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Annual Report 2008

Stefan Meyer Institute (SMI) for Subatomic Physics

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Mission Statement

The Stefan Meyer Institute (SMI) is devoted to basic research in the field of subatomic physics. Our research focuses on the study of ***fundamental symmetries and interactions***, addressing the following questions:

- What are the properties of the forces that exist in nature?
- What is the origin of the masses of the visible universe?
- Why do the remains of the Big Bang consist only of matter and not of antimatter?

We specialize in precision spectroscopy of ***exotic atoms***[1] and ***exotic meson-nucleus bound states*** as an integral part of international collaborations at large-scale research facilities including

- CERN (Geneva, Switzerland),
- LNF-INFN (Frascati, Italy),
- J-PARC (Tokai, Japan),
- GSI (Darmstadt, Germany),

and, in the future,

- FAIR (Darmstadt, Germany).

These are among the world's leading facilities for subatomic physics and our projects are subject to rigorous annual evaluation to monitor their progress in a dynamic and expanding field.

We aspire to perform research that increases the understanding of fundamental physics principles while simultaneously providing opportunities for young Austrians to obtain valuable experience at institutes unavailable to them at home.

The current two main fields of focus at SMI are:

- Study of the ***strong interaction*** and its corresponding theory, quantum chromodynamics (QCD), at low energies in the non-perturbative regime and at intermediate energies. Chiral symmetry and its breaking or restoration plays an important role. They contribute to the origin of the masses of hadrons. The sum of the masses of the three quarks adds up to only a few percent of the measured hadron mass, which originates mainly from the dynamic interaction between the quarks and the exchange particles of the strong interaction, the gluons. The underlying mechanism is, to date, not understood at all. The experimental approach is the spectroscopy of meson-nucleus bound states using large 4π detectors like FOPI and PANDA, and to measure the effect of the strong interaction on the low-lying atomic states of simple exotic atoms by X-ray spectroscopy.

- ***Matter-antimatter symmetry***, especially the study of the underlying ***CPT symmetry***. This symmetry is a property of all field theories used hitherto to describe nature, but is in contrast to the observed matter dominance of the visible universe. Furthermore, not all mathematical prerequisites of the CPT theorem are valid in modern theories like string theory or quantum gravity. Experimentally the matter-antimatter symmetry is investigated by precision measurements of properties of the antiproton (mass, charge, magnetic moment) in antiprotonic atoms and antihydrogen, comparing them to known properties of the proton.

Further activities include an underground laboratory experiment at Laboratori Nazionali di Gran Sasso (Italy) on a high-sensitivity test of the Pauli principle, in the VIP (Violation of the Pauli Principle) experiment.

[1] Atoms that contain another particle (e.g. an antiproton, kaon, muon or pion) in their shell instead of an electron.

1. Scientific Activity 2008

1.1. Zusammenfassung des wissenschaftlichen Berichts 2008

Das Jahr 2008 bedeutete einen wesentlichen Schritt vorwärts für das **SIDDHARTA** Experiment. Nach mehr als 4 Jahre dauernden Vorbereitungn begann die Datenerfassung in zwei Stufen am Elektron-Positron-Collider DAΦNE am LNF Frascati. Zuerst wurde mit einem reduzierten Aufbau, bestehend aus einigen der später verwendeten SDD-Detektoren aber einer vorläufigen Elektronik, und Stickstoff als Targetgas eine Testmessung durchgeführt. Diese ergab wichtige Erkenntnisse zu der Effizienz der Untergrund-unterdrückung durch die Koinzidenz zwischen SDDs und den Kaonen und diente ebenso als Test für den DAΦNE Beschleuniger, der ein Programm zur Erhöhung der Luminosität durchführte. Darauffolgend wurde als erste Stufe des eigentlichen Experimentes eine Testmessung mit dem endgültigen Aufbau und Heliumgas durchgeführt, das verglichen mit Wasserstoff eine wesentlich höhere Ausbeute für die Röntgenstrahlen hat. Der Test war erfolgreich und lieferte darüberhinaus die erste Messung des kaonischen *3d-2p* Röntgenübergangs in gasförmigem ^{4}He, der als Überprüfung der von uns im Jahr 2007 veröffentlichten Messung in flüssigem Helium am KEK dient. Das Ziel des SIDDHARTA Experiments ist die präzise Messung der durch die starke Wechselwirkung verursachten Verschiebung und Verbreiterung des Grundzustands von kaonischem Wasserstoff und Deuterium. Für Wasserstoff wird erwartet, die existierende Inkonsistenz zwischen früheren Messungen zu beheben, während für Deuterium diese Größen erstmals gemessen werden sollen. Diese Messungen werden im Jahr 2009 durchgeführt werden. Parallel dazu wurden Vorbereitungen begonnen, zum ersten Mal überhaupt die Röntgenübergänge von $\boldsymbol{K^{-}}$**^{3}He** an J-PARC zu messen, um die Isospinabhängigkeit der Kaon-Nukleon Wechselwirkung auch in etwas schwereren Systemen zu untersuchen.

Ein weiterer Schwerpunkt im Gebiet der Kaon-Nukleon-Wechselwirkung ist die Suche nach **tiefgebundenen Kaon-Clustern**, die aufgrund der in der Röntgenspektroskopie von kaonischen Wasserstoff beobachteten stark anziehenden Wechselwirkung zwischen Antikaon und Nukleon theoretisch vorhergesagt wurden. Mitarbeiter des SMI sind seit längerem an der Analyse von Daten des DISTO Experiments (Saclay) beteiligt, die nun einen zusätzlichen Hinweis auf die Existenz des leichtesten K-Clusters $K^{-}pp$ lieferte. Dieser Zustand soll mit Hilfe des FOPI Detektors an der GSI Darmstadt in einem Experiment, in dem das SMI einer der wesentlichen Partner ist, genauer untersucht werden. 2008 wurden hierzu Vorbereitungen für das eigentliche Experiment getroffen, das im Herbst 2009 stattfinden soll.

An Antiproton Decelerator des CERN in Genf wurde im Rahmen der **ASACUSA** Kollaboration eine systematische Untersuchung der Hyperfeinstruktur (HFS) des (37,35)-Zustandes von **antiprotonischem Helium** erfolgreich abgeschlossen. Die in diesem exotischen Dreikörpersystem gemessenen Mikrowellenübergänge sind empfindlich auf den Wert des magnetischen Momentes des Antiprotons, das nur auf 0,3% genau bekannt ist. Durch den Vergleich der experimentellen Ergebnisse mit Drei-Körper QED Rechnungen kann ein neuer Wert für das magnetische Moment des Antiprotons bestimmt werden, was eine Überprüfung der fundamentalen CPT Symmetrie darstellt. 2008 wurde das vorläufig endgültige Resultat der Messung erzielt. Damit ergibt sich eine unabhängige Bestimmung des magnetischen Moment mit einer Genauigkeit, die geringfügig besser als die der bisherigen Messung ist. Ein neues gemeinsames österreichisch-russisches Projekt wurde gestartet mit dem Ziel, die HFS anderer Zustände sowohl in ^{3}He als auch in ^{4}He zu untersuchen sowie die theoretische Beschreibung zu verbessern.

Bei der Laserspektroskopie von antiprotonischem Helium, die bereits verbesserte Werte für Masse und Ladung des Antiprotons mit einer Genauigkeit von 2 ppb lieferte, wurde durch das Studium mehrerer Methoden der Zwei-Photonen-Spektroskopie Fortschritt auf dem Weg zu höherer Präzision erzielt.

Im Rahmen von ASACUSA ist unser Langzeitziel die Messung der Hyperfeinaufspaltung von **Antiwasserstoff**, was eine von zwei der die höchste Genauigkeit versprechenden Größen im Vergleich zwischen Wasserstoff und Antiwasserstoff und damit einen der genauesten Tests der CPT Symmetrie verspricht. Das SMI ist für das eigentliche Spektrometer zur Messung der HFS verantwortlich. Simulationen von Teilchenbahnen in Wien sowie das vorläufige Hochfrequenzdesign einer Spin-Flip-Kavität am CERN wurden abgeschlossen. Eine Marktstudie sowie eine anschließende internationale Ausschreibung für einen supraleitenden Sextupolmagneten wurden über das CERN ausgeführt.

Innerhalb des **PANDA** Experiments an der in der Planung befindlichen FAIR Anlage in Darmstadt wurden technische Entwicklungen sowie die Simulation eines Physikkanals durchgeführt. Das SMI beteiligt sich an der Entwicklung des Cluster-Jet Targets und dem Studium von Silizium-Photomultipliern für Cherenkov-Zähler sowie dem PANDAGrid. Simulationen wurden zum Studium der Wechselwirkung von Charmonium mit Kernmaterie durchgeführt, deren Kenntnis unerlässlich für die Benützung der Unterdrückung der J/ψ Produktion als Hinweis auf die Entstehung des Quark-Gluon-Plasma in relativistischen Schwerionenstößen ist.

Die Analyse des Experiments zu **pionischem Wasserstoff** geht zu Ende, wobei am SMI die Breite des πH-

Grundzustandes bestimmt wird und andere Mitglieder der Kollaboration dessen Verschiebung sowie andere systematische Tests wie z.B. das Studium der Linienbreite in müonischem Wasserstoff, wo keine starke Wechselwirkung herrscht, durchführen. Das **VIP Experiment**, das nach durch das Pauli-Prinzip verbotenen Röntgenübergängen sucht, begann am Gran Sasso Labor Daten zu nehmen. Eine vorläufige Analyse zeigt, dass bereits jetzt ein besserer oberer Grenzwert bestimmt werden kann als wir bei unseren früheren Messungen im Labor erhalten hatten. Ein Experiment am Speicherring ESR der GSI Darmstadt zeigt Modulationen des Zerfalls **wasserstoffartiger schwerer Ionen** durch Elektroneneinfang, die möglicherweise mit Oszillationen massiver Neutrinos zusammenhängen und somit einen unabhängigen Zugang zu dieser wichtigen Fragestellung ermöglichen könnten.

Das herausragende Ereignis im letzen Jahr waren die beiden internationalen Konferenzen **EXA08** und **LEAP08**, die von uns zeitlich überlappend veranstaltet wurden. Bei EXA handelt es sich um den dritten in Wien organisierten internationalen Workshop über exotische Atome und verwandte Themen. LEAP ist eine internationale Konferenz über „Low Energy Antiproton Physics" die bisher acht Mal an verschiedenen Orten veranstaltet wurden. Etwa 180 Teilnehmer gaben 104 Vorträge in 22 Sitzungen.

Im Jahr 2008 endete das große Projekt **I3 Hadron Physics** im sechsten Rahmenprogramm der Europäischen Union, an dem das Stefan-Meyer-Institut mit den Projekten SIDDHARTA und PANDA beteiligt war. Im Nachfolgeprojekt **Hadron Physics 2**, das im 7. Rahmenprogramm genehmigt wurde, hat sich das SMI noch stärker engagiert und stellt zwei Koordinatoren für eine Joint Research Activity JointGEM zur Entwicklung großflächiger GEM Detektoren sowie für das Netzwerk LEANNIS „Low energy antikaon-nucleon and -nucleus interaction studies". Die Mitarbeit in Projekte zu Silizium-Photomultipliern sowie Gas-jet Targets gehen weiter.

1.2. Summary of the scientific report 2008

The year 2008 marked a major step ahead in the **SIDDHARTA** experiment. After more than 4 years of preparations, data taking started in two steps at the electron-positron collider DAΦNE at LNF Frascati. First with a reduced setup using the real SDD detectors but not the final electronics, a run was performed with nitrogen gas. Valuable information was gained regarding the efficiency of background suppression using timing cuts between the SDDs and kaons, as well as for the DAΦNE machine, which at the same time commenced a program to upgrade its luminosity. A first phase of data taking using the full setup but helium gas because of its larger yield of X-ray transitions was performed in fall 2008 in order to thoroughly test the full apparatus. The test was successful and in addition provided a first measurement of the *3d-2p* transition in gaseous ^{4}He which will be a cross-check of our measurement in liquid ^{4}He at KEK published in 2007. The final goal of the SIDDHARTA experiment is the precise measurement of the strong-interaction induced shift and width of the ground-state of kaonic hydrogen and deuterium. For hydrogen it will solve an existing inconsistency with earlier measurements, in the case of deuterium it will provide the first measurement ever. This measurement will take place during 2009. Preparations for a new experiment at J-PARC (Japan) to measure – for the first time ever – the X-ray transition of **K^-^{3}He** to explore the isospin dependence of the kaon-nucleon interaction in a slightly heavier system have begun.

A further topic within the subject of kaon-nucleon interaction is the search for **deeply bound kaonic nuclear clusters** predicted theoretically due to the strong antikaon-nucleon interaction observed in the X-ray spectroscopy of kaonic hydrogen. SMI staff participated in the analysis of older data of the DISTO experiment at Saclay which provided an additional hint for the existence of the lightest cluster K^-pp. This state will be thoroughly examined in an experiment using the FOPI detector at GSI in which SMI is one of the major participants. In 2008 preparations were done for the final measurement planned in early fall of 2009.

Within the **ASACUSA** collaboration at the Antiproton Decelerator of CERN, a systematic study of the hyperfine structure (HFS) of the (37,35) state of **antiprotonic helium** has been successfully terminated. The microwave transitions measured in this exotic three-body system are sensitive to the magnetic moment of the antiproton, a quantity that is known to only 0.3%. By comparing the experimental values to results of three-body QED calculations, a new value for the antiproton magnetic moment can be derived resulting in a test of the fundamental CPT symmetry. In 2008 we obtained an experimental value exceeding the theoretical precision by more than a factor of 10, which resulted in an independent determination of the antiproton magnetic moment with slightly better precision than earlier measurements. A new joint Austria-Russia project has been started to continue the investigation by measuring the HFS of other states in both ^{3}He and ^{4}He and to improve the theoretical treatment.

In the laser spectroscopy of antiprotonic helium, which has already provided improved values of the antiproton mass and charge down to a level of 2 ppb, progress has been made towards higher precision by studying several two-photon transition techniques capable of reaching this goal in the future.

Our long-term goal within ASACUSA is the measurement of the hyperfine structure of **antihydrogen**, which is one of the two quantities in the comparison of hydrogen and antihydrogen promising a test of CPT with highest precision. SMI is in charge of the spectrometer beam line to measure the hyperfine splitting. Simulations have been performed on particle trajectories as well as a preliminary radio-frequency design of a spin-flip cavity at CERN. A market survey and subsequent call for tender for a superconducting sextupole magnet have been launched through CERN.

Within the **PANDA** experiment at the upcoming FAIR facility in Darmstadt, technical developments as well as simulations of one physics channel have been performed. SMI participates in the development of the cluster-jet target and the study of silicon photomultipliers for the use in Cherenkov counters as well as in developments for the PANDAGrid computing. Simulations are being done to study charmonium interaction with nuclear matter using the PANDA detector, which is prerequisite for the use of J/ψ suppression as a signature for quark-gluon formation in relativistic heavy-ion collisions.

The analysis of the **pionic hydrogen** experiment is finishing with SMI analysing the width of the ground state of πH and other collaborators the shift as well as auxiliary measurements like the determination of the line shape by studying muonic hydrogen where no strong interaction is present. The **VIP experiment** which looks at X-ray transitions to atomic states which are Pauli-forbidden is now data taking at Gran Sasso and preliminary analysis shows already an improved upper limit on the Pauli principle violation compared to our earlier results in the laboratory. An experiment at the storage ring ESR at GSI Darmstadt shows oscillations in the **electron-capture decays** of hydrogen-like heavy ions which potentially can be related to oscillations of massive neutrinos and may allow an independent access to this important question.

A major event in the last year was the organization of two partly overlapping major international conferences, **EXA08** and **LEAP08**, in Vienna. EXA is a series of international workshops on Exotic Atoms and Related topics pioneered by SMI and now organized for the third time in Vienna. LEAP is an international conference on Low Energy Antiproton Physics with eight previous conferences held in various places in the

world. About 180 participants came and presented 104 talks in 22 sessions.
The year 2008 marks the end of the **I3 Hadron Physics** project in the 6th framework program of the European Union, in which SMI was involved with SIDDHARTA and PANDA. A successor project, **Hadron Physics 2**, was approved in FP7, and SMI became stronger involved, coordinating one Joint Research Activity JointGEM (development of large-area gas-electron-multiplier detectors) and one network LEANNIS (Low energy antikaon-nucleon and -nucleus interaction studies). The involvement in the work on silicon multipliers and gas-jet targets will continue.

1.3. Report on the scientific activity during 2008

The research programme of our institute consists of three research foci and associated research projects. Following is a short overview on the projects which are described in more detail in the next chapters.

- 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 using proton induced reaction
  - FS1_d: AMADEUS at DAΦNE2
  - FS1_g: Study of kaon-nucleon interaction @ J-PARC
    - FS1_g_a Precision spectroscopy of kaonic ^{3}He
- 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
    - FS3_c_c: Cherenkov Imaging Detectors (DIRACsecondary beams)
    - FS3_c_d: Development and tests of novel matrix avalanche photo detectors for PANDA
    - FS3_c_e: Charmonium interaction with nuclear matter
  - FS3_d: Antiproton Ion Collider
- Other Projects
  - Pion-Nucleon Interaction
  - X-ray spectroscopy at the VERA accelerator (PIXE)
  - SUNS – Spallation Ultra Cold Neutron Source at PSI, Source Development
  - VIP @ Gran Sasso (VIolation of the Pauli Exclusion Principle Experiment)
  - Time modulation of orbital electron capture decays of H- and He-like ions

1.3.1. FS1_A: Kaon-Nucleon Interaction: Kaonic atoms and kaonic nuclei

Although still fundamental questions to be answered exist, the low energy QCD with light *u*, *d* quarks has reached by now the precision of a quantitative science. In this sector there is a rich, high-precision experimental data set available and chiral perturbation theory with the pion as a good approximation of the Nambu-Goldstone boson works pretty well, and is also in a good agreement with Lattice QCD.

The situation in the strangeness sector, however, is quite opposite. The basic low energy *K-N* interaction has a difficulty in the theoretical treatment mainly due to the strong coupling between *KN* and $\pi\Sigma$ channels.

The two latest precise measurements of the kaonic hydrogen energy shift and width from *KpX* at KEK and DEAR at LNF-INFN set empirical constraints on calculation of the *K-N* interaction. A chiral SU(3) unitary approach with coupled-channel has been applied and reproduces both data, however, it suffers from uncertainties of the data, which meanwhile became not satisfactory (Fig. 1).

The SIDDHARTA experiment has been launched in

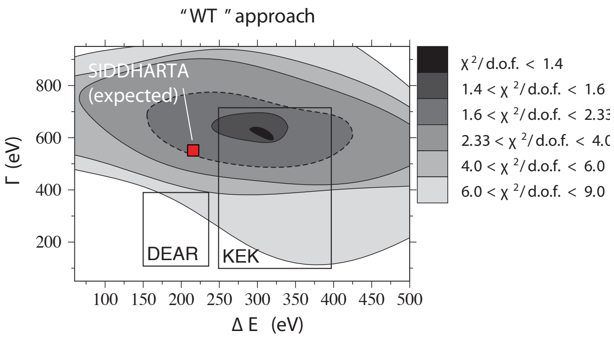

Fig. 1: Energy shift and width of kaonic hydrogen obtained from a Chiral SU(3) unitary calculation compared with the KpX experiment at KEK and the DEAR experiment at LNF - INFN. The 1σ confidence region is bordered by the dashed line. "WT approach" refers to the fact that in the calculation only the leading order Weinberg-Tomozawa term is included [B. Borasoy, U. - G. Meißner, R. Nißler; Phys. Rev. C 74 055201 (2006)]. The expected precision of SIDDHARTA experiment is also indicated.

2008 and the above mentioned situation is expected to be solved. SIDDHARTA aims at improving the precision of the kaonic hydrogen data significantly, and also to measure kaonic deuterium for the first time to examine the isospin dependence of the *K-N* interaction.

The KEK-PS E570 experiment determined the 2p energy shift of kaonic ^{4}He. The existing old data were inconsistent to other kaonic atom measurements, which had been a long standing puzzle. The newly arrived accurate data agrees with the other kaonic atom data, and preliminary data from SIDDHARTA confirmed this result (see Fig. 2).

The possible existence of kaonic nuclear states is a very hot topic in this field. The ongoing discussion covers extensively – from both experimental and theoretical point of view – the primary K^-ppn system, the prototype K^-pp system, the still-not-well-known nature of $\Lambda(1405)$, and the above-mentioned kaonic ^{4}He puzzle. Planned experiments and ongoing theoretical work will result in an advance overall understanding of the *K-N* interaction. A well established fact is for instance the limited prediction power of the *K-N* interaction when extrapolating far below threshold, motivating the SIDDHARTA and AMADEUS experiments to enhance the basic experimental data set to provide more constrains to the theory.

The K^-pp system is the most fundamental system of the kaonic nuclear states and has been discussed especially extensively during the last year. Its binding energy and width was first calculated by Akaishi and Yamazaki based on the so-called $\Lambda(1405)$ Ansatz [the $\Lambda(1405)$ is assumed to be a I = 0, *K-N* quasi-bound state with binding energy B_K =27 MeV]. In their approach they found a total binding energy of B_K = 48 MeV, resulting in a mass M = 2322 MeV/c^2 and width Γ = 61 MeV for the K^-pp. Recent Faddeev calculations also predict the K^-pp to be deeply-bound. On the other hand, a theory based on chiral dynamics and

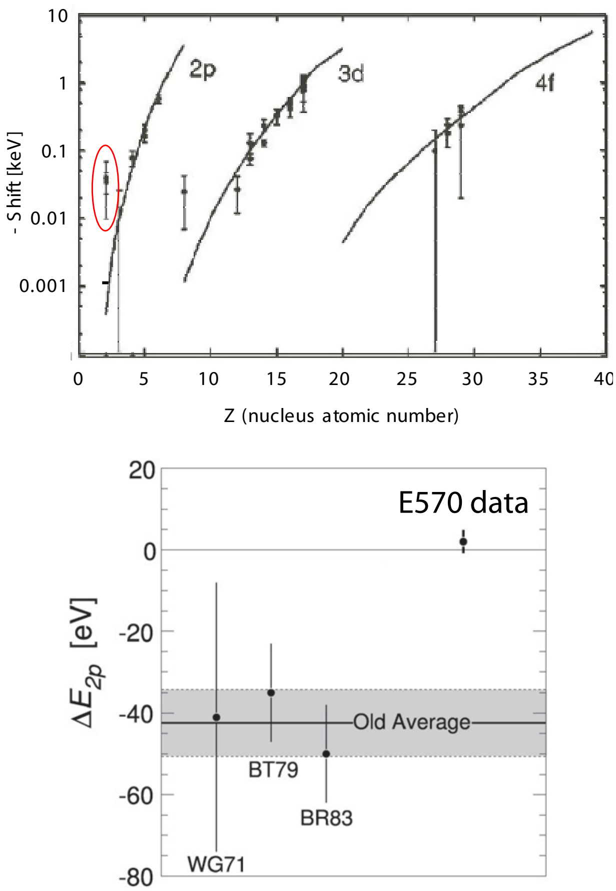

Fig. 2: (top) Strong interaction shifts of kaonic atoms. Theoretical curves are in good agreement with data except for ^{4}He (indicated with a red circle) and ^{16}O cases [S. Hirenzaki et al., Phys. Rev. C 61 (2000) 55205].

(bottom) The *2p* level shift of kaonic ^{4}He obtained from the E570 experiment, compared with old data, solving the kaonic helium puzzle [S. Okada *et al.*, Phys. Lett. B 653, 387 (2007)].

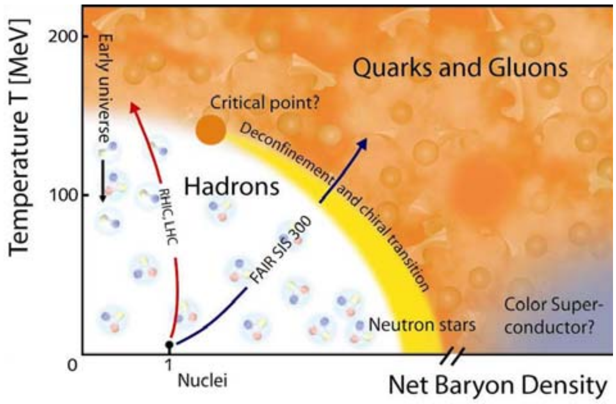

Fig. 3: Phase diagram of nuclear matter.

the "two-pole structure" Ansatz of the Λ(1405) prefers "weak" binding. An experiment providing conclusive data to answers this issue is strongly awaited.

Very recently, double K^- systems K^-K^-pp and K^-K^-ppn have also been predicted to be high-density systems. Such compact nuclear systems, which can be called "*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 or represent colour superconducting systems with high di-quark content (see Fig. 3). Of course, information whether kaon condensation can occur in nuclear matter will have direct applications in astrophysics (neutron stars, strange stars).

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

- The KEK experiment PS-E570 has finished the measurement of the *2p* shift and width of kaonic helium, induced by strong interaction. The data analysis has shown, in contradiction to the "old" measurements, that the *2p* shift of kaonic helium is much smaller and comparable with zero, with an error of 5 eV.
- The precision studies of kaonic hydrogen and kaonic deuterium with SIDDHARTA will set new constraints in the description of Λ(1405). In addition a first test measurement with the SIDDHARTA apparatus, with helium as target confirms the result of the KEK experiment PS-E570.
- With FOPI at GSI a search of deeply bound nuclear clusters like K^-pp, will be performed, using proton induced reactions.
- To study the formation of antikaon-mediated bound nuclear systems in full detail will be the goal of the AMADEUS project, which will use the KLOE apparatus with a dedicated inner target and tracker system. Beside the work on the hardware, in collaboration with the KLOE analysis group, a sub-set of the KLOE data are analysed by AMADEUS to look for indications of deeply bound kaon clusters within the KLOE drift chamber, which could be seen as active target.

Outlook

In the beginning of 2009 SIDDHARTA will start to take data at DAΦNE. Depending on the final delivered luminosity and the achieved background conditions it is foreseen to measure kaonic hydrogen and deuterium until October 2009.

In parallel to the work for SIDDHARTA there will be beam times at GSI for further developments and tests for the new forward detector system for FOPI, which is essential for the upcoming production run in the second half of 2009, with the goal to search for deeply bound K^-pp clusters.

For AMADEUS design studies of an inner tracker system are foreseen, together with the detector group at LNF as well as a continuation of the KLOE data analysis.

In addition SMI is coordinating the work package WP31 (WP31: Ultra light – ultra-large tracking systems based on GEM technology) in Hadron Physics 2 within the EU program FP7. The Hadron Physics 2 proposal was accepted and will be signed by the EU in the beginning of 2009. It is clear that this type of tracking devices will be essential for the forthcoming experiments AMADEUS and FOPI.

Furthermore, SMI is participating in the day-one experiments *E15: A search for deeply-bound kaonic nuclear states by in-flight* $^3He(K^-, n)$ *reaction* and *E17: Precision spectroscopy of kaonic* ^3He $3d \rightarrow 2p$ *X-rays*. The participation at E17 is funded by the Austrian Science Fund (FWF).

1.3.1.1. FS1_b_A: Kaonic hydrogen and deuterium: SIDDHARTA

SIDDHARTA (SIlicon Drift Detector for Hadronic Atom Research by Timing Application) aims for a precise determination of the shift and width of kaonic hydrogen at the percent level. To achieve this goal large area detectors (SDDs – Silicon Drift Detector) have been developed within a European Joint Research Project (FP6 – Hadron Physics).

A first measurement with a prototype setup of the "new developed" SDD detector system at the DAΦNE e^+e^- collider was started spring 2008 with the aim to study this new detector system in the environment of DAΦNE and to reduce the machine background by timing applications. The main background source in DAΦNE is originated from e^+e^- lost from the beam pipes, the Touschek effect and the interaction with the residual gas. The timing of these background particles is not synchronized to the timing of K^+K^- pair productions. Thus, using the time information on the K^+K^-

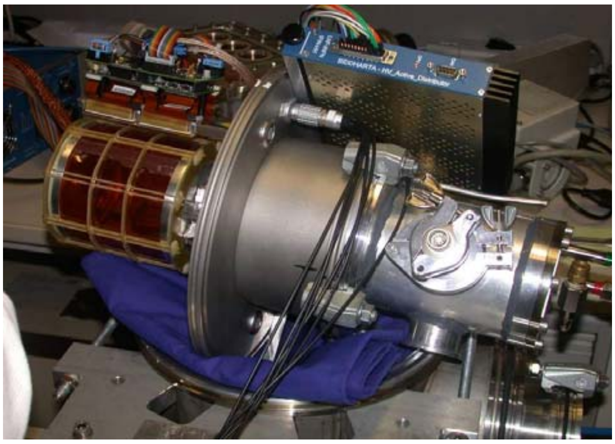

Fig. 5: Day-1 setup showing the SDDs and the cryogenic target system.

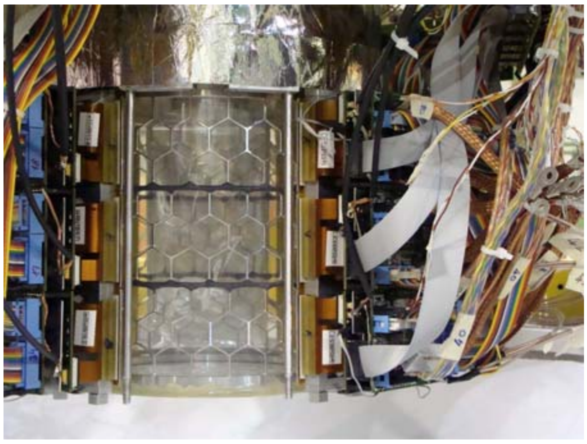

Fig. 6: Cryogenic target cell surrounded by SDDs.

pair production together with the SDD time information a significant background rejection can be achieved.

Before starting the kaonic hydrogen measurement, a test of the SDDs using a nitrogen gas target was performed from March to May 2008 (DAY-1 measurement). In particular, in this DAY-1 measurement, the background reduction with the triple coincidence of the K^+, K^- and SDD timing was examined. Tests of the background reduction are very important inputs, since for the first time SDDs are used in an accelerator environment. The information of the background reduction and of the condition of the beam background is crucial for the success of the kaonic hydrogen X-ray measurements.

The readout system for the DAY-1 setup was specially developed and designed for this DAY-1 experiment by SMI.

Fig. 4 shows the SDD energy spectra with and without triple coincidence. The top figure shows the energy spectrum without coincidence. Cu and Mn X-ray peaks are clearly seen, which were produced from a Cu foil and an Fe-55 source to provide the calibration lines. The bottom shows the energy spectrum using the triple coincidence. The kaonic nitrogen peaks at 4.6, 7.6 and 14 keV are clearly seen with a S/N ratio of about 1:1. In addition, the Cu and Mn calibration lines are seen because of accidental coincidence events. Comparing the intensities of the calibration lines with and without the coincidence, a background rejection capability of more than 10^4 was obtained.

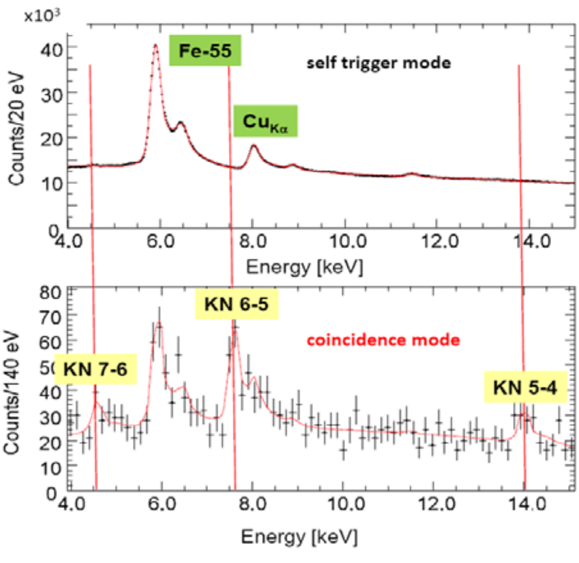

Fig. 4: Comparison of the energy spectra with/without triple coincidence. Do to the achieved background suppression of the applied coincidence method three lines of kaonic nitrogen are clearly seen.

During August and September 2008 the final setup was moved to DAΦNE and installed at the interaction region. The final system consists of a cryogenic target cell surrounded by SDDs with an active area of total 144 cm^2 (see Fig. 6). The target cell and the SDDs are working at low temperatures: 25 K and 170 K, respectively. Therefore, the whole setup has to be placed inside a vacuum chamber with an insulation vacuum below 10^{-5} mbar, achieved by a wide range turbo molecular pump.

After a debugging phase a first data taking period started from October to December 2008 (but only in parasitic mode), with the main goals to optimize the kaon stops in the target cell and to proof the stability of the detector system in the harsh environment of an electron-positron collider. The target cell was filled with gaseous helium and the kaonic helium L-lines were measured (the X-ray yield in this case is at least a factor of 10 higher than for kaonic hydrogen). With this measurement we were able to proof that the developed detector system fulfils all our requirements and in addition, this measurement was so successful that the kaonic helium data will be published within the first half of 2009.

Outlook

A measuring period is foreseen to determine shift and width of kaonic hydrogen and deuterium from January to October 2009. The second half of the year is clearly devoted to analyze the two measured data sets of hydrogen and deuterium. In addition, we plan to ask for beam time end of 2009 to perform a precision measurement of kaonic helium isotopes.

1.3.1.2. FS1_b_b: SIDDHARTA: Joint Research Activity 10 in I3 Hadron Physics

(finished on 31.12.2008.)

Silicon Drift Detectors (SDDs) have very good energy resolution (in the order of 135 eV at 6 keV) and good timing resolution (about 500 ns FWHM for an active area of 1 cm^2). This makes them well suited for X-ray spectroscopy in the environment of an accelerator, in our case in experiments measuring X-ray transitions in kaonic atoms. Up to now no large area devices were available (available sizes up to 10 mm^2, first prototypes with 30 mm^2). Therefore, the SIDDHARTA (Silicon Drift Detector for Hadronic Atom Research by Timing Applications) collaboration was formed to develop large area SDD devices within the 6th Framework Program of the EU (I3-Hadron Physics). The goal was to build SDD chips with a total active area of 300 mm^2, consisting of 3 individual elements on one chip (see Fig. 7). The whole detector system was planned for a total active area of 150 to 200 cm^2 together with a newly built front-end electronics.

In spring 2008 a first measurement of 12 cm^2 SDDs with the DAY-1 setup took place, in order to test the performance of SDDs in the environment of an accelerator. It was possible to prove successfully that the SDDs are working during the collision phase and the expected background suppression of almost 4 orders of magnitude was clearly achieved.

The final setup (see Fig. 8) with a total SDD active area of 144 cm^2 was moved into DAΦNE in summer 2008 and the first measurement, with the SIDDHARTA setup, started in October 2008.

The 6th Framework Program project of the EU I3-Hadron Physics has ended with December 31, 2008.

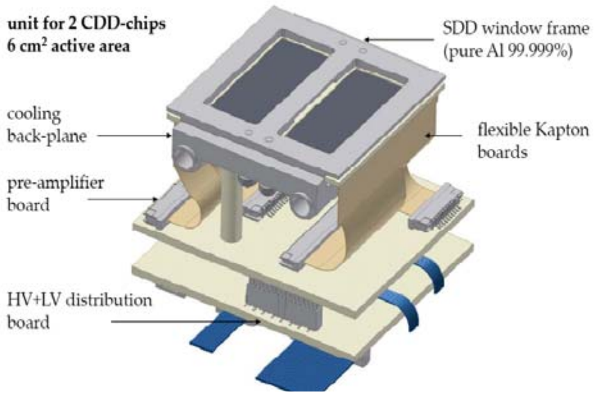

Fig. 7: Sketch of an SDD module of 2×3 cm^2 active area.

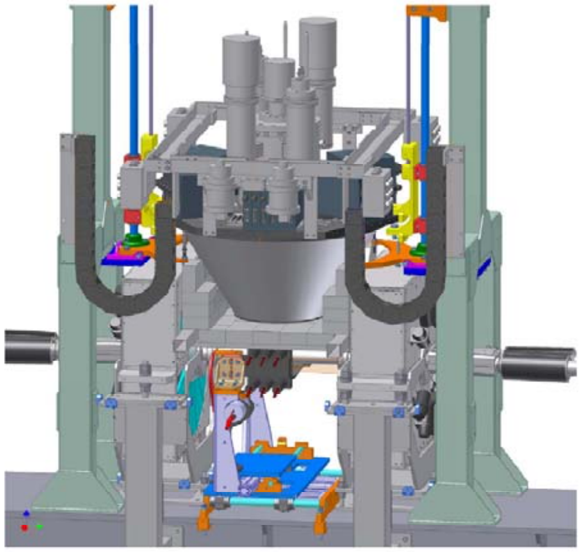

Fig. 8: The final SIDDHARTA setup at DAΦNE.

1.3.1.3. FS1_c: Deeply bound kaonic nuclei using proton induced reaction

The main goal of this project is to search for the kaonic nuclear bound state K^-pp with the FOPI detector at GSI exploiting an exclusive measurement of $p + p \rightarrow K^-pp + K^+ \rightarrow p + \Lambda + K^+$ reaction at $T_p = 3.0$ GeV. The possible existence of the kaonic nuclear states has been extensively discussed in the last years, especially the issue of the K^-pp system.

The K^-pp system is a prototype of the kaonic nuclear state and its binding energy and width was first calculated by Akaishi and Yamazaki based on the so-called $\Lambda(1405)$ Ansatz [the $\Lambda(1405)$ is assumed to be a $I = 0$, $\bar{K}N$ quasi-bound state with $B_K = 27$ MeV]. In their approach they found a total binding energy of $B_K = 48$ MeV, resulting in a mass $M = 2322$ MeV/c^2 and width $\Gamma = 61$ MeV for the K^-pp state. Recent Faddeev calculations also predict the K^-pp to be deeply-bound. On the other hand, a theory based on chiral dynamics and the "two-pole structure" Ansatz of the $\Lambda(1405)$ prefers "weak" binding. An experiment providing conclusive data to answers this issue is strongly awaited.

We therefore started to investigate the NN reaction, a unique and promising approach. Based on the results and lessons learned from a test beam time in fall 2005, we submitted in March 2007 a new proposal to the Program Advisory Committee of GSI to investigate the $p + p \rightarrow K^-pp + K^+$ reaction at an incident proton energy of $T_p = 3.0$ GeV where the K^-pp undergoes a successive decay $K^-pp \rightarrow \Lambda + p$ $[p + \pi] + p$. A theoretical study triggered by this project suggested that the strongly bound K^-pp system with a short p-p distance is populated quite favorably in a $p + p \rightarrow K^-pp + K^+$ reaction since at large momentum transfer a high sticking probability of $\Lambda(1405) + p \rightarrow K^-pp$ is predicted. The proposal obtained a very positive evaluation.

With the FOPI apparatus, which has a ~4π acceptance, we are able to measure the missing mass $MM(pp\text{-}K^+)$

and the invariant mass $M_{inv}(\Lambda\text{-}p)$ simultaneously. In this way, the background is strongly suppressed, an ambiguity of identifying the exotic object is avoided and the ambitious goal of this project, namely to obtain a conclusive information on the issue of the deeply bound kaonic state, can be achieved.

Fig. 9 shows schematically the setup of the experiment on which a typical event example is overlaid. The charged kaon is emitted and detected mostly in the backward detector region with a combination of the central drift chamber and the new RPC TOF wall in the 0.6 T magnetic field. The decay product of the K^-pp is measured in the forward region with a combination of the silicon tracker, the forward drift chamber and the forward TOF wall. A pair of multiplicity counters (Lambda trigger) effectively selects an event which involves a short-lived neutral Lambda particle at online level.

Simultaneously we started to analyze a vast data set of $p + p \rightarrow p + \Lambda + K^+$ process collected at T_p = 2.85 GeV, 2.5 GeV and 2.15 GeV by the DISTO experiment. The reaction aimed by the FOPI experiment shares the same final states. The DISTO data allows a similar analysis strategy, namely the $MM(pp\text{-}K^+)$ and the $M_{inv}(\Lambda\text{-}p)$. A preliminary result was presented at the EXA08 conference, showing an identical deep and broad structure in both $MM(pp\text{-}K^+)$ and the $M_{inv}(\Lambda\text{-}p)$ spectra at T_p = 2.85 GeV, which is unlikely to be explained by a final state interaction of the direct $p + p \rightarrow p + \Lambda + K^+$ Dalitz process, implying a possible interpretation of an existence of the K^-pp.

Though an analysis of the DISTO data is continuing, from this lesson we obtained several invaluable inputs to optimize further the forthcoming FOPI experiment. Not-yet-analyzed DISTO data sets of T_p = 2.5 GeV and 2.15 GeV will deepen our understanding of the $p + p \rightarrow p + \Lambda + K^+$ background process.

The activities of SMI during 2008 were largely devoted to the development of the various subsystems. SMI is responsible for the development and operation of a new start counter, a beam profile monitor, a veto detector, and finally also the liquid hydrogen target. After several test beam times at the Beam Test Facility at LNF, Frascati (January), at the Proton Irradiation Facil-

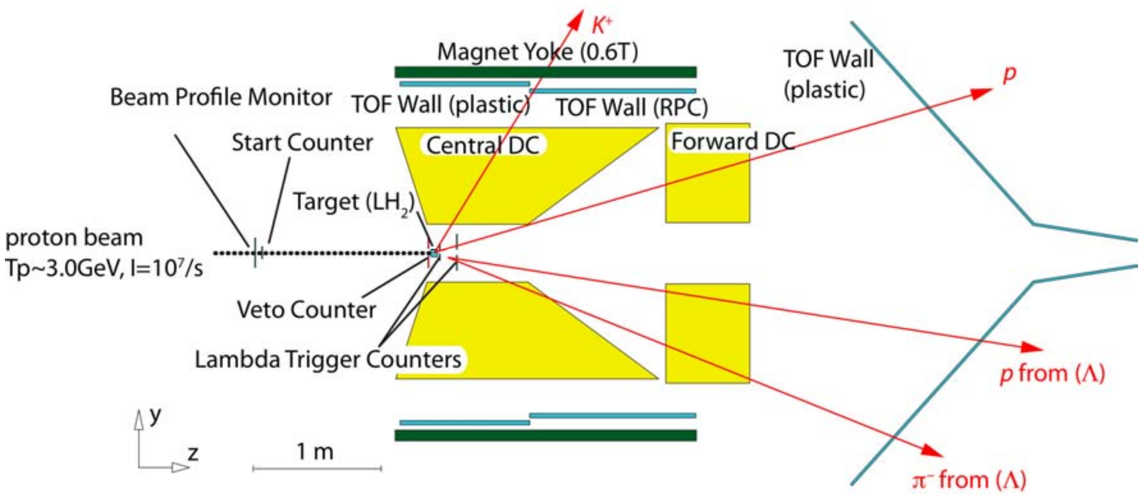

Fig. 9: A schematic setup of the experiment. A typical event example is overlaid.

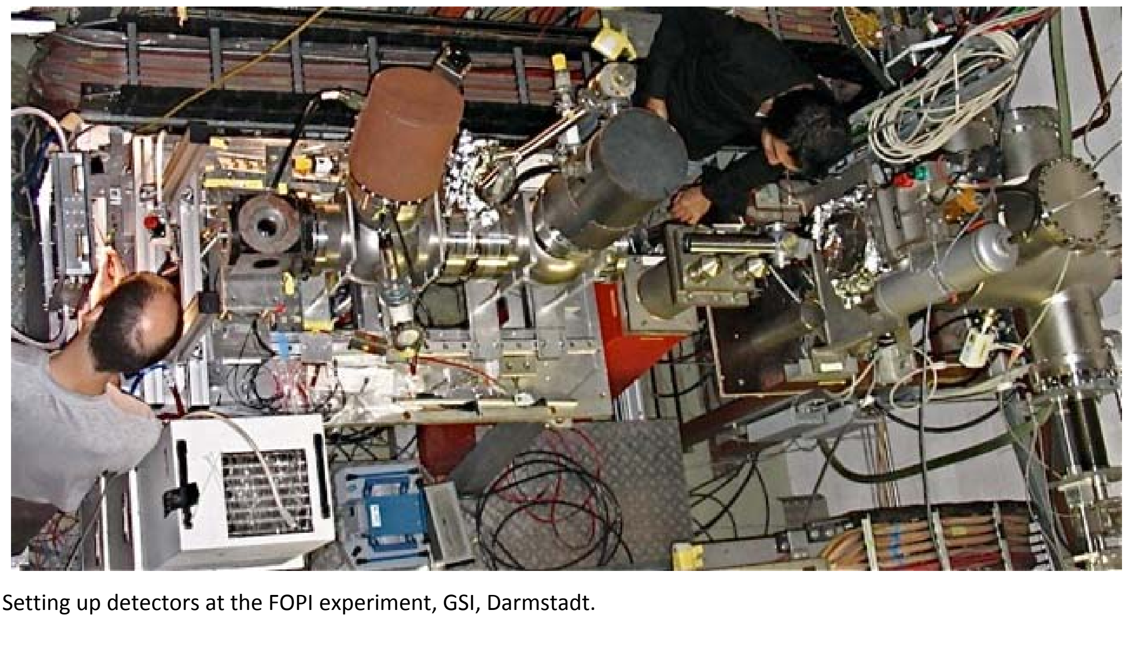

Fig. 10: Setting up detectors at the FOPI experiment, GSI, Darmstadt.

ity at PSI, Switzerland (March) and at the COSY-TOF experiment at the Forschungszentrum Jülich (July), we integrated all the detectors into FOPI at GSI and tested the system in September 2008 (Fig. 10). Except for the target system which was not built in during this test, all subsystems have been operated.

Outlook
In April 2009 it is planned to run a further test with the entire detector configuration to test the whole setup and check the background situation (15 shifts). The production run is scheduled for August 2009 (60 shifts).

1.3.1.4. FS1_d: AMADEUS at DAΦNE2

The idea of AMADEUS is to make use of the KLOE detector at DAΦNE with specific components added, like a cryogenic gas target for stopping the charged kaons (see Fig. 11) and an inner detector system. AMADEUS will perform, for the first time, a systematic and complete spectroscopic study of kaon nucleon interaction at low energy and will especially look for antikaon-mediated bound nuclear states. By measuring all particles in the formation and in the decay processes of two- and three-baryon states with strangeness $S = -1$ a kinematically complete study will be performed.
A special work started already in 2007 to analyse part of the existing KLOE data, which was continued to 2008, with the main objectives to search for events with the signature of kaon-nucleon-clusters for kaons stopped in the thin gas of the drift chamber (room temperature, atmospheric pressure). Therefore, one main project of the analysis was the reconstruction of Lambda particles in the He-isobutane gas mixture of the drift chamber, because Lambda particles are one of the main decay products of tri-baryon states with strangeness. In addition the knowledge gained during this analysis, namely of reconstruction and detector efficiencies and techniques of particle identification, especially for protons (and deuterons), are essential for the design of the AMADEUS experiment.

Outlook
The successful analysis of the KLOE data to look for antikaon-mediated deeply bound nuclear clusters is going on and publishable results are expected for 2009. The working group to study the inter-changeability between the KLOE and AMADEUS setup, with the involvement of the DAΦNE machine group, will continue their work.
An agreement has been worked out to regulate the work for the maintenance and upgrade of the KLOE detector between KLOE and the AMADEUS collaboration, which will be signed beginning of 2009.

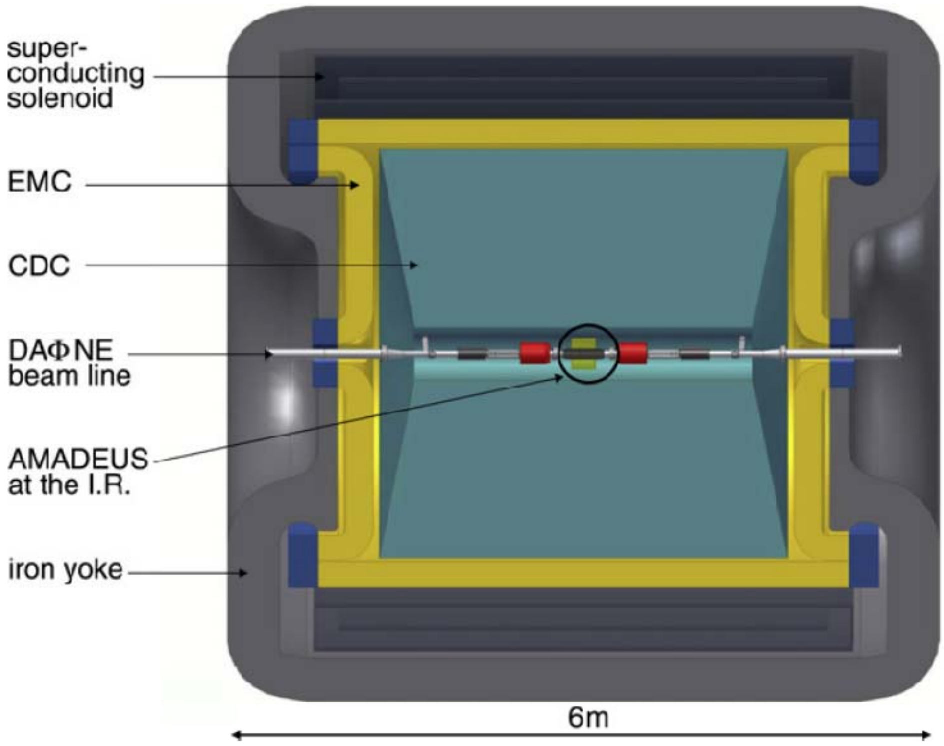

Fig. 11:
The KLOE detector with the AMADEUS setup placed in the centre of KLOE around the interaction region of DAΦNE.

1.3.1.5. FS1_g: Study of kaon-nucleon interaction @ J-PARC

J-PARC (Japan Proton Accelerator Research Complex) is a facility finishing construction as a joint venture of KEK and JAEA (Japan Atomic Energy Agency) in Tokai-mura, Ibaraki, Japan (see Fig. 12). Using a 50 GeV high-intensity proton synchrotron, secondary kaon beams of the highest intensity ever reached will become available from spring 2009. Fig. 13 shows the status of the hadron hall in spring 2008. Now everything is finished and first slow extracted beams have reached the experimental area in January 2009.
SMI joined two proposals, which were both approved as day-1 experiments:

- E15: A search for deeply-bound kaonic nuclear states by in-flight ^{3}He(K^-, n) reaction.
- E17: Precision spectroscopy of kaonic ^{3}He $3d \rightarrow 2p$ 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 (see Fig. 14). This feature will be required from all 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 late 2009.

Fig. 12: Aerial view of the new J-PARC accelerator center in Tokai-mura.

Fig. 13: Photograph of the hadron hall in J-PARC with indications of the beam lines. Our experiments will be located at K1.8BR.

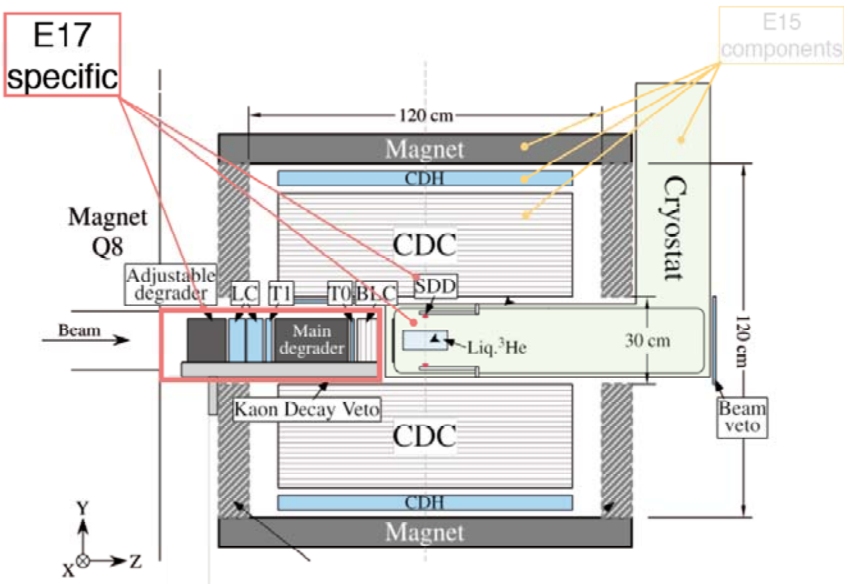

Fig. 14:
Schematic setup of E15 and E17.

Outlook

Both experiments are in preparation and expected to start data taking in 2009 and 2010. E17 can finish with 1-4 weeks of data taking depending on the initial performance of the accelerator, while E15 will require about 8 weeks of full phase-1 beam intensity.

1.3.1.6. FS1_g_a: Precision spectroscopy of kaonic ^{3}He

The E17 experiment will be performed from autumn 2009 onward at J-PARC (Japan Proton Accelerator Research Facility). It is the successor of the E570 experiment at KEK in which SMI has already been involved. An FWF Austria-Japan joint grant fully supports one doctoral student, one postdoc, and the purchase of SDD detectors within this project.

Due to the strong interaction between kaons and nucleons, the low-lying atomic states are shifted. This can be understood with optical potential models for $Z > 3$[2]. The shift of the kaonic hydrogen *1p* state had a large discrepancy between theory and experiments, this so called "kaonic hydrogen puzzle", could be solved in the late 1990's by the experiments KpX[3] and in succession DEAR[4].

Also a discrepancy at the kaonic ^{4}He 2p state was existent: in the 1970's and 1980's, three groups[5,6,7] obtained a large repulsive shift of about −40 eV. Theory, calculated with optical models, predicts ~0 eV[8,9], and even theoretical calculations which use a model assuming the existence of deeply bound kaonic nuclear states[10,11], predict a shift of ~10 eV for ^{3}He and ^{4}He. Nevertheless, both models are in contradiction against experimental results.

With E570 this problem was solved by an X-ray spectroscopy experiment of the kaonic ^{4}He *2p* state ($3d \rightarrow 2p$ X-ray transition). Measurements were done with a super fluid liquid helium target, Ti/Ni calibration foils and eight SDD's with high resolution in energy and good timing capability. The obtained shift on the kaonic helium *2p* state is 2 ± 2(stat) ± 2(sys) eV[12] which is consistent with the theoretically calculated values by both the optical potential models and the model predicting deeply bound kaonic states, and is in disagreement with past experiments. Consequently it was concluded that the previous three experiments were wrong.

In E17, this $3d \rightarrow 2p$ X-ray transition shall now be measured in liquid ^{3}He, because shift and width of the ^{3}He *2p* state have not been measured before. The theoretical calculations for kaonic ^{3}He predict a shift of ~0 eV for the *2p* level. Furthermore, the comparison of kaonic ^{3}He and ^{4}He data will deliver more information on the isospin dependence, more precisely on the isoscalar and isovector strengths of the kaon-nucleus interaction at the low energy limit. It will provide crucial data to understand the basis of the Akaishi-Yamazaki[10] prediction of deeply-bound kaonic nuclei.

A similar setup to E570 is used for E17:

- Eight or twelve (depending on geometric restrictions) SDD's are used instead of Si(Li) X-ray detectors. The advantage of SDDs are that the anode size can be kept small and therefore the capacitance is small too, which make it possible to achieve a very good energy resolution in spite of the large effective area. An energy resolution of about 180 eV at ~6 keV is achieved; 6 keV corresponds to the energy of the $3d \rightarrow 2p$ X-ray transition in ^{3}He.
- Moreover, background can be reduced by a so called "fiducial volume cut", where the reaction vertex of an incident kaon and a secondary charged particle is traced within the liquid helium target using the E15 tracking chambers.
- The energy calibration will be done by characteristic X-rays induced by the incident beam on pure foils, which are measured simultaneously to the kaonic helium X-rays.

A sketch of the device is shown in Fig. 15. With this setup (see Fig. 16), an accuracy of better than 2 eV is expected.

The facility at J-PARC is partly under construction at the moment, the first kaon beam will be extracted in January 2009. A 50 GeV high-intensity proton synchrotron it used to produce secondary kaon beams of the highest intensity ever reached. In order to coordinate the work for E17 at J-PARC, a group meeting was organized at KEK and J-PARC at the end of 2008.

Currently at SMI, we check those detectors and preamplifiers which are required for E17, in systematic tests. Therefore, several parameters such as temperature, voltages at the preamplifier and electronic configuration are adjusted and optimized. In these – since summer 2008 performed – measurements, we analyze spectra of an ^{55}Fe source in order to optimize energy resolution and stability of the new bought prototype SDD (see Fig. 17). Subsequently, we plan to mount the preamplifier inside the vacuum to obtain again an improvement in energy resolution. Using these data the optimization of the remaining seven or eleven, respectively, detectors will be continued during spring/summer 2009.

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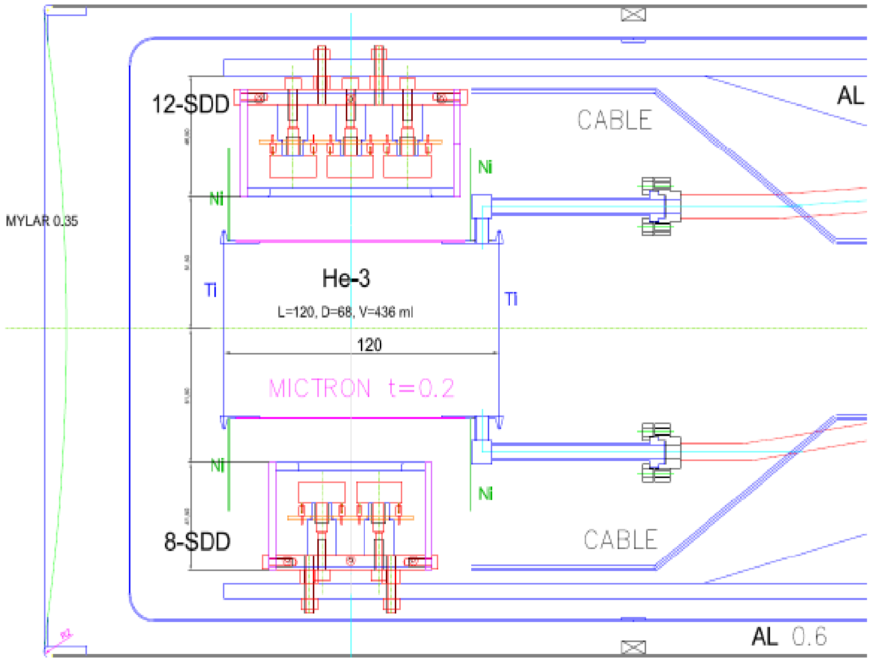

Fig. 15:
Sketch of the setup for J-PARC, with a liquid ^{3}He-target in the middle and eight or twelve, respectively, SDD's surrounding it.

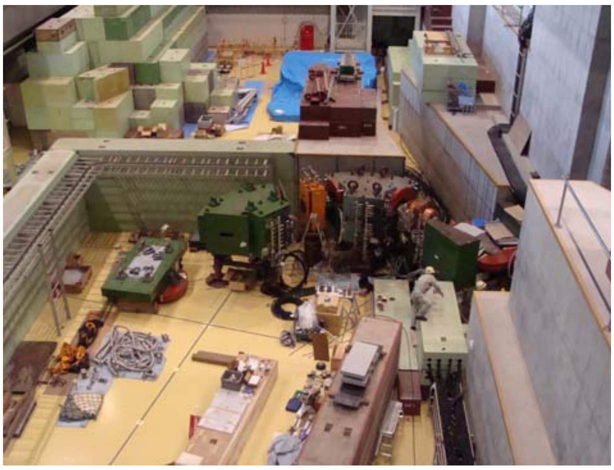

Fig. 16: Beamline under construction for E17 at J-PARC (status November 2008).

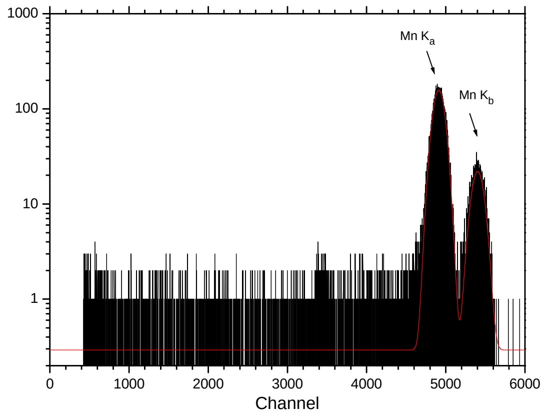

Fig. 17: Typical spectrum of an ^{55}Fe source (Mn K_α and K_β lines, fitted with Gaussian), with an energy resolution of about 200 eV (FWHM of Mn K_α).

1.3.2. FS2_A: Matter – antimatter symmetry: ASACUSA @ CERN

This is the second main scientific program at SMI. Within the ASACUSA program, SMI is involved in the precision laser and microwave 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) 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. SMI is the leading institute in the antiprotonic helium microwave spectroscopy and the antihydrogen projects, while the University of Tokyo is leading the antiprotonic helium laser spectroscopy project.

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 (see Fig. 18).

Antiprotonic helium[13] is a neutral three-body system consisting of a helium nucleus, an antiproton, and an electron (see Fig. 19). The energy levels of the antiproton have been measured by precision laser spectroscopy to an accuracy of about 10^{-8}. Each level is split into a quadruplet due to the magnetic interaction of the electron spin, the antiproton angular momentum and the antiproton spin (see Fig. 20).

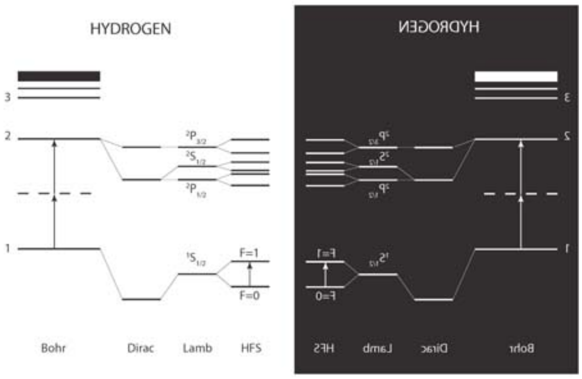

Fig. 18: Energy levels of hydrogen and antihydrogen.

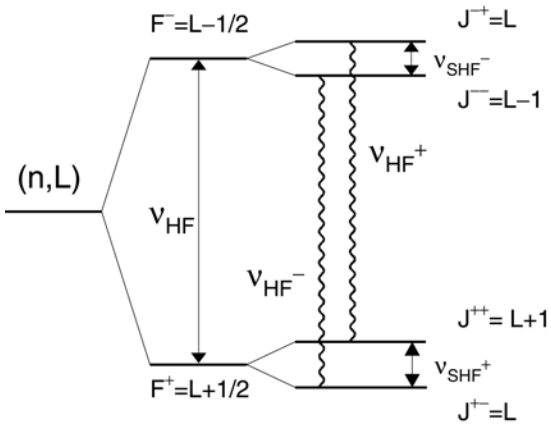

Fig. 20: Hyperfine structure of antiprotonic ^{4}He.

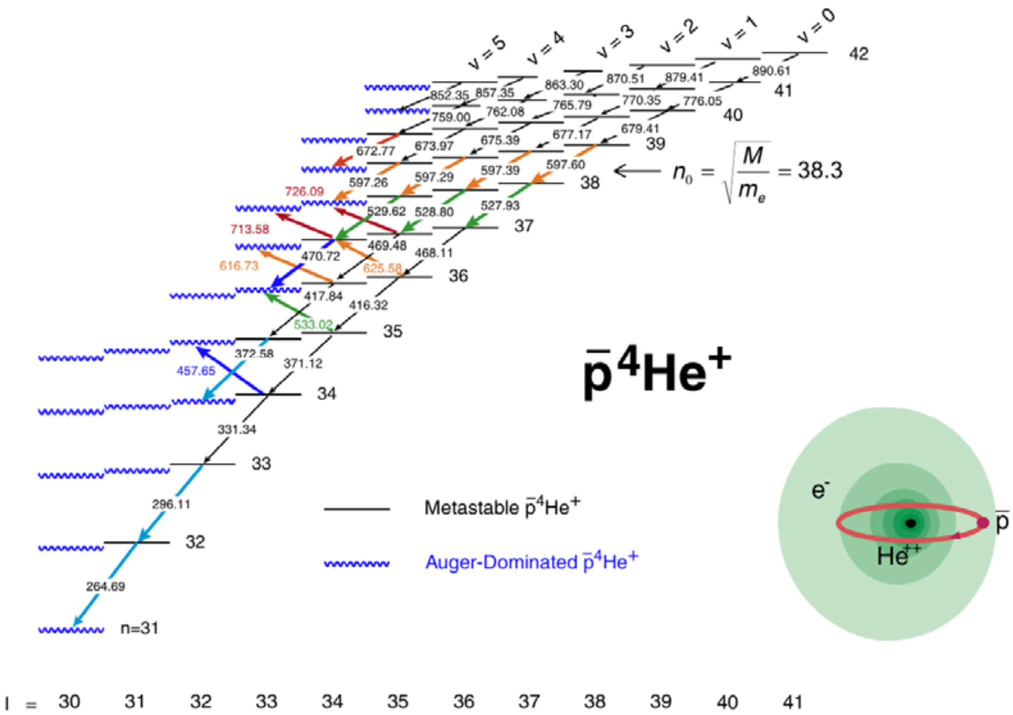

Fig. 19:
Energy level diagram of antiprotonic helium.

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1.3.2.1. FS2_b: Hyperfine structure of antiprotonic helium

HFS of antiprotonic ^{4}He

A measurement of the hyperfine (HF) structure can be compared with QED calculations to determine the difference between the antiproton and proton spin magnetic moment. In 2001 this was measured to a precision of 1.6%[14], while the current most precise measurement is 0.3%[15]. This year we have reached the same precision and verified the value by a different technique.

The hyperfine structure of antiprotonic helium ($\bar{p}He^+$) was investigated by a laser-microwave-laser spectroscopy method, where a first laser pulse was used to depopulate one of the hyperfine (HF) doublets, a microwave pulse transferred population from F^- to F^+, and a second laser pulse measured the population change caused by the microwave pulse.

In 2008 five weeks of beam time were allotted to this experiment to complete a systematic measurement commenced in 2006[16]. The aim was to measure the hyperfine splitting of the $\bar{p}^4He^+$ $(n, l) = (37, 35)$ state to the precision of theory (33 kHz). High statistics measurements were made at target pressures $p = 150$ mbar and 500 mbar. A power dependent measurement at $P = 3$ W, 5 W and 15 W was also performed.

The data has been analysed and, coupled with the data published in April[17], a new value for the spin magnetic moment of the antiproton has been calculated, which will soon be submitted for publication. Fig. 21 shows the agreement between experiment and theory. The individual HF transitions have been measured a factor of 20 better than theory while the difference has been

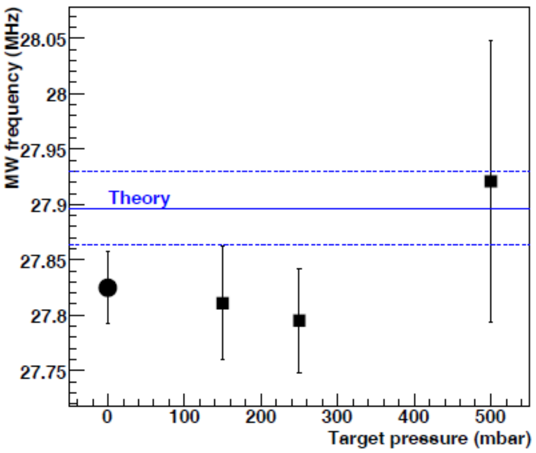

Fig. 21: The HF splitting difference between experiment and the most precise theory as a function of target pressure. The experimental values are shown as squares. The point shown at $x = 0$ and represented by a full circle indicates the average of the total data.

determined with a factor 10 increase in precision over our first measurement.

The theoreticians are working on a calculation of the order α^6 which may allow a more precise determination of the magnetic moment.

Relaxation-inducing collisions

In addition to comparing measurements of the HF spitting to three-body QED calculations, a comparison can be made between them and predictions of collision rates. Our recent results have shown that collisional broadening effects are much smaller than previously expected[18]. In 2008 we collected data concerning the inelastic collisions which result in a relaxation of the induced population asymmetry required for the HF structure measurement.

The relaxation rate was measured by observing the population of the F^+ state at time $T = 50$-1000 ns after initial depopulation. Data were taken at three different target pressures $p = 150$ mbar, 250 mbar and 500 mbar. The results are in agreement with new calculations[19] and should be submitted for publication in the first part of 2009.

HFS of antiprotonic ^{3}He

A new 11 GHz cavity designed to measure M1 transitions in the $\bar{p}^3He^+$ $(n, l) = (36, 34)$ state, is under construction at SMI. Simulations were carried out to determine the cavity dimensions and optimize the construction materials. Incorporated in the new design is a new compressor cooled cryostat. This removes the dependence on liquid helium and allows the experiment to run without interruption. Design and cooling tests are being carried out on this apparatus. An FWF Austria-Russia joint grant fully supports one doctoral student, one postdoc and new microwave hardware within this project.

Outlook

The goal for 2009 is to make the first measurements of $\bar{p}^3He^+$ $(n, l) = (36, 34)$, for which we have recently received FWF funding. This will be the first measurement of $\bar{p}^3He^+$ and will address a small deviation from theory that was observed in laser spectroscopy experiments. The system has a more complex structure because of the additional interaction of the helion spin. Eight supersuper-hyperfine (SSHF) states exist and four electron spin flip transitions can be stimulated with an oscillating magnetic field instead of two, see Fig. 22. In the (36, 34) state, two occur in the 11 GHz region and two in the 16 GHz region. Because a different cavity is required for each, it is planned to measure one frequency each year.

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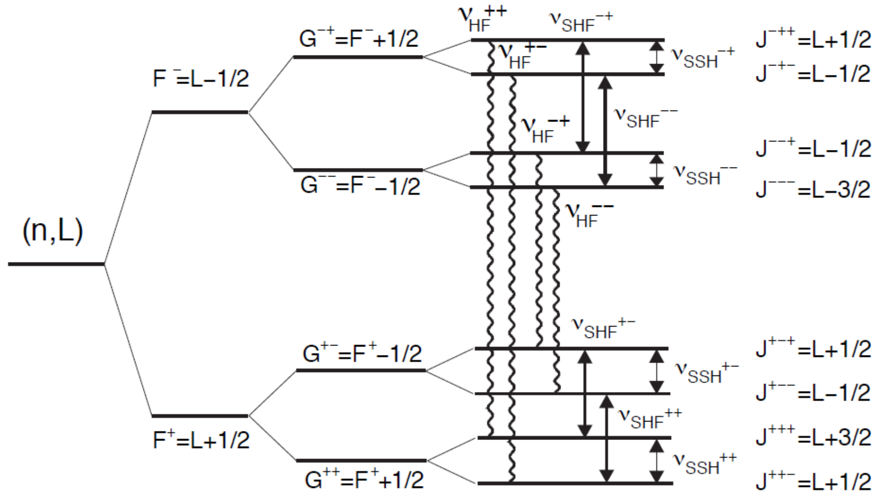

Fig. 22: Schematic view of the SSHF splitting of the $\bar{p}^3He^+$. The M1 transitions are shown as wavy lines.

Completion of the cryostat and the 11 GHz cavity is planned for the early part of 2009 in preparation for the beam time at the end of the year.

1.3.2.2. FS2_c: Precision laser spectroscopy of antiprotonic helium

In 2008, 3.5 weeks of usable beam were dedicated to three different experiments: sub-Doppler two photon measurement in deep UV (DUV), see Fig. 23, sub-Doppler two-colour saturation spectroscopy and single-colour saturation spectroscopy.

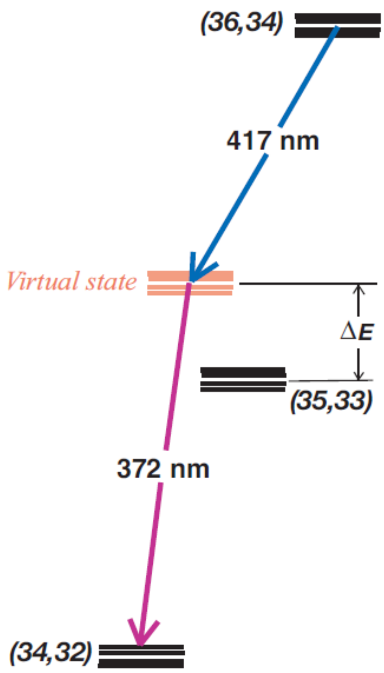

Fig. 23: Level diagram to show the two-photon laser spectroscopy method. Two counter propagating lasers transfer the population from (*n, l*) to (*n*-2, *l*-2) via an intermediate virtual state that lies Δ*E* from a real state.

A new DUV sub-Doppler two-photon transition was measured in antiprotonic ^{4}He to highest precision (3-4 ppb) so far, shown in Fig. 24. If one assumes no CPT violation, then this measurement is expected to lead to a better determination of m_p/m_e, where m_p and m_e are the mass of the proton and electron.

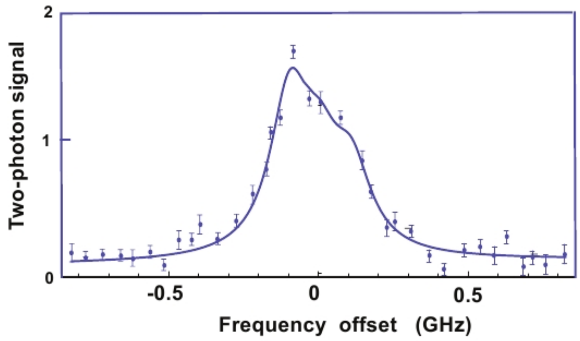

Fig. 24: DUV two-photon transition measured in 2008. Wavelenght 139.6 nm, with the two transitions (*n, l*) = (33, 32) and (31, 30), i.e. laser wavelengths 264 nm and 296 nm.

A Ti:S laser with 5 MHz linewidth was constructed for the measurements in 2008 and verified that spectroscopy with precision of 1.4 ppb is possible[20]. A first saturation spectroscopy of antiprotonic helium was attempted using two different colour saturation spectroscopy techniques. In principle two lasers were used. The first laser created a "hole" in the thermal distribution of $\bar{p}He^+$, which was then probed by the second laser. The advantage of single-colour spectroscopy is that the first-order Doppler width $\Delta\nu$ is completely cancelled, whereas in the other two methods there is a small residual Doppler broadening. Both spectroscopy methods yielded positive results, but the measurements have to be repeated with improved laser conditions in 2009 to achieve publishable results. All two-photon transition results agree with experiment with a precision of <3 ppb, even for antiprotonic ^{3}He.

[20] M. Hori, A. Dax, Opt. Lett. 34, 1273 (2009).

Outlook

The goals for 2009 will be to demonstrate the new saturation spectroscopy technique, using a better laser and more beamtime than in 2008. Higher statistics and higher signal-to-noise ratio are needed to obtain publishable results. The laser linewidth should be improved by a factor of 10; also the laser power stability must be increased. Improvements will further be done on the target (side-irradiation geometry, achievement of still lower temperatures < 1.8 K) and the counter (present counter has 3 times better signal-to-noise ratio than the one used in 2004). Further a new source of systematic error ("Doppler-free saturation effects") has been identified and therefore earlier single-photon experiments have to be remeasured with a new setup.

1.3.2.3. FS2_d: Measurement of the ground-state hyperfine structure of antihydrogen

The ground-state hyperfine splitting (GS-HFS) of antihydrogen is caused by the interaction between the antiproton spin magnetic moment and the positron spin magnetic moment, and (in the first order) directly proportional to the antiproton magnetic moment. Thus by measuring the antihydrogen GS-HFS, which in itself is a good CPT test, we can also obtain a value for the antiproton magnetic moment, which is currently know to a precision of only 0.3%[15].

The ASACUSA collaboration plans to measure the ground-state hyperfine splitting of antihydrogen using an atomic beam method, similarly to the measurements of the early days of hydrogen spectroscopy. This method has the advantage that it does not require the trapping of antihydrogen, which would be very difficult to achieve. Instead, this measurement requires a beam line, the development of which is being performed at the Stefan Meyer Institute. The beam line will be connected to an antihydrogen source, of which two versions are being developed. One of them is a superconducting radiofrequency Paul trap, which is being built at CERN, but it will take a few more years until it can produce antihydrogen. The other source is a cusp trap (i.e. a pair of anti-Helmholtz coils), which was built at RIKEN, Japan. It is already installed at the Antiproton Decelerator at CERN, but no antihydrogen atoms have been produced with it yet. The advantage of this cusp trap is that in principle it can produce a (partially) polarized antihydrogen beam. This beam will then pass through a radiofrequency resonator (operating at 1.42 GHz), which will flip the spin of the antihydrogen atoms when on resonance with the hyperfine splitting frequency, thus changing the polarization of the beam. The beam will then pass through a superconducting sextupole magnet, which will either focus the atoms onto an antihydrogen detector or defocus them, depending on their polarization state, thus the count rate in the detector will vary with the resonator frequency (see Fig. 25). This way the ground-state hyperfine splitting can be determined with a precision of $\sim 10^{-7}$. However, according to a theoretical model, which assumes CPT violation by introducing Lorentz symmetry violating and CPT violating terms in the Standard Model Lagrangian[21], it is not the relative precision of a measurement but its absolute precision on the energy scale which matters when doing a CPT test. Thus a measurement of the 1.42 GHz GS-HFS with a relative accuracy of only 10^{-4} can already be competitive to the measured relative mass difference of 10^{-18} between K^0 and $\overline{K}^0$, which is often quoted as the most precise CPT test so far. See Fig. 26 for a more

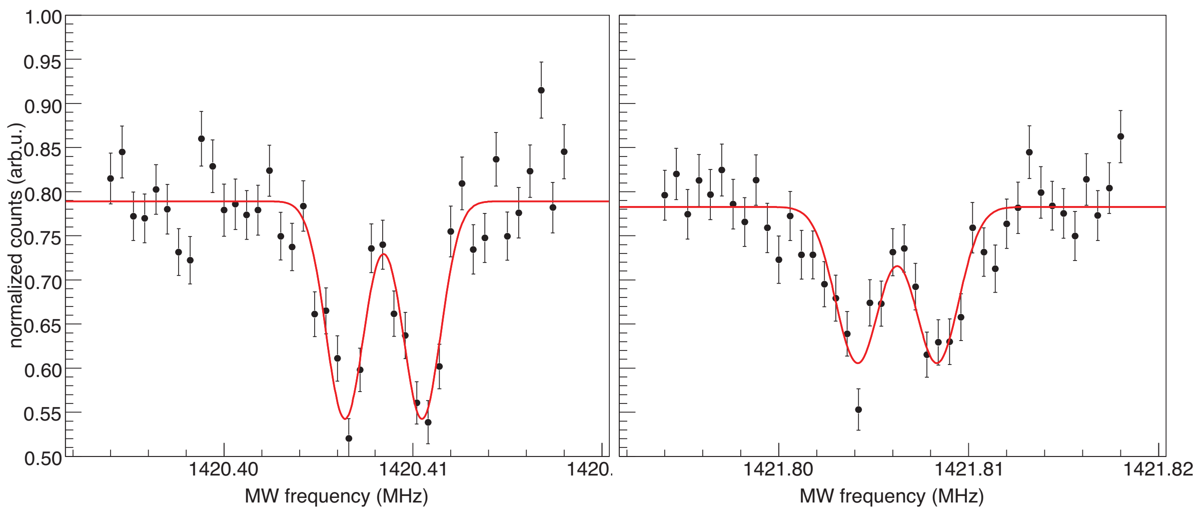

Fig. 25: Simulated resonance profiles of the two observable hyperfine transitions: σ_1 (left) and π_1 (right).

[21] R. Bluhm, V.A. Kostelecky, N. Russell, Phys. Rev. Lett. 82, 2254 (1999).

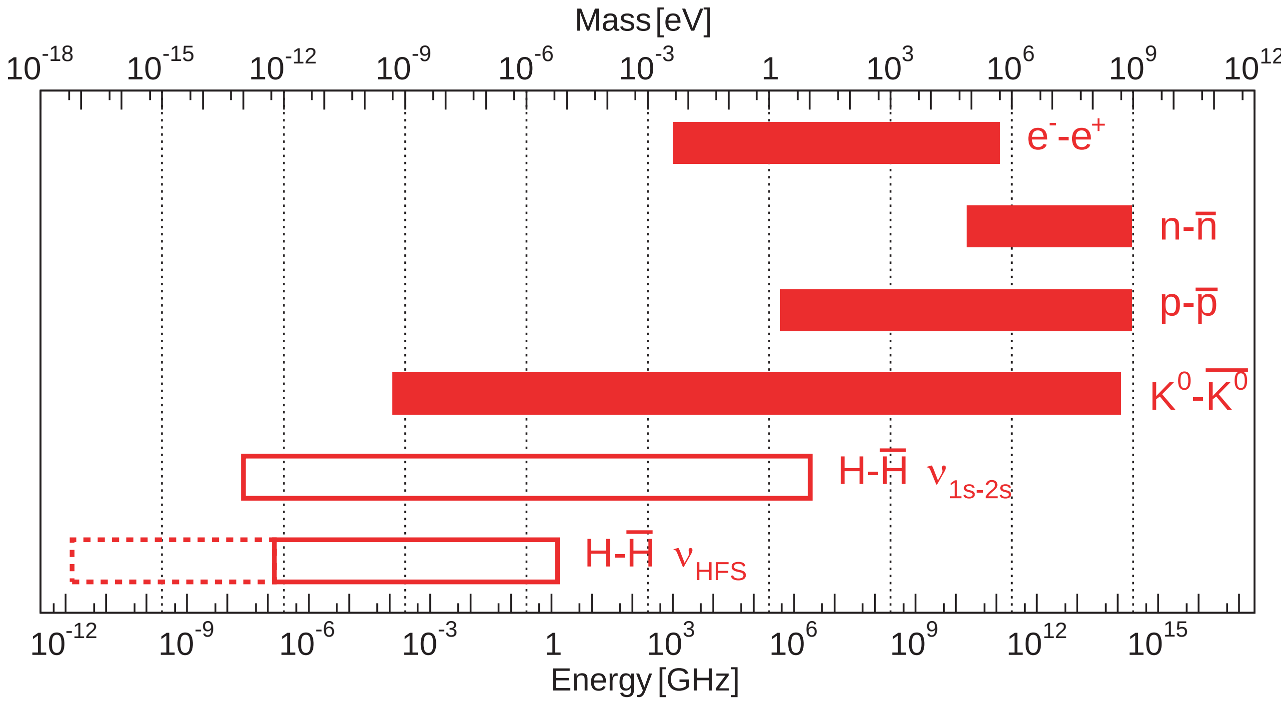

Fig. 26: CPT tests: masses and transition frequencies of various physical systems (from top to bottom: electron, neutron, proton, neutral kaon, hydrogen *1s-2s* transition, hydrogen GS-HFS) and their antimatter counterparts. The right edge of each stripe represents the absolute magnitude of the physical quantity (mass or transition energy), the left edge the absolute experimental accuracy of the matter-antimatter comparison measurement, thus the length of each stripe shows the relative accuracy of the comparison measurement. The bottom two hydrogen-antihydrogen stripes are hollow to indicate that antihydrogen has not been measured yet, thus in these cases the left edges represent the expected absolute experimental precision. The dashed stripe of the antihydrogen GS-HFS assumes that the antihydrogen GS-HFS has been measured to the same experimental precision as the hydrogen GS-HFS; this is, however, unlikely to be achieved in the near future. It can be seen that the K^0-$\overline{K^0}$ mass comparison has a very high relative precision of 10^{-18}, but due to the large mass of the K^0, the absolute precision is worse compared to the hydrogen-antihydrogen comparisons.

detailed explanation.

When using the Paul trap, another sextupole magnet has to be installed between the trap and the radiofrequency resonator, which will polarize the unpolarized antihydrogen atoms coming from the Paul trap.

In 2008, the conceptual design of the sextupole magnet has been finalized. It was decided that the magnet will be manufactured by a commercial company, which also has to make the final engineering design of the magnet following our detailed technical specifications. The magnet is being bought via CERN and following the CERN purchasing procedures. Thus first a market research has been conducted in 2008, where several companies have shown interest in building the magnet. The market research will be followed by the tendering process in 2009, after which the company to build the magnet is expected to be chosen in March 2009. The sextupole magnet will be financed jointly by the Stefan Meyer Institute and the University of Tokyo, Komaba, in a 2:1 ratio.

Outlook

Following the tendering process and choosing the winning company, the superconducting magnet is expected to be delivered by the end of 2009. Following its commissioning, it will be installed at the Antiproton Decelerator in 2010. First it will be directly connected to the cusp trap so that it can be used to analyze the antihydrogen atoms which will hopefully be created by the cusp trap by that time. Afterwards the radiofrequency resonator will be installed between the two devices and the real measurements of the ground-state hyperfine transitions will start.

In the meantime, the development of the radiofrequency resonator will start. There is already a conceptual design[22], but several technical problems are still to be solved. Firstly, the large stray magnetic fields of the cusp trap and the sextupole magnet have to be shielded from the resonator. Secondly, a low homogeneous static magnetic field (0.3-3 G) has to be created in the resonator in such a way that the static and the radiofrequency magnetic fields are at an angle of 45° with respect to each other. A CERN doctoral student of the CERN-Austria exchange program will start to work on the design and building of the resonator from February 2009.

[22] T. Kroyer, CERN-AB-Note-2008-016 (2008).

1.3.3. FS3_A: Antiprotons at FAIR

FAIR, the Facility for Antiproton and Ion Research will be an extension of the existing Gesellschaft für Schwerionenforschung (GSI) near Darmstadt[23]. It will be an international research institute for nuclear and hadron physics, with 25% of the construction cost to be 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 Austrian Ministry for Science and Research has decided to sign the memorandum of understanding of FAIR in February 2007 and has shown willingness to significantly contribute to the construction and operation of the FAIR facility.

Even though the complete external contribution has not yet been secured, the project was formally started with a kick-off event in November 2007. This marked the start of phase A of the project which is based on the available funding of 940 M€. Phase B will be started as soon as the remaining 250 M€ will become available. In October 2008, the basic legal documents were finalized and are currently being translated into the language of several participating countries. The process is expected to end in summer 2009 and the formation of the FAIR company is foreseen soon after. The time schedule anticipates an end of construction earliest in 2015, and a start of the antiproton operation soon after. 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 (cf. Fig. 27).

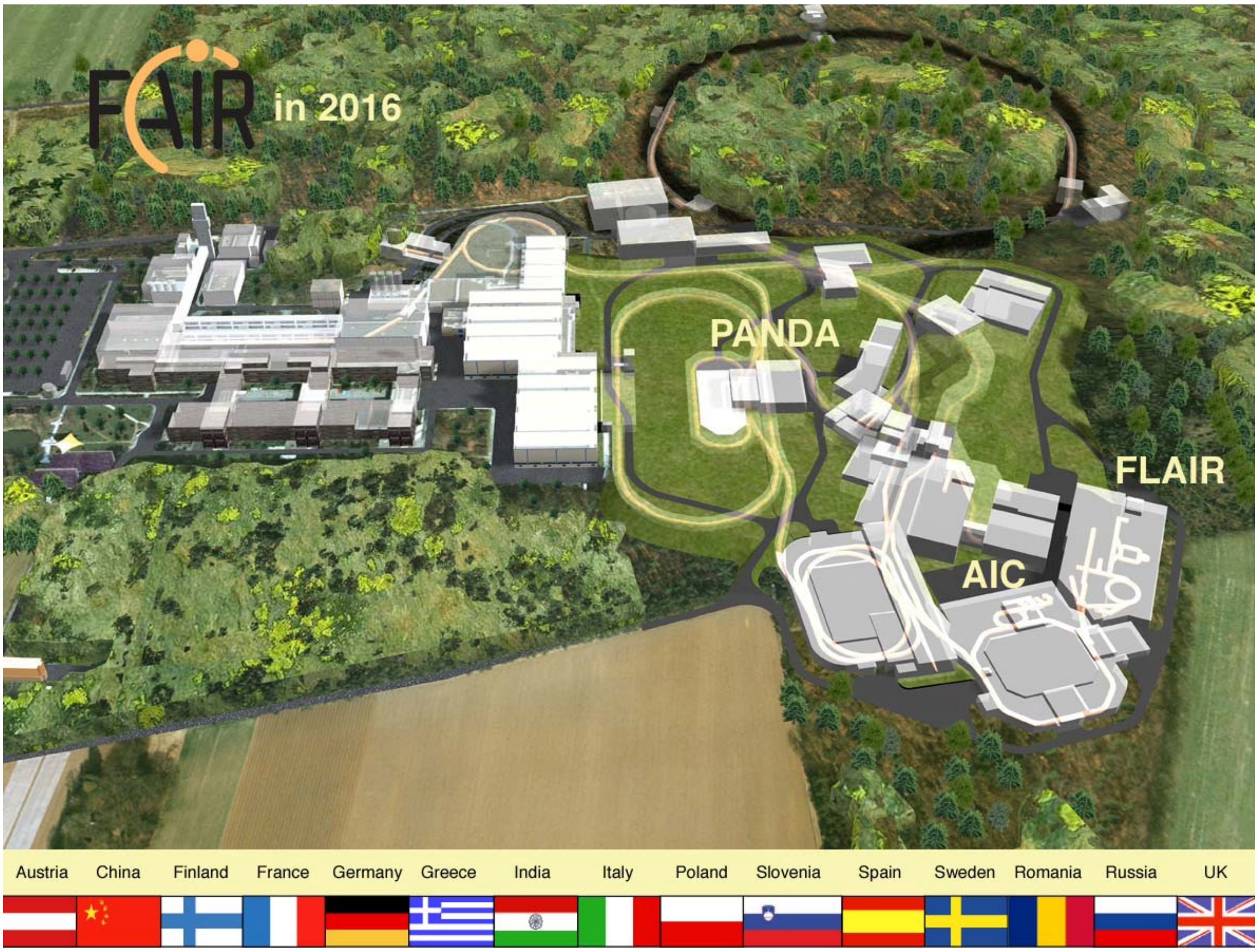

Fig. 27: FAIR in 2016.

[23] FAIR Baseline Technical Report 2006, http://www.gsi.de/fair/reports/btr.html

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 several decelerators – the Low-energy Storage Ring LSR, the Ultra-low energy Storage Ring USR, and the trap facility HITRAP – 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 the scientific goal and technical aspects of these experiments are presented in the FLAIR Technical Proposal[24]. E. Widmann was chairman of the steering committee of FLAIR from the beginning and has been elected spokesman in the last collaboration meeting.

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. In 2008 a formal evaluation of two possible solutions for the LSR rings was performed and it was decided to choose the existing CRYRING at the Manne Siegbahn Laboratory, Stockholm, which will be modified for its use of FLAIR by MSL and provided by Sweden as an in-kind contribution to FAIR. HITRAP is currently being commissioned for operation with highly charged ions at GSI and will later on be moved to FLAIR and modified for operation with both antiprotons and highly charged ions. The USR is a very challenging new development as no electrostatic ring with variable energy has ever been built. It is developed by a Helmholtz Young Investigators group at GSI and University of Heidelberg led by Dr. Carsten Welsch, who recently moved to the Cockcroft Institute in UK. A similar but even more challenging ring called CSR is being developed at Max Planck Institute for Nuclear Physics, Heidelberg, and will serve as a prototype for the design of the USR.

Fig. 28 shows the detailed ion optical layout of the first part of the beam lines in the FLAIR hall which has been done at GSI. Overall the layout is consistent with the shape of the building. A fine tuning with the architects is currently under way.

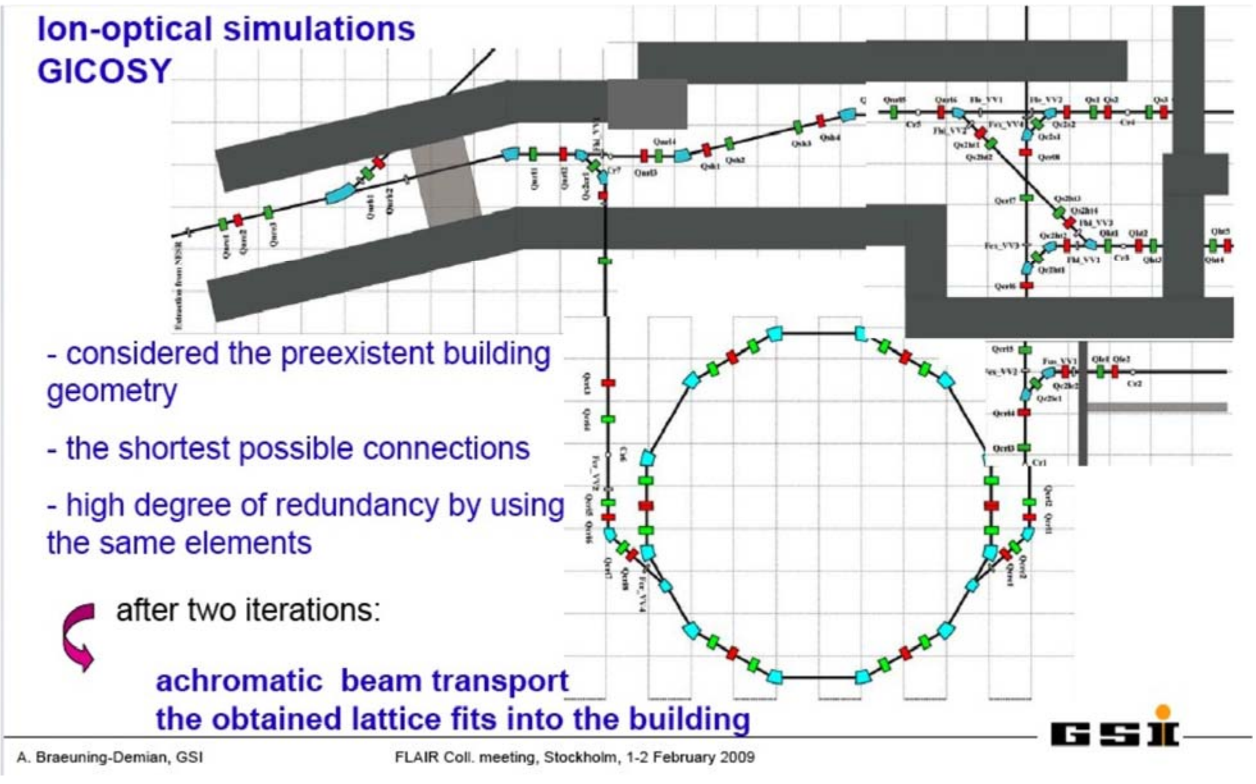

Fig. 28: Result of detailed ion-optical simulation of the FLAIR beam lines done at GSI.

[24] FLAIR Technical proposal – update (2005), http://www.oeaw.ac.at/smi/flair/TP.html

1.3.3.2. FS3_c_A: PANDA: Proton Antiproton Annihilations at Darmstadt

The universal PANDA detector (see Fig. 29) will be built by an international collaboration consisting of 400 physicists to attack open fundamental problems in strong interaction physics. PANDA is devoted to strong interaction precision studies in the transition energy range of perturbative QCD and the non-perturbative QCD regime which exhibits large complexity but is essential for the understanding of nature (e.g. regime of confinement, generation of hadron masses). Experiments with the PANDA detector will take place at the HESR (high energy storage ring) of the FAIR international research center in Darmstadt, Germany.

The high-energy storage ring HESR will deliver antiproton beams in the momentum range 1.5–15 GeV/c of unprecedented precision ($\Delta p/p \sim 10^{-5}$) and intensity (10^{11} circulating antiprotons in normal operation). Using the HESR antiproton beam resonance scans of even very narrow charmonium states (formation experiment) are feasible. All states of charmonium can be formed and studied in a direct way which is a tremendous advantage compared with production experiments. The main experimental topics of PANDA will be high-precision measurements of the strong interaction in the following fields:

- Charmonium spectroscopy: precision measurement of mass, width and decay branches of all charmonium states in order to extract information on the quark-confining potential.
- Exotic states: establishment of the QCD-predicted gluonic excitations (charmed hybrids, glueballs) in the charmonium mass range (3-5 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.

The PANDA project showed significant progress in 2008: The technical design report for the electromagnetic calorimeter (EMC – see Fig. 30) was finalized and published. First crystals for the EMC were already ordered. Very important was also the compilation of the PANDA Physics Book which will be published 2009. The Technical Design Report for PANDA on Solenoid and Dipole Spectrometer was prepared in 2008 and is published in February 2009.

Our institute is taking part in the PANDA international collaboration with more than 50 participating institutes. Within the EU programme of FP6, SMI contributed to the following tasks: optimisation studies of the (hydrogen) cluster-jet target and design of the PANDA interaction zone (JRA7 in I3-Hadron Physics), as well as the development of imaging Cherenkov detectors (work package PANDA1 in DIRACsecondary Beams and INTAS project on novel silicon photo detectors).

PANDA Grid

In order to fulfill the computing demands of the experiments at PANDA a dedicated computing infrastructure will be required. A conceivable way of acquiring and managing the necessary computing power for simulations and data analysis is the Grid model. As an alternative to a centralized computing centre this model allows to pool independent resources from multiple institutes or organizations.

Although PANDA is not expected to acquire data before the year 2016 the PANDA collaboration is already experimenting with the PANDA Grid. At the end of 2008 the PANDA Grid consisted of 10 sites. The underlying software allows the Grid to be expanded without disturbing its continuous operation. The PANDA analysis software (PandaRoot) is installed on the different sites and so the PANDA Grid is able to

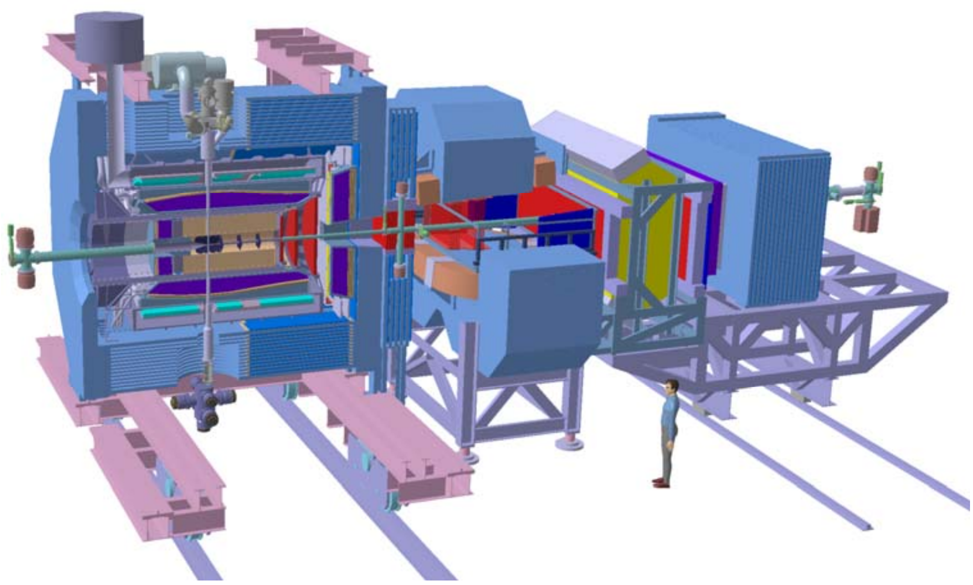

Fig. 29: Artistic view of the PANDA detector.

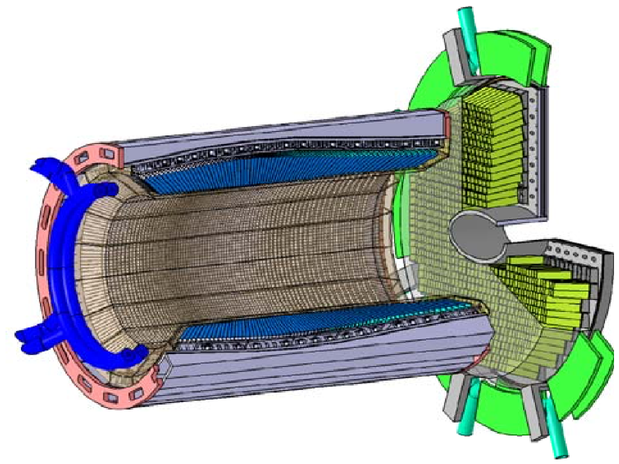

Fig. 30: EMC calorimeter of PANDA.

perform PANDA related tasks.
SMI is actively taking part in building up, developing, testing, and running the PANDA Grid. In 2008 a new batch farm was installed at SMI and included into the PANDA Grid. In 2008 we also had two data challenges during which large quantities of data were produced via a full chain of simulation, digitization, and reconstruction. This data is analyzed and used to improve the design of the PANDA detector.

Physics Outlook
The PANDA detector will cover the physics of strong interaction and will address several fundamental questions in this field. Antiprotons stored in the accelerator HESR will hit an internal target. This target will be mainly a high-luminosity hydrogen cluster-jet target. The interactions between beam antiprotons and target protons will generate, amongst others, mesons and baryons consisting of the heavier strange and charm quarks and will produce a lot of gluons.
The high mass of the charm quark ($\sim$1.5 GeV/c^2) allows applying non-relativistic potential models with correct asymptotic behaviour for the description of QCD. The free parameters in these models are determined from the comparison with experimental data. Therefore the precise spectroscopy of masses and widths of mesons with "hidden charm" (charmonium) produced in these antiproton-proton annihilations will be a powerful tool for the understanding of QCD.
Simulation studies of selected charmonium states produced in antiproton-proton and antiproton-nucleus annihilations by using the cluster-jet target have been and will be carried out at SMI (see Section 1.3.3.6 on page 29) in cooperation with theorists. The simulation results of these important benchmark channels were directly used for the "PANDA Physics Book", which is ready for publication now.
In the next years the institute will continue the work on the construction and commissioning of the PANDA detector.

1.3.3.3. FS3_c_b: Internal target system for PANDA

Within FP6 and FP7 SMI takes part in the development of the internal target system of PANDA as well as in the design of the vacuum system and the interaction zone of the PANDA detector. Our contribution lies in research and development of the (hydrogen) cluster-jet target with the Genova cluster-jet target at GSI. With several setups at SMI we carry out studies on the possibility to use NEG-coated beam pipes near a high-luminosity internal target. This is supplemented by calculations of the vacuum conditions in PANDA.

Genova cluster-jet target at GSI
The Genova/Fermilab cluster-jet target, which was set up at GSI, operates with a gas supply system with up to 20 bar inlet pressure for raising the density of the jet.
In several series of measurements between 2005 and 2007 several parameters of the cluster-jet target were measured. For example it was found out that the cluster-jet at the interaction point has a diameter of 6.15 mm with a low density "halo" of 0.1 mm around it. Later, such a "halo" has been also found at the cluster-jet target in Münster[25].

The maximum target thickness, which could be reached at GSI with this target was 1.4×10^{15} atoms/cm^2 (5×10^{14} atoms/cm^2 was the record at E835, Fermilab). Increasing the target density further was impossible, as we reached the limit of the cooling power of the nozzle head.
In order to overcome these limitations and to optimise the geometry of the nozzle-skimmer arrangement, it was decided to modify this cluster-jet target. In 2008 the concepts for this process were studied, all technical drawings were prepared (see Fig. 31) and all new parts were ordered or manufactured.

Nozzle tests
PANDA has to operate at a luminosity of 10^{32} cm^{-2}s^{-1}. Therefore the target thickness of the cluster-jet target has to be high ($\sim5\times10^{15}$ protons/cm^2). Optimisation of the nozzle shape and the position of the first skimmer have a strong influence on the density of the cluster beam. A measuring device, which measures the density distribution of the cluster-jet right after the nozzle, was constructed at SMI. It turned out in 2008 that the construction of a new cold head for this setup would put too much workload on the mechanical workshop at SMI. Therefore it was considered advantageous to wait and to mount this measuring system

[25] J. Otte, Diploma thesis, WWU Münster (2007).

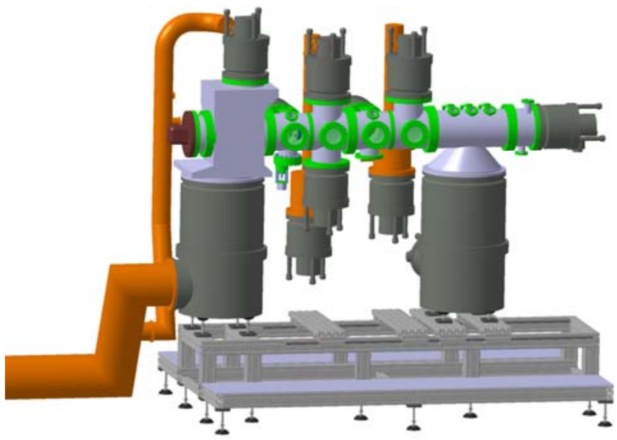

Fig. 31: CAD drawing of the rebuilt cluster-jet target at GSI.

inside the Genova/GSI/SMI cluster-jet target, once it is producing a cluster-jet again.

PANDA interaction zone with NEG-coated beam pipes

To achieve the desired luminosity in PANDA, not only the target density has to be increased, but also the gas load in the interaction zone has to be minimised. Since it is impossible to install UHV pumps near the interaction zone, we are carrying out investigations on the feasibility of using NEG coated beam pipes at PANDA.

For this purpose we have set up a test system at SMI, which simulates the PANDA interaction zone. It consists of 6 NEG-coated pipes with a 1 μm thin film of Ti(30at%)Zr(30at%)V(40at%) as getter. For (re)activation of the getter we have developed a heating system with backing pumps.

The final aim of several measurements is the value of the duration of the service live till reactivation becomes necessary under conditions similar to the ones in PANDA. For making supplementary measurements we set up a separate UHV-system with a single coated tube, which was NEG-coated at GSI and installed at SMI in 2007.

Unfortunately the coating of this pipe got irreversibly saturated due to a leak during reactivation. Therefore this tube could not be used anymore for further measurements.

After reactivation of the test system with the 6 NEG-coated pipes, there were indications in 2008 that the getter had suffered under the big hydrogen load during one test. A test of the functionality of the NEG-coating on each single pipe revealed that in 4 pipes the coating had gone brittle and in the 2 others the getter had only a very limited pumping speed. Since removing the coating and sputter coating the 6 pipes anew is no option, this system was shut down and by and by dismounted.

The vacuum group at GSI has delivered in 2008 a similar tube, like the one of the supplementary system, so that the remaining measurements can be carried out in the first half of 2009.

Calculations of the PANDA vacuum system

Besides the experimental efforts regarding the internal target and the vacuum system of PANDA it is necessary to also calculate pressure profiles. This helps tremendously in the design of the detector, as the dimensions of the beam pipes are not completely fixed yet.

Calculations for the optimisation of the geometry of the PANDA vacuum system were carried out in 2008, like the pumping system behind the Target Spectrometer, the target beam dump and questions on joining together beam tubes with different diameter. Due to the layout of the interaction cross (only 20 mm inner diameter) and the long distance to the next pumps (~3 m in upstream and downstream directions) the effective pumping speed at the interaction point is extremely low (30 l/s in upstream and 5 l/s in downstream directions). The resulting high density of the residual gas would drastically reduce the current of the antiproton beam and cause a lot of unwanted background events.

In connection with these calculations also the planning and design of the vacuum system has been taken up in 2008. In order to make meaningful simulation studies, CAD drawings of this system have been made by SMI. For the full scale Monte Carlo calculations, which are planned to be carried out in 2009, the 2D CAD drawings have been converted into a 3 dimensional model of the complete target/antiproton beam line (see Fig. 32).

This 3D-model was presented to the collaboration and integrated into the existing "official" CAD model of the PANDA detector. Changes to the model are constantly being made in close contact with technicians at GSI.

Outlook

In the first half of 2009 the Genova/Fermilab cluster-jet target at GSI will be modified according to the designs made in 2008. The cluster production at this Genova/GSI/SMI target will start again after this. Renewed tests to run the target in high-pressure mode will be carried out to produce a cluster-jet with the desired density for PANDA. Furthermore we plan to mount pipes to this target, which will simulate the vacuum system of the PANDA Target Spectrometer in its complete length. This has been seen as a necessary step in order to measure the vacuum situation while running the target, since the gas input of the target cannot be completely simulated by numerical calculations. Additionally a new control and read-out system will be set up by INFN Genova and SMI.

When the Genova/GSI/SMI cluster-jet target will be up again, we will carry out a dedicated beam-time for the measurement of the pressure profiles behind the nozzle with our Pitot tube device and also test alternative nozzle designs.

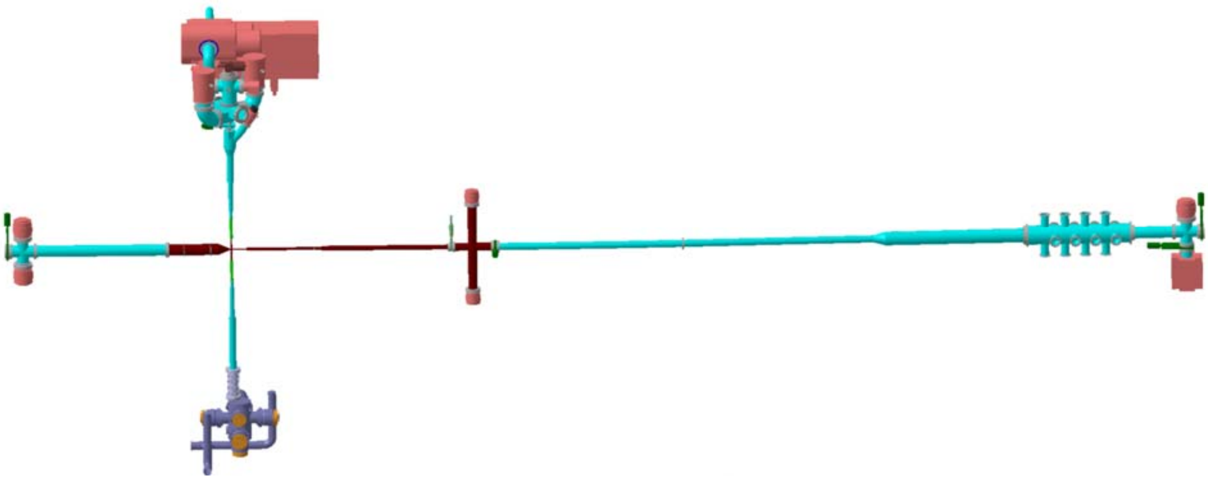

Fig. 32: 3D CAD design of PANDA's target/antiproton beam line with cluster-jet target and target beam dump.

In the first half of 2009 the remaining measurements of the NEG-sorption will be carried out. With this the feasibility study on using NEG-coating near a high density target will be finalised and the results will be published.
The calculation of the vacuum situation in PANDA will go on in 2009, in order to decide details of the layout and questions in dispute. Especially the Monte Carlo simulations in 2009 will have some impact on the design of the vacuum system.
A Target Technical Design Report (TDR) is planned to be published in 2009. SMI is in charge of some chapters of this report and contributes to several others.

1.3.3.4. FS3_c_c: Cherenkov Imaging Detectors (DIRACsecondary beams)

Our institute participated till the end of the project (January 31, 2009) in the EU Design Study "DIRAC-secondaryBeams" which was part of the technical developments for the new international research center FAIR at Darmstadt. We worked on the task PANDA1 within this design study. This sub-project aimed 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[26].
We are studying the application of new matrix avalanche photo-detectors (SiPMs) 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) and these devices are insensitive to magnetic fields.
The development of SiPMs is proceeding fast and new photon detectors optimized for short wavelengths and exhibiting high photo-detection efficiency are available. For the design study we tested the newest generation of SiPMs concerning dark count rate, subnanosecond timing resolution, temperature effects on gain and noise etc. In 2008 we continued the tests of various SiPMs using a test setup contained in a light-tight box (black box) with temperature stabilization. All optical components can be mounted on an optical table (breadboard) and operated inside the black box.
We evaluated several kinds of SiPMs from different manufacturers with different sizes of cells, sensitive area and with different photo sensitivity. Proper temperature and bias voltage control of the device was found inevitable for a stable operation. Especially the SiPMs from Hamamatsu showed very strong temperature coefficient (see Fig. 33), significantly higher than the one from Photonique. Due to the temperature sensitivity for practical applications the temperature has to be stabilized and preferably the detectors have to be operated at low temperatures. Therefore, a cooling method using Peltier elements for SiPMs to be operated in vacuum – to avoid condensation of water

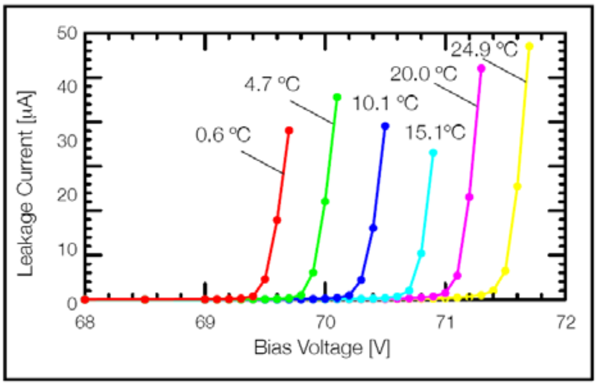

Fig. 33: Leakage current of a Hamamatsu SiPM as function of the bias voltage measured at different temperatures.

[26] http://www-panda.gsi.de

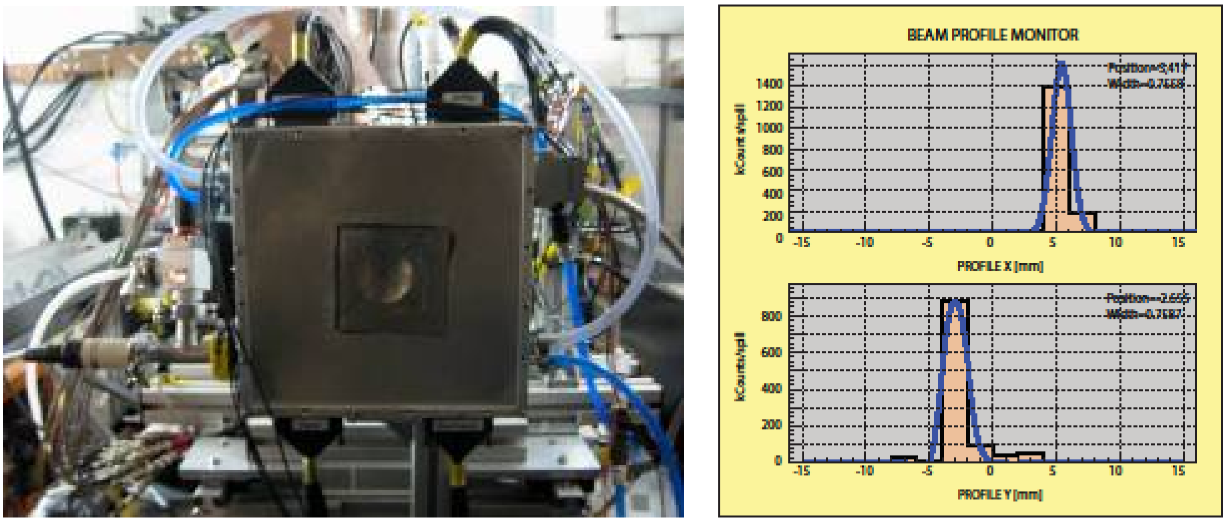

Fig. 34: Left: Beam profile monitor monted at FOPI/GSI. Right: proton beam profile measured in x- and y-axis.

vapor – was developed.
A fast pulsed blue laser system is used to evaluate the timing performance of the devices. We gained experience in operating SiPMs in beam: SiPMs in combination with a 16×16 scintillating fiber grid in 2 planes were used for a beam profile monitor for the FOPI experiment. This device was successfully operated in beam at GSI (see Fig. 34).

1.3.3.5. FS3_c_d: Development and tests of novel matrix avalanche photo detectors for PANDA

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 continued in 2008. New silicon photomultiplier (SiPM) developed by Russian scientists and manufactured by Zecotek/Singapore were delivered to SMI in autumn 2008 for evaluation. Our institute participates with a task concerning the studying the limits of SiPMs parameters for fast timing detectors. A dedicated test arrangement was setup at SMI to test SiPMs with Peltier cooling in a vacuum vessel. A picosecond laser system serves a pulsed light source for testing the timing performance.
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 with a scintillator/radiator array in order to demonstrate its practical application in low level 2D light detection. SMI is working on the evaluation of SiPMs from Zecotek and other SiPMs (e.g. Hamamatsu SiPM as reference SiPM) where important parameters like the noise as a function of temperature and the timing performance are studied in detail (see Fig. 35).
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 to demonstrate possibilities of using SiPMs in various applications. First results were presented in an INTAS meeting in Cracow (June 2008).

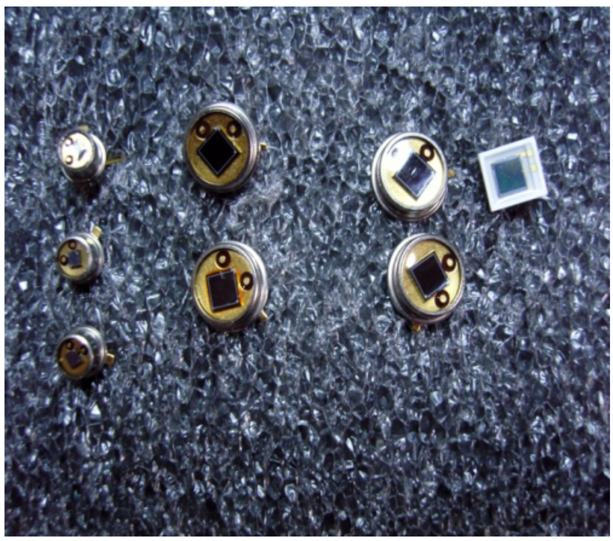

Fig. 35: SiPMs in evaluation manufactured by Zecotek (right, 1×1 mm, 3×3 mm) and Hamamatsu (left, 3×3 mm).

1.3.3.6. FS3_c_e: Charmonium interaction with nuclear matter

The concept of confinement, i.e. the fact that quarks only appear in bound states (hadrons) in nature, has not ceased to puzzle physicists up to now. However, if one goes to high energies the formation of so-called Quark-Gluon-Plasma (QGP) could be possible and the suppressed production of charmonium (J/ψ) in relativistic heavy ion collisions is claimed to be a signature for QGP due to colour screening effects in the plasma. This means that the quarkonia potential range becomes shorter than the size of the resonance making it impossible for the quark and the antiquark to "see" each other and the quarkonium dissociates. More precisely, this phenomenon is probably a complex interplay between suppression of co-mover collisions, colour screening, initial state effects which destroy quarkonia binding processes and the enhancement of charm and anticharm recombination. However, the fact that the magnitude of the J/ψ suppression observed at SPS and RHIC is similar while the centre-of-mass-energy is quite different remains an unsolved mystery. So in order to evaluate and furthermore understand the effect of J/ψ suppression, it is necessary to investigate its dissociation cross section in nuclear matter.
The future experiment PANDA (AntiProton ANnihilations in DArmstadt) at FAIR, which will provide a 1-15 GeV/c antiproton beam, is planned to cover a wide range of QCD-physics topics including reactions $\bar{p}$ + A $\rightarrow J/\psi$ + A-1. J/ψ can be produced at resonance at an incident beam momentum of 4.05 GeV/c following the Breit-Wigner-formula for hadronic resonances. The J/ψ then propagates through the nucleus, with a survival probability proportional to the dissociation cross section, leaves the nucleus and decays. Its leptonic decay channels ($J/\psi \rightarrow e^+e^-$, $J/\psi \rightarrow \mu^+\mu^-$) can then be used to detect and reconstruct the event. The respective cross sections are of the order of 100 pb (Fig. 36 [27]), the total cross section is around 1 b, so a good background suppression of >10^{10} is needed. Since the leptonic decay channels are rather "clean", kinematic and topologic cuts can be applied in order to single out the desired events.
The aim of this work is to implement the theoretical model of the J/ψ interaction with the nuclear environment which was developed by A. Sibirtsev et al.[28,29] in an event generator for Monte Carlo studies with the simulation and analysis software PandaROOT. The base for the event generator is the software package EvtGen which was developed originally for BaBar and contains decay tables according to the PDG and several decay model routines that can be used independently to model any event of interest.
The data produced with that event generator can then be processed in PandaROOT (which is based on the CERN packages ROOT and GEANT, Fig. 37) to simulate events and signals in the detector. UrQMD (Ultrarelativistic Quantum Molecular Dynamics) data will be used to simulate the background.
Furthermore, a detailed study of the actual experimental observables will be done, resulting in a qualitative estimate of the measurability of the J/ψ dissociation cross section with the PANDA experimental setup.
First tests of the EvtGen package and the performance of PandaROOT have been made (Fig. 38 and Fig. 39) and an event generator containing the relevant physics is currently in progress.

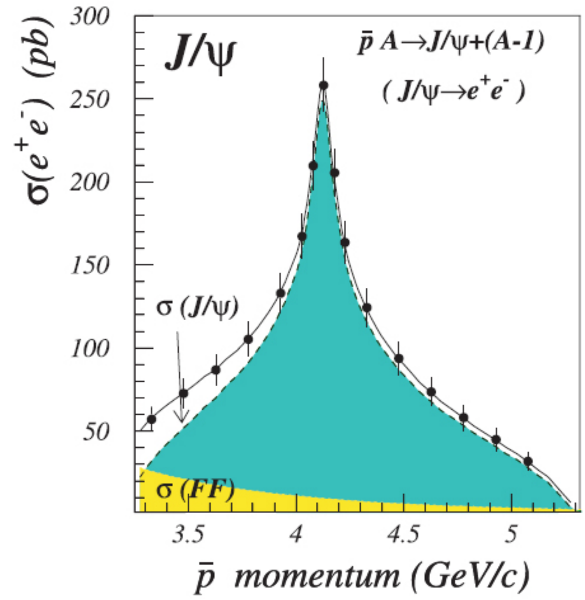

Fig. 36: Simulated cross section for resonant J/ψ production on nuclear protons with internal Fermi momentum distribution as a function of the antiproton momentum.

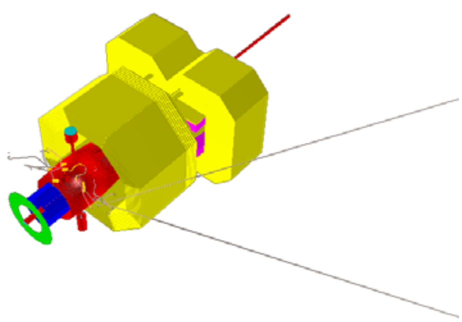

Fig. 37: Event Display in PandaROOT.

[27] K. Seth, Proceeding of the International Workshop on the Structure of Hadrons, Hirschegg, Austria, p. 183 (2001).
[28] A, Sibirtsev, K. Tsushima, A. W. Thomas, Phys. Rev. C 63, 044906 (2001).
[29] A. Sibirtsev, H.-W. Hammer, U.-G. Meissner, arXiv:0802.3373 [nucl-th].

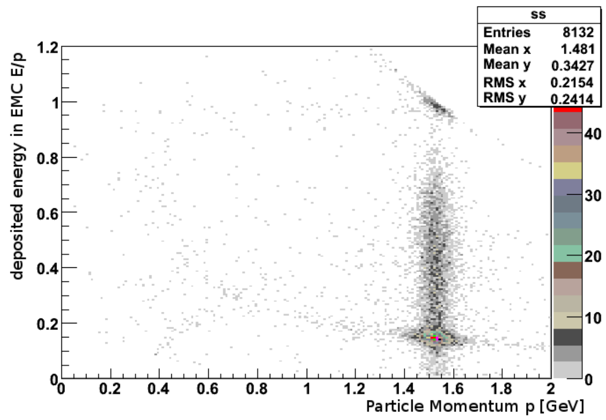

Fig. 38: E/p as a function of momentum in the EMC used for particle identification.

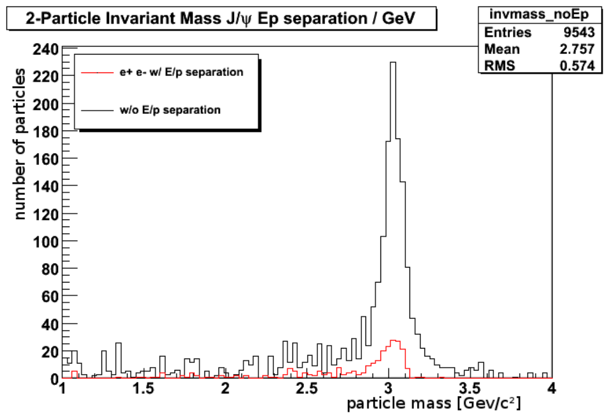

Fig. 39: Invariant mass reconstruction of a J/ψ from e^+e^- events.

1.3.3.7. FS3_d: Antiproton Ion Collider

A Technical Proposal for the Design, Construction, Commissioning and Operation of an Antiproton Ion Collider (AIC) was delivered to the GSI FAIR Project in 2006. 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.

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 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.

Studies are continued on the optimization of the interaction zone as well as for the design of the in-ring detectors, for which SMI has the responsibility. In addition work started for a novel physics project, namely to bread anti-deuterons with the AIC.

1.3.4. Other projects

1.3.4.1. Pion-Nucleon Interaction

The pionic hydrogen experiment (PSI-Experiment R-98-01) aims at a precision determination of the hadronic shift (ε_{1s}) and width (Γ_{1s}) of the ground state in pionic hydrogen by measuring the $4p \rightarrow 1s$, $3p \rightarrow 1s$ and $2p \rightarrow 1s$ X-ray transitions by means of ultimate resolution X-ray spectroscopy (Fig. 40). The measurements were performed at the low-energy pion channel of the Paul Scherrer Institute and data taking has been completed recently.

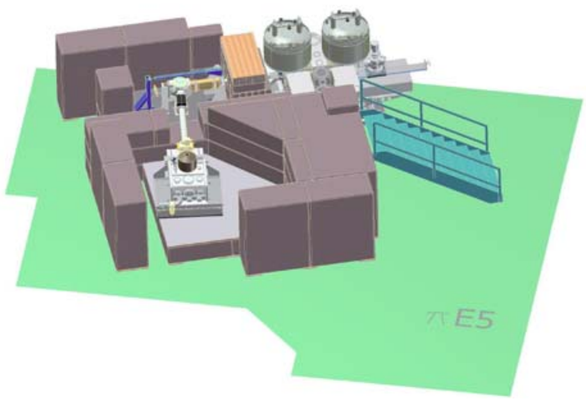

Fig. 40: Sketch of the setup of the pionic hydrogen experiment at the PSI.

The quantities ε_{1s} and Γ_{1s} are directly connected to the pion-nucleon isoscalar and isovector scattering lengths, which in turn can be confronted with results from continuing theoretical efforts within the framework of Chiral Perturbation Theory. The width Γ_{1s} is connected to the pion-nucleon coupling constant $f_{\pi N}$ allowing an accurate determination of the Goldberger-Treiman discrepancy, which constitutes a measure of chiral symmetry breaking due to non-vanishing quark masses. From the shift and the width together, the isoscalar scattering length is extracted serving to extrapolate to the Cheng-Dashen-point, yielding the pion-nucleon sigma term.
The final value of the shift ε_{1s} was already obtained and the result is[30]

$$\varepsilon_{1s} = +7.120 \pm 0.008 \pm 0.006 \text{ eV},$$

which corresponds to an error of 0.2%, whereas the extraction of Γ_{1s} from the data is still in progress.
In a PhD thesis[31] in our institute an elaborate analysis method to extract Γ_{1s} from the data, based on extensive Monte Carlo studies, was developed and first applied to the $4p \rightarrow 1s$ transition in pionic hydrogen. A preliminary value for the strong interaction width of the ground state in pionic hydrogen was given and it reads:

$$\Gamma_{1s} = 765 \pm 56 \text{ meV}.$$

This corresponds to an error of 7.3% and, by using the $4p \rightarrow 1s$ transition only, already constitutes an improvement, compared to the predecessor experiment[32], where an error of 9% was given.
The analysis routine takes into account the instrument's response function, measured using narrow X-ray transitions, produced in an electron cyclotron resonance ion trap (ECRIT)[33] as well as a the changing kinetic energy distribution of the formed pionic hydrogen atoms, leading to a Doppler broadening of the emitted X-rays.
The kinetic energy distribution is approximated by so-called Doppler boxes, an approach which was verified in a measurement of muonic hydrogen[34]. Muonic hydrogen is similar to pionic hydrogen, but the muon is not affected by strong interaction. With the response function given, it therefore offers a unique opportunity to study the influence of the kinetic energy distribution on the line shape of emitted X-rays.
The above mentioned analysis method is being applied to the $3p \rightarrow 1s$ and $2p \rightarrow 1s$ transitions also and will substantially decrease the systematic error of the hadronic width of the ground state in pionic hydrogen. Finally, a relative error of 2-3% is envisaged for Γ_{1s}.

Outlook

Currently the analysis method, developed in our institute, is applied to all measured transitions from all measurement periods. The analysis is scheduled to be completed in the middle of 2009, which also represents the end of the pionic hydrogen experiment.
Additionally, the analysis method is used for the determination of the hadronic width from the measured $3p \rightarrow 1s$ transition in pionic deuterium. The analysis is performed at a collaborating institute and will be finished in the middle of the year 2009 as well.

[30] M. Hennebach, PhD thesis, Universität zu Köln (2003).
[31] A. Hirtl, PhD thesis, TU Wien (2008).
[32] H.C. Schröder *et al.*, Eur. Phys. J. C 21, 473 (2001).
[33] L.M. Simons *et al.*, Nucl. Instrum. Methods A 545, 217 (2005).
[34] D.S. Covita *et al.*, Phys. Rev. Lett. 102, 023401 (2009)

1.3.4.2. X-ray spectroscopy at the VERA accelerator (PIXE)

The experimental setup for non-destructive elemental analysis using the Particle Induced X-ray Emission (PIXE) method at the 3-MV tandem accelerator at VERA (Vienna Environmental Research Accelerator) has been used for the elemental analysis of the setup materials in the kaonic atom X-ray experiments at SIDDHARTA (LNF), E570 (KEK) and E17 (J-PARC). These experiments will measure the kaonic atom X-rays in the energy region of 6-8 keV. In this region, commonly used materials in experimental apparatus, such as Fe and Cu, produce fluorescence X-rays. Thus, material selection with a small contamination of such elements is a key point for the success of the kaonic X-ray measurements.

The materials used in the SIDDHARTA experiment were carefully selected with the PIXE measurements at VERA, including support materials of the SDD chips, wiring lines, as well as X-ray detection area of SDDs. The SIDDHATRA experiment was started on April 2008, and the kaonic atom nitrogen and helium X-ray lines were clearly observed as reported in this annual report without problems of contamination of the commonly used materials. This PIXE project brought the success of the SIDDHARTA experiment.

Using the PIXE setup at VERA, test measurements of new X-ray/gamma-ray detectors can be performed, as well as new elemental analysis, and the PIXE measurements encourages further developments of the new detectors.

1.3.4.3. SUNS – Spallation Ultra Cold Neutron Source at PSI, Source Development

(finished on 20.10.2008.)

The Stefan Meyer Institut contribution to the PSI UCN Source project is connected with the investigation of the properties of solid deuterium (D_2) as the UCN converter and comparison with other possible converter materials: solid oxygen (O_2) and solid heavy methane (CD_4). The experimental program was performed at the FUNSPIN beamline of the Swiss Spallation Neutron Source (SINQ) at PSI and the properties of D_2, O_2 and CD_4 in the temperature range between 8 K and room temperature have been measured. The detailed description of the obtained results can be found in the PhD thesis of M. Kasprzak[35].

The development of high intensity ultracold neutron (UCN) sources is important for improving the accuracy of the experiments investigating fundamental properties of the neutron, e.g. the search for the electric dipole moment[36]. Presently there are several projects to build new UCN sources in order to provide the desired increase in intensity. At the Paul Scherrer Institute (PSI) we are setting up a high intensity UCN source[37] with the aim to increase the available flux and densities by two orders of magnitude compared to the strongest source currently available [UCN densities of about 50 UCN per cm^3 are available at Institut Laue-Langevin (ILL)].

One of the ways to increase the UCN intensity is to use an appropriate material as UCN converter, i.e. a medium that converts cold neutrons (CN) into UCN by inelastic scattering; the converter must have specific properties such as energy levels and excitations that enable the down-scattering to take place. This mechanism differs from a typical scheme of neutron moderation used in the CN sources, i.e. the neutrons do not reach thermal equilibrium with the moderator material. This method of UCN production, superthermal UCN production, was first proposed by Golub and Pendlebury[38] and is used in the PSI UCN source as well as in the other new UCN sources.

Overview of the PSI UCN source

In the PSI UCN source (see Fig. 41) fast neutrons of average energy of about 2 MeV are produced by the spallation reaction of protons with an energy of 590 MeV hitting a lead target[39]. The proton beam with an intensity of about 2 mA is delivered from the ring cyclotron with a low duty cycle ~1%, i.e. with 4 to 8 s beam on every 400-800 s. The protons generate neutrons on the target consisting of lead filled in zircaloy tubes. The spallation neutrons (about 10 neutrons per proton) are first moderated in a 3.3 m^3 tank of heavy water at room temperature and then further cooled and down-scattered into the UCN energy range in 30 dm^3 of solid deuterium (sD_2) at low temperature ~5 K. The neutrons exit sD_2 and gain energy because of the material optical potential (for sD_2 at 5 K it is 105 neV) and then are further transported vertically 1.1 m upwards loosing energy due to gravity and reach the storage volume where the neutrons with energies below 250 neV can be trapped and guided to the experiments. The sD_2 converter and the UCN storage tank are separated from each other using a valve to reduce neutron loss during storage. During the proton pulse, the valve to the storage volume is open and the UCN from the sD_2 converter fill the storage vessel. After the proton pulse is over, the shutter closes and UCN are transported to the experiments. The storage volume has a size of about 80 × 80 × 240 cm^3 and serves as intermediate UCN storage between the pro-

[35] M. Kasprzak, PhD Thesis, University of Vienna (2008). Available online: http://ucn.web.psi.ch/papers/MKasprzak_thesis2008.pdf
[36] C.A. Baker *et al.*, Phys. Rev. Lett. 97, 131801 (2006).
[37] http://ucn.web.psi.ch/
[38] R. Golub, J.M. Pendlenbury, Phys. Lett. 53A, 133 (1975).
[39] M. Wohlmuther, G. Heidenreich, Nucl. Instrum. Methods A 564, 51 (2006).

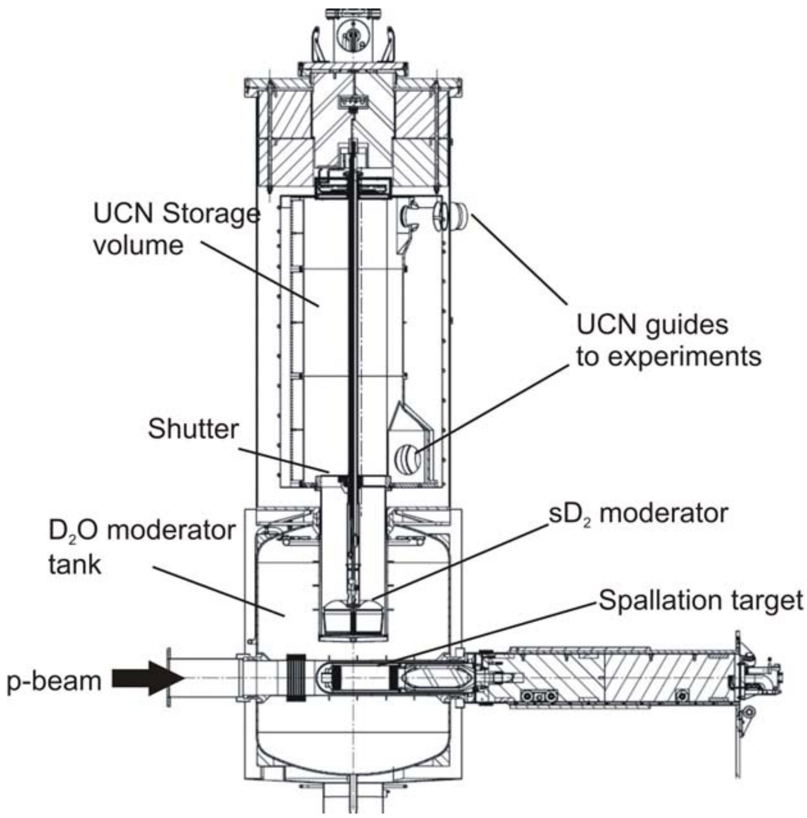

Fig. 41:
Layout of the UCN source at PSI. The proton beam hits the spallation target from the left. Spallation neutrons will be thermalized in the ambient temperature D_2O moderator, further cooled and downscattered into the UCN regime in the cold sD_2 moderator. Through a vertical neutron guide, the UCN reach the storage volume where they can be trapped and distributed to the experiments.

ton beam pulses, thus allowing for quasi continuous availability of the UCN from the source. Storage of UCN relies on the possibility to totally reflect these neutrons under all angles of incidence from suitable materials i.e. diamond-like carbon (DLC) coated materials[40].

Overview of the experimental results

Our investigations of UCN production started in the summer 2004 at the Swiss Spallation Neutron Source (SINQ) at PSI, using the polarized CN beamline for fundamental physics (FUNSPIN). Two experiments based on the same concept of measuring UCN produced from the CN beam were performed. The first experiment took 10 days of beam time and we have successfully measured the absolute UCN production cross sections in gaseous, liquid, and solid deuterium[41] and the temperature dependence of the UCN production in sD_2. Additionally the polarization of UCN produced from polarized CN in sD_2 was measured. The second experiment was conducted in autumn 2005 at the same beamline. During 5 weeks of beam time we have measured the production of UCN from the CN beam in D_2, O_2, and CD_4 as well as the CN transmission through all three all three materials[42]. Moreover, in order to understand underlying processes of UCN production in gaseous and solid D_2, the CN energy dependent UCN production was measured[43].

The idea of the performed experiments is simple: cold neutrons arrive via a “flight tube” (1 in Fig. 42) to the target cell (2), the CNs and UCNs leaving the cell are measured by a detector system. The target cell is mounted on a cryostat and can be filled with D_2, O_2 or CD_4, as appropriate, in the temperature range between 8 K and room temperature. The CNs interact with the material in the cell and some of them get downscattered to UCN energies.

Both the CNs and the UCNs enter the guide system following the target cell and after roughly 0.6 m the UCNs are separated from the CNs by a mirror (3) which is usually a silicon wafer coated with UCN reflecting material with high Fermi potential[44]. The UCNs are reflected upwards by this mirror and after 1 m are again reflected by a second mirror (4) into a horizontal guide section. This section consists of a storage tube (6) and two UCN shutters: the entrance shutter (5) and the exit shutter (7). The UCNs that passed the storage tube are later detected by the ^3He UCN detector (8).

The assembly of items 5-8 is rotated by 90 degrees around the vertical guide so that the UCN detector is moved out of the CN beam axis. The CNs are transmitted through the lower mirror (3) and then pass through a chopper (9), enter the time of flight tube (10), and are detected in the CN detector (11).

40 F. Atchison *et al.*, Nucl. Instrum. Methods A 587, 82 (2008).
41 F. Atchison *et al.*, Phys. Rev. C 71, 054601 (2005).
42 F. Atchison *et al.*,to be published in Nucl. Instrum. Methods A.
43 F. Atchison *et al.*, Phys. Rev. Lett. 99, 262502 (2007).
44 K. Bodek *et al.*, Nucl. Instrum. Methods A 597, 222 (2008).

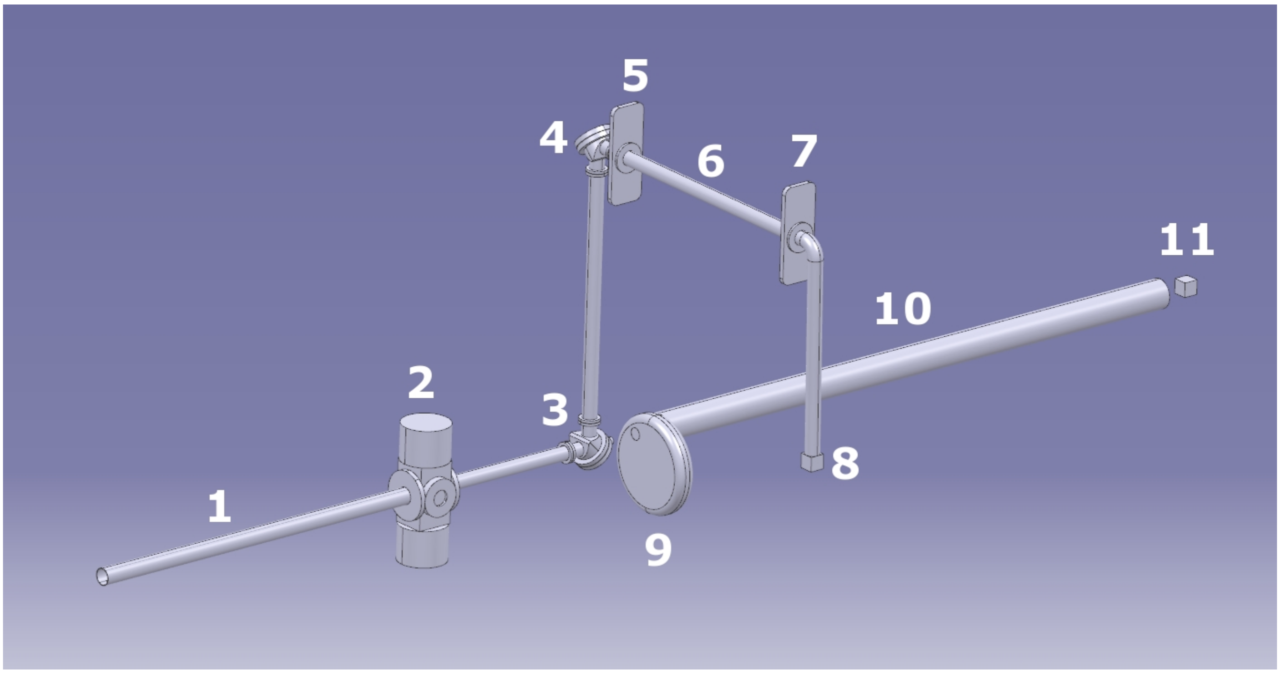

Fig. 42: A 3D view of the experimental setup. (1) CN "flight tube", (2) cryostat with the target cell, (3) & (4) UCN reflecting mirrors, (5) entrance UCN shutter, (6) storage tube, (7) exit UCN shutter, (8) UCN detector, (9) CN chopper, (10) CN TOF tube, (11) CN detector. For the CN transmission and UCN production measurements we have used the full CN beam. For the CN energy dependent UCN production measurements, a velocity selector was mounted upstream of the cryostat.

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

The Pauli Exclusion Principle (PEP) plays a fundamental role in our understanding of many phenomena in chemistry and physics, e.g. periodic table of the elements, electric conductivity in metals, degeneracy pressure (responsible for the stability of white dwarfs and neutron stars). PEP can be explained as a consequence of spin statistics. Although it has been spectacularly confirmed by the number and accuracy of its predictions, the foundation of PEP lies deep in the structure of quantum field theory and no simple proof can be given up to now.

In autumn 2008 an international Workshop on the theoretical and experimental aspects of the spin-statistics connection and related symmetries took place in Trieste. Our institute was co-organizing this event which exhibited the huge interest in PEP and in the connection to spin-statistics[45]. A lively debate on its limits is going on and many experiments to search for tiny violations of PEP are under way. The most precise study of PEP for electrons is represented by VIP in which our institute is participating.

Based on an experimental procedure performed by Ramberg and Snow, the VIP experiment aims for a substantial improvement of the upper limit for PEP for electrons (improvement by 2-4 orders of magnitude) by using a high sensitivity apparatus in the low background environment of the underground laboratory of Laboratori Nazionali di Gran Sasso (LNGS).

The experimental method (see Fig. 43) is based on introducing new electrons into a copper strip and to look for X-rays resulting from the $2p \rightarrow 1s$ anomalous (spin-statistics forbidden) X-rays 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 electrons of opposite spin. The energy of this transition would differ from the normal Kα-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 X-ray detector system used for the DEAR (DAΦNE Exotic Atom Research) experiment, which has successfully completed its program at the DAΦNE collider at LNF-INFN[46].

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

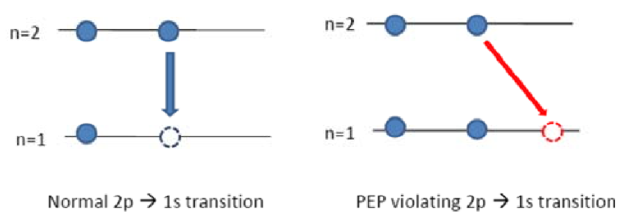

Fig. 43: Principle used in VIP for the PEP test.

[45] CERN Courier, *"The Pauli principle faces testing times"*, January 27, 2009.

[46] G. Beer *et al.*, Phys. Rev. Lett. 94, 212302 (2005).

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 VIP apparatus is installed and is taking data in the Gran Sasso underground laboratory. A substantially improved upper limit of 6×10^{-29} for PEP violation for electrons was obtained (see Fig. 44) thus improving the limit by a factor of about 300 compared to the result of Ramberg and Snow. Today this is the best value ever reached on the probability of PEP violation for electrons.

Outlook

The data taking will continue in 2009. In parallel a further improved experiment (VIP2) employing new X-ray detectors (SDDs) and an active shielding is in discussion in order to improve the limit further down to the region 10^{-30}–10^{-31}. Feasibility studies will take place during 2009 in the laboratory as well as in LNGS.

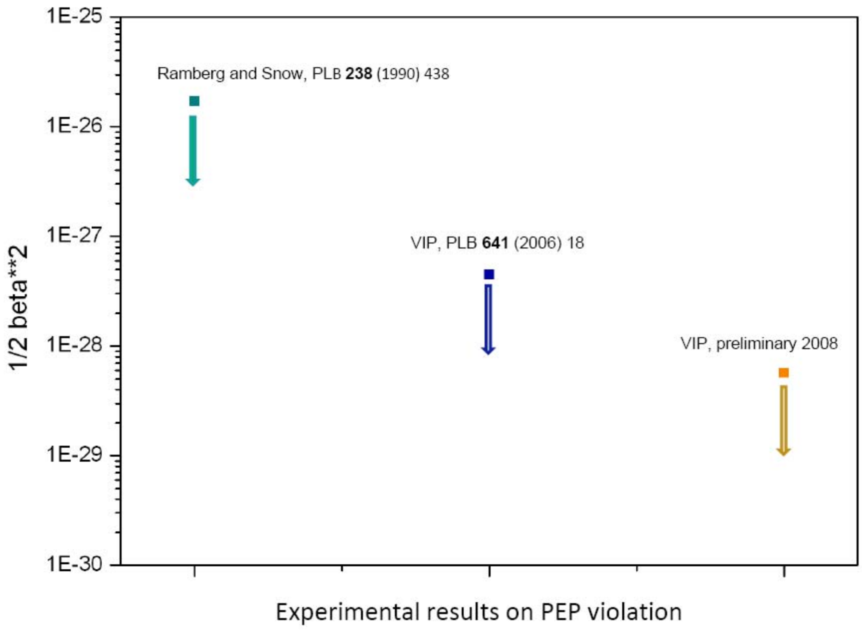

Fig. 44: Experimental results on the upper limit of Pauli principle violation: VIP results 2006 and 2008 in comparison with the result of Ramberg and Snow 1990.

1.3.4.5. Time modulation of orbital electron capture decays of H- and He-like ions

We report on studies of electron capture decays (EC) of highly ionized nuclei with one or two electrons in their K-orbit (H- and He-like ions) in the Experimental Storage Ring (ESR) of GSI, Darmstadt. These experiments allow for the first time investigating two-body weak decays with a pair of entangled lepton states with quasi mono-energetic massive neutrinos, the properties of which can thus be studied without the inefficient neutrino detection.

In recent experiments[47,48] we found that the H-like $^{140}Pr^{58+}$ and $^{142}Pm^{60+}$ ions decay 1.49(8) and 1.44(6) times faster than the He-like $^{140}Pr^{57+}$ and $^{142}Pm^{59+}$ ions. This anomaly is explained by spin effects due to the hyperfine structure of the H-like ions[49]. The EC/β^+ branching ratios are consistent with expectations from standard weak decay theories within 3%[49].

Even more surprising is the recently observed time dependence of the electron capture rate of H-like $^{140}Pr^{58+}$ and $^{142}Pm^{60+}$ ions[50]. It is not exponential but time modulated with amplitudes of a = 0.18(3) and 0.22(3), and periods of T = 7.06(8) s and 7.10(22) s, respectively. It corresponds to an energy difference of 8.6×10^{-16} eV for a quantum beat type phenomenon. We attribute[51,52] it to the small recoil energy difference ΔE of the detected entangled daughter ions induced by the kick of mixed massive neutrinos with masses m_1 and m_2. Using the cm relation $\Delta E = \Delta m^2/2M$, derived from energy and momentum conservation in the decay of a nucleus with mass M and neutrinos with a mass difference $\Delta m = m_2 - m_1$, a squared mass difference $\Delta m^2 = 2.22(3)\times10^{-4}\ \mathrm{eV}^2$ is derived[51,52]. It is 2.9 times larger than reported recently by the KamLAND neutrino oscillation experiment[53]. We have discussed this difference in terms of

47 Yu.A. Litvinov *et al.*, Phys. Rev. Lett. 99, 262504 (2007).
48 N. Winckler *et al.*, GSI Annual Report 2008.
49 A.N. Ivanov, M. Faber, R. Reda, P. Kienle, Phys. Rev. C 78, 025503 (2008).
50 Yu.A. Litvinov *et al.*, Phys.Lett. B 664, 162 (2008).
51 A.N. Ivanov, R. Reda, P. Kienle, arXiv: 0801.2121v5 [nucl-th].
52 H. Kleinert, P Kienle, arXiv: 0803.2938 [nucl-th].
53 S. Abe *et al.* (KamLAND), Phys.Rev. Lett. 100, 221803 (2008).

neutrino mass modification by lepton-W boson loops in the high Coulomb field of the heavy daughter nucleus[54], but the large difference in Δm^2 is not understood. A further problem is the small modulation amplitude with an average value <*a*> = 0.20(2), which would lead to a small neutrino mixing angle θ ~ 6° compared with a value of about 34° from sun neutrino oscillations[55]. The modulation amplitude may be reduced by the preceding photon decay in H-like ions. In a preliminary analysis[56] of the ß⁺ branch of ^{142}Pm we found no modulation with a < 0.03 of this three-body decay with a broad neutrino spectrum in accordance with our theoretical prediction[57]. If verified, this is direct evidence that the modulation is caused by mixed massive neutrinos from quasi-free two-body decays.

In August 2008 we studied the EC decay of H-like ^{122}I and a preliminary analysis[56] shows again a modulation with a reduced period of about 6 s, compared with the ^{140}Pr and ^{142}Pm results and expected from the scaling of the period *T* proportional to the ion mass *M* [51,52].

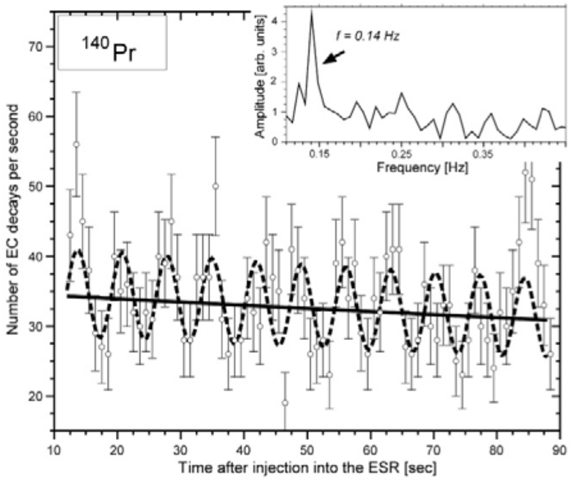

Fig. 45: Number of EC-decays of H-like ^{140}Pr ions per second as a function of the time after the injection into the ring. The solid and dashed lines represent fits without and with modulation, respectively. The inset shows the Fast Fourier Transform of these data. A clear frequency signal is observed at 0.14 Hz (laboratory frame). From [50].

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[54] A.N. Ivanov, E.L. Kryshen, M. Pitschmann, P. Kienle, arXiv: 0804.1311 [nucl-th].

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1.4. Publications/speeches/poster presentations 2008

1.4.1. Publications in peer-reviewed journals or collections

F. Atchison, A. Bergmaier, M. Daum, M. Döbeli, G. Dollinger, P. Fierlinger, A. Foelske, R. Henneck, S. Heule, M. Kasprzak, K. Kirch, A. Knecht, M. Kuźniak, A. Pichlmaier, R. Schelldorfer, G. Zsigmond,
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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A **597**, 222 (2008).

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The DIRC detectors of the PANDA experiment at FAIR.
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A **595**, 88 (2008).

M. Hoek, E.D. Bennet, D. Branford, E. N. Cowie, M. Düren, K. Föhl, D. Glazier, R. Kaiser, A. Lehmann, S. Lu, J. Marton, R. Ostendorf, G. Schepers, C. Schwarz, B. Seitz, A. Teufel, D. Watts,
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PHYSICAL REVIEW C **78**, 025503 (2008).

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NUCLEAR PHYSICS A **804**, 286 (2008).

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Observation of non-exponential orbital electron capture decays of hydrogen-like ^{140}Pr and ^{142}Pm ions.
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Improved study of the antiprotonic helium hyperfine structure.
JOURNAL OF PHYSICS B: ATOMIC, MOLECULAR AND OPTICAL PHYSICS **41**, 081008 (2008).

M. Sato, H. Bhang, J. Chiba, S. Choi, Y. Fukuda, T. Hanaki, R. S. Hayano, M. Iio, T. Ishikawa, S. Ishimoto, T. Ishiwatari, K. Itahashi, M. Iwai, M. Iwasaki, P. Kienle, J. H. Kim, Y. Matsuda, H. Ohnishi, S. Okada, H. Outa, S. Suzuki, T. Suzuki, D. Tomono, E. Widmann, T. Yamazaki, H. Yim,
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L. Sperandio, S. Bartalucci, S. Bertolucci, M. Bragadireanu, M. Cargnelli, M. Catitti, C. Curceanu (Petrascu), S. Di Matteo, J.-P. Egger, C. Guaraldo, M. Iliescu, T. Ishiwatari, M. Laubenstein, J. Marton, E. Milotti, D. Pietreanu, T. Ponta, D. L. Sirghi, F. Sirghi, O. Vazquez Doce, E. Widmann, J. Zmeskal,
New limit on the Pauli Exclusion Principle violation by electrons.
NUOVO CIMENTO B **122**, 641 (2008).

J. Zmeskal,
From kaonic atoms to kaonic nuclei: A search for antikaon-mediated bound nuclear systems.
PROGRESS IN PARTICLE AND NUCLEAR PHYSICS **61**, 512 (2008).

1.4.2. Longer publications in non-peer-reviewed journals or collections

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New precision measurements of the strong interaction in kaonic hydrogen.
Proceedings of the International Conference on Muon Catalized Fusion and Related Topics (μCF), Dubna, JINR, p. 214 (2008).

C. Curceanu, J. Zmeskal,
Kaonic Atoms/Nuclei Measurements at DAΦNE: SIDDHARTA and AMADEUS.
MODERN PHYSICS LETTERS A **23**, 2524 (2008).

D. Gotta, F. Amaro, D.F. Anagnostopoulos, S. Biri, D.S. Covita, H. Gorke, A. Gruber, M. Hennebach, A. Hirtl, T. Ishiwatari, P. Indelicato, Th. Jensen, E.-O. Le Bigot, J. Marton, M. Nekipelov, J. M. F. Dos Santos, S. Schlesser, Ph. Schmid, L. M. Simons, Th. Strauch, M. Trassinelli, J. F. C. A. Veloso, J. Zmeskal,
Conclusions from recent pionic-atom experiments.
AIP CONFERENCE PROCEEDINGS **1037**, 162 (2008).

R. S. Hayano, G. Beer, H. Bhang, M. Cargnelli, J. Chiba, S. Choi, C. Curceanu, Y. Fukuda, T. Hanaki, M. Iio, T. Ishikawa, S. Ishimoto, T. Ishiwatari, K. Itahashi, M. Iwai, M. Iwasaki, B. Juhász, P. Kienle, J. Marton, Y. Matsuda, H. Ohnishi, S. Okada, H. Outa, M. Sato, P. Schmid, S. Suzuki, T. Suzuki, H. Tatsuno, D. Tomono, E. Widmann, T. Yamazaki, H. Yim, J. Zmeskal,
Solving the Kaonic-Helium Puzzle.
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J. Kurcewicz, Yu. A. Litvinov, F. Bosch, H. Geissel, Z. Patyk, N. Winckler, L. Batist, K. Beckert, P. Beller, D. Boutin, C. Brandau, L. Chen, C. Dimopoulou, T. Faestermann, L. Grigorenko, P. Kienle, R. Knoebel, C. Kozhuharov, S. A. Litvinov, L. Maier, M. Mazzocco, F. Montes, G. Muenzenberg, A. Musumarra, C. Nociforo, F. Nolden, M. Pfuetzner, W. Plass, C. Scheidenberger, M. Steck, B. Sun, H. Weick, M. Winkler,
Orbital electron capture and β^+ decay of H-like ^{140}Pr ions.
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Low-energy kaon-nucleon interaction studies with x-ray spectroscopy.
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A new high sensitivity test of the Pauli Exclusion Principle.
Proceedings of the 1st AFI Symposium „From the Vacuum to the Universe", Innsbruck, 2007, Conference Series, Innsbruck University Press, p. 40 (2008).

T. Pask, D. Barna, A. Dax, R. S. Hayano, M. Hori, D. Horváth, B. Juhász, C. Malbrunot, J. Marton, N. Ono, K. Suzuki, J. Zmeskal, E. Widmann,
Collisional Effects on the Antiprotonic Helium Hyperfine Structure Measurement.
AIP CONFERENCE PROCEEDINGS **1037**, 148 (2008).

T. Suzuki, M. Iio, K. Itahashi, M. Iwasaki, Y. Matsuda, H. Ohnishi, S. Okada, H. Outa, D. Tomono, T. Yamazaki, H. Bhang, S. Choi, J. H. Kim, H. Yim, J. Chiba, T. Hanaki, Y. Fukuda, M. Sato, R. S. Hayano, T. Ishikawa, S. Ishimoto, M. Iwai, S. Suzuki, T. Ishiwatari, P. Kienle, E. Widmann,
YN correlations from the stopped K^- reaction on ^{4}He.
MODERN PHYSICS LETTERS A **23**, 2520 (2008).

E. Widmann,
The hyperfine structure of antiprotonic helium and the antiproton magnetic moment.
Proceedings of the International Conference on Muon Catalized Fusion and Related Topics (μCF), Dubna, JINR, p. 159 (2008).

1.4.3. Book chapters

D. Gotta, F. Amaro, D. F. Anagnostopoulos, S. Biri, D. S. Covita, H. Gorke, A. Gruber, M. Hennebach, A. Hirtl, T. Ishiwatari, P. Indelicato, Th. Jensen, E.-O. Le Bigot, J. Marton, M. Nekipelov, J. M. F. dos Santos, S. Schlesser, Ph. Schmid, L. M. Simons, Th. Strauch, M. Trassinelli, J. F. C. A. Veloso, J. Zmeskal,
Pionic Hydrogen.
Lecture Note in Physics **745**: Precision Physics of Simple Atomic Systems, Springer Verlag, p. 168 (2008)

E. Widmann,
Fundamental Tests with Trapped Antiprotons.
Lecture Notes in Physics **749**: Trapped Charged Particles and Fundamental Interactions, Springer Verlag, p. 155 (2008).

1.4.4. Dissertations

A. Hirtl,
Determination of the Strong Interaction Ground State Width in Pionic Hydrogen.
Doctoral thesis, Technical University, Vienna (2008).

M. Kasprzak,
Ultracold Neutron Converters.
Doctoral thesis, University of Vienna (2008).

T. Pask,
A Precision Measurement of the Antiprotonic Helium Hyperfine Structure.
Doctoral thesis, University of Vienna (2008).

1.4.5. Keynote scientific talks

E. Widmann,
Perspectives of Low-energy Antiproton Physics at FAIR.
German Physical Society Meeting (Nuclear Division), GERMANY

E. Widmann,
FAIR, das zukünftige Zentrum für Kern- und Hadronenphysik in Europa.
Highlights aus den Fachbereichen presented at the ÖPG meeting in Leoben, AUSTRIA

1.4.6. Invited scientific talks

T. Ishiwatari,
SDDs for exotic atoms.
International Conference on Exotic Atoms and Related Topics (EXA08), Vienna, AUSTRIA

B. Juhász,
Measurement of the ground-state hyperfine splitting of antihydrogen.
International Conference on Low Energy Antiproton Physics (LEAP08), Vienna, AUSTRIA

J. Marton,
Perspectives in experimental hadronic atom research.
International Workshop on Nuclear and Particle Physics at J-PARC (NP08), Mito, JAPAN

J. Marton,
New precision experiments with kaonic atoms: Strong interaction studies at lowest energies.
Seminar talk at Institute for Nuclear and Particle Physics, Prag, CZECH REPUBLIC

J. Marton,
New high precision experiments on kaonic hydrogen and helium atoms.
Seminar talk at Institut fuer Kern- und Teilchenphysik (iktp), TU Dresden, Dresden, GERMANY

J. Marton,
The strange world of kaonic atoms: Clarified puzzles and open questions.
Seminar talk at the Frankfurt Institute for Advanced Studies (FIAS), Frankfurt, GERMANY

T. Pask,
A Precise Measurement of the Antiprotonic Helium Hyperfine Structure.
International Conference on Low Energy Antiproton Physics (LEAP08), Vienna, AUSTRIA

K. Suzuki,
Search for the kaonic nuclear state K^-pp in the p+p reaction.
International Conference on Exotic Atoms and Related Topics (EXA08), Vienna, AUSTRIA

E. Widmann,
Kaonic Atoms at DAΦNE: the SIDDHARTA experiment.
Workshop on Meson Production, Properties and Interaction, Cracow, POLAND

E. Widmann,
Precision spectroscopy of antiprotonic helium.
WE-Heraeus School on Highly Charged Ions and Antiprotons, Physikzentrum Bad Honnef, GERMANY

E. Widmann,
FLAIR physics program.
WE-Heraeus School on Highly Charged Ions and Antiprotons, Physikzentrum Bad Honnef, GERMANY

E. Widmann,
Experimental low-energy antiproton physics.
Workshop on Critical Stability, Ettore Majorana Centre, Erice, ITALY

E. Widmann,
Nuclear and particle physics with low-energy antiprotons.
Workshop on Recent Advances in Strangeness Nuclear Physics and Related Subjects, Tel Aviv, ISRAEL

E. Widmann,
Studying exotic atoms and nuclei with low-energy antiprotons.
International Symposium on Heavy Ion Physics (ISHIP 2008), GERMANY

E. Widmann,
Status and opportunities of FLAIR.
Workshop on Cold Antimatter Plasmas and Application to Fundamental Physics (pbar08), Naha, Okinawa, JAPAN

1.4.7. Other scientific talks

P. Buehler,
$\bar{p}+A \rightarrow J/\psi + (A\text{-}1) \rightarrow e^+ + e^- + (A\text{-}1)$.
PANDA collaboration Meeting (GSI), Darmstadt, GERMANY

P. Buehler,
$\bar{p}+A \rightarrow J/\psi + X$*, a simulation study.*
PANDA collaboration Meeting (Universitaet Krakau), Cracow, POLAND

P. Buehler,
PANDA.
Scientific Advisory Board meeting at SMI, Vienna, AUSTRIA

A. Gruber,
Vacuum calculations for PANDA beam pipes.
PANDA Collaboration meeting (GSI), Darmstadt, GERMANY

A. Gruber,
Target-Beam pipes: Dimensions.
XXVII. PANDA Collaboration meeting, Darmstadt, GERMANY

A. Gruber,
Target TDR: Target beam dump & vacuum issues.
XXVII. PANDA Collaboration meeting, Darmstadt, GERMANY

A. Gruber,
Development of a cluster-jet target for PANDA.
Fachausschußtagung Kern- und Teilchenphysik (FAKT) 2008, Österreichische Physikalische Gesellschaft (ÖPG), Aflenz, AUSTRIA

A. Gruber,
Some vacuum issues of the PANDA CJ-target.
XXV. PANDA collaboration meeting, Cracow, POLAND

A. Hirtl,
Pionic Hydrogen.
Particles and Nuclei International Conference (PANIC08), Eilat, ISRAEL

A. Hirtl,
Pionischer Wasserstoff.
ÖPG-FAKT Tagung 2008, Aflenz, AUSTRIA

B. Juhász,
Testing CPT with the ground-state hyperfine splitting of antihydrogen.
Symposium on Prospects in the Physics of Discrete Symmetries (DISCRETE'08), Valencia, SPAIN

B. Juhász,
Sextupole beam line: STATUS.
ASACUSA collaboration meeting, Tokyo, JAPAN

B. Juhász,
Measurement of the ground-state hyperfine splitting of antihydrogen.
Workshop on Cold Antimatter Plasmas and Application to Fundamental Physics (pbar08), Naha, Okinawa, JAPAN

B. Juhász,
ASACUSA @ SMI: Spectroscopy of antiprotonic helium and antihydrogen.
Scientific Advisory Board meeting at SMI, Vienna, AUSTRIA

J. Marton,
New X-ray Detectors for Exotic Atom Research.
Symposium on Radiation Measurements and Applications (SORMA West 2008), Berkeley, UNITED STATES

J. Marton,
Tests of Matrix Geiger-mode APDs at SMI/Vienna.
PANDA collaboration Meeting, Ferrara, ITALY

J. Marton,
Tests of Matrix Geiger-mode APDs at SMI/Vienna.
Meeting on SiPMs, Frascati, ITALY

J. Marton,
Low-energy kaon-nucleon interaction studies with x-ray spectroscopy.
XLVI International Winter Meeting on Nuclear Physics, Bormio, ITALY

J. Marton,
Investigation of the limits of AMPD parameters for fast timing detectors.
INTAS Meeting, Cracow, POLAND

J. Marton,
SMI in EU FP6&FP7.
SMI Scientific Advisory Board Meeting, Vienna, AUSTRIA

J. Marton,
Violation of the Pauli Principle (VIP experiment).
SMI Scientific Advisory Board Meeting, Vienna, AUSTRIA

T. Pask,
An Improved Measurement of The Hyperfine Structure of Antiprotonic Helium.
Workshop on Cold Antimatter Plasmas and Application to Fundamental Physics (pbar08), Naha, Okinawa, JAPAN

T. Pask,
A Precise Measurement of the Antiprotonic Helium Hyperfine Structure.
Fachausschußtagung Kern- und Teilchenphysik (FAKT) 2008, Österreichische Physikalische Gesellschaft (ÖPG), Aflenz, AUSTRIA

K. Suzuki,
Search for the kaonic nuclear state K^-pp in the p+p reaction.
Particles and Nuclei International Conference (PANIC08), Eilat, ISRAEL

E. Widmann,
Antiprotonic Helium and CPT Invariance.
Symposium on Prospects in the Physics of Discrete Symmetries (DISCRETE'08), Valencia, SPAIN

E. Widmann,
Kaonic Atoms at DAΦNE: the SIDDHARTA experiment.
Particles and Nuclei International Conference (PANIC08), Eilat, ISRAEL

E. Widmann,
Status of FAIR.
Fachausschußtagung Kern- und Teilchenphysik (FAKT) 2008, Österreichische Physikalische Gesellschaft (ÖPG), Aflenz, AUSTRIA

1.4.8. Poster presentations

A. Gruber,
Using NEG-pumping near a high density internal target.
Fachausschußtagung Kern- und Teilchenphysik (FAKT) 2008, Österreichische Physikalische Gesellschaft (ÖPG), Aflenz, AUSTRIA

A. Hirtl,
Pionic Hydrogen.
International Conference on Exotic Atoms and Related Topics (EXA08), Vienna, AUSTRIA

T. Pask,
The Precise Measurement of the Antiprotonic Helium Hyperfine Structure.
WE-Heraeus School on Highly Charged Ions and Antiprotons, Physikzentrum Bad Honnef, GERMANY

K. Suzuki,
Matrix Geiger-mode APD developments at SMI.
5th International Conference on New Developments In Photodetection 2008, Dresden, GERMANY

K. Suzuki,
Matrix Geiger-mode APD in fast timing application.
IEEE Dresden 2008, Dresden, GERMANY

1.5. Scientific cooperation 2008

1.5.1. EXA08 and LEAP08 conferences in Vienna

About 180 scientists (see Fig. 46) from Europe, Japan, China, Russia, USA, and Canada participated in the international conferences EXA08 (Exotic Atoms and Related Topics) and LEAP08 (Low Energy Antiproton Physics) between 15th-19th September 2008 in Vienna. Both conferences have been organized by the Stefan Meyer Institute of the Austrian Academy of Sciences (SMI). The EXA conference was introduced in 2002, when the first very successful conference was organized by SMI (at that time IMEP) in Vienna. SMI is one of the leading institutes in exotic atom research since some decades and is involved in many highly visible experiments in this field. It is partner in experimental research on exotic atoms at AD/CERN, LNF/Frascati and J-PARC/Tokai/Japan.

In 2008 the EXA08 Conference was organized in overlap with LEAP08, the 9th conference in a series starting in 1990 in Stockholm, with recent meetings taking place in Yokohama (2003) and Bonn (2005). Both conferences were structured in 22 sessions (18 sessions with plenary talks and 4 parallel sessions) and one poster session.

The first speaker, Ryu Hayano (Tokyo) pointed out the bridge between the two conferences: the physics of exotic atoms is not only the link between EXA08 and LEAP08, this research topic is also of high interest in many fields of current research in physics addressing fundamental open questions, thus also linking different research fields in physics. It should be noted that Ryu Hayano received the prestigious Nishina prize for research in this field shortly after the EXA08 and LEAP08 conferences.

Some highlights in the EXA08 conference are addressed in the following. Evidence for the existence of dibaryon states with strangeness extracted from the analysis of pp reactions at 2.85 GeV energy measured by the DISTO collaboration was presented by T. Yamazaki (Tokyo). Data from the OBELIX collaboration (P. Salvini/Pavia) also support the idea of a new form of strongly bound nuclear clusters produced in antiproton annihilation reactions. Reports about experiments searching for strongly bound kaonic nuclear clusters at KEK (T. Suzuki/Tokyo) and LNF Frascati (O. Vazquez-Doce/LNF) were given as well as plans for a new experiment with FOPI/GSI (K. Suzuki, Vienna). This topic and its quantitative parameters like binding energy and decay width were lively discussed by experimentalists as well as by theoreticians, with A. Gal (Jerusalem) presenting the theoretical overview of the field. Another highlight was the presentation by F. Bosch (GSI) on the time modulation of weak two-body decays, with a possible explanation described by A. Ivanov (Vienna/St. Petersburg) based on a mixture of massive neutrinos.

Broad room in the LEAP08 conference was given to the research performed at the Antiproton Decelerator at CERN like precision studies of antiprotonic atoms and antihydrogen which address fundamental questions like CPT and the gravitational force on neutral antimatter. All major antiproton experiments at AD like AEGIS, ALPHA, ASACUSA and ATRAP presented the status and the future plans. Concerning future CPT tests B. Juhasz (Vienna) reported about the plans for the first measurement of the hyperfine structure of antihydrogen within ASACUSA, and C. L. Cesar (Rio de Janeiro) described the status of neutral-atom traps for antihydrogen spectroscopy. New ideas to breed antideuterons were discussed by P. Kienle (Vienna/Munich). In the context of strongly bound kaonic nuclear clusters a new experimental approach with antiproton annihilation was presented by J. Zmeskal (Vienna). Last but not least future experiments on hadron physics – like PANDA – and exotic atoms, especially the experiments foreseen to be performed at the upcoming FAIR facility in Darmstadt, were presented and discussed in detail. A special session was devoted to emerging research facilities including the next-generation low-energy antiproton facility FLAIR at FAIR and new instrumentation techniques.

An evening talk about Stefan Meyer – an Austrian pioneer of research on radioactivity, after whom the Stefan Meyer Institute is named – was given by W. Reiter. He provided an interesting insight in the history of nuclear science in Austria.

The next Conference of the EXA series will be hosted again by the Stefan Meyer Institute and will take place in Vienna. The international advisory committee of LEAP08 decided that the follow-up LEAP conference will take place in Vancouver/Canada.

The Proceedings of EXA08 and LEAP08 will appear in the journal Hyperfine Interactions.

Fig. 46: Photo of the EXA08 and LEAP08 participants in the „Festsaal“ of the Austrian Academy of Sciences, where all plenary sessions took place.

1.5.2. External partners in research programs

Andrzej Soltan Institute for Nuclear Studies, Warsaw, POLAND
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research
FS3_d: Antiproton Ion Collider

Atomic Physics Laboratory, RIKEN, Saitama, JAPAN
FS1_g: Study of kaon-nucleon interaction @ J-PARC
FS2_d: Measurement of the ground-state hyperfine structure of antihydrogen
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

BINP – Budker Institute of Nuclear Physics, Novosibirsk, RUSSIAN FEDERATION
FS3_d: Antiproton Ion Collider

CERN – European Organization for Nuclear Research / Laboratory for Particle Physics, Geneva, SWITZERLAND
FS2_b_A: Hyperfine structure of antiprotonic helium
FS2_c: Precision laser spectroscopy of antiprotonic helium
FS2_d: Measurement of the ground-state hyperfine structure of antihydrogen

D.I. Mendeleev Institute for Metrology (VNIIM), St. Petersburg, RUSSIAN FEDERATION
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Department for Physics and Astronomy, Aarhus University, Aarhus, DENMARK
FS2_d: Measurement of the ground-state hyperfine structure of antihydrogen
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Department of Atomic Physics, Stockholm University, Stockholm, SWEDEN
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Department of Experimental Physics, University of Debrecen, Debrecen, HUNGARY
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Department of Physics and Astronomy, York University, Toronto, CANADA
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Department of Physics, Harvard University, Cambridge, Massachusetts, UNITED STATES
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Department of Physics, St. Petersburg State University, St. Petersburg, RUSSIAN FEDERATION
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Department of Physics, Texas A&M University, College Station, Texas, UNITED STATES
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Department of Physics, University of Tokyo, Tokyo, JAPAN
FS2_b_A: 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_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Department of Physics, University of Wales Swansea, Swansea, UNITED KINGDOM
FS2_d: Measurement of the ground-state hyperfine structure of antihydrogen
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Dipartimento di Chimica e Fisica per l'Ingegneria e per i Materiali, Brescia, ITALY
FS2_d: Measurement of the ground-state hyperfine structure of antihydrogen
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Dipartimento di Fisica, Laboratorio LENS, INFN, Universita' degli Studi di Firenze, Florence, ITALY
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Dipartimento di Fisica, Univ. di Trieste und INFN Trieste, Triest, ITALY
O: VIP @ Gran Sasso (VIolation of the Pauli Exclusion Principle Experiment)

FOM Institute for Atomic and Molecular Physics, Amsterdam, NETHERLANDS
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Forschungszentrum Jülich GmbH, Jülich, GERMANY
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research
FS3_c_A: PANDA: Proton Antiproton Annihilations at Darmstadt

GSI – Gesellschaft für Schwerionenforschung mbH, Darmstadt, GERMANY
FS1_c: Deeply bound kaonic nuclei with FOPI at GSI
FS3_c_A: PANDA: Proton Antiproton Annihilations at Darmstadt
FS3_c_c: Cherenkov Imaging Detectors (DIRACSecondary beams)
FS3_c_e: Charmonium Interaction with Nuclear Matter
FS3_d: Antiproton Ion Collider
Z: Ph.D.: Charmonium Interaction with Nuclear Matter (Nikolics)

Heavy Ion Laboratory, Warsaw University, Warsaw, POLAND
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

INFN, Laboratori Nazionali di Frascati, Frascati, ITALY
FS1_b_A: Kaonic hydrogen and deuterium: SIDDHARTA
FS1_d: AMADEUS at DAΦNE2
FS3_c_A: PANDA: Proton Antiproton Annihilations at Darmstadt
O: VIP @ Gran Sasso (VIolation of the Pauli Exclusion Principle Experiment)

Indiana University, Bloomington, Indiana, UNITED STATES
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Institute of Nuclear Research (ATOMKI) of the Hungarian Academy of Sciences, Debrecen, HUNGARY
FS2_c: Precision laser spectroscopy of antiprotonic helium
FS2_d: Measurement of the ground-state hyperfine structure of antihydrogen
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Institute of Physical and Chemical Research (RIKEN), Saitama, JAPAN
FS1_c: Deeply bound kaonic nuclei with FOPI at GSI

Institute of Physics and Nuclear Engineering „Horia Hulubei", Bucharest - Magurele, ROMANIA
O: VIP @ Gran Sasso (VIolation of the Pauli Exclusion Principle Experiment)

Institut de Physique, Univ. de Neuchâtel, Neuchâtel, SWITZERLAND
O: VIP @ Gran Sasso (VIolation of the Pauli Exclusion Principle Experiment)

Institut für Angewandte Physik, Universität Frankfurt, Frankfurt, GERMANY
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Institut für Kernchemie, Universität Mainz, Mainz, GERMANY
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Institut für Kernphysik, Universität Frankfurt, Frankfurt, GERMANY
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Institut für Kernphysik, Universität Gießen, Gießen, GERMANY
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Institut für Physik, Humboldt-Universität zu Berlin, Berlin, GERMANY
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Institut für Physik, Universität Mainz, Mainz, GERMANY
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Institut für Theoretische Physik, TU Dresden, Dresden, GERMANY
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Institut für Theoretische Physik, Wien, AUSTRIA
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Institute for Experimental and Theoretical Physics, Moscow, RUSSIAN FEDERATION
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Institute for Storage Ring Facilities (ISA), Aarhus, DENMARK
FS2_d: Measurement of the ground-state hyperfine structure of antihydrogen
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Institute of Nuclear Physics, Moscow State University, Moscow, RUSSIAN FEDERATION
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Institute of Physics, University of Tokyo, Tokyo, JAPAN
FS2_b_A: 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_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Institute of Spectroscopy of the Russian Academy of Sience, Troitsk, Troitsk, RUSSIAN FEDERATION
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Institute of Theoretical Physics, Warsaw University, Warsaw, POLAND
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Istituto Nazionale di Fisica Nucleare – INFN, Genoa, ITALY
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

JINR - Joint Institute for Nuclear Research, Dubna, RUSSIAN FEDERATION
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research
FS3_c_A: PANDA: Proton Antiproton Annihilations at Darmstadt

Justus-Liebig Universität Giessen, Gießen, GERMANY
FS3_d: Antiproton Ion Collider

KEK, High Energy Accelerator Research Organization, Tokyo, JAPAN
FS1_g: Study of kaon-nucleon interaction @ J-PARC

KFKI Research Institute for Particle and Nuclear Physics, Hungarian Academy of Sciences, Budapest, HUNGARY
FS2_b_A: 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_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

KVI Kroningen, Kroningen, NETHERLANDS
FS3_c_A: PANDA: Proton Antiproton Annihilations at Darmstadt

LANL Los Alamos USA, Los Alamos, UNITED STATES
FS3_c_A: PANDA: Proton Antiproton Annihilations at Darmstadt

Laboratoire Kastler-Brossel, École Normale Supérieure et Univ. Pierre et Marie Curie, Paris, FRANCE
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Laser Centre Vrije Universiteit, Faculty of Science, Amsterdam, NETHERLANDS
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Manne Siegbahn Laboratory (MSL), Stockholm, SWEDEN
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Massachusetts Institute of Technology, Duke University, North Carolina, UNITED STATES
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Max-Planck-Institut für Kernphysik, Heidelberg, GERMANY
FS2_d: Measurement of the ground-state hyperfine structure of antihydrogen
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Niels Bohr Institute, Copenhagen, DENMARK
FS2_d: Measurement of the ground-state hyperfine structure of antihydrogen

Northwestern Univ. Evanston, Evanston, UNITED STATES
FS3_c_A: PANDA: Proton Antiproton Annihilations at Darmstadt

Osaka E-C, Osaka, JAPAN
FS1_g: Study of kaon-nucleon interaction @ J-PARC

Osaka University, Osaka, JAPAN
FS1_g: Study of kaon-nucleon interaction @ J-PARC

Paul Scherrer Institut (PSI), Villigen, SWITZERLAND
Z: Ph.D.: Ultracold Neutron Converters (Kasprzak)

Politechnico Torino, Turin, ITALY
FS3_c_A: PANDA: Proton Antiproton Annihilations at Darmstadt

Queens University, Belfast, IRELAND
FS2_d: Measurement of the ground-state hyperfine structure of antihydrogen
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Ruhr-Universität Bochum, Bochum, GERMANY
FS3_c_A: PANDA: Proton Antiproton Annihilations at Darmstadt

SINS, Warsaw, POLAND
FS3_c_A: PANDA: Proton Antiproton Annihilations at Darmstadt

Seoul National Univsersity, Seoul, REPUBLIC OF KOREA
FS1_g: Study of kaon-nucleon interaction @ J-PARC

St. Petersburg Nuclear Physics Institute (PNPI), St. Petersburg, RUSSIAN FEDERATION
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

TRIUMF, Vancouver, Vancouver, CANADA
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

TSL – The Svedberg Laboratory Uppsala, Uppsala, SWEDEN
FS3_c_A: PANDA: Proton Antiproton Annihilations at Darmstadt

Technische Universität Dresden, Dresden, GERMANY
FS3_c_A: PANDA: Proton Antiproton Annihilations at Darmstadt

Technische Universität München, Munich, GERMANY
FS1_c: Deeply bound kaonic nuclei with FOPI at GSI
FS3_c_A: PANDA: Proton Antiproton Annihilations at Darmstadt
FS3_d: Antiproton Ion Collider

Temple University, Philadelphia, UNITED STATES
FS1_g: Study of kaon-nucleon interaction @ J-PARC

University Brescia, Brescia, ITALY
FS3_c_A: PANDA: Proton Antiproton Annihilations at Darmstadt

University Cracow, Cracow, POLAND
FS3_c_A: PANDA: Proton Antiproton Annihilations at Darmstadt

University Frankfurt, Frankfurt, GERMANY
FS3_c_A: PANDA: Proton Antiproton Annihilations at Darmstadt

University Silesia, Silesia, POLAND
FS3_c_A: PANDA: Proton Antiproton Annihilations at Darmstadt

Univerità di Torino, Turin, ITALY
FS3_c_A: PANDA: Proton Antiproton Annihilations at Darmstadt

Univerität Erlangen, Erlangen, GERMANY
FS3_c_A: PANDA: Proton Antiproton Annihilations at Darmstadt

University Edinburgh, Edinburgh, UNITED KINGDOM
FS3_c_c: Cherenkov Imaging Detectors (DIRACSecondary beams)

University Glasgow, Glasgow, UNITED KINGDOM
FS3_c_c: Cherenkov Imaging Detectors (DIRACSecondary beams)

University of New Mexico, Albuquerque, New Mexiko, UNITED STATES
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

University of Tokyo, Tokyo, JAPAN
FS1_g: Study of kaon-nucleon interaction @ J-PARC
FS3_d: Antiproton Ion Collider

Università degli Studi di Trieste; Triest, ITALY
FS3_c_A: PANDA: Proton Antiproton Annihilations at Darmstadt

Università di Catania, Catania, ITALY
FS3_c_A: PANDA: Proton Antiproton Annihilations at Darmstadt

Università di Genova, Genoa, ITALY
FS3_c_A: PANDA: Proton Antiproton Annihilations at Darmstadt

Università di Pavia, Pavia, ITALY
FS3_c_A: PANDA: Proton Antiproton Annihilations at Darmstadt

Universität Bonn, Bonn, GERMANY
FS3_c_A: PANDA: Proton Antiproton Annihilations at Darmstadt

Universität Gießen, Gießen, GERMANY
FS3_c_A: PANDA: Proton Antiproton Annihilations at Darmstadt

Universität Heidelberg, Heidelberg, GERMANY
FS1_c: Deeply bound kaonic nuclei with FOPI at GSI

Universität Mainz, Mainz, GERMANY
FS3_c_A: PANDA: Proton Antiproton Annihilations at Darmstadt
FS3_c_c: Cherenkov Imaging Detectors (DIRACSecondary beams)

Universität Münster, Münster, GERMANY
FS3_c_A: PANDA: Proton Antiproton Annihilations at Darmstadt

Universität Tübingen, Tübingen, GERMANY
FS3_c_A: PANDA: Proton Antiproton Annihilations at Darmstadt

UoS – University of Saitama, Saitama, Saitama, JAPAN
FS3_d: Antiproton Ion Collider

Uppsala University, Uppsala, SWEDEN
FS3_c_A: PANDA: Proton Antiproton Annihilations at Darmstadt

Variable Energy Cyclotron Center, Kolkata, Kolkata, INDIA
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

1.6. Public outreach

1.6.1. SMI at the "Lange Nacht der Forschung"

During the "Lange Nacht der Forschung" on 11th November 2008 the SMI and a dozen of other institutes from the OEAW presented their research activities in the "Aula der Akademie der Wissenschaften". Several thousands of visitors had the opportunity to see a variety of exhibitions. Even the minister of science visited the event (see Fig. 47).

SMI showed a series of videos and webcasts produced by CERN. These presentations illustrated antimatter and its impact. Besides topics like *"The history of antimatter"* and *"Antimatter in the Universe"* the visitors were informed about experiments at the Antiproton Decelerator at CERN and the next generation antimatter facility at FAIR. A partial setup of the microwave-experiment on antiprotonic helium – carried out by the ASACUSA-collaboration at CERN – was used for show-and-tell. Two talks on *"Antimaterie im Praxistest"* by Prof. Widmann completed the programme. During the evening some interesting discussions evolved among several guests and the SMI staff.

Fig. 47: Federal Minister of Science and Research Dr. Johannes Hahn with Prof. Widmann at the „Lange Nacht der Forschung".

Fig. 48: Visitors watch a talk given by Prof. Widmann during the „Lange Nacht der Forschung".

1.6.2. ESOF2008 in Barcelona July 18-22

The EuroScience Open Forum 2008 in Barcelona was the third Open Forum. The Forums are interdisciplinary meetings of scientists, young researchers, politicians, policy-makers, innovators, business people, media and communicators.
ESOF typically features over 70 scientific sessions in topics ranging from nanosciences to ethics, natural disasters to tissue engineering, and international security to the human mind. EuroScience Open Forums provide an Europe-wide opportunity for everyone working in or with research to meet and debate the direction that European research is taking or the issues that research is raising. ESOF2008 was organised by Euroscience and hosted by the Catalan Foundation for Research and Innovation. The programme provides opportunities both for scientists and for the general public. Euroscience has over 2300 members from 40 countries uniting professional researchers, scientific managers, political decision-makers, scientific communicators, professors, students, engineers, business people, and individuals engaged in science and technology in Europe. It represents European scientists of all disciplines in the public sector, universities, research institutes as well as in business and industry.
Euroscience aims are:

1. To provide an open forum for debate on science and technology,
2. To strengthen the links between science and society,
3. To contribute to the creation of an integrated space for science and technology in Europe, and
4. To influence science and technology policies.

Scientific Programme

The programme addressed and expanded on the topics chosen as ESOF2008 themes. After a Call for Proposals, the Programme Committee selected those proposals that offered high-quality scientific sessions. These took the format of presentations and debates, mostly with a number of featured panellists. Nobel Prize winners and trend-setting innovators will participate as speakers in the Scientific Programme.

In Science and Society, the Scientific Programme encourages analysis and debate on how science, technology and the humanities impact societies and their economies.
The third aspect of the Scientific Programme focussed on careers in science and technology.

Outreach Activities

Outreach Activities are dynamic presentations and activities aimed at engaging citizens in science and technology issues.
ESOF2008 welcomes ideas for creative projects that through interactive and

Presentation on low-energy antiprotons

E. Widmann applied together with C. Welsch (Heidelberg University and GSI (Germany), now Cockcroft Institute (UK) for one of the few slots. We were granted a session of 90 minutes length for a common presentation entitled “Low-energy antiprotons – exploring nature in all its facets”, which covered both the production of low-energy antiprotons as well as current and future experiments with them.

1.7. Staff members

Name	Position	Funding
Prof. Eberhard Widmann	Director	ÖAW
Priv. Doz. Johann Marton	Deputy director	ÖAW
Dr. Johann Zmeskal	Senior scientist, workshop supervisor	ÖAW
Dr. Michael Cargnelli	Senior scientist	ÖAW
Dr. Paul Bühler	Junior scientist	ÖAW
Dr. Bertalan Juhasz	Junior scientist	ÖAW
Dr. Ken Suzuki	Junior scientist	ÖAW
Dr. Thomas Pask	Junior scientist	ÖAW
Dr. Albert Hirtl	Junior scientist	ÖAW /EU
Dr. Tomoichi Ishiwatari	Junior scientist	FWF
Dr. Olaf Hartmann	Junior Scientist	TU Munich
Susanne Friedreich	Ph.D. student	ÖAW
Alexander Gruber	Ph.D. student	ÖAW/EU
Katalin Nikolics	Ph.D. student	ÖAW
Malgorzata Kasprzak	Ph.D. student	ÖAW/PSI
Barbara Wünschek	Ph.D. student	FWF
Gamal Saber Ahmed	Ph.D. student	Egypt
Oswald Massiczek	Diploma student	ÖAW
Matthias Schafhauser	Intern	EU
Prof. Paul Kienle	Emeritus	ÖAW
Leopold Stohwasser	Mechanical engineer	ÖAW
Ing. Doris Stückler	Design engineer	ÖAW
Ing. Herbert Schneider	Electronics engineer	ÖAW
Ing. Roland Gsell	Computer, web services	ÖAW
Fiona Boes	Secretary	ÖAW