Diffusion of μp in the hyperfine splitting experiment at PSI

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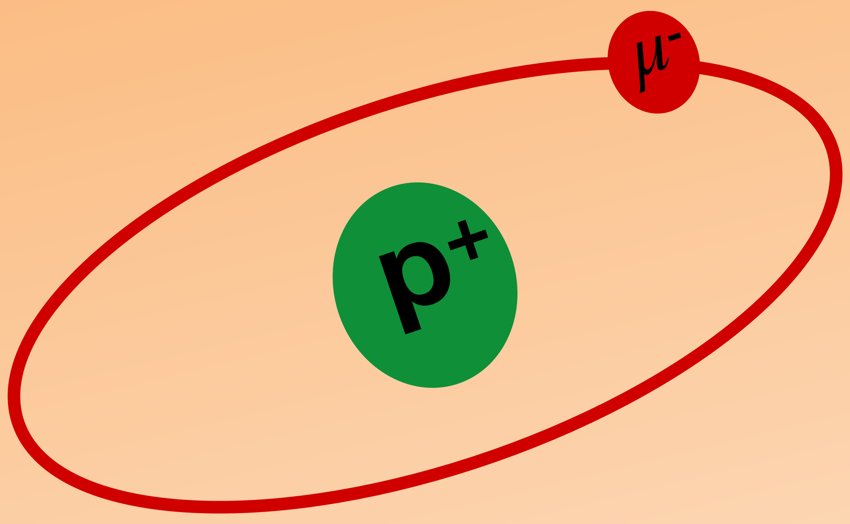
Motivation for the experiment



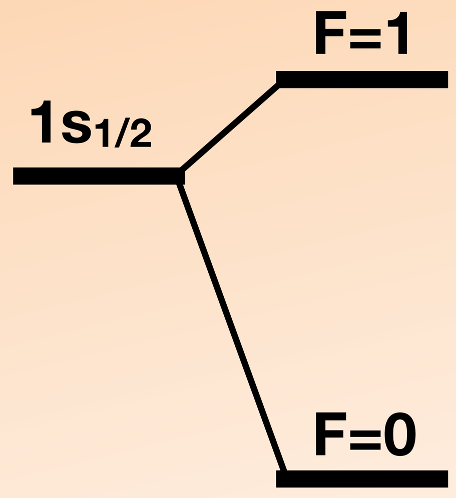
The proton structure has a strong impact on the energy levels of muonic hydrogen

- Aim: Measurement of the ground-state hyperfine splitting in muonic hydrogen
- The experiment is sensitive to higher order corrections of the hyperfine splitting:

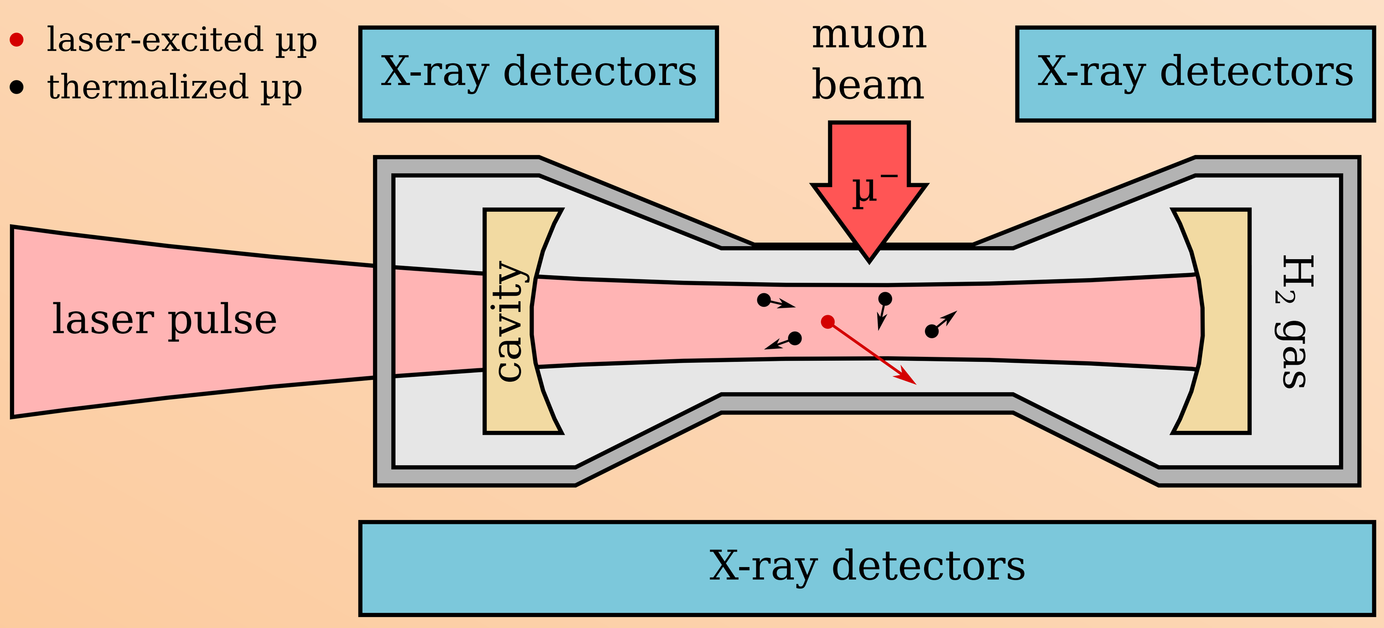
$$E_{HFS} = \left(1 + \Delta_{structure} + \Delta_{weak} + \Delta_{QED}\right) \cdot E_F$$

Learn about electro-magnetic structure of the proton

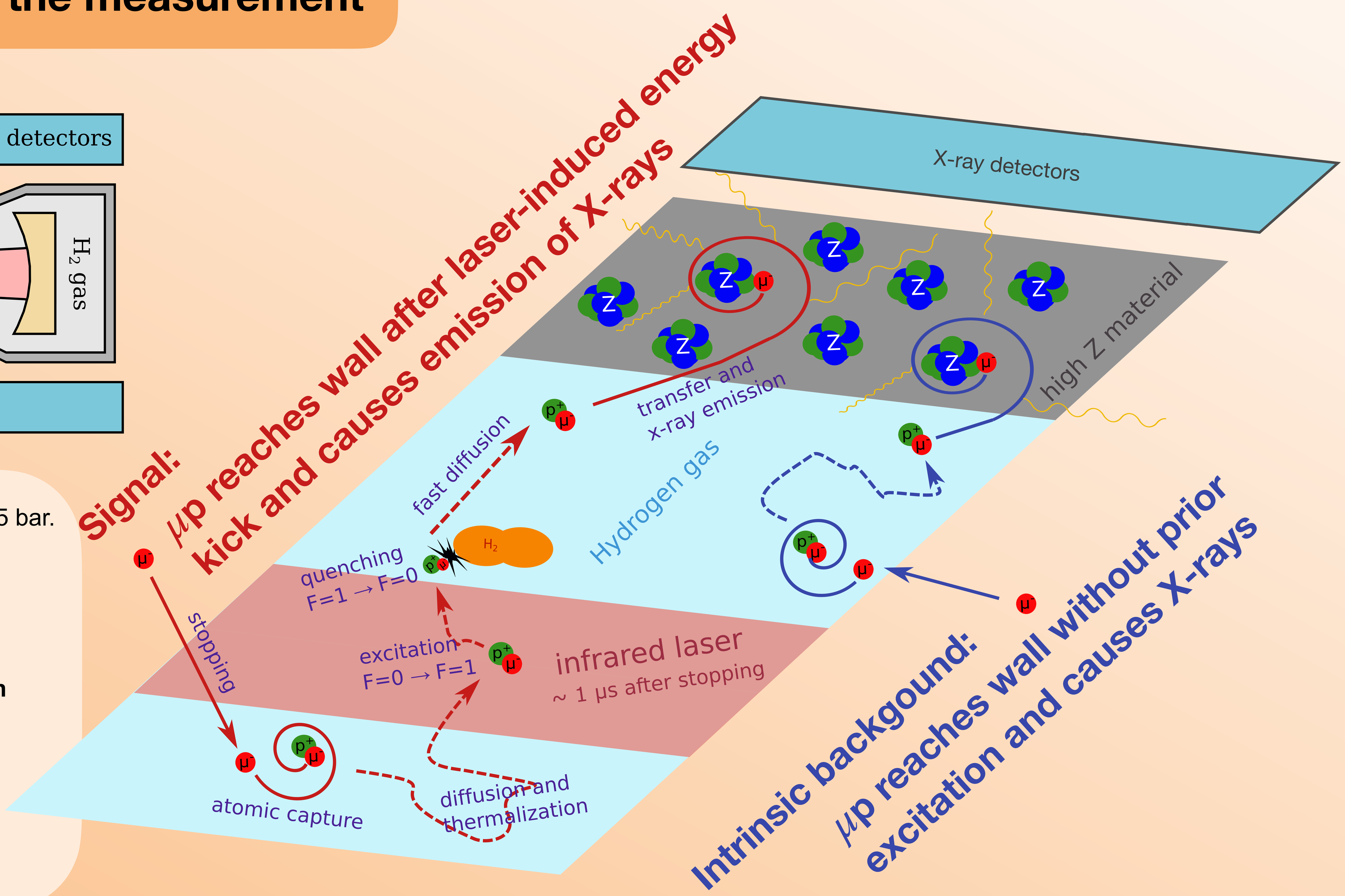
Test bound-state QED



Principle of the measurement



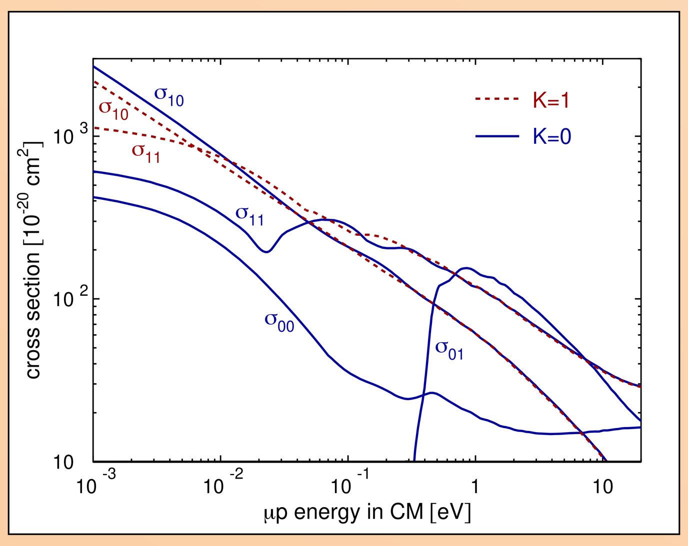
- Stop muon beam in 1 mm H_2 gas target at 22 K, 0.5 bar.
- Wait until μp atoms de-excite and thermalise.
- Laser pulse: μp(F=0) + γ → μp(F=1)
- De-excitation: μp(F=1) + H2→μp(F=0) + H2 + **Ekin**
- μp diffuses to Au-coated target walls
- formed μAu* de-excites producing X-rays
- Plot number of X-ray events vs laser frequency



μp diffusion and simulation of event rates

Monte Carlo simulations of μp diffusion

- Implementation of molecular scattering processes in Geant4: $\mu p\,(F) + H_2 \longrightarrow \mu p\,(F') + H_2^*$
- Diffusion simulations are used to define experimental parameters and to predict accuracy reached by the experiment.

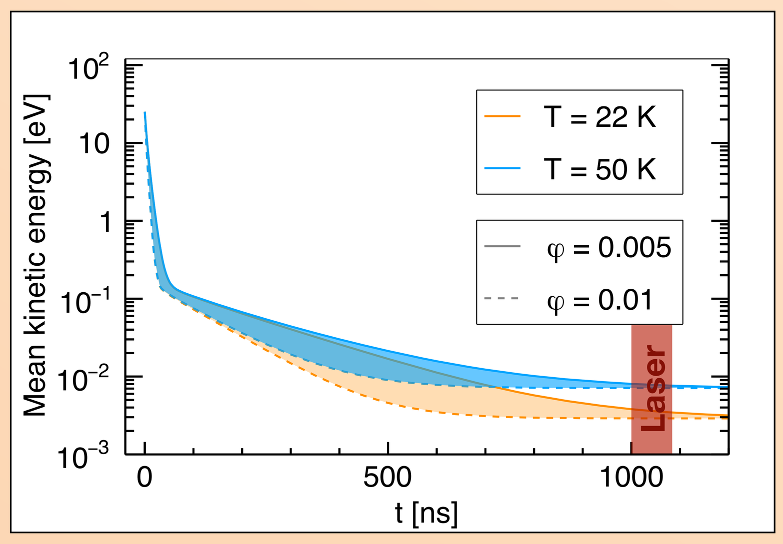


Cross sections for $\mu p - H_2$ scattering, calculation described in [1]

Diffusion and thermalization before laser excitation

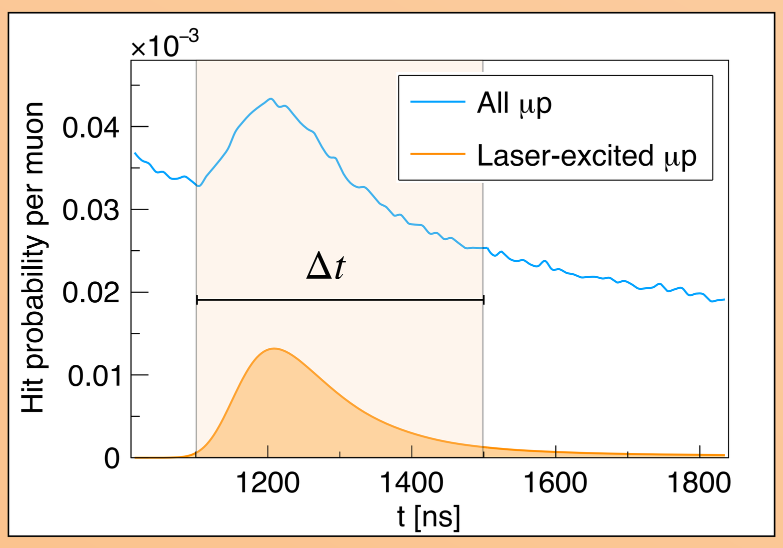
After formation, μp atoms thermalise and are quenched to the F=0 state in molecular collisions.

Most μp atoms hit the wall during thermalisation and are lost for the measurement. Additional losses are caused by the muon decay.



Average kinetic energy of μp atoms after formation

Diffusion of μp after laser excitation $(t > 1\ \mu s)$



Number of μp reaching the walls

An intrinsic background of μp reaches the walls independently of the laser frequency.

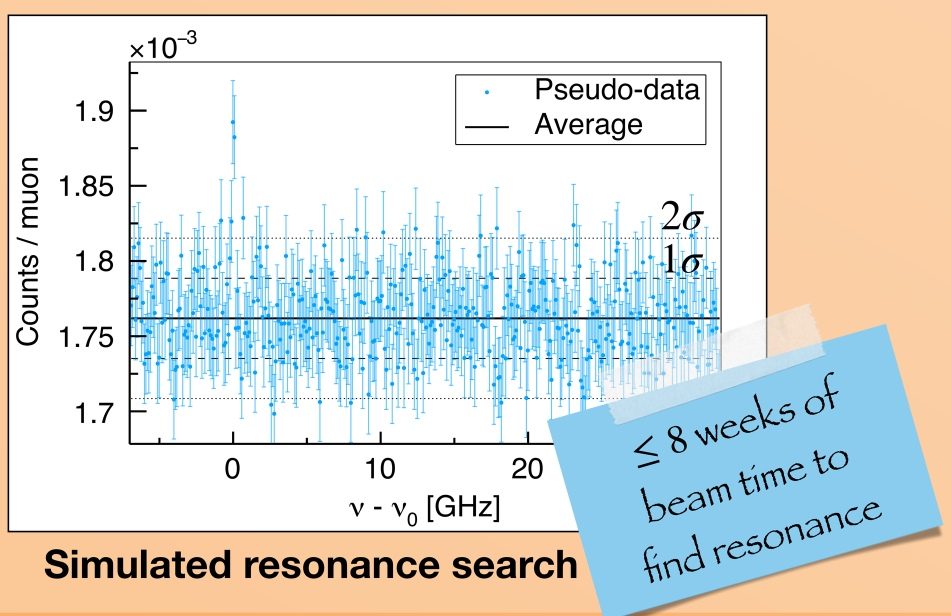
On resonance, the laser additionally enables μp from the target center to reach the walls.

Counting the muonic X-rays detected within a time window Δt after the laser, the resonance frequency can be determined.

Search of the resonance and statistical accuracy

Resonance search:

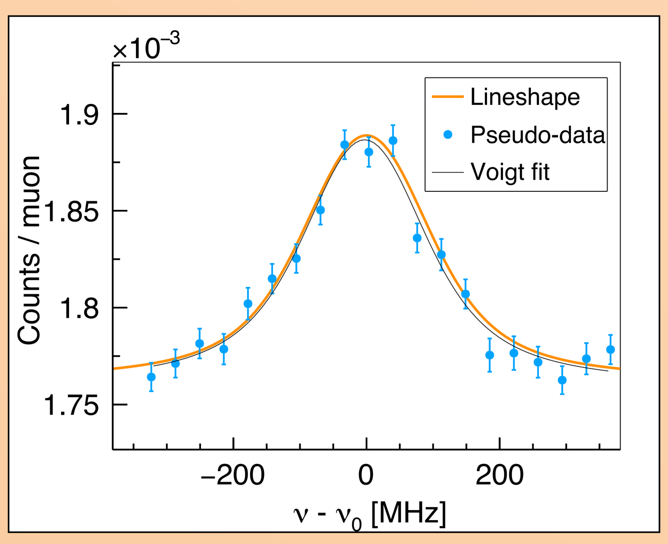
On resonance, it takes about 1 hour to obtain a 4σ deviation.



Simulated resonance search

Precision scan of the resonance:

Within 3 weeks of beam time, the HFS frequency can be measured with a statistical uncertainty of ≤ 0.1 ppm.



Simulated precision scan of the resonance

[1] A. Adamczak, Phys. Rev. A 74, 042718 (2006)