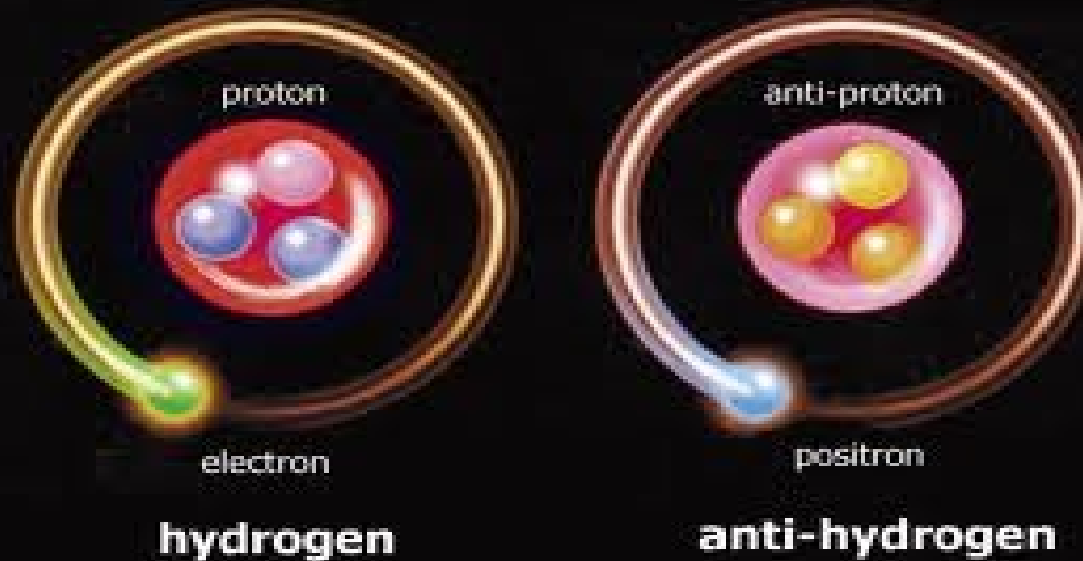


Anti-Hydrogen



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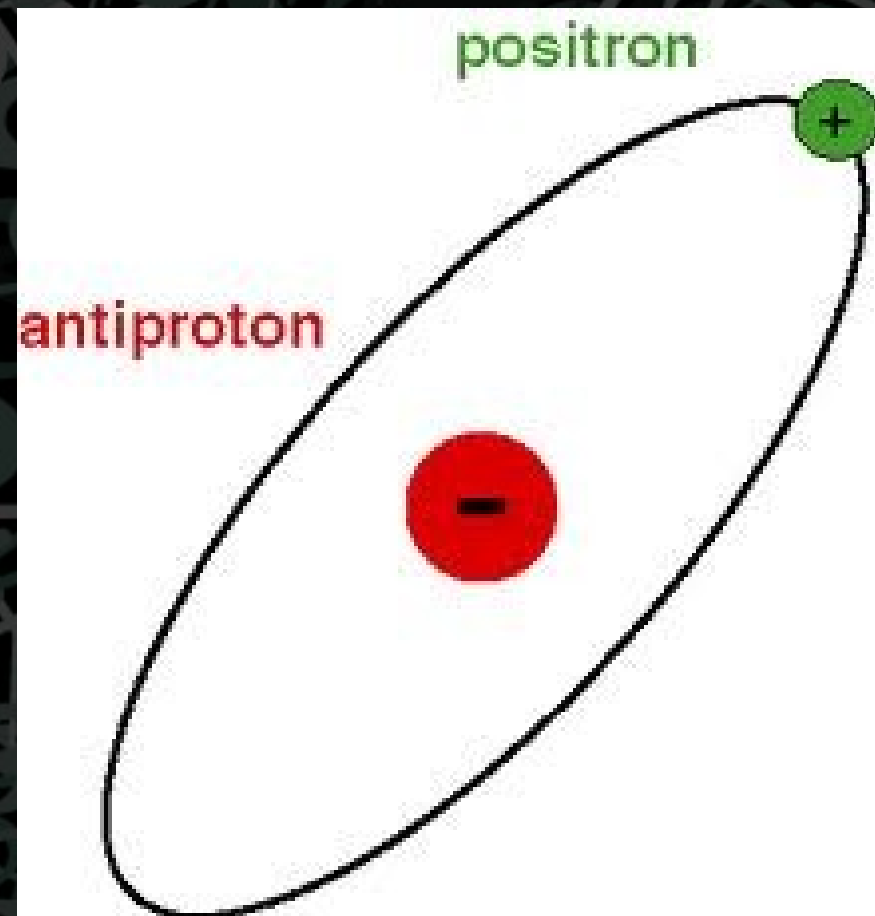
OUTLINE

- WHAT IS ANTI-HYDROGEN?
- HISTORY
- IMPORTANCE
- THEORY
- HOW TO MAKE ANTI-HYDROGEN
- OTHER ANTI-MATTER EXPERIMENTS
- CONCLUSION

WHAT IS ANTI-HYDROGEN?

Anti-hydrogen is composed of a Positron(anti-electron) and anti-Proton.

Anti-Hydrogen atom is analogous to the Hydrogen atom.



Positron

- Dirac's equation predicted Positron(1931)
- Carl D. Anderson found Positron experimentally (1932)
- Same mass as an electron
- Opposite charge of an electron

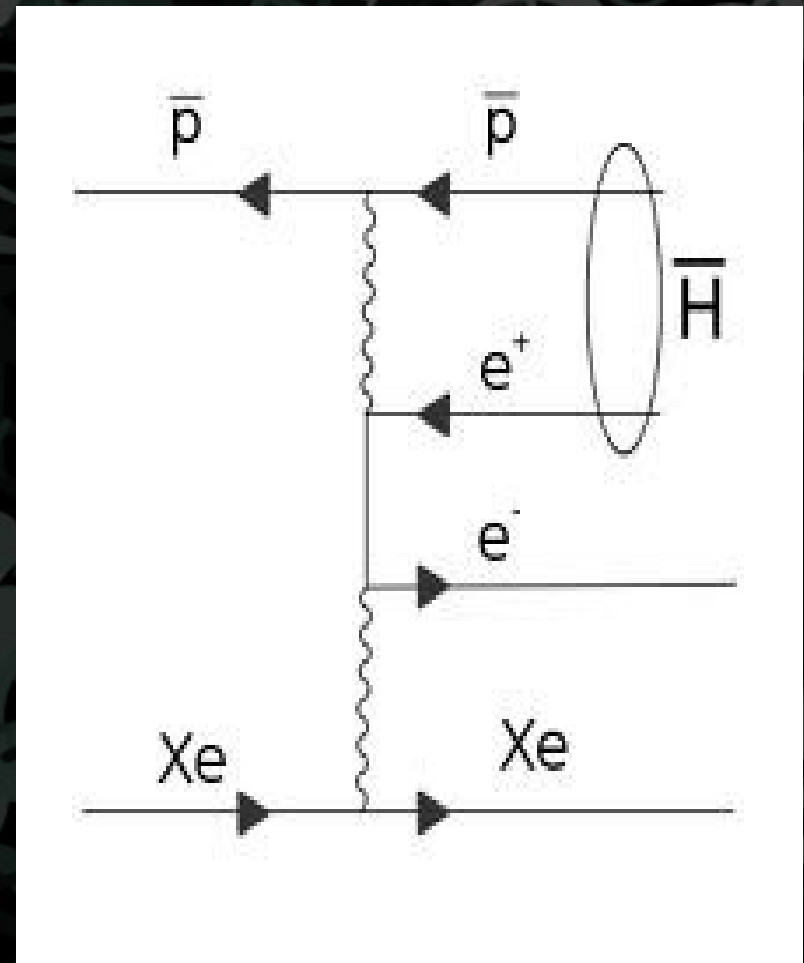
Anti-Proton



- Predicted by Dirac (1933)
- Experimentally confirmed by Emilio Segre and Owen Chamberlain (1955)
- Same mass but opposite charge of a proton

Anti-Hydrogen

- Neutral Atom
- Small Permanent Magnetic Moment



HISTORY

- 1995
 - First Anti-Hydrogen Atoms Produced at CERN by Walter Oelert (made 9 atoms)
 - Important Success as this allows the chance to understand Matter-Anti Matter Symmetry

HISTORY

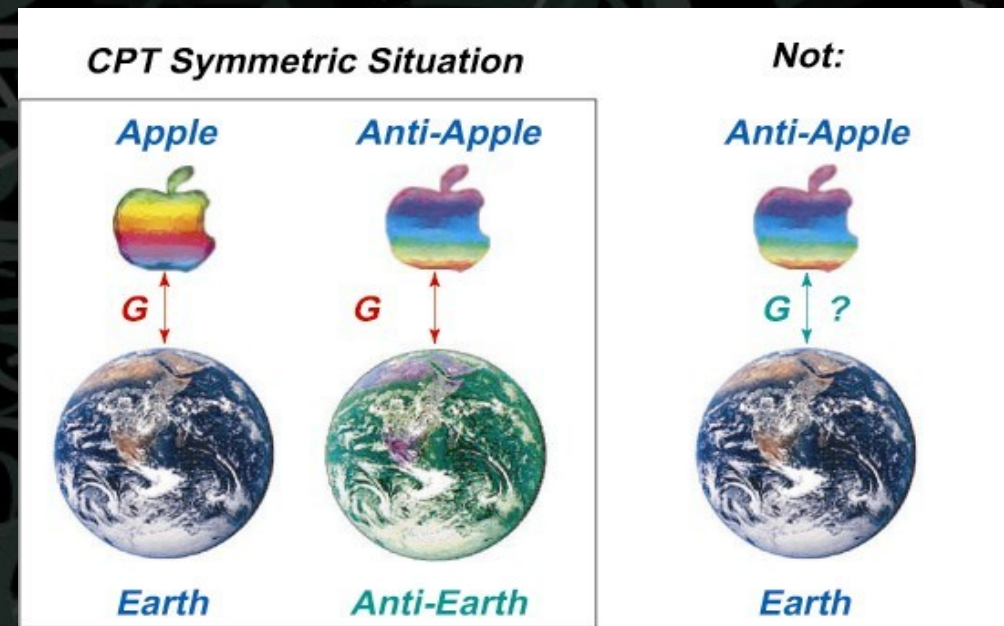
- 2002
 - The race between two groups, Athena and Atrap, makes progress by competing to produce the most Anti-Hydrogen atoms.
 - They are able to produce tens of thousand atoms (not really trap)

HISTORY

- PRESENT (as of Nov 17, 2010)
 - “Trapped” 38 Anti-Hydrogen atoms and held them for about a sixth of a second
 - This took about 335 tries/cycles
 - Trap about 1 Anti-Hydrogen atom every 20 seconds

THEORY

- It all started with Dirac, leading to CPT
 - Why is this important?
 - CPT implies that if there is matter, then there is anti-matter



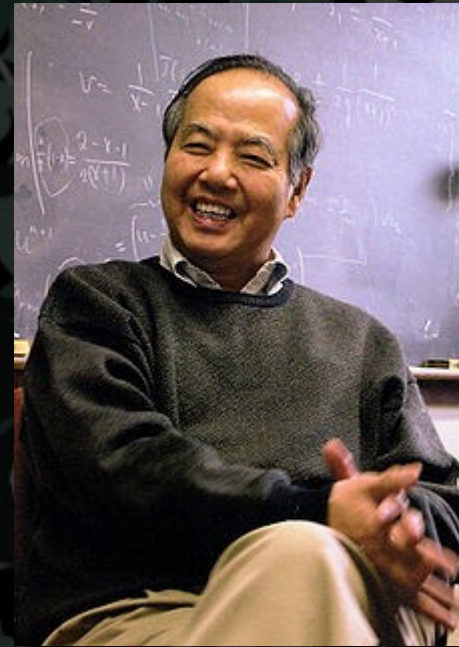
THEORY

$$E^2 - (pc)^2 = (mc^2)^2$$

- A quadratic equation will have 2 roots
- Dirac proposed that the negative energy corresponds to positively charged electrons

THEORY

- But it can come to an end, according to T.D. Lee
- He showed that CPT theorem breaks down at plank scale (10^{19}GeV) where Grand Unification happens (Lee 1995)



THEORY

- So how do we deal/fix this?
- We need to do CPT test experimentally to confirm what actually happens

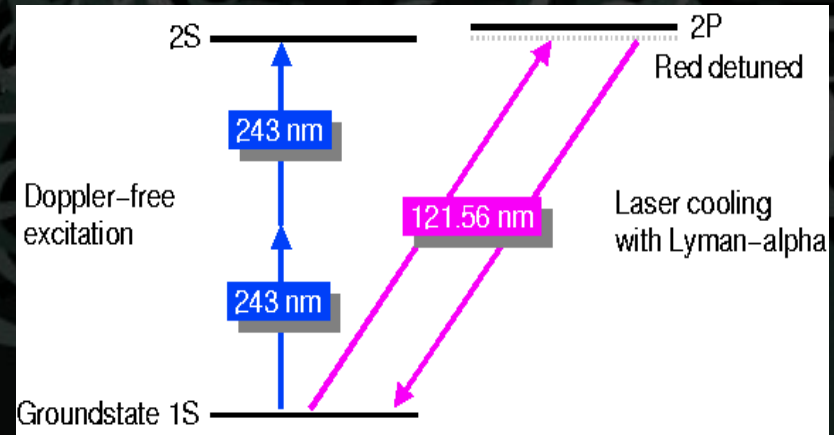


THEORY

- We treat Anti-Hydrogen in the Plasma Regime
- As we can not treat this as a gas or a system of particles, new theories need to be developed

IMPORTANCE

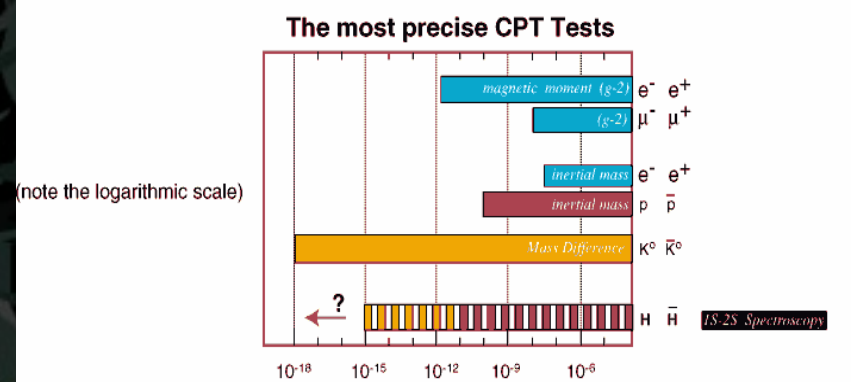
- CPT Testing
 - 1S-2S Transition
 - Compare transitions to Hydrogen
 - How similar are the two atoms?
- Weak Equivalence Principle
 - How does anti-matter respond to gravity?



★ Any local quantum field theory, obeying Lorentz invariance and usual spin-statistics connection → CPT Invariance

G. Lüders, Ann. Phys. 2, 1-15 (1957)
(also: W. Pauli, J. Schwinger)

MATTER = ANTIMATTER at any level of precision



How to Make Anti-Hydrogen?

- What is the recipe?
- Any secret ingredients?
- We need cold Positrons and cold Anti-Protons and trap them
- Seems too easy, right?



How to Make Anti-Hydrogen?

- Problem

- Anti-Protons are too hot

- Leads to high energy, making them hard to trap
 - Temperatures at around 100 K
 - New methods ~ 10 K

- Solution

- Ideal Temperature < 0.5 K
 - Collisions with electrons, so that can carry/absorb energy/momentum

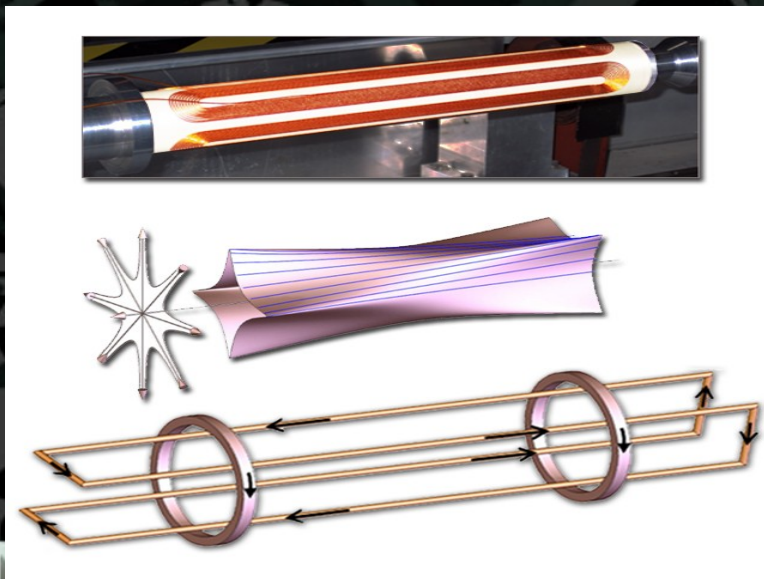
How to Make Anti-Hydrogen?

- Problem
 - Anti-Hydrogen is a neutral atom
 - Ordinary traps only trap charged particles
- Solution
 - Superimpose a Penning-Malmberg trap with a Minimum B trap
 - Allows us to use the small permanent magnetic moment of Anti-Hydrogen

How to Make Anti-Hydrogen?

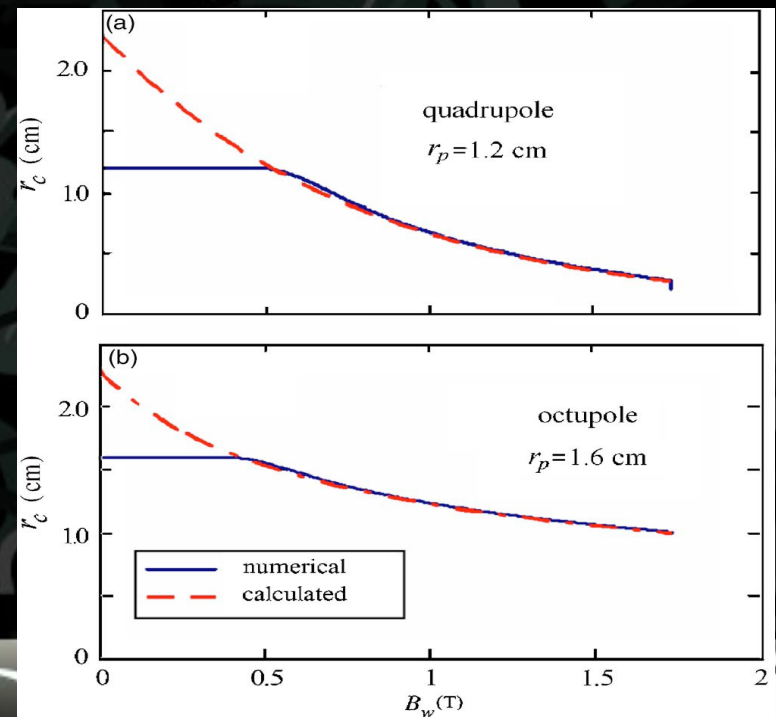
- Problem

- Superimposing the two traps destroy confinement of constituents

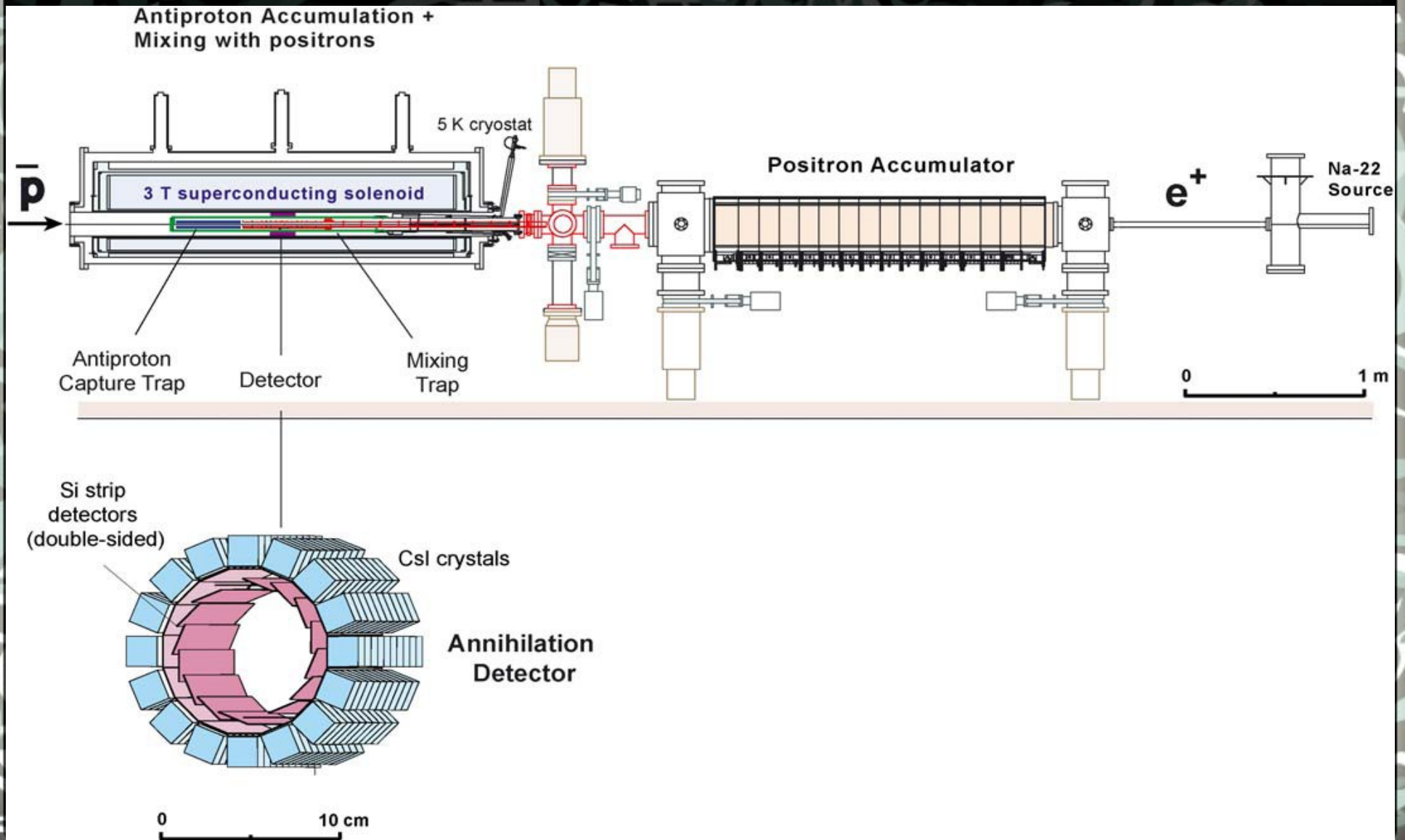


- Solution

- Apply a high order magnetic multi-poles



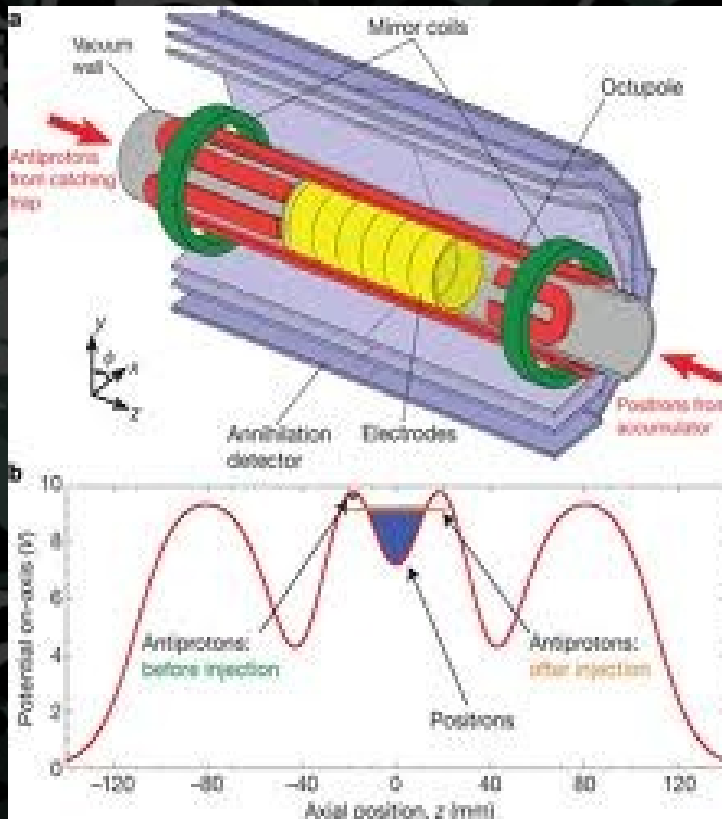
How to Make Anti-Hydrogen?



How to Make Anti-Hydrogen?

- “Catching trap”-The first 12 electrodes catch, cool, and accumulate anti-protons
- “Mixing trap”-where anti-protons merge with positron plasma
- Last section of electrodes- Positron transfer and recapture procedure

How to Make Anti-Hydrogen?

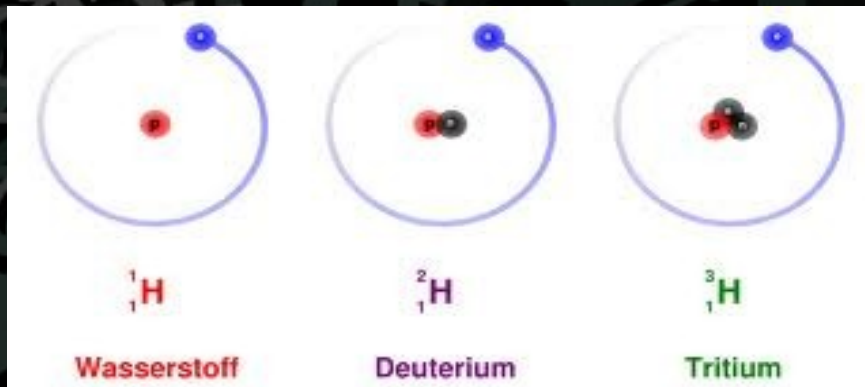


- Double-Well Trap
 - Three types of collisions
- Lower potentials to start mixing/cooling

OTHER ANTI-MATTER EXPERIMENTS

- Anti-Deuterium

- If we can make Anti-Deuterium, then it follows that other Anti-Elements must exist
- Shows that there is “anti-glue”



CONCLUSION

- As we improve our technique and understanding of anti-matter experiments, we will be able to efficiently trap and run test on anti-matter, which will provide a result to the Matter-Anti Matter Symmetry Problem
- What will we do with the anti-elements?
 - Anti-fire?
 - Anti-clone?

REFERENCES

- <http://athena-positrons.web.cern.ch/ATHENA->
- <http://socrates.berkeley.edu/~fajans/pub/pdffile>
- <http://www.nature.com/nature/journal/vaop/ncu>