Measuring the hyperfine splitting in anti-hydrogen to test for CPT violation

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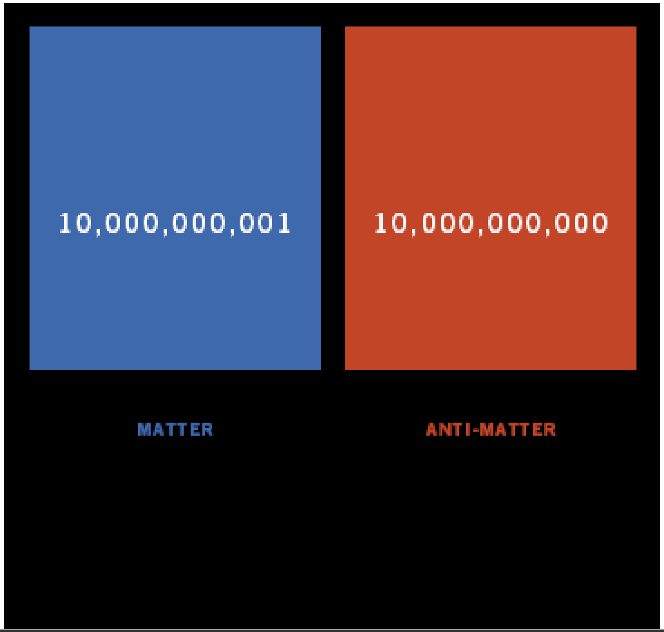
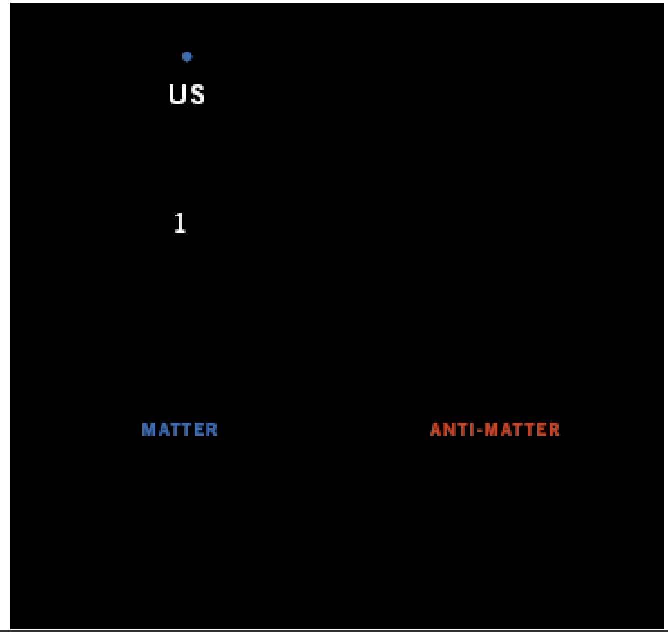
Image credits: European Space Agency & NASA





Matter : Anti-Matter

We only need a $1:10^{-10}$ asymmetry since matter:photon density from astronomical measurements is ~6×10^{-10}.

Image credit: interactions.org

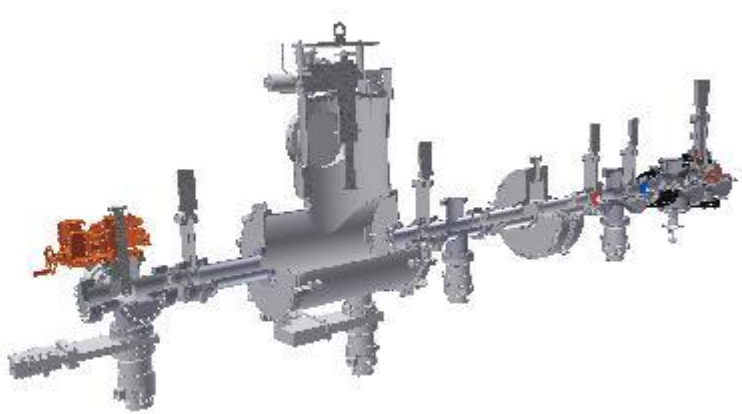
Standard model: exactly 50:50

- Why? Because it has CPT invariance.
- We need CPT violation to explain the dominance of matter

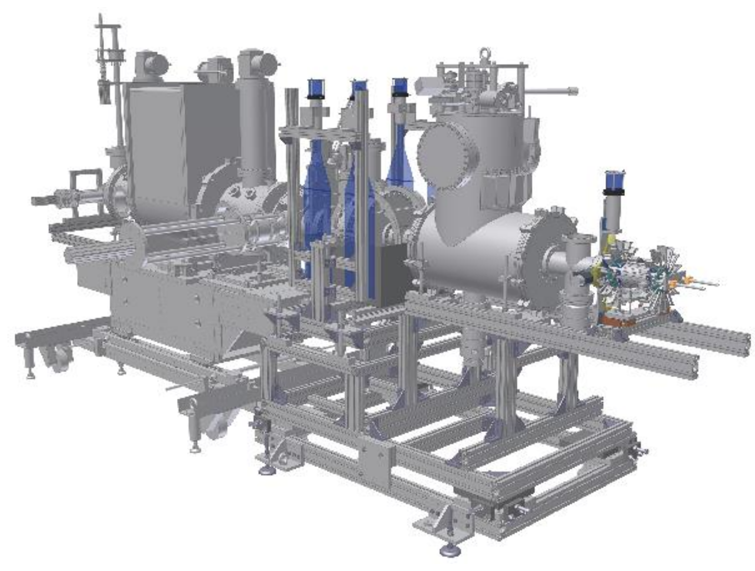
Something's gotto give

Two parts of the experiment

Hydrogen Beam

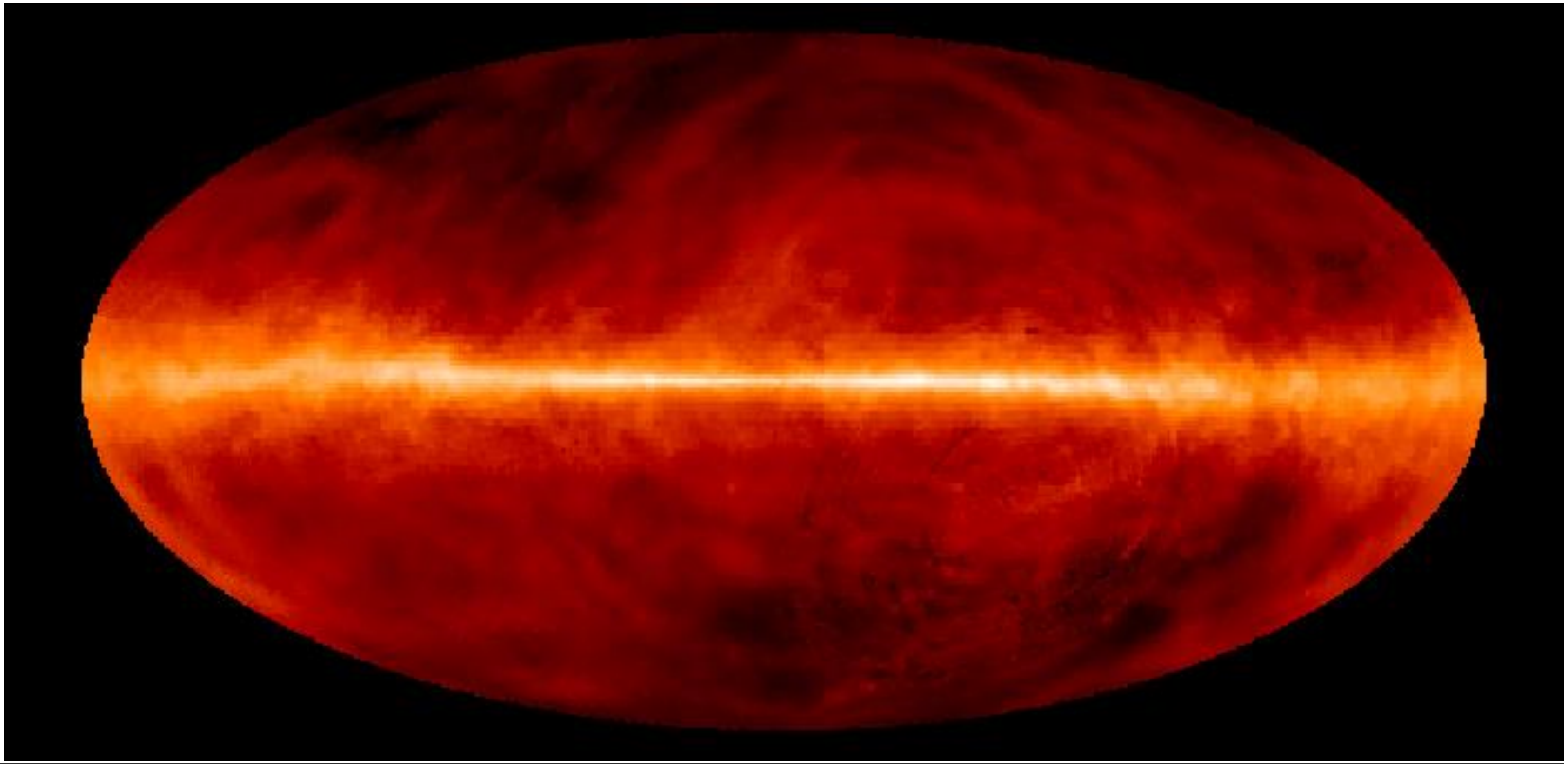


Anti-Hydrogen Beam



Outline

- Hyperfine splitting in H and $\bar{H}$
- Hydrogen beam setup
- Outlook

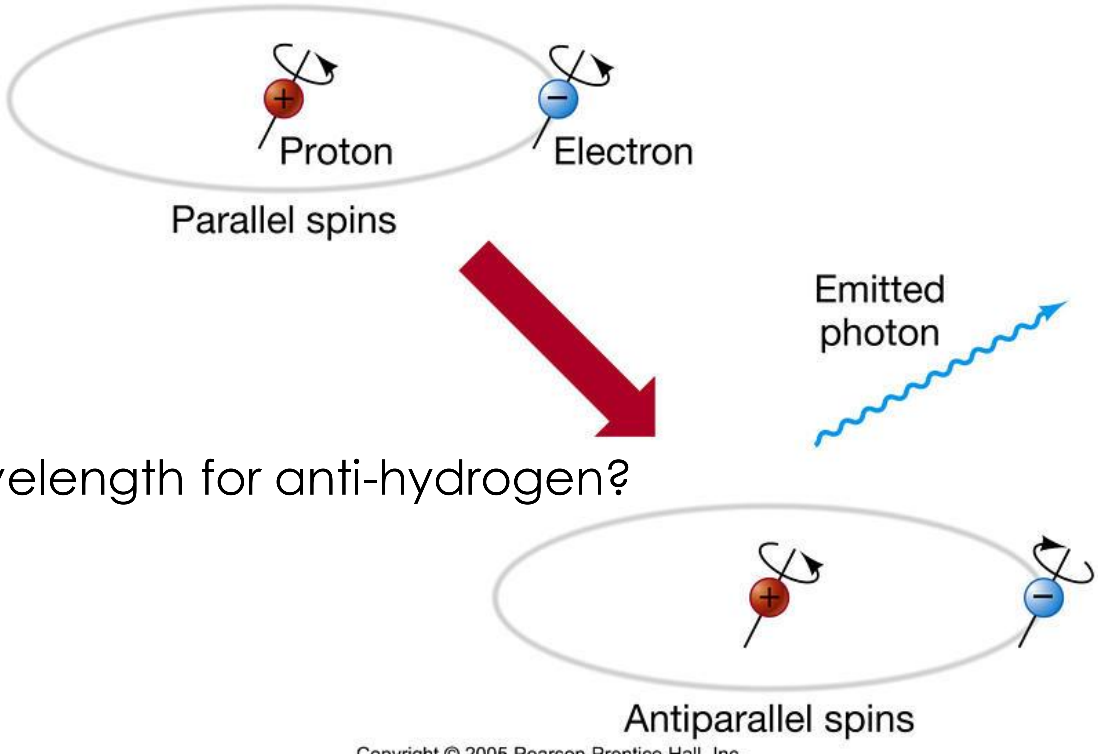


Hyperfine Splitting

Hyperfine splitting gives rise to the famous 21 cm line

Image credit: NASA APOD

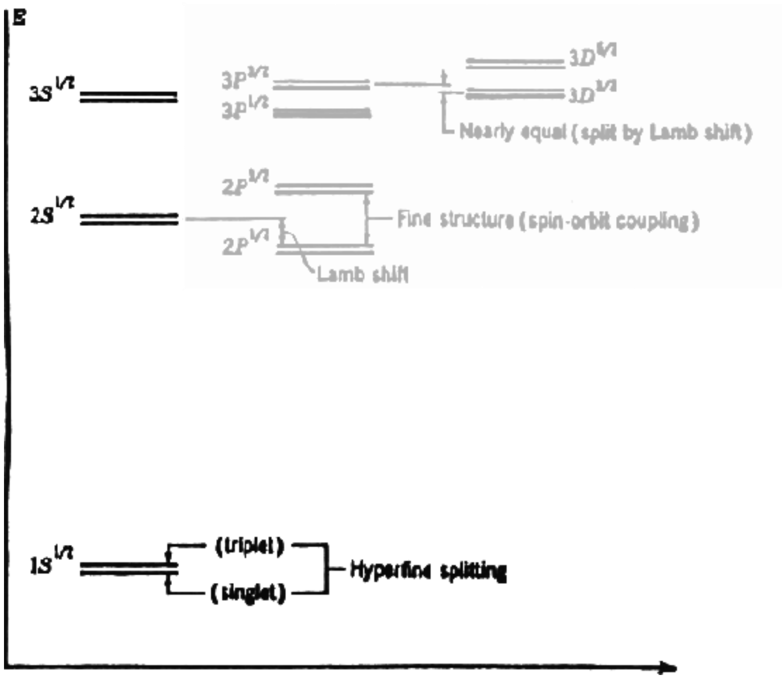
Origin of Hyperfine splitting



Is this the same wavelength for anti-hydrogen?

Hyperfine splitting of Ground State

Without external field



External B field

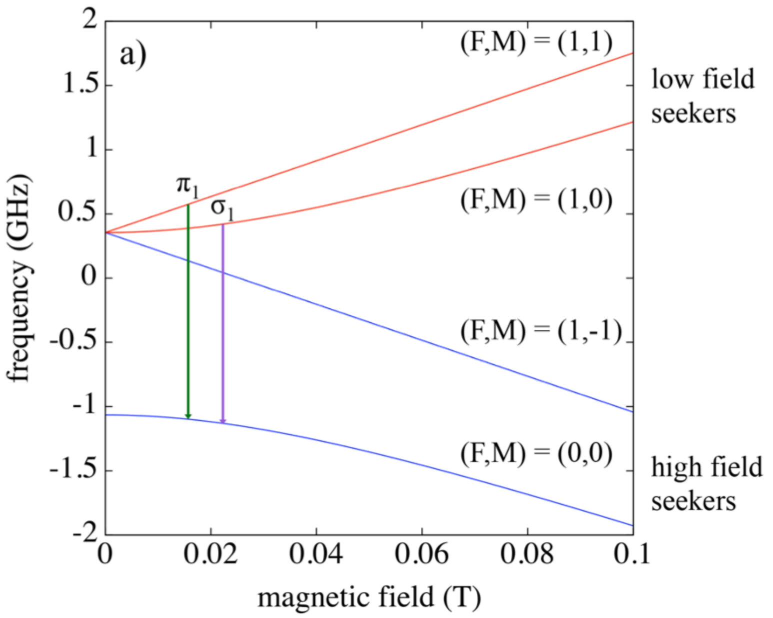
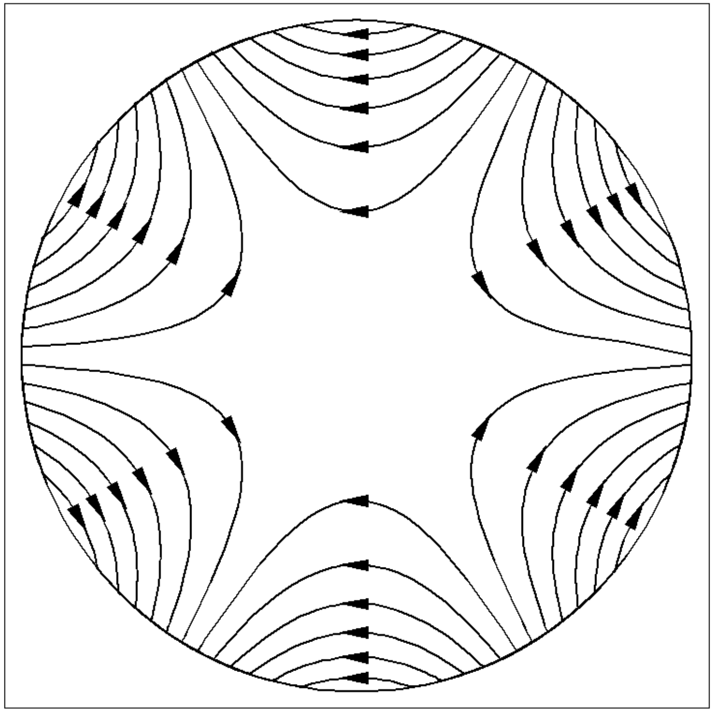


Image credit: pha.jhu.edu

Polarization



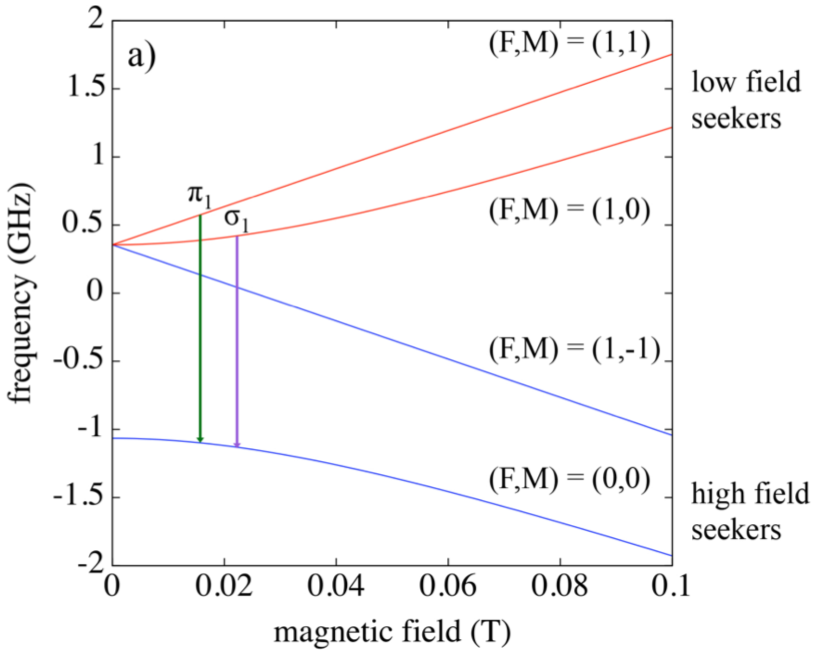
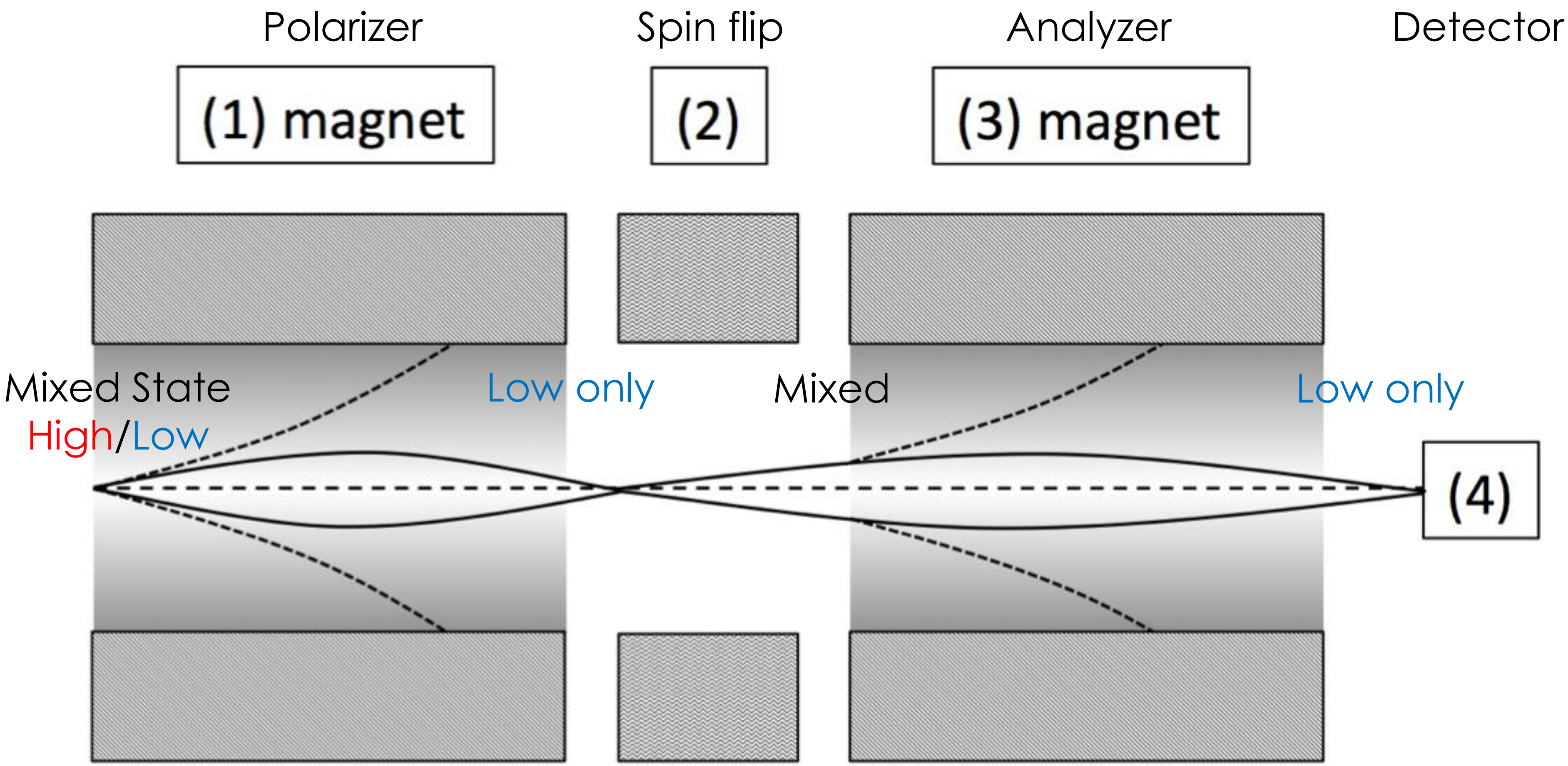
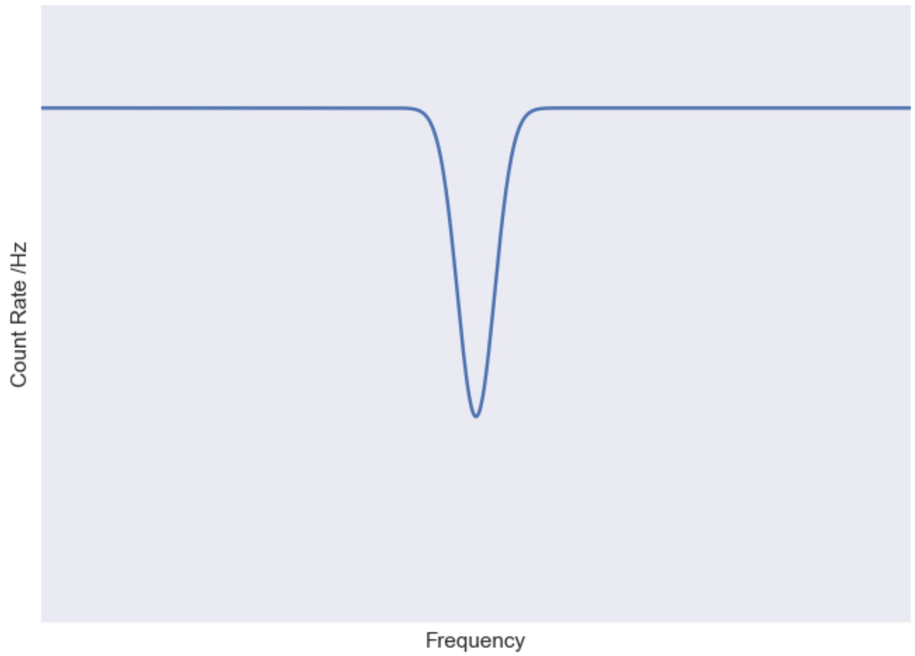


Image credits: cds.cern.ch

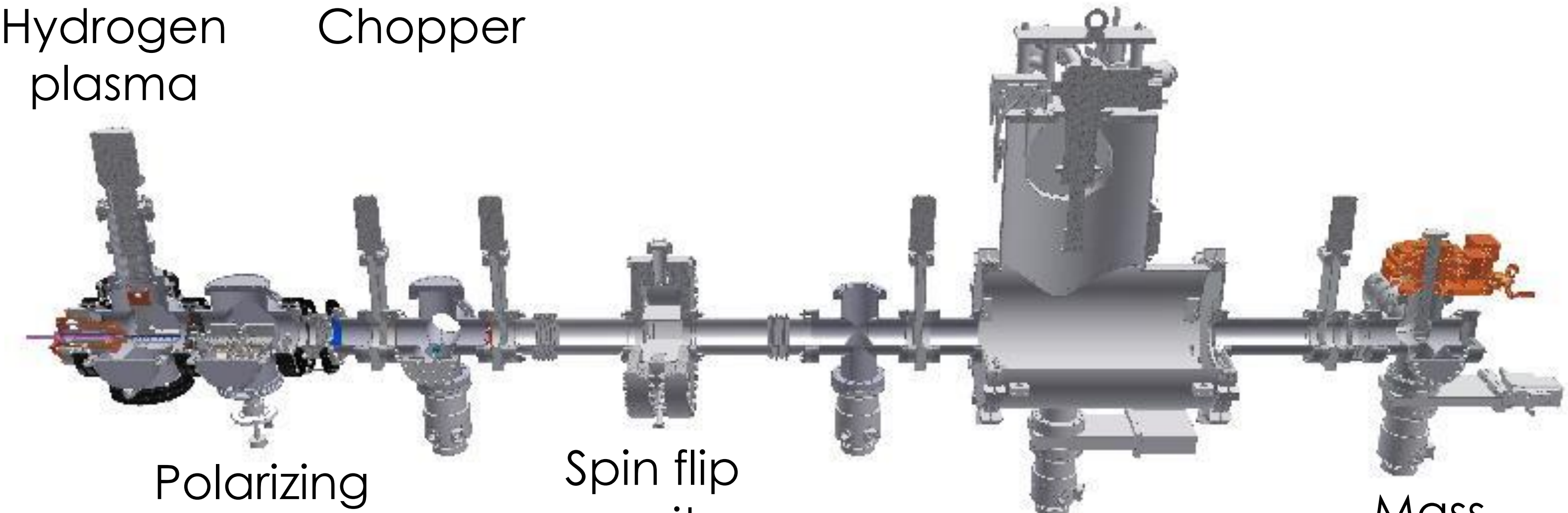
Experimental Outline



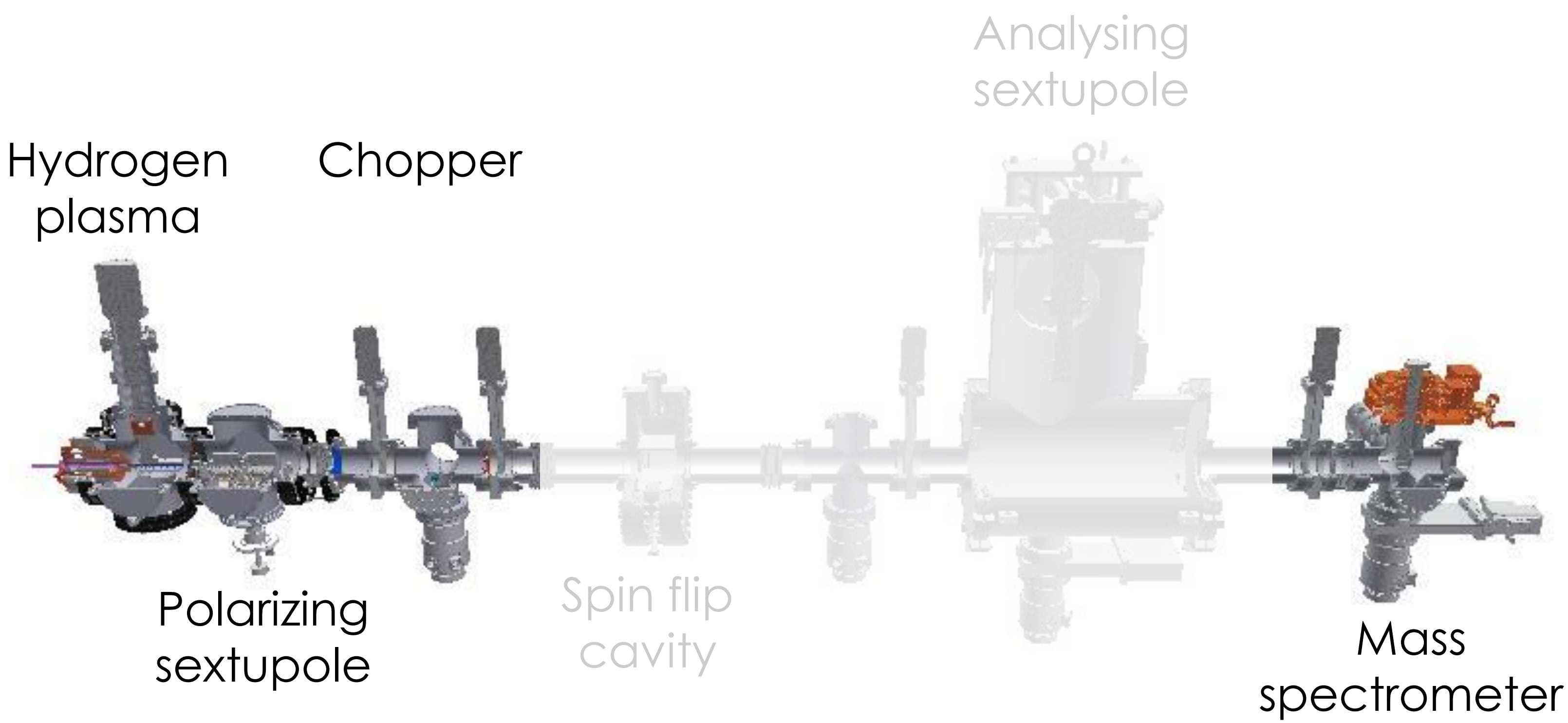
Meanwhile, at the detector…



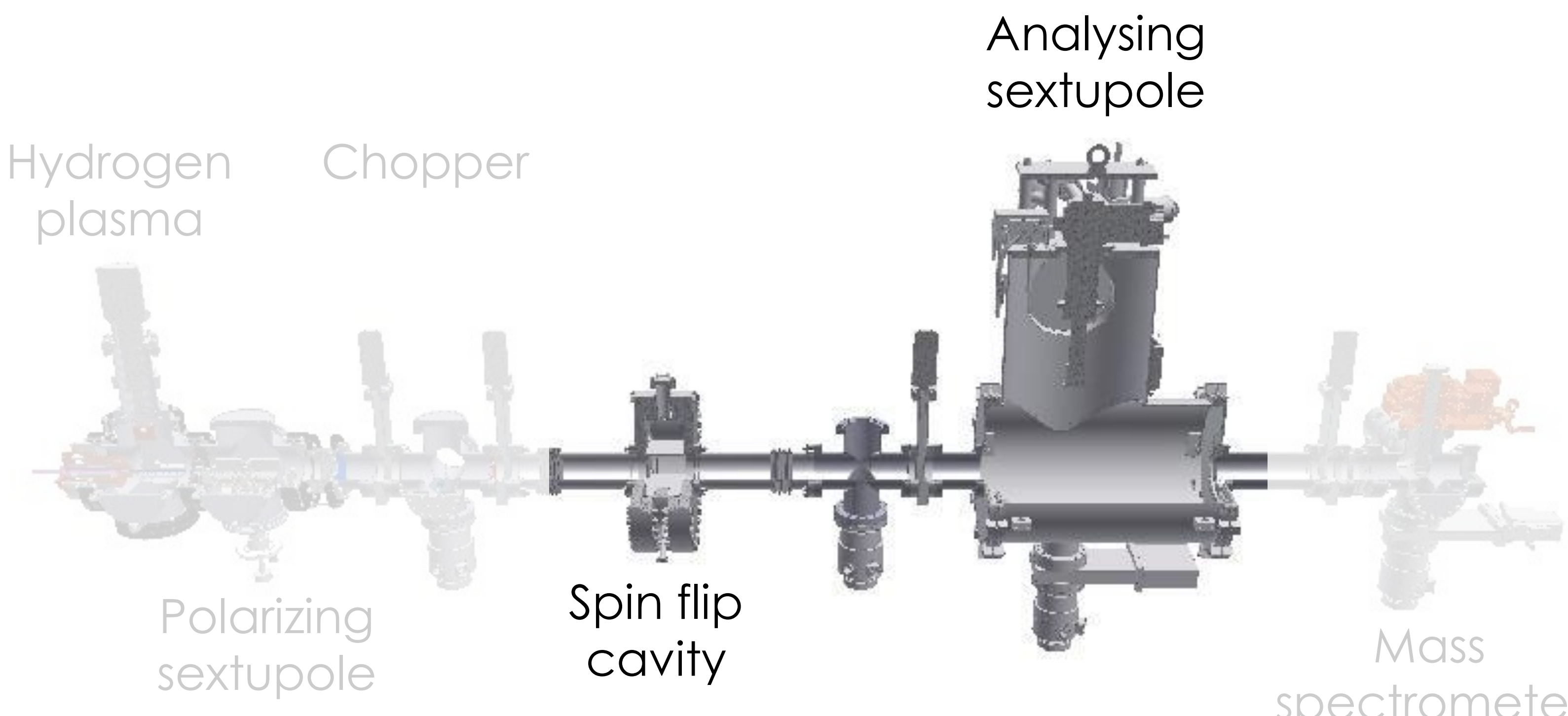
Hydrogen beam setup

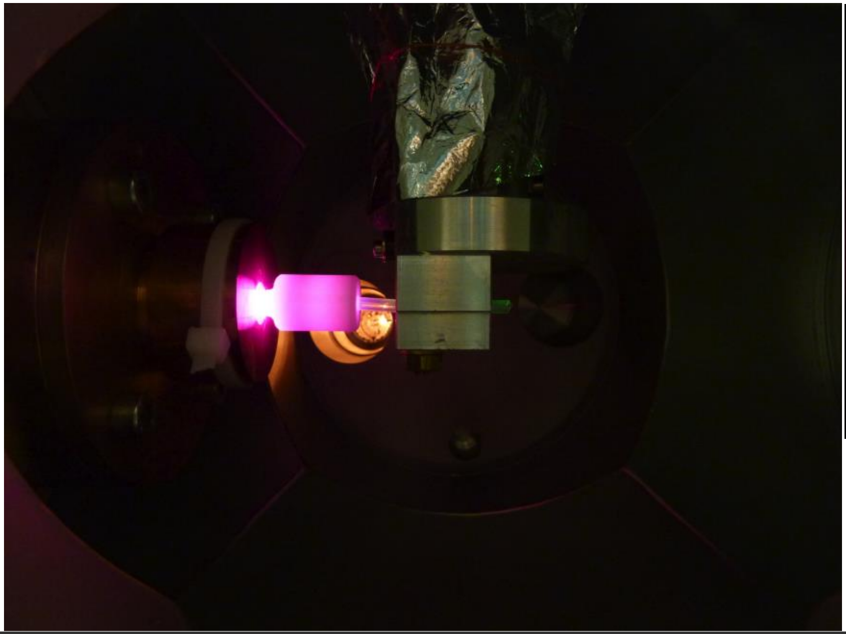


Hydrogen beam setup

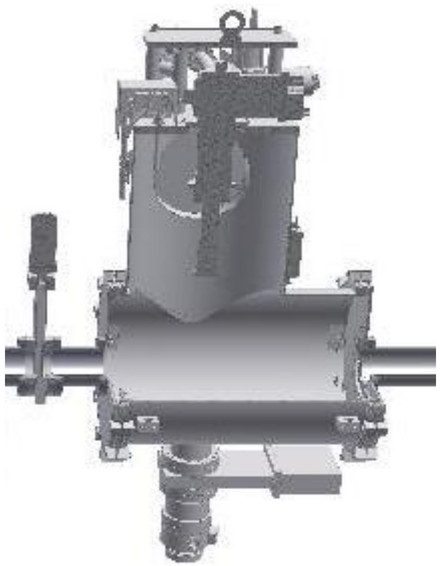


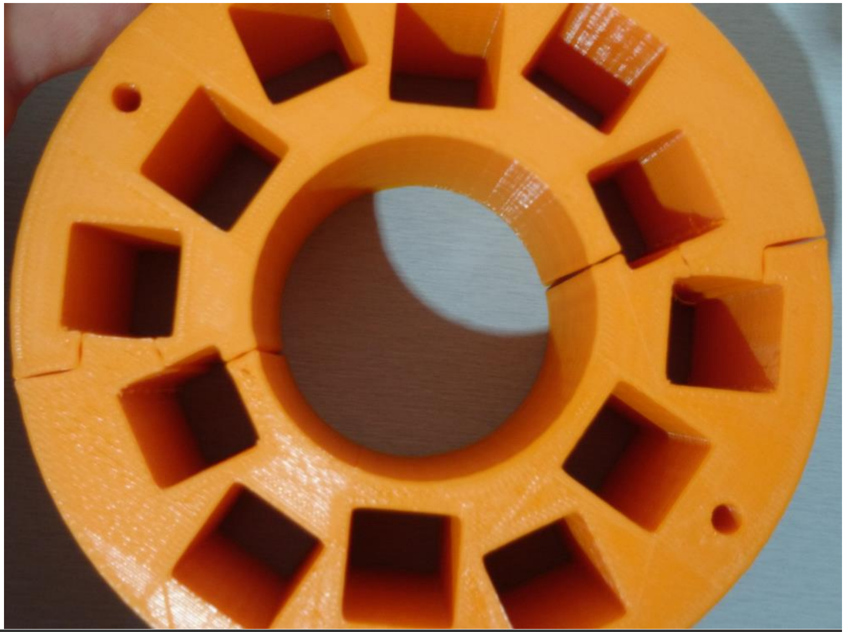
Comparison with anti-hydrogen





Hydrogen Plasma



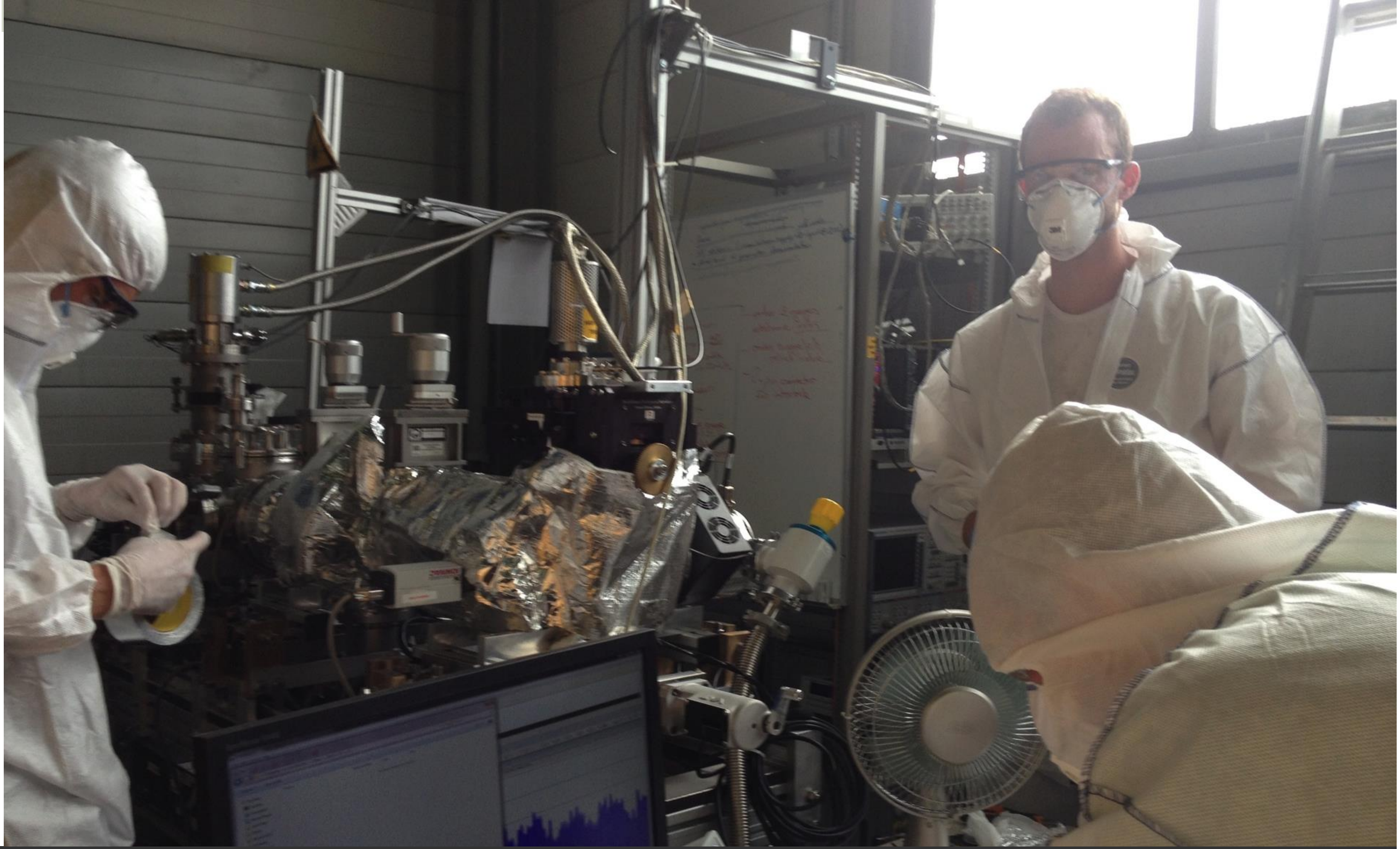


Future – permanent sextupoles

Replace superconducting sextupoles by 1T permanent magnet array
Reason: superconducting sextupoles is in use at the antimatter factory

Future

- Characterize H beam
  - Velocity distribution
- Build the analyzing sextupoles
- Include RF cavity and analyzing sextupoles in setup
- Start measurements!
  - Measure the σ and π resonances

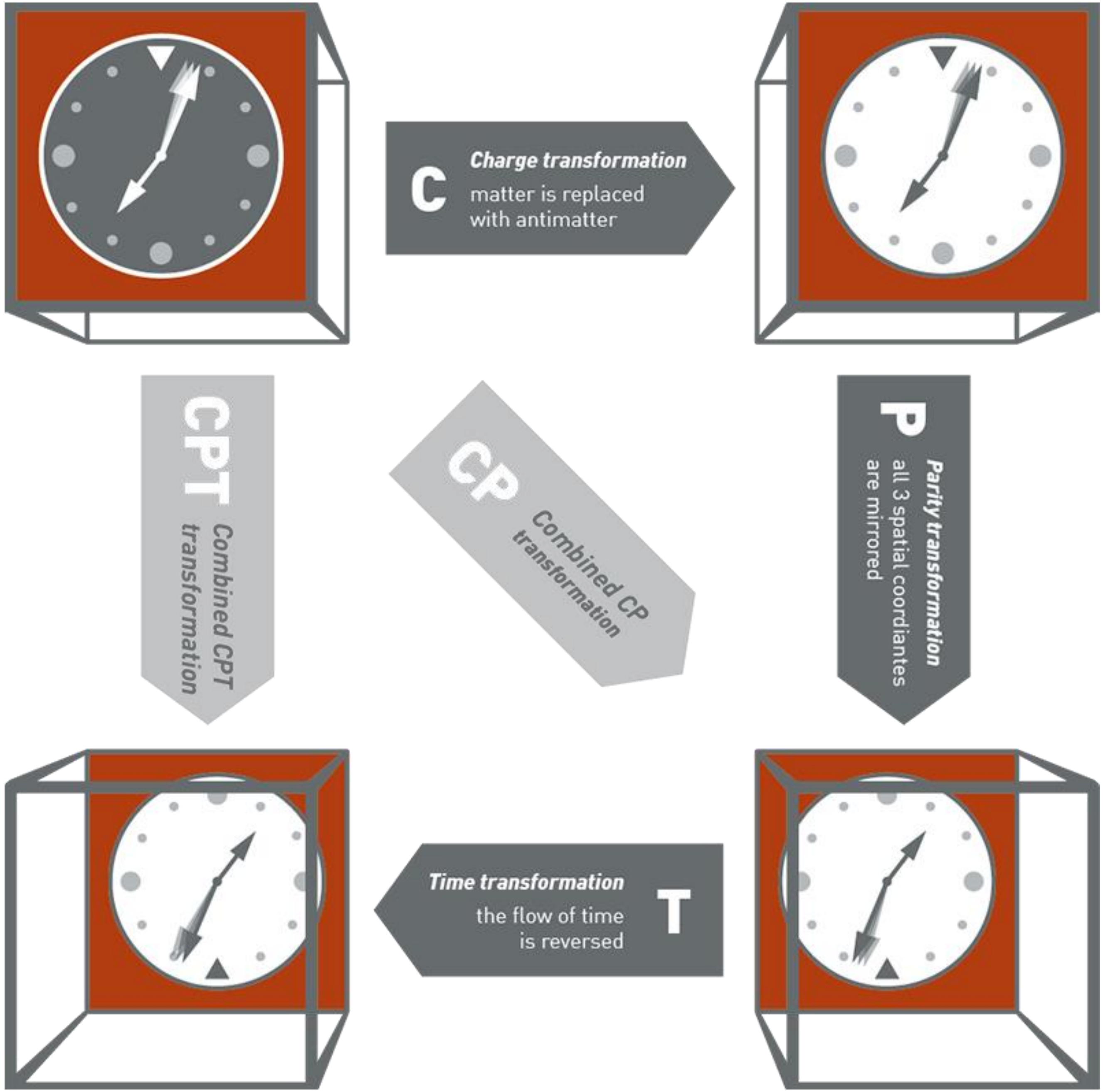


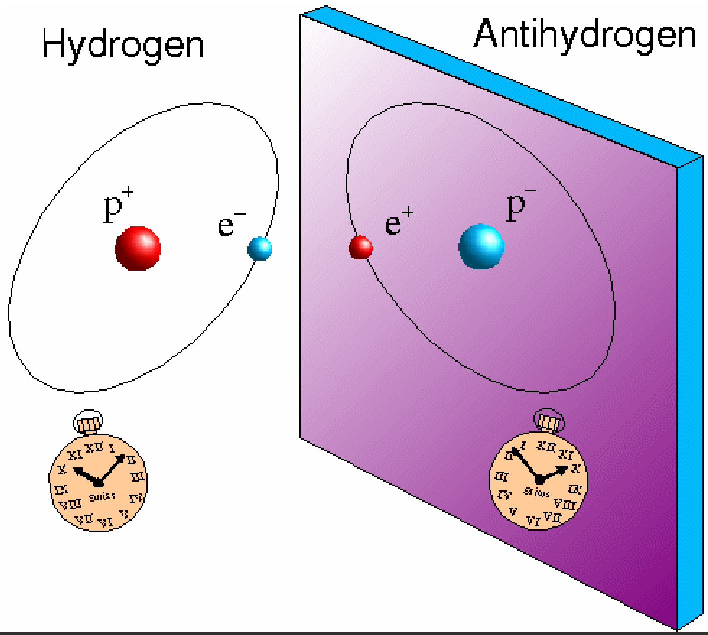
Thank you for your attention

Supporting Slides

Lorentz Violation -> CPT Violation

- If CPT violation: no Lorentz Invariance!

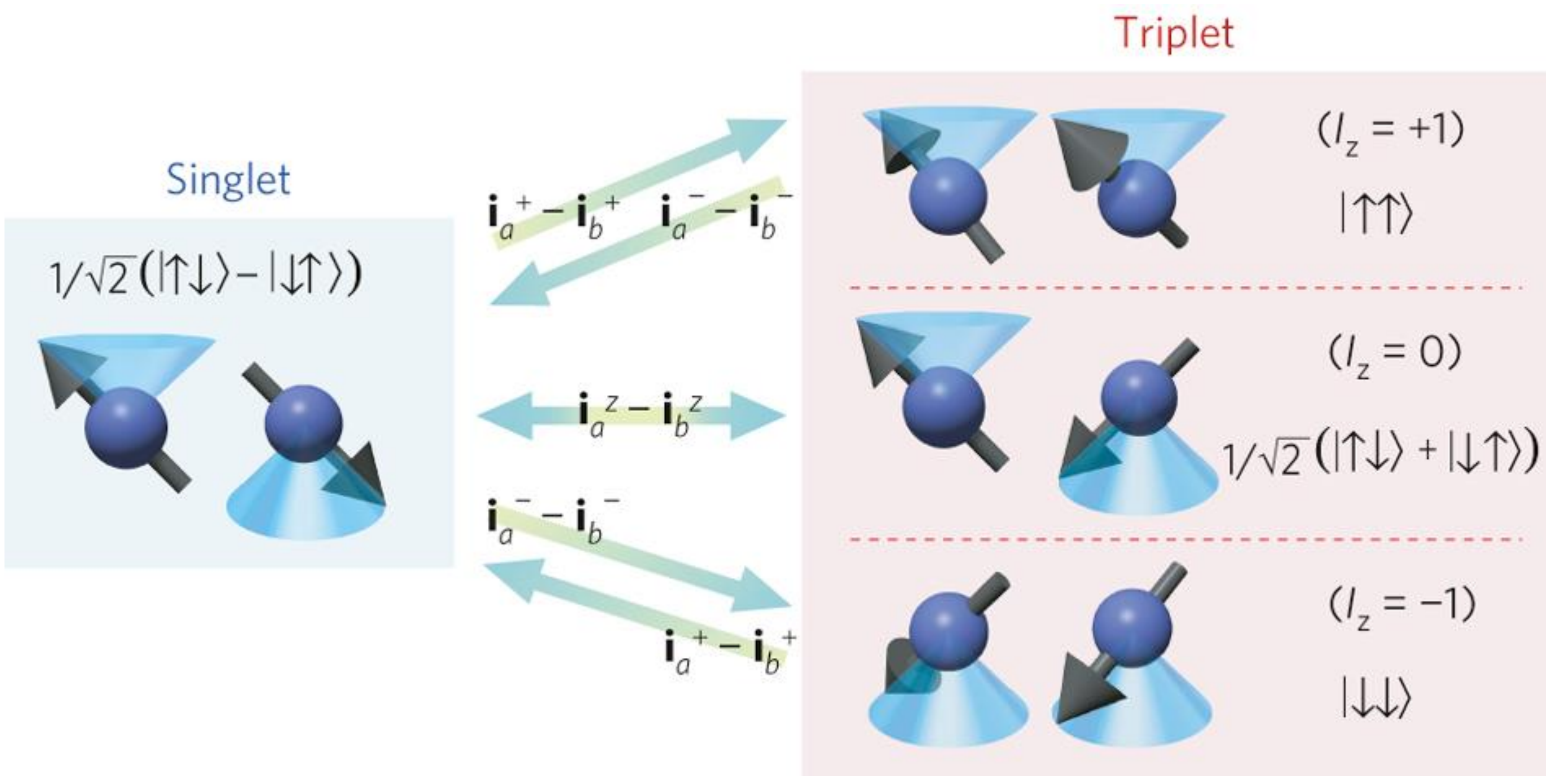

C
Charge transformation
matter is replaced with antimatter
P
Parity transformation
all 3 spatial coordiantes are mirrored
CP
Combined CP transformation
T
Time transformation
the flow of time is reversed
CPT
Combined CPT transformation



Compare $\bar{H}$ to H

CPT turns matter into anti-matter

Addition of angular momentum



Addition of angular momentum

$$M = 1 \qquad M = 0 \qquad M = -1$$

$$|p\rangle + |e\rangle = \begin{array}{l} |- \, -\rangle, \quad \dfrac{|- \; \overline{\ }\rangle + |\overline{\ } \; -\rangle}{\sqrt{2}}, \quad |\overline{\ }\,\overline{\ }\rangle \qquad S = 1 \\ \qquad\qquad\qquad \oplus \\ \qquad\qquad \dfrac{|- \; \overline{\ }\rangle - |\overline{\ } \; -\rangle}{\sqrt{2}} \qquad\qquad S = 0 \end{array}$$