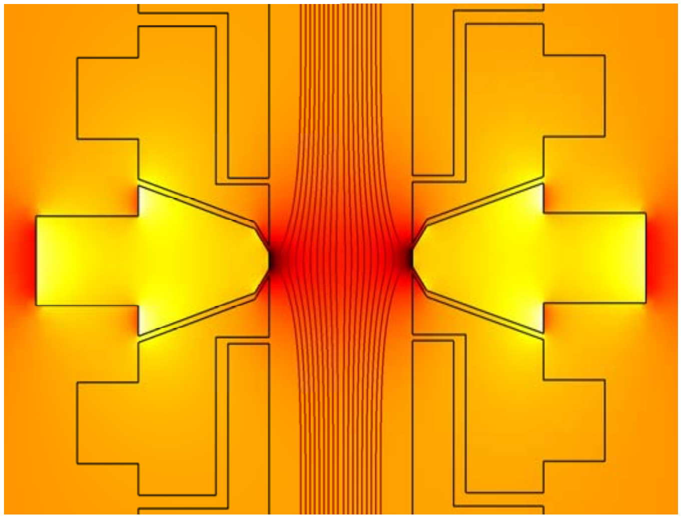
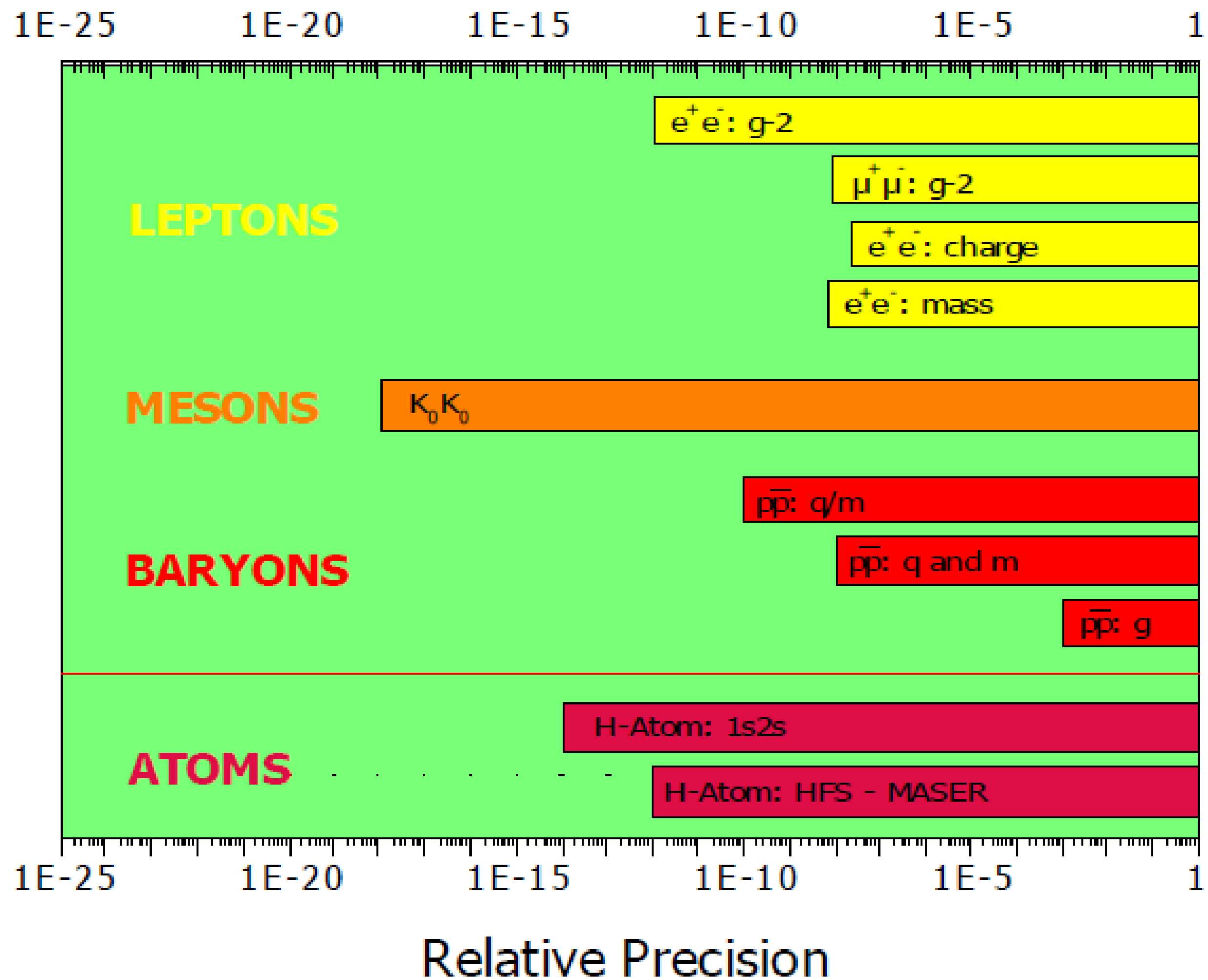
Single Proton Spin Flips



Wolfgang Quint
GSI Darmstadt and Univ. Heidelberg

Motivation: Test of CPT-Symmetry

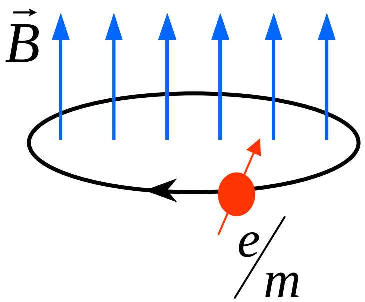
CPT TESTS:



Determination of the Proton g-Factor

$$\omega_c = \frac{e}{m_p} B$$

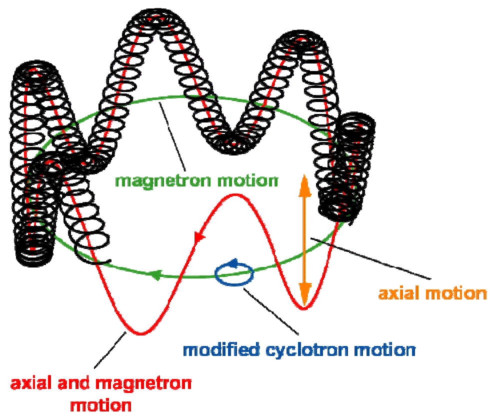
Cyclotron frequency



$$\omega_c = \sqrt{\omega_+^2 + \omega_-^2 + \omega_z^2}$$

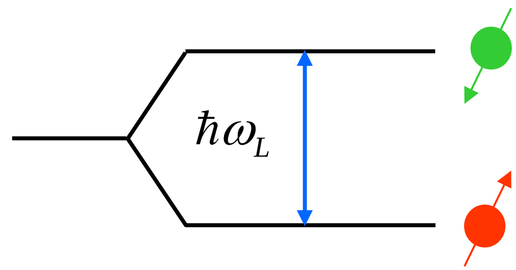
$$\omega_+ \approx 2\pi \cdot 29\,\text{MHz}$$
$$\omega_z \approx 2\pi \cdot 690\,\text{kHz}$$
$$\omega_- \approx 2\pi \cdot 8.5\,\text{kHz}$$

$$g = 2\frac{\omega_L}{\omega_c}$$

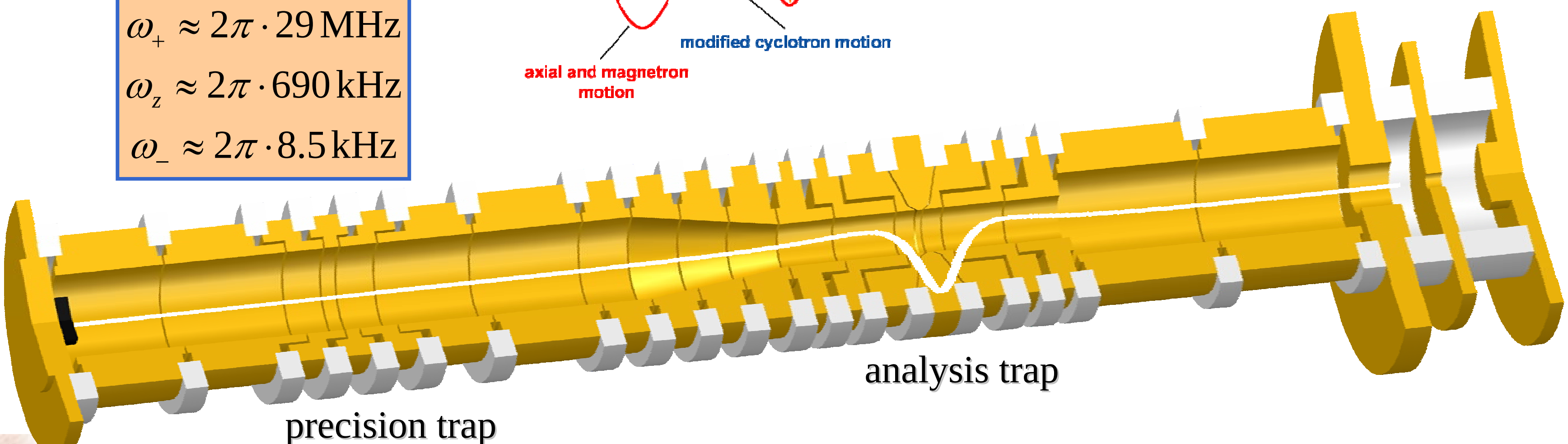


$$\omega_L = g \frac{e}{2m_p} B$$

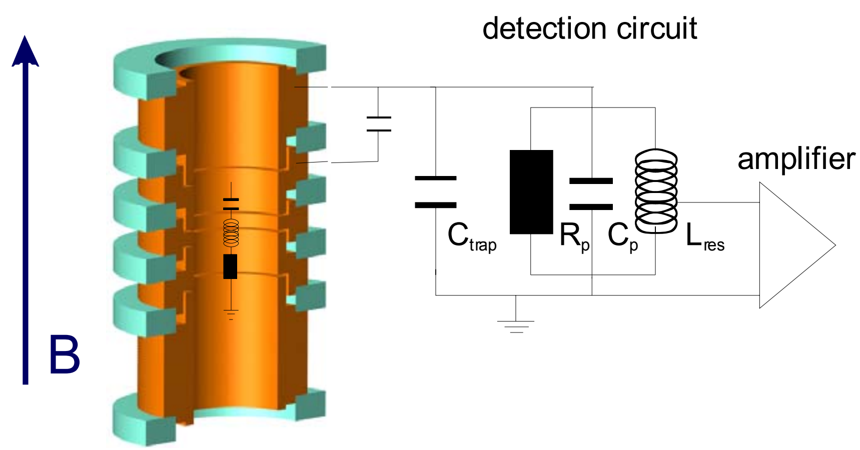
Larmor frequency



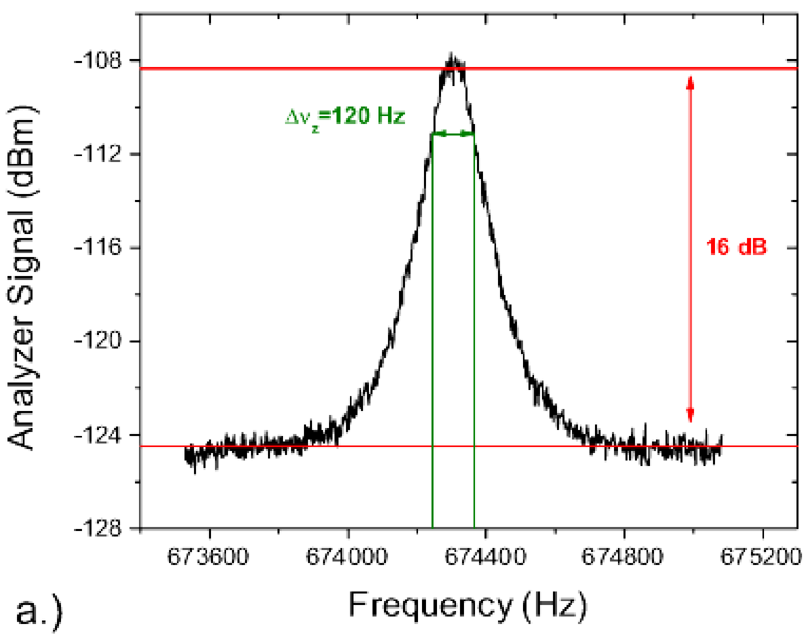
$$\omega'_z(\uparrow) - \omega'_z(\downarrow) = \Delta\omega_z$$

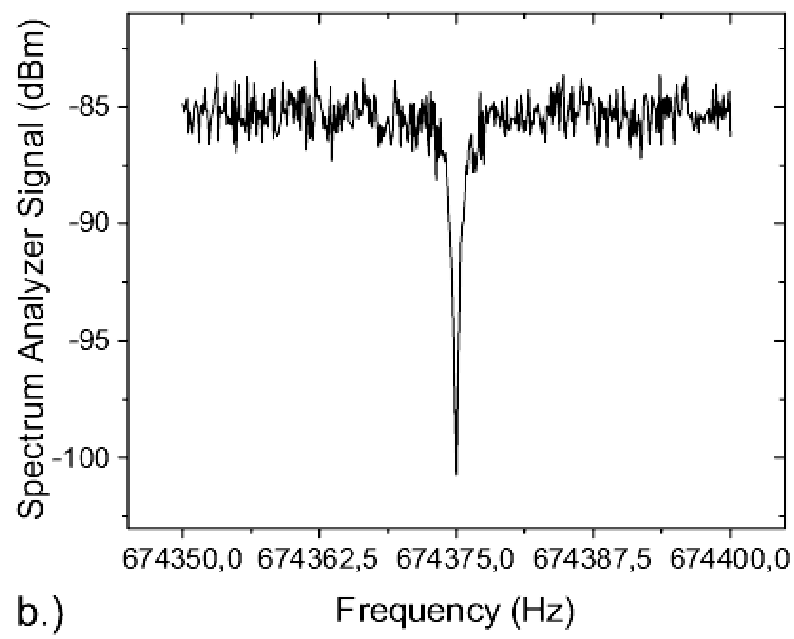


Measurement of the Axial Frequency of a Single Trapped Proton



- proton in thermal equilibrium at cryogenic temperature
- proton = series LC-circuit
- proton shorts detector noise at ν_z
- minimum in FFT spectrum





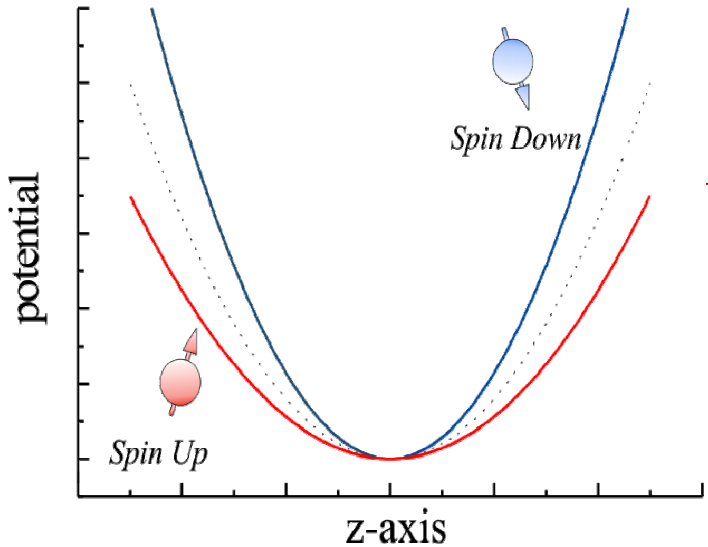
A Single Trapped Proton and the Continuous Stern-Gerlach Effect

axial frequency shift due to spinflip:

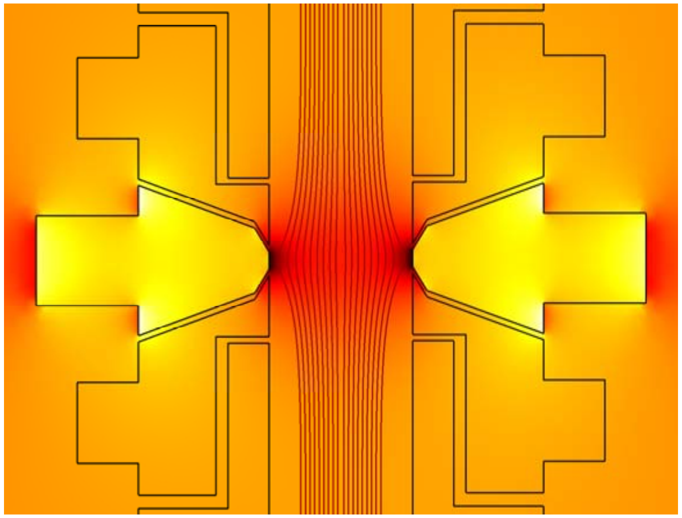
$$\Delta\nu_z \approx \frac{1}{2\pi^2}\frac{\mu_z B_2}{m\nu_z}$$

⇩

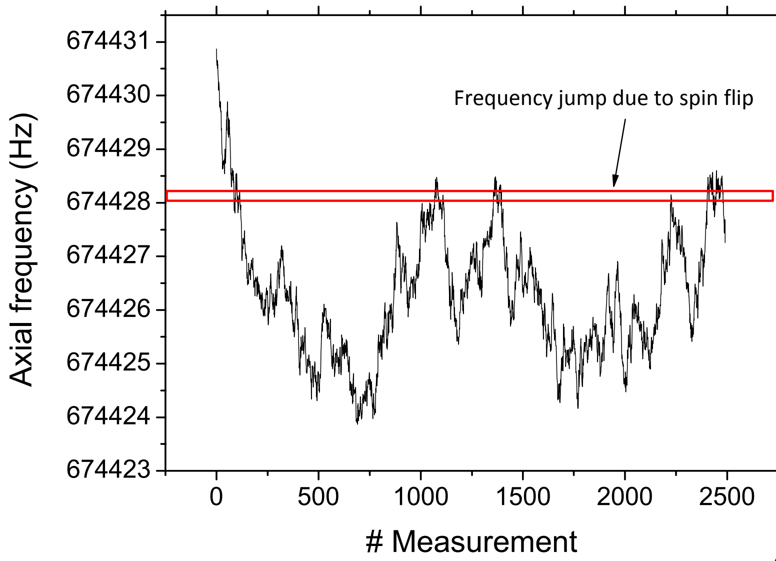
Proton measurement is 10 000 times harder compared to electron g-2 measurement.



B_2 = 0.3 T/mm²
$\Delta\nu_z$= 190 mHz



Time-Averaged Axial Frequency Fluctuation Ξ of a Single Proton

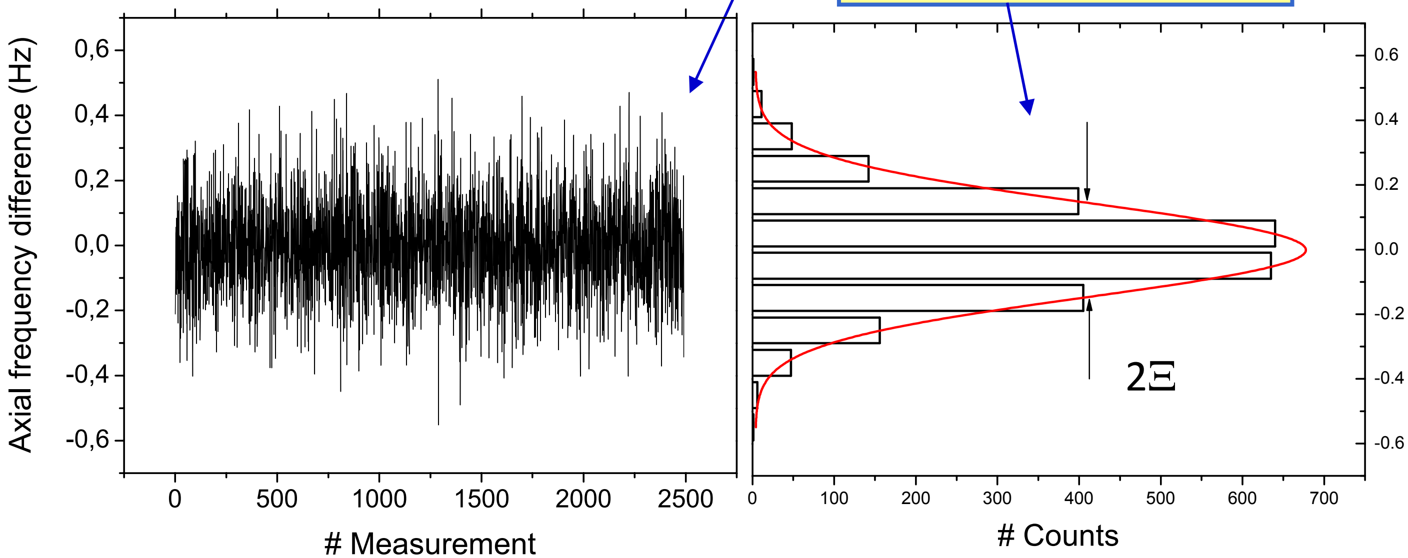


Axial frequency difference

$$\Delta\nu_z = (\nu_z(t+T) - \nu_z(t))$$

Axial frequency fluctuation

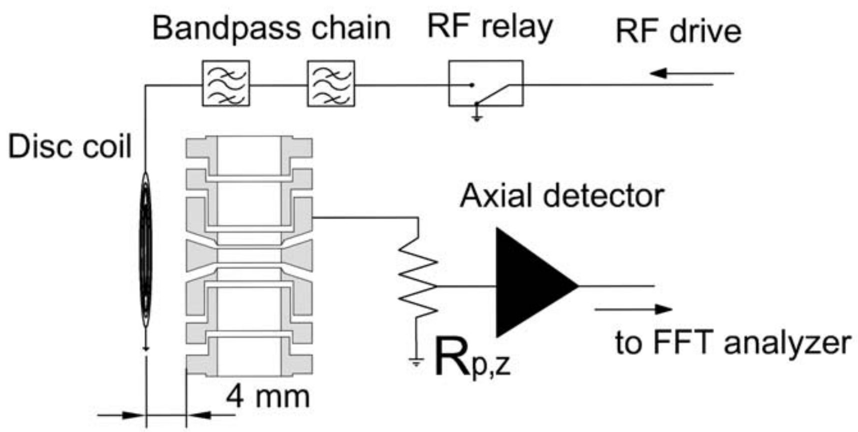
$$\Xi^2 = \frac{1}{n}\sum(\Delta\nu_z - \overline{\Delta\nu_z})^2$$



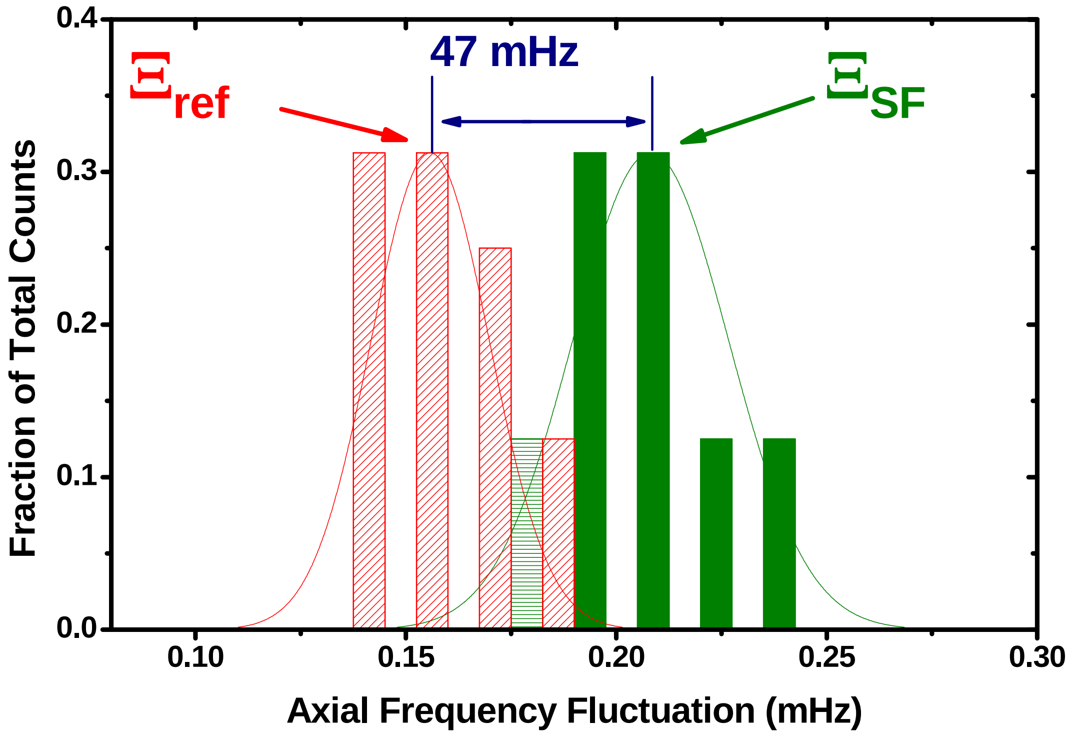
Ξ = 150mHz

Goal: See increase of frequency fluctuations due to spinflips

Detecting Spinflips of a Single Trapped Proton in the Analysis Trap



Measure Ξ_{SF} and Ξ_{ref}
→ Obtain SF-Probability!!!

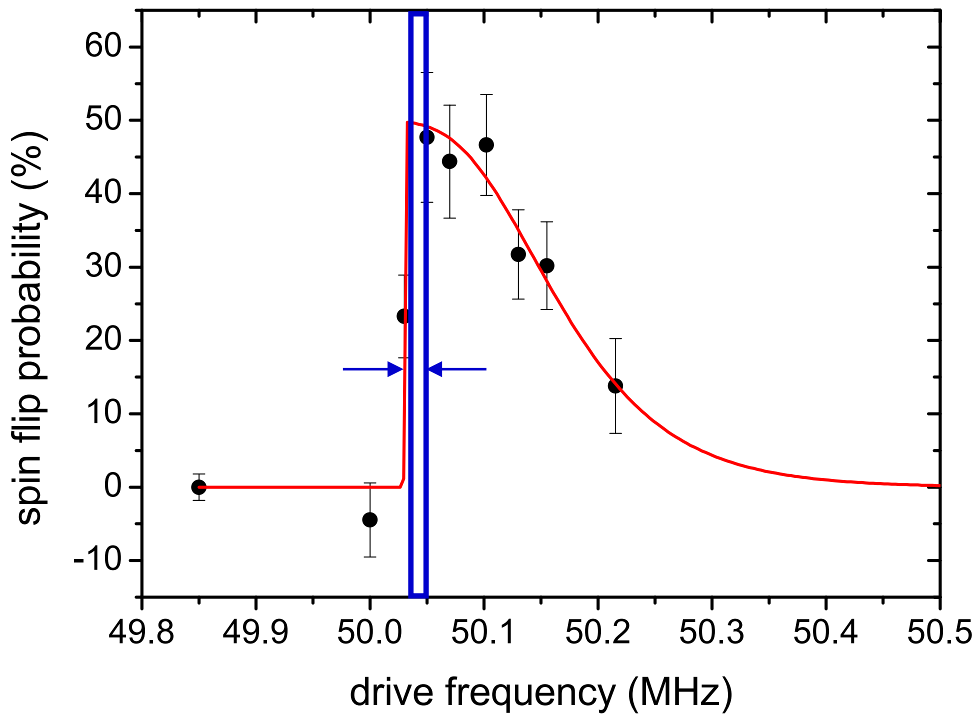


First Larmor Resonance Curve of a Single Proton in the Analysis Trap

✓ Axial frequency fluctuation reduced
✓ Larmor resonance curve measured

$$\frac{\Delta g}{g} = 2 \cdot 10^{-4}$$

$$g = 2\frac{\nu_L}{\nu_c}$$



Next step:
- Reduce axial temperature to get sharper linewidth in analysis trap

First Larmor Resonance Curve of a Single Proton in the Analysis Trap

✓ Axial frequency fluctuation reduced
✓ Larmor resonance curve measured

$$\frac{\Delta g}{g} = 2 \cdot 10^{-4}$$

$$g = 2\frac{\nu_L}{\nu_c}$$

Selected for a Viewpoint in *Physics*

PRL **106**, 253001 (2011) PHYSICAL REVIEW LETTERS week ending 24 JUNE 2011

Observation of Spin Flips with a Single Trapped Proton

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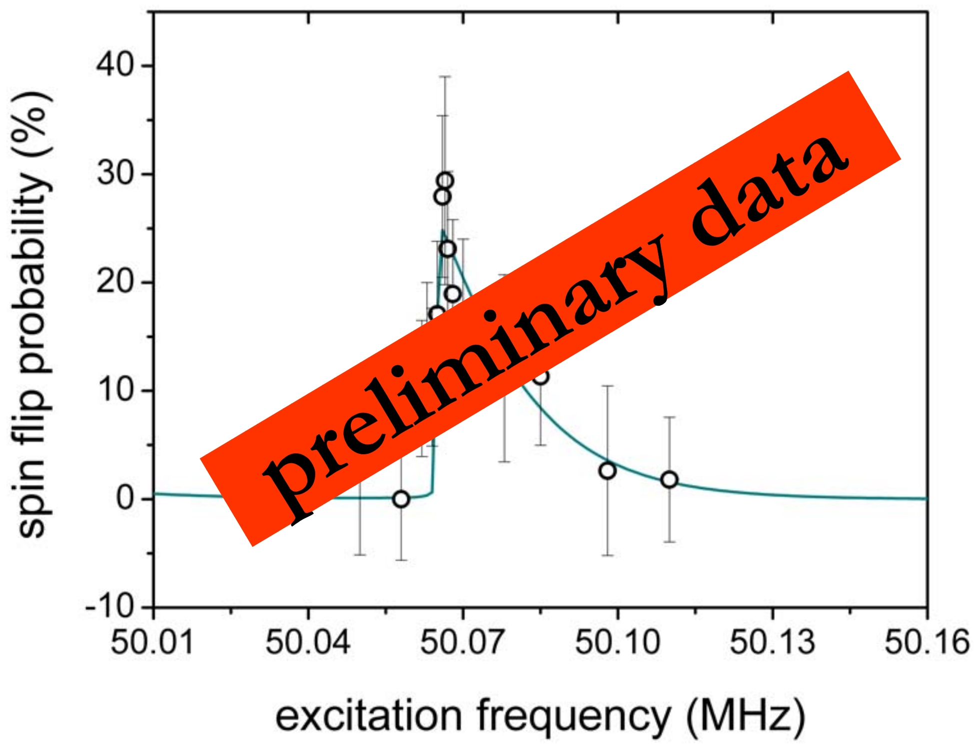
Radio-frequency induced spin transitions of one individual proton are observed. The spin quantum jumps are detected via the continuous Stern-Gerlach effect, which is used in an experiment with a single proton stored in a cryogenic Penning trap. This is an important milestone towards a direct high-precision measurement of the magnetic moment of the proton and a new test of the matter-antimatter symmetry in the baryon sector.

Improvement of Larmor Resonance Curve

✓ Axial temperature reduced
✓ Larmor resonance narrower



$$\frac{\Delta \nu_L}{\nu_L} = 1.2 \cdot 10^{-6}$$

$$g = 2\frac{\nu_L}{\nu_c}$$

Next steps:

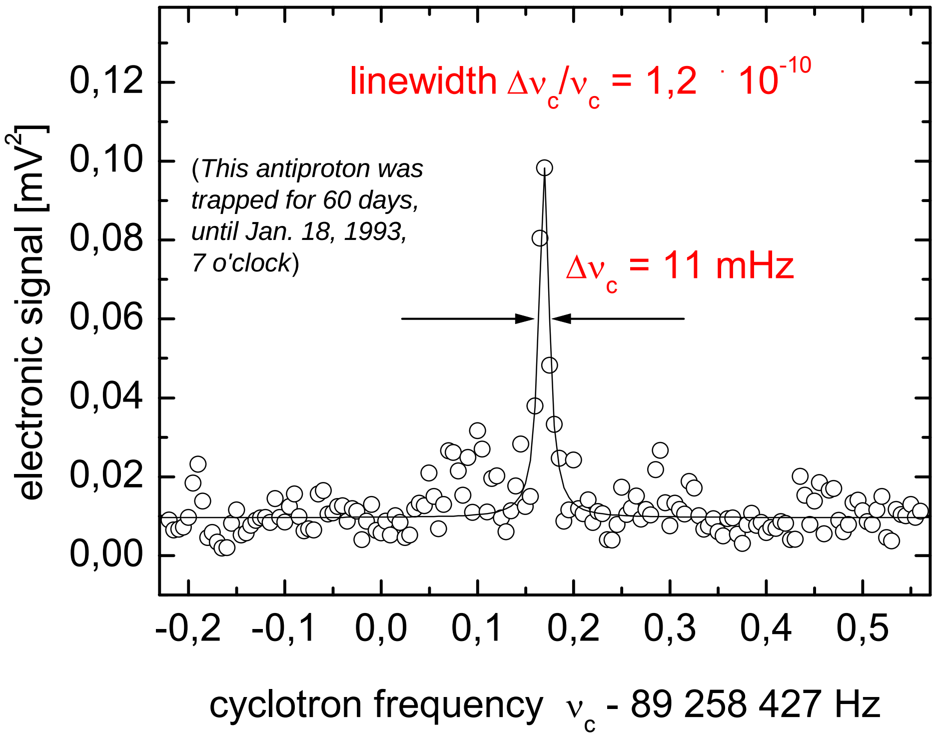
- Reduce axial frequency fluctuations further
- Direct observation of spinflips
- Apply double-trap method. Magnetic field in precision trap is more homogeneous by 4 orders of magnitude → improvement to

$$\frac{\Delta g}{g} = 10^{-9}$$ expected

Outlook

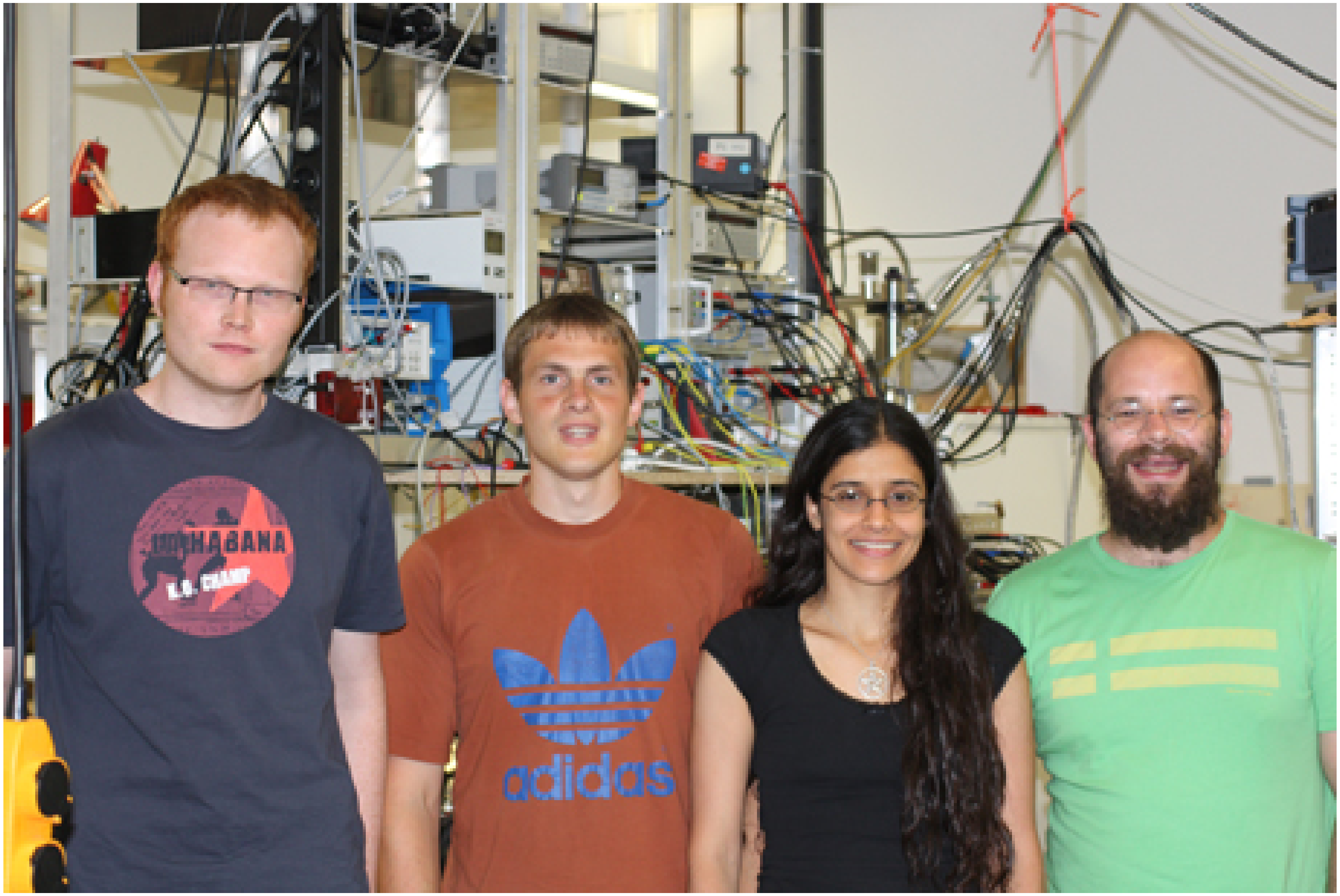
Goals:

- **Single antiproton stored in a Penning trap at T = 4 K.**
- **Measurement of the g-factor with an accuracy of 1 x 10^{-9}.**



- **Improvement of accuracy in g_{pbar} by six orders of magnitude.**
- **Test of CPT invariance for baryons.**

The (Anti)Proton g – Factor Team



Andreas Mooser **Holger Kracke** **Cricia Rodhegeri** **Stefan Ulmer**

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Thank you for your attention!