

# **7th International Symposium on Symmetries in Subatomic Physics (SSP2018)**



## **Report of Contributions**

Contribution ID: 2

Type: **not specified**

## Using Nab to determine correlations in unpolarized neutron decay

*Tuesday, June 12, 2018 4:30 PM (20 minutes)*

With precise determinations of the lifetime and angular correlations in the decay of the neutron, we can characterize the left-handed nature of the weak interaction and search for the influence of new interactions. The Nab experiment's primary goal is to determine the ratio of the hadronic axial-vector and vector form factors with a goal sensitivity of  $\delta\lambda/\lambda \sim 0.03\%$ , which will allow for a competitive test of unitarity of the Cabibbo Kobayashi Maskawa quark mixing matrix. The parameter  $\lambda$  will be extracted from the correlation between the antineutrino and electron emitted in the decay, determined from the three-body kinematics using the momentum of the proton and the electron energy. In addition, Nab will search for a distortion of the energy spectrum of the electron caused by the Fierz interference term at the level of  $\delta b \sim 3 \times 10^{-3}$ , which could indicate the presence of Beyond Standard Model scalar or tensor currents. Nab implements a 7 m tall asymmetric magnetic spectrometer to collect the charged decay particles with  $4\pi$  acceptance, with a field expansion in the long arm to determine the proton's momentum from its time of flight with sub ns average precision. The proton and electron are detected in coincidence by a detection system with fast timing ( $< 50$  ns) and good energy resolution ( $\sim 3$  keV FWHM at 30 keV) based on thick, large area, segmented silicon detectors. The spectrometer is currently commissioning at the Fundamental Neutron Physics Beamline at the Spallation Neutron Source and final development of the fully instrumented detection system is underway. An overview of Nab's approach to achieve these science goals and early demonstrations of the capabilities of the experiment will be presented.

**Primary author:** BROUSSARD, Leah (Oak Ridge National Laboratory)

**Presenter:** BROUSSARD, Leah (Oak Ridge National Laboratory)

**Session Classification:** parity violation/weak interaction

Contribution ID: 3

Type: **Talk**

## Physics beyond the Standard Model from hydrogen molecules

*Thursday, June 14, 2018 9:00 AM (30 minutes)*

The hydrogen molecule is the smallest neutral chemical entity and a benchmark system of quantum physics and chemistry. The comparison between highly accurate measurements of transition frequencies and level energies with quantum calculations including all known phenomena (relativistic, vacuum polarization and self energy) provides a tool to search for physical phenomena in the realm of the unknown: are there forces beyond the three included in the Standard Model of physics plus gravity, are there extra dimensions beyond the 3+1 describing space time? Comparison of laboratory wavelengths of transitions in hydrogen may be compared with the lines observed during the epoch of the early Universe to verify whether fundamental constants of Nature have varied over cosmological time. These concepts, as well as the precision laboratory experiments and the astronomical observations used for such searches of new physics will be discussed.

**Primary author:** UBACHS, Wim (VU University Amsterdam)

**Presenter:** UBACHS, Wim (VU University Amsterdam)

**Session Classification:** General

Contribution ID: 4

Type: **Talk**

## Improved Measurement of the Permanent Electric Dipole Moment of $^{199}\text{Hg}$

*Tuesday, June 12, 2018 11:20 AM (20 minutes)*

This talk will cover the latest results on the permanent electric dipole moment (EDM) of neutral  $^{199}\text{Hg}$  atoms. The EDM is manifested as a small perturbation to the Larmor precession frequency due to the interaction energy of the electric dipole with a static electric field. The atoms are prepared in four separate glass vapor cells using optical pumping with resonant 254 nm laser light and allowed to precess in a common magnetic field and oppositely-directed electric fields. The precession frequency difference in a pair of cells is derived from the accumulated phase difference between two probe periods separated in time. Using this technique, we find the EDM projection onto the nuclear spin axis  $d_{Hg} = (2.20 \pm 2.75_{stat} \pm 1.48_{syst}) \cdot 10^{-30}$  e·cm. While consistent with zero, this result places a new upper limit on the EDM  $|d_{Hg}| < 7.4 \cdot 10^{-30}$  e·cm (95% C.L.), improving the previous best limit by a factor of  $>4$ .  $^{199}\text{Hg}$  continues to have the most stringent limits for the EDM of any atomic or molecular system. The new limit constrains theories of physics beyond the Standard Model which incorporate new sources of time-reversal or CP symmetry violation.

**Primary authors:** Dr GRANER, Brent (University of Washington); Prof. HECKEL, Blayne (University of Washington); Ms CHEN, Yi (University of Washington); Mr LINDAHL, Eric (University of Washington)

**Presenter:** Dr GRANER, Brent (University of Washington)

**Session Classification:** EDM

Contribution ID: 5

Type: **Talk**

## How to master light meson dynamics: From hadron spectroscopy to CP phases

*Friday, June 15, 2018 9:25 AM (25 minutes)*

Heavy meson decays into light hadrons are a prime source to access CP violating phases. Since these show up via the interference of different amplitudes it is mandatory - especially to get sensitive to very small signals as expected, e.g., in D-decays - to model independently control the hadronic final state interactions. In this talk it is discussed to what extent this goal can be achieved already now and also what are the perspectives for the future.

**Primary author:** Prof. HANHART, Christoph (IKP/IAS Forschungszentrum Jueliche)

**Presenter:** Prof. HANHART, Christoph (IKP/IAS Forschungszentrum Jueliche)

**Session Classification:** CP violation/T violation

Contribution ID: 6

Type: **Talk**

## Searches for $\mu \rightarrow e\gamma$ : present and future

*Thursday, June 14, 2018 11:00 AM (30 minutes)*

The quest for  $\mu \rightarrow e\gamma$  is one of the most important endeavors to search for New Physics beyond the Standard Model. In this talk I will review the current status of the experimental searches by the MEG Collaboration at PSI. I will also present a study of the experimental limiting factors that will define the ultimate performances, and hence the sensitivity, in the search for  $\mu \rightarrow e\gamma$  with continuous muon beams of extremely high rate (one or even two orders of magnitude larger than the present beams), whose construction is under consideration for the next decade.

**Primary author:** RENGA, Francesco**Presenter:** RENGA, Francesco**Session Classification:** lepton universality, lepton flavor violation

Contribution ID: 7

Type: **Talk**

## The P2 experiment: A high precision determination of the weak mixing angle at low momentum transfer

*Wednesday, June 13, 2018 9:00 AM (30 minutes)*

The P2 experiment aims for a new, high precision determination of the weak mixing angle at low momentum transfer. The expected accuracy is around 0.15% which is comparable to the existing most precise measurements at the Z pole. The experimental method is the measurement of the parity violating asymmetry in the cross section of the elastic scattering of polarized electrons off unpolarized hydrogen. A number of innovative technologies had to be developed. The expected asymmetry is of the order of 30 parts per billion (ppb). This measurement will be carried out at the new electron accelerator MESA in Mainz. In this talk, the physics motivation for the experiment will be presented as well as the numerous experimental challenges associated with the measurement of such a small asymmetry. We will also show the current status of the work.

**Primary author:** MAAS, Frank (H)

**Presenter:** MAAS, Frank (H)

**Session Classification:** parity violation/weak interaction

Contribution ID: 8

Type: **Talk**

## Time dependent CP-violation sensitivity at Belle II

*Friday, June 15, 2018 9:50 AM (20 minutes)*

Time dependent CP-violation phenomena are a powerful tool to precisely measure fundamental parameters of the Standard Model and search for New Physics. The Belle II experiment is a substantial upgrade of the Belle detector and will operate at the SuperKEKB energy-asymmetric  $e^+e^-$  collider. The accelerator has already successfully completed the first phase of commissioning in 2016 and first electron positron collisions in Belle II are expected for April 2018. The design luminosity of SuperKEKB is  $8 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}$  and the Belle II experiment aims to record  $50 \text{ ab}^{-1}$  of data, a factor of 50 more than the Belle experiment. This dataset will greatly improve the present knowledge, particularly on the CKM angles  $\beta$  and  $\alpha$  by measuring a wide spectrum of B-meson decays, including many with neutral particles in the final state. In this talk we will present estimates of the sensitivity to  $\beta$  in the golden channels  $B \rightarrow c\bar{c}s$  and in the penguin-dominated modes  $B^0 \rightarrow \eta' K^0, \phi K^0, K_S \pi^0(\gamma)$ . A study for the time-dependent analysis of  $B^0 \rightarrow \pi^0 \pi^0$ , relevant for the measurement of  $\alpha$ , and feasible only in the clean environment of an  $e^+e^-$  collider, will also be given.

**Primary author:** PERUZZI, Ida (Laboratori Nazionali di Frascati dell'INFN)

**Presenter:** ABUDINEN, Fernando (Max-Planck-institut für Physik)

**Session Classification:** CP violation/T violation



Contribution ID: **10**Type: **Talk**

## Lorentz Violation in Hadronic Physics

*Monday, June 11, 2018 5:30 PM (30 minutes)*

The effects of quark-sector Lorentz violation on deep inelastic electron-proton scattering are studied. We show that existing data can be used to establish first constraints on numerous coefficients for Lorentz violation in the quark sector at an estimated sensitivity of parts in a million. We calculate the expected bounds that can be extracted from existing HERA data and the reach of the proposed Electron-Ion Collider (in the JLAB and BNL configurations).

**Primary author:** Dr LUNGHI, Enrico (Indiana University (US))

**Co-authors:** KOSTELECKY, Alan (unknown); Dr VIEIRA, Alexandre; Mr SHERRILL, nathan (Indiana University)

**Presenter:** Dr LUNGHI, Enrico (Indiana University (US))

**Session Classification:** CPT

Contribution ID: 12

Type: **Talk**

## Search for $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ at NA62

*Wednesday, June 13, 2018 11:00 AM (20 minutes)*

The decay  $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ , with a very precisely predicted branching ratio of less than  $10^{-10}$ , is one of the best candidates to reveal indirect effects of new physics at the highest mass scales. The NA62 experiment at CERN SPS is designed to measure the branching ratio of the  $K^+ \rightarrow \pi^+ \nu \bar{\nu}$  with a decay-in-flight technique, novel for this channel. NA62 took data in 2016, 2017 and another year run is scheduled in 2018. Statistics collected in 2016 allows NA62 to reach the Standard Model sensitivity for  $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ , entering the domain of  $10^{-10}$  single event sensitivity and showing the proof of principle of the experiment. The  $K^+ \rightarrow \pi^+ \nu \bar{\nu}$  analysis data is reviewed and the preliminary result from the 2016 data set presented.

**Presenter:** LENTI, Massimo (Universita e INFN, Firenze (IT))

**Session Classification:** CP violation/T violation

Contribution ID: 14

Type: **Talk**

## Challenges to Lepton Universality in B Meson Decays

*Thursday, June 14, 2018 11:30 AM (30 minutes)*

One of the key assumptions of the Standard Model of particle physics is that the interactions of the charged leptons, namely electrons, muons and taus, differ only because of their different masses. Recent studies of B-meson decays involving the higher-mass tau lepton have resulted in observations that challenge lepton universality at the level of four standard deviations. A summary of recent measurements by the BABAR, Belle, and LHCb experiments will be presented. A confirmation of these results would point to new particles or interactions, and could have profound implications for our understanding of particle physics.

**Primary author:** LUTH, Vera**Presenter:** LUTH, Vera**Session Classification:** lepton universality, lepton flavor violation

Contribution ID: 17

Type: **Talk**

## Measurement of the fine-structure constant as a test of the Standard Model

*Friday, June 15, 2018 11:00 AM (30 minutes)*

Measurements of the fine-structure constant require methods from across subfields and are thus powerful tests of the consistency of theory and experiment in physics. Using the recoil frequency of cesium-133 atoms in a matter-wave interferometer, we recorded the most accurate measurement of the fine-structure constant to date:  $\alpha = 1/137.035999046(27)$  at  $2.0 \times 10^{-10}$  accuracy. Using multiphoton interactions (Bragg diffraction and Bloch oscillations), we demonstrate the largest phase (12 million radians) of any Ramsey-Bordé interferometer and control systematic effects at a level of 0.12 part per billion. Comparison with Penning trap measurements of the electron gyromagnetic anomaly  $g-2$  via the Standard Model of particle physics is now limited by the uncertainty in  $g-2$ ; a 2.5-sigma tension rejects dark photons as the reason for the unexplained part of the muon's magnetic moment at a 99% confidence level. Implications for dark-sector candidates and electron substructure may be a sign of physics beyond the Standard Model that warrants further investigation.

**Primary author:** PARKER, Richard**Presenter:** PARKER, Richard**Session Classification:** QED

Contribution ID: 18

Type: **Talk**

## Dark matter and violation of symmetries

*Tuesday, June 12, 2018 9:00 AM (30 minutes)*

Low-mass boson dark matter particles produced after Big Bang form classical field and/or topological defects. In contrast to traditional dark matter searches, effects produced by interaction of an ordinary matter with this field and defects may be first power in the underlying interaction strength rather than the second power or higher (which appears in a traditional search for the dark matter). This may give an enormous advantage since the dark matter interaction constant is extremely small.

Effects of dark matter and dark energy include apparent violation of the fundamental symmetries: oscillating or transient atomic electric dipole moments, precession of electron and nuclear spins about the direction of Earth's motion through the axion dark matter (the axion wind effect), and axion-mediated spin-gravity couplings [1-3], violation of Lorentz symmetry and Einstein equivalence principle [4]. Recent measurements by nEDM collaboration [5] improved the limits on interaction of the low-mass axion with gluons and nucleons up to 3 orders of magnitude. Improved limits on the axions and low mass  $Z'$ -bosons have been derived from the measurements of atomic and molecular electric dipole moments [6] and parity violating effects [7].

Interaction between the density of the dark matter particles and ordinary matter produces both 'slow'

cosmological evolution and oscillating variations of the fundamental constants including the fine structure

constant  $\alpha$  and particle masses. Atomic Dy, Rb and Cs spectroscopy measurements and the primordial helium abundance data allowed us to improve on existing constraints on the quadratic interactions of the scalar dark matter with the photon, electron, quarks and Higgs boson by up to 15 orders of magnitude. Limits on the linear and quadratic interactions of the dark matter with W and Z bosons have been obtained for the first time [8,9].

We also discuss parity violating effects produced in atoms and molecules by the nuclear weak quadrupole moment [4], enhanced EDM in atoms and molecules produced by the collective nuclear magnetic quadrupole moments [10], and 7 orders of magnitude improvement of the limits on the anisotropy of the speed of light [11] (firstly measured in the famous Michelson-Morley experiment). This anisotropy leads to the anisotropy of the Coulomb interaction affecting nuclear and atomic spectra.

References.

[1] Axion-induced effects in atoms, molecules and nuclei: Parity nonconservation, anapole moments, electric dipole moments, and spin-gravity and spin-axion momentum couplings. Y. V. Stadnik and V. V. Flambaum. Phys. Rev. D 89, 043522 (2014).

[2] Limiting P-odd Interactions of Cosmic Fields with Electrons, Protons and Neutrons. B. M. Roberts, Y. V. Stadnik, V. A. Dzuba, V. V. Flambaum, N. Leefer and D. Budker. Phys. Rev. Lett. 113, 081601 (2014).

[3] Parity-violating interactions of cosmic fields with atoms, molecules and nuclei: Concepts and calculations for laboratory searches and extracting limits. B. M. Roberts, Y. V. Stadnik, V. A. Dzuba, V. V. Flambaum, N. Leefer and D. Budker. Phys. Rev. D 90, 096005 (2014).

[4] Enhanced violation of the Lorentz invariance and Einstein equivalence in atoms and nuclei, V.V. Flambaum. Phys. Rev. Lett. 2016.

[5] C. Abel et al. (nEDM collaboration), Phys. Rev. X7, 041034 (2017).

- [6] Improved limits on axion-like-particle-mediated P,T-violating interactions between electrons and nucleons from electric dipole moments of atoms and molecules, Y. V. Stadnik, V. A. Dzuba, V. V. Flambaum, Phys. Rev. Lett. 120, 0132024 (2018)
- [7] Probing low-mass vector bosons with parity nonconservation and nuclear anapole moment measurements in atoms and molecules. V. A. Dzuba, V. V. Flambaum, Y. V. Stadnik, Phys. Rev. Lett. 119, 223201 (2017)
- [8] Can dark matter induce cosmological evolution of the fundamental constants of Nature? Y. V. Stadnik and V. V. Flambaum. Phys. Rev. Lett. 115, 201301 (2015).
- [9] Improved limits on interactions of low-mass spin-0 dark matter from atomic clock spectroscopy, Y. V. Stadnik, V. V. Flambaum, Phys. Rev. A 94, 022111, (2016).
- [10] Time-reversal symmetry violation in molecules induced by nuclear magnetic quadrupole moments, V. V. Flambaum, D. DeMille, and M. G. Kozlov, Phys. Rev. Lett. 113, 103003 (2014).
- [11] Effects of the Lorentz invariance violation on Coulomb interaction in nuclei and atoms. Limits on Lorentz invariance violation from Coulomb interactions in nuclei and atoms. V.V. Flambaum, M.V. Romalis, Phys. Rev. Lett. 118, 142501 (2017).

**Primary authors:** FLAMBAUM, Victor (University of New South Wales); STADNIK, Yevgeny (University of New South Wales)

**Presenter:** FLAMBAUM, Victor (University of New South Wales)

**Session Classification:** dark matter/cosmology

Contribution ID: 19

Type: Talk

## Measurement of the Parity-odd Gamma-ray Asymmetry in the Capture of Polarized Neutrons on Hydrogen: The NPDGamma Experiment

Wednesday, June 13, 2018 10:00 AM (30 minutes)

NPDGamma is an experimental collaboration which for over 20 years has made an effort in research and development to measure the parity-violating gamma-ray asymmetry in the capture of polarized low-energy neutrons on hydrogen. This asymmetry is dominated by a  $\Delta I = 1$   $^3S_1 - ^3P_1$  parity-odd transition in the  $n - p$  system. In the more traditional theoretical framework, the one-meson-exchange model, developed in the 80's by Desplanques, Donoghue and Holstein (among others), this asymmetry is related to the weak pion-exchange coupling constant  $h_{\pi}^1$ , which characterizes the longest-range contribution in the Hadronic Weak Interaction (HWI). This system has the advantage of not being obscured by the lack of knowledge, to a sufficient precision, of nuclear wave functions; *ab initio* calculations are possible for the  $n - p$  system. Additional scientific interest in this system comes from the fact that charged currents are suppressed in the  $\Delta I = 1$  channel, so it constitutes one of the few systems available to study neutral currents at low energies. More modern theoretical approaches have implemented Effective Field Theories (EFT) in the study of the HWI. At low-energies, in the pion-less EFT, the weak interaction is characterized by five low-energy constants (LECs) related to the possible  $S - P$  transitions, and in the expansion to infinite number of colors,  $N_c$ , applied to the HWI by Schindler, Springer and Vanasse, a hierarchization of the LECs has been achieved. Particularly, the LEC related to the  $^3S_1 - ^3P_1$  transition is expected to be suppressed. Testing the large- $N_c$  expectations is an important step towards a better understanding of the HWI. In this talk I will describe the different stages of the experiment and will present the final result achieved by the NPDGamma collaboration.

**Primary authors:** Dr BARRÓN-PALOS, Libertad (Universidad Nacional Autónoma de México); THE NPDGAMMA COLLABORATION

**Presenter:** Dr BARRÓN-PALOS, Libertad (Universidad Nacional Autónoma de México)

**Session Classification:** parity violation/weak interaction

Contribution ID: 20

Type: **Talk**

## Towards parts per trillion mass measurements on the proton and other light nuclei at LIONTRAP

*Thursday, June 14, 2018 9:30 AM (30 minutes)*

The precise knowledge of the atomic masses of various light nuclei, e.g. of the proton, deuteron, helium and triton are of utmost importance for several tests of fundamental physics. For example, the mass of the proton itself and the mass ratio of the electron and the proton are important input parameters for experiments in atomic physics. Furthermore, an essential consistency check of the KATRIN experiment will require an ultra-precise measurement of the mass difference of triton and helium on a so far unrivalled level of precision of 6meV or smaller. However, five sigma discrepancies between high-precision measurements of these light nuclear masses question their current literature values and give strong motivation for a new and independent experiment, LIONTRAP (Light ION TRAP), aiming for relative uncertainties of a few parts per trillion.

The new setup contains a cryogenic stack of five cylindrical Penning traps enclosed in hermetically sealed vacuum chamber. The measurement principle is based on a non-destructive phase-sensitive comparison of the single proton's cyclotron frequency to that of a single bare carbon nucleus. In order to measure both frequencies in the same electric and magnetic field configuration, both single ions are transported alternately into an ultra-harmonic, doubly compensated Penning trap. Exactly the same electric field configuration for both ions with different charge/mass ratio requires two separate, precisely tuned axial resonators for non-destructive frequency detection. To overcome the statistically limiting magnetic field fluctuations, simultaneous phase-sensitive measurements are planned in neighbouring traps.

At this conference, the new LIONTRAP setup including a variety of novel techniques and improvements will be introduced. Furthermore, first results on the atomic mass of the proton will be presented. This new proton mass value is 3 times more precise than the current literature value and reveals a disagreement of about 3 standard deviations to it [1].

[1] F. Heiße et al., Phys. Rev. Lett. 119, 033001 (2017)

**Primary author:** KÖHLER-LANGES, Florian (Max Planck Institute for Nuclear Physics (MPIK))

**Presenter:** KÖHLER-LANGES, Florian (Max Planck Institute for Nuclear Physics (MPIK))

**Session Classification:** General



Contribution ID: 21

Type: **Talk**

## Laser spectroscopy of muonic atoms and the proton charge radius

*Thursday, June 14, 2018 10:00 AM (30 minutes)*

Laser spectroscopy of muonic hydrogen [1,2] yielded a proton rms charge radius which is 4% (or  $\sim 6$  sigmas) smaller than the CODATA value [3]. This discrepancy is now called the “proton radius puzzle” [4]. Also the deuteron charge radius from muonic deuterium [5] is 6 sigmas smaller than the CODATA value, but consistent with the smaller proton inside the deuteron.

These smaller charge radii, when combined with precision measurements of the 1S-2S transitions in regular (electronic) hydrogen [6] and deuterium [7], yield a 6 sigmas smaller value of the Rydberg constant [8], compared to the CODATA value.

In this talk I will report about a new measurement of the Rydberg constant from the 2S-4P transition in regular hydrogen performed in Garching [9], which supports the smaller, “muonic” value. Even more recently, a new measurement of the 1S-3S transition in Paris, however, confirmed the larger proton radius [10].

The situation is further complicated by new measurements in electronic and muonic helium. I will attempt to give an overview of the situation.

- [1] Pohl et al. (CREMA Coll.), Nature 466, 213 (2010)
- [2] Antognini et al. (CREMA Coll.), Science 339, 417 (2013)
- [3] Mohr et al. (CODATA 2014), Rev. Mod. Phys. 88, 035009 (2016)
- [4] Hill, EPJ Web Conf. 137, 012023 (2017)
- [5] Pohl et al. (CREMA Coll.), Science 353, 669 (2016)
- [6] Parthey et al., PRL 107, 203001 (2011)
- [7] Parthey et al., PRL 104, 233001 (2010)
- [8] Pohl et al., Metrologia 54, L1 (2017)
- [9] Beyer et al., Science 358, 79 (2017)
- [10] Fleurbaey et al., arxiv 1801.08816 PRL, accepted (2018)

**Primary author:** POHL, Randolph (Johannes Gutenberg University Mainz, Germany)

**Presenter:** POHL, Randolph (Johannes Gutenberg University Mainz, Germany)

**Session Classification:** General

Contribution ID: 22

Type: **Talk**

## Stringent tests of QED using highly charged ions

*Friday, June 15, 2018 11:30 AM (30 minutes)*

Present status of tests of QED with highly charged ions is discussed. The high-precision calculations of the Lamb shift, hyperfine splitting, and bound-electron g factor are compared with the corresponding experimental data. The calculations of the electron-positron pair-creation probabilities in low-energy heavy-ion collisions are considered. Special attention is focused on tests of QED at strong coupling regime within and beyond the Furry picture and in supercritical fields.

**Primary author:** Prof. SHABAEV, Vladimir (St.Petersburg State University)

**Presenter:** Prof. SHABAEV, Vladimir (St.Petersburg State University)

**Session Classification:** QED

Contribution ID: 23

Type: **Poster**

## Development of compact highly sensitive beam position monitors for storage rings

Thursday, June 14, 2018 3:38 PM (2 minutes)

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\documentclass[12 pt]{article}
\author{Falastine Abusaif/for the JEDI collaboration/\RWTH Aachen University/J\"ulich Forschungszen-
trum}
\begin{document}
\title{Development of compact highly sensitive beam position monitors for storage rings}
\maketitle
\begin{abstract}
The history of the search for electric dipole moment (EDM) takes us back in time for more than five
decades. EDMs have gained interest due to the fact that they violate the  $CP$  symmetry. Hence
potentially provide additional sources of  $CP$  violation and possibly contribute to the resolution
of one of the greatest puzzles of cosmology; namely to explain the matter abundance in the uni-
verse.\\
\\
The JEDI collaboration is currently preparing for measuring the Deuteron EDM in the COoler
SYnchrotron (COSY). One of the major challenges that one needs to worry about is the precise
knowledge about the beam position along the ring. Transverse beam positions largely control the
systematic errors. Thus the development of compact and highly sensitive Beam Position Monitors
(BPMs) is particularly important for precision experiment like the EDM searches.\\
\\
This poster describes the development process of the latest set of Rogwoski coils as compact beam
position monitors. It also describes some of the future plans towards optimizing the sensitivity of
these coils by cooling (down to 10 K) to reduce the thermal noise. These BPMs were installed in
COSY at the entrance and exit of the wave-guide RF-Wien filter. Another two sets of coils will be
used at the entrance and exit of the static precision solenoid that will be prepared for installation
by the end of 2018/beginning of 2019 as a novel spin manipulator.
\end{abstract}
\end{document}

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**Primary author:** Mrs ABUSAIF, Falastine (J\"ulich Forschungszentrum/RWTH Aachen University)

**Presenter:** Mrs ABUSAIF, Falastine (J\"ulich Forschungszentrum/RWTH Aachen University)

**Session Classification:** poster

Contribution ID: 24

Type: **Poster**

## Beam based alignment tests at the Cooler Synchrotron (COSY)

*Thursday, June 14, 2018 3:40 PM (2 minutes)*

The Jülich Electric Dipole moment Investigation (JEDI) Collaboration works on a measurement of the electric dipole moment (EDM) of charged hadrons using a storage ring. Such a dipole moment would violate CP symmetry, providing a test for physics beyond the Standard Model. The JEDI experiment requires a small beam orbit RMS in order to control systematic uncertainties. Therefore an ongoing upgrade of the Cooler Synchrotron (COSY) is done in order to improve the precision of the beam position. This poster will present the first results of the beam based alignment method that was tested with one quadrupole in the ring.

**Primary author:** Mr WAGNER ON BEHALF OF THE JEDI COLLABORATION, Tim (IKP, Forschungszentrum Jülich / III. Physikalisches Institut B, RWTH Aachen University)

**Presenter:** Mr WAGNER ON BEHALF OF THE JEDI COLLABORATION, Tim (IKP, Forschungszentrum Jülich / III. Physikalisches Institut B, RWTH Aachen University)

**Session Classification:** poster

Contribution ID: 25

Type: **Talk**

## Ultracold Neutron Sources World-Wide

*Tuesday, June 12, 2018 3:30 PM (30 minutes)*

Ultracold neutrons (UCN) have been established as a valuable tool in precision fundamental neutron physics research since many years.

In order to perform precision measurements with UCN, strong and reliable UCN sources are needed, and such sources are being operated at several universities and research centers world-wide. The density of UCN provided to experiments at a UCN source is an important benchmark parameter. In 2015 we have performed UCN density measurements with a 'standard' UCN storage bottle of 30L volume at all operating UCN sources world-wide, in order to establish a standard procedure and setup for comparable UCN density measurements.

Ultracold neutrons and their unique properties will be introduced. The published results of the 2015 UCN density measurement campaign will be presented, later measurements with the same setup at new and upgrades sources will be briefly discussed, as well as upcoming sources currently in construction or commissioning.

**Primary author:** RIES, Dieter (Johannes Gutenberg University Mainz)

**Presenter:** RIES, Dieter (Johannes Gutenberg University Mainz)

**Session Classification:** neutron

Contribution ID: 26

Type: **Talk**

## Muon g-2 Experiment at Fermilab: First Run

*Tuesday, June 12, 2018 2:00 PM (30 minutes)*

Precision measurements of the anomalous magnetic moment of the muon,  $a_\mu$ , are a stringent test of the Standard Model. The last measurement of  $a_\mu$  at Brookhaven National Laboratory differs from the Standard Model prediction by  $3-4\sigma$  – a possible indication of New Physics. A successor to this experiment has been constructed at Fermilab, with the aim of reducing the experimental uncertainty by a factor of four to 140 ppb.

The measurement technique adopts the storage ring concept used at Brookhaven, with muons contained in a highly uniform magnetic dipole field. The spin precession frequency is extracted from the modulation of the rate of higher-energy positrons from muon decays, detected by 24 calorimeters and 3 straw tracking detectors. Compared to the previous experiment, muon beam preparation, storage ring internal hardware, field measuring equipment, and detector and electronics systems are all new or significantly upgraded.

In this talk, a brief overview of the theoretical value of  $a_\mu$  will be given, followed by an overview of the experiment. Data from the run will be presented and the current status, including the anticipated timeline for a new result, will be outlined.

**Primary author:** MOTT, James

**Presenter:** MOTT, James

**Session Classification:** muon g-2

Contribution ID: 27

Type: **Poster**

## Electrostatic deflector development for JEDI collaboration

*Thursday, June 14, 2018 3:42 PM (2 minutes)*

The direct measurement of the proton or deuteron Electric Dipole Moment (EDM) has never been performed before. These experiments can be done at electrostatic storage ring. As a starting point the magnetic storage ring COSY at Forschungszentrum Jülich can be used. It will require implementation of the electrostatic or electromagnetic beam-bending elements. For testing the electrodes material, shape, surface treatment and high voltage, a real size 1m large deflector is developed and will be checked in a magnetic field of a large-gap dipole magnet. The experimental setup and laboratory tests will be presented.

**Primary author:** Dr GRIGORYEV, Kirill (Forschungszentrum Jülich)

**Presenter:** Dr GRIGORYEV, Kirill (Forschungszentrum Jülich)

**Session Classification:** poster

Contribution ID: 28

Type: **Talk**

## Time-Reversal Invariance Violation in Neutron Interactions with Nuclei

*Friday, June 15, 2018 10:10 AM (20 minutes)*

Time Reversal Invariance Violating (TRIV) effects in neutron transmission through nuclear targets are discussed. The absence of final state interactions for the set of specific observables makes these experiments complementary to neutron and atomic electric dipole moment (EDM) measurements. We explore important advantages of the search for TRI violation in neutron nuclei interactions and show that neutron scattering experiments at new high flux Spallation Neutron Sources can essentially improve the current limits on the TRIV interactions obtained from neutron and atomic EDMs.

**Primary author:** GUDKOV, Vladimir (University of South Carolina)

**Presenter:** GUDKOV, Vladimir (University of South Carolina)

**Session Classification:** CP violation/T violation



Contribution ID: 29

Type: **Poster**

## Heavy neutral lepton (HNL) production searches at NA62

*Thursday, June 14, 2018 3:44 PM (2 minutes)*

Searches for heavy neutral lepton (HNL) production in charged kaon decays using the data collected by the NA62 experiment at CERN are reported. Upper limits are established on the elements of the extended neutrino mixing matrix for heavy neutral lepton mass in the range 130-450 MeV, improving on the results from previous HNL production searches. The status and prospects of searches for lepton flavour and lepton number violation in kaon decays at the NA62 experiment is also presented.

**Primary author:** BRUNETTI, Maria Brigida (University of Birmingham (GB))

**Session Classification:** poster

Contribution ID: 30

Type: **Talk**

## A precision measurement of the beta asymmetry parameter using laser-cooled $^{37}\text{K}$

*Tuesday, June 12, 2018 4:50 PM (30 minutes)*

Nuclear beta decay has a long-standing history of shaping and testing the standard model of particle physics, and it continues to this day with elegant, ultra-precise low-energy nuclear measurements. Experiments observing the angular correlations between the electron, neutrino and recoil momenta following nuclear beta decay can be used to search for exotic currents contributing to the dominant V-A structure of the weak interaction. Precision measurements of the correlation parameters to  $<0.1\%$  would be sensitive to (or meaningfully constrain) new physics, complementing other searches at large-scale facilities like the LHC.

Atom traps provide an ideal source of very cold, short-lived radioactive nuclei in an extremely clean and open environment. As such, they are invaluable tools for precision measurements of beta-decay parameters. The TRIUMF Neutral Atom Trap (TRINAT) collaboration utilizes neutral atom-trapping techniques with optical pumping methods to highly polarize ( $>99\%$ )  $^{37}\text{K}$  atoms. Recently, we determined the beta asymmetry parameter,  $A_{\beta}$ , to  $0.3\%$ , which is comparable to or better than any other nuclear measurement, including the neutron. In terms of minimal left-right symmetric models, this implies a limit of  $>351$  GeV for the mass of a possible right-handed W. Alternatively, one may interpret the result as a 4.4x better measurement of  $V_{ud}$  from  $^{37}\text{K}$ .

**Primary authors:** Prof. MELCONIAN, Dan (Texas A&M University); Dr FENKER, Benjamin (Texas A&M University); Dr GORELOV, Alexandre (TRIUMF); BEHR, John (TRIUMF); Ms ANHOLM, Melissa (University of Winnipeg); Prof. ASHERY, Danny (Tel Aviv University); Prof. GWINNER, Gerald (University of Winnipeg)

**Presenter:** Prof. MELCONIAN, Dan (Texas A&M University)

**Session Classification:** parity violation/weak interaction

Contribution ID: 31

Type: **Talk**

## Measurement of the Xe-129 EDM

*Tuesday, June 12, 2018 11:00 AM (20 minutes)*

W. Heil, F. Allmendinger, O. Grasdijk, K. Jungmann, H.-J. Krause, A. Offenhäusser, M. Repetto, U. Schmidt, L. Willmann, S. Zimmer

(MIXed collaboration)

a Institut für Physik, Johannes Gutenberg-Universität, 55099 Mainz, Germany

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d Peter Grünberg Institut (PGI-8), Forschungszentrum Jülich, 52425 Jülich, Germany

Precision measurements of fundamental symmetry violations in atoms can be used as a test of the Standard Model of elementary particles and to search for new physics beyond it. Electric Dipole Moments (EDMs) of fundamental or composite particles are excellent candidates to look for new sources of CP violation. We describe a setup to measure the CP violating permanent EDM of the neutral  $^{129}\text{Xe}$  atom. Our goal is to improve the present experimental limit ( $d_{\text{Xe}} < 3 \times 10^{-27}$  ecm [1]). The experimental approach is based on the free precession of co-located nuclear spin polarized  $^3\text{He}$  and  $^{129}\text{Xe}$  atoms in a homogeneous magnetic guiding field of about 400 nT [2, 3]. A finite EDM is indicated by a change in the precession frequency as an electric field is periodically reversed with respect to the magnetic guiding field. To render the experiment insensitive to fluctuations and drifts of the magnetic guiding field, the principle of co-magnetometry is used. The experiment strongly benefits from long spin-coherence times of several hours [4]. In the talk we report on technical improvements and first experimental results achieved within the MIXed collaboration.

[1] M. Rosenberry, T. Chupp; "Atomic Electric Dipole Moment Measurement Using Spin Exchange Pumped Masers of  $^{129}\text{Xe}$  and  $^3\text{He}$ ", Phys. Rev. Lett 86 (2001).

[2] W. Heil et al., Ann. Phys. (Berlin) 525 (2013).

[3] F. Allmendinger et al., Phys. Rev. Lett 112 (2014).

[4] F. Allmendinger et al., "Precise Measurement of Magnetic Field Gradients from Free Spin Precession Signals of  $^3\text{He}$  and  $^{129}\text{Xe}$  Magnetometers" Eur. Phys. J. D 71 (2017).

**Primary author:** Prof. HEIL, Werner (Insitut für Physik)

**Presenter:** Prof. HEIL, Werner (Insitut für Physik)

**Session Classification:** EDM

Contribution ID: 32

Type: **Talk**

## Weak Interaction Physics at SARAF

*Thursday, June 14, 2018 2:55 PM (15 minutes)*

In this talk I will review the current status of the radioisotopes trapping program at the Soreq Applied Research Accelerator Facility (SARAF), and prospects for measurements at the upgraded accelerator: SARAF-II.

In our new lab complex, situated above the SARAF target room, we utilize two systems: An electrostatic-ion-beam-trap, designed for trapping various radioactive ions, starting with  ${}^6\text{He}$ ; and a magneto-optical trap, which is designated for various rare neon isotopes, starting with  ${}^{23}\text{Ne}$ .

Both traps are equipped with novel designs for the detection of recoiling particles from nuclear  $\beta$ -decay and precise measurements of the kinematic correlations between them. These correlations are sensitive to scalar- and tensor-current interactions which are suggested by some beyond standard model (BSM) theories [2]. Bounds on exotic interactions from the precision and high-energy frontiers are interpreted in the framework of a model-independent effective field theory approach [3].

[1] I. Mardor *et. al.*, **The Soreq Applied Research Accelerator Facility (SARAF) - Overview, Research Programs and Future Plans** (2018).

[2] J A Behr and G Gwinner, **Standard model tests with trapped radioactive atoms** (2009).

[3] M. Gonzalez-Alonso, O. Naviliat-Cuncic, N. Severijns. **New physics searches in nuclear and neutron  $\beta$ -decay** (2018).

**Primary author:** Mr OHAYON, Ben (Racah Institute of Physics)

**Co-authors:** Dr RAHANGDALE, Hitesh (Racah Institute of Physics, The Hebrew University, Israel); Mr MISHNAYOT, Yonatan (Racah Institute of Physics, The Hebrew University, Israel. Soreq Nuclear Research Center, Israel); Dr MUKUL, Ish (RIUMF National Particle Accelerator Center, Canada); Mr JOEL, Chocron (Racah Institute of Physics, The Hebrew University, Israel); Dr HIRSH, Tsviki (Soreq Nuclear Research Center, Israel); Dr VAINTRAUB, Sergei (Soreq Nuclear Research Center, Israel); Mrs GLICK-MAGID, Ayala (Racah Institute of Physics, The Hebrew University, Israel); Prof. GAZIT, Doron (Racah Institute of Physics, The Hebrew University, Israel); Prof. RON, Guy (Hebrew University of Jerusalem); Prof. HABER, Oded (Weizmann Institute of Science, Israel)

**Presenter:** Mr OHAYON, Ben (Racah Institute of Physics)

**Session Classification:** parity violation/weak interaction

Contribution ID: 33

Type: **Talk**

## Towards parity nonconservation measurements in francium

*Thursday, June 14, 2018 2:30 PM (25 minutes)*

We are developing experiments to study parity nonconservation effects in neutral francium atoms at the ISAC radioactive beam facility at TRIUMF. We are using laser cooling and trapping techniques to prepare the atoms for our measurements and our current effort is based on optical spectroscopy of Stark induced  $7s$ - $8s$  atomic transitions aiming at Standard Model test of the strength of the electron-quark weak neutral coupling. We have observed this transition in several isotopes of francium using an equal frequency two photon excitation scheme. We have measured the isotope shifts in the  $7s$ - $8s$  transition and combining our measurements with previously measured isotope shifts of the  $7s$ - $7p_{1/2}$  transition obtained the ratio of the field shift constants. Our measured value of the field shift ratio ( $1.228 \pm 0.019$ ) is in good agreement with ab-initio theory [see M. Kalita et al. Phys. Rev. A accepted]. This ratio is sensitive to the electron wavefunctions near the nucleus, needed to interpret the planned parity nonconservation measurements. We will also discuss recent developments towards observing the Stark-induced  $7s$ - $8s$  transitions in francium and the equivalent  $5s$ - $6s$  transitions in rubidium.

**Primary author:** Dr KALITA, Mukut Ranjan (TRIUMF)

**Presenter:** Dr KALITA, Mukut Ranjan (TRIUMF)

**Session Classification:** parity violation/weak interaction

Contribution ID: 34

Type: **Poster**

## Precision Measurement of the $\beta$ -energy Spectrum in ${}^6\text{He}$ Decay

*Thursday, June 14, 2018 3:46 PM (2 minutes)*

Precision measurements of the  $\beta$ -energy spectrum in nuclear and neutron decays have a great potential to find possible signatures of new physics beyond the standard electroweak model. Such signatures would produce a distortion of the  $\beta$ -energy spectrum relative to the Standard Model prediction. In Gamow-Teller transitions, these distortions would indicate the presence of the exotic tensor type interactions. An interesting candidate for this study is  ${}^6\text{He}$  because the simplicity of its decay and other nuclear properties allow an accurate theoretical description of the spectrum shape.

At the National Superconducting Cyclotron Laboratory we have used a calorimetric technique for measuring the shape of the  $\beta$ -energy spectrum in  ${}^6\text{He}$  decay. The radioactive ions were implanted into the active volume of a detector; this eliminates the critical instrumental effect related to the backscattering of  $\beta$  particles. The first goal of the experiment is to determine the weak magnetism form factor which has never been measured in  ${}^6\text{He}$  decay. The presentation reports the status of the data analysis, focusing on the study of the main systematic effects, as well as the projected sensitivity of the first measurement.

**Acknowledgement:** this work is supported by the National Science Foundation (US) under grant number PHY-11-02511.

**Primary authors:** Ms HUYAN, Xueying (National Superconducting Cyclotron Laboratory; Department of Physics and Astronomy, Michigan State University); Prof. NAVILIAT-CUNCIC, Oscar (National Superconducting Cyclotron Laboratory; Department of Physics and Astronomy, Michigan State University); Prof. BAZIN, Daniel (National Superconducting Cyclotron Laboratory); Prof. GADE, Alexandra (National Superconducting Cyclotron Laboratory; Department of Physics and Astronomy, Michigan State University); Mr HUGHES, Maximilian (National Superconducting Cyclotron Laboratory; Department of Physics and Astronomy, Michigan State University); Prof. LIDDICK, Sean N. (National Superconducting Cyclotron Laboratory; Department of Chemistry, Michigan State University); Prof. MINAMISONO, Kei (National Superconducting Cyclotron Laboratory; Department of Physics and Astronomy, Michigan State University); Dr NOJI, Shumpei (National Superconducting Cyclotron Laboratory); Dr PAULAUSKAS, Stanley V. (National Superconducting Cyclotron Laboratory); Prof. VOYTAS, Paul A. (Department of Physics, Wittenberg University); Dr WEISSHAAR, Dirk (National Superconducting Cyclotron Laboratory); Prof. SIMON, Anna (National Superconducting Cyclotron Laboratory; Department of Physics, University of Notre Dame)

**Presenter:** Ms HUYAN, Xueying (National Superconducting Cyclotron Laboratory; Department of Physics and Astronomy, Michigan State University)

**Session Classification:** poster

Contribution ID: 35

Type: **Poster**

## Spin tune mapping at COSY

*Thursday, June 14, 2018 3:48 PM (2 minutes)*

In precision searches for electric dipole moments of charged particles using storage rings, one needs to quantify background signals that stem from false rotations of the magnetic dipole moments in the horizontal magnetic fields of the storage ring. Mapping the spin tune response of a machine with artificially applied longitudinal magnetic fields allows one to probe the magnetic imperfection field content of the ring. The novel technique, called spin tune mapping, emerges as an extremely powerful probe of the spin dynamics in storage rings. The technique was experimentally tested by JEDI at COSY, and for the first time, the angular orientation of the stable spin axis has been determined to an unprecedented accuracy of  $2.8 \mu\text{rad}$ .

**Primary author:** SALEEV, Artem (Forschungszentrum Juelich)

**Presenter:** SALEEV, Artem (Forschungszentrum Juelich)

**Session Classification:** poster

Contribution ID: 36

Type: **Talk**

## Tests of discrete symmetries with the neutral kaon system at the KLOE and KLOE-2 experiments

*Wednesday, June 13, 2018 12:00 PM (20 minutes)*

The KLOE-2 experiment continues and extends the program of its predecessor KLOE in the field of discrete symmetry tests with the K meson system, among other studies which comprise light meson spectroscopy, dark matter searches and  $\gamma\gamma$  physics. Together, KLOE and KLOE-2 have recorded the largest sample (almost  $8 \text{ fb}^{-1}$ ) of e+e- collisions at the energy equal to  $\phi$  meson mass, amounting to  $2.4 \times 10^{10}$  of produced  $\phi$  mesons.

The talk will report on the latest results and ongoing analyses of KLOE and KLOE-2 concerning discrete symmetry tests and measurements of symmetry-violating observables. A measurement of the CPT violation sensitive asymmetry in semileptonic decays of  $K_S$  with  $1.7 \text{ fb}^{-1}$  of KLOE data will be presented, which improves the sensitivity w.r.t. previous measurements about twice. Moreover, status of direct tests of T and CPT in transitions of neutral kaons performed with the  $\phi \rightarrow K_S K_L \rightarrow \pi e \nu, 3\pi^0 (2\pi^0)$  processes will be reported, followed by the search of the CP-violating decay  $K_S \rightarrow 3\pi^0$  using the recently acquired data of KLOE-2.

**Primary author:** Mr GAJOS, Aleksander (Jagiellonian University in Krakow, Poland)

**Presenter:** Mr GAJOS, Aleksander (Jagiellonian University in Krakow, Poland)

**Session Classification:** CPT



Contribution ID: 37

Type: **Poster**

## Towards parity nonconservation measurements in francium

*Thursday, June 14, 2018 3:50 PM (2 minutes)*

We are developing experiments to study parity nonconservation effects in neutral francium atoms at the ISAC radioactive beam facility at TRIUMF. We are using laser cooling and trapping techniques to prepare the atoms for our measurements and our current effort is based on optical spectroscopy of Stark induced 7s-8s atomic transitions aiming at Standard Model test of the strength of the electron-quark weak neutral coupling. We have observed this transition in several isotopes of francium using an equal frequency two photon excitation scheme. We will discuss our recent progress towards observation of the single photon Stark induced 7s-8s transition; in particular our experiences with generating an electric field with transparent electrodes and building a power build up cavity in vacuum.

**Primary author:** Dr KALITA, Mukut Ranjan (TRIUMF)

**Presenter:** Dr KALITA, Mukut Ranjan (TRIUMF)

**Session Classification:** poster

Contribution ID: 38

Type: **Talk**

## Review of solar and geo-neutrino studies

*Monday, June 11, 2018 11:00 AM (30 minutes)*

The Borexino liquid scintillator neutrino observatory is devoted to perform high-precision neutrino observations, and it is optimized for measurements in the low energy (sub-MeV) region of the neutrino spectrum. The direct measurements, already accomplished, of the interaction rates from pp,  $^7\text{Be}$ , pep,  $^8\text{B}$  neutrinos put Borexino in the unique situation of being the only experiment able to validate the MSW-LMA oscillation paradigm across the full solar energy range. Very recently, high-precision determinations (down to  $\sim 2.8\%$  in the  $^7\text{Be}$  component) have been attained using new techniques and enlarged statistics from the post-scintillator-purification phase.

The exceptional radiopurity is the key to the uniqueness of the detector's results and the base for providing good sensitivity to faint signals such as the ones induced by geo-neutrinos, the antineutrinos released in the decays of radioactive elements distributed through the Earth. The geo-neutrino fluxes, detected by Borexino with a statistical significance of  $5.9\sigma$ , are in a well-fixed ratio with the total mass of radioactive elements inside the Earth, thus, it is possible to extract geological information unreachable by other means and fundamental to understand the Earth's heat balance.

The present talk is aimed to present results achieved by Borexino on geo-neutrinos fluxes and on all the solar neutrino species and based on the full 10 years data sample and, in particular, on the more radiopure phase 2 data, taken after the detector purification campaigns in 2010-11. In the solar neutrino analysis, a new multivariate method has been developed to extend the data fitting procedure over a broad energy range and to contemporarily extract the different solar neutrino components. The new results will be helpful to constrain the solar metallicity and to validate MSW-LMA paradigm and to explore the upturn energy region where the effect of possible non-standard interactions could be exposed. The talk will be concluded highlighting the perspectives for the final stage of the solar program of the experiment, centered on the goal to fully complete the solar spectroscopy with the missing piece of the CNO neutrinos.

**Primary author:** ZAVATARELLI, sandra (INFN Genova Italy)

**Presenter:** ZAVATARELLI, sandra (INFN Genova Italy)

**Session Classification:** Neutrinos

Contribution ID: 39

Type: Talk

## High-Precision Comparisons of the Fundamental Properties of Protons and Antiprotons at BASE

Monday, June 11, 2018 5:00 PM (30 minutes)

The Baryon Antibaryon Symmetry Experiment (BASE-CERN) at CERN's antiproton decelerator facility conducts high-precision comparisons of the fundamental properties of protons and antiprotons, such as their charge-to-mass ratios, magnetic moments and lifetimes. These experiments provide sensitive tests of charge-parity-time (CPT) invariance in the baryon sector. BASE was approved in 2013 and has since used single-particle multi-Penning-trap techniques to measure the antiproton-to-proton charge-to-mass ratio with a fractional precision of 69 p.p.t. [1]. The antiproton magnetic moment has been measured with a fractional precision of 0.8 p.p.m. [2] and subsequently at the level of 1.5 p.p.b. [3]. At our matter companion experiment BASE-Mainz, we have performed proton magnetic moment measurements with fractional uncertainties of 3.3 p.p.b. [4] and 0.3 p.p.b. [5]. By combining the data of both experiments we provide a baryon-magnetic-moment based CPT test  $g_{\bar{p}}/g_p = 1.0000000002(15)$ , which improves the uncertainty of previous experiments by more than a factor of 3000 [6]. In this talk I will review the achievements of BASE, focusing on the antiproton-to-proton charge-to-mass ratio and magnetic moment measurements conducted at BASE-CERN.

- [1] S. Ulmer *et al.*, *Nature* **524**, 196 (2015).
- [2] H. Nagahama *et al.*, *Nat. Commun.* **8**, 14084 (2017).
- [3] C. Smorra *et al.*, *Nature* **550**, 371 (2017).
- [4] A. Mooser *et al.*, *Nature* **509**, 596 (2014).
- [5] G. Schneider *et al.*, *Science* **358**, 1081 (2017).
- [6] J. DiSciaccia *et al.*, *Phys. Rev. Lett.* **110**, 130801 (2013).

**Primary authors:** DEVLIN, Jack (RIKEN (JP)); SMORRA, Christian (RIKEN (JP)); SELNER, Stefan (RIKEN (JP)); BORCHERT, Matthias Joachim (Universitaet Hannover (DE)); HARRINGTON, James Anthony (Max-Planck-Gesellschaft (DE)); HIGUCHI, Takashi (University of Tokyo (JP)); NAGAHAMA, Hiroki (RIKEN (JP)); TANAKA, Toya (RIKEN (JP)); BLESSING, Pascal (GSI - Helmholtzzentrum fur Schwerionenforschung GmbH (DE)); MOOSER, Andreas Hannes (RIKEN (JP)); SCHNEIDER, Georg Ludwig (Johannes Gutenberg Universitaet Mainz (DE)); BOHMAN, Matthew Anders (Max-Planck-Gesellschaft (DE)); BLAUM, Klaus (Max-Planck-Gesellschaft (DE)); MATSUDA, Yasuyuki (University of Tokyo (JP)); OSPELKAUS, Christian (Universitaet Hannover (DE)); QUINT, Wolfgang (GSI - Helmholtzzentrum fur Schwerionenforschung GmbH (DE)); WALZ, Jochen (Johannes Gutenberg-Universitaet (DE)); YAMAZAKI, Yasunori (RIKEN (JP)); ULMER, Stefan (RIKEN (JP))

**Presenter:** DEVLIN, Jack (RIKEN (JP))

**Session Classification:** CPT

Contribution ID: 40

Type: **Poster**

## The neutron lifetime experiment $\tau$ SPECT

*Thursday, June 14, 2018 3:52 PM (2 minutes)*

The decay of the free neutron into a proton, electron and antineutrino is the simplest example of the nuclear beta decay. The lifetime of this process is measured either by beam or by storage experiments. Currently, their results show a discrepancy of about 7 s which is also known as the “neutron lifetime puzzle”. Two major systematic effects in neutron experiments are losses due to up-scattering and material wall collisions. The experiment  $\tau$ SPECT aims to avoid these effects by using a three-dimensional magnetic storage of ultracold neutrons (UCN) produced by the recently upgraded UCN source at TRIGA Mainz [1]. Two separate methods will be used for the determination of the neutron lifetime: Detection of decay protons during storage, and counting of remaining neutrons afterwards. It is aimed for a final accuracy of 0.3 s. Earlier test measurements have successfully demonstrated the storage of UCN in the longitudinal magnetic field of  $\tau$ SPECT, while still using material wall storage in radial direction [2]. Phase 1 of the  $\tau$ SPECT experiment is currently being commissioned and enables full magnetic storage of UCN along with in-situ UCN detection. The presented poster gives an overview and discusses the current status of  $\tau$ SPECT.

[1] J. Kahlenberg et al., Eur. Phys. J. A 53, 226-236 (2017)

[2] J. Karch, PhD thesis, <http://nbn-resolving.de/urn:nbn:de:hebis:77-diss-1000016406> (2017)

**Primary author:** Ms ROSS, Kim Ulrike (Institute of Nuclear Chemistry, Johannes Gutenberg University Mainz)

**Co-author:** TAUSPECT COLLABORATION

**Presenter:** Ms ROSS, Kim Ulrike (Institute of Nuclear Chemistry, Johannes Gutenberg University Mainz)

**Session Classification:** poster

Contribution ID: 41

Type: **Talk**

## Measuring the Neutron Lifetime at Los Alamos National Lab with UCN $\tau$

*Thursday, June 14, 2018 12:00 PM (30 minutes)*

The mean lifetime for  $\beta$ -decay of a free neutron is an interesting empirical target because it is an input for calculation of light element abundances in the early universe, affects predictions from cosmic microwave background data about the number of effective neutrino species, and in combination with other  $\beta$ -decay observables can provide sensitive tests for physical phenomena not currently included in the Standard Model. Theoretical uncertainties and uncertainties in astrophysical measurements make the interesting precision band for measurements of  $\tau_n$  between 0.1% and 0.01%. Current experimental techniques have the capability to reach precisions in this range, but a clear application of the resulting measurements is hampered by a nearly four-sigma discrepancy between the two prevalent methods, called the “beam” and “bottle” techniques. The recent UCN $\tau$  result  $\begin{equation} \tau_n = 877.7 \pm 0.7_{\mathrm{(stat)}} + 0.4/-0.2_{\mathrm{(sys)}} \end{equation}$  is of the latter type, and maintains the discrepancy between beam and bottle determinations despite using a large-volume magneto-gravitational trap which eliminates the dominant systematic effect in material bottle experiments and features new detection techniques that allow direct empirical characterization of residual systematic effects. This result has led to renewed interest in possible exotic explanations for the beam/bottle discrepancy. I will describe the experimental developments leading to our new result, the current status of the UCN $\tau$  experiment, and our plans for future measurements.

**Primary author:** Prof. HOLLEY, Adam (Tennessee Technological University)

**Presenter:** Prof. HOLLEY, Adam (Tennessee Technological University)

**Session Classification:** neutron

Contribution ID: 42

Type: **Talk**

## Review of absolute neutrino mass measurements

*Monday, June 11, 2018 9:30 AM (30 minutes)*

Neutrino flavor oscillation experiments have firmly established that neutrinos do have non-zero masses. This is a contradiction to the minimal Standard Model (SM) of Particle Physics. While being insensitive to the absolute neutrino mass scale, flavor oscillation experiments provide lower mass limits, depending on the neutrino mass ordering. Direct neutrino mass measurements establish upper limits and probe extensions of the SM employed to explain finite neutrino masses. Furthermore, comparison with neutrino masses extracted from cosmological observations can provide a non-trivial test of the Standard Model of Cosmology. The Mainz and Troitsk experiments established upper limits of  $\leq 2 \text{ eV}/c^2$  on the effective nuclear beta decay electron neutrino mass. The KATRIN experiment aims to reduce these limits down to  $\leq 200 \text{ meV}/c^2$  and will probe the quasi degenerate regime of neutrino mass ordering. I will review the current status of KATRIN and of fundamentally new laboratory approaches currently under development to either confirm a positive result independently or to push the sensitivity limit towards the  $40 \text{ meV}/c^2$  range, the lowest allowed electron neutrino mass under the inverted mass ordering. The new approaches (Project 8, ECHo, Holmes, ...) uniquely combine new radioactive source concepts with novel schemes of decay electron spectroscopy to address the statistical and systematic challenges presented by this ambitious sensitivity goal. Major financial support by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics to the University of Washington under Award Number DE-FG02-97ER41020 is acknowledged.

**Primary author:** Prof. FERTL, Martin (University of Washington)

**Presenter:** Prof. FERTL, Martin (University of Washington)

**Session Classification:** Neutrinos

Contribution ID: 43

Type: **Talk**

## Modern reanalysis of the reactor anomaly conversion method

*Monday, June 11, 2018 2:30 PM (30 minutes)*

The field of reactor neutrino physics has accumulated a series of anomalies over the years, the most recent of which occurs with reactor antineutrinos. The appearance of such an anomaly relies on an exquisite knowledge of both beta spectrum shapes and isotopic abundance inside the reactor medium. In an attempt to mitigate the uncertainties of the latter, a conversion method is typically used utilising virtual beta branches relative to experimental cumulative beta spectra of several fission actinides measured at the Institut Laue-Langevin. Currently, the parametrisation of these virtual branches is drastically oversimplified and suffers from several flaws, ranging from the treatment of nuclear structure influences to forbidden decays and Coulomb corrections. This, in turn, results in an underestimation of the uncertainty and systematic shift in the central value of the anomaly. Faced with the enormity of the number of participating branches, we present a modern reanalysis method based on machine learning techniques in combination with Monte Carlo methods. Using clustering algorithms, we find high-dimensional correlations in the nuclear databases to open up the parameter space of the virtual branch construction. Together with results from forbidden transitions, we perform Monte Carlo sampling in an attempt to quantitatively discuss the uncertainty on the reactor anomaly. We will show that also ab initio methods can benefit from these techniques.

**Primary author:** Mr HAYEN, Leendert (KU Leuven)

**Co-authors:** Prof. SEVERIJNS, Nathal (KU Leuven); Prof. SUHONEN, Jouni (University of Jyväskylä); Mr KOSTENSALO, Joel (University of Jyväskylä)

**Presenter:** Mr HAYEN, Leendert (KU Leuven)

**Session Classification:** Neutrinos

Contribution ID: 44

Type: **Poster**

## First commissioning results of the waveguide RF Wien filter

*Thursday, June 14, 2018 3:54PM (2 minutes)*

The JEDI (Jülich Electric Dipole Investigations) Collaboration aims to carry out a long term project for the measurement of the permanent electric dipole moments of charged particles in a storage ring. As a proof-of-concept, the COoler SYnchrotron (COSY) was equipped with a waveguide RF Wien filter designed to operate at some harmonics of the spin precession frequency ranging from 0.1 to 2 MHz. This device maintains the corresponding ratio between the RF electric and magnetic fields necessary not to induce any beam excitation and most importantly acts as a spin flipper.

In the course of 2017, the waveguide RF Wien has been successfully commissioned and tested. The ability of the device to produce a Lorentz Force compensation and to rotate the particles' polarization vector has been verified. Driven vertical spin oscillations and vertical polarization build-up has been observed.

**Primary author:** SLIM, Jamal (RWTH Aachen University)

**Presenter:** SLIM, Jamal (RWTH Aachen University)

**Session Classification:** poster



Contribution ID: 45

Type: **Talk**

## Precise spectroscopy of muonium hyperfine structure at J-PARC

*Friday, June 15, 2018 12:00 PM (30 minutes)*

Our experimental group, MuSEUM (Muonium Spectroscopy Experiment Using Microwave), has been doing a precise spectroscopy of muonium ground state hyperfine splitting (MuHFS) with high-intensity pulsed muon beam supplied from J-PARC. We aim ten-fold improvement of the preceding measurement of the experimental value of MuHFS both at zero magnetic field and in high magnetic field (1.7 T). Muonium is the bound state of a positive muon and an electron, both of which are leptons. This means that muonium is free from the finite-size effect of nucleons and thus the theoretical value of MuHFS can be determined precisely. Also we can measure the experimental value of it precisely compared with other exotic atoms such as positronium. Therefore we can compare the two values precisely and accordingly say that muonium is one of the most preferable system for the rigorous test of bound-state quantum electrodynamics (QED) theory. In addition, we can also obtain the value of the muon-proton magnetic moment ratio ( $\mu_\mu/\mu_p$ ) in the high-field measurement. Precise determinations of it can contribute to solving the muon anomalous magnetic moment (muon  $g-2$ ) puzzle because it is used to determine the experimental value of muon  $g-2$ . In this presentation, we report the result of the measurements in zero magnetic field and also the R&D of the high field measurement.

**Primary author:** SEO, Shun (The University of Tokyo)

**Presenter:** SEO, Shun (The University of Tokyo)

**Session Classification:** QED

Contribution ID: 46

Type: **Talk**

## Searches for the electric dipole moment of the neutron

*Tuesday, June 12, 2018 12:00 PM (20 minutes)*

Searches for electric dipole moments (EDM) of fundamental particles are considered one of the most sensitive approaches to physics beyond the Standard Model of particle physics (SM). A non-SM mechanism violating the combined symmetry of charge conjugation and parity inversion (CP-violation) could help to explain the observed baryon asymmetry of the Universe while manifesting itself as electric dipole moment of the neutron.

A discovery of an EDM of the neutron (nEDM) would indicate a violation of parity and time reversal symmetry (T) and assuming CPT invariance a violation of CP-symmetry. No nEDM has yet been observed. Several groups worldwide try to improve on the current best limit of  $d_n < 3 \times 10^{-26} \text{ e cm}$  (90% C.L.) [Pendlebury et al. PRD92(2006)092003].

In this overview talk I will explain the principal experimental techniques, give an overview of the world wide efforts and finally discuss the status and newest results from the nEDM-collaboration at the Paul Scherrer Institute in Switzerland.

**Primary author:** Dr SCHMIDT-WELLENBURG, Philipp

**Presenter:** Dr SCHMIDT-WELLENBURG, Philipp

**Session Classification:** EDM

Contribution ID: 47

Type: **Talk**

## Status and prospects of neutrino mass hierarchy and CP-violation measurements

*Monday, June 11, 2018 10:00 AM (30 minutes)*

With the discovery of the 3rd neutrino mixing angle,  $\theta_{13}$ , in 2012 a door was opened to answer the remaining unknowns in neutrino oscillations: the mass hierarchy, whether  $\theta_{23}$  is larger/smaller or exactly 45 degrees, and whether CP symmetry is violated. Several experiments have exciting new data and are exploring this landscape. I will review the current results and consider the prospects for the future.

**Primary author:** Prof. HARTNELL, Jeff (University of Sussex)

**Presenter:** Prof. HARTNELL, Jeff (University of Sussex)

**Session Classification:** Neutrinos

Contribution ID: 48

Type: **Talk**

## Measuring the hadronic contributions to $g-2$ of the muon

*Tuesday, June 12, 2018 2:30 PM (30 minutes)*

The final interpretation of the upcoming new measurements of anomalous magnetic moment of the muon,  $g-2$ , at Fermilab and at JPARC, require an improved Standard Model prediction of this quantity. The Standard Model calculation is entirely limited by strong interactions with two dominating contributions: (i) the hadronic vacuum polarization contribution, and (ii) the hadronic-light-by-light contribution. We review the status of these two diagrams and comment on the progress, which is expected in the upcoming years. As will be shown, precise measurements of form factors are required to significantly improve the present accuracy.

**Primary author:** Prof. DENIG, Achim (JGU Mainz)

**Presenter:** Prof. DENIG, Achim (JGU Mainz)

**Session Classification:** muon  $g-2$

Contribution ID: 49

Type: **Talk**

## Review on sterile neutrinos

*Monday, June 11, 2018 11:30 AM (30 minutes)*

I review the experimental indications in favor of short-baseline neutrino oscillations and I discuss their interpretation in the framework of 3+1 neutrino mixing with a sterile neutrino at the eV scale. I show that the recent results of the NEOS and DANSS reactor neutrino experiments give a new model-independent indication in favor of short-baseline electron antineutrino disappearance, confirming the reactor and Gallium anomalies. On the other hand, the recent result of the MINOS+ experiment disfavors the LSND anomaly. I also discuss the interpretation of the Daya Bay fuel evolution data.

**Primary author:** GIUNTI, Carlo (INFN - National Institute for Nuclear Physics)

**Presenter:** GIUNTI, Carlo (INFN - National Institute for Nuclear Physics)

**Session Classification:** Neutrinos

Contribution ID: 51

Type: **Talk**

## The n<sup>3</sup>He experiment: A new era in Hadronic Parity Violation

*Wednesday, June 13, 2018 9:30 AM (30 minutes)*

Parity violation (PV), first observed in semileptonic decays, has been determined precisely for quarks and leptons as part of the standard model. At the hadronic level, it offers a unique probe of nucleon structure and the underlying low-energy behavior of non-perturbative QCD. The hadronic weak interaction is characterized in terms of five spin and isospin dependent S-P transition amplitudes. There is an active program to determine these low energy couplings from hadronic PV observables using cold neutron beams at the Spallation Neutron Source (ORNL) and the NCNR reactor (NIST). These experiments are carried out in few-body observables, for which the nuclear wave functions are exactly calculable, but the effects are dominated by the strong interaction by seven orders of magnitude. The n<sup>3</sup>He experiment recently completed a measurement of the PV directional proton asymmetry with respect to the neutron spin in the reaction  $n + \text{}^3\text{He} \rightarrow p + \text{}^3\text{H}$ . We will report this result, which is sensitive to the  $\Delta I = 0, 1$  transition amplitudes. This is a major milestone in the road to mapping out the spin and isospin dependence of the hadronic weak interaction.

**Primary author:** CRAWFORD, Christopher (University of Kentucky)

**Presenter:** CRAWFORD, Christopher (University of Kentucky)

**Session Classification:** parity violation/weak interaction

Contribution ID: 52

Type: **Talk**

## Status of direct dark matter search and prospectives for ton and multi-ton scale detectors

*Tuesday, June 12, 2018 9:30 AM (30 minutes)*

The recent decade saw a tremendous improvement of sensitivities in direct searches for dark matter, which keep improving at a rate of about an order of magnitude every couple of years. The major improvements so far have been mostly in scaling up the size and exposure of the experiments, with all of the related challenges.

I will review some of the basic rules dominating this line of searches, and will focus on the recent years results and developments of upcoming multi ton (G3) scale experiments, along with some alternative directions.

**Primary author:** BUDNIK, Ranny (Weizmann Institute of Science)

**Presenter:** BUDNIK, Ranny (Weizmann Institute of Science)

**Session Classification:** dark matter/cosmology

Contribution ID: 53

Type: **Talk**

## The future of neutrino physics

*Monday, June 11, 2018 3:30 PM (30 minutes)*

In the recent years neutrino physics achieved very important goals like the discovery of neutrino oscillations, proving that neutrino have mass.

These discoveries open the door to even more ambitious searches like the hunt for CP violation in neutrino oscillations, the quest for the absolute neutrino mass and the ordering of the three neutrino masses, the question if neutrinos are their own antiparticles and the possibility that more neutrino species exist, not participating to weak interactions.

The talk will try to discuss the international panorama of future projects with a little more attention to those related to neutrino oscillations.

**Primary author:** Dr MEZZETTO, Mauro (INFN Padova)

**Presenter:** Dr MEZZETTO, Mauro (INFN Padova)

**Session Classification:** Neutrinos



Contribution ID: 54

Type: **Talk**

## Stringent tests of bound-state QED using highly charged ions

*Friday, June 15, 2018 12:30 PM (30 minutes)*

The ultra-precise determination of the  $g$ -factor of highly charged ions is a unique possibility to test the validity of the Standard Model, particularly Quantum Electrodynamics (QED) in extreme electric fields up to  $10^{16}$  V/cm. While the weak-field regime has been exquisitely tested, in the presence of strong fields higher-order contributions beyond the Standard Model might become significant. It is possible to sensitively search for such effects by measuring the Larmor- and cyclotron frequencies of single, highly charged ions in a cryogenic Penning trap with high precision. This way, by measuring the  $g$ -factor of medium heavy hydrogenlike ions with previously unprecedented precision, we have been able to perform the most stringent test of QED in strong fields. Particularly the effect of the nucleus on the  $g$ -factor of the electron is a novel and unique access to nuclear size and structure information.

To push these tests far into the strong-field, heavy ion regime, in the past years we have set up a new setup, ALPHATRAP at the Max-Planck-Institut für Kernphysik in Heidelberg. ALPHATRAP has been successfully commissioned in the last months and is now setting out to perform measurements of the  $g$ -factor of the heaviest elements up to hydrogenlike  $^{208}\text{Pb}^{81+}$ . This will not only enable the most sensitive tests of QED, but also open a unique access to fundamental constants as the atomic mass of the electron and the finestructure constant  $\alpha$ .

**Primary author:** Dr STURM, Sven (Max-Planck Institut für Kernphysik)

**Presenter:** Dr STURM, Sven (Max-Planck Institut für Kernphysik)

**Session Classification:** QED

Contribution ID: 55

Type: **Talk**

## Recent Progress of the JEDI Collaboration

*Tuesday, June 12, 2018 11:40 AM (20 minutes)*

Electric Dipole Moments (EDMs) of elementary particles are important candidates for CP violation and hence possible sources for the observed matter-antimatter asymmetry in the universe. The Jülich Electric Dipole Moment Investigation (JEDI) collaboration is searching for EDMs of light nuclei. Ideally this would be done in a designated storage ring using the frozen spin concept. Such a ring does not exist currently but is in the design phase. The COSY ring in Jülich is used to study various issues of a designated ring and uses an rf-Wienfilter to measure the EDM of the deuteron for the first time. This talk gives an overview of the experimental techniques with a focus on recent achievements and highlights their relevance for a designated EDM ring.

**Primary author:** GAISSER, Martin (RWTH Aachen University)

**Presenter:** GAISSER, Martin (RWTH Aachen University)

**Session Classification:** EDM

Contribution ID: 56

Type: **Talk**

## Discrete Symmetries, Neutrino Mixing and Leptonic CP Violation

*Monday, June 11, 2018 3:00 PM (30 minutes)*

The current status of our knowledge of the 3-neutrino mixing parameters and of the CP violation in the lepton sector is summarised.

The non-Abelian discrete symmetry approach to understanding the observed pattern of neutrino mixing and the related predictions for neutrino mixing angles and leptonic Dirac CP violation are reviewed.

**Primary author:** Prof. PETCOV, Serguey (SISSA/INFN, Trieste, Italy, and Kavli IPMU, Univ. of Tokyo, Jaopan)

**Presenter:** Prof. PETCOV, Serguey (SISSA/INFN, Trieste, Italy, and Kavli IPMU, Univ. of Tokyo, Jaopan)

**Session Classification:** Neutrinos

Contribution ID: 57

Type: **Talk**

## Review on high energy neutrino measurements

*Monday, June 11, 2018 2:00 PM (30 minutes)*

High-energy neutrinos are an important messenger particle to understand the high-energy universe. In 2013, the IceCube Neutrino Observatory has reported the first observation of a flux of high-energy astrophysical neutrinos with energies reaching above PeV. However, the sources of these neutrinos remain a puzzle. Since then, these measurements have been refined and the observation has been confirmed with independent data sets. This talk will give an overview of the observations with a focus on the most recent results and gives an outlook to the future.

**Primary author:** WIEBUSCH, Christopher (Rheinisch Westfaelische Tech. Hoch. (DE))

**Presenter:** WIEBUSCH, Christopher (Rheinisch Westfaelische Tech. Hoch. (DE))

**Session Classification:** Neutrinos

Contribution ID: 58

Type: **Talk**

## In-beam hyperfine spectroscopy of (anti)hydrogen

*Monday, June 11, 2018 4:30 PM (30 minutes)*

The ground-state hyperfine structure (GS-HFS) of hydrogen is known from the hydrogen maser to relative precision of  $10^{-12}$ . It is of great interest to measure the same quantity for its antimatter counterpart, antihydrogen, to test the fundamental CPT symmetry, which states that all particles and antiparticles have exactly equal or exactly opposite properties. Since CPT is strictly conserved in the Standard Model of particle physics, a violation, if found, would point directly to theories behind this framework. The application of the maser technique requires the confinement of the atoms in a matter box for 1000 seconds and is currently not applicable to antihydrogen. Therefore, the ASACUSA collaboration at the Antiproton Decelerator of CERN has built a Rabi-type beam spectroscopy setup for a measurement of GS-HFS.

With the initial aim of characterizing the setup devised to measure the GS-HFS and to evaluate its potential, a beam of cold, polarized, monoatomic hydrogen was built and used together with the microwave cavity and sextupole magnet designed for the antihydrogen experiment. The  $(F,M)=(1,0)$  to  $(0,0)$  transition was measured to a precision of 2.7 ppb [1], more than a factor 10 better than in the previous measurement using a hydrogen beam. This result shows that the apparatus developed is capable of making a precise measurement of the GS-HFS of antihydrogen provided a beam of similar characteristics (velocity, polarization, quantum state) becomes available.

In a recent publication on the non-minimal Standard Model Extension (SME), describing possible violations of Lorentz and CPT invariance, Kostelecky and Vargas [2] conclude that the in-beam hyperfine measurements of hydrogen alone can be used to constrain certain coefficients of their model, which have never been measured before. The status and prospects of in-beam measurements of hydrogen and antihydrogen will be presented.

[1] M. Diermaier et al., Nat. Commun. 8, 15749 (2017), arxiv:1610.06392

[2] V.A. Kostelecky and A.J. Vargas, Physical Review D 92, 056002 (2015).

**Primary author:** WIDMANN, Eberhard (Austrian Academy of Sciences (AT))

**Presenter:** WIDMANN, Eberhard (Austrian Academy of Sciences (AT))

**Session Classification:** CPT

Contribution ID: 59

Type: **Poster**

## The EDM Polarimeter Development at COSY-Jülich

*Thursday, June 14, 2018 3:56 PM (2 minutes)*

The JEDI (Jülich Electric Dipole moment Investigations) collaboration performs a set of experiments at the COSY storage ring in Jülich, within the R&D phase to search for the Electric Dipole Moments (EDMs) of charged particles. A measurement of proton and deuteron EDMs is a sensitive probe of yet unknown CP violation. An EDM observation would also be an indication for physics beyond the Standard Model.

The method of charged particle EDM search will exploit stored polarized beams in order to observe a miniscule rotation of the polarization axis as a function of time due to the interaction of a finite EDM with large electric fields. Key challenge is the provision of a sensitive and efficient method to determine the tiny change of the beam polarization. Elastic scattering of the beam particles on carbon nuclei will provide the polarimetry reaction.

To perform these measurement, an EDM polarimeter needs to be developed. The polarimetry concept developed within the JEDI collaboration is based on a heavy crystal (LYSO) hadron calorimeter. LYSO as a fast, dense and radiation hard, novel scintillating material was chosen to fulfill these specifications. The polarimeter is designed in a compact and modular fashion consisting of modules made from LYSO crystals coupled to silicon photomultipliers (SiPM).

An overview on the development of this polarimeter will given in this poster presentation.

**Primary author:** Mr MÜLLER, Fabian (Forschungszentrum Jülich, RWTH Aachen)

**Presenter:** Mr MÜLLER, Fabian (Forschungszentrum Jülich, RWTH Aachen)

**Session Classification:** poster

Contribution ID: 61

Type: **Poster**

## **New read-out electronics for the ICARUS LAr-TPC detector at Fermilab**

The ICARUS T600, a liquid argon time projection chamber (LAr-TPC), underwent a major overhauling at CERN in 2015-2017, which included also a new design of the read-out electronics, in view of its operation in Fermilab on the Short Baseline Neutrino (SBN) program. The new more compact electronics showed capability of handling more efficiently also the signals in the intermediate Induction 2 wire plane with a significant increase of S/N, allowing charge measurement. The new front-end and the AD conversion (ADC) system are presented together with the results of the tests on 50 liters liquid argon TPC performed in CERN with cosmic rays.

**Primary author:** MENEGOLLI, Alessandro

**Presenter:** MENEGOLLI, Alessandro

**Session Classification:** poster

Contribution ID: 64

Type: **not specified**

## Precision Experiments with Trapped Antihydrogen at ALPHA

Hydrogen is the best studied physical system, both theoretically and experimentally, therefore antihydrogen, the antimatter equivalent of hydrogen, offers a unique way to test matter-antimatter symmetry. In particular, the CPT invariance theorem implies that hydrogen and antihydrogen have the same spectrum. The ALPHA experiment at CERN can synthesize and confine a large number of antihydrogen atoms for extended periods of time. This enabled successful experimental campaigns to measure the frequency of the 1S-2S transition [1, 2] and the hyperfine splitting of the ground state [3], owing to improved antihydrogen production techniques [4, 5]. An important aspect of the ALPHA experimental methodology is the identification of the antihydrogen annihilations by means of the silicon vertex detector. The combination of the above techniques allowed ALPHA to probe the CPT symmetry to an absolute energy sensitivity of  $2 \times 10^{-20}$  GeV.

- [1] Ahmadi, M. et al. , Nature 548, 506 (2017)\
- [2] Ahmadi, M. et al. , Nature 557, (2018)\
- [3] Ahmadi, M. et al., Nature 541, 66 (2017)\
- [4] Ahmadi, M. et al. , Nature Comm. 8, 681 (2017)\
- [5] Ahmadi, M. et al., Phys. Rev. Lett. 120 , 025001 (2018)

**Presenter:** ANDREA, Capra (Alpha Collaboration, TRIUMF)



Contribution ID: 65

Type: **Talk**

## Precision Spectroscopy of Trapped Antihydrogen in the ALPHA Experiment

*Wednesday, June 13, 2018 11:20 AM (20 minutes)*

Precision measurements of magnetically trapped antihydrogen provides a unique and powerful way to test fundamental symmetries. A cornerstone of the standard model, CPT symmetry demands that the spectrum of antihydrogen be identical to that of its ordinary matter counterpart. Of particular interest is the 1S-2S transition which has been measured in hydrogen[1] with the remarkable relative precision of a few parts in  $10^{15}$ , and promises a particularly elegant and high precision test of CPT symmetry by comparison to antihydrogen.

In 2016, the ALPHA collaboration made the first observation[2] of the 1S-2S transition in antihydrogen, and very recently this measurement was drastically improved[3] to reach a fractional precision of  $2 \times 10^{-12}$ . The observed frequency in antihydrogen is consistent with CPT symmetry at the current level of precision.

In this talk, I will present this latest measurement of the 1S-2S transition and introduce the methods of anti-atom spectroscopy developed by ALPHA. Finally, I will touch on future improvements needed to take this milestone measurement to the same precision as its hydrogen counterpart.

[1] Parthey, C.G. et al, Phys. rev. lett. 107, 203001 (2011).

[2] Ahmadi, M. et al, Nature 541, 506-510 (2017).

[3] Ahmadi, M et al, Nature (2018)

**Primary authors:** RASMUSSEN, Chris (CERN); ON BEHALF OF THE ALPHA COLLABORATION

**Presenter:** RASMUSSEN, Chris (CERN)

**Session Classification:** CPT

Contribution ID: 66

Type: **Talk**

## Single Trapped Ions for Atomic Parity Violation Measurements

*Tuesday, June 12, 2018 5:20 PM (30 minutes)*

Searches for violations of the fundamental discrete symmetries parity (P), time reversal (T) and charge conjugation (C) provide guidelines for model building beyond the Standard Model of the electroweak interactions (SM).

Measurements of atomic parity violation (APV) provide a test the electroweak interactions at low energies, while other experiments like searches for permanent electric dipole moments look for physics not yet described in the SM.

Symmetry violating effects are strongly enhanced in heavy atomic systems and become measurable in precision atomic physics experiment. In particular, technology of single ion trapping for optical clocks and alkaline earth ions such as  $\text{Ba}^+$  or  $\text{Ra}^+$  open the pathway to a new determination of atomic parity violation. Understanding of the precision of such an experiment as well as the extraction of atomic structure is the most challenging task. Along this way experimental input for the determination of atomic wavefunctions is indispensable. We will discuss the determination of metastable state lifetime in  $\text{Ba}^+$  [1], absolute transition frequency determination [2] and modeling of the observed lineshapes in an APV experiment. With these steps a precision determination of the weak charge suitable for extracting the weak mixing angle (Weinberg angle) with five-fold improvement over best existing experiment on with neutral cesium becomes feasible.

[1] E.A. Dijck et al., Lifetime of the  $5d\ ^2D_{5/2}$  level of  $^{138}\text{Ba}^+$  from quantum jumps with single and multiple  $\text{Ba}^+$  ions. *Physical Review A* 97, 32508 (2018).

[2] E.A. Dijck et al., Determination of transition frequencies in a single  $^{138}\text{Ba}^+$  ion. *Physical Review A* 91, 060501 (2015).

**Primary author:** WILLMANN, Lorenz (University of Groningen/ NL)

**Presenter:** WILLMANN, Lorenz (University of Groningen/ NL)

**Session Classification:** parity violation/weak interaction

Contribution ID: 67

Type: Talk

## Positronium and Muonium 1S-2S laser spectroscopy

*Wednesday, June 13, 2018 12:20 PM (30 minutes)*

Positronium and muonium, being purely leptonic, are very interesting systems to test bound state QED free of finite size effects and hadronic corrections [1]. They are also very sensitive probes to search for New Physics [2] and can be used to extract fundamental constants such as the muon mass and magnetic moment [3].

In this talk, we report the current status of the ongoing experiment at ETH Zurich [4] aiming to improve the accuracy on the 1S-2S transition frequency of positronium in order to cross check the latest QED calculations [5]. We will present some preliminary results including the technique we developed to correct for the second order Doppler shift, the main systematic uncertainty in this experiment.

We will show that with the recent advances in UV laser technology, our novel cryogenic muonium converters and the detection techniques we developed for positronium spectroscopy, a 1000-fold improvement in the determination of the same transition in muonium compared to the current results [6] will be possible using the LEM beamline at PSI. This will provide the best determination of the muon mass at the 1 ppt level. It can also be used to extract the muon  $g-2$  from the ongoing experiment at Fermilab which have a projected accuracy of 0.1 ppm [7]. In fact at this level, the comparison with the theoretical value will be limited by the current knowledge of the muon magnetic moment or the muon mass.

Moreover, by using the expected results of the ongoing hyperfine splitting measurement of muonium in Japan at JPARC [8], it will provide one of the most sensitive tests of bound-state Quantum Electrodynamics. It will also allow to determine the Rydberg constant free from nuclear and finite-size effects at a level of  $10^{-12}$  which is interesting in light of the proton charge radius puzzle [9] and provide a new determination of the fine structure constant at a level of 1 ppb. This has to be compared with the electron  $g-2$  experiment at Harvard (0.24 ppb) [10], the Rubidium experiment at Laboratoire Kastler Brossel (0.62 ppb) [11] and the very recent experiment using matter-wave interferometry with a cloud of cesium atoms (0.12 ppb) [12].

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`\textbf{References}\par`

`\footnotesize`

`\vspace{0.5cm}`

[1] S. Karshenboim, Phys. Rep. **422**, 1 (2005).

[2] see e.g. L. Willmann et al., Phys. Rev. Lett. **82**, 49 (1999); A. Badertscher et al., Phys. Rev. D **75**, 032004 (2007).

[3] P. J. Mohr, D. B. Newell and B. N. Taylor, Rev. Mod. Phys. **88**, 035009 (2016).

[4] D. Cooke et al., Hyperfine Int. **233**, 67 (2015).

[5] G. S. Adkins et al., Phys. Rev. Lett. **115** 233401 (2015) and references therein

[6] V. Meyer et al., Phys Rev. Lett. **84**, 1136 (2000).

[7] W. Gohn, FERMILAB-CONF-17-602-PPD, arXiv:1801.00084 [hep-ex].

[8] P. Strasser et al., Hyperfine Interact. **237**, 124 (2016).

[9] R. Pohl et al., Nature **466**, **213** (2010); A. Antognini et al., Science **339**, 417 (2013).

[10] B. Rym et al., Phys. Rev. Lett. **106** 080801 (2010).

[11] D. Hanneke, S. Fogwell, and G. Gabrielse, Phys. Rev. Lett. **100**, 120801 (2008).

[12] R. H. Parker et al. Science **360**, 191 (2018)

**Primary author:** CRIVELLI, Paolo (ETH Zurich (CH))

**Presenter:** CRIVELLI, Paolo (ETH Zurich (CH))

**Session Classification:** QED

Contribution ID: 68

Type: **Poster**

## Reduction of the $^{14}\text{C}$ -background in JUNO

*Thursday, June 14, 2018 3:58 PM (2 minutes)*

The Jiangmen Underground Neutrino Observatory (JUNO) will be a 20\,kt liquid scintillator neutrino detector located at Kaiping, Jiangmen in South China. With the data acquisition starting in 2021, its main goal is the determination of the neutrino mass hierarchy from a precise measurement of the energy spectrum of anti-electron-neutrinos 53\,km away from the reactor. To precisely measure the oscillation pattern of the reactor spectrum an unprecedented energy resolution for this kind of detector of 3% at 1\,MeV is needed. Pile-up events with background from radioactive decays such as those from  $^{14}\text{C}$  can spoil the reconstruction of the neutrino energy. On this poster methods for detecting spoiled pile-up events are presented. In addition to a simple clusterization algorithm on the hit times, the utilization of spherical harmonics of the event distribution as well as a Likelihood-test of the hit times are used to tag pile-up events.

**Primary author:** KAMPMANN, Phillipp (Forschungszeuntrum J\”ulich/RWTH Aachen University)

**Presenter:** KAMPMANN, Phillipp (Forschungszeuntrum J\”ulich/RWTH Aachen University)

**Session Classification:** poster

Contribution ID: 69

Type: **Talk**

## Atomic parity violation in ytterbium and dysprosium

*Tuesday, June 12, 2018 5:50 PM (30 minutes)*

In the study of electroweak interactions, atomic parity violation (PV) experiments form a powerful tool, providing valuable information about the Standard Model and low-energy nuclear physics. Ytterbium (Yb) and dysprosium (Dy) are good systems for such studies, due to their strong PV effect (to be confirmed for Dy) and the availability of many stable isotopes. This brings within reach the possibility to perform high-precision measurements of the isotopic dependence of the PV effect, which would serve as a probe of the neutron skin variation among these different isotopes of the ytterbium and dysprosium nuclei. In addition, a determination of the nuclear spin-dependent contributions to the PV effect would be an observation of the nuclear anapole moment, and would yield information about nucleon-nucleon weak meson couplings.

Our programme in Yb parity violation in Mainz has reached in early 2018 its first milestone, namely the observation for the first time, of the isotopic variation of the PV effect, as predicted by the electroweak theory. We will present the result of these measurements, and discuss future prospects for determining nuclear spin-dependent PV effects as well as neutron distributions in ytterbium. We will also discuss the status of the Dy PV experiment, which is currently ongoing in our laboratory.

**Primary author:** ANTYPASA, Dionysios (Helmholtz-Institut Mainz, Mainz, Germany)

**Presenter:** ANTYPASA, Dionysios (Helmholtz-Institut Mainz, Mainz, Germany)

**Session Classification:** parity violation/weak interaction

Contribution ID: 70

Type: **Poster**

## Ramsey set-up for (anti-)hydrogen hyperfine spectroscopy

*Thursday, June 14, 2018 4:00 PM (2 minutes)*

In the framework of the Standard Model, CPT symmetry demands the same fundamental properties for matter and antimatter. The precise measurement of the ground state hyperfine structure of antihydrogen and its comparison to that of hydrogen is a sensitive test of CPT invariance. A Ramsey type beam spectroscopy method [1] has the potential to improve this precision by a factor of 10 over the existing Rabi type setup [2] at CERN. The design phase for this new set-up is underway and the case studies considering the microwave cavities and surface coils, which shall be used for perturbations will be presented. The most optimal solution from these cases will govern the decision whether to adapt to a longitudinal or transverse static magnetic field design. Although the characterisation of the spectrometer line will be done using hydrogen, its scalability for the case of antihydrogen shall also be discussed.

**Primary authors:** NANDA, Amit (Austrian Academy of Sciences (AT)); ON BEHALF OF THE ASACUSA CUSP COLLABORATION

**Presenter:** NANDA, Amit (Austrian Academy of Sciences (AT))

**Session Classification:** poster

Contribution ID: 72

Type: **Talk**

## Review on neutrino-less double beta decay experiments

*Monday, June 11, 2018 12:00 PM (30 minutes)*

The observation of neutrinoless double beta decay would unambiguously demonstrate that neutrinos are Majorana particles and would provide unique information about the ordering and absolute scale of neutrino masses. This very rare decay is actively searched for in a number of candidate isotopes. It violates lepton-number and is predicted by many extensions of the standard model. The most recent experimental results are reviewed. The technological advances and the most compelling requirements for the new generation of experiments are discussed.

**Primary author:** CREMONESI, Oliviero (INFN)

**Presenter:** CREMONESI, Oliviero (INFN)

**Session Classification:** Neutrinos



Contribution ID: 73

Type: **Talk**

## Theory predictions for $g-2$ of the muon

*Tuesday, June 12, 2018 3:00 PM (30 minutes)*

The magnetic moment of the muon  $g - 2$  is sensitive to all interactions of the Standard Model and to a variety of hypothetical new physics scenarios. Future measurements will lead to important constraints on new physics, and they might even establish the existence of new physics contributions to  $g-2$ . The talk will describe the theoretical calculations of  $g-2$  both in the SM and beyond the SM. Improvements in the SM prediction for  $g-2$  have already significantly sharpened the current deviation from the measured value. In selected new physics models similarly accurate predictions are available. The talk will also give a phenomenological overview of the range and model dependence of new physics contributions to  $g - 2$ .

**Primary author:** STOECKINGER, Dominik (TU Dresden)

**Presenter:** STOECKINGER, Dominik (TU Dresden)

**Session Classification:** muon  $g-2$

Contribution ID: 74

Type: **Talk**

## ACME Measurements of the Electron EDM

*Tuesday, June 12, 2018 10:00 AM (30 minutes)*

The ACME Collaboration has made the most sensitive measurement of the electric dipole moment of the electron. This moment is of great interest because the Standard Model predicts it should be too small to measure, supersymmetric and other model predict it should be small but measurable, and not nearly enough CP violation has been discovered to account for how a universe could survive the big bang. The latest result from ACME will be presented.

**Primary author:** GABRIELSE, Gerald (Harvard University)

**Presenter:** GABRIELSE, Gerald (Harvard University)

**Session Classification:** EDM

Contribution ID: 75

Type: **Talk**

## Final Results from the Qweak Experiment: A Search for New Physics via a Measurement of the Proton's Weak Charge

*Thursday, June 14, 2018 2:00 PM (30 minutes)*

The Qweak experiment precisely measures the proton's weak charge using parity-violating elastic electron scattering from the proton at Jefferson Laboratory. The Standard Model makes a firm prediction for the proton's weak charge, thus providing a sensitive test for new physics beyond the Standard Model. This talk will cover the measurement methodology, key technical challenges, and the most significant aspects of the data analysis. Final results for the proton's weak charge and resulting extracted values of the weak mixing angle and vector weak quark couplings will be presented along with the implications for new beyond-the-Standard-Model physics. This work was supported by DOE Contract No. DEAC05-06OR23177, under which Jefferson Science Associates, LLC operates Thomas Jefferson National Accelerator Facility. Construction and operating funding for the experiment was provided through the U.S. Department of Energy (DOE), the Natural Sciences and Engineering Research Council of Canada (NSERC), and the National Science Foundation (NSF) with university matching contributions from the College of William and Mary, Virginia Tech, George Washington University, and Louisiana Tech University.

**Primary authors:** PITT, Mark (Virginia Tech); FOR THE QWEAK COLLABORATION

**Presenter:** PITT, Mark (Virginia Tech)

**Session Classification:** parity violation/weak interaction

Contribution ID: 76

Type: **Talk**

## Toward a Measurement of the Antihydrogen Free Fall

*Wednesday, June 13, 2018 11:40 AM (20 minutes)*

In recent years, increasingly larger amounts of cold antihydrogen has been confined in the ALPHA magnetic trap [1] and has become available to perform precise measurements of its spectrum [2, 3]. Owing to this advancement, the Universality of Free Fall, a pillar of General Relativity, is put to test in a novel apparatus, named ALPHA-g, scheduled to take its first data in 2018. The ALPHA-g apparatus is designed to confine antihydrogen in a magnetic trap whose axis is aligned to the Earth's gravitational field, i.e., it is vertical. The magnetic trap is constituted by an octupole magnet, which provides the radial confinement, and a set of "mirror" coils, which provide the vertical confinement. The antihydrogen gravitational mass can be inferred via the measurement of the annihilation distribution of antihydrogen under the influence of gravity. A crucial piece of equipment to perform this measurement is the radial Time Projection Chamber, or rTPC, that enables the identification of the antihydrogen annihilation position.

In this talk, I will give an overview of the ALPHA-g experiment, with an emphasis on the annihilation detectors.

[1] Ahmadi, M. et al., Nature Comm. 8, 681 (2017)

[2] Ahmadi, M. et al., Nature 541, 66 (2017)

[3] Ahmadi, M. et al., Nature 557, (2018)

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**Session Classification:** CPT

Contribution ID: 77

Type: **Poster**

## Development of the Radial Time Projection Chamber for the ALPHA-g antimatter gravity experiment

*Thursday, June 14, 2018 4:02 PM (2 minutes)*

Antimatter is believed to be affected by gravity in exactly the same way as ordinary matter for a variety of good reasons [1], however this has never been measured directly. This will be tested by the ALPHA-g project, which uses a new vertical antihydrogen trap based on the previous ALPHA design (Antihydrogen Laser Physics Apparatus, the first experiment to trap antihydrogen in 2010 [2]). As in previous ALPHA experiments, the trapped antihydrogen is detected via its charged annihilation products after switching off the trap. In order to be sensitive to small gravitational effects, the setup extends more than 2 metres in the vertical direction, requiring the particle detection system to cover a large volume with good tracking accuracy. The design chosen to replace the previous experiments' silicon strip detectors is a radial time-projection-chamber (rTPC) filled with an Argon/CO<sub>2</sub> gas mixture.

Following successful tests with a smaller prototype, the full-scale chamber was completed in early 2018 and the basic functionality of the detector was established. Soon after, initial tests with cosmic rays lead to the observation of tracks due to charged particles. The concept and status of the detector system will be presented.

The specific parameters of the chamber together with the necessity to observe minimum-ionizing particles leads to relatively complex signals on the detector electrodes, which have to be deconvolved in an iterative process. The deconvolution algorithm and its results for both simulated and prototype signals are described.

[1] M. M. Nieto and J. T. Goldman, Phys. Rep. 205, 221-281 (1991).

[2] G. B. Andresen et al., Nature 7324, 673 (2010).

**Primary author:** MARTIN, Lars (TRIUMF)

**Presenter:** MARTIN, Lars (TRIUMF)

**Session Classification:** poster

Contribution ID: 78

Type: **Talk**

## Electric Dipole Moments of the Nucleon and Light Nuclei in Chiral Effective Field Theory

*Friday, June 15, 2018 9:00 AM (25 minutes)*

A nonzero electric dipole moment (EDM) of the neutron, proton, deuteron or helion, in fact, of any finite system necessarily involves the breaking of a symmetry, either by the presence of external fields (i.e., electric fields leading to the case of induced EDMs) or explicitly by the breaking of the discrete parity and time-reflection symmetries in the case of permanent EDMs.

Recent results for the relevant matrix elements of nuclear EDM operators based on calculations in chiral effective field theory ( $\chi$ EFT) are presented. Furthermore, strategies are discussed for disentangling the underlying sources of CP breaking beyond what is generated by the Kobayashi–Maskawa quark-mixing mechanism in the Standard Model.

**Primary author:** Dr WIRZBA, Andreas (Forschungszentrum Jülich GmbH)

**Presenter:** Dr WIRZBA, Andreas (Forschungszentrum Jülich GmbH)

**Session Classification:** EDM

Contribution ID: 79

Type: **Talk**

## Search for new physics in CP violation with beauty and charm decays at LHCb

*Thursday, June 14, 2018 3:10 PM (20 minutes)*

Precision measurements of CP violating observables in the decays of b and c hadrons are powerful probes to search for physics beyond the Standard Model.

The most recent results on CP violation in the decay, mixing and interference of both b and c hadrons obtained by the LHCb Collaboration with Run I and years 2015-2016 of Run II are reviewed. In particular world best constraints and world first measurements are provided for CKM elements, unitarity angles and charm parameters

**Primary author:** KECKE, Matthieu (Ruprecht Karls Universitaet Heidelberg (DE))

**Presenter:** KECKE, Matthieu (Ruprecht Karls Universitaet Heidelberg (DE))

**Session Classification:** CP violation/T violation

Contribution ID: **80**

Type: **not specified**

## Welcome Address

*Monday, June 11, 2018 9:05 AM (10 minutes)*

Prof. Dr. S. Schael (Dean Faculty of Mathematics, Computer Science and Natural Sciences)

**Presenter:** SCHAEEL, Stefan (Rheinisch Westfaelische Tech. Hoch. (DE))

**Session Classification:** General



Contribution ID: **81**

Type: **not specified**

## **Organizational Matters**

*Monday, June 11, 2018 9:15 AM (15 minutes)*

**Presenter:** PRETZ, Joerg (Forschungszentrum Juelich/RWTH Aachen University)

**Session Classification:** General

Contribution ID: **82**

Type: **not specified**

## **Closing Remarks**

*Friday, June 15, 2018 1:00 PM (20 minutes)*

**Presenter:** STROEHER, Hans (Forschungszentrum Juelich GmbH)

**Session Classification:** General