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Annual Report 2011

Stefan Meyer Institute (SMI) for subatomic Physics

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Content

1. Mission Statement

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

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

We specialize in precision spectroscopy of exotic atoms and exotic meson-nucleus bound states as an integral part of international collaborations at largescale research facilities including

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

These are among the world's leading facilities for subatomic physics and our projects are subject to rigorous annual evaluation to monitor their progress in a dynamic and expanding field. We aspire to perform research that increases the understanding of fundamental physics principles while simultaneously providing opportunities for young researchers in Austria to obtain valuable experience at institutes unavailable to them at home.

The current three main fields of activity at SMI are:

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

- **Hadron physics:** here we study the strong interaction and its corresponding theory, quantum chromodynamics (QCD), at low energies in the non-perturbative regime and at intermediate energies. Chiral symmetry and its breaking or restoration plays an important role. They contribute to the origin of the masses of hadrons. The masses of the three current quarks add up to only a few percent of the measured hadron mass, which originates mainly from the dynamic interaction between the quarks and the exchange particles of the strong interaction, the gluons. The underlying mechanism is, to date, not understood at all. The experimental approach is the spectroscopy of meson-nucleus bound states using large 4π detectors like FOPI and PANDA, and the measurement of the effect of the strong interaction on the low-lying atomic states of simple exotic atoms by X-ray spectroscopy.
- **Advanced instrumentation:** progress in experimental physics needs new or improved instrumentation and methodology. In this field we currently work on three experimental projects funded within the EU FP7 Integrated Activity HadronPhysics2: novel photon detectors (SiPM, silicon photomultipliers) for use in Cherenkov detectors, large size tracking detectors based on GEM (Gas Electron Multiplier) technology, and the development of high-intensity gas jets to be used as internal targets in accelerators. SMI also hosts one site of the PANDA Grid computer network and participates in the development of Grid software.

Further activities include an underground laboratory experiment at Laboratori Nazionali di Gran Sasso (Italy) on a high-sensitivity test of the Pauli principle, in the **VIP** (Violation of the Pauli Principle) experiment. SMI also participates in the analysis of an experiment investigating two-body decays of stored and cooled ions at GSI. A network within the EU FP7 Integrated Activity HadronPhysics2 bringing together experimentalists and theoreticians working on strangeness nuclear physics, **LEANNIS**, is coordinated at SMI.

2. Scientific Avtivity 2011

2.1 Zusammenfassung des wissenschaftlichen Berichts 2011 (deutsch)

E. Widmann erhält ERC Advanced Grant für die Hyperfeinspektroskopie von Antiwasserstoff

Durch den Erhalt des ERC Advanced Investigators Grants von Eberhard Widmann ist die Durchführung des Projektes „Messung der Hyperfeinstruktur des Grundzustandes von Antiwasserstoff“ auf 5 Jahre gesichert. Die genaue Bestimmung der Hyperfeinstruktur von Antiwasserstoff ist ein empfindlicher Test für die CPT Symmetrie. Die Messung wird am CERN unter Leitung des SMI, innerhalb der ASACUSA Kollaboration durchgeführt.

Materie-Antimaterie Symmetrie: ASACUSA @ CERN-AD

Hyperfeinstruktur des Grundzustandes von Antiwasserstoff

Der Vergleich der Hyperfeinstruktur von Wasserstoff und Antiwasserstoff erlaubt einen sehr genauen Test der Materie-Antimaterie Symmetrie. Für die erste Phase der Messung der Hyperfeinstruktur von Antiwasserstoff wurden 2011 erste Elemente der dafür benötigten experimentellen Einrichtung am CERN installiert, unter anderem eine Mikrowellenkavität und ein Sextupolmagnet. Während der Strahlzeit konzentrierten wir uns darauf die Parameter des polarisierten Antiwasserstoffstrahls zu optimieren. Am SMI wurde eine Vorrichtung zur Erzeugung eines monoatomaren Wasserstoffstrahles entwickelt, welcher für die Kalibrierung des Antiwasserstoffapparates verwendet werden wird.

Präzisionsspektroskopie von antoprotonischem Helium

Die Präzisionsspektroskopie von antiprotonischem Helium wurde mittels Laser- und Mikrowellenspektroskopie durchgeführt. Durch den Vergleich der Messungen mit QED Berechnungen konnte das Verhältnis der Massen von Antiproton und Elektron mit verbesserter Genauigkeit bestimmt werden. Zudem haben wir die Messung der Übergänge zwischen Hyperfeinzuständen von antiprotonischem ^{3}He weitergeführt. Die Resultate weisen einen um 25% reduzierten Fehlerbereich aus und sind konsistent mit neuesten Berechnungen. Da eine Verbesserung der Genauigkeit, weder im experimentellen noch theoretischen Bereich zu erwarten sind, haben wir dieses Projekt damit abgeschlossen.

Hadronen Physik

Mit der Untersuchung von Hadronen mit „strangeness“ versucht man die komplexe Dynamik und Phänomene von Quarks und Gluonen, welche durch die Quantenchromodynamik (QCD) beschrieben werden, zu verstehen, z.B. Symmetriebrechungsgesetze, Enstehung der Massen von Hadronen, die Veränderung der Eigenschaften von Hadronen in Kernmaterie, neue Formen von Hadronen.

Röntgenspektroskopie kaonischer Atome – das SIDDHARTA Experiment

Kaonen sind stark wechselwirkende Teilchen und enthalten ein „strange“ Quark. Um kaonische Atome zu erzeugen, wird ein Elektron aus der Atomhülle durch ein Kaon ersetzt. Da Elektronen im Gegensatz zu Kaonen nicht stark wechselwirken, wird durch diesen Austausch des Elektrons die atomare Struktur des Atoms verändert. Diese Veränderung wird sichtbar durch die Messung der Energieverteilung der charakteristischen Röntgenstrahlung aus der man wiederum Rückschlüsse auf die Wechelwirkung von Kaonen und Nukleonen bei kleinen Energien gewinnen kann. Die Grösse ist wichtig für das Verständnis der Mechanismen die zur Erzeugung der Hadronenmassen beitragen. 2011 wurden die Daten der SIDDHARTA Messung von kaonischem Wasserstoff fertig ausgewertet und das Resultat wurde publiziert. Die gewonnen Werte der Verschiebung und Breite der Röntgenlinien von kaonischem Wasserstoff setzen bezüglich ihrer Genauigkeit neue Maßstäbe und sind für die theoretischen Betrachtungen der niederenergetischen Kaon-Nukleon Wechselwirkung von weitreichender Bedeutung.

FOPI @ GSI

Mit dem FOPI Detektor wurde ein Experiment mit einem Pionenstrahl durchgeführt. Dabei wurden Pionen mit einem Impuls von 1.7 GeV/c auf Targets aus Kohlenstoff, Kupfer und Blei geschossen. Durch die Messung der Produktionwarscheinlichkeit von K^+K^- Paaren und von Φ Mesonen als Funktion der Atommasse des Targetmaterials kann Einsicht in das Verhalten von Hadronen in Kernmaterie gewonnen werden. Bei der Messung kam auch eine GEM-TPC (Gas Electron Multiplication – Time Projection Chamber) erfolgreich zum Einsatz, welche als Prototyp für das PANDA Experiment gebaut wurde. Mit der GEM-TPC konnte die Nachweisqualität des FOPI Detektors von Teilchen die in Vorwärtsrichtung fliegen verbessert werden.

Das PANDA Experiment

Das PANDA Experiment ist eines der großen FAIR – Projekte um die Annihilation von Protonen mit Antiprotonen im Energiebereich von Hadronen mit „strange“ und „charm“ Quarks zu untersuchen. Das SMI leistet Beiträge zu PANDA im Bereiche der Entwicklung von Simulations- und Analysesoftware, dem Betreiben des PANDAGrid und der R&D des Wasserstoff cluster-jet Targets, sowie von Anwendungen der GEM Technik für das Tracking und der Entwicklung von Sensoren für Cerenkovlicht. Mit dem Einreichen eines SFB Antrages an das FWF zusammen mit Kollegen der Universität Graz und der Technischen Universität Wien und dem Beitritt zur BELLE Kollaboration in enger Zusammenarbeit mit der Gruppe von Ch. Schwanda vom HEPHY, sind wir bestrebt unseren Beitrag zum experimentellen Program von PANDA zu verstärken.

LEANNIS

LEANNIS ist ein Netzwerk im Rahmen des von der EU finanzierten FP7 Integrated Activity HadronPhysics2 Program. Es unterstützt die Zusammenarbeit von experimentellen und theoretischen Physikern im Bereiche der „strangeness“ Physik und wird vom SMI koordiniert. An einem Treffen in Heidelberg im July 2011 wurden die neuesten Entwicklungen und Resultate auf dem Gebiet diskutiert.

R&D von Detektorkomponenten

Wichtige Komponenten von Messanordnungen werden am SMI konstruiert und gefertigt um anschließend an Beschleunigeranlagen, wie CERN (Schweiz), GSI (Deutschland), LNF (Italien) und J-PARC (Japan) zum Einsatz zu kommen. Die R&D in 2011 erfolgte hauptsächlich im Rahmen der „Joint Research Activities“ des von der EU finanzierten Projektes HadronPhysics2. Das SMI ist an 3 Subprojekten beteiligt, dem WP19: Future Jet (Kryogenische Strahlen von Teilchen mit einer Grösse im Nano- und Mikrometerbereich für den Einsatz in kernphysikalischen Experimenten), WP24: JointGEM (sehr leichte und große auf GEM basierende Trackingdetektoren) und WP28: SiPM (Silizium Photonenvervielfacher für den Einsatz in zukünftigen Detektorsystemen). Das Subprojekt

JointGEM wird vom SMI geleitet. Zusätzlich wurde für die Messung der Hyperfeinaufspaltung in antiprotonischem Helium am CERN-AD eine neue Mikrowellentargetzelle enwickelt und für das FOPI Experiment an der GSI wurde ein neuer Vetodetektor gebaut. Technische Berichte (TDR) für die GEM-TPC und das Targetsystem für PANDA wurden ausgearbeitet.

Internationale Konferenz über Exotische Atome (EXA2011)

Die EXA Konferenz wurde das vierte Mal vom SMI organisiert und durchgeführt (5. – 9. September 2011) und hat über 120 Wissenschaftler nach Wien gelockt. Ein spezieller Glanzpunkt der vierten Durchführung war die Sitzung zum 20 jährigen Jubiläum von antiprotonischem Helium, einem Forschungsbereich in welchem der Direkor des SMI, E. Widmann seit den Anfängen aktiv beteiligt ist. Zur Feier des 80. Geburtstag des vormaligen SMI Direktors, P. Kienle, wurde das Symposium „Creativity-Innovation – the seed for Frontier Science“ abgehalten.

2.2 Highlights 2011 (deutsch)

Genaueste Messung der Energien der charakteristischen Röntgenstrahlung von kaonischem Wasserstoff

Mit SIDDHARTA gelang die genaueste Messung des atomaren Grundzustandes in kaonischem Wasserstoff, einem Atom welches aus einem negativ geladenen Kaon und einem Proton besteht. Diese Messung erlaubt die Wechselwirkung zwischen Kaon und Proton bei kleineren Energien zu bestimmen als es mit herkömmlichen Streuexperimenten möglich ist und stellt eine wichtige Referenzmarke für theoretische Berechnungen dar.

Five most important publications 2011

- Bazzi, M.; Beer, G.; Bombelli, L.; Bragadireanu, A. M.; Cargnelli, M. et al., A new measurement of kaonic hydrogen X-rays, *Physics Letters B* **704** (2011) 113-117.

  In dieser Publikation werden die Resultate des SIDDHARTA Experimentes beschrieben. Es gelang die bisher genaueste Messung der Energie und Breite, der für den 2p-1s Übergang charakteristischen Röntgenlinie in kaonischem Wasserstoff. Die publizierten Werte sind wichtige Referenzen für die Entwicklung von theoretischen Modellen der Kaon-Nukleon Wechselwirkung.

- Hori, M.; Sótér, A.; Barna, D.; Dax, A.; Hayano, R. et al., Two-photon laser spectroscopy of antiprotonic helium and the antiproton-to-electron mass ratio, *Nature* **475** (2011) 484–488.

  Die bis anhin genaueste Bestimmung des Verhältnisses der Antiproton- und Elektronmasse gelang mit Zwei-Photonen Laserspektroskopie am CERN-AD. Die neue Technik ermöglichte es uns die Genauigkeit der Messung um eine Faktor 3 zu steigern. Die Masse des Antiprotons ist damit mit ähnlicher Genauigkeit bekannt wie die Masse des Protons und das Resultat bestätigt die CPT Symmetrie mit einer Genauigkeit von 0.7 ppb.

- Friedreich, S.; Barna, D.; Caspers, F.; Dax, A.; Hayano, R. S. et al., First observation of two hyperfine transitions in antiprotonic (3)He*, Physics Letters B* **700** (2011) 1-6.

  Zum ersten Mal gelang es den Übergang zwischen Hyperfeinzuständen in antiprotonischem ^{3}He zu beobachten. Die Resultate stimmen mit Berechnungen gut überein. Damit ist uns ein erster wichtiger Schritt gelungen das komplexe Dreikörpersystem, in dem jeder Zustand in 8 Hyperfeinzustände aufgespalten ist besser zu verstehen. Die Resultate bestätigen auch unsere Resultate mit ^{4}He, aus denen wir durch Vergleich von Messwert und Berechnung einen Wert für das magnetische Moment des Antiprotons abgeleitet haben.

- Massiczek, O.; Friedreich, S.; Juhasz, B.; Widmann, E.; Zmeskal, J., Liquid helium-free cryostat and hermetically sealed cryogenic microwave cavity for hyperfine spectroscopy of antiprotonic helium, *Nuclear Instruments & Methods in Physics Research A* **659** (2011) 55-60.

  Für die Messung der Hyperfeinstruktur von antiprotonischem Helium wurde am SMI ein Kryostat entwickelt der ohne Kühlflüssigkeit auskommt. Der Hauptteil des Systems ist eine Mikrowellenkavität für Frequenzen zwischen 11 und 16 GHz, welches Eintrittsfenster für den Antiprotonenstrahl sowie für eine Laserstrahl enthält. Mit diesem System war eine unterbruchsfreie Messung möglich womit die Messzeit effektiver genutzt werden konnte.

- Strauch, Th.; Amaro, F.; Anagnostopoulos, D.; Bühler, P.; Covita, D. et al., Pionic deuterium, *European Physical Journal A* **47** (2011) 1-19.

  Das in dieser Veröffentlichung beschriebene Experiment wurde am Paul Scherrer Institut (PSI) in der Schweiz durchgeführt. Mit einem Kristallspektrometer und einer Zyklotronfalle wurde die Verschiebung und Verbreiterung der charakeristischen Röntgenlinien in pionischem Deuterium gemessen wodurch man u.a. Informationen über die Pion-Nukleon Streulänge ableiten kann.

2.3 Summary of the scientific report 2011

ERC Grant awarded to E. Widmann for the hyperfine spectroscopy of antihydrogen

The project of measuring the ground-state hyperfine structure of antihydrogen as a sensitive test of CPT symmetry, which within the ASACUSA collaboration is led by SMI, received a strong boost by the award of an ERC Advanced Investigators Grant to SMI director E. Widmann. This will allow to fully pursue this project for the next five years.

Matter-Antimatter Symmetry: ASACUSA @CERN-AD

Ground-state hyperfine structure of antihydrogen

The hyperfine structure is one of two properties of antihydrogen that promise some of the most sensitive test of matter-antimatter symmetry since the value for hydrogen is known to very high precision. In 2011 the atomic beam line apparatus for the first phase of the measurements including a microwave cavity and a sextupole magnet was completed and installed at CERN. The efforts during the beam time concentrated on improving the antihydrogen production scheme to optimize the parameters of the polarized antihydrogen beam needed for the hyperfine structure measurements. At SMI the development of a mono-atomic hydrogen beam started which will be used to offline commission the atomic beam line.

Precision spectroscopy of antiprotonic helium

The precision spectroscopy of antiprotonic helium, an exotic three-body system where the antiproton occupies highly-excited metastable states, was pursued with laser and microwave spectroscopy. Using two-photon laser spectroscopy and comparing the results to state-of-the-art three-body QED theory, a new value of the antiproton-to-electron mass ratio was obtained that is three times better than our previous result. The determination of two transitions within a hyperfine multiplet of anitprotonic ^{3}He was continued resulting in a 25% reduced error bar. The results are consistent with the most recent calculations and both experiment and theory have reached a level where no further improvements are expected, therefore this project will now be discontinued.

Hadron Physics

Strangeness hadron physics tries to reveal the complex dynamics and phenomena of quarks and gluons, e.g., symmetry breaking pattern and hadron mass generation, hadron properties in nuclear medium, new forms of hadrons, which are described by Quantum Chromodynamics (QCD).

X-ray spectroscopy of kaonic atoms – the SIDDHARTA experiment

Kaons are strongly interacting particles containing a "strange" quark. When implanted in matter they are slowed down and form kaonic atoms by replacing an electron of the atom. While electrons do not feel the strong interaction, the atomic structure of kaonic atoms is changed, leading to a modification of the energy of emitted X-rays. Measuring this energy modification we can gain information on the kaon-nucleon interaction. Quantum Chromodynamics (QCD) cannot describe this low-energy process quantitatively using quarks and gluons. Instead "effective models" are used which need experimental data as input. The special importance of these processes lies in the possibility to obtain information on "chiral symmetry breaking" and thus on the mechanism of hadron mass generation (e.g. protons or neutrons). In 2011 the final results of kaonic hydrogen was published which provide new benchmark data for theory by determining the shift and width of kaonic hydrogen X-ray lines to the highest precision so far. The data are in better agreement with theory than previous results and thus have a big impact on the understanding of low-energy kaon-nucleon interaction.

FOPI at GSI

Using the FOPI detector at GSI we studied the strangeness production of π^{-} - induced reactions on nuclei. A π^{-} beam with a momentum of 1.7 GeV/c was used and data were collected with carbon, copper and lead targets during a 17-days beam time. The prototype of a GEM-TPC (Gas Electron Multiplier – Time Projection Chamber), originally built for R&D studies for PANDA, was just as well successfully operated in this experiment, improving the tracking capability of the FOPI drift chamber.

The production of $K^{+}K^{-}$ as a function of the target mass number and a transparency ratio measurement of Φ mesons would gain insight of properties of hadrons in the nuclear medium.

The PANDA Experiment

The PANDA Experiment is one of the large-scale projects at FAIR to study antiproton annihilations on nucleons and nuclei in the energy range of strange and charmed hadrons. The SMI activities in the PANDA project are contributions to the software framework and simulation/analysis, contributing to the development of the PandaGrid, as well as R&D activities for the hydrogen cluster jet target, applications of the GEM technique to tracking detectors and Cerenkov counters of the DIRC type. In order to strengthen our physics contributions in the fields relevant to PANDA we submitted an SFB proposal to the FWF together with colleagues from the University of Graz and the Technical University of Vienna.

LEANNIS

A network within the EU FP7 Integrated Activity HadronPhysics2 bringing together experimentalists and theoreticians working on strangeness nuclear physics, called LEANNIS, which is coordinated by SMI. In the LEANNIS Meeting in Heidelberg in July 2011 the present status and the future directions of theoretical and experimental work were discussed, attended by distinguished researches and young scientists, showing clearly the strong interest in this field.

Advanced Instrumentation

Important parts for our experiments are designed and constructed at SMI, for the use at foreign accelerator facilities, where the experiments are performed, e.g.: CERN-AD, Switzerland; GSI, Germany; LNF, Italy and J-PARC, Japan.

For the measurements of the hyperfine splitting in the antiprotonic helium system at the CERN-AD a new microwave target cell was developed. For the pion experiment at GSI with the FOPI detector system we have developed a veto counter within the vacuum beam pipe, fitting within a prototype TPC, which was built to demonstrate the proof of principle that such a TPC with GEM readout is feasible to be used as inner tracker for PANDA.

In addition R&D work is performed mainly in the framework of “Joint Research Activities”, within the HadronPhysics2 project funded by the EU. The Institute participates in 3 work packages: WP19: FutureJet - Cryogenic jets of nano- and micrometer-sized particles for hadron physics, WP24: JointGEM - Ultra-light and ultra-large tracking systems based on GEM technology and WP28: SiPM - Avalanche Micro-Pixel Photo-Diodes for Frontier Detector Systems. WP24 is led by SMI.

A Technical Design Report (TDR) for a GEM-TPC as central tracker of PANDA was prepared. Furthermore, the TDR for the PANDA targets has been presented to the collaboration in December 2011 and will be submitted to FAIR in the first half of 2012.

International Conference on Exotic Atoms (EXA2011)

The fourth EXA Conference was organized by SMI from September 5th to 9th, 2011. It attracted more than 120 scientists working in the broad research field of exotic atoms and related topics. A special highlight was a session on „20 years of antiprotonic helium“, a field that SMI director E. Widmann pursues since its beginning. On the occasion of the 80th birthday of P. Kienle (former director of SMI) a symposium “Creativity-Innovation-the Seed for Frontier Science“ took place in the framework of EXA.

2.4 Highlights 2011

Most precise determination of the X-ray energies of kaonic hydrogen

The final result of the SIDDHARTA experiment gave the most precise measurement of the effect of the strong interaction to the ground state of kaonic hydrogen, an exotic atom consisting of a negative kaon bound to a proton. This way the interaction between kaon and proton can be measured at much lower energies compared to usual scattering experiments, giving very precise constraints to theory. The new results are in closer agreement with calculations than the ones before and thus will have an important impact on theoretical studies in this field.

Five most important publications 2011

- Bazzi, M.; Beer, G.; Bombelli, L.; Bragadireanu, A. M.; Cargnelli, M. et al., A new measurement of kaonic hydrogen X-rays, *Physics Letters B* **704** (2011) 113-117.

  This paper reported the final result of the SIDHHARTA experiment on the energy of the 2p-1s X-rays in kaonic hydrogen which is the most precise determination of strong-interaction induced shift and broadening of the ground state of kaonic hydrogen. The result, which is fundamental in understanding the low-energy kaon-nucleaon interaction, improved the previous inconsistency between the experimental DEAR result and scattering data and thus has a large impact on theoretical studies in this field.

- Hori, M.; Sótér, A.; Barna, D.; Dax, A.; Hayano, R. et al., Two-photon laser spectroscopy of antiprotonic helium and the antiproton-to-electron mass ratio, *Nature* **475** (2011) 484–488.

  The currently most precise determination of the antiproton-to-electron mass ratio has been obtained by two-photon laser spectroscopy of antiprotonic helium at the Antiproton Decelerator at CERN. The two-photon technique allowed us to improve our own previous value by a factor 3, showing that the antiproton mass is now known to the same order of magnitude than the proton mass. This can be interpreted as a test of CPT symmetry at an accuracy of 0.7 ppb, or - assuming that CPT is conserved - be used as a contribution to the table of fundamental constants issued by CODATA.

- Friedreich, S.; Barna, D.; Caspers, F.; Dax, A.; Hayano, R. S. et al., First observation of two hyperfine transitions in antiprotonic (3)He, *Physics Letters B* **700** (2011) 1-6.

  The first ever observation of two hyperfine transitions in antiprotonic ^{3}He was reported. The results agreed well within errors to state-of-the-art theoretical results. This constitutes an important step in the understanding of this complex three-body system where each state is split in eight hyperfine levels. The results make us more confident in our results in ^{4}He where we used the agreement between theory and experiment to extract an improved value on the magnetic moment of the antiproton.

- Massiczek, O.; Friedreich, S.; Juhasz, B.; Widmann, E.; Zmeskal, J., Liquid helium-free cryostat and hermetically sealed cryogenic microwave cavity for hyperfine spectroscopy of antiprotonic helium, *Nuclear Instruments & Methods in Physics Research A* **659** (2011) 55-60.

  For the measurements of the hyperfine structure of antiprotonic helium a new liquid-helium free cryostat was constructed at SMI. The core piece is a cryogenic hermetically sealed microwave cavity at central frequencies between 11 and 16 GHz that has windows for both antiproton and laser breams to enter. The main practical advantage was the ability of uninterrupted operation which saved a significant amount of beam time.

- Strauch, Th.; Amaro, F.; Anagnostopoulos, D.; Bühler, P.; Covita, D. et al., Pionic deuterium, *European Physical Journal A* **47** (2011) 1-19.

  The experiment was performed at PSI with the crystal spectrometer and the cyclotron trap to measure the pionic deuterium shift, which will provide important additional constraints for the pion-nucleon isospin scattering lengths. The measured hadronic broadening of pionic deuterium is related to the pion absorption and production at threshold and together with the ^{3}He data at threshold the determination of the effective couplings for s-wave pion absorption on isoscalar and isovector nucleon-nucleon pairs is possible.

2.5 Report on the scientific activity during 2011

The research program of our institute consists of two main research topics ("Forschungsschwerpunkte"): **Matter-Antimatter symmetry** (ASACUSA @ CERN) and **Hadron physics**. Both are divided into individual projects. A third main topic is **Advanced instrumentation**, and there are also a few smaller research projects.

2.5.1 Matter-Antimatter Symmetry: ASACUSA @ CERN-AD

(Supported by bm_wf, ERC advanced Grant of E. Widmann)

This is one of the main scientific programs at SMI. Physical laws are believed to be invariant under the combined transformations of charge (C), parity (P), and time (T) reversal. This CPT symmetry implies that antimatter particles have exactly the same mass and charge as their particle counterparts. Within the ASACUSA program, SMI is involved in the precision laser and microwave spectroscopy of antiprotonic helium, and the development of a spectrometer beam line for the measurement of the ground-state hyperfine splitting of antihydrogen. These experiments investigate the CPT symmetry as well as the accuracy of state-of-the-art three-body QED calculations via the precision laser and microwave spectroscopy of atoms containing antiprotons. SMI is the leading institute in the antiprotonic helium microwave spectroscopy experiment and the antihydrogen project.

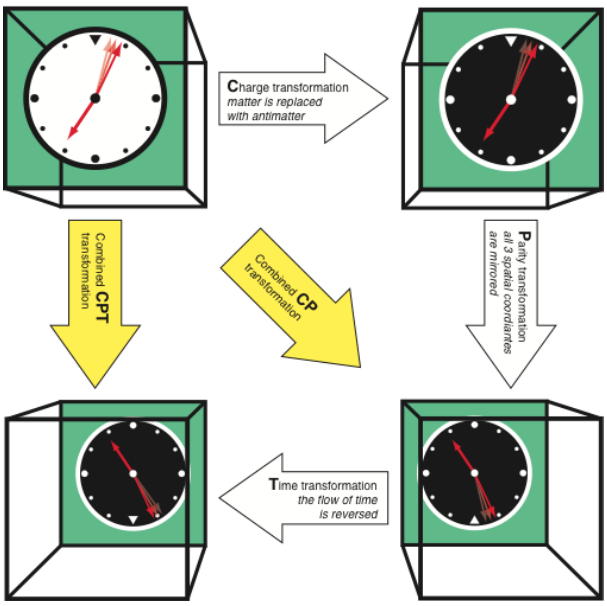


Figure 1: Illustration of the C, CP, and CPT symmetries.

Antiprotonic helium is a neutral three-body system consisting of a helium nucleus, an antiproton and an electron. The energy levels of the antiproton have been measured by precision laser spectroscopy to an accuracy of about 10^{-8}. Furthermore, each level is split into quadruplet (octuplet) sublevels in ^{4}He (^{3}He) due to the magnetic interaction of the electron spin, the antiproton angular momentum and the antiproton spin (and the helium nucleus). The energy difference between these sublevels can be measured with microwave spectroscopy, and from the obtained transition frequencies, the antiproton magnetic moment can be determined. With our measurement performed in 2011 (see section 2.5.1.2) we completed our research programme. Since the precison in both, experiment and theory of the HFS measurement of $\bar{p}$He can not be improved any more SMI will concentrate from 2012 on the measurement of the HFS of Antihydrogen, a programme which is the topic of the ERC Advanced Grant of E. Widmann. Antihydrogen, the simplest antimatter atom consisting of a positron and an antiproton, is a promising tool for testing CPT symmetry, because its CPT conjugate system, hydrogen, has been measured to a precision of ~10^{-14} for the 1s-2s two-photon laser transition and ~10^{-12} for the ground-state hyperfine structure. Even if antihydrogen cannot be measured to this high precision, it can rival the best CPT tests on an absolute scale.

2.5.1.1 Antihydrogen

(Ph.D. thesis of S. Federmann)

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

The ASACUSA collaboration at CERN's Antiproton Decelerator is planning to measure the ground-state hyperfine splitting (GS-HFS) of antihydrogen ($\bar{H}$) using an atomic beam apparatus [1] similar to the ones which were used in the early days of hydrogen HFS spectroscopy. The apparatus will use antihydrogen atoms produced in a superconducting cusp trap (i.e. anti-Helmholtz coils), which has been developed by collaborators from the University of Tokyo. Due to the strongly inhomogeneous magnetic field of this trap, the antihydrogen atoms emerging from the trap will either be focused onto a 1.42-GHz radio-

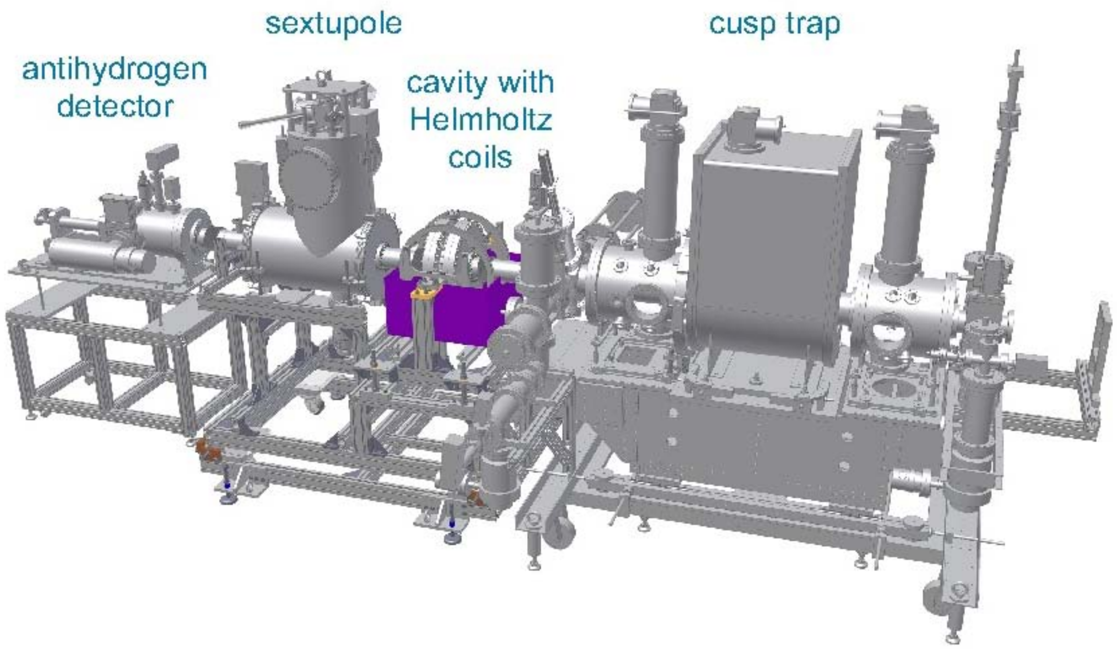


Figure 2: Drawing of the full setup of the Hbar HFS measurement at CERN including the cusp trap, atomic beam line, and antihydrogen detector.

frequency resonator, or defocused, depending on their spin direction. Thus the H̄ beam entering the resonator will be partially polarized. The oscillating magnetic field in the resonator can flip the spin of the H̄ atoms when it is on resonance with one of the hyperfine transitions. A superconducting sextupole magnet installed after the resonator will then act as a spin analyzer, and will focus the atoms onto an antihydrogen detector, or defocus them, depending on their spin direction. This forms the basis of the spectroscopy method: when the radiofrequency field in the resonator is on resonance with one of the ground-state hyperfine transitions, fewer atoms will reach the antihydrogen detector.

In 2011, the superconducting sextupole magnet has been delivered to CERN, where it successfully passed the necessary cryogenic and magnetic tests. The radiofrequency resonator has also been fully manufactured and tested, and was found to conform to the radiofrequency and vacuum specifications. A pair of Helmholtz coils have been designed, manufactured and installed around the resonator to produce a weak (1 - 10 G) homogeneous magnetic field in the centre of the resonator. In order to decrease the strong stray magnetic field of the cusp trap inside the resonator, a cylindrical soft iron shield has been installed downstream of the cusp trap, and a cube-shaped, double-layered mu-metal shield has been installed around the resonator and the Helmholtz coils. All these components have been installed in the ASACUSA experimental zone, downstream of the cusp trap, where they were successfully tested.

During the beam time, antihydrogen atoms were created, just like last year, in a cusp trap by mixing antiprotons coming from an antiproton catching trap, and positrons coming from a positron accumulator. The antiproton annihilations were observed by a 3D tracking detector surrounding the cusp trap. This year, however, not the same antihydrogen production method was tried as last year but another one called autoresonant excitation. This method promises to produce antihydrogen atoms not in highly excited but in lower-lying states, which are more suitable for our experiment. The autoresonance method has been successfully employed by the ALPHA collaboration to produce antihydrogen atoms. In our case, however, the production rate was too low to attempt any spectroscopy measurements. Therefore in 2012 we will try this method again; we have several ideas how to increase the production rate. If successful, the first measurements can commence using the antihydrogen spectroscopy beam line, which will be the first ever spectroscopy measurement of an atomic system consisting entirely of antimatter**.**

(1) B. Juhász, E. Widmann, Hyp. Int. 193, 305 (2009)

2.5.1.2 Atomic hydrogen beam

(Diploma thesis of M. Diermaier)

The antihydrogen experiment setup at the CERN facility should be tested with normal hydrogen atoms instead of antihydrogen, because hydrogen atoms are easy and cheap to produce. A source with an atomic hydrogen beam had to be designed. A dissociation source for the production of atomic hydrogen was provided to us by the University of Aarhus. With this source a beam line was set up at SMI - consisting of the dissociation source, a vacuum system and a mass spectrometer to analyze the beam (Figure 3) - to make a proof the concept. Finally, this source will be used in the antihydrogen experiment at CERN to test the whole hyperfine apparatus. First successful tests were performed at SMI which showed that we have to improve the detection system of hydrogen atoms. This new detection system, consisting of a cross-beam ion source is under construction.

Figure 3: Picture of the beam test stand for mono-atomic hydrogen production.

2.5.1.3 Precision spectroscopy of antiprotonic helium

(Supported by FWF grant I-198-N20)

Microwave spectroscopy

(Ph.D. thesis of S. Friedreich, Diploma thesis of O. Massiczek)

A precise measurement of the antiprotonic helium hyperfine structure (HFS) can be compared with three-body quantum electrodynamics (QED) calculations as a test of their predictions. The hyperfine structure of antiprotonic helium ($\bar{p}He^+$) was investigated by a laser-microwave-laser spectroscopy method, where a first laser pulse was used to depopulate half of the hyperfine (HF) states. A microwave pulse transferred population between two of the hyperfine substates and a second laser pulse to the same transition as before measured the population change caused by the microwave pulse. A comparison between the measured transition frequencies and three-body QED calculations can be used to determine the antiproton spin magnetic moment $\mu_{\bar{p}}$. In $\bar{p}^3He^+$ eight HF substates exist and thus there are four electron spin flip transitions which can be stimulated with an oscillating magnetic field. The additional spin of the nucleus compared to $\bar{p}^4He+$ [2] leads to a more complex structure for $\bar{p}^3He+$ and thus this system provides a more stringent test of the theory. In 2010 the first microwave spectroscopic measurement of the hyperfine structure of $\bar{p}^3He^+$ was successfully performed (see Figure 4). The first results were presented at the LEAP2011 Conference in Vancouver/Canada and published in Physics Letters B [3]. During the beamtime 2011 an improved statistics for these two transitions of the (n,L)=(36,34) state, where n stands for the principal quantum number and L for the angular momentum quantum number, was achieved. The error for the single lines could be further reduced by more than 25%. The final values for the measured frequencies of the individual transitions are 11.12548(10) GHz and 11.15739(13) GHz, less than 0.5 MHz higher than the current theoretical values and still within their estimated errors. Also the frequency difference between the two HF lines agrees with theoretical calculations. This difference is proportional to the magnetic moment of the antiproton. Due to the limits in measurement time and beam quality as well as the complexity of this three-body-system no further improvement can be expected. Also from a theoretical point of view it is unlikely that the precision can still be increased. Consequently the microwave spectroscopy measurements on the hyperfine structure of $\bar{p}^{3}He^{+}$ have been concluded in 2011. A detailed publication with the final results is currently in preparation.

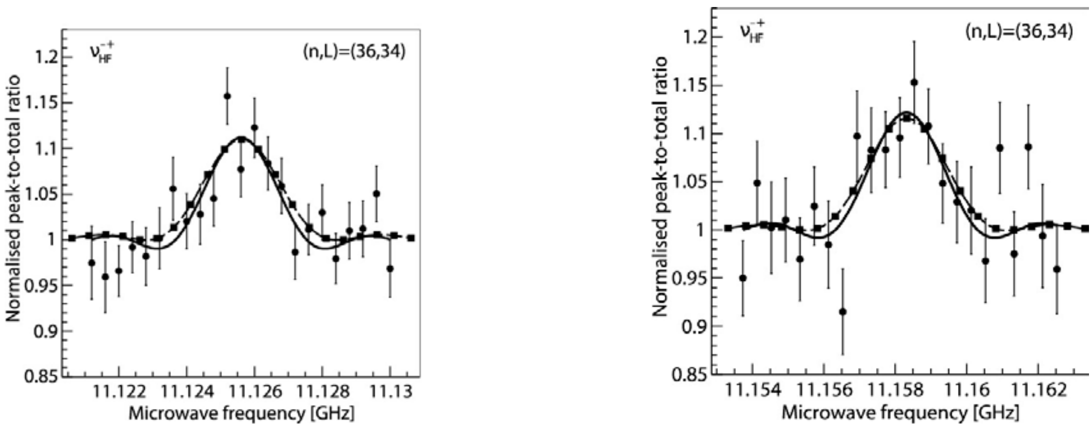


Figure 4: Scan over the microwave frequency for the 11.12548(10) GHz (left panel) and 11.15793(13) GHz (right panel) oft he (n,L) = (36, 34) state of $\bar{p}^{3}He^{+}$. The dashed curves show simulations using the same parameters as the measurements.

Laser spectroscopy

These three-body systems are also amenable to precision laser spectroscopy, the results of which can be used to determine the antiproton-to-electron mass ratio and to constrain the equality between proton and antiproton masses and charges. This experiment is performed under the responsibility of the collaborators from Max-Planck-Institut für Quantenoptik in Munich. $\bar{p}^{3}He+$ and $\bar{p}\,^{4}He^{+}$ isotopes were irradiated with two counter-propagating laser beams, thereby exciting some non-linear two-photon transitions of the antiproton of the type (n,L)=(n-2,l-2) at the deep UV wavelengths λ=139.8, 193.0 and 197.0 nm. This partially cancelled the Doppler broadening of the laser resonance caused

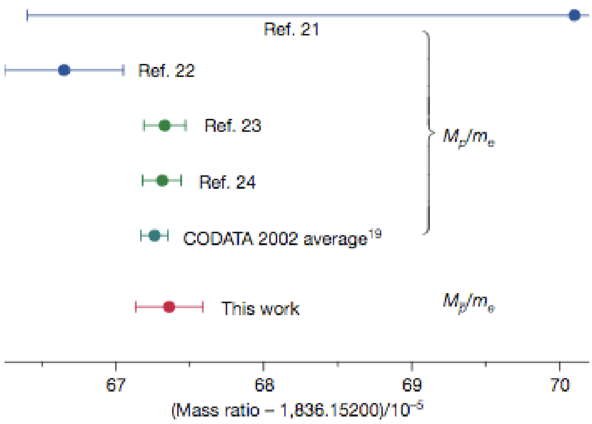


Figure 5: Antiproton-to-electron and proton-to-electron mass ratios. The antiproton-to-electron mass ratio determined by two-photon spectroscopy agrees to within a fractional precision of < 1.3 ppb with the proton-to-electron values measured in previous experiments (Ref. 21 [4], Ref. 22 [5], Ref. 23 [6], Ref. 24 [7]) and the CODATA 2002 [8] recommended value obtained by averaging them.

by the thermal motion of the atoms. The resulting narrow spectral lines allowed to measure three transition frequencies with fractional precisions of 2.3 – 5 parts in 10^9. By comparing the results with three-body QED calculations, the antiproton-to-electron mass ratio could be derived as 1836.1526736(23). This agrees with the proton-to-electron value known to a similar precision. It is the best agreement between theoretical and experimental values and the most precise measurement for the antiproton mass to date [9]. These results have been published in Nature [10] in 2011.

The measurements of eleven single photon transitions at a temperature of 1.5 K (compared to ~10 K previously) could be completed in 2010-2011. At this low temperature the Doppler effect is further reduced and the signal-to-noise ratio improved. A publication of the final results is currently in progress.

(2) T. Pask et al., Phys. Lett. B, 678 (2009) 6.
(3) S. Friedreich et al., Phys. Lett. B, 700 (2011) 1.
(4) R.S. Jr. Van Dyck et al., Bull. Am. Phys. Soc., 31 (1986).
(5) D.L. Farnham et al., Phys. Rev. Lett., 75 (1995).
(6) T. Beier et al., Phys. Rev. Lett., 88 (2002).
(7) J. Verdu et al., Phys. Rev. Lett., 92 (2004).
(8) P.J. Mohr et al., Rev. Mod. Phys., 77 (2005).
(9) M. Hori et al., CODATA, submitted (2011).
(10) M. Hori et al., Nature, 475 (2011) 484.

2.5.2 Hadron Physics

The physics of strongly interacting particles – hadrons – is dealing with topics which have profound consequences for the understanding of basic questions like the generation of the mass of the visible Universe or the structure of exotic objects – e.g. neutron stars – in the Universe. To gain information on how strong interaction works, exotic atoms with strangeness provide a unique insight. For example the low-energy observables of the strong interaction of the negatively charged kaon with the proton can be extracted from X-ray spectroscopy of kaonic hydrogen atoms with very high precision. On the other hand, new dedicated experiments are devoted to the search of systems bound by the attractive interaction of negatively charged kaons (antikaons) with nuclei. Many experiments are in preparation at different facilities at J-PARC, GSI and LNF. Moreover, the strong interaction in the field of charm quarks will be studied in the PANDA experiment at FAIR. Equally important is the further development of the theory of strong interaction in the field of strange and charm quarks, especially in the low energy regime (low-energy QCD). A networking activity LEANNIS on the antikaon nucleon and nuclei interaction (led by SMI) was very successful in the European project HadronPhysics2 which ended in December 31, 2011. LEANNIS is being continued in the new European project HadronPhysics3, started in January 2012, and bridges the gap between experimental and theoretical studies in hadron physics with strangeness.

2.5.2.1 LEANNIS

(Supported by I3HP2)

LEANNIS (**L**ow **E**nergy **A**ntikaon**N**ucleon and **N**uclei **I**nteraction **S**tudies) is a networking activity devoted to frontier studies on the interaction of antikaons with nucleons and nuclei. The LEANNIS topics comprehend precision x-ray studies of kaonic atoms, the nature of resonances with strangeness like Lambda(1405), the quest for kaonic nuclear bound states and in-medium modifications.

In 2011 the progress in experiment and theory was remarkable. On the one hand the experimental data of SIDDHARTA on the antikaon-proton strong interaction observables was published providing stringent constraints for theory. Consequently new results on the K-p scattering lengths at threshold were obtained in new theorical studies in the framework of effective field theory with coupled channels. The search for kaonic nuclear clusters were continued in various experiments like FOPI encouraged by the results of the analys of data from the DISTO experiment. The present status and the future directions of theoretical and experimental work were discussed and defined in the LEANNIS Meeting in Heidelberg attended by distinguished researches and young scientists (see photo below). Moreover, many results in the research field were presented in the International Conference EXA2011 organized by SMI.

Participants of the LEANNIS Meeting in Heidelberg (July 2011).

2.5.2.2 Kaonic atoms (SIDDHARTA and E17)

(Partly supported by FWF grant P20651-N20, Ph.D. thesis of B. Wünschek)

X-ray spectroscopy of kaonic atoms plays an important role for understanding the low-energy K^-N interaction. In particular, the result of kaonic hydrogen by the DEAR experiment caused a theoretical inconsistency compared to the K^-p scattering data [11]. To clarify this situation, the SIDDHARTA experiment measured the shift and width of the kaonic hydrogen X-rays more precisely. In 2011, the SIDDHARTA experiment reported a new value of the strong-interaction shift and width of the kaonic hydrogen *1s* state [12], as well as the first determination of the shift of the kaonic helium-3 *2p* state [13]. Figure 6 shows the energy spectrum of kaonic hydrogen K series X-ray lines. The shift of ε_{1s}=−283±36(stat)±6(syst) eV, and the width of Γ_{1s}= 541±89(stat)±22(syst) eV were determined by the fit, as plotted in Figure 7. Theoretical studies using the SIDDHARTA result have progressed recently [14], and the importance of the kaonic deuterium X-rays was suggested for the study of isospin dependence of K^-N interaction. The first measurement of kaonic deuterium X-rays is planned in the **SIDDHARTA-2** experiment. Because of 10 times lower X-ray yields of kaonic deuterium compared to kaonic hydrogen, the improvement of the signal-to-background ratio and the larger solid angle is required for the success of the X-ray observation. In the new setup, identification of the sign of charged kaons will be performed by installing an additional scintillator. In addition, charged particle veto counters will be installed. The preparation and simulation studies of the SIDDHARTA-2 setup have progressed.

The energy shift of the kaonic helium-3 2p state was determined to be ε_{2p}=−2±2(stat)±4(syst) eV in the SIDDHARTA experiment. Combined with the result of kaonic ^{4}He by SIDDHARTA [15] and E570 [16], the energy shifts both of kaonic ^{3}He and ^{4}He are found to be as small as a few eV. The precision measurement of the strong-interaction shift and width of the kaonic ^{3}He and ^{4}He *2p* states is planned in the J-PARC E17 experiment. The beam time was scheduled in 2011. However, because of the great East Japan Earthquake on 11th March, the facility of J-PARC was damaged [17]. There were no serious structural damages by the earthquake and Tsunami, but there are severely damages on roads, power supplies, water lines, etc. Fortunately, no injuries are observed for J-PARC related persons and no radiation problems have happened. The post-quake recovery of the J-PARC facility including infrastructure has been performed. A test run of the beam for the accelerators was started from 9th December 2011.

(11) See e.g. W. Weise Nucl. Phys. A 835 (2010) 51
(12) SIDDHARTA Collaboration, Phys. Lett. B 704 (2011) 113.
(13) SIDDHARTA Collaboration, Phys. Lett. B 697 (2011) 199

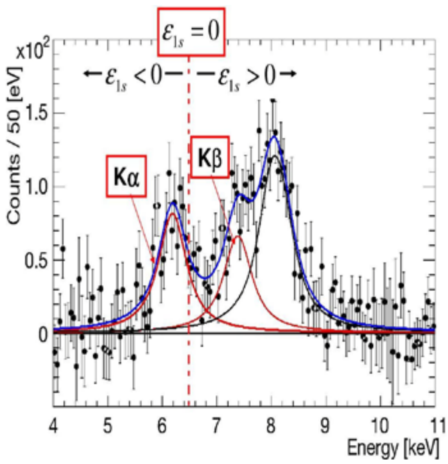


Figure 6: Energy spectra of kaonic hydrogen

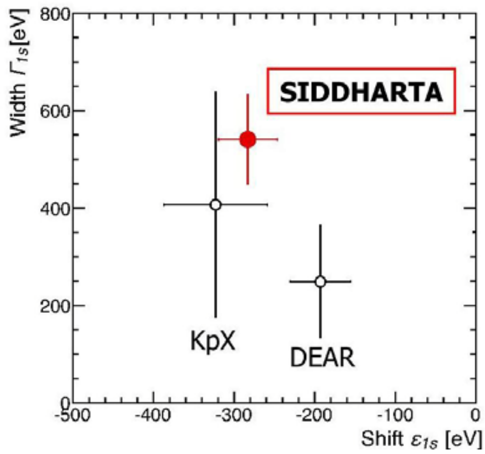


Figure 7: Energy shift and width of kaonic hydrogen *1s* state

(14) See e.g. M. Döring & U.-G. Meißner, Phys. Lett. B 704 (2011) 663, Y. Ikeda et al., Phys. Lett. B 706 (2011) 63
(15) SIDDHARTA Collaboration, Phys. Lett. B 681 (2009) 310
(16) S. Okada et al., Phys. Lett. B653 (2007) 387
(17) http://j-parc.jp/en/topics/2011/en.html

5.2.2.3 Kaonic Nuclei

(Supported partly by FWF grant P21457, Diploma thesis of K. Isepp, Ph.D. thesis of I. Carevic (guest from Split))

Strangeness hadron physics tries to reveal the complex dynamics and phenomena of quarks and gluons, e.g., hadron properties in nuclear medium, symmetry breaking pattern and hadron mass generation, new forms of hadrons, which are described by the Quantum Chromodynamics (QCD). The "strong" QCD interaction is characterized by color confinement and asymptotic freedom, namely the interaction becomes weak at short distances (at high energies) and can be treated perturbatively, on the contrary at long distances (at the temperature of the present universe) the interaction stays strong and color charges are confined. The chiral symmetry and the heavy quark symmetry play a role in the QCD at the light quark sector (m_u, $m_d \ll \Lambda_{QCD}$) and at the heavy quark sector (m_c, m_b, $m_t \gg \Lambda_{QCD}$), respectively. At the energy scale of the strange quark mass ($\approx \Lambda_{QCD}$), however, neither of the symmetries is good enough and the dynamics of the strange quark is thus very sensitive to the dynamics of QCD.

In 2011 we studied strangeness production in π^- induced reactions on nuclei at a π^- beam momentum of 1.7 GeV/c. The experiment is carried out with the secondary π^- beam from ^{14}N beam provided by SIS-18 at GSI and with the **FOPI** detector. Data was collected with carbon, copper and lead target during the 17-day beam time. The investigation of the production of K^+K^- as a function of the target mass number and a transparency ratio measurement of Φ meson allows to gain insight on the hadron properties in nuclear medium.

We continued diligently the program of searching for exotic kaonic nuclear states, whose existence is predicted by various calculations but its nature is still not well understood. We reported in 2010 a new resonance *X(2265)* with a mass of 2267 MeV and a width 118 MeV in a $pp \rightarrow XK^+$ reaction found in an exclusive data set of $pp \rightarrow p\Lambda K^+$ at T_p = 2.85 GeV recorded by **DISTO** collaboration. The *X* resonance has a baryon number 2 and a strangeness −1, and it is supposed to be a candidate of the long-searched $(K^-NN)_{S=0,\ I=1/2}$ kaonic nuclear dibaryon system, often called K^-pp. For a further study of the nature of the *X(2265)* we investigated in 2011 the energy dependence of the production rate of the *X(2265)* in the $pp \rightarrow XK^+$ two-body reaction by analyzing the $pp \rightarrow p\Lambda K^+$ reaction data set at T_p = 2.5 GeV of the DISTO collaboration. If the *X(2265)* is produced in a similar mechanism as a hyperon production in the $pp \rightarrow p\Lambda K^+$ or in the $pp \rightarrow p\Sigma K^+$ reaction as an empirical formula $\sigma \propto (1\text{-}s_0/s)^{1.8}(s_0/s)^{1.5}$, where $\sqrt{s_0}$ is the production threshold and $\sqrt{s}$ ist the center-of-mass energy, then the *X(2265)* at T_p=2.5 GeV would be produced as much as 33% of the T_p=2.85 GeV case. However if the *Λ(1405)* plays an important role as a door way to the high density kaonic nuclear systems, then the production of the *X(2265)* would be strongly suppressed at 2.5 GeV as the beam energy is too close to the production threshold of the *Λ(1405)* and therefore *Λ(1405)* is merely produced at that energy. We found in the data essentially no sign of an existence of the *X(2265)* at T_p=2.5 GeV, which fits to the latter scenario and thus supports that the *X(2265)* is the K^-pp system. This scenario can be endorsed if with the $pp \rightarrow p\Lambda K^+$ at T_p = 3.1 GeV data taken with the FOPI apparatus at GSI, and which is currently analysed, the *X(2265)* resonance is observed and its production rate turns out to be around 50% higher than at 2.85 GeV, as is expected according to the above mentioned relation.

The **E15** experiment located at J-PARC, Tokai, Japan, that also aims at searching for the K^-pp state with $^3He(K^-, n)$ reaction, complementary to the *pp* reaction at DISTO/FOPI, using a newly available high intensity, high quality Kaon beam, was supposed to run in 2011. A delay was forced due to the massive earthquake in east Japan on 11.3.2011 which caused a serious damage on the accelerator and the experimental area. With an enormous recovery work, the first beam was back at the facility by the Christmas 2011. The team is now trying to finalize the recovery work to get ready for a beam in 2012.

The **AMADEUS** experiment at LNF-INFN (Frascati, Italy) is a project to perform a complete study of decay modes of the kaonic nuclei in particular the Σ-π channel which will be missing in its preceding experiments. The AMADEUS apparatus works in combination of the existing KLOE detector and cylindrical cryogenic target system, inner tracker and trigger counter. In 2011 a comprehensive Monte-Carlo study was carried out in order to optimize the experimental condition and the production of the prototype detector has began. AMADEUS could take beam at DaΦne after SIDDHARTA-2 is finished in 3 years.

2.5.2.4 The PANDA Experiment

(partly supported within the 7th EU Framework Programme – HadronPhysics2)

The PANDA [18] Experiment is one of the large scale projects at FAIR [19]. It will study antiproton annihilations on nucleons and nuclei in the energy range of strange and charmed hadrons. A synchrotron and storage ring (HESR) will provide an antiproton beam with very small momentum spread ($2 \cdot 10^{-5}$) or high luminosity ($2 \cdot 10^{32}$ $cm^{-2}s^{-1}$). The construction of the so-called "Modularized Start Version" of FAIR, which includes the HESR and PANDA, has started in early winter 2011. The SMI activities in the PANDA project are contributions to the software framework and simulation/analysis, contributing to the development of the PandaGrid [20] computing network and maintaining a PandaGrid site, as well as R&D activities for the hydrogen cluster jet target, applications of the GEM technique to tracking detectors and Cerenkov counters of the DIRC type.

We also took measures to strengthen our future physics contributions to PANDA. In collaboration with colleagues from the University of Graz and the Technical University of Vienna, we submitted an SFB proposal for FWF, proposing a comprehensive study of charmed hadronic states in preparation of the PANDA experimental program. We also joined, in a consortium with the group of Ch. Schwanda from the High Energy Physics Institute of the ÖAW (HEPHY) the BELLE collaboration, to analyze the BELLE data in view of PANDA relevant topics.

The software framework of the PANDA experiment is called PandaRoot, which is based on the ROOT [21] software package from CERN. It contains the detector description as well as the full data reconstruction and analysis chain which will be used also for real experimental data to come. An application of a full simulation with PandaRoot is shown in Figure 8. The events were generated by the DPM [22] generator which calculates the emitted particles from antiproton-proton collisions at 15 GeV/c beam momentum and afterwards transported using the GEANT3 package. The energy deposition has been registered for all available detector volumes and converted into an energy dose. The result in Figure 8 shows the energy dose, scaled to one year (effectively 0.5 years) of running at the highest luminosity, projected into the *r,z* plane. The shapes of the PANDA materials can be clearly recognized. As expected, the tracking detectors around the interaction point (*z=r=0*) and the calorimeter crystal get a high energy dose of more than 100 Gy in the most exposed regions. Similar calculations are available for antiproton-nucleus reactions, too. A detailed implementation of the beam pipe to PandaRoot has been done (visible in Figure 8 at small values of *r*, downstream of the dipole the beam is bend in the *x,z* plane).

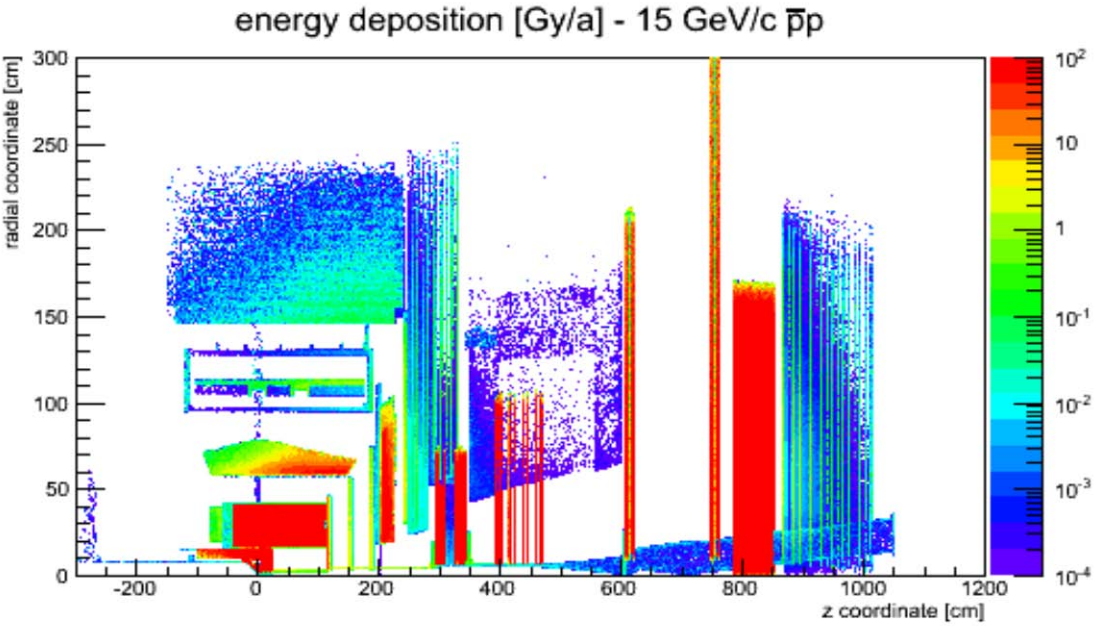


Figure 8: Energy dose (colour code) of the PANDA detector per year of running (PandaRoot simulation). An upper threshold of 100 Gy/a has been put to the histogram.

The activities in the R&D (see also section 2.5.3. Advanced Instrumentation for more detailes about the R&D activities) for silicon photomultipliers (SiPM) continued, and as an application, the technique was used for a VETO counter in the FOPI pion beam experiment. SiPM are candidates for the readout of PANDA's Cherenkov- and time of flight detectors.

The prototype of a GEM-TPC, originally built for R&D studies for PANDA, was just as well successfully operated in the FOPI experiment. A Technical Design Report (TDR) for a GEM-TPC as central tracker of PANDA was prepared. The PANDA collaboration decided however to use a different detector (STT) for this purpose.

Furthermore, the TDR for the PANDA targets has been presented to the collaboration in December 2011 and will be submitted to FAIR in the first half of 2012. The SMI is one of the main groups contributing to the cluster jet target.

(18)http://www-panda.gsi.de/

(19)http://www.fair-center.org/

(20)http://mlr2.gla.ac.uk/

(21)http://root.cern.ch

(22)Dual Parton Mode

2.5.3 Advanced Instrumentation

(Supported by EU-FP7 HadronPhysics2)

The Stefan Meyer Institute has well equipped mechanic and electronic workshops, perfect suited for the needs of our institute doing experimental work in the field of subatomic physics. Together with our design and construction office we are able to produce the important parts for our experiments at foreign accelerator facilities: CERN-AD, Switzerland; GSI, Germany; LNF, Italy and J-PARC, Japan.

For the measurements of the hyperfine splitting in the anti-proton helium system at the CERN-AD a new microwave target cell was developed. For the pion experiment at GSI with the FOPI detector system we have developed a veto counter within the vacuum beam pipe, fitting within a prototype TPC, which was build to demonstrate the proof of principle that such a TPC with GEM readout is feasible to be used as inner tracker for PANDA. In addition R&D work is performed mainly in the framework of "Joint Research Activities", within the 7th Framework Programme of the EU: HadronPhysics2. The Institute participates in 3 work packages: WP19: FutureJet - Cryogenic jets of nano- and micrometer-sized particles for hadron physics, WP24: JointGEM - Ultra-light and ultra-large tracking systems based on GEM technology and WP28: SiPM - Avalanche Micro-Pixel Photo-Diodes for Frontier Detector Systems. WP24 is led by SMI. In total 5 PhD students (A.Gruber, L.Gruber, S.Brunner, G.Ahmed, P. Müllner and B. Wünschek) are involved in this R&D work. For the next EU call within FP7, a proposal was submitted in November 2010, called HadronPhysics3, in which we plan to extend our work on FutureJet, JointGEM and SiPM. The proposal was accepted and starts on January 1, 2012.

WP19 – FutureJet

(Ph.D thesis of A. Gruber)

Within WP19 FutureJet our Institute contributes to studies of the (hydrogen) cluster-jet target of PANDA. The upgrade of the INFN-SMI-GSI cluster-jet device at GSI has been finished (see Figure 9), which was necessary to investigate higher cluster-jet densities and to measure cluster size and velocity of the produced hydrogen beam. First tests at GSI were performed with this new setup to optimise the cluster jet density by varying temperature and pressure of the hydrogen gas in front of the nozzle. In addition, the design of the complete PANDA vacuum and pumping system has been worked out. The

Figure 9: During the upgrade work of the INFN-SMI-GSI cluster-jet device.

effect on the rest gas conditions in the antiproton beam line have been evaluated for both targets (cluster-jet and pellet target within the PANDA section).

WP24 – JointGEM

(Ph.D. thesis of P. Müllner)

The next generation of experiments in hadron physics aims at studying rare processes with drastically improved sensitivity. The technical requirements to reach this goal include high beam intensity and luminosity, fast detectors with large acceptance and high resolution. An essential part of all these experiments is a detector for charged particles with excellent tracking capabilities covering large areas or volumes with an extremely low material budget in order not to spoil the energy and mass resolution of the apparatus. In addition the rate capability has to match the required high luminosities. To demonstrate the proof of principle a high-rate Time Projection Chamber (TPC) with GEM readout has been constructed, similar in size as planned for the inner tracker of AMADEUS at LNF and PANDA at FAIR. This prototype has an active length of 600 mm, an outer diameter of 300 mm and an inner diameter of 100 mm. The hexagonal pad read-out consists of about 10000 channels (Figure 10, left panel). For the first test measurement of the GEM-TPC at GSI under beam conditions a gas-mixing apparatus was build at SMI with a quadrupole mass spectrometer (QMS) attached to the gas outlet to monitor the gas composition of the TPC gas mixture. Because the final goal is to run the TPC with Neon (drift time faster, but expensive), a closed cycle gas system was development with a special gas cleaning device to keep the impurity level of the TPC gas mixture in the level of a few ppm. The closed cycle system (Figure 10, right panel) was already successfully installed during the

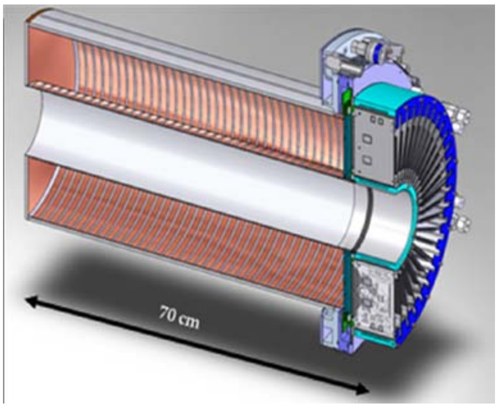


Figure 10: Left panel: Sketch of the TPC-GEM prototype. Right panel: Setup of the closed-cycle gas system at SMI during test phase, before shipping to GSI.

beam time of the pion experiment, while the cleaning cycle is still undergoing tests. In addition R&D work is ongoing of large-area planar GEM detectors capable of withstanding very high beam rates, as envisaged for the forward tracking system of PANDA or E15 at J-PARC.

WP28: SiPM

(Ph.D. theses of G. Ahmed and L. Gruber, Diploma theses of F. Schilling and M. Rihl)

New photon detectors – Geiger mode operated avalanche micro-pixel photo sensor matrices (AMPD), also called silicon photo multipliers (SiPM) – are ideally suited for future photonic systems in a broad field of basic science in physics, especially in hadron physics. These devices combine performances of traditional phototubes like high quantum efficiency and signal amplification with extremely important features like low-cost voltage supply and electronics. Contrary to photomultipliers the device is insensitive to magnetic fields and mechanically robust thus suitable for harsh environments.

A 64-channel Cherenkov detector:

A prototype of a position sensitive photo-detector with 5.6 x 5.6 cm^2 detection area readout with 64 Hamamatsu MPPCs (S10931-100P) with 3 x 3 mm^2 active area each has been built and tested (Figure 11). The photo-sensors are arranged in an 8 x 8 array with a quadratic mirror light guide on top. The module is currently readout by in-house developed preamplifier boards but employing existing ASIC chips optimized for SiPM readout is also planned. Such a device is one of the candidates to be used for photon detection in the PANDA DIRC detectors. The SiPM array has been tested at the T9 test beam at CERN. The data taken in 10 days beam time are currently analysed.

Figure 11: 64-channel SiPM prototype setup with preamplifiers sealed in a light-tight box.

Recovery time measurements:

One of the important parameters of photo sensors is the performance in high rate environments, where a good double hit resolution is required. For example experiments like AMADEUS within the KLOE detector at LNF or PANDA at FAIR run in such an environment. Therefore, in order to characterize the rate capability and the double hit resolution, we performed an experimental study to determine the cell recovery time for various SiPMs. We evaluated the recovery time constant by measuring the sensor response to two consecutive laser pulses, with a varying relative time difference of a few ns up to a few 100 ns. The delay of the second pulse is either done with multiple reflections using mirrors (up to 50 ns, Figure 12) or for larger delays (up to 600 ns) by coupling the light into optical fibers of different length (20 m to 200 m). The influence of the overvoltage on the recovery time is also studied.

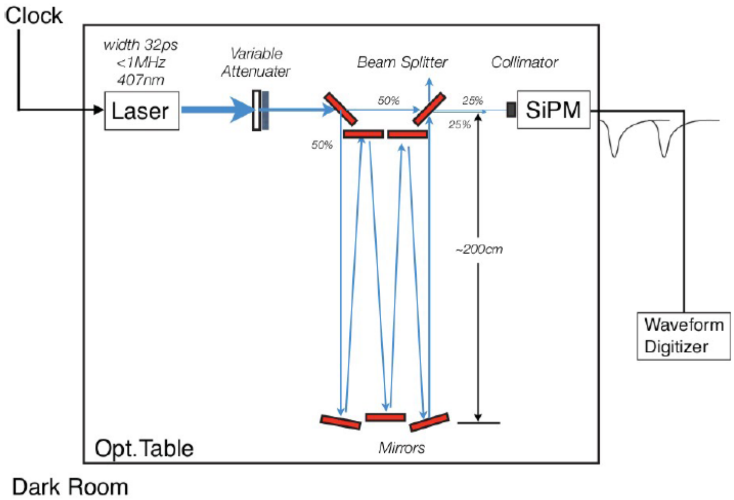


Figure 12: Sketch of the setup to produce two light pulses spaced between 5 to 50 ns.

ToF-PET detector for medical applications

(Ph.D. thesis of S. Brunner, Diploma thesis of M. Jankovec)

To improve the spatial resolution of a PET (Positron Emission Tomography) device a promising way could be the use of the ToF (Time-of-Flight) technique. That means the time resolution of the (PET) detector system has to be improved drastically to get good spatial resolution measurements. Using the fast Cherenkov process instead of the timing given by the scintillation light, it might be possible to obtain a time resolution in the order of 100 pico-seconds. Goal of this work at SMI is to improve the time resolution for ToF-PETs using Silicon photomultipliers (SiPM) and the Cherenkov effect at gamma energies of 511 keV. As Cherenkov photons are emitted almost instantaneously, compared to scintillation photons, the ability to detect and distinguish them from the scintillation signals, provide precise time stamps for ToF. First measurements have been accomplished successfully. For the development of a future ToF-PET prototype, Monte Carlo (MC) simulations using the framework GATE (Geant4 Application for Tomographic Emission) are performed to optimize the experimental setup (pixel size, material, arrangement of the SiPMs). For the simulations, a dedicated computer cluster, consisting of currently 64 CPUs, located at Meduni Wien is available. MC simulations of different scanner geometries (different radii, source distributions and detector layouts) have been performed on this computer grid and have proven the feasibility of our approach.

The increased number of channels for a future ToF-PET prototype and therefore the increased volume of data can be processed using dedicated ASICs, which are currently being tested for implementation. An application to FWF for support of this work was prepared and submitted in Fall 2011.

Cherenkov fiber tests at LNF

Detection of Cherenkov photons produced in quartz fibers with 320 nm, 600 nm and 1000 nm diameter readout with Hamamatsu MPPC S10362-11-050C with 1 x 1 mm^2 active area (Figure 13) were performed at the Beam Test Facility at LNF. Applications in mind are fast position sensitive detectors, e.g. a beam profile monitor with very fine grid. Data are currently under investigation.

Figure 13: Test setup for 320 nm, 600 nm and 1000nm fibers coupled to SiPMs.

Pion induced reactions on nuclei with FOPI at GSI

Using pion induced reaction on nuclei to measure the strangeness production and propagation in a nuclear medium the FOPI detector system has to be enlarged with the GEM-TPC (developed in WP24: JointGEM; SMI is participating in the development of the GEM-TPC). Additional beam veto counter have been developed at SMI to suppress the background produced by pions stopping in material, surrounding the target. The veto counter is using SiPM (experience gained from WP28: SiPM) for detecting the light from the plastic scintillators, which allowed a very compact design necessary to fit into the opening of the GEM-TPC and in addition it has to work in the environment of a strong magnetic field. The data are currently analysed.

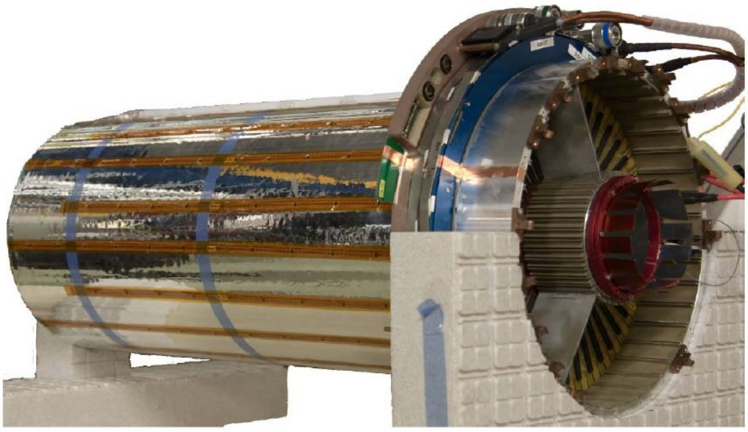


Figure 14: GEM-TPC prototype installed at FOPI at GSI for the pion-run.

2.5.4 Smaller Physics Projects

2.5.4.1 VIP @ Gran Sasso

In 2011 the next stage of the VIP experiment (VIP2) was planned which is devoted to a precision test of the Pauli Exclusion Principlefor electrons in the Gran Sasso Underground Laboratory. Many technical improvements like higher x-ray efficiency and suppression of background events are foreseen in a completely new experimental apparatus. We expect a much higher sensitivity arriving in the range of 10^{-31} for the Pauli Exclusion Principle violation parameter – thus improving the limit by about 2 orders of magnitude.

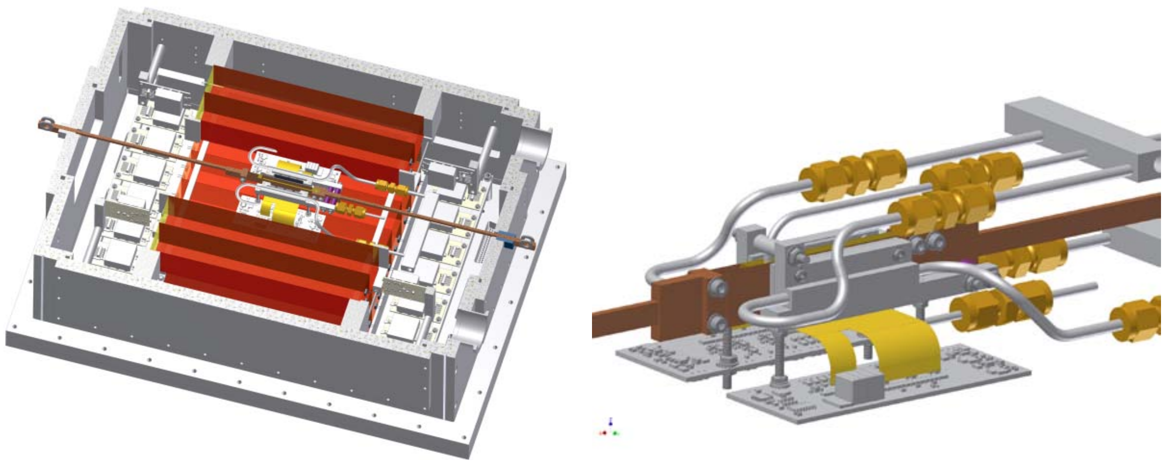


Figure 15: Design of the VIP2 apparatus. The inner part of the apparatus consists of the copper stripe conducting the current and SDD detectors searching for non-Paulian transitions in the copper (right figure). The inner part is surrounded by plastic scintillators providing an active shielding. This arrangement is mounted in a housing which will be passively shielded by lead.

2.5.4.2 EC-decay of highly ionized atoms

Measurements at the Experimental Storage Ring at GSI of the life time of highly ionized atoms decaying by electron capture have revealed a deviation from the expected exponential decay law [23]. The decay curve was found to be better represented by an exponential function with an additional oscillatory component with a period of approximately 7 seconds. In May 2010 the experiment has been repeated with participation of the SMI, with an additional sensor with improved sensitivity to determine the modulation parameters with higher accuracy as was possible in the original experimental run. Part of this data has been analyzed at SMI in 2011. With the new data set the oscillatory modulation of the decay curve was observed again with the previously determined modulation frequency, but only in a selection of the data which was restricted to a specific time window. The in such a way reduced data set was not sufficient to improve the determination of the modulation parameters as anticipated. The reason for this inconsistency is unclear. However it was argued, that the imperfect functioning of the ion removal mechanism from the ESR, could have lead to a reduction of the observed modulation. In order to clarify the situation a further run time of 10 days was granted, which took place in October 2011. In this run special care has been taken to remove all ions from the ESR after each measurement cycle. The data is currently analysed.

(23) Y.A. Litvinov et al., Phys. Lett. B **664** (2008) 162-168

2.5.4.3 Deeply bound pionic atoms

Deeply bound pionic atom were discovered at GSI, Darmstadt in 1996 using (*d,*^{3}He) reaction on heavy element (Pb, Sn). The precisely determined π-nucleus potential lead to a unique determination of a reduction of the quark condensation in a nuclear medium by ~35% [24]. In order to further improve an experimental precision and hence to better constrain the theoretical scenario of the dynamical generation of hadron masses from spontaneously broken chiral symmetry, a new series of experiments is proposed to make use of high intensity deuteron beam which became recently available at the new RI Beam Facility and the fragment separator (BigRIPS) at RIKEN, Japan. Already in the short pilot run in 2010, primarily meant to develop the required special momentum-matching beam optics, we succeeded to collect a similar statistics as the preceding GSI experiment and observed deeply-bound *1s, 2s, 2p* peaks of ^{121}Sn for the very first time. We also succeeded to observe an angular dependence of the production of the deeply-bound states in the (*d*,^{3}He) reaction for the first time thanks to the large angular acceptance of the BigRIPS. The successful pilot run lead naturally the project to go on for a further systematic study. An isotonic scan is intended that will reduce the biggest uncertainty in the analysis of the preceding experiment, the uncertainty of the neutron density distributions of the core nucleus.

(24)K. Suzuki *et al.*, Precision Spectroscopy of Pionic 1s state of Sn Nuclei and Evidence for Partial Restoration of Chiral Symmetry in the Nuclear Medium, Phys. Rev. Lett. **92** (2004) 072302,

2.5.4.4 FLAIR and ELENA

When the modularized start version (MSV) of FAIR was decided in 2009, the FLAIR (Facility for Low-energy Antiproton and Ion Research) extension of FAIR was left outside together with the NESR storage ring needed for deceleration. This left FLAIR in a situation where substantial additional funding is needed (more than 100 M€), forcing the FLAIR collaboration to rethink its strategy. In a collaboration meeting in 2011 E. Widmann announced that he would step down as spokesperson of FLAIR because of time constraints, and subsequently K. Blaum (Heidelberg) was elected spokesperson. The change over will take effect in a FLAIR workshop in early May 2012.

At the same time the collaboration list was updated and a new web page FLAIRatFAIR.eu was prepared in Heidelberg. In discussions with the Swedish group at MSL Stockholm that finished modifying the CRYRING storage ring to be used for FLAIR a new idea of an early usage of this ring at GSI as a further deceleration stage behind the ESR for the HITRAP facility came up that is discussed now. This would enable an early start of the highly charged ion program of FLAIR.

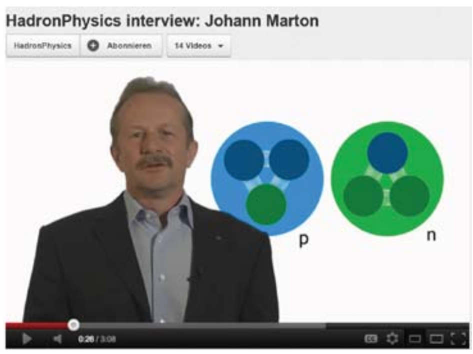
On the other hand, CERN announced the approval of the ELENA storage ring at the AD of CERN to decelerate antiprotons to about 150 keV energy, moving one step towards FLAIR and both allowing the trapping of a larger number of antiprotons for the existing experiment as well as enabling new experiments by providing an additional extraction. Thus low-energy antiprotons will have a secured future for the next 10-15 years.

2.5.5 Outreach

(Partly supported by FFG)

Several outreach activities took place in 2011. In course of the EU funded projects within HadronPhysics2, interviews for the public, with the two SMI colleagues who are project leaders have been recorded and published [25, 26]. A lecture in the framework of the "University meets public [27]" cycle at the Vienna adult education centres has been presented. In July and August, two practical courses within the "Generation Innovation [28]" project were offered at the SMI, which catered to schoolgirls and -boys. Furthermore, two students of the Lycée Français de Vienne were supervised at the SMI for an one week hands-on training.

Moreover, a delegation of the WWTF [29] with the mayor of Vienna in front visited the experimental facilities at CERN, and in particular the ASACUSA experiment was presented by the group of the SMI.



Hadron Physics explained by Hannes Zmeskal and Johann Marton from SMI on youtube.

(25)http://www.youtube.com/watch?v=VqsKTvsly3E

(26)http://www.youtube.com/watch?v=m4_YrDQ7RVk

(27)http://www.vhs.at/universitymeetspublic.html

(28)http://www.generationinnovation.at

(29)http://www.wwtf.at

2.6 Publications / talks / poster presentations 2011

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- M. Wolf, Testing the Standard Model
- Ch. Klaushofer, Theoretical Aspects of Primary Cosmic Radiation

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- Curceanu (Petrascu), C.; Bartalucci, S.; Bertolucci, S.; Bragadireanu, M.; Cargnelli, M. et al., Experimental tests of quantum mechanics: Pauli Exclusion Principle Violation (the VIP experiment) and future perspectives, 2nd International Workshop on the Physics of fundamental Symmetries and Interactions - PSI2010, *Physics Procedia* **17** (2011) 40-48.
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Talks and Poster presentations:

- Ahmed, Gamal (March 22, 2011) SiPMs for particle detection, Oral presentation at: DPG Fruehjahrstagung, Muenster/GERMANY.
- Bühler, Paul (June 14, 2011) Measuring the J/Psi-Nucleon dissociation cross section with PANDA, Oral presentation at: Hadron 2011, Muenchen/GERMANY .
- Bühler, Paul (May 11, 2011) Automatic analysis of the data acquired by the new resonant pick-up, Oral presentation at: GO collaboration meeting/GERMANY.
- Bühler, Paul (September 8, 2011) Studying Hadrons in Matter with PANDA, Oral presentation at: EXA 2011, Vienna/AUSTRIA .
- Cargnelli, Michael (December 12, 2011) Status of the Kd paper; Study of hadronic background in SIDDHARTA and simulations, Oral presentation at: Siddharta meeting/ITALY.
- Cargnelli, Michael (October 10, 2011) Results from the kaonic hydrogen X-ray measurement at DAFNE and outlook to future experiments, Oral presentation at: STORI'11/ITALY.
- Cargnelli, Michael (September 6, 2011) Results from the kaonic hydrogen X-ray measurement at DAFNE and outlook to future experiments, Oral presentation at: EXA 2011, Vienna/AUSTRIA.
- Federmann, Silke (January 28, 2011) A 1.42 GHz Spin-Flip Cavity for Hyperfine Structure Transition Measurements, Oral presentation at: SMI seminar/AUSTRIA.
- Federmann, Silke (June 28, 2011) The atom completed and a new particle, Oral presentation at: Seminar Experimental particle physics, Vienna University/AUSTRIA.
- Friedreich, Susanne (April 27, 2011) Spectroscopy of the antiprotonic helium hyperfine structure, Oral presentation at: LEAP 2011, Vancouver/CANADA .
- Friedreich, Susanne (February 24, 2011) Antimaterie im Labor, Lecture at: 65. Fortbildungswoche für Physik und Chemie/AUSTRIA .

- Friedreich, Susanne (September 5, 2011) Microwave Spectroscopy of the Antiprotonic He-3 Hyperfine Structure, Oral presentation at: EXA 2011, Vienna/AUSTRIA.
- Gamal, Ahmed (November 22, 2011) Silicon photomultiplier for subatomic physics experiments, Oral presentation at: NUPPAC 11/EGYPT.
- Gamal, Ahmed (September 6, 2011) New veto detector for the pion beam at FOPI. Poster Presentation at: EXA 2011, Vienna/AUSTRIA.
- Gruber, Lukas (April 4, 2011) Position sensitive SiPM Detectors for Cherenkov applications, Oral presentation at: DIRC 2011/GERMANY .
- Hartmann, Olaf (December 12, 2011) Status of the Phi Analysis in pi-A, Oral presentation at: FOPI collaboration meeting/GERMANY.
- Hartmann, Olaf (July 1, 2011) Status: Pion induced reactions with FOPI, Oral presentation at: Leannis meeting, Heidelberg/GERMANY.
- Hartmann, Olaf (June 30, 2011) S339 beamtime summary, Oral presentation at: FOPI collaboration meeting, Heidelberg/GERMANY.
- Hartmann, Olaf (March 16, 2011) Radiation Map for the Panda Detector - Status Report, Oral presentation at: XXXVI. Panda Collaboration Meeting/GERMANY.
- Hartmann, Olaf (March 21, 2011) Investigating the in-medium properties of the Phi(1020), Oral presentation at: DPG Fruehjahrstagung, Muenster/GERMANY.
- Hartmann, Olaf (November 17, 2011) Strangeness Physics with FOPI at GSI-SIS, Oral presentation at: Seminar of the Institute of Experimental Physics, Warsaw University, Warsaw/POLAND.
- Hartmann, Olaf (September 23, 2011) FOPI and the Physics of Strangeness, Oral presentation at: Highlights in Heavy-Ion Physics, Symposium in Honour of Nikola Cindro, Split/CROATIA (local name: Hrvatska).
- Ishiwatari, Tomoichi (December 12, 2011) Upper limit of strong Interaction width of KHHe3 and 4 2p states, Oral presentation at: Siddharta meeting/ITALY.

- Ishiwatari, Tomoichi (July 1, 2011) SIDDHARTA results on kaonic atom X-ray spectroscopy, Oral presentation at: LEANNIS meeting, Heidelberg/GERMANY.
- Ishiwatari, Tomoichi (June 12, 2011) X-ray yield of kaonic Kapton, Possible determination of the Khe 2p level width using SDDs, Oral presentation at: SIDDHARTA meeting/ITALY.
- Ishiwatari, Tomoichi (June 13, 2011) Kaonic ^{3}He and ^{4}He X-ray measurements in SIDDHARTA, Oral presentation at: Hadron 2011, Muenchen/GERMANY .
- Ishiwatari, Tomoichi (September 6, 2011) Kaonic ^{3}He and ^{4}He X-ray measurements in SIDDHARTA, Oral presentation at: EXA 2011, Vienna/AUSTRIA.
- Juhasz, Bertalan (April 28, 2011) Measurement of the ground-state hyperfine splitting of antihydrogen, Oral presentation at: LEAP 2011/CANADA.
- Juhasz, Bertalan (November 29, 2011) Measurement of the ground-state hyperfine splitting of antihydrogen, Oral presentation at: Pbar 11, Matsue, Shimane/JAPAN.
- Marton, Johann (November 21, 2011) New experimental results on the low-energy antikaon nucleon and nucleus interaction. Oral presentation at: NUPPAC 11, Hurghada/EGYPT.
- Marton, Johann (January 24, 2011) Low-energy antikaon interaction revisited. Oral presentation at: XLIV International Winter Meeting on Nuclear Physics, Bormio/ITALY.
- Marton, Johann (June 27, 2011) New experimental results on the strong interaction in kaonic atoms. Oral presentation at: Seminar TU Muenchen, Muenchen/GERMANY.
- Marton, Johann (January 11, 2011) Grundlagenforschung als Beruf. Oral presentation at: University meets Public, Vienna/AUSTRIA.
- Marton, Johann (May 2, 2011) Low-energy antikaon nucleon and nucleus interaction studies. Oral presentation at: APS April Meeting 2011/UNITED STATES.

- Marton, Johann (April 28, 2011) Low-energy antikaon nucleon and nucleus interaction studies. Oral presentation at: 4th Workshop of the Topical Group on Hadron Physics of APS, 2011/UNITED STATES.
- Marton, Johann (July 1, 2011) Welcome and LEANNIS status. Oral presentation at: LEANNIS meeting, Heidelberg/GERMANY.
- Suzuki, Ken (November 14, 2011) Applying for membership of Belle, Oral presentation at: Belle General Meeting, Tsukuba/JAPAN.
- Suzuki, Ken (October 6, 2011) Review: Vienna detector R&D with SiPM, Oral presentation at: I3HPSiPM-FP7 workshop, Darmstadt/GERMANY.
- Suzuki, Ken (September 7, 2011) News from DISTO, Oral presentation at: EXA 2011, Vienna/AUSTRIA.
- Widmann, Eberhard (September 2, 2011) Testing CTP symmetry with antiprotonic helium and antihydrogen. Oral presentation at: ECT* workshop, Speakable in quantum mechanics: atomic, nuclear and subnuclear physics tests/ITALY.
- Widmann, Eberhard (November 29, 2011) Hyperfine structure of antiprotonic helium and antihydrogen. Oral presentation at: pbar 11/JAPAN.
- Widmann, Eberhard (April 28, 2011) Opportunities at FLAIR. Oral presentation at: LEAP 2011/CANADA.
- Widmann, Eberhard (March 16, 2011) Testing CPT with antiprotonic helium and antihydrogen. Oral presentation at: Kolloquium Aarhus University, Aarhus/DENMARK.
- Widmann, Eberhard (June 30, 2011) Studying fundamental symmetries and interactions with low-energy antiprotons. Oral presentation at: Seminar at Main University, Mainz/GERMANY.
- Widmann, Eberhard (July 25, 2011) Testing CPT with Antiprotonic Helium and Antihydrogen. Oral presentation at: PANIC 2011, Boston/UNITED STATES.
- Widmann, Eberhard (October 14, 2011) FLAIR, a next-generation facility for low-energy antiprotons. Oral presentation at: STORI'11/ITALY.
- Widmann, Eberhard (March 11, 2011) Subatomic physics at Stefan Meyer Institute. Oral presentation at: RECFA 2011, Austria/AUSTRIA.

- Zmeskal, Johan (September 21, 2011) PANDA at Fair - an overview, Oral presentation at: phipsi 11, Novosibirsk/RUSSIAN FEDERATION.
- Zmeskal, Johann (October 5, 2011) FLAIR at FAIR, Oral presentation at: Indian Summer School/CZECH REPUBLIC

2.7 Scientific events

Conferences/Workshops/Meetings

- 05. – 09.09.2011: EXA 2011

International Conference on Exotic Atoms (EXA 2011)

The fourth EXA Conference took place in Vienna, in the Theatersaal of the Austrian Academy of Sciences from September 5th to 9th, 2011. Like the previous EXA Conferences it was organized by SMI (Co-Chairmen: J. Marton, E. Widmann and J. Zmeskal). EXA 2011 attracted more than 120 scientists working in the broad research field covered by this conference on exotic atoms and related topics. The Conference was opened by Eberhard Widmann. In the first session the extremely successful two decades of research on antiprotonic helium was celebrated in an overview talk by Ryu Hayano followed by presentations about current research and results in theory and experiment. The recent advances in antihydrogen studies and CPT and gravity tests with antimatter were discussed by distinguished speakers from the collaborations working at the AD of CERN. Another session was devoted to other exotic atoms where an exciting new result on the size of the proton was one of the highlights.

Hot topics in precision experiments - using different probes like neutrons and muons - were discussed. The topic strong interaction with strangeness in the low energy regime was presented in talks on kaonic atoms and nuclei. The new result of the SIDDHARTA experiment at DAFNE/LNF on the strong interaction observables from kaonic hydrogen - representing another highlight of EXA 2011- was discussed by M. Cargnelli/SMI. On the occasion of the 80th birthday of P. Kienle a symposium „Creativity-Innovation-the Seed for Frontier Science“ took place in the framework of EXA 2011. The talks were given by distinguished scientists and summarized the scientific topics in which P. Kienle delivered and delivers new ideas with crucial impact.

Many young scientists attended the Conference and gave very interesting talks respectively poster presentations about their work. This fact is an extremely good sign for the future research in the broad scientific field covered by the EXA Conference series.

The Proceedings of EXA 2011 will by published in the peer-refereed journal „Hyperfine Interactions“ with P. Bühler, O. Hartmann, J. Marton, K. Suzuki, E. Widmann and J Zmeskal serving as guest editors.

Photo of the EXA 2011 participants.

- 29.08. – 02.09.2011: ECT* workshop 2011, Speakable in quantum mechanics: atomic, nuclear and subnuclear physics tests

International Workshop „Speakables in quantum mechanics: atomic, nuclear and subnuclear physics tests"

The international workshop "Speakable in quantum mechanics: atomic, nuclear and subnuclear physics tests", devoted to the hot topics of quantum mechanics, took place on 29 August – 2 September. The workshop was organized by Catalina Curceanu (LNF-INFN, Frascati), Johann Marton (SMI) and Edoardo Milotti (University and INFN Trieste). About 40 scientists participated, with a well-balanced mix of theoreticians and experimentalists. Distinguished scientists like F. de Martini, A. di Domenico, H. Rauch – to name a few - gave stimulating talks. Moreover, many young scientists participated, gave interesting talks and contributed to the lively discussions. In summary the Workshop was extremely successful in showing new theoretical understanding and promising future breakthroughs in quantum mechanics. The outcome of the workshop was condensed in Mini-Proceedings (arXiv:1112.1273, authors: C. Curceanu, J. Marton, December 2011).

- 30.06. – 01.07.2011: LEANNIS meeting, Heidelberg
- 04. – 05.03.2011: Wien Houdankai (workshop on strangeness nuclear physics)
- 14. – 18.02.2011: PANDA Grid workshop

University Lectures

University Vienna

- Detector and detector systems for particle and nuclear physics II, SS 2011, Zmeskal, Johann
- Experimental Particle Physics II, SS 2011, Widmann, Eberhard
- Seminar on current topics in subatomic physics, SS 2011, Widmann, Eberhard & Zmeskal, Johann
- Seminar zur Experimentellen Teilchenphysik, SS 2011, Widmann, Eberhard
- Seminar Series Particles and Interactions, SS 2011, Widmann, Eberhard
- 65. Fortbildungswoche für Physik und Chemie, SS 2011, Friedreich, Susanne & Widmann, Eberhard
- Experimental Particle Physics I, WS 2011/2012, Widmann, Eberhard
- Spezialisierungsmodul Kern- und Isotopenphysik, WS 2011/2012, Widmann, Eberhard & Zmeskal, Johann
- Seminar on current topics in subatomic physics, WS 2011/2012, Widmann, Eberhard & Zmeskal, Johann
- Seminar zur Experimentellen Teilchenphysik, WS 2011/2012, Widmann, Eberhard

Technical University Vienna

- Graduierten Seminar Teilchen und Wechselwirkungen, SS 2011, Marton, Johann
- Projektarbeit Subatomare Physik, SS 2011, Marton, Johann
- Privatissimum für Dissertanten, SS 2011, Marton, Johann
- Physics of Exotic Atoms, WS 2011/2012, Marton, Johann
- Projektarbeit Subatomare Physik, WS 2011/2012, Marton, Johann
- Privatissimum für Dissertanten, WS 2011/2012, Marton, Johann

2.8 Scientific cooperation 2011

Matter - antimatter symmetry: ASACUSA @ CERN - ASACUSA

DENMARK, Aarhus C., Department for Physics and Astronomy, Aarhus University.
DENMARK, Aarhus C., Institute for Storage Ring Facilities (ISA).
DENMARK, Kopenhagen, Niels Bohr Institute.
GERMANY, Heidelberg, Max-Planck-Institut für Kernphysik.
HUNGARY, Budapest, KFKI Research Institute for Particle and Nuclear Physics, Hungarian Academy of Sciences.
HUNGARY, Debrecen, Inst. of Nuclear Research (ATOMKI) of the Hungarian Acad. of Sciences.
IRELAND, Belfast, Queens University, Belfast, Ireland.
ITALY, Brescia, Dipartimento di Chimica e Fisica per l'Ingegneria e per i Materiali.
JAPAN, Saitama, Atomic Physics Laboratory, RIKEN.
JAPAN, Tokio, Institute of Physics, University of Tokyo.
JAPAN, Tokyo, Department of Physics, Univ. of Tokyo.
SWITZERLAND, Genf, CERN - European Organization for Nuclear Research.
UNITED KINGDOM, Swansea, Department of Physics, University of Wales Swansea.

Kaonic hydrogen and deuterium: SIDDHARTA

CANADA, Victoria B.C., Department of Physics and Astronomy, Univ. of Victoria.
ITALY, Frascati, INFN, Laboratori Nazionali di Frascati.
JAPAN, Saitama, Inst. of Physical and Chemical Research (RIKEN).
JAPAN, Tokyo, Department of Physics, Univ. of Tokyo.
ROMANIA, Bukarest, Department of High Energy Physics, Inst. of Physics and Nuclear Engineering, Bukarest.

PANDA: Antiproton Annihilations at Darmstadt

CHINA, Peking, Institute of High Energy Physics, Chinese Academy of Sciences.

FINLAND, Helsinki, University of Helsinki - Helsinki Institute of Physics.

GERMANY, Bochum, Ruhr-Universität Bochum.

GERMANY, Bonn, Universität Bonn.

GERMANY, Darmstadt, GSI - Gesellschaft für Schwerionenforschung mbH.

GERMANY, Dresden, Technische Universität Dresden.

GERMANY, Erlangen, Universität Erlangen.

GERMANY, Frankfurt, Univ. Frankfurt.

GERMANY, Gießen, Universität Gießen.

GERMANY, Jülich, Forschungszentrum Jülich GmbH.

GERMANY, Mainz, Universität Mainz.

GERMANY, Muenchen, Technische Universität München.

GERMANY, Münster, Universität Münster.

GERMANY, Tübingen, Universität Tübingen.

ITALY, Brescia, Univ. Brescia.

ITALY, Ferrara, Istituto Nazionale di Fisica Nucleare Sezione di Ferrara (INFN).

ITALY, Frascati, INFN, Laboratori Nazionali di Frascati.

ITALY, Genua, Istituto Nazionale di Fisica Nucleare - INFN, Genova .

ITALY, Genua, Università di Genova.

ITALY, Mailand, Dipartimento di Fisica, Università degli Studi di Milano e Sezione di Milano, INFN.

ITALY, Pavia, Università di Pavia.

ITALY, Triest, Dipartimento di Fisica, Univ. di Trieste und INFN Trieste.

ITALY, Turin, Politechnico Torino.

ITALY, Turin, Univerità di Torino.

NETHERLANDS, Kroningen, KVI Kroningen.

POLAND, Krakau, Univ. Cracow.

POLAND, Silesia, Univ. Silesia.

POLAND, Warschau, SINS.

ROMANIA, Bucharest - Magurele, Inst. of Physics and Nuclear Engineering „Horia Hulubei“.

RUSSIAN FEDERATION, Dubna, JINR - Joint Institute for Nuclear Research.

RUSSIAN FEDERATION, Novosibirsk, BINP - Budker Institute of Nuclear Physics,

Novosibirsk.
RUSSIAN FEDERATION, St. Petersburg, St. Petersburg Nuclear Physics Institute (PNPI).
SPAIN, Valencia, IFIC - Instituto de Fisica Corpuscular Edificio Institutos de Investigacion.
SWEDEN, Stockholm, Department of Physics, Stockholm University.
SWEDEN, Uppsala, TSL - The Svedberg Laboratory Uppsala.
SWEDEN, Uppsala, Uppsala University.
SWITZERLAND, Basel, Universitaet Basel.
UNITED KINGDOM, Edinburgh, University of Edinburgh.
UNITED KINGDOM, Glasgow, University Glasgow.
UNITED STATES, Evanston, Northwestern Univ. Evanston.
UNITED STATES, Los Alamos, LANL Los Alamos USA.

Deeply bound kaonic nuclei with FOPI at GSI

CHINA, Lanzhou, Institute of Modern Physics.
CROATIA (local name: Hrvatska), Split, University of Split.
CROATIA (local name: Hrvatska), Zagreb, Ruđer Bošković Institute.
FRANCE, Aubière, Laboratoire de Physique Corpusculaire Clermont-Ferrand.
FRANCE, Clermont-Ferrand, Clermont Université, Université Blaise Pascal.
FRANCE, Strasbourg, Institut de Recherches Subatomiques.
GERMANY, Darmstadt, GSI - Gesellschaft für Schwerionenforschung mbH.
GERMANY, Dresden, Institut für Strahlenphysik, Forschungszentrum Dresden Rossendorf.
GERMANY, Heidelberg, Universität Heidelberg.
GERMANY, München, Technische Universität München.
HUNGARY, Budapest, KFKI Research Institute for Particle and Nuclear Physics, Hungarian Academy of Sciences.
JAPAN, Saitama, Inst. of Physical and Chemical Research (RIKEN).
JAPAN, Tokio, University of Tokyo.
KOREA, REPUBLIC OF, Seoul, Korea University.
POLAND, Warschau, Institute of Experimental Physics, Warsaw University.
ROMANIA, Bucharest, Institute for Nuclear Physics and Engineering.

RUSSIAN FEDERATION, Moskau, Institute for Experimental and Theoretical Physics, Moskva.
RUSSIAN FEDERATION, Moskau, Kurchatov Institute.

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

ITALY, Frascati, INFN, Laboratori Nazionali di Frascati.
ROMANIA, Bucharest - Magurele, Inst. of Physics and Nuclear Engineering „Horia Hulubei".

Study of kaon-nucleon interaction @ J-PARC

JAPAN, Osaka, Osaka University.
JAPAN, Saitama, Atomic Physics Laboratory, RIKEN.
JAPAN, Tokio, University of Tokyo.
JAPAN, Tokyo, KEK, High Energy Accelerator Research Organization.
KOREA, REPUBLIC OF, Seoul, Korea University.
UNITED STATES, Philadelphia, Temple University.

Theoretical Studies of Low Energy QCD, Investigated with Exotic Atoms

AUSTRIA, Wien, Atominstitut der Österreichischen Universitäten (Technische Universität Wien).

AMADEUS at DAPHNE2

AUSTRIA, Wien, Atominstitut der Österreichischen Universitäten (Technische Universität Wien).
CANADA, Toronto, Department of Physics and Astronomy, York University, Toronto.
CANADA, Vancouver, TRIUMF, Vancouver.
CANADA, Victoria B.C., Department of Physics and Astronomy, Univ. of Victoria.
GERMANY, Bonn, Universität Bonn.
GERMANY, Darmstadt, GSI - Gesellschaft für Schwerionenforschung mbH.

GERMANY, Heidelberg, Universität Heidelberg.
GERMANY, Jülich, Forschungszentrum Jülich GmbH.
GERMANY, Muenchen, Technische Universität München.
GERMANY, Tübingen, Universität Tübingen.
ITALY, Catania, Università di Catania e Sezione dell' INFN.
ITALY, Cosenza, Dipartimento di Fisica, Universita' della Calabria.
ITALY, Florenz, Università di Firenze e Sezione dell' INFN.
ITALY, Frascati, INFN, Laboratori Nazionali di Frascati.
ITALY, Mailand, Dipartimento di Fisica, Università di Milano-Bicocca e Sezione di Milano, INFN .
ITALY, Mailand, Politecnico Di Milano.
ITALY, Perugia, Università di Perugia e Sezione dell' INFN.
JAPAN, Saitama, Inst. of Physical and Chemical Research (RIKEN).
JAPAN, Tokyo, KEK, High Energy Accelerator Research Organization.
POLAND, Krakau, Jagellonian Univ. Cracow.
POLAND, Warschau, Andrzej Soltan Institute for Nuclear Studies, Warsaw.
ROMANIA, Bucharest - Magurele, Inst. of Physics and Nuclear Engineering „Horia Hulubei“.
RUSSIAN FEDERATION, Moskau, Institute for Experimental and Theoretical Physics, Moskva.
SWITZERLAND, Fribourg, University of Fribourg.
SWITZERLAND, Genf, CERN - European Organization for Nuclear Research.
UNITED STATES, Berkeley, University of California, Berkeley.

FLAIR: Facility for Low-Energy Antiproton and Ion Research

AUSTRIA, Wien, Institute for Theoretical Physics, Vienna University of Technology.
CANADA, Toronto, Department of Physics and Astronomy, York University, Toronto.
CANADA, Vancouver, TRIUMF, Vancouver.
DENMARK, Aarhus C., Department for Physics and Astronomy, Aarhus University.
FRANCE, Paris, Laboratoire Kastler-Brossel, École Normale Supérieure et Univ. Pierre et Marie Curie.
GERMANY, Berlin, Institut für Physik, Humboldt-Universität zu Berlin.
GERMANY, Darmstadt, GSI - Gesellschaft für Schwerionenforschung mbH.

GERMANY, Dresden, Institut für Theoretische Physik, TU Dresden.
GERMANY, Frankfurt, Institut für Angewandte Physik, Universität Frankfurt.
GERMANY, Frankfurt, Institut für Kernphysik, Universität Frankfurt.
GERMANY, Gießen, Institut für Kernphysik, Universität Gießen.
GERMANY, Heidelberg, Max-Planck-Institut für Kernphysik.
GERMANY, Jülich, Forschungszentrum Jülich GmbH.
GERMANY, Mainz, Institut für Physik, Universität Mainz.
GERMANY, Tübingen, Universität Tübingen.
HUNGARY, Budapest, KFKI Research Institute for Particle and Nuclear Physics, Hungarian Academy of Sciences.
HUNGARY, Debrecen, Department of Experimental Physics, University of Debrecen.
INDIA, Variable Energy Cyclotron Center, Kolkata.
ITALY, Brescia, Dipartimento di Chimica e Fisica per l'Ingegneria e per i Materiali.
ITALY, Genua, Istituto Nazionale di Fisica Nucleare - INFN, Genova .
JAPAN, Saitama, Atomic Physics Laboratory, RIKEN.
JAPAN, Tokio, Institute of Physics, University of Tokyo.
NETHERLANDS, Amsterdam, Laser Centre Vrije Universiteit, Faculty of Science, Amsterdam.
POLAND, Warschau, Andrzej Soltan Institute for Nuclear Studies, Warsaw.
POLAND, Warschau, Heavy Ion Laboratory, Warsaw University.
POLAND, Cracow, Jagiellonian University, Cracow
RUSSIAN FEDERATION, Dubna, JINR - Joint Institute for Nuclear Research.
RUSSIAN FEDERATION, St. Petersburg, D.I. Mendeleev Institute for Metrology (VNIIM), St. Petersburg.
RUSSIAN FEDERATION, St. Petersburg, Department of Physics, St. Petersburg State University.
RUSSIAN FEDERATION, St. Petersburg, St. Petersburg Nuclear Physics Institute (PNPI).
RUSSIAN FEDERATION, Troitsk, Institute of Spectroscopy of the Russian Academy of Sience, Troitsk.
SWEDEN, Stockholm, Department of Atomic Physics, Stockholm University.
SWEDEN, Stockholm, Manne Siegbahn Laboratory (MSL), Stockholm.
SWEDEN, Uppsala, Department of Physical And Analytical Chemistry, Quantum Chemistry, Uppsala University

SWEDEN, Lund, European Spallation Source ESS AB, Lund
UNITED KINGDOM, Swansea, Department of Physics, University of Wales Swansea.
UNITED KINGDOM, London, Department of Physics, Blackett Laboratory, Imperial College London.
UNITED KINGDOM,Liverpool, University of Liverpool, Liverpool.
UNITED STATES, Indiana, Indiana University, Bloomington.
UNITED STATES, Massachusetts, Department of Physics, Harvard University, Cambridge.
UNITED STATES, New Mexiko, Pbar Labs, LLC Santa Fe.
UNITED STATES, New Mexiko, University of New Mexico, Albuquerque.
UNITED STATES, Florida, Florida State University, Department of Physics, Tallahassee.
UNITED STATES, Texas, Department of Physics, Texas A&M University, College Station.
UNITED STATES, Missouri, Missouri University, Rolla.

Antiproton Ion Collider - AIC

GERMANY, Darmstadt, GSI - Gesellschaft für Schwerionenforschung mbH.
GERMANY, Gießen, Justus-Liebig Universität Giessen.
GERMANY, München, Technische Universität München.
JAPAN, Saitama, UoS - University of Saitama, Saitama.
JAPAN, Tokio, University of Tokyo.
POLAND, Warschau, Andrzej Soltan Institute for Nuclear Studies, Warsaw.
RUSSIAN FEDERATION, Novosibirsk, BINP - Budker Institute of Nuclear Physics, Novosibirsk.

Röntgenspektroskopie an der VERA – Beschleunigeranlage (PIXE)

AUSTRIA, Wien, Institut für Isotopenforschung und Kernphysik, Universität Wien.

2.9 Scientific co-workers

Name	Position	Funding
Prof. Dr. Eberhard Widmann	Director	ÖAW
Privatdozent Dr. Johann Marton	Senior scientist, vice director	ÖAW
Privatdozent Dr. Johann Zmeskal	Senior scientist, workshop supervisor	ÖAW
Dr. Paul Bühler	Senior scientist	ÖAW
Dr. Michael Cargnelli	Senior scientist	ÖAW
Dr. Olaf Hartmann	Junior scientist	FWF
Dr. Tomoichi Ishiwatari	Junior scientist	FWF/EU
Dr. Bertalan Juhasz	Junior scientist	ÖAW
Dr. Ken Suzuki	Junior scientist	ÖAW
DI Alexander Gruber	Ph.D. student	EU
Gamal Saber Ahmed	Ph.D. student	Egypt
DI Stefan Brunner	Ph.D. student	EU
Mag. Susanne Friedreich	Ph.D. student	FWF
DI Lukas Gruber	Ph.D. student	EU
Mag. Philipp Müllner	Ph.D. student	EU
Mag. Barbara Wünschek	Ph.D. student	FWF
Martin Diermaier	Diploma student	ÖAW
Oswald Massiczek	Diploma student	ÖAW
Florian Schilling	Diploma student	ÖAW
Katharina Isepp	Diploma student	ÖAW
Mariana Rihl	Diploma student	ÖAW