AD-Physics in 2006 and beyond

Walter Oelert
Research Centre Jülich, Germany
Ruhr Universität Bochum, Germany
CERN
24. January 2007

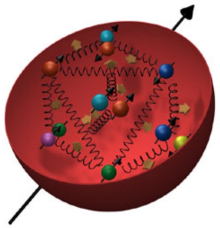
AD-1	*ATHENA completed*
AD-2	*(ATRAP)* Cold Antihydrogen for Precise Laser Spectroscopy
AD-3	*(ASACUSA)* Atomic Spectroscopy and Collisions Using Slow Antiprotons The ASACUSA Collaboration
AD-4	*(ACE)* Relative Biological Effectiveness and Peripheral Damage of Antiproton Annihilation
AD-5	*(ALPHA)* Antihydrogen Laser PHysics Apparatus

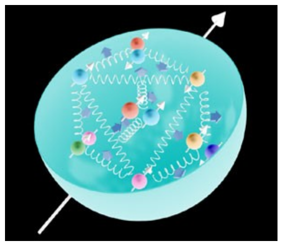
new, to come:

AEGIS: a new proposal in preparation and it will be submit within 2007
The main goal is a direct gravity measurement on antihydrogen
Antiproton beam time: probably in 2009
We are planning to install the apparatus in the actual DEM zone
ELENA will be welcome and we support it.

Gemma Testera

The PAX collaboration





Motivation
make and study **Cold Antihydrogen**

- CPT invariance
  - high precision spectroscopy
- gravitation
  - matter - antimatter

CPT invariance
fundamental feature
of local relativistic
quantum field theories

gravitational force
between matter and antimatter
is essentially unknown
even in the sign

more general motivations

Test CPT invariance in lepton and baryon system

- Local, Lorentz-invariant quantum field theory → CPT invariance
- Need extensions to the standard model to get a CPT violation

e.g. R. Bluhm, V.A.Kostelecky, N. Russell, Phys. Rev. D **57**, 3932 (1998), …

Baryon-Antibaryon Asymmetry in Universe is not understood

Standard Explanation

- CP violation
- Violation of baryon number
- Thermodynamic non-equilibrium

Alternate

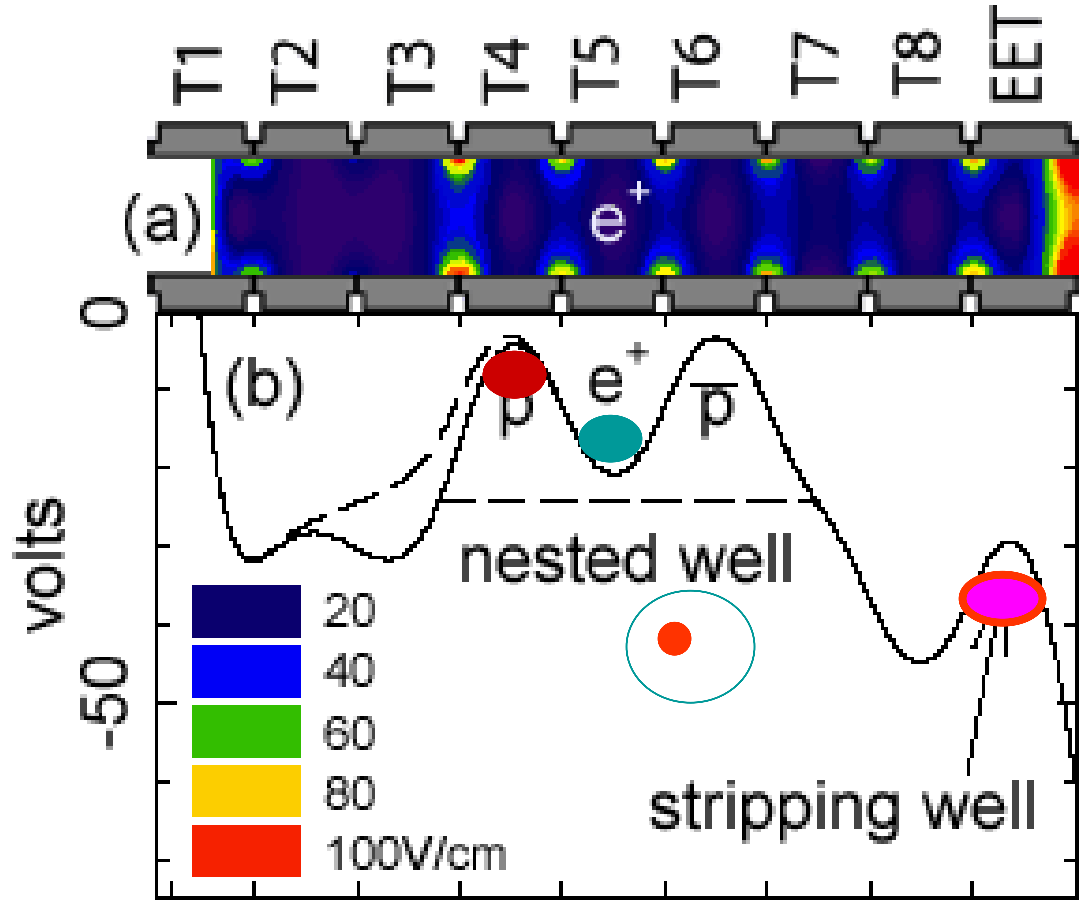
- CPT violation
- Violation of baryon number
- Thermo. equilib.

Bertolami, Colladay, Kostelecky, Potting: Phys. Lett. B 395, 178 (1997)

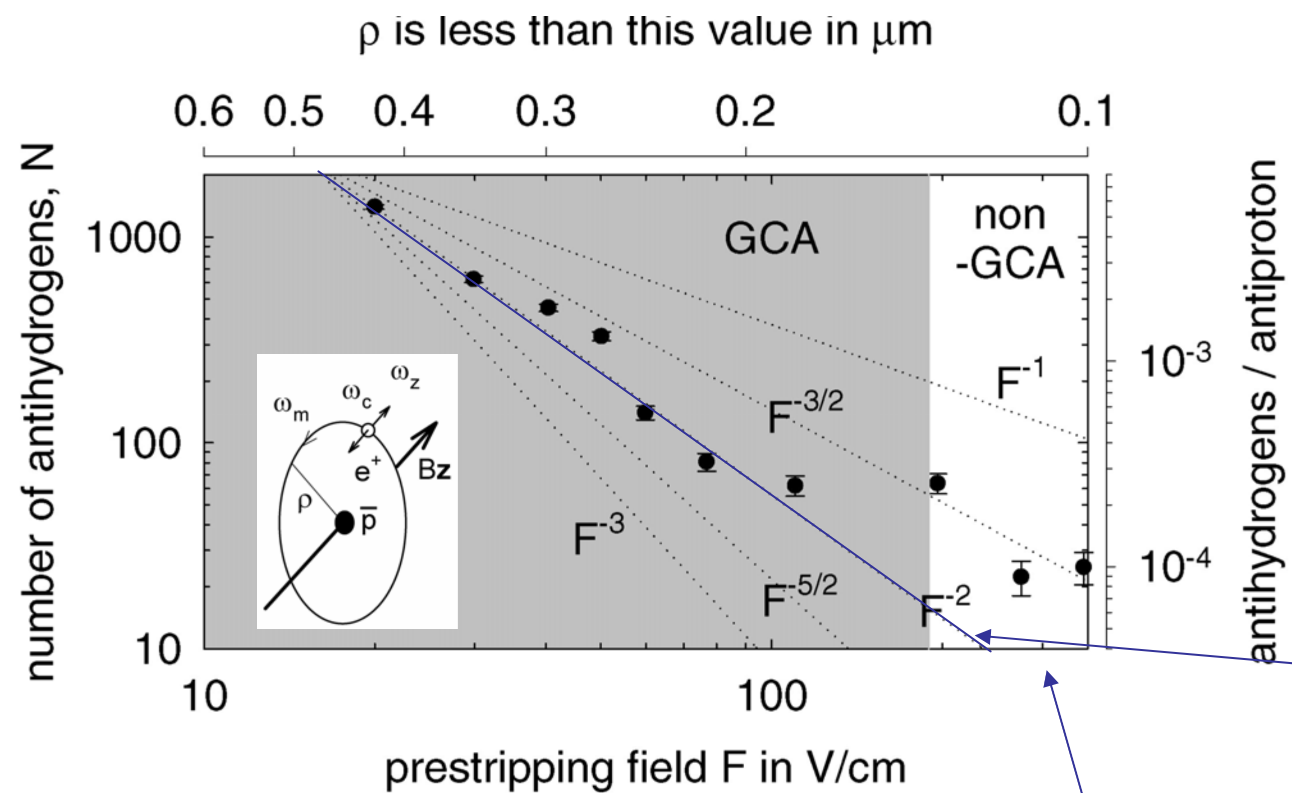
CPT in String Theory

- No CPT theorem in general
- Get CPT theorem if go to the limit of a quantum field theory

Makes sense to investigate these fundamental symmetries in the few places that we can hope to do so very **precisely**.


T1
T2
T3
T4
T5
T6
T7
T8
EET
(a)
e+
0
-50
volts
(b)
p
e+
p̄
nested well
20
40
60
80
100V/cm
stripping well

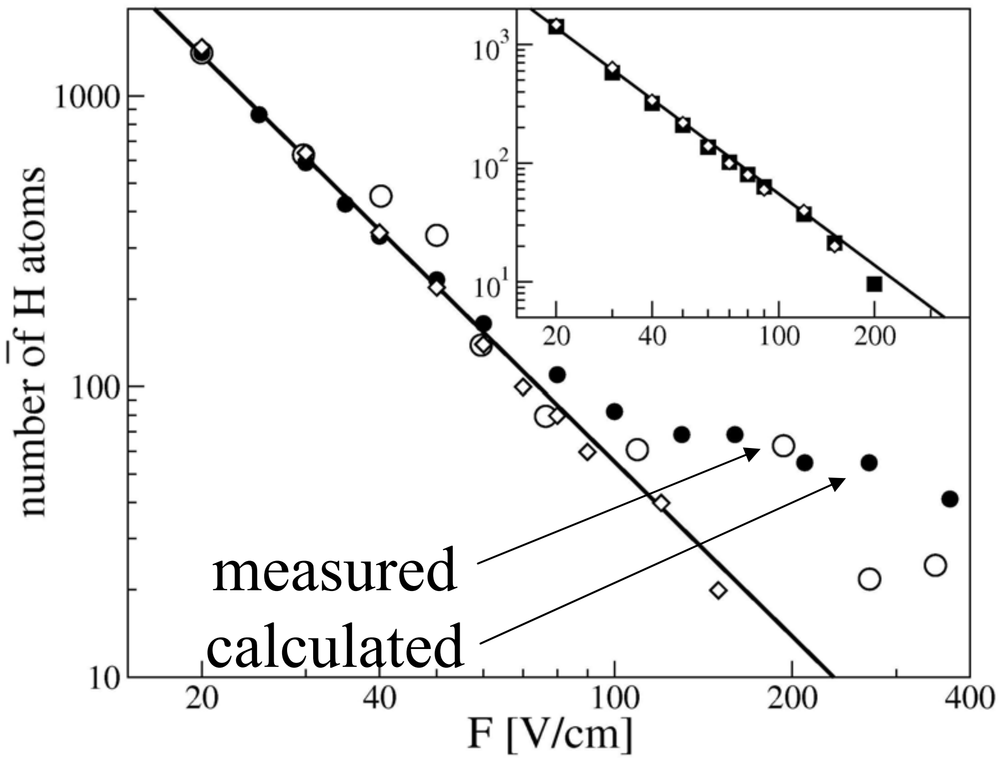
observed antihydrogen atoms are very weakly bound



relatively enhanced over F^{-2}

breakdown of the GCA picture → chaotic motion

Theory Progress: can now calculate the field ionization spectrum



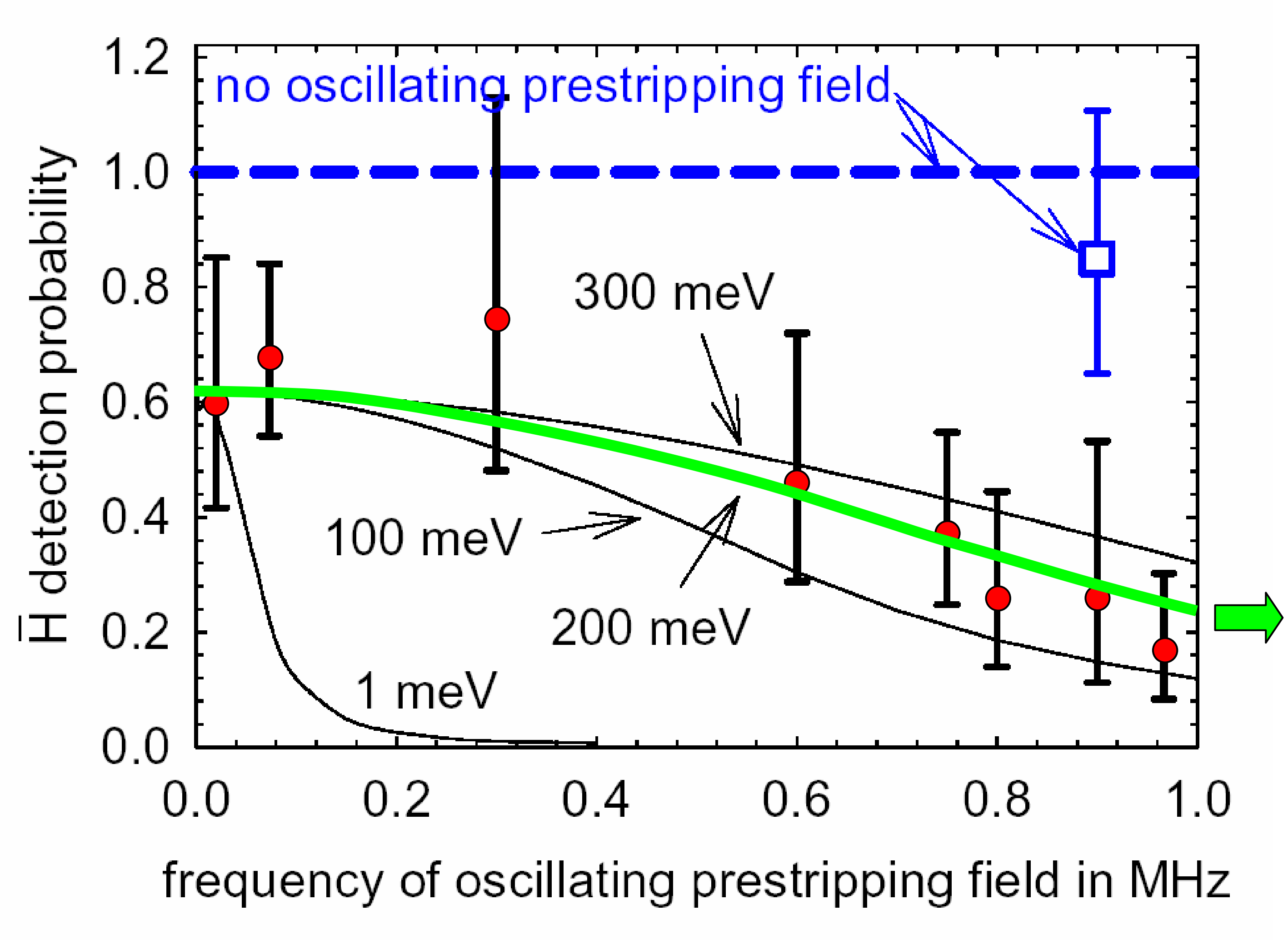
Get the F^{-2} dependence for small ionization field F

Get enhanced production of more tightly bound states (need to abandon the guiding center approximation)

"New Interpretations of Measured Antihydrogen Velocities and Field Ionization Spectra"
T. Pohl, H.R. Sadeghpour, and G. Gabrielse
Phys. Rev. Lett. **97**, 143401 (2006)

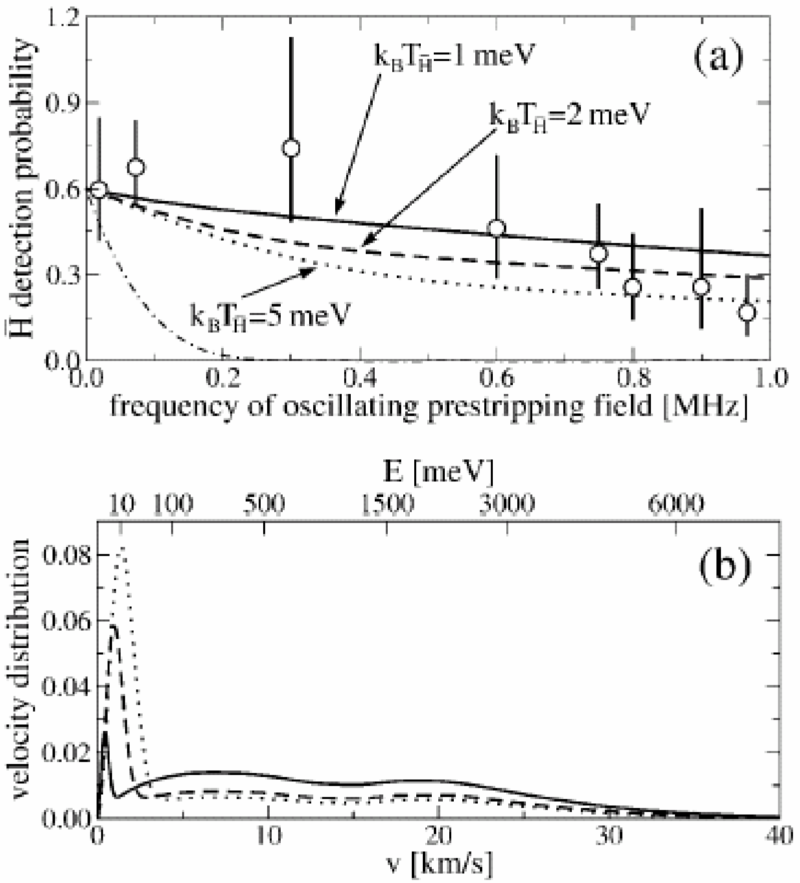
velocity measurement

published in PRL



$\bar{H}$ are hotter than expected – too hot to handle favourable interpretation of the antihydrogen velocity measurement

observed fast antihydrogen atoms were generated from
slow antihydrogen after antiproton charge exchange processes



as consistent with measurements
as is high speed, monoenergetic
antihydrogen

→ means that cold antihydrogen
is likely also being produced

"New Interpretations of Measured Antihydrogen Velocities and Field Ionization Spectra"
T. Pohl, H.R. Sadeghpour, and G. Gabrielse
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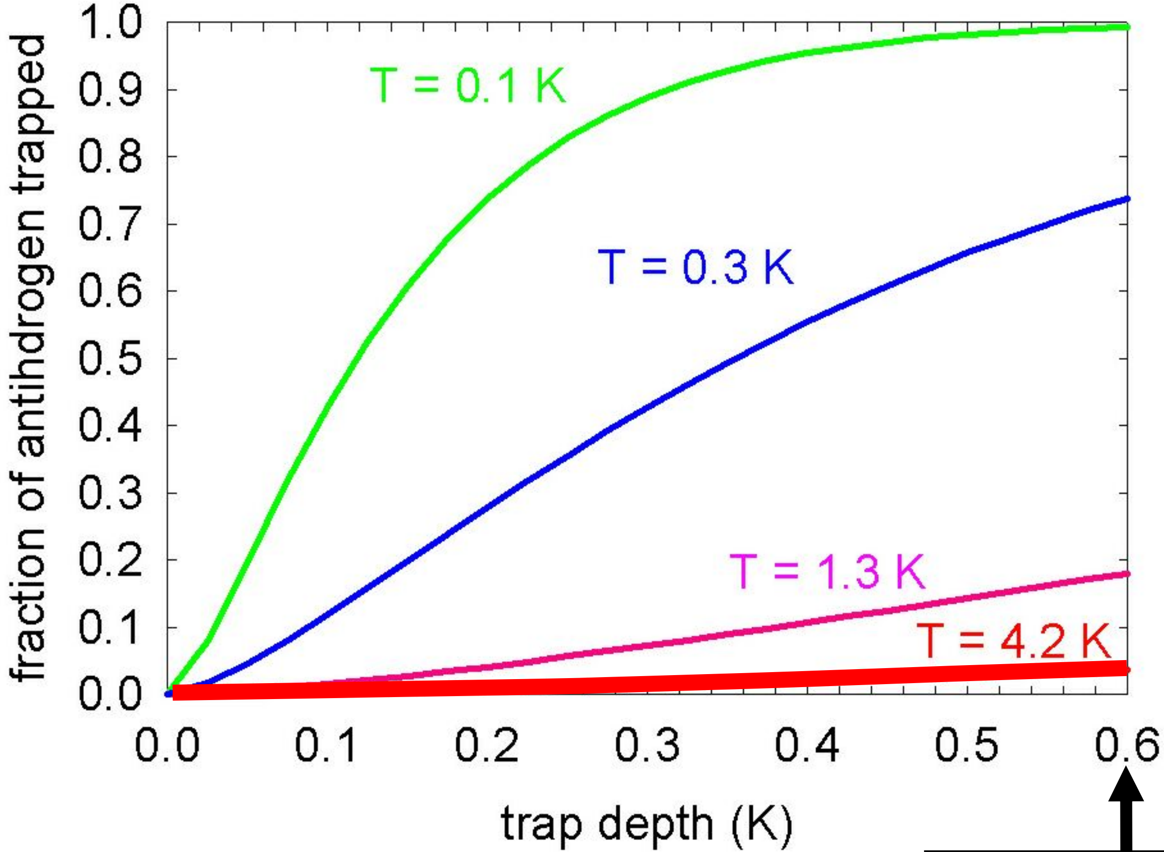
$\overline{H}$ trapping efficiency

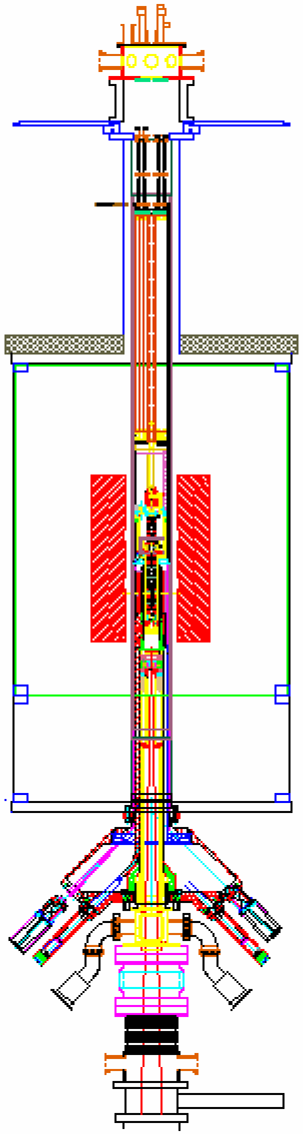
< 5 % (4.2 K , ΔB=1T)

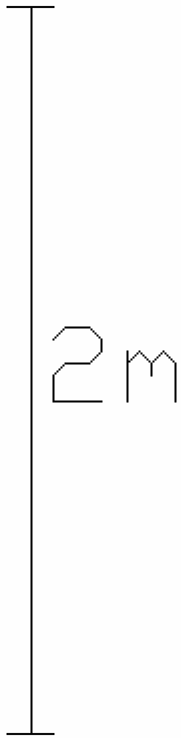


ΔB ~ 1T

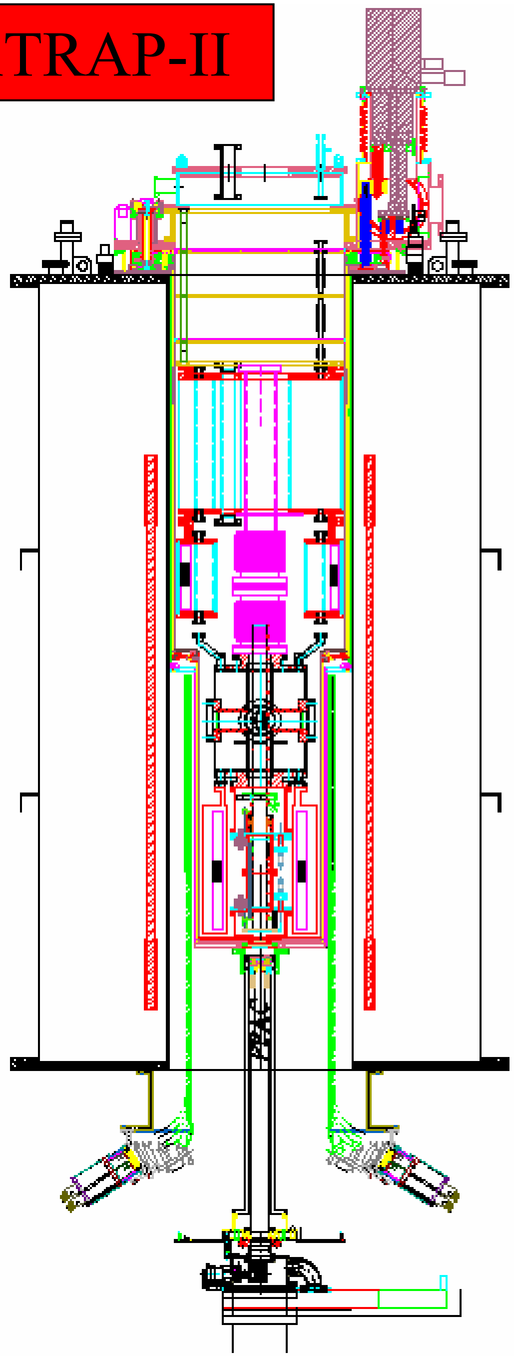
magnetic quadrupol trap (Ioffe trap)

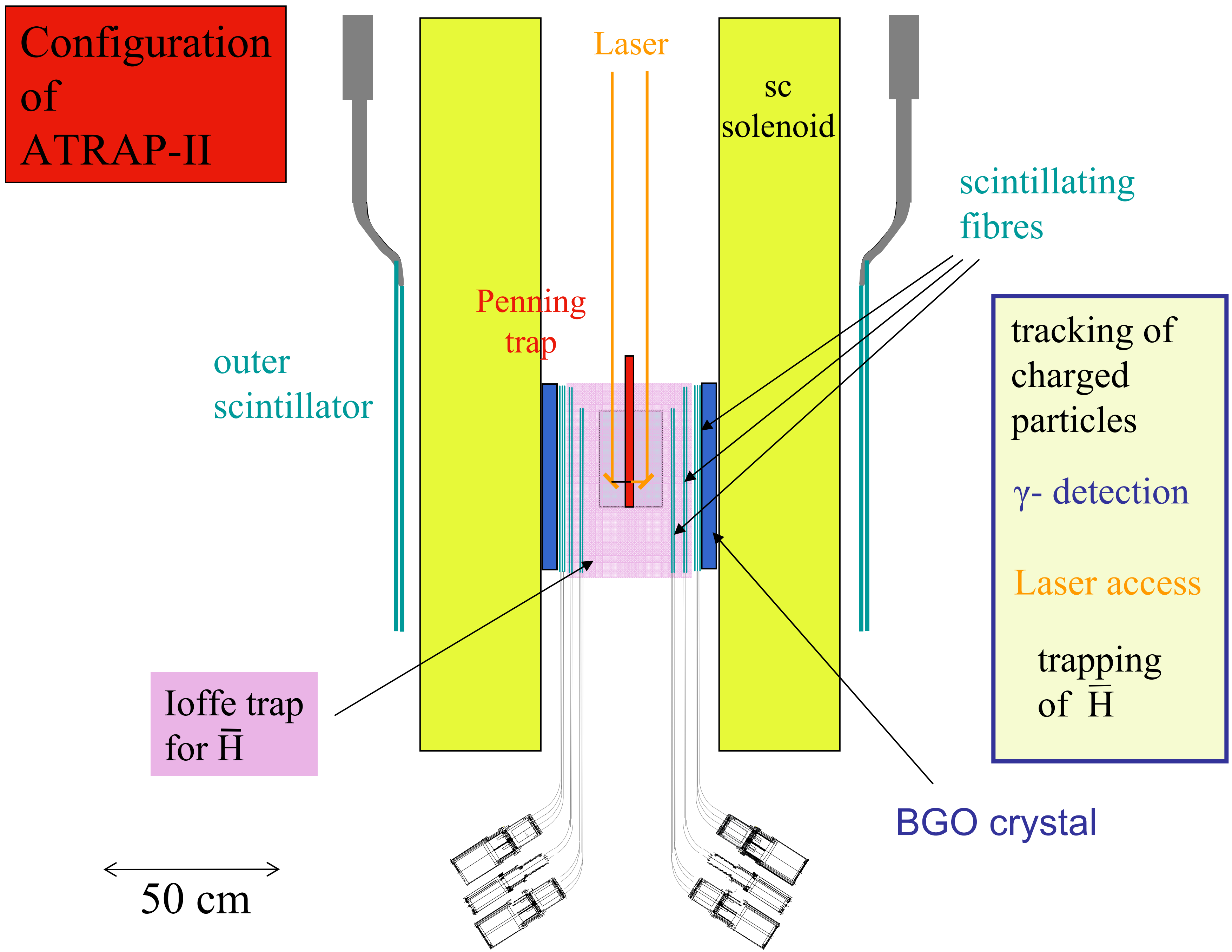
ATRAP-I



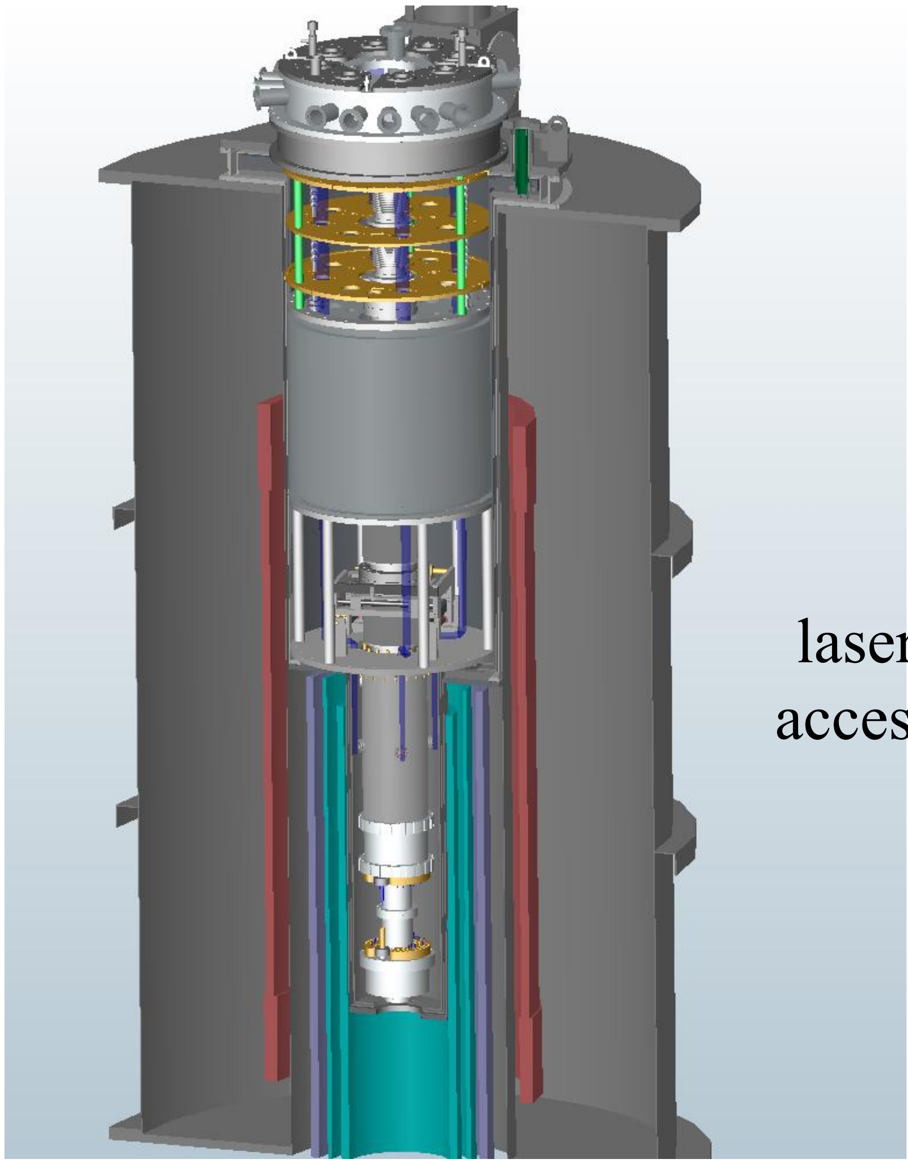


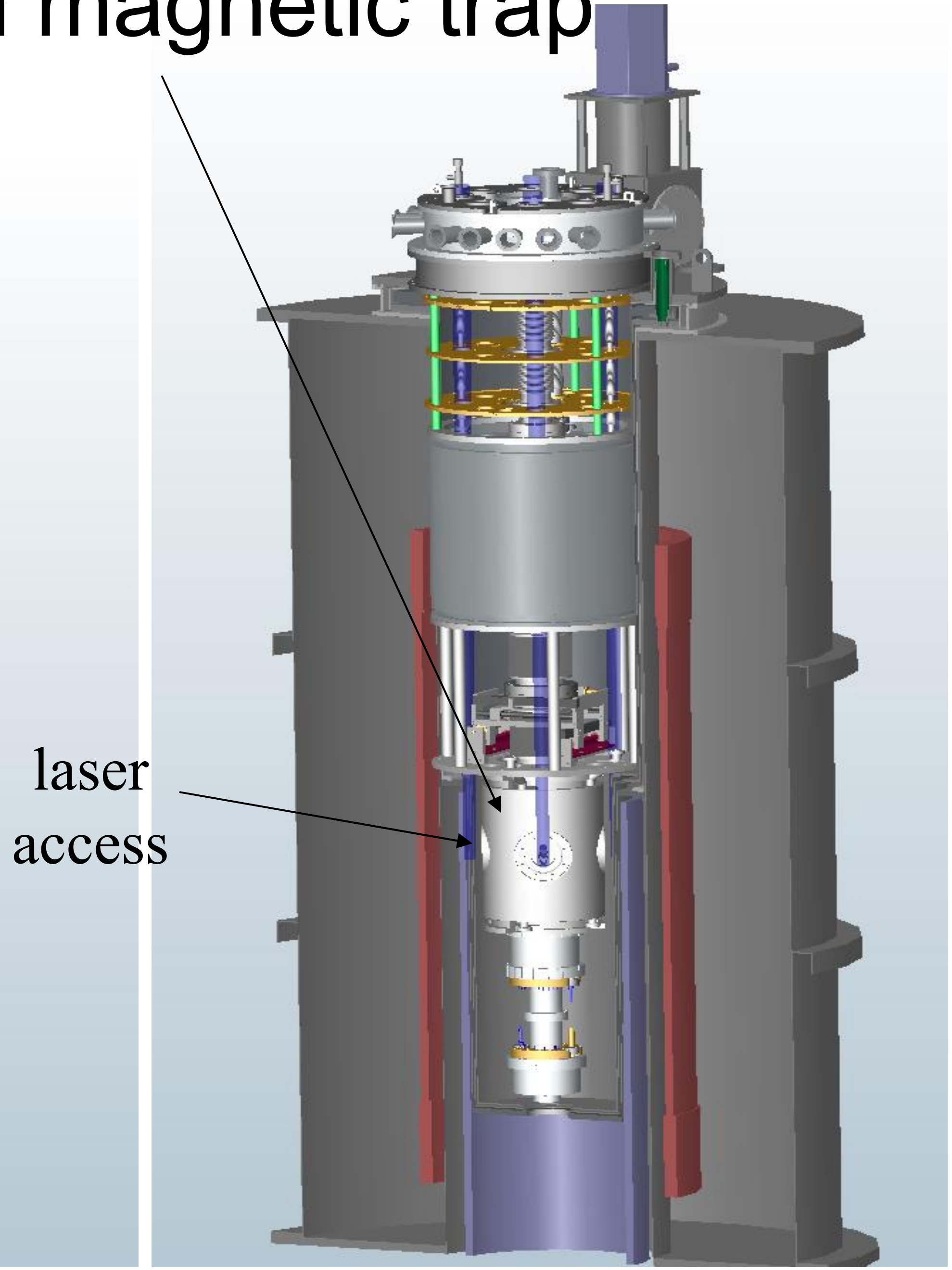
ATRAP-II

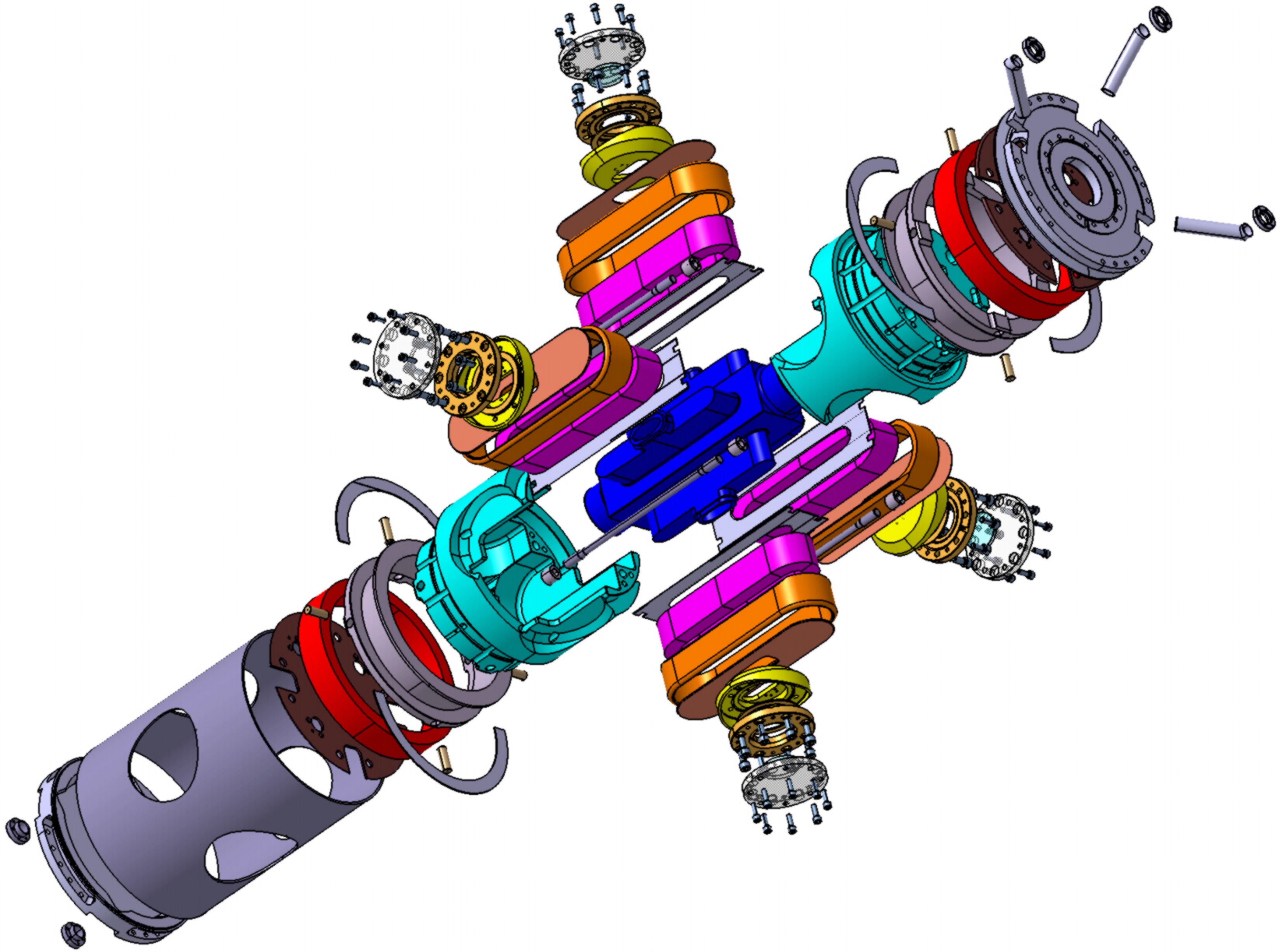


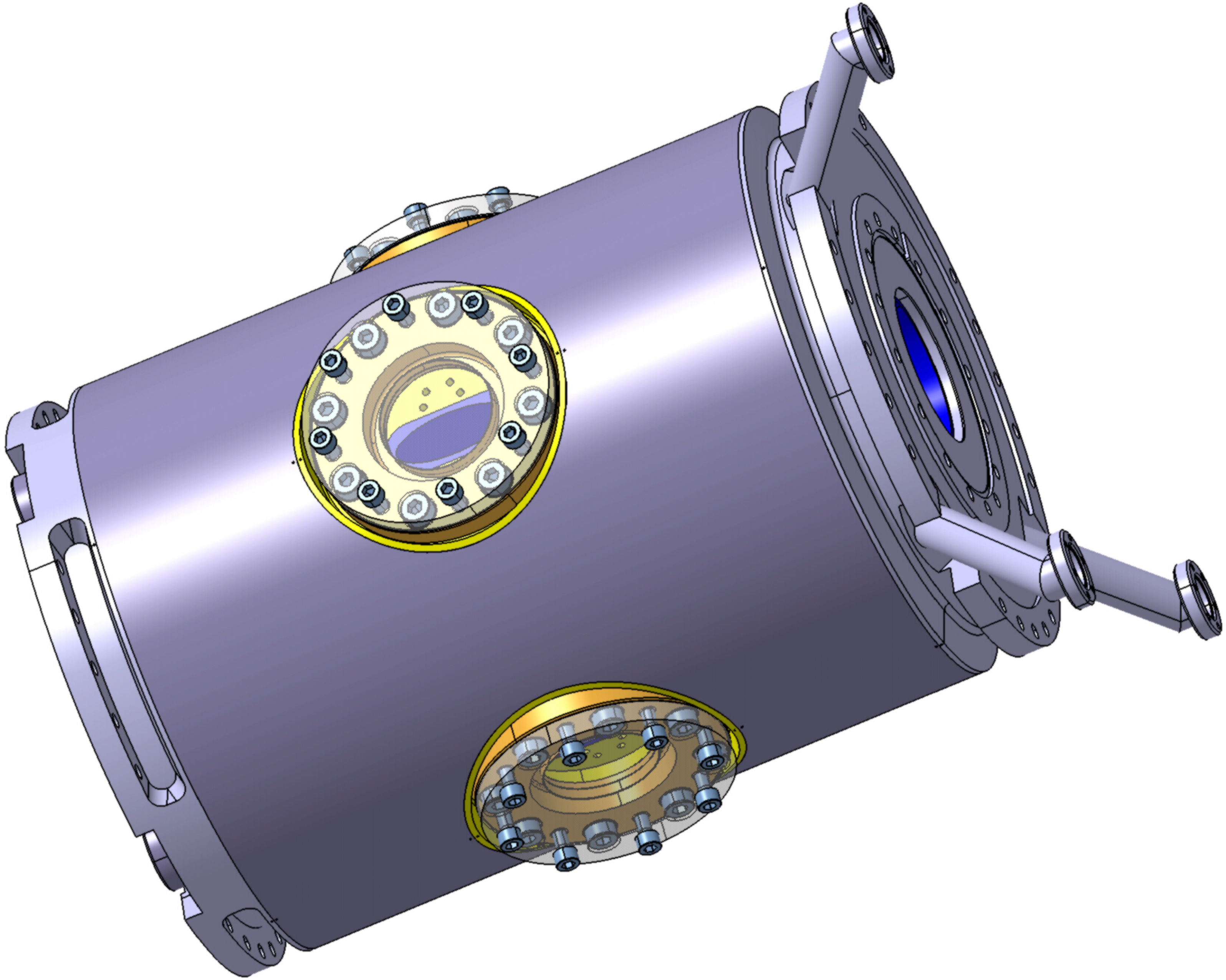

Configuration of ATRAP-II
Laser
sc solenoid
scintillating fibres
Penning trap
outer scintillator
tracking of charged particles
γ- detection
Laser access
trapping of H̄
Ioffe trap for H̄
BGO crystal
50 cm

without and with magnetic trap

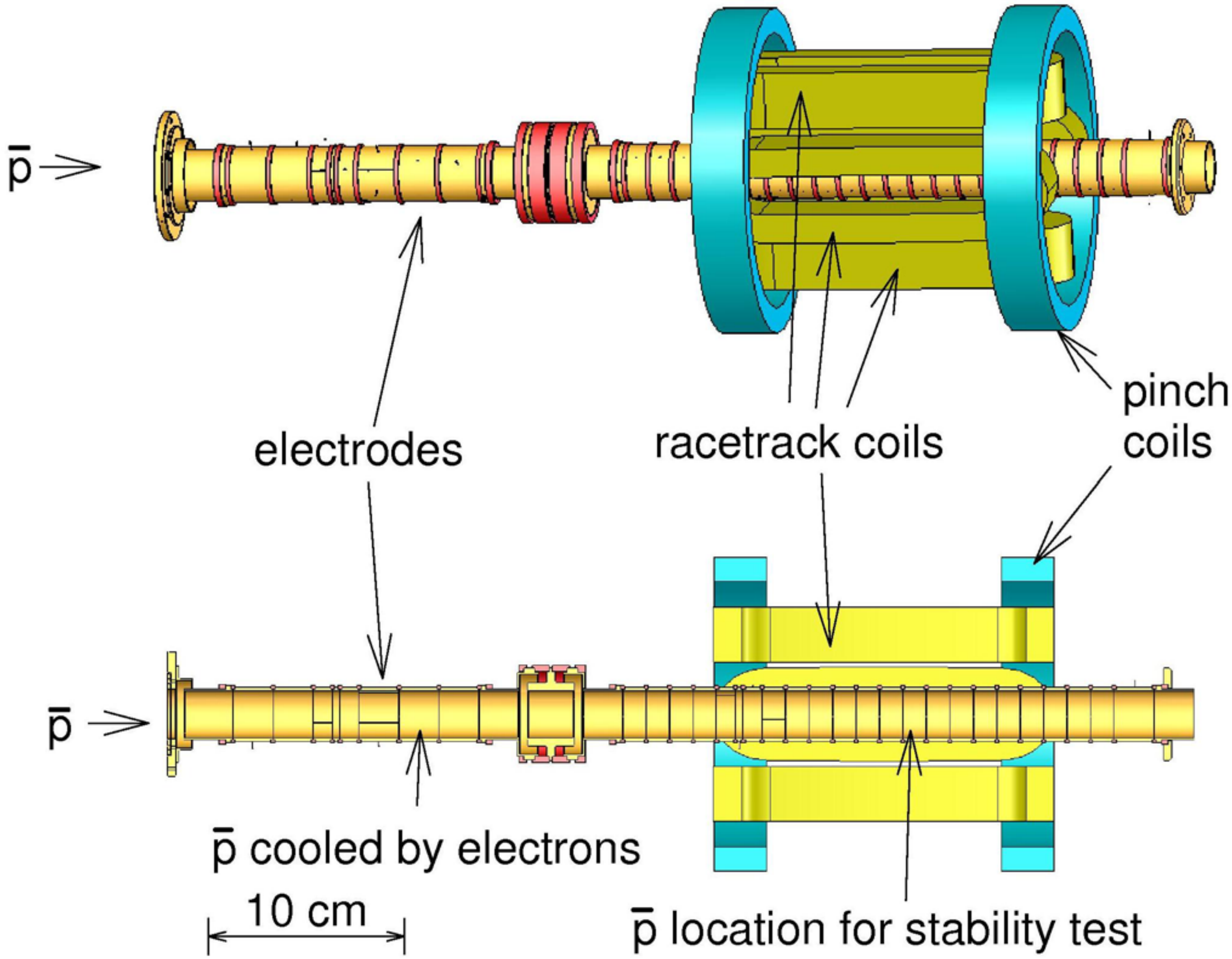




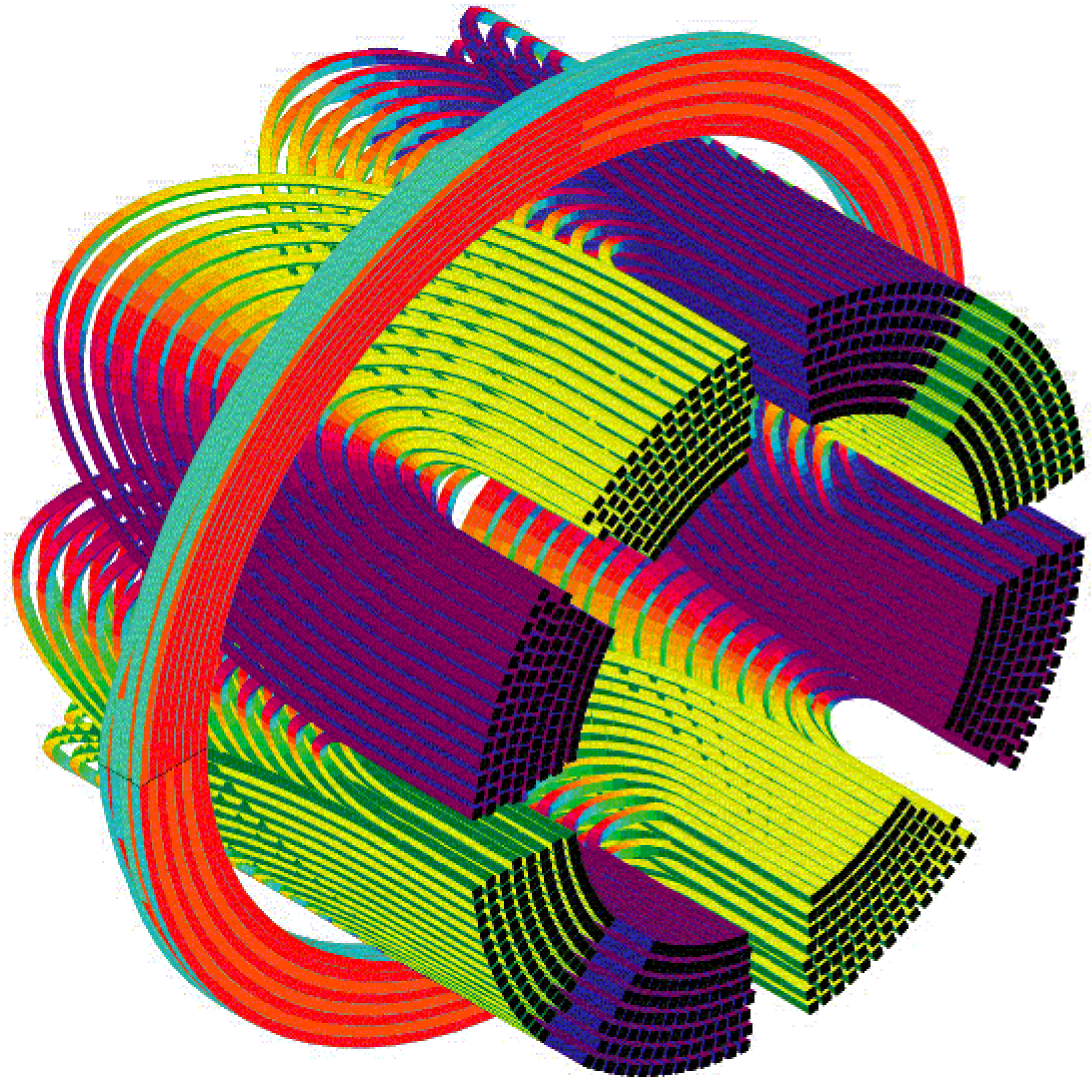


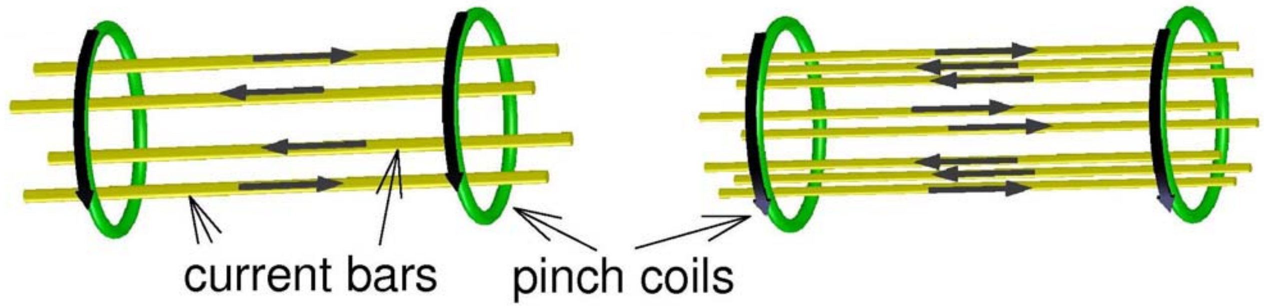


ATRAP Penning-Ioffe trap



ALPHA higher order Ioffe trap



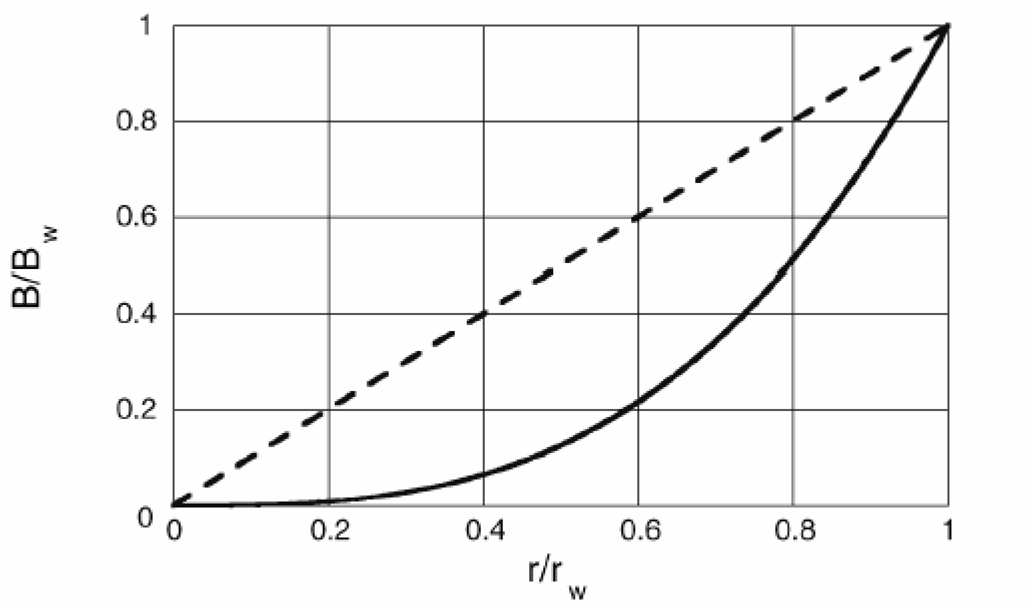


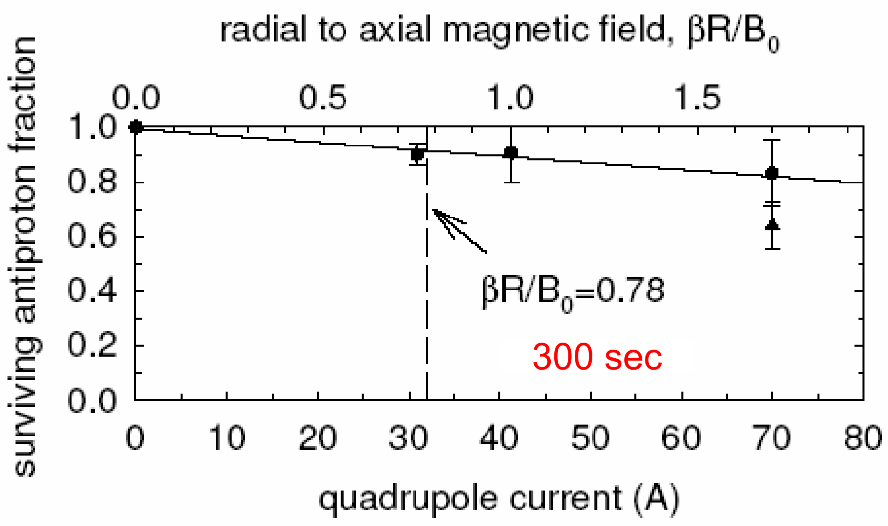
quadrupole-Ioffe trap

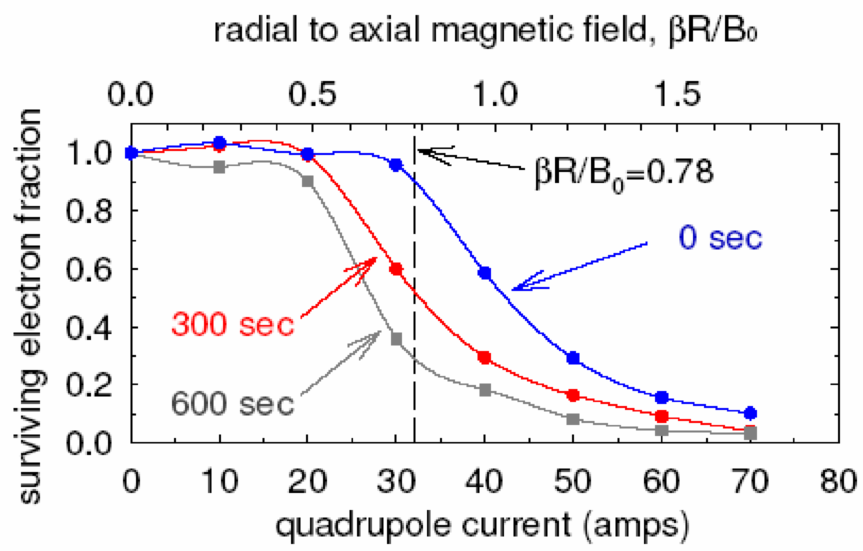
- Deeper antihydrogen well within trap electrodes (in principle)
- Tighter confinement of antihydrogen
- Easier radial access for cooling and spectroscopy lasers

higher order Ioffe trap

- Less magnetic gradient gives longer charged particle storage

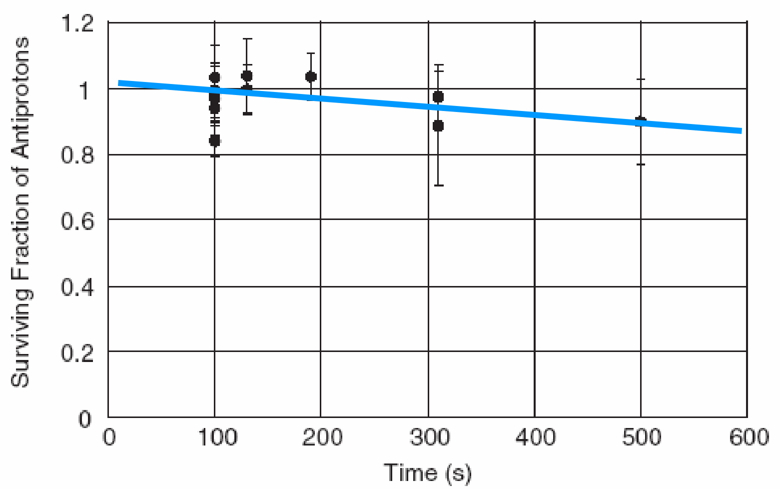


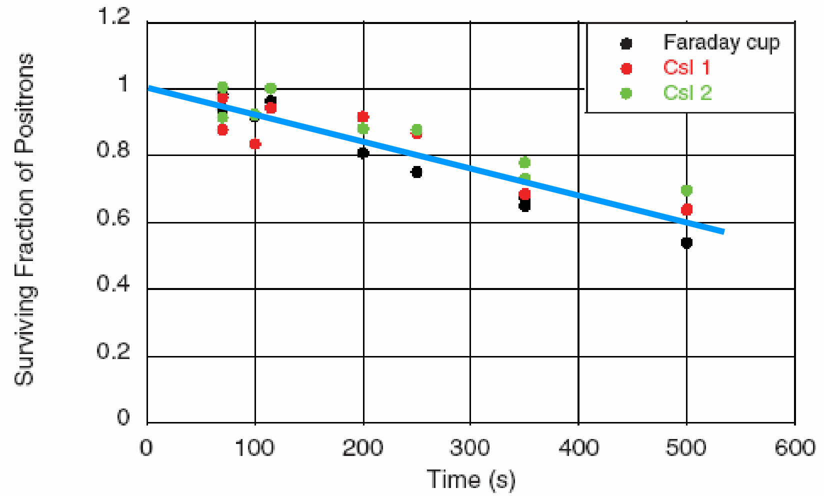




ATRAP

antiprotons, positrons (anti-positrons) are long enough stable to make antihydrogen!



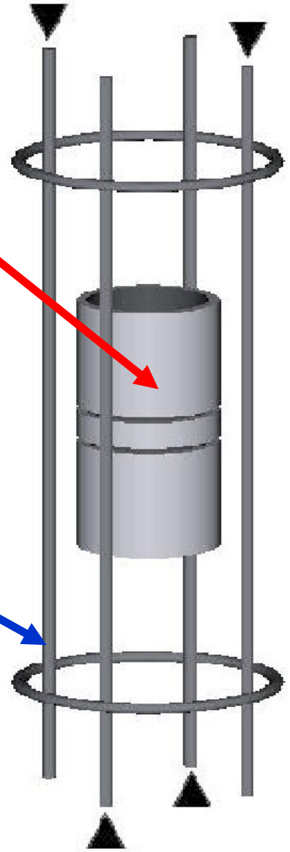


ATRAP and ALPHA:

demonstration of stable confinement of antiprotons and (anti-)positrons in a Penning-Ioffe trap

Penning trap – needed to trap antiprotons and positrons long enough to form antihydrogen

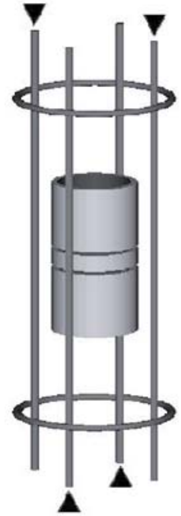
Ioffe trap – needed to catch the antihydrogen



can we superimpose them without losing the antiprotons and positrons and produce antihydrogen ?

different answers have been given

(about effect of an added radial quadrupole-Ioffe field)



T. Squires, P. Yesley, G. Gabrielse,
Phys. Rev. Lett. **86**, 5266 (2001)

- charged particles will remain trapped if their density is low
- expect instability at some high density (unknown)

E.P. Gilson, J. Fajans
Phys. Rev. Lett. **90**, 01501 (2003)

- diffusive particle loss would "very likely … destroy the confinement of positrons and antiprotons."

J. Fajans, W. Bertsche, K. Burke, S.F. Chapman and D.P. van der Werf
Phys. Rev. Lett. 95, 155001 (2005).

- quadrupole Ioffe traps cannot be used to trap antihydrogen … in all currently described [antihydrogen] production schemes."

- Seems like it should be possible to make antihydrogen by laser-controlled charge exchange within a quadrupole Penning-Ioffe trap.

- Whether this is so for producing antihydrogen in a nested Penning trap during the positron cooling of antiprotons remains to be studied.

- More detailed studies will take place when antiprotons again are available in 2007 and beyond

- Cold antihydrogen is still required. We may have this. It may be possible to trap highly excited antihydrogen

- There may be a role for quadrupole Ioffe traps and of higher order Ioffe traps.

Spin-off Measurement: Antiproton

$$g_{\bar{p}} = 5.601(18)$$

Make a one proton (antiproton) self-excited oscillator

→ try to detect a proton (and antiproton) spin flip

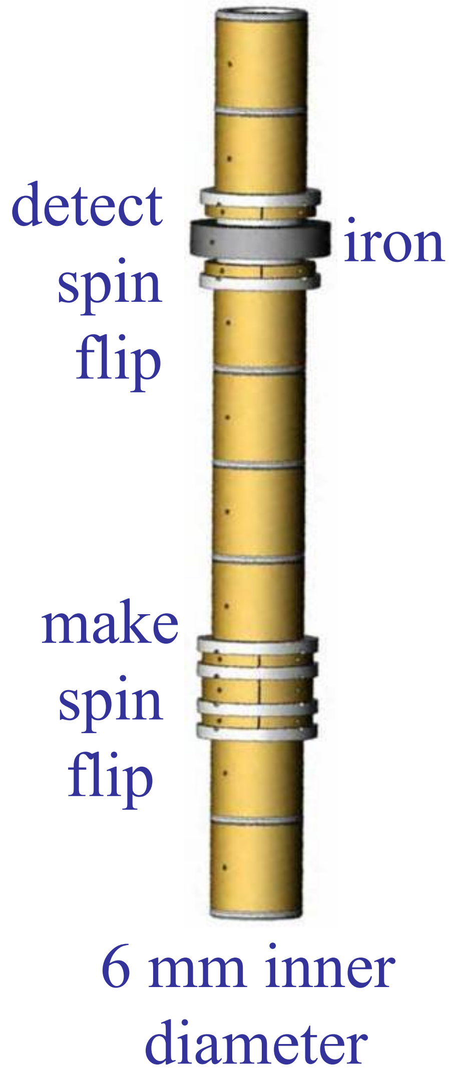
- Hard: nuclear magneton is 500 times smaller
- Apparatus constructed and being tried
  - → Harvard
  - → also Mainz and GSI (without SEO) (build upon bound electron g values)

→ measure proton spin frequency

→ we already accurately measure antiproton cyclotron frequencies

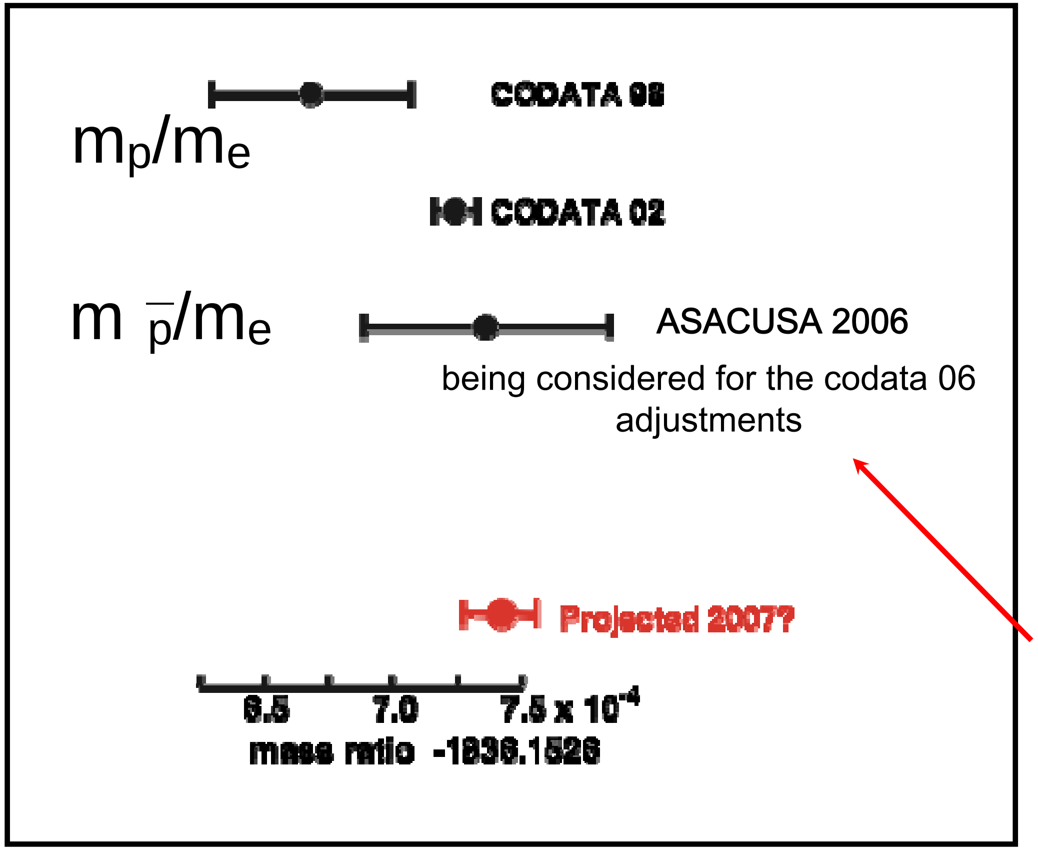
→ get antiproton g value

(Improve by factor of a million or more)



ASACUSA Status 1

$\bar{p}$He laser spectroscopy: $m_{\bar{p}}/m_e$ determination



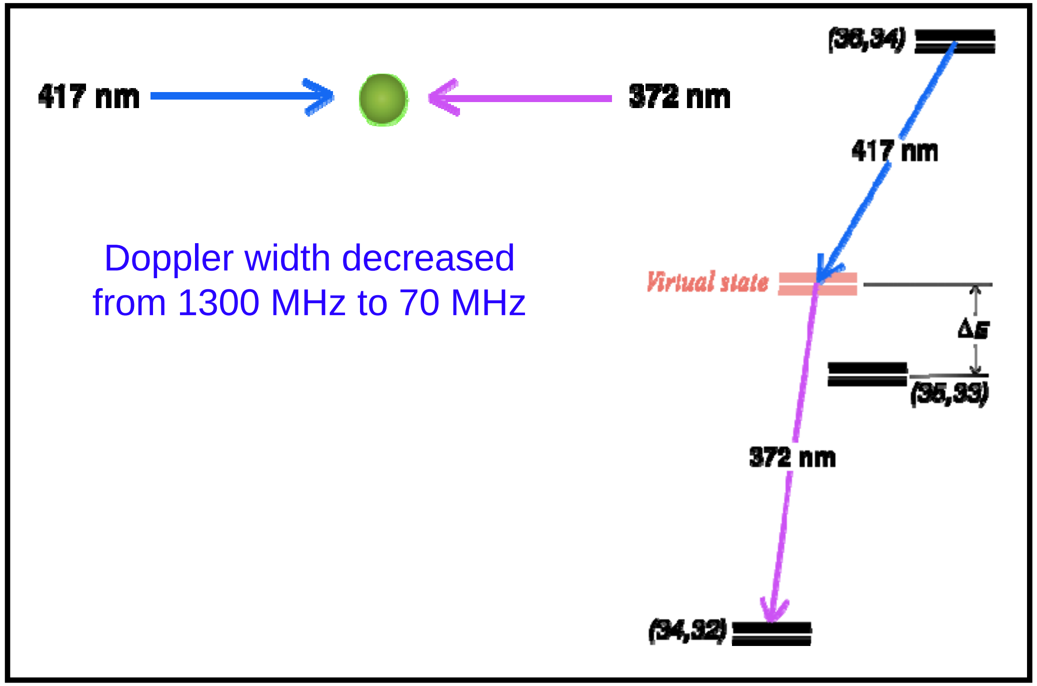
antiproton/electron mass ratio measured to 10 digits using $\bar{p}$He laser spectroscopy:

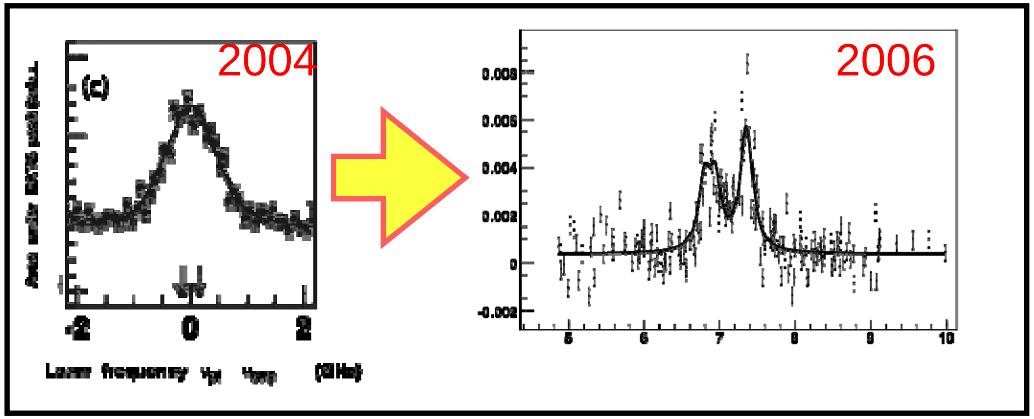
M. Hori et al., PRL 96, 243401 (2006)

$$M_{\bar{p}}/m_e \doteq 1836.152\,674(5)$$

R.S. Hayano, University of Tokyo (ASACUSA)

$\bar{p}$He laser spectroscopy: $m_{\bar{p}}/m_e$ further improvement in 2007

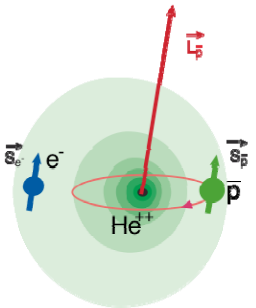




- test experiment in 2006 succeeded in achieving higher resolution
- high statistics measurement in 2007 will improve $m_{\bar{p}}/m_e$ to ~0.5 ppb (as precise as m_p/m_e)

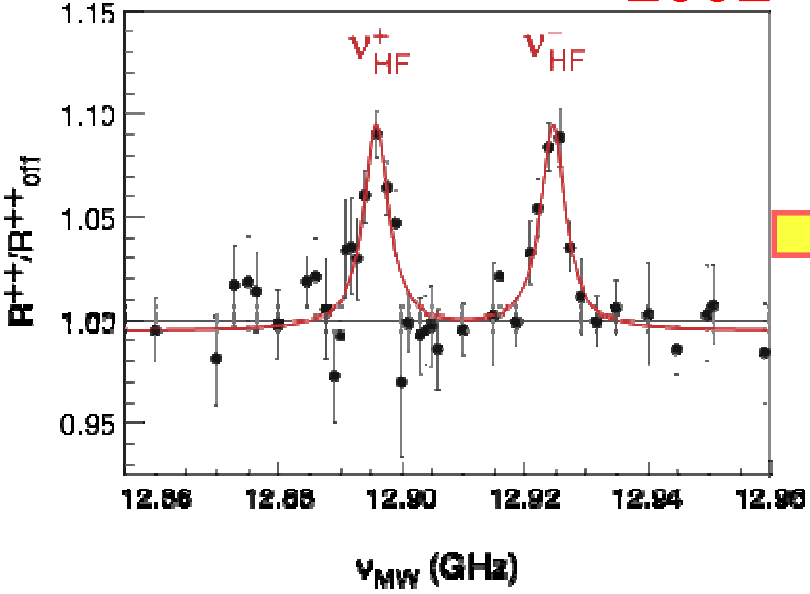
ASACUSA Status 2

$\bar{p}$He microwave spectroscopy: $\mu_{\bar{p}}$ measurement

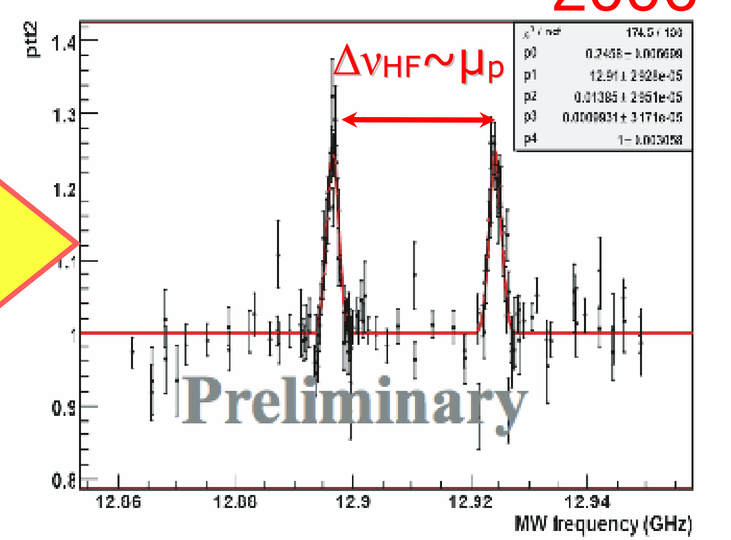


antiproton magnetic moment; laser-microwave-laser triple resonance resolution much improved in 2006; present PDG value ($\Delta\mu/\mu$ ~ 0.3%) to be improved in high-statistics measurements in 2007

2002

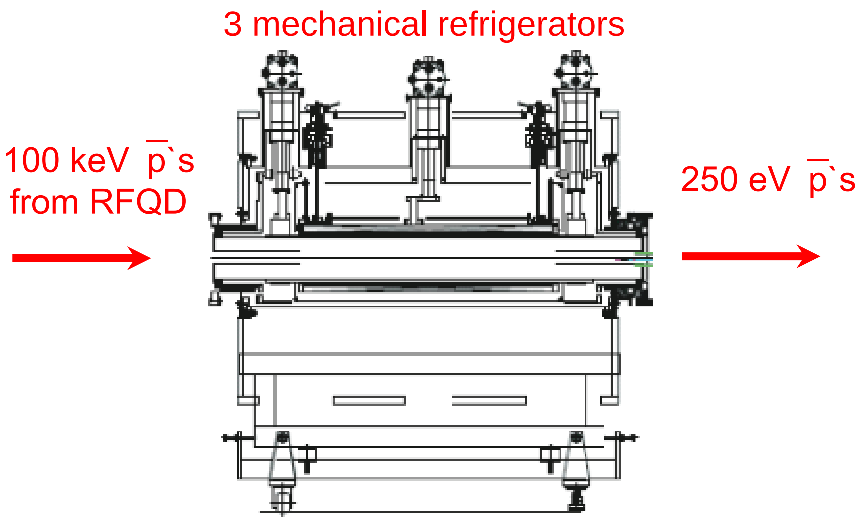


2006



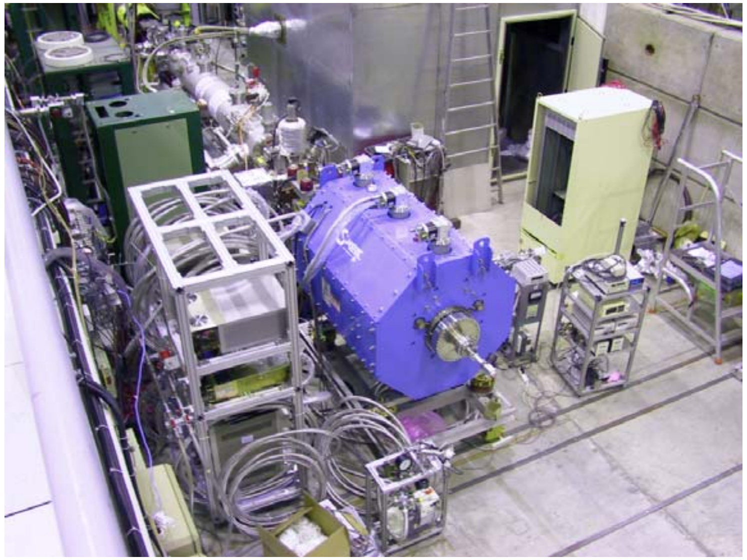
ASACUSA Status 3

Ultra-slow antiproton beam production



10^5 antiprotons extracted @ 250 eV from a Penning trap;

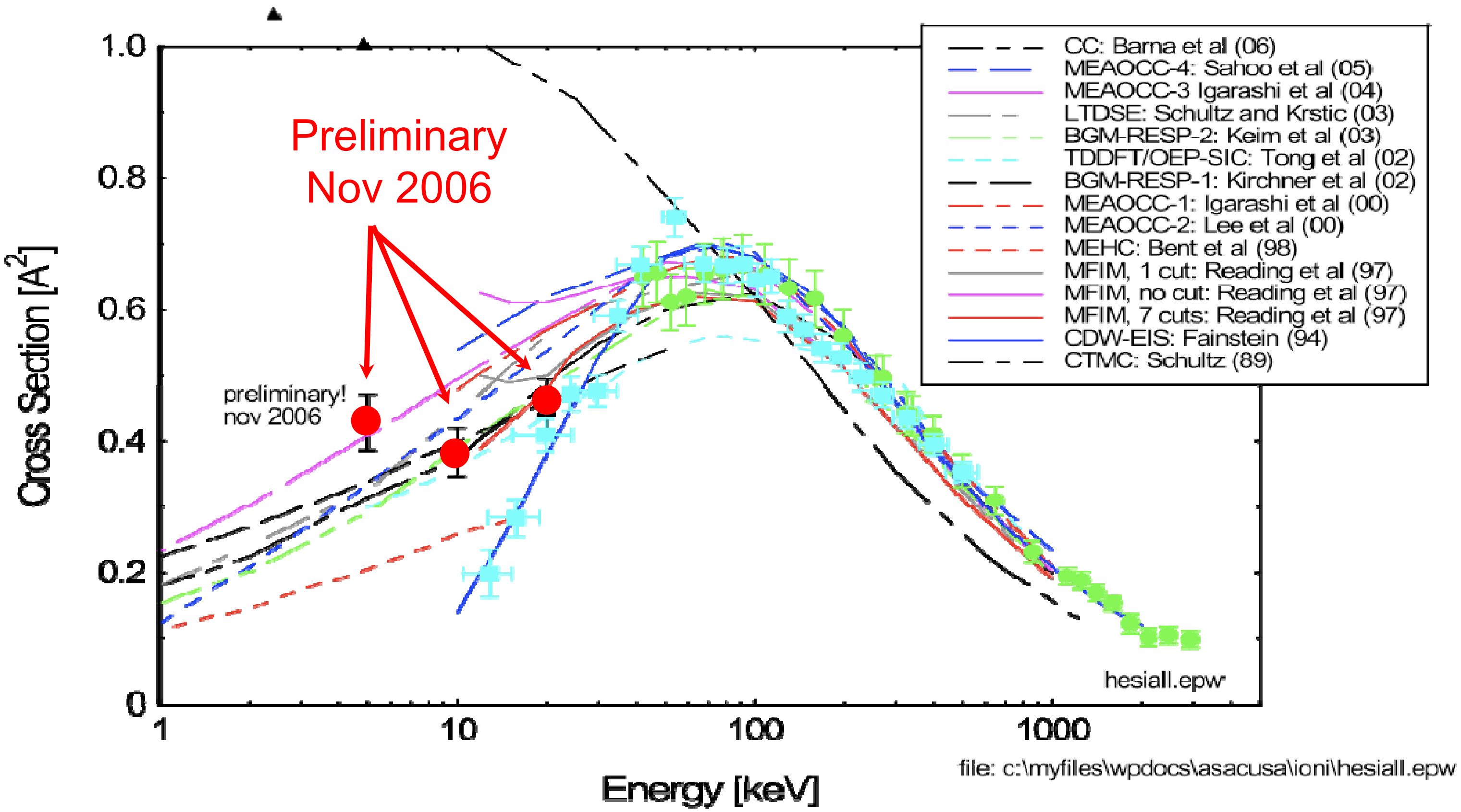
now a routine operation using a new superconducting solenoid cooled by mechanical refrigerators



microchannel plate (MCP) & phosphor screen

ASACUSA Status 4

Helium ionization by slow $\bar{p}$ impact



He ionization by $\bar{p}$ impact measured for the first time down to 5 keV (reaccelerated from the 250 eV beam); previous LEAR measurements (●) found to be flawed - new measurements (●) show better agreement with theories. Further confirmation needed in 2007.

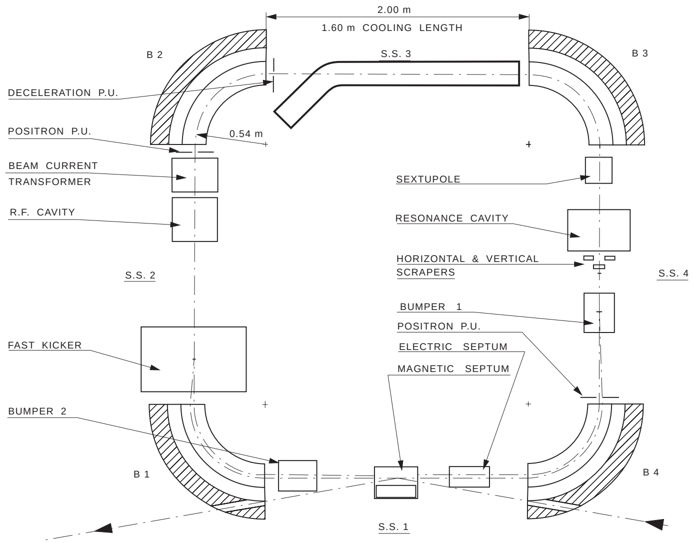
This was nearly all for:
AD-Physics in 2006 and beyond,
I should not stop without giving some thoughts to the
AD-performance during 2006 and the hopes for 2007 and beyond.

The AD-users appreciate very much the effort, work and inputs
from all people being involved in the complicated operation
of the CERN accelerator system down to the AD.

However, we do observe a substantial decrease in the reliability
of the regular performance as:
Instabilities and not optimal intensities reduce the efficiencies of the experiments,
shifts of beam time by weeks cause schedule problems of the experimentalists
coming from all over the world.

We do hope for a continuous smooth running in 2007 and beyond
with as many p-bars as possible, stable and precise.

I hope that I could convince you that the experiments make good use
of the expensive and unique p-bar beam from AD
which we will need for our physics to the benefit for all of us.



ELENA

-

to increase the efficiency
by a factor of about 100

AD-4: (ACE)

Relative Biological Effectiveness and Peripheral Damage of Antiproton Annihilation

We had a good week of data taking at 125 MeV kinetic energy.

The AD team did a great job delivering beam under these entirely new specifications within the first 12 hours after start-up.

Thank you to Tommy, Pavel, and all the others in the AD control room to make this happen.

We spent the first three days on dosimetry issues.

The last three days we spent on biological measurements irradiating V-79 Chinese Hamster.

In addition we irradiated two samples using
human cancer cells (FaDu) and will use a microarray
assay to look for changes in the RNA due to the irradiation.

Still, we cannot predict the outcome,
but are very much interested to see what we will get and
plan the next sequence of experiments based on these
results.

CERN is a very unique facility and
we would not be able to perform any of these studies
anywhere else.

Thanks again to everybody at CERN who was involved in one way or another
to assist us in this work.

Michael Holzscheiter
AD-4 Spokesperson

Niels Bassler
AD-4 Co-Spokesperson

Towards Polarized Antiprotons

http://www.fz-juelich.de/ikp/pax

PAX Collaboration

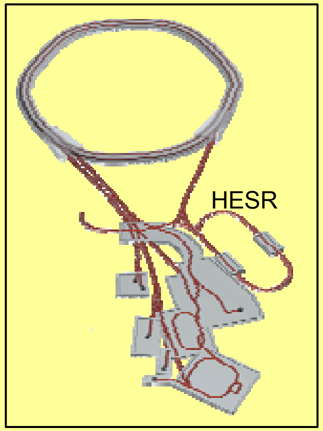
180 physicists

35 institutions (15 EU, 20 Non-EU)

Spokespersons:

Paolo Lenisa lenisa@mail.desy.de
Frank Rathmann f.rathmann@fz-juelich.de

QCD Physics at FAIR:
unpolarized Antiprotons in HESR



PAX → Polarized Antiprotons

Central PAX Physics Case:

Transversity distribution of the nucleon in Drell-Yan processes:
→ FAIR

- last missing piece of the QCD description for the partonic structure of the nucleon
- observation of the structure of the valence quarks of the proton
  ($h_1^q(x,Q^2)$ A_{TT} in Drell-Yan >0.2)
  - transversely polarized proton beam or target (✓)
  - transversely polarized antiproton beam (×)

Spin Filtering: Present Status

Spin filtering works, but:

1. Controversial interpretations of FILTEX experiment
    - Further experimental tests necessary
        - How does spin filtering work?
        - Which role do electrons play?

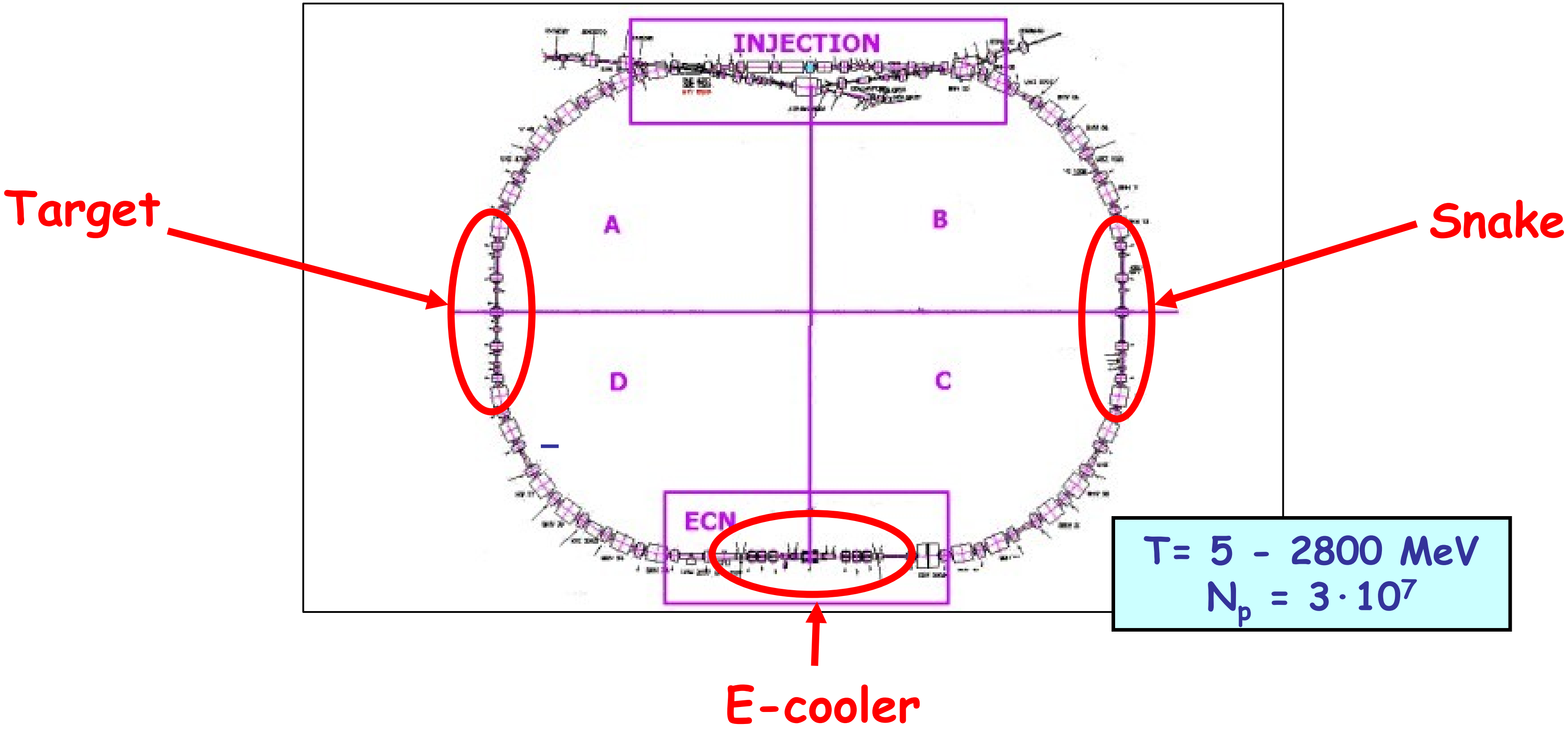
    → Tests with protons at COSY

2. No data to predict polarization from filtering with antiprotons

    → Measurements with antiprotons at AD/CERN

AD Ring at CERN

Study of spin filtering in pbar-p (pbar-d) scattering

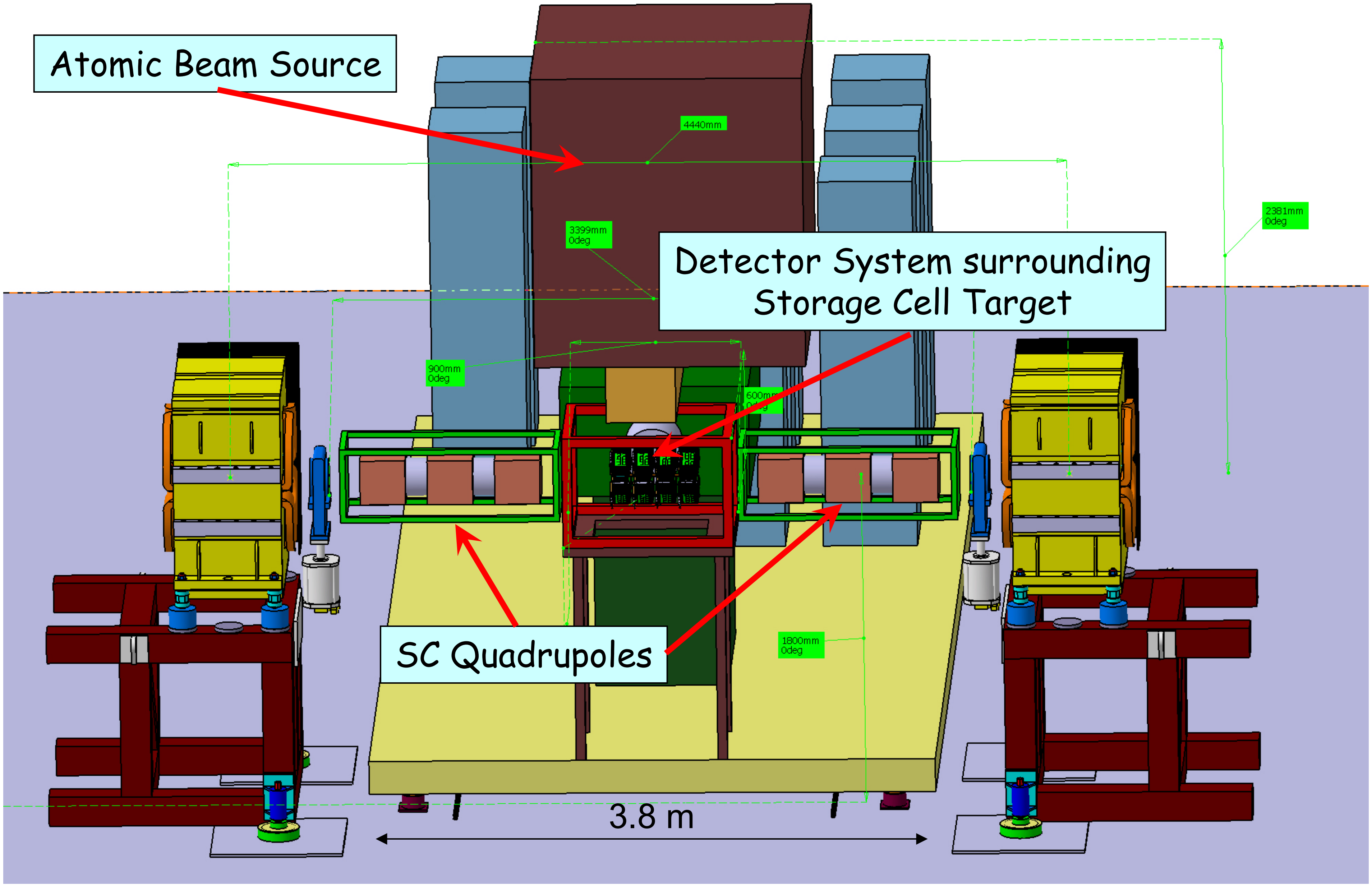


Measurement of effective polarization build-up cross-section

- Measure both transverse and longitudinal build-up
- Variable acceptance at target
- Utilize also polarized D target

First measurement for spin correlations in pbar-p (and pbar-d)

Layout of PAX Target Section (schematic)



Timeline

Fall 2005	LOI to SPSC for Spin-Filtering Studies (✓)
Fall 2006	Submission of Proposal to COSY-PAC (✓)
	Beam depolarization & lifetime studies
2006 - 2008	Design and Construction Phase
	Dec 2006: Technical Boundaries, AD visit
	early 2008: ~ Pioneering Experiment (Proposal)
Fall 2007	Technical proposal to COSY-PAC for Spin Filtering
	Technical proposal to SPSC for Spin Filtering at AD
2009	Spin-Filtering Studies at COSY
2010	Installation and Commissioning of AD experiment
	Spin-Filtering Studies at AD

AD-Physics in 2006/7 and beyond

Walter Oelert
Research Centre Jülich, Germany
Ruhr Universität Bochum, Germany
CERN
24. January 2007

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new, to come:

AEGIS: a new proposal in preparation and it will be submit within 2007
The main goal is a direct gravity measurement on antihydrogen
Antiproton beam time: probably in 2009
We are planning to install the apparatus in the actual DEM zone
ELENA will be welcome and we support it.

Gemma Testera

The PAX collaboration