

Angels, demons, CERN



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STORY LINE



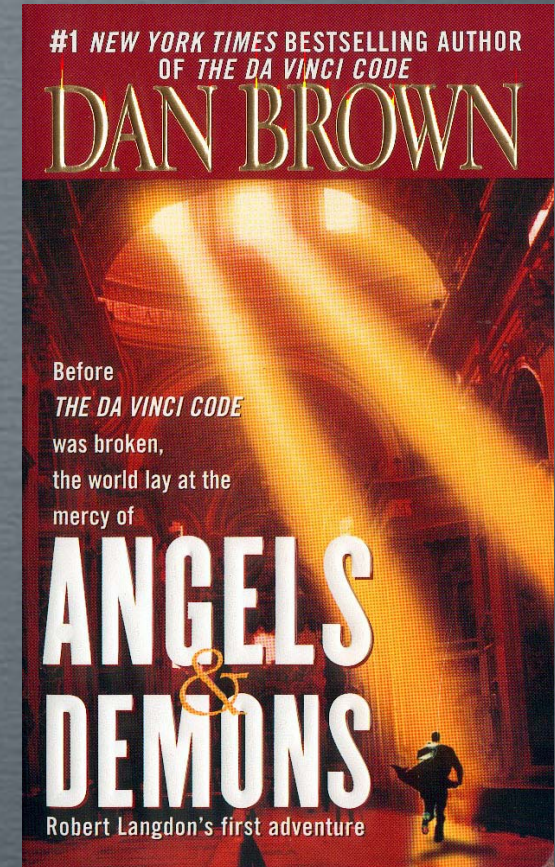
Detective story about a
secret society which ...



... 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?

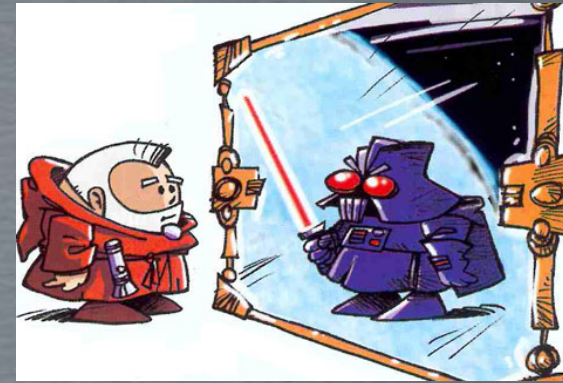
Is it a dangerous weapon?

Are there other uses of antimatter?

Why does CERN produce antimatter?

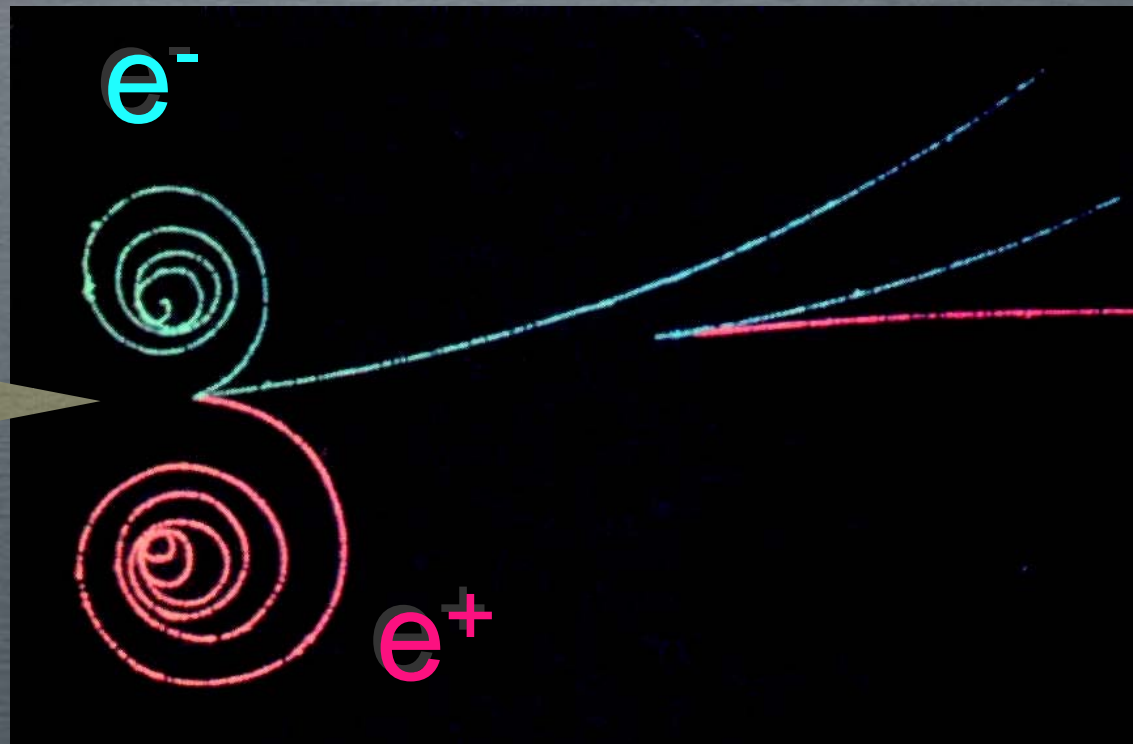
DOES ANTIMATTER EXIST ?

Yes: $E = mc^2$
+
Quantum Theory

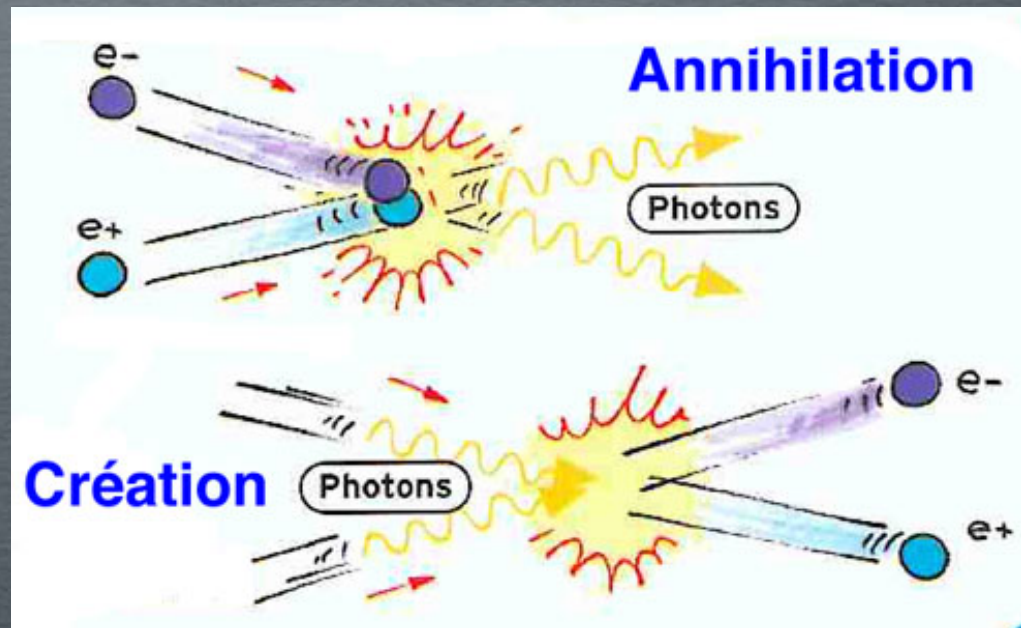


Same mass, opposite charge

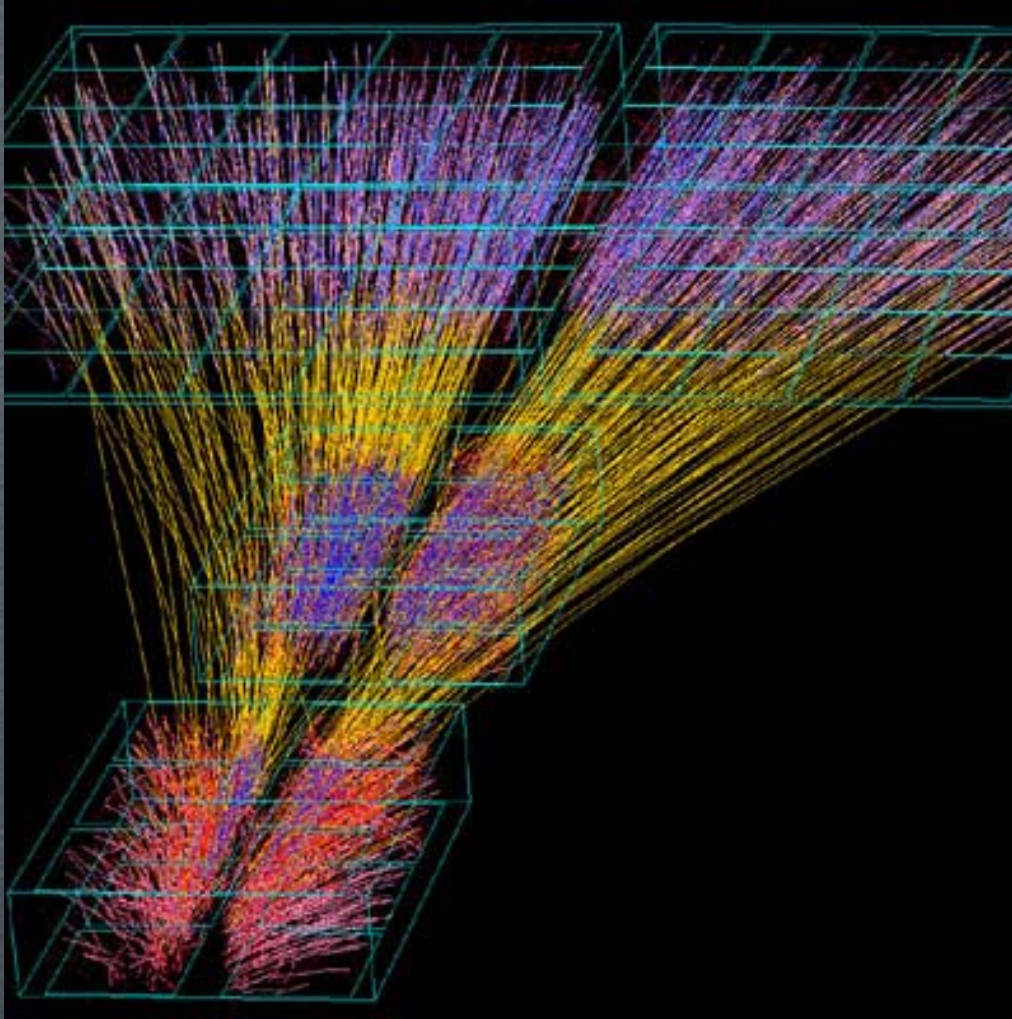
Energy
(e.g. photon)



Mass



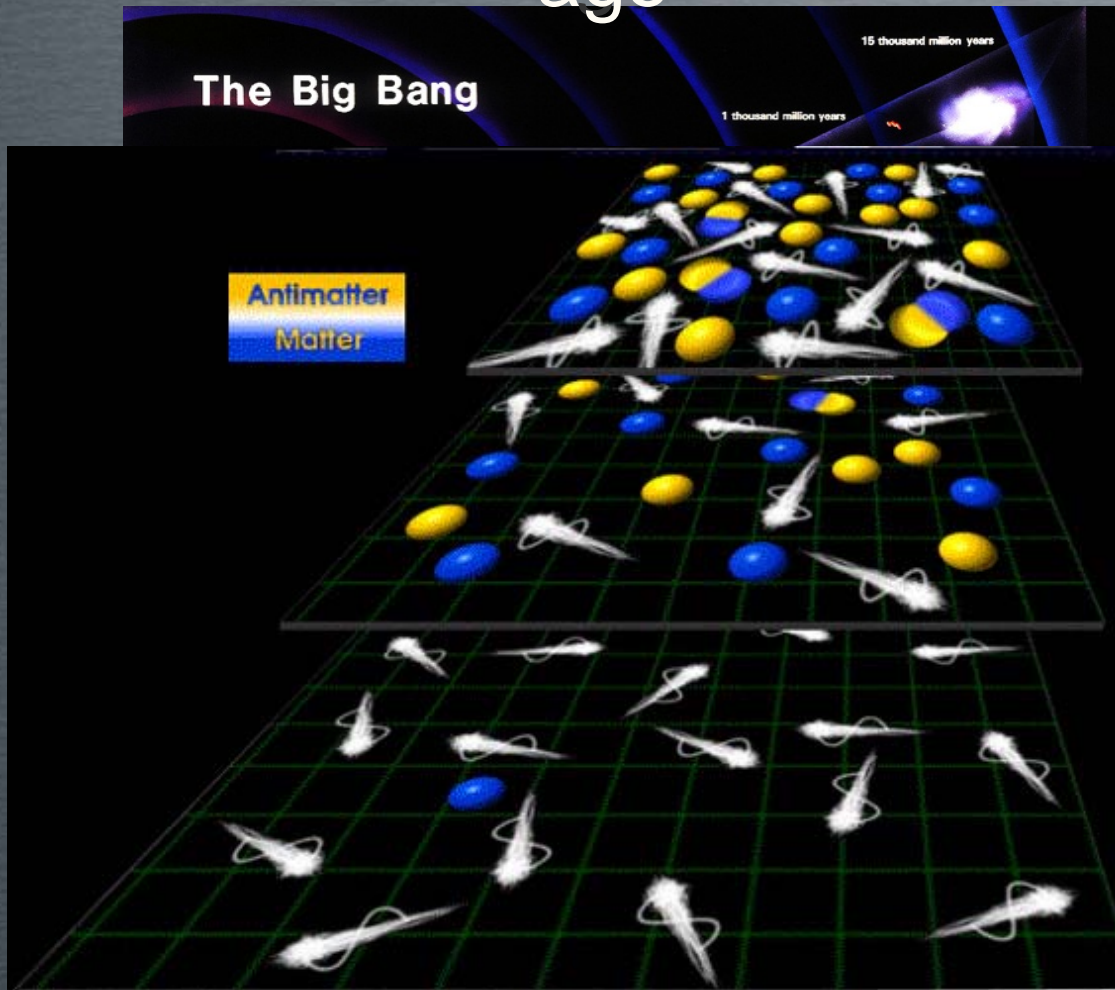
ANTIMATTER PRODUCTION



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

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

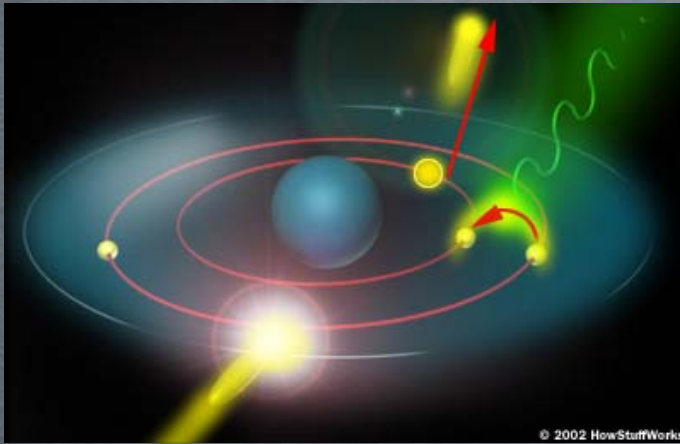
$t < 0.001$ s :

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

reason ?

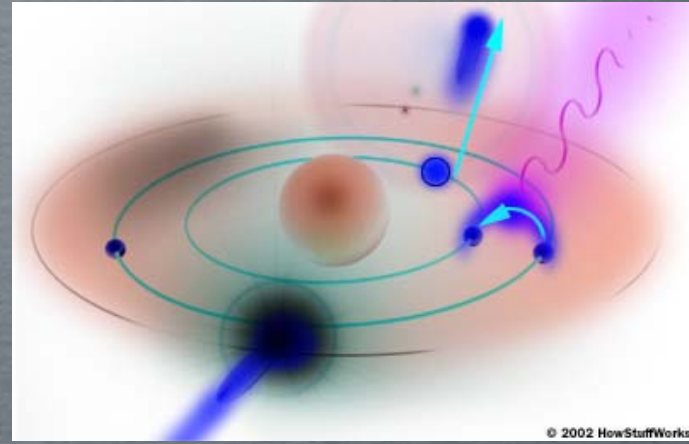
IS THERE A DIFFERENCE ?

PRECISION STUDIES WITH ANTIHYDROGEN

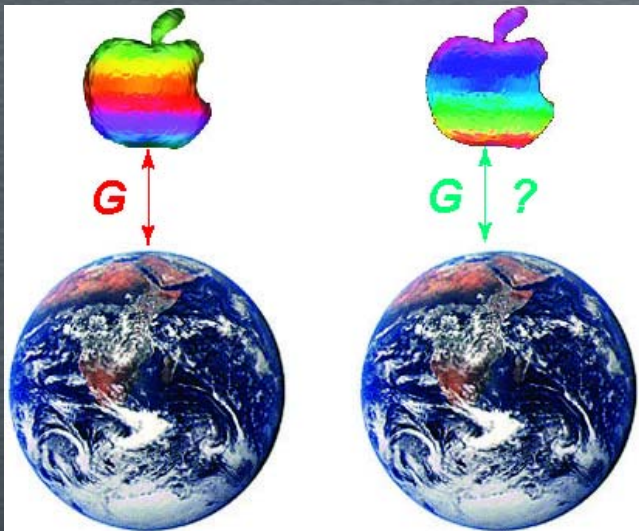


?

≡



ATOMIC LEVELS OF HYDROGEN AND ANTIHYDROGEN



ANTIHYDROGEN -
GRAVITATION ?

Two Milestones in Antihydrogen Physics

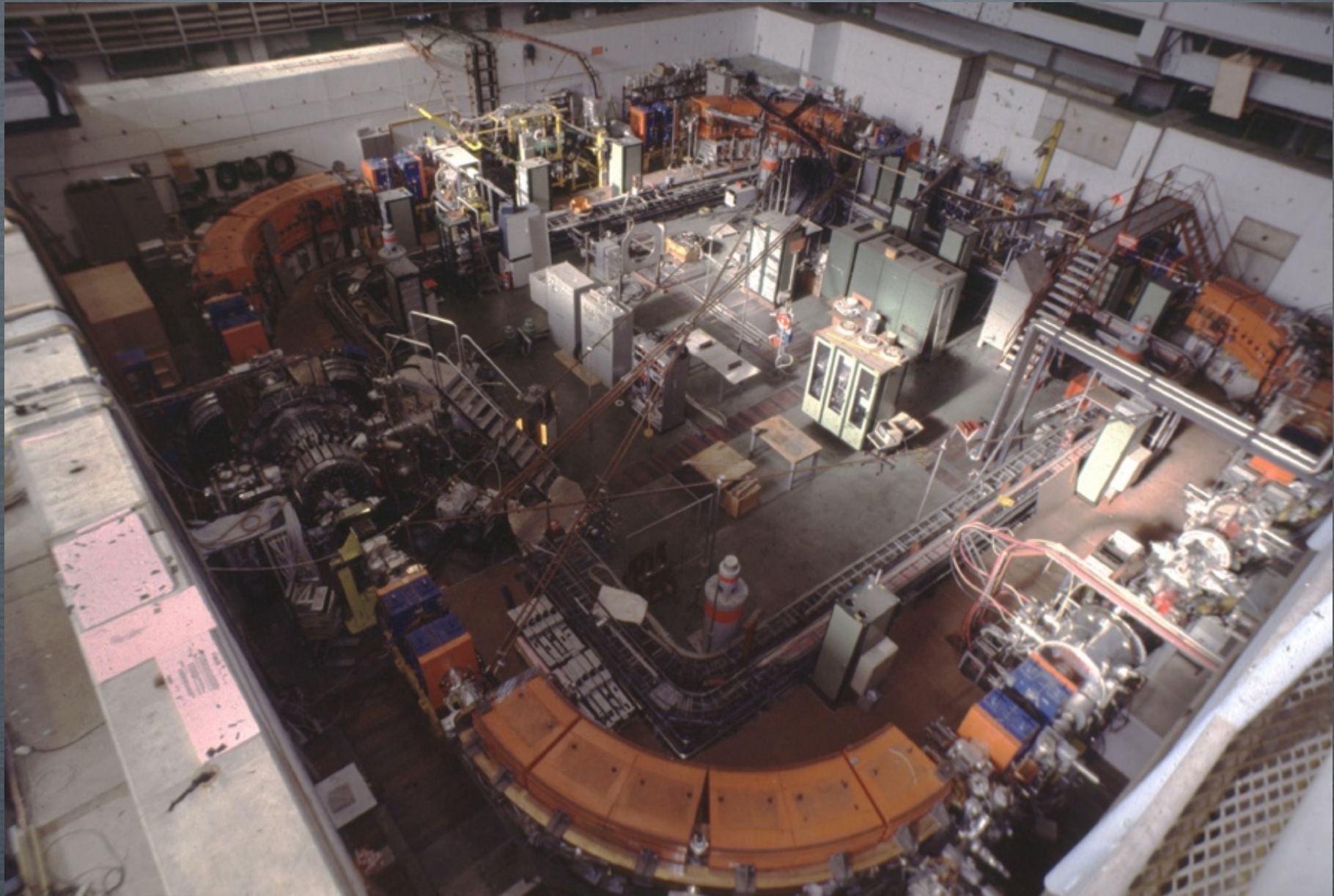
1996:

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

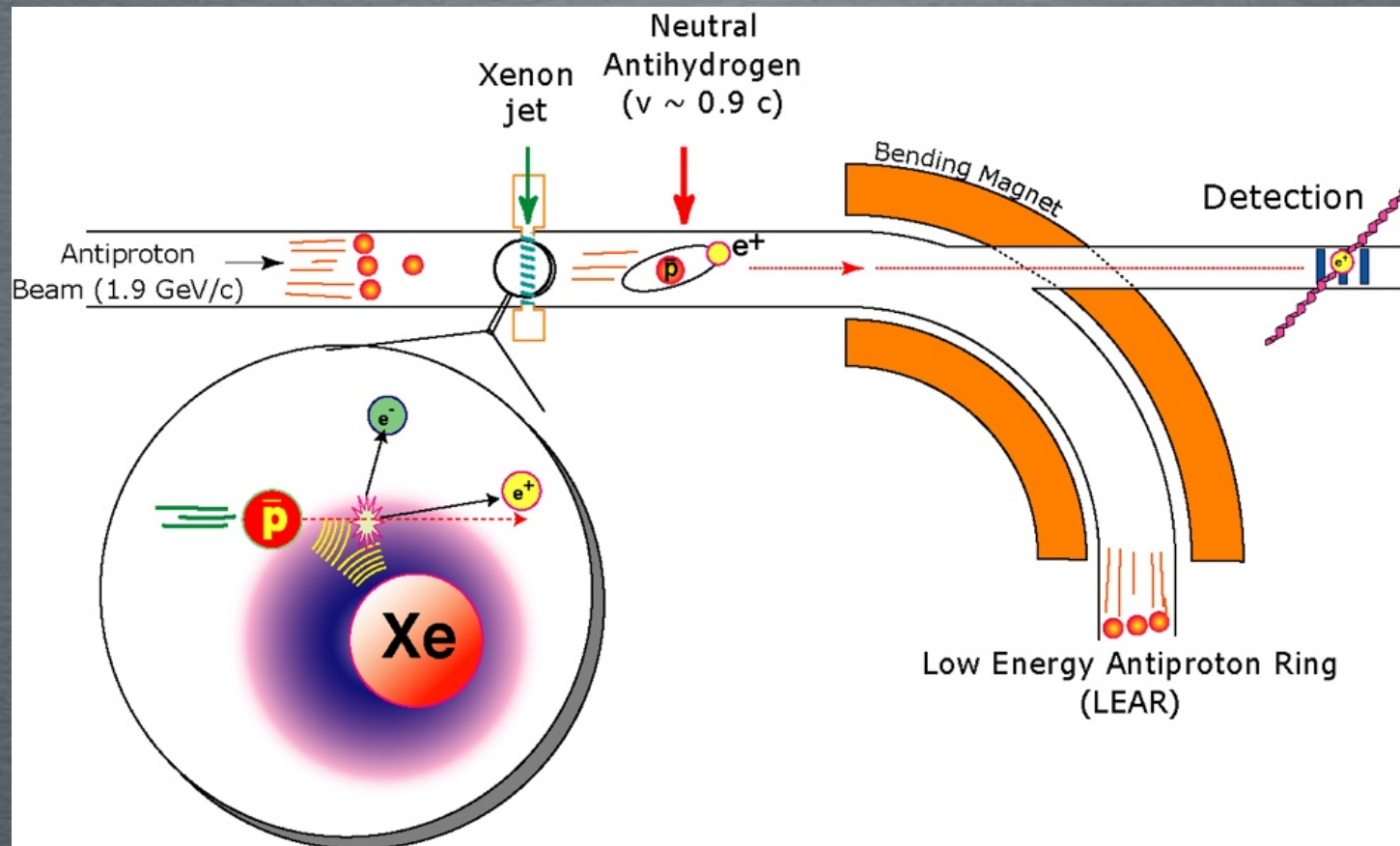
2002:

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)

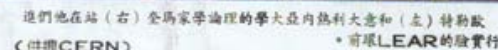
“Liberation” (France)

報時國中

"Ant



。源能新於用能不亦，義意大重有算不還上學科在但，錄記先領到得難



由德國物理教授勞特（H. 勞特）領導的實驗組，是用歐洲核子物理研究所中心（CERN）一九八一年完成的低能電子雷打增（LEIS）中的反電子束，通過一個低電壓喇叭，而產生出反物質的。

四三萬噸。伏特的一個反質子，是以每秒三百萬公分的速率，和通過它上面某一點的氫原子噴發交錯而過，而在十分之一的機會中，一個反質子會因為和氫原子碰撞而散射，而將其一部分能量轉化為一個電子和反電子對。

在比較簡單地產生電子和反電子對更小的機會中，反電子（帶正電）的速度由鈷和反質子（帶負電）的速度正好一分接近，因而就結合而形成一個反質子。

反質子由於有帶正電的反電子和帶負電的質子，整個來說就是中性的，因而在到達它的靶的瞬間時，不會發生反質子被吸收而產生一個輻射，而直接進入靶設計的個值中的真正區域中。這個反質子輻射到靶徑中相當的區域。

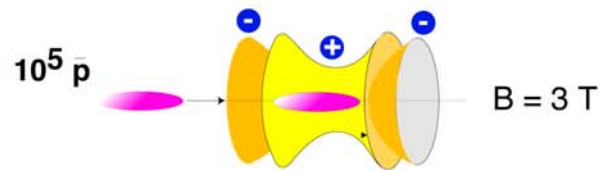
由於產生到一個輻射場，因此由其產生到輻射場，飛行時間是四十個奈秒。正是這些反質子存留也特有的實驗觀察了反質子通過氫氣後，創生反質子是依靠輻射場而確定他們真正創生了反質子。理論上反質子是永遠存在的，低質子更能量高。他們下長久存在的反物質質子（電荷、宇稱和時間反演）平衡和狹窄的輻射推進是極輕反質子在重力下的

選錄中，已經開闢出了許多「反」能量大關，要使這些「反」反粒子，「安定」下來結合是不可能的。

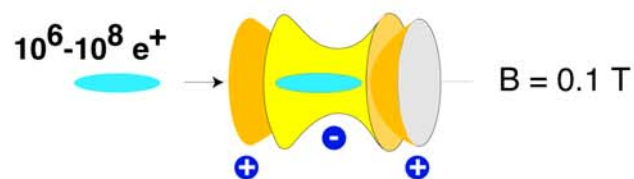
因此，在十多年前，研究反反提出許多降低反反粒子能量的創生出反反所用到的 EPR 的 (EPR)，就已經可以將其降低到六百萬電子伏特以下，學來能量以，要使反反粒子，能量必須降至幾千電子伏，由於要將高能反反質子束，技術方面困難很多，所以，氣貫雲空的物理學家，來自，紐倫堡大學歐勒特教授，論學家的構想。

How to produce more + colder antihydrogen ?

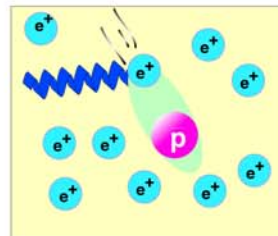
1 Antiproton Capture into Penning Trap



2 Positron Accumulation from Na-22 source



3 Positron-Antiproton Recombination in multi-ring trap



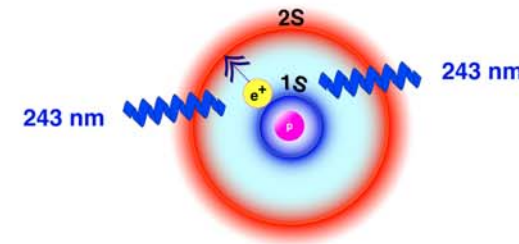
4 Antihydrogen Detection

- 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

ANTIHYDROGEN PRODUCTION

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

energy source of the future ?

$$E = mc^2$$

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



Energy
conservation !

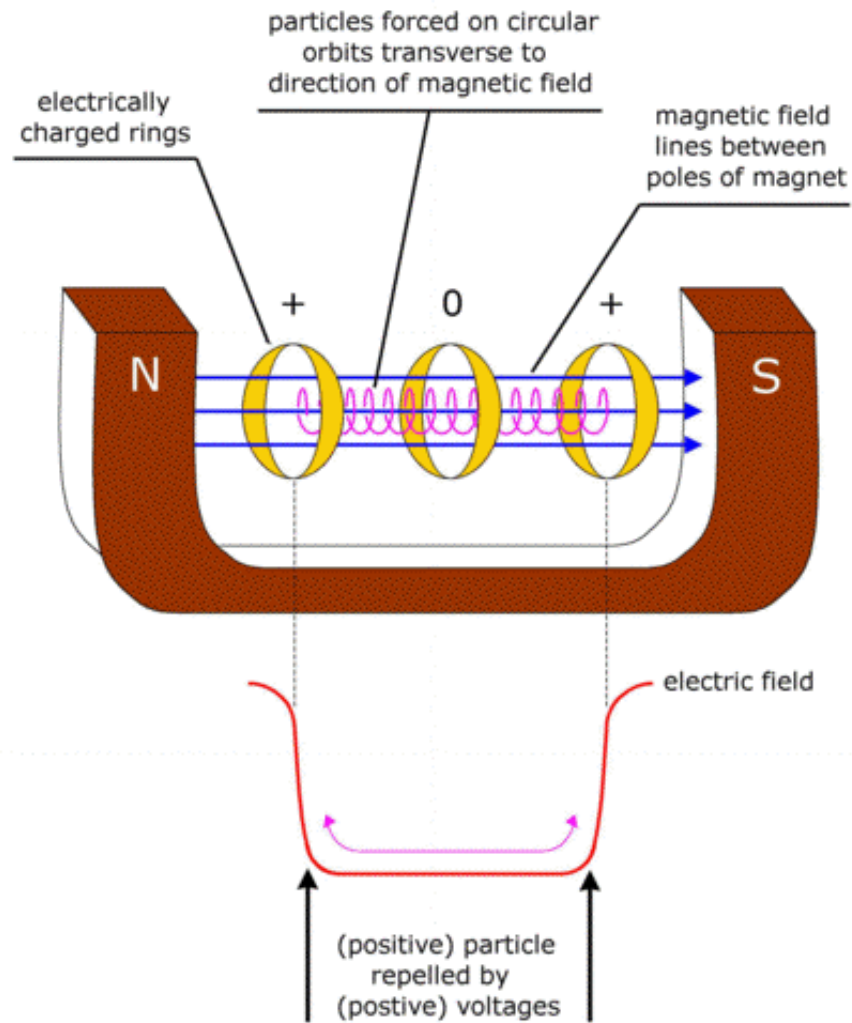
10^{12} antiprotons (10^{-12} g) \sim 30 MW \cdot day
 $\sim 10^6$ kWh \sim 100 k€

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

No antimatter mines!

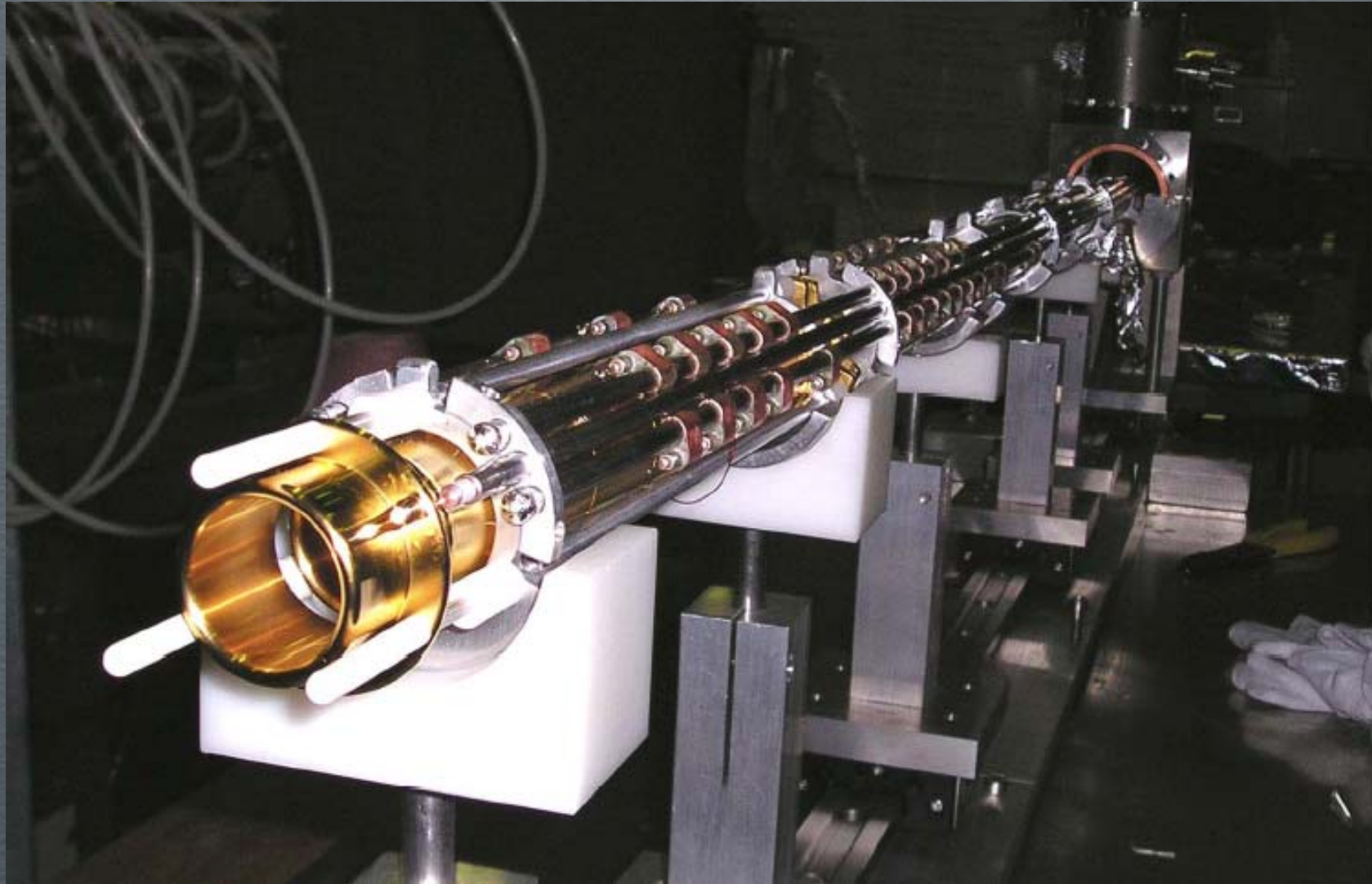
PARTICLE TRAPS

HOW A TRAP WORKS



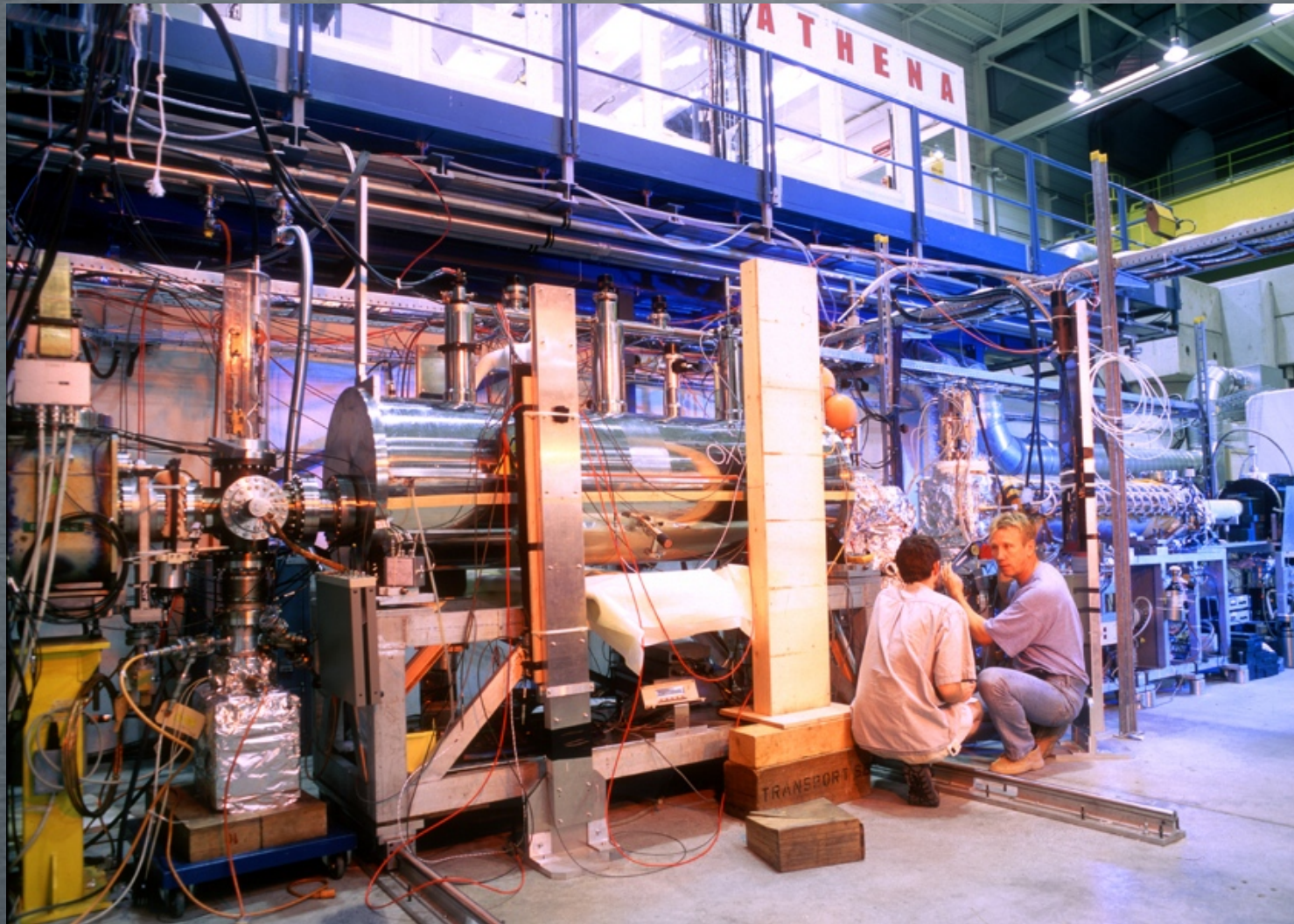
Particles fired into such a ring system are completely trapped by the electric and magnetic fields applied.

2002 - athena experiment



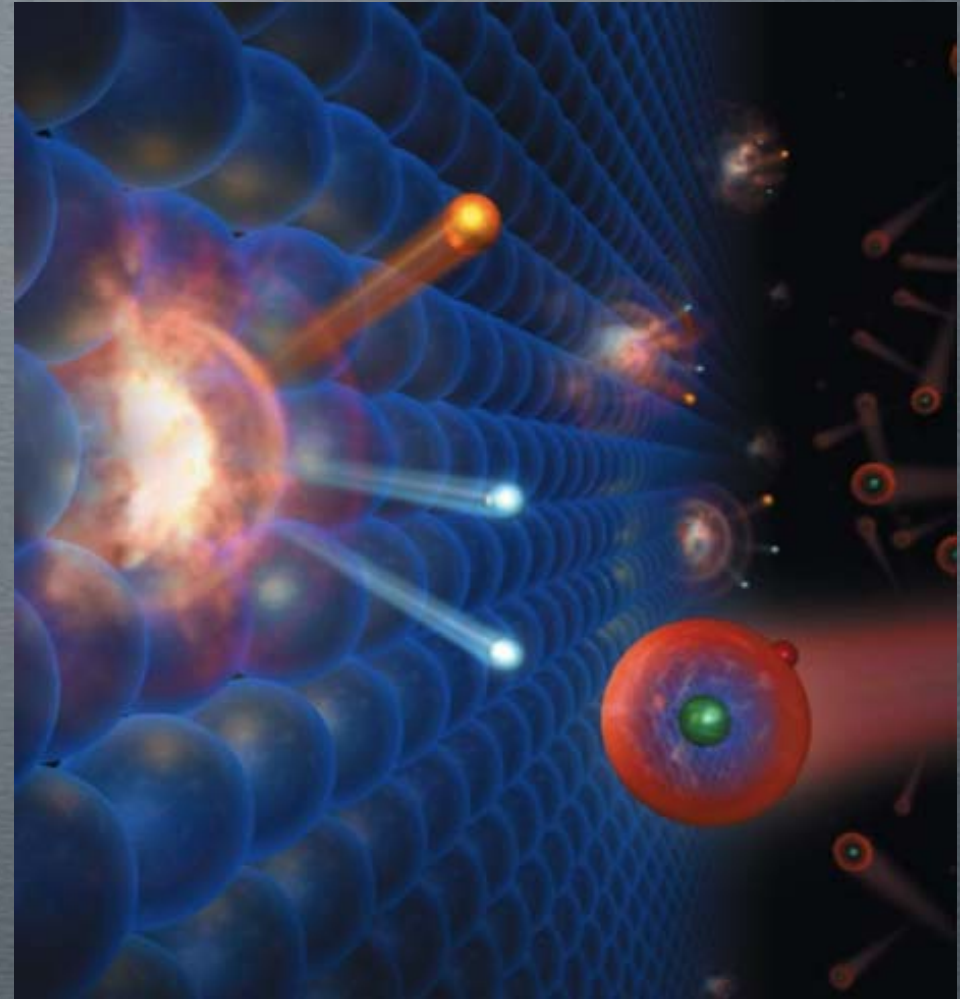
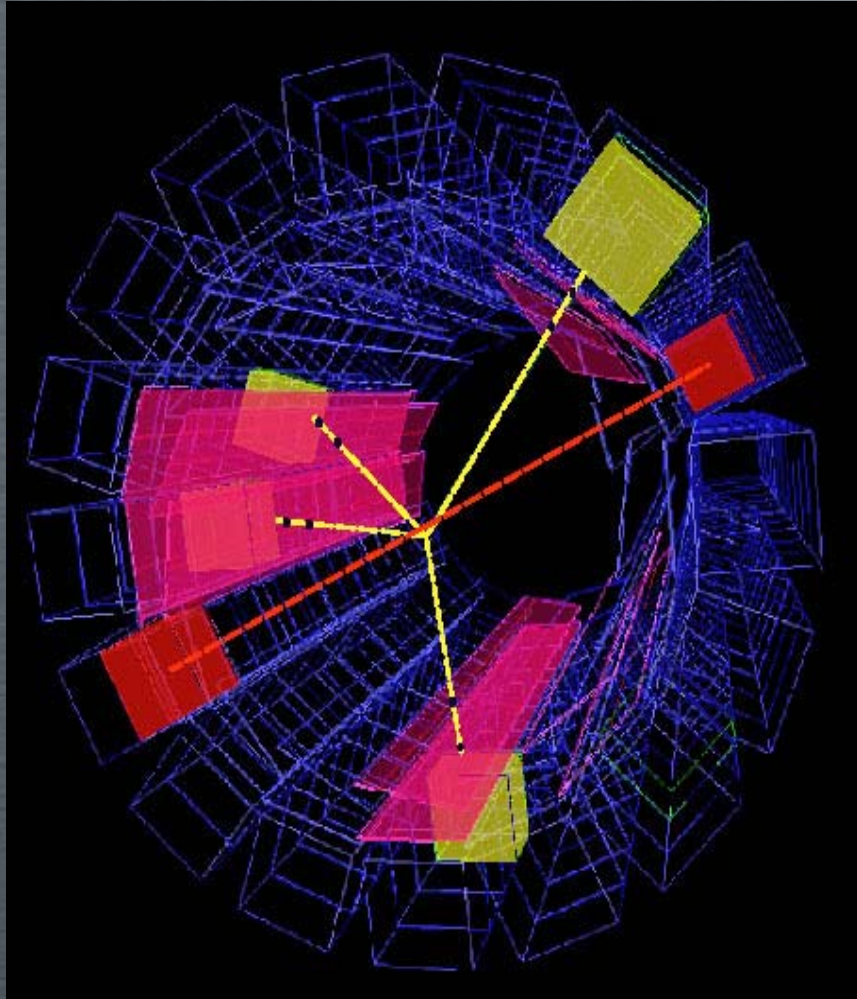
Trap for antiparticle storage

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

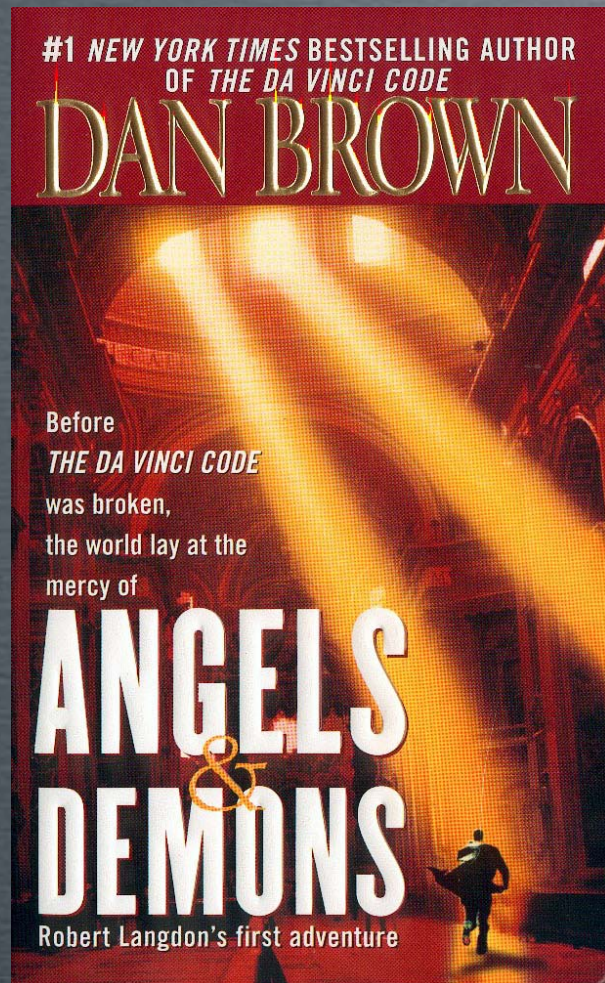
$$E = mc^2$$

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

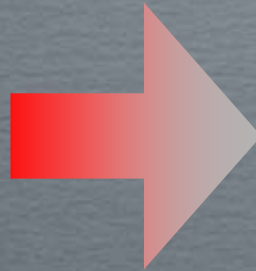
0.5 g antimatter + 0.5 g
matter

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

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



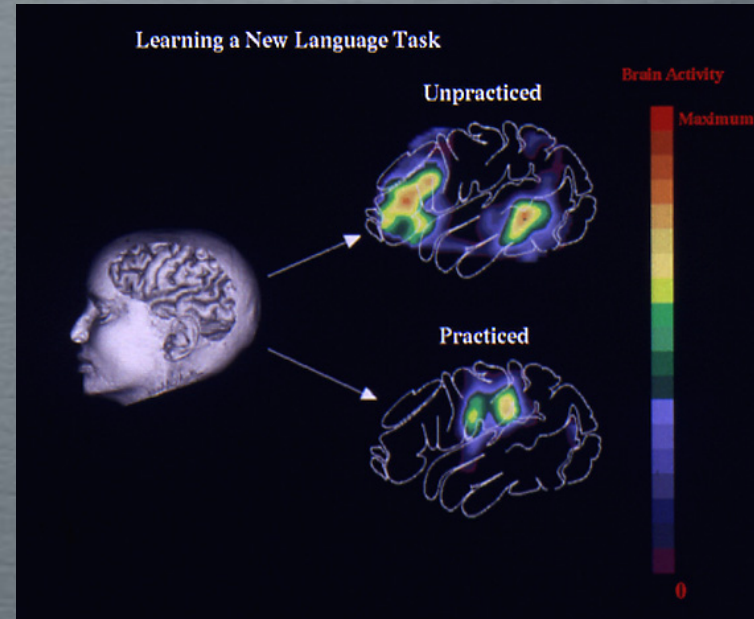
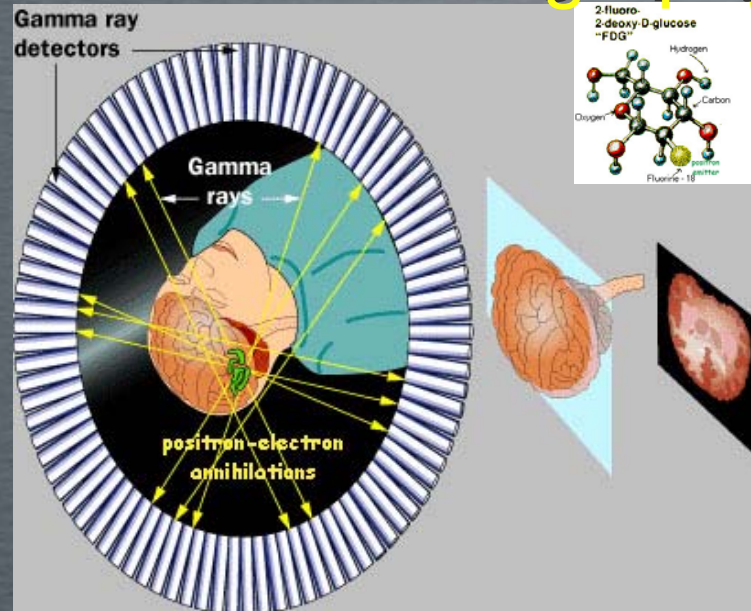
LEONARDO
VETRA



Promotion to 'CERN demon'
(thanks, Dan)

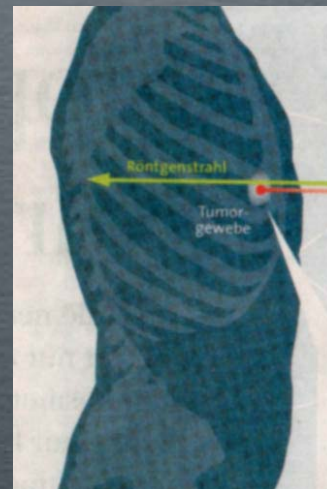
other uses of antimatter

Positron Emission Tomography



Tumour treatment with antiprotons ?

(CERN experiment AD-4/ACE)



Thank you
for your attention