

# International Conference on Precision Physics and Fundamental Physical Constants FFK2023



## Report of Contributions

Contribution ID: 2

Type: **Oral presentation**

## Neutron lifetime measurement using magneto-gravitational trap at LANL

Beta decay of a free neutron is the simplest form of “semi-leptonic” weak interaction and is free from nuclear structure effects. Despite the simplicity of the process, its lifetime measurement remains one of the most challenging measurements, bearing different results depending on the technique (“bottle” or “beam”) [1, 2]. Another critical measurement from the decay is the correlation ( $A_0$ ) between the neutron’s initial spin and emitted electron’s momentum. Neutron lifetime and axial neutron charge determined using  $A_0$  are inputs to determine the magnitude of the Cabibbo-Kobayashi-Maskawa (CKM) matrix element ( $V_{ud}$ ) and provide a means to study physics beyond the Standard Model.

Los Alamos National Laboratory hosts the neutron lifetime experiment  $UCN\tau$  by exploiting the ultra-cold neutron (UCN) beam. UCNs at LANL are produced via the down scattering of moderated spallation neutrons in a solid deuterium crystal and are polarized via transport through magnets [3]. The UCNs are then polarized and guided to be stored in a magneto-gravitational trap. The surviving neutrons are then counted using a  $^{10}\text{B}$ -coated-ZnS scintillator. The experiment has produced the world’s most precise neutron lifetime measurement. The  $UCN\tau$  experiment is undergoing further degradation to implement an elevator loading method to achieve more storage of UCNs to gain higher sensitivity limits and better precision (about three times). This contribution will discuss details of the  $UCN\tau$  experiment, its analysis techniques, and expected new results.

References:

1. Golub, R., D. Richardson, and S. K. Lamoreaux, 1991, *Ultra-Cold Neutrons* (Adam Hilger, Bristol, England).
2. D. J. Salvat *et al.*, *Phys. Rev. C* 89, 052501, 2014.
3. T. M. Ito *et al.*, *Phys. Rev. C* 97, 012501(R), 2018.

**Primary author:** SINGH, Maninder (Los Alamos National Laboratory)

**Presenter:** SINGH, Maninder (Los Alamos National Laboratory)

**Session Classification:** Tuesday 4

**Track Classification:** tests and extensions of the Standard Model of elementary particles

Contribution ID: 4

Type: **Oral presentation**

# Testing the photon and foundations of electromagnetism

*Monday, 22 May 2023 14:25 (25 minutes)*

## Collaboration

Benetti M. (Napoli), Bentum M.-J. (Eindhoven), Bonetti L. (Orléans), Capozziello S. (Napoli), dos Santos Filho L.R. (Rio de Janeiro), Ellis J. (CERN London), Helayël-Neto J.A. (Rio de Janeiro), Lämmerzahl C. (Bremen), López-Corredoira M. (La Laguna), Mavromatos N.E. (CERN London), Perlick V. (Bremen), Randriamboarison O. (Orléans), Retinò A. (Paris), Sakharov A.S. (CERN), Sarkisyan-Grinbaum E.K.G. (CERN), Sarracino G. (Napoli), Spallicci A.D.A.M. (Orléans), Vaivads A. (Stockholm).

The Standard-Model Extension (SME) induces a mass to a photon [1,2], the only SM free massless particle. Observations of Fast Radio Bursts [3-5] and solar wind plasma [6,7] allowed estimates and limits listed in the Particle Data Group reviews. SME, classic (de Broglie-Proca and others) massive and non-linear electromagnetism theories (Born-Infeld, Heisenberg-Euler and others) determine a frequency shift of the photon in presence of a background, with which it exchanges energy [8]. This shift, added to expansion red shift, determines new cosmological scenarios, e.g., without recurring to the accelerated expansion to explain Supernovae data [9-11]. The upper limit of this shift would be  $7.7 \times 10^{-27}$  Delta  $f/f$  per metre which implies  $2.9 \times 10^{-18}$  in Delta  $f/f$  for an interferometer simulating the Earth-Moon distance. Finally, we apply the Heisenberg principle in the energy-time form to cosmological scales and read the Hubble constant as quantum measurement [12,13].

[1] 2017, Phys. Lett. B, 764, 203

[2] 2018, Eur. Phys. J. C, 78, 811

[3] 2016, Phys. Lett. B, 757, 548

[4] 2017, Phys. Lett. B, 768, 32

[5] 2017, Adv. Space Res., 59, 736

[6] 2016, Astropart. Phys., 82, 49

[7] 2022, arXiv:2205.02487 [hep-ph]

[8] 2019, Eur. Phys. J. C, 79, 590

[9] 2021, Eur. Phys. J. C, 81, 4

[10] 2022, Eur. Phys. J. Plus, 137, 253

[11] 2022, Eur. Phys. J. Plus, 137, 1386

[12] 2020, Found. Phys. 50, 893

[13] 2022, Found. Phys. 52, 23

**Primary author:** SPALLICCI, Alessandro (Université d'Orléans - CNRS)

**Presenter:** SPALLICCI, Alessandro (Université d'Orléans - CNRS)

**Session Classification:** Monday 3

**Track Classification:** precision measurements in fundamental physics, astrophysics and cosmology

Contribution ID: 6

Type: **Oral presentation**

## **Matrix elements of the energy-momentum tensor in the hydrogen atom**

*Monday, 22 May 2023 14:50 (25 minutes)*

**Primary author:** CZARNECKI, Andrzej

**Presenter:** CZARNECKI, Andrzej

**Session Classification:** Monday 3

**Track Classification:** quantum electrodynamics of bound systems

Contribution ID: 8

Type: **Oral presentation**

## Cavity-enhanced double resonance spectroscopy of HD

*Tuesday, 23 May 2023 10:05 (20 minutes)*

Precision spectroscopy of molecular hydrogen and its isotopes, combined with accurate calculations, allows us to test the fundamental quantum chemistry theory and to determine the fundamental physical constants such as the proton-to-electron mass ratio[1,2]. In general, high overtone transitions may allow for measurements with a better fractional accuracy. However, direct measurement of high overtones, for example, the  $v = 4 - 0$  one, turns out to be difficult because the transition moment is extremely small. It is possible to access the  $v = 4$  state with two-photon spectroscopy, in which two-step excitation is involved.

Here we present the low-temperature comb-lock Cavity-enhanced system to determine highly-excited rotation-vibration energies of HD with high precision. As a demonstration, the V-type double resonance spectroscopy of HD is measured by pumping the P(1) ( $2 - 0$ ) line and probing the R(1) line in the same overtone band[3]. In the future, we propose to use this method to determine the rotationless overtone band center ( $4-0$ ) of HD. The DR method is feasible to determine the pure vibrational frequency  $E_{v=4} - E_{v=0}$  ( $J = 0$ ) with an accuracy of a few kHz, which allows for a test of the high-order ab initio calculation.

**Primary author:** LIU, QianHao (University of Science and Technology of China)

**Co-authors:** CHENG, Cunfeng (University of Science and Technology of China); HU, Shuiming (Univ Sci & Tech China)

**Presenter:** LIU, QianHao (University of Science and Technology of China)

**Session Classification:** Tuesday 1

**Track Classification:** precision measurements in fundamental physics, astrophysics and cosmology

Contribution ID: 9

Type: **Oral presentation**

## **High precision calculations for helium and helium-like ions**

*Wednesday, 24 May 2023 11:30 (25 minutes)*

abstract provided as attached pdf-file

**Primary author:** PATKOS, Vojtech (Charles University)

**Presenter:** PATKOS, Vojtech (Charles University)

**Session Classification:** Wednesday 2

**Track Classification:** quantum electrodynamics of bound systems

Contribution ID: 10

Type: **Poster presentation**

## Theoretical hyperfine splittings of $7,9\text{Be}^{2+}$ ions for future studies of nuclear properties

*Tuesday, 23 May 2023 19:35 (20 minutes)*

**Primary authors:** Dr QI, Xiao-Qiu (Physics Department of Zhejiang Sci-Tech University); Dr ZHANG, Pei-Pei (Wuhan Institute of Physics and Mathematics, Innovation Academy for Precision Measurement Science and Technology, Chinese Academy of Sciences); Prof. YAN, Zong-Chao (Department of Physics, University of New Brunswick); Prof. SHI, Ting-Yun (Wuhan Institute of Physics and Mathematics, Innovation Academy for Precision Measurement Science and Technology, Chinese Academy of Sciences); Prof. DRAKE, Gordon (Canterbury College and Department of Physics, University of Windsor); Prof. CHEN, Ai-Xi (Physics Department of Zhejiang Sci-Tech University); Prof. ZHONG, Zhen-Xiang (Center for Theoretical Physics, Hainan University)

**Presenter:** Prof. YAN, Zong-Chao (Department of Physics, University of New Brunswick)

**Session Classification:** Poster Session 2

**Track Classification:** quantum electrodynamics of bound systems

Contribution ID: 11

Type: **Poster presentation**

## **Tabletop Experiment for beyond Standard Model Physics: Cesium embedded in a Cryogenic Argon Matrix**

*Tuesday, 23 May 2023 19:45 (15 minutes)*

see attachment

**Primary author:** LAHS, Sebastian (Laboratoire Aimé Cotton)

**Presenter:** LAHS, Sebastian (Laboratoire Aimé Cotton)

**Session Classification:** Poster Session 2

**Track Classification:** precision measurements in fundamental physics, astrophysics and cosmology



Contribution ID: 12

Type: **Oral presentation**

## Fano-like Resonance due to Interference with Distant Transitions

*Tuesday, 23 May 2023 09:45 (20 minutes)*

Precision spectroscopy of narrow transitions of atoms and molecules has been the subject of numerous studies in recent decades and has been widely applied in sensing, metrology, and frequency references for optical clocks. Narrow optical resonances also provide excellent probes for determining fundamental physics constants, such as the Rydberg constant and the proton-to-electron mass ratio. In these studies, accurate transition centers derived from fitting the measured spectra are demanded, which critically rely on the knowledge of spectral line profiles.

Here, we propose a new mechanism of Fano-like resonance induced by distant discrete levels and experimentally verify it with Doppler-free spectroscopy of vibration-rotational transitions of CO<sub>2</sub>. The observed spectrum has an asymmetric profile and its amplitude increases quadratically with the probe laser power. Our results facilitate a broad range of topics based on narrow transitions.

**Primary author:** Dr SUN, Yu**Co-author:** HU, Shuiming (Univ Sci & Tech China)**Presenter:** Dr SUN, Yu**Session Classification:** Tuesday 1**Track Classification:** precision measurements in fundamental physics, astrophysics and cosmology

Contribution ID: 13

Type: **Poster presentation**

## **Doppler-free spectroscopy of an atomic beam probed in traveling-wave fields**

*Tuesday, 23 May 2023 19:35 (20 minutes)*

**Primary author:** Mr WEN, Jinlu (University of Science and Technology of China)

**Presenter:** Mr WEN, Jinlu (University of Science and Technology of China)

**Session Classification:** Poster Session 2

**Track Classification:** precision measurements in fundamental physics, astrophysics and cosmology

Contribution ID: 14

Type: **Invited Talk**

## Precision spectroscopy of molecular hydrogen ions: recent advances

*Thursday, 25 May 2023 09:00 (45 minutes)*

We present our recent experimental advances on laser spectroscopy of cold, trapped molecular hydrogen ions. The contribution to the determination of fundamental constants and tests of physical laws is discussed.

**Primary author:** SCHILLER, Stephan

**Co-authors:** WELLERS, Christian; KORTUNOV, Ivan; SCHENKEL, Magnus R.; ALIGHANBARI, Soroosh; VOGT, Victor

**Presenter:** SCHILLER, Stephan

**Session Classification:** Thursday 1

**Track Classification:** fundamental physical constants

Contribution ID: 15

Type: **Poster presentation**

## **Efficient evaluation of the non-linear vacuum polarization density in the finite basis Dirac problem**

*Tuesday, 23 May 2023 19:35 (20 minutes)*

abstract provided as attached pdf-file.

**Primary author:** SALMAN, Maen

**Co-author:** Prof. SAUE, Trond (CNRS)

**Presenter:** SALMAN, Maen

**Session Classification:** Poster Session 2

**Track Classification:** quantum electrodynamics of bound systems

Contribution ID: **18**

Type: **Invited Talk**

## **Measurement of the mass difference between tritium and helium-3**

*Thursday, 25 May 2023 14:15 (45 minutes)*

Abstract is attached as a pdf.

**Primary author:** MYERS, Edmund (Florida State University)

**Presenter:** MYERS, Edmund (Florida State University)

**Session Classification:** Thursday 3

**Track Classification:** precision measurements in fundamental physics, astrophysics and cosmology

Contribution ID: 19

Type: **Oral presentation**

## **Precision spectroscopy of the 2S-6P transition in atomic hydrogen and deuterium**

*Monday, 22 May 2023 15:15 (15 minutes)*

see attached pdf

**Primary author:** WIRTHL, Vitaly

**Presenter:** WIRTHL, Vitaly

**Session Classification:** Monday 3

**Track Classification:** quantum electrodynamics of bound systems

Contribution ID: 20

Type: **Oral presentation**

## Towards High-Precision Spectroscopy of the 1S–2S Transition in He<sup>+</sup>

*Wednesday, 24 May 2023 09:45 (25 minutes)*

The energy levels of hydrogen-like atoms and ions are accurately described by bound-state quantum electrodynamics (QED). The frequency of the narrow 1s-2s transition of atomic hydrogen has been measured with a relative uncertainty of less than  $10^{-14}$ . In combination with other spectroscopic measurements of hydrogen and hydrogen-like atoms, the Rydberg constant and the proton charge radius can be determined. The comparison of the physical constants obtained from different combinations of measurements serves as a consistency check for the theory [\cite{Udem2018}](#). The hydrogen-like He<sup>+</sup> ion is another interesting spectroscopic target for QED tests. Due to their charge, He<sup>+</sup> ions can be held nearly motionless in the field-free environment of a Paul trap, providing ideal conditions for high-precision measurements. Interesting higher-order QED corrections scale with large exponents of the nuclear charge, making this measurement much more sensitive to these corrections compared to the hydrogen case. The measurement of a transition in He<sup>+</sup> will extend the test of QED beyond the long-studied hydrogen. In this talk, we describe our progress towards precision spectroscopy of the 1S-2S two-photon transition in He<sup>+</sup> [\cite{Herrmann2009}](#). The transition can be directly excited by an extreme-ultraviolet frequency comb at 60.8~nm generated by a high-power infrared frequency comb using high-order harmonic generation (HHG). A femtosecond enhancement resonator with non-collinear geometry is used for this purpose. The spectroscopic target is a small number of He<sup>+</sup> ions trapped in a linear Paul trap and sympathetically cooled by co-trapped Be<sup>+</sup> ions. After successful excitation to the 2S state, a significant fraction of the He<sup>+</sup> ions are further ionized to He<sup>2+</sup> that remain in the Paul trap. Sensitive mass spectrometry using secular excitation will reveal the number of trapped He<sup>2+</sup> ions and will serve as a single-event sensitive spectroscopy signal.

**Primary author:** Dr OZAWA, Akira (Max-Planck-Institute of Quantum Optics)

**Co-authors:** Dr SCHMID, Fabian; Mr MORENO, Jorge; WEITENBERG, Johannes; UDEM, Thomas; W. HAENSCH, Theodor

**Presenter:** Dr OZAWA, Akira (Max-Planck-Institute of Quantum Optics)

**Session Classification:** Wednesday 1

**Track Classification:** precision measurements in fundamental physics, astrophysics and cosmology

Contribution ID: 21

Type: **Poster presentation**

# **Rovibrational and Hyperfine Structure of the Molecular Hydrogen Ion from Spectroscopy of Rydberg-Stark Manifolds**

*Monday, 22 May 2023 19:40 (20 minutes)*

abstract provided as attached pdf-file

**Primary author:** Ms DORAN, Ioana (ETH Zurich)

**Co-authors:** Prof. BEYER, Maximilian (VU Amsterdam); Prof. MERKT, Frédéric (ETH Zurich)

**Presenter:** Ms DORAN, Ioana (ETH Zurich)

**Session Classification:** Poster Session 1

**Track Classification:** fundamental physical constants



Contribution ID: 22

Type: **Oral presentation**

## **Calculation of isotope shifts and King plot nonlinearities in Ca<sup>+</sup>**

*Monday, 22 May 2023 11:35 (15 minutes)*

abstract provided as attached pdf-file

**Primary author:** Dr VIATKINA, Anna

**Co-authors:** Prof. SURZHYKOV, Andrey; Dr YEROKHIN, Vladimir

**Presenters:** VIATKINA, Anna; Dr VIATKINA, Anna

**Session Classification:** Monday 1&2

**Track Classification:** precision measurements in fundamental physics, astrophysics and cosmology

Contribution ID: 23

Type: **Oral presentation**

## **Towards a bound-state relativistic QED approach**

*Thursday, 25 May 2023 17:35 (12 minutes)*

abstract provided as attached pdf-file

**Primary authors:** FERENC, David (ELTE, Eötvös Loránd University, Institute of Chemistry, Budapest, Hungary); Dr MÁTYUS, Edit (ELTE, Eötvös Loránd University, Institute of Chemistry, Budapest, Hungary); JESZENSZKI, Péter (Postdoc); Dr MARGÓCSY, Ádám (ELTE, Eötvös Loránd University, Institute of Chemistry, Budapest, Hungary)

**Presenter:** FERENC, David (ELTE, Eötvös Loránd University, Institute of Chemistry, Budapest, Hungary)

**Session Classification:** Thursday 4

**Track Classification:** quantum electrodynamics of bound systems

Contribution ID: 24

Type: **Oral presentation**

## **State preparation for rovibrational transition frequency measurement of HD+**

*Thursday, 25 May 2023 09:45 (30 minutes)*

abstract provided as attached pdf-file

**Primary authors:** Dr HE, Sheng-Guo; ZHANG, Yong; ZHANG, Qian-Yu; BAI, Wen-Li; AO, Zhi-Yuan; PENG, Wen-Cui; Prof. TONG, Xin

**Presenter:** Dr HE, Sheng-Guo

**Session Classification:** Thursday 1

**Track Classification:** precision measurements in fundamental physics, astrophysics and cosmology

Contribution ID: 25

Type: **Oral presentation**

## **An update on the muonic fine-structure puzzle**

*Friday, 26 May 2023 09:55 (20 minutes)*

abstract provided as attached pdf-file

**Primary author:** VALUEV, Igor A.

**Co-authors:** KEITEL, Christoph H.; COLÒ, Gianluca; BEYER, Konstantin; TAMBURINI, Matteo; ORESHKINA, Natalia S.; ROCA-MAZA, Xavier

**Presenter:** VALUEV, Igor A.

**Session Classification:** Friday 1

**Track Classification:** spectroscopy of exotic atoms

Contribution ID: 26

Type: **Poster presentation**

## **Determination of the adiabatic and nonadiabatic corrections for HeH<sup>+</sup> in Kolos-Wolniewicz basis**

*Monday, 22 May 2023 19:40 (20 minutes)*

abstract provided as attached pdf-file

**Primary author:** BOGUSZYŃSKA, Wiktoria (Adam Mickiewicz University, Poznań, Poland)

**Presenter:** BOGUSZYŃSKA, Wiktoria (Adam Mickiewicz University, Poznań, Poland)

**Session Classification:** Poster Session 1

**Track Classification:** quantum electrodynamics of bound systems

Contribution ID: 27

Type: **Oral presentation**

## **Laser spectroscopy of antiprotonic helium embedded in liquid and superfluid helium**

*Friday, 26 May 2023 12:20 (30 minutes)*

**Primary authors:** DAX, Andreas Josef (Department of Physics Particle Physics); Dr SOTER, Anna (ETH Zürich); Dr BARNA, Daniel (Wigner Research Centre for Physics); AGHAI KHOZANI, Hossein (Max-Planck-Gesellschaft (DE)); VENTURELLI, Luca (Universita di Brescia (IT)); HORI, Masaki (Johannes Gutenberg University Mainz and Imperial College London)

**Presenters:** HORI, Masaki (Johannes Gutenberg University Mainz and Imperial College London); HORI, Masaki (Johannes Gutenberg University Mainz and Imperial College London)

**Session Classification:** Friday 2

**Track Classification:** spectroscopy of exotic atoms

Contribution ID: 29

Type: **Oral presentation**

## **Precision Measurement of Muonium Hyperfine Structure at J-PARC**

*Wednesday, 24 May 2023 16:00 (35 minutes)*

abstract provided as attached pdf-file

**Primary author:** NISHIMURA, Shoichiro (KEK IMSS)

**Presenter:** NISHIMURA, Shoichiro (KEK IMSS)

**Session Classification:** Wednesday 4

**Track Classification:** spectroscopy of exotic atoms

Contribution ID: **30**

Type: **Poster presentation**

## **Development for the precise microwave spectroscopy of muonium with a high magnetic field**

*Monday, 22 May 2023 19:40 (20 minutes)*

abstract provided as attached pdf-file

**Primary author:** TADA, Hiroki (Nagoya University)

**Presenter:** TADA, Hiroki (Nagoya University)

**Session Classification:** Poster Session 1

**Track Classification:** spectroscopy of exotic atoms



Contribution ID: 31

Type: **Oral presentation**

# Probing Nuclear Size Effects with Precision Spectroscopy of Quantum Degenerate Metastable Helium

*Wednesday, 24 May 2023 11:55 (25 minutes)*

abstract provided as attached pdf file

**Primary author:** Ms VAN DER WERF, Yuri (Vrije Universiteit Amsterdam)

**Co-authors:** Mr STEINEBACH, Kees; Dr JANNIN, Raphael; Prof. BETHLEM, Hendrick L.; Prof. EIKEMA, Kjeld S.E.

**Presenter:** Ms VAN DER WERF, Yuri (Vrije Universiteit Amsterdam)

**Session Classification:** Wednesday 2

**Track Classification:** precision measurements in fundamental physics, astrophysics and cosmology

Contribution ID: 33

Type: **Poster presentation**

## **Precise determination of the W-boson mass in $U(1)_Z$ extensions of the standard model**

*Tuesday, 23 May 2023 19:40 (20 minutes)*

Abstract provided as attached pdf-file.

**Primary author:** PÉLI, Zoltán (Institute for Theoretical Physics, ELTE Eötvös Loránd University)

**Presenter:** PÉLI, Zoltán (Institute for Theoretical Physics, ELTE Eötvös Loránd University)

**Session Classification:** Poster Session 2

**Track Classification:** tests and extensions of the Standard Model of elementary particles

Contribution ID: 34

Type: **Poster presentation**

# Ramsey-Comb Spectroscopy of the Q0 and Q1 Transitions in Molecular Hydrogen and Deuterium

*Monday, 22 May 2023 19:40 (20 minutes)*

As the simplest neutral molecule, molecular hydrogen ( $H_2$ ) is a good testing ground for molecular quantum theory. Its dissociation energy  $D_0$  has become a benchmark value to test ab initio quantum molecular calculations. An experimental value for  $D_0$  can be obtained by relating the ionization energy of  $H_2$ , to the ionization energy of atomic hydrogen and the dissociation energy of the  $H_2$  ion. By combining our measurements of the X to EF Q0 and Q1 transitions with the determination of the energy difference between the EF state and the continuum carried out at the ETH Zurich [1], we can provide an experimental value for the ionization energy of  $H_2$ , and therefore of  $D_0$ . In order to measure the Q0 transition in  $H_2$ , we perform 2-photon Ramsey-comb Spectroscopy (RCS) [2] in the VUV at 202 nm. RCS uses two amplified and up-converted pulses out of the infinite pulse train of a frequency comb (FC) laser to perform a Ramsey-like excitation. Recent improvements to the experimental setup allowed to determine the X to EF transition frequency in  $H_2$  and  $D_2$  with 30 and 19 kHz accuracy, respectively [4]. We will report on these measurements and discuss their implications regarding an improved determination of the dissociation energy of  $H_2$  and  $D_2$ , and a comparison with theory.

[1] Hölsch et al., PRL 122, 103002 (2019)

[2] Morgenweg et al, Nat. Phys. 10, 30–33 (2014)

[3] Altmann et al., PRL 120, 043204 (2018)

[4] Roth et al., Manuscript submitted (2023)

**Primary author:** MARTINEZ DE VELASCO, Andres

**Presenter:** MARTINEZ DE VELASCO, Andres

**Session Classification:** Poster Session 1

**Track Classification:** precision measurements in fundamental physics, astrophysics and cosmology

Contribution ID: 35

Type: **Oral presentation**

## Superweak extension of the Standard Model

*Tuesday, 23 May 2023 15:20 (15 minutes)*

The superweak (SW) force is a minimal, anomaly-free  $U(1)$  extension of the standard model (SM), designed to explain the origin of (i) neutrino masses and mixing matrix elements, (ii) dark matter, (iii) cosmic inflation, (iv) stabilization of the electroweak vacuum and (v) leptogenesis. In this talk we discuss how the parameter space of the model is constrained by providing viable scenarios for the first four of this list. The talk will summarize the findings published in the following research articles on the arXiv: 1812.11189, 1911.07082, 2104.11248, 2104.14571, 2105.13360, 2204.07100 and 2301.06621.

**Primary author:** TROCSANYI, Zoltan Laszlo (ELTE Eotvos Lorand University (HU))

**Presenter:** TROCSANYI, Zoltan Laszlo (ELTE Eotvos Lorand University (HU))

**Session Classification:** Tuesday 3

**Track Classification:** tests and extensions of the Standard Model of elementary particles

Contribution ID: 36

Type: **Poster presentation**

## Precision Spectroscopy of Atomic and Molecular Negative Ions at the Frankfurt Low Energy Storage-Ring FLSR

*Tuesday, 23 May 2023 19:25 (20 minutes)*

Negative ions are complex quantum systems in which an additional electron is bound to the neutral atom or molecule by a weak van der Waals force resulting from polarization of the electron shell. This binding depends strongly on the electron configuration of the shell and is therefore sensitive to electron correlation effects. Due to the lack of long ranged Coulomb force the resulting binding energies are small (typically around 1 eV) and exhibit rarely any excited states. Further there are almost no states with opposite parity and therefore lack of optically allowed transitions. The binding energy (electron affinity, EA) is typically the only accessible parameter in the spectroscopy of negative ions. The currently most precise measurement of the EA is by laser photodetachment threshold spectroscopy (LPT), where a narrow linewidth tunable laser is intersected with negative ions and the photon energy is scanned around the threshold, followed by detection of neutralized atoms.

Recently, the room-temperature electrostatic storage ring FLSR [1] at the University of Frankfurt was equipped with a source of negative ions and negative atomic and molecular ions have been successfully stored [2]. A high repetition-rate tunable Ti:sapphire laser pumped by a frequency doubled Nd:YAG laser developed at the University of Mainz has been installed and first photodetachment studies of  $O^-$  were performed. As a next step photodetachment studies of heavy atomic and molecular negative ions will be performed which will challenge state-of-the-art theoretical models. Results of the measurements will be presented and an outlook into future studies will be given.

[1] K.E. Stiebing et al., Nucl. Instr. and Meth. A 614 (2010) 10-16

[2] O. Forstner et al., Hyp. Int. 241 (2020) 53

**Primary author:** Dr FORSTNER, Oliver (Friedrich-Schiller-Universitaet Jena (DE))

**Presenters:** FORSTNER, Oliver (Friedrich-Schiller-Universitaet Jena (DE)); Dr FORSTNER, Oliver (Friedrich-Schiller-Universitaet Jena (DE))

**Session Classification:** Poster Session 2

**Track Classification:** precision measurements in fundamental physics, astrophysics and cosmology

Contribution ID: 37

Type: **Oral presentation**

## **Ultrastable clock transitions in highly charged ions**

*Thursday, 25 May 2023 11:55 (15 minutes)*

**Primary author:** LYU, Chunhai (Max Planck Institute for Nuclear Physics, Heidelberg, Germany)

**Presenter:** LYU, Chunhai (Max Planck Institute for Nuclear Physics, Heidelberg, Germany)

**Session Classification:** Thursday 2

**Track Classification:** quantum standards

Contribution ID: 38

Type: **Poster presentation**

# **Towards Precision Tests of Bound-state QED in $U^{90+}$ Using Novel Metallic Magnetic Calorimeter Detectors**

*Monday, 22 May 2023 19:40 (20 minutes)*

abstract provided as attached pdf-file

**Primary author:** PFÄFFLEIN, Philip

**Presenter:** PFÄFFLEIN, Philip

**Session Classification:** Poster Session 1

**Track Classification:** precision measurements in fundamental physics, astrophysics and cosmology

Contribution ID: 39

Type: **Poster presentation**

## **Report on Cryogenic Micro-Calorimeter Detectors in High-Precision X-Ray Spectroscopy Experiments at GSI/FAIR**

*Monday, 22 May 2023 19:40 (20 minutes)*

*abstract provided as attached pdf-file*

**Primary author:** Mr HERDRICH, Marc Oliver (Helmholtz-Institut Jena)

**Presenter:** Mr HERDRICH, Marc Oliver (Helmholtz-Institut Jena)

**Session Classification:** Poster Session 1

**Track Classification:** precision measurements in fundamental physics, astrophysics and cosmology



Contribution ID: 40

Type: **Oral presentation**

## LEMING: Towards the measurement of the gravitational acceleration of muonium atoms

*Wednesday, 24 May 2023 17:00 (15 minutes)*

Muonium ( $\text{Mu} = \mu^+ + e^-$ ) is a purely leptonic, two-body exotic atom amenable to laser spectroscopy, which provides precision measurements of fundamental constants ( $m_\mu, \mu_\mu$ ), and tests of bound state QED. It also provides a unique probe to test the weak equivalence principle on elementary antimatter of the second generation using a system without large contributions to the mass from the strong interaction.

In the newly approved LEMING experiment at the Paul Scherrer institute we aim to measure the free fall of Mu, and pave the way for improved laser spectroscopy measurements. Both experimental goals rely on a novel, cold vacuum muonium source instead of using state-of-the-art thermal sources. We have demonstrated the working principle of a novel Mu source based on muonium conversion of conventional muon beams in thin a layer of superfluid helium, that provided nearly  $\sim 20\%$  conversion efficiency to a  $\sim 30$  mrad angular divergence. Such an Mu beam may be amenable to atom interferometry measurements that provide a  $\sim 1\%$  precision on the gravitational acceleration of Mu, and has the potential to improve the fractional precision of Mu 1S-2S measurements by more than an order of magnitude, assuming the MuMass excitation scheme.

In this talk, new measurements on the first observation of Mu emitted from superfluid helium and an initial characterization of the novel Mu source are presented. Prospects of this newly developed atomic Mu beam from superfluid helium in the context of future gravity and spectroscopy experiments will be discussed.

**Primary author:** ZHANG, Jesse (ETH Zürich)

**Presenter:** ZHANG, Jesse (ETH Zürich)

**Session Classification:** Wednesday 4

**Track Classification:** spectroscopy of exotic atoms

Contribution ID: 41

Type: **Oral presentation**

## **Present status of spectroscopy of the hyperfine structure and repolarization of muonic helium atoms at J-PARC**

*Friday, 26 May 2023 09:30 (25 minutes)*

abstract provided as attached pdf-file

**Primary author:** FUKUMURA, Seiso (Nagoya University)

**Co-authors:** SHIMIZU, Hirohiko; TADA, Hiroki (Nagoya University); TORII, Hiroyuki (University of Tokyo (JP)); SHIMOMURA, Koichiro (KEK); KITAGUCHI, Masaaki (Nagoya University); STRASSER, Patrick (KEK); IWAI, Ryoto (KEK); KAWAMURA, Shiori (Nagoya University); NISHIMURA, Shoichiro; Dr KANDA, Sohtaro; INO, Takashi (KEK); OKU, Takayuki (JAEA); OKUDAIRA, Takuya (Nagoya University); GOTO, Yu (Nagoya University)

**Presenter:** FUKUMURA, Seiso (Nagoya University)

**Session Classification:** Friday 1

**Track Classification:** spectroscopy of exotic atoms

Contribution ID: 42

Type: **Invited Talk**

## **First Observation of the He+ 1S-2S Transition in an Atomic Beam**

*Wednesday, 24 May 2023 09:00 (45 minutes)*

Abstract provided as attached pdf-file

**Primary authors:** Mr MARTINEZ DE VELASCO, Andrés (Vrije Universiteit Amsterdam); Mr GRÜNDEMAN, Elmer (Vrije Universiteit Amsterdam); Prof. EIKEMA, Kjeld (Vrije Universiteit Amsterdam); Dr COLLOMBON, Mathieu (Vrije Universiteit Amsterdam); Dr BARBÉ, Vincent (Vrije Universiteit Amsterdam)

**Presenter:** Prof. EIKEMA, Kjeld (Vrije Universiteit Amsterdam)

**Session Classification:** Wednesday 1

**Track Classification:** precision measurements in fundamental physics, astrophysics and cosmology

Contribution ID: 44

Type: **Poster presentation**

## **Towards Ramsey-Comb Spectroscopy of the 1S-2S Transition in He<sup>+</sup>**

*Monday, 22 May 2023 19:40 (20 minutes)*

abstract provided as attached pdf-file

**Primary author:** Mr GRUNDEMAN, Elmer (Vrije Universiteit Amsterdam)

**Presenter:** Mr GRUNDEMAN, Elmer (Vrije Universiteit Amsterdam)

**Session Classification:** Poster Session 1

**Track Classification:** precision measurements in fundamental physics, astrophysics and cosmology

Contribution ID: 45

Type: **Invited Talk**

# Two-Photon Exchange in Precision Measurements of Nucleon Electromagnetic Form Factors

*Monday, 22 May 2023 10:15 (45 minutes)*

**Primary author:** Prof. AFANASEV, Andrei

**Presenters:** AFANACIEV, Andrei; Prof. AFANASEV, Andrei

**Session Classification:** Monday 1&2

**Track Classification:** precision measurements in fundamental physics, astrophysics and cosmology

Contribution ID: 46

Type: **Poster presentation**

# Hydrogen Optical Lattice Clock

*Tuesday, 23 May 2023 18:45 (20 minutes)*

Defining the values of constants is the best method to define units since it separates the definition from the realization. For example, there are two very different methods to realize the kg. In the future, there can be other methods of realizing the kg that adapt to possible advancements in technology without changing the definition. With the reform of the SI system, all but one of the units are now based on defined constants. The only remaining (natural) object is the cesium atom that is used to define and realize the SI second. A hydrogen lattice clock would allow us to complete the process and remove the last object from the SI system.

We propose a trap for atomic hydrogen that is not more complex than a usual optical atomic clock. It is based on a magic wavelength optical dipole trap, similar to the current most accurate optical clocks. The trap can be loaded without Doppler cooling which avoids an extremely difficult 121 nm laser. The  $1S - 2S$  transition with a natural linewidth of 1.3 Hz would be the clock transition driven in a Doppler-free manner. Hence, only moderate temperature and no Doppler cooling are required. Our compact setup could be operated as a computable optical clock to redefine the SI-second as well as to improve spectroscopic data to test Quantum Electrodynamics.

**Primary author:** AMIT, Omer (Max-Planck-Institut für Quantenoptik)

**Presenter:** AMIT, Omer (Max-Planck-Institut für Quantenoptik)

**Session Classification:** Poster Session 2

**Track Classification:** quantum standards

Contribution ID: 47

Type: **Oral presentation**

## **High-precision hyperfine structure measurements on hydrogen-like $^3\text{He}$ and $^9\text{Be}$**

*Wednesday, 24 May 2023 10:10 (25 minutes)*

**Primary author:** DICKOPF, Stefan

**Presenter:** DICKOPF, Stefan

**Session Classification:** Wednesday 1

**Track Classification:** precision measurements in fundamental physics, astrophysics and cosmology

Contribution ID: 48

Type: **Oral presentation**

## **QED theory of the g factor of Li-like ions**

*Thursday, 25 May 2023 16:20 (25 minutes)*

**Primary author:** Dr YEROKHIN, Vladimir (Max Planck Institute for Nuclear Physics)

**Presenter:** Dr YEROKHIN, Vladimir (Max Planck Institute for Nuclear Physics)

**Session Classification:** Thursday 4

**Track Classification:** quantum electrodynamics of bound systems



Contribution ID: 49

Type: **Poster presentation**

## Variational Dirac–Coulomb approach with explicitly correlated basis functions

*Monday, 22 May 2023 19:30 (20 minutes)*

The no-pair Dirac–Coulomb(–Breit) equation is solved with high-accuracy \cite{allorder,DiracCoulomb,Breit,LScoupling} to provide a starting point for a new alternative theoretical method in relation with high-resolution atomic and molecular spectroscopy \cite{QEDcorr}. The sub-parts-per-billion convergence of the energy is achieved by considering the relativistic symmetry with an  $LS$  coupling scheme and expanding the relativistic wave function with an explicitly correlated Gaussian (ECG) basis set. The ECG significantly improves the description of the electron correlation compared to {it e.g.,} a determinant basis set, but the positive-energy projection is more complicated due to the lack of the underlying one-electron picture. Therefore, several positive-energy projectors are examined to achieve and justify the parts-per-billion convergence of the energy. The no-pair Dirac–Coulomb energy is compared with perturbative results for atomic and molecular systems with small nuclear charge numbers and it reproduces the perturbative expressions \cite{SucherPHD} up to  $\alpha^3 E_h$  order.

**Primary author:** JESZENSZKI, Péter (Postdoc)

**Co-author:** MÁTYUS, Edit (ELTE, Eötvös Loránd University, Institute of Chemistry, Budapest, Hungary)

**Presenter:** JESZENSZKI, Péter (Postdoc)

**Session Classification:** Poster Session 1

**Track Classification:** quantum electrodynamics of bound systems

Contribution ID: 50

Type: **Poster presentation**

## **Pre-Born–Oppenheimer Dirac–Coulomb–Breit computations for two-fermion systems**

*Monday, 22 May 2023 19:10 (20 minutes)*

abstract provided as attached pdf-file

**Primary authors:** FERENC, David (ELTE, Eötvös Loránd University, Institute of Chemistry, Budapest, Hungary); Dr MÁTYUS, Edit (ELTE, Eötvös Loránd University, Institute of Chemistry, Budapest, Hungary)

**Presenter:** FERENC, David (ELTE, Eötvös Loránd University, Institute of Chemistry, Budapest, Hungary)

**Session Classification:** Poster Session 1

**Track Classification:** quantum electrodynamics of bound systems

Contribution ID: 51

Type: **Oral presentation**

## Accurate calculations of transition energies in doubly ionized Carbon ion (C III)

*Tuesday, 23 May 2023 17:50 (20 minutes)*

In this work, we present benchmark variational calculations for the ground and 15 lowest bound excited 1S and 1P states of doubly ionized Carbon (C III). The nonrelativistic wave function of each of these states is generated in an independent calculation by expanding it in terms of a large number (8,000–12,000) of all-electron explicitly correlated Gaussian functions (ECG) whose nonlinear parameters are extensively optimized. A finite nuclear mass value is used in the calculations and the motion of the nucleus is explicitly included in the zero-order nonrelativistic Hamiltonian. The leading relativistic and quantum electrodynamics (QED) corrections to the energy levels are subsequently computed using the perturbation theory. The obtained energies and corrections allow us to determine highly accurate interstate transition frequencies for all naturally occurring stable carbon isotopes ( $^{12}\text{C}^{++}$ ,  $^{13}\text{C}^{++}$ , and  $^{14}\text{C}^{++}$ ) as well as for the model ion with an infinitely heavy nucleus,  $\infty\text{C}^{++}$ .

abstract provided as attached pdf-file.

**Primary authors:** Dr NASIRI, Saeed (Department of Physics, Nazarbayev University); Prof. BUBIN, Sergiy (Nazarbayev University, Astana, Kazakhstan); Prof. ADAMOWICZ, Ludwik (Department of Chemistry and Biochemistry, University of Arizona, Tucson, Arizona 85721, USA)

**Presenter:** Dr NASIRI, Saeed (Department of Physics, Nazarbayev University)

**Session Classification:** Poster Session 2

**Track Classification:** quantum electrodynamics of bound systems

Contribution ID: 52

Type: **Invited Talk**

## Determination of the Cabibbo-Koyabashi-Maskawa matrix elements $|V_{cb}|$ and $|V_{ub}|$ at Belle and Belle II

*Tuesday, 23 May 2023 14:00 (40 minutes)*

A precise knowledge of the elements  $|V_{cb}|$  and  $|V_{ub}|$  of the CKM matrix is important to constraint the Standard Model of particle physics and predict the rate of ultra-rare  $B$  meson decays such as  $B \rightarrow \mu\nu$  or  $B \rightarrow K\nu\bar{\nu}$ . In this talk I will review the experimental status of these fundamental parameters with a focus on the latest developments and new results from the Belle and Belle II experiments.

**Primary author:** SCHWANDA, Christoph (Austrian Academy of Sciences (AT))

**Presenters:** SCHWANDA, Christoph; SCHWANDA, Christoph (Austrian Academy of Sciences (AT))

**Session Classification:** Tuesday 3

**Track Classification:** tests and extensions of the Standard Model of elementary particles

Contribution ID: 53

Type: **Oral presentation**

## Lamb dip of a quadrupole transition in H2

*Tuesday, 23 May 2023 11:35 (25 minutes)*

abstract provided as attached pdf-file

**Primary author:** DIOUF, Meissa

**Co-authors:** COZIJN, Frank (VU University Amsterdam); UBACHS, Wim (VU University Amsterdam)

**Presenter:** DIOUF, Meissa

**Session Classification:** Tuesday 2

**Track Classification:** precision measurements in fundamental physics, astrophysics and cosmology

Contribution ID: 54

Type: **Oral presentation**

## **Precision spectroscopy of transitions from the metastable $2^3S_1$ state of $^4\text{He}$ to high- $n$ p Rydberg states**

*Wednesday, 24 May 2023 12:20 (15 minutes)*

abstract provided as attached pdf-file

**Primary author:** CLAUSEN, Gloria (ETH Zürich)

**Co-authors:** MERKT, Frédéric (ETH Zurich); SCHMUTZ, Hansjürg (ETH Zürich); AGNER, Josef A. (ETH Zürich); SCHEIDEGGER, Simon

**Presenter:** CLAUSEN, Gloria (ETH Zürich)

**Session Classification:** Wednesday 2

**Track Classification:** precision measurements in fundamental physics, astrophysics and cosmology

Contribution ID: 56

Type: **Oral presentation**

## Towards an Atomic Mass Measurement of the ${}^3\text{He}$ Nucleus with Parts-per-trillion Precision

*Thursday, 25 May 2023 15:00 (25 minutes)*

abstract provided as attached pdf-file

**Primary author:** BEZRODNOVA, Olesia (Max Planck Institute for Nuclear Physics, Heidelberg, Germany)

**Co-authors:** BLAUM, Klaus (Max Planck Institute for Nuclear Physics, Heidelberg, Germany); SASIDHARAN, Sangeetha (Max Planck Institute for Nuclear Physics, Heidelberg, Germany; GSI Helmholtzzentrum, Darmstadt, Germany); RAU, Sascha (Max Planck Institute for Nuclear Physics, Heidelberg, Germany); STURM, Sven (Max Planck Institute for Nuclear Physics, Heidelberg, Germany); QUINT, Wolfgang Peter (GSI Helmholtzzentrum, Darmstadt, Germany)

**Presenter:** BEZRODNOVA, Olesia (Max Planck Institute for Nuclear Physics, Heidelberg, Germany)

**Session Classification:** Thursday 3

**Track Classification:** precision measurements in fundamental physics, astrophysics and cosmology

Contribution ID: 57

Type: **Oral presentation**

# High Precision Measurements of Single Ions in the ALPHATRAP Penning Trap Setup

Thursday, 25 May 2023 15:25 (25 minutes)

The \textsc{Alphatrap} experiment \cite{alphatrap} is a double Penning trap setup at the Max Planck Institute for Nuclear Physics in Heidelberg, Germany. The cryogenic trap setup allows for high precision spectroscopic measurements on single ions while utilizing the continuous Stern-Gerlach effect for state detection \cite{csge}.

It is connected to a room temperature beamline with access to several different ion sources and thus a wide range of charge states are available for measurements. A cryogenic valve results in a residual pressure of below  $10^{-16}$  mbar in the trap section leading to trapping times of several months.

%\noindent

In this contribution, I will give an overview of our setup and recent measurement campaigns. With our recent determination of the  $g$  factor of the bound electron of hydrogen-like tin, we have probed QED in the extreme electric field of the nucleus of  $10^{17}$  V/m. The direct electron  $g$ -factor difference of 2 coupled neon ions ( $^{20}\text{Ne}^{9+}$  and  $^{20}\text{Ne}^{9+}$ ) measured to 0.56 ppt has, for the first time, resolved the nuclear QED recoil effect \cite{NeTim}.

I will focus on the spectroscopy of single molecular hydrogen ions, in particular the hyperfine spectroscopy of  $\text{HD}^+$  probing spin-spin interaction theory and the current steps towards rovibrational laser spectroscopy en route to high-precision measurements on single  $\text{H}_2^+$  ions for future matter-antimatter comparisons \cite{myers18}.

%References (<10)

\begin{thebibliography}{9.}

%\frenchspacing

\setlength{\itemsep}{0em}

\setlength{\parskip}{0em}

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H. Dehmelt, Proc. Natl. Acad. Sci. USA \textbf{83}, 2291 (1986)

\bibitem{NeTim}

T. Sailer, \textit{et al.}, Nature Physics, \textbf{606}, pages 479–483 (2022)

\bibitem{myers18}

E. Myers, Phys. Rev. A \textbf{98}, 010101(R) (2018)

\end{thebibliography}

**Primary author:** KONIG, Charlotte

**Co-authors:** HEISSE, Fabian; MORGNER, Jonathan; Dr SAILER, Tim; Dr TU, Bingsheng; STURM, Sven (Max Planck Institute for Nuclear Physics, Heidelberg, Germany); BLAUM, Klaus (Max Planck Institute for Nuclear Physics, Heidelberg, Germany)

**Presenter:** KONIG, Charlotte



**Session Classification:** Thursday 3

**Track Classification:** precision measurements in fundamental physics, astrophysics and cosmology

Contribution ID: 58

Type: **Oral presentation**

## **Nuclear structure effects in the Lamb shift of $\mu\text{H}$ and $\mu\text{D}$**

*Friday, 26 May 2023 09:00 (30 minutes)*

The abstract is provided in the attached pdf file.

**Primary author:** LENSKY, Vadim (JGU Mainz)

**Co-authors:** HAGELSTEIN, Franziska (JGU Mainz & PSI); Dr PASCALUTSA, Vladimir (University of Mainz)

**Presenter:** LENSKY, Vadim (JGU Mainz)

**Session Classification:** Friday 1

**Track Classification:** spectroscopy of exotic atoms

Contribution ID: 59

Type: **Oral presentation**

## **Towards a precision measurement of charge radii of light nuclei**

*Friday, 26 May 2023 10:15 (20 minutes)*

Abstract provided as attached pdf-file

**Primary author:** Dr OHAYON, Ben (Physics Department, Technion —Israel Institute of Technology)

**Presenters:** OHAYON, Ben (Racah Institute of Physics); Dr OHAYON, Ben (Physics Department, Technion —Israel Institute of Technology)

**Session Classification:** Friday 1

**Track Classification:** spectroscopy of exotic atoms

Contribution ID: 60

Type: **Poster presentation**

## **Path integral formalism for radiative corrections in bound-state QED**

*Tuesday, 23 May 2023 19:35 (20 minutes)*

Abstract provided as an attached pdf file.

**Primary authors:** BANERJEE, Sreya (Max Planck Institute for Nuclear Physics); Dr HARMAN, Zoltán (Max Planck Institute for Nuclear Physics)

**Presenter:** BANERJEE, Sreya (Max Planck Institute for Nuclear Physics)

**Session Classification:** Poster Session 2

**Track Classification:** quantum electrodynamics of bound systems

Contribution ID: 61

Type: **Invited Talk**

## **Energy levels of the hydrogen molecule from relativistic nonadiabatic calculations**

*Tuesday, 23 May 2023 11:00 (35 minutes)*

abstract provided as attached pdf-file

**Primary author:** KOMASA, Jacek

**Presenter:** KOMASA, Jacek

**Session Classification:** Tuesday 2

**Track Classification:** quantum electrodynamics of bound systems

Contribution ID: 62

Type: **Oral presentation**

## **Theory of the magnetic moments and hyperfine splitting of ${}^3\text{He}^+$**

*Wednesday, 24 May 2023 10:35 (12 minutes)*

abstract provided as attached pdf-file

**Primary author:** SIKORA, Bastian

**Presenter:** SIKORA, Bastian

**Session Classification:** Wednesday 1

**Track Classification:** quantum electrodynamics of bound systems

Contribution ID: 63

Type: **Poster presentation**

## **Two-loop self-energy corrections to the bound-electron g-factor: Status of M-term calculations**

*Monday, 22 May 2023 19:40 (20 minutes)*

abstract provided as attached pdf-file

**Primary author:** SIKORA, Bastian

**Presenter:** SIKORA, Bastian

**Session Classification:** Poster Session 1

**Track Classification:** quantum electrodynamics of bound systems

Contribution ID: 65

Type: **Invited Talk**

## **Measurement of hyperfine structure and the Zemach radius in $6\text{Li}^+$ using optical Ramsey technique**

*Monday, 22 May 2023 11:00 (35 minutes)*

Abstract provided as attached pdf-file.

**Primary author:** Mr GAO, Kelin (Chinese Academy of Sciences)

**Presenter:** Mr GAO, Kelin (Chinese Academy of Sciences)

**Session Classification:** Monday 1&2

**Track Classification:** precision measurements in fundamental physics, astrophysics and cosmology



Contribution ID: 66

Type: **Poster presentation**

## **Search for the electric dipole moment of the electron using BaF molecules**

*Monday, 22 May 2023 18:50 (20 minutes)*

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

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

**Session Classification:** Poster Session 1

**Track Classification:** precision measurements in fundamental physics, astrophysics and cosmology

Contribution ID: 67

Type: **Oral presentation**

## Dark Matter Searches at LNF with the PADME detector

*Monday, 22 May 2023 14:00 (25 minutes)*

The evidence of dark matter so far is based only on gravitational effects observed at cosmological level. To explain these effects, many theoretical models suggest other non-gravitational very-weak interactions between dark matter and ordinary matter. To test this hypothesis, different experiments are trying to directly produce dark matter at particle accelerators.

The Positron Annihilation into Dark Matter Experiment (PADME), ongoing at the Laboratori Nazionali di Frascati of INFN, is looking for signals of hidden particles by studying positron-electron annihilations.

The experiment was built and commissioned at the end of 2018 and collected  $\approx 5 \times 10^{12}$  positrons on target in two distinct run periods.

The dark photon signal is searched studying the reaction  $e^+e^- \rightarrow \gamma A'$  and evaluating the missing-mass spectrum of single photon final states. This requires a precise calibration of the experimental setup that has been performed evaluating the cross section of the process  $e^+e^- \rightarrow \gamma\gamma(\gamma)$  at  $\sqrt{s}=20$  MeV. The obtained results is the most precise determination of this physics quantity ever done, at it shows a good agreement with NLO-QED predictions.

In 2022 PADME had also a new data taking to study “X17 anomaly”, a tricky phenomenon observed by the Atomki collaboration of Debrecem in the de-excitation via internal-pair-creation of some light nuclear systems (i.e.  ${}^8\text{Be}$ ,  ${}^4\text{He}$ ,  ${}^{12}\text{C}$ ). PADME owns the unique opportunity to test the particle hypothesis of such anomaly. Therefore, with a slightly modifying experimental setup, a dedicated data taking was performed. In the talk the details of the ongoing analyses will be presented.

**Primary authors:** FERRAROTTO, Fabio (INFN - National Institute for Nuclear Physics); Dr GIANOTTI, Paola (INFN Laboratori Nazionali di Frascati (IT))

**Presenter:** FERRAROTTO, Fabio (INFN - National Institute for Nuclear Physics)

**Session Classification:** Monday 3

**Track Classification:** precision measurements in fundamental physics, astrophysics and cosmology

Contribution ID: 68

Type: **Poster presentation**

## **Progress on the Dirac Equation for the hydrogen molecular ion**

*Tuesday, 23 May 2023 19:35 (20 minutes)*

**Primary author:** Mr NOGUEIRA, Hugo D. (Laboratoire Kastler Brossel (Sorbonne Université, CNRS))

**Co-author:** Dr KARR, Jean-Philippe (Laboratoire Kastler Brossel (Sorbonne Université, CNRS))

**Presenter:** Mr NOGUEIRA, Hugo D. (Laboratoire Kastler Brossel (Sorbonne Université, CNRS))

**Session Classification:** Poster Session 2

**Track Classification:** quantum electrodynamics of bound systems

Contribution ID: **69**

Type: **Poster presentation**

## Testing Lorentz symmetry using Deuterium

*Monday, 22 May 2023 18:30 (20 minutes)*

abstract provided as attached pdf file

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

**Co-authors:** WIDMANN, Eberhard (Austrian Academy of Sciences (AT)); SIMON, Martin (Austrian Academy of Sciences (AT))

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

**Session Classification:** Poster Session 1

**Track Classification:** tests and extensions of the Standard Model of elementary particles

Contribution ID: 70

Type: **Oral presentation**

## **Hydrogen molecular ions, fundamental constants, and new physics**

*Thursday, 25 May 2023 10:15 (25 minutes)*

**Primary author:** Dr KARR, Jean-Philippe (Laboratoire Kastler Brossel (Sorbonne Université, CNRS))

**Co-author:** KOELEMIEJ, Jeroen (VU University)

**Presenters:** KARR, Jean-Philippe (Laboratoire Kastler Brossel (FR)); Dr KARR, Jean-Philippe (Laboratoire Kastler Brossel (Sorbonne Université, CNRS))

**Session Classification:** Thursday 1

**Track Classification:** fundamental physical constants

Contribution ID: 71

Type: **Poster presentation**

## Ground state preparation for HD+ rovibration transition measurement

*Monday, 22 May 2023 18:10 (20 minutes)*

Generation of ground state HD+ based on the [2+1'] resonance-enhanced threshold photoionization (RETPI) is provided for rovibrational transition frequency measurement. Using state-selected [1+1'] resonance-enhanced multiphoton dissociation, the yield of rovibrational ground state HD+ is evaluated. The state preparation of HD+ lay an important basis of the proceed measurement which detects the  $(v=0, j=0) \rightarrow (v=6, j=1)$  rovibrational transition frequency.

**Primary authors:** ZHANG, QianYu (APM of CAS); Mr ZHANG, Yong (APM of CAS); Mr HE, ShengGuo (APM of CAS); Mr TONG, Xin (APM of CAS)

**Presenter:** ZHANG, QianYu (APM of CAS)

**Session Classification:** Poster Session 1

**Track Classification:** fundamental physical constants

Contribution ID: 72

Type: **Poster presentation**

## Precise determination of the $2s22p^5 - 2s2p^6$ transition energy in fluorine-like $Ni^{19+}$ utilizing a low-lying dielectronic resonance

High precision spectroscopy of the low-lying dielectronic resonances in fluorine-like  $Ni^{19+}$  ions was studied by employing the electron-ion merged-beams method at the heavy-ion storage ring CSRm. The measured dielectronic-recombination (DR) resonances are identified by comparison with relativistic calculations utilizing the flexible atomic code (FAC). The lowest-energy resonance at about 86 meV is due to DR via  $(2s2p^6[2S1/2]6s)J=1$  intermediate state. The position of this resonance could be determined within an experimental uncertainty of as low as  $\pm 4$  meV. The binding energy of the 6s Rydberg electron in the resonance state was calculated using two different approaches, the Multi-Configurational Dirac-Hartree-Fock (MCDHF) method and the Stabilization Method (SM). The sum of the experimental  $(2s2p^6[2S1/2]6s)J=1$  resonance energy and the theoretical 6s binding energies from the MCDHF and SM calculations, yields the following values for the  $2s22p^5 2P_{3/2} \rightarrow 2s2p^6 2S_{1/2}$  transition energy  $149.056(4)\text{exp}(20)\text{MCDHF}$  and  $149.032(4)\text{exp}(6)\text{SM}$ , respectively. The theoretical calculations reveal that second-order QED and third-order correlation effects contribute together about 0.1 eV to the total transition energy. The present precision DR spectroscopic measurement builds a bridge which enables comparisons between different theories.

**Primary author:** Dr WEN, Wei-Qiang

**Presenter:** Dr WEN, Wei-Qiang

**Session Classification:** Poster Session 2

**Track Classification:** quantum electrodynamics of bound systems

Contribution ID: 74

Type: **Poster presentation**

# Development of Electrodes for the Muon Penning Trap Experiment

*Tuesday, 23 May 2023 18:05 (20 minutes)*

**Primary author:** KOKUBO, Hiroto (Ibaraki University)

**Presenter:** KOKUBO, Hiroto (Ibaraki University)

**Session Classification:** Poster Session 2

**Track Classification:** fundamental physical constants



Contribution ID: 75

Type: **Oral presentation**

## High-precision calculations of the electron anomalous magnetic moment in quantum electrodynamics

*Wednesday, 24 May 2023 15:15 (15 minutes)*

The electron anomalous magnetic moment is the most precise value in microphysics. The agreement between theoretical calculations and experiments is good, but last years it became not so ideal due to an improved experimental precision. The current status of this agreement/disagreement for the electron  $g-2$  will be reviewed as well as for the fine-structure constant.

In 2019 the author has computed a large part of the 5-loop contribution to the electron  $g-2$ . It is known that there is a discrepancy between this value and the previously known value. The current status of this discrepancy and independent calculations will be revealed.

Author's method of calculation will be briefly explained, since all computations of this precision level require special methods to make them realizable on existing computers. A progress in further calculations will be demonstrated.

**Primary author:** VOLKOV, Sergey**Presenter:** VOLKOV, Sergey**Session Classification:** Wednesday 3**Track Classification:** fundamental physical constants

Contribution ID: 76

Type: **Oral presentation**

## **Sub-Doppler ro-vibrational spectroscopy on HT**

*Tuesday, 23 May 2023 12:00 (15 minutes)*

**Primary author:** COZIJJN, Frank (VU University Amsterdam)

**Co-authors:** DIOUF, Meissa; UBACHS, Wim (VU University Amsterdam)

**Presenter:** COZIJJN, Frank (VU University Amsterdam)

**Session Classification:** Tuesday 2

**Track Classification:** precision measurements in fundamental physics, astrophysics and cosmology

Contribution ID: 77

Type: **Oral presentation**

## Tests of physics beyond the standard model with the $g$ factor of few-electron ions

*Thursday, 25 May 2023 16:45 (25 minutes)*

In this contribution, we discuss the theory of the bound-electron  $g$  factor. This quantity can be measured nowadays to high precision in Penning-trap setups. The collaboration of theory and experiment enables impactful and detailed tests of quantum electrodynamics in a strong background electric field, and a competitive determination of fundamental constants [1] and nuclear properties [2]. Very recently, we have shown that such studies also allow to test certain extensions of the standard model of particle physics [3]: in study addressing the isotope shift of the  $g$  factor of H-like Ne ions, a competitive bound was set on the strength of a hypothetical fifth force by combining the experimental value of the isotope shift with the precision theory of nuclear recoil within QED.

[1] V. A. Yerokhin, E. Berseneva, Z. Harman *et al.*, Phys. Rev. Lett. **116**, 100801 (2016).

[2] A. Schneider, B. Sikora, S. Dickopf *et al.*, Nature **606**, 878 (2022).

[3] V. Debierre, C. H. Keitel, Z. Harman, Phys. Lett. B **807**, 135527 (2020); arXiv:2202.01668 (2022);

V. Debierre, N. S. Oreshkina, I. A. Valuev, Z. Harman, C. H. Keitel, Phys. Rev. A **106**, 062801 (2022).

[4] T. Sailer, V. Debierre, Z. Harman *et al.*, Nature **606**, 479 (2022).

**Primary author:** Dr HARMAN, Zoltan (Max Planck Institute for Nuclear Physics)

**Presenter:** Dr HARMAN, Zoltan (Max Planck Institute for Nuclear Physics)

**Session Classification:** Thursday 4

**Track Classification:** tests and extensions of the Standard Model of elementary particles

Contribution ID: 78

Type: **Oral presentation**

## **Nonadiabatic QED correction for hydrogen molecule**

*Tuesday, 23 May 2023 12:15 (15 minutes)*

Abstract provided as an attached pdf file.

**Primary author:** Dr CZACHOROWSKI, Paweł (Adam Mickiewicz University, Poznań)

**Presenter:** Dr CZACHOROWSKI, Paweł (Adam Mickiewicz University, Poznań)

**Session Classification:** Tuesday 2

Contribution ID: 79

Type: **Oral presentation**

## The n2EDM experiment searching for a neutron electric dipole moment

*Tuesday, 23 May 2023 16:10 (25 minutes)*

Searches for permanent electric dipole moments (EDM) of fundamental particles and systems are among the most sensitive probes for CP violation beyond the Standard Model, which is required in order to explain the baryon asymmetry of the Universe. The current limit on the EDM of the neutron is set by our collaboration,  $|d_n| < 1.8 \times 10^{-26}$  ecm (C.L. 90%) in the nEDM experiment. Presently, a next-generation apparatus - n2EDM - is in the commissioning phase at the ultracold neutron source at the Paul Scherrer Institute (PSI) with the aim of improving the sensitivity by an order of magnitude with provision for further substantial improvements. This presentation will provide an overview of the experiment as well as the commissioning status of the apparatus. Focusing on the most recent progress, we will in particular report on the characterization and optimization of the magnetic environment of the central part of the apparatus, which is a crucial condition to achieve the desired sensitivity.

**Primary author:** SVIRINA, Kseniia (LPSC, Université Grenoble Alpes)

**Presenter:** SVIRINA, Kseniia (LPSC, Université Grenoble Alpes)

**Session Classification:** Tuesday 4

**Track Classification:** tests and extensions of the Standard Model of elementary particles

Contribution ID: **80**Type: **Oral presentation**

## **Status and prospects of the muon magnetic anomaly measurement at FNAL**

*Wednesday, 24 May 2023 14:00 (30 minutes)*

The Muon g-2 experiment at FNAL measured the muon magnetic anomaly to 0.46 ppm in 2021 and expects to increase the precision on this quantity to 0.23 ppm in 2023 and to 0.14 ppm in 2025, providing a stronger test of the Standard Model prediction, whose uncertainty has been recently estimated at 0.37 ppm. We report on how the measurement is performed, on the improvements with respect to the 2021 published result and on the estimated precision of the incoming measurements.

**Primary author:** LUSIANI, Alberto (Scuola Normale Superiore and INFN, sezione di Pisa)

**Presenter:** LUSIANI, Alberto (Scuola Normale Superiore and INFN, sezione di Pisa)

**Session Classification:** Wednesday 3

**Track Classification:** tests and extensions of the Standard Model of elementary particles

Contribution ID: **81**

Type: **Oral presentation**

## **Recoil and Radiative-Recoil Corrections in Muonium**

*Wednesday, 24 May 2023 16:35 (25 minutes)*

abstract attached as a pdf file

**Primary author:** Prof. ADKINS, Gregory (Franklin & Marshall College)

**Co-authors:** SHINN, Evan (Franklin & Marshall College); LI, Yanxi (Franklin & Marshall College); GOM-  
PRECHT, Jonathan (Franklin & Marshall College)

**Presenter:** Prof. ADKINS, Gregory (Franklin & Marshall College)

**Session Classification:** Wednesday 4

**Track Classification:** quantum electrodynamics of bound systems

Contribution ID: 82

Type: **Poster presentation**

## **Experimental measurement of the energy dependence of the rate of muon transfer to oxygen at low energies**

*Tuesday, 23 May 2023 19:35 (20 minutes)*

abstract attached as pdf

**Primary author:** BAKALOV, Dimitar (Institute for Nuclear Research and Nuclear Energy, BAS)

**Presenter:** BAKALOV, Dimitar (Institute for Nuclear Research and Nuclear Energy, BAS)

**Session Classification:** Poster Session 2

**Track Classification:** spectroscopy of exotic atoms



Contribution ID: **83**

Type: **Invited Talk**

# Cavity-Enhanced Precision Spectroscopy of Molecules

*Tuesday, 23 May 2023 09:00 (45 minutes)*

abstract attached as pdf

**Primary author:** HU, Shuiming (Univ Sci & Tech China)

**Presenter:** HU, Shuiming (Univ Sci & Tech China)

**Session Classification:** Tuesday 1

**Track Classification:** precision measurements in fundamental physics, astrophysics and cosmology

Contribution ID: **84**

Type: **Invited Talk**

# **An Optical Atomic Clock Based on a Highly Charged Ion**

*Thursday, 25 May 2023 11:10 (45 minutes)*

abstract attached as pdf

**Primary author:** SCHMIDT, Piet Oliver

**Presenter:** SCHMIDT, Piet Oliver

**Session Classification:** Thursday 2

**Track Classification:** quantum standards

Contribution ID: 85

Type: **Invited Talk**

# Higgs Boson Searches Beyond the Standard Model from ATLAS and CMS

*Tuesday, 23 May 2023 14:40 (40 minutes)*

The latest results of Higgs boson searches beyond the Standard Model are reviewed from the ATLAS and CMS experiments. This includes searches for additional neutral, charged and double charged Higgs-like bosons, searches for dark matter produced in association with a Higgs boson and searches for new physics in Higgs boson pair production processes. Exotic Higgs boson decays are addressed as well. Interpretations are given in the hMSSM, a special parameterization of the Minimal Supersymmetric extension of the Standard Model in which the mass of the lightest Higgs boson is set to the LHC measured 125 GeV.

**Primary author:** SOPCZAK, Andre (Czech Technical University in Prague (CZ))

**Presenter:** SOPCZAK, Andre (Czech Technical University in Prague (CZ))

**Session Classification:** Tuesday 3

**Track Classification:** tests and extensions of the Standard Model of elementary particles

Contribution ID: **86**

Type: **Invited Talk**

## **Avogadro and Planck constants, two fundamental pillars of the SI**

*Monday, 22 May 2023 16:00 (40 minutes)*

abstract attached as pdf

**Primary author:** Prof. MASSA, Enrico (Istituto Nazionale di Ricerca Metrologica)

**Presenter:** Prof. MASSA, Enrico (Istituto Nazionale di Ricerca Metrologica)

**Session Classification:** Monday 4

**Track Classification:** fundamental physical constants

Contribution ID: 87

Type: **Poster presentation**

## **Precision spectroscopy of the 2S-6P transition in atomic hydrogen and deuterium**

*Monday, 22 May 2023 19:40 (20 minutes)*

see attached pdf

**Primary author:** WIRTHL, Vitaly

**Presenter:** WIRTHL, Vitaly

**Session Classification:** Poster Session 1

**Track Classification:** quantum electrodynamics of bound systems

Contribution ID: **88**

Type: **Poster presentation**

## **Theory of the magnetic moments and hyperfine splitting of ${}^3\text{He}^+$**

*Tuesday, 23 May 2023 19:35 (20 minutes)*

abstract provided as attached pdf-file

**Primary author:** SIKORA, Bastian

**Presenter:** SIKORA, Bastian

**Session Classification:** Poster Session 2

**Track Classification:** quantum electrodynamics of bound systems

Contribution ID: 89

Type: **Poster presentation**

## Cryogenic muonium beam for the LEMING experiment

*Tuesday, 23 May 2023 17:45 (20 minutes)*

We are developing a high intensity, low-emittance atomic muonium ( $\text{Mu} = \mu^+ + e^-$ ) beam, which would enable improving the precision of Mu spectroscopy measurements and may be amenable to a direct measurement of the gravitational acceleration of Mu. Measuring the free fall of Mu atoms would be the first test of the weak equivalence principle using elementary antimatter of the second generation and, additionally, using a system without large contributions to the mass from the strong interaction.

We have demonstrated the working principle of a novel Mu source based on stopping a conventional muons beam in a thin layer of superfluid helium and the subsequent observation of Mu emission from the helium target. In this contribution, technical details from the first observation of Mu emitted from superfluid helium are presented. The experimental set up including detection schemes at below 0.2 K temperature will be described. An initial characterization of the novel Mu source shows sub-thermal beam dynamics with a  $\sim 30$  mrad angular divergence and a high Mu conversion efficiency of nearly  $\sim 20$  %. Implications of the newly developed Mu source on the prospective gravity experiment and the potential to improve the precision of Mu 1S-2S spectroscopy will be discussed.

**Primary author:** ZHANG, Jesse (ETH Zürich)

**Presenter:** ZHANG, Jesse (ETH Zürich)

**Session Classification:** Poster Session 2

**Track Classification:** spectroscopy of exotic atoms

Contribution ID: 90

Type: **Oral presentation**

## Electroweak nuclear radii constrain isospin-breaking corrections to $V_{ud}$

*Wednesday, 24 May 2023 17:15 (15 minutes)*

The most precise determination of the top-left corner element of the CKM quark mixing matrix  $V_{ud}$  is obtained from accurate measurements of superallowed nuclear  $\beta$  decays. Among the theoretical ingredients in this determination, the isospin symmetry-breaking (ISB) correction  $\delta_C$  plays a crucial role in aligning the  $Ft$ -values across all superallowed transitions. This alignment allows for a joint analysis of many transitions in terms of  $V_{ud}$ , while remaining misalignments are used to set stringent limits on BSM scalar currents. Until recently,  $\delta_C$  could not be directly constrained by observables remaining a purely theoretical input, and the respective uncertainty was hard to estimate reliably. In a series of recent works, we construct combinations of the nuclear charge and weak radii which are connected to  $\delta_C$ . These nuclear radii can be obtained experimentally from a combination of muonic atom spectroscopy, isotope shift measurements, and parity violation in electron scattering, and the corresponding experimental uncertainties can be used for a robust, data-driven and model-independent uncertainty on  $\delta_C$ , empowering tests of CKM unitarity and constraints on BSM with nuclear  $\beta$  decays.

**Primary author:** GORSHTEYN, Misha (Mainz University)

**Presenter:** GORSHTEYN, Misha (Mainz University)

**Session Classification:** Wednesday 4

**Track Classification:** tests and extensions of the Standard Model of elementary particles



Contribution ID: 91

Type: **Poster presentation**

## A positron trap for observing molecules containing positronium

*Monday, 22 May 2023 17:30 (20 minutes)*

A positron trap is a powerful and adaptable tool for performing experiments with positrons and positronium. These devices use a strong magnetic field, a stepped potential well and Nitrogen and CF<sub>4</sub> buffer gas. Positrons are initially trapped via the electronic excitation of N<sub>2</sub>, CF<sub>4</sub> is added for efficient cooling via vibrational and rotational excitations. This type of positron trap can typically produce  $\sim 10^5$  e<sup>+</sup>/s in bunches with a diameter of 1-2 mm and an energy spread of approximately 50 meV [e.g. 1,2].

We aim to use the positron pulses from such a trap to observe molecules containing positronium, such as PsH [3] and PsO [4] via collisions in gases such as methane and carbon dioxide. By using a high mass resolution ion spectrometer to detect fragments from dissociation, precise measurement of their binding energy will be performed.

This poster will describe the positron beam, trap, and ion spectrometer from the newly constructed positron beamline in Vienna.

[1] J. P. Sullivan, A. Jones, P. Caradonna, C. Makochekanwa, and S. J. Buckman, "A positron trap and beam apparatus for atomic and molecular scattering experiments", *Review of Scientific Instruments* 79, 113105 (2008).

[2] J. Clarke, D.P. van der Werf, B. Griffiths, D.C.S. Beddows, M. Charlton, H.H. Telle, P.R. Watkeys, Design and operation of a two-stage positron accumulator, *Review of Scientific Instruments*. 77 (2006) 063302.

[3] D.M. Schrader, F.M. Jacobsen, N.-P. Frandsen, U. Mikkelsen, Formation of positronium hydride, *Phys. Rev. Lett.* 69 (1992) 57–60.

[4] X. Cheng, D. Babikov, D.M. Schrader, Binding-energy predictions of positronium-atom systems, *Phys. Rev. A*. 85 (2012) 012503.

**Primary author:** WEISER, Alina (Austrian Academy of Sciences (AT))

**Presenter:** WEISER, Alina (Austrian Academy of Sciences (AT))

**Session Classification:** Poster Session 1

**Track Classification:** spectroscopy of exotic atoms

Contribution ID: 96

Type: **Invited Talk**

## Tension for the anomalous magnetic moment of the muon: 4.2 sigma, indeed?

*Wednesday, 24 May 2023 14:30 (45 minutes)*

Twenty years ago, in an experiment at Brookhaven National Laboratory, physicists detected what seemed to be a discrepancy between measurements of the muon's magnetic moment and theoretical calculations of what that measurement should be, raising the tantalizing possibility of physical particles or forces as yet undiscovered. The Fermilab team has announced that their precise measurement supports this possibility. The reported significance for new physics is 4.2 sigma just slightly below the discovery level of 5 sigma. However, an extensive new calculation of the muon's magnetic moment using lattice QCD by the BMW-collaboration reduces the gap between theory and experimental measurements. In this talk both the theoretical and experimental aspects are summarized with two possible narratives: a) almost discovery or b) Standard Model re-inforced. Some details of the lattice calculation are also shown.

**Primary author:** FODOR, Zoltan**Presenter:** FODOR, Zoltan**Session Classification:** Wednesday 3**Track Classification:** tests and extensions of the Standard Model of elementary particles

Contribution ID: 97

Type: **Oral presentation**

## Penning trap PENTATRAP for fundamental physics

*Thursday, 25 May 2023 12:10 (15 minutes)*

The Penning-trap mass spectrometer Pentatrap [1] located at the Max Planck Institute for Nuclear Physics in Heidelberg is performing mass-ratio measurements with a relative uncertainty in the  $10^{-11}$  regime. One of the unique features of the Pentatrap experiment is the external ion source producing a wide range of charge states from gaseous or solid-state samples down to only  $10^{15}$  atoms. the detection systems with single-ion sensitivity and the simultaneous measurements of two out of three eigenfrequencies in two adjacent traps.

Due to its versatility and high accuracy, Pentatrap can contribute to a variety of topics of fundamental physics. Among them are a test of bound-state QED in strong fields, a search for atomic long-lived metastable states in highly charged ions [2], and a search of dark matter by means of isotope shift spectroscopy. The setup overview and the latest results at Pentatrap will be presented.

1. Repp, J. et al. Appl. Phys. B 107 (2012) 983.
2. Schüssler, R. et al. Nature 581 (2020) 46.

**Primary author:** Mr FILLANIN, Pavel (MPIK)

**Co-authors:** Ms KROMER, Kathrin (MPIK); Mr DOOR, Menno (MPIK); Mr HERKENHOFF, Jost (MPIK); Mr SCHWEIGER, Christoph (MPIK); Dr ELISEEV, Sergey (MPIK); Prof. BLAUM, Klaus (MPIK)

**Presenter:** Mr FILLANIN, Pavel (MPIK)

**Session Classification:** Thursday 2

**Track Classification:** precision measurements in fundamental physics, astrophysics and cosmology

Contribution ID: 98

Type: **Invited Talk**

## Testing fundamental physics with trapped antihydrogen

*Friday, 26 May 2023 11:00 (40 minutes)*

**Primary author:** FRIESEN, Tim (Dep. of Phys. and Astronomy University of Calgary (CA))

**Presenter:** FRIESEN, Tim (Dep. of Phys. and Astronomy University of Calgary (CA))

**Session Classification:** Friday 2

**Track Classification:** spectroscopy of exotic atoms

Contribution ID: 99

Type: **Invited Talk**

## High Precision Experiments with Cold and Ultra-Cold Neutrons

*Tuesday, 23 May 2023 16:50 (45 minutes)*

The Neutron and Quantum Physics Group at TU Wien pursues various research approaches in the field of particles and cosmology.

In this talk, I will present a precise determination of the weak axial vector coupling  $g_A$  from a measurement of the  $\beta$ -asymmetry in the decay of free neutrons and the relationship to the unitarity of the CKM matrix. New symmetry tests of various kinds are coming within reach with the neutron decay facility PERC at Munich research reactor FRM2 or at ESS, the European Spallation Source. In focus are searches for possible deviations from the Standard Model (SM) of particle physics with cold and ultra-cold neutrons.

Next, we present a novel direct search strategy with neutrons based on a quantum bouncing ball in the gravity potential of the earth. The aim is to test the law of gravitation with a quantum interference technique, providing constraints on dark matter and dark energy.

**Primary author:** ABELE, Hartmut

**Presenter:** ABELE, Hartmut

**Session Classification:** Tuesday 4

**Track Classification:** tests and extensions of the Standard Model of elementary particles

Contribution ID: **100**

Type: **Invited Talk**

## **Testing the quantum nature of gravity in table top experiments**

*Monday, 22 May 2023 16:40 (40 minutes)*

not yet available

**Primary author:** ASPELMEYER, Markus (University of Vienna)

**Presenter:** ASPELMEYER, Markus (University of Vienna)

**Session Classification:** Monday 4

**Track Classification:** quantum standards

Contribution ID: **102**

Type: **Social**

## WELCOME

*Monday, 22 May 2023 10:00 (15 minutes)*

**Presenters:** WIDMANN, Eberhard (Austrian Academy of Sciences (AT)); SIMON, Martin (Austrian Academy of Sciences (AT)); KARSHENBOYM, Savely (LMU, MPQ)

Contribution ID: **103**

Type: **Oral presentation**

## **Three-Loop Corrections to Lamb Shift in Muonium and Positronium**

*Thursday, 25 May 2023 17:10 (25 minutes)*

Hard spin-independent three-loop radiative corrections to energy levels in muonium and positronium are calculated.

These corrections could be relevant for the new generation of precise 1S-2S and 2S-2P measurements in muonium and positronium.

**Primary author:** Prof. EIDES, Michael (University of Kentucky)

**Presenter:** Prof. EIDES, Michael (University of Kentucky)

**Session Classification:** Thursday 4

**Track Classification:** quantum electrodynamics of bound systems



Contribution ID: 104

Type: **Poster presentation**

## In-beam measurements of the hydrogen hyperfine splitting to constrain SME coefficients

*Tuesday, 23 May 2023 17:50 (2h 10m)*

The ASACUSA-CUSP experiment located at CERN's antiproton decelerator aims at measuring the ground state hyperfine splitting of antihydrogen ( $\bar{H}$ ) using a beam technique to test CPT symmetry. For this purpose, a beam of cold ( $\sim 50$ K) hydrogen has been developed to characterize the antihydrogen spectroscopy apparatus [1]. Beyond serving as a test bench for the  $\bar{H}$  experiment, the hydrogen beamline offers on its own a variety of possible measurements especially in the context of the Standard Model Extension (SME). The SME is an effective field theory that allows CPT and Lorentz symmetries to be broken [2]. A precise measurement of the hydrogen ground state hyperfine splitting was realized in 2017 using the extrapolation of a single hyperfine transition ( $\sigma_1$ ) reaching a relative precision of 2.7 ppb [3]. Since then several additions to the setup were made allowing the precise measurement of the  $\pi_1$  transition which provides sensitivities to some SME coefficients [4, 5]. A new measurement campaign on hydrogen started in 2022 and focused on  $\pi_1$  precision measurements with swapping external magnetic fields using the  $\sigma_1$  transition as a reference to constrain SME coefficients. An overview on the underlying theory and the experimental setup will be provided. The blind analysis of the collected data is effectively completed, and the contributions to the error budget, as well as peculiar effects originating from the static magnetic field, will be presented.

**Primary author:** NOWAK, Lilian (Austrian Academy of Sciences (AT))

**Presenter:** NOWAK, Lilian (Austrian Academy of Sciences (AT))

**Session Classification:** Poster Session 2

**Track Classification:** tests and extensions of the Standard Model of elementary particles

Contribution ID: 105

Type: **Poster presentation**

## Future BSM studies using UPCs with ALICE at the LHC

*Monday, 22 May 2023 17:50 (2h 10m)*

The search for physics beyond the Standard Model (BSM) is one of the main goals of the LHC. Compared to standard proton-proton collision studies, heavy-ion collisions provide unique and complementary means to search for new phenomena. In particular, ultra-peripheral collisions (UPCs) of heavy ions offer a natural environment for the studies of photon-mediated processes, such as light-by-light scattering, axion-like particle searches and  $\tau g - 2$  measurements.

A precise experimental determination of the tauon anomalous electromagnetic moment  $a_\tau$  is of great interest, since it increases the sensitivity to BSM physics by a factor of  $m_\tau/m_\mu \sim 280$  compared to measurements with muons. However, while the anomalous electromagnetic moments of the electron and muon were measured with high precision, results on tauons are still rather poor. The current best limits are 15 years old and were obtained by the DELPHI collaboration by a measurement of the  $e^+e^- \rightarrow e^+e^-\tau\tau$  cross section. Here we will discuss a method for measuring  $a_\tau$  in heavy-ion UPCs and provide prospects for such a measurement with ALICE in the LHC Run 3.

In addition we will provide an outlook on measurements with ALICE 3, the proposed next-generation LHC experiment for LHC Run~5 and beyond. At that time, the upgraded LHC accelerator will deliver beams of high luminosity, which together with a novel detector design will enable detailed studies of light-by-light scattering and to search for axion-like particles in a poorly explored range of diphoton invariant masses from 50 MeV/ $c^2$  to 5 GeV/ $c^2$ .

**Primary author:** LAVICKA, Roman (Austrian Academy of Sciences (AT))

**Presenter:** LAVICKA, Roman (Austrian Academy of Sciences (AT))

**Session Classification:** Poster Session 1

**Track Classification:** tests and extensions of the Standard Model of elementary particles

Contribution ID: **107**

Type: **Social**

## Poster Awards

*Thursday, 25 May 2023 12:25 (20 minutes)*

sponsored by the Physics Journal

**Primary authors:** WIDMANN, Eberhard (Austrian Academy of Sciences (AT)); SIMON, Martin (Austrian Academy of Sciences (AT))

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

Contribution ID: 108

Type: **Invited Talk**

## Studies of Exotic Physics with Antiprotons and Protons

*Friday, 26 May 2023 11:40 (40 minutes)*

The Standard Model of particle physics is incredibly successful and glaringly incomplete. Among the questions left open is the striking imbalance of matter and antimatter in our universe, which inspires experiments to compare the fundamental properties of matter/antimatter conjugates with high precision. The BASE collaboration at the antiproton decelerator of CERN is performing such high-precision comparisons with protons and antiprotons. Using advanced cryogenic Penning traps, we have recently performed the most precise measurement of the proton-to-antiproton charge-to-mass ratio with a fractional uncertainty of 16 parts in a trillion [1]. In another measurement, we have invented a novel spectroscopy method, that allowed for the first direct measurement of the antiproton magnetic moment with a fractional precision of 1.5 parts in a billion [2]. Together with our last measurement of the proton magnetic moment [3] this improves the precision of previous magnetic moment based tests of the fundamental CPT invariance by more than a factor of 3000. A time series analysis of the sampled magnetic moment resonance furthermore enabled us to set first direct constraints on the interaction of antiprotons with axion-like particles (ALPs) [4], and most recently, we have used our ultra-sensitive single particle detection systems to derive constraints on the conversion of ALPs into photons [5]. In parallel we are working on the implementation of new measurement technology to sympathetically cool antiprotons [6] and to apply quantum logic inspired spectroscopy techniques [7]. I will review the recent results produced by BASE, with particular focus on the recent 16 p.p.t. comparison of the antiproton-to-proton charge-to-mass ratio and recent developments towards an improved measurement of the antiproton magnetic moment.

*Abstract with references and complete authors list attached.*

**Primary author:** Prof. ULMER, Stefan (RIKEN (JP))

**Presenter:** Prof. ULMER, Stefan (RIKEN (JP))

**Session Classification:** Friday 2

**Track Classification:** precision measurements in fundamental physics, astrophysics and cosmology

Contribution ID: 109

Type: **Poster presentation**

## The SIDDHARTA-2 Experiment: Investigating the Strong Interaction with Kaonic Atoms

*Tuesday, 23 May 2023 17:50 (2h 10m)*

The antikaon-nucleon interaction in the low-energy regime of QCD is, to this day, not fully understood and theoretical models need experimental constraints. Kaonic atoms are ideal candidates to study this regime of QCD including strangeness without the need for extrapolation to zero relative energy. The SIDDHARTA-2 experiment, located at the DAΦNE collider at LNF in Italy, can provide this input via X-ray spectroscopy of light kaonic atoms, in particular by measuring the ( $2p \rightarrow 1s$ ) transition in kaonic deuterium. In combination with the results for kaonic hydrogen obtained by SIDDHARTA, this will enable the extraction of the isospin-dependent antikaon-nucleon scattering lengths  $a_0$  and  $a_1$ , which are crucial parameters for the theoretical descriptions. SIDDHARTA-2 performed its first periods of data acquisition in 2021 with a reduced setup, called SIDDHARTINO, and the full SIDDHARTA-2 setup in 2022. From these data, a new result for the ( $3d \rightarrow 2p$ ) transition in kaonic  ${}^4\text{He}$  was extracted. Moreover, several transition energies in intermediate-mass kaonic atoms were measured for the first time. In preparation for the kaonic deuterium run, the setup was optimised via the implementation of a new SDD cooling system and additional veto detectors. The obtained results and optimisations of the apparatus are presented.

**Primary author:** TUECHLER, Marlene**Presenter:** TUECHLER, Marlene**Session Classification:** Poster Session 2**Track Classification:** spectroscopy of exotic atoms

Contribution ID: 110

Type: **Poster presentation**

## **Utilising the 1s-2s transition for a selective detection of hydrogen**

*Tuesday, 23 May 2023 19:40 (20 minutes)*

**Primary author:** RHEINFRANK, Simon (Austrian Academy of Sciences (AT))

**Presenter:** RHEINFRANK, Simon (Austrian Academy of Sciences (AT))

**Session Classification:** Poster Session 2

**Track Classification:** tests and extensions of the Standard Model of elementary particles

Contribution ID: 111

Type: **Poster presentation**

## Study of Annihilations with Slow Extracted Antiprotons

*Monday, 22 May 2023 17:30 (2h 30m)*

A number of experiments at CERN's Antiproton Decelerator aim to measure the properties of anti-hydrogen to find structural differences hinting at CPT symmetry breaking that would explain the observed baryon-antibaryon asymmetry in our universe. These experiments detect antihydrogen through annihilation making the antiproton-nucleus ( $\bar{p}A$ ) annihilation one of the main processes of interest.

The Monte Carlo simulations of these events rely on physics models developed for high energies and theoretically extrapolated to lower energies. Previous measurements from the AD experiments, including the ASACUSA-Cusp collaboration show that the simulations do not reproduce the measured data. As even the annihilation mechanism itself is not well understood, a permanent beamline for slow extraction of sub-keV antiprotons is being set up at the ASACUSA facility, in order to measure the  $\bar{p}A$  annihilation at rest for fifteen nuclei. The total multiplicity of the prongs and their kinetic energy distribution will be measured with a novel detection system using Timepix4 pixel detectors covering most of the solid angle. Individual annihilation events will be reconstructed by extrapolating the recorded pion tracks, revealing their angular distribution. This poster will give an overview of the experiment whose results will be implemented in a new simulation code for  $\bar{p}A$  reactions.

**Primary author:** KRAXBERGER, Viktoria (Austrian Academy of Sciences (AT))

**Presenter:** KRAXBERGER, Viktoria (Austrian Academy of Sciences (AT))

**Session Classification:** Poster Session 1

**Track Classification:** tests and extensions of the Standard Model of elementary particles

Contribution ID: 112

Type: **Poster presentation**

## Positron manipulation and control at ASACUSA

*Tuesday, 23 May 2023 17:50 (2h 10m)*

The ASACUSA-Cusp experiment aims to perform spectroscopy of the hyperfine structure of anti-hydrogen by producing a beam of cold, spin polarised, ground state antihydrogen. The beam will be produced by mixing positrons and antiprotons in our unique Cusp trap which uses a pair of superconducting coils in an anti-Helmholtz configuration to produce a magnetic field capable of both confining the charged particles radially and polarizing the antihydrogen atoms.

Thus far, the collaboration has observed antihydrogen 2.7 m from the production region and measured the distribution of principal quantum number of these atoms. This weak beam was not suitable for the spectroscopy measurement so work commenced on improving the beam intensity and skewing the distribution towards ground state atoms. Simulations showed that the route towards this aim was producing colder dense positron plasmas.

Recently, a major technological milestone was achieved by the collaboration. Antihydrogen produced via three-body recombination will have an isotropic distribution so a large open solid angle is needed for the antiatoms to escape. This has the disadvantage that the production region is illuminated by a hot (300 K) black body. Previously, it has not been possible to cool plasma below 130 K, however, a new electrode stack and coldbore with a focus on blocking microwaves from the room temperature region has allowed particles to cool to 25 K maintaining the large open solid angle for the beam to escape.

In this presentation I will discuss the methods used by the ASACUSA Cusp experiment to manipulate and control positrons and give details on the most recent work on plasma handling and beam production in the new Cusp trap.

**Primary author:** Dr MURTAGH, Daniel James (Austrian Academy of Sciences (AT))

**Presenter:** Dr MURTAGH, Daniel James (Austrian Academy of Sciences (AT))

**Session Classification:** Poster Session 2

**Track Classification:** spectroscopy of exotic atoms



Contribution ID: 113

Type: **Oral presentation**

## Cs in a cryogenic matrix: towards a measurement of the electron electric dipole moment

*Tuesday, 23 May 2023 16:35 (15 minutes)*

To explain the open questions in the fundamentals of physics, new theories that reach beyond the standard model of particle physics are needed. A great number of these indirectly predict electric dipole moments (EDM) of fundamental particles in ranges that are just within reach for modern atomic and molecular physics experiments. While measurements in atomic and molecular beams, and more recently in ion traps, provided the most successful null measurements of the electron EDM over the past decades, only quite recently did the method of matrix isolation spectroscopy arise. It has the potential advantage of performing spectroscopy on unprecedented numbers of atoms/molecules at once. To perform such a measurement in the future, it is however necessary to first understand how the trapping of atoms inside the cryogenic matrix looks like in detail. In this contribution, I would like to present what we learned so far through experiments and simulations of cesium trapped in an inert argon matrix and which future steps we are planning to take toward a measurement of the electron EDM and other beyond standard model effects.

**Primary author:** LAHS, Sebastian (Laboratoire Aimé Cotton)**Presenter:** LAHS, Sebastian (Laboratoire Aimé Cotton)**Session Classification:** Tuesday 4**Track Classification:** precision measurements in fundamental physics, astrophysics and cosmology

Contribution ID: **114**

Type: **Social**

## **Announcements for Poster Session 1**

*Monday, 22 May 2023 17:20 (10 minutes)*

**Presenter:** SIMON, Martin (Austrian Academy of Sciences (AT))

Contribution ID: 115

Type: **Social**

## **Announcements for Poster Session 2**

*Tuesday, 23 May 2023 17:35 (10 minutes)*

**Presenter:** SIMON, Martin (Austrian Academy of Sciences (AT))

Contribution ID: **116**

Type: **Social**

## Conference Photo

*Wednesday, 24 May 2023 11:12 (18 minutes)*

**Presenter:** SZOKOL, Peter

Contribution ID: **117**

Type: **Social**

## FAREWELL

*Friday, 26 May 2023 12:50 (10 minutes)*

**Co-author:** SIMON, Martin (Austrian Academy of Sciences (AT))

**Presenter:** KARSHENBOYM, Savely (LMU, MPQ)