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PI: Prof. Dr. Eberhard Widmann
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Measuring the Ground State Hyperfine Splitting of Antihydrogen

B. Kolbinger[1], C. Amsler[1], A. Capon[1], M. Diermaier[1], P. Dupré[2], M. Fleck[1], C. Kaga[3], T. Kobayashi[4], M. Leali[5], E. Lodi-Rizzini[5], V. Mäckel[1], C. Malbrunot[1,6], V. Mascagna[5], O. Massiczek[1], T. Matsudate[4], Y. Nagata[2,7], B. Radics[2,*], C. Sauerzopf[1], M.C. Simon[1], M.Tajima[4], H.A. Torii[4], J. Zmeskal[1], H. Breuker[6], H. Higaki[3], Y. Kanai[2], N. Kuroda[4], Y. Matsuda[4], S. Ulmer[8], L. Venturelli[5], E. Widmann[1], Y. Yamazaki[2,4]

[1] *Stefan Meyer Institute for Subatomic Physics,* [2] *Atomic Physics Laboratory, RIKEN,* [3] *Graduate School of Advanced Science of Matter, Hiroshima University,*
[4] *Graduate School of Arts and Sciences, University of Tokyo,* [5] *Universit di Brescia & Instituto Nazionale di Fisica Nucleare,* [6] *CERN,*
[7] *Department of Applied Physics, Tokyo University of Agriculture and Technology,* [8] *Ulmer Initiative Research Unit, RIKEN,*
** present address: ETH Zürich, Institute for Particle Physics*

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Outline

Motivation

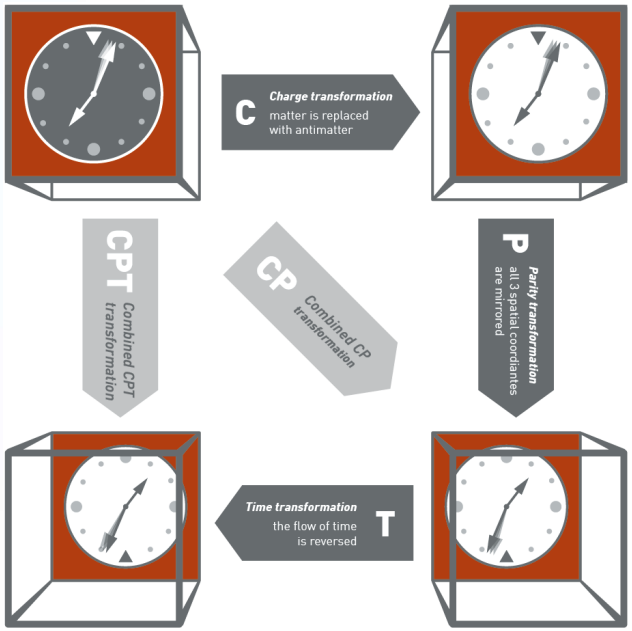
Experiment

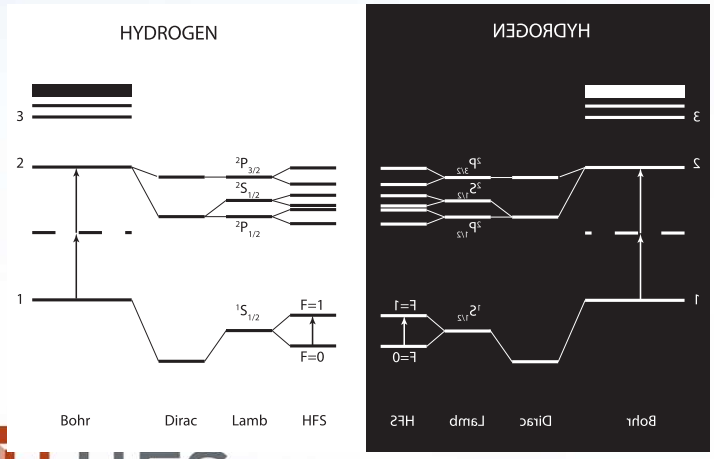
Antihydrogen detector
- Tracking detector
- Beamtime 2016

Summary and Outlook

Motivation – testing CPT

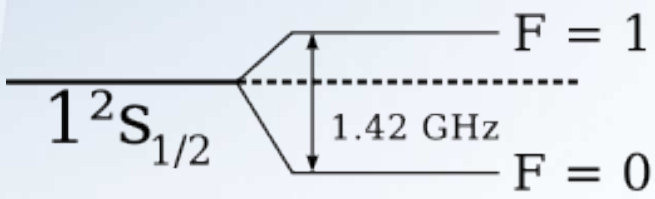
- **CPT theorem:** CPT (**C**harge, **P**arity, **T**ime) is exact for relativistic local QFT
- predicts: particles and anti-particles have identical or sign-opposite properties
- CPT theorem $\rightarrow \bar{\mathrm{H}}$ and H **same spectrum**





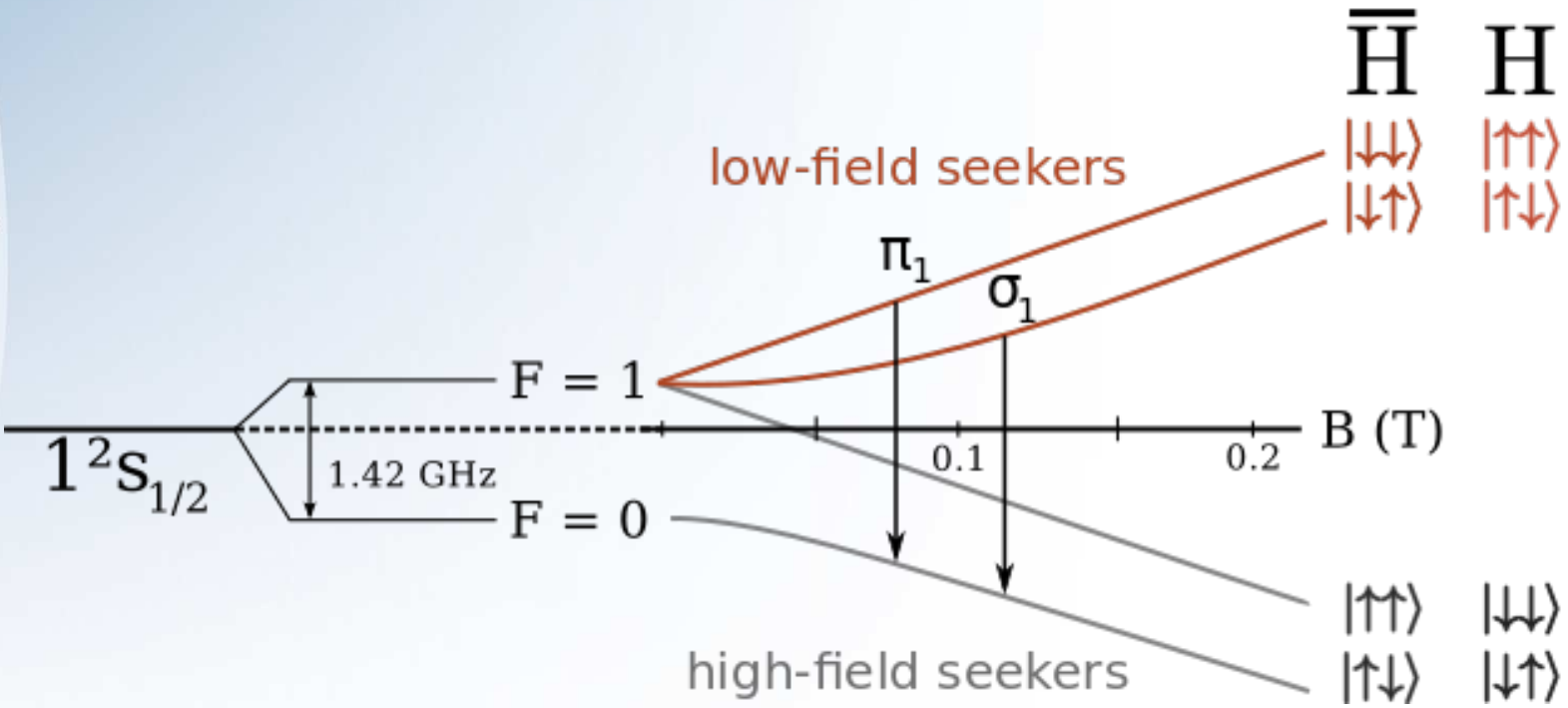
- hyperfine transition frequency of H – one of most accurately measured quantities
- **compare GS HFS** $\rightarrow$ yields one of the most sensitive experimental CPT tests
- goal: $\Delta\nu/\nu = 10^{-7}$

Ground state hyperfine structure of H / $\bar{H}$



- **Ground state**: singlet state: total angular momentum QN F=0 and triplet state with F=1

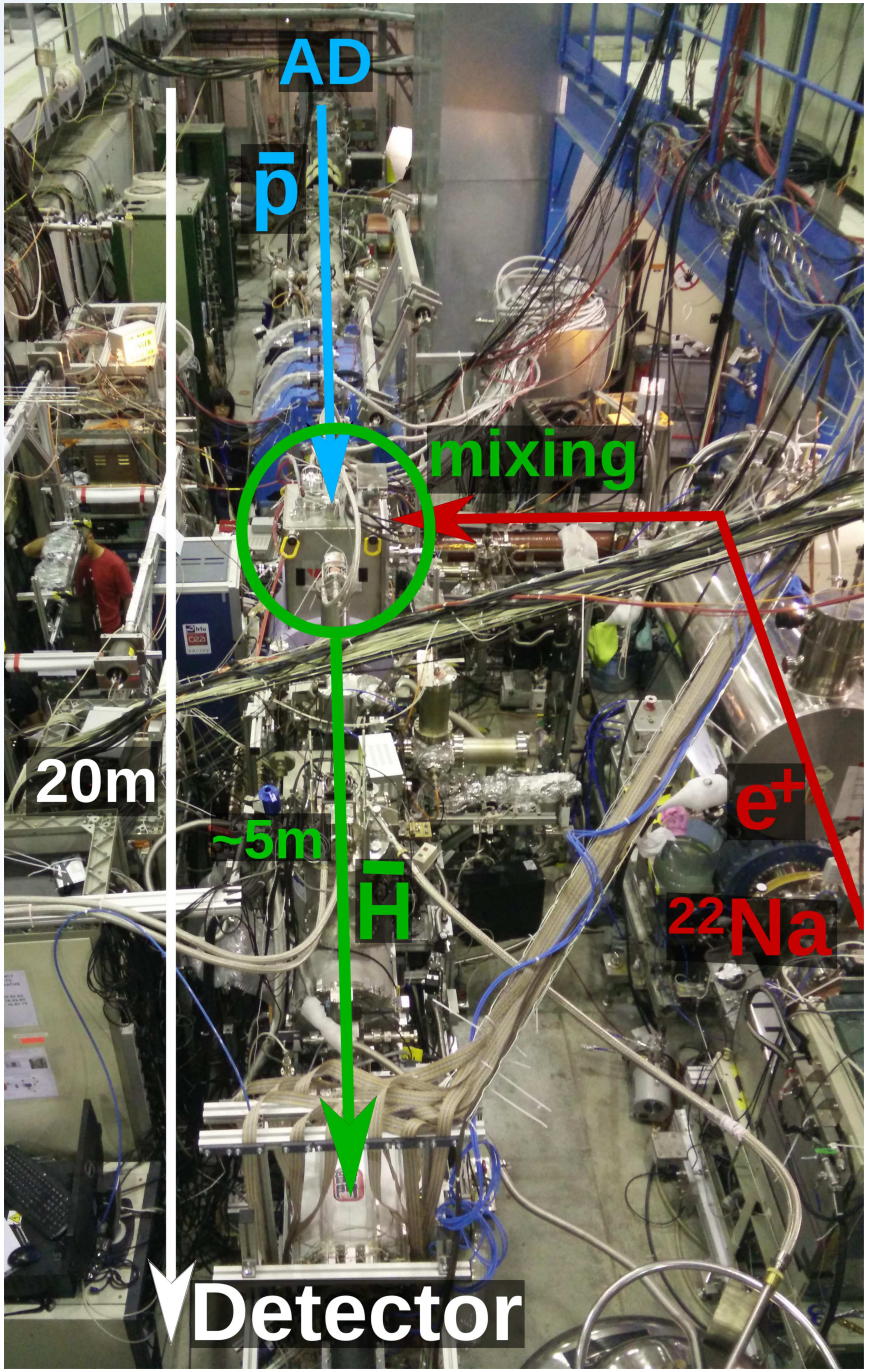
Ground state hyperfine structure of H / $\bar{H}$



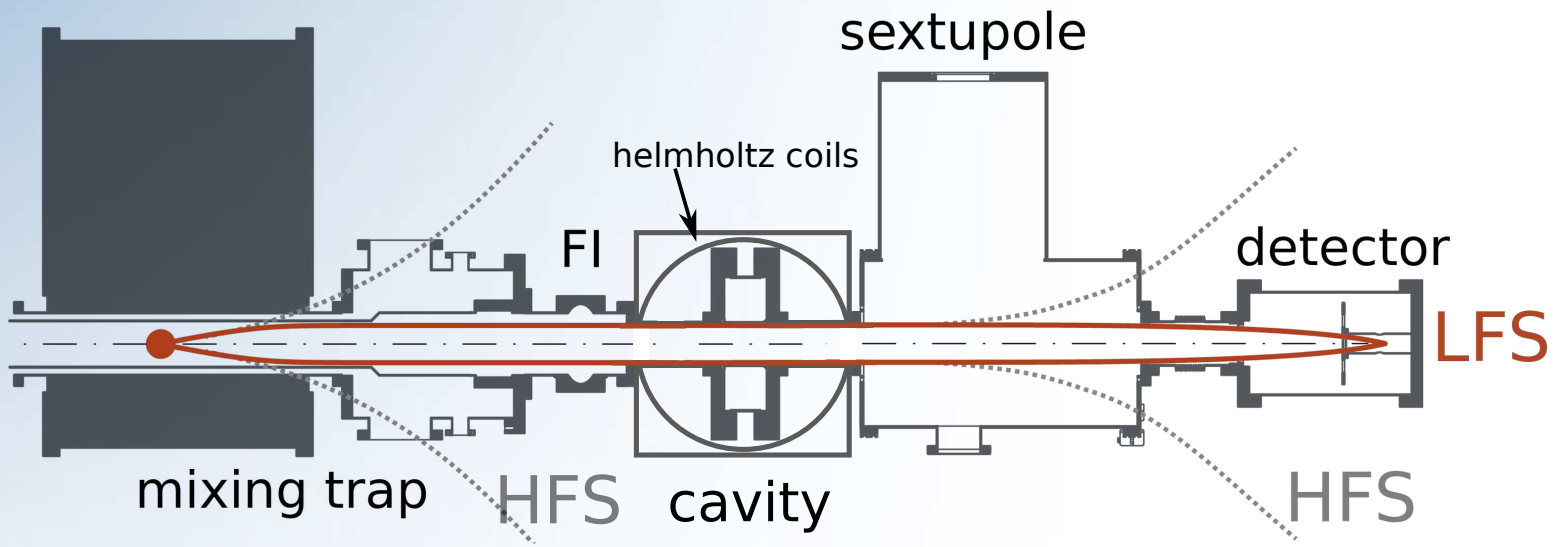
- **in static magnetic field**: Zeeman splitting
- behaviour in **inhomogeneous magnetic field**: low and high field seeking states

Overview of $\bar{H}$ HFS experiment

- slow antiprotons from CERN's Antiproton Decelerator, trapped with 115 keV
- Positrons from ^{22}Na source
- cold $\bar{H}$ is formed within CUSP trap in a mixing process (meV)
- neutral antiatoms will escape trap, enter spectroscopy beam line
- $\bar{H}$ detection



Measurement principle



- production of $\bar{H}$ in the 'CUSP' trap – polarized beam
- induction of spin-flips by microwave cavity
- sextupole analyzes spinstates
- detector counts $\bar{H}$
- frequency scan $\rightarrow$ change in count rate on resonance

Antihydrogen detector

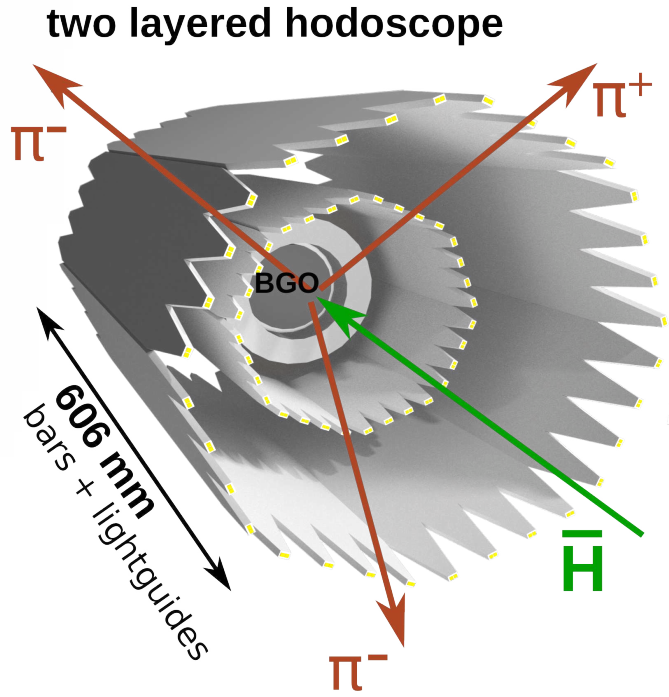
low $\bar{H}$ production rate $\rightarrow$ **requirements**: efficiently detect annihilation, background suppression

central calorimeter:

- detect antiproton annihilations
- BGO disc ($\oslash$ 9cm, 5mm thickness)
- read out by 4 MAPMTs $\rightarrow$ **energy and position information**

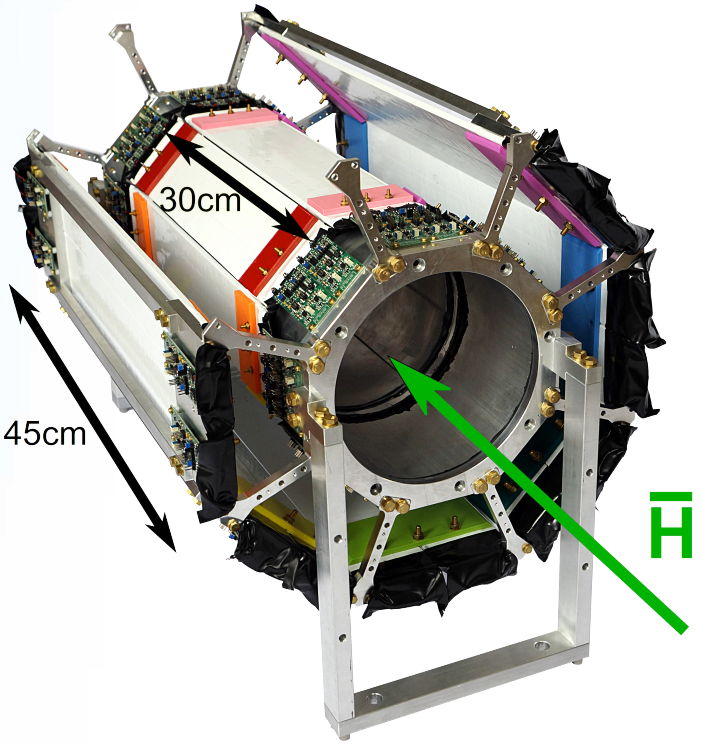
2-layered hodoscope for tracking:

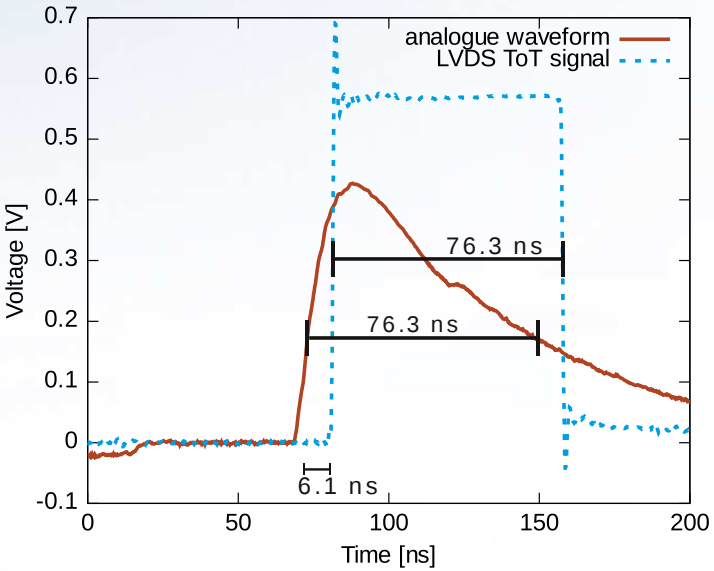
- 32 plastic scintillating bars per layer
- discriminate between background and antihydrogen signal by **tracking** secondary particles from antiproton annihilation, cosmic particles etc.

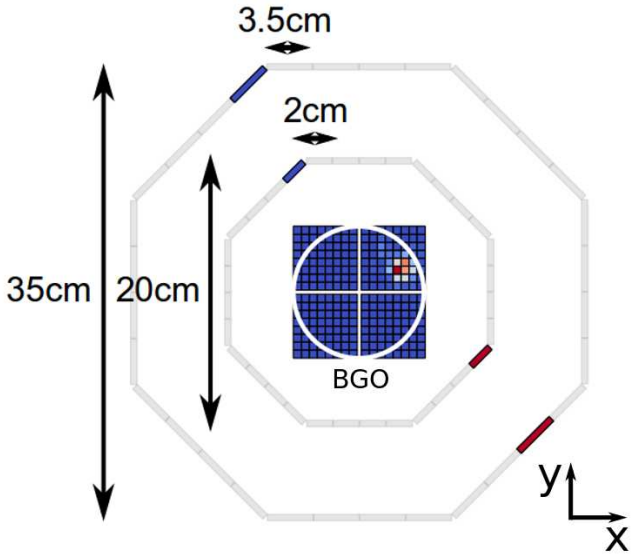


Tracking detector I

- scintillating light detection with **silicon photomultipliers** (SiPMs) on both sides of bars
- SiPMs are read out and powered by preamplifier boards: analogue and digital signal output



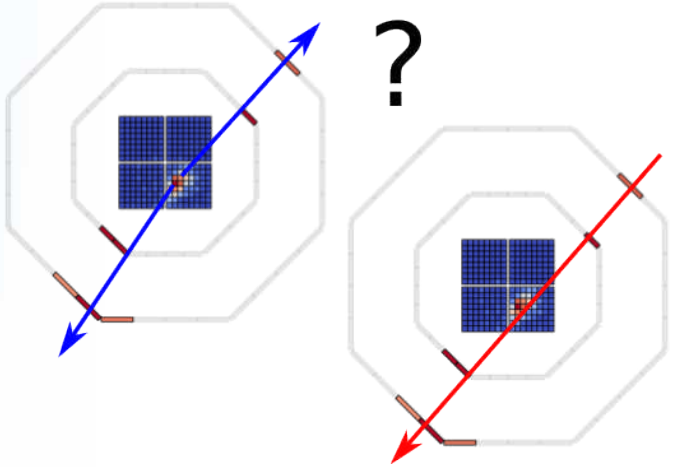




Tracking detector II

measurements in the lab with cosmics:

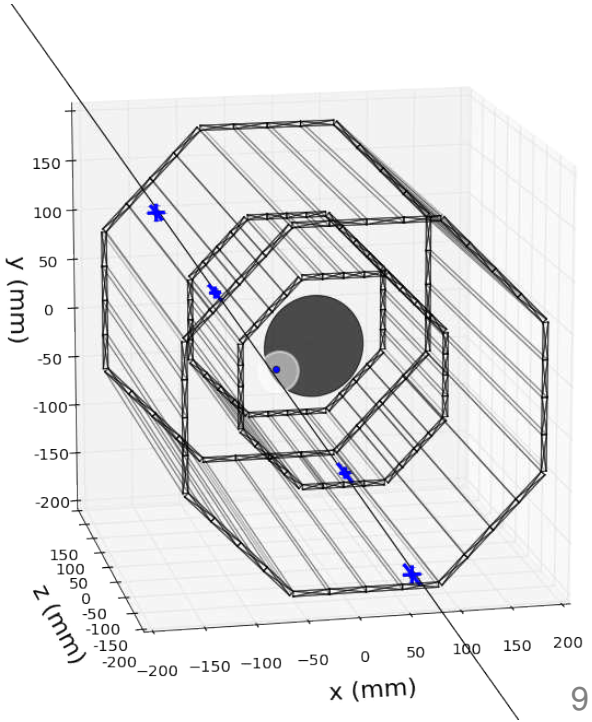
- **timing**: diameter of outer hodoscope 35 cm $\rightarrow$ ToF possible with time resolution < 600 ps, discriminate: particles from outside or inside detector!



outer: 551 $\pm$ 5 ps (FWHM)
inner: 497 $\pm$ 3 ps

- **hit position in beam direction**: from timing information of up and downstream SiPM signals

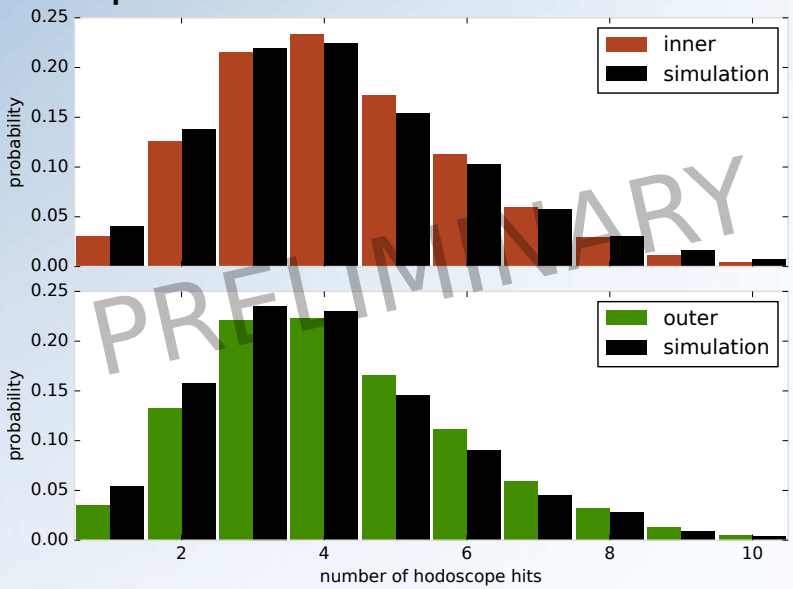
outer: 7.3 $\pm$ 0.3 cm (FWHM)
inner: 5.9 $\pm$ 0.4 cm

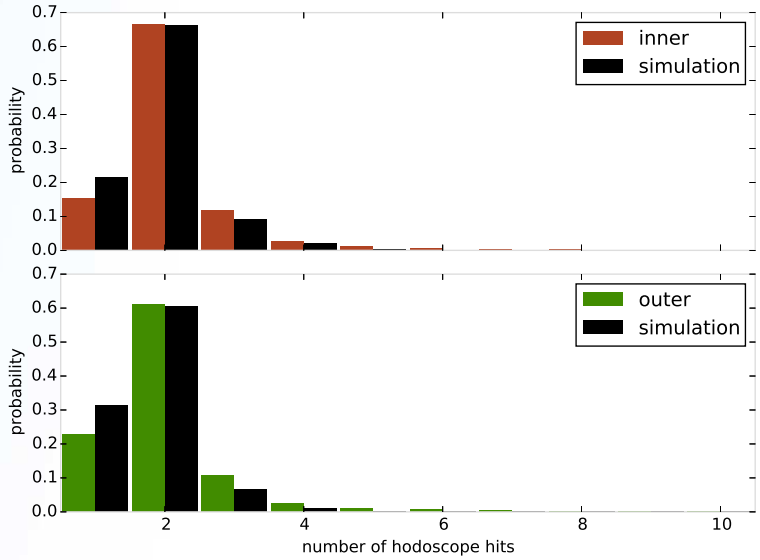


length of bars: inner: 30 cm, outer: 45 cm

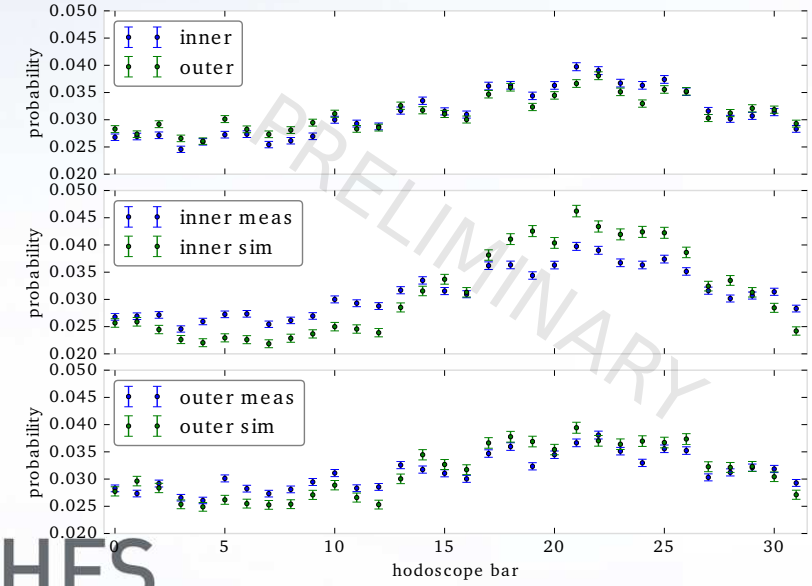
Antiprotons vs cosmics: preliminary results, beamtime 2016

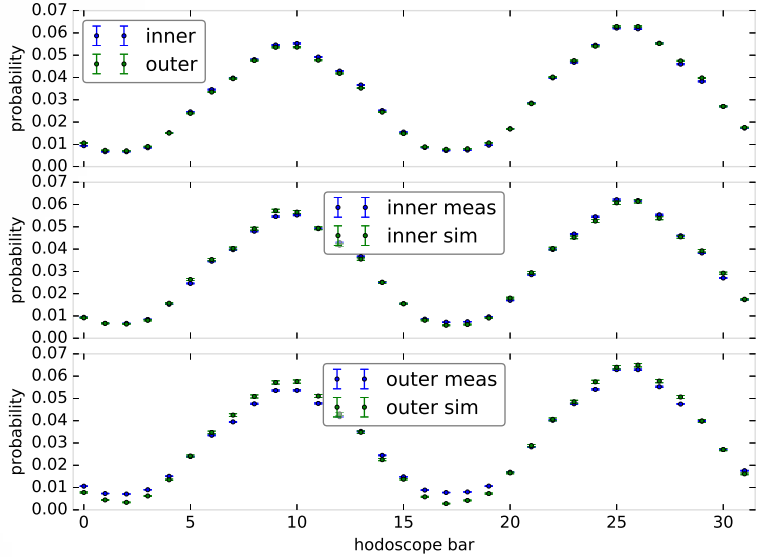
multiplicities:





angular distributions:

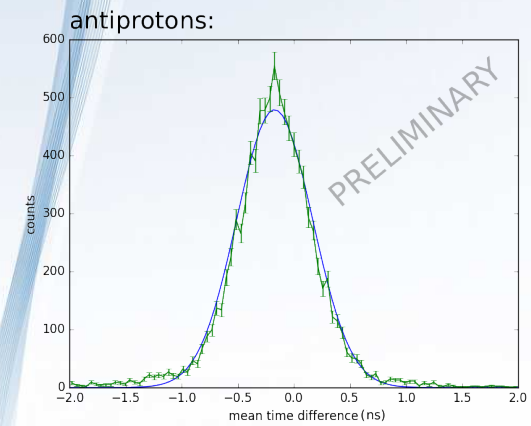


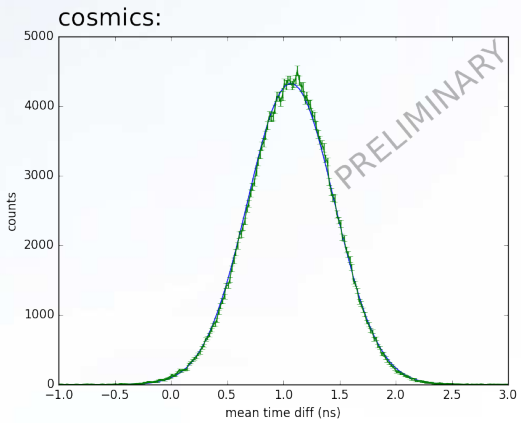


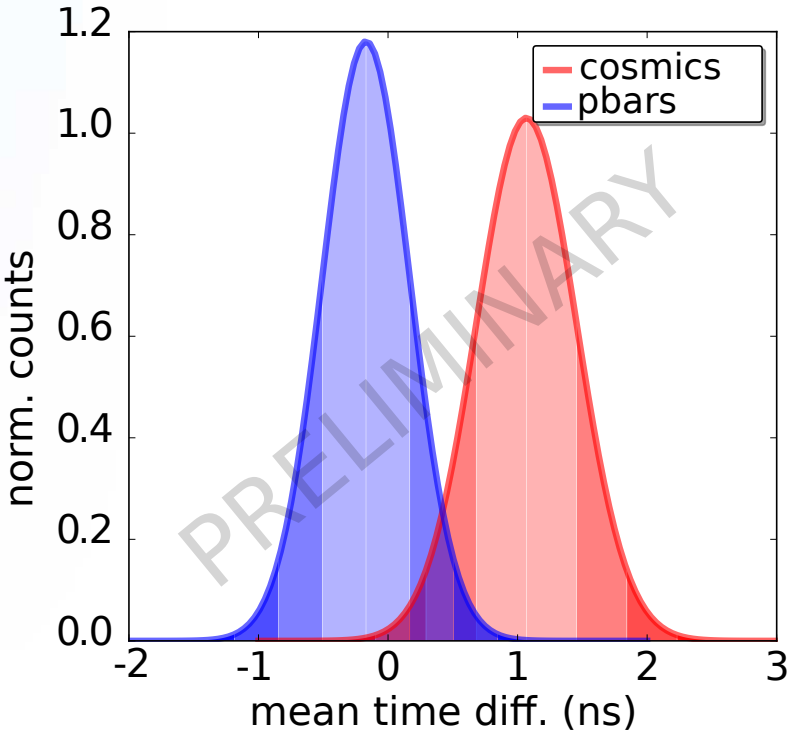
Antiprotons vs cosmics: timing, beamtime 2016

Time of flight measurements with whole detector setup, outer hodoscope:

antiprotons: FWHM $\approx$ 790 ps
cosmics: FWHM $\approx$ 911 ps



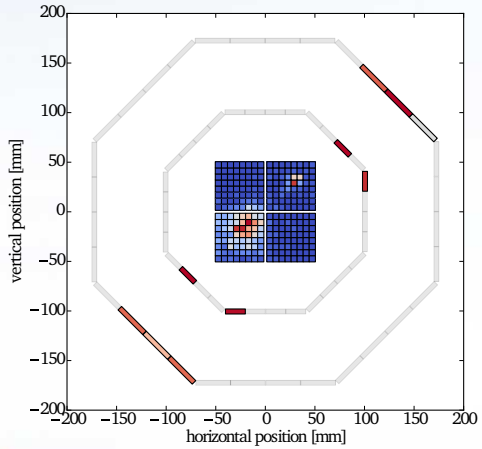


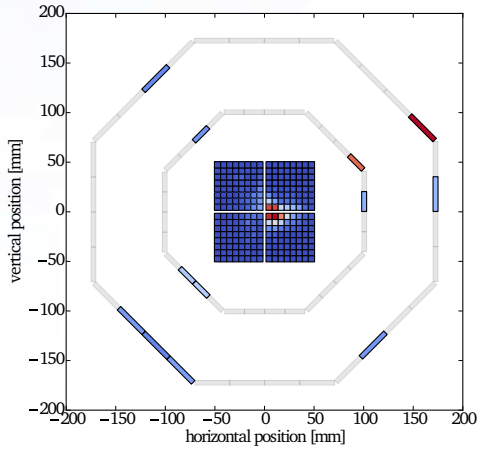


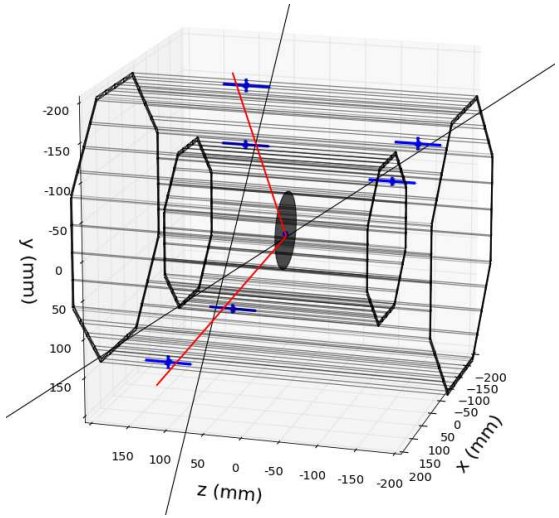
slightly different from laboratory results: likely due to differences in the data acquisition system, under investigation

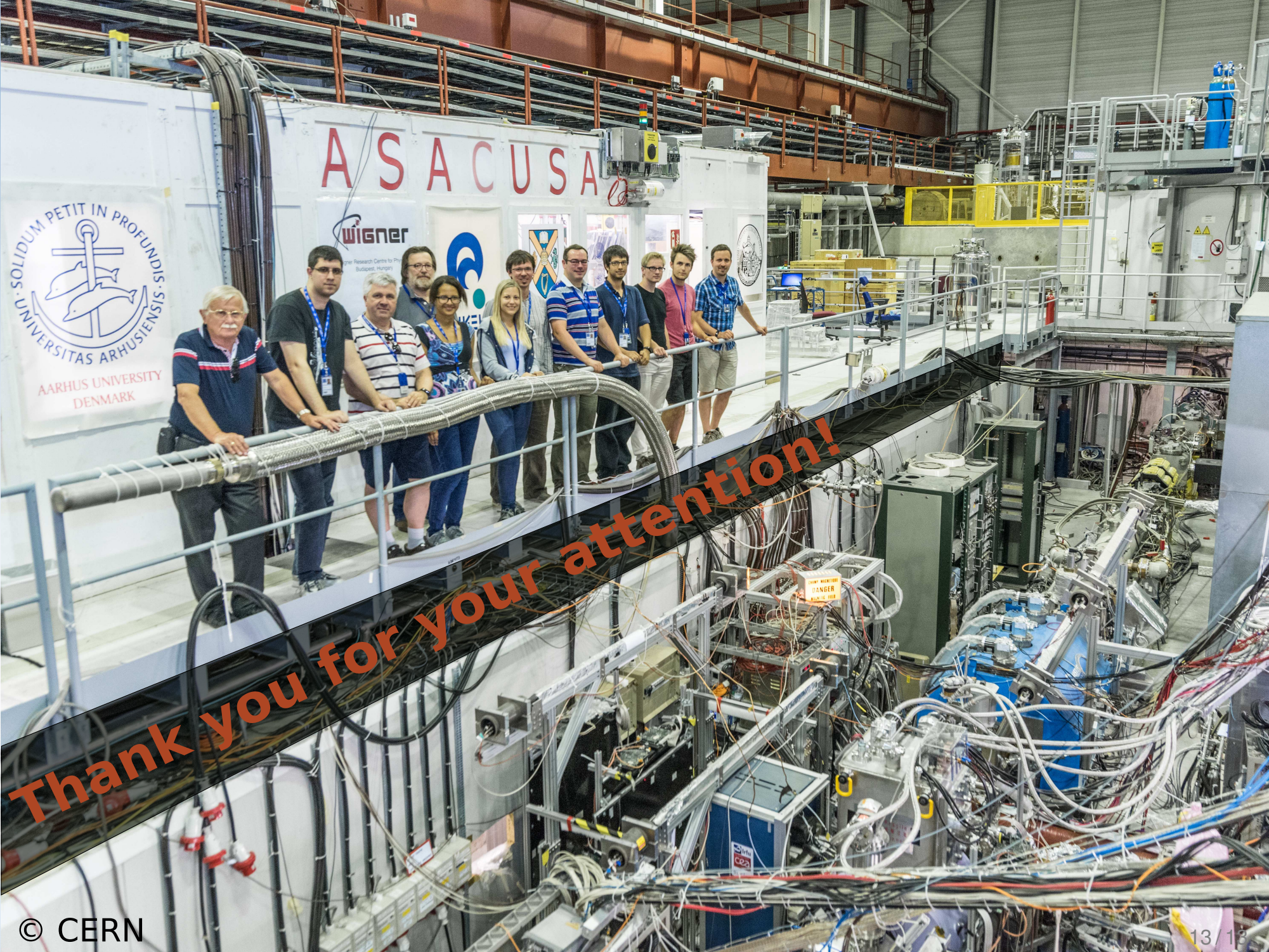
Summary and Outlook

- low antihydrogen countrate $\rightarrow$ essential to learn about the signal, antiproton extractions during beamtime 2016
- time resolution good enough for ToF
- detailed analysis in progress:
  - tracking
  - pattern recognition techniques and multivariate algorithms
- possible upgrade to improve position resolution in beam direction?





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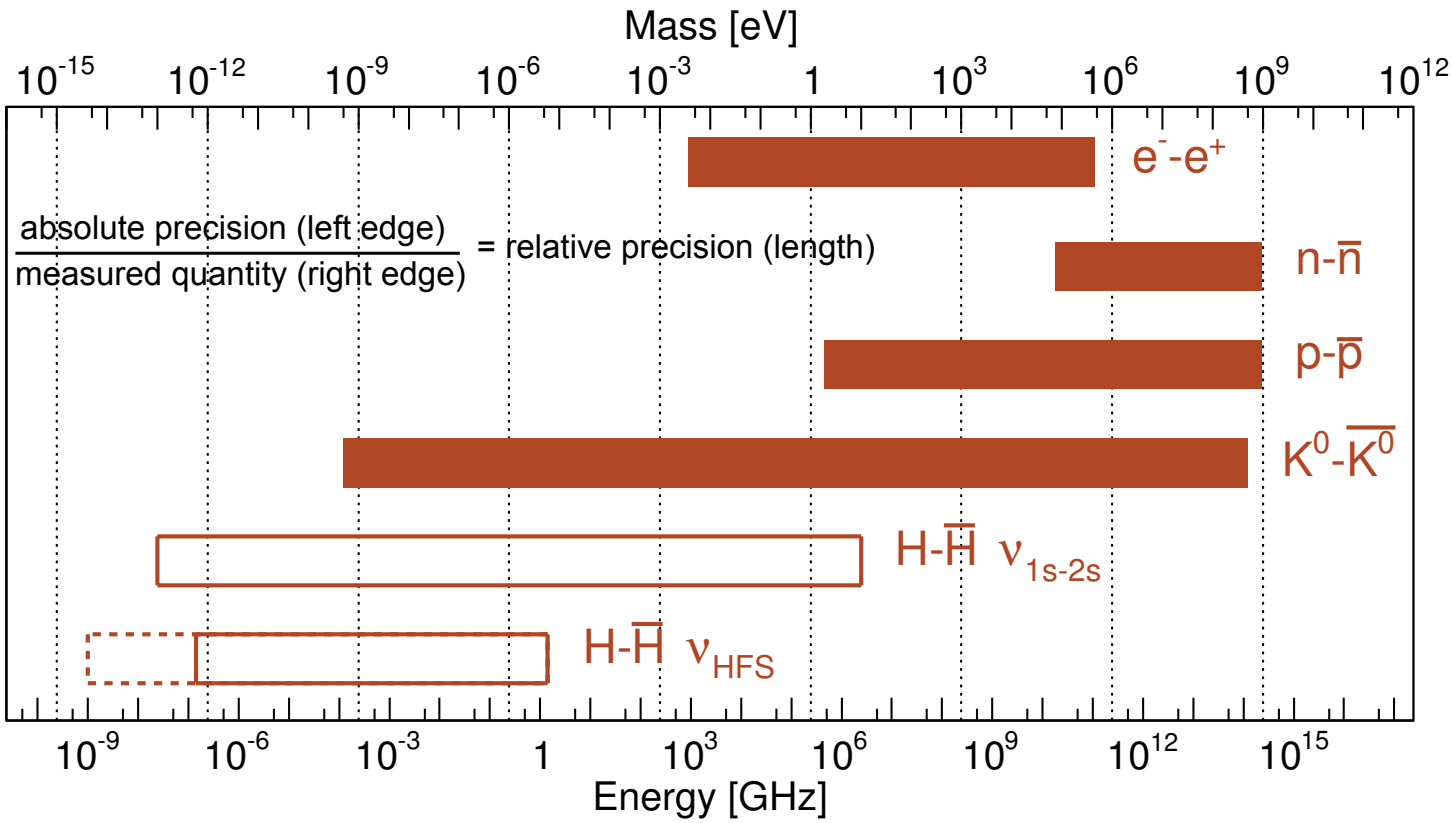
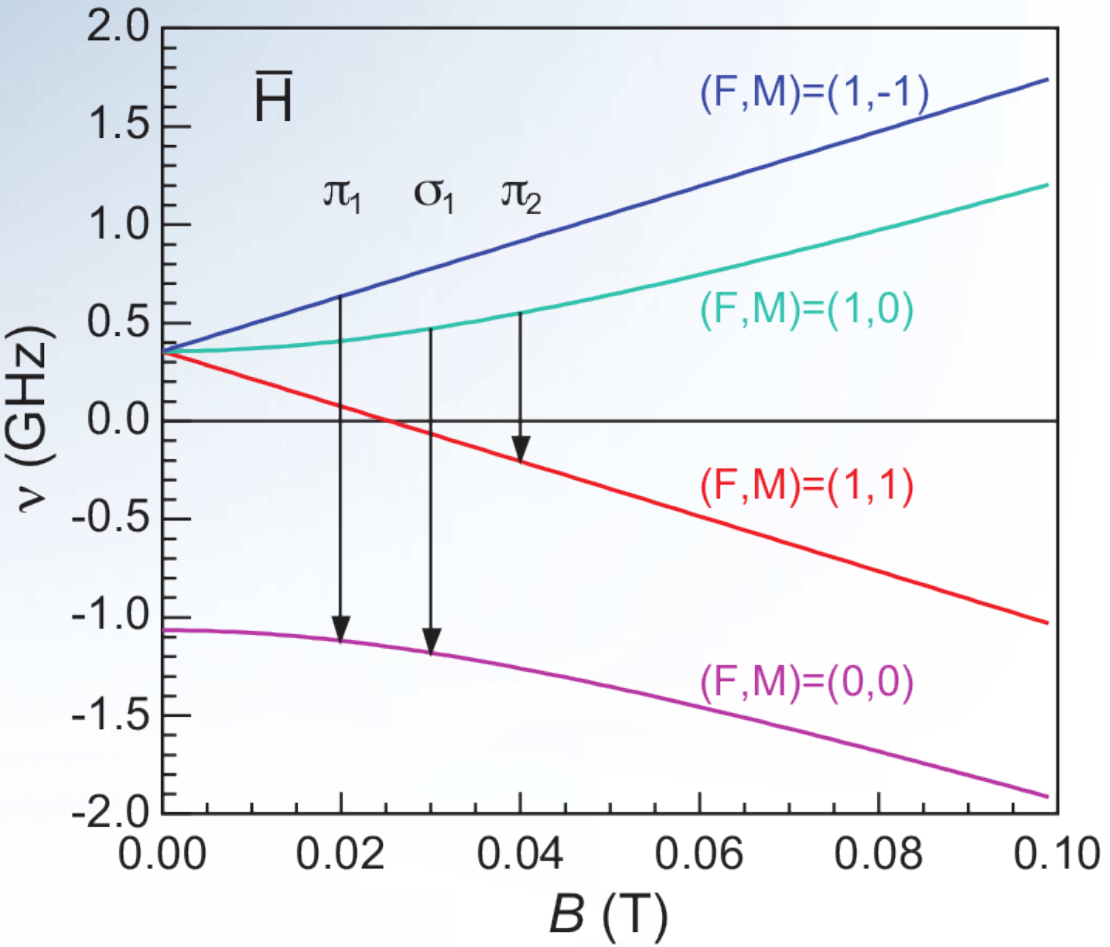
Thank you for your attention!

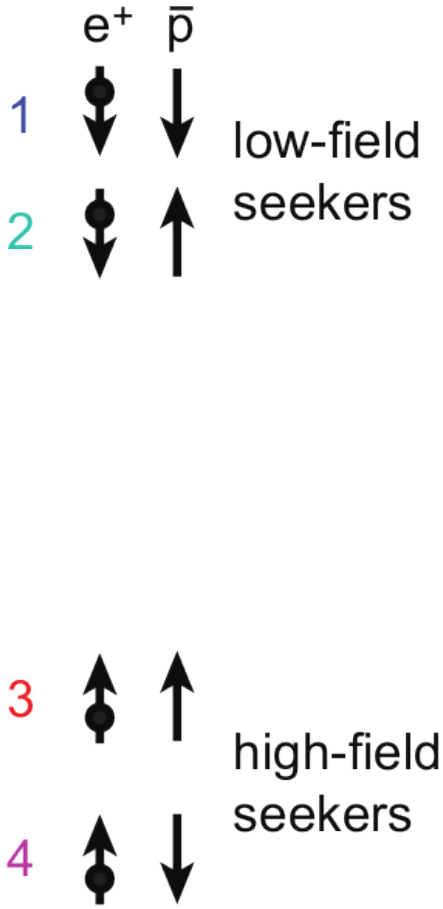
Back up

CPT testing experiments

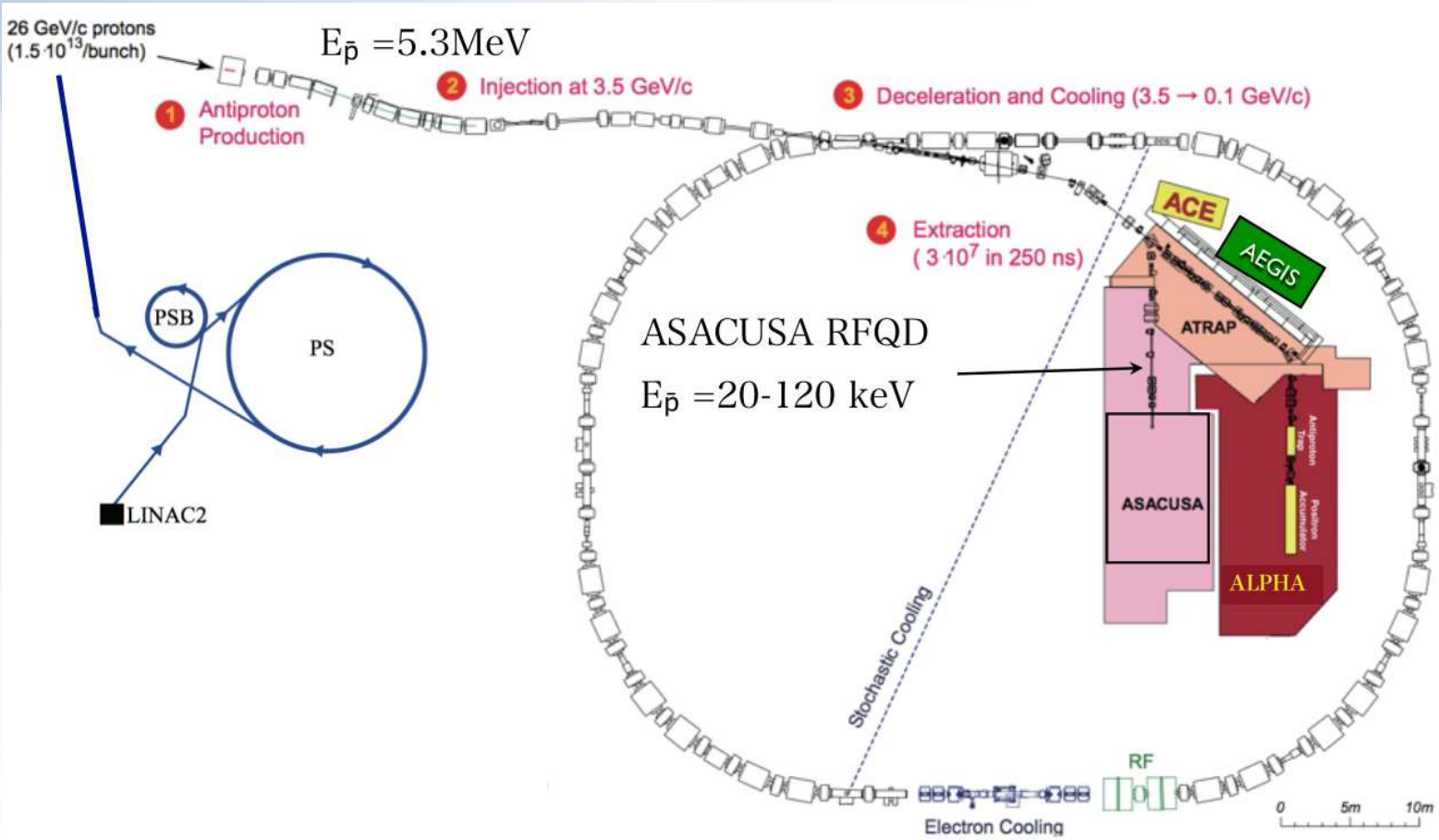


Breit-Rabi diagram

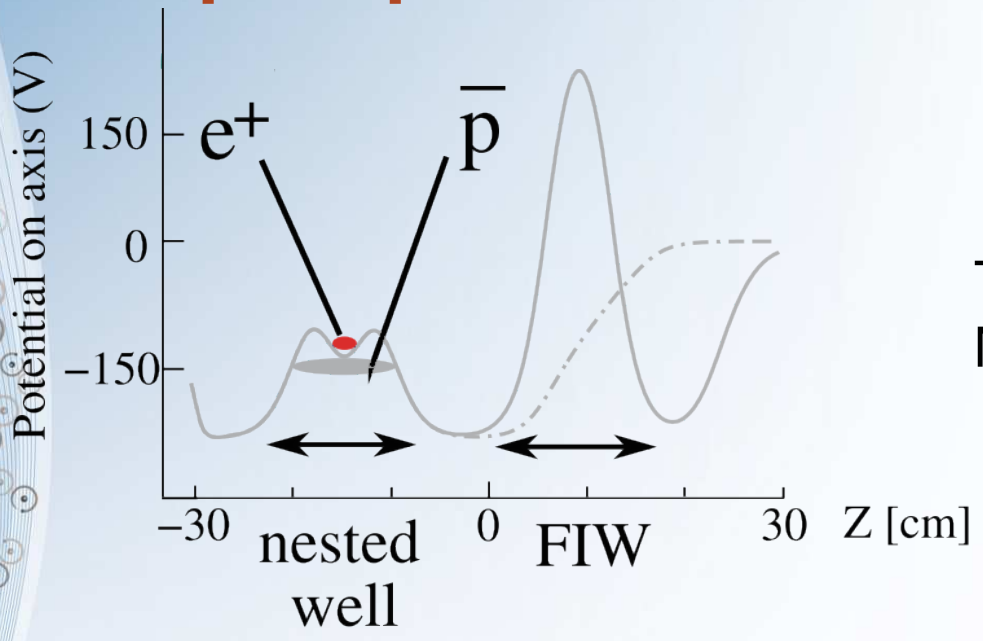




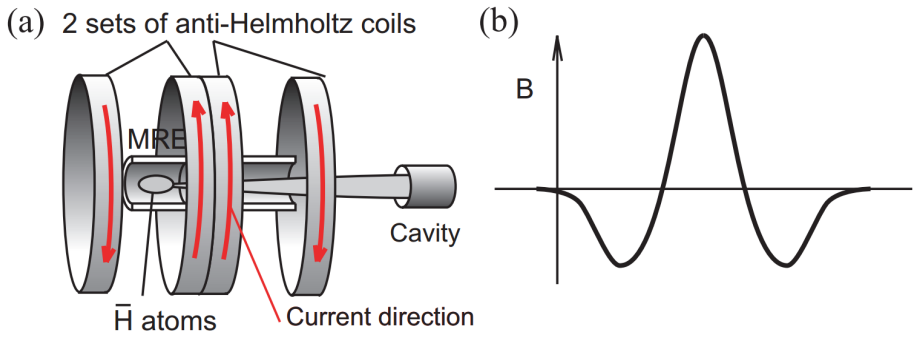
Antiproton Decelerator



Cusp Trap



Top: electric Potential of Trap MRE

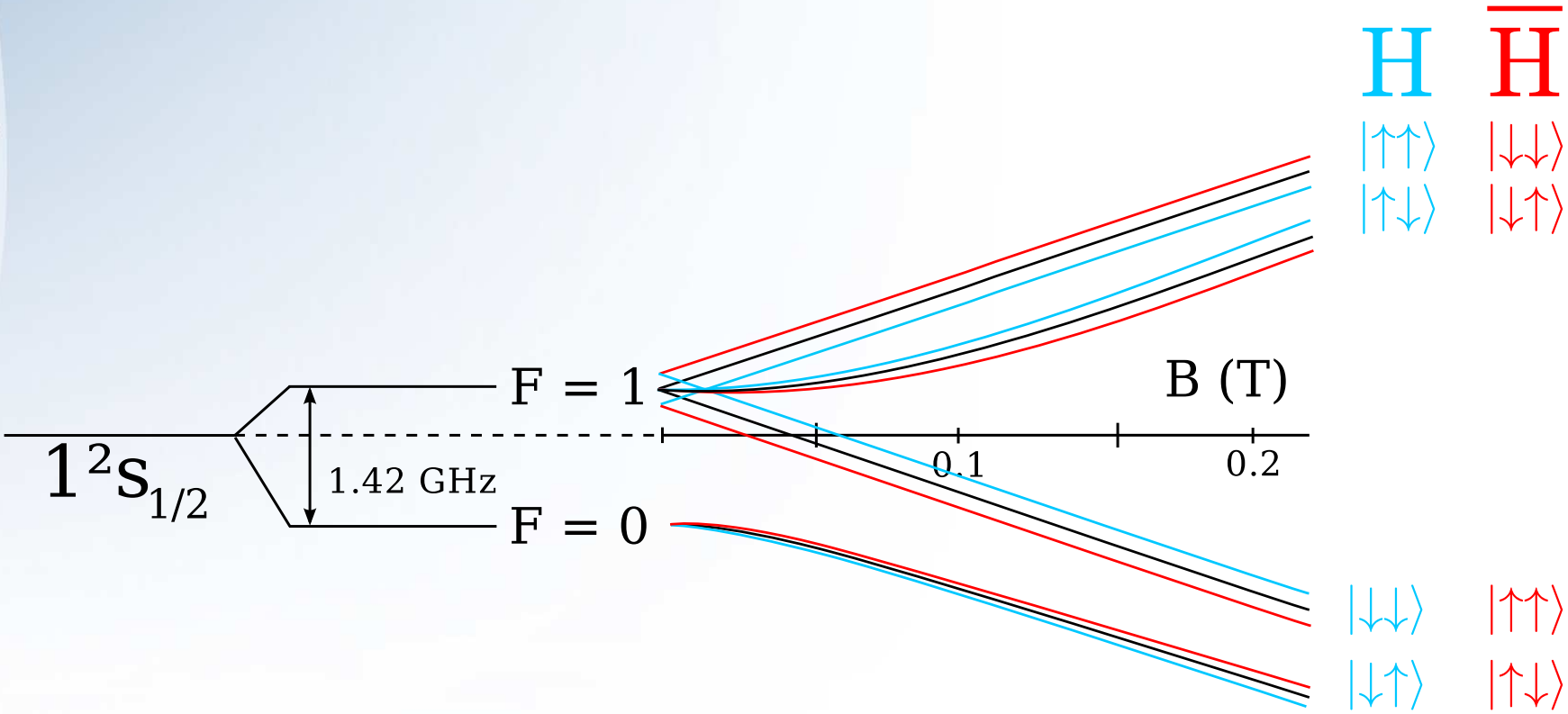


Bottom: anti-Helmholtz coils, magnetic field in z direction on axis

mixing processes: radiative ($\bar{p} + e^+ \rightarrow \bar{H} + \gamma$) or three body recombination ($\bar{p} + e^+ + e^+ \rightarrow \bar{H} + e^+$)

N. Kuroda et al, A source of antihydrogen for in-flight hyperfine spectroscopy, 2014, Nat. comm., DOI = 10.1038/ncomms4089

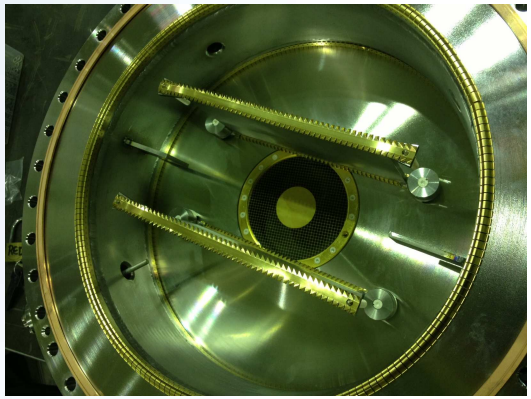
Standard Model Extension

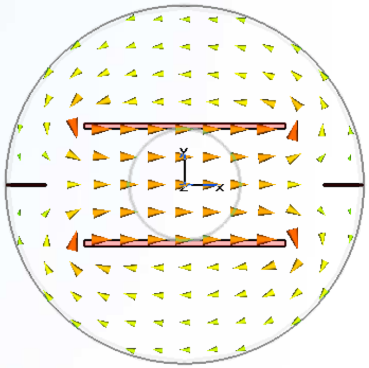


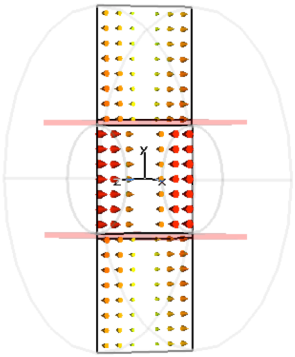
Kostelecký, V. Alan and Vargas, Arnaldo J., Lorentz and *CPT* tests with hydrogen, antihydrogen, and related systems, Phys. Rev. D, 92, 2015, DOI=10.1103/PhysRevD.92.056002

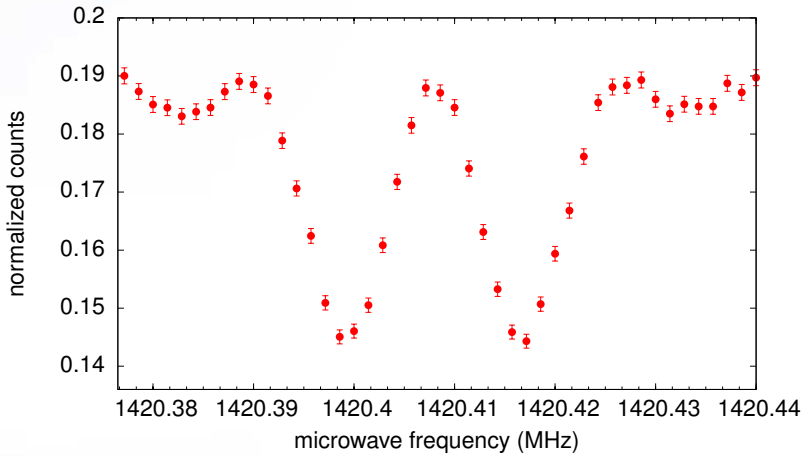
Spin-flip cavity

- oscillating magnetic field, MW frequency 1.42 GHz
- length: 10 cm
- static magnetic field: Helmholtz coils. field homogeneity!
- shielding
- depending on angle between fields: σ_1 and π_1 transistion

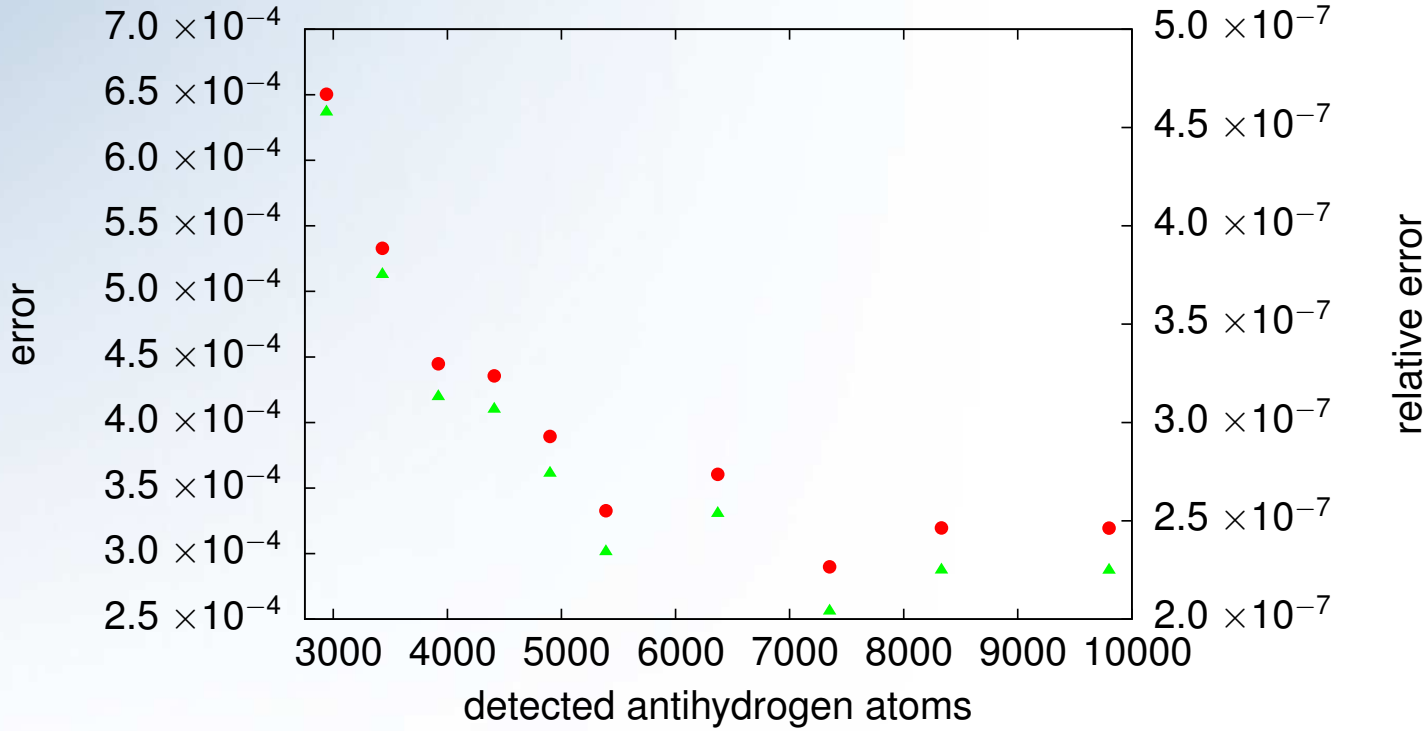








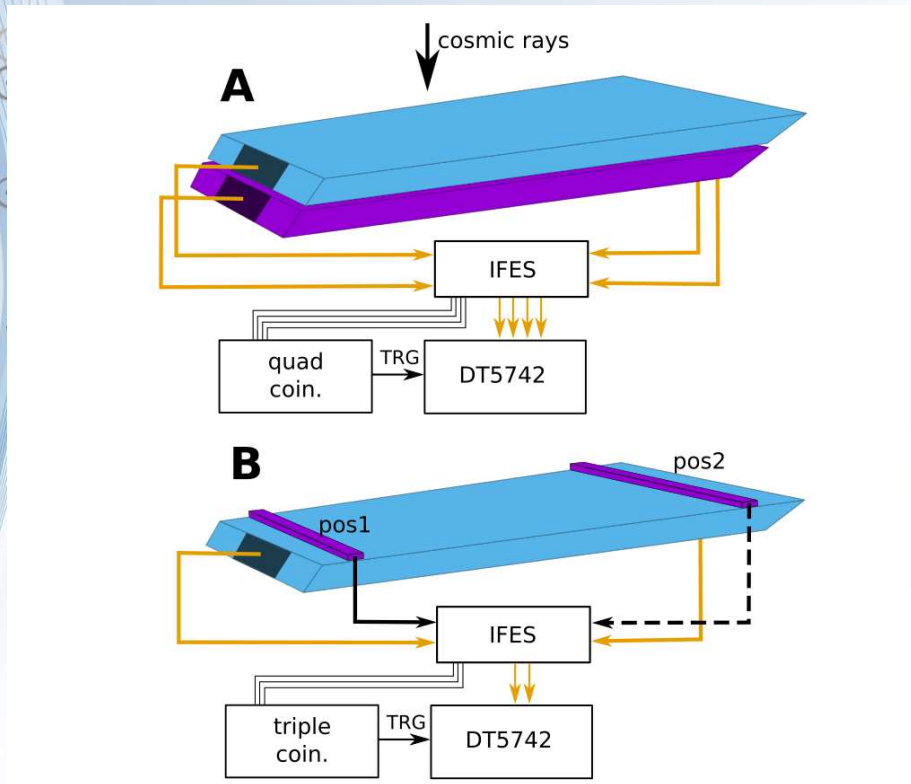
Dependence of Transition Frequency on Statistics (Geant4 Simulations)

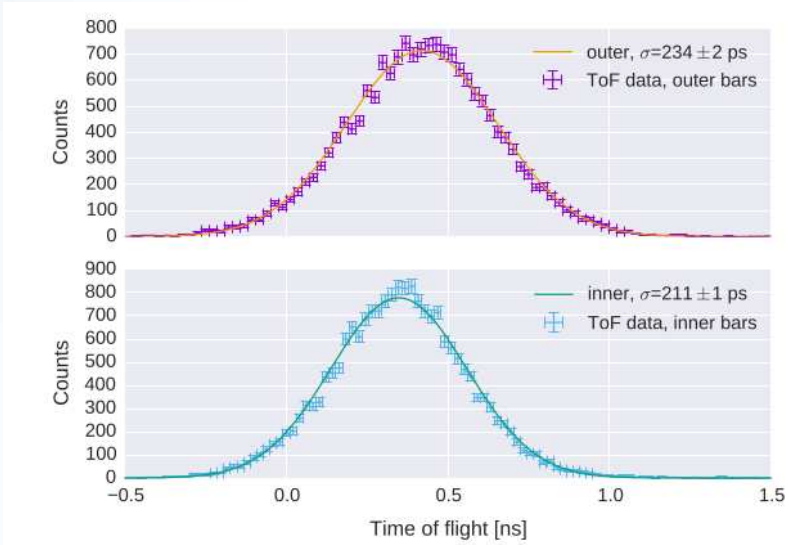


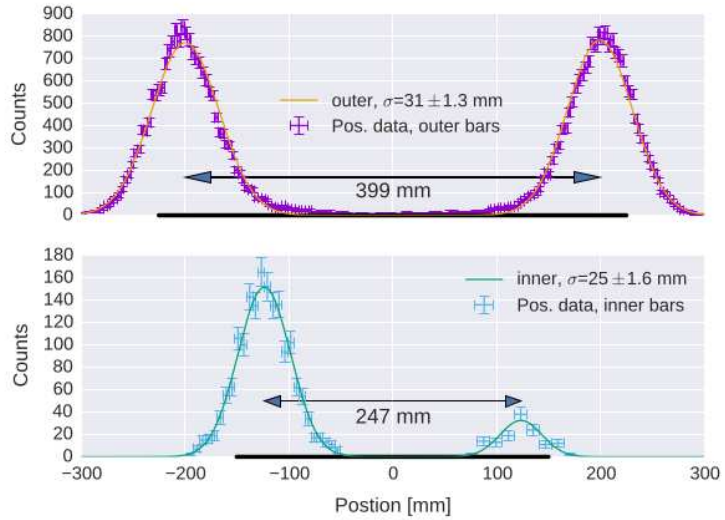
Error and relative error of ν_0 determined by extrapolation to zero B-field in dependence of number of particles per scan

B. Kolbinger et al, Numerical simulations of hyperfine transitions of antihydrogen, 2015, Hyperfine Interactions, DOI=10.1007/s10751-015-1130-3

Lab measurements







C.Sauerzopf et al: Annihilation Detector for an In-Beam Spectrsocopy Apparatus to Measure the Ground State Hyperfine Splitting of Antihydrogen, 2016, NIMA, doi:10.1016/j.nima.2016.06.023

Energy deposit in BGO