$\bar{p}$He & $\bar{H}$ spectroscopy
→CPT, fundamental const.

50 keV $\bar{p}$s (RFQD)
100 eV $\bar{p}$s ("MUSASHI" trap)

ASACUSA

Atomic Spectroscopy And Collisions Using Slow Antiprotons

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Press Release

CERN sets course for extra-low-energy antiprotons

PR20.11
28.09.2011

Geneva, 28 September 2011. The kick-off meeting for ELENA, the Extra Low Energy Antiproton Ring, starts today at CERN[1]. Approved by CERN Council in June this year, ELENA is scheduled to deliver its first antiprotons in 2016. This week's kick-off meeting brings together scientists from Canada, Denmark, France, Germany, Japan, Sweden, the UK and the USA. The project is led by CERN.

"ELENA is a new facility aimed to deliver antiprotons at the lowest energies ever reached in order to improve the study of antimatter," said CERN's Stéphan Maury, Head of the ELENA project.

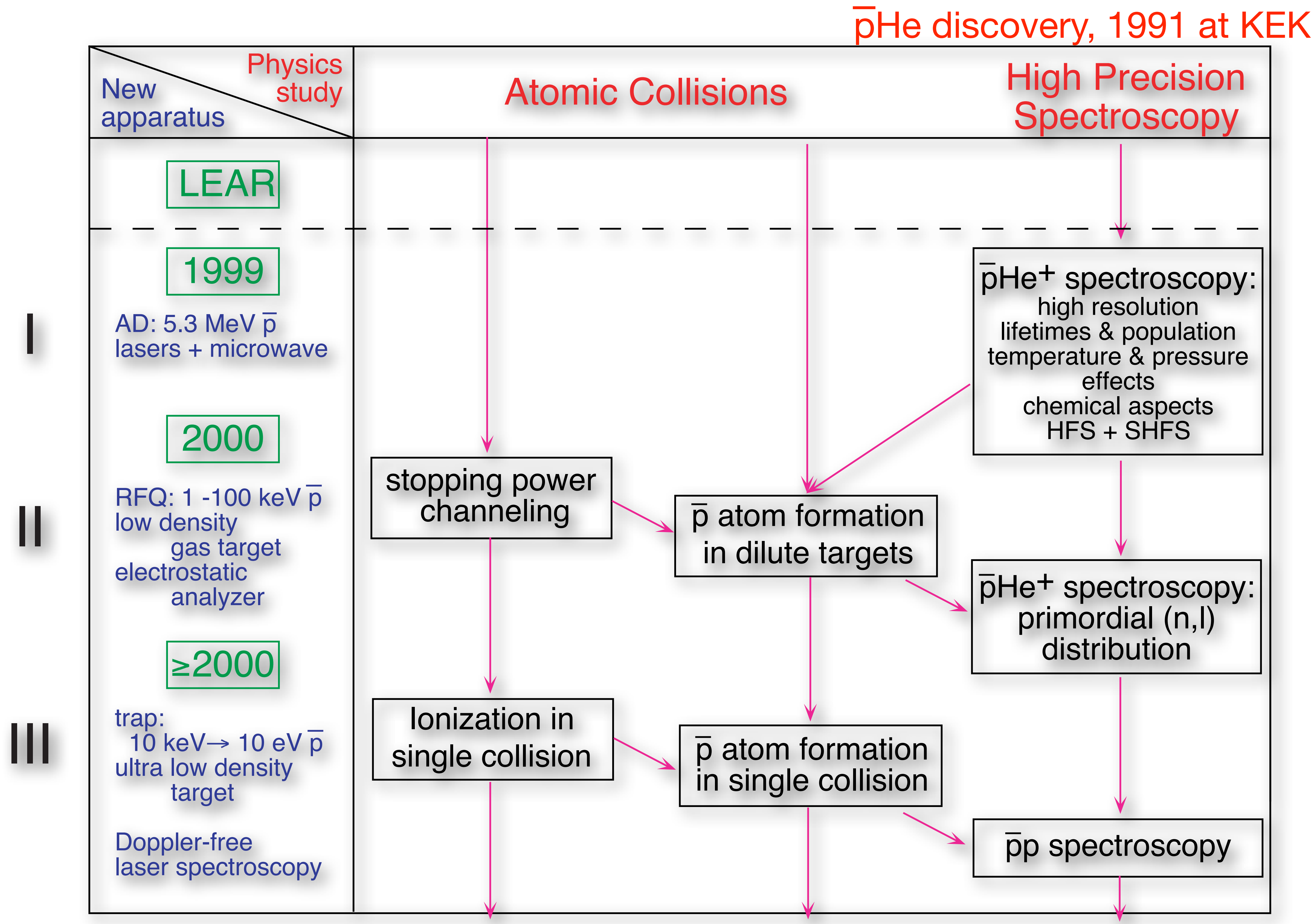
ELENA will consist of a small new decelerator ring that will be installed in same building that houses CERN's existing Antiproton Decelerator (AD). It will slow antiprotons down to under a fiftieth of the current AD energy, bringing an improvement of a factor of 10-100 in antiproton trapping efficiency. At the AD, antiprotons have to be slowed down by passing them through a series of foils, a process that results in the loss of some 99.9% of the antiprotons extracted from the AD before they reach the experiments.

"This is a big step forward for antimatter physics. Going to extra low energy increases the trapping efficiency for antiprotons, which will not only improve the research potential of existing experiments, but will also allow CERN to support a wider range of antimatter experiments," said Walter Oelert, an antimatter pioneer at CERN, who has actively supported the ELENA project.

Ever since the Nobel Prize wining discovery of antiprotons in 1955, these particles have proved to be an important research tool. In the 1980s, they played a pivotal role in the discovery of the W and Z particles at CERN, which also led to a Nobel Prize.

CERN's achievements with low-energy antiprotons include the trapping and accumulation of large numbers of antiprotons in the early 1990s, which led to very precise comparisons of protons and antiprotons. In 1995, the first antiatoms - antihydrogen - were created at CERN, opening the way to new experiments on antimatter and, more recently, the trapping of antihydrogen atoms. One experiment at the AD has also made preliminary studies of the potential for using antiprotons in cancer therapy. In the future, experiments will make detailed comparisons of hydrogen and antihydrogen atoms, and measure the influence of gravity on antiprotons.

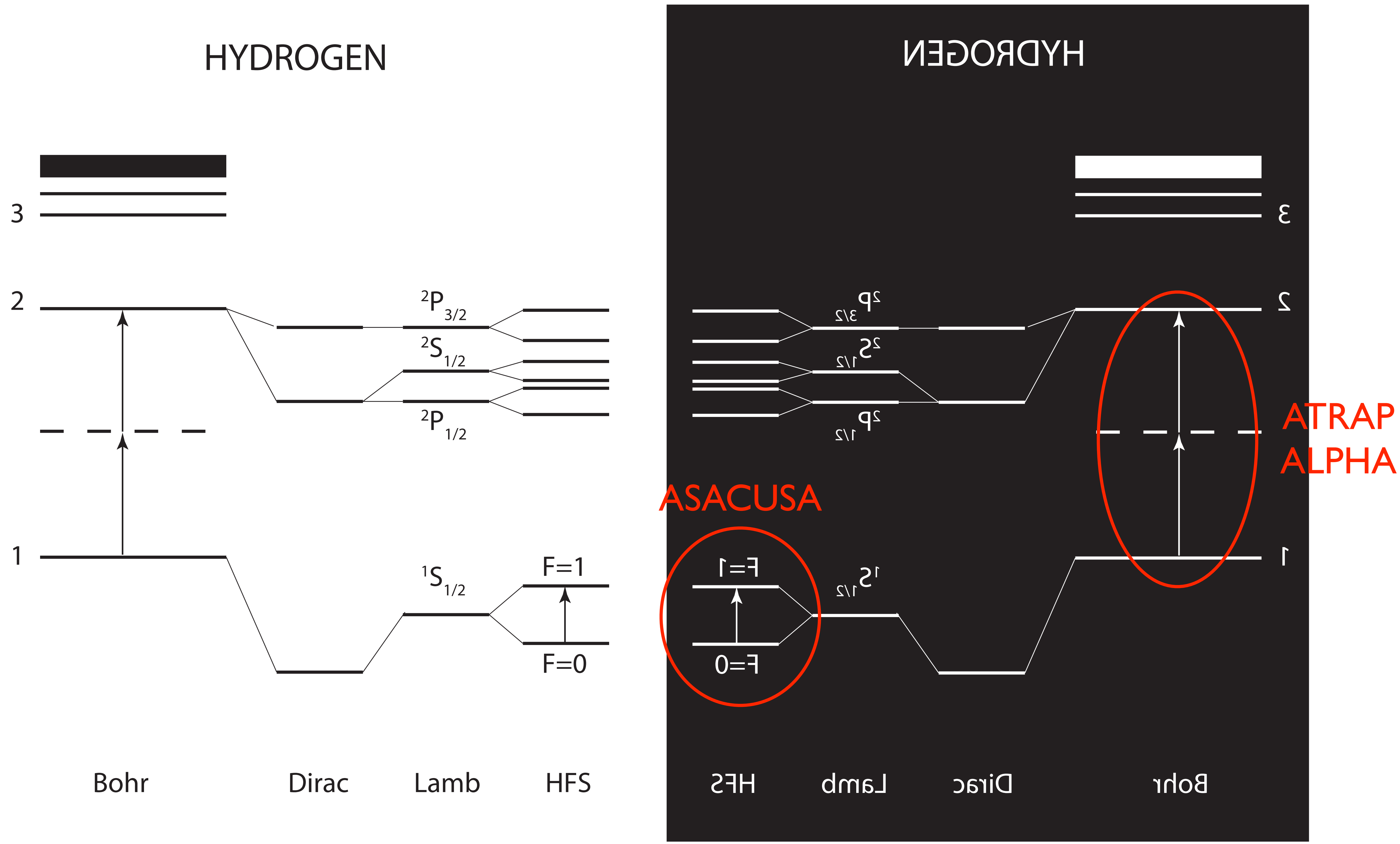
ASACUSA roadmap shown at SPSC in 1997



revised roadmap shown at SPSC in 2005

Part I: Continuation of the approved ASACUSA programme	Spectroscopy (CPT)	Antiprotonic helium atoms & ions	antiproton mass << 10^{-9} magnetic moment < 10^{-3}
	Collision	Ionization & atom formation cross section	Use ultra-slow antiprotons extracted from the trap
Part II: Extending ASACUSA programme	Spectroscopy (CPT)	Antihydrogen ground-state hyperfine splitting	Sensitivity to CPTV higher than the K^0 system
	Collision	antiproton-nucleus cross section	Extend the LEAR measurements to much lower energies, relevant to fundamental cosmology

added in 2005 $\bar{H}$ ground-state HFS



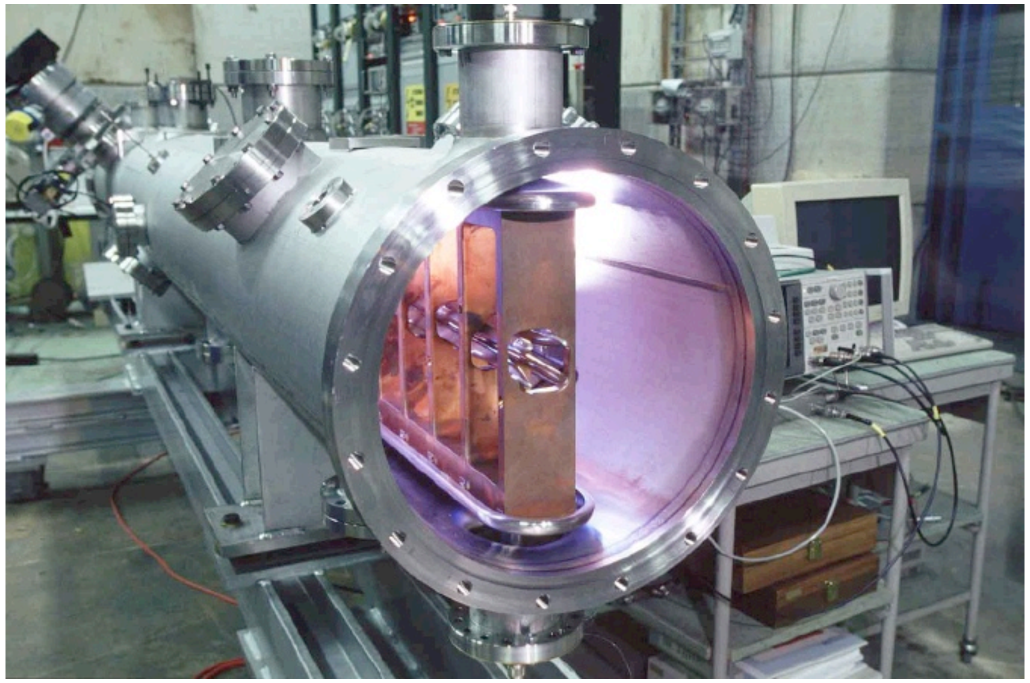
RFQD

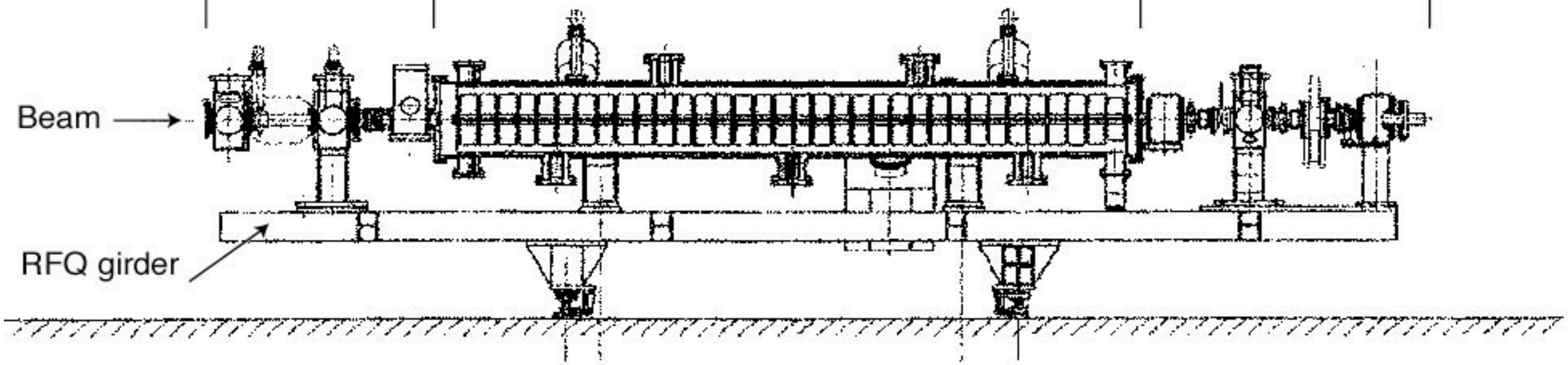
5 MeV to 100 keV

~25% efficiency

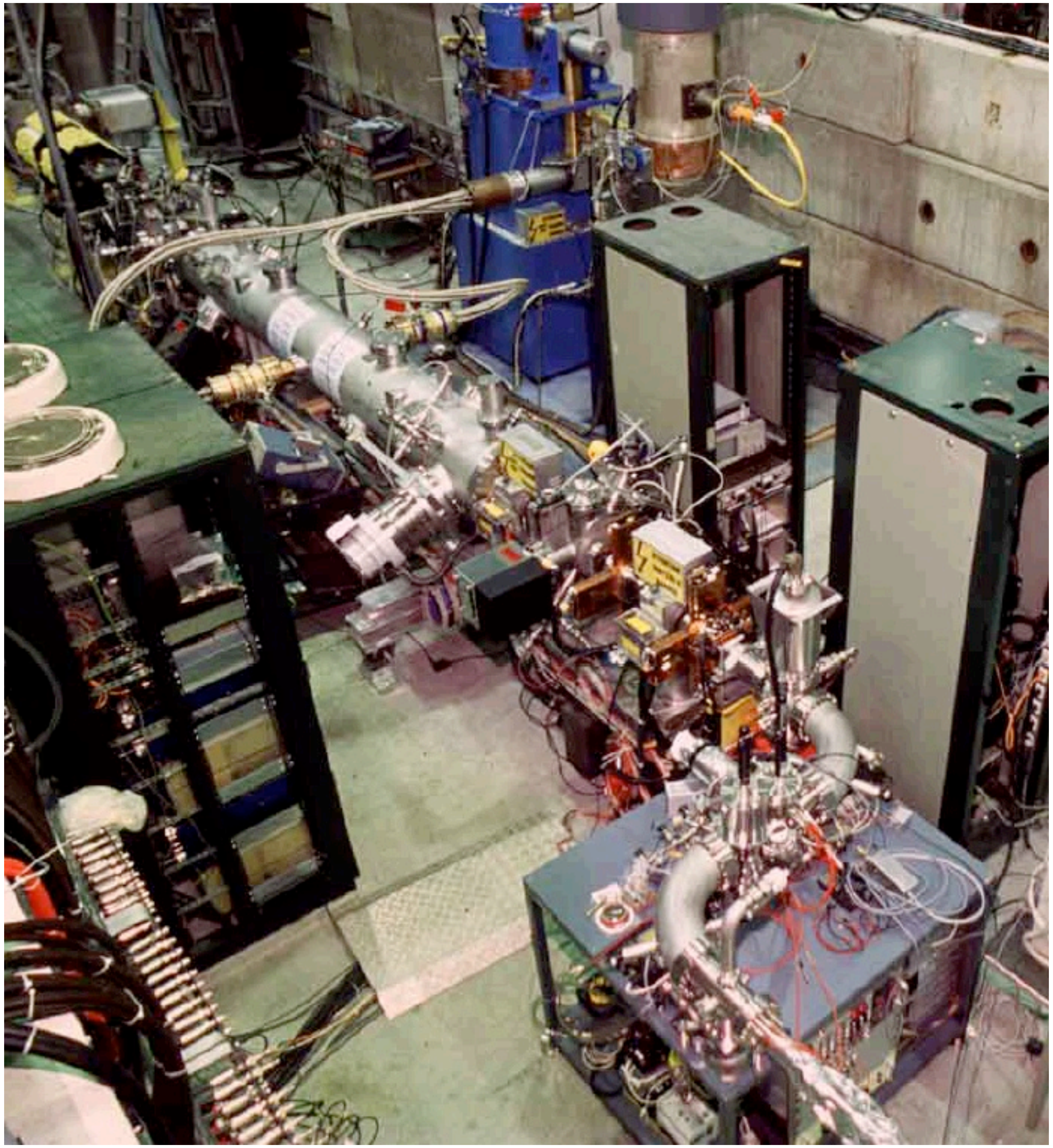
RFQD - shown at SPSC 2001

– Buncher + HEBT + Energy corrector + 200 MHz RFQ + LEBT
– ~44 % deceleration efficiency expected
– Variable output energy (RF electrodes floated)





SPSC 2001 First RFQD experiment - $\bar{p}$ dE/dx

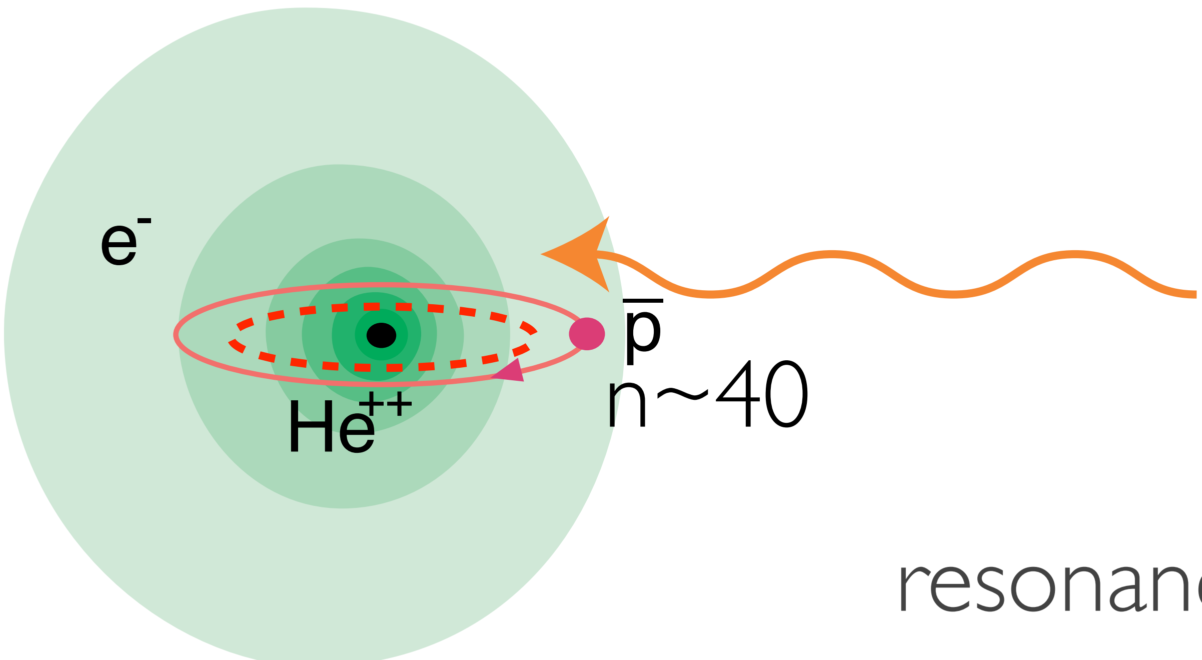


RFQD & ESA in the AD hall

- Energy varied between 60 - 8 keV
- dE/dx measurement, 1 point / hour after optimization

laser-spectroscopy of ultra-cold $\bar{p}$He atoms

$\bar{p}$He laser spectroscopy contributes to m_p/m_e



laser pulse changes the $\bar{p}$ orbit

resonance detection via $\bar{p}$ annihilation

Frequency

$$\nu_{n,\ell\rightarrow n',\ell'} = Rc\,\frac{m^*_{\bar{p}}}{m_e}\,Z^2_{\text{eff}}\left(\frac{1}{n'^2}-\frac{1}{n^2}\right) + QED$$

$\bar{p}$ (p) - e mass ratio

Theory

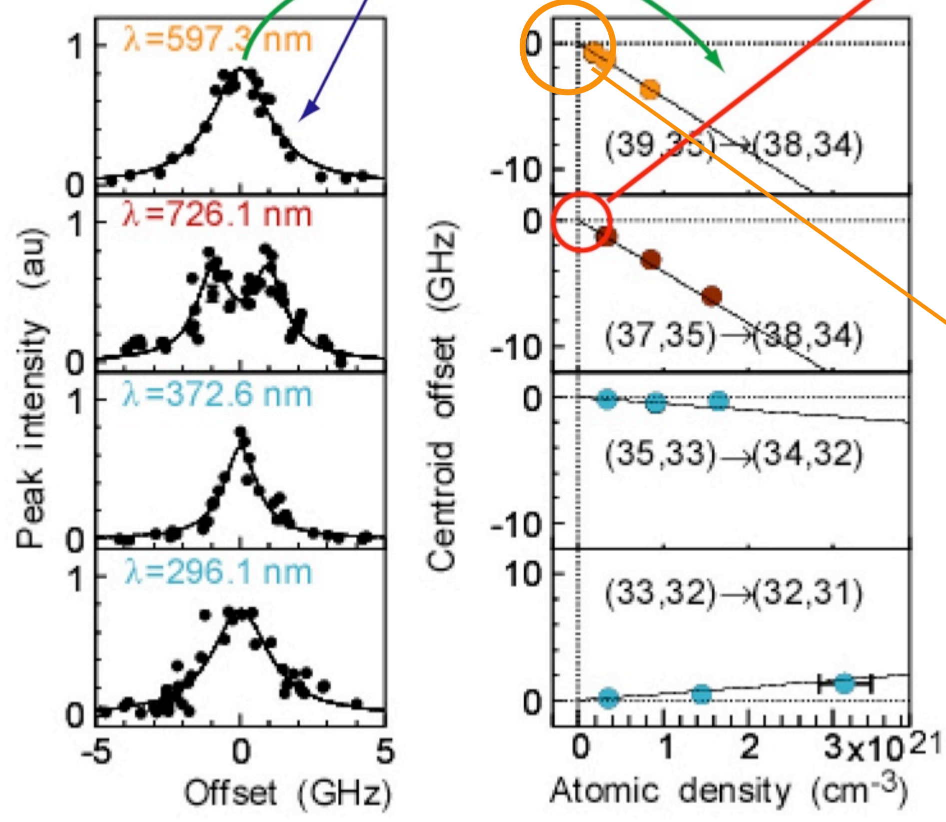
SPSC 2002 $\bar{p}$He result using RFQD

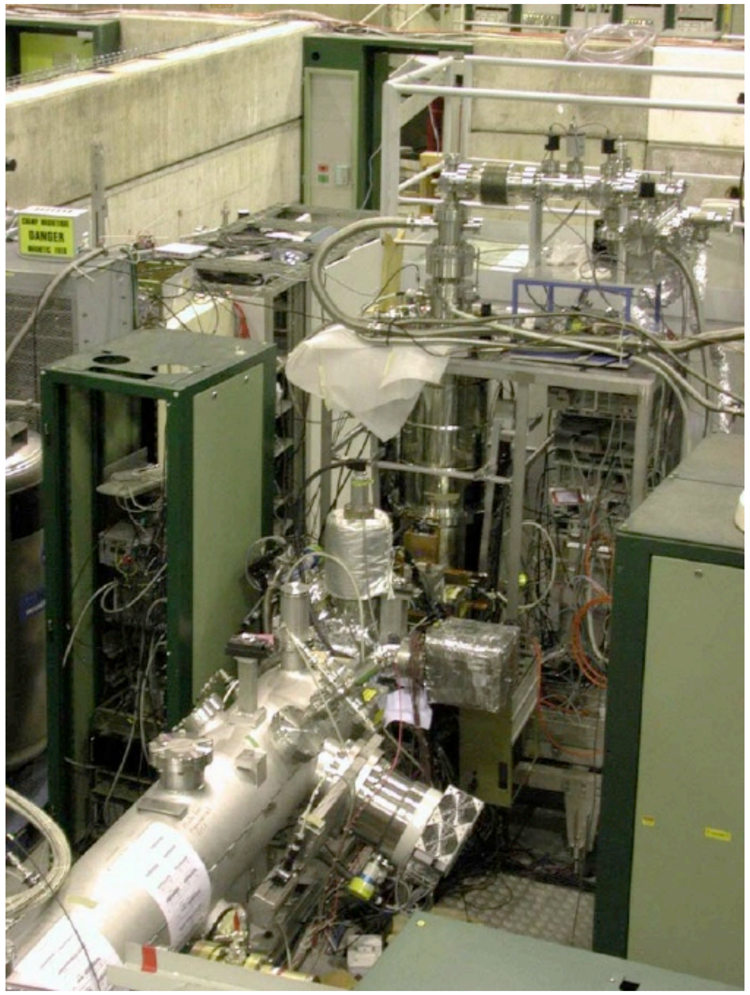
Spectroscopy at “zero density”

Laser resonance profiles
(each data point = 1 AD shot)

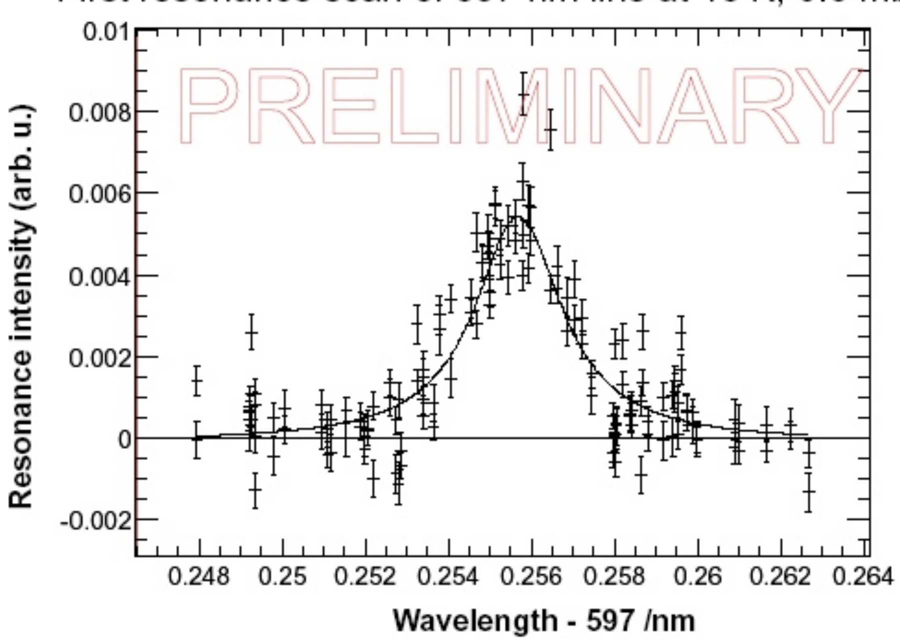
Line centers
measured at
different helium
densities

Zero-density
values compared
with the state-of-the-art
three-body
QED calculations





First resonance scan of 597 nm line at 15 K, 0.8 mbar



- So far, exp-theory comparison done after extrapolating exp values to “zero” helium density
- With the RFQD beam, measurements at “zero density” has become possible

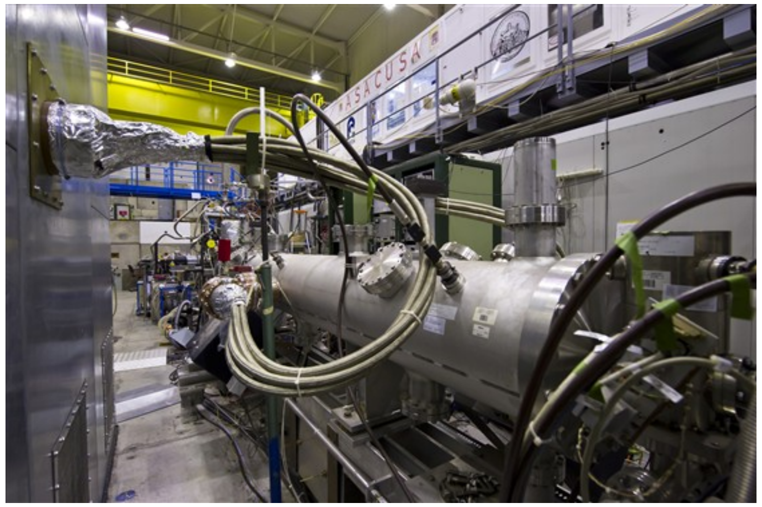
$\bar{p}$He - recent CERN press release

CERN Press Release

CERN experiment weighs antimatter with unprecedented accuracy

PR10.11
28.07.2011

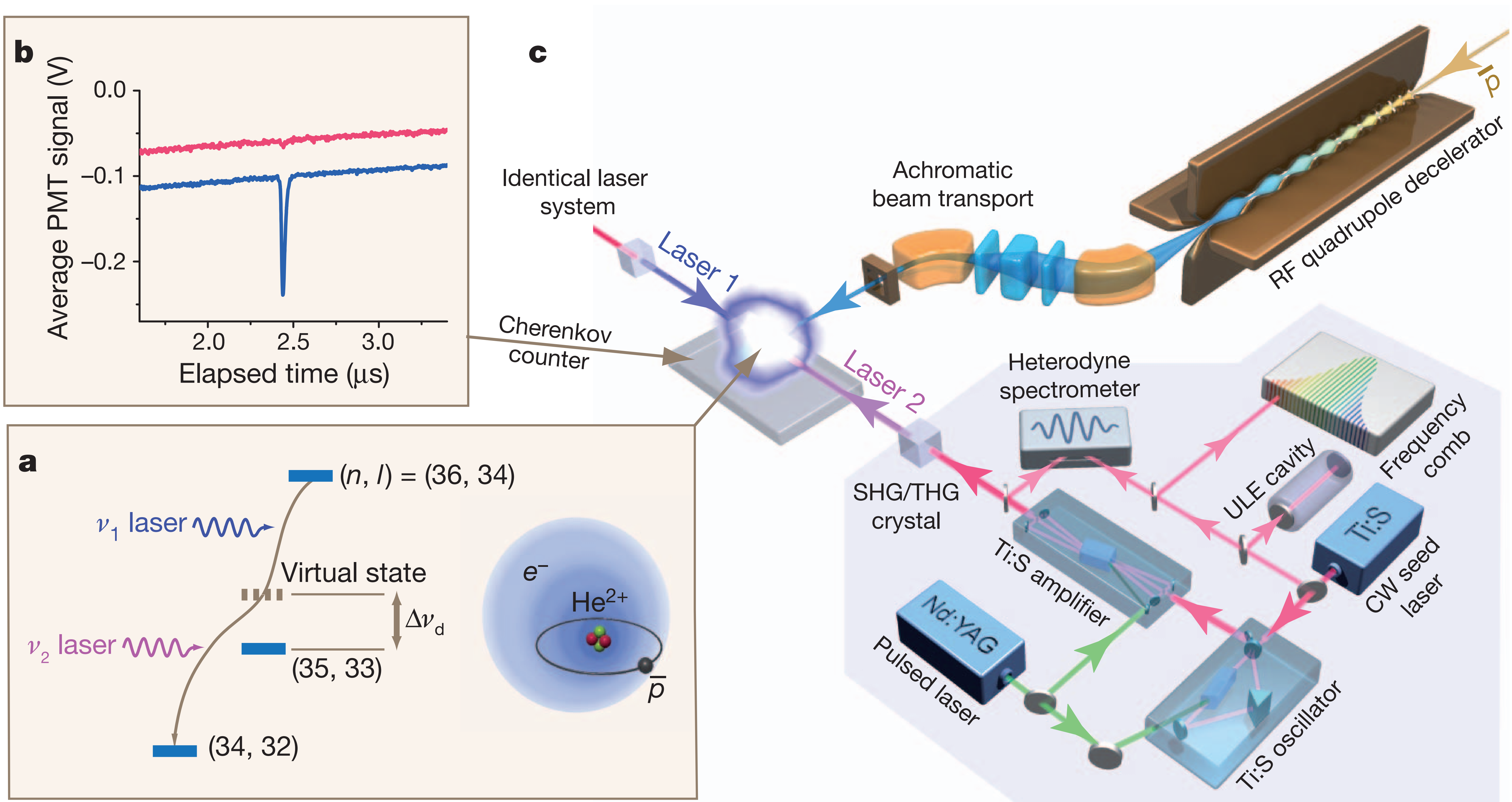
Geneva, 28 July 2011. In a paper published today in the journal Nature, the Japanese-European ASACUSA experiment at CERN[1] reported a new measurement of the antiproton's mass accurate to about one part in a billion. Precision measurements of the antiproton mass provide an important way to investigate nature's apparent preference for matter over antimatter.


The ASACUSA experiment.
More photos: 1 - 2.

"This is a very satisfying result," said Masaki Hori, a project leader in the ASACUSA collaboration. "It means that our measurement of the antiproton's mass relative to the electron is now almost as accurate as that of the proton."

Ordinary protons constitute about half of the world around us, ourselves included. With so many protons around it would be natural to assume that the proton mass should be measurable to greater accuracy than that of antiprotons. After today's result, this remains true but only just. In future experiments, ASACUSA expects to improve the accuracy of the antiproton mass measurement to far better than that for the proton. Any difference between the mass of protons and antiprotons would be a signal for new physics, indicating that the laws of nature could be different for matter and antimatter.

$\bar{p}$He spectroscopy: RFQD + lasers



$\bar{p}$He spectroscopy: errors

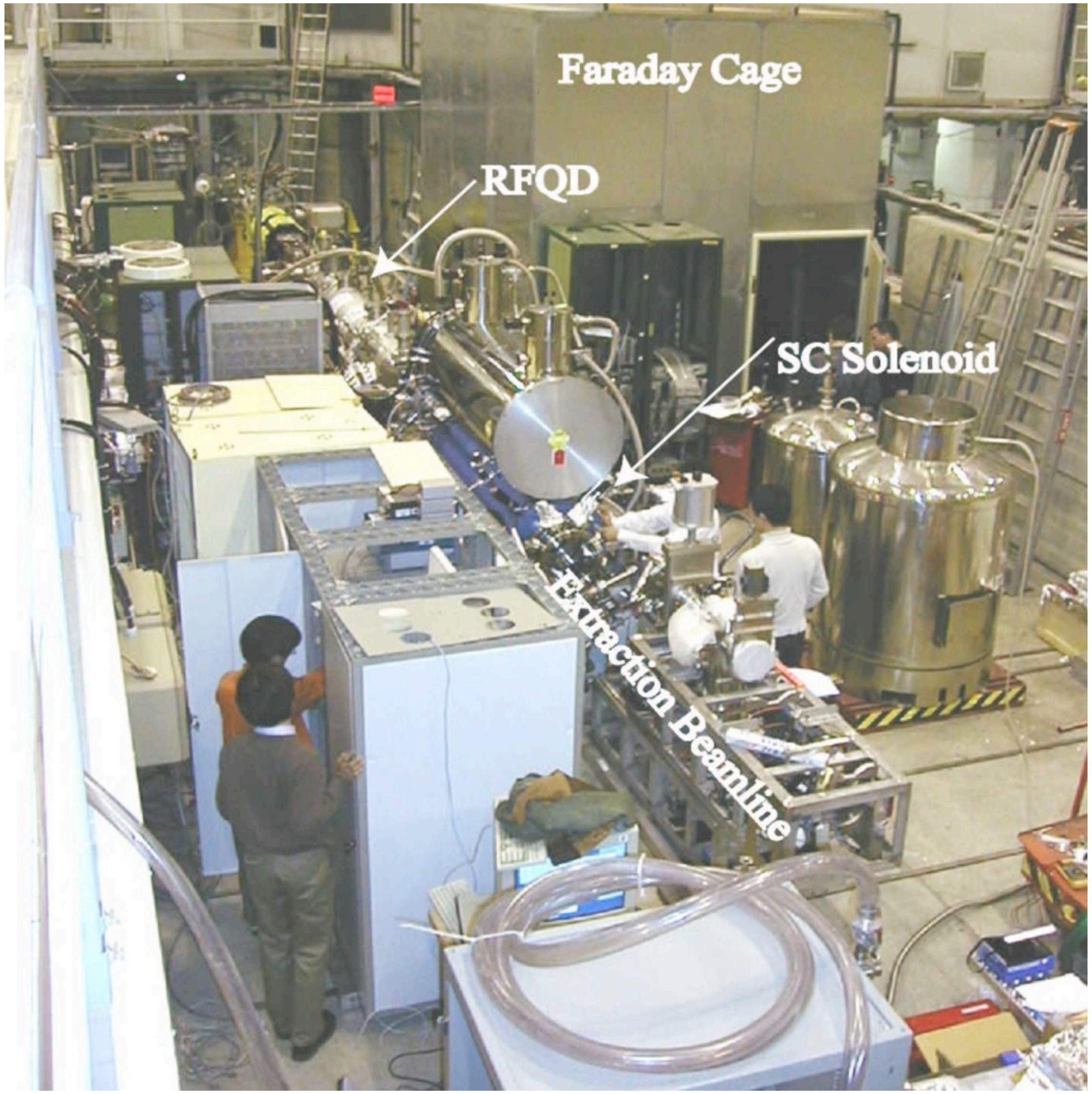
Table 2 | Errors for transition $(n, l) = (36, 34) \rightarrow (34, 32)$ of $\bar{p}^4He^+$

Datum	Error (MHz)
Experimental errors	
Statistical error, σ_{stat}	3
Collisional shift error	1
A.c. Stark shift error	0.5
Zeeman shift	<0.5
Frequency chirp error	0.8
Seed laser frequency calibration	<0.1
Hyperfine structure	<0.5
Line profile simulation	1
Total systematic error, σ_{sys}	1.8
Total experimental error, σ_{exp}	3.5
Theoretical uncertainties	
Uncertainties from uncalculated QED terms*	2.1
Numerical uncertainty in calculation*	0.3
Mass uncertainties*	<0.1
Charge radii uncertainties*	<0.1
Total theoretical uncertainty*, σ_{th}	2.1

Experimental errors and theoretical uncertainties are 1 s.d.
* Ref. 3 and V. I. Korobov, personal communication.

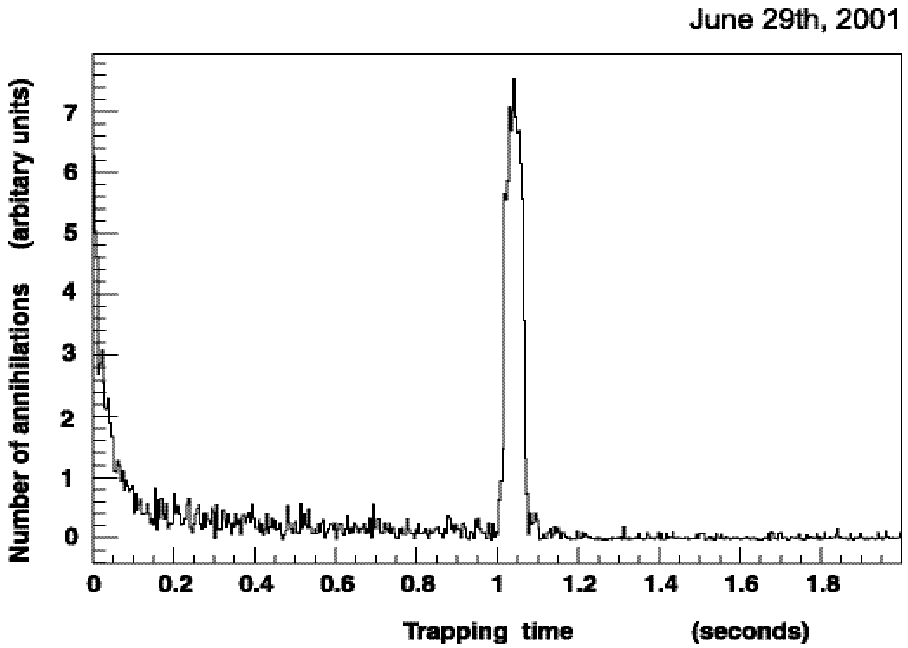
2. $\bar{H}$ formation
&
GS HFS spectroscopy

SPSC 2002: RFQD+TRAP



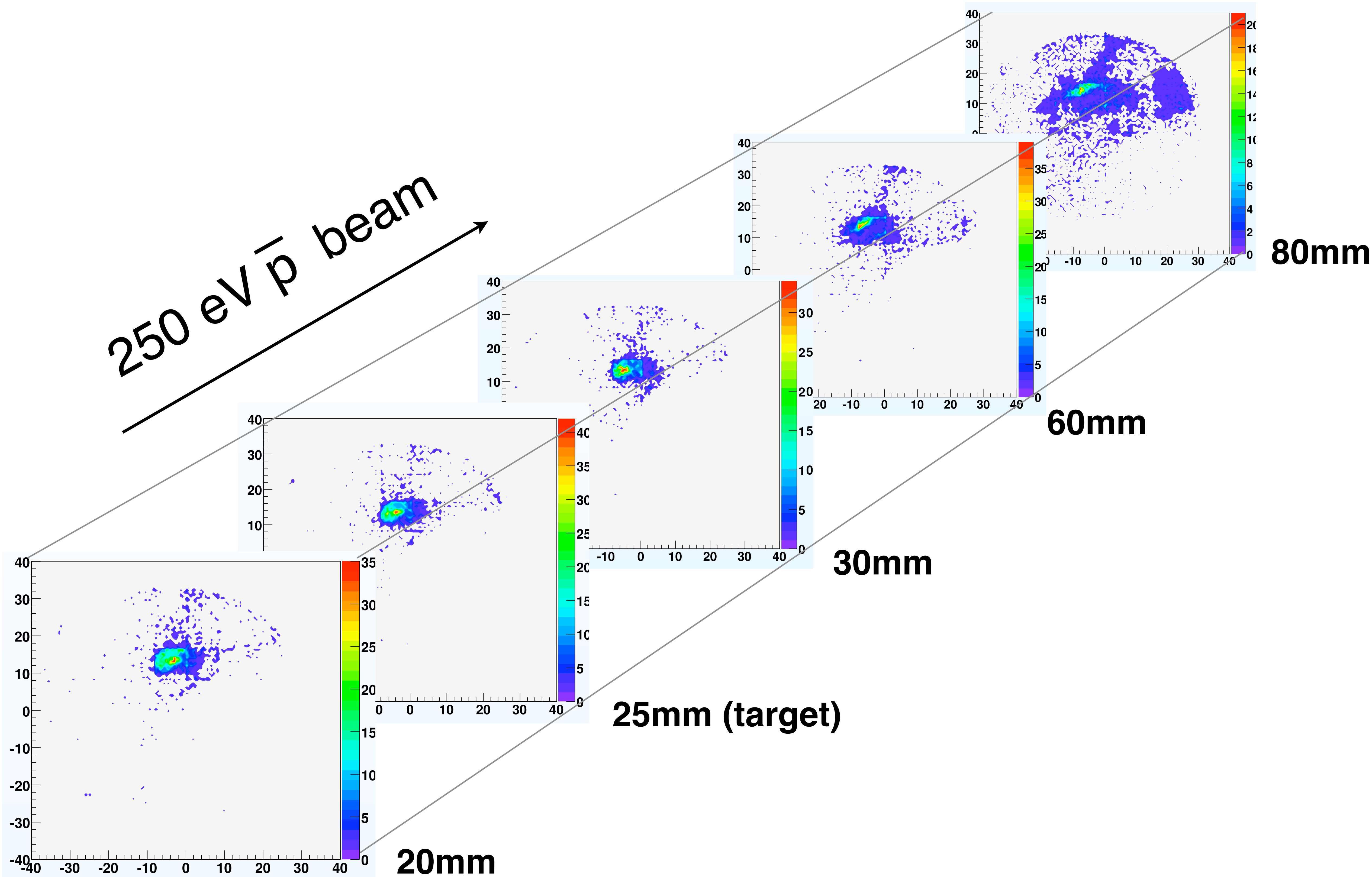
Capture of Millions of Slow Antiprotons & extraction at 10 eV

- First signal from RFQD+trap, June 29, 2001
- Catch pbars & release after 1s



SPSC 2007

MCP images



$\bar{\mathrm{H}}$ production in the “cusp” trap

Physics World reveals its top 10 breakthroughs for 2010

Dec 20, 2010 25 comments

It was a tough decision, given all the fantastic physics done in 2010. But we have decided to award the *Physics World* 2010 Breakthrough of the Year to two international teams of physicists at CERN, who have created new ways of controlling antiatoms of hydrogen.

Shared glory at CERN as antihydrogen research takes the gong

The ALPHA collaboration announced its findings in late November, which involved trapping 38 antihydrogen atoms (an antielectron orbiting an antiproton) for about 170 ms. This is long enough to measure their spectroscopic properties in detail, which the team hopes to do in 2011.

Just weeks later, the ASACUSA group at CERN announced that it had made a major

Summary

RFQD - a big success

ELENA will be a bigger success

- statistics x 10 (or more) for $\bar{p}$ mass measurement
- beam brightness, stability will improve $\bar{p}$ trapping efficiency & $\bar{H}$ production
- Paul trap (for $\bar{p}$He & $\bar{H}$) will also be deployed
- internal target $\bar{p}$-H collision experiment may be possible