

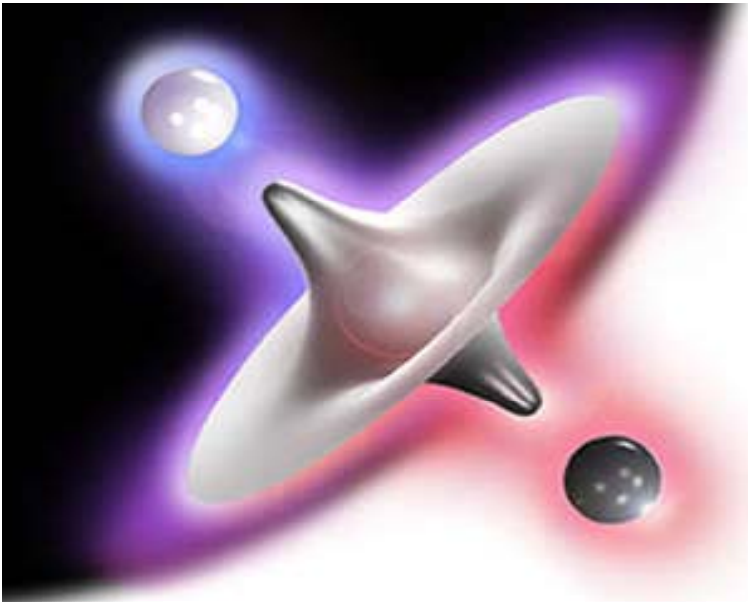
Antimatter Mysteries

Rolf Landua

Research physicist - Head of Education

CERN

Antimatter Questions



Seven questions

What is antimatter

How is antimatter made

Where is antimatter made

The mystery of antimatter

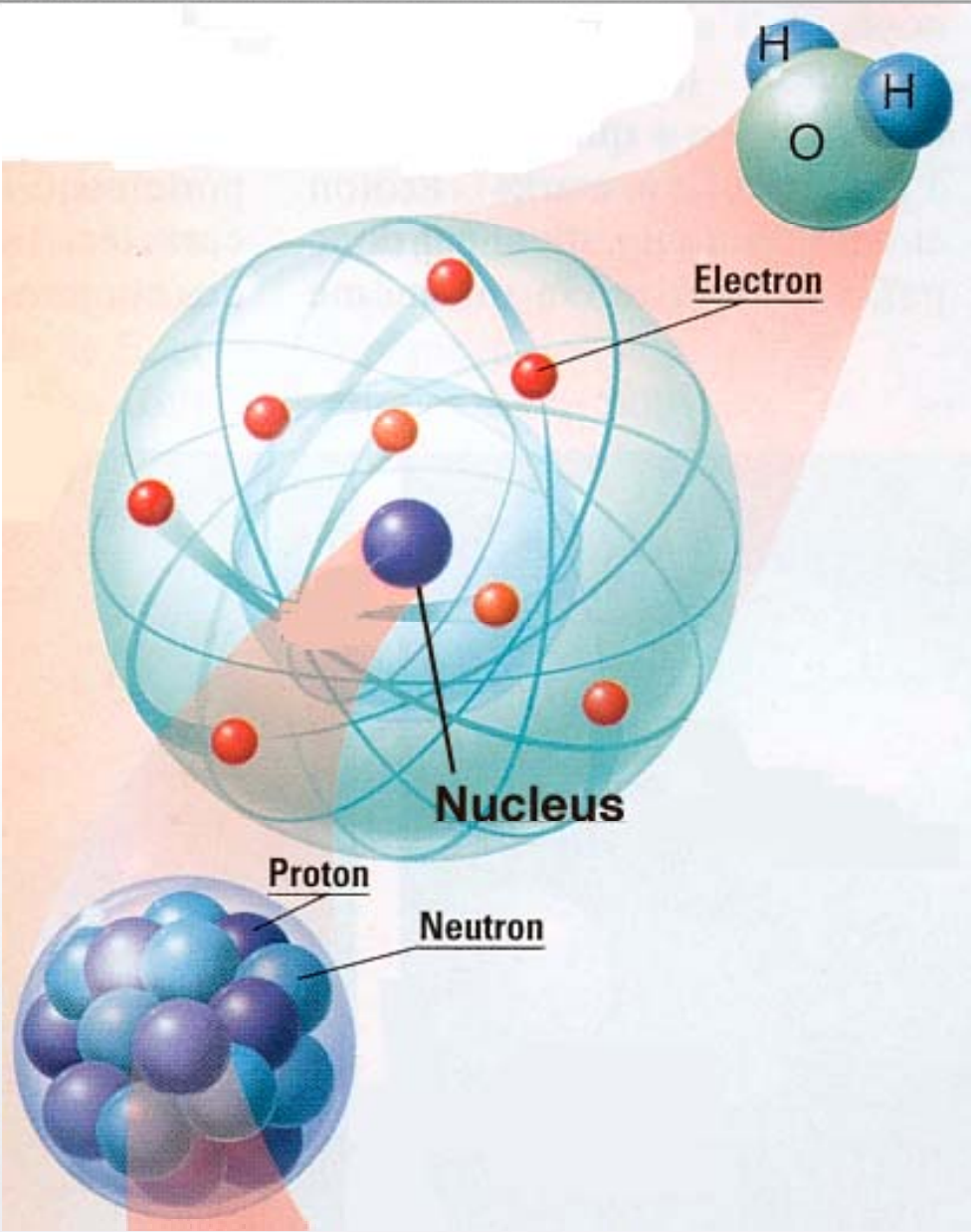
How to study antimatter

Energy source, weapon, Star Trek

Applications in medicine

1 What is antimatter ?

1 What is antimatter ?



Matter is made of **particles**

Electrons
Protons
Neutrons } Quarks

1 What is antimatter ?

Particles have specific **masses** and **charges**

Name	Electric Charge [e]	Mass [GeV*]
Electron	- 1	0.0005
Proton	+ 1	0.938
Neutron	0	0.941

*GeV = Giga-Electron Volt = 1,000,000,000 Electron-Volt = $1.8 \cdot 10^{-27}$ kg

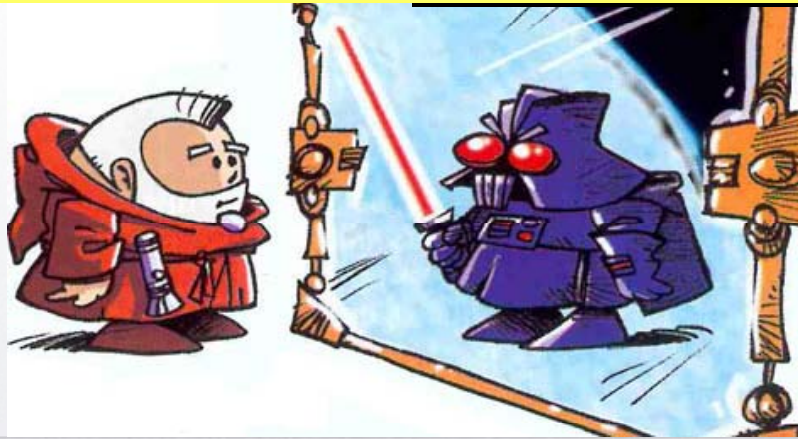
1 What is antimatter ?

Anti-Particles have the **same mass**, but **opposite charge**

Name	Electric Charge [e]	Mass	Electric Charge [e]	Name
Electron	- 1	0.0005	+ 1	Positron
Proton	+ 1	0.938	- 1	Antiproton
Neutron	0	0.941	0	Antineutron



Particles



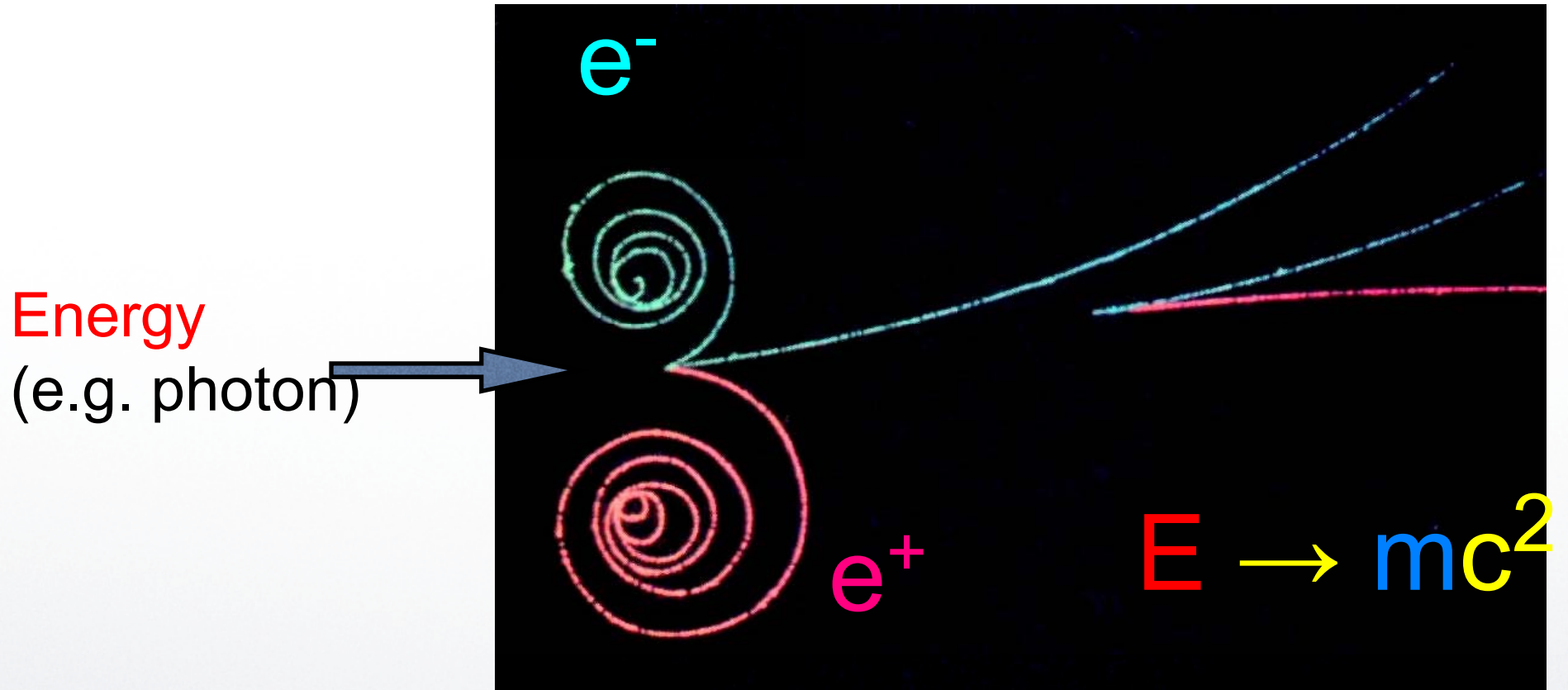
Anti-Particles

Antimatter Mysteries

2 How is antimatter made ?

2 How is antimatter made ?

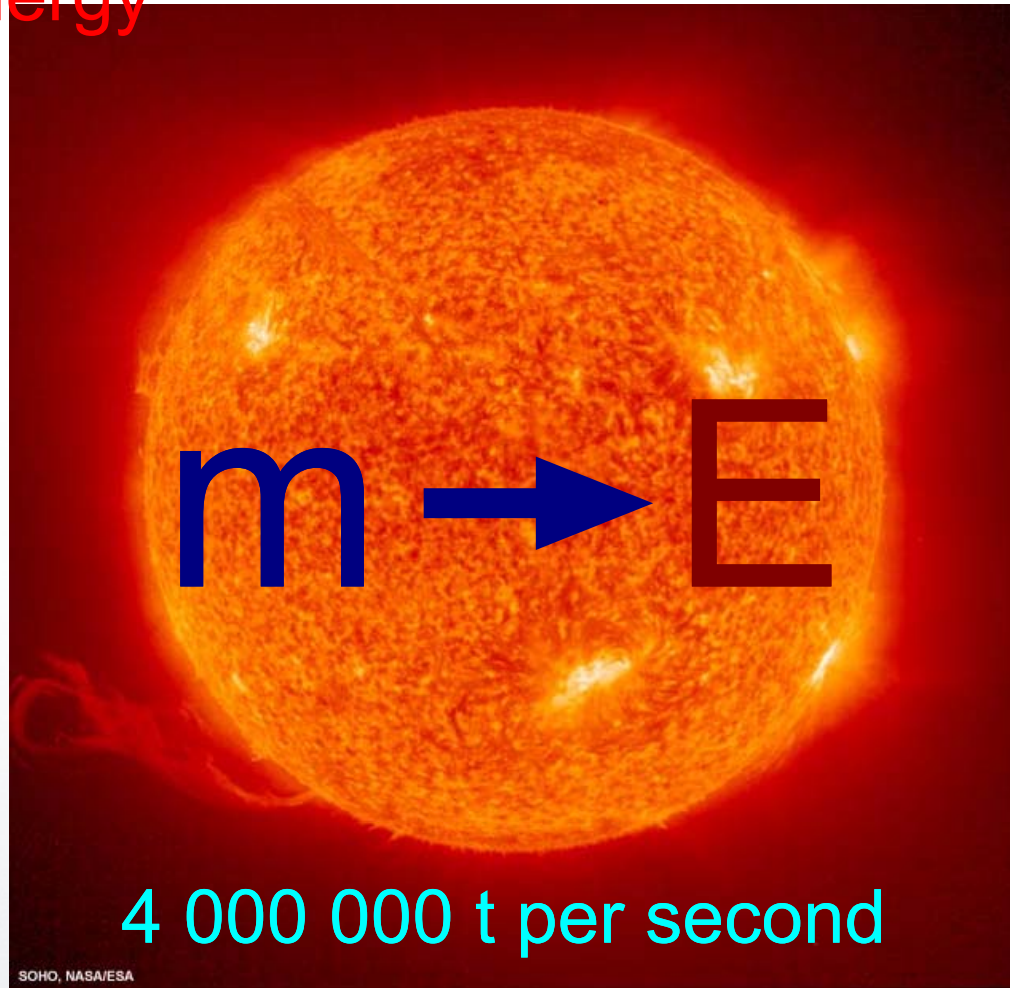
Energy is converted to mass



Mass of electron and positron

2 How is antimatter made ?

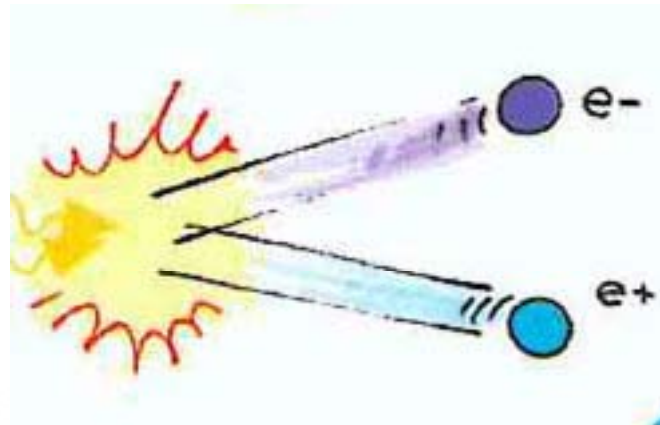
In the Sun, mass is converted to
energy



2 How is antimatter made ?

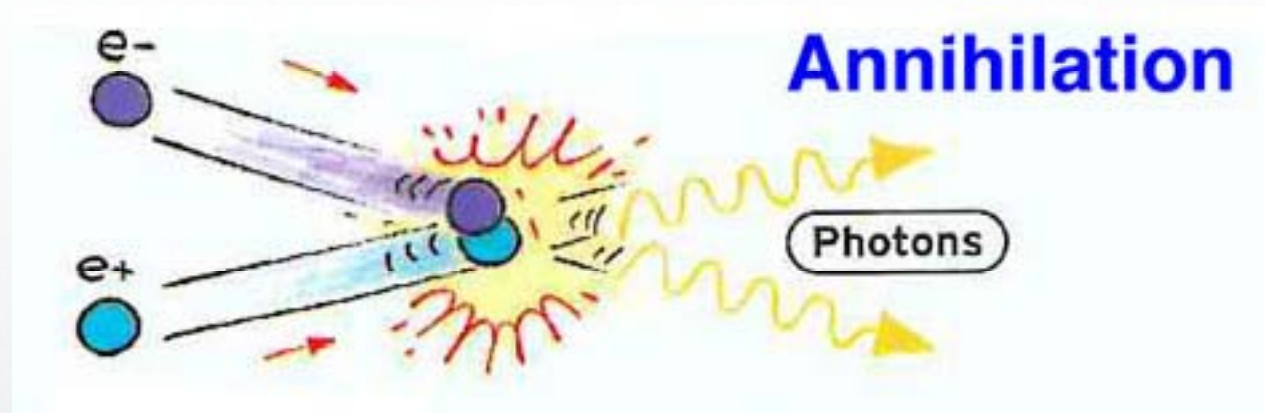
Particles and antiparticles are always **created in pairs** ...

Energy to mass:

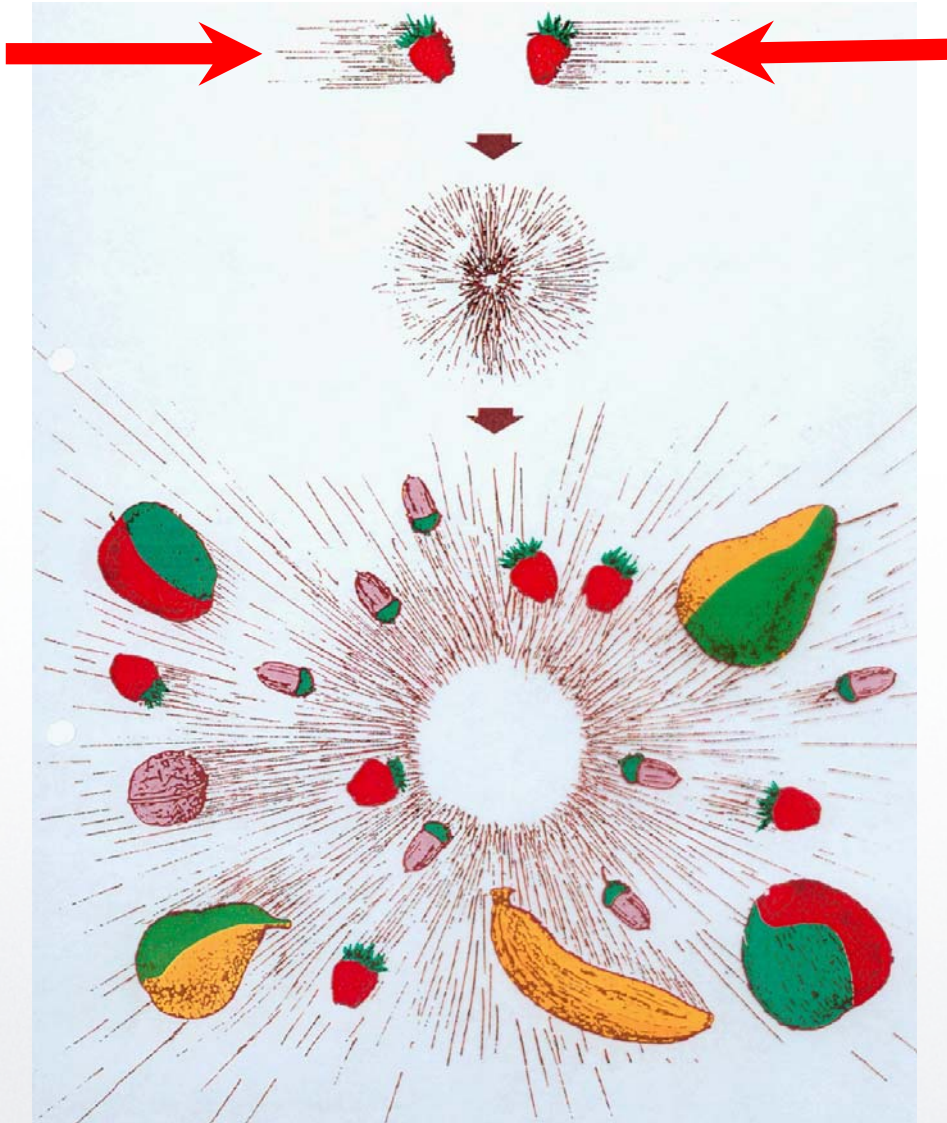


... and they can also **annihilate** each other

Mass to energy:



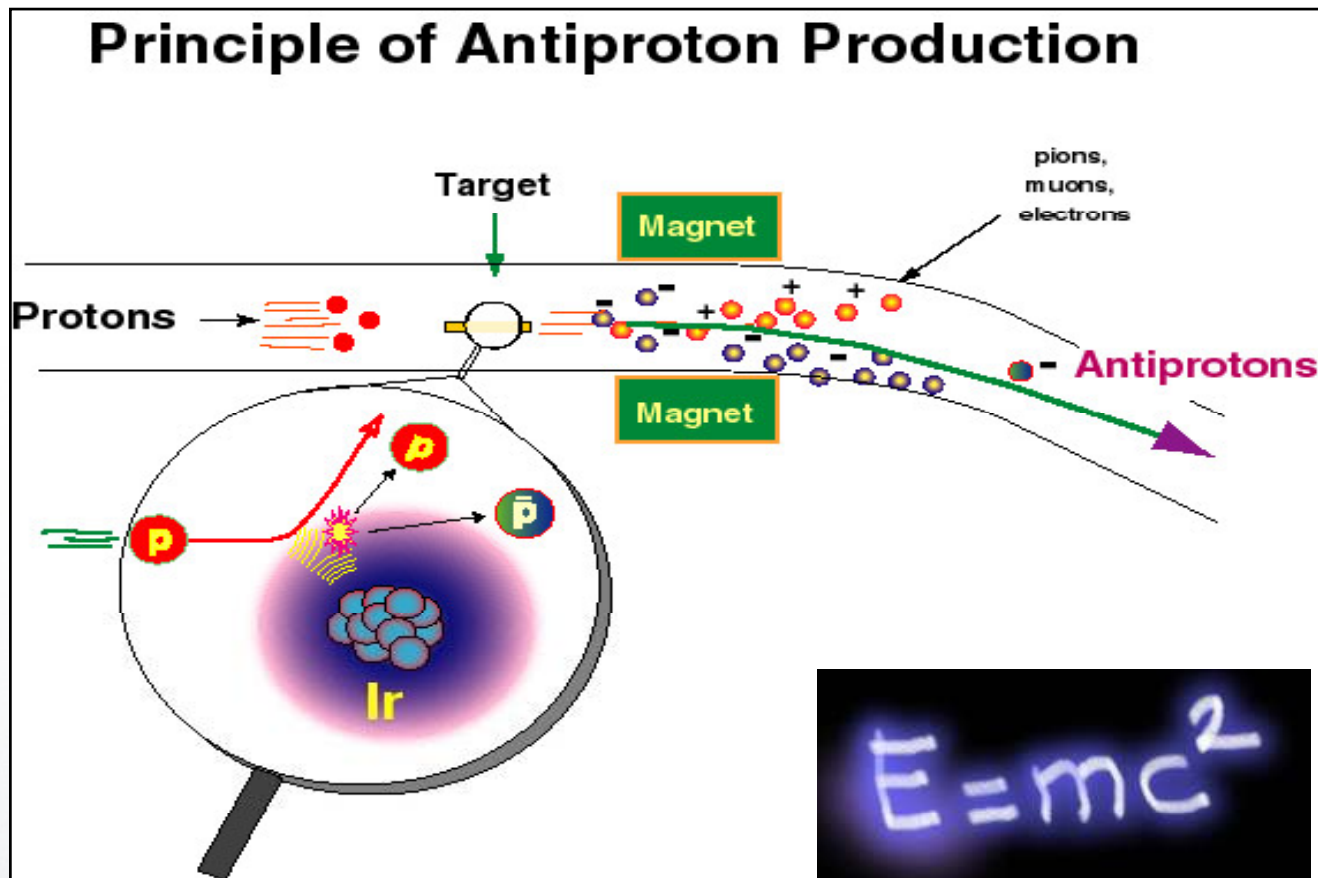
2 How is antimatter made ?



New particles and antiparticles are created in collisions

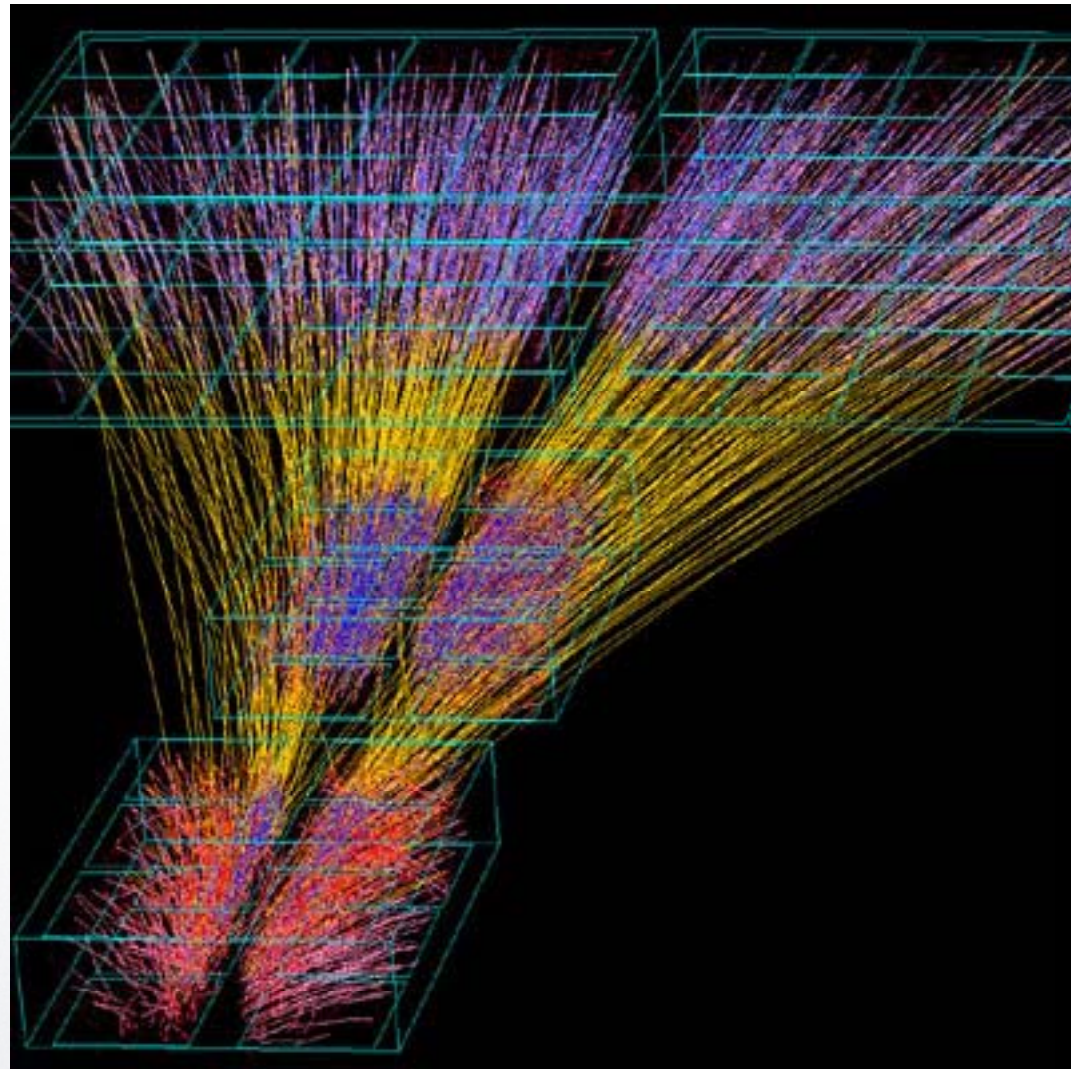
2 How is antimatter made ?

Energy is carried by **accelerated** particles



Energy is converted to mass in **collisions**

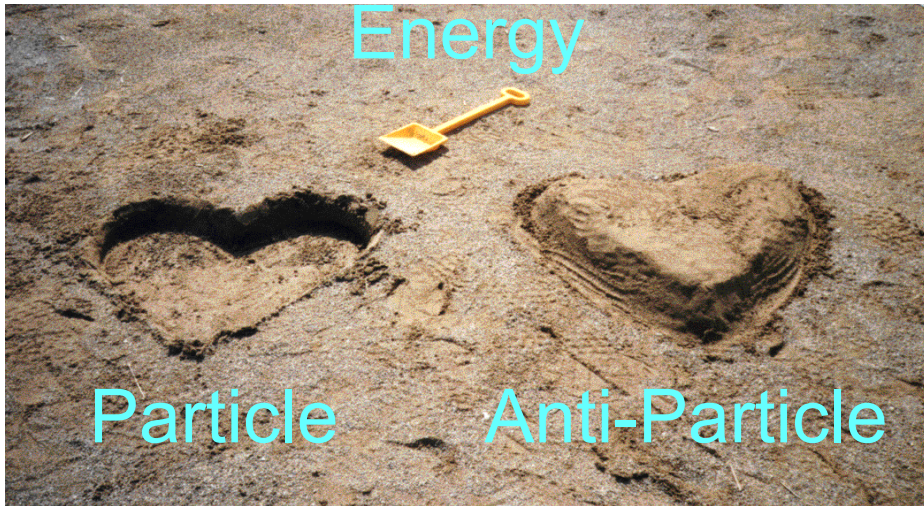
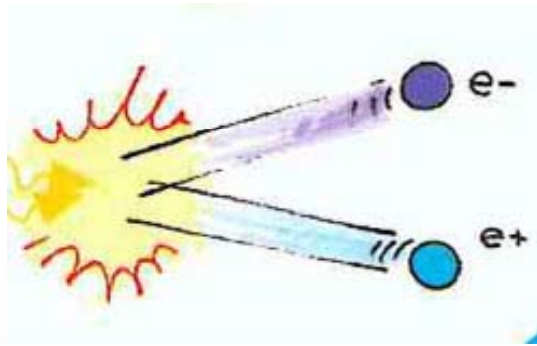
2 How is antimatter made ?



When energy is transformed to mass,
equal amounts of particles and antiparticles are created

2 How is antimatter made ?

What is an anti-particle?



Anti-Particles are as real as particles

A world made of antiparticles could exist - and it would look the same as our world.

2 How is antimatter made ?

Careful with “antimatter E.T.” !



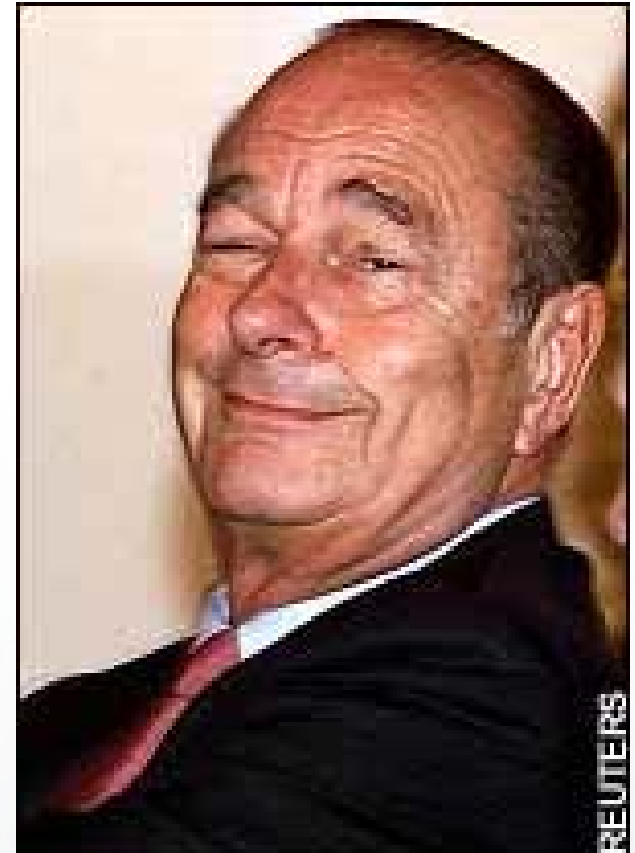
2 How is antimatter made ?

Bush



≠

Anti-Bush?



False analogy: matter and antimatter would look identical

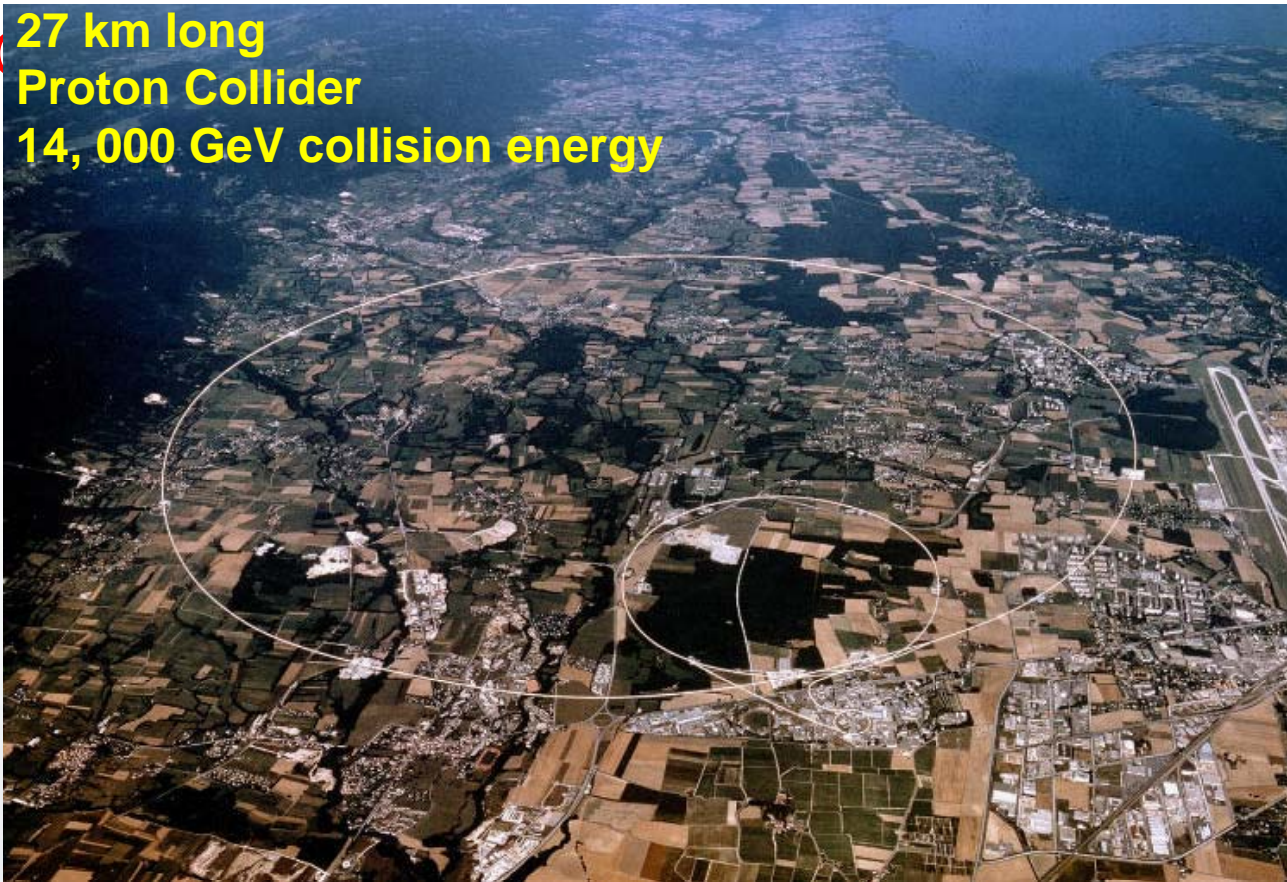
3 Where is antimatter made

3 Where is antimatter made ?

Antiparticles are produced using accelerators

The largest accelerator laboratory in the world is CERN in Geneva
(CH)

27 km long
Proton Collider
14,000 GeV collision energy



‘Nucléaire’

7500 physicists
from 104 countries

3 Where is antimatter made ?

CERN = 'Conseil Européen pour la Recherche Nucléaire'

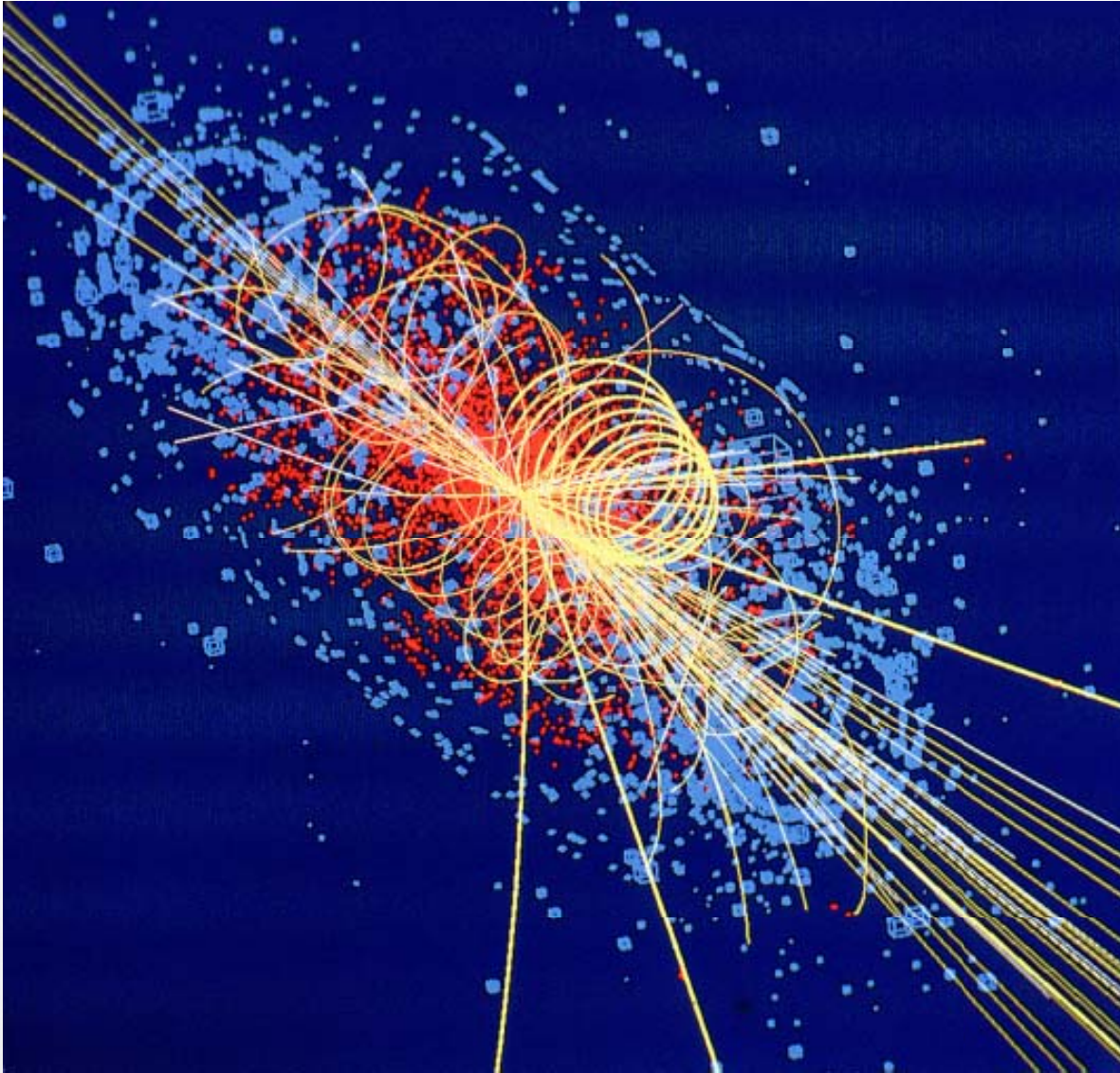
European Laboratory for Particle Physics



Large
Hadron
Collider

The most powerful
particle
accelerator in the
world

3 Where is antimatter made ?

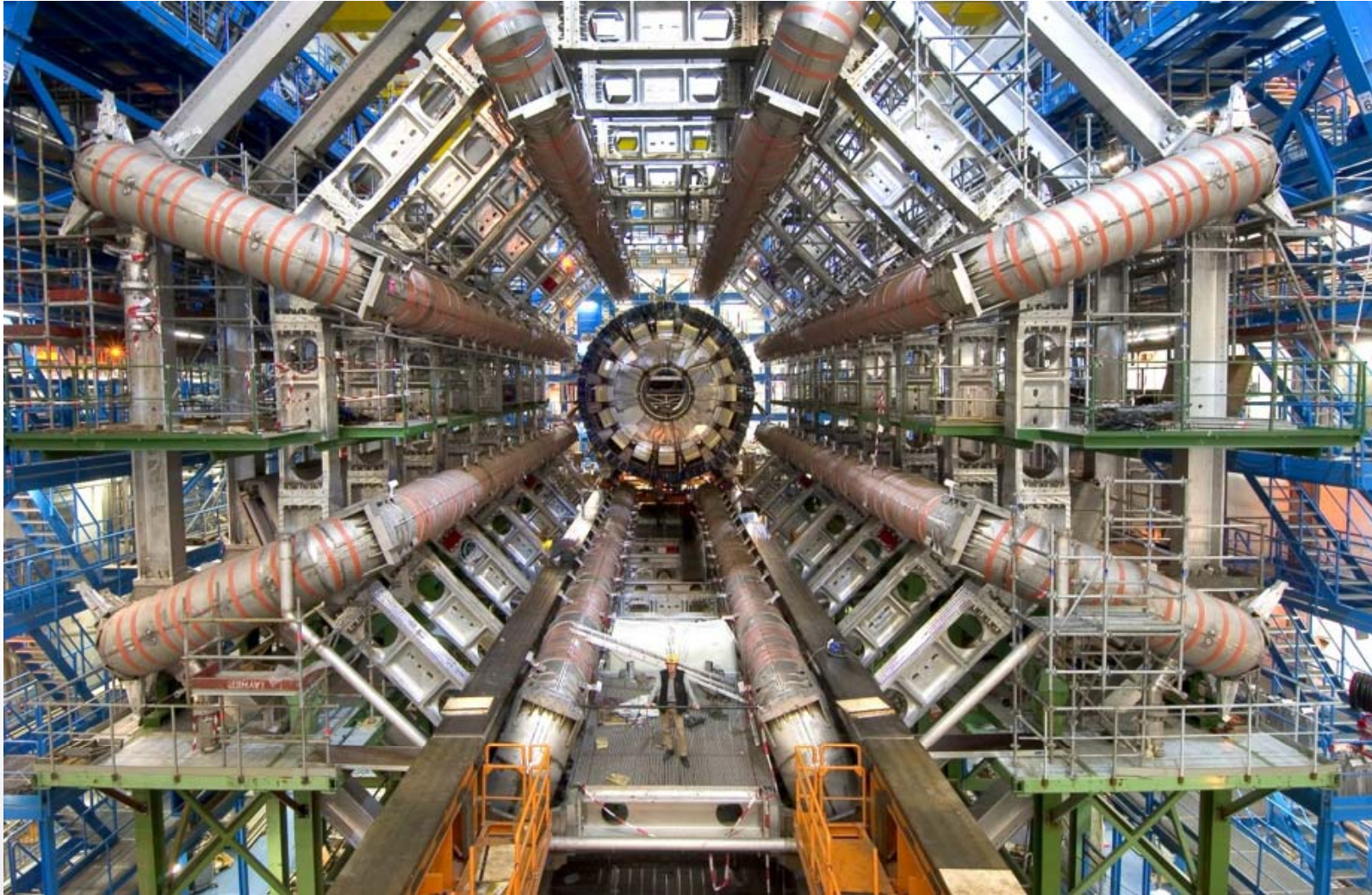


New particles will be created that only existed shortly after the Big Bang

- Generation of mass ?
- Dark Matter ?
- Extra dimensions ?
- Antimatter properties ?

3 Where is antimatter made ?

The ATLAS detector is one of four giant detectors at the LHC



Antimatter Mysteries

3 Where is antimatter made ?

The ATLAS detector is as large as a 5-story building



4 The mystery of antimatter

4 The mystery of antimatter



Why is there no antimatter anywhere in the Universe?

Solar System ? No !

4 The mystery of antimatter

In galaxies far, far away ... ?

No

There seems to be no antimatter in the Universe !

4 The mystery of antimatter

No antimatter in the Universe ??????

Why not ?

4 The mystery of antimatter

The Universe started 13 700 million years ago



$\sim 10^{72}$

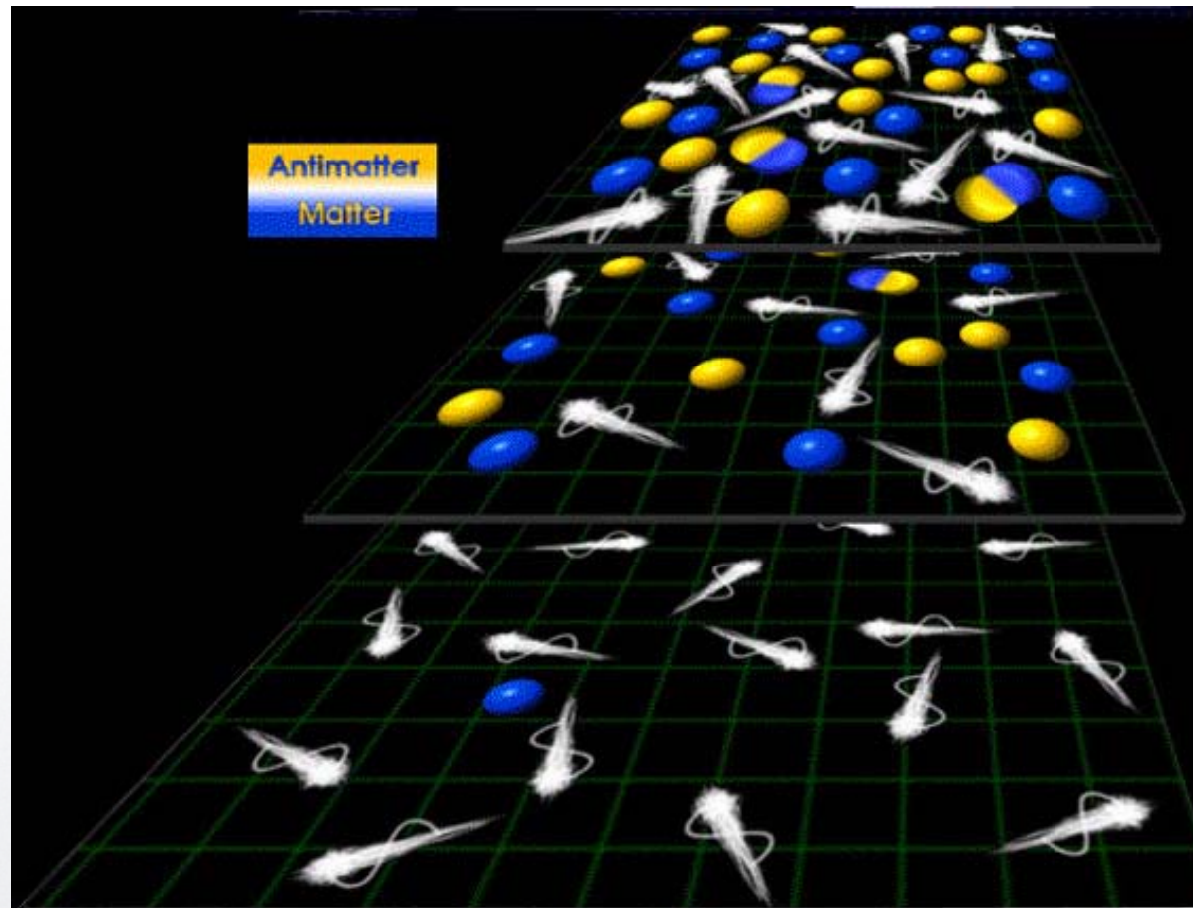
Joule



Size (x 100) of the visible Universe
[at the 'Planck' time $t = 10^{-43}$ s]

4 The mystery of antimatter

13,700 million years ago: The Big Bang



Transformation of energy into mass on a gigantic scale

$t \sim 0$:

matter = antimatter

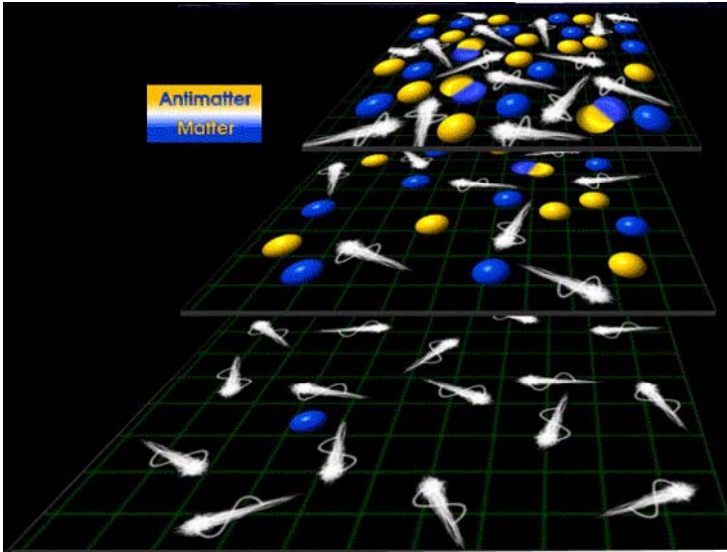
$t \sim 0.001$ s :

all antimatter has disappeared,
but some matter (us!) left;
energy is carried by light particles

Today :

>2,000,000,000 photons per
proton or neutron

4 The mystery of antimatter



Scientists want to understand **why** the Universe contains **only matter!**

Is it because matter and antimatter have (slightly) different properties*?

*Mass, charge, magnetic moment, ...?

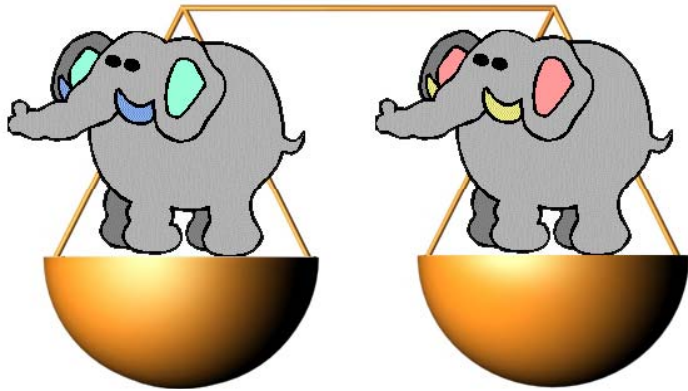
Is it because matter and antimatter have different decay* properties ?

*CP violation

5 How to study antimatter ?

5 How to study antimatter ?

Compare properties of antimatter and matter **very precisely**



difference less than one dust grain

Mass of proton and antiproton ?

Present result: $\Delta M/M < 0.000\,000\,000\,1$



Magnetic moment of electron and positron ?

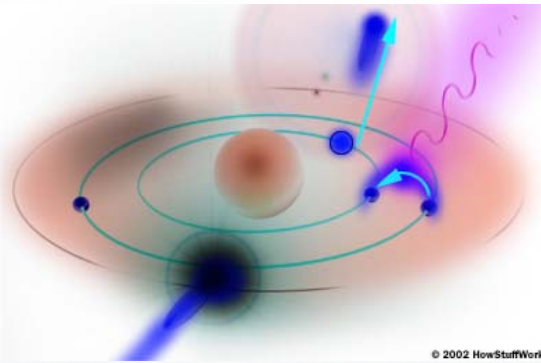
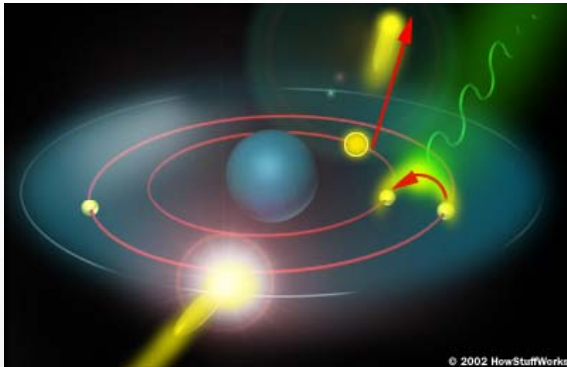
Present result: $\Delta\mu/\mu < 0.000\,000\,000\,001$

Present status: excellent agreement !

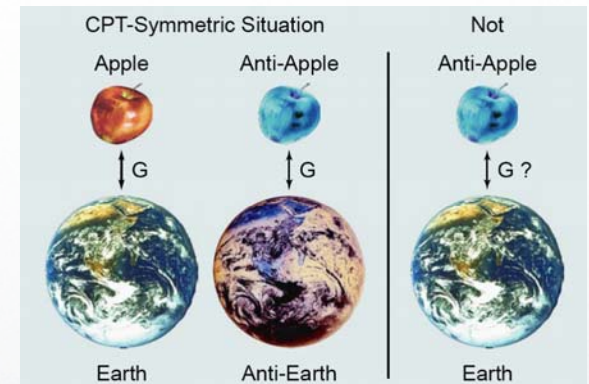
5 How to study antimatter ?

Compare properties of antimatter and matter **even more precisely**

- 1) Produce **antihydrogen atoms** from antiprotons and positrons
- 2) Trap antihydrogen atoms
- 3) Measure their properties



Energy levels



Gravity

5 How to study antimatter ?



Antimatter factory at
CERN
Antiproton Decelerator
produces antiprotons
and slows them down

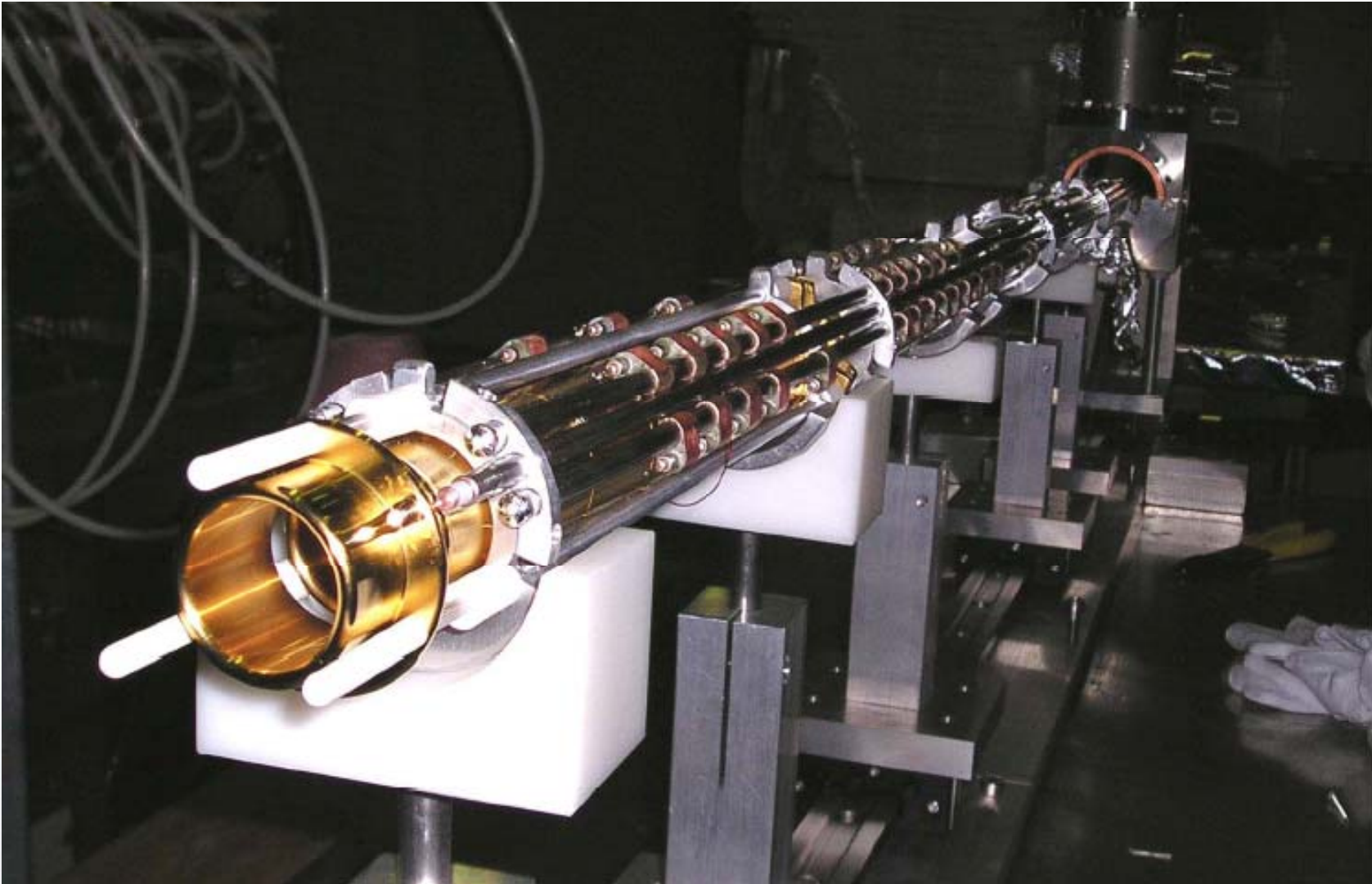
188 m long

Antiproton Production:
100,000,000 antiprotons per
minute

Deceleration
96 % \rightarrow 10 % speed of
light

5 How to study antimatter ?

Then, antiprotons (and positrons) are trapped



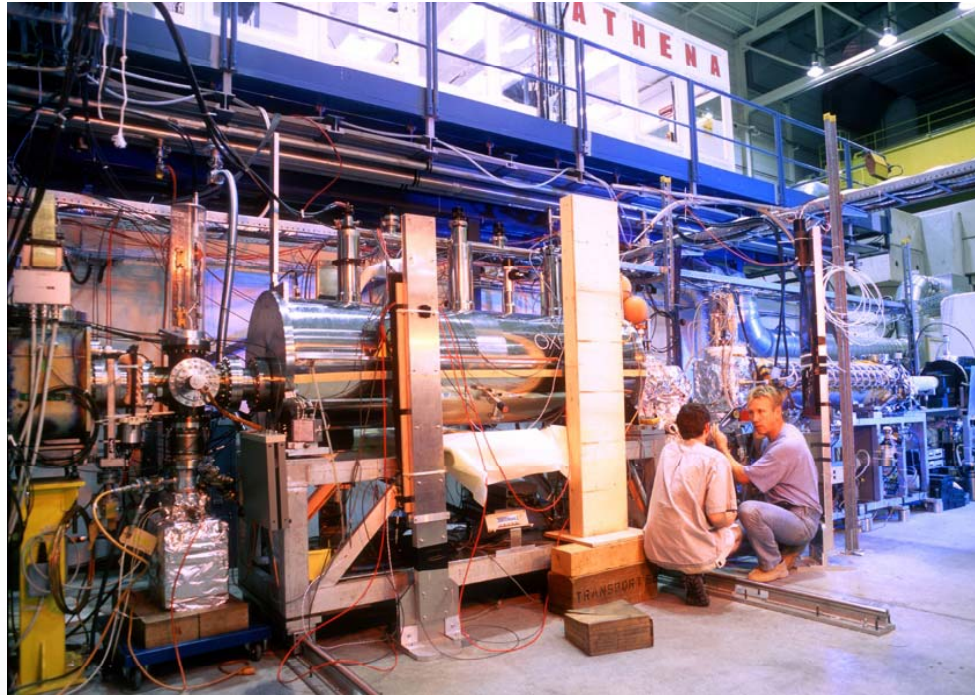
5 How to study antimatter ?

Animation: How antihydrogen is produced at the AD

QuickTime™ and a
MPEG-4 Video decompressor
are needed to see this picture.

5 How to study antimatter ?

ATHENA Experiment (2002), at the AD facility

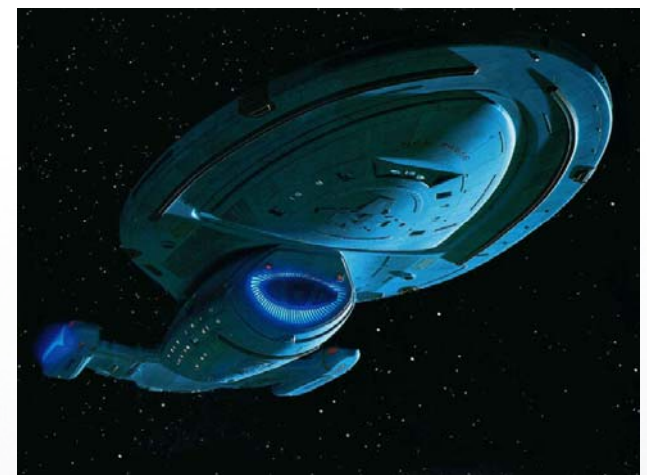


Status:

- More than 1 million antihydrogen atoms produced
- Small kinetic energy (< 0.01 eV)
- Next step (in progress): trap antihydrogen atoms

6 Energy source? Weapon? Star Trek?

Angels & Demons



6 Energy source? Weapon? Star Trek?

The story line of ...



Wuminati

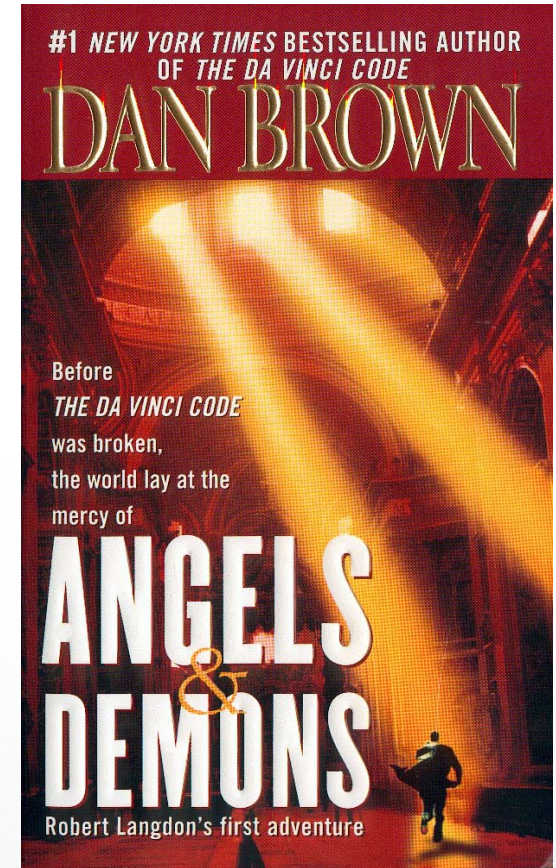
Detective story about a secret society which ...



... steals 1 g of antimatter from a physicist at the 'LHC' in a place called "CERN" ...



... to blow up the Vatican, an old "enemy of science and CERN".



6 Energy source? Weapon? Star Trek?

The 'Angels and Demons' movie is being prepared.

Director: Ron Howard
Robert Langdon : Tom Hanks

What did Ron Howard* say after he had seen CERN?



That's how small I feel after seeing the huge machines ...

That's the budget of my new movie "Angels and Demons"

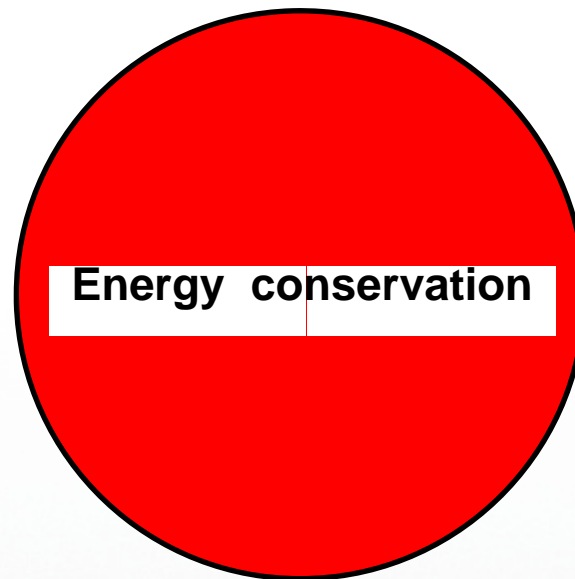
This much science will be in the "Angels and Demons" movie ...

This is what Dan Brown understands about antimatter

*Da Vinci Code, Apollo 13, Beautiful mind, ...

6 Energy source?

Dan Brown: Antimatter is the energy source of the future.



No

Antimatter production **requires energy**

1,000,000,000 times more energy invested than released by annihilation

6 Antimatter bombs ?

*Dan Brown is right:
only 0.5 g antimatter makes an 'anti-atomic
bomb'*

BUT:

0.5 g antimatter = $4.5 \cdot 10^{13}$ J

Total energy needed (efficiency = 10^{-9}) : $4.5 \cdot 10^{22}$ J

↓
Electricity discount price CERN

[1 kWh = $3.6 \cdot 10^6$ J = 0.1 €]

Price ~ 1,000,000,000,000,000 €

Delivery time ~ 1 000 000 000 years

20 kt TNT = $8.4 \cdot 10^{13}$ J
0.5 g antimatter + 0.5 g
matter

6 Star Trek?



Antimatter as fuel for space ships ?

No!

Energy needed to accelerate a 10-ton space ship to 95 % of the speed of light:

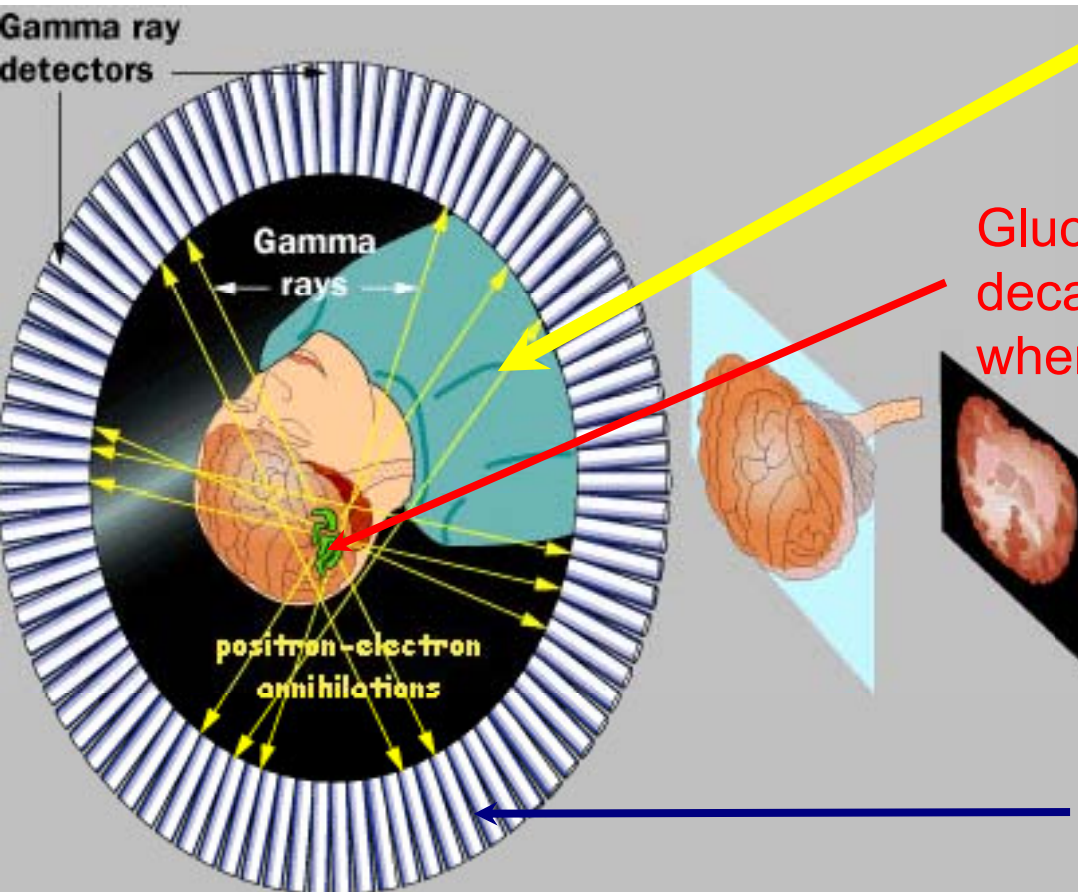
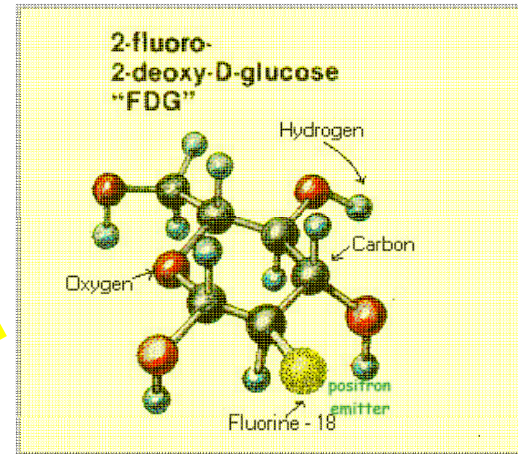
$$E = \gamma mc^2 \sim 10 \cdot 10^4 \text{ kg} =$$

Needs 50 tons of antimatter

7 Applications in medicine

7 Positron Emission Tomography

Add **positron** emitting isotopes (e.g. F-18) to glucose molecule and inject into blood stream

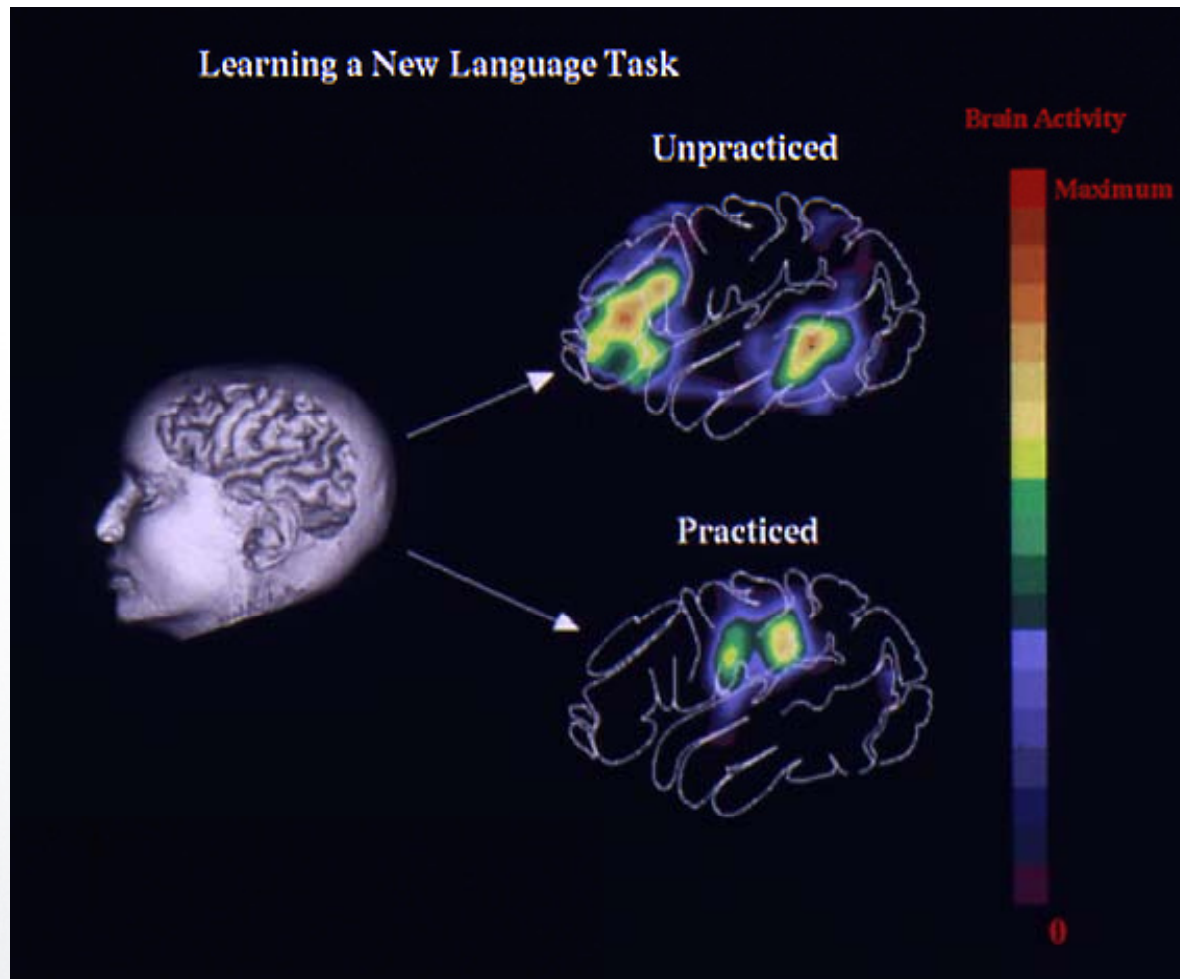


Glucose molecules accumulate (and decay) where energy is needed

Use detector to reconstruct place of positron annihilation

7 Positron Emission Tomography

Antimatter annihilations help to understand how the brain works



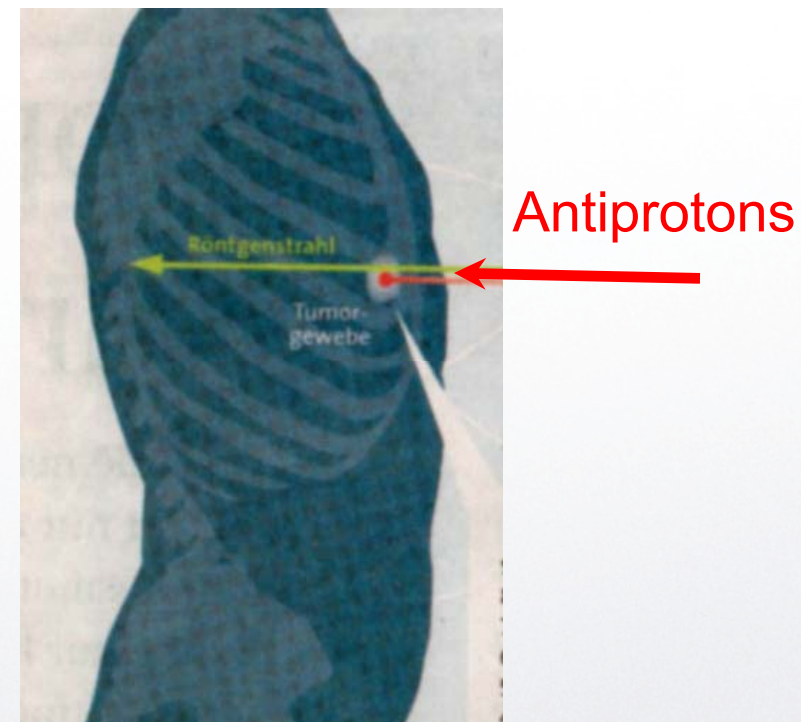
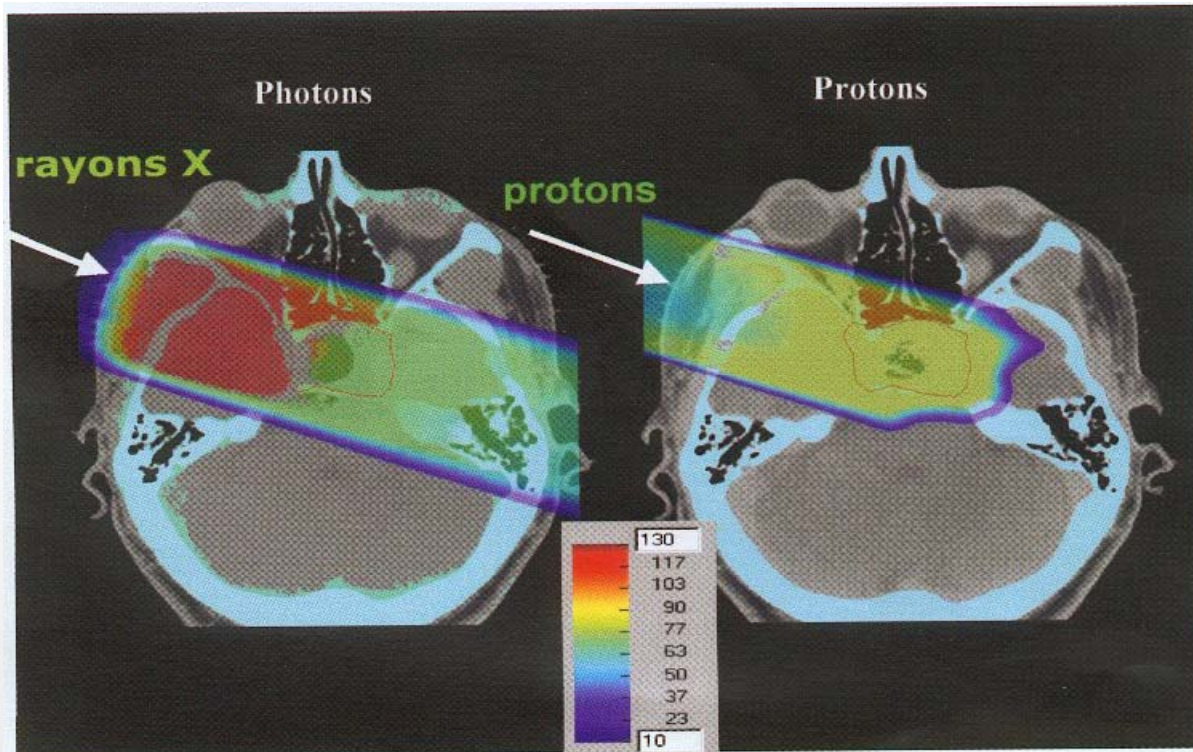
7 Tumour therapy with antiprotons ?

Radiation destroys tumour cells, but also healthy cells

Gamma radiation: more healthy than tumour cells destroyed

Protons deliver more energy in tumour cells

Antiprotons are 3x better than protons (but expensive)



The 'Angels and Demons' antimatter movie

What did
Ron Howard
say after his
visit to
CERN?



Thank you for your attention.