Early Career Conference in Trapped Ions (ECCTI) 2020

Report of Contributions

https://indico.cern.ch/e/ECCTI_2020

Contribution ID: **2** Type: **Oral**

Welcome to ECCTI 2020

Monday 13 January 2020 11:00 (30 minutes)

The Early Career Conference in Trapped Ions aims to give PhD students and early career researchers the opportunity to present their work to a supportive international audience. The conference should be of interest to researchers in quantum information and technology, quantum optics, precision frequency measurements, atomic clocks, antimatter and quantum simulation. Attendees will have the chance to take part in fruitful discussions concerning important topics in physics research today, build networks with potential future colleagues/ collaborators and attend interactive sessions supporting the development of skills necessary for a career in research or industry. The conference will culminate with visits to various facilities at CERN.

The conference organizers, April Cridland and Muhammed Sameed, welcome you to ECCTI 2020. We look forward to an eventful week ahead.

Presenters: CRIDLAND, April Louise (University of Swansea); SAMEED, Muhammed (University of Manchester (GB))

Session Classification: Welcome

Contribution ID: **39** Type: **Poster**

Trap assisted giant molecular ions in a radio-frequency trap

In CERN's Alpha Experiment, clouds of positrons and anti-protons are merged to produce anti-hydrogen. The issue of low antimatter yield from this experiment has been addressed by various design alternatives in past, among which a proposal to use a two-frequency ion trap is probably the newest [1]. Here I present a concept of a new experiment that takes this technology and applies it to a field of quantum simulation.
According to theoretical predictions [2], giant molecular ions trapped in an ion trap can be used to simulate high temperature superconductivity more efficiently than experiments with ultra-cold atoms in optical lattices. A practical realisation of the idea would bring a revolution in designing of super-conductive materials that can be used in super-efficient power generators, for example.
However the giant molecular ions have never been observed, as low-energy electrons get lost during their production, mainly because state-of-the-art ion traps can not confine ultra-cold atomic ions and electrons at the same time.
This limitation can be overcome by a radio-frequency ion trap that operates with two frequencies at once. Stable trapping parameters in such a trap have been mathematically derived just recently by Foot et al. [3], and I am working on plans for a practical realisation of this idea. In the experiment I am designing, the ultra-low temperature mixture of ions and electrons will be produced by photo-ionisation of laser-cooled atomic ions. The electrons will attach to Rydberg levels of the atomic ions and start being exchanged with the ions in the closest neighbourhood. This process can result in the creation of giant molecular ions under certain trapping conditions. The formation of the molecular ions will be inferred from fluorescence images of the laser-cooled atomic ions.
Besides the implications to the field of condensed matter theory, the huge dipole and magnetic moments of the molecular ions could be utilised in quantum sensors of electromagnetic fields.

References
[1] Leefer, Nathan, Kai Krimmel, William Bertsche, Dmitry Budker, Joel Fajans, Ron Folman, Hartmut Häffner, and Ferdinand Schmidt-Kaler. 'Investigation of Two-Frequency Paul Traps for Antihydrogen Production'. Hyperfine Interactions 238, no. 1 (28 December 2016): 12. https://doi.org/10.1007/s10751-016-1388-0.
[2] Lesanovsky, I., M. Müller, and P. Zoller. 'Trap-Assisted Creation of Giant Molecules and Rydberg-Mediated Coherent Charge Transfer in a Penning Trap'. Physical Review A 79, no. 1 (14 January 2009): 010701. https://doi.org/10.1103/PhysRevA.79.010701.
[3] Foot, C. J., D. Trypogeorgos, E. Bentine, A. Gardner, and M. Keller. 'Two-Frequency Operation of a Paul Trap to Optimise Confinement of Two Species of Ions'. International Journal of Mass Spectrometry 430 (1 July 2018): 117–25. https://doi.org/10.1016/j.ijms.2018.05.007.

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Session Classification: Poster Session

Track Classification: Quantum Simulation

Contribution ID: **41** Type: **Oral**

Data Science with Python: Good practices

Tuesday 14 January 2020 16:30 (2 hours)

In this session, you will learn some good practices that will help you improve the quality of your Python code. First, you will discover the guidelines for formatting Python code, how to keep it clean and help other developers (including your future self) to understand it more easily. Next, you will learn how to use logging to keep track of what your code is doing while you are not over the screen to supervise it, including how to send mail notifications to yourself when it fails or stops. Finally, you will learn about unit tests and how they can help you validate that your code works as expected.

Author: GEORGIOU, Mary (CERN)

Presenter: GEORGIOU, Mary (CERN)

Session Classification: Interactive Skills Session 2

Contribution ID: **42** Type: **Poster**

Towards Remote Entanglement of Trapped Ions Systems

Towards Remote Entanglement of Trapped Ion Systems

Cavity quantum electrodynamics (cQED) with trapped ions are a strong candidate for the implementation of distributive quantum computing [1]. A prerequisite for deterministic control of the ion-photon system is the strong coupling between the atomic ion and the optical cavity. This was recently achieved for the first time at Sussex with an end cap Paul trap with an integrated fibre cavity [2].
To improve the current system, we are in the procress of designing and building a new ion-cavity setup with improved optical access and cavity stability.
We present the preliminary components, design and simulation results of the next generation cQED system. Such will include a reengineered endcap electrode-cavity structure for improved mechanical stability. We propose a novel means of controlling the ion's position that will be achieved by distorting the trapping potential by mechanically altering the positions of the electrodes that provide the RF ground. To this end we present data from a finite element modelling program that simulate the behaviour of the trapping potential under different conditions and model the various secular frequencies of the ion.
Lastly our cQED system will feature modified fibre cavities with integrated mode matching optics comprised of a single mode-GRIN-multimode assembly [3]. Said modified cavities feature a mode matching efficiency of up to 90% (cavity lengths = 400um) and will greatly enhance the coupling of the photons from the cavity into the single mode fibre.

References

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[2] H. Takahashi, E. Kassa, C. Christoforou, and M. Keller, arXiv preprint arXiv:1808.04031 (2018).

[3] Gurpreet Kaur Gulati, Matthias Keller Scientific Reports 7, Article number: 5556 (2017)

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Presenter: Mr SHOKEIR, Hamzah (University of Sussex)

Session Classification: Poster Session

Track Classification: Quantum Information & Computing

Contribution ID: **43** Type: **Oral**

Towards precision spectroscopy of molecular hydrogen ions

Monday 13 January 2020 15:30 (30 minutes)

The molecular hydrogen ion is a promising candidate for the metrology of fundamental constants, as its rovibrational transition frequencies can be calculated to the few-10^{-12} accuracy level [1]. Measuring the transition frequencies between the levels with similar precision will provide an independent determination of the proton to electron mass ratio m_p/m_e and possibly of the proton radius. I will present our recent progress towards this goal. In particular, I will show experimental results of state-selective preparation of molecular hydrogen ions in the $v = 0$ and $v = 1$ states and a demonstration of our detection mechanism via photodissociation of the excited state. Very recently, we have embedded sympathetically cooled, state-selected H_2^+ ions in a cloud of laser cooled Be^+ ions and will soon attempt to observe the two-photon vibrational transition at 9.17µm [2].

[1] V.I. Korobov et al., PRL 118, 233001 (2017)
[2] F. Bielsa et al., Opt. Lett. 32, 1641 (2007)

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Presenter: SCHMIDT, Julian (LKB)

Session Classification: Precision Measurements 1

Track Classification: Precision Measurements

Contribution ID: **44** Type: **Oral**

Combining a cryogenic Paul trap and an electrostatic ion beam trap to explore the most exotic nuclides with high-resolution laser spectroscopy

Wednesday 15 January 2020 09:30 (30 minutes)

Collinear laser spectroscopy (CLS) is a powerful tool to access nuclear ground state properties of short-lived radionuclides by measuring the atomic or ionic hyperfine structure [1,2]. This technique uses fast (˜30 keV) beams to minimize the Doppler broadening and thus, approaching the natural linewidth which is necessary to resolve the hyperfine structure. However, in order to explore the most exotic nuclides far away from stability, more sensitive methods are needed. For this reason, the novel MIRACLS (Multi Ion Reflection Apparatus for Collinear Laser Spectroscopy) project at ISOLDE/CERN, aims to combine the high spectral resolution of conventional CLS with high experimental sensitivity.

This increase in sensitivity is achieved by trapping ion bunches in a novel 30 keV electrostatic ion beam trap (EIBT) [3], in which the ions bounce back and forth between two electrostatic mirrors such that the laser-ion interaction time is increased with each revolution.

The combination of CLS and EIBT techniques in MIRACLS constitutes stringent requirements on the emittance of the probed ion bunches. A low energy spread (< 1 eV) to minimize the CLS Doppler broadening is as essential as a temporally narrow ion-bunch profile (< 500 ns) for EIBT operation. Moreover, the transversal emittance should be as small as possible to maintain ion trajectories parallel to the laser-beam axis over thousands of revolutions inside the EIBT.

Although specialized linear Paul traps have explored the benefits of cryogenic environments cooled by LN2 [4], conventional devices for buffer-gas cooling and bunching at RIB facilities operate at room temperature. As the emittance scales linearly with the "buffer gas temperature"[5], a compact, linear Paul trap with cryogenic cooling down to < 40 K is currently designed, to meet the emittance requirements at MIRACLS.

This presentation will introduce the MIRACLS concept, present the first results from a proof-of-principle experiment [6,7] and give an outlook to the design of a 30 keV EIBT including a cryogenic, linear Paul trap for optimal beam preparation.

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[2] P. Campbell et al., Prog. Part. and Nucl. Phys. 86, 127-180 (2016)
[3] S. Sels et al., Nucl. Inst. Meth. Phys. Res. Sec. B, ISSN 0168-583X (2019)
[4] S. Schwarz et al., Nucl. Inst. and Meth. in Phys. Res. Sec. A 816, 131 (2016)
[5] R. B. Moore et al., Phys. Scr. T59, 93 (1995)
[6] F.M. Maier et al. Hyperfine Interact. 240: 54 (2019)
[7] S. Lechner et al. Hyperfine Interact. 240: 95 (2019)

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Session Classification: Precision Measurements 2

Track Classification: Precision Measurements

Contribution ID: **45** Type: **Oral**

Cavity-Enhanced Ion-Ion Remote Entanglement

Wednesday 15 January 2020 14:30 (30 minutes)

Trapped ions are a promising platform for quantum information processing. However, it is difficult to scale up the number of qubits in a single trap. One potential scaling approach lies in building multiple traps and entangling ions from different traps through quantum channels. Such entanglement mediated by photons has been demonstrated experimentally. In this scheme, the polarization of each photon is entangled with the spin state of each ion. The two photons are then mixed by a beamsplitter to erase which-path information, followed by polarization-sensitive detection on the two output ports. Coincidence detection of the two photons projects the ion-photon state onto an ion-ion Bell state. However, this isotropic spontaneous emission has low capture probability due to the limited optical access offered in many ion traps, resulting in a very low entanglement rate (5 Hz is state-of-the-art [1]). One way to increase the photon collection efficiency is to couple the ion to a high-finesse optical cavity, which enhances photon emission into the cavity mode. Much work has been done towards the experimental demonstration of ion-cavity coupling, most of which use a cavity-enhanced Raman process in calcium to achieve ion-photon entanglement. The cavity-enhanced Raman scheme has the general advantage of coherent control, high photon collection, and detection efficiencies. However, no cavity-enhanced ion-ion remote entanglement has been shown. It is currently not clear whether the photons thus produced are suitable for mediating ion-ion entanglement.

We propose an ion-ion entanglement protocol based on a coherent Raman-cavity process similar to reference [2]. We choose $\mathrm{Sr}^{+}5D_{3/2}$, $m_J = 1/2, 3/2$ as the spin states, which are entangled with the polarizations of the cavity photon. The longer wavelength (1092 nm) of these photons makes cavity coupling easier as well as lying in the telecom band. We argue that the temporal-mode purity of the photon plays a crucial role in achieving high fidelity remote entanglement. Cavity photons generated by cavity-enhanced Raman scheme have imperfect temporal-mode purity due to the spontaneous decay of the intermediate state $\mathrm{Sr}^{+}5P_{1/2}$ to initial state $\mathrm{Sr}^{+}5S_{1/2}$. However, this spontaneous decay can be reduced by clever choices of the cavity parameters and the temporal shape of the Raman field. We model this process taking into account common experimental errors, such as Raman laser phase noise, Raman laser light path fluctuation, cavity mirror misalignment, photon light path fluctuation and detection time jitter. Our research has laid a theoretical foundation for achieving ion-ion remote entanglement with good fidelity and high entanglement rate. We designed a micro 3-D Paul trap integrated with micro-cavity and based on this model, we predict that with current mirror fabrication technology, ion-ion remote entanglement with a fidelity of 96% at a rate of 100 kHz may be achieved.

[1] D. Hucul, et.al., Nature Physics 11,37 EP (2014).
[2] A. Stute, et.al., Nature 485, 482 EP (2012).

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Session Classification: Quantum Information & Computing 2

Track Classification: Quantum Information & Computing

Contribution ID: **46** Type: **Oral**

Toward an experimental comparative study of the Doppler effect contribution between quadrupole and multipole traps

Thursday 16 January 2020 12:00 (30 minutes)

The trapping of charged particles by radiofrequency (RF) electric fields has proven to be both a powerful and versatile tool for experimental exploration in physics and chemistry and linear ion trap happen to be candidate of choice for the design of micro-wave atomic clock for spacecraft navigation [1]. The main factor limiting the stability of such clocks is the second order Doppler effect arising from the forced micro-motion of the ions in the RF confining field. From a theoretical point of view, this effect can be reduced by the use of higher order multipole traps. This has led to the crafting of multipole traps with an increased number of RF electrodes.

It is our objective to evaluate experimentally the interest of this trade-off between mechanical complexity and reduction of micro-motion induced Doppler effect, for no direct measurement of the reduction in the Doppler effect contribution by the use of higher order multipole trap has yet been done. Our experiment, TADOTI, is equipped to trap large cold Ca+ ion clouds. Shuttling of the ions is possible between a quadrupole section and an octupole section, making for an excellent ground for the comparison of both traps'properties.

The measurement of the Doppler Effect impact is to be conducted through the use of a 3-photon dark resonance in the Ca+ ion cloud. The coherent process leading to this dark line is obtained by taking a traditional Λ-shaped configuration and coupling on a weak transition to form a N-shaped system [2]. Coherent population trapping is achieved if a proper combination of detunings between the lasers is respected. When observed in the fluorescence of an ion cloud, this 3-photon resonance has a smaller linewidth than the natural fluorescence transition or the 2-photon dark resonance and gives (theoretically) full control over the Doppler effect, given a tight control of the relative phase of each laser.

The crafting itself of multipole traps has proven challenging. Experimental realisation of cold ion clouds in our octupole have shown surprising results: instead of the tube-like structure expected from the simulations, the ions organize themselves in three distinct clouds. This is the result from a symmetry breaking in the traps'electrode arrangement that split the degeneracy of the solutions into three minima in the pseudo-potential well in which the cold ions accumulate. The potential surface is very sensitive to any form of symmetry breaking and an electrode mechanical misplacement of about 0.2% of the trap inner radius is enough to observe the splitting [3]. It is crucial to diagnose and compensate any mechanical defect of the trap before any measurement can be considered in the octupole.

[1] Good, A. (2018, February 6). NASA Tests Atomic Clock for Deep Space Navigation. Retrieved from : https://www.jpl.nasa.gov/news/news.php?feature=7053
[2] M. Collombon et. al. "Experimental Demonstration of Three-Photon Coherent Population Trapping in an Ion Cloud."Physical Review Applied 12, 034035 (2019).
[3] J. Pedregosa-Gutierrez et. al. "Symmetry breaking in linear multipole traps". Journal of Modern Optics, 65:5-6, 529-537 (2018).

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Session Classification: Precision Measurements 3

Track Classification: Precision Measurements

Contribution ID: **48** Type: **Poster**

Trapped ^{171}Yb$^+$ ion for optical frequency metrology

By exploiting narrow optical transitions in trapped atoms, optical clocks have surpassed the frequency stability and accuracy of caesium microwave clocks, the current standard for the SI second, by up to two orders of magnitude [1]. With more progress on the horizon, it is anticipated that the SI second will soon be redefined in terms of an optical frequency standard [2].

For frequency metrology it is important to minimise systematic shifts of the transition frequency caused by external perturbations and to characterise their magnitude. In order to gain confidence in the performance of a clock, international measurement campaigns are regularly carried out to compare the frequencies of distant clocks through optical fibre links, verifying that they agree to within their measured uncertainties.

At the National Physical Laboratory (UK), we use a single ytterbium ion confined in an RF Paul end-cap trap [3] as an atomic frequency reference. This poster will present the advantages of using ^{171}Yb$^+$ and the properties that make it an ideal candidate for a precise frequency standard. Moreover, it will expand on the different types of systematic frequency shifts that need to be accounted for and their evaluation, leading to a total fractional uncertainty in the 10^{-18} range.

References:

[1] S. M. Brewer *et al.*, *Phys. Rev. Lett.*, 123, 033201, 2019.

[2] F. Riehle, *Comptes Rendus Physique*, 16(5), 506 –515, 2015.

[3] P. B. R. Nisbet-Jones, S. A. King, J. M. Jones *et al.*, *Appl. Phys. B*, 122, 57, 2016.

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Session Classification: Poster Session

Track Classification: Atomic Clocks

Contribution ID: **49** Type: **Oral**

High Fidelity Microwave Gates with Ca43

Thursday 16 January 2020 09:00 (30 minutes)

We present progress towards improved microwave driven quantum logic gate speeds and fidelities in a next-generation surface-electrode ion-trap.

Trapped ions are a leading candidate for building a general-purpose quantum computer [1]. As spontaneous emission is an incoherent process, good candidate qubits for such a device are separated by a dipole forbidden transition. Common choices are optical frequency electric-quadrupole transitions [2] and ground-state, hyperfine magnetic-dipole transitions in the microwave regime [3]. For both qubit choices, quantum logic operations are usually driven by lasers, achieving two-qubit entangling gate operation timescales of microseconds and fidelities exceeding 99.9%. However, laser driven quantum logic gates can only offer a limited fidelity due to photon scattering processes. As ion-trap quantum processors increase in size, coherent, individual addressing of qubits also becomes more challenging. Microwave driven logic gates between hyperfine qubits don't suffer from this fidelity limitation. In addition, microwaves can be easily integrated into microfabricated surface-traps which may simplify scalability requirements. Analogously to laser driven gates, microwave driven two-qubit logic gates rely on coupling the ion state to the ion-crystal motion. This can be achieved using far-field microwaves in combination with a strong static magnetic field gradient [4]. An alternative approach is to exploit near-field microwave interference to generate large amplitude gradients, which are determined by the electrode geometries [5, 6]. Operating in this near-field regime, we have previously realised two-qubit gates with $99.7(1)\%$ fidelity, approaching the state-of-the-art laser driven gate fidelities [7].

We present progress towards improving the state-of-the-art microwave driven two-qubit gate speed and fidelity. This is enabled through a novel qubit choice and an improved trap design. Operating at the 288 G hyperfine clock π-transition of $^{43}\mathrm{Ca}$ reduces spectator transition effects due to increased transition splittings. The trap is designed to produce a large magnetic field gradient whilst passively nulling the microwave field at the ions position. This design offers reduced off resonant excitation for a given two-qubit gate speed. Larger gradients are also facilitated by reducing the ion-electrode separation to 40 microns, half of our previous separation [7]. The reduced ion-electrode separation comes at the cost of increased electric field noise, which couples to the ions motion and hence is detrimental to gate fidelities. The trap is designed to suppress the motional heating rate by operating cryogenically at ˜20 K [8].

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Session Classification: Quantum Information & Computing 3

Track Classification: Quantum Information & Computing

Contribution ID: **50** Type: **Oral**

An ytterbium ion clock and its role in the search for dark matter

Monday 13 January 2020 11:30 (30 minutes)

Optical atomic clocks are amongst the most sensitive instruments ever to have been created. Although their only output is a stable frequency, their intense precision allows them to probe tiny effects at the edge of our understanding of physics. These devices measure the energy difference between two atomic energy levels by relating it to the frequency of light. In doing so, they create astonishingly accurate frequency references: the current state-of-the-art has an estimated fractional frequency uncertainty of 9.5×10^{-19} [1].

This ability to resolve even the tiniest effects means that optical atomic clocks have more applications than simply timekeeping: they are sensitive probes of our universe. The field of laboratory cosmology might sound unlikely but is emerging as a new frontier in physics [2]. As a fledgeling research area, its contributions will soon grow further, but already are substantial.

At NPL, a frequency standard based on the octupole transition of a trapped ytterbium ion is operated as an optical clock. The structure of $^{171}\mathrm{Yb}^{+}$ is particularly well-suited for tests of fundamental physics - the excitation of an electron from deep within the ion gives ytterbium the highest sensitivity to change in the fine-structure constant of optical clock candidate species currently in use, as well as an exceptional sensitivity to effects violating Lorentz symmetry [2,3].

In this work, we give an example of how a single ion of ytterbium can help us address questions about the universe's makeup. We briefly cover the design of our clock, and those features relevant to searches for change in the fine structure constant. We also present a recent collaboration amongst European partners where a network of clocks was used to search for transient variation in the fine structure constant, a proposed indicator of topological dark matter in the form of an ultralight boson field [4]. By operating six clocks simultaneously across three institutions over a month, constraints for this form of dark matter were extended over several orders of magnitude, particularly for transients of long duration [5].

[1] Brewer, S. M., et. al. (2019). Physical Review Letters, 123, 033201. DOI: 10.1103/PhysRevLett.123.033201
[2] Safronova, M. S., et. al. (2018). Reviews of Modern Physics, 90(2), 025008 DOI:10.1103/RevModPhys.90.025008
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[4] Derevianko, A., & Pospelov, M. (2014). Nature Physics, 10(12), 933–936. DOI:10.1038/nphys3137
[5] Roberts, B. M., et. al. (2019). arXiv:1907.02661

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Session Classification: Special Focus

Track Classification: Atomic Clocks

Contribution ID: **51** Type: **Hot Topic**

Using sympathetically laser cooled positrons for improved antihydrogen trapping

Wednesday 15 January 2020 12:15 (15 minutes)

The ALPHA colaboration has recently demonstrated laser and microwave spectroscopy of several different transitions in the antihydrogen atom. Since we typically trap around only twenty antihydrogen atoms per experimental cycle, in these experiments we choose to accumulate hundreds
of antihydrogen atoms over time scales ranging from tens of minutes to many hours in order to have
a sufficient number of antihydrogen atoms for a given measurement. These long experimental runs
limit the number of experiments that can be performed, especially due to our finite allocation of the antiproton beam.
To increase the rate of data aquisition, and potentially the precision of future spectroscopic measurements, we are currently working towards increasing the antihydrogen trapping rate. The positron temperature is thought to play a vital role in both the rate of antihydrogen formation, and
on the trapping rate of antihydrogen. Currently, positrons that we use for antihydrogen synthesis reach a temperature of around 30K. By lowering the positron temperature, significantly more antihydrogen atoms should be trapped.
We propose sympathetically cooling the positrons using laser cooled beryllium ions, 9Be+, a technique that has previously been demonstrated. Simulations in ALPHA have shown that the temperature of the positrons could potentially be reduced to less than 5K if cooling is maintained during antihydrogen formation. We have recently demonstrated trapping and laser cooling of beryllium ions, using an ion source which was designed to operate under the significant constraints imposed by the ALPHA apparatus. We are currently performing experiments where we mix the laser cooled ions with positrons and will present our latest results towards sympathetic cooling.

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Presenter: JONES, Jack Mccauley (Swansea University (GB))

Session Classification: Antimatter 1

Track Classification: Antimatter

Contribution ID: **52** Type: **Poster**

High fidelity microwave driven quantum logic for a scalable trapped ion quantum computing architecture

We report on a new experiment to demonstrate high-fidelity quantum logic operations, towards a scalable quantum computing architecture, based on designs put forth by Lekitsch et al.[1]. To realise the scalability conditions per reference [1], micro-fabricated, surface ion traps are required to create a modular, planar array on which quantum computation can be carried out. This approach requires the use of microwave fields and a magnetic field gradient for quantum state manipulation. The magnetic field gradient provides sufficient coupling through phonon modes in the ion trap to achieve multi-qubit gates [2]. A high two-qubit gate fidelity is required to make a quantum computer sufficiently fault tolerant to be practical and scalable. Gate fidelity can be improved by cooling the ion and minimising environmental noise which causes qubit decoherence [3]. Cryogenically cooling the ion traps to minimise anomalous heating and incorporating sympathetic cooling by a second ion species should improve gate fidelity [1,4].

We present experimental progress and plans. The experiment incorporates a micro-fabricated, surface ion trap and aims to demonstrate a two-qubit gate using a microwave field scheme mediated by a magnetic field gradient. A two qubit gate operation will be demonstrated by applying microwave fields to trapped Ytterbium, $^{171}\mathrm{Yb}^{+}$. A strong magnetic field gradient, with a simulated magnitude of 140 Tm^{-1}, is created by permanent magnets mounted under the chip. The strong magnetic field gradient will allow high-speed quantum state manipulation to achieve a quantum gate fidelity above the fault tolerant threshold; a requirement to realise practical, scalable quantum computing [1]. The microwave fields are applied via in-vacuum antennae, which significantly improves interaction strength due to the high field density near the ion. The system incorporates atomic ovens for providing two atomic species. $^{171}\mathrm{Yb}^{+}$, will serve as the qubit via the hyperfine splitting of the electronic ground state. A Barium oven is incorporated to demonstrate sympathetically cooling $^{171}\mathrm{Yb}^{+}$ by laser cooling Barium, $^{138}\mathrm{Ba}^{+}$ in the trap. The system includes an in-vacuum heat exchanger connected to a pressurised Helium cryogenic system for cooling the chip below 50 K, to reduce anomalous heating and improve gate fidelity [3].

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Session Classification: Poster Session

Track Classification: Quantum Information & Computing

Contribution ID: **53** Type: **Oral**

Sub-microsecond entangling gate between trapped ions via Rydberg interaction

Tuesday 14 January 2020 11:00 (30 minutes)

Trapped Rydberg ions are a novel approach for quantum information processing [1]. By combining the high degree of control of trapped ion systems with the long-range dipolar interactions of Rydberg atoms [2], fast entanglement gates may be realized in large ion crystals [1,3].

Quantum information processing in such a system uses low-lying electronic states for storage of qubits and strongly interacting Rydberg states for entanglement operations. In our experiment, we trap 88Sr+ ions and excite them to Rydberg states using two UV laser fields [4]. We have observed coherent phenomena during excitation of Rydberg ions, including Rabi oscillations and stimulated Raman adiabatic passage (STIRAP). We have also carried out a single-qubit Rydberg phase gate [5].

Due to the higher core charge the van-der-Waals interaction between Rydberg ions is much weaker than for neutral atoms. Therefore, interactions between Rydberg ions rely upon microwave (MW) fields to induce large dipole moments in the Rydberg ions. Utilizing such MW-dressed Rydberg states we recently realized the first two-ion entangling gate via Rydberg interaction with a gate fidelity of 78% and a gate time of 700ns [6]. Furthermore, MW-dressing allows for the creation of Rydberg states with zero polarizability, thus mitigating the otherwise considerable large mechanical forces and resulting energy shifts affecting bare Rydberg states [7]. This may be crucial for implementing fast two-ion entangling gates in large or even multidimensional ion crystals. We recently realized Rydberg states with vanishing polarizability, observed negligible energy shifts even in presence of excess micro-motion and performed Rabi oscillations between low-lying electronic states and zero-polarizability Rydberg states without the implementation of sideband cooling.

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Session Classification: Quantum Simulation & Technology

Track Classification: Quantum Simulation

Contribution ID: **54** Type: **Poster**

Developing a multi-qubit gate zone for use in a large scale ion shuttling architecture

The field of quantum computing with trapped ions has seen many milestone achievements, the challenge for the future lies in scaling ion processors to qubit numbers capable of tackling interesting problems –without forgoing the high fidelities seen in smaller prototypes. One class of large-scale ion trapping architecture comprises dedicated regions for trapping, measurement, storage and interaction between the qubits, combined with the ability to shuttle ions between regions.

We encode qubits in the hyperfine ground state manifold of trapped Yb+171 ions. Quantum control utilises global microwave fields provided via in-vacuum antennae and a static magnetic field gradient [1]. Ions are off resonant with the global fields until shuttled to interaction zones at designated positions in the gradient, altering their Zeeman splitting accordingly. In addition to providing individual qubit addressability, the magnetic field gradient couples the spin and motional degrees of freedom of the ions, allowing use of the motional state as a quantum bus. The strength of the gradient dictates the strength of the spin-motion coupling, which further determines the speed and fidelity of quantum gates. The microwave scheme seeks to address some of the challenges associated with scaling up laser-based schemes, only a fixed number of global fields are required independent of system size in contrast to a number of lasers that scales with the qubit number. In addition the scheme benefits from the relative maturity of commercially available microwave technology.

Previous work has relied on permanent precisely aligned magnets to produce the required magnetic field gradient for the microwave gate scheme. We seek to create a strong on-chip gradient utilising wires beneath the chip surface, which would allow the gradient to be switched on and off, not possible with permanent magnets. Without switching of the gradient idle ions must be shuttled through regions of large magnetic field, rendering them susceptible to dephasing –problematic for realizing quantum algorithms. Furthermore, the buried wire layer can be incorporated as a step in chip production using standard micro-fabrication processes, suitable for use in large-scale ion trap arrays.
We present work towards realising a multi-qubit 'interaction'region, designed to be easily integrated as a repeating unit in micro-fabricated ion trapping chips, in line with the road map to a large-scale quantum computer as outlined in [2].

[1] S.Weidt et al. Phys. Rev. Lett. 117, 220501 (2016)
[2] Bjoern Lekitsch et al. Science Advances 3.2 (2017)

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Session Classification: Poster Session

Track Classification: Quantum Information & Computing

Contribution ID: **55** Type: **Oral**

A modular approach to a shuttling-based quantum processor in a 2D trap array

Wednesday 15 January 2020 15:00 (30 minutes)

Trapped ion qubits achieve excellent coherence times and gate fidelities, well below the threshold for fault tolerant quantum error correction. A key challenge now is to scale ion quantum processors to the large number of qubits required for error-corrected algorithms to run. We present progress on the implementation of high fidelity ion qubits in a modular architecture designed for true scalability, based on robust microwave-driven quantum gates and physical shuttling of ion qubits. [1]

We describe an X-junction surface ion trap, made using industrial silicon microfabrication techniques. The multi-arm geometry permits dedicated operational zones, optimised for ion loading, memory, entangling interactions and readout, and also permits 2-dimensional ion transport as required by the surface code error-correction scheme. [2]

Qubits are defined in the internal hyperfine states of the 171Yb+ ion. We utilise different qubit representations within the four natural spin states defined by the electron and nuclear spins, performing readout based on natural state dependent fluorescence and also dressing the states to engineer an artificial clock-like qubit less sensitive to environmental noise. [3]

Entanglement is generated by modulating the Coulomb interaction between ion pairs in a strong magnetic field gradient. Driving the spin-motion entangling (Molmer-Sorenen) gate directly with global AC magnetic fields rather than using locally focussed laser excitation relives much of the complexity in laser engineering found in traditional ion trap processors based on optical transitions. [4]

We outline progress in dynamically generating the strong magnetic field gradients used for entanglement generation, using switchable currents through microfabricated coils embedded locally within the trap substrate. This integrated strategy facilitates ion transport within our architecture despite strong field gradients, but also necessitates careful management of the heat dissipated on-chip.

Our modular architecture deliberately avoids photonic interconnects, and instead takes advantage of the inherent mobility of trapped-ion qubits to achieve the large-scale entanglement required for fault-tolerant quantum computing.

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Session Classification: Quantum Information & Computing 2

Track Classification: Quantum Information & Computing

Contribution ID: **56** Type: **Oral**

Benchmarking high-fidelity mixed-species entangling gates

Thursday 16 January 2020 10:00 (30 minutes)

The simultaneous trapping of two different species of ion allows the manipulation of one species without corruption of the electronic state of the other. Mixed-species systems therefore provide access to powerful tools such as sympathetic cooling and low cross-talk or quantum non-demolition measurement [1]. A high-fidelity entangling gate between two species offers the freedom to select ions with desirable properties for different tasks, and to transfer information from one to the other depending on the task at hand. Such a gate is an essential element in quantum logic spectroscopy [2], quantum networking [3] and quantum information processing.

In particular, $^{43}Ca^{+}$ and $^{88}Sr^{+}$ are well-suited for different aspects of quantum computing. Due to the transition frequencies in these two species, a two-qubit $\sigma_z \otimes \sigma_z$ gate [4] may be driven on both species simultaneously using a single pair of Raman beams, derived from a single frequency-doubled Ti:Sapphire laser. I present such a gate with fidelity 99.8(2)%, pushing mixed-species gate fidelities close to the best single-species entangling gates (99.9(1)% [5,6]). We use different methods to perform a full characterisation of this gate: with two-qubit randomised benchmarking we measure a fidelity of 99.72(6)% (99.60(5)%) with sequences involving up to 75 (125) entangling gates (or 30 (50) interleaved entangling gates). From gateset tomography we deduce a fidelity of 99.4(4)% for the two-qubit operations.

I further present progress towards a comparison of the $\sigma_z \otimes \sigma_z$ gate with a Mølmer-Sørensen gate [7] on the same mixed-species crystal.

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Session Classification: Quantum Information & Computing 3

Track Classification: Quantum Information & Computing

Contribution ID: **57** Type: **Oral**

Development of a portable optical atomic clock based on a single Ca+ ion

Tuesday 14 January 2020 10:00 (30 minutes)

Optical clocks are the most accurate time keeping instruments to date. However, widespread use is being prevented by their large size, high cost and high technical complexity of operation. To overcome these hindrances we are developing a compact, turn-key-operation portable optical clock based on trapped single Ca^+ ions. The system fits in a 4 unit 19 inch module box (500x520x160 mm), with a target weight under 20 kg and a target power consumption under 100 W. The expected fractional uncertainty of our system is ~10^{-16}.
The miniaturisation of the system is made possible by recent developments in optical fibres and optical fibre components. A fibre based compact laser system provides all the necessary frequencies to ionise and laser-cool a Ca^+ ion, which sits inside an endcap Paul trap. Light is delivered onto the ion via polarisation maintaining optical fibres, which make their way into the vacuum chamber eliminating the need for windows. Fluorescence from the ion is collected directly using multimode fibres embedded inside the trap electrode structure, eliminating the need for bulky high NA lenses. The reference laser is stabilised to an ultra-stable optical cavity developed at NPL, and then locked to the Ca^+ quadrupole transition at 729 nm. On-board electronics controlling the various subsystems will provide the necessary intelligence to run the system autonomously, making it a "black box"from the user's perspective. We believe this approach will make our system suitable for integration in a wide variety of environments.

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Session Classification: Atomic Clocks

Track Classification: Atomic Clocks

Contribution ID: **58** Type: **Poster**

Constructing a modular microwave trapped ion quantum computer prototype

Trapped ions are a promising tool for building a large scale quantum computer. We present work towards a prototype demonstrating the key methods required to realise a scalable trapped-ion quantum computer architecture based on tileable, repeating modules [1].

To find practical applications, quantum computers need to scale significantly. A quantum computing architecture is best constructed in a modular way, where each future stand-alone unit incorporates a large number of zones for state preparation, entanglement and detection and is connected to other modules to execute quantum algorithms. Ion transport operations relying on the precise and synchronised delivery of voltages to DC electrodes is used to transfer the ion qubit between zones and connect arbitrarily many module.

At the centre of this scheme, high-fidelity single and two qubit-gates are realised via the interaction of our trapped ions with global microwaves and RF radiations combined with a local magnetic fields [2].

In our demonstrator device being constructed, embedded current-carrying wires within the substrate of a 2D surface-trap will generate a large local magnetic field gradient, which drives the entanglement between designated pairs of ions. We present the successful fabrication of current-carrying copper microstructures into a silicon substrate. We have successfully applied a current density >106 A/cm2 equating to a gradient exceeding 185 T/m. Ion traps can now be fabricated on top of such a structure for full integration.

To allow for the distribution and reconfiguration of our ion qubit ensemble within and in-between modules, we present the development and fabrication of a single X-junction surface ion trap module as well as a method for preparing well-defined module edges which paves the way towards coherent module-to-module shuttling of ion qubits. We measure alignment control capability between surface ion traps of <10 µm in the planar directions and 15 µm within the vertical direction using piezo actuators.

Finally, to reduce the ion motional heating rate and to efficiently dissipate heat away from the module, the system is best operated at 60K. We present the operation and characterisation of a scalable closed-loop circulating helium gas cryostat capable of independently cooling multiple ion trapping experiments [3].

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Session Classification: Poster Session

Track Classification: Quantum Information & Computing

Contribution ID: **59** Type: **Poster**

Towards high-resolution spectroscopy of N_2^+

High resolution spectroscopy of molecular nitrogen ions is a prime candidate to measure potential temporal changes in the proton-to-electron mass ratio, μ [1].
Ion traps facilitate a high degree of localisation in a highly isolated and stable environment. In addition, the shared motional modes of ions co-trapped in the same potential enable techniques such as sympathetic cooling [2] and quantum logic spectroscopy [3]. These techniques allow cooling and read-out of the internal state of a molecular ion, provided a suitable auxiliary ion can be found.
In this experiment, a single $^{14}N_2^+$ ion will be co-trapped, in a linear Paul trap, with a $^{40}Ca^+$ ion which will act as a frequency reference and be used for the sympathetic cooling and state detection of the nitrogen ion. A vibrational Raman transition in the electronic ground state of $^{14}N_2^+$ will be compared to a quadrupole transition in the $^{40}Ca^+$ ion. After excitation, the state of the $^{14}N_2^+$ ion will be transferred to the $^{40}Ca^+$ ion via the shared motion of the ions in a quantum logic spectroscopy scheme.
Prerequisite to this are the preparation of $^{14}N_2^+$ into a specific rovibronic state and its non-destructive state detection. Recently, a 2+1'resonance-enhanced multiphoton ionisation (REMPI) scheme was developed, using the $a^1\Sigma_g(\nu=6) \leftarrow X^1\Sigma_g^+(\nu=0)$ band in $^{14}N_2$ for the resonant excitation. This scheme was demonstrated to prepare $^{14}N_2^+$ in the rovibronic ground state with high purity [4].

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Keywords: high resolution spectroscopy, REMPI, molecular ions

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Session Classification: Poster Session

Track Classification: Atomic Clocks

Contribution ID: **60** Type: **Poster**

An optimised, end-cap style Paul trap for high-precision optical frequency metrology

Optical atomic frequency standards and clocks are continuing to push the boundaries of precision measurement with fractional frequency uncertainties from systematic offsets now below $1\text{x}10^{-18}$ [1]. With this high level of performance comes the ability to not only carry out precision frequency metrology [2] but also to investigate fundamental physics such as local Lorentz invariance [3] and to perform searches for dark matter [4,5]. Additionally, the anticipated redefinition of the SI second, which is expected to be based on an optical frequency, makes this a particularly exciting time for frequency metrologists.

At the National Physical Laboratory (NPL) in the UK we have constructed an optical frequency standard based on a single $^{171}\text{Yb}^{+}$ ion tightly confined in space by an end-cap style Paul trap [6]. We will describe our current generation trap and experimental apparatus focussing on the trap design, which we determine to contribute only a $0.5\text{x}10^{-18}$ fractional uncertainty to the clock uncertainty budget. We will also present our new generation of ion trap currently under construction. Based largely on the previous design but with some significant upgrades, this trap provides a highly controllable environment, as well as excellent optical access for probing the ion.

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Session Classification: Poster Session

Track Classification: Atomic Clocks

Contribution ID: **61** Type: **Poster**

Gravity vector detection by extended orbits of trapped charged microobjects

Introduction: In the present, RF traps for charged particles containment get a widespread use as a tool for work with single particles, like spores [1]. Wherein trapping of the particle can occur in a vacuum and in a medium, which more suitable for biological and medical research [2]. The motion in dissipative medium gets special role in studying charged particle's trajectories, because path's configuration carries information not only of a confined particle (for example particle size or particle shape), but also of the physical characteristics of the medium [3]. One of the manifestation of atypical particle dynamics are so-called extended orbits (similar to ZC-orbits in a linear ion trap under linear friction [2]). The formation of extended orbits significantly depends on unneutralized gravity. **Methods:** Paul's radiofrequency trap is designed with a single AC voltage toroidal electrode with a mechanical rotational degree of freedom ϕ for experimental studying of influence of the gravity projection g_{eff}. Dried spores Lycopodium Clavatum with a characteristic size of $= 32 \pm 2$ µm were used as a confined particle. Secular motion of particle is absent because of dissipative terms presence in motion equations, thus the particle oscillation frequency is determined by the RF field frequency $\Omega = 50$Hz. Effect of the period doubling occurs with increasing voltage and the frequency of the particle decreases to $\Omega/2$ in the radial direction. An orbit of the localized particle is symmetric at the tilt angle $\phi = \pi/2$. Asymmetry of the orbit is observed with a gradual change of the tilt angle of the electrode. The extended orbit shape caused by tilt angle of the ring electrode relative to the gravity vector g_{eff} and is uniquely defined as $\phi = \arcsin(R_1/R_2)$, where R_1 and R_2 are the lengths of the arms of orbit measured from the «nodal point» of the extended orbit. **Results:** A significant difference between the formation of extended orbits and localization in linear traps was obtained and the distinctive features of the formation of extended orbits in Paul trap were studied. A direct dependence of the numerical characteristic of the asymmetry of the orbits on the value of the tilt angle ϕ is shown. **Discussion:** The maximum resolving power for this trap configuration is 11 arc minutes with a laser $\lambda = 532$ nm. This resolution is not limiting and depends on the laser wavelength, particles and orbit size and can reach angular seconds. The proposed estimates bear testimony to the possibility of using method as a gravity anomaly detector by observing the deviation of the gravity vector.

Reference list:

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Session Classification: Poster Session

Track Classification: Precision Measurements

Contribution ID: **62** Type: **Oral**

Photon-recoil assisted rovibrational spectroscopy of the ^{24}MgH^{+} ion

Monday 13 January 2020 15:00 (30 minutes)

Precision spectroscopy of molecules promises a wealth of interesting applications e.g. for better determination of natural constants, for tests of fundamental particle theories, and for qubit realizations. Unfortunately, most molecules do not possess closed transitions for laser cooling, crucial for obtaining temperatures low enough for exploiting this novel realm of physics.
A way to circumvent this issue is to work with a trapped molecular ion, and sympathetically cool its translational degrees of freedom by Coulomb interaction with a co-trapped atomic ion possessing suitable transitions for laser cooling. Doppler laser cooling will lead to the formation of a two-ion Coulomb crystal, which can then be prepared in the ground state of motion via the sideband cooling technique.
Having prepared this system, it is possible to detect a change of the internal state of the molecular ion by monitoring the common motional state on the cooling ion, a technique called quantum logic spectroscopy (QLS), first proposed by Schmidt et al. [1]. In our group, an extension of QLS called photon-recoil spectroscopy (PRS) [2], where the target ion absorbs more than one photon, is used. So far we have successfully performed PRS of a dipolar transition in the atomic ion ^{24}Mg^{+} of 280 nm, to verify that the technique works. The light-ion interaction has been modeled by rate equations, and my simulations are in good agreement with our experimental results [3].
The next goal is to perform PRS on the closed rovibrational transition v = 0, J = 1 $\leftrightarrow$ v = 1, J = 0 in ^{24}MgH^{+} of 6.17 μm, to show the applicability to transitions resulting in very low photon recoil. We have so far modeled this system and produced simulated spectra as guidelines for the ongoing experiments.
The ultimate goal is to drive purely rotational transitions in ^{24}MgH^{+}, with energy splittings in the THz range, resulting in photon recoil too low for detection by PRS. The solution is to drive Raman transitions with counter-propagating laser beams, since the effective k-vector is then given by the difference of the two k-vectors driving the transition: $\vec{k}_{Raman} = \vec{k}_1 - \vec{k}_2 \approx 2\vec{k}_1$.
The ideal choice of laser for this is a femtosecond frequency comb for two reasons: 1) $\vec{k}_{Raman}$ can be made up of any two k-vectors with the right frequency difference, hence the different teeth of the comb can all work in pairs to drive the transition, and the full power of the comb is exploited. 2) The frequency difference between the teeth is easily changed by tuning the repetition rate, making the comb extremely versatile: Any transition within the spectral bandwidth of the comb ($\sim$ 8 THz) can be driven.
Frequency comb driven Raman transitions of 1.8 THz between D-finestructure levels in ^{40}Ca^{+} has recently been demonstrated in our group [4], laying a strong foundation for the future ^{24}MgH^{+} experiments.

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Session Classification: Precision Measurements 1

Track Classification: Precision Measurements

Contribution ID: **63** Type: **Oral**

Ion transport simulations, recent hardware upgrade and current status of TITAN's cooler Penning trap

Wednesday 15 January 2020 10:00 (30 minutes)

Atomic mass measurements are vital to improve our understanding of the nuclear structure, astrophysical reaction paths, and test predictions of physics beyond Standard model. The measurement Penning trap at TRIUMF's Ion Trap for Atomic and Nuclear science (TITAN) facility is dedicated to performing high-precision mass measurements of short-lived radioactive isotopes. With the availability of highly charged ions produced in the TITAN electron beam ion trap, the sub-ppb mass measurement precision can be improved by an order of magnitude or more. The charge breeding, however, introduces an energy spread that can cause additional challenges to these mass measurements.

With TITAN's cooler Penning trap (CPET), we intend to further improve the precision by sympathetically cooling these highly charged ions with room temperature electron plasma in order to reduce the energy spread from a few 10 eV/q to 1 eV/q. Ion injection and extraction simulations were performed with the SIMION package to optimize the operational conditions of the off-line/development setup and for guiding the integration into the on-line setup. Transmission efficiency and the transversal and longitudinal emittance of the ion beam were found to be sensitive to the trap axial potential, extraction potential and the length of the ion beam. Upgrades motivated by the simulation results were performed to increase the efficiency of ion/electron transmission and trapping. Successful co-trapping of electrons and ions in the TITAN CPET was demonstrated for the first time including the verification of self-cooling of the electrons. We present the simulation results, current status of the trap and our approach towards achieving cooling of highly charged ions with electron plasma.

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Session Classification: Precision Measurements 2

Track Classification: Precision Measurements

Contribution ID: **64** Type: **Oral**

Non-destructive detection of molecules without mass limitation

Thursday 16 January 2020 11:30 (30 minutes)

Our project is aimed at using a laser-cooled trapped ion cloud as a detector for very heavy molecules. The basic principle is to propel a heavy molecular ion with a low charge through an ion cloud while monitoring the fluorescence of the latter. Current techniques have many disadvantages we propose to overcome. While current detection techniques for giant molecules are limited to relatively low mass-to-charge ratios, the high sensitivity of this technique allows detection in cases where the quantity of available sample is very small or when samples are not highly charged.

Numerical simulations using experimentally-accessible parameters predict that it is possible to detect individual, singly-charged molecular ions of unlimited mass using this method. An experimental proof-of-concept set-up is currently under construction. It is based on three elements. Heavy molecular ions are produced with an electrospray source, then guided with electrostatic fields through a $^{40}Ca^{+}$ ion-cloud, i.e our "sensor". This cloud is laser-cooled and trapped in a linear quadrupole Paul trap. Then the fluorescence is monitored and the detection signal is expected to appear in the change in fluorescence intensity due to Doppler effect. Thus the quality of the detection depends on the amplitude and duration of the perturbation of the ion cloud by the giant molecule.

In order to achieve high sensitivity we need to optimize a variety of parameters, including the trapping potential, laser-cooling conditions, and cloud size. The energy of the molecular ion and its trajectory in the cloud must also be well constrained. With both the sensitivity and the operation range of the detector depending on these key parameters, the main goal of our current work is their characterization.

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Session Classification: Precision Measurements 3

Track Classification: Precision Measurements

Contribution ID: **65** Type: **Oral**

Novel quantum computing architectures with Barium ions

Tuesday 14 January 2020 11:30 (30 minutes)

With solely visible and near-infrared wavelength fine-structure transitions, and isotopes with diverse nuclear spins, Barium makes an ideal candidate for developing novel quantum computing architectures. I will present our designs for a versatile and open-access quantum computer which leverages these favorable features of Barium. The visible and near-infrared wavelengths allows for the use of fibre and integrated optic technologies which increases the mechanical stability of the optical systems required to prepare laser light for interfacing with a chain of trapped Barium ions. The Raman beams for manipulating the hyperfine states are at a wavelength of 532 nm and I will present a design based on femtosecond laser direct-written waveguides and fibre-based AOMs for preparing a set of 16 individually controlled Raman beams at the ion positions. The chains of isotopically pure $^{133}Ba^{+}$ ions will be loaded using laser ablation, and I will present preliminary loading statistics from laser ablating barium chloride towards our final goal of isotope selective loading of Barium ions. The quantum computer will be enabled by an advanced control system based on a set of tightly coupled FPGA boards. The control system will parse remote commands by a user and translate them into trapped ion experimental sequences, while maintaining the stability and calibration of the system. This will allow for members of the research community to access an advanced ion trap set up, decreasing barriers to testing of new theoretical protocols.
The spin-3/2 nucleus of $^{137}Ba^{+}$ provides an ideal testbed for exploring higher dimensional quantum logic in trapped ions. Typically, hyperfine states of the $S_{1/2}$ manifold are used to encode qubit states, and efforts are taken to prevent population of the other states. We propose using these additional hyperfine states to store *qudits*. Using the known error sources from qubit manipulations in trapped ions, we have quantified the realistic, expected fidelities for universal qudit quantum computation with trapped Barium ions [1]. I will outline modified protocols for state preparation, single-qudit gates, two-qudit gates, and measurements. For qutrits we calculate that expected fidelities are all above the 99.25% fault tolerance threshold. Five level qudits have >99% fidelities, with the exception of two-qudit gate fidelities being reduced by undesired couplings to other hyperfine states. We expect these reduced two-qudit gate fidelities could be improved using a different encoding or entangling scheme and are not a fundamental limitation.

[1] Low, Pei Jiang, et al. "Practical trapped-ion protocols for universal qudit-based quantum computing." arXiv preprint arXiv:1907.08569 (2019).

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Session Classification: Quantum Simulation & Technology

Track Classification: Quantum Simulation

Contribution ID: **67** Type: **Poster**

Symmetry breaking in a four-bar multipole trap

Octupole and other multipole ion traps are widely used as precision devices for ion transport and localization. In particular, octupole ion guides have found application in particle accelerators, the Orbitrap mass analyzer, and other complex setups. The multipole field is formed in a standard fashion as in a quadrupole Paul trap design, but with additional electrodes. In both quadrupole traps and multipole traps, voltages are applied with different phases on neighboring electrodes: 0 and π, respectively [1]. It should be noted that this scheme is a universal one, and the description of the electrostatic field in the trap in terms of harmonic polynomials applies in all of its manifestations [2, 3]. At the same time, the electrostatic field depends on many factors, for example, the electrode geometry [4, 5], the modulation of the radio-frequency voltage applied to the electrodes [6], and the spatial positions of the electrodes [7, 8]. Even a small change, to the in-phase voltage, for example, can lead to significant deformation of the effective potential from a quadratic form. In this case, we still retain the condition of a sign-alternating voltage, so that the equations of motion will satisfy Earnshaw's theorem, but the stability of localization is no longer obvious, and additional research on this topic is required.
In our work, we show that a real in-phase trap creates a quasi-octupole effective potential with symmetry breaking. The existence of three stability points is confirmed. We design and construct a prototype of the proposed trap, and experimental results obtained on localization confirm our theoretical results. The obtained result can be useful in the high-precision measurements both mass-spectrometry and other applications.

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[8] J. Pedregosa-Gutierrez, C. Champenois, M. Kamsap, G. Hagel, M. Houssin, M. Knoop, Journal of Modern Optics 65 (5-6) (2018) 529–537

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Session Classification: Poster Session

Track Classification: Precision Measurements

Contribution ID: **68** Type: **Poster**

Progress towards realization of an optical frequency standard using trapped Ba+ ions

We aim at realization of an optical frequency standard with barium ion (Ba^+). The $^2S_{1/2}$ $(F = 2, m_F = 0)$ - $^2D_{3/2}$ $(F = 0, m_F = 0)$ clock transition in odd isotopes $^{135}Ba^+$ or $^{137}Ba^+$ is insensitive to quadrupole electric field[1]. Therefore, it is possible to improve the frequency stability by increase of the number of ions without degradation of uncertainty.

As a first step, we are developing an optical clock referenced to the $^2S_{1/2}$ - $^2D_{5/2}$ transition at 1.76 μm in $^{138}Ba^+$ ions[2-5]. So far, we conducted single-ion spectroscopy of the clock transition using a linenarrowed external-cavity laser diode (ECLD) and resolved motional sidebands [6]. To accelerate the detection of the spectra of the clock transition, we employed deexcitation of the $^2D_{3/2}$ state owing to its long lifetime of 31 s. We first drove the $^2D_{5/2}$ - $^2P_{3/2}$ transition at 614 nm by irradiating with radiation from an orange LED. The deexcitation rate was measured to be ⊠ 10 s. Then, we irradiated with radiation around 614 nm from an optical frequency comb (OCF) based on a Yb:KYW laser[6] to further accelerate the deexcitation. We estimated the deexcitation time to be 200 ms, where the optical power in 30-nm bandwidth was 40 μW. This is a similar approach to use of an amplified spontaneous-emission in a Yb-doped fiber amplifier for deexcitation of the $^2D_{5/2}$ state in Sr^+ ions[8].

We also succeeded in laser cooling of single $^{137}Ba^+$ ions loaded through odd-isotope-selective photoionization[9]. We employ two-step photoionization of Ba atoms using the $^1S_0$ - $^1P_1$ transition at 553 nm as the first excitation. Ba atoms in the $^1P_1$ state is further excited using the second radiation above the ionization potential. Radiation at 553 nm is generated using a frequency-doubled ECLD and the second radiation is generated from a laser diode (LD) at 396 nm. Radiation for the first excitation is blue-detuned by 500 MHz from the absorption line of $^{138}Ba^+$ ions. We laser cooled $^{137}Ba^+$ ions by driving the $^2S_{1/2}$ - $^2P_{1/2}$ transition using two frequency-doubled ECLDs at 493 nm to avoid optical pumping in the hyperfine structures. We simultaneously drove the $^2D_{3/2}$ - $^2P_{1/2}$ transition using three ECLDs at 650 nm. We detected the fluorescence of a photon counting rate of 700 s^{-1} for a $^{137}Ba^+$ ion.

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Session Classification: Poster Session

Track Classification: Atomic Clocks

Contribution ID: **70** Type: **Oral**

Accumulation of positrons from a linac based source

Thursday 16 January 2020 15:30 (30 minutes)

The aim of the GBAR experiment is to measure the effect of gravity on antihydrogen atoms [1]. Those are created by interactions of antiprotons with a dense positronium cloud. The antiprotons are obtained from the decelerator complex at CERN now composed of two steps: the Antiproton Decelerator, in which the beam reaches 5 MeV energy, and ELENA where it is further decelerated to 100 keV. Positronium (Ps) is obtained by implantation of 4 keV positrons onto a mesoporous silica film. The goal is to obtain a cloud of the order of 10ˆ10 positrons. In order to obtain the necessary intense positron beam, a 9 MeV linac, accelerates electrons toward a tungsten target equipped with a mesh moderator. The resulting slow positron beam is then transported to a buffer gas trap where particles are cooled by interaction with nitrogen and CO2 and accumulated in a 5T multi-ring Penning-Malmberg trap.
We present the performances of trapping and accumulation of positrons.

[1] P. Pérez et al., Hyperfine interaction 223,21 (2015)

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Session Classification: Antimatter 2

Track Classification: Antimatter

Contribution ID: **72** Type: **Oral**

Ultra-High Precision Measurements of the Proton-to-Antiproton Charge-to-Mass Ratio

Monday 13 January 2020 12:00 (30 minutes)

The BASE collaboration, situated at CERN's Antiproton Decelerator facility, uses Penning traps to test the Charge-Parity-Time (CPT) symmetry by measuring the fundamental properties of protons and antiprotons to ultra-high precision [1].

One such property which can be directly measured in Penning traps is the proton-to-antiproton charge-to-mass ratio, $(q/m_{\mathrm{p}})\,/\,(q/m_{\bar{\mathrm{p}}})$. Here, the free-cyclotron frequency, $\omega_c = qB_0/m_{\bar{\mathrm{p}},\mathrm{H}^-}$, of both $\bar{\mathrm{p}}$ and H^- are compared –with the H^- serving as a proxy for the proton. ω_c is determined by measuirng the three eigen-frequencies, $\omega_{-,z,+}$, of the trapped particle and applying an invariance theorem; $\omega_c^2 = \omega_-^2 + \omega_z^2 + \omega_+^2$. The BASE collaboration has previously measured this quantity to a precision of 69 ppt [4]. This result is consistent with CPT invariance. The proton-to-antiproton charge-to-mass ratio also serves as a test of the weak equivalence principle and can be used to constrain the gravitational anomaly parameter, α_g. The BASE collaboration has constrained this parameter to $|\alpha_g - 1| < 8.7 \times 10^{-7}$ in the case of baryonic matter.

During the current measurement campaign performed by BASE, several technical and methodological improvements have recently been made. The implementation of a new superconducting modified-cyclotron frequency detection system allows direct measurements of ω_+, for both $\bar{\mathrm{p}}$ and H^-. This contrasts with previous measurements where ω_+ is measured indirectly by coupling axial and modified-cyclotron modes [4]. The addition of a resonance-frequency tuneable circuit to the axial detection system, in conjunction with significant improvement to the magnetic field homogeneity, has eliminated the principal systematic error of the previous 69 ppt result [4]. These new implementations allow the 69 ppt CPT invariance test to be improved upon, and measuring the proton-to-antiproton charge-to-mass ratio at different points in the sidereal year allow improved constraints on the gravitational anomaly parameter.

In this talk preliminary results of the recent proton-to-antiproton charge-to-mass ratio charge to mass ratio campaign will be presented, along with details of the methodologies and improvements used to achieve them.

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[3] C. Smorra et al., Nature, 550, (2017), 371-374

[4] S. Ulmer et al., Nature, 524, (2015), 196-199

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Session Classification: Special Focus

Track Classification: Antimatter

Contribution ID: **73** Type: **Hot Topic**

Hybrid quantum systems of ultracold atoms and ions

Tuesday 14 January 2020 12:15 (15 minutes)

Ultracold atoms and trapped ions are among the most studied physical systems in experimental quantum physics. On the one hand, ultracold neutral atoms form coherent ensembles of a great number of particles whose interactions, dimensionality and motion can be precisely controlled by well-established techniques. On the other hand, trapped ions constitute smaller samples that can be efficiently confined for long periods of time. Due to Coulomb repulsion, trapped ions crystallize in spatially well-separated structures, hence granting the possibility of detecting and addressing a single ion more easily with respect to neutral atoms. Together, atom-ion quantum mixtures are promising candidates for investigating several open problems in experimental quantum physics and condensed matter physics from a different standpoint [1].
In addition to the features of each individual quantum system, this hybrid system gives rise to atom-ion interactions, which are more long-ranged than atom-atom ones. Atom-ion interactions can represent an extremely useful tool in order to simulate condensed matter problems, to explore new hardware for quantum technologies, to investigate fundamental chemical reactions, and to advance metrology standards. Elastic collisions between ions and atoms can be exploited to sympathetically cool the ions and try to reach the elusive s-wave scattering regime, in which atom-ion collisions can lead to a quantum coherent evolution of the composite system.

Creating an ultracold atom-ion quantum mixture represents a remarkable experimental challenge, since two complex setups must be integrated in the same apparatus. Moreover, the ultracold atom-ion mixtures realized so far were not brought to the s-wave scattering regime because of the so-called "micromotion", a driven motion affecting the dynamics of the ions trapped in Paul traps.
From the experimental point of view, the main levers upon which to act in order to reach the s-wave scattering regime are basically two. The choice of the atomic species and the trapping strategy for confining the ions. For what regards the pair of atomic species, these must be carefully chosen on the basis of their mass ratio and the characteristics of their mutual interaction. We opted for fermionic Lithium for the atoms and Barium for the ions, since in their ground states they are chemically stable against charge-exchange reactions. For what concerns the ions'trapping strategy, the micromotion arising in radiofrequency traps is formed by different contributions and could be reduced by applying static and dynamics electric fields. We designed our trap with four radiofrequency electrodes and six DC electrodes of different shapes for generating a trapping potential along the three orthogonal directions. For the micromotion compensation, extra DC voltages can be applied to each of these ten electrodes.
Even if the experiment is currently under construction, the "ion"side of the apparatus has already been implemented. Since it is able to work independently from the rest of the setup, the first attempts of ion trapping and cooling in Italy are already possible.

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Presenter: PEREGO, Elia

Session Classification: Quantum Simulation & Technology

Track Classification: Quantum Simulation

Contribution ID: **74** Type: **Poster**

A quantum compiler for small-scale trapped ion quantum processors

Trapped ions are a promising basis for quantum computers. They feature excellent quantum gate fidelities, long coherence times, as well as the ability to shuttle the qubits around the processor, enabling near error-free and arbitrary qubit connectivity. As for any quantum hardware implementation, the physical quantum gate set available with trapped ions is limited - in this case with rotation gates and the Mølmer–Sørensen gate - and most quantum circuits must be decomposed into executable sequences of physical gates before being run. The decomposition should also optimized, with the shortest circuit possible, in order to maximize fidelity [1].

The Ion Quantum Technology group at the University of Sussex is developing technologies enabling the construction of large-scale quantum computers as laid down in a blueprint published in 2017 [2]. Therefore, multiple prototype processors with different ion trap layouts and hardware controls are currently in operation in the same laboratory. The ability to compile generic quantum circuit code, and run it on any targeted prototype will provide flexibility, boost the speed and efficiency of experiments using quantum algorithms, and also provide a solid base for testing quantum error correction algorithms and other large-scale quantum computer software requirements.

We present a full software and hardware stack, which is being implemented to calibrate and run multiple small size quantum computers. It relies on a layer-based compiler architecture as presented in [3], uses already developed software and hardware modules but innovates through the scalability of its architecture, it's resilience to hardware errors and its ergonomic use from the end-user writing quantum circuits to the quantum engineer operating the prototype hardware.

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[3] A Software Methodology for Compiling Quantum Programs, T. Häner, D. S. Steiger, K. M. Svore, and M. Troyer, Quantum Sci. Technol. 3, 020501 (2018)

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Session Classification: Poster Session

Track Classification: Quantum Information & Computing

Contribution ID: **75** Type: **Oral**

Ultra-low heating rates for high precision measurements on antiprotons

Wednesday 15 January 2020 11:30 (30 minutes)

The observed baryon asymmetry in our universe challenges the Standard Model of particle physics and motivates sensitive tests of CPT invariance. Inspired by this, the BASE experiment at CERN compares the fundamental properties of antiprotons and protons with high precision using an ultra-low noise cryogenic multi-Penning trap apparatus.
One particular challenge is imposed by electric-field noise that fundamentally affects the spin-state detection fidelity in magnetic moment measurements. Recently, we reported on the first heating rate determination in a cryogenic Penning trap [1], the measured electric field noise is more than 100 times better than in room temperature Penning traps and more than 1000 times lower as in Paul traps. In this contribution, recent experimental developments and future measurement prospects will be discussed.

[1] M. J. Borchert et al., Phys. Rev. Lett. 122, 043201 (2019)

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Session Classification: Antimatter 1

Track Classification: Antimatter

Contribution ID: **76** Type: **Oral**

Experimental realisation of quantum networks

Tuesday 14 January 2020 15:30 (30 minutes)

The trapped-ion quantum computer platform benefits from long coherence times [1] and high gate fidelities [2]. Due to the spectral density of motional modes, co-trapping and mutually controlling a large number of ionic qubits in a single trap is technically challenging. Therefore, large-scale trapped-ion quantum computers will require interfaces connecting many individual traps [3-5]. We present a photonic link entangling two Sr-88 ions trapped in physically separate systems with unprecedented fidelity and entangling rate, which renders entanglement distillation viable in future high-fidelity quantum networking applications.

With quantum computers available on a cloud-computing basis, the question of accessibility, privacy and information security arises. Measurement-based blind quantum computing [6] enables remote steering and control of quantum algorithms on a server without disclosing the details of the computation to the provider. We discuss a scheme to implement blind quantum computing experimentally via an optical fibre cable connecting a trapped-ion quantum computer with a client-controlled high-speed polarisation analyser.

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[5] B. Lekitsch et al., Science Advances 3(2), e1601540 (2017).
[6] J. F. Fitzsimons, npj Quantum Information 3(1), 23 (2017)

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Session Classification: Quantum Information & Computing 1

Track Classification: Quantum Information & Computing

Contribution ID: **77** Type: **Oral**

Laser Spectroscopy of Antihydrogen

Wednesday 15 January 2020 11:00 (30 minutes)

Antihydrogen is an exciting tool for testing fundamental physics. Antihydrogen can reproducibly be synthesized and trapped in the laboratory for extended periods of time [1][2], offering an opportunity to study its properties with high precision. Of particular interest is the two-photon 1S-2S transition, due to the staggering precision of which it has been measured in hydrogen [3]. Since only a relatively small number of antihydrogen atoms are available, spectroscopy techniques must take advantage of the high efficiency at which matter-antimatter annihilations can be detected. I will discuss how experimental methods have been developed by the ALPHA collaboration to first observe [4] and later characterise [5] the 1S-2S transition in antihydrogen, and how hydrogen-like precision may soon be within reach.

[1] G. B. Andresen et al. (ALPHA collaboration). Trapped Antihydrogen. Nature 468, 673-676 (2010).
[2] G. B. Andresen et al. (ALPHA collaboration). Confinement of antihydrogen for 1,000 seconds. Nature Physics 7, 558–564 (2011)
[3] C. G. Parthey et al. Improved Measurement of the Hydrogen 1S - 2S Transition Frequency. Phys. Rev. Lett. 107, 203001 (2011).
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[5] M. Ahmadi et al. (ALPHA collaboration). Characterization of the 1S-2S Transition in Antihydrogen. Nature 557, 71-75 (2018).

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Session Classification: Antimatter 1

Track Classification: Antimatter

Contribution ID: **78** Type: **Oral**

High precision tests of Proton-Antiproton symmetry: Towards a 100 p.p.t. antiproton g-factor measurement

Thursday 16 January 2020 14:30 (30 minutes)

Throughout its existence, the Standard Model has proven very successful in describing fundamental interactions of elementary particles. However, one observation, which has yet to be understood, is the asymmetry between the abundance of matter and antimatter in the universe. The BASE experiment, located at CERN's Antiproton Decelerator (AD) facility, measures the fundamental properties of protons and antiprotons in order to test CPT symmetry with high precision.
In the recent years, BASE has compared the charge-to-mass ratio of protons and antiprotons at a fractional precision of 69 parts-per-trillion (p.p.t.) [1]. Additionally, the first ever non-destructive observation of spin flips with a single trapped antiproton was demonstrated [2], allowing the measurement of the antiproton's magnetic moment to a fractional precision of 1.5 parts-per-billion (p.p.b.) [3], which improved results by other groups by about a factor of 3000 [4].
In my talk, I will give an overview of the BASE experiment and review the two particle/three trap magnetic moment measurement scheme. I will discuss limitations of the 1.5 p.p.b. measurement of the antiproton's magnetic moment and present a new technique for the detection of a single trapped antiproton's spinstate, which will allow for measurements at increased sampling rate and cyclotron-temperature acceptance. The application of this scheme and the introduction of additional experiment upgrades will enable an antiproton g-factor measurement with a fractional uncertainty of 100 p.p.t. on the short term.

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Session Classification: Antimatter 2

Track Classification: Antimatter

Contribution ID: **79** Type: **Oral**

An XUV frequency comb using HHG for metrology of Highly Charged Ions

Tuesday 14 January 2020 09:00 (30 minutes)

Forbidden optical transitions in highly charged ions (HCI) are the most sensitive systems for probing the variation of the fine structure constant α [1]. Moreover, they have been proposed as novel frequency standards due to their low polarizability and insensitivity to black body radiation [2]. HCI are typically produced in an electron beam ion trap (EBIT) with MK temperatures, which restricts the achievable accuracy in frequency determinations to ppm levels [3]. However, recent developments at our institute have overcome these limitations by extracting, slowing and subsequent retrapping the HCI in a Paul Trap, where they are sympathetically cooled by a Be^{+} crystal [4]. This has enabled the first high precision laser spectroscopy of Ar^{13+} using quantum logic spectroscopy, gaining many orders of magnitude in precision compared to all previous experimental measurements [5].
The experiment presented here aims at high precision spectroscopy in the extreme ultraviolet (XUV), where many transitions, from dipole-allowed (E1) to highly forbidden, take place. Femtosecond pulses from a 100 MHz phase stabilized infrared (IR) frequency comb around 1035 nm are amplified and fed into an enhancement cavity inside the UHV vacuum chamber [6]. In the tight focus (waist size ≈ 15 μm) of the cavity, where intensities of up to $2{\cdot}10^{14}$W/cm^2 are reached, the IR light interacts with a noble gas inserted from a nozzle with a very high backing pressure. High harmonics are generated collinearly with the cavity beam and are spatially separated using a shallow diffraction grating etched in one of the cavity mirrors [7]. In this way, we can now generate XUV radiation with wavelengths ranging from 35 to 150 nm. Since each harmonic is a coherent copy of the infrared frequency comb [8], any of the comb teeth in any of the harmonics can be used to resonantly drive an electronic transition in the highly charged ion. Using this technique of direct frequency comb spectroscopy, absolute transition energies can be determined with an unprecedented precision in the XUV [9]. The measured output power of 10 μW per harmonic is already feasible for fluorescent detection of dipole-allowed transitions in HCI. The latest results and current work on further increasing and stabilizing the output power will be presented, as well as its future prospects in ultra-high precision spectroscopy of cooled and trapped HCI.

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Session Classification: Atomic Clocks

Track Classification: Atomic Clocks

Contribution ID: **80** Type: **Poster**

Particle detectors for precision atomic experiments in ALPHA

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 important milestones, from demonstrating the ability to trap and confine neutral cold antihydrogen, to performing precision spectroscopic measurements with antihydrogen.

The principal tool for antihydrogen detection in the ALPHA experiment is a particle track detector: the Silicon Vertex Detector (SVD) built using 72 double-sided silicon strip hybrid modules and designed to surround the neutral atom trap.

The SVD is used to image single annihilation events, reconstructing spatial and timing data of antiproton annihilation. With the aid of machine learning, the detector can be utilised in various modes, application modes include low background counting experiments, accurate vertex reconstruction and collective plasma behaviour studies. Experimental methodology, recent progress with analytical methods and experimental results will be presented

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Session Classification: Poster Session

Track Classification: Antimatter

Contribution ID: **81** Type: **Oral**

Trapped-Ion Entangling Gates Robust Against Qubit Frequency Errors

Thursday 16 January 2020 09:30 (30 minutes)

Entangling operations are a necessary tool for large-scale quantum information processing, but experimental imperfections can prevent current schemes from reaching sufficient fidelities as the number of qubits is increased. Previous theoretical and experimental work has considered classes of errors including static offsets in the motional frequency, heating of the bus mode and timing errors in gate operation [1, 2], and shown analytically that these can be simultaneously minimised by a particular multi-toned modification to the Mølmer–Sørensen scheme.

We treat the hitherto neglected errors in qubit frequencies, which do not permit a closed-form analytic solution. We show numerically that simliar generalisations of the standard entangling gate can be made robust against noise and mis-sets of the frequencies of the individual qubits, including the case of separated carrier frequencies. We find numerically that a small-amplitude second tone can reduce the infidelity expectation by a factor of nearly four at the fault-tolerant limit, and additional tones can further improve this. This comes at the cost of a similar order increase in gate time, but significantly relaxes the degree of homogeneity required in the trapping field, making physically larger systems more practical.

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Session Classification: Quantum Information & Computing 3

Track Classification: Quantum Information & Computing

Contribution ID: **82** Type: **Poster**

Microwave-driven two-qubit entangling gate with $^{9}\mathrm{Be}^{+}$ ions in a scalable microfabricated surface-electrode ion trap

Two-qubit gates with high fidelities are an essential ingredient to perform universal operations on a quantum information processor.
One promising candidate to implement such a device are trapped ions in microfabricated surface-electrode ion traps as envisioned by the QCCD architecture [1, 2].
In this approach, the quantum information is encoded in the electronic spin states of the ions, which can be moved between highly specialized trap zones via ion transport.
In the work presented here, we demonstrate a QCCD-compatible module for entangling gate operations following the Mølmer-Sørensen protocol using near-field microwaves [3] instead of the typically used laser approach.
We utilize the microwave-driven gate interaction to entangle two $^{9}\mathrm{Be}^{+}$ ions and find the resulting state preparation fidelity of a maximally entangled state to be higher than 98% [4].

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Session Classification: Poster Session

Track Classification: Quantum Information & Computing

Contribution ID: **83** Type: **Oral**

Production and trapping of C_2^- in a digital RF trap

Thursday 16 January 2020 15:00 (30 minutes)

C_2^- and other anionic molecules are produced with an electric discharge valve and accelerated to 1.8 keV in a pulsed electric field. The C_2^- are then mass selected in a Wien filter. Subsequently the C_2^- are decelerated in the static electric field of a resistive tube with a potential difference of 1.798 kV to reduce the energy of the particles to a trappable range. A digital RF trap on the same potential stores the C_2^- molecules before they are detected on a MCP.
This apparatus is suitable to test subsequent laser cooling of C_2^-. A successful cooling of anionic C_2^- would open up novel experiments based on the sympathetic cooling of antiprotons and other anionic systems to sub-Kelvin temperatures.

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Session Classification: Antimatter 2

Track Classification: Antimatter

Contribution ID: **84** Type: **Oral**

Probing the proton-electron mass ratio through Doppler-free two-photon spectroscopy of HD+

Wednesday 15 January 2020 09:00 (30 minutes)

We have performed Doppler-free two-photon spectroscopy of cold, trapped HD^+ ions to measure a ro-vibrational transition frequency with a relative uncertainty of a few parts-per-trillion. Using highly precise *ab-initio* calculations [1], these measurements allow –for the first time –to determine the proton-electron mass ratio, μ, from molecular spectroscopy with a precision competitive with that of state-of-the-art Penning trap mass measurements [2, 3]. Hence, our method provides both a new value of μ and a cross check of existing methods. In addition, our results provide an indication of the values of the proton radius and Rydberg constant, and may even serve as a probe of physics beyond the Standard Model.

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Session Classification: Precision Measurements 2

Track Classification: Precision Measurements

Contribution ID: **85** Type: **Oral**

Microfabricated 2D array of ion traps

Wednesday 15 January 2020 15:30 (30 minutes)

Quantum computers need to fulfill five criteria as stated by DiVincenzo [1]. Trapped-ion quantum computers excel in all but one criterion: scalability remains hindered by challenges on system- and device-level. To that end, the quantum CCD architecture (QCCD) [2,3] has been introduced for scalable quantum computation and simulation. As a first step in this direction we demonstrate the microfabrication of 2D ion trap arrays and present first experimental results.
Fabrication of the ion trap is carried out in a state-of-the-art industrial facility to guarantee high process reproducibility and therefore identical ion traps. A three-metal-layer structure provides high performance and flexibility of the ion trap. A screening metal layer both screens the ion from charge carriers in the silicon substrate while also shielding the substrate from the RF field. Therefore, micromotion [4] and RF losses [5] are minimized. An interconnect metal layer connects the DC island electrodes to the bonding pads for electrical contact and thereby facilitates complex layouts like the QCCD architecture. The top metal layer is optimized for high currents to guarantee low Ohmic losses during RF operation. All metal layers are connected through vertical interconnect access (via).
Careful electrical characterization is conducted before device shipping: the Ohmic resistance of metal layers and vias as well as the capacitance between metal layers is determined. Additionally, DC dielectric breakdown voltages of the inter-metal oxide are measured at both room temperature and cryogenic temperature. Typical DC breakdown voltages show values of around 800 V at cryogenic temperatures. This exceeds the operating RF voltage of around 200 V and demonstrates reliable trap fabrication.
The presented geometry allows for ion shuttling in each of the two 1D arrays and adjusting the inter-ion distance inside each 1D array. Furthermore, lowering the RF voltage in between the two 1D arrays enables tuning of the inter-ion distance in between the two ion chains. This allows Coulomb coupling of ions inside one 1D array as well as in between the 1D arrays [6]. Therefore, in future experiments a rectangular or triangular lattice of coupled ions might be realized.
As a first experimental result the heating rate of the ion trap is measured to be 60 phonons per second. This value already allows for various fundamental investigations. Up to six ions located in both chains are trapped simultaneously. Finally, simultaneous shuttling of ions throughout both chains reveals the feasibility of implementing a QCCD architecture.
In summary, our work demonstrates that industrial fabrication of ion traps is an important step towards quantum computing by offering highly reproducible ion traps with unprecedented performance and flexibility.

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Session Classification: Quantum Information & Computing 2

Track Classification: Quantum Information & Computing

Contribution ID: **87** Type: **Hot Topic**

Characteristics of hybrid laser cooling of Yb-doped nanocrystals

Tuesday 14 January 2020 12:00 (15 minutes)

The field of optical cooling concerns many areas of current scientific research, among which are quantum simulation [1], frequency standards [2], Bose-Einstein condensation [3], atom optics [4]. Recent studies often focus on the cooling of various nanoparticles and nanoclusters using cavity cooling [5], feedback cooling [6], and laser cooling based on resonant transitions in impurities [7]. The application of deep optical cooling that arouses the most interest is the obtaining of macroscopic quantum states, in which the de Broglie wavelength of a nanoparticle becomes comparable with its size [8].

Recently we suggested the scheme of optical cooling of Yb-doped nanocrystals, which combines a quadruple radio-frequency trap (RFT) with coherent population transfer in Yb impurities. We considered two cases of this transfer, namely, ultraviolet (UV) Raman pulses [8] and time-separated UV optical excitation referred to as Stimulated Raman Adiabatic Passage (STIRAP) [9]. These approaches demonstrate the possibility to cool both the center-of-mass (COM) motion and the phonon modes of a 100 nm Yb-doped fluorite nanocrystal. However, coherent population transfer techniques are limited by infrared (IR) feedback loop, which inevitably introduces additional heat to the system while monitoring the location of a nanocrystal within the RFT. This disadvantage is not present in the Doppler-like noncavity cooling [7], which utilizes RFT localization and continuous IR illumination and allows to efficiently reduce external temperatures of Yb-doped nanocrystals.

In this work we continue to investigate the deep IR cooling of a Yb-doped fluorite nanocrystal in RFT. We consider the interaction between nanocrystal's internal and external degreees of freedom. The former are optical phonon modes that are conjugated with the transitions in Yb ions upon Doppler-like cooling, and the latter simply refer to COM motion of nanocrystal. We describe these degrees of freedom as three-dimensional harmonic oscillators [10]. Knowing the features of interaction between nanocrystal's degrees of freedom can sufficiently advance the understanding of processes behind the laser cooling of solid nanoparticles.

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Session Classification: Quantum Simulation & Technology

Track Classification: Theoretical Quantum Technologies

Contribution ID: **89** Type: **Oral**

Non-destructive detection in 87Sr optical lattice clocks

Tuesday 14 January 2020 09:30 (30 minutes)

Optical clocks have reached an impressive level of stability and accuracy.
Many of the systematic uncertainties can now be measured and controlled at the fractional level of 10 −18 , with stability in the low 10 −16 at 1 s integration time.
The stability of the clocks is technically limited by the Dick effect, which is an aliasing of high frequency noise projected in the low frequency range, hence degrading the long term stability. In order to minimize this technical limitation, here we present a non–destructive detection of trapped strontium atom clock as opposed to the usual flourescence–based destructive detection system. Because the loading and atomic preparation time are less significant with respect to the duty cycle in this scheme, the result can lower the dead time and provide better stability. In addition, we will discuss how spin squeeze states can be used in this non-destrucitve detection setup to overcome the fundamental quantum limit. Here we also present a discussion about the accuracy budget in the 87Sr clocks at SYRTE with a special attention to the frequency shift on the clock transition due to the hot background gas collision with the cold atom clock.

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Session Classification: Atomic Clocks

Track Classification: Atomic Clocks

Contribution ID: **90** Type: **Poster**

Planar trap for quantum information processing with atomic ions interacting via MAGIC

We designed a micro-segmented planar ion trap for trapping atomic ions in a 2-dimensional array by electrodynamic fields. The electrode structures allow for varying the ion-surface separation. Additionally, the trap chip has resonant structures incorporated to enhance microwave-frequency magnetic fields, which will be used for all coherent operations on the hyperfine manifold of $^{171}Yb^{+}$ ions. The ions interact via magnetic gradient induced coupling (MAGIC) [1]. Reducing the magnetic field noise at the ions' location plays an important role in this experiment. In order to reduce the effect of the chamber on ambient magnetic fields and protect the hyperfine states from magnetic field noise, we employ a custom aluminum vacuum chamber and placed a mu-metal shield inside this chamber. Furthermore, for reduction of electric field noise due to electrodes surface contamination, the experimental setup includes an Ar^{+} ion gun for in situ cleaning.
Initial characterization of the current experimental setup has been carried out. Also, coherence properties of magnetic sensitive states, which are used for quantum information processing via MAGIC have been studied and are presented here.

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Presenter: Mr OKHRIMENKO, Bogdan (University of Siegen)

Session Classification: Poster Session

Track Classification: Quantum Information & Computing

Contribution ID: **91** Type: **Poster**

The Geonium Chip Penning Trap

The Geonium Chip group (University of Sussex, UK) is in the process of building a unique scalable Penning Trap for use in quantum technology. We present an innovative PCB-chip-based Penning Trap system for quantum-non-demolition measurements of single microwave photons.
One such innovation is the design, build and implementation of a planar magnetic field source whose field may be changed in-situ. At the heart of the technology lies a single trapped electron, which will be the quantum transducer for single microwave photon detection and emission.

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Session Classification: Poster Session

Track Classification: Precision Measurements

Contribution ID: **92** Type: **Hot Topic**

Towards Sympathetic Cooling of Single Protons and Antiprotons

Wednesday 15 January 2020 12:00 (15 minutes)

We, the BASE collaboration, perform most precise tests of the CPT symmetry in the baryon sector by measurements of the fundamental properties of protons and antiprotons. Our recent 300 ppt measurement of the proton magnetic moment at the proton g-factor experiment in Mainz is predominantly limited by statistics [1]. The reason is that the current use of sub-thermal cooling of a single proton by a resistive method is extremely time-consuming and leads to cycle times of hours.

To overcome this limitation, sympathetic cooling by laser-cooled Be^{+} ions in a common-end-cap Penning trap is being developed [2]: The method not only promises to produce protons and antiprotons with mK temperatures within tens of seconds but also achieves separation of the cooled and the refrigerator ion.

We present the current setup of the proton g-factor experiment and report on the status and recent achievements, such as in-trap detection of fluorescence photons using SiPMs at 4 K, located 12 mm from the Be+ ion cloud.

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Session Classification: Antimatter 1

Track Classification: Antimatter

Contribution ID: **93** Type: **Oral**

Towards testing Fundamental Physics using Ramsey-Comb Spectroscopy on He^{+}+

Monday 13 January 2020 14:30 (30 minutes)

Simple atomic systems are the ideal probe to test fundamental physics. For example, for hydrogen the 1S-2S transition frequency can nowadays be calculated with an impressive relative accuracy of 10^{-12} [1], and measurements reach an even higher relative accuracy of 10^{-15}[2]. Combining different measurements in hydrogen has been used to determine fundamental constants such as the Rydberg constant and the proton charge radius. These constants are also required to compare theory with experiment, e.g. to test bound state Quantum Electrodynamics (QED). However, it can lead to conflicting results. Measurements in muonic hydrogen resulted in a surprisingly small proton charge radius [3], known as the "proton radius puzzle". Since then, an increasing number of high-precision atomic physics experiments are performed in order to solve this puzzle.

An alternative system to study QED and finite nuclear size effects is singly-ionized helium. We aim to measure the 1S-2S transition in He^{+} at 30 nm with 1 kHz accuracy. Such a measurement poses a QED test by probing difficult to calculate 2-loop contributions which scale with large powers of the nuclear charge. Those contributions currently limit the theory of the 1S-2S transition in hydrogen-like atoms.

The measurement is performed using Ramsey-comb spectroscopy (RCS) [4], where two pulses from the pulse train of a frequency comb laser (FC) create a Ramsey-like excitation in the optical domain. By selecting different pairs of pulses from the FC we can record a series of Ramsey fringes from which we can accurately determine the transition frequency. Systematics which are constant between different pulse pairs, such as the AC Stark shift, cancel. The pulse pairs are amplified to the mJ-level which enables upconversion of the fundamental at 790 nm to its 25^{th} harmonic (32 nm) using high-harmonic generation (HHG). We drive the transition in He^{+} with two copropagating unequal photons, 790 and 32 nm, in order to enhance the transition probability. The helium ion is trapped in a linear Paul trap and sympathetically cooled with a beryllium ion. Any frequency shift due to the motion of the helium ion is significantly reduced by synchronizing the repetition rate of the laser with the secular frequency of the trap.

In order to characterize possible delay-dependent phase shifts in the HHG process, we performed a measurement of the $5p^6 - 5p^5 8s^2 [3/2]_1$ one-photon transition in xenon at 110 nm. We reached the highest accuracy to date with a HHG source [5]. Moreover, the results show that delay-dependent phase shifts are only present at very short pulse delays (< 16 ns), not relevant for the future measurement of the 1S-2S transition in He+.

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Presenter: Mr GRUNDEMAN, Elmer (Vrije Universiteit Amsterdam)

Session Classification: Precision Measurements 1

Track Classification: Precision Measurements

Contribution ID: **94** Type: **Oral**

Penning mass spectrometry using optical detection with 40Ca+ as sensor ion in an unbalanced crystal

Thursday 16 January 2020 11:00 (30 minutes)

A Penning mass spectrometry technique based on optical detection is under development in the University of Granada [1]. This technique is universal, non-destructive, and single ion-sensitive. The scattered photons by a $^{40}Ca^{+}$ ion will be used to measure the normal mode eigenfrequencies of the unbalanced crystal formed by this ion and the target one [2]. The dynamics of the two-ion crystal has been already studied, including the quantification of frequency shifts due to the Coulomb repulsion. Experimentally, the magnetic field of the Penning trap is the largest ever-used in laser-cooling experiments, which together with the level structure of the calcium ion, makes the cooling challenging. So far, Doppler cooling of small clouds in all the degrees of freedom has been demonstrated. However, residual pressure in the trap area prevents single ion sensitivity. In this contribution, we will describe the TRAPSENSOR facility, the results obtained so far, and the expected performance of the single-ion as sensor in the 7-tesla magnetic field. Also, we will present results regarding the detection of induced image currents using a new amplifier circuit developed by the group in collaboration with the University of Mainz (Block's group) and the company Seven Solutions and, for the first time in the field, using quartz crystal as resonant element [3]. We will end underlining the changes in our setup in order to develop a cryogenic Penning trap.

[1] M. J. Gutiérrez et al., *New J. Phys.* **21**, 023023 (2019)
[2] M. J. Gutiérrez et al., *arXiv:1907.08045* (2019)
[3] S. Lohse et al., *Rev. Sci. Instrum.* **90**, 063202 (2019)

Authors: Mr BERROCAL SÁNCHEZ, Joaquín (Universidad de Granada); Mr GUTIÉRREZ TORRES, Manuel Jesús (Universidad de Granada); Mr DOMÍNGUEZ GONZÁLEZ, Francisco (Universidad de Granada); Prof. RODRÍGUEZ RUBIALES, Daniel (Universidad de Granada)

Presenter: Mr BERROCAL SÁNCHEZ, Joaquín (Universidad de Granada)

Session Classification: Precision Measurements 3

Track Classification: Precision Measurements

Contribution ID: **95** Type: **Oral**

Quantum Networking with Trapped-Ion Qubits at AFRL

Tuesday 14 January 2020 15:00 (30 minutes)

Quantum networks promise the ultimate in secure connectivity providing channels of communication that are both tamper proof and tamper evident. A quantum network can be executed by remotely linking distance memory nodes comprising trapped-ion qubits via photon-based qubit interconnects. AFRL is pursuing a multi-pronged approach to develop in-house quantum networking capabilities that ultimately may move beyond a well-controlled research laboratory environment towards a fieldable demonstration.

Authors: Dr RUTBECK-GOLDMAN, Harris (Air Force Research Lab Information Directorate); HAAS, Paige (Technergetics LLC); Dr HUCUL, David (Air Force Research Lab Information Directorate); PHILLIPS, Justin (Northeastern University); Dr TABAKOV, Boyan (Air Force Research Lab Information Directorate); WILLIAMS, James (Air Force Research Lab Information Directorate); Dr SODERBERG, Kathy-Anne (Air Force Research Lab Information Directorate)

Presenter: Dr RUTBECK-GOLDMAN, Harris (Air Force Research Lab Information Directorate)

Session Classification: Quantum Information & Computing 1

Track Classification: Quantum Information & Computing

Contribution ID: **96** Type: **Oral**

Coherent manipulation of a single ion inside and outside the Lamb-Dicke regime

Tuesday 14 January 2020 14:30 (30 minutes)

While three-dimensional sub-Doppler cooling of ions in a Paul trap has become routine, such cooling is harder to realise in a Penning trap. We have recently demonstrated optical sideband cooling of a single ion as well as the axial and planar configurations of a 2 ion crystal [1,2]. We will present preliminary results of the creation of a superposition of motional states to investigate interference fringes using more than two Fock states.

Since the initial proposal of using trapped ions for quantum information processing [3], a considerable amount of research has been put into satisfying the criteria for a universal quantum computer. State preparation and readout of a single qubit have been realised with infidelities below the threshold for fault tolerant quantum computing [4,5]. Entangled states of up to 14 ions have been prepared [6] and single and two-qubit gates have been realised with infidelities as low as 10^{-6} and 10^{-3} respectively [7] in linear Paul traps. However, heating rates and off-resonant excitations are still a main limitation when increasing the gate speed and reducing the ion-electrode distance.

We are investigating the implementation of gates outside the Lamb-Dicke regime. A higher Lamb-Dicke (LD) parameter leads to a stronger interaction between the ion's internal degrees of freedom as well as larger amplitudes of higher order red and blue sideband transitions. We therefore investigate how to mitigate higher order sideband effects in gate operations with the goal of reducing gate time and also relaxing the temperature constraints associated with it.

We have built a new large-scale linear Paul trap with blade design that will be driven at low frequencies in order to reach a high LD parameter, while keeping low heating rates. We will initially work with an optical qubit driven by narrow-band radiation at 729nm. We also intend to use a Zeeman qubit that will be driven with Raman transitions in order to reach a higher effective LD parameter. Preliminary results of single qubit gates will be presented.

[1] G. Stutter et al., J. Mod. Opt. 65, 549 (2018)
[2] M. K. Joshi et al. Phys. Rev. A 99, 013423 (2019)
[3] A. Sørensen and K. Mølmer, Phys. Rev. Lett. 82, 1971 (1999).
[4] A. Myerson et. al., Phys. Rev. Lett. 100, 200502 (2008).
[5] T. Harty et. al., Phys. Rev. Lett. 113, 220501 (2014).
[6] T. Monz et. al., Phys. Rev. Lett. 106, 130506 (2011).
[7] C. Ballance et. al., Phys Rev Lett. 117, 060504 (2016).

Author: MOSCA TOBA, Jacopo (Imperial College London)

Co-authors: CORFIELD, Oliver (Imperial College London); Mr LEE, Chungsun (Imperial College London); Dr HEINRICH, Johannes (Imperial College London); Dr WEBSTER, Simon (Imperial College London); Dr MINTERT, Florian (Imperial College London); THOMPSON, Richard Charles

Presenter: MOSCA TOBA, Jacopo (Imperial College London)

Session Classification: Quantum Information & Computing 1

Track Classification: Quantum Information & Computing

Contribution ID: **108** Type: **Oral**

How to Write a Good Journal Paper (or Thesis)

Monday 13 January 2020 16:30 (2 hours)

The tutorial will present a recipe for writing good “research reports”, including theses, internal reports, and especially journal papers. The critical elements of each section of the “research report”will be reviewed, and content, organization, and style conventions will be discussed. The research report should be centered on a well defined “research question”. In the Introduction, the importance of a clear gap sentence and statement of purpose will be emphasized. The requirement for providing sufficient detail in the Methodology section for duplicating results will be explained. The differences in theoretical papers will be explained. The proper order for presenting Results – location, presentation, and comment - will be explained. The principle of heads-up display in technical drawings will be presented. The need to differentiate between results and interpretation will be emphasized. The organization of the discussion, from narrow comments to broad implications, will be presented, and appropriate language to express the relative certainty of explanations, i.e. from speculation to proof, will be explained. Answering the “research question”and summarizing the key results and their implications in terms of 3 points the author wishes the reader to remember will be suggested as the organizational mode for the Conclusions. The difference between an indicative and an informative Abstract will be explained, as well as the need for the latter. Finally, suggestions for interacting with journal editors and responding to reviewers’comments will be presented.

Author: BOXMAN, Ray

Presenter: BOXMAN, Ray

Session Classification: Interactive Skills Session 1

Contribution ID: **109** Type: **Oral**

Effective digital science communication

Thursday 16 January 2020 16:30 (1h 30m)

The advent of social media has allowed for easier communication of ideas at present than at any other time in human history. But in a crowded marketplace - and one full of disinformation - how can good science cut through the noise? In this session I will critically deconstruct several of my outreach projects, and offer practical advice to those wishing to broadcast their research in a variety of formats. In particular we will focus on video formats, but also discuss podcasting, livestreaming, and the broader use of social media. We will cover the conceptualisation of a media project, effective writing, production tips, post-production workflows, and more.

Author: Dr CLARK, Simon

Presenter: Dr CLARK, Simon

Session Classification: Interactive Skills Session 3

Contribution ID: **111** Type: **Visit**

LHCb Cavern

Friday 17 January 2020 17:30 (2 hours)

David Bretaud
Stefan Erlewein
Markus Wiesinger
Peter Granum
April Louise Cridland
Hiroto Fujisaki
Peter Drmota
Michal Hejduk
Billy Robertson
Ryan Shaffer
Alexandra Tofful
Vera Schäfer
Alex Owens
Julian Schmidt
Charles Baynham
H Evans
Bianca Veglia
Elmer Grundeman
Matthias Germann
Ivan Kosternoy
Bruno Ximenez
Nicolas Pulido Mateo
Sam Hile
Matthew Day
Elia Perego
Fabian Pokorny
Chiara Decaroli
Shaobo Gao
Tatiana Vovk
Ryan Willetts
Foni Raphael Lebrun-Gallagher
Simon Clark
Chris Whitty
Emilie Hindbo Clausen
Joaquín Berrocal Sánchez
Alberto Uribe
Mitchell Peaks

Presenter: MATHAD, Abhijit (Universitaet Zuerich (CH))

Session Classification: CERN Tours

Contribution ID: **112** Type: **Visit**

CMS Cavern

Friday 17 January 2020 08:30 (2 hours)

David Bretaud
Stefan Erlewein
Markus Wiesinger
Peter Granum
April Louise Cridland
Hiroto Fujisaki
Peter Drmota
Michal Hejduk
Billy Robertson
Ryan Shaffer
Alexandra Tofful
Vera Schäfer
Alex Owens
Julian Schmidt
Charles Baynham
H Evans
Bianca Veglia
Elmer Grundeman
Matthias Germann
Ivan Kosternoy
Bruno Ximenez
Nicolas Pulido Mateo
Sam Hile
Matthew Day
Elia Perego
Fabian Pokorny
Chiara Decaroli
Shaobo Gao
Tatiana Vovk
Ryan Willetts
Foni Raphael Lebrun-Gallagher
Simon Clark
Chris Whitty
Emilie Hindbo Clausen
Joaquín Berrocal Sánchez
Alberto Uribe
Mitchell Peaks

Presenters: LANTWIN, Oliver (Universitaet Zuerich (CH)); SHARMA, Vivek (Univ. of California San Diego (US))

Session Classification: CERN Tours

Contribution ID: **114** Type: **Visit**

Antiproton Decelerator 1

Friday 17 January 2020 11:00 (1 hour)

David Bretaud
Hiroto Fujisaki
Michal Hejduk
Billy Robertson
Ryan Shaffer
Alexandra Tofful
Vera Schäfer
Alex Owens
Julian Schmidt
Charles Baynham
André Kulosa
Bogdan Okhrimenko
H Evans

Presenter: JONES, Jack Mccauley (Swansea University (GB))

Session Classification: CERN Tours

Contribution ID: **115** Type: **Visit**

Antiproton Decelerator 2

Friday 17 January 2020 12:00 (1 hour)

Marylise Marchenay
Elmer Grundeman
Matthias Germann
Roshani Silwal
Laura Blackburn
Silke Auchter
Adrien Poindron
Jacopo Mosca Toba
Joseph Goodwin
Elia Perego
Emilie Hindbo Clausen
Shaobo Gao
Tatiana Vovk
Janko Nauta
Joaquín Berrocal Sánchez
Jonathan Pinder
Alberto Uribe

Presenters: HODGKINSON, Danielle Louise (University of Manchester (GB)); ERLEWEIN, Stefan (Max-Planck-Gesellschaft (DE))

Session Classification: CERN Tours

Contribution ID: **116** Type: **Visit**

Antiproton Decelerator 3

Friday 17 January 2020 13:00 (1 hour)

Simon Lechner
Nicolas Pulido Mateo
Sam Hile
Bruno Ximenez
Chiara Decaroli
Mitchell Peaks
Simon Clark
Chris Whitty

Presenters: MC KENNA, Joseph (Aarhus University (DK)); ERLEWEIN, Stefan (Max-Planck-Gesellschaft (DE)); JONES, Steven Armstrong (Aarhus University (DK))

Session Classification: CERN Tours

Contribution ID: **117** Type: **Visit**

ATLAS Cavern 1

Friday 17 January 2020 08:00 (1 hour)

David Bretaud
Bogdan Okhrimenko
Adrien Poindron
Samuel Niang
Jacopo Mosca Toba
Joseph Goodwin

Presenter: CRIDLAND, April Louise (University of Swansea)

Session Classification: CERN Tours

Contribution ID: **118** Type: **Visit**

ATLAS Cavern 2

Friday 17 January 2020 10:00 (1 hour)

Marylise Marchenay
André Kulosa
Roshani Silwal
Sam Hile
Laura Blackburn
Silke Auchter

Presenter: CRIDLAND, April Louise (University of Swansea)

Session Classification: CERN Tours

Contribution ID: **119** Type: **Visit**

ATLAS Cavern 3

Friday 17 January 2020 12:00 (1 hour)

Markus Wiesinger
Christian Zimmer
Peter Drmota
H Evans
Bianca Veglia
Ivan Kosternoy

Presenter: CRIDLAND, April Louise (University of Swansea)

Session Classification: CERN Tours

Contribution ID: **120** Type: **Visit**

ATLAS Cavern 4

Friday 17 January 2020 13:00 (1 hour)

Peter Granum
Hiroto Fujisaki
Michal Hejduk
Billy Robertson
Ryan Shaffer
Alexandra Tofful

Presenter: CRIDLAND, April Louise (University of Swansea)

Session Classification: CERN Tours

Contribution ID: **121** Type: **Poster**

Deexcitation and cooling techniques for precision measurements with antihydrogen

Antihydrogen is routinely produced at CERN in a broad range of Rydberg states. The experiments located around the Antiproton Decelerator (AD) aim to perform precision measurements on these anti-atoms with a main focus on spectroscopy of ground-state atoms (1S-2S transition or GS-HFS) and to study gravitational interaction for which GS is also required to minimize the sensitivity of the $\bar{H}$ to electromagnetic fields.

So far antihydrogen in GS is accumulated only via spontaneous decay in magnetic traps, which is not an option for in beam experiments like AEGIS or ASACUSA, which will have to rely on an active deexcitation method. Assuming a formation of $\bar{H}$ at 50K, the stimulated deexcitation should ideally happen within a few or tens of microseconds. This will either allow the formation of a beam of GS atoms via magnetic focusing or allow the re-excitation to well-defined states for Stark acceleration.

Since collaborations at the AD have adopted different $\bar{H}$ formation mechanisms, excitation schemes were developed, which fulfill the specific requirements of the respective formation scheme. This is especially of importance since resonant charge exchange (CE) is a pulsed production scheme whereas 3 body recombination (3BR) operates in a continuous mode.

My poster will present several mechanisms which have been investigated to efficienctly and rapidly deexcite $\bar{H}$ atoms. The main idea is to couple the many Rydberg states produced (either via electric and magnetic fields [1] or via THz and microwave light [2]) to each other, in order to be able to drive the population down with lasers to states which spontaneously decay fast enough.
Furthermore, we found the fast manipulation of Rydbgerg states to have potential applications for cooling of $\bar{H}$ held in magnetic traps. The mechanism relies on fast deexcitation of circular states at the edge of the magnetic trap to reduce the potential energy of the system when it is at its maximum, an idea which was pointed out by Cesar and Pohl et al. [3, 4] and that we further investigated and optimized in the framework of the studied deexcitation techniques.

Author: NOWAK, Lilian (University of Vienna (AT))

Presenter: NOWAK, Lilian (University of Vienna (AT))

Session Classification: Poster Session

Track Classification: Antimatter

Contribution ID: **122** Type: **Poster**

Quantum Control via Enhanced Shortcuts to Adiabaticity

Shortcuts to Adiabaticity (STA) are a collection of quantum control techniques that allow perfect state transfer for certain quantum systems. In this work we develop and apply a new analytic extension to existing Shortcuts to Adiabaticity (STA) techniques, termed enhanced Shortcuts to Adiabaticity (eSTA). This new method works for previously intractable Hamiltonians by creating an analytic correction to existing STA schemes. The correction can be easily calculated and the resulting protocol may even be outside the original class of STA schemes.

We demonstrate the effectiveness of eSTA by simulating several examples: population transfer in two-level systems beyond the rotating wave approximation, as well as one and two (interacting) ion transport in non-harmonic traps.

Ref.: C.Whitty, A. Kiely and A. Ruschhaupt, in preparation.

Author: WHITTY, Chris (University College Cork)

Presenter: WHITTY, Chris (University College Cork)

Session Classification: Poster Session

Track Classification: Theoretical Quantum Technologies