Testing CPT with antiprotonic helium and Antihydrogen

Eberhard Widmann

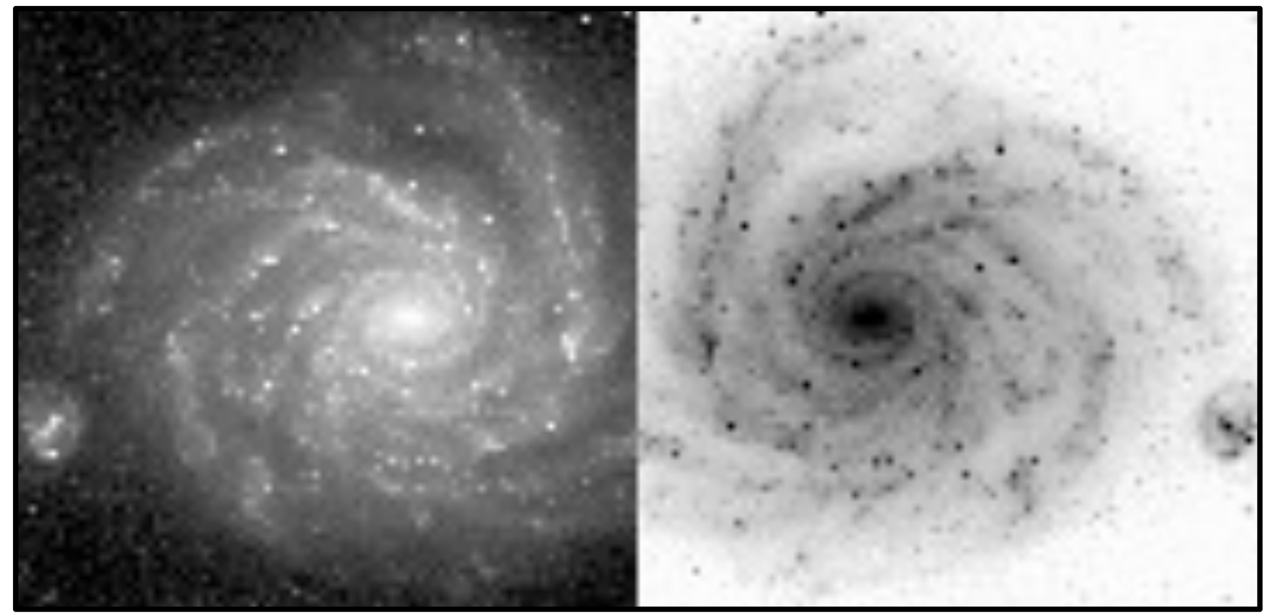
PANIC Conference

MIT, July 25, 2011

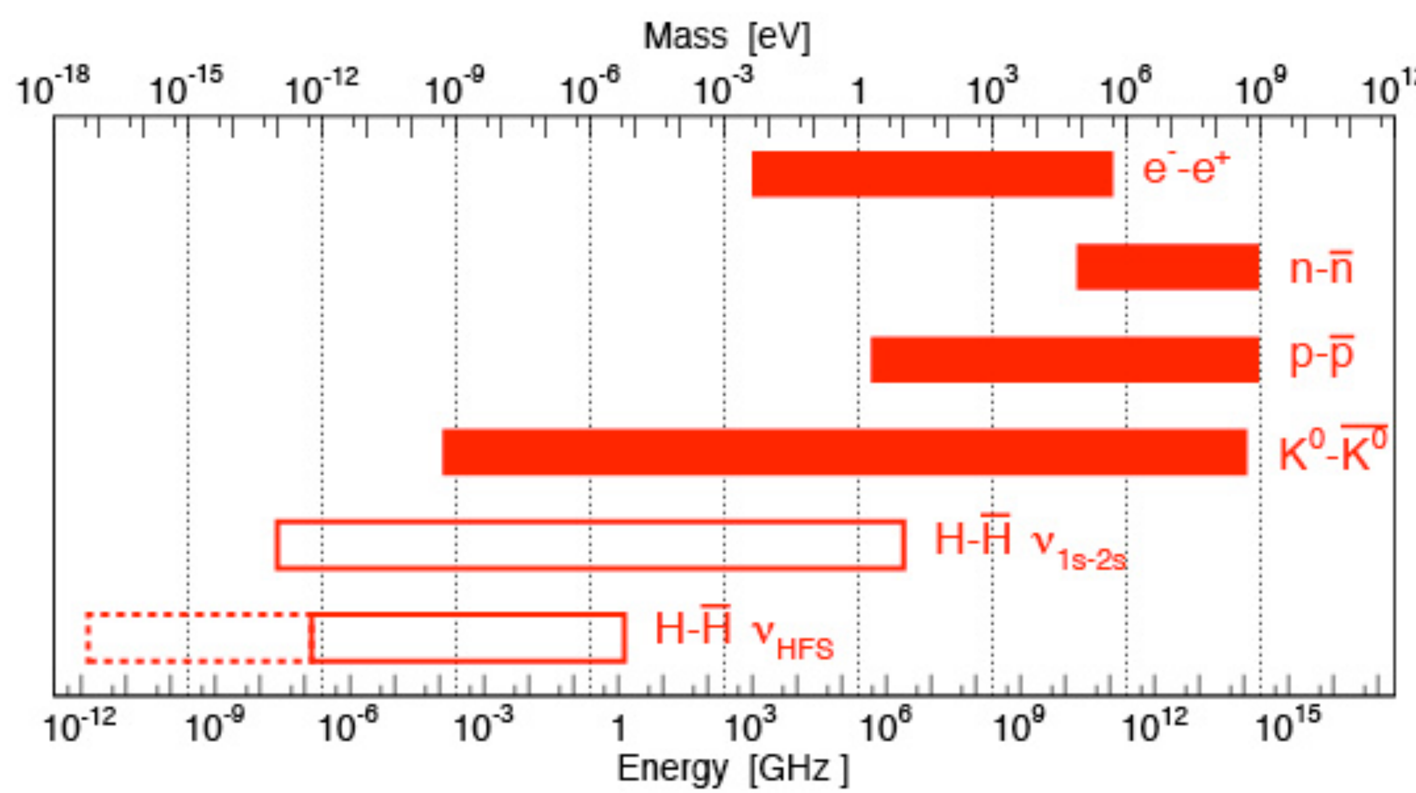
Stefan Meyer Institute for Subatomic Physics, Vienna

Matter-antimatter symmetry

- Cosmological scale:
  - asymmetry



- CPT violation
  - Microscopic: symmetry?



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Ways to violate CPT

- SME Kostelecky

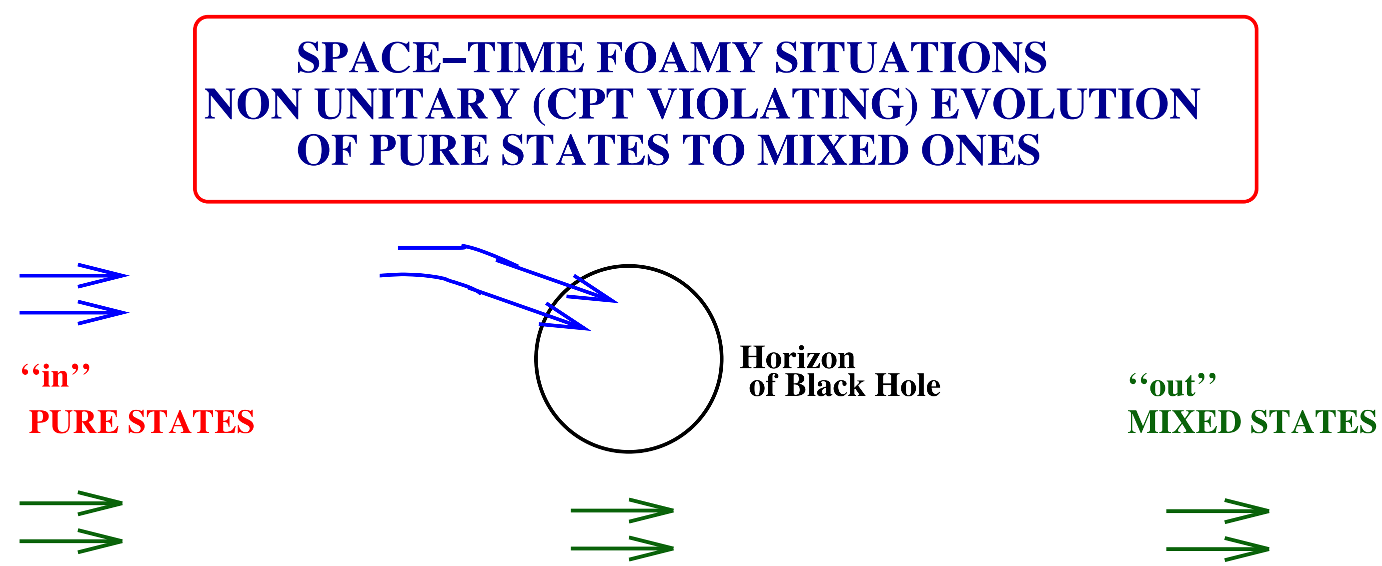
CPT & Lorentz violation

$$(i\gamma^{\mu}D_{\mu} - m_e - \boxed{a^e_{\mu}\gamma^{\mu} - b^e_{\mu}\gamma_5\gamma^{\mu}}$$

$$- \boxed{\tfrac{1}{2}H^e_{\mu\nu}\sigma^{\mu\nu} + ic^e_{\mu\nu}\gamma^{\mu}D^{\nu} + id^e_{\mu\nu}\gamma_5\gamma^{\mu}D^{\nu}})\psi = 0\,.$$

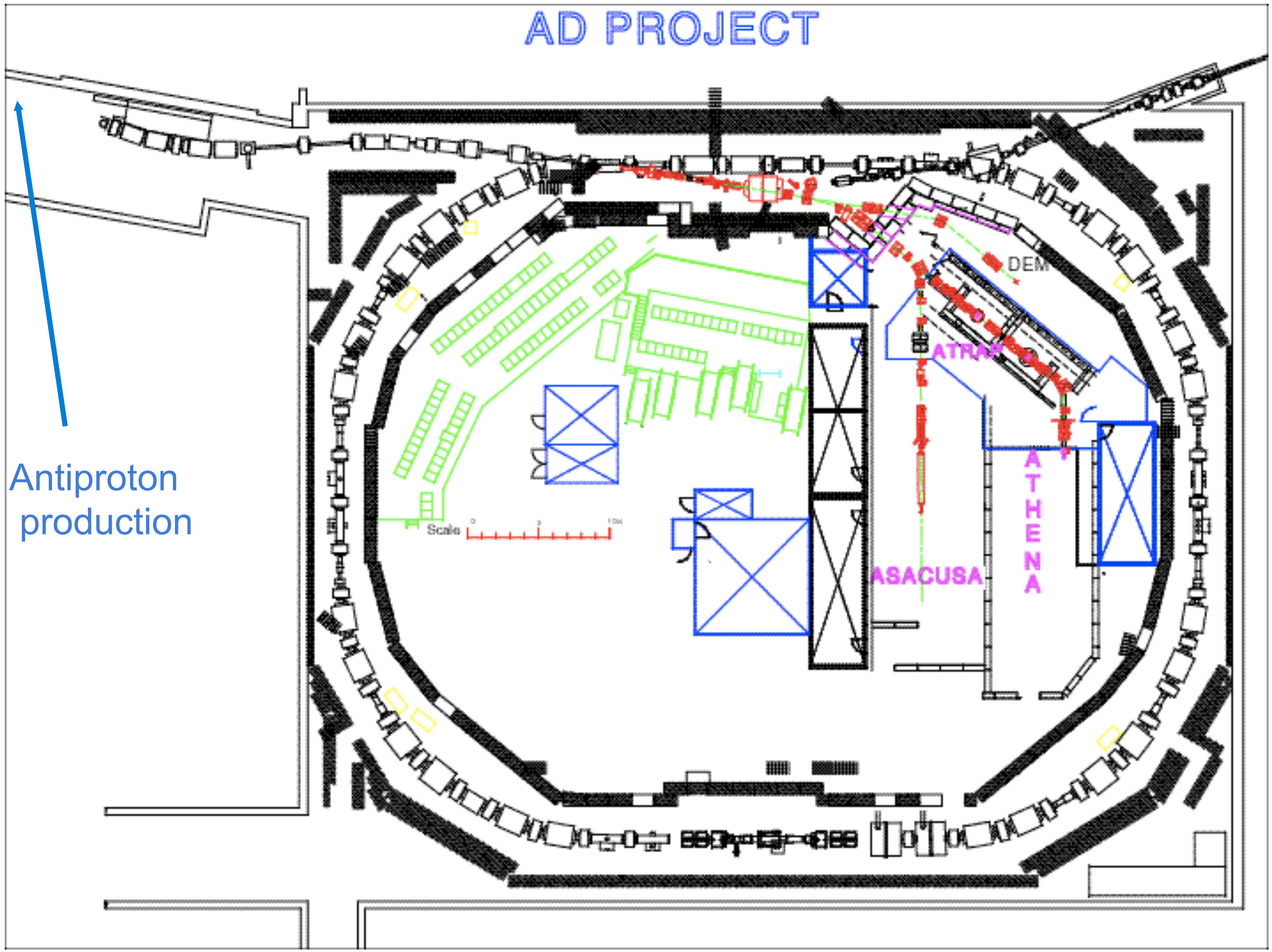
Lorentz violation

- Foam and unitarity violation



After S. Weinberg 1999

Current source: AD @ CERN



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ASACUSA collaboration @ CERN-AD

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Asakusa Kannon Temple
by Utagawa Hiroshige (1797-1858)

Atomic **S**pectroscopy **A**nd **C**ollisions
Using **S**low **A**ntiprotons

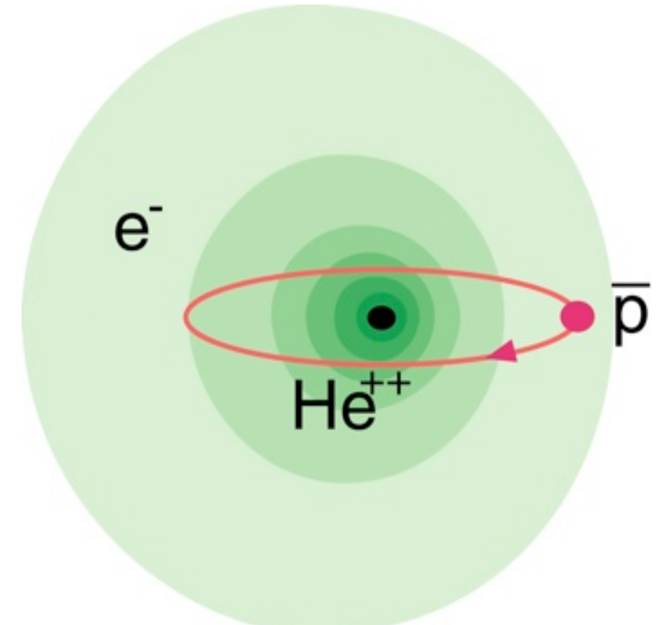
Spokesperson: R.S. Hayano, University of Tokyo

- University of Tokyo, Japan
  - College of Arts and Sciences, Institute of Physics
  - Faculty of Science, Department of Physics
- RIKEN, Saitama, Japan
- SMI, Austria
- Aarhus University, Denmark
- Max-Planck-Institut für Quantenoptik, Munich, Germany
- KFKI Research Institute for Particle and Nuclear Physics, Budapest, Hungary
- ATOMKI Debrecen, Hungary
- Brescia University & INFN, Italy
- University of Wales, Swansea, UK
- The Queen's University of Belfast, Ireland

~ 44 members

Spectroscopy for tests of CPT and QED

- Antiprotonic helium
  - laser and microwave spectroscopy CPT test antiproton properties
    - mass, charge: 2×10^{-9}
    - magnetic moment: 2.9×10^{-3}
  - most precisely calculated 3-body system



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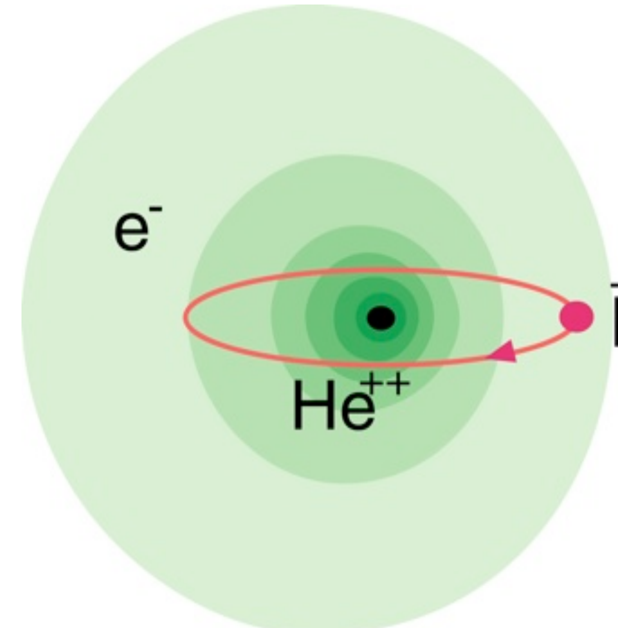
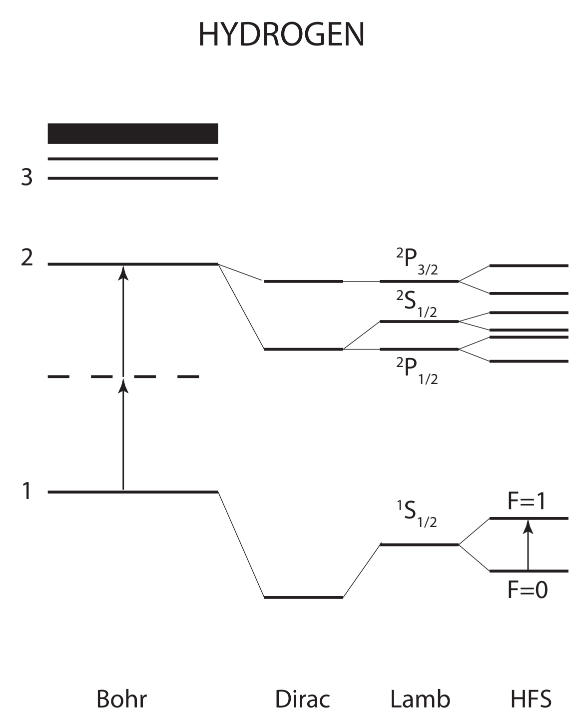
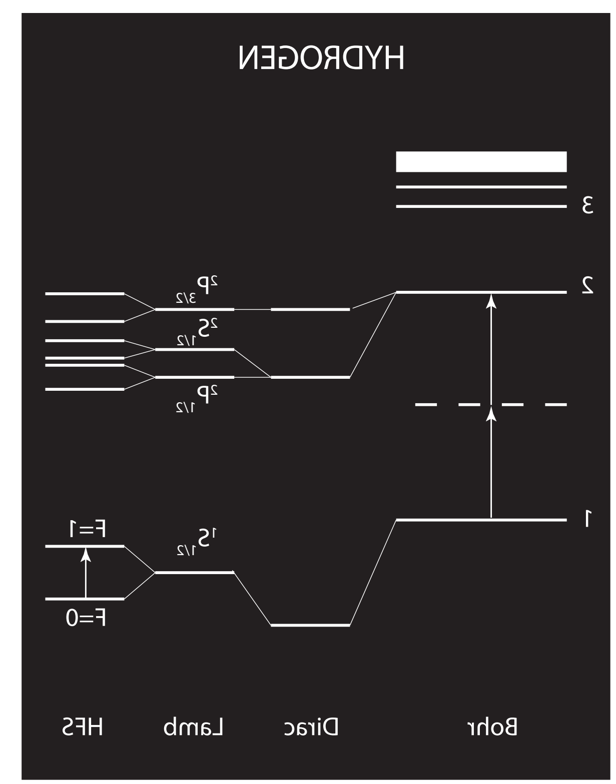
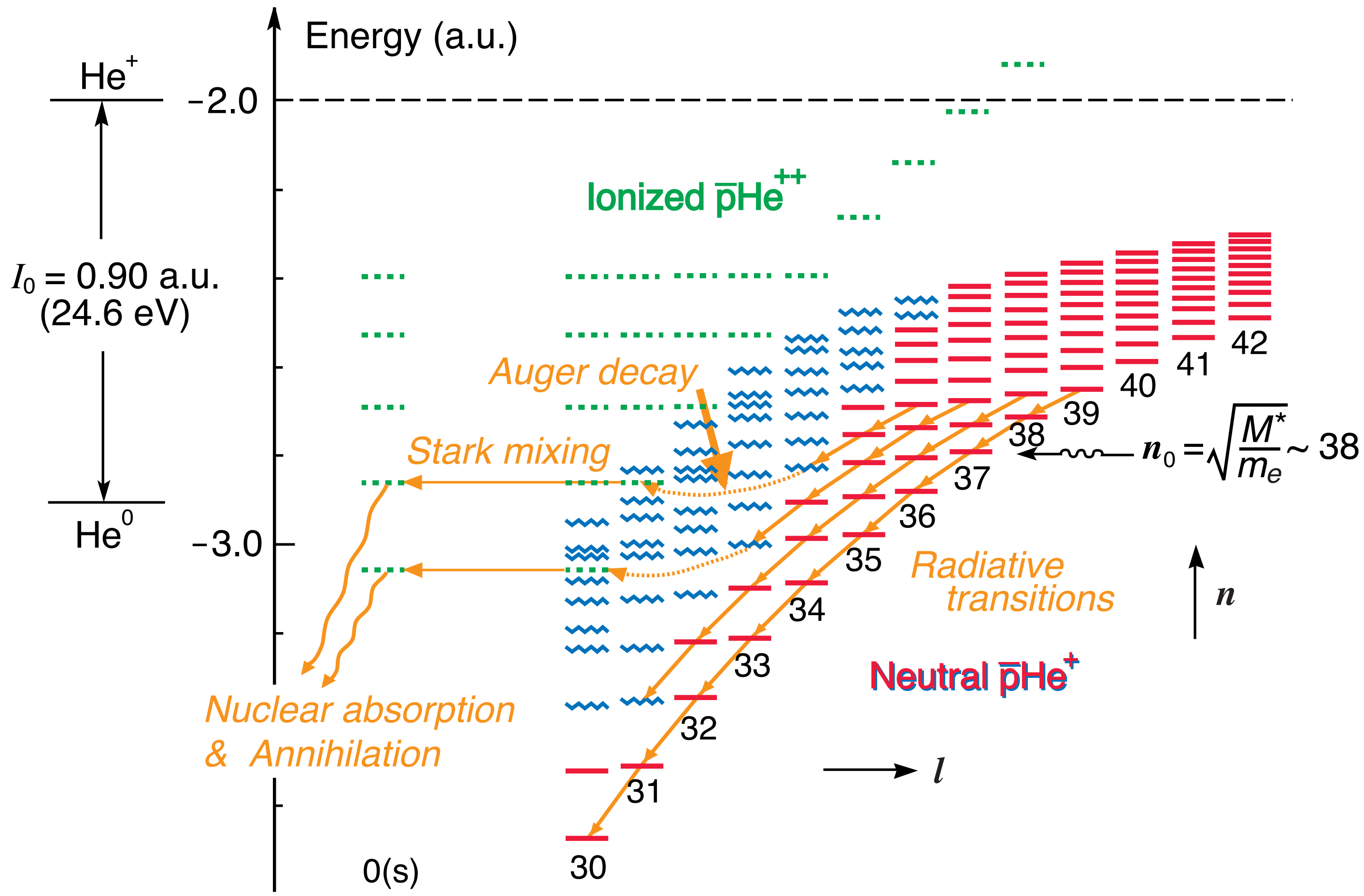


- Antihydrogen
  - hydrogen measured to the highest precision
    - 1S-2S: 10^{-14}
    - ground-state HFS: 10^{-12}





Antiprotonic helium „atomcule“



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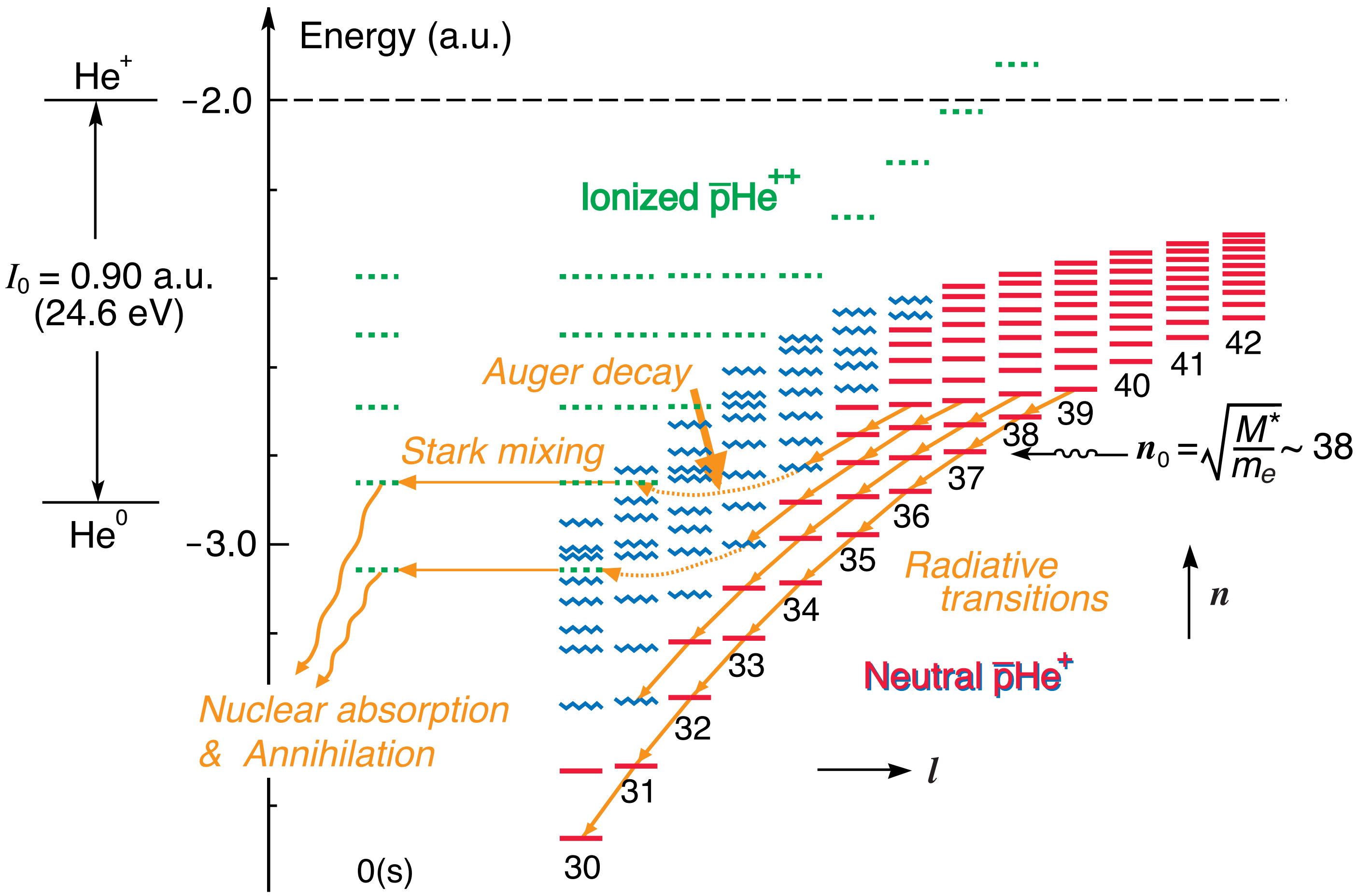

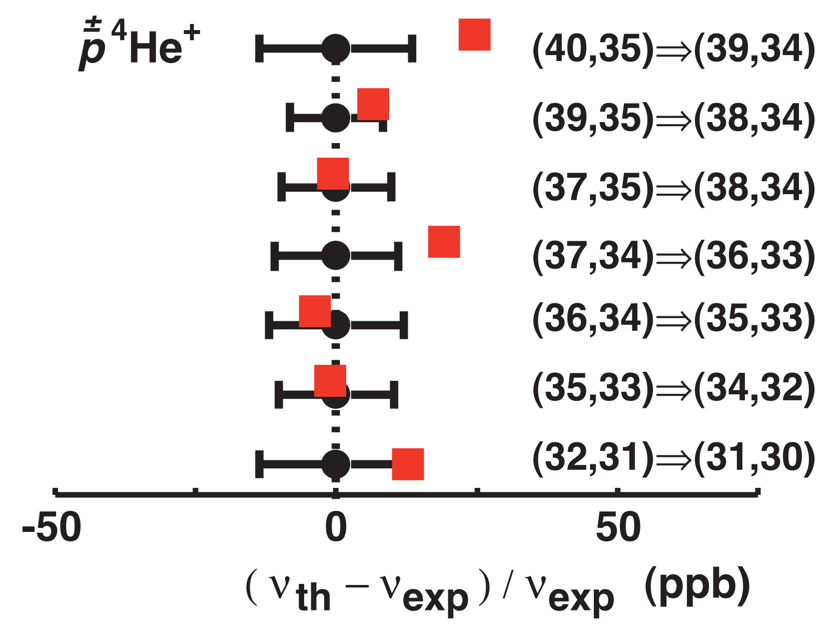

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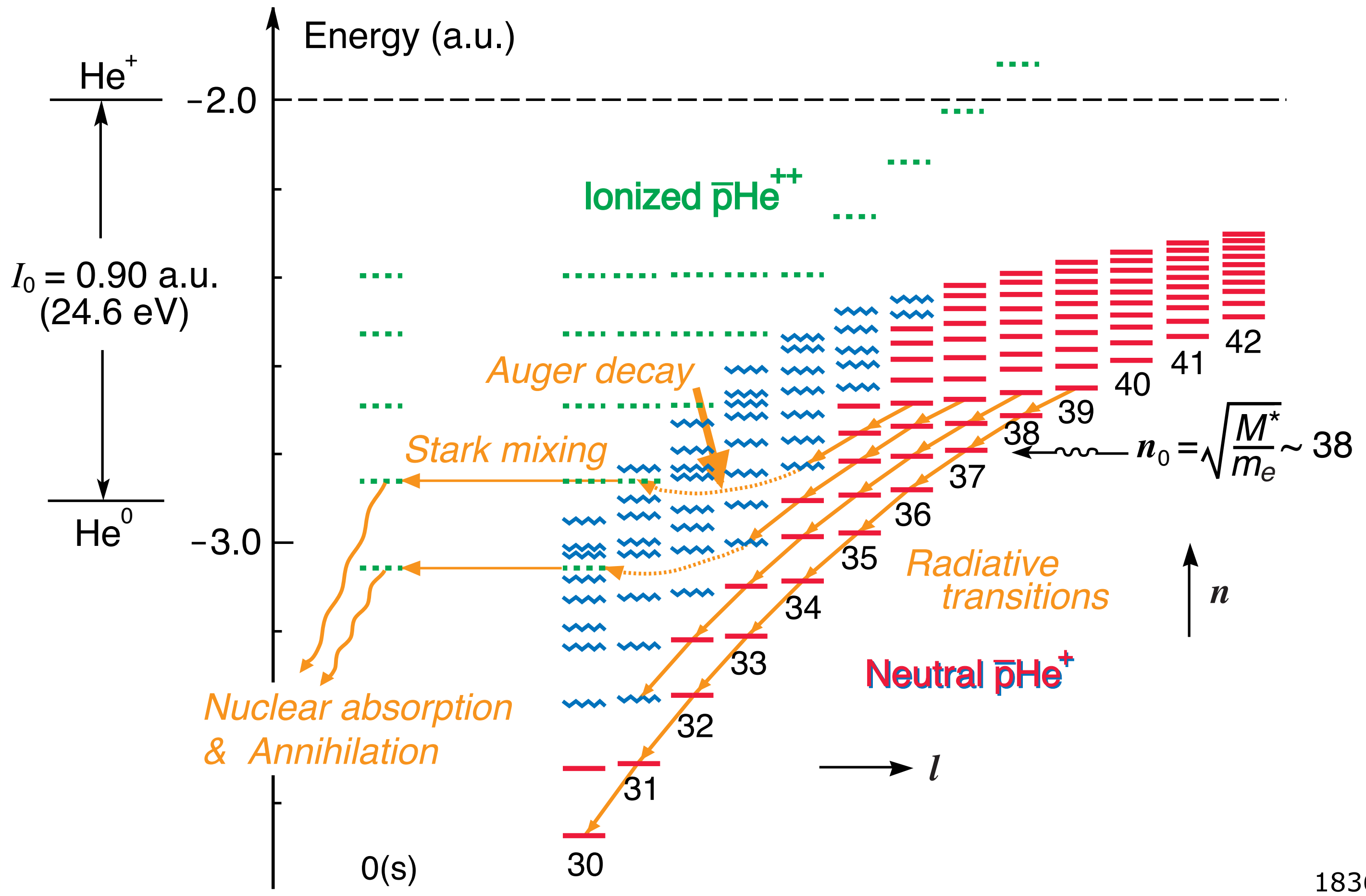
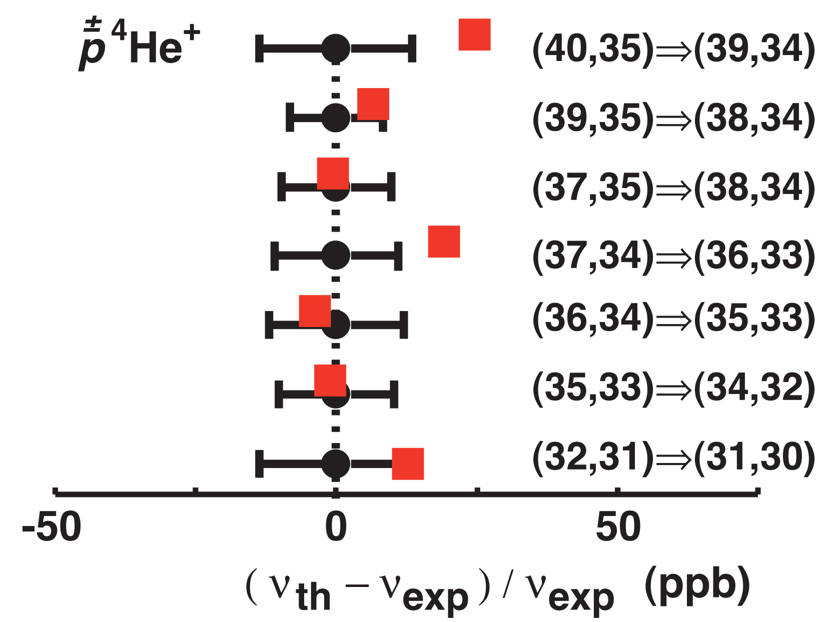
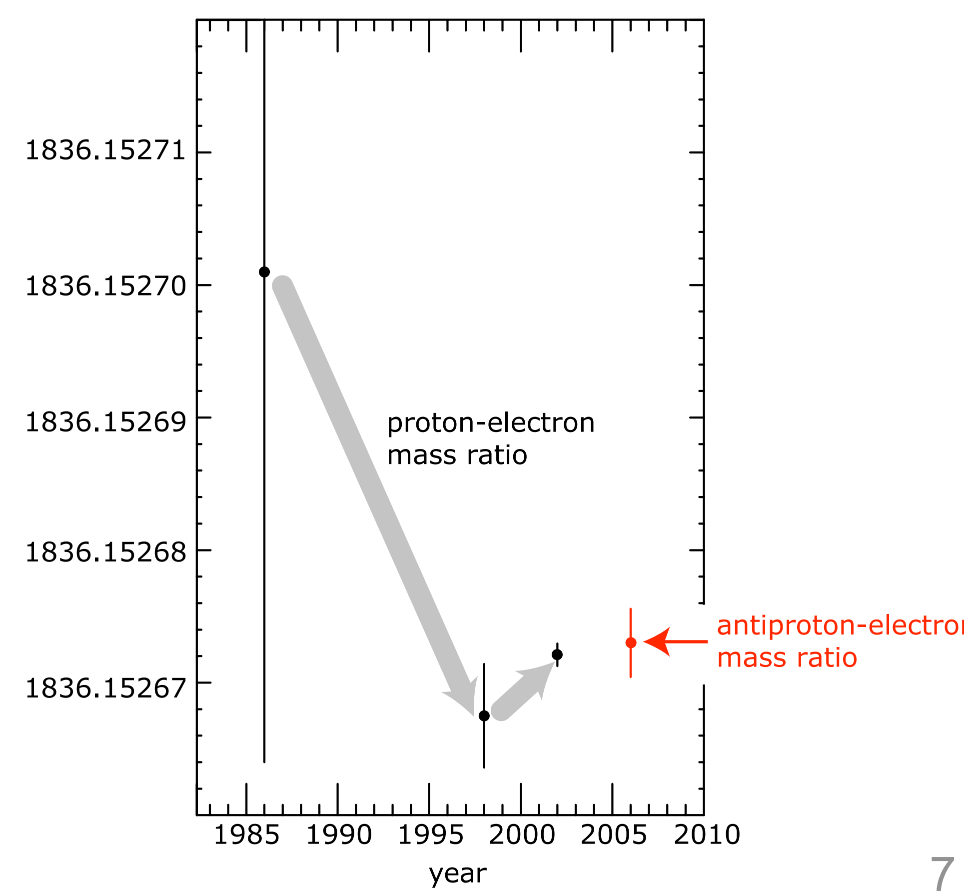


theory vs. experiment



laser spectroscopy:
$m_{\bar{p}}/m_e$ = 1836.152674(5)

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



listed in PDG
included in CODATA as proton value

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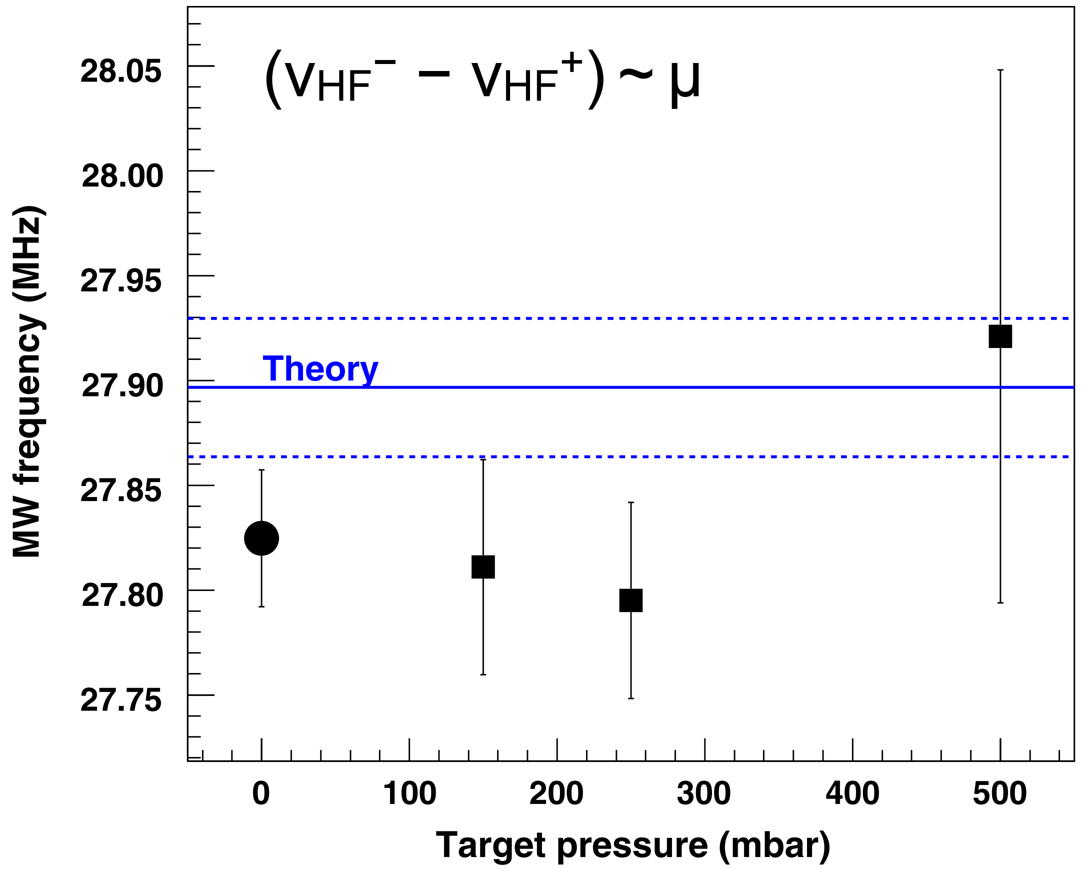
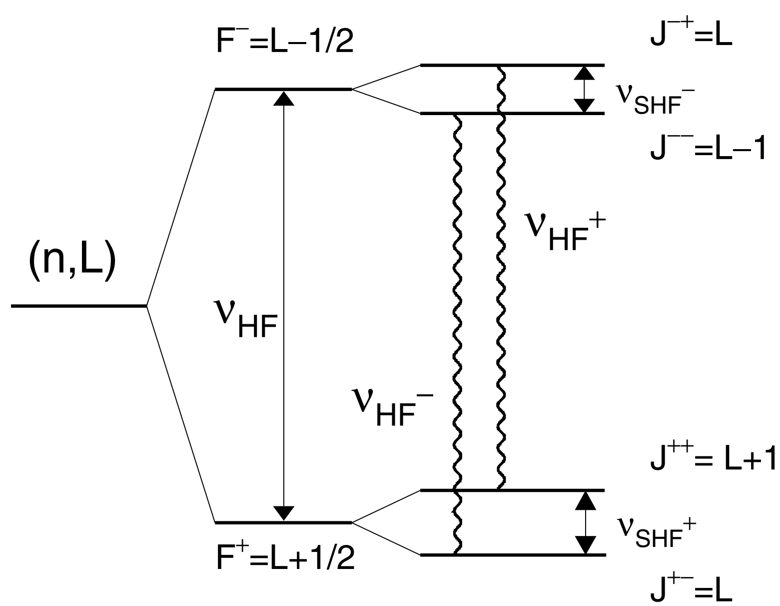
Magnetic moment of the antiproton



Hyperfine structure



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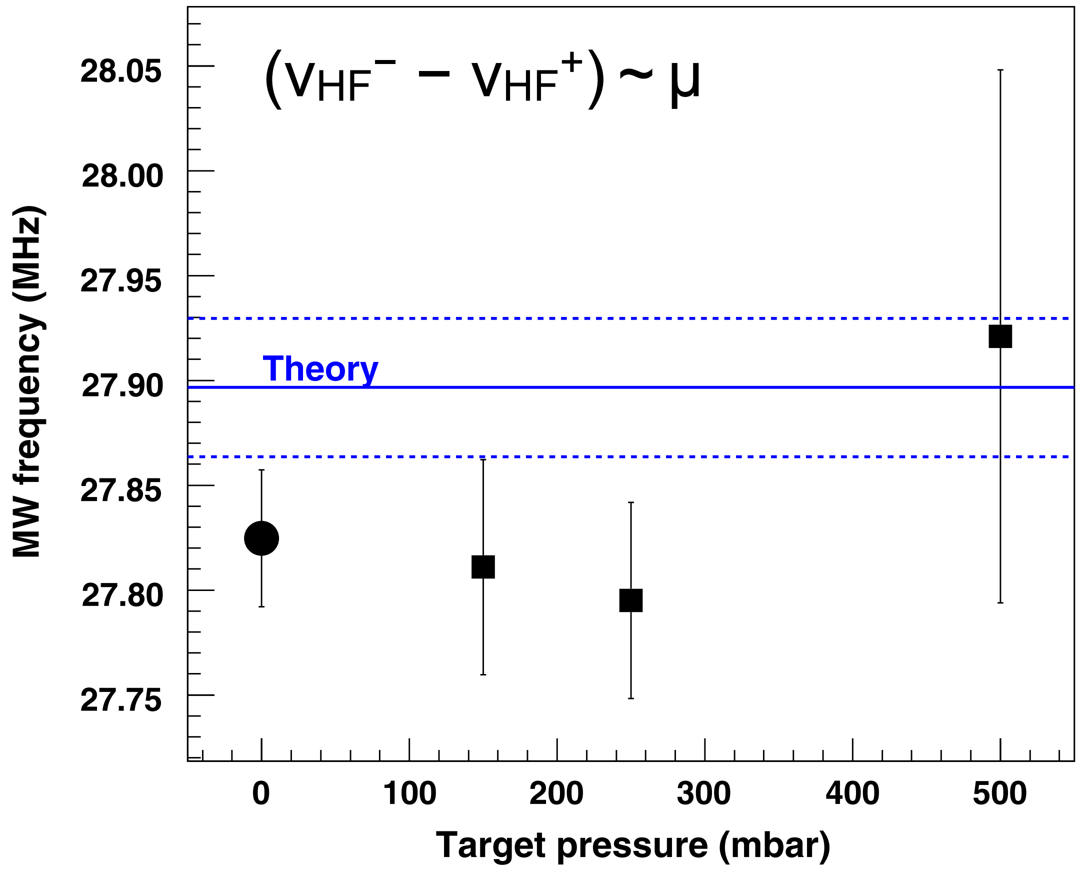

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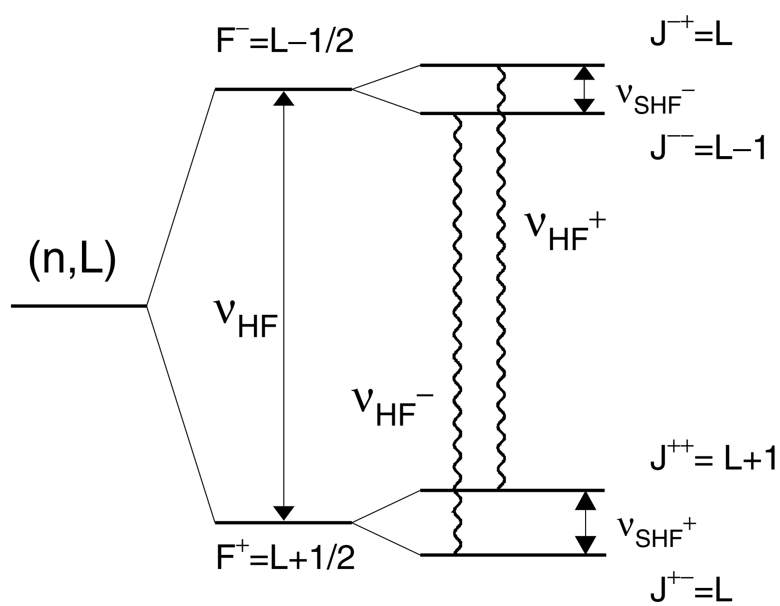

Comparison theory-experiment

$$\mu_s^{\bar{p}} = -2.7862(83)\mu_N$$

$$\frac{\mu_s^p - |\mu_s^{\bar{p}}|}{\mu_s^p} = (2.4 \pm 2.9) \times 10^{-3}$$

T. Pask et al. / Physics Letters B 678 (2009) 55–59

listed in PDG

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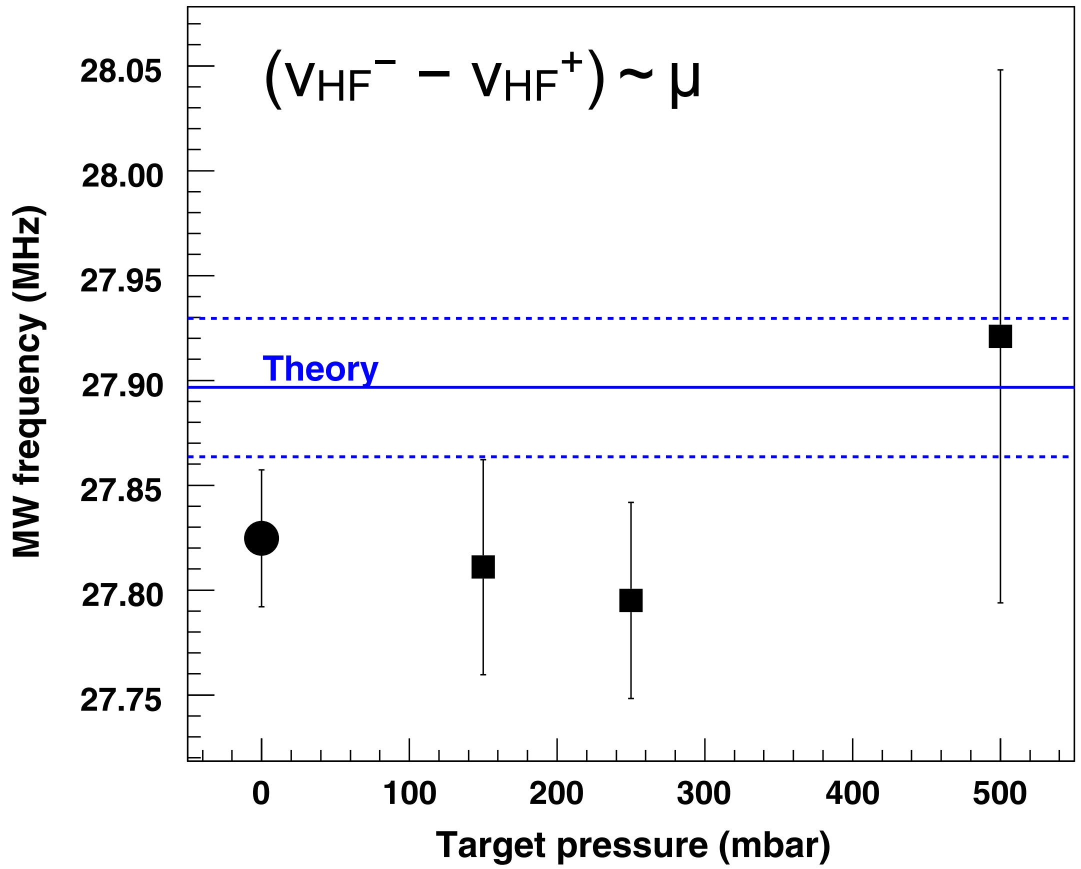

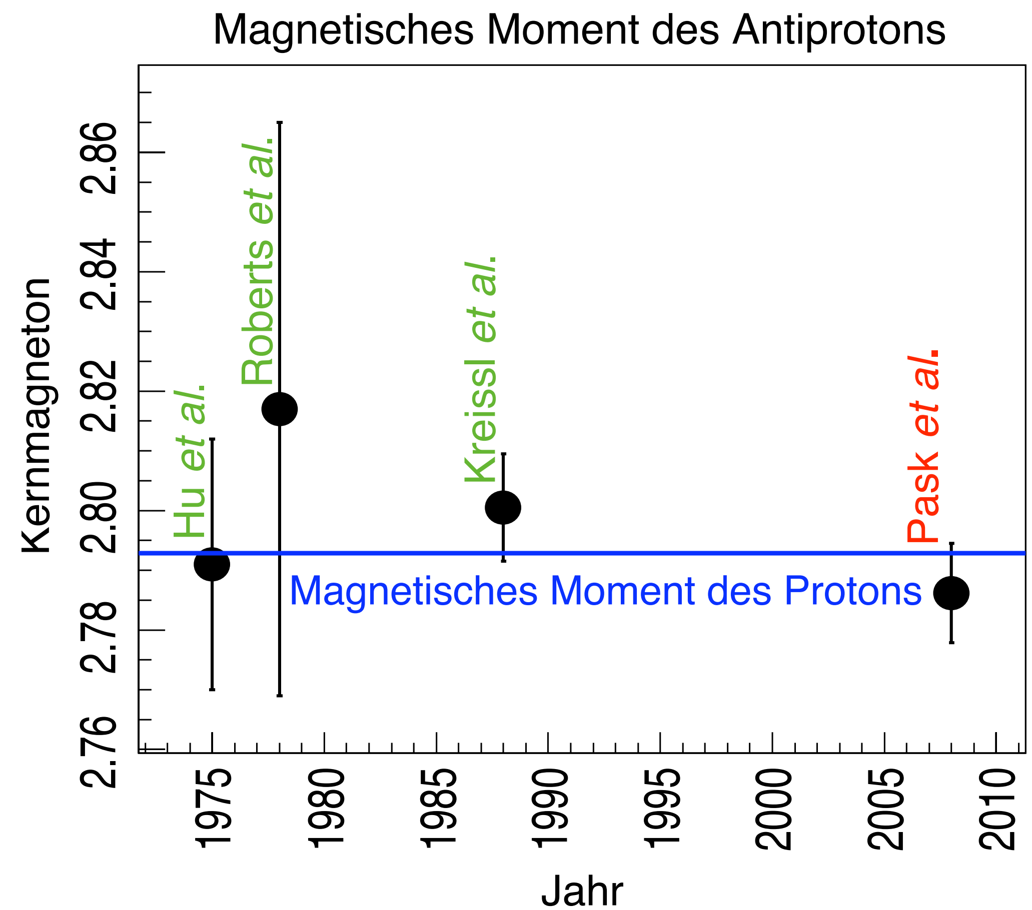

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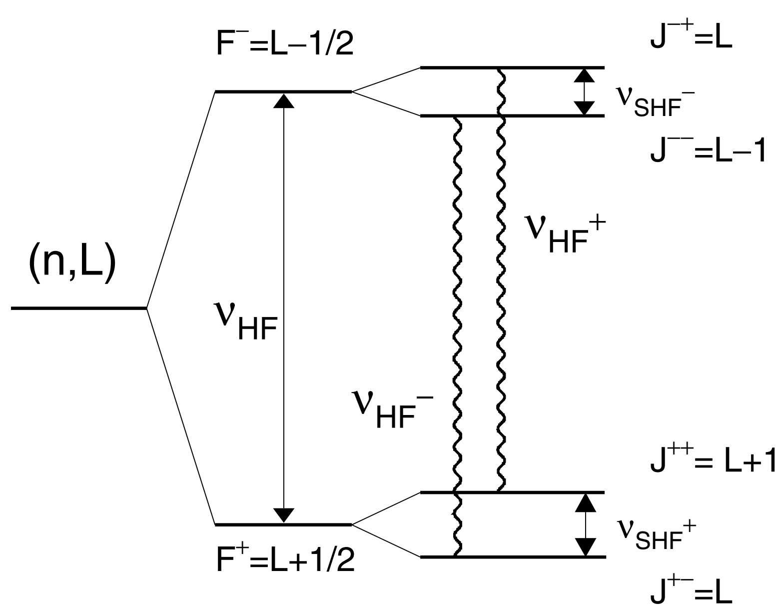

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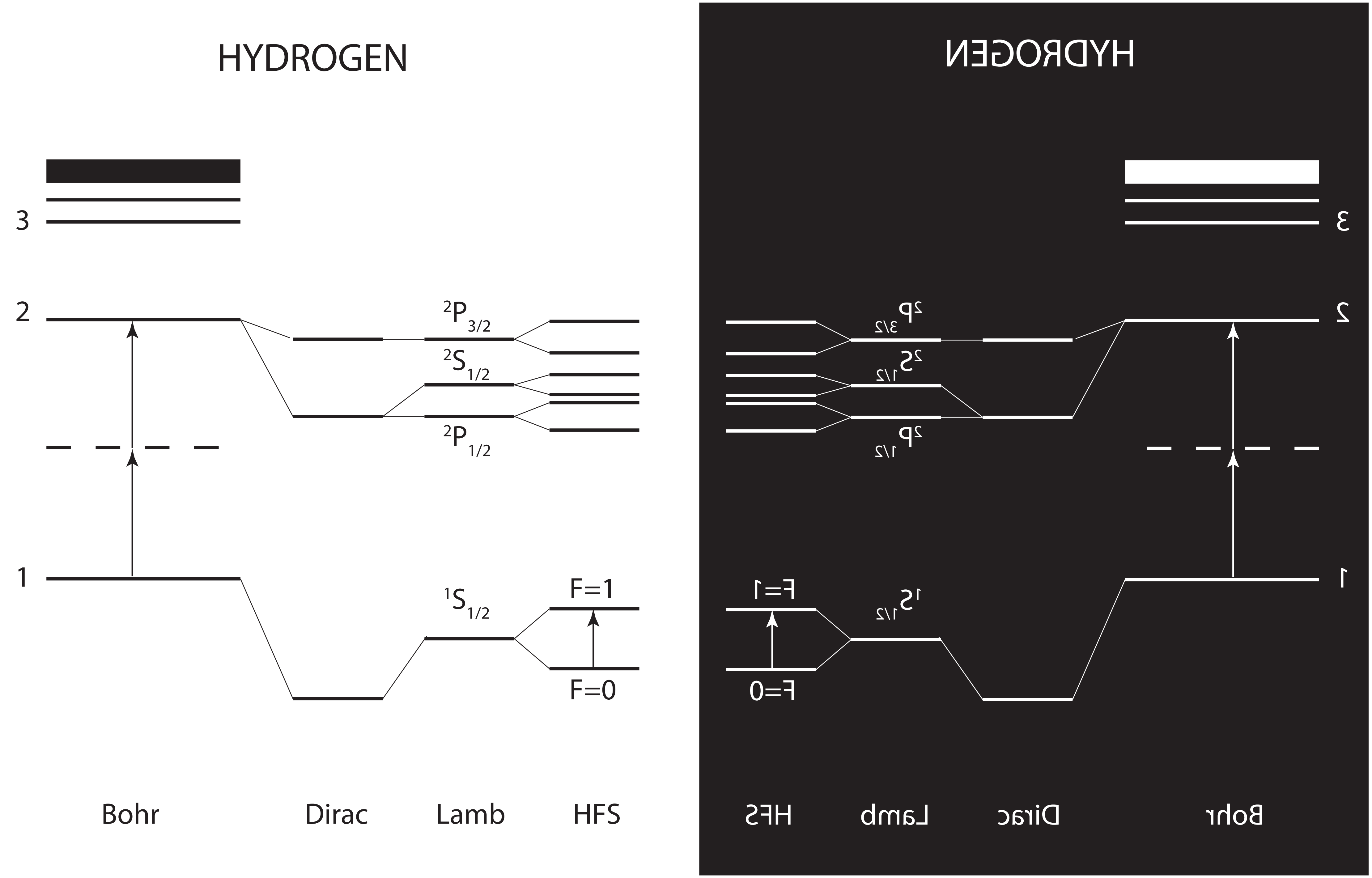
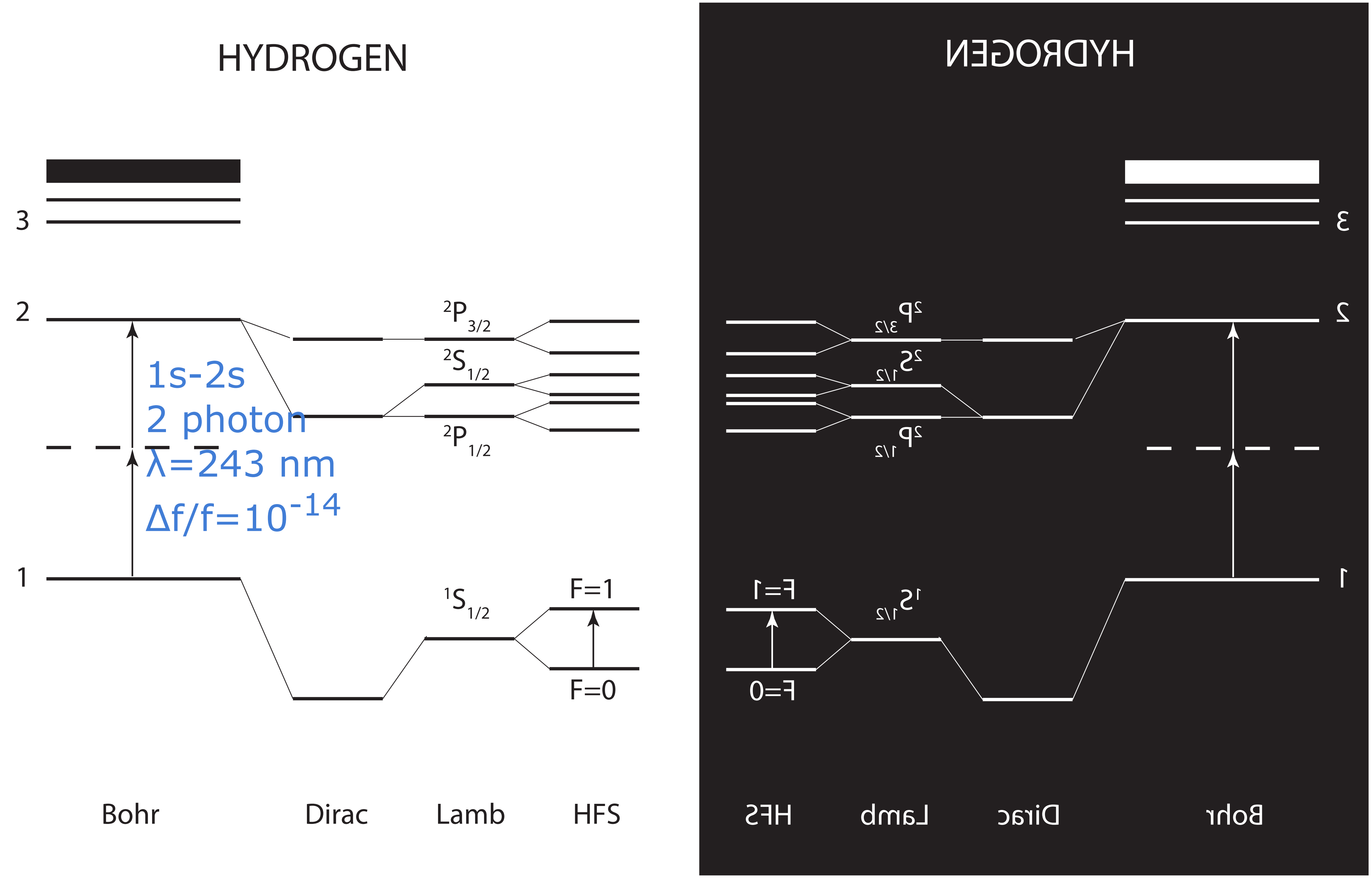
Hydrogen and Antihydrogen



Hydrogen and Antihydrogen



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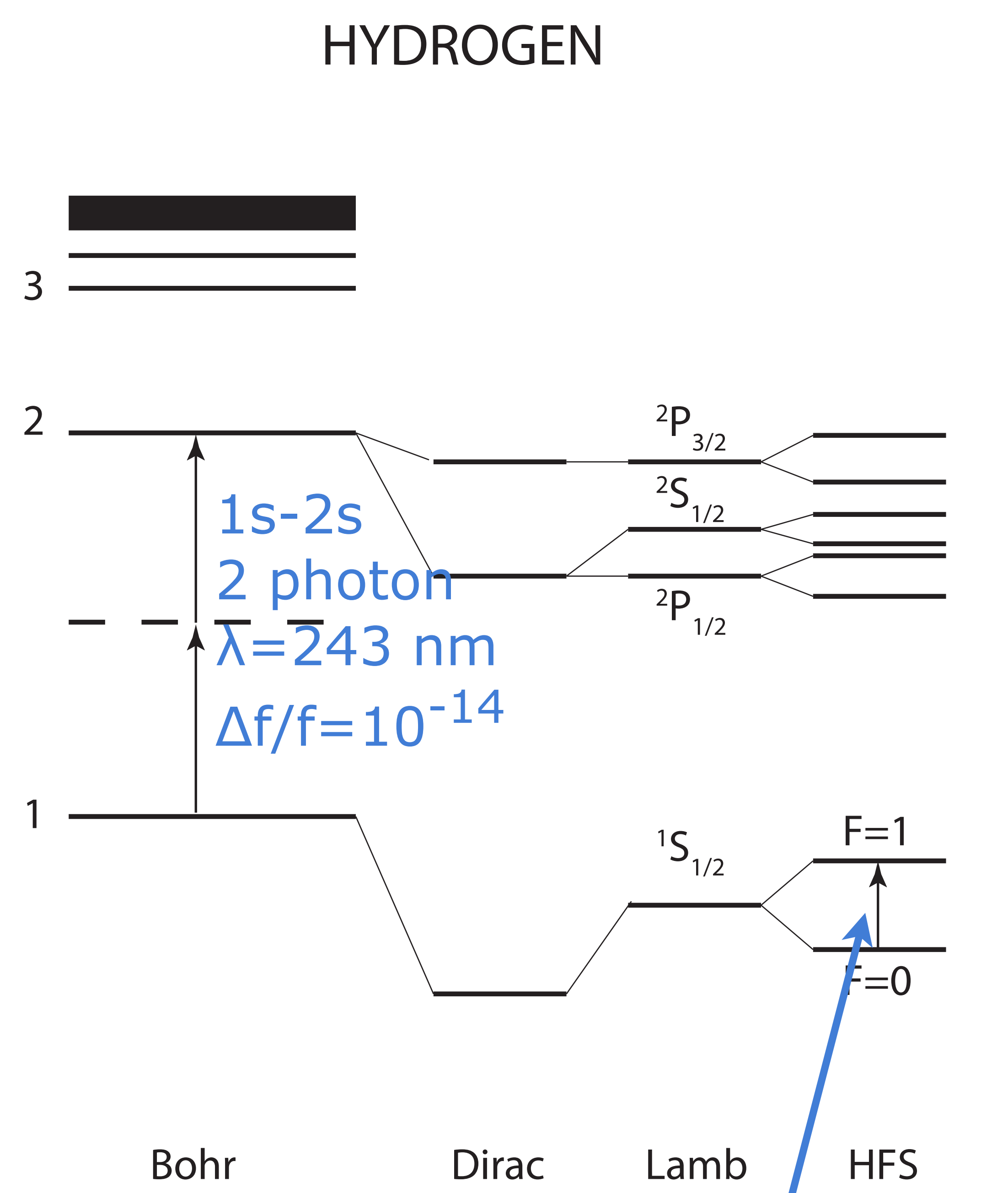
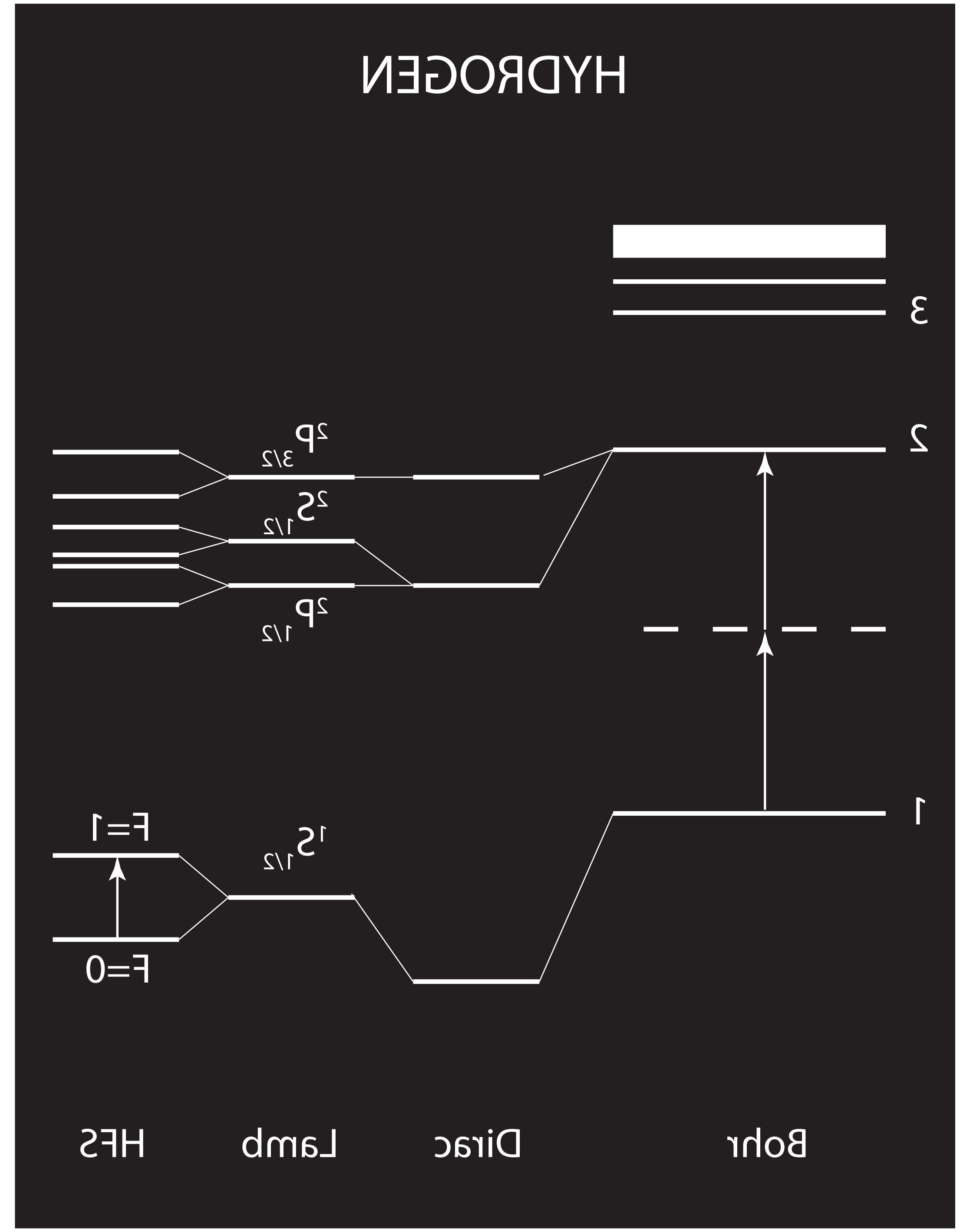
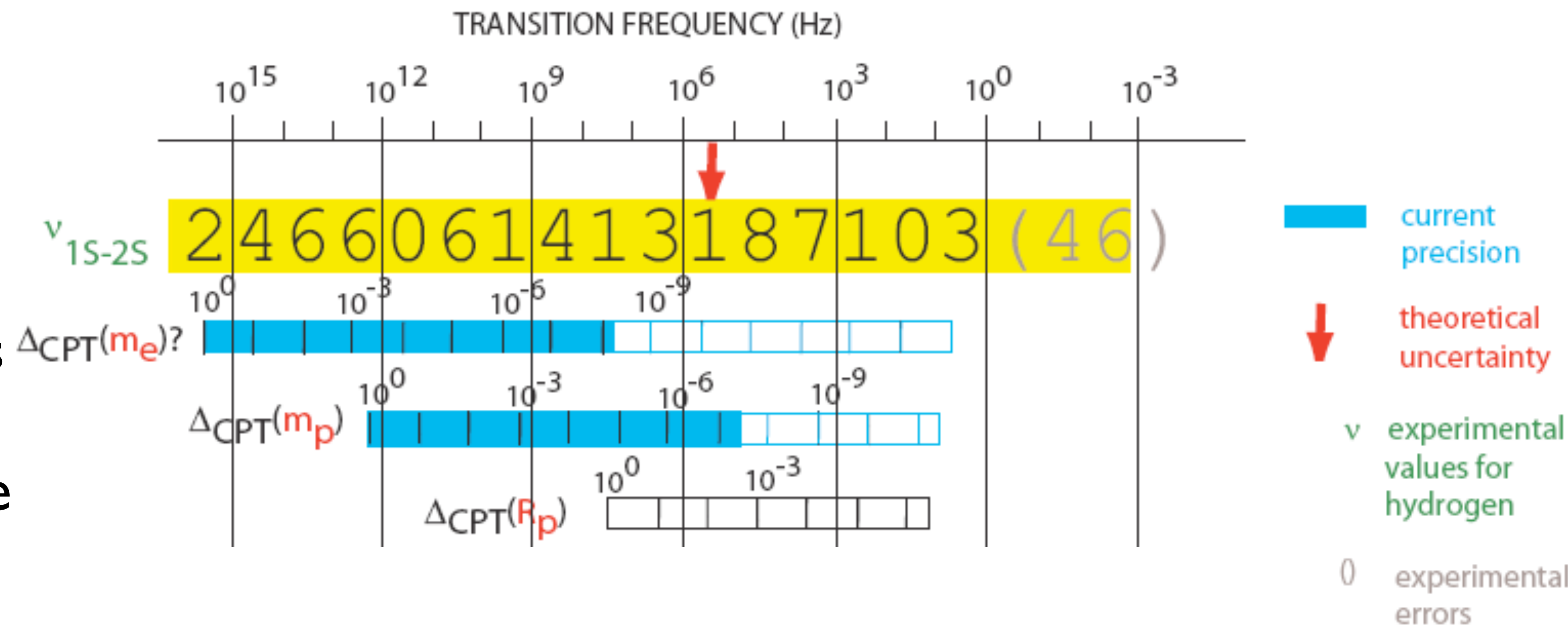




Ground state
hyperfine splitting
f = 1.4 GHz
$\Delta f/f=10^{-12}$

Precision Spectroscopy of Hydrogen and CPT

- Sensitivities
- 1S-2S
  - Electron mass
  - Proton mass
  - proton charge



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Precision Spectroscopy of Hydrogen and CPT

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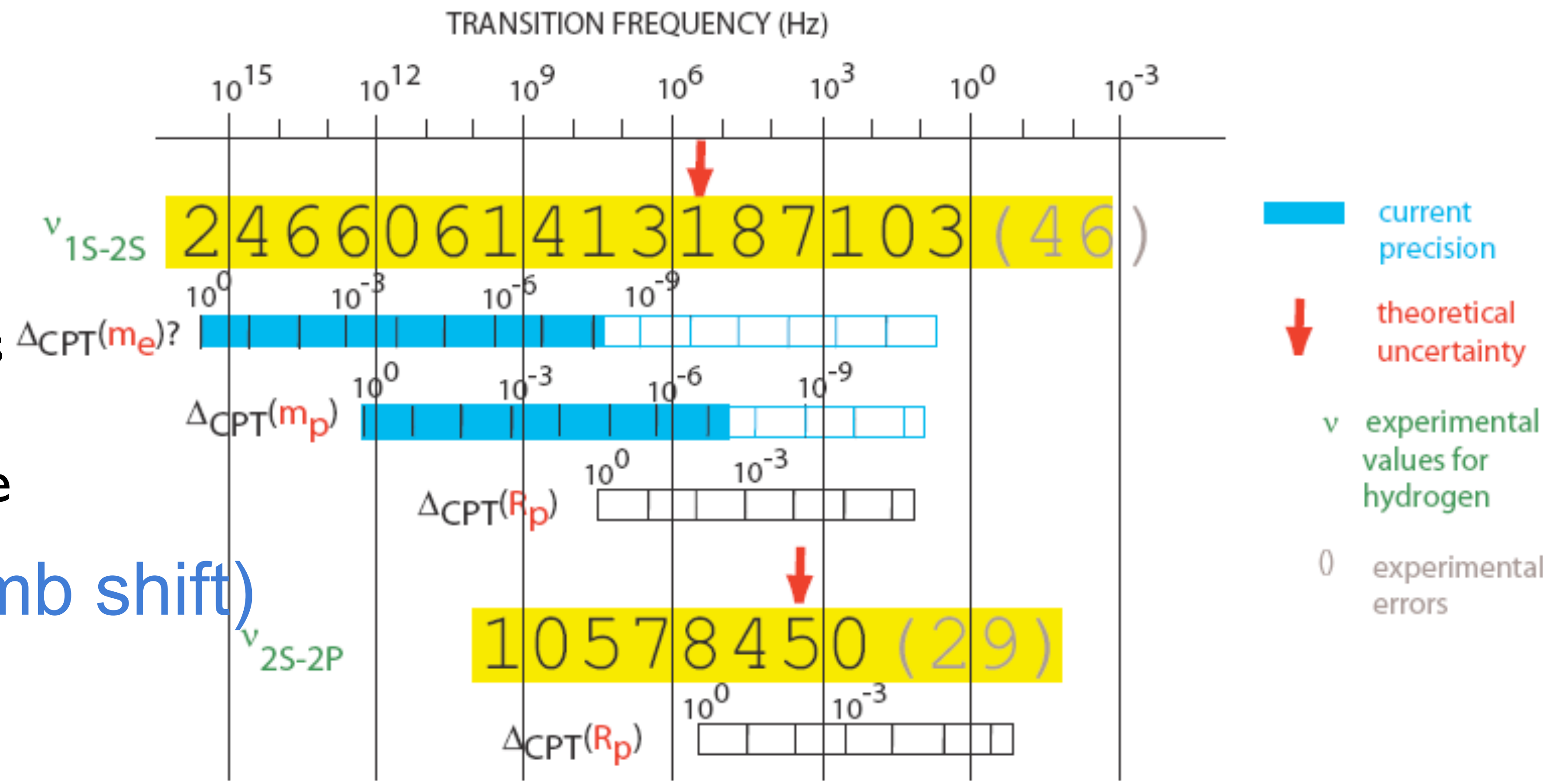
- 2S-2P (Lamb shift)
  - R_p



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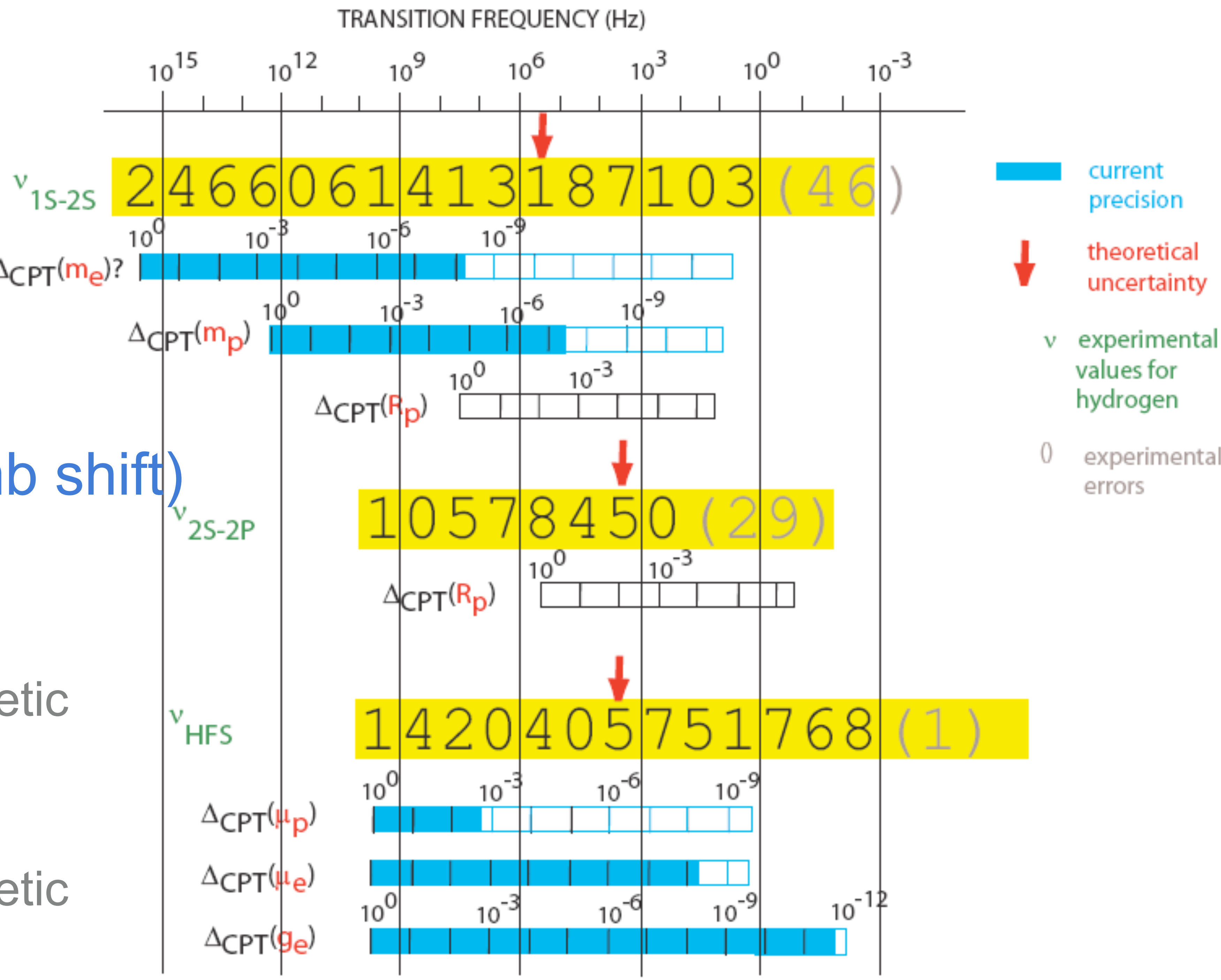
  - Proton magnetic moment μ_p
  - μ_e
  - Proton magnetic radius R_M
- Theory
  - R_p and R_M



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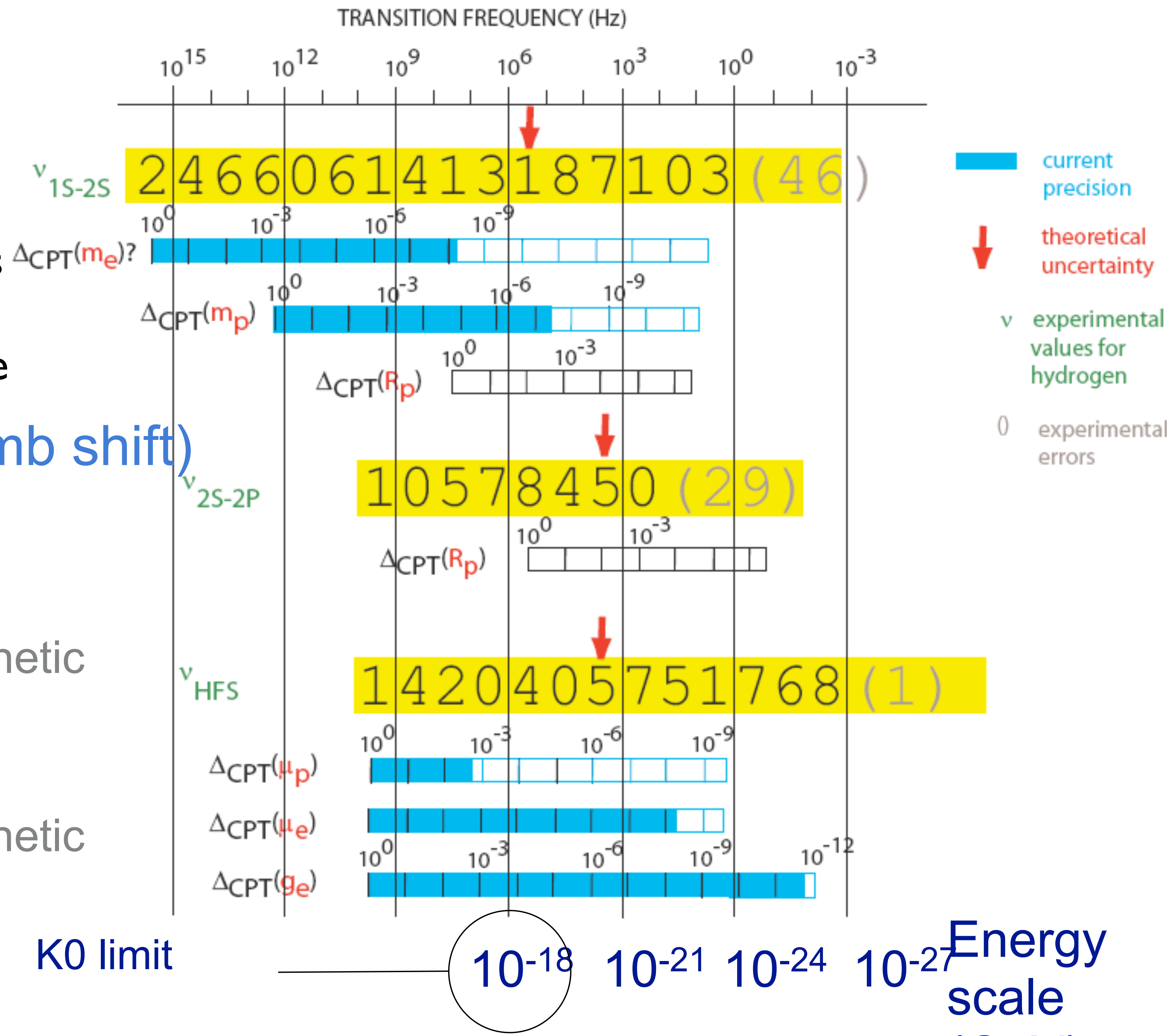
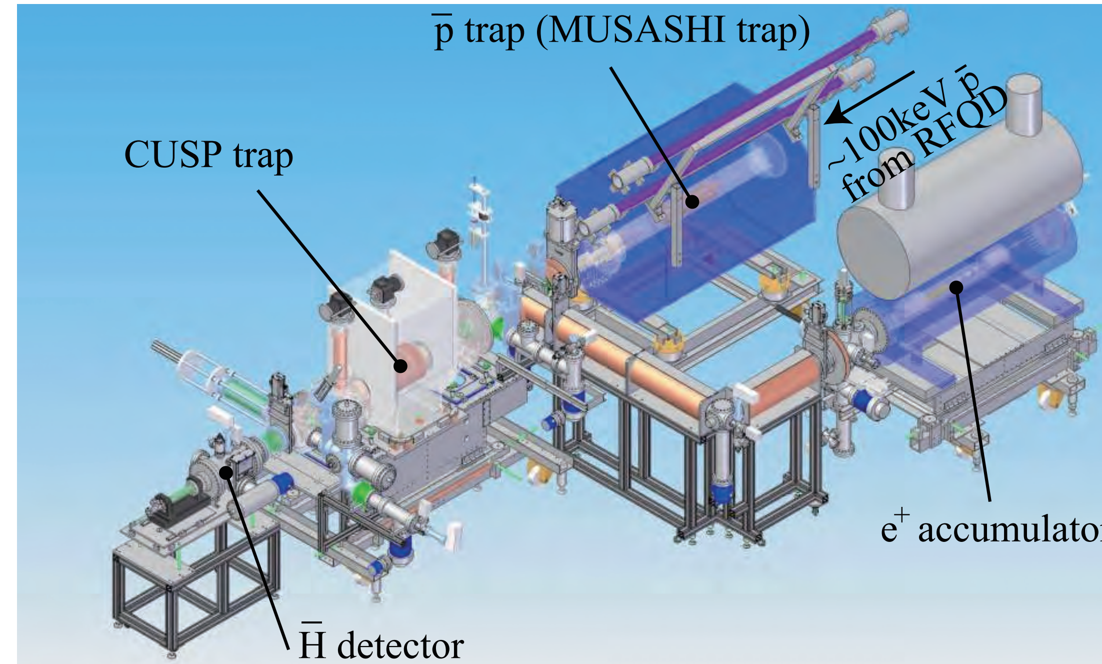
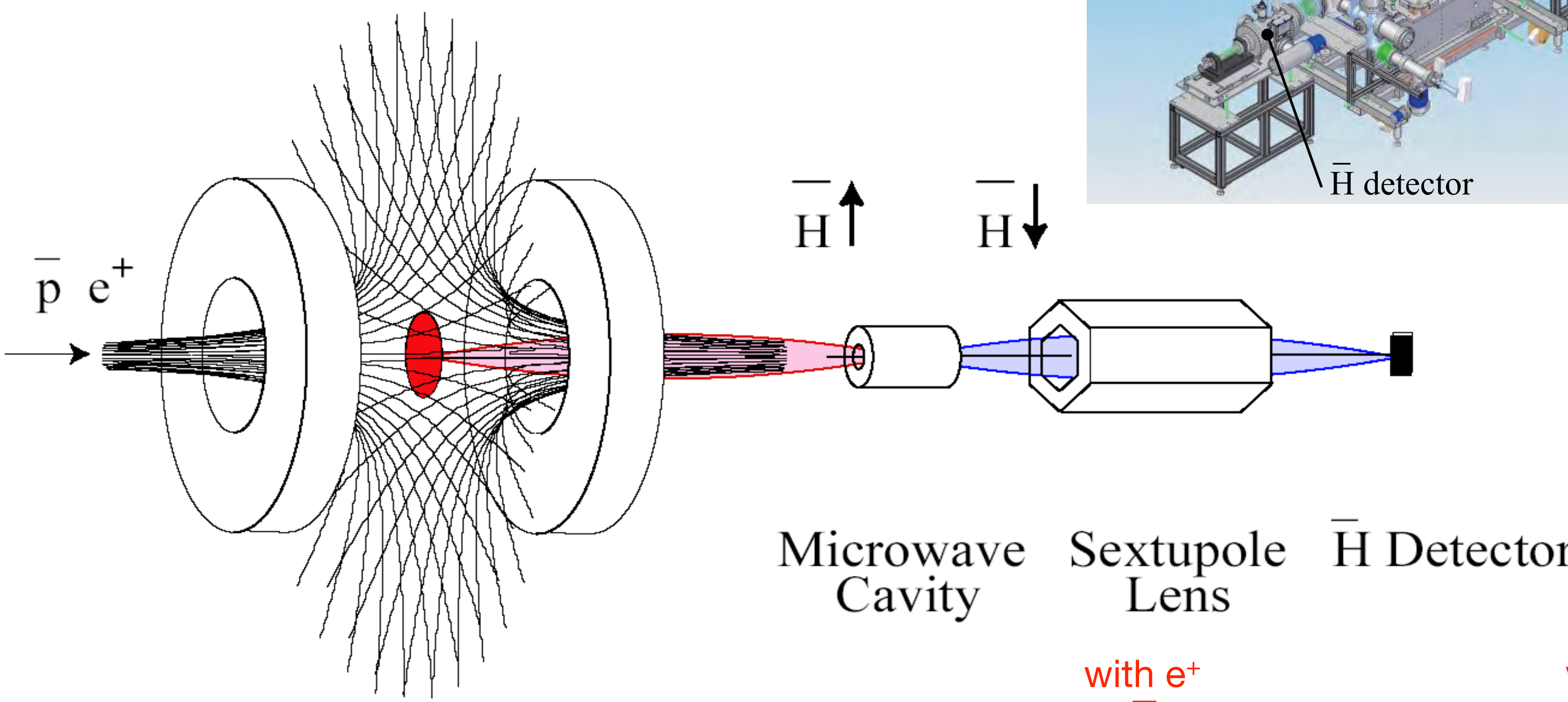


New idea: $\bar{H}$ Formation in a "cusp" trap

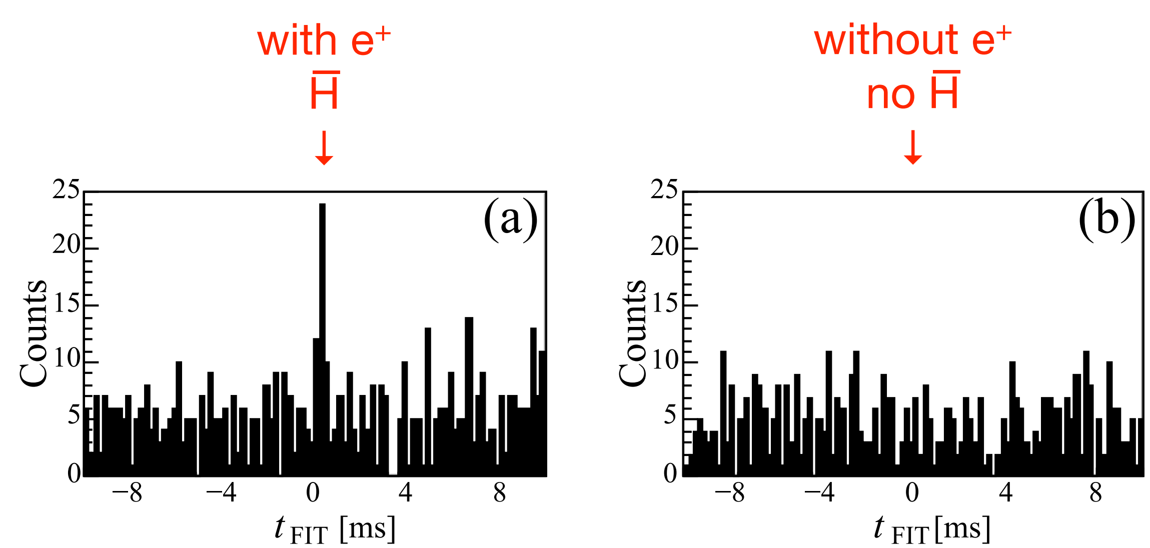
- First antihydrogen production in 2010
  - expectation: polarized beam





Y. Yamazaki,
A. Mohri
RIKEN/Japan

Y. Enomoto et al.
Phys. Rev. Lett 243401, 2010



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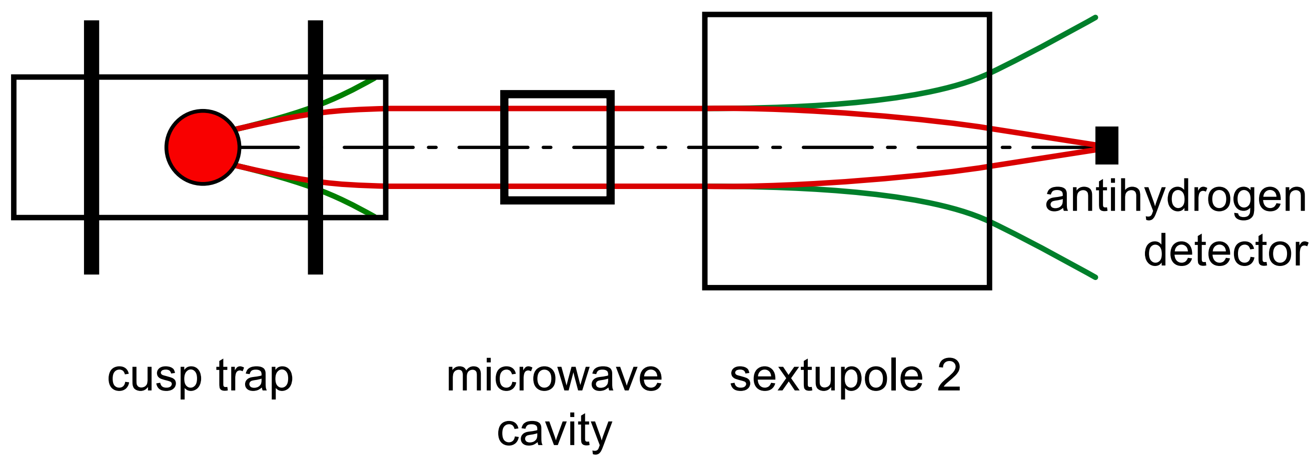
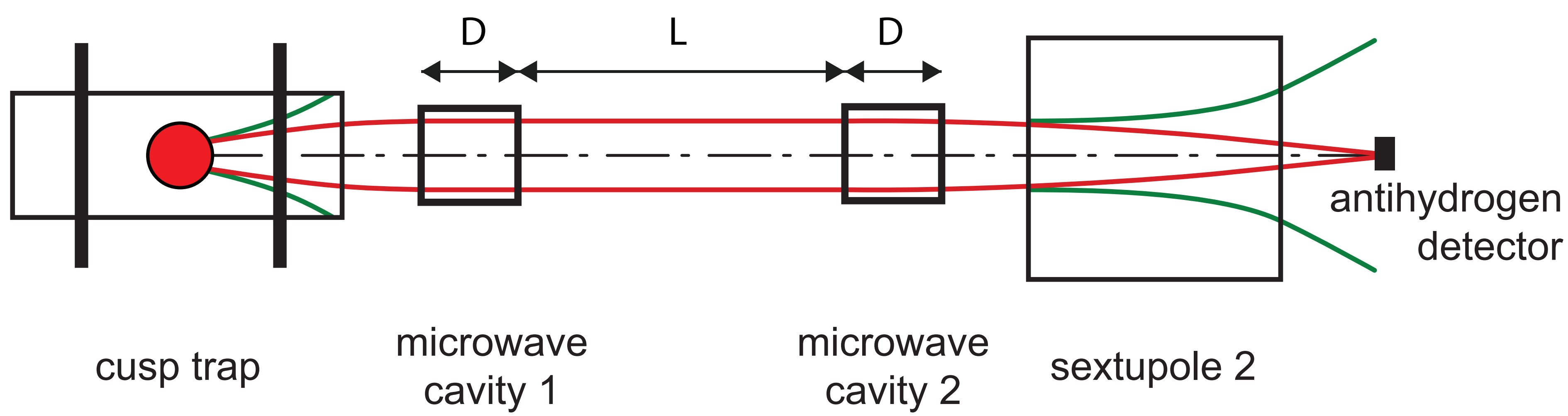
Experiments

- Ongoing: Rabi method



$\Delta\nu/\nu \sim 10^{-7}$

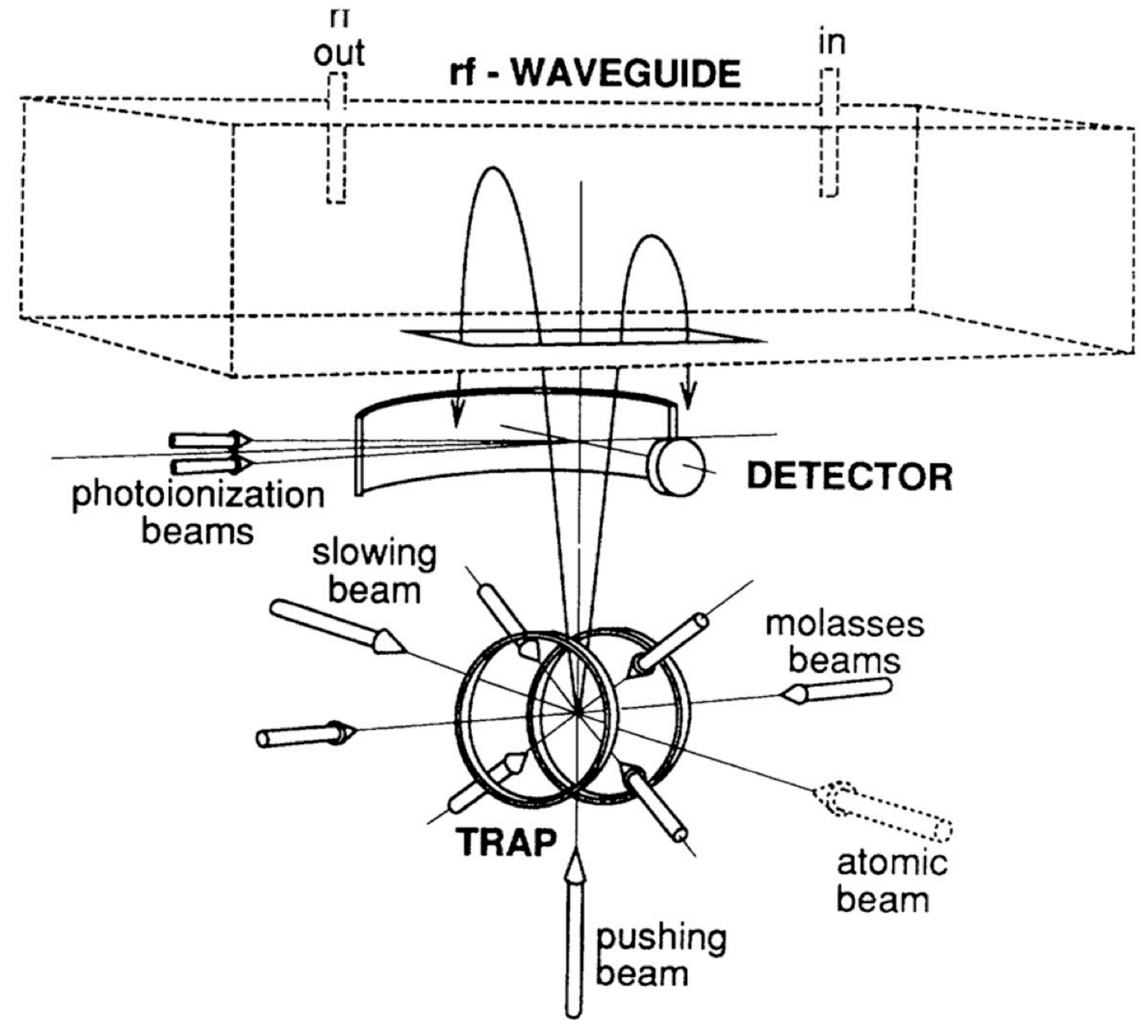
- Phase 2: Ramsey separated oscillatory fields



Linewidth reduced by D/L

Future experiments

- Phase 3: trapped Hbar
  - Hyperfine spectroscopy in an atomic fountain of antihydrogen



M. Kasevich, E. Riis, S. Chu, R. DeVoe,
PRL 63, 612–615 (1989)

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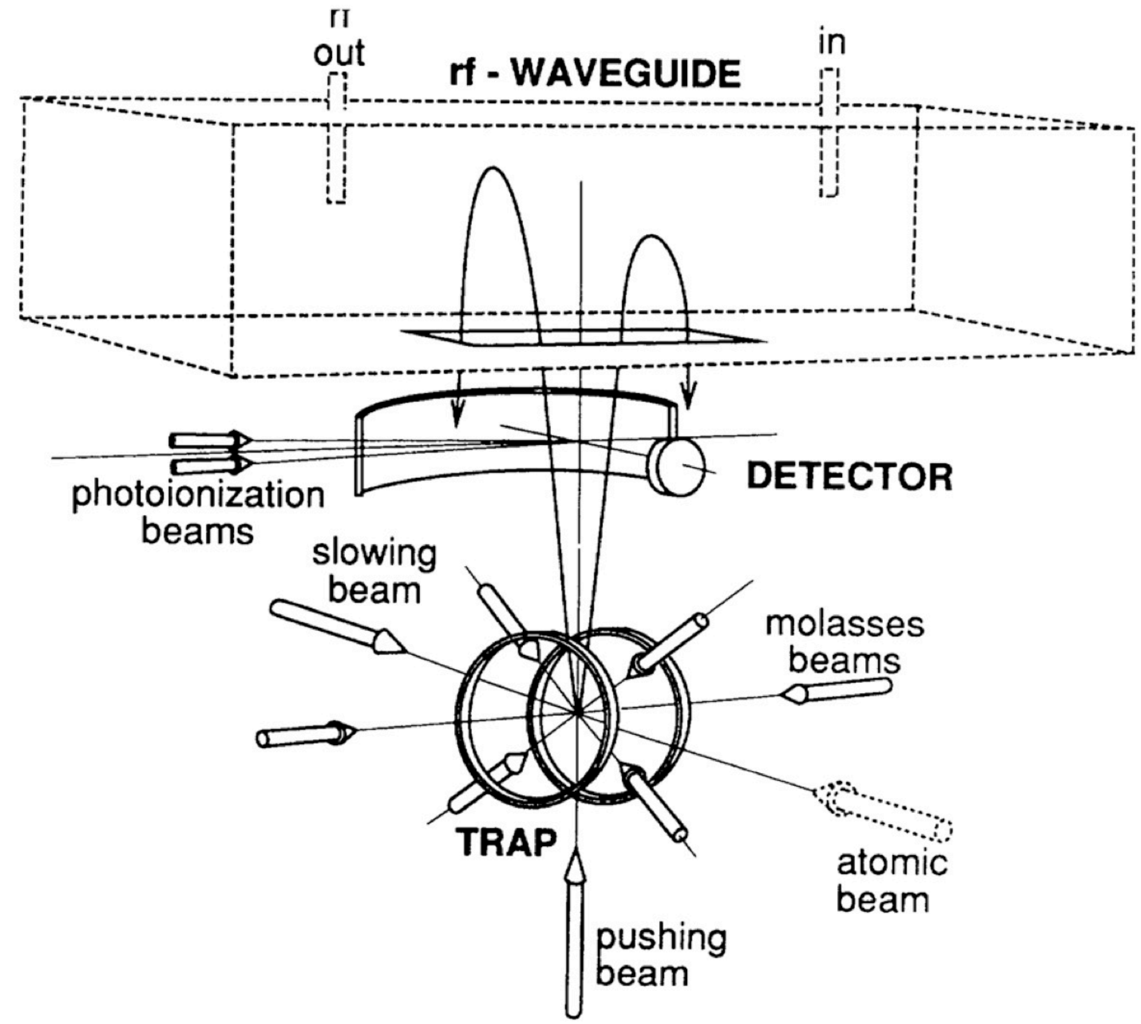

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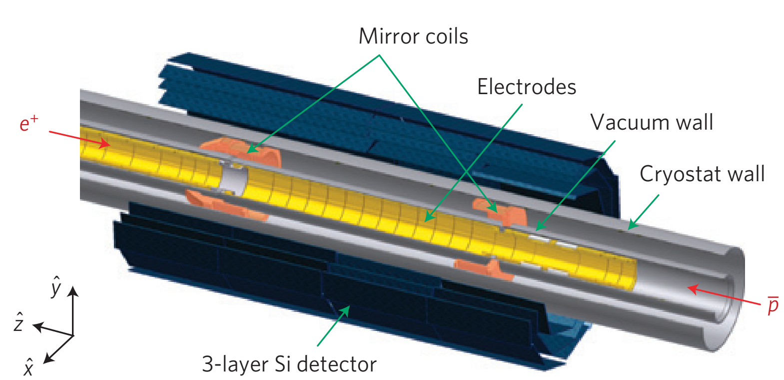
nature physics | ARTICLES
PUBLISHED ONLINE: 5 JUNE 2011 | DOI: 10.1038/NPHYS2025

Confinement of antihydrogen for 1,000 seconds

The ALPHA Collaboration*



ALPHA collaboration
G. B. Andresen et al.
Nature Physics, 7, 1–7 (2011)

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Summary and Outlook

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Summary and Outlook

- Low energy antiprotons offer exciting possibilities for a variety of fields
  - Fundamental symmetries, gravitation, nuclear & atomic physics

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  - determine mass, charge, magnetic moment of the antiproton

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  - Long-term high-precision experiments need
    - Time, Care and Particles

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- More low-energy antiprotons needed
  - ELENA upgrade at CERN (recently approved, start 2014?)
  - FLAIR at FAIR (next decade)