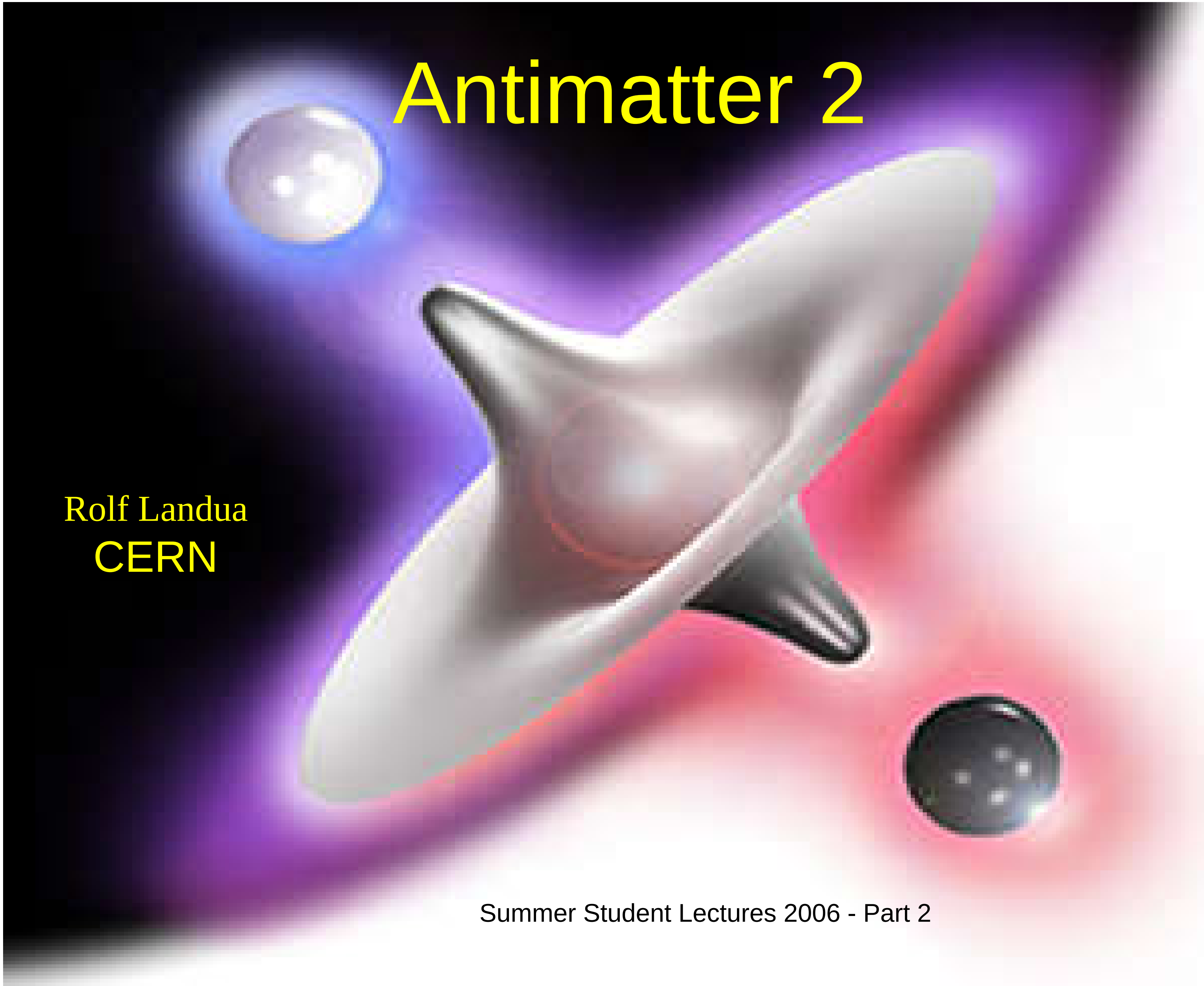
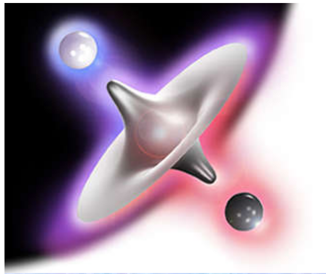
Antimatter 2



Rolf Landua
CERN



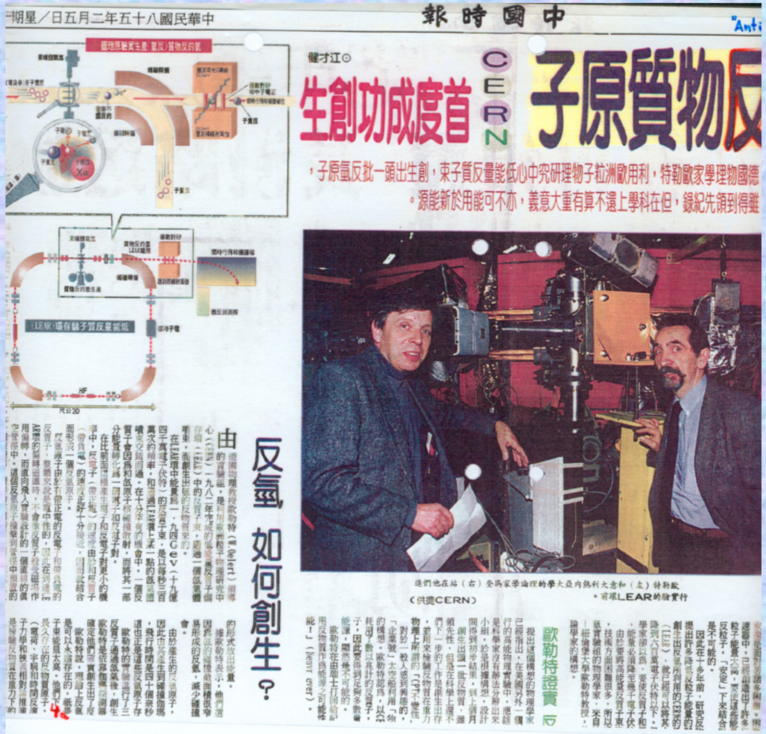
Overview Lecture 2

Antimatter 'Factory'
- Short history
- How are antiprotons made?

Antihydrogen
- ATHENA and ATRAP
- Making antihydrogen
- Future developments

Antimatter technology
- PET
- Antiproton therapy?
- Rocket propulsion??

The first nine antihydrogen atoms at CERN (1996)



中國時報

中華民國八十五年二月五日／星期一

CERN

反物質原子首度成功創生

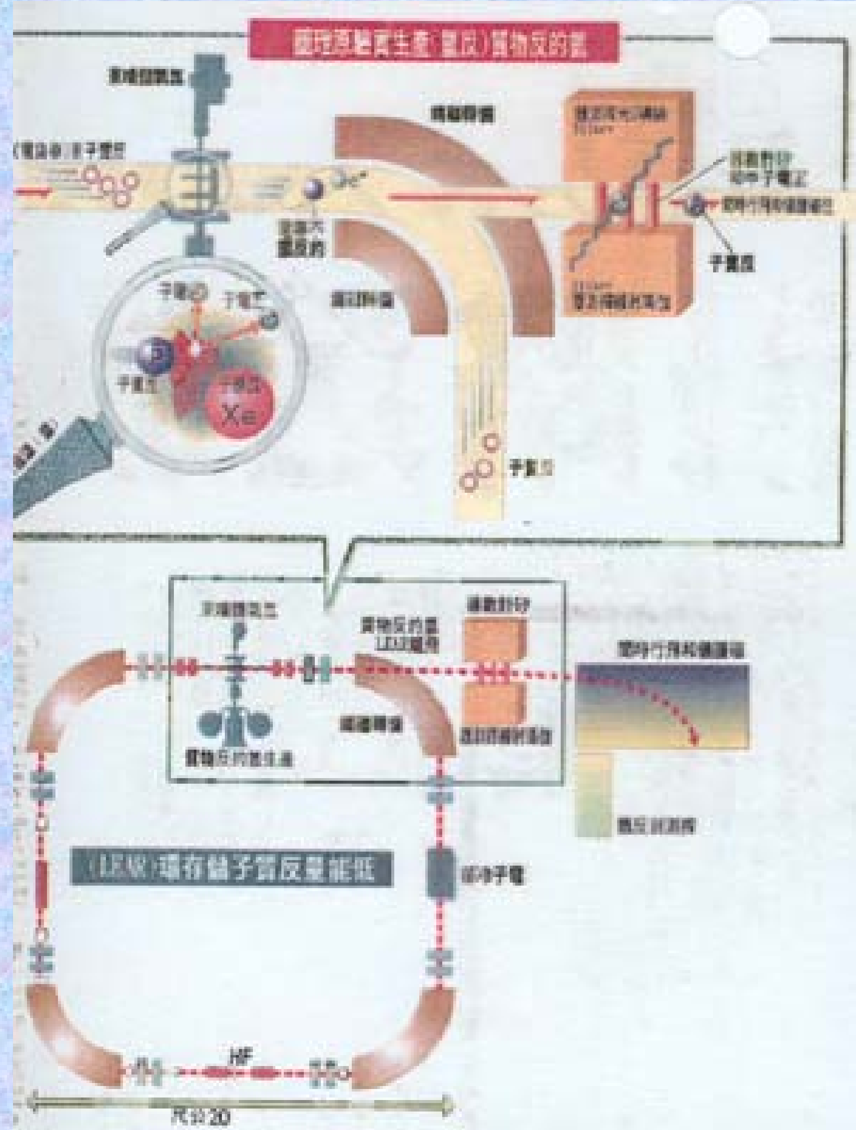
江才健⊙

德國物理學家歐勒特，利用歐洲粒子物理研究中心低能量反質子束，創生出頭一批反氫原子，雖得到領先紀錄，但在科學上還不算有重大意義，亦不可能用於新能源。

反氫 如何創生？

歐勒特語實

（供應CERN）



Further media coverage ….

"Blick" (Switzerland)


2 BLICK • Samstag, 6. Januar 1996 AKTUELL

E.T., wir kommen!

In Genf wurde Wunder-Energie entdeckt

VON WERNER BUCHER

"Liberation" (France)


Libération

Premiers pas dans l'antimonde

«C'est mille fois plus puissant qu'une réaction nucléaire normale»

Le Pr Oelert ne nie pas un possible usage militaire des antiatomes.

Walter Oelert, professeur à l'Institut de recherches nucléaires de Jülich en Allemagne, dirige la petite équipe germano-italienne réunie en 1993 qui a obtenu neuf antiatomes d'hydrogène.

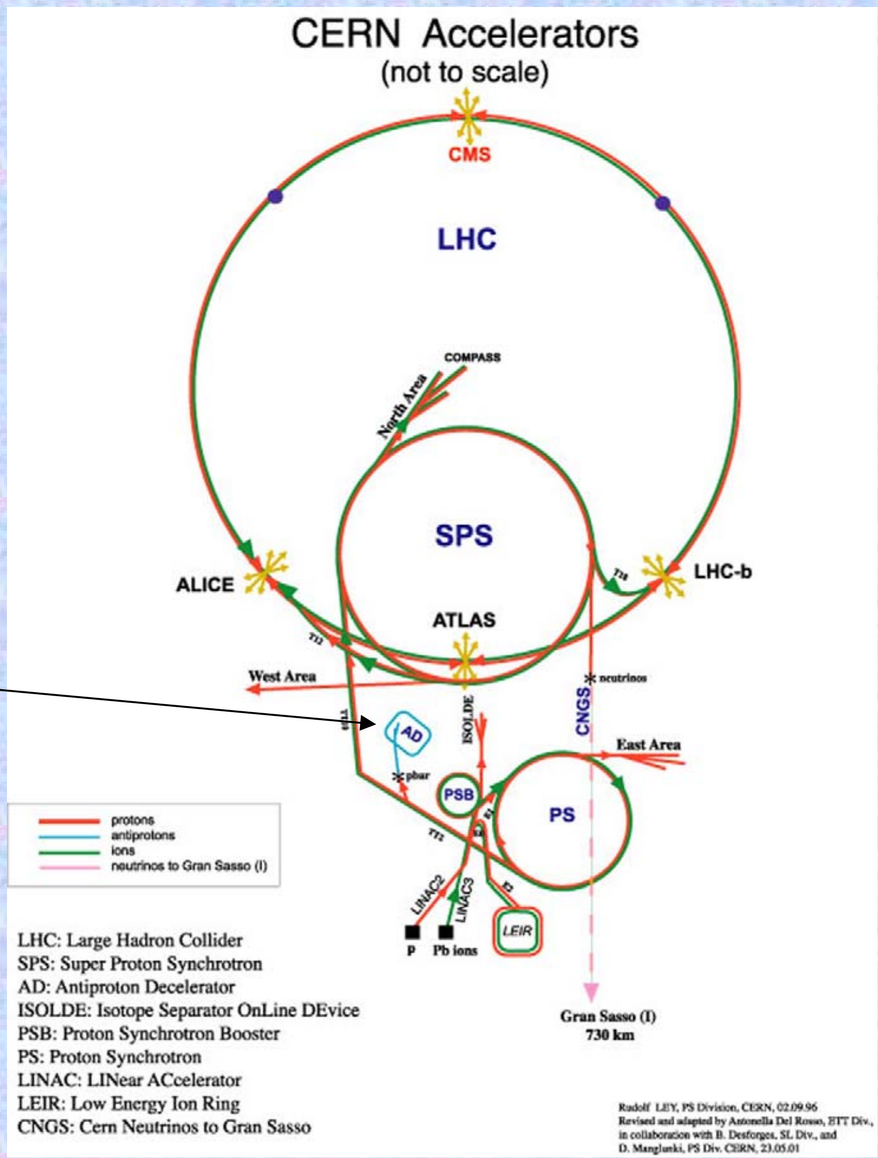
puis se sont déchirés en tombant sur le détecteur de silicium, l'antiproton d'un côté, l'antiélectron de l'autre. **Pourrait-on faire une bombe avec cette antimatière?**

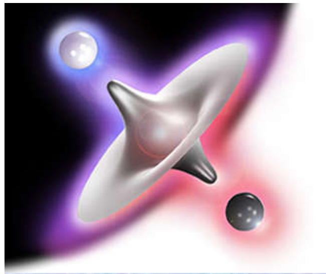
III. ANTIMATTER 'FACTORY'

(also-known-as: "Antiproton Decelerator")

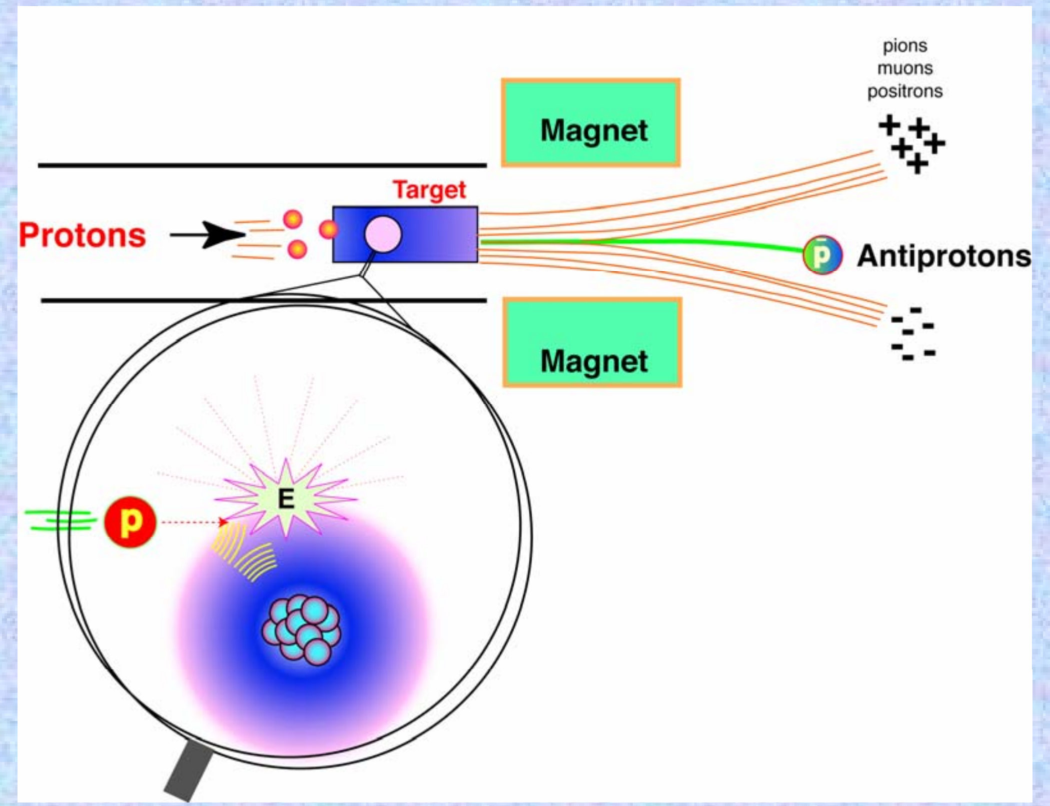
The Antiproton Decelerator (AD)

QuickTime™ and a
GIF decompressor
are needed to see this picture.





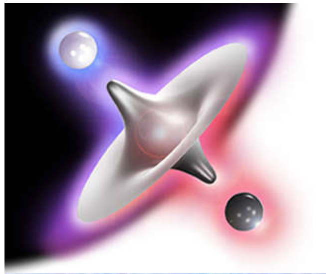
An accelerator ‘condenses’ energy* in collisions



Peak production at CERN ~ 200,000,000,000,000 antiprotons/year

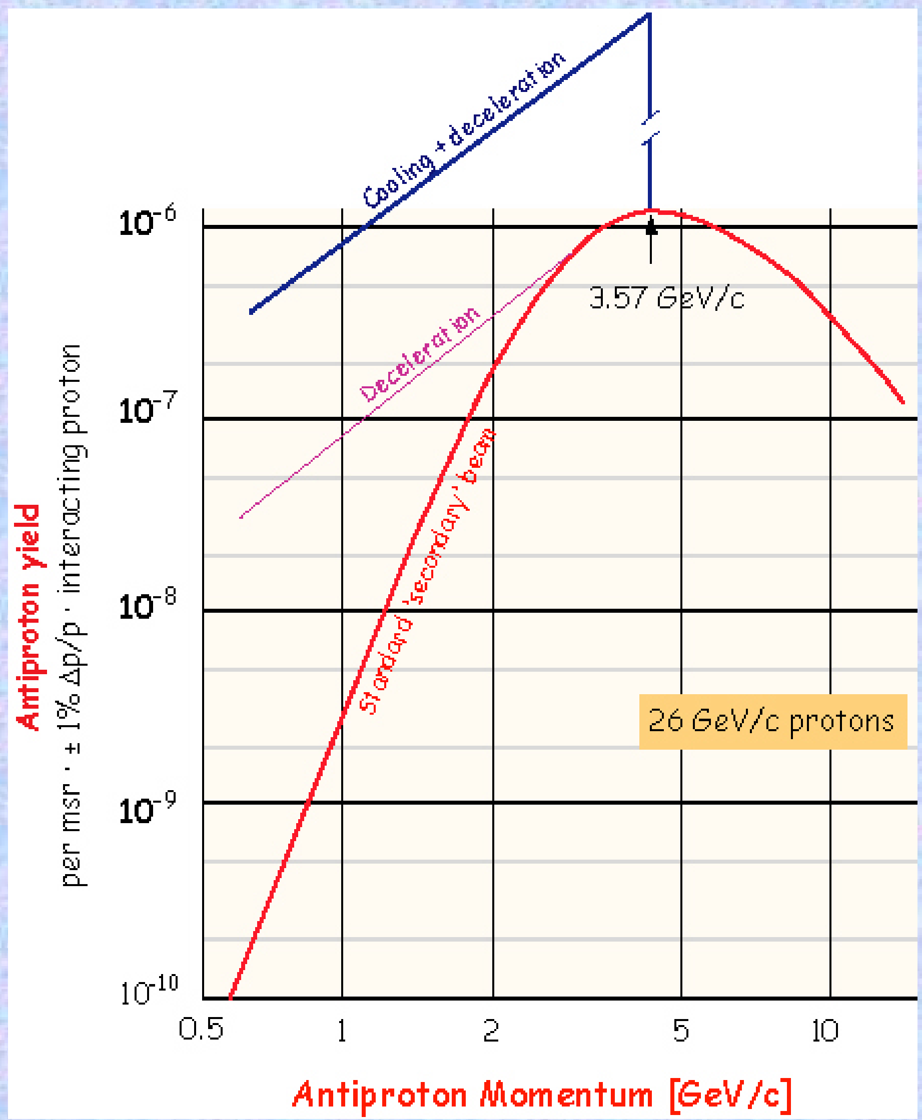
This is only 0.3 nano-gram !!

[* A tiny percentage of the initial kinetic energy]



Efficiency of antiproton production (at 26 GeV/c)

~ few 10^{-6}
(per proton-on-target)



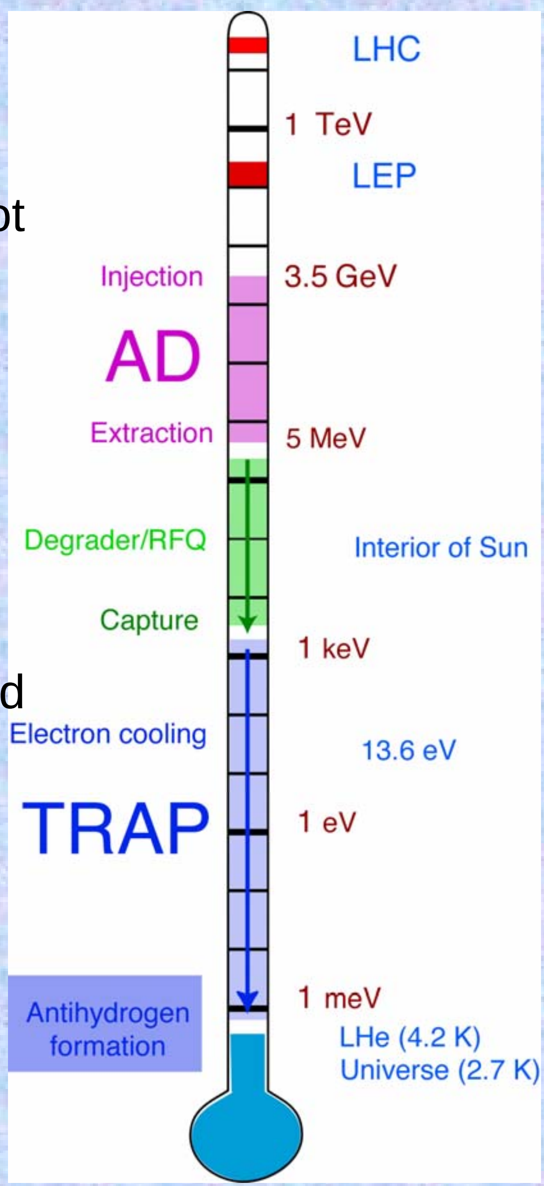
Challenge of antihydrogen production

Antiprotons and positrons (when young) are hot

Hydrogen atom is a weakly bound system:

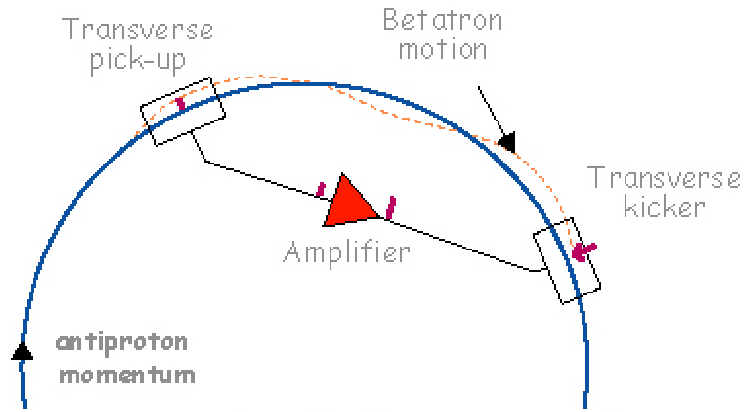
E (1s) = - 0.000 000 013 6 GeV

Constituents need to chill before getting married



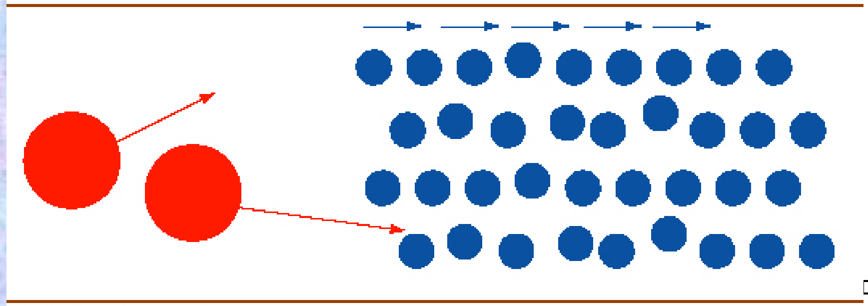
The Antiproton Decelerator (AD)

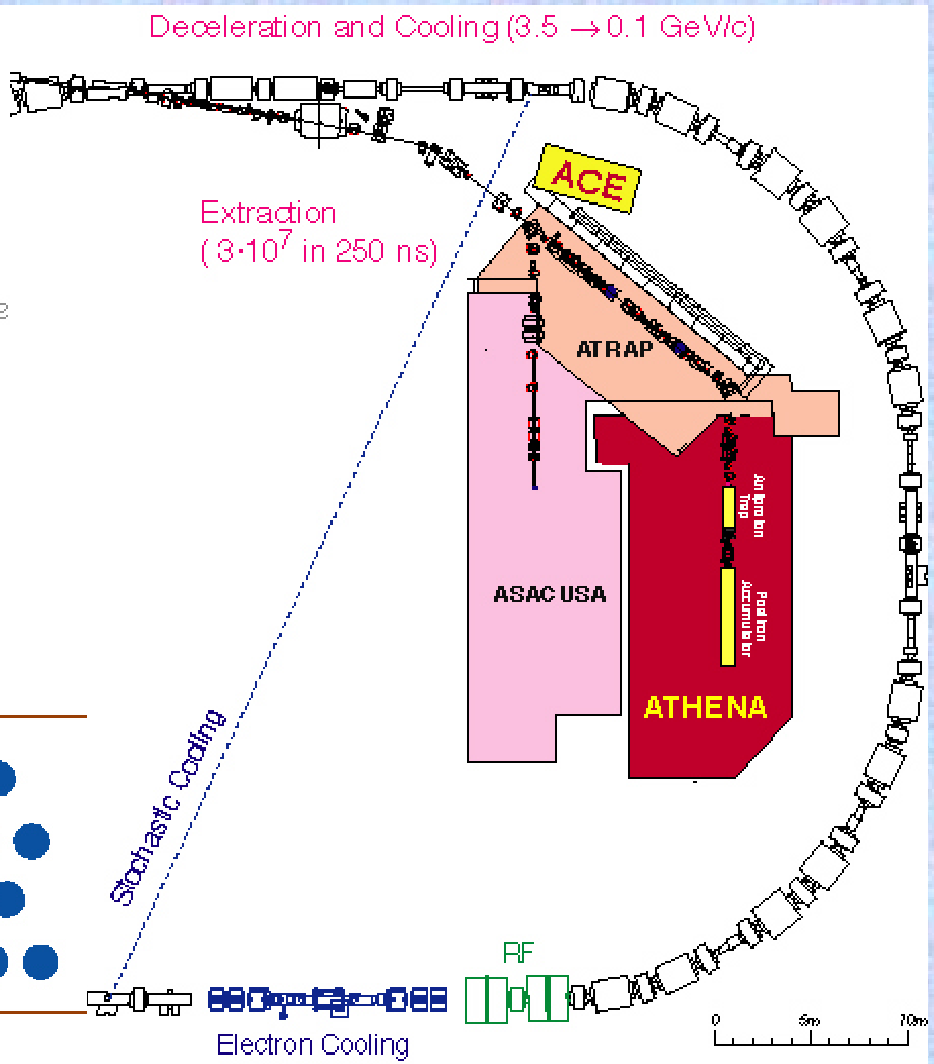
Principle of stochastic cooling



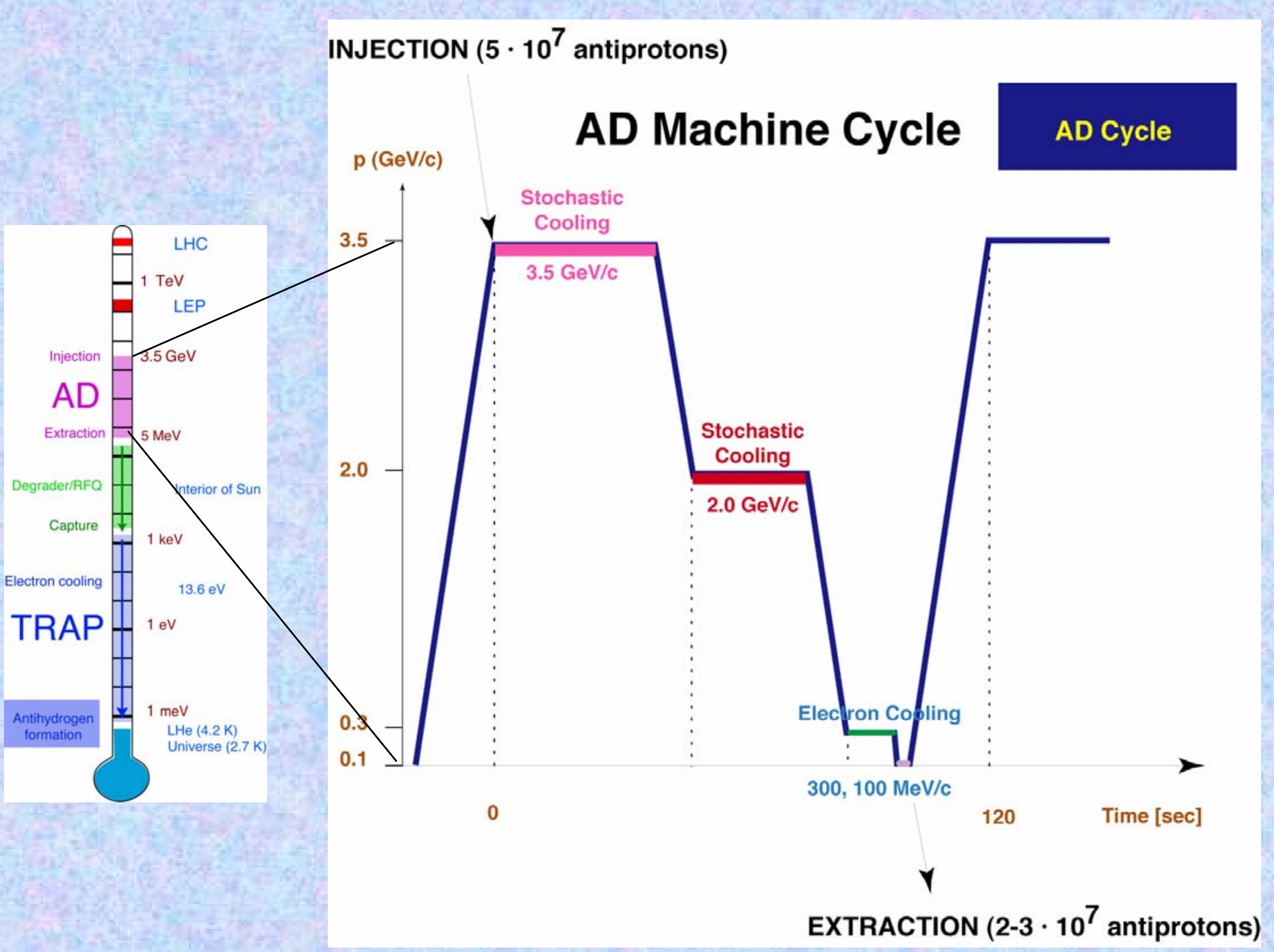
Principle of electron cooling

$\langle V_{(antiprotons)} \rangle = \langle V_{(electrons)} \rangle$





The Antiproton Decelerator (AD)



Antiproton Decelerator (Photos)

The AD family photo

The AD movie

QuickTime™ and a
DV - PAL decompressor
are needed to see this picture.

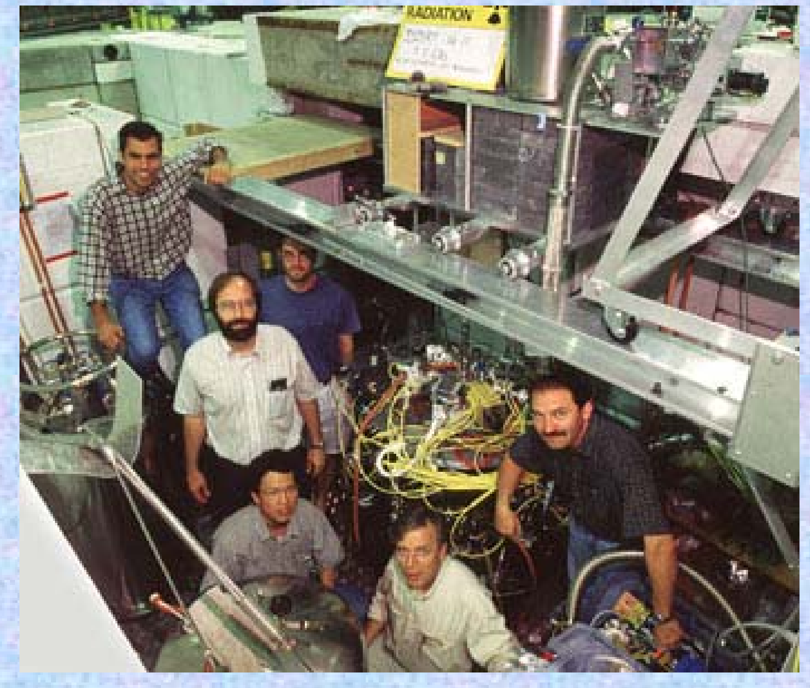
IV. ANTIHYDROGEN

Antihydrogen

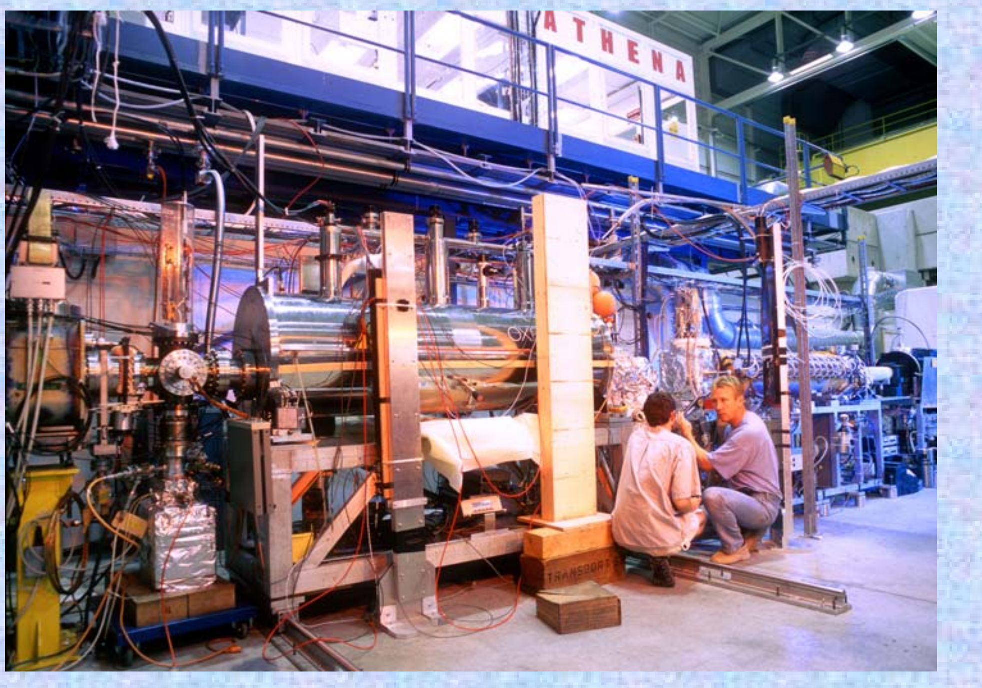
ATHENA and ATRAP - Experiments (Start 2000)

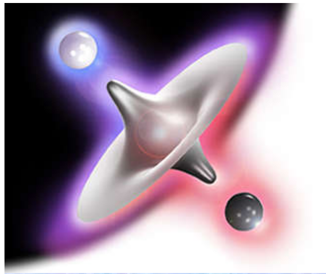
Find a way to make cold antihydrogen (done)
Trap and cool antihydrogen
Precision measurements

ATRAP

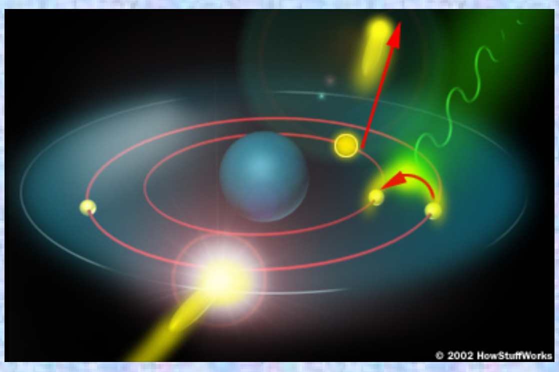


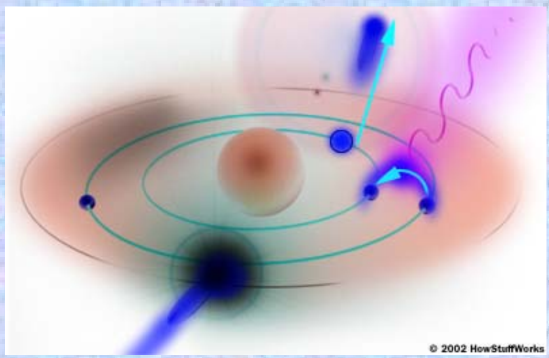
ATHENA

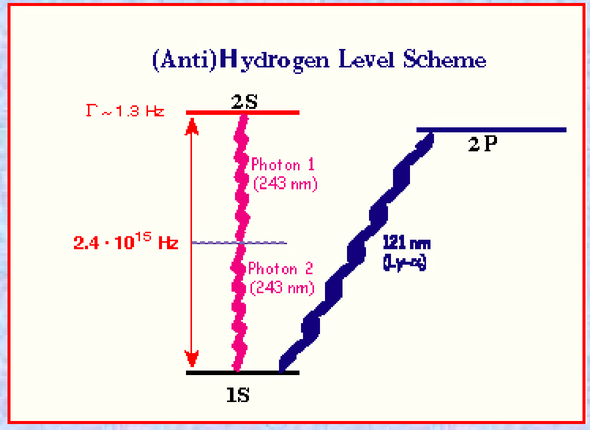




Antihydrogen = Hydrogen ??





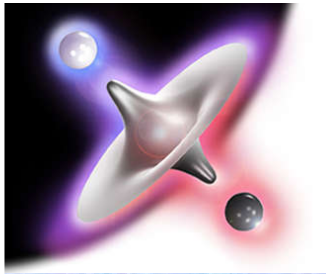


2S level is metastable (T ~ 120 ms)

→ Two photon laser-spectroscopy (1S-2S energy difference

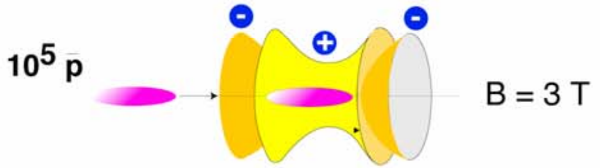
→ very narrow line width = high precision: $\Delta\nu/\nu \sim 10^{-15}$

→ Long observation time - need trapped (anti)atoms

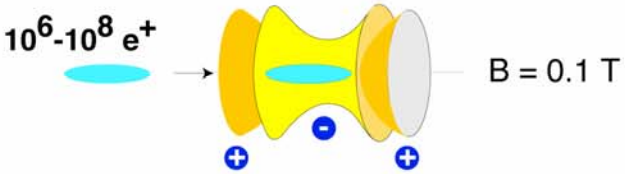


Antihydrogen milestones

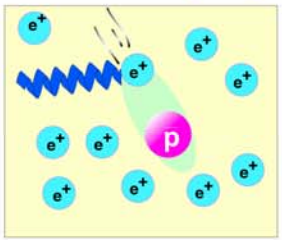
1. Antiproton Capture into Penning Trap



2. Positron Accumulation from Na-22 source



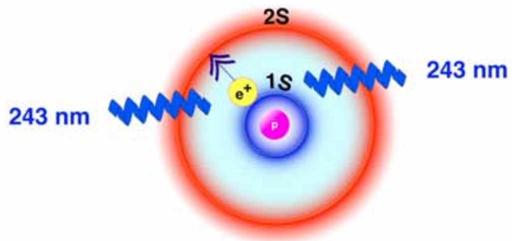
3. Positron-Antiproton Recombination in multi-ring trap



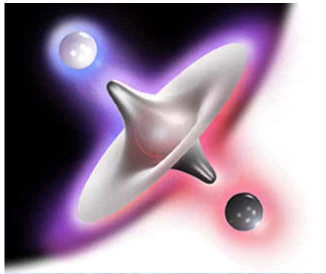
4. Antihydrogen **Detection**
   - Annihilation products: 2 layers x 16 Si Strips
   - 511 keV Gammas: 192 CsI Xtals + Photodiodes

5. Antihydrogen **Storage** in Magnetic Bottle
   Magnetic well depth ~ 0.35 K (35 μeV)
   (PHASE 2)

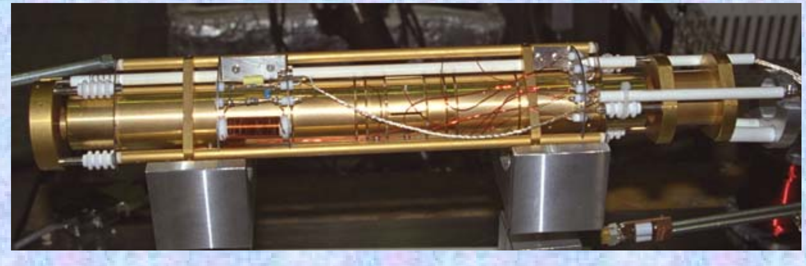
6. 2-Photon Laser **Spectroscopy**: ΔE (1S-2S)
   (PHASE 2)

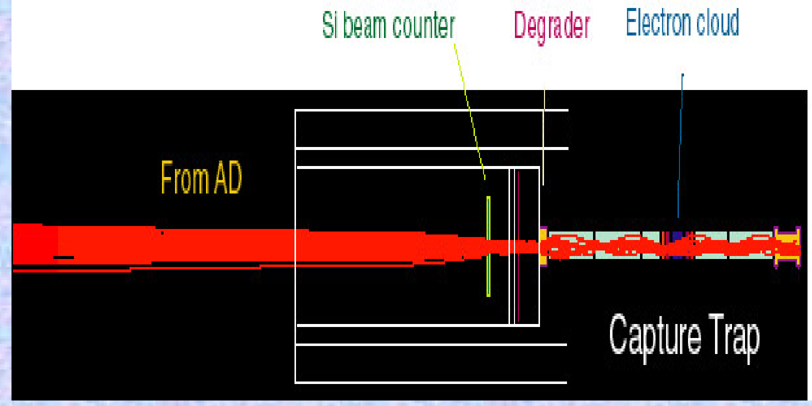


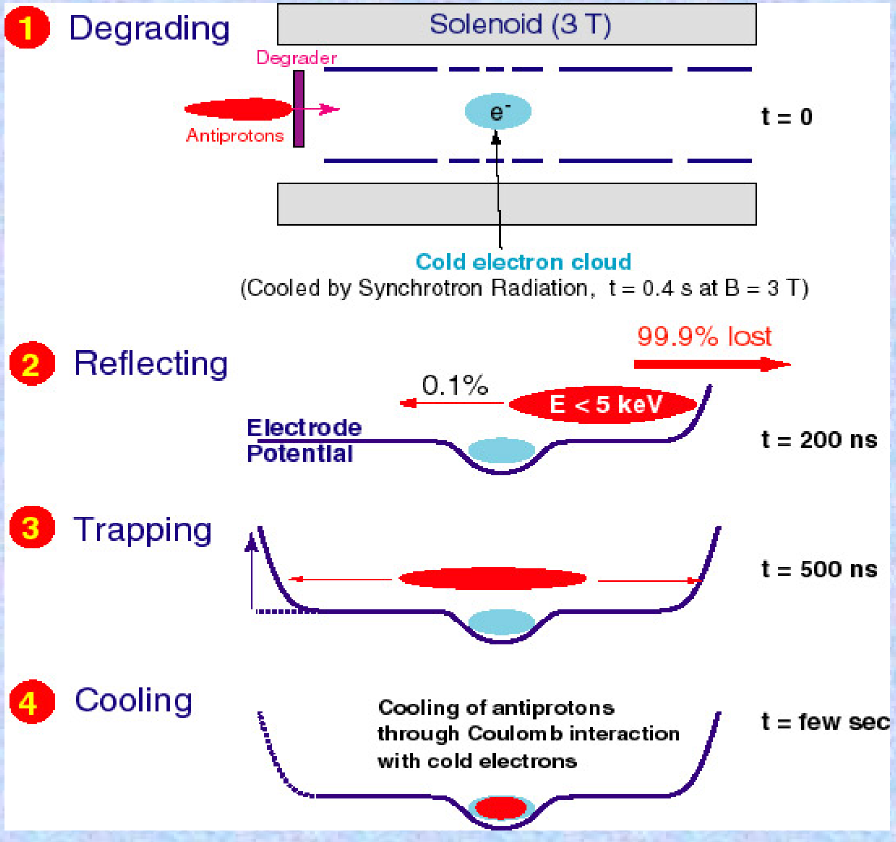
Comparison $\bar{H}$: H with precision 10^{-12} ...10^{-15}



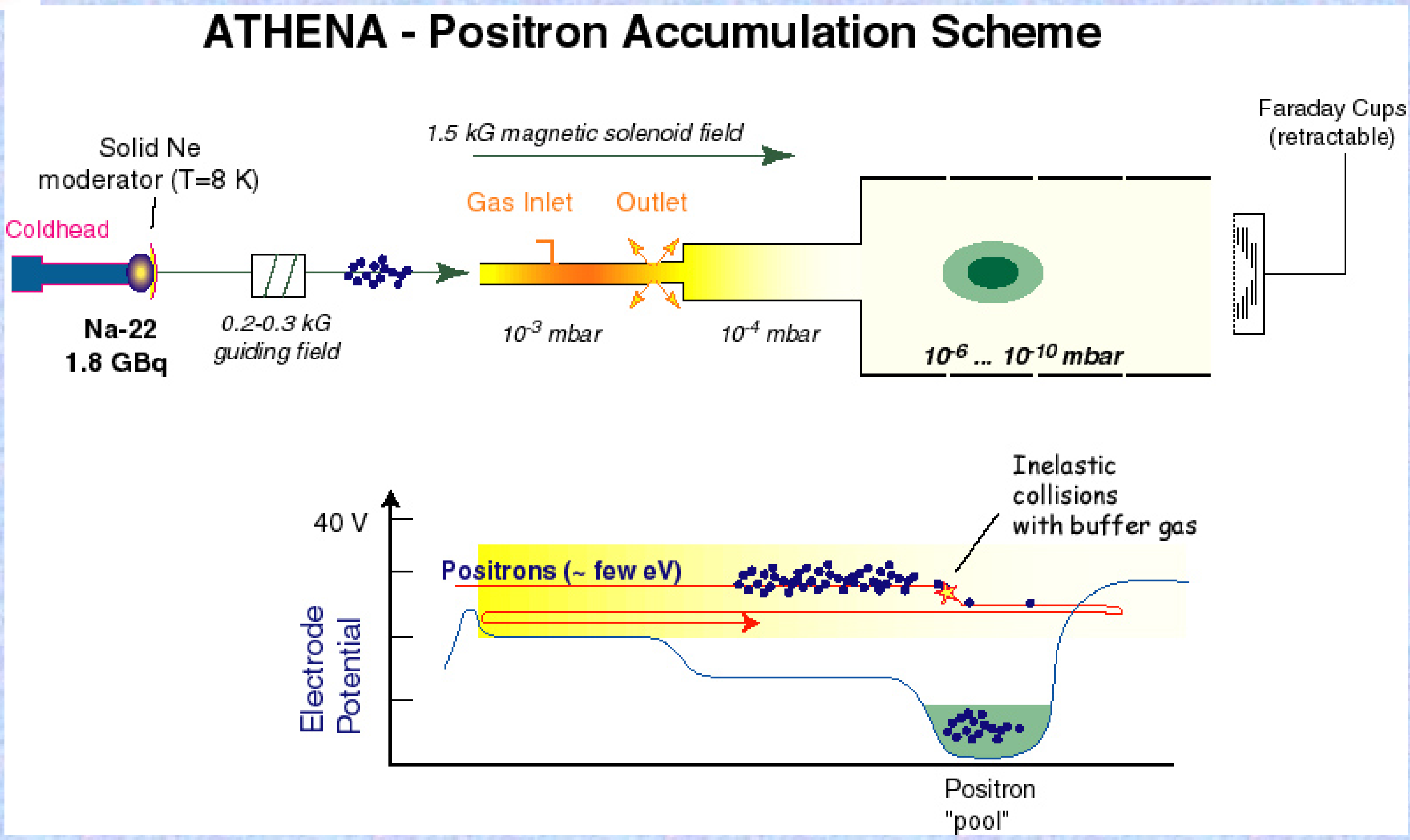
Trapped antiprotons*





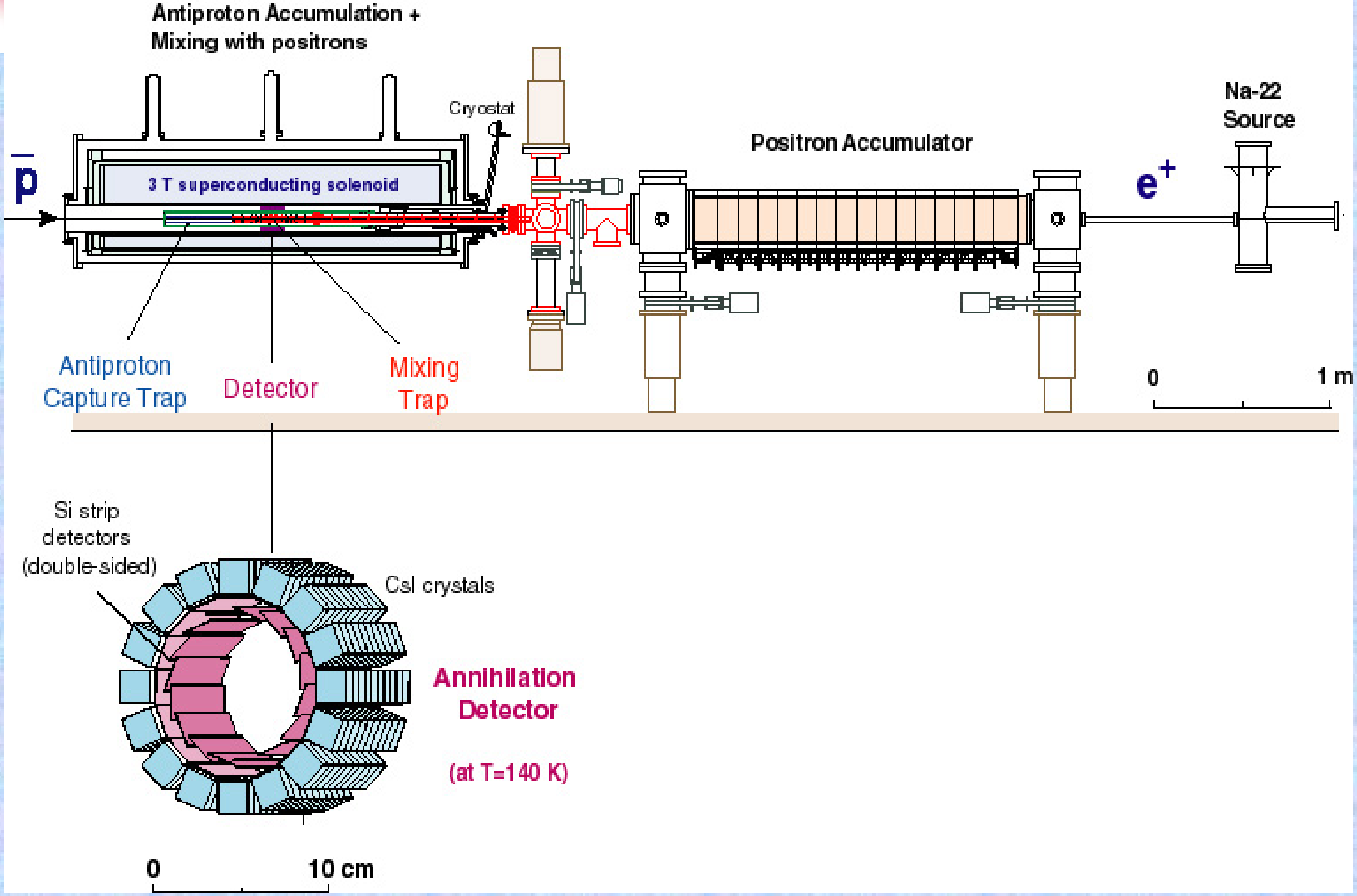


Positron Accumulation (ATHENA)



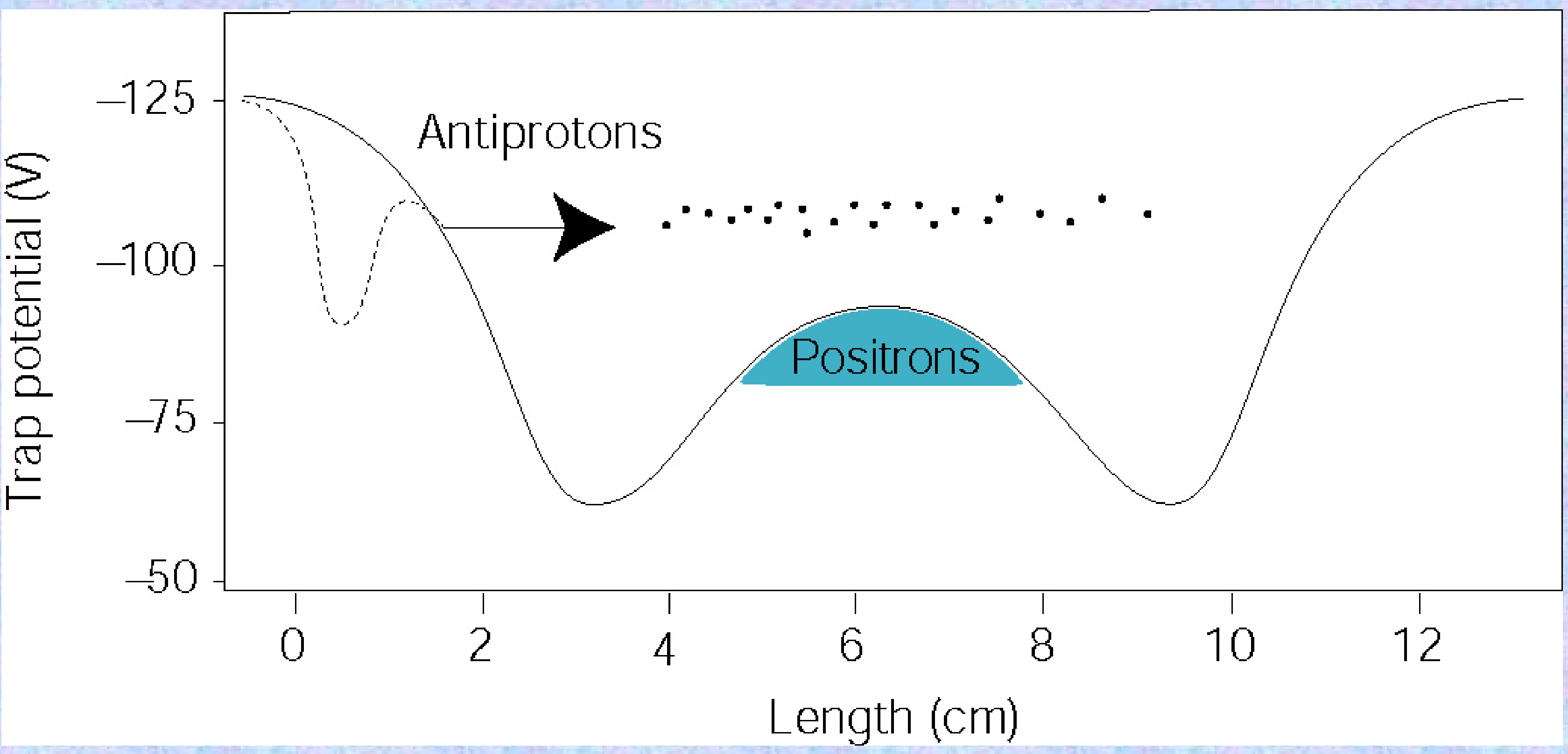
100 million positrons in 2 min

Overview - ATHENA / AD-1



Recombination

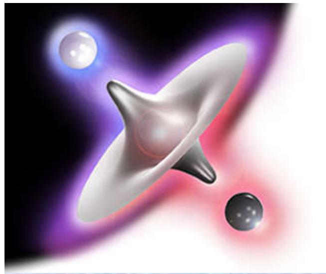
Recombine free positrons + antiprotons using "nested traps"

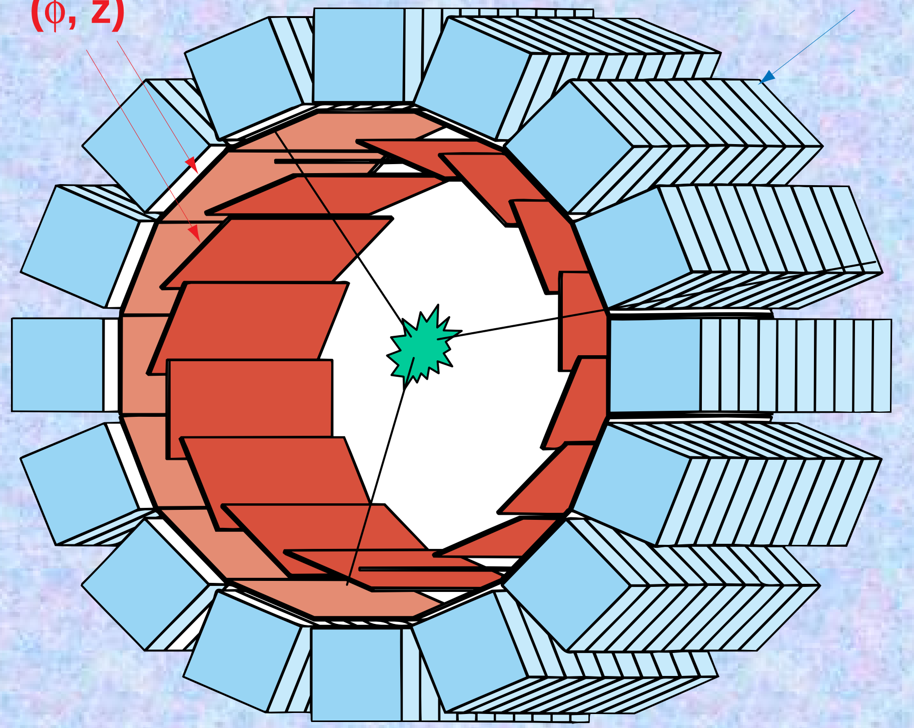


Antihydrogen - The Movie

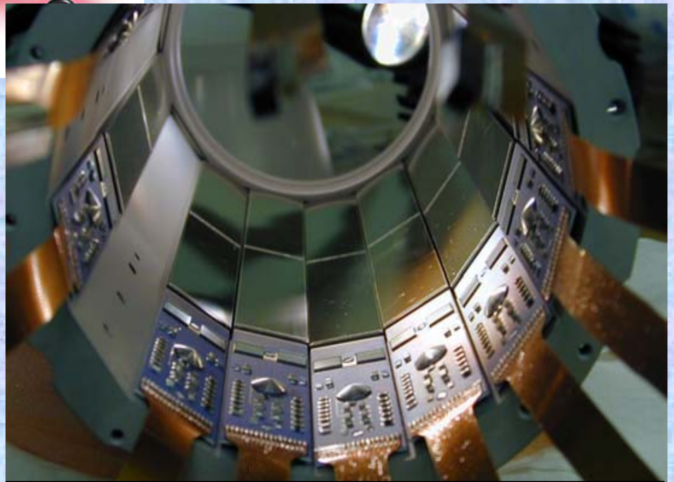
QuickTime™ and a Sorenson Video decompressor are needed to see this picture.

Antihydrogen Detector



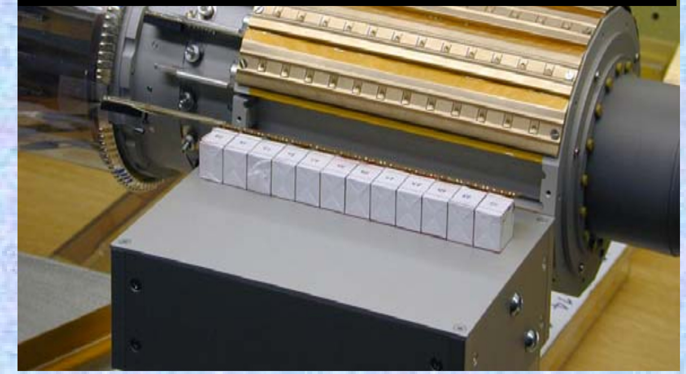


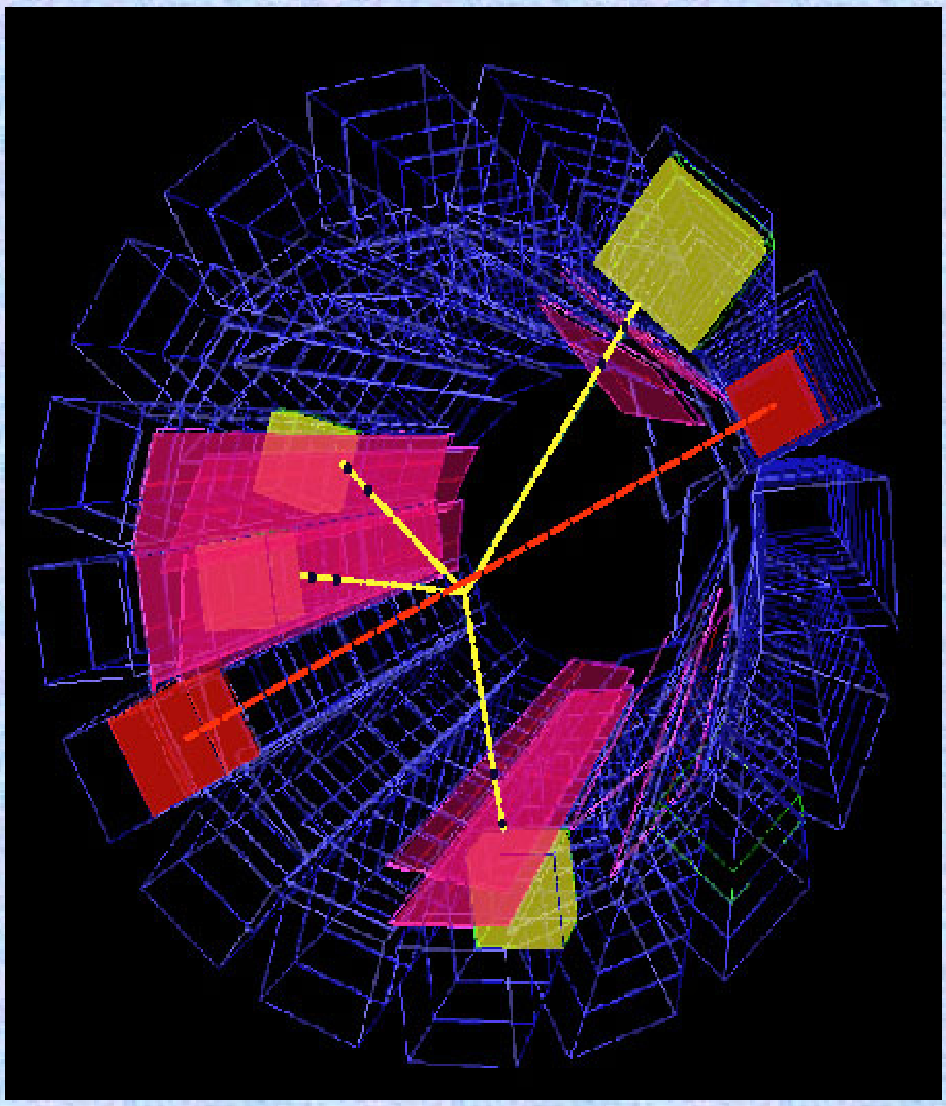
Antihydrogen Detector



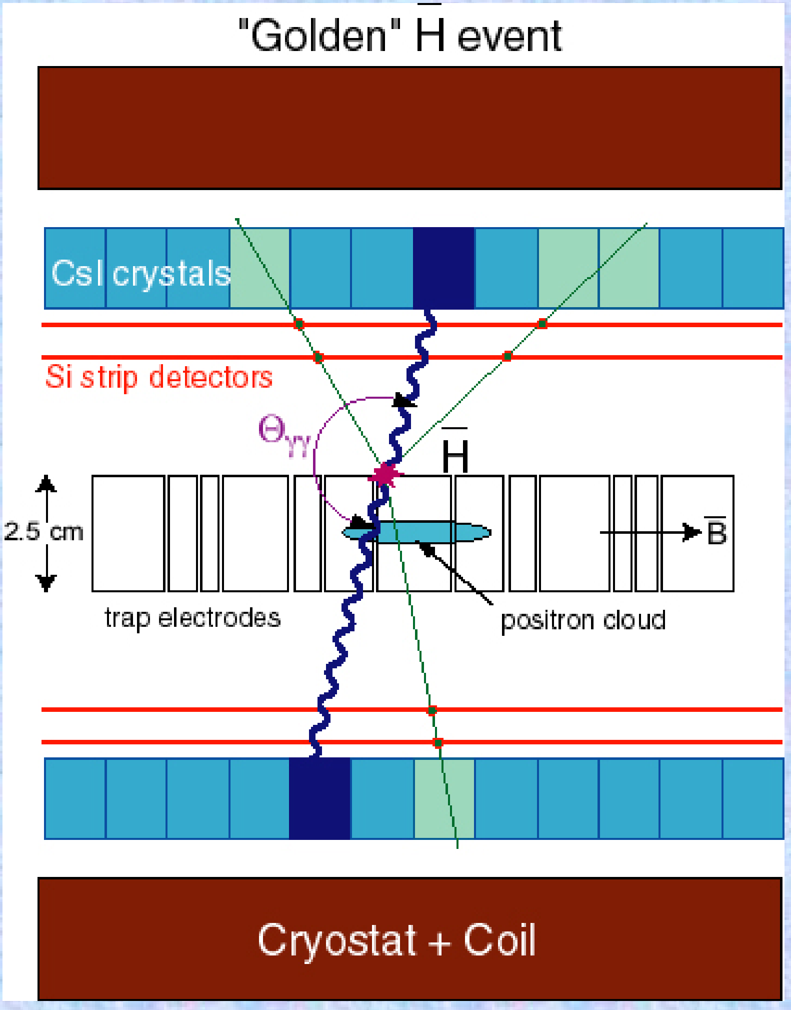
Operated at 140K, 3T, small space

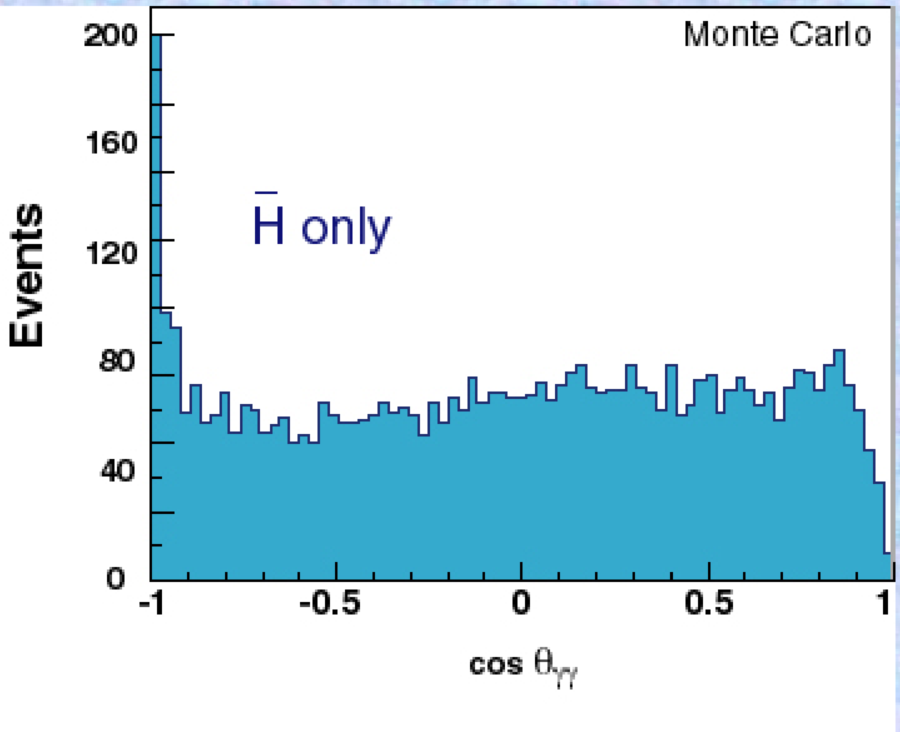
- 2 x 16 Si microstrip detectors
- 192 CsI crystals, APD readout



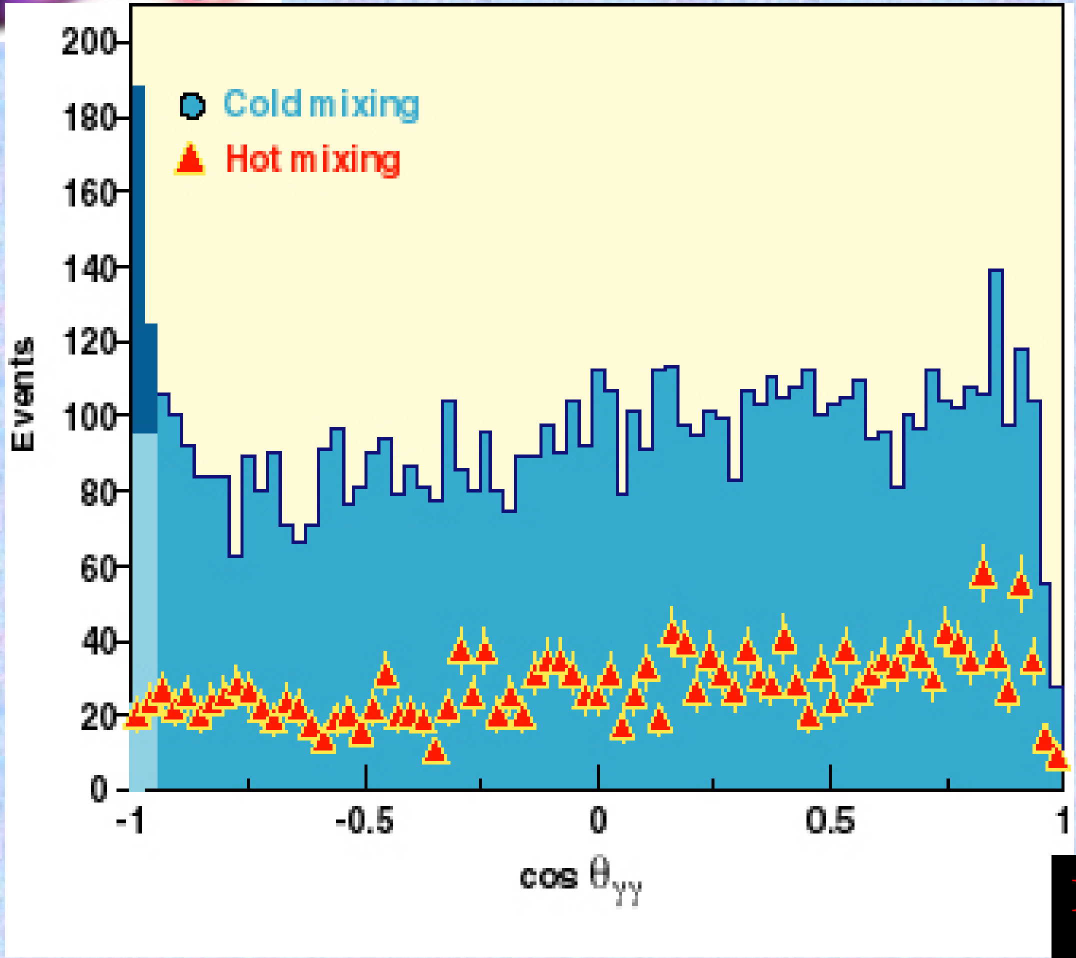


Expected antihydrogen signal (simulation)





First observation of cold antihydrogen



M. Amoretti et al., ***Nature*** **419**, 456 (2002)

Aug 2002:

131 ± 22 events

(above flat spectrum at cos < -0.95)

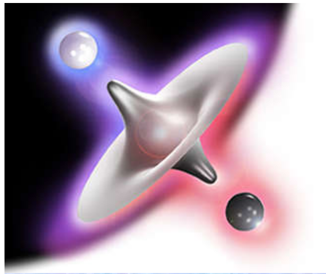
> 50,000 produced antihydrogen

(conservative estimate)

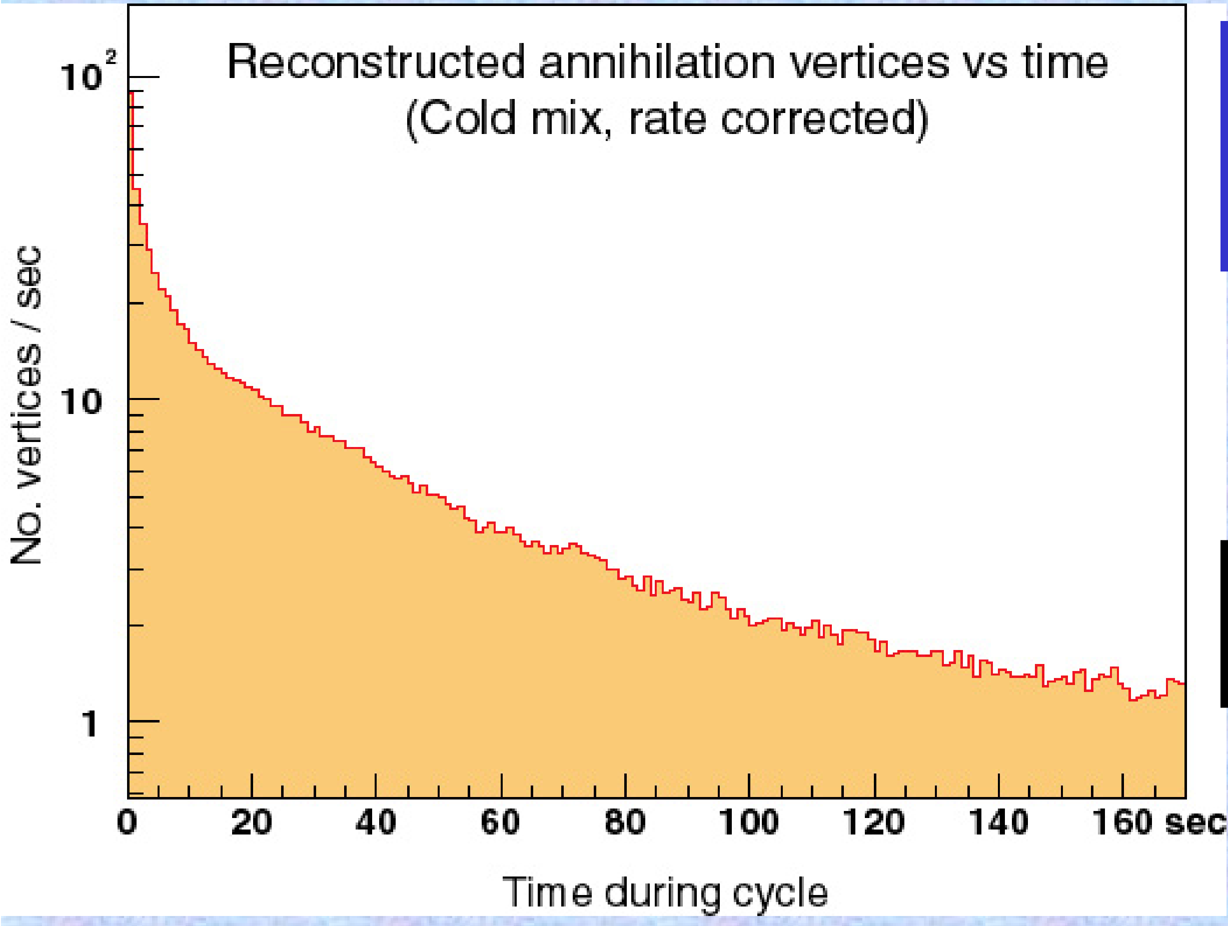
Background:

Mixing with 'hot' positrons(~ 3000 K)

[suppressed recombination]



Rate of antihydrogen production



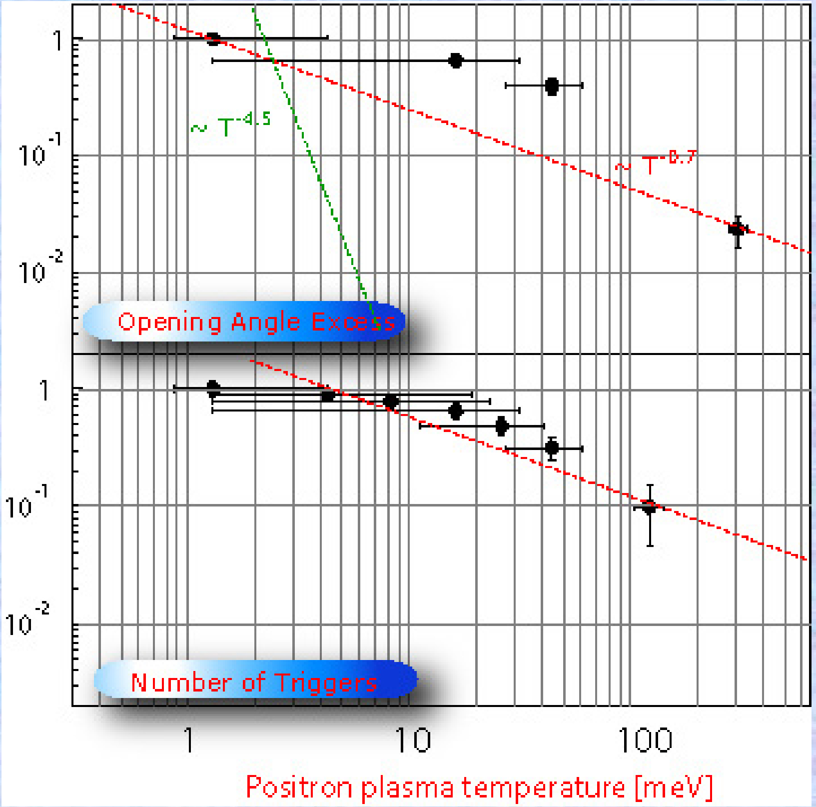
Analysis:

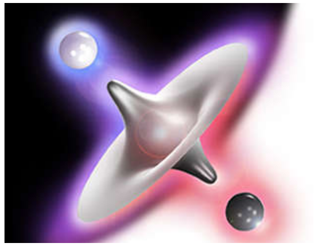
- 65 ± 10 % antihydrogen
- ~ 50 % vertex / annihilation

High Initial Rate **(> 100 Hz)**

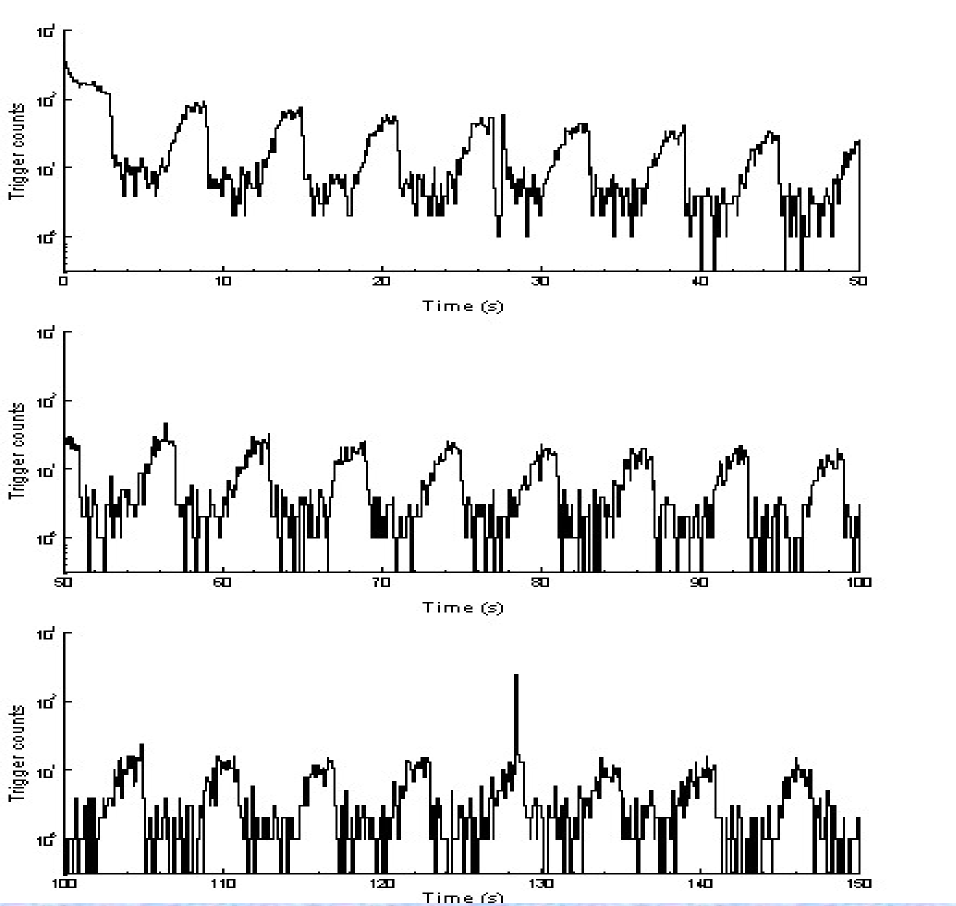
High S/B (~ 10:1) in first seconds

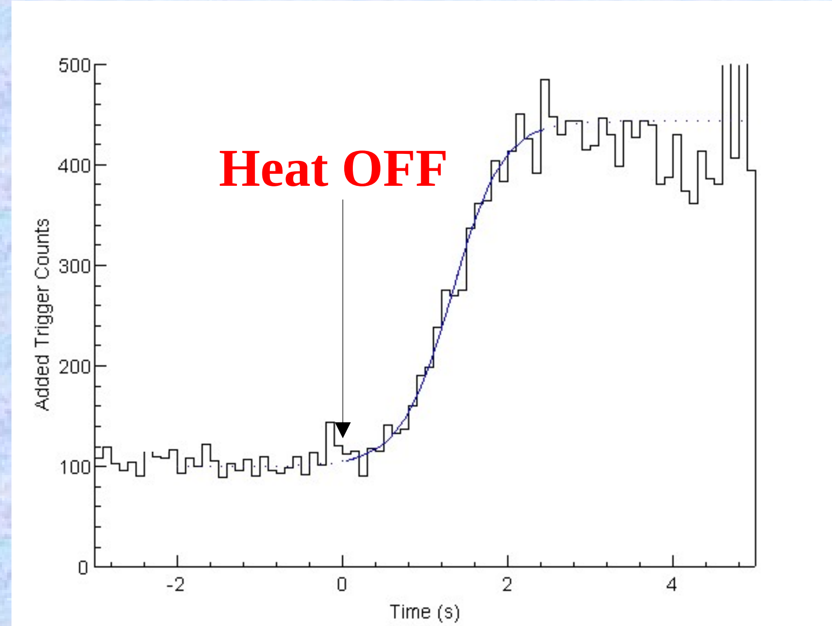
Rate dependence on temperature





Pulsed antihydrogen production



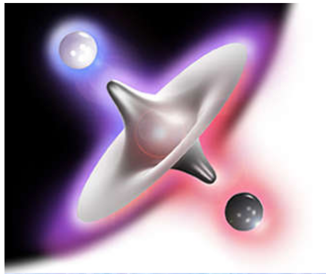


Heat On/Off every 3 sec

Rise time contains physics:

Positron cooling time (τ ~ 0.4 sec)

Temperature dependence of antihydrogen form



Summary

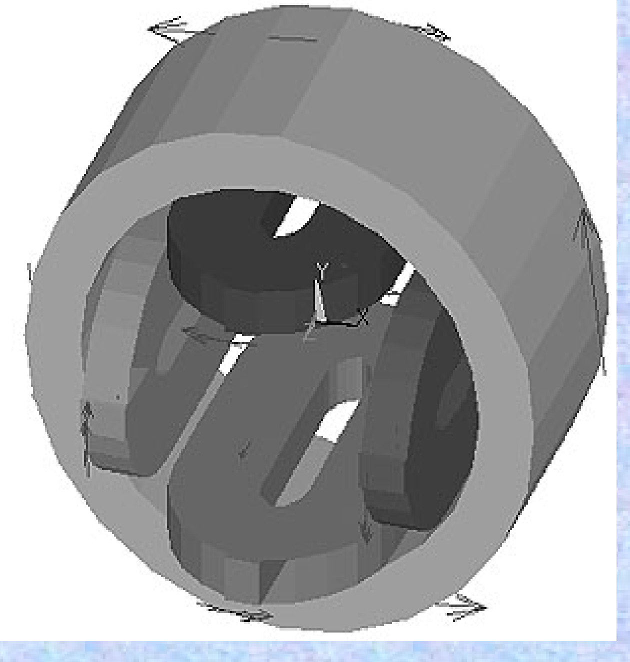
	Number of produced antihydrogen atoms	Energy
1996:	9 (PS210, CERN)	2 GeV
1998:	60 (Fermilab)	3 GeV
2002:	~ 1,000,000 (ATHENA, ATRAP)	0.001 eV

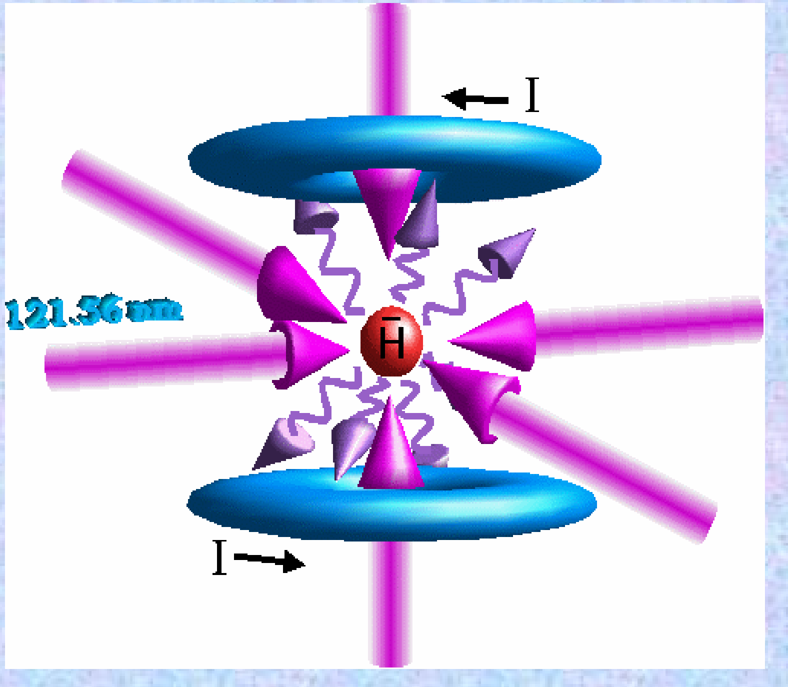
Antihydrogen trapping and cooling

Antihydrogen trapping by magnetic gradient field

Problem: very shallow potential (~ 0.07 meV/Tesla)

Antihydrogen laser cooling (121 nm) (2002: 50 nW)

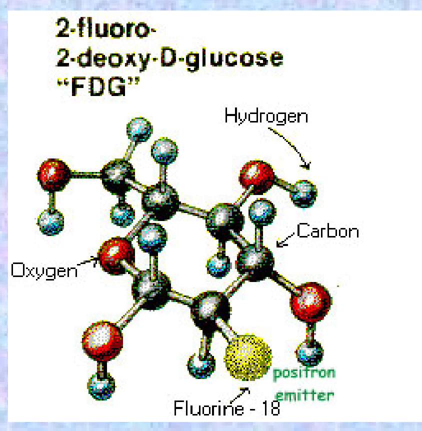




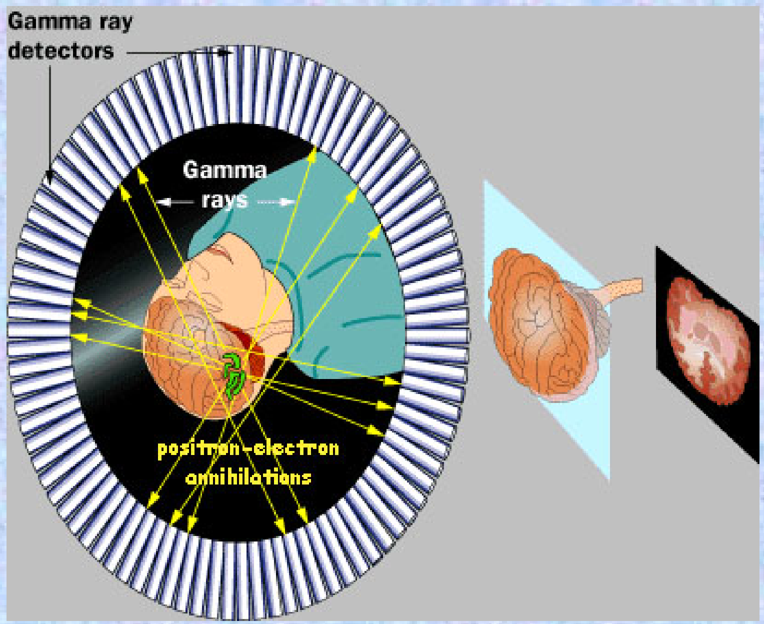
V. APPLICATIONS

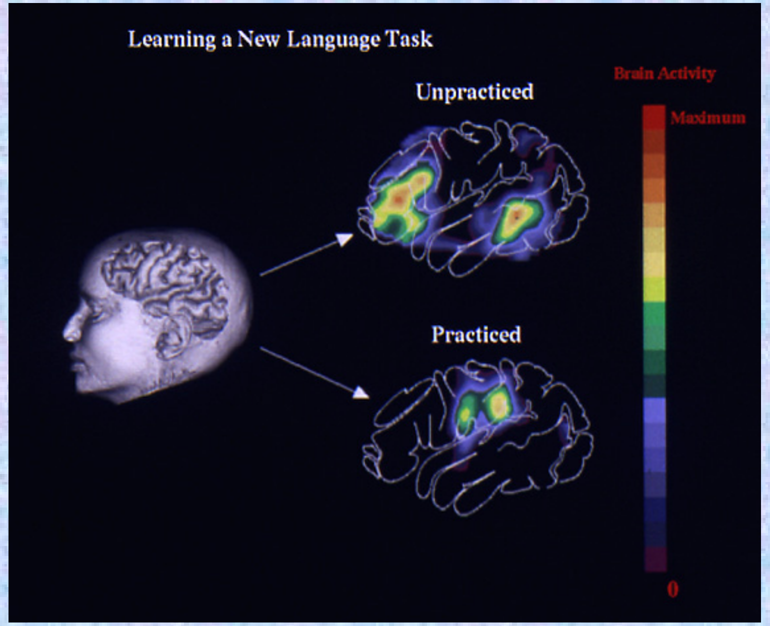
Applications of antimatter - PET

Insert e+ emitting isotopes (C-11, N-13, O-15, F-18) into physiologically relevant molecules (O_2, glucose, enzymes) and inject into patient.



Study positron annihilation with crystal calorimeter (Positron Emission Tomography, PET)

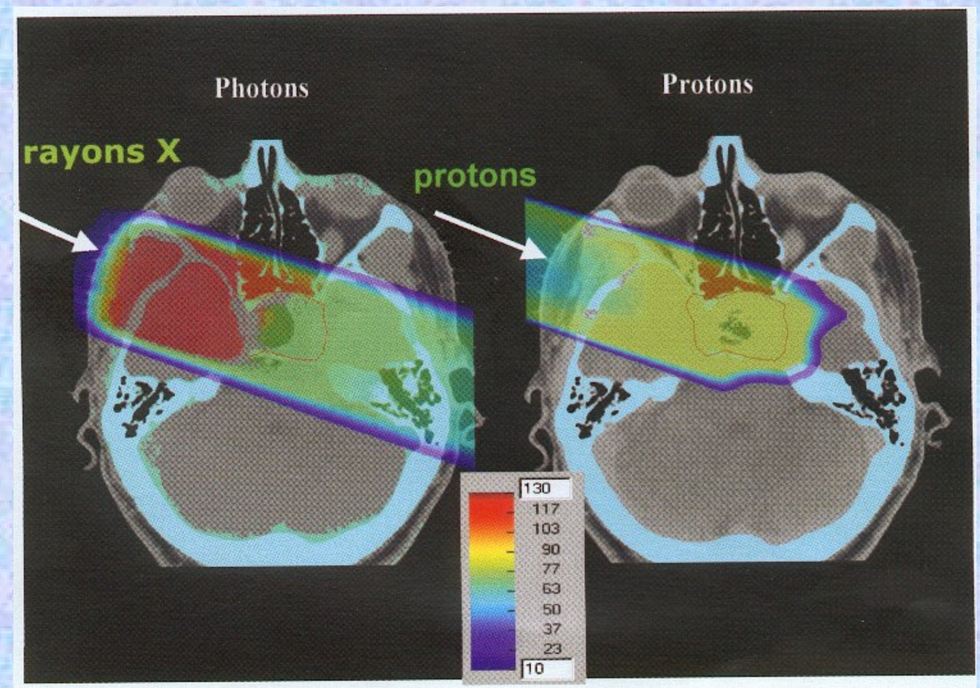




Applications of antimatter - Tumour therapy?

Goal: destroy tumour without (too much) harm to healthy tissue

Gammas: exponential decay (peaks at beginning)
Charged particles: Bragg peak (Plateau/Peak better for high Z)
Antiprotons: like protons, but enhanced Bragg peak from annihilation



AD-4 “ACE”

Test experiment at CERN

Explores relative biological effectiveness in cells

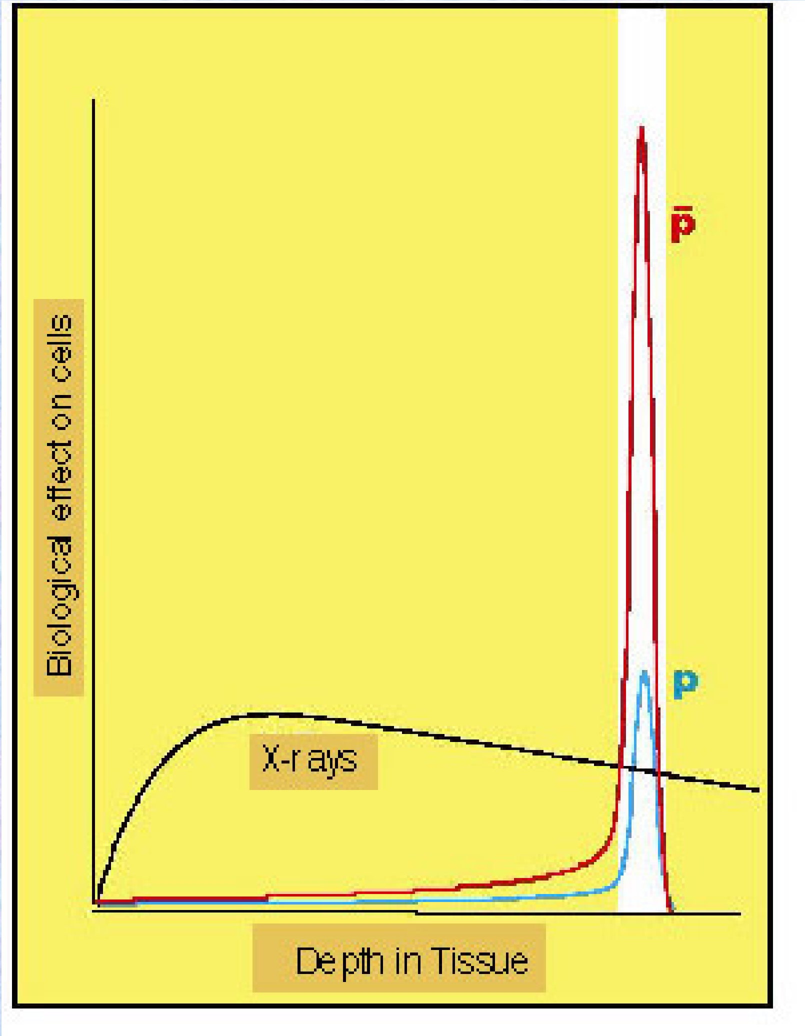
- antiprotons annihilate;
- nuclear fragments have short range,
- destroy surrounding tissue (<< 1 mm)

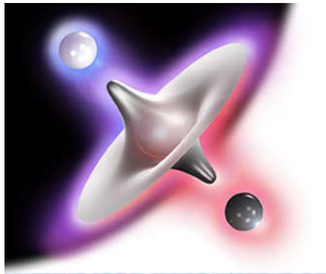
Compare to protons

-> decide about future measurements

If big advantage over heavy ions -

-> construct dedicated antiproton facility

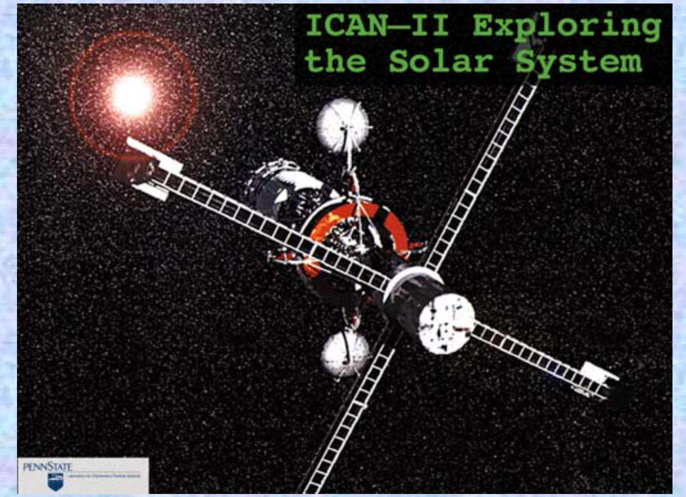




Antimatter driven space engines?

PROBLEMS:

1) Extremely low production rates (ng/yr)
2) Extremely low efficiency (~10^{-8})
3) Difficult storage (space charge) of antiprotons
4) More difficulties for antihydrogen



Until somebody finds a clever way around these problems, all this will stay fiction:


AKTUELL

E.T., wir kommen!

In Genf wurde Wunder-Energie entdeckt

The End.