Progress report of the ASACUSA $\bar{\mathrm{H}}$ HFS experiment

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on behalf of the ASACUSA collaboration

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Hyperfine Structure of Antihydrogen
ERC Advanced Grant
PI: Prof. Dr. Eberhard Widmann

Introduction

- Lorentz symmetry is a cornerstone of modern physics
  - Quantum Field Theory (QFT)
  - Einstein's theory of general relativity
- Ongoing search for new theories
  - Gravity not incorporated in QFT, dark matter, missing antimatter in universe...
  - Many theories break Lorentz symmetry at some small level
  - Finding Lorentz violating effects could lead to new physics
- Standard Model Extension (SME) by Alan Kostelecky: Parameterization of Lorentz-violating effects
  - Allows for direct comparison of many experiments
  - Compare groundstate hyperfine splitting (GS-HFS) in $H + \bar{H}$: potential for highest sensitivity on absolute energy scale

Asacusa collaboration aims at measuring the GS-HFS of $\bar{H}$

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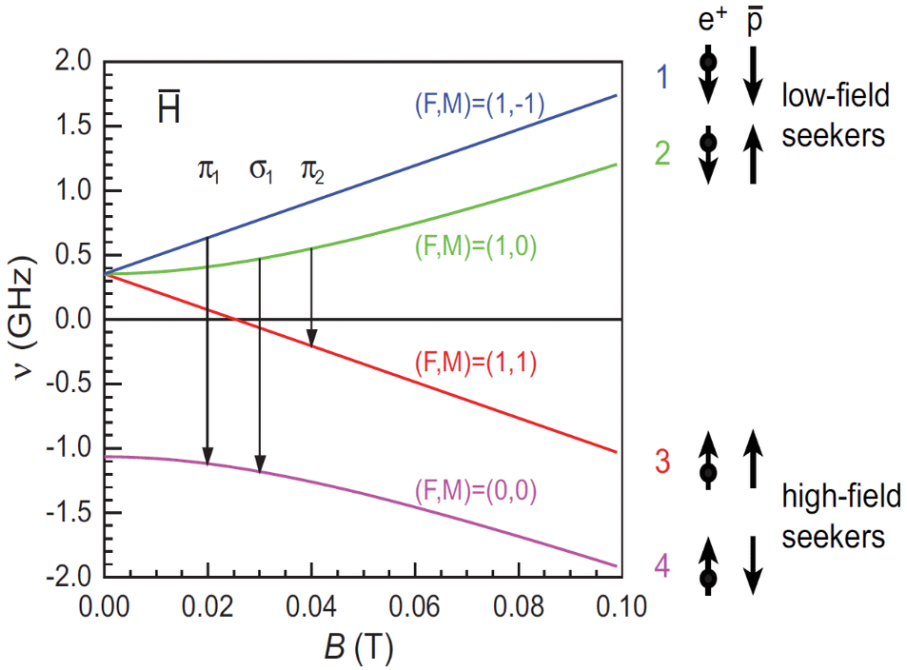
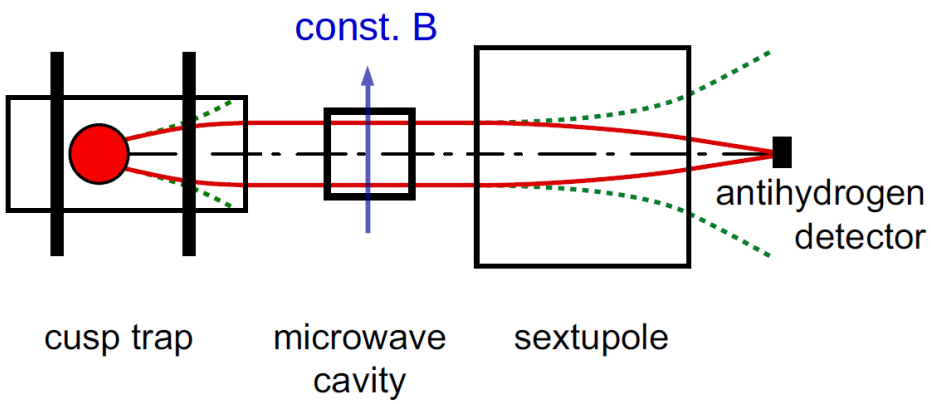
Measurement principle





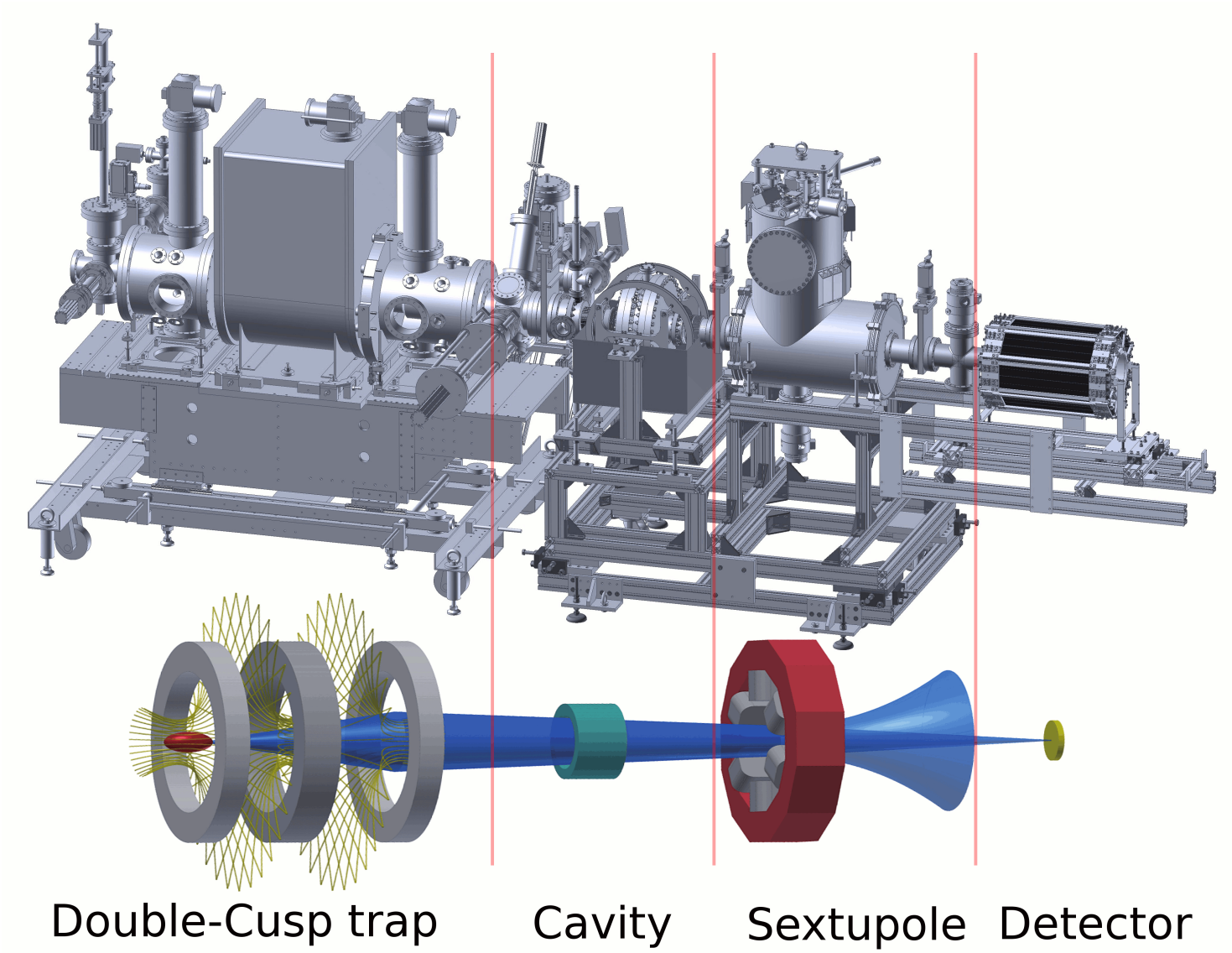
- Production of $\bar{H}$ in dedicated trap
- Trap emits beam of polarized LFS $\bar{H}$
- Induce spin-flips with microwave cavity: LFS become HFS
- Analyze spin states with sextupole
- Detector counts $\bar{H}$

Status of GS-HFS measurements

- H: GS-HFS known with a precision of 1.4×10^{-12}
  - Only need to measure $\bar{\mathrm{H}}$
- $\bar{\mathrm{H}}$: Recent measurement by ALPHA: 4×10^{-4}
  - Trapping $\bar{\mathrm{H}}$ with strong inhomogenic magnetic fields
  - Get HFS by difference between π_1 and π_2 transitions
  - Result is consistent with GS-HFS in H
  - Not sensitive to CPT within the mSME
- ASACUSA will measure HFS B-field free using $\bar{\mathrm{H}}$-beam, measure transition directly

Experimental Setup

Mixing trap + spectroscopy beamline

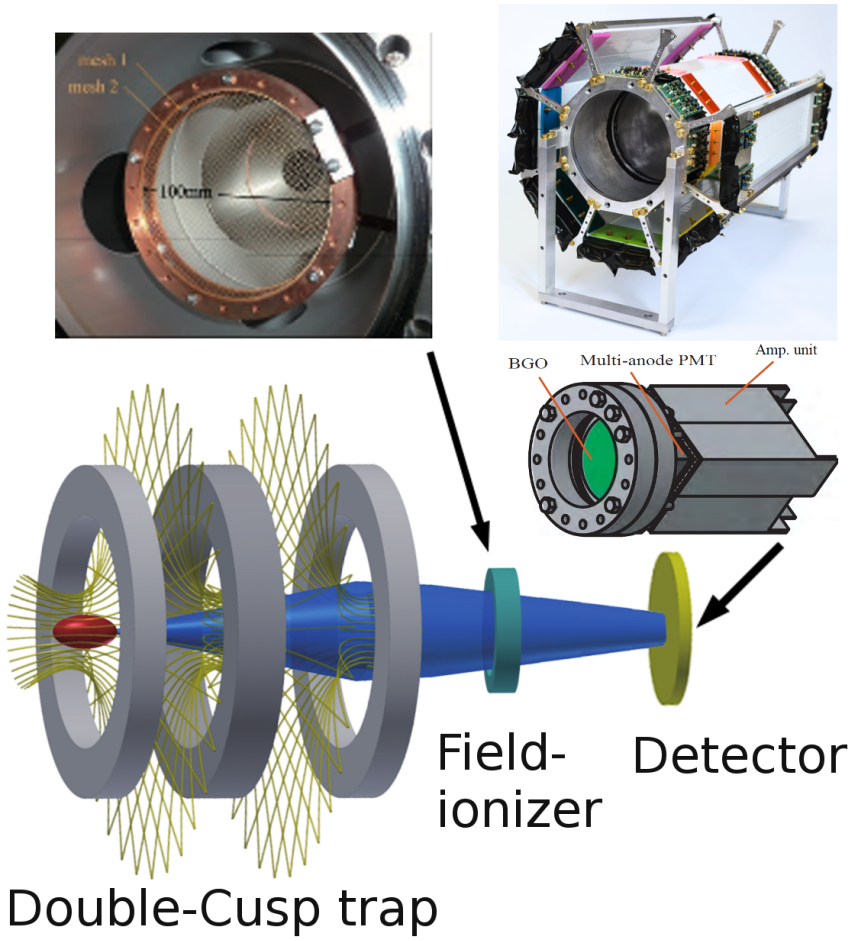


Mixing pbar and positrons

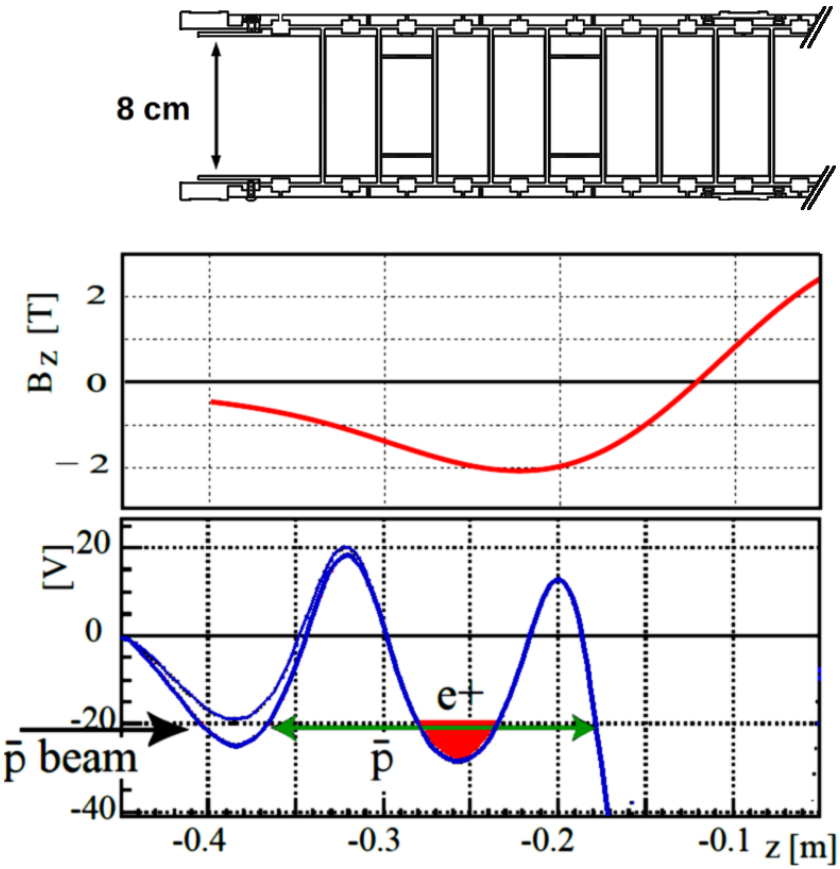
- Spectroscopy part: fully tested with hydrogen beamline
- Current work: optimizing $\bar{H}$ production (mixing $\bar{p}$ and e^+)

Optimization of mixing:

- Short setup: mount detector close to trap
- Fieldionizer before detector: ionizes and blocks $\bar{H}$ above a given n-state
- $\bar{H}$ with lower n-state are counted



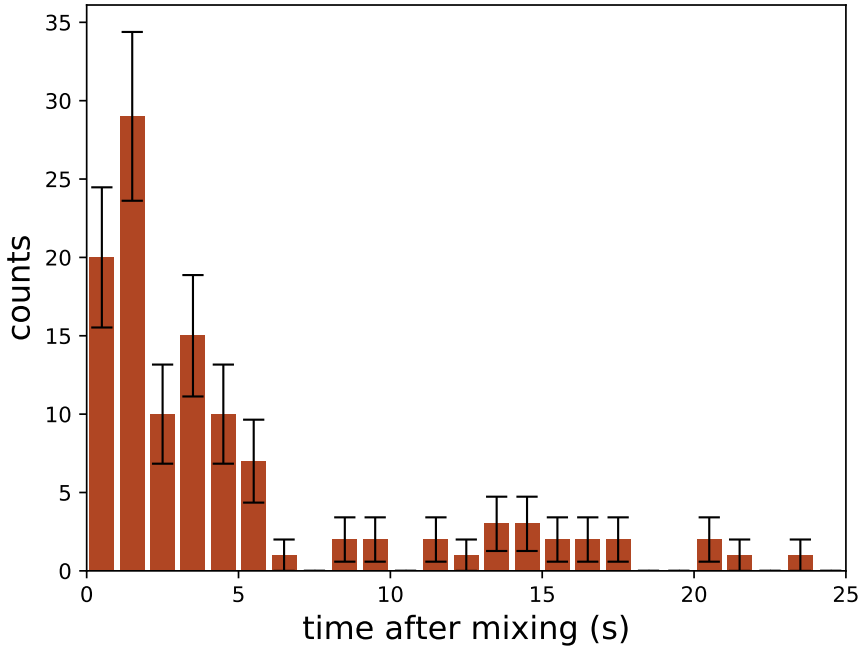
Mixing antiprotons and positrons

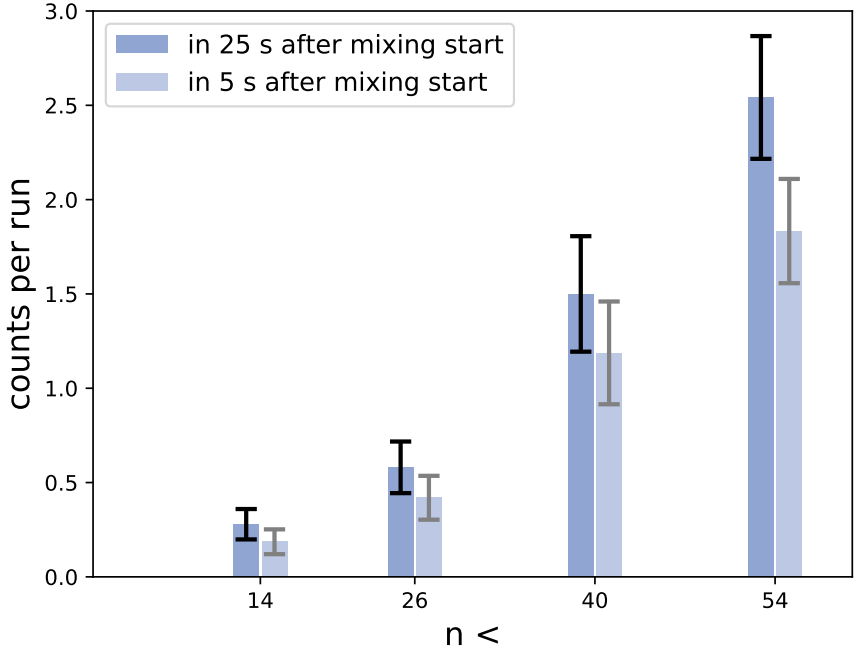


- Trapping of $\bar{p}$ and positrons
  - axially by MRE
  - radially by magnetic field
- prepare $\approx 60 \times 10^6$ e^+
- inject $\approx 3 \times 10^6$ $\bar{p}$
- pull up upstream potential barrier
- only neutral $\bar{H}$ can leave trap

Results: Measurement of n-state distribution

Time and quantum distribution of detected $\bar{H}$





- 43 mixing runs in total
- False positive rate: 0.0038 s^{-1}
- n<14 significance: 6 σ τ (n=14) $\approx$ 50 μs

Outlook

What are the next steps?

- Optimize production of $\bar{H}$ in ground state
- Scan GS-HFS
  - Goal: 10^{-6} precision
  - 8000 $\bar{H}$ in ground state needed
- Proton size correction contributes in the order of 10^{-5}
- Assuming QED obeys CPT:
  Determine Zemach and magnetic radii of antiproton

Thank you very much for your attention!