UNIMAN ESR15 – Degrader integration, improved beam injection, and high precision magnetic field measurement

AVA Kickoff Meeting, Jan 12 – 13, 2017
University of Liverpool

Dr. Will Bertsche
University of Manchester and the Cockcroft Institute

University of Manchester

- Major research-intensive university in the UK:
  - Member of the UK Russel Group
  - 27,085 undegraduates, 11,350 postgraduates
- School of physics
  - 150 research staff
  - Institutes: Cockcroft Institute, Photon Science Institute, Jodrell Bank, John Dalton Institute for Nuclear Physics, Graphene Institute
  - Many technical workshops in the School as well as across the faculty

Background

- Research background in Plasma Physics
- ALPHA: Fundamental measurements with trapped antihydrogen atoms
- Cockcroft Institute – focus on low energy beams

- First collaboration to trap antihydrogen and perform measurements with the trapped population

LETTER

doi:10.1038/nature09610

Trapped antihydrogen

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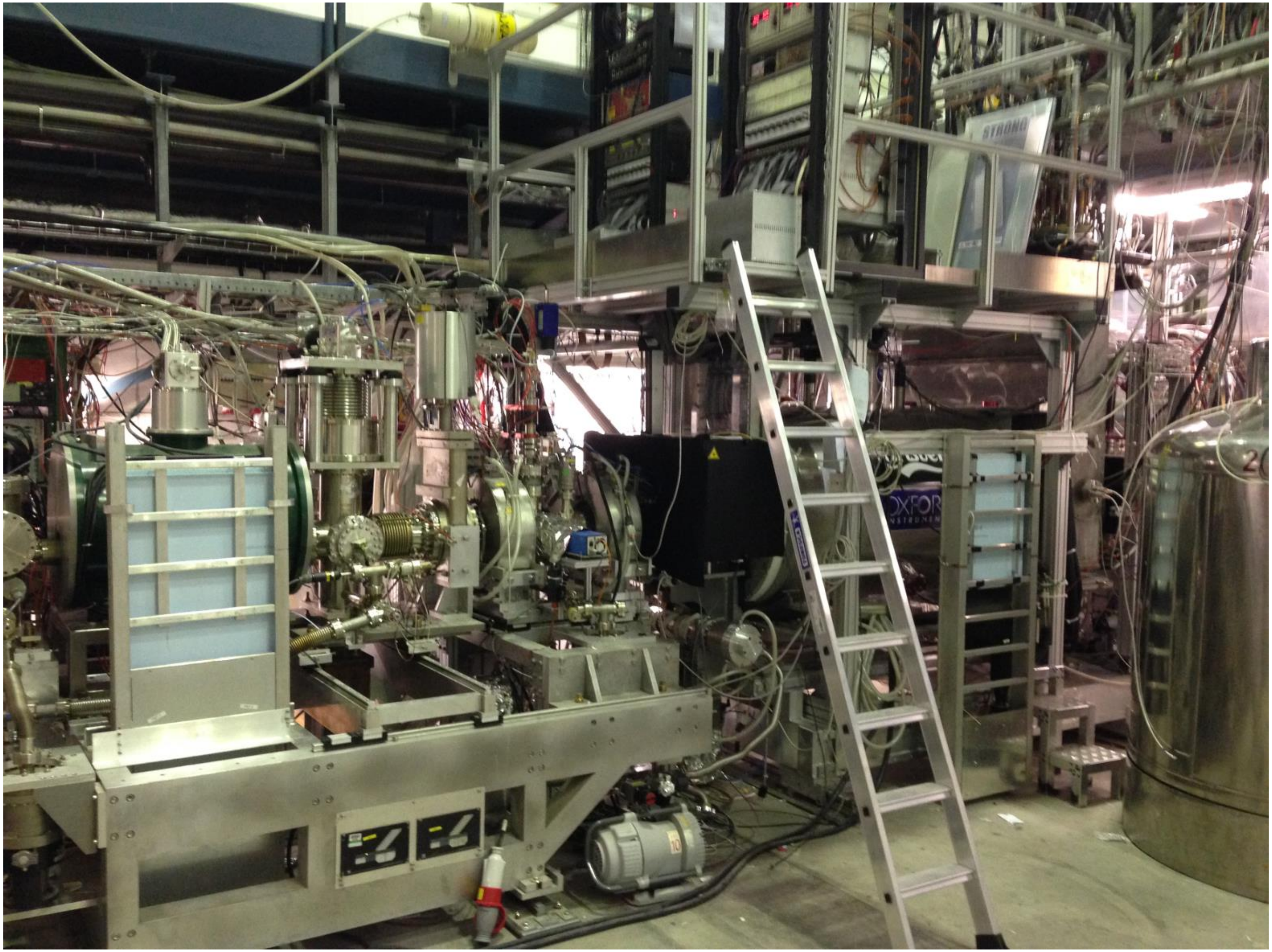
LETTER

doi:10.1038/nature10942

Resonant quantum transitions in trapped antihydrogen atoms

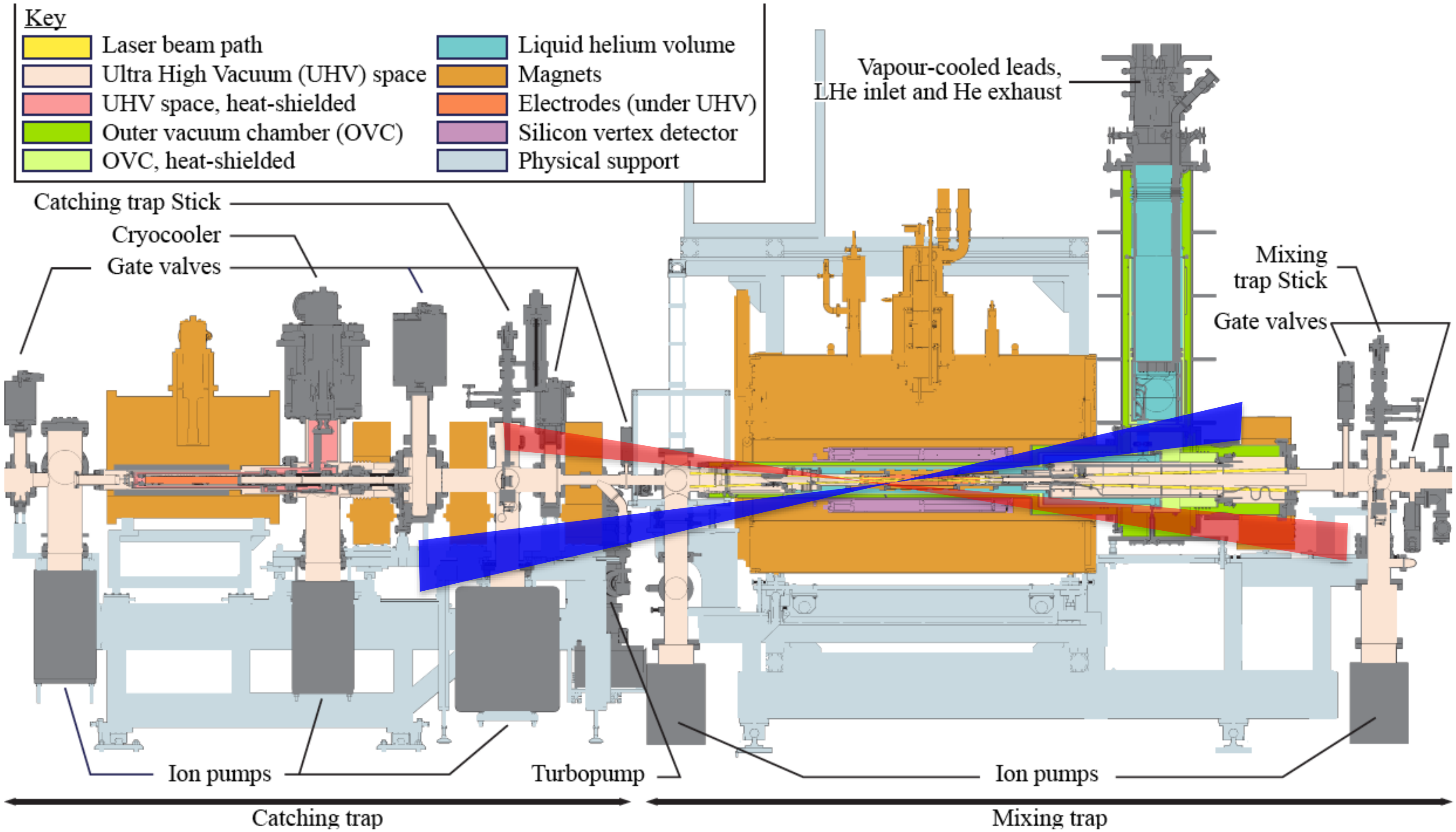
C. Amole[1], M. D. Ashkezari[2], M. Baquero-Ruiz[3], W. Bertsche[4,5,6], P. D. Bowe[7], E. Butler[8], A. Capra[1], C. L. Cesar[9], M. Charlton[4], A. Deller[4], P. H. Donnan[10], S. Eriksson[4], J. Fajans[3,11], T. Friesen[12], M. C. Fujiwara[12,13], D. R. Gill[13], A. Gutierrez[14], J. S. Hangst[7], W. N. Hardy[14,15], M. E. Hayden[2], A. J. Humphries[4], C. A. Isaac[4], S. Jonsell[16], L. Kurchaninov[13], A. Little[3], N. Madsen[4], J. T. K. McKenna[17], S. Menary[1], S. C. Napoli[4], P. Nolan[17], K. Olchanski[13], A. Olin[13,18], P. Pusa[17], C. Ø. Rasmussen[7], F. Robicheaux[10], E. Sarid[19], C. R. Shields[4], D. M. Silveira[20]†, S. Stracka[13], C. So[3], R. I. Thompson[12], D. P. van der Werf[4] & J. S. Wurtele[3,11]

The ALPHA-2 Experiment



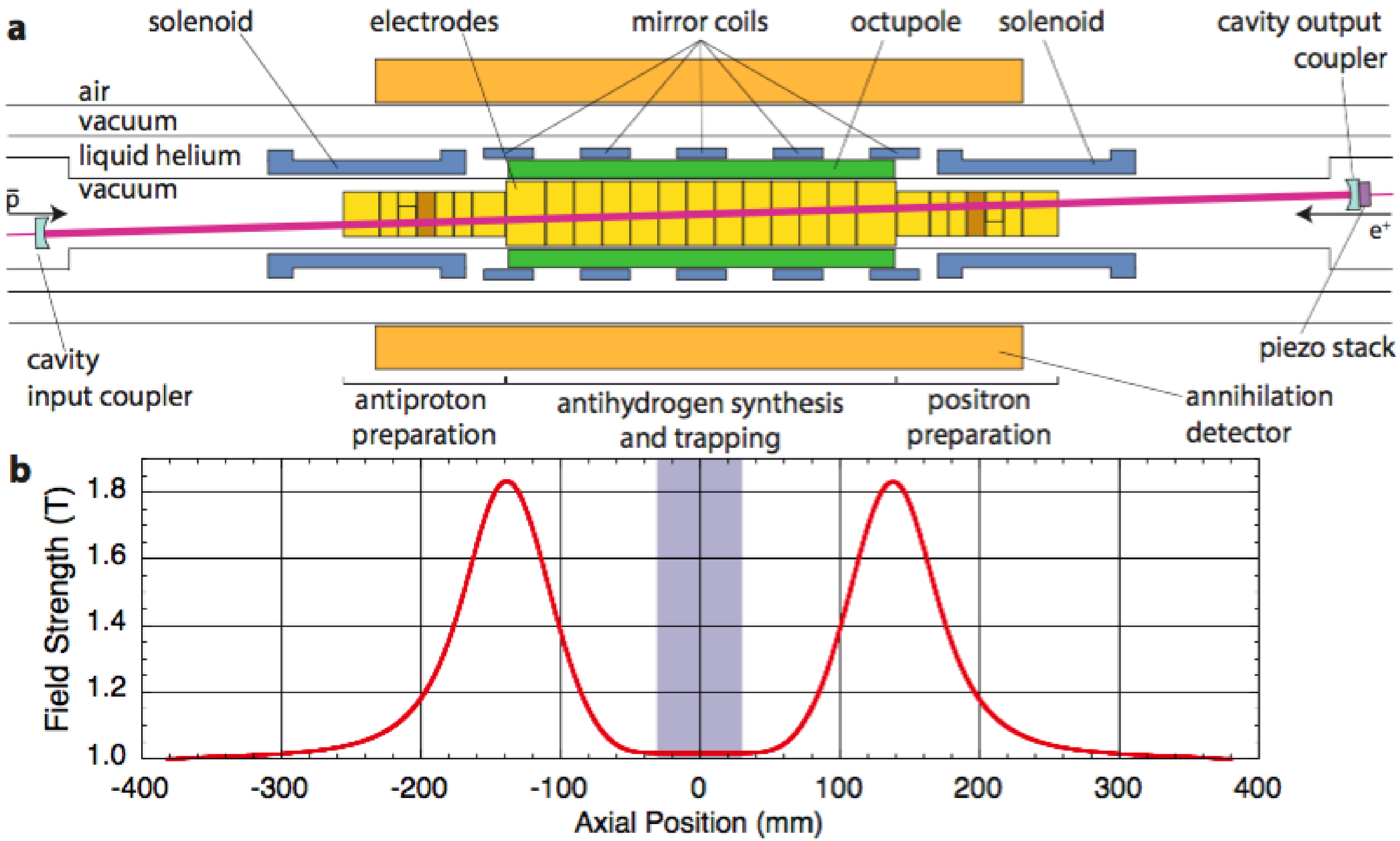
Current Activities: ALPHA-2

- Modularised to allow laser access (2012 – present)
- Anticipating ELENA



ALPHA-2 Internals

- Penning-Malmberg plasma trap
- Octupole – based Ioffe-Pritchard Atom trap
- Silicon Vertex Detector



ALPHA-2 well underway

- 1S – 2S transition observed (2016)!
  - 1-sided bound – working on line shape
- Critical to the success of this experiment was consistently high antihydrogen trapping rate
- Improved control and knowledge of charged ingredients (antiprotons and leptons) was (and remains) critical to this result

NATURE | LETTER Accelerated Article Preview

Observation of the 1S–2S transition in trapped antihydrogen

M. Ahmadi, B. X. R. Alves, C. J. Baker, W. Bertsche, E. Butler, A. Capra, C. Carruth, C. L. Cesar, M. Charlton, S. Cohen, R. Collister, S. Eriksson, A. Evans, N. Evetts, J. Fajans, T. Friesen, M. C. Fujiwara, D. R. Gill, A. Gutierrez, J. S. Hangst, W. N. Hardy, M. E. Hayden, C. A. Isaac, A. Ishida, M. A. Johnson + *et al.*

Affiliations

Nature (2016) | doi:10.1038/nature21040

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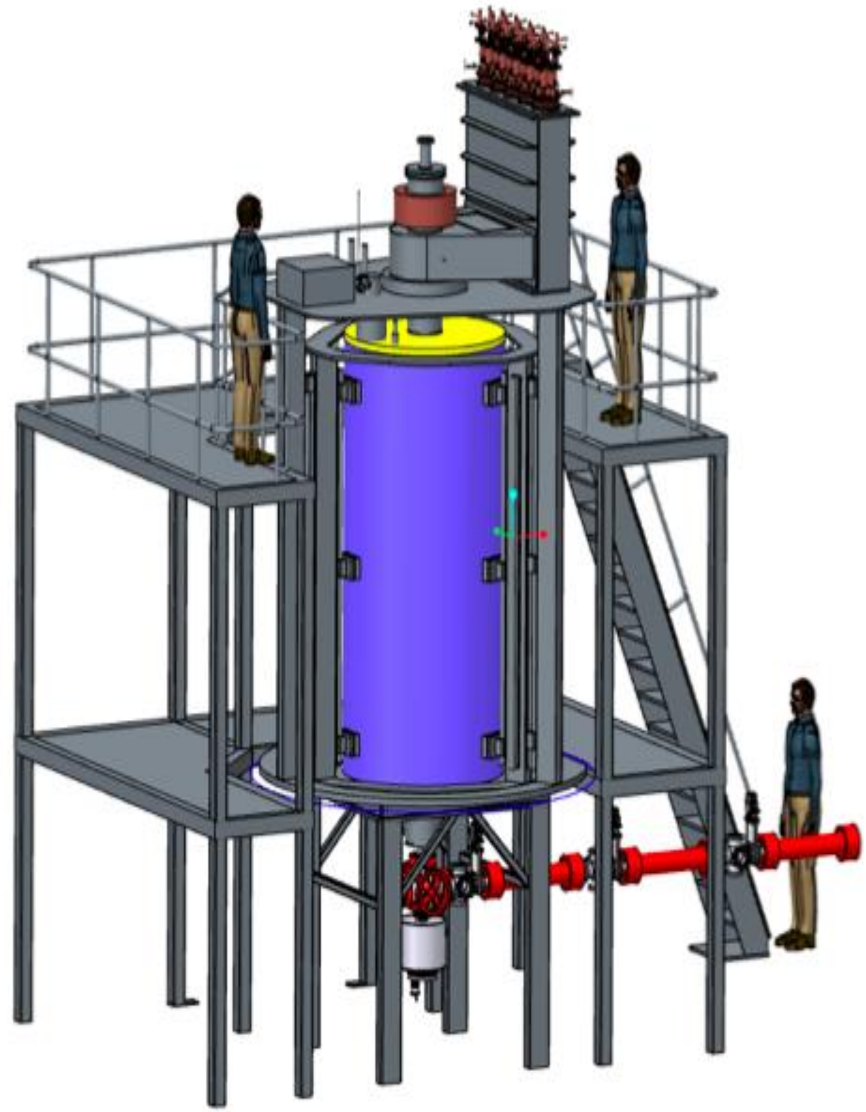
The Cockcroft Institute of Accelerator Science and Technology

Future: ALPHA-g: Antimatter gravitation

- ~ 2 m tall antihydrogen trap
- Release + detect falling Hbar
- Measure sign of gbar
  - ~ 1 year
- Measure gbar @ 1%
  - 4 - 5 years

- Magnetic field is a the critical systematic



Future: ELENA

- AD: ~ $3 \cdot 10^7$ at 5.3 MeV
  - Trap experiments using foil degraders: < .1% efficiency
  - ~ 250,000 antiprotons / spill

- ELENA: ~ $1 \cdot 10^7$ at 100 keV: up to 50% efficiency
  - ***~ 10 Million*** antiprotons / spill

- 24-hour antiproton availability
  - Rapid experiment switching
  - Multiple-bunch extraction

Challenges posed by ELENA

- A vast increase in the number of antiprotons available in ALPHA presents significant physics challenges
  - Antiproton space charge becomes a significant player
  - Current trend towards mixing with fewer antiprotons
    - May be due to lack of control / stability

- Utilizing a high antiproton uptime requires improved online monitoring and control
  - Operating within the constraints of manpower

Proposal to address these issues

- **Consistent antiproton capture and cooling**
  - Detailed simulation and analysis of degrading and re-capture dynamics from ELENA

- **Non-destructive antiproton plasma diagnostics** [1]: Characterize antiproton number
  - Design penning trap for optimal monitoring of antiproton number
  - Online diagnostic based on monitoring of plasma mode frequency and response (Number, aspect ratio)

- **Non-destructive extraction current measurements**
  - Downsteam single-pass current measurement (from CT to experiments)

1) M. Amoretti, et al. DOI: http://dx.doi.org/10.1063/1.1591187 (2003)

Continuing on…

- This has applications to improved **precision measurement of magnetic field measurements** [1]
  - Increased sensitivity → smaller plasmas → better local magnetic field measurements

- *Improved magnetic field measurements address systematics in magnetic field critical to higher precision microwave spectroscopy, optical spectroscopy, and gravitational measurements.*

- Extraction studies can be extended to include the possibility of developing **a zero-(magnetic) field antiproton source for use in future precision measurements**

1) C. Amole, et al. *New Journal of Physics. 16* 013037 (2014)

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Secondments

- STEL
  - Cryogenic electronics

- CERN / Aarhus
  - Integration of diagnostics with antihydrogen experiments

Training

- Fellow will earn a PhD from the University of Manchester
- Fellow will attend network training events,
- Fellow attend the extensive courses in the University of Manchester postgraduate course
  - Professional development
- Fellow will present findings in conferences
- Fellow will write at least one publication on the integration of a non-destructive charge measurement system to an antiproton catching trap.

ESR outcomes

- Plasma physics and simulation for trapped, charged plasmas
- Design and control of charged particle traps
- Design and integration of cryogenic diagnostics in said traps
- Expert in low energy charge sources for use in antimatter experiments