# Physics With Trapped Antihydrogen


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and the ALPHA Collaboration


First ELENA Construction Meeting
CERN, October 28, 2011

# Antihydrogen:

# Trapped!

LETTER

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**Trapped antihydrogen**

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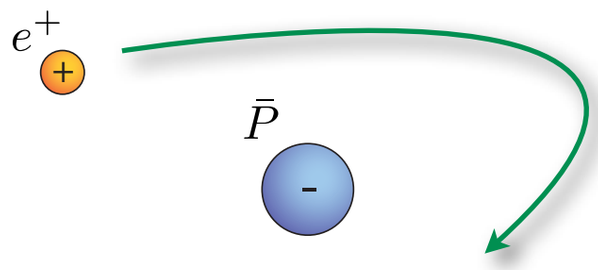
A few atoms for
100's of ms




Hundreds of atoms!

ARTICLES
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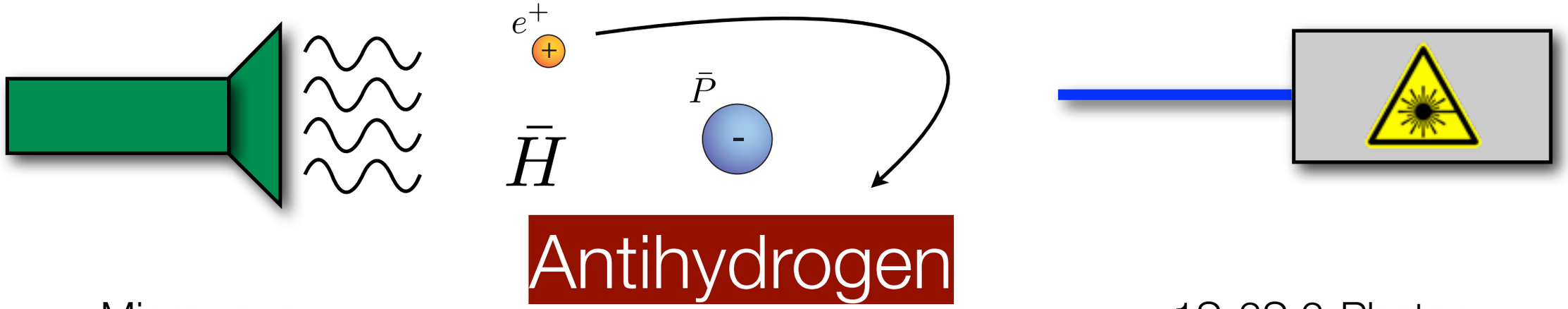
nature physics

**Confinement of antihydrogen for 1,000 seconds**

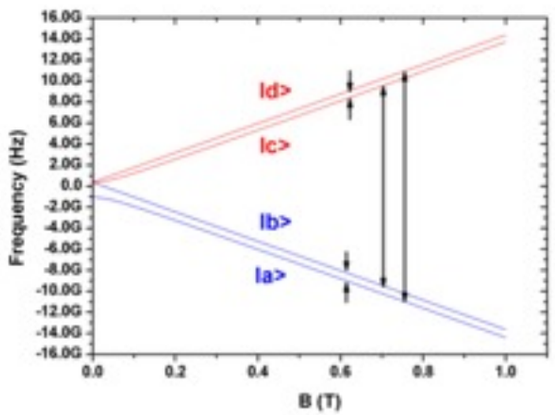
The ALPHA Collaboration*

# Antihydrogen Measurements in ALPHA

- Test Charge / Parity / Time Symmetry




Microwave
Hyperfine Spectroscopy




1S-2S 2-Photon
Doppler-Free Spectroscopy

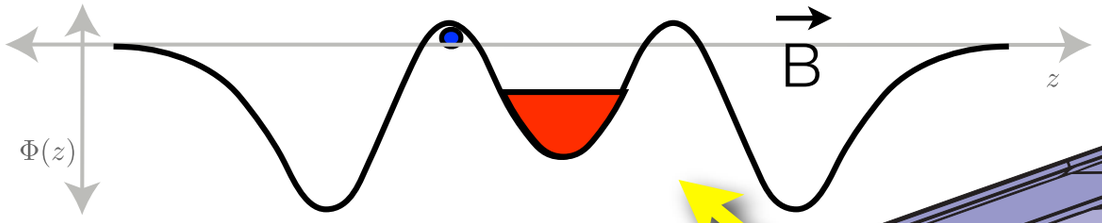

$\nu_{\mathrm{HF}} = 1\ 420\ 405\ 751.7667 \pm 0.0009\,\mathrm{Hz}$ $\qquad$ $\nu_{1S-2S} = 2\ 466\ 061\ 102\ 474\ 851 \pm 34\,\mathrm{Hz}$

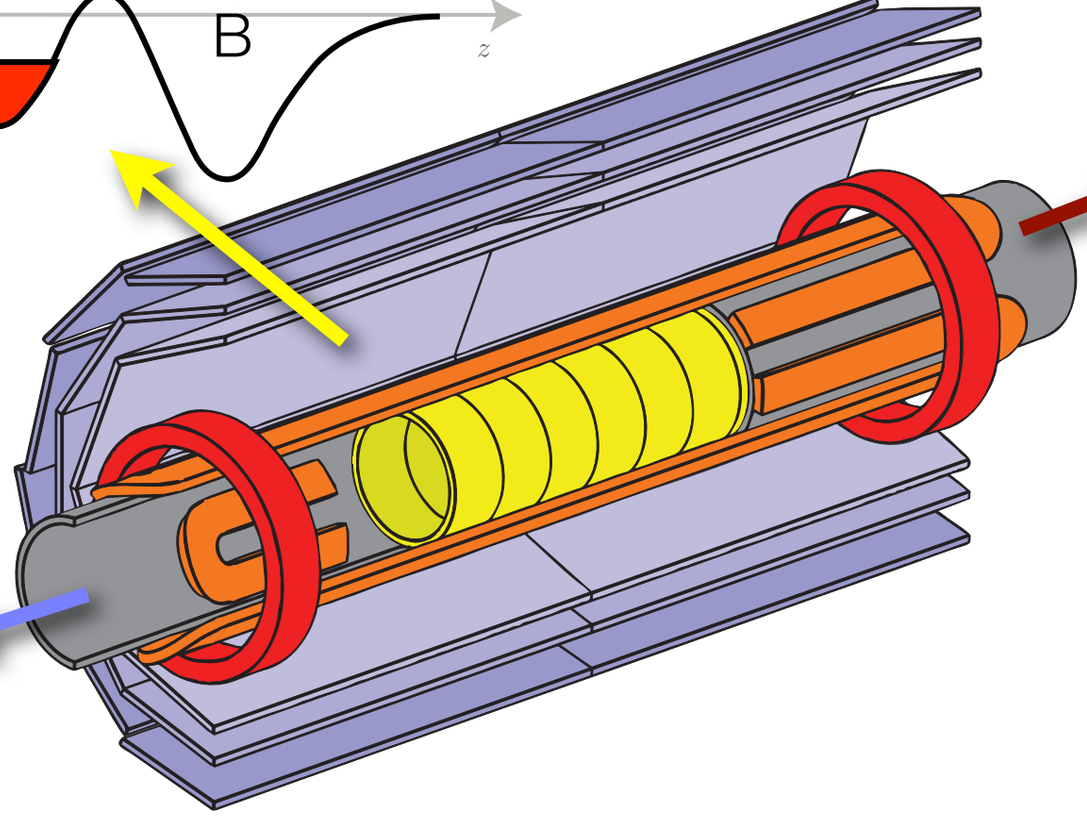

Swansea University
Prifysgol Abertawe

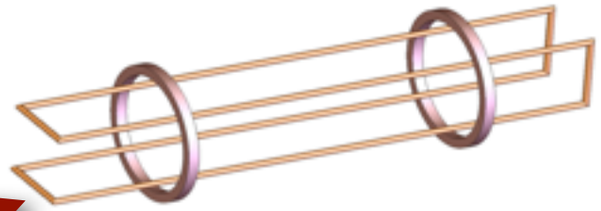
Dr. William Bertsche ELENA @ CERN, October 2011

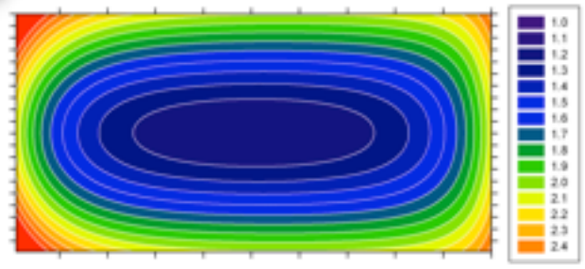
# The ALPHA Experiment

- Penning-Malmberg Trap (Ingredient plasmas)
- Octupole-Ioffe Trap (Minimum-B Magnetic Trap)
- Position-sensitive Silicon Vertex Detector



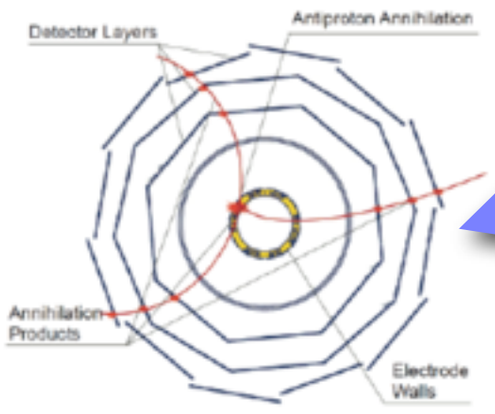







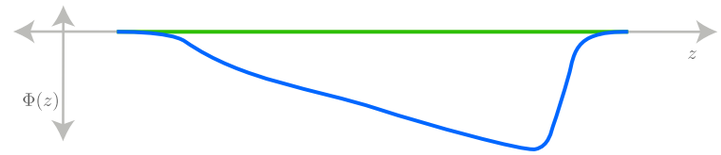
$$F = \nabla(\mu \cdot B)$$

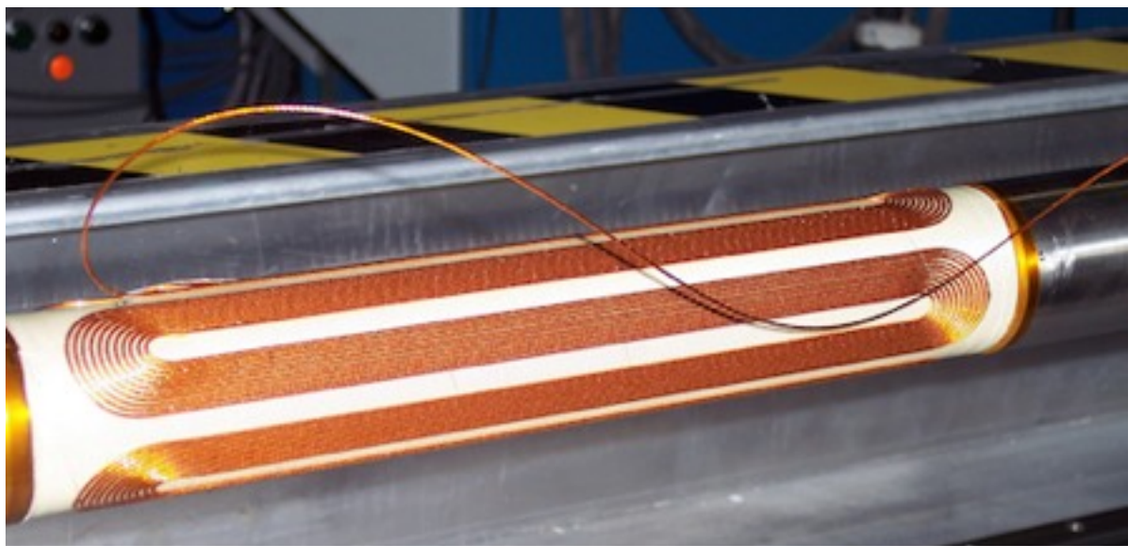
$$T < 0.5\ K$$

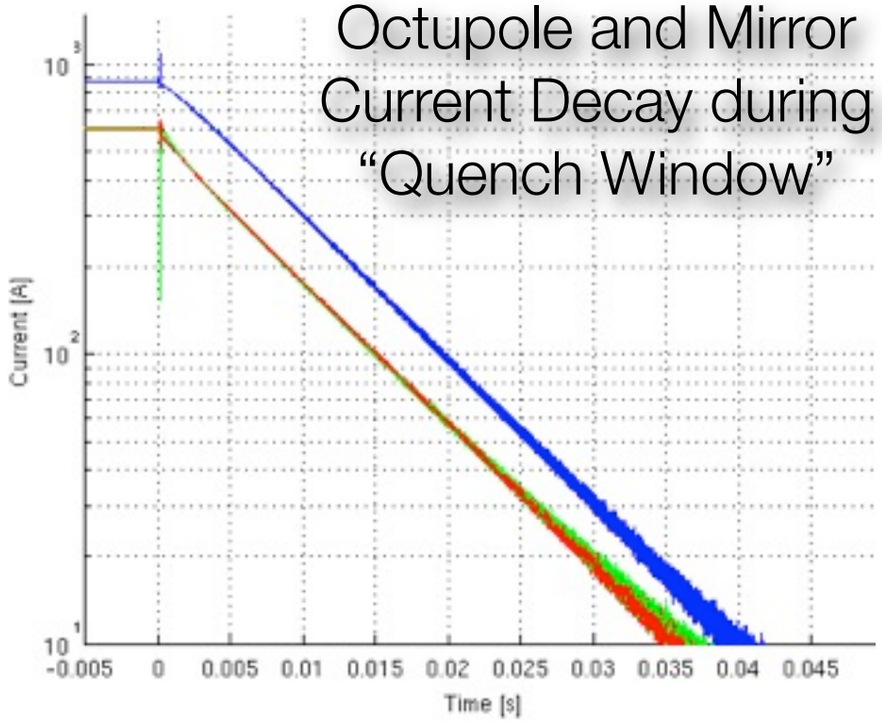


# Trapping Antihydrogen: Search

1. Energize magnetic trap
2. Mix and Form Antihydrogen
3. Stop formation; Eject remaining charged particles
4. Rapidly (~ 10's ms) shut off neutral trap (Quench!)
5. Antihydrogen annihilations on wall?



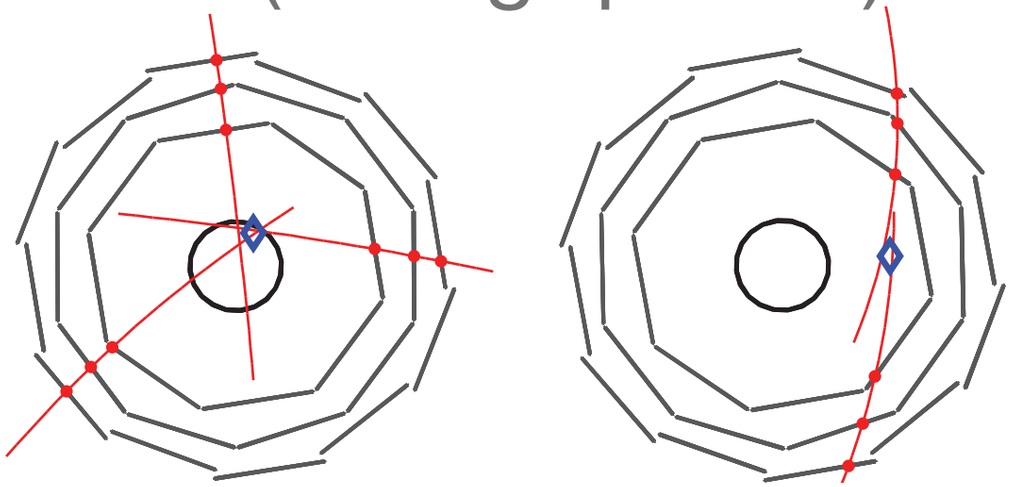





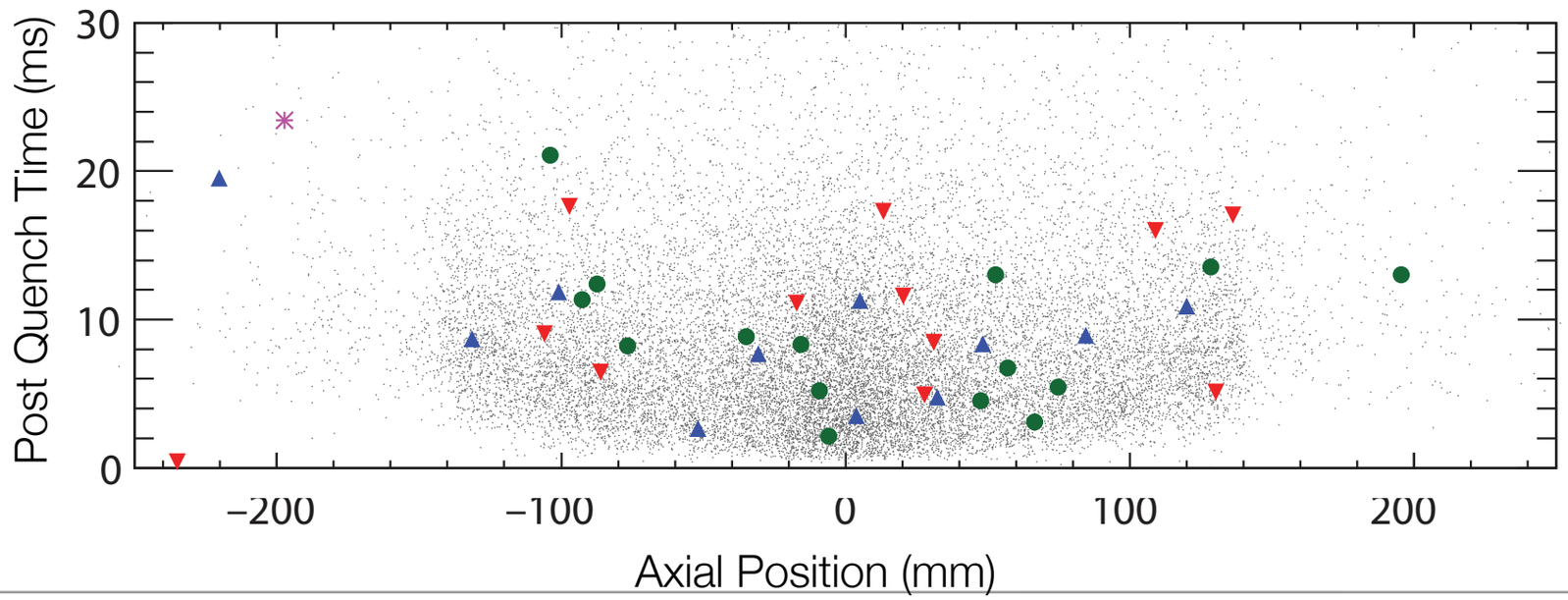
# Trapping Antihydrogen 2010: 38 Candidates

- Events are selected from cuts which exclude cosmics
- Events cut in time (during quench) and space (in trap)

Antiproton Annihilation



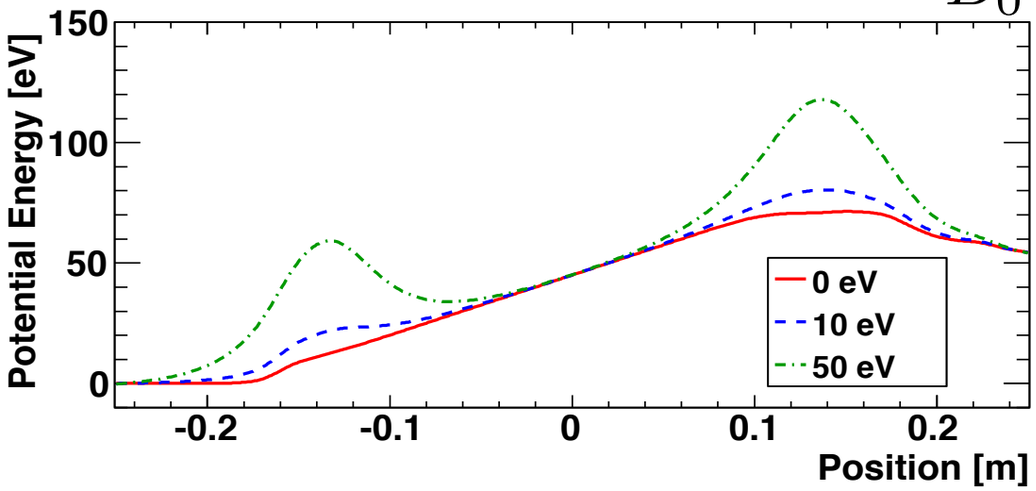
Cosmic Ray

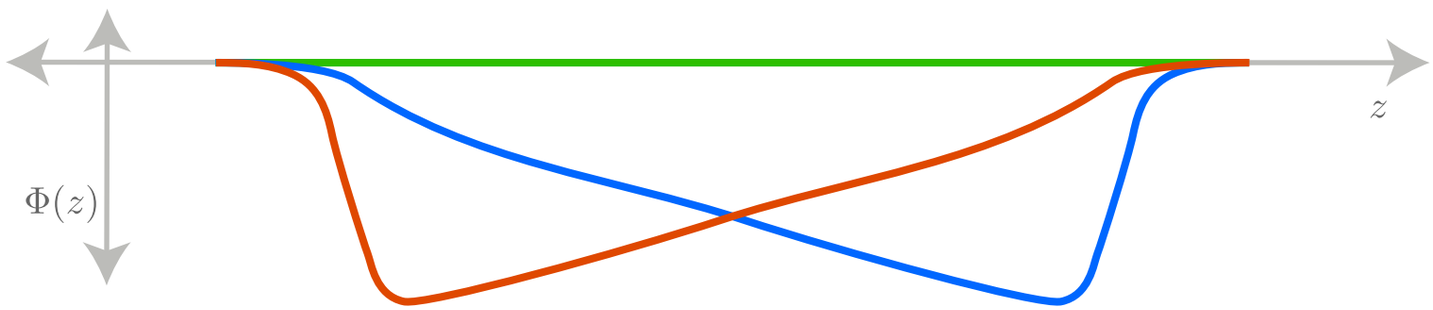


# Trapping Antihydrogen 2010: Systematic Effects?

- Possible Systematic Error: Mirror-trapped Antiprotons
- Bias by applying electric fields during quench

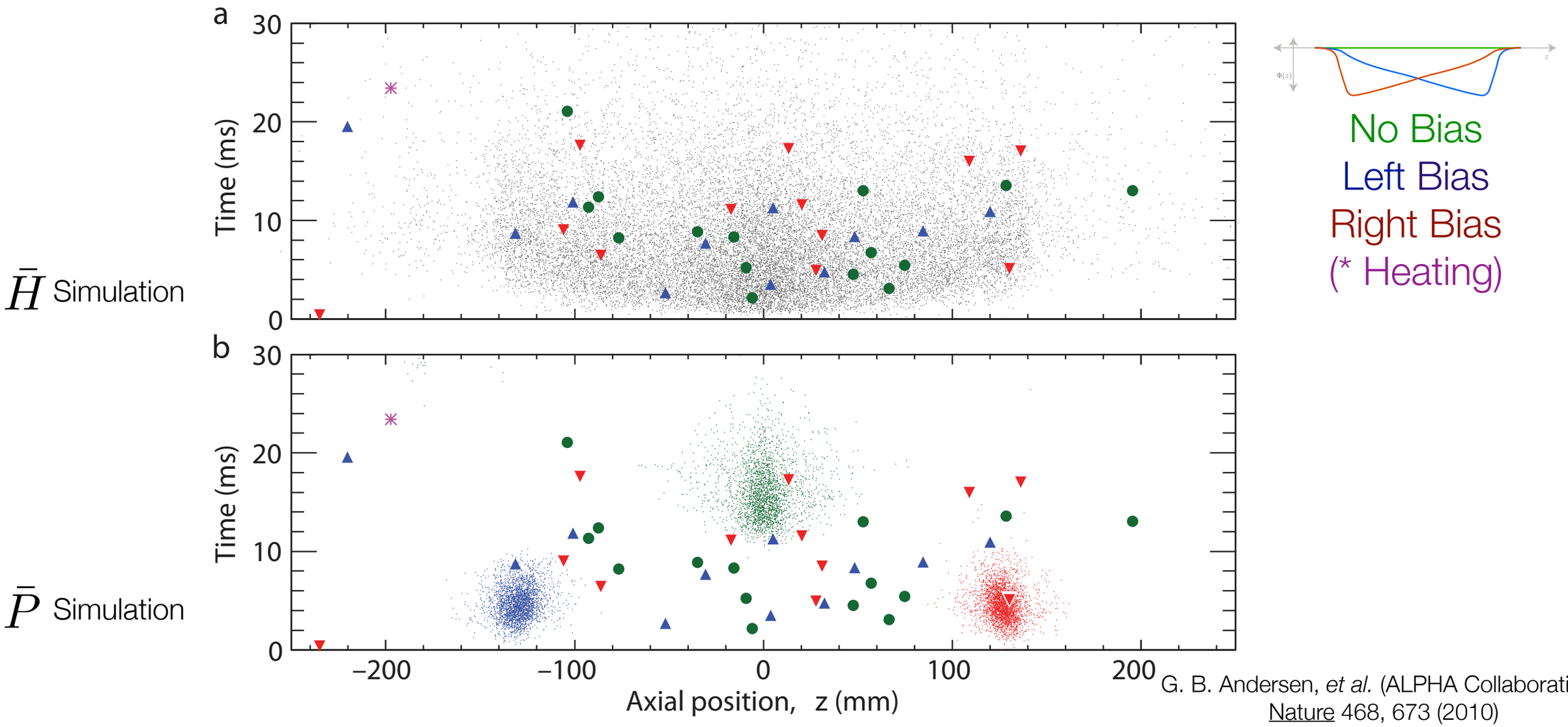
$$U_{\mathrm{tot}}(z, r=0) = q(\phi - \phi_0) + E_{\perp}\frac{B_{\parallel} - B_0}{B_0}$$



# No Bias = Trapped Antihydrogen!

- No spatial bias in signal; Heating ‘turns off’ signal



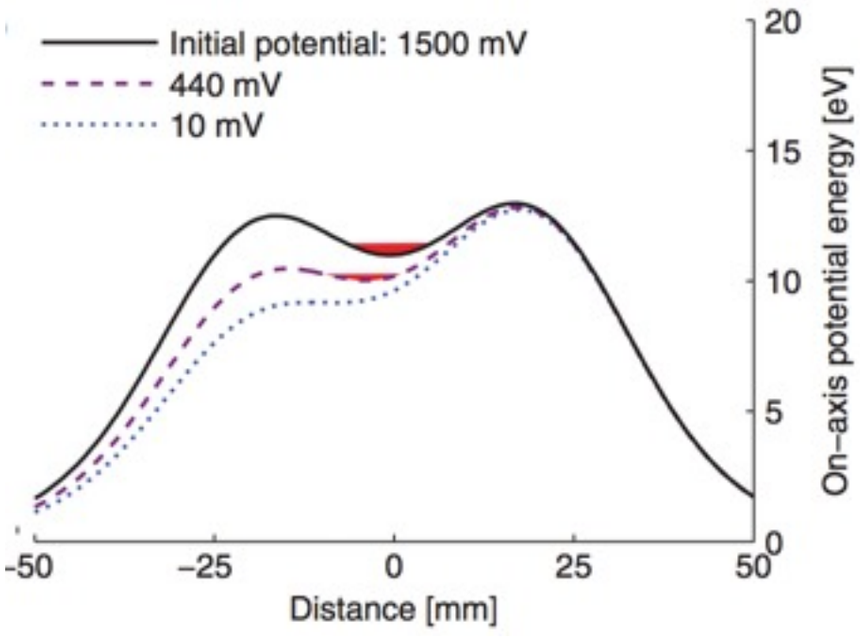


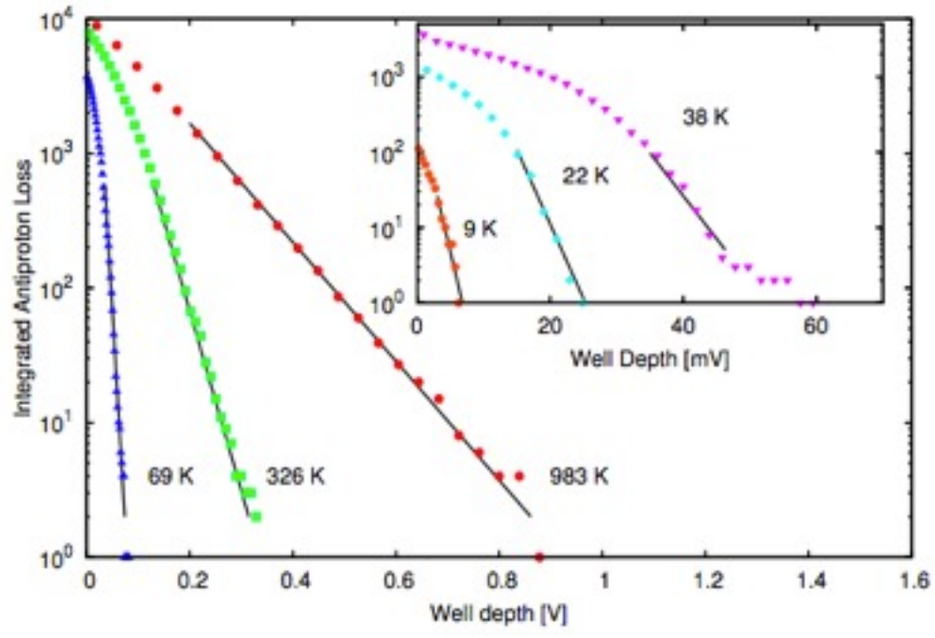

No Bias
Left Bias
Right Bias
(* Heating)

G. B. Andersen, *et al.* (ALPHA Collaboration), Nature 468, 673 (2010)

# Pre-cool the ingredients: Evaporative Cooling

- Coulomb collisions kick high-energy tail out of the potential, cooling distribution
- Ramp to shallower potentials to cool distribution
- First demonstration with plasmas
- Positron T < 40 K, Pbar T < 10 K

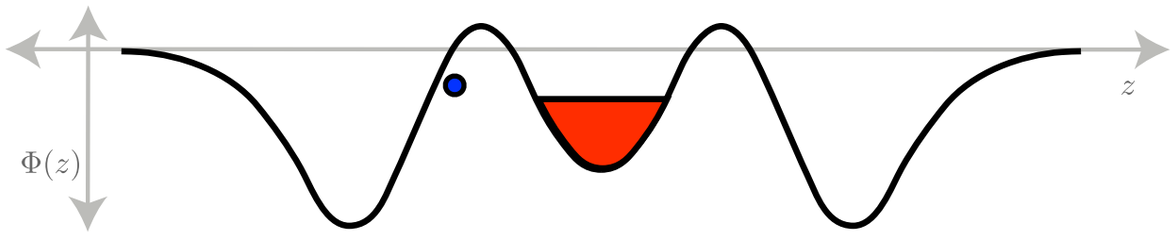


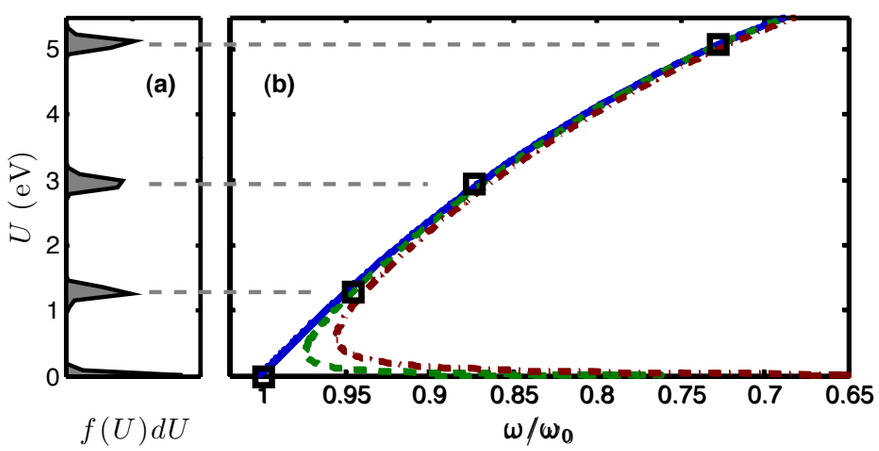

G. B. Andersen, *et al. (ALPHA Collaboration)*
Phys. Rev. Lett. **105**, 013003 (2010)

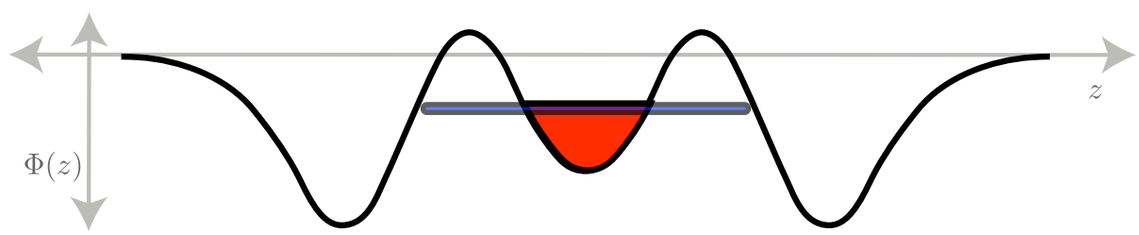
# Improved injection accuracy: Autoresonance

- Cold, dense antiprotons behave as nonlinear pendulum
- Antiproton energy set with swept-frequency drive (Autoresonance)
- Antiprotons driven just up to the energy of positrons




$$\ddot{\theta} + \omega_0^2 \sin\theta = \bar{\epsilon}\cos(\omega t)$$

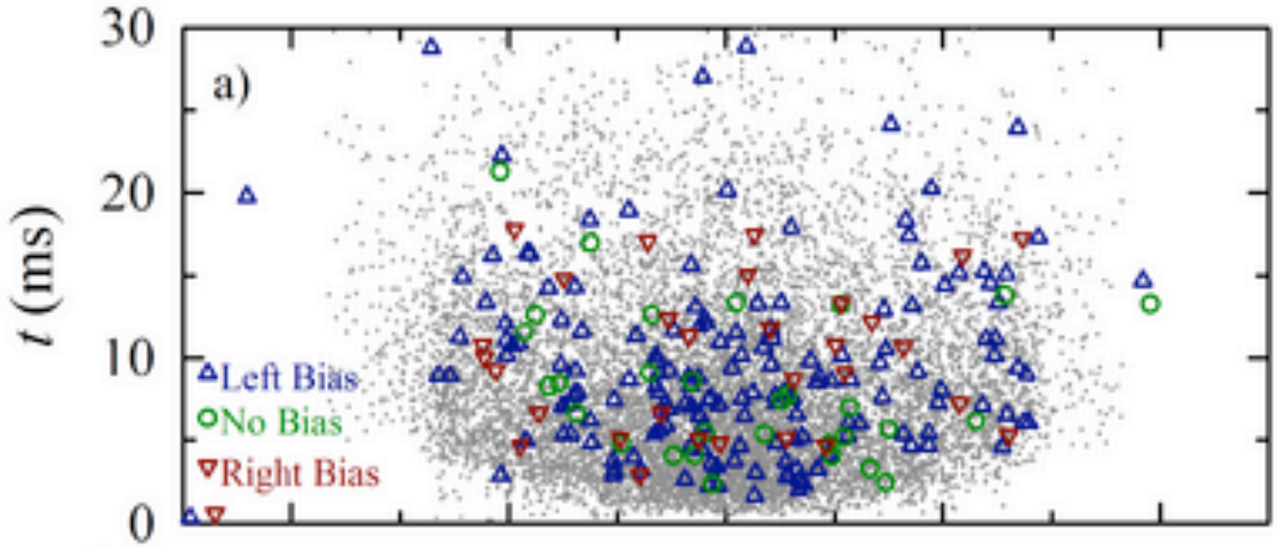



G. B. Andersen, *et al.* (ALPHA Collaboration), Phys. Rev. Lett. 106, 025002 (2011)

# Increased rates!

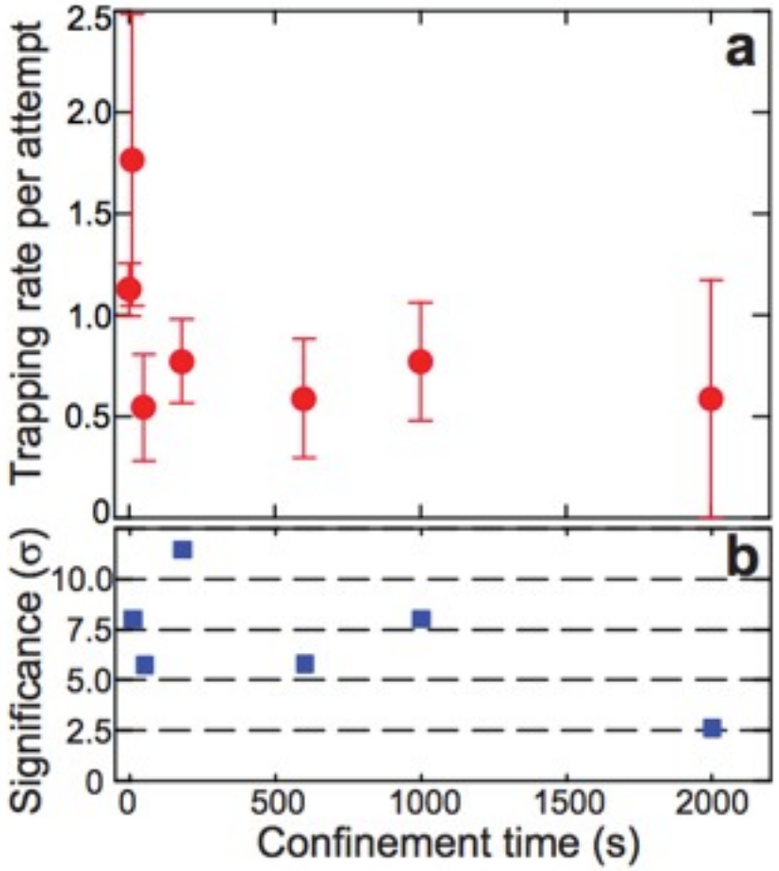
- Rates are going up




| Year | Events | “Rate” | Hold (s) | T (K) |
|---|---|---|---|---|
| 2010 | 38 | 0.12 | 173 ms | 90K |
| 2010+ | 100’s | 0.75 | 100+ s | 70K |

# Antihydrogen Survival Times

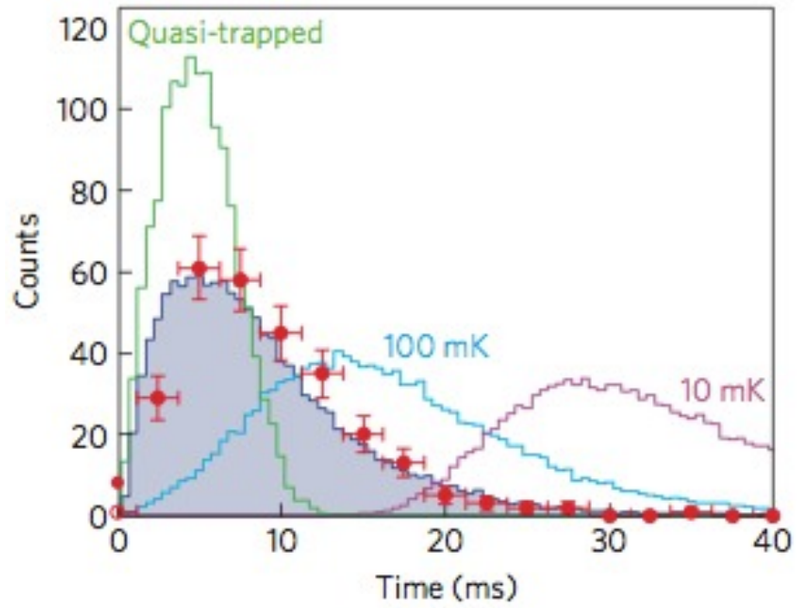
- Survival times in trap of 100's of seconds
- Hold times > 1 s imply ground state atoms
- Both facts allow atomic measurements on few atoms

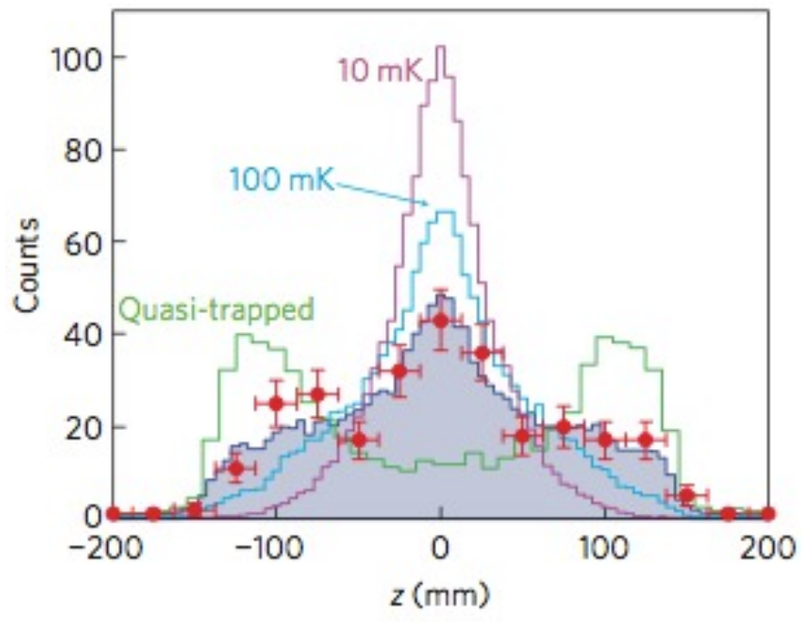



G. B. Andersen, *et al.* (ALPHA Collaboration), Nature Physics, 7, 558 (2011)

# Trapped Antihydrogen Energy Distribution

- Unique spatial/temporal resolution allows detailed comparison to simulation
- Population is mostly trapped, not quasi-trapped orbits (important for spectroscopy)
- Good agreement with simulation implies future tools for determining efficacy of cooling techniques



# Current and Future Work

- Ongoing work to improve trapping rates
- Commissioning hardware for hyperfine structure measurements
- Preparation for ALPHA-2
- Bright horizons for Antihydrogen physics!
- Many thanks for all the antiprotons and many more to come!