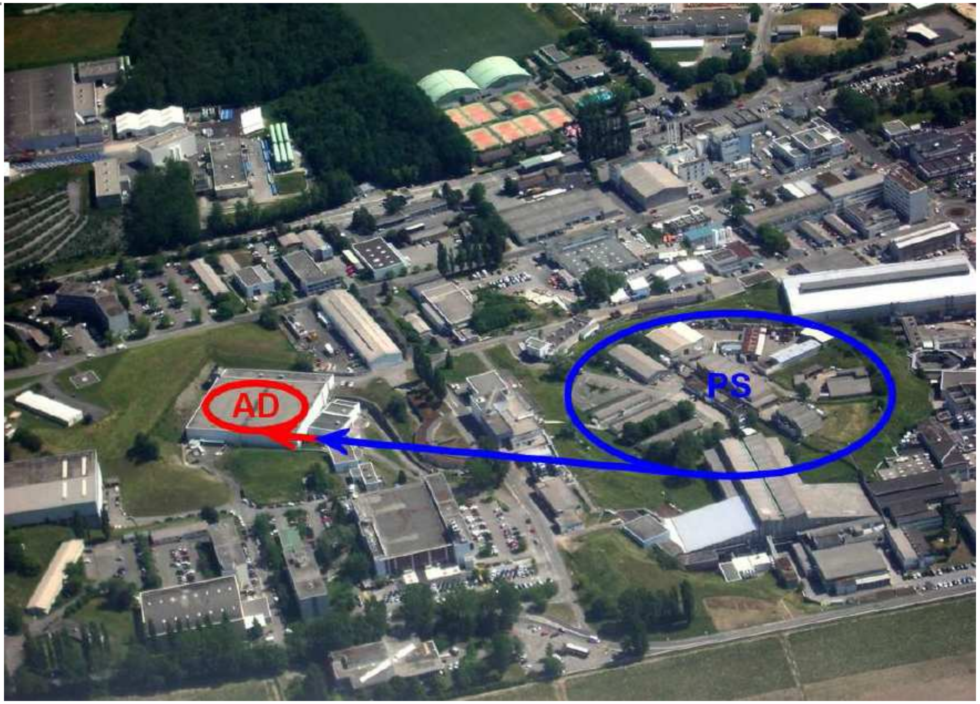
The ASACUSA (AD-3) experiment

Dezső Horváth

KFKI Research Institute for Particle and Nuclear Physics, Budapest
and Institute of Nuclear Research (ATOMKI), Debrecen

- The ASACUSA collaboration at CERN
- $\overline{\mathrm{p}}$-He Spectroscopy
- The Charge and Mass of the Antiproton
- The Magnetic Moment of the Antiproton
- Outlook: Antihydrogen

The ASACUSA collaboration at CERN



The Antiproton Decelerator at CERN is built to test *CPT* invariance

ASACUSA:

Atomic Spectroscopy And Collisions Using Slow Antiprotons

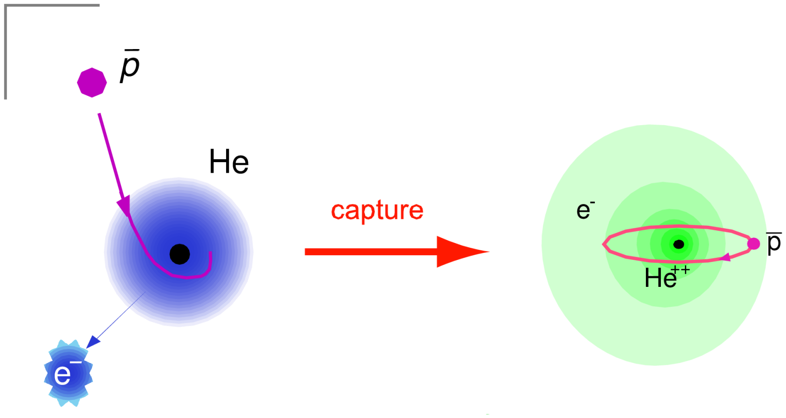
Tokyo, Budapest, Debrecen, Vienna, Aarhus, Brescia, + Munich

Budapest: Anna Sótér, Dániel Barna, Dezsõ Horváth, Péter Zalán

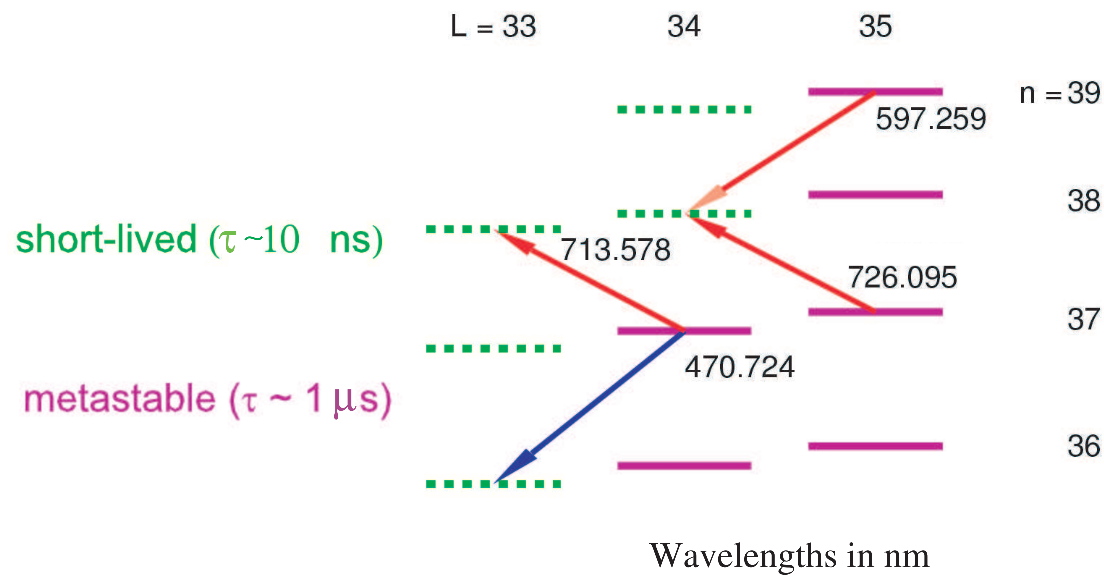
Debrecen: Bertalan Juhász (now in Vienna), Károly Tõkési

Simulations, positioning stands, analysis, $\overline{\mathrm{H}}$ trap, detectors

Mass and Charge of Antiproton



Trap $\overline{\mathrm{p}}$ in a long-lived
3-body system



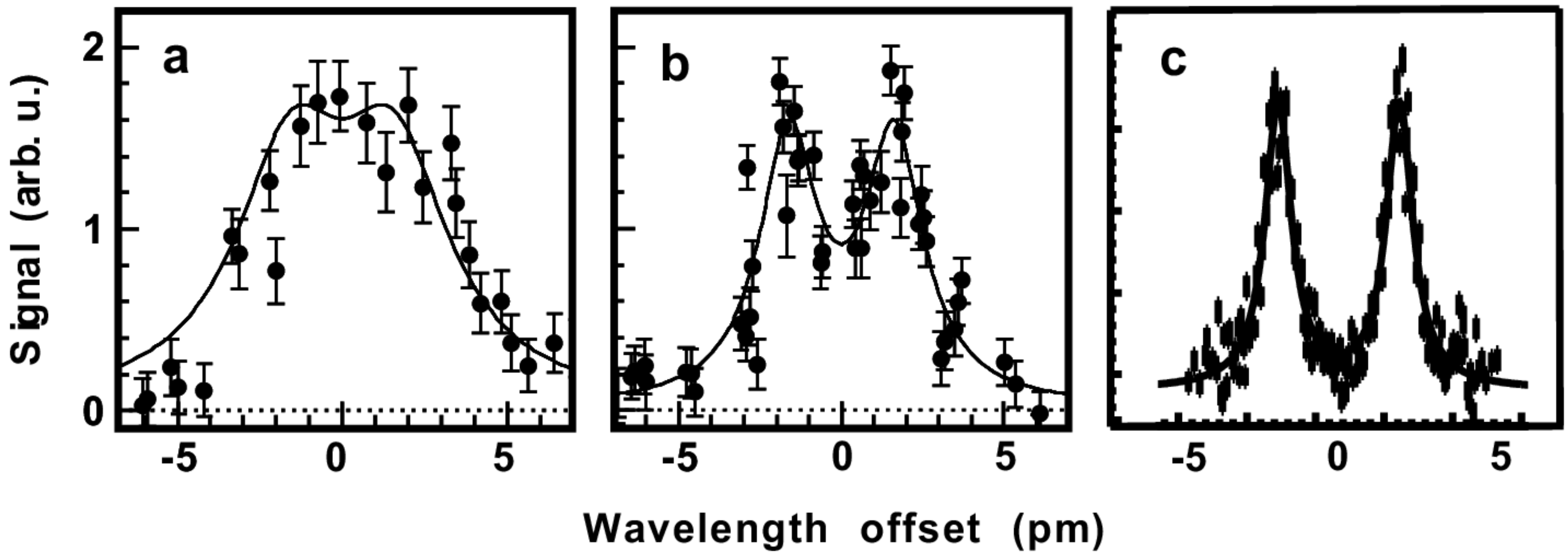
Laser spectroscopy: induce resonance transitions
between long-lived and short-lived states
$\Rightarrow$ prompt annihilation $\Rightarrow$ measuring transition energy

PDG: Most precise measurement of $m(\overline{\mathrm{p}})/m(\mathrm{e}^-)$

R. S. Hayano, M. Hori, D. Horváth, E. Widmann:
Reports on Progress in Physics **70** (2007) 1995-2065.

Resolution development

2000 2002 2004



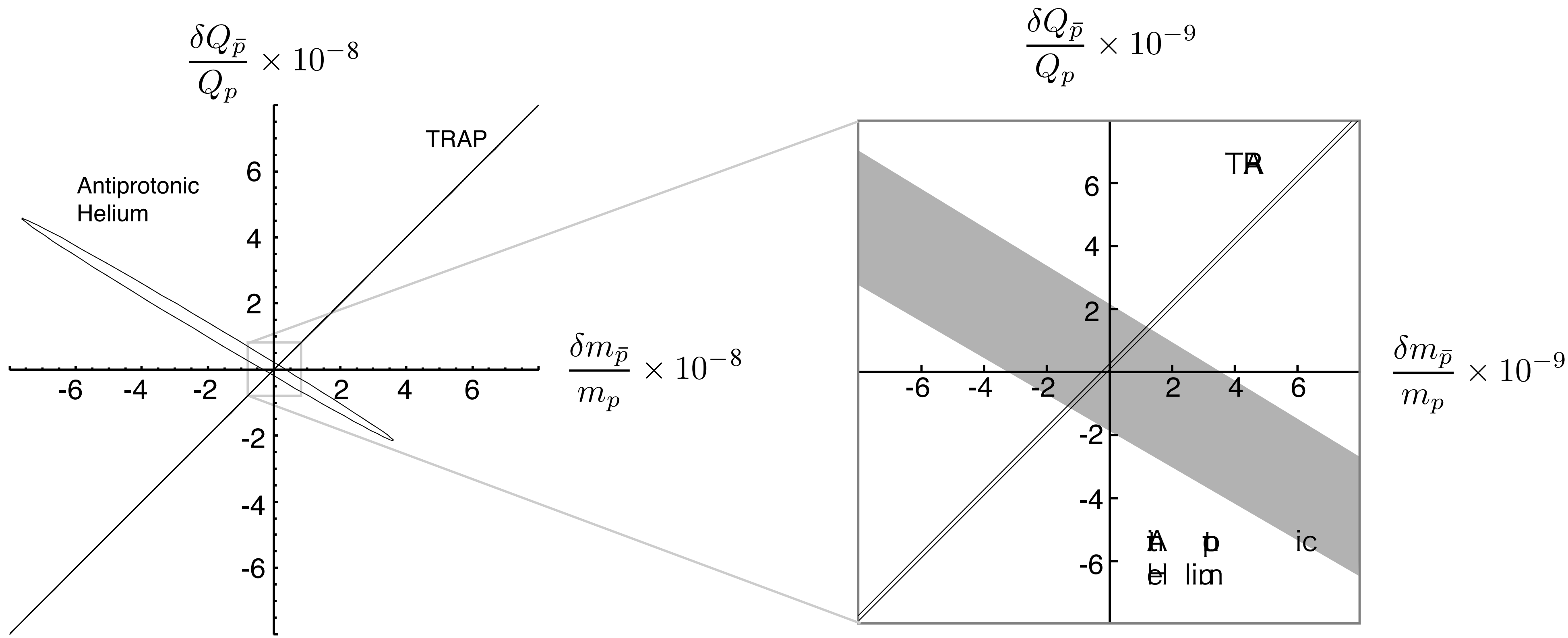
Resonance profile of the

$(n,\ell) = (37,35) \rightarrow (38,34)$ $\overline{\mathrm{p}}$-He transition at $\lambda = 726.1$ nm

Resolution and stability

Now developing: Doppler-free two-photon spectroscopy

Determination of $m(\bar{\mathrm{p}}), q(\bar{\mathrm{p}})$

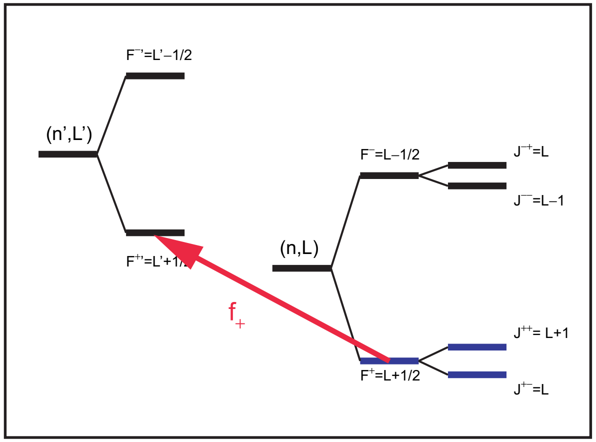


Determination of antiproton mass and charge:
possible deviation from those of the proton

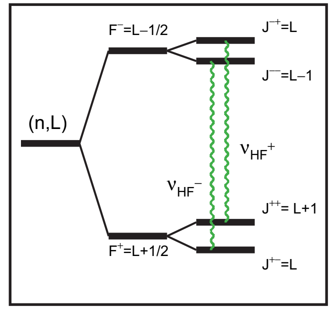
Last published CPT-violation limit: 2 ppb (2×10^{-9})

M. Hori, A. Dax, ... B. Juhász, D. Barna, D. Horváth: **Phys. Rev. Lett.** *96* (2006) 243401.

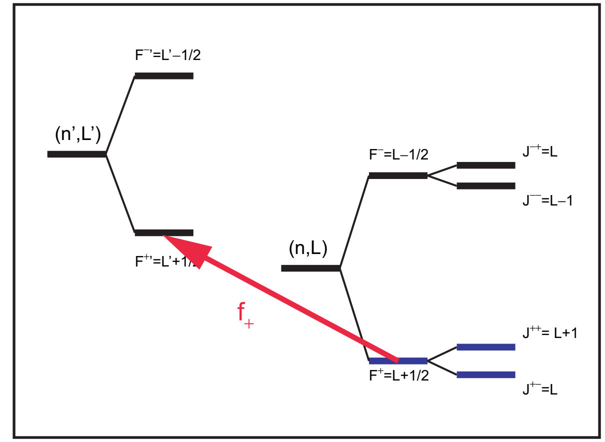
$\mu(\bar{p})$: level splitting in $\bar{p}He^{+}$ atoms



Step 1: depopulation of F^{+} doublet with f_{+} laser pulse



Step 2: equalization of populations of F^{+} and F^{-} by microwave



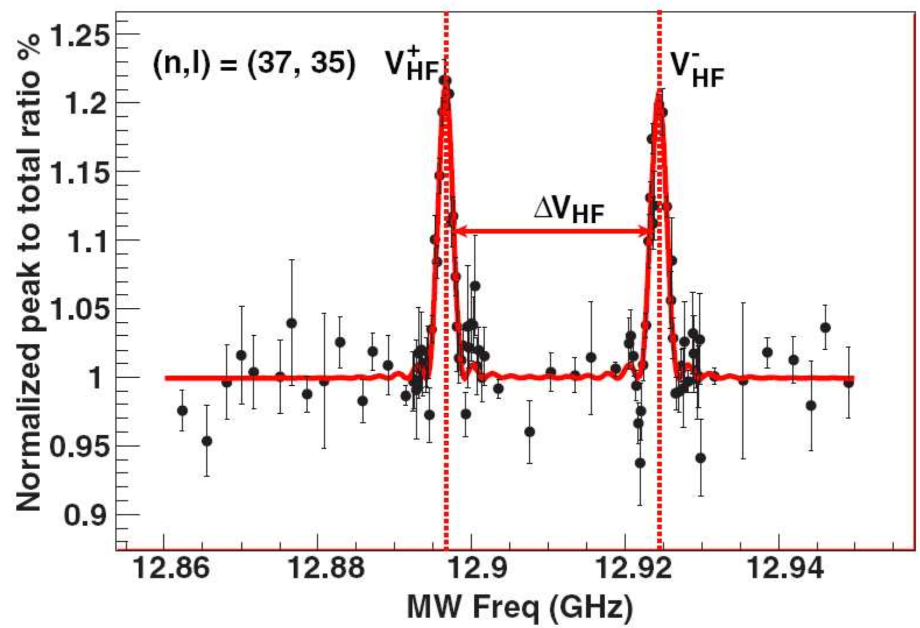
Step 3: probing of population of F^{+} doublet with 2nd f_{+} laser pulse

$\Delta\nu_{HF}$ measured within 0.2%

$\Rightarrow$ *CPT* invariance OK

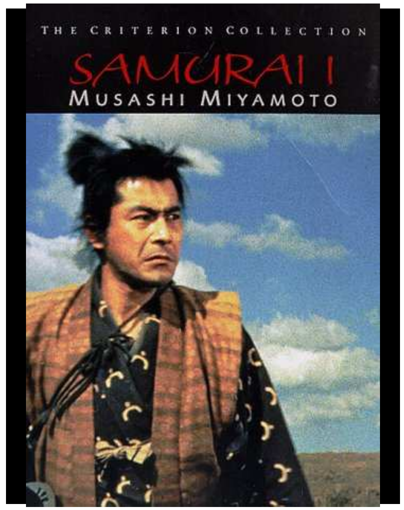
T. Pask, D. Barna, A. Dax, R.S. Hayano, M. Hori, D. Horváth, B. Juhász, C. Malbrunot, J. Marton, N. Ono, K. Suzuki, J. Zmeskal, E. Widmann:

J. Phys. B: At. Mol. Opt. Phys. *41* (2008) 081008.



MUSASHI: slow antiproton beam

Monoenergetic
Ultra
Slow
Antiproton
Source for
High–precision
Investigations

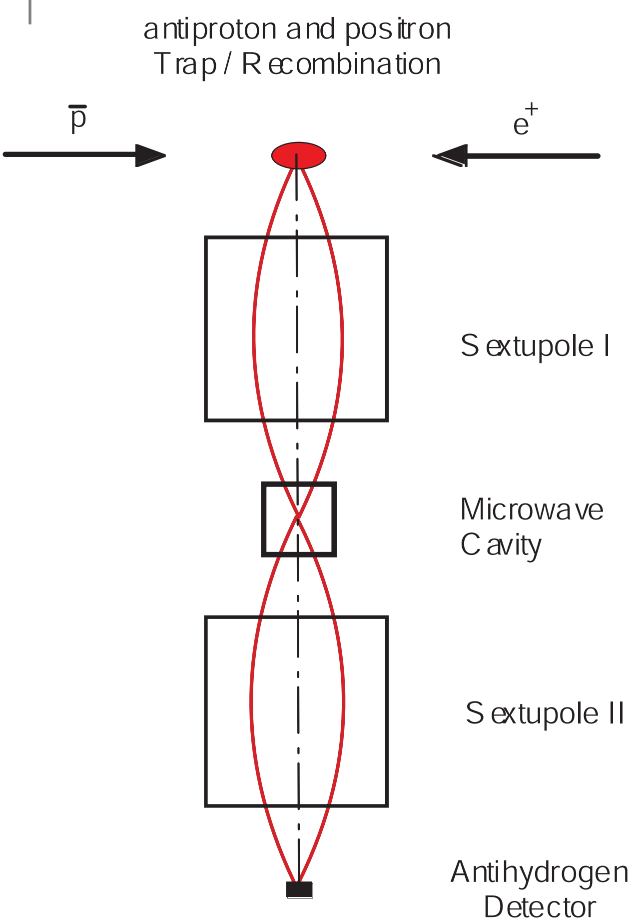


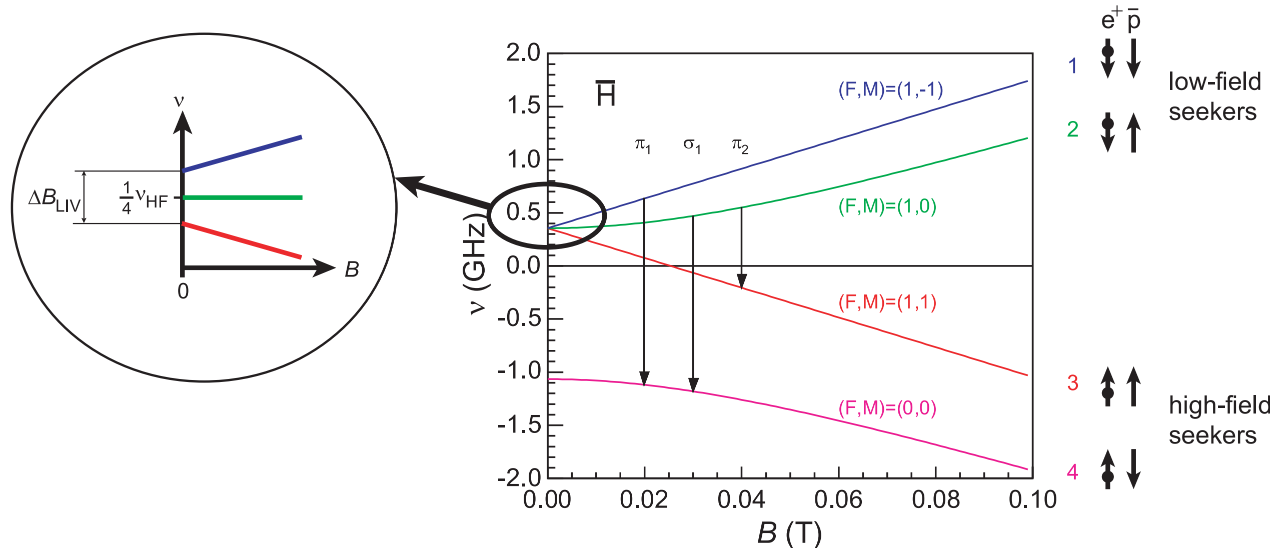
- 5.8 MeV $\bar{p}$ injected into RFQD
- 100 keV $\bar{p}$ injected into trap
- 10^6 $\bar{p}$ trapped and cooled (2002)
- Slow $\bar{p}$ extracted (2004)
- 5×10^5 $\bar{p}$ compressed in trap (2007)

N. Kuroda,...D. Barna, D. Horváth, Y. Yamazaki:

Phys. Rev. Lett. *100* (2008) 203402.

Hyperfine structure of antihydrogen





Possible CPT-violation predicted by

R. Bluhm et al., Phys. Rev. Lett. 82 (1999) 2254.

$v(\bar{p}) \sim$ 350m/s, L(MW cavity) = 20 cm

$\Delta\nu_{HF} \sim$ 3kHz $\Rightarrow$ ppm precision

B. Juhász, D. Barna, J. Eades, R.S. Hayano, M. Hori, D. Horváth, W. Pirkl, E. Widmann and T. Yamazaki: **AIP Conf.Proc.** *796* (2005) 243-246.

Conclusion

- Our last published result on the $\overline{\mathrm{p}}$ mass using laser spectroscopy on 7 $\overline{\mathrm{p}}^4\mathrm{He}^+$ and 5 $\overline{\mathrm{p}}^3\mathrm{He}^+$ transitions is:
  $$m_{\overline{\mathrm{p}}}/m_{\mathrm{e}} = 1836.152674(5)$$
  (M. Hori *et al.*, Phys. Rev. Letters **96** (2006) 243401.)
- Present *CPT*-limit on $\overline{\mathrm{p}}$ charge and mass 2×10^{-9} at 90% confidence level
- Assuming *CPT* validity our result can be combined with those for the proton:
  Precision of $m_{\mathrm{p}}/m_{\mathrm{e}}$ 0.46% (CODATA 2002)
  $$\Downarrow$$
  0.43% (CODATA 2006)

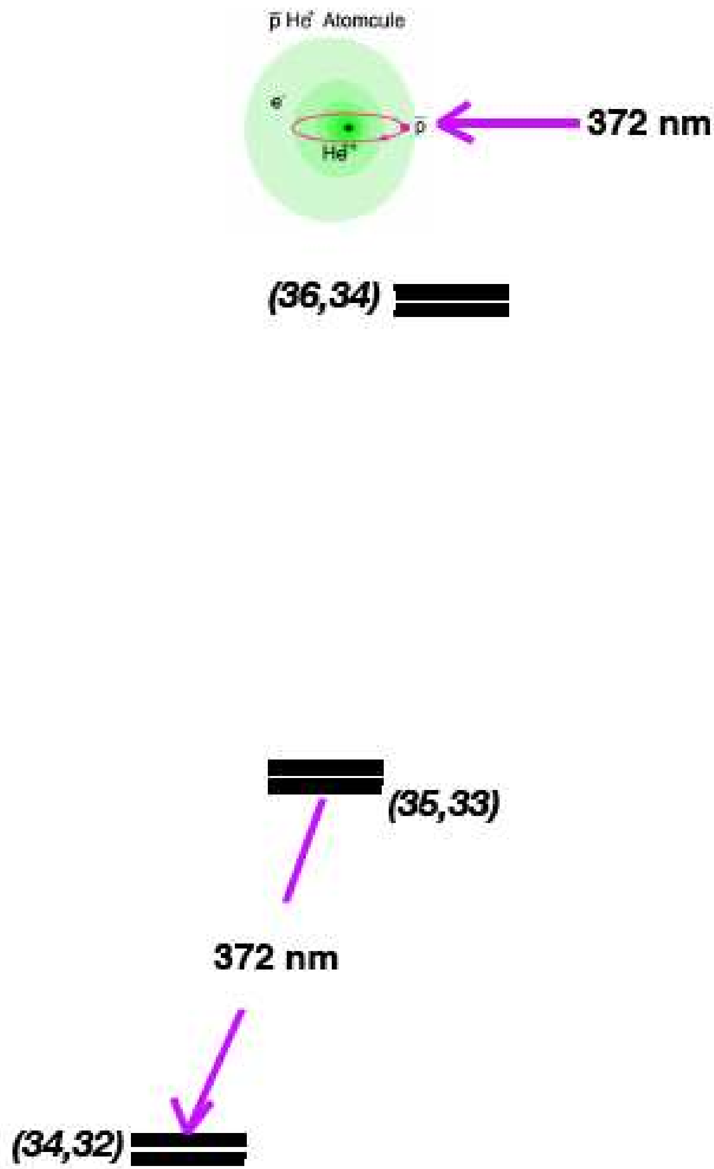
Acknowledgement

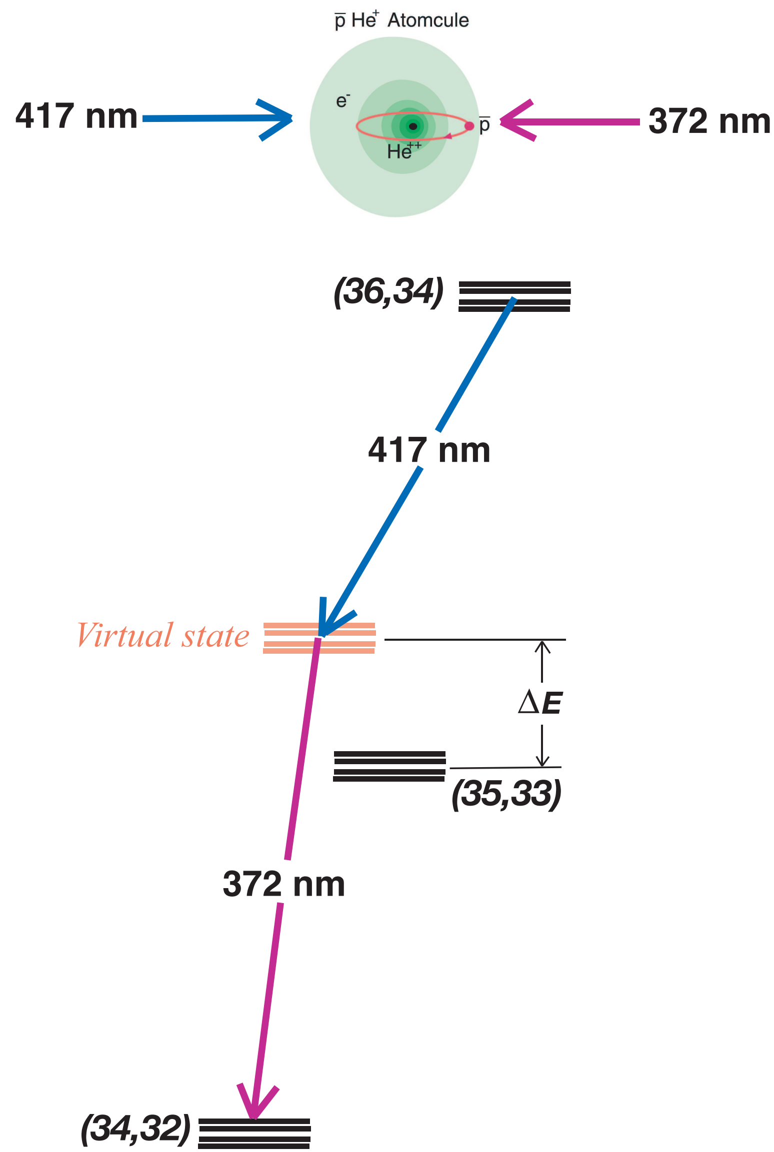
This work is supported by:

- Monbukagakusho (Grant No. 15002005),
- the Hungarian National Research Foundation (OTKA)
  and the National Office for Research and Development (NKTH)
  (Contracts NN 67974, 72172 and 73153)
- and EU FP6 Project MKTD-CT-2004-509252.

Spare slides

1-photon vs 2-photon spectroscopy





Near-resonant two-photon spectroscopy

$$(n,\ell) = (36,34) \rightarrow (34,32)$$

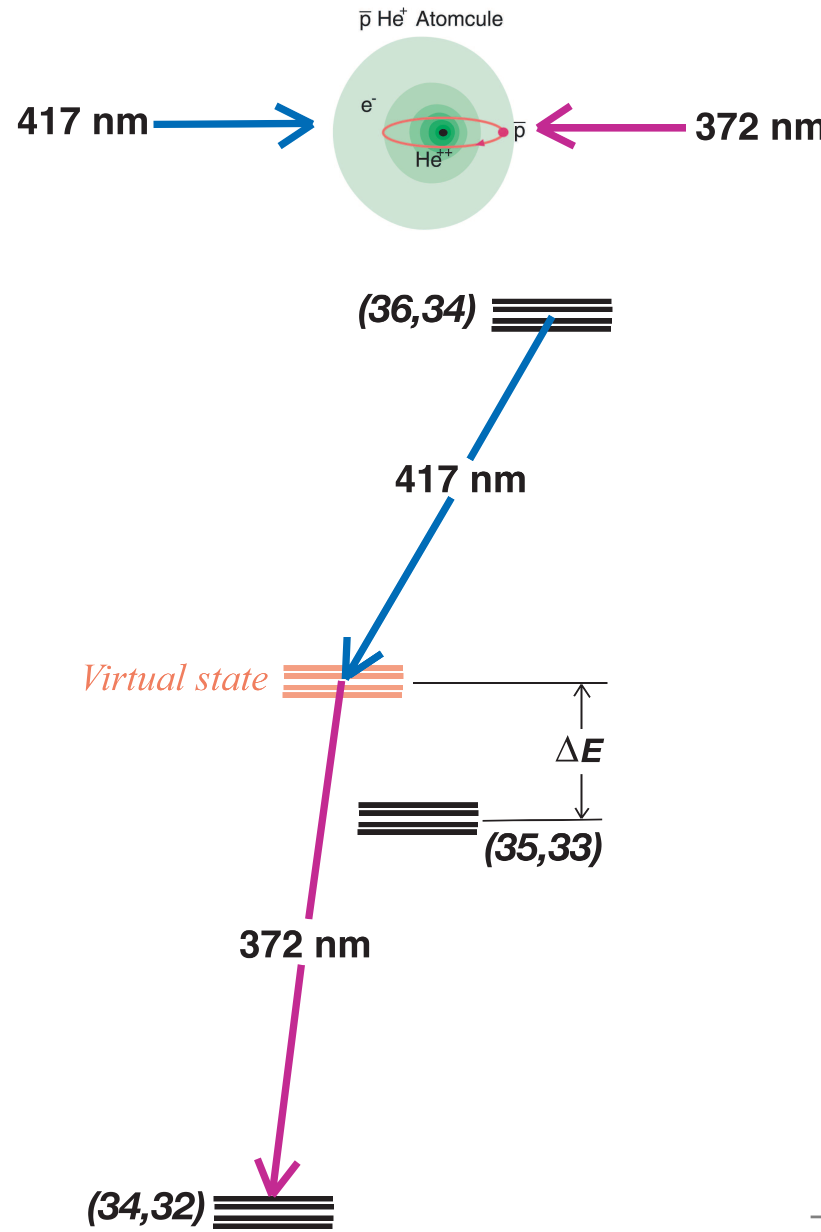
Doppler suppression:

$$\Delta\nu_{\gamma_1\gamma_2} = \left|\frac{\nu_1 - \nu_2}{\nu_1 + \nu_2}\right| \Delta\nu_{\mathrm{Doppler}}$$

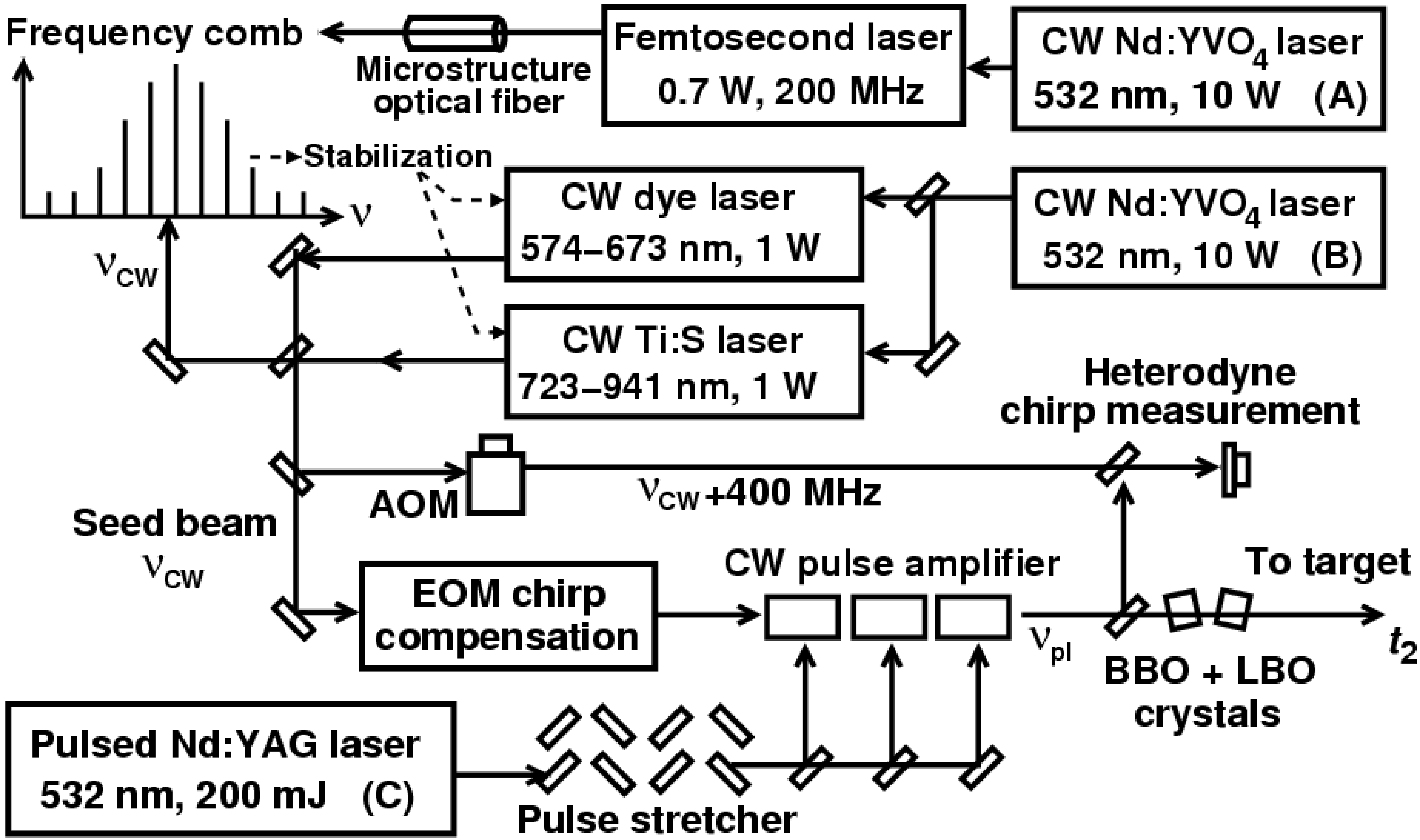
Gain: $\sim 20\times$

Limitation: residual Doppler, frequency chirp systematics

Expected $\Delta f \sim$ few MhZ
(solid-state lasers $\Rightarrow$ lower chirp)



Laser system with frequency comb



$|\frac{\Delta f}{f}| < 4 \times 10^{-10}$ (M. Hori, A. Dax, R. S. Hayano, unpublished)