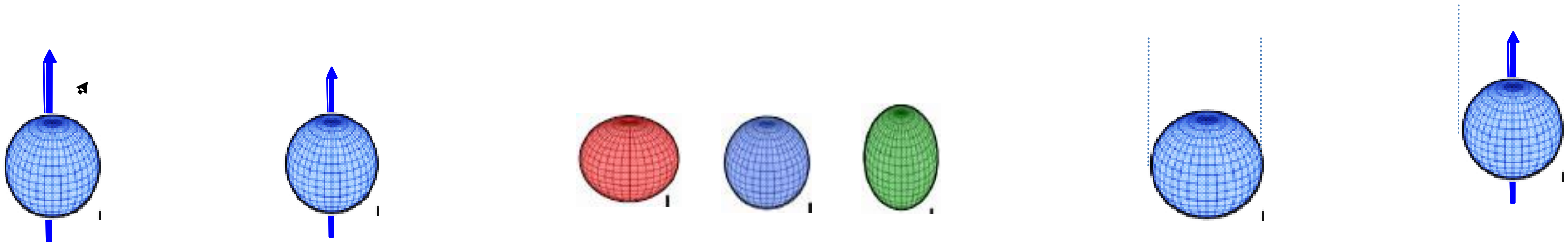
Towards the nuclear magnetization distribution with laser-rf double resonance spectroscopy

Mark Bissell on behalf of the VITO collaboration

Laser Spectroscopy Observables



Spin I

Spin I   Magnetic moment μ   Quadrupole moment Q_s Charge radii $\delta\langle r^2\rangle$ + Hyperfine Anomalies

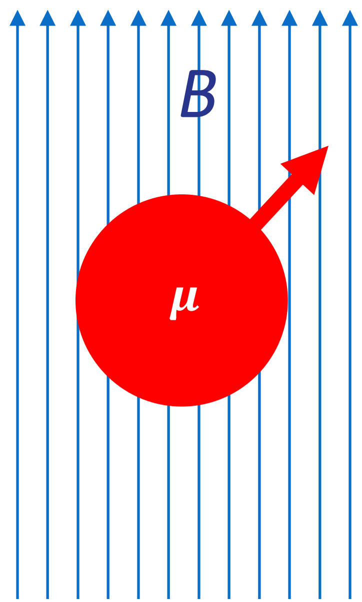
Structure / wave function

Correlations and deformation

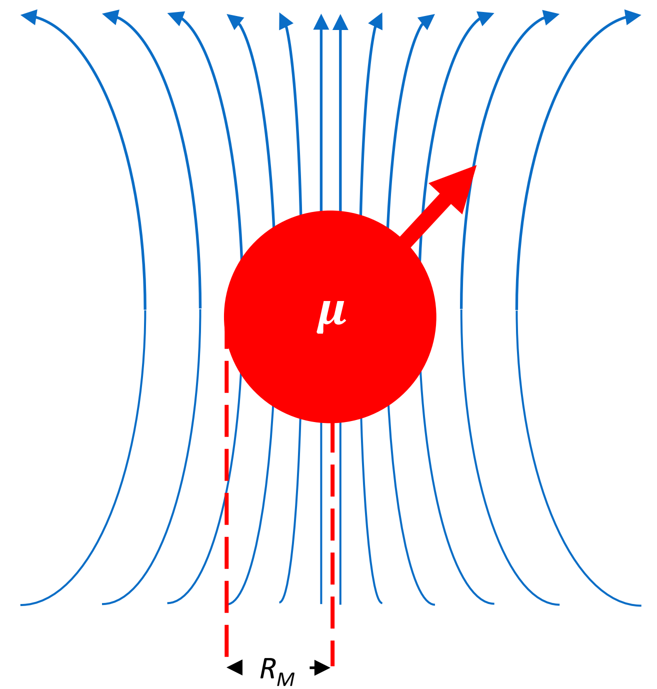
Shape coexistence

Nuclear Magnetization Radius

What is the Hyperfine Anomaly?



$$\Delta(R_1, R_2) = \frac{A_1}{A_2} / \frac{\nu_1}{\nu_2} - 1$$



$$\frac{\nu_1}{\nu_2} = \frac{\mu_1/I_1}{\mu_2/I_2}$$

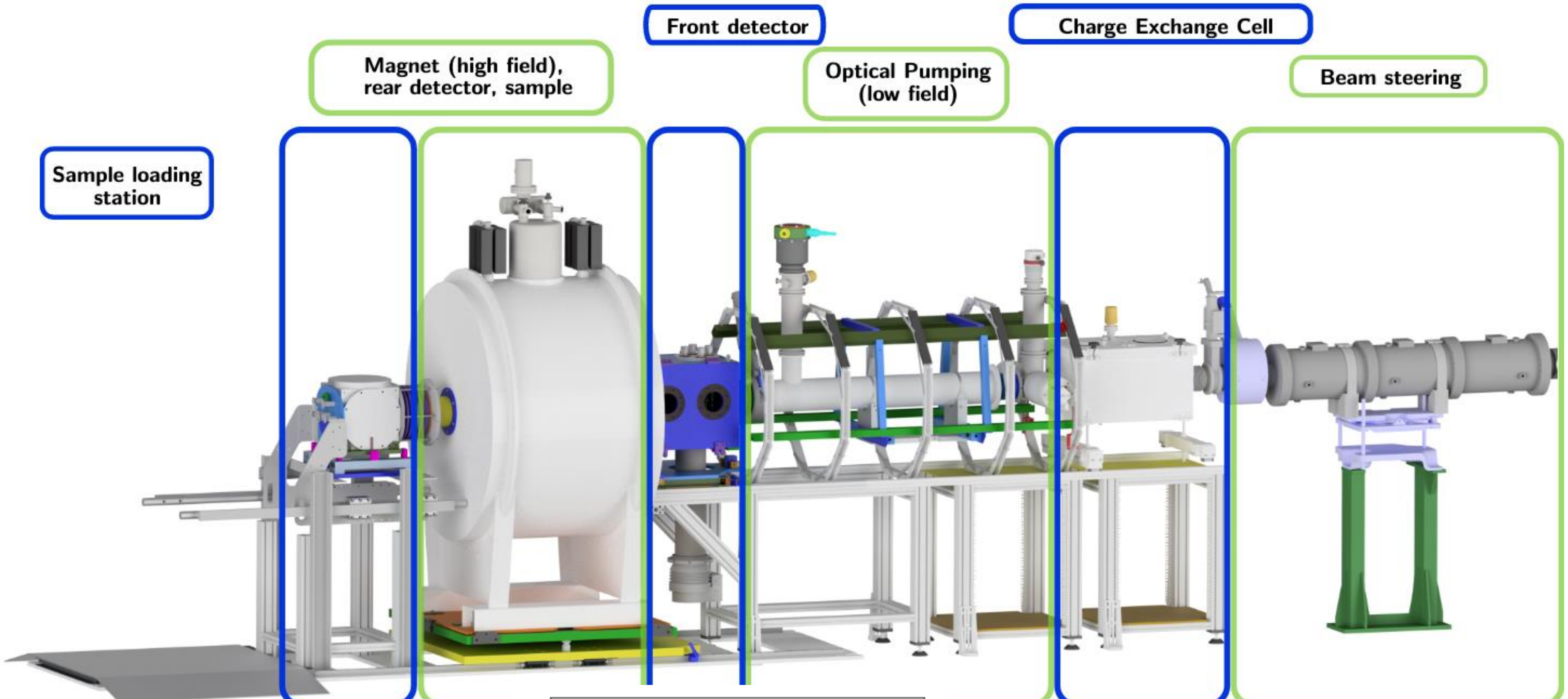
NMR

$$\frac{A_1}{A_2} = \frac{\mu_1/I_1}{\mu_2/I_2}(1 + \Delta(R_1, R_2))$$

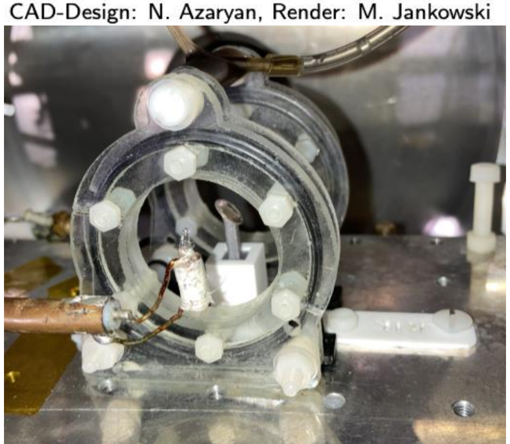
Atomic Spectroscopy

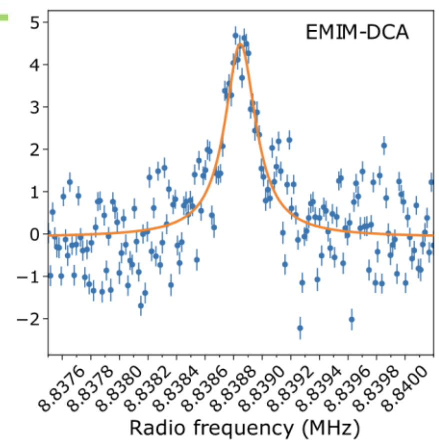
$\langle r^2 \rangle_{ch}$	$\langle r^2 \rangle_{M}$
All protons contribute equally (collective)	Only unpaired nucleons contribute (single particle)
Indirect influence of neutrons on charge distribution	Direct contribution of unpaired neutrons

Liquid State β-NMR



CAD-Design: N. Azaryan, Render: M. Jankowski

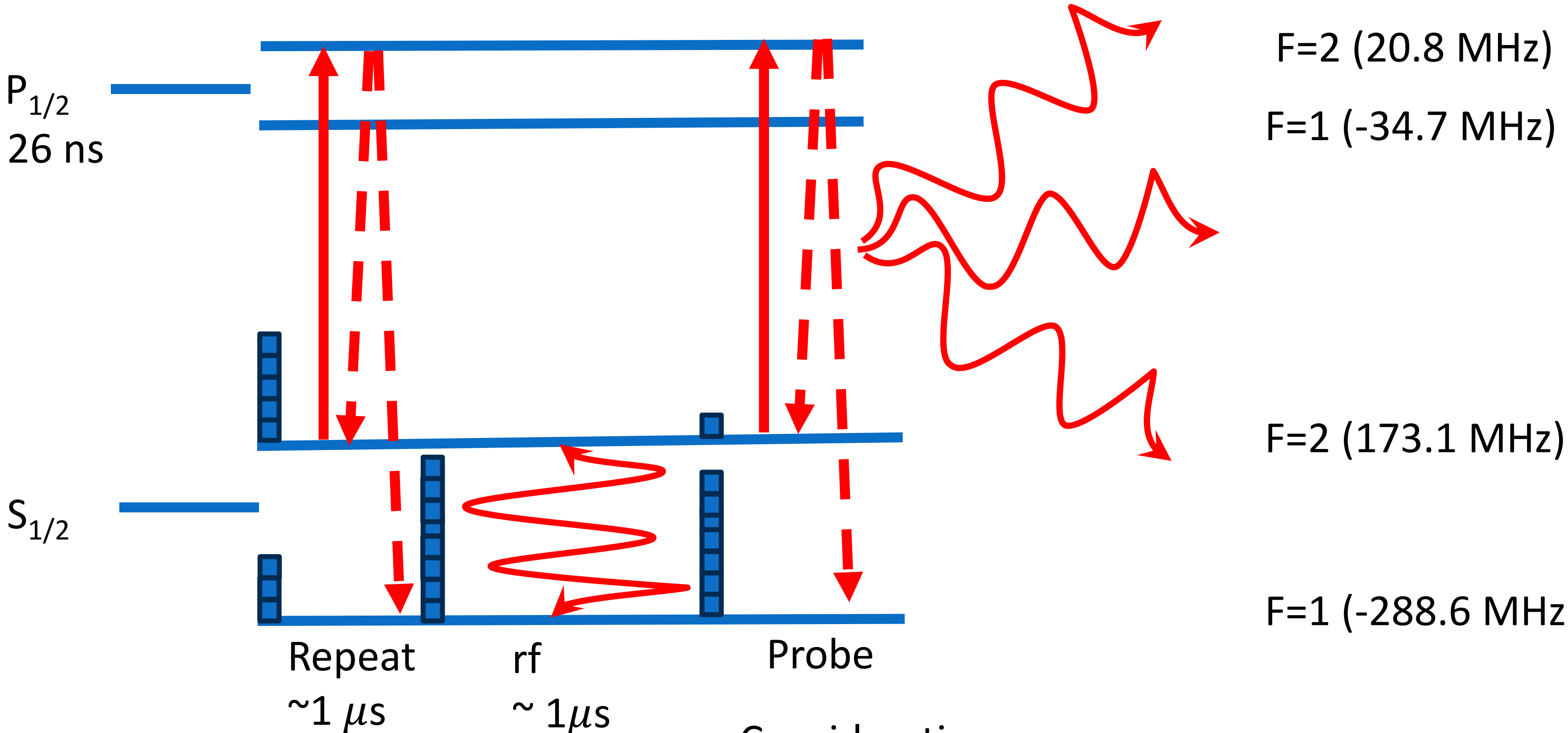




R. D Harding *et al*., PHYS. REV. X 10, 041061 (2020)

For latest developments see poster: Nikolay Azaryan

How to measure the HFS?

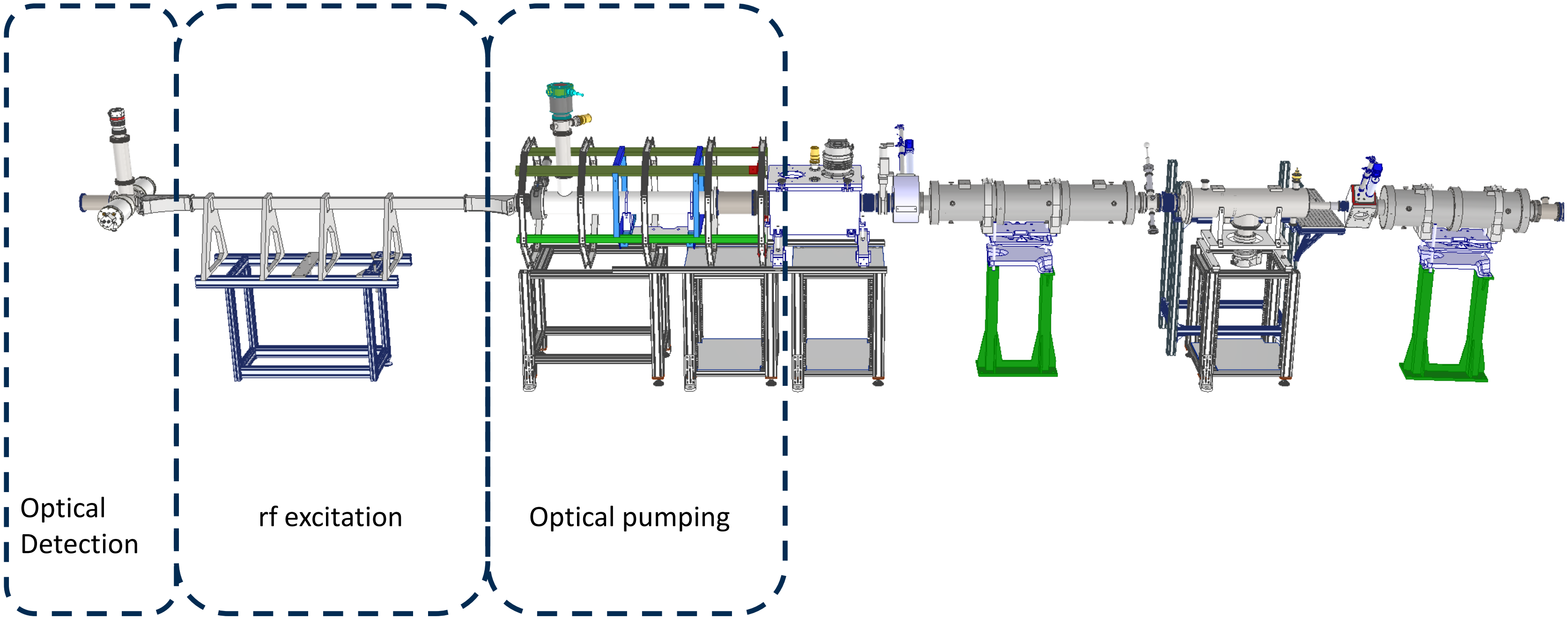


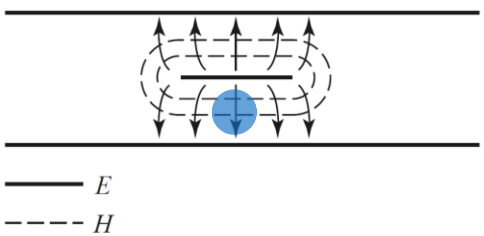
$$N(t) = \frac{\Omega(B)^2 \sin^2(\frac{t}{2}\sqrt{\Omega(B)^2 + \Delta^2})}{\Omega(B)^2 + \Delta^2}$$

Considerations:

- Flight time limits resolution ~2m required
- All atoms should experience the same rf-field strength to obtain maximal transfer.
- Frequency is doppler shifted – avoid reflection of rf.

What will it look like in practice?



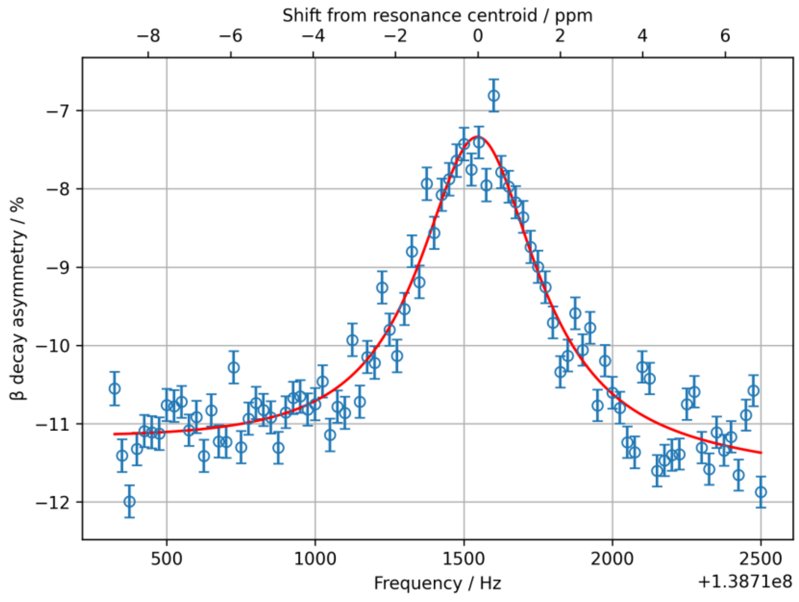


Vacuum spaced stripline geometry:

- How to connect to coaxial cable without reflections?

➢ See poster by Daniel Havranek

Recent measurement: ^{47}K



Preliminary Experimental result:

$$\frac{\nu(^{47}K, EMIM\ DCA)}{\nu\ (^{2}H, D_2O)} = 4.510\,701\ (2)$$

See poster: Marcus Jankowski

Literature[1] stable MNR:

$$\frac{\nu(^{39}K,\ H_2 0)}{\nu\ (^{2}H, D_2O)} = 0.303\,984\,85(9)$$

$$\frac{\nu(^{47}K, EMIM\ DCA)}{\nu\ (^{39}K,\ H_2O)} = 14.838570(6)$$

Correcting for chemical shielding and susceptibility: (Poster Andrej Hurajt)

$$\frac{\nu(^{47}K)}{\nu\ (^{39}K)} = 14.83787(9)$$

COLLAPS HFS measurements[2]:

$$\frac{A(^{47}K)}{A\ (^{39}K)} = 14.785(1)$$

$$^{39}\Delta^{47} = 0.358\ (7)\ \%$$

1) W. Sahm, A. Schwenk, Z. Nat. **29 a,** 1754 (1974)

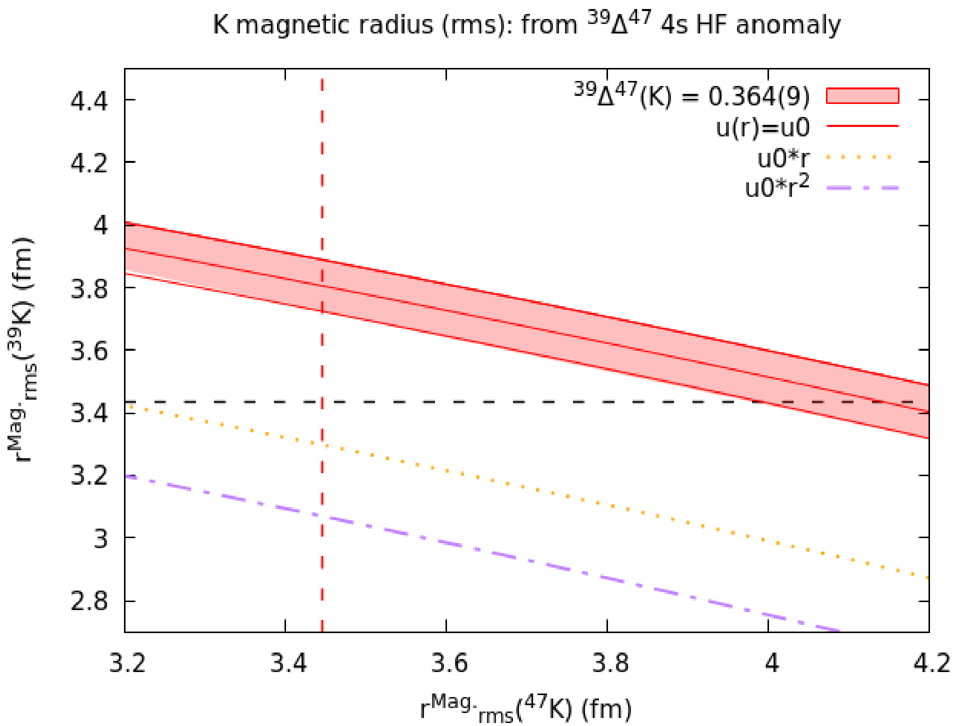
2) J. Papuga *et al*., Phys. Rev. C **90**, 034321 (2014)

^{47}K : Theory

$^{39}\Delta^{47} = 0.358\,(7)\,\%$

cf literature value: $^{39}\Delta^{47} = 0.28\,(16)\,\%$

Single particle estimate with $\langle r^2 \rangle_m = \langle r^2 \rangle^{ch}$: $^{39}\Delta^{47} = 0.29\,\%$



Atomic theory (Jacinda Ginges, Benjamin Roberts)

\+

Density Functional Theory (Jacek Dobaczewski)

work ongoing…

Initial calculations look extremely promising!

Future Measurements: ^{11}Be

PRL **112**, 162502 (2014) PHYSICAL REVIEW LETTERS week ending 25 APRIL 2014

Hyperfine Structure Constant of the Neutron Halo Nucleus $^{11}Be^{+}$

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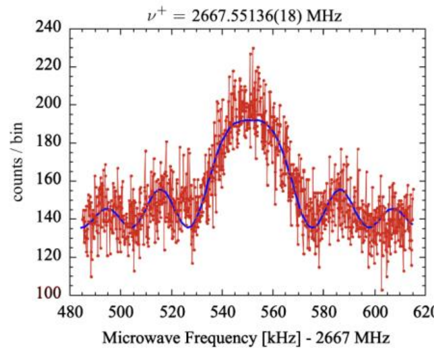

TABLE III. Magnetic hyperfine structure constants A of the ground $2s^2 S_{1/2}$ state ions and nuclear magnetic moments for all odd beryllium isotopes.

Isotope	A [MHz]	μ_I [n.m.]	$\langle\mu_I$ [n.m.]$\rangle^{a}$
^{7}Be	−742.772 28(43)^{c}		−1.399 28(2)^{c}
^{9}Be	−625.008 837 048(10)^{d}	−1.177 432(3)^{e}	
^{11}Be	−2677.302 988(72)^{b}	−1.6816(8)^{f}	−1.681 66(11)^{b}

[a]Indirectly from A.
[b]This work.
[c]Okada *et al.*, 2008 [8].
[d]Wineland *et al.*, 1983 [13].
[e]Itano, 1983 [14].
[f]Geithner *et al.*, 1999 [17].

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Hyperfine anomaly of Be isotopes and anomalous large anomaly in ^{11}Be

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(Received 10 September 1998)

A new result of investigations of the hyperfine structure (hfs) anomaly in Be isotopes is presented. The hfs constant for ^{11}Be is obtained by using the core plus neutron type wave function $|2s_{1/2}\rangle + |1d_{5/2}\times 2^{+};\frac{1}{2}^{+}\rangle$. A large hfs anomaly of ^{11}Be is found, which is mainly due to the large radius of the halo single-particle state. [S0556-2813(99)04701-9]

PACS number(s): 21.10.Ky, 21.60.Cs, 27.20.+n, 32.10.Fn

Only the magnetic moment of ^{11}Be not known with sufficient precision:

- Proposal accepted to measure this with liquid state $\boldsymbol{\beta}$-NMR.
- See poster: Daniel Paulitsch

Thanks to

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European Research Council

Established by the European Commission

How to measure the HFS ?