

What's the Matter with Antimatter?

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About Me

2011 Bachelor, Aarhus University

2014 MSc, Aarhus University

2016 PhD, Aarhus University

Have been working on the
ALPHA experiment since 2010



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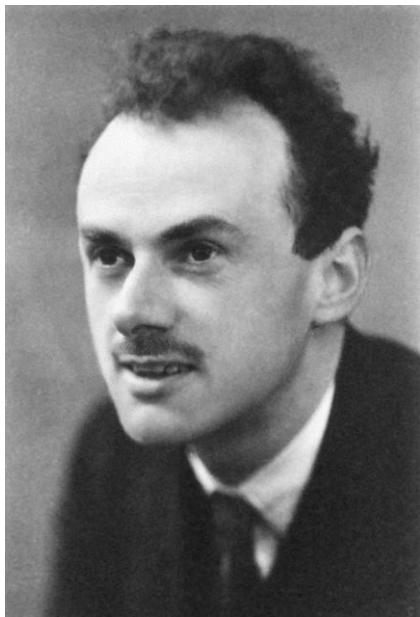
Antimatter

Paul A. M. Dirac

1928 Publishes his equation
of motion for the electron

1931 Predicts the existence
of the positron

$$i\hbar\gamma^\mu\partial_\mu\psi - mc\psi = 0$$

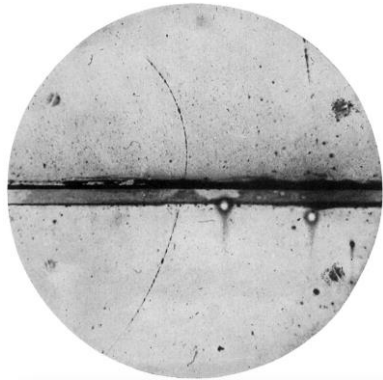


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Discovery of the Positron

Carl D. Anderson, 1932

- Studying cosmic particles with a bubble chamber
- Particles would lose energy in lead barrier, allowing the charge to be determined
- Found a light, positively charged particle



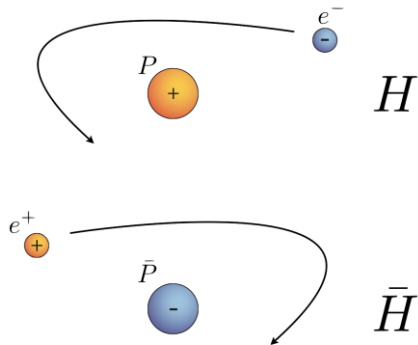
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What is Antimatter?

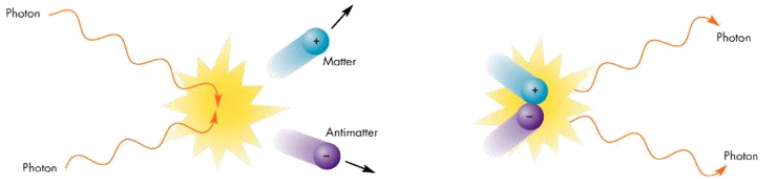
Every particle has an antimatter counterpart with:

- Identical mass
- Identical lifetime
- Opposite charge
- Opposite spin

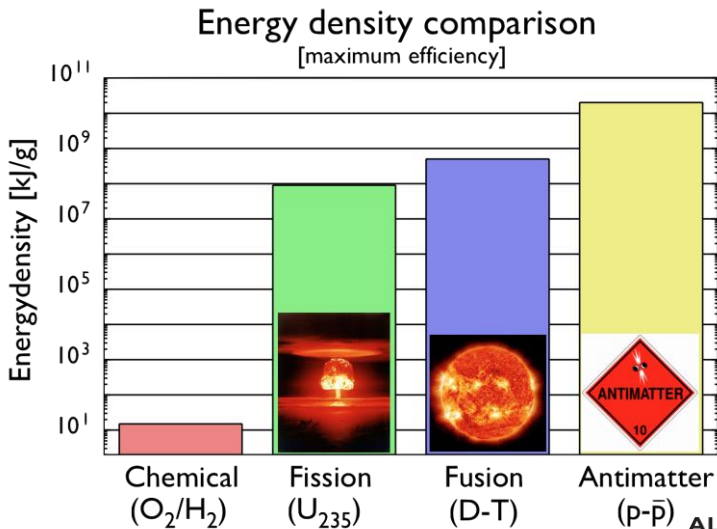


Antimatter Annihilates

$$E = mc^2$$



Antimatter Annihilates



Antimatter as Rocket Fuel?



No!

Highest production of \bar{p} : 10^{11} per hour (1.67×10^{-13} g/h)

Would take 5 years to boil 1L of water.



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(Serious) Reasons for Studying Antimatter

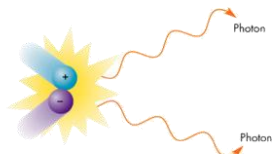
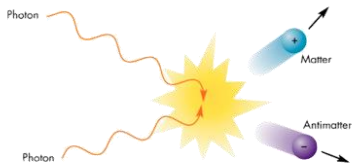
Antimatter allows for direct tests of fundamental symmetries and may hold clues to some of the biggest unanswered questions in physics:

- Why is there no antimatter in the Universe (Baryon asymmetry)
- Is CPT symmetry conserved?
- Does the weak equivalence principle hold for antimatter?



Baryon Asymmetry

- Observations show no evidence for large scale antimatter in the Universe
- No satisfactory explanation, consistent with experiment, has been given
- This is one of the main arguments for the incompleteness of the Standard Model in its current form



CPT Symmetry

- Combination of the Charge conjugation, Parity inversion, and Time reversal symmetries
- C, P, and CP are each broken in the standard model
- No process has been observed to break CPT symmetry
- CPT symmetry is proven to hold in any quantum field theory which:
 - Is Lorentz invariant
 - Is local
 - Has a Hermitian Hamiltonian
 - Is flat



Antimatter gravity: The Weak Equivalence Principle

In Einstein's general relativity, *any body must experience the same acceleration in the gravitational field, regardless of its composition*

This is expected to hold true for antimatter, but a direct, model-independent test has not been made



AD



The AD Experiments

- 6 experiments share the beam from the Antiproton Decelerator
- All are built to compare matter to antimatter at low energy and with high precision
- This is the only place in the world that low energy antimatter can be studied

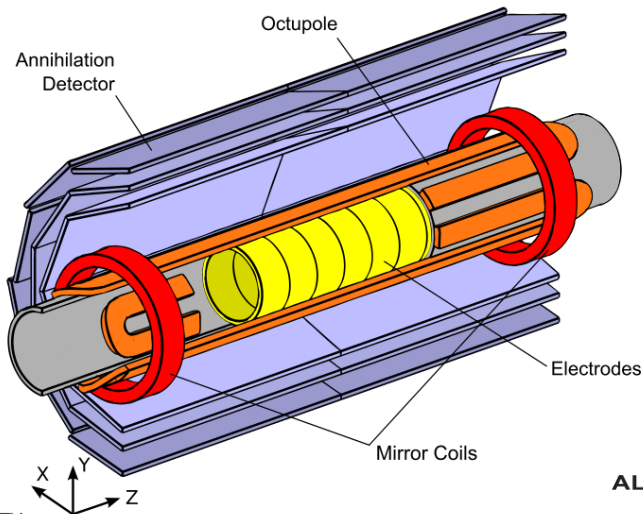


ATRAP



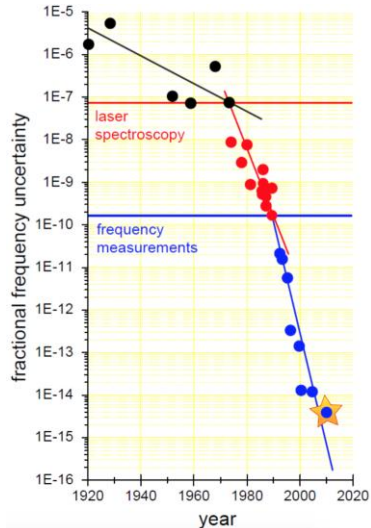
The ALPHA Experiment

Antihydrogen Laser **PH**ysics **A**pparatus



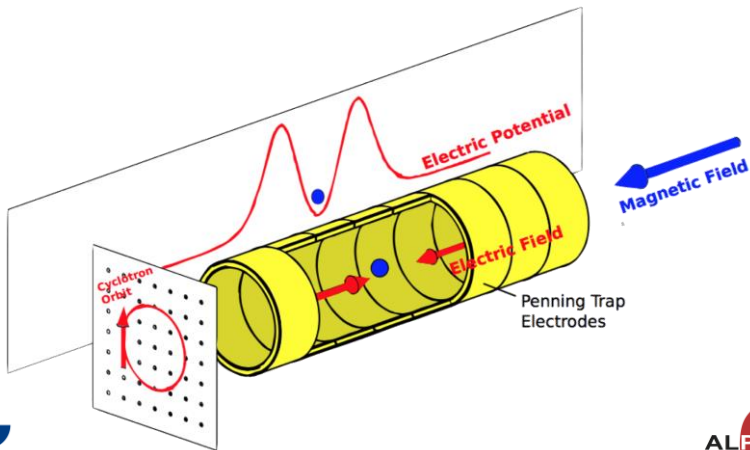
Why Antihydrogen?

- Antihydrogen is the only pure antimatter atom we can make so far
- Hydrogen is the best understood atomic system
- Comparing the two can test matter-antimatter asymmetry and CPT
- Antihydrogen is neutral (important for gravity)



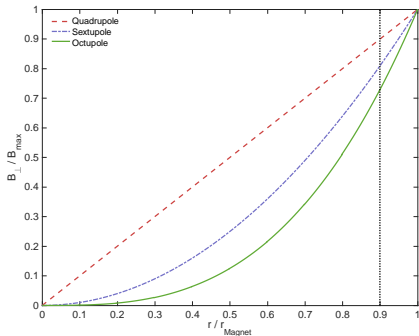
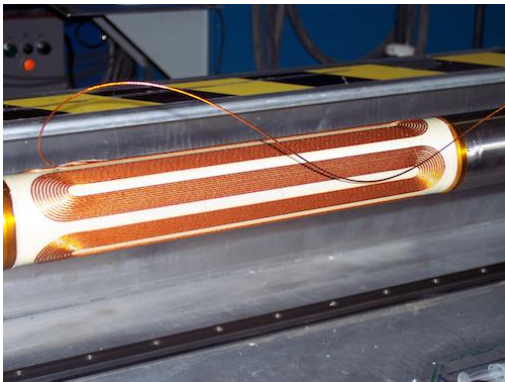
Penning trap

Charged particles are contained by an axial magnetic field and a series of cylindrical electrodes.



Magnetic Minimum Trap

Create a minimum of the magnetic field in 3D

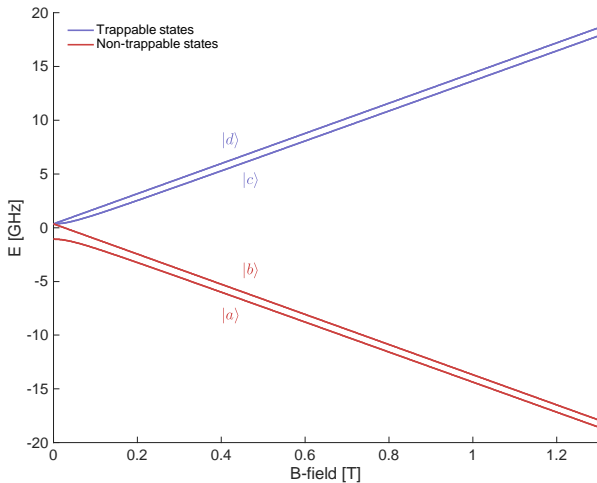


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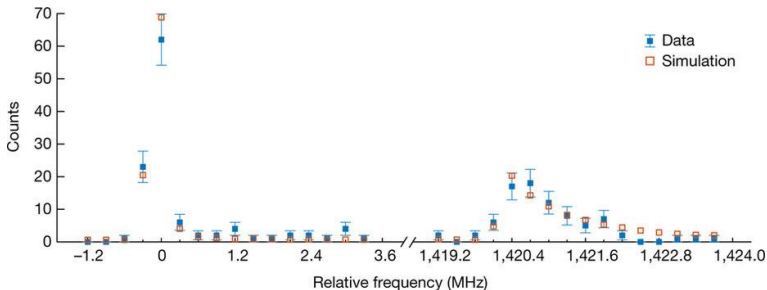
Microwave Spectroscopy in Antihydrogen

Flip the spin of the positron to expel atoms from the trap

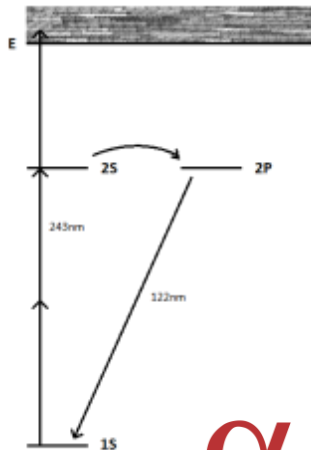
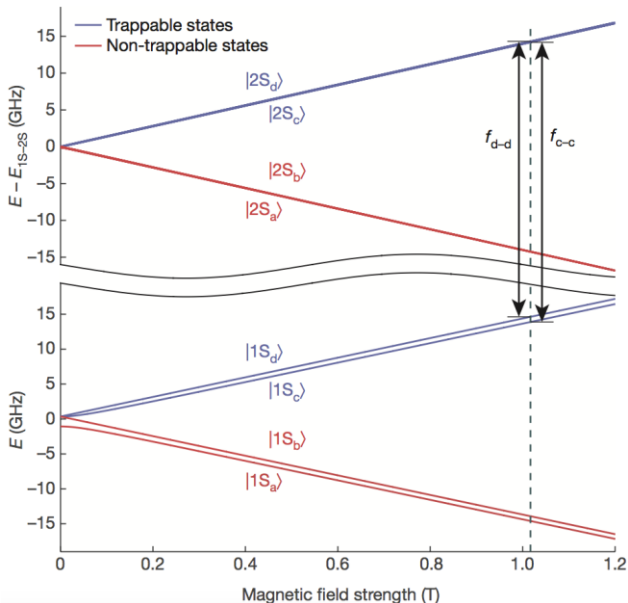


Microwave Spectroscopy in Antihydrogen

Two transitions with constant separation



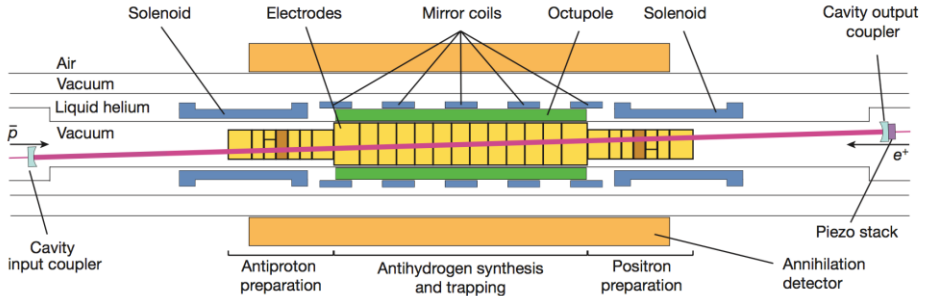
Laser Spectroscopy in Antihydrogen



ALPHA α

Laser Cavity

Mirrors are in UHV and at cryogenic temperatures.



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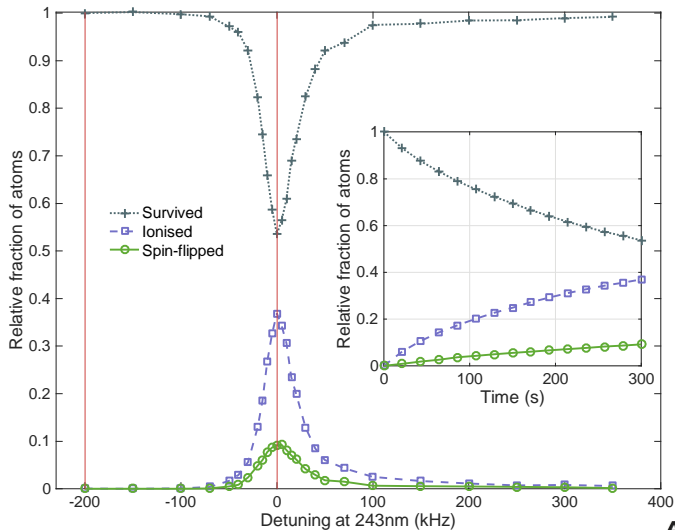
Video!



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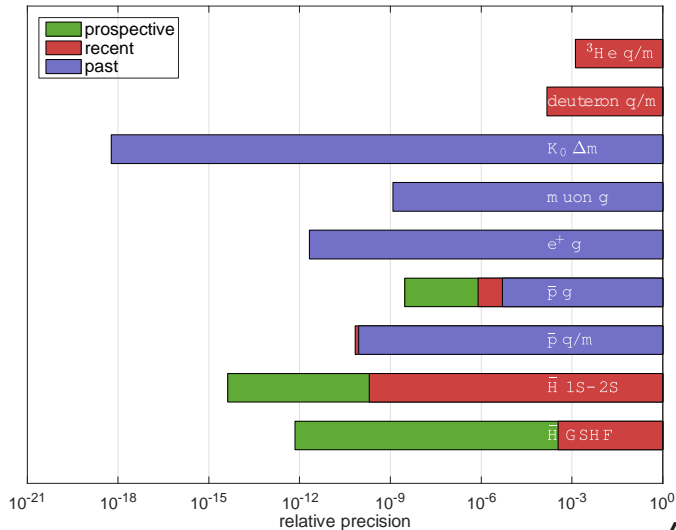
1S-2S Spectroscopy



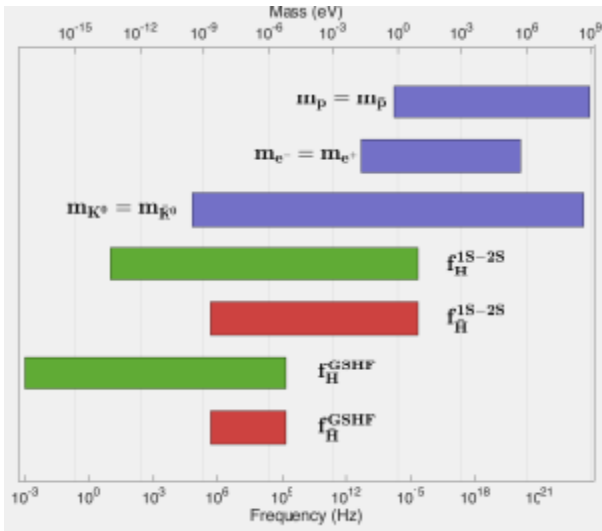
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CPT Tests and Relative Precision



CPT Tests and Relative Precision



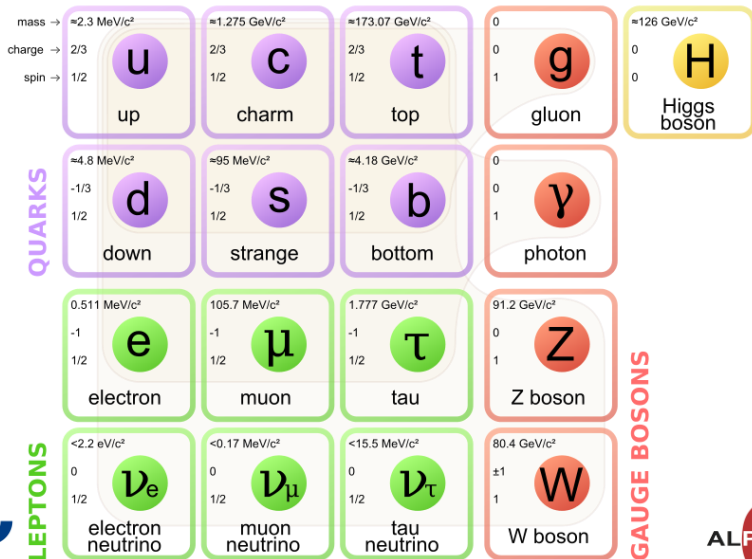
Any Questions?



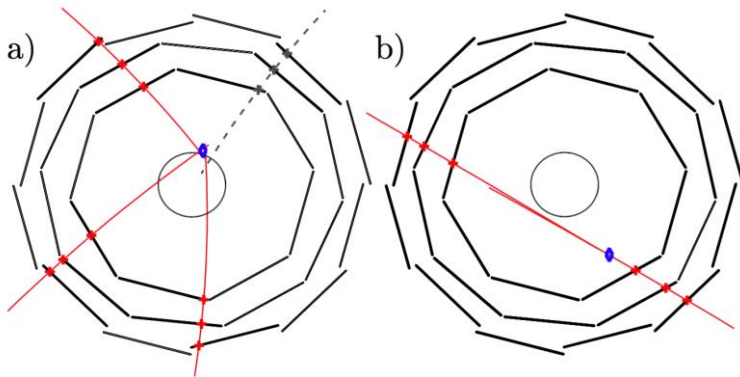
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The Elementary Particles of the Standard Model



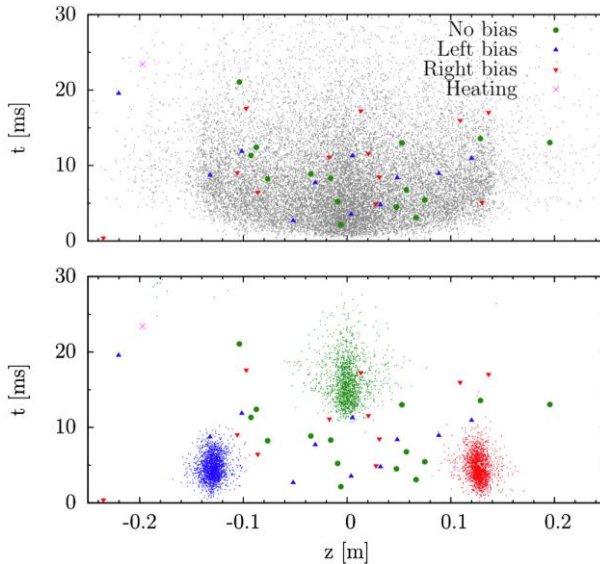
Cosmic Event Rejection



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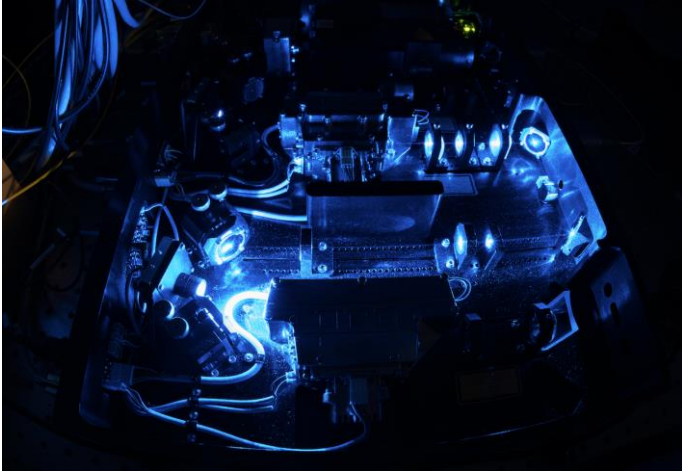
Antiproton Discrimination



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Spectroscopy Laser



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