The nd-Experiment

a high-accuracy experiment to measure the spin-dependent neutron-deuteron scattering length $a_{i,d}$

Florian Piegsa

3rd meeting 'Polarized Nucleon Targets for Europe' in the 6th European Framework Program

February, 4th 2006 - Rech, Germany

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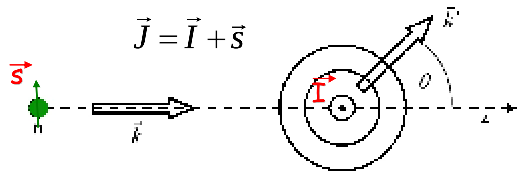
overview

- **Experimental Technique**
- **Ramsey-Setup for neutrons**
- **Results Beamtimes Summer/Winter 2005**
- **Summary / Outlook**

reminder - a_i

$$\vec{J} = \vec{I} + \vec{s}$$



$$\psi(\vec{r}) \propto e^{i\vec{k}\vec{r}} + f(\Theta)\cdot\frac{e^{ikr}}{r} \xrightarrow{\text{s-wave approx.}} e^{i\vec{k}\vec{r}} - a\cdot\frac{e^{ikr}}{r}$$

f(Θ) = scatt. amplitude

a = free scatt. length [fm]

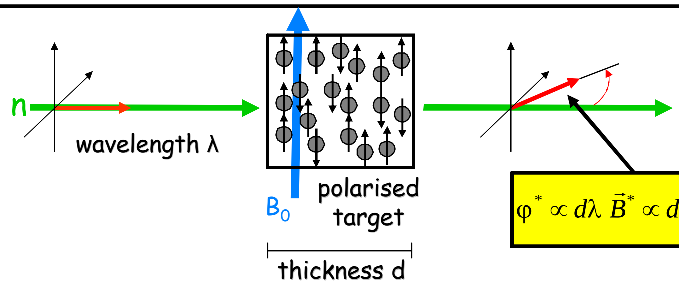
$$a = a_c + \frac{2\,a_i}{\sqrt{I(I+1)}}\,\vec{s}\cdot\vec{I}$$

a_c = coherent / spin-independent scatt. length

a_i = incoherent / spin-dependent scatt. length

pseudomagnetic precession

[V. Barychevsky, M. Podgoretsky, JETP **20** (1965) 704]
[A. Abragam, H. Glättli et al., PRL **31** (1973) 776]



$$\varphi^* \propto d\lambda\,\vec{B}^* \propto d\lambda\,a_i\,\frac{N}{V}P$$

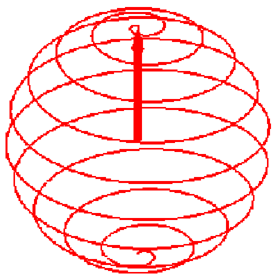
Polarised neutrons see a spin-dependent potential V_{spin} in a target containing polarised nuclei, due to spin-dependent strong-interaction.

$$V_{spin} \propto a_i\,\vec{s}\cdot\vec{P} \propto a_i\,\vec{\mu}_n\cdot\vec{P} \equiv -\vec{\mu}_n\cdot\vec{B}^*$$

V_{spin} is the sum over all Fermi-potentials

$$\vec{B}^* = -\frac{N}{V}\frac{4\pi\hbar}{m\gamma_n}a_i\sqrt{\frac{I}{I+1}}\vec{P} \quad\Rightarrow\quad \vec{\omega}_{Larmor} = \gamma_n(\vec{B}_0 + \vec{B}^*)$$

pseudo-magnetic field B* is typ. a few Tesla.

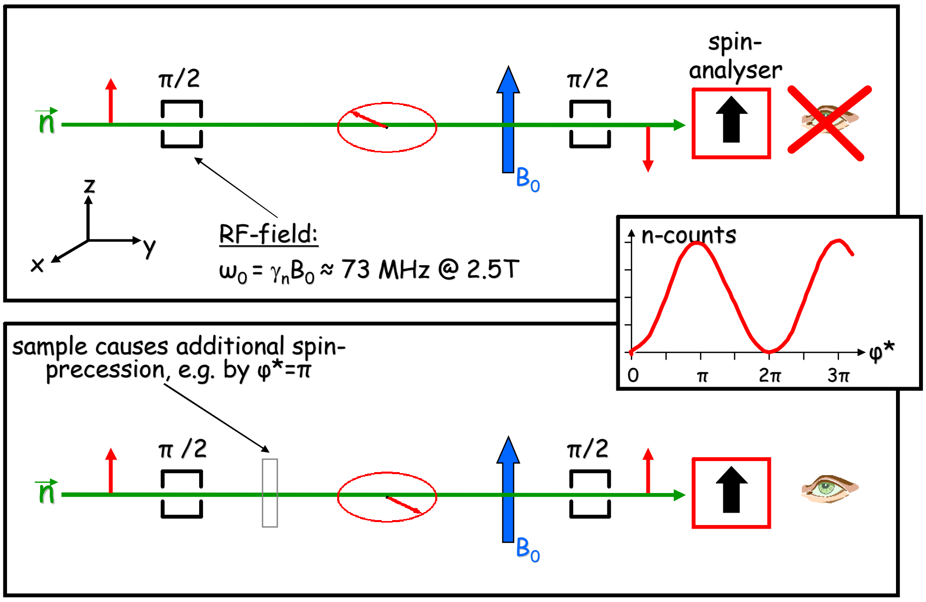


TECHNIQUES OF THE EXPERIMENT

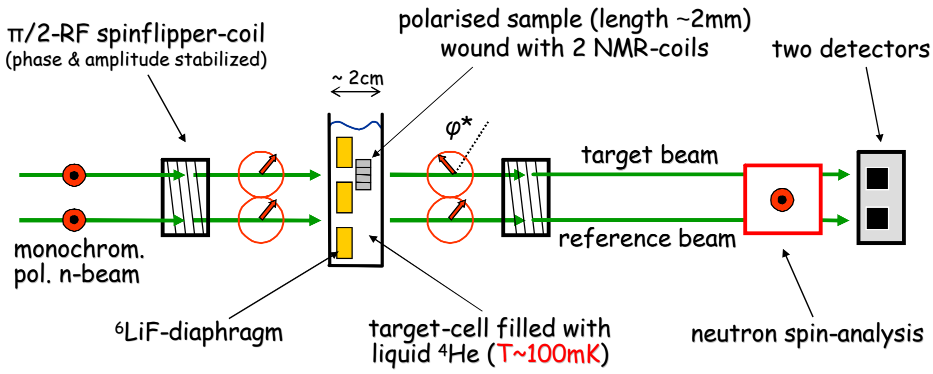
[B.v.d. Brandt et al., NIM A **526** (2004) 81-90]

Ramsey's technique

[N.F. Ramsey, Phys. Rev. **78** (1950) 695]

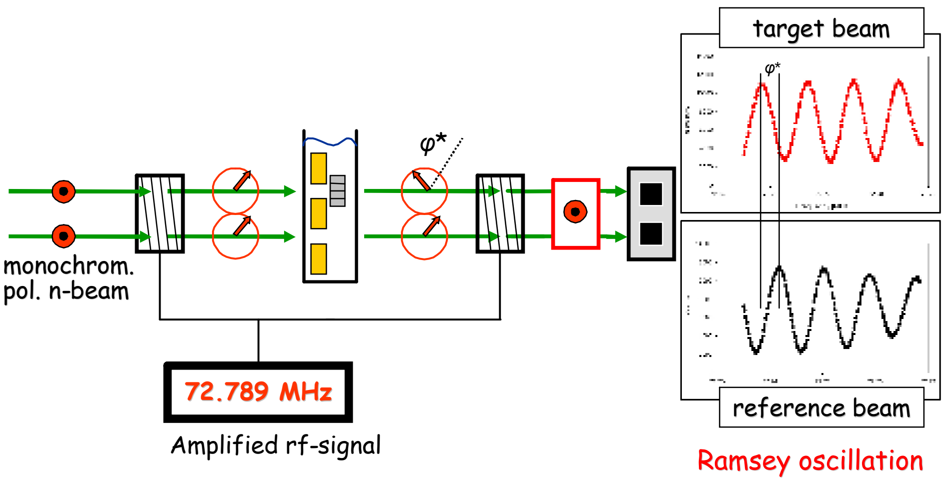


split beam-method



magnetic field of approx. 2.5 Tesla
perpendicular to the drawing plane.

how to measure φ* ? – frequency scan



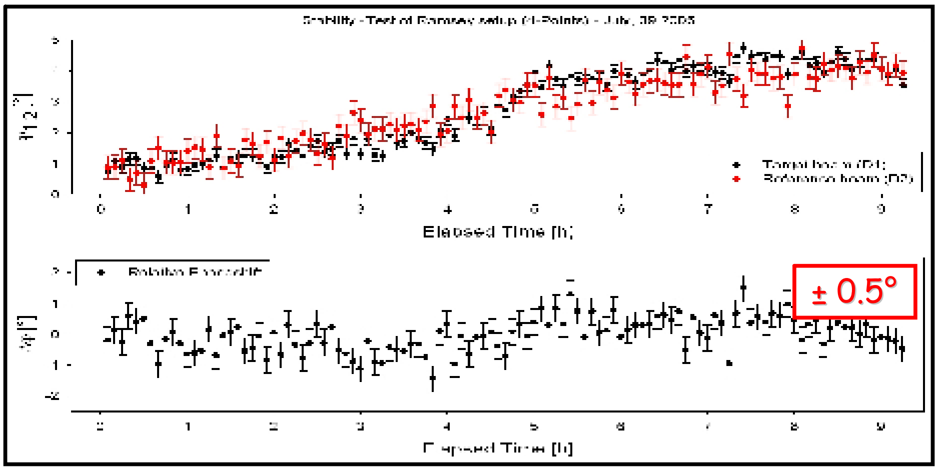
Ramsey oscillation patterns

The neutron-spin makes several thousand precessions on the way between the two spin-flippers -- we need to measure the phase-shift better than 0.5° to achieve our accuracy-goal.

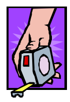
phase-stability test

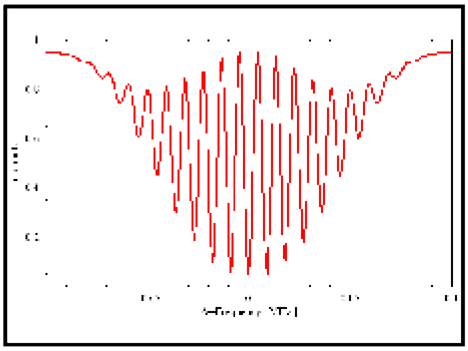
· relative phase between the spinflippers is stabilized better than ±0.04°
· magnetic field is stabilized by NMR-probes to $\pm 5\times10^{-7}$

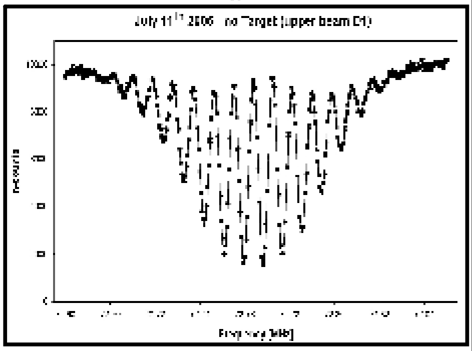
→ Nevertheless general drifts can occur (e.g. temperature-drifts):



example: simulated & measured data

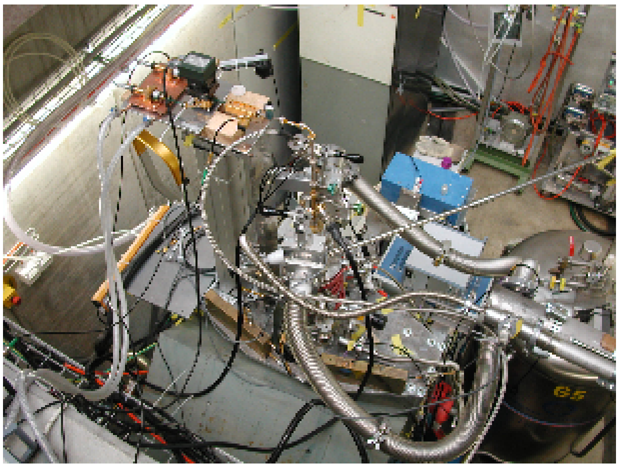






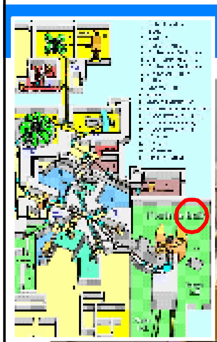
Simulation-parameters:
P_n = 90%, λ_{center} = 4.9Å , Δλ/λ = 8%
Rf-flipper distance = 8cm
Rf-flipper coil-length = 0.8cm

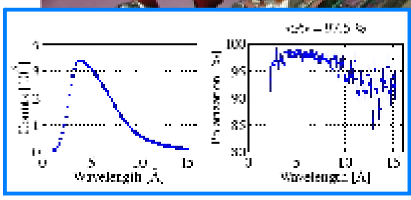
Measured Ramsey-patterns are in excellent agreement with the theory.



EXPERIMENTAL SETUP

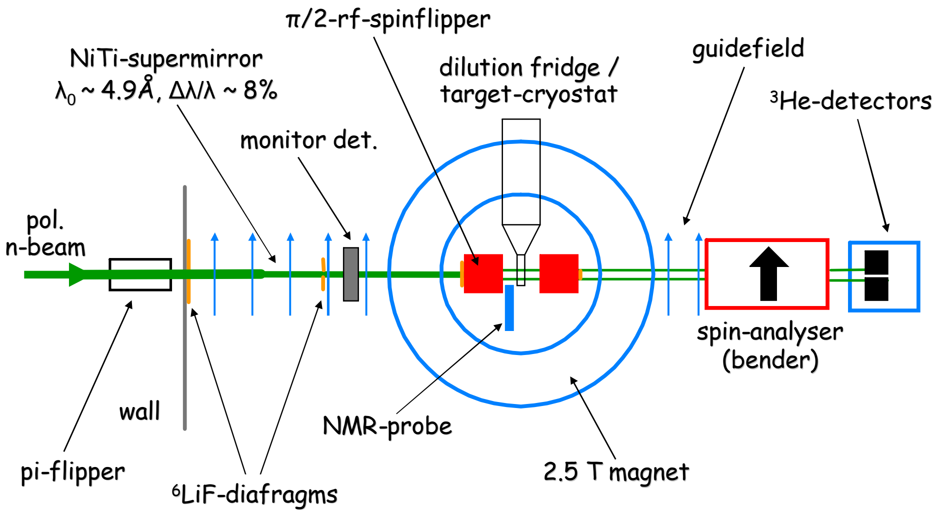
cold, polarised neutron beam „FUNSPIN“





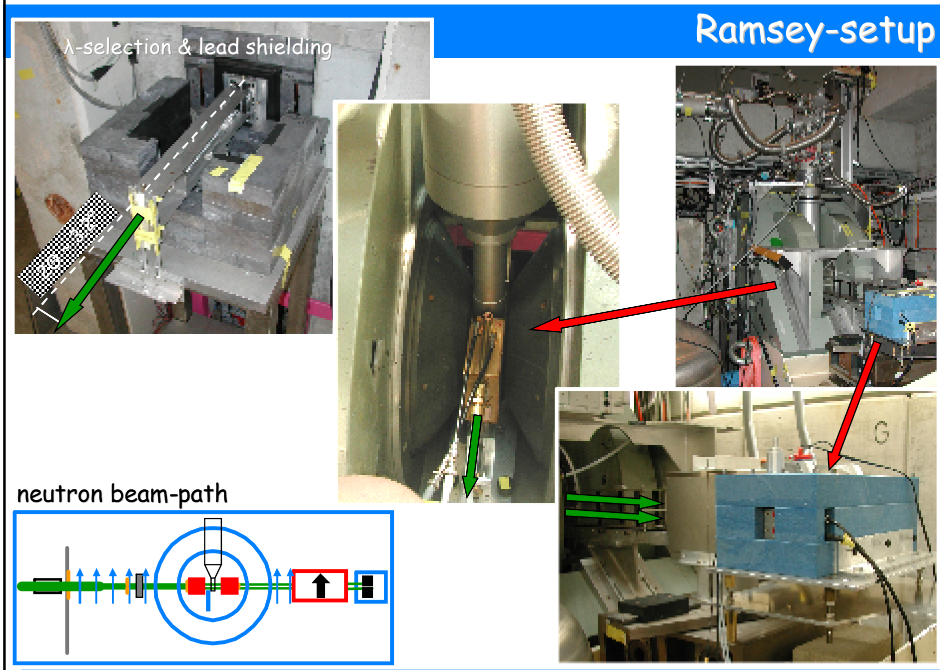
wavelength-integrated neutron-flux density:
$\Phi = 2.46 \times 10^8$ [n/cm²·s·mA] - **polarised** !!

scatch of the Ramsey-setup



Rech, Germany - F.Piegsa - 04.02.06

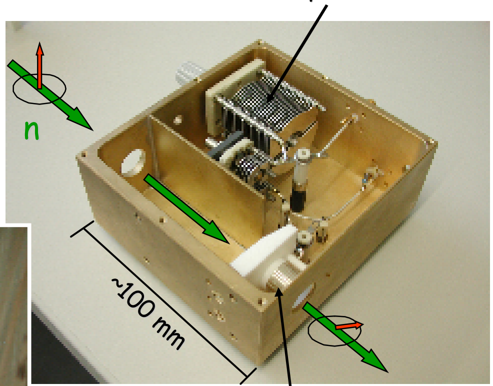
Ramsey-setup

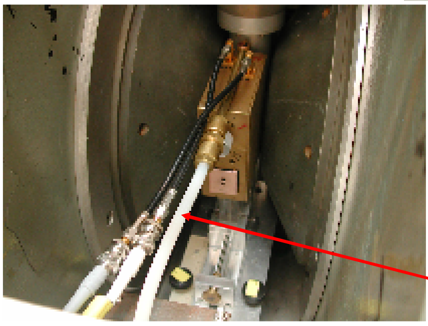


Rech, Germany - F.Piegsa - 04.02.06

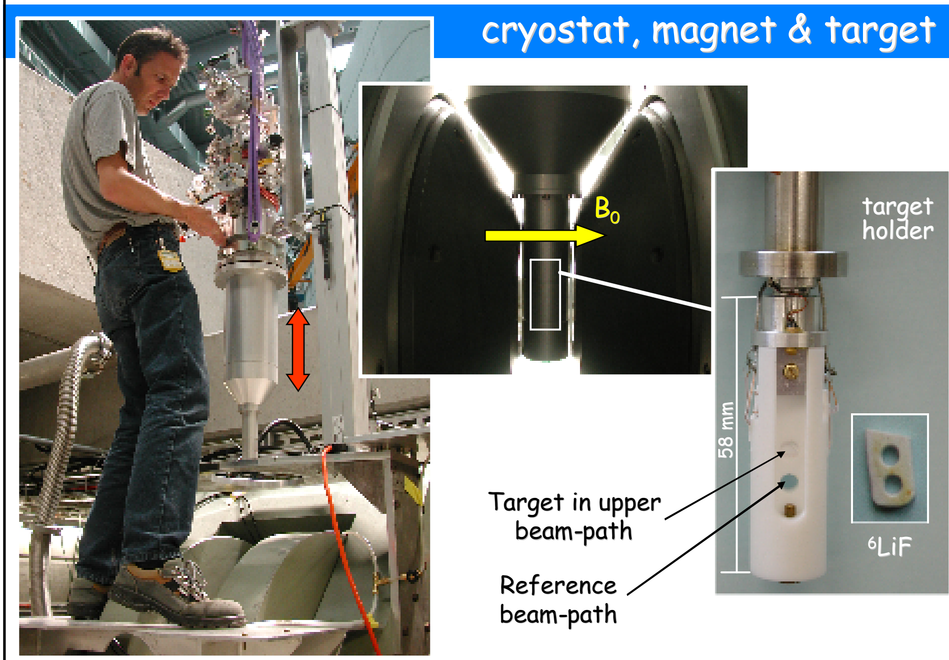
π/2 - neutron spin-flipper

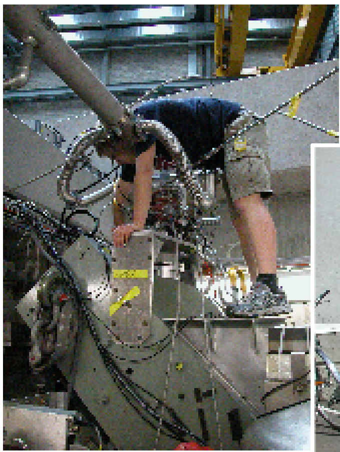
The π /2-spin-flippers are matched resonant-circuits at 73 MHz (2.5T):





cryostat, magnet & target



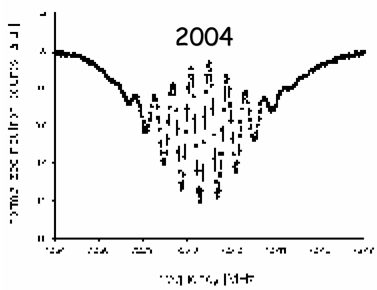


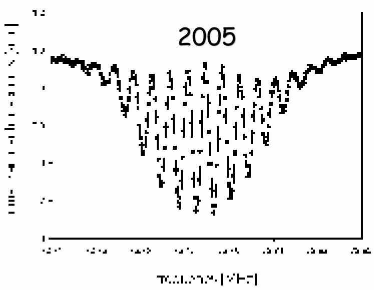
BEAMTIME SUMMER 2005

improved Ramsey-signals in 2005

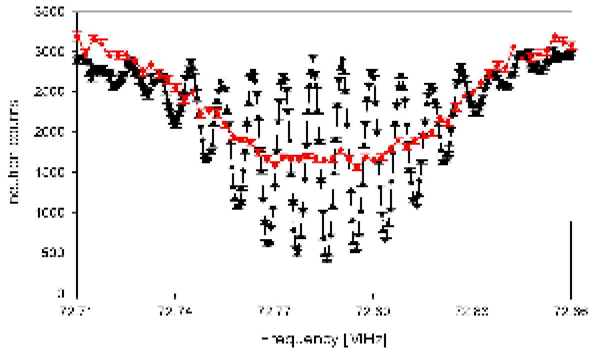
- new supermirror wavelength-selectors
- an improved neutron collimation system
- new designed $\pi/2$-spinflippers

→ more Ramsey-wiggles visible
→ increase of the amplitude
→ broadening of the resonance (approx. 15-20%)





but then …



- ● : unpolarised sample
- ● : polarised sample

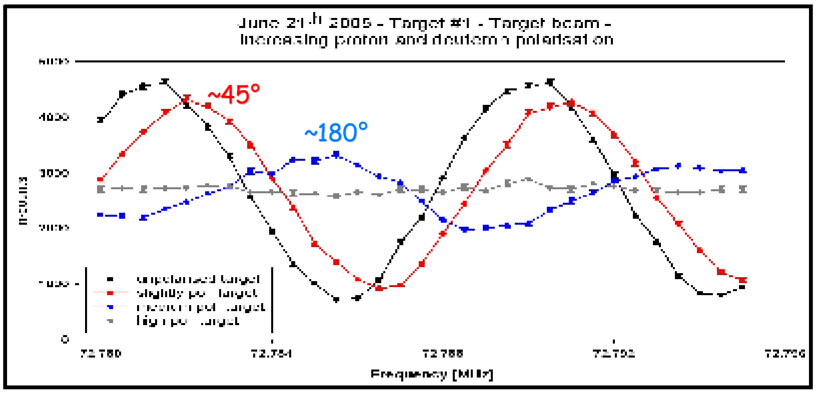
The Ramsey-Signal was not visible anymore. Reason(s) ???

phase-shift is far bigger than expected ??

sample inhomogeneities ??

density — thickness — polarisation

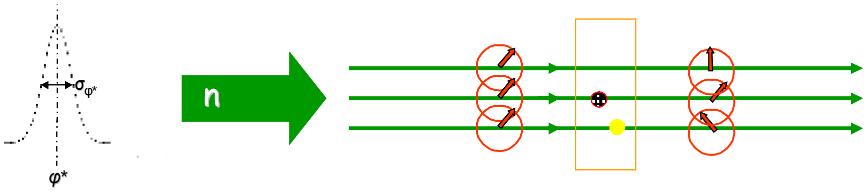
polarise only a little



Phase-shift increases with increasing nuclear polarisation, but is accompanied by a loss in signal-visibility.

This loss is maybe due to target inhomogeneities.

sample inhomogeneities – we take a step back …



Inhomogeneities in the sample destroy the neutron spin-phase coherence, which leeds to a damping of the Ramsey-signal.

↓

We had to test more samples & maybe alter the production process in the next beamtime.

Our dilution fridge doesn't allow for a quick change of samples.

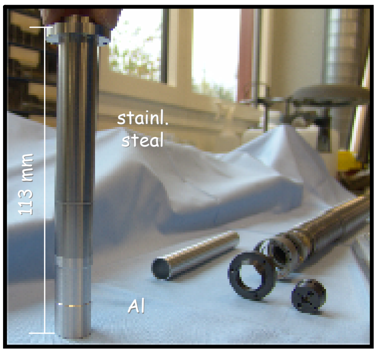
In order to find an appropriate sample, we decided to construct an 1 Kelvin ^{4}He-bath cryostat, which does.

BEAMTIME WINTER 2005

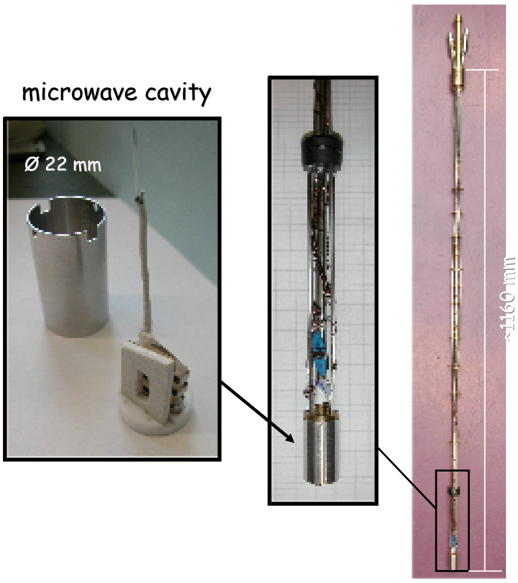
Rech, Germany – F.Piegsa – 04.02.06

some parts constructed for the 1K-cryostat

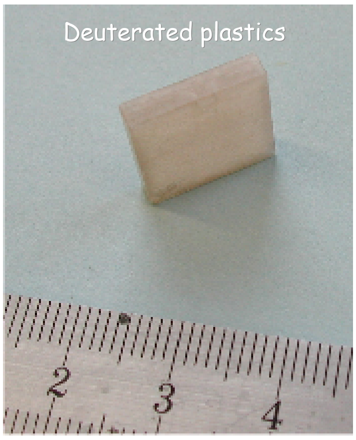
vacuum-nose / refrigerator insert

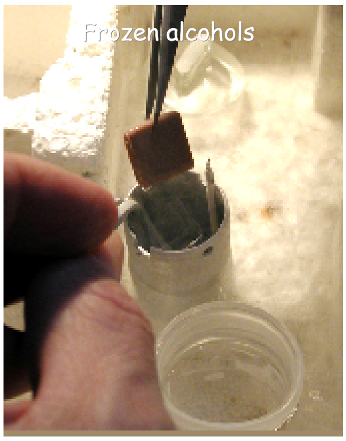


microwave cavity

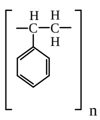


commonly used samples

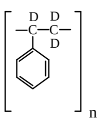




n-PS

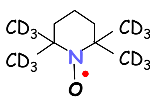


d-PS

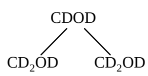


+

d-TEMPO

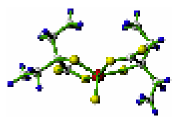


D_2O + d-Glycerol

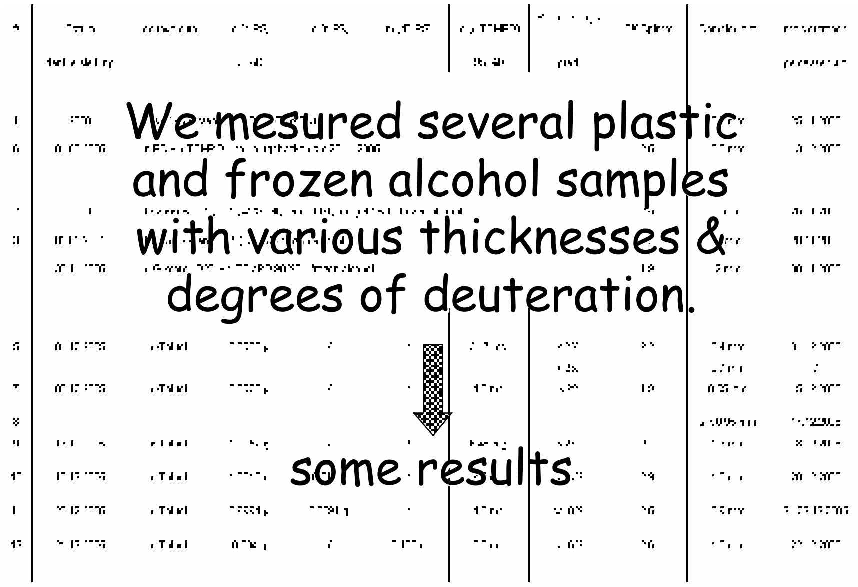


+

EHBA/EDBA-Cr(V)



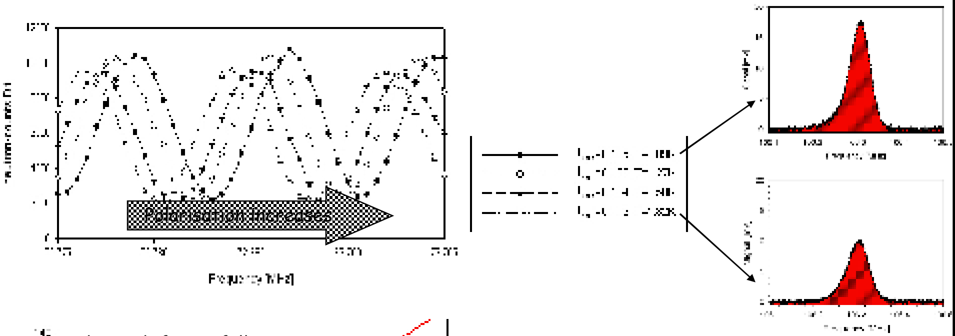
measured samples - winter 2005

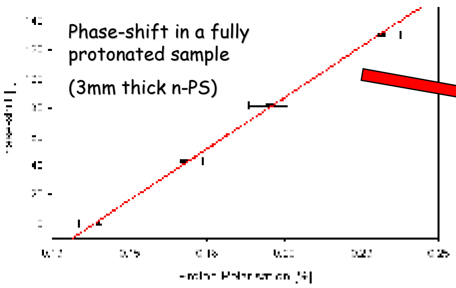


We mesured several plastic and frozen alcohol samples with various thicknesses & degrees of deuteration.

some results

pseudomagn. phase-shift due to TE-polarisation



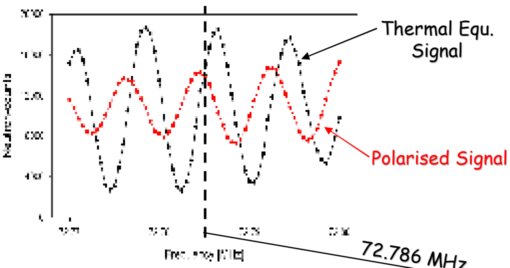


Result:	$b_{i,p}$ = (28.5 ± 4.6) fm
Literature:	$b_{i,p}$ = 25.217(6) fm

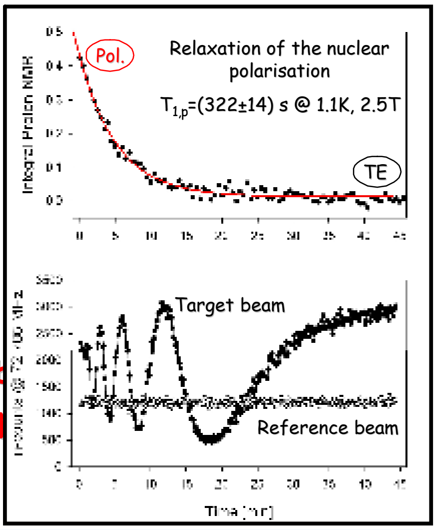
The error is mainly caused by the uncertainty of the proton-density and the polarisation of the sample.

pseudomagn. phase-shift due to DNP

Sample: d-PS (ARMAR: 98%D) doped with: 2.7×10^{19} d-TEMPO/ml
thickness = 1.6 mm - 16.12.2005



Measuring time: 45 min each !



How b... ap...

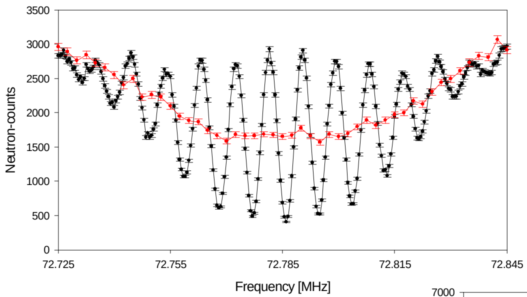
P_p = 17% P_d = 12%   (from NMR)

$\varphi^*_{expect.}$ = (1503 ± 132)°

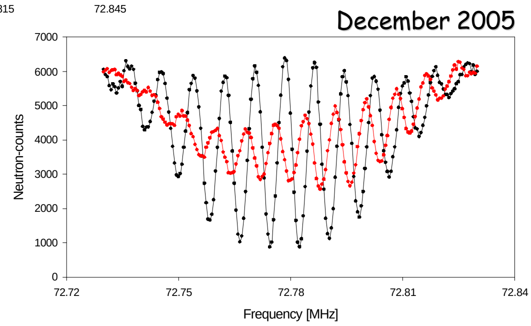
$\varphi^*_{meas.}$ = (1350.2 ± 1.5)° → 10^{-3}

new samples work

June 2005



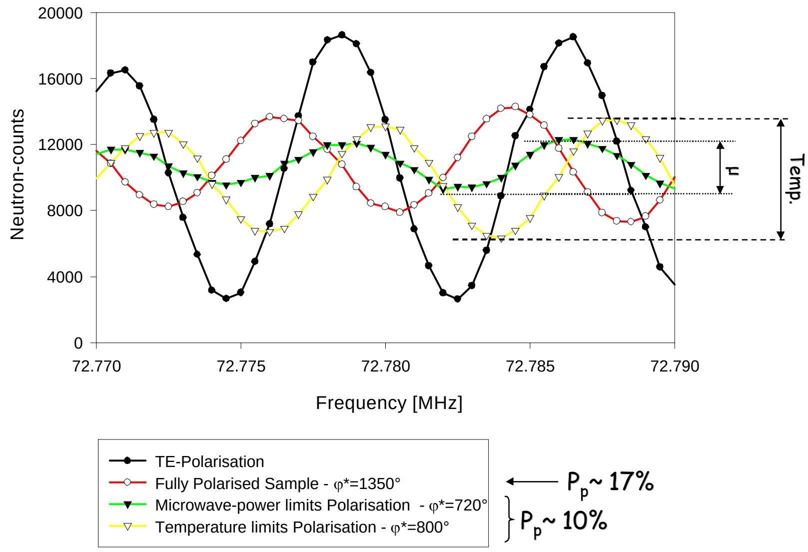
December 2005



- After slight modification of the production process, we can now reliably produce working samples.
- Phase-shifts up to 1500° have been observed.

interesting: sources of inhomogeneities

1. Limitation of the polarisation



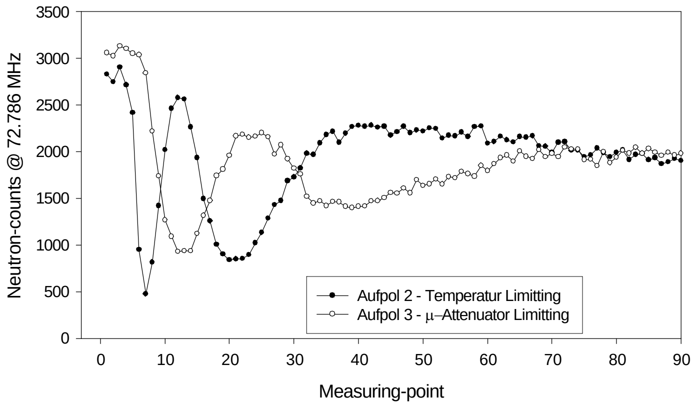
P_p~ 17%

P_p~ 10%

interesting: sources of inhomogeneities

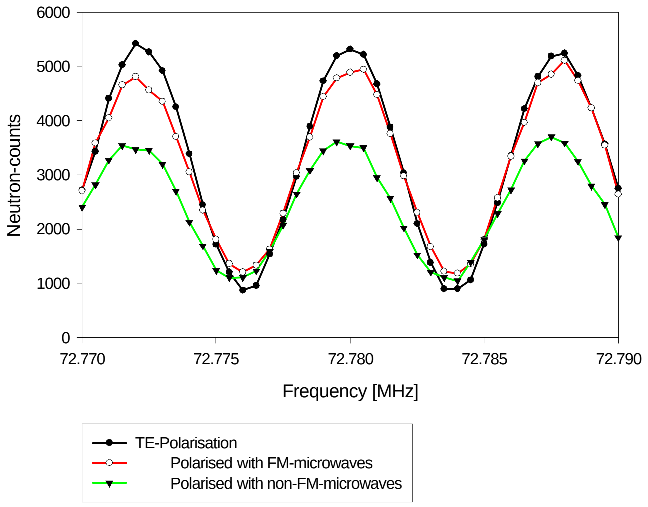
1. Limitation of the polarisation

Also obserable during the polarisation-process:



interesting: sources of inhomogeneities

2. non-FM / FM – microwaves (diff. target than before)



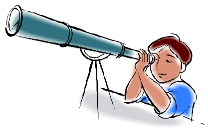
summary of the beamtimes so far

2004: - successful setup of the stabilized Ramsey-apparatus with two separated neutron-beams – phase-stability: ±0.5°

2005 I: - completed setup by adding the dilution fridge (100mK) with a polarised deuterated target
- observed pseudomagn. phase-shifts, but the signal-visibility was reduced more than expected

2005 II: - we can now reliably produce targets, with which we will be able to carry out a succesful experiment
- observed phase-shifts up to 1500°, with acceptable signal damping
- reached relativ accuracy: 10^{-3} in 90 min – needed: $5x10^{-4}$

outlook



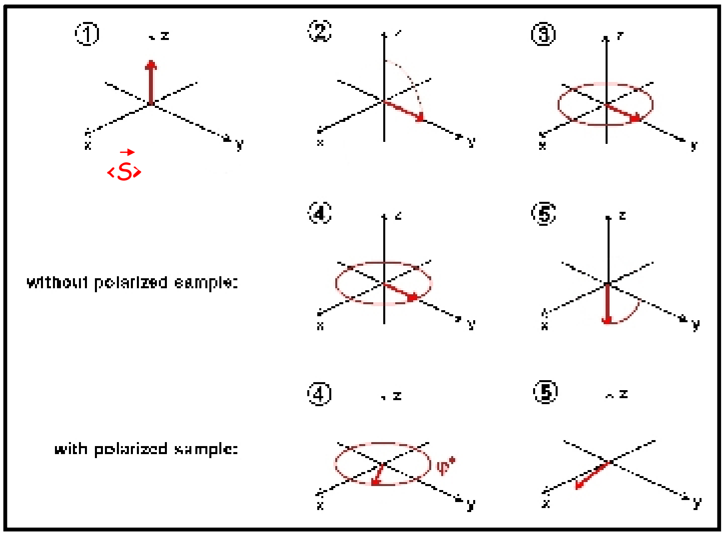
- Polarisation-properties of candidate samples will be further investigated at dilution fridge temperatures in the lab
  - done at the moment
- Choose then the ideal sample for the first precision measurement of the nd spin-dependent scattering length.
- Next beamtime planned for summer 2006 – after the start of SINQ - and another one in winter 2006.

Thanks for your attention.

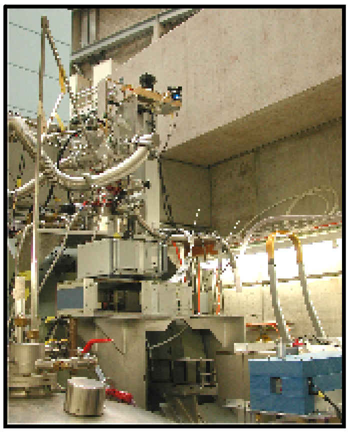
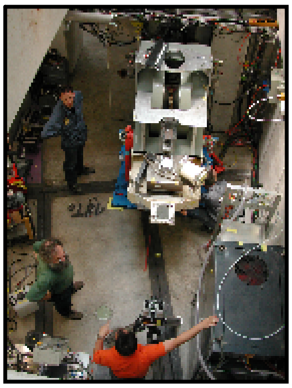
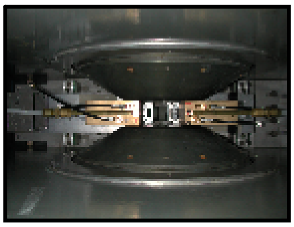
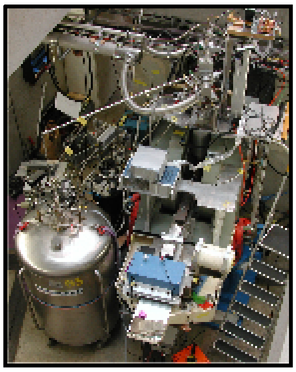
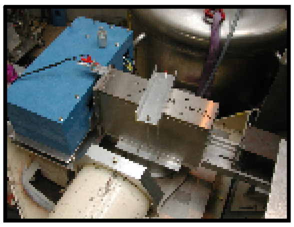
contact: florian.piegsa@psi.ch

[B.v.d. Brandt et al., NIM A 526 (2004) 81-90]
[P.Hautle et al., Proc. 16th Int. Symp. High Energy Spin Physics SPIN 2004, 669-672]
[B.v.d. Brandt et al., Proc. PANIC'05 – to be published]

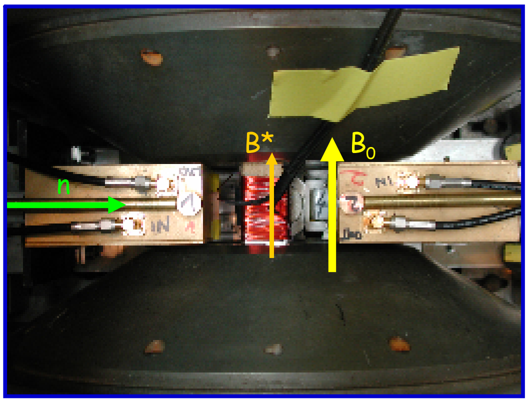
pseudomagnetic phase in the rotating frame



1. inital state
2. first Pi/2-Flip
3. free precession
4. additional phase
5. final state after second Pi/2-Flip


simulated polarised target



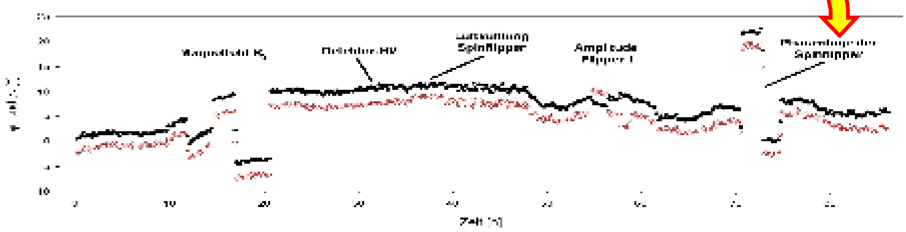
- the auxiliary coil produces an additional magnetic field (anti-) parallel to the main field
- simulates the pseudomagnetic field of a polarised target

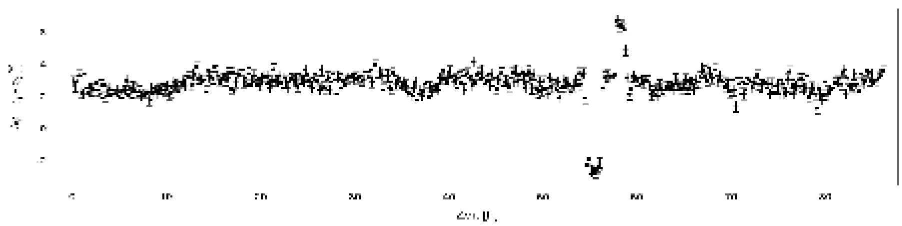
  acts as a substitute for the real target ➔ „Pseudotarget"-coil

phase stability test (2004)

Idea: use a reference beam to correct for drifts

Therefore: check sensetivity on changes of apparatus parameters

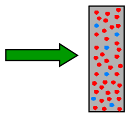




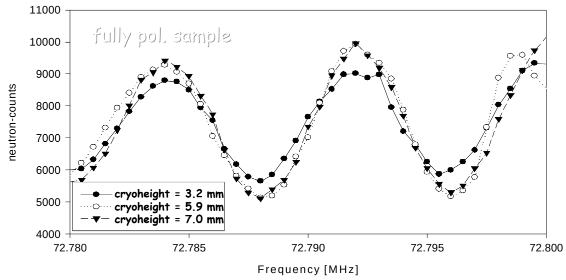
→ phase fluctuations are dominated by statistics.

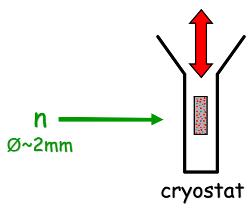
methods

- DNP: dynamic nuclear polarisation
- why deep temp.: - polarisation
  - frozen spin-mode → no cross and „normal" spin-relaxation
- selectively destroyable nuclear-polarisation via RF-pulses (AFP) help to measure φ^*_{p+d}, φ^*_d, φ^*_p and φ^*_0
- the relative phase of the spinflippers is stabilized better than … 0.04° - amplitude better than 0.15%.



measure at different target spots





<u>Results:</u> - pseudomagnetc shift is approx. equal at each target spot

- mean polarisation over the sample is equal, but the inhomogeneity can vary

interesting

Potential-models for nuclei have no real predictive power and need an enormous amount of input parameters. E.g. modern NN-potentials fail to describe 3-nucleon observables.

[H. Witala et al., Phys Rev. C **68**, 034002 (2003)]

PHYSICAL REVIEW C 68, 034002 (2003)

Modern nuclear force predictions for the neutron-deuteron scattering lengths

H. Witała,[1,2] A. Nogga,[3] H. Kamada,[4] W. Glöckle,[2] J. Golak,[1] and R. Skibiński[1]

The neutron-deuteron (*nd*) doublet ($^2a_{nd}$) and quartet ($^4a_{nd}$) scattering lengths were calculated based on the nucleon-nucleon (*NN*) interactions CD Bonn 2000, AV18, Nijm I, II, and 93 alone and in selected combinations with the Tucson-Melbourne (TM), a modified version thereof, TM99, and the Urbana IX three-nucleon (3*N*) forces. For each *NN* and 3*N* force combination the ^{3}H binding energy was also calculated. In case of TM99 and Urbana IX the 3NF parameters were adjusted to the ^{3}H binding energy. In no case (using *np-nn* forces) the experimental value of $^2a_{nd}$ was reached. We also studied the effect of the electromagnetic interac-

… the nd-team …