# Austrian Academy of Sciences

## Annual Report 2012

## Stefan Meyer Institute (SMI)
## for subatomic Physics

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| REPORTING PERIOD: | 1.1.2012 – 31.12.2012 |
| DIRECTOR OF THE REPORTING RESEARCH INSTITUTION: | Prof. Eberhard Widmann |
| ADDRESS: | Boltzmanngasse 3<br>1090 Vienna |

# Content

## 1. Mission Statement

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

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

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

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

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

**The current three main fields of activity at SMI are:**

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

- **Hadron physics:** here we study the strong interaction and its corresponding theory, quantum chromodynamics (QCD), at low energies in the non-perturbative regime and at intermediate energies. Chiral symmetry and its breaking or restoration plays an important role. They contribute to the origin of the masses of hadrons. The masses of the three current quarks add up to only a few percent of the measured hadron mass, which originates mainly from the dynamic interaction between the quarks and the exchange particles of the strong interaction, the gluons. The underlying mechanism is, to date, not understood at all. The experimental approach is the spectroscopy of meson-nucleus bound states using various reactions, and the measurement of the effect of the strong interaction on the low-lying atomic states of simple exotic atoms by X-ray spectroscopy. In the field of hadron physics new opportunities will be opened by PANDA at FAIR/Darmstadt with antiproton annihilation which provides an elegant way to study hadron physics in the charm quark regime in a rather direct way. It is one of the major experiments at FAIR and our institute participates in the technical development of the complex PANDA detector system. Prior to PANDA our institute takes advantage of experimental data collected by BELLE at KEK/Japan.
- **Advanced instrumentation:** progress in experimental physics needs new or improved instrumentation and methodology. In this field we currently work on three experimental projects funded within the EU FP7 Integrated Activity HadronPhysics3: novel photon detectors (SiPM, silicon photomultipliers) for use in Cherenkov detectors, large size tracking detectors based on GEM (Gas Electron Multiplier) technology, and the development of high-intensity gas jets to be used as internal targets in accelerators. SMI also hosts one site of the PANDA Grid computer network and participates in the development of Grid software.

Further activities include an underground laboratory experiment at Laboratori Nazionali di Gran Sasso (Italy) on a high-sensitivity test of the Pauli principle, in the **VIP** (Violation of the Pauli Principle) experiment. SMI also participates in the analysis of an experiment investigating two-body decays of stored and cooled ions at GSI. A network within the EU FP7 Integrated Activity HadronPhysics3 bringing together experimentalists and theoreticians working on strangeness nuclear physics, **LEANNIS**, is coordinated at SMI.

## 2. Scientific Activity 2012

### 2.1 Zusammenfassung des wissenschaftlichen Berichts 2012 (deutsch)

#### Materie-Antimateriesymmetrie

Nach dem Erhalt eines ERC Advanced Grants durch E. Widmann zur Untersuchung der Hyperfeinstruktur von Antiwasserstoff konzentrieren sich die Aktivitäten des SMI nun auf diese Messung, die eine der genauesten Überprüfungen der Materie-Antimateriesym-met-rie verspricht. Die letzten Daten zur Mikrowellenspektroskopie von antiprotonischem Helium wurden im Rahmen einer Dissertation ausgewertet und stimmen mit theoretischen Voraussagen überein.

Der ERC Grant begann im März und erlaubte die Anstellung von zwei Postdocs und zwei Dissertanten. Mit erheblichem Aufwand gelang es, die Apparatur zur Messung der Hyperfeinstruktur rechtzeitig zur Strahlzeit im Sommer fertigzustellen und einen vollständig neuen segmentierten Detektor zum Nachweis der Antiprotonenannihilation herzustellen. Im Experiment am Antiproton Decelerator des CERN wurde vornehmlich an der Erzeugung eines Antiwasserstoffstrahles gearbeitet, die daraus resultierenden Daten werden noch ausgewertet. Parallel dazu wurde am SMI an der Erzeugung eines polarisierten atomaren Wasserstoffstrahls gearbeitet, der dazu dienen wird, die Apparatur zu charakterisieren.

#### Hadronenphysik

Unser Interesse ist gegenwärtig auf die starke Wechselwirkung mit Seltsamkeit (strangeness) fokussiert, welche die Dynamik und Phänomene der leichten Quarks (up, down, strange) beinhaltet. Präzisionsexperimente mit Röntgenspektroskopie von exotischen Atomen und die Suche nach Bindungszuständen von Kaonen und Nukleonen mit verschiedenen Reaktionen können Aufschluss über die Hadronenphysik mit Strangeness bei niedrigen Energien geben. Dies wird in den 2012 erschienenen Proceedings der "International Conference on Exotic Atoms and Related Topics", herausgegeben von Wissenschaftern des SMI, ausführlich beschrieben. Dieser Band enthält auch viele Beiträge über die Fortschritte und gegenwärtigen Entwicklungen im Forschungsgebiet der Hadronenphysik. Im Jahr 2012 wurde ein neues EU-Projekt HadronPhysics3 begonnen. Das SMI nimmt an vier Arbeitspaketen teil, davon werden zwei Arbeitspakete von Wissenschaftern des SMI geleitet.

*Untersuchungen zur Antikaon-Nukleon Wechselwirkung in kaonischen Atomen*

Die Analyse von Daten des SIDDHARTA Experimentes am LNF ergab neue wesentliche Erkenntnisse zur starken Wechselwirkung von Antikaonen mit Nukleonen und Kernen. Die gemessene hadronische Verschiebung des 2p Zustandes in kaonischem Helium-4 ist viel kleiner als die der Experimente der 1970er und 1980er Jahre. Somit wurde das Resultat unseres Experimentes am KEK verifiziert. Die experimentellen Ergebnisse sind in Übereinstimmung mit Ergebnissen der Theorie. Im Berichtsjahr 2012 wurde die offene Frage nach der hadronischen Breite des 2p Zustandes geklärt. Für die Breite des 2p Zustandes wurde ein viel kleinerer Wert gefunden als die alten Experimente ergaben. Wie im Fall der Verschiebung des 2p Zustandes zeigte auch die Breite von kaonischen Helium-3 und Helium-4 keinen signifikanten Isotopieeffekt.

*Suche nach kaonischen Kernbindungszuständen*

Die Suche nach neuen durch Antikaonen vermittelten hadronischen Bindungszuständen wird in verschiedenen Experimenten ausgeführt: DISTO, FOPI, E15 und AMADEUS. Im Jahr 2012 wurden neue Resultate der Datenanalyse des DISTO-Experimentes publiziert. Die beobachtete Energieabhängigkeit der Bildung einer Resonanz bei der Masse von 2267 MeV/$c^2$ und einer Breite von 118 MeV unterstützt die Interpretation von X(2267) als Antikaon-Bindungszustand Kpp. Diese Resultate stellen eine der wenigen Evidenzen für die Existenz dieser exotischen Bindungszustände dar. Die Analyse von Daten des FOPI Experimentes zu Proton-Proton und Pion-induzierten Reaktionen wurde fortgesetzt. Das dezidierte Experiment E15 zur Suche nach dem $K^-pp$ Bindungszustand wurde fertigestellt und im Strahl von J-PARC/Japan getestet. Im Berichtsjahr 2012 wurden am LNF Frascati in den KLOE Detektor ein Kohlenstofftarget eingebaut und Daten aufgenommen. Diese Studien haben die Untersuchung der Wechselwirkung negativ geladener Kaonen mit leichten Kernen zum Ziel. Wertvolle Informationen zur Λ(1405) Resonanz können damit gewonnen werden, die extrem wichtig für die Dynamik der Bildung kaonischer Bindungszuständen ist.

*PANDA*

Das PANDA Experiment wird den Hochenergie-Speicherring von FAIR in Darmstadt zur Untersuchung von stark-wechselwirkender Materie mit Antiprotonenannihilation benutzen. Das Physikprogramm ist sehr vielseitig und beinhaltet Studien exotischer und nicht-exotischer Resonanzen im Charm-Quark Bereich, Exotische Objekte wie Gluonbälle, Formfaktoren und Hyperkerne. 2012 machte das Projekt signifikante Fortschritte: drei

Technische Design Reports wurden bei FAIR eingereicht. Das SMI beteiligt sich an der technischen Entwicklung von wichtigen Detektorteilen: Internes Targetsystem und DIRC-Teilchen-Identifikationssystem. Der teilweise Aufbau des PANDA Detektors in Jülich wurde geplant. SMI ist auch im Bereich der Computersoftware und der Simulationen von PANDA beteiligt.

*LEANNIS*

Das Netzwerk setzt die sehr erfolgreiche Arbeit in HadronPhysics3 fort, welche im vorangegangenen HadronPhysics2 Projekt begonnen wurde. LEANNIS bringt Experimentalphysiker und Theoretiker zusammen, die im Bereich der starken Wechselwirkung mit Strangeness arbeiten LEANNIS steht in engem Zusammenhang mit unseren experimentellen Aktivitäten. Es hilft Prioritäten in den experimentellen Untersuchungen festzulegen und Interpretationen der experimentellen Ergebnissen im Rahmen der theoretischen Beschreibungen zu finden. Im Berichtsjahr 2012 wurden im Zusammenhang mit LEANNIS Arbeitstreffen in Prag und Trento organisiert.

**Instrumentelle Entwicklung**

Am SMI werden wichtige Teile unserer Experimente entworfen, entwickelt und gebaut, wobei der Bau entweder im Institut oder durch externe Firmen erfolgt. Dies betrifft mechanische und elektronische Teile sowie Detektorkomponenten. Wir nutzen den Vorteil von neuen Technologien wie Gas-Elektronen Vervielfacher (GEM) und neuen Festkörper-Photodetektoren (SiPM). Einige dieser Aktivitäten werden im Rahmen des EU Projekts HadronPhysics3 seit Jänner 2012 durchgeführt. Einige Entwicklungen sind für Anwendungen von Interesse wie z.B. Verbesserungen der Zeitnehmung durch neue Photodetektoren in der Flugzeit-Positronen-Emissions- Tomographie.

## 2.2 Highlights 2012 (deutsch)

Five most important publications 2012

- Bazzi, M., Beer, G., Bombelli, L., Bragadireanu, A.M., Cargnelli, M. et al. (SIDDHARTA collaboration), Measurements of the strong-interaction widths of the kaonic 3He and 4He 2p levels, *Physics Letters B* **714** (2012) 40-43.

Im Rahmen unserer Untersuchungen der niederenergetischen Wechselwirkung von Antikaonen mit Nukleonen und Kernen mit dem Experiment SIDDHARTA konnten wir die durch die starke Wechselwirkung verursachte Breite des 2p-Zustandes von Helium-3 und Helium-4 genau bestimmen. Es hat sich dabei gezeigt, dass Messungen aus den 1970er und 1980er Jahren einen zu grossen Wert ergeben haben. Zusammen mit unseren schon veröffentlichten Messungen der Verschiebung des 2p-Zustandes haben wir ein verbessertes quantitatives Verständnis der starken Wechselwirkung von Antikaonen mit Heliumkernen erreicht.

- Bazzi, M., Beer, G., Bombelli, L., Bragadireanu, A. M., Cargnelli, M. et al. (SIDDHARTA collaboration), Kaonic hydrogen X-ray measurement in SIDDHARTA, *Nuclear Physics A* **881** (2012) 88-97.

Ebenfalls mit SIDDHARTA wurden die beim Übergang vom 2p- in den Grundzustand von kaonischem Wasserstoff emittierten Röntgenstrahlen gemessen. Die dabei bestimmten Werte fuer die Breite und Verschiebung des 1s-Zustandes sind für die Verifizierung von theoretischen Modellen der niederenergetischen Antikaon-Nukleon Wechselwirkun wichtige Referenzpunkte.

- Schwarz, C., Britting, A., Bühler, P. et al. (PANDA collaboration), The Barrel DIRC of PANDA, *Journal of Instrumentation* **7** (2012) C02008.

Im PANDA Experiment wird die Teilchenidentifikation mittels ring-imaging Cherenkov Detektoren erreicht. Das DIRC (detection of internally reflected Cherenkov light) ist Teil des Target-Spektrometers, besteht aus einer zylindrischen Anordnung von Kristallen um das Strahlrohr und ist für PANDA von zentraler Bedeutung. In dieser Publikation werden der Aufbau und die charakteristischen Eigenschaften des Barrel DIRC besprochen.

- Bühler, P., Hartmann, O., Marton, J., Suzuki, K., Widmann, E., Zmeskal, J., Proceedings of the International Conference on Exotic Atoms and Related Topics (EXA 2011) held in Vienna, Austria, 5-9 September 2011, PART I-III, 352 p, 60 articles, *Springer Verlag, ISBN 978-94-007-4889-7*

Dieser Konferenzband enthält 60 Beiträge von der 4. EXA Konferenz (EXA 2011) welche im September 2011 in Wien ausgetragen wurde. Die Veranstaltung wurde vom SMI organisiert und der Proceedingsband wurde von O.N. Hartmann, P. Bühler, J. Marton, K. Suzuki, E. Widmann, and J. Zmeskal editiert.

- Kienle, P., Maggiora, M., Suzuki, K., et al. (DISTO collaboration), Formation of the S = -1 Resonance X(2265) in the Reaction pp → X+K+ at 2.50 and 2.85 Gev, *European Physical Journal A* **48** (2012) 183.

Mit Hilfe von Daten des DISTO Experiments untersuchen wir die Produktions-warscheinlichkeit der X(2265)-Resonanz, die wir kürzlich mit einer Masse von $M_X$= 2267 MeV/$c^2$ und einer Breite von $\Gamma_X$= 118 MeV in der Reaktion $pp \rightarrow p\Lambda K^+$ bei einer Energie von $T_p$= 2.85 GeV nachgewiesen haben. Bei $T_p$= 2.5 GeV finden wir nun, dass die Produktion um mindestens einen Faktor 3 kleiner ist als man aus rein kinematischen Überlegungen erwarten würde. Dies ist konsistent mit der kleinen Produktionswarscheinlichkeit der Resonanz Λ(1405), woraus wir schliessen, dass Λ(1405) bei der Bildung von X(2265) eine entscheidende Rolle spielt.

## 2.3 Summary of the scientific report 2012

### Matter-antimatter symmetry

With the receipt of an ERC Advanced Grant by E. Widmann to study the hyperfine structure of antihydrogen, SMI is now concentrating on this measurement which promises one of the most precise tests of matter-antimatter symmetry. The final data on the microwave spectroscopy of antiprotonic helium were analyzed in a Ph.D. thesis and showed good agreement within the errors with theory.

The ERC grant started in March 2012 and two new Postdocs and two Ph.D. students were hired. With a strong effort the atomic beam line to measure the hyperfine structure was finished and a segmented detector for antiproton annihilation was built and tested. The formation of an antihydrogen beam was studied during the beam time at AD in summer, data analysis is still in progress. In parallel a source of polarized atomic hydrogen is being developed at SMI to characterize the hyperfine structure spectroscopy apparatus.

### Hadron Physics

Our interest is currently focussed on the strong interaction with strangeness which is dealing with the dynamics and phenomena of the light quarks (up, down, strange). Precision experiments employing x-ray spectroscopy of exotic (kaonic) atoms and searches for nuclear bound states of kaons and nucleons with different reactions can shed light onto strangeness hadron physics at low energy. This is nicely portrayed in the proceedings of the International Conference on Exotic Atoms and Related Topics edited by SMI scientists and published last year, in which many contributions exhibit the advances and current trends in the field of hadron physics. In 2012 a new EU project HadronPhysics3 was started, where SMI participates in four work packages, two out of them being led by SMI scientists.

*Studies of the antikaon-nucleon interaction in kaonic atoms.*

The analysis of data collected in the SIDDHARTA experiment at LNF yielded new significant results on the strong interaction of antikaons with nucleons and nuclei. The hadronic shift of the 2p state in kaonic helium-4 was found to be smaller than the results of experiments of the 1970's and 1980' – thus verifying the result obtained in our experiment at KEK. The experimental values are in agreement with theoretical results. In 2012 the open question about the hadronic width of the 2p state of kaonic helium isotopes was clarified. The 2p state width was found to be much smaller than given by the old experiments, again in agreement with theory. Like in the case of the shift of the 2p state, its widths for both kaonic helium-3 and helium-4 show no significant isotopic effect within the errors.

*Searches for kaonic nuclear bound states*

The search for new hadronic bound states mediated by antikaons is conducted in different experiments: DISTO, FOPI, E15 and AMADEUS. In 2012 new results of DISTO data analysis were published. The energy dependence of the formation of a resonance structure at amass of 2267 MeV/$c^2$ and a width of 118 MeV was investigated, supporting the interpretation of X(2267) as antikaon-nuclear bound state $K^-pp$. These results constitute one of the few evidences for the existence of this kind of exotic bound states.
The analysis of the FOPI/GSI data on proton-proton and pion induced reactions was continued. A dedicated experiment E15 searching for the K-pp bound state became ready and was tested in beam at J-PARC/Japan. In 2012 at LNF data were taken with a carbon target inserted in the KLOE apparatus aiming at studies of negatively charged kaons interacting with light nuclei. Valuable information about the elusive Λ(1405) resonance can be deduced which seems to be extremely important for the dynamics of the formation of kaonic bound states.

*PANDA*

The PANDA experiment will use the high-energy storage ring of FAIR at Darmstadt to study strongly interacting matter with antiproton annihilations. The physics program is very rich including exotic and non-exotic resonances in the charm quark regime exotic objects like glueballs, time-like form factors and hypernuclei. In 2012 the project made significant advances: three Technical Design Reports were submitted to FAIR. SMI is participating in the technical development of important detector parts of PANDA: Internal target system and DIRC-particle identification system. The partial setup of the PANDA detector in Jülich is planned. Moreover SMI contributes to the Computer software and simulation framework of PANDA.

*LEANNIS*

The network, which already started within the preceding HadronPhysics2 project, continues to be very fruitful also in HadronPhysics3. It brings together experimentalists and theoreticians working in the field of strong interaction with strangeness. LEANNIS has to be seen in the context of our experimental activities in hadron physics. It helps to prioritize the experimental studies and to interpret the experimental results in the theoretical framework. In 2012 meetings in connection with LEANNIS were organized in Prague and Trento.

### Advanced Instrumentation

At SMI essential parts of our experiments are designed, developed and built either in the institute workshop or made to order by external companies. This concerns mechanical, electronic parts as well as detector components. We take advantage of new technologies like gas-electron multipliers (GEM) and novel solid state photon detectors (SiPM). Some of these activities are performed within the EU project HadronPhysics3. The spin-off of this R&D work is also interesting for applications in medicine like improvements of the timing performance of Time-of-Flight Positron Emission Tomography systems.

## 2.4 Highlights 2012

Five most important publications 2012

- Bazzi, M., Beer, G., Bombelli, L., Bragadireanu, A.M., Cargnelli, M. et al. (SIDDHARTA collaboration), Measurements of the strong-interaction widths of the kaonic 3He and 4He 2p levels, *Physics Letters B* **714** (2012) 40-43.

In the framework of our studies on low-energy interactions of antikaons with nucleons and nuclei with SIDDHARTA we succeeded to clarify the question about the strong interaction width of the 2p quantum state of kaonic helium isotopes (helium-3 and helium-4). It was found that the value of the 2p state width in kaonic helium-4 is much smaller than the results of experiments performed in the 1970's and 1980's. Thus, together with our earlier published results on the strong interaction 2p-state shift we obtained a new quantitative insight into the antikaon interaction with helium nuclei.

- Bazzi, M., Beer, G., Bombelli, L., Bragadireanu, A. M., Cargnelli, M. et al. (SIDDHARTA collaboration), Kaonic hydrogen X-ray measurement in SIDDHARTA, *Nuclear Physics A* **881** (2012) 88-97.

Within the SIDDHARTA experiment at LNF the most important result was the measurement of the kaonic hydrogen x-rays emitted in the transition from the 2p state to the ground state. The up-to-now most accurate results on the observables (energy shift and broadening of the 1s state) were determined. These results provide stringent constraints for the theoretical description of the low-energy antikaon-nucleon interaction leading to a consistent synopsis.

- Schwarz, C. Britting, A. Bühler et al. (PANDA collaboration), The Barrel DIRC of PANDA*, Journal of Instrumentation* **7** (2012) C02008.

The particle identification in the PANDA detector will be performed by ring-imaging Cherenkov detectors. The DIRC (detection of internally reflected Cherenkov light) detector system consisting of a barrel-shaped radiator arrangement will be mounted inside the 4π target spectrometer. The DIRC is in development now. The principle and performance studies of this extremely important detector part are discussed.

- Bühler, P. Hartmann, O. Marton, J. Suzuki, K. Widmann, E. Zmeskal, J., Proceedings of the International Conference on Exotic Atoms and Related Topics (EXA 2011) held in Vienna, Austria, 5-9 September 2011, PART I-III, 352 p, 60 articles, *Springer Verlag, ISBN 978-94-007-4889-7*

This proceedings volume contains 60 contributions of the 4th EXA Conference (EXA 2011) which took place in Vienna in September 2011. The Conference was organized by the SMI and the proceedings edited by O.N. Hartmann, P. Bühler, J. Marton, K. Suzuki, E. Widmann, and J. Zmeskal.

- Kienle, P. Maggiora, M. Suzuki, et al. (DISTO collaboration), Formation of the S = -1 Resonance X(2265) in the Reaction pp → X+K+ at 2.50 and 2.85 Gev, *European Physical Journal A* **48** (2012) 183.

Recently the so-called X(2265)-resonance with $M_X$= 2267 MeV/$c^2$ and $\Gamma_X$= 118 MeV was discovered in the analysis of the DISTO data of $pp \to p\Lambda K^+$ at $T_p$= 2.85 GeV. A new analysis revealed that the yield of X(2265) at 2.50 GeV is at least a factor 3 less than an expected from kinematical considerations. This is consistent with the very weak production of Λ(1405) at that energy, indicating that Λ(1405) plays an important role as a doorway state for the formation of X(2265).

## 2.5 Report on the scientific activity during 2012

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

### 2.5.1 Matter-Antimatter Symmetry: ASACUSA @ CERN-AD

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

This is one of the main scientific programs at SMI. Physical laws are believed to be invariant under the combined transformations of charge (C), parity (P), and time (T) reversal. This CPT symmetry implies that antimatter particles have exactly the same mass and charge as their particle counterparts. Within the ASACUSA program, SMI is involved in the measurement of the ground-state hyperfine splitting of antihydrogen, supported by the ERC Advanced Grant 291242-HBAR-HFS. The main focus of this experiment is the investigation of the CPT symmetry via precision microwave spectroscopy of antihydrogen, the simplest antimatter atom consisting of a positron and an antiproton. Antihydrogen is a promising tool for testing CPT symmetry, because its CPT conjugate system, hydrogen, has been measured to a precision of $\sim 10^{-14}$ for the 1s-2s two-photon laser transition and $\sim 10^{-12}$ for the ground-state hyperfine structure. Even if antihydrogen cannot be measured to this high precision, it can rival the best CPT tests on an absolute scale. This experiment is one of the main topics of the ASACUSA collaboration at CERN-AD of which SMI is a leading member. As part of the ERC Grant project, SMI also joined the AEgIS collaboration which develops an ultra-low energy beam of antihydrogen atoms. The main focus of AEgIS is a measurement of the gravitational interaction of antihydrogen, but its beam is also well suited for a measurement of the hyperfine splitting.

The ERC project started in March and allowed to recruit two Postdocs and two Ph.D. students. Because the beam time in 2012 was scheduled during summer and no beam is available at CERN during 2013 and the first half of 2014, a major effort was placed in finishing the spectrometer beam line and to build a new detector for antihydrogen annihilations based on our expertise with SiPM photodetectors. All parts were ready and we could gain valuable information on their operation during the beam time.

SMI was within ASACUSA previously responsible for the microwave spectroscopy of the hyperfine structure of antiprotonic helium, a neutral three-body system consisting of a helium nucleus, an antiproton and an electron. The energy levels of the antiproton have been measured by precision laser spectroscopy to an accuracy of about $10^{-9}$. Furthermore, each level is split into quadruplet (octuplet) sublevels in $^{4}He$ ($^{3}He$) due to the magnetic interaction of the electron spin, the antiproton angular momentum and the antiproton spin (and the helium nucleus). The energy difference between these sublevels can be measured with microwave spectroscopy, and from the obtained transition frequencies, the antiproton magnetic moment can be determined. With our measurement performed in 2011 and finally analysed in 2012 (see section 2.5.1.2) we completed our research programme, since the precision in both experiment and theory cannot be improved any more. Furthermore, in 2012 ATRAP has measured the magnetic moment of the antiproton to almost a factor 1000 better than our previous measurement using a Penning trap, with has the potential for another three orders of magnitude improvement. Hyperfine measurements using antiprotonic atoms cannot compete with this accuracy.

### 2.5.1.1 Antihydrogen ground-state hyperfine structure measurement

(Ph.D. theses of S. Federmann and C. Sauerzopf)

The ground-state hyperfine splitting (GS-HFS) of antihydrogen ($H^{bar}$) is caused by the interaction between the antiproton spin magnetic moment and the positron spin magnetic moment. A measurement of the $H^{bar}$ GS-HFS would enable a comparison with the same quantity already precisely measured in hydrogen. This comparison would provide the first atomic test of the CPT theorem.

The ASACUSA collaboration at CERN's Antiproton Decelerator is planning to measure the GS-HFS of $H^{bar}$ using an atomic beam apparatus [1] similar to the ones which were used in the early days of hydrogen HFS spectroscopy. The apparatus will use $H^{bar}$ atoms produced in a superconducting cusp trap (anti-Helmholtz coil configuration), which has been developed by collaborators from RIKEN and the University of Tokyo. Due to the strongly inhomogeneous magnetic field of this trap, the $H^{bar}$ atoms emerging from the trap will either be focused onto a 1.42-GHz radio-frequency resonator, or defocused, depending on their spin direction. Thus the $H^{bar}$ beam entering the resonator will be partially polarized. The oscillating magnetic field in the resonator can flip the spin of the $H^{bar}$ atoms when it is on resonance with one of the hyperfine transitions. A superconducting sextupole magnet installed after the resonator will then act as a spin analyzer, and will focus the atoms onto an $H^{bar}$ detector, or defocus them, depending on their spin direction. This forms the basis of the spectroscopy method: when the

radiofrequency field in the resonator is on resonance with one of the ground-state hyperfine transitions, fewer atoms will reach the $H^{bar}$ detector.
SMI was responsible for designing and developing the spectroscopy part of the apparatus which include a microwave cavity, a sextupole and an $H^{bar}$ detector.

*Apparatus*

The sextupole was delivered to CERN in May 2011 but did not fulfill the requirements in terms of maximum magnetic field strength. It was sent back to the manufacturer (Tesla Engineering Ltd) at the end of 2011 for repair. In May 2012 it was operated at full current (400 A) in the CERN cryogenic lab and was hence accepted by the collaboration. The sextupole was then installed downstream of the CUSP toward the end of the CUSP 2012 beamtime.
The radiofrequency resonator was assembled and tested in preparation of the 2012 beamtime. It was conform to the radiofrequency and vacuum specifications. Although the cavity was not added to the full setup during the 2012 beamtime, measurements of the efficiency of the cavity shielding and field homogeneity inside the cavity were performed in the ASACUSA zone during beamtime. Silke Federmann (CERN/SMI) received a Ph.D. in October 2012 for her work on the cavity.

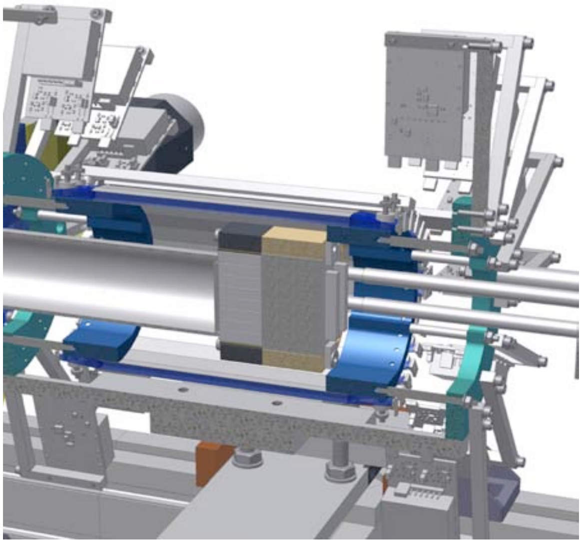

Figure 2: Design of the central segmented detector surrounded by the hodoscope.

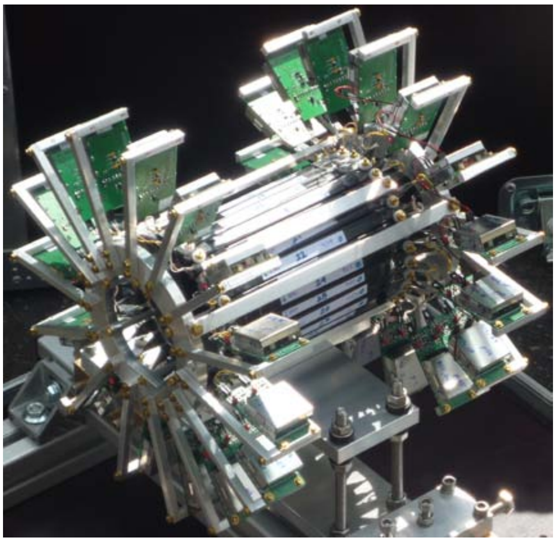

Figure 3: Picture of the hodoscope and the silicon photomuliplier preamplifier boards.

A set of plastic scintillators were prepared for the 2012 beamtime in order to detect the annihilation of unpolarized H^bar at the entrance of the cavity (for normalization purposes) and high-field seekers H^bar on the beampipe flanges (to veto undesired annihilation products hitting the H^bar detector). The H^bar detector was consisting of a central segmented (8×8 pixels for a total active area of 23 $cm^2$) plastic scintillator read out by a multi-channel PMT assembled immediately downstream of a steel plate on which the H^bar would annihilate. This detector would trigger the data acquisition system. An 8 cm diameter hodoscope made of 30 plastic scintillator bars read out by silicon photomultipliers, see figures 2 and 3, was surrounding the central detector to detect the pions coming from the H^bar annihilation (see also chapter 2.5.3 Advanced Instrumentation). All those detectors were successfully tested in 2012. Figure 4 shows a cosmic event crossing the detectors.

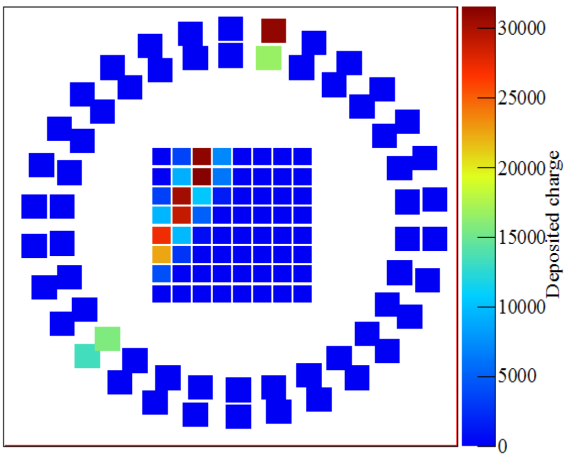


Figure 4: A cosmic event in the online display. The two layers surrounding the segmented inner detector represent each end of the hodoscope bars.

*2012 beamtime*

During the beam time, H^bar atoms were created in the CUSP trap by mixing antiprotons coming from an antiproton catching trap, and positrons coming from a positron accumulator. The antiproton annihilations were observed directly downstream of the cusp trap by a BGO detector surrounded by plastic scintillators prepared by collaborators from the University of Tokyo.

The H^bar production rate was too low to attempt any spectroscopy measurements. Thus the cavity and the H^bar detectors describe above were not used. However the sextupole was installed directly behind the cusp toward the end of the beamtime and energized in the presence of $H^{bar}$. The data recorded are currently being analyzed.

During the CERN long accelerator shutdown (from January 2013 to July 2014) the apparatus (cavities and sextupole) to measure the hyperfine splitting of $H^{bar}$ will be tested using an hydrogen beam.

*Further development*

A second cavity, identical to the first, was manufactured by the CERN main workshop. It has been delivered in November 2012 and was found to be conform with the radiofrequency specifications. This cavity will be added to the hydrogen setup during the CERN accelerator shutdown period and should improve the measurement precision by a factor 10 compared to a single cavity measurement. Additional shielding and Helmholtz coils configuration are being developed.

Several upgrades on the detectors will be done during the shutdown. In particular, a new design of the silicon photomultiplier circuit will allow self-triggering and remote gain adjustment. A second (larger) hodoscope layer will be manufactured. In combination with the already existing inner layer it will provide a precise vertex reconstruction and good suppression of cosmic events with very good time resolution. Additionally several detector configurations will be studied to enhance the flexibility of the setup. For example the outer hodoscope layer could be used in combination with a small calorimeter (similar to the BGO used in 2012) for early diagnostics downstream of the CUSP.

References:

[1] E. Widmann et al., Hyperfine Interactions (2013) DOI 10.1007/s10751-013-0809-6

### 2.5.1.2 Atomic hydrogen beam

(Diploma and Ph.D. thesis of M. Diermaier and Diploma thesis of M. Wolf)

Between late 2012 through to 2014, the AD will be shutdown because of the LHC upgrade at CERN, and during this time the AD will be unable to provide antiprotons. This period gives experimentalists the perfect opportunity to test the performance of the experiment which is designed to take precise measurements of the structure of antihydrogen.

Researchers and students at SMI are currently constructing a cryogenically cooled polarized Atomic Hydrogen Beamline (AHB) which will be used to simulate an antihydrogen beam. Once constructed, the AHB will be transported to CERN where it will

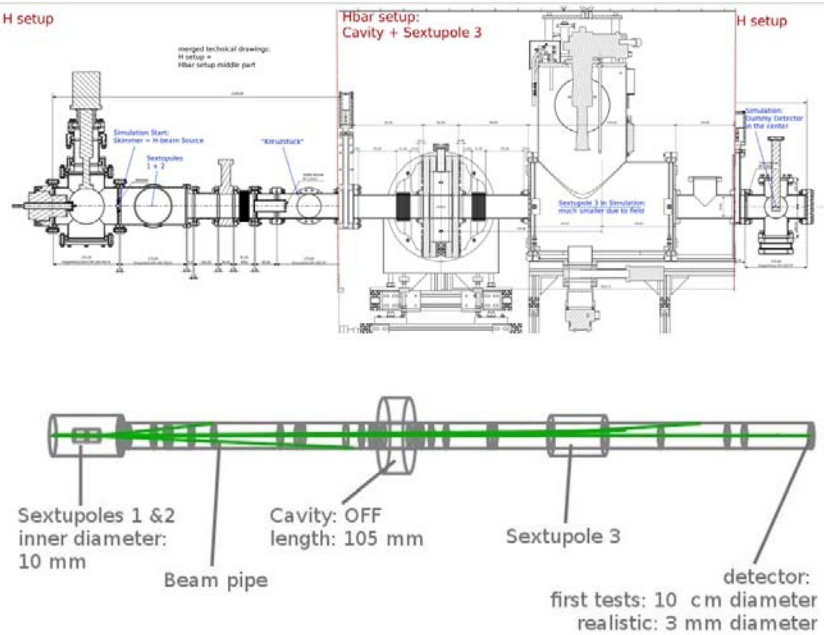


Figure 5: The atomic hydrogen beam (AHB) connected to the hyperfine structure spectrometer line.

be used to test the resonance cavity (which flips the spin of anti-hydrogen/hydrogen atoms) and the superconducting sextupole magnet (which acts as a spin analyser).

*Geant4 simulations of sextupoles*

The optimization of the setup for the Atomic Hydrogen Beamline (AHB) is supported by simulations with geant4, a program well suited for studies of charged particle beams, but which was modified to also allow the tracking of neutral atoms through inhomogeneous magnetic fields. Special attention is paid to the choice of the dimensions of the sextupole magnets located at the beginning of the setup, which are supposed to separate the low field seekers (LFS) from the high field seeker (HFS) in the beam. Due to the characteristics of the sextupole field- for a certain particle velocity range hydrogen atoms with spin states classified as LFS are focused, while HFS are defocused. Several magnet lengths, field strengths and magnet positions have been simulated in order to reach a good polarization (i.e. a high number of LFS at the end of the setup) on the one hand, and on the other hand to reach a focused beam as well as a realistic velocity distribution of the atoms. The schematic picture shows the cross section of simulated particle tracks of LFS, focused by the sextupole magnets when travelling through them. It was found that magnet lengths of around 60 mm and magnetic fields of about 1.3 Tesla lead to a well focused beam, with a polarization of more than 90% LFS and to an averaged particle velocity of 1200 m/s.

### 2.5.1.3 Precision spectroscopy of antiprotonic helium

(Supported by FWF grant I-198-N20)

<u>Microwave spectroscopy</u>

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

In 2012 the data taken in 2011 were analyzed by Susanne Friedreich who successfully defended her Ph.D. thesis in August. Two publications (a physics and an instrumentation paper) based on this thesis [2] are about to be submitted. The final results were obtained by adding previously published data taken in 2010 [3] to the new data. The results are displayed in figure 6 in comparison with simulation curves based on solutions of the optical Bloch equations [2]. The Bloch equations describe the depopulation of states, in this experiment induced by laser light and microwave radiation and under the influence of collisional effects. For most parameters such as laser and microwave fluence the measured values were taken. The rates of collisional effects - inducing relaxations between the hyperfine states - were obtained from adjusting the simulation to the experimental results. The extracted values for the elastic collision rate is $\gamma_e$ = 3.5 ± 1.1 MHz and the inelastic collision rate $\gamma_i$ = 0.5 ± 0.1 MHz, similar to those extracted from only the 2010 data [2] and in agreement with theoretical predictions by the group of G. Korenman (Moscow State University) [5].

Two of the four favoured transitions in antiprotonic ${}^3$He were observed and are in agreement with theory [6,7,8] within the estimated theoretical error (cf. Figure 7). The experimental errors have been decreased by 43% for $\nu_{HF}^{--}$ and 25% for $\nu_{HF}^{-+}$ compared to

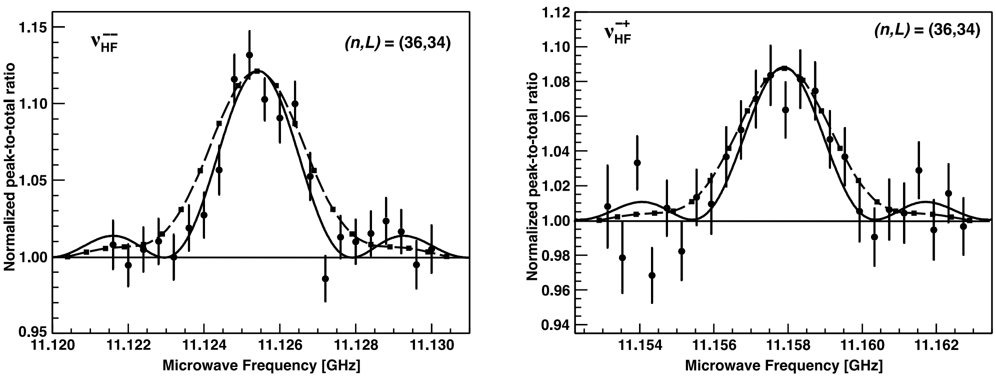


Figure 6: (Left) Scan over the microwave frequency for the $\nu_{HF}^{--}$ transition of the (n,L)=(36,34) state in antiprotonic ${}^3$He, fitted with the theoretical line shape of an ideal two-level system (solid line). The dashed curve shows a simulation using collision rates obtained from comparison between experiment and simulation. (Right) Same for the $\nu_{HF}^{-+}$ transition.

previously published results [4]. The value for $\nu_{HF}^{-+}$ agrees better with theory than before. While the experimental error is much smaller than the theoretical one for the observed individual lines, it is large compared to theory in the case if the difference $\Delta\nu_{HF}^{\pm}$. This is because theory can calculate this quantity directly, whereas the experimental value is determined from the difference of two large frequencies.

The measured hyperfine transition frequencies agree with theory within 0.2-0.5 MHz (18−43 ppm). The current precision is still worse than for the most recent results antiprotonic $^4$He, which gave an error of 3 ppm for the individual transition lines [9]. Due to limitations in antiproton beam quality this precision is not likely to be improved anymore. However, it is also unlikely to achieve an error with antiprotonic $^3$He as small as that for antiprotonic $^4$He. There are eight instead of four SSHF energy levels in antiprotonic $^3$He and thus the measured signal will be only about half of the signal obtained for antiprotonic $^4$He. With this study the spectroscopic measurements of the hyperfine structure of antiprotonic helium are concluded. There are no further measurements planned. Based on the current experimental conditions no improvement of precision can be expected. Also

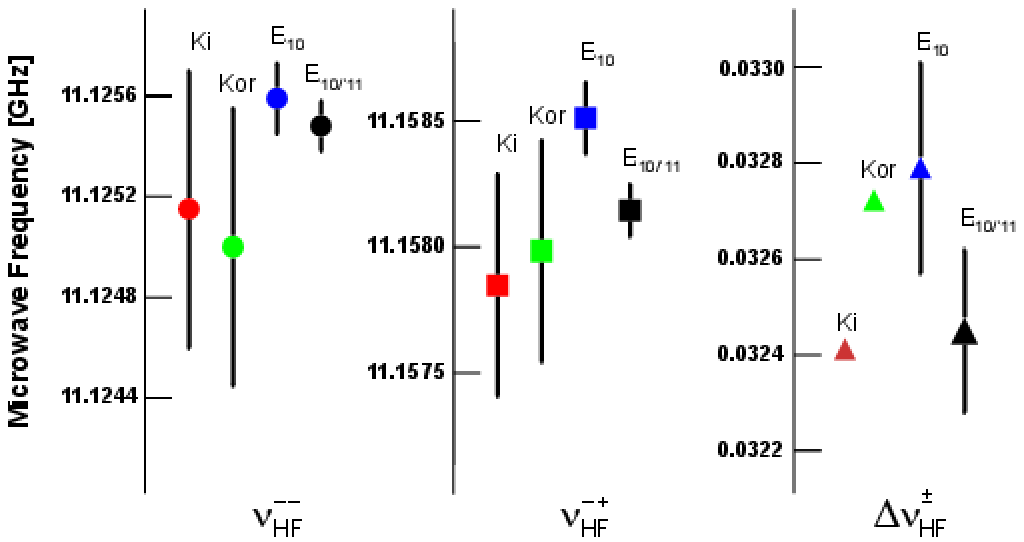


Figure 7: This graph summarizes the results for the two measured hyperfine $\nu_{HF}^{--}$ and $\nu_{HF}^{-+}$ as well as the frequency difference $\Delta\nu_{HF}^{\pm}$ ($E_{'10}$ [5]) for the first measurement period in 2010 and $E_{'10/'11}$ for the combined result of all data recorded in the years 2010 and 2011. It further provides a comparison of these values with the respective theoretical calculations [6,7,8]. The frequency difference of the experimental data for the 11.15773 GHz resonance between the first year of measurements and the combined results of all recorded data may be explained by the slightly different microwave power used for the measurement period in 2010 and also by the lower statistics for this transition in the first year. For the case of $\Delta\nu_{HF}^{\pm}$ the theoretical error is smaller than the size of the symbols.

the theory reached its limits using the calculation methods available at present. Furthermore, the magnetic moment of the antiproton has just been measured in a Penning trap to 4.4 ppm, almost three order of magnitudes better than our previous result from the HFS of $p^{bar}$ $He^4$ [10].

References:

[2] S. Friedreich, Hyperfine Structure Measurements of Antiprotonic $^3$He using Microwave Spectroscopy, *Ph.D. thesis*, Vienna University (2012).

[3] S. Friedreich et al., *Phys. Lett. B* **700(1)** (2011) 1-6.

[4] S. Friedreich et al., *Hyp. Int.* **212** (2012) 167-177.

[5] S.N. Yudin, G.Y. Korenman, Proceedings EXA2011, Vienna, *Hyp. Int.* **209** (2012) 21-24.

[6] V.I Korobov, *Phys. Rev. A* **73** (2006) 022509.

[7] V.I. Korobov, *private communication* (2010).

[8] Y. Kino et al., *Hyp. Int.* **146-147** (2003) 331-336.

[9] T. Pask et al., *Phys. Lett. B* **678** (2009) 55-59.

[10] ATRAP collaboration, arXiv:1301.6310 [physics.atom-ph]

### 2.5.2 Hadron Physics

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

#### 2.5.2.1 LEANNIS

(Networking Activity in EU-HadronPhysics3, Spokesperson J. Marton)

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

In 2012 the progress in experiment and theory continued. On the one hand the experimental data of SIDDHARTA on the strong interaction induced width in kaonic helium isotopes was published. The SIDDHARTA results on kaonic hydrogen led to refinements in the theoretical studies in the framework of effective field theory with coupled channels. The search for kaonic nuclear clusters was continued in various experiments like FOPI encouraged by the positive findings in the analyses of data from the DISTO experiment. The present status and the future directions of theoretical and experimental work were

discussed and defined in the LEANNIS Meeting in Prague attended by distinguished researches and young scientists (see photo below). Moreover, many results in the research field were presented in various international conferences.
A special Meeting on the scientific topics of LEANNIS was organized (J. Marton, co-organizer) at the European Center for Theoretical Studies (ECT) in Trento.

Figure 8: Participants of the LEANNIS meeting in Prague, May 2012

### 2.5.2.2 Kaonic atoms (SIDDHARTA and E17)

(Ph.D. thesis by Barbara Wünschek and Diploma thesis by Carolina Berucci, Supported by FWF grants P20651-N20 and P24756-N20)

X-ray spectroscopy of kaonic atoms plays an important role for understudying the low energy $K^{bar}N$ interaction. In particular, we have measured the strong-interaction shifts and widths of light kaonic atoms in three experimental projects – SIDDHARTA and SIDDHARTA2 at LNF Frascati and E17 at J-PARC.
The data taking of the SIDDHARTA experiment was completed in 2009, and the data analysis has been ongoing until 2012. The measurements of the kaonic $^4$He X-rays performed in the 70's and 80's resulted in inconsistency between theory and experiment both in the shift and width of the kaonic $^4$He 2p state. With the new precise measurements by the KEK E570 and SIDDHARTA experiments, the shift was found to be at most a few

eV both for kaonic $^{3}He$ and $^{4}He$, resolving the experimental problem on the shifts. However, the problem on the width of kaonic $^{4}He$ was still remaining.

In 2012, new values of the widths both of kaonic $^{3}He$ and $^{4}He$ were determined [11], where the width of kaonic $^{3}He$ was measured for the first time. The results of the widths as well as the shifts are plotted figure 9. Our measurements showed much smaller shifts and widths than the old measurement. These new results are in good agreement with theoretical estimations of the shift of about 0 eV. Thus, the long-standing problem of kaonic helium is now resolved.

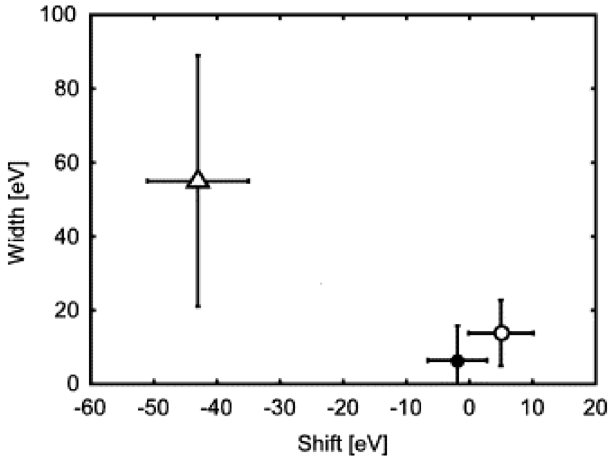


Figure 9: Comparison of experimental results. Open circle: $K^{-4}He$ 2p state; filled circle: $K^{-3}He$ 2p state. Both are determined by the SIDDHARTA experiment. The average value of the $K^{-4}He$ experiments performed in the 70's and 80's is plotted with the open triangle.

In addition to the shifts and widths, the yields of the kaonic helium X-ray transitions in the gas targets were determined for the first time. They are very important parameters for developing cascade models of kaonic helium, related to the density dependency and the Stark mixing effect.

By comparing the kaonic helium data to Monte Carlo simulations, the yields were determined: $Y_{3d\text{-}2p}$ = 23.4±5.4%, $Y_{4d\text{-}2p}$ = 3.5±0.9%., $Y_{5d\text{-}2p}$ = 1.3±0.5% for 0.96 g/l of $^{3}He$, and $Y_{3d\text{-}2p}$ = 18.7±4.6%. $Y_{4d\text{-}2p}$ = 3.7±1.6%. $Y_{5d\text{-}2p}$ = 1.1±0.9% for 1.65 g/l of $^{4}He$. These results were presented in a Ph.D. thesis of B. Wünschek [12].

The analysis of the data taken with the deuterium gas was performed as the first study of kaonic deuterium X-rays [13]. The X-ray spectrum of kaonic deuterium is shown in figure 10. No significant evidence of the signals corresponding to the kaonic deuterium K-series X-rays was found.

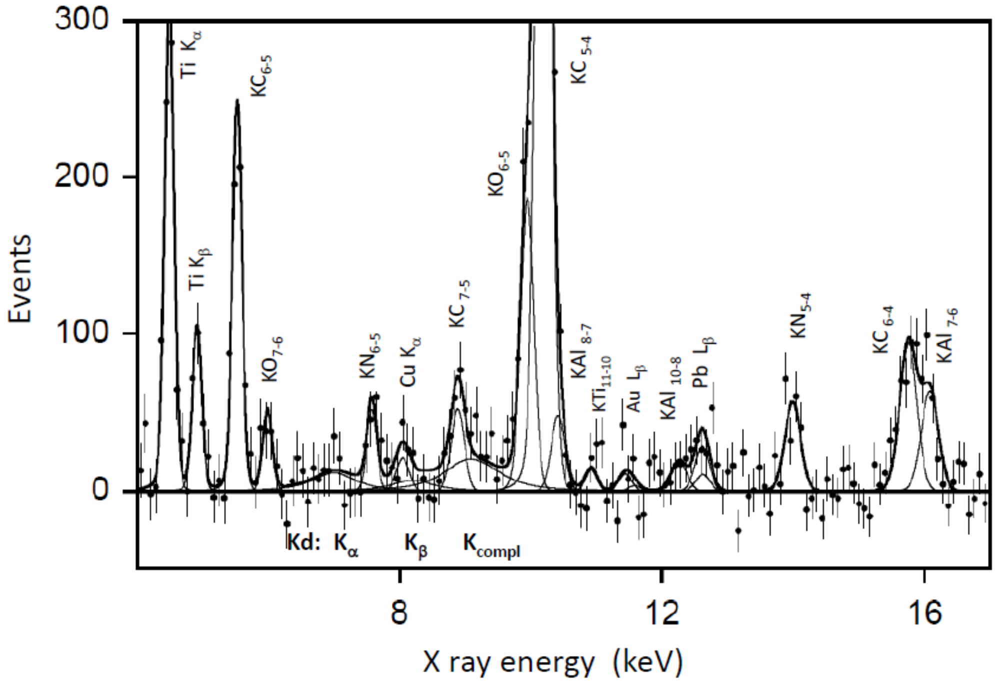


Figure 10: X-ray spectrum of kaonic deuterium, where the continuous background components were subtracted. The fit lines of kaonic deuterium were evaluated using the estimated shift, width, and yield ratios.

The possible yields of the K-series X-rays were evaluated with estimated shift and width values. A total number of the kaonic deuterium X-rays was obtained as $N_X$ = 518±250 (stat.) ±180 (syst.). The presence of the signals has a significance of about 1.7 sigmas.

With the Monte Carlo simulations of the kaon stops and the X-ray detection efficiencies, the absolute X-ray yields were determined: the total kaonic deuterium K-series X-ray yield $Y(K_{tot})$ = 0.0077± 0.0051. Assuming that the ratio of $Y(K\alpha)/Y(K_{tot})$ is the same as the case of kaonic hydrogen, the Kα yield Y(Kα) = 0.0019±0.0012. The upper limit of the yields are, then, calculated as $Y(K_{tot}) < 0.0143$, and $Y(K\alpha) < 0.0039$ (C.L. 90%) [13]. These values are consistent with the expected yields, e.g. about 10 times smaller yield compared to the kaonic hydrogen Kα yield (~1-2 %).

In the data of the deuterium gas, the kaonic atom X-rays produced in a target window material of Kapton were observed. These X-ray lines were measured for the first time, and thus it is interesting to study their X-ray yields. The data analysis and the Monte Carlo simulations have progressed, and the results of the yields will be published soon.

To measure the kaonic deuterium X-rays, a new experiment (SIDDHARTA2) was proposed. A related FWF application of T. Ishiwatari ("Selbstantragsteller") was approved. Because of low yields of the kaonic deuterium X-rays, significant improvement of the signal-to-background ratio is a key issue. The configuration of the new setup together with the Monte Carlo simulations based on the results of SIDDHARTA was studied. A new vacuum chamber, SDDs, kaon triggers, and veto counters have been tested in 2012.

The accuracy of the shifts and widths of kaonic helium determined in SIDDHARTA is limited due to the intrinsic resolution of about 150 eV of the SDD detectors. Possible small shift and width of an order of few eV are therefore not excluded yet. Thus, the J-PARC E17 experiment aims at determining the shifts and widths more precisely. Based on the SIDDHARTA results, the E17 experiment plans to measure both of the kaonic $^3$He and $^4$He X-rays. In addition, using an Nd foil as an X-ray filter, the width of the kaonic $^3$He 2p state can be measured more precisely. The drift chambers used for the reconstruction of the kaon stopping points were tested in the beam time at K1.8BR line. An excellent performance of these detectors was successfully achieved.

References

[11] SIDDHARTA Collaboration, Phys. Lett. B 714 (2012) 40.

[12] B. Wünschek., Comparison of the measured X-ray yields of kaonic helium-3 and helium-4, Vienna University, 2012, http://othes.univie.ac.at/19834/.

[13] SIDDHARTA Collaboration, arXiv:1302.2797 [nucl-ex]

### 5.2.2.3 Strangeness Hadron Physics

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

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

*DISTO*

In 2012 we continued diligently the program of searching for exotic kaonic nuclear states, whose existence is predicted by various calculations but its nature is still not well understood yet. The so-called *X(2265)* state has been found in an exclusive data set of $pp \rightarrow p\Lambda K^+$ at $T_p$ = 2.85 GeV of DISTO data with a mass of 2267 MeV/$c^2$ and a width 118 MeV and has a baryon number 2 and a strangeness −1. The X state is possibly a candidate of the long-searched $(K^{bar}NN)_{S=0,\ I=1/2}$ kaonic nuclear dibaryon system, often called $K^-pp$, but further careful investigation is expected. In 2012 we published the energy dependence study of the production rate of the *X(2265)* in the DISTO $pp \rightarrow p\Lambda K^+$ data at $T_p$ = 2.5 GeV. If the *X(2265)* is produced in a similar mechanism as a hyperon production in the $pp \rightarrow p\Lambda K^+$ or in the $pp \rightarrow p\Sigma K^+$ reaction as an empirical formula $\sigma \propto (1-s_0/s)^{1.8}(s_0/s)^{1.5}$, where $\sqrt{s_0}$ is the production threshold and $\sqrt{s}$ ist the center-of-mass energy, then the *X(2265)* at $T_p$=2.5 GeV would be produced as much as 33% of the $T_p$=2.85 GeV case. However if the *Λ(1405)* plays an important role as a door way to the high density kaonic nuclear systems, then the production of the *X(2265)* would be strongly suppressed at 2.5 GeV as the beam energy is too close to the production threshold of the *Λ(1405)* and therefore *Λ(1405)* is merely produced at that energy. We found in the data essentially no sign of an existence of the *X(2265)* at $T_p$=2.5 GeV, which fits to the latter scenario and thus supports that the *X(2265)* is the $K^-pp$ system [14]. This scenario can be endorsed when the $pp \rightarrow p\Lambda K^+$ at $T_p$ = 3.1 GeV data taken with the FOPI apparatus at GSI and currently being analysed observes the *X(2265)* resonance and its production rate is 50% more than that at 2.85 GeV as expected from the above mentioned formula.

*J-PARC*

The E15 experiment located at J-PARC, Tokai, Japan [15], that also aims at searching for the $K^-pp$ state with $^3$He($K^-$, n) reaction, complementary to the *pp* reaction at DISTO/FOPI, using a newly available high intensity, high quality kaon beam. The accelerators and the experimental areas which were substantially damaged by the Great East Japan Earthquake on 11.3.2011 are now fully back in operation with a colossal effort. The test beamtimes of the E15 experiment were allocated at the K1.8BR beam line in 2012. Enough data for the beam tuning and for the detector tests were collected. With the data analysis, excellent performance of the detectors was found. All the systems are now ready for the data taking of the experiment, which will be performed in 2013.

*AMADEUS*

The proposed AMADEUS programme at LNF-INFN (Frascati, Italy) plans to perform a complete study of the low-energy interactions of the negatively charged kaons with light nuclei [16]. Such type of physics is extremely important for the understanding of the non-perturbative QCD in the strangeness sector. The AMADEUS apparatus works in combination with the existing KLOE detector and a special designed cylindrical cryogenic target system, an inner tracker and trigger counter. Mid of 2012 we have got the possibility to start a first part of the AMADEUS programme with the aim is to study the low-energy

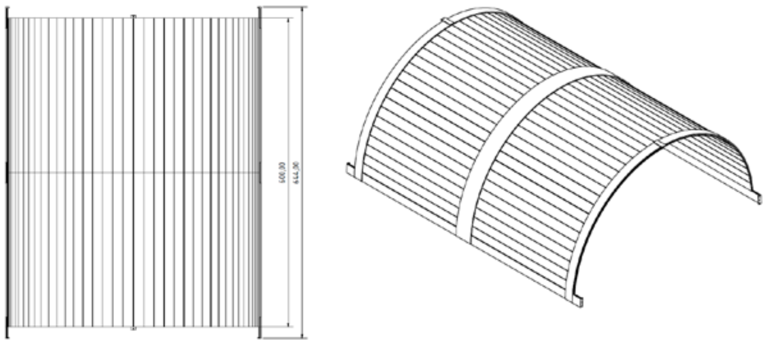

Figure 10: Sketch of the pure carbon target to be installed in KLOE between interaction region and the drift chamber.

interactions of the negatively charged kaons with light nuclei. At SMI we have designed and built a pure carbon target. The pure carbon target was installed within the KLOE detector in August 2012 (figure 10). This target will in special allow to investigate the $\Sigma^0\pi^0$ channel generated by $K^-$ absorptions on $^{12}C$. The $\Sigma^0\pi^0$-channel is privileged to explore the yet unsolved structure of the $\Lambda(1405)$ resonance, since it is free from the dominant $\Sigma(1385)$ background. Data were taken November and December 2012, the analysis is in progress.

*FOPI*

Furthermore we are analyzing data from an experiment carried out with the FOPI detector taken in 2011. In this experiment $\pi^-$ induced reactions on nuclei at a beam momentum of 1.7 GeV/c are used to investigate $\Phi$ meson properties in nuclear medium. In that FOPI run a newly developed GEM/TPC prototype [17] was built into the FOPI setup and was used as an inner tracker. In 2012 we were working on the integration of this additional data into the FOPI analysis framework. At SMI we concentrated on the issues related to the forward tracking. Results of this effort are described in detail in Ph.D. thesis of Philipp Müllner [18].

Figure 11 illustrates the improvements in mass resolution which are achieved by the usage of the GEM/TPC prototype in FOPI.

In 2012 Ivana Carević from the University of Split was spending her Marie Curie FP7 People Intra-European Fellowship at SMI to work on the analysis of a similar experiment carried out in 2009 with FOPI [19].

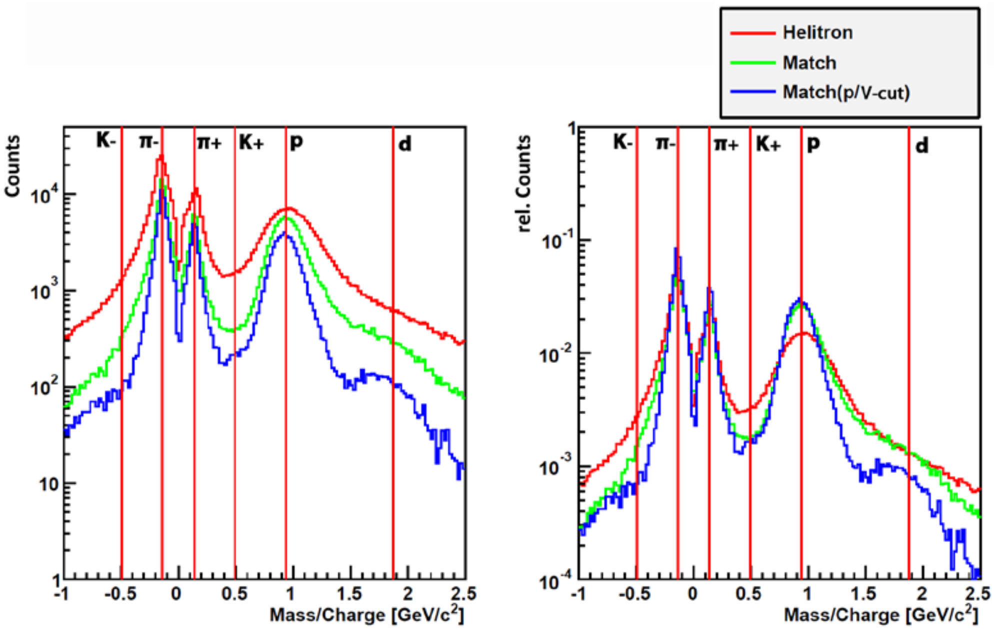


Figure 11: Mass distributions measured with FOPI in forward direction using the GEM/TPC prototype. The red line shows results obtained without GEM.TPC and the green and blue distributions show the results with TPC. The blue line is obtained with additional cuts on the momentum and closest approach of the particle track to the nominal vertex position. With the TPC the mass resolution is clearly improved [18].

References

[14] Kienle et al. (DISTO collaboration), *European Physical Journal A* **48** (2012) 183.

[15] Agari et al., Progress of Theoretical and Experimental Physics **02B011** (2012) 02B011.

[16] Pisciccia et al. (AMADEUS collaboration), Nuclear Physics B **210-211** (2011) 223.

[17] Ketzer et al. (GEM-TPC collaboration), arXiv 1207.0013v1.

[18] P. Müllner, Ph.D. thesis, University Vienna, 2013

[19] Carević et al., Hyperfine Interactions 210 (2012) 115.

### 2.5.2.4 The PANDA Experiment

(partly supported within the 7th EU Framework Programme – HadronPhysics3)

The PANDA [20] Experiment is one of the large scale projects at FAIR [21]. It will study antiproton annihilations on nucleons and nuclei in the energy range of strange and charmed hadrons. A synchrotron and storage ring (HESR) will provide an antiproton beam with very small momentum spread ($2 \cdot 10^{-5}$) or high luminosity ($2 \cdot 10^{32}$ $cm^{-2}s^{-1}$). The commissioning of the experiment at FAIR is planned to start in 2018. The SMI activities in the PANDA project are contributions to the software framework and simulation/analysis, contributing to the development of the PandaGrid [22] computing network and maintaining a PandaGrid site, as well as R&D activities for the hydrogen cluster jet target, applications of the GEM technique to tracking detectors and Cerenkov counters of the DIRC type.

In 2012 further progress has been made in the design and definition of the detector components. In PANDA Cherenkov counters within the target spectrometer take care of the charged particle identification. The target spectrometer houses a Barrel DIRC and an Endcap DIRC, called the 3D Disc-DIRC (figure 12). SMI is involved in the ongoing R&D to define the optimum position sensitive photon readout scheme for the DIRC detectors [23]. Progress has also been made with contributions from SMI with the target system for which a Technical Design Report has been completed. Figure 13 shows a sketch of the complex cluster-jet source. The design has been optimized to produce cluster beam densities above $10^{15}$ atoms/$cm^2$ [24], which is a prerequisite for reaching the design luminosity.

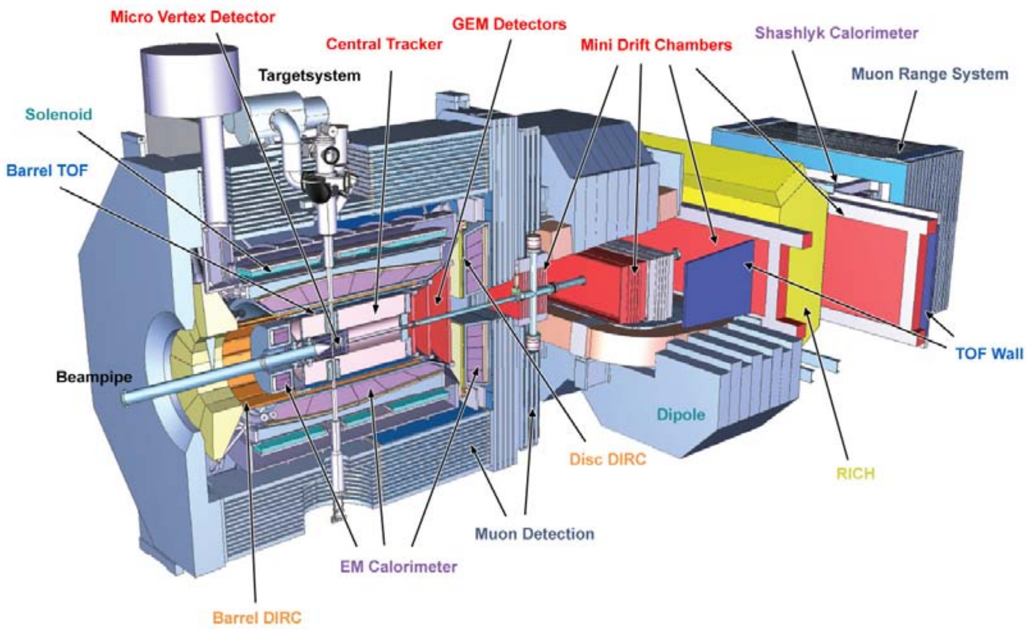


Figure 12: View of the PANDA detector with its various sub-components.

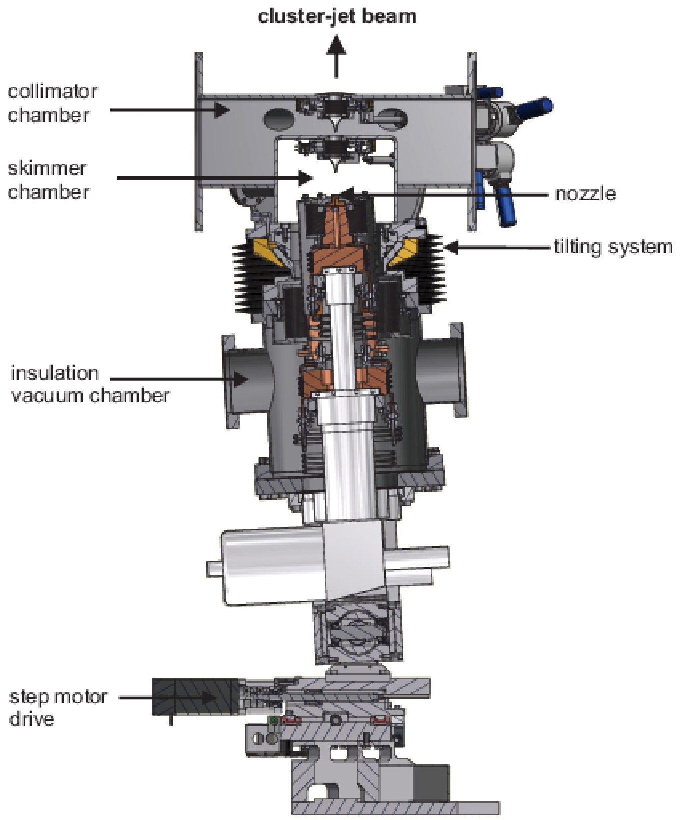


Figure 13: Sketch of the complex cluster-jet source for PANDA.

In addition the Technical Design Reports for the Micro Vertex Detector [25] as well as the Straw Tube tracker [26] have been reviewed and released by the collaboration.

The activities in the PANDA related R&D are described in more detail in section 2.5.3.

References

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

[21] http://www.fair-center.org/

[22] http://serpiero.to.infn.it/

[23] Schwarz et al. (PANDA collaboration), *Journal of Instrumentation* **7** (2012) C02008.

[24] Täschner et al., Nucl. Instr. Meth. Phys. Res. A **711** (2011) 8.

[25] Micro Vertex Detector Technical Design Report (2012), http://arxiv.org/abs/1207.6581v2

[26] Straw Tube Tracker Technical Design Report (2012), http://arxiv.org/abs/1205.5441v2

### 2.5.3 Advanced Instrumentation

(Supported by EU-FP7 HadronPhysics3)

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

R&D work is performed mainly in the framework of the newly obtained, “Joint Research Activities”, within the 7th Framework Programme of the EU: HadronPhysics3 started January 2012. The Institute participates in 3 work packages: WP19: FutureJet - Cryogenic jets of nano- and micrometer-sized particles for hadron physics, WP24: JointGEM - Ultra-light and ultra-large tracking systems based on GEM technology and WP28: SiPM - Avalanche Micro-Pixel Photo-Diodes for Frontier Detector Systems. WP24 is led by SMI.

In addition, to study the anti-hydrogen production and extraction at the CERN-AD with the CUSP trap a central pion tracking detector was built.

In total 5 Ph.D. (L.Gruber, S.Brunner, P. Müllner, C. Sauerzopf and B. Wünschek) and 2 Diploma (A. Berisha and M. Rihl) students are at least partly involved in this R&D work.

*WP19 – FutureJet*

Within WP19 FutureJet our Institute contributes to studies of the (hydrogen) cluster-jet target of PANDA. Test measurements of the upgraded INFN-SMI-GSI cluster-jet device at GSI have been performed, studying higher cluster-jet densities and measure cluster size and velocity of the produced hydrogen beam. Further test measurements with new build nozzles are planned for the coming year.

The design of the complete PANDA vacuum and pumping system has been worked out. To test the vacuum calculations a setup with the proposed beam dimensions has been built. Tests with different gas loads as expected during operation with high intense cluster-jet beams have been performed, showing a good agreement with the calculations done at SMI.

*WP24 – JointGEM*

(Ph.D. thesis of P. Müllner)

The next generation of experiments in hadron physics aims at studying rare processes with drastically improved sensitivity. The technical requirements to reach this goal include high beam intensity and luminosity, fast detectors with large acceptance and high resolution. An essential part of all these experiments is a detector for charged particles with excellent tracking capabilities covering large areas or volumes with an extremely low material budget in order not to spoil the energy and mass resolution of the apparatus. In addition the rate capability has to match the required high luminosities.

To show the proof of principle a high-rate Time Projection Chamber (TPC) with GEM readout has been constructed and tested in collaboration with TUM and GSI within the FOPI detector system at GSI. This prototype has an active length of 600 mm, an outer diameter of 300 mm and an inner diameter of 100 mm. The hexagonal pad read-out consists of about 10000 channels [17].

For the first test measurement of the GEM-TPC at GSI under beam conditions a gas-mixing unit was built at SMI with a quadrupole mass spectrometer (QMS) attached to the gas outlet to monitor the gas composition of the TPC gas mixture. Because the final goal is to run the TPC with Neon (drift time faster, but expensive), a closed cycle gas system was

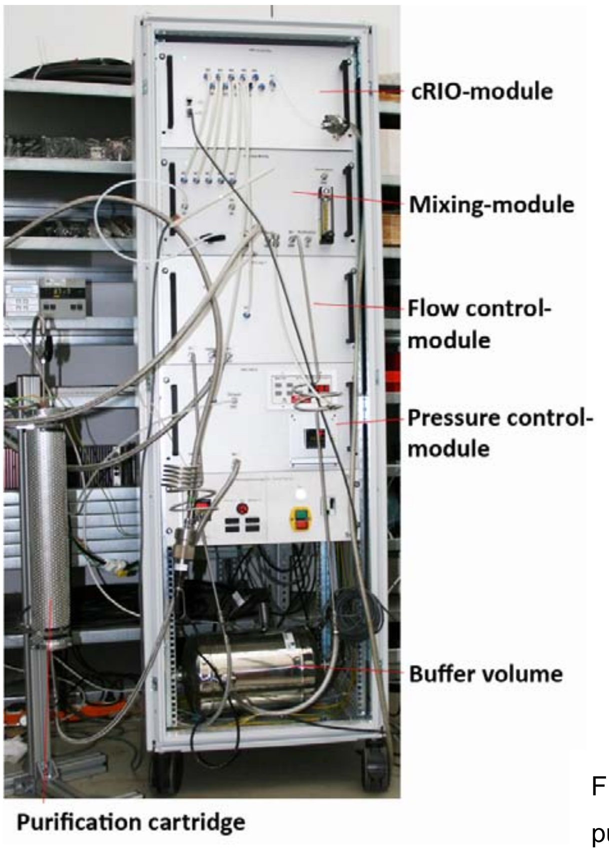


Figure 14: GEM-TPC closed cycle gas system with purification cartridge attached [18].

development with a special gas cleaning device to keep the impurity level of the TPC gas mixture in the level of a few ppm. In spring 2012 the gas purification system for $O_2$ adsorption was built and tested at SMI. After these tests the purification cartridge was brought to GSI, Darmstadt, where it was implemented in the GEM-TPC gas system (figure 14). Therefore, it became possible to run the first performance test of the whole GEM-TPC gas system in circular operation mode including the gas purification system in June 2012.
Already the first tests have shown that the expectations of the different gas system features like gas stability and purity, pressure stability and system safety were fulfilled. The pressure stability of the gas system even exceeded the expectations.
In addition the design and first simulations of an active target TPC have been started, while work on a large-area planar GEM detector is still going on, with possible applications as a forward tracking system of PANDA or E15 at J-PARC.

*WP28: SiPM*

( Ph.D. theses of L. Gruber and S. Brunner, Diploma theses of M. Rihl and A. Berisha)

New photon detectors – Geiger mode operated avalanche micro-pixel photo sensor matrices (AMPD), also called silicon photo multipliers (SiPM) - are ideally suited for future photonic systems in a broad field of basic science in physics, especially in hadron physics [27]. These devices combine performances of traditional phototubes like high quantum efficiency and signal amplification with extremely important features like low-cost voltage supply and electronics. Contrary to photomultipliers the device is insensitive to magnetic fields and mechanically robust thus suitable for harsh environments. Therefore, the possible applications of these devices cover also other fields, like space research, biology, medical diagnostics and eventually environmental technology.

The investigations carried out with SiPM sensors at SMI are the following:

A prototype of a position sensitive photo-detector

A prototype with 5.6 x 5.6 $cm^2$ detection area readout with 64 Hamamatsu SiPMs (S10931-100P) with 3 x 3 $mm^2$ active area each has been built and tested (see figure 15) [28]. The photo-sensors are arranged in an 8 x 8 array with a quadratic mirror light guide on top. The module is currently readout by in-house developed preamplifier boards but employing existing ASIC chips optimized for SiPM readout is also planned. Such a device is one of the candidates to be used for photon detection in the PANDA DIRC detectors.

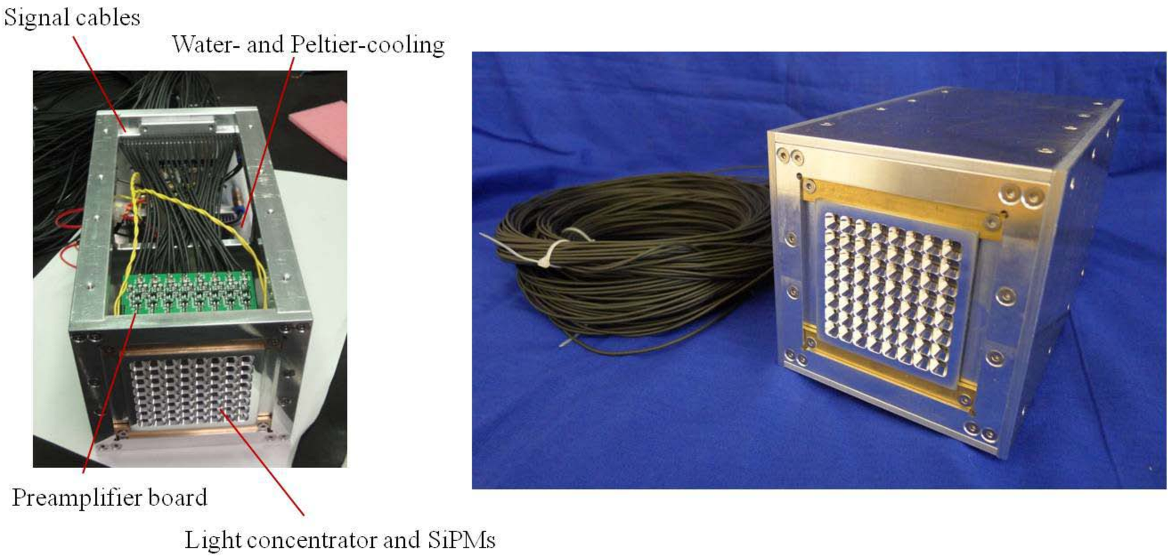


Figure 15: Experimental setup using the Philips digital SiPM

Measurements on the efficiency of the light guide were done using pulsed LEDs mounted on step motors with a spatial resolution of 100 μm. The measured mean efficiency was 85.97 ± 0.51% for an incident beam angle of 0° and 56.68 % ± 0.44 % for 15°.

## Recovery Time Measurements

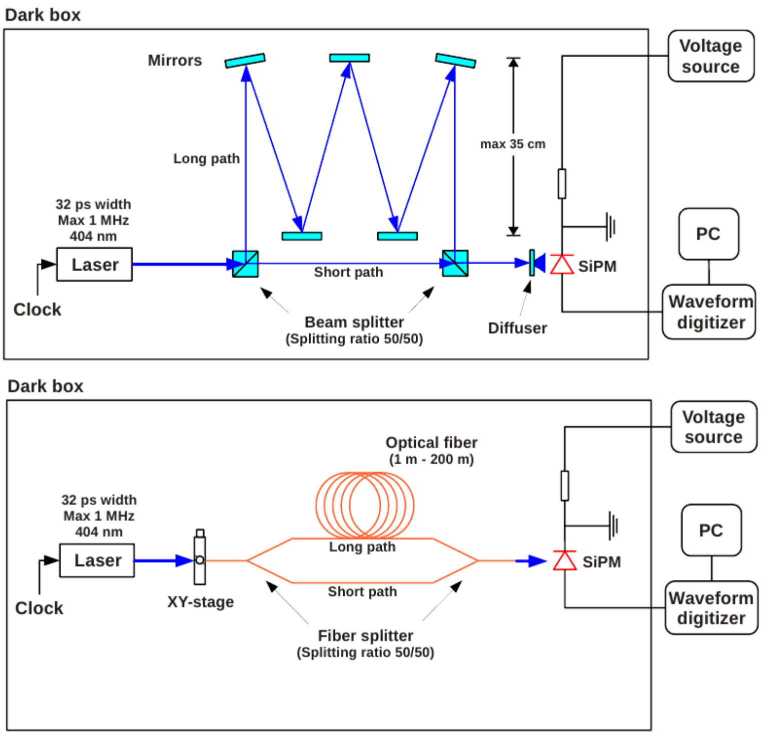


Figure 16: Schematic drawings of the different setups using mirrors (top) for a short delay of the after pulse and optical fibers (bottom) for longer delay times.

One of the important parameters of photo sensors is the performance in high rate environments. For experiments like AMADEUS within the KLOE detector at LNF, where the detector system will be exposed to a very high rate shortly after the $e^+/e^-$ injection, an overall rate capability is required. A charged kaon decay-mode tagging to distinguish $K^+$ and $K^-$ is also very crucial to suppress the background. Therefore, a good double hit resolution is required.

In order to characterize the rate capability and the double hit resolution, we performed an experiment to study the cell recovery time for various SiPMs. We evaluated the recovery time constant by measuring the sensor response to two consecutive laser pulses, with a varying relative time difference of a few ns up to a few 100 ns. The delay of the second pulse is either done with multiple reflections using mirrors (up to 5 ns, see figure 16, top) or for larger delays (up to 1 µs, see figure 16, bottom) by coupling the light into optical fibres of different length (1 m to 200 m). The influence of the overvoltage on the recovery time is also studied. A simulation toolkit was developed to simulate the SiPM recovery process and in order to study the influence of SiPM parameters like after-pulsing, cross-talk and dark-noise on the recovery time (see figure 17).

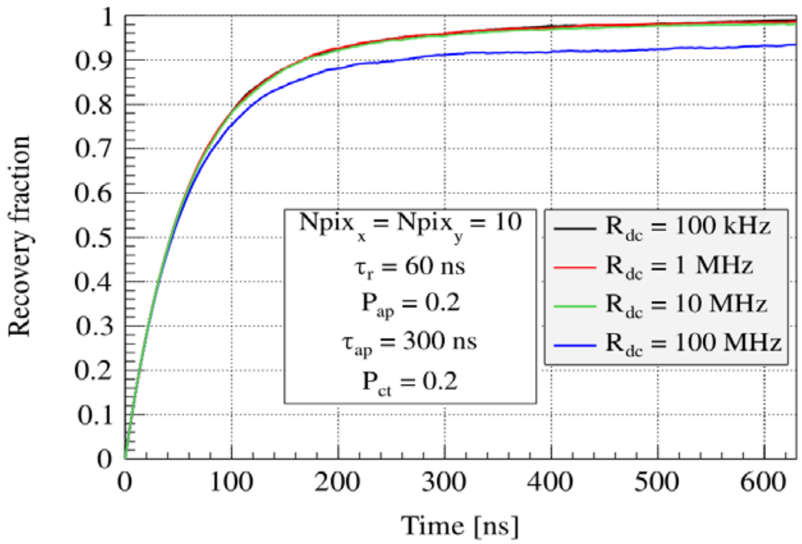


Figure 17: Simulated SiPM recovery fraction

## TOF-PET detector

Goal of this work is the improvement of time resolution for TOF-PET using Silicon photomultipliers (SiPM) and the Cherenkov effect. The use of the Cherenkov effect at gamma energies of 511 keV should help to improve time resolution of PET detectors. As Cherenkov photons are emitted almost instantaneously, compared to scintillation photons,

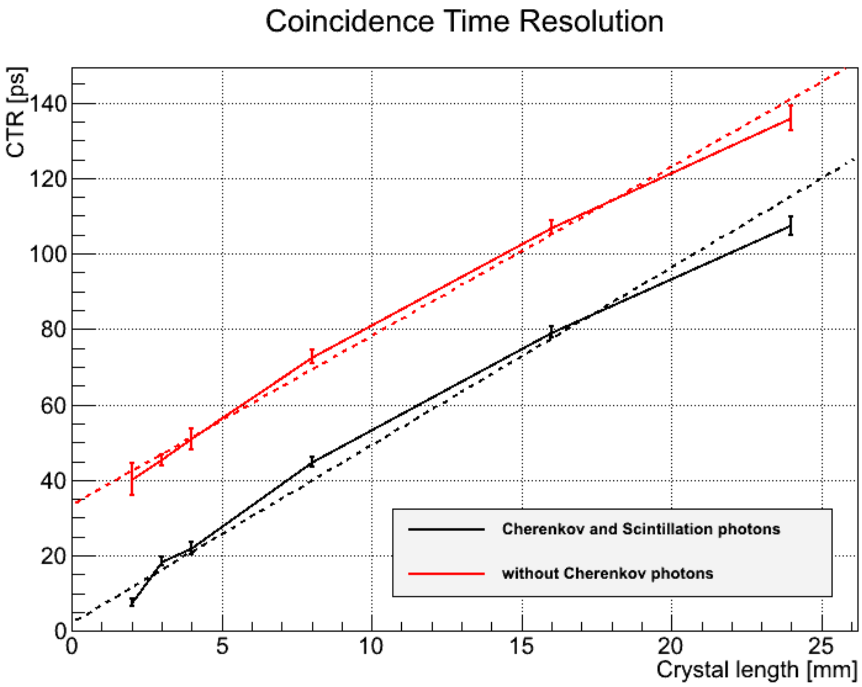


Figure 18: Simulated coincidence time resolution of LSO using scintillation photons (red) and using both, scintillation photons and Cherenkov photons. The impact of the photosensor on the time resolution was neglected.

the ability to detect and distinguish them from the scintillation signals, provide precise time stamps for TOF.

For the development of a future TOF-PET prototype, Monte Carlo (MC) simulations using Geant4 were performed to optimise the experimental setup (scintillator material, crystal dimensions, photo detector positioning). For the simulations, a dedicated computer cluster, consisting of currently 150 CPUs, located at MedUni Wien is available. The simulation results show the impact on timing of implementing the Cherenkov photons for scintillation. Experimental measurements using different types of SiPM (Hamamtsu, SensL, Ketek and Advansid, and Philips digital SiPM) were performed. First measurements have been accomplished successfully, achieving a time resolution below 250 ps FWHM. Work is going on to further improve the time resolution.

In parallel electronics readout possibilities were improved. In house developed dual channel preamplifier-discriminator boards were adapted to provide dual readout of SiPMs (both the cathode and anode are used for readout), reducing drastically the pick-up noise.

The Scintillator Tile Hodoscope for PANDA

The Scintillator Tile Hodoscope (SciTil) will be a sub-detector inside the PANDA experiment for timing measurements with a time resolution of about 100 ps. This will be achieved by using thin plastic scintillator tiles which are readout directly by Silicon Photomultipliers (SiPMs). The Stefan Meyer Institute (SMI) joined the SciTil collaboration and participates in the project.

The SMI is involved in testing of prototypes at the detector laboratory, using a pico-second laser system, radioactive sources or cosmic rays. Furthermore simulations will be performed using a Monte Carlo framework for optical photon propagation, i.e. Slitrani. First experimental tests (see figure 19) using a Strontium 90 source resulted in a time resolution of 230 ps. The timing and efficiency can be improved by using smaller scintillator tiles and by optimizing the coupling of the photo sensor to the scintillator. In this context a digital SiPM form Philips was studied. Because of its large active area, one can cover a whole scintillator tile (30x30x5 mm³) and study the optimal position of the sensor on the surface by switching on/off individual pixels of the digital SiPM. Additional tests and simulations will be performed to finalize the detector layout of the SciTil (geometry of tiles, number and arrangement of photo sensors, wrapping, ..) and to find the optimal photo sensor and scintillator for this application.

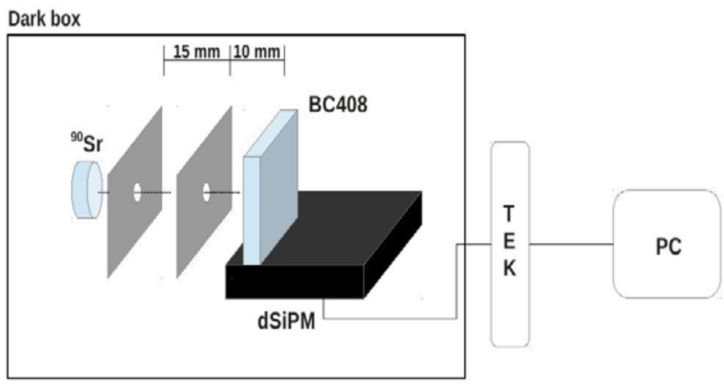


Figure 19: Sketch of the scintillator tile test setup

The Compact Pion Tracking Detector (CPT detector)

To study the ground state hyperfine splitting of anti-hydrogen at the CERN-AD the anti-hydrogen production and extraction using a CUSP trap, as well as the pass of the anti-hydrogen beam through the spectrometer (cavity, sextupole) needs to be optimised. After leaving the cavity and passing through the sextupole, the hydrogen atoms are focused at the end of the setup. For the detection of the anti-proton annihilation products at the end of

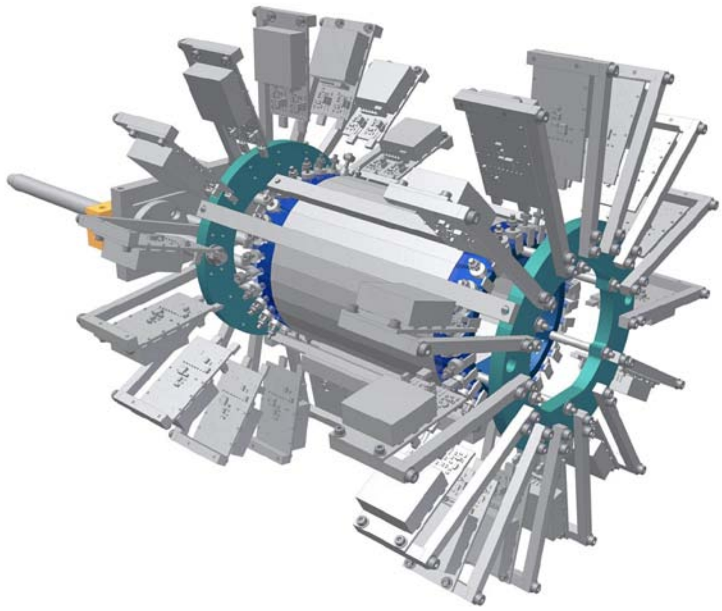

Figure 20: 3D model of the CPT detector: the cylindrically arranged scintillator bars surround the quadratic central detector (not visible); the preamplifiers of the SiPMs are mounted radially on the rack.

the setup a multi-detector system was developed and built by the SMI: the *compact pion tracking (CPT) detector*. The anti-hydrogen atoms hit a few mm thick stainless steel end plate of the vacuum system and annihilate. Immediately behind the plate a quadratically shaped scintillator, divided into 64 cells, is positioned in the centre of the beam axis. The antiproton annihilation products (mainly pions) are detected by this compact detector and by a cylindrical hodoscope surrounding the central detector. The hodoscope is made out of thirty scintillator bars, readout at both ends by one silicon photo multiplier (SiPM). The corresponding preamplifiers, adjustable separately, are radially mounted on the detector rack, which is illustrated in figures 2, 3, and 19. In advance, the hodoscope has been carefully tested and adjusted at SMI. In front of the CPT detector, additional so-called Veto counters are installed. These large area scintillators detect charged particles in the hydrogen beam in order to reduce the background.

References:

[27] Ahmed et al., Hyperfine Interactions **210** (2012) 49.

[28] Gruber et al., Journal of Instrumentation **6** (2011) C11024.

## 2.5.4 Smaller Physics Projects

### 2.5.4.1 VIP2: Pauli exclusion principle test in an underground laboratory

The Pauli Exclusion Principle (PEP) is one of the pillars of quantum physics and the foundation of modern physics. It is at the basis of our understanding of nature and has consequences for the world of elementary particles up to compact objects (e.g. neutron stars) in the universe - but it has no simple explanation. We know that the Pauli Principle is very well fulfilled leaving still the question open about the limit of validity. A possible (tiny) violation of this principle would point to new physics possibly showing up at the Planck scale but might be present at lower energies. A method to test the PEP experimentally was developed by Ramberg-Snow. PEP is tested for electrons, i.e. elementary particles having no interaction with the studied system thus circumventing the Messiah-Greenberg super-selection rule. These new electrons are provided by a strong electric current which flowing through a piece of solid metal. Pauli-forbidden transitions in this metal exhibit an energy shift in the transition energy resolvable by x-ray spectroscopy. A search for x-ray transition events can be performed with high sensitivity but requires substantial background discrimination. In our previous VIP experiment [29] at the underground laboratory LNGS (Gran Sasso) we used an improved Ramberg-Snow experimental setup exploiting charge coupled devices as x-ray detectors. In this experiment we could deduce an upper limit for the Pauli exclusion principle violation in the order of $10^{-29}$. The follow-up VIP2 experiment will be performed in the underground laboratory LNGS in Gran Sasso taking again advantage of the excellent shielding against cosmic rays. A strongly improved compact setup with passive and active shielding will be used. Silicon drift detectors will serve as x-ray detectors providing a timing signal used in anticoincidence with scintillators (veto counters) to suppress actively background events.

With the VIP2 experiment we want to improve the limit for PEP violation by 2 orders of magnitude reaching the range of $10^{-31}$. In the framework of this proposed project all steps from the setup, test and running of the experiment at LNGS up to data analysis and studies of systematics are foreseen. The VIP2 project is accepted by LNGS according to the Scientific Committee' conclusions. In 2012 a FWF project was approved ensuring third party funding of VIP2 for a 3 year period.

References:

[29] Curceanu et al., Journal of Physics Conference Series **361** (2012) 012006.

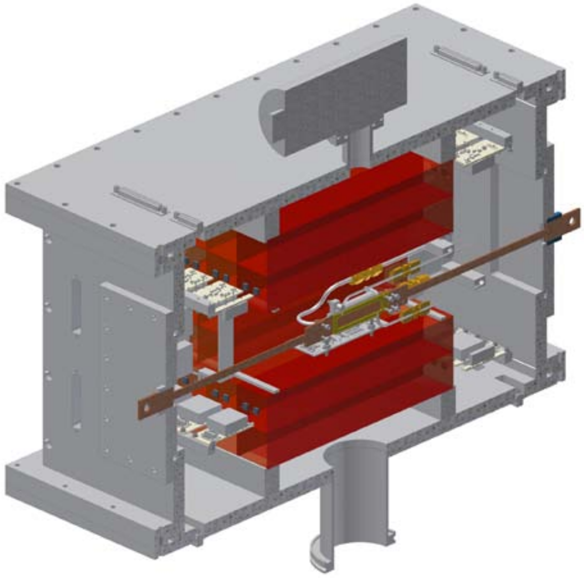

Figure 21: Setup of the VIP2 apparatus without the passive shielding. In the middle the Copper foil with SDD x-ray detectors is positioned. The current is supplied by copper lines. This inner part is surrounded by plastic scintillation detectors (in red) for active shielding.

### 2.5.4.2 EC-decay of highly ionized atoms

Measurements at the Experimental Storage Ring at GSI of the life time of highly ionized atoms decaying by electron capture have revealed a deviation from the expected exponential decay law [30]. The decay curve of hydrogen-like $^{142}Pm^{60+}$ was found to be better represented by an exponential function with an additional oscillatory component with a period of approximately 7 seconds. In May 2010 the experiment has been repeated with participation of the SMI, with a new 245 MHz resonator with improved sensitivity to determine the modulation parameters with higher accuracy as was possible in the original experimental run. With the new data set the oscillatory modulation of the decay curve was observed again with the previously determined modulation frequency, but only in a selection of the data which was restricted to a specific time window. In 2012 we worked out different tests for the significance of the measured oscillations. Results were summarized and are currently prepared for publication. Figure 21 shows the decay rate of $^{142}Pm^{60+}$ as recorded with the new resonator. The inset displays the $\chi^2$ values versus the modulation frequency ω for fitted modulation amplitude and phase. The $\chi^2$ minimum at ω=0.885 (T =7.14 s) is very distinct.


References:

[30] Y.A. Litvinov et al., *Phys. Lett. B* **664** (2008) 162.

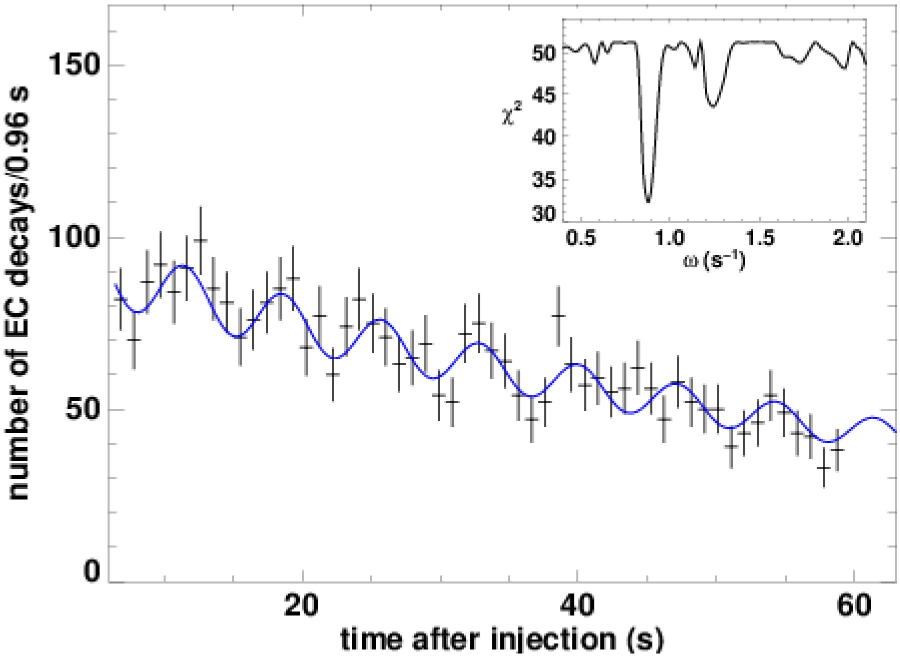


Figure 22: Number of EC decays per time bin of hydrogen-like $^{142}Pm^{60+}$. The blue line shows a fit of with a modulated exponential function with a period of T =7.14 s. In the inset the $\chi^2$ is plotted versus the modulation frequency ω for fitted modulation amplitude and phase. The $\chi^2$ distribution exhibits a distinct minimum at $\omega$=0.88 $s^{-1}$ (T =7.14 s).

### 2.5.4.3 Deeply bound pionic atoms

Deeply bound pionic atom state was discovered at GSI, Darmstadt in 1996 using (*d*, $^3$He) reaction on heavy element (Pb, Sn). The precisely-determined π-nucleus potential lead to a unique determination of a reduction of the quark condensation in a nuclear medium by ~35% [31]. In order to further improve an experimental precision and hence to better constrain the theoretical scenario of the dynamical generation of hadron masses from spontaneously broken chiral symmetry, a new series of experiments is proposed to make use of high intensity deuteron beam which became recently available at the new RI Beam Facility and the fragment separator (BigRIPS) at RIKEN, Japan. In the short pilot experiment in 2010, primarily meant to develop the required special momentum-matching beam optics, we succeeded to collect an equivalent statistics as the preceding GSI experiment and observed deeply-bound *1s*, *2s*, *2p* peaks of $^{121}$Sn for the very first time. We also succeeded to observe an angular dependence of the production of the deeply-bound states in the (*d*, $^3$He) reaction for the first time thanks to the large angular acceptance of the BigRIPS. The successful pilot experiment lead naturally the project to go on for a further systematic study. An isotonic scan on N=68 line as well as an isotopic scan on Z=50 line (Sn) are intended, that will reduce the biggest uncertainty in the analysis of the preceding experiment, the uncertainty of the neutron density distributions of the core nucleus. In 2012 we worked on a preparation for the main beamtime anticipated in the early 2013.

References:

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

### 2.5.4.4 Spectroscopy of η' mesic nuclei with (*p, d*) reaction

The $U_A(1)$ problem is a long-standing question on the low-energy spectrum and dynamics of the pseudoscalar mesons in QCD. The η' meson is, in a naïve picture, one of the Nambu-Goldstone bosons associated with the spontaneous breakdown of the $U(3)_L \times U(3)_R$ chiral symmetry to the $U_V(3)$ flavour symmetry. The gluon dynamics, however, plays an important role here. The quantum anomaly effect of non-perturbative gluon dynamics induces the QCD vacuum to be non-trivial, resulting the η' meson to acquire a peculiarly larger mass than other pseudoscalar mesons e.x. π, K, and η. The mass generation of the η' meson is therefore a result of the interplay of quark symmetry and gluon dynamics but quantitative understanding is yet to be achieved.

An in-medium property of η' will give a vital constraint on the theory. At a finite density where chiral symmetry is partially restored, it is expected that the η' mass is reduced. The Nambu–Jona-Lasinio model suggests a mass reduction of 150 MeV/$c^2$ [32]. This indicates that the interaction between an η' meson and a nucleus is attractive and that an η'-nucleus bound state may exist. While there is no experimental information on the strength of the interaction nor the existence of the bound state, a small absorption width of η' at the normal nuclear density (15-25 MeV) is reported by CBELSA/TAPS [33]. The suggested narrow absorption width stimulates an experimental study of η' mesic nuclei.

We plan a missing-mass spectroscopy experiment at GSI by using a (*p*,*d*) reaction off $^{12}C$ target [34]. The fragment separator FRS is used as a spectrometer. We have submitted a Letter-of-Intent to GSI PAC which was very well received. The Eta-Prime collaboration was formed and in February 2012 a kick-off meeting took place in Gießen [35]. In October 2012 we tested the HIRAC detector under development with beam at Cave-B, GSI. The Cherenkov based HIRAC detector is the key to reduce the expected high background from quasi-free multi-pion production reaction, $p+N \rightarrow d+\pi s$. The HIRAC showed a sufficient performance, readying the collaboration for the experiment.

References:
[32] H. Nagahiro, M. Takizawa, and S. Hirenzaki, Phys. Rev. C 74, 045203 (2006).
[33] M. Nanova et al., Phys. Lett. B 710, 600 (2012).
[34] K. Itahashi et al., Letter of Intent for GSI-SIS (2011); K. Itahashi et al., Prog. Theor. Phys. 128, 601 (2012).
[35] http://www.giessener-anzeiger.de/lokales/hochschule/11645457.htm

### 2.5.4.5 FLAIR

A workshop was held at EMMI in early 2012 [36] marking the handover of the FLAIR spokespersonship from E. Widmann to K. Baum (MPI-K Heidelberg); E. Widmann stays on as a co-spokesperson. The workshop attracted a large number of speakers form the active experiments at CERN-AD as well as from other fields of atomic and nuclear physics. 29 talks and 5 posters covered the spectrum from currently ongoing experiments with antiprotonic atoms and antihydrogen to future projects and ideas.

Previous discussions of using the CRYRING storage ring being modified by Manne Siegbahn Laboratory (Stockholm) for FLAIR already at GSI as a further deceleration stage behind the ESR for the HITRAP facility matured further. CRYRING in connection with the ESR would already now offer exciting new physics opportunities particularly in the realm of atomic physics and nuclear physics as it was already anticipated by the physics program with heavy ions for the FLAIR facility at FAIR. Moreover, CRYRING at the ESR might play a very valuable role as a test bench for accelerator relevant developments for FAIR and for R&D related to experimental setups.

CRYRING@ESR has a strong relevance for the physics with low-energy antiprotons and with beams of rare isotopes. For both, this project is very valuable assuming that a transfer beamline will become possible, connecting the FAIR facilities with the ESR. In this way we can realize rapidly at FAIR the experiments with slow anti-protons as well as with slow rare isotopes. This project will be very stimulating for the whole anti-proton FLAIR community as well as for colleagues interested in nuclear- and hadron physics at FLAIR. Agreement was reached between the Swedish funding agency, FAIR, and GSI on a transfer of CRYRING to GSI which has in the meantime taken place. This will enable an early start of the highly charged ion program of FLAIR.

References:

[36] http://www.mpi-hd.mpg.de/blaum/events/emmi2012/index.en.html

### 2.5.5 Outreach

SMI at the „Lange Nacht der Forschung 2012“

The ”Lange Nacht der Forschung“ was held on April 27 2012, and took place in 184 places around Austria, with the event hosting as much as 1382 stands. Through the website www.lnf2012.at, people could inform themselves in advance about the event and were provided with abstracts on the scope of the exhibition. SMI participated with its contribution at the ”Aula der Wissenschaften“ in the 1st district in Vienna. The space available was about 40 $m^2$ and four big posters were presented which provided an overview of SMI general scientific activities. Other posters illustrated the research done on positron emission tomography (PET) in cooperation with the Allgemeines Krankenhaus Wien (AKH) and the silicon drift detectors (SDD) (state of the art detectors used for high precision experiments with exotic atoms). In particular, these spectroscopy experiments, as well as the involvement of so-called strange particles were presented via a comic illustration for children. The detection characteristics of the silicon drift detectors were demonstrated using a remote experiment.

A video was also produced which explained how Antihydrogen is formed using positrons and Antiprotons and how the subsequent spectroscopy was accomplished by the ASACUSA collaboration at the CERN-AD (see also: http://www.youtube.com/watch?v=KmDaJj-pSYw).

The highlight for most visitors was a little cloud chamber installed in a darkened room. This cloud chamber (operated with hot water and dry ice) was designed as tabletop experiment which had the ability to detect cosmic rays which were discovered 100 years ago by Victor Franz Hess. Another highlight was a talk on “Matter matters – Präzisionsexperimente zur Physik der Hadronen” (“precision experiments on hadron physics”) given by Johann Marton, in a separate lecture room. During the event, scientists and students from SMI were available to interact directly with the audience.

Antimatter.at webpage for ERC Grant

To fulfil part of the outreach requirements of ERC, a webpage was developed by SMI staff including the graphics layout and web site (see figure 23). It aims at explaning the project at several levels, from a short summary also in German for a general audience to a detailed description of the project. Part of this effort was also the creation of the above-mentioned video.

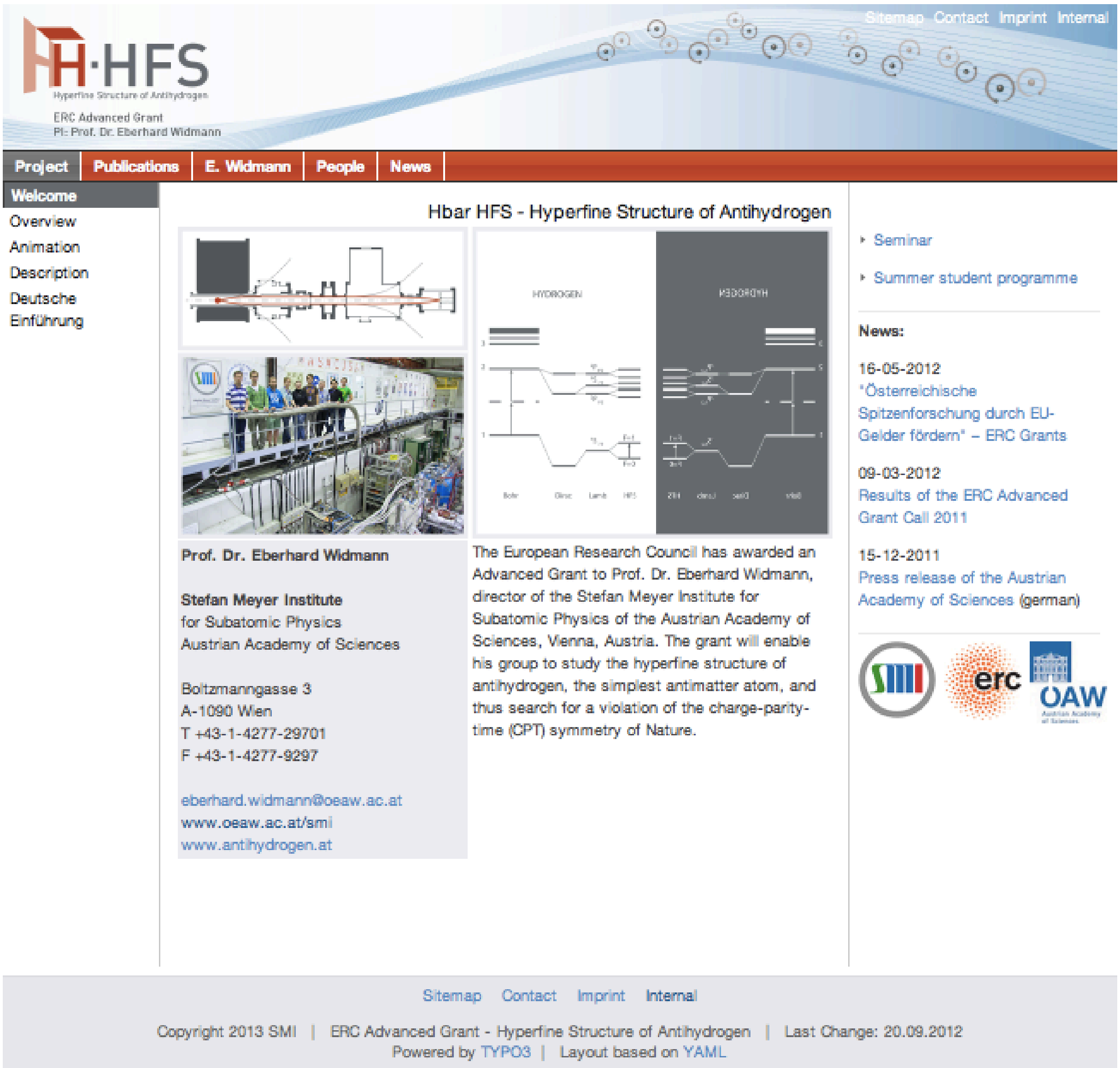


Figure 23: Entrance page of the Antimatter.at website.

### 2.6 Publications / talks / poster presentations 2012

Publications:

- Bühler, P., Hartmann, O., Marton, J., Suzuki, K., Widmann, E. et al., Proceedings of the International Conference on Exotic Atoms and Related Topics (EXA 2011) held in Vienna, Austria, 5-9 September 2011, PART I-III., 1. Aufl.: Springer.
- Bazzi, M., Beer, G., Bombelli, L., Bragadireanu, A. M., Cargnelli, M. et al. (2012, online: 2012) Kaonic hydrogen X-ray measurement in SIDDHARTA. NUCLEAR PHYSICS A, Bd. 881, S. 88-97 .
- Kienle, P., Maggiora, M., Suzuki, K., Yamazaki, T., Alexeev, M. et al. (2012, online: 2012) Formation of the S = -1 Resonance X(2265) in the Reaction Pp → X+K+ at 2.50 and 2.85 Gev. The European Physical Journal A, Bd. 48, S. 183.
- Schwarz, C., Britting, A., Bühler, P., Cowie, E., Dodokhov, V. K.h et al. (2012, online: 2012) The Barrel DIRC of PANDA. Journal of Instrumentation, Bd. 7, S. C02008.
- Agari, Keizo; Ajimura, Shuhei; Beer, George; Bhang, Hyoungchan; Bragadireanu, Mario et al. (2012, online: 2012) The K1.8BR spectrometer system at J-PARC. Progress of Theoretical and Experimental Physics, Bd. 02B011, S. 02B011.
- Ahmed, Gamal; Bühler, Pual; Hartmann, Olaf; Marton, Johann; Suzuki, Ken et al. (2012, online: 2012) SiPM-based veto detector for the pion beam at FOPI. Hyperfine Interactions, Bd. 210, S. 49-52.
- Atanasov, D. R., Winckler, N., Balabanski, D., Batist, L., Bosch, F. et al. (2012, online: 2012) Half-life measurements of stored fully ionized and hydrogen-like 122 I ions. European Physical Journal A, Bd. 48, S. 1-6.
- Bühler, P. (2012, online: 2012) Studying hadrons in matter with PANDA. Hyperfine Interactions, Bd. 209, S. 105-110.
- Carević, Ivana; Hartmann, Olaf; Dželalija, Mile (2012, online: 2012) Investigating in-medium lambda production in pion induced reactions. Hyperfine Interactions, Bd. 210, S. 115-118.
- Cargnelli, Michael; Bazzi, M., Beer, G., Berucci, C., Bombelli, L. et al. (2012, online: 2012) Results from the kaonic hydrogen X-ray measurement at DAFNE

and outlook to future experiments. Hyperfine Interactions, Bd. 209, S. 121-126.

- Doce, O. Vázquez; Bazzi, M., Berucci, C., Bombelli, L., Bragadireanu, A. M. et al. (2012, online: 2012) Studies of the K-N interaction at DAPHNE. Hyperfine Interactions, Bd. 210, S. 107-110.
- Friedreich, Susanne; Barna, Daniel; Caspers, Fritz; Dax, Andreas; Hayano, Ryugo et al. (2012, online: 2012) Microwave spectroscopy measurements of the hyperfine structure in antiprotonic 3He. Hyperfine Interactions, Bd. 212, S. 167-177.
- Gotta, D., Amaro, F. D., Anagnostopoulos, D. F., Bühler, P., Gorke, H. et al. (2012, online: 2012) Pionic hydrogen and deuterium. Hyperfine Interactions, Bd. 209, S. 57-62.
- Hartmann, O., Bühler, P., Marton, J., Suzuki, K., Widmann, E. et al. (2012, online: 2012) Editorial Foreword. Hyperfine Interactions, Bd. 209, S. 1-7.
- Ishiwatari, T., Bazzi, M., Beer, G., Berucci, C., Bombelli, L. et al. (2012, online: 2012) Kaonic 3He and 4He X-ray measurements in SIDDHARTA. Hyperfine Interactions, Bd. 209, S. 139-143.
- Itahashi, Kenta; Berg, Georg P. A., Fujioka, Hiroyuki; Geissel, Hans; Hayano, Ryugo S. et al. (2012, online: 2012) Editorial Foreword. Hyperfine Interactions, Bd. 209, S. 51-56.
- Itahashi, Kenta; Fujioka, Hiroyuki; Geissel, Hans; Hayano, Ryugo S., Hirenzaki, Satoru et al. (2012, online: 2012) Feasibility Study of Observing eta Mesic Nuclei with (p, d) Reaction. PROGRESS OF THEORETICAL PHYSICS, Bd. 128, S. 601-613.
- Juhász, Bertalan (2012, online: 2012) Towards the measurement of the ground-state hyperfine splitting of antihydrogen. Hyperfine Interactions, Bd. 212, S. 69-80.
- Kuroda, N., Enomoto, Y., Michishio, K., Kim, C. H., Higaki, H. et al. (2012, online: 2012) Antihydrogen atom formation in a CUSP trap towards spin polarized beams. Hyperfine Interactions, Bd. 212, S. 31-40.
- Marton, Johann; Widmann, Eberhard; Zmeskal, Johann (2012, online: 2012) Creativity-innovation - the seed for frontier science. Hyperfine Interactions, Bd. 211, S. 57-58.

- Ohnishi, H., Bühler, P., Cargnelli, M., Curceanu, C., Guaraldo, C. et al. (2012, online: 2012) A search for phi meson nucleus bound state using antiproton annihilation on nucleus. Hyperfine Interactions, Bd. 213, S. 23-29.
- (Petrascu), C Curceanu; Bartalucci, S; Bassi, A; Bertolucci, S; Bragadireanu, M et al. (2012, online: 2012) Experimental tests of Quantum Mechanics: from Pauli Exclusion Principle Violation to spontaneous collapse models., Bd. 361, S. 012006.
- Sakuma, Fuminori; Curceanu, Catalina; Iwasaki, Masahiko; Kienle, Paul; Ohnishi, Hiroaki et al. (2012, online: 2012) Double antikaonic nuclear clusters in antiproton-3He annihilation at J-PARC. Hyperfine Interactions, Bd. 213, S. 51-61.
- Suzuki, Ken; Kienle, Paul; Maggiora, Marco; Yamazaki, Toshimitsu (2012, online: 2012) Population of the X(2265) resonance in the p+p→X+K+ reaction at Tp=2.5 GeV. Hyperfine Interactions, Bd. 210, S. 71-75.

Dissertations:

- Federmann, Silke (2012, online: 2012) A spin-flip cavity for microwave spectroscopy of antihydrogen., Fakultaet fuer Physik, Universität Wien.
- Friedreich, Susanne (2012, online: 2012) Hyperfine Structure Measurments of Antiprotonic He-3 using Microwave Spectroscopy., Fakultät für Physik, Universität Wien.
- Wuenschek, B. (2012, online: 2012) A comparison of the measured X-ray yields in kaonic helium-3 and helium-4., Fakultät für Physik, Universität Wien.

Master theses

- Diermaier, Martin (2012, online: 2012) Design and construction of a monoatomic hydrogen beam. Master Thesis, Fakultät für Physik, Universität Wien.
- Isepp, Katharina (2012, online: 2012) Study of Strangeness Production in p-p Collisions at FOPI. Master Thesis, Fakultät für Physik, Universität Wien.
- Jankovec, Martin (2012, online: 2012) Optimierung eines Positronen Emissions Tomographie Prototypen mittels Monte-Carlo Simulationen. Master Thesis, MedUnin Wien.

Bachelor theses:

- Pipper, Florian, Hadron therapy and Medaustron. Bakkalaureatsarbeit, Universität Wien.

Conference Proceedings and other types of publications:

- Bühler, P. (2012) Measuring the J/Psi-Nucleon dissociation cross section with PANDA. (Hadron 2011).
- Curceanu, C, Bartalucci, S, Bassi, A, Bertolucci, S, Bragadireanu, M. et al., (2012, online: 2012) A glimpse into the Pandora box of the quantum mechanics: The Pauli exclusion principle violation and spontaneous collapse models put at test. In Reihe: AIP Conference Proceedings, hrsg. v. Physics, American Institute of, S. (1508) 136.
- Fujioka, Hiroyuki; Itahashi, Kenta; Geissel, Hans; Hayano, Ryugo S, Hirenzaki, Satoru et al., (2012, online: 2012) Spectroscopy of η′-nucleus bound states at GSI-SIS. (MESON 2012 – 12th International Workshop on Production, Properties and Interaction of MESONS) In Reihe: Volume 37, 2012: EPJ Web of Conferences, S. 02005.
- Ishiwatari, T, Bazzi, M, Beer, G, Berucci, C, Bombelli, L. et al., (2012, online: 2012) Kaonic 3He and 4He X-ray measurements in SIDDHARTA. (Hadron 2011).
- Marton, J. (2012, online: 2012) Progress in the research on the antikaon-nucleon and nucleus interaction. (50th International Winter Meeting on Nuclear Physics) In Reihe: PoS(Bormio2012), Bd. 210; Bormio, S. 026.
- Rizzo, A, Bazzi, M, Beer, G, Berucci, C, Bombelli, L. et al., (2012, online: 2012) Kaonic atoms measurements at the DAFNE collider: the SIDDHARTA experiment. In Reihe: Journal of Physics: Conference Series, Bd. 383, S. 012004.
- PANDA collaboration (2012, online: 2012) Micro Vertex Detector Technical Design Report. arXiv 1207.6581v2.
- PANDA collaboration (2012, online: 2012) Straw Tube Tracker Technical Design Report. arXiv 1205.5441v2.
- Hartmann, O.; Bühler, P.; Marton, J.; Suzuki, K.; Widmann, E. et al., (2012, online: 2012) Foreword - Proceedings of the International Conference on

Exotic Atoms and Related Topics (EXA 2011). Hyperfine Interactions, Bd. 209, S. 1-3.

- Hewett, J.L.; Weerts, H.; Brock, R.; Butler, J.N.; Casey, B.C.K. et al., (2012, online: 2012) Fundamental Physics at the Intensity Frontier. arXiv 1205.2671v1.
- Ketzer, B.; Fabbietti, L.; Arora, R.; Ball, M.; Beck, R. et al., (2012, online: 2012) Technical Design Study for the PANDA Time Projection Chamber,. arXiv 1207.0013v1.

Talks and Poster presentations:

- Marton, Johan (07.05.2012) New experiments on light kaonic atoms. Vortrag bei: Seminar at Weizmann Institute, Rehovot/ISRAEL., Sonstiger **eingeladener** Veranstaltungsbeitrag.
- Marton, Johann (26.07.2012) X-ray spectroscopy of light kaonic atoms - new results and perspectives. Vortrag bei: BEACH 2012/UNITED STATES., Sonstiger **eingeladener** Veranstaltungsbeitrag (internationale Veranstaltung).
- Widmann, Eberhard (10.09.2012) Precision Spectroscopy of Antihydrogen. Vortrag bei: Conference on Precision Physics and Fundamental Physical Constants, Stara Lesna/SLOVAKIA (Slovak Republic)., Sonstiger **eingeladener** Veranstaltungsbeitrag (internationale Veranstaltung).
- Widmann, Eberhard (21.06.2012) The hyperfine structure of antihydrogen. Vortrag bei: SSP 2012, Groningen/NETHERLANDS., Sonstiger **eingeladener** Veranstaltungsbeitrag (internationale Veranstaltung).
- Zmeskal, Johann (01.06.2012) Studying strong interaction with SIDDHARTA. Vortrag bei: MESON 2012/POLAND ., Sonstiger **eingeladener** Veranstaltungsbeitrag (internationale Veranstaltung).

- Bühler, Paul (04.06.2012) Charmonium Spectroscopy at PANDA and Belle. Vortrag bei: Workshop on hadron physics with strangeness and beyond/AUSTRIA., Sonstiger Veranstaltungsbeitrag (internationale Veranstaltung).

- Bühler, Paul (11.12.2012) Status of the PANDAGrid. Vortrag bei: PANDA collaboration meeting/GERMANY., Sonstiger Veranstaltungsbeitrag (internationale Veranstaltung).
- Cargnelli, Michael (17.10.2012) The study of kaonic deuterium X rays at DAΦNE. Vortrag bei: New trends in the low-energy QCD in the strangen (ECT*), Trento/ITALY., Sonstiger Veranstaltungsbeitrag (internationale Veranstaltung).
- Cargnelli, Michael (21.05.2012) Results and outlook of the kaonic hydrogen and deuterium experiments at DAFNE. Vortrag bei: Leannis HP3 meeting, Prague/CZECH REPUBLIC., Sonstiger Veranstaltungsbeitrag (internationale Veranstaltung).
- Gruber, Lukas (06.03.2012) Status of the SiPM detector CERN data analysis. Vortrag bei: XL. Panda collaboration meeting, GSI, Darmstadt/GERMANY., Sonstiger Veranstaltungsbeitrag (internationale Veranstaltung).
- Gruber, Lukas (21.09.2012) Recovery Time Measurements of SiPMs using a Double Pulsed Laser. Vortrag bei: OEPG 2012, Graz, Graz/AUSTRIA., Sonstiger Veranstaltungsbeitrag.
- Hartmann, Olaf (04.06.2012) Strange and charmed hadrons in matter at GSI and FAIR. Vortrag bei: Workshop on hadron physics with strangeness and beyond/AUSTRIA., Sonstiger Veranstaltungsbeitrag (internationale Veranstaltung).
- Hartmann, Olaf (18.04.2012) Antiproton-Nucleus Reactions at PANDA. Vortrag bei: QNP2012 - Sixth International Conference on Quarks and Nuclear Physics/FRANCE., Sonstiger Veranstaltungsbeitrag (internationale Veranstaltung).
- Hartmann, Olaf (20.03.2012) Production of Strangeness in $\pi^-$ induced Reactions. Vortrag bei: DPG 2012, Fachverband Physik der Hadronen und Kerne, Main/GERMANY., Sonstiger Veranstaltungsbeitrag (internationale Veranstaltung).
- Hartmann, Olaf (21.05.2012) New from FOPI data. Vortrag bei: Leannis HP3 meeting, Prague/CZECH REPUBLIC., Sonstiger Veranstaltungsbeitrag (internationale Veranstaltung).

- Ishiwatari, Tomoichi (01.10.2012) Strong interaction shifts and widths of kaonic helium isotopes. Vortrag bei: HYP2012, Barcelona/SPAIN ., Sonstiger Veranstaltungsbeitrag (internationale Veranstaltung).
- Ishiwatari, Tomoichi (04.06.2012) X-ray spectroscopy of kaonic helium atoms. Vortrag bei: Workshop on hadron physics with strangeness and beyond/AUSTRIA., Sonstiger Veranstaltungsbeitrag (internationale Veranstaltung).
- Ishiwatari, Tomoichi (21.05.2012) Strong-interaction widths of kaonic helium isotopes. Vortrag bei: Leannis HP3 meeting, Prague/CZECH REPUBLIC., Sonstiger Veranstaltungsbeitrag (internationale Veranstaltung).
- Malbrunot, Chloe (06.12.2012) Measurement of the ground-state hyperfine splitting of antihydrogen at CERN. Vortrag bei: DISCRETE 2012/PORTUGAL., Sonstiger Veranstaltungsbeitrag (internationale Veranstaltung).
- Marton, Johan (18.09.2012) New experiments on light kaonic atoms. Vortrag bei: OEPG 2012, Graz, Graz/AUSTRIA., Sonstiger Veranstaltungsbeitrag.
- Marton, Johan (21.05.2012) he LEANNIS network in HADRONPHYSICS3. Vortrag bei: LEANNIS kick-off meeting, Prague/CZECH REPUBLIC., Sonstiger Veranstaltungsbeitrag (internationale Veranstaltung).
- Marton, Johann (01.03.2012) The Pauli Exclusion Principle for electrons -- a high sensitivity test in Gran Sasso underground laboratory. Vortrag bei: APS March meeting, 2012, Boston/UNITED STATES., Sonstiger Veranstaltungsbeitrag (internationale Veranstaltung).
- Marton, Johann (06.12.2012) Testing the Pauli Exclusion Principle for Electrons. Vortrag bei: DISCRETE 2012/PORTUGAL., Sonstiger Veranstaltungsbeitrag (internationale Veranstaltung).
- Marton, Johann (24.01.2012) Progress in the research on the antikaon-nucleon and nucleus interaction. Vortrag bei: 50. International Winter Meeting on Nuclear Physics, Bormio/ITALY., Sonstiger Veranstaltungsbeitrag (internationale Veranstaltung).
- Marton, Johann (30.11.2012) Protonencomputertomographie. Vortrag bei: Symposium MedAustron, Wiener Neustadt/AUSTRIA., Sonstiger Veranstaltungsbeitrag (internationale Veranstaltung).
- Marton, Johannes (19.10.2012) LEANNIS in HP3. Vortrag bei: New trends in the low-energy QCD in the strangeness sector: experimental and theoretical

aspects (ETC*)/ITALY., Sonstiger Veranstaltungsbeitrag (internationale Veranstaltung).

- Sauerzopf, Clemens (18.09.2012) Measuring the Hyperfine-Splitting of Antihydrogen. Vortrag bei: OEPG 2012, Graz, Graz/AUSTRIA., Sonstiger Veranstaltungsbeitrag.
- Suzuki, Ken (21.03.2012) Precise spectroscopy of pionic atoms at RIKEN. Vortrag bei: DPG 2012, Fachverband Physik der Hadronen und Kerne, Main/GERMANY., Sonstiger Veranstaltungsbeitrag (internationale Veranstaltung).
- Widmann, Eberhard (01.06.2012) The hyperfine structure of antiprotonic helium and antihydrogen. Vortrag bei: CIPANP 2012, St. Petersburg, Florida/UNITED STATES., Sonstiger Veranstaltungsbeitrag (internationale Veranstaltung).
- Widmann, Eberhard (04.05.2012) The Hyperfine Structure of Antihydrogen. Vortrag bei: EMMI Workshop - Physics Prospects at FLAIR/GERMANY., Sonstiger Veranstaltungsbeitrag (internationale Veranstaltung).
- Widmann, Eberhard (06.12.2012) Hyperfine Structure of Antiprotonic Helium and the Antiproton Magnetic Moment. Vortrag bei: DISCRETE 2012/PORTUGAL., Sonstiger Veranstaltungsbeitrag (internationale Veranstaltung).
- Widmann, Eberhard (17.11.2012) The Hyperfine Structure of Antihydrogen. Vortrag bei: A Day of Science with Austrian ERC/FWF Awardees (Austrian Academy of Sciences), Wien/AUSTRIA., Sonstiger Veranstaltungsbeitrag.
- Widmann, Eberhard (26.06.2012) The Hyperfine Structure of Antihydrogen. Vortrag bei: AEgIS Collaboration Meeting/SWITZERLAND., Sonstiger Veranstaltungsbeitrag (internationale Veranstaltung).
- Wuenschek, Barbara (18.09.2012) A comparison of the measured X-ray yields in kaonic helium-3 and helium-4. Vortrag bei: OEPG 2012, Graz/AUSTRIA., Sonstiger Veranstaltungsbeitrag.
- Zmeskal, Johann (02.11.2012) Future for FOPI: Searching for cold strange baryonic matter. Vortrag bei: FOPI Group Meeting, Darmstadt/GERMANY., Sonstiger Veranstaltungsbeitrag (internationale Veranstaltung).
- Zmeskal, Johannes (16.10.2012) Perspectives of new experiments searching for strange baryonic matter. Vortrag bei: New trends in the low-energy QCD in

the strangeness sector: experimental and theoretical aspects (ETC*)/ITALY., Sonstiger Veranstaltungsbeitrag (internationale Veranstaltung).

- Malbrunot, Chloe (17.07.2012) Measurement of the hyperfine structure of antihydrogen at CERN. Posterpräsentation bei: ICAP 2012 - Summer School, Paris/FRANCE., Sonstiger Veranstaltungsbeitrag (internationale Veranstaltung).

## 2.7 Scientific events

Conferences/Workshops/Meetings

- 26.11.2012 - 28.11.2012 - SPARC Collaboration meeting.

  The 9th International Topical SPARC Workshop, organized by the Stored Particles Atomic Physics Research Collaboration (SPARC), the Stefan Meyer Institute for subatomic Physics, Austrian Academy of Sciences (Vienna, Austria) and the Vienna University of Technology, was held in Vienna from 26th to 28th of November 2012. The three days of the workshop were dedicated to the latest developments concerning the scientific program of the collaboration, the related technical issues as well as the financial and organizational aspects in the light of the newest on going FAIR activities. The main topics discussed are:

  - the atomic physics experimental program at storage rings: the High Energy Storage Ring (HESR) and CRYRING@ESR
  - issues related to the preparation of Technical Design Reports for the SPARC subprojects

  as well as new ways to strengthen the collaborative activities between the different SPARC members and to investigate new possible sources for additional funding.
- 15.10.2012 - 19.10.2012 - New trends in the low-energy QCD in the strangeness sector: experimental and theoretical aspects.
- 26.11.2012 - 28.11.2012 - SPARC Collaboration meeting.
- 19.03.2012 - 19.03.2012 - Festveranstaltung zur Eröffnung des Victor-Franz-Hess-Jahres.
- 21.05.2012 - 22.05.2012 - LEANNIS Kick-off Meeting, HadronPhysics3, FP8.
- 04.06.2012 - 04.06.2012 - Workshop on hadron physics with strangeness and beyond.

University Lectures

University Vienna

- Experimental Particle Physics II, Sommersemester 2012, K. Suzuki

- Seminar on atomic and subatomic physics, Sommersemester 2012, E. Widmann und J. Zmeskal
- Seminar zur Experimentellen Teilchenphysik, Sommersemester 2012,E. Widmann
- Spezialisierungsmodul Kern- und Isotopenphysik - Betreuung von Masterarbeiten auf dem Gebiet der subatomaren Physik, experimentelle Arbeiten an internationalen Beschleunigerzentren, Sommersemester 2012,E. Widmann und J. Zmeskal
- Detector and detector systems for particle and nuclear physics I, Wintersemester 2012/2013, J. Zmeskal
- Experimental Particle Physics I, Wintersemester 2012/2013, E. Widmann
- Kern- und Teilchenphysik, Wintersemester 2012/2013, E. Widmann
- Seminar on atomic and subatomic physics, Wintersemester 2012/2013, E. Widmann und J. Zmeskal
- Seminar zur Experimentellen Teilchenphysik, Wintersemester 2012/2013, E. Widmann
- Spezialisierungsmodul Kern- und Isotopenphysik - Betreuung von Masterarbeiten auf dem Gebiet der subatomaren Physik, experimentelle Arbeiten an internationalen Beschleunigerzentren, Wintersemester 2012/2013, E. Widmann und J. Zmeskal

Technical University Vienna

- Privatissimum für Diplomanden, Sommersemester 2012, J. Marton
- Privatissimum für Dissertanten, Sommersemester 2012, J. Marton
- Projektarbeit Subatomare Physik, Sommersemester 2012, J. Marton
- Physics of Exotic Atoms, Wintersemester 2012/2013, J. Marton
- Privatissimum für Dissertanten, Wintersemester 2012/2013, J. Marton
- Projektarbeit Subatomare Physik, Wintersemester 2012/2013, J. Marton

## 2.8 Scientific cooperation 2012

### Matter - antimatter symmetry: ASACUSA @ CERN - ASACUSA

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

### Kaonic hydrogen and deuterium: SIDDHARTA

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

**PANDA: Antiproton Annihilations at Darmstadt**

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

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

GERMANY, Bochum, Ruhr-Universität Bochum.

GERMANY, Bonn, Universität Bonn.

GERMANY, Darmstadt, GSI - Gesellschaft für Schwerionenforschung mbH.

GERMANY, Dresden, Technische Universität Dresden.

GERMANY, Erlangen, Universität Erlangen.

GERMANY, Frankfurt, Univ. Frankfurt.

GERMANY, Gießen, Universität Gießen.

GERMANY, Jülich, Forschungszentrum Jülich GmbH.

GERMANY, Mainz, Universität Mainz.

GERMANY, Muenchen, Technische Universität München.

GERMANY, Münster, Universität Münster.

GERMANY, Tübingen, Universität Tübingen.

ITALY, Brescia, Univ. Brescia.

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

ITALY, Frascati, INFN, Laboratori Nazionali di Frascati.

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

ITALY, Genua, Università di Genova.

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

ITALY, Pavia, Università di Pavia.

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

ITALY, Turin, Politechnico Torino.

ITALY, Turin, Univerità di Torino.

NETHERLANDS, Kroningen, KVI Kroningen.

POLAND, Krakau, Univ. Cracow.

POLAND, Silesia, Univ. Silesia.

POLAND, Warschau, SINS.

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

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

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

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

### Deeply bound kaonic nuclei with FOPI at GSI

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

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

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

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

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

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

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

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

**AMADEUS at DAPHNE2**

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

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

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

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

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

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

### Antiproton Ion Collider - AIC

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

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

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

## 2.9 Scientific co-workers

| Name | Position | Funding |
|---|---|---|
| Prof. Dr. Eberhard Widmann | Director | ÖAW |
| Privatdozent Dr. Johann Marton | Senior scientist, vice director | ÖAW |
| Privatdozent Dr. Johann Zmeskal | Senior scientist, workshop supervisor | ÖAW |
| Dr. Paul Bühler | Senior scientist | ÖAW |
| Dr. Michael Cargnelli | Senior scientist | ÖAW |
| Dr. Ken Suzuki | Senior scientist | ÖAW |
| Dr. Pietro Cardonna | Junior Scientist | ERC |
| Dr. Olaf Hartmann | Junior scientist | FWF |
| Dr. Tomoichi Ishiwatari | Junior scientist | FWF/EU |
| Dr. Bertalan Juhasz | Junior scientist | ÖAW |
| Dr. Chloe Malbrunot | Junior scientist | ERC |
| Gamal Saber Ahmed | Ph.D. student | Egypt |
| Carolina Berucci | Ph.D. student | FWF |
| Stefan Brunner | Ph.D. student | EU/ÖAW |
| Silke Federmann | Ph.D. student | CERN/bmwf |
| Susanne Friedreich | Ph.D. student | FWF/ERC |
| Lukas Gruber | Ph.D. student | EU/ÖAW |
| Philipp Müllner | Ph.D. student | EU |
| Barbara Wünschek | Ph.D. student | FWF/ERC |
| Martin Diermaier | Ph.D student | ERC |
| Clemens Sauerzopf | Ph.D. student | ERC |
| Albulena Berisha | Diploma student | ÖAW |
| Oswald Massiczek | Diploma student | ÖAW |
| Florian Schilling | Diploma student | ÖAW |
| Katharina Isepp | Diploma student | ÖAW |
| Martin Jankovec | Diploma student | |
| Mariana Rihl | Diploma student | ÖAW |
| Michael Wolf | Diploma student | ÖAW |
| Florian Pipper | Bachelor student | |

## 3. Attachment: Data report from AkademIS (CD-ROM)