Fundamental Symmetries

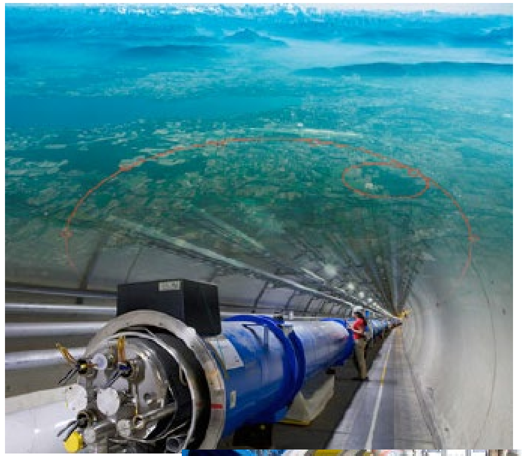
Austrian Roadmap Roundtable Meeting

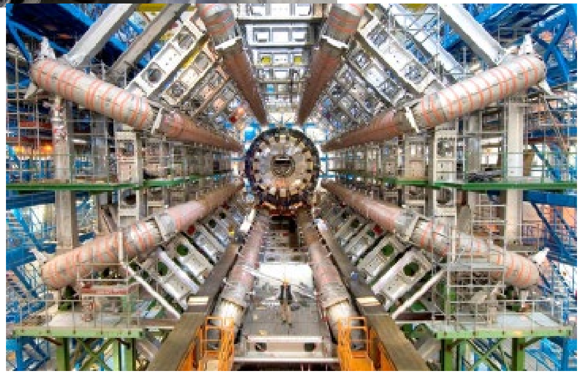
10/6/2024

D. Murtagh

New knowledge in subatomic physics

- High energies
  - Direct observation





- Low energies
  - Precision experiments

Exotic Atoms

- Antihydrogen, muonium, positronium :
  - QED
  - Gravitational Interaction of antimatter
  - Fundamental Symmetries

Exotic Atoms

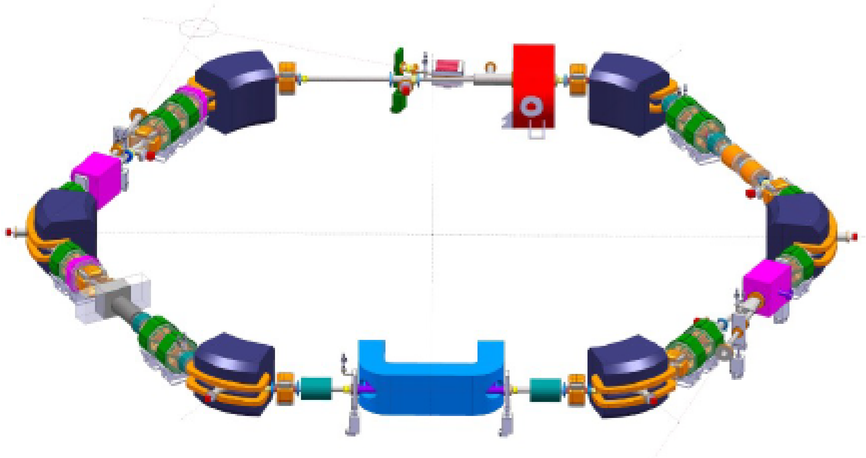
- Antihydrogen, muonium, positronium :
  - QED
  - Gravitational Interaction of antimatter
  - Fundamental Symmetries
- Observed matter-antimatter asymmetry in nature

$$\eta = \frac{n_b - n_{\bar{b}}}{n_\gamma} \sim 6.1 \times 10^{-10}$$

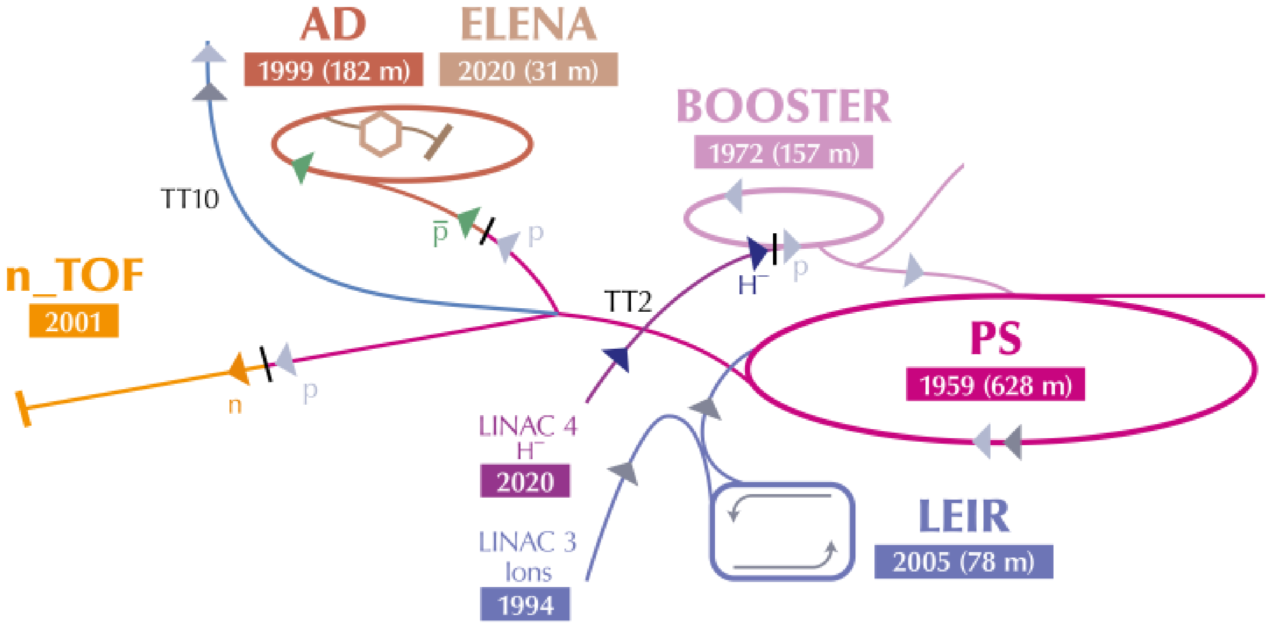
  - Where n_b and $n_{\bar{b}}$ are number densities of baryons and antibaryons and n_γ the number density of cosmic background radiation photons

Komatsu, E., J. Dunkley, M. R. Nolta, C. L. Bennett, B. Gold, G. Hinshaw, N. Jarosik, et al. 'FIVE-YEAR WILKINSON MICROWAVE ANISOTROPY PROBE OBSERVATIONS: COSMOLOGICAL INTERPRETATION'. *The Astrophysical Journal Supplement Series* 180, no. 2 (February 2009): 330–76. https://doi.org/10.1088/0067-0049/180/2/330.

The Antiproton Decelerator + ELENA

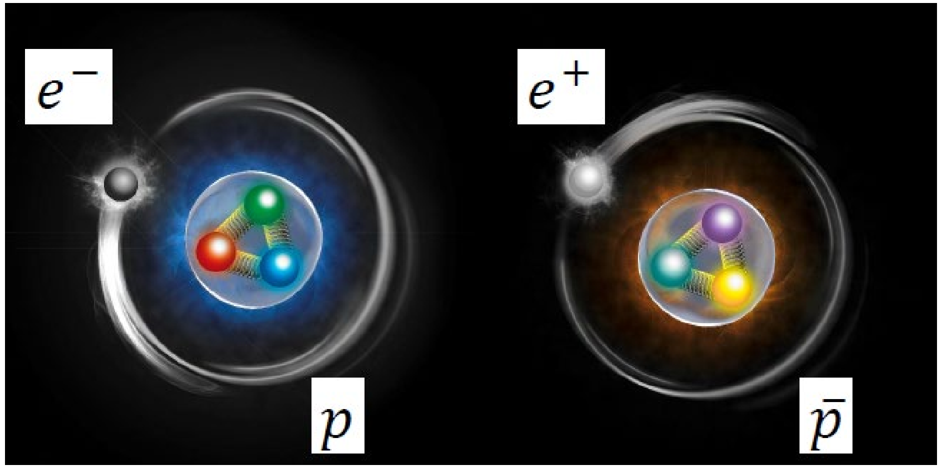


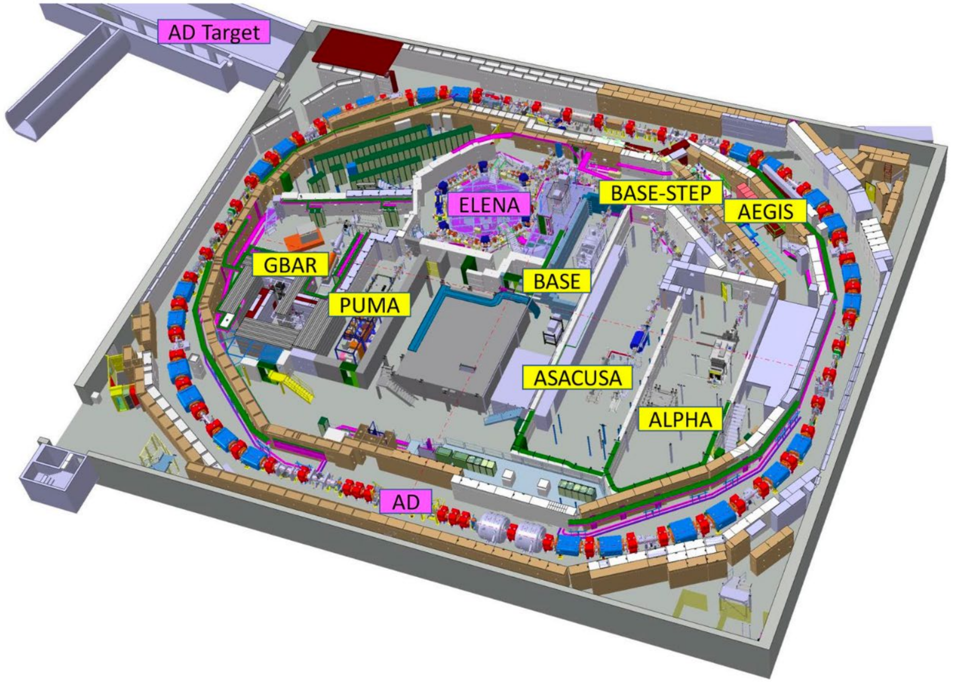
Energy range, MeV	5.3 - 0.1
Intensity of ejected beam	1.8×10^7
$\varepsilon_{x,y}$ of extracted beam, π·mm·mrad, [95%], standard	4 / 4
Δp/p of extracted beam, [95%], standard	$8 \cdot 10^{-3}$



The ASACUSA-Cusp Experiment

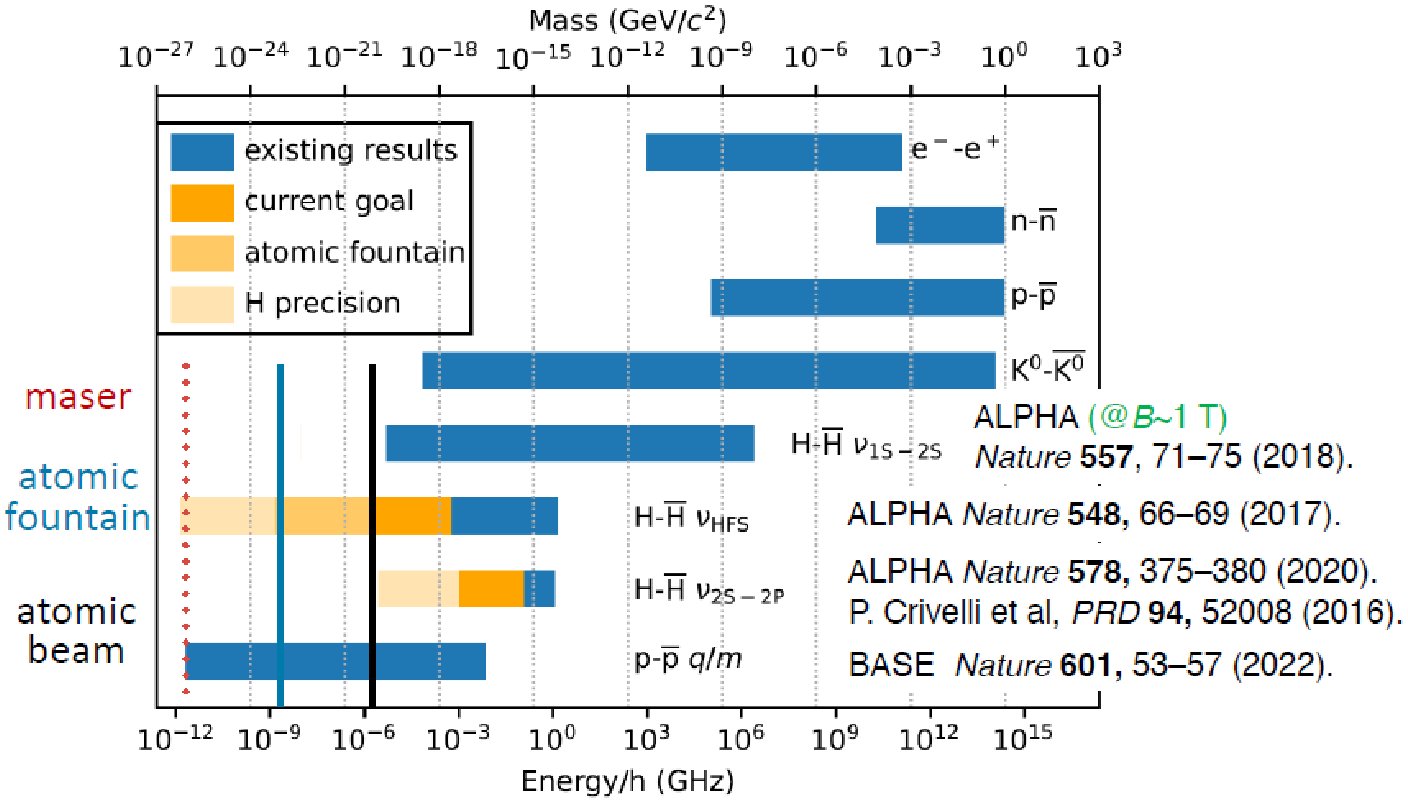
- The ASACUSA Cusp experiment focuses on producing a beam of antihydrogen for the measurement of the transition frequency ground state hyperfine splitting in a **field free region**.





Why the HFS of antihydrogen

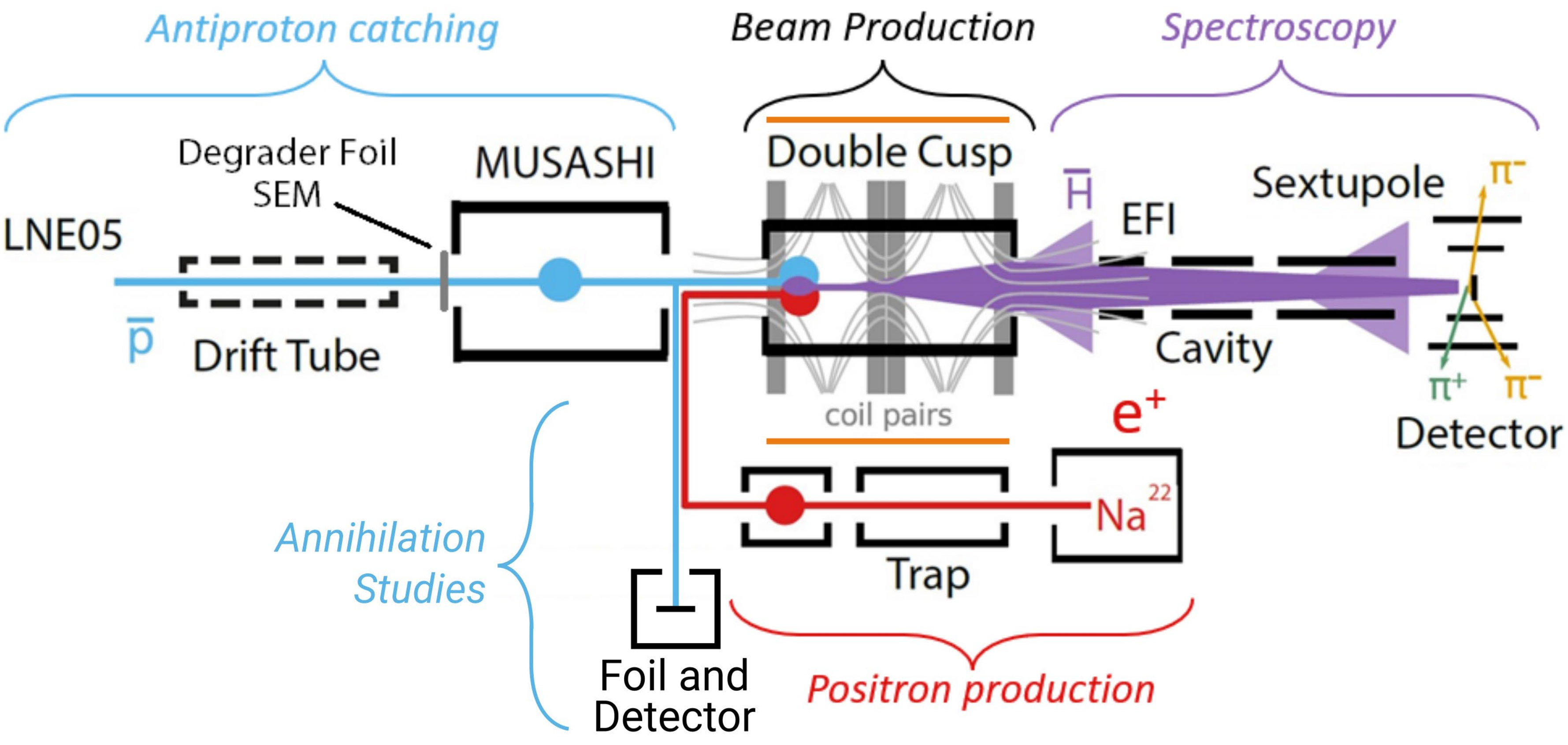
- Key :
  - Right edge: value
  - Bar length: relative precision
  - Left edge: absolute sensitivity
    - Blue: measured
    - Orange: planned
    - Yellow: potentially measurable

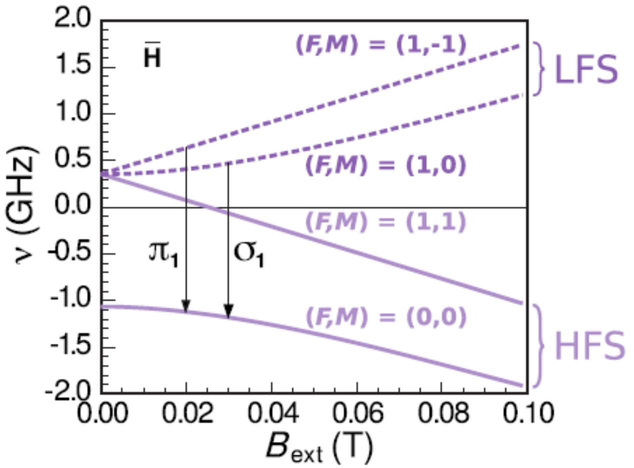


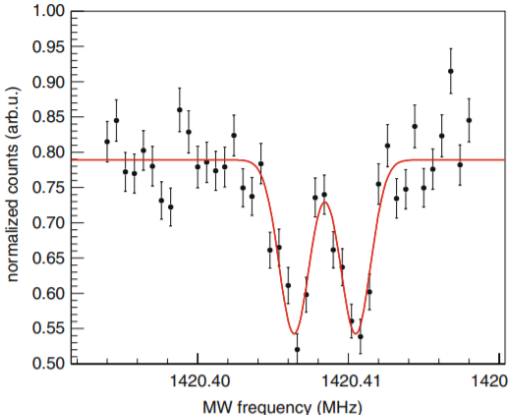
See https://arxiv.org/2111.0456v2 for details

P.A. Zyla et al. (Particle Data Group), Prog. Theor. Exp. Phys. 2020, 083C01 (2020)

$$\bar{p} + e^+ + e^+ \rightarrow \bar{H} + e^+$$





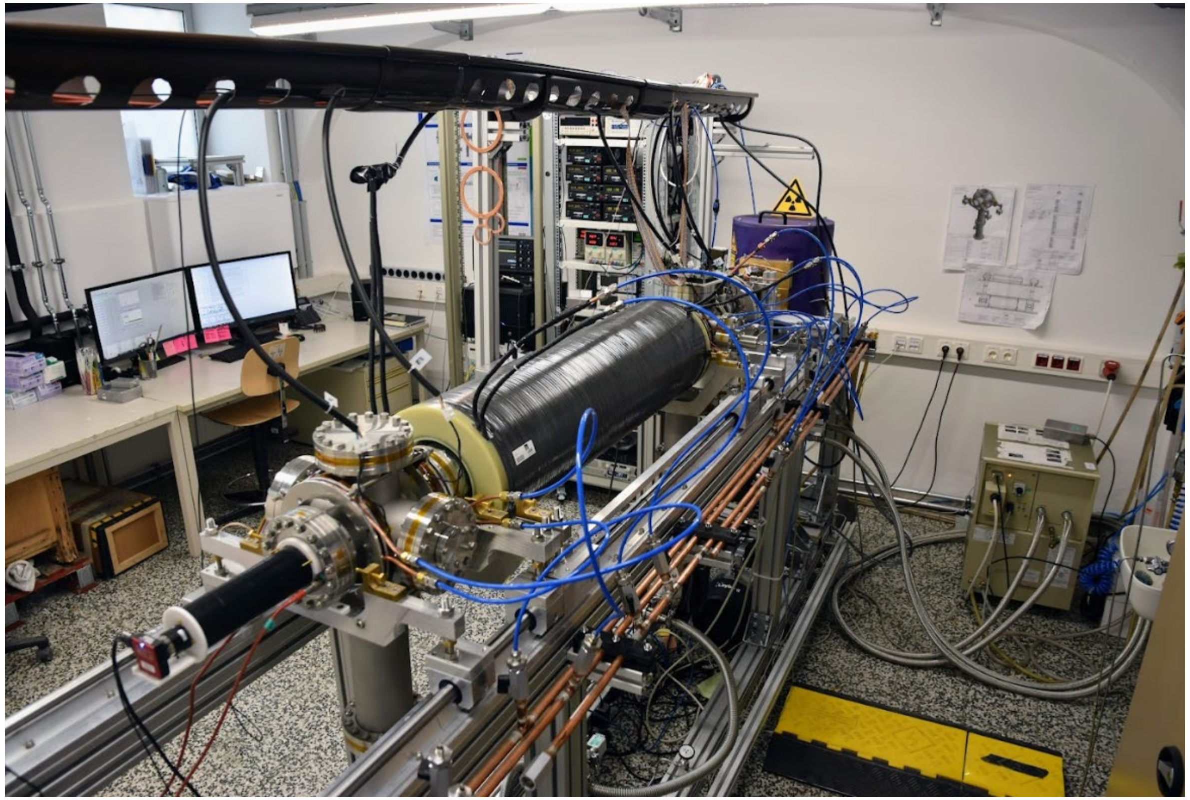


Future program

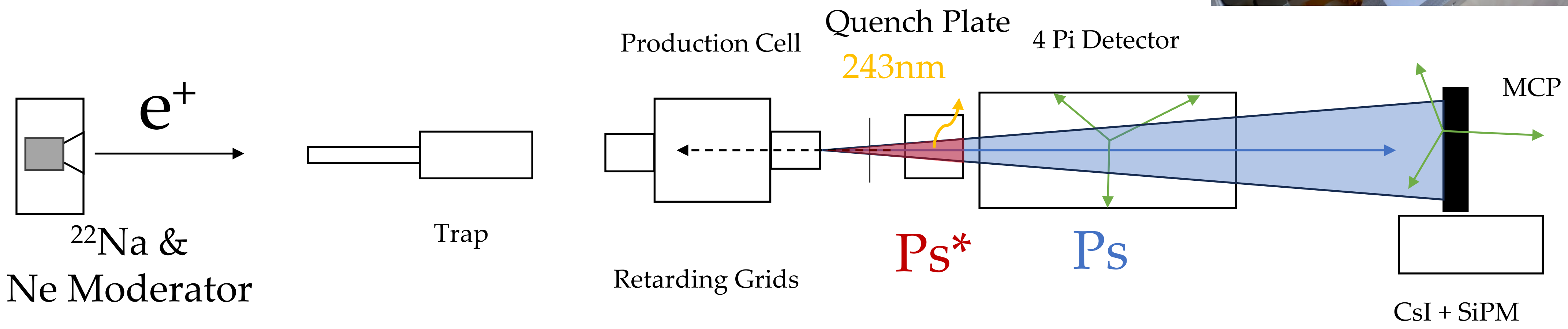
- ASACUSA plan to measure the GS-HFS in beam to the highest possible precision (ppm → ppb)
  - R&D with H to produce ultra cold beams → below ppb
  - Community aims (ALPHA) $\overline{\mathrm{H}}$(1S→2S) precision goal 10^{-14} estimated by 2040
- Antihydrogen is the simplest stable antiatom → add complexity
  - Antihydrogen chemistry → $\overline{\mathrm{H}}^{+}$($2e^{+}$, pbar), $\overline{\mathrm{H}}_2^{-}$($1e^{+}$, 2pbar), $\overline{\mathrm{H}}_2$($2e^{+}$, 2bar).
  - Community interest in $\overline{\mathrm{H}}_2^{-}$
  - We don't know how to efficiently make these states yet → formation process is the key.
- Charged molecular species are stable, trappable and have internal structure so could be laser cooled.
- Low number of antideuterons produced by the AD
  - measurements with antideuterium ($\overline{\mathrm{D}}$)

Positron beamline @ SMI

- Laboratory based positron beams are generated by a ^{22}Na source moderated by a Neon ice
- ^{22}Na sources are only available from iThemba labs (SA)
  - Potential problems in the future if production halts.



Measuring rare decays



- Previous 'ALP' searches and CP tests have formed Ps in a material e.g. Aerogel and not made use of 'new' beam technology
- By producing a beam of 2S positronium a quench plate can be used to make a start signal for accurate lifetime measurements
- Detecting the 243nm photon (difficult) would mean searches for exotic decays are possible

P.A. Zyla et al. (Particle Data Group), Prog. Theor. Exp. Phys. 2020, 083C01 (2020) and 2021 update (https://pdglive.lbl.gov/DataBlock.action?node=S029AXD)

Summary

- Current activates :
  - ASACUSA antihydrogen experiment
    - Measurements of GS-HFS & antiproton annihilation
  - Positron beam at SMI
    - Measurements of Ps molecular states
    - Measurement of the 3γ-ray distribution from O-Ps
- the long-term goals:
  - Precision measurement of antihydrogen GS-HFS in a low magnetic field region (ppm → ppb)
  - Place high precision (> 10^{-5}) Limits on CP/CPT violation from Ps annihilation
- facilities which will be needed to achieve this:
  - The antiproton decelerator + ELENA is the only available source of low energy antiprotons suitable for antihydrogen
  - Continued reliable production of large (2GBq) ^{22}Na sources is required for positron production.
- Synergies with other groups in Austria, and other large-scale efforts
  - Atominstitut → (spectroscopy and experimental techniques , laser spectroscopy of ultra-cold hydrogen, theory).
  - HEPHY → potential dark matter studies with Ps, H and Hbar, Cryo4ppp lab, particle detection techniques.
  - VERA and MedAustron → detector tests.
  - ASACUSA works closely with Japan (Tokyo, Hiroshima, RIKEN), Italy (INFN, Milan (P+U), Brescia), Denmark (Aarhus), UK (ICL), Germany (JGU, Max Plank) and makes use of CERN facilities. Co-spokesperson E. Widmann Austria, (SMI)