

Angels, demons, CERN



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Head of Education Group

STORY LINE



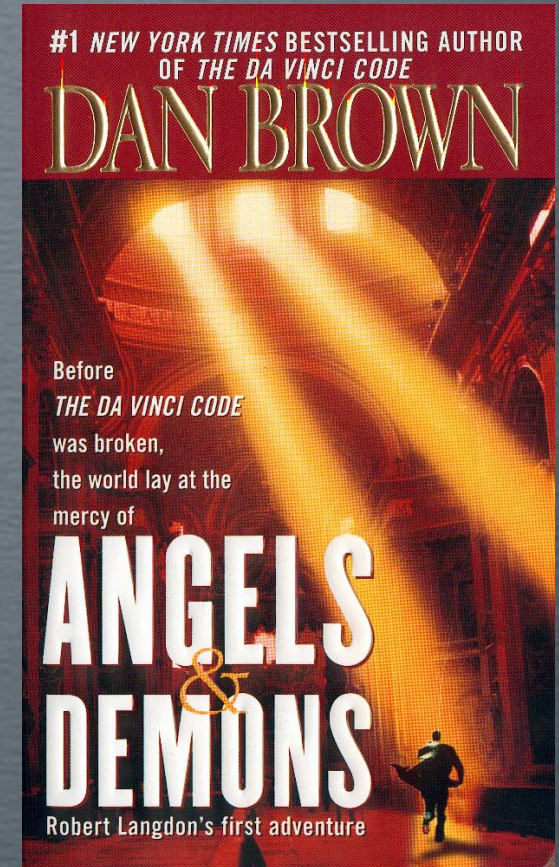
Detective story about a
secret society which ...



... steals 1 g of antimatter
from a place called "CERN" ...



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



A mix of fact and fiction. What is true? What is false?

Questions

Does antimatter exist?

Is it the energy source of the future?

Is it a dangerous weapon?

Are there other uses of antimatter?

Why does CERN produce antimatter?

DOES ANTIMATTER EXIST ?

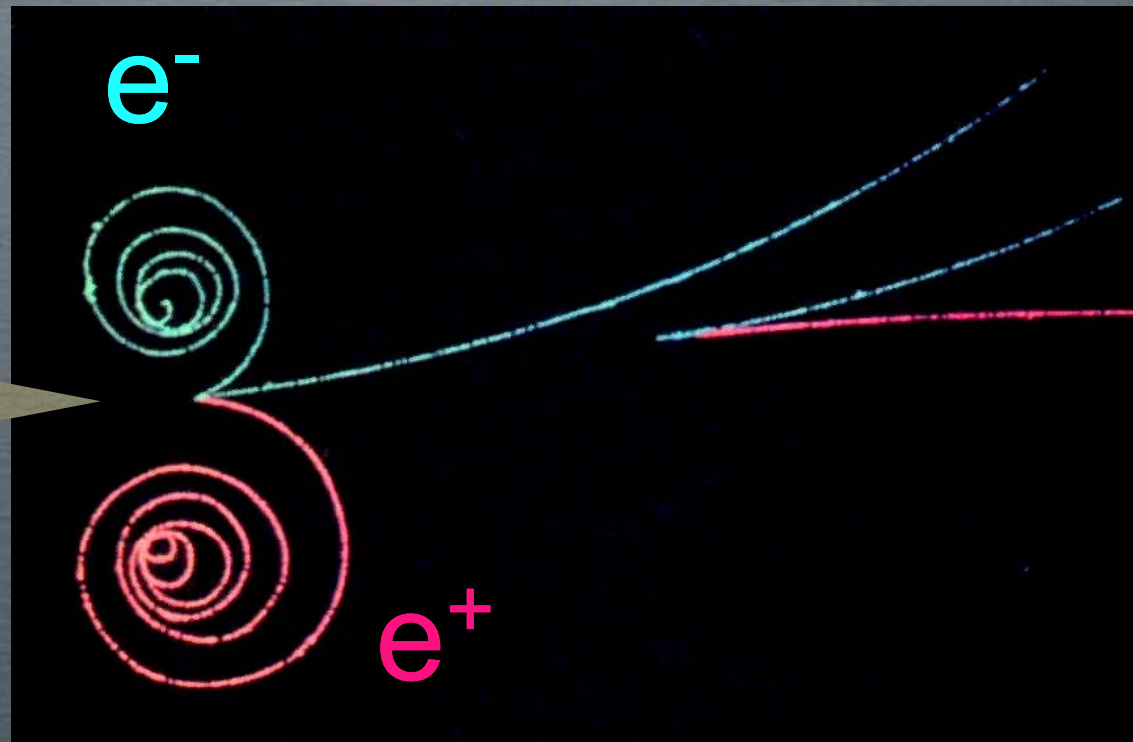
Yes!

$E = mc^2$
+
Quantum Theory

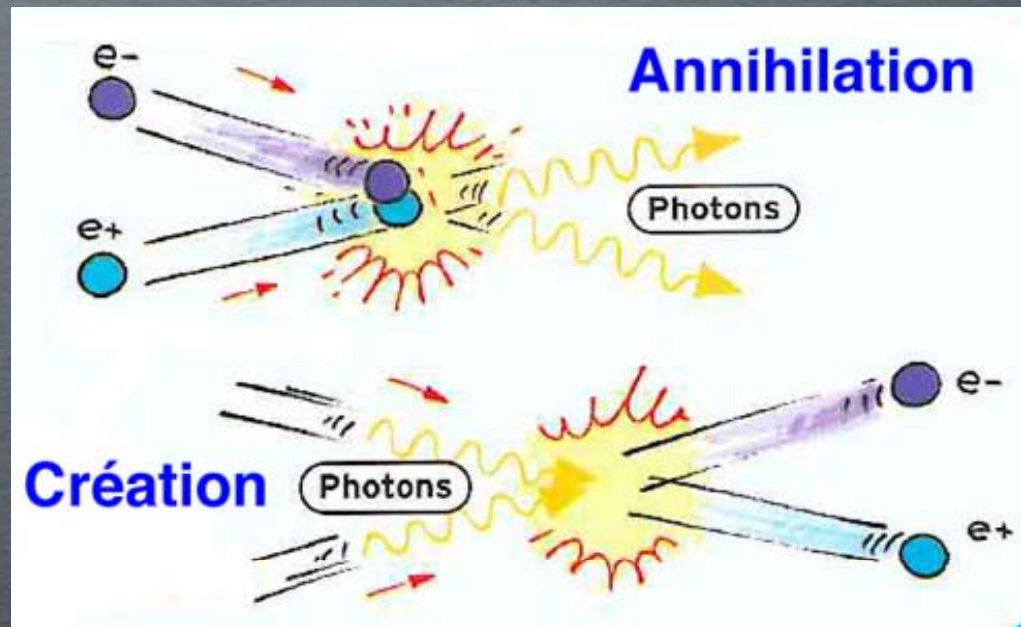


Same mass, opposite charge

Energy
(e.g. photon)

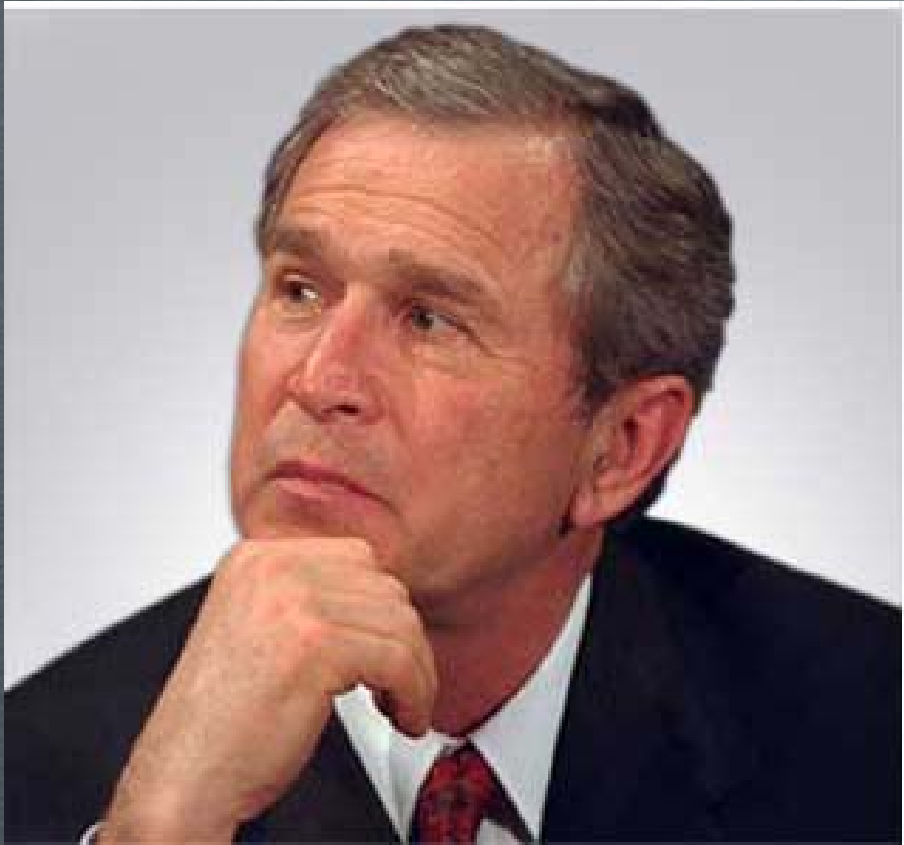


Mass



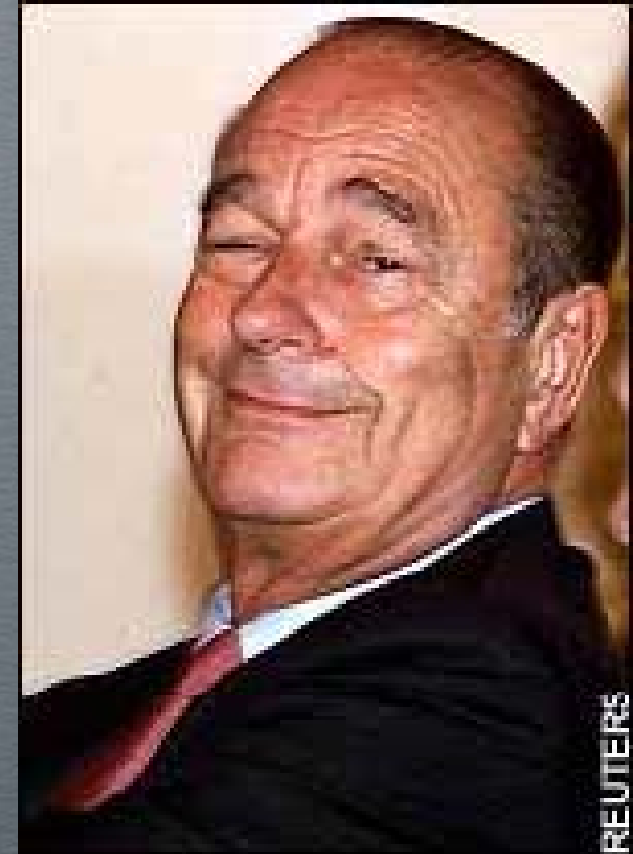
False Analogy

Bush



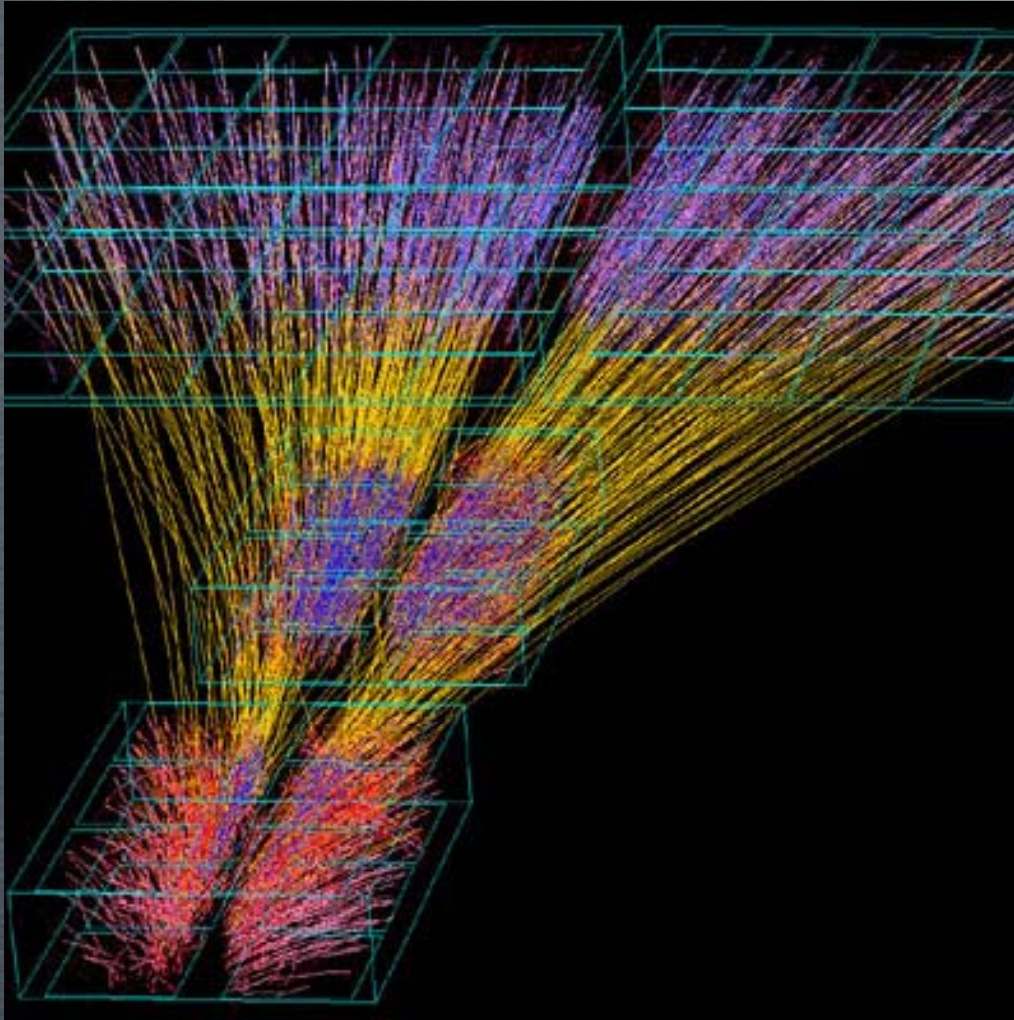
≠

Anti-Bush?



Matter and Antimatter Objects are optically identical

ANTIMATTER PRODUCTION



When very high energy particles collide, 50% of the newly created mass goes into antiparticles

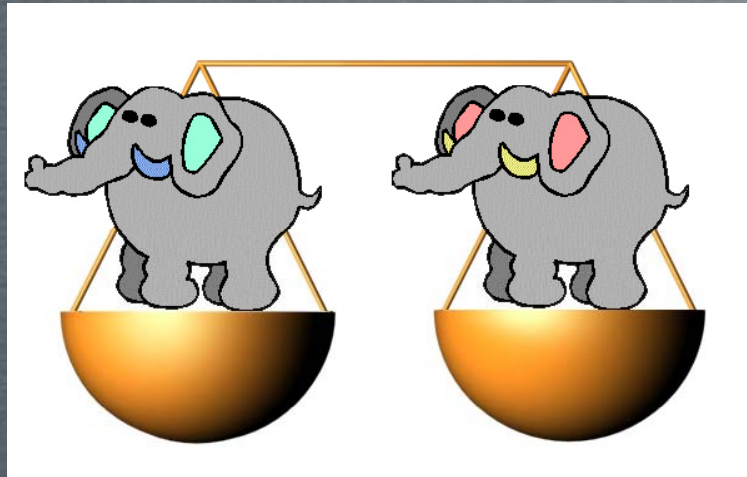
Paul DIRAC* (1933) NOBEL-PRIZE

"If we accept the view of **complete symmetry** between positive and negative electric charge so far as concerns the fundamental laws of Nature, we must regard it rather as an accident that the Earth (and presumably the whole solar system), contains a preponderance of negative electrons and positive protons. It is quite possible that for some of the stars it is the other way about, **these stars being built up mainly of positrons and negative protons**. In fact, there may be half the stars of each kind. The two kind of stars would both show **exactly the same spectra**, and there would be no way of distinguishing them by present astronomical methods."

- 1) **Matter - Antimatter Symmetry?**
- 2) **Antimatter in the Universe ?**
- 3) **Antihydrogen Spectrum ?**

A PERFECT SYMMETRY ?

Present measurements say: YES



Mass of proton =
mass of antiproton

to 10 significant digits

For comparison:
mass difference between two elephants
less than one dust grain



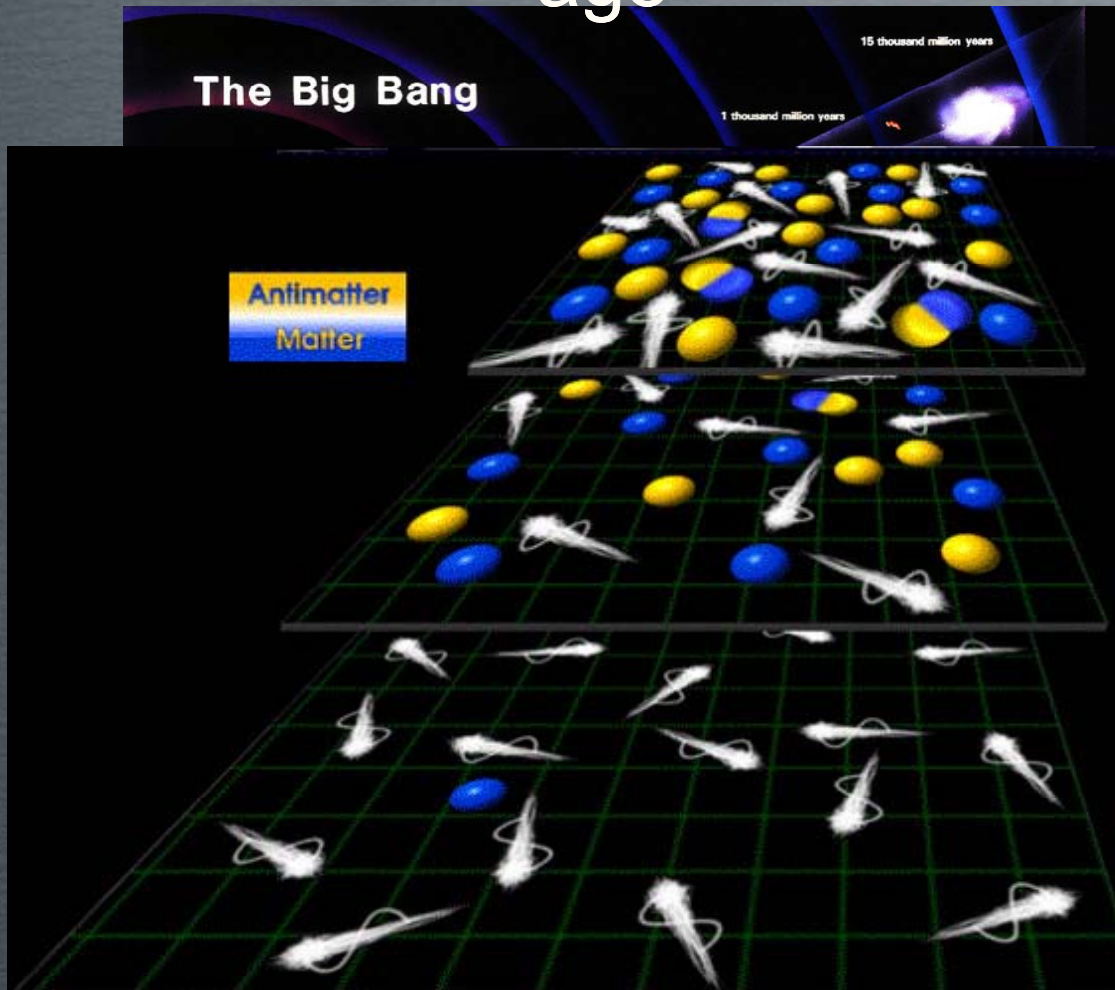
Magnetic moment: 10^{-12}

Charge:

10^{-8}

WHY STUDY ANTIMATTER ?

13,700 million years
ago



Transformation of energy into
mass

on a gigantic scale

$t \sim 0$:

equal amounts of
matter/antimatter

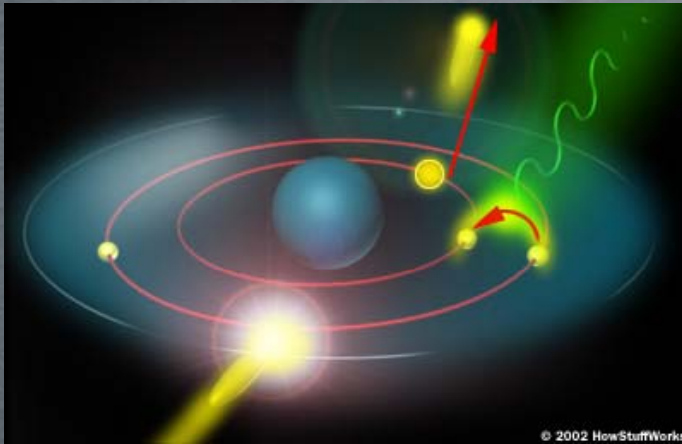
$t < 0.001$ s :

all antimatter has
disappeared,
but some matter (us!) left

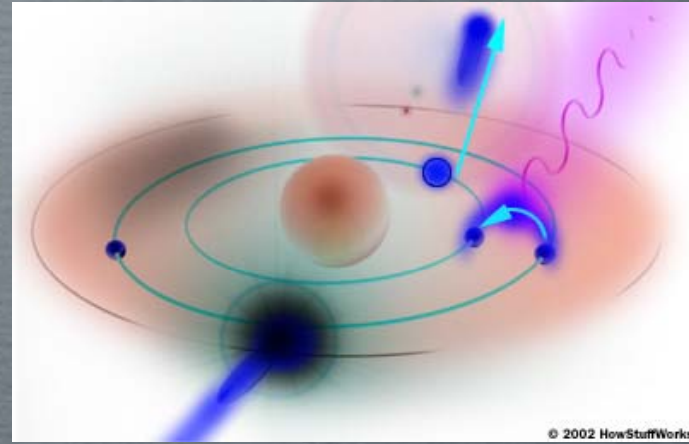
reason ?

IS THERE A DIFFERENCE ?

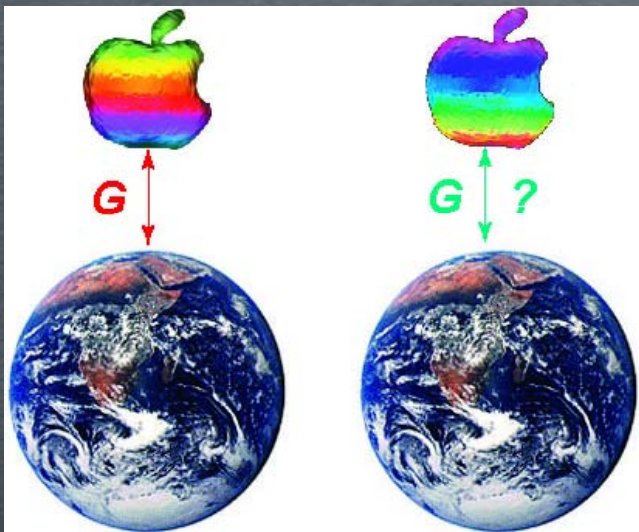
PRECISION STUDIES WITH ANTIHYDROGEN



?



ATOMIC LEVELS OF HYDROGEN AND ANTIHYDROGEN



ANTIHYDROGEN -
GRAVITATION ?

Two Milestones in Antihydrogen Physics

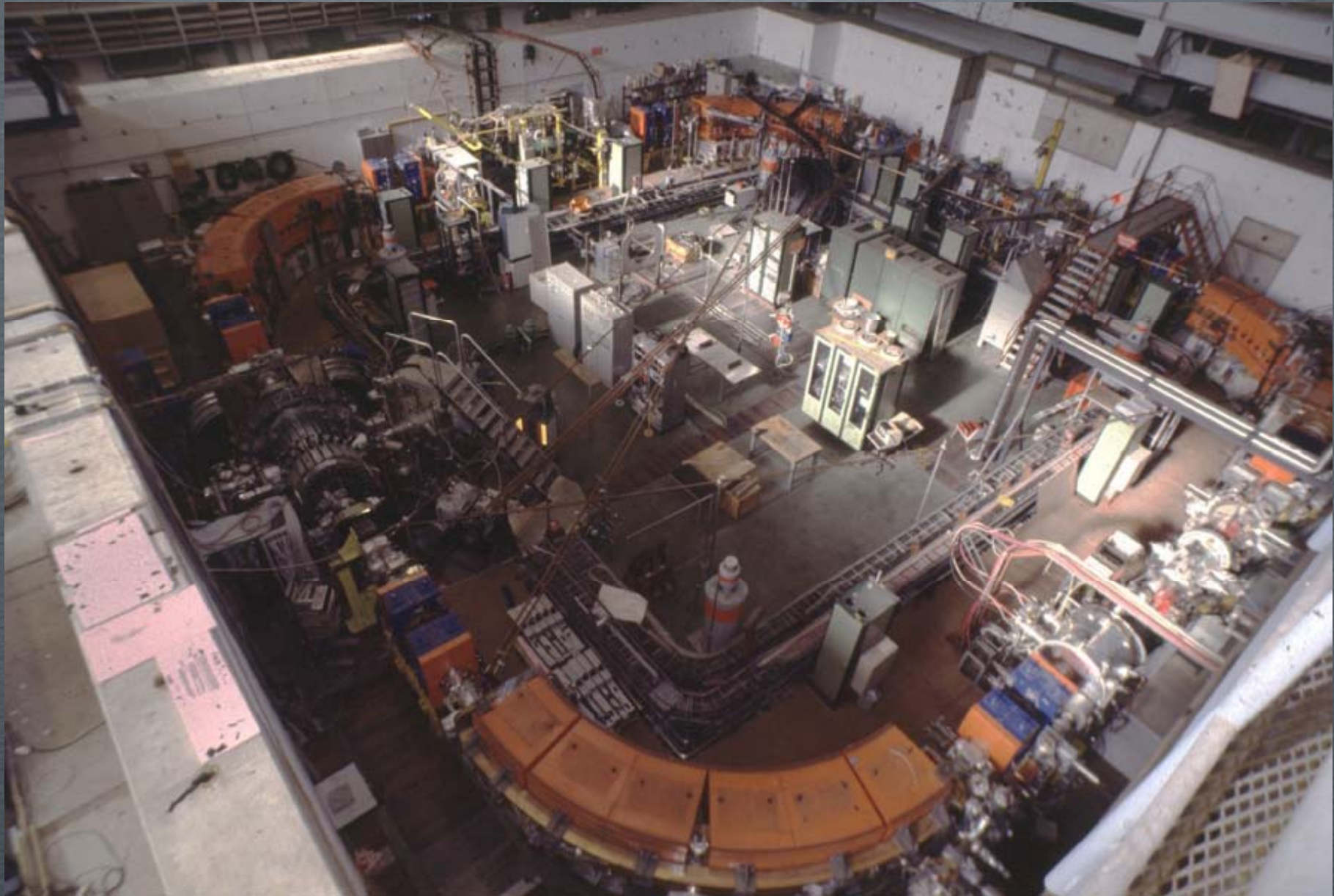
1996:

**First production of 9 antihydrogen atoms at LEAR (CERN),
moving with 90% of the speed of light**

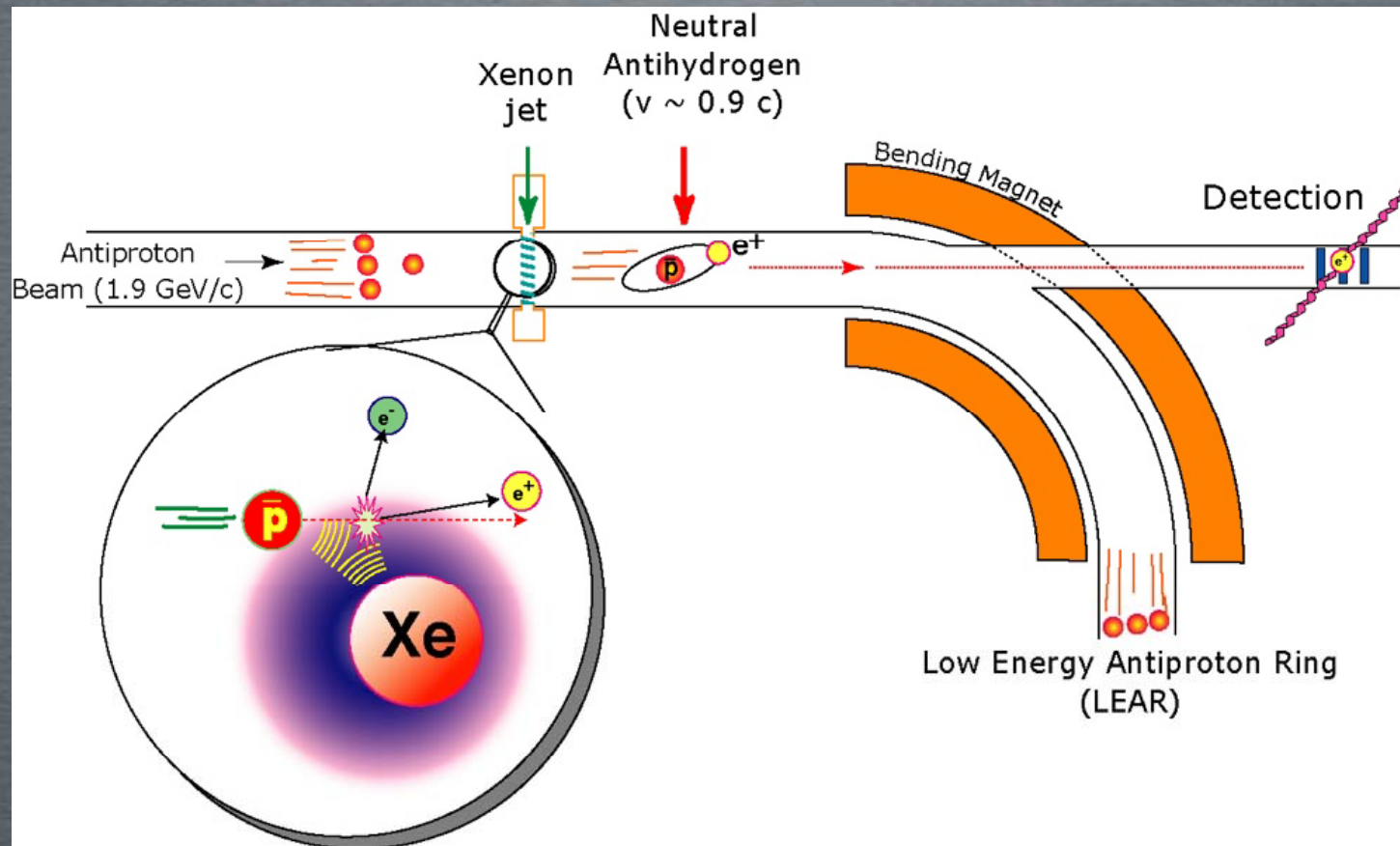
2002:

**Production of 1,000,000 antihydrogen atoms at the AD
(CERN),
moving with $1/1,000,000$ of the speed of light**

Low Energy Antiproton Ring



1996: FIRST PRODUCTION AT LEEAR



VERY EXCITING START OF ANTIHYDROGEN PROGRAM AT CERN

NOT VERY USEFUL FOR PRECISION EXPERIMENTS (too fast)

1996: HEADLINES AROUND THE WORLD

“Liberation” (France)

期星/日五月二年五十八國民華中

報時國中

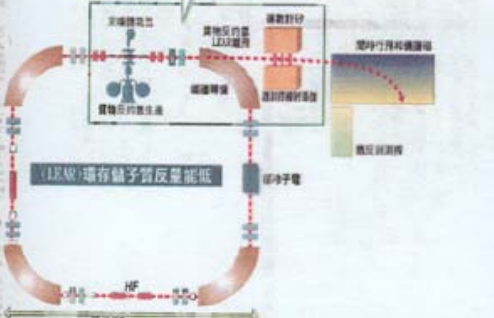
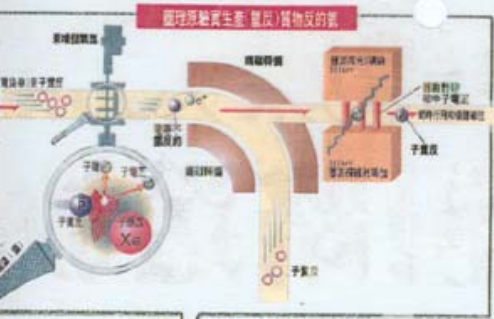
Ant

反物質原子的首創

子原質反批一頭出生創，束子質反量能低心中究研理物子粒洲歐用利，特勒歐家學理物國德。源能新於用能可不亦，義意大重有算不還上學科在但，錄紀先領到得難

健才江◎

CERN



由德國物理教授歐勒特 (W. Oelert) 領導的實驗組，是歐洲核子物理研究中心 (CERN) 一九八一年完成的低能反質子儲存環 (LEAR) 中的反質子束，通過一個低能電子束，而產生出低能反質子束。

在 CERN 中，能產生出低能反質子束，是以每秒三百萬次的頻率，和通過 CERN 上某一點的氦原子噴束交錯而過。在十分鐘的機會中，一個反質子會因為和氦原子核碰撞而散射，而將其一部分能量轉化為一個質子和反質子對。


在比前面所產生質子和反質子對更小的機會中，反質子 (帶正電) 的速度由於和反質子 (帶負電) 的速度正好十分接近，因而就結合而形成一個反氦原子。

反氦原子由於有帶正電的反質子和帶負電的反質子，整個來說就是中性的，因此在到達 CERN 的磁場邊緣時，不會被反質子殺死而散射，而會向內飛入實驗設計的一個直徑約為一公尺的真空管中，這個反氦原子會受到電場中而產生的形式放出能量。

據歐勒特表示，他們還因為氦的碰撞而產生出很多反質子，減少碰撞會。

由於產生的反氦原子，因此由其產生到碰撞而飛行的時間是四十個奈秒，這也是這些反氦原子儲存歐勒特的實驗進行了三反質子通過氦氣後，產生歐勒特是低能反質子束，確定他們確實創造出了反氦原子。

歐勒特說，理論上反氦是可以永遠存在的，低能反氦原子束能存在，他們長久存在的反物質原子 (電荷、半衰期和時間) 力學和核力學相輔相成是實驗反物質在重力的



他們在站 (右) 安馬家學物理的學大亞內熱利大和 (左) 特勒歐

(供提CERN)

• 前項LEAR的證實行

歐勒特證實反

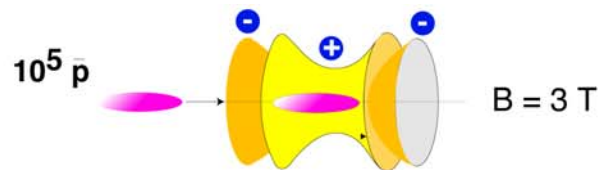
提出這個構想的物理學家已經指出，在英國另外一個行的高能物理實驗中，應該是有科學家沒有辦法分析出來小組，於是根據構想，設計開關到初步結果，到上個月創生出第一批反物質。雖然在，但是是產生出存門下一步的工作是產生出存物理上所謂的 CPT 不變性，對於一般人感到興趣的，「企業號」太空船利用「物理構想」歐勒特認為，以消耗了數以百計的反質子，因此要得到足夠多的能量，雖然是不可能的。歐勒特在由瑞士打出的論用反物質作為能源之可能特能！ (Never over)。

歐勒特證實反

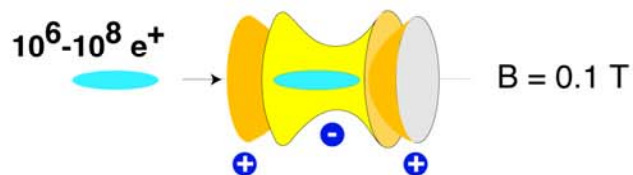
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How to produce more + colder antihydrogen ?

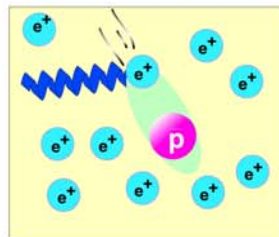
1 Antiproton Capture into Penning Trap



2 Positron Accumulation from Na-22 source



3 Positron-Antiproton Recombination in multi-ring trap



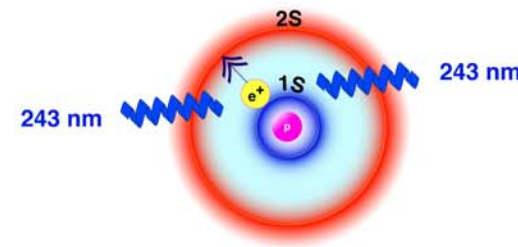
4 Antihydrogen Detection

- Annihilation products: 2 layers x 16 Si Strips
- 511 keV Gammas: 192 CsI Xtals + Photodiodes

5 Antihydrogen Storage in Magnetic Bottle

Magnetic well depth $\sim 0.35 \text{ K}$ ($35 \mu\text{eV}$)
(PHASE 2)

6 2-Photon Laser Spectroscopy: ΔE (1S-2S) (PHASE 2)



Comparison $\bar{\text{H}} : \text{H}$ with precision $10^{-12} \dots 10^{-15}$

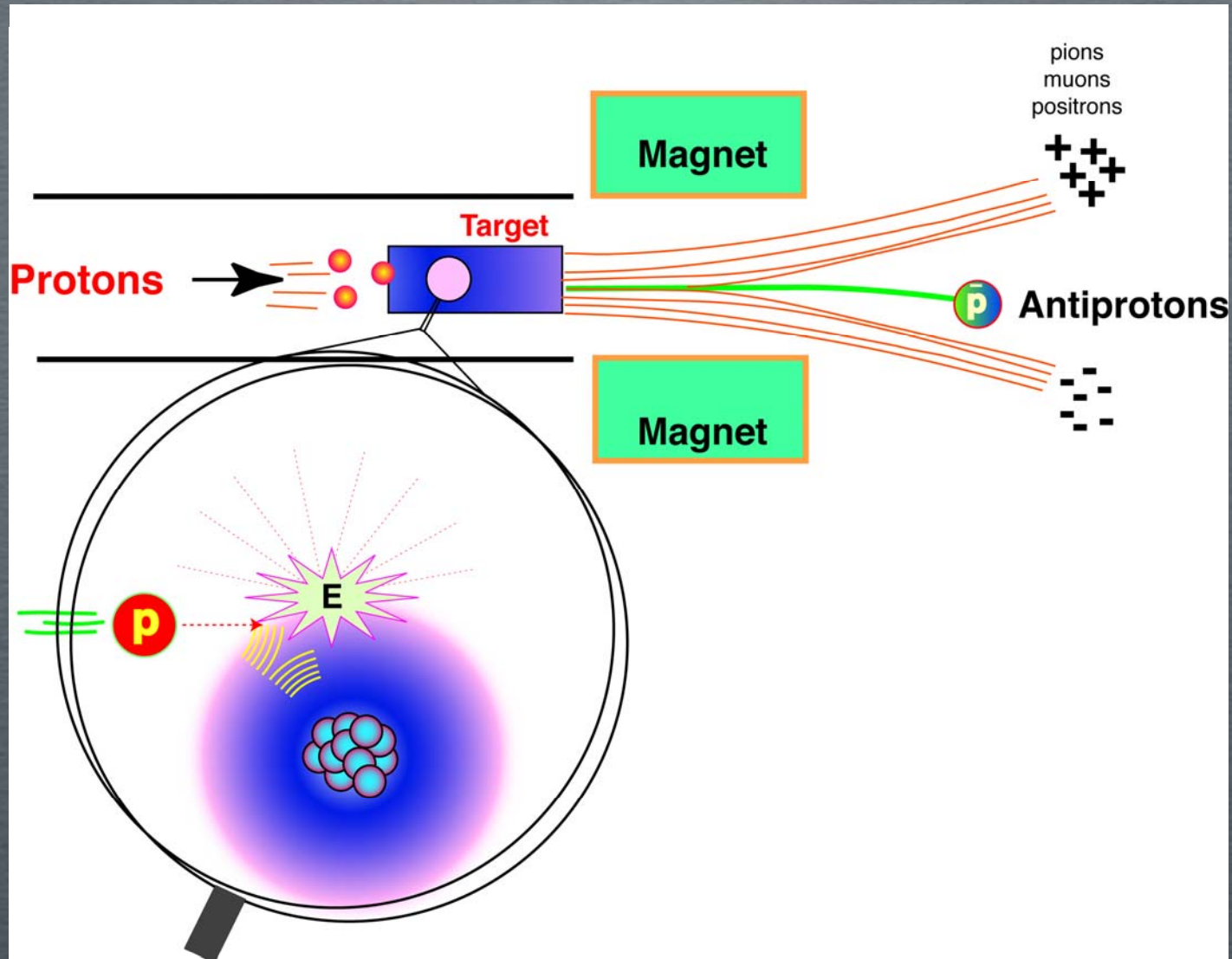
ANTIPROTON DECELERATOR (AD)



188 m long
Antiproton Production,
Storage and Deceleration
3 - 0.005 GeV energy

Original motivation
(~1980):
Make antiproton beams
for acceleration in the
'SPS collider' - to
produce 'vector bosons':
**NOBEL PRIZE FOR TWO
CERN PHYSICISTS**

ANTIPROTON PRODUCTION



ANTIHYDROGEN PRODUCTION

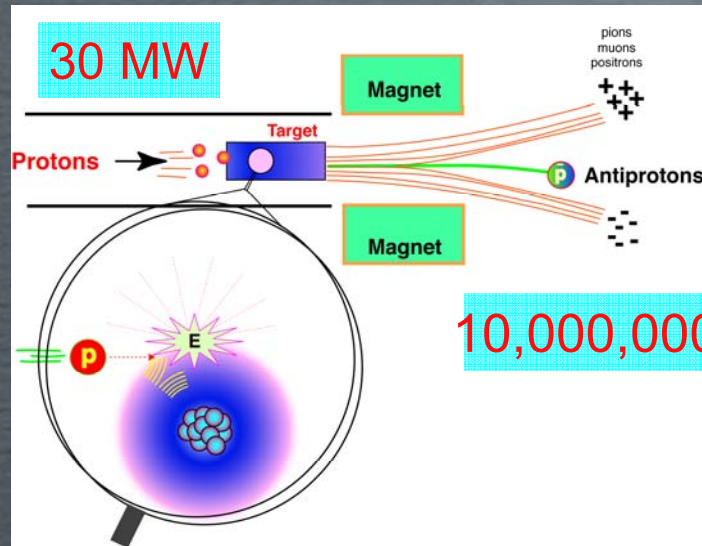
QuickTime™ and a
MPEG-4 Video decompressor
are needed to see this picture.

Antiproton Annihilation in einem Detektor (“Channel Plate”)

QuickTime™ and a
Motion JPEG OpenDML decompressor
are needed to see this picture.

the COST of ANTIMATTER

602 300 000 000 000 000 000 000 000 Antiprotons per gram



CERN Production per day:

10^{12} Antiprotons ($\sim 10^{-12}$ g)

Energy consumption $\sim 30,000$ kW \cdot 24 h

Electricity cost (10^6 kWh) $\sim 100,000$ €

1 g antiprotons $\sim 100,000$ trillion €*

*Comparison: US National Debt (25/4/07): 8.83 trillion \$ (6.5 trillion €)

energy source of the future ?

$$E = mc^2$$

$$1 \text{ kg} = 9 \cdot 10^{16} \text{ J} = 2.9 \text{ GW yr}$$



Energy
conservation !

10^{12} antiprotons (10^{-12} g) $\sim 30 \text{ MW} \cdot \text{day}$
 $\sim 10^6 \text{ kWh} \sim 100 \text{ k€}$

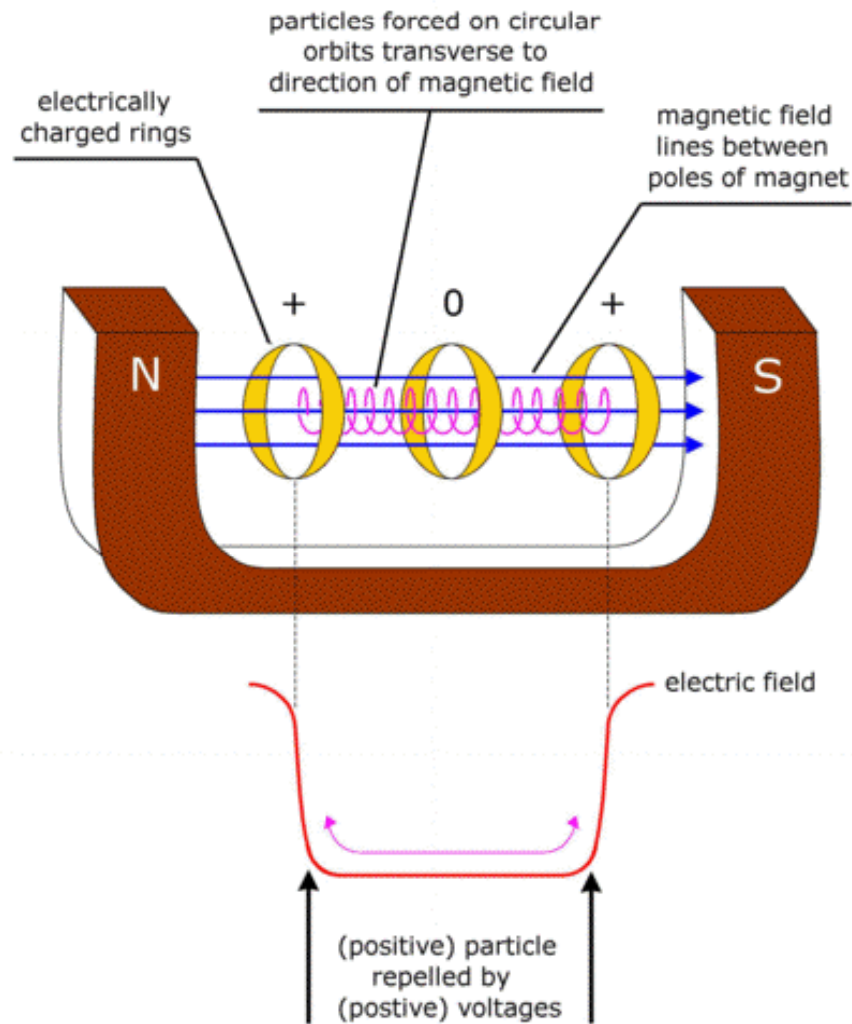
1 g antimatter $\sim 100,000,000$ billion €

Efficiency: $\sim 10^{-9}$

No antimatter mines!

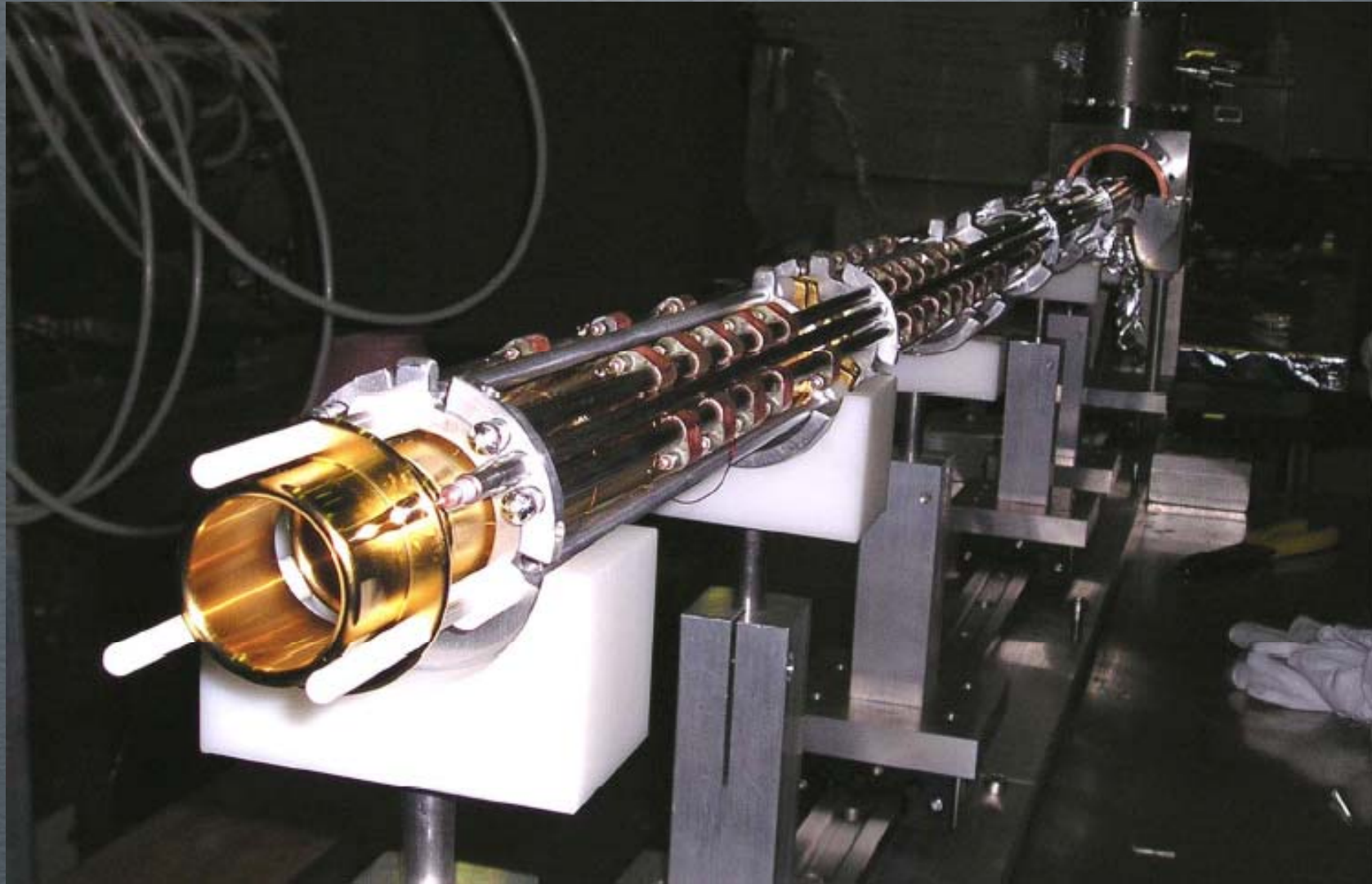
PARTICLE TRAPS

HOW A TRAP WORKS



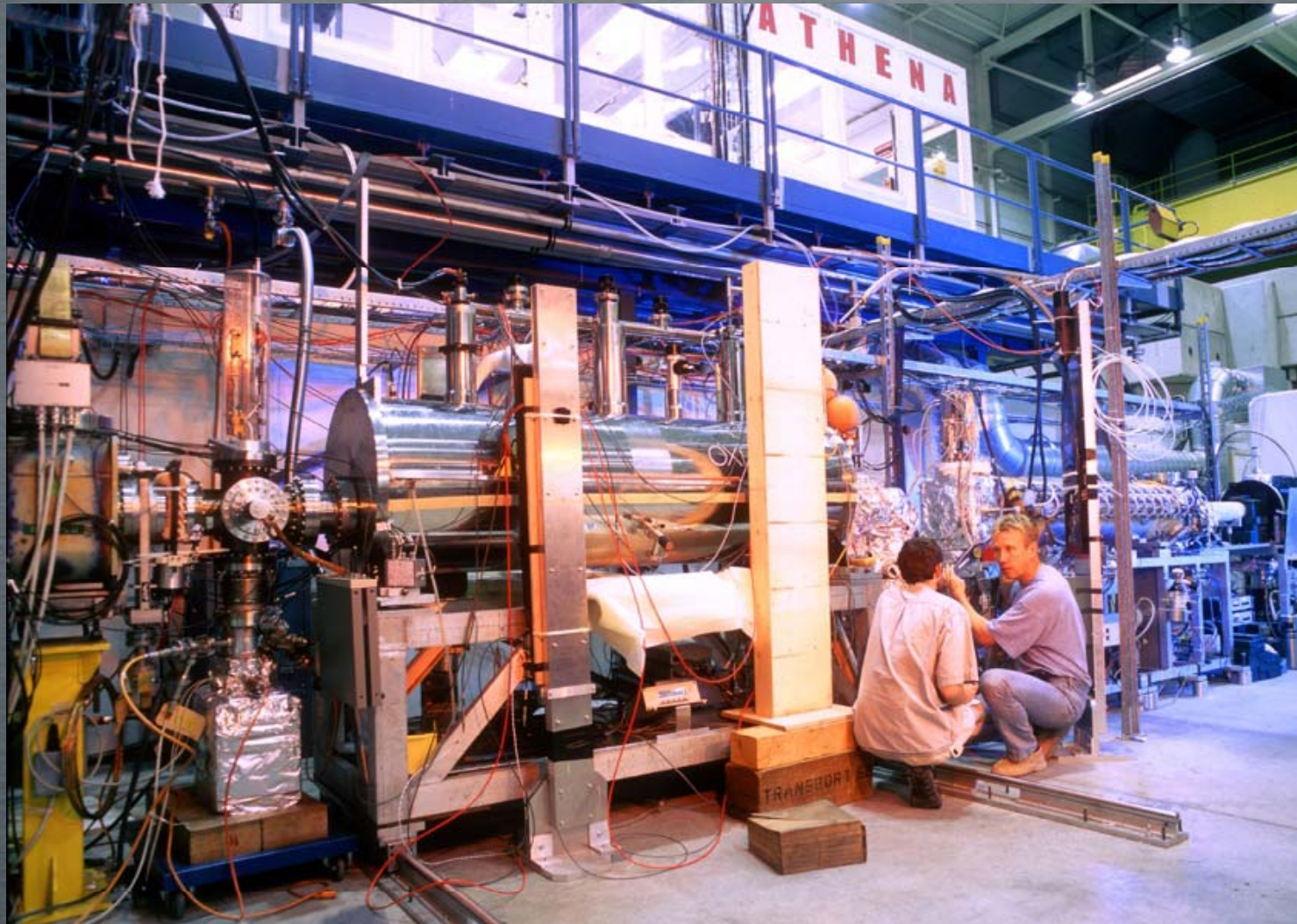
Particles fired into such a ring system are completely trapped by the electric and magnetic fields applied.

2002 - athena experiment



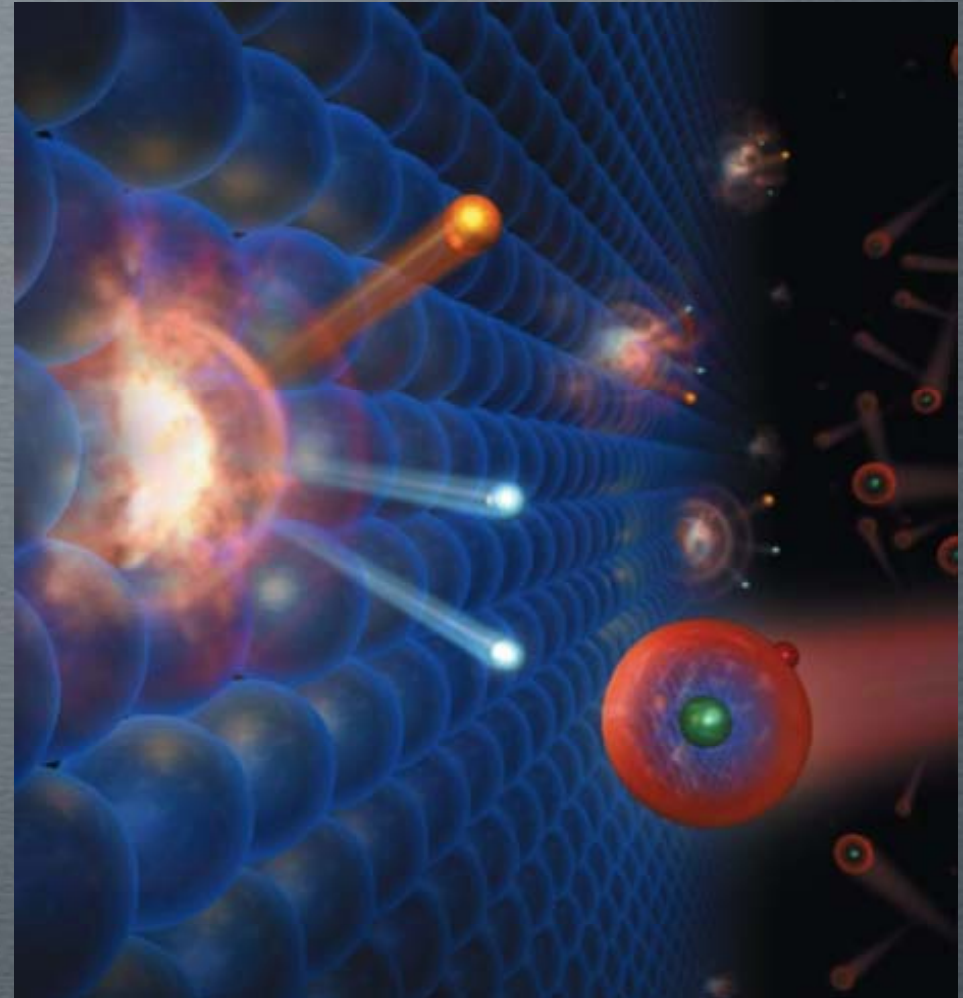
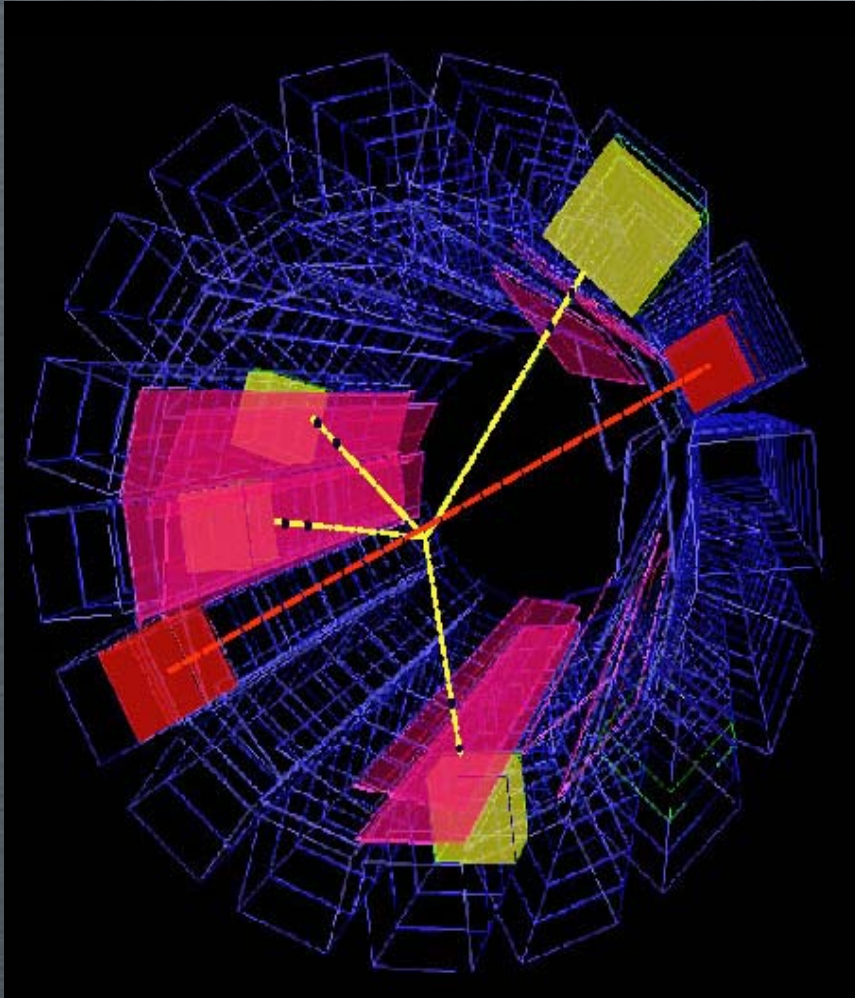
Trap for antiparticle storage

2002 - athena experiment



First production of more than
1 million antihydrogen atoms

2002 - athena experiment produces
1 million antihydrogen atoms



Signature of antihydrogen
anti-atoms are not trapped and annihilate at the wall

ANTIMATTER : A DANGEROUS WEAPON ?



Hiroshima Atomic Bomb

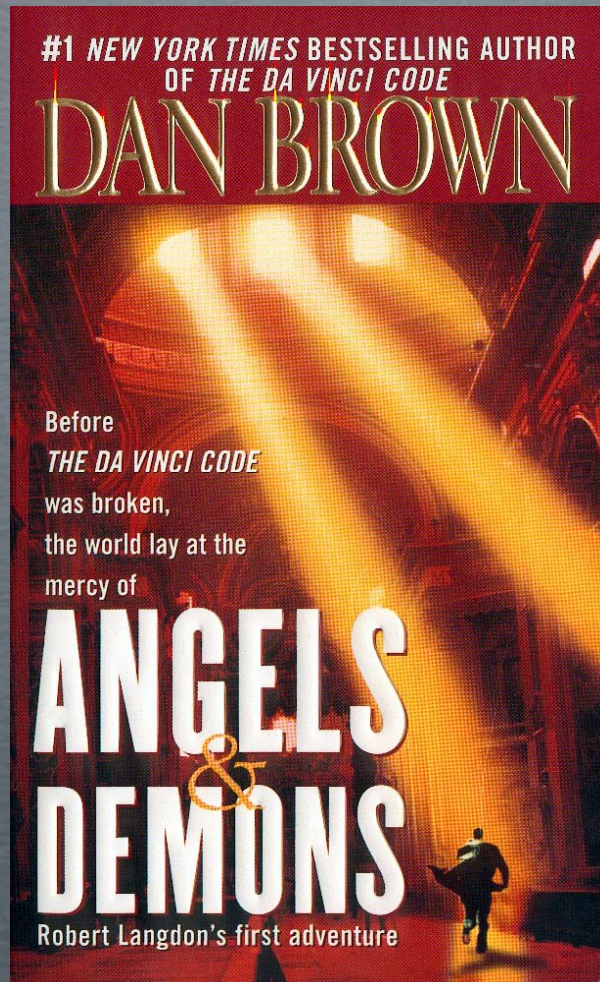
$$E = mc^2$$

20 kt TNT = $8.4 \cdot 10^{13}$ J

0.5 g antimatter + 0.5 g
matter

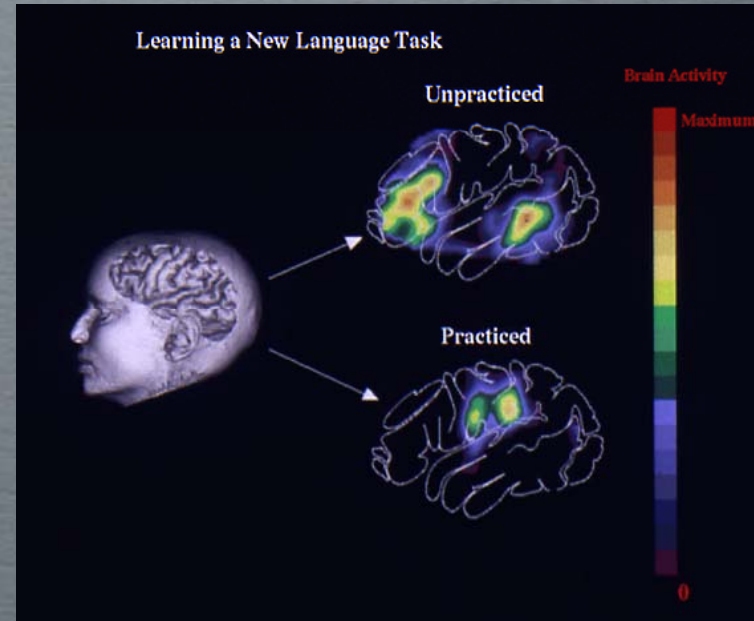
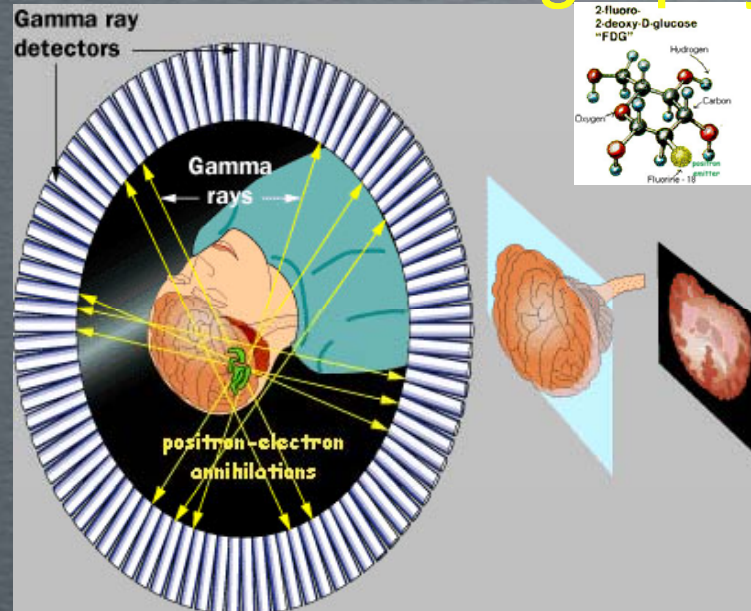
Cost: 50,000,000 billion €
Production time: ~ 3 billion years

2002: STILL A LOT OF HEADLINES, AND... AS A BY-PRODUCT



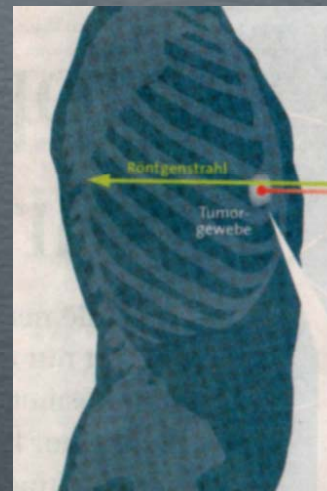
other uses of antimatter

Positron Emission Tomography



Tumour treatment with antiprotons ?

(CERN experiment AD-4/ACE)



Thank you
for your attention