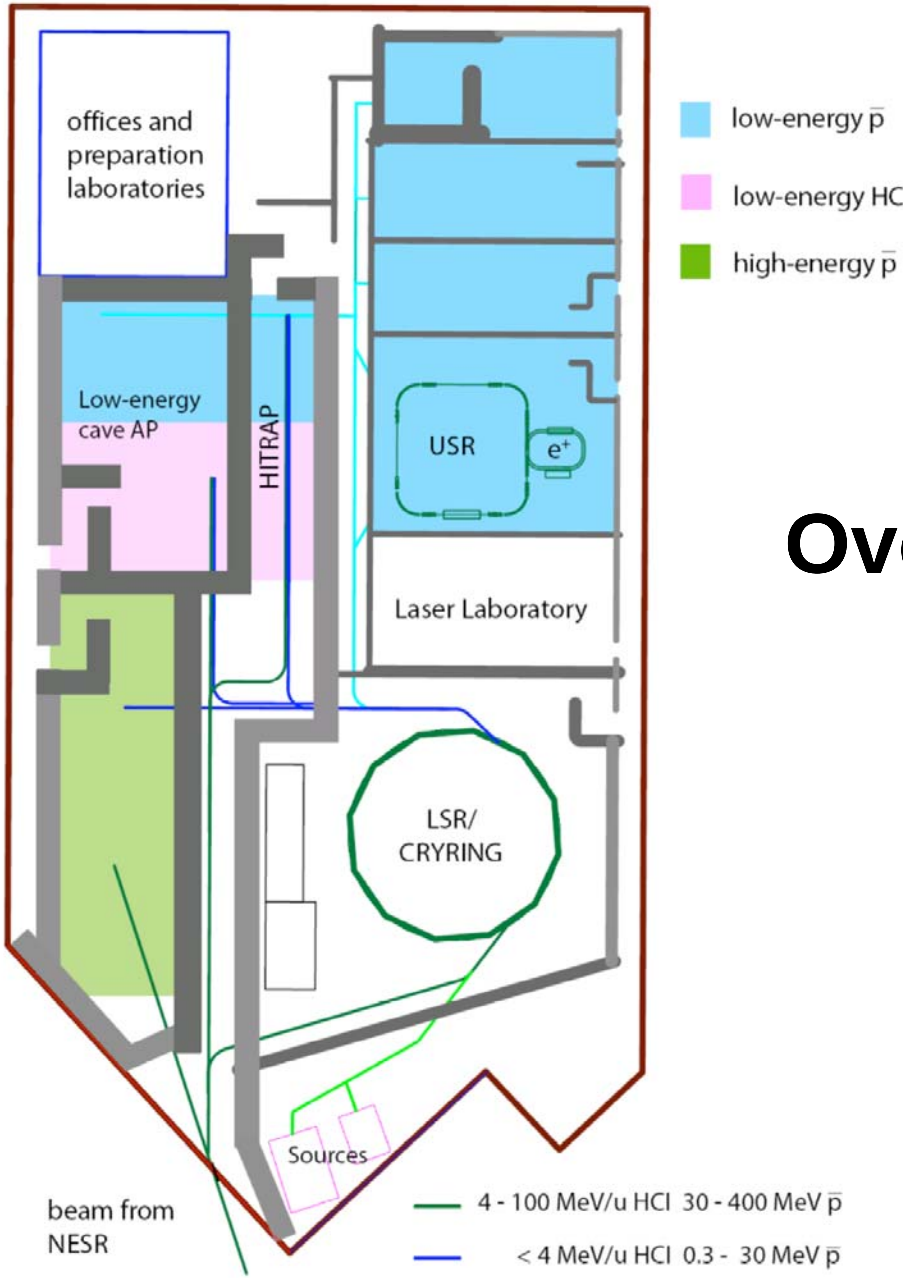
Antimatter research at F(L)AIR

D.P. van der Werf

University of Wales Swansea



Overview of the Flair facility

Physics at FLAIR

- Antihydrogen spectroscopy
- Gravitational acceleration of amtihydrogen
- G-factor of the antiproton
- Antiprotonic atom spectroscopy
- Protonium
- Atomic collision studies
- Antiprotons as Hadronic probes
- Tumor therapy

A multi-disciplinary team :

Athena/AD-1 Collaboration

Aarhus
P.Bowe, J.S. Hangst, N. Madsen

Brescia
E. Lodi-Rizzini, L. Venturelli

CERN
G. Bonomi, M. Doser, M. Holzscheiter,
A. Kellerbauer, R. Landua

Genoa
M. Amoretti, C. Carraro, V. Lagomarsino, M. Macri, G. Manuzio,
G. Testera, A. Variola

Pavia
V. Filippini, A. Fontana, P. Genova
P. Montagna, A. Rotondi

Rio de Janeiro (URFJ)
C. Lenz Cesar

Swansea
M. Charlton, L. Jørgensen,
D. Mitchard, D.P. van der Werf

Tokyo/Riken
M. Fujiwara, R. Funakoshi,
R. Hayano, Y. Yamazaki

Zurich
C. Amsler, I Johnson, H. Pruys,
C. Regenfus, J Rochet

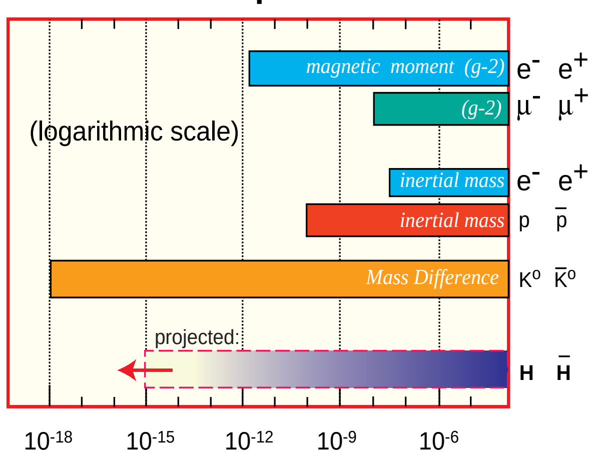
Goal

| Antihydrogen | = | Hydrogen | ?

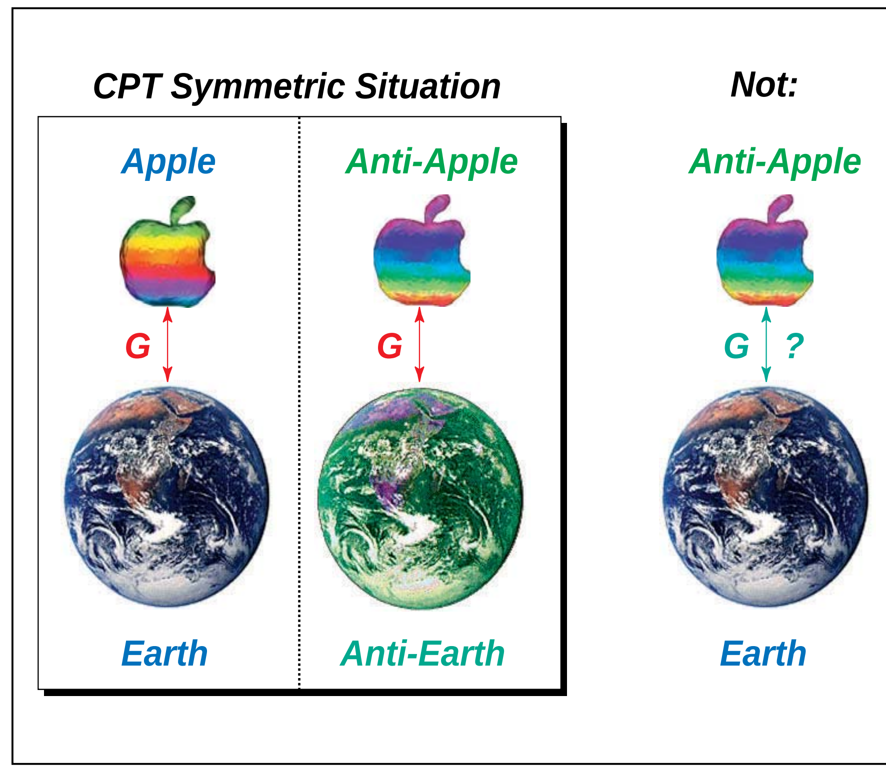
CPT

Any local quantum field theory, obeying Lorentz invariance and usual spin-statistics connection → CPT Invariance

Some of the most precise CPT Tests

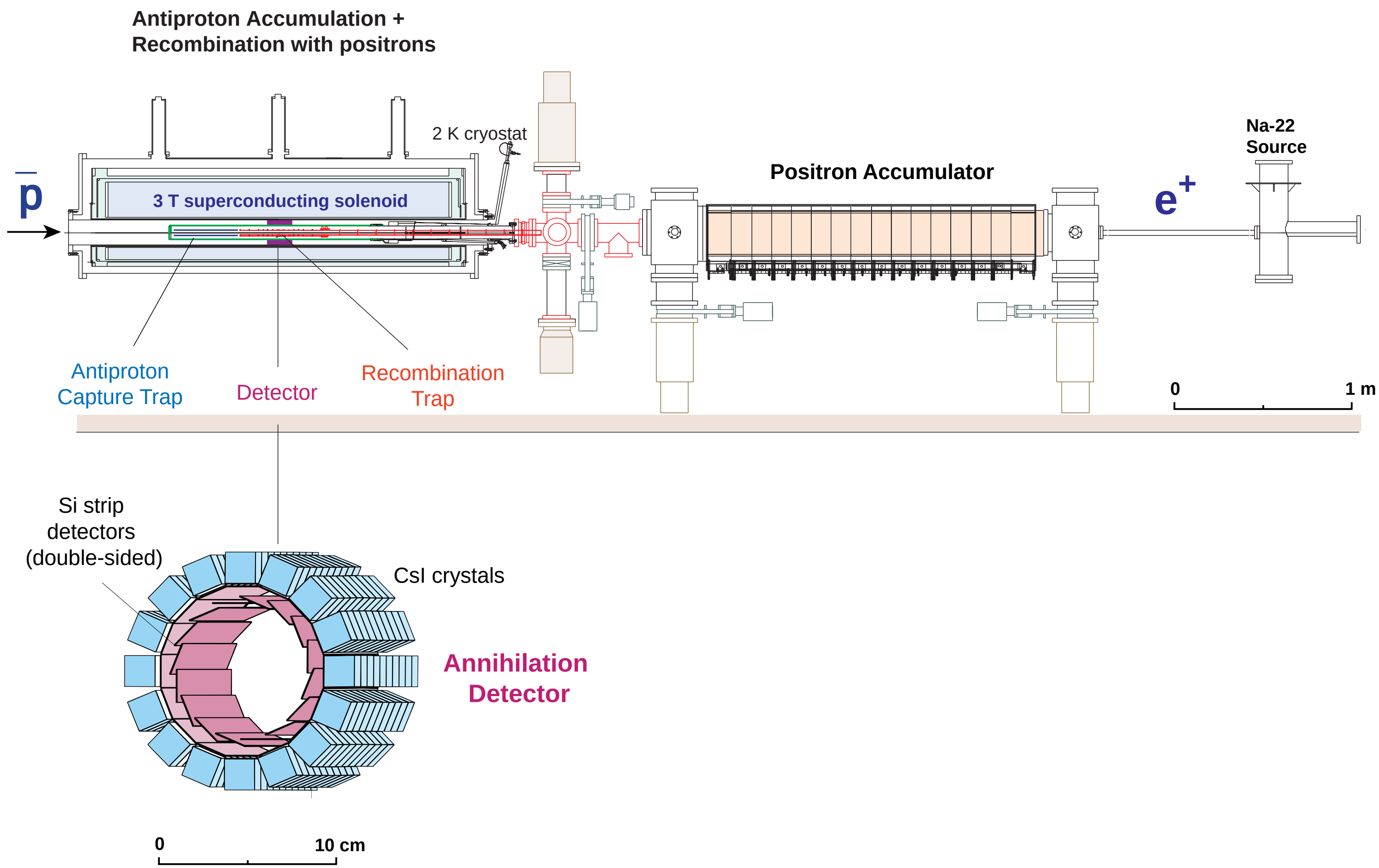


Gravity

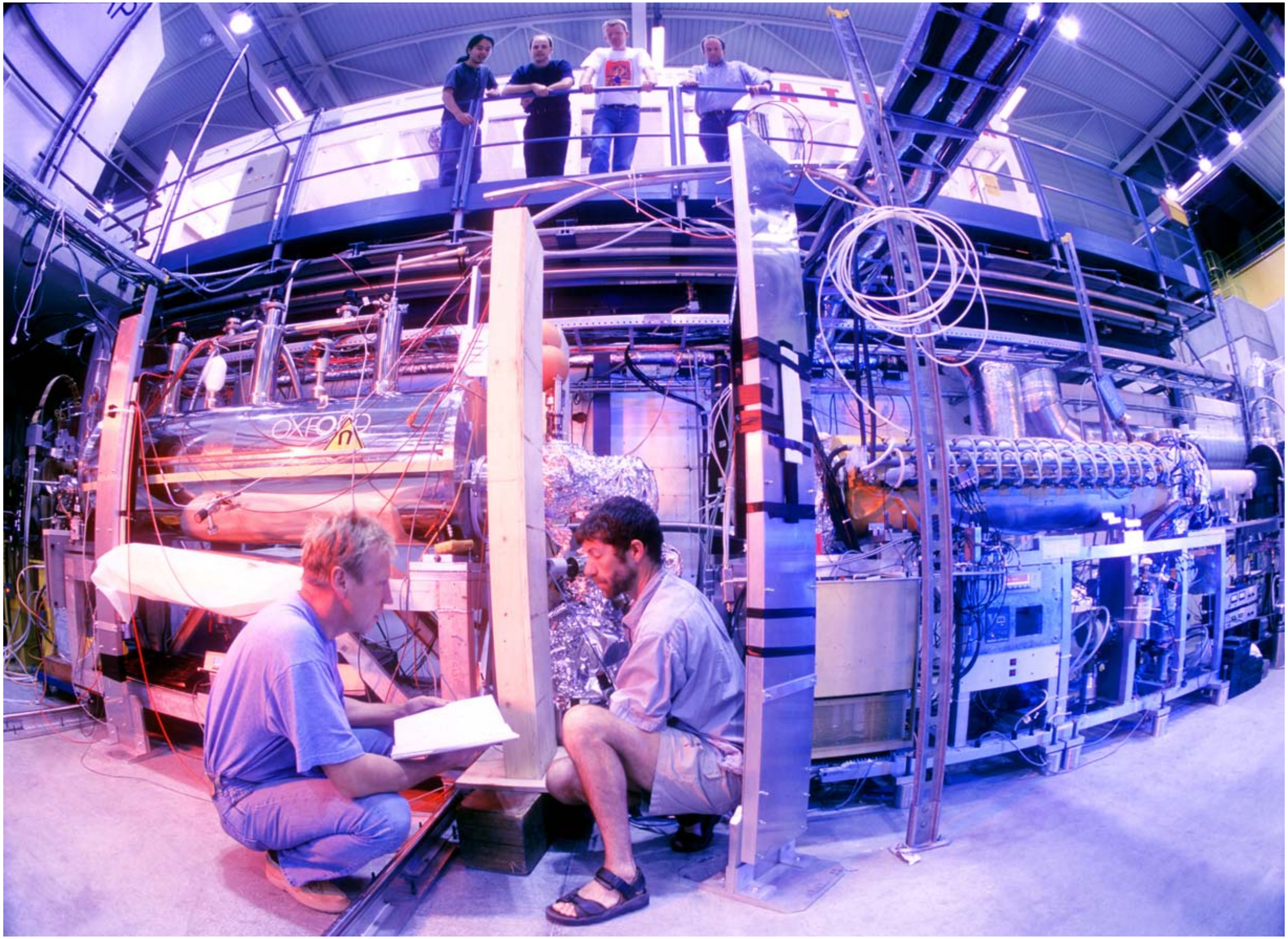


Overview - Apparatus

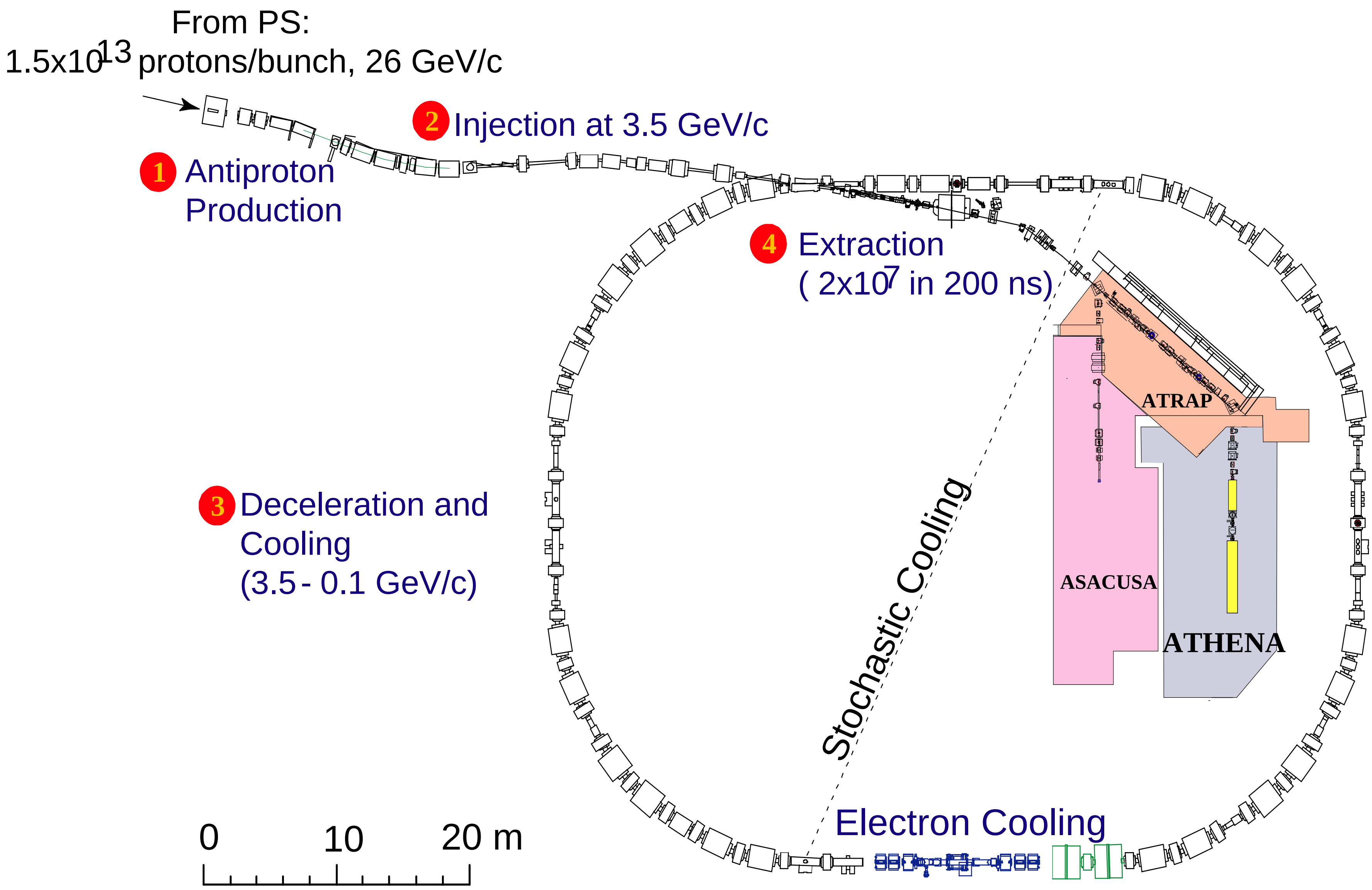
ATHENA / AD-1 : Antihydrogen Production



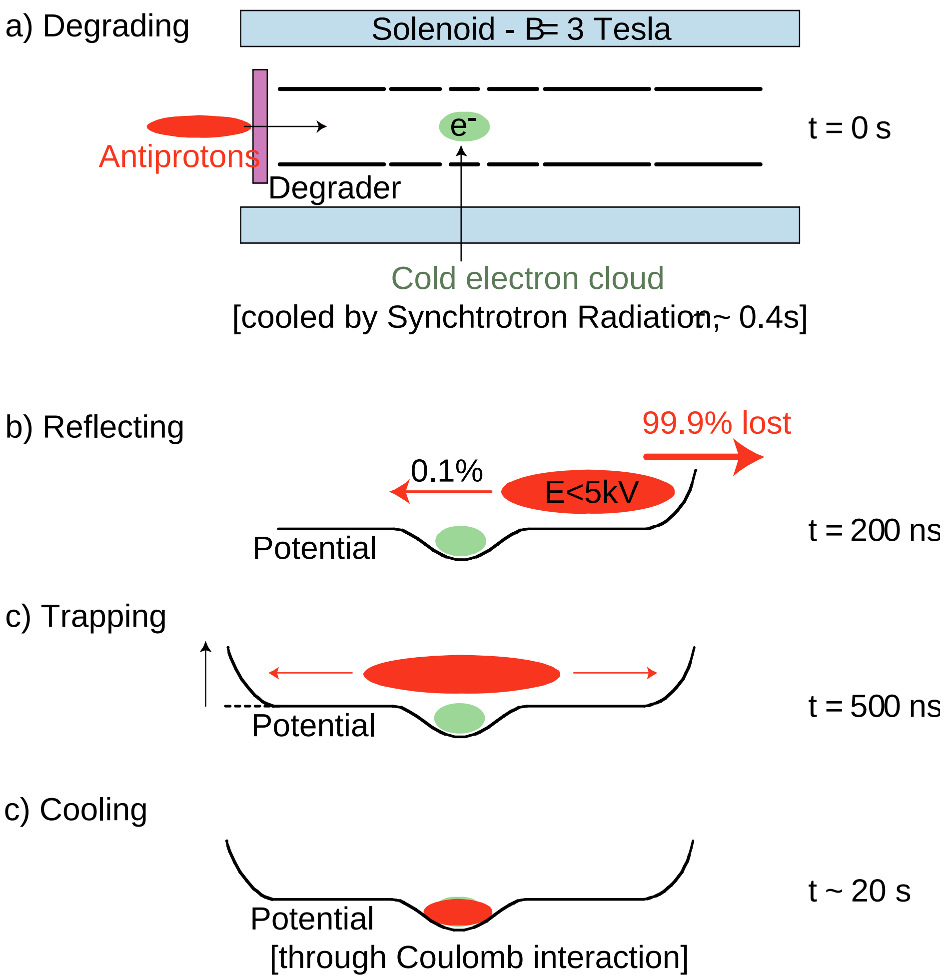
Overview - Apparatus



Antiproton Decelerator

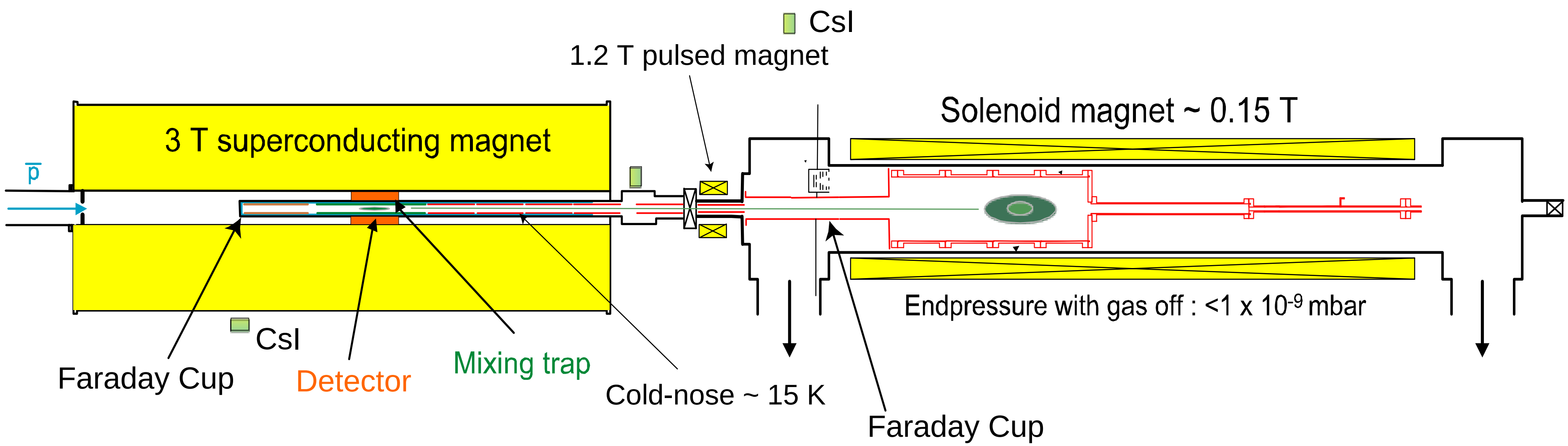


Antiprotons - Capture and Cooling



Antiproton Capture Trap

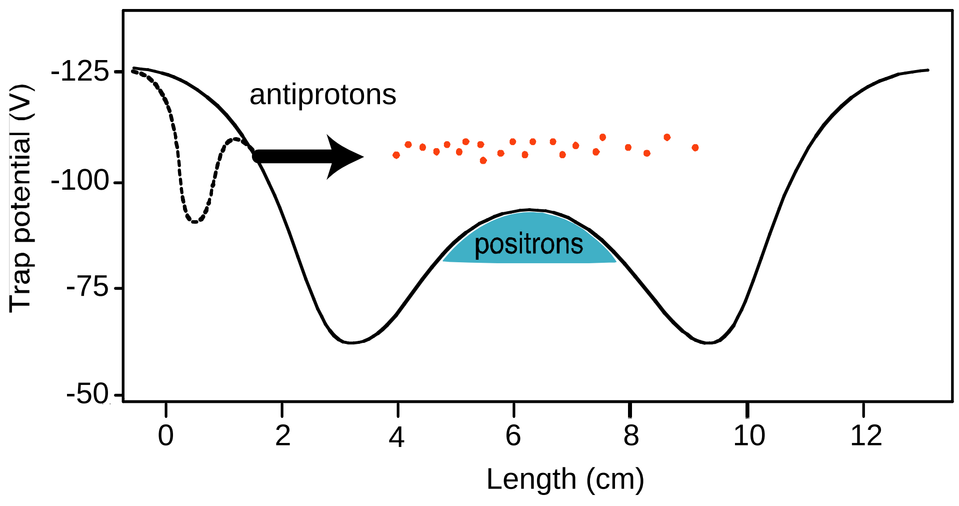
Positron Accumulation+Transfer



- Typically 75 million positrons every 5 minutes
- Maximum number trapped 1.2 ⟐ 10^9 e^+
- Highest density 2 ⟐ 10^{10} cm^{-3} with 25 million positrons

Antihydrogen Production

1. Fill positron well in mixing region with $75 \cdot 10^6$ positrons;
   allow them to cool to ambient temperature (15 K)
2. Launch 10^4 antiprotons into mixing region
3. Mixing time 190 sec - continuous monitoring by detector
4. Repeat cycle every 5 minutes (data for 165 cycles)



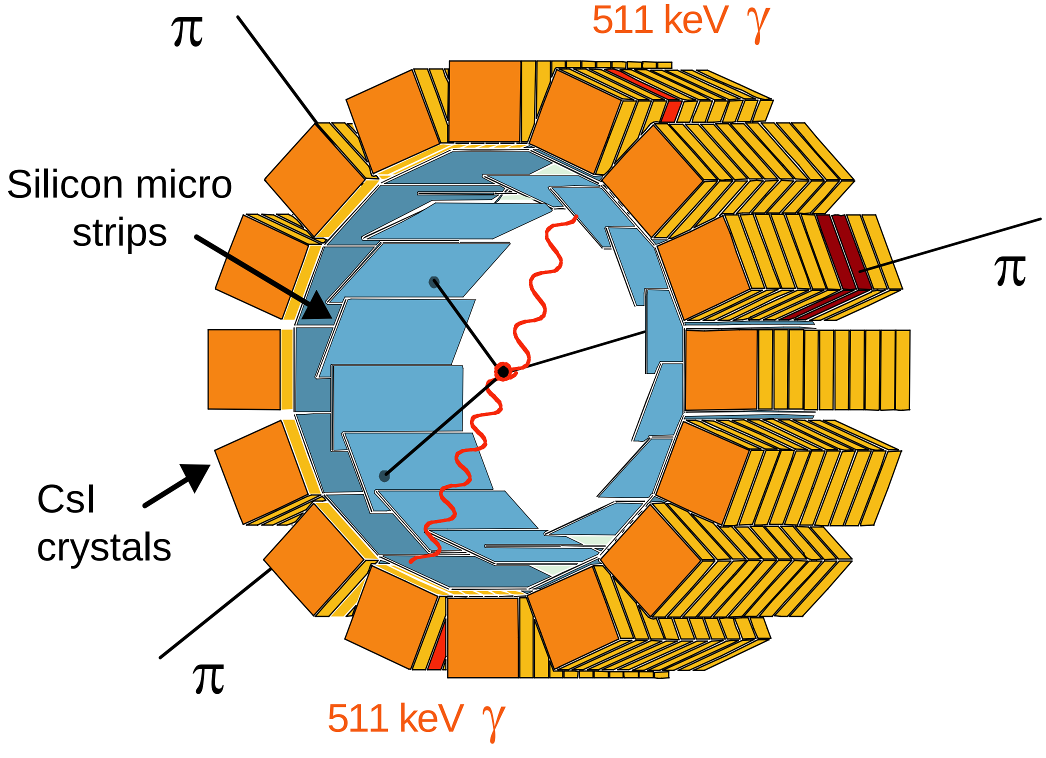
For comparison:

"hot" mixing = continuous RF heating of positron cloud

(suppression of formation)

Antihydrogen Detection

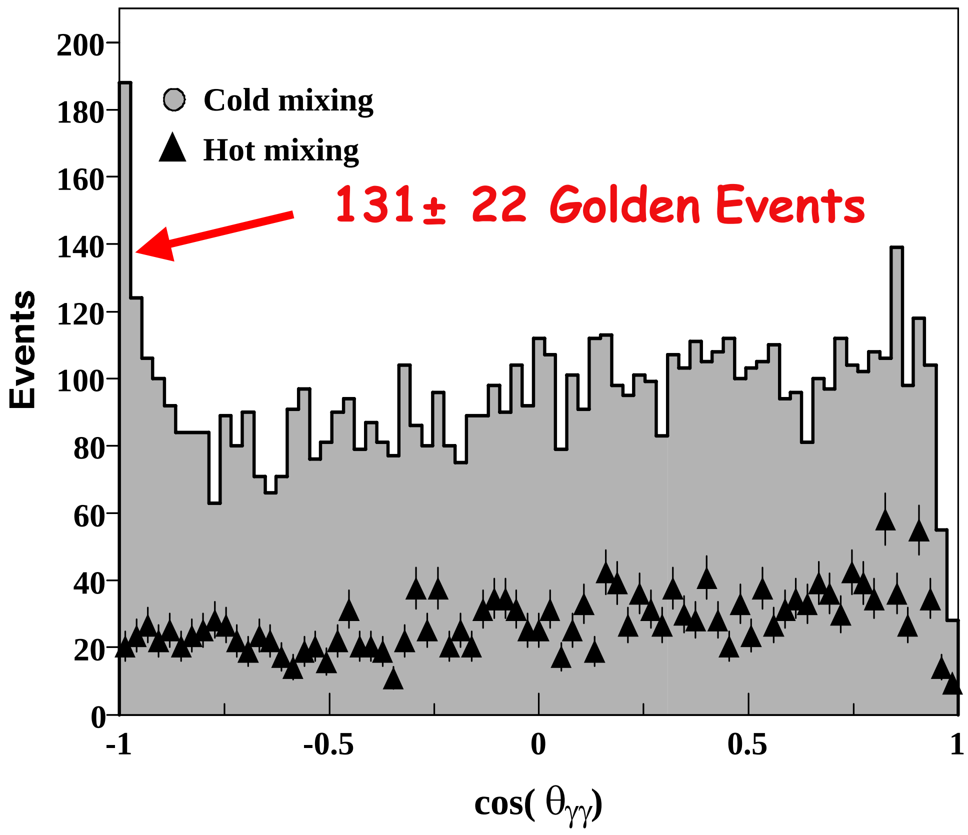
- Charged tracks to reconstruct antiproton annihilation vertex.
- Identify 511 keV photons from e^+-e^- annihilations.
- Identify space and time coincidence of the two.

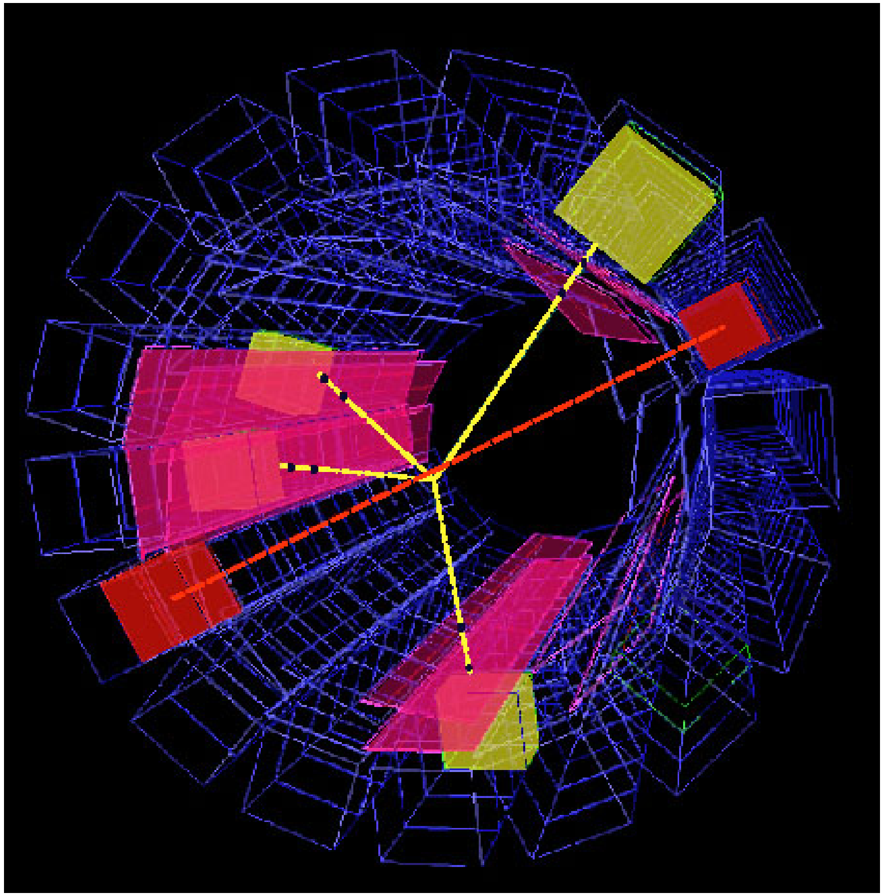


- Compact (3 cm thick)
- Solid angle > 70%
- High granularity
- Operation at 140K, 3 T

First Cold antihydrogen

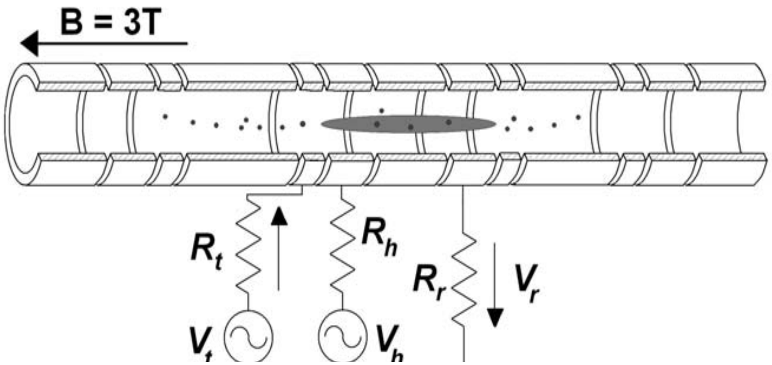
Amoretti et al., ***Nature*** 419 (2002) 456





> 50000 Cold antihydrogen

Plasma Diagnostics and Control

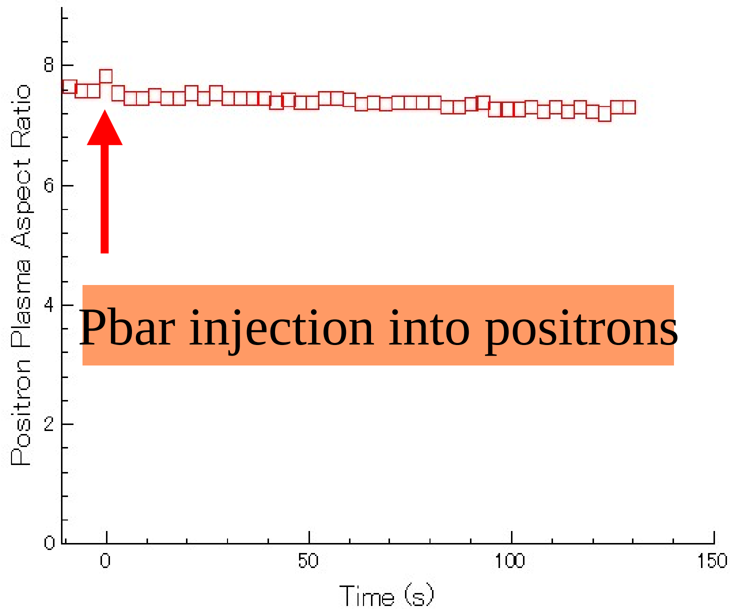


Equivalent Circuit Model

RF Plasma Heating

Non-destructive
Simultaneous
determination

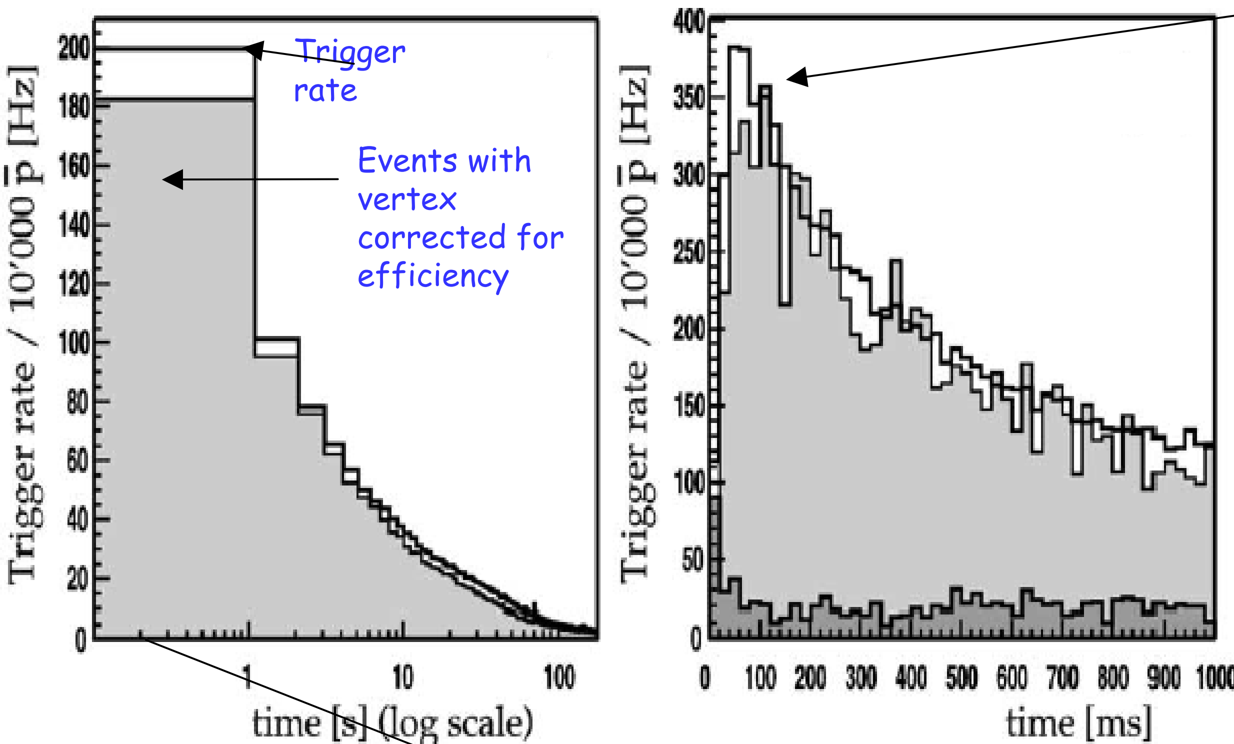
Plasma Shape, Density,
Particle Number,
Temperature



Monitoring of plasma → no change due to pbars

Production and trigger rate

Trigger rate vs time during cold mixing



•85% of initial (<1s) trigger rate is due to antihydrogen

• Peak rate >300 Hz

17% of the injected antiprotons recombine

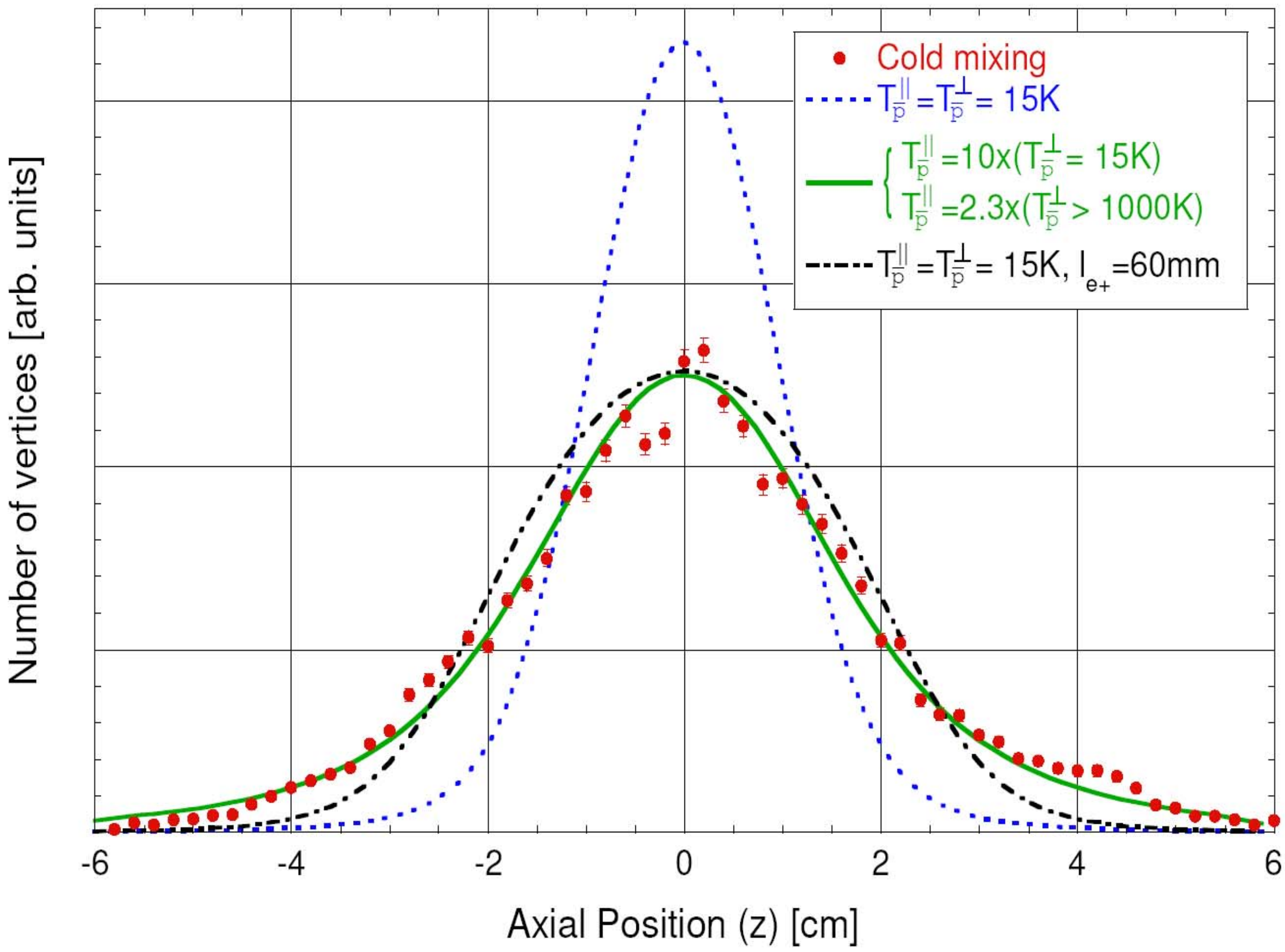
• Trigger rate is a good proxy for the antihydrogen signal

zoom of the first sec of mixing time

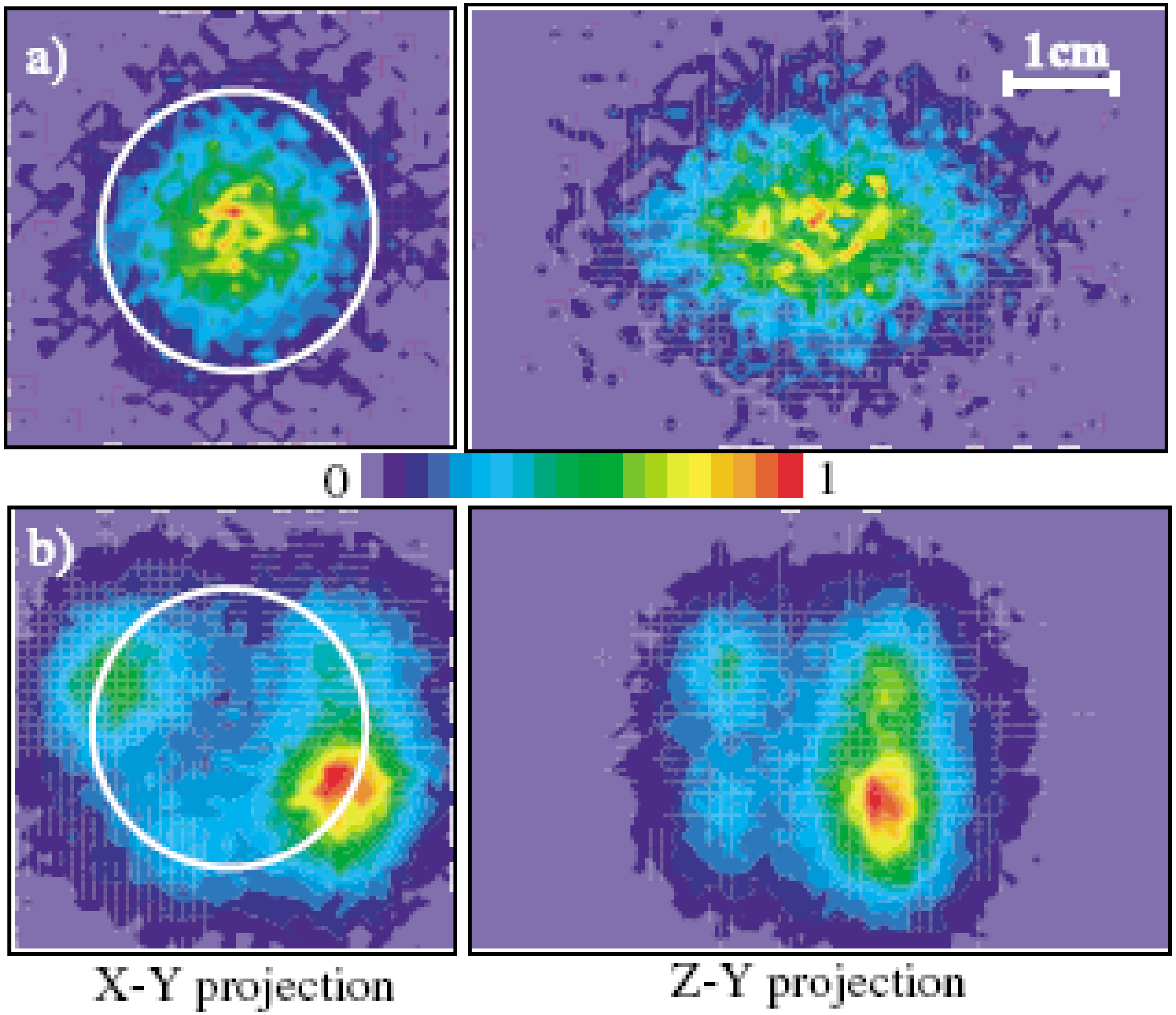
From Amoretti et al. Phys. Letts B 578 (2004) 23

Antihydrogen Emission Angles

Vertex Z Distribution



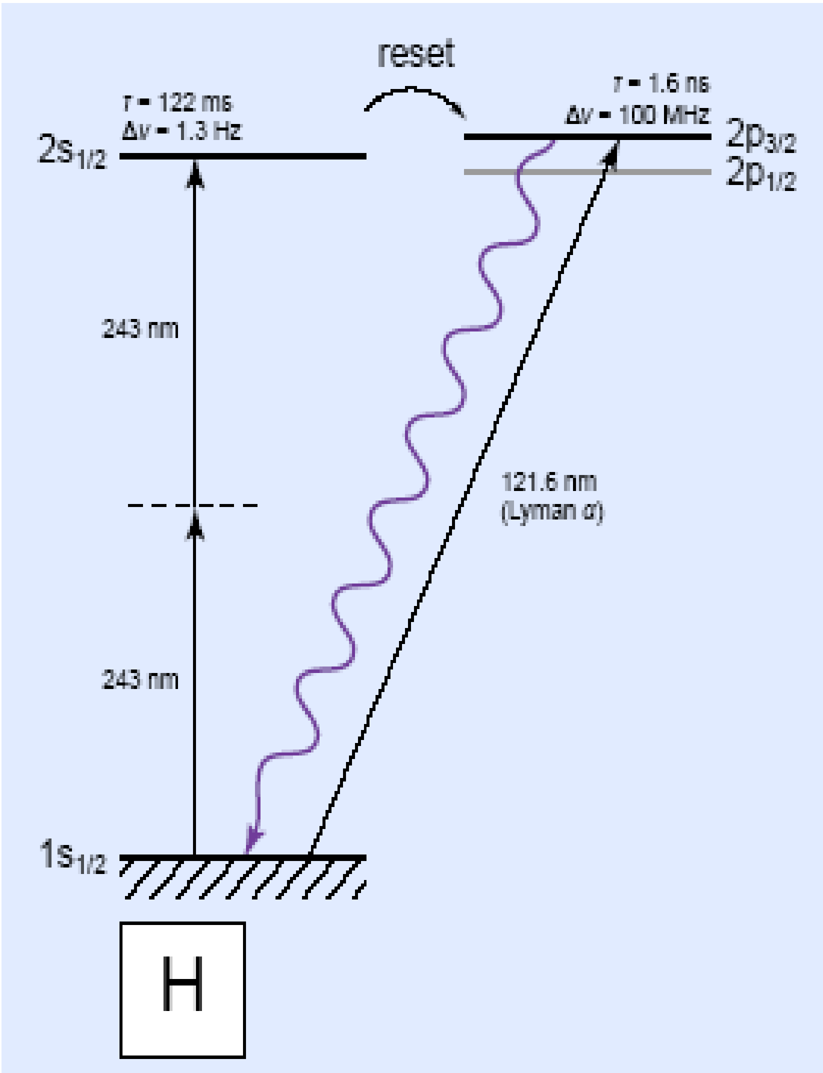
Imaging



α Antihydrogen Laser PHysics Apparatus

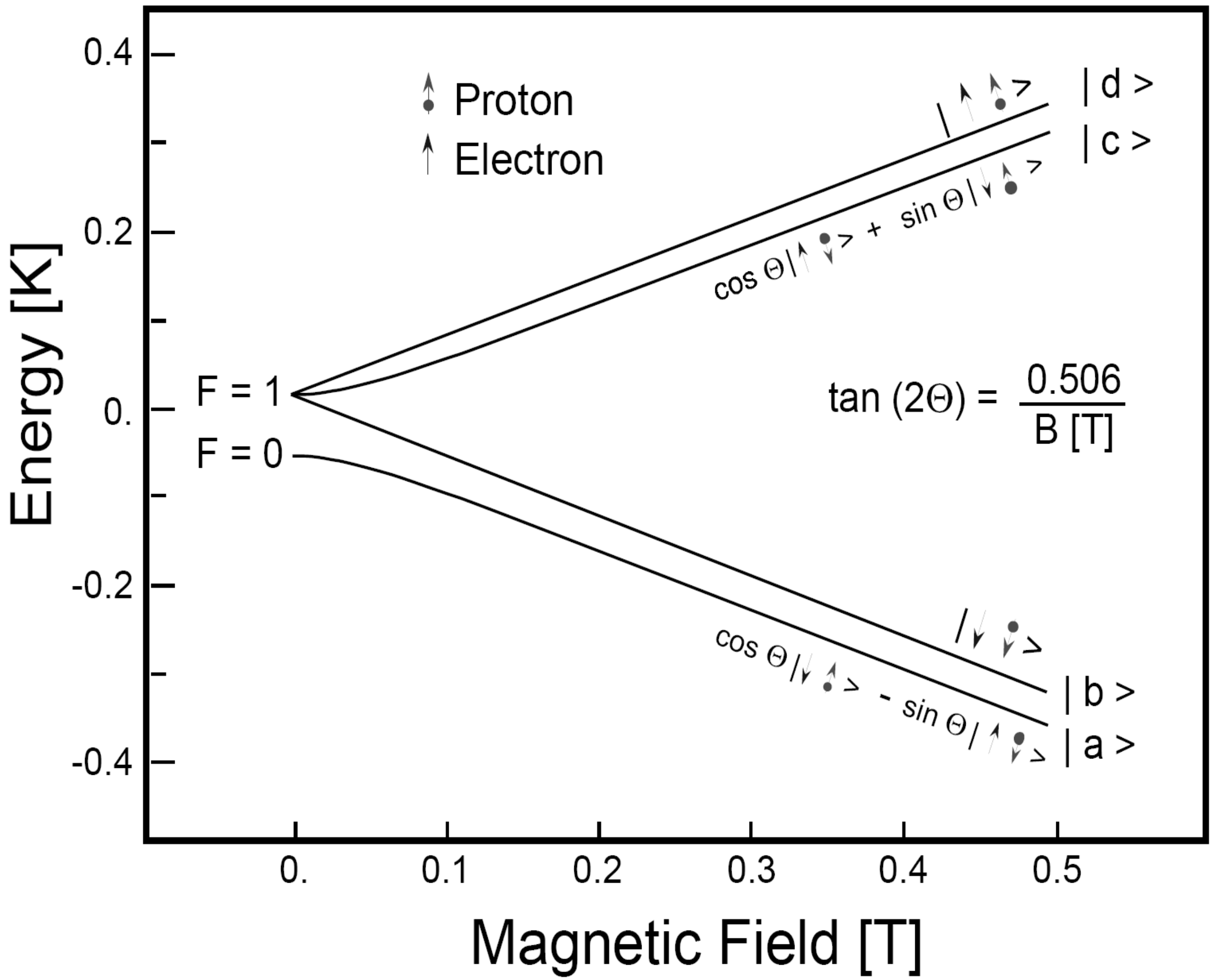
University of Aarhus:	***P.D. Bowe, J.S. Hangst***
Auburn University:	***F. Robicheaux***
University of California, Berkeley and:	***W. Bertsche, S.Chapman, A. Deutsch, A. Povilus,***
Lawrence Berkeley National lab	***P. Ko, J. Wurtele, J. Fajans***
University of Calgary:	***R.I. Thompson***
University of Liverpool:	***A. Boston, P. Nolan, M. Chartier, R.D. Page***
NCRN-Nuclear research center Negev:	***E. Sarid***
Riken:	***Y. Yamazaki***
Federal University of Rio de Janeiro:	***D. Miranda Silveria, C.L. Cesar***
University of Tokyo:	***R. Funakoshi, L.G.C. Posada, R.S. Hayano***
TRIUMF:	***J. Dilling, D.Gill, K. Ochanski, A. Olin, M.C. Fujiwara,***
University of Wales, Swansea:	***M. Jenkins, L. V. Jørgensen, N. Madsen,***
	D.P. van der Werf, H.H. Telle, M. Charlton
University of Manitoba:	***G. Gwinner***
University of Calgary:	***R.I. Thompson***

2 photon Spectroscopy

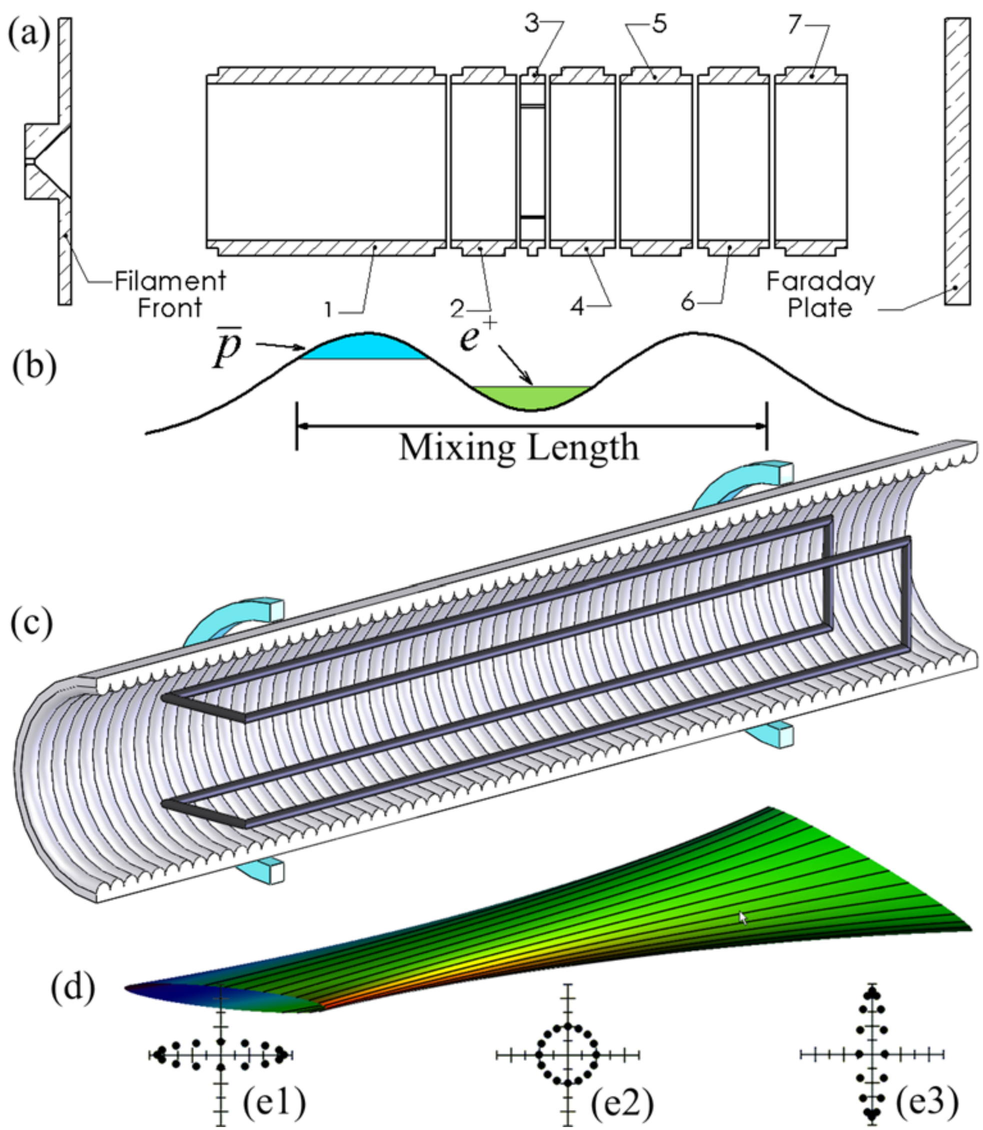


Highest Resolution: 4 ⯑ 10^{-16}

Energy level diagram



Quadrupole



R_w=1.00cm

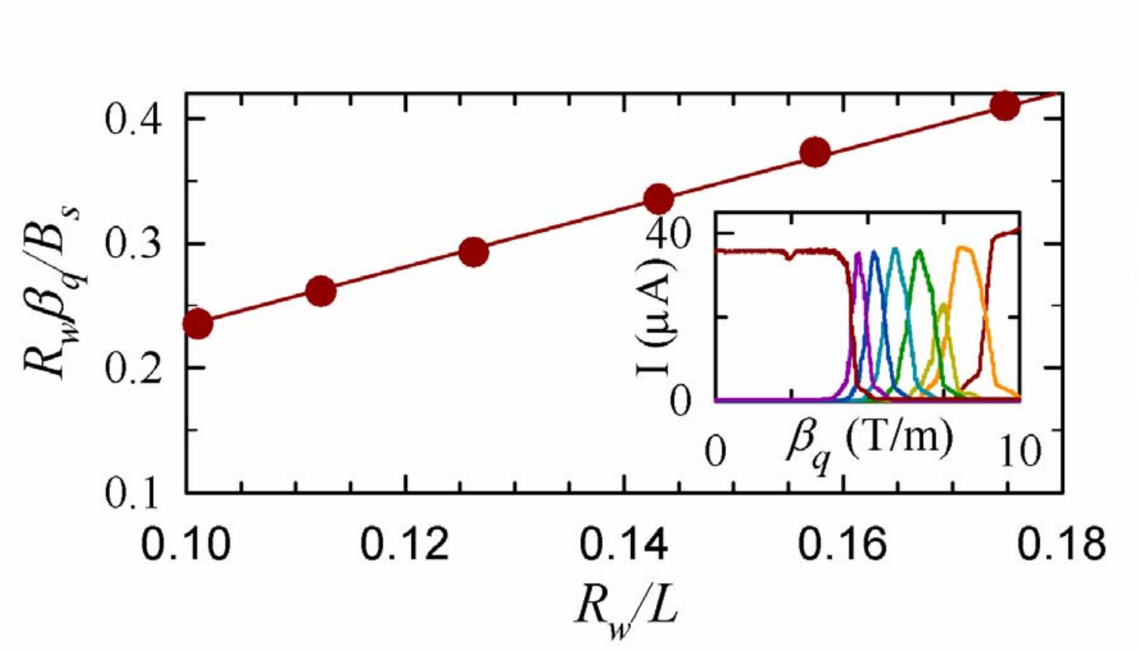
Cylinder 1: 3.00cm

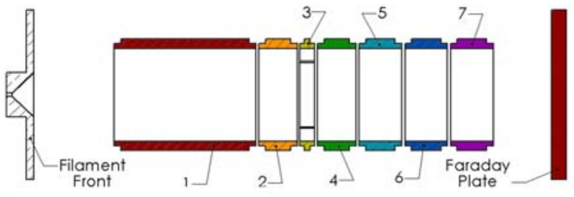
Cylinders 2&4: 0.84cm

Cylinder 3: 0.40cm

Cylinders 5,6,7 1.00cm

$$B = B\hat{z} + \beta_q \left(x\hat{x} - y\hat{y} \right)$$

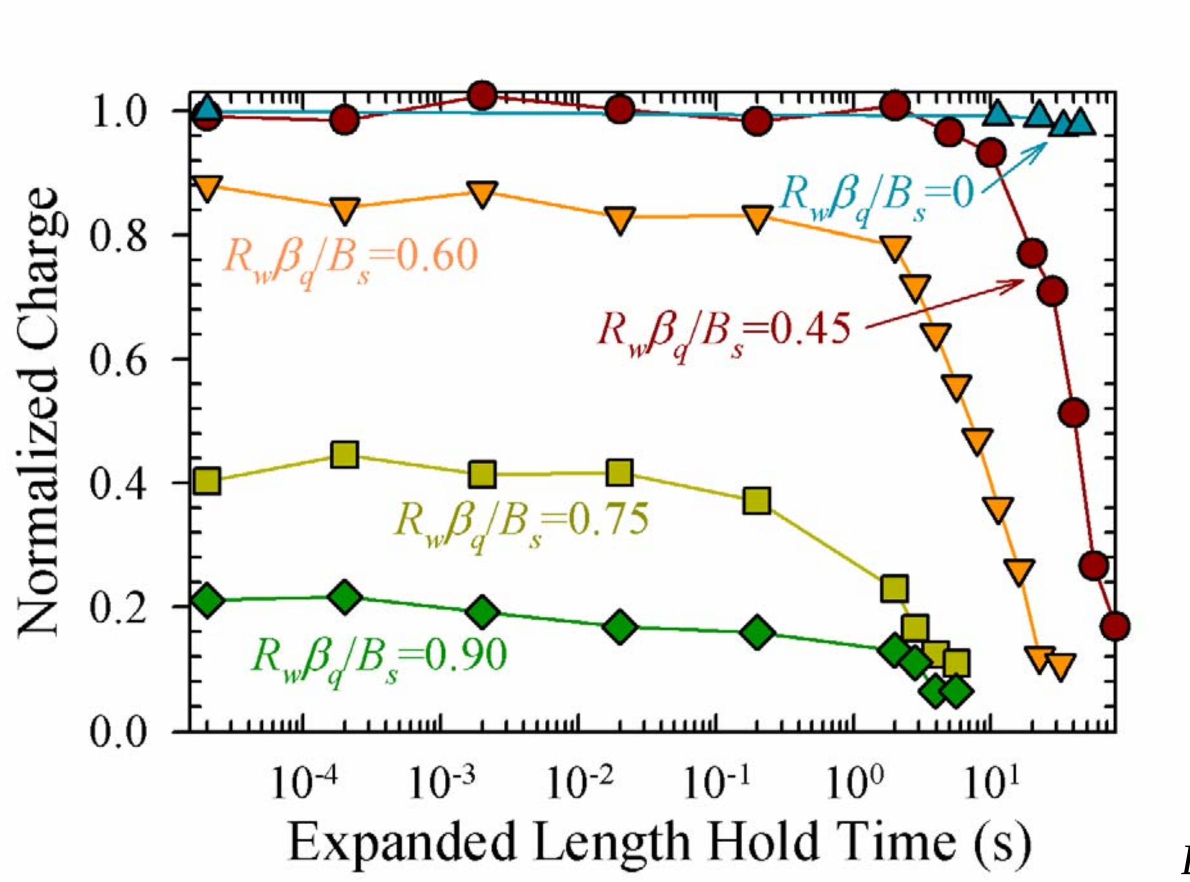




Beam expands like: $\exp\left(\frac{\beta_q}{B_s}z\right)$

It is impossible to propagate a beam into a quadrupole.

Plasma stability

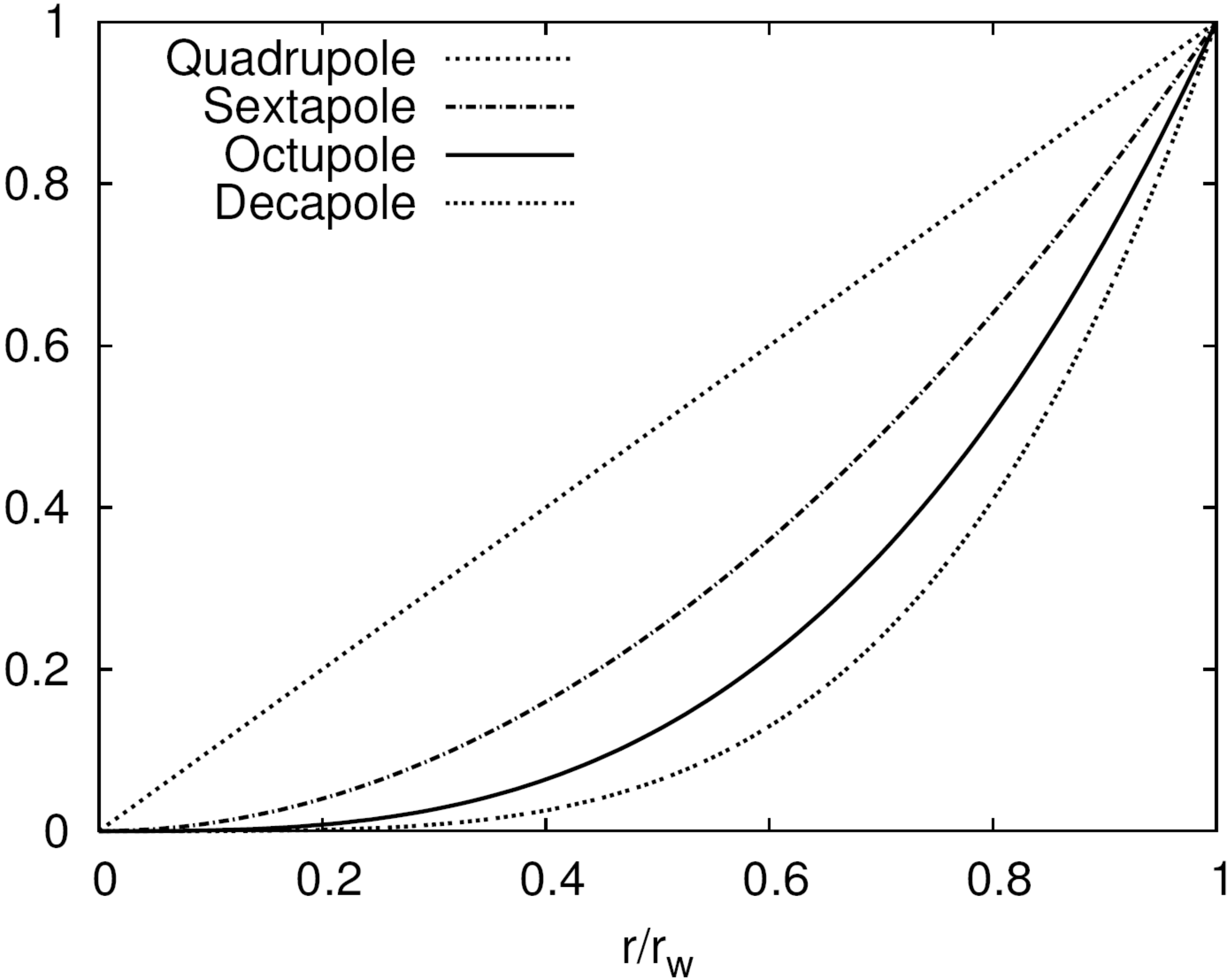


Expansion from 1cm to 4cm well

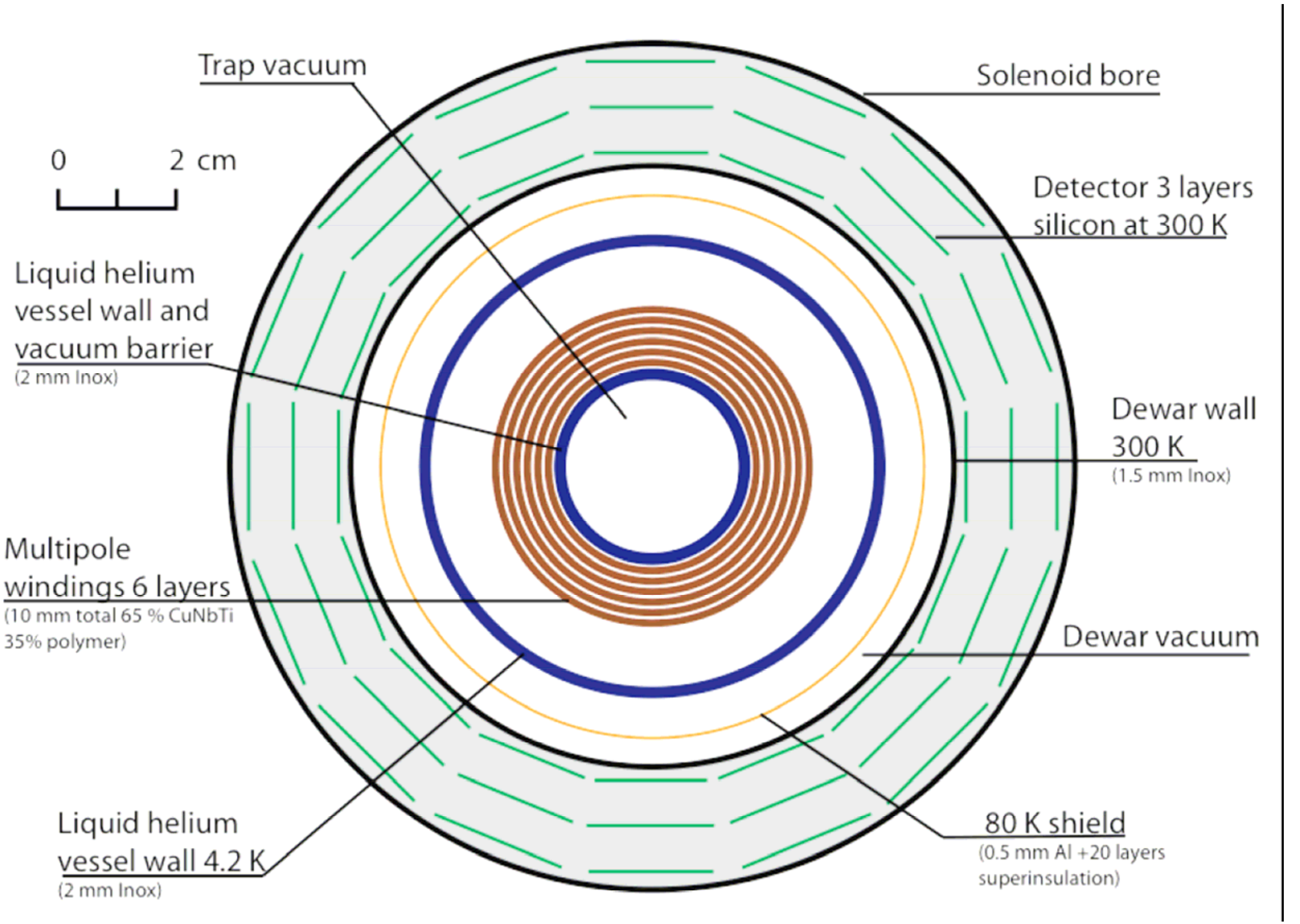
$B_s = 0.4\mathrm{T}$

At high quadrupole fields, most of the charge is lost "instantly."

At intermediate fields, the remaining charge is lost ~1-100s


Quadrupole
Sextapole
Octupole
Decapole
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
r/r_w

Detector



Trap vacuum
Solenoid bore
0 2 cm
Detector 3 layers
silicon at 300 K
Liquid helium
vessel wall and
vacuum barrier
(2 mm Inox)
Dewar wall
300 K
(1.5 mm Inox)
Multipole
windings 6 layers
(10 mm total 65 % CuNbTi
35% polymer)
Dewar vacuum
Liquid helium
vessel wall 4.2 K
(2 mm Inox)
80 K shield
(0.5 mm Al +20 layers
superinsulation)

Summary

•**Results:**

- **We produced Millions Hbars in the last years**
- **High initial rate production > 300 Hz**
- **Many measurements: plasma modes, mixing processes, emission angles, imaging, temperature dependence, …**
- **Quadrupole does not work**

Outlook

- **This year:**
  - **Commission most of the apparatus before beamtime**
  - **Produce antihydrogen in ATHENA conditions**
  - **Produce antihydrogen in multipolar fields**
  - **Maybe capture of antihydrogen**

- **Precision spectroscopy**
  - **1S-2S**
  - **Hyperfine**

- **Gravity measurements**