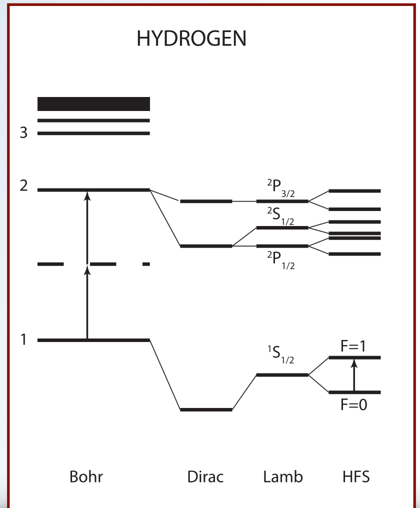

LATEST RESULTS OF THE ASACUSA ANTIHYDROGEN PROGRAM

Chloé Malbrunot [1,2]

[1] CERN, Geneva, SWITZERLAND

[2] Stefan Meyer Institute for Subatomic Physics, Vienna, AUSTRIA

ANTIMATTER - MATTER ASYMMETRY

- No evidence of primary antimatter anywhere in the universe

- Baryon asymmetry produced by a <u>very small deviation</u> $\frac{n(B) - n(\bar{b})}{n(\gamma)} < 10^{-9}$

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Time reversal

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Lorentz invariance
Locality
Unitarity

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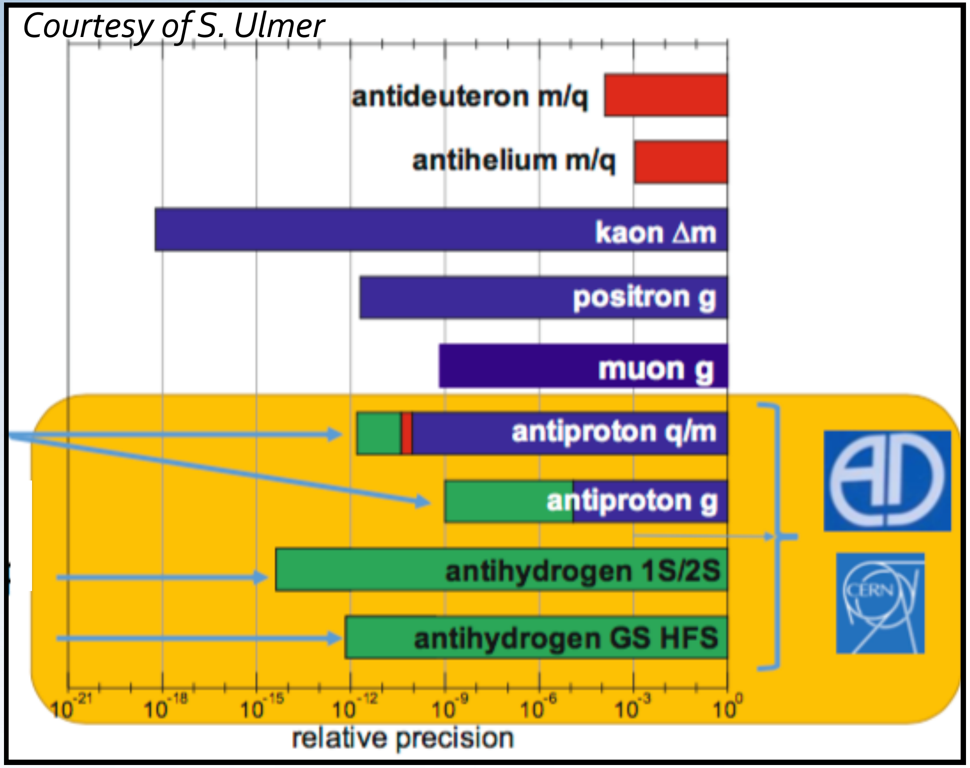
If **CPT symmetry holds**: properties of matter & antimatter particles have to be exactly equal (mass) or opposite (charge, magnetic moment). Atomic structures identical

ANTIMATTER - MATTER ASYMMETRY



Tests in different systems:

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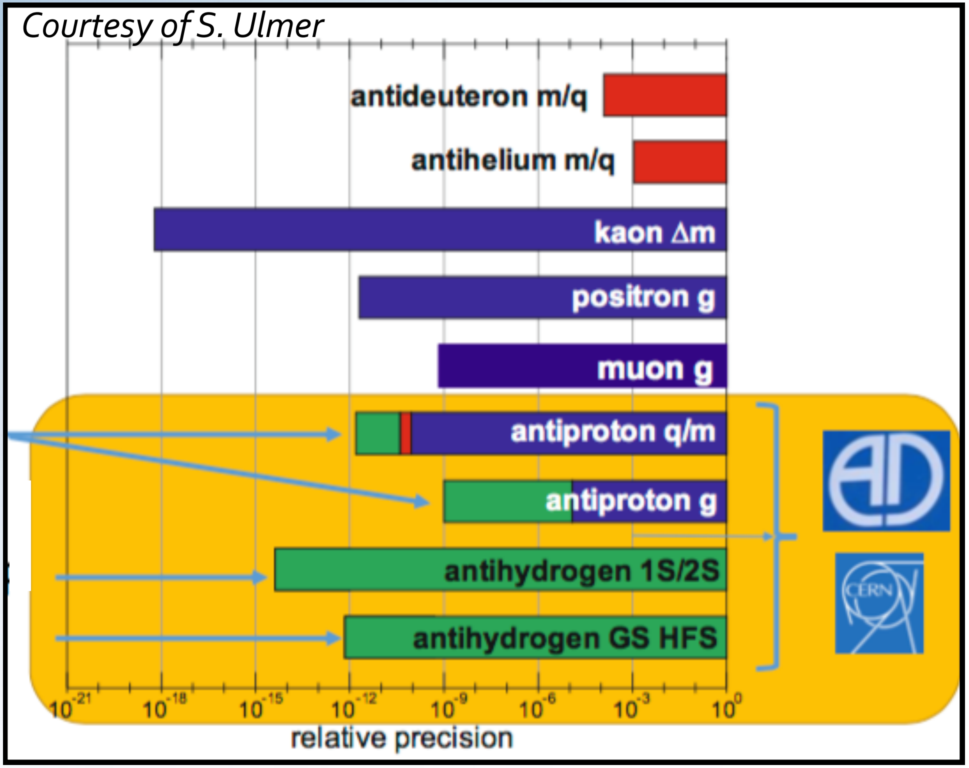

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Standard model extension (SME)

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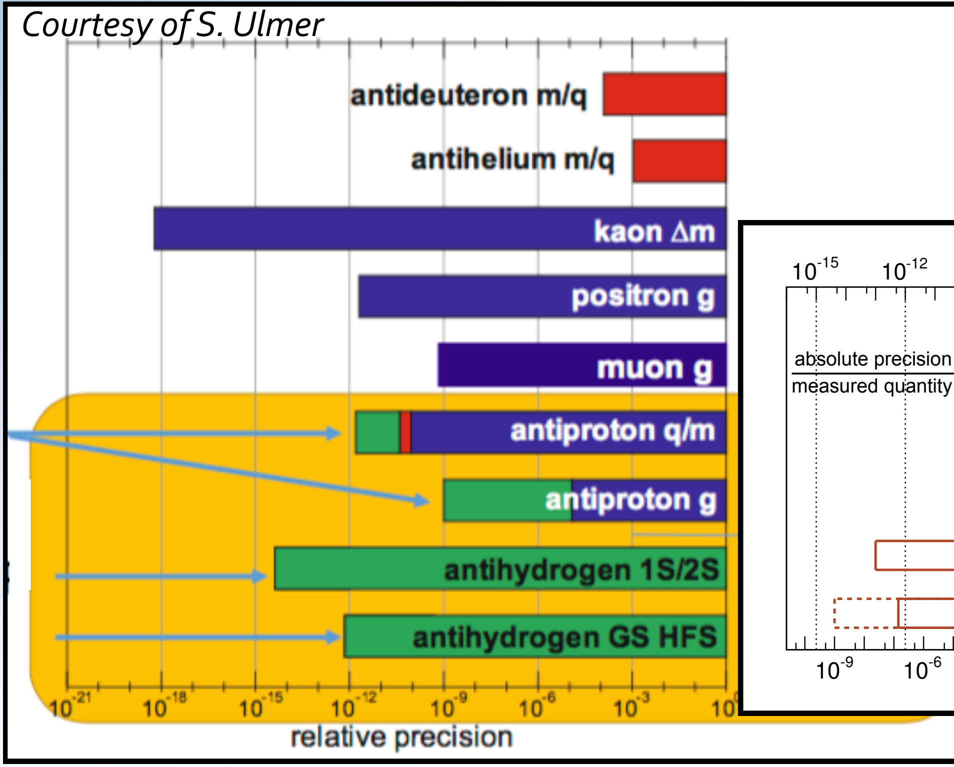

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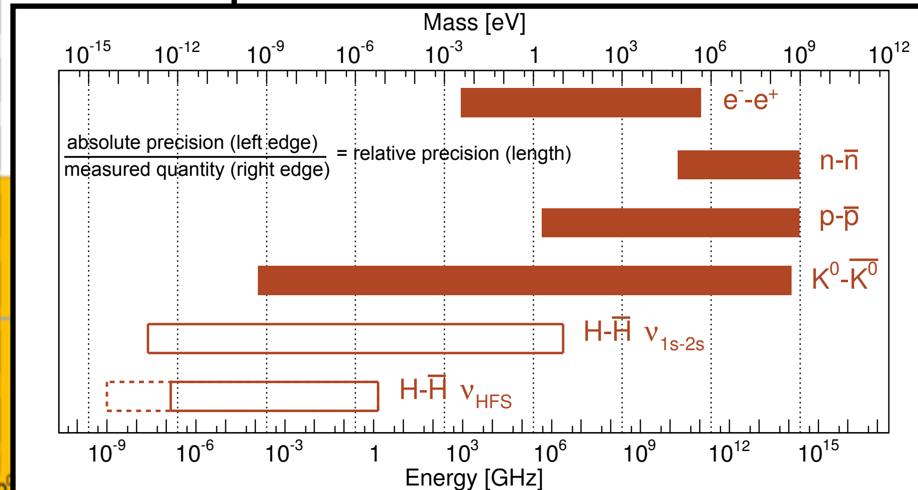

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GS-HFS MEASUREMENT

$$\nu = 1.420405751768(1)\ \mathrm{GHz}$$

S. G. Karshenboim, Precision Physics of Simple Atomic Systems, pages 142–162, Springer, Berlin, Heidelberg, 2003, hep-ph/0305205.

Leading term: **Fermi contact term**

has been measured to 5ppm

DiSciacca et al, Phys. Rev. Lett. 110, 13 (2013)

A. Mooser et al, Nature 509, 596–599 (2014)

$$\nu_F = \frac{16}{3}\left(\frac{M_p}{M_p + m_e}\right)^3 \frac{m_e}{M_p}\frac{\overline{\mu}_p}{\mu_N}\alpha^2 c R_y$$

Finite electric and magnetic radius (**Zemach corrections**): ~-41ppm

access to the electric and magnetic form factors of the antiproton

$$\Delta\nu(\mathrm{Zemach}) = \nu_{\mathrm{F}} \frac{2Z\alpha m_e}{\pi^2} \int \frac{d^3p}{p^4} \left[\frac{G_E(p^2)G_M(p^2)}{1+\kappa} - 1\right]$$

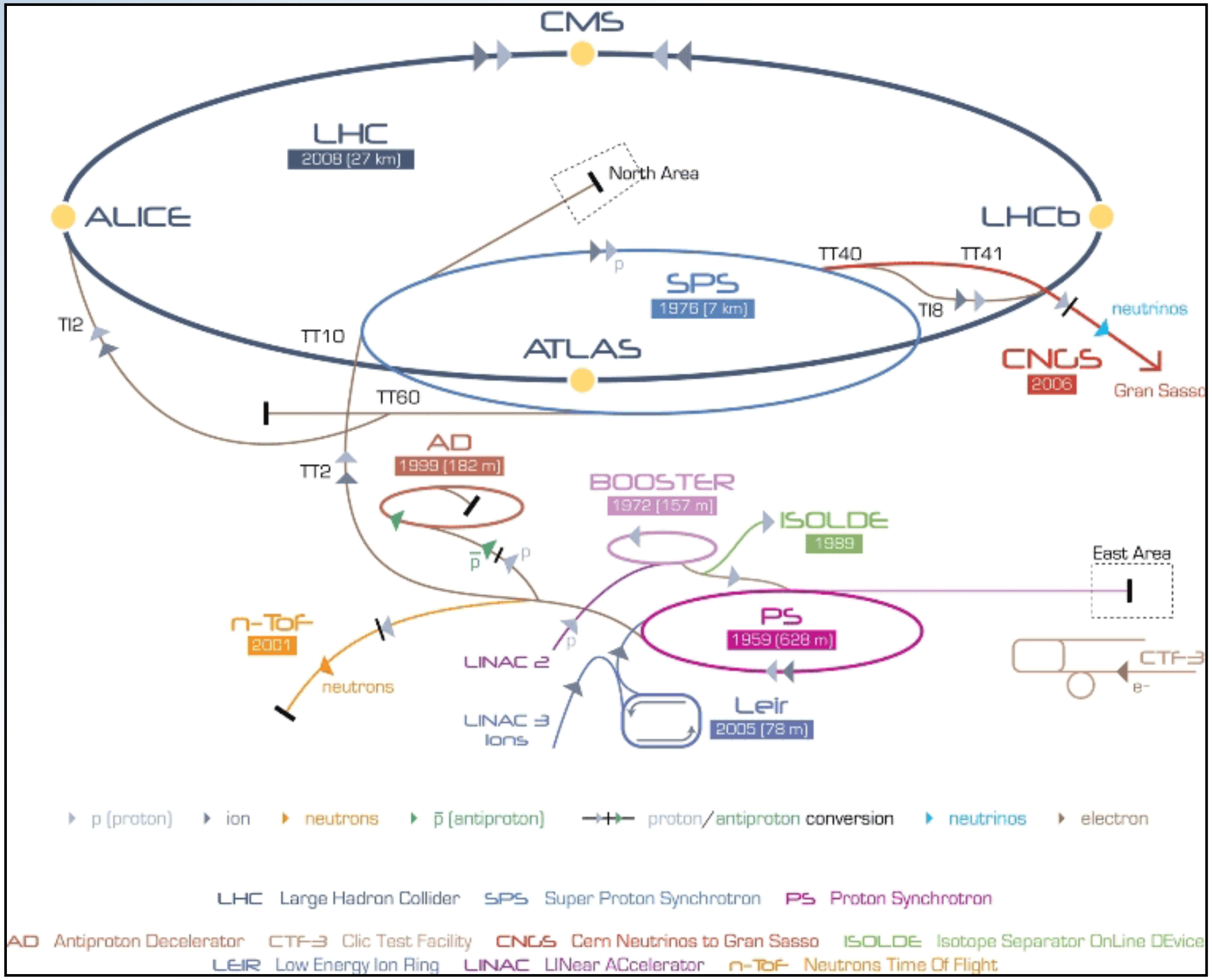
e.g Friar et al. Phys.Lett. B579 (2004)

Polarizability of p(bar) =1.88±0.64 ppm

Carlson, Nazaryan, and Griffioen PRA 78, 022517 (2008)

Remaining deviation theory-experiment: **0.86±0.78 ppm**

ANTIHYDROGEN EXPERIMENTS @ CERN



CERN-AD is the <u>only</u> facility in the word which can produce <u>low energy</u> antiprotons

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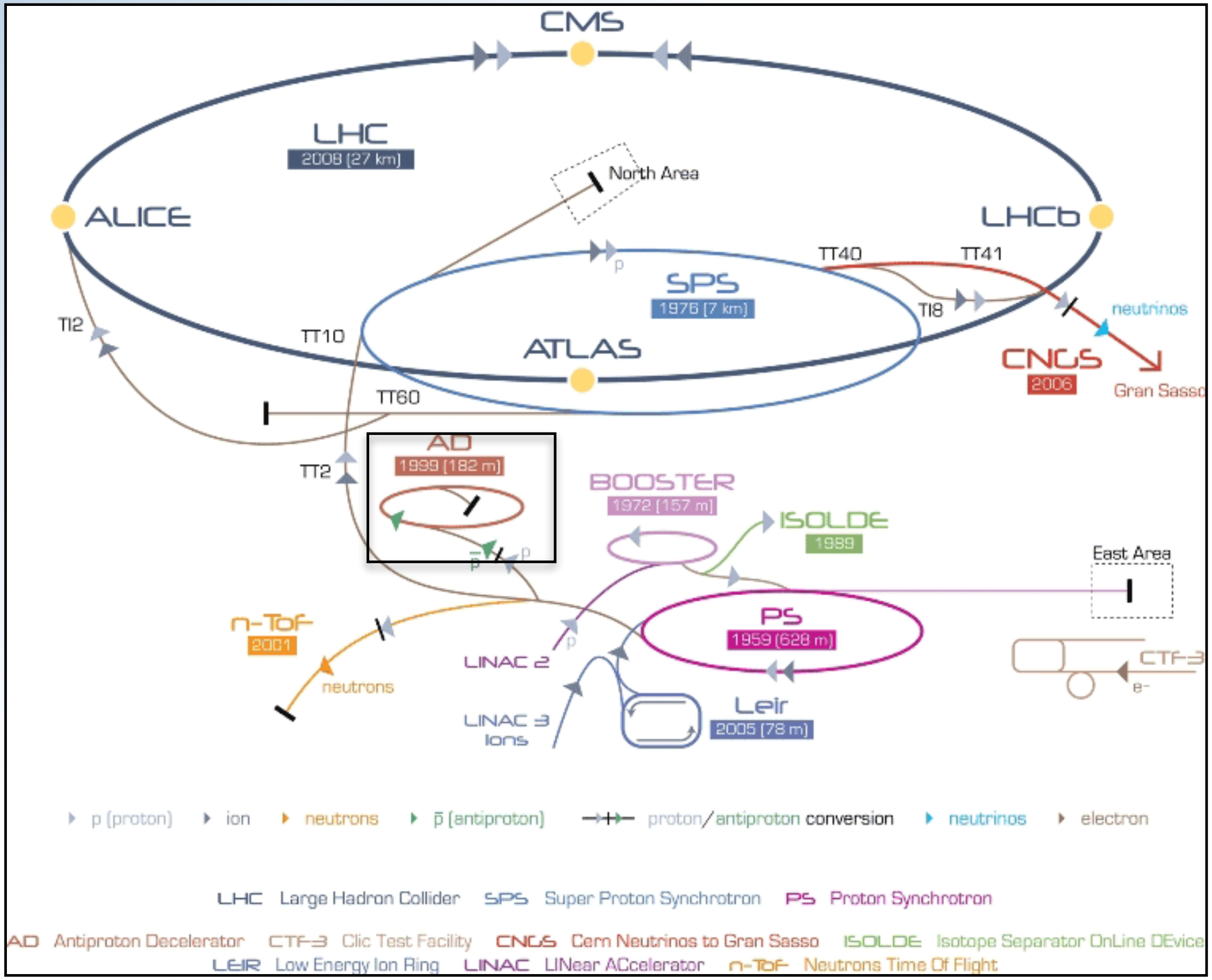

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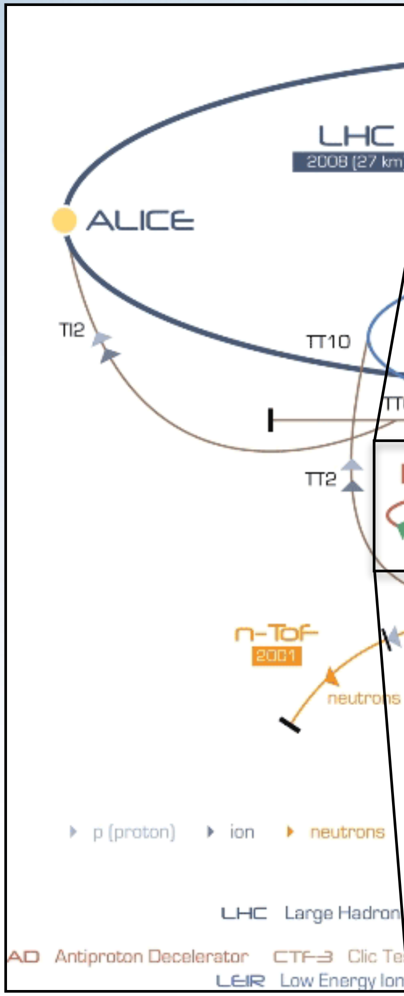

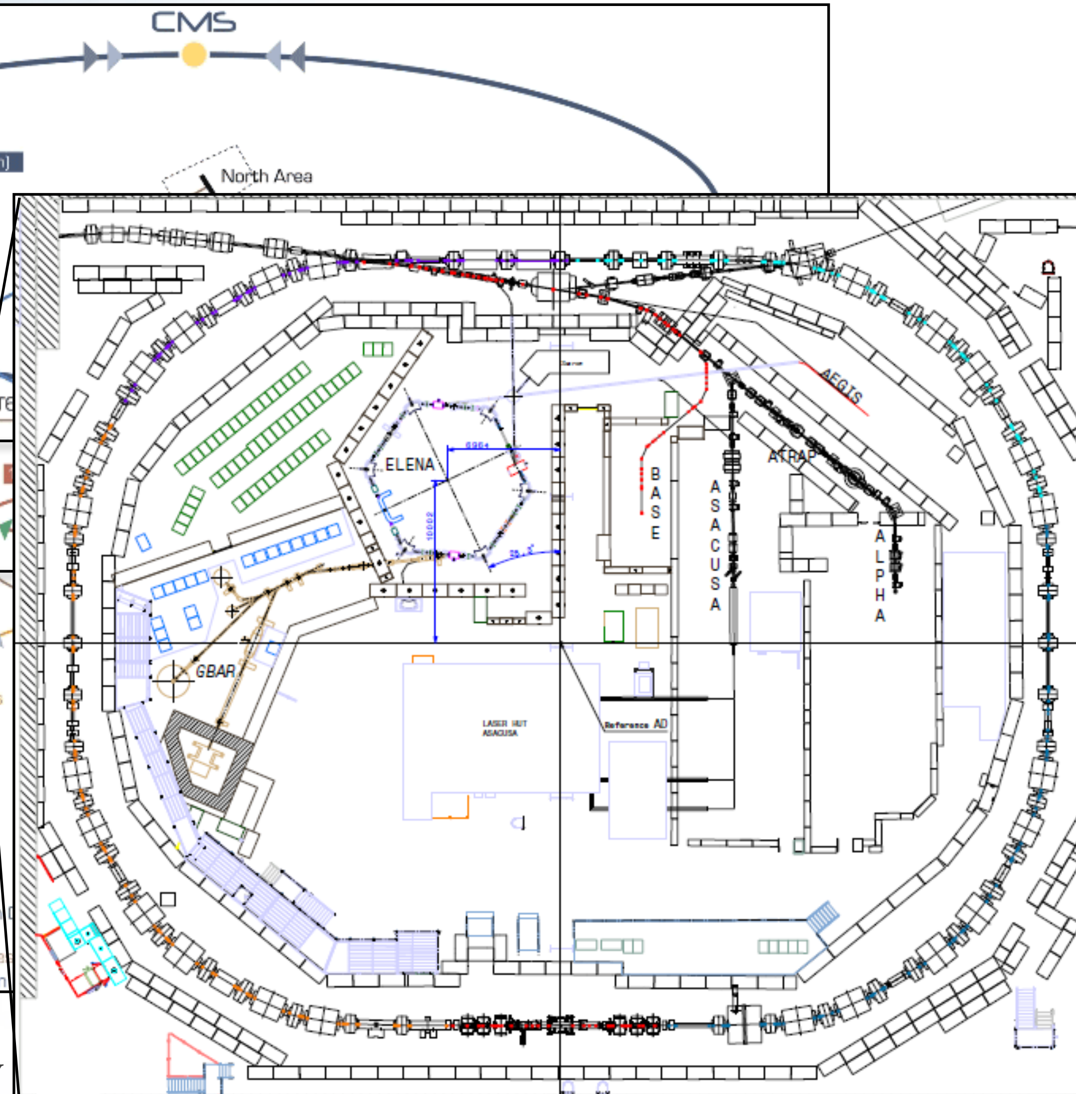

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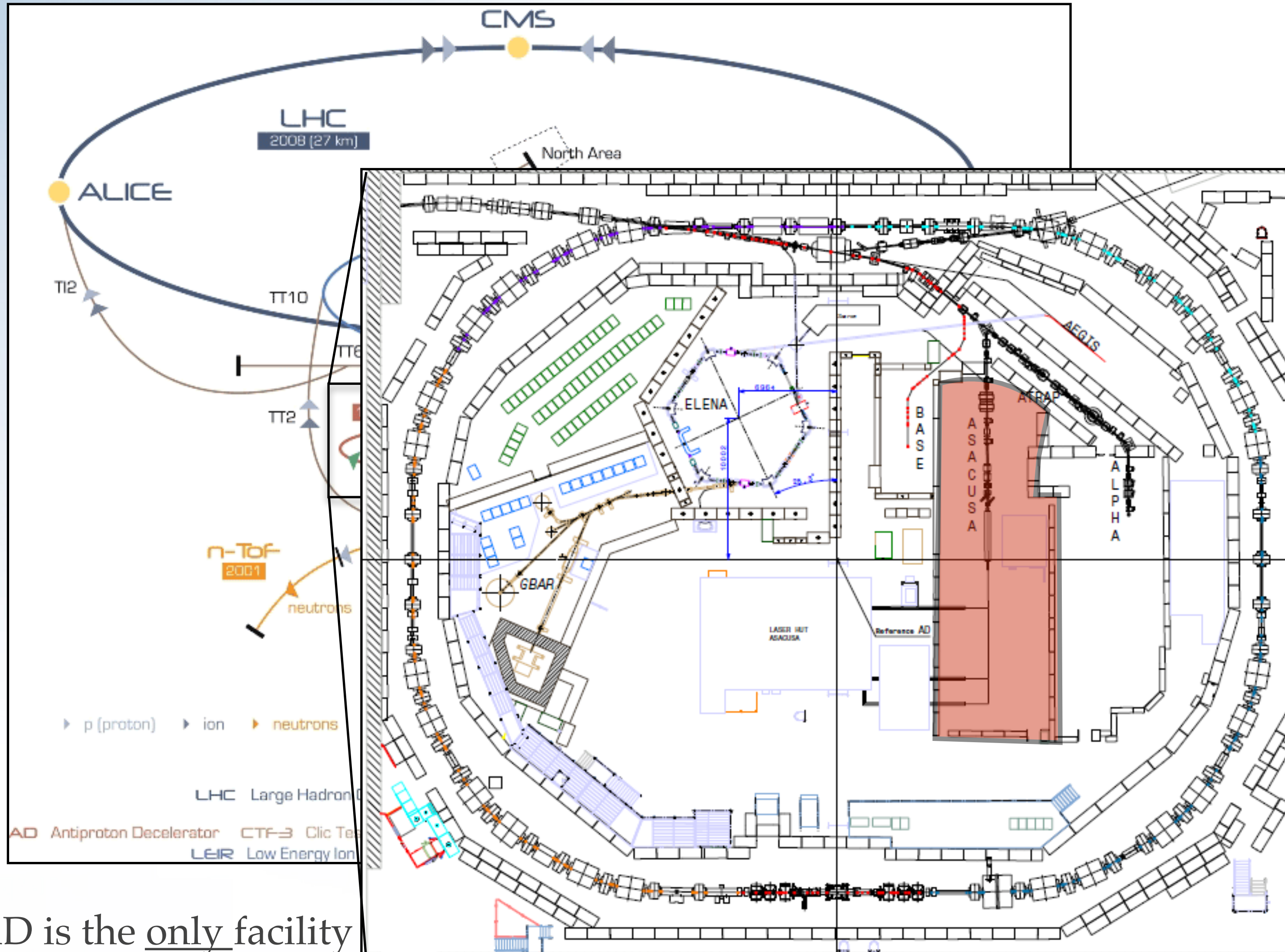
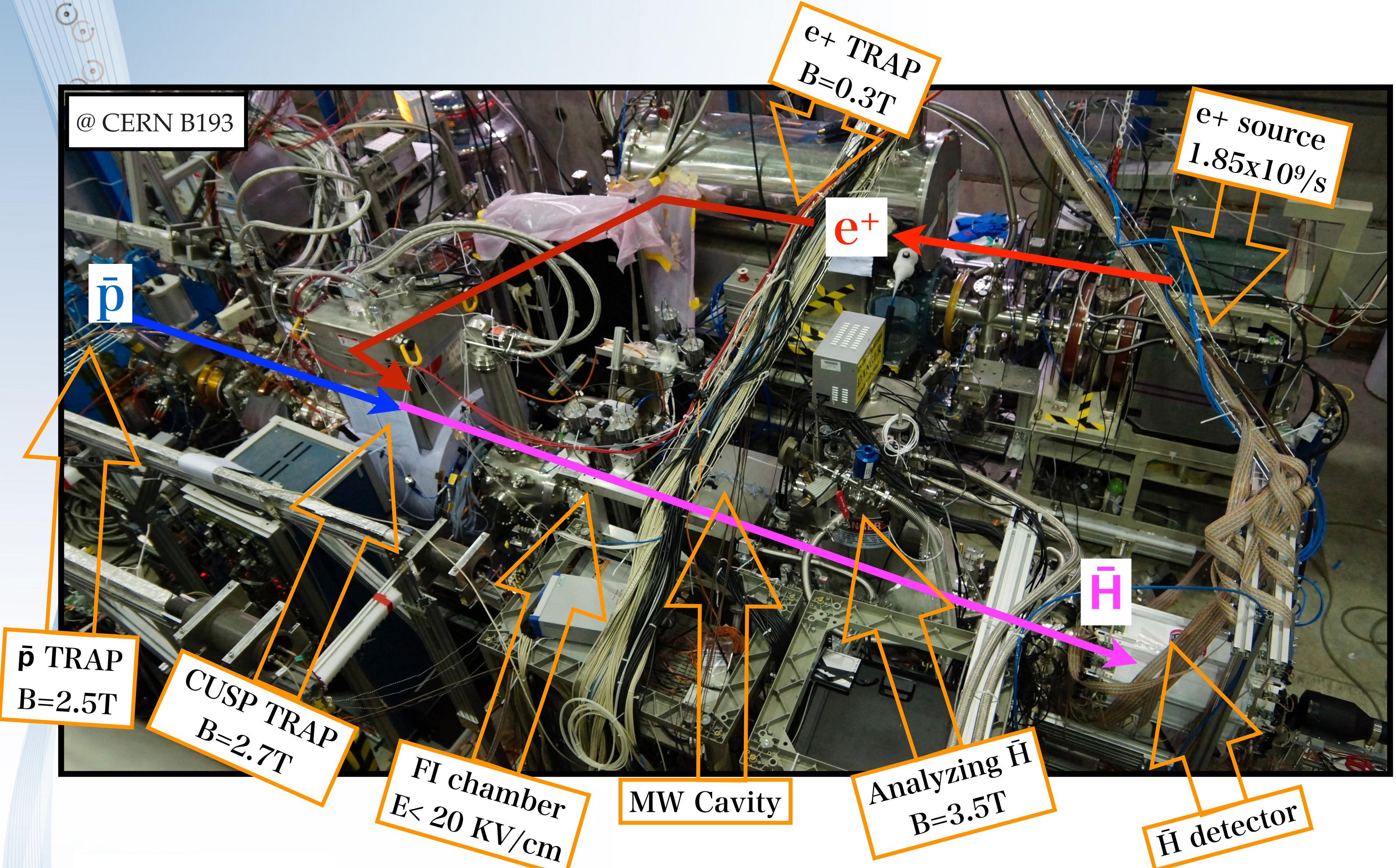
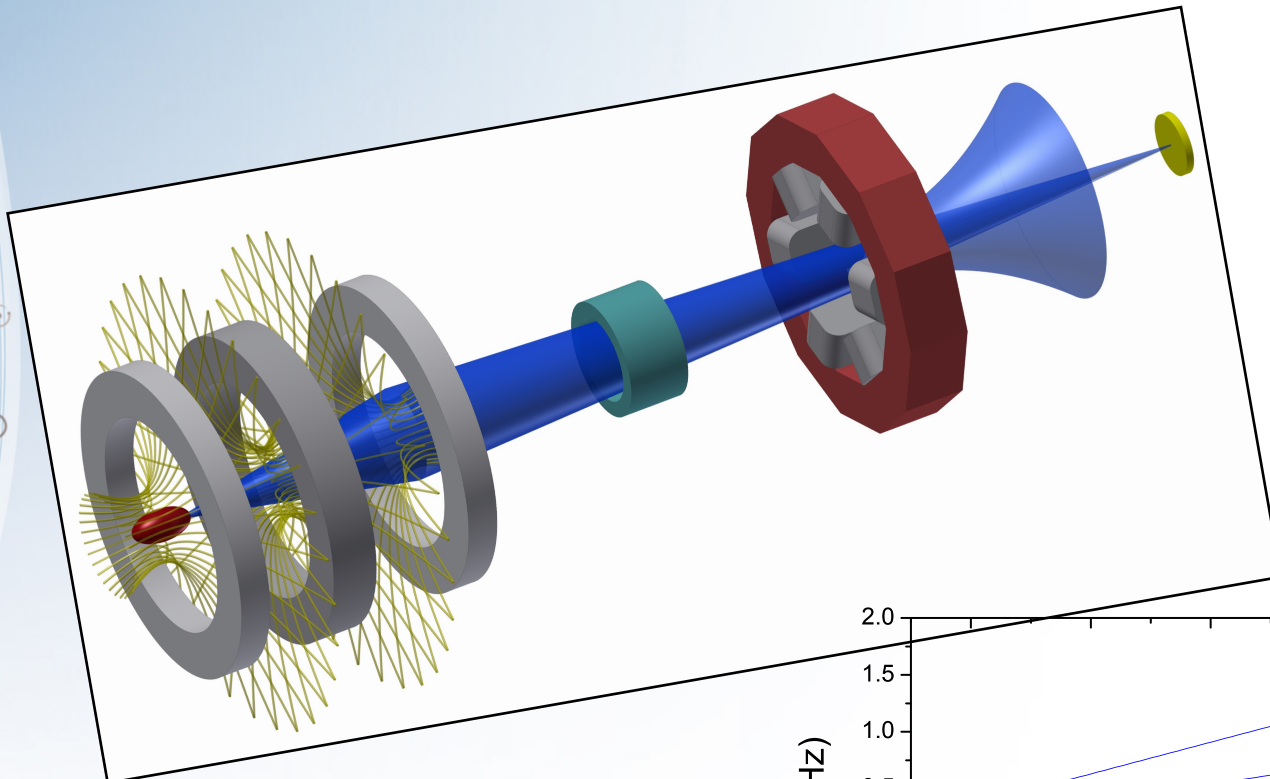


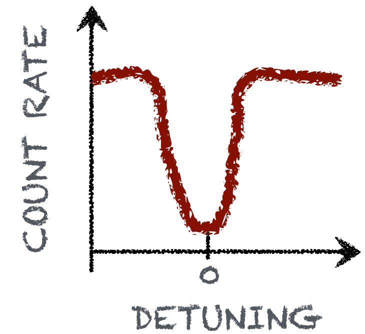
CERN-AD is the only facility … ns

ASACUSA ANTIHYDROGEN BEAMLINE



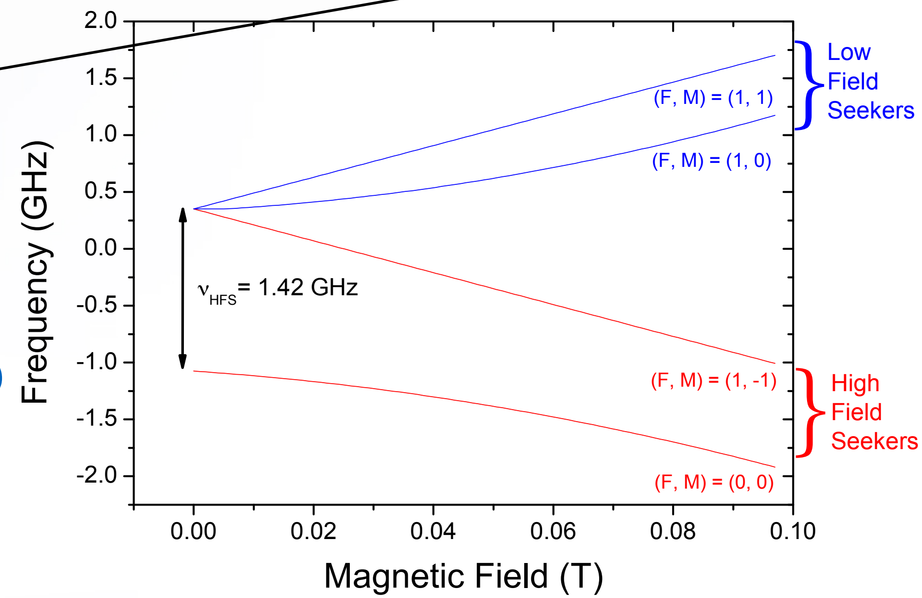
MEASUREMENT PRINCIPLE



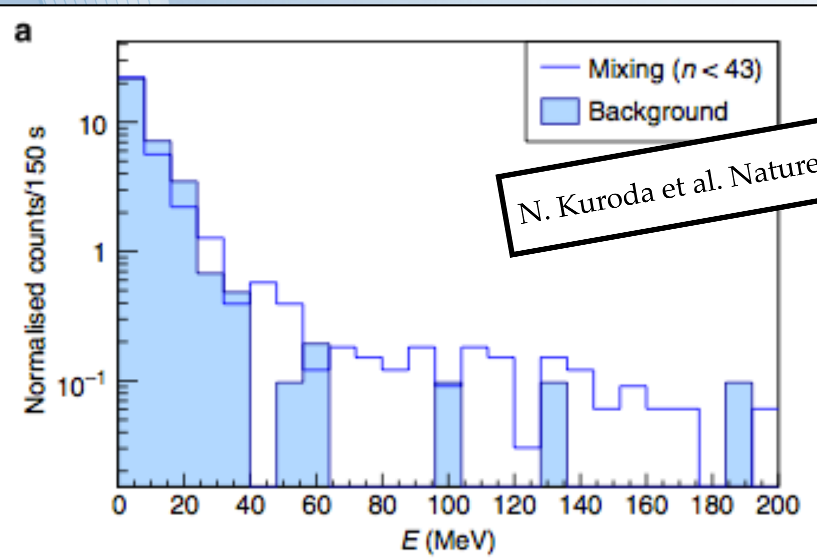


Atomic beam with RF resonance

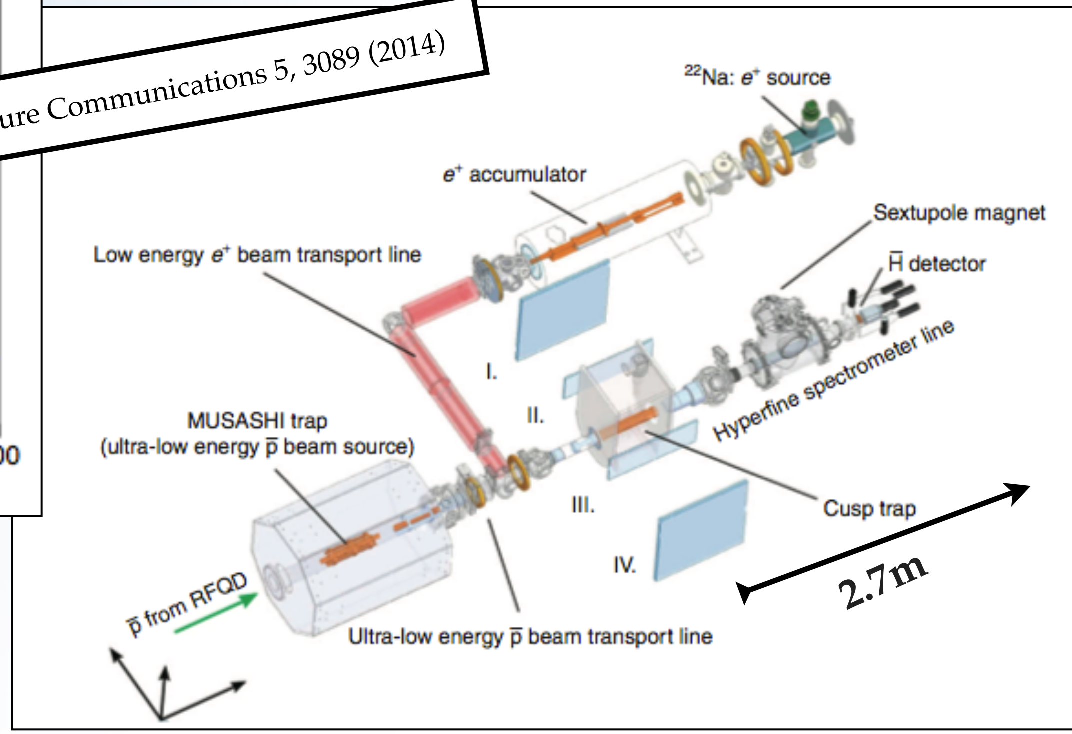
- no $\bar{H}$ trapping needed (can work up to 50-100 K)
- $\bar{H}$ atoms can be guided with inhomogeneous magnetic field



“BEAM” OBSERVATION



N. Kuroda et al. Nature Communications 5, 3089 (2014)



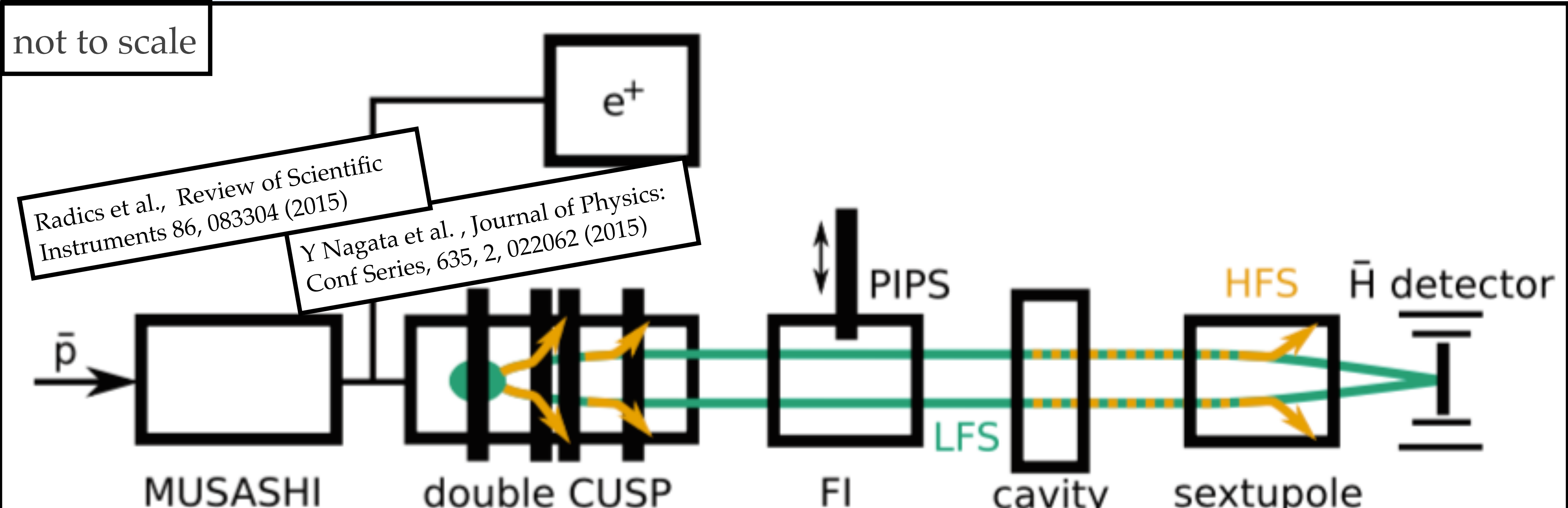
80 atoms detected in a field-free region

Internal CUSP field ionizer to investigate the time structure of antihydrogen formation
Field ionizer before the detector : detection of n<43 (some n<29)

NEXT:
1) Further characterization of the antihydrogen beam : Quantum state distribution, velocity, polarisation
2) Characterization of spectroscopy beamline

NEWER ADDITIONS TO THE ANTIHYDROGEN BEAMLINE

Poster: N. Kuroda
Development of a double-cusp trap for ground-state hyperfine spectroscopy of antihydrogen atoms



C. Sauerzopf et al. Hyperfine Interact (2016) 237:103

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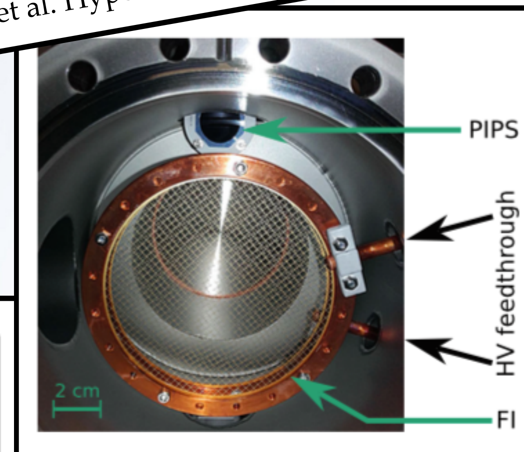

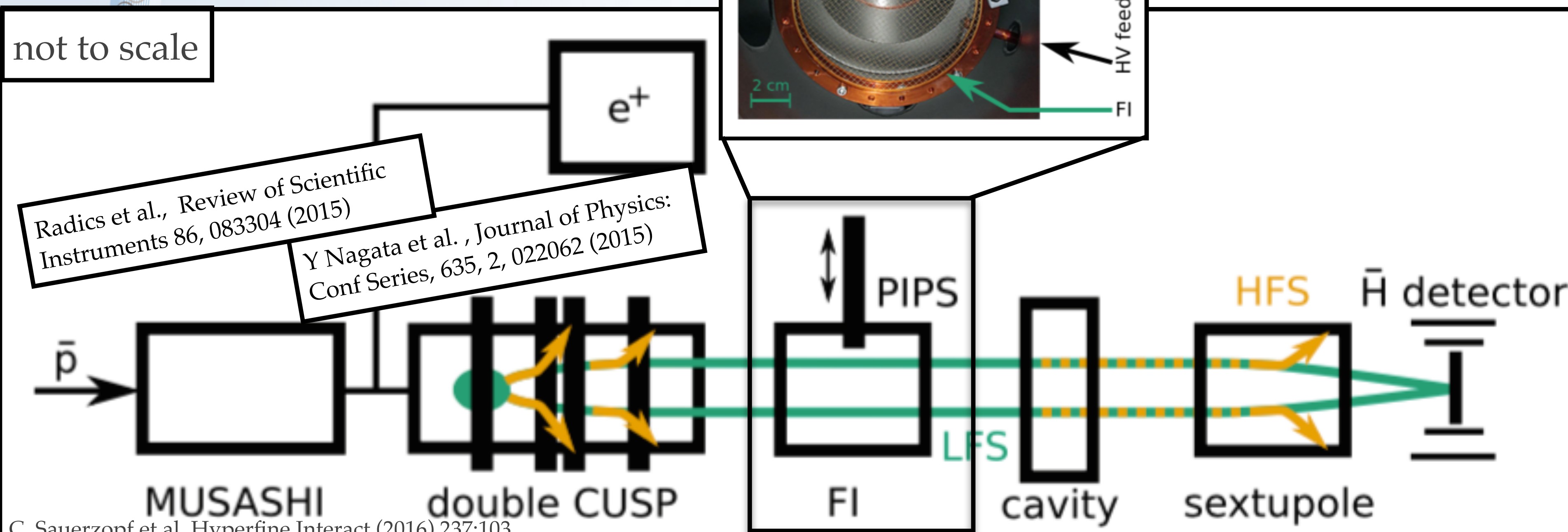

Radics et al., Review of Scientific Instruments 86, 083304 (2015)

Y Nagata et al. , Journal of Physics: Conf Series, 635, 2, 022062 (2015)

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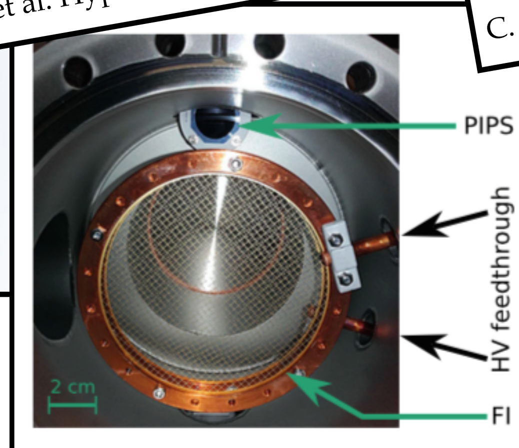
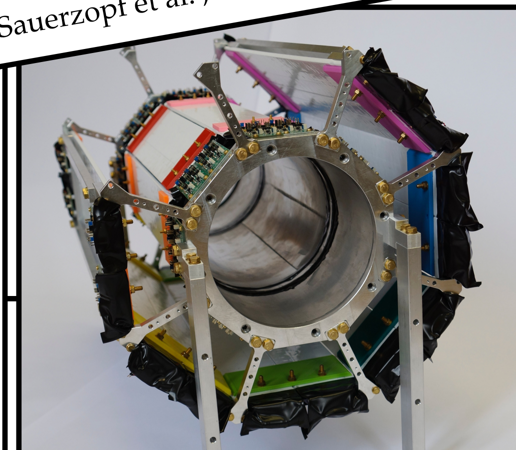


C. Sauerzopf et al. , NIM A , 0168-900 (2016)



not to scale

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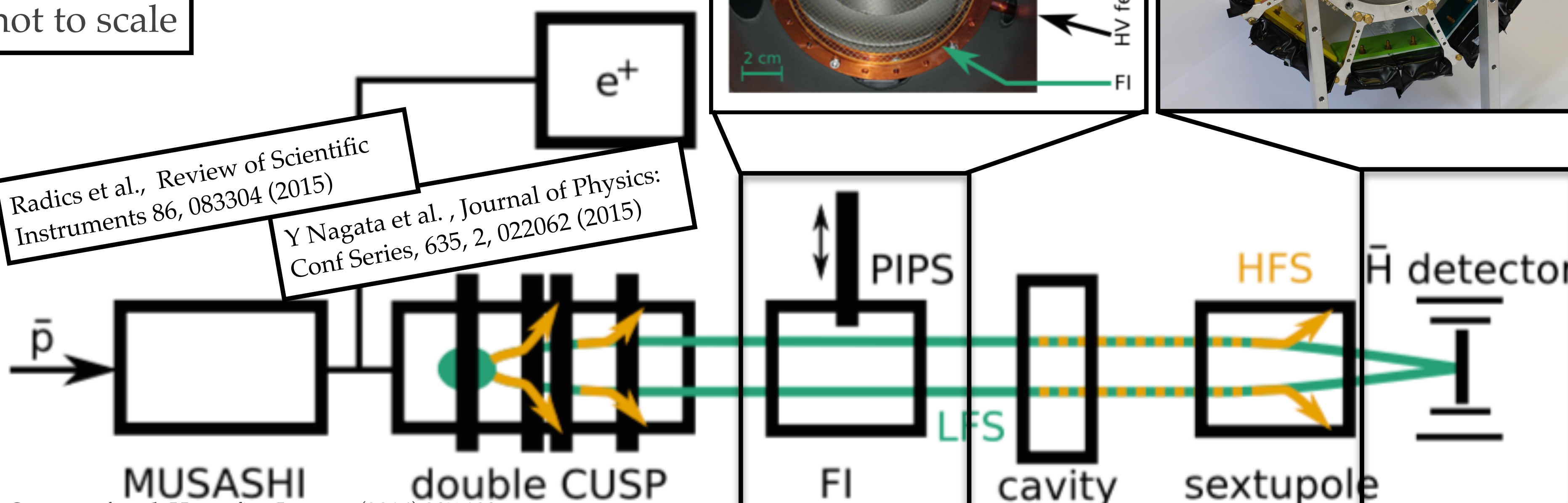

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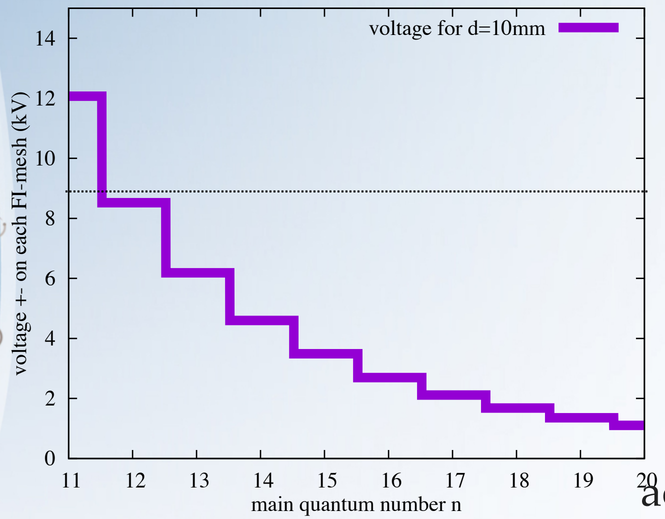
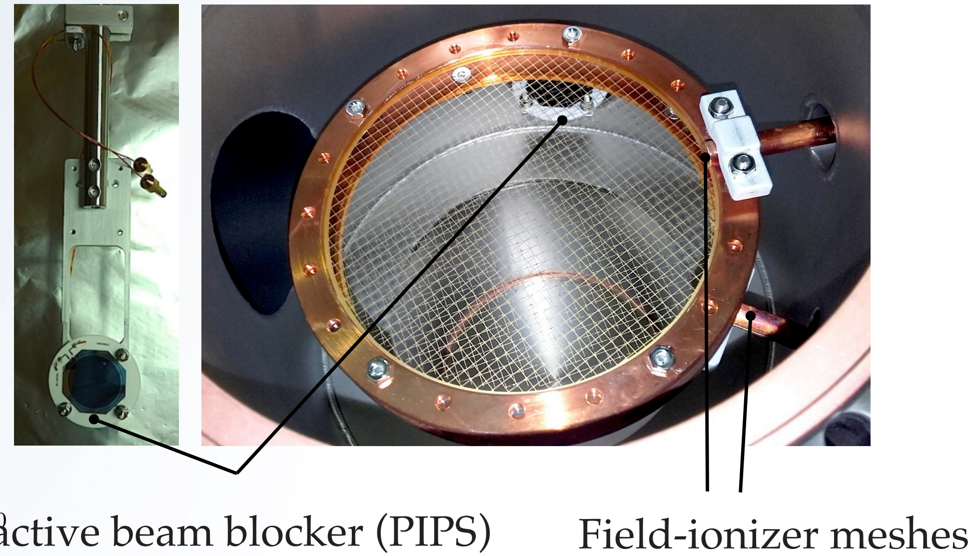
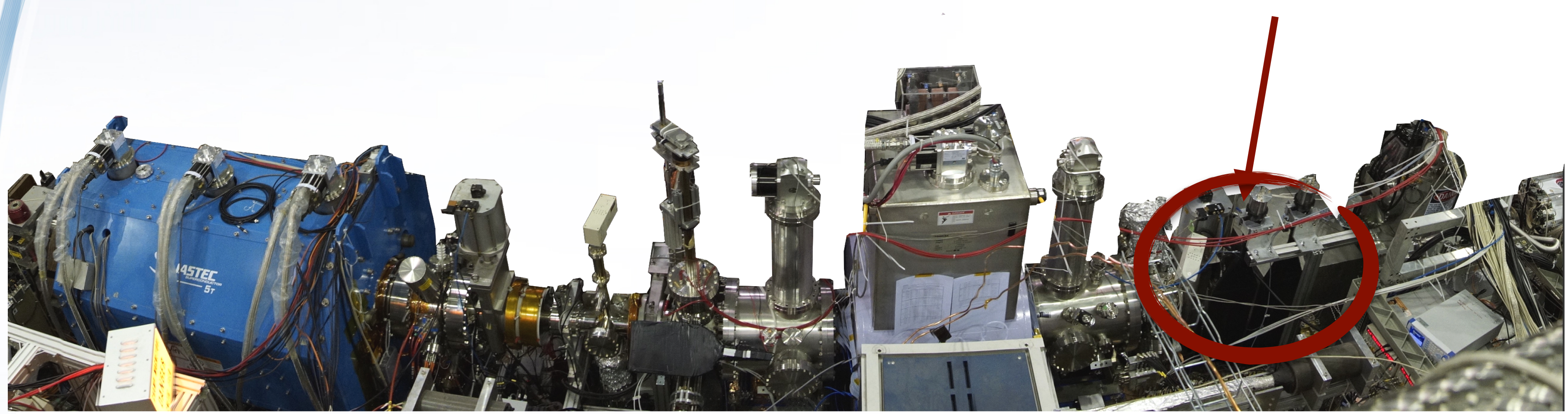
$\bar{H}$ CHARACTERIZATION

Field Ionizer





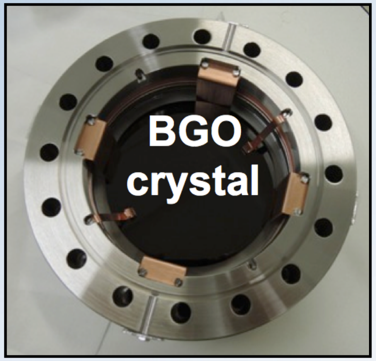
PIPS + Normalization counter



$\bar{H}$ CHARACTERIZATION

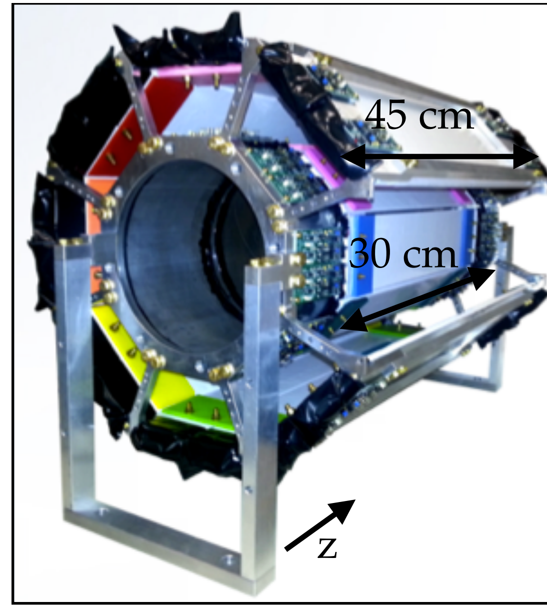
$\bar{H}$ Detector

Solid angle (mixing point - detector): ~0.004%

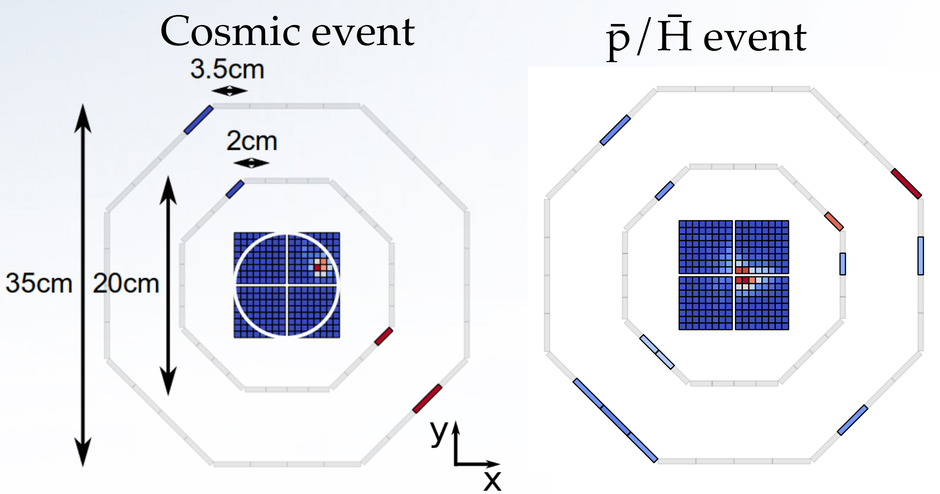


Annihilation: BGO crystal (position sensitive calorimeter)

read out by MchPMT array of 16x16 for position resolution



- 2 layers hodoscope
- 32 (8x4) scintillator bars each
- SiPMs on each side
- axial resol. by time difference (vertex reconstruction capability
- fast timing enables cosmic discrimination
- >50% efficiency, <1% false IDs



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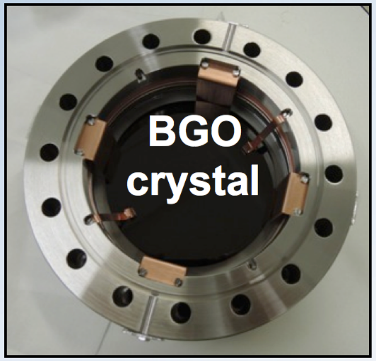

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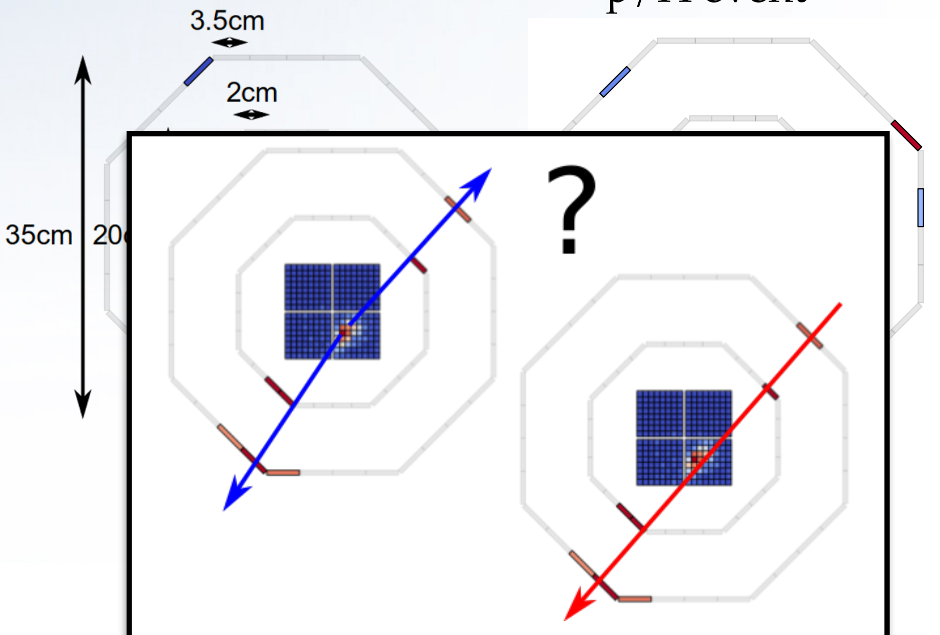
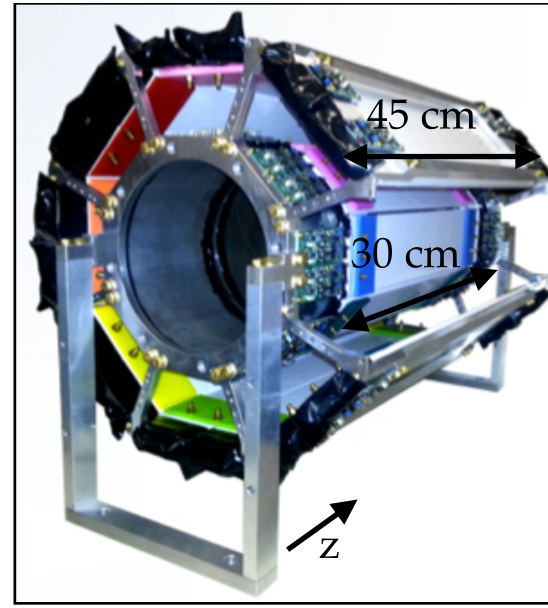
Cosmic event

$\bar{p}/\bar{H}$ event





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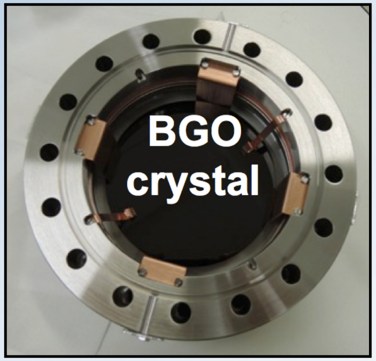

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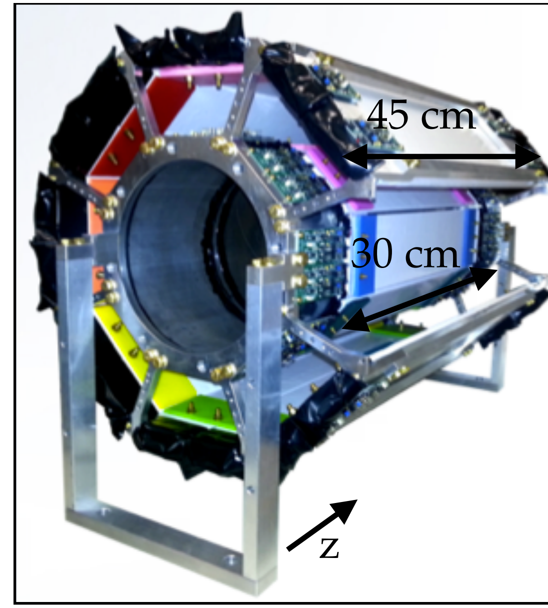

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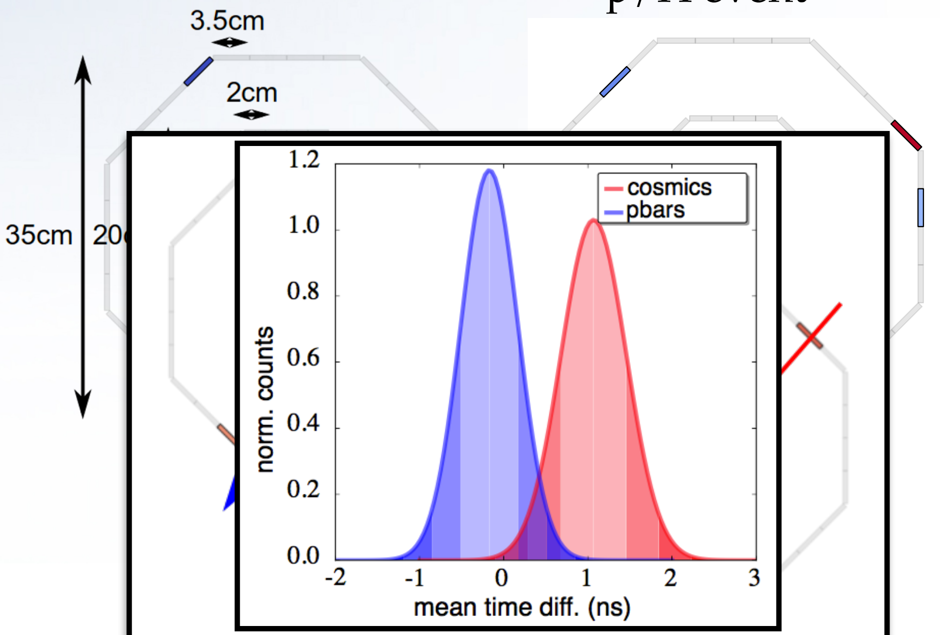


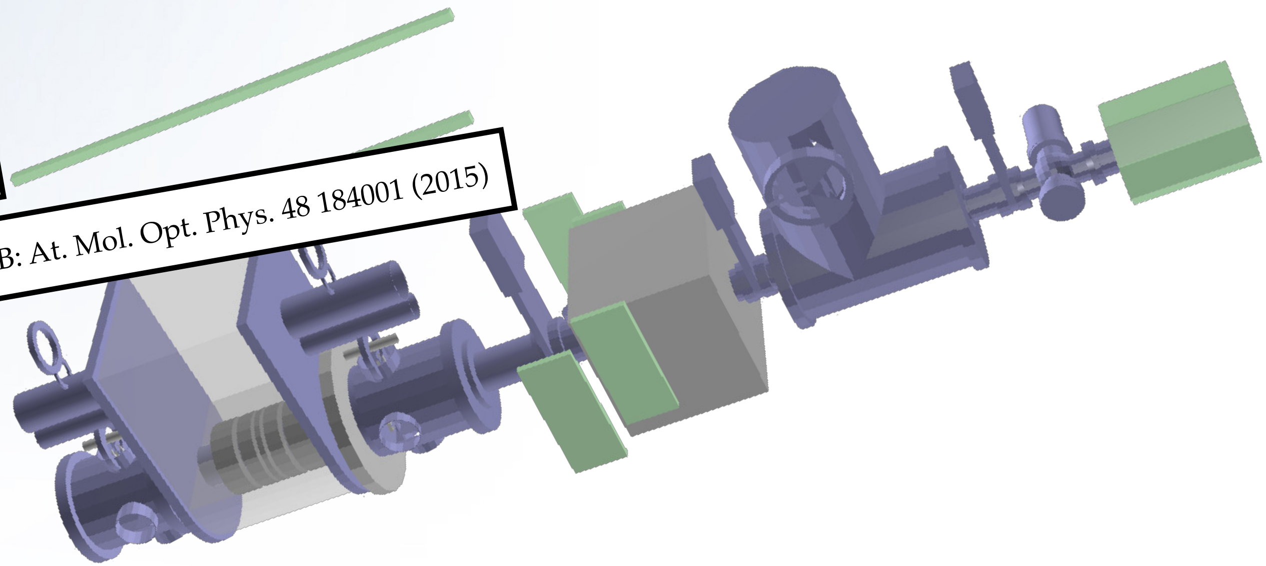
"RESULTS"/STATUS

Status:

- Shorter setup. First probing of the n-state distribution
- Improved detection efficiency
- High background rejection
- Simulation

B. Radics et al., Phys. Rev. A 90, 032704 (2014)

R Lundmark et al., J. Phys. B: At. Mol. Opt. Phys. 48 184001 (2015)



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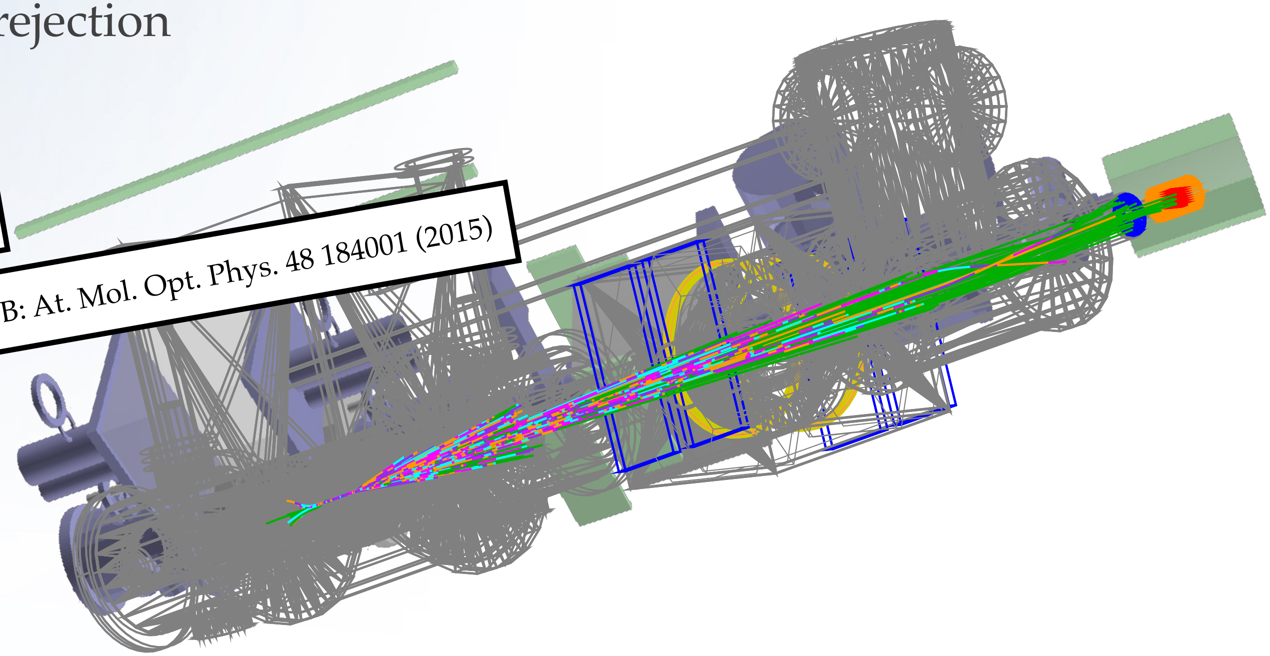

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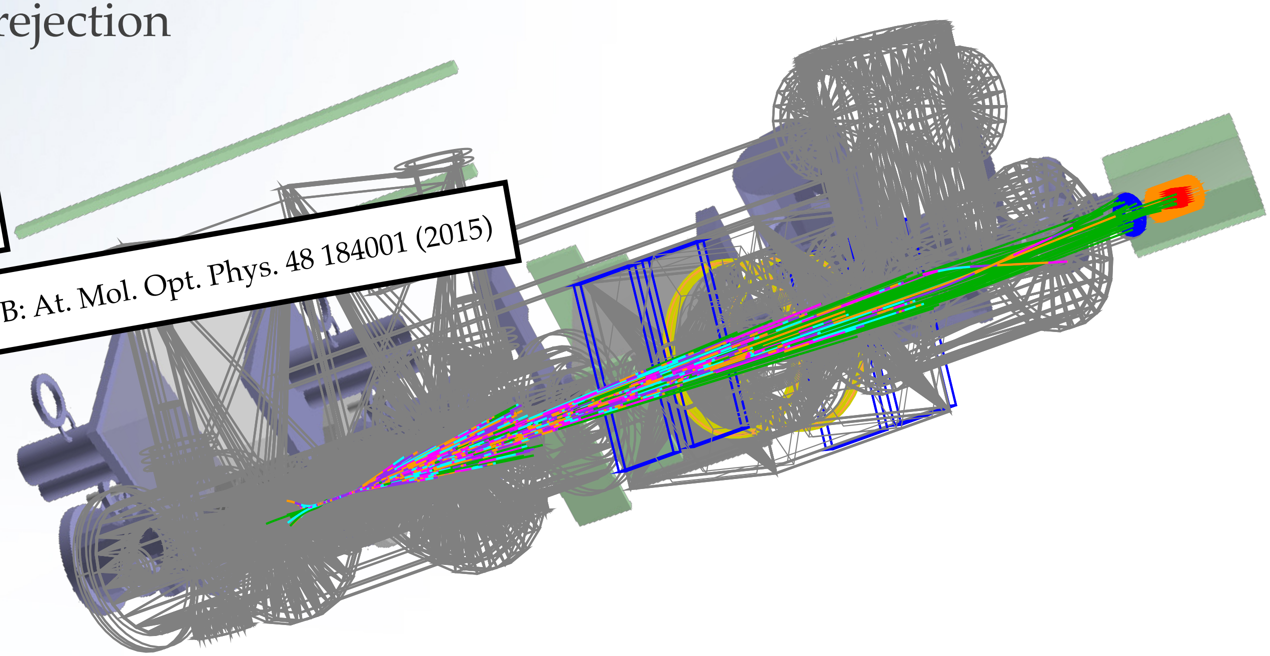
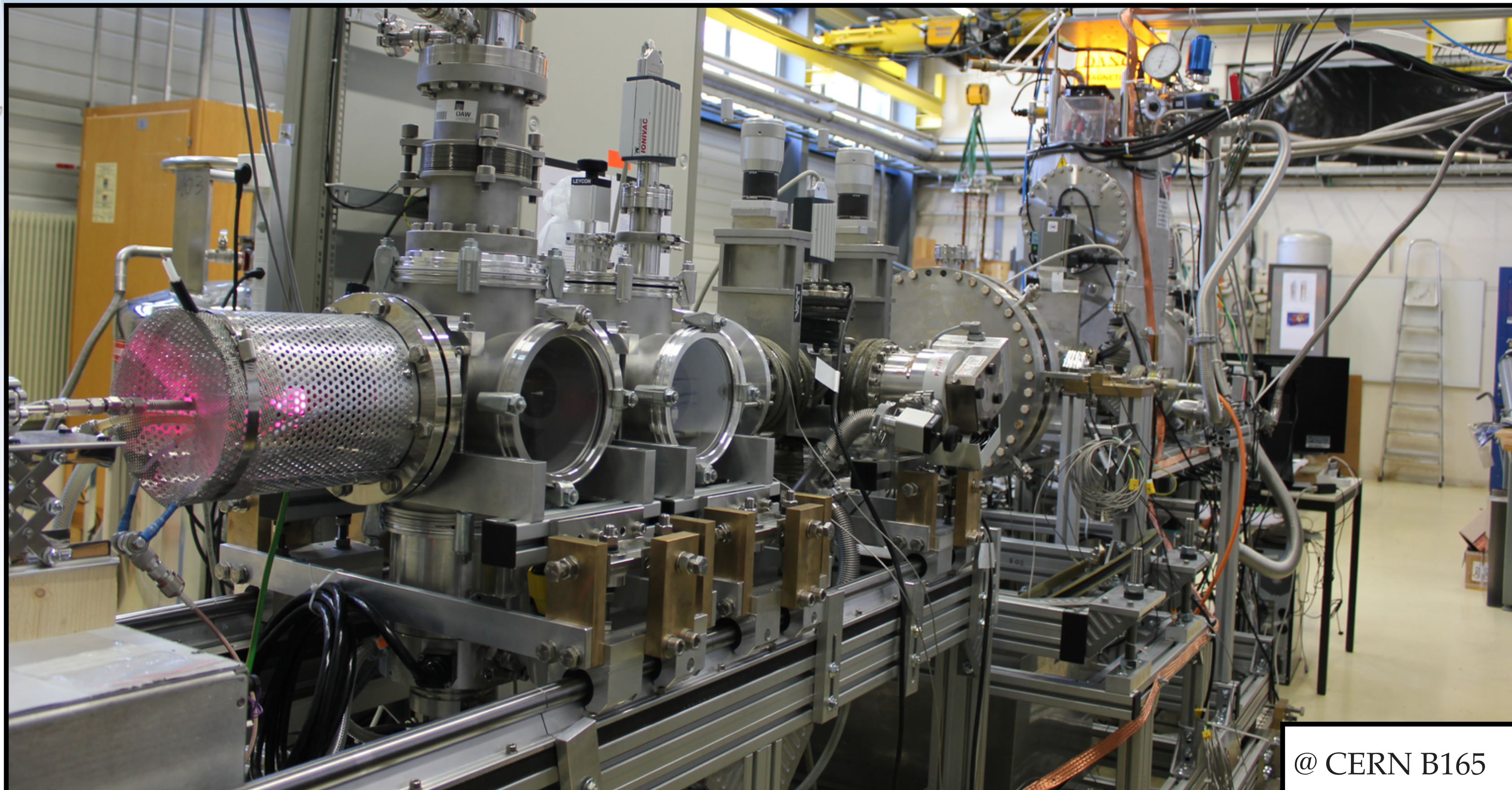


Focus of coming years:

- Deexcitation
- Enhance # of atoms
- Temperature & polarization measurement

ASACUSA (ANTI)HYDROGEN BEAMLINE



@ CERN B165

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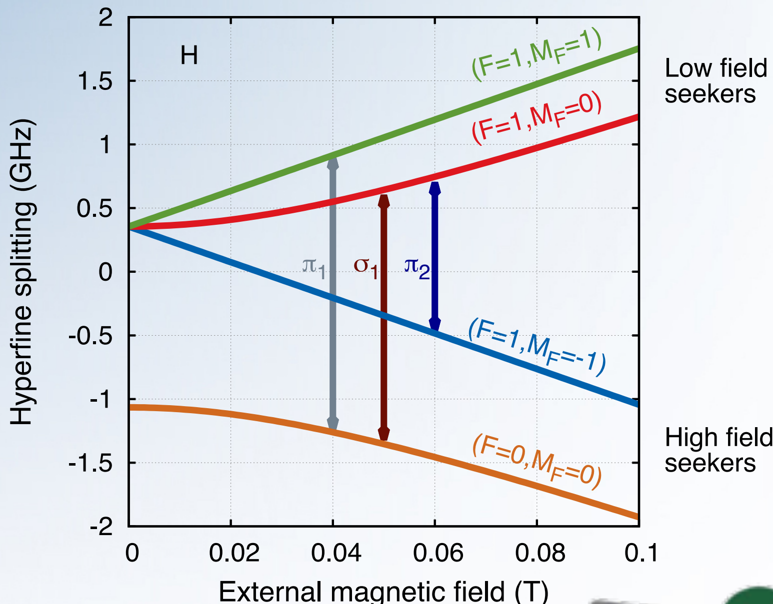
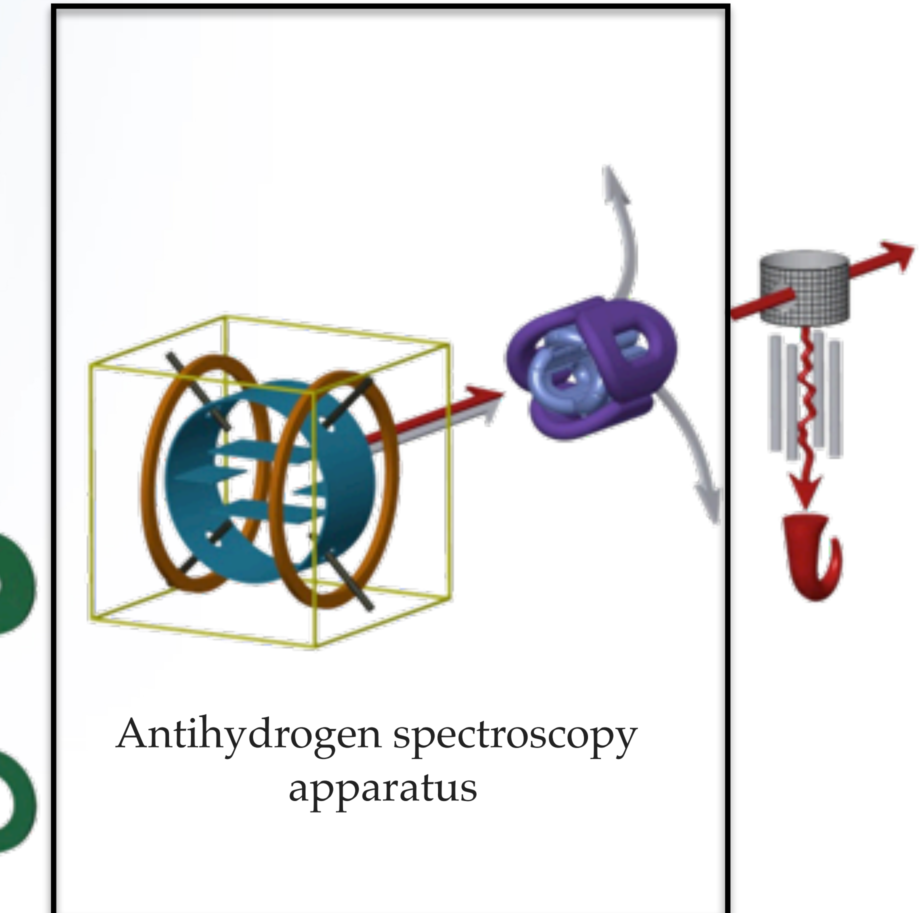
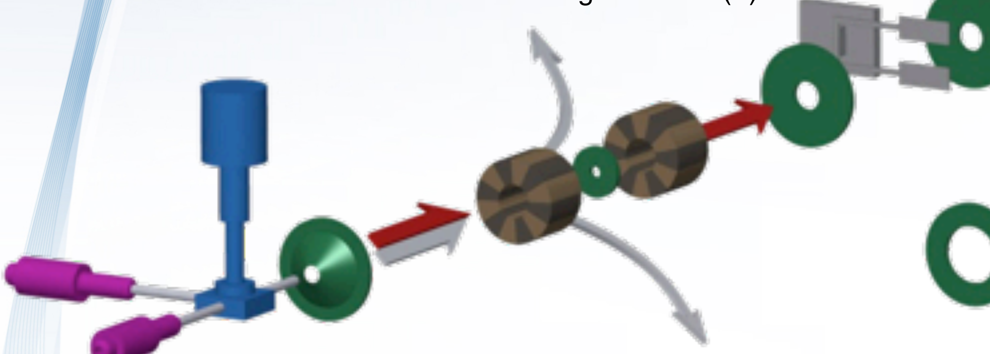
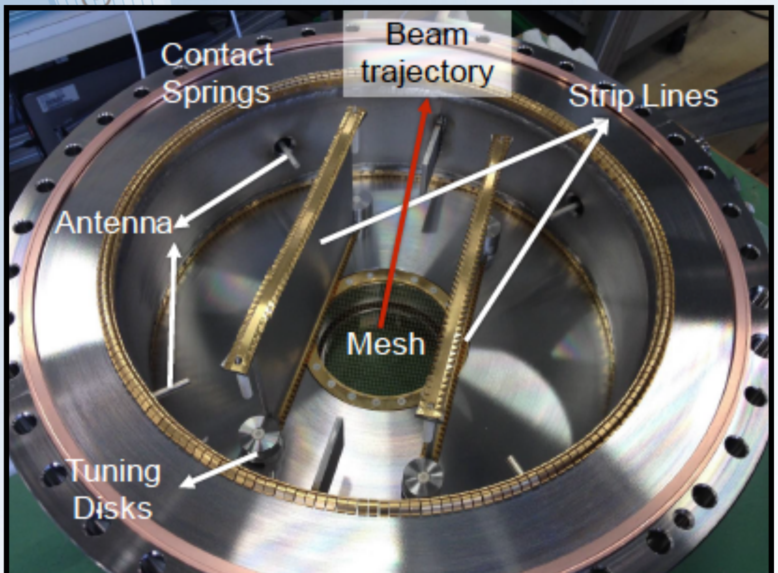


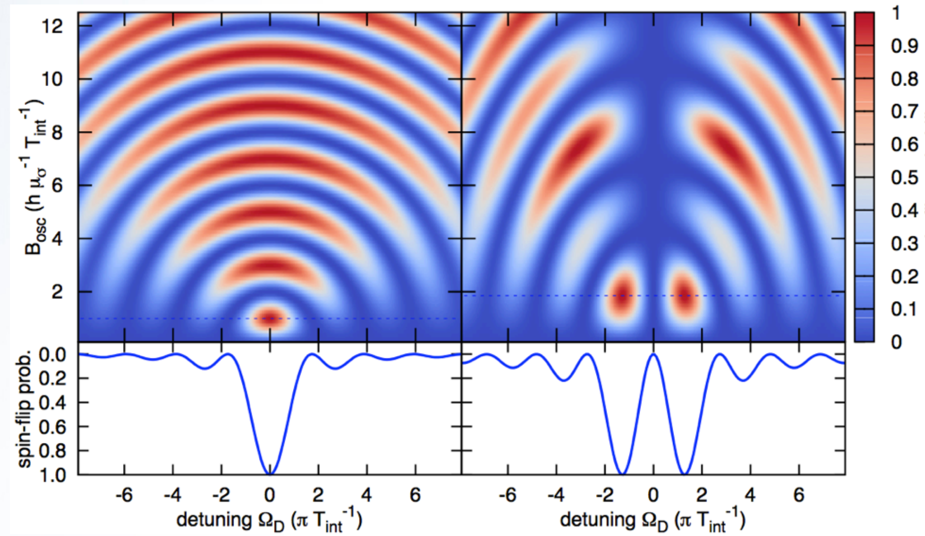


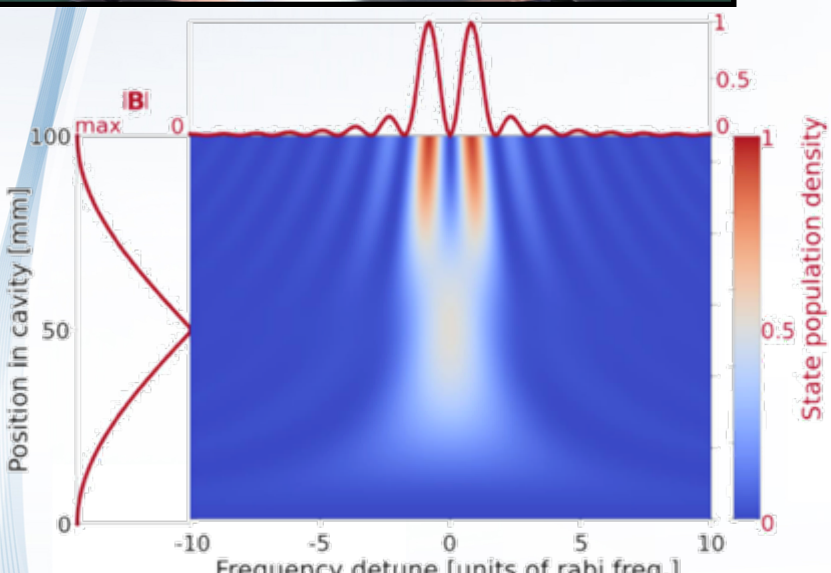


MEASUREMENT OF σ RESONANCE

"strip-line" cavity design







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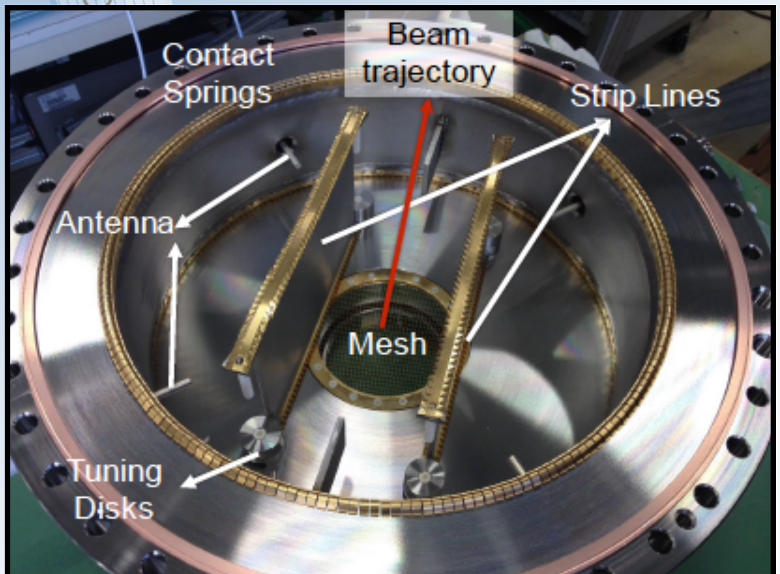
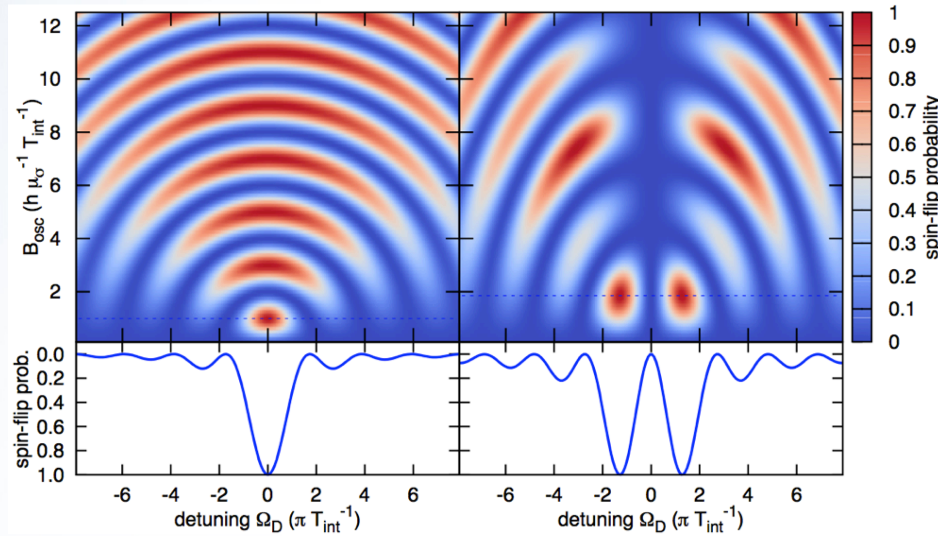
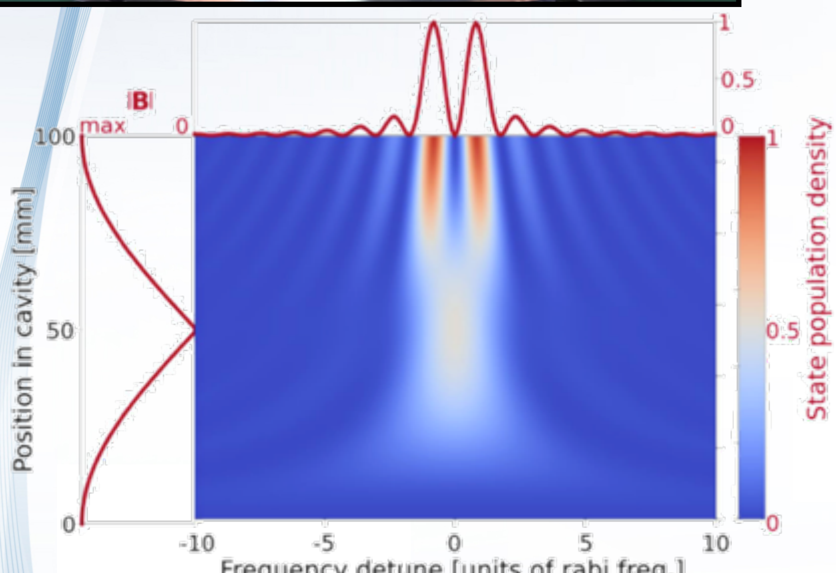
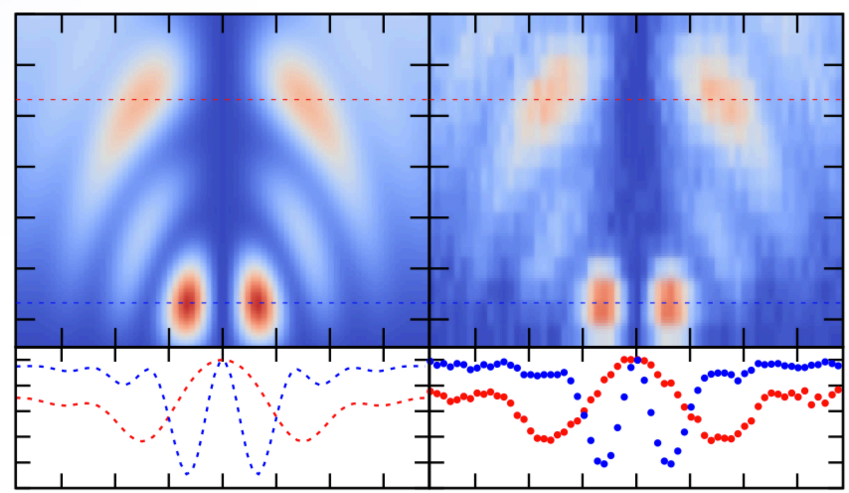
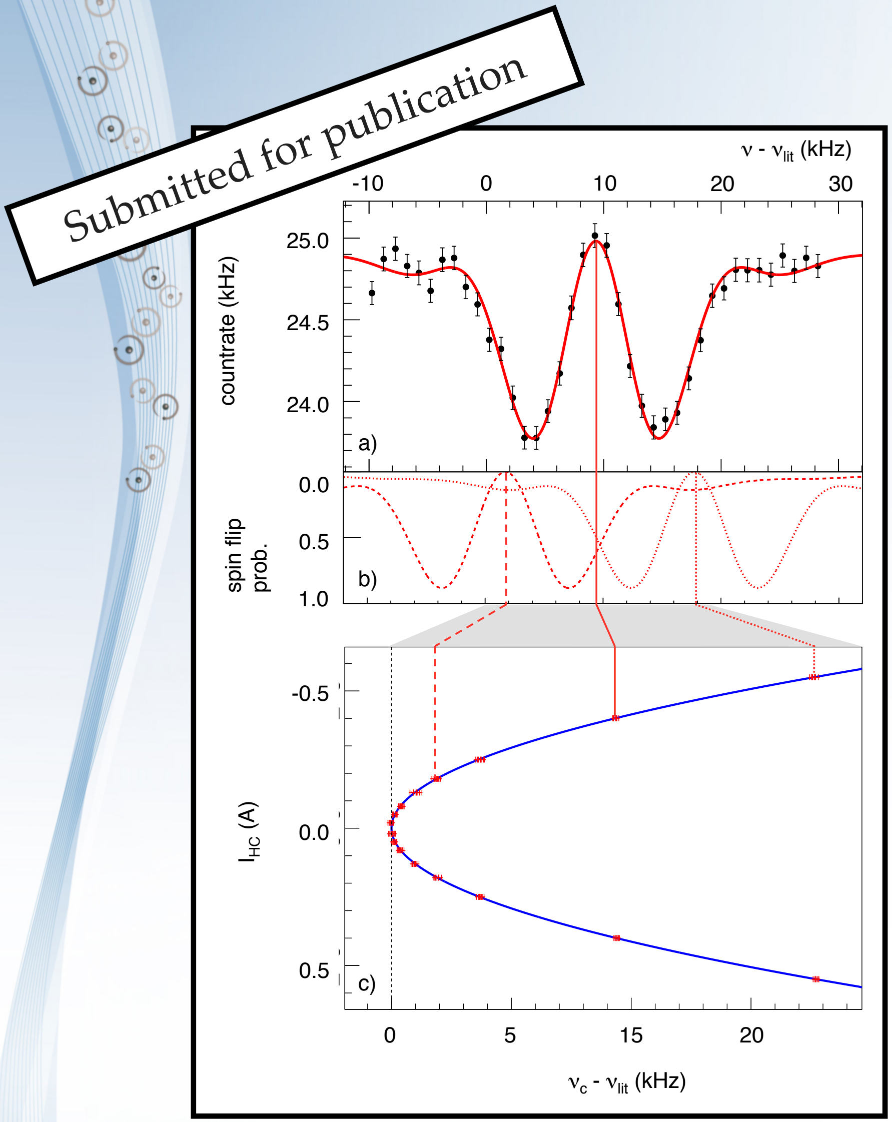








RESULTS



$\Delta\nu/\nu = 2.7$ ppb

$$\nu_{HF} = 1\ 420\ 405\ 748.4(3.4)(1.6)\ \text{Hz}$$

Robust lineshape fit
Extraction of amplitude of oscillatory field, velocity and velocity spread

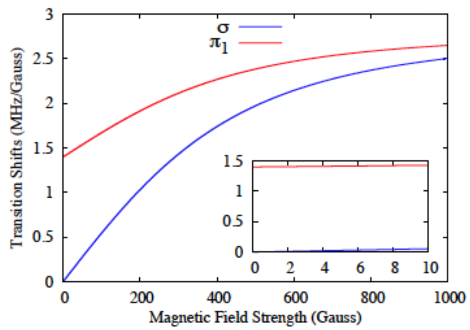
The spectroscopy apparatus if fully commissioned

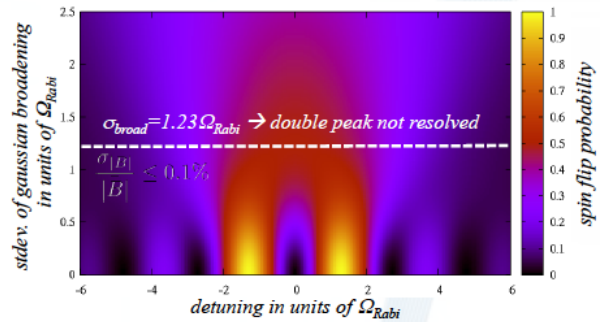
ppm result with antihydrogen should be in reach if enough statistics can be gathered

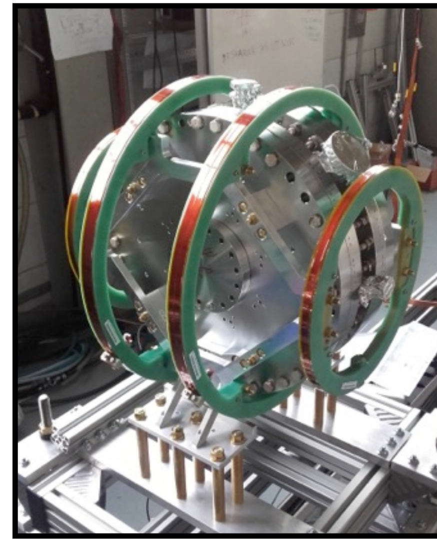
MEASURING π RESONANCE

$$\Delta f = \frac{\partial f}{\partial B}\Delta B \approx \frac{\mu_B}{h}\sigma_B \approx 1.4\frac{\text{MHz}}{\text{Gauss}}\sigma_B$$

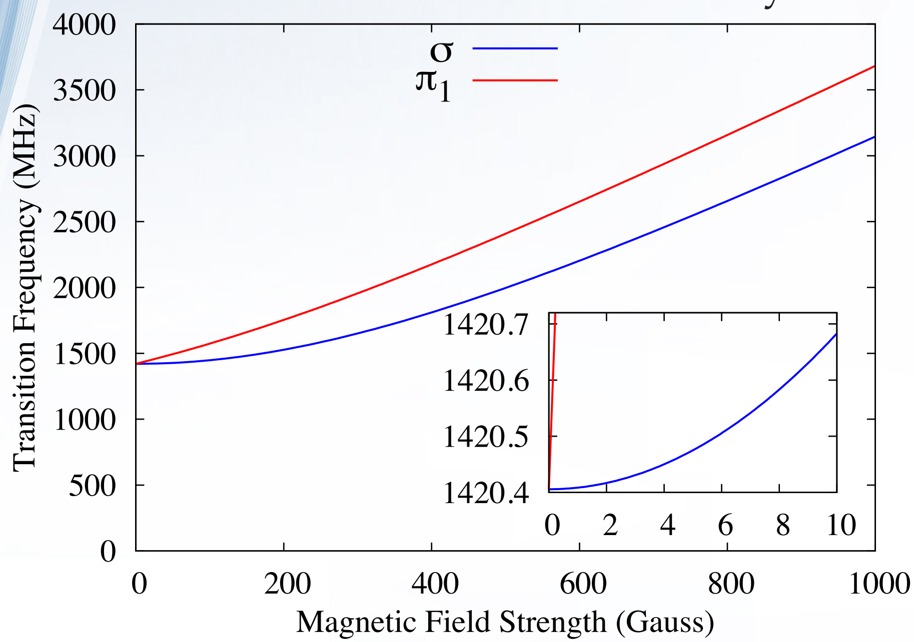
$$\delta f \propto \frac{v_{\bar{H}}}{L_{\text{cav}}} \approx \frac{1\text{km/s}}{0.1\text{m}} \approx 10\text{kHz}$$

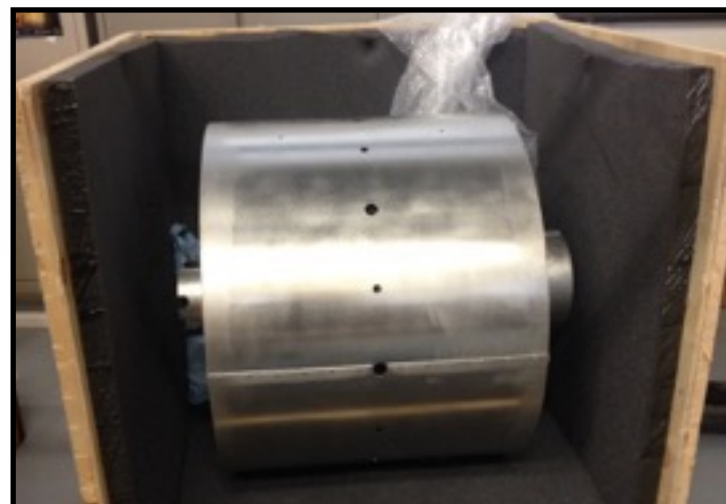






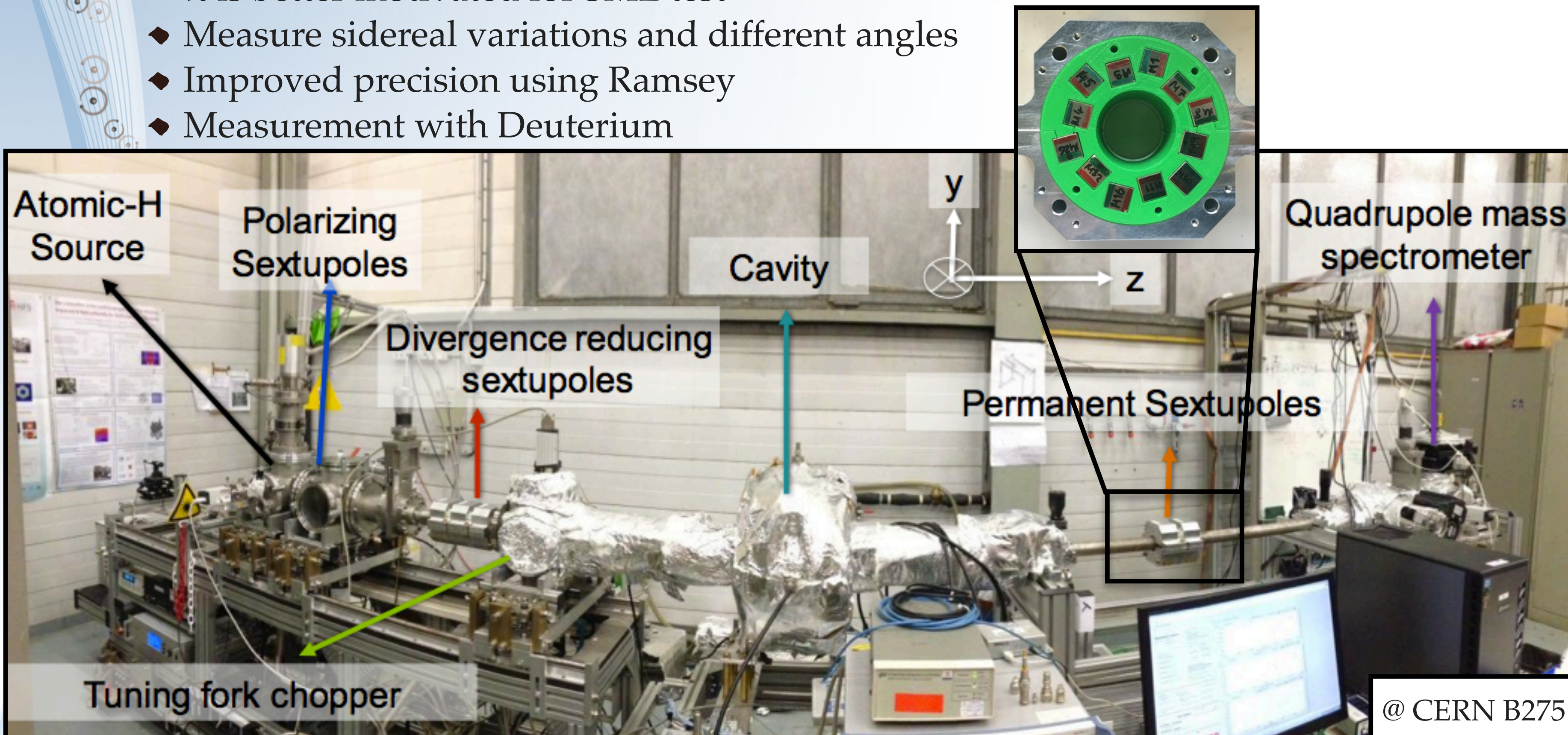
New coil and new 3-layers Mu metal shielding



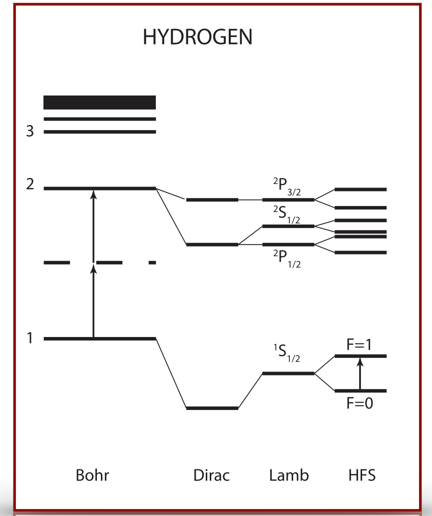


MEASURING π RESONANCE

- π and σ sigma can be measured "simultaneously"
- π is better motivated for SME test
- Measure sidereal variations and different angles
- Improved precision using Ramsey
- Measurement with Deuterium



CONCLUSIONS



First "beam" of $\bar{H}$ observed in field-free region 2.7m away from production

rate 25/hour
high n states
velocity unknown

Since then upgrades: AMT, double CUSP, diagnostic tools, improved detector

Two fronts:

- Characterization of $\bar{H}$ beam —> towards spectroscopy
- Hydrogen beam: ppb measurement achieved on σ transition

Current Focus:

- optimize $\bar{H}$ rate
- check polarization
- determine quantum state distribution
- velocity (time dependent field ionizer, scan of sextupole field)

Full new program with Hydrogen : π measurement (new setup ready), sidereal variations
Further steps: Ramsey, Deuterium


ACCELERATORS
VALIDATING
ANTIMATTER
PHYSICS
Open Positions
in the
AVA Project
Antimatter experiments are at the cutting edge of science. They are, however, very difficult to realise. The AVA project aims at enabling new antimatter experiments, probing the fundamental laws of nature.
Accelerators Validating Antimatter physics (AVA) is the aim of a new European research and training network.
AVA addresses the challenges in antimatter facility design and optimization, beyond state of the art beam diagnostics, and novel antimatter experiments.
The network is currently offering Fellowships to 15 talented, energetic, highly motivated early career researchers who will be employed by the different beneficiary partners across Europe. Possibilities for enrolling into a PhD programme exist.
Each Fellow will benefit from a wide ranging training that will take advantage of both local and networkwide activities. Excellent salaries will be offered.
Application deadline:
31st January 2017
Contact and further detail:
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