Austrian Academy of Sciences

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Annual Report 2009

Stefan Meyer Institute (SMI)
for Subatomic Physics

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Contents

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

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

and, in the future,

- FAIR (Darmstadt, Germany).

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

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

The current two main fields of focus at SMI are:

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

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

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

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

1. Scientific Activity 2009

1.1. Zusammenfassung des wissenschaftlichen Berichts 2009

1.1.1. Highlights 2009

Röntgenspektroskopie kaonischer Atome – das SIDDHARTA Experiment

Kaonen sind stark wechselwirkende Teilchen, die ein „Strange-Quark" enthalten. Werden sie in leichte Materie eingeschossen, so erfolgt die Abbremsung und anschließend ersetzt das Kaon ein Elektron des Atoms und bildet ein „kaonisches Atom". Während die Elektronen nicht der starken Wechselwirkung unterliegen, bewirkt diese bei Kaonen eine Modifikation des Atomaufbaues, was sich in der Energie der emittierten Röntgenquanten auswirkt. Durch die Messung dieser Röntgenstrahlung gewinnen wir Information über die Kaon-Nukleon Wechselwirkung. Die Quantenchromodynamik (QCD) kann diesen „in Ruhe" stattfindenden Prozess nicht mittels Quarks und Gluonen quantitativ beschreiben, vielmehr werden „effektive Modelle" benötigt, die wiederum experimentelle Daten als Parameter verwenden. Die besondere Bedeutung dieser Niederenergieprozesse liegt darin, Information über die „chirale Symmetriebrechung" und damit über die Massengenerierung der Hadronen (z.B. Proton, Neutron) zu erlangen. Die Messung der Röntgenstrahlung kaonischer Wasserstoff, Deuterium- und Heliumatome war das Ziel des SIDDHARTA Projektes. Dazu wurden im Rahmen eines EU Projektes neuartige Detektoren und Elektronik Module entwickelt. Die Datenaufnahme am Elektron-Positron Collider DAFNE in Frascati wurde 2009 fertiggestellt, wir erwarten das bisher genauste existierende Ergebnis für kaonischen Wasserstoff. Ein Ergebnis für kaonisches Helium, das eine wichtige Bestätigung für frühere Messungen am KEK/Japan liefert, liegt bereits vor und wurde 2009 publiziert[2].

Neuer Wert für das magnetische Moment des Antiprotons

Antiprotonisches Helium ist ein neutrales, exotisches Atom, bestehend aus einem Heliumkern, einem Elektron und einem Antiproton, das am „Antiproton Decelerator" des CERN (Genf) innerhalb der internationalen Kollaboration ASACUSA mittels Laser- und Mikrowellenspektroskopie untersucht wird. Ein Vergleich der gemessenen Übergangsfrequenzen mit theoretischen Berechnungen kann herangezogen werden, um fundamentalen Eigenschaften des Antiprotons wie Masse, Ladung oder magnetisches Moment zu bestimmen. Der Vergleich mit den entsprechenden Eigenschaften des Protons dient als Test der Materie-Antimaterie Symmetrie, die im Kosmos offensichtlich verletzt ist, da das uns bekannte Weltall fast ausschließlich aus Materie besteht. Die Wechselwirkungen des magnetischen Moments des Antiprotons mit denen der anderen Bestandteile führt zur sogenannten *Hyperfeinstruktur* (HFS). Aus den von uns durchgeführten Messungen ergibt sich so ein neuer, genauerer Wert des magnetischen Moments, der 2009 veröffentlicht wurde[3]. Er stimmt innerhalb des Fehlers mit dem Wert des Protons überein.

Suche nach gebundenen Kaon-Nukleon Zuständen mit FOPI

Wegen der starken Anziehung von Antikaonen und Nukleonen scheint es möglich, dass diese gebundene Zustände bilden können, ähnlich den Neutronen und Protonen im Kern eines Atoms. Die Existenz von gebundenen Kaon-Nukleon Zuständen ist jedoch umstritten und kann nur durch ein dediziertes Experiment entschieden werden. Das SMI ist federführend an einem solchen Experiment an der GSI (Darmstadt) beteiligt. Mit Hilfe von Proton-Proton Kollisionen im FOPI Detektor wird versucht den Kaon-Nukleon Zustand $K^{-}pp$ nachzuweisen. Nach zweijähriger intensiver Vorbereitungszeit wurde das vom FWF geförderte Experiment im August des Jahres 2009 durchgeführt. An der Auswertung der gewonnen Daten wird momentan gearbeitet und erste Resultat werden 2010 erscheinen.

PANDA an FAIR

Ein weiterer wichtiger Schritt im PANDA Projekt an der geplanten FAIR-Anlage in Darmstadt wurde im Jahr 2009 durch die Veröffentlichung des „physics book"[4] gesetzt, welches das breite Spektrum der Forschungsthemen (QCD Bindungszustände, nicht-perturbative QCD-Dynamik, Hadronen in Kernmaterie, Hyperkerne, elektromagnetische Prozesse zur Struktur von Nukleonen) beschreibt. Wichtige Entwicklungsarbeiten und Studien wurden 2009 im EU-Projekt des 7. Rahmenprogrammes „Hadronphysics2" gefördert, in dem das SMI die Leitung von zwei Teilprojekten innehat.

Symposien und Veranstaltungen 2009

Im Jahr 2009 wurden die Proceedings der internationalen Konferenzen *Exotic Atoms 2008* (EXA08) und *Low Energy Antiproton Physics 2008* (LEAP08), die vom SMI in der ÖAW veranstaltet wurden, in der Fachzeitschrift Hyperfine Interactions (Springer Verlag) unter der Editorenschaft des SMI veröffentlicht[5]. Im Oktober 2009 wurde ein internationaler Workshop am „European Centre for Theoretical Studies in Nuclear Physics and Related Areas" ECT* (Trento) mit dem Focus auf Kaon-Nukleon Wechselwirkung unter Teilnahme zahlreicher internationaler Top-Wissenschaftler veranstaltet.

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[2] M. Bazzi et al., Physics Letters B 681, 310-314 (2009).
[3] T. Pask et al., Physics Letters B 678, 55-59 (2009) 55-59.
[4] arxiv:0903.3905v1
[5] Eds. B. Juhasz, J. Marton, K. Suzuki, E. Widmann, J. Zmeskal, Hyperfine Interactions 193 (2009).

1.1.2. Kurzfassung der wissenschaftlichen Tätigkeit 2009

Starke Wechselwirkung mit Strangeness

Das Kaon ist das leichteste Elementarteilchen, das ein strange-Quark enthält. Besonders interessant ist die starke Wechselwirkung von negativ-geladenen Kaonen (K^-) bei niedrigen Energien. Auf diesem Gebiet wird ein internationales Netzwerk (LEANNIS) im EU-Projekt HadronPhysics2 vom SMI geleitet. Das Studium der starken Wechselwirkung Kaon-Kern bei niedrigen Energien ist am genauesten durch die Spektroskopie der Röntgenlinien von kaonischen Wasserstoff (ein K^-, das an ein Proton gebunden ist) möglich. Dies war das Ziel des **SIDDHARTA**-Experiments an DAΦNE, an dem das SMI maßgeblich beteiligt ist. Nach intensiver Entwicklungsarbeit (u. a. neue großflächige Siliziumdetektoren mit guter Zeitauflösung) wurde während eines Großteils des Jahres 2009 Daten zu kaonischem Wasserstoff, Deuterium sowie Helium gesammelt. Erste Ergebnisse zu kaonischem ^{4}He wurden bereits publiziert und bestätigten eindeutig frühere Messungen unter Beteiligung des SMI am KEK/Japan, die ein 30 Jahre altes Rätsel der starken Wechselwirkung gelöst hatten. Die Resultate zu kaonischem Wasserstoff werden von der Community der theoretischen Physik mit Spannung erwartet. Die Vorbereitungen für ein Experiment zur Messung der Röntgenenergie von K^{-3}He an J-PARC (**E17**) laufen auf Hochtouren. Dies Experiment wird eines der ersten sein, die an J-PARC stattfinden, und wird wichtige Erkenntnisse zur Isospinabhängigkeit der KN-Wechselwirkung liefern.

Nach mehrjährigen Vorbereitungsarbeiten wurde ein Experiment mit dem **FOPI**-Detektor an der GSI Darmstadt zur Suche nach dem einfachsten tiefgebundenen Kaon-Nukleon-System K^-pp durchgeführt. Der FOPI-Detektor musste um ein neuentwickeltes Detektorsystem und ein Flüssig-Wasserstofftarget erweitert werden, um K^-pp in Proton-Proton-Kollisionen nachzuweisen. Die Auswertung von Daten aus dem früheren Experiment **DISTO**, die in derselben Reaktion bei niedrigeren Energien gemessen wurden, ergab einen positiven Hinweis auf die Existenz des K^-pp Zustandes. Das Resultat wurde zur Publikation angenommen.

Das Experiment **AMADEUS** an DAΦNE wird unter Verwendung des KLOE-Detektors erstmals eine systematische und komplette Untersuchung der Kaon-Nukleon und –Nukleus Wechselwirkung bei niederen Energien liefern, einschliesslich von Kaon-Nukleon Bindungszuständen. Durch die Detektion aller Teilchen in Bildungs- und Zerfallskanälen von Zwei- und Dreibaryonenzuständen mit Strangeness $S = -1$ können diese kinematisch vollständig untersucht werden. 2009 wurde die Analyse existierender KLOE-Daten am LN Frascati weitergeführt um Ereignisse mit der Signatur eines gebundenen Kaon-Nukleon Systems, erzeugt von Kaonen, die im Heliumgas in der KLOE Driftkammer gestoppt wurden, zu finden. Dies dient auch dazu, die Fähigkeit des KLOE Detektor zu untersuchen, solche Ereignisse zu rekonstruieren. Am SMI wurde das Design des kryogenen Targetsystems, das die Wechselwirkungszone umgibt, begonnen. Ein Prototyp für den Kaonentrigger bestehend aus Szintillationsfibern, die von SiPM ausgelesen werden, wurde gebaut und während des SIDDHARTA-Experiments im Strahl getestet. Eine Vereinbarung für die Aufteilung der Arbeiten für die Instanthaltung und den Upgrade des KLOE Detektors wurde zwischen den Kollaborationen AMADEUS und KLOE ausgehandelt und Mitte des Jahres 2009 unterzeichnet.

Materie-Antimaterie Symmetrie

Durch Präzisionsspektroskopie von Atomen, die ein Antiproton (das negativ geladene Antiteilchen des Protons) enthalten, können aus den gemessenen Spektren durch Vergleich mit modernen QED-Rechnungen die Eigenschaften des Antiprotons genau bestimmt werden. Im Rahmen der ASACUSA Kollaboration am AD des CERN wurde mittels Laser- und Mikrowellenstrahlung das exotische Atom **antiprotonisches Helium** genau untersucht. Die Ergebnisse können als Test der fundamentalen Materie-Antimaterie-Symmetrie, der CPT Symmetrie, interpretiert werden. Die Überprüfung der Erhaltung der CPT-Symmetrie ist u. a. durch das Überwiegen der Materie im Weltall gerechtfertigt, da die Erhaltung der Symmetrie während des Urknall zu einer gleichen Anzahl von Materie und Antimaterie führen sollte.

Eine interessante Größe hierbei ist das magnetische Moment des Antiprotons, das bisher nur auf 0,3% genau bekannt ist. Unter Federführung des SMI wurde eine mehrjährige Messreihe unter Verwendung einer kombinierten Methode aus Laser- und Mikrowellenspektroskopie abgeschlossen, mit der unsere früheren Resultate um einen Faktor 5 verbessert werden konnten. Mit dieser Präzision konnte das magnetische Moment des Antiprotons durch Vergleich der Messergebnisse mit QED-Rechnungen genauer als bisher jemals bestimmt werden. Der neue Wert stimmt gut mit früheren Messungen sowie dem Wert für das Proton überein.

Im Jahr 2009 begannen wir mit der Messung der Hyperfeinstruktur von antiprotonischem ^{3}He ($\bar{p}^3He^+$), das eine komplexere Niveaustruktur aufweist und somit eine strengere Überprüfung der Theorie ermöglicht. Das Experiment wird innerhalb eines österreichisch-russischen Gemeinschaftsprojekt von FWF und RFBR gefördert, das zusammen mit den führenden Theoriegruppen von JINR Dubna und der Moscow State University durchgeführt wird. Eine neue hermetisch abgeschlossene kryogene Kavität mit mechanischem Kompressorkühler wurde am SMI gebaut und in erfolgreich in Betrieb genommen. Im ersten Versuch im Jahr 2009 konnte noch kein Mikrowellensignal beobachtet werden.

Langfristig ist das Hauptexperiment der ASACUSA Kollaboration die Messung der Grundzustands-Hyperfeinaufpaltung von **Antiwasserstoff**. Dies Verspricht einen äußerst genauen Test der CPT Symmetrie da die entsprechende Größe im Wasserstoffmaser mit einer Genauigkeit von 10^{-12} bestimmt wurde. Das SMI ist dabei für die Spektrometer-Strahlführung zuständig. 2009 wurde das Design eines Sextupolmagenten fertiggestellt und dieser über eine internationale Ausschreibung am CERN bestellt. Er wird zu zwei Dritteln von der ÖAW und zu einem Drittel von der Universität Tokio finanziert. Der Magnet wird im Frühjahr 2010 geliefert. Parallel dazu wurde das Design einer Spin-Flip-Kavität von einer Dissertantin, die über das CERN-Austria Fellowship Program in der Hochfrequenzgruppe der AB Division des CERN arbeitet, weitergeführt.

FAIR

Das Institut ist an der zukünftigen Facility for Antiproton and Ion Research (FAIR) mit drei Experimenten (FLAIR, PANDA und AIC) beteiligt. 2009 wurde es klar, dass aufgrund von Kostensteigerung nur ein Teil der FAIR-Anlage in der ersten Phase fertiggestellt werden kann. Im Projekt **PANDA**, einem der Hauptprojekte an FAIR, das in der ersten Phase in Betrieb gehen wird, werden Antiprotonen bei hoher Energie für Studien im Bereich der charm-Quarks eingesetzt. Das Forschungsgebiet erhielt neue Impulse durch die Entdeckung von neuen Teilchen im Energiebereich von PANDA, deren Natur ungeklärt ist. Im Jahr 2009 wurde mit Beteiligung des SMI das vielfältige Forschungsprogramm von PANDA in einem Physics Book publiziert. Das SMI beschäftigte sich mit Simulationen zur Wechselwirkung von Charmonium in Kernmaterie und arbeitete an dem Design des Targetsystems von PANDA sowie an der Evaluierung neuer Detektortechnologien für PANDA (Gas-Elektron Multiplier, neuartige Photosensoren).

Sonstige Physikprojekte

In der Studie der **Pion-Kern-Wechselwirkung** wurden die Ergebnisse vom pionischen Deuterium zur Veröffentlichung eingereicht. Die Auswertung der Breite des durch die starke Wechselwirkung verbreiterten 1s Zustandes in pionischen Wasserstoff wird weitergeführt. Das Experiment **VIP** (Violation of the Pauli Principle) läuft am LN Gran Sasso weiter und hat die Obergrenze für eine mögliche Verletzung des Pauliprinzips gegenüber früheren Experimenten bereits um einen Faktor 300 verbessert. Tests für einen verbesserte Apparatur mit einem Veto gegen Höhenstrahlung wurden durchgeführt.

R&D Projekte

Die Entwicklungen für das Target von PANDA werden im Rahmen des Working Packages **FutureJET** des EU-Projektes HadronPhysics2 weitergeführt. Ein Technical Design Report (TDR) wird gerade ausgearbeitet. Das SMI ist für das Design des Vakuumsystemes und der Wechselwirkungszone verantwortlich. Dazu wurden auch Berechnungen des Vakuums durchgeführt, da dies sehr wichtig für die Lebensdauer des Antiprotonenstrahls ist und unerwünschten Untergrund verursachen könnte.

Die Entwicklung neuartiger Matrix-Avalanche-Photodetektoren (**silicon photomultipliers - SiPMs**) wird, unterstützt durch mehrere EU-Projekte, weiter vorangetrieben. Wir waren bis zum Ende der Designstudie "DIRACSecondary berams" am 31.1.2009 beteiligt. Das Ziel war die Entwicklung von Cherenkov Detektoren für die DIRC und RICH Detektoren von PANDA. Ein INTAS Projekt wurde 2009 weitergeführt, wobei wir von russischen Wissenschaftlern entwickelte neue SiPMs über die Firma Zecotek/Singapur zur Evaluierung erhielten. Seit Angang 2009 läuft ein Projekt SiPM (Avalanche Micro-Pixel Photo Diodes for Frontier Detector Systems) im Rahmen von HadronPhysics2. Wir beteiligen uns mit Tests von zeitgebenden Cherenkovzählern mit SiPM-Auslese. Ein Protoyp wurde am 500 MeV Elektronenstrahl der Beam Test Facility des LN Frascati getestet und ergab eine Zeitauflösung von etwa 400 ps. Dies stellt einen ersten Schritt in Richtung schneller Cherenkovzähler, die in der Nähe starker Magnetfelder operieren, dar.

Wir konnten weiter Erfahrung mit dem Betrieb von SiPM-Zähler an Teilchenbeschleunigern gewinnen. Gekühlte, temperaturstabilisierte SiPM wurden zusammen mit einem 16x16 Gitter aus Szintillationsfibern als Strahlmonitor des FOPI-Experimentes benutzt. In der Zukunft woillen wir solche Systeme als positionsempfindliche Detektoren im AMADEUS-Experiment benutzen.

Im vom SMI geleiteten working Package **JointGEM** von HadronPhysics2 werden schnelle großflächige Detektoren für die nächste Generation von Experimenten der Hadronenphysik entwickelt, um seltene Prozesse mit drastisch erhöhter Empfindlichkeit beobachten zu können. Sogenannte Micropattern Gas Detectors (MPGDs) basierend auf

Gas Electron Multiplier (GEM) Technologie versprechen einen hervorragenden Zugang zu dieser Thematik. Am SMI begannen wir mit der Entwicklung eines Gassystems mit geschlossenem Kreislauf für eine Time Projection Chamber (TPC) auf GEM-Basis, und dem Aufbau eines Protoyps eines Triple-GEM Detektors. Dieser Detektor dient als Testaufbau für die Charakterisierung von GEM-Folien und den Test verschiedener Auslesemethoden.

1.2. Summary of the scientific report 2009

1.2.1. Highlights 2009

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 generation of hadron masses (e.g. protons or neutrons). The measurement of X-rays of kaonic hydrogen, deuterium and helium was the goal of the SIDDHARTA project. For that we developed novel X-ray detectors and electronics within an EU project. Data taking was finished at the electron-positron collider DAFNE in Frascati in 2009, and we expect to obtain the most precise result so far for kaonic hydrogen. A first result for kaonic helium, which gave a very important confirmation of an earlier result obtained at KEK/Japan, was already published[6].

New value of the magnetic moment of the antiproton

Antiprotonic helium is a neutral exotic atom consisting of a helium nucleus, an electron and an antiproton. It is being studied at the „Antiproton Decelerator" at CERN (Geneva) within the international collaboration ASACUSA using laser and microwave spectroscopy. By comparing the measured transition frequencies with theoretical calculations, fundamental properties of the antiproton like mass, charge or magnetic moment can be obtained. Comparing them to the corresponding properties of the proton yields a test of matter-antimatter symmetry, which is obviously violated in the cosmos since the known universe consists entirely of matter. The interaction of the magnetic moment of the antiproton with those of the other constituents leads to a *hyperfine structure* (HFS). From our measurements a new value of the magnetic moment of the antiproton which is more precise than previous measurements was obtained and published in 2009[7]. It agrees within the error with the value of the proton.

Search for kaon-nucleon bound states with FOPI

The strong attraction between antikaons and nucleons could make it possible to form bound states similar to neutrons and protons in an atomic nucleus. The existence of kaon-nucleon bound states is however strongly debated and can only be proven by a dedicated experiment. SMI is a leading participant in such an experiment at GSI (Darmstadt). Using proton-proton collisions and the FOPI detector we try to find the simplest kaon-nucleon bound state $K^{-}pp$. After two years of intense preparations with the support of FWF, the experiment took place in August 2009. The data are currently being analysed and first results are expected in 2010.

PANDA at FAIR

An important step for the PANDA project at the planned FAIR facility in Darmstadt was the publication of a „physics book"[8] in 2009. It covers the broad range of research themes (QCD bound states, non-perturbative QCD dynamics, hadrons in nuclear matter, hypernuclei, electromagnetic processes and the structure of nucleons). Important R&D studies are funded since 2009 within the EU project in the 7. Framework Programme „Hadronphysics2", where SMI is leading two working packages.

Symposia und events 2009

In 2009 the proceedings of the international conferences *Exotic Atoms 2008* (EXA08) and *Low Energy Antiproton Physics 2008* (LEAP08) organized by SMI in the ÖAW head quarters were published in the journal Hyperfine Interactions (Springer)[9]. In October 2009 an international workshop was organized at the „European Centre for Theoretical Studies in Nuclear Physics and Related Areas" ECT* (Trento). It focussed on the kaon-nucleon interaction and attracted numerous international scientists.

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[6] M. Bazzi et al., Physics Letters B 681, 310-314 (2009).
[7] T. Pask et al., Physics Letters B 678, 55-59 (2009).
[8] arxiv:0903.3905v1
[9] Eds. B. Juhasz, J. Marton, K. Suzuki, E. Widmann, J. Zmeskal, Hyperfine Interactions 193 (2009).

1.2.2. Abstract of the scientific activity during 2009

Strong interaction with strangeness

The kaon is the lightest particle containing a strange quark. Of special interest is the interaction of negatively charged kaons (K^-) at low energies. An international network (LEANNIS) dealing with this topic is led by SMI within the EU project HadronPhysics2. The study of the strong kaon-nucleon interaction at low energy can be most precisely done through the X-ray spectroscopy of kaonic hydrogen (a K^- bound to a proton). This was the goal of the **SIDDHARTA** experiment at DAΦNE in which SMI is a key participant. After intense R&D work (e.g. an array of novel large-area silicon detectors with good timing resolution) data were taken throughout most of 2009 on kaonic hydrogen, deuterium, and helium. First results on ^{4}He were already published and clearly reproduced our earlier results taken at KEK/Japan, which finally solved a 30-year old puzzle of strong interaction. The results on kaonic hydrogen are eagerly awaited by the theoretical community. Preparations are ongoing for an experiment to measure the X-ray energies of K^-^{3}He at J-PARC (**E17**). The experiment is the first one to be performed at J-PARC and will yield important information on the isospin dependence of the KN interaction.

After several years of preparations an experiment searching for the simplest deeply bound system K^-pp using the **FOPI** detector at GSI was carried out in 2009. The FOPI detector had to be upgraded by a newly developed detector system and a liquid hydrogen target to allow for the detection of K^-pp in proton-proton collisions. Data taken in an earlier experiment **DISTO** in the same reaction at lower energies were analyzed and a result showing an indication for the K^-pp bound state was accepted for publication.

AMADEUS at DAΦNE will make use of the KLOE detector to perform, for the first time, a systematic and complete spectroscopic study of kaon nucleon/nucleus interaction at low energy including antikaon-mediated nuclear bound states. By measuring all particles in the formation and in the decay processes of two- and three-baryon states with strangeness $S = -1$ a kinematically complete study will be performed.

A dedicated work to analyze part of the existing KLOE data was continued in 2009 at LN Frascati, with the main objectives to search for events with the signature of kaon-nucleon bound states for kaons stopped in the thin gas of the drift chamber and to examine the capability of KLOE to reconstruct such events. R&D work was started at SMI mainly to design the cryogenic target system around the interaction region. A first prototype of a section of the kaon trigger was constructed and tested during the SIDDHARTA beam time using SiPM to read out scintillating fibers. An agreement has been worked out to regulate the work for the maintenance and upgrade of the KLOE detector between KLOE and the AMADEUS collaboration, which was signed middle of 2009.

Matter-antimatter symmetry

Precision spectroscopy of atoms containing an antiproton (the negatively charged antiparticle of the proton) allows to precisely determine the properties of the antiproton by comparing the measured spectra with modern QED calculations. Within the ASACUSA collaboration at CERN-AD we investigated the exotic atom **antiprotonic helium** by laser and microwave spectroscopy. The results can be regarded as a test of the fundamental matter-antimatter symmetry, i.e. CPT symmetry. Testing CPT conservation is in part motivated by the observed matter-antimatter asymmetry of the universe, because the conservation of CPT would lead to the creation of equal amounts of matter and antimatter.

An interesting quantity hereby is the magnetic moment of the antiproton, which is currently known only to 0.3%. Under the leadership of SMI a series of measurements of the hyperfine structure (HFS) of antiprotonic ^{4}He ($\bar{p}^4He^+$) was carried out over several years using a combined method of laser and microwave spectroscopy. The final result of the data analysis yielded an improvement of a factor 5 over our earlier measurements, which allowed us to determine the magnetic moment of the antiproton by comparison with three-body QED calculations with higher precision than before. The new value agrees well with earlier measurements and with the value of the proton.

In 2009 we started a measurement of the HFS of antiprotonic ^{3}He ($\bar{p}^3He^+$), which has a more complex level structure and thus constitutes a more thorough test of theory. The project is funded within the framework of a joint Austrian-Russian FWF-RFBR project together with the leading theoretical groups at JINR Dubna and Moscow State University. A new hermetically sealed liquid helium-free cryogenic cavity was built and successively operated at CERN-AD. In the first run in 2009 a microwave signal could not be observed, the experiment will be continued in 2010 after some improvements.

The major long-term goal within ASACUSA is the determination of the ground-state hyperfine structure of **antihydrogen**, which offers an extremely precise test of CPT symmetry because its counterpart is measured in the hydrogen maser to a relative precision of 10^{-12}.

SMI is in charge of the spectrometer line to measure the HFS frequency. In 2009 the design of a sextupole magnet was finished and a magnet was ordered through an international tender at CERN, financed 2/3 by ÖAW and 1/3 by the University of Tokyo. The magnet will arrive in spring of 2010. The design of a spin-flip resonator was continued with the help of a Ph.D. student financed through the CERN-Austrian Fellowship program and working in the radio frequency group of the CERN accelerator division.

FAIR

SMI participates in three experiments of the future FAIR facility (FLAIR, PANDA, and AIC). In 2009 it was decided that due to a cost increase of the FAIR facility, only a part of the planned infrastructure can be constructed in the first phase. **PANDA**, one of the main experiments of FAIR which remains in the first phase, uses high-energy antiprotons for studies involving charm quarks. The field received a new push from the discovery of new particle states in the accessible energy range which are of currently unknown nature. In 2009 the diverse physics program was published in a physics book. SMI participates in the physics topic "hadrons in medium" by performing simulations of the interaction of charmonium in matter, and in the design of the target system as well as in the evaluation of new detector technologies for PANDA (gas-electron multipliers, novel photo detectors).

Smaller physics projects

In the study of the **pion-nucleon interaction** the result of measurements with pionic deuterium has been submitted for publications. Efforts are contunuing to finish the analysis of the strong-interaction induced width of the 1s state of pionic hydrogen. The **VIP** (Violation of the Pauli principle) experiment continues to take data at LN Gran Sasso and yielded a new upper limit for a violation of the Pauli Principle by a factor 300 compared to previous experiments. Test have been done with an improved version of the setup using an active cosmic ray shielding.

R&D projects

For the PANDA target, work is continuing within the working package **FutureJET** of HadronPhyscs2. A technical design report (TDR) is being prepared. SMI has taken the lead in the design of the vacuum system and the interaction zone of the PANDA detector. This was supplemented by calculations of the vacuum conditions in PANDA, which is very important since a high density of residual gas would drastically reduce the amount of the stored antiprotons and cause a lot of unwanted background events.

The development of new matrix avalanche photo-detectors (**silicon photomultipliers – SiPMs**) is going on supported by several projects funded by the European Community. Our institute participated till the end of the project (January 31, 2009) in the EU Design Study "DIRACsecondaryBeams" which was part of the technical developments for the new international research center FAIR at Darmstadt, aimed at the development of imaging Cherenkov detectors proposed for the DIRC and the forward RICH detector of PANDA. A project within INTAS was continued in 2009. New silicon photomultipliers developed by Russian scientists and manufactured by Zecotek/Singapore were delivered to SMI for evaluation. With January 1st, 2009 the work on a project (WP28, SiPM – Avalanche Micro-Pixel Photo Diodes for Frontier Detector Systems) within the EU project HadronPhysics2 dealing with SiPMs was started. The kick-off meeting took place in February 2009 at GSI. Our institute was working on the development and testing of a Cherenkov timing device employing SiPM readout. The detector prototype was tested with 500 MeV electrons at the Beam Test Facility in Frascati. We found a timing resolution of about 400 ps with the detector prototype which represents a first step in the development of fast Cherenkov trigger detectors suitable for the operation in the vicinity of strong magnetic fields.

We gained experience in operating SiPMs in experiments at particle accelerators. Cooled and temperature stabilized SiPMs were used in combination with a 16x16 scintillating fiber grid in 2 planes for a beam profile monitor for the FOPI experiment. This device was successfully operated in beam at GSI. In the future SiPM readout of scintillating fibers will be applied for a position-sensitive kaon trigger in the AMADEUS experiment.

Within the working package **JointGEM** (led by SMI), fast detectors with large acceptance and high resolution are developed for the next generation of experiments in hadron physics aiming at studying rare processes with drastically improved sensitivity. Micropattern Gas Detectors (MPGD) based on the Gas Electron Multiplier (GEM) technology provide a very promising path towards these goals. SMI started to develop a closed cycle gas handling system for TPC-GEM systems and in addition is working on a prototype triple-GEM detector system. The triple-GEM system will act as a test-bench apparatus for the characterisation of GEM foils and for the test of different readout structures.

1.3. Report on the scientific activity during 2009

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

- FS1_A: Kaon-Nucleon Interaction: Kaonic atoms and kaonic nuclei
  - FS1_b_A: Kaonic hydrogen and deuterium: SIDDHARTA
  - FS1_c: Strangeness physics with FOPI at GSI
  - FS1_d: DISTO data analysis
  - FS1_e: AMADEUS at DAΦNE2
  - FS1_f: Study of kaon-nucleon interaction @ J-PARC
  - FS1_g: Precision spectroscopy of kaonic ^{3}He (FWF project)
  - FS1_h: LEANNIS
- FS2_A: Matter - antimatter symmetry: ASACUSA @ CERN
  - FS2_b: Hyperfine structure of antiprotonic helium
  - FS2_c: Precision laser spectroscopy of antiprotonic helium
  - FS2_d: Measurement of the ground-state hyperfine structure of antihydrogen
- FS3_A: Antiprotons at FAIR
  - FS3_b: PANDA: Proton Antiproton Annihilations at Darmstadt
  - FS3_c: Hadrons in medium
  - FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research
    - FS3_z_c: Cherenkov Imaging Detectors (DIRACsecondary beams)
    - FS3_z_d: Development and tests of novel matrix avalanche photo detectors for PANDA
- Smaller physics projects
  - Pion-Nucleon Interaction
  - Two-body decays of stored and cooled ions
  - VIP @ Gran Sasso (VIolation of the Pauli Exclusion Principle Experiment)
- R&D projects
  - FS4_a: JointGEM
  - FS4_b: SiPM
  - FS4_c: FutureJet
  - FS4_d: PANDA Grid

1.3.1. Strong interaction with strangeness

Low energy QCD with light *u*, *d* quarks has reached by now a precision of quantitative science. In this sector there is a rich, high-precision experimental data set available. Chiral perturbation theory with the pion as a good approximation of the Nambu-Goldstone boson works pretty well and is in a good agreement with Lattice QCD.

The situation in the strangeness sector, however, is quite to the contrary due to the opposite reason as mentioned in the *u*, *d* sector. The basic low energy *K-N* interaction is difficult in the theoretical treatment due to a strong coupling between KN-$\pi\Sigma$ channels.

Two modern, precise measurements of the kaonic hydrogen energy shift and width from KpX at KEK and DEAR at LNF-INFN set a tight constraint to calculations of the $\overline{K}N$ interaction. A chiral SU(3) unitary approach using coupled-channel techniques has been applied and reproduces both data sets. However, it suffers from the uncertainty of the data (Fig. 1).

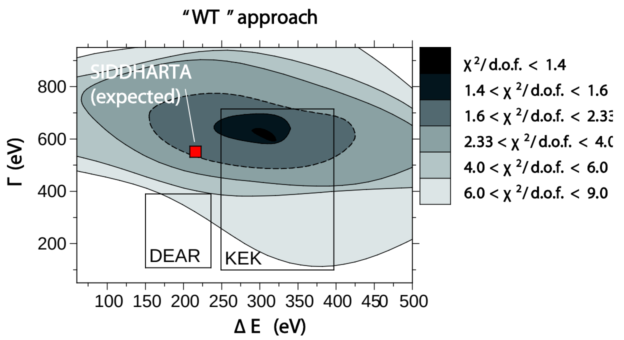

Fig. 1: (a) Energy shift and width of kaonic hydrogen calculated in a chiral SU(3) unitary calculation, compared to the KpX (KEK) and the DEAR (LNF-INFN) data [B. Borasoy, U.-G. Meißner, R. Nißler; Phys. Rev. C 74, 055201 (2006)]. The expected precision of the SIDDHARTA experiment is indicated, too.

The SIDDHARTA experiment aims to improve the precision of the kaonic hydrogen data significantly and started its data taking in 2008 and completed it in 2009. It also measured kaonic deuterium for the first time to examine the isospin dependence of the $\overline{K}N$ interaction.

Furthermore, the KEK-PS E570 experiment determined the *2p* energy shift of kaonic ^{4}He. The existing old data are inconsistent with other measurements of kaonic atoms, which had been a long standing puzzle. The newly analysed very accurate KEK-PS E570 data agree with the other kaonic atom data, and the new data from SIDDHARTA confirmed this result (see Fig. 2). The precision studies of kaonic hydrogen, kaonic deuterium and kaonic helium allow to study the energy dependence of the $\overline{K}N$ interaction, which will vitally improve the extrapolation of the $\overline{K}N$ interaction to the subthreshold region and set new constraints on the description of the $\Lambda(1405)$ resonance.

In this context, the possible existence of kaonic nuclear states has been and is a very hot topic in this field. The discussion heavily involves both the experimental as well as the theoretical part of the subject. The primary interests are in the K^-ppn system, the fundamental K^-pp system, the still not well known nature of $\Lambda(1405)$, and the above-mentioned kaonic ^{4}He puzzle, hence in an advance of the overall understanding of the $\overline{K}N$ interaction.

The prediction power of the $\overline{K}N$ interaction extra-polated in the subthreshold region is limited. This fact encourages the SIDDHARTA and the AMADEUS experiments to provide comprehensive basic experimental data which allow to put more stringent constraints to the theory.

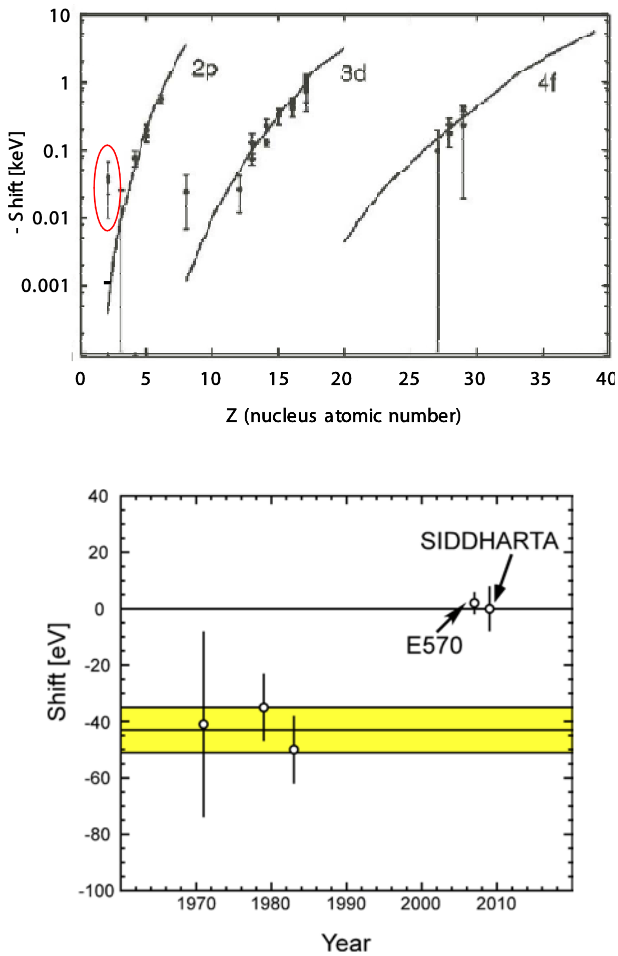

Fig. 2: (top) Strong interaction shifts of kaonic atoms. Theo-retical curves are in good agreement with data except for ^{4}He (indicated with a red circle) and ^{16}O cases.
(bottom) The *2p* level shift of kaonic ^{4}He obtained from the E570 and SIDDHARTA experiments, compared with old data, solving the kaonic helium puzzle.

The K^-pp system is the most fundamental system of the kaonic nuclear states and has been discussed extensively in the past year. Its binding energy and width was first calculated by Akaishi and Yamazaki based on the so-called $\Lambda(1405)$ Ansatz [i.e. the $\Lambda(1405)$ is assumed to be a $I = 0$, $\overline{K}N$ quasi-bound state with $B_K = 27$ MeV]. In their approach they found a total binding energy of $B_K = 48$ MeV, resulting in a mass $M = 2322$ MeV/c^2 and width $\Gamma = 61$ MeV for the K^-pp. Recent Faddeev calculations also predict the K^-pp to be deeply-bound. On the other hand, a theory based on chiral dynamics and a "two-pole structure" of the $\Lambda(1405)$ prefers "weak" binding. The presently disputed situation of the K^-pp is summarized in Fig. 3. An experiment providing conclusive data to answer this issue is strongly awaited.

SMI has been working on experimental searches of such kaonic nuclear bound states. In 2009 we measured the pp reaction at $T_p = 3.1$ GeV using the FOPI detector at the GSI to search for the most fundamental dibaryon system $(\overline{K}NN)_{S=0,\, I=1/2}$ usually called K^-pp, to be formed in the two body process $pp \rightarrow K^+X$, where $X = K^-pp$. Earlier experimental studies of kaonic nuclear states using nuclear targets were influenced by the background and final state interactions with spectator nucleons. The pp reaction is more direct and less ambiguous in its interpretation.

Data in the same channel $pp \rightarrow pK^+\Lambda$, acquired by the DISTO collaboration, have been re-analysed. Those data, though obtained at a lower beam energy of $T_p = 2.85$ GeV and hence not optimal in terms of the S/N ratio and background shape, indicate that the quoted two body process works: a structure of large binding energy (~100 MeV) and small width (~100 MeV) could be identified.

The upcoming AMADEUS project, an extension of the KLOE-II experiment, plans to measure low energy kaon cross sections with p, d, ^{3}He, and ^{4}He target nuclei in order to supply a missing part of the basic database of the $\overline{K}N$ interaction. AMADEUS will also study kaonic nuclei, in particular their full decay pattern, including the neutral channels. A further complementary study of the kaonic nuclear state K^-pp using in-flight (K^-,n) reactions is planned together with the E15 experiment at J-PARC.

Finally, to the experimental campaigns a program to study the production and propagation of strange hadrons using pion induced reactions will be added. The measurement will be carried out at the GSI using the FOPI detector.

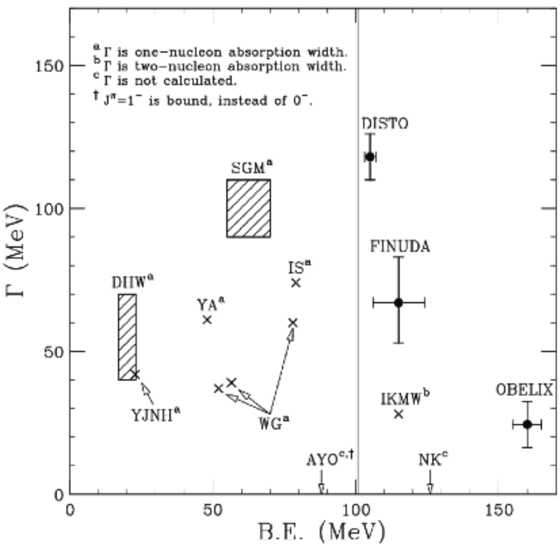

Fig. 3: Current status of the "K^-pp puzzle" in the binding energy and width presentation summarized in the reference T. Koike and T. Harada, Phys. Rev. C 80 (2009) 055208. Theoretical calculations with the $I = 1/2$, $J = 0^-$ state are predicted by YA (Yamazaki, Akaishi), SGM (Shevchenko, Gal, Mareš), IS (Ikeda, Sato), DHW (Doté, Hyodo, Weise), IKMW (Ivanov, Kienle, Marton, Widmann), NK (Nishikawa, Kondo), YJNH (Yamagata, Jido, Nagahiro, Hirenzaki), and WG (Wycech, Green); the $I = 1/2$, $J = 1^-$ state by AYO (Arai, Yasui, Oka). Black circles are the data from the FINUDA, OBELIX and DISTO experiments which are claimed to be as a candidate of the K^-pp state. It should be noted, however, that an assignment of the data to the K^-pp is still controversial.

1.3.1.1. Kaonic light atoms: SIDDHARTA & E17

(E17 is supported by FWF grant P20651)

(E17 is the Ph.D. thesis of B. Wünschek)

SIDDHARTA (SIlicon Drift Detector for Hadronic Atom Research by Timing Application) aims for a precise determination of the strong interaction induced shift and width of the ground state of kaonic hydrogen at the percent level. To achieve this goal large area detectors (SDDs – Silicon Drift Detector) have been developed within a European Joint Research Project (FP6 – Hadron Physics). In 2009 the experiment was running from the beginning of the year until October, when data taking was finished. The data taking period started with a calibration measurement done with helium followed by measurements of hydrogen and deuterium. Finally at the end of the data taking period it was possible to use the excellently tuned apparatus for a first successful measurement of ^{3}He, a system for which no experimental data existed up to now. A dedicated

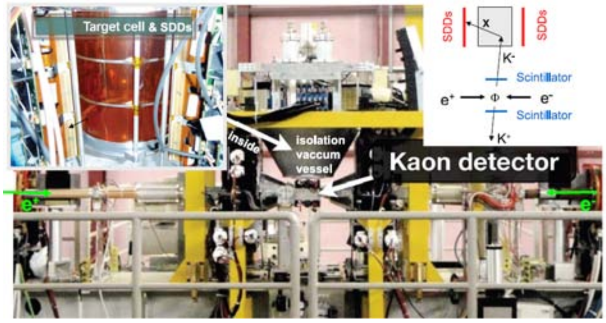

Fig. 4: The experimental apparatus of SIDDHARTA in place at DAFNE. Upper left insert: the target cell, right: scheme of the triggered detection system for kaonic X-rays.

experiment for K-^{3}He is planned at J-PARC: experiment E17.

To test and optimize our experimental technique we measured the L-transitions of kaonic helium using different degraders, collimators and shielding structures and we worked out the energy calibration procedure. A part of the data was taken with a ^{55}Fe source mounted inside the apparatus. This allowed detailed studies of the systematics of the calibration procedure. The high yield of the K-He L-transitions made it possible to collect enough statistics in the X-ray spectra within a day.

The kaonic helium has physics-interest in itself: Before the KEK E570 experiment the experimental data were in contradiction with theory. The new value for the ^{4}He 2p shift from E570 is now confirmed by our measurement, we published first results in 2009. Using our total ^{4}He data we will derive a yield pattern for the transitions. Since our target was gaseous helium, whereas E570 used liquid, the atomic cascades (and correspondingly the yields) are different and so complementary information will be gained.

During the summer machine shutdown a drastic improvement in signal rate and in backgound reduction was achieved by optimizing the experimental setup and by better machine performance.

Among the light kaonic atom systems, one of the most important data is the strong-interaction shift and width of kaonic ^{3}He 2p state. No data on the kaonic ^{3}He shift and width are available, and also theoretically poorly known. For example, a theory that constructs the deeply bound kaonic nuclear states predicts a possible maximum shift of 10 eV, which depends on a parameter of the potential depth. Therefore, the experimental results on the kaonic ^{3}He provide crucial information on the developments of theories.

The Experiment E17, called: Precision spectroscopy of kaonic ^{3}He 3d → 2p X-rays, will use one of the kaon

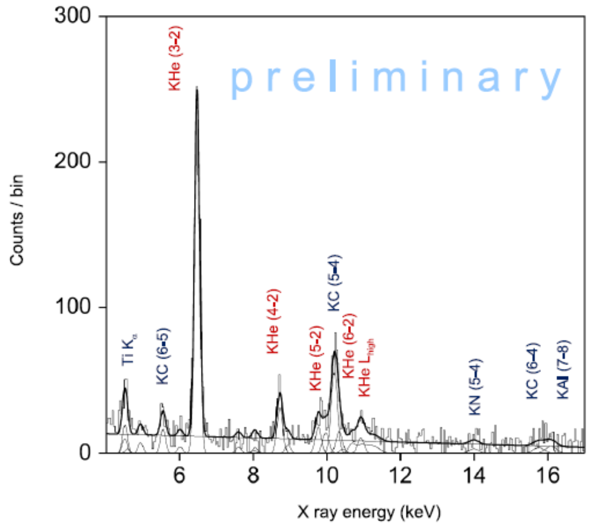

Fig. 5: X-ray spectrum showing the L-series lines of kaonic ^{4}He and kaonic lines from kaon stops in the target walls.

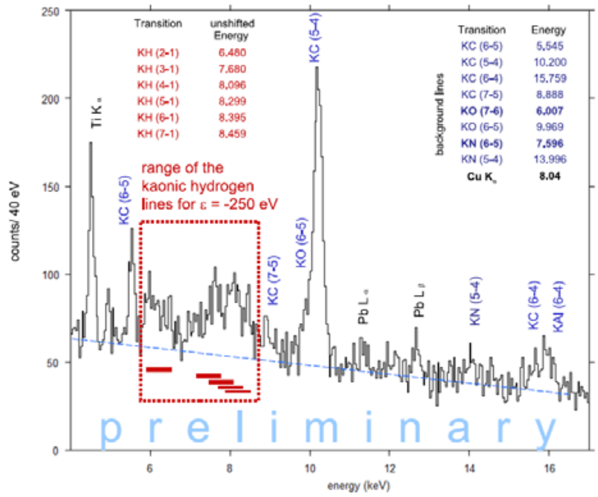

Fig. 6: X ray spectrum for a data subset of the K-H measurement. The dotted box shows the region of interest for the kaonic hydrogen K-lines.

beam lines in the Hadron Hall facility (K1.8 BR) in J-PARC (Tokai, Japan). This experimental project was approved as Stage-2 (fully approved) in the J-PARC PAC meeting. E17 is the first experiment to be performed at the J-PARC Hadron Hall facility.

The goal of the E17 experiment is the determination of the strong-interaction shift and width of the kaonic ^{3}He 2p state with a precision of 2 eV, by measuring the kaonic helium Balmer series X-rays using a liquid ^{3}He target. A similar setup, as already successfully used in the KEK PS E570 experiment, will be constructed. Kaonic ^{3}He X-rays will be measured with eight or twelve (depending on geometric requirement) SDDs, which have good resolution both in energy and timing. Background events are suppressed by detecting the secondary charged particles produced by the kaon-helium reactions using tracking chambers. Fluorescence X-ray lines induced by the incident beam on pure foils, whose energy values are well known, are used for the calibration of the X-ray energy scale.

The E17 experimental setup has some improvements compared to the E570 setup. The ^{3}He target cell is made of 0.3 mm-thick beryllium instead of commonly used Kapton or Mylar. Due to a smaller size of the target cell compared to that used in E570, the Compton tail of the kaonic X-ray peaks is reduced, which could provide a smaller systematic error in the determination of the kaonic X-ray energy. In addition, the kaonic helium 3d-2p line will be measured without overlapping of other kaonic atom X-ray lines (e.g. kaonic oxygen lines). The SDDs are installed closer to the target cell and the pre-amplifiers are installed inside the vacuum chamber. Due to the shorter distance between the SDDs and pre-amplifiers, a reduction of noise and an improvement

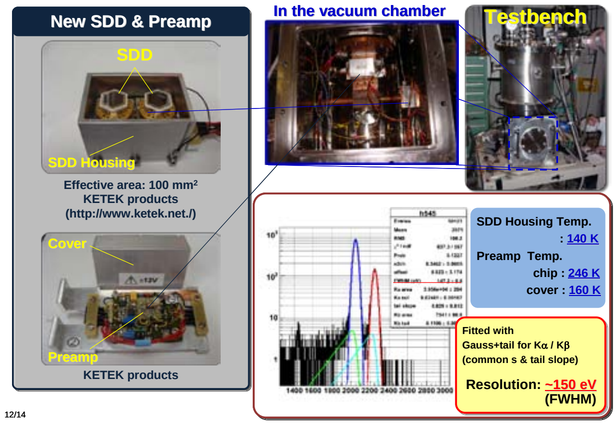

Fig. 7: SDD test measurements.

of the X-ray energy resolution are expected. The construction and test measurements have been progressed, as well as the kaon beam line tuning.

1.3.1.2. Strangeness physics with FOPI at GSI

(Supported by FWF grant P21457)

FOPI is a fixed-target experiment primarily designed to investigate hadron properties at different temperatures and densities using heavy ion collisions. The apparatus has nearly 4π coverage of geometrical acceptance and a very good tracking and particle identification capability. Our activity mostly focuses on strangeness physics. The *strange* quark is the next heavy quark after the *up* and *down* quarks of which nucleons and nuclei consist, and it is a key topic of modern nuclear physics, e.g. $\bar{K}N$ interaction, hyper nuclei, kaon condensation and neutron star, and more recently a new possible form of exotic hadrons.

A possible existence of kaonic nuclear bound states has been a recent hot topic as such states may have unusual high density. The most fundamental dibaryon system $(\bar{K}NN)_{S=0,\, I=1/2}$ often called $K^{-}pp$ was predicted to have an antikaon binding energy of B_K = 48 MeV and width of Γ = 61 MeV[10], based on the so-called $\Lambda(1405)$ Ansatz (the $\Lambda(1405)$ is assumed to be a $I = 0$, $\bar{K}N$ quasi-bound state with B_K = 27 MeV). Recent Faddeev calculations also predict the $K^{-}pp$ to be deeply-bound. On the other hand, a theory based on chiral dynamics and the "two-pole-structure" Ansatz of the $\Lambda(1405)$ prefers "weak"-binding. An experiment pro-

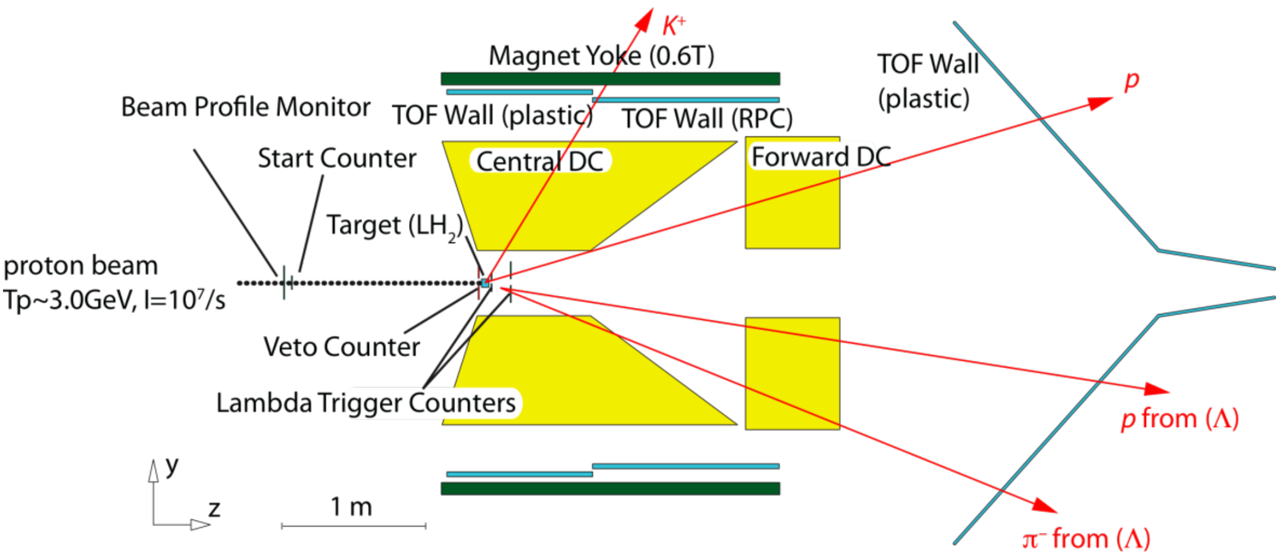

Fig. 8: Schematics of the experimental setup of *p+p* reaction at FOPI in search for a kaonic nuclear state, $K^{-}pp$.

viding conclusive data to answers this issue is strongly awaited[11].

We investigate the $p+p \to K^{-}pp + K^{+} \to p + \Lambda + K^{+}$ reaction in which the $K^{-}pp$ with a short p-p distance can be formed with a very large sticking probability between $\Lambda(1405)$ and p due to the short range and high momentum transfer of the pp reaction. Thus, the issue whether the $K^{-}pp$ and other kaonic nuclei have unusual high nuclear density or not can be answered by examining this prediction experimentally. The experimental setup of experiment S349 at GSI is schematically shown in Fig. 8 in which a typical event example is overlaid. The charged kaon is emitted and detected mostly in the backward detector region with a combination of the central drift chamber and the new RPC (Resistive Plate Chamber) TOF wall in the 0.6 T magnetic field. The decay product of the $K^{-}pp$ is measured in the forward region with a combination of the silicon tracker, the forward drift chamber and the forward TOF wall. A pair of multiplicity counters (Lambda trigger) effectively selects an event which involves a short-lived neutral Lambda particle online.

In the first half of 2009 we completed a development and installation of a new start counter, a beam profile monitor, a veto detector, and a liquid hydrogen target. In August-September 2009 we carried out a production beamtime with a beam energy of 3.1 GeV. Through the 3 weeks of beamtime we collected 80 million “Lambda-Trigger” events. Currently data analysis is going on.

Complementary information on the interaction of K mesons with nuclei can be obtained using pion induced reactions. At GSI-SIS a secondary pion beam in the appropriate energy range is available. In 2007 the FOPI experiment S339[12] “*Pion induced in-medium production and propagation of strangeness*” has been approved. A π^{-} beam of ~1.7 GeV/c, which is closed to the threshold for the production of the $\Phi(1020)$/ $K^{+}K^{-}$, will interact with the target nuclei ^{1}H, ^{12}C, ^{63}Cu, and ^{208}Pb. The FOPI detector will measure the final state particles with particular emphasis on the charged and neutral K mesons ($K^{+}K^{-}$, K^{0}_{S}). The Φ meson yield as a function of the target mass number will be used to determine the in-medium Φ-nucleon cross sections. The comparison of the spectral shapes of non-resonant pair-produced K^{+} and K^{-} mesons will provide information about the in-medium potential of charged kaons. SMI is involved in this experiment in terms of the co-spokespersonship and design, building and operating a liquid hydrogen target system as well as a VETO counter.

The detailed preparation of the experiment has been started in 2009. More in-depth simulations have been started using FLUKA[13], GiBUU[14] and GEANT[15].

As an example, Fig. 9 shows the momentum space of charged kaons from the liquid hydrogen target as calculated with FLUKA. Most of the kaons are emitted under small (<25°) polar angles. So far the simulations are consistent with the assumptions in the proposal.

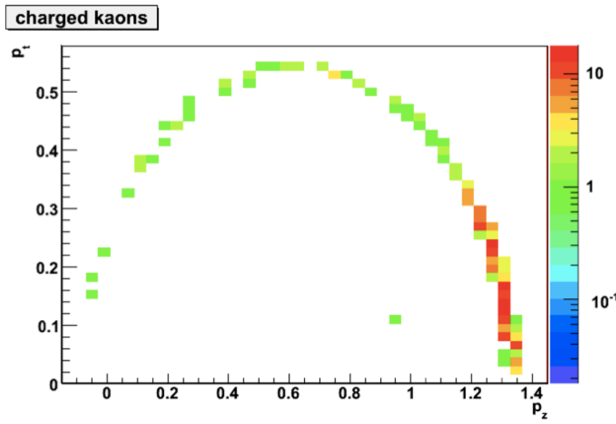

Fig. 9: FLUKA: momentum space of charged kaons.

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

11 The workshop, “Hadronic Atoms and Kaonic Nuclei - solved puzzles, open problems and future challenges in theory and experiment “, is one of the most recent workshop in which this topic was discussed.

12 https://www.gsi.de/documents/DOC-2008- Apr-60-1.pdf

13 G. Battistoni, S. Muraro, P.R. Sala, F. Cerutti, A. Ferrari, S. Roesler, A. Fasso`, J. Ranft, AIP Conference Proceeding 896, 31-49, (2007); A. Fasso`, A. Ferrari, J. Ranft, and P.R. Sala, CERN-2005-10 (2005), INFN/TC_05/11, SLAC-R-773

14 http://gibuu.physik.uni-giessen.de

15 CERN Program Library Long Writeups Q123

1.3.1.3. DISTO data analysis

A quest for a kaonic nuclear bound state: strongly or weakly bound, narrow or broad width, whether it has unusual high density or not, is a subject of vigorous discussion. Apart from its exoticness, it can have following major impacts on state of the art in the nuclear physics; (i) unusual high density ($\rho > \rho_0$) can be explored at well-defined temperature (T = 0) as well-defined quantum state. This may provide information on the hadron property at extreme conditions complementary to the heavy-ion-collision experiments which typically demands long term operation of high power accelerators, (ii) new forms of hadrons other than so far known meson ($q\bar{q}$) and baryon (qqq) seems to be present. The $\Lambda(1405)$ in dispute, which turned out to be a key ingredient of kaonic nuclear bound state, is also a candidate of multi-quark state,

(iii) an insertion of kaon into nucleus will test and expand the limitation of our knowledge on nucleus which has been constructed with proton and neutron as constituent, so as the study of hyper nuclei will do.

The DISTO spectrometer[16] was aimed to investigate hyperon and meson productions in *pp* collisions via a complete kinematic reconstruction of hyperon production like $pp \rightarrow pK^+\Lambda$ and $pp \rightarrow pK^+\Sigma^0$, making use of the transversely polarized proton beam of SATURNE (Saclay, France) and of an unpolarized liquid hydrogen target.

The exclusive $pp \rightarrow pK^+\Lambda$ production acquired at T_p = 2.85 GeV have been re-analysed in order to search for a deeply bound K^-pp (= X) state, to be formed in the binary process $pp \rightarrow K^+X$. Earlier experimental studies of the K^-pp system using nuclear targets were influenced by the background and final state interactions with spectator nucleons. The *pp* reaction is more direct and less ambiguous in its interpretation.

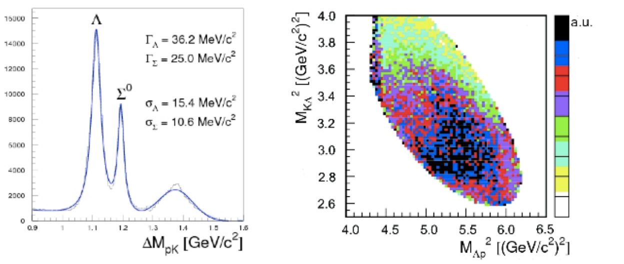

Fig. 10: (Left) A $\Delta M(pK^+)$ spectrum of raw data. (Right) An acceptance-corrected Dalitz plot of the exclusive $pp \rightarrow p\Lambda K^+$ reaction products at 2.85 GeV.

The missing-mass spectrum $\Delta M(pK^+)$ is shown on the left of Fig. 10. We selected about 177,000 exclusive $p\Lambda K^+$ events by setting the Λ gate on it. Fig. 1 (right) shows an acceptance-corrected Dalitz plot of all the $p\Lambda K^+$ events in the plane of $x = M(p\Lambda)^2$ *vs.* $y = M(\Lambda K)^2$. The expected Dalitz distribution of the "ordinary" three body process ($pp \rightarrow pK^+\Lambda$) is continuous without any local bump structure. However, the observed distribution exhibits a certain structure which is therefore not to be explained by the "ordinary" process, suggesting an "exotic" binary process $pp \rightarrow K^+X$ followed by a decay $X \rightarrow p\Lambda$ which has same final state as the "ordinary" process. A monoenergetic component of kaon enforces an existence of the binary process.

The spectra of the K^+ missing-mass $\Delta M(K^+)$ and the $p\Lambda$ invariant-mass $M(p\Lambda)$ with high transverse momenta of *p* and K^+ show broad peaks with a mass M = 2265 MeV and a width 118 MeV. They are found to be nearly identical to each other, which gives additional confidence on the current procedure of analysis (Fig. 11).

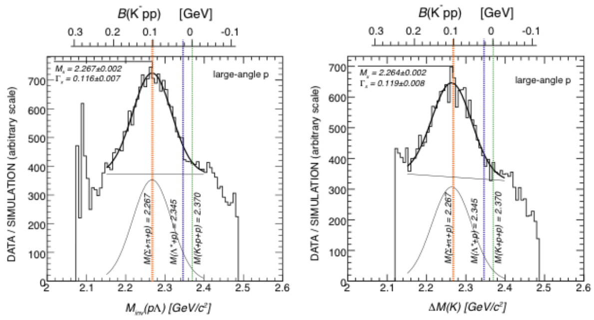

Fig. 11: The the $p\Lambda$ invariant-mass $M(p\Lambda)$ and the K^+ missing-mass spectrum $\Delta M(K^+)$ with high transverse momenta of *p* and K^+ show a broad structure with a mass M = 2265 MeV and a width 118 MeV.

Preliminary analysis status has been reported at EXA08 conference in Vienna and Hyp-X conference in Tokai, and conference proceedings have been published[17]. We submitted this analysis to a refereed journal at the end of 2009.

[16] F. Balestra *et al.* [DISTOCollaboration], Nucl. Instrum. Meth. A426 (1999) 385.
[17] T. Yamazaki et al., Hyperfine Interactions 193, 181 (2009), M. Maggiora et al., Proc. Int. Conf. Hyp-X (Tokai, 2009); arXiv:0912.5116 [hep-ex].

1.3.1.4. AMADEUS at DAΦNE2

The idea of AMADEUS is to make use of the KLOE detector at DAΦNE with specific components added, like a cryogenic gas target for stopping the charged kaons (see Fig. 12) and an inner detector system.

AMADEUS will perform, for the first time, a systematic and complete spectroscopic study of kaon nucleon/nucleus interaction at low energy and will especially look for antikaon-mediated bound nuclear states. By measuring all particles in the formation and in the decay processes of two- and three-baryon states with strangeness $S = -1$ a kinematically complete study will be performed.

A dedicated work to analyze part of the existing KLOE data was continued in 2009 at LN Frascati, with the main objectives to search for events with the signature of kaon-nucleon-clusters for kaons stopped in the thin gas of the drift chamber (room temperature, atmospheric pressure). Therefore, one main project of the analysis was the reconstruction of Lambda particles (see Fig. 13) in the He-isobutane gas mixture of the drift chamber, because Lambda

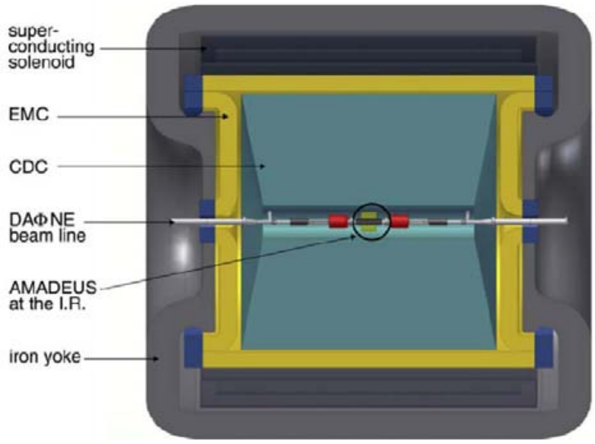

Fig. 12: The KLOE detector with the AMADEUS setup placed in the centre of KLOE around the interaction region of DAΦNE.

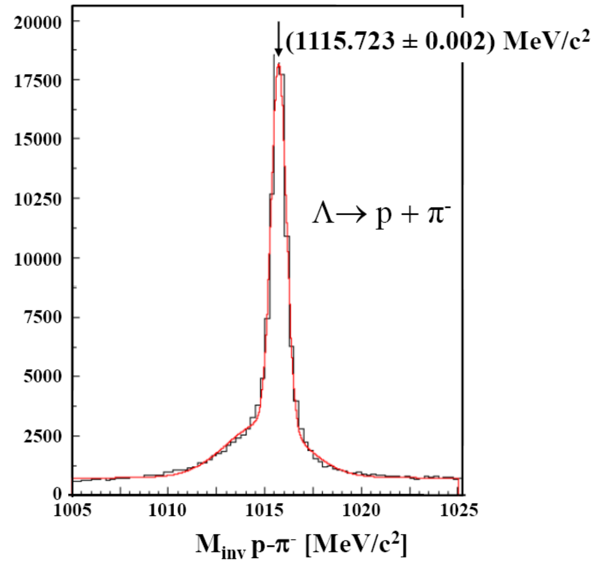

Fig. 13: Sample of Λ data analyzed for a total integrated luminosity of 1.1 fb^{-1}.

particles are one of the main decay products of tri-baryon states with strangeness. In addition the knowledge gained during this analysis, namely of reconstruction and detector efficiencies and techniques of particle identification, especially for protons (and deuterons), are essential for the design of the AMADEUS experiment. The design of the AMADEUS apparatus is under the leadership of SMI, while the planning of the insertions of the AMADEUS apparatus into the KLOE system is splited between LN Frascati and SMI.
R&D work was started at SMI mainly to design the cryogenic target system around the interaction region.

A first prototype of a section of the kaon trigger was constructed and tested during the SIDDHARTA beam time using SiPM to read out scintillating fibers.
An agreement has been worked out to regulate the work for the maintenance and upgrade of the KLOE detector between KLOE and the AMADEUS collaboration, which was signed mid of 2009.

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

J-PARC (Japan Proton Accelerator Research Complex) is a facility constructed as a joint venture of the High Energy Accelerator Research Organization (KEK) and the Japan Atomic Energy Agency (JAEA). Using a 50-GeV high-intensity proton synchrotron, secondary kaon beams will be available with the highest intensity in the world.
SMI and other collaborators have proposed the following two experiments, both of which were approved as Stage-2 (fully approved) in the J-PARC PAC meeting.

- E15: A search for deeply-bound kaonic nuclear states by in-flight ^{3}He(K^-,n) reaction.
- E17: Precision spectroscopy of kaonic ^{3}He 3d → 2p X-rays.

In these experiments, main parts of the experimental apparatus are used in common. The detector devices are developed by the both experimental collaborators. These experiments will carry out at one of the kaon beam lines in the Hadron Hall facility (K1.8 BR).

The E15 experiment studies the simplest system of the K-cluster (K^-pp system) using the in-flight (K^-,n) reactions. This reaction process suppresses the two-nucleon absorption of kaons, which was the largest contribution in background in the previous experiments because of the stopped-kaon reactions. The second advantage is the combination of the missing-mass and invariant mass measurements by detecting all reaction particles from the decay of the K-clusters. These features allow better knowledge of the formation and decay mechanism of the deeply bound kaonic states.
The experimental setup (Fig. 14) consists of four parts: beamline spectrometer, cylindrical detector system (CDS) together with the liquid ^{3}He target, beam sweeping magnet, and neutron TOF wall counters. A secondary kaon beam with 1.0 GeV/c is identified and analyzed by the beamline spectrometer. The decay particles from the reactions of $pp \to \Lambda p \to p\pi^- p$ are detected by CDS. The scattered neutrons are detected by the neutron TOF wall, which located 15 m away from the target.

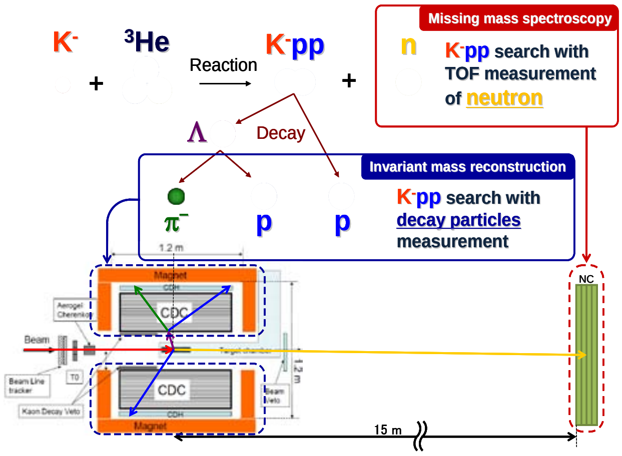

Fig. 14: E15 experimental setup and schematic figure of the reaction processes.

The kaon beams at the Hadron Hall is partly under construction. The beamline spectrometer consists of beamline magnets, beam trackers, kaon identification detectors, and times zero counters. The trajectory of the incident kaon beam is tracked by the beam trackers. The momentum of the kaons is analyzed with this tracking information together with the beam optics of the beamline magnets. The momentum of the incident kaons is 1.0 GeV/c with a design intensity of 0.6 × 10^6 kaons per 3.5 s spill (the flat top of the spill is 0.7 s).

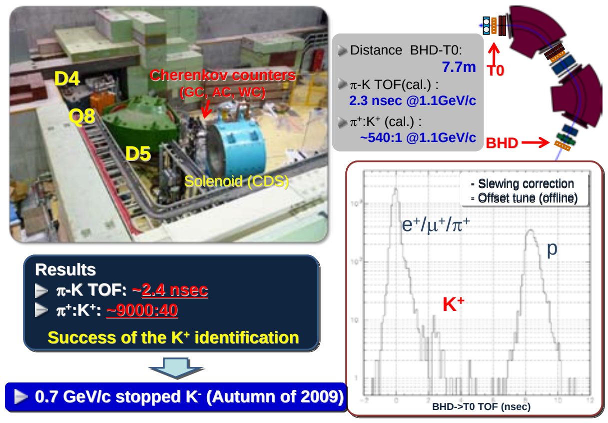

Fig. 15: First observation of kaons in J-PARC.

The expected momentum resolution of the incident kaons in the location of the beamline spectrometer is 0.1%.

At the end of January 2009, the first beam was delivered to the Hadron Experimental Hall and the beam tuning was started. The kaons with the beam momentum of 1.1 GeV/c were successfully identified using time-of-flight method, for the first time (Fig. 15). On the autumn of 2009, the beam tuning was started with the momentum of 0.75 GeV K^-, using which the E17 experiment will be performed.

1.3.1.6. LEANNIS

The Network LEANNIS (Low-energy Antikaon Nucleon and Nucleus Interaction) is devoted to the current research in experiment as well as in theory on kaonic atoms and kaonic nuclei bound by the strong force.

The Network LEANNIS is one of the eight networks within the Integrated Activity EU project HadronPhysics2. This network brings together experimentalists and theoreticians working in frontier research on antikaon interaction which is conducted at various European and non-European research centers.

12 institutes from 5 EU countries (Austria, Finland, Germany, Italy and Poland) and institutes from the associated country Japan participate in LEANNIS. Project leader of LEANNIS is J. Marton from SMI. The project was started by January 1st, 2009.

Many open questions are addressed in new experiment like SIDDHARTA at LNF and FOPI. For the interpretation of the experimental data a close connection with theoreticians is essential and provided by the network.

The field of low-energy antikaon interaction has many facets. Even the study of the most simple kaonic atom – kaonic hydrogen – is a challenge in experiment and theory.

On the other hand the corresponding observables of kaonic deuterium are a hot topic since they are necessary to extract the isospin-dependent antikaon-nucleon scattering lengths. For the first time kaonic deuterium was studied by SIDDHARTA very recently. The extraction of the scattering lengths is subject of intense theoretical work taking into account the corrections (e.g. isospin breaking) to the Deser-Trueman formula.

Many questions about kaonic nuclei are still open like the production mechanism, binding energy, decay widths etc. Experimental data claim the observation of kaonic nuclei in different reactions using stopped K^-, proton-induced reaction or antiproton absorption. However, the overall picture is not coherent since the binding energies and decay width extracted from data with different production reactions vary in a broad range. On the theoretical side studies with effective field approaches, Faddeev calculations and phenomenological approaches also differ in a wide range. Certainly this situation calls for new dedicated experiments (fully exclusive experiments) and also new theoretical studies in order to design the experiments.

To promote the field the LEANNIS activities are concentrated on developing new strategies, both in experimental and theoretical sectors, to attack the still many open problems in the field. The development of new experimental methods and techniques will profit from this coordinated network. Furthermore, major European institutes working in this field are participating in this network, therefore a platform is created to strengthen and bundle the research efforts.

The first international meeting (Kick-off meeting) organized by SMI took place in March 2009 in the main building of the Austrian Academy of Sciences in Vienna. In October 2009 an international Workshop supported by LEANNIS on "Hadronic Atoms and Kaonic Nuclei" was organized by members of LEANNIS at the European Centre for Theoretical Studies in Nuclear Physics ECT* in Trento/Italy (organizers: C. Curceanu, C. Guaraldo, P. Kienle, J. Marton, W. Weise). This Workshop was attended by leading experts in the field as well as by young scientists. A report about this Workshop ("The fascinating world of strange exotic atoms") was published in the CERN Courier January/February 2010.

Fig. 16: Participants of a international workshop at ECT*/Trento related to the topics of LEANNIS and organized by members of the network. (CERN Courier Jan./Feb. 2010, vol. 50, issue 1)

1.3.2. Matter–antimatter symmetry: ASACUSA @ CERN

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

Antiprotonic helium is a neutral three-body system consisting of a helium nucleus, an antiproton and an electron (see Fig. 17). The energy levels of the antiproton have been measured by precision laser spectroscopy to an accuracy of about 10^{-8}. Each level is split into a quadruplet due to the magnetic interaction of the electron spin, the antiproton angular momentum and the antiproton spin (see Fig. 18).

SMI is further participating in the laser spectroscopy experiment. Its emphasis is on improving and finding new methods to do spectroscopy as well as the systematic determination of Auger rates for comparison with theory.

Antihydrogen, the simplest antimatter atom consisting of a positron and an antiproton, is a promising tool for testing CPT symmetry because the CPT conjugate system, hydrogen, has been measured to precision of $\sim 10^{-14}$ for the 1s-2s two-photon laser transition and $\sim 10^{-12}$ for the ground-state hyperfine structure (see Fig. 19). Even if antihydrogen cannot be measured to this high precision, it can rival the best CPT tests in the absolute scale; see Fig. 20 for a more detailed explanation.

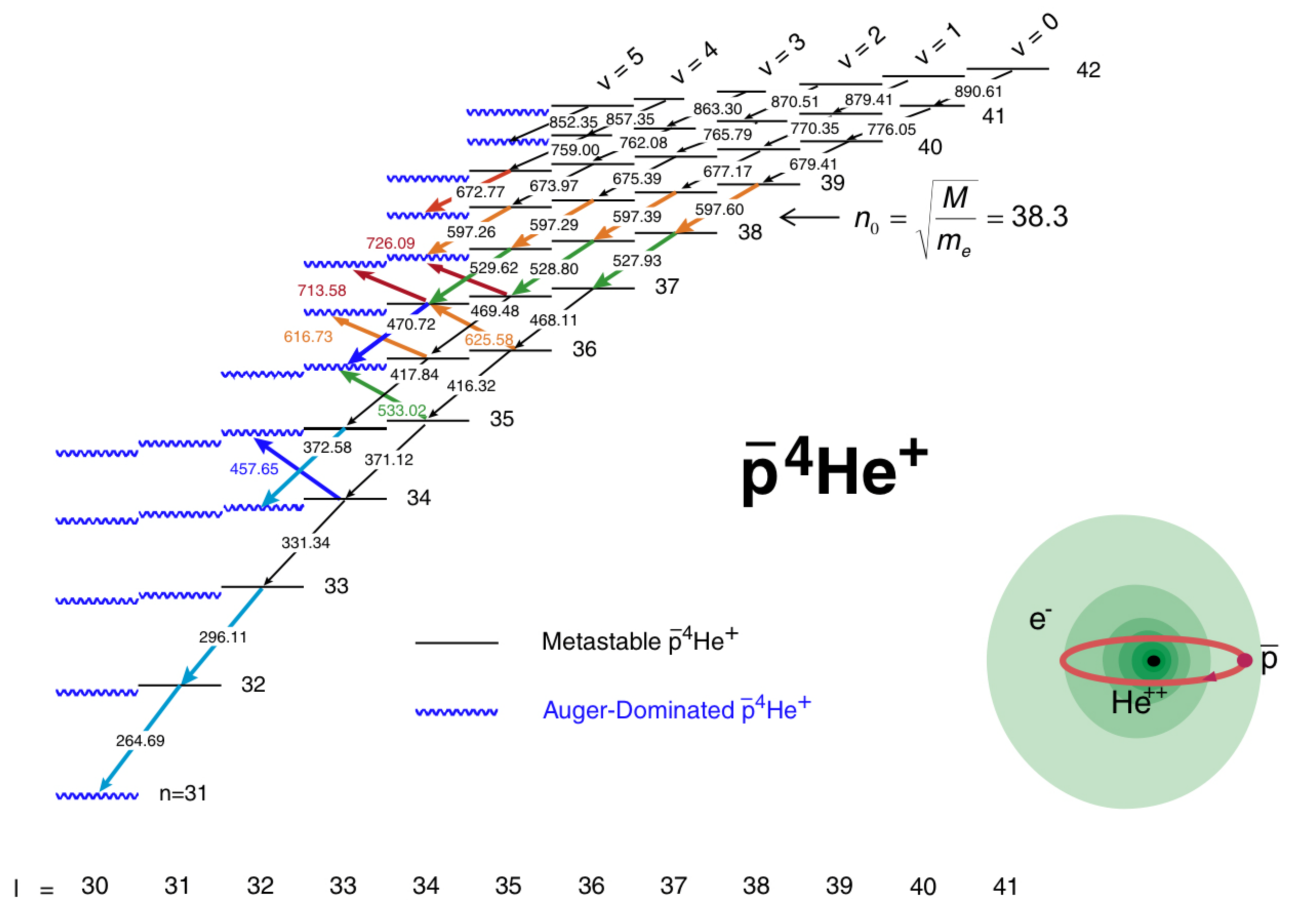

Fig. 17: Energy level diagram of antiprotonic helium.

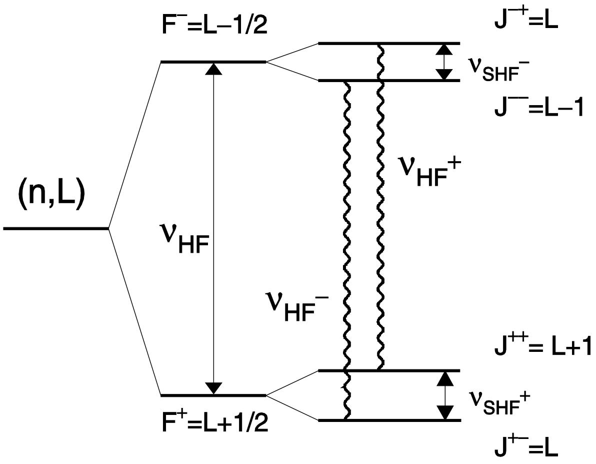

Fig. 18: Hyperfine splitting (HFS) of a state (n, l) of $\bar{p}^4He^+$. The wavy lines denote allowed M1 transitions that can be stimulated by microwave radiation.

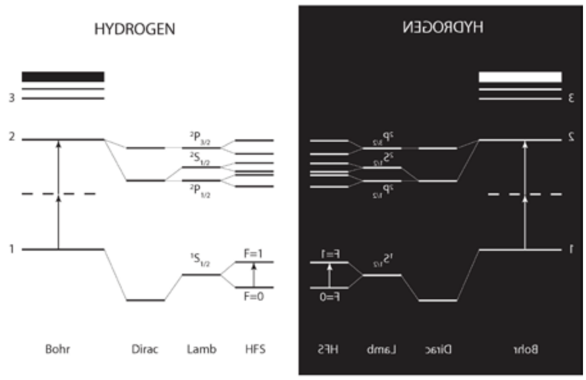

Fig. 19: Energy levels of the ground state and first excited state of hydrogen and antihydrogen.

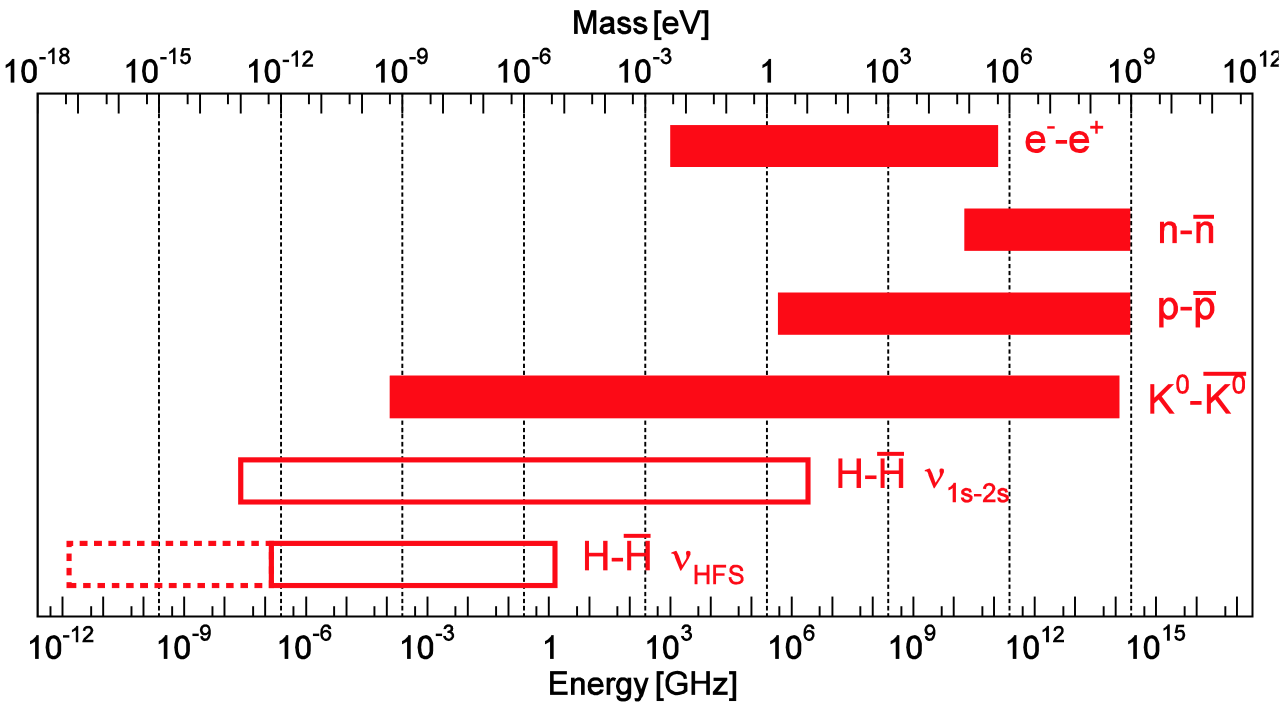

Fig. 20: CPT tests: masses and transition frequencies of various physical systems (from top to bottom: electron, neutron, proton, neutral kaon, hydrogen *1s-2s* transition, hydrogen GS-HFS) and their antimatter counterparts. The right edge of each stripe represents the absolute magnitude of the physical quantity (mass or transition energy), the left edge the absolute experimental accuracy of the matter-antimatter comparison measurement, thus the length of each stripe shows the relative accuracy of the comparison measurement. The bottom two hydrogen-antihydrogen stripes are hollow to indicate that antihydrogen has not been measured yet, thus in these cases the left edges represent the expected absolute experimental precision. The dashed stripe of the antihydrogen GS-HFS assumes that the antihydrogen GS-HFS has been measured to the same experimental precision as the hydrogen GS-HFS; this is, however, unlikely to be achieved in the near future. It can be seen that the K^0-$\bar{K}^0$ mass comparison has a very high relative precision of 10^{-18}, but due to the large mass of the K^0, the absolute precision is worse compared to the hydrogen-antihydrogen comparisons.

1.3.2.1. Precision spectroscopy of antiprotonic helium

Microwave spectroscopy

(Supported by FWF grant I198)
(Ph.D. thesis of S. Friedreich)

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 one of the hyperfine (HF) doublets, a microwave pulse transferred population from F^- to F^+, and a second laser pulse measured the population change caused by the microwave pulse.

Four super-hyperfine (SHF) states exist in $\bar{p}^4He^+$ and thus two electron spin flip transitions can be stimulated with an oscillating magnetic field.

A comparison between the measured transition frequencies and three-body QED can be used to determine the antiproton spin magnetic moment $\mu_{\bar{p}}$. Such a comparison between the proton and antiproton can be used as a test of CPT invariance. The most precise measurement of the proton to antiproton spin magnetic moment ratio to date is 0.3%. This is illustrated in comparison to previous measurements in Fig. 21.

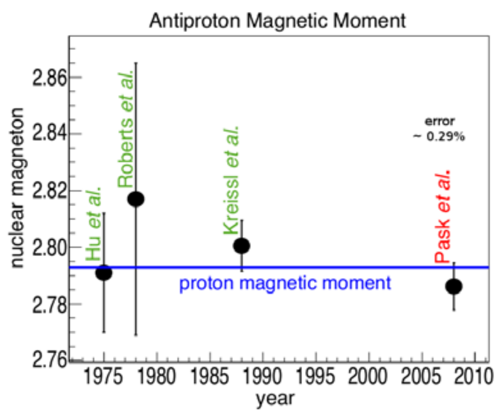

Fig. 21: Determination of the magnetic moment of the antiproton as a function of time. [E. Hu et al., Nucl. Phys. A 254, 403 (1975); B. L. Roberts et al., Phys. Rev. D 12, 1232 (1975); A. Kreissl et al., Z. Phys. C 37, 557 (1988); T. Pask et al., Phys. Lett. B 678, 55 (2009)]

The HFS of the (n,l) = (37,35) state of in $\bar{p}^4He^+$ has now been thoroughly measured in terms of the energy eigenvalues. Our new measurements of $\nu_{HF^{\pm}}$ agree with the theoretical values within the calculation error. Recent results have reduced the statistical error associated with the individual transitions ν_{HF^+} and ν_{HF^-}. The precision is now a factor of 20 higher than that of initial calculations[18]. This has motivated theoreticians to improve their calculations. Their new results are a factor 3 more precise than before and agree with our latest results[19].

There is also good agreement between experiment and theory for the difference $\Delta\nu_{HF} = \nu_{HF^-} - \nu_{HF^+}$ between the two transitions. This difference is important, as it is proportional to the spin magnetic moment of the antiproton. $\Delta\nu_{HF}$ has been resolved to a precision comparable to that of theory (33 kHz), a factor of 10 improvement over our first measurement.

In 2009, a proceedings paper from the LEAP08 conference and a final publication summarizing our measurements of the (n,l) = (37,35) state of $\bar{p}^4He^+$ were published.

By comparing the measured and calculated value of $\Delta\nu_{HF}$ and taking into account the sensitivity of $\Delta\nu_{HF}$ on $\mu_{\bar{p}}$, a new experimental value of the spin magnetic moment of the antiproton was obtained as

$$\mu_{\bar{p}} = -2.7862(83)\mu_N,$$

slightly better than the previously best measurement which so far dominates the PDG value. Comparison to the proton magnetic moment gives

$$(\mu_p - |\mu_{\bar{p}}|)/\mu_p = (2.4 \pm 2.9) \times 10^{-3}.$$

In addition to comparing measurements of the HF spitting to three-body QED calculations, a comparison can be made between them and predictions of collision rates. Our recent results have shown that collisional broadening effects are much smaller than previously expected[20].

A study of the collisional relaxation processes was commenced but could not be completed due to lack of time. As the values of the cross sections for spin-flip collisions are of interest to theory, further measurements of this quantity are still needed.

The precision achieved for the (37,35) state of $\bar{p}^4He^+$ cannot be improved further due to fluctuations of the antiproton beam. Therefore a first measurement of the (37,35) state of $\bar{p}^3He^+$ has been proposed which can be performed with a similar experimental setup. We have received FWF funding (proposal number I-198-N20) for this three year project. This FWF Austria-Russia joint grant fully supports one doctoral student, one postdoc and new microwave hardware within this project.

Antiprotonic ^3He is a more complex system than antiprotonic ^4He. Due to the extra spin of the helium nucleus, each antiprotonic state is split into not four but eight supersuper-hyperfine states (see Fig. 22 and compare it with Fig. 18). Thus not two but four allowed M1 hyperfine transitions can be excited. A comparison between the theoretical calculations and experimental results would lead to a more rigorous test of the theory and address any systematic errors therein. It would address a small deviation from theory that was observed in laser spectroscopy experiments.

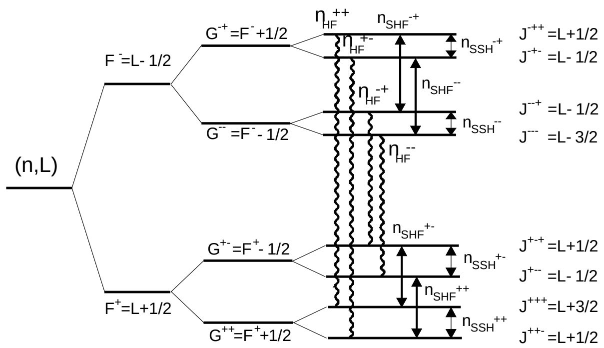

Fig. 22: Hyperfine splitting (HFS) of a state (n,L) of $\bar{p}^3He^+$. The wavy lines denote allowed M1 transitions that can be stimulated by microwave radiation.

A new 11 GHz cavity to measure two M1 transitions in the $\bar{p}^3He^+$ (n,l) = (36,34) state has been designed and constructed at SMI. A measurement of this state would be the first HF measurement on $\bar{p}^3He^+$. Incorporated in the new design is a new compressor cooled cryostat. This removes the dependence on liquid helium and allows the experiment to run without interruption.

In 2009, the measurement of the new state has been started. However, a significant signal could not yet be observed, but the measurements will be continued in 2010 with an improved experimental setup.

Laser spectroscopy

The laser spectroscopy experiment puts its emphasis on improving and finding new methods to do spectroscopy. This is done in collaboration with the Max Planck Institute for Quantum Optics in Garching (Munich). Another important goal is the systematic determination of Auger rates for comparison with theory.

In 2009 has been used a new laser system and a better experimental target to measure four transition frequencies in $\bar{p}^3He^+$ which had in previous experiments showed a 2σ difference compared to the results ν_{th} of three-body QED calculations. It was found that the newly measured frequencies ν_{exp} are all within 10-15 parts per billion of ν_{th}.

The Committee on Data for Science and Technology (CODATA) has recently published the 2006 values of the basic constants and conversion factors of physics and chemistry for international use. Twelve transition frequencies ν_{exp} in the $\bar{p}^4He^+$ and $\bar{p}^3He^+$ isotopes measured by ASACUSA's laser spectroscopy experiments to a fractional precision of $\sim 10^{-8}$ were included as part of this data set to determine the electron-to-(anti)proton mass ratio (m_e/m_p). This result, when combined with the cyclotron frequency of the antiproton measured by the ATRAP experiment to a much higher precision of 9 parts in 10^{11} also indicate that any CPT-violating difference between the antiproton mass and charge and those of the proton must be less than 2 parts in 10^9.

In 2009 we re-measured the Auger decay rates of six states in $\bar{p}^3He^+$ using the new laser with a linewidth ~10 times narrower than before. All measured Auger rates γ_A now agree with theoretical calculations within the experimental errors of 10-25%.

[18] T. Pask et al., Phys. Lett. B 678, 55 (2009).
[19] V.I. Korobov and Z.-X. Zhong, Phys. Rev. A 80, 042506 (2009).
[20] G.Y. Korenman, S.N. Yudin, J. Phys. B: At. Mol. Opt. Phys. 39, 1473 (2006).

1.3.2.2. Measurement of the ground-state hyperfine structure of antihydrogen

The ground-state hyperfine splitting (GS-HFS) of antihydrogen is caused by the interaction between the antiproton spin magnetic moment and the positron spin magnetic moment, and (in the first order) directly proportional to the antiproton magnetic moment. Thus by measuring the antihydrogen GS-HFS, which in itself is a good CPT test, we can also obtain a value for the antiproton magnetic moment, which is currently know to a precision of only 0.3%[21].

The ASACUSA collaboration is planning to measure the ground-state hyperfine splitting (GS-HFS) of antihydrogen ($\bar{H}$) using an atomic beam apparatus[22,23] similar to the ones which were used in the early days of hydrogen HFS spectroscopy. The apparatus will use antihydrogen atoms produced either in a superconducting radiofrequency Paul trap[22] or in a superconducting cusp trap[24] (i.e. anti-Helmholtz coils). In the former case, the apparatus would consist of two sextupole magnets for the selection and analysis of the spin of the $\bar{H}$ atoms, respectively, and a 1.4-GHz radiofrequency resonator in between them to flip the spin. In the latter case, the first sextupole could be omitted because the cusp trap should be able to provide a partially polarized antihydrogen beam. This atomic beam method has the advantage that antihydrogen atoms of temperatures up to 150 K can be used.

A CERN doctoral student of the CERN-Austria exchange program started to work on the design and building of the radiofrequency resonator from February 2009. Previous simulations[25] showed that with a double stripline design the required strength and homogeneity of the oscillating magnetic field can be reached. Major vacuum components (pumps, gauges, gate valves) have already been purchased.

Another important component of the atomic beam apparatus is the superconducting sextupole magnet. This device has been ordered in 2009 through CERN from Tesla Engineering in the UK, following a market survey and a tendering process at CERN. Tesla will design and build the magnet based on our detailed specifications. The deadline for the delivery of the magnet is the end of March, 2010.

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[21] A. Kreissl et al., Z. Phys. C 37, 557 (1988); T. Pask et al., Phys. Lett. B 678, 55 (2009)

[22] ASACUSA collaboration, Proposal CERN-SPSC 2005-002, SPSC P-307 Add. 1, 2005.

[23] B. Juhász, E. Widmann, Hyp. Int. 193, 305 (2009).

[24] A. Mohri, Y. Yamazaki, Europhys. Lett. 63, 207 (2003).

[25] T. Kroyer, CERN-AB-Note-2008-016.

1.3.3. Antiprotons at FAIR

(Partially supported by the EU FP7 grant Hadron Physic2)

FAIR, the Facility for Antiproton and Ion Research will be an extension of the existing GSI Helmholtzzentrum für Schwerionenforschung mbH near Darmstadt[26]. It will be an international research institute for nuclear and hadron physics, with 25% of the construction cost to be provided from countries outside Germany. The physics program of FAIR consists of four "pillars":

APPA: Atomic and plasma physics, and applied sciences in the bio, medical, and material sciences:

CBM: Physics of hadrons and quarks in compressed nuclear matter, hypernuclear matter;

NuSTAR: Structure of nuclei, physics of nuclear reactions, nuclear astrophysics and radioactive ion beams;

PANDA: Hadron structure and spectroscopy, strange and charm physics, hypernuclear physics with antiproton beams.

FAIR will become the most important centre for hadron physics in Europe. The Austrian Ministry for Science and Research has signed the memorandum of understanding of FAIR in February, but it is currently uncertain whether it will be able to contribute to the construction and operation of the FAIR facility.

The project was formally started with a kick-off event in November 2007, which marked the start of phase A of the project. A cost revision in August 2009 led to a raise in the construction costs of this phase, which was then divided into 6 modules (cf. Fig. 23). Modules 0 to 3 are covered by commitments from the partners and will form the start phase. Modules 4, 5 and Phase B will be started as soon as the remaining funding will become available. In November 2009, the basic legal documents were finalized and are currently being translated into the languages of several participating countries. The process is expected to end in summer 2010 and the formation of the FAIR company is foreseen soon after. The time schedule anticipates an end of construction of module 3 earliest in 2016, and a start of the antiproton operation soon after. Regarding FAIR, the focus of the Stefan Meyer Institute lies in the physics program with antiprotons and the institute is involved in PANDA, FLAIR and the Antiproton Ion Collider (AIC). HESR and PANDA are covered in module 3, so their construction is secured financially. FLAIR will be in module 4, taking another decade to

Fig. 23: Modules 0 to 3 of FAIR. Module 0: green; module 1: red; module 2: yellow; module 3: orange.

materialize. Until then, our participation in the PANDA program will b strengthened and the efforts foreseen for FLAIR will go into a stronger involvement in the ASACUSA project at CERN-AD. The AIC is in phase B and currently no activities are planned.

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

1.3.3.1. PANDA: Proton Antiproton Annihilations at Darmstadt

The PANDA (antiProton Annihilation at Darmstadt) experiment aims at precision studies of the strong interaction in the energy range where perturbative treatment of the QCD is no longer possible. Here the hadrons are the relevant degrees of freedom. Thus it is very important in connection with the question of the origin of hadron masses.

The HESR (High Energy Storage/Synchroton Ring) will deliver an Antiproton beam in a momentum range between 1.5 and 15 GeV/c with a momentum resolution of up to 10^{-5}. Together with a very good, versatile and modular detector (see Fig. 24) PANDA will address the main physics topics[27]:

- Hadron Spectroscopy
- Nucleon Structure
- Hadrons in Medium
- Hypernuclei

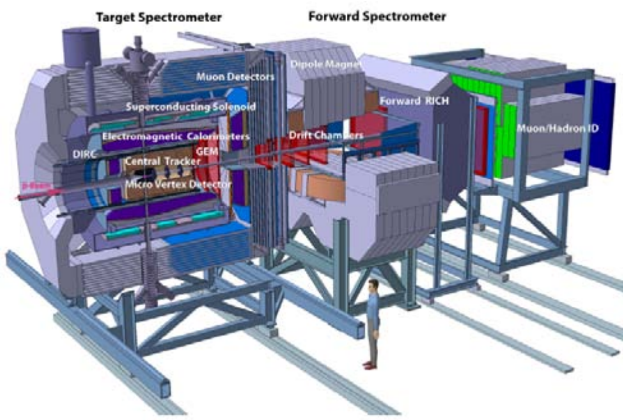

Fig. 24: Artistic view of the PANDA detector with cluster-jet target.

At SMI simulation studies for the Hadrons in Medium are pursued, see the appropriate section below. The PANDA project showed the following progress in 2009: During August and September 2009 the PANDA Cherenkov group successfully tested the performance of three different prototypes of Cherenkov detectors, using a proton beam at GSI.

The Technical Design Report[28] (TDR) for the Solenoid and Dipole Magnets of the PANDA Spectrometer was published in February 2009 and approved by the FAIR committee for Scientific and Technical Issues (STI) in May 2009.

The preparation of the documents for the tendering process has been started.

A very important achievement was the publication of the PANDA Physics Performance Report[29] ("Physics Book") in March 2009.

The SMI is taking part in the international PANDA collaboration together with more than 50 participating institutes. Within the EU programme of FP6, which finished end of 2008,, SMI contributed to the following tasks: optimisation studies of the (hydrogen) cluster-jet target and design of the PANDA interaction zone (JRA7 in I3-Hadron Physics), as well as the development of imaging Cherenkov detectors (work package PANDA1 in DIRACsecondary Beams and INTAS project on novel silicon photo detectors).

Since 2009 SMI works within the EU programme of FP7 on the following subjects: further optimisation studies of the (hydrogen) cluster-jet target and design of the vacuum and pumping in the interaction region (FutureJet in I3-Hadron Physics2), development of prototype Gas Electron Multiplier (GEM) detectors for PANDA (SMI is the leader of the JointGem work package in I3-Hadron Physics2) and further development and prototyping of imaging Cherenkov detectors (work package SiPM in I3-Hadron Physics2). Within the networking activity FAIRnet SMI is also taking part in many PANDA-related projects.

Charmonium interaction with matter

Understanding the charmonium interaction with nuclear matter is important for the description of the photo- and hadro-production of charmonium and charmed hadrons on nuclear targets as well as for diagnostics of hadronic final states in heavy-ion collisions. The suppression of charmonium production in heavy ion collisions e.g. is proposed to be a signal for the formation of Quark-Gluon-Plasma (QGP). Investigating the absorption cross section of charmonium in nuclear matter should yield valuable information on this process. The first excited state of charmonium, J/ψ, can be produced in antiproton-nucleus collisions which will be studied at the PANDA experiment. In the reaction $\bar{p}$ + A → J/ψ + A–1, J/ψ is formed at resonance at an incident beam momentum of 4.065 GeV/c and can be identified via its leptonic decay channels. Its interaction with nucleons in the nuclear environment, in particular the J/ψ-nucleon dissociation cross

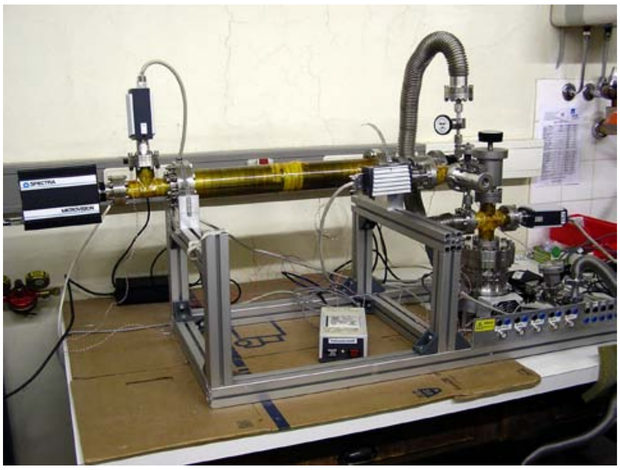

Fig. 25: Setup for auxiliary NEG-measurements at SMI.

Fig. 26: New INFN/SMI/GSI cluster-jet target at GSI.

section can be deduced from the measurement of its production as a function of the size of the target nucleus. The respective cross sections are of the order of 100 pb whereas the total cross section is around 1 b. Therefore, to indentify the signal a background suppression of >10^{10} is needed. Since the leptonic decay channels are rather "clean", kinematic and topologic cuts can be applied in order to single out the desired events. The feasibility of this measurement, especially the efficient suppression of the dominating background events, has been studied at SMI in the framework of the PANDA „Physics Book"[30] by Monte Carlo simulations. Further studies are ongoing which aim at the development of methods to accurately deduce the J/ψ dissociation cross section from a series of $\bar{p}$ + A measurements with different nuclei at PANDA.

Internal target system for PANDA
(Ph.D. thesis of A. Gruber)
Within FP6 and FP7 SMI takes part in the development of the internal target system of PANDA, especially the optimisation of the cluster-jet target. Furthermore SMI has given important contributions to the design of the vacuum system and the interaction zone of the PANDA detector. With a prototype setup at SMI we carried out a feasibility study for the PANDA interaction region using NEG-coated beam pipes (see Fig. 25). The design of the PANDA vacuum and pumping system is supplemented by calculations of the vacuum conditions in PANDA. Furthermore the PANDA Target group is working on a Technical Design Report about both target types and related systems. SMI is in charge of two chapters of this report (vacuum system, target gas system).
In 2009 a modified INFN/SMI/GSI cluster-jet target was assembled (see Fig. 26). A major issue in 2009 was the development of a slow control system for this apparatus, which is based on the hardware side on the CompactRIO system of National Instruments and is driven on the software side by several LabView programmes. First tests have already been carried out successfully with the new cluster-jet target.

27 PANDA Physics Performance Report, http://arxiv.org/abs/0903.3905v1
28 PANDA Magnet TDR, http://arxiv.org/abs/0907.0169
29 PANDA Physics Performance Report, http://arxiv.org/abs/0903.3905v1
30 PANDA Physics Performance Report, http://arxiv.org/abs/0903.3905v1

1.3.3.2. FLAIR: Facility for Low-Energy Antiproton and Ion Research

In February 2009 a collaboration meeting was held at MSL Stockholm, which received a grant from the Swedish government and started the design work for the adoption of CRYRING for its use at FAIR. E. Widmann was elected spokesperson of FLAIR, with H. Danared (MSL Stockholm) and Th. Stöhlker (GSI Darmstadt) becoming deputies. Design work on the layout of the FLAIR experimental hall and the ion optical layout of the beam lines continued at GSI with the help of A. Hirtl and later O. Hartmann from SMI.
In the fall it became apparent that the rise in construction costs at FAIR would lead to a delay of construction of FLAIR beyond the startup of FAIR, so design activities are reduced now.

1.3.4. Smaller physics projects

Pion-Nucleon Interaction

The goal of the new pionic hydrogen experiment (PSI-Experiment R-98-01) is a precise determination of the hadronic width (Γ_{1s}) and shift (ε_{1s}) of the ground state of pionic hydrogen using a high precision Bragg spectrometer. By measuring three different transitions, the 4p → 1s, 3p → 1s and 2p → 1s transitions, the accuracy of the results for Γ_{1s} and ε_{1s} is expected to be improved, since the influence given by the strong interaction on the ground state must be the same for all three respective transitions.

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

The main effort in the year 2009 was put into finishing the analysis of the pionic hydrogen data by using an analysis method developed in our institute in a PhD thesis[31] and is based on extensive Monte Carlo studies. The dedicated analysis routine takes into account the response function of the whole experimental apparatus as well as the kinetic energy distribution of the pionic hydrogen gas in the target, leading to a Doppler broadening of the emitted X-rays[32].

The same analysis code and method was used and successfully applied to the 3p → 1s transition of pionic deuterium (measured in 2006) by a collaborating institution[33,34].

[31] A. Hirtl, PhD thesis, TU Wien (2008).
[32] D.S. Covita et al., Phys. Rev. Lett. 102, 023401 (2009).
[33] T. Strauch, PhD thesis, Univ. Köln, 2009.
[34] T. Strauch et al., submitted to PRL, 2010.

Two-body decays of stored and cooled ions

The analysis of the orbital Electron Capture (EC) of H-like ^{122}I, observed in the ESR storage ring of GSI, Darmstadt, in August 2008 was continued. The observed time modulation with a period of about 6s and amplitude of 20%[35,36] [1, 2] was confirmed in two independent analyses with a reduced data set in which only the time of the well marked first decays were determined. Together with the previously[37] observed time-modulation of the EC decays of H-like ^{140}Pr and ^{142}Pm with periods of about 7s and amplitudes of about 20% a scaling law of the modulation period proportional to the mass of the decaying ion is now well established.

We have shown recently[38] that these data can be explained in terms of the interference of massive neutrino mass–eigenstates. The appearance of the interference term is due to overlap of massive neutrino mass–eigenstates energies and of the wave functions of the daughter ions in two–body decay channels, caused by the energy and momentum uncertainties introduced by time differential detection of the daughter ions. But in course of these studies it became clear that in a standard weak interaction theory with massive neutrinos and unitary flavour mixing matrix the interference terms of different flavours cancel in decays in which the neutrino can only be observed after the decay[39]. Since time-modulations are observed with amplitudes of 20 % one must conclude that for partial restoration of the interference term unitarity of the flavour mixing matrix must be violated[40].

A new Schottky pick-up detector has been designed and constructed. This detector shall enhance significantly the signal-to-noise ratio indispensable for our future measurements. The first tests of this pick-up will be performed early in 2010.

[35] N. Winckler et al., GSI Scient. Report 2008, 2009-01 (2009).
[36] P. Kienle, Nucl. Phys. A 827, 510c (2009).
[37] Yu. A. Litvinov et al., Phys. Lett. B 664, 162 (2008).
[38] A.N. Ivanov, P. Kienle, Phys. Rev. Lett. 103, 062502 (2009).
[39] P. Kienle, Prog. Part. Nucl. Phys. doi:10.1016/j.ppnp.2009.12.070.
[40] H. Kleinert, and P. Kienle, EJTP 6, 107 (2009); Preprint nucl-th/0803.2938v4.

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

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

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

The experimental method is based on introducing new electrons into a copper strip and to look for X-rays resulting from the 2p $\rightarrow$ 1s anomalous (spin-statistics forbidden) X-rays emitted if one of the new electrons would be captured by a Cu atom and cascades down to the 1s state already filled with two electrons of opposite spin. The energy of this transition would differ from the normal Kα-transition by about 400 eV (7.64 keV instead of 8.04 keV), providing a clear signal of the PEP violation. For the X-ray detection we employ the CCD X-ray detector system used for the DEAR (DAΦNE Exotic Atom Research) experiment, which has successfully completed its program at the DAΦNE collider at LNF-INFN.

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

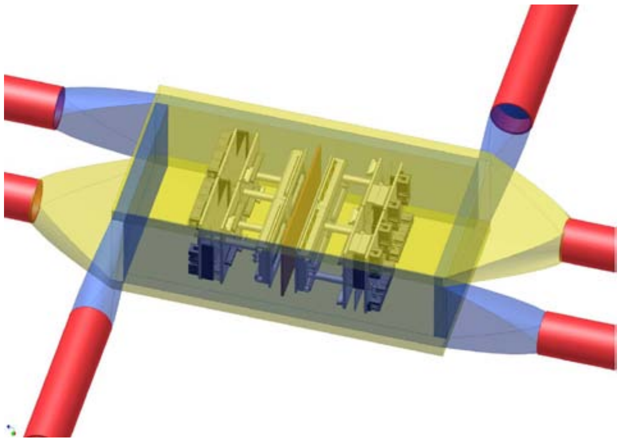

Fig. 27: Principle of a new detector setup with anticoincidence shielding by scintillation detectors arranged around the copper target and SDD detectors.

The rather straightforward analysis consists of the evaluation of the statistical significance of the normalized subtraction of the two spectra in the region of interest. In 2009 the measurements with CCDs in LNGS were continued and an upper limit for PEP violation for electrons was obtained 6×10^{-29} thus improving the limit by a factor of about 300 compared to the result of Ramberg and Snow.

Also in 2009 first studies of an improved version of the VIP experiment was worked out (see Fig. 27). The heart of the new version is a new X-ray detector system with cosmic ray active shielding.

1.3.5. R&D projects

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 intensities and luminosities, fast detectors with large acceptance and high resolution. Examples are, among others, the KLOE2 and AMADEUS experiments at DAFNE-LNF, Frascati, Italy and PANDA and CBM at FAIR, Darmstadt, Germany. 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 a rate capability matching the envisaged high luminosities is required.

Micropattern Gas Detectors (MPGD) based on the Gas Electron Multiplier (GEM) technology provide a very promising path towards these goals. Within an Joint Research Activity in FP7 HadronPhysics2 we plan to study and develop prototypes of a number of innovative detectors far beyond the current state-of-the-art:

- active areas of the order of m^2,
- spatial resolutions of ~100 μm to 500 μm,
- time resolutions of the order of a few ns,
- low material budget inside the active area, 1.5 % of a radiation length for the whole tracking detector,
- rate capability up to several tens of kHz per mm^2.

SMI is leading this activity and starts to develop a closed cycle gas handling system for TPC-GEM systems and in addition is working on a prototype triple-GEM detector system. The triple-GEM system will act as a test-bench apparatus (Fig. 28) for the characterisation of GEM foils and for the test of different readout structures.

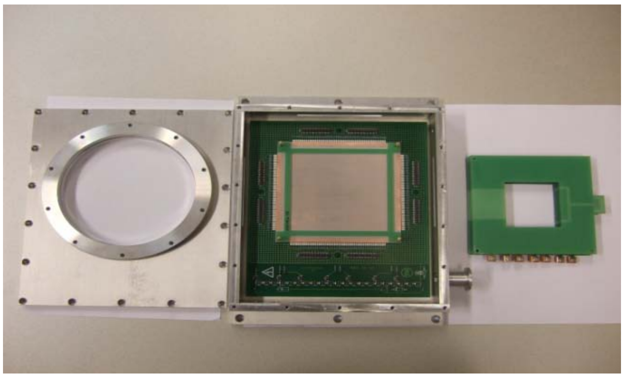

Fig. 28: Parts made at SMI for the test-bench triple GEM apparatus.

Development and testing of silicon photomultipliers

(Ph.D. thesis of G. Ahmed)

We are studying the application of new matrix avalanche photo-detectors (silicon photomultipliers – SiPMs) operating in the Geiger-mode. This photo detector exhibits a high gain in the order of 10^6 for single photons comparable with the gain of photomultipliers. The complexity of SiPMs is low (no vacuum tube, no high voltage supply necessary) and these devices are insensitive to magnetic fields. The development of SiPMs is proceeding fast and new photon detectors optimized for short wavelengths and exhibiting high photo-detection efficiency are available.

Our institute participated till the end of the project (January 31, 2009) in the EU Design Study "DIRACsecondaryBeams" which was part of the technical developments for the new international research center FAIR at Darmstadt. We worked on the task PANDA1 within this design study. This sub-project aimed at the development of imaging Cherenkov detectors proposed for the DIRC (detection of internally reflected Cherenkov light) and for the forward RICH detector of PANDA[41].For the design study we tested the newest generation of SiPMs concerning dark count rate, sub-nanosecond timing resolution, temperature effects on gain and noise etc.). In 2009 we continued the tests of various SiPMs using a test setup contained in a light-tight box (black box) with temperature stabilization. All optical components can be mounted on an optical table (breadboard) and operated inside the black box. We evaluated several kinds of SiPMs from different manufacturers with different sizes of cells, sensitive area and with different photo sensitivity. Proper temperature and bias voltage control of the device was found inevitable for a stable operation. Especially the SiPMs from Hamamatsu showed very strong temperature coefficient, significantly higher than the one from Photonique. Due to the temperature sensitivity for practical applications the temperature has to be stabilized and preferably the detectors have to be operated at low temperatures. Therefore, a cooling method using Peltier elements for SiPMs to be operated in vacuum – to avoid condensation of water vapour – was developed.

A fast picosecond laser system working at 400 nm is used to evaluate the timing performance of the devices.

We gained experience in operating SiPMs in experiments at particle accelerators. Cooled and temperature stabilized SiPMs were used in combination with a 16x16 scintillating fiber grid in 2 planes for a beam profile monitor for the FOPI experiment. This device was successfully operated in beam at GSI (see Fig. 29). In the future SiPM readout of scintillating fibers will be applied for a position-sensitive kaon trigger in the AMADEUS experiment.

A project within INTAS (International Association for the promotion of co-operation with scientists from the New Independent States of the former Soviet Union) was continued in 2009. New silicon photomultipliers (SiPM with micro-wells and very high pixel densities – see Fig. 30) developed by Russian scientists and manufactured by Zecotek/Singapore were delivered to SMI for evaluation. Our institute participates with a task concerning the studying the limits of SiPMs parameters (dark current, time resolution) for fast timing detectors. A dedicated test arrangement was setup at SMI to test SiPMs with Peltier cooling in a vacuum

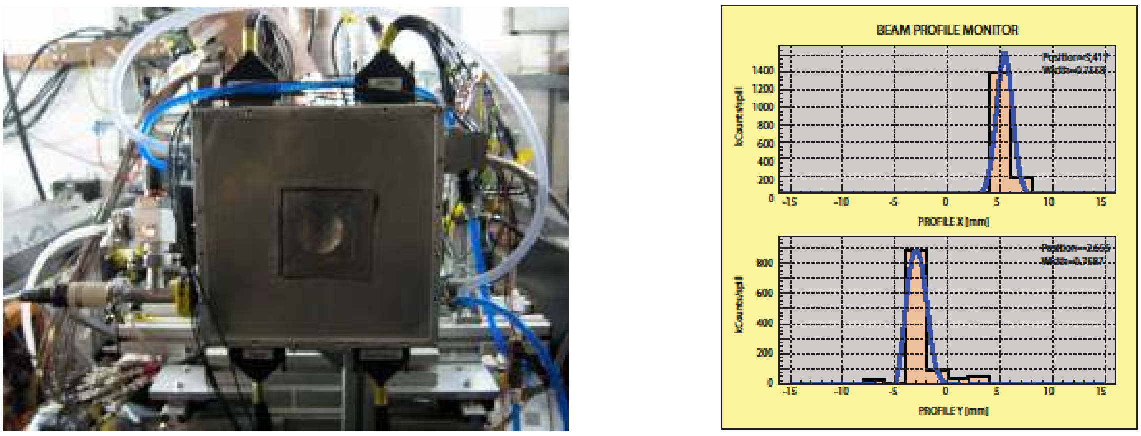

Fig. 29: Left: Beam profile monitor monted at FOPI/GSI, right: proton beam profile measured in x- and y axis.

vessel. A picosecond laser system serves a pulsed light source for testing the timing performance.
The main objective of the project is the development of an ultra fast, low-cost, matrix solid-state photo detector based on the new SiPMs with high photon detection efficiency for a spectral range between 200-600 nm. The SiPM matrix will be combined with a scintillator/radiator array in order to demonstrate its practical application in low level 2D light detection. SMI is working on the evaluation of SiPMs from Zecotek and other SiPMs (eg. Hamamatsu SiPM as reference SiPM), where important parameters like the noise as a function of temperature and the timing performance are studied in detail.
Some expected results of the project are: development of the SiPM matrix with characteristics needed for the light detection in experimental nuclear and particle physics, as well as for Cherenkov detectors and time-of-flight system applications in the PANDA experiment at FAIR/GSI; set up of laboratories for detector tests and education of experts as well as development of the laboratory infrastructure of the partner institutes from Russia.
The objective of the work to be done by SMI is the detailed investigation of SiPM parameters to demonstrate possibilities of using SiPMs in various applications. Results were presented in an INTAS meeting in GSI (February 2009). The project was finalized in Autumn 2009.

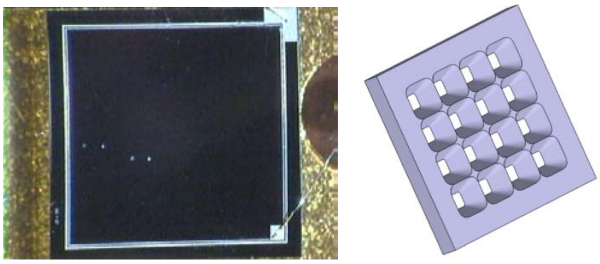

Fig. 30: Left: Zecotek 3x3 mm matrix Geiger-mode sensor. Right: Light catcher design for the position-sensitive photon read-out of a Cherenkov detector to be instrumented with 3x3 mm sensors.

With January 1st, 2009 the work on a project (WP28, SiPM – Avalanche Micro-Pixel Photo Diodes for Frontier Detector Systems) within the EU project HadronPhysics2 dealing with SiPMs was started. The kick-off meeting took place in February 2009 at GSI. Our institute was working on the development and testing of a Cherenkov timing device employing SiPM readout. The detector prototype was tested with 500 MeV electrons at the Beam Test Facility in Frascati. We found a timing resolution of about 400 ps with the detector prototype which represents a first step in the development of fast Cherenkov trigger detectors suitable for the operation in the vicinity of strong magnetic fields.

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

FutureJET

The proposed Joint Research Activity will advance the science and technology of cryogenically cooled beam sources with applications in various research fields. The goal of the proposed project is focused on the development of droplet beams of the low-*Z* elements (H2, D2, He) into unique boundary-free targets for hadron physics at storage rings. Outstanding examples for the many scientific endeavours at FAIR are highly complex internal-target experiments, e.g. PANDA. For PANDA the internal targets must be optimized in terms of maximum luminosity, i.e. the target density times the ion-beam current, and small spatial target extensions. Thus, it appears clear that the design and development of a low-*Z* internal target is a scientifically important and technically challenging aspect of FAIR, and represents a major goal of the proposed joint research activity within FP7 HadronPhysics2.

The main work was concentrated to modify the already existing cluster-jet target, by which already a maximum target thickness, of 1.4×10^{15} atoms/cm^2 (5×10^{14} atoms/cm^2) could be reached, mainly by improving the the cooling power of the nozzle head and by increasing the gas pressure. SMI was taking part in the development and setup, including the work of the slow control, of the cluster-jet apparatus at GSI.

PANDA Grid

In order to fulfil the computing demands of the experiments at PANDA, a dedicated computing infrastructure will be required. A conceivable way of acquiring and managing the necessary computing power for simulations and data analysis is the Grid model. As an alternative to a centralized computing centre this model allows to pool independent resources from multiple institutes or organizations. Although PANDA is not expected to acquire data before the year 2016, the PANDA collaboration is already experimenting with the PANDA Grid. Currently the PANDA Grid consists of a main node hosted by the University of Glasgow and several sites at PANDA collaboration institutes. The underlying software allows the Grid to be expanded without disturbing its continuous operation. The PANDA analysis software (PandaRoot) is installed on the different sites and so the PANDA Grid is able to perform PANDA related tasks.

SMI is actively taking part in building up, developing, testing, and running the PANDA Grid. SMI is operating a grid site and takes a leading role in the data production process on the grid for the PANDA collaboration.

1.4. Research program 2010

1.4.1. Strong interaction with strangeness

The publication of the **kaonic deuterium** results is expected for 2010 as well as further results for kaonic ^{4}He and also for kaonic ^{3}He which was not measured before at all. We will derive line intensity pattern and absolute yields. The analysis of kaonic hydrogen will be going on during 2010. A possible future continuation of SIDDHARTA with improved techniques using the experiences learned in this run period will be studied in detail.

The developments of the experimental detectors of the **E17** experimental setup have been finalized. The development and tests of the liquid ^{3}He target system will be completed in the beginning of 2010. Detail performance tests of the SDDs inside the experimental apparatus are carried out, as well as detector response tests with several conditions (e.g. rate dependency, position dependency, energy linearity, temperature dependency of the energy and timing resolutions). Beam tuning at the K1.8 BR channel has been performed. A first test experiments studying kaonic ^{3}He X-rays using the SDDs is planned in the second half of 2010.

A crucial point of the **FOPI** experiment with a secondary pion beam at GSI-SIS[42] is the available beam intensity. To ensure that the values assumed in the proposal can be reached, in 2010 two test beam times will take place. The beam optics for the secondary beam will be optimized to minimize possible losses due to the beam transport from the pion production target to the experiment using a primary beam at the same beam momentum.

Since the intensity of the primary beam on the production target directly translates into the secondary beam rate[43], the operation of the SIS close to the space charge limit is necessary. The maximization of the current of a ^{14}N beam onto the production target and subsequently the pion transport will be trained in a few days test beam. If the test will conclude as envisaged, the main experiment (ca. 16 days of beam) can take place in 2010, too. In the first part the liquid hydrogen part will be irradiated, and the solid targets like carbon and lead will follow.

On the side of the S349 experiment whose data taking is completed, we continue its precise evaluation of the data. This type of data analysis has not been done in the framework and new code and algorism have to be developed. We plan to obtain the first result within the year 2010.

In the submitted paper about the **DISTO** data analysis we analyzed only the $pp \rightarrow pK^+\Lambda$ process at T_p = 2.85 GeV and focused on reporting that unexpected structure was observed which can not be explained by the "ordinary" process, but leaving its detailed interpretation. In 2010 we will work also on its theoretical implication. We will analyze also the $pp \rightarrow pK^+\Sigma^0$ process and systematically study the data at T_p = 2.5 GeV, T_p = 2.145 GeV in order to enforce the evidence of the existence of the kaonic nuclear bound state.

Comparison to the on-going analysis of p+p reaction at T_p = 3.1 GeV using the FOPI apparatus[44] will be done as well. It is going to be a crucial cross check on it.

R&D work for **AMADEUS**, especially a first prototype of the cryogenic target cell will be built and tested in 2010. In addition a detailed Monte Carlo study at SMI will deliver solid expectations on the performance of the experimental setup. We will investigate various scenarios to learn about the needed detector components and the necessary beam time. One important issue is the ability to distinguish particles originating from kaons stopped and absorbed in the He gas from those coming from wall and window materials.

The developments of the experimental detectors of the **E15** experiment at J-PARC have progressed. The development and tests of the liquid ^{3}He target system will be completed. The beam tuning at the K1.8 BR channel have been performed. The detector test with the kaon beam will be performed during the E17 beam time.

In April 2010 a **LEANNIS** Meeting will take place in Frascati. The status of the data analysis of experiments (e.g. SIDDHARTA, FOPI) will be discussed in detail. Another topic foreseen is the planning of the next generation of experiments at LN-Frascati (SIDDHARTA2, AMADEUS) and the preparation of a follow-up network project in EU-FP7. Recently an ECT* Workshop on "Strangeness in Nuclei" in the scope of LEANNIS was approved. Many important results in the field can be expected since experiments will start at GSI (pion-induced kaonic nuclei production) and J-PARC (kaonic ^{3}He X-ray spectroscopy).

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[42] http://www.gsi.de/beschleuniger/

[43] J. Diaz et al., Nucl. Instrum. Methods A 487 (2002) 511

[44] See the section "Strangeness physics with FOPI at GSI" on page 10.

1.4.2. Matter–antimatter symmetry: ASACUSA @ CERN

In 2009, the measurement of the new state in $\bar{p}^3He^+$ has been started. A significant signal could not yet be observed. The measurement will be repeated in 2010 with an optimized experimental setup.
This antiprotonic system has a more complex structure because of the additional interaction of the helion spin. Eight supersuper-hyperfine (SSHF) states exist and four electron spin flip transitions can be stimulated with an oscillating magnetic field instead of two. In the (n,l)= (36, 34) state, two occur in the 11 GHz region and two in the 16 GHz region. Therefore a different cavity is required for each. Preparations for the second cavity will be carried out within 2010 and the two transitions at 16 GHz are planned to be measured in 2011. It is further planned for 2010 to complete the study of collisional relaxation processes in $\bar{p}^4He^+$. A Diploma thesis as well as a technical publication on the hermetic cryogenic cavity will be finished in 2010.
The work on the **antihydrogen** ground-state hyperfine splitting project will continue in 2010 with the detailed engineering design of the radiofrequency resonator, together with the design of the magnetic shield around the resonator. This shielding is necessary because of the strong stray magnetic fields of the cusp trap and the sextupole magnet.
The other important component of the antihydrogen beamline, the superconducting sextupole magnet is expected to arrive at CERN in March 2010. Afterwards it will be tested and commissioned, so that it is ready for the beam time in 2010. During the second half of the cusp trap beam time period the magnet will be connected to the cusp trap exit (i.e. without the RF resonator between the two) to test the performance of the combined vacuum systems and the effect of the sextupole magnet on the particles emitted from the cusp trap, which will hopefully include antihydrogen atoms too. To detect these particles, 10-cm diameter multi-channel plate (MCP) detector will be installed downstream of the sextupole magnet.
In order to more efficiently manage and work on the antihydrogen project and to supervise the doctoral student who is working on the resonator, Dr. B. Juhász has been stationed at CERN starting from February 2010.

1.4.3. Antiprotons at FAIR

In 2010 the work on the remaining technical design reports for the **PANDA** subsystems will continue. The tracking detectors and target TDRs shall be submitted in 2010 and reviewed by the FAIR-STI.
One of the main tasks of the PANDA target group in 2010 will be the completion of the Target Technical Design Report and its publication. Also in 2010 a PhD. thesis about this topic will be finished.
Genova/GSI/SMI cluster target: After the successful modification of the cluster-jet apparatus the further measurement programme for 2010 and 2011 foresees:

- Measurements towards highest cluster-jet densities
- Nozzle and skimmer developments (optimisation by changing distance nozzle-skimmer and tilting nozzle)
- Development of diagnostic tools.

Later on we plan to attach to this target several pipes, so that the vacuum system of the PANDA Target Spectrometer will be simulated in its complete length.
Nozzle tests: Optimisation of the nozzle shape and the position of the first skimmer have a strong influence on the density of the cluster beam. A measuring device, which measures the density distribution of the cluster-jet right after the nozzle, was constructed at SMI. This Pitot tube measuring system will be mounted in 2010 or 2011 inside the Genova/GSI/SMI cluster-jet target or the cluster-jet target in Münster to carry out these important tests. These measurements will also help in testing alternative nozzle designs.
Non-evaporative Getter: Despite the failure of the third NEG-coated system there is enough data from all former measurements to draw conclusions on the feasibility of using NEG coating in PANDA. The data analysis is in progress and a definite conclusion will be published in 2010 in the framework of a PhD thesis. A final paper will be published in 2011.
Vacuum: Also in 2010 calculations of the vacuum situation in PANDA will go on in order to decide details of the layout. These could be supported by full scale Monte Carlo simulations. In connection with these calculations the CAD model of the vacuum system will have to be constantly updated. Furthermore measurements are planned at the Genova/GSI/SMI cluster target or the cluster target in Münster to simulate the vacuum situation in PANDA. This has been seen as a necessary step in order to measure the vacuum situation while running the target, since the gas

input of the target itself cannot be completely simulated by numerical calculations.
Additionally we plan to develop a carbon-based baffle type cryopump, which would support the pumping power in the upstream direction of PANDA.
Understanding the **charmonium interaction** with nuclear matter is important for the description of the photo- and hadro-production of charmonium and charmed hadrons on nuclear targets as well as for diagnostics of hadronic final states in heavy-ion collisions. The suppression of charmonium production in heavy ion collisions e.g. is proposed to be a signal for the formation of Quark-Gluon-Plasma (QGP). Investigating the absorption cross section of charmonium in nuclear matter should yield valuable information on this process.
The first **excited state of charmonium**, J/ψ, can be produced in antiproton-nucleus collisions which will be studied at the PANDA experiment. In the reaction $\bar{p}$ + A $\rightarrow J/\psi$ + A–1, J/ψ is formed at resonance at an incident beam momentum of 4.065 GeV/c and can be identified via its leptonic decay channels. Its interaction with nucleons in the nuclear environment, in particular the J/ψ-nucleon dissociation cross section can be deduced from the measurement of its production as a function of the size of the target nucleus. The respective cross sections are of the order of 100 pb whereas the total cross section is around 1 b. Therefore, to indentify the signal, a background suppression of >10^{10} is needed. Since the leptonic decay channels are rather "clean", kinematic and topologic cuts can be applied in order to single out the desired events. The feasibility of this measurement, especially the efficient suppression of the dominating background events, are under study at SMI by Monte Carlo simulations. Further studies will go on with the aim to develope methods to accurately deduce the J/ψ dissociation cross section from a series of $\bar{p}$ + A measurements with differnt nuclei at PANDA.
Until the end of 2010 we plan to work out a detailed concept for the measurement of the J/ψ-nucleus dissociation cross section with PANDA.

1.4.4. Other projects

An improved experiment (**VIP2**) employing new X-ray detectors with timing capability – silicon drift detectors (SDDs) – and an active shielding will be tested at SMI aiming at the improvement of the Pauli violation limit down to the region 10^{-30}–10^{-31}. Studies will take place during 2010 in the laboratory as well as in the underground lab of LNGS.
The final analysis of the **pionic hydrogen** data is in progress. The main task left is the determination of the systematic error stemming from the complicated fit-model used in the analysis routine. Extensive Monte Carlo studies are still necessary in order to achieve the high precision envisaged. There are two main remaining challenges under intensive investigation: First, the quantification of the numeric bias of the analysis routine itself, see Fig. 31, and, second, the quantification of the systematic error due to the delicate model for describing the Doppler broadening of the measured X-ray lines.
The collaborating institutions are intensively working on finalizing the analysis and it is planned to be finished during the year 2010.
The **SiPM** testing and development of matrices instrumented by SiPMs will continue in 2010. A 8x8 array of light concentrators is presently in preparation which can be used for the position-sensitive photon detection at very low light levels. Also interesting in this context is an array of SiPMs like the prototype shown in Fig. 32 which are becoming available now.

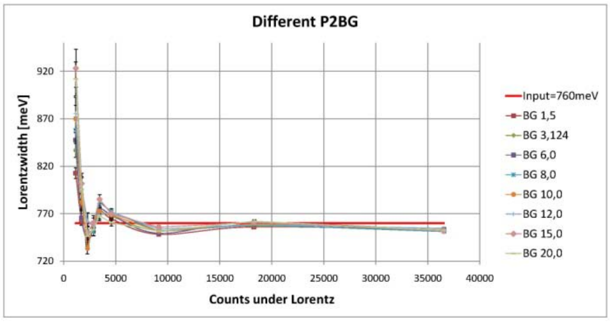

Fig. 31: Determination of the numeric bias of the analysis routine using Monte Carlo studies for the 4p →1s transition. Each point in the plot represents the mean value of 400 Monte Carlo simulations with known input and subsequent fits with the dedicated analysis routine for different peak-to-background levels. The difference between the known input value for the hadronic width (760 meV) and the result given by the analysis routine quantifies the numeric bias of the analysis routine.

A main part of the work done at SMI within the **Joint-GEM** project will be the design and construction of a prototype gas system for a large TPC (1000 l/s) working in a closed cycle mode with a purification unit (water vapour and oxygen contamination <10 ppm) and a gas analysis system. This prototype gas system will be ready for test measurements mid of 2010. The construction of a triple GEM test-bench apparatus for the characterisation of GEM foils, different readout structures, testing gas-mixtures, stability and so on will be finished in spring 2010. The test measurements are planned to be finished with this device until end of 2010, with valuable input for the further design of large area GEMs.

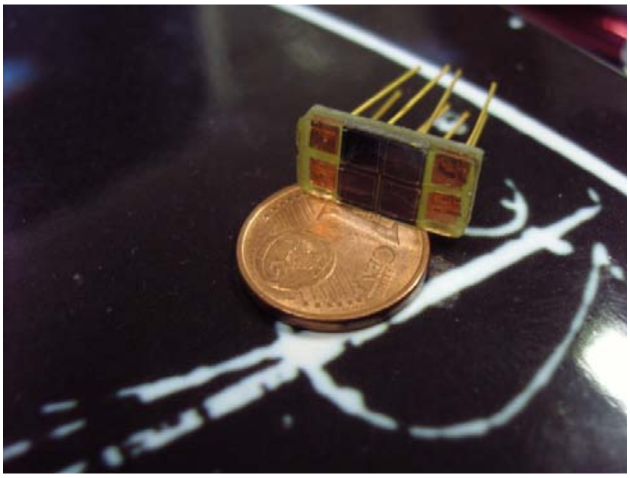

Fig. 32: Prototype of a 4x4 array of SiPMs (3x3 mm each) manufactured by Zecotek.

1.5. Current version of the medium-term research program for 2011-2013

1.5.1. Overview of the projects

The research program of the Stefan Meyer Institute consists of three physics topics (in parantheses the research centers where the experiments are performed):

- Strong interaction with strangeness (LN Frascati, J-Parc),
- Matter-antimatter symmetry (CERN),
- Physics with antiprotons (FAIR).

An overview is shown in Fig. 33. Compared to previous plans, a slight change of focus has been applied due to delays in the start-up of two major accelerator facilities, FAIR and J-PARC. At FAIR it became obvious that PANDA will be the only one of the projects we are involved in that will be running in the first phase. Consequently, our participation in PANDA will be strengthened and the manpower foreseen for FLAIR (which will take in the order of a decade to become operational) will go into a stronger involvement in the ASACUSA program at CERN-AD. The experiments planned at J-PARC will take longer than foreseen to run because the available beam time and intensity for slow extracted kaon beams is less than originally promised.
Such changes in the availability of particle beams at facilities that are largely unique in the world and at

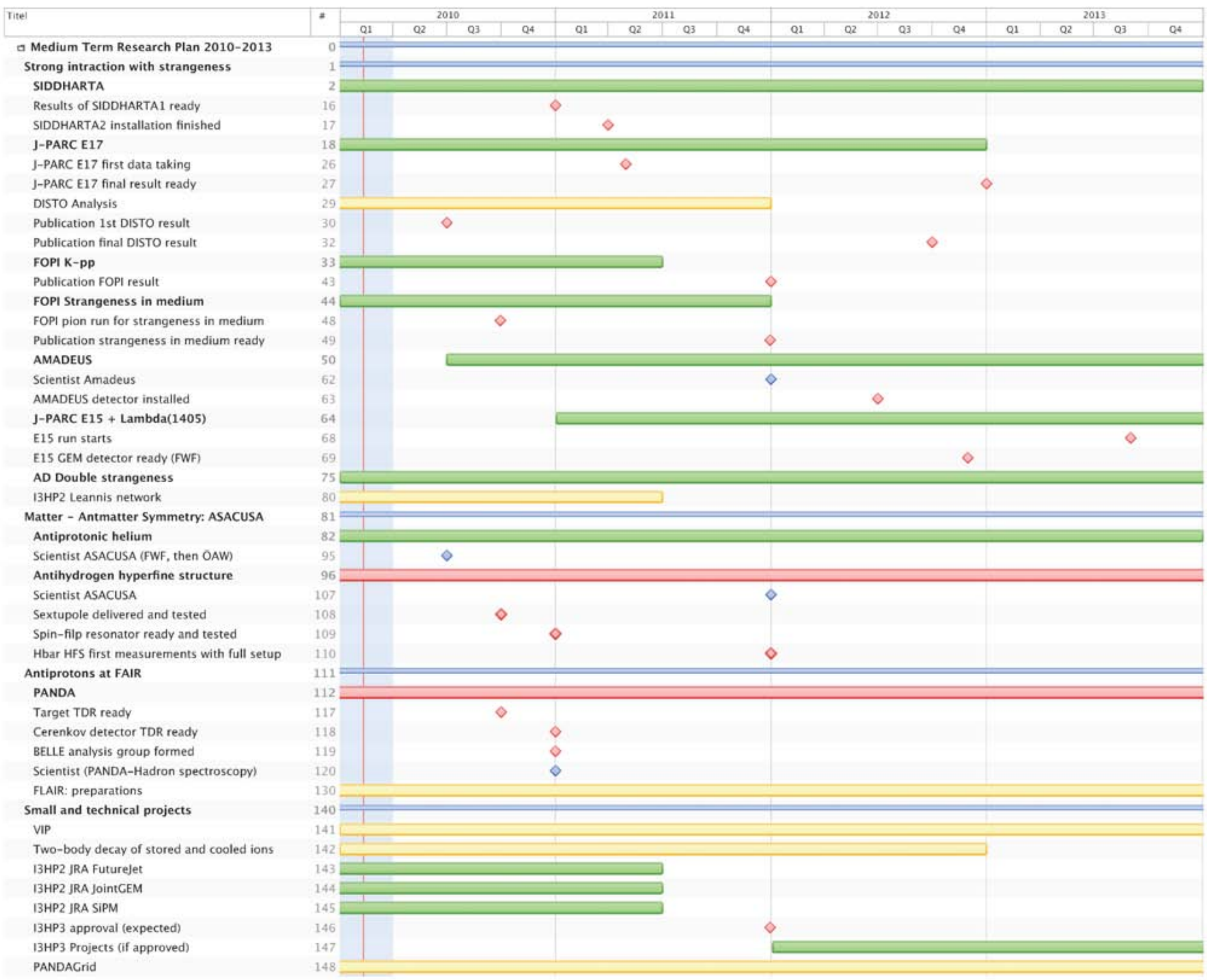

Fig. 33: Overview on the scientific program in the years 2009 – 2013. The color of bars symbolizes the amount of manpower needed for the different tasks: yellow: ≤ 1 FTE, green: 1-2 FTE, red: > 2 FTE. Red diamonds symbolize milestones and blue diamonds the hiring of new staff members.

the frontier of technology are unavoidable in our research field and thus the time schedules of experiments are estimated according the present knowledge.

In accordance to previous plans and reflecting new initiatives in our research fields, intensified activities are planned in the main research areas leading to a moderate increase in necessary investment as well as personnel.

A further development, the formation of a new Institute for Particle Physics combing two institutes of the Academy, SMI and HEPHY, has not yet been taken into account in the current planning since the necessary construction of a new common building will not be finished in 2013. Some of the planned experiments requiring additional manpower and resources could be facilitated by synergies connected with the new institute.

1.5.2. Strong interaction with strangeness

This research focus summarizes a series of experiments devoted to a deeper understanding of the strong interaction in the most challenging low-energy regime, in systems involving strange quarks. Here the perturbative Quantum Chromodynamics, which is very well working at high energies, faces problems. The main question to be answered is how the mechanism of chiral symmetry breaking works and how a possible partial restoration of chiral symmetry in nuclear medium is connected to the hadron masses and therefore to the mass of the visible universe. The quarks masses contribute only a few percent to the observed hadron masses. Using X-ray spectroscopy of kaonic atoms (exotic atoms containing a negative antikaon (K^-) instead of an electron), the antikaon-nucleon interaction can be studied at threshold, where scattering experiments are not possible. Here sub-threshold resonances of hitherto unclear structure like the famous $\Lambda(1405)$ resonance influence the character of the strong interaction at threshold and accordingly the observables measured by X-ray detection. Some discrepancies were resolved in our recent experiments but still the sub-threshold resonances can be regarded a key for antikaon-nuclei interaction: Based on the observed strong attraction between antikaons and nucleons below threshold bound states of antikaons in few-nucleon systems (antikaon bound states, AKBS) were predicted. Indications for the existence of AKBS were observed, but a new generation of fully inclusive experiments is needed to clarify the nature like production mechanism, binding energies, decay widths and therefore to reach a final conclusion. A complementary approach is the study of the production of K mesons in pion induced reactions. With a pion beam, mesons with strangeness can be produced in nuclei at very low momenta and should feel possible in-medium effects.

SIDDHARTA – Silicon Drift Detector for Hadronic Atom Research by Timing Application – *Laboratori Nationali di Frascati (LNF), Italy*

Kaonic hydrogen and for the first time kaonic deuterium atoms have been produced at the electron-positron collider DAΦNE. The unique mono-energetic kaons from the two-body decay of Φ mesons enable precision measurements in the field of antikaon-nucleon interaction in the low-energy regime. New large triggerable X-ray detectors (silicon drift detectors, SDDs, with 1 cm^2 active area) allow a background suppression of several orders of magnitude by making use of the antikaon - X-ray correlation. The development of those new X-ray detectors was funded by the European Commission within the 6th framework program in the I3 Hadron Physics project. The goal of the experiment is the exact determination of the shift and width of the ground state of kaonic hydrogen and deuterium using precision spectroscopy of the X-ray transitions leading to these states. Strong interaction effects cause a shift and broadening of the states. These threshold data can be regarded as benchmark for theories and consequently for the understanding of the low-energy antikaon-nucleon interaction. Furthermore, from these observables one can determine the isospin-dependent antikaon-nucleon scattering lengths at threshold, yielding important information about chiral symmetry breaking in the strangeness sector in a fairly direct approach without extrapolation like in the case of scattering experiments. The first phase of data taking was finished in 2009, data analysis of the kaonic hydrogen experiment is ongoing and supposed to be finished end of 2010, with a publication expected in 2011. In the case of kaonic deuteriuma a first measurement was performed, in which only an indication could be observed. In order to extract strong interaction observables we need a second dedicated running period planned for 2011 and 2012, with a following period for analysis and publication. The start of data taking for SIDDHARTA2 in spring 2011 is a major milestone for this experiment.

J-PARC-E17 – *Japan Proton Accelerator Research Complex*

The J-PARC facility started operation in 2009 with the aim of delivering kaon beams with the highest intensity in the world. The first beam was extracted at still low intensity into the hadron hall in early 2009. SMI is involved in two experiments, which have been accepted as day-one experiments. E17, for which SMI received a grant from FWF to supply the SDD X-ray detectors, makes use of the same setup as E15 to measure the 3p-2s X-ray transition of $K^{-3}He$ using SDD detectors. A comparison with results of the predecessor experiment E570 at KEK-PS in $K^{-4}He$ will yield important information on the isospin dependence of the kaon-nucleon interaction. Due to a slower than predicted increase of the intensity of extracted Kaon beams at J-PARC, E17 is expected to start taking data in the first half of 2011.

FOPI – 4π – *GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt*

Using the existing detector FOPI at GSI a search for antikaon bound states was performed in 2009, where SMI provided a major part of the needed start and tracking detectors. Using the FOPI detector, the simplest predicted AKBS K^-pp can be produced and studied in proton-proton collisions. The formation of larger AKBS with several nucleons can be studied in heavy ion collisions in FOPI. AKBS are of special interest since the strongly attractive anti-kaon nucleon interaction may lead to densities significantly larger than normal nuclear matter. The publication of the results of the 2009 run is foreseen in early 2011. In parallel analysis of data taken by the DISTO collaboration is going on in the short term, looking for the same signatures.

Furthermore, FOPI has started a program to investigate in-medium effects of particles with strangeness produced by a pion beam. For 2010/11 an experiment will be carried out where the production and propagation of the $\Phi(1020)$ and co-produced K^+K^-, respectively, will be studied (close to threshold). The data should shed light on the in-medium phi-nucleon cross section and the kaon in-medium potential. SMI is involved in the co-spokespersonship, Monte-Carlo simulations, experimental equipment (start-veto-target system) and data analysis.

AMADEUS– *Laboratori Nationali di Frascati (LNF), Italy*

The experiment AMADEUS aims at becoming a European counter piece to in-flight experiments planned at the J-PARC facility in Japan. AMADEUS wants to make use of the KLOE detector, which could for the first time detect all decay particles of the AKBS including neutral ones with high efficiency. This feature is extremely important to unambiguously identify the AKBS and to determine their properties like density etc. Work is going on in analyzing existing KLOE data looking for Λ's and possible signatures for bound states. A working group is investigating the interchangeability between the KLOE and AMADEUS setup, with the involvement of the DAΦNE machine group. AMADEUS is supposed to be installed after a 1-2 year data taking period of KLOE which will end in 2012. Before, a dedicated target and inner tracker system has to be built and tested in collaboration between SMI and LNF. SMI is responsible for the design of the AMADEUS apparatus and will lead the coordination of the setup work (technical director). A Junior Scientist is needed from 2012 for this line of research.

J-PARC – E15 and new proposals – *Japan Proton Accelerator Research Complex*

E15 will search for antikaon bound states using the (K^-,π^-) reaction with kaon beams of about 1 GeV/c momentum. This project is complementary to AMADEUS, where AKBS will be investigated with stopped kaons. E15, which needs an order of magnitude higher beam intensity than E17, will be able to run earliest end of 2012. Together with Prof. M. Iwasaki of RIKEN, SMI has submitted a joint JSPS-FWF proposal to obtain funding for the detectors needed to measure the (stopped K^-,p) channel in addition to the (stopped K^-,n) one looking at the isospin-dependence of the K-cluster formation. If approved, development and construction of GEM detectors will be done at SMI in 2011 and 2012. A further experiment investigating the shape of the $\Lambda(1405)$ resonance, which plays a central role in the description of the kaon-nucleon interaction, within the E15 setup was recently approved by the J-PARC PAC. A new idea to use the secondary high-momentum antiproton beam of J-PARC to study the mass shift of the Φ-meson in nuclear matter or the double-strangeness production in antiproton annihilations is currently being investigated.

Double-strangeness production with stopped antiprotons

Recently published production cross sections of multi-strangeness production in antiproton annihilation on helium at LEAR show unusual large values. This indicates some not understood mechanism and might be related to the prediction that few-nucleon systems with two bound antikaons exist. As a possible effort to further study this phenomenon, estimates for the possibility of performing an experiment with the slow extracted beam from MUSASHI at CERN-AD or a secondary high-momentum beam available at J-PARC have been made. A Letter of Intent to J-PARC was submitted in 2009 and the idea of an experiment at the AD was presented at a workshop on future opportunities at CERN. The development of a 4π detector for charged and neutral particles is needed. As a central tracking detector a TPC like the prototype being developed within the JointGEM activity in the HadronPhysics2 project is a good candidate. A scientific collaboration has to be formed pursuing this idea and being able to build such a complex and expensive detector.

1.5.3. Matter - Antimatter Symmetry: ASACUSA @ CERN

ASACUSA – Atomic Spectroscopy And Collisions Using Slow Antiprotons – *Antiproton Decelerator (AD) of CERN, Geneva, Switzerland*

The international collaboration ASACUSA performs precision spectroscopy of antiprotonic helium (an exotic three-body system consisting of a helium nucleus, an electron, and an antiproton) and antihydrogen (the simplest atom composed entirely of antimatter, consisting of an antiproton and a positron). Its goal is to determine the mass, charge, and magnetic moment of the antiproton as precisely as possible and to perform a precise test of CPT Symmetry by comparing these properties to those of the proton.

Antiprotonic helium spectroscopy

Using laser spectroscopy of antiprotonic helium and comparison of the results with calculations we could obtain the most accurate limit on the equality of mass and charge of proton and antiproton of 2 ppb and to determine the ratio of the antiproton-to-electron mass for the first time with the same accuracy. The determination of the hyperfine structure of antiprotonic helium, which is the responsibility of SMI, is aimed at measuring the magnetic moment of the antiproton to a higher accuracy than currently known. In 2009, a new value of the magnetic moment of the antiproton with slightly smaller error than the previous measurements was obtained from the microwave spectroscopy of antiprotonic ^{4}He. Measurements in antiprotonic ^{3}He for a more thorough test of QED calculations and of another transition in antiprotonic ^{4}He are planned with a FWF project lasting until 2012-2013.
Participation in the two-photon laser spectroscopy effort to further improve the charge and mass of the antiproton will continue.

Antihydrogen ground-state hyperfine structure

As major long-term project, ASACUSA has proposed to measure for the first time the ground sate hyperfine structure (GS-HFS) of hydrogen. This measurement is one of three experiments in the world that aim at determining the two most precisely measured quantities of hydrogen (GS-HFS and the 1s–2s two-photon transition) also for its antimatter equivalent. Both quantities are among the most precisely determined physical quantities at all and their measurement for antihydrogen therefore promises to yield one of the most precise tests of CPT symmetry. SMI is in charge of the spectrometer line, an atomic beam line consisting of a spin-flip cavity, a sextupole magnet for spin selection, and an antihydrogen detector. Simulations have been performed to determine the parameters of the sextupole, and after an international bidding procedure done at CERN the company TESLA has been chosen to build the magnet, which will be delivered early 2010. A first design of the spin-flip cavity is currently being optimized by a Ph.D. student at CERN and construction and tests of the cavity should be done in 2010. Test for the formation of a polarized beam of antihydrogen by a "cusp trap" have started in 2008 by the MUSASHI group from University of Tokyo in Komaba. An assembly of the full setup can be done earliest during 2011 with first experiments starting in 2012.

In order to ensure a significant contribution of SMI to our major international collaborations, we intended to open a new position in 2009 for ASACUSA. Due to the financial situation of the academy this was not possible but we succeeded in obtaining a FWF project for the hyperfine spectroscopy of antiprotonic helium which includes a Postdoc and a Ph.D. position. We continue to obtain support for collaboration costs by the ministry bm_wf from 2007 till currently 2010. For the experiment E17 at J-PARC a project was approved by FWF including a post-doc and a PhD position for 3 years as well as money for new X-ray detectors and travel funds. One Post-doc as well as equipment through an application with the FWF for the FOPI experiment was also approved in 2009, after a 6 months delay due to uncertainties in the funding of the FWF. SMI participated in two calls for Research Infrastructures in the 7th framework programme of the EC: in three Joint Research Activities and one Network of the Integrating Activity HadronPhysics2 as well as in the role of coordinator for the Integrated Activity FUNDAMENTAL. HadronPhysics2 was successful and will provide funds for 30 months starting January 2009, with the JRA JointGEM and the network LEANNIS being coordinated at SMI.
Due to the increased activity in the planned experiments at LNF and PANDA as well as the construction and testing of the spectrometer line for ASACUSA marking the start of the antihydrogen experiment,

additional manpower is needed and we intend to open one new position for PANDA in 2011, and one each for AMADEUS and for ASACUSA in 2012.

1.5.4. Antiprotons at FAIR

In the long term we plan to enlarge our participation in projects at the FAIR Facility (Facility for Antiproton and Ion Research) in Darmstadt. FAIR will be the most important facility for hadron physics in Europe, and produce the first antiproton beams around the year 2018. SMI participates in several experiments with antiproton: FLAIR, PANDA, and AIC (Antiproton Ion Collider). Recent developments towards the foundation of FAIR have shown that only PANDA will be running in the first phase of FAIR (expected start around 2018), while FLAIR is in the next phase and the AIC will come in even a later stage. The focus in this part has therefore been shifted towards a stronger participation in PANDA.

PANDA – Antiproton Annihilation at Darmstadt

The PANDA experiment at FAIR makes use of antiprotons of small momentum spread for highest precision investigations. The strong interaction determines the microscopic structure of matter. It dominates the interaction of nuclei in the atomic nucleus and is responsible for the interaction of quarks und gluons in the nucleon as well as in other hadrons (mesons). The current description of the strong interaction is Quantum Chromodynamics (QCD). While QCD in the realm of small distances and corresponding high energies can be treated perturbatively which allows quantitative predictions, perturbative QCD fails at distances between quarks that are similar to the dimensions of the nucleons. Experiments in this region can be done with heavy quarkonia, e.g. bound quark systems of charm-anti-charm (charmonium). In the sector of hadron spectroscopy many facets are already under examination with experiments at B-factories like BES (China) and BELLE (KEK/Japan). For instance charmonium states and recently discovered states of yet unknown nature can be studied in B-decays. At this point, the detection and analysis of such reactions is very similar to many expected channels of PANDA. As a consequence, a closer collaboration with an experiment like BELLE should be arranged for. There would be an excellent opportunity to train analysis strategies with real experimental data.

The possibility to study antiproton annihilations on nuclei is a unique feature of the PANDA experiment. The study of in-medium effects, which so far concentrated on the light and strange quark sector, can be extended into the charm quark region. Predictions of significant mass shifts of D mesons can be investigated by comparing cross sections in $\bar{p}p$ with $\bar{p}$A. Even if the predicted mass shift of charmonium states is small, it is of particular relevance to study the charmonium absorption cross section in nuclei. The suppression of charmonium states is interpreted as a hint of the formation of a Quark-Gluon-Plasma in high energy heavy ion reactions. However it is not clear to which extent hadronic interactions contribute to the dissociation of charmonium. For those reactions model calculations are needed as input for Monte-Carlo simulations and the preparation of the appropriate analysis tools to extract the relevant information. That knowledge is important in the context of hadron masses and a possible connection to a partial restoration of the broken chiral symmetry of QCD in cold nuclear matter.

It is aimed at a closer connection to the theory groups working on this subject in form of a network.

The role of the gluons and their dynamics is a crucial ingredient of QCD especially related to the question of the nature of the hadron masses. It is a special feature of the strong interaction that its exchange particles, the gluons, carry colour charges and hence interact among themselves. As a consequence systems consisting purely of gluons (glueballs) are predicted whose masses are exclusively determined by the strong interaction. The finding of such states would be a strong indication for the correctness of the current description of hadronic matter

To this end a universal detector system with an internal hydrogen jet target is being developed in an international collaboration of 47 institutions. SMI takes part in this collaboration and participates in the development of the internal target and several detector systems (Cherenkov counters, GEM detectors for tracking). These activities are being funded by the European Commission through Integrated Activity projects both in FP6 and FP7.

FLAIR – Facility for Low-energy Antiproton and Ion Research

FLAIR is a next generation low-energy antiproton facility that goes far beyond the existing Antiproton Decelerator (AD) of CERN by providing cooled slow and fast extracted beams of antiprotons at a factor 100 lower energy, allowing a factor 100 higher rate of stopped antiprotons. SMI is strongly involved since E. Widmann is chairman of the FLAIR steering committee since its beginning. Due to the delay of the FAIR facility, in the medium term only coordinating activities are needed which are funded until 2010 through a FP7 preparatory phase contract.

1.5.5. Small, technical and/or third-party funded projects

SMI staff is furthermore participating in short-term but highly visible physics projects (experiment to test the Pauli exclusion principle (VIP) at the underground laboratory of Gran Sasso and its successor VIP2, investigation of exotic non-exponential decays of stored ions in a storage ring at GSI) and technical developments (e.g. development of the PANDAGrid computing system). SMI is participating in three working packages of the EU FP7 HadronPhysics2 project having the leadership of one of them (JointGEM). Activities are already ongoing to participate in the successor application for which the consortium received an invitation to participate in a closed call.

1.6. Publications/talks/poster presentations 2009

1.6.1. Publications in peer-reviewed journals or collections

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E. Widmann
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Orbital electron capture decay of hydrogen- and helium-like ^{142}*Pm ions*
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J. Zmeskal, M. Bazzi, G. Beer, L. Bombelli, A.M. Bragadireanu, P. Bühler, M. Cargnelli, C. Curceanu Petrascu, C. Fiorini, C. Guaraldo, R.S. Hayano, M. Iliescu, T. Ishiwatari, M. Iwasaki, P. Kienle, A. Longoni, V. Lucherini, J. Marton, K. Nikolics, S. Okada, D. Pietreanu, T. Ponta, A. Romero Vidal, P.L. Sandri, A. Scordo, D.L. Sirghi, F. Sirghi, K. Suzuki, H. Tatsuno, O. Vazquez Doce, E. Widmann,
Kaonic Atoms at DAFNE
International Journal of Modern Physics A **24**, 190 (2009).

J. Zmeskal, P. Bühler, M. Cargnelli, T. Ishiwatari, P. Kienle, J. Marton, K. Suzuki, E. Widmann
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1.6.2. Longer publications in non-peer-reviewed journals or collections

S. Bartalucci, S. Bertolucci, M. Bragadireanu, M. Catitti, M. Cargnelli, C. Curceanu (Petrascu), S. Di Matteo, J.-P. Egger, C. Guaraldo, M. Iliescu, T. Ishiwatari, M. Laubenstein, J. Marton, E. Milotti, D. Pietreanu, T. Ponta, D.L. Sirghi, F. Sirghi, L. Sperandio, O. Vasquez Doce, E. Widman, J. Zmeskal
The VIP experiment
Journal of Physics: Conference Series **174** (DICE2008, Fourth International Workshop), 012065 (2009).

E.O. Le Bigot, S. Boucard, D.S. Covita, D. Gotta, A. Gruber, A. Hirtl, H. Fuhrmann, P. Indelicato, J.M.F. dos Santos, S. Schlesser, L.M. Simons, L. Stingelin, M. Trassinelli, J.F.C.A. Veloso, A. Wasser, J. Zmeskal
High-Precision X-ray Spectroscopy in Few-Electron Ions
Physica Scripta T134, 014015 (2009).

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Physics Performance Report for:PANDA
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New experimental limit on the Pauli Exclusion Principle violation by electrons (the VIP experiment)
Journal of Physics: Conference Series **171** (DISCRETE 08, Symposium on Prospects in the Physics of Discrete Symmetries), 012031 (2009).

P. Kienle
Two-body weak decay studies in an ion storage ring
Journal of Physics: Conference Series **171** (DISCRETE 08, Symposium on Prospects in the Physics of Discrete Symmetries), 012065 (2009).

1.6.3. Book chapters

F. Aumayr, G. Badurek, M. Benedikt, M. Hajek, E. Jericha, P. Kienle, M. Krammer, H. Leeb, J. Marton, E. Widmann, H.W. Weber
Physics Opportunities at MedAustron – White Book
Schriftenreihe der Technischen Universität Wien

1.6.4. Keynote scientific talks

E. Widmann: *Precision spectroscopy of antiprotonic atoms and antihydrogen*
41st EGAS Conference, Gdansk, POLAND

1.6.5. Invited scientific talks

M. Cargnelli: *Kaonic Atoms studies at DAFNE in SIDDHARTA experiment*
10th Conference on Hypernuclear and Strange Particle Physics (Hyp-X), JAPAN

J. Marton: *Low-energy interaction of anti-kaons*
7th Conference on Nuclear and Particle Physics, Sharm El-Sheikh, EGYPT

J. Marton: *Kaonic atoms and nuclei: solved puzzles, open questions and challenges*
Kernphysikalisches Kolloquium, Helmholtz Institut für Strahlen- und Kernphysik, Bonn, GERMANY

E. Widmann: *The AMADEUS experiment*
10th Conference on Hypernuclear and Strange Particle Physics (Hyp-X), JAPAN

E. Widmann: *Perspectives of low-energy antiproton physics at FLAIR*
Graduiertenkolleg und EMG Seminar (Johannes Gutenberg-Universität), Mainz, GERMANY

J. Zmeskal: *Kaonischer Wasserstoff*
Seminar für Neutronen-, Festkörper- und Quantenphysik; ATI, Wien, AUSTRIA

1.6.6. Other scientific talks

P. Bühler: *PANDAGrid experiences with AliEn*
ALICE-LCG Task Force weekly, SWITZERLAND

P. Bühler*: GRID: DC & production tools*
XXXI. PANDA Collaboration meeting, GERMANY

P. Bühler: *The PANDA Grid*
European Nuclear Physics Conference & DPG-Fruehjahrstagung (Ruhr-Universitaet Bochum), Bochum, GERMANY

P. Bühler: *Apr09 test run – start counter*
FOPI weekly group meeting, GERMANY

M. Cargnelli: *Kaonic X-ray experiments at DAFNE*
Jahrestagung der Oesterreichischen Physikalische Gesellschaft, Innsbruck, AUSTRIA

M. Cargnelli: *Kaonic X-ray experiments at DAFNE*
European Nuclear Physics Conference & DPG-Fruehjahrstagung (Ruhr-Universitaet Bochum), Bochum, GERMANY

S. Friedreich: *Preparations for HFS Spectroscopy of Antiprotonic ^{3}He*
Jahrestagung der Oesterreichischen Physikalische Gesellschaft, Innsbruck, AUSTRIA

S. Friedreich: *Preparations for HFS Spectroscopy of antiprotonic ^{3}He*
Heraeus Seminar Bad Honnef, Precision Experiments at Lowest Energies for Fundamental Tests and Constants, Bad Honnef, GERMANY

A. Gruber: *Vacuum conditions in PANDA pbar-line*
XXVIII. PANDA Collaboration meeting, GERMANY

A. Gruber: *Opening angle of upstream cone & influence on vacuum*
XXVIII. PANDA Collaboration meeting, GERMANY

A. Gruber: *A cluster-jet target for PANDA and the PANDA vacuum system*
Jahrestagung der Oesterreichischen Physikalische Gesellschaft, Innsbruck, AUSTRIA

A. Gruber: *Requested changes of IP-cross and effects on the vacuum*
XXX. PANDA Collaboration meeting, GERMANY

A. Gruber: *Vacuum calculations for TDR - first iteration*
XXXI. PANDA Collaboration meeting, GERMANY

A. Gruber: *Changes in design of beam line and effects on the vacuum*
XXX. PANDA Collaboration meeting, GERMANY

A. Gruber: *Mechanical issues of the beam pipe system*
XXXI. PANDA Collaboration meeting, GERMANY

A. Gruber: *Using NEG-pumping near a high density internal target*
European Nuclear Physics Conference & DPG-Fruehjahrstagung (Ruhr-Universitaet Bochum), Bochum, GERMANY

O.N. Hartmann: *Search for a bound state with FOPI*
International Workshop on Hadronic Atoms and Kaonic Nuclei - Solved Puzzles, Open Problems and Future Challenges in Theory and Experiment (ECT*), Trento, ITALY

T. Ishiwatari: *Precision spectroscopy of Kaonic Helium-3 and Helium-4 3d->2p X-rays*
XIII International Conference on Hadron Spectroscopy (Hadron 09), UNITED STATES

T. Ishiwatari: *Kaonic He-4 X-ray measurement with SIDDHARTA*
International Workshop on Hadronic Atoms and Kaonic Nuclei - Solved Puzzles, Open Problems and Future Challenges in Theory and Experiment (ECT*), Trento, ITALY

T. Ishiwatari: *Precision spectroscopy of Kaonic Helium-3 3d-2p X-rays*
European Nuclear Physics Conference & DPG-Fruehjahrstagung (Ruhr-Universitaet Bochum), Bochum, GERMANY

B. Juhász: *Antimatter does matter: Testing the CPT symmetry in the ASACUSA collaboration*
Seminar, University of Vienna, AUSTRIA

B. Juhász: *Status of the antihydrogen beam line*
ASACUSA collaboration meeting, Geneva, SWITZERLAND

P. Kienle*: Double Antikaon Production in Nuclei by Stopped Antiproton Annihilation*
International Workshop on Hadronic Atoms and Kaonic Nuclei - Solved Puzzles, Open Problems and Future Challenges in Theory and Experiment (ECT*), Trento, ITALY

J. Marton: *Low-energy anti-kaon nucleon and nuclei interactions*
19th IUPAP Conference on Few Body Problems, Bonn, GERMANY

J. Marton: *Research at SMI*
NUPPEC Meeting, Vienna, AUSTRIA

J. Marton: *LEANNIS: a liason between theory and experiment in antikaon physics*
International Workshop on Hadronic Atoms and Kaonic Nuclei - Solved Puzzles, Open Problems and Future Challenges in Theory and Experiment (ECT*), Trento, ITALY

J. Marton: *Kaonic Atom X-ray Spectra - SIDDHARTA at LNFrascati*
Tenth Conference on the Intersections of Particle and Nuclear Physics, UNITED STATES

J. Marton: *Low-energy (anti)kaon nucleon and nucleus interaction studies*
Third Workshop of the American Physical Society Topical Group on Hadron Physics, UNITED STATES

J. Marton: *Studies of APD properties*
Workshop on Fast Cherenkov Detectors - Photon Detection, DIRC Design and DAQ, GERMANY

O. Massiczek: *A New Cryogenic Target and Microwave Cavity for Hyperfine Structure Spectroscopy of Antiprotonic Helium*
Jahrestagung der Oesterreichischen Physikalische Gesellschaft, Innsbruck, AUSTRIA

K. Suzuki: *Search for kaonic nuclear state, K^-pp, in the $p+p \to K^+X$ reaction*
3rd Joint Meeting of the APS Division of Nuclear Physics and the Physical Society of Japan, UNITED STATES

K. Suzuki: *Status of kaonic nuclear state search at FOPI using proton induced reaction*
European Nuclear Physics Conference & DPG-Fruehjahrstagung (Ruhr-Universitaet Bochum), Bochum, GERMANY

K. Suzuki: *Analysis status*
FOPI pp2KX data analysis meeting, München, GERMANY

K. Suzuki: *Round-up of April Run: Beam, Beamline Counters*
FOPI collaboration meeting, GERMANY

K. Suzuki: *Proton Beamtime and misc.*
FOPI collaboration meeting, POLAND

E. Widmann: *Precision physics with low-energy antiprotons at FLAIR*
5th SPARC Collaboration Symposium, Lisbon, PORTUGAL

E. Widmann: *Opportunities with low-energy antiprotons at FLAIR*
Arctic FIDIPRO-EFES Workshop, Saariselkä, FINLAND

E. Widmann: *Precision experiments with low-energy antiprotons from AD to FLAIR*
XXXI Mazurian Lakes Conference on Physics, Piaski, POLAND

J. Zmeskal: *The AMADEUS experiment*
International Workshop on Hadronic Atoms and Kaonic Nuclei - Solved Puzzles, Open Problems and Future Challenges in Theory and Experiment (ECT*), Trento, ITALY

1.6.7. Poster presentations

T. Ishiwatari: *Adjustment of the SDDs for experiment E17 at J-PARC*
10th Conference on Hypernuclear and Strange Particle Physics (Hyp-X), JAPAN

T. Ishiwatari: *Precision spectroscopy of kaonic 3He 3d->2p X-rays at J-PARC*
10th Conference on Hypernuclear and Strange Particle Physics (Hyp-X), JAPAN

1.6.8. Edited publications

Proceedings of the International Conference on Exotic Atoms and Related Topics (EXA08) and International Conference on Low Energy Antiproton Physics (LEAP08): Hyperfine Interactions 193-194
Editors: B. Juhász, J. Marton, K. Suzuki, E. Widmann, J. Zmeskal

1.7. Scientific cooperation 2009

1.7.1. External partners in research programs

Andrzej Soltan Institute for Nuclear Studies, Warsaw, POLAND
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Atomic Physics Laboratory, RIKEN, Saitama, JAPAN
FS1_f: Study of kaon-nucleon interaction @ J-PARC
FS2_d: Measurement of the ground-state hyperfine structure of antihydrogen
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

CERN – European Organization for Nuclear Research / Laboratory for Particle Physics, Geneva, SWITZERLAND
FS2_b: Hyperfine structure of antiprotonic helium
FS2_c: Precision laser spectroscopy of antiprotonic helium
FS2_d: Measurement of the ground-state hyperfine structure of antihydrogen

D.I. Mendeleev Institute for Metrology (VNIIM), St. Petersburg, RUSSIAN FEDERATION
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Department for Physics and Astronomy, Aarhus University, Aarhus, DENMARK
FS2_d: Measurement of the ground-state hyperfine structure of antihydrogen
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Department of Atomic Physics, Stockholm University, Stockholm, SWEDEN
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Department of Experimental Physics, University of Debrecen, Debrecen, HUNGARY
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Department of Physics and Astronomy, York University, Toronto, CANADA
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Department of Physics, Harvard University, Cambridge, Massachusetts, UNITED STATES
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Department of Physics, St. Petersburg State University, St. Petersburg, RUSSIAN FEDERATION
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Department of Physics, Texas A&M University, College Station, Texas, UNITED STATES
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Department of Physics, University of Tokyo, Tokyo, JAPAN
FS2_b: Hyperfine structure of antiprotonic helium
FS2_c: Precision laser spectroscopy of antiprotonic helium
FS2_d: Measurement of the ground-state hyperfine structure of antihydrogen
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Department of Physics, University of Wales Swansea, Swansea, UNITED KINGDOM
FS2_d: Measurement of the ground-state hyperfine structure of antihydrogen
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Dipartimento di Chimica e Fisica per l'Ingegneria e per i Materiali, Brescia, ITALY
FS2_d: Measurement of the ground-state hyperfine structure of antihydrogen
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Dipartimento di Fisica, Laboratorio LENS, INFN, Universita' degli Studi di Firenze, Florence, ITALY
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

FOM Institute for Atomic and Molecular Physics, Amsterdam, NETHERLANDS
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Forschungszentrum Jülich GmbH, Jülich, GERMANY
FS3_b: PANDA: Proton Antiproton Annihilations at Darmstadt
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research
Z: Ph.D.: Charmonium Interaction with Nuclear Matter (Nikolics)

GSI – Gesellschaft für Schwerionenforschung mbH, Darmstadt, GERMANY
FS1_c: Strangeness physics with FOPI at GSI
FS3_b: PANDA: Proton Antiproton Annihilations at Darmstadt
FS3_c: Hadrons in medium
Z: Ph.D.: Charmonium Interaction with Nuclear Matter (Nikolics)

Heavy Ion Laboratory, Warsaw University, Warsaw, POLAND
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

INFN, Laboratori Nazionali di Frascati, Frascati, ITALY
FS1_b_A: Kaonic hydrogen and deuterium: SIDDHARTA
FS1_e: AMADEUS at DAPHNE2
FS3_b: PANDA: Proton Antiproton Annihilations at Darmstadt

Indiana University, Bloomington, Indiana, UNITED STATES
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Institute of Nuclear Research (ATOMKI) of the Hungarian Academy of Sciences, Debrecen, HUNGARY
FS2_b: Hyperfine structure of antiprotonic helium
FS2_c: Precision laser spectroscopy of antiprotonic helium
FS2_d: Measurement of the ground-state hyperfine structure of antihydrogen
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Institut für Angewandte Physik, Universität Frankfurt, Frankfurt, GERMANY
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Institut für Kernchemie, Universität Mainz, Mainz, GERMANY
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Institut für Kernphysik, Universität Frankfurt, Frankfurt, GERMANY
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Institut für Kernphysik, Universität Gießen, Gießen, GERMANY
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Institut für Physik, Humboldt-Universität zu Berlin, Berlin, GERMANY
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Institut für Physik, Universität Mainz, Mainz, GERMANY
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Institut für Theoretische Physik, TU Dresden, Dresden, GERMANY
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Institut für Theoretische Physik, Wien, AUSTRIA
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Institute for Experimental and Theoretical Physics, Moscow, RUSSIAN FEDERATION
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Institute for Storage Ring Facilities (ISA), Aarhus, DENMARK
FS2_d: Measurement of the ground-state hyperfine structure of antihydrogen
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Institute of Nuclear Physics, Moscow State University, Moscow, RUSSIAN FEDERATION
FS3_b: FLAIR: Facility for Low-Energy Antiproton and Ion Research
Y: Hyperfine structure of antiprotonic helium (FWF)

Institute of Physics, University of Tokyo, Tokyo, JAPAN
FS2_b_A: Hyperfine structure of antiprotonic helium
FS2_c: Precision laser spectroscopy of antiprotonic helium
FS2_d: Measurement of the ground-state hyperfine structure of antihydrogen
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Institute of Spectroscopy of the Russian Academy of Sience, Troitsk, Troitsk, RUSSIAN FEDERATION
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Institute of Theoretical Physics, Warsaw University, Warsaw, POLAND
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Istituto Nazionale di Fisica Nucleare – INFN, Genoa, ITALY
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

JINR - Joint Institute for Nuclear Research, Dubna, RUSSIAN FEDERATION
FS3_b: PANDA: Proton Antiproton Annihilations at Darmstadt
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research
Y: Hyperfine structure of antiprotonic helium (FWF)

KEK, High Energy Accelerator Research Organization, Tokyo, JAPAN
FS1_f: Study of kaon-nucleon interaction @ J-PARC

KFKI Research Institute for Particle and Nuclear Physics, Hungarian Academy of Sciences, Budapest, HUNGARY
FS2_b: Hyperfine structure of antiprotonic helium
FS2_c: Precision laser spectroscopy of antiprotonic helium
FS2_d: Measurement of the ground-state hyperfine structure of antihydrogen
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

KVI Kroningen, Kroningen, NETHERLANDS
FS3_b: PANDA: Proton Antiproton Annihilations at Darmstadt

LANL Los Alamos USA, Los Alamos, UNITED STATES
FS3_b: PANDA: Proton Antiproton Annihilations at Darmstadt

Laboratoire Kastler-Brossel, École Normale Supérieure et Univ. Pierre et Marie Curie, Paris, FRANCE
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Laser Centre Vrije Universiteit, Faculty of Science, Amsterdam, NETHERLANDS
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Manne Siegbahn Laboratory (MSL), Stockholm, SWEDEN
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Massachusetts Institute of Technology, Duke University, North Carolina, UNITED STATES
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Max-Planck-Institut für Kernphysik, Heidelberg, GERMANY
FS2_d: Measurement of the ground-state hyperfine structure of antihydrogen
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Max-Planck-Institut für Quantenoptik, Garching, GERMANY
FS2_c: Precision laser spectroscopy of antiprotonic helium

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

Northwestern Univ. Evanston, Evanston, UNITED STATES
FS3_b: PANDA: Proton Antiproton Annihilations at Darmstadt

Osaka E-C, Osaka, JAPAN
FS1_f: Study of kaon-nucleon interaction @ J-PARC

Osaka University, Osaka, JAPAN
FS1_f: Study of kaon-nucleon interaction @ J-PARC

Politechnico Torino, Turin, ITALY
FS3_b: PANDA: Proton Antiproton Annihilations at Darmstadt

Queens University, Belfast, IRELAND
FS2_d: Measurement of the ground-state hyperfine structure of antihydrogen
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

Ruhr-Universität Bochum, Bochum, GERMANY
FS3_b: PANDA: Proton Antiproton Annihilations at Darmstadt

SINS, Warsaw, POLAND
FS3_b: PANDA: Proton Antiproton Annihilations at Darmstadt

Seoul National Univsersity, Seoul, REPUBLIC OF KOREA
FS1_f: Study of kaon-nucleon interaction @ J-PARC

St. Petersburg Nuclear Physics Institute (PNPI), St. Petersburg, RUSSIAN FEDERATION
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

TRIUMF, Vancouver, Vancouver, CANADA
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

TSL – The Svedberg Laboratory Uppsala, Uppsala, SWEDEN
FS3_b: PANDA: Proton Antiproton Annihilations at Darmstadt

Technische Universität Dresden, Dresden, GERMANY
FS3_b: PANDA: Proton Antiproton Annihilations at Darmstadt

Technische Universität München, Munich, GERMANY
FS1_c: Deeply bound kaonic nuclei with FOPI at GSI
FS3_b: PANDA: Proton Antiproton Annihilations at Darmstadt

Temple University, Philadelphia, UNITED STATES
FS1_f: Study of kaon-nucleon interaction @ J-PARC

University Brescia, Brescia, ITALY
FS3_b: PANDA: Proton Antiproton Annihilations at Darmstadt

University Cracow, Cracow, POLAND
FS3_b: PANDA: Proton Antiproton Annihilations at Darmstadt

University Frankfurt, Frankfurt, GERMANY
FS3_b: PANDA: Proton Antiproton Annihilations at Darmstadt

University Silesia, Silesia, POLAND
FS3_b: PANDA: Proton Antiproton Annihilations at Darmstadt

Univerità di Torino, Turin, ITALY
FS3_b: PANDA: Proton Antiproton Annihilations at Darmstadt

University of New Mexico, Albuquerque, New Mexiko, UNITED STATES
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

University of Tokyo, Tokyo, JAPAN
FS1_f: Study of kaon-nucleon interaction @ J-PARC

Università degli Studi di Trieste; Triest, ITALY
FS3_b: PANDA: Proton Antiproton Annihilations at Darmstadt

Università di Catania, Catania, ITALY
FS3_b: PANDA: Proton Antiproton Annihilations at Darmstadt

Università di Genova, Genoa, ITALY
FS3_b: PANDA: Proton Antiproton Annihilations at Darmstadt

Università di Pavia, Pavia, ITALY
FS3_b: PANDA: Proton Antiproton Annihilations at Darmstadt

Universität Bonn, Bonn, GERMANY
FS3_b: PANDA: Proton Antiproton Annihilations at Darmstadt

Universität Gießen, Gießen, GERMANY
FS3_b: PANDA: Proton Antiproton Annihilations at Darmstadt

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

Universität Mainz, Mainz, GERMANY
FS3_b: PANDA: Proton Antiproton Annihilations at Darmstadt

Universität Münster, Münster, GERMANY
FS3_b: PANDA: Proton Antiproton Annihilations at Darmstadt

Universität Tübingen, Tübingen, GERMANY
FS3_b: PANDA: Proton Antiproton Annihilations at Darmstadt

Uppsala University, Uppsala, SWEDEN
FS3_b: PANDA: Proton Antiproton Annihilations at Darmstadt

Variable Energy Cyclotron Center, Kolkata, Kolkata, INDIA
FS3_e: FLAIR: Facility for Low-Energy Antiproton and Ion Research

1.8. Public outreach 2009

1.8.1. SMI at the "Lange Nacht der Forschung"

On Saturday, November 7th, 2009, the SMI participated in the „Lange Nacht der Forschung".
At this event, research and educational institutions are opened for the public from afternoon to midnight. In 2009, for the third time several institutes, universities and research groups presented their actual research program and their results at more than 570 stations in seven towns in Austria.
The public could visit any station for free, listen to talks, explore experiments or simply walk through exhibition rooms.
A well-arranged program, a bodacious internet and medial presence (www.langenachtderforschung.at) and a – especially provided for this evening – shuttle bus system guided and carried the visitors to the desired stations.
At the "Aula der Akademie der Wissenschaften" in 1010, Vienna, the SMI offered together with several other institutes an overview of their research projects. For the second time, people of SMI presented their recent research fields and results at the "Lange Nacht der Forschung". This year, the event lasted from sunset, 16:27 o'clock in Vienna, to midnight and was extraordinarily well attended.
We could elate our visitors with experiments and posters on about $50 m^2$ exhibition space. Furthermore, twice this evening, a talk of twenty minutes was given about "the secrets of strong interaction", where our primary research field, its theoretical background and the basic ideas of our experiments, were explained.
With two typical experiments we had the possibility to give an imagination of the detector systems we use in our daily life as physicists:
A plastic scintillator detected incident cosmic rays (high energetic particles, coming from outer space) which were monitored by an oscilloscope.
A webcam was installed in one of our test laboratories at SMI, which monitored a simultaneously performed X-ray measurement. With a remote desktop control, the visitors could control this measurement from the exhibition room and observe the in situ data acquisition of X-ray spectra.
Additionally, we showed on one screen a live view of a so-called "counter hall" at CERN, where our colleagues ambitiously performed measurements and took data.

On another screen, a picture presentation of several accelerator facilities in the world was presented.
Together with our colleagues from HEPHY, we created an area of cumulated research fields in experimental particle physics within the "Aula der Wissenschaften". While HEPHY resumed the experimental work at CERN and explanations of the standard model and emphasized the Austrian participation at CERN, the SMI concentrated on the presentation of experimental and theoretical studies at other accelerator facilities such as J-PARC in Japan, DAFNE in Italy or FAIR in Germany.
Our corporate exhibition room offered a precise and clear overview of current results and status quo of recent developments in particle and subatomic physics.
Over the whole night, thousands of visitors, among others the former minister of "Wissenschaft und Forschnung", walked through our presentations, served by a constantly present manpower of at least three SMI researchers or students, respectively. We were surprised how many people from other research fields, as well as laymen and children, showed strong interest in our studies.
We enjoyed having the possibility to present the fascinating world of strong interactions to scientists and other interested people.

Further information:
http://www.langenachtderforschung.at
http://www.oeaw.ac.at/smi/about-us/outreach/

1.9. Staff members and students

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