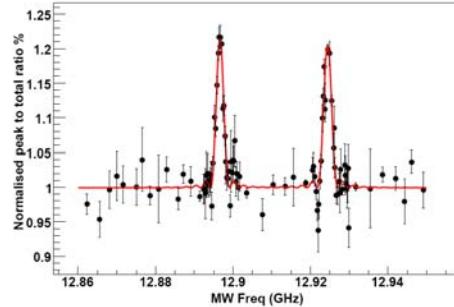
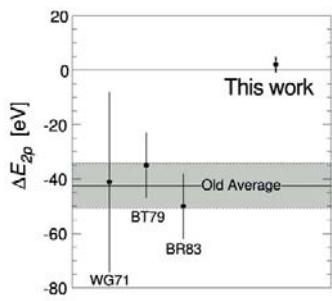


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Mission Statement

Das Stefan Meyer Institut bearbeitet Forschungsthemen auf dem Gebiet der subatomaren Physik. Dazu gehört das Studium der *fundamentalen Symmetrien und Wechselwirkungen* mit *Antimaterie*. Als wesentliche Methode wenden wir Präzisionsspektroskopie von *exotischen Atomen* an. Das sind Atome, die anstelle eines Elektrons ein anderes Elementarteilchen in der Atomhülle enthalten.

Experimente mit exotischen Atomen benötigen Teilchenbeschleuniger, die die Elementarteilchen erzeugen. Deshalb handelt es sich bei unseren Experimenten in der Regel um mittel- bis langfristige Projekte, die in internationalen Kooperationen an ausländischen Großforschungseinrichtungen durchgeführt werden, z.B. CERN Genf, LNF Frascati, GSI Darmstadt, J-PARC in Japan und langfristig FAIR in Darmstadt.

Ein Themenschwerpunkt ist das Studium der *starken Wechselwirkung* und der sie beschreibenden Theorie, der Quantenchromodynamik (QCD), bei niederen Energien *im nichtperturbativen Bereich*. Eine wichtige Rolle spielt hierbei die chirale Symmetrie und deren Brechung bzw. Wiederherstellung. Diese trägt entscheidend zur Entstehung der Massen der Hadronen, d.h. der Kernbausteine, bei. Die Hadronen bestehen aus drei Quarks, den elementarsten Bausteinen der Materie. Die Summe der drei Quarkmassen macht jedoch nur wenige Prozent der gemessenen Hadronenmassen aus, sodass der weitaus größte Teil der Masse aus der dynamischen Wechselwirkung zwischen den Quarks und den Austauschteilchen der starken Wechselwirkung, den Gluonen, entsteht. Der zugrunde liegende Mechanismus ist bisher völlig unverstanden. Experimente zu diesem Themenkreis sind die Messungen an pionischem und kaonischem Wasserstoff sowie die Untersuchung tiefgebundener Kanonenzustände in Kernen und PANDA.

Der zweite Themenschwerpunkt ist das Studium der *Materie/Antimaterie Symmetrie*, insbesondere das Studium der grundlegenden *CPT Symmetrie*. Diese Symmetrie, eine Eigenschaft aller zur Beschreibung der Natur bisher benützten Feldtheorien, steht im Gegensatz zu der beobachteten Materiedominanz des sichtbaren Weltalls. Wenn die CPT Symmetrie zur Zeit des Big Bangs bei der Entstehung des Universums gültig war, so müssten gleiche Teile von Materie und Antimaterie entstanden sein. Eine befriedigende quantitative Erklärung des trotzdem beobachteten Materieüberschusses gibt es bisher nicht, so dass durchaus Zweifel an der CPT Symmetrie gerechtfertigt sind. Darüber hinaus gelten die mathematischen Grundlagen des CPT Theorems nicht mehr in modernen Theorien wie der Stringtheorie und der Quantengravitation. Experimentell untersucht wird die Materie-Antimateriesymmetrie durch Präzisionsmessungen von Eigenschaften des Antiprotons (Masse, Ladung, magnetisches Moment) in antiprotonischen Atomen und Antiwasserstoff, die mit den bekannten Eigenschaften des Protons verglichen werden.

1 WISSENSCHAFTLICHE TÄTIGKEIT

1.1 Zusammenfassung des wissenschaftlichen Berichts 2007

Die Schwerpunkte der wissenschaftlichen Tätigkeit lagen 2007 bei Experimenten zur Untersuchung der Kaon-Nukleon Wechselwirkung und der CPT Symmetrie sowie bei Vorbereitungen für Experimente mit Antiprotonen an der zukünftigen Großforschungsanlage FAIR in Deutschland.

Die Auswertung des Experiments zur Kaon-Nukleon Wechselwirkung in kaonischem Helium der KEK-Kollaboration E570 wurde 2007 fertig gestellt und die Ergebnisse publiziert¹. Es gelang mit diesem Experiment eine seit 30 Jahren bestehende Diskrepanz zwischen Theorie und Experiment zu klären. Beide stimmen nun im Rahmen der Messgenauigkeit mit einer sehr kleinen, sogar mit Null verträglichen Verschiebung des 2p-Niveaus in $K^{-4}\text{He}$ überein, was auch Auswirkungen auf die Existenz der vorhergesagten Kaon-Cluster hat. Der Bereich der Parameter des benützten Kaon-Nukleon Potentials wurde eingeschränkt.

Mit dem Projekt SIDDHARTHA am LNF in Frascati, Italien wird die Kaon-Nukleon Wechselwirkung durch ihre Wirkung auf die Röntgenübergänge in kaonischen Atomen studiert. Im Jahr 2007 wurde die Design- und Bauphase abgeschlossen. Die neuen Detektoren und sämtliche Elektronikkomponenten sind verfügbar und einsatzbereit. Eine Reihe von Testmessungen wurde in Wien und in Frascati durchgeführt um die Experimentiertechnik zu optimieren. Im Jahr 2008 ist die Datenaufnahme am Elektron-Positron-Collider DAFNE in Frascati geplant.

Eine andere Auswirkung der Kaon-Nukleon Wechselwirkung betrifft die Frage ob durch Kaonen gebundene Nukleon Cluster existieren. Mit einem Experiment an der GSI Darmstadt, Deutschland, aufbauend auf den dort vorhandenen FOPI ($= 4\pi$) Detektor, wird mittels Proton-Proton Stößen die mögliche Bildung von $\text{pp}K^-$ Clustern untersucht. Im Jahr 2007 wurden apparative Entwicklungen, Testmessungen und Simulationsrechnungen durchgeführt.

Im Rahmen des AMADEUS Projekts wird mit in Helium gestoppten Kaonen die mögliche Bildung von Kaonischen Clustern ($\text{ppn}K^-$, $\text{pnn}K^-$) untersucht. Das ist an DAFNE (Frascati) unter Verwendung des KLOE Detektors geplant. Im Berichtsjahr wurden vorhandene KLOE Experimentdaten in Hinblick auf Lambda-Hyperonen ausgewertet und unter Verwendung der so gewonnenen Information Planungen für das zukünftigen AMADEUS Experiment durchgeführt, insbesondere der zu KLOE zusätzlich benötigten Komponenten.

Das Studium der CPT Symmetrie mit antiprotonischem Helium und Antiwasserstoff erfolgt innerhalb der ASACUSA Kollaboration am CERN-AD. Bei unseren CPT Experimenten wird die Materie-Antimateriesymmetrie durch Präzisionsmessungen von Eigenschaften des Antiprotons (Masse, Ladung, magnetisches Moment) in antiprotonischen Atomen und Antiwasserstoff untersucht, die mit den bekannten Eigenschaften des Protons verglichen werden.

Im Berichtsjahr gelang es, zwei Übergangsfrequenzen von antiprotonischen Heliumatomen - mittels 2-Photon-Spektroskopie - mit einer gegenüber unseren vorherigen Messungen verbesserten Genauigkeit zu bestimmen. Wieweit die bisherige Präzision von 3 ppb (3×10^{-9}), das die weltweit genaueste Messung dieser Übergänge bisher ist, verbessert werden konnte, steht noch nicht fest, da die Auswertung noch im Gange ist. Die Hyperfeinaufspaltung wurde mit der Laser-Mikrowelle-Laser Methode gemessen und eine Verbesserung der Genauigkeit um einen Faktor 5 erreicht.

¹ S. Okada *et al.*, Phys.Lett. B 653 (2007) 387.

Die Vorbereitung der geplanten Messung der Grundzustands-Hyperfeinaufspaltung von Antiwasserstoff wurde mit dem Design der Strahlführung und Monte Carlo Studien fortgesetzt. Der Antiwasserstoff wird in einer „cusp trap“ gespeichert werden, diese Komponente wurde bereits am RIKEN, Japan entwickelt und am CERN installiert.

Der dritte Forschungsschwerpunkt des SMI bezieht sich auf Experimente mit Antiprotonen an der geplanten FAIR Anlage in Darmstadt. Hierzu werden ein Cluster Jet Target sowie neuartige Photodetektoren für Cerenkovzähler als Teil von EU FP6 Projekten am SMI entwickelt. Ein wesentlicher Meilenstein stellte das kick-off meeting im November dar, das den offiziellen Start des FAIR Projektes markierte.

Ein zukünftiges Arbeitsgebiet des SMI wird die Beteiligung an Experimenten an der Großforschungsanlage J-PARC in Japan sein, das wichtigste davon ist die Messung des 3d-2p Röntgenübergangs in kaonischem ^3He . Ein Finanzierungsantrag beim FWF wurde 2007 eingereicht und ist mittlerweile bewilligt.

1.2 Summary of the scientific report 2007

The central points of the scientific work in 2007 were experiments on kaon-nucleon interaction and on CPT symmetry as well as preparations for experiments with antiprotons at the future accelerator complex FAIR in Germany.

The data analysis of the kaon-nucleon-interaction X-ray measurement in kaonic helium of the KEK-collaboration E570 was finished in 2007 and the results were published². With this experiment we succeeded to settle a discrepancy which existed between theory and experiment for 30 years. Both agree now that the shift of the 2p state in $K^-{}^4He$ is compatible with zero, which has also an impact on the possible existence of the predicted deeply-bound kaon clusters. The range of the parameters used for the theoretical description of the kaon-nucleon potential has been restricted.

Within the project SIDDHARTA at LNF in Frascati, Italy, the kaon-nucleon interaction is studied by its effect on X-ray transitions in kaonic atoms. In 2007 the design- and construction phase was finished. The new detectors and all electronic components are available and operational. A series of test measurements was accomplished in Vienna and Frascati to optimize the experimental techniques. In 2008 the data acquisition at the electron-positron collider DAFNE in Frascati is planned.

Another consequence of kaon-nucleon interaction concerns the question whether clusters of nucleons bound by kaons, exist. With an experiment at GSI in Darmstadt, Germany, the possible formation of ppK^- clusters is investigated by proton-proton collisions, using the existing FOPI ($= 4\pi$) detector. In 2007 additional experimental equipment was designed, built and tested, and computer simulations were carried out.

In the framework of the AMADEUS project we study the kaon-nucleon interaction using stopped kaons in helium to produce eventual kaonic clusters ($ppnK^-$, $pnnK^-$). That is planned at DAFNE (Frascati) using the KLOE detector. In the year under report existing KLOE data were analyzed with respect of the lambda hyperon production by charged kaon absorption. Using these experiences the design of the AMADEUS experiment was worked out, especially for the additional components to be implemented in the KLOE detector.

The study of CPT-symmetry with antiprotonic helium and antihydrogen is done within the ASACUSA collaboration at CERN-AD. In our CPT experiments the matter-antimatter symmetry is investigated via precision measurements of properties of the antiproton (mass, charge, magnetic moment) in antiprotonic atoms and antihydrogen which are compared to the precisely known properties of the proton.

In 2007 we succeeded to measure two transition frequencies of antiprotonic helium atoms - by 2-photon spectroscopy - with improved precision compared to our earlier measurements. It is not yet clear by how much our earlier precision of 3 ppb (3×10^{-9}) could be improved, which is worldwide by far the most precise measurement of these transitions. The data analysis is still in progress. The hyperfine splitting was measured with the laser-microwave-laser method and an increase of precision of a factor of 5 was achieved.

The preparation of the planned measurement of the ground state hyperfine splitting in antihydrogen was continued with the design of the beam line and with Monte Carlos studies. The antihydrogen will be stored in "cusp trap"; this component was developed at RIKEN, Japan, and installed at CERN.

² S. Okada *et al.*, Phys.Lett. B 653 (2007) 387.

The third main scientific topic of the SMI concerns experiments with antiprotons at the upcoming FAIR facility in Darmstadt. For the PANDA experiment a cluster jet target and a new type of photon detectors for Cerenkov counters were developed as part of EU FP6 projects. A main step forward was done in 2007 by the kick-off meeting in November which marks the official start of the FAIR project.

A future topic will be the participation in experiments at the facility J-PARC in Japan, one of which is the measurement of the 3d-2p X-ray transition in kaonic ${}^3\text{He}$. An application to the Austrian Science Fund was worked out in 2007, submitted, and recently granted.

1.3 Scientific report 2007

The scientific activities of SMI are arranged in three main focuses and several research sub-projects. The following gives an overview of the projects.

➤ **FS1_A: Kaon-Nucleon Interaction: Kaonic atoms and kaonic nuclei**

- FS1_b_A: Kaonic hydrogen and deuterium: SIDDHARTA
 - FS1_b_b: SIDDHARTA: Joint Research Activity 10 in I3 Hadron Physics
- FS1_c: Deeply bound kaonic nuclei with FOPI at GSI
- FS1_d: AMADEUS at DAΦNE2
- FS1_e: Deeply bound kaonic nuclei K–ppn and K–pnn: Experiment E549 at KEK
- FS1_f: Kaonic helium X-rays: Experiment E570 at KEK
- FS1_g: Study of kaon-nucleon interaction @ J-PARC

➤ **FS2_A: Matter - antimatter symmetry: ASACUSA @ CERN**

- FS2_b: Hyperfine structure of antiprotonic helium
- FS2_c: Precision laser spectroscopy of antiprotonic helium
- FS2_d: Measurement of the ground-state hyperfine structure of antihydrogen

➤ **FS3_A: Antiprotons at FAIR**

- FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research
- FS3_c_A: PANDA: Proton Antiproton Annihilations at Darmstadt
 - FS3_c_b: Internal target system for PANDA: Joint Research Activity 7 in I3 Hadron Physics
 - FS3_c_c: Cherenkov Imaging Detectors (DIRACsecondary beams)
 - FS3_c_d: Development and tests of novel matrix avalanche photo detectors for PANDA
- FS3_d: Antiproton Ion Collider

➤ **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)
- Other activities

1.3.1 Abgeschlossene Forschungsprojekte

1.3.1.1 H: Strong Interaction Studies Using Exotic Atom Spectroscopy

Habilitationsprojekt (abgeschlossen)

Beginn: 23.02.2007, Abschluss: 21.09.2007

Wissenschaftliche MitarbeiterInnen:

Name	Funktion	Funktion: Zeitraum
Marton, Johann	Allein Durchführende(r)	01.01.2007 bis 21.09.2007

Publikationen:

Marton, Hans (2007) Strong Interaction Studies Using Exotic Atom Spectroscopy.
Habilitationsschrift, Technische Universitaet Wien, Wien. [Marton, J. (AlleinautorIn)]

1.3.1.1.2 FS1_e: Deeply bound kaonic nuclei K–ppn and K–pnn: Experiment E549 at KEK

Sonstiges Einzelforschungsprojekt (abgeschlossen)

Beginn: 01.11.2004, Abschluss: 31.12.2007

We report here on the progress of the analysis of the high statistics stopped K^- absorption in ^4He performed in 2005 as last experiments (E549/570) at the KEK proton synchrotron. In these experiments the setup was substantially upgraded compared to the proceeding experiment E471 to confirm the observation of strange tribaryon systems in the inclusive missing mass spectra of protons³ and neutrons⁴ with improved accuracy and 8-10 times higher statistics. A detailed analysis of the present data and simulations showed that the peak in the proton spectrum, interpreted as evidence for a $S^0(3115)$ tribaryon³, was an artifact⁵.

Very recently we published the complete analysis of the inclusive proton missing mass spectrum from the K^- stopped ($^4\text{He}, p$)X reaction⁶. No significant narrow structure was found in the mass region of 3000–3200 MeV/ c^2 . The upper limits of the formation branching ratios were determined as $(0.4 \sim 6) \times 10^{-4}$, $(0.2 \sim 6) \times 10^{-3}$, and $(0.06 \sim 5) \times 10^{-2}$ per stopped K^- with 95% confidence level assuming narrow states with widths of 0, 20 and 40 MeV, respectively.

A similar analysis of the inclusive neutron spectra is still in progress with a report of preliminary results given at the HYP2006 conference in Mainz⁷. Despite 8 times higher statistics compared to the original E471 data⁴ no confirmation of the previous indication of a line at a mass of 3112 MeV/ c^2 was found. On the other hand by selecting low momentum antihyperons using pion trajectory defined hyperon motion, an about 40 MeV broad line at a mass of 3122 MeV/ c^2 is indicated which has to be studied more carefully^{5,8}.

Following a very successful reconstruction of Λ and Σ^+ hyperons produced in stopped K^- reactions in ^4He using invariant mass spectroscopy of their decay particles ($p\pi$ and $n\pi$) a program was started for the study of hyperon-deuteron and hyperon-nucleon correlations in an exclusive search for possible strange di- and tri-baryonic states with broad widths which could not be detected in exclusive proton and neutron spectra. The Λd invariant mass spectra for exclusive Λdn events and back-to-back observation of Λd pairs showed the first clear evidence for a three-nucleon K^- absorption process⁹. In addition a broad distribution between invariant masses of 3220 MeV/ c^2 and 3100 MeV/ c^2 is revealed. Its origin is not known yet. It is even more clearly observed in 90 degree Λd pairs with extended sensitivity to masses as low as $M_{\Lambda d} \sim 2990$ MeV/ c^2 . Unfortunately we can not assign yet this interesting signal to a strange tribaryon state or as a result of a cascade reaction and $\Sigma-\Lambda$ conversion. For this we need absolute efficiency calibrations which are under way.

Furthermore hyperon-nucleon correlations were analysed following stopped K^- reactions in ^4He . As one result we have clearly observed the isospin dependence of the two-nucleon absorption in the ΛN invariant mass spectra. In addition we have observed a relatively strong component of the non-mesonic decay channel which might originate from strange di/tri-baryonic systems¹⁰.

³ T. Suzuki *et al.*, Phys. Lett. B 597 (2004) 263.

⁴ T. Suzuki *et al.*, Nucl. Phys. A 745 (2005) 375c.

⁵ M. Iwasaki *et al.*, Nucl. Phys. A in press (2008).

⁶ M. Sato *et al.*, Phys. Lett. B659 (2008) 107.

⁷ H. Yim *et al.*, in Proceedings of the IX international Conference on Hypernuclear and Strange Particle Physics (Mainz, Germany, 2006) p. 201.

⁸ M. Iwasaki *et al.*, arXiv: nucl-ex/0310018.

⁹ T. Suzuki *et al.*, Phys. Rev. C 76 (2007) 068202.

¹⁰ T. Suzuki *et al.*, arXiv: nucl-ex/0711.4943

Wissenschaftliche MitarbeiterInnen:

Name	Funktion	Funktion: Zeitraum
Ishiwatari, Tomoichi	Projektmitarbeit	01.11.2004 bis 31.12.2007
Kienle, Paul	Projektmitarbeit	01.11.2004 bis 31.12.2007
Widmann, Eberhard	Projektleitung, Projektmitarbeit	01.11.2004 bis 31.12.2007

Publikationen:

T. Suzuki, 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, M. Sato, S. Suzuki, D. Tomono, E. Widmann, T. Yamazaki, H. Yim (2007) Lambda-d correlation from ${}^4\text{He}(\text{stopped K-}, \text{d})$. Physics Review C, Bd. 76, S. 068202. [Ishiwatari, T. (KoautorIn); Kienle, P. (KoautorIn); Widmann, E. (KoautorIn)]
Yim, H.; Ishiwatari, T.; Kienle, P.; Widmann, E. (01.01.2007) Experimental search of strange tribaryons in the ${}^4\text{He}(\text{K}^-_{-\text{stopped}}, \text{n})$ reaction., Proceedings of The IX International Conference on Hypernuclear and Strange Particle Physics (IX International Conference on Hypernuclear and Strange Particle Physics): Springer Verlag, S. 201. [Ishiwatari, T. (KoautorIn); Kienle, P. (KoautorIn); Widmann, E. (KoautorIn)]
M. Iwasaki, .., T. Ishiwatari, P. Kienle, E. Widmann (01.10.2007) Search fo a kaonic nuclear state via ${}^4\text{He}(\text{K-}, \text{N})$ reaction at rest., Proceedings of The IX International Conference on Hypernuclear and Strange Particle Physics (The IX International Conference on Hypernuclear and Strange Particle Physics): Springer Verlag, S. 195. [Ishiwatari, T. (KoautorIn); Kienle, P. (KoautorIn); Widmann, E. (KoautorIn)]

1.3.1.1.3 FS1_f: Kaonic helium X-rays: Experiment E570 at KEK

Sonstiges Einzelforschungsprojekt (abgeschlossen)

Beginn: 01.10.2004, Abschluss: 31.12.2007

E570 settled a more than 30 year old discrepancy between theory and experiments on the strong interaction shift of the kaonic ${}^4\text{He}$ 2p state by an X-ray spectroscopy experiment at KEK in Japan. The experimental results were published in Physics Letters B on 13th August 2007¹¹. This news was also reported in Austria Presse Agentur (APA) on 11th October, Österreichischer Rundfunk (ORF)¹² on 12th October, and Der Standard¹³ on 12th October.

Studies of the low-energy $\bar{K}N$ strong interaction with strangeness have been performed by measuring the kaonic atom X-rays with atomic numbers $Z = 1\text{--}92$. The shifts and widths due to the strong interaction can be systematically understood using phenomenological optical potential models for $Z > 2$ ¹⁴.

The shift of the kaonic hydrogen 1p state (kaonic atoms with $Z = 1$) had a large discrepancy between theories and experiments¹⁵—even the sign of the shift disagreed (“kaonic hydrogen puzzle”), which was solved by the experiments KpX¹⁶ and DEAR¹⁷. They showed that the previously measured values were inaccurate, and confirmed that the sign of the shift agrees with the theories. A more precise value of the shift will be obtained in the SIDDHARTA experiment¹⁸.

A discrepancy between theories and experiments on the kaonic helium 2p state (kaonic atoms with $Z = 2$) remained. A large repulsive shift (about -40 eV) was obtained by three experimental groups^{19,20,21} in the 1970's and 80's, while a very small shift (< 1 eV) was predicted by the optical models calculated from the kaonic atom X-ray data with $Z > 2$ ^{22,23}. This significant disagreement (a difference of more than 5 standard deviations) between the experimental results and the theoretical calculations was known as the “kaonic helium puzzle”.

A possible larger shift (in the order of 10 eV) was predicted using the model assuming the existence of deeply bound kaonic nuclear states^{24,25}. However, even using this model, the large shift of -40 eV measured in the experiments cannot be explained²⁵. A re-measurement of the shift of the kaonic helium X-rays was therefore one of the top priorities in the field of kaon-nucleon interaction.

The new measurement of the kaonic helium X-ray was performed using the KEK-PS K5 kaon beam channel in 2005. As a target, super fluid liquid helium was used. The kaonic atom production points were detected by tracking the incoming kaons and outgoing protons or pions

¹¹ S. Okada *et al.*, Phys. Lett. B 653 (2007) 387.

¹² <http://science.orf.at/science/news/149763>

¹³ <http://derstandard.at/?url=/?id=3071897>

¹⁴ C. J. Batty, E. Friedman, and A. Gal, Phys. Rep. 287, 385 (1997).

¹⁵ C. J. Batty and A. Gal, Nuovo Cim A 102 (1989) 255.

¹⁶ M. Iwasaki *et al.*, Phys. Rev. Lett. 78 (1997) 3067.

¹⁷ G. Beer *et al.*, Phys. Rev. Lett. 94 (2005) 212302.

¹⁸ <http://www.lnf.infn.it/esperimenti/siddharta>

¹⁹ C.E. Wiegand *et al.*, Phys. Rev. Lett. 27(1971) 1410.

²⁰ C.J. Batty *et al.*, Nucl. Phys. A 326 (1979) 455.

²¹ S. Baird *et al.*, Nucl. Phys. A 392(1983) 297.

²² C. J. Batty, Nucl. Phys. 508, A89 (1990).

²³ S. Hirenzaki *et al.*, Phys. Rev. C 61, 055205 (2000).

²⁴ Y. Akaishi and T. Yamazaki, Phys. Rev. C 65, 044005 (2002).

²⁵ Y. Akaishi, proceedings for International Conference on Exotic Atoms (EXA05), Austrian Academy of Sciences Press, Vienna p. 45 (2005).

and in addition, the stopped kaon events in the helium target were selected using counters measuring the kaon velocity. The X-rays from the kaonic atoms and the Ti/Ni calibration foils were detected using 8 Silicon Drift Detectors (SDDs), which have excellent resolution in energy [~ 190 eV (FWHM) at 6.5 keV] and timing [~ 160 ns (rms)]. In total, about 2000 events of the kaonic helium $L\alpha$ X-rays were collected.

The fit functions of the X-ray peaks were carefully studied. The function to fit the pileup events were obtained using the flash ADC data, in which the signal shape of the SDDs were recorded. The functions to fit the low energy tails were deduced from the fit of the Ti/Ni peaks. The effects of the incoherent (Compton) scattering caused in helium were estimated by GEANT4 simulations. In addition, the possible energy shifts caused by the pion-induced fluorescence X-rays were checked in a measurement using pion beams at PSI in Switzerland. The systematic error of the fit functions was found to be 2 eV.

The energy spectra of the kaonic helium X-rays are shown in Fig. 1. The helium L -series lines ($L\alpha$, $L\beta$, $L\gamma$ and $L\delta$) are clearly observed. A comparison of the previous experimental results is shown in Fig. 2. Three times higher statistics of the kaonic events, twice better energy resolution, and six times higher signal-to-background ratio were obtained. The obtained shift on the kaonic helium 2p state is $2 \pm 2(\text{stat}) \pm 2(\text{sys})$ eV. This shift is consistent with the theoretically calculated values by both the optical potential models^{22,23} (~ 0 eV) and the model predicting the deeply bound kaonic states ($< \pm 10$ eV)^{25,24}, while it disagrees with the values in the past experiments (~ -40 eV)^{19,20,21}. Therefore, we conclude that the results of the three previous experiments were disproved, and the long-standing problem in the energy level of the kaonic helium-4 2p state is solved.

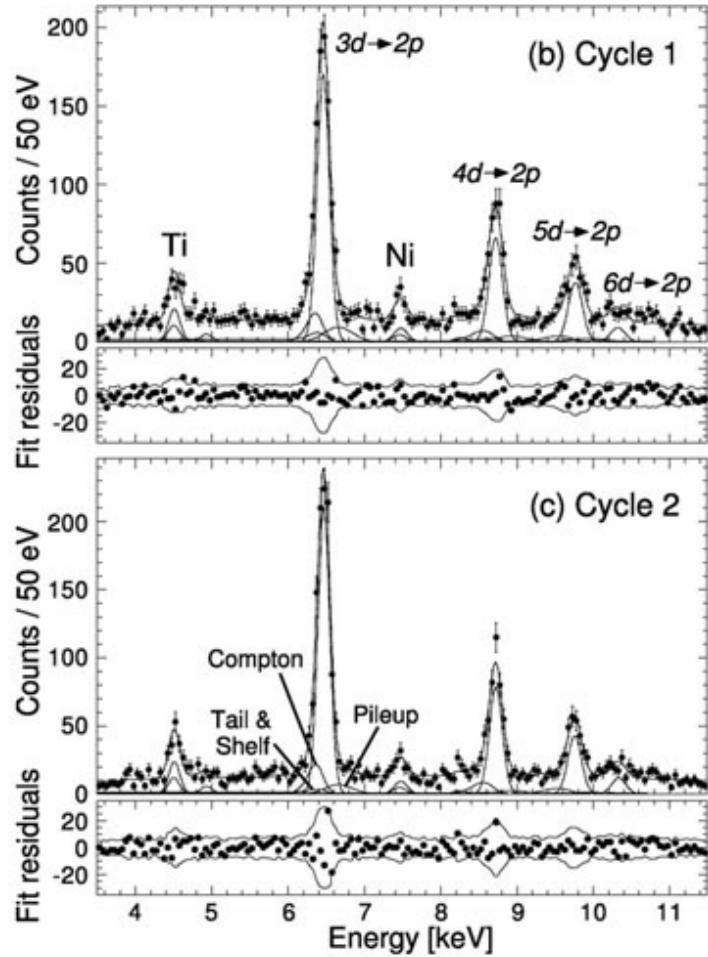


Fig. 1: Energy spectra of kaonic helium after selecting data of drift chamber and timing between the kaon events and the X-ray events. Three lines of the kaonic He L transitions are clearly seen.

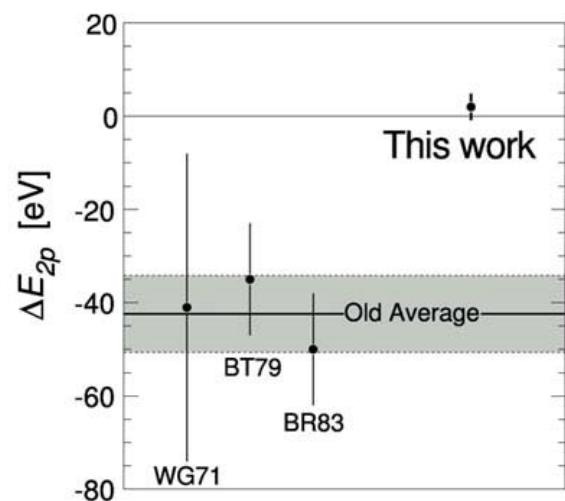


Fig. 2: Comparison of values of the strong interaction shift on the kaonic helium-4 2p state.

Outlook

According to the Akaishi-Yamazaki theory, the energy shifts and widths of the kaonic ^3He and ^4He are very sensitive to the potential depths²⁵. Because the nature of deeply-bound kaonic states is related to these potential depths, precision X-ray measurements of both the kaonic ^3He and ^4He are important, as well as kaonic hydrogen and deuterium. To understand further information on the low-energy $\bar{K}N$ interaction, new experiments to determine the shift and width of kaonic helium-3 and of kaonic hydrogen/deuterium are now in preparation at E17 (J-PARC) and SIDDHARTA (LNF).

Wissenschaftliche MitarbeiterInnen:

Name	Funktion	Funktion: Zeitraum
Cagnelli, Michael	Projektmitarbeit	01.10.2004 bis 31.12.2007
Ishiwatari, Tomoichi	Projektmitarbeit	01.10.2004 bis 31.12.2007
Juhasz, Bertalan	Projektmitarbeit	01.09.2006 bis 31.12.2007
Marton, Johann	Projektmitarbeit	01.10.2004 bis 31.12.2007
Schmid, Philipp	Projektmitarbeit	01.06.2005 bis 31.12.2007
Widmann, Eberhard	Projektleitung	01.11.2004 bis 31.12.2007
Zmeskal, Johann	Projektmitarbeit	01.10.2004 bis 31.12.2007

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1.3.2 Laufende Forschungsprojekte

1.3.2.1 FS1_A: Kaon-Nucleon Interaction: Kaonic atoms and kaonic nuclei

Forschungsschwerpunkt an der Forschungseinrichtung (laufend)

Beginn: 01.01.1997, geplanter Abschluss: 31.12.2013

One of the outstanding fundamental problems in hadron physics today is the question of the origin of the large hadron masses made up of light quarks. The current mass of the up and down quarks is two orders of magnitude smaller than a typical hadron mass of about 1 GeV. This extraordinary phenomenon is proposed to originate from spontaneous breaking of chiral symmetry of

massless quarks in strong interaction physics²⁶. It results in a ground state – the vacuum state – with a finite expectation value of quark-antiquark pairs, the chiral quark condensate²⁷. The hadrons are considered to be quasi-particle excitations of this chiral condensate.

Since long time it is known that the anti-kaon-nucleon (\bar{K} -N) interaction around threshold is dominated by the $\Lambda(1405)$ baryon resonance located 27 MeV below the K^-p threshold, which can be interpreted as a K^-p bound state. The \bar{K} -N amplitude, calculated by a coupled channel approach in the resonance regime^{28,29}, shows in the real part of the isospin $I = 0$, K^-p amplitude a dispersive behaviour, being strongly attractive below the resonance and repulsive

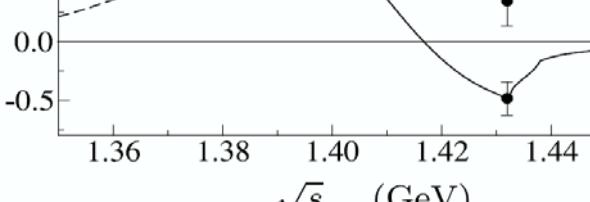


Fig. 3: Real and imaginary parts of the K^-p forward elastic scattering amplitude calculated in the Chiral SU(3) Coupled Channels approach. Real and imaginary parts of the scattering length deduced from the DEAR kaonic hydrogen measurements are also shown, with \sqrt{s} as being the invariant K -N center-of-mass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

above it (see Fig. 3). The latter is experimentally reflected by the \bar{K} -N scattering cross section³⁰, the X-ray results from kaonic hydrogen experiments KpX ³¹ at KEK and recently DEAR³² at LNF-INFN, which show repulsive shifts. Precision X-ray spectroscopy on kaonic hydrogen to study the chiral symmetry breaking scenario in the strangeness sector will be continued with SIDDHARTA investigating the K^-p and, for the first time, K^-d s-wave interaction at threshold.

Another way to gain information how the hadron mass is generated will be the study how the hadron mass changes in a nuclear medium. The mass shift of a meson in a nuclear medium gives an evidence of the partial restoration of spontaneous chiral symmetry breaking in QCD. A new

²⁶ Y. Nambu and G. Jona-Lasinio, Phys. Rev. 122 (1961) 345.

²⁷ U. Vogl and W. Weise, Prog. Part. Nucl. Phys. 27 (1991) 195.

²⁸ N. Kaiser, P. B. Siegel and W. Weise, Nucl. Phys. A594 (1995) 325

²⁹ N. Kaiser, T. Waas and W. Weise, Nucl. Phys. A612 (1997) 297.

³⁰ A. D. Martin, Nucl. Phys. B179 (1981) 33.

³¹ M. Iwasaki *et al.*, Phys. Rev. Lett. 78 (1997) 3067.

³² G. Beer *et al.*, Phys. Rev. Lett. 94 (2005) 212302.

way of in-medium hadron mass spectroscopy has started with a series of experiments at GSI, which observed deeply bound pionic 1s and 2p states in Pb and Sn nuclei³³.

Recently, exotic nuclear systems involving a \bar{K} (K^- or \bar{K}^0) as a constituent have been investigated theoretically^{34,35} based on phenomenological constructed \bar{K} -N interactions, which reproduce low energy \bar{K} -N scattering data³⁰, kaonic hydrogen atom data (KpX³¹ and DEAR³²) and the binding energy and decay width of $\Lambda(1405)$. These interactions, which are consistent with the prediction based on a chiral SU(3) effective Lagrangian as well as the recent experimental indication on decreased in-medium K^- mass from sub-threshold nuclear reactions, are characterized by a strongly attractive $I = 0$ part, causing drastic shrinkage of \bar{K} -bound nuclei and increasing the binding energies in proton-rich nuclei. The predicted \bar{K} -bound states have high average nucleon densities, several times the normal nuclear density, with large binding energies.

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

Very recently, double K^- systems $pp\bar{K}K^-$ and $ppn\bar{K}K^-$ have also been predicted to be high-density systems³⁶. Such compact nuclear systems, which can be called “ \bar{K} -clusters”, may be beyond the scope of the present theoretical treatment based on hadronic structure and interactions, as they are likely to be in a new phase of nuclear matter. “Antikaon mediated bound nuclear systems”, with quarks, anti-quarks and gluons as constituents are microscopic building blocks of kaon condensed matter³⁷ or represent colour superconducting systems with high di-quark content (see Fig. 4). 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 $\Lambda(1405)$.
- With FOPI at GSI a search of deeply bound nuclear clusters, like K^-pp , will be performed, using proton induced reactions and heavy ion collisions.

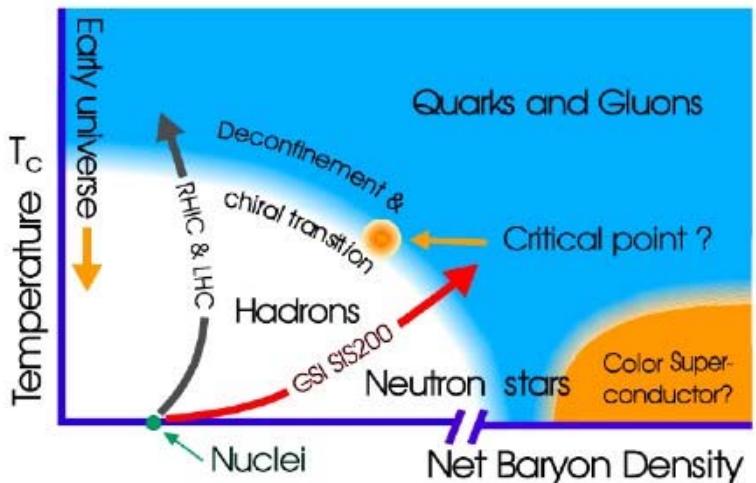


Fig. 4: Phase diagram of nuclear matter.

³³ P. Kienle, T. Yamazaki, Progress in Particle and Nuclear Physics 52 (2004) 85.

³⁴ Y. Akaishi and T. Yamazaki, Phys. Rev. C 65 (2002) 044005.

³⁵ T. Yamazaki and Y. Akaishi, Phys. Lett. B 535 (2002) 70.

³⁶ T. Yamazaki, A. Doté and Y. Akaishi, Phys. Lett. B 587 (2004) 167.

³⁷ G.E. Brown, C.H. Lee, M. Rho and V. Thorsson, Nucl. Phys. A567 (1994) 937.

- 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 inner tracker system, 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 2008 SIDDHARTA will be installed at DAΦNE. Data taking is planned to start in spring and will last at least until autumn 2008, depending on delivered luminosity and the achieved background conditions.

In parallel to the work for SIDDHARTA there will be beam times at GSI for further developments and tests of prototypes of the new forward detector system for FOPI, which is essential for the upcoming programme 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 for the Hadron Physics 2 proposal within the next EU program FP7, which will be submitted in February 2008 (WP31: Ultra light – an ultra-large tracking systems based on GEM technology). 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 will be funded by the Austrian Science Fund (FWF).

Wissenschaftliche MitarbeiterInnen:

Name	Funktion	Funktion: Zeitraum
Bühler, Paul	Projektmitarbeit	01.01.2006 bis 31.12.2013
Cargnelli, Michael	Projektmitarbeit	01.01.1997 bis 31.12.2013
Ishiwatari, Tomoichi	Projektmitarbeit	01.04.2002 bis 31.12.2013
Kienle, Paul	Projektmitarbeit	01.03.2002 bis 31.12.2013
Marton, Johann	Projektmitarbeit	01.01.1997 bis 31.12.2013
Nikolics, Katalin	Projektmitarbeit	01.01.2007 bis 31.12.2011
Suzuki, Ken	Projektmitarbeit	01.12.2006 bis 30.11.2012
Widmann, Eberhard	Projektmitarbeit	01.11.2004 bis 31.12.2013
Zmeskal, Johann	Projektleitung	01.01.1997 bis 31.12.2013

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1.3.2.1.1 FS1_b_A: Kaonic hydrogen and deuterium: SIDDHARTA

Sonstiges Einzelforschungsprojekt (laufend)

Beginn: 01.01.2004, geplanter Abschluss: 31.12.2009



Fig. 5: DAFNE interaction zone 1, the 350 μm kaon window is still covered. The electron and positron ring intersect in the center.

optics schema (“crabbed waist”) and is expected to increase the luminosity above $10^{32} \text{ cm}^{-2}\text{s}^{-1}$. By the beginning of 2008 the machine was up and running again and the kaon detector system of the SIDDHARTA experiment was installed and successfully tested. (See Fig. 5 and Fig. 6.)

The first part of the SIDDHARTA program, a precision measurement of kaonic hydrogen, is a continuation of DEAR, but will improve the precision of the DEAR data at least by a factor of 10. The second part includes the first measurement of kaonic deuterium. In addition the strong interaction shift and width of the L-state of kaonic ^4He and of kaonic ^3He will be measured. The installation of the target and X-ray detector system will start in spring 2008 after DAΦNE reaches its performance goals.

The SIDDHARTA setup was designed at SMI and built and tested in 2007. All parts besides the large vacuum chamber were built at SMI including delicate items like the light weight, high pressure cryogenic target cell, the vacuum feed-throughs, the cooling lines for the target cell as well as for the SDDs. The construction phase is finished and the equipment is ready to be installed at DAΦNE.

The goal of SIDDHARTA (Silicon Drift Detector for Hadronic Atom Research by Timing Applications) is to perform precision measurements of the shift and width of kaonic atoms at the percent level. Therefore, large area detectors with good energy resolution ($\text{FWHM} < 150 \text{ eV}$ at 6 keV) and in addition with good timing capability (better than 1 μs) are essential. These detectors and their electronics were developed, built and tested in a European Joint Research Project (see also FS1_b_b).

The upgrade of the DAΦNE collider started in 2007. It uses a new beam



Fig. 6: The kaon detectors were installed at DAFNE in January 2008.

Outlook

The installation of SDDs at DAΦNE is planned for March 2008. Using the beam tuning time we will work with only 12 cm² of SDDs, to protect the main group of detectors from radiation damage by bad beams. The main goal of these first measurements is the study of the background and its suppression by the coincidence with the kaon detector. Furthermore the efficiency of kaon-stopping in the gas will be optimized by working on the kaon degrader.

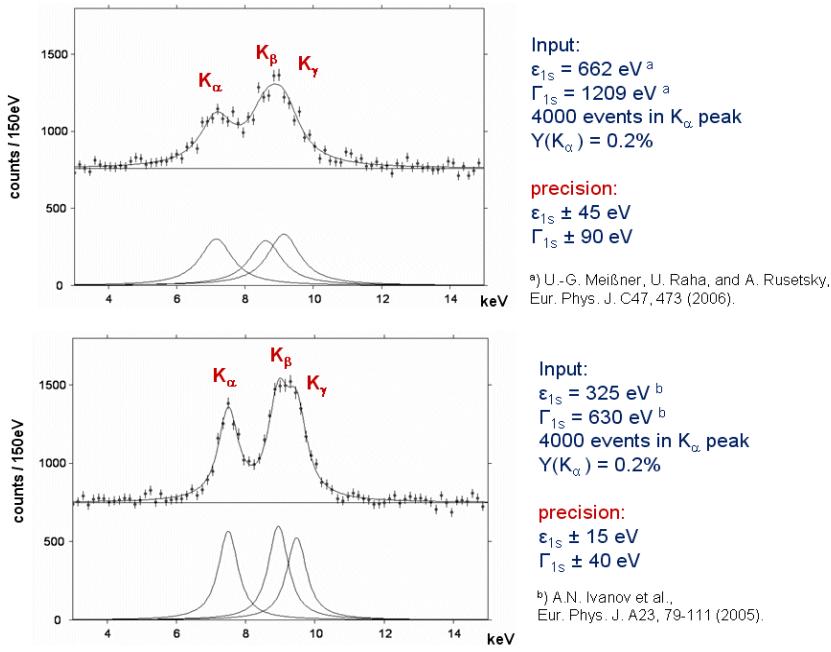


Fig. 7: Monte Carlo simulation of kaonic deuterium X-rays, assuming background intensities as measured in the DEAR experiment. Note the good background suppression which is due to the kaon trigger.

Once DAΦNE is working at an average luminosity of 10³² cm⁻²s⁻¹ and the beam background is acceptable, we will install the full setup of 216 cm² SDDs. Then in about 60 days of beam time more than 50000 kaonic hydrogen K α events will be collected – enough to fulfill the goal of a percent level measurement.

For the deuterium case a Monte Carlo simulation³⁸ shows that a kaonic deuterium measurement becomes feasible. The obtainable precision in shift and width depends on the actual width of the lines (see Fig. 7).

Wissenschaftliche MitarbeiterInnen:

Name	Funktion	Funktion: Zeitraum
Bühler, Paul	Projektmitarbeit	01.01.2006 bis 31.12.2009
Cagnelli, Michael	Projektmitarbeit	01.01.2004 bis 31.12.2009
Ishiwatari, Tomoichi	Projektmitarbeit	01.01.2004 bis 31.12.2009
Kienle, Paul	Projektmitarbeit	01.01.2004 bis 31.12.2009
Marton, Johann	Projektleitung	01.01.2004 bis 31.12.2009
Nikolics, Katalin	Projektmitarbeit	01.01.2007 bis 31.12.2009
Scordo, Alessandro	Projektmitarbeit	10.04.2007 bis 08.06.2007
Suzuki, Ken	Projektmitarbeit	01.12.2006 bis 31.12.2009
Vietauer, Martin	Forschungsassistenz	03.09.2007 bis 28.09.2007

³⁸ M. Cagnelli on behalf of the SIDDHARTA collaboration, Proceedings of the Kaon International Conference '07, Frascati, Italy, published on [POS \(Proceedings of Science\)](#).

Weigl, Ines	Forschungsassistenz	02.07.2007 bis 22.07.2007
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Zmeskal, Johann	Projektleitung, Projektmitarbeit	01.01.2004 bis 31.12.2009

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Michael, Cagnelli (22.05.2007) Kaonic X-ray experiments at DAFNE using SIDDHARTA. Vortrag: KAON 07 (LNF), Frascati/ITALY. [Cagnelli, Michael]
Michael, Cagnelli (10.05.2007) In-line energy calibration for SIDDHARTA. Vortrag: Amadeus/Siddharta workshop (LNF), Frascati/ITALY. [Cagnelli, Michael]

1.3.2.1.2 FS1_b_b: SIDDHARTA: Joint Research Activity 10 in I3 Hadron Physics

*Sonstiges Einzelforschungsprojekt (laufend)
Beginn: 01.01.2004, geplanter Abschluss: 31.12.2008*



Fig. 8: Assembled SDD module of 2 x 3 cm² active area.

Very good energy resolution (in the order of 135 eV at 6 keV), good timing resolution (about 500 ns FWHM) and robustness are the main features of Silicon Drift Detectors (SDDs). 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. To stop kaons in a gas a considerable volume is needed and thus large area detectors. Up to now no such devices were available (available sizes up to 10 mm², first prototypes with 30 mm²). 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 mm², consisting of 3 individual elements on one chip. The whole detector system has a total active area of more than 200 cm². The front-end electronics (servicing 200 detector channels) had to be newly designed and built. The X-ray timing signal will be used together with the time signal of the back-to-back K^+K^- pair measured in a scintillator arrangement (the “kaon-detector”) to set up a triple coincidence. With this coincidence method it will be possible to suppress the background by about three orders of magnitude, compared with the situation in the DEAR experiment.

To achieve the required energy resolution of the X-ray detector system, the SDD chips have to be cooled to ~170 K and the preamplifier electronics have to be closely mounted at the backside of the SDD chip. Two 3 cm² SDD chips are mounted in an aluminum case (Fig. 8) with three aluminum cases connected to build up a sub-unit. Twelve of these sub-units are arranged around the target cell, with an active detector area of 216 cm².

The SDD chips were produced at the MPI-Halbleiterlabor, München. The status of production and testing is given in the following table:

SDDs required by the experiment	72 chips	216 cm ²
SDDs produced at MPI-HLL and PNSensor	90 chips	270 cm ²
SDDs tested and available for SIDDHARTA	80 chips	240 cm ²

The production chain (e.g. gluing and bonding, then mounting in the ceramic holders and various tests) was under the supervision of SMI and seamlessly documented for each chip.

All chips were subject to final tests at SMI in Vienna – first an optical inspection by microscope took place, then the electrical characteristic of each chip was determined and compared with the MPI data (see Fig. 9). Finally spectroscopic measurements were performed, showing very good energy resolution of about 140 eV at 6 keV.

For use in the day-1 setup at DAΦNE, a special electronic circuit was developed, built and tested at SMI, the “pulsed reset” which will allow to operate the SDD using standard front-end components.

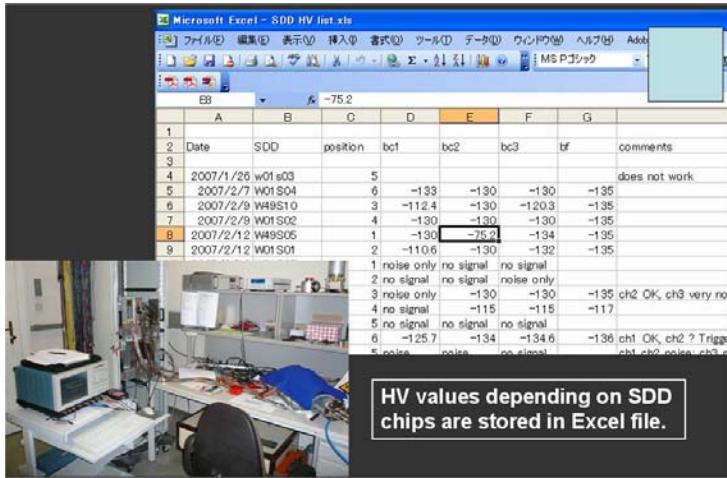


Fig. 9: Electrical tests at the SMI lab using a testbox for 1 SI subunit of 18 cm².

protect the main group of detectors from radiation damage by bad beams. The main goal of these first measurements is the study of the machine background and its suppression by the coincidence with the kaon detector. Furthermore the efficiency of kaon stopping in the gas will be optimized by working on the kaon degrader.

Once DAΦNE is working at an average luminosity of 10³² cm⁻²s⁻¹ and the beam background is acceptable, we will install the full setup of 216 cm² SDDs and start the physics program.

Wissenschaftliche MitarbeiterInnen:

Name	Funktion	Funktion: Zeitraum
Bühler, Paul	Projektmitarbeit	01.01.2004 bis 31.12.2007
Cargnelli, Michael	Projektmitarbeit	01.01.2004 bis 31.12.2007
Ishiwatari, Tomoichi	Projektmitarbeit	01.01.2004 bis 31.12.2007
Marton, Johann	Projektleitung	01.01.2004 bis 31.12.2007
Nikolics, Katalin	Projektmitarbeit	01.01.2007 bis 31.12.2007
Widmann, Eberhard	Projektmitarbeit	01.01.2004 bis 31.12.2007
Zmeskal, Johann	Projektmitarbeit	01.01.2004 bis 31.12.2007

Publikationen:

Ishiwatari, T. (2007) Silicon drift detectors for the kaonic atom X-ray measurements in the SIDDHARTA experiment. Nuclear Inst. and Methods in Physics Research, Bd. A581, S. 326.
[Ishiwatari, T. (AlleinautorIn)]

Bazzi, M.; Beer, G.; Cargnelli, M.; Ishiwatari, T.; Kienle, P. et al. [...] (01.10.2007) The SIDDHARTA experiment at DAPHNE and future perspectives., Proceedings of The IX International Conference on Hypernuclear and Strange Particle Physics (The IX International Conference on Hypernuclear and Strange Particle Physics); Mainz: Springer Verlag. [Cargnelli, M. (KoautorIn); Ishiwatari, T. (KoautorIn); Kienle, P. (KoautorIn); Marton, J. (KoautorIn); Widmann, E. (KoautorIn); Zmeskal, J. (KoautorIn)]

In March 2007 a test measurement using the 510 MeV electrons of the “beam test facility” at DAΦNE, LNF, was done to measure the timing resolution (Fig. 10) and to study the background rejection capability.

Outlook

The installation of SDDs at DAΦNE is planned for March 2008. Using the beam tuning time we will work with only 12 cm² of SDDs, to

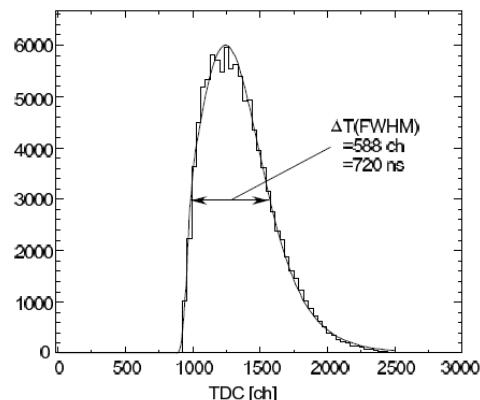


Fig. 10: Measured timing resolution of 1 cm² SDD.

FS1_c: Deeply bound kaonic nuclei with FOPI at GSI

Sonstiges Einzelforschungsprojekt (laufend)

Beginn: 01.09.2004, geplanter Abschluss: 31.12.2009

The goal of this project is to investigate the possible existence of kaonic nuclear bound states with the FOPI detector at GSI. 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 (PAC) of GSI and proposed to investigate the $p + p \rightarrow K^+ + K^- pp$ reaction at an incident proton energy of $T_p = 3.0$ GeV. $K^- pp$, the most fundamental of the kaonic nuclear bound states, undergoes a successive decay $K^- pp \rightarrow \Lambda + p \rightarrow [p + \pi^-] + p$. By detecting all the reaction products of this two-body one can obtain information on $K^- pp$ from both the missing mass $M_M(pp-K^+)$ and the invariant mass $M_{inv}(\Lambda-p)$. The PAC did rank the request category A and recommended to grant 54 shifts (à 8 hours) to conduct this experiment. The experiment is currently planned to take place in the first half of year 2009.

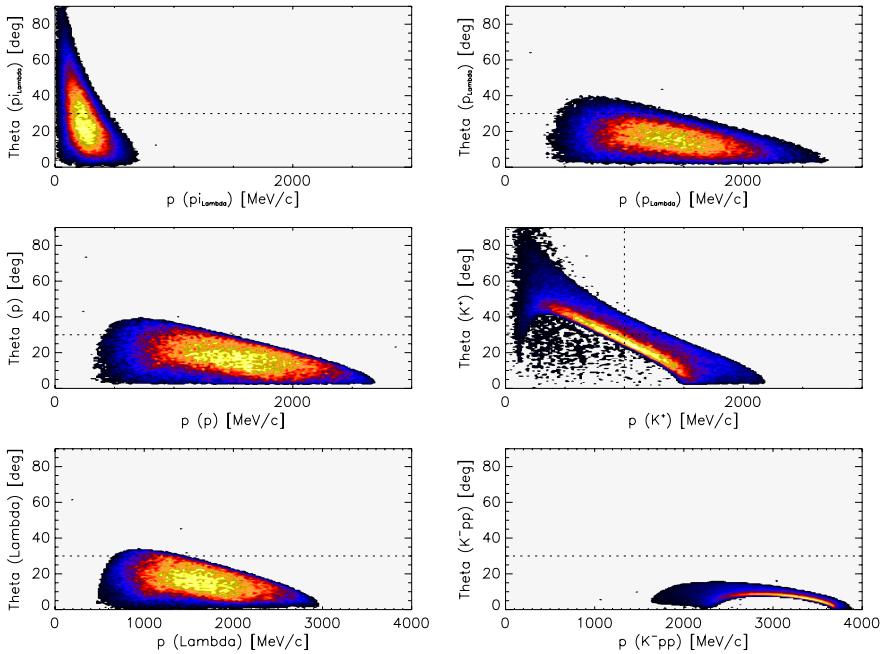


Fig. 11: Kinematic plots for $pp \rightarrow K^+ + K^- pp \rightarrow K^+ + \Lambda + p \rightarrow K^+ + [p + \pi^-] + p$.

Fig. 11 shows momenta p versus the azimuthal angle θ in the laboratory frame for all the produced particles at $T_p = 3.0$ GeV (from simulations). The particles are emitted mainly in forward direction ($\theta < 30^\circ$). Exceptions are the pion from the Λ -decay and the K^+ .

The K^+ at $\theta > 30^\circ$ are measured with the central drift chamber (CDC). Together with a recently installed and in 2007 commissioned RPC it allows the characterization of K^+ up to 1 GeV/c. In order to efficiently reconstruct the Λ 's emitted in forward direction and to suppress non-strangeness background events at the hardware level, the existing FOPI setup has to be supplemented with a new detector system. A scheme of the proposed system is depicted in Fig. 12. O is the reaction point and O_Λ the point where the Λ decays. The system consists of two planar detectors, L0 and L1. L0 is placed as close as possible to the target and L1 is placed around 15 cm downstream. Good events can be selected by means of the hit multiplicities in both detectors. In good events the hit-multiplicity n_0 in L0 is 1 or 2, whereas the hit-multiplicity of L1 must be $n_1 = n_0 \geq 2$. In this way the selectivity for events, in which a Λ is produced and which decays in the volume between the two detector layers, is enhanced.

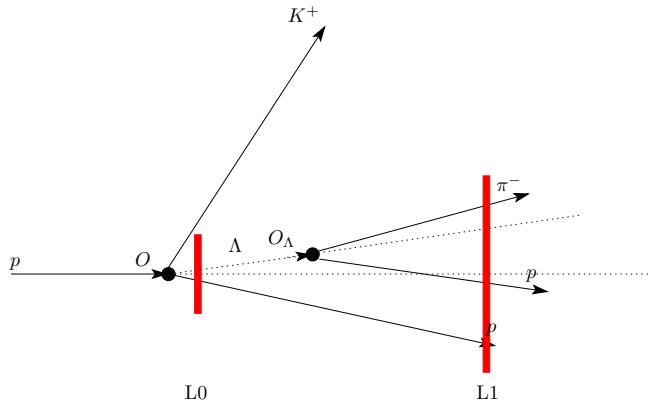


Fig. 12: Schematic drawing of the proposed forward detector system for FOPI.

Both detectors though need to deliver hit multiplicities. For L1 in addition a good spatial resolution is required to supplement the Helitron (FOPI's drift chamber in the forward direction) for the reconstruction of the charged particle tracks. Besides this a new start/veto counter system suitable for minimum ionizing particles (MIPs) at high rates (10^7 p/s) and providing a time resolution of below 100 ps, a beam profile monitor (BPM) to monitor the position and focus of the proton beam, as well as a liquid hydrogen target have to be developed.

The activities during 2007 were dominated by the development of the various subsystems.

L1 as well as L0 are planned to be made of silicon detectors, which have been shown in a test experiment in 2007 to be suitable for this purpose. These detectors are mounted and optimized by colleagues at the Technical University of Munich.

The BPM will be made of scintillating fibers read out with Multi-Pixel Geiger-mode APD (or often called Silicon Photomultiplier, SiPM). During 2007 we tested single fibers and demonstrated the feasibility to detect MIPs with our setup. The construction and assembly of the final BPM are going on at SMI.

For the start counter we are investigating two different concepts. The first one is a scintillating detector with Photomultiplier (PMT) read-out and the second one is a Cherenkov detector with SiPM as photo sensing elements. SiPMs are unaffected by magnetic fields, are operated at low voltages, and are relatively cheap which make them attractive alternatives to PMTs. On the other hand they are small (typically 1x1 mm sensitive surface) which makes it difficult to use them to read out larger detectors. First results on elements of both concepts were obtained during test campaigns in spring and fall of 2007 at GSI. Optimization studies and tests are continued.

Outlook

It is planned to finalize the various subsystems in 2008.

Wissenschaftliche MitarbeiterInnen:

Name	Funktion	Funktion: Zeitraum
Bühler, Paul	Projektmitarbeit	01.09.2004 bis 31.12.2009
Cargnelli, Michael	Projektmitarbeit	01.09.2004 bis 31.12.2009
Kienle, Paul	Projektmitarbeit	01.09.2004 bis 31.12.2009
Marton, Johann	Projektmitarbeit	01.09.2004 bis 31.12.2009
Schmid, Philipp	Projektmitarbeit	01.06.2005 bis 30.03.2007
Suzuki, Ken	Projektmitarbeit	01.12.2006 bis 30.11.2009
Widmann, Eberhard	Projektmitarbeit	01.11.2004 bis 31.12.2009
Zmeskal, Johann	Projektleitung, Projektmitarbeit	01.09.2004 bis 31.12.2009

Publikationen:

Lopez, X; Herrmann, N; Crochet, P; Andronic, A; Barret, V; Basrak, Z; Bastid, N;
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Benabderrahmane, ML; Buehler, P; Cagnelli, M; Caplar, R; Cordier, E; Dupieux, P; Dzelalija, M; Fabbietti, L; Fodor, Z; Gasparic, I; Grishkin, Y; Hartmann, ON; Hildenbrand, KD; Hong, B; Kang, TI; Kecskemeti, J; Kirejczyk, M; Kim, YJ; Kis, M; Koczon, P; Korolija, M; Kotte, R; Lebedev, A; Leifels, Y; Manko, V; Marton, J; Matulewicz, T; Merschmeyer, M; Neubert, W; Pelte, D; Petrovici, M; Piasecki, K; Rami, F; Reisdorf, W; Ryu, MS; Schmidt, P; Schuttauf, A; Seres, Z; Sikora, B; Sim, KS; Simion, V; Siwek-Wilczynska, K; Smolyankin, V; Stoica, G; Suzuki, K; Tyminski, Z; Wagner, P; Widmann, E; Wisniewski, K; Wohlfarth, D; Xiao, ZG; Yushmanov, I; Zhang, XY; Zhilin, A; Zmeskal, J; Kienle, P; Yamazaki, T (2007) Subthreshold production of Sigma(1385) baryons in Al+Al collisions at 1.9A GeV. PHYSICAL REVIEW C, Bd. 76 (5), S. 052203. [Bühler, P. (KoautorIn); Cagnelli, M. (KoautorIn); Kienle, P. (KoautorIn); Marton, J. (KoautorIn); Suzuki, K. (KoautorIn); Widmann, E. (KoautorIn); Zmeskal, J. (KoautorIn)]

Schmid, Philipp (2007) Fluessig-Deuterium Target zur Untersuchung von starkgebundenen Kaonischen Kernzustaenden. Diplomarbeit, Universitaet Wien, Wien. [Schmid, P. (AlleinautorIn)]

P. Buehler, M. Cagnelli, L. Fabbietti, P. Kienle, H. Marton, K. Suzuki, T. Yamazaki, E. Widmann, J. Zmeskal and FOPI collaboration (2007) Experimental proposal to GSI: Search for the kaonic nuclear cluster K-pp in the p+p-> k+ + K-pp -> K+ + p + Lambda reaction with FOPI. [Bühler, P. (KoautorIn); Cagnelli, M. (KoautorIn); Kienle, P. (KoautorIn); Marton, J. (KoautorIn); Suzuki, K. (KoautorIn); Widmann, E. (KoautorIn); Zmeskal, J. (KoautorIn)]

Vorträge/Posterpräsentationen:

Buehler, Paul (13.03.2007) Observation of Sigma(1385) in proton induced reactions at FOPI. Vortrag: DPG Fruehjahrstagung (Universitaet Giessen), Giessen/GERMANY. [Bühler, Paul]

Buehler, Paul (25.09.2007) Search for Kbar nuclear clusters in proton induced reactions with FOPI at GSI. Vortrag: OEPG/Fakt Jahrestagung (Donau-Universitaet Krems), Langenlois/AUSTRIA. [Bühler, Paul]

Buehler, Paul (22.02.2007) Invariant mass and missing mass analysis of simulated p+p reactions. Vortrag: FOPI collaboration meeting (GSI), Darmstadt/GERMANY. [Bühler, Paul]

Buehler, Paul (09.11.2007) Sigma(1385) in the proton experiment S297. Vortrag: FOPI collaboration meeting (GSI), Darmstadt/GERMANY. [Bühler, Paul]

1.3.2.1.3 FS1_d: AMADEUS at DAΦNE2

Sonstiges Einzelforschungsprojekt (laufend)

Beginn: 22.08.2005, geplanter Abschluss: 31.12.2012

The change of the hadron masses and hadron interactions in the nuclear medium and the structure of cold dense hadronic matter are hot topics of hadron physics today. These important, yet unsolved, problems will be the research field of AMADEUS (Antikaonic Matter At DAFNE: Experiments with Unravelling Spectroscopy)³⁹.

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

The hypothesis of the existence of deeply bound kaonic nuclear states was already formulated in 1986 by Wycech⁴⁰ but is only a few years old in the structured form of a phenomenological model formulated by Akaishi and Yamazaki⁴¹. The existence of such a deeply bound system is presently matter of lively discussions among theoreticians and experimentalists.

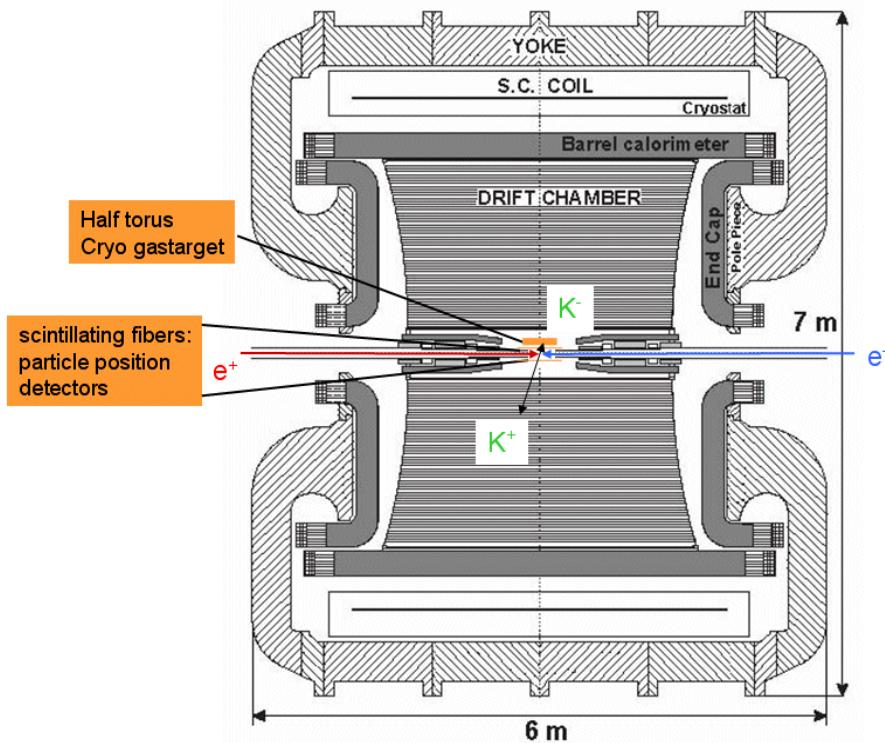


Fig. 13: Top view of the KLOE detector with the AMADEUS components added.

The project AMADEUS will use the KLOE detector at DAΦNE with specific components added, like a cryogenic gas target for stopping the charged kaons (see Fig. 13). It will perform, for the first time, a systematic and complete spectroscopic study by measuring all particles in the formation and in the decay processes.

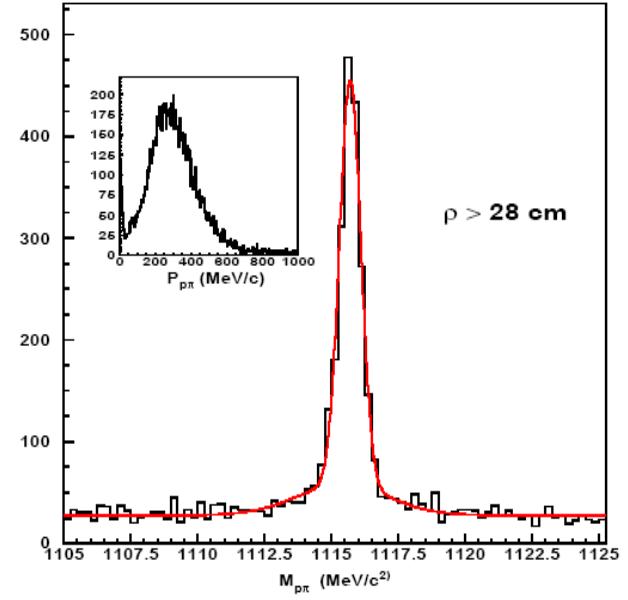
In 2007 scientists from our institute, who are members of the *charged kaon group* of the KLOE collaboration, were entitled to analyze the existing KLOE data. One of the main objectives was the search for events with the signature of kaon-nucleon-clusters for kaons stopped in the thin gas of

³⁹ AMADEUS LOI, www.lnf.infn.it (Nuclear Physics – SIDDHARTA).

⁴⁰ S. Wycech, Nucl. Phys. A450 (1986) 399c.

⁴¹ Y. Akaishi and T. Yamazaki, Phys. Rev. C 65 (2002) 044005.

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 (see spectrum of Λ particles in Fig. 14), because lambda particles are one of the main decay products of kaon-nucleon clusters. In addition the information of efficiencies and techniques of particle identification (see Fig. 15), especially for protons (and deuterons), are essential for the design of the AMADEUS experiment. Up to now, the statistics of reconstructed lambdas, for example with deuterons, coming from the same origin, which might indicated the decay of a formed cluster event, are not sufficient enough to allow significant statements on the production of kaon nucleon clusters. In a dedicated cryogenic helium target, which has more than 50 times the density of the drift chamber, the fraction of stopped kaons will be 500 times higher. Together with the increased luminosity of DA Φ NE2 a high statistics experiment will be possible.



*Fig. 14: Mass spectrum of Λ particles produced in the drift chamber gas.
Insert: momentum distribution.*

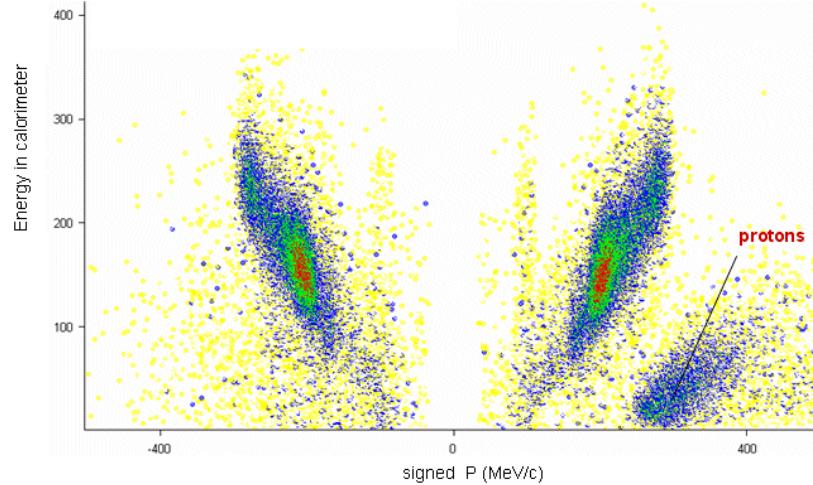


Fig. 15: Identification of protons in KLOE data.

Outlook

SMI will be strongly involved in the development of an inner tracker system for AMADEUS. Two options are under considerations: A cylindrical GEM detector system or a TPC (time protection chamber) with a GEM amplification stage and pixel readout. The importance of GEM devices as part of inner tracker systems for hadron physics experiments are evident and as result a work package in the proposal of Hadron Physics 2 within the 7th Framework Programme of the EU is devoted to develop large area GEM detector systems. This work package is lead by SMI.

In addition a prototype of a kaon monitor made of a scintillating fibre array with Geiger-mode APD readout is planned for 2008. This work is also of great interest for FOPI, where a forward detector is under consideration to be made of a similar scintillating fibre X-Y-array.

The already successful analysis of the KLOE data to look for antikaon-mediated deeply bound nuclear clusters is going on and first results are expected to be published in 2008.

A working group to study the inter-changeability between the KLOE and AMADEUS setup, involving the DAΦNE machine group, is considered to start their work in the beginning of 2008.

Wissenschaftliche MitarbeiterInnen:

Name	Funktion	Funktion: Zeitraum
Bühlner, Paul	Projektmitarbeit	01.01.2006 bis 31.12.2012
Cagnelli, Michael	Projektmitarbeit	22.08.2005 bis 31.12.2012
Ishiwatari, Tomoichi	Projektmitarbeit	22.08.2005 bis 31.12.2012
Marton, Johann	Projektmitarbeit	22.08.2005 bis 31.12.2012
Suzuki, Ken	Projektmitarbeit	01.12.2006 bis 30.11.2012
Widmann, Eberhard	Projektmitarbeit	22.08.2005 bis 31.12.2012
Zmeskal, Johann	Projektleitung	22.08.2005 bis 31.12.2012

Publikationen:

Zmeskal, J. (2007) Search for kaonic nuclei at DAFNE 2: the AMADEUS project. International Journal of Modern Physics A, Bd. 22, S. 374. [Zmeskal, J. (HauptautorIn)]
Kienle, P. (01.10.2007) The AMADEUS project., Proceedings of The IX International Conference on Hypernuclear and Strange Particle Physics (The IX International Conference on Hypernuclear and Strange Particle Physics); Main: Springer Verlag. [Kienle, P. (AlleinautorIn)]

Vorträge/Posterpräsentationen:

Michael, Cagnelli (30.01.2007) Monte Carlo studies for AMADEUS day-1. Vortrag: Work meeting Munich (TUM), Munich/GERMANY. [Cagnelli, Michael]

1.3.2.1.4 FS1_g: Study of the Kaon-Nucleon interaction @ J-PARC

Sonstiges Einzelforschungsprojekt (laufend)

Beginn: 01.01.2006, geplanter Abschluss: 31.12.2012

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

SMI joined two proposals, which were both approved as day-1 experiments:

- E15: A search for deeply-bound kaonic nuclear states by in-flight ${}^3\text{He}(K^-, n)$ reaction.
- E17: Precision spectroscopy of kaonic helium-3 $3d \rightarrow 2p$ 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. 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 2009.



Fig. 16: Aerial view of the new J-PARC accelerator center in Tokai-mura.

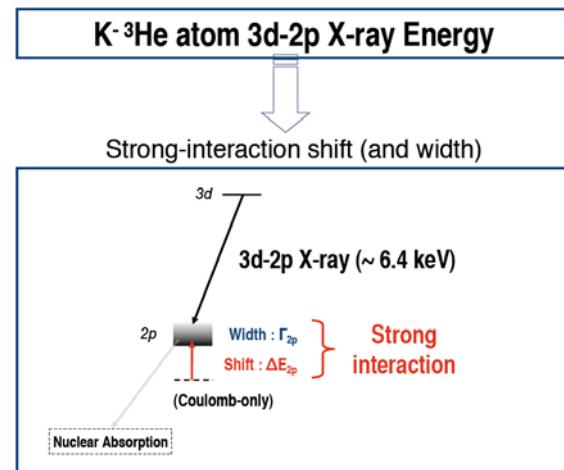
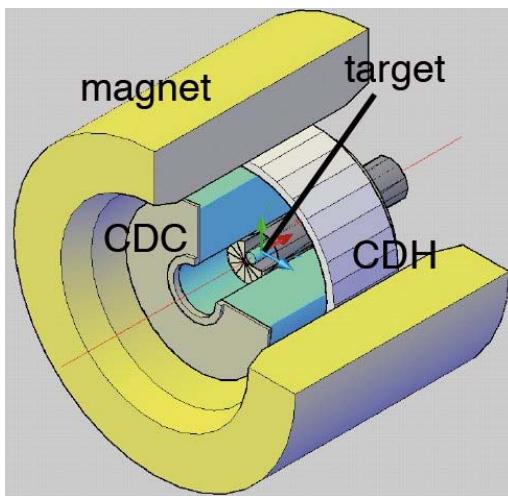


Fig. 17: Schematic setup of E15 (left). Principle of the E17 precision experiment on the strong interaction kaon-He-3 nucleus (right).

E17 proposes to essentially perform an analogue measurement of $3d \rightarrow 2p$ X-ray transitions in ^3He as E570 performed it for ^4He (see Fig. 17). The comparison of kaonic ^3He and ^4He will provide crucial information on the isospin-dependent kaon -nucleus strong interaction at the low energy limit, and will provide decisive data to understand the basis of the Akaishi-Yamazaki prediction of deeply-bound kaonic nuclei.

E17 will make use of the liquid ^3He -target, which is being constructed for E15, with some modifications to put SDD X-ray detectors close to it. As extensive experience was gained in operating SDDs in a high-intensity hadron beam, the experiment will be rather straight-forward. SMI will participate – as before in E570 – by providing new SDD detectors in clusters as developed for SIDDHARTA. These SDDs have less dead areas to increase the solid angle. A joint project between Austria (Austrian Science Foundation) and Japan (JSPS) was approved recently. This funding allows SMI to purchase the SDD detectors and to finance additional manpower as well as travel expenses.

Outlook

Both experiments are in preparation and expected to start data taking in 2009. 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.

Wissenschaftliche MitarbeiterInnen:

<i>Name</i>	<i>Funktion</i>	<i>Funktion: Zeitraum</i>
Bühler, Paul	Projektmitarbeit	01.01.2006 bis 31.12.2012
Cagnelli, Michael	Projektmitarbeit	01.01.2006 bis 31.12.2012
Ishiwatari, Tomoichi	Projektmitarbeit	01.01.2006 bis 31.12.2012
Kienle, Paul	Projektmitarbeit	01.01.2006 bis 31.12.2012
Marton, Johann	Projektleitung, Projektmitarbeit	01.01.2006 bis 31.12.2012
Suzuki, Ken	Projektmitarbeit	01.12.2006 bis 30.11.2012
Widmann, Eberhard	Projektmitarbeit	01.01.2006 bis 31.12.2012
Zmeskal, Johann	Projektmitarbeit	01.01.2006 bis 31.12.2012

1.3.2.2 FS2_A: Matter - antimatter symmetry: ASACUSA @ CERN

Forschungsschwerpunkt an der Forschungseinrichtung (laufend)
Beginn: 01.11.2004, geplanter Abschluss: 31.12.2012

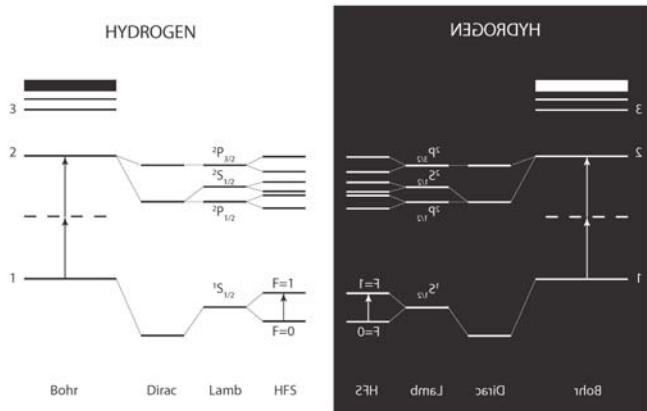


Fig. 18: Energy levels of hydrogen and antihydrogen.

This is the second main scientific program at SMI. Within the ASACUSA program, SMI is involved in the precision spectroscopy of antiprotonic helium and the development of a spectrometer beam line for the measurement of the ground-state hyperfine splitting of antihydrogen. These experiments investigate the matter-antimatter symmetry (CPT symmetry) as well as the accuracy of state-of-the-art three-body QED calculations via the precision laser and microwave spectroscopy of atoms containing antiprotons.

Antihydrogen, the simplest antimatter

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

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

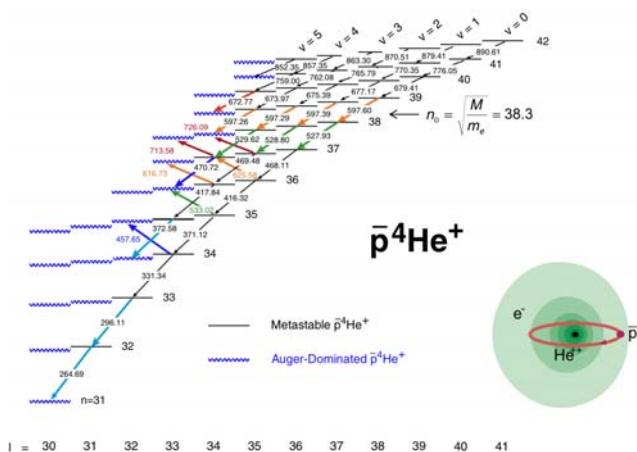


Fig. 19: Level diagram of antiprotonic helium.

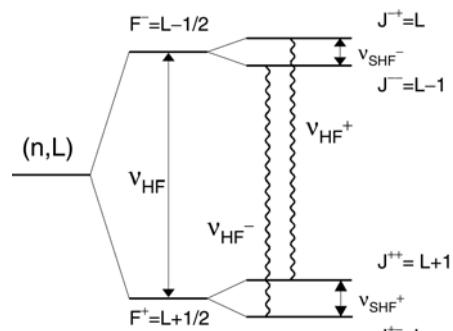


Fig. 20: Hyperfine structure of anti-protonic ${}^4\text{He}$.

Wissenschaftliche MitarbeiterInnen:

Name	Funktion	Funktion: Zeitraum
Juhasz, Bertalan	Projektmitarbeit	01.07.2005 bis 31.12.2012
Malbrunot, Chloe	Projektmitarbeit	01.07.2006 bis 30.06.2007

Marton, Johann	Projektmitarbeit	01.11.2004 bis 31.12.2012
Pask, Thomas	Projektmitarbeit	01.07.2005 bis 31.12.2012
Reichhart, Lea	Forschungsassistenz	09.07.2007 bis 12.08.2007
Suzuki, Ken	Projektmitarbeit	01.12.2006 bis 30.11.2012
Widmann, Eberhard	Projektleitung, Projektmitarbeit	01.11.2004 bis 31.12.2012
Zmeskal, Johann	Projektmitarbeit	01.11.2004 bis 31.12.2012

Publikationen:

Malbrunot, Chloe (2007) Collisional effects in the measurement of the hyperfine structure of antiprotonic helium. Diplomarbeit, Technical University of Vienna, Wien. [Malbrunot, C. (AlleinautorIn)]

Vorträge/Posterpräsentationen:

Juhasz, Bertalan (27.03.2007) ASACUSA: Testing the CPT symmetry with antiprotons. Vortrag: Seminar at York University, Toronto/CANADA. [Juhasz, Bertalan]

1.3.2.2.1 FS2_b: Hyperfine structure of antiprotonic helium

Sonstiges Einzelforschungsprojekt (laufend)

Beginn: 01.11.2004, geplanter Abschluss: 31.12.2010

The hyperfine structure of antiprotonic helium ($\bar{p}^4\text{He}^+$) is investigated by a laser-microwave-laser method, where a first laser pulse is used to depopulate one of the hyperfine (HF) doublets, a microwave pulse to transfer population from F^- to F^+ , and a second laser pulse to detect the population change caused by the microwave pulse. A new pulse-amplified cw laser system now makes it possible to increase the precision, relative to the 2001 measurement.

Four weeks of beam time were allotted to this experiment in 2007 with the intention to measure the hyperfine HF splitting of the $\bar{p}^4\text{He}^+ (n,l) = (37,35)$ state to the highest possible degree of meaningful precision. Technical problems with the Antiproton Decelerator (AD) meant that half the beam time was lost to repairs and the signal relative to 2006 was reduced by 30%. The required quantity of statistics was not attainable and as a result a high statistical measurement of a single density (250 mbar) was made.

The data has been analysed and, coupled with the 2006 measurements, the results will be publishable. The line of the HFS measurements has been fitted with the expected shape instead of a Lorentzian function. The width has been decreased by a factor of 3 and the signal-to-noise ratio has been increased by the same factor. The HF splitting has been measured with a factor 5 increase in precision.

The microwave scans were measured with a laser separation of 350 ns. Fig. 21 shows the 2001 (left) microwave scan next to the averaged data that was measured during the 2006-2007 beam time. The new measurement has a resolution of 60 kHz (a factor of 5 better than the 300 kHz resolution in 2001) and a line width of 2.4 MHz (5.3 MHz in 2001). Fig. 22 shows a close up of each of the lines where the side bands of the fit can be seen.

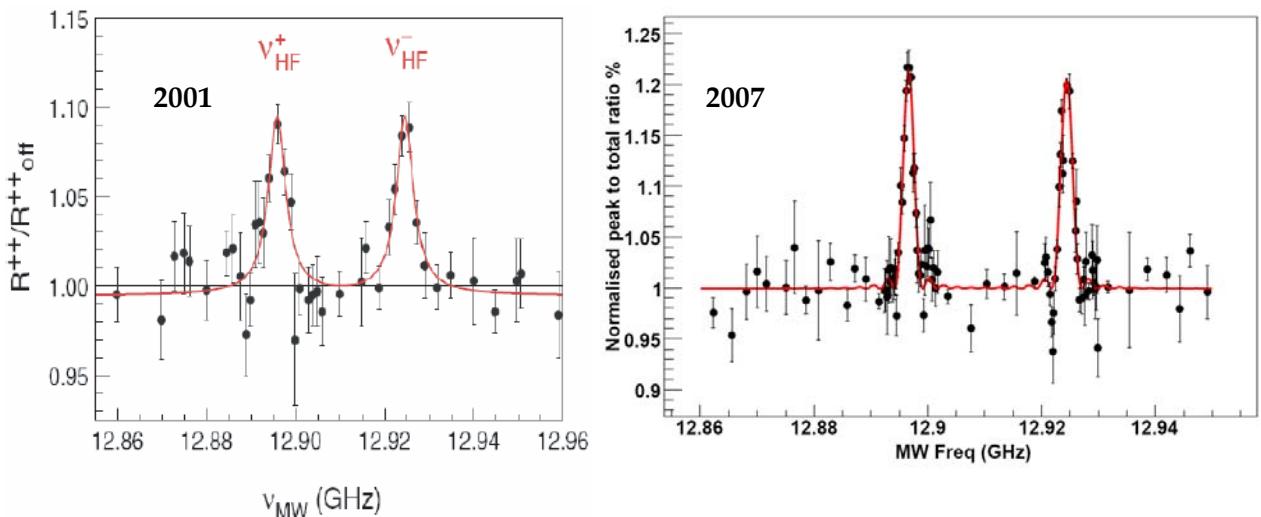


Fig. 21: Microwave resonance profiles of the (37, 35) metastable state of antiprotonic helium. The data was taken at the AD ring in CERN in 2001 (left) and 2006-7 (right).

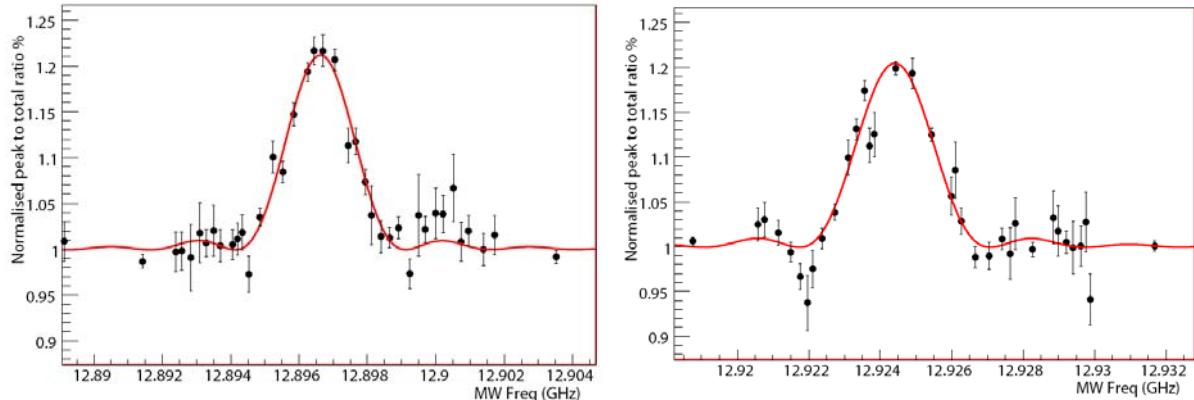


Fig. 22: A close up of the microwave resonance profiles lines of the (37, 35) metastable state of antiprotonic helium: v^{+}_{HF} (left) and v^{-}_{HF} (right).

An experimental measurement of the hyperfine structure (HFS) can be compared with QED calculations to determine the difference between the antiproton and proton spin magnetic moments. In 2001 this was measured to an accuracy of 1.6%⁴², while the current most precise measurement is 0.3%⁴³.

If the hyperfine structure can be measured to a resolution of 33 kHz for the (37, 35) state, the precision of the antiprotonic spin magnetic moment will be known to 0.1%⁴⁴, a factor of three better. Measuring the state (39, 35) to the same absolute precision will even yield an improvement of a factor 9.

Outlook

The goal for 2008 is to measure $\bar{p}^4\text{He}^+ (n,l) = (37,35)$ to the highest possible degree of meaningful precision. The precision can be improved to 33 kHz (the estimated precision of theory) with more statistics and a density dependence study. Whether or not there is a power dependence must also be established. In 2006, the population time evolution and the effect of collision induced relaxations were studied. These initial results suggest that the theoretical predictions overestimate the collision rate. Further measurements taken over a 8 hour period should result in an accurate measurement of this rate.

After this year other hyperfine states are of interest. The entire program is expected to take 2-3 years. During this period the first measurements on $\bar{p}^3\text{He}^+$ are intended. A new cavity for $\bar{p}^3\text{He}^+$ was manufactured and tested last year, showing that such a device can be scaled to suit different frequency requirements. For these laser transitions, agreement between theory and experiment is not so clear. A second $\bar{p}^4\text{He}^+$ state, for an even better test of CPT theory, is also planned.

Wissenschaftliche MitarbeiterInnen:

Name	Funktion	Funktion: Zeitraum
Juhasz, Bertalan	Projektmitarbeit	01.07.2005 bis 31.12.2009
Malbrunot, Chloe	Projektmitarbeit	01.06.2006 bis 31.05.2007
Marton, Johann	Projektmitarbeit	01.11.2004 bis 31.12.2009
Pask, Thomas	Projektmitarbeit	01.07.2005 bis 31.12.2009

⁴² E. Widmann et al., Phys. Rev. Lett. 89 (2002) 243402.

⁴³ A. Kreissl et al., Z. Phys. C 37, 557 (1988).

⁴⁴ D. Bakalov, E. Widmann, Phys. Rev. A 76, 012512 (2007)

Suzuki, Ken	Projektmitarbeit	01.12.2006 bis 30.11.2012
Widmann, Eberhard	Projektleitung, Projektmitarbeit	01.11.2004 bis 31.12.2009
Zmeskal, Johann	Projektmitarbeit	01.11.2004 bis 31.12.2009

Publikationen:

Bakalov, D.; Widmann, E. (2007) Determining the antiproton magnetic moment from measurements of the hyperfine structure of antiprotonic helium. Physical Review A, Bd. 76, S. 012512. [Widmann, E. (KoautorIn)]

Vorträge/Posterpräsentationen:

Widmann, Eberhard (18.06.2007) The Hyperfine Structure of Antiprotonic Helium and the Antiproton Magnetic Moment. Vortrag: International Conference on Muon Catalyzed Fusion and Related Topics, Dubna/RUSSIAN FEDERATION . [Widmann, Eberhard]

Pask, Thomas (01.12.2007) HFS Beam Time Proposal. Vortrag: ASACUSA Collaboration meeting (CERN), Geneva/SWITZERLAND. [Pask, Thomas]

Pask, Thomas (11.12.2007) Improved Measurement of the HFS of Antiprotonic Helium. Vortrag: Project status report (Stefan Meyer Institut), Vienna/AUSTRIA. [Pask, Thomas]

1.3.2.2.2 FS2_c: Precision laser spectroscopy of antiprotonic helium

Sonstiges Einzelforschungsprojekt (laufend)

Beginn: 01.11.2004, geplanter Abschluss: 31.12.2010

Two-photon laser spectroscopy

In 2007, the transition frequencies of antiprotonic helium atoms⁴⁵ ($\bar{p}^3\text{He}^+$ and $\bar{p}^4\text{He}^+$) were measured to a relative precision of a few parts per billion (preliminary result), which is by far the most precise measurement to date of any $\bar{p}^4\text{He}^+$ transitions. This was achieved by using a sub-Doppler non-linear two-photon laser spectroscopy method. Through comparison of these experimental values with three-body QED calculations, a new value for the antiproton-to-electron mass ratio improving on the previous measurement⁴⁶ is expected.

After preliminary measurements were taken in 2006 a six week period was dedicated to this experiment. An AC Stark shift produces a systematic error that required many power and density dependence measurements. Fig. 23 shows the resonance profile of the Doppler-broadened single-photon transition $(n,l) = (36,34) \rightarrow (35,33)$ of $\bar{p}^4\text{He}^+$ measured in 2004 (top) where the arrows denote the theoretical positions of the hyperfine components compared to the sub-Doppler resonance profile (bottom) of the two-photon transition $(n,l) = (36, 34) \rightarrow (34, 32)$ measured in 2007 using two counter propagating laser beams.

Outlook

The experimental precision achieved in 2007 represents the best value that can be obtained using nanosecond-scale pulsed lasers due to shot-to-shot fluctuations in the laser frequency and to nonlinear systematic effects. Therefore it is planned in 2008, to start an entirely different type of spectroscopy utilising two continuous-wave lasers, which can solve the problems inherent to high-power pulsed lasers, and may improve the precision of the antiproton/electron mass ratio.

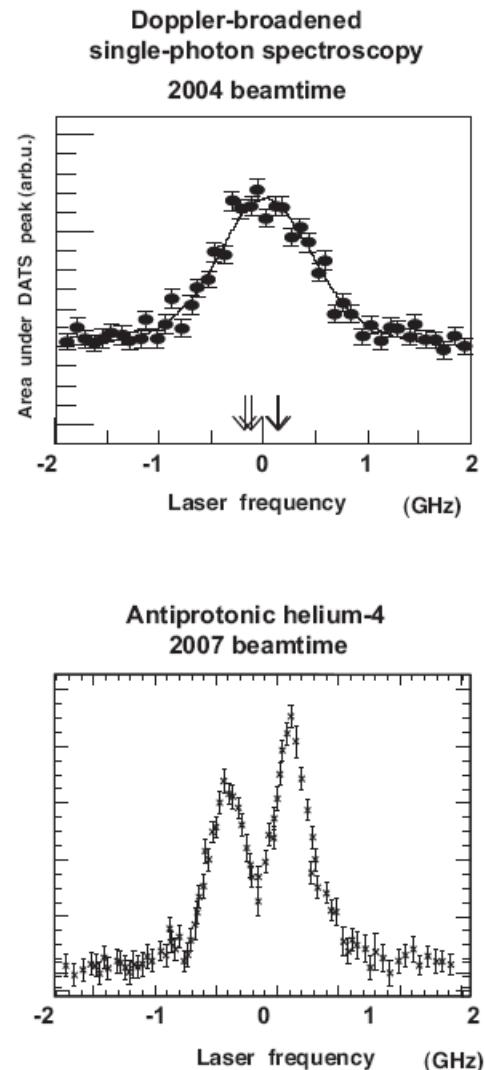


Fig. 23: Resonance profile of the Doppler-broadened single-photon transition $(n,l) = (36, 34) \rightarrow (35, 33)$ of ${}^4\text{He}^+$ measured in 2004 (top). Arrows denote the theoretical positions of the hyperfine components. Sub-Doppler resonance profile of the two-photon transition $(n,l) = (36, 34) \rightarrow (34, 32)$ measured in 2007 using two counter propagating laser beams (bottom).

⁴⁵ T. Yamazaki et al., Phys. Rep. 366, 183 (2002).

⁴⁶ M. Hori et al., Phys. Rev. Lett. 96, 243401 (2006).

Wissenschaftliche MitarbeiterInnen:

Name	Funktion	Funktion: Zeitraum
Juhasz, Bertalan	Projektmitarbeit	01.07.2005 bis 31.12.2009
Malbrunot, Chloe	Projektmitarbeit	01.07.2006 bis 30.06.2007
Marton, Johann	Projektmitarbeit	01.11.2004 bis 31.12.2009
Pask, Thomas	Projektmitarbeit	01.08.2005 bis 31.12.2009
Puhm , Andrea	Projektmitarbeit	03.07.2006 bis 31.01.2007
Suzuki, Ken	Projektmitarbeit	01.12.2006 bis 30.11.2012
Widmann, Eberhard	Projektleitung	01.11.2004 bis 31.12.2009
Zmeskal, Johann	Projektmitarbeit	01.11.2004 bis 31.12.2009

Vorträge/Posterpräsentationen:

Widmann, Eberhard (15.01.2007) Precision Spectroscopy of Antiprotonic Helium. Vortrag: XLV INTERNATIONAL WINTER MEETING ON NUCLEAR PHYSICS, Bormio/ITALY. [Widmann, Eberhard]

1.3.2.2.3 FS2_d: Measurement of the ground-state hyperfine structure of antihydrogen

Sonstiges Einzelforschungsprojekt (laufend)

Beginn: 01.11.2004, geplanter Abschluss: 31.12.2012

The measurement of the ground-state hyperfine splitting of antihydrogen will require a beamline, the development of which is being done at the Stefan Meyer Institute. The original design of the beamline consisted of two superconducting sextupole magnets and a radiofrequency (1.42 GHz) resonator in between them. The first sextupole would only allow antihydrogen atoms in 2 of the 4 possible spin states to pass through, effectively polarizing the beam. The resonator would then flip the spin of the atoms if it is on resonance with a hyperfine transition, and the second sextupole would analyze the spin state of the atom.

In 2007, the design of the beamline continued. An antihydrogen source, a cusp trap was developed at RIKEN, Japan, and was installed at CERN. According to simulations, this trap could produce a partially polarized antihydrogen beam, thus the first sextupole could be omitted from the beamline.

Extensive Monte Carlo

simulations at SMI showed that the sextupole beamline indeed can work with only the RF resonator and one sextupole magnet (see Fig. 24).

An important part of the beamline is the radiofrequency resonator. Ideally, this should produce in a $\sim 10 \times 10 \times 10$ cm volume a resonating RF field which is perfectly homogenous in all three directions. Unfortunately, such an RF field cannot be created, because Maxwell's laws forbid it. The best possibility is homogeneity in two directions; the third direction has to be inhomogeneous. Such an RF field can be created by a double strip resonator, which consists of two parallel plates placed above each other around the beam. The magnetic component of the RF field

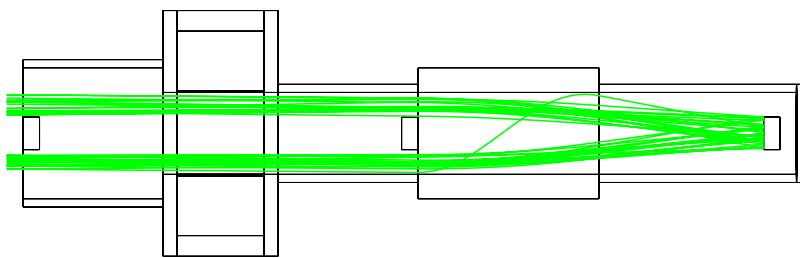


Fig. 24: Monte Carlo simulation of the trajectories of antihydrogen atoms in the beam line, connected to the cusp trap (not shown). To the left is the radiofrequency resonator, while the sextupole magnet is on the right.

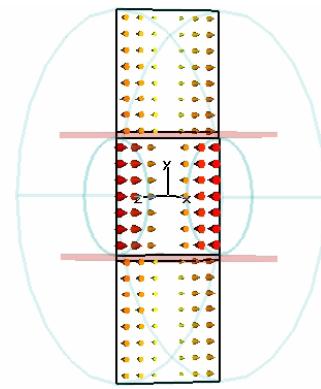
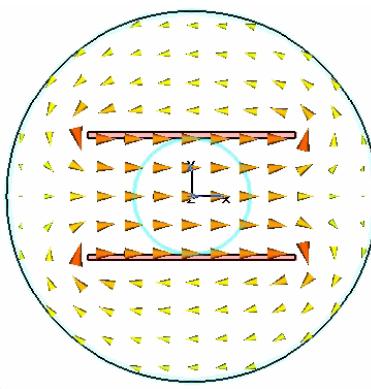
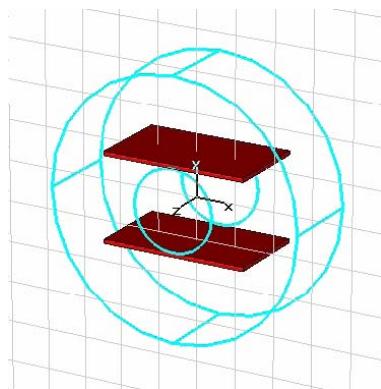


Fig. 25: Left: view of the double strip resonator placed in a cylindrical box. Centre: Magnetic component of the RF field in the X-Y plane. Right: Magnetic field in the Y-Z plane. It can be seen that in the central plane of the cylinder, the magnetic field is zero, corresponding to $\sin(Z=0) = 0$. From T. Kroyer, CERN.

produced by this device has very good homogeneity in the X-Y directions, and has a sinus distribution in the Z (i.e. beam) direction (see Fig. 25).

Such a $\sin(Z)$ distribution of the resonating magnetic field causes not the usual one but two peaks in the measured hyperfine spectrum (see Fig. 26). This has certain advantages, e.g. the shape of the two peaks is largely independent of the applied RF power, which is not true in case of a single peak. The two peaks are also less sensitive to the velocity distribution of the antihydrogen atoms.

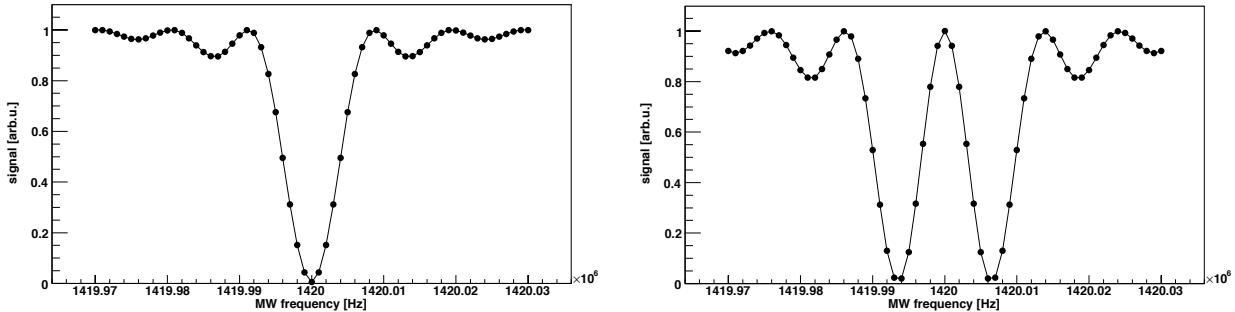


Fig. 26: Left: resonance peak using an ideal (but non-existing) radiofrequency field. Right: double resonance peak using a double strip resonator.

The measurements of the two possible hyperfine transitions have to be done in a small (0.1-1 gauss) homogenous static magnetic field to prevent the spontaneous spin flip of the antihydrogen atoms. Such a field slightly shifts the transition frequencies, but by measuring the two transitions in the same static magnetic field, the ground-state hyperfine transition frequency in zero magnetic field can be calculated. Simulations at SMI showed that a relative precision of 10^{-7} can be reached in determining the ground-state hyperfine transition frequency.

The first radiofrequency components (frequency generator, signal analyzer) were bought for the radiofrequency resonator setup. Several companies were contacted who could build the superconducting sextupole magnet for us.

Outlook

The cusp trap, which was developed at RIKEN, was already operational at CERN in 2007, and it could successfully trap a large number of antiprotons. The positron source, however, will only be installed at CERN in 2008. If the commissioning is successful, the ASACUSA collaboration will be able to produce antihydrogen atoms in 2008, and the first measurements using the sextupole beamline could take place in 2009. Thus the sextupole magnet has to be ordered in 2008 for a delivery in 2009. The sextupole magnet will be financed jointly by the Stefan Meyer Institute and the University of Tokyo, Komaba, in a 2/3-1/3 ratio.

The design of the radiofrequency resonator will also continue. Several technical problems have to be solved. Firstly, the large stray magnetic field of the cusp trap has to be shielded from the resonator. Secondly, a low static magnetic field (0.1-1 gauss) has to be created in the resonator in such a way that the static and the RF magnetic fields are on a 45 degree angle to each other. It is foreseen that a doctoral student will work on the design and building of the resonator.

A preliminary design of the sextupole beamline (with an RF resonator and one sextupole magnet) connected to the cusp trap is shown in Fig. 27. Since the exit of the cusp trap is at room temperature, the RF resonator will also be at room temperature, which simplifies its design considerably.

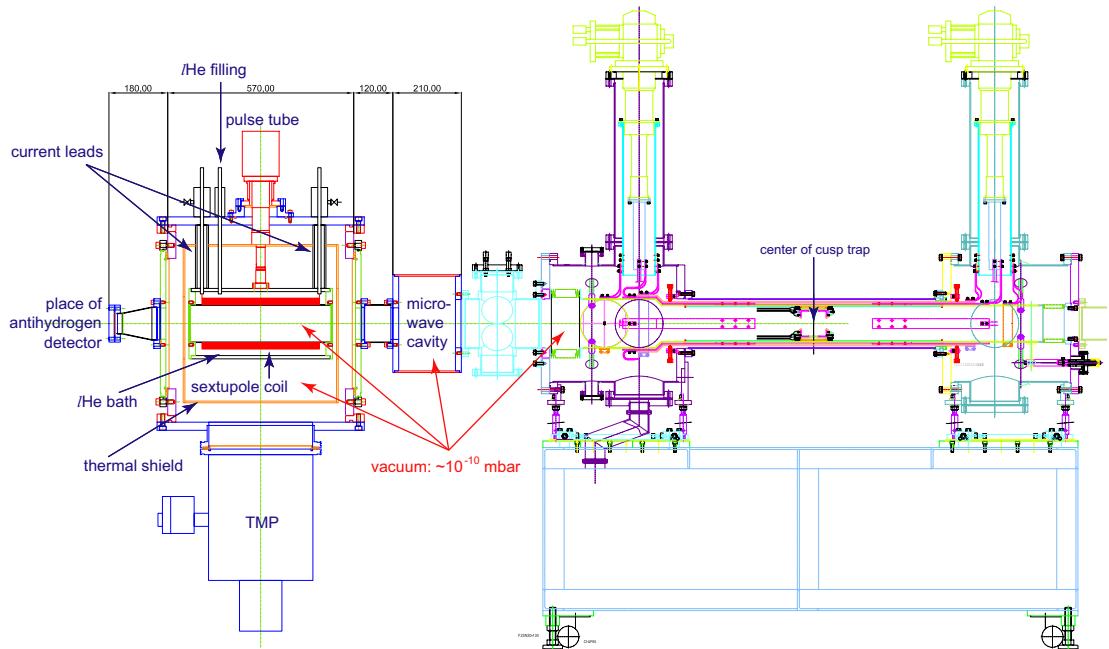


Fig. 27: Preliminary design of the antihydrogen cusp trap and the attached sextupole beam line.

Wissenschaftliche MitarbeiterInnen:

Name	Funktion	Funktion: Zeitraum
Juhasz, Bertalan	Projektmitarbeit	01.07.2005 bis 31.12.2012
Marton, Johann	Projektmitarbeit	01.11.2004 bis 31.12.2012
Widmann, Eberhard	Projektleitung, Projektmitarbeit	01.11.2004 bis 31.12.2012
Zmeskal, Johann	Projektmitarbeit	01.11.2004 bis 31.12.2012

Publikationen:

- B. Juhász, E. Widmann, D. Barna, J. Eades, R.S. Hayano, M. Hori, W. Pirkl, D. Horváth, T. Yamazaki (10.09.2007) An atomic beamline to measure the ground-state hyperfine splitting of antihydrogen. In: Tomohiro Uesaka, Hideyuki Sakai, Akihiro Yoshimi, Koichiro Asahi (Hrsg.), Proceedings of The 11th International Workshop on Polarized Sources and Targets (11th International Workshop on Polarized Sources and Targets); New York: World Scientific, Singapore. [Juhász, B. (KoautorIn); Widmann, E. (KoautorIn)]
- B. Juhász, E. Widmann (13.06.2007) Proposed measurement of the ground-state hyperfine structure of antihydrogen., Hyperfine Interactions, volume 172 (TCP'06); Parksville, S. 107-110. [Juhász, B. (KoautorIn); Widmann, E. (KoautorIn)]

Vorträge/Posterpräsentationen:

- Juhasz, Bertalan (22.03.2007) Sextupole magnets for the measurement of the ground-state hyperfine splitting of antihydrogen. Vortrag: Seminar at Brookhaven National Laboratory, Brookhaven/UNITED STATES. [Juhász, Bertalan]
- Juhasz, Bertalan (09.08.2007) Measurement of the ground-state hyperfine splitting of antihydrogen. Vortrag: Fourth Meeting on CPT and Lorentz Symmetry (CPT'07), Bloomington/UNITED STATES. [Juhász, Bertalan]
- Juhász, Bertalan (01.12.2007) Measurement of the ground-state hyperfine splitting of

antihydrogen: Status. Vortrag: ASACUSA collaboration meeting, Geneva/SWITZERLAND.
[Juhasz, Bertalan]

1.3.2.3 FS3_A: Antiprotons at FAIR

Forschungsschwerpunkt an der Forschungseinrichtung (laufend)
Beginn: 01.04.2005, geplanter Abschluss: 01.01.2025



Fig. 28: FAIR kick-off event.

FAIR welcomes Austria



Dr. Vierkorn-Rudolph, German Ministry of Research and Education and Dr. Daniel Weselka, Head of Division in the Austrian Ministry of Education, Science and Culture

During the Meeting of the International Steering Committee (ISC) on February 26th, 2007 at GSI, Dr. Daniel Weselka, Head of Division in the Austrian Ministry for Education, Science and Culture, signed the FAIR Memorandum of Understanding for Austria. As one of the observer countries in all important committees, Austria has already been involved in the initial and recent developments of the FAIR project and one of the largest experiment collaborations of FAIR has an Austrian spokesperson. By now 14 countries declared their intention to contribute to the FAIR project.

Fig. 29: Extract from GSI Kurier, March 2007.

Wissenschaftliche MitarbeiterInnen:

Name	Funktion	Funktion: Zeitraum
Bühler, Paul	Projektmitarbeit	01.04.2005 bis 01.01.2025
Cagnelli, Michael	Projektmitarbeit	01.04.2005 bis 01.01.2025

⁴⁷ FAIR Baseline Technical Report 2006.

FAIR, the Facility for Antiproton and Ion Research, will be an extension of the existing Gesellschaft für Schwerionenforschung (GSI) near Darmstadt⁴⁷. 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 marks 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. The current time schedule foresees an end of construction in 2015, where the antiproton part will be ready around 2014. 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.

Gruber, Alexander	Projektmitarbeit	01.04.2005 bis 01.01.2025
Juhasz, Bertalan	Projektmitarbeit	01.04.2005 bis 01.01.2025
Kienle, Paul	Projektmitarbeit	01.04.2005 bis 01.01.2025
Marton, Johann	Projektmitarbeit	01.04.2005 bis 01.01.2025
Suzuki, Ken	Projektmitarbeit	01.12.2006 bis 01.01.2025
Widmann, Eberhard	Projektleitung	01.04.2005 bis 01.01.2025
Zmeskal, Johann	Projektmitarbeit	01.04.2005 bis 01.01.2025

Vorträge/Posterpräsentationen:

Widmann, Eberhard (25.09.2007) FAIR Status. Vortrag: ÖFAIR meeting, Krems/AUSTRIA.
[Widmann, Eberhard]

Widmann, Eberhard (15.11.2007) FAIR - Facility for Antiproton and Ion Research. Vortrag:
Integrating Research Infrastructures Veranstaltung ffg/bm_wf, Wien/AUSTRIA. [Widmann,
Eberhard]

Widmann, Eberhard (27.03.2007) Österreichische Projekte an FAIR. Vortrag:
Industriellenvereinigung Wien, Wien/AUSTRIA. [Widmann, Eberhard]

1.3.2.3.1 FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Sonstiges Einzelforschungsprojekt (laufend)

Beginn: 01.11.2004, geplanter Abschluss: 31.12.2025

The proposed Facility for Low-energy Antiproton and Heavy-Ion Research combines low energy antiproton beams and stable and instable highly-charged ions for atomic, nuclear and particle physics research. The key features of the facility will be the cooled, highly intense beams of antiprotons and bare and few-electron heavy ions. The combination of two decelerators – the Low-energy Storage Ring LSR and the Ultra-low energy Storage Ring USR – and different ion/antiproton traps will provide beams of excellent emittance covering energies from 100 MeV/u down to few eV. Over 15 different experiments have been proposed to be located at FLAIR and use the provided beams. Details about the scientific goal and technical aspects of these experiments are presented in the FLAIR Technical Proposal⁴⁸. E. Widmann is chairman of the steering committee of FLAIR.



Fig. 30: 3D-view of the FLAIR building: the ground level (bottom) and the upper level (top).

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

A design study application in the Research Infrastructures part of the EU FP7 program was submitted in May 2007. It was the only application of three FAIR-related projects that exceeded the threshold in the evaluation (it received 12.5 out of 15 points), but was finally not financed because of lack of funding in the EC program.

Fig. 30 shows the latest layout of the building which may still change as – due to outside constraints – the position of the FLAIR building might change and as a consequence the shape and layout may need to be modified. Once this is decided, a detailed design of the beam lines will start.

Wissenschaftliche MitarbeiterInnen:

<i>Name</i>	<i>Funktion</i>	<i>Funktion: Zeitraum</i>
Cargnelli, Michael	Projektmitarbeit	01.11.2004 bis 31.12.2025
Juhasz, Bertalan	Projektmitarbeit	01.12.2006 bis 28.02.2009
Kienle, Paul	Projektmitarbeit	01.11.2004 bis 31.12.2025
Marton, Johann	Projektmitarbeit	01.11.2004 bis 31.12.2025

⁴⁸ FLAIR Technical proposal – update (2005).

Widmann, Eberhard	Projektleitung	01.11.2004 bis 31.12.2025
Zmeskal, Johann	Projektmitarbeit	01.11.2004 bis 31.12.2025

Vorträge/Posterpräsentationen:

Widmann, Eberhard (13.11.2007) Status and Opportunities at FLAIR. Vortrag: SFAIR (Swedish FAIR Consortium) Meeting, Göteborg/SWEDEN. [Widmann, Eberhard]

Widmann, Eberhard (08.03.2007) FLAIR - A facility for low-energy antiproton and ion research. Vortrag: Seminar at UniWien (VERA), Wien/AUSTRIA. [Widmann, Eberhard]

Widmann, Eberhard (06.09.2007) Status and opportunities of FLAIR. Vortrag: Seminar at ATOMKI, Debrecen/HUNGARY. [Widmann, Eberhard]

Widmann, Eberhard (26.11.2007) Status and opportunities of FLAIR. Vortrag: Seminar at Jyväskylä University, Jyväskylä/FINLAND. [Widmann, Eberhard]

Widmann, Eberhard (03.12.2007) Antiproton requirements for FLAIR. Vortrag: pbar at FAIR Workshop, Darmstadt/GERMANY. [Widmann, Eberhard]

1.3.2.3.2 FS3_c_A: PANDA: Proton Antiproton Annihilations at Darmstadt

Sonstiges Einzelforschungsprojekt (laufend)
Beginn: 01.01.2004, geplanter Abschluss: 31.12.2025

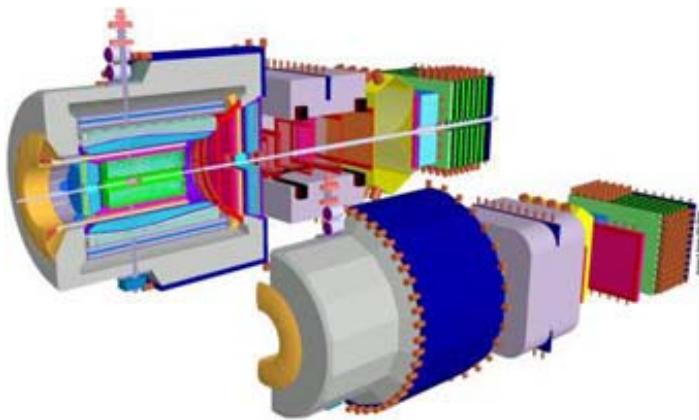


Fig. 31: Sketch of the PANDA detector.

The study of fundamental questions of hadron and nuclear physics will be possible with the universal PANDA detector^{49,50}. The experiments will use antiproton-proton annihilations for creating interactions with nucleons and nuclei and will produce gluonic excitations and particle-antiparticle pairs. PANDA will carry out spectroscopic studies with extremely high statistics of particles consisting of strange and charm quarks.

The main experimental topics of PANDA will be high-precision tests 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 ($3\text{-}5 \text{ GeV}/c^2$)
- Search for modifications of meson properties in the nuclear medium in the charm sector and their possible relationship to partial restoration of chiral symmetry

Our institute is taking part in this international collaboration with more than 50 participating institutes. Within the EU programme of FP6, SMI contributes 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 (JRA in DIRACsecondary Beams).

Additionally we are also part of a collaboration to work on the future computing infrastructure for PANDA within the PANDAgrid. This grid framework will combine the computing resources of the participating institutes and will provide a common environment to perform the highly demanding computing tasks of the PANDA project.

SMI is an active partner in this consortium and maintains a node of the PANDA grid. From 1.10. - 5.10.2007 our institute hosted the semi-annual workshop of the node administrators.

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

⁴⁹ PANDA Letter of Intent (2004).

⁵⁰ PANDA Technical Progress Report (2005).

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 ($\sim 1.5 \text{ GeV}/c^2$) 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.

In 2008 simulation studies of selected charmonium states produced in antiproton-proton and antiproton-nucleus annihilations by using the cluster-jet target will be carried out at SMI in cooperation with theorists. The simulation results of these important benchmark channels will directly be used for the “PANDA Physics Booklet”, which should be finished by October 2008.

From 2009 to 2014 the institute will participate in the construction and commissioning of the PANDA detector.

Wissenschaftliche MitarbeiterInnen:

<i>Name</i>	<i>Funktion</i>	<i>Funktion: Zeitraum</i>
Bühler, Paul	Projektmitarbeit	01.01.2006 bis 31.12.2025
Gruber, Alexander	Projektmitarbeit	01.01.2004 bis 31.12.2025
Kienle, Paul	Projektmitarbeit	01.01.2004 bis 31.12.2025
Marton, Johann	Projektmitarbeit	01.01.2004 bis 31.12.2025
Suzuki, Ken	Projektmitarbeit	01.01.2007 bis 31.12.2025
Widmann, Eberhard	Projektmitarbeit	01.11.2004 bis 31.12.2025
Zmeskal, Johann	Projektleitung, Projektmitarbeit	01.01.2004 bis 31.12.2025

1.3.2.3.3 FS3_c_b: Internal target system for PANDA: Joint Research Activity 7 in I3 Hadron Physics

Sonstiges Einzelforschungsprojekt (laufend)
Beginn: 01.01.2004, geplanter Abschluss: 31.12.2008

Within the framework of FP6 SMI is involved 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 work consists of research and development of the (hydrogen) cluster-jet target with the Genova cluster-jet target at GSI. As well a setup for nozzle tests was built at SMI. Furthermore with a setup at SMI, which simulates the PANDA vacuum system, we are carrying out feasibility studies to use NEG-coated beam pipes near a high-luminosity internal target. Additionally calculations of the PANDA vacuum system have been started in 2007.

Our contribution can be divided into 4 sub-projects:

Genova cluster-jet target at GSI

The Genova/Fermilab cluster-jet target, which was set up at GSI, is now fully operational, including the gas-supply-system with Pd-filter for hydrogen purification, which was built by SMI in 2005 and 2006. Due to the installation of a purifier with higher gas throughput it is now possible to operate the cluster-jet with up to 18 bar inlet pressure for raising the density of the jet. The purification of hydrogen is of vital importance for the cluster-jet, as otherwise impurities would freeze out in the cold nozzle and block the gas flow.

The diameter of the cluster-jet is an important parameter for calculating its density and target thickness. Therefore a thorough investigation to extract a more precise value has been carried out. The previous value mentioned by Fermilab experiment E835⁵¹ has been stated to be ~7 mm. The data of all pressure profile measurements up to date have been compared to a fit-model. From this fit (see Fig. 32) we could deduce that the cluster-jet at the interaction point of the Genova cluster-jet target at GSI has a diameter of 6.15 mm.

In a series of measurements in 2006 we reached the limit of the cooling power of the nozzle head due to the rise in pressure from destruction of clusters by the residual gas in the first chamber. Before further increasing the target density by raising the inlet pressure, it was necessary to investigate this destruction of clusters in more detail. For this purpose a series of measurements was carried out in 2007.

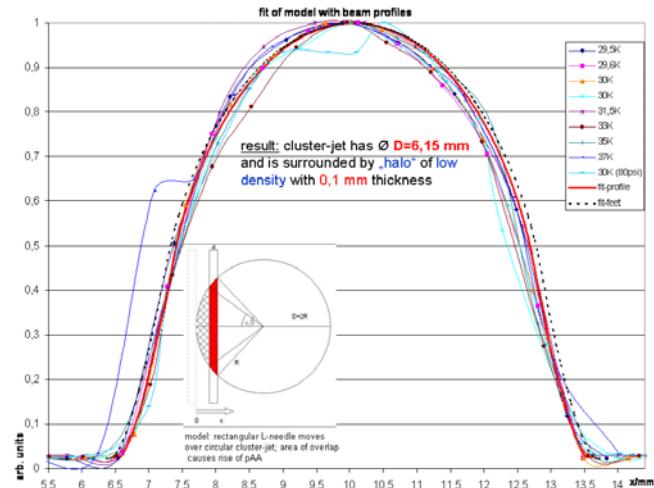


Fig. 32: Profile of cluster-jet beam at GSI.

⁵¹D. Allspach et al., NIM A410 (1998) 195

In these measurements the destruction of the clusters was achieved by influx of hydrogen gas into chamber J1 (surrounding the cold head of the nozzle). A clear decrease of the density of the cluster-jet and the target thickness by increasing the density of the residual gas in chamber J1 was noticed (see Fig. 33). This is attributed to the destruction of the clusters due to the high level of surrounding gas. Additionally an increase of the temperature of the nozzle of up to 20 K could be measured.

Tests on the gas load, which we can expect at the interaction point of PANDA due to a cluster-jet with and without interactions with antiprotons were done, too. By linearly extrapolating the results of these tests to an inlet pressure of 20 bar, we can expect a pressure increase at the interaction point of up to 5×10^{-5} mbar.

Nozzle tests

PANDA has to operate at a luminosity of $L > 10^{32} \text{ cm}^{-2}\text{s}^{-1}$. Therefore the target thickness of the cluster-jet target has to be more than $\sim 10^{15}$ protons/cm². In order to reach this goal an optimisation of the cluster production and the nozzle-skimmer arrangement is essential.

It was found out that the nozzle shape has a strong influence on the production of the clusters⁵². Until now all used nozzles were Laval-nozzles with a trumpet shaped opening. R&D for increasing the target density with other alternative nozzle shapes has started. These tests will be carried out at SMI with the setup for measuring the density distribution of the cluster-jet right after the nozzle and with the cluster-jet targets at GSI and Münster.

To start with, trumpet shaped Laval nozzles with changeable orifices will be constructed (see Fig. 34). Orifices made of Molybdenum with holes of 10 to 50 μm diameter have already been delivered to GSI. The production of the body of the nozzle is much more difficult due to the desired shape and still small opening (diameter of 0.1 mm). SMI is in contact with a company capable to produce these parts. Efforts to find a second company failed due to the stringent requirements.

Meanwhile tests were carried out at GSI with modified Laval nozzles. The old nozzles produced at CERN were taken as the body and the new orifices were inserted with the smallest opening. The tests successfully demonstrated the feasibility of this design.

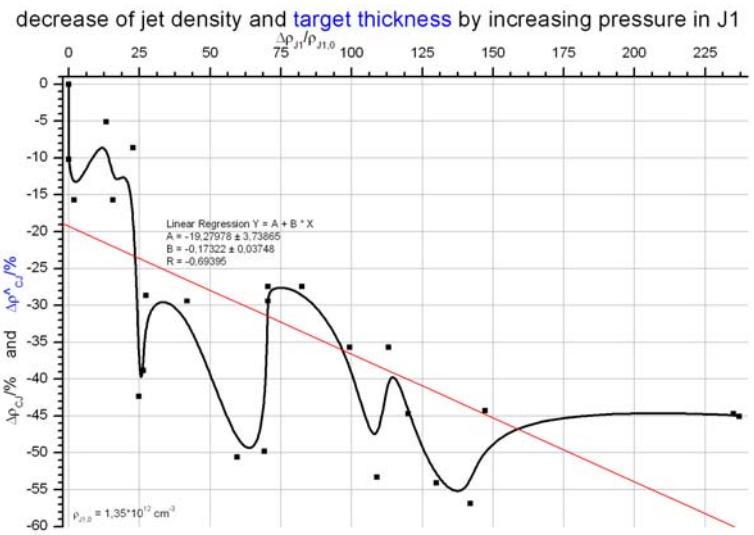


Fig. 33: Decrease of target thickness by increase of density of residual gas in J1.

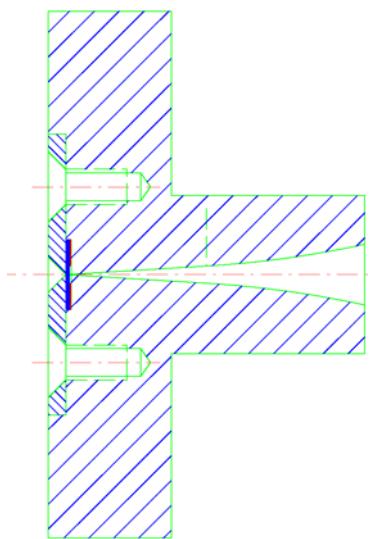


Fig. 34: Design of new Laval nozzles with exchangeable orifice.

⁵²M. Macri, Proceedings of Cern Accelerator School 11.-21.10.1983 (1984) 469

Not only the nozzle shape, but also the position of the first skimmer has a strong influence on the cluster beam. To learn more about the cluster beam profile in between the laval nozzle and the first skimmer an apparatus was constructed at SMI, which will measure the density distribution of the cluster-jet right after the nozzle by moving a Pitot tube inside the jet. The Pitot tube, movable by remote controlled stepper motors, was already successfully tested. The construction of a new cold head has been delayed because of major modifications in 2008 at both cluster-jet targets at GSI and Münster. So it was considered advantageous to wait and to construct identical cold heads to make it possible to interchange the nozzle on all three sites and have systems close to the final one to perform all necessary test measurements, including long term studies.

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 at SMI a test system to simulate the PANDA interaction zone, consisting of 6 NEG-coated pipes with a 1 μm thin film of Ti(30 at%)Zr(30 at%)V(40 at%) as getter. For (re)activation of the getter we have developed a heating system with backing pumps.

The aim of these measurements is the gain of knowledge on the service live till reactivation becomes necessary under conditions similar to the PANDA ones.

In addition it was considered useful to make preliminary measurements separately on a single coated tube. Therefore a tube with 500 mm length and 66 mm diameter was NEG-coated at GSI and installed at SMI in 2007. With this tube the following measurements are planned:

- the material constants A, B in the formula for the H-concentration (Sieverts' formula),
- the concentration of hydrogen in the getter depending on the regeneration (heating) time,
- the storage capacity for hydrogen and
- the pumping speed for H_2 as a function of the H-concentration in the bulk getter.

After three times activation and some leaks a test of the functionality of the NEG-coating was carried out, which revealed that the pumping speed for H_2 in this tube is only about $0.01 \text{ ls}^{-1}\text{cm}^{-2}$, whereas the typical pumping speed of a TiZrV coating is around $0.5 \text{ s}^{-1}\text{cm}^{-2}$ for H_2 ⁵³. So it is obvious that the getter is irreversibly saturated. The vacuum group at GSI has been requested to coat a similar tube, which will be delivered at the beginning of 2008, so that the measurements can finally be carried out in the first half of 2008.

Following observations have been made during heating and outgassing tests:

In a system with inactive NEG-coating the main components of the pumped gas are (in order of decreasing amount): H_2O , H_2 , CO_2 , CO .

The main components of the gas desorbing from the getter at room temperature are (in order of decreasing amount): CO , H_2 , CO_2 , H_2O . The values of the partial pressures depend on if the coating was heated before or not.

Hydrogen gets released from the getter in considerable quantities only above 150°C , which corroborates our measurements from 2006. That means that the activation process starts at above 150°C and all consecutive activation cycles have to be carried out at increasing temperatures⁵⁴. The

⁵³C. Benvenutti et al., Vacuum 53 (1999) 219

⁵⁴J. Kural, private communications

main gases getting released at 250°C during activation are (in order of decreasing amount): H₂(90%), H₂O, CO, CO₂.

The test system had a thermal insulation of several layers of fibre glass with a total thickness of 18.5 mm. The measurements showed that during the heating of the pipes at 250°C for several hours, around 100°C developed on the outer surface of the insulation. So any electrical components in PANDA have to be placed at least 3 cm away from the beam pipes, where the temperature due to radiation would only be around 50°C.

The test system with the 6 NEG-coated pipes was rebuilt in September 2007. It was assumed that due to a too strong influx of hydrogen in one pipe the coating there had gone brittle. Some granules of NEG-material fell out during dismounting and were photographed under the microscope with wires of different diameters for comparison of size (see Fig. 35). One can see that when the getter gets brittle due to a too high concentration of hydrogen atoms in the bulk material, corns of around 50–200 μm flocculate from the walls of the vacuum vessel.

Later the coating was reactivated by heating up to 200°C for 67 hours. Before and after activation outgassing measurements and mass scans were carried out. The results underline similar tests mentioned above that the main components of the desorbing gas at room temperature are (in order of decreasing amount): CO, H₂, H₂O, CO₂. After activation the fraction of CO has decreased from 80% to 58%.

Calculations of the PANDA vacuum system

Besides the experimental efforts regarding the internal target and the vacuum system of PANDA it has been considered necessary to tackle these issues also from the theoretical side by calculating pressure profiles of the target vacuum system and the antiproton-beam vacuum system, especially since the dimensions of the beam pipes are not completely fixed yet.

Therefore calculations of the vacuum situation in PANDA were started at SMI in 2007. Some rough calculations of several “what-if” scenarios for the PANDA Target Spectrometer were carried out (see Fig. 36). By assuming a hydrogen flux of 10⁻⁴ mbar l/s from the target into the beam pipes one obtains a maximum pressure of 3x10⁻⁶ mbar near the interaction point. This value can only be reduced by increasing the diameter of the interaction cross (pipe 3 & 4 in

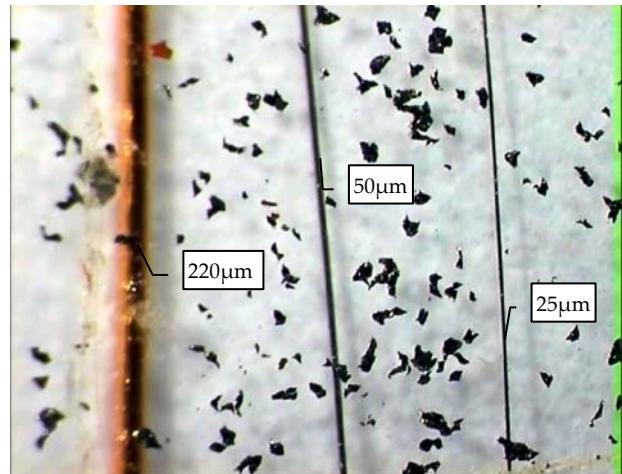


Fig. 35: Granules of NEG material after exceeding embrittlement limit for H₂.

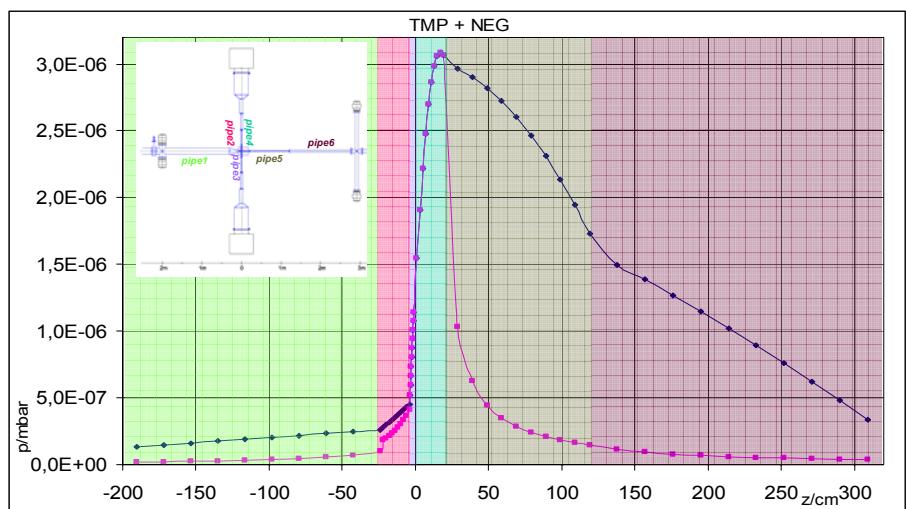


Fig. 36: Calculated pressure profile in PANDA Target Spectrometer.

inlay of Fig. 36).

The density of the residual gas is the main cause for background events during data taking. Due to the limitation of conductance, the residual gas is quite prominent along the beam pipes downstream of the interaction point, if the system gets pumped by turbo pumps only (blue line). By applying NEG-coating to the beam pipes, the density of the residual gas decreases by a factor of 5 (pink line). Further reduction of the gas load downstream could be achieved by increasing the diameter of the beam pipes in this section.

As an alternative to NEG-coating the use of large area cryopumps was investigated. Here the improvement was calculated to be a factor of 7.

It has been decided that these calculations will be expanded into full scale Monte Carlo calculations in 2008. The results of several calculations of "what-if" scenarios will be the basis for the decision of the final layout of the antiproton-beam pipes for PANDA.

Outlook

A major reconstruction of the Genova/Fermilab cluster-jet target at GSI is planned for 2008 in order to reach PANDA geometry (ca. 2 m distance nozzle–interaction zone and interaction zone–beam dump). Additionally a new control and read-out system will be set up during 2008 by INFN Genova and SMI. Together with the University Münster new cold heads and new nozzles will be built. Thereafter renewed tests to run the target in high-pressure mode will be carried out and we will try to produce a cluster jet with the desired density for PANDA.

In connection with the construction of new cold heads and new nozzles also the measurements of the cluster-beam profiles will continue in 2008. We will measure the jet profiles of different types of gases (hydrogen, nitrogen, argon, ...) with different nozzle sizes (15 µm to 40 µm) and different inlet pressures up to 20 bar in the temperature range from 20 K to 100 K. Also alternative nozzle designs will be tested, which will then be used in the cluster-jet targets at GSI and in Münster.

After the delivery of the new coated tube from GSI at the beginning of 2008 the preliminary measurements on the characterisation of the NEG coating will be carried out. The tests on the service live of the getter during high influx of hydrogen gas will commence immediately after the preliminary measurements.

During 2008 also the Monte Carlo simulations of the antiproton beam pipes will be carried out. Several "what-if" scenarios will be calculated and finally presented to the collaboration for deciding the final layout of the PANDA detector.

Wissenschaftliche MitarbeiterInnen:

Name	Funktion	Funktion: Zeitraum
Cagnelli, Michael	Projektmitarbeit	01.01.2004 bis 31.12.2007
Gruber, Alexander	Projektmitarbeit	01.01.2005 bis 31.12.2007
Marton, Johann	Projektmitarbeit	01.01.2004 bis 31.12.2007
Widmann, Eberhard	Projektmitarbeit	01.01.2005 bis 31.12.2007
Zmeskal, Johann	Projektleitung	01.01.2004 bis 31.12.2007

Vorträge/Posterpräsentationen:

Gruber, Alexander (16.03.2007) Vacuum scenarios in PANDA. Vortrag: Seminar zu aktuellen Themen der subatomaren Physik (SMI), Wien/AUSTRIA. [Gruber, Alexander]
--

Gruber, Alexander (27.03.2007) Some calculations of vacuum scenarios in PANDA. Vortrag: XX. PANDA Collaboration meeting (INFN Genova), Genova/ITALY. [Gruber, Alexander]
--

1.3.2.3.4 FS3_c_c: Cherenkov Imaging Detectors (DIRACsecondary beams)

Sonstiges Einzelforschungsprojekt (laufend)

Beginn: 01.02.2005, geplanter Abschluss: 31.01.2008

Our institute participates in the EU Design Study “DIRACsecondaryBeams” which is part of the technical developments for the new international research center FAIR at Darmstadt. We work on the task PANDA 1 within this design study. This sub-project is aiming at the development of imaging Cherenkov detectors proposed for the DIRC (detection of internally reflected Cherenkov light) and for the forward RICH detector of PANDA⁵⁵.

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), therefore the costs for detector and electronics are advantageous.

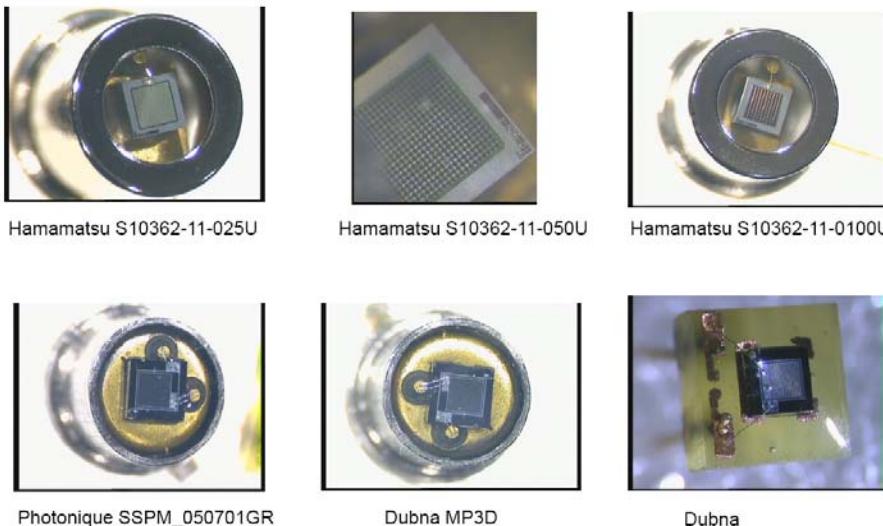


Fig. 37: Various SiPMs tested at SMI in 2007.

The development of SiPMs is proceeding fast and new photon detectors optimized for the short wavelengths and exhibiting high photo-detection efficiency are available. For the design study we are testing the newest generation of SiPMs concerning dark count rate, sub-nanosecond timing resolution, temperature effects on gain and noise etc.). In 2007 we conducted tests of various SiPMs (see Fig. 37) 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, ~ 3 times higher than the one from Photonique. A fast pulsed blue laser system is used to evaluate the timing performance of the devices. A large area ($2 \text{ mm} \times 2 \text{ mm}$) SiPM from Photonique was tested for the first time, showed however much higher dark count rate ($> 1 \text{ MHz}$ at 0°C). We also gained experience in operating SiPMs in beam, SiPMs in combination with scintillating fibers and

⁵⁵ <http://www-panda.gsi.de>

Cherenkov radiators were tested in beam at the accelerator centers GSI and LNF. Focusing of light onto the standard size of SiPM, 1 mm², is still a challenge to be overcome.

Outlook

The tests will be continued in 2008 with new generations of SiPMs. In this context a common project (INTAS) with Russian partner institutions is especially important since new non-commercial SiPMs can be characterized and evaluated for applications in Cherenkov detectors. The timing performance of the various SiPMs will be studied in detail.

Wissenschaftliche MitarbeiterInnen:

<i>Name</i>	<i>Funktion</i>	<i>Funktion: Zeitraum</i>
Cargnelli, Michael	Projektmitarbeit	01.02.2005 bis 31.01.2008
Fossati, Stefan	Projektmitarbeit	01.10.2006 bis 31.01.2007
Marton, Johann	Projektleitung	01.02.2005 bis 31.01.2008
Novotny, Christian	Forschungsassistenz	16.07.2007 bis 10.08.2007
Schafhauser, Matthias	Projektmitarbeit	28.08.2006 bis 31.01.2007
Suzuki, Ken	Projektmitarbeit	01.01.2007 bis 31.01.2008
Zmeskal, Johann	Projektmitarbeit	01.02.2005 bis 31.01.2008

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

Sonstiges Einzelforschungsprojekt (laufend)
Beginn: 01.11.2006, geplanter Abschluss: 30.04.2009



Fig. 38: SiPM test setup at SMI.

An INTAS (International Association for the promotion of co-operation with scientists from the New Independent States of the former Soviet Union) project coordinated by GSI was started. In November 2007 a "Kick-off" Meeting took place in the Joint Institute for Nuclear Research (JINR) in Dubna/Russia. It is anticipated that new silicon photomultiplier (SiPM) developed within this INTAS grant will be available for the evaluation in 2008. 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 (see Fig. 38).

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.

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

in the PANDA experiment at FAIR/GSI; set up of infrastructure of the partner institutes from Russia.

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

Wissenschaftliche MitarbeiterInnen:

<i>Name</i>	<i>Funktion</i>	<i>Funktion: Zeitraum</i>
Marton, Johann	Projektleitung	01.11.2006 bis 30.04.2009
Schweinzer, Christian	Forschungsassistenz	02.07.2007 bis 03.08.2007

1.3.2.3.6 FS3_d: Antiproton Ion Collider

*Sonstiges Einzelforschungsprojekt (laufend)
Beginn: 16.12.2004, geplanter Abschluss: 31.12.2025*

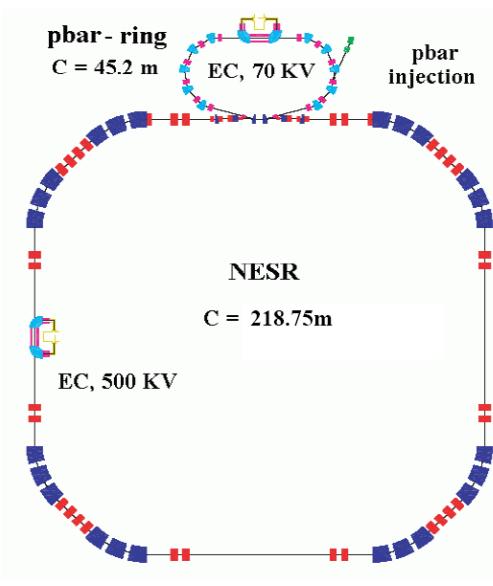


Fig. 39: Layout of AIC.

In January 2006 we delivered to the GSI FAIR Project a Technical Proposal for the Design, Construction, Commissioning and Operation of an Antiproton-Ion Collider (Fig. 39). We propose to use intermediate energy antiproton-ion collisions to determine the neutron and proton root-mean-square (rms) radii of stable and neutron-rich exotic nuclei by measuring the antiproton-nucleus absorption cross sections along isotopic chains in inverse kinematics in an Antiproton-Ion Collider (AIC).

The kinematically forward emitted (A-1) absorption products are completely identified so one can determine at the same time the cross section for the absorption on the neutrons and protons, respectively. The expected effects are studied theoretically in a microscopic model⁵⁶. The mass dependence of the absorption cross sections is found to follow closely the nuclear rms radii. The total absorption cross section is shown to be a superposition of cross sections describing partial absorption on neutrons and protons, respectively. Thus the measured differential cross sections for absorption on neutrons and protons will give information on their respective distributions.

The AIC Technical proposal has been accepted by the FAIR Management with the request that some technical aspects have to be settled in a Technical Design Report for the Antiproton Ion Collider.

In the first half of 2007 the proposal for a design study project within FP7 was finished and submitted. Unfortunately our Design Study proposal was not funded despite the fact that the scientific case was judged as very interesting.

Outlook

In 2008 the design study of the in-ring detectors, for which SMI has the responsibility, will continue and a first prototype will be constructed. The collaboration with our partners from BINP Novosibirsk has to be prolonged with the goal to work on the final design of the injector and collider section of AIC.

Wissenschaftliche MitarbeiterInnen:

Name	Funktion	Funktion: Zeitraum
Bühler, Paul	Projektmitarbeit	16.12.2004 bis 31.12.2025
Cargnelli, Michael	Projektmitarbeit	16.12.2004 bis 31.12.2025
Hirtl, Albert	Projektmitarbeit	16.12.2004 bis 31.12.2025
Kienle, Paul	Projektmitarbeit	16.12.2004 bis 31.12.2025
Marton, Johann	Projektmitarbeit	16.12.2004 bis 31.12.2025

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

Suzuki, Ken	Projektmitarbeit	01.01.2007 bis 31.12.2025
Widmann, Eberhard	Projektmitarbeit	16.12.2004 bis 31.12.2025
Zmeskal, Johann	Projektleitung	16.12.2004 bis 31.12.2025

Publikationen:

H. Lenske, P. Kienle (2007) Probing matter radii of neutron-rich nuclei by antiproton scattering. Physics Letters B, Bd. 647, S. 82. [Kienle, P. (KoautorIn)]
--

1.3.2.4 Sonstiges Einzelforschungsprojekte

1.3.2.4.1 Pion-Nucleon Interaction

Sonstiges Einzelforschungsprojekt (laufend)

Beginn: 01.04.1998, geplanter Abschluss: 01.08.2008

The goal of the pionic hydrogen experiment is the accurate measurement of the strong interaction shift (ε_{1s}) and width (Γ_{1s}) of the ground state in pionic hydrogen. The desired precision is better than 1% for the shift and about 2% for the width.

The quantities ε_{1s} and Γ_{1s} are related to the isoscalar (a^+) and isovector (a^-) pion-nucleon scattering lengths at threshold. Furthermore, the isovector scattering length (a^-) is connected to the pion nucleon coupling constant, which describes the strength of the coupling of the pion to the nucleon. An accurate knowledge of the pion-nucleon coupling constant is needed, for instance, for a precise calculation of the Goldberger-Treiman discrepancy, which constitutes a measure of chiral symmetry breaking due to non-vanishing quark masses.

It is expected, that an improved knowledge of ε_{1s} and Γ_{1s} will allow an important crosscheck for rapidly improving calculations done within the framework of low energy effective field theories, such as for instance Chiral Perturbation Theory (ChPT). ChPT is formulated in the so-called chiral limit, i.e., for vanishing quark masses and is an expansion of the effective Lagrangian in powers of

(small) momenta and the chiral symmetry breaking terms (light quark masses and the fine structure constant α).

The measurements were performed using the high-intensity pion beam available at the Paul Scherrer Institute (PSI) accelerator facility. X-rays emitted during the transition into the ground state of pionic hydrogen, i. e., the $\pi^- p_{np \rightarrow 1s}$ transitions with $n = 2, 3, 4$, were measured. In contrast to the energy of these radiative transitions (a few keV), the hadronic effects are only of the order of a few eV. Thus, in order to access such small effects, the use of a high-resolution crystal spectrometer is indispensable.

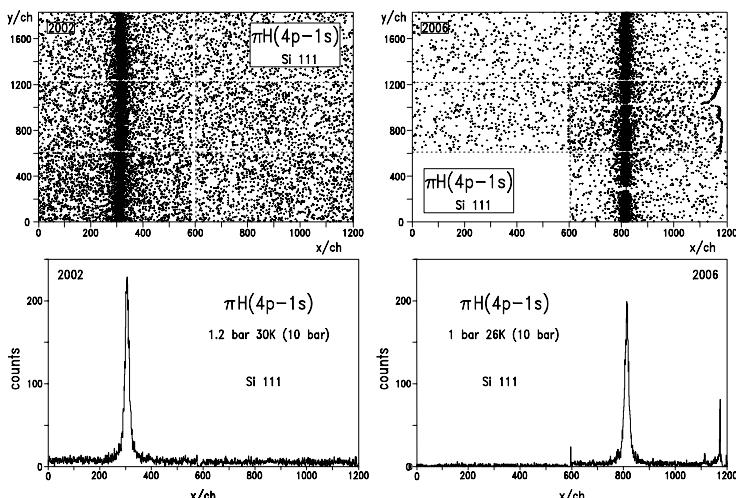


Fig. 40: Two dimensional plots of data and one dimensional position spectra of the $4p \rightarrow 1s$ transition measured in the years 2002 and 2006. The structure seen in the 2006 data on the right is due to the malfunction of one CCD chip and will be cut away for analysis.

The final value of the shift ε_{1s} was already obtained and the result is⁵⁷

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

which corresponds to an error of 0.2%, whereas the extraction of Γ_{1s} from the data is still in progress.

The main effort in the year 2007 was devoted to data analysis. In particular, an analysis routine and method to extract the strong interaction width from the data was developed in a PhD thesis at

⁵⁷ M. Hennebach, PhD thesis, Universität zu Köln, 2003.

our institute and first applied to the $4p \rightarrow 1s$ transition in pionic hydrogen (see Fig. 40). The choice to use the $4p \rightarrow 1s$ transition for the development of the analysis method was due to the fact that this transition is least affected by the so-called Coulomb de-excitation. Coulomb de-excitation is a collisional process occurring during the so-called atomic cascade, where the de-excitation energy is converted into kinetic energy of the colliding atoms, leading to a Doppler broadening of the measured X-ray lines. Atomic cascade is the collective term for all de-excitation processes occurring in the pionic atom after the pion was captured into a high orbit.

The developed analysis routine takes into account the motion (i.e. the kinetic energy distribution) of the formed pionic atoms, which substantially influences the width of the pionic transitions in question. Furthermore it uses the response function of the apparatus, measured with the ECRIT (Electron Resonance Ion Trap) in previous years. The ECRIT was setup in order to characterize the used crystals with narrow X-ray lines and hence to get accurate knowledge of their response functions.

In addition, this analysis method is based on thorough Monte Carlo studies to find out (1) the strong correlation between the background level and the strong interaction width, and (2) the dependence of the result on the low (i.e. Poisson) statistics of the pionic hydrogen data. A preliminary value for the strong interaction width was given and it reads⁵⁸:

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

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 experiment⁵⁹, where an error of 9% was given.

Outlook

The analysis method developed in our institute and first applied to the $4p \rightarrow 1s$ transition will be the basis for the evaluation of the X-ray spectra from the $3p \rightarrow 1s$ and $2p \rightarrow 1s$ transitions. This will significantly decrease the systematic error for the hadronic width of the ground state of pionic hydrogen. From the accumulated statistics for all transitions, finally an accuracy of about 2-3% for the strong interaction ground state width should be attainable

Furthermore, the developed analysis routine and method will also be used in the analysis of the $3p \rightarrow 1s$ transition in pionic deuterium. Pionic deuterium was measured in 2006 and its analysis is subject of a PhD thesis in a collaborating institute.

The analysis of pionic hydrogen data will be completed by the end of 2008 and with the resulting final publication the pionic hydrogen experiment ends.

Wissenschaftliche MitarbeiterInnen:

Name	Funktion	Funktion: Zeitraum
Gruber, Alexander	Projektmitarbeit	01.04.1998 bis 01.08.2008
Hirtl, Albert	Projektmitarbeit	01.03.2002 bis 01.08.2008
Juhasz, Bertalan	Projektmitarbeit	01.07.2005 bis 01.08.2008
Marton, Johann	Projektmitarbeit	01.04.1998 bis 01.08.2008
Pask, Thomas	Projektmitarbeit	01.06.2005 bis 01.08.2008
Widmann, Eberhard	Projektmitarbeit	01.11.2004 bis 01.08.2008
Zmeskal, Johann	Projektleitung	01.04.1998 bis 01.08.2008

⁵⁸ A. Hirtl, PhD thesis, TU Wien, 2008.

⁵⁹ H.C. Schröder et al, EPJ C21 (2001)473.

Publikationen:

- Indelicato, P.; Boucard, S.; Covita, D. S.; Gotta, D.; Gruber, A.; Hirtl, A.; Fuhrmann, H.; Le Bigot, E.-O.; Schlessler, S.; dos Santos, J. M. F.; Simons, L. M.; Stingelin, L.; Trassinelli, M.; Veloso, J.; Wasser, A.; Zmeskal, J. (2007) Highly charged ion X-rays from Electron-Cyclotron Resonance Ion Sources. NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH A, Bd. 580, S. 8. [Gruber, A. (KoautorIn); Hirtl, A. (KoautorIn); Zmeskal, J. (KoautorIn)]
- Marton, J (2007) Precision studies on strong interaction in pionic hydrogen. NUCLEAR PHYSICS A, Bd. 790, S. 328C. [Marton, J. (AlleinautorIn)]
- M Trassinelli, S Boucard, D S Covita, D Gotta, A Hirtl, P Indelicato, É-O Le Bigot, J M F dos Santos, L M Simons, L Stingelin, J F C A Veloso, A Wasser, J Zmeskal (2007) He-like argon, chlorine and sulfur spectra measurement from an Electron Cyclotron Resonance Ion Trap. Journal of Physics Conference Series, Bd. 58, S. 129-132. [Hirtl, A. (KoautorIn); Zmeskal, J. (KoautorIn)]

Vorträge/Posterpräsentationen:

- Albert, Hirtl (25.09.2007) Pionischer Wasserstoff: Präzisionsmessung zur starken Wechselwirkung. Vortrag: Fachausschusstagung Kern- und Teilchenphysik 2007, Langenlois/AUSTRIA. [Hirtl, Albert]
- Hirtl, Albert (10.12.2007) Determination of the strong interaction ground state width in pionic hydrogen. Vortrag: Seminar über Atomare und Subatomare Physik (Institut für Kernphysik, TU-Wien), Wien/AUSTRIA. [Hirtl, Albert]

1.3.2.4.2 X-ray spectroscopy at the VERA accelerator (PIXE)

Sonstiges Einzelforschungsprojekt (laufend)

Beginn: 20.01.2004, geplanter Abschluss: 31.12.2008

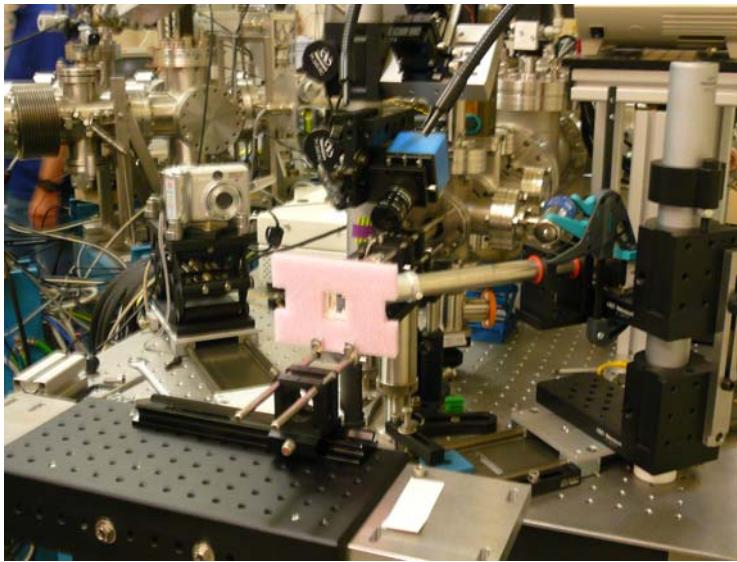


Fig. 41: PIXE setup at VERA. The picture shows the measurements of a KETEK SDD chip.

Particle Induced X-ray Emission (PIXE) is a powerful method for non-destructive elemental analysis. A new PIXE setup has been developed using a 3-MV tandem accelerator at VERA (Vienna Environmental Research Accelerator), together with the Institut fuer Isotopenforschung und Kernphysik der Universitaet Wien. Elemental analysis of the setup materials used for the kaonic atom X-ray experiments at SIDDHARTA (LNF), E570 (KEK) and E17 (J-PARC) is very important. These experiments will measure the kaonic atom X-

rays in an energy region of 6-8 keV, where yields are small. Therefore, the setup materials should be selected with a small contamination of the materials producing 6-8 keV fluorescence X-rays. The elements Fe and Cu, which are commonly used for setup materials, produce fluorescence X-rays within our interesting energy region. Thus, material selection with a small contamination of such elements is a key point for the success of the kaonic X-ray measurements.

The material selection for the SIDDHARTA experiment has been performed with the PIXE measurements at VERA, and the SIDDHARTA setup was constructed with the materials having small contents of Fe and Cu by analysis of the PIXE data. Also, effects of energy shifts of fluorescence X-rays due to satellite peaks were studied, as well as the test measurements of Silicon Drift Detectors (SDDs).

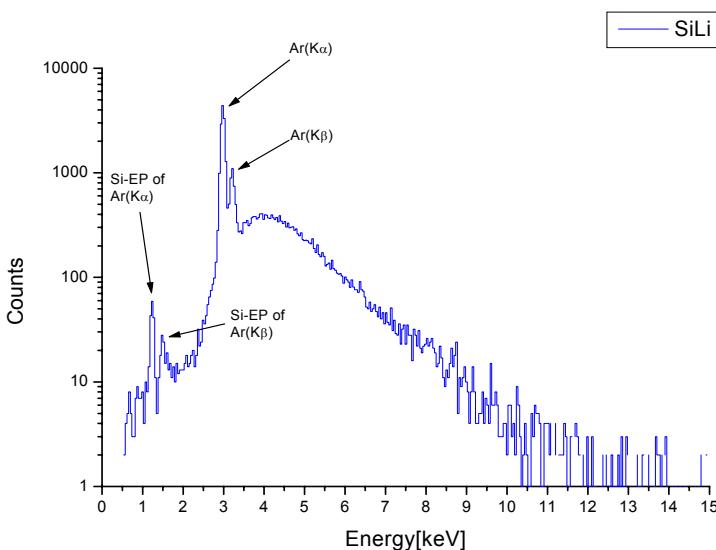


Fig. 42: Si central part of SIDDHARTA SDD by PIXE. Contamination of Fe and Cu are below the detection limit.

In 2007, elemental analysis of SDD chips was performed using Si(Li) and SDD X-ray detectors. In the measurements, the SIDDHARTA SDD chips and a SDD chip made by KETEK were used as targets of PIXE. Supports of the SDD chips, wiring lines, as well as X-ray detection area of SDDs were carefully measured. Since the solid angles of these parts seen by the SDDs in the SIDDHARTA setup are large, determination of Fe/Cu contaminations of them is

needed. Fig. 42 shows the X-ray energy spectra of the center of the SIDDHARTA SDD chip. The Ar X-ray peaks, which were used as calibration lines, were produced by air between the X-ray detectors and the target material. The amount of the Cu/Fe X-ray peaks in this SDD position was below the detection limit. The data of the element analysis are very important for the determination of a systematic error of the shift and width of the kaonic X-ray lines, and promise the success of the SIDDHARTA experiment.

Wissenschaftliche MitarbeiterInnen:

Name	Funktion	Funktion: Zeitraum
Cargnelli, Michael	Projektmitarbeit	20.01.2004 bis 31.12.2008
Ishiwatari, Tomoichi	Projektmitarbeit	20.01.2004 bis 31.12.2008
Marton, Johann	Projektmitarbeit	20.01.2004 bis 31.12.2008
Zmeskal, Johann	Projektleitung	20.01.2004 bis 31.12.2008

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

Sonstiges Einzelforschungsprojekt (laufend)
Beginn: 01.09.2004, geplanter Abschluss: 30.05.2008

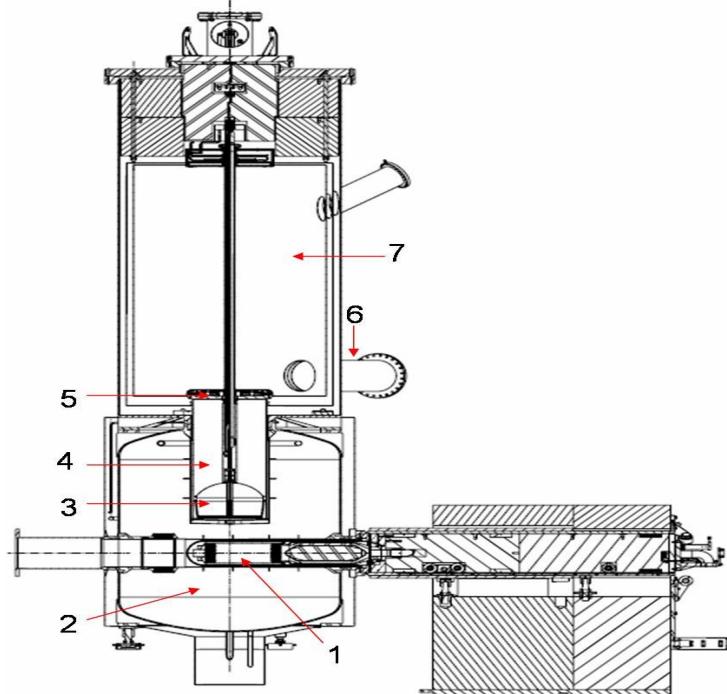


Fig. 43: Schematic view of the PSI ultra cold neutron source.
 1 - spallation target, 2 - heavy water moderator, 3 - solid deuterium moderator, 4 - vertical UCN guide, 5 - UCN valve, 6 - UCN guide (guiding UCN's to the experiments), 7 - UCN storage volume of 2 m³.

material. The aim of this project is to understand the physics processes of UCN neutron production in three different materials D₂, CD₄ and O₂. Our approach was to investigate those materials in a UCN production experiment. One of the investigated topics deals with the cold neutron energy dependent UCN production in solid and gaseous D₂⁶⁰.

In the case of D₂ gas the neutron scattering is described in terms of the double differential cross section by Young and Koppel (Y-K). Solid D₂ requires another approach because of the proximity of the molecules and thus different from gas properties. The results of other UCN experiments with solid D₂ (UCN lifetime in sD₂, total scattering and UCN production cross section) pointed out that the neutron–solid D₂ interaction can be well described by a theoretical model in which one calculates the downscattering of cold neutrons via phonon creation in solid D₂.

In our experiment we have explicitly measured energy dependent UCN production in gas D₂ at 25K and in solid D₂ at 8K using a velocity selected cold neutron beam. The experiment was performed on the CN beam line for fundamental physics (FUNSPIN) at the Swiss spallation neutron source SINQ. UCN production cross sections were extracted from the measured UCN rates (corrected for background) and normalized to the CN flux as corrected for extraction efficiency. The cross section values are shown in Fig. 44 for gaseous ortho D₂ and in Fig. 45 for

A new high intensity ultracold neutron (UCN) source (Fig. 43) is under construction at the Paul Scherrer Institut. The source is working in the pulsed mode (1% duty cycle) and uses the 1.2 MW proton beam from the PSI 600 MeV Ring Cyclotron for production of the spallation neutrons on the lead target. The produced neutrons are moderated to the ultracold neutron energies (a few hundreds neV) by a system consisting of about 4 m³ of heavy water at room temperature and 30 dm³ of solid deuterium at the temperature of about 5 K. The UCN's leave the solid deuterium moderator and, after passing through the vertical guide, enter the storage volume. Afterwards the UCN's are transported to the experiments (e.g. nEDM, neutron life time).

The performance of the UCN sources depends strongly on the properties of the moderator

⁶⁰ PRL, 99, 262502 (2007)

solid ortho D₂. For each data point the normalized velocity-selected CN spectrum is displayed on the CN energy axis. Along with the data, the model calculations are shown as continuous function of CN energy (black line) and averaged over the velocity-selected CN spectra (red squares),

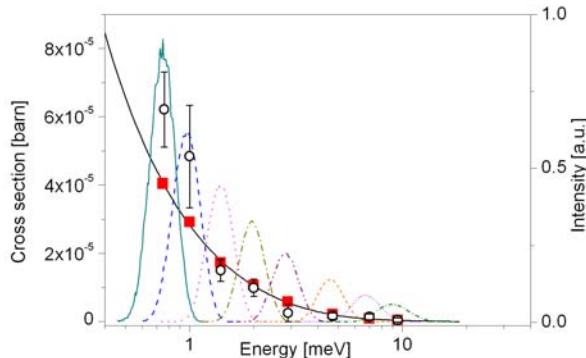


Fig. 44: Scaled measured (open circles) and calculated UCN production cross sections per molecule (Young and Koppel model: continuous black line and red squares, see text) for gaseous ortho D₂ at 0.12 MPa and 25 K. The velocity selected CN intensity distributions are normalised to the same intensity.

respectively.

Outlook

The data presented here form a part of the Ph.D. thesis of M. Kasprzak which is expected to be finished in May 2008.

Wissenschaftliche MitarbeiterInnen:

Name	Funktion	Funktion: Zeitraum
Kasprzak, Małgorzata	Projektmitarbeit	01.09.2004 bis 30.05.2008
Widmann, Eberhard	Projektmitarbeit	01.11.2004 bis 30.05.2008

Publikationen:

Atchison, F.; Blau, B.; Daum, M.; Fierlinger, P.; Geltenbort, P.; Gupta, M.; Henneck, R.; Heule, S.; Kasprzak, M.; Knecht, A.; Kuzniak, M.; Kirch, K.; Meier, M.; Pichlmaier, A.; Reiser, R.; Theiler, B.; Zimmer, O.; Zsigmond, G. (2007) Measurement of the Fermi potential of diamond-like carbon and other materials. NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION B, Bd. 260, S. 647. [Kasprzak, M. (KoautorIn)]
Heule, S.; Atchison, F.; Daum, M.; Foelske, A.; Henneck, R.; Kasprzak, M.; Kirch, K.; Knecht, A.; Kuzniak, M.; Lippert, T.; Meier, M.; Pichlmaier, A.; Straumann, U. (2007) Diamond-like carbon coated ultracold neutron guides. APPLIED SURFACE SCIENCE, Bd. 253, S. 8245. [Kasprzak, M. (KoautorIn)]
Atchison, F.; Brys, T.; Daum, M.; Fierlinger, P.; Foelske, A.; Gupta, M.; Henneck, R.; Heule, S.; Kasprzak, M.; Kirch, K.; Koetz, R.; Kuzniak, M.; Lippert, T.; Meyer, C. -F.; Nolting, F.; Pichlmaier, A.; Schneider, D.; Schultrich, B.; Sieniroth, P.; Straumann, U. (2007) Structural characterization of diamond-like carbon films for ultracold neutron applications. DIAMOND AND RELATED

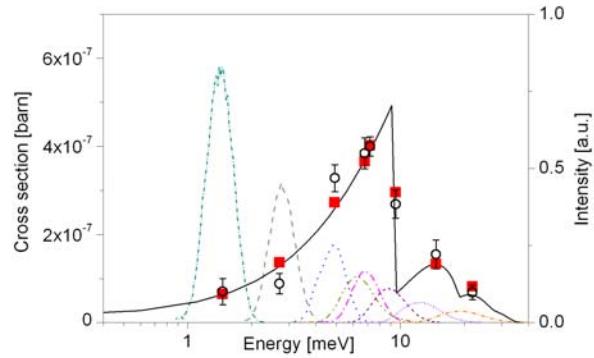


Fig. 45: Scaled measured (open circles) and calculated UCN production cross sections per molecule (multiphonon Debye model: continuous black line and red squares, see text) for solid ortho D₂ at 8 K. The velocity selected CN intensity distributions are normalised to the same intensity.

MATERIALS, Bd. 16, S. 334. [Kasprzak, M. (KoautorIn)]

Atchison, F.; Brys, T.; Daum, M.; Fierlinger, P.; Geltenbort, P.; Kasprzak, M. et al. (2007) Loss and spinflip probabilities for ultracold neutrons interacting with diamondlike carbon and beryllium surfaces. Physical Review C, Bd. 76, S. 044001. [Kasprzak, M. (KoautorIn)]

Ban, G.; Bodek, K.; Daum, M.; Henneck, R.; Heule, S.; Kasprzak, M. et al. (2007) Direct Experimental Limit on Neutron-Mirror-Neutron Oscillations. Physical Review Letters, Bd. 99, S. 161603. [Kasprzak, M. (KoautorIn)]

Atchison, F.; Blau, B.; Bodek, K.; Brandt van der, B.; Brys, T.; Kasprzak, M. et al. (2007) Cold neutron energy dependent production of ultracold neutrons in solid deuterium. Physical Review Letters, Bd. 99, S. 262502. [Kasprzak, M. (KoautorIn)]

Vorträge/Posterpräsentationen:

Kasprzak, Malgorzata (20.02.2007) The PSI ultracold neutron source and solid deuterium. Vortrag: Swiss Physical Society Meeting, Zürich/SWITZERLAND. [Kasprzak, Malgorzata]

Kasprzak, Malgorzata (25.04.2007) Measurement of UCN production and CN transmission of D2, O2 and CD4. Vortrag: International Collaboration on Advance Neutron Sources, Dongguan/CHINA. [Kasprzak, Malgorzata]

Kasprzak, Malgorzata (25.09.2007) Converters for ultracold neutron source. Vortrag: 57. Jahrestagung der OEPG, Langenlois/AUSTRIA. [Kasprzak, Malgorzata]

Kasprzak, Malgorzata (04.10.2007) Ultracold neutron production and cold neutron transmission for deuterium, oxygen and heavy methane. Vortrag: Seminar at the Institut fuer Isotopenforschung und Kernphysik, Wien/AUSTRIA. [Kasprzak, Malgorzata]

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

*Sonstiges Einzelforschungsprojekt (laufend)
Beginn: 01.10.2004, geplanter Abschluss: 31.12.2008*

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.

A lively debate on its limits is going on and many experiments to search for tiny violations of PEP were carried out. Based on an experimental procedure performed in 1988 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).

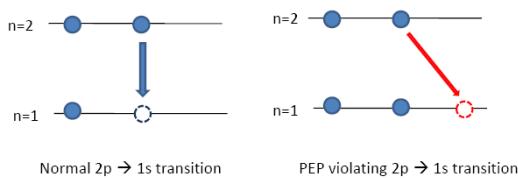


Fig. 46: Principle of the PEP test performed in the VIP experiment.



Fig. 47: VIP setup with shielding in the underground laboratory of LNGS.

The experimental method (see Fig. 46) is based on introducing new electrons into a copper strip and to look for X-rays resulting from the $2p \rightarrow 1s$ anomalous 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 $K\alpha$ -transition by about 400 eV (7.64 keV instead of 8.04 keV), providing an unambiguous signal of the PEP violation. For the X-ray detection we employ the CCD 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-INFN⁶¹.

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

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

The VIP apparatus is installed and is taking data in the Gran Sasso underground laboratory (see Fig. 47). A substantially improved value for

⁶¹ G. Beer et al, Phys. Rev. Lett. 94 (2005) 212302.

the probability of PEP violation for electrons was found by VIP ($< 4.5 \times 10^{-28}$) already in a test experiment in 2005.

In the measurements in 2007 this limit was further improved by nearly one order of magnitude⁶² ($< 6.0 \times 10^{-29}$, preliminary value) thus improving the limit by a factor of 250 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 2008. In parallel a further improved experiment (VIP2) employing new X-ray detectors 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 2008 in the laboratory as well as in LNGS.

Wissenschaftliche MitarbeiterInnen:

Name	Funktion	Funktion: Zeitraum
Cargnelli, Michael	Projektmitarbeit	01.10.2004 bis 31.12.2008
Ishiwatari, Tomoichi	Projektmitarbeit	01.10.2004 bis 31.12.2008
Kienle, Paul	Projektmitarbeit	01.10.2004 bis 31.12.2008
Marton, Johann	Projektmitarbeit	01.10.2004 bis 31.12.2008
Widmann, Eberhard	Projektmitarbeit	01.11.2004 bis 31.12.2008
Zmeskal, Johann	Projektleitung	01.10.2004 bis 31.12.2008

Publikationen:

E. Milotti; 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; D. Pietreanu; T. Ponta; D. L. Sirghi; F. Sirghi; L. Sperandio; E. Widmann; J. Zmeskal, (2007) VIP: An Experiment to Search for a Violation of the Pauli Exclusion Principle. International Journal of Modern Physics A, Bd. 22, S. 242. [Cargnelli, M. (KoautorIn); Ishiwatari, T. (KoautorIn); Marton, J. (KoautorIn); Widmann, E. (KoautorIn); Zmeskal, J. (KoautorIn)]
Bartalucci, S.; Bertolucci, S.; Bragadireanu, M.; Cargnelli, M.; Catitti, M.; Petrascu, C. Curceanu; Di Matteo, S.; Egger, J. -P.; Guaraldo, C.; Iliescu, M.; Ishiwatari, T.; Laubenstein, M.; Marton, J.; Milotti, E.; Pietreanu, D.; Ponta, T.; Sirghi, D. L.; Sirghi, F.; Sperandio, L.; Widmann, E.; Zmeskal, J. (2007) The VIP (violation of the Pauli exclusion principle) experiment. INTERNATIONAL JOURNAL OF QUANTUM INFORMATION, Bd. 5, S. 299. [Cargnelli, M. (KoautorIn); Ishiwatari, T. (KoautorIn); Marton, J. (KoautorIn); Widmann, E. (KoautorIn); Zmeskal, J. (KoautorIn)]
Cargnelli, M.; Curceanu, C.; Ishiwatari, T.; Kienle, P.; Marton, J. et al. [...] (15.06.2007) New experimental limit on Pauli Exclusion Principle violation by electrons (VIP experiment at Gran Sasso)., Journal of Physics: Conference Series 67 (Third International Workshop DICE2006 - Quantum Mechanics between Decoherence and Determinism: new aspects from particle physics to cosmology); London: Institute of Physics, S. 012033. [Cargnelli, M. (KoautorIn); Ishiwatari, T. (KoautorIn); Kienle, P. (KoautorIn); Marton, J. (KoautorIn); Widmann, E. (KoautorIn); Zmeskal, J. (KoautorIn)]

⁶² J. Marton et al., „A high sensitivity test of the Pauli Exclusion Principle“, Proceedings of the 1st Austria-France-Italy Symposium „From the vacuum to the universe“, Univ. Innsbruck, 2007

Vorträge/Posterpräsentationen:

Marton, Johann (19.10.2007) High Sensitivity Test of the Pauli Exclusion Principle using X-ray Spectroscopy. Vortrag: 1st AFI Symposium/AUSTRIA. [Marton, Johann]

Marton, Johann (25.10.2007) High Sensitivity Test of the Pauli Exclusion Principle using X-ray Spectroscopy. Vortrag: Fachausschuss Kern- und Teilchenphysik der Österr. Physikalischen Gesellschaft/AUSTRIA. [Marton, Johann]

Marton, Johann (21.05.2007) High Sensitivity Test of the Pauli Exclusion Principle using X-ray Spectroscopy. Vortrag: IQOQI Seminar, Vienna/AUSTRIA. [Marton, Johann]

1.3.2.4.5 Other activities

Sonstiges Einzelforschungsprojekt (laufend)
Beginn: 01.10.2004, geplanter Abschluss: 31.12.2008

Wissenschaftliche MitarbeiterInnen:

Name	Funktion	Funktion: Zeitraum
Kienle, Paul	Projektmitarbeit	01.01.2007 bis 31.12.2025
Marton, Johann	Projektmitarbeit	01.01.2007 bis 31.12.2025
Reda, Ranja	Projektmitarbeit	01.01.2007 bis 31.12.2007
Widmann, Eberhard	Projektmitarbeit	01.01.2007 bis 31.12.2025
Zmeskal, Johann	Projektmitarbeit	01.01.2007 bis 31.12.2025

Publikationen:

Yu.A. Litvinov, F. Bosch, H. Geissel, J. Kurcewicz, Z. Patyk, N. Winckler, L. Batist, K. Beckert, D. Boutin, C. Brandau, L. Chen, C. Dimopoulou, B. Fabian, T. Faestermann, A. Fragner, L. Grigorenko, E. Haettner, S. Hess, P. Kienle, R. Knöbel, C. Kozhuharov, S. A. Litvinov, L. Maier, M. Mazzocco, F. Montes, G. Münzenberg, A. Musumarra, C. Nociforo, F. Nolden, M. Pfützner, W. R. Plaß, A. Prochazka, R. Reda, R. Reuschl, C. Scheidenberger, M. Steck, T. Stöhlker, S. Torilov, M. Trassinelli, B. Sun, H. Weick, and M. Winkler (2007) Measurement of the β^+ and Orbital Electron-Capture Decay Rates in Fully Ionized, Hydrogenlike, and Heliumlike ^{140}Pr Ions. Physical Review Letters, Bd. 99, S. 262501. [Kienle, P. (KoautorIn); Reda, R. (KoautorIn)]
B. Kłos, A. Trzcińska, J. Jastrzebski, T. Czosnyka, M. Kisieliski, P. Lubiski, P. Napiorkowski, L. Piekowski, F. J. Hartmann, B. Ketzer, P. Ring, R. Schmidt, T. von Egidy, R. Smolaczuk, S. Wycech, K. Gulda, W. Kurcewicz, E. Widmann, B. A. Brown (2007) Neutron density distributions from antiprotonic ^{208}Pb and ^{209}Bi atoms. Physical Review C, Bd. 76, S. 014311. [Widmann, E. (KoautorIn)]
Reda, Ranja (2007) Neutrino Quantum Beats. Diplomarbeit, Technical University of Vienna, Wien. [Reda, R. (AlleinautorIn)]

1.3.3 Medienpräsenz

Datum	Medium	Titel	Schlagwort
2007.05.11	derstandard.at	Österreich beteiligt sich an Teilchenbeschleuniger FAIR	FAIR Schwerionenforschung
2007.05.11	APA J Forschung	Roadmap für Forschungs-Großprojekte	FAIR Schwerionenforschung
2007.05.11	APA-ZukunftWissen	Österreich beteiligt sich an geplantem neuen Beschleuniger FAIR	FAIR Schwerionenforschung
2007.10.11	APA-ZukunftWissen OM	30 Jahre altes Physik-Rätsel gelöst	K-Mesonen in Atomkernen
2007.10.12	APA J Forschung	Altes Rätsel um "Starke Wechselwirkung" gelöst	K-Mesonen in Atomkernen
2007.10.12	APA-ZukunftWissen	Physiker lösten altes Rätsel um Starke Wechselwirkung	K-Mesonen in Atomkernen
2007.10.12	Österreich Journal	30 Jahre altes Rätsel gelöst	K-Mesonen in Atomkernen
2007.10.13	ORF ON science.orf.at	Physiker lösten Rätsel um Starke Wechselwirkung	K-Mesonen in Atomkernen
2007.10.17	sfg.at	Rätsel um Starke Wechselwirkung gelöst	K-Mesonen in Atomkernen
2007.11.06	Bohmann Business	30 Jahre altes Physik-Rätsel gelöst	K-Mesonen in Atomkernen
2007.12.01	at.venture	Reich beschenkt – Wundertüte Wissenschaft	Jahresrückblick

2. Tabellarische Darstellung und wissenschaftliche Kennzahlen

17. Wissenschaftliche Publikationen		gesamt
A) Bücher / Monographien oder Editionen		1
A) Peer-reviewte Beiträge in Fachzeitschriften oder Sammelwerken		32
· davon in indizierten Fachzeitschriften		26
B) Herausgeberschaften		0
B) längere Beiträge ohne Peer-Review in Fachzeitschriften oder Sammelwerken		1
C) Sonstige wissenschaftliche Publikationen		1
Veröffentlichungen von Nachwuchswissenschaftler(inne)n		
· Diplomarbeiten		3
· Dissertationen		0
· Habilitationen		1
Lexikonartikel		0

17. Liste

A) Peer-reviewte Beiträge in Fachzeitschriften oder Sammelwerken

Atchison, F.; Blau, B.; Bodek, K.; Brandt van der, B.; Brys, T.; Kasprzak, M. et al. (2007) Cold neutron energy dependent production of ultracold neutrons in solid deuterium. Physical Review Letters, Bd. 99, S. 262502. [Kasprzak, Malgorzata: KoautorIn]; peer-rev. indiziert

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2. Tabellarische Darstellung und wissenschaftliche Kennzahlen

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Zmeskal, J.; Bazzi, M.; Beer, G.; Bombelli, L.; Bragadirean, A. M.; Cargnelli, M.; Catitti, M.; Curceanu (Petrascu), C.; Fiorini, C.; Frizzi, T.; Ghio, F.; Girolami, B.; Guaraldo, C.; Iliescu, M.; Curceanu(Petrascu), C.; Ishiwatari, T.; Kienle, P.; Lechner, P.; Sandri, P.; Levi; Lucherini, V.; Longoni, A.; Marton, J.; Pietreanu, D.; Ponta, T.; Sirghi, D. L.; Sirghi, F.; Soltau, H.; Strueder, L.; Widmann, E. (2007) Experimental studies on kaonic atoms at DAPHNE. NUCLEAR PHYSICS A, Bd. 790, S. 667C. [Ishiwatari, Tomoichi: KoautorIn; Widmann, Eberhard: KoautorIn; Kienle, Paul: KoautorIn; Zmeskal, Johann: KoautorIn; Marton, Johann: KoautorIn; Cargnelli, Michael: KoautorIn]; peer-rev. indiziert

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B) längere Beiträge ohne Peer-Review in Fachzeitschriften oder Sammelwerken

M Trassinelli, S Boucard, D S Covita, D Gotta, A Hirtl, P Indelicato, É-O Le Bigot, J M F dos Santos, L M Simons, L Stingelin, J F C A Veloso, A Wasser, J Zmeskal (2007) He-like argon, chlorine and sulfur spectra measurement from an Electron Cyclotron Resonance Ion Trap. Journal of Physics Conference Series, Bd. 58, S. 129-132. [Zmeskal, Johann: KoautorIn; Hirtl, Albert: KoautorIn]; lang

C) Sonstige wissenschaftliche Publikationen

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Habilitationen

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