Antimaterie

Spiegelbild des Universums

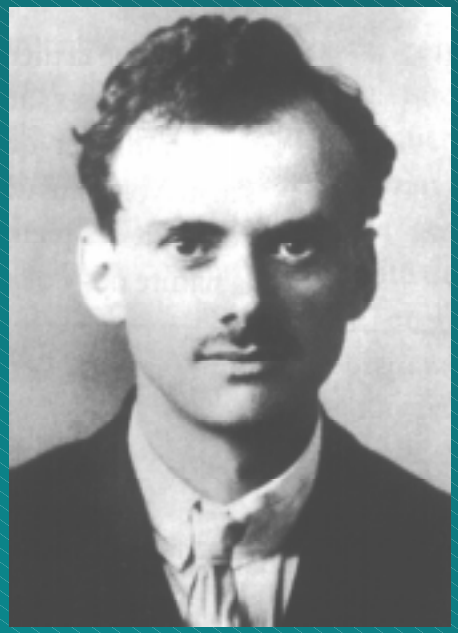
Rolf Landua

CERN, 7 Februar 2000

Inhalt

1 Antimaterie?

Paul Dirac (1929)

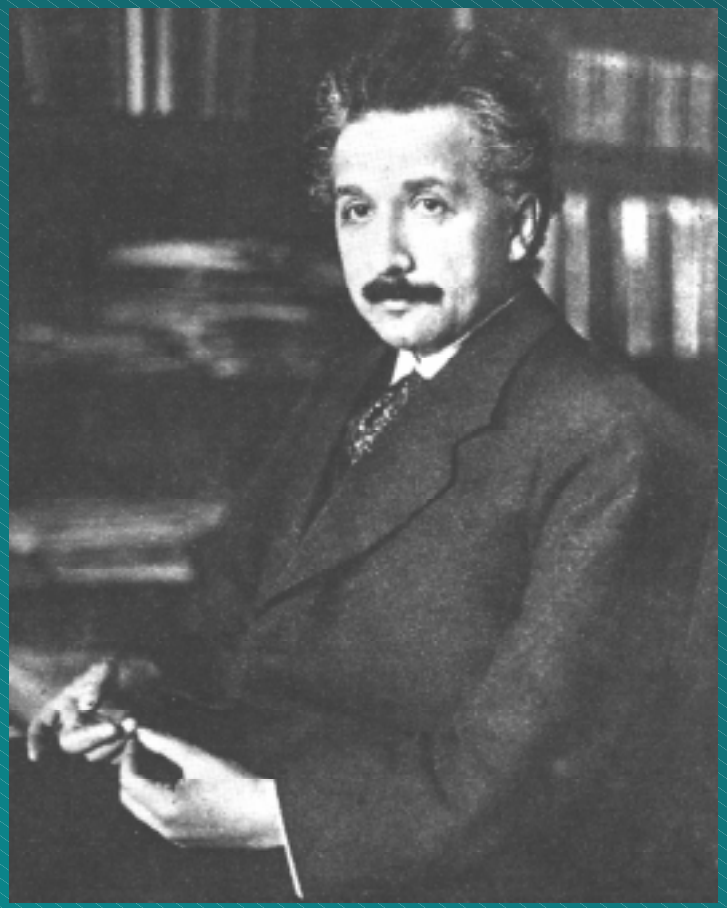


Kein ausgezeichnetes Bezugssystem (Rel. theorie) + Quantentheorie :
Beschreibung eines ‘einzelnen’ Elektrons unmöglich, braucht ‘Anti-Elektron’ als Partner

1932: ‘Positron’ in kosmischer Höhenstrahlung entdeckt

~1950: Besseres Verständnis der Feldtheorien: völlige Symmetrie Teilchen-Antiteilchen !

2 $E = m c^2$



Masse = konzentrierte Energie

Potentielle - kinetische - Feldenergie ?
Umtauschbar ...

Energie =
der 'Euro' des Universums

2 $E = mc^2$ (II)

Umtauschkurs (günstig): c^2 ***($9 \cdot 10^{16}\ m^2 s^{-2}$)***

d.h. 1 kg produziert 3 GW für ein Jahr, oder
1 VW Polo fährt ~ 100,000 Jahre

2 $E = mc^2$ (III)

Die 'Münzen' des Universums

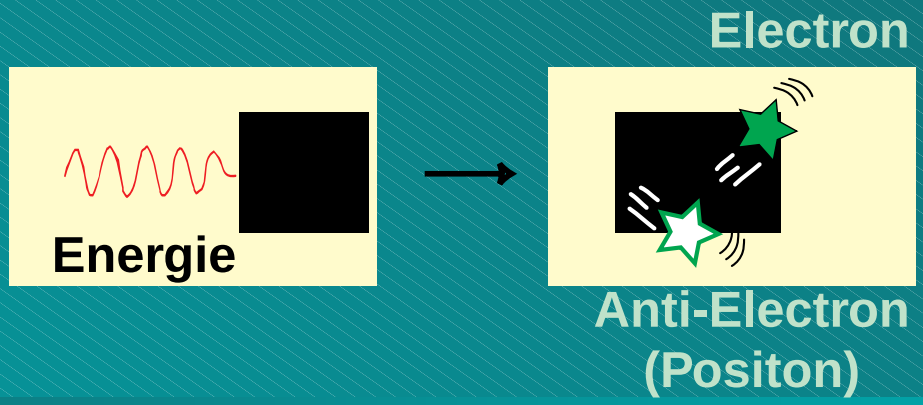
0.511 (e)
105.6 (m)
1777 (t)

? (Neutrinos)

3 (u)
5 (d)
100 (s)
1200 (c)
4300 (b)
174000 (t)

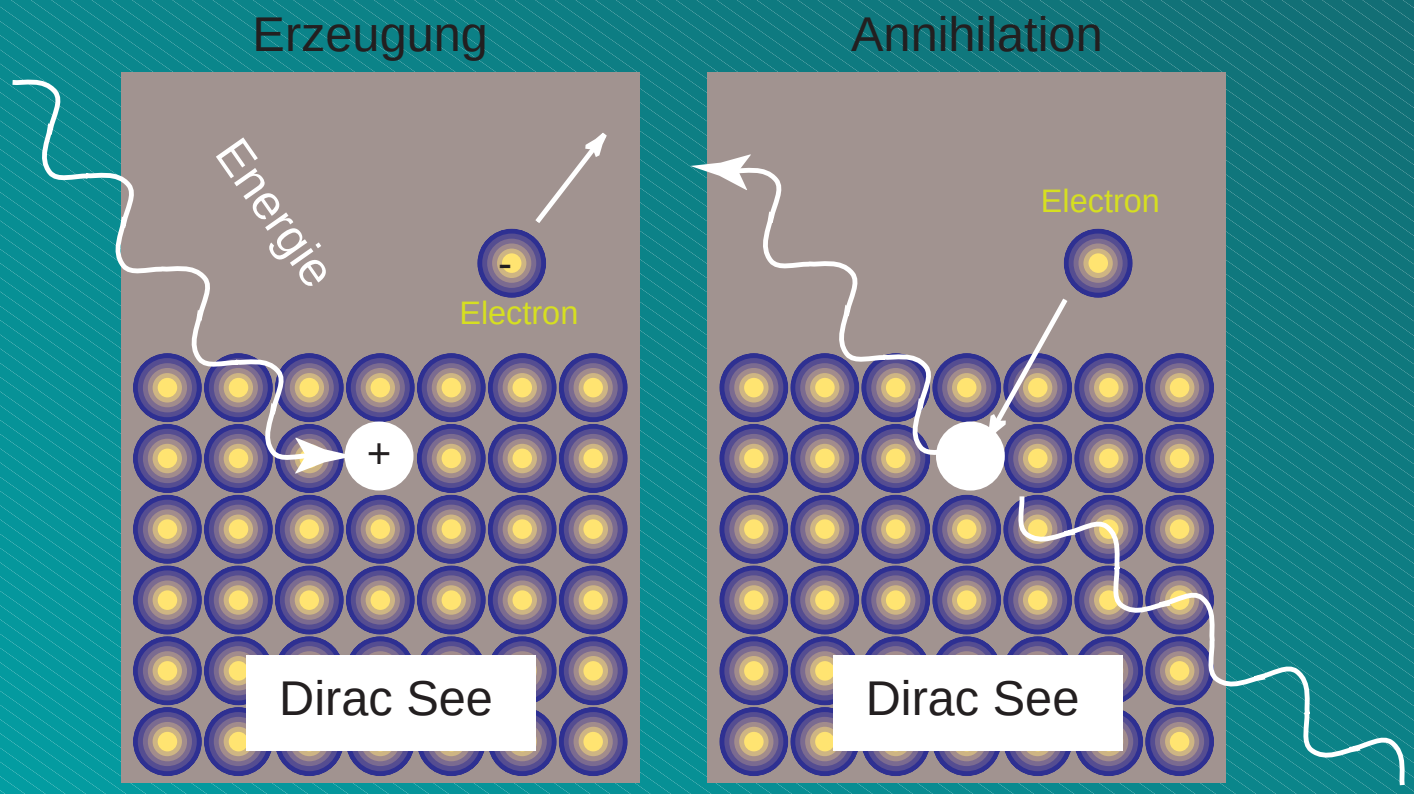
Toys 'R Us
Jeu de
Construction

PARTICULES 'LÉGERS'	QUARKS
electron	Up
neutrino	Down



3 Löcher im Vakuum

Erzeugung von Antimaterie



3 Löcher im Vakuum (II)

Pizza Modell

Electron

Proton

Valentinstag-Modell

3 Löcher im Vakuum (III)

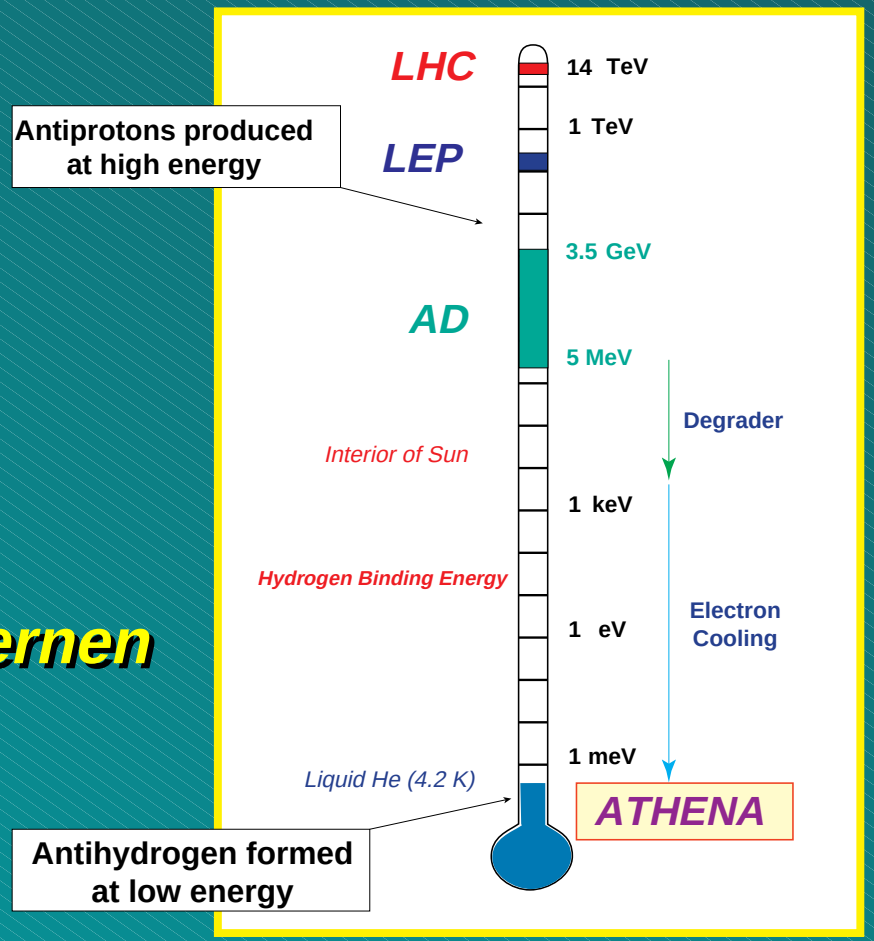
Energie - Materie : reine Theorie??

1938 - Kernspaltung
1945 - Atombombe (Spaltung)
1954 - Wasserstoffbombe (Fusion)
1955 - Antiproton-Erzeugung (Berkeley)
> 1960 - Nutzung in Beschleunigern
> 1980 - Antiproton-Proton Speicherring (CERN)

4 Antimaterie - Suppe

Cool Energy of Antiprotons by

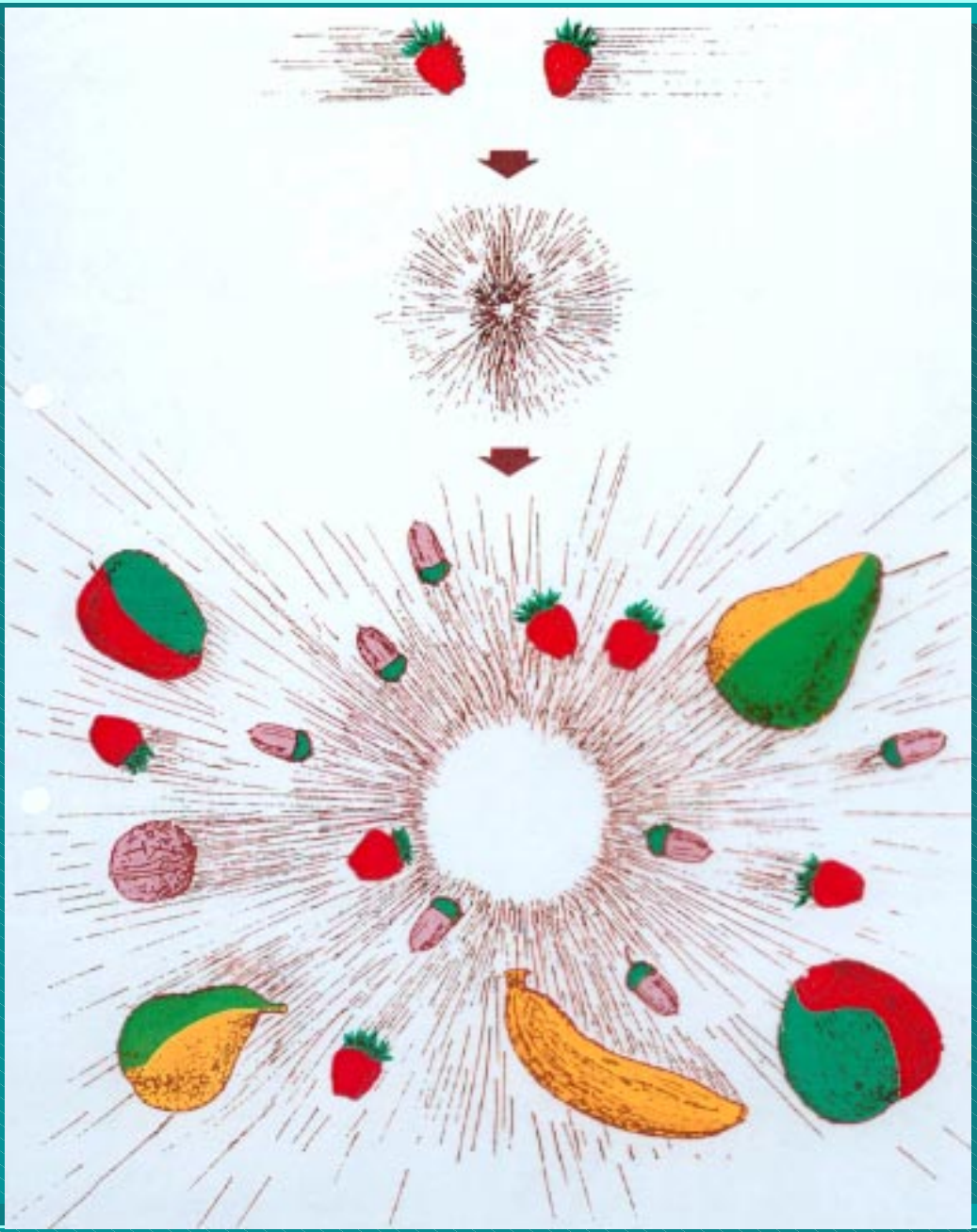
13 orders of magnitude !



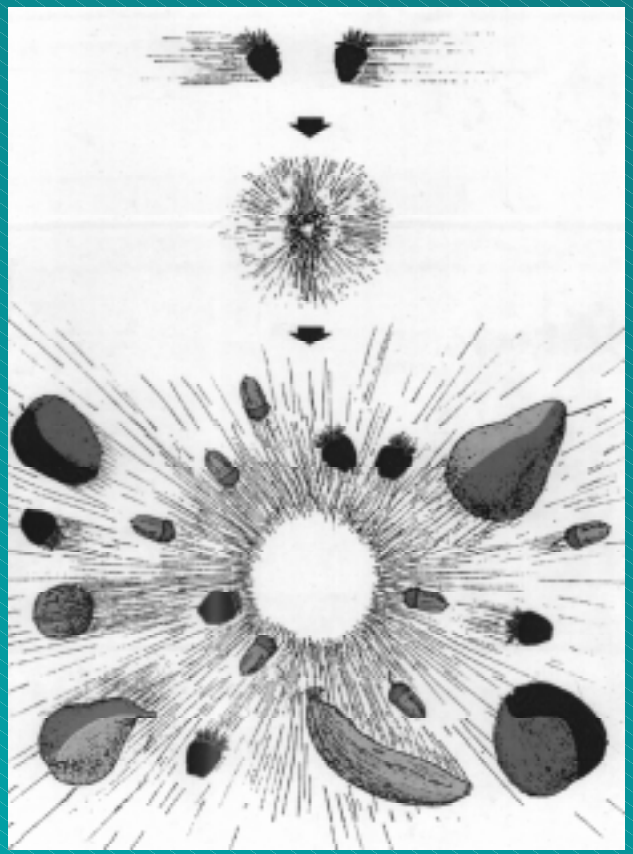
"Verdampfung des Vakuums"
(T ~10,000,000,000,000 K)

in Kollisionen von Protonen mit Kernen

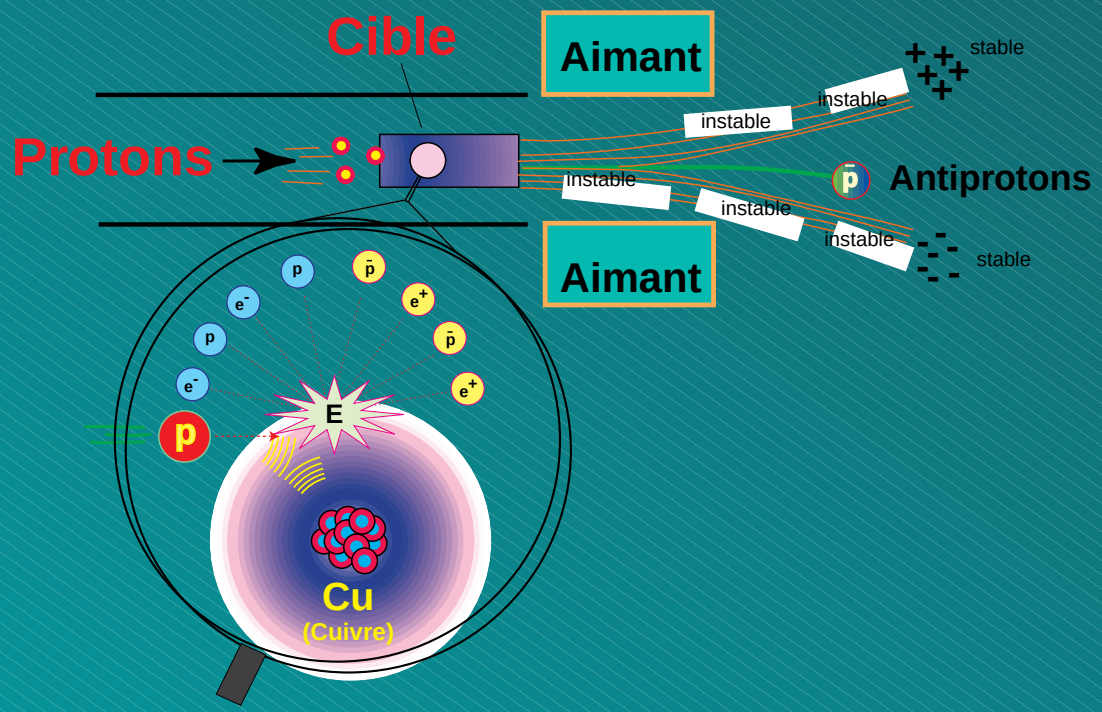
4 Erdbeeren auf Kollisionskurs ...



4 Antimaterie-Suppe (II)



Am CERN:



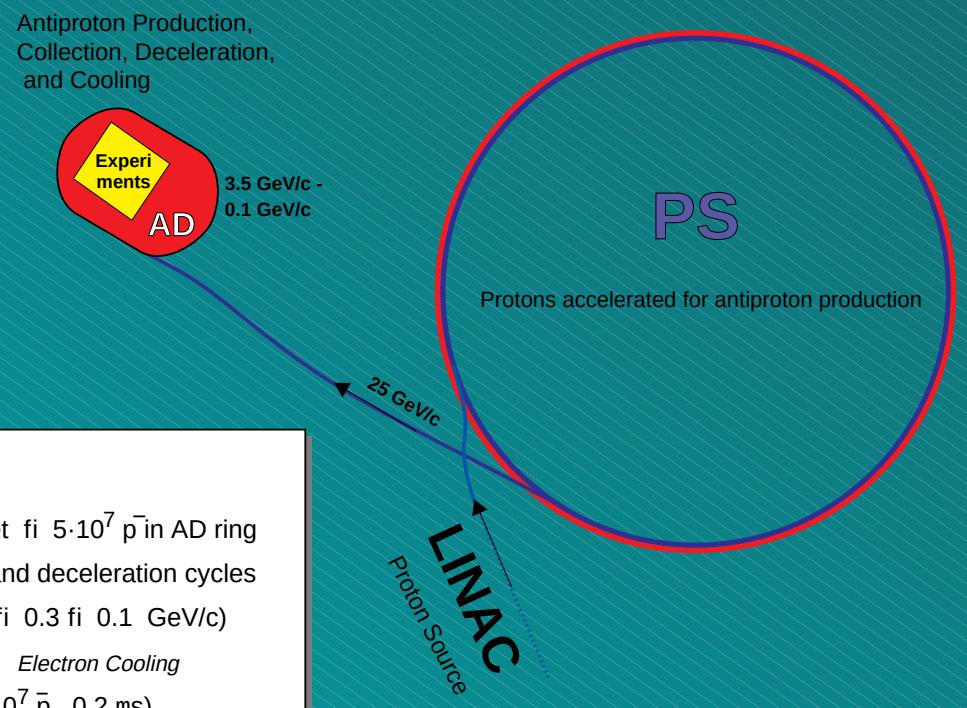
4 Antimaterie-Suppe (III)

Konzept:

a) Erzeugung bei hohen Energien (3-4 GeV)
b) Sammeln der Antiprotonen, Kühlung
c) Abbremsung, weitere Kühlung
d) Extraktion bei 5 MeV -> Experiment
e) Weitere Kühlung in der Antiprotonen-Falle

5 Antiproton Decelerator (AD)

AD Antiproton Complex at CERN



AD Cycle

- $5 \cdot 10^{13}$ p on target fi $5 \cdot 10^{7}$ $\bar{p}$ in AD ring
- Several cooling and deceleration cycles
  (3.5 fi 2.0 fi 0.3 fi 0.1 GeV/c)
  Stochastic *Electron Cooling*
- Fast extraction (10^{7} $\bar{p}$, 0.2 ms)
- Dp/p ~ 10^{-3}
- Cycle time ~ 1 minute

6 Wir und das Rätsel der Antimaterie

Warum sind wir hier?

- *1929 Hubble (Expansion)*
- *1948 Gamov (Big Bang)*
- *1963 Penzias & Wilson (CBR)*
- *1967 Sakharov (Asymmetrisches Universum)*
- *2000 Baryogenesis??*

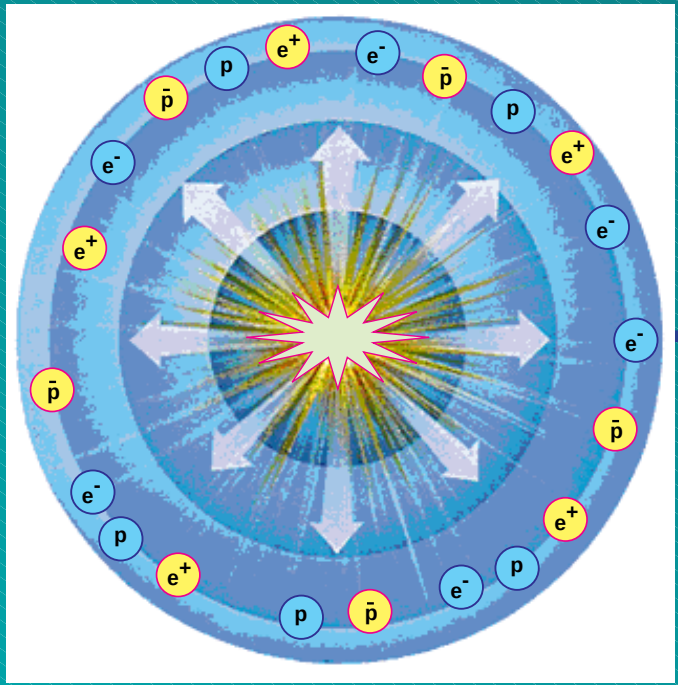
6 Wir und das Rätsel der Antimaterie (II)

Wo ist die Antimaterie?

BIG BANG

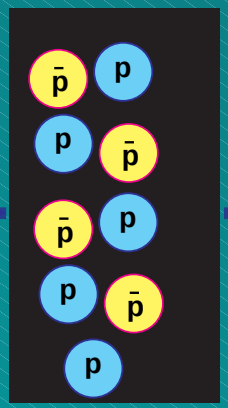
T = 10^{-43} s: Matter = Antimatter ?

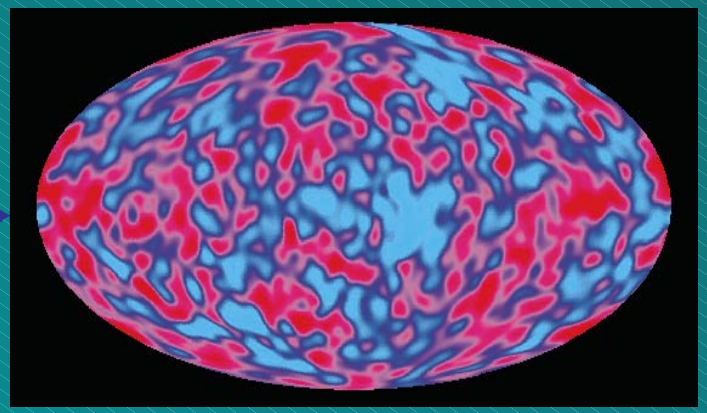
Universe filled with remnants of initial matter-antimatter annihilation (Cosmic Microwave Background)



Asymmetry ?

100,000,001:100,000,000

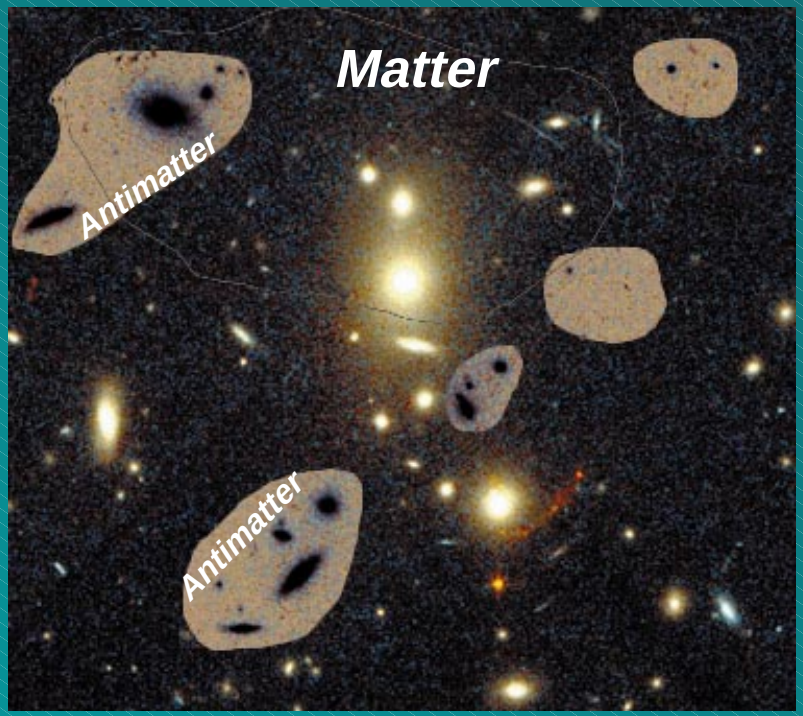




6 Wir und das Rätsel der Antimaterie (III)

Wo ist die Antimaterie?

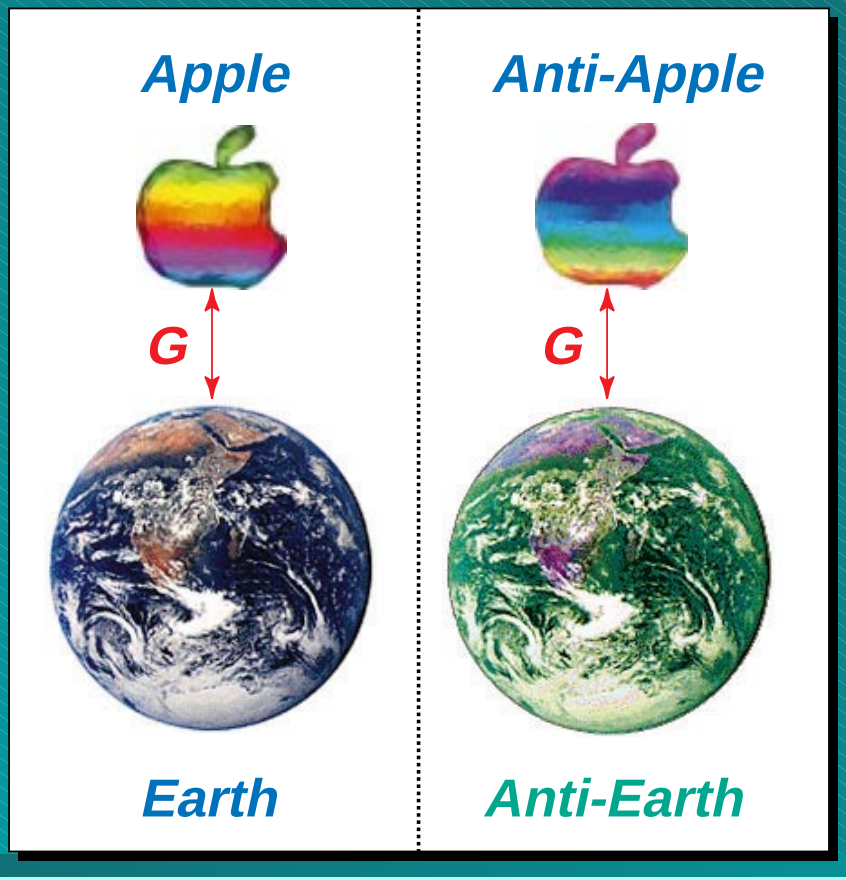
Antimatter Domains in the Universe?



6 Wir und das Rätsel der Antimaterie (IV)

Anti-Gravitation?

CPT Symmetric Situation



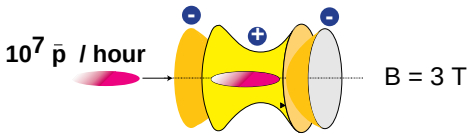
Not:

7 Wir basteln ein Anti-Atom

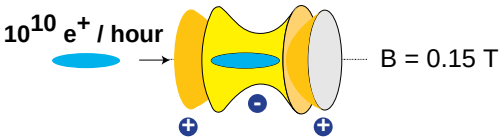
ATHENA (Antihydrogen Apparatus)

ATHENA Collaboration *

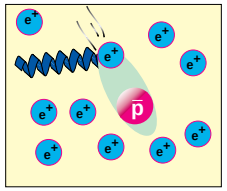
1. Antiproton **Capture** into Penning Trap



2. Positron Accumulation from Na-22 source



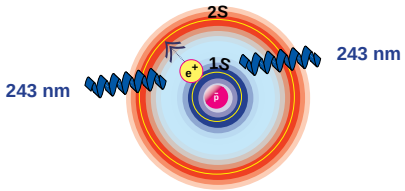
3. Positron-Antiproton Recombination in multi-ring trap at 4.2 K



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

5. Antihydrogen **Detection**
- Annihilation products: Si Pad Detectors
- 511 keV Gammas: CsI or BGO + Photodiodes

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



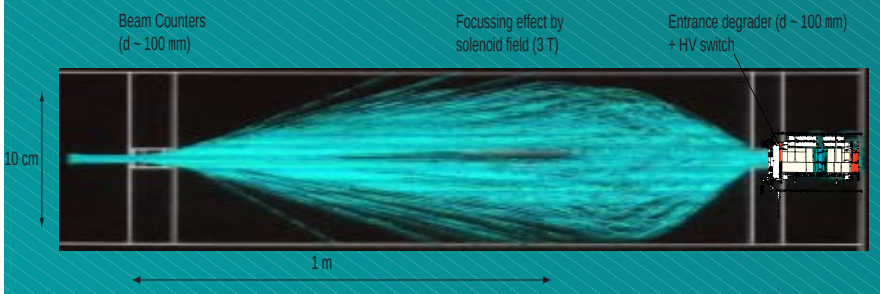
Comparison $\bar{H}$: H with precision 10^{-12} ...10^{-15}

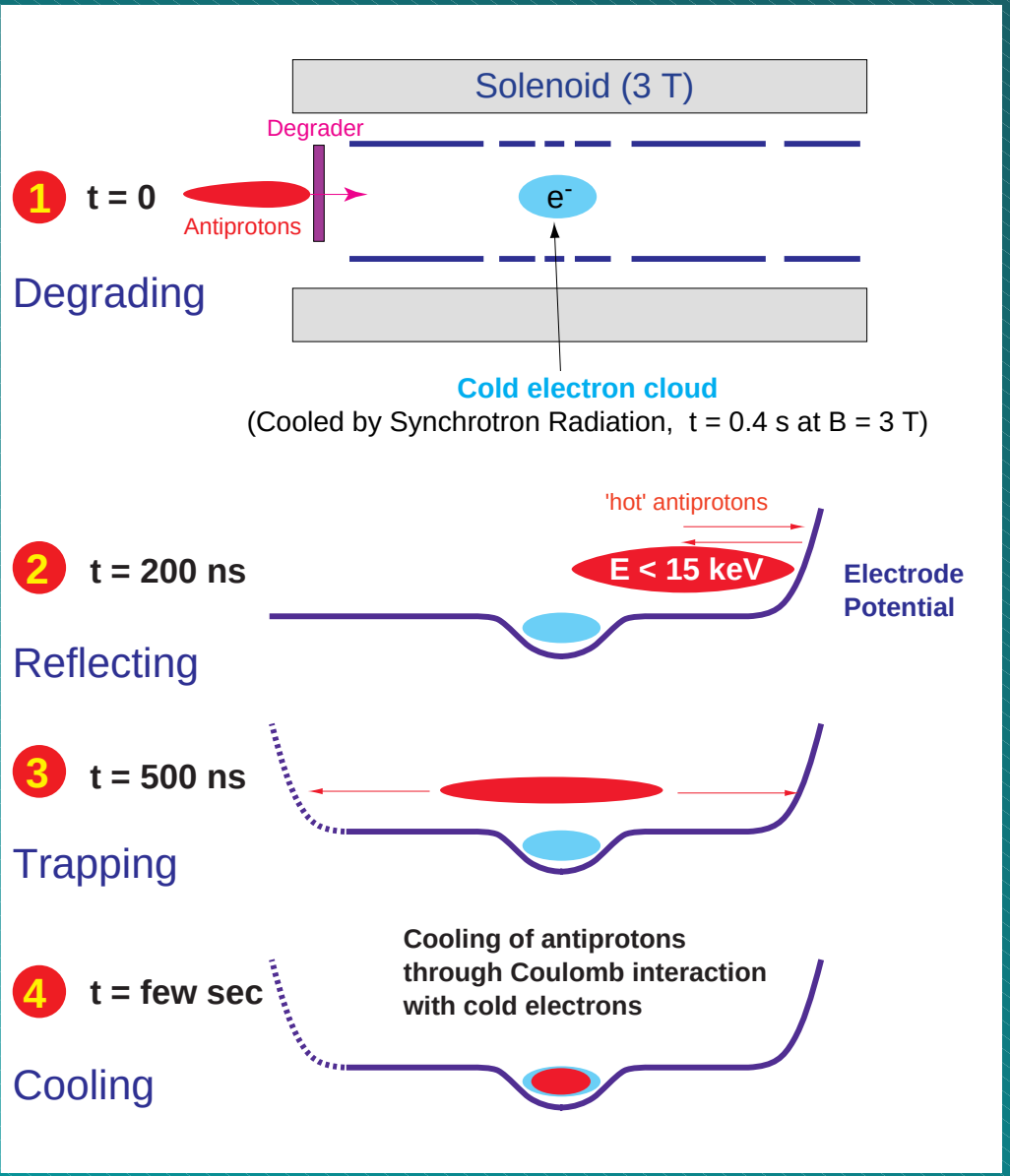
Data taking: 1999 -

* Aarhus, Brescia, CERN, Genoa, UC London, MIT, Pavia, Penn State, Pisa, Rio de Janeiro, Rome, Stockholm, Tokyo, Zurich (14 institutes, ~ 50 physicists)

7 Anti-Atom (II)

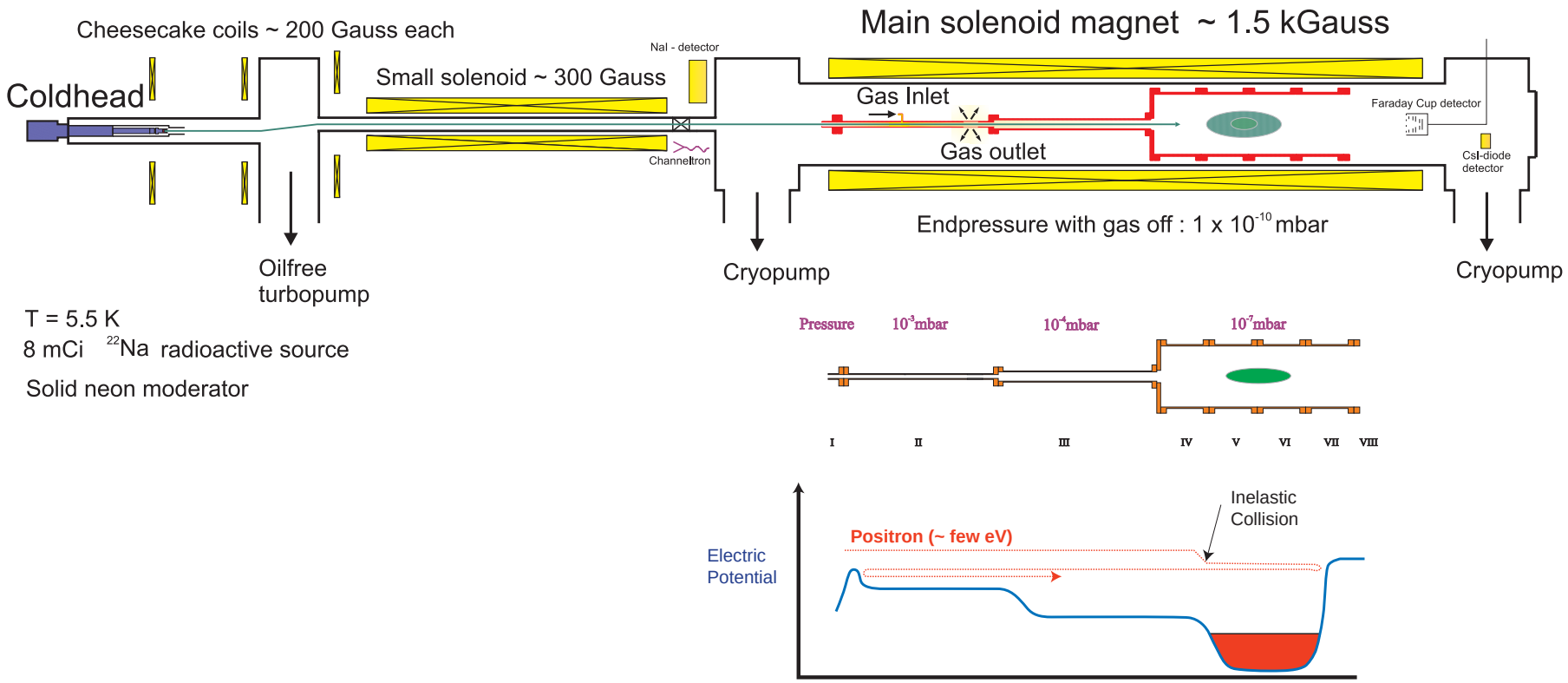
Antiprotonen





7 Anti-Atom (III)

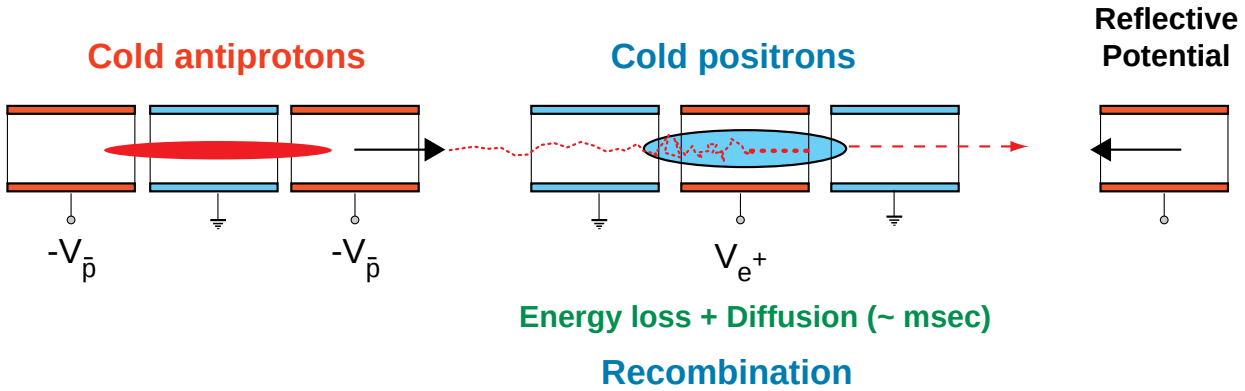
Positronen



7 Anti-Atom (IV)

Rekombination

At energies below ~ 1 eV:
DE/dx ~ 100 meV/cm in positron plasma (T= 4.2 K, n = 10^8 cm^{-3})

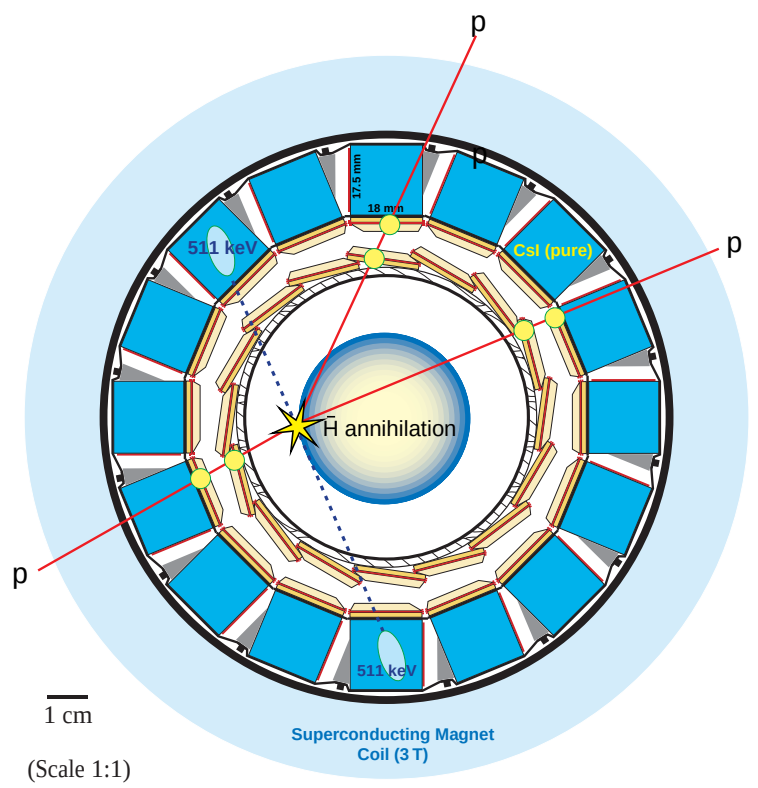


Estimate for spontaneous radiative recombination (to low-n levels):
[10^5 antiprotons, 10^8 positrons, L=10 cm, T = 4 K, n_b = 10 Hz]

~ 20 - 200 antihydrogen atoms / second

7 Anti-Atom (V)

Detektion der Annihilation



Discriminate Antihydrogen Annihilation from background of Antiproton annihilation and Positron annihilation

Good spatial resolution (< 1 cm) of vertex for

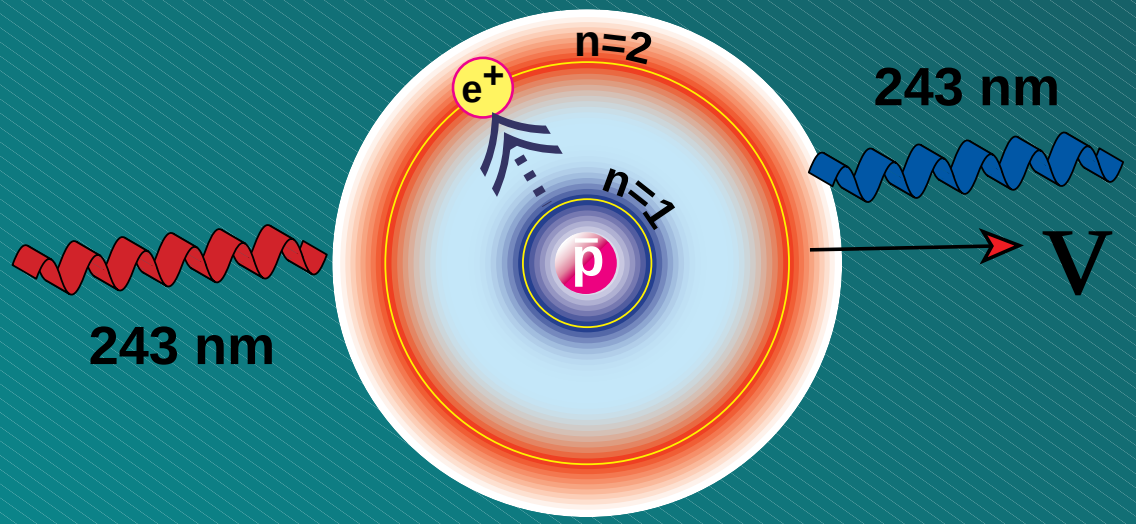
- **Antiproton Annihilation (2 prongs)**
- **Positron Annihlation (2 x 511 keV g)**

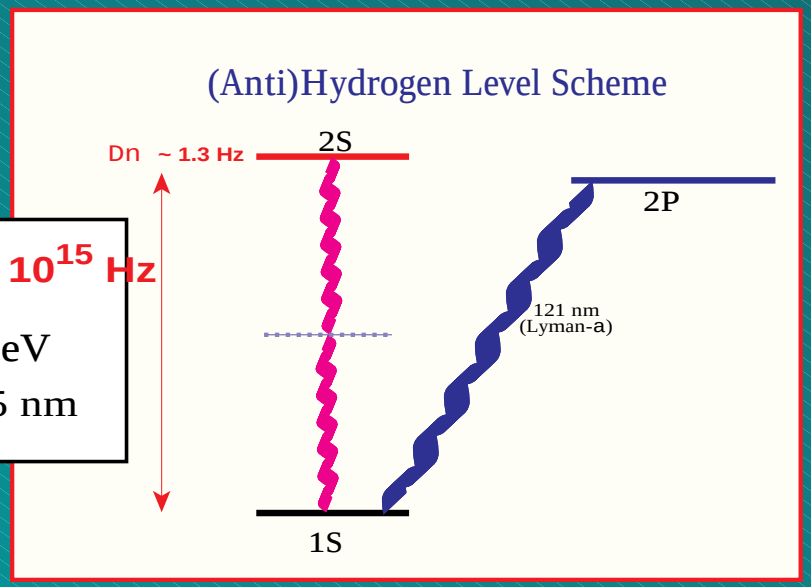
Time coincidence (~ 1 msec)

High rate capability

7 Anti-Atom (VI)

Laser-Spektroskopie





$n = 2.4 \cdot 10^{15}$ Hz

DE = 10.2 eV

l = 121.5 nm