MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

High-precision measurement of the HFS of $^{3}He^{+}$ in a Penning trap

A. Schneider, B. Sikora, S. Dickopf, M. Müller, N. Oreshkina, A. Rischka, I. Valuev, S. Ulmer, J. Walz, Z. Harman, C. Keitel, A. Mooser, K. Blaum

RIKEN

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

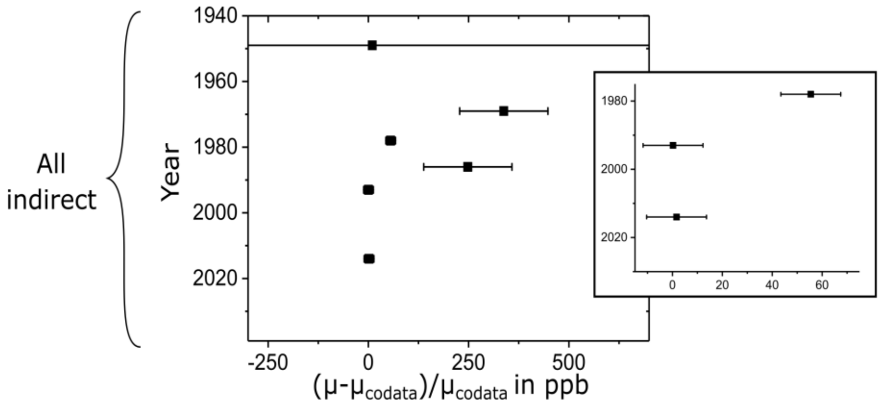
JG|U

HELMHOLTZ Institut Mainz

TC FS

Motivation

First direct high-precision measurement of ^{3}He nuclear magnetic moment with ppb precision



Previous measurements:

- Comparisons of ^{3}He and H_2O or H_2 probe only
- μ_{He} known to $1.2*10^{-8}$ only

  limited by knowledge of shielded proton magnetic moment

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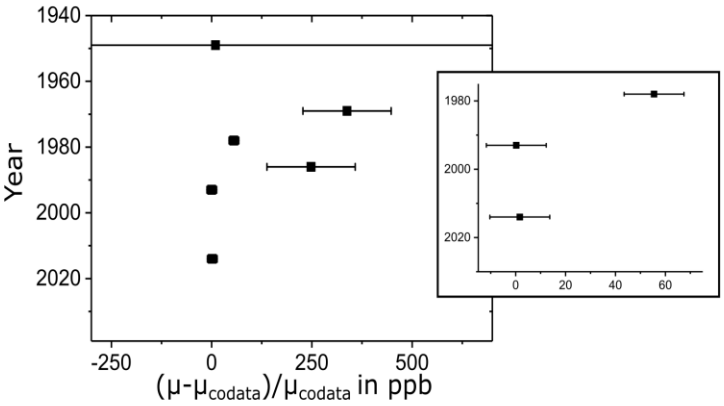
All indirect



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Establish hyper-polarized ^3He NMR probes as independent standard for precision magnetometry

	Water NMR		^3He
Dependence on temperature	1	>	1/100
Dependence on probe shape	1	>	1/1000
Diamagnetic shielding	1 measured	>	1/10 calculated

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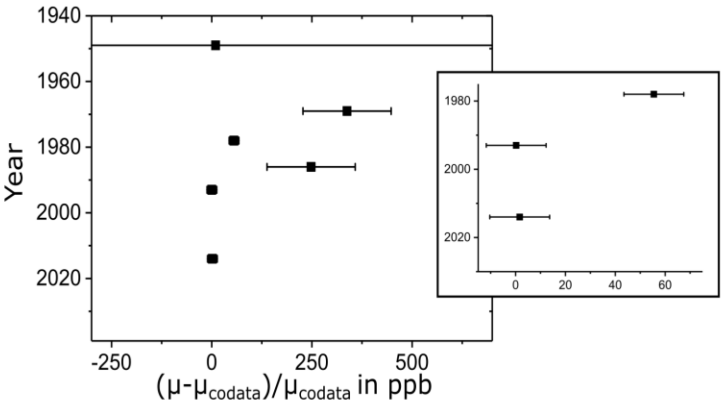

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➡ Application: muon g-2

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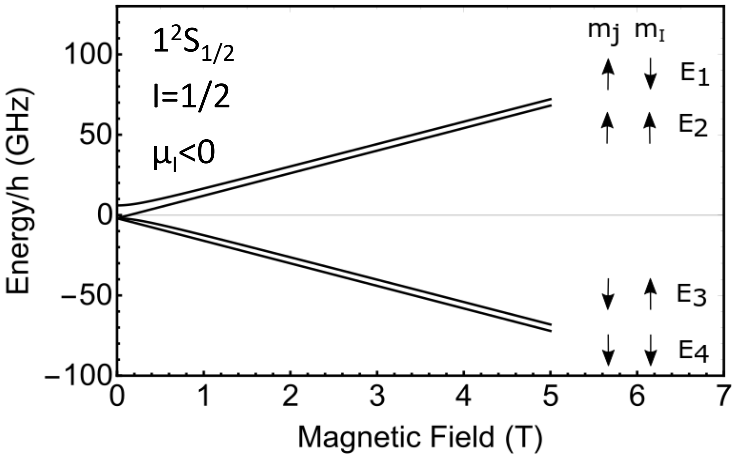


Zero-field splitting:

$$\Delta E^{HFS} = E^F(1 + \delta^{QED} + \delta^{rec} + \delta^{str} + \delta^{nucl})$$

with Fermi contact energy E^F

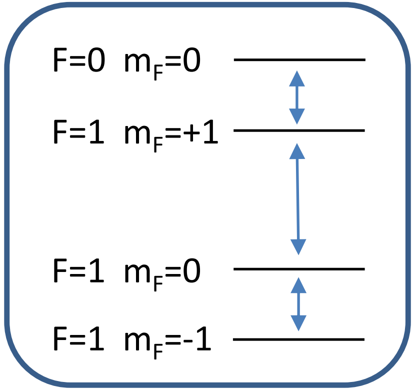
determination of e.g. nuclear structure effect δ^{nucl}

ΔE^{HFS} known to 1.1 ppb (Schuessler et al., Phys. Rev. **187** 5 (1968))

We aim for measurement of order 10ppt

Magnetic Moments in Penning Traps

Determination of energy splitting between spin-states



$$\omega_{F=I\pm\frac{1}{2}}\,(g_I, g_j\,, \Delta E^{HFS}, B)$$

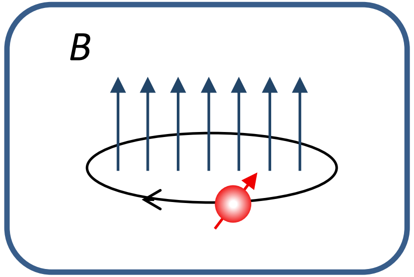
$^3He^+$

$1^2S_{1/2}$

$I=1/2$

$\mu_I<0$

Simultaneous cyclotron frequency measurement



$$\omega_c = \frac{e}{m_{He}} B$$

B-field independent measurement of g_I,g_j and ΔE^{HFS}

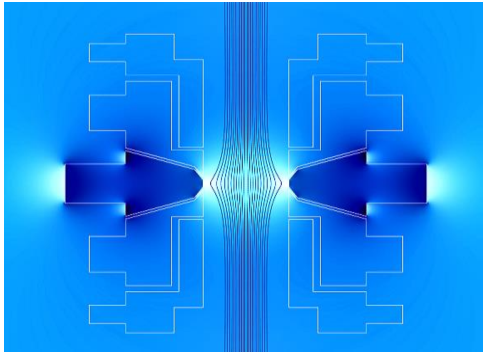
Detection of Spin-State - Continuous Stern-Gerlach Effect

Magnetic field inhomogeneity

$$B_z = B_0 + B_2\left(z^2 - \frac{\rho^2}{2}\right)$$

⇒ axial frequency dependent on magnetic moment

Ring electrode made of CoFe



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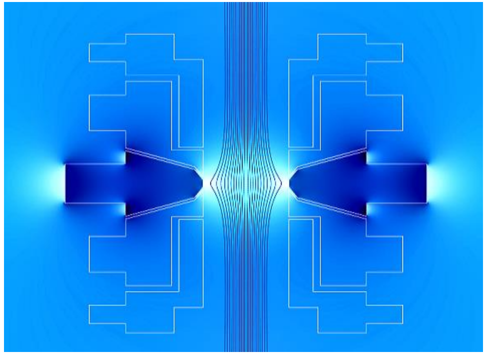
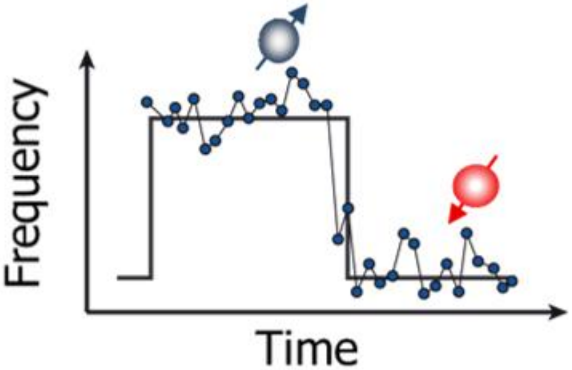


Spin-transition induces frequency jump



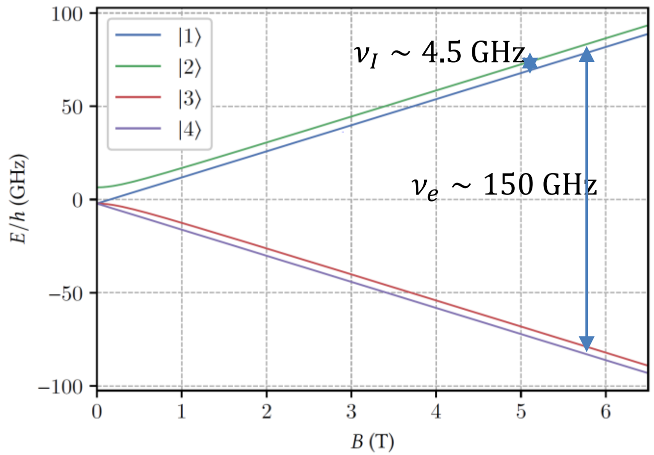
$\Delta\nu_{z,SF} \sim \mu/(qm)^{1/2}$

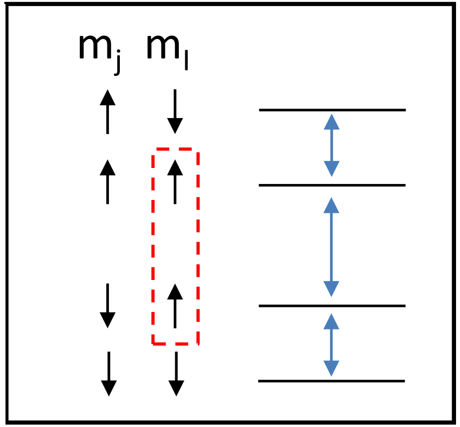
$\Delta\nu_p/\Delta\nu_e = 10^{-4}$

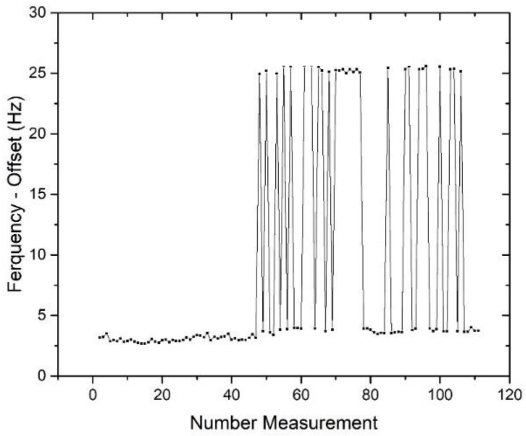
$\Delta\nu_{He}/\Delta\nu_p = 0.3$

Spin-State Detection $^3He^+$

➡ $\Delta\nu_{z,SF}$ of $20Hz$, much easier to detect compared to 90mHz

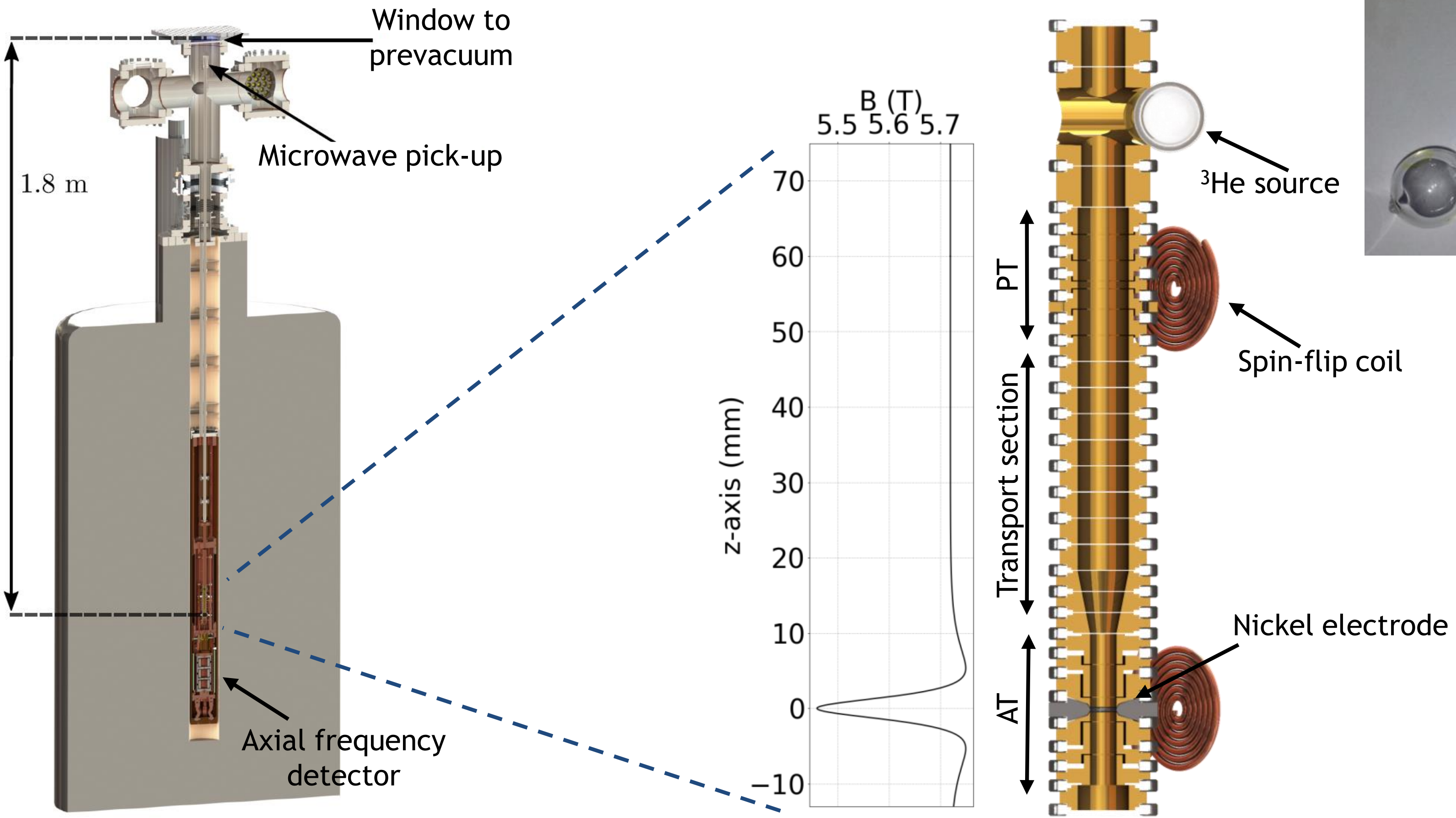






Map readout of nuclear spin-state onto detection of electronic transitions

Setup



Window to prevacuum
Microwave pick-up
1.8 m
Axial frequency detector
B (T)
5.5 5.6 5.7
z-axis (mm)
70
60
50
40
30
20
10
0
−10
PT
Transport section
AT
³He source
Spin-flip coil
Nickel electrode