NEWS letter

MIRROR

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Highlights

Exciting research results, new Fellows & upcoming events

Our colleagues from the BASE collaboration at CERN have been able to measure the magnetic force of antiprotons with excellent precision, beating their own previous record. Their measurements revealed a large overlap between protons and antiprotons, thus confirming the Standard Model of particle physics. **Congratulations to Stefan and his team !**

Almost all of the Fellowships in the AVA project have now been filled and the project's research is running at full steam. The Fellows joined the network from all parts of the world and are now embedded into the international training and research framework which our project provides. There are only two vacancies left (at COSYLAB and at GSI) and in case you know of any excellent early stage researchers, please encourage them to get in touch with me to find out more details.

Finally, our international AVA events are now starting: All Fellows will come to Liverpool in January 2018 for a full week of complementary skills training. They will be joined by a cohort of students from the LIV.DAT Center for Doctoral Training. This week will be followed by a week in Manchester's media city where they will receive training in state-of-the-art video production techniques and prepare their own video about the project! We go international with a week-long school on antimatter physics at CERN at the end of June 2018. Registration is now open and you will find more details in this issue of MIRROR.

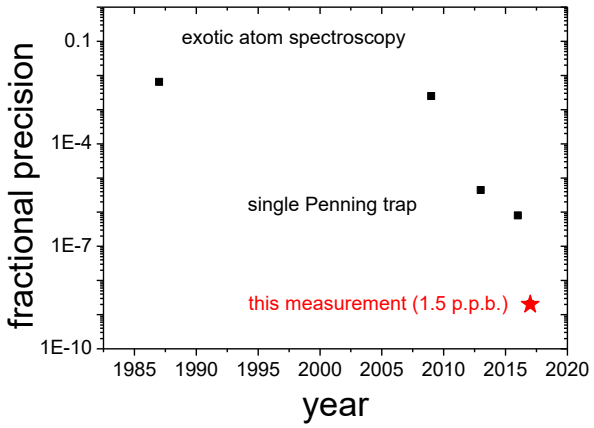
Prof Carsten P Welsch
AVA Coordinator

Antiproton Magnetic Moment Measured with 350-fold Improved Precision

Stefan Ulmer, RIKEN

Very recently, the BASE collaboration at the antiproton decelerator of CERN, reported on an improved measurement of the magnetic moment of the antiproton [1]. The new measurement outperforms the previous best measurement [2] by a factor of 350 in experimental precision. The updated value $g_{\bar{p}}/2$=2.792 847 344 1 (42) is consistent with the magnetic moment of the proton $g_p/2$=2.792 847 350 (9), and thus supports the combined charge, parity, and time-reversal (CPT) invariance of the Standard Model of particle physics [3]. Remarkably, this is the first time physicists have published a more precise measurement on antiprotons than on protons. Together with the exciting recent antihydrogen results [4], this milestone achievement is a demonstration of the immense progress made at CERN's antiproton decelerator facility.

This extraordinary improvement in experimental accuracy was made possible by the invention of a novel two particle multi Penning trap method, which combines the non-destructive detection of the antiproton's spin quantum state with particle-based high-resolution magnetic field measurements.



Fractional precision achieved in measurements of the antiproton magnetic moment. The most recent two particle measurement [1] improves the fractional precision of the previous best measurement [2] by a factor of 350.

The determination of the magnetic moment of a single trapped particle is based on the measurement of two characteristic frequencies, the cyclotron frequency ν_c , which describes the particle's revolutions per second in the magnetic field of the Penning trap, and the second, the precession frequency ν_L of the particle's spin. Together, these allow access to the particle's magnetic moment. Previous antiproton measurements, such as those performed in [2, 5], used a single Penning trap with a superimposed *magnetic bottle*. This strong inhomogeneity in the magnetic field allows for non-destructive detection of the particle's spin-quantum-state, a precursor to any determination of the Larmor frequency. However, such a bottle broadens the particle's resonance lines and limits the precision of the measurement, typically to the parts per million level.

To overcome this limitation, experimentalists apply a two trap method which separates the high-precision frequency measurements to a homogeneous precision trap and the spin state analysis to a trap with the superimposed magnetic inhomogeneity. While an elegant technique, this double trap method is very challenging to implement. It took seven years of research and development work until BASE was able to demonstrate this double-trap method with a single trapped proton, and later applied it in a measurement of the proton magnetic moment to nine significant figures [3].

In the recently reported measurement, the BASE team has extended the double-trap technique to a three trap / two particle scheme, in which a "hot" particle with an effective temperature of 300K for magnetic field measurements and a cold particle at 0.12K for spin transition spectroscopy are used. By alternatingly shuttling the two particles to the precision trap the team was able to sample cyclotron and Larmor frequencies by a fast adiabatic particle exchange in the same homogeneous magnetic field.

However, unlike the double trap method, the two particle technique avoids time consuming resistive cooling cycles to sub-thermal temperatures, and thus, enables measurements at drastically improved frequency sampling rate, which was the major breakthrough to accomplish the goal of measuring the antiproton magnetic moment with parts per billion precision.

By combining the new 350-fold improved antiproton result with the previously measured proton result, one of the most precise tests of CPT invariance in the baryon sector is obtained, which sets drastically improved constraints on CPT-violating extensions of the Standard Model.

[1] Smorra, C. et al., A parts per billion measurement of the antiproton magnetic moment, *Nature* **550**, 371 (2017).
[2] Nagahama, H. et al., Six-fold improved single particle measurement of the magnetic moment of the antiproton, *Nature Comms.* **8**, 14084 (2017).
[3] Mooser, A. et al., High-precision measurement of the magnetic moment of the proton, *Nature* **509**, 596 (2014).
[4] Amole, C. et al., Resonant quantum transitions in trapped antihydrogen atoms, *Nature* **483**, 439-442 (2012).
[5] DiSciacca, J. et al. One-particle measurement of the antiproton magnetic moment, *Phys. Rev. Lett.* **110**, 130801 (2013).

The Royal Society Welcomes ELENA

This year the Theo Murphy International Scientific Meeting has been dedicated to "Antiproton physics in the ELENA era". The meeting was held at Chicheley Hall, an English country house built in the 18th century, situated in Buckinghamshire. The purpose of this two day meeting (4th-5th September 2017) was to bring together members of the antimatter research community to the state-of-the-art and perspectives of the antimatter physics studies from both theoretical and experimental point of view, and discuss the impact of the new antiproton decelerator ELENA (Extra Low Energy Antiproton ring) when it starts up later this year.

The first antiproton beam in ELENA was injected on the 2nd August this year, thus achieving a fundamental milestone for the antimatter physics community. Currently the ELENA antiproton storage ring and its transfer line are under commissioning to obtain the required beam properties which will allow to increase massively both the availability and the number of low energy antiprotons for the experiments.

The first day of the meeting, the theoretical aspects of antimatter physics investigated in different experiments of the AD-ELENA complex were reviewed. Potential observables and predicting constraints were identified to the measurement precision of matter-antimatter asymmetry measurements in CPT violation, antihydrogen spectroscopy and antigravity. ELENA will open unique opportunities to investigate gravity-antigravity asymmetries in experiments as GBAR and AEgIS and ALPHA-g.

After reviewing the theoretical prospects, the current status of each experiment in the AD-ELENA hall was presented, with remarkable improvements on the antiproton traps, spectroscopy techniques and detectors to significantly increase the precision of the measurements. The accelerator physics aspects of ELENA had also a relevant space in the agenda, with a talk presenting the current status of the ELENA machine and the commissioning progress.

The meeting was ideal to discuss the exciting physics prospects at ELENA and to hear the latest news from the world of antimatter research. More information can be found on the workshop website:

https://royalsociety.org/science-events-and-lectures/2017/09/antiproton-physics/

AVA presented at IBIC 17

The annual International Beam Instrumentation Conference (IBIC) took place in Grand Rapids, USA between 20-24 August 2017. IBIC is a fruitful gathering of the world's beam instrumentation community and encourages international collaboration in the field of beam instrumentation for accelerators. The conference is dedicated to exploring the physics and engineering challenges of beam diagnostic and measurement techniques for particle accelerators worldwide.

AVA Coordinator Prof Carsten Welsch attended the conference to present an invited talk on *"Low energy, low intensity beam diagnostics"* with a focus on devices relevant for antimatter facilities He also contributed several posters to the scientific programme, including an overview of the beam instrumentation work package within AVA. Further project news were presented via a dedicated industry stand. This included the AVA leaflet containing information about partner institutions and research projects within the network.

Alexandra presenting a range of accelerator projects the University of Liverpool is involved in.

Upcoming events such our AVA Antimatter Physics School end of June 2018, and the EuPRAXIA Symposium in Liverpool in July 2018 were also announced for the first time.

Meet our AVA Fellows (continued from last issue)

Below we present the Fellows that have recently started work in their host institutions, with other Fellows to be introduced in the next issue.

Welcome to AVA!

Volodymyr Rodin obtained his Master's degree in 2017 with a thesis 'Development of Wavelength-shifting Optical Module simulation model in GEANT4 for SHiP experiment'. The work consisted of creating the comprehensive simulation of WOM and its verification with experimental data.
Volodymyr will be based at the Cockcroft Institute / University of Liverpool, where he will develop a project on " 6-D studies into beam motion in low energy storage rings".

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Indrajeet Prasad graduated in Electronics and Instrumentation Engineering from West Bengal University of Technology, India, where his bachelor thesis was focused on "Micro-controller based home security system". His Master's degree in Control in Electrical Engineering is from Wroclaw University of Technology, Poland with a thesis focused on "Line differential protection insensitive to CT saturation". He has worked as an Assistant Researcher at Transilvania University of Brasov, Romania under the FP7 Marie Curie Research project "EMVeM: Energy Efficiency Management for Electrical Vehicle and Machines". He has also worked as a Scientific and Technical Specialist at AGH University of Science and Technology in Poland.

Indrajeet joined AVA at FOTON in The Czech Republic and he will pursue his doctoral degree at Czech Technical University, Prague. He is working on the project: *"High Stability, Rampable Power Supplies for Accelerator Application (e.g. keV Ion Beams)"*.

Ilia Blinov graduated from the Volga State University of Technology (Russia Federation) with a Master's degree in Design and Technology in Electronics Engineering during which he designed wireless environment monitoring equipment with low power consumption. After obtaining his degree, Ilya co-founded Pharad LLC, where he designed wireless telemetry devices, smart meters, measure equipment and motion control systems.

Ilia joined Stahl-Electronics as a PhD student in 2017 with the aiming at the development of *novel super-sensitive charge sensors*, which will be used in ion and antimatter research.

Dominika Alfs graduated from the Faculty of Physics, Astronomy and Applied Computer Science of the Jagiellonian University in Kraków.
She has worked on data analysis and software development for detector calibration. For her Master's thesis she performed drift chamber calibration and prepared methods for 3d track reconstruction.

Within the AVA project, Dominika will work in Forschungszentrum Jülich on the development of *liquid target-based detectors for hadron physics experiments* induced by the annihilation of stopped antiprotons and the investigation of beam monitoring.

Bruno Galante studied Physics at the University of Parma where he graduated in 2016 with Master's Degree specialising in the physics of matter and functional materials, working on an experimental project "Carbon Nanostructures for Symmetric Supercapacitors".

Following a period working for a consulting company as a business analyst and blockchain developer, Bruno joined AVA as a fellow at CERN and is part of a project involving the *generation of cold electrons for the cooling of an antiproton beam* due to reduce or eliminate the emittance blow-up caused by the deceleration process.

Partner News

AVA partner awarded Fellowship of The American Physical Society

AVA partner, Dr William Bertsche, lecturer in the Accelerator Physics group of the University of Manchester School of Physics and Astronomy and the Cockcroft Institute, has just been elected as Fellow of The American Physical Society (APS) for seminal contributions to the trapping of antihydrogen atoms and subsequent spectroscopic measurements on them; in particular for the development, of the auto-resonant mixing technique and other non-neutral plasma manipulations crucial to the first demonstration of anti-atom trapping in 2010. He was nominated by the division of Plasma Physics.

The APS Fellowship Program was created to recognize members who may have made advances in knowledge through original research and publication or made significant and innovative contributions in the application of physics to science and technology. They may also have made significant contributions to the teaching of physics or service and participation in the activities of the Society. Each year, no more than one-half of one percent of the then current membership of the Society are recognized by their peers for election to the status of Fellow in The American Physical Society.

Congratulations!

LIVDAT – A Big Data Training Centre

The University of Liverpool and Liverpool John Moores University have been awarded £1M from the Science and Technology Facilities Council (STFC) for a new collaborative Centre for Doctoral Training (CDT) in data intensive science (LIVDAT).

Thanks to increasingly powerful technology, researchers can gather, store and utilise vast amounts of data, but to make sense of this data expert scientists are needed.
The LIVDAT CDT will address this skills need by training fellows to analyse data from astrophysics, accelerator science, nuclear or particle physics research, and to address problems posed by industry and other organisations. Fellows will make use of sophisticated computational, statistical and programming techniques, including AI and machine learning to extract insights from huge datasets and make new discoveries.
LIVDAT shares philosophies and goals in its training methodologies and secondments with AVA and it is planned that Fellows from both initiatives will meet on a regular basis over the next few years.

More information: http://www.livdat.org/

Upcoming Events

Marie Skłodowska-Curie Anniversary Event, 7th November 2017

This year marks the 150th birth anniversary of Marie Skłodowska-Curie and the 20th anniversary of the EU's Marie Skłodowska-Curie Actions.

We will celebrate these milestones with a **special celebration on 7th November** with hands-on activities at CERN, Munich and Liverpool. Presentations will be live-streamed and available to participants from around the world.
Please bring this to the attention of colleagues at your institute and encourage them to join us on the day via internet. You might even wish to consider screening the talks in a lecture theatre so more colleagues can join in and organise other themed activities yourselves, e.g. about gender balance in science, the importance of international mobility and collaboration, life-long learning and of course your own research projects.

Full details of the programmes can be found on the event website. Links to the live streams will be available closer to the event. **Join in!**

AVA Skills and Media Workshops, January 2018

There will be a Researcher Skills School for AVA Fellows in Liverpool from 8th – 12th January 2018.
This will be followed by a media skills workshop at Manchester Media City from 15th – 19th January during which all Fellows will contribute to the creation of an AVA promotional film.
During the first week, AVA fellows will be joined by fellows from LIVDAT, a big-data research network based in Liverpool.

Emittance Measurements for Light Sources and FELs workshop, January 2018

The Topical Workshop on "Emittance Measurements for Light Sources and FELs" will be held at ALBA Synchrotron, Barcelona, from 29th -30th January 2018.
This is the first of a sub-series of workshops on "Advanced Diagnostics for Accelerators" (ADA) within the newly EU funded ARIES programme (Accelerator Research and Innovation for European Science and Society). Experts from the scientific community working on emittance measurements for electron machines (including light sources, damping rings, FELs and future e+/e- circular colliders), will gather with the aim to present the status of the different beam size measurement techniques, discuss the challenges that the community faces for the next generation of ultra-low emittance machines, and enhance synergies between the different communities.

https://indico.cells.es/indico/event/128/overview

PSAS2018, May 2018

The international conference on precision physics of simple atomic systems will be held from the 14th – 18th May 2018 in Vienna by the Stefan Meyer Institute.
This will be the 10th conference in a series established in 2000 by Savely Karshenboim with topics spanning precision spectroscopy of matter and antimatter atoms, QED, precision measurements and fundamental constants.

More details are available at www.psas2018.at.

International School on Low Energy Antimatter Physics, June 2018

A week-long International School on Low Energy Antimatter Physics will be held at CERN on 25th – 29th June 2018. It will cover the challenges in antimatter facility design and optimization, beyond state of the art beam diagnostics and advanced detectors, as well as novel antimatter experiments.
In addition to lectures by research leaders, there will be study groups, a poster session and a dedicated industry session. There will also be opportunities for discussion and networking at evening events and a tour of CERN's unique accelerator facilities.

Several scholarships for early stage researchers from outside of the AVA network will be available. Application deadline: 28th February 2018

Registration and further details can be found here: https://indico.cern.ch/event/677170/

Registration deadline: 30th April 2018

Quantum Leap towards the Next Generation of Accelerators, July 2018

The EuPRAXIA consortium will be holding a Symposium 'Quantum Leap towards the Next Generation of Accelerators', on 6th July 2018, at ACC Liverpool, UK.
A new technology has emerged that may reduce dramatically the size and cost of particle accelerators, facilitating the access of hospitals and universities to these tools and multiplying its applications. Plasma accelerators, using high-power laser or electron beams, can generate several billion volts of electricity in a gas cell, accelerating electrons to near the speed of light in just a few millimetres.

Whether you are a scientist, a manufacturer, or a student, you can now be part of the future of particle accelerators.

World-renowned scientists will present research highlights on the next generation of accelerators and their enormous impact on science and society. They will be joined by scientists from the EuPRAXIA network and relevant industries who will present their innovations and share their fascination for science.

More information can be found here.

Position Vacancies

Early Stage Researcher Fellowship within the AVA project at Cosylab d.d.
'Development of a versatile control system'
More information can be found here: https://www.liverpool.ac.uk/ava/projects/cosylab/

Early Stage Researcher Fellowship within the AVA project at GSI
'Reservoir Trap to Deliver Single Antiparticles to Penning Trap Experiments'
More information can be found here: https://www.liverpool.ac.uk/ava/projects/gsi/#d.en.818584

News from FAIR

Arrival of First Main Magnet for New Large Ring Accelerator

Big progress is being made in the production of the components of FAIR. At the heart of the future facility will be the 1.1-kilometer ring accelerator SIS100. This is a very challenging accelerator from a technological point of view.

An important step has now been taken in the accelerator's construction in the delivery of the first series-production main magnet for the new heavy-ion ring accelerator. The manufacture of magnets weighting several tons requires high-precision mechanical processing and precision analysis methods. A total of 110 magnets will be supplied by 2019. Each magnet undergoes four weeks of testing once at GSI. Magnets that successfully pass these tests will be stored and installed into the final tunnel from 2021. The assembled particle accelerator is scheduled to be cooled to its operating temperature of -270 degrees Celsius for the first time in 2023. Find out more.

FLAIR
Facility for Low-energy Antiproton and Ion Research

Events

6th - 10th November 2017	2nd OMA School – Monte Carlo Simulations, LMU Munich, Germany
7th November 2017	Marie Skłodowska-Curie Anniversary Event, Liverpool, UK
8th - 12th January 2018	AVA Skills and Media Workshops, University of Liverpool, UK
15th – 19th January 2018	Media Skills Workshop, Media City, Manchester, UK
29th - 30th January 2018	Emittance Measurements for Light Sources and FELs Workshop, Barcelona, Spain
14th - 18th May 2018	PSAS2018. Stefan Meyer Institute, Vienna, Austria
25th - 29th June 2018	International School on Low Energy Antimatter Physics, CERN, Switzerland
6th July 2018	Symposium: Quantum Leap towards the Next Generation of Accelerators, Liverpool, UK

Notice Board

There are now only two Fellowships available within AVA. Please encourage suitable candidates to apply.

This newsletter will be published on a quarterly basis. Help us keep it interesting by providing your news and updates.

DEADLINE FOR THE NEXT NEWSLETTER CONTRIBUTIONS: 15th January 2018

www.ava-project.eu

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