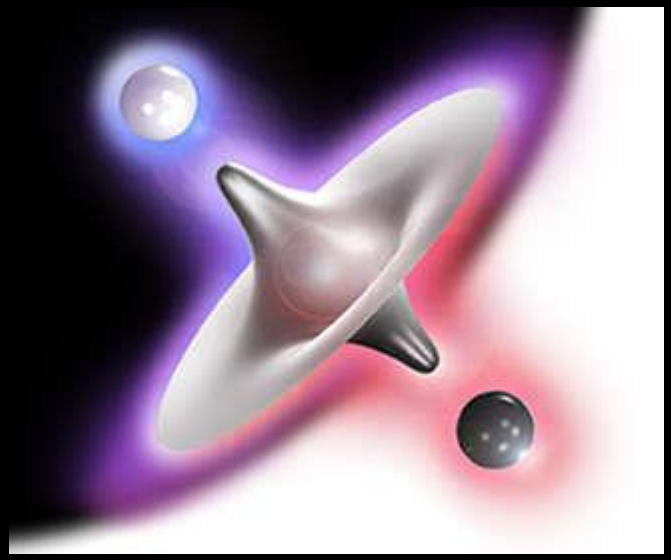
Cold Antimatter at CERN



Lars V. Jørgensen
CERN

Outline

- What is antimatter?
- Why is it interesting?
  - Pure research
  - Practical uses?
- How do we make it?
  - Making atoms of it
  - Holding on to the atoms

Antimatter – What is it?

$$(i\gamma^\mu\partial_\mu - m)\psi = 0$$

An equation from Quantum Mechanics

Dirac's equation: (1928)

$$x^2 = K$$

Has 2 solutions
- *One positive*
- *One negative*

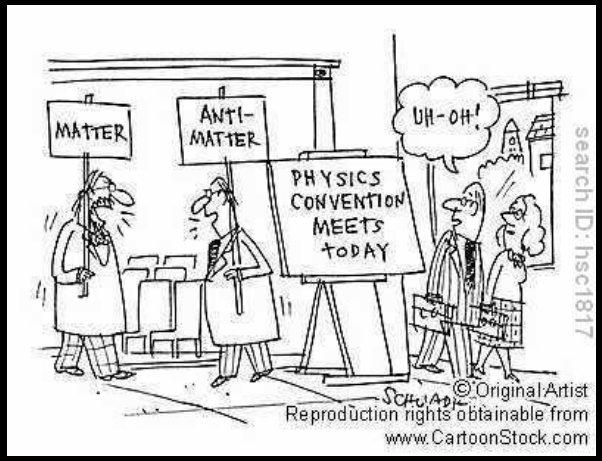
Positive solution fits normal matter
i.e. electron, protons, etc.

What is the negative solution ???

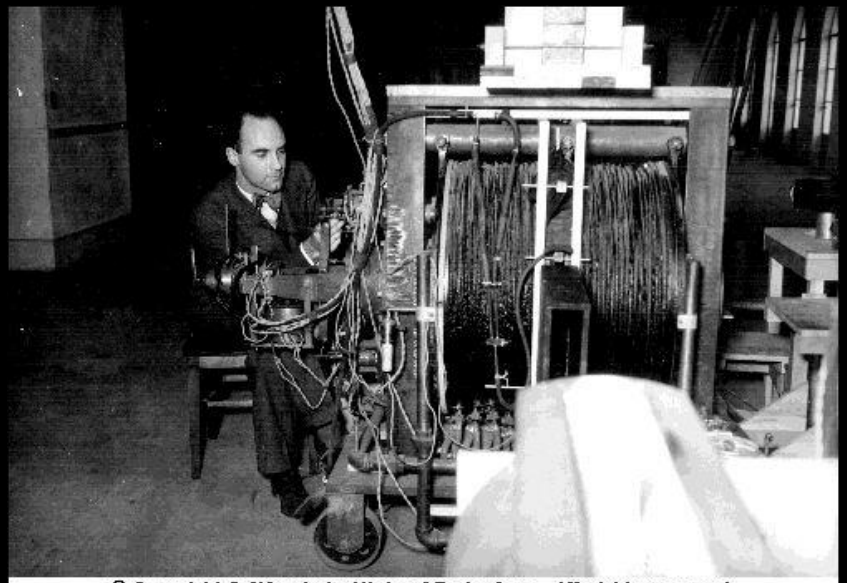
Antimatter – What is it?

Anti-particles:

- **Opposite charge**
- **Same mass**
- **Exactly cancels out it's normal matter 'partner'**



The first antimatter is discovered.



Carl Anderson at Cal Tech observes the first positron from cosmic ray showers in 1932

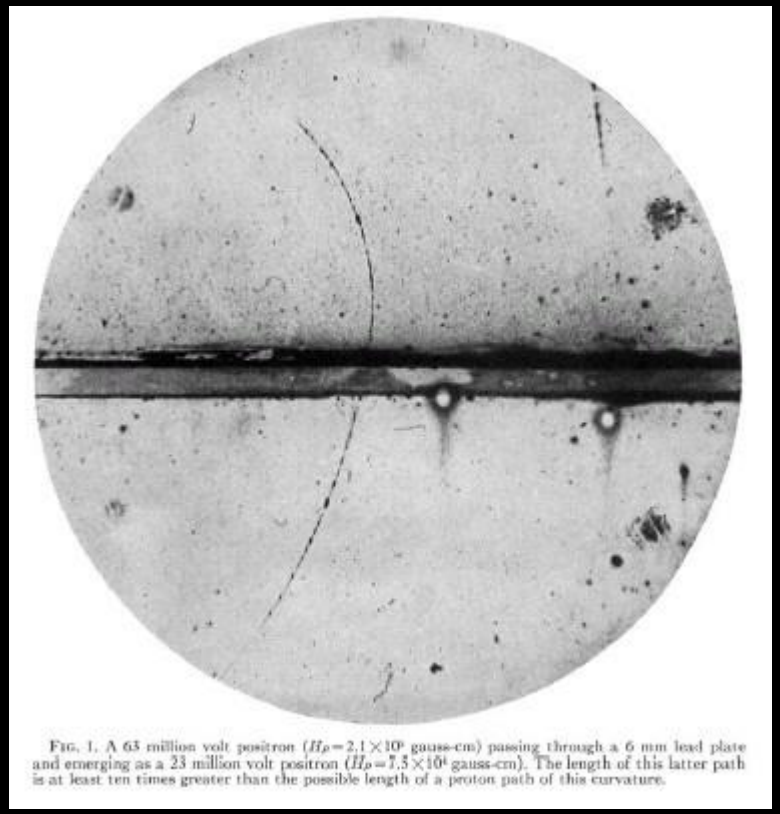


FIG. 1. A 63 million volt positron ($H\rho = 2.1 \times 10^5$ gauss-cm) passing through a 6 mm lead plate and emerging as a 23 million volt positron ($H\rho = 7.5 \times 10^4$ gauss-cm). The length of this latter path is at least ten times greater than the possible length of a proton path of this curvature.

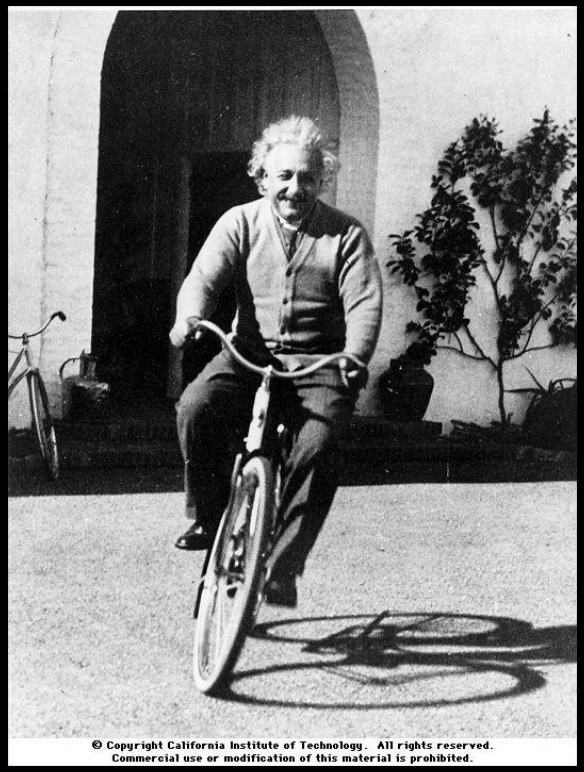
PAUL A. M. DIRAC

Theory of electrons and positrons

Nobel Lecture, December 12, 1933

Quick Nobel Prizes:
Dirac 1933
Anderson 1936

Discovering more anti-particles



$$E = m c^2$$

Mass is energy (nuclear power)
-But also: Energy is mass
High Energy Physics !!

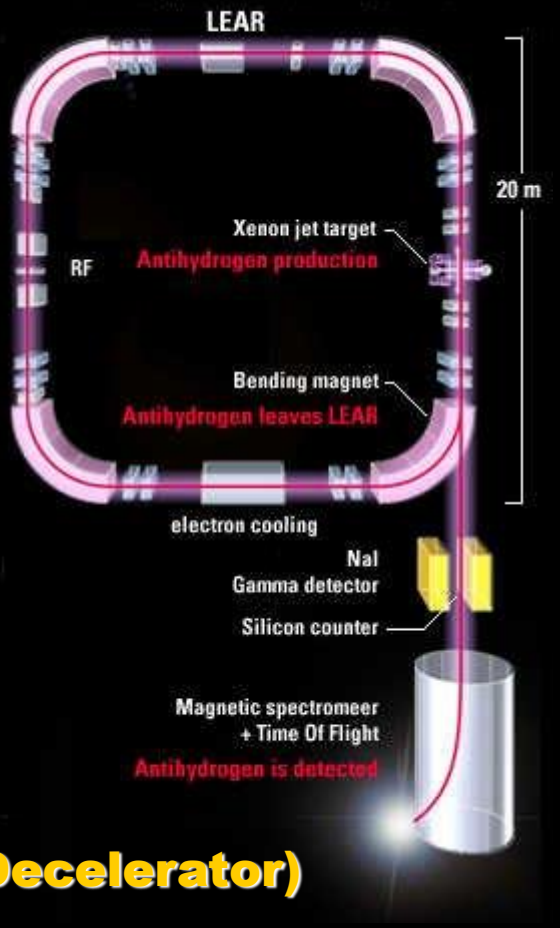
Pair Creation:
With high enough energy
a pair of matter-antimatter
Particles can be created

Surrounding Edward Lofgren (center), head of the Bevatron, are discoverers of the antiproton, (left to right) E.Segre, C.Wiegand, O. Chamberlain and T.Ypsilantis.

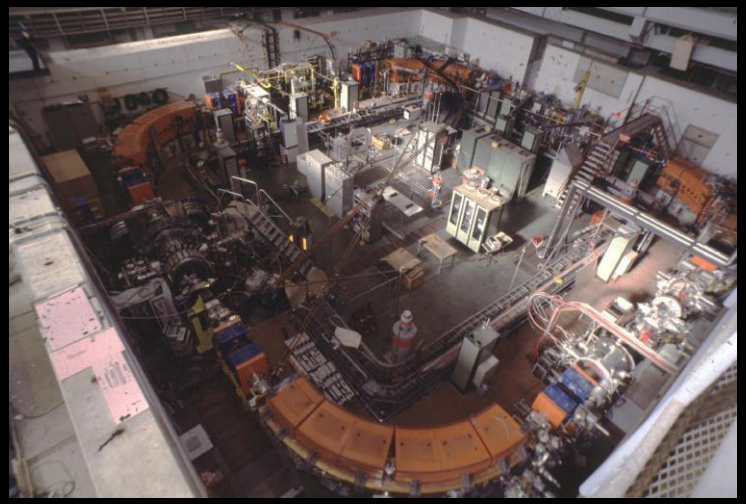
Antiproton – 1955
Antineutron – 1957
Antideuteron – 1965
Antihelium-3 – 2011!

Anti – atoms?

- In 1995 9 atoms of antihydrogen was made at CERN's LEAR machine
- All these atoms were at very high energy
- To study antihydrogen we need it at much lower energies



CERN's LEAR Machine

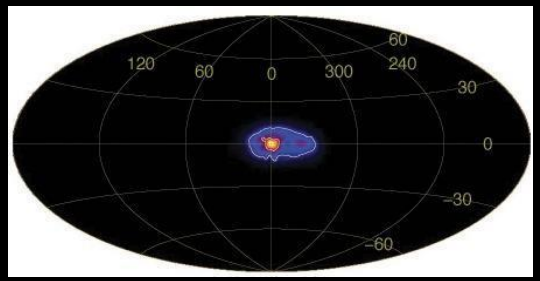


CERN built the AD (Antiproton Decelerator) to achieve this! It started operation in 2000

Why is antimatter interesting?

Why are we here?

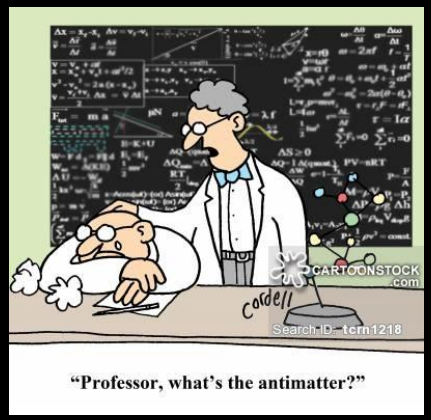
- If the Big Bang was Pair Creation there should be equal amounts of matter and antimatter in the universe
- We know from measurements that there is almost no antimatter in the universe
- Why is this ??



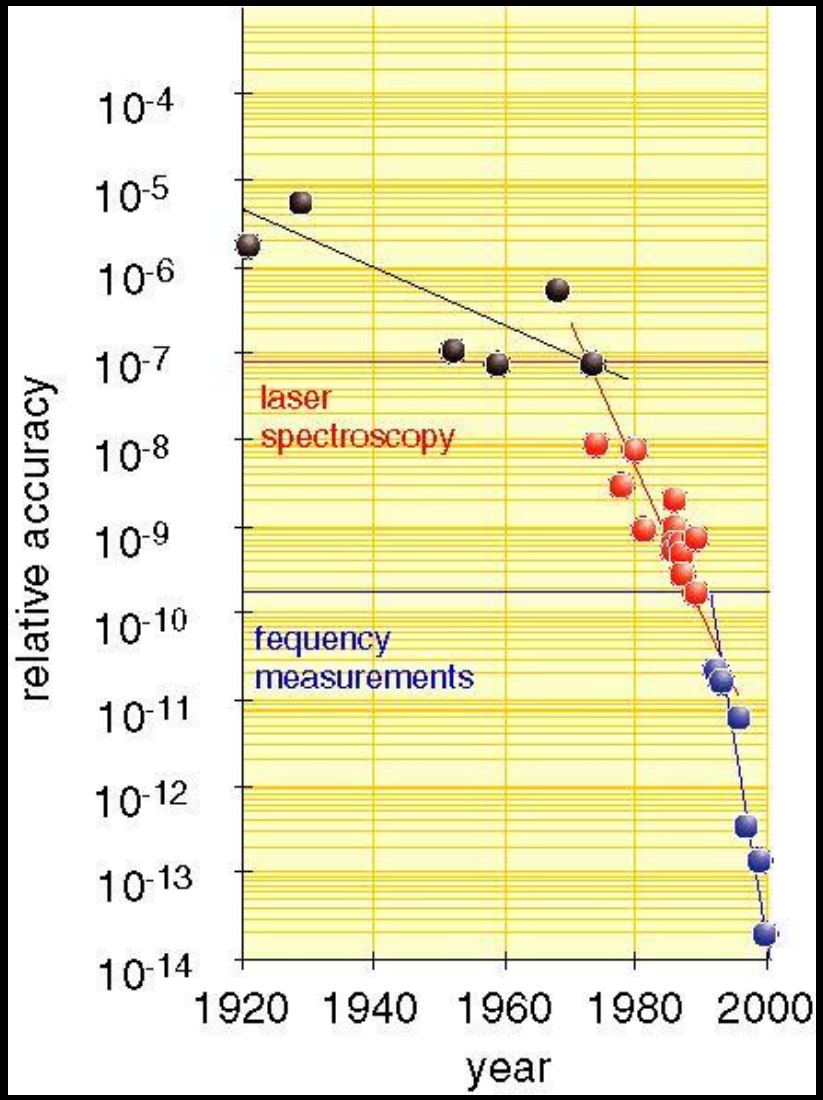
Antimatter at the center of the Milky Way

Fundamental studies of anti-hydrogen

- **Spectroscopy – checking if the energy-levels are the same in hydrogen and antihydrogen**
- **This tests some very fundamental theories in physics – the standard model and the CPT Theorem (C=charge, P=parity and T=time)**



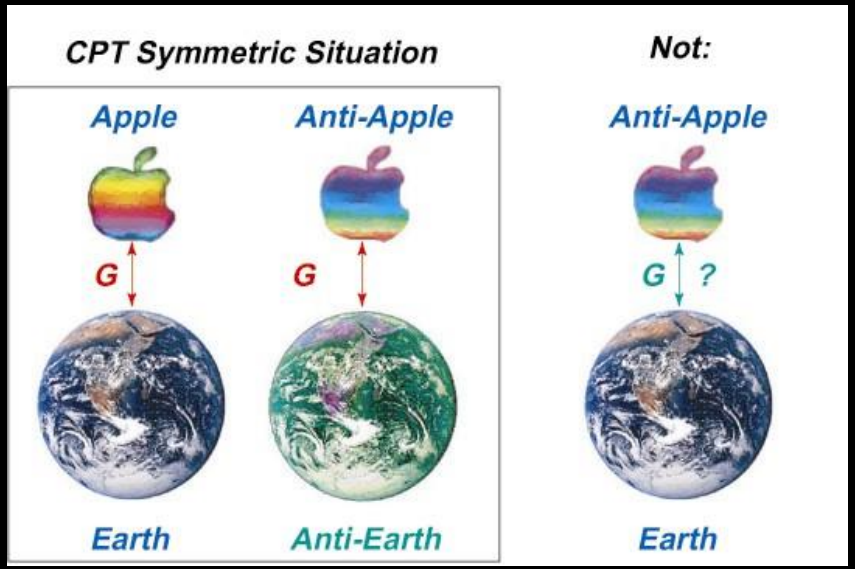
"Hänsch Plot"



What about Gravity?

Does antimatter fall up ??

Gravity is a very, very weak force
compared to the other forces
e.g. Electro-magnetism



This makes an experiment VERY difficult
- but neutral atoms are necesary

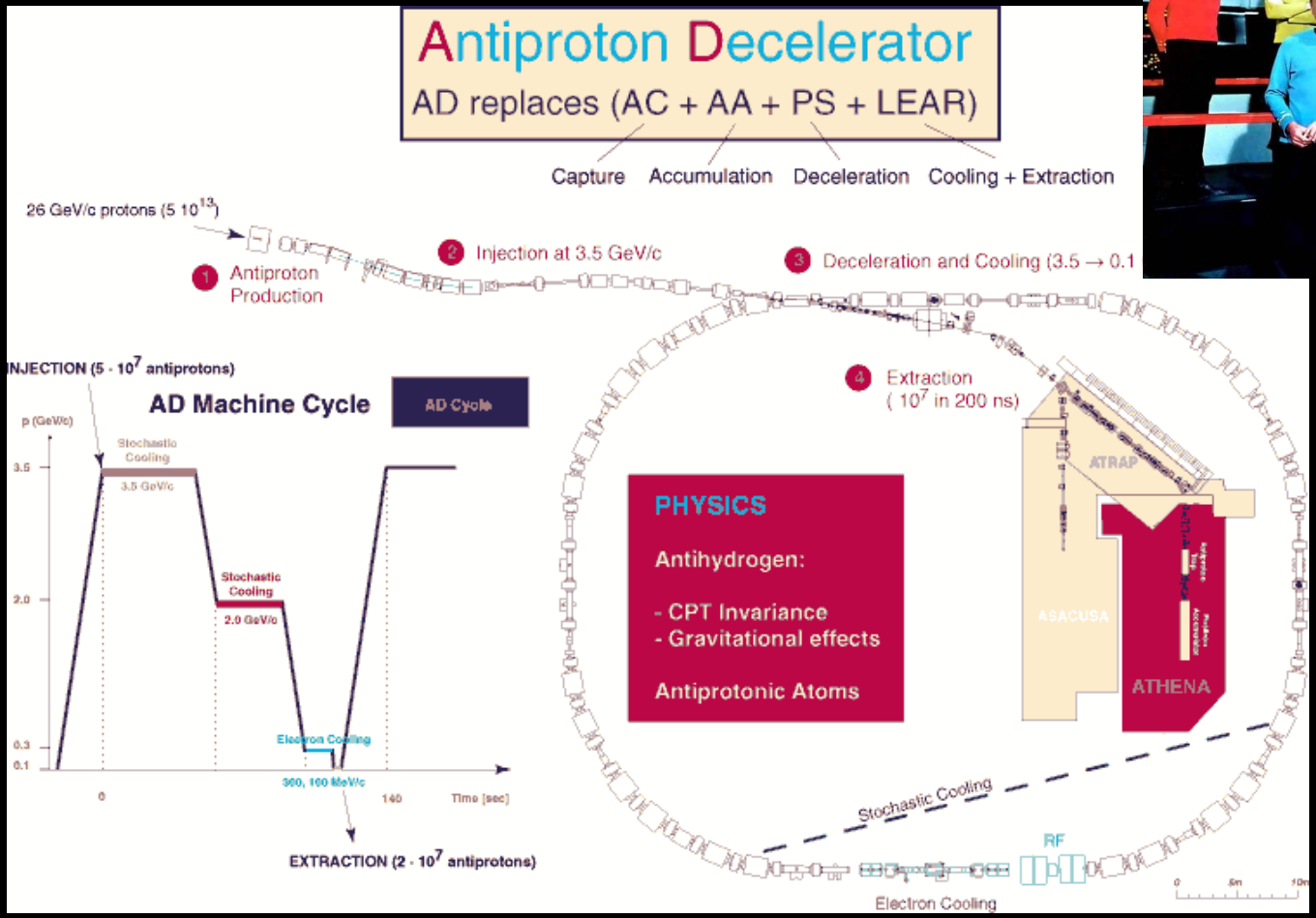
Theory is not so clear !
… But most people expect it to behave like matter

New experiment at the AD now under construction:
AEGIS - Antimatter Experiment: Gravity, Interferometry, Spectroscopy

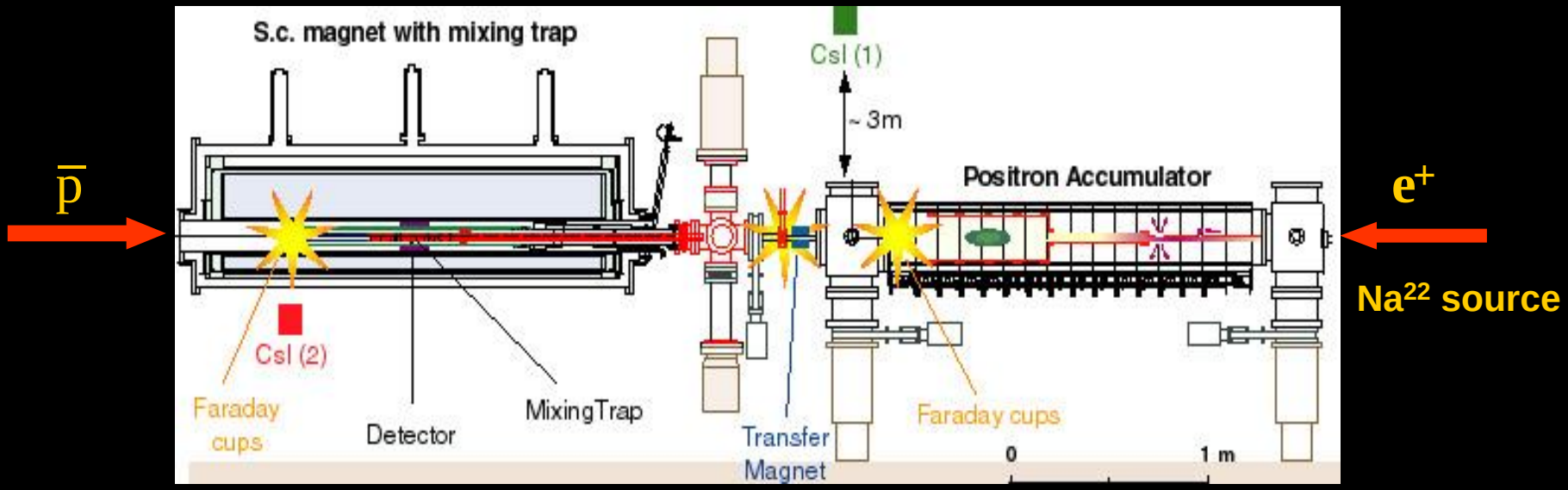
Are there practical things where antimatter might be useful ?

Passing into the antiworld?

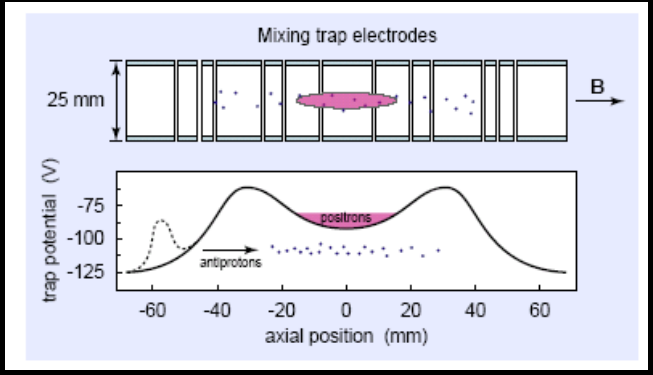
How do we make anti-matter ?



Making antihydrogen

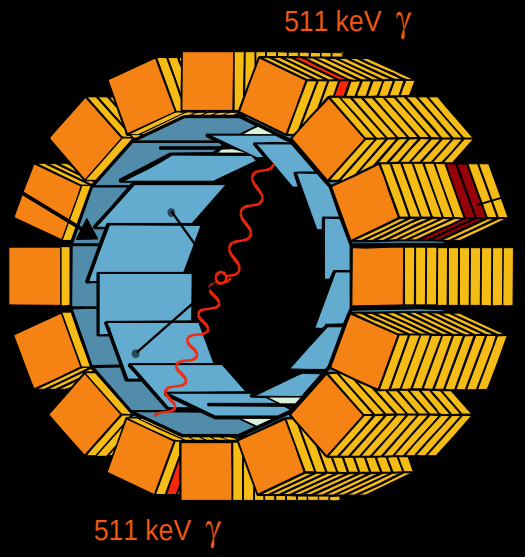


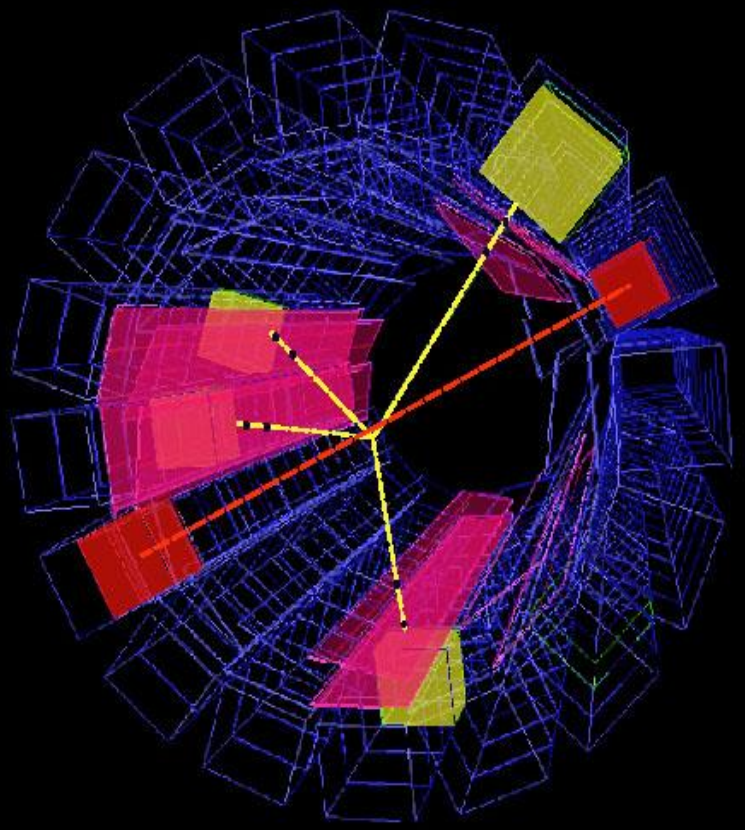
- We take antiprotons and slow them down MUCH, MUCH more
- We collect a lot of positrons
- We get them together
- They make antihydrogen and fly to the wall
- We detect them



Detecting that we have made antihydrogen

- **We build a detector that can measure the annihilation of an antiproton and a positron at the same time and at the same place**





Next step: Trapping antihydrogen

Antihydrogen Trapped!
***Nature*, 17 Nov. 2010**

More antihydrogen trapped for 1000 seconds!
***Nature Physics*, 5 June 2011**

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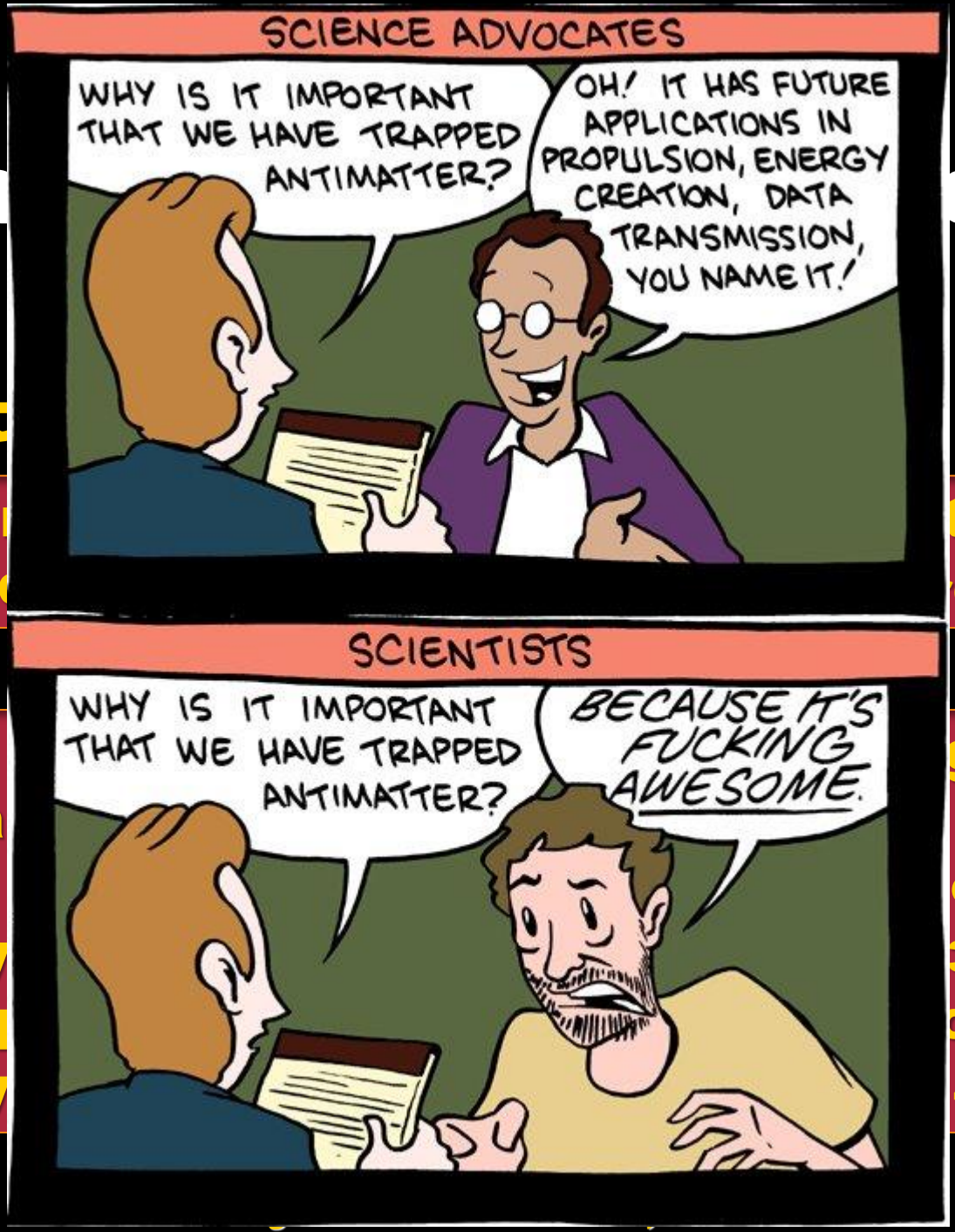

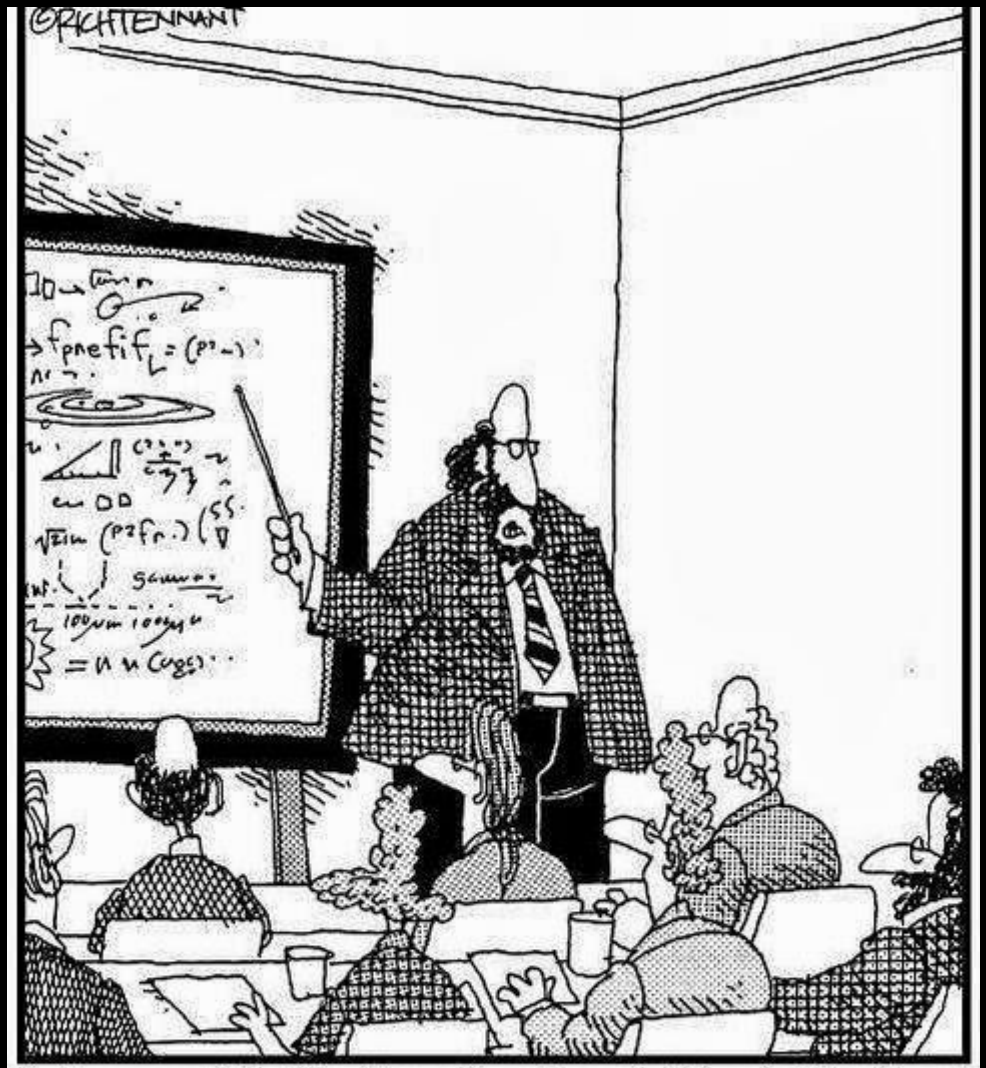

A (hopefully) great year ahead at the AD!

Thank you for listening !