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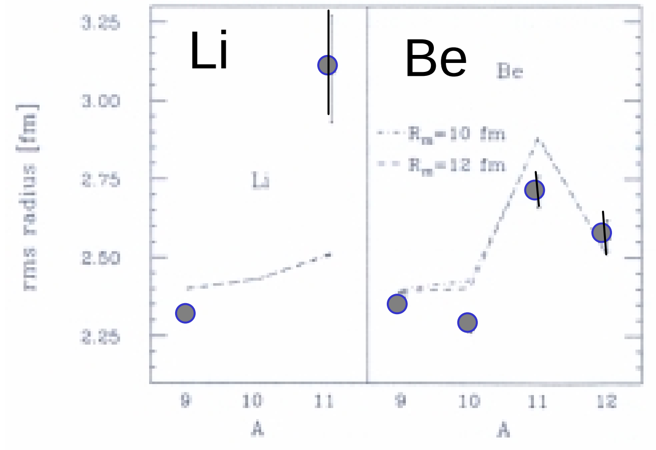
Static moments of exotic ground states: examples

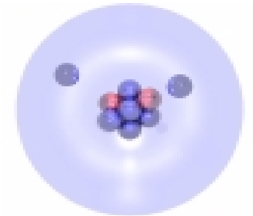
Moments of halo nuclei

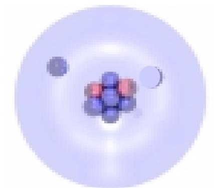
What are Halo Nuclei ?

nuclei with an extended
mass distribution (large rms **mass** radius)
(larger than ‘normal’).



Examples:

^{9}Li   ^{11}Li = ^{9}Li + 2 loosely bound neutrons

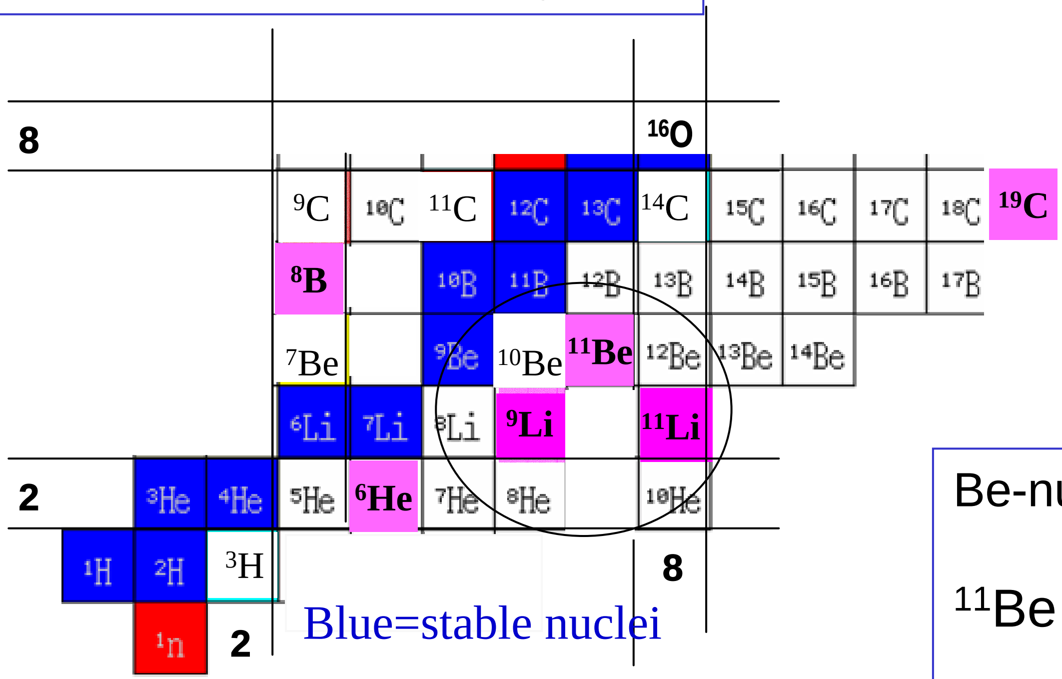
^{10}Be   ^{11}Be = ^{10}Be + 1 loosely bound neutron

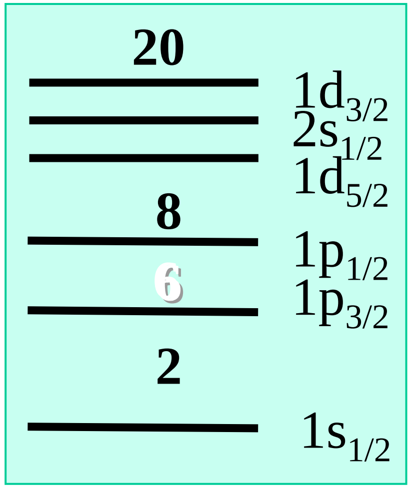
Questions:

which orbits are occupied by the loosely bound neutrons → the magnetic moment
do the the loosely bound neutrons induce deformation → the quadrupole moment
(core polarization or static deformed core ?)
is there also a large charge radius → indirectly (Q), directly (rms **charge** radius)

Ref: NPA 614 (1997) 44, PRC 49 (1994) 886, NPA 506 (1990) 271,

Halo Nuclei: where do they occur





Be-nuclei : Z = 4

^{11}Be = ^{10}Be + n
= 0^+ + n

Halo neutron determines the spin

^{11}Be: $I^\pi = ½^+$

→ neutron in intruder $2s_{1/2}$ orbit ?
or : $2^+ \times 1d_{5/2}$?

→ g-factor can reveal information
(unfortunately Qs = 0)

Li-nuclei : Z = 3

^{11}Li = ^{9}Li + 2n
= $(\pi p_{3/2} + 6n)$ + 2n
= $\pi p_{3/2} + 8n$

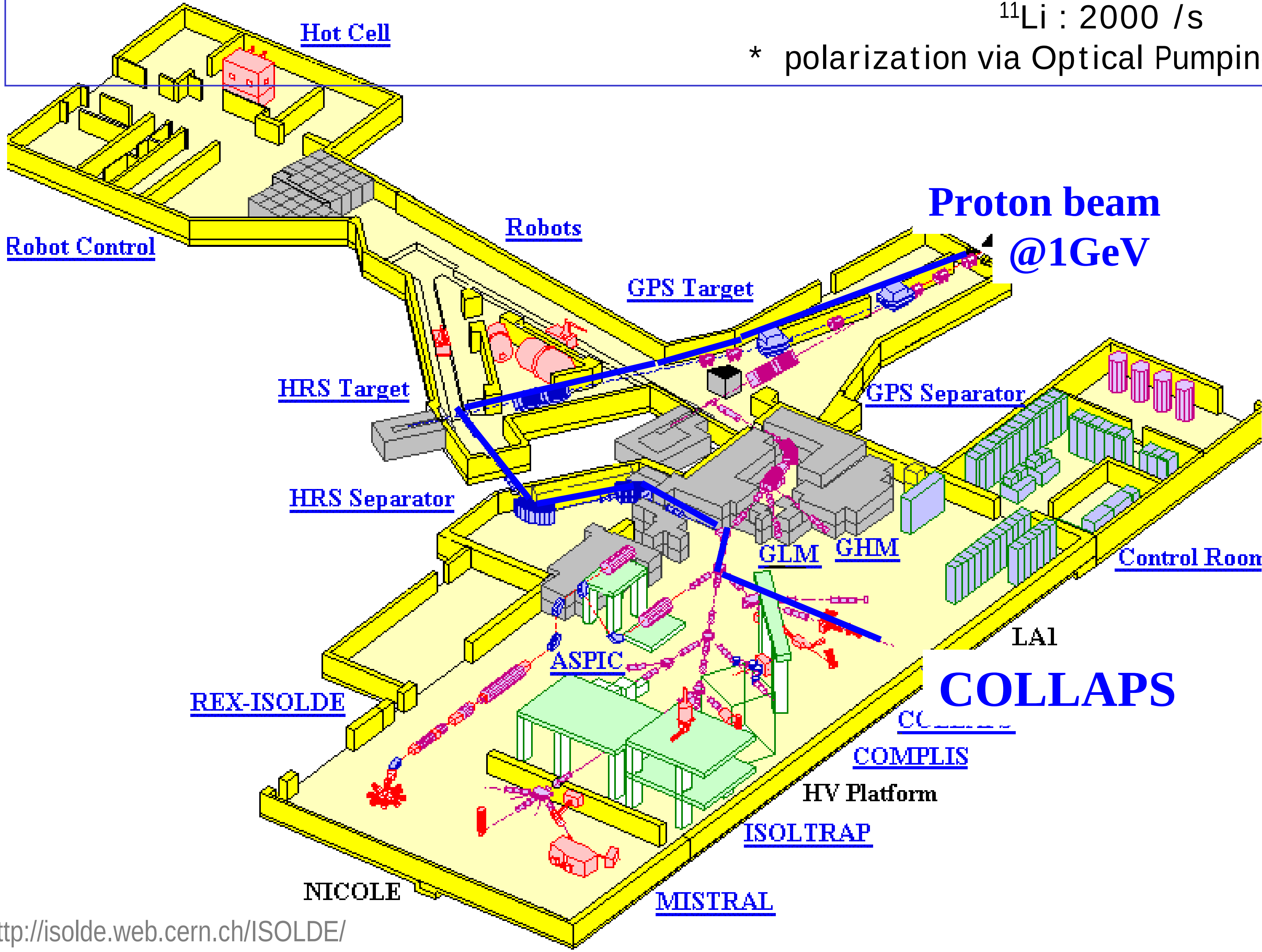
Odd proton determines the spin

^{11}Li: $I^\pi = 3/2^-$

The halo neutrons: in which orbitals (p or sd) ? Do they polarized the core ?

Halo Nuclei : how are they produced and polarized (in this case) ?

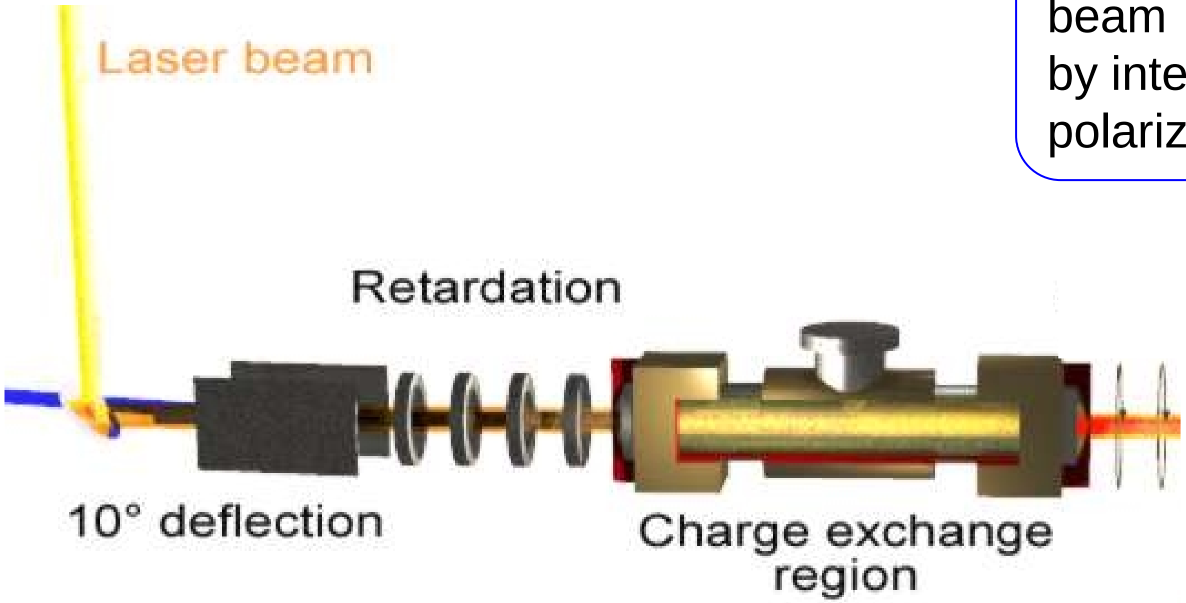
→ using the ISOL method at ISOLDE-CERN : * high rates → ^{11}Be : 5 10^5 /s
^{11}Li : 2000 /s
* polarization via Optical Pumping with laser



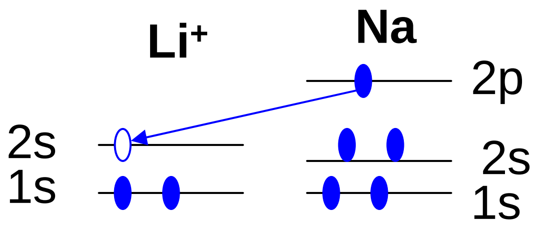
http://isolde.web.cern.ch/ISOLDE/

COLLAPS (Collinear Laser Spectroscopy) setup

Spin-polarized (atom or ion) beam
by interaction with circularly polarized laser light



Neutralize the ion beam via interaction with Na vapor

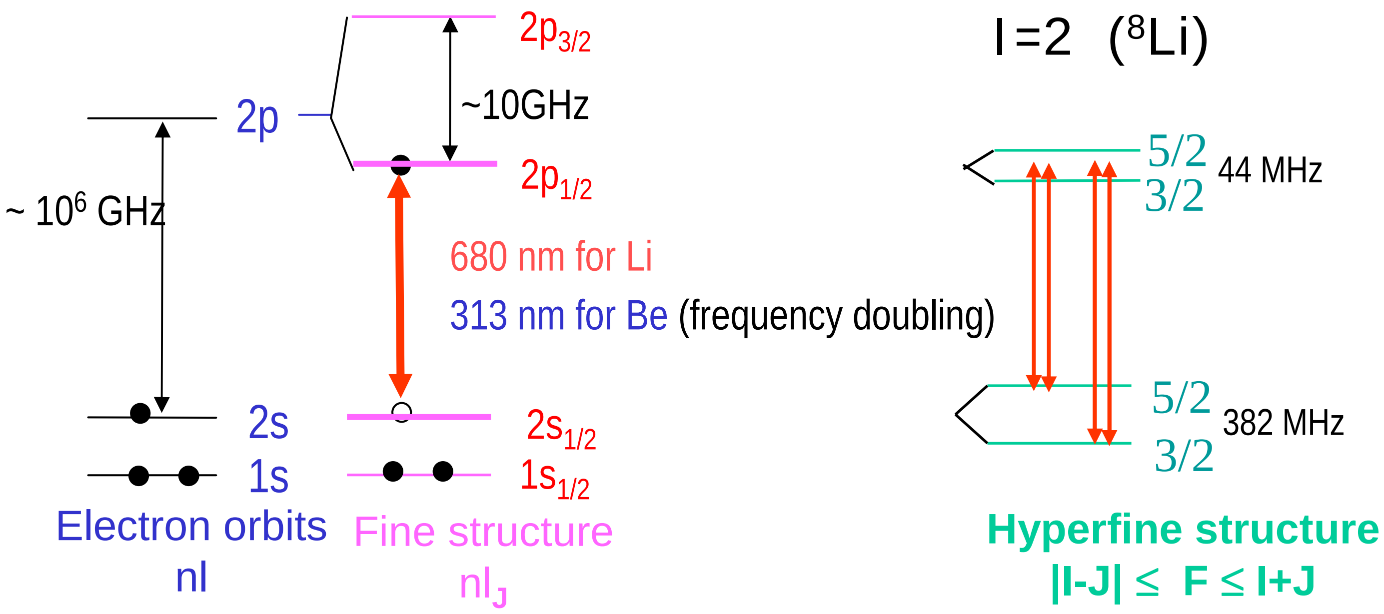


Polarize the Li-atom, not the ion

For Be: the ion is Li-like → polarize the Be-ion

Halo Nuclei : how are they polarized

Excite an electron in the atom (or ion) from the $2s_{1/2}$ to the $2p_{1/2}$ orbit with circularly circularly polarized laser light
→ produce a polarized atom (or ion) beam



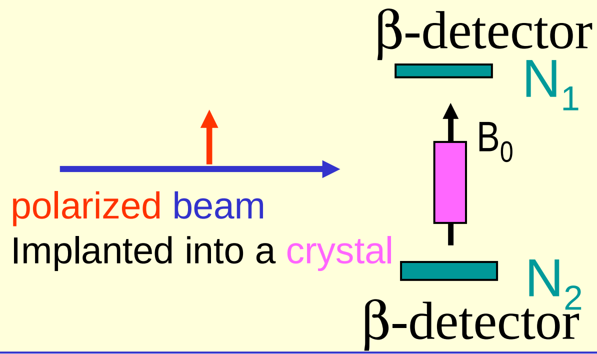
The lower hyperfine levels can be resolved in the hyperfine scan
→ Choose transition with largest induced nuclear polarization

Need good energy resolution of ion beam to resolve the hyperfine structure levels

Halo Nuclei : example of nuclear polarization induced in the ^{8}Li atom beam

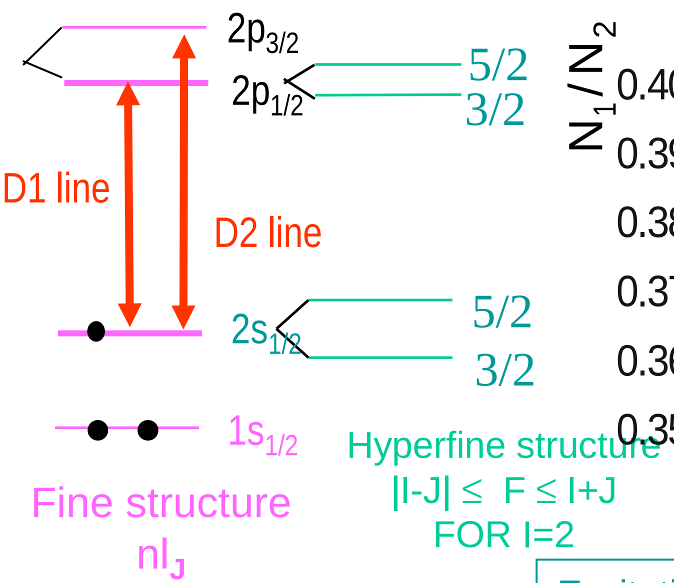
Measure → β-asymmetry of the ^{8}Li isotopes

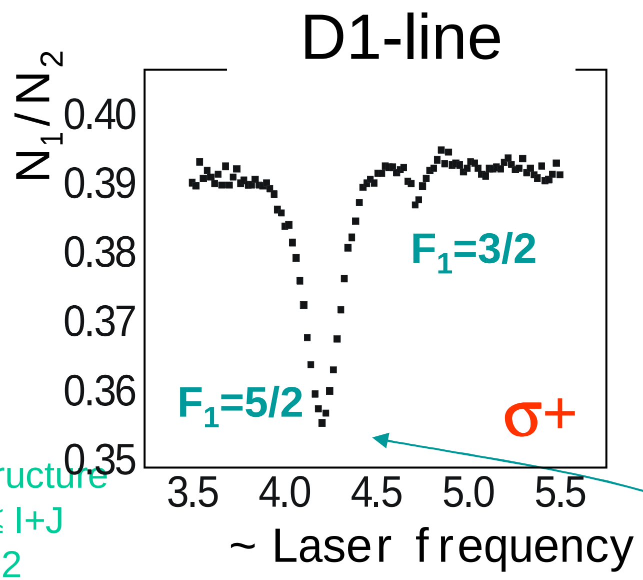
N_1/N_2

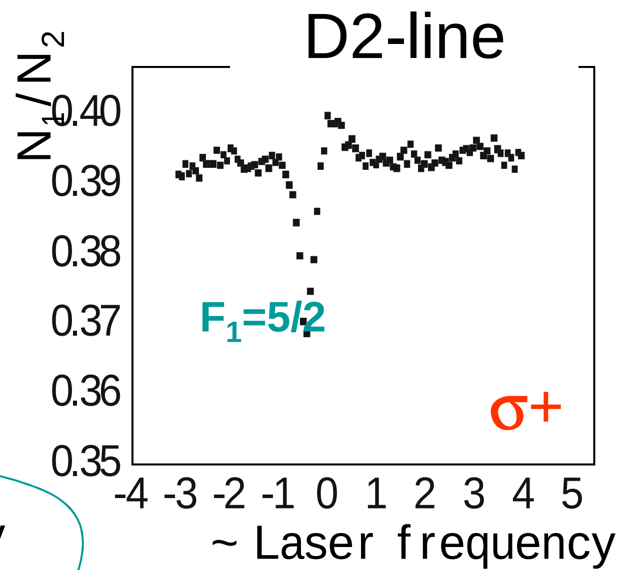


Fine structure levels $p_{1/2}$ and $p_{3/2}$ are scanned with different laser wavelengths (D1 and D2)

Only in the ground state $2s_{1/2}$ the hyperfine structure levels are resolved







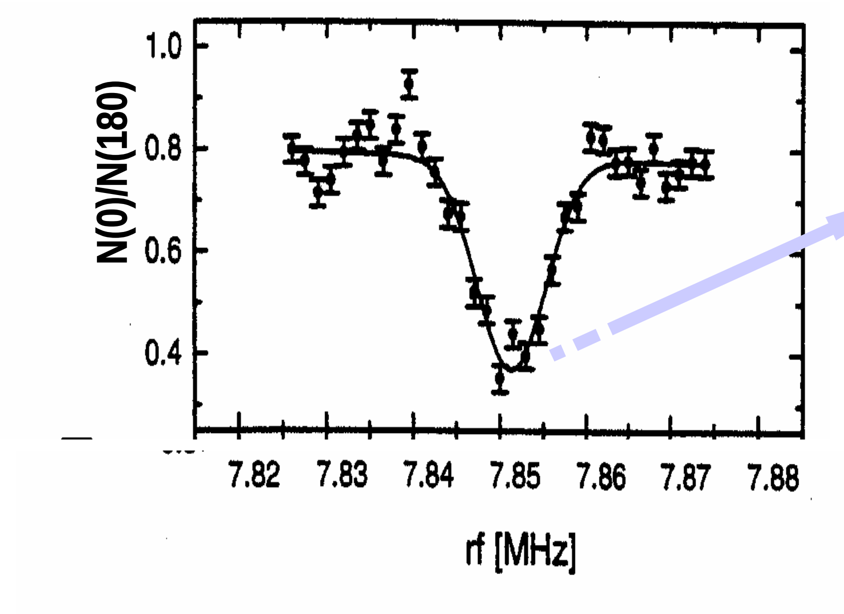
Excitation from the F=5/2 level gives the highest nuclear polarization !
fix laser to this frequency

Magnetic moment of ^{11}Be: the experiment

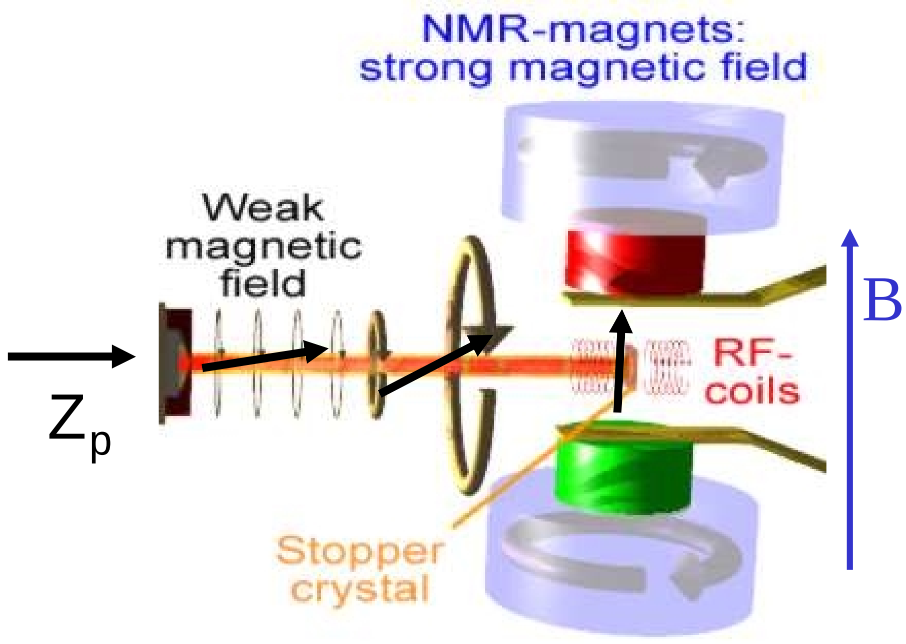
Method: β-NMR on laser polarized **ion** beam

- adiabatic rotation of the polarization axis using a small longitudinal magnetic field and a strong vertical magnetic field

- implantation of the beam into a crystal with cubic lattice structure, to maintain spin-orientation
  Be single crystal



Experimental set-up at COLLAPS



g = - 3.3632(16) (sign follows from the laser scan)

μ (^{11}Be, I= 1/2) = -1.6816(8) μ_N

W. Geithner et al. , PRL 83 (1999) 3732

Magnetic moment of ^{11}Be : the result

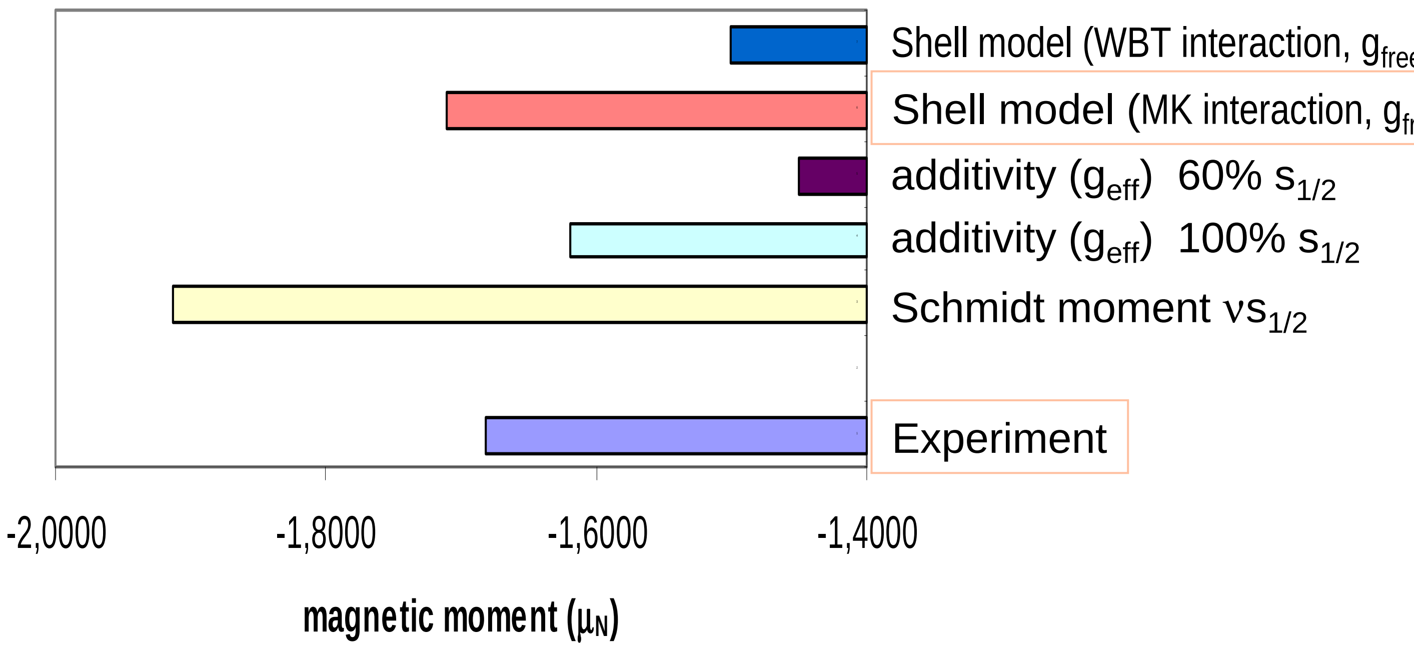
^{11}Be: $I^{\pi} = ½^{+}$ Z=4,N=7

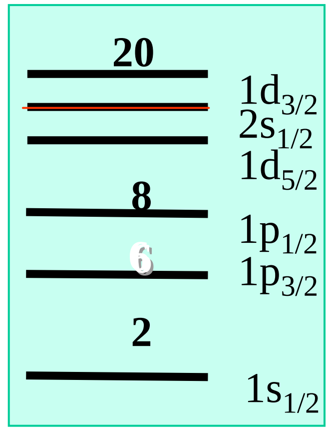
→ neutron in intruder $2s_{1/2}$ orbit ?   YES (magnetic moment close to Schmidt value)
($p_{1/2}$ neutron has $\mu_{schmidt}$ = +0.64)

→ admixture with $\nu(2^{+} \times 1d_{5/2})_{1/2+}$?   YES, β^2 is about 20%

Apply additivity rule for $|^{11}\text{Be}, ½+\rangle = \alpha\ [\nu 2s_{1/2}] + \beta\ [\nu(2^{+} \otimes 1d_{5/2})_{1/2+}]$

Collective excitation of the 10Be core



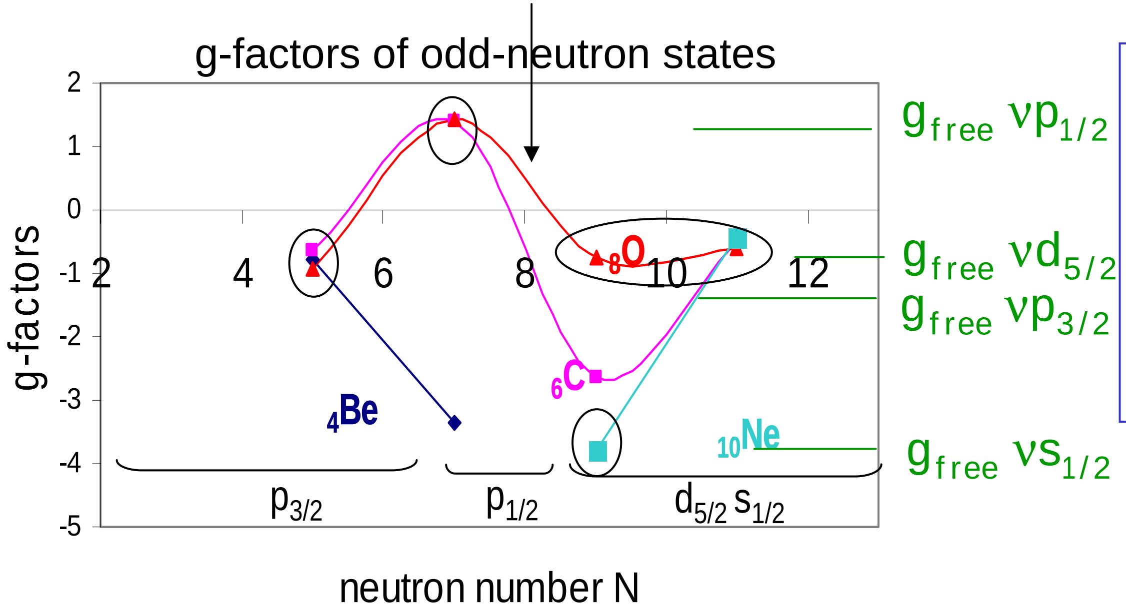


Magnetic moment of ^{11}Be : the result

The ground state of ^{11}Be

→ a neutron in the $s_{1/2}$ intruder orbit, not in the normal $p_{1/2}$ orbit

→ is N=8 a good shell closure ?



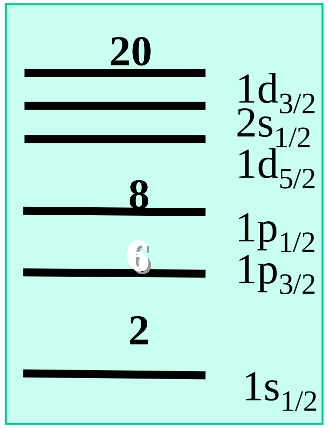
O-isotopes (Z=8) : all g-factors close to Schmidt value

Ne-isotopes (Z=10): N=9 g-factor → $s_{1/2}$ orbit !!!

C-isotopes (Z=6): N=9 g-factor suggests mixed $s_{1/2} - d_{5/2}$ configuration

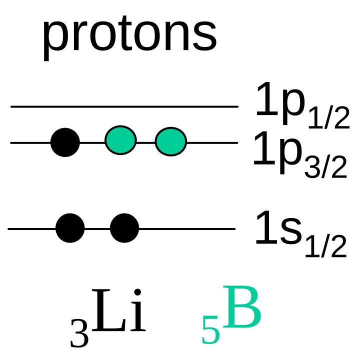
Be-isotopes (Z=4): N=7 g-factor in agreement with $s_{1/2}$-$d_{5/2}$ admixture

Conclusion : only for Z=8 the neutron N=8 is a good shell closure as soon as proton holes or particles occur around Z=8, the neutron-proton interaction (particle-core) seems to modify the shell structure.

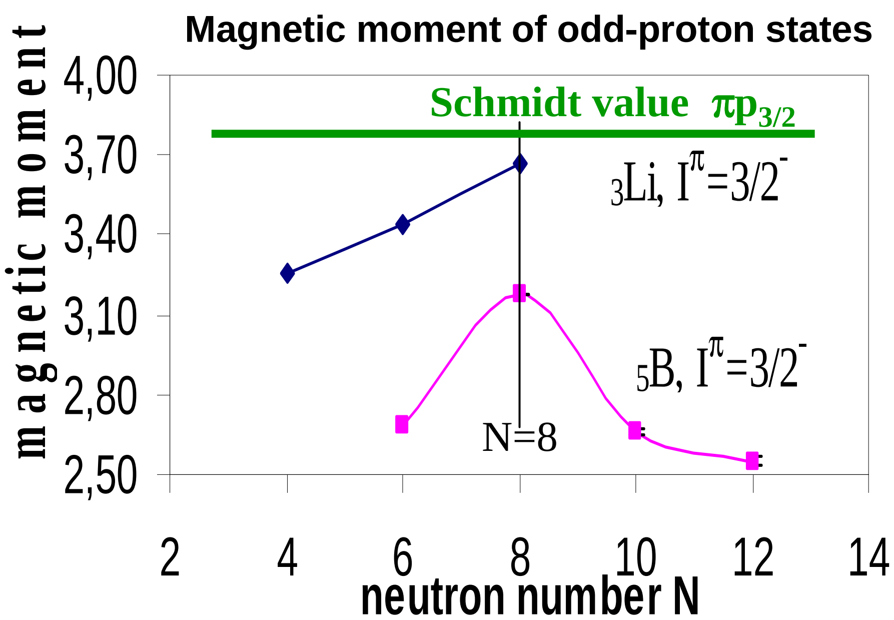


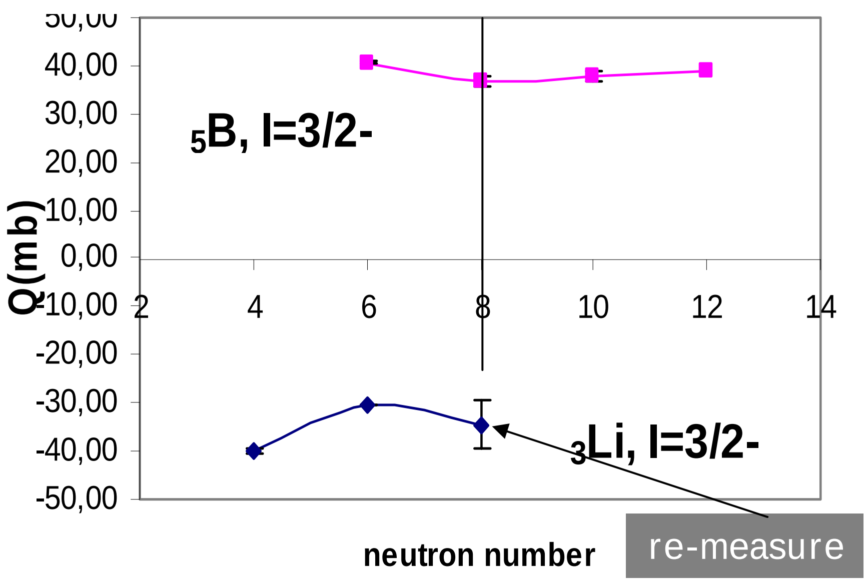
Conclusion: only for Z=8 nuclei,
the N=8 is a good neutron shell closure
as soon as proton holes or particles occur around Z=8,
the residual interaction of the valence neutron with
these proton particles/holes
seems to modify the NEUTRON shell structure

→ visible in the magnetic moments of odd-neutron states
→ shift of the neutron single particle energies as a function of proton number $\boxed{\varepsilon_n \neq \text{constant}}$ BUT $\varepsilon_n(Z)$!



vice-versa: is the disappearance of the N=8 shell closure also visibly through
the static dipole and quadrupole moments of odd-proton states ???





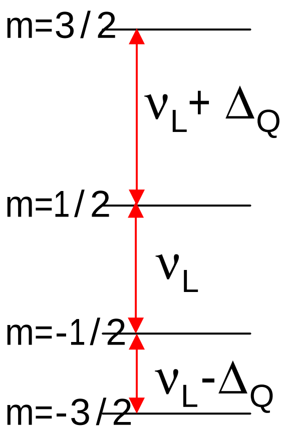
g-factor: no influence

Precision measurements of magnetic and quadrupole moments of Li-isotopes

Motivation 1: precision measurement of the ^{11}Li quadrupole moment
→ study the influence of the halo neutrons on the nuclear deformation ?

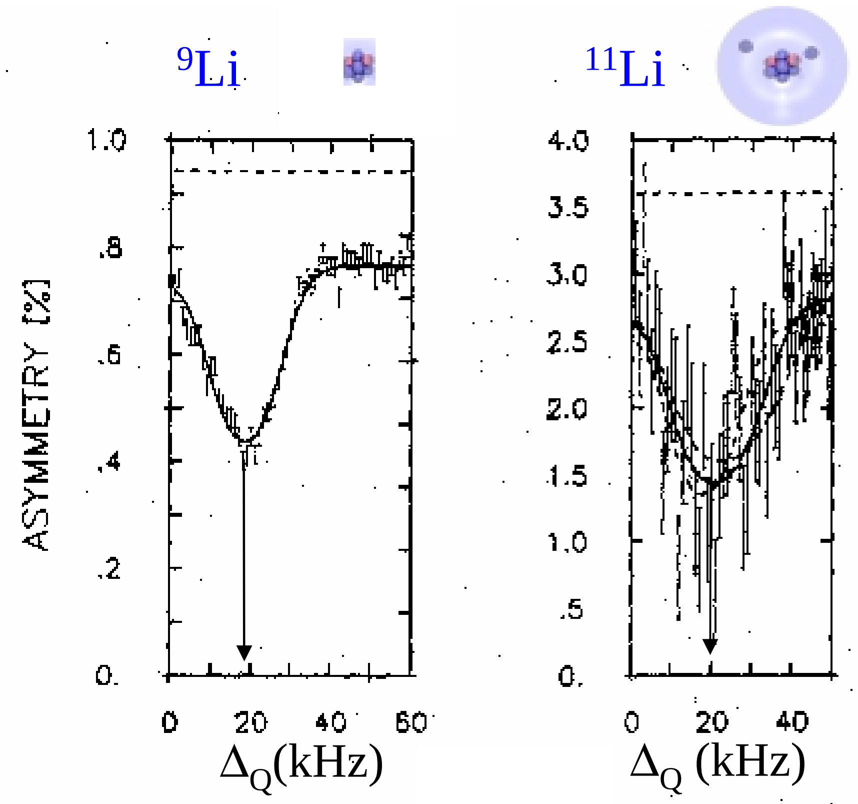
Results from earlier work: at COLLAPS (ISOLDE-CERN)

I=3/2



Multiple rf NQR

Crystal : $LiNbO_3$



$$\left| \frac{Q(^{11}Li)}{Q(^{9}Li)} \right| = 1.14(16)$$

Within (15%) error same value (even maybe smaller)

E.Arnold et al.;Phys. LettersB 281 (1992)16-19

Improve error on ratio → find crystal with narrower line width !

Preparation for precision measurements

- * find crystals with small line width (for NMR and NQR)
- * optimize the production of polarization (laser power, suitable crystal)
- * make precision measurement of Larmor frequency
  → needed to perform a precision multiple rf measurement
- * study properties of NQR and multiple rf-NQR → influence on result ?

Beta-detection rates at ISOLDE:		**Beta-asymmetries:**
^{8}Li : 500.000/s	**($T_{1/2}$ = 840 ms)**	**~ 8 %**
^{9}Li : 200.000/s	**($T_{1/2}$ = 179 ms)**	**~ 3 %**
^{11}Li: 80/s	**($T_{1/2}$ = 8 ms !!!)**	**~ 5 %**

→ Use ^{8}Li for testing (find optimal crystal and polarization conditions) I = 2

→ Use ^{9}Li as calibration for the Q-moment measurement
I = 3/2 (same multiple rf spectrum as ^{11}Li)

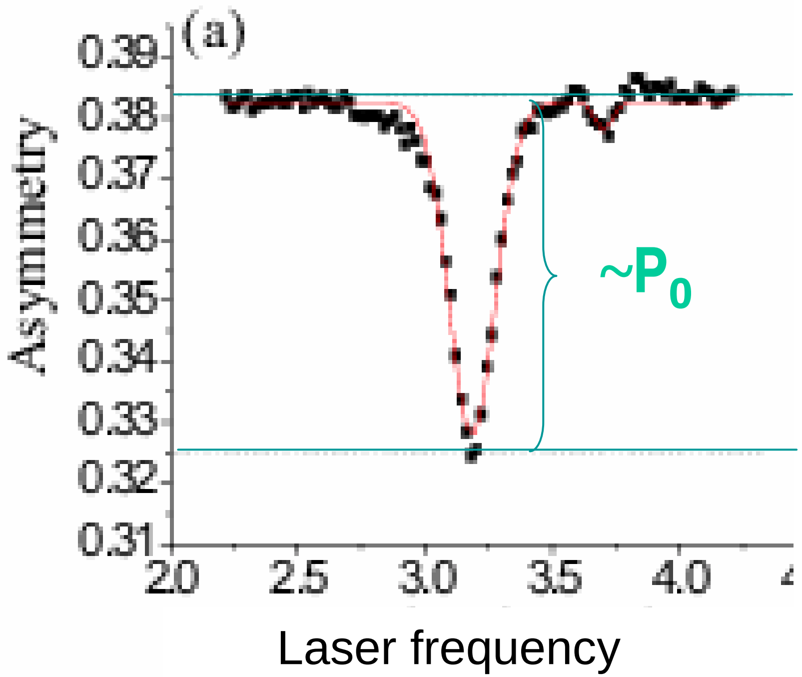
Preparation for NMR-precision measurement

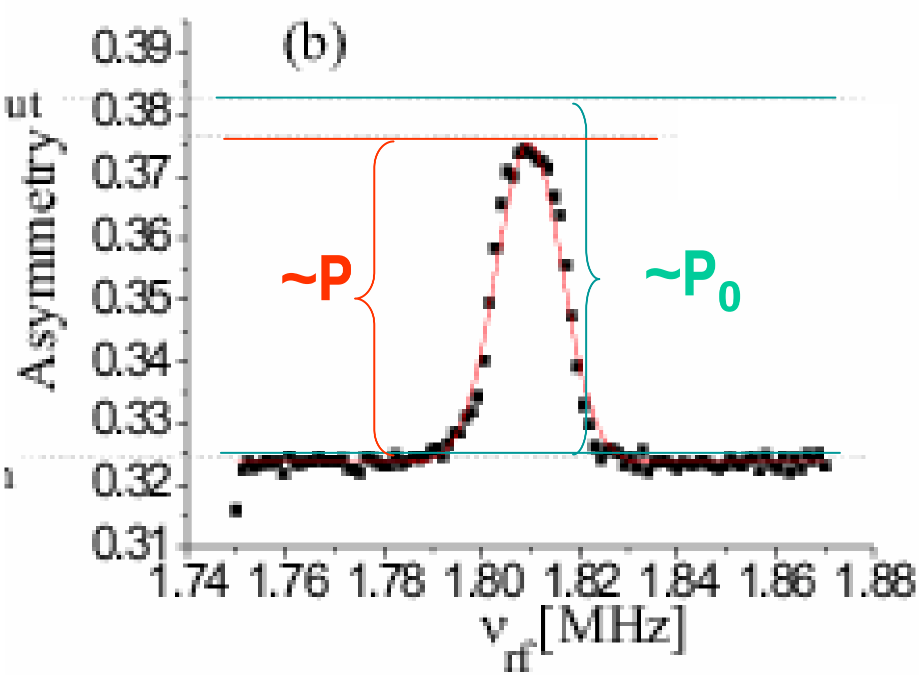
→ find a crystal

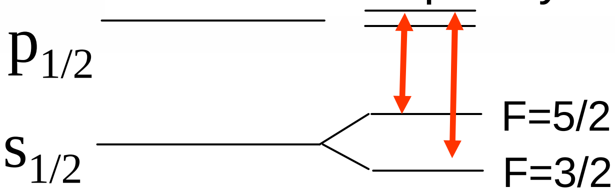
- **which maintains the produced polarization P_0**
- **with optimal destruction of P via NMR**
- **giving with small NMR line width**

Laser scan of the hyperfine spectrum
Measurement of **produced polarization**

NMR scan:
Amount of **destroyed polarization**



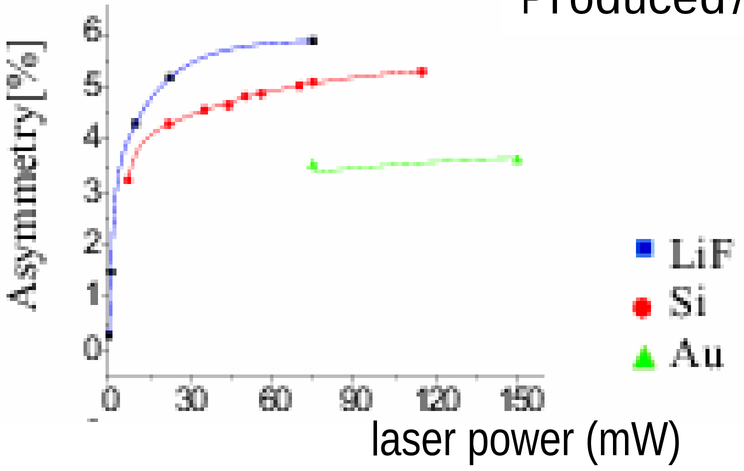




Aim: maximize P_0 **AND P**

Hyperfine scans and NMR scans for ^{8}Li in LiF, Si, Au

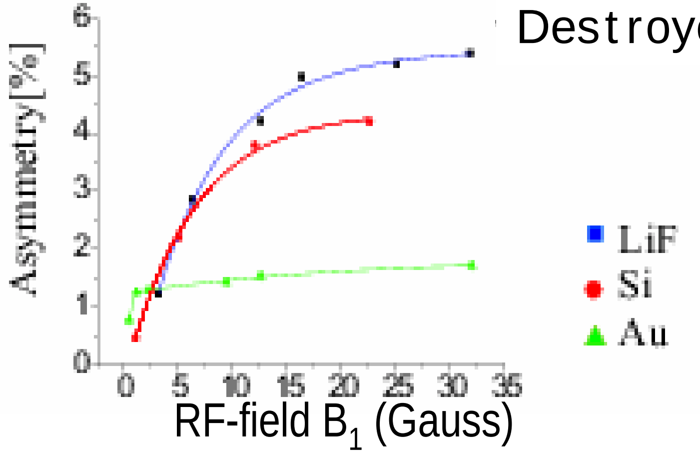
Produced/maintained Polarization



LiF: highest P_0 produced

Si: good as well

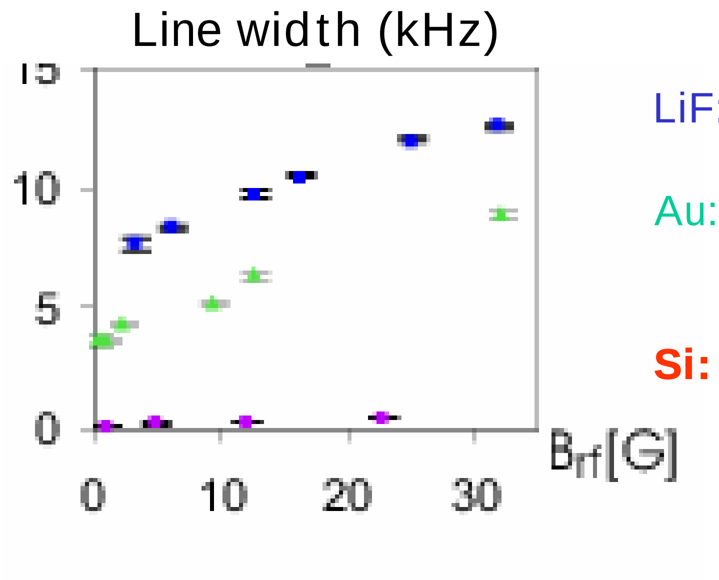
Destroyed Polarization



LiF and **Si:** nearly full destruction ($P \sim P_0$)

Au: bad (impurities)

Line width of NMR scans for ^{8}Li in LiF, Si, Au



LiF: very high line width

Au: medium

Si: very narrow line width !!!!

Si: good P_0

Si: nearly full destruction of P_0

CONCLUSION:
Si best crystal for NMR on Li-isotopes → precision 0.005% reached on μ

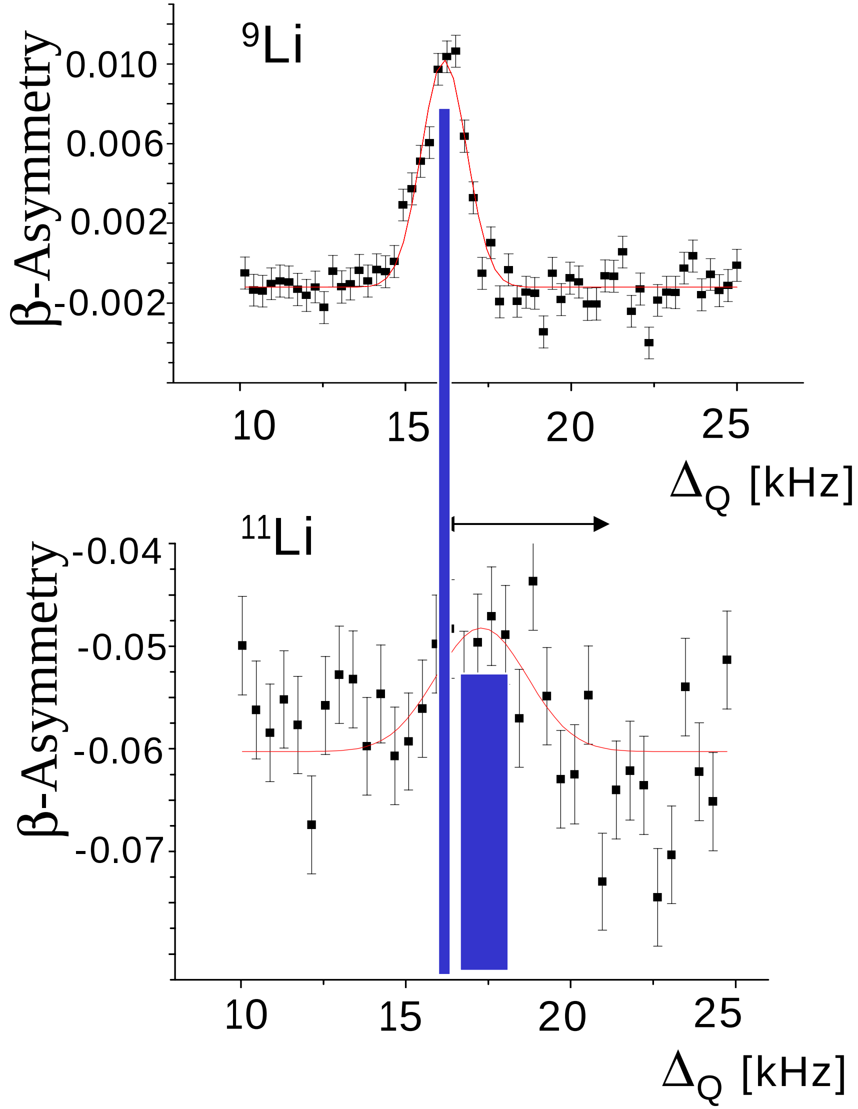
(see poster Magda Kowalska for results)

Preparation for NQR-precision measurement

→ **find a crystal**
- * **with optimal production of polarization**
- * **with optimal destruction of P via NQR**
- * **giving with small NQR line width**

in Zn-crystal

$\nu_Q = 2\,\Delta \sim\ Q\ V_{zz}$



Conclusion :

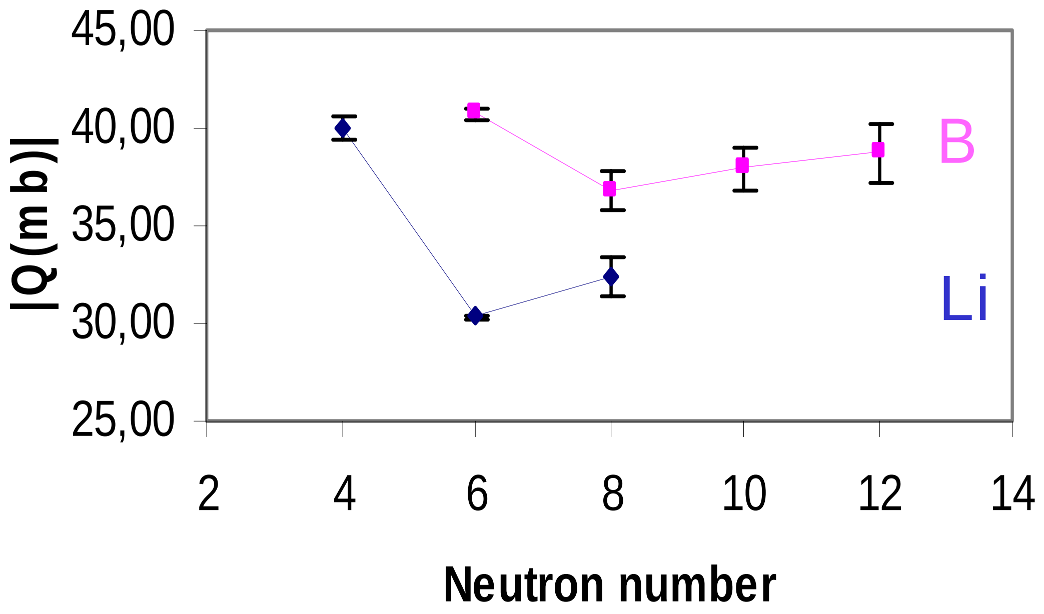
Large improvement on ratio of Q-moments !
~ 3 % accuracy

Absolute Q-moments more accurate
(measured in several crystals)
→ error Q(^{9}Li) ~ 1 %
→ error Q(^{11}Li) ~ 3 %

Q(^{11}Li) > Q(^{9}Li)

Preliminary !

Magnetic moment of ^{11}Li : the PRELIMENARY result



N=8 → still a good shell closure for B-isotopes (Z=5)

N=8 → not good shell closure for Be-isotopes (Z=4)

N=8 → not good shell closure for Li-isotopes (Z=3)
or influence of halo neutrons occupying non-spherical orbits ???