International Conference on Precision Physics and Fundamental Physical Constants (FFK-2015)

Monday 12 October 2015 - Friday 16 October 2015

Hungarian Academy of Sciences

Book of Abstracts

All sessions and social events will take place in the central palace of the Hungarian Academy of Sciences (1051 Budapest, Széchenyi tér 9.). The talks will be in the Small Conference Room (Kis terem) on the 2nd floor, the coffee breaks, the cold lunches and social events in Vörösmarty room on the ground floor.

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Registration

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On the electric dipole moment of the electron and the P, T-odd electron-nucleus interaction in highly-charged heavy ions

Mr. LABZOWSKY, Leonti[1]

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It is demonstrated that the effect of the electric dipole moment of electron and of the P, T-odd electron-nucleus interaction can be well distinguished in the experiments with H-like (or Li-like) higly charged ions in storage rings. These two effects cannot be separated in the experiments with a certain atom or molecule. Possible experiments for the search of P, T-odd effects with H-like ions in storage rings are discussed and the parameters of these experiments (observation time, field control) are estimated.

2

Precision measurements on H2 in search for new physics

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Molecular hydrogen is the smallest neutral molecule and the most abundant molecular species in the Universe. High-resolution spectroscopic studies of this benchmark system can serve as a test for various directions in the exploration of new physics. Several of those have been pursued:

- The search for a variation of the proton-electron mass ratio in earlier phases of the Universe; this is done via the analysis of absorption systems in the line-of-sight of quasars.
- The search for a possible dependence of the proton electron mass ratio depending on environmental conditions, such as the local gravitational field; this is done via the analysis of absorption spectra of the photosphere of white dwarf stars.
- The search for possible fifth forces between hadrons; this is done via precision measurement of the dissociation limit of the H2 molecule and a measurement of the vibrational ground tone splitting.
- The same experimental data can also be employed to detect possible extra dimensions beyond the known 3+1 space-time dimensionality.

All of these directions will be highlighted and the possibility for improvements and tighter constraints discussed.

3

Precision measurement of the hyperfine splitting of positronium

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Positronium (Ps) is an ideal system for precision test of bound-state Quantum Electrodynamics (QED). The hyperfine splitting (HFS) of the ground-state Ps has a discrepancy of 16 ppm (4.5 σ) between the averaged previous experimental value and the theoretical calculation with $O(\alpha^3)$ corrections. A new experiment which reduced possible systematic uncertainties, which are Ps thermalization effect and non-uniformity of magnetic field, was performed to check the discrepancy. It revealed that the Ps thermalization effect was as large as 10$\pm$2 ppm, which could have been underestimated as a systematic uncertainty in the previous experiments. Treating this effect correctly, a new independent experimental result of 203.3942$\pm$ 0.0016(stat., 8.0 ppm) $\pm$ 0.0013(syst., 6.4 ppm) GHz was obtained. This result is consistent with the QED prediction within 1.1 σ, whereas it disfavours the previous experimental average by 2.6 σ. It shows that the Ps thermalization effect is crucial for precision measurement of HFS. In this presentation, I will explain the details of the new experiment. Future prospects for improved precision will be also briefly discussed.

4

Spin-statistic selection rules for multiphoton transitions in atomic systems

Author(s): Mr. ZALIALIUTDINOV, Timur[1]
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We establish the existence of spin-statistic selection rules (SSSRs) for multiphoton transitions with equal photons in atomic systems. These selection rules are similar to those for systems of many equivalent electrons in atomic theory. The latter are a direct consequence of the Pauli exclusion principle. In this sense, the SSSRs play the role of the exclusion principle for photons: they forbid some particular states for the photon systems. We established several SSSRs for few-photon systems. (i) First rule: two equivalent photons involved in any atomic transition can have only even values of the total angular momentum, J. This selection rule is an extension of the Landau-Yang theorem to the photons involved in atomic transitions. (ii) Second rule: three equivalent dipole photons involved in any atomic transition can have only odd values of the total angular momentum, J=1,3. (iii) Third rule: four equivalent dipole photons involved in any atomic transition can have only even values of the total angular momentum, J=0,2,4. We also suggest a method for a possible experimental test of these SSSRs by means of laser experiments with Helium.

5

Constraints on neutrino magnetic moment and millicharge

Prof. STUDENIKIN, Alexander[1]

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Abstract:
A short introduction to the present status of neutrino electromagnetic properties and neutrino electromagnetic interactions is presented. We start with consideration of the electromagnetic

form factors for the Dirac and Majorana neutrinos. Then we discuss experimental constraints on neutrino magnetic and electric dipole moments, electric millicharge, charge radius and anapole moments from the terrestrial laboratory experiments. The main manifestation of neutrino electromagnetic interactions, such as: 1) the radiative decay in vacuum, in matter and in a magnetic field, 2) the Cherenkov radiation, 3) the plasmon decay, 4) spin light in matter, 5) spin and spin-flavour precession, 6) neutrino pair production in a strong magnetic field, and the related processes and their astrophysical phenomenology are considered. The astrophysical constraints on neutrinos electromagnetic properties are also reviewed. The talk is based, in particular, on our recent papers:

[1]. C.Giunti, A.Studenikin, "Electromagnetic interactions of neutrinos: a window to new physics", arXiv: 1403.6344v2, Feb 23, 2015, accepted for publication in Rev.Mod.Phys. (2015), 79 p.

[2]. K.Kouzakov, A.Studenikin, "Theory of neutrino-atom collisions: the history, present status and BSM physics", Adv.High Energy Phys. 2014 (2014) 569409 (16 p.).

[3]. C.Broggini, C.Giunti, A.Studenikin, "Electromagnetic properties of neutrinos", Adv. High Energy Phys. 2012 (2012) 459526 (47 p.).

[4]. A. Studenikin, I. Tokarev, "Millicharged neutrino with anomalous magnetic moment in rotating magnetized matter", Nucl. Phys. B 884 (2014) 396-407.

[5]. A. Studenikin, "New bounds on neutrino electric millicharge from limits on neutrino magnetic moment", Europhys. Lett. 107 (2014) 21001 (5 p.).

[6]. V.Brudanin, D. Medvedev, A.Starostin, A. Studenikin, "New bounds on neutrino electric millicharge from GEMMA experiment on neutrino magnetic moment", arXiv: 1411.2279.

[7]. I.Balantsev, A.Studenikin, "Spin light of relativistic electrons in neutrino fluxes", Int.J.Mod.Phys.A 30 (2015) 15300044, arXiv: 1502.05346 (8 p.).

6

Nanoplasmonics for ultimate spatiotemporal characterization of optical near-fields

Dr. DOMBI, Péter[1]

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Nano-optical near fields already play a fundamental role in many nanotechnology applications including photovoltaics, sensorics and biomedicine. The characterization of nanoscale changes of the electromagnetic field on ultrashort (femto- and attosecond) time-scales is a core requirement for developing applications. I will show how ultrafast photoemission from and photoelectron spectroscopy on nanoscale systems can help to achieve these goals.

7

Nuclear astrophysics experiments underground

Prof. FÜLÖP, Zsolt[1]

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Cosmic ray induced background can seriously limit the determination of nuclear reaction cross sections at low collision energies relevant to astrophysical processes.

Underground sites, however, can drastically reduce the cosmic ray background, opening the way towards ultra low cross section determination.

Based on the experience of LUNA (Laboratory for Underground Nuclear Astrophysics) located at the LNGS underground facility in Italy a summary of the technology applied is given, recent results are discussed and future plans are summarized.

See the web pages *www.lngs.infn.it*; *luna.lngs.infn.it*.

8

Quantum electromagnetic nonlinearity affecting charges and dipole moments

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Owing to the virtual electron-positron pair creation, quantum electrodynamics (QED) may be effectively treated as a nonlinear classical theory of electromagnetic fields. The corresponding mutual and self- interaction of electromagnetic fields is important where these are as strong as magnetic fields of magnetars, electric fields of quark stars, and fields in close vicinity of elementary particles generated by their charges and/or electric and magnetic dipole moments. We claim that the electromagnetic self-coupling of the dipole moments makes it necessary to subject their values to a sort of renormalization after being calculated following one or another method of strong interaction theory, say QCD or lattice approach. This correction is estimated to be at the brink of the present-day experimental possibilities. We also report on two magneto-electric effects of nonlinearity. The first is that the nonlinear response of the vacuum with a strong constant magnetic field in it to an applied Coulomb field of an electric monopole turns it into magnetic dipole in QED and into magnetic monopole in a theory with violated parity, the Coulomb field itself certainly undergoing a correction, too. The second is that if there are two, mutually non-orthogonal, strong constant fields in the vacuum, electric and magnetic, then already in QED an electric charge produces magnetic monopole field. We also state that a point electric charge possesses a finite electrostatic self-energy due to the self-interaction, if its field is treated within classical electrodynamics nonlinearly extrapolated to its close neighborhood via quantum QED corrections.

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The use of precise molecular line spectroscopy in a search for m_e/m_p variations

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We report results of precise laboratory spectroscopy for a set of astropysically important species carried out at the Institute of Applied Physics of the RAS over the last years. The investigations are based on Lamb-dip measurements at mm−sub-mm wavelengths with the developed sub-Doppler spectrometer. In particular, from a comparison of precise radio astronomical and laboratory frequencies of CH_3OH lines we estimate the upper limit on the possible m_e/m_p variation in dark interstellar clouds as $\leq 1.5 \times 10^{-8}$.

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H2+ spectroscopy - status and perspectives

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Ro-vibrational spectroscopy of the hydrogen molecular ions H2+ and HD+ is a promising path for fundamental constants metrology. It could improve the current knowledge of the proton-to-electron mass ratio and contribute to resolving the current discrepancy on the proton charge radius and/or Rydberg constant. Very precise predictions of the transition frequencies, taking high-order QED corrections into account, are required for these objectives. The theoretical accuracy has been improved by several order of magnitude in recent years, reaching the 10^{-12} range [1]. I will describe the calculation of vacuum polarization contributions involving the Uehling potential [2]. The satus of our experiment for two-photon spectroscopy of H2+ will also be presented.
[1] V.I. Korobov, L. Hilico, and J.-Ph. Karr, Phys. Rev. Lett. 112, 103003 and Phys. Rev. A 89, 032511 (2014). [2] J.-Ph. Karr, L. Hilico, and V.I. Korobov, Phys. Rev. A 90, 062516 (2014).

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Observation of long-lived states of hydrogen-like atom consisting of π^+ and π^- mesons.

AFANASYEV, Leonid[1]

[1] *Joint Inst. for Nuclear Research (RU)*

DIRAC experiment at the CERN PS accelerator observes for the first time long-lived states of hydrogen-like atom consisting of π^+ and π^- mesons with lifetimes of about 10−11˜s and more. There were observed 436 ± 61 characteristic pion pairs resulting from the long-lived states breakup, that corresponds to a signal-to-error ratio of better than 7 standard deviations. Together with measurement of the ground state lifetime of $\pi^+\pi^-$ atom, this observation opens a new possibility for detailed study of $\pi\pi$ scattering lengths.

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High precision spectroscopy of Ps

COOKE, David[1] ; CRIVELLI, Paolo[2]

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Positronium is an excellent test-bed for bound-state QED, owing to its purely leptonic nature. This allows its properties to be calculated very precisely in terms of the fine structure constant, with no contributions from hadronic interactions (weak interactions can also be neglected at the present experimental level). A measurement of the 1S-2S transition frequency of poitronium (at a precision level of less than 1 ppb (an improvement of a factor of five on the current measurement [1]) is sufficient to check the most recent calculations [2]. The limitation on improving the precision of this measurement much beyond this level is the high velocity of positronium at room temperature. Simulations show that Stark deceleration of Rydberg state positronium from room temperature (around 70000 m/s) to below 1000 m/s should be possible with reasonable efficiency. In this case, a measurement of the transition frequency at the level of a few kHz would be feasible, allowing a possible independent determination of the Rydberg constant. Progress towards such a measurement is reported here, including preliminary results, positron beam technology and strategies for reaching the required precision.
[1] M. S. Fee, A. P. Mills, S. Chu, E. D. Shaw, K. Danzmann, R. J. Chichester and D. M. Zuckerman, Phys. Rev. Lett. 70, 1397 (1993) [2] K. Pachucki and S. G. Karshenboim, Phys. Rev. A60, 2792 (1999)

15

THE NEW SYSTEM OF UNITS BASED ON FUNDAMENTAL PHYSICAL CONSTANTS. THE NEXT APROACH

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The possibility or even necessity of revising definitions of some of the base units of the present SI has been discussed over the past 25 years. Taking advantage of recent achievements of physical science it is possible to construct quantum standards of units which use fundamental physical constants or atomic constants. The last 25th General Conference of Weights and Measures (2014) expressed their intention to accept the new system of units in next future. In the system of units four basic units will be new defined: the kilogram (on a base of the Planck constant, h), the ampere (by the elementary charge, e), the kelvin (by the Boltzmann constant, kB), and the mole (by the Avogadro constant, NA). The values of this four fundamental physical constants (h, e, kB and NA) will be fixed as known exactly. The new SI system will be proposed if new definitions will be ready for all four base units. The new definition of the kilogram, based on the Planck constant, h, is crucial. Therefore, in 2010 the Consultative Committee for Mass set out three requirements (confirmed in February 2013), concerning uncertainty in determination of h, which should be fulfilled before the ICPM will to an official proposal to the CGPM conference. Requirements on determination of the Planck constant, h:

- At least three independent results (watt balance and XRCD) with relative uncertainty ur $< 5 \times$ 10-8.
- At least one result with relative uncertainty ur $\leq 2 \times$ 10-8 ;
- Results consistent.

These requirements are not fulfilled up today. The next chance to accept the new system of units will be in 2018, at 26th CGPM conference.

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Bound-state QED calculations and the hydrogen molecular ion spectroscopy

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In our presentation we would like to discuss calculating of the largest contributions to the ro-vibrational energies at $m\alpha^8$ order for the hydrogen molecular ions H_2^+ and HD^+ (HMI). We expect to provide new data, which enable to achieve a relative precision of 10^{-11} and even better for the fundamental transitions in HMI. Along with experimental results that should have a strong impact on determination of the Rydberg constant, proton-to-electron mass ratio, and proton charge radius.

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Theory of the bound-electron g-factor

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Quantum electrodynamic (QED) effects in strong fields can be scrutinized to high precision in Penning trap experiments: a recent measurement yielded a value for the g-factor of hydrogenlike

silicon with a 5×10^{-10} fractional uncertainty, allowing to test certain higher-order QED corrections for the first time [1]. The measured g-factor is in excellent agreement with the state-of-the-art theoretical value, which includes QED contributions up to the two-loop level of the order of $(Z\alpha)^2$ and $(Z\alpha)^4$. At the above experimental accuracy, also nuclear structural effects start to be visible. We determined the nuclear root-mean-square radius of ^{28}Si from the comparison of experimental and theoretical g-factors and found agreement to tabulated values within our limits of error [1]. As a further nuclear contribution, we investigated the influence of nuclear deformation, and found the leading correction to become significant for mid-Z ions and for very heavy elements to even reach the 10^{-6} level [2].
Furthermore, we present theoretical results of a recent determination of the electron mass via measurement of the Larmor and cyclotron frequencies in a $^{12}C^{5+}$ ion confined in a Penning trap [3]. The electron mass was determined with a relative uncertainty more than an order of magnitude better than the established literature value by means of comparison of the theoretical prediction for $g\left(^{12}C^{5+}\right)$ and the experimental frequencies. In order to reduce the uncertainty on the theory's side, the unknown two-loop higher-order correction to $g\left(^{12}C^{5+}\right)$ was estimated. The electron mass is closely linked to other fundamental constants, such as the Rydberg constant R_∞ and the fine-structure constant α. Thus the current improvement of its value paves the way for future fundamental physics experiments and further precision tests of the Standard Model.

[1] S. Sturm, A. Wagner, B. Schabinger, J. Zatorski, Z. Harman, W. Quint, G. Werth, C. H. Keitel, K. Blaum, Phys. Rev. Lett. 107, 023002 (2011).
[2] J. Zatorski, N. Oreshkina, C. H. Keitel, Z. Harman, Phys. Rev. Lett. 108, 063005 (2012).
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18

Shifts and widths of magnetic Feshbach resonances in atomic traps

Prof. MELEZHIK, Vladimir[1]

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We have developed and analyzed in application to experimentally interesting cases a theoretical approach to study magnetic Feshbach resonances in atomic traps [1,2]. The program was realized by extending (to confined geometry of the traps) the two-channel model of Lange et al [3] suggested for parametrization of resonances in free-space. In our approach, the experimentally known parameters of Feshbach resonances in free-space are used as an input. We have calculated the shifts and widths of s- and p-wave magnetic Feshbach resonances of ^{133}Cs and ^{40}K atoms emerging in harmonic waveguides as s- and p-wave confinement induced resonances (CIRs)[4,5]. Particularly, we show a possibility to control the width and shift of the s- and p-wave CIRs by the trap frequency and the applied magnetic field which could potentially be used in corresponding experiments. For example, it is shown that in a harmonic waveguide there is a possibility to decrease dramatically the width of the Feshbach resonances by decreasing the trap frequency.
We have also found the importance of including the effective range terms in the computational schemes for the description of the p-wave CIRs contrary to the case of s-wave CIRs where the impact of the effective range is negligible [4,6]. In previous investigations of the p-wave CIRs in harmonic waveguides [2,5,7] the effects due to the effective range have been neglected. Thus, our model permits to extract the precise information about low-energy atom-atom interaction, such as s- and p-wave scattering lengths and effective ranges, from the width and shifts of magnetic Feshbach resonances in atomic traps.

{1} S. Saeidian, V.S. Melezhik, and P. Schmelcher, Phys. Rev. {\bf A76} (2012) 62713. {2} S. Saeidian, V.S. Melezhik, and P. Schmelcher, J. Phys. {\bf B48} (2015) 155301. {3} A.D. Lange, K. Pilch, A. Prantner, F. Ferlaino, B. Engeser, H.-C. N\"agerl, R. Grimm, and C. Chin, Phys. Rev. {\bf A79} (2009) 013622. {4} M. Olshanii, Phys. Rev. Lett. {\bf 81} (1998) 938. {5} B.E. Granger and D. Blume, Phys. Rev. Lett. {\bf 92} (2004) 133202. {6} E.

Haller, M.J. Mark, R. Hart, J.G. Danzl, L. Reichs\"ollner, V. Melezhik, P. Schmelcher, and H.C. N\"agerl, Phys. Rev. Lett. {\bf 104} (2010) 153203. {7} J.I. Kim, V.S. Melezhik, and P. Schmelcher, Progr. Theor. Phys. Supp. {\bf 166} (2007) 159.

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Pion polarizabilities: Theory vs Experiment

Prof. IVANOV, Mikhail[1]

[1] *JINR DUBNA*

In the wake of new measurement of pion polarizability by COMPASS Collaboration I review our study of this quantity in the framework of ChPT at two-loop level.

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Nuclear polarizability effects in muonic deuterium

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The nuclear charge radius can be determined from spectroscopic measurements in muonic atoms, provided the atomic structure is well known and the influence of nuclear excitation on atomic levels is properly accounted for. The latter is problematic due to the difficulty in solving quantum chromodynamics in low energy scale. We perform calculations in perturbative approach by the expansion in ratio of the nuclear excitation energy over the muon mass. We pay special attention on the nuclear mass dependence and separation of the so-called pure recoil corrections. We aimed to calculate the nuclear effects as accurately as possible, in order to extract precise nuclear charge radii from the muonic atom spectroscopy. Numerical results for muonic deuterium is obtained by using the AV18 potential with the help of a discrete variable representation method for solving the Schroedinger equation. The obtained result for the 2P-2S transition serves for determination of the nuclear charge radius from the spectroscopic measurement in muonic deuterium.

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

Author(s): ULMER, Stefan[1]

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[11] -

The Standard Model of particle physics – the theory that best describes particles and their fundamental interactions – is known to be incomplete, inspiring various searches for "new physics" that goes beyond the model. These include tests that compare the basic characteristics of matter particles with those of their antimatter counterparts. While matter and antimatter particles can differ, for example, in the way they decay (a difference often referred to as violation of CP symmetry), other fundamental properties, such as the absolute value of their electric charges and masses, are predicted to be exactly equal. Any difference – however small — between the properties of protons and antiprotons would break a fundamental law known as CPT symmetry. This symmetry reflects well-established properties of space and time and of quantum mechanics, so such a difference would constitute a dramatic challenge not only to the Standard Model, but also to the basic theoretical framework of particle physics.
The goal of the BASE collaboration is to perform such tests comparing the fundamental properties of protons and antiprotons at lowest energies and with greatest precision, by using single particles in Penning traps. By applying such techniques, we recently performed a high-precision comparison of the antiproton-to-proton charge-to-mass ratio with a fractional precision of 69 parts in a trillion. The measurement was inspired by methods developed by the TRAP collaboration, which compared cyclotron frequencies of antiprotons and negatively charged hydrogen ions. Another goal of the BASE collaboration is the high-precision comparison of the magnetic moments of the proton and the antiproton. In this context we applied the double Penning trap technique to the proton and performed the to-date most precise and first direct high precision measurement of the particles magnetic moment. In a next step this method will be applied to the antiproton.
In the talk I will give a summary on recent BASE results and give an outlook towards the future goals of BASE.

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Precision Physics with LHCb: overview of the latest LHCb results

TO BE DEFINED, speaker[1]

[1] *LHCb collanoration*

The LHCb experiment is designed to perform high-precision measurements of CP violation and search for New Physics using the enormous flux of beauty and charmed hadrons produced at the LHC. The LHCb experiment collected unprecedented samples of heavy flavoured hadrons from pp collisions. Precision measurements of CP-violating observables and studies of rare decays are providing the some of the strongest constraints on scenarios beyond the Standard Model and have excellent potential to reveal new physics as the precision is improved. Its forward acceptance puts it in an ideal position for precision QCD as well as electroweak measurements. Recently we reported the most precise measurement of sin2thetaW_eff at the LHC.

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Towards antihydrogen 1s-2s Spectroscopy

LENZ CESAR, Claudio[1]

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The Charge-Parity-Time (CPT) symmetry predicts a perfect matching between an atom's and the antiatom's quantum structure. Following the production and trapping of antihydrogen ($\overline{\mathrm{H}}$) atoms in experiments at CERN's Antiproton Decelerator (AD), it is now possible to attempt a high-precision comparison of the spectra of H and $\overline{\mathrm{H}}$. There are interests in the hyperfine structure, in the two-photon 1s-2s transition and in the Lyman-α 1s-2p transition for detection and cooling. In this contribution I mostly discuss the 1s-2s spectroscopy. I review results with hydrogen and the future prospects for precisions beyond parts in 10^{15}. I discuss a detection method for the initial spectroscopy in the ALPHA experiment. I also discuss a new cold hydrogen beam setup developed in Rio for a direct comparison of the two conjugate species, as well as a possibility to integrate both species in the same trapping environment.

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New results in Higgs physics at the LHC

PASZTOR, Gabriella[1]

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New results on the SM Higgs boson property measurements and searches for additional scalar bosons with the ATLAS and CMS experiments at the LHC will be presented. The prospects for future Higgs studies will also be summarised.

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Recent progress in determination of fundamental constants

Prof. KARSHENBOIM, Savely[1]

[1] *MPQ and Pulkovo Observatory*

I will present results of the recent evaluation of the fundamental constants by CODATA. I will in particular discuss the general structure of the data as well as progress in the determination of the most important constants, such as the Rydberg constant, the proton charge radius, the electron-to-proton mass ratio, the fine structure constant, the Planck and Avogadro constant, the elementary charge.

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Theory of Lamb Shift in Muonic Hydrogen

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There has been for a while a large discrepancy between the values of the proton charge radius measured by the Lamb shift in muonic hydrogen and by other methods. It has already been clear that theory of muonic hydrogen is reliable at the level of this discrepancy and an error there cannot be a reason for the contradiction. Still the status of theory at the level of the uncertainty of the muonic-hydrogen experiment (which is two orders of magnitude below the discrepancy level) requires an additional clarification. We revisit theory of the 2p − 2s Lamb shift in muonic hydrogen. We summarize all the theoretical contributions in order α^5 m, including pure quantum electrodynamics (QED) ones as well as those which involve the proton-structure effects. Certain enhanced higher-order effects are also discussed. We basically confirm former QED calculations of other authors, present a review of recent calculations of the proton-structure effects, and treat self-consistently higher-order proton-finite-size corrections. Eventually, we derive a value of the root-mean-square proton charge radius. It is found to

be 0.84029(55) fm, which is slightly different from that previously published in the literature (0.84087(39) fm [Antognini et al., Science 339, 417 (2013)]).

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Direct detection of Dark Matter particles

Prof. BERNABEI, Rita[1]

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The present status of direct detection of Dark Matter (DM) particles will be summarized, with particular care to the DAMA model-independent DM annual modulation results. Arguments on comparisons will be addressed showing that there is large room for compatibility between the various published experimental results, considering both the different adopted procedures and techniques, the different experimental observables, the different exposures, the existing experimental and theoretical uncertainties and the widely open scenarios for astrophysical, particle and nuclear Physics aspects. Recent results on diurnal investigation will also be mentioned. Realistic experimental perspectives will be, finally, addressed with attention to some particular cases.

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Recoil correction to the proton finite-size contribution to the Lamb shift in muonic hydrogen

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The Lamb shift in muonic hydrogen was measured some time ago to a high accuracy. The theoretical prediction of this value is very sensitive to the proton finite-size effects. The proton radius extracted from muonic hydrogen is in contradiction with the results extracted from elastic electron-proton scattering. That creates a certain problem for the interpretation of the results from the muonic hydrogen Lamb shift. For the latter we need also to take into account the two-photon-exchange contribution with the proton finite size involved. The only way to describe it relies on the data from the scattering, which may produce an internal inconsistency of theory. Recently the leading proton-finite-size contribution to the two-photon exchange was found within the external field approximation. The recoil part of the two-photon-exchange has not been considered. We revisit calculation of the external-field part and take the recoil correction to the finite-size effects into account.

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Cosmology with Planck: a checkpoint on the health of the ΛCDM model

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I will discuss highlights from the recent Planck 2015 release and present the most stringent bounds to date on a widely accepted cosmological picture, including the latest results from

the joint Planck/Bicep effort on the quest for primordial gravitational waves. The ΛCDM model withstood a wide collection of tests at increasing precision over the last decade and has, with the latest Planck results, surely gained further strength. At the same time, we still see small quirks in the data that may or not hint to new physics.

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The exclusive decays $J/\psi \to D_{(s)}^{(*)-}\ell^+\nu_\ell$ \\ in a covariant constituent quark model with infrared confinement

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We investigate the exclusive semileptonic decays $J/\psi \to D_{(s)}^{(*)-}\ell^+\nu_\ell$\,, where $\ell = e, \mu$, within the Standart Model. The relevant transition form factors are calculated in the framework of a relativistic constituent quark model with built-in infrared confinement. Our calculations predict the branching fractions $\mathcal{B}(J/\psi \to D_{(s)}^{(*)-}\ell^+\nu_\ell)$ to be of the order of 10^{-10} for $D_s^{(*)-}$ and 10^{-11} for $D^{(*)-}$. Most of our numerical results are consistent with other theoretical studies. However, some branching fractions are larger than those calculated in QCD sum rules approaches but smaller than those obtained in the covariant light-front quark model by a factor of about $2-3$.

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Status of the Antihydrogen Hyperfine Structure Measurement in ASACUSA

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On behalf of the ASACUSA-CUSP Collaboration
The ASACUSA-CUSP collaboration at the CERN antiproton Decelerator (AD) aims at probing CPT symmetry through the precise comparison of hyperfine transitions in hydrogen and its CPT-conjugate: antihydrogen. The ground state hyperfine transition in hydrogen has been measured more than half a century ago in a beam with a relative precision of $4 \times$ 10e−8 [1] and later to a much improved relative precision of 10e−12 in a maser [2]. Given the inapplicability of the latter for antimatter, the ASACUSA-CUSP collaboration has adopted a similar experimental concept for the measurement of the hyperfine splitting of antihydrogen as the 1950's measurement in hydrogen : a polarized beam of antihydrogen interacts with a microwave field within a cavity which on resonance drives the hyperfine transition [3]. This method benefits, over measurements with trapped antihydrogen atoms, from the high magnetic field homogeneity achievable in the region where atoms undergo the transitions and hence has the potential to reach a ppm-level precision with a relatively low number of antihydrogen atoms detected. After the recent production of antihydrogen atoms [4] and their detection in a magnetic field-free region [5] 2.7m away from the ASACUSA antihydrogen production trap, efforts have been dedicated to the upgrade of the apparatus in order to produce an intense beam of antihydrogen and for its efficient detection. In parallel to those developments the spectroscopy apparatus [6] was tested with a source of cold polarized hydrogen. This confirmed the high precision and accuracy which can be achieved [7]. After shortly describing the experimental setup and discussing its sensitivity, I will highlight the latest developments and the upcoming experimental challenges.
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Nuclear structure from light muonic atoms (Beatrice Franke on behalf of the CREMA Collaboration)

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Muonic atoms have an increased sensitivity on finite size effects of the nucleus due to the ˜200-fold mass of the muon compared to the electron. The CREMA collaboration has measured the Lamb shift in muonic hydrogen and muonic deuterium atoms, as well as in muonic helium-4 and helium-3 ions. These measurements allow to determine charge radii and other nuclear properties with improved precision compared to previously conducted measurements. Contributions to solving the proton radius puzzle as well as the discrepancy in electronic isotope-shift measurements from the collected data will be discussed. A status update of CREMA's ongoing data analysis towards charge radius extractions of the deuteron, helion, and the alpha particle will be given. Current analysis-related topics such as theory issues and possible systematics will be shown, together with an outlook for possible future measurements using bound muonic systems.

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Investigating CP-violating exotic interactions using a neutron bottle (Beatrice Franke on behalf of the nEDM Collaboration)

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Low energetic neutrons are stored inside the apparatus searching for a permanent electric dipole moment of the neutron at the Paul Scherrer Institute. Precisely comparing the Larmor precession frequency of the neutrons spins to that of cohabiting 199Hg atoms spins, allows to investigate possible exotic short range spin-dependent interactions. Such an interaction could be mediated by axions or axion-like particles and its strength is proportional to the CP-violating product of scalar and pseudoscalar coupling constants gSgP. Our measurement result confirms limits on gSgP from complementary experiments with spin-polarized nuclei in a model-independent way. Limits from other neutron experiments are improved by up to two orders of magnitude in the interaction range of 10^-6 m < lambda < 10^-4 m.

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Two-Photon Direct Frequency Comb Spectroscopy oft the 1s3s Transition in Hydrogen with an Absolute Accuracy of 17kHz.

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High precision spectroscopy has been always the driving force for new fundamental theories in physics. The so called proton size problem is a so far unexplained disagreement of the value of

the proton charge radius extracted from the muonic spectroscopy, hydrogen spectroscopy and elastic electron-proton scattering by more than 5 sigma \cite{Antognini2013}. Our experiment is highly suitable to verify or falsify the true existence of this problem since it is based on a completely different spectroscopy method than previously performed hydrogen spectroscopy experiments. \newline In our experiment we were able recently to give a preliminary value of the 1s3s two-photon transition frequency with an accuracy of 17kHz for the first time with the Direct Frequency Comb Spectroscopy (DFCS) \cite{Baklanov1977}. This measurement was limited by an so far unobserved effect, which occurs in DFCS with chirped pulses and atomic beams. It can be understood as Chirp-Induced First Order Residual Doppler Shift (FORDS) and it is an important effect for future XUV and VUV DFCS experiments. \newline In our setup we produce a frequency comb at 205 nm (2ps) by two subsequent frequency doubling cavities from a Ti:Sa mode-locked laser at 820 nm \cite{Peters2013}. The atomic beam of hydrogen atoms is excited in an enhancement cavity and photons from 3s2p transition are collected and detected.

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FAMU experiment: characterization of target and detectors and measurements of muonic transfer rate from hydrogen to heavier gases

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[3] *U*

The precise measurement of the hyperfine splitting of the muonic-hydrogen atom ground state requires advanced technology both in the construction of a gas target and of the detectors. In June 2014, the FAMU pressurized gas target was exposed to the low energy muon beam at the RIKEN RAL muon facility. The objectives of the test were to characterize both the target and the X-ray detectors and to measure the transfer rate of muons from hydrogen to heavier gases. The detection system consisted in detectors made with high purity Germanium and Lanthanum Bromide crystals. Preliminary results of the measurement of the transfer rate from hydrogen to oxygen and argon will be presented.

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Laser spectroscopy of antiprotonic helium

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The precision of laser spectroscopy of antiprotonic helium (a helium atom with one of its electrons replaced by an antiproton) has improved by almost 4 orders of magnitude over its 20 years of history. Experimental transition frequencies can be compared to 3-body QED calculations to derive the antiproton-electron mass ratio.
The history and latest results of this research, carried out at the Antiproton Decelerator (AD) of CERN, will be presented, followed by an outlook to the new facility ELENA (Extra Low ENergy Antiproton ring), which is being constructed as the extension of the AD.

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The search for an electric dipole moment of the neutron at PSI

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Searches for electric dipole moments (EDM) of fundamental particles are considered to be one of the most sensitive approaches to physics beyond the Standard Model (SM) of particle physics. A non-SM mechanism that violates the combined symmetry of charge conjugation and parity inversion (CP-violation) could help to explain the huge discrepancy between the observed and predicted baryon asymmetry of the Universe. The discovery of an EDM of the neutron (nEDM) would indicate a violation of time reversal symmetry (T) and, assuming CPT invariance, CP-violation. No nEDM has yet been observed, while the current best upper limit $d_n < 2.9 \times 10^{-26}$ ecm (90% C.L.) [Baker et al. PRL(2006)131801] was published in 2006. At the Paul Scherrer Institute (PSI) in Villigen, Switzerland a measurement of the nEDM is presently running with the highest daily sensitivity ever obtained. In this talk I will discuss the principal experimental techniques, recent advances in sensitivity, and plans for future upgrades.

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Antimatter gravity measurement in a beam - the AEgIS experiment

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The gravitational interaction between matter and antimatter has never been precisely measured, despite its fundamental nature. With the successful formation of antihydrogen atoms at the Antiproton Decelerator of CERN, a test of the Weak Equivalence Principle for antimatter by determining the acceleration of antihydrogen atoms in the Earth's gravitational field becomes possible.
The AEgIS collaboration aims at performing such a test by producing a horizontal beam of cold antihydrogen atoms and measuring its gravity-induced fall over a distance of about one meter. The beam will be produced by a charge exchange reaction between excited Rydberg positronium and traverse a moiré deflectometer. The vertical displacement of the beam will be determined by a position and time sensitive detector. The produced antihydrogen beam could ultimately also be used for precision hyperfine spectroscopy as a test of CPT symmetry. The status of the experiment which is currently taking data at the AD will be reviewed.

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Newton force with a delay: 5th digit of G

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I have recently proposed a slight non-relativistic modification of the Newton law of universal gravitation [1,2]. Accordingly, the 1/r Newton field is following the motion of the source with a certain
laziness characterized by the delay time τ_G. The background motivation came from quantum foundational
speculations [3,4] yielding an estimate τ_G ~ 1ms. Surprisingly, in the simplest model of lazy Newton force, a 1ms delay predicts significant effect on the notorious 5th digit of the Newton constant G determined in a Cavendish experiment despite its poor time-resolution.

In 2014, Yang, Miao and Chen advocated independently the concept of finite emergence time of gravity [5], along with a cautious analysis of cosmologic, celestial and laboratory evidences, suggesting stringent upper bounds on τ_G at low frequency cosmological phenomena and weaker upper bounds from laboratory experiments at higher frequencies, mentioning my 1ms in the middle. I'll briefly discuss their work.

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Precision Tests of Quantum Electrodynamics with Highly Charged Ions

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Precise measurements of magnetic moments and masses with individual particles in Penning traps have opened opportunities for fundamental tests of physical theories. The determination of the magnetic moment of the electron bound in highly charged ions is a sensitive test of the theory of bound-state Quantum Electrodynamics. At the same time, such precision experiments - together with atomic theory - make it possible to determine fundamental constants, like the electron mass, the fine-structure constant, and the proton magnetic moment.

Supported by BMBF, DFG, the Helmholtz Association, HGS-HIRE, IMPRS for Quantum Dynamics, and the Max-Planck Society.

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Absolute mass measurement of oxygen-16 at THe-Trap

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THe-Trap is a Penning-trap mass spectrometer that aims to measure the atomic mass ratio of tritium to helium-3 with a relative uncertainty of 1 · 10−11 . To test the experiment's accuracy and precision, we measured the mass ratio of carbon-12 to oxygen-16, which is one of the most precisely determined mass ratios [1]. In 2014 we reported a measurement of this mass ratio with a relative uncertainty of 6.3 · 10−11 [2], which was limited by systematic effects. Since then we upgraded the experiment, including the ion source, the vacuum system, and the amplifier for the detection of the induced image current. Due to the improved ion storage times we were able to characterize the amplitude dependent systematic shifts [3] and reach a significantly lower uncertainty that approaches the uncertainty of the literature value.

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Ionization of atoms by positron and positronium impact

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Understanding the ionization process during atomic collisions is fundamental both from the experimental and theoretical points of view. Ionization by positron impact has also been extensively studied in recent decades. In most cases noble gas atoms were used as the target For designing new experiments, such as production of antimatter, ionization cross sections for any other atoms are also necessary. Recently, improvements in experimental techniques have enabled the determination of inner shell ionization cross sections by positron impact. During the last two decades more and more studies also became available for positronium impact.
In the present work, K-shell ionization cross sections by positron impact have been calculated for Cu in the binary-encounter approximation by the use of velocity distribution of the target electron from the nonrelativistic and relativistic hydrogenic models [1]. The results are compared with the values obtained with velocity distribution in the free-fall model. The effect of choice of atomic models on the ionization cross sections is discussed. We found that the present results are in agreement with the experimental data and other theoretical values.
Moreover, we also investigated the interaction between positronium and a helium atom using the 5-body classical trajectory Monte Carlo method [2]. We present the total cross sections for the dominant channels, namely for single ionization of the target, and ionization of the projectile, resulting from pure ionization and also from electron transfer (capture or loss) processes for 1–5.7 a.u. incident velocities of the positronium atom. Our results are compared with the calculated data using hydrogen projectiles having the same velocities as well as with the experimental data in collisions between H and He [3]. We analyze the similarities and deviations for ionization of helium atoms by positronium and hydrogen projectile impact.
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The Proton Radius - Current Measurements and New Ideas

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The radius of the proton, generally assumed to be a well measured and understood quantity has recently come under scrutiny due to highly precise, yet conflicting, experimental results. These new results have generated a host of interpretations, none of which are completely satisfactory.
I will discuss the existing results, focusing on the discrepancy between the various extractions. I will briefly discuss some theoretical attempts at resolution and focus on new scattering measurements, both planned and already underway, that are attempting to resolve the puzzle.

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The new SI: progress and prospects

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Most national metrology laboratories and some major physics laboratories have been working for decades to improve the determination of several fundamental physical constants. As the

uncertainty in the measurements tends to the accuracy of the materializations of the present relevant SI units, time has come for a major change in the SI definitions, where the units will be scaled relative to fixed values of a set of fubndamental constants of nature.
The frame of this new SI was proposed 10 years ago. Major resolutions were adopted by the CIPM and the CGPM to fix which conditions should be fulfilled before a final decision for the change. Such a decision is expected to be taken in 2018. A draft of the future SI brochure, with the new definition of the kelvin, is on the way. The new SI will highly improve the accuracy and the sustainability of the set of references. It will also open the way to an easier traceability at the nano- and quantum scales.
The talk will especially highlight the case of the new kelvin, which will be linked to a fixed value of the Boltzmann constant k.