3rd International Workshop on Antimatter and Gravity

WAG2015 - Programme

05 - 07 August 2015

WAG 2015

Welcome to University College London and the 3rd International Workshop on Antimatter and Gravity (WAG2015). The workshop aims to bring together those interested in all aspects of antimatter and gravity, from fundamental theory to direct tests of the weak equivalence principle of general relativity using antiparticles or elements that contain antimatter, e.g. positronium, muonium, or antihydrogen.

The workshop lectures will be held in room G06 (Sir Ambrose Fleming LT) of the Roberts building (access from Malet Pl.). An informal poster session will be held during the Thursday morning coffee break. The conference dinner will start at 19:30 on Thursday evening at the Ambassadors Bloomsbury Hotel (12 Upper Woburn Pl, WC1H 0HX), a short walk from the main UCL campus.

Local Organising Committee

- D. B. Cassidy (UCL, UK) (chair)
- S. Hogan (UCL, UK)
- A. Deller (UCL, UK)
- M. Charlton (Swansea University, UK)
- N. Madsen (Swansea University, UK)
- D. P. van der Werf (Swansea University, UK)
- S. Erikson (Swansea University, UK)

International Advisory Committee

- C. Amsler (Berne, Switzerland)
- D. Cassidy (UCL, UK)
- M. Charlton (Swansea University, UK)
- M. Doser (CERN, Switzerland)
- M. Oberthaler (Heidelberg University, Germany)
- V.V. Nesvizhevsky (ILL, Grenoble, France)
- J. Oppenheim (UCL, UK)
- P. Perez (CEA, France)
- Y. Sacquin (CEA, France)
- G. Testera (INFN-Genova, Italy)
- P. von Ballmoos (IRAP, Toulouse, France)
- Y. Yamazaki (RIKEN, Japan)

Programme

Tuesday 04 August

Welcome Reception

20:00 - 22:30
North Cloisters, UCL Campus

Wednesday 05 August

Opening Address (10:00 - 11:00)

10:00 - 10:15
Welcome to WAG2015

10:15 - 11:00
Free Fall Experiments with Charged Particles - A historical journey
Presenter: Prof. HOLZSCHEITER, Michael (University of New Mexico)
[page 11]

Coffee Break (11:00 - 11:30)

Session A (11:30 - 12:30)

11:30 - 12:00
Advances in antiproton and positron trapping in the AEGIS experiment
Presenter: CARAVITA, Ruggero (CERN, Universita degli Studi di Genova)
[page 12]

12:00 - 12:30
The ALPHA experiment
Presenter: MADSEN, Niels (Swansea University) [page 12]

Lunch (12:30 - 14:00)

Session B (14:00 - 15:30)

14:00 - 14:30
Towards High-Precision Investigations of the Fundamental Properties of the Antiproton
Presenter: SMORRA, Christian (CERN) [page 13]

14:30 - 15:00
Reaction cross section measurements for the positive antihydrogen ion production in the GBAR experiment
Presenter: Dr. LISZKAY, Laszlo (IRFU CEA Saclay) [page 13]

15:00 - 15:30
Techniques for ground state cooling of anti-Hydrogen-ions
Presenter: WOLF, Sebastian (Johannes Gutenberg-Univesity Mainz) [page 14]

Coffee Break (15:30 - 16:00)

Session C (16:00 - 17:00)

16:00 - 16:30
Studying Antimatter Gravity with Muonium
Presenter: KAPLAN, Daniel (Illinois Institute of Technology) [page 15]

16:30 - 17:00
Towards a novel high-brightness muon beam line for next generation precision experiments
Presenter: EGGENBERGER, Andreas (ETH Zurich) [page 15]

Thursday 06 August

Session D (09:00 - 10:30)

09:00 - 09:30
Positronium laser excitation and its detection in the AEgIS experiment
Presenter: MAZZOTTA, Zeudi (Università degli Studi e INFN Milano) [page 16]

09:30 - 10:00
High precision spectroscopy of Ps
Presenter: COOKE, David (ETH Zurich) [page 17]

10:00 - 10:30
Rydberg-Stark states of positronium
Presenter: DELLER, Adam (University College London) [page 17]

Coffee Break (10:30 - 11:15)

Session E (11:15 - 12:15)

11:15 - 11:45
Gravitation astrometric tests in the internal Solar System: the Astrometric Gravitation Probe mission goals
Presenter: GAI, Mario (Istituto Nazionale di Astrofisica) [page 18]

11:45 - 12:15
On principles of repulsive gravity: the Elementary Process Theory
Presenter: CABBOLET, Marcoen (Free University of Brussels) [page 18]

Lunch (12:15 - 14:00)

Session F (14:00 - 15:30)

14:00 - 14:30
Rydberg positronium for tests of antimatter gravity
Presenter: Dr. HOGAN, Stephen (University College London) [page 19]

14:30 - 15:00
Accelerating positronium using pulsed travelling optical lattices
Presenter: Prof. CHARLTON, Mike (Swansea University) [page 20]

15:00 - 15:30
On the use of Atom Optical Tools for Antimatter Experiments
Presenter: BRÄUNIG, Philippe (Ruprecht-Karls-Universitaet Heidelberg [page 21]

Coffee Break (15:30 - 16:00)

Session G (16:00 - 17:00)

16:00 - 16:30
Imaging of antihydrogen – A Vertexing Detector overview
Presenter: MC KENNA, Joseph (TRIUMF) [page 21]

16:30 - 17:00
Updated status of the GRANIT facility
Presenter: ROULIER, Damien (Institut Laue Langevin) [page 22]

Conference Dinner

19:30 - 22:30
Ambassadors Bloomsbury Hotel (12 Upper Woburn Pl, WC1H 0HX)

Friday 07 August

Session H (09:30 - 11:00)

09:30 - 10:00
What if quantum vacuum fluctuations are virtual gravitational dipoles?
Presenter: HAJDUKOVIC, Dragan (Institute of Physics, Astrophysics and Cosmology; Cetinje, Montenegro) [page 22]

10:00 - 10:30
Gravitation astrometric tests in the Solar System: the QVADIS collaboration goals
Presenter: GAI, Mario (Istituto Nazionale di Astrofisica) [page 23]

10:30 - 11:00
Do black holes create polyamory?
Presenter: Prof. OPPENHEIM, Jonathan (UCL) [page 23]

Coffee Break (11:00 - 11:30)

Session I (11:30 - 12:30)

11:30 - 12:00
ALPHA-g: a precision antimatter gravity experiment with a magnetic trap
Presenter: FUJIWARA, Makoto (TRIUMF) [page 24]

12:00 - 12:30
Status and prospects for the AD and ELENA
Presenter: JØRGENSEN, Lars Varming (CERN) [page 24]

Summary Talk (12:30 - 13:15)

Presenter: PÉREZ, Patrice (CEA/IRFU,Centre d'etude de Saclay Gif-sur-Yvette)

List of Abstracts

Free Fall Experiments with Charged Particles - A historical journey

Wed 05/08, 10:15 - 11:00
Presenter: Prof. HOLZSCHEITER, Michael (University of New Mexico)

The possible difference of gravitational interaction of matter and antimatter with the gravitational field of the Earth is an important open question in fundamental physics. Many indirect arguments against a possible difference have been put forward and have been summarized in a Physics Report by Goldman and Nieto in 1991. But no experimental answer to this question has been provided up to date.

An experiment to directly measure the difference in gravitational attraction by the Earth' gravitational field for electrons and positrons was launched in the 1960s by Witteborn and Fairbank. But due to the lack of low energy positrons at the time only the measurement with electrons was performed. This incomplete experiment raised many questions concerning stray electric fields in the apparatus and numerous studies were performed in subsequent years by the original authors and other groups around the world.

In 1985 we proposed an experiment based on the original ideas of Witteborn and Fairbank using antiprotons and protons. While this should be 1836 times easier than the measurement for electrons and protons it could not be completed in time before the shutdown of LEAR in 1996. Meanwhile several experiments at the AD have proposed studying gravitational properties of cold antihydrogen, which avoids issues of electric stray fields interacting with charged particles, but no results at any reasonable precision has yet been presented.

I will present details on the original experiment by Witteborn and Fairbank as well as the results of extensive studies by other groups on the observed apparent shielding of electrical stray fields at low temperatures.

Advances in antiproton and positron trapping in the AEGIS experiment

Wed 05/08, 11:30 - 12:00
Presenter: CARAVITA, Ruggero (CERN, Universita degli Studi di Genova)

The direct measurement of Earth's gravitational acceleration on a purely antimatter system has been a dream of experimental particle physics for more than twenty years, since the first antiproton cooling attempts at CERN's Low Energy Antiproton Ring. The efficient production of antihydrogen atoms in traps at CERN's Antiproton Decelerator in 2002, opened a possibility to perform such measurement of a neutral antimatter system, overcoming the difficulties experienced with charged antiparticles. This is the ambitious objective of the AEgIS collaboration: perform a precise and direct gravity measurement on cold antihydrogen. A survey of the performances of the catching traps in the last run with antiprotons, positrons and electrons will be presented. Efficient catching of antiprotons and cooling by electrons was achieved in a Malmberg trap by controlling the density of the electron plasma with the rotating wall technique. Centrifugal separation of the two particle plasma was observed, setting some coarse limits on the temperature of the resulting antiproton plasma. Finally, optimal transfer conditions for positrons were studied in detail: stable transfer efficiencies close to 100% were achieved between the 0.1 T buffer-gas accumulator to the 4.46 T ultra-high vacuum catching trap by careful tuning of transfer parameters.

The ALPHA experiment

Wed 05/08, 12:00 - 12:30
Presenter: MADSEN, Niels (Swansea University)

The ALPHA experiment aims to perform precision studies of antihydrogen and comparisons with hydrogen as a test of fundamental symmetries. Since 2010 ALPHA routinely traps antihydrogen and has demonstrated the first measurement of the internal structure of an antihydrogen atom by using microwaves to induce a resonant spin flip in the trapped antiatoms. ALPHA has also ventured to estimate its experimental sensitivity to gravitational effects and a putative non-zero charge of the antihydrogen atom.

ALPHA is now preparing for the first laser-spectroscopy of an antiatom and has recently commissioned a new apparatus that allows laser-access as well as a number of other improvements. In this presentation we will present an overview of the ALPHA results to date as well as discuss the upgrade and the first results from commissioning of the new apparatus. We will also discuss steps towards the first laser-spectroscopy of an antiatom and what implications the current state-of-the-art of trapping has on the potential for precision measurements.

Towards High-Precision Investigations of the Fundamental Properties of the Antiproton

Wed 05/08, 14:00 - 14:30
Presenter: SMORRA, Christian (CERN)

CPT symmetry in the Standard Model reflects the equivalence of antiparticles and their matter conjugates in the fundamental interactions, excluding gravity. It predicts that such conjugate pairs have identical masses, lifetimes, charges and magnetic moments, the latter two of opposite sign.

Single antiprotons confined and thermalized in a cryogenic Penning-trap system allow performing high-precision measurements of the fundamental properties of the antiproton. Its magnetic moment is determined from measuring the ratio of the spin-precession frequency to the cyclotron frequency. For this purpose, the continuous Stern-Gerlach effect is applied, which allows to perform spectroscopy of the spin-precession frequency by non-destructive detection of the antiproton's spin state, whereas the cyclotron frequency is measured by image current detection. Using these methods in the double Penning-trap measurement scheme, we recently achieved the today's most precise measurement of the proton magnetic moment with 3.3 ppb uncertainty [1]. Applying the same method to the antiproton will yield a thousand-fold improved test of CPT invariance in the baryon sector.

In addition, we are planning to improve the 90 ppt uncertainty in proton/antiproton charge-to-mass ratio measurements by comparing the cyclotron frequencies of the proton modelled by an H- ion and the antiproton. By using newly developed fast particle exchange techniques and phase-sensitive detection methods, we target an improvement by at least one order of magnitude. Assuming that CPT invariance holds, this measurement can be interpreted as a test of the weak equivalence principle by the gravitational redshift.

In this talk, I will review the proton measurement and present the status of the antiproton trap system BASE, Baryon Antibaryon Symmetry Experiment, which was commissioned at CERN's antiproton decelerator and the results from its first antiproton physics run in 2014.

[1] A. Mooser et al., Nature 509, 596 (2014).

Reaction cross section measurements for the positive antihydrogen ion production in the GBAR experiment

Wed 05/08, 14:30 - 15:00
Presenter: Dr. LISZKAY, Laszlo (IRFU CEA Saclay)

A key step of the GBAR experiment (Gravitational Behaviour of Antihydrogen at Rest) is the production of the positively charged antihydrogen ion. It can be cooled to cryogenic temperature and used for the creation of a cold neutral antihydrogen atom for the direct measurement of the effect of gravitation. The ion will be produced in two steps. The first is the charge exchange reaction between an antiproton and a positronium in a dense positronium cloud, which produces an antihydrogen atom at keV energy. Positive ions are produced in a second reaction, between the anti-atom and a second positronium. We are setting up an experiment to measure the cross section of both reactions. In the first phase, a proton beam will be used to measure the matter equivalent of the reactions, using positronium in 1S, 2P and 3D states. In the second phase antiprotons from the CERN AD/ELENA facility will be used to study the reactions producing antihydrogen atoms and, eventually, positive antihydrogen ions. We will present the experimental setup and discuss the results expected on the basis of theoretical calculations.

Techniques for ground state cooling of anti-Hydrogen-ions

Wed 05/08, 15:00 - 15:30
Presenter: WOLF, Sebastian (Johannes Gutenberg-Univesity Mainz)

We aim for free-fall experiments with antimatter atoms to determine its acceleration in the earth gravitational field. In such drop experiments and with drop heights below 1 m a temperature of a few μK is crucial to achieve the targeted accuracy of $\Delta g/g$ at the sub-percent level.

The GBAR-collaboration will use positively charged anti-Hydrogen ions ($p^- + 2e^+$) formed at the ELENA facility at CERN, which are captured, and trapped in a Paul trap in combination with Beryllium matter ions [1]. After sympathetic Laser cooling to the motional ground state a photo-detachment pulse generates neutral anti-Hydrogen and starts the drop experiment. The detection is accomplished from the annihilation once the anti-Hydrogen reaches the wall of the UHV system.

In the actual experiments, we establish sympathetic cooling for large mass ratio differences with 40-Calcium and 9-Beryllium ions. In the talk, we show results of the side-band cooling with single Calcium ions and ion crystals. A new trap design using electro-plated electrodes promises extremely low motional heating rates. This is a key for an optimized adiabatic expansion [2] of the axial potential which will be used to reduce the ion momentum distribution, thus improving the measurement accuracy of g. We discuss the ionization and cooling laser setup for Beryllium ions to realize mixed crystals of Calcium and Beryllium, and Beryllium and anti-Hydrogen in the later run. Actually, the observation of interference patterns in the far field of an ion crystal allows for a determination of the motional wave packet size [3]. We present schemes for cooling of mixed two-ion crystals with large mass-to-charge-ratio difference, improving the coupling of motional modes [4,5]. Experiments will be performed at ultra-high vacuum conditions in a cryogenic trap setup.

[1] Perez and Saquin, Class. Qantum Grav. 29, 184008 (2012).

[2] G. Poulsen et al., Phys. Rev. A 86, 051402(R) (2012).

[3] U. Eichmann et al., Phys. Rev. Lett. 70, 2359 (1993).

[4] D. J. Gorman et al., Phys. Rev. A 89, 062332 (2014).

[5] J. B. Wübbena et al., Phys. Rev. A 85, 043412 (2012).

Studying Antimatter Gravity with Muonium

Wed 05/08, 16:00 - 16:30
Presenter: KAPLAN, Daniel (Illinois Institute of Technology)

The gravitational acceleration of antimatter, $\bar{g}$, has never been directly measured and could bear importantly on our understanding of gravity, the possible existence of a fifth force, and the nature and early history of the universe. Only two avenues for such a measurement appear to be feasible: antihydrogen and muonium. The muonium measurement requires a novel, monoenergetic, low-velocity, horizontal muonium beam directed at an atom interferometer. The precision three-grating interferometer can be produced in silicon nitride or ultrananocrystalline diamond using state-of-the-art nanofabrication. The required precision alignment and calibration at the picometer level also appear to be feasible. With 100 nm grating pitch, a 10% measurement of $\bar{g}$ can be made using some months of surface-muon beam time, and a 1% or better measurement with a correspondingly larger exposure. This could constitute the first gravitational measurement of leptonic matter, of 2nd-generation matter and, possibly, the first measurement of the gravitational acceleration of antimatter.

Towards a novel high-brightness muon beam line for next generation precision experiments

Wed 05/08, 16:30 - 17:00
Presenter: EGGENBERGER, Andreas (ETH Zurich)

A recently proposed technique to significantly increase the brilliance of a muon (μ^+) beam [1, 2] opens the way for next generation low-energy particle physics experiments with both μ^+ and muonium (Mu = μ^+e$^-$). Precision experiments with μ^+, such as measurements of the muon g-2 or searches for the muon electric dipole moment, have the potential to find "new physics" at the multi-TeV scale. Interesting tests of bound-state QED as well as the determination of fundamental constants (m_μ, α, R_∞) can be achieved by means of Mu spectroscopy. Furthermore, Mu is a purely leptonic system consisting to 99.5% of antimatter because of the much higher mass of the μ^+ compared to the e$^-$. Performing for example interferometric experiments may allow to test the gravitational interaction of antimatter.

The novel muon beam line is a tertiary beam line, which decreases the phase space of an already existing beam line by a factor of 10^{10} with an efficiency of 10^{-3}, given mainly by the lifetime of the μ^+ and the time (8 μs) required to manipulate the μ^+: stop, compress and re-extract into vacuum. The basic idea is to stop MeV μ^+ from a standard surface muon beam in a helium gas target and compress the μ^+ swarm in several successive stages using crossed electric and magnetic fields. In the end the muons are extracted into vacuum again and accelerated, providing a pulsed eV-beam with 10 ns time information or a micro-beam with 10 keV energy of the order of 10 μm diameter.

The working principle is based on a position-dependent muon drift velocity vector $\vec{v}_D$. In a first stage the muons are stopped in a cryogenic helium gas target with a vertical gas density gradient (from 4 K to 12 K) inside a strong, longitudinal magnetic field. High, stationary electric fields compress the stopped muon swarm in transversal direction and guide it towards the second stage, which is at room temperature. In the second stage the muons are compressed in longitudinal direction and pushed towards the final stage, where a last compression occurs before the muons are extracted through a small hole into vacuum.

The second stage – the longitudinal compression – has been successfully demonstrated during our beam time in December 2014 at the new πE1 beam line at the Paul Scherrer Institute. Preliminary results from these experiments will be presented. Also, an overview over the ongoing preparations for the next beam time in December 2015 is given, which will focus on demonstrating transversal compression at cryogenic temperatures.

This work has been supported by the Swiss National Science Foundation under grant 200020_146902.

[1] D. Taqqu, Compression and extraction of stopped muons. Phys. Rev. Lett., 97 (2006).

[2] Y. Bao, et al. Muon cooling: Longitudinal compression. Phys. Rev. Lett., 112 (2014).

[3] http://www.edm.ethz.ch/research/muoncooling.html

Positronium laser excitation and its detection in the AEgIS experiment

Thu 06/08, 09:00 - 09:30
Presenter: MAZZOTTA, Zeudi (Università degli Studi e INFN Milano)

The AEgIS experimental program on antimatter systems involves the formation of antihydrogen atoms for gravitational and CPT studies. One of the key ingredients of the AEgIS strategy for the synthesis of antihydrogen atoms is the creation and manipulation of Positronium (Ps) atoms laser excited in Rydberg states ($n > 15$). Ps is very interesting in its own right. Ps is indeed a truly ”elementary atom”, a purely leptonic system holding important possibilities for modern research topics such as Bose-Einstein condensation, higher-order QED corrections and laser cooling. In AEgIS, Ps will be produced in bunched mode and its Rydberg excitation will be provided with a two laser pulse technique by passing through an $n = 3$ intermediate level. Because excitation on Ps $n = 3$ state has been never proposed before, in AEgIS several detection strategies are being studied in order to observe the first measurement ever on this interesting process.

There are two well known detection strategies, already used in $n = 2$ Ps excitation experiments: the first of them is based on the modification of the single shot gamma ray lifetime spectra from Ps annihilation in presence of a magnetic field, the second one is the laser ionization of the excited atoms, followed by charged particle collection. A third strategy is the detection of the infrared radiation emitted in the spontaneous radiative decay $n = 3 \rightarrow n = 2$. This one, in particular, can be implemented only in the specific case of $n = 3$ excitation.

High precision spectroscopy of Ps

Thu 06/08, 09:30 - 10:00
Presenter: COOKE, David (ETH Zurich)

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). In addition to probing QED, a sufficiently precise measurement of the 1S-2S transition frequency (at the level of a few kHz) can also provide a model-independent limit on the effect of gravity on antimatter, revealed through seasonal variation (or lack thereof) as a result of the change in gravitational potential between peri- and aphelion. Progress towards such a measurement is reported here, including preliminary results, positron beam technology and strategies for reaching the required precision.

Rydberg-Stark states of positronium

Thu 06/08, 10:00 - 10:30
Presenter: DELLER, Adam (University College London)

Recent advances in positron trapping techniques, positron to positronium (Ps) converter materials, and commercially available pulsed laser sources has greatly simplified the generation of Rydberg states of Ps. Highly-excited states of this exotic atom are listed in several schemes being developed for synthesis of antihydrogen for (anti)gravity measurements. In contrast to its ground-state, which rapidly self-annihilates, prolonged measurements of Ps* are possible: an element interesting in its own right for being a purely leptonic, bound-state system.

A experiment designed for laser-spectroscopy of Ps and optical preparation of Rydberg states is presented. Tailoring of the electric field in the excitation region is demonstrated as a means to select specific Stark states of the $n = 11$ manifold. These states are significant for having large electric-dipole moments, which can be exploited to manipulate the atoms. Such techniques can in principle be employed to electrostatically focus a cold Ps beam, and eventually to measure gravitational deflection of the part-antimatter pair.

Gravitation astrometric tests in the internal Solar System: the Astrometric Gravitation Probe mission goals

Thu 06/08, 11:15 - 11:45
Presenter: GAI, Mario (Istituto Nazionale di Astrofisica)

High precision astrometry at the microarcsecond level is a promising tool for Fundamental Physics tests in the Solar system, reaching a sensitivity adequate to set stringent constraints on the competing theories of gravitation, including General Relativity, and on effects induced by quantum mechanics related phenomena.

In the weak field limit of gravitation applicable to the Sun neighbourhood, General Relativity and competing gravity models can be expressed in a common framework, in particular the Parametrised Post-Newtonian (PPN) and Parametrised Post-Post-Newtonian (PPPN) formulations. Micro-arcsec astronomy is able to verify the predictions of theoretical models of gravitation by a modern rendition of two Einstein's classical tests: deflection of the light around the Sun, and perihelion precession of Mercury and other orbiting bodies. Local constraints on gravitation have also implications on fundamental principles like the Equivalence Principle and the Local Lorentz invariance and, through extrapolation at cosmological level, on the distribution of Dark Matter and Dark Energy. Astrometric Gravitation Probe (AGP) is the concept of a space mission for gravitation tests in the Solar system through coronagraphy and Fizeau interferometry for differential astrometry. The equivalent precision goal on the "γ" and "β" PPN parameters is respectively in the 10^{-8} and 10^{-6} range. The design is focused on systematic error control through multiple field simultaneous observation and calibration. The main science goals of AGP are presented, as well as the measurement approach and a sketch of the implementation concept.

On principles of repulsive gravity: the Elementary Process Theory

Thu 06/08, 11:45 - 12:15
Presenter: CABBOLET, Marcoen (Free University of Brussels)

Since the coupling of rest-mass-having antimatter with the gravitational field of ordinary rest-mass-having matter has thus far not been established experimentally, it cannot be excluded that this coupling will be found to be negative - corresponding to a repulsion. That being said, the purpose of this talk is to give a comprehensible introduction to the fundamentally new physical principles underlying a matter-antimatter gravitational repulsion laid down in the Elementary Process Theory (EPT).

First of all, it should be clear that principles of repulsive gravity have to be formulated outside the framework of modern physics: if antimatter with positive rest mass has negative gravitational mass - and it does if repulsive gravity is a fact of nature, as shown by Morrison and Gold - then not only the Weak Equivalence Principle of General Relativity (GR) is violated, but also C-inversion, the symmetry between matter and antimatter properties of the Standard Model (SM). The extensions of GR by Santilli and Villata that predict antigravity of antimatter are incompatible with observed discreteness of the microcosmos, and Kowitt's extension of Dirac's theory that adjusts C-inversion is incompatible with the outcome of Eötvös-like experiments.

Having settled that point, the EPT is essentially a mathematically rigorous scheme of formulas together with a physical interpretation: from that interpretation, in which new physical concepts are applied, it is clear that the EPT expresses new physical principles that differ fundamentally from GR and the SM. In the universe of the EPT, the observable process of evolution is indexed by discrete 'degrees of evolution', and at every such degree of evolution there are a finite number of individual processes from that degree of evolution to the next. The EPT then describes how new constituents, called: 'phase quanta', are formed from existing ones by discrete transitions in these individual processes: these are essentially all the same, regardless which type of interaction takes place - the EPT thus brings about unification of individual processes. Rest-mass-having entities like protons and electrons exhibit stepwise motion, alternating between a motionless particlelike state of rest and a wavelike state of motion. Gravitation takes place in a wavelike state, with normal matter having a characteristic number of normality $+1$, thus tending to move towards a stronger field, and antimatter having a characteristic number of normality -1, thus tending to move towards a weaker field (antigravity).

The main issue is that the EPT is not proven to satisfy the correspondence principle, although correspondence to Special Relativity (SR) has recently been shown by postulating that space-time has five dimensions (three "regular" spatial dimensions; one curled-up dimension of degrees of evolution; one temporal dimension). For any displacement $(\Delta x, \Delta y, \Delta z, \Delta n, \Delta t)$ of any particle in 5D space-time, the observed duration Δt is then the Euclidean measure of the displacement $(\Delta x, \Delta y, \Delta z, \Delta n)$ in 3D space and degrees of evolution, with the observer-independent displacement in degrees of evolution Δn being numerically identical to the invariant interval Δs of SR. This result lays the groundwork for further developments towards a full proof of correspondence of the EPT.

Rydberg positronium for tests of antimatter gravity

Thu 06/08, 14:00 - 14:30
Presenter: Dr. HOGAN, Stephen (University College London)

In its triplet ground state the positronium (Ps) atom self-annihilates on a timescale of 142 ns [1]. This short lifetime rules out the possibility of performing tests of antimatter gravity using ground state Ps atoms. However, when excited to Rydberg states with high principal quantum number [2], direct self-annihilation can become negligible and the Ps lifetime is dominated by radiative decay. The radiative lifetimes of Rydberg states of Ps are twice as long as those of states with the same value of n in the hydrogen atom, as are the maximal induced electric dipole moments. The combination of these long radiative lifetimes, large electric dipole moments, and the low mass of the Ps atom, makes Rydberg

Ps ideally suited to focussing, deceleration and trapping using inhomogeneous electric fields (see, e.g., [3]).

In this talk, experiments in which Rydberg-Stark states of Ps with electric dipole moments as large as 840 D have been prepared will be presented [4]. Experimental methods, presently developed for the manipulation of beams of helium Rydberg atoms [5], but which may be extended to guide and confine Rydberg Ps for gravity measurements, will also be discussed along with possible spectroscopic tests of antimatter gravity with Rydberg Ps.

[1] R. S. Vallery, P.W. Zitzewitz, and D.W. Gidley, Phys. Rev. Lett. 90, 203402 (2003).

[2] D. B. Cassidy, T. H. Hisakado, H. W. K. Tom, and A. P. Mills, Jr., Phys. Rev. Lett. 108, 043401 (2012).

[3] S. D. Hogan, M. Motsch, and F. Merkt, Phys. Chem. Chem. Phys., 13, 18705 (2011).

[4] T. E. Wall, A. M. Alonso, B. S. Cooper, A. Deller, S. D. Hogan, and D. B. Cassidy, Phys. Rev. Lett., 114, 173001 (2015).

[5] H. Ko and S. D. Hogan, Phys. Rev. A, 89, 053410 (2014).

Accelerating positronium using pulsed travelling optical lattices

Thu 06/08, 14:30 - 15:00
Presenter: Prof. CHARLTON, Mike (Swansea University)

The creation of tunable beams of positronium atoms using the optical dipole force from short, pulsed accelerating optical lattices has been studied. Using the favourable polarizability-to-mass ratio of positronium we show that accelerations in excess of 10^{14}g are possible. Simulations have been performed for several cases in which lattice beams capture a significant fraction of ground state ortho- positronium atoms in a cloud at an initial temperature of 300 K. We show that using conventional laser sources, bunches of positronium atoms can be accelerated well within the ortho-positronium vacuum lifetime of 142 ns. Kinetic energies in the eV to 100 eV range, with well-defined energy spreads and final kinetic energy, appear feasible. These parameters can be tuned using laser intensity, pulse duration or the acceleration of the lattice. We show that this approach is feasible by describing experiments that have demonstrated the acceleration of neutral argon atoms over a range of energies using accelerated optical lattices.

[1] P. F. Barker and M. Charlton, New J. Phys. 14, 045005 (2012)

[2] C. Maher-McWilliams, P. Douglas and P. F. Barker, Nature Photonics 6, 386 (2012)

On the use of Atom Optical Tools for Antimatter Experiments

Thu 06/08, 15:00 - 15:30
Presenter: BRÄUNIG, Philippe (Ruprecht-Karls-Universitaet Heidelberg

The field of atom optics has seen tremendous development during the past decades. Tools and methods from this field have evolved from proof-of-principle experiments to reliable instruments with unprecedented precision and are now utilized to tackle fundamental questions – also in different fields of physics. The AEgIS collaboration has used such a tool known as moiré deflectometer, an instrument that can be described with classical particle trajectories, to measure electromagnetic forces on antiprotons. The ultimate goal of this ongoing effort is to build a device for future measurements of antihydrogen's gravitational acceleration in Earth's field. Towards this challenging goal, one is interested in increasing the sensitive of the measuring apparatus. A promising way is to push the moiré deflectometer into the wave-regime, where it can be regarded as a Talbot-Lau interferometer. Realizing such an interferometer for antiprotons would represent an important, intermediate experimental step.

Imaging of antihydrogen – A Vertexing Detector overview

Thu 06/08, 16:00 - 16:30
Presenter: MC KENNA, Joseph (TRIUMF)

The aim of the ALPHA experiment at CERN is to trap cold atomic antihydrogen, study its properties, and ultimately to perform precision comparison between the hydrogen and antihydrogen atomic spectra. Recently the collaboration has reached several important milestones. Firstly, demonstrating the ability to trap and confine neutral cold antihydrogen [1][2]; secondly, performing the first spectroscopic measurements of antihydrogen [3]; and of late, through demonstrations of the first application of a new technique, to set limits on the possible anomalous gravitational mass of antihydrogen [4].

The principle tool for antihydrogen detection in the ALPHA experiment is a Silicon Vertex Detector (SVD), built using 72 double-sided silicon strip hybrid modules and designed to surround the neutral atom trap. Recently upgraded [6], the SVD is used to image single annihilation events, reconstructing spatial and timing data of antiproton annihilation. The detector can be operated in various optimised modes; application modes include low background counting experiments, accurate vertex reconstruction and collective plasma behaviour studies, giving insight into the formation processes of antihydrogen.

A description of the SVD performance, characteristics and an overview of applications in the ALPHA experiment will be given along with a summary of recent results, performance improvements and outlook for probing antihydrogen formation.

[1] G. B. Andresen et al, Nature, 468, 673 (2010)

[2] G. B. Andresen et al, Nature Physics, 7, 558 (2011)

[3] C. Amole et al, Nature, 483, 439 (2012)

[4] A. E. Charman et al, Nature Communications, 4, 1785 (2013)

[5] G. B. Andresen et al, JINST, 7, C01051 (2012)

[6] C. Amole et al, Nucl. Inst. Method in Phys. Res. A 732 134-136 (2013)

Updated status of the GRANIT facility

Thu 06/08, 16:30 - 17:00
Presenter: ROULIER, Damien (Institut Laue Langevin)

The GRANIT facility is designed to study quantum states of Ultra Cold Neutrons (UCNs) bouncing over a mirror in the gravitational field.

The UCNs are produced by a dedicated superthermal helium source installed at the ILL reactor. The source is now connected to the GRANIT spectrometer, and improvements have been implemented to make the source more reliable and extract the UCNs more efficiently. New measurements have been made and confirm the validity of our choices. Several developments are also made to produce efficient detectors for GRANIT.

The next step will consist in inducing resonant transitions between quantum states in a flow through mode using an oscillating magnetic field gradient. Searching for deviations of the expected resonant frequencies we can test the weak equivalence principle in a quantum context and/or probe the existence of a new fundamental force.

What if quantum vacuum fluctuations are virtual gravitational dipoles?

Fri 07/08, 09:30 - 10:00
Presenter: HAJDUKOVIC, Dragan (Institute of Physics, Astrophysics and Cosmology; Cetinje, Montenegro)

The hypothesis stated in the title might be the basis for a new model of the Universe. According to the new model, the only content of the Universe is the known Standard Model matter (i.e. matter made from quarks and leptons interacting through the exchange of gauge bosons) immersed in the quantum vacuum “enriched” with virtual gravitational dipoles. Apparently, what we call dark matter and dark energy, can be explained as the local and global effects of the gravitational polarization of the quantum vacuum by the immersed baryonic matter. Further, the hypothesis leads to a cyclic model of the Universe with cycles alternatively dominated by matter and antimatter; with each cycle beginning with a macroscopic size and the accelerated expansion. Consequently, there is no singularity and there is an elegant explanation of the matter-antimatter asymmetry in the universe: our universe is dominated by matter because the previous cycle of the Universe was dominated by antimatter.

The forthcoming experiments (AEGIS, ALPHA, GBAR ...) will reveal if particles and antiparticles have gravitational charge of the opposite sign, while study of orbits of tiny satellites in trans-Neptunian binaries (e.g. UX25, Eris-Dysnomia ...) can be a reasonable test of some astronomical predictions of the theory.

Gravitation astrometric tests in the Solar System: the QVADIS collaboration goals

Fri 07/08, 10:00 - 10:30
Presenter: GAI, Mario (Istituto Nazionale di Astrofisica)

High precision astrometry at the microarcsecond level is a promising tool for Fundamental Physics tests in the Solar system, reaching a sensitivity adequate to set stringent constraints on the competing theories of gravitation, including General Relativity, and on effects induced by quantum mechanics related phenomena.

In the latter case, it may evidence the gravitational properties of anti-matter by verification of some basic theoretical assumptions, e.g. the hypothesis that conventional and anti-matter may act in a repulsive way on each other, retaining the attractive interaction among homologous matter type particles. Then, Quantum Vacuum might have gravitational effects due to polarisation of the matter-antimatter virtual particle pairs in an external gravitational field, since polarisation will act as an additional field. In turn, this may induce an excess shift of the longitude of the pericenter in the orbit of a binary system, in particular located at large distance from the main local gravity source. Assessments of the expected level on the trans-neptunian binary system UX25 was estimated by Hajdukovic (2014) to be about 0.23 arcsec per orbit. We discuss the verification of such effect by state-of-the-art or near-future astronomical infrastructures, either on ground or in orbit, evidencing its feasibility in a reasonable experimental framework. The observation implications of effect discrimination from disturbances due to other physical reasons (e.g. object shape and structure) are reviewed.

Do black holes create polyamory?

Fri 07/08, 10:30 - 11:00
Presenter: Prof. OPPENHEIM, Jonathan (UCL)

I'll review the black hole information problem and its sharper version, the firewall paradox. I'll describe some recent contributions found in http://arxiv.org/abs/1506.07133 and http://arxiv.org/abs/1401.1523

ALPHA-g: a precision antimatter gravity experiment with a magnetic trap

Fri 07/08, 11:30 - 12:00
Presenter: FUJIWARA, Makoto (TRIUMF)

ALPHA-g is a new initiative by the ALPHA collaboration, whose primary goal is to study the gravitational interaction of antihydrogen atoms in a magnetic trap. In this talk, I will give an overview of the ALPHA-g experiment, and discuss the prospects for precision measurements of antimatter gravity which this apparatus will offer.

Status and prospects for the AD and ELENA

Fri 07/08, 12:00 - 12:30
Presenter: JØRGENSEN, Lars Varming (CERN)

A brief update will be given on the current status of the Antiproton Decelerator at CERN and the consolidations plans, both ongoing and future, will be presented. A brief description of the Extra Low ENergy Antiproton ring (ELENA) currently under construction at CERN will be presented and the future plans and options for this machine will be discussed.

Timetable

	Wednesday, 5 August	Thursday, 6 August	Friday, 7 August
08:30	Registration		
09:00		Session D	
09:30			Session H
10:00	Opening Address		
10:30		Coffee Break	
11:00	Coffee Break	Session E	Coffee Break
11:30	Session A		Session I
12:00		Lunch	
12:30	Lunch		Summary talk
13:00			
13:30			
14:00	Session B	Session F	
14:30			
15:00			
15:30	Coffee Break	Coffee Break	
16:00	Session C	Session G	
16:30			
17:00			

19:30 – 23:00
Conference Dinner
Ambassadors Bloomsbury Hotel