Group 5 presents…

# SYNTHESIS OF ANTIHYDROGEN IN A CUSP TRAP

Enomoto, Kurota, Michisimo, et al. (2010)

DOI: 10.1103/PhysRevLett.105.243401

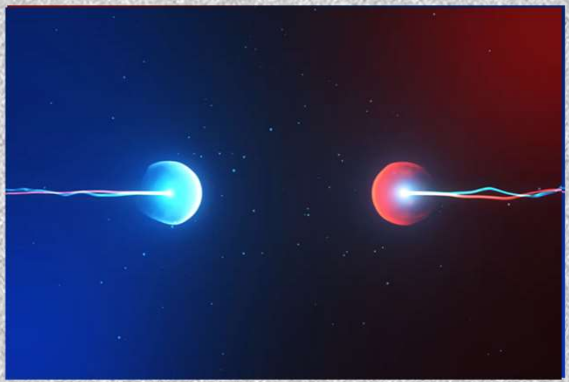
# OUTLINE

# BACKGROUND AND SUMMARY

# BACKGROUND

## Antimatter

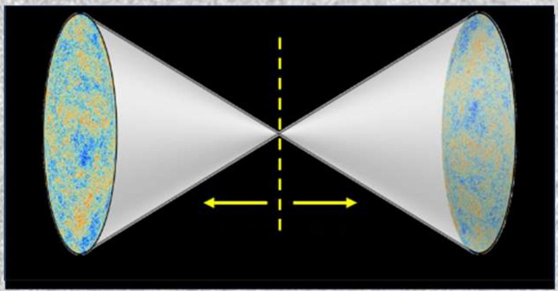
- Quantum field theory predicts matter and antimatter.



https://newatlas.com/physics/what-is-antimatter-explainer-primer/

## CPT Symmetry

- Physical laws are invariant under charge conjugation (C), parity inversion (P), and time-reversal (T).
- Testing CPT tests quantum field theory

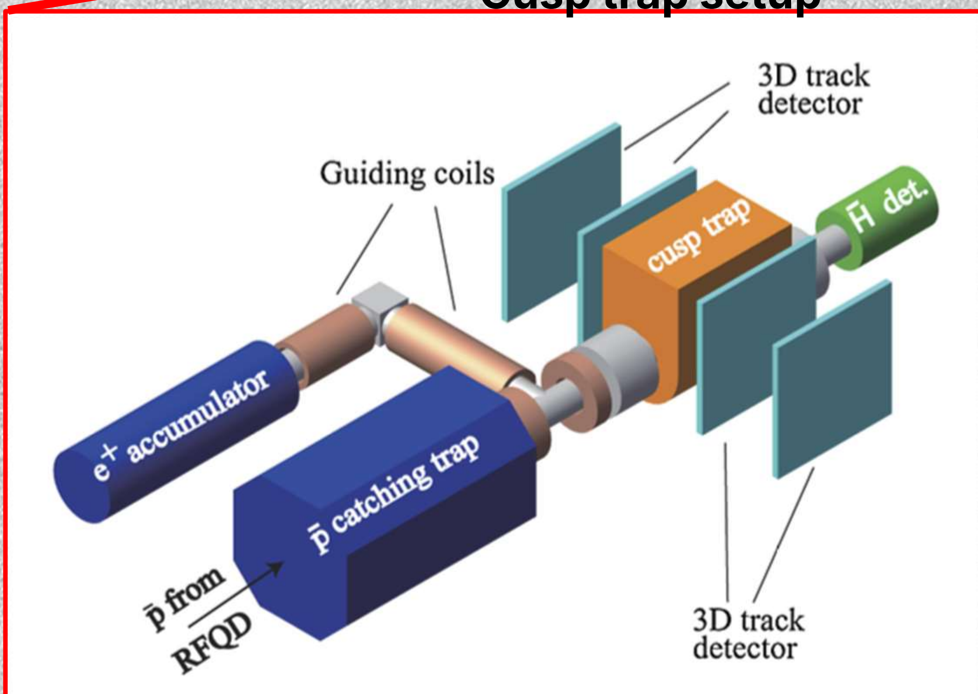


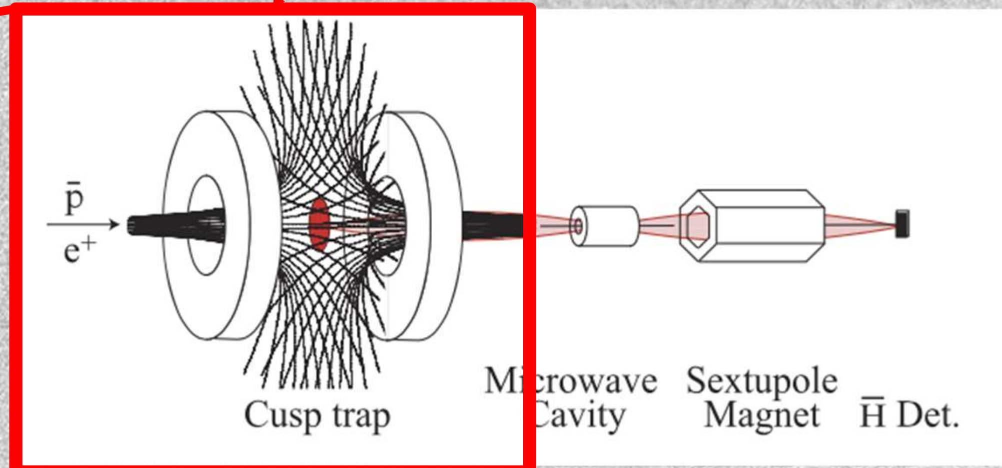
https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.121.251301

# SUMMARY

this paper

Cusp trap setup

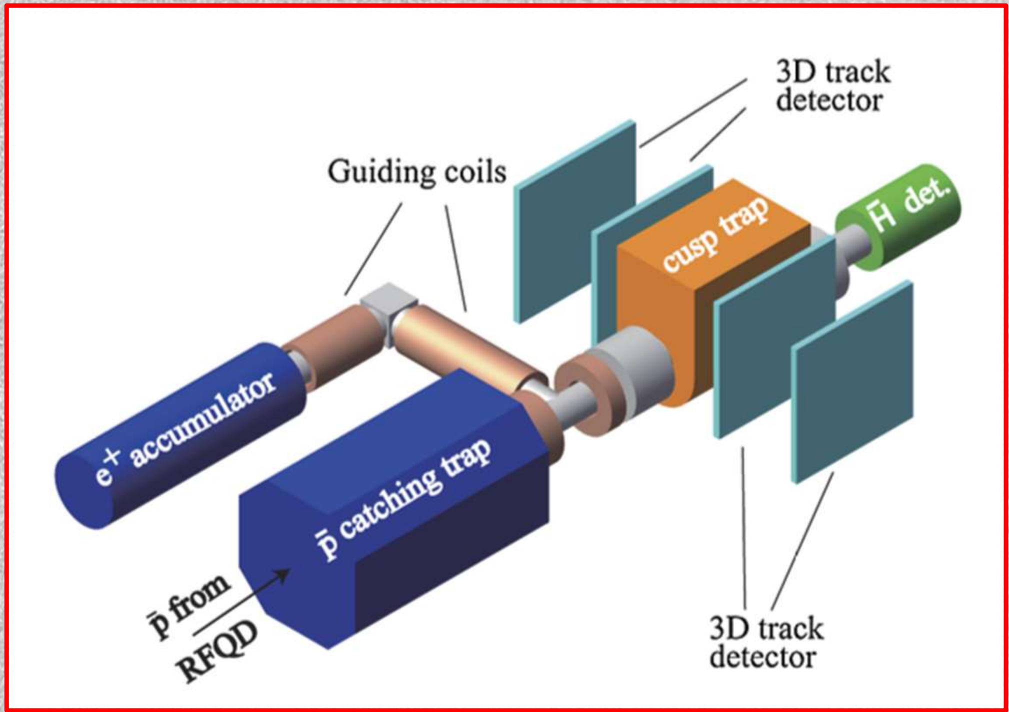



**<u>Ultimate goal:</u> microwave spectroscopy of antihydrogen**

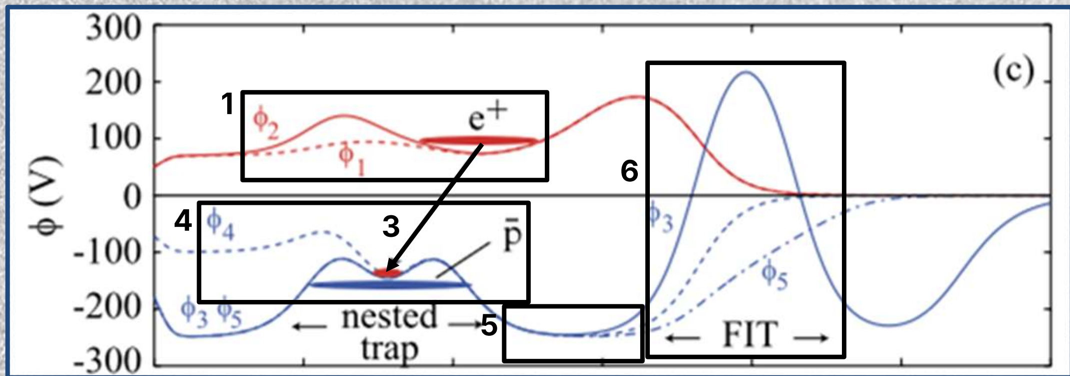
# SUMMARY

1. Antiprotons from CERN antiproton decelerator
2. Radioactive Sodium-22 positron source
3. Cusp trap consists of superconducting anti-Helmholtz coil and stack of multiple ring electrodes (MRE)
4. Scintillators detect antiproton annihilations



# SUMMARY

1. Inject and cool positrons
2. Compress positrons using rotating electric field
3. Compressed positrons moved to nested trap
4. Place antiprotons into nested trap
   i. neutral antihydrogen forms, then escapes trap
5. Highly excited antihydrogen are field-ionized
   i. antiprotons accumulate at field-ionization trap (FIT)
6. FIT-stored antiprotons periodically released




Position (inside cusp trap)

# PREVIOUS WORK

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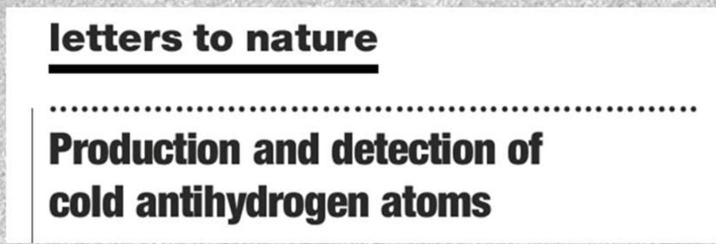
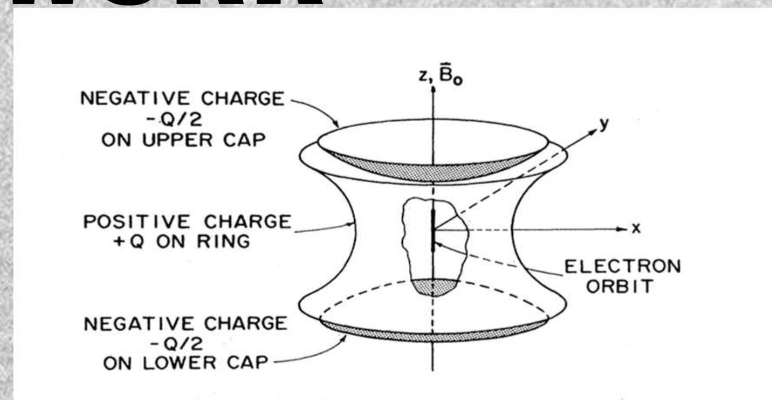
**Goal:**

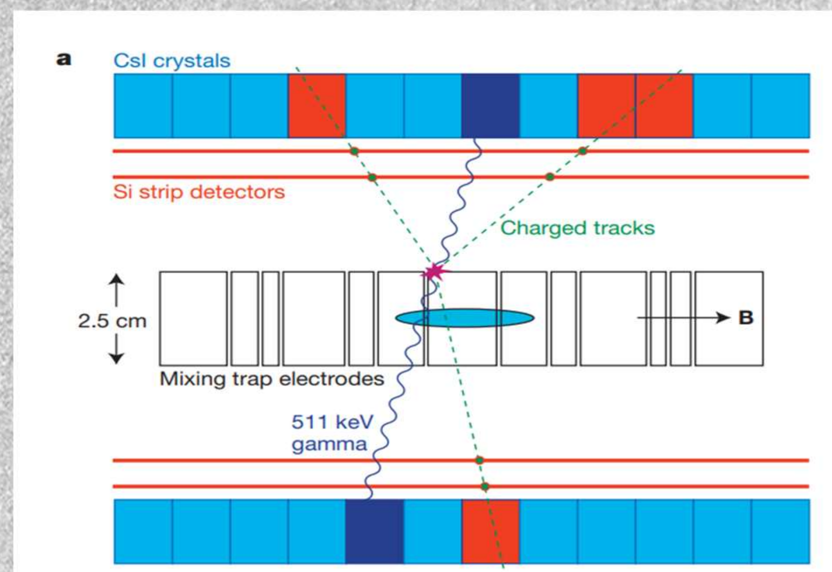


letters to nature

**Production and detection of cold antihydrogen atoms**




**Methodology:** Penning trap - uses magnetic fields and electrodes to trap particles inside a small region.




Successful trapping, hot mixing had 4 times lower annihilation rate

Trapping mechanism only works on ground state atoms

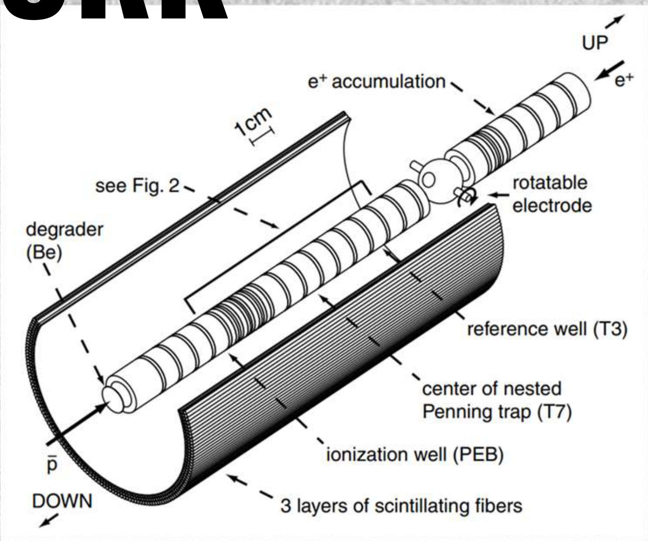
# PREVIOUS WORK


VOLUME 89, NUMBER 21 PHYSICAL REVIEW LETTERS 18 NOVEMBER 2002

**Background-Free Observation of Cold Antihydrogen with Field-Ionization Analysis of Its States**

G. Gabrielse,[1,*] N. S. Bowden,[1] P. Oxley,[1] A. Speck,[1] C. H. Storry,[1] J. N. Tan,[1] M. Wessels,[1] D. Grzonka,[2] W. Oelert,[2] G. Schepers,[2] T. Sefzick,[2] J. Walz,[3] H. Pittner,[4] T.W. Hänsch,[4,5] and E. A. Hessels[6]

(ATRAP Collaboration)

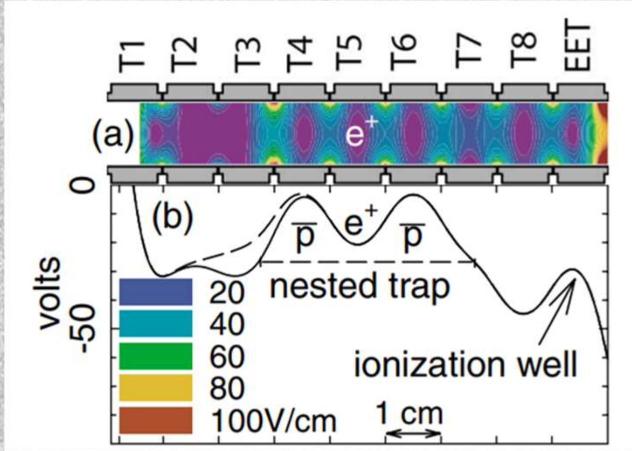



**Goal:** synthesize anti H atoms cold enough to be trapped for laser spectroscopy

**Methodology:** Nested penning trap

Very high efficiency, 11% of antiprotons form anti-hydrogen

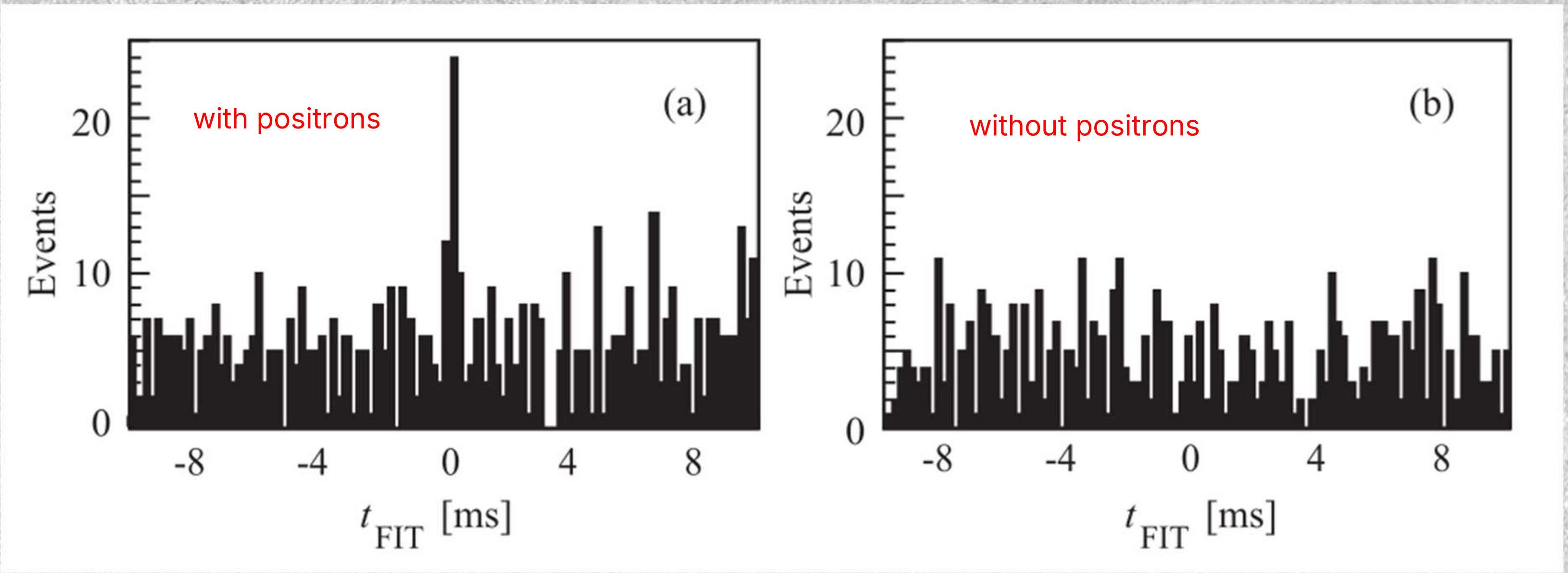
Still requires deexcitation of the highly magnetized, highly excited states observed



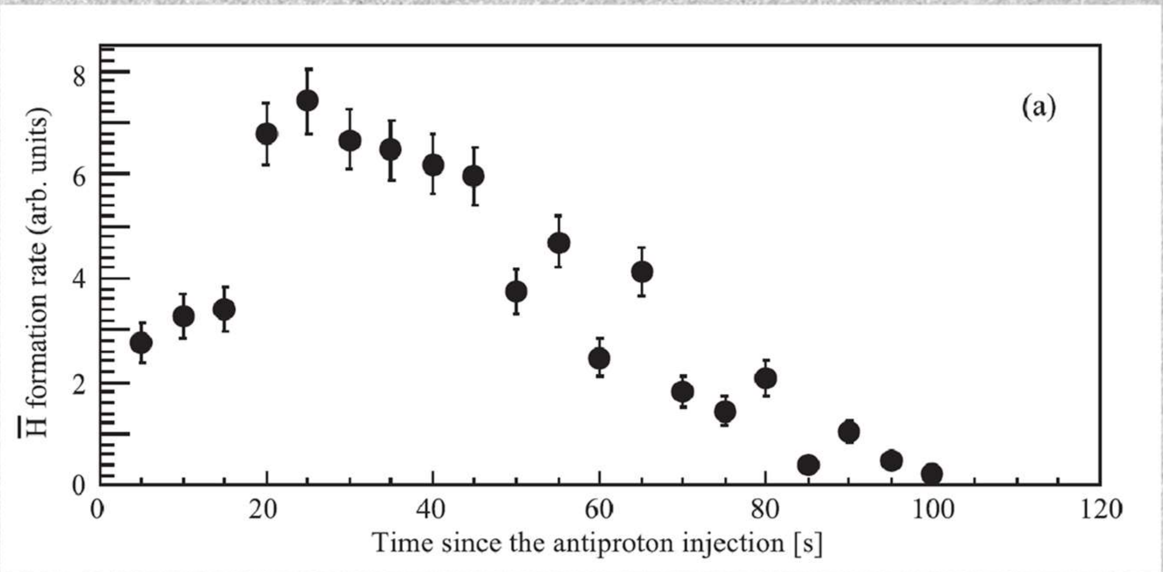
# RESULTS

# Field ionization trap populations

- The following figures show the counts (synchronized to FIT release) from 3-d track detector during mixing of antiprotons.
- Peak is seen in case of positrons in nested trap. Background is due to residual gas
- If positrons are r-f heated the peak is reduced



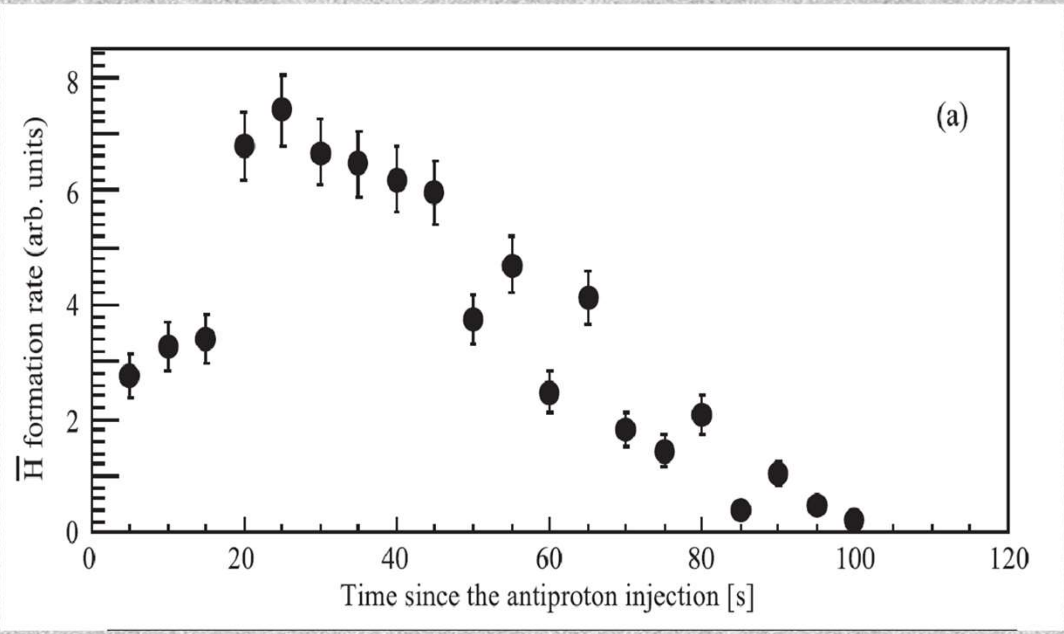
# Variation in number of ionized $\overline{\mathrm{H}}$




Experiment started with 3E5 antiprotons and 3E6 positrons in nested trap

- Number decrease is hypothesized due to separation of positron and antiproton clouds in nested trap

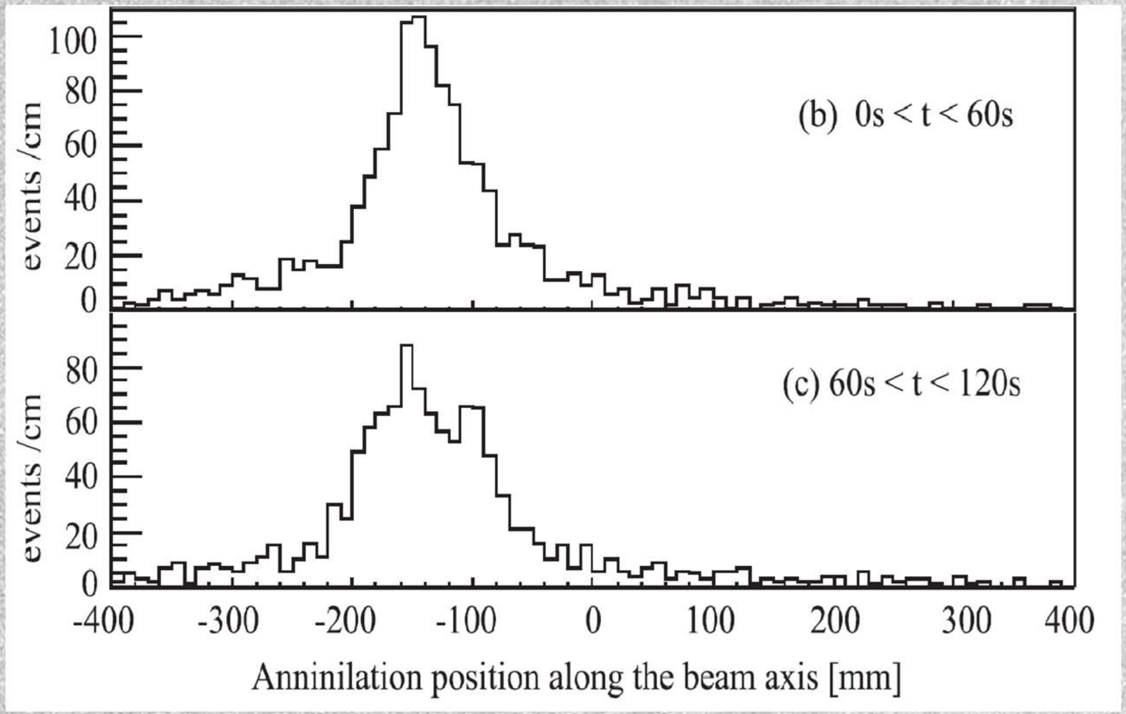
# Variation in number of ionized $\overline{\mathrm{H}}$




- Rydberg anti-Hydrogen formation efficiency of 2% which increases to 7% by reducing the initial population of antiproton.
- Smaller antiproton populations implies earlier peaking of anti-Hydrogen synthesis rate and shorter synthesis periods

# Antiproton annihilation location

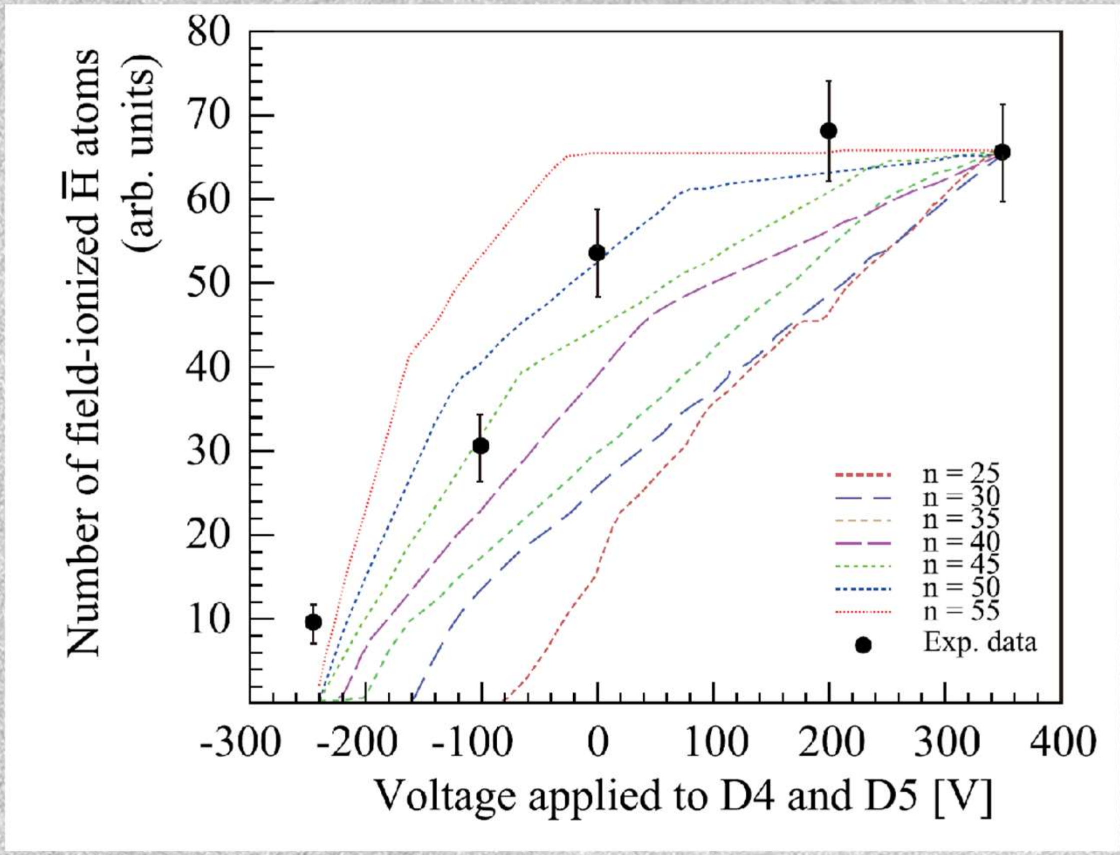
- Most annihilation occurs within the nested trap due to residual gas
- Broadening of the peak is due to axial separation of anti-protons and positrons



# Estimation of Q-number of $\overline{H}$

- Number of Field-ionized antihydrogen atoms is determined by number of counts detected by 3-d detector compensated for isotropic angular distribution in 4π. Observation is consistent with n ~ 45,50.

- The field ionization simulations were conducted and are shown.The n ≥ 55 states are ionized before they reach the FIT.



# CRITICAL ANALYSIS

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## Strengths

- **Cusp trap is new and effective!**
- **Successfully made antihydrogen in cusp trap**
- **Makes use of existing CERN facilities**
- **First step toward microwave spectroscopy of antihydrogen**
- **Strong justification of presented results and conclusions with suitable control experiments**

# CRITICAL ANALYSIS

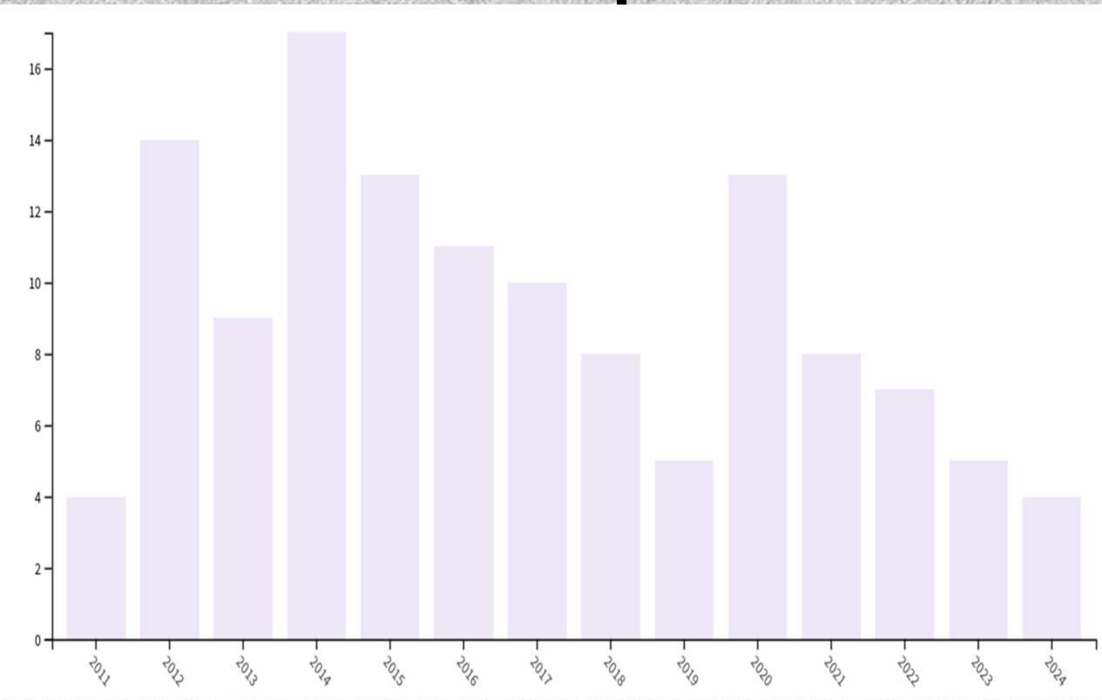
## Weaknesses/Criticisms

- Low antihydrogen synthesis efficiency
- Intermediate measurement techniques not given
- Minimal discussion of positron and antiproton density effect on efficiency
- Simulation results mentioned once but never discussed in context of experimental results
- Didn’t measure beam polarization
- Didn’t detect low-n states
- Didn’t say whether planned measurement was feasible
- Didn’t utilize position resolution
- Too much discussion of future experiment
- Lack of supplementary material

# IMPACT

# CITATIONS BY FIELD AND YEAR

**# of Citations per Year**

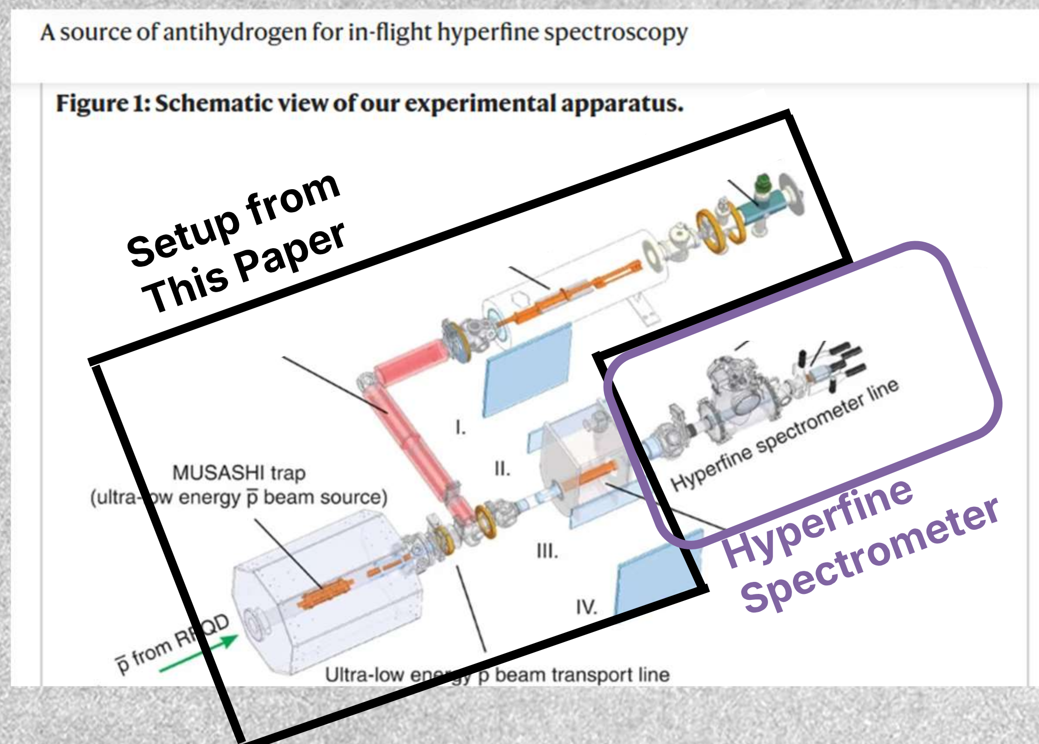



- Relevance of paper slowly waning since 2015.
- Relevant to:
  - Fundamental/particle physics
  - Optics
  - Chemistry
  - A few others

# PROGRESS

## Testing CPT Symmetry & Weak Equivalence Principle

- **Production of Antihydrogen is first step to antimatter measurements**
  - Hyperfine spectroscopy
    - Image: Exact experiment suggested in our paper's Introduction



# PROGRESS

## Testing CPT Symmetry & Weak Equivalence Principle

- **Production of Antihydrogen is first step to antimatter measurements**
  - Hyperfine spectroscopy
  - 1S-2S spectroscopy
    - Uses trapped antihydrogen

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

M. Ahmadi[1], B. X. R. Alves[2], C. J. Baker[3], W. Bertsche[4,5], E. Butler[6], A. Capra[7], C. Carruth[8], C. L. Cesar[9], M. Charlton[3], S. Cohen[10], R. Collister[7], S. Eriksson[3], A. Evans[11], N. Evetts[12], J. Fajans[8], T. Friesen[2], M. C. Fujiwara[7], D. R. Gill[7], A. Gutierrez[13], J. S. Hangst[2], W. N. Hardy[12], M. E. Hayden[14], C. A. Isaac[3], A. Ishida[15], M. A. Johnson[4,5], S. A. Jones[3], S. Jonsell[16], L. Kurchaninov[7], N. Madsen[3], M. Mathers[17], D. Maxwell[3], J. T. K. McKenna[7], S. Menary[17], J. M. Michan[7,18], T. Momose[12], J. J. Munich[14], P. Nolan[1], K. Olchanski[7], A. Olin[7,19], P. Pusa[1], C. Ø. Rasmussen[2], F. Robicheaux[20], R. L. Sacramento[9], M. Sameed[3], E. Sarid[21], D. M. Silveira[9], S. Stracka[22], G. Stutter[2], C. So[11], T. D. Tharp[23], J. E. Thompson[17], R. I. Thompson[11], D. P. van der Werf[3,24] & J. S. Wurtele[8]

# PROGRESS

## Testing CPT Symmetry & Weak Equivalence Principle

- **Production of Antihydrogen is first step to antimatter measurements**
  - Hyperfine spectroscopy
  - 1S-2S spectroscopy
  - Antihydrogen charge

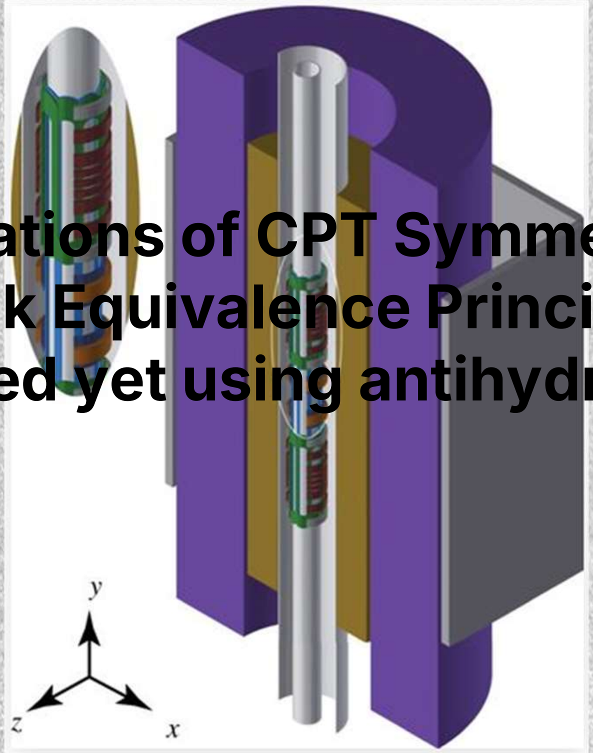
An experimental limit on the charge of antihydrogen

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

# PROGRESS

## Testing CPT Symmetry & Weak Equivalence Principle

- **Production of Antihydrogen is first step to antimatter measurements**
  - Hyperfine spectroscopy
  - 1S-2S spectroscopy
  - Antihydrogen charge
  - Antihydrogen mass
    - Freefall is observed
    - Mass measurement ongoing




**No violations of CPT Symmetry or Weak Equivalence Principle observed yet using antihydrogen.**

# THANK YOU

## QUESTIONS?