THE ALPHA COLLABORATION

Aarhus University, Denmark

University of British Columbia, Canada

University of California Berkeley, USA

University of Calgary, Canada

Imperial College London

University of Liverpool, UK

University of Manchester, UK

NRCN - Nuclear Res. Center Negev, Israel

Purdue University, West Lafayette, USA

Federal University of Rio de Janeiro, Brazil

Stockholm University, Sweden

Simon Fraser University, Canada `

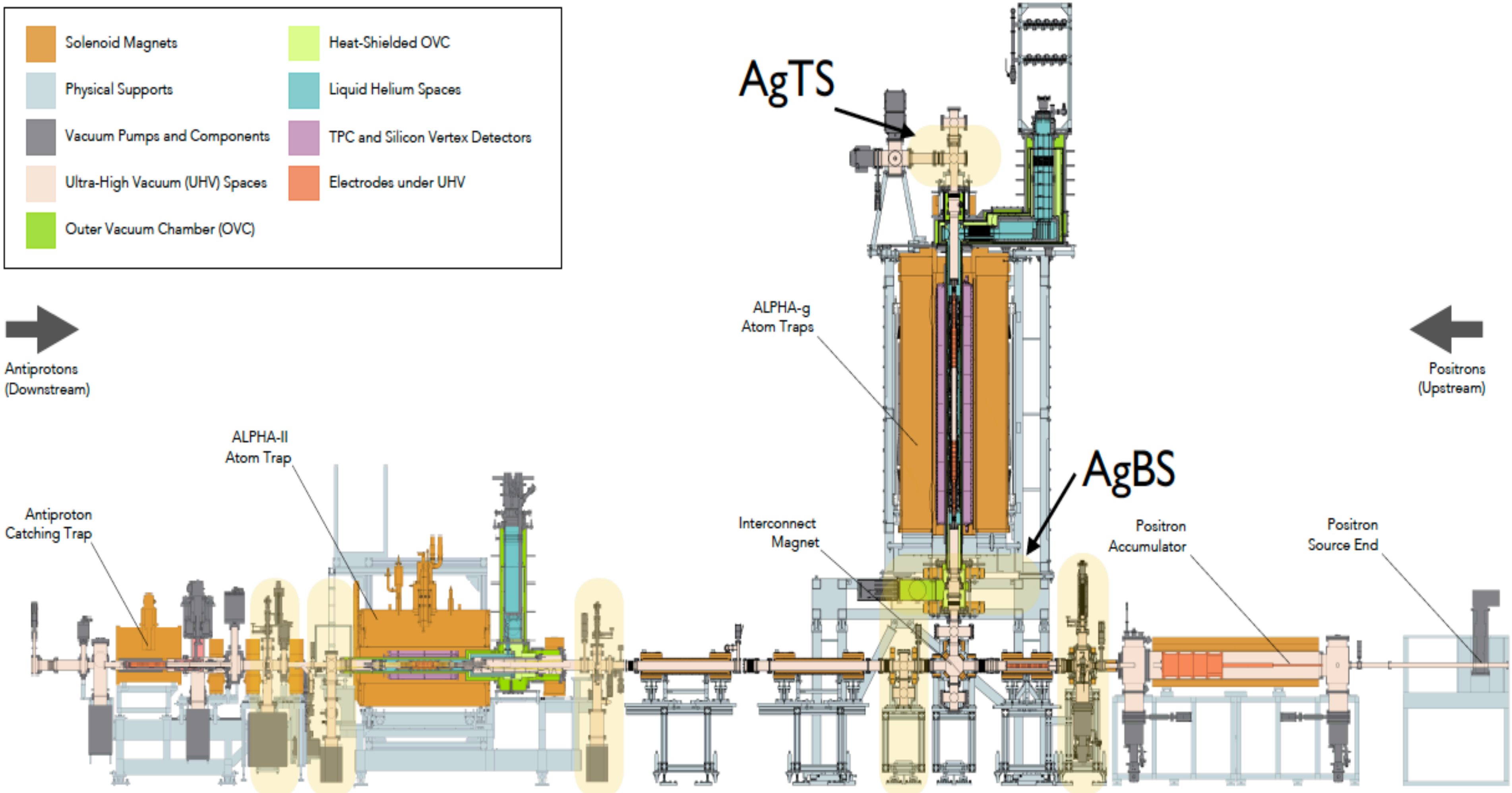
TRIUMF, Canada

University of Wales Swansea, UK

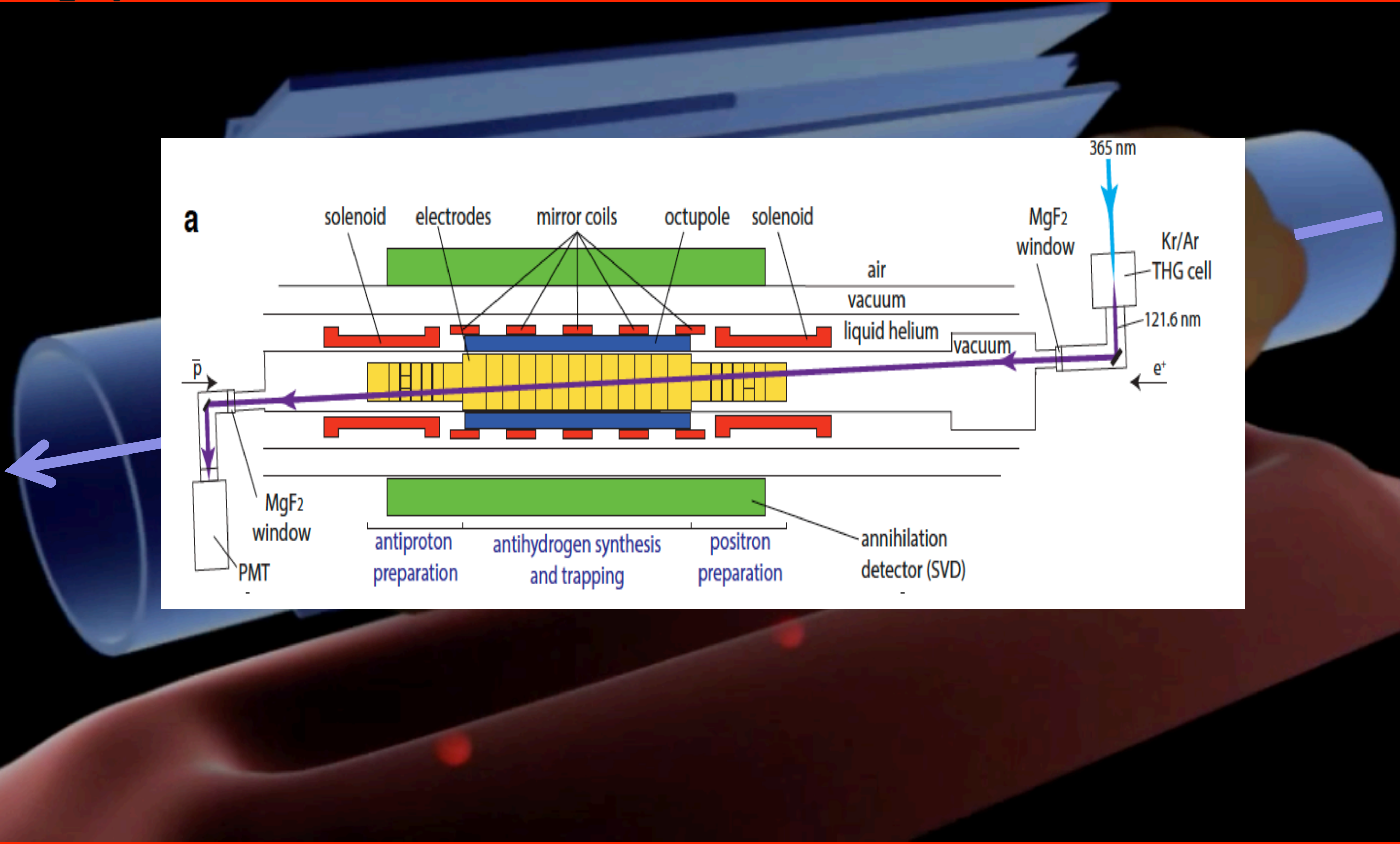
Cockcroft Institute, UK

York University, Canada

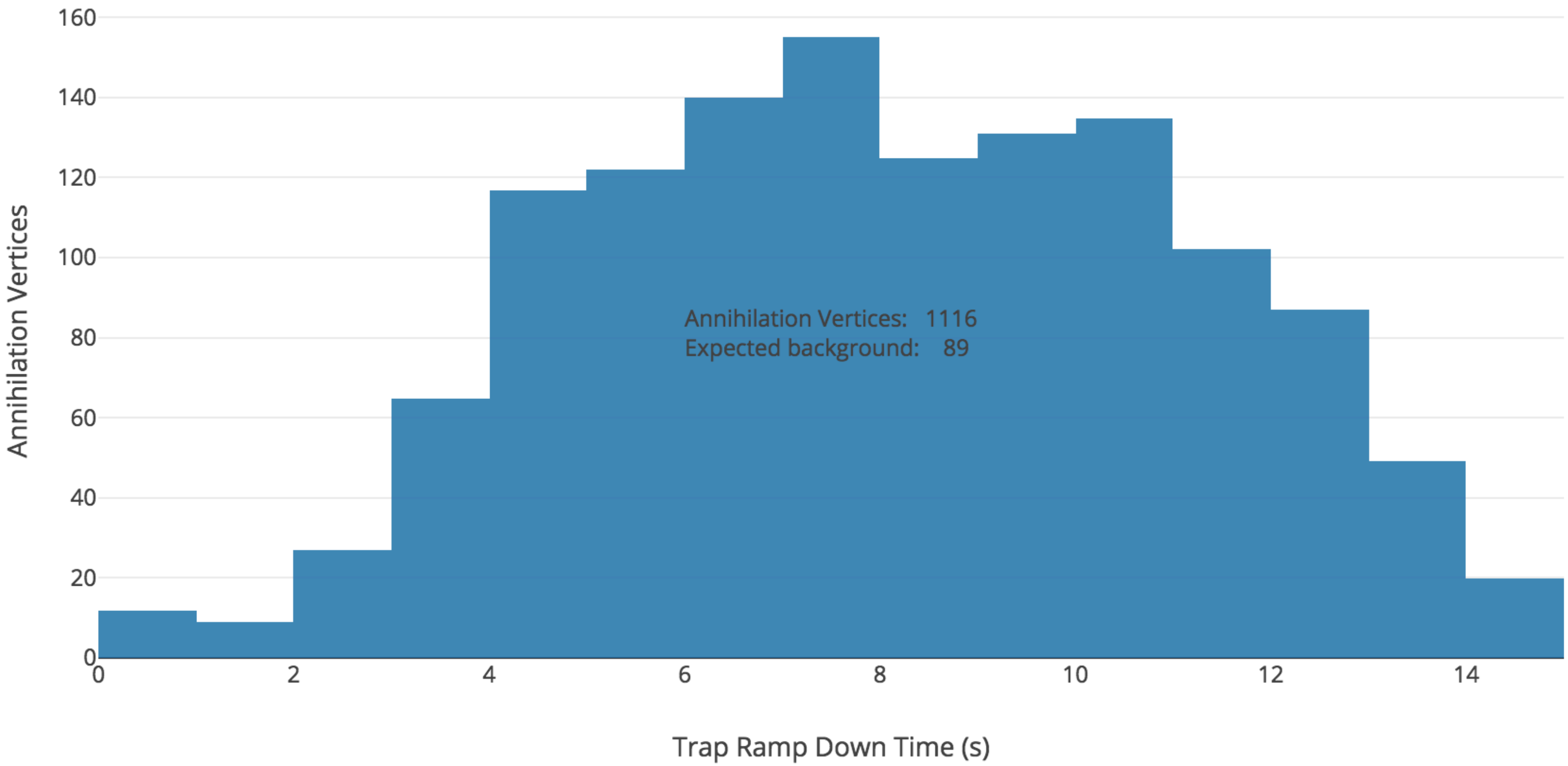
ALPHA-2 and ALPHA-g



ALPHA Geometry – PULSED Lyman-alpha laser (121 nm)



RECALL: Accumulating Antihydrogen Atoms 18 December 2017



6 hour accumulation, > 1000 antihydrogen atoms trapped

this is now fairly routine

Data Published in 2018

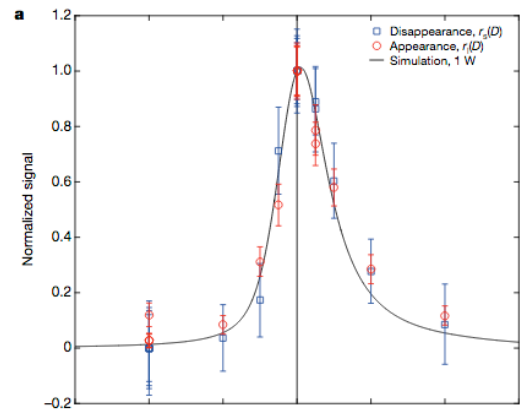
LETTER

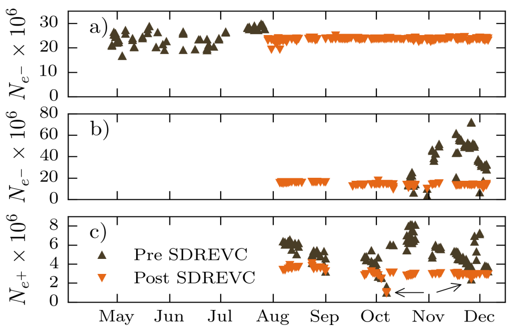
OPEN

https://doi.org/10.1038/s41586-018-0017-2

Characterization of the 1S–2S transition in antihydrogen

M. Ahmadi[1], B. X. R. Alves[2], C. J. Baker[3], W. Bertsche[4,5], A. Capra[6], C. Carruth[7], C. L. Cesar[8], M. Charlton[3], S. Cohen[9], R. Collister[6], S. Eriksson[3], A. Evans[10], N. Evetts[11], J. Fajans[7], T. Friesen[2], M. C. Fujiwara[6], D. R. Gill[6], J. S. Hangst[2]*, W. N. Hardy[11], M. E. Hayden[12], C. A. Isaac[3], M. A. Johnson[4,5], J. M. Jones[3], S. A. Jones[2,3], S. Jonsell[13], A. Khramov[6], P. Knapp[3], L. Kurchaninov[6], N. Madsen[3], D. Maxwell[3], J. T. K. McKenna[6], S. Menary[14], T. Momose[11], J. J. Munich[12], K. Olchanski[6], A. Olin[6,15], P. Pusa[1], C. Ø. Rasmussen[2], F. Robicheaux[16], R. L. Sacramento[8], M. Sameed[3,4], E. Sarid[17], D. M. Silveira[8], G. Stutter[2], C. So[10], T. D. Tharp[18], R. I. Thompson[10], D. P. van der Werf[3,19] & J. S. Wurtele[7]





PHYSICAL REVIEW LETTERS **120,** 025001 (2018)

Editors' Suggestion

Enhanced Control and Reproducibility of Non-Neutral Plasmas

M. Ahmadi,[1] B. X. R. Alves,[2] C. J. Baker,[3] W. Bertsche,[4,5] A. Capra,[6] C. Carruth,[7,*] C. L. Cesar,[8] M. Charlton,[3] S. Cohen,[9] R. Collister,[6] S. Eriksson,[3] A. Evans,[10] N. Evetts,[11] J. Fajans,[7] T. Friesen,[2] M. C. Fujiwara,[6] D. R. Gill,[6] J. S. Hangst,[2] W. N. Hardy,[11] M. E. Hayden,[12] C. A. Isaac,[3] M. A. Johnson,[4] S. A. Jones,[2,3] S. Jonsell,[13] L. Kurchaninov,[6] N. Madsen,[3] M. Mathers,[14] D. Maxwell,[3] J. T. K. McKenna,[6] S. Menary,[14] T. Momose,[15] J. J. Munich,[12] K. Olchanski,[6] A. Olin,[6,16] P. Pusa,[1] C. Ø. Rasmussen,[2] F. Robicheaux,[17] R. L. Sacramento,[8] M. Sameed,[3,4] E. Sarid,[18] D. M. Silveira,[8] C. So,[6,10] G. Stutter,[2] T. D. Tharp,[19] J. E. Thompson,[14] R. I. Thompson,[6,10] D. P. van der Werf,[3,20] and J. S. Wurtele[7]

(ALPHA Collaboration)

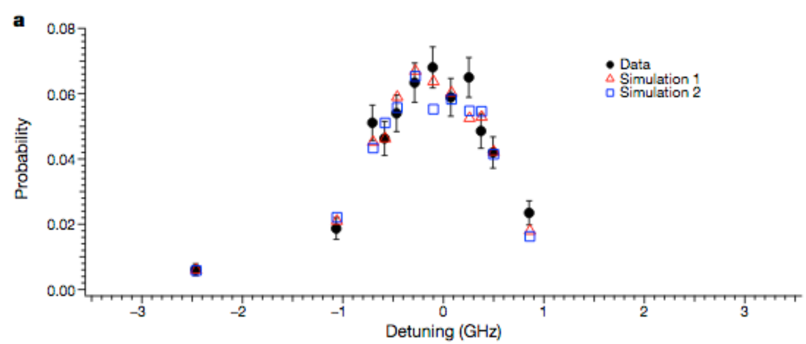
LETTER

OPEN

https://doi.org/10.1038/s41586-018-0435-1

Observation of the 1S–2P Lyman-α transition in antihydrogen

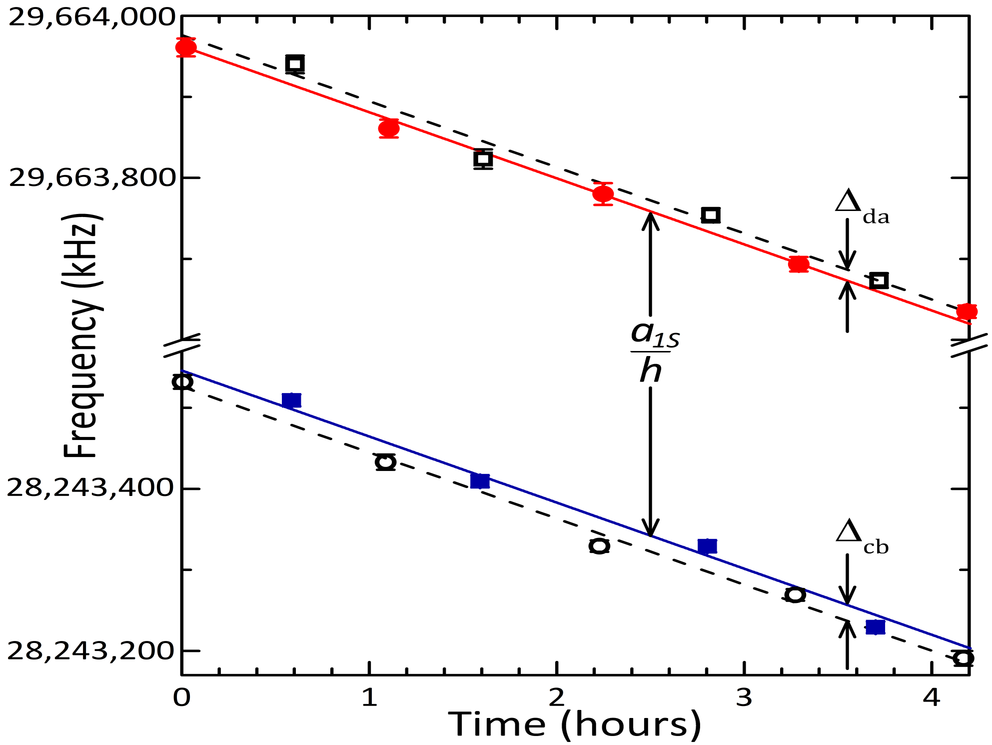
M. Ahmadi[1], B. X. R. Alves[2], C. J. Baker[3], W. Bertsche[4,5], A. Capra[6], C. Carruth[7], C. L. Cesar[8], M. Charlton[3], S. Cohen[9], R. Collister[6], S. Eriksson[3], A. Evans[10], N. Evetts[11], J. Fajans[7], T. Friesen[2,10], M. C. Fujiwara[6]*, D. R. Gill[6], J. S. Hangst[2]*, W. N. Hardy[11], M. E. Hayden[12], E. D. Hunter[7], C. A. Isaac[3], M. A. Johnson[4,5], J. M. Jones[3], S. A. Jones[2,3], S. Jonsell[13], A. Khramov[6], P. Knapp[3], L. Kurchaninov[6], N. Madsen[3], D. Maxwell[3], J. T. K. McKenna[6], S. Menary[14], J. M. Michan[6,15], T. Momose[11,16]*, J. J. Munich[12], K. Olchanski[6], A. Olin[6,17], P. Pusa[1], C. Ø. Rasmussen[2], F. Robicheaux[18], R. L. Sacramento[8], M. Sameed[4], E. Sarid[19], D. M. Silveira[8], D. M. Starko[14], G. Stutter[2], C. So[10], T. D. Tharp[20], R. I. Thompson[6,10], D. P. van der Werf[3,21] & J. S. Wurtele[7]

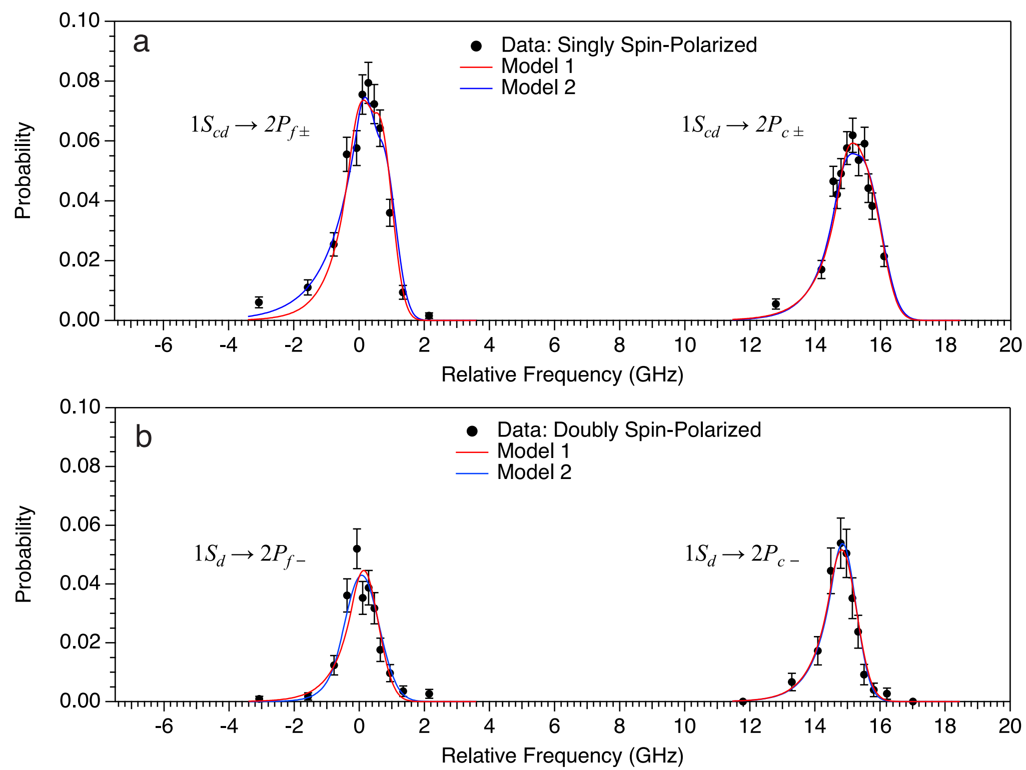


results yet to be published - 2017 run

determination of the GSHF splitting to 9 ppm (submitted to *Nature)*

investigation of the fine structure (and Lamb shift) in antihydrogen (submitted to *Nature*)

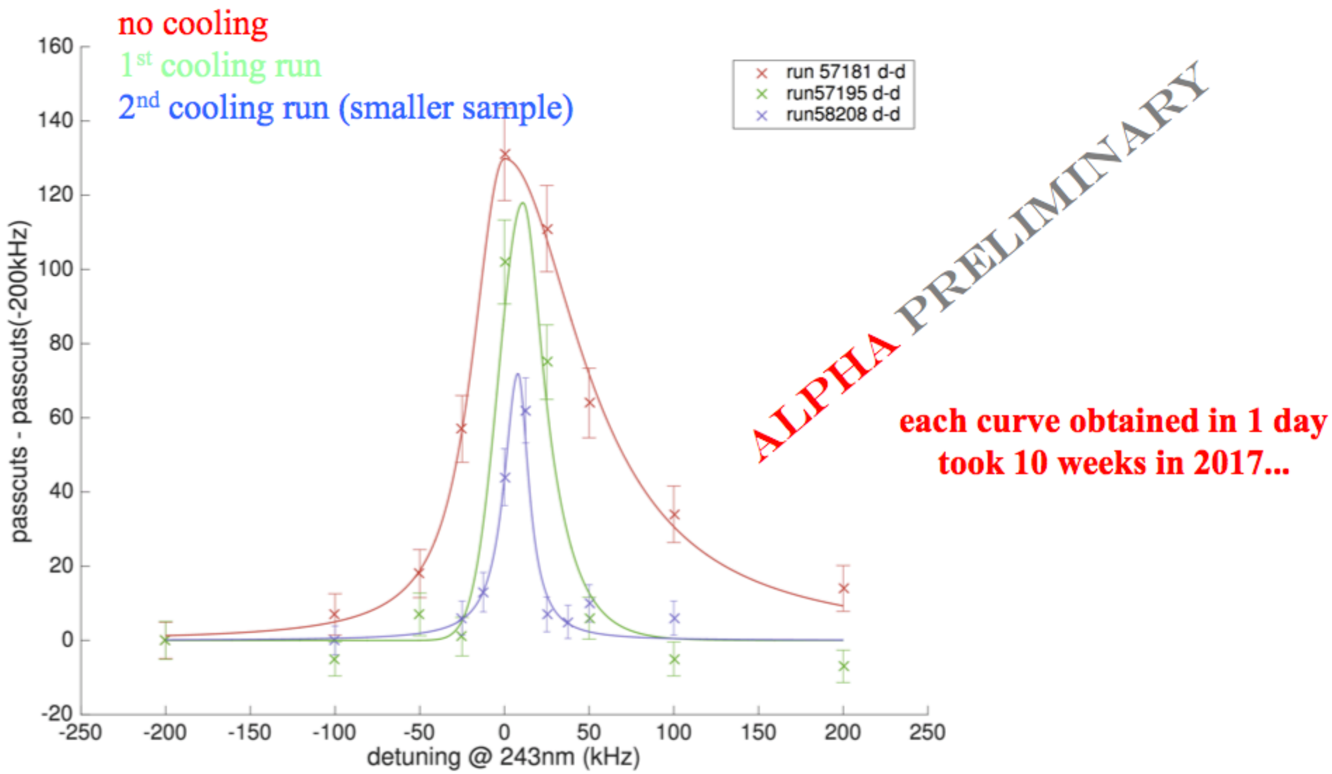




results yet to be published - 2018 run

laser cooling of trapped antihydrogen (manuscript under internal review)

1S-2S spectroscopy of laser cooled antihydrogen (manuscript under internal review)

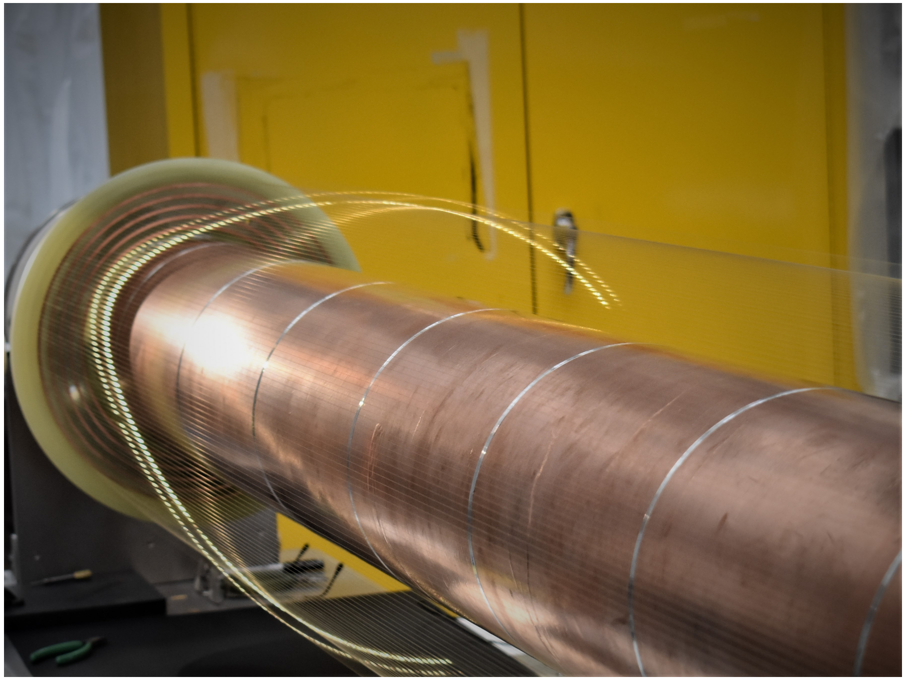


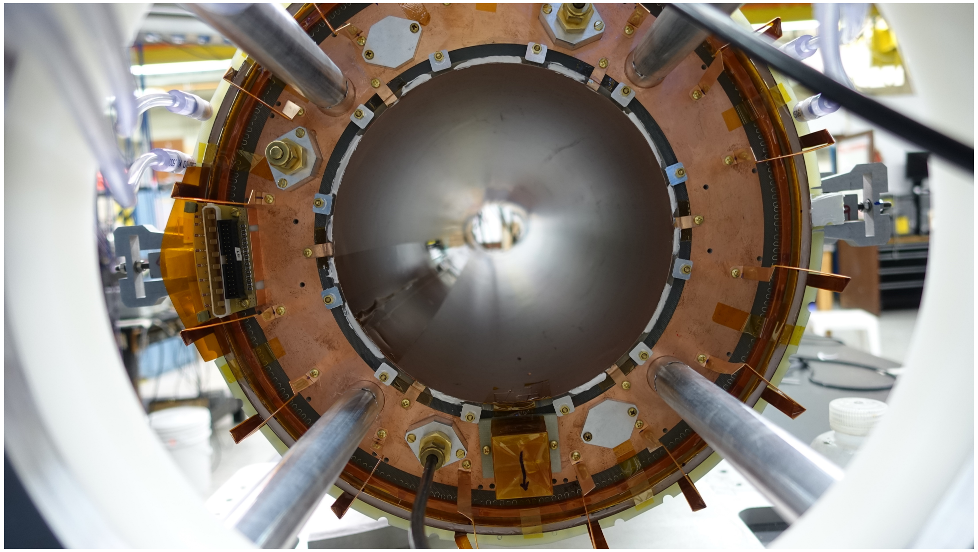
LS2 Plans in Brief

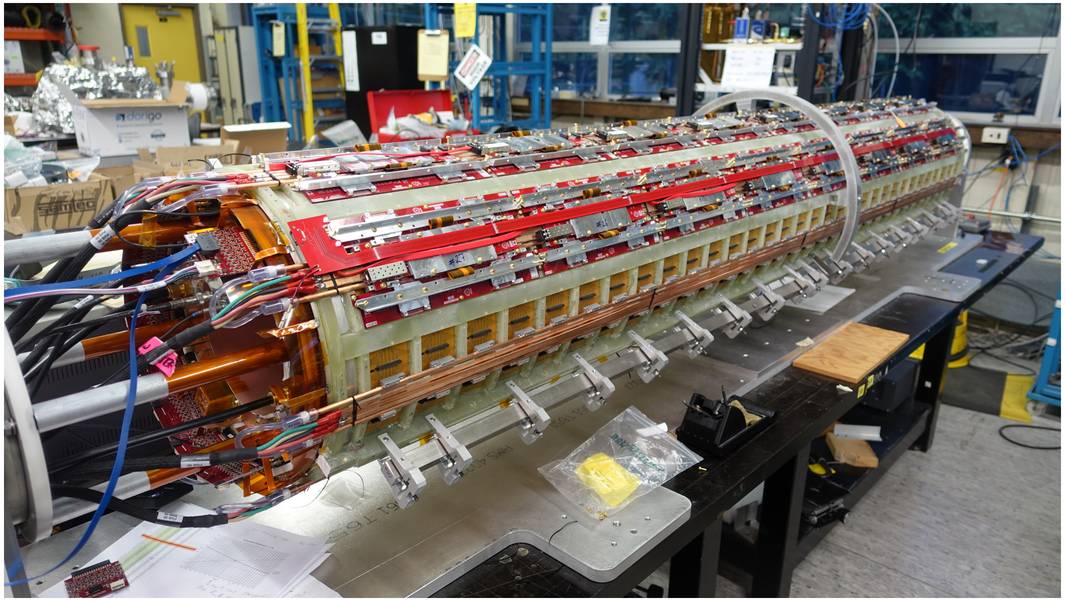
- install second set of atom trap magnets in the ALPHA-g cryostat (return to BNL for winding)
- modifications to ALPHA-g external solenoid and ALPHA-g cryostat, 2^{nd} Penning trap
- modify catching trap for operation with ELENA
- cooling of positrons by laser cooled Be ions
- generation of protons in the catching trap
- ALPHA-3: upgrade of the spectroscopy experiment (in planning phase; S. Eriksson)
  - new laser for 1S-2S
  - new frequency comb...
  - improved time standards: hydrogen maser and a Cs fountain clock (1.5 MGBP)
  - new metrology lab in 393 (F. Butin)
  - new optical systems, cavities; for new wavelengths
  - *in situ* fluorescence detection (cryo/vacuum tests in progress)

We are also studying putting hydrogen in both machines.

ALPHA-g Radial TPC (TRIUMF)

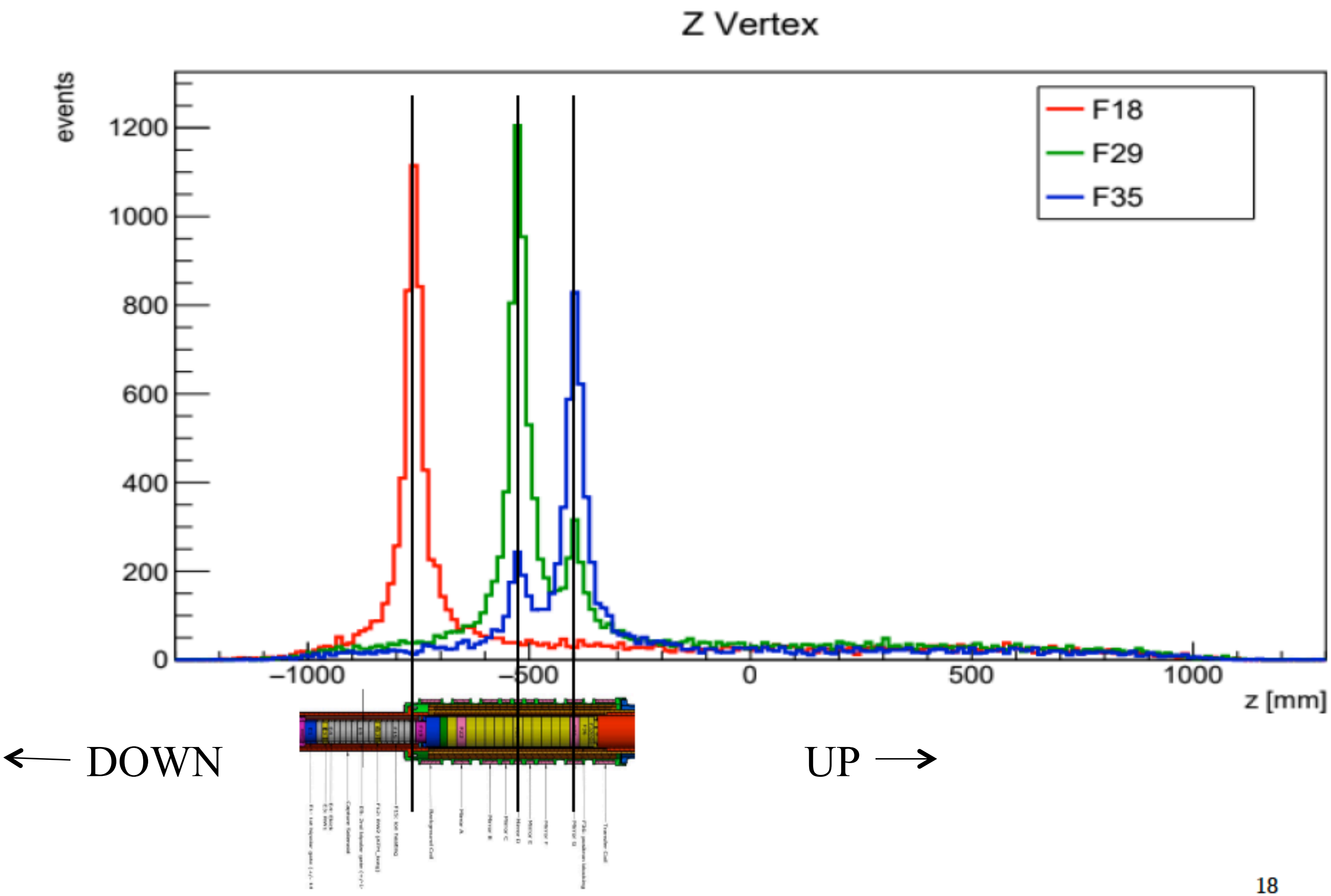


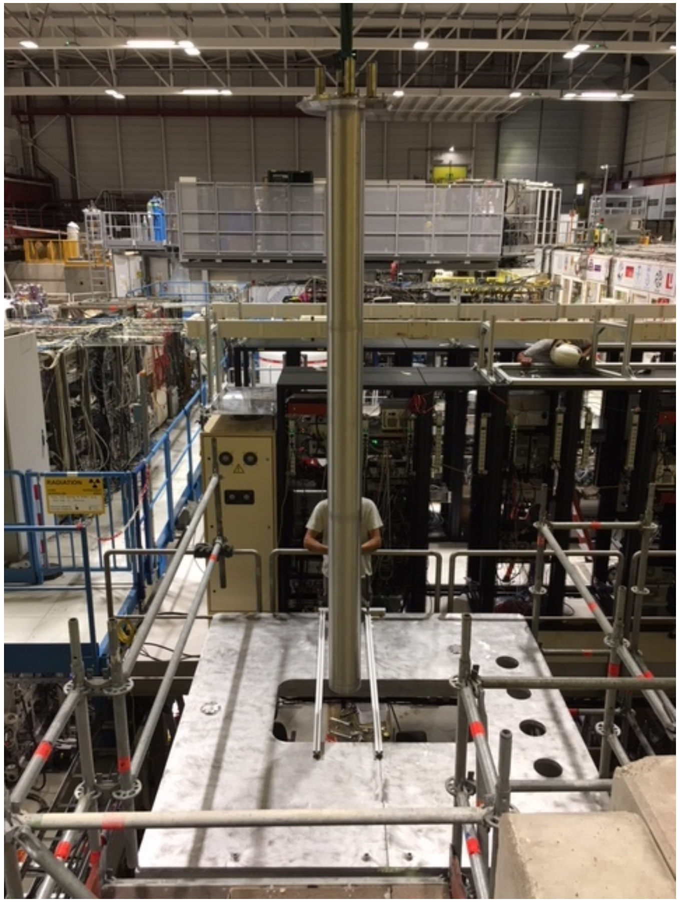


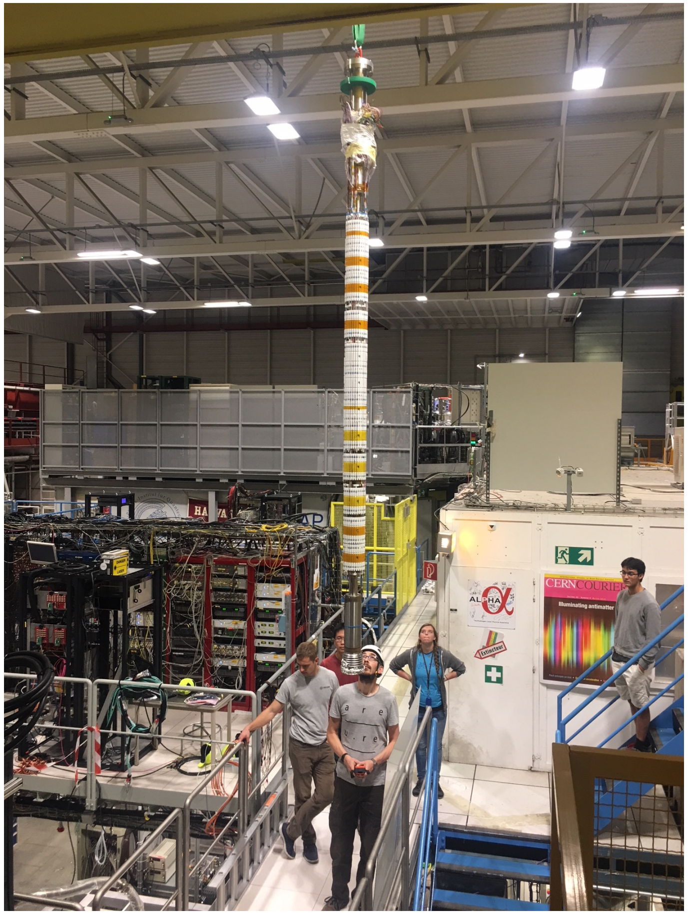


currently at TRIUMF for geometry checks/corrections

Antiproton Annihilations observed in ALPHA-g







external solenoid

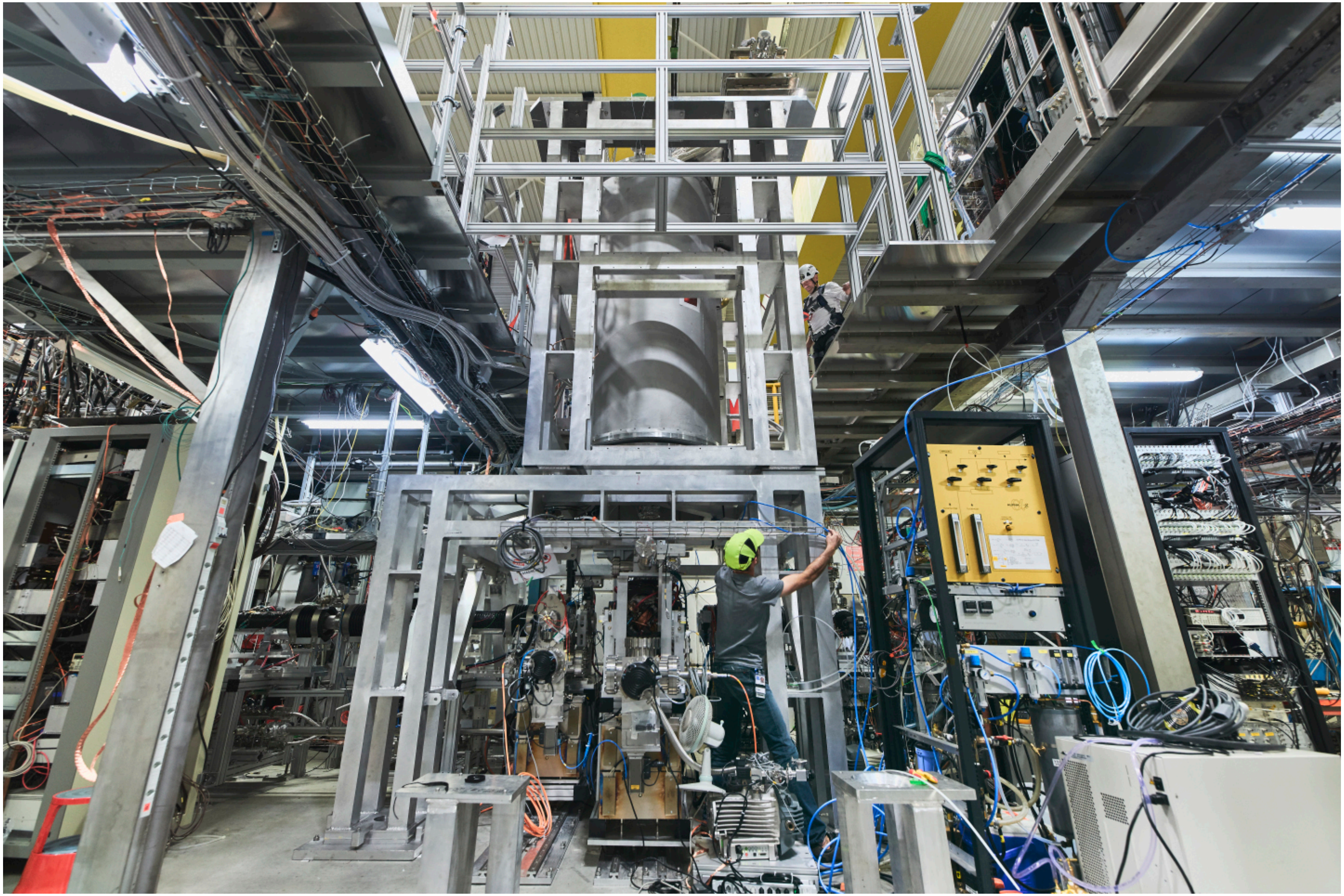
to be shimmed

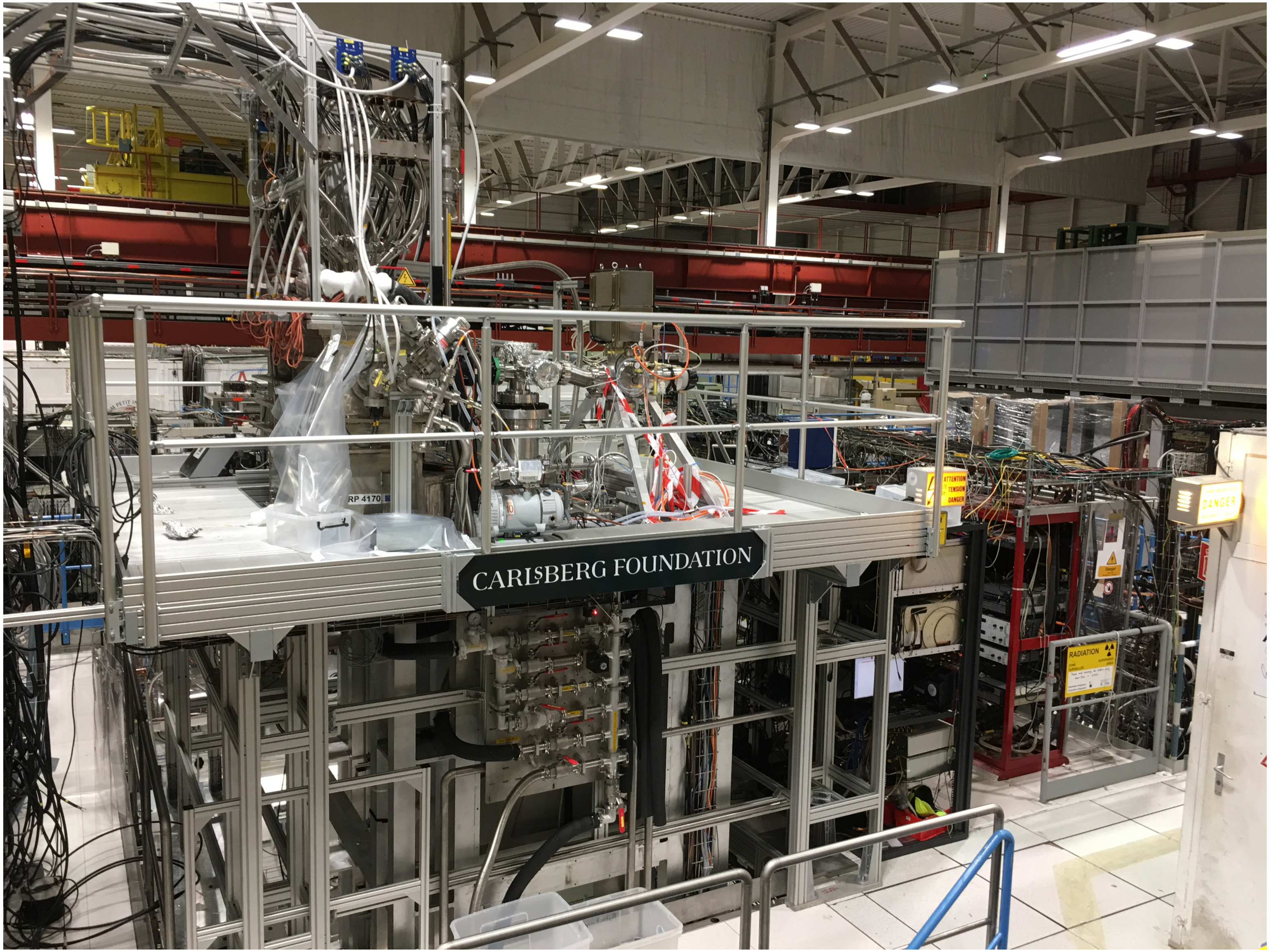
cryostat OVC

modifications underway

Atom trap magnets

at BNL now




CARLSBERG FOUNDATION
RP 4170
DANGER
RADIATION

ALPHA-g Status – end of 2018

- the apparatus planned for 2018 was installed
- we trapped antiprotons, positrons and electrons
- multiple new diagnostic stations commissioned (MCP, Faraday cup, electron guns) in beamline and ALPHA-g
- 12 days with antiproton beam
- antiproton annihilations imaged in the rTPC; lots of cosmic data accumulated
- control system, helium system, DAQ functional
- atom trap SC magnets not yet commissioned
- UHV system was marginal (not enough baking time) antihydrogen not yet produced...

Physics Perspectives

We will start up in 2021 by prioritizing commissioning and measurements with ALPHA-g. The first goal is to determine the sign of the gravitational force.

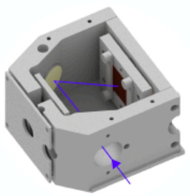
The ALPHA-3 physics program will focus on efforts to achieve hydrogen-like precision in the 1S-2S spectroscopy, and on efforts to address other spectral lines to study the Lamb shift, the antiproton charge radius, etc.

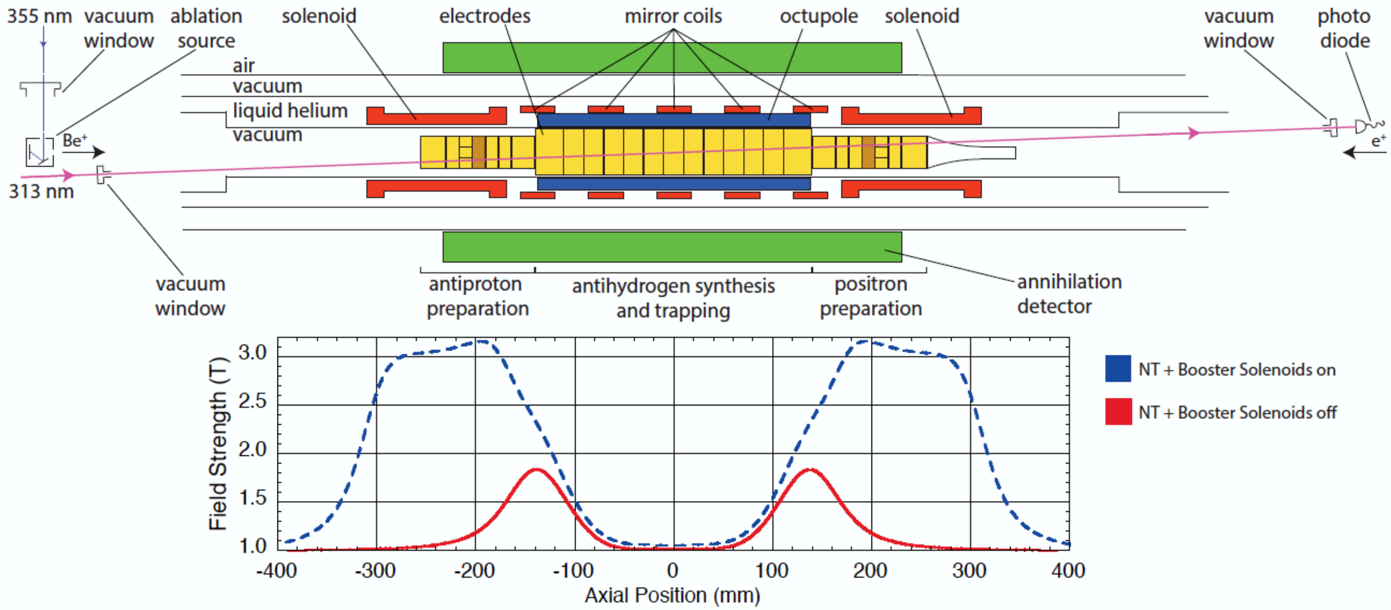
The possibility of directly exciting the GSHF transition is also under consideration.

We intend to have both machines ready for the 2021 start-up.

Be+ laser-cooling

- Be^+ can be loaded from an ablation source located on axis external to the cryogenic region.
- Laser-cooled to ~200mK

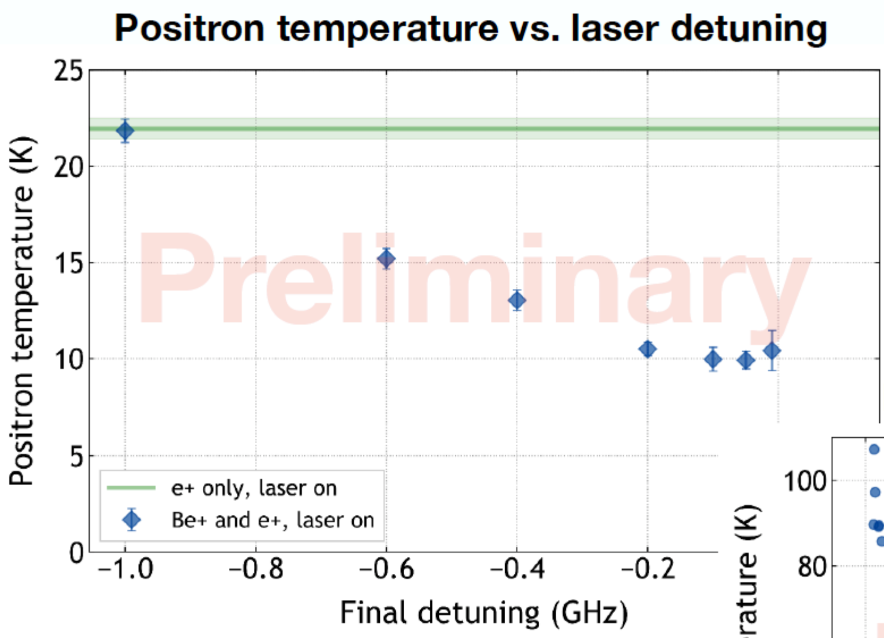


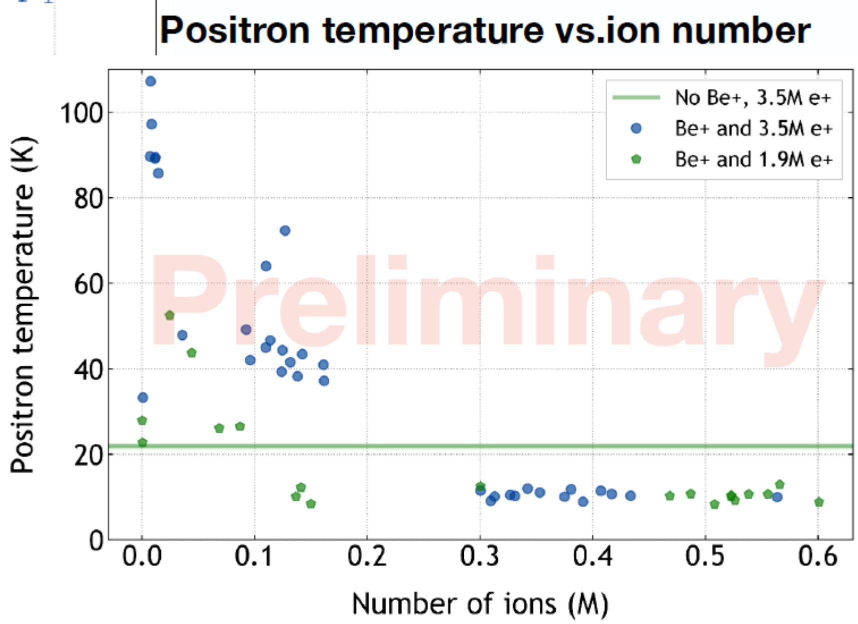


- **production of *cold* H-bar depends strongly on e^+ temperature**
- **typically 15 − 20 K until now**
- **use laser-cooled Be ions to sympathetically cool positrons**
- **ALPHA-2 has been operating all year, when He has been available**

Sympathetic cooling of e+

N. Madsen, D. Maxwell, J. Jones, J. Peszka

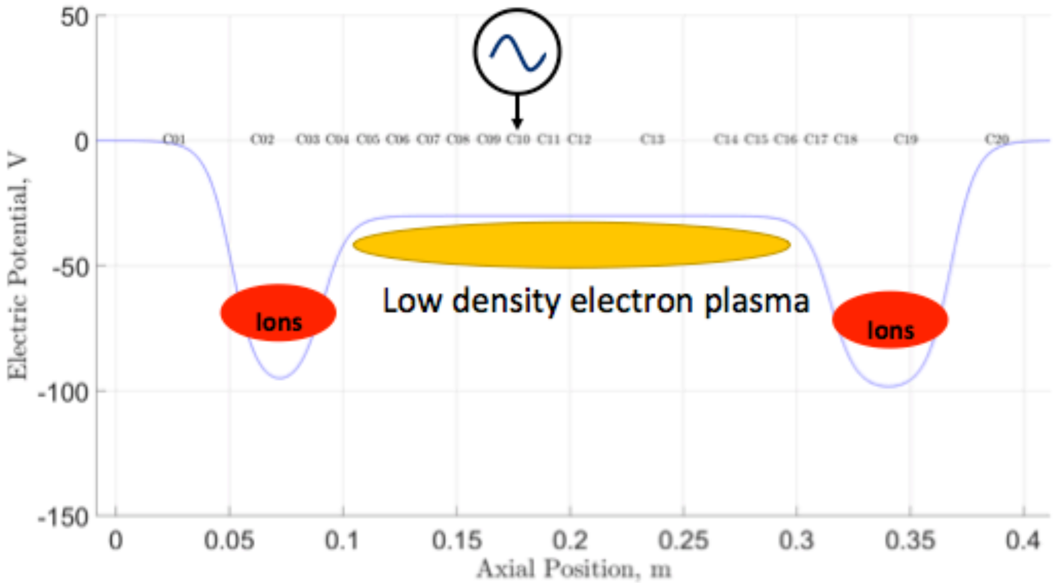


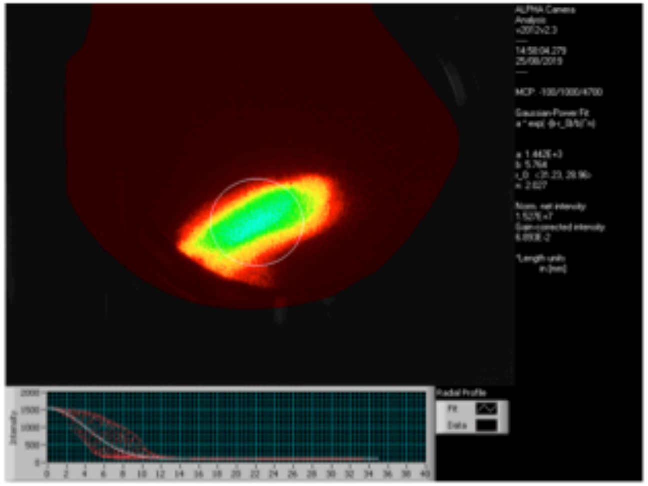


Generating *protons* in the ALPHA catching trap

oh, forgot, need to ruin the vacuum first...

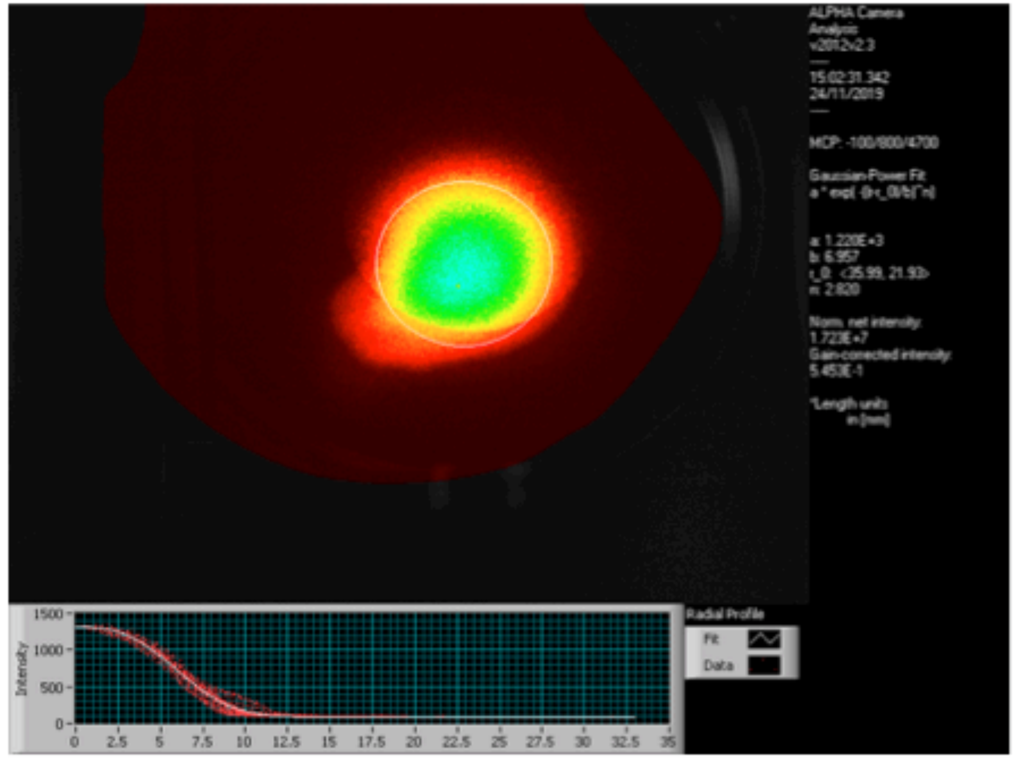
- Load roughly 100 Million electrons
- Hold in long well, to reduce plasma density (increase thermalization time)
- Apply 1 Volt peak-to-peak White noise to electrode 10
- Driven electrons create positive ions, which collect in side wells





- then: use positrons to cool the ions
- use rotating wall to compress the mixture
- use autoresonance to separate the protons
- re-cool and compress with more positrons

Purified plasma with second shot of positrons

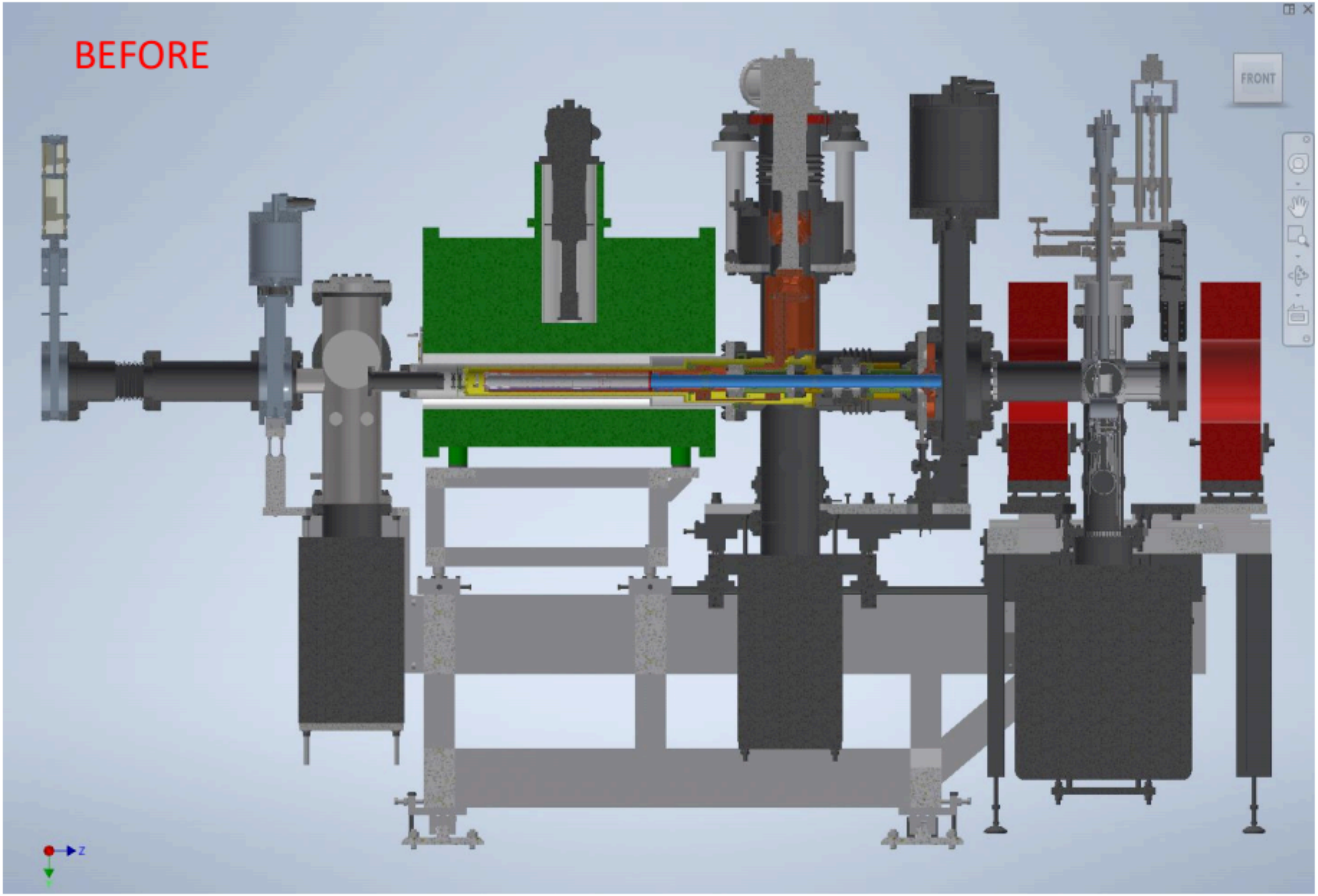


Can be used for:

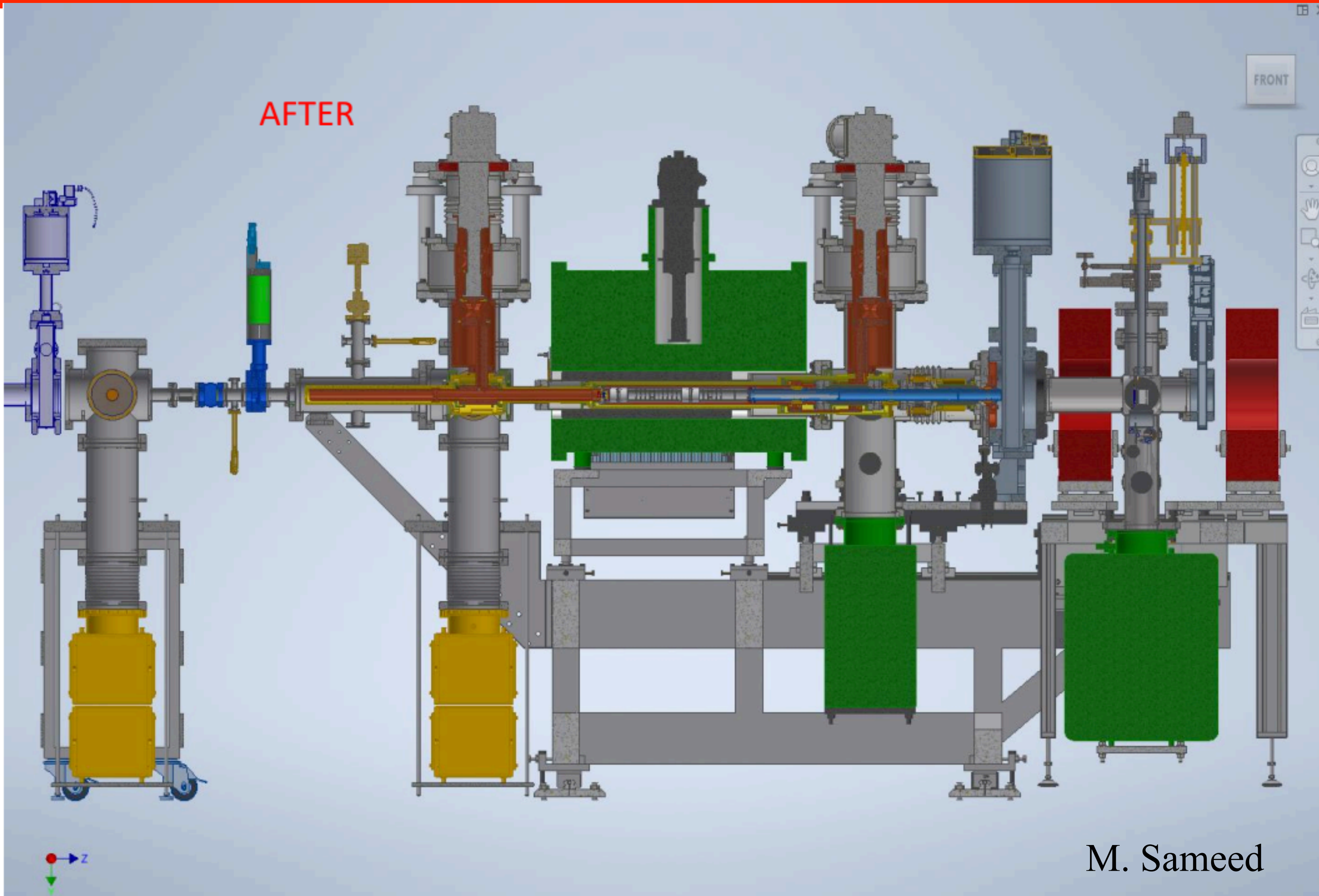
- studies of antiproton transfer between ALPHA experiments
- synthesis of cold hydrogen

W. Bertsche, P. Mullan and S. Fabbri

Existing Catching Trap



Catching Trap for ELENA beam



Other work in progress at CERN

- major improvement to annihilation event reconstruction speed (J. McKenna)
- ALPHA-g cryostat (P. Grandemange, G. Stutter)
- NMR magnetometry (N. Evetts)
- ALPHA-g magnet controls; QPS (D. Hodgkinson, P. Granum, D. Maxwell)
- Penning trap fabrication improvements (A. Cridland, A. Powell)
- thin foils for catching trap (M. Sameed, S. Fabbri)
- laser system improvements (S. Jones)
- new ALPHA-g magnets, and all of the above: C. Rasmussen

Disclaimer

ars TECHNICA

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AXION-AND-OFF —

Dark matter link to regular matter's dominance fails to show up

If axions influence antimatter's behavior, the effects are tiny.

JOHN TIMMER - 11/16/2019, 2:30 PM

Maximilien Brice, Julien Ordan/CERN

Enlarge / Given how messy a typical physics lab is, CERN is just as likely to lose the antimatter it intends to store.

Our lab is NOT messy!