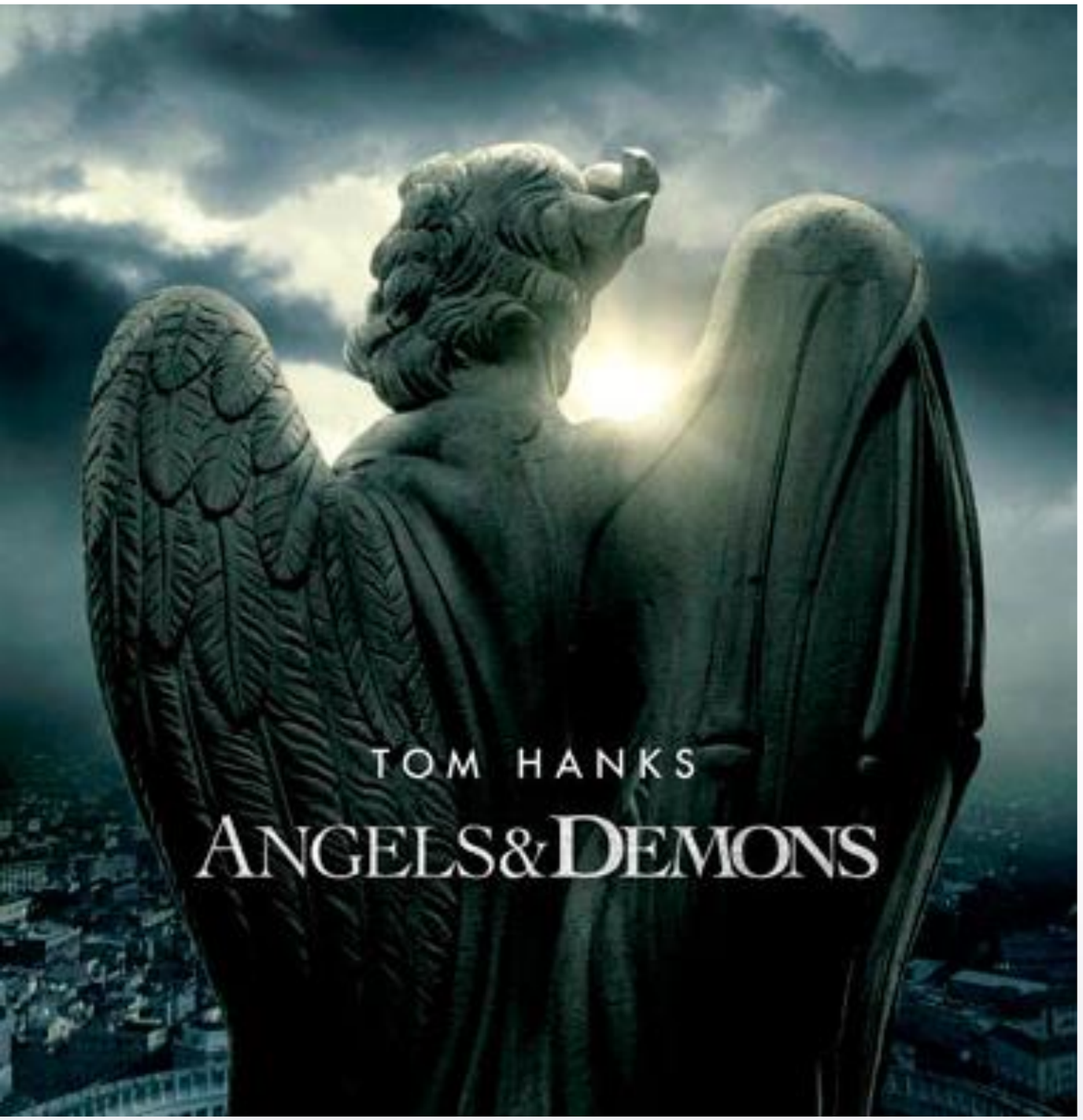


Angels&Demons

The Physics Behind the Mov

Rolf Landua

CERN

The story line of Angels & Demons

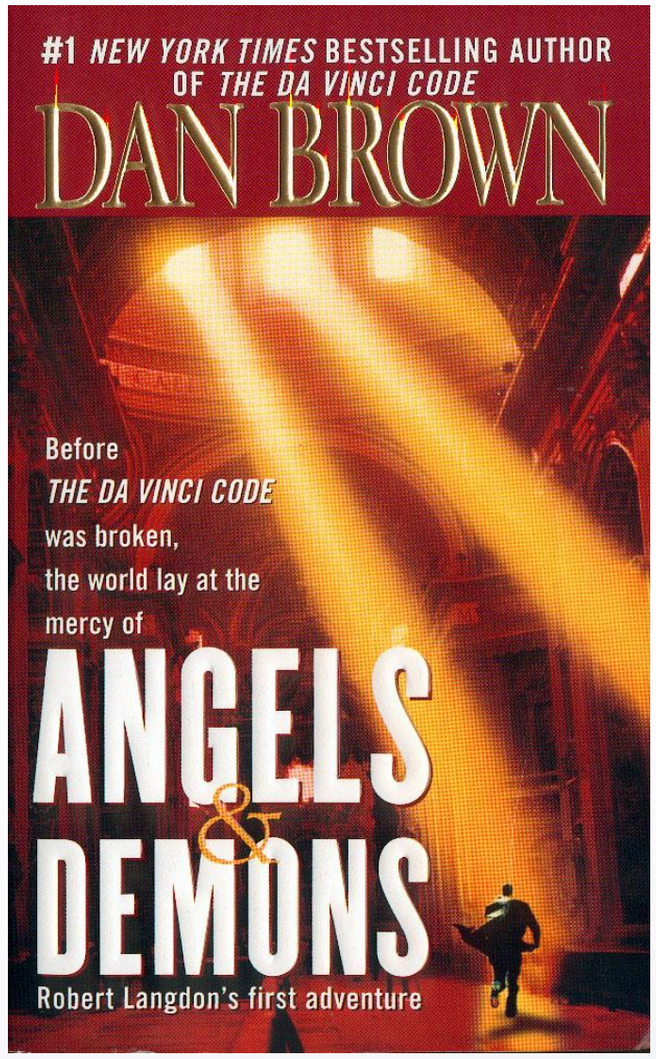
Illuminati

Detective story about a secret society which ...

CERN

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

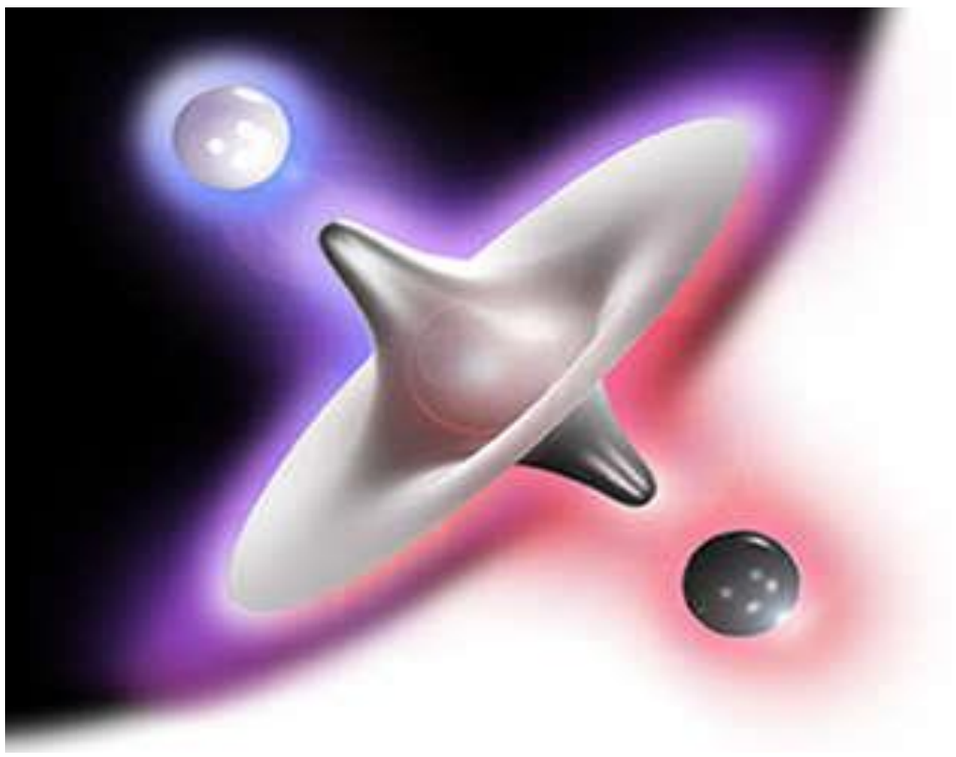
... to blow up the Vatican, an old "enemy of science and CERN".



What's true ? What's false ? Antimatter seems myster

Angels & Demons - The Physics behind the Movie

Antimatter Questions



Seven questions

What is antimatter ?

Where is antimatter made ?

How is antimatter made ?

The mystery of antimatter ?

How to study antimatter ?

Energy source? A bomb ?

Antimatter in daily life ?

Angels & Demons - The Physics behind the Movie

Angels & Demons: The Director

In 2007, to prepare his movie, Ron Howard visited CERN to find out more about antimatter traps.

What did he say after his guided tour at 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 ....

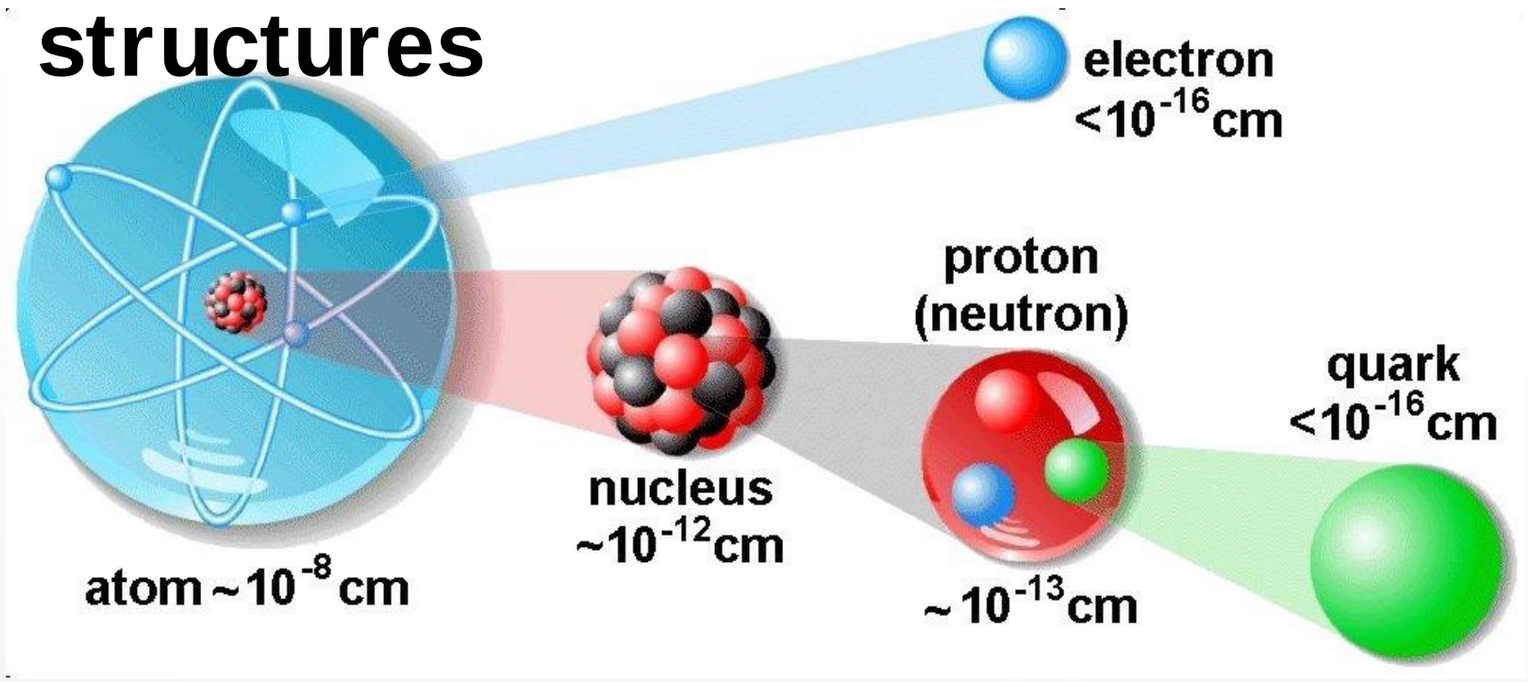
Angels & Demons - The Physics behind the Movie

1 What is antimatter

1 What is antimatter ?

Everything is made of matter
(We, animals, plants, rocks)

Hierarchy of matter structures



Electrons
Protons } Quarks
Neutrons

Matter is made of **particles**

The whole (visible) Universe is made of 3 building blocks

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

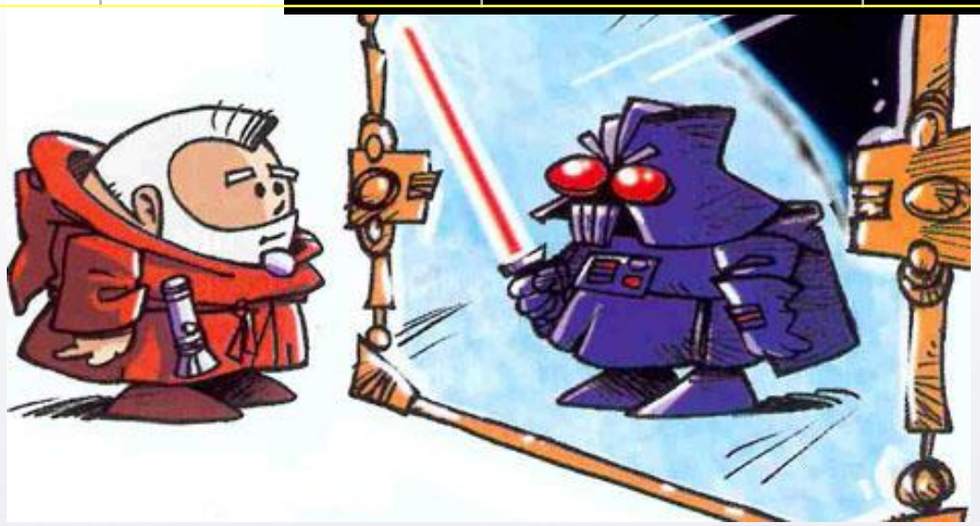
*GeV = Giga-Electron Volt = 1,000,000,000 Electron-Volt = $1.8 \cdot 10^{-27}$ kg

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

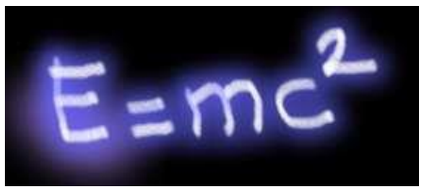
Particles



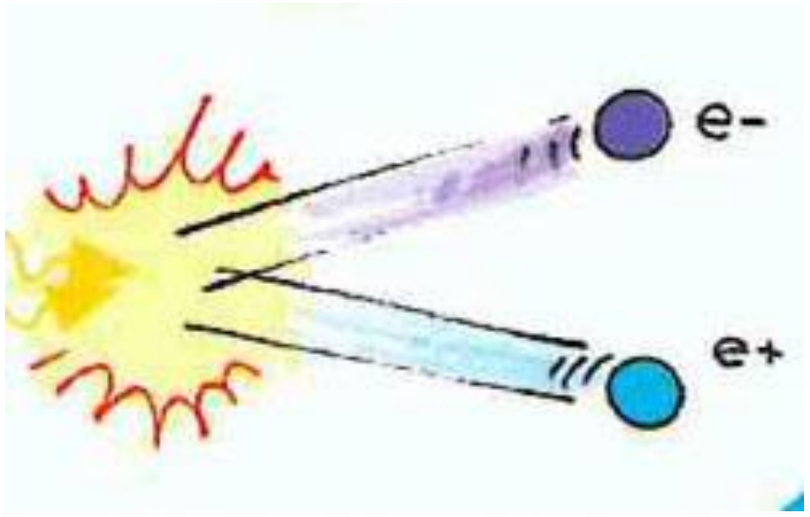
Anti-particles

1 What is antimatter ?

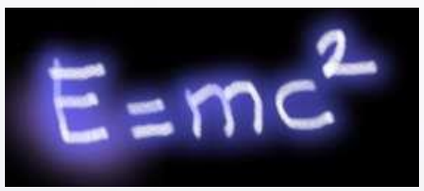
Particles and anti-particles are always **created in pairs** …



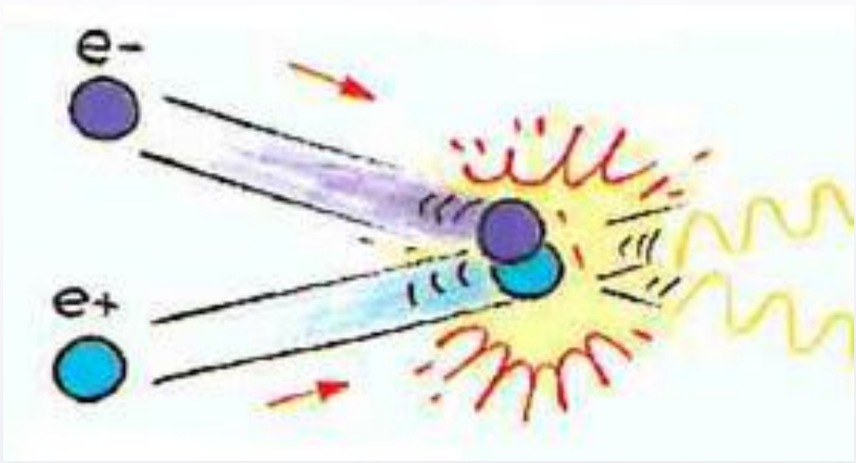
Energy to mass:



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

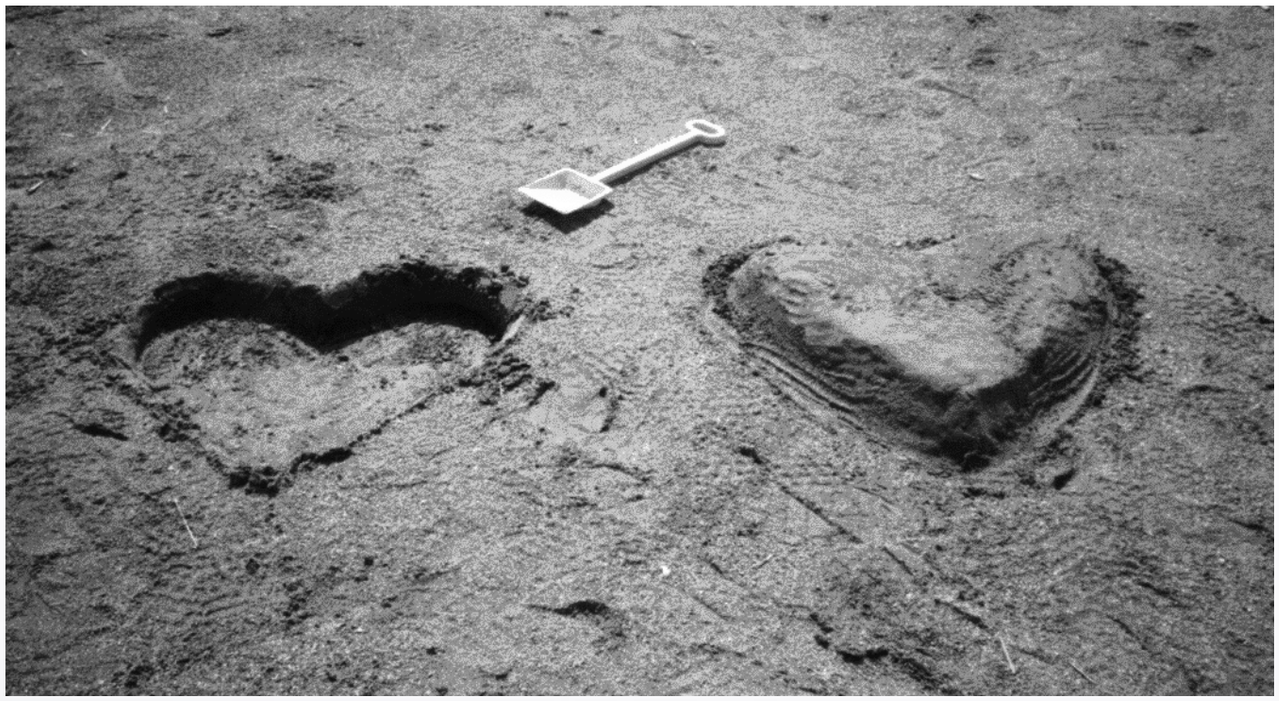


Mass to energy:

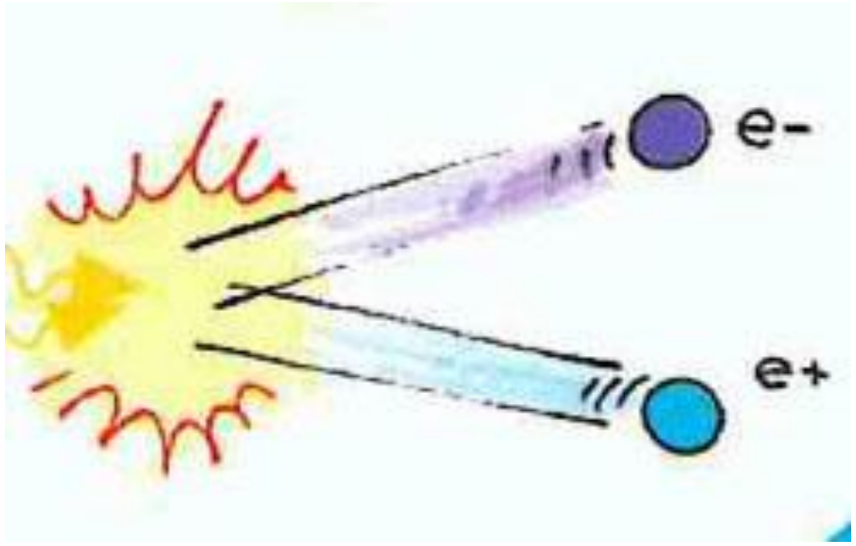


1 What is antimatter ?

Metaphors for the relation between particles and anti-particles



1 What is antimatter ?



Press here

Anti-particles are **as real** **as** particles

Matter becomes antimatter

A world made of antiparticles would look the same as our world.

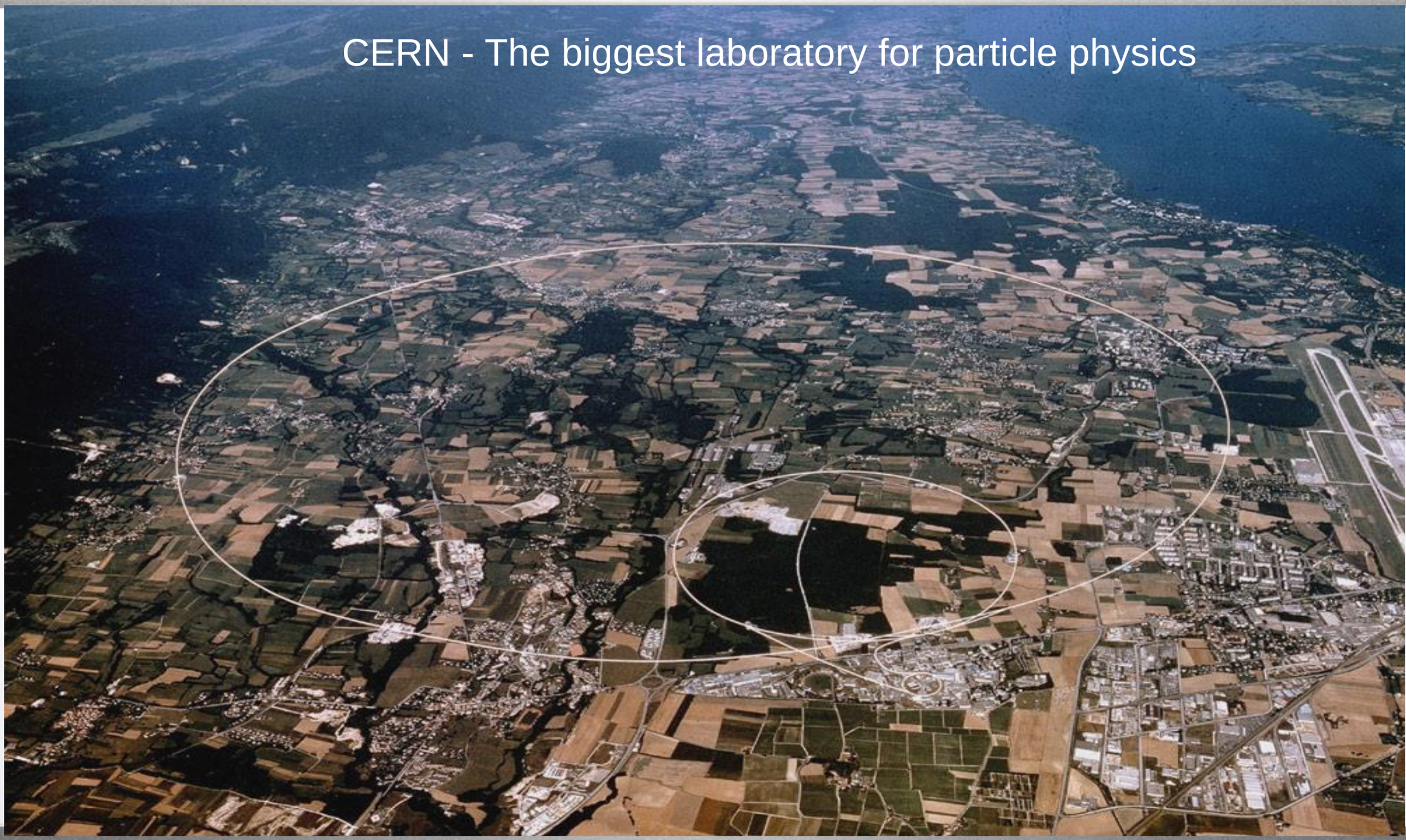
Angels & Demons - The Physics behind the Movie

1 What is antimatter ?

Careful with “antimatter E.T.” !

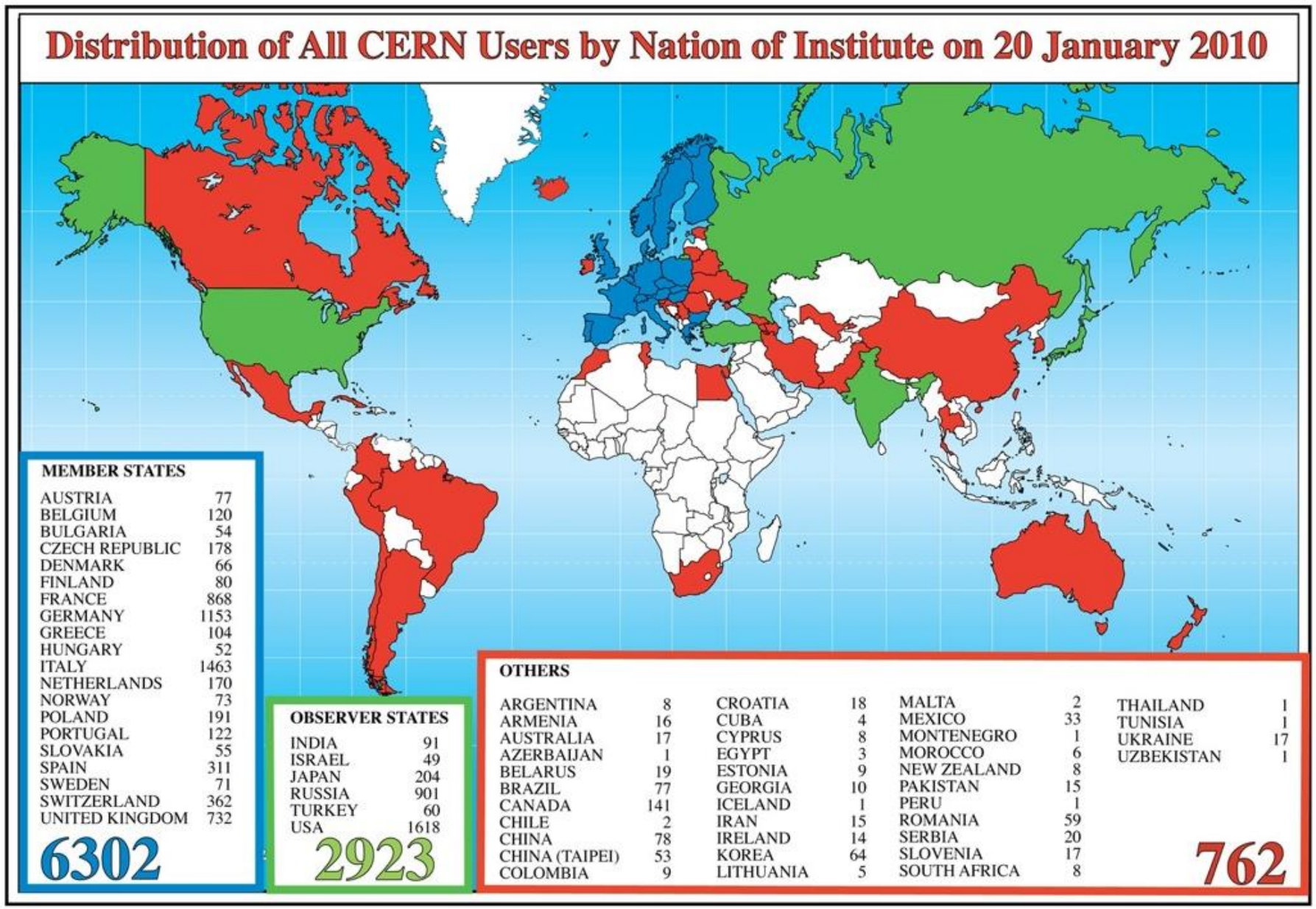
2 Where is antimatter mad

2 Where is antimatter made ?



Angels & Demons - The Physics behind the Movie

2 Where is antimatter made ?



10,000+ scientists from 104 countries work at CERN

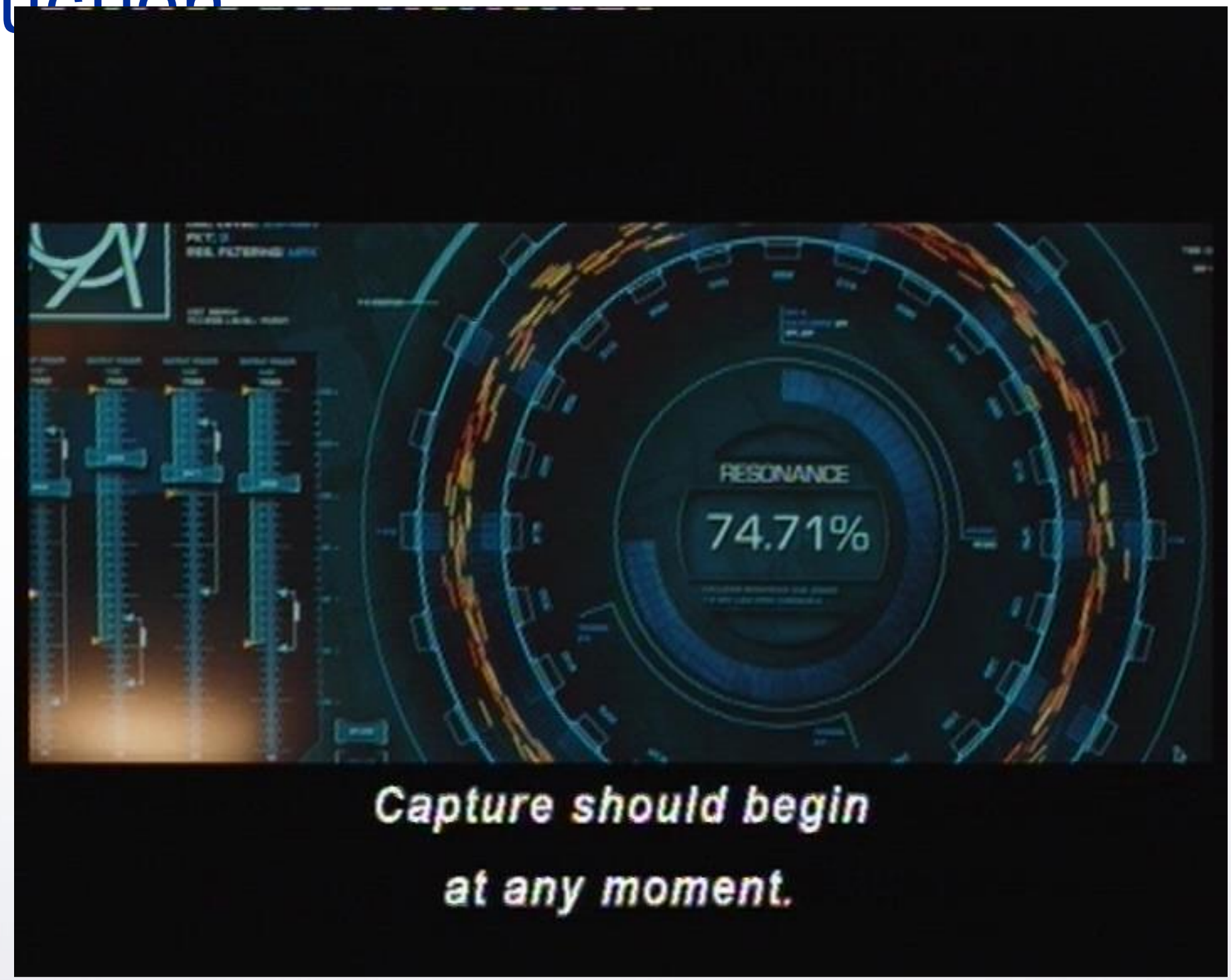
2 Where is antimatter made ?

Angels & Demons - The Physics behind the Movie

LHC experiments are in caverns 100 m underground

Angels & Demons - The Physics behind the Movie

The Hollywood version of antimatter production



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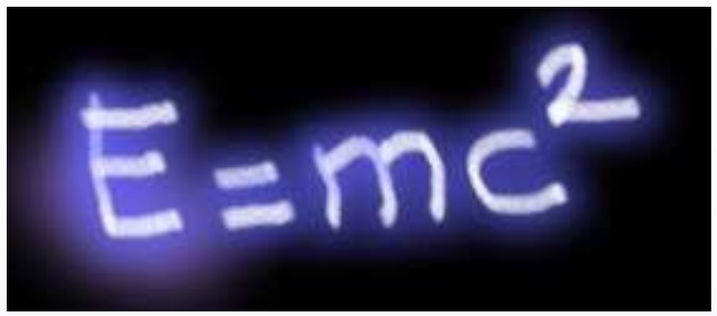
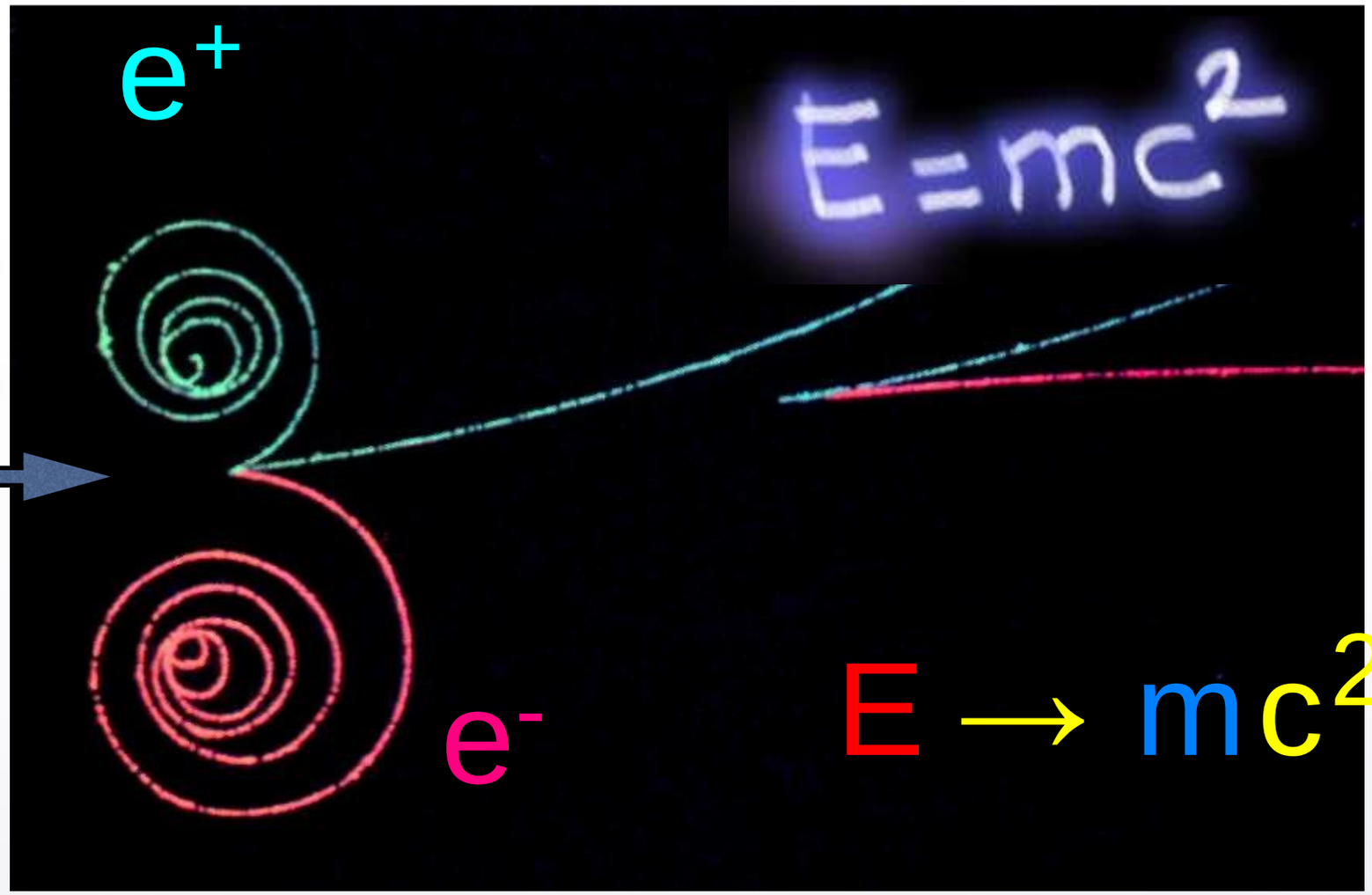
3 How is antimatter made



3 How is antimatter made ?

Energy is converted to mass

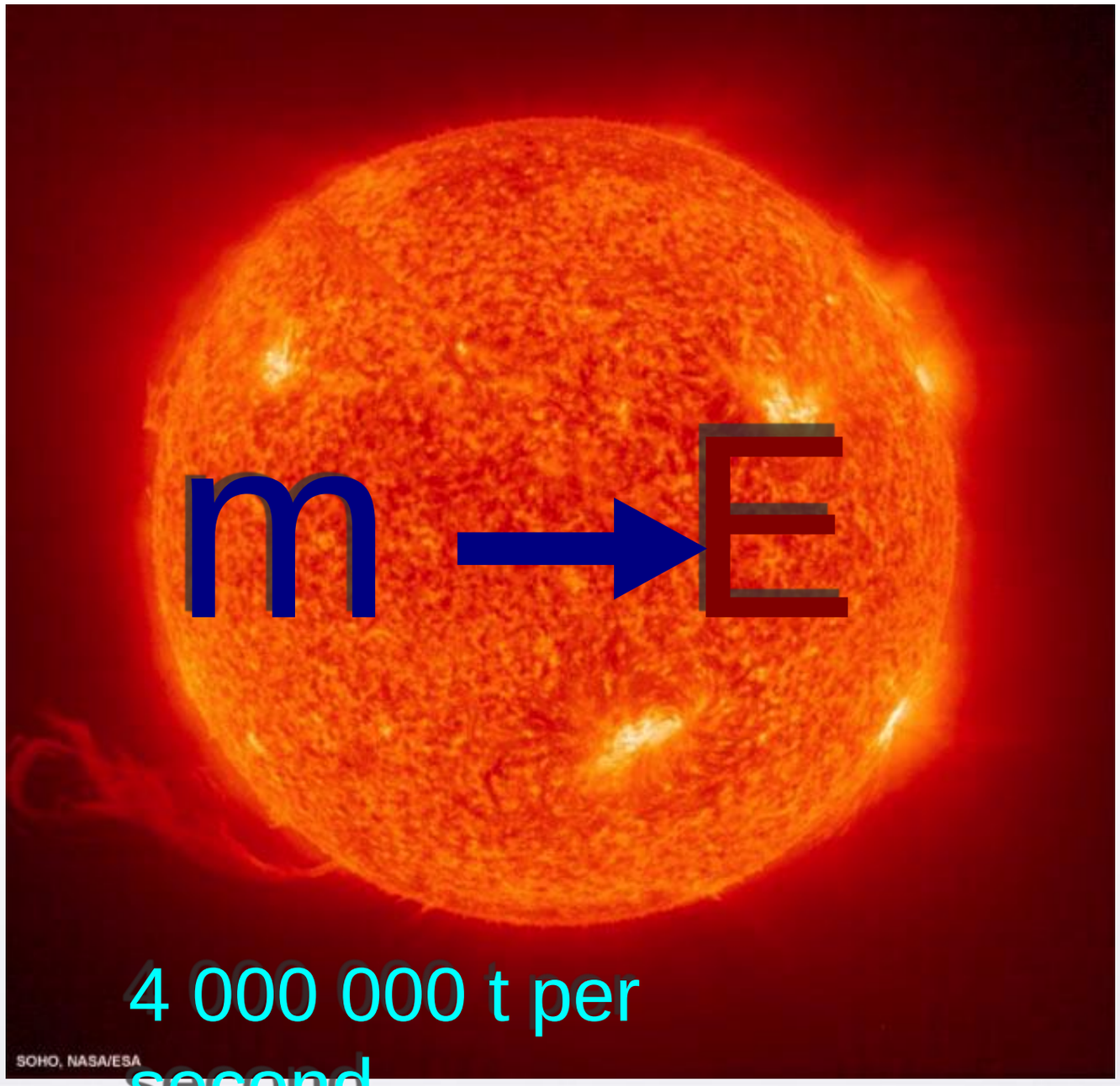
Energy
(e.g. photon)



Mass of electron and positron

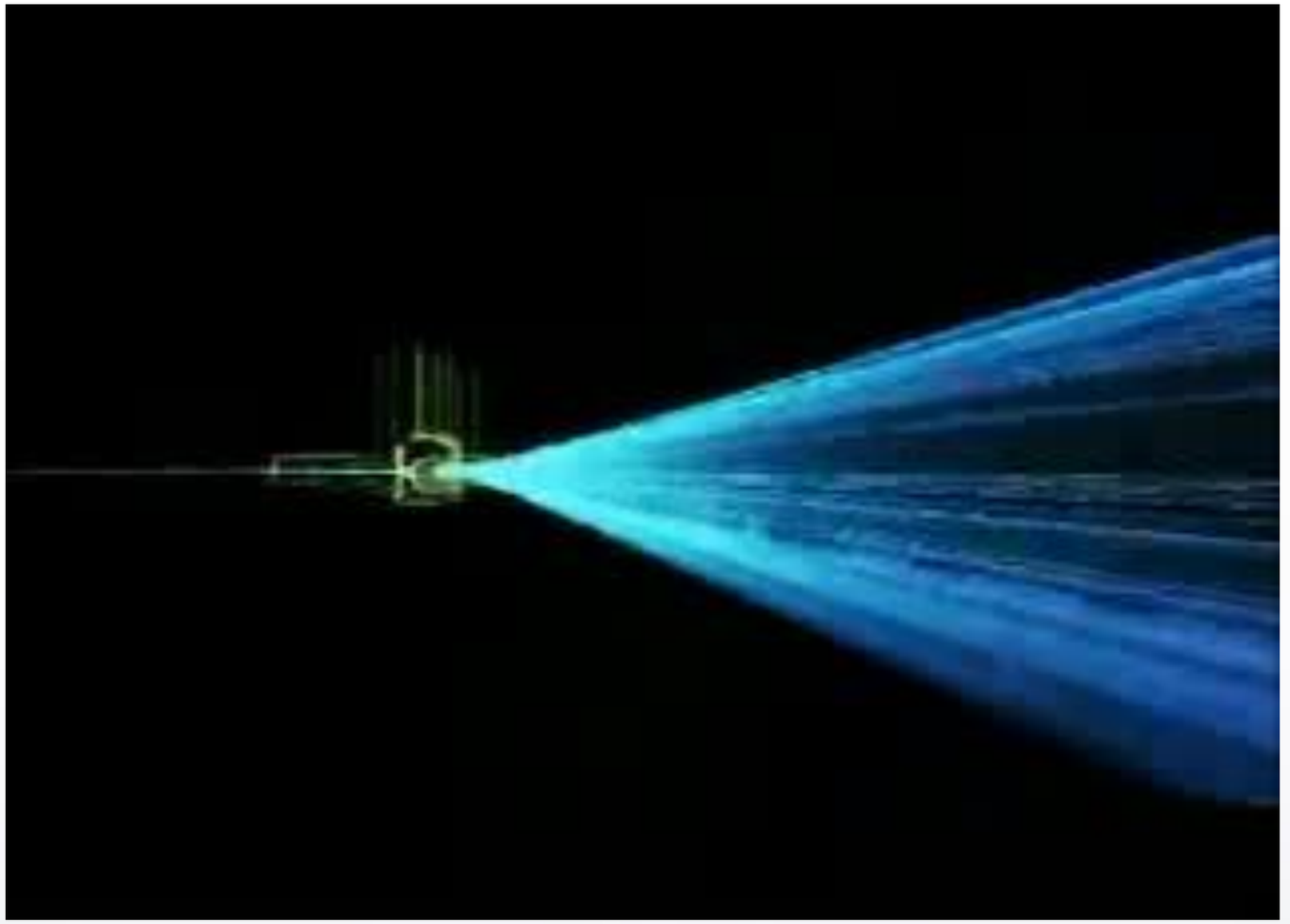
3 How is antimatter made ?

In the centre of the Sun, mass is converted to energy



3 How is antimatter made ?

In particle collisions, energy is transformed into matter and antimatter



3 How is antimatter made ?

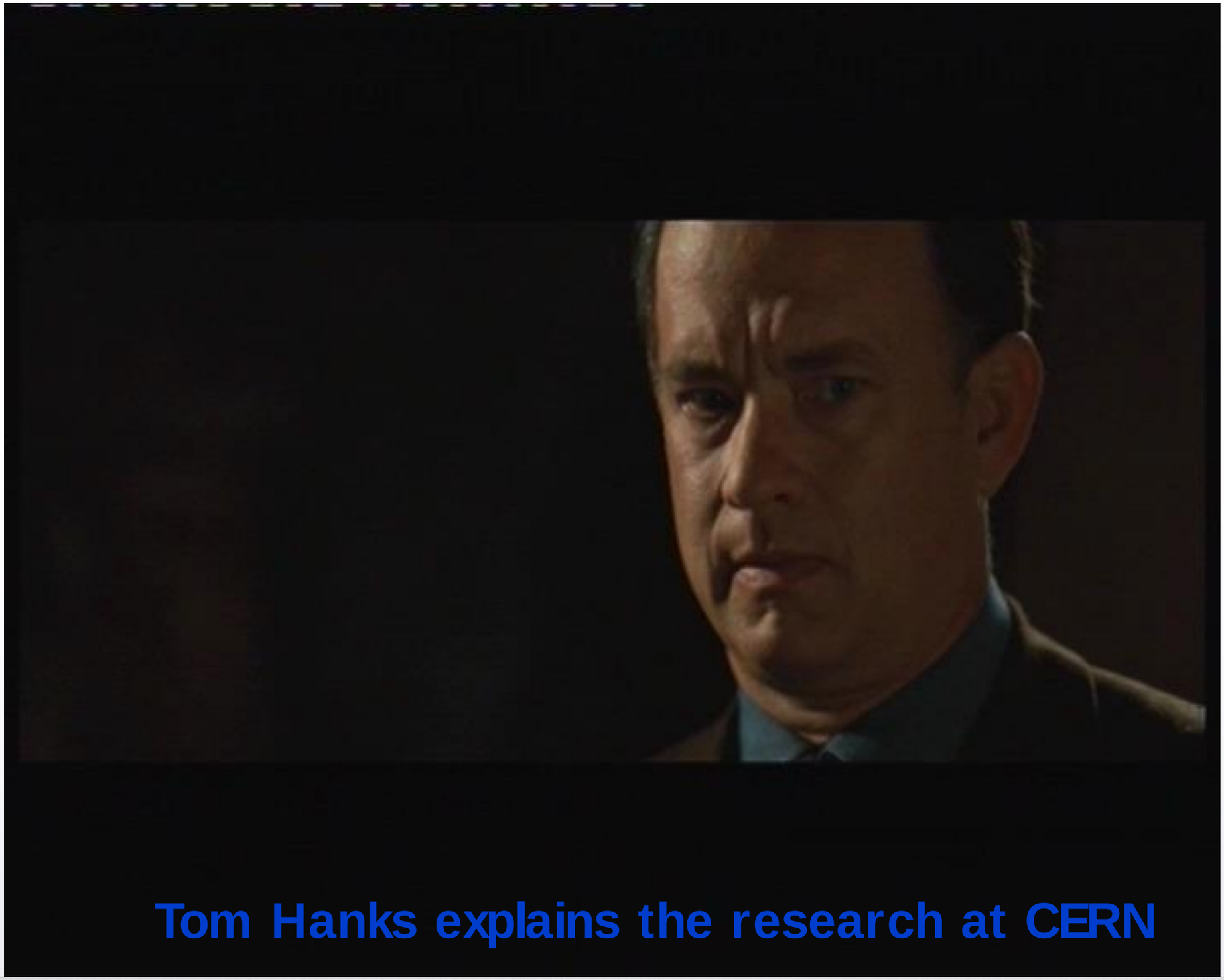
New particles and antiparticles are produced in collisions

4 antimatter

The mystery of

Angels & Demons - The Physics behind the Movie

4 The mystery of antimatter



Tom Hanks explains the research at CERN

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Antimatter and ...

God particle ?? No.

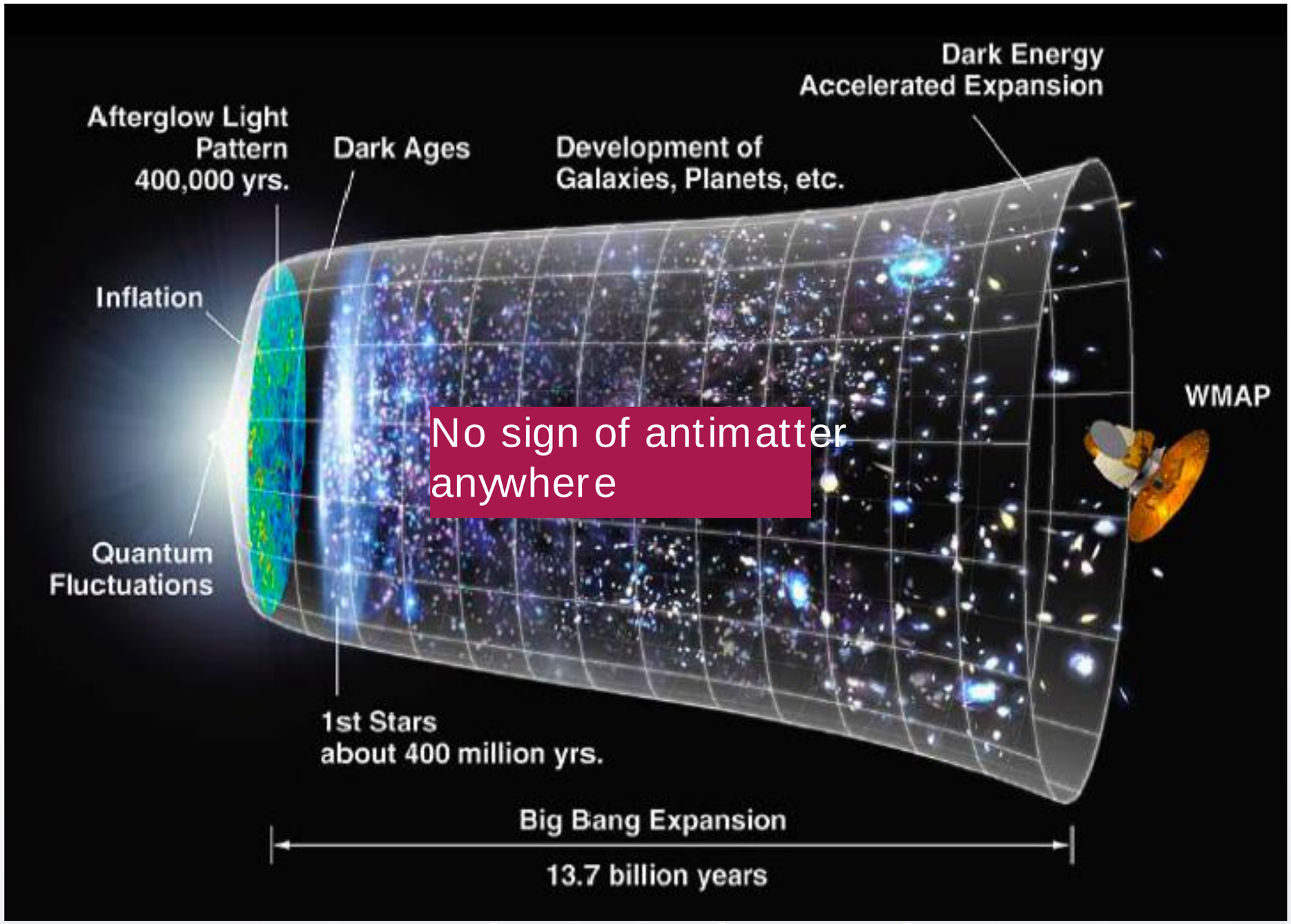
Implications for energy research ? Hmmm.

Combustible substance ? May be.

An airtight nanocomposite container with magnets ....

The moment of creation ...

4 The mystery of antimatter



Big Bang model: the evolution of the Universe

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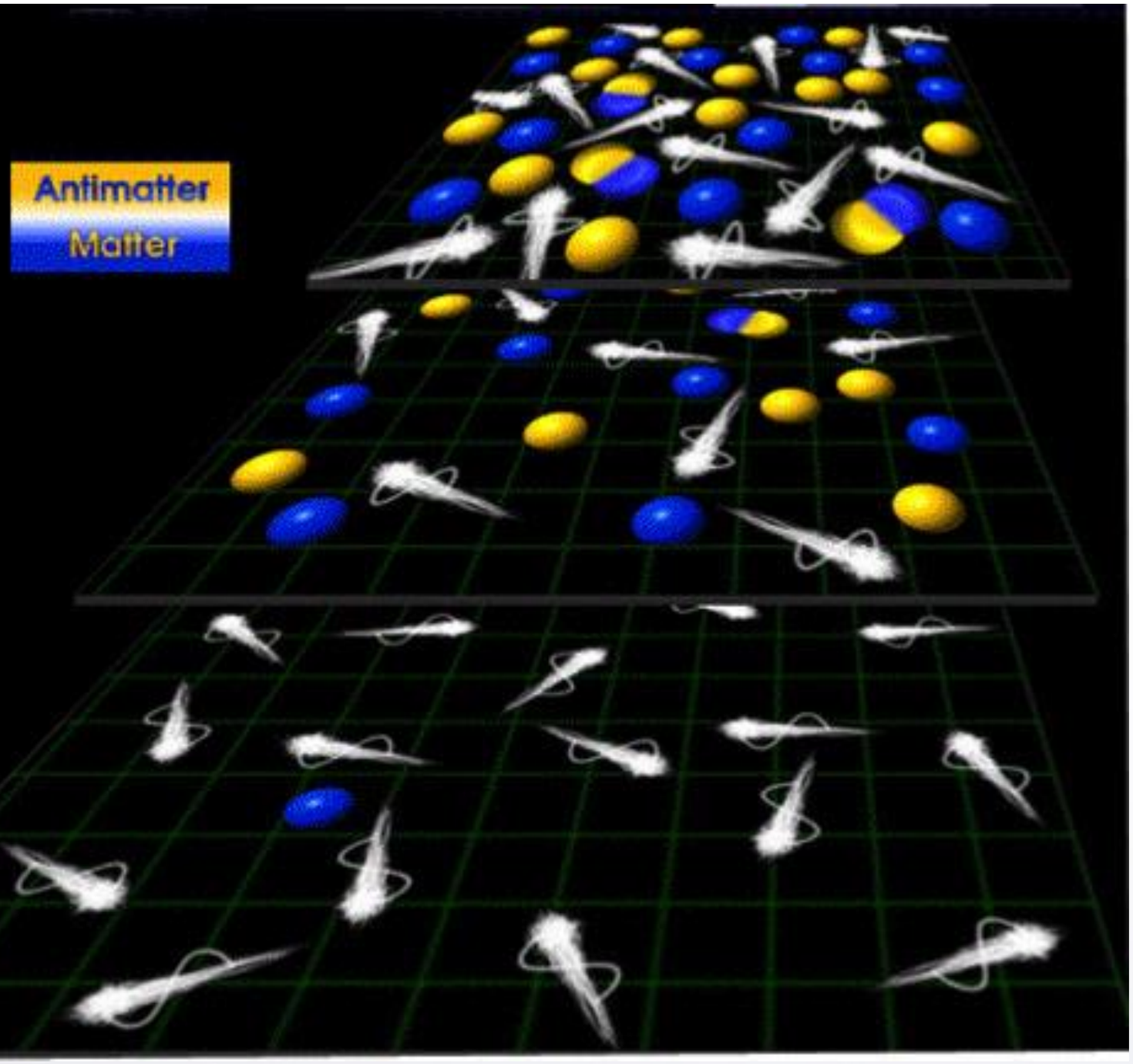
4 The mystery of antimatter

4 The mystery of antimatter

No antimatter in the Universe ?

Why not ???

The mystery of antimatter



Cosmic CSI

Big Bang:
Energy transforms to mass
< 1 µs: **matter = antimatter**

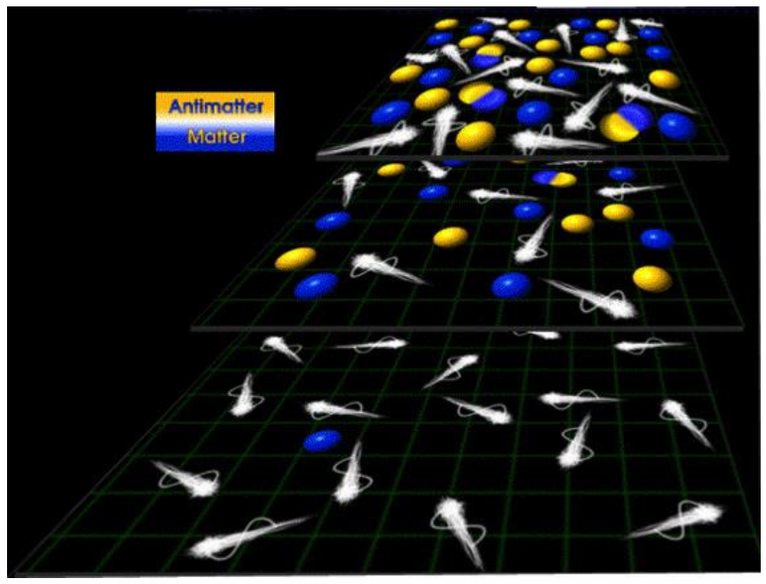
Annihilation battle

1 s: **all antimatter has disappeared**,

some particles left (all stars/ planets)
loads of 'photons' (left from annihilation)

Universe filled with light (cosmic microwave backg.)

4 The mystery of antimatter



Why did all antimatter disappear,
but a little bit of matter was left?

Matter and antimatter: (slightly) different properties?

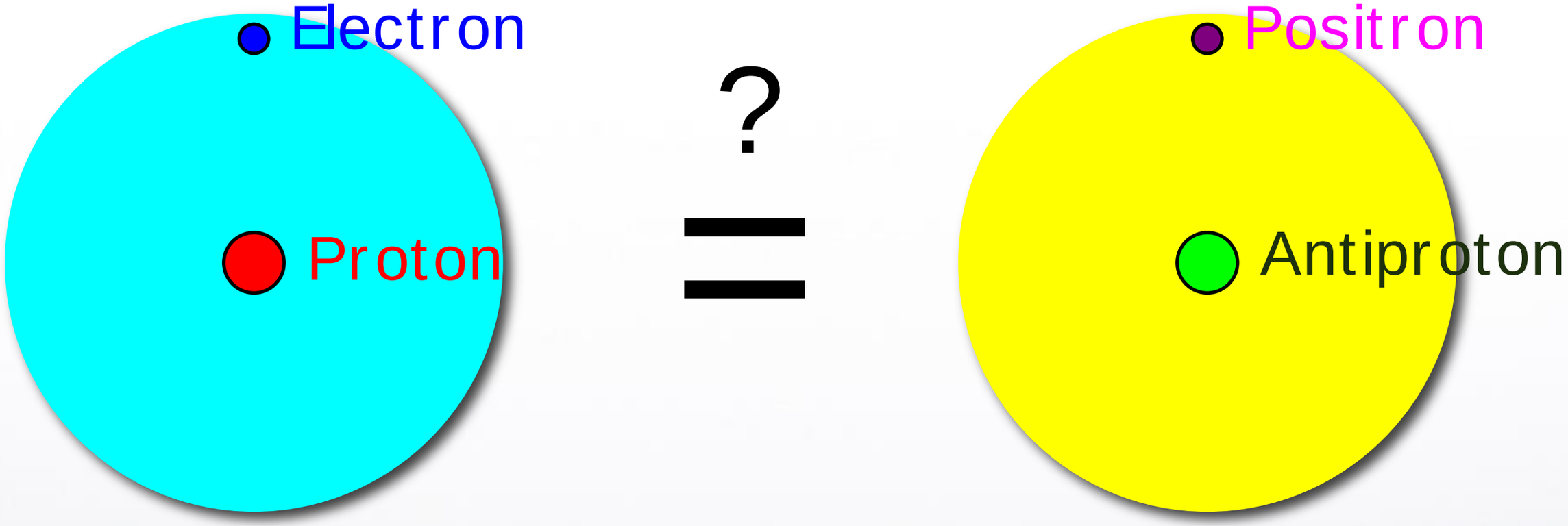
Mass, charge, magnetic moment (CERN: Antihydrogen experiments)
CP violation (CERN: LHCb experiment)

5 How to study antimatter ?

The antihydrogen route ...

5 How to study antimatter ?

Compare hydrogen with **antihydrogen** atom



Measure differences to a precision of
0.000 000 000 000 001 %

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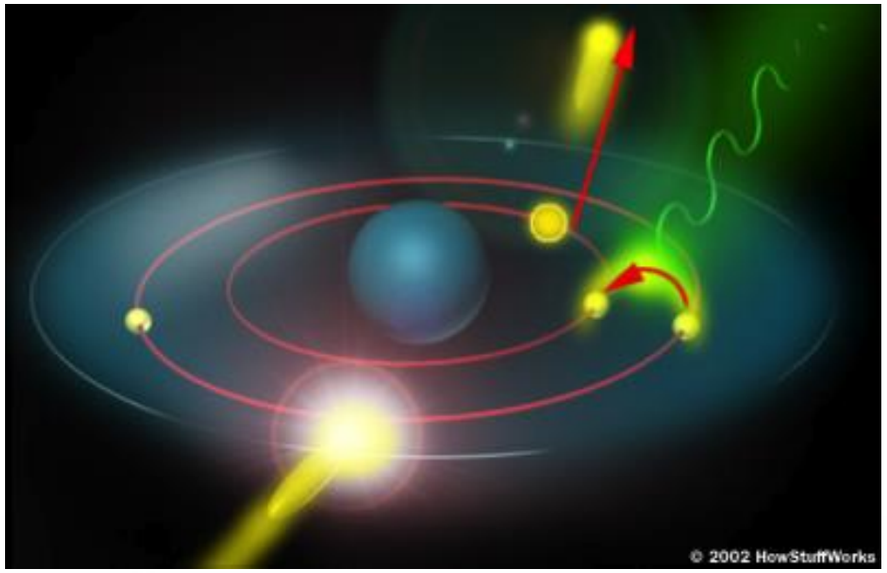
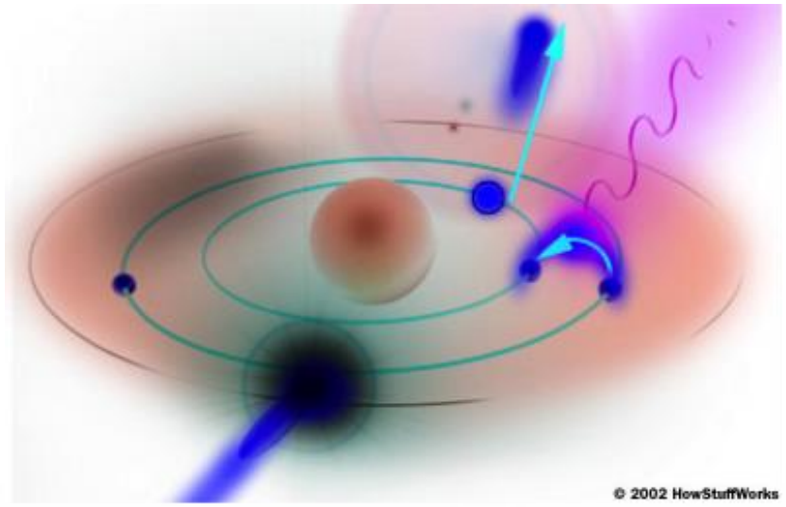
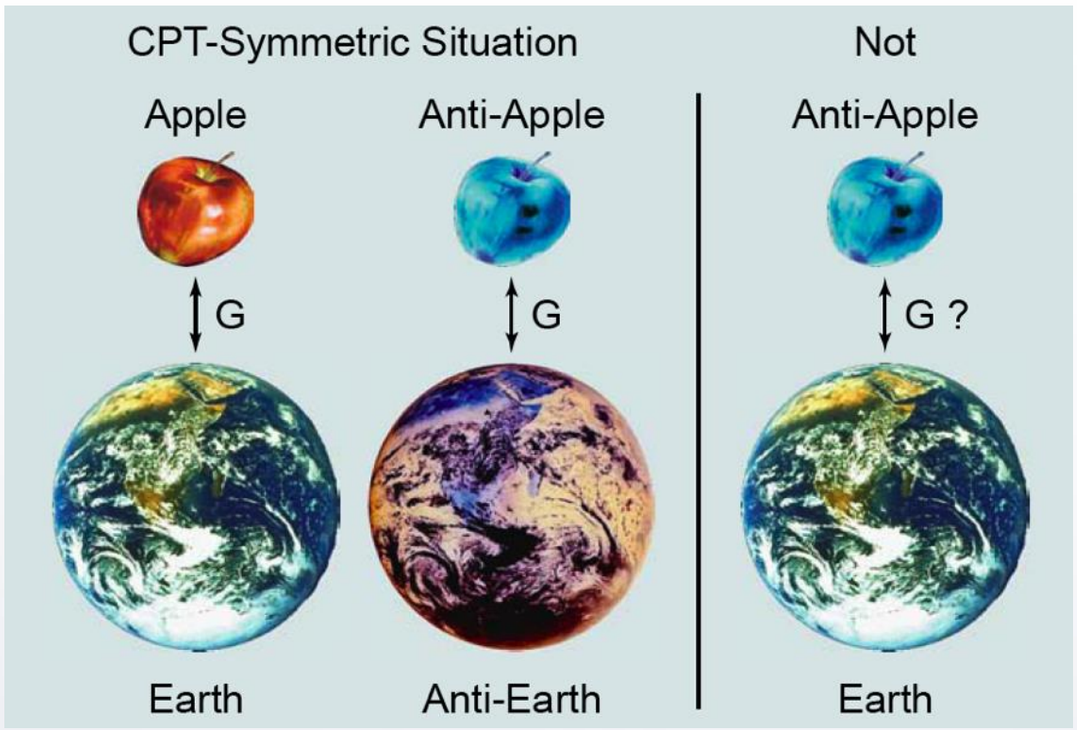
5 How to study antimatter ?





Same energy levels ?



Same gravity ?

5 How to study antimatter ?

How to make millions of antihydrogen atoms (ATHENA, 2002)

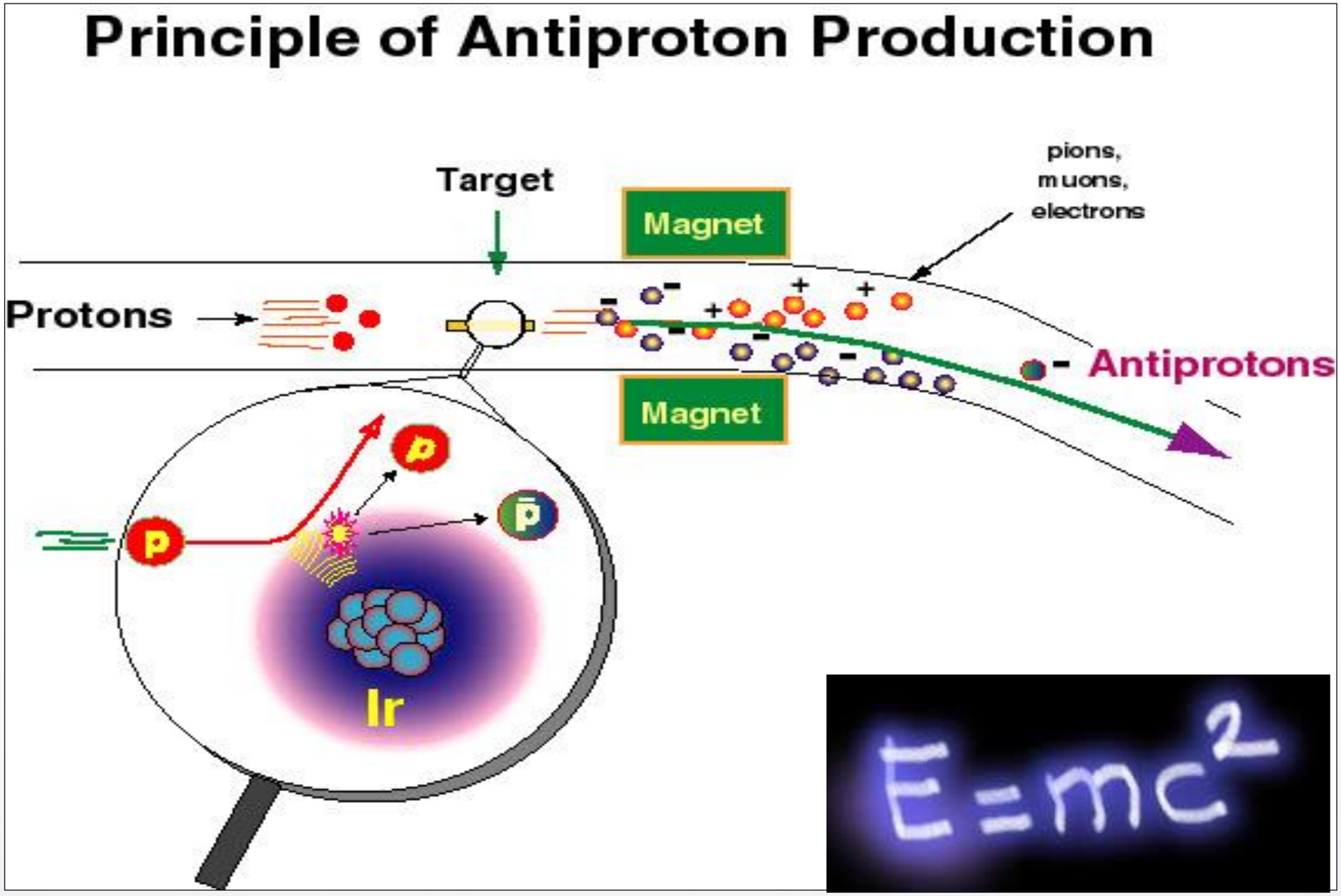
1 - Produce, decelerate, and trap antiprotons

2 - Produce and trap positrons

3 - Merge antiproton and positron plasmas

4 - Produce antihydrogen atoms (recently: trap antihydrogen)

5 How to study antimatter ?



Antiprotons are made in collisions of protons with nucle

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5 How to study antimatter ?

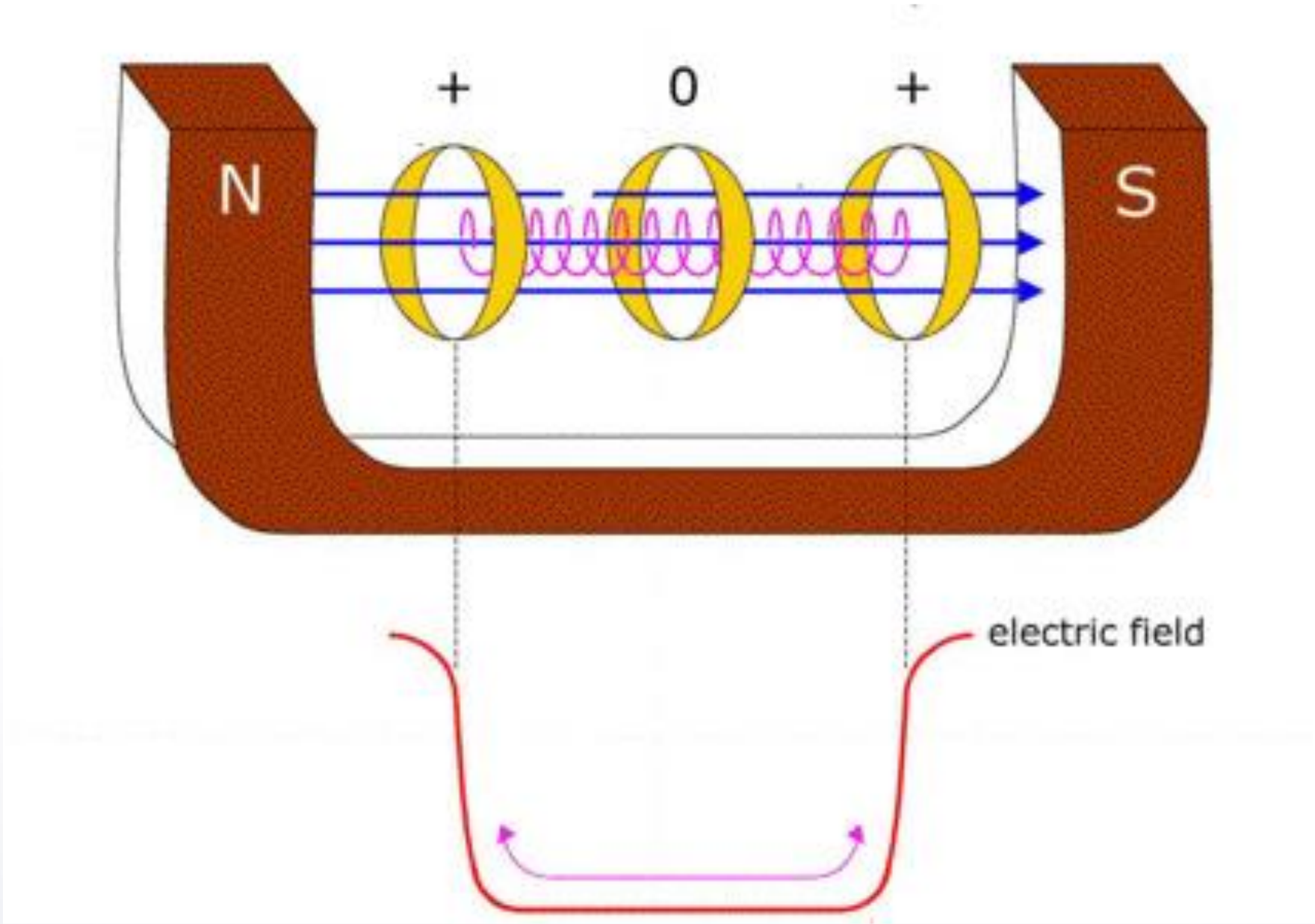
Antiproton Decelerator

produces 100,000,000 antiprotons per minute

Slows them down to 10 % of the speed of light

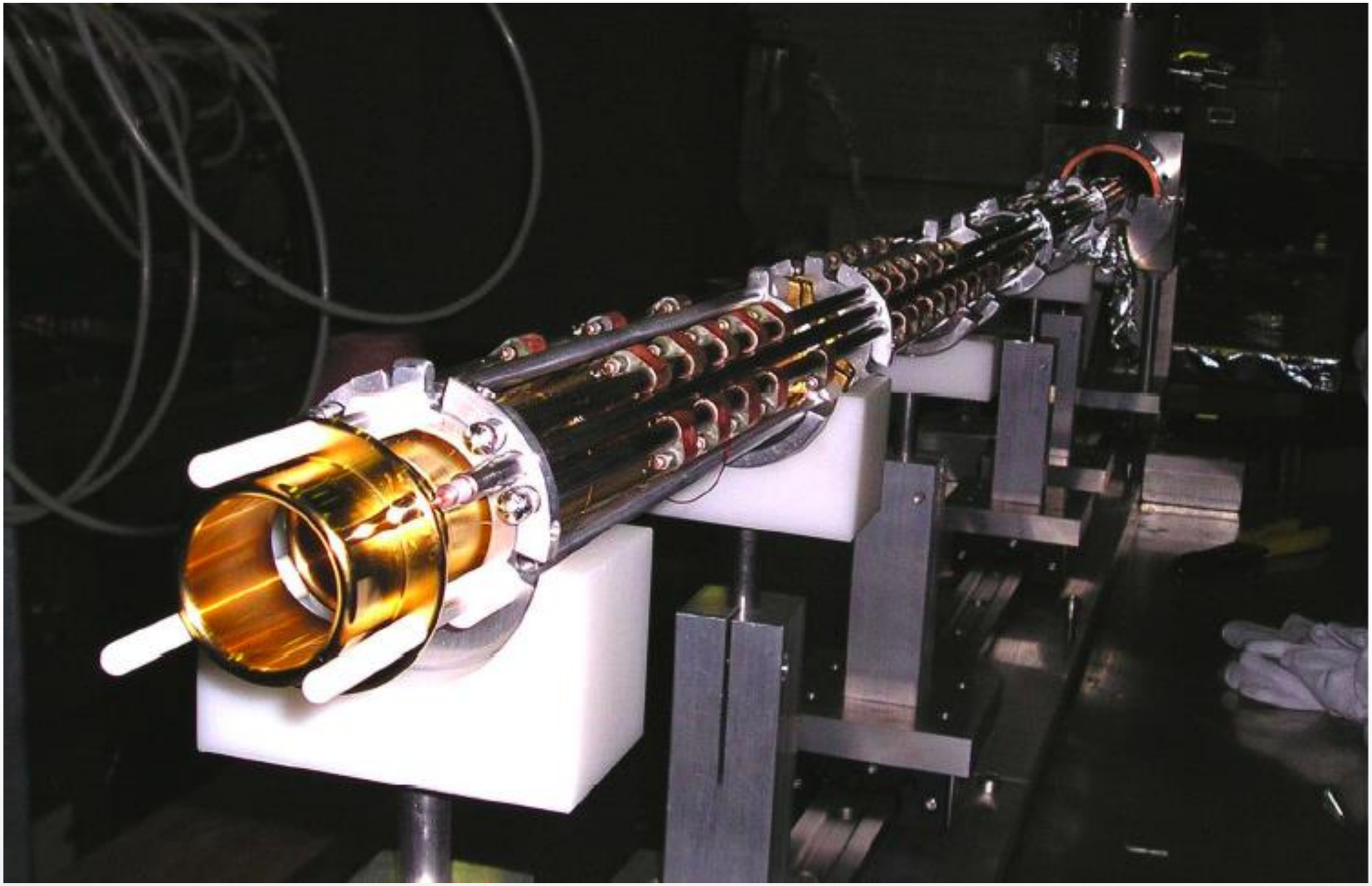
Antiproton Decelerator at CERN

5 How to study antimatter ?

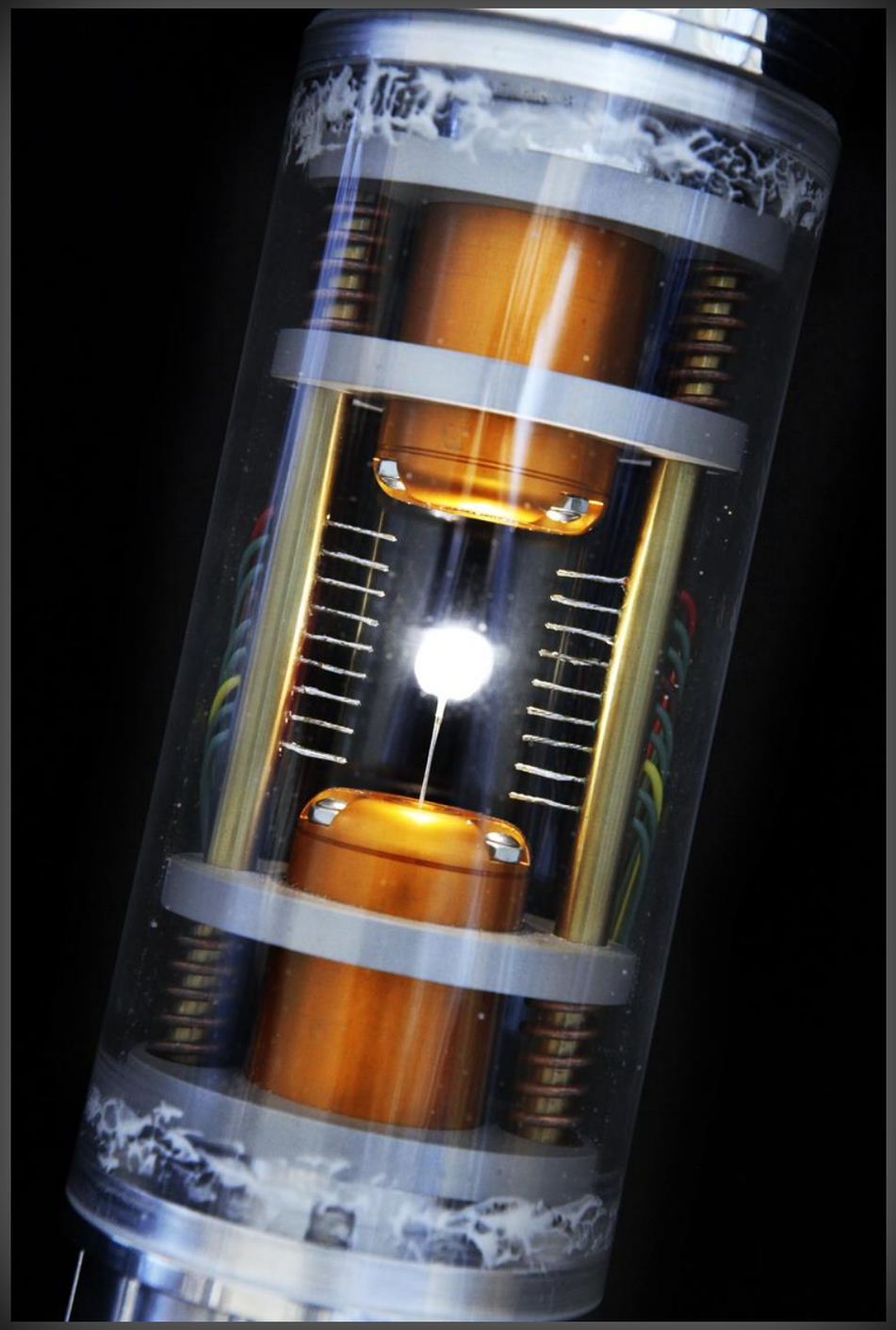


Principle of antiparticle trapping

5 How to study antimatter ?



The real antimatter trap at CERN

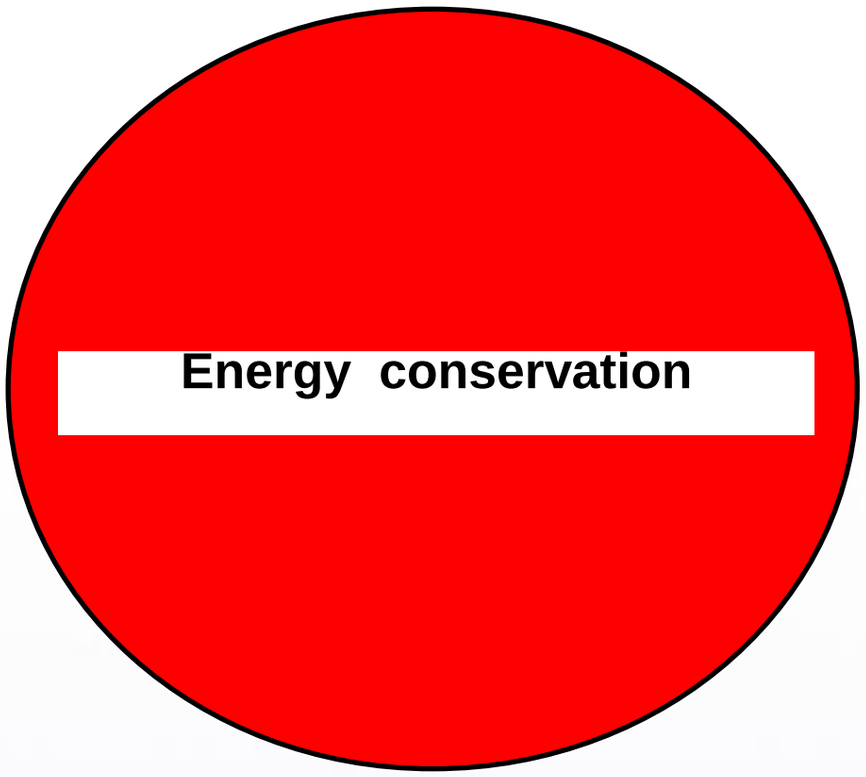


The “Angels & Demons” version

6 An energy source? A bom

An energy source? A bomb?

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

Angels & Demons - The Physics behind the Movie

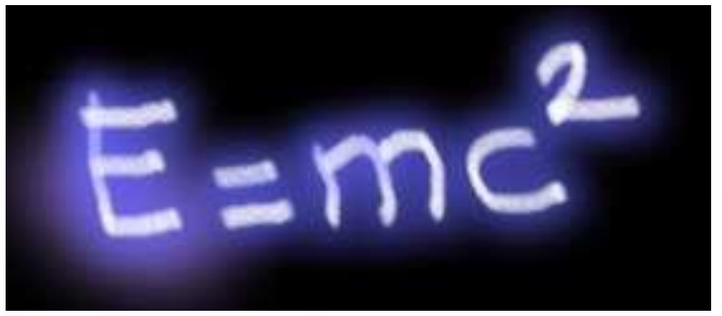
Antimatter explosion in “Angels & Demons”

6 An energy source? A bomb?

Hiroshima - 20 kt TNT equivalent

Dan Brown:

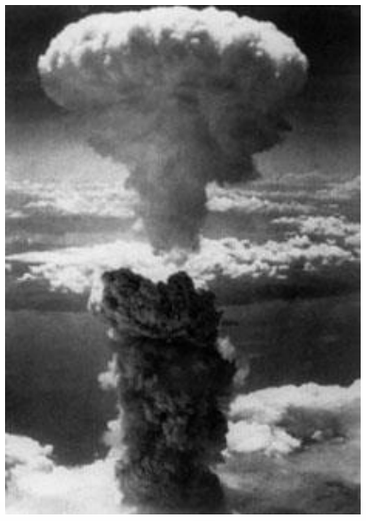
“0.5 g antimatter makes a powerful bomb”



22 kt TNT = $9 \cdot 10^{13}$ J =
0.5 g antimatter + 0.5 g matter

So this is correct, but ….

6 An energy source? A bomb?



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

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

Even with electricity discount price CERN by EDF
[1 kWh = $3.6 \cdot 10^{6}$ J = 0.1 €]

Price **1,000,000,000,000,000 €**

Delivery time **1 000 000 000 years**

7 Antimatter in daily life ?

7 Antimatter in daily life ?

Antimatter in your body !

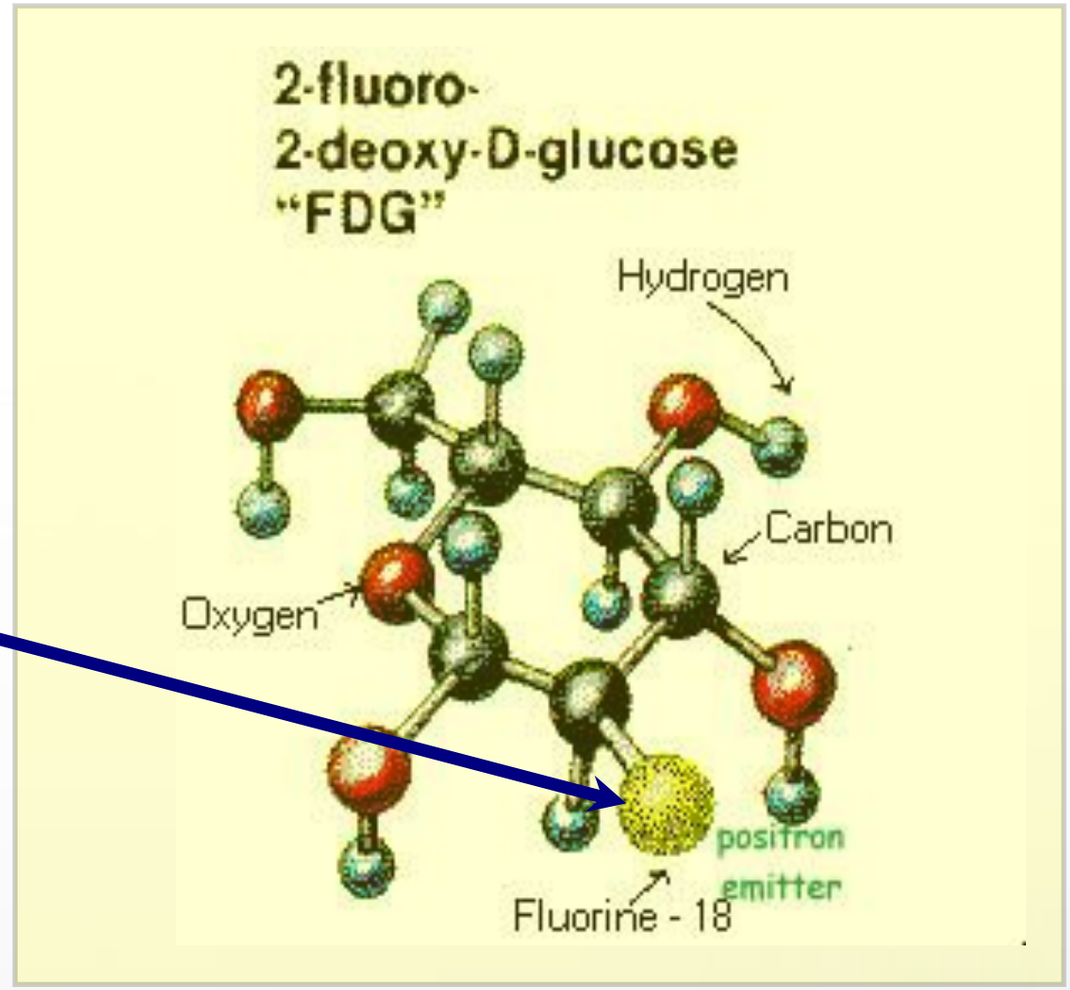
Glucose supplies energy

Add **positron** emitting isotopes (e.g. F-18) to glucose

Inject into blood stream

Glucose accumulates where energy is needed

Positron emission and annihilation - detect where glucose is !



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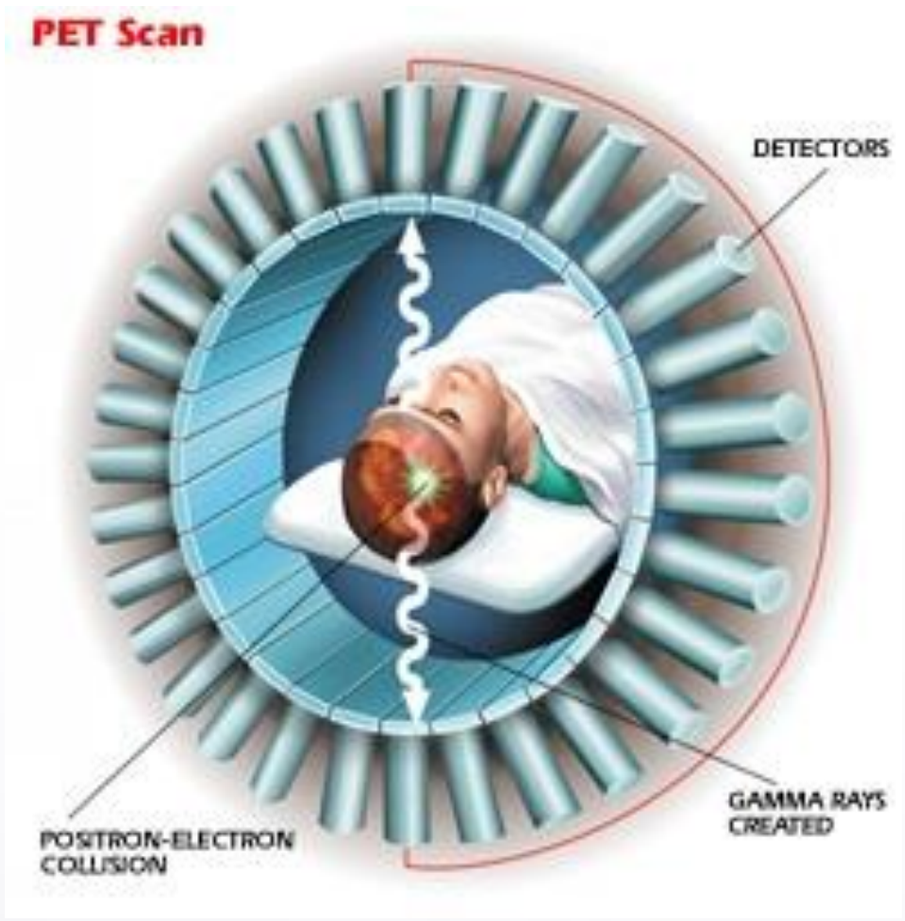
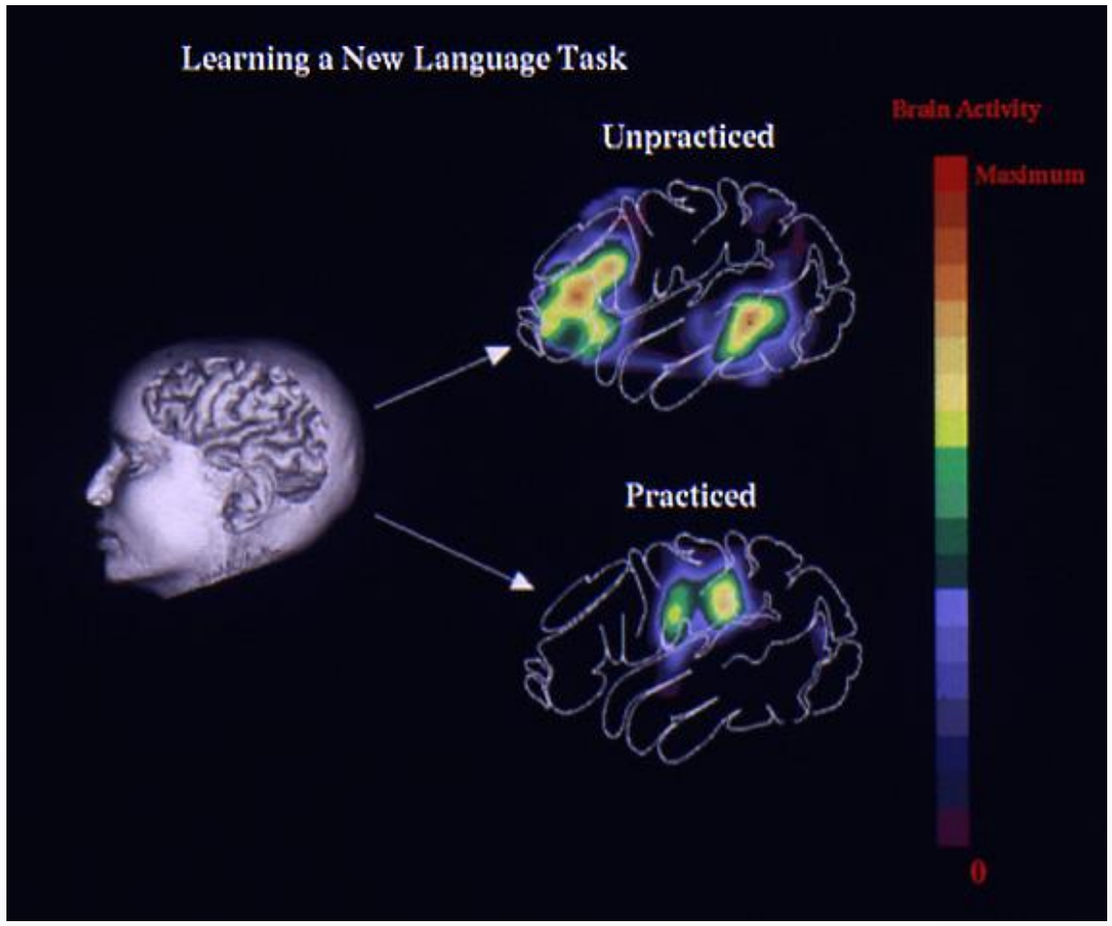
7 Antimatter in daily life ?

Positron Emission Tomography ("PET Scan")





Antimatter helps
- to understand how the brain works
- to find tumours

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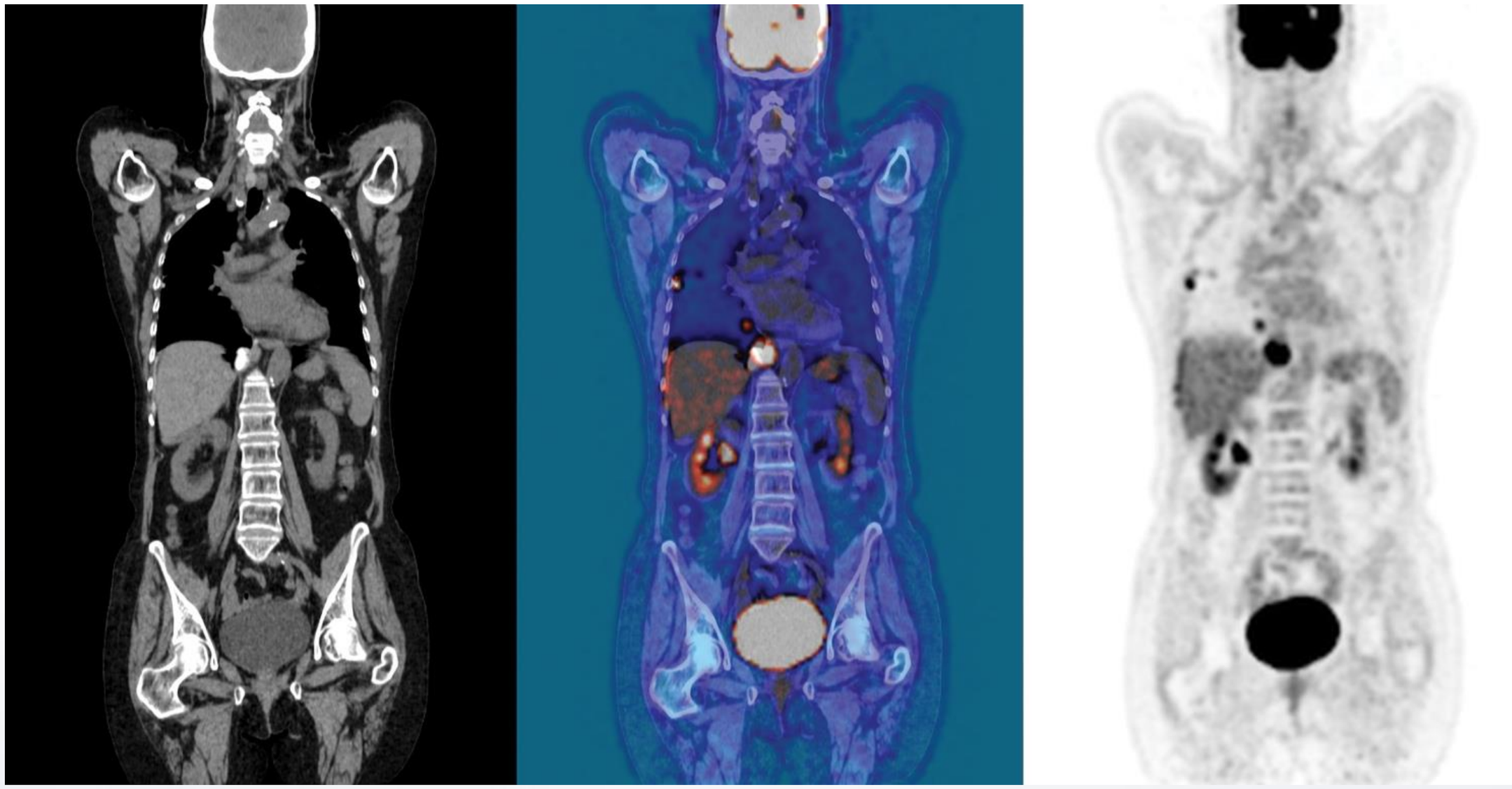
7 Antimatter in daily life ?

Positron Emission Tomography ("PET Scan")



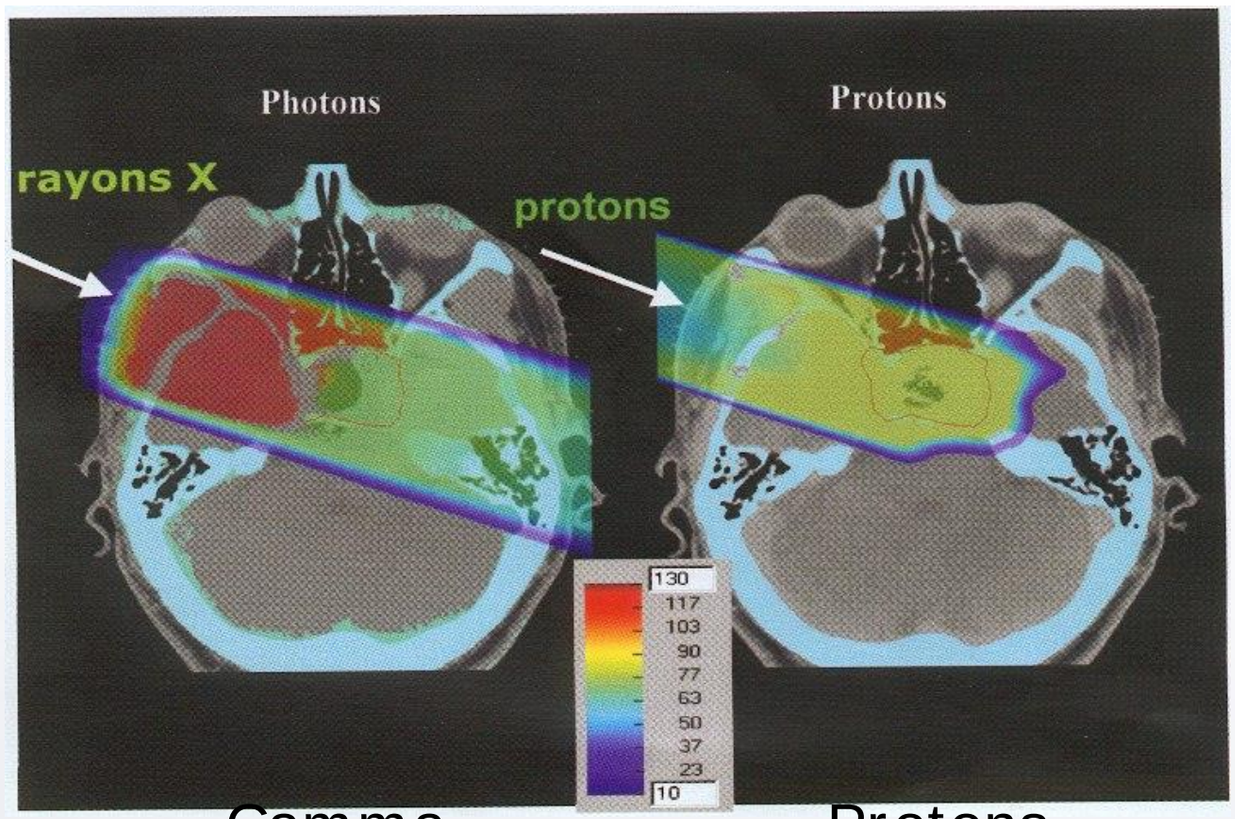
Antimatter helps to find tumours

7 Antimatter in daily life ?

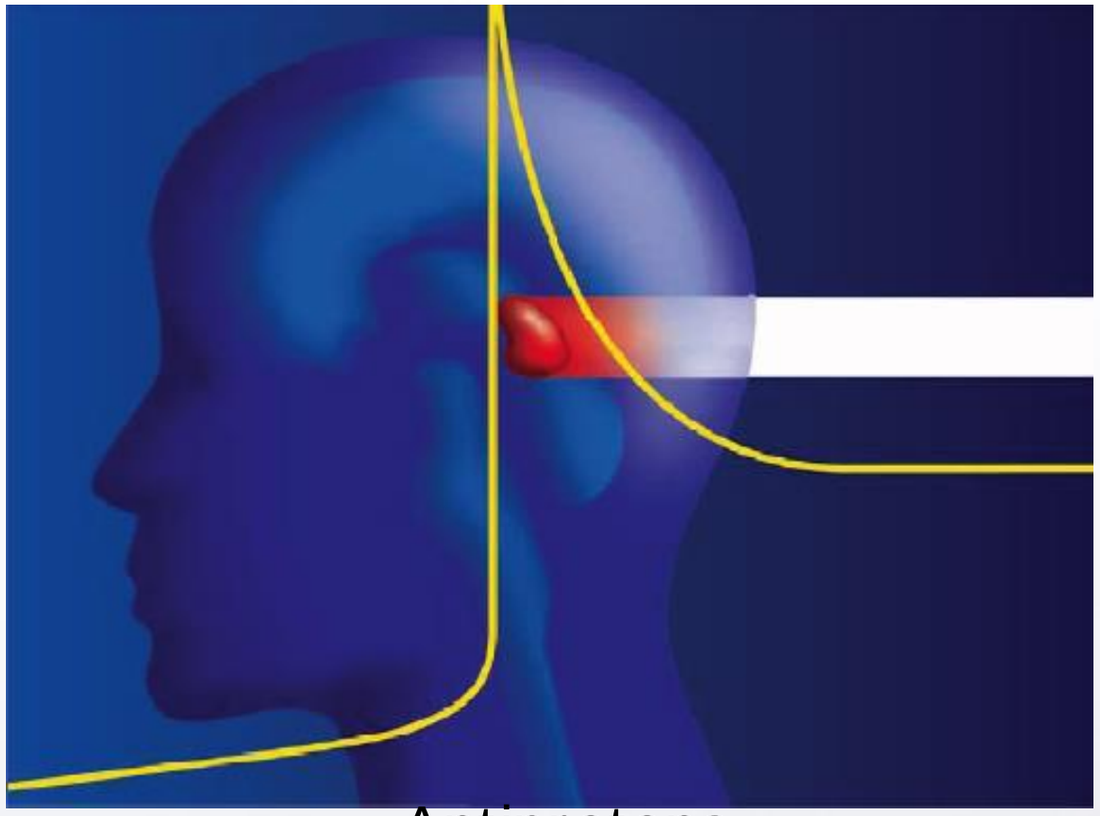
Tumour therapy with antiprotons ?

Gamma radiation destroys many healthy cells
Protons deliver radiation more specifically to tumour cells

Antiprotons would be 3 x more efficient than protons (annihilation!)



Gamma radiation



Protons

Antiprotons

What did Ron Howard say?

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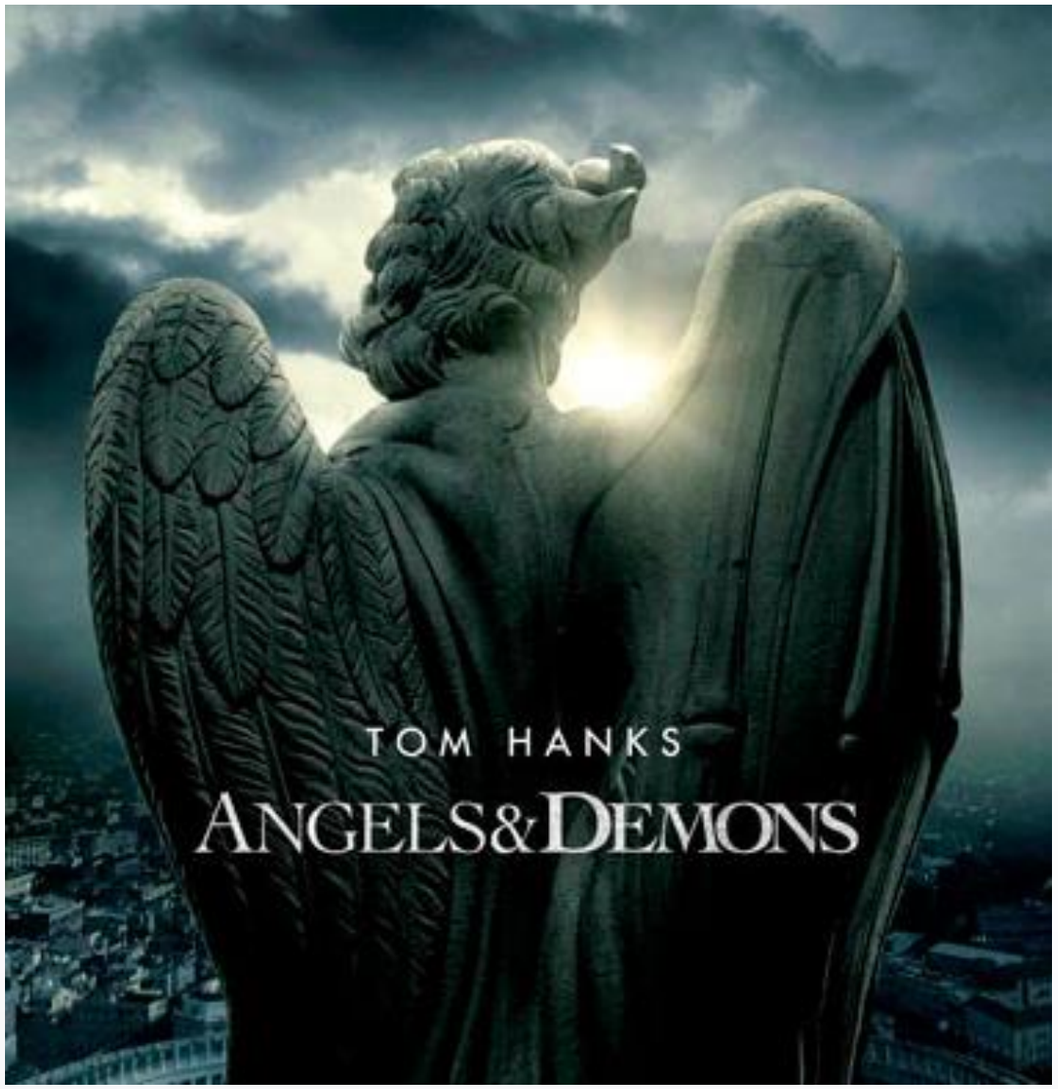


Angels&Demons

The Physics Behind the Movie

Rolf Landua

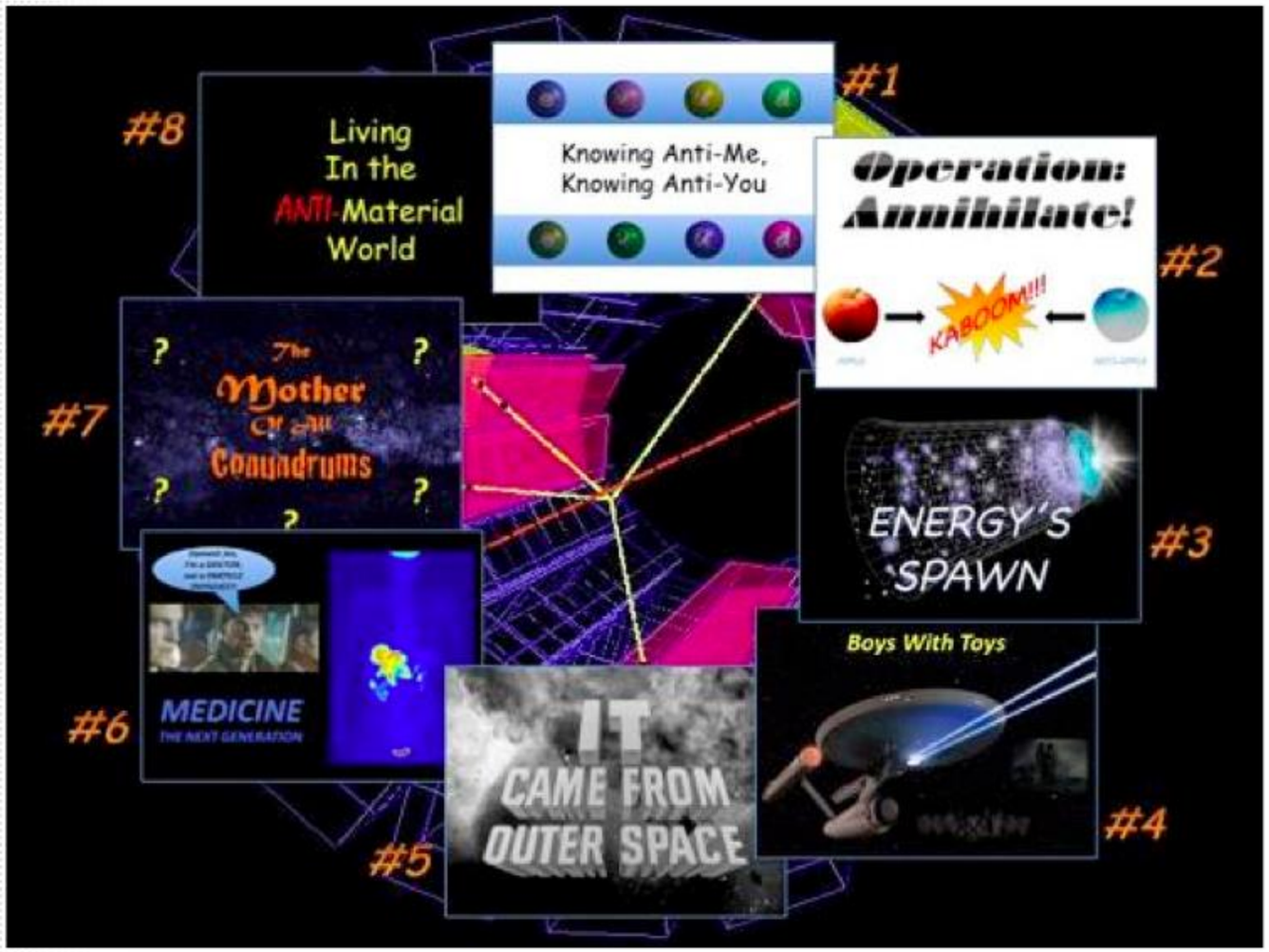
CERN

Thank you for your attention.

Antimatter @ School

Teaching Resources - Antimatter Teaching Module

>> Lesson Plans



Back to Antimatter Teaching Module

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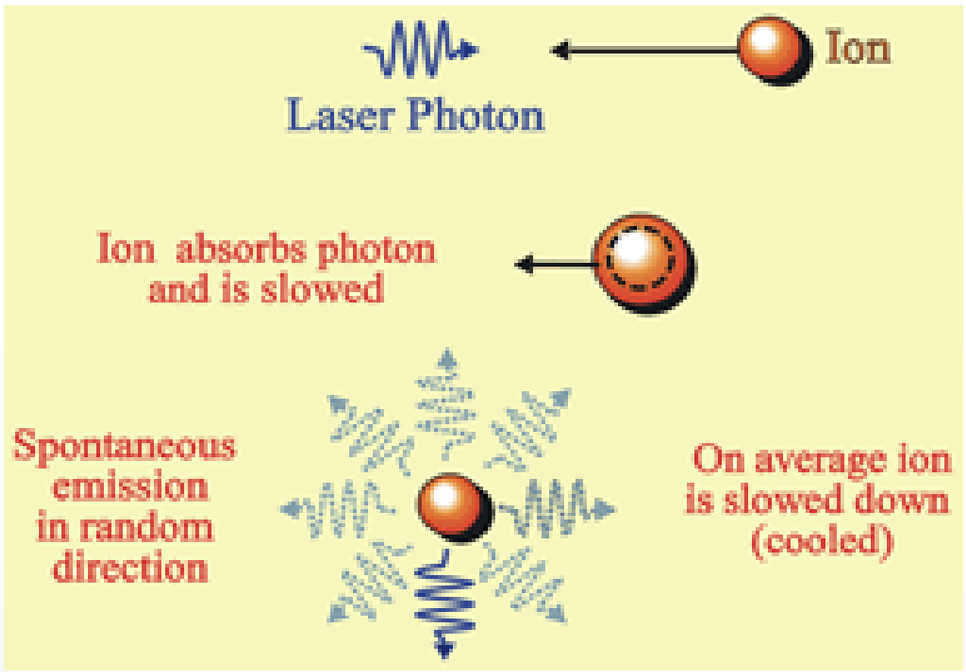
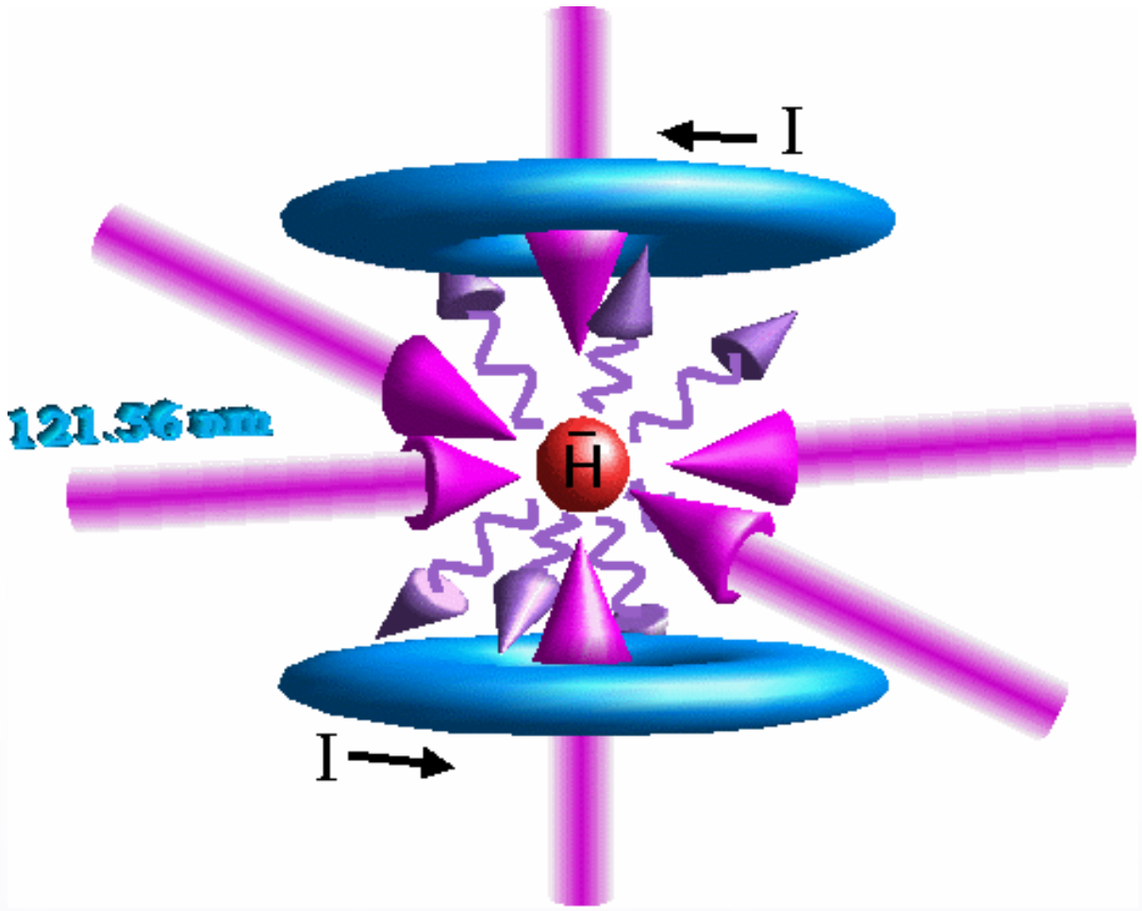
Bill Clinton explains the structure of matter

WEF 2011, Davos

Laser cooling



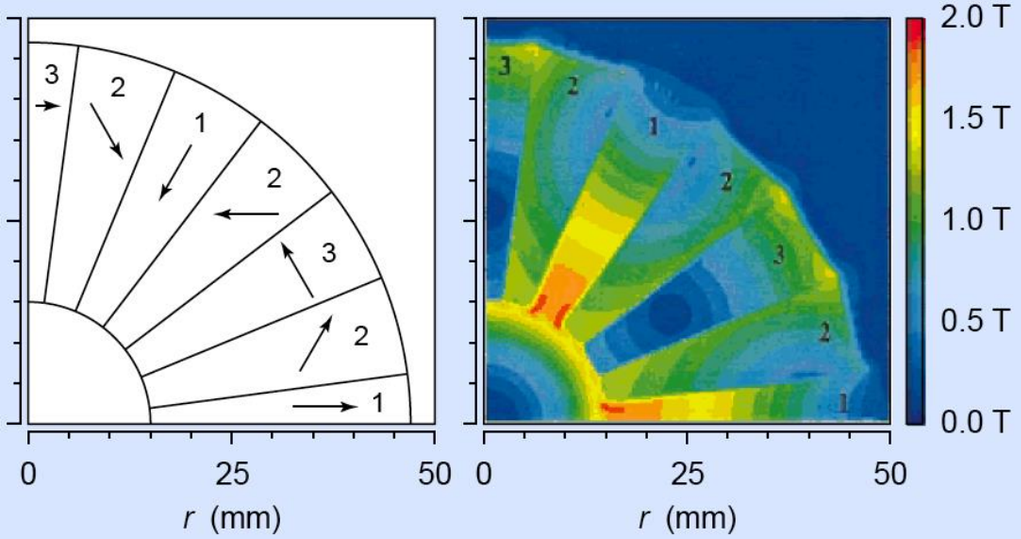


121 nm laser needed

Prototype at MPI Munich

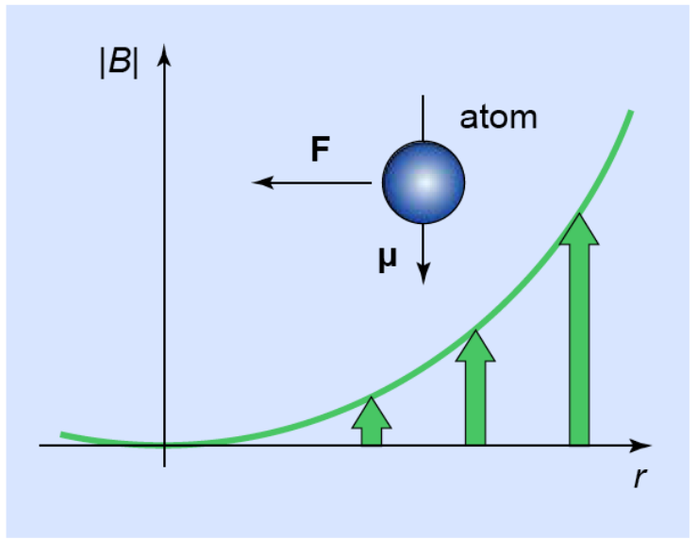
… only 50 nW

Magnetic multipole traps ?



$$U = -\vec{\mu}\vec{B}$$

$$\vec{F} = -\vec{\nabla}U$$



Low field seeking atoms (50%) at r=0

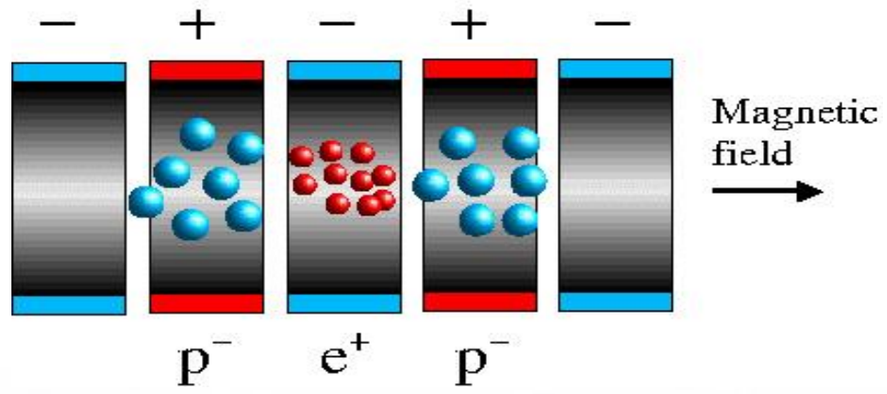
BUT: Very shallow potential (~ 0.07 meV/T)

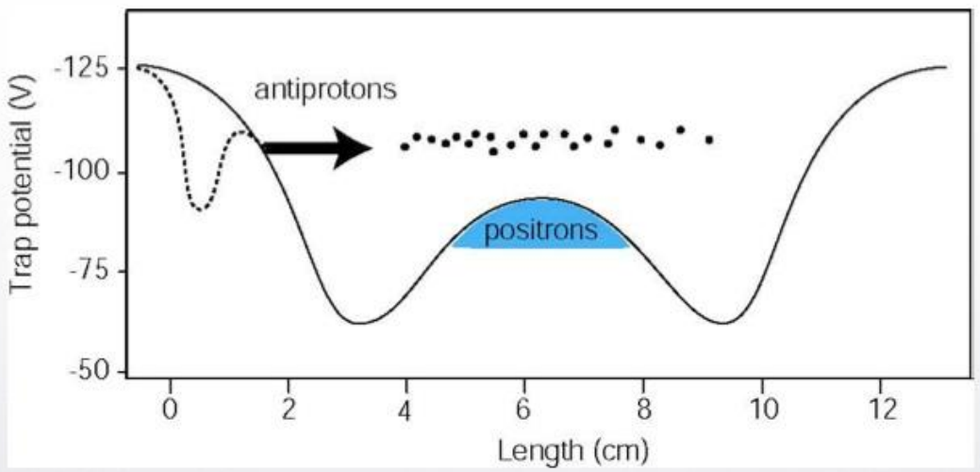
Realistic ΔB ~ 0.2-0.3 T ➪ **E < 0.02 meV**

(reminder: produced antihydrogen has E_{kin} ~ 1-200 meV)

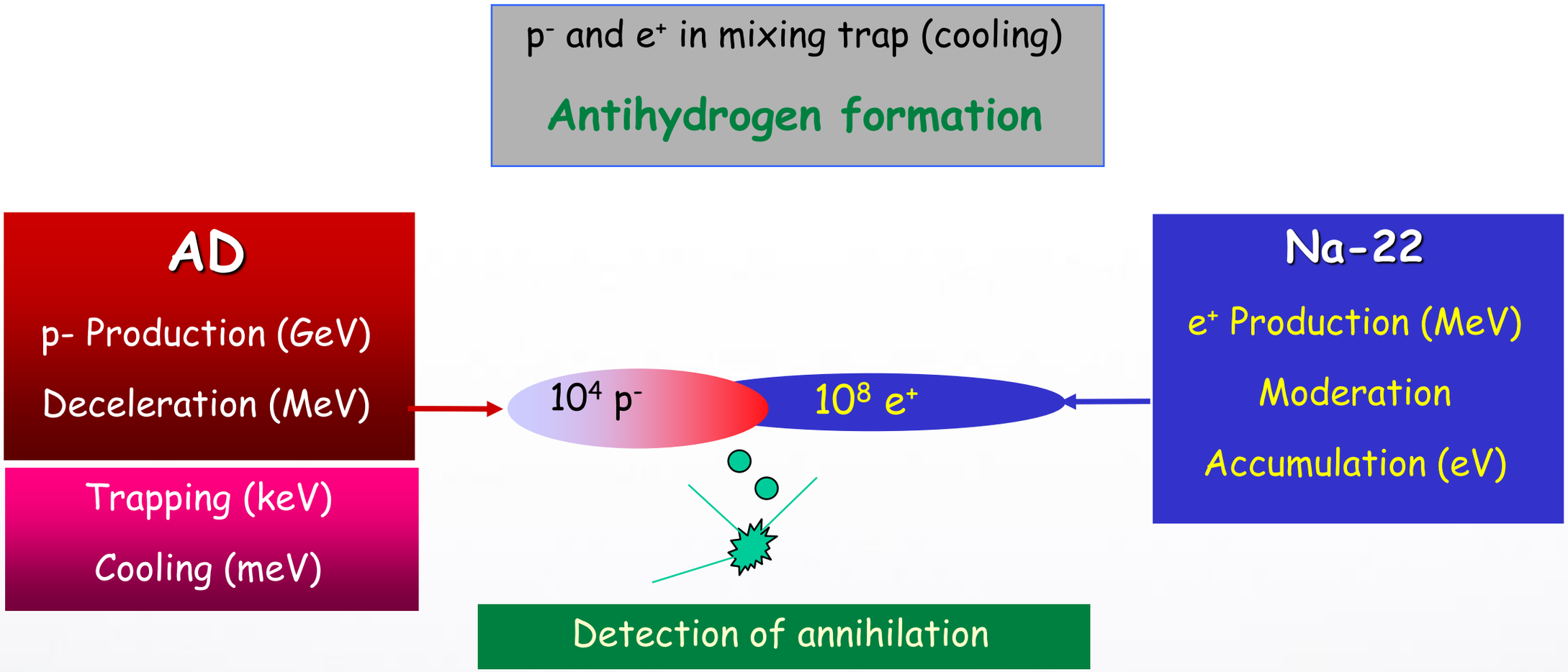
Trap antihydrogen from low energy 'Boltzmann tail' ?

Example: Sextupole magnet





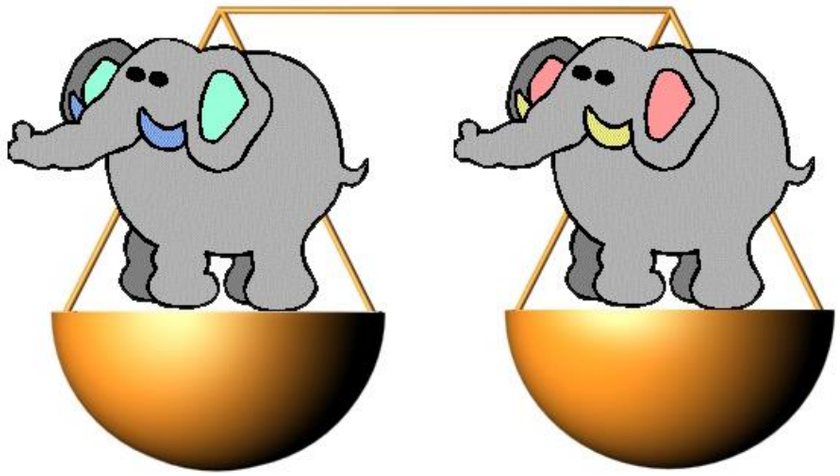
- More than 1 million antihydrogen atoms produced
- Small kinetic energy (< 0.01 eV)
- Next step (in progress): trap antihydrogen atoms



Antihydrogen milestones

Angels & Demons - The Physics behind the Movie

Is that true? Make very precise comparisons!



difference less than one dust grain

Mass of proton and antiproton ?

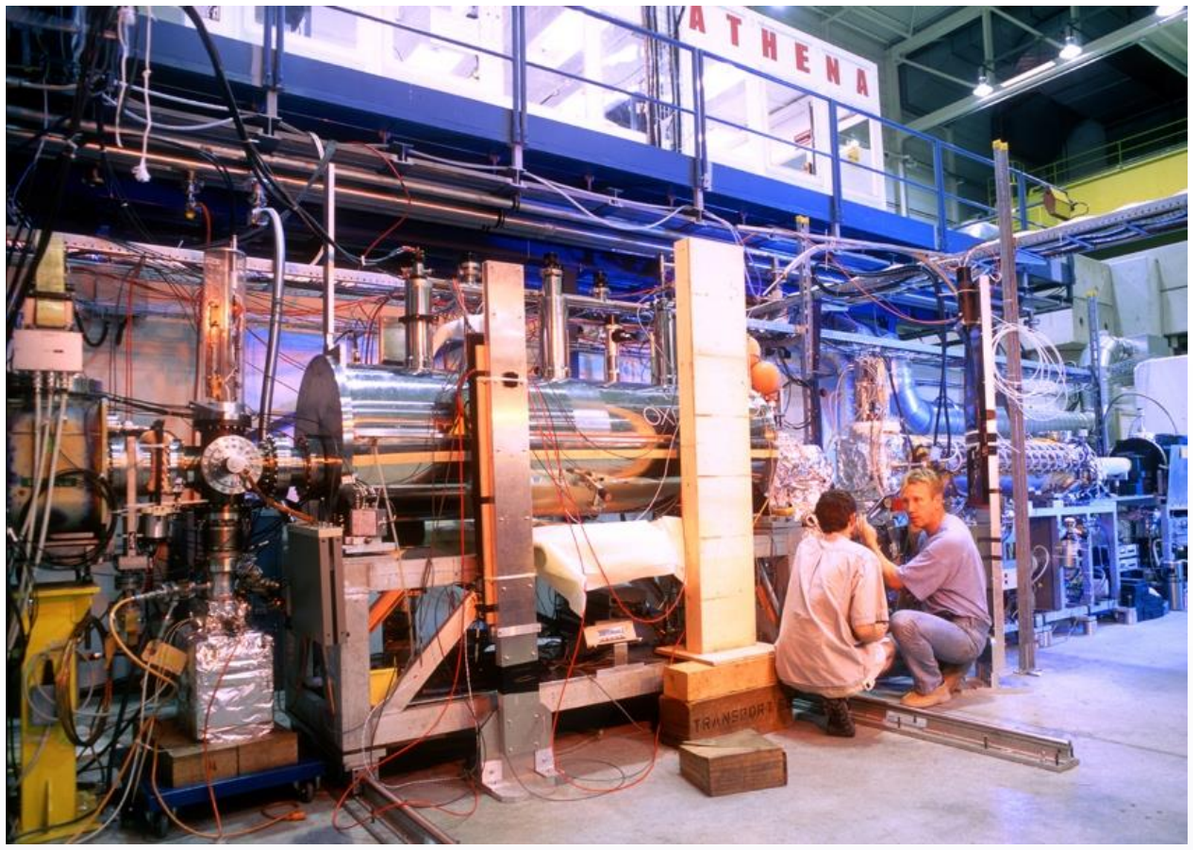
Present result: $\Delta M/M < 0.000\,000\,000\,1$

Magnetic moment of electron and positron ?

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

Present status: excellent agreement !

ATHENA Experiment (2002), at the AD facility



- More than 1 million antihydrogen atoms produced
- Small kinetic energy (< 0.01 eV)
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2002: 'Cold' antihydrogen production by AD experime

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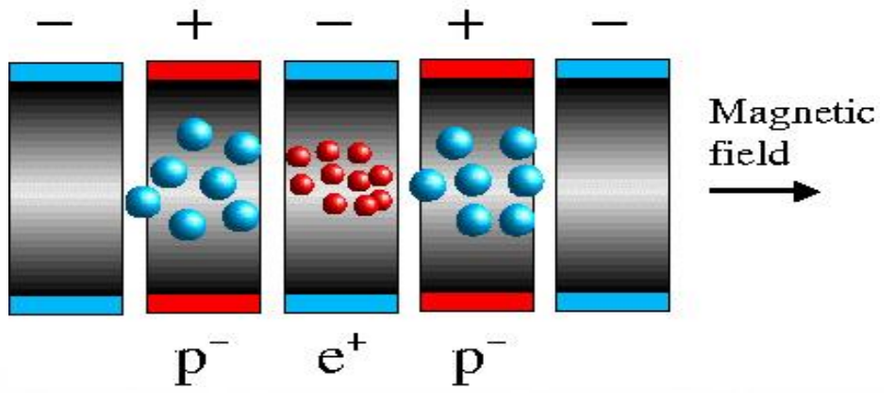
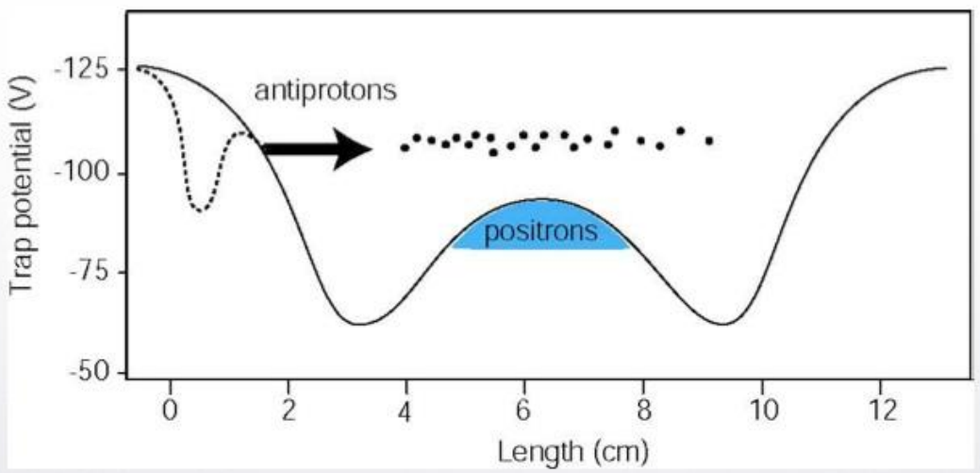
Recombination





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

Next step: Trapping antihydrogen

Neutral (anti-) atoms escape from Penning trap