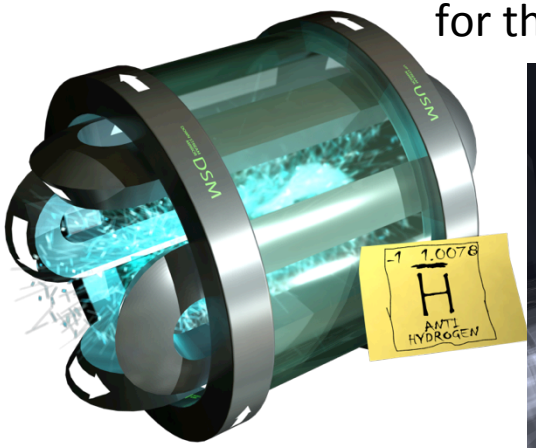
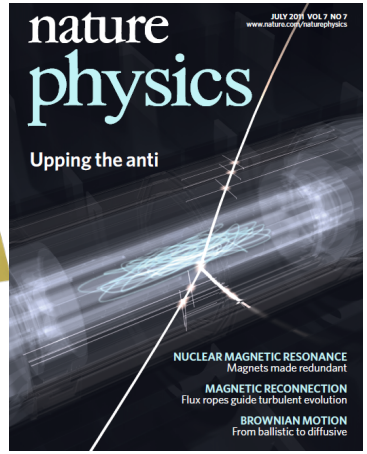
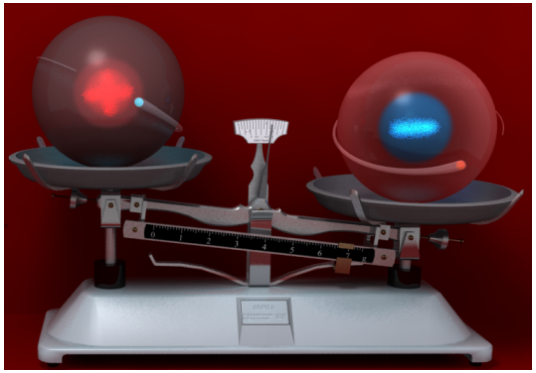
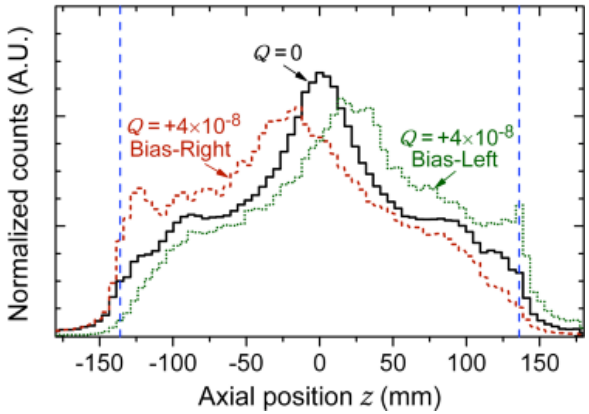
The ALPHA Collaboration
Antihydrogen Physics

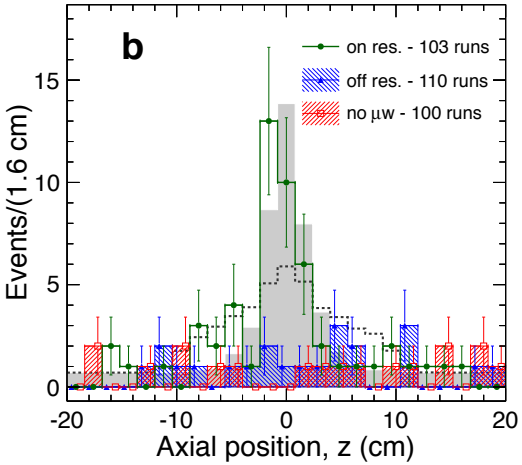
Nuclear Physics Town Meeting
September 29, 2014
Jonathan Wurtele
U.C. Berkeley
for the ALPHA Collaboration











ALPHA: Antihydrogen Laser PHysics Apparatus

Synthesize, trap and probe antihydrogen

Test the foundations of physics through precision measurements of its characteristics.

Precision measurements to test CPT

1S-2S spectroscopy

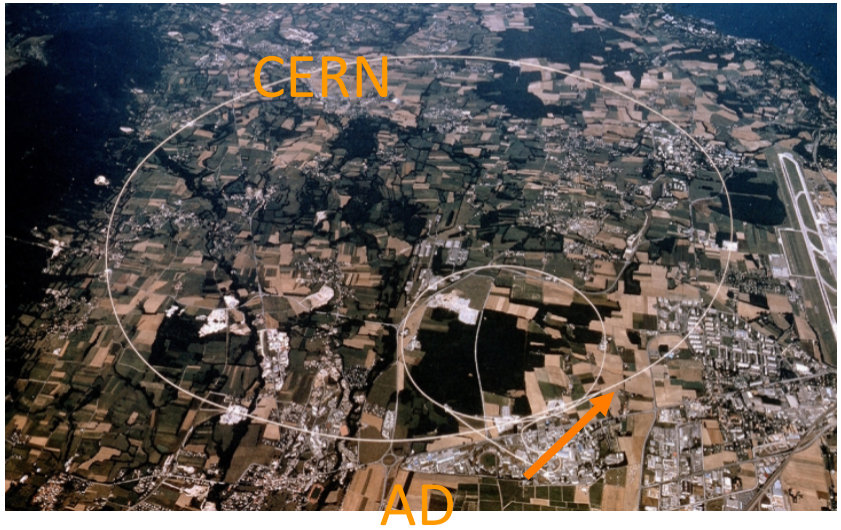
Hyperfine spectroscopy

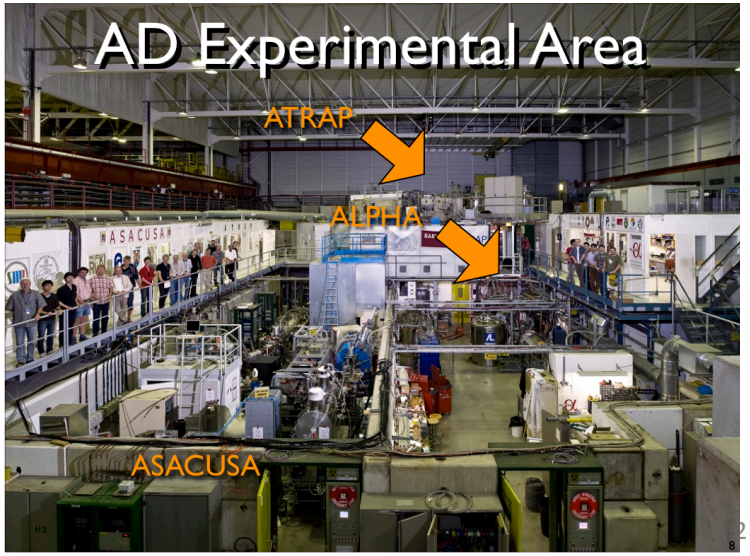
Charge neutrality

Gravitational force (test the Einstein Equivalence Principle)

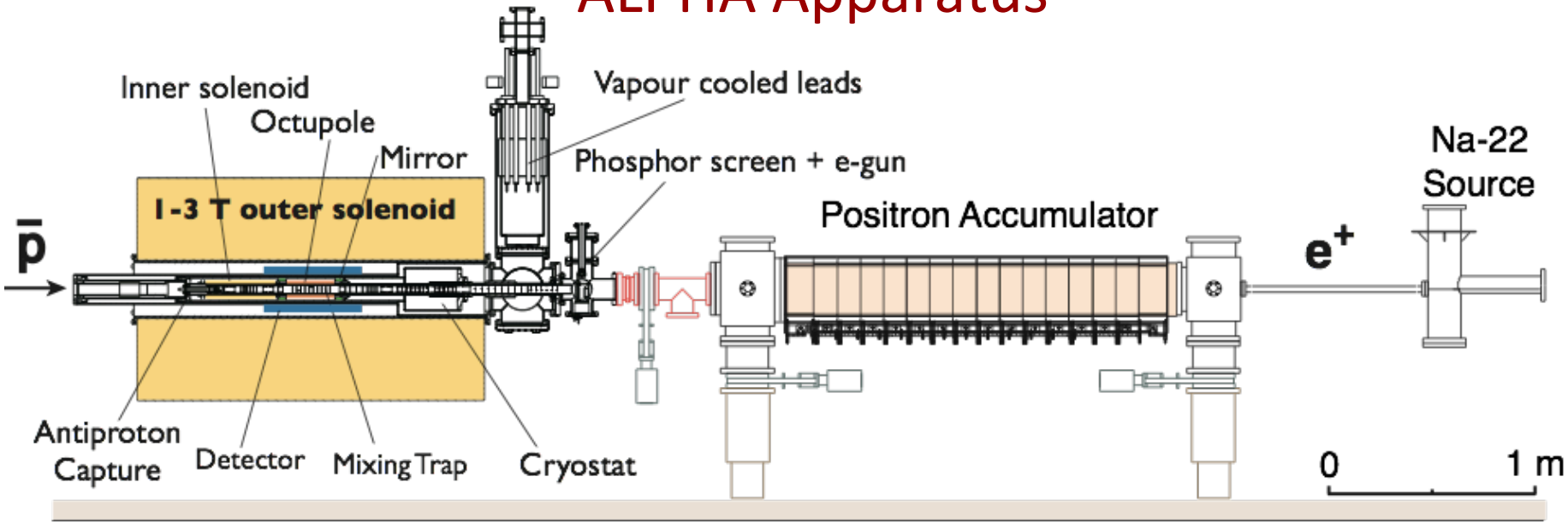
The ALPHA Collaboration:

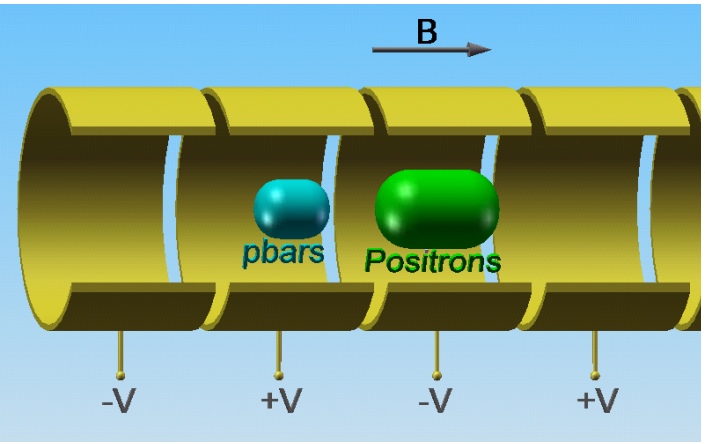
- *Founded in 2005; 40-50 members from 14-15 institutions in 8 countries*
- **Experiment at the Antiproton Decelerator (AD) Facility at CERN**

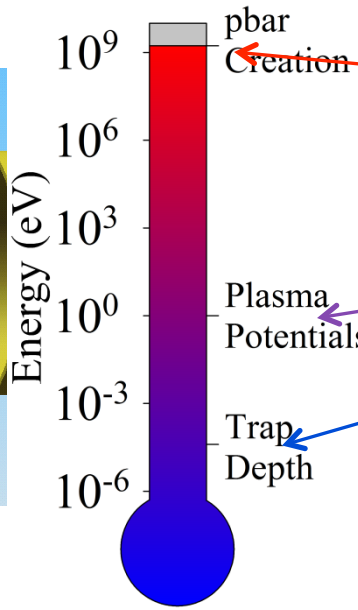




ALPHA Apparatus







Antiproton Creation: 1.7GeV

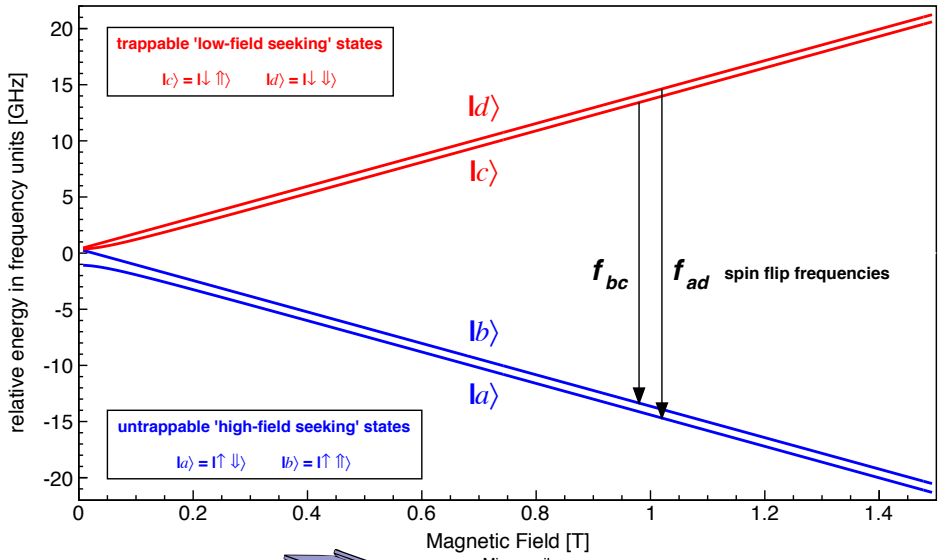
Self-Potential: 30mV-10V

Trap Depth: 0.5K or 40μeV

$$\frac{\text{Collective Potential}}{\text{Neutral Trap Depth}} = 10^3 - 10^5$$

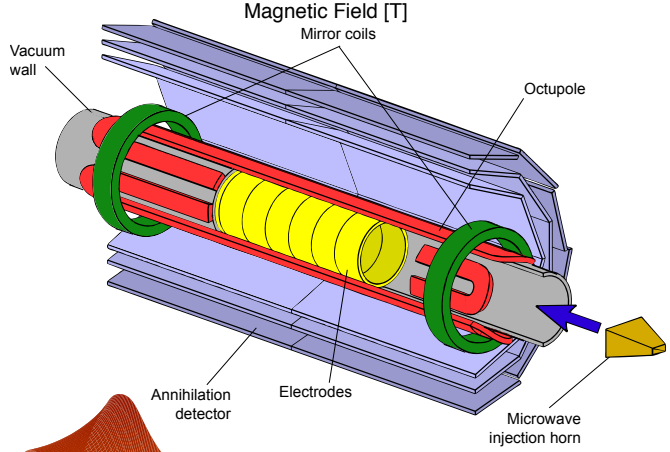
ATRAP apparatus broadly similar.

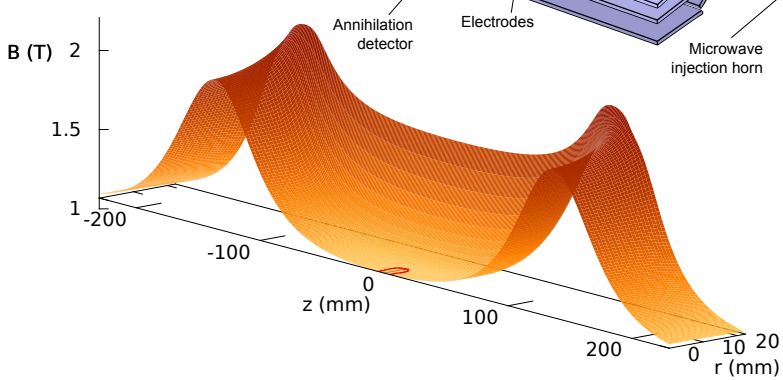
Microwave Spectroscopy



$$\nu_{\bar{H}}^{hfs} = 1.42 \pm .10\ GHz$$

ALPHA Nature **483**, 439 (2012)

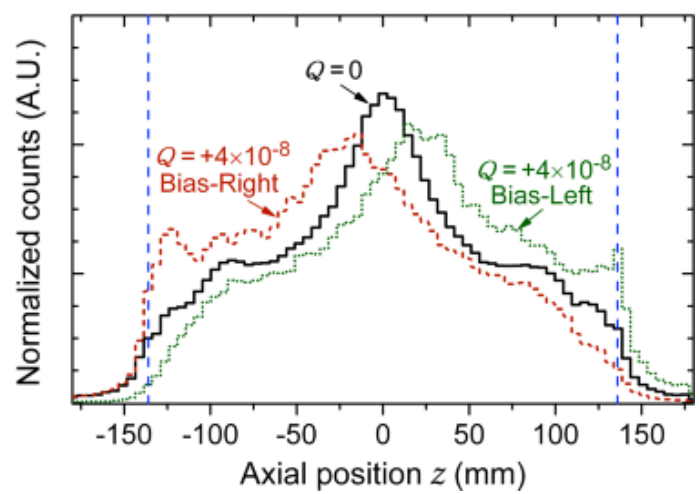




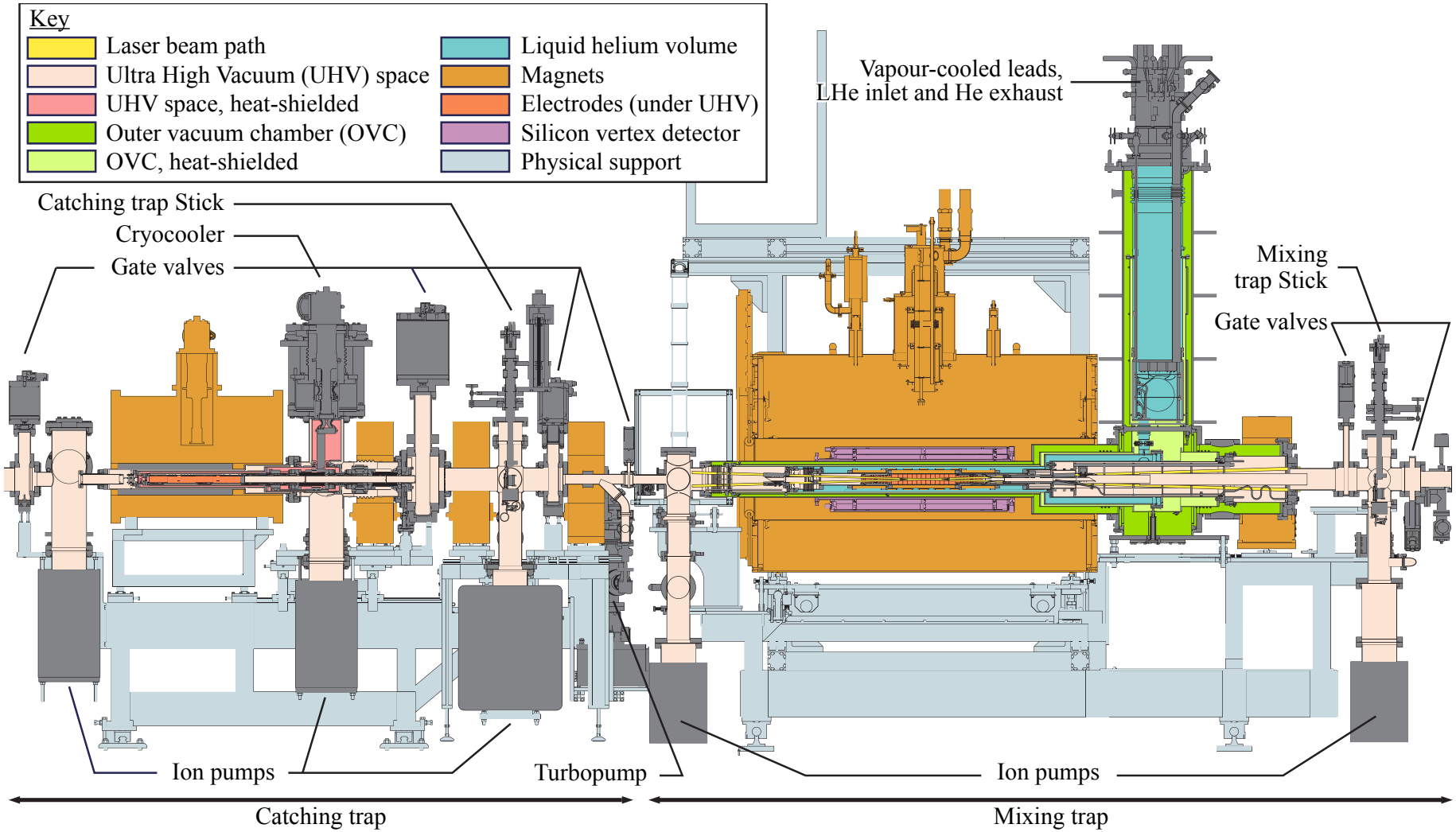
Charge Neutrality

$$\left| q_{\bar{p}} + q_{e^+} \right| < (-1.3 \pm 1.1 \pm 0.4) \times 10^{-8} e$$

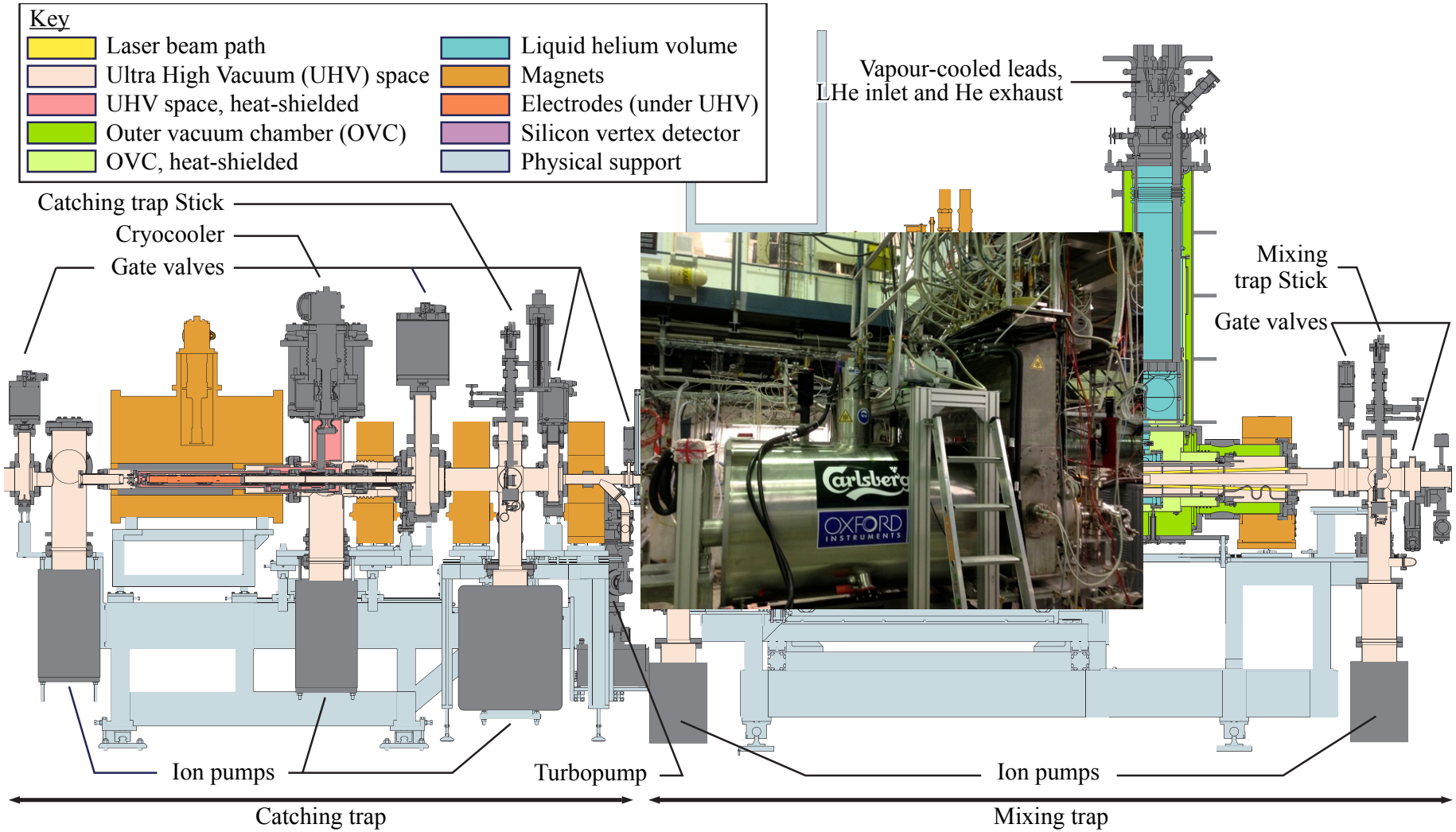
ALPHA Nature Comm. **5**, 3955 (2015)



New ALPHA-II Apparatus



ALPHA-II Apparatus

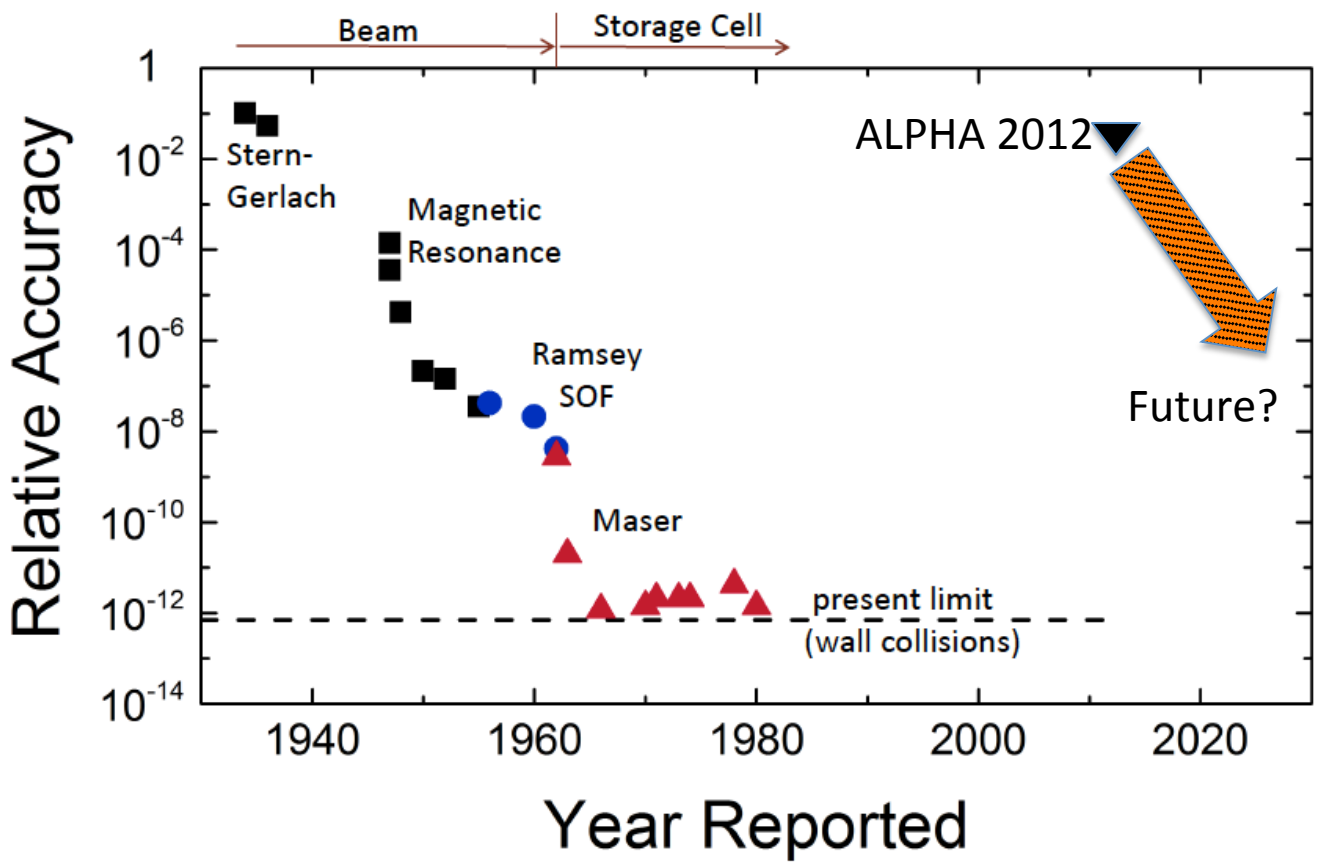


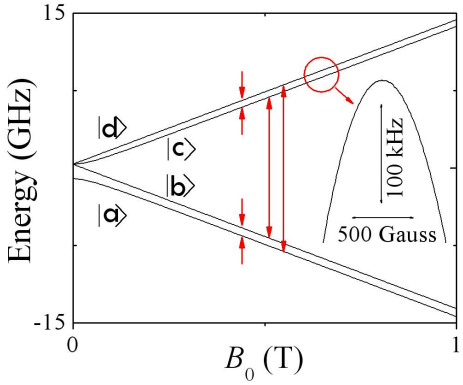
Antihydrogen $\nu_{\bar{H}}^{hfs} = 1.42\ (10)\ \mathrm{GHz}$ ALPHA Nature **483**, 439 (2102)

Hydrogen $\nu_{H}^{hfs} = 1.420405751768\ (1)\ \mathrm{GHz}$

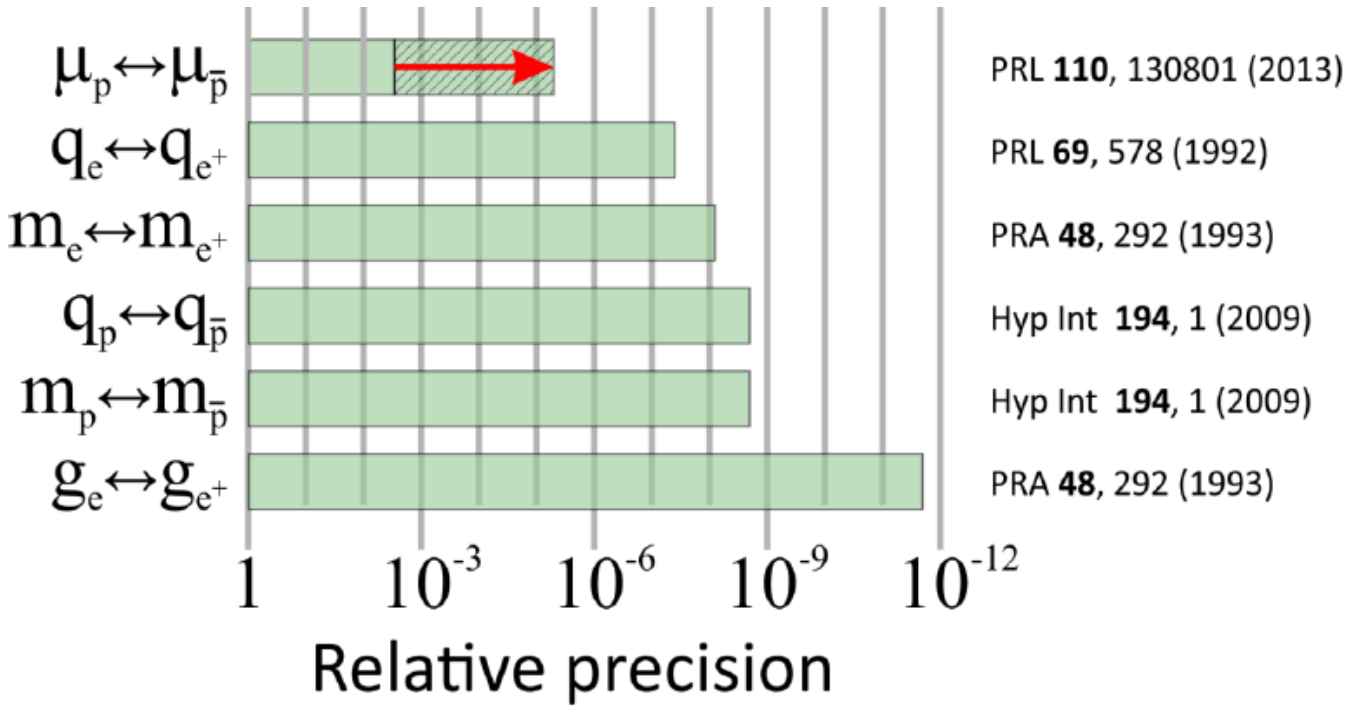
Hyperfine measurements on antihydrogen constrain standard model extension (SME)

Colladay & Kostelecky, PRD (1997)
Bluhm et al., PRL (1999)





Matter $\left|q_p + q_e\right| < 1 \times 10^{-21} e$



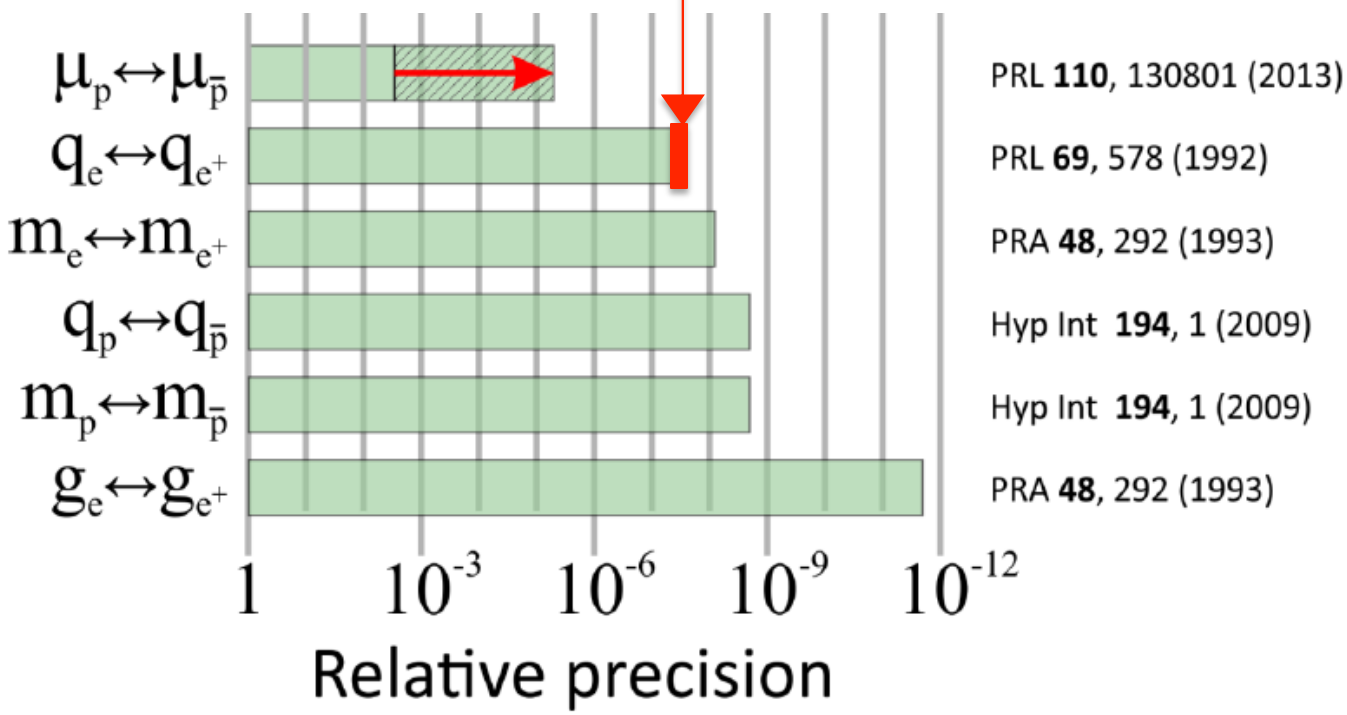
Matter $\left|q_p + q_e\right| < 1\times10^{-21} e$

ALPHA Nat. Comm. **5**, 3955 (2014)

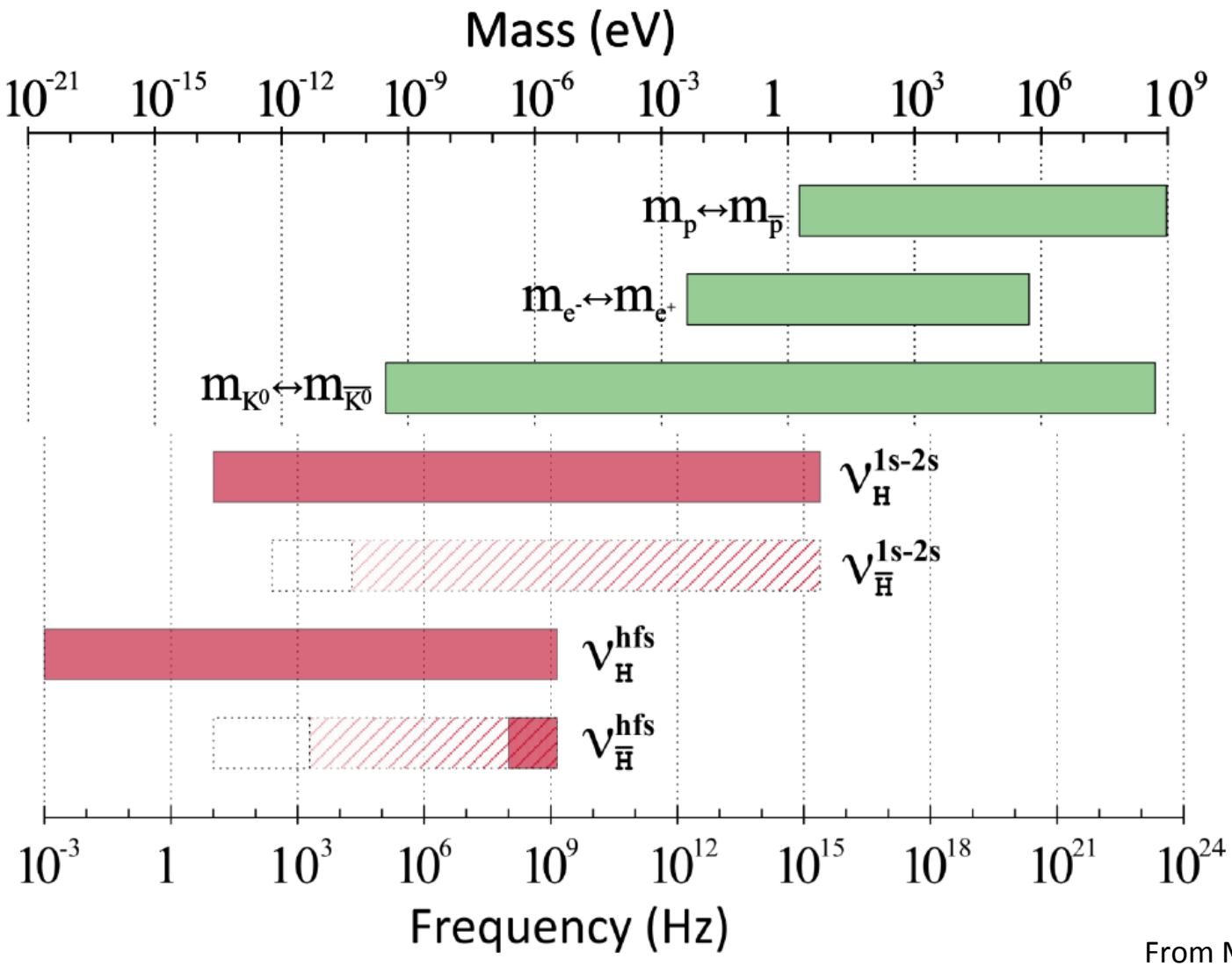
Antihydrogen $\left|q_{\bar{p}} + q_{e^+}\right| < (-1.3 \pm 1.1 \pm 0.4)\times10^{-8} e$

$potential \Rightarrow 10^{-10} e \text{ to } 10^{-12} e$

Stochastic acceleration, NJP 2014

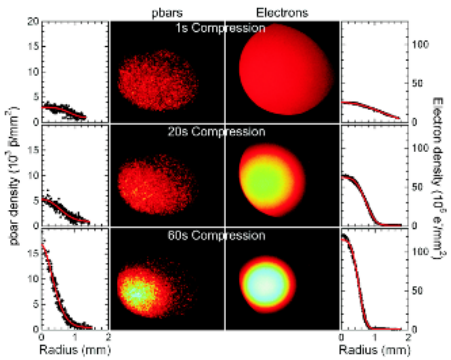


One perspective on future measurements



From M.Hayden

ALPHA Antihydrogen Progress



Antimatter Beam/ plasma physics:

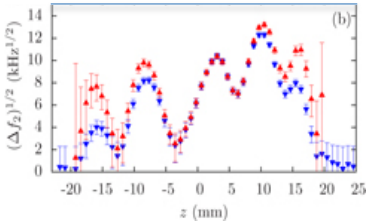
Cooling, manipulating

Physical Review Letters 2006
Physical Review Letters 2007
Physical Review Letters 2008
Physical Review Letters 2010
Physical Review Letters 2011
Physical Review Letters 2011

Trapped Antihydrogen

> 1000 s

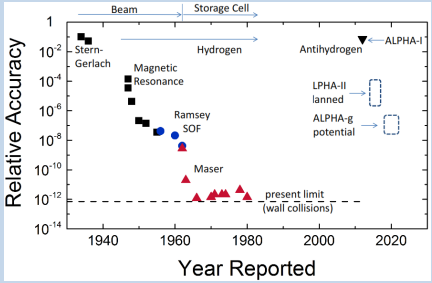
Nature 2010
Physics Letters B 2010
Nature Physics 2011
New Journal of Physics 2012



Develop Antimatter Applications

Field measurements, gas detection

New Journal of Physics 2014
Reviews of Sci. Instrum. 2013

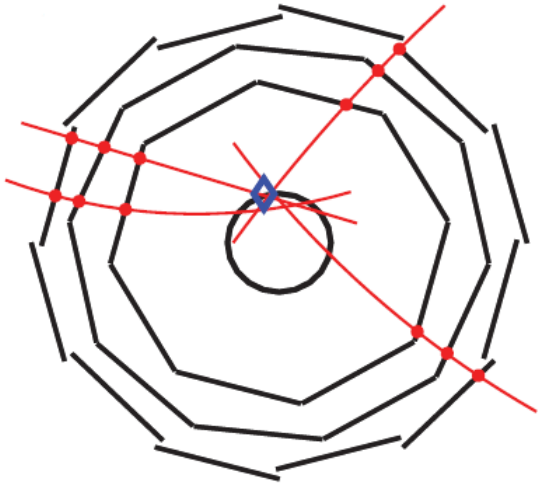


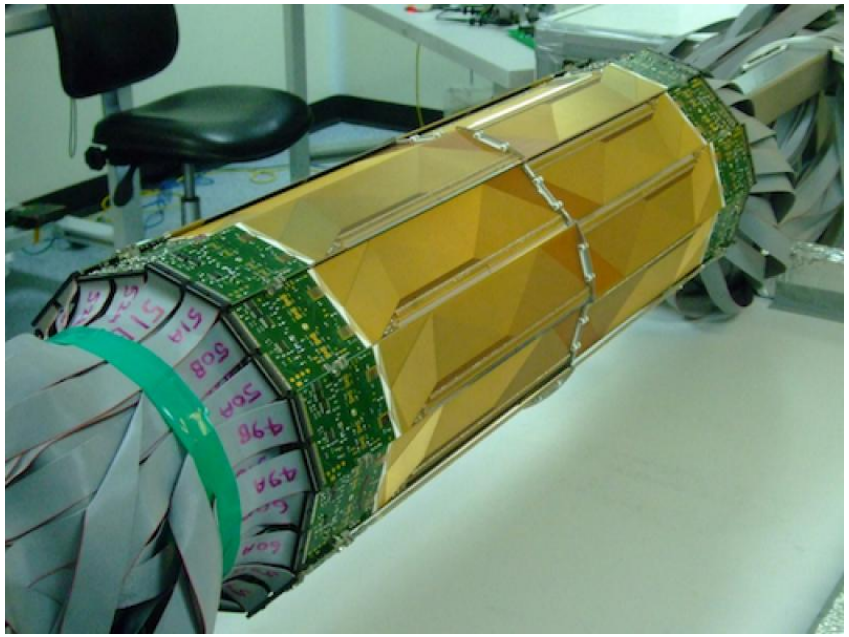
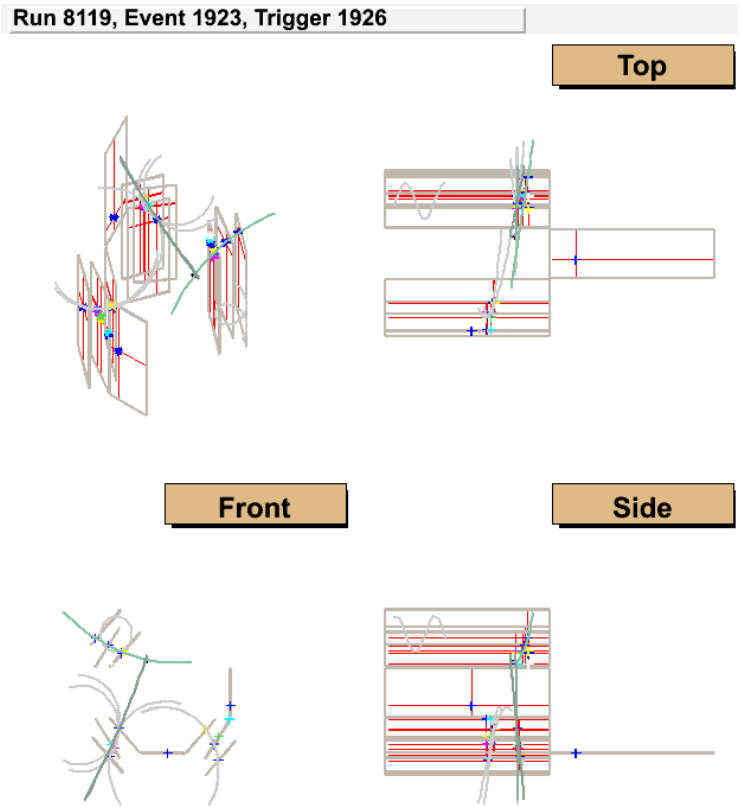
Measure Anti-H

Microwave Spectrum
Gravity
Charge

Nature 2012
Nature Communications 2013
Nature Communications 2014

Antihydrogen Atoms Annihilate





ALPHA Vertex Imaging Detector
Detector is over 50% efficient, and locates annihilations to better than 10mm.