THE ALPHA COLLABORATION

Aarhus University, Denmark

University of Brescia, Italy

University of British Columbia, Canada

University of California Berkeley, USA

University of Calgary, Canada

University of Groningen, Holland

Pisa and Pavia Italy

University of Manchester, UK

NRCN - Nuclear Res. Center Negev, Israel

Purdue University, USA

Federal University of Rio de Janeiro, Brazil

Stockholm University, Sweden

Simon Fraser University, Canada `

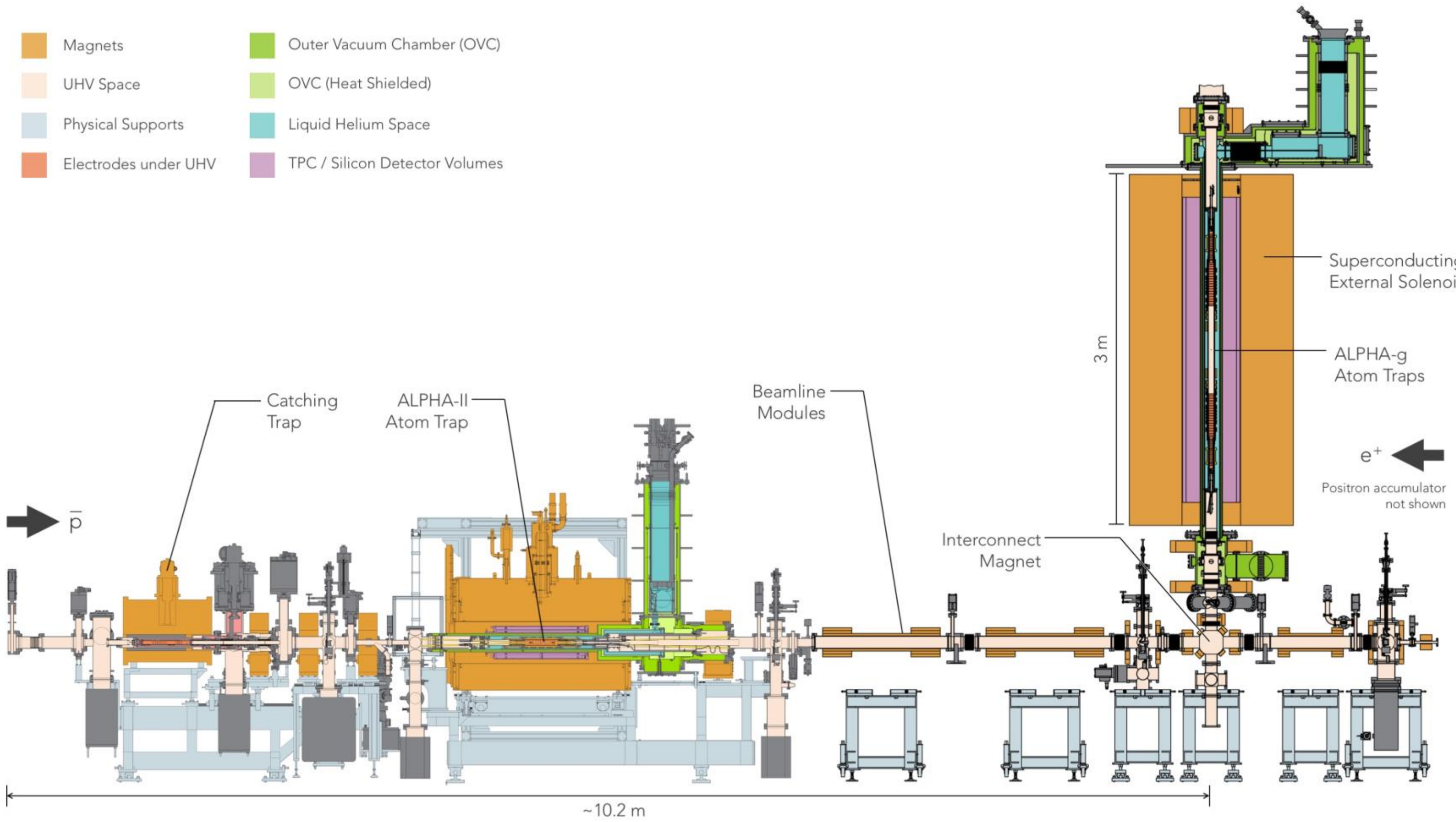
TRIUMF, Canada

University of Wales Swansea, UK

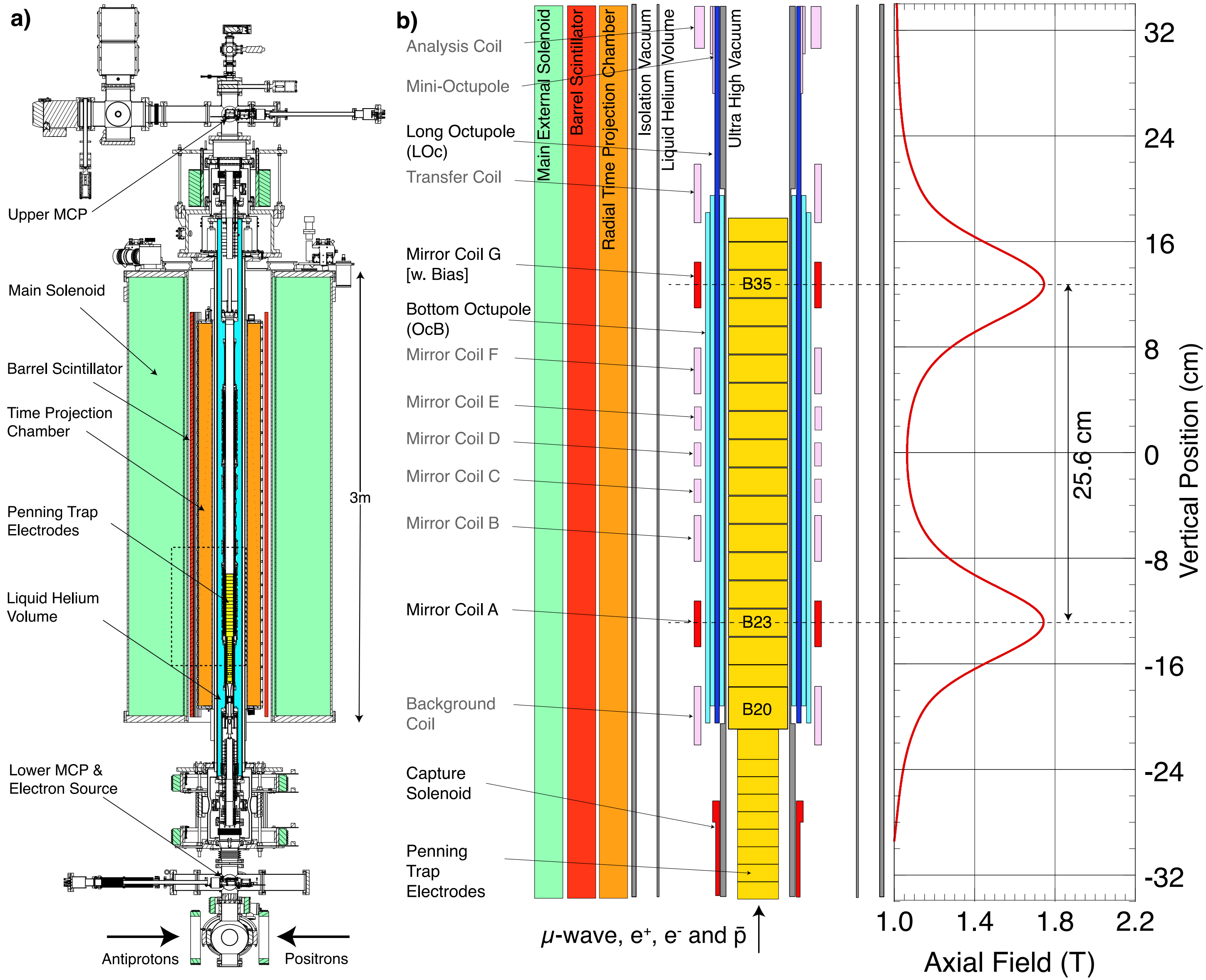
Cockcroft Institute, UK

York University, Canada

ALPHA spectroscopy and gravitation



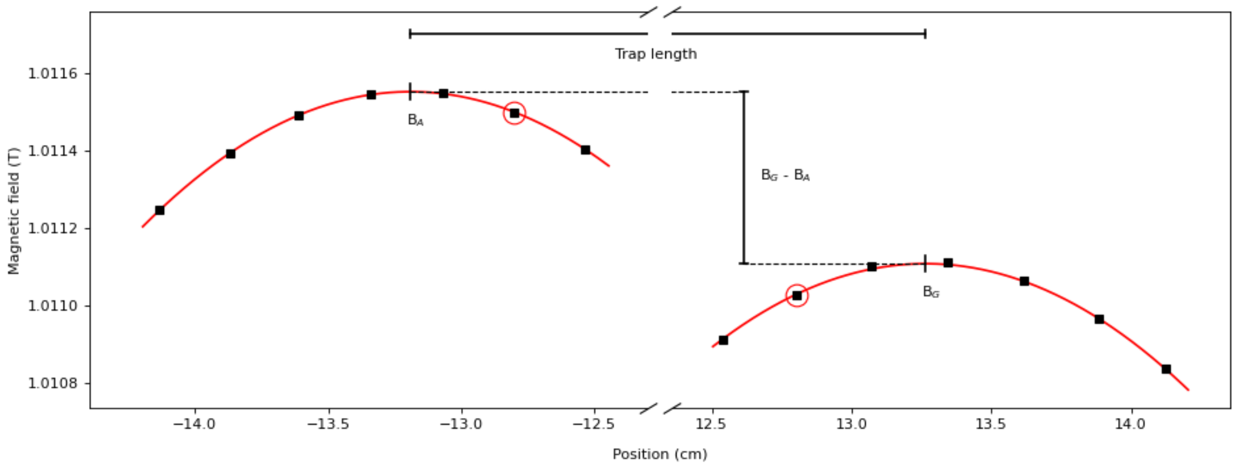
ALPHA-g Schematic



Magnetic bias concept (J. Fajans)

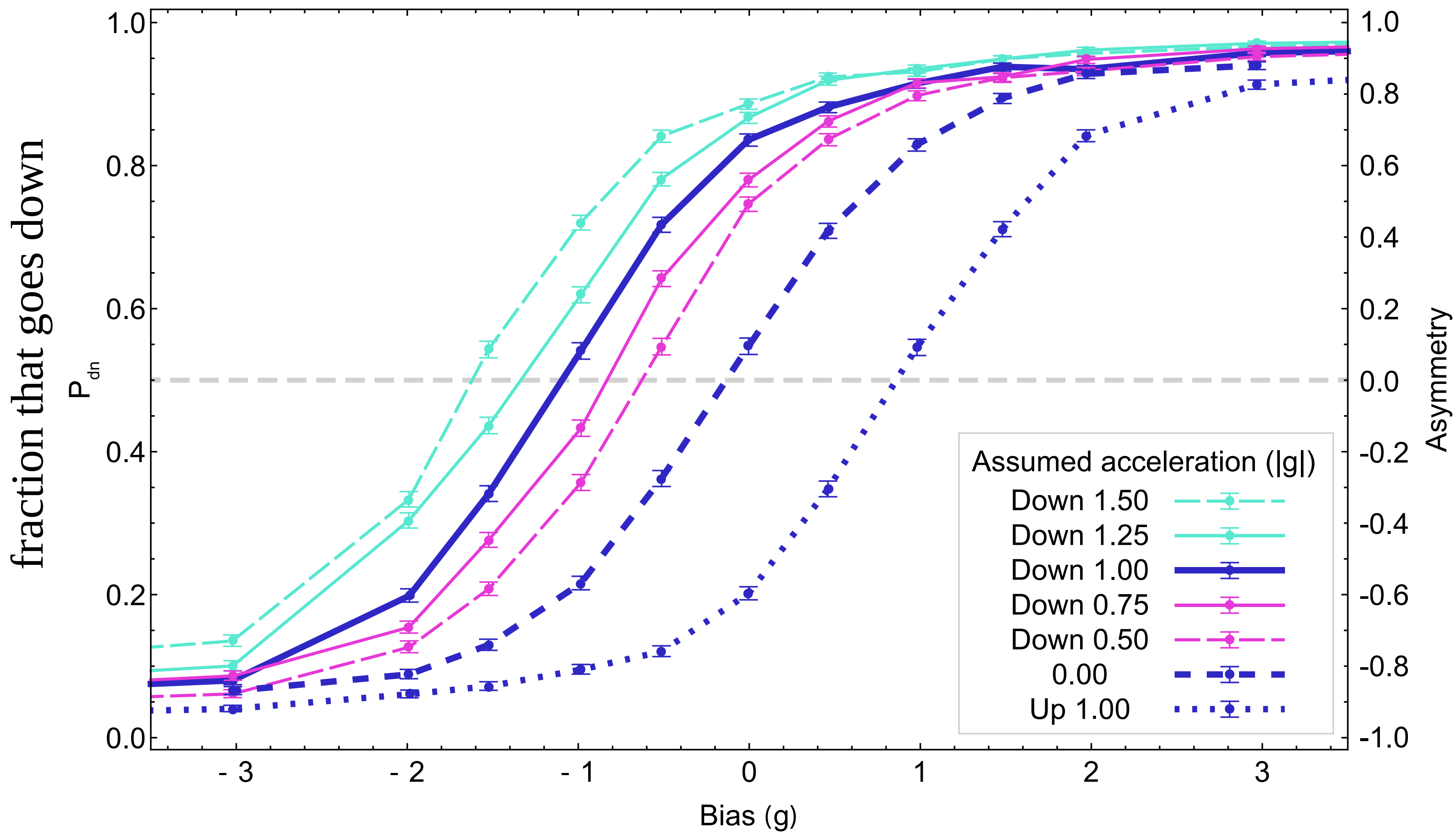
Add a differential current to one of the mirror coils

$$\frac{\mu_B(B_G - B_A)}{m_H(z_G - z_A)}$$ we call this the bias – units of acceleration

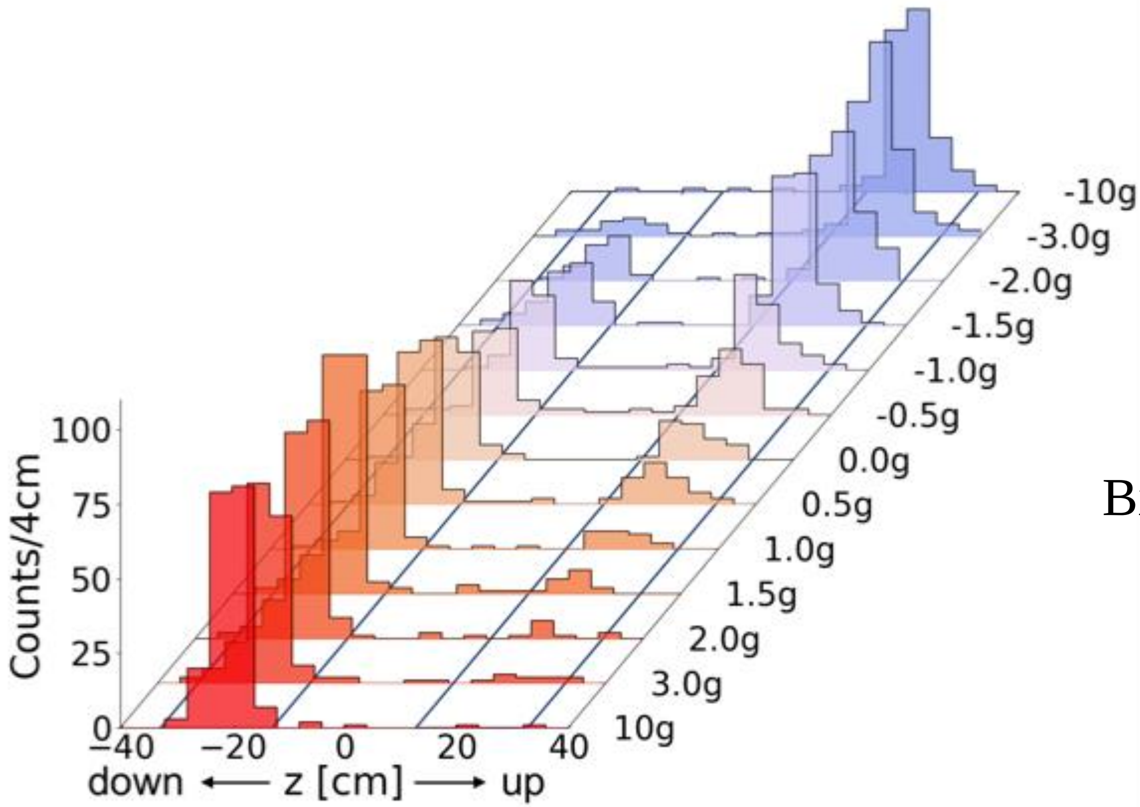


in a real experiment – ramp both mirror currents down while maintaining this difference

The S-curve - simulation

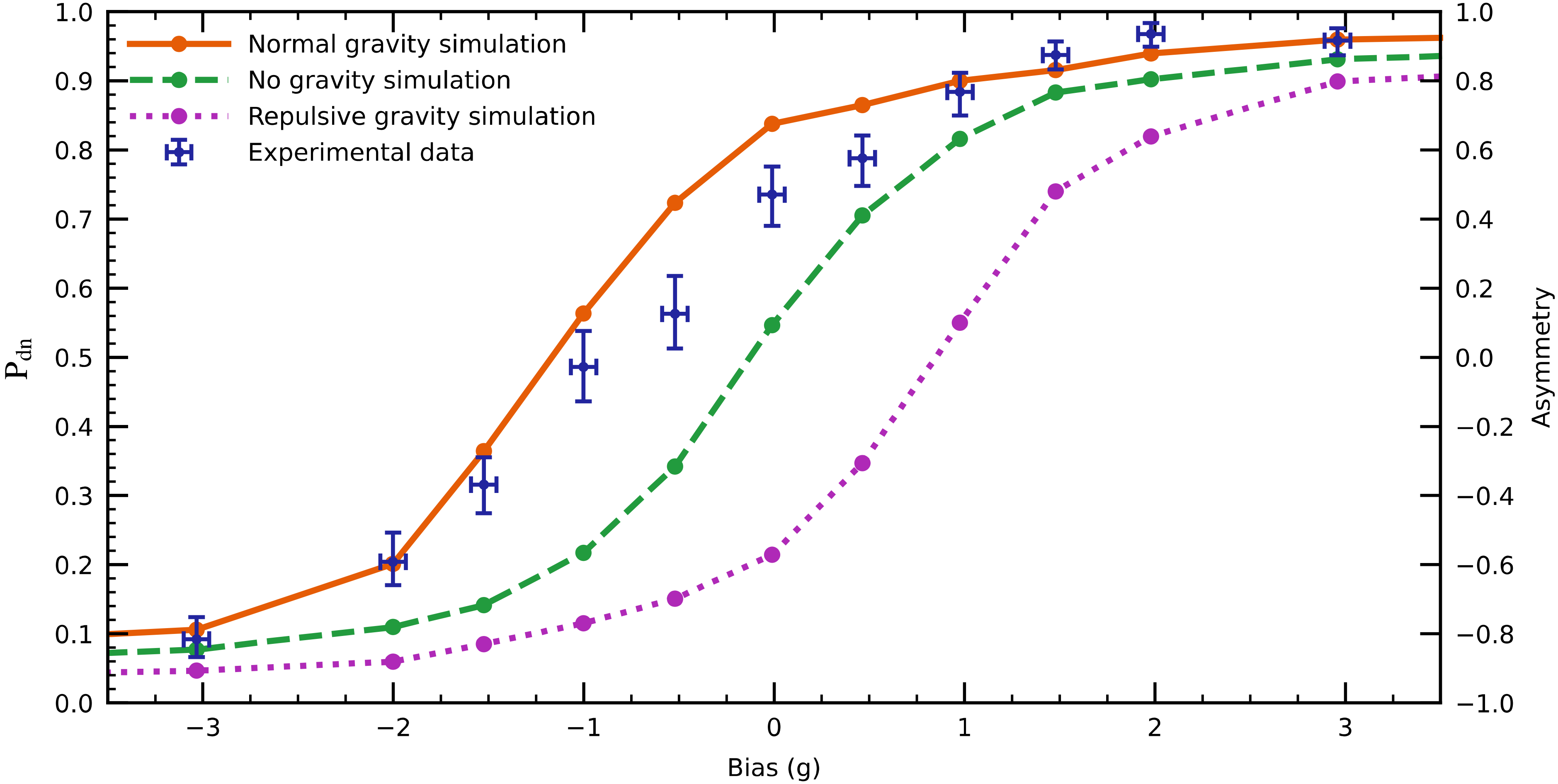


Data from 2022 run



Bias

The Result



$a_{\bar{g}}$ = (0,75 ± 0,13 (stat. + syst.) ± 0,16 (simulation)) • g where g = 9,81 m/s^2

nature

Article | Open access | Published: 27 September 2023

Observation of the effect of gravity on the motion of antimatter

E. K. Anderson, C. J. Baker, W. Bertsche, N. M. Bhatt, G. Bonomi, A. Capra, I. Carli, C. L. Cesar, M. Charlton, A. Christensen, R. Collister, A. Cridland Mathad, D. Duque Quiceno, S. Eriksson, A. Evans, N. Evetts, S. Fabbri, J. Fajans, A. Ferwerda, T. Friesen, M. C. Fujiwara, D. R. Gill, L. M. Golino, M. B. Gomes Gonçalves, ... J. S. Wurtele + Show authors

Nature **621**, 716–722 (2023) | Cite this article

THE TIMES

Pillow talk Do you speak marriage language?

Ryder Cup preview 12-page pullout

Labour set to close tax loopholes to fund £4bn war chest

No 10 backs threat to leave rights convention

Braverman delivers 'warning shot' to Strasbourg

Antimatter falls in line with theory of gravity

Schoolgirl stab horror

Le Monde

L'antimatière ne « tombe » pas vers le haut

Une équipe internationale a observé, pour la première fois, le comportement d'antiatomes en chute libre

Installation de l'expérience Alpha-g dans le hall de l'usine à antimatière du CERN, à Meyrin, en Suisse, en octobre 2018.

« C'est l'une des plus importantes expériences de physique fondamentale jamais réalisées »

STEFAN ULMER responsable du programme antimatière du CERN

DAVID LAROUSSERIE

Feu vert pour l'exploitation d'un champ pétrolier en mer du Nord

Le gouvernement britannique, qui soutient la décision, défend la « sécurité énergétique » du Royaume-Uni et inquiète les défenseurs du climat

Dans les faits, le pétrole extrait sera vendu sur les marchés internationaux, et pas en priorité au Royaume-Uni

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Science

Scientists get closer to solving mystery of antimatter

27 September

SAKKMESTERKE/SCIENCE PHOTO LIBRARY

Artwork: shortly after the Big Bang which created the Universe, matter and antimatter existed in equal amounts

By Pallab Ghosh

Science correspondent

Scientists have made a key discovery about antimatter - a mysterious

physicsworld
TOP 10 BREAKTHROUGH 2023

third time ALPHA has been nominated

2010: trapping of antihydrogen (won)

2021: laser cooling of antihydrogen (didn’t win)

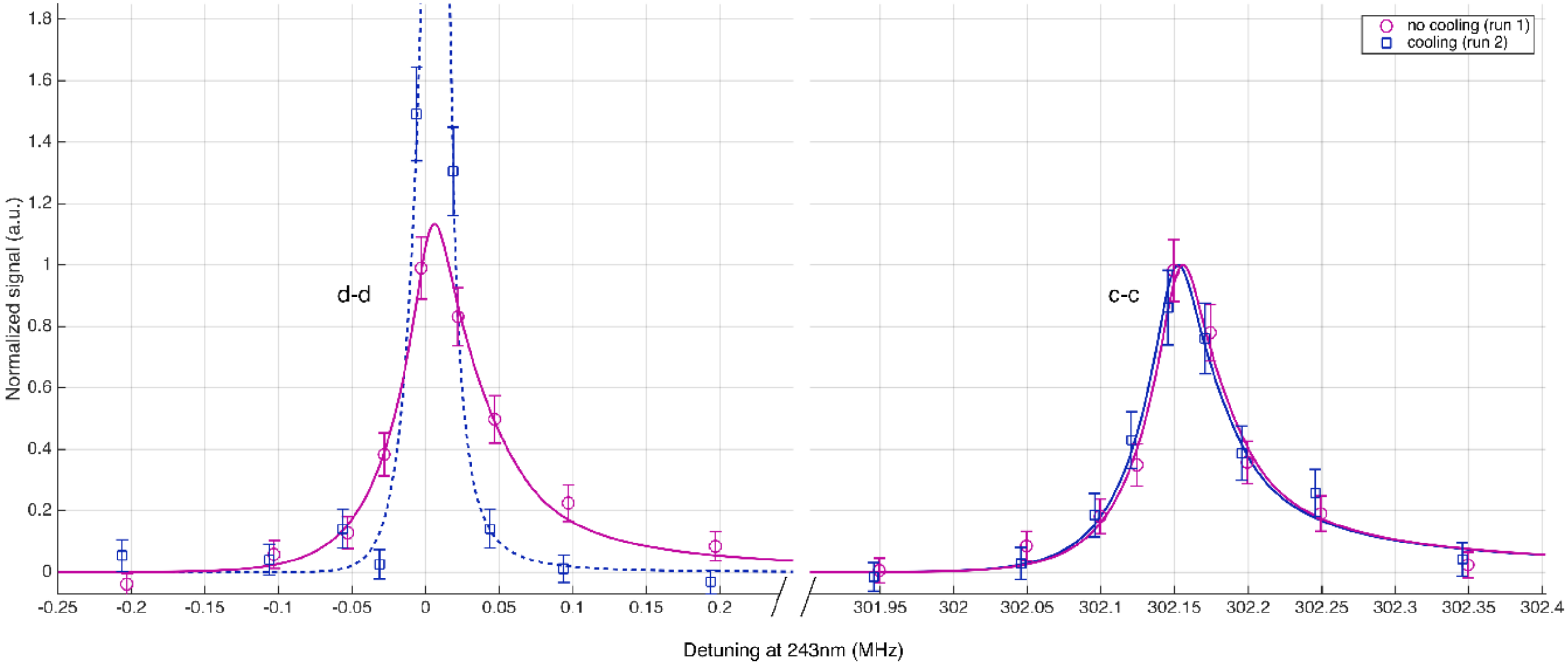
2023: gravity experiment (didn’t win again)

ALPHA

New Publication coming in *Nature Physics*

"Precision spectroscopy of the hyperfine components of the 1S-2S transition in antihydrogen"

(data pre-LS2)



each curve obtained in 1 day
took 10 weeks in 2017...

one goal of 2023 run was to improve this

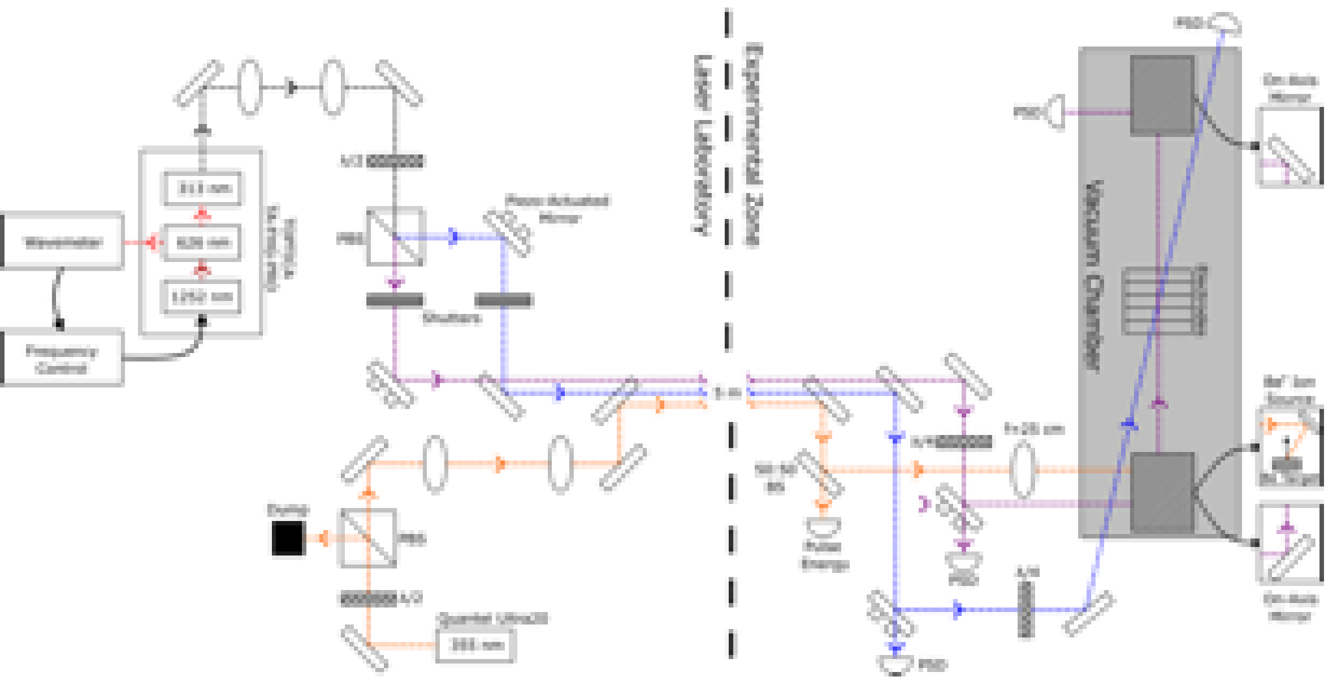
ALPHA in 2023

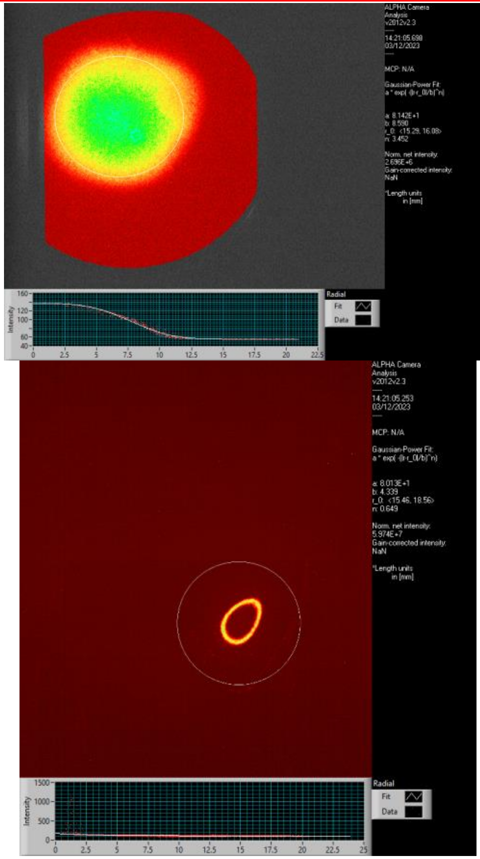
- ALPHA-g was disassembled for external solenoid magnet upgrade; this was completed successfully and ALPHA-g is back in position

- we only ran ALPHA-2 during the 2023 pbar beamtime

- we have seven new physics results for which publications are in preparation

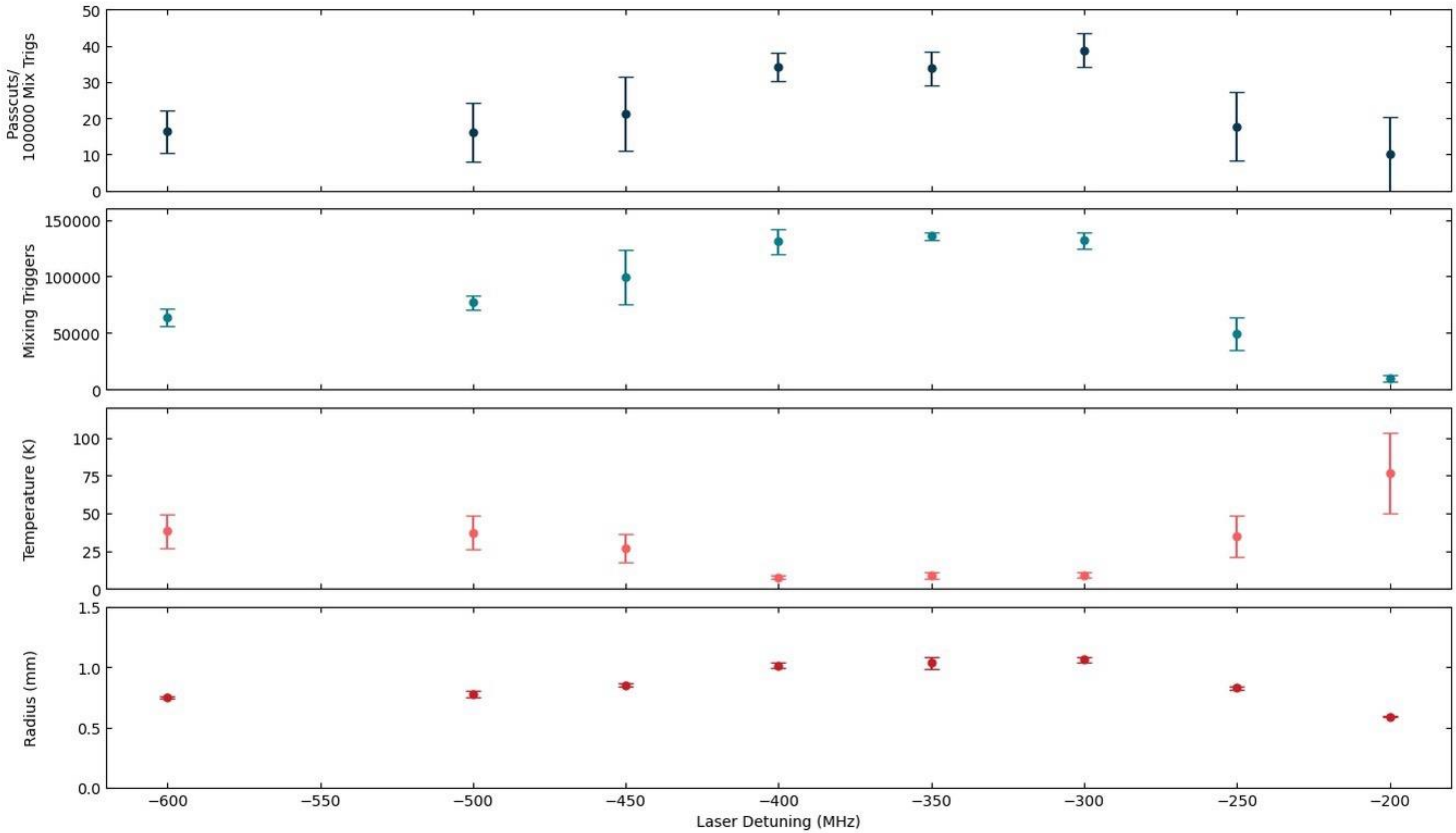
I. Accumulation of 10^4 hbars using laser-cooled Be ions



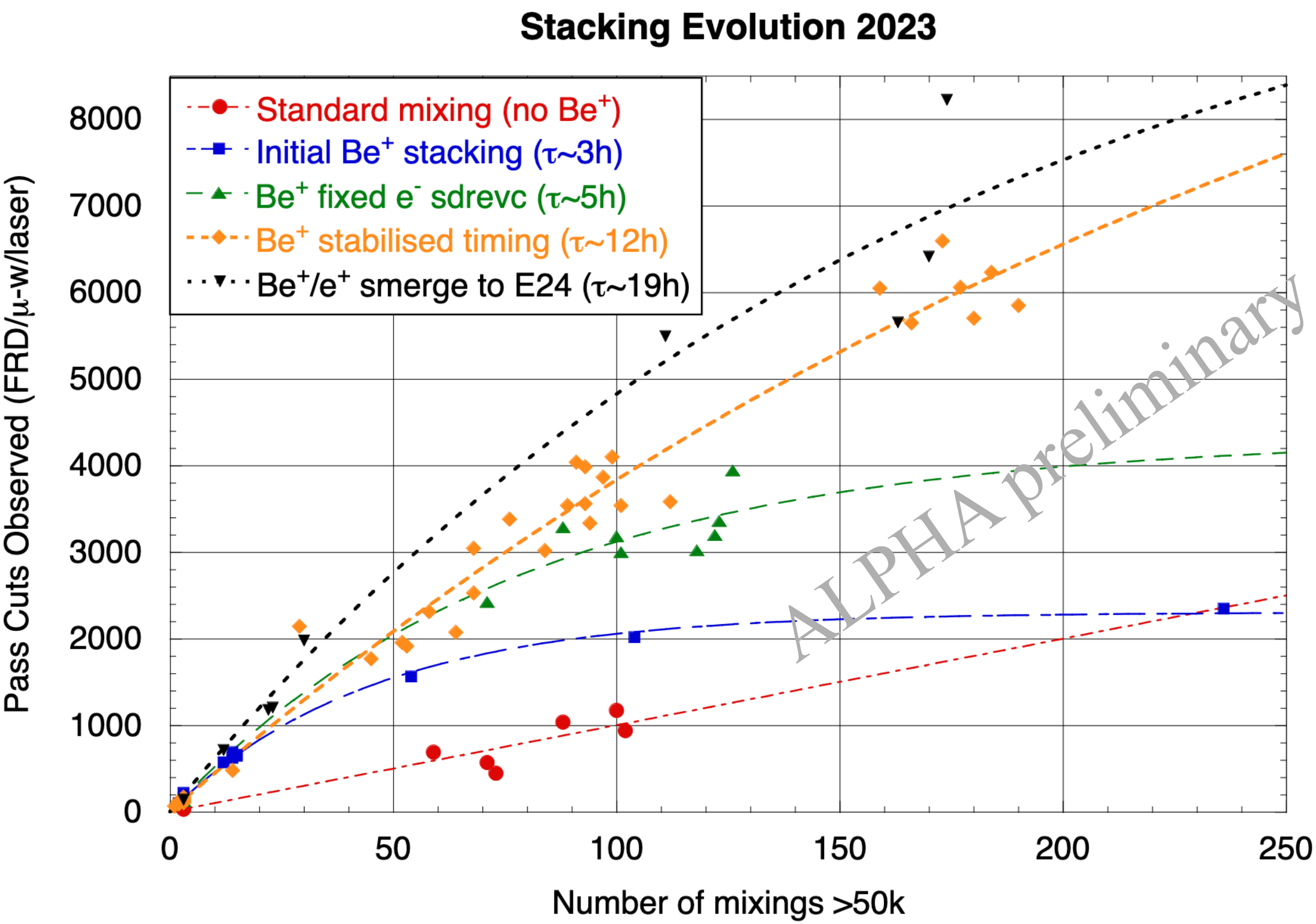


- from 13 years of trapping experience: positron temperature has a big effect on # of hbars produced and the *trappable fraction* Recall the trap is about 0.5K deep.
- mixed plasma 1.5 x10^5 Be^+ ions and 3 x10^6 e^+
- laser cool Be ions - positrons are sympathetically cooled by Coulomb interaction
- positron T of a few K, maybe diagnostics limited
- typical T without Be cooling is 15-20K

I. Accumulation of 10^4 hbars using laser-cooled Be ions



I. Accumulation of 10^4 hbars using laser-cooled Be ions



average 15 mixings per hour

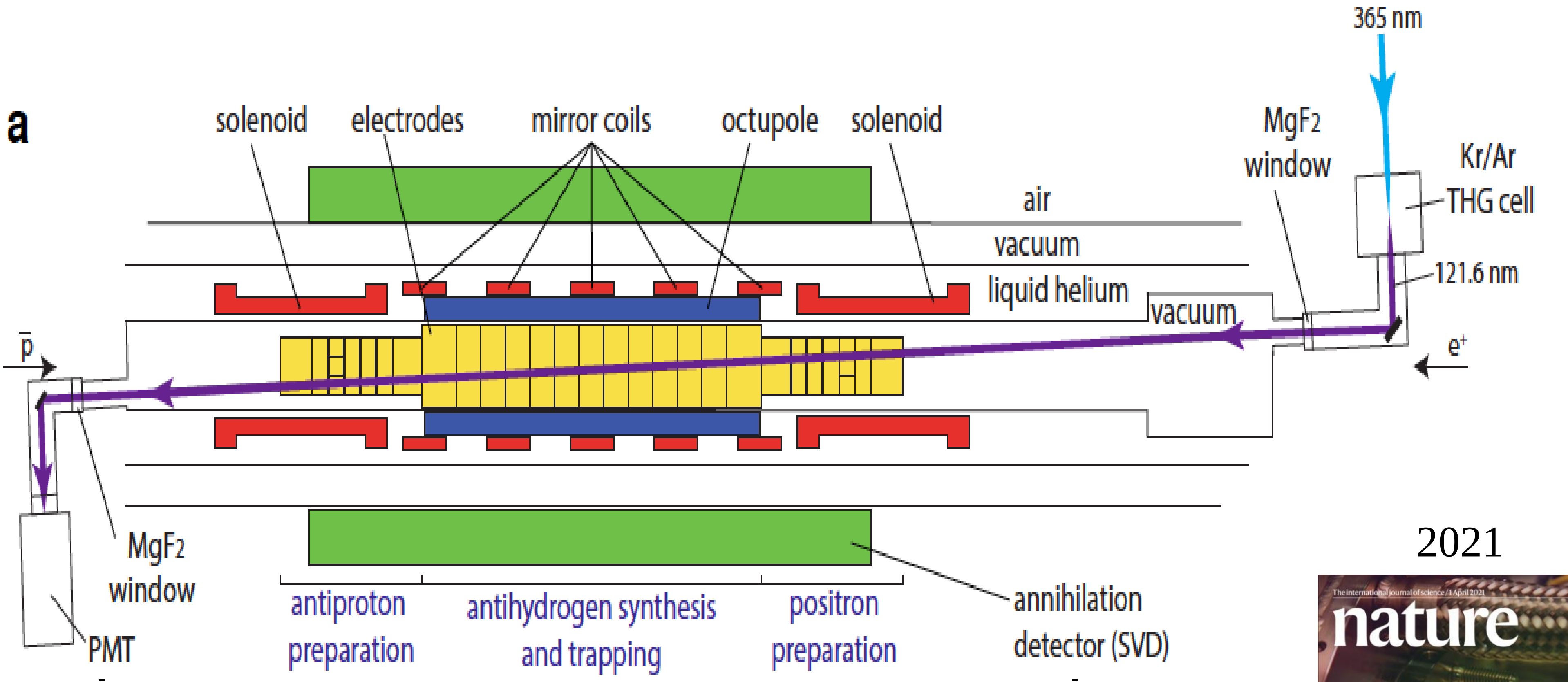
N. Madsen,
M. Goncalves,
K. Thompson *et al.*

maximum short term result: 20 stacks with average of 73 atoms per stack

this is about 650 times the rate from 2010

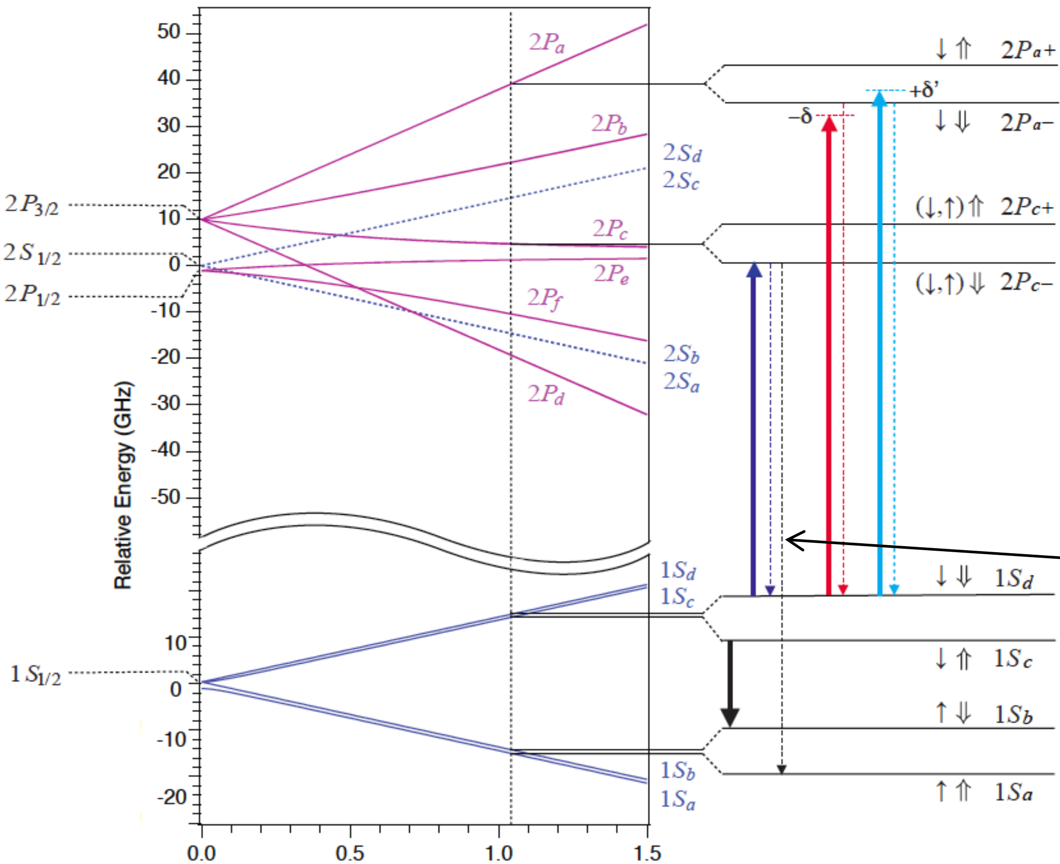
typically stack on night shift – then (cool and) measure

II. Laser Cooling of Antihydrogen



2021

II. Laser Cooling of Antihydrogen

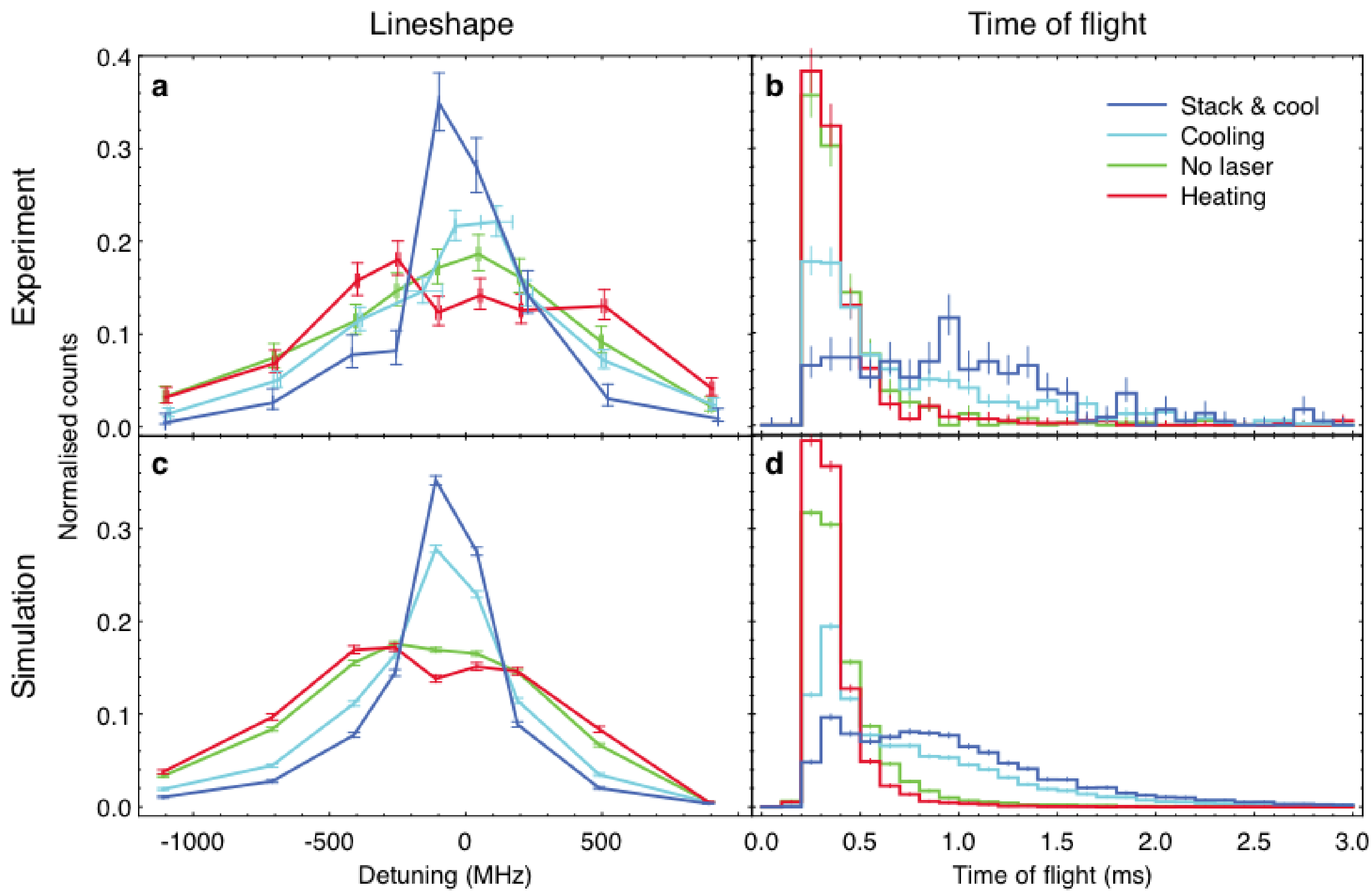


1S – 2P transitions in (anti)hydrogen

probing

probe the sample after cooling
atom will sometimes spin-flip and then annihilate
longitudinal velocity information from Doppler broadening
measure TOF between laser pulse and annihilation – gives information about tranverse speeds

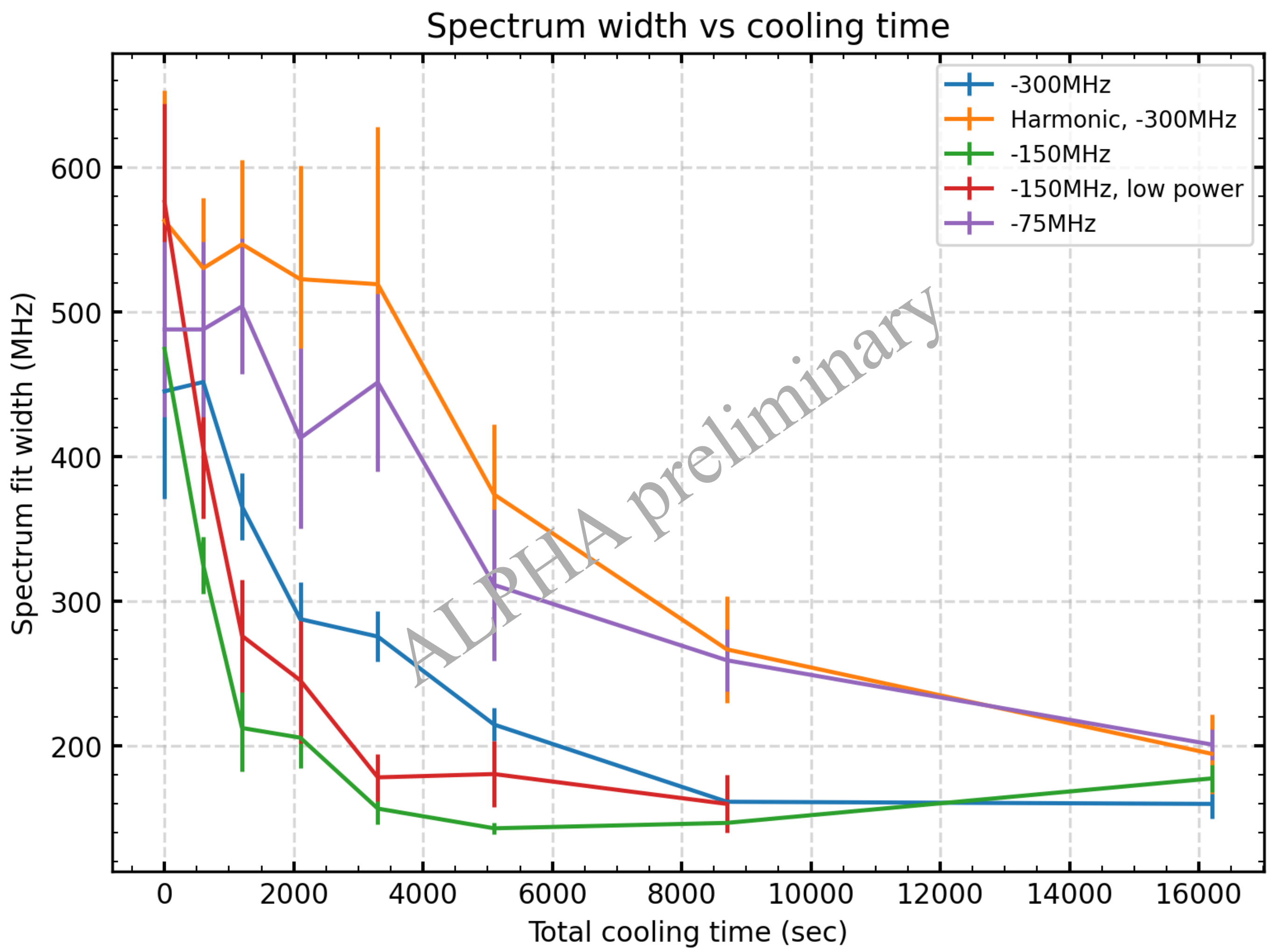
II. Laser Cooling of Antihydrogen



2021 article

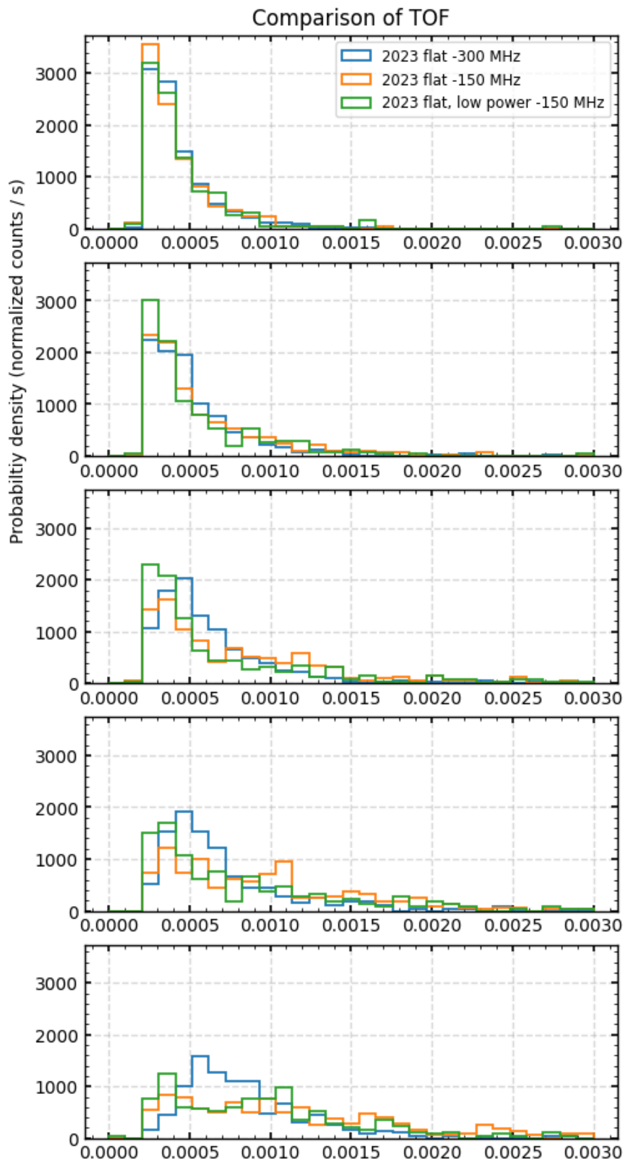
II. Laser Cooling of Antihydrogen

2023: Measured 1S-2P linewidth versus cooling time for various conditions (laser detuning, trap potential shape)



II. Laser Cooling of Antihydrogen

2023: TOF data



0 minutes

10 minutes

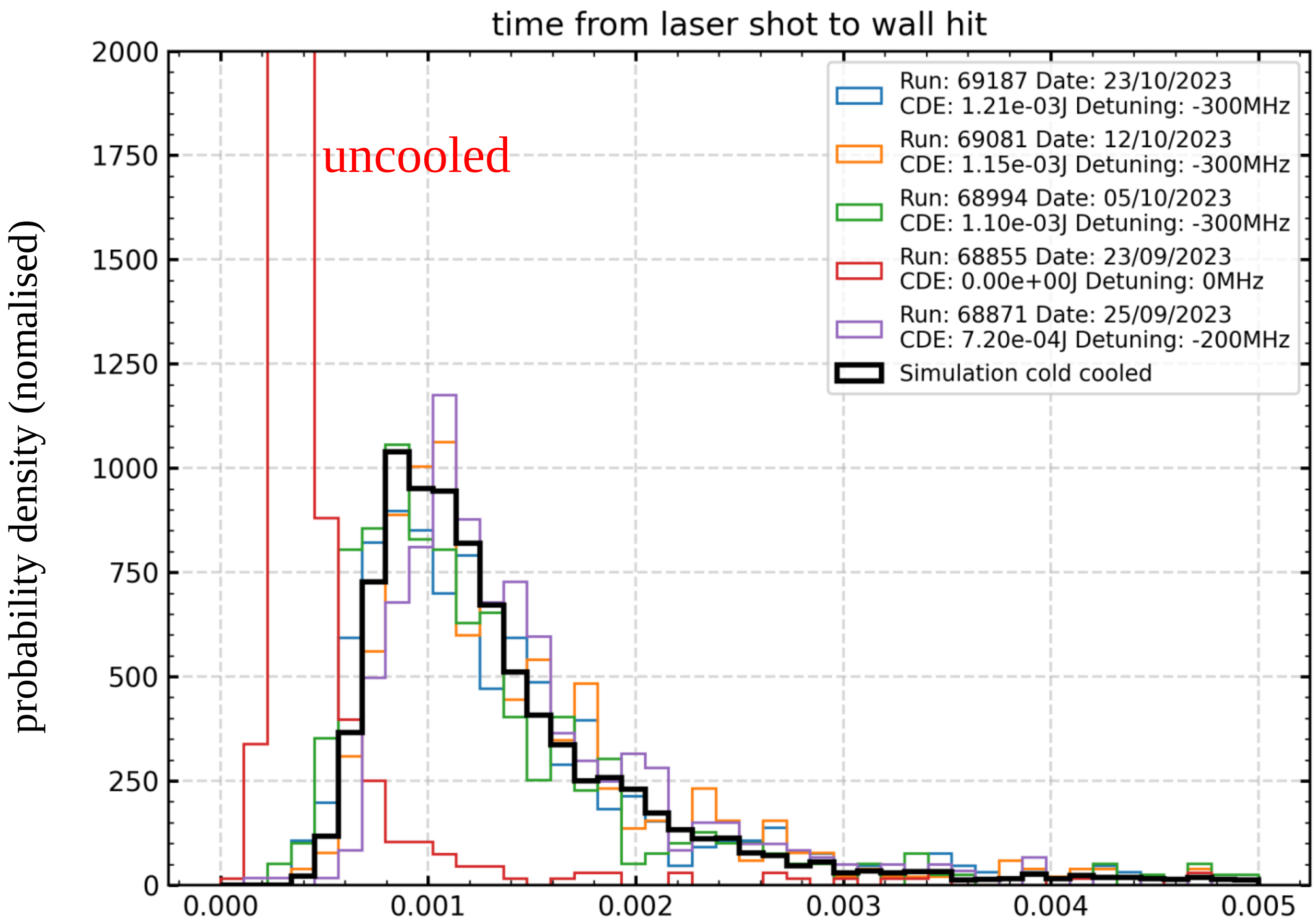
20 minutes

35 minutes

50 minutes

II. Laser Cooling of Antihydrogen

2023: TOF data – reproducibility and comparison with 15 mK simulation

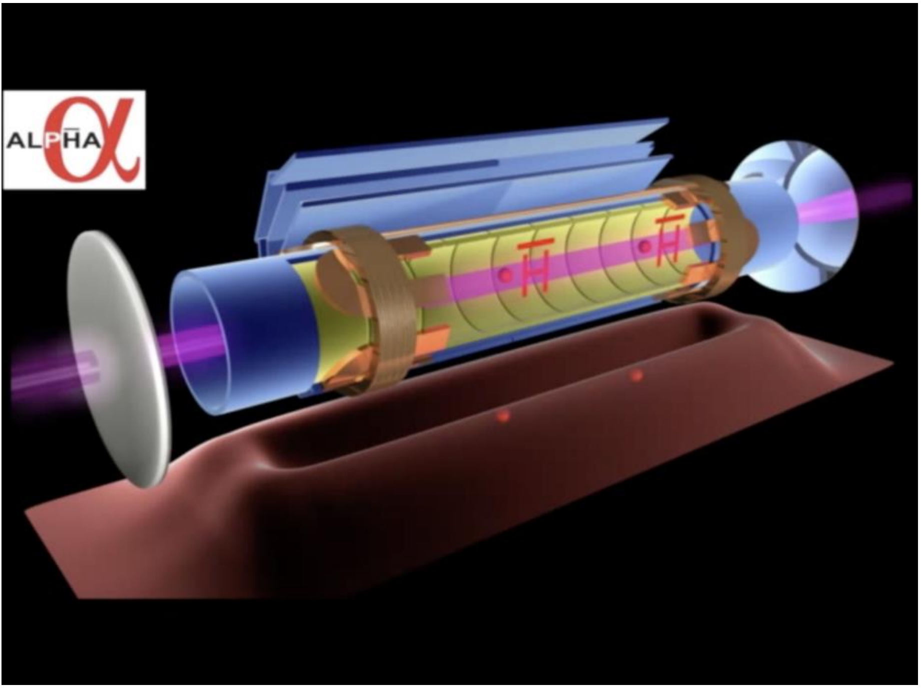


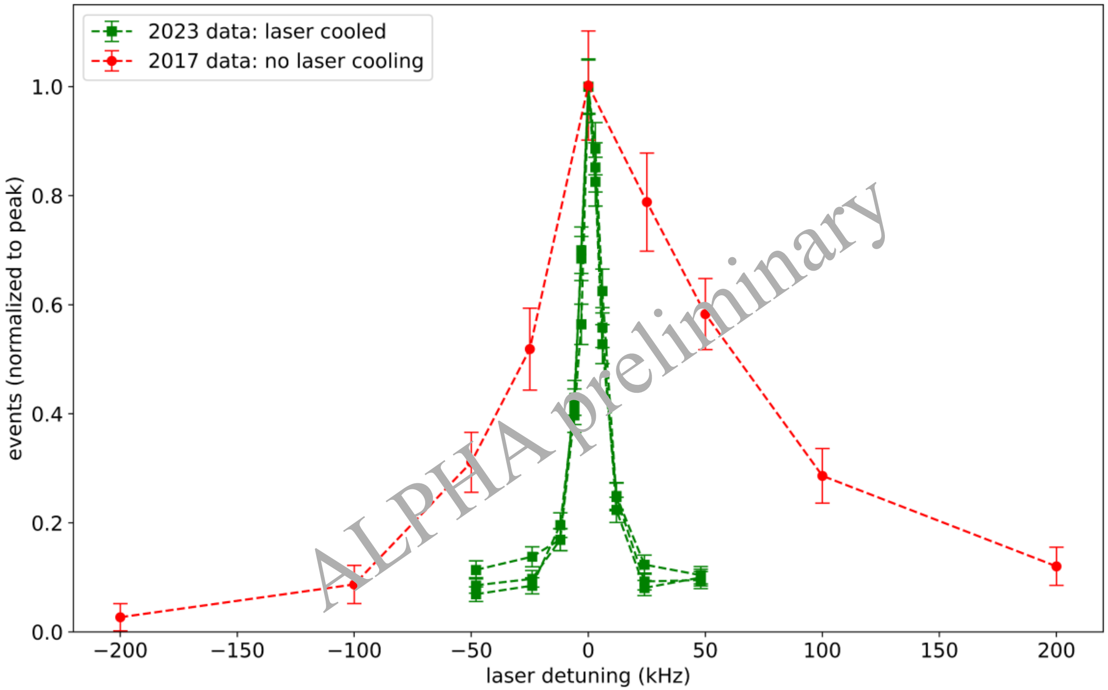
I &II summary

- start stacking in the evening – 22:00
- laser cool the following morning
- up to 10K antihydrogen atoms at 15 mK by late afternoon

- **Complete paradigm shift – with help from ELENA!**

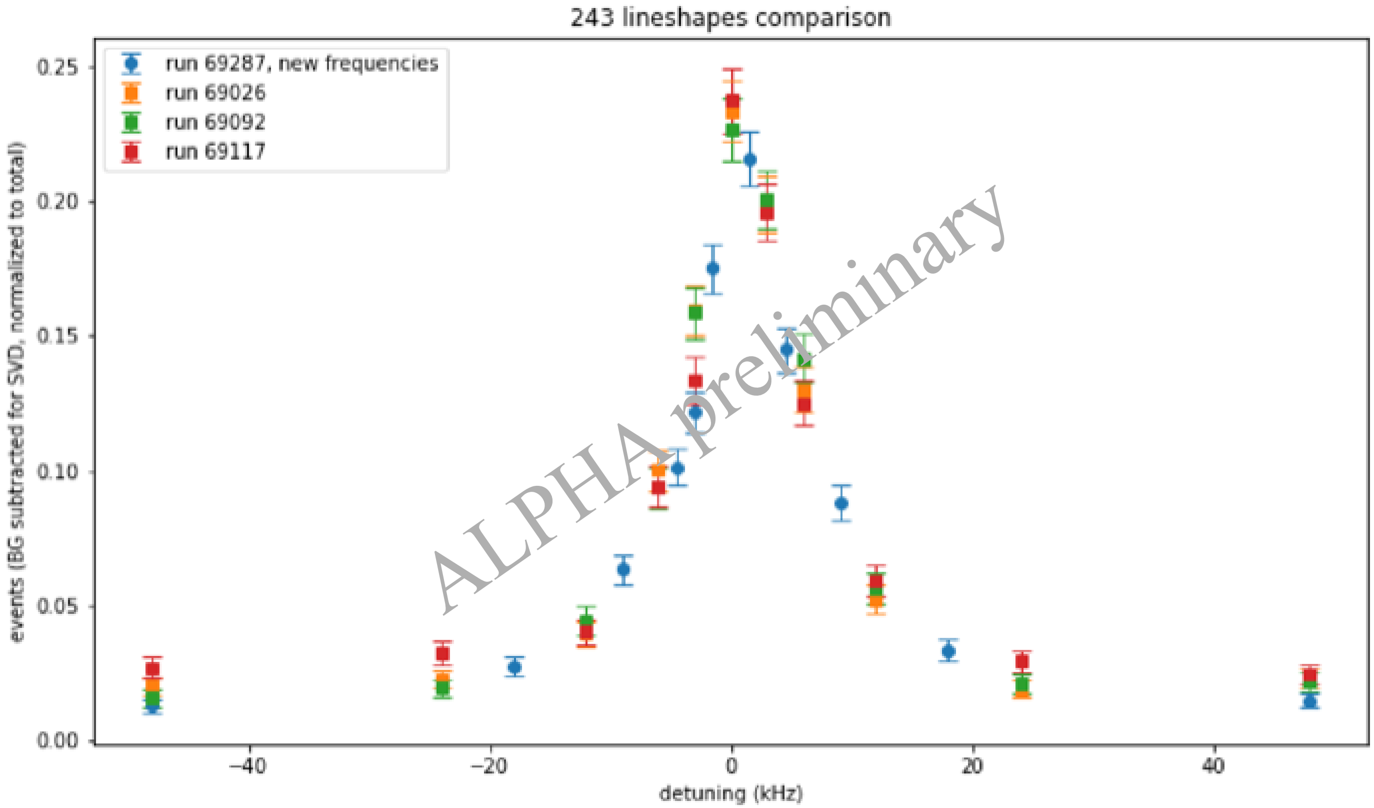
III. the 1S-2S transition with laser cooling





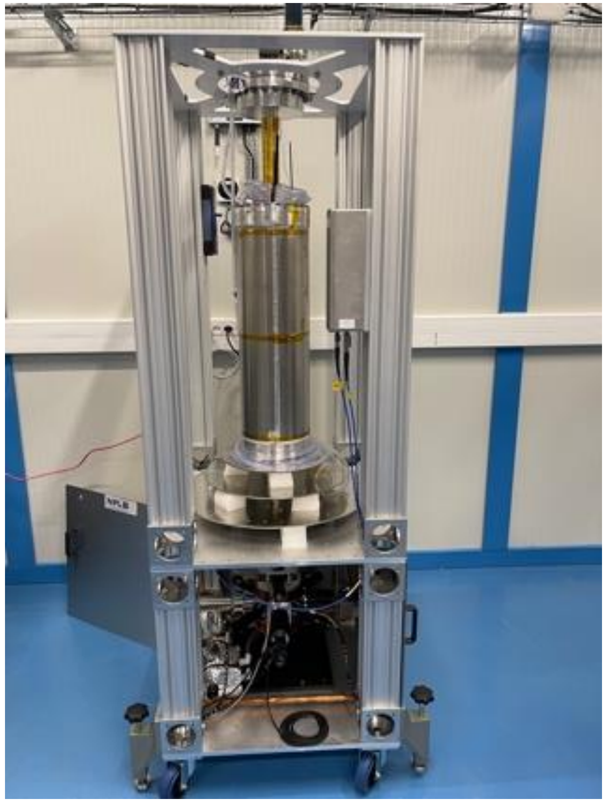
III. the 1S-2S transition with laser cooling

We can now do a complete cycle of this in one day.
Analysis in progress – MVA, magnetic field, velocity distribution, *etc*.
With lots of atoms, we can user *lower* laser power



III. the 1S-2S transition with laser cooling

Frequency Metrology Lab



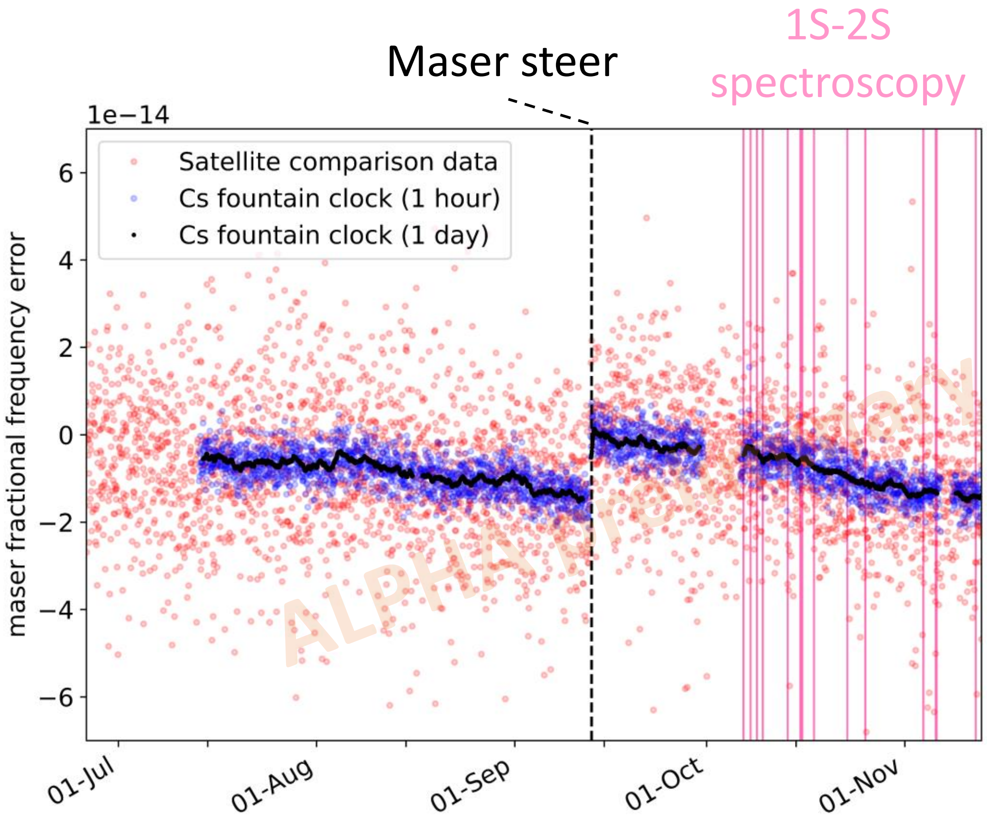
Cesium fountain clock from NPL

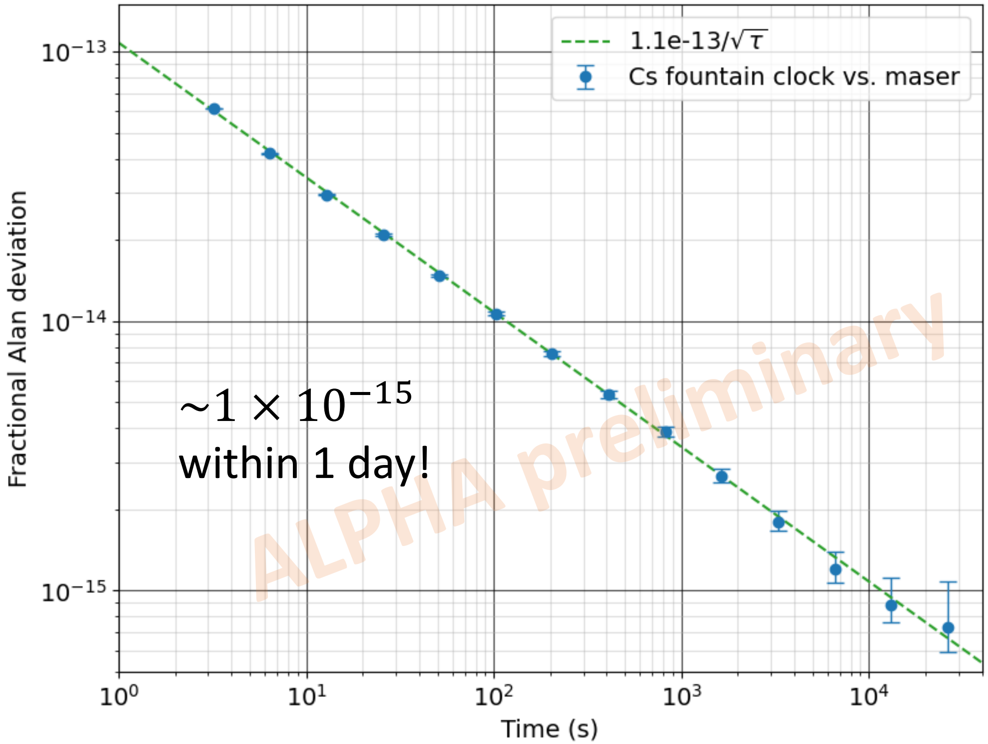
Hydrogen maser

III. the 1S-2S transition with laser cooling

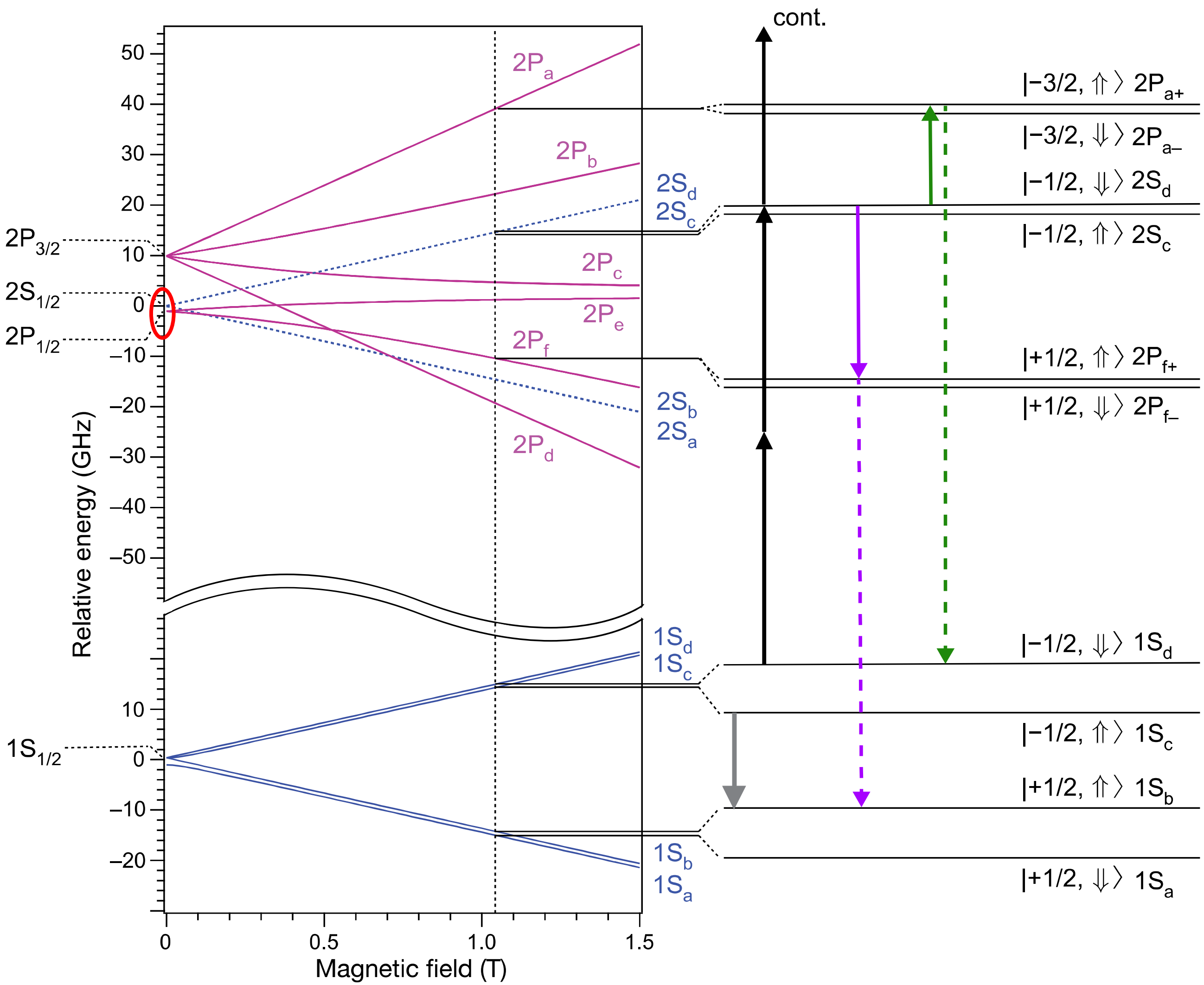
Cs fountain clock performance

Similar to clocks that contribute to UTC (or even slightly better)



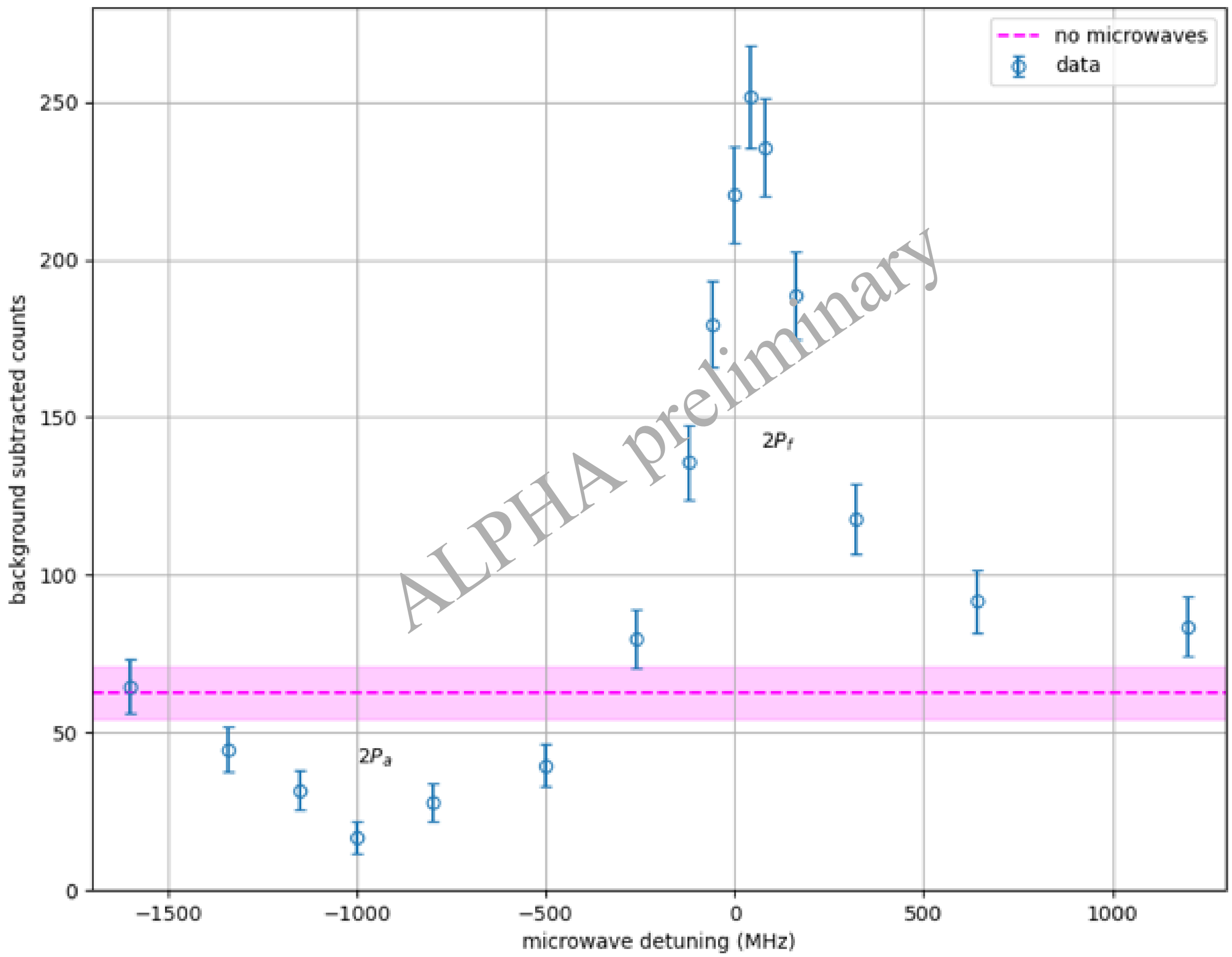


IV. excited state spectroscopy: the 2S-2P transition

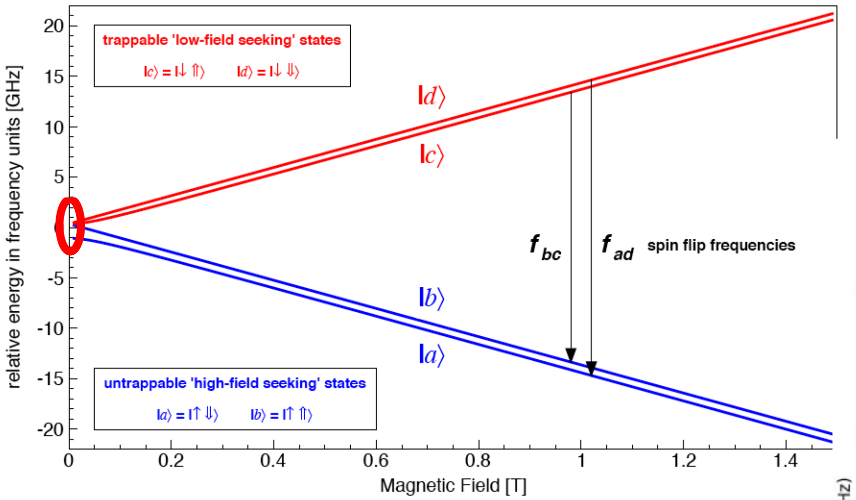


Double resonant:
two-photon excitation to 2S
microwave excitation to 2P

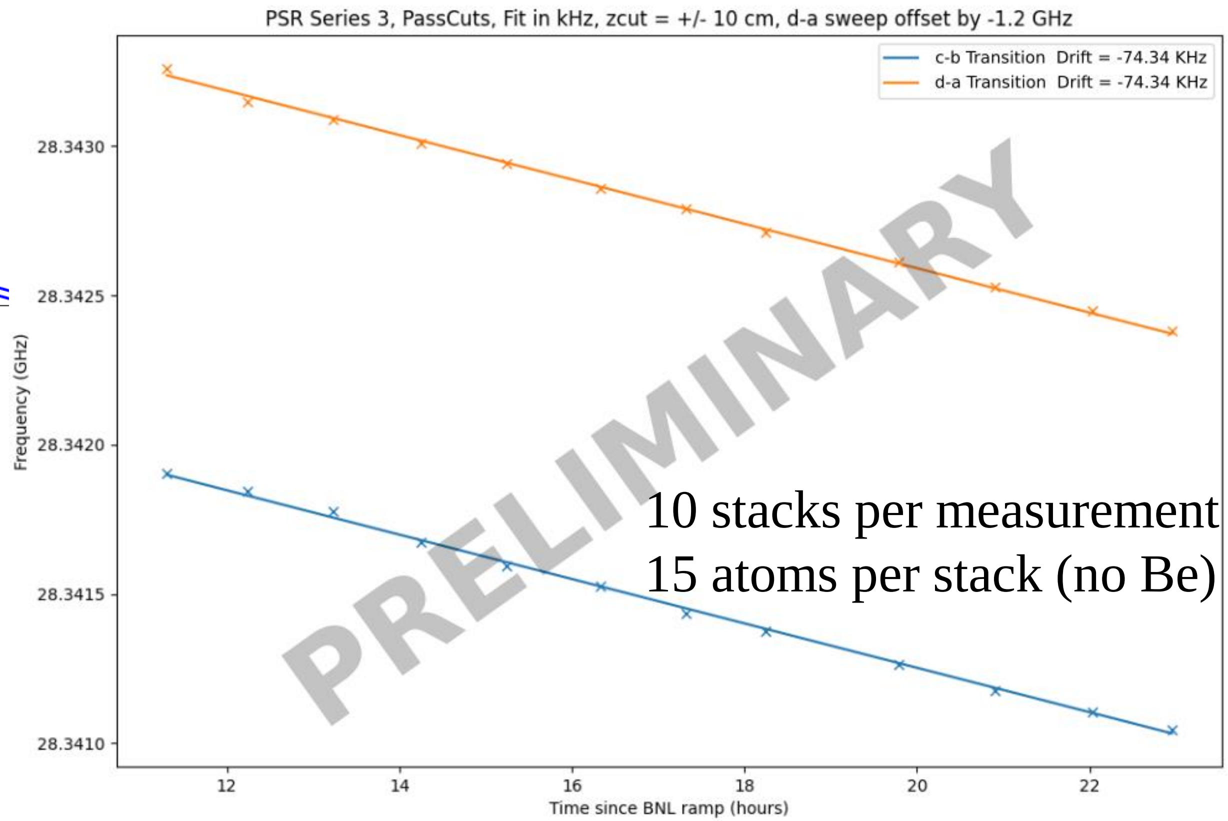
IV. excited state spectroscopy: the 2S-2P transition



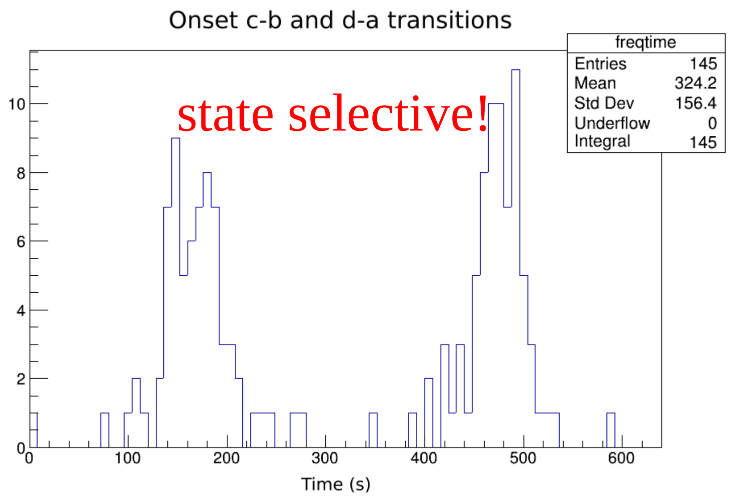
V. positron spin resonance: GSHFS



resonant, microwave driven spin flips



10 stacks per measurement
15 atoms per stack (no Be)

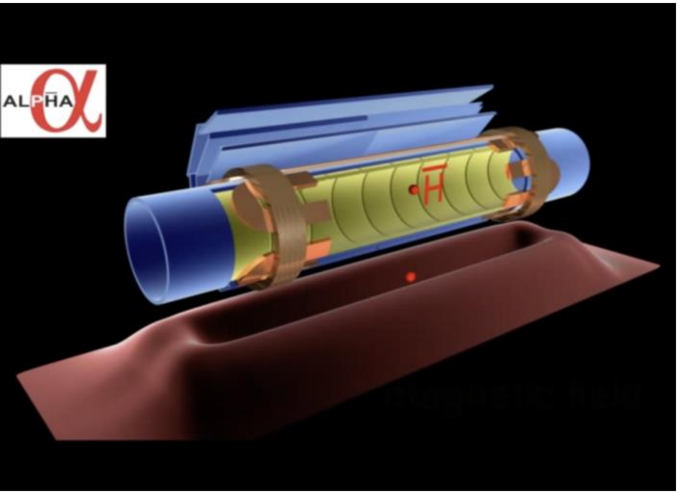


state selective!

scan microwave frequency →

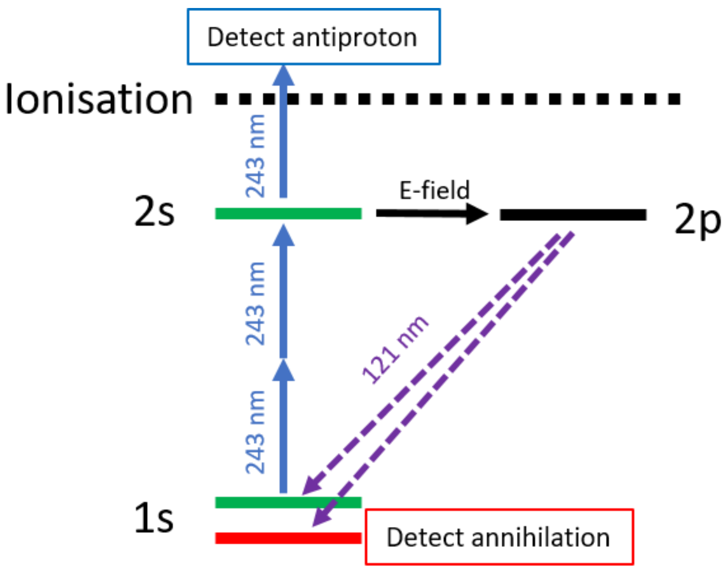
We have previously measured the splitting to a few parts in 10000. Hoping for ppm here.

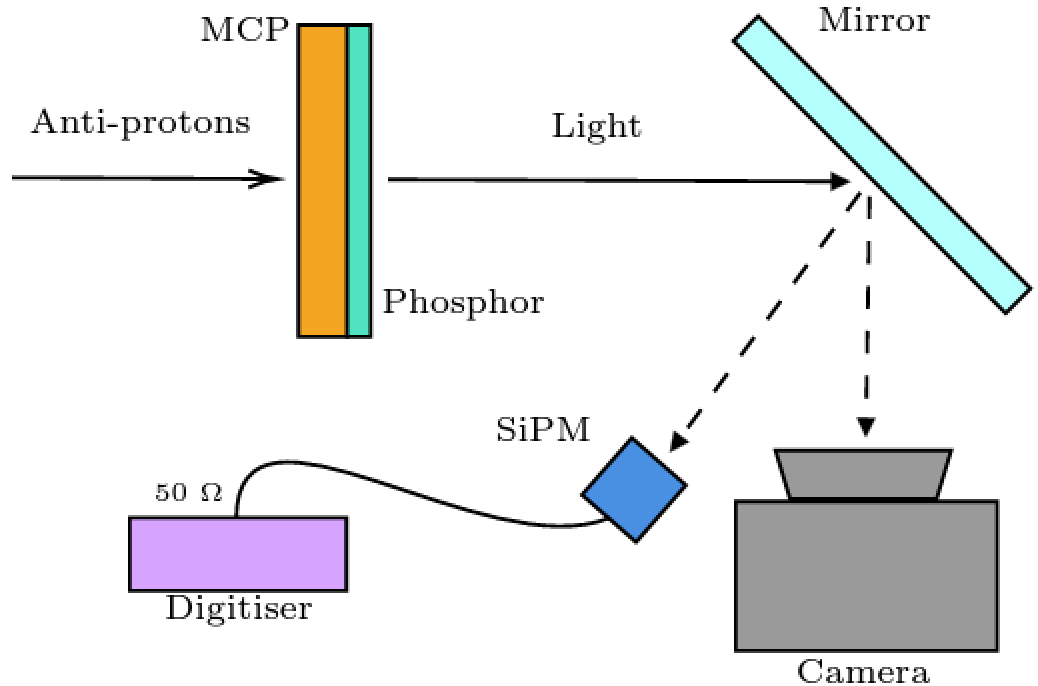
VI. MCP detection for spectroscopy experiments



Recapture ionised (anti)hydrogen in Penning trap.
Detect (anti)protons by ejecting them to an MCP.

S. Jones





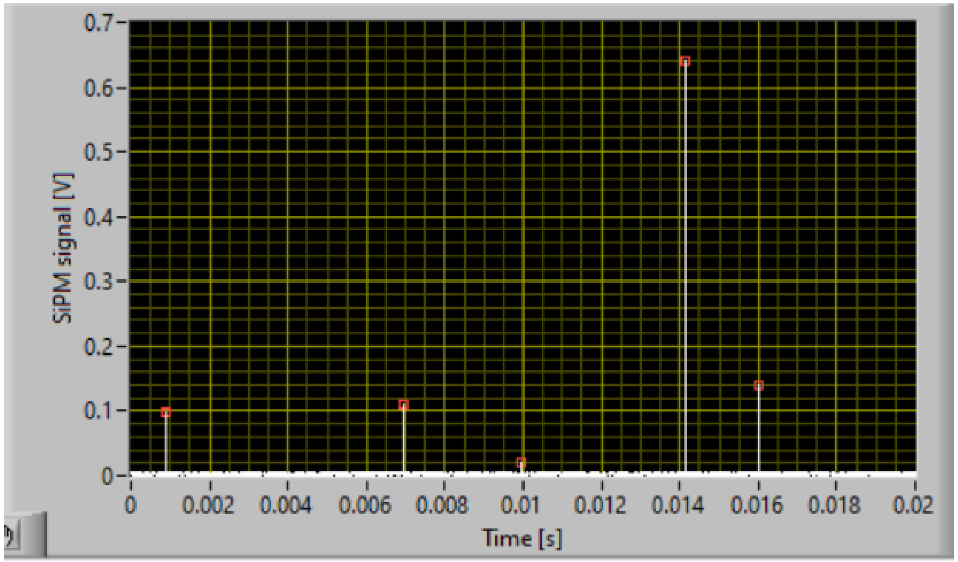
VI. MCP detection for spectroscopy experiments

Detection efficiency

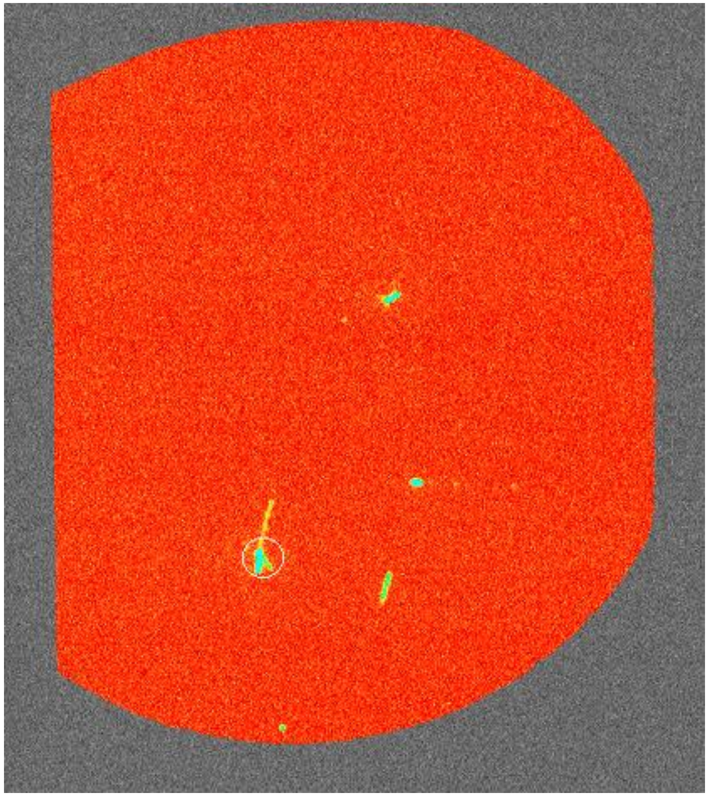
Antiprotons: 94% (measured)

Protons: ~50% (K. Fehre et al., Rev. Sci. Instr. 89, 045112, 2018)

S. Jones



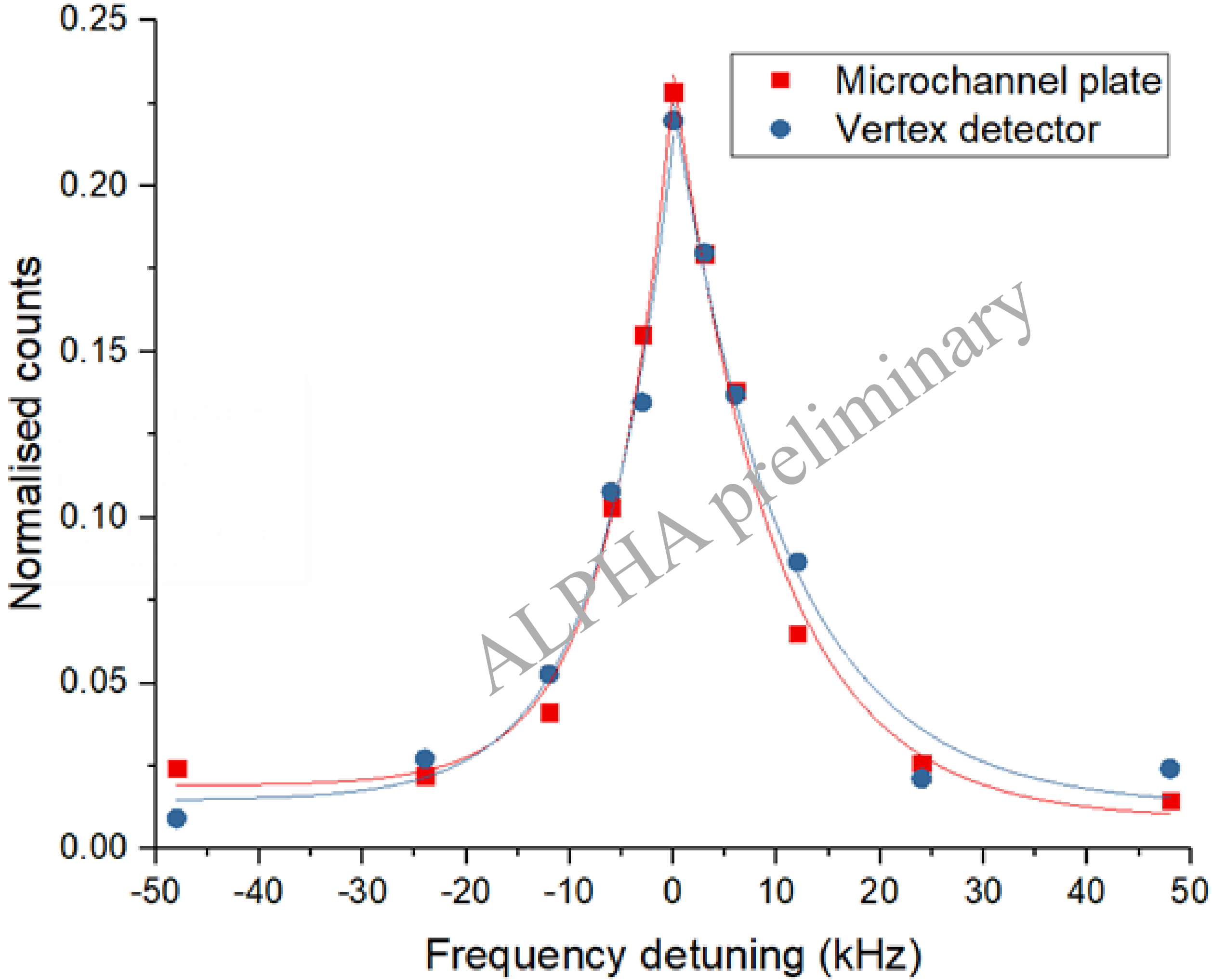
SiPM signal



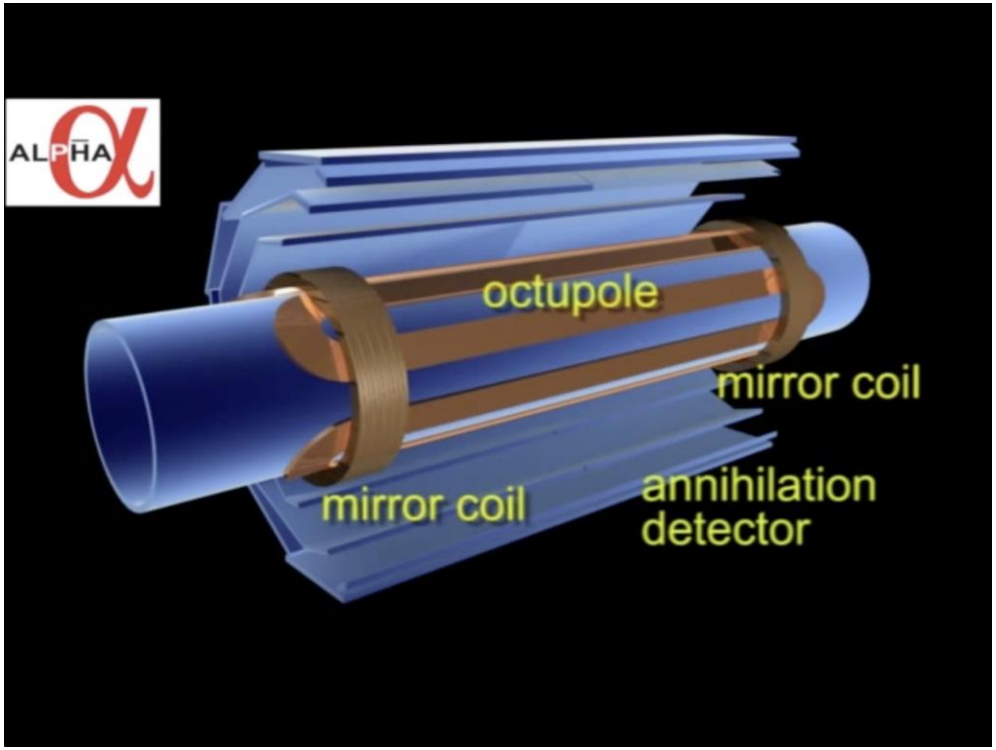
Camera signal

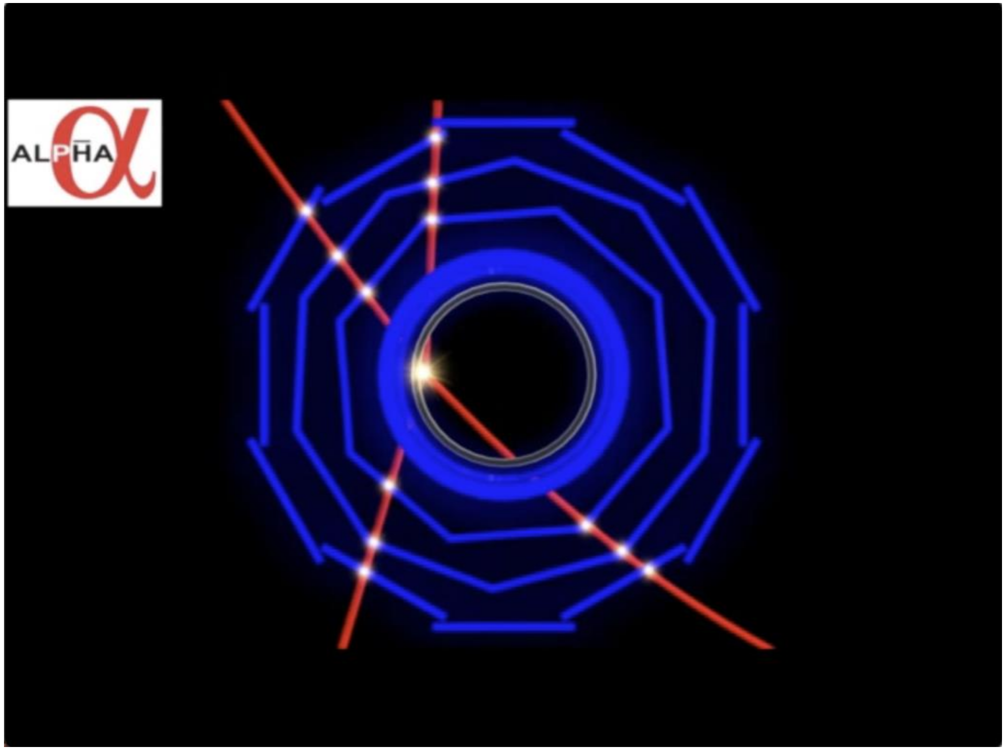
VI. MCP detection for spectroscopy experiments

<u>Comparison of MCP vs SVD spectra</u>
(qualitatively the same - linewidth as narrow as annihilation method)



VII. Energy diagnostics using octupole rampdown





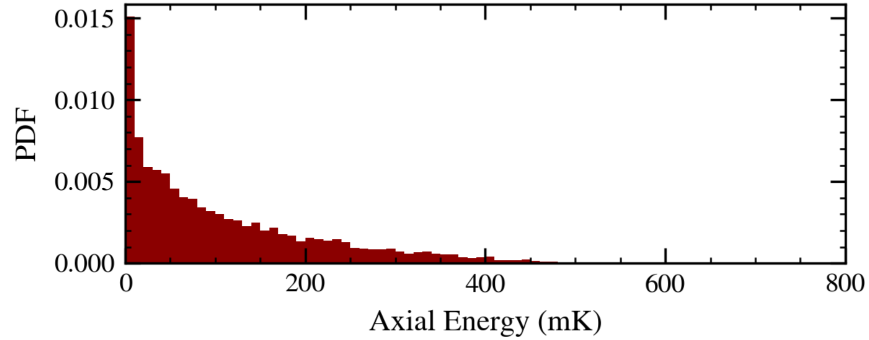
- knowledge of hbar energy distribution is important for most experiments, and for benchmarking simulations
- release trapped hbar by ramping down the octupole current – *e.g.* over 15 s ("FRD")
- record annihilations on the silicon vertex detector: temporal and spatial distributions
- can study energy distributions, time evolution, mixing between dynamical d.o.f, etc.
- can compare to other techniques such as 1S-2P TOF

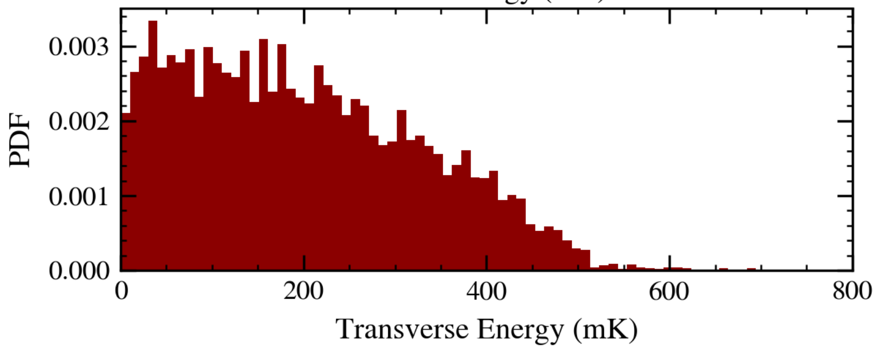
D. Hodgkinson

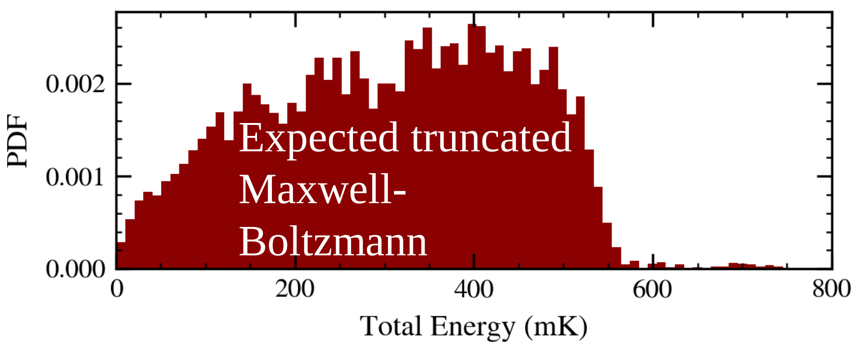
VII. Energy diagnostics using octupole rampdown

Uncooled Antihydrogen

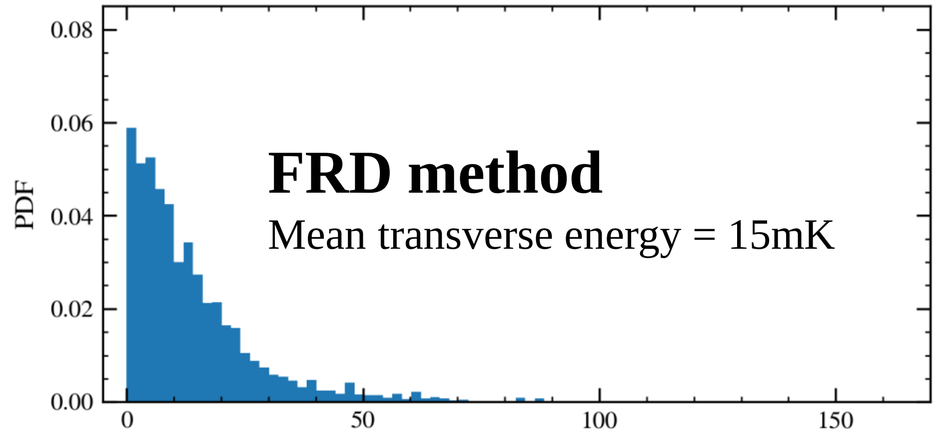
FRD method

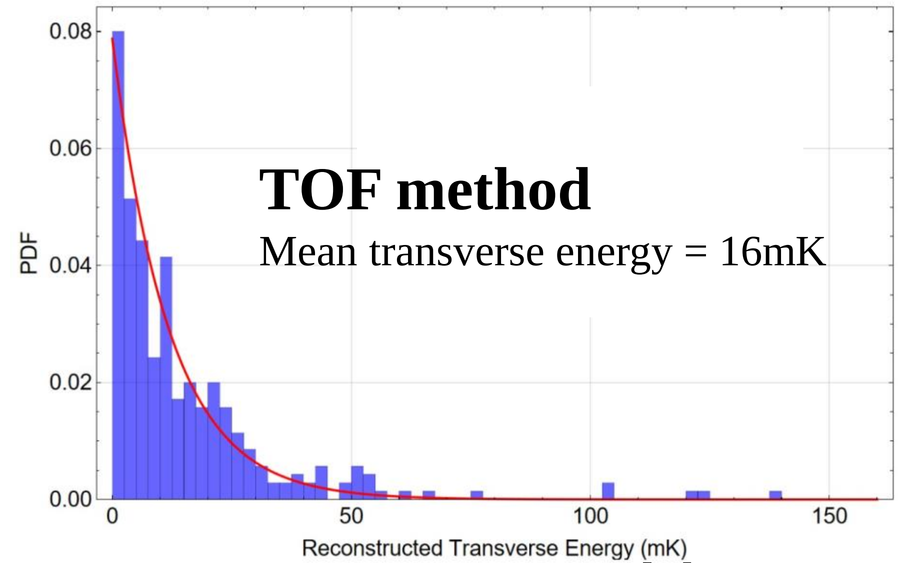






Laser Cooled Antihydrogen





D. Hodgkinson

Other news for 2024

new, rigid LHe transfer line fabricated and installed; not tested yet; should reduce ALPHA-g consumption: thanks to Laura Stewart and her crew!

- new CERN Fellow for 2024: Janko Nauta

- new coordinator for detectors and analysis: Ina Carli

farewell and good luck to Joseph McKenna!

ALPHA from 2024 onward

- gravity with antimatter – precision measurements
1. laser cooling in ALPHA-g
2. Be system for ALPHA-g
3. commissioning of the other traps in ALPHA-g

- antimatter spectroscopy to hydrogen-like precision

now have 10^4 anti-atoms that are colder than the hydrogen used for the most precise measurements on matter…

- excited state spectroscopy: other spectral lines – antiproton charge radius (*e.g.* 2S-3S; 2S-4P)

- ***in situ*** measurements on *hydrogen* with ALPHA-developed techniques MCP diagnostics

- long-term possibility: anti-deuterium?? Davide Gamba has agreed to look for some…

As always…

Thanks to the AD/ELENA crew, the cryo and transport teams, the workshops, procurement, stores and other CERN groups who make this all possible!

Thanks to our referees for their patience and hard work.