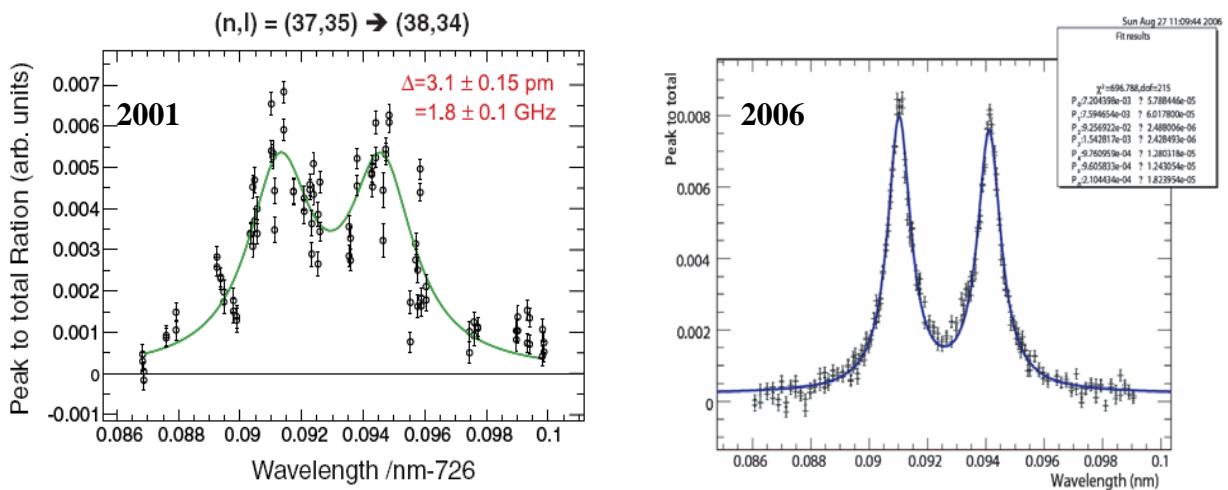
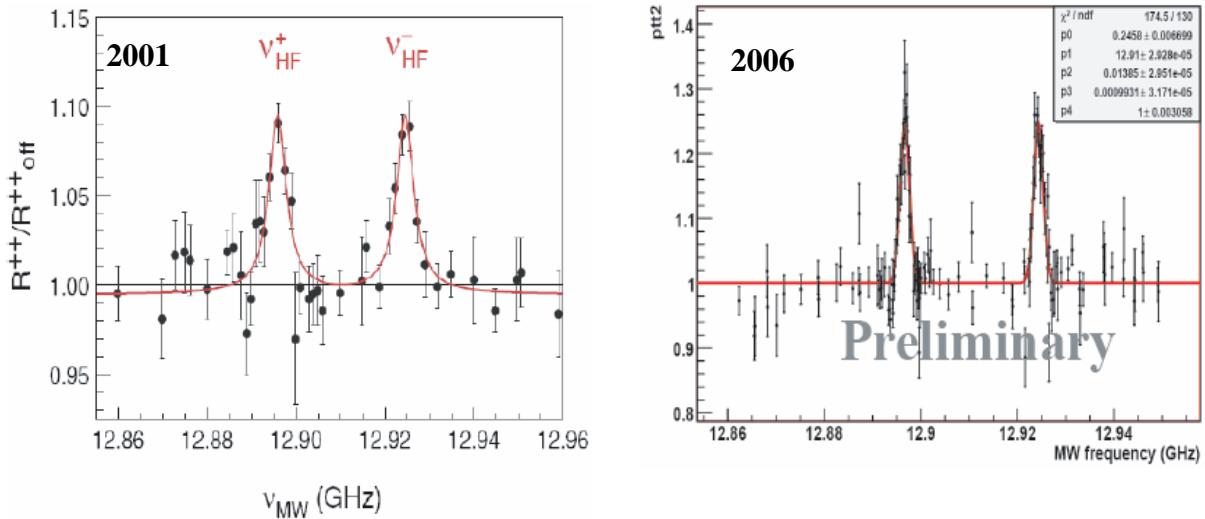


Fig. 22: Laser resonance profile of the  $(n, l) = (37, 35)$  to  $(38, 34)$  transition measured at the AD ring in 2001 (left) and 2006 (right).



*Fig. 23: Microwave resonance profiles of the (37, 35) metastable state. The data was taken at the AD ring in CERN in 2001 (left) and 2006 (right).*

The microwave scans were measured with a laser separation of both 350 ns and 500 ns during the last 3 shifts of the 2006 beam time. It was concluded that the 350 ns scan was more statistically significant. Fig. 23 shows the 2001 (left) microwave scan next to data that was measured over a period of 12 hours during the 2006 beam time. The new measurement has a preliminary resolution of 60 kHz (a factor of 5 better than 300 kHz resolution in 2001) and a line width of 2 MHz (6 MHz in 2001). Analysis to determine the cause of systematic errors is on going.

The building of a new cavity for future measurements on the 11 GHz splitting in  $\bar{p}^3\text{He}^+$  has begun. The dimensions have been scaled from the previous cavity designed to study the (37,35) state of  $\bar{p}^4\text{He}^+$ . Measurements on the microwave reflection and transmission characteristics of this new cavity, coupled to the waveguide, are currently under study. The size of the iris (cf. Fig. 24) between the cavity and the waveguide is being increased gradually to reach the optimal coupling.

Moreover, numerical simulations have been performed to model the population evolutions of the state under study. Measurements of the hyperfine structure in antiprotonic  ${}^3\text{He}$  are planned for 2008.

An experimental measurement of the hyperfine structure (HFS) can be compared with QED calculations to determine the difference between the antiproton and proton spin magnetic moment. In 2001 this was measured to an accuracy of 1.6%<sup>43</sup>, while the current most precise measurement is 0.3%<sup>44</sup>. A major progress in understanding the achievable improvement of this quantity by measuring the HFS of antiprotonic helium came through extensive discussions with Dimatar Bakalov from INRE Sofia, which lead to a publication<sup>45</sup>, submitted during his stay at SMI in November 2006. The questions addressed are the sensitivity of the observable transitions to the antiproton spin magnetic moment and the limits coming from the omission of terms of order  $\alpha^2$  in the theoretical treatment. It was shown that if the hyperfine structure can be measured to a resolution of 30 kHz for the (37,35) state, the precision of



*Fig. 24: New microwave cavity for 11 GHz.*

<sup>43</sup> E. Widmann et al., Phys. Rev. Lett. 89 (2002) 243402.

<sup>44</sup> A. Kreissl et al., Z. Phys. C 37, 557 (1988).

<sup>45</sup> D. Bakalov, Eberhard Widmann, arXiv:physics/0612021 submitted to PRA

the antiprotonic spin magnetic moment will be known to 0.1%, a factor of three better. Measuring the state (39,35) to the same absolute precision will even yield an improvement of a factor 9.

This result is an essential prerequisite for an application to FWF as the potential of the method to improve the value of the magnetic moment of the antiproton is now clear, and the best energy levels to be studied have been identified. An application, which had initially been planned to be submitted during 2006, is now being prepared.

### **Outlook**

The goal for 2007 is to measure the  $\bar{p}^4\text{He}^+$  ( $n, L = (37,35)$ ) state to the highest possible degree of meaningful precision. The precision can be improved to 30 kHz by collecting four times the statistics of 2006. The density dependence must also be determined so the same statistics over three different densities is needed. Therefore four weeks of running period have been allocated in 2007.

After this year other hyperfine states are of interest. The entire program is expected to take 2-3 years. During this period the first measurements on  $\bar{p}^3\text{He}^+$  are intended, where agreement between theory and experiment, in the laser transitions, is not so clear. The investigation of a second  $\bar{p}^4\text{He}^+$  state (39,35), for an even better test of CPT theory, is also planned.

### **PERSONEN:**

Name	Funktion	Funktion: Zeitraum	
Dr. Bertalan Juhasz	Projektmitarbeit	01.07.2005	bis 31.12.2009
Chloe Malbrunot	Projektmitarbeit	01.06.2006	bis 31.05.2007
Dipl.-Ing. Dr. Johann Marton	Projektmitarbeit	01.11.2004	bis 31.12.2009
B. Sc. with 1st degree honours Thomas Pask	Projektmitarbeit	01.07.2005	bis 31.12.2009
Dr. Ken Suzuki	Projektmitarbeit	01.12.2006	bis 30.11.2012
Univ.-Prof. Dr. Eberhard Widmann	Projektleitung, Projektmitarbeit	01.11.2004	bis 31.12.2009
Dr. Johann Zmeskal	Projektmitarbeit	01.11.2004	bis 31.12.2009

### **VORTRAG/POSTERPRÄSENTATION:**

Bakalov, Dimitar (08.11.2006) Can antiproton magnetic moment be determined from the hyperfine structure of antiprotonic helium?. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Bakalov, Dimitar]

Pask, T. (18.10.2006) Preliminary Results From the Microwave Experiment. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Pask, Thomas]

Pask, T.; Malbrunot, C. (07.12.2006) Results of ASACUSA run 2006. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Malbrunot, Chloe; Pask, Thomas]

Pask, Thomas (18.09.2006) An Improved Measurement of the Hyperfine Structure of Anti-protonic Helium. Reducing the Upper Limit on CPT theory?. Vortrag: Fachausschusstagung Kern- und Teilchenphysik 2005 (Österreichische Physikalische Gesellschaft), Maria Lankowitz/AUSTRIA.  
[Pask, Thomas]

### 1.3.2.2 FS2\_c: Precision laser spectroscopy of antiprotonic helium

#### Determination of the antiproton-to-electron mass ratio

High-precision laser spectroscopy experiments were carried out on antiprotonic helium atoms<sup>46</sup> ( $\bar{p}\text{He}^+$ ) in 2004 using a femtosecond optical frequency comb and a continuous-wave pulse-amplified laser. The transition frequencies between different antiprotonic states have been measured with an accuracy of  $\sim 10^{-8}$ . Comparing these results with three-body QED calculations, we could deduce an antiproton-to-electron mass ratio of  $M_{\bar{p}}/m_e = 1836.152674(5)$ <sup>47</sup>.

This is consistent with the value for the proton (see Fig. 25). We also concluded that the mass and charge of the antiproton agree with those of the proton to a precision of  $2 \times 10^{-9}$ . A press release on this article was published through the press office of the Austrian Academy of Sciences.

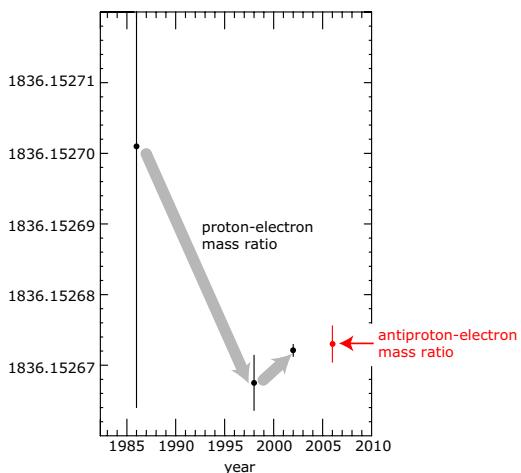


Fig. 25: Proton to electron mass ratio over the years and new antiproton to electron mass ratio.

protostellar clouds, including our own solar system. However, no data on the reaction rate of these exchange reaction exist at such low temperatures due to various technical difficulties.

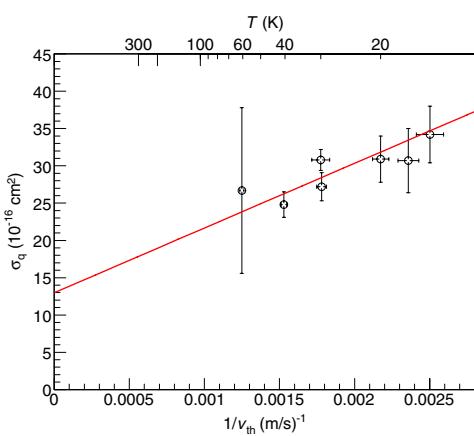


Fig. 26: Quenching cross section  $\sigma_q$  of the antiprotonic state  $(n,l) = (39,35)$  in antiprotonic helium as a function of the inverse thermal velocity  $v_{th}$ .

Simple hydrogenic exchange reactions like  $\text{D} + \text{H}_2 \rightarrow \text{H} + \text{DH}$  at low temperatures (10-50 K) play an important role in the early development of interstellar and

The antiprotonic helium atom,  $\bar{p}\text{He}^+$  consists of a helium nucleus, an antiproton, and an electron. From the electron's point of view, the helium nucleus and the antiproton together appear as a single 'nucleus' with an effective charge of +1.7 e. Thus an antiprotonic helium atom behaves as an exotic, 'heavy' hydrogen atom in collisions with other molecules including  $\text{H}_2$  or  $\text{D}_2$ . In these reactions, the  $\text{H}_2/\text{D}_2$  molecules are most likely dissociated, and one of the H/D atoms is attached to the  $\bar{p}\text{He}^+$  molecule to form a compound molecule. This compound molecule is short-lived, and its destruction ('quenching') is immediately followed by the annihilation of the antiproton. Since these annihilations are easy to detect, we can measure the cross section (i.e. the reaction rate) of the collisions, which can provide an insight into the behaviour of the above-mentioned hydrogenic exchange reactions as well.

<sup>46</sup> T. Yamazaki et al., Phys. Rep. 366, 183 (2002).

<sup>47</sup> M. Hori et al., Phys. Rev. Lett. 96, 233401 (2006).

The ASACUSA collaboration at CERN used laser spectroscopy to measure the quenching cross sections of several different states of antiprotonic helium at various temperatures in 2003. After a careful analysis of the data, the results were published in 2006<sup>48</sup>. They revealed that all but one state behaved as expected from a simple activation barrier model i.e. their cross sections decreased with decreasing temperature. However, the cross section of one state increased with decreasing temperature, showing a  $1/v$  dependence on the thermal velocity (see Fig. 26). This suggests that there is no activation barrier for this state, and is consistent with the Wigner threshold law of exothermic reactions involving neutral particles.

An article on this result and the observation of protonium formation through a chemical reaction in the Penning trap of the ATHENA collaboration appeared in the December 2006 issue of the CERN Courier under the title “Serendipity at the Antiproton Decelerator opens the way to new antiproton chemistry”.

### *Two-photon laser spectroscopy*

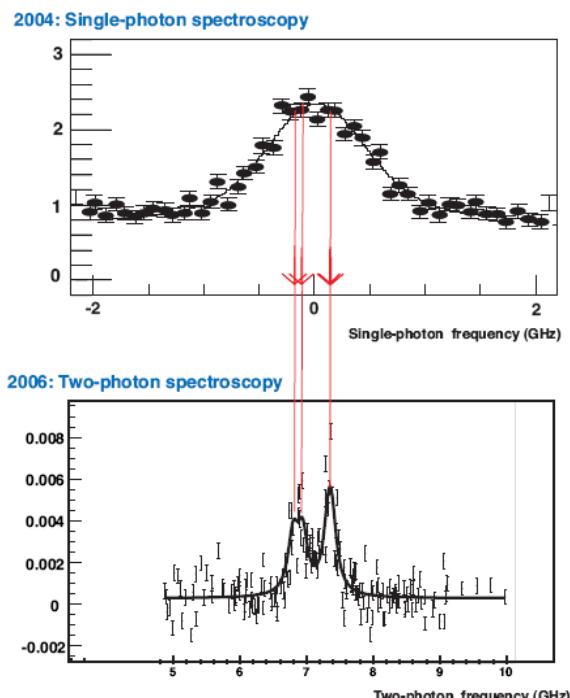


Fig. 27: Single-photon (top) and two-photon (bottom) scan.

### **Outlook**

In 2007, detailed and systematic measurements of the two-photon transitions in both  $\bar{p}^3\text{He}^+$  and  $\bar{p}^4\text{He}^+$  are planned. These studies will immediately lead to an improvement of the known value of the antiproton-to-electron mass ratio of a factor of 2-4. The laser system is being improved so that with a higher laser intensity and resolution the signal-to-noise ratio of the two-photon signal should be improved by a factor of 5-10 compared to the 2006 results.

During the beam time of 2006, the ASACUSA collaboration successfully carried out preliminary sub-Doppler laser spectroscopy experiments of antiprotonic helium atoms. The resonance profile of the transition  $(n,l) = (36,34) \rightarrow (35,33)$  at wavelength  $\lambda = 417$  nm has a width of  $\sim 1$  GHz, mainly due to the Doppler broadening. A two-photon technique was used to eliminate this Doppler broadening to the first order.

Two laser beams arranged in a counter propagating geometry, had non-equal frequencies adjusted such that their combined frequencies were tuned to the two-photon transition  $(n,l) = (36,34) \rightarrow (34,32)$  where the virtual intermediate state was tuned to within a few GHz of a real state  $(n,l) = (35,33)$ . Fig. 27 shows that, in comparison to the single photon in 2004, with two-photon spectroscopy the hyperfine structure is now resolvable.

<sup>48</sup> B. Juhász et al., Chem. Phys. Lett. 427, 246 (2006).

### *Antiprotonic helium ion*

During the 2006 beam time, the first laser spectroscopy measurements of  $\bar{p}\text{He}^{2+}$  were attempted. These antiprotonic helium ions are two body systems which are much more easily calculated, and therefore less dependent on theory than neutral three-body  $\bar{p}\text{He}^+$  systems. The disadvantage of measuring such systems is their short lifetimes (5-6 ns), and the fact that the difference between the lifetimes of the parent and daughter states is too small compared to our experimental resolution. Despite taking a lot of statistics, the results were inconclusive, and therefore no further measurements are intended for the ion.

#### PERSONEN:

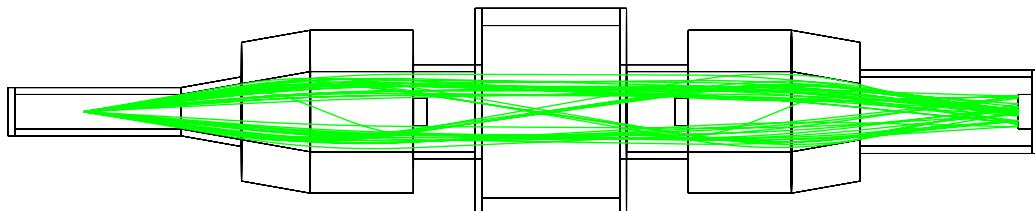
Name	Funktion	Funktion: Zeitraum
Dr. Bertalan Juhasz	Projektmitarbeit	01.07.2005 bis 31.12.2009
Chloe Malbrunot	Projektmitarbeit	01.07.2006 bis 30.06.2007
Dipl.-Ing. Dr. Johann Marton	Projektmitarbeit	01.11.2004 bis 31.12.2009
B. Sc. with 1st degree honours Thomas Pask	Projektmitarbeit	01.08.2005 bis 31.12.2009
Andrea Puhm	Projektmitarbeit	03.07.2006 bis 31.01.2007
Dr. Ken Suzuki	Projektmitarbeit	01.12.2006 bis 30.11.2012
Univ.-Prof. Dr. Eberhard Widmann	Projektleitung	01.11.2004 bis 31.12.2009
Dr. Johann Zmeskal	Projektmitarbeit	01.11.2004 bis 31.12.2009

#### PUBLIKATIONEN:

Hori, M.; Dax, A.; Eades, J.; Gomikawa, K.; Hayano, R.S. et al. [..] (2006) Determination of the Antiproton-to-Electron Mass Ratio by Precision Laser Spectroscopy of pHe+. Physical Review Letters, Bd. 96, S. 243401. [Juhasz, B. (KoautorIn); Widmann, E. (KoautorIn)]
Juhasz, B.; Barna, D.; Eades, J.; Fuhrmann, H.; Hayano, R.S. et al. [..] (2006) Low temperature behaviour of collisions between antiprotonic helium and hydrogenic molecules and an indication of the Wigner threshold law. Chemical Physics Letters, Bd. 427 (4-6 ), S. 246-250. [Juhasz, B. (HauptautorIn); Widmann, E. (KoautorIn); Zmeskal, J. (KoautorIn)]

### 1.3.2.3 FS2\_d: Measurement of the ground-state hyperfine structure of antihydrogen

The simulation and design of the beamline, which will be used to measure the ground-state hyperfine splitting of antihydrogen, continued in 2006. This beamline will consist of two sextupole magnets, a resonance microwave cavity between them, and an antihydrogen detector. It was decided that superconducting magnets will be used for the sextupoles. Different designs were simulated, and we found that the best shape for the sextupoles is a half tapered (i.e. conical), half



*Fig. 28: Monte Carlo simulation of the trajectories of antihydrogen atoms in the spectrometer line. The two sextupoles can be seen, with the microwave cavity inbetween them.*

straight design (see Fig. 28). This provides relatively high efficiency in a compact size.

Fig. 29 shows a preliminary design of the spectrometer line, including the two sextupoles and the microwave cavity, connected to a superconducting two-frequency cylindrical Paul trap, which can produce the required antihydrogen atoms by simultaneously trapping antiprotons and positrons. This Paul trap is in turn connected to another, linear Paul trap, which will capture and cool antiprotons. The building of the latter trap and its cryostat (as shown in Fig. 29) has already started at CERN, Geneva, Switzerland.

Another option to produce antihydrogen atoms is a cusp trap (i.e anti-Helmholtz coils). The building of this trap is already finished at RIKEN, Japan, and now is awaiting extensive tests.

## Outlook

Two antihydrogen sources are being built now: two superconducting Paul traps (which are connected to each other) at CERN, Switzerland, and a cusp trap (i.e. anti-Helmholtz coils) at RIKEN, Japan, both by Japanese collaborators. The building of the first Paul trap has started at CERN, and will be finished in 2007. The testing of this trap with antiprotons will most likely happen during the beamtime of 2008.

The cusp trap is already built, and will soon be tested with protons. Since this trap might be able to produce polarized and focussed antihydrogen atoms, the first sextupole might not be needed if this trap is used, since this sextupole essentially just polarizes the antihydrogen atoms. SMI will carry out simulations to determine the quality of the antihydrogen beam that will come out of the cusp trap. Based on the results, SMI will design the sextupole magnet(s) for this setup too.

SMI also took responsibility to design, build and commission the spectrometer line, which has to be ready and working by 2009, when it will be connected to the antihydrogen source. Thus the spectrometer line will be designed in 2007, and the construction will start at the end of that year. We will visit the Superconducting Magnet Group at the Brookhaven National Laboratory in the United States, who has a large experience in building similar magnets. Thus they might build the sextupoles for us, but we will also talk with other groups or companies as well. Previously, the time schedule of the antihydrogen production traps was not clear, and some delay was caused by

the technical and conceptual complexity of these devices. With the cusp trap now being tested with protons and electrons, and the Paul trap being built, the time horizon has become well defined so that the construction of the spectrometer line has to start end of 2007 to be ready in time. Thus a fraction of the investment money will already be needed in 2007.

One important part of the experimental setup is the antihydrogen detector. Since the detection rate will be very low (1-2 atoms per minute), it is important to suppress the background coming from cosmic rays (mostly muons). This task is not simple, and different detector designs are currently investigated by SMI.

#### PERSONEN:

Name	Funktion	Funktion: Zeitraum
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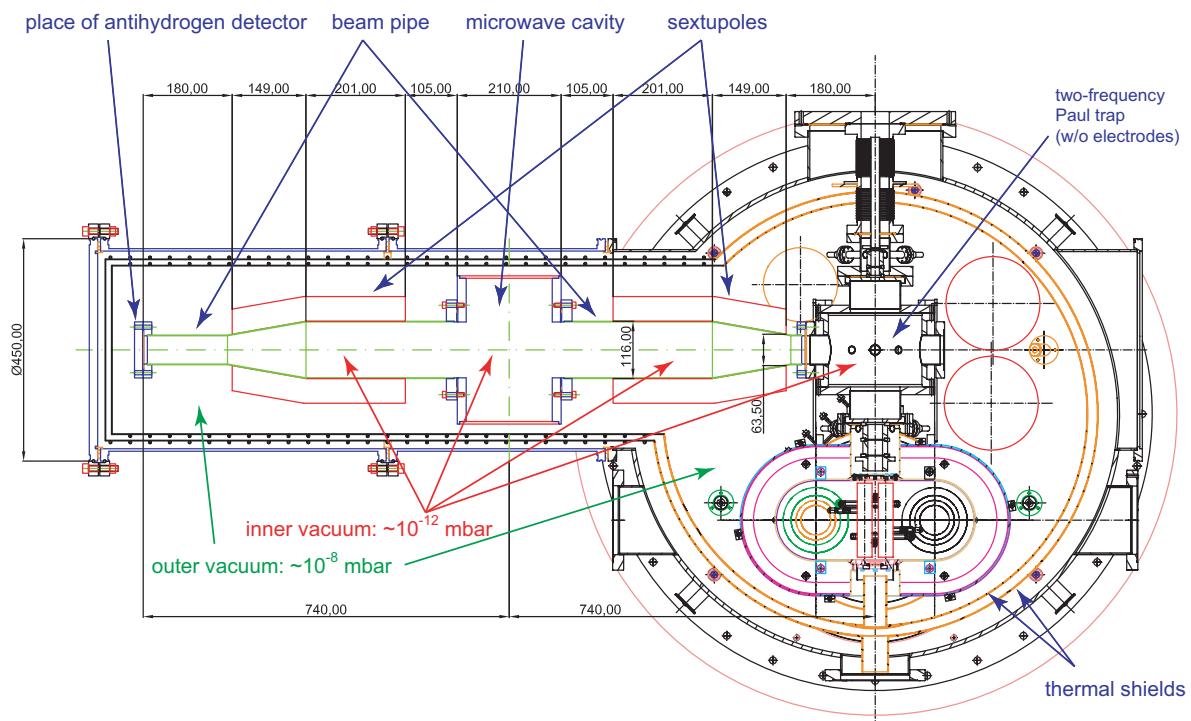


Fig. 29: Preliminary design of the antihydrogen recombination trap and the attached spectrometer line.

Dr. Bertalan Juhasz	Projektmitarbeit	01.07.2005 bis 31.12.2012
Dipl.-Ing. Dr. Johann Marton	Projektmitarbeit	01.11.2004 bis 31.12.2012
Univ.-Prof. Dr. Eberhard Widmann	Projektleitung, Projektmitarbeit	01.11.2004 bis 31.12.2012
Dr. Johann Zmeskal	Projektmitarbeit	01.11.2004 bis 31.12.2012

#### PUBLIKATIONEN:

Juhasz, B.; Widmann, B. (15.06.2006) Measurement of the ground-state hyperfine structure of antihydrogen. (International Workshop Exotic hadronic atoms, deeply bound kaonic nuclear states and antihydrogen: present results, future challenges). [Juhasz, B. (HauptautorIn); Widmann, E. (KoautorIn)]

#### VORTRAG/POSTERPRÄSENTATION:

Juhasz, Bertalan (01.12.2006) Sextupole beam line for ASACUSA. Vortrag: Seminar zu aktuellen

Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA.  
[Juhasz, Bertalan]

Juhasz, Bertalan (04.09.2006) Measurement of the ground-state hyperfine structure of antihydrogen. Vortrag: International Conference on Trapped Charged Particles and Fundamental Physics (TCP06), Parksville/CANADA. [Juhasz, Bertalan]

Juhasz, Bertalan (18.09.2006) Measurement of the ground-state hyperfine splitting of antihydrogen. Vortrag: ÖPG Fachausschusstagung Kern- und Teilchenphysik 2006, Maria Lankowitz/AUSTRIA. [Juhasz, Bertalan]

Juhasz, Bertalan (18.10.2006) Ground-state hyperfine structure of antihydrogen:STATUS. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Juhasz, Bertalan]

Juhasz, Bertalan (21.06.2006) Measurement of the ground-state hyperfine structure of antihydrogen. Vortrag: International Workshop Exotic hadronic atoms, deeply bound kaonic nuclear states and antihydrogen: present results, future challenges (ECT\*), Trento/ITALY. [Juhasz, Bertalan]

Schmid, Philipp (10.03.2006) Experimental studies on antihydrogen in-flight. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Schmid, Philipp]

### 1.3.3 FS3\_A: Antiprotons at FAIR



*Fig. 30: Sketch of FAIR.*

FAIR, the Facility for Antiproton and Ion Research, will be an extension of the existing Gesellschaft für Schwerionenforschung (GSI) near Darmstadt<sup>49</sup>. It will be an international research institute for nuclear and hadron physics, with 25 % of the construction cost provided from countries outside Germany. The physics program of FAIR covers a wide range of topics, such as high-energy antiproton beams for hadron physics in the charmonium range

(PANDA), low-energy antiproton beams for fundamental symmetries and atomic physics studies (FLAIR), high – energy heavy ion collisions (CBM), radioactive ion beams for nuclear structure studies (NUSTAR) and atomic physics with highly charged ions (SPARC / FLAIR). FAIR will become the most important center for hadron physics in Europe. The discussions with potential member states are currently going on and are expected to become final in middle of 2007. At the time of writing this report, the Austrian Ministry of Science has decided to sign the memorandum of understanding of FAIR and has shown willingness to significantly contribute to the construction and operation of the FAIR facility.

Due to delays in the process of forming the FAIR member structure, the time schedule has been updated and it now foresees an end of construction in 2015, where the antiproton part will be ready around 2014, 2 years later as assumed before. Regarding FAIR, the focus of the Stefan Meyer Institute lies in the physics program with antiprotons and the institute is involved in FLAIR, PANDA, and the Antiproton Ion Collider (AIC) which is part of NUSTAR.

#### PERSONEN:

Name	Funktion	Funktion: Zeitraum
Dr. Paul Bühler	Projektmitarbeit	01.04.2005 bis 01.01.2019
Dipl.-Ing. Dr. Michael Cagnelli	Projektmitarbeit	01.04.2005 bis 01.01.2025
Mag. Alexander Gruber	Projektmitarbeit	01.04.2005 bis 01.01.2019
Prof. Dr. Paul Kienle	Projektmitarbeit	01.04.2005 bis 01.01.2019
Dipl.-Ing. Dr. Johann Marton	Projektmitarbeit	01.04.2005 bis 01.01.2019
Dr. Ken Suzuki	Projektmitarbeit	01.12.2006 bis 30.11.2012
Univ.-Prof. Dr. Eberhard Widmann	Projektleitung	01.04.2005 bis 01.01.2019

<sup>49</sup> FAIR Baseline Technical Report 2006.

Name	Funktion	Funktion: Zeitraum
Dr. Johann Zmeskal	Projektmitarbeit	01.04.2005 bis 01.01.2019

#### VORTRAG/POSTERPRÄSENTATION:

Kienle, Paul (04.07.2006) Perspectives of Antiproton and Antikaon Physics. Vortrag: International Workshop, Observables of Antiproton Interactions and Their Relevance to QCD, Trento/ITALY. [Kienle, Paul]

Widmann, Eberhard (18.09.2006) Antiproton Physics at FAIR. Vortrag: ÖPG-FAKT Tagung, Maria Lankowitz/AUSTRIA. [Widmann, Eberhard]

Widmann, Eberhard (30.03.2006) Present and future of exotic atom research with antiprotons. Vortrag: Symposium (MPI Heidelberg), Heidelberg/GERMANY. [Widmann, Eberhard]

### 1.3.3.1 FS3\_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

The proposed Facility for Low-energy Antiproton and Heavy-Ion Research combines low energy antiproton beams and stable and instable highly-charged ions for atomic, nuclear and particle physics research. The key features of the facility will be the cooled, highly intense beams of antiprotons and bare and few-electron heavy ions. The combination of two decelerators – the Low-energy Storage Ring LSR and the Ultra-low energy Storage Ring,USR – and different ion/ antiproton traps will provide beams of excellent emittance covering energies from 100 MeV/u down to few eV. Over 15 different experiments have been proposed to be located at FLAIR and use the provided beams. Details about scientific goal and technical aspects of these experiments are presented in the FLAIR Technical Proposal <sup>50</sup>. E. Widmann is chairman of the steering committee of FLAIR.

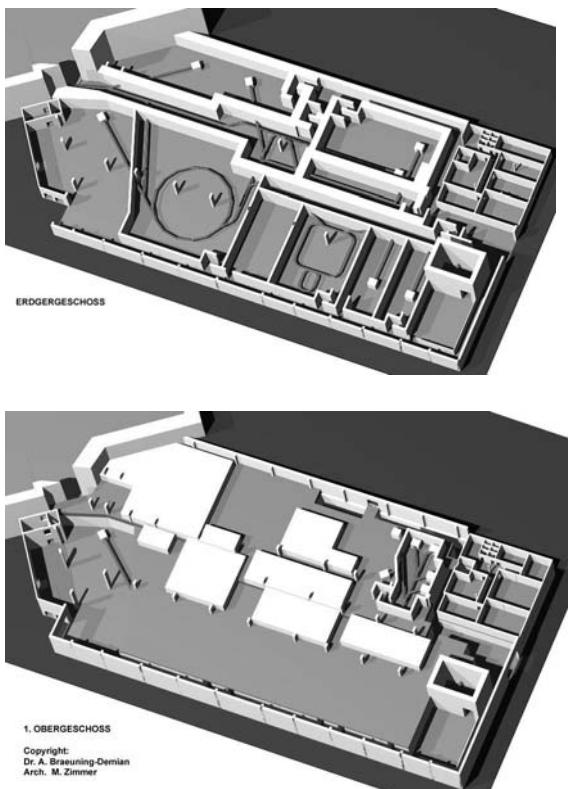


Fig. 31: 3D-view of the FLAIR building: the ground level (top) and the upper level (bottom).

delivered via LSR and USR. The large diversity of the experiments planned at FLAIR requires a complex beam sharing inside the facility and a good matching with the FAIR accelerator system.

The FLAIR collaboration held two collaboration meetings in 2006, one in May 2–3 at SMI and a second on December 19–20 at CERN. The latter one was completely devoted to the preparation of the design study in the Research Infrastructures part of the EU FP7 for which the call deadline is May 2007. SMI will take over the role of coordinator of the design study application and project, if successful.

During fall of 2006 a more detailed cost estimate was performed and the documents were submitted to the CORE-E review committee of FAIR. Currently estimates of operation costs are under way. Further progress has been made in the design of the FLAIR building at GSI.

In 2005 the STI committee decided to include FLAIR into the core-program of FAIR and the FLAIR building into the civil construction budget. The remainder of the facility, the storage rings, beam lines and experiments, are expected to be funded by the collaboration. To this end, the decision in spring of 2007 of the Austrian Ministry of Science to sign the memorandum of understanding and to consider substantial contributions to FAIR will help significantly. The LSR will be contributed by Sweden by adapting the existing CRYRING at Manne Siegbahn Laboratory, Stockholm, and the USR by Dr. Carsten Welsch (who obtained a Helmholtz Young Investigators group at GSI and University of Heidelberg) together with the Max Planck Institute for Nuclear Physics, Heidelberg.

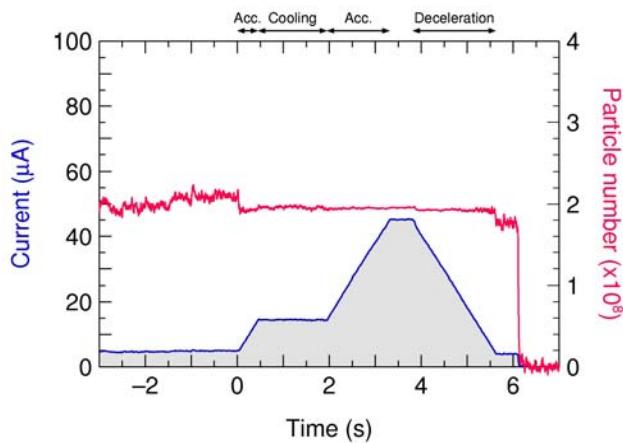
The integration of the LSR in the larger frame of the FAIR accelerator system was discussed at the "First Technical FLAIR Meeting on the Integration of CRYRING into FLAIR" (GSI, Mar. 20-21, 2006). For most of the FLAIR experiments, the antiproton and ion beams will be

<sup>50</sup> FLAIR Technical proposal – update (2005).

Fig. 31 shows the latest layout of the building which may still change as – due to outside constraints – the position of the FLAIR building might change and as a consequence the shape and layout may need to be modified. Once this is decided, a detailed design of the beam lines will start.

Tests with deceleration of protons have been performed at CRYRING in order to verify that the present machine configuration is adequate for antiproton deceleration at FLAIR. More specifically, the aim of the tests was to show that CRYRING can decelerate a sufficiently large number of particles, through the full energy range from 30 MeV to 300 keV, with acceptable particle losses.

CRYRING has already been used for deceleration in a few cases where users have requested light ions at energies lower than the injection energy of 300 keV per nucleon, as given by the RFQ. Since this injection energy is fixed, tests of deceleration of protons from 30 MeV must be made by first accelerating the particles from 300 keV to 30 MeV. This does not imply, however, that deceleration can be performed just by reversing the magnet and rf ramps used for acceleration. Remanence and hysteresis effects in the magnets make the deceleration process dependent of the acceleration.



**Fig. 32:** Particle number (upper curve) and proton beam current (lower curve) as functions of time during acceleration and deceleration. The curves are averages from many machine cycles.

start of operations at FLAIR is defined to occur when  $1 \times 10^8$  antiprotons have been decelerated to 300 keV. This limit was exceeded by almost a factor three in these tests.

## Outlook

During spring 2007 the design study application in FP7 of the EU will be completed. In this process a final meeting end of March in Vienna is planned. If the application is successful, the next 3 years (2008-2010) will be spent designing the core components of the facility. SMI will participate as coordinator and in a working package on beam diagnostics. After that both the preparations for the construction of the facility itself as well as of the experiments will be done. It is expected that the AD of CERN will continue to operate until middle of the next decade so that a smooth transition of the experiments from AD to FLAIR can take place.

Fig. 32 shows an example of beam current and corresponding particle number during an acceleration-deceleration cycle. The beam current was measured using a DC current transformer, and to get a sufficiently good reading of the current, many injection pulses were accumulated at 300 keV. Protons were injected in batches every 0.5 s while the electron cooling was on, moving the particles away from the injection orbit and continuously increasing the beam current and the phase-space density of the beam. The resulting stepwise increase of the particle number can be hinted in the figure. Acceleration starts at time zero when the current has reached  $4.9 \mu\text{A}$ , corresponding to  $2.1 \times 10^8$  stored particles. According to the present planning for FAIR, the end of the commissioning period and the

PERSONEN:

Name	Funktion	Funktion: Zeitraum
Dipl.-Ing. Dr. Michael Cargnelli	Projektmitarbeit	01.11.2004 bis 31.12.2025
Dr. Bertalan Juhasz	Projektmitarbeit	01.12.2006 bis 28.02.2009
Prof. Dr. Paul Kienle	Projektmitarbeit	01.11.2004 bis 31.12.2025
Dipl.-Ing. Dr. Johann Marton	Projektmitarbeit	01.11.2004 bis 31.12.2025
Univ.-Prof. Dr. Eberhard Widmann	Projektleitung	01.11.2004 bis 31.12.2025
Dr. Johann Zmeskal	Projektmitarbeit	01.11.2004 bis 31.12.2025

PUBLIKATIONEN:

Currell, F. J.; Widmann, E. (2006) Challenges for atomic and fundamental physics with highly charged ions and antiprotons. Nuclear Physics News, Bd. 16 (1), S. 24-28. [Widmann, E. (KoautorIn)]

VORTRAG/POSTERPRÄSENTATION:

Widmann, Eberhard (03.02.2006) Physics with low-energy antiprotons – from AD to FLAIR. Vortrag: XLIV International Winter Meeting on Nuclear Physics , Bormio /ITALY. [Widmann, Eberhard]

Widmann, Eberhard (05.04.2006) Fundamental tests with trapped antiprotons part 1. Vortrag: Trapped charged particles for fundamental interactions, WE Heraeus Winter School, Hirschegg/AUSTRIA. [Widmann, Eberhard]

Widmann, Eberhard (05.04.2006) Fundamental tests with trapped antiprotons part 2. Vortrag: Trapped charged particles for fundamental interactions, WE Heraeus Winter School, Hirschegg/AUSTRIA. [Widmann, Eberhard]

Widmann, Eberhard (07.04.2006) Fundamental tests with trapped antiprotons part 3. Vortrag: Trapped charged particles for fundamental interactions, WE Heraeus Winter School, Hirschegg/AUSTRIA. [Widmann, Eberhard]

Widmann, Eberhard (07.04.2006) Fundamental tests with trapped antiprotons part 4. Vortrag: Trapped charged particles for fundamental interactions, WE Heraeus Winter School, Hirschegg/AUSTRIA. [Widmann, Eberhard]

Widmann, Eberhard (14.09.2006) Physics with low-energy antiprotons Part 1. Vortrag: 6th Euro-school on Exotic Beams, ECT\* Trento, Trento/ITALY. [Widmann, Eberhard]

Widmann, Eberhard (14.09.2006) Physics with low-energy antiprotons Part 2. Vortrag: 6th Euro-school on Exotic Beams, ECT\* Trento, Trento/ITALY. [Widmann, Eberhard]

Widmann, Eberhard (15.09.2006) Physics with low-energy antiprotons Part 3. Vortrag: 6th Euro-school on Exotic Beams, ECT\* Trento, Trento/ITALY. [Widmann, Eberhard]

Widmann, Eberhard (27.03.2006) Current and future experiments with low-energy ANTIPROTONS. Vortrag: Seminar Inst. f. theoret. Physik TU Wien, Wien/AUSTRIA. [Widmann, Eberhard]

### 1.3.3.2 FS3\_c\_A: PANDA: Proton Antiproton Annihilations at Darmstadt

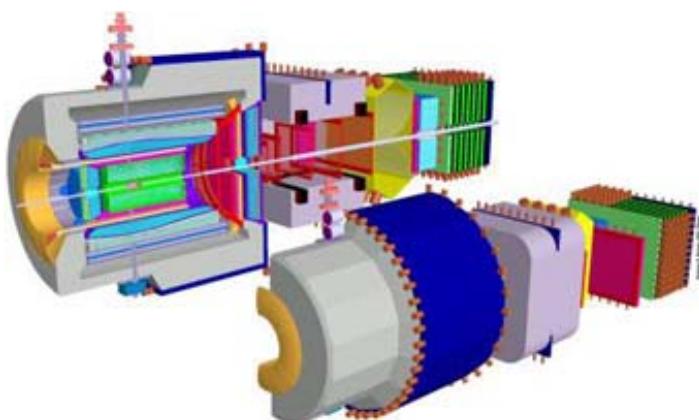


Fig. 33: Sketch of the PANDA detector.

possibility to firmly establish the QCD-predicted gluonic excitations (hybrids, glueballs) in the charmonium range, since alternative methods have severe limitations. The study of glueballs is a key to the understanding of long-distance QCD. The necessary precision and high statistics can be generated with sufficient luminosity by a hydrogen cluster-jet target.

Following major experimental topics of PANDA will benefit from the extremely high statistics and will therefore be high-precision tests of the strong interaction:

- Charmonium spectroscopy: precision measurement of mass, width and decay branches of all charmonium states in order to extract information on the quark-confining potential.
- Establishment of the QCD-predicted gluonic excitations (charmed hybrids, glueballs) in the charmonium mass range ( $3\text{-}5 \text{ GeV}/c^2$ ).
- Search for modifications of meson properties in the nuclear medium in the charm sector and their possible relationship to partial restoration of chiral symmetry.

Our institute is part of this international collaboration. Within the 6<sup>th</sup> framework program of the EU, SMI contributes to the following tasks: Optimisation studies of the (hydrogen) cluster-jet target (I3-Hadron Physics), design of the PANDA interaction zone and the development of imaging Cherenkov detectors (DIRACsecondary Beams).

Additionally we are also taking part in building up and experimenting with the future computing infrastructure for PANDA. PANDA grid is a framework, which is built around Open Source components. Its main task is to combine the computing resources of the participating institutes in a structured manner and to provide a common environment to perform highly demanding computing tasks for the PANDA project. The grid was initially developed by the ALICE collaboration as environment for simulation, reconstruction and analysis of detectors and particle events.

SMI is an active partner in this consortium and maintains a node of the PANDA grid. Semi-annual workshops are effected to keep the node administrators up-to-date with new developments and to perform coordinated updates of the systems. The next meeting will be organized by SMI and will take place in Vienna in summer 2007.

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<sup>51</sup> PANDA Letter of Intent (2004).

<sup>52</sup> PANDA Technical Progress report (2005).

The PANDA experiment<sup>51,52</sup> at the accelerator HESR (FAIR / GSI) addresses several fundamental questions in the physics of strong interaction. Antiproton beams stored in the HESR will hit an internal target in fixed target experiments. These interactions will generate a lot of mesons and baryons consisting of the heavier strange and charm quarks and will copiously produce gluons. Antiproton-proton annihilations are a unique

## Outlook

The research and development for the internal target system of PANDA and photodetectors for Cherenkov detectors will be continued.

### PERSONEN:

Name	Funktion	Funktion: Zeitraum
Dr. Paul Bühler	Projektmitarbeit	01.01.2006 bis 31.12.2025
Mag. Alexander Gruber	Projektmitarbeit	01.01.2004 bis 31.12.2025
Prof. Dr. Paul Kienle	Projektmitarbeit	01.01.2004 bis 31.12.2025
Dipl.-Ing. Dr. Johann Marton	Projektmitarbeit	01.01.2004 bis 31.12.2025
Univ.-Prof. Dr. Eberhard Widmann	Projektmitarbeit	01.11.2004 bis 31.12.2025
Dr. Johann Zmeskal	Projektleitung, Projektmitarbeit	01.01.2004 bis 31.12.2025

### PUBLIKATIONEN:

Gruber, A.; Marton, J.; Widmann, E.; Zmeskal, J. (17.11.2006) Precision hadron spectroscopy in the charmonium mass region using antiproton annihilation. (9th International Conference on Hyper-nuclear and Strange Particle Physics) In Reihe: AIP Conference Proceedings - Volume 870: American Institute of Physics, S. 394-397. [Gruber, A. (KoautorIn); Marton, J. (HauptautorIn); Widmann, E. (KoautorIn); Zmeskal, J. (KoautorIn)]

### VORTRAG/POSTERPRÄSENTATION:

Marton, Johann (01.06.2006) Precision hadron spectroscopy in the charmonium mass region using antiproton annihilation. Vortrag: 9th Conference on the Intersections of Particle and Nuclear Physics CIPANP06, Rio Mar/UNITED STATES. [Marton, Johann]

### 1.3.3.3 FS3\_c\_b: Internal target system for PANDA

In the framework of FP6 SMI is involved in the development of the internal target system of PANDA. The work consists of research and tests on the optimisation of the (hydrogen) cluster-jet target and on the design of the PANDA vacuum system. So our contribution can be divided into 3 sub-projects:



Fig. 34: Pitot-tube setup with 3 stepper motors.

In order to reach the desired target thickness with a cluster-jet target -  $\sim 10^{15}$  protons/cm<sup>2</sup> to achieve the anticipated luminosity of  $L > 10^{32}$  cm<sup>-2</sup>s<sup>-1</sup> – an optimisation of the cluster production and the nozzle-skimmer arrangement is essential. It is known that there are periodic contractions of the gas/cluster density in the free jet behind nozzle<sup>53</sup>. Therefore one can separate the cluster-jet from the surrounding gas effectively by positioning the first skimmer near the waist of the jet structure. This means that the distance nozzle-skimmer has a strong influence on the beam density. So the knowledge of the density profile of the

cluster-jet is of vital importance for the optimisation of the target density.

A system to measure the density distribution of the cluster-jet right after the nozzle by moving a Pitot-Tube inside the jet was installed at SMI.

Test measurements in 2006 with a capillary tube showed successfully the feasibility of the method, but also some limitations. Therefore a major change of the experimental setup with remote controlled stepper motors (see Fig. 34) and a cooling system with additional insulation was carried out. First measurements started by producing cluster-jets of Argon.

The Genova/Fermilab cluster-jet target, which was set up for R&D purposes at GSI with contribution from SMI, is now fully operational. In 2006 we were rebuilding the gas-supply-system of the cluster-jet target at GSI due to the installation of a bigger hydrogen purifier. This Pd-filter is of vital importance for the running of the jet target, because impurities in commercially available hydrogen (impurity content > 1ppm) would freeze out in the cold nozzle and block the gas flow.

Additionally we constructed a movable Pitot tube, which was used in test measurements in July/August 2006.

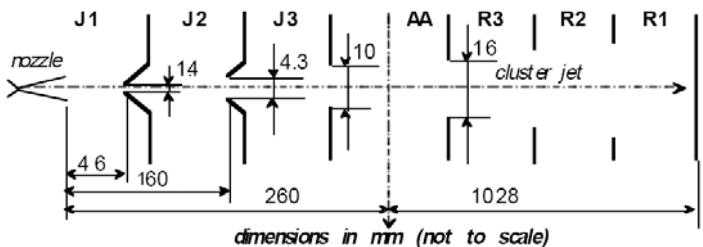


Fig. 35: Geometry of the Genova cluster-jet target arrangement.

<sup>53</sup> W. Tietsch, K. Bethge, H. Feist and E.Schopper, NIM 158 (1979) 41.

The pumping speed for hydrogen in the individual sections of the cluster-jet vacuum chamber (Fig. 35) was measured.

In a series of measurements in November 2006 we measured the cluster-jet profile at the interaction region with different nozzle temperatures and inlet pressures. We could verify successfully the jet dimensions, which were mentioned by the Fermilab experiment E835<sup>54</sup> (7 mm Ø). We also corroborated the former statements that the jet width is independent of temperature and pressure and that the position of the beam is stable within  $\pm 0.3$  mm. By comparing all profile scans it is evident that the beam density increases with increasing inlet pressure as well as with decreasing temperature (see Fig. 36). One can conclude that in order to increase the hydrogen jet density it is useful to operate the target only below 32 K. The maximum target thickness reached during these measurements was  $1 \times 10^{14}$  atoms/cm<sup>2</sup> at 6.9 bar and 29.5 K.

In a second series of measurements we tried to increase the target density by increasing the inlet pressure. We raised the jet density to a new record for this machine:  $1.2 \times 10^{15}$  atoms/cm<sup>2</sup>. The inlet pressure was on the limit of the cooling power of the nozzle head, therefore further development in this direction has to be made.

In order to reach the desired luminosity of  $L > 10^{32}$  cm<sup>-2</sup>s<sup>-1</sup> it is of vital importance not only to enhance the target density, but also to minimise the gas load in the interaction zone. Due to the design of the PANDA detector it is impossible to install high-vacuum pumps near the interaction zone. Therefore it was proposed to use integrated pumping by installing beam pipes, which have been sputter-coated on the inside with non-evaporative-getter material (NEG).

We have set up a test system as simulation of the PANDA interaction zone, consisting of 6 NEG-coated pipes with a 1 µm thin film of Ti-Zr-V as getter material. With this test system we have performed the following measurements, which will help to decide the finale layout of the PANDA interaction region:

- pumping speed of the NEG-system,
- storage capacity for hydrogen,
- service live till a reactivation becomes necessary.

After first activation of the getter, the pumping speed was measured by the pressure increase due to the inlet of hydrogen gas. From these data we calculated the integral pumping speed of the getter material to be  $\sim 180$  l/s. The storage capacity of the getter for hydrogen was measured too. The system was regenerated several times showing that hydrogen desorption occurs at temperatures above 180°C as specified by the producer.

## Outlook:

In 2007 beam profiles with different nozzle types and different diameters will be measured at SMI with the Pitot-tube setup. We will measure the jet profiles with hydrogen gas using different nozzle sizes (15 µm to 40 µm) as well as different inlet pressures up to 20 bar, in the temperature range from 20 K to 40 K. According to these data we will select appropriate nozzles for final tests

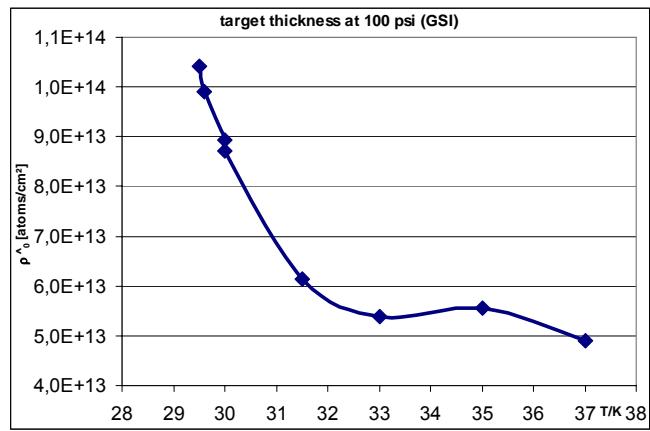


Fig. 36: Increase of target density with temperature.

<sup>54</sup> D. Allspach et al., NIM A410 (1998) 195

with the Genova cluster-jet target at GSI. The results of this study will be essential for the final design of the PANDA cluster-jet target.

With the cluster-jet target at GSI we will perform further tests in 2007 in high-pressure mode under stable conditions. Our goal is to produce cluster densities compatible with the luminosity requirements of PANDA. A major upgrade of the Genova cluster-jet target is planned for 2007 to get better access to the nozzle and skimmer region. Furthermore a new control and read-out system will be set up during 2007/08 by INFN Genova and SMI. The studies of the NEG-coated beam pipes will be continued in 2007.

#### PERSONEN:

Name	Funktion	Funktion: Zeitraum
Dipl.-Ing. Dr. Michael Cargnelli	Projektmitarbeit	01.01.2004 bis 31.12.2007
Mag. Alexander Gruber	Projektmitarbeit	01.01.2005 bis 31.12.2007
Dipl.-Ing. Dr. Johann Marton	Projektmitarbeit	01.01.2004 bis 31.12.2007
Univ.-Prof. Dr. Eberhard Widmann	Projektmitarbeit	01.01.2005 bis 31.12.2007
Dr. Johann Zmeskal	Projektleitung	01.01.2004 bis 31.12.2007

#### VORTRAG/POSTERPRÄSENTATION:

Gruber, Alexander (18.09.2006) Development of a cluster-jet target for PANDA. Vortrag: ÖPG-FAKT Tagung 2006, Maria Lankowitz/AUSTRIA. [Gruber, Alexander]

Gruber, Alexander (18.10.2006) Status report of PANDA activities at SMI for 2006. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik, Wien/AUSTRIA. [Gruber, Alexander; Hirtl, Albert]

### 1.3.3.4 FS3\_c\_c: Cherenkov Imaging Detectors (DIRACSecondary beams)

Our institute participates in the EU Design Study “DIRACsecondaryBeams” which is part of the technical developments for the new FAIR facility at GSI. We are partner in the international collaboration for the task PANDA 1 within this design study. This sub-project is aiming at the development of imaging Cherenkov detectors proposed for the DIRC (detection of internally reflected Cherenkov light) and for the forward RICH detector of PANDA<sup>55</sup>.

We are studying the application of new matrix avalanche photo-detectors operating in the Geiger-mode. This photo detector exhibits a high gain in the order of  $10^6$  for single photons comparable with the gain of photomultipliers. The complexity of SiPMs is low (no vacuum tube, no high voltage supply necessary), therefore the costs for detector and electronics are advantageous.

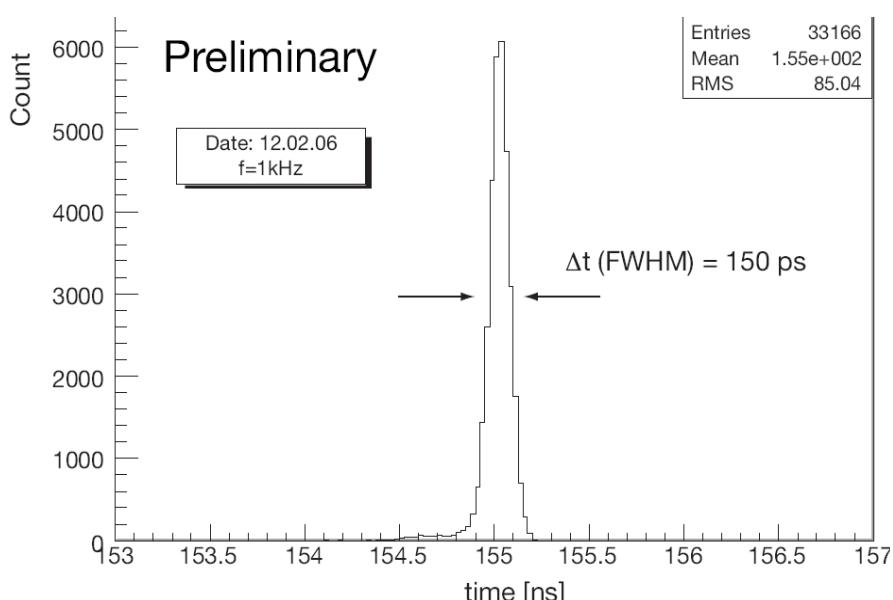


Fig. 37: Measured time resolution of a SiPM triggered by a pico-second laser at 407 nm.

box (black box) with temperature stabilization.

The timing performance of SiPMs can be tested using a pico-second laser as light source. All optical components can be mounted and operated inside the black box. A VME-based data acquisition system was setup to record pulse-height and time spectra. First results showed a good time resolution of 1 mm<sup>2</sup> SiPMs in the order of 150 ps (FWHM). An example is shown in Fig. 37. This timing performance opens the way to many applications like scintillating fiber detectors or the development of a 3D-DIRC (position sensitive detection combined with timing).

## Outlook

The tests are continued in 2007 with new generations of SiPMs. In this context a common project (INTAS) with Russian partner institutions is especially important since new non-commercial SiPMs can be characterized and evaluated for applications in Cherenkov detectors. The performance SiPMs as function of temperature will be studied in detail.

The development of SiPMs is proceeding fast and new photon detectors optimized for the short wavelengths and exhibiting high photo-detection efficiency are already in production. For the design study we have to test the newest generation of SiPMs concerning dark count rate, sub-nanosecond timing resolution, temperature effects etc.). In 2006 we constructed a test setup for SiPMs consisting of a light-tight

<sup>55</sup> J. Marton for the PANDA Collaboration, Proc. CIPANP06, AIP Conf. Proc., in print

PERSONEN:

Name	Funktion	Funktion: Zeitraum
Isabel Burian	Projektmitarbeit	31.07.2006 bis 31.08.2006
Dipl.-Ing. Dr. Michael Cargnelli	Projektmitarbeit	01.02.2005 bis 31.01.2008
Stefan Fossati	Projektmitarbeit	01.10.2006 bis 31.01.2007
Dipl.-Ing. Dr. Johann Marton	Projektleitung	01.02.2005 bis 31.01.2008
Matthias Schafhauser	Projektmitarbeit	28.08.2006 bis 31.01.2007
Florian Schilling	Projektmitarbeit	19.08.2006 bis 01.09.2006
Dr. Johann Zmeskal	Projektmitarbeit	01.02.2005 bis 31.01.2008

VORTRAG/POSTERPRÄSENTATION:

Marton, Johann (04.09.2006) SiPMT test setup at SMI. Vortrag: PANDA Meeting, Wien/AUSTRIA.  
[Marton, Johann]

### 1.3.3.5 FS3\_d: Antiproton Ion Collider

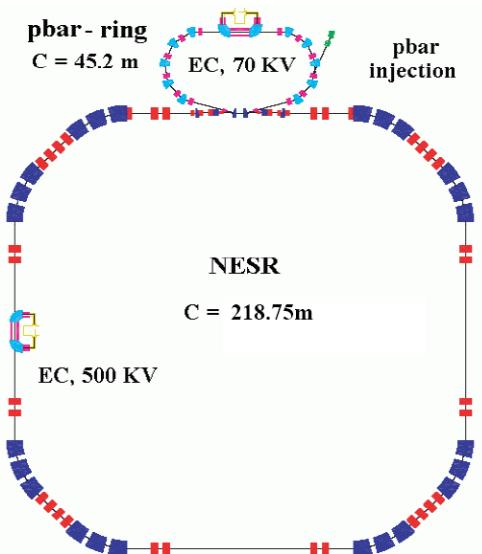


Fig. 38: Layout of AIC.

In January 2006 we delivered to the GSI FAIR Project a Technical Proposal for the Design, Construction, Commissioning and Operation of an Antiproton-Ion- Collider (Fig. 38). We propose to use intermediate energy antiproton-ion collisions to determine the neutron and proton root-mean-square (rms) radii of stable and neutron-rich exotic nuclei by measuring the antiproton-nucleus absorption cross sections along isotopic chains in inverse kinematics in an Antiproton-Ion Collider (AIC).

The kinematically forward emitted (A-1) absorption products are completely identified so one can determine at the same time the cross section for the absorption on the neutrons and protons, respectively. The expected effects are studied theoretically in a microscopic model<sup>56</sup>. The mass dependence of

the absorption cross sections is found to follow closely the nuclear rms radii. The total absorption cross section is shown to be a superposition of cross sections describing partial absorption on neutrons and protons, respectively. Thus the measured differential cross sections for absorption on neutrons and protons will give information on their respective distributions.

The AIC Technical proposal has been accepted by the FAIR Management with the request that some technical aspects have to be settled in a Technical Design Report for the Antiproton Ion Collider. In November 2006 an AIC design study meeting took place in Munich. The goal was to discuss the concept for a AIC-Design Study FP-7 Proposal to the European Union to be delivered in 2007. The participants in this design study are: TU München, Germany, GSI Darmstadt, Germany, Stefan Meyer Institut, Wien, Austria, BINP Novosibirsk, Russia, Justus Liebig University Giessen, Germany, KVI Groningen, Netherlands, IPJ Warsaw, Poland. The design study will be structured in 4 tasks: Collider, Theory and Simulations, Schottky Detection, and In-ring Detectors. SMI will coordinate the In-ring Detector task.

#### Outlook

In the first half of 2007 the proposal for a design study project within FP7 has to be finished. First simulations and feasibility studies on in-ring detector systems will be carried out.

#### PERSONEN:

Name	Funktion	Funktion: Zeitraum
Dr. Paul Bühler	Projektmitarbeit	16.12.2004 bis 31.12.2025
Dipl.-Ing. Dr. Michael Cagnelli	Projektmitarbeit	16.12.2004 bis 31.12.2025
Dipl.-Ing. Albert Hirtl	Projektmitarbeit	16.12.2004 bis 31.12.2025
Prof. Dr. Paul Kienle	Projektmitarbeit	16.12.2004 bis 31.12.2025

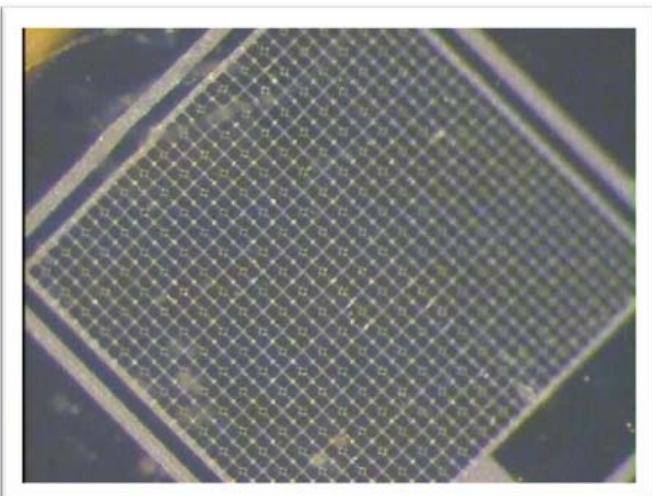
<sup>56</sup> H. Lenske and P. Kienle, Phys. Lett. B, (dated February 13, 2007)

Name	Funktion	Funktion: Zeitraum
Dipl.-Ing. Dr. Johann Marton	Projektmitarbeit	16.12.2004 bis 31.12.2025
Univ.-Prof. Dr. Eberhard Widmann	Projektmitarbeit	16.12.2004 bis 31.12.2025
Dr. Johann Zmeskal	Projektleitung	16.12.2004 bis 31.12.2025

PUBLIKATIONEN:

Beller, P.; Franzke, B.; Kienle, P.; Kruecken, R.; Koop, I. et al. [...] (20.03.2006) Antiproton – Ion Collider for FAIR Project. (International Workshop on Beam Cooling and Related Topics - COOL05) In Reihe: American Institute of Physics Conference Proceedings - Volume 821: American Institute of Physics, S. 108-112. [Kienle, P. (KoautorIn); Widmann, E. (KoautorIn)]

### 1.3.3.6 FS3\_e: Development and tests of novel matrix avalanche photo detectors for PANDA



*Fig. 39: Matrix of a prototype SiPM under test at SMI.*

with a scintillator/radiator array in order to demonstrate its practical application in low level 2D light detection.

Some expected results of the project are: Development of the SiPM matrix with characteristics needed for the light detection in experimental nuclear and particle physics, as well as for Cherenkov detectors and time-of-flight system applications in the PANDA experiment at FAIR/GSI; set up of laboratories for detector tests and education of experts as well as development of the laboratory infrastructure of the partner institutes from Russia.

The objective of the work to be done by SMI is the detailed investigation of SiPM parameters (timing information and other relevant parameters) to demonstrate possibilities of using SiPMs in various applications.

An INTAS (International Association for the promotion of co-operation with scientists from the New Independent States of the former Soviet Union) project coordinated by GSI was started end of 2006. Our institute participates with a task concerning the limits of silicon photomultiplier (SiPM) parameters for fast timing detectors.

The main objective of the project is the development of an ultra fast, low-cost, matrix solid-state photo detector based on the new SiPMs with high photon detection efficiency for a spectral range between 200-600 nm. The SiPM matrix will be combined

#### PERSONEN:

Name	Funktion	Funktion: Zeitraum
Dipl.-Ing. Dr. Johann Marton	Projektleitung	01.11.2006 bis 30.04.2009

## 1.3.4 Sonstige Forschungsprojekte

### 1.3.4.1 Pion-Nucleon Interaction

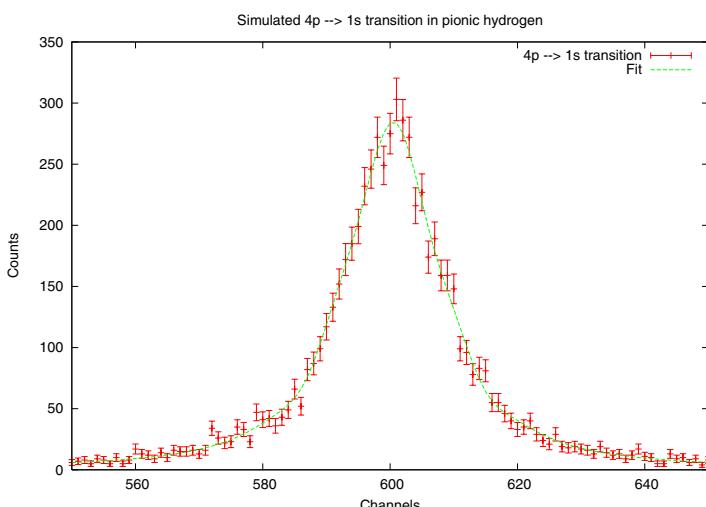
The final goal of the pionic hydrogen experiment is the extraction of the pion nucleon scattering lengths, based on the most precise values for the observables (strong interaction shift and width of the ground state). The final value of the shift was already obtained, whereas the analysis to determine the width is in progress, to get an accuracy of about 10 meV. Such an accuracy can only be achieved by using a high resolution Bragg spectrometer, measuring the energy of radiative transitions ( $2p \rightarrow 1s$ ,  $3p \rightarrow 1s$  and  $4p \rightarrow 1s$ ) feeding the ground state.

In the beginning of 2006 an addendum to the pionic hydrogen experiment was submitted to the PSI – “Benutzerversammlung”. Beam time for measuring the ground state shift ( $\varepsilon_{1s}$ ) and width ( $\Gamma_{1s}$ ) in pionic deuterium was requested. It was proposed to measure the hadronic shift  $\varepsilon_{1s}$  to an accuracy of 0.5% and to reduce the uncertainty for  $\Gamma_{1s}$  by a factor of 3. This request was approved by the PSI “Benutzerversammlung” and therefore the experimental activities in 2006 focused on measuring  $\varepsilon_{1s}$  and  $\Gamma_{1s}$  in pionic deuterium. The beam time at PSI took place in July and August 2006.

An accurate knowledge of  $\varepsilon_{1s}$  and  $\Gamma_{1s}$  will substantially improve the values for the  $\pi N$  isospin scattering lengths  $a^+$  and  $a^-$ . In consequence, improved values for the  $\pi N$   $\sigma$ -term and the  $\pi N$  coupling constant will be obtained. Moreover it is expected, that an improved knowledge of  $\varepsilon_{1s}$  and  $\Gamma_{1s}$  will allow an important crosscheck for rapidly improving calculations done within the framework of Chiral Perturbation Theory.

In parallel to the experimental activities regarding pionic deuterium, great effort was invested into the analysis of spectra measured with the ECRIT (Electron Resonance Ion Trap) in previous years. The ECRIT was setup in order to characterize the used crystals with narrow X-ray lines and hence to get accurate knowledge of their response functions. Knowing the response function, an analysis program for analyzing the pionic hydrogen data was developed and tested at SMI.

## Outlook



**Fig. 40:** Simulated spectrum for the  $4p \rightarrow 1s$  transition in pionic hydrogen including kinetic energy distributions of the formed pionic atoms.

No further experimental activity is planned. Emphasis will be placed on the finishing of the data analysis for pionic hydrogen, i. e. to determine the hadronic width of the ground state in pionic hydrogen –  $\Gamma_{1s}$  – with an accuracy of ~ 1%. In particular, since the motion (i.e. the kinetic energy distribution) of the formed pionic atoms influences the width of the transitions in question, detailed studies of the Doppler-broadening of the measured spectra will be performed (see Fig. 40) and taken into account during the analysis process. In order to obtain detailed information on the influence of the kinetic energy distribution of

atoms, various simulations will be performed and hence the behavior of the system will be studied.

With the completion of the analysis the pionic hydrogen experiment meets its final stage. In the frame of the analysis, a doctoral dissertation is being written at SMI which will be finished by the end of 2007. The final publication is expected to be finished in the year 2008.

#### PERSONEN:

Name	Funktion	Funktion: Zeitraum
Mag. Alexander Gruber	Projektmitarbeit	01.04.1998 bis 31.12.2006
Dipl.-Ing. Albert Hirtl	Projektmitarbeit	01.03.2002 bis 31.12.2006
Dr. Bertalan Juhasz	Projektmitarbeit	01.07.2005 bis 31.12.2006
Dipl.-Ing. Dr. Johann Marton	Projektmitarbeit	01.04.1998 bis 31.12.2006
B. Sc. with 1st degree honours Thomas Pask	Projektmitarbeit	01.06.2005 bis 31.12.2006
Univ.-Prof. Dr. Eberhard Widmann	Projektmitarbeit	01.11.2004 bis 31.12.2006
Dr. Johann Zmeskal	Projektleitung	01.04.1998 bis 31.12.2006

#### PUBLIKATIONEN:

Gotta, D.; Gruber, A.; Hirtl, A.; Indelicato, P.; Marton, J. et al. [...] (10.01.2006) Addendum to proposal R-98.01 at PSI: Pionic Deuterium. [Cargnelli, M. (KoautorIn); Gruber, A. (KoautorIn); Hirtl, A. (KoautorIn); Marton, J. (KoautorIn); Widmann, E. (KoautorIn); Zmeskal, J. (KoautorIn)]

Gotta, D.; Marton, Johann; Hirtl, Albert; Simons, L.; Zmeskal, Johann (11.07.2006) Pionic hydrogen: Precision measurements at PSI. (PARTICLES AND NUCLEI: Seventeenth International Conference on Particles and Nuclei) In Reihe: AIP Conference Proceedings - Volume 842: American Institute of Physics, S. 796-798. [Hirtl, A. (KoautorIn); Marton, J. (HauptautorIn); Zmeskal, J. (KoautorIn)]

#### VORTRAG/POSTERPRÄSENTATION:

Hirtl, Albert (15.05.2006) Strategy for the ECRIT and piH-Analysis. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Hirtl, Albert]

Hirtl, Albert (18.09.2006) Pionic Hydrogen. Vortrag: ÖPG-FAKT Tagung 2006 (Österreichische Physikalische Gesellschaft), Maria Lankowitz/AUSTRIA. [Hirtl, Albert]

Hirtl, Albert (28.09.2006) Status of the piH Experiment. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Hirtl, Albert]

Marton, Johann (10.01.2006) Exotische Wasserstoffatome – Präzisionsmessungen zur starken Wechselwirkung. Vortrag: Institutsseminar (Institut für Allgemeine Physik, TU Wien), Wien/AUSTRIA. [Marton, Johann]

Marton, Johann (17.01.2006) Hadronic Hydrogen Atoms – New Precision Studies of Studies of Strong Interaction. Vortrag: Institutsseminar (ETH Zurich), Zürich/SWITZERLAND. [Marton, Johann]

Marton, Johann (25.08.2006) Precision Studies on Strong Interaction in Pionic Hydrogen. Vortrag: International IUPAP Conference on Few Body Problems in Physics FB18,, São Paulo/BRAZIL. [Marton, Johann]

### 1.3.4.2 Röntgenspektroskopie an der VERA – Beschleunigeranlage (PIXE)

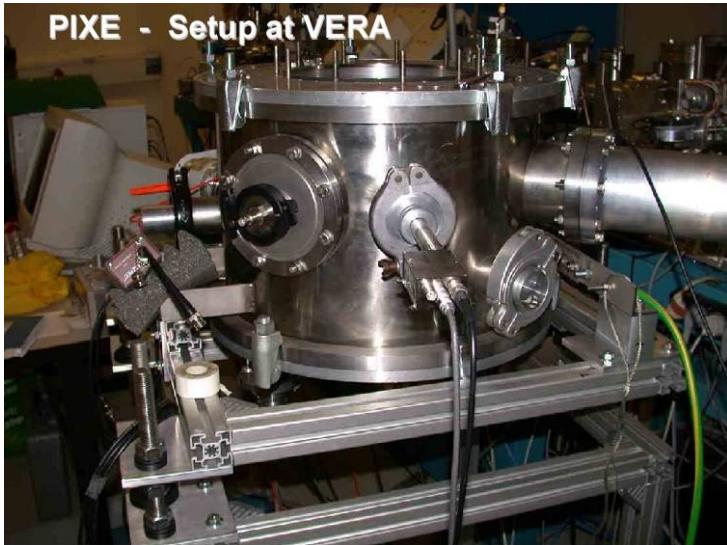


Fig. 41: Vacuum-chamber for PIXE-measurements @ VERA.

difference of the Ti K $\beta$  and Ni K $\beta$  lines between the experimental data and the reference data is about 5-10 eV. To reduce this systematic error, studies to understand the energy spectra in the kaonic helium X-ray measurements (E570) were performed.

The possible reasons for the energy shifts could be 1) a high-energy side tail on the peaks due to pile-up events, 2) contaminations of other materials in the Ti and Ni foils, 3) energy shifts due to the satellite lines of Ti and Ni, and 4) asymmetry of the SDD response function. For 1), the events caused by the pile-up events can be rejected using Flash-ADC data. To understand the possible effects of 2) and 3), we measured fluorescence X-rays with metal target foils at VERA in 2006.

The Ti and Ni X-ray lines measured at E570 were induced by high-energy pions, which are a contamination of the kaon beam at KEK. In the case of X-ray production induced by charged particles, the satellite lines (X-ray emission with different electron configurations) can be produced in addition to the usual X-ray transitions. Because of the energy resolution of the SDDs, the satellite lines can not be seen separately, but the existence of the satellite lines could cause the energy shift of the peaks.

The activation of fluorescence X-rays with protons at VERA and with pions at PSI shows that no satellite peaks could be detected and thus can not cause the energy shifts measured in E570.

## Outlook

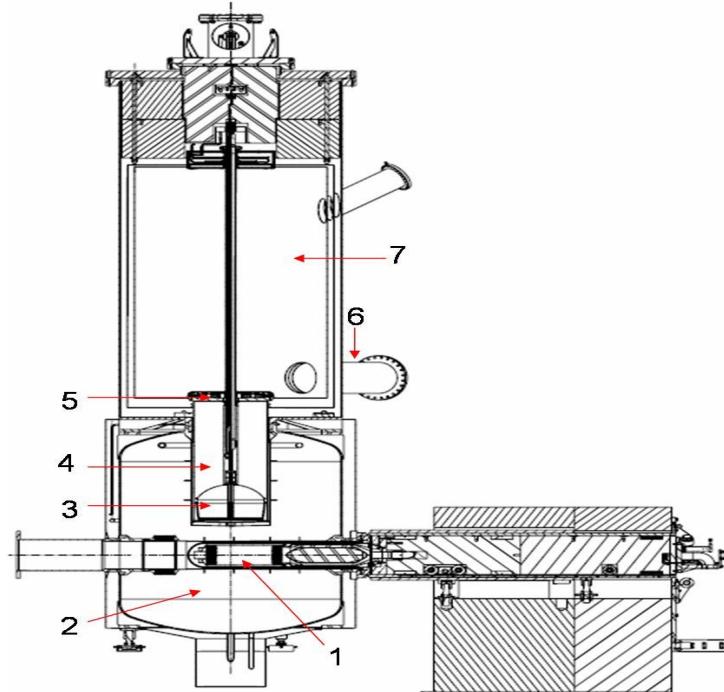
In 2007, we will analyze the impurity content of materials used for the SIDDHARTA setup. Contaminations of the materials which produce X-ray lines close to the kaonic X-rays (e.g. Fe, Cu) cause a problem for the determination of the shift and width of the kaonic lines. Also, studies of the response function of the SDDs, as well as measurements of the time resolution, will be performed at VERA.

The PIXE measurements with the proton beam at VERA are very important for the kaonic X-ray measurements at SIDDHARTA (LNF), E570 (KEK) and E17 (J-PARC). In E570, the Ti and Ni X-ray lines were used for the energy calibration. However, the analysis of the kaonic helium data shows that the energy calibration using the above 4 lines gives an unexpected large systematic error, which could not be explained by non-linearity in energy. If we use the Ti K $\alpha$  and Ni K $\alpha$  lines as calibration points, the energy

PERSONEN:

Name	Funktion	Funktion: Zeitraum
Dipl.-Ing. Dr. Michael Cargnelli	Projektmitarbeit	20.01.2004 bis 01.01.2007
Dr. Tomoichi Ishiwatari	Projektmitarbeit	20.01.2004 bis 01.01.2007
Dipl.-Ing. Dr. Johann Marton	Projektmitarbeit	20.01.2004 bis 01.01.2007
Dr. Johann Zmeskal	Projektleitung	20.01.2004 bis 01.01.2007

### 1.3.4.3 SUNS - Spallation Ultra Cold Neutron Source at PSI, Source Development



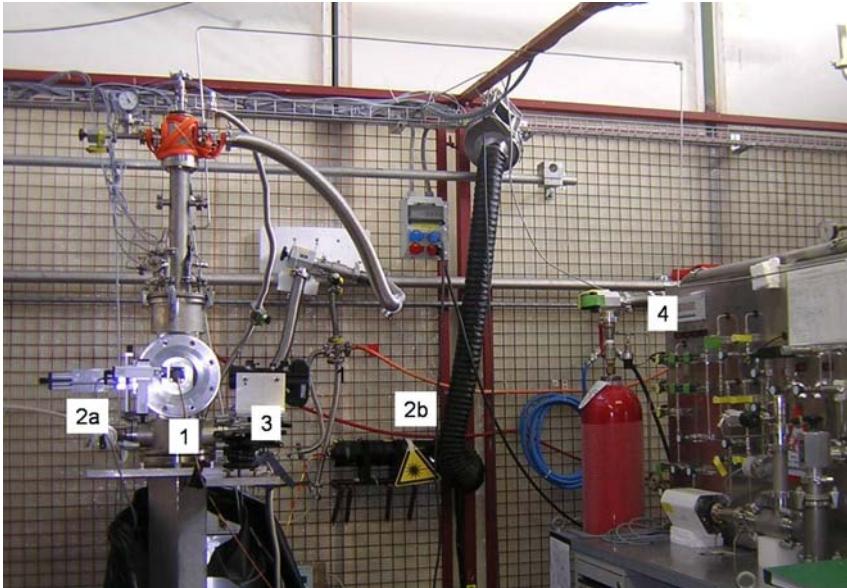
*Fig. 42: Schematic view of the PSI ultracold neutron source (1 - spallation target, 2 - heavy water moderator, 3 - solid deuterium moderator, 4 - vertical UCN guide, 5 - UCN valve, 6 - UCN guide (guiding UCN's to the experiments), 7 - UCN storage volume of 2 m<sup>3</sup>).*

A new high intensity ultra-cold neutron (UCN) source (Fig. 42) is under construction at the Paul Scherrer Institut. The source is working in the pulsed mode (1% duty cycle) and uses the 1.2 MW proton beam from the PSI 600 MeV Ring Cyclotron for production of the spallation neutrons on the lead target. The produced neutrons are moderated to the ultracold neutron energies (a few hundreds neV) by a system consisting of about 4 m<sup>3</sup> of heavy water at room temperature and 30 dm<sup>3</sup> of solid deuterium at the temperature of about 5K. The UCN's leave the solid deuterium moderator and, after passing through the vertical guide, enter the storage volume. Afterwards the UCN's are transported to the experiments (e.g. nEDM, neutron life time).

The performance of the UCN sources depends strongly on the properties of the moderator material. The aim of this project is to understand the physics processes of UCN neutron production in three different materials D<sub>2</sub>, CD<sub>4</sub> and O<sub>2</sub>.

As a part of this project, we have done a series of measurements in 2006 on the para-to-ortho conversion in solid deuterium catalysed by molecular oxygen.

Deuterium exists in two spin (S) – rotational number (J) configurations: ortho (S = 0, 2; J = 0) and para (S = 1; J = 1). The lifetime of UCN in pure para and ortho-D<sub>2</sub> solid at 5K, are 1.5 ms and 150 ms, respectively. Hence, to obtain high UCN from the moderator, the para-D<sub>2</sub> concentration should be as low as possible. At room temperature D<sub>2</sub> is a mixture of 67 % ortho and 33% para (so called normal D<sub>2</sub>). The increase in ortho-D<sub>2</sub> concentration is possible by converting para molecules to ortho molecules, which can be done by using paramagnetic catalyst like molecular oxygen. Measurements investigating catalysing properties of O<sub>2</sub> have started at PSI in summer 2006.



**Fig. 43:** The experimental setup (1 – the cryostat with the D<sub>2</sub> cell inside, 2a – the Raman head, 2b – the Raman laser, 3 – the mounted camera for optical investigation of the crystal, 4 – the gas system with the deuterium storage tank ).

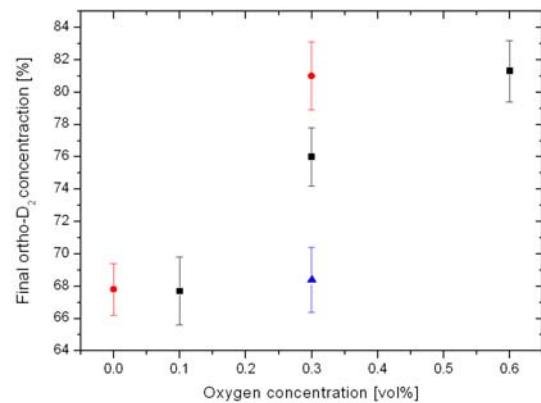
The measurements have been done with essentially the same apparatus that has been used for the UCN transmission and production experiments<sup>57</sup>. The main parts of the setup are the D<sub>2</sub> cell mounted on the cryostat, the deuterium gas system, the Raman spectroscopy system and the optical photography system (Fig. 43)<sup>58</sup>. The basic idea of the experiment is to mix, at room temperature, normal D<sub>2</sub> with small amounts of O<sub>2</sub> and to freeze the mixture from the gas phase in order to obtain a homogeneous distribution of the O<sub>2</sub> in the D<sub>2</sub> crystal.

neous distribution of the O<sub>2</sub> in the D<sub>2</sub> crystal. The ortho/para ratio in the sample is measured with the Raman spectroscopy as a function of time, temperature and O<sub>2</sub> concentration. The determination of the ortho concentration is done in the liquid phase, due to bad signal-to-background ratio in the solid phase. The procedure of the measurements is the following. The Raman spectra are taken first for liquid D<sub>2</sub> before adding O<sub>2</sub> to confirm 67% concentration of ortho-D<sub>2</sub> in the sample. Then the mixture is frozen and kept in a solid state for a few hours (up to ~ 30 hours). Afterwards the crystal is melt and the Raman measurements are done again for liquid D<sub>2</sub>.

We have observed the para-to-ortho conversion in D<sub>2</sub> for the O<sub>2</sub> admixtures of 0.3-0.6 vol % (see Fig. 44). The conversion shows a dependence on the O<sub>2</sub> concentration. The homogeneous distribution of O<sub>2</sub> in D<sub>2</sub> crystal plays a crucial role. However, because we couldn't measure the conversion *in situ*, we cannot be absolutely sure if the conversion takes place in the solid.

## Outlook

The presented results and conclusions are preliminary. We plan to improve the signal-to-background ratio in the solid and do another series of measurements of the para-to-ortho conversion in May/June 2007



**Fig. 44:** The resulting ortho-D<sub>2</sub> concentration as a function of oxygen content. The red circles refer to the measurements done with more homogeneous distribution of O<sub>2</sub> than the black squares. The blue triangle is the result of the measurement with separate freezing of oxygen and deuterium without mixing.

<sup>57</sup> K.Bodek *et al* An apparatus for the investigation of solid D<sub>2</sub> with respect to ultra-cold neutron sources, NIM A533, 491 (2004).

<sup>58</sup> AK. Sanchez, Diploma thesis, ETH Zurich, 2006.

to confirm that the conversion takes place in solid D<sub>2</sub>.

The Ph.D. thesis of M. Kasprzak is expected to be finished in 2007 and thus the involvement of SMI in this project will end.

#### PERSONEN:

Name	Funktion	Funktion: Zeitraum
Mag. Małgorzata Kasprzak	Projektmitarbeit	01.09.2004 bis 31.12.2007
Univ.-Prof. Dr. Eberhard Widmann	Projektmitarbeit	01.11.2004 bis 31.12.2007

#### PUBLIKATIONEN:

Atchison, F.; Blau, B.; Daum, M.; Fierlinger, P.; Foelske, A. et al. [...] (2006) Diamondlike carbon can replace beryllium in physics with ultracold neutrons. Physics Letters B, Bd. 642 (1-2), S. 24-27. [Kasprzak, M. (KoautorIn)]

Atchison, F.; Blau, B.; Daum, M.; Fierlinger, P.; Geltenbort, P. et al. [...] (2006) Storage of ultracold neutrons in a volume coated with diamondlike carbon. Physical Review C, Bd. 74, S. 55501 . [Kasprzak, M. (KoautorIn)]

#### VORTRAG/POSTERPRÄSENTATION:

Kasprzak, Małgorzata (13.02.2006) Thermal up-scattering of VCN in solid D<sub>2</sub>. Vortrag: Present Status and Future of Very Cold Neutron Applications/SWITZERLAND. [Kasprzak, Małgorzata]

Kasprzak, Małgorzata (13.02.2006) UCN production efficiency of solid D<sub>2</sub>, O<sub>2</sub> and CD<sub>4</sub>. Vortrag: Present Status and Future of Very Cold Neutron Applications/SWITZERLAND. [Kasprzak, Małgorzata]

Kasprzak, Małgorzata (14.02.2006) Measurement of the ultracold neutron production efficiency of solid D<sub>2</sub>, O<sub>2</sub> and CD<sub>4</sub>. Vortrag: Swiss Physical Society Meeting/SWITZERLAND. [Kasprzak, Małgorzata]

Kasprzak, Małgorzata (15.02.2006) UCN production efficiency of solid D<sub>2</sub>, O<sub>2</sub> and CD<sub>4</sub>. Vortrag: Open user meeting BV37/SWITZERLAND. [Kasprzak, Małgorzata]

Kasprzak, Małgorzata (20.01.2006) Measurement of the ultracold neutron (UCN) production efficiency of solid D<sub>2</sub>, CD<sub>4</sub> and O<sub>2</sub>. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Kasprzak, Małgorzata]

Kasprzak, Małgorzata (22.11.2006) Energy dependent ultracold neutron (UCN) production in deuterium (D<sub>2</sub>). Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Kasprzak, Małgorzata]

Kasprzak, Małgorzata (22.11.2006) Para to ortho conversion in solid D<sub>2</sub> catalyzed by molecular oxygen. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik, Wien/AUSTRIA. [Kasprzak, Małgorzata]

#### 1.3.4.4 VIP @ Gran Sasso (VIolation of the Pauli Exclusion Principle Experiment)

The Pauli Exclusion Principle (PEP) represents a basic principle of quantum mechanics and therefore one of the fundamental principles of modern physics.

*The history of the exclusion principle is already an old one,  
but its conclusion has not yet written (Pauli, 1946)*

There are no compelling reasons to doubt its validity, but there is still a lively debate on its limits going on, due to the lack of an explanation of PEP based on fundamental principles. Therefore, it is possible to speculate that PEP might represent only an approximation of a more fundamental law, and consequently, to search for possible tiny violations is very important.

One possible experiment is to test the validity of PEP with electrons. In 1988, Ramberg and Snow<sup>59</sup> searched for anomalous X-rays emission, signalling a small violation of the PEP in a copper conductor. The result of the experiment was a probability limit for PEP violation  $< 1.7 \times 10^{-26}$  that a new electron circulating in the conductor would form a mixed symmetry state with the remaining copper electrons.

In the VIP project we repeat this experiment with substantially higher sensitivity. Our aim is to lower the limit by 4 orders of magnitude by using high resolution charge-coupled devices (CCDs) as soft X-rays detectors. To decrease the background only carefully chosen materials were used and the measurement will be performed in an underground laboratory.

The experimental method consists of introducing new electrons into a copper strip and to look for X-rays resulting from the  $2p \rightarrow 1s$  anomalous X-rays transitions emitted if one of the new electrons would be captured by a Cu atom and cascades down to the  $1s$  state already filled with two

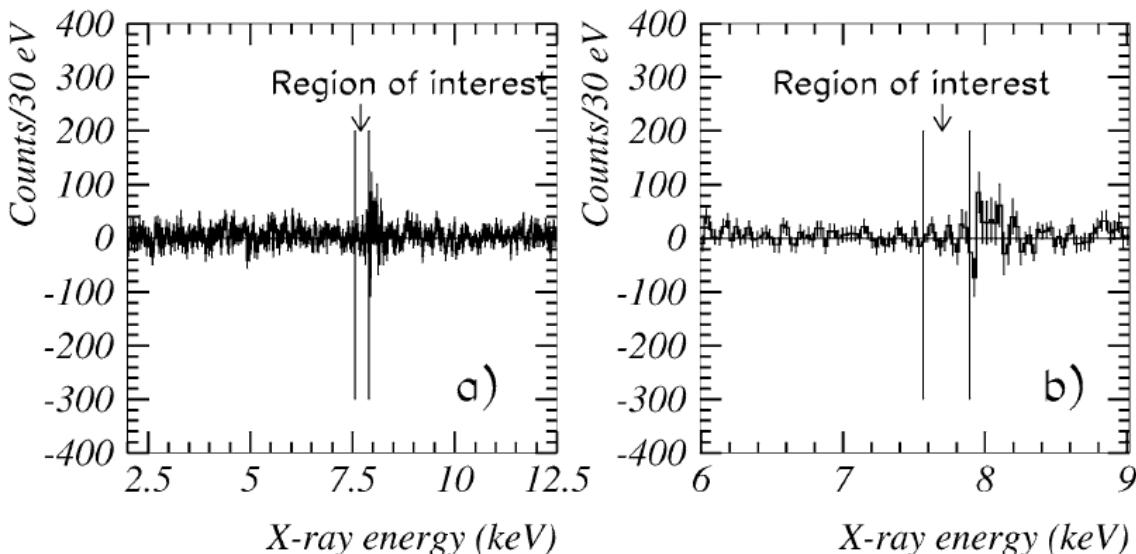


Fig. 45: Subtracted spectra (current on/current off). In a) the whole energy range, b) the region of interest is displayed. No indications of a peak are found – thus setting the limit on the PEP.

electrons of opposite spin. The energy of this transition would differ from the normal  $K\alpha$ -transition by about 400 eV (7.64 keV instead of 8.04 keV), providing an unambiguous signal of the PEP violation. For the X-ray detection we employ the CCD detector system used for the DEAR

<sup>59</sup> E. Ramberg, G. Snow, Phys. Lett. B238 (1990) 438.

(DAΦNE Exotic Atom Research) experiment, which has successfully completed its program at the DAΦNE collider at LNF-INFN<sup>60</sup>.

The measurement alternates periods with no current in the Cu strip, in order to evaluate the X-ray background in conditions where no PEP violating transitions are expected to occur, with periods with current through the Cu strips, thus providing "fresh" electrons, which might possibly violate PEP.

The rather straightforward analysis consists of the evaluation of the statistical significance of the normalized subtraction of the two spectra in the region of interest.

The results of measurements performed end of 2005 were analyzed and the results published in 2006<sup>61</sup>. We found a limit  $\leq 4.5 \times 10^{-28}$  which improves the existing limit by about 2 orders of magnitude. In 2006 the VIP apparatus was installed in the Gran Sasso underground laboratory (LNGS) and measurements were started already in spring 2006.

## Outlook

A measurement period of about 2 years is foreseen (integrated time with and without current about one year each). The goal is to improve the limit further down to the region  $10^{-30} - 10^{-31}$ . In parallel discussions and feasibility studies on the further increase of the sensitivity of the VIP experiment will go on.

### PERSONEN:

Name	Funktion	Funktion: Zeitraum
Dipl.-Ing. Dr. Michael Cagnelli	Projektmitarbeit	01.10.2004 bis 31.12.2008
Dr. Tomoichi Ishiwatari	Projektmitarbeit	01.10.2004 bis 31.12.2008
Prof. Dr. Paul Kienle	Projektmitarbeit	01.10.2004 bis 31.12.2008
Dipl.-Ing. Dr. Johann Marton	Projektmitarbeit	01.10.2004 bis 31.12.2008
Univ.-Prof. Dr. Eberhard Widmann	Projektmitarbeit	01.11.2004 bis 31.12.2008
Dr. Johann Zmeskal	Projektleitung	01.10.2004 bis 31.12.2008

### PUBLIKATIONEN:

Bartalucci, S.; Bertolucci, S.; Bragadireanu, M.; Cagnelli, M.; Catitti, M. et al. [...] (2006) New experimental limit on the Pauli exclusion principle violation by electrons. Physics Letters B, Bd. 641 (1), S. 18-22. [Cagnelli, M. (KoautorIn); Ishiwatari, T. (KoautorIn); Marton, J. (KoautorIn); Widmann, E. (KoautorIn); Zmeskal, J. (KoautorIn)]

### VORTRAG/POSTERPRÄSENTATION:

Marton, Johann (20.07.2006) New Experimental Test of the Pauli Exclusion Principle. Posterpräsentation: International Conference on Atomic Physics ICAP 2006, Innsbruck/AUSTRIA. [Marton, Johann]

Marton, Johann (01.11.2006) Some possibilities / perspectives of VIP. Vortrag: Mini-Workshop VIP, Frascati/ITALY. [Marton, Johann]

<sup>60</sup> G. Beer et al, Phys. Rev. Lett. 94 (2005) 212302.

<sup>61</sup> S. Bartalucci et al., Phys. Lett. B641 (2006) 18.

### 1.3.4.5 Dissertationen und Diplomarbeiten am SMI

#### Dissertationsprojekt

Pion-Nucleon Interaction

**TITEL: Z: Determination of the groundstate width in pionic hydrogen**

PERSONEN:

Name	Funktion	Funktion: Zeitraum
Dipl.-Ing. Albert Hirtl	Projektmitarbeit	01.03.2002 bis 31.12.2007

#### Dissertationsprojekt

FS3\_c\_b: Internal target system for PANDA

**TITEL: Z: Development of a cluster-jet target for PANDA**

PERSONEN:

Name	Funktion	Funktion: Zeitraum
Mag. Alexander Gruber	Projektmitarbeit	15.03.2005 bis 14.03.2008

#### Sonstiges Einzelforschungsprojekt

FS2\_b: Hyperfine structure of antiprotonic helium

**TITEL: Z: Diplomarbeit - Collisional Effects In the Measurement of the Hyperfine Structure of Antiprotonic Helium**

PERSONEN:

Name	Funktion	Funktion: Zeitraum
Chloe Malbrunot	Projektmitarbeit	01.06.2006 bis 30.06.2007

#### Sonstiges Einzelforschungsprojekt

FS1\_c: Deeply bound kaonic nuclei with FOPI at GSI

**TITEL: Z: Diplomarbeit - Flüssig Deuterium Target zur Untersuchung von stark gebundenen Kaonischen Zuständen**

PERSONEN:

Name	Funktion	Funktion: Zeitraum
Philipp Schmid	Projektmitarbeit	01.06.2005 bis 15.04.2007

#### Dissertationsprojekt

FS2\_b: Hyperfine structure of antiprotonic helium

**TITEL: Z: Improved Measurements of the Hyperfine Structure of Antiprotonic Helium**

PERSONEN:

Name	Funktion	Funktion: Zeitraum
B. Sc. with 1st degree honours Thomas Pask	Projektmitarbeit	01.08.2005 bis 31.07.2009

## Dissertationsprojekt

SUNS - Spallation Ultra Cold Neutron Source at PSI, Source Development

**TITEL:** Z: Properties of solid deuterium ( $D_2$ ) as an ultracold neutron moderator and comparison with other possible moderator materials: solid oxygen ( $O_2$ ) and solid heavy methane ( $CD_4$ ).

### PERSONEN:

Name	Funktion	Funktion: Zeitraum
Mag. Małgorzata Kasprzak	Projektmitarbeit	01.09.2004 bis 21.12.2007

## 1.4 Forschungsergebnisse 2006

### 1.4.1 Veröffentlichungen

#### Beitrag in Fachzeitschrift

wissenschaftlich, referiert

Atchison, F.; Blau, B.; Daum, M.; Fierlinger, P.; Foelske, A. et al. [..] (2006) Diamondlike carbon can replace beryllium in physics with ultracold neutrons. Physics Letters B, Bd. 642 (1-2), S. 24-27. [Kasprzak, M. (KoautorIn)]

Atchison, F.; Blau, B.; Daum, M.; Fierlinger, P.; Geltenbort, P. et al. [..] (2006) Storage of ultracold neutrons in a volume coated with diamondlike carbon. Physical Review C, Bd. 74, S. 55501 . [Kasprzak, M. (KoautorIn)]

Bartalucci, S.; Bertolucci, S.; Bragadireanu, M.; Cagnelli, M.; Catitti, M. et al. [..] (2006) New experimental limit on the Pauli exclusion principle violation by electrons. Physics Letters B, Bd. 641 (1), S. 18-22. [Cagnelli, M. (KoautorIn); Ishiwatari, T. (KoautorIn); Marton, J. (KoautorIn); Widmann, E. (KoautorIn); Zmeskal, J. (KoautorIn)]

Ericson, T.E.O.; Ivanov, A. (2006) Dispersive e.m. corrections to pi N scattering lengths. Physics Letters B, Bd. 634 (1), S. 39-47. [Ivanov, A. (KoautorIn)]

Hori, M.; Dax, A.; Eades, J.; Gomikawa, K.; Hayano, R.S. et al. [..] (2006) Determination of the Antiproton-to-Electron Mass Ratio by Precision Laser Spectroscopy of pHe+. Physical Review Letters, Bd. 96, S. 243401. [Juhasz, B. (KoautorIn); Widmann, E. (KoautorIn)]

Juhasz, B.; Barna, D.; Eades, J.; Fuhrmann, H.; Hayano, R.S. et al. [..] (2006) Low temperature behaviour of collisions between antiprotonic helium and hydrogenic molecules and an indication of the Wigner threshold law. Chemical Physics Letters, Bd. 427 (4-6 ), S. 246-250. [Juhasz, B. (HauptautorIn); Widmann, E. (KoautorIn); Zmeskal, J. (KoautorIn)]

Mulhauser, F; Adamczak, A; Beer, GA; Bystritsky, VM; Filipowicz, M et al. [..] (2006) Ramsauer-Townsend effect in muonic atom scattering. Physical Review A, Bd. 73, S. 034501 . [Zmeskal, J. (KoautorIn)]

#### Beitrag in Fachzeitschrift

wissenschaftlich, nicht referiert

Curceanu, C.; Rusetski, A.; Widmann, E. (2006) Exotic atoms cast light on fundamental questions. CERN Courier, Bd. 46 (9), S. 32-34. [Widmann, E. (KoautorIn)]

Currell, F. J.; Widmann, E. (2006) Challenges for atomic and fundamental physics with highly charged ions and antiprotons. Nuclear Physics News, Bd. 16 (1), S. 24-28. [Widmann, E. (KoautorIn)]

#### Forschungsbericht

wissenschaftlich, nicht referiert

Buehler, P.; Cagnelli, M.; Hirtl, A.; Ishiwatari, T.; Kienle, P. et al. [..] (15.06.2006) Technical proposal to J-PARC: A search for deeply-bound kaonic nuclear states byin-flight  ${}^3\text{He}(\text{K}^-, \text{n})$  reaction. [Bühler, P. (Ko-

autorIn); Cargnelli, M. (KoautorIn); Hirtl, A. (KoautorIn); Ishiwatari, T. (KoautorIn); Kienle, P. (KoautorIn); Marton, J. (KoautorIn); Widmann, E. (KoautorIn); Zmeskal, J. (KoautorIn)]

Buehler, P.; Cargnelli, M.; Hirtl, A.; Ishiwatari, T.; Kienle, P. et al. [...] (15.06.2006) Technical proposal to J-PARC: Precision spectroscopy of Kaonic Helium 3d → 2p X-rays. [Bühler, P. (KoautorIn); Cargnelli, M. (KoautorIn); Hirtl, A. (KoautorIn); Ishiwatari, T. (KoautorIn); Marton, J. (KoautorIn); Widmann, E. (KoautorIn); Zmeskal, J. (KoautorIn)]

Cargnelli, M.; Curceanu, C.; Faber, M.; Guaraldo, C.; Hirtl, A. et al. [...] (01.03.2006) Letter of Intent: Study of deeply bound kaonic nuclear states at DAΦNE2. [Bühler, P. (KoautorIn); Cargnelli, M. (KoautorIn); Hirtl, A. (KoautorIn); Ishiwatari, T. (KoautorIn); Kienle, P. (KoautorIn); Marton, J. (KoautorIn); Widmann, E. (KoautorIn); Zmeskal, J. (KoautorIn)]

Gotta, D.; Gruber, A.; Hirtl, A.; Indelicato, P.; Marton, J. et al. [...] (10.01.2006) Addendum to proposal R-98.01 at PSI: Pionic Deuterium. [Cargnelli, M. (KoautorIn); Gruber, A. (KoautorIn); Hirtl, A. (KoautorIn); Marton, J. (KoautorIn); Widmann, E. (KoautorIn); Zmeskal, J. (KoautorIn)]

### Konferenzbeitrag: Publikation in Proceedingsband

**wissenschaftlich, nicht referiert**

Beller, P.; Franzke, B.; Kienle, P.; Kruecken, R.; Koop, I. et al. [...] (20.03.2006) Antiproton – Ion Collider for FAIR Project. (International Workshop on Beam Cooling and Related Topics - COOL05) In Reihe: American Institute of Physics Conference Proceedings - Volume 821: American Institute of Physics, S. 108-112. [Kienle, P. (KoautorIn); Widmann, E. (KoautorIn)]

Bühler, P.; Cargnelli, M.; Kienle, P.; Marton, J.; Widmann, E. et al. [...] (15.06.2006) AMADEUS at DAFNE 2. (International Workshop Exotic hadronic atoms, deeply bound kaonic nuclear states and antihydrogen: present results, future challenges). [Cargnelli, M. (KoautorIn); Ishiwatari, T. (KoautorIn); Kienle, P. (KoautorIn); Marton, J. (KoautorIn); Widmann, E. (KoautorIn); Zmeskal, J. (HauptautorIn)]

Bühler, P.; Cargnelli, M.; Kienle, P.; Marton, J.; Widmann, E. et al. [...] (15.06.2006) Search for ppK- in p+d-reaction with FOPI. (International Workshop Exotic hadronic atoms, deeply bound kaonic nuclear states and antihydrogen: present results, future challenges). [Bühler, P. (HauptautorIn); Cargnelli, M. (KoautorIn); Kienle, P. (KoautorIn); Marton, J. (KoautorIn); Widmann, E. (KoautorIn); Zmeskal, J. (KoautorIn)]

Cargnelli, M.; Ishiwatari, T.; Kienle, P.; Marton, J.; Widmann, E. et al. [...] (17.11.2006) New Precision Studies of Strong Interaction in Exotic Atoms: Kaonic Hydrogen and Deuterium. (9th Conference on the Intersections of Particle and Nuclear Physics CIPANP06) In Reihe: AIP Conference Proceedings - Volume 870: American Institute of Physics, S. 475-477. [Cargnelli, M. (KoautorIn); Ishiwatari, T. (KoautorIn); Kienle, P. (KoautorIn); Marton, J. (HauptautorIn); Widmann, E. (KoautorIn); Zmeskal, J. (KoautorIn)]

Cargnelli, M.; Ishiwatari, T.; Kienle, P.; Marton, J.; Widmann, E. et al. [...] (15.06.2006) Kaonic Hydrogen Experiment. (International Workshop Exotic hadronic atoms, deeply bound kaonic nuclear states and antihydrogen: present results, future challenges) In Reihe: Mini-proceedings of: International Workshop Exotic hadronic atoms, deeply bound kaonic nuclear states and antihydrogen: present results, future challenges. [Cargnelli, M. (KoautorIn); Ishiwatari, T. (KoautorIn); Kienle, P. (KoautorIn); Marton, J. (HauptautorIn); Widmann, E. (KoautorIn); Zmeskal, J. (KoautorIn)]

Ericson, Torleif E. O.; Ivanov, Andrei (11.07.2006) Dispersive e.m. corrections to pi N scattering at threshold. (PARTICLES AND NUCLEI: Seventeenth International Conference on Particles and Nuclei) In Reihe: AIP Conference Proceedings - Volume 842: American Institute of Physics, S. 525-527. [Ivanov, A. (KoautorIn)]

Gotta, D.; Marton, Johann; Hirtl, Albert; Simons, L.; Zmeskal, Johann (11.07.2006) Pionic hydrogen: Precision measurements at PSI. (PARTICLES AND NUCLEI: Seventeenth International Conference on Particles and Nuclei) In Reihe: AIP Conference Proceedings - Volume 842: American Institute of Physics, S. 796-798. [Hirtl, A. (KoautorIn); Marton, J. (HauptautorIn); Zmeskal, J. (KoautorIn)]

Gruber, A.; Marton, J.; Widmann, E.; Zmeskal, J. (17.11.2006) Precision hadron spectroscopy in the charmonium mass region using antiproton annihilation. (9th International Conference on Hypernuclear and Strange Particle Physics) In Reihe: AIP Conference Proceedings - Volume 870: American Institute of Physics, S. 394-397. [Gruber, A. (KoautorIn); Marton, J. (HauptautorIn); Widmann, E. (KoautorIn); Zmeskal, J. (KoautorIn)]

Ishiwatari, T.; Sato, M.; Widmann, E. (11.07.2006) Experimental study of strange tribaryons in the  $4^{\text{He}}(\text{K}^-, \text{p})$  reaction. (PARTICLES AND NUCLEI: Seventeenth International Conference on Particles and Nuclei) In Reihe: AIP Conference Proceedings - Volume 842: American Institute of Physics, S. 480-482. [Ishiwatari, T. (KoautorIn); Widmann, E. (KoautorIn)]

Ivanov, A.; Marton, J. (15.06.2006) Phenomenological quantum field theoretic model of Kaonic Nuclear Clusters K-pp, K-pnn and so on. (International Workshop Exotic hadronic atoms, deeply bound kaonic nuclear states and antihydrogen: present results, future challenges). [Ivanov, A. (HauptautorIn); Marton, J. (KoautorIn)]

Juhasz, B.; Widmann, B. (15.06.2006) Measurement of the ground-state hyperfine structure of antihydrogen. (International Workshop Exotic hadronic atoms, deeply bound kaonic nuclear states and antihydrogen: present results, future challenges). [Juhasz, B. (HauptautorIn); Widmann, E. (KoautorIn)]

Kienle, P. (15.06.2006) Probing the structure of nuclei bound by antikaons. (International Workshop Exotic hadronic atoms, deeply bound kaonic nuclear states and antihydrogen: present results, future challenges) In Reihe: Mini-proceedings of: International Workshop Exotic hadronic atoms, deeply bound kaonic nuclear states and antihydrogen: present results, future challenges. [Kienle, P. (HauptautorIn)]

Marton, Johann (11.07.2006) Experimental studies on kaonic atoms at DAFNE: Recent results and perspectives. (PARTICLES AND NUCLEI: Seventeenth International Conference on Particles and Nuclei) In Reihe: American Institute of Physics Conference Proceedings - Volume 842: American Institute of Physics, S. 256-258. [Marton, J. (HauptautorIn)]

Marton, Johann (15.06.2006) Exotic Atom Research Using Large Area Silicon Drift Detectors. (International Symposium On Detector Development For Particle, Astroparticle And Synchrotron Radiation Experiments (SNIC 2006)). [Marton, J. (HauptautorIn)]

Okada, S.; Cagnelli, M.; Ishiwatari, T.; Juhaesz, B.; Kienle, P. et al. [...] (17.11.2006) Precise measurement of kaonic helium 3d  $\rightarrow$  2p x-rays. (Conference on the Intersections of Particle and Nuclear Physics) In Reihe: AIP Conference Proceedings - Volume 870: American Institute of Physics, S. 493-495. [Cagnelli, M. (KoautorIn); Ishiwatari, T. (KoautorIn); Juhaesz, B. (KoautorIn); Kienle, P. (KoautorIn); Marton, J. (KoautorIn); Schmid, P. (KoautorIn); Widmann, E. (KoautorIn); Zmeskal, J. (KoautorIn)]

## 1.4.2 Vorträge / Posterpräsentationen

### Posterpräsentation

#### wissenschaftlich

Marton, Johann (03.04.2006) Exotic Atom Research using Large Area Silicon Drift Detectors. Posterpräsentation: International Symposium on Detector Development, Stanford/UNITED STATES. [Marton, Johann]

Marton, Johann (20.07.2006) New Experimental Test of the Pauli Exclusion Principle. Posterpräsentation: International Conference on Atomic Physics ICAP 2006, Innsbruck/AUSTRIA. [Marton, Johann]

Marton, Johann (20.07.2006) New Precision Studies of Kaonic Hydrogen Atoms. Posterpräsentation: International Conference on Atomic Physics ICAP 2006, Innsbruck/AUSTRIA. [Marton, Johann]

Marton, Johann (20.07.2006) Testing Matter/Antimatter Symmetry with Antiprotonic Atoms and Antihydrogen. Posterpräsentation: International Conference on Atomic Physics ICAP 2006, Innsbruck/AUSTRIA. [Marton, Johann]

### Vortrag

#### wissenschaftlich

Bakalov, Dimitar (08.11.2006) Can antiproton magnetic moment be determined from the hyperfine structure of antiprotonic helium?. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Bakalov, Dimitar]

Bühler, Paul (15.09.2006) Particle reconstruction in the p+X experiment using CDC and Helitron/Plawa . Vortrag: FOPI collaboration meeting, Warschau/POLAND. [Bühler, Paul]

Bühler, Paul (17.10.2006) p+X @ FOPI - status. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Bühler, Paul]

Bühler, Paul (22.06.2006) Search for ppK- in p+d-reaction with FOPI . Vortrag: International Workshop Exotic hadronic atoms, deeply bound kaonic nuclear states and antihydrogen: present results, future challenges (ECT\*), Trento/ITALY. [Bühler, Paul]

Bühler, Paul (27.04.2006) The search for kaonic nuclear clusters - a status report. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Bühler, Paul]

Cargnelli, Michael (07.08.2006) Data from p (3.5GeV) + plastic at FOPI (Oct. 2005). Vortrag: Workmeeting "Study of Kaonic nuclear clusters at FOPI" (TU München), München/GERMANY. [Cargnelli, Michael]

Cargnelli, Michael (07.08.2006) Simulation of K-cluster at FOPI. Vortrag: Meeting "Study of Kaonic nuclear clusters at FOPI" (TU München), München/GERMANY. [Cargnelli, Michael]

Cargnelli, Michael (13.06.2006) Kaonic hydrogen X rays - experiments at DAFNE. Vortrag: International Workshop on Precision Physics of Simple Atomic Systems (PSAS 2006), Venedig/ITALY. [Cargnelli, Michael]

Cargnelli, Michael (17.10.2006) Simulations for pp2KX. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Cargnelli, Michael]

Cargnelli, Michael (27.04.2006) AMADEUS - Study of deeply bound kaonic nuclear states at DAFNE2 . Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Cargnelli, Michael]

Gruber, Alexander (18.09.2006) Development of a cluster-jet target for PANDA. Vortrag: ÖPG-FAKT Tagung 2006, Maria Lankowitz/AUSTRIA. [Gruber, Alexander]

Gruber, Alexander (18.10.2006) Status report of PANDA activities at SMI for 2006. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik, Wien/AUSTRIA. [Gruber, Alexander; Hirtl, Albert]

Hartmann, Olaf (04.05.2006) Charming Hadrons in Nuclear Matter. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Hartmann, Olaf]

Hirtl, Albert (15.05.2006) Strategy for the ECRIT and piH-Analysis. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Hirtl, Albert]

Hirtl, Albert (18.09.2006) Pionic Hydrogen. Vortrag: ÖPG-FAKT Tagung 2006 (Österreichische Physikalische Gesellschaft), Maria Lankowitz/AUSTRIA. [Hirtl, Albert]

Hirtl, Albert (28.09.2006) Status of the piH Experiment. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Hirtl, Albert]

Ishiwatari, T. (28.09.2006) Status report for E570. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik)/AUSTRIA. [Ishiwatari, Tomoichi]

Ishiwatari, Tomoichi (10.05.2006) Precision spectroscopy of Kaonic Helium 3d->2p X-rays. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Ishiwatari, Tomoichi]

Ishiwatari, Tomoichi (12.05.2006) Precision measurements with SDD. Experience gained at KEK . Vortrag: SIDDHARTA Collaboration Meeting , Frascati/ITALY. [Ishiwatari, Tomoichi]

Ivanov, Andrei (11.09.2006) Phenomenological model of Kaonic Nuclear Clusters K-pp, K -pnn and so on. Vortrag: Symposium QCD: Facts and Prospects, Oberwölz, Steiermark/AUSTRIA. [Ivanov, Andrei]

Ivanov, Andrei (21.06.2006) Phenomenological quantum field theoretic model of Kaonic Nuclear Clusters K-pp, K-pnn and so on. Vortrag: International Workshop Exotic hadronic atoms, deeply bound kaonic nuclear states and antihydrogen: present results, future challenges (ECT\*), Trento/ITALY. [Ivanov, Andrei]

Juhasz, Bertalan (01.12.2006) Sextupole beam line for ASACUSA. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Juhasz, Bertalan]

Juhasz, Bertalan (04.09.2006) Measurement of the ground-state hyperfine structure of antihydrogen. Vortrag: International Conference on Trapped Charged Particles and Fundamental Physics (TCP06), Parksville/CANADA. [Juhasz, Bertalan]

Juhasz, Bertalan (06.10.2006) ASACUSA: Testing the CPT symmetry with antiprotons. Vortrag: ECFA meeting, Debrecen/HUNGARY. [Juhasz, Bertalan]

Juhasz, Bertalan (18.09.2006) Measurement of the ground-state hyperfine splitting of antihydrogen. Vortrag: ÖPG Fachausschusstagung Kern- und Teilchenphysik 2006, Maria Lankowitz/AUSTRIA. [Juhasz, Bertalan]

Juhasz, Bertalan (18.10.2006) Ground-state hyperfine structure of antihydrogen:STATUS. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Juhasz, Bertalan]

Juhasz, Bertalan (21.06.2006) Measurement of the ground-state hyperfine structure of antihydrogen. Vortrag: International Workshop Exotic hadronic atoms, deeply bound kaonic nuclear states and antihydrogen: present results, future challenges (ECT\*), Trento/ITALY. [Juhasz, Bertalan]

Kasprzak, Malgorzata (13.02.2006) Thermal up-scattering of VCN in solid D2. Vortrag: Present Status and Future of Very Cold Neutron Applications/SWITZERLAND. [Kasprzak, Malgorzata]

Kasprzak, Malgorzata (13.02.2006) UCN production efficiency of solid D2, O2 and CD4. Vortrag: Present Status and Future of Very Cold Neutron Applications/SWITZERLAND. [Kasprzak, Malgorzata]

Kasprzak, Malgorzata (14.02.2006) Measurement of the ultracold neutron production efficiency of solid D2, O2 and CD4. Vortrag: Swiss Physical Society Meeting/SWITZERLAND. [Kasprzak, Malgorzata]

Kasprzak, Malgorzata (15.02.2006) UCN production efficiency of solid D2, O2 and CD4. Vortrag: Open user meeting BV37/SWITZERLAND. [Kasprzak, Malgorzata]

Kasprzak, Malgorzata (20.01.2006) Measurement of the ultracold neutron (UCN) production efficiency of solid D2, CD4 and O2. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Kasprzak, Malgorzata]

Kasprzak, Malgorzata (22.11.2006) Energy dependent ultracold neutron (UCN) production in deuterium (D2). Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Kasprzak, Malgorzata]

Kasprzak, Malgorzata (22.11.2006) Para to ortho conversion in solid D2 catalyzed by molecular oxygen. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik, Wien/AUSTRIA. [Kasprzak, Malgorzata]

Kasprzak, Malgorzata (26.04.2006) Antimatter gravity. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Kasprzak, Malgorzata]

Kienle, P. (17.10.2006) HYP 2006 Report and Strategies. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik)/AUSTRIA. [Kienle, Paul]

Kienle, Paul (03.04.2006) Experimental Studies of Antikaon Mediated Nuclear Bound States. Vortrag: ISHIP 2006, Frankfurt/ Main/GERMANY. [Kienle, Paul]

Kienle, Paul (04.07.2006) Perspectives of Antiproton and Antikaon Physics. Vortrag: International Workshop, Observables of Antiproton Interactions and Their Relevance to QCD, Trento/ITALY. [Kienle, Paul]

Kienle, Paul (04.12.2006) Experimental Studies of Chiral Symmetry Restoration. Vortrag: Yukawa International Seminar 2006, New Frontiers in QCD, Kyoto/JAPAN. [Kienle, Paul]

Kienle, Paul (11.10.2006) The AMADEUS Project. Vortrag: IX International Conference on Hypernuclear and Strange Particle Physics, Mainz/GERMANY. [Kienle, Paul]

Kienle, Paul (12.06.2006) Deeply Bound Kaonic Nuclear States. Vortrag: MESON 2006, Krakau/POLAND. [Kienle, Paul]

Kienle, Paul (22.06.2006) Probing the structure of nuclei bound by antikaons. Vortrag: Exotic hadronic atoms, deeply bound kaonic nuclear states and antihydrogen: present results, future challenges, Trento/ITALY. [Kienle, Paul]

Marton, Johann (01.06.2006) Precision hadron spectroscopy in the charmonium mass region using antiproton annihilation. Vortrag: 9th Conference on the Intersections of Particle and Nuclear Physics CIPANP06, Rio Mar/UNITED STATES. [Marton, Johann]

Marton, Johann (01.11.2006) Some possibilities / perspectives of VIP. Vortrag: Mini-Workshop VIP, Frascati/ITALY. [Marton, Johann]

Marton, Johann (04.09.2006) SiPMT test setup at SMI. Vortrag: PANDA Meeting, Wien/AUSTRIA. [Marton, Johann]

Marton, Johann (10.01.2006) Exotische Wasserstoffatome – Präzisionsmessungen zur starken Wechselwirkung. Vortrag: Institutsseminar (Institut für Allgemeine Physik, TU Wien), Wien/AUSTRIA. [Marton, Johann]

Marton, Johann (17.01.2006) Hadronic Hydrogen Atoms – New Precision Studies of Studies of Strong Interaction. Vortrag: Institutsseminar (ETH Zurich), Zürich/SWITZERLAND. [Marton, Johann]

Marton, Johann (20.06.2006) Kaonic Hydrogen Experiment. Vortrag: International Workshop Exotic hadronic atoms, deeply boundkaonic nuclear states and antihydrogen: present results, future challenges, Trento/ITALY. [Marton, Johann]

Marton, Johann (25.08.2006) Precision Studies on Strong Interaction in Pionic Hydrogen. Vortrag: International IUPAP Conference on Few Body Problems in Physics FB18,, Sao Paulo/BRAZIL. [Marton, Johann]

Marton, Johann (30.05.2006) New Precision Studies of Strong Interaction in Exotic Atoms: Kaonic Hydrogen and Deuterium. Vortrag: 9th Conference on the Intersections of Particle and Nuclear Physics CIPANP06, Rio Mar/UNITED STATES. [Marton, Johann]

Pask, T. (18.10.2006) Preliminary Results From the Microwave Experiment. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Pask, Thomas]

Pask, T.; Malbrunot, C. (07.12.2006) Results of ASACUSA run 2006. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Malbrunot, Chloe; Pask, Thomas]

Pask, Thomas (18.09.2006) An Improved Measurement of the Hyperfine Structure of Anti-protonic Helium. Reducing the Upper Limit on CPT theory?. Vortrag: Fachausschusstagung Kern- und Teilchenphysik 2005 (Österreichische Physikalische Gesellschaft), Maria Lankowitz/AUSTRIA. [Pask, Thomas]

S., Karshenboim (08.05.2006) Precision tests of bound state QED. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Karshenboim, Savely]

Schmid, Philipp (10.03.2006) Experimental studies on antihydrogen in-flight. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Schmid, Philipp]

Schmid, Philipp (18.09.2006) Experimental search for deeply bound kaonic states. Vortrag: ÖPG-FAKT Tagung 2006 (Österreichische Physikalische Gesellschaft), Maria Lankowitz/AUSTRIA. [Schmid, Philipp]

Suzuki, Ken (20.10.2006) Simulation on the  $p + p \rightarrow K+ + K-pp$  reaction with FOPI in Search for the kaonic nuclear cluster  $K-pp$ . Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Suzuki, Ken]

Widmann, Eberhard (03.02.2006) Physics with low-energy antiprotons – from AD to FLAIR. Vortrag: XLIV International Winter Meeting on Nuclear Physics , Bormio /ITALY. [Widmann, Eberhard]

Widmann, Eberhard (05.04.2006) Fundamental tests with trapped antiprotons part 1. Vortrag: Trapped charged particles for fundamental interactions, WE Heraeus Winter School, Hirschegg/AUSTRIA. [Widmann, Eberhard]

Widmann, Eberhard (05.04.2006) Fundamental tests with trapped antiprotons part 2. Vortrag: Trapped charged particles for fundamental interactions, WE Heraeus Winter School, Hirschegg/AUSTRIA. [Widmann, Eberhard]

Widmann, Eberhard (06.11.2006) Studying fundamental symmetries and interactions with exotic atoms. Vortrag: Seminar zur starken Wechselwirkung (TU München), München/GERMANY. [Widmann, Eberhard]

Widmann, Eberhard (07.04.2006) Fundamental tests with trapped antiprotons part 3. Vortrag: Trapped charged particles for fundamental interactions, WE Heraeus Winter School, Hirschegg/AUSTRIA. [Widmann, Eberhard]

Widmann, Eberhard (07.04.2006) Fundamental tests with trapped antiprotons part 4. Vortrag: Trapped charged particles for fundamental interactions, WE Heraeus Winter School, Hirschegg/AUSTRIA. [Widmann, Eberhard]

Widmann, Eberhard (12.10.2006) Studying fundamental interactions and symmetries with exotic atoms. Vortrag: Seminar physics department (Uppsala University), Uppsala /SWEDEN. [Widmann, Eberhard]

Widmann, Eberhard (14.09.2006) Physics with low-energy antiprotons Part 1. Vortrag: 6th Euroschool on Exotic Beams, ECT\* Trento, Trento/ITALY. [Widmann, Eberhard]

Widmann, Eberhard (14.09.2006) Physics with low-energy antiprotons Part 2. Vortrag: 6th Euroschool on Exotic Beams, ECT\* Trento, Trento/ITALY. [Widmann, Eberhard]

Widmann, Eberhard (15.09.2006) Physics with low-energy antiprotons Part 3. Vortrag: 6th Euroschool on Exotic Beams, ECT\* Trento, Trento/ITALY. [Widmann, Eberhard]

Widmann, Eberhard (18.09.2006) Antiproton Physics at FAIR. Vortrag: ÖPG-FAKT Tagung, Maria Lankowitz/AUSTRIA. [Widmann, Eberhard]

Widmann, Eberhard (27.03.2006) Current and future experiments with low-energy ANTIPROTONS. Vortrag: Seminar Inst. f. theoret. Physik TU Wien, Wien/AUSTRIA. [Widmann, Eberhard]

Widmann, Eberhard (30.03.2006) Present and future of exotic atom research with antiprotons. Vortrag: Symposium (MPI Heidelberg), Heidelberg/GERMANY. [Widmann, Eberhard]

Zmeskal, Johann (12.06.2006) Search for kaonic nuclei at DAFNE 2: the AMADEUS project. Vortrag: 9th International Workshop on Meson Production, Properties and Interaction - MESON 06, Krakow/POLAND. [Zmeskal, Johann]

Zmeskal, Johann (17.10.2006) Search for antikaon-mediated bound nuclear clusters with FOPI, AMADEUS and P15. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Zmeskal, Johann]

Zmeskal, Johann (18.09.2006) Search for antikaon-mediated bound nuclear clusters with FOPI and AMADEUS. Vortrag: Seminar TU München, München/GERMANY. [Zmeskal, Johann]

Zmeskal, Johann (23.06.2006) AMADEUS at DAFNE 2. Vortrag: International Workshop: Exotic hadronic atoms, deeply bound kaonic nuclear states and antihydrogen: present results, future challenges (ECT\*), Trento/ITALY. [Zmeskal, Johann]

Zmeskal, Johann (25.08.2006) Experimental Studies on Kaonic Atoms at DAFNE. Vortrag: 18th International IUPAP Conference on Few-Body Problems in Physics, Santos/BRAZIL. [Zmeskal, Johann]

Zmeskal, Johann (27.11.2006) SIDDHARTA Program, Preparations and Outlook. Vortrag: 33rd LNF Scientific Committee Meeting, Frascati/ITALY. [Zmeskal, Johann]

Zmeskal, Johann (28.09.2006) SIDDHARTA Status September 2006. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (Stefan Meyer Institut für subatomare Physik), Wien/AUSTRIA. [Zmeskal, Johann]

### 1.4.3 Medienpräsenz

Datum	Medium	Titel	Schlagwort	Medienkategorie
19-Jun-06	derstandard.at	Massegleichheit von Teilchen und Antiteilchen durch neuen Test nicht widerlegt	Antiprotonenmasse	Internet
19-Jun-06	APA J For-schung	Rekord-Bestimmung der Masse des Antiprotons	Antiprotonenmasse	Internet
19-Jun-06	APA-ZukunftWissen OM	Genaueste Bestimmung der Antiprotonenmasse	Antiprotonenmasse	Internet
19-Jun-06	APA-ZukunftWissen	Akademie-Physiker: Rekord-Bestimmung der Masse des Antiprotons	Antiprotonenmasse	Internet
20-Jun-06	ORF ON science.orf.at	Präziseste Bestimmung der Anti-Proton-Masse	Antiprotonenmasse	Internet
20-Jun-06	Die Presse	Symmetrie der Physik	Antiprotonenmasse	Print
20-Jun-06	diepresse.com	Symmetrie der Physik	Antiprotonenmasse	Internet
21-Jun-06	Wiener Zeitung	Proton und Antiproton gleich	Antiprotonenmasse	Print
11-Aug-06	APA-ZukunftWissen OM	Hadronenphysik mit Antiprotonen - Internationales PANDA-Meeting in Wien	PANDA-Meeting	Internet
16-Aug-06	Der Standard	Was kommt: PANDA	PANDA-Meeting	Print
20-Sept-06	FAZ	Pauli-Prinzip mit höchster Präzision getestet: Kein Widerspruch zum Ausschließungsprinzip	VIP	Print
20-Dez-06	Die Presse	Die Welt der kleinsten Teilchen Die Institute: Daten & Fakten	Physikinstitute (Medienkooperation)	Print
20-Dez-06	Die Presse	Teilchenphysik: wo sich Materie und Licht verschränken	Physikinstitute (Medienkooperation)	Print

## **1.5 Wissenschaftliche Zusammenarbeit 2006**

### **1.5.1 Zusammenarbeit mit in- und ausländischen Instituten**

#### **Titel: AMADEUS at DAPHNE2**

Typ: Forschungsprojekt

Art: Rahmenvereinbarung (schriftlich)

Dauer: 22.08.2005 - ?

Partnerinstitutionen: INFN, Laboratori Nazionali di Frascati, Italy, Atomic Institute of the Austrian Universities, Vienna University of Technology, Austria, University of Toronto, Ontario, Canada, Helmholtz-Institut für Strahlen und Kernphysik, Univ. Bonn, Germany, GSI, Germany, Forschungszentrum Juelich, Germany, Institut fur Theoretische Physik, Universität Tübingen, Germany, Universität Heidelberg, Germany, Technische Universität München, Germany, Department of Physics & Meteorology Indian Institute of Technology, Kharagpur, India, Department of Physics, Isfahan University of Technology, Isfahan, Iran, Istituto Superiore di Sanita', Roma, Italy, Politecnico Milano, Italy, University of Milano and INFN Milano, Italy, University of Firenze and INFN Firenze, Italy, Laboratori Nazionali del Sud dell'INFN, Catania, Italy, KEK, Japan, RIKEN, Japan, Soltan Institute for Nuclear Studies, Swierk/Otwock, Poland, Institute of Physics, Jagellonian University, Cracow, Poland, "Horia Hulubei" National Institute of Physics and Nuclear Engineering, Bucharest - Magurele, Romania, University of Bucharest, Faculty of Physics, Bucharest - Magurele, Romania, ITEP, Moscow, Russia, Johannesburg University, South Africa, Univ. of Fribourg, Fribourg, Switzerland, CERN, Switzerland, Lawrence Berkeley National Laboratories, Berkeley, United States

#### **Titel: Antiproton Ion Collider - AIC**

Typ: Forschungsprojekt

Art: Rahmenvereinbarung (schriftlich)

Dauer: 16.12.2004 - ?

Partnerinstitutionen: Andrzej Soltan Institute for Nuclear Studies, Warsaw, BINP - Budker Institute of Nuclear Physics, Novosibirsk, GSI - Gesellschaft für Schwerionenforschung mbH, Justus-Liebig Universität Giessen, Technische Universität München, University of Tokyo, UoS - University of Saitama, Saitama

#### **Titel: Deeply bound kaonic nuclei K-ppn and K-pnn: Experiment E549 at KEK**

Typ: Forschungsprojekt

Art: Rahmenvereinbarung (schriftlich)

Dauer: 01.11.2004 - ?

Partnerinstitutionen: Department of Physics, Univ. of Tokyo, Inst. of Physical and Chemical Research (RIKEN), KEK, High Energy Accelerator Research Organization, Seoul National University, Korea, Tokyo Institute of Technology

#### **Titel: Deeply bound kaonic nuclei with FOPI at GSI**

Typ: Forschungsprojekt

Art: Rahmenvereinbarung (schriftlich)

Dauer: 01.09.2004 - ?

Partnerinstitutionen: GSI - Gesellschaft für Schwerionenforschung, Darmstadt, Physikalisches Institut der Universität Heidelberg, Laboratoire de Physique Corpusculaire, Clermont-Ferrand, Rudjer Boskovic Institute, Zagreb, Stefan Meyer Institut für Subatomare Physik, Wien, University

of Split, Technische Universität München, KFKI Research Institute for Particle and Nuclear Physics, Budapest, Institute for Theoretical and Experimental Physics, Moscow, Department of Physics, Korea University, Seoul, Institut of Experimental Physics, Nuclear Physics Division, Warszawa, Institut für Strahlenphysik, Forschungszentrum Dresden-Rossendorf, Dresden, Russian Research Center, Moscow, Institute for Physics and Nuclear Engineering, Bucharest, Institut de Recherches Subatomiques, Strasbourg, Institute of Modern Physics, Lanzhou, China, Heavy-Ion Nuclear Physics Laboratory (RIKEN), Japan

**Titel: FLAIR: Facility for Low-Energy Antiproton and Ion Research**

Typ: Forschungsprojekt

Art: Rahmenvereinbarung (schriftlich)

Dauer: 01.11.2004 - ?

Partnerinstitutionen: Andrzej Soltan Institute for Nuclear Studies, Warsaw, Atomic Physics Laboratory, RIKEN, D.I. Mendeleev Institute for Metrology (VNIIM), St. Petersburg, Department for Physics and Astronomy, Aarhus University, Department of Atomic Physics, Stockholm University, Department of Experimental Physics, University of Debrecen, Department of Physics and Astronomy, York University, Toronto, Department of Physics, Harvard University, Cambridge, Department of Physics, St. Petersburg State University, Department of Physics, Texas A&M University, College Station, Department of Physics, University of Wales Swansea, Dipartimento di Chimica e Fisica per l'Ingegneria e per i Materiali, Dipartimento di Fisica, Laboratorio LENS, INFN, Università degli Studi di Firenze, FOM Institute for Atomic and Molecular Physics, Amsterdam, Forschungszentrum Jülich GmbH, GSI - Gesellschaft für Schwerionenforschung mbH, Heavy Ion Laboratory, Warsaw University, Indiana University, Bloomington, Inst. of Nuclear Research (ATOMKI) of the Hungarian Acad. of Sciences, Institut für Angewandte Physik, Universität Frankfurt, Institut für Kernphysik, Universität Frankfurt, Institut für Kernphysik, Universität Gießen, Institut für Physik, Humboldt-Universität zu Berlin, Institut für Physik, Universität Mainz, Institut für Theoretische Physik, TU Dresden, Institute for Experimental and Theoretical Physics, Moskva, Institute for Storage Ring Facilities (ISA), Institute for Theoretical Physics, Vienna University of Technology, Institute of Nuclear Physics, Moscow State University, Institute of Physics, University of Tokyo, Institute of Spectroscopy of the Russian Academy of Science, Troitsk, Institute of Theoretical Physics, Warsaw University, Istituto Nazionale di Fisica Nucleare - INFN, Genova, JINR - Joint Institute for Nuclear Research, KFKI Research Institute for Particle and Nuclear Physics, Hungarian Academy of Sciences, Laboratoire Kastler-Brossel, École Normale Supérieure et Univ. Pierre et Marie Curie, Laser Centre Vrije Universiteit, Faculty of Science, Amsterdam, Manne Siegbahn Laboratory (MSL), Stockholm, Max-Planck-Institut für Kernphysik, Pbar Labs, LLC Santa Fe, Queens University, Belfast, Ireland, St. Petersburg Nuclear Physics Institute (PNPI), TRIUMF, Vancouver, University of New Mexico, Albuquerque, Universität Tübingen

**Titel: Kaonic helium X-rays: Experiment E570 at KEK**

Typ: Forschungsprojekt

Art: Rahmenvereinbarung (schriftlich)

Dauer: 01.10.2004 - ?

Partnerinstitutionen: Department of Physics, Univ. of Tokyo, INFN, Laboratori Nazionali di Frascati, Inst. of Physical and Chemical Research (RIKEN), KEK, High Energy Accelerator Research Organization, Seoul National University, Korea, Tokyo Institute of Technology

**Titel: Kaonic hydrogen and deuterium: SIDDHARTA**

Typ: Forschungsprojekt

Art: Rahmenvereinbarung (schriftlich)

Dauer: 01.01.2004 - ?

Partnerinstitutionen: Department of High Energy Physics, Inst. of Physics and Nuclear Engineering, Bukarest, Department of Physics and Astronomy, Univ. of Victoria, Department of Physics and Astrophysics, California State Univ. Northridge, Department of Physics, Hokkaido Univ., Dipartimento di Fisica, Univ. di Trieste und INFN Trieste, INFN, Laboratori Nazionali di Frascati, Inst. de Physique, Univ. de Fribourg, Inst. of Physical and Chemical Research (RIKEN), Institut de Physique, Univ. de Neuchâtel, KEK, High Energy Accelerator Research Organization, Tokyo Institute of Technology , W. K. Kellogg Radiation Laboratory, California Institute of Technology Pasadena

**Titel: Matter - antimatter symmetry: ASACUSA @ CERN - ASACUSA**

Typ: Forschungsprojekt

Art: Rahmenvereinbarung (schriftlich)

Dauer: 01.11.2004 - ?

Partnerinstitutionen: Atomic Physics Laboratory, RIKEN, CERN - European Organization for Nuclear Research, Department for Physics and Astronomy, Aarhus University, Department of Physics, Univ. of Tokyo, Department of Physics, University of Wales Swansea, Dipartimento di Chimica e Fisica per l'Ingegneria e per i Materiali, Inst. of Nuclear Research (ATOMKI) of the Hungarian Acad. of Sciences, Institute for Storage Ring Facilities (ISA), Institute of Physics, University of Tokyo, KFKI Research Institute for Particle and Nuclear Physics, Hungarian Academy of Sciences, Max-Planck-Institut für Kernphysik, Niels Bohr Institute, Queens University, Belfast, Ireland

**Titel: PANDA: Proton Antiproton Annihilations at Darmstadt**

Typ: Forschungsprojekt

Art: Rahmenvereinbarung (schriftlich)

Dauer: 01.01.2004 - ?

Partnerinstitutionen: Universität Basel, IHEP Beijing, Ruhr-Universität Bochum, Universität Bonn, Università di Brescia + INFN, IFIN Bucharest, Università di Catania, University of Silesia, Catowice, University Cracow, GSI, Darmstadt, TU Dresden, JINR Dubna, University Edinburgh, Universität Erlangen, Northwestern University, Evanston, INFN Sezione di Ferrara, Universität Frankfurt, LNF-INFN, Frascati, INFN Sezione di Genova, Università di Genova, Universität Gießen, University of Glasgow, KVI Groningen, Institute of Physics Helsinki, FZ Jülich, IMP Lanzhou, Universität Mainz, Università di Milano, Research Institute for Nuclear Problems, Minsk, TU München, Universität Münster, BINP Novosibirsk, IPN Orsay, Università di Pavia, PNPI Gatchina, St. Petersburg, IHEP Protvino, Stockholm University Università di Torino, Università de Piemonte Orientale, Alessandria, Torino, Università di Trieste + INFN, Universität Tübingen, Uppsala Universitet, TSL Uppsala, Universidad de Valencia, SINS Warschau

**Titel: Pion-Nucleon Interaction**

Typ: Forschungsprojekt

Art: Rahmenvereinbarung (schriftlich)

Dauer: 01.04.1998 - ?

Partnerinstitutionen: Forschungszentrum Jülich GmbH, Inst. of Nuclear Research (ATOMKI) of the Hungarian Acad. of Sciences, Institut de Physique, Univ. de Neuchâtel, Laboratoire Kastler-Brossel, École Normale Supérieure et Univ. Pierre et Marie Curie, Space Research Center, Department of Physics and Astronomy, Univ. of Leicester, Univ. of Ioannina

**Titel: Röntgenspektroskopie an der VERA – Beschleunigeranlage (PIXE)**

Typ: Forschungsprojekt

Art: Informelle Kooperationsvereinbarung

Dauer: 20.01.2004 - ?

Partnerinstitutionen: Institut für Isotopenforschung und Kernphysik, Universität Wien

**Titel: SUNS - Spallation Ultra Cold Neutron Source at PSI, Source Development**

Typ: Forschungsprojekt

Art: Informelle Kooperationsvereinbarung

Dauer: 01.09.2004 - ?

Partnerinstitutionen: Inst. Laue-Langevin, Jagellonian Univ. Cracow, Paul Scherrer Institut (PSI), St. Petersburg Nuclear Physics Institute (PNPI)

**Titel: Study of kaon-nucleon interaction @ J-PARC**

Typ: Forschungsprojekt

Art: Rahmenvereinbarung (schriftlich)

Dauer: 01.01.2006 - ?

Partnerinstitutionen: High Energy Accelerator Research Organization (KEK), Osaka University, Osaka Electro-Comm. University, RIKEN, University of Tokyo, Seoul National University, Temple University

**Titel: Theoretical Studies of Low Energy QCD, Investigated with Exotic Atoms**

Typ: Forschungsprojekt

Art: Informelle Kooperationsvereinbarung

Dauer: 01.01.2003 - ?

Partnerinstitutionen: Atominstitut der Österreichischen Universitäten

**Titel: VIP @ Gran Sasso (VIolation of the Pauli Exclusion Principle Experiment)**

Typ: Forschungsprojekt

Art: Rahmenvereinbarung (schriftlich)

Dauer: 01.10.2004 - ?

Partnerinstitutionen: INFN, Laboratori Nazionali di Frascati, Inst. of Physics and Nuclear Engineering „Horia Hulubei“

## 1.5.2 Organisation von wissenschaftlichen Veranstaltungen

Im Jahr 2006 wurden verschiedene wissenschaftliche Veranstaltungen organisiert: mehrere Kollaborationstreffen sowie ein Symposium in Wien, und von E. Widmann zusammen mit C. Curceanu (LNF Frascati) und A. Rusetzki (U Bonn) ein einwöchiger Workshop bei ECT\* Trento.

*Workshop Exotic hadronic atoms, deeply bound kaonic nuclear states and antihydrogen: present results, future challenges*



Der Workshop "Exotic hadronic atoms, deeply bound kaonic nuclear states and antihydrogen: present results, future challenges" fand vom 19.-24. Juni 2006 bei ECT\* in Trento statt und führte 50 Experten aus dem Bereich exotische Atome und Kernen zusammen. Das Ziel war, den momentanen experimentellen und theoretischen Stand zu erkunden und die wichtigsten Themen für die Zukunft zu identifizieren. Das Programm erstreckte sich von pionischen, kaonischen, und antiprotonischen Atomen bis zu Antiwasserstoff und tiefgebundenen K-Cluster.

*Symposium: Highlights and Perspektiven - zu Ehren von Paul Kienle - Wie kommt man auf einfaches Neues?*

Im Festsaal der ÖAW fand am 1. September 2006 ein Symposium statt über subatomare Physik - Highlights and Perspektiven - zu Ehren von Paul Kienle - Wie kommt man auf einfaches Neues? Etwa 100 Wissenschaftler darunter eine große Zahl von in- und ausländischen Spitzenforscher nahmen an diesem Symposium teil. Insbesondere die Forschung an der GSI, an der Prof. Kienle wissenschaftlicher Direktor war, und die Physik am zukünftigen Forschungszentrum FAIR standen im Vordergrund dieser Veranstaltung.



*PANDA collaboration meeting 2006*



Anschließend an das oben genannte Symposium fand ein internationales Treffen der PANDA Kollaboration im Hauptgebäude der ÖAW statt (2. – 5.9.2006). Etwa 130 Wissenschaftler nahmen an dieser vom SMI organisierten internationalen Veranstaltung teil. Der gegenwärtige Stand der Entwicklung des PANDA-Detektorsystems und Planungen für die weiteren Stufen des Projekts wurden vorgestellt und diskutiert.

**FLAIR**

Im Jahr 2006 wurden vom SMI zwei Kollaborationstreffen der FLAIR-Kollaboration organisiert. Das erste fand am 2. und 3. Mai in Wien statt und hatte 24 Teilnehmer aus Europa und Japan. Das

zweite wurde am 19. und 20. Dezember am CERN in Genf abgehalten und diente als „kick-off“ Meeting für einen Design-Study Antrag für FP7. Die ca. 20 Teilnehmer setzten sich aus den Leitern der Unterprojekte von FLAIR sowie an einer Teilnahme an der Design Study interessierten Kollaborationspartnern zusammen. FLAIR Kollaborationstreffen Mai

### 1.5.3 Angebotene Lehrveranstaltungen

Mitarbeiter	Funktion	Veranstaltung
<b>Lehrveranstaltung an Universität</b>		
Univ.-Prof. Dr. Eberhard Widmann	OrganisatorIn, TeilnehmerIn	Seminar zu aktuellen Themen der subatomaren Physik - SS 2006 Hörsaal, Stefan Meyer Institut für subatomare Physik, Boltzmanngasse 3, 1090 Wien 01.03.2006 bis 30.06.2006
Univ.-Prof. Dr. Eberhard Widmann	OrganisatorIn, ReferentIn	Vorlesung - Experimentelle Elementarteilchenphysik II Hörsaal, Stefan Meyer Institut für subatomare Physik, Boltzmanngasse 3, 1090 Wien 01.03.2006 bis 30.06.2006
Dipl.-Ing. Dr. Johann Marton	OrganisatorIn, ReferentIn	Physik mit exotischen Atomen Seminarraum 134, TU Wien 03.10.2006 bis 31.01.2006
Univ.-Prof. Dr. Eberhard Widmann	OrganisatorIn, ReferentIn	Physik mit Niederenergetischen Antiprotonen Stefan Meyer Institut für subatomare Physik, Boltzmanngasse 3, 1090 Wien 19.10.2006 bis 25.01.2007

### 1.5.4 Vorträge von Gästen

Gast	Herkunftsinstitution	Vortragstitel
Dr. Vsevolod Balashov	Institute of Nuclear Physics, Moscow State University	Charge asymmetry in alignment of atomic excited states in proton-atom and antiproton-atom collisions
Dr. Steven Bass	Universität Innsbruck	Where does the proton's spin come from?
Dr. Diego Betttoni	Istituto Nazionale di Fisica Nucleare Sezione di Ferrara (INFN)	Charmonium Spectroscopy
Dr. Wulf Fettscher	Eidgenössische Technische Hochschule Zürich; ETH Zürich	Muon Decay and the Standard Model
Dr. Peter Fierlinger	Stanford University	The Enriched Xenon Observatory for Double Beta Decay
Dr. Detlev Gotta	Forschungszentrum Jülich GmbH	Pionic Deuterium
Dr. Walter Greiner	Frankfurt Institute for Advanced Studies	Superschwere Kerne - Zeitverzögerung im Schwerionenstoß -Superkritische Felder
Dr. Olaf Hartmann	INFN, Laboratori Nazionali di Frascati	Charming Hadrons in Nuclear Matter
Mag. Małgorzata Kasprzak	Paul Scherrer Institut (PSI)	Antimatter gravity
Mag. Małgorzata Kasprzak	Paul Scherrer Institut (PSI)	Measurement of the ultracold neutron (UCN) production efficiency of solid D2, CD4 and O2
Mag. Małgorzata Kasprzak	Paul Scherrer Institut (PSI)	1. Energy dependent ultracold neutron (UCN) production in deuterium (D2) 2. Para to ortho conversion in solid D2 catalyzed by molecular oxygen.
Dr. Roger Stuewer	University of Minnesota, Minneapolis	The Cambridge-Vienna Controversy on Nuclear Disintegration
Toshimitsu Yamazaki	Inst. of Physical and Chemical Research (RIKEN)	Deeply bound kaonic nuclear clusters - status

## 1.6 Aufenthalte von Gastwissenschaftlern 2006

Name	Herkunftsinstitution	Dauer	Zweck
Dr. Dimitar Bakalov	Българска академия на науките	01.11.2006 10.11.2006	- Forschungstätigkeit
Dr. George Beer	Department of Physics and Astronomy, Univ. of Victoria	08.06.2006 10.06.2006	- Projekttreffen
Dr. Mario Bragadirceanu	INFN, Laboratori Nazionali di Frascati	03.05.2006 06.05.2006	- Projekttreffen
Dr. Catalina Curceanu	INFN, Laboratori Nazionali di Frascati	25.01.2006 26.01.2006	- Projekttreffen
Dr. Catalina Curceanu	INFN, Laboratori Nazionali di Frascati	24.02.2006 26.02.2006	- Projekttreffen
Dr. Laura Fabbietti	Technische Universität München	24.01.2006 25.01.2006	- Projekttreffen
Dr. Mark Faifman	Kurchatov Institute	20.11.2006 19.12.2006	- Forschungstätigkeit
Dr. Carlo Guaraldo	INFN, Laboratori Nazionali di Frascati	24.02.2006 26.02.2006	- Projekttreffen
Dr. Carlo Guaraldo	INFN, Laboratori Nazionali di Frascati	25.01.2006 26.01.2006	- Projekttreffen
Dr. Andrei Ivanov	Department of Physics, St. Petersburg State University	01.06.2006 31.07.2006	- Forschungstätigkeit
Dr. Saveliy Karschenboim	D.I. Mendeleev Institute for Metrology (VNIIM), St. Petersburg	05.05.2006 09.05.2006	- Forschungstätigkeit
Dr. Grigori Korrenman	Institute of Nuclear Physics, Moscow State University	30.11.2006 24.12.2006	- Forschungstätigkeit
Dr. Vladimir Korobov	JINR - Joint Institute for Nuclear Research	10.10.2006 09.11.2006	- Forschungstätigkeit
Dr. Herbert Orth	GSI - Gesellschaft für Schwerionenforschung mbH	29.01.2006 02.02.2006	- Forschungstätigkeit
Dr. Leopold Simons	Paul Scherrer Institut (PSI)	18.12.2006 21.12.2006	- Forschungstätigkeit
Dr. Florin Sirghi	INFN, Laboratori Nazionali di Frascati	02.05.2006 07.05.2006	- Projekttreffen
Dr. Ken Suzuki	Technische Universität München	24.01.2006 25.01.2006	- Projekttreffen
Dr. Carsten Welsch	CERN - European Organization for Nuclear Research	29.04.2006 04.05.2006	- Projekttreffen

## 1.7 Ausbildung und Schulung 2006

Name	Herkunftsinstitution	Dauer	Ausbildungsziel
DI Albert Hirtl	Technische Universität Wien, Wien, AUSTRIA	01.03.2002 bis 31.12.2007	Dr.techn.
Mag. Alexander Gruber	Universität Wien, Wien, AUSTRIA	15.03.2005 bis 14.03.2008	Dr.rer.nat.
Mag. Małgorzata Kasprzak	Universität Wien, Wien, AUSTRIA	01.09.2004 bis 21.12.2007	Dr.rer.nat.
Chloe Malbrunot	Technische Universität Wien, Wien, AUSTRIA	01.06.2006 bis 30.06.2007	Dipl.-Ing.
B. Sc. with 1st degree honours Thomas Pask	Universität Wien, Wien, AUSTRIA	01.08.2005 bis 31.07.2009	Dr.rer.nat.
Philipp Schmid	Universität Wien, Wien, AUSTRIA	01.06.2005 bis 30.09.2006	Mag.rer.nat.