3rd meeting 'Polarized Nucleon Targets for Europe'
in the 6th European Framework Program
February 2 - 4, 2005, Rech, Germany

Polarised Solid Targets at PSI: recent developments & projects

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Outline

DNP with Bi- and Tri-radicals – Comparison to Monoradicals

- shape of the radicals, doping methods
- achieved polarisations
- interpretation of the results

Thin Targets for RI beam experiments

- technical realisation
- recent test results, status
- test of principle: Ay of p – ^{12}C reaction

Frozen Spin Target for a Cold Neutron Beam

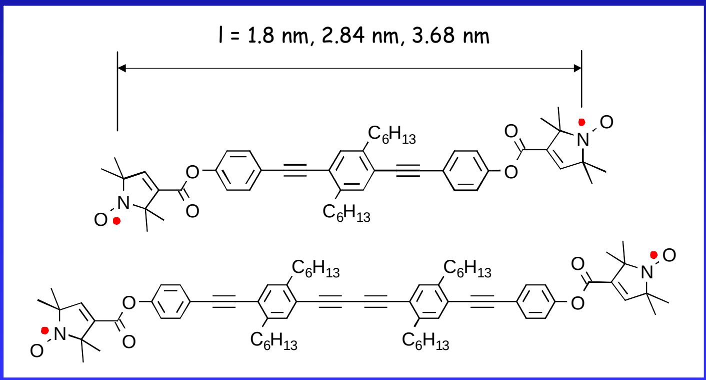
- The spin dependent neutron scattering length of the deuteron
- Constraints -> Concept & Layout of the Dilution Refrigerator

Florian Piegsa

DNP with Bi- and Tri-radicals
Comparison to Monoradicals

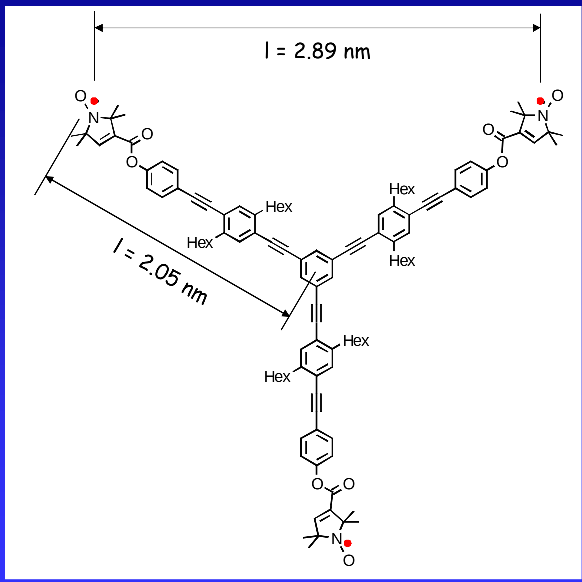
Shape-persistent Bi- & Tri-radicals

Synthesized and kindly provided by
A. Godt, Universität Bielefeld, Germany



Structure of the shape-persistent biradicals

Triradical

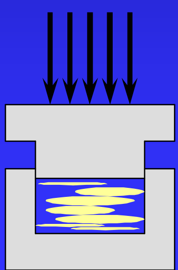


Introduce Radicals in Polymers

by solution

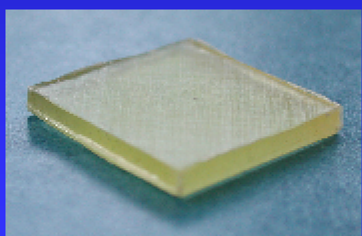
- dissolve polymer in toluene
- add free radical
- let the toluene evaporate at RT

20 - 40 μm thick films: bubble free and transparent, homogeneous radical distribution



warm pressing

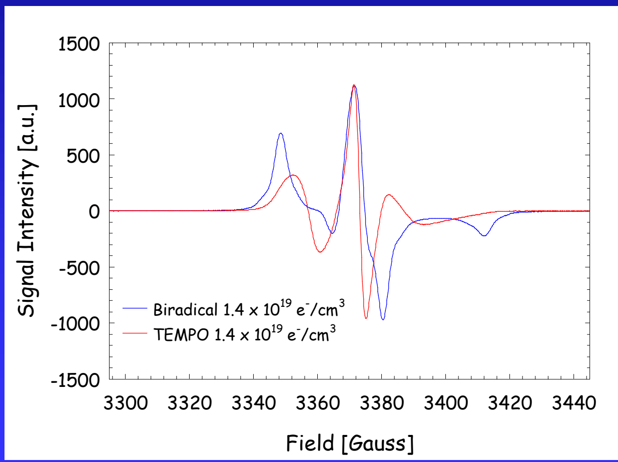
1 - 4 h at 100 °C - 130 °C



2 x 18 x 18 mm blocks

X-Band ESR

X-Band ESR
"monoradical" TEMPO vs 3.68 nm Biradical



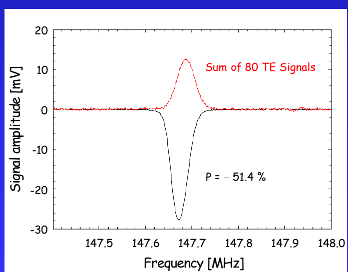
DNP Apparatus

^{4}He cryostat

base temperature T ~ 1 K
cooling power: 10 mW @ 1 K, 100 mW @ 1.2 K
superconducting solenoid B_{max} = 5 T
sample change in 15 min

Microwave Sources

impatt diodes: 70 GHz, 98 GHz, 140 GHz
clystron: 98 GHz



sample holder

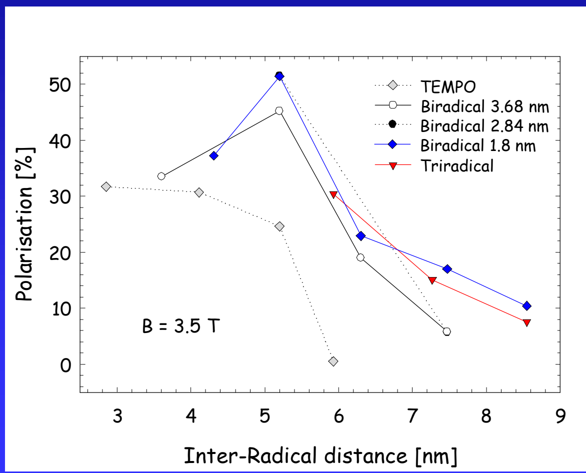
Cavity and NMR Coil
(with sample inside)

Standard PSI Laboratory Cryostat

Polarisation Measurement

cw-NMR Q-meter system, LabView control program
Polarisation calibrated with thermal equlibrium signal

DNP results I: Radical Concentration



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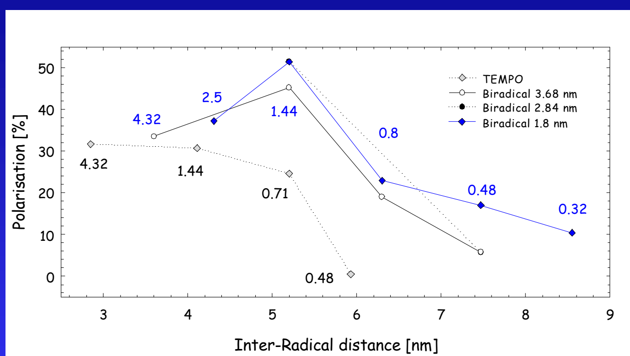
Interptretation: TEMPO vs Bi-Radicals



High radical concentration (~ 2 - 4 x 10^{19} e^{-}/cm^{3})

- mean distance between two unpaired electrons in the TEMPO doped samples is comparable to the intraradical distance in the biradical doped samples
- Pure thermal mixing is observed
- comparable polarisations can be achieved with both types of dopants

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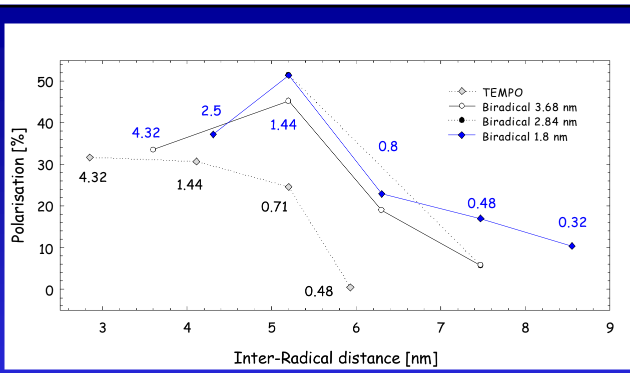


Lower number of unpaired electrons (~ 2 -> 0.3 x 10^{19} e^-/cm^3)

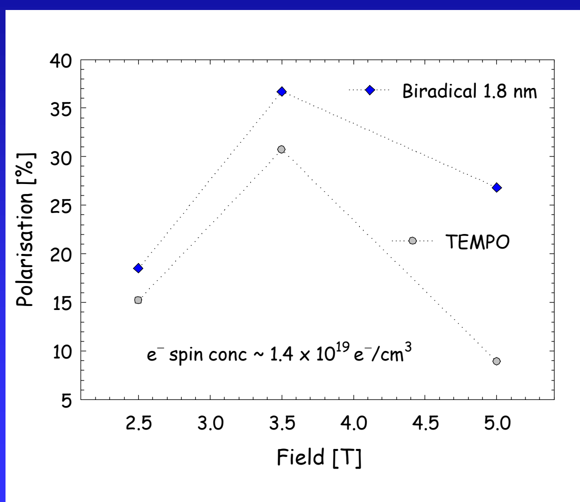
inhomogeneous broadening of the EPR line → e^- - e^- cross relaxation less efficient

TEMPO doped samples: maximum achievable polarisation drops rapidly

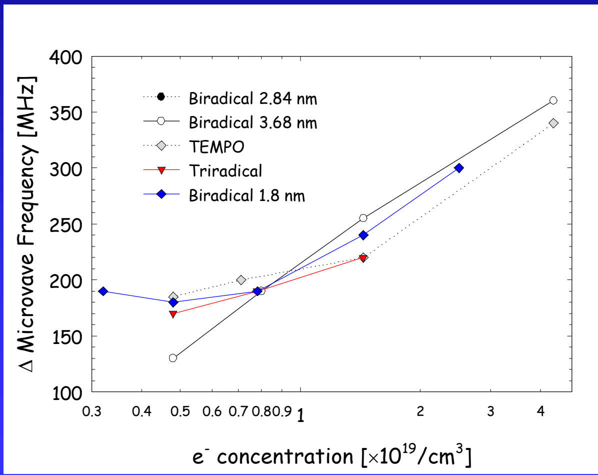
biradical doped samples:

- pairs of interacting electrons relax a nuclear spin in a three-spin process
- electron non-Zeeman reservoir contains contributions from two "interaction systems":
  1. the dipolar interaction of all electron spins with each other (interradical)
  2. the coupled electrons within the same radical (intraradical)
- Two proton Zeeman relaxation times observed in medium doped biradical samples

DNP results II: Field dependence



DNP results III: MW Frequencies



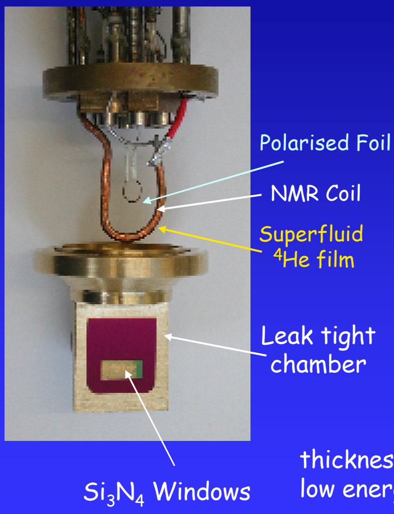
Development of a Dynamically Polarised Target for RIB-Induced Reactions

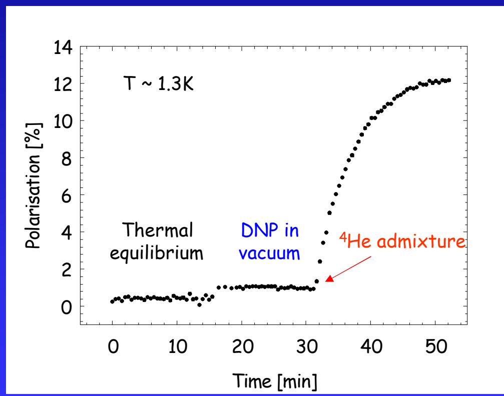
J. P. Urrego-Blanco, B. van den Brandt, A. Galindo-Uribarri, P. Hautle, J. A. Konter

Technical Challenges:

Operation in vacuum

Minimization of material in particle path



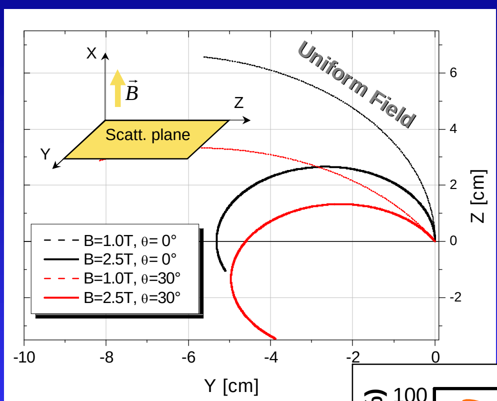


thicknesses between 50-300 nm

low energy losses: < 10 keV for 10 MeV protons

< 270 keV for 60 MeV ^{12}C ions

Effect of the Magnetic Field

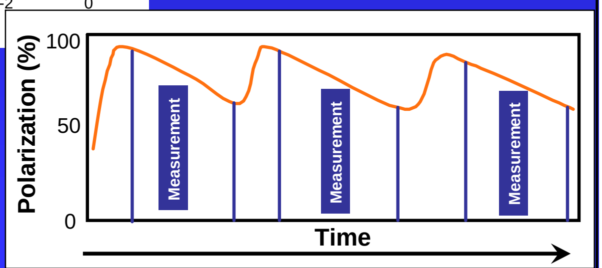


- Trajectories of the particles
- Performance of the detecting system
- Placement of the detectors and associated instrumentation

Operate Target in FSM

Holding field required

Relaxation Times?

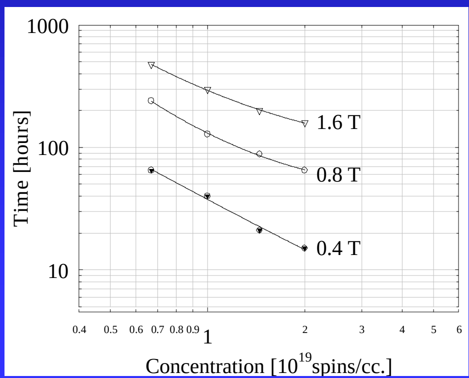


DNP Results from 5 mm Platelets

PS based scintillator + TEMPO 2.10^{19} Spins/cc

P_{max} = +84 / -83 %

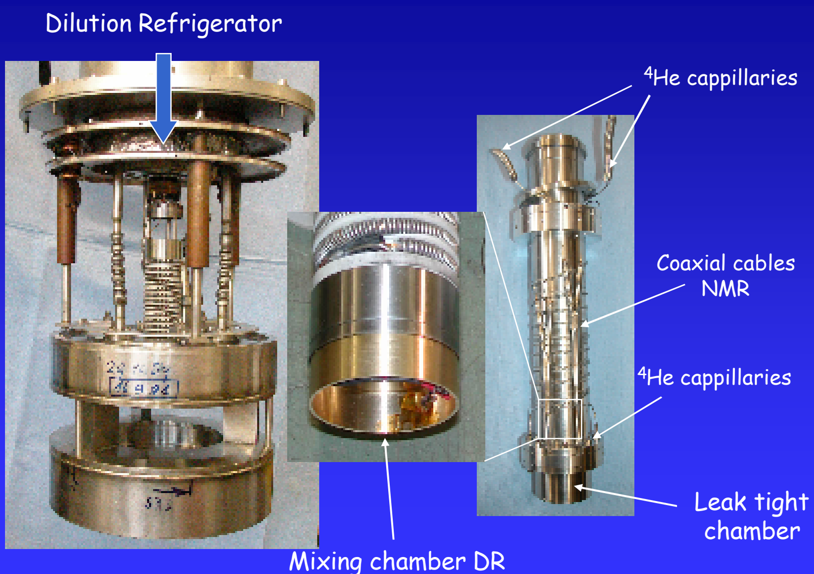
polarization from 0 % to 60 % in 85 min
-80 % to 80 % in 7 hours



Relaxation at 100 mK
Frozen Spin Mode (FSM)

B. van den Brandt, E.I. Bunyatova, P. Hautle, J.A. Konter. S. Mango, *Polarized scintillator targets*, Nucl. Instr. Meth. **A446** (2000) 592

Cryostat Design

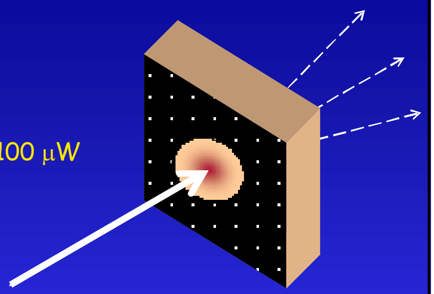


Effects of the RI beam

Beam heating effect

Energy deposited on target by the beam:

beam intensity ~ 10^7 pps @ 80MeV ➡ ~ 100 μW



Cooling power of the cryogenic setup has to be determined

Radiation Damage

Bombardment with heavy ions creates free electrons (PM centres)

Typical „doping dose“ ~ 10^{15} e^-/cm^2

for a 2 mm^2 beam of ~ 10^7 pps

➡ Typical dose attained in > 1000 h

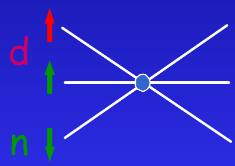
Needs investigation

If significant, beam might scan the target during experiments

Summary & Outlook

- Film cooling sufficient for DNP of thin 25 µm foils
- Vaccum cell with ultra thin Si-Ni foil windows
- Leak tightness of windows: different methods are under test
- Construction of Dilution refrigerator with separate ^4He cell finished -> to be tested
- Adaption to the beamline + Detector test: March/April 2006
- Proof of Principle: Analysing Power Ay of ^{12}C – p: May 2006

High-accuracy measurement of the spin dependent neutron-scattering length of the deuteron

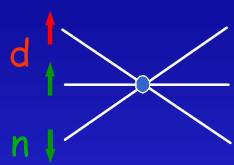


TUMünchen

CEA Saclay

Nuclear Forces at Low Energy: Description ?

- **Potential Models**
  - no real predictive power
  - enormous number of input parameters needed



- **Effektive Field Theories (EFT's)** New
  - Systematic and model independent description
  - only point like interactions between nuclei
  - few experimental input parameters needed

Need two independent experimental input parameters to make predictions on 1% precision level

Triton Binding Energy (5×10^{-7})

Spin dependent nd-scattering length (6 % !!)

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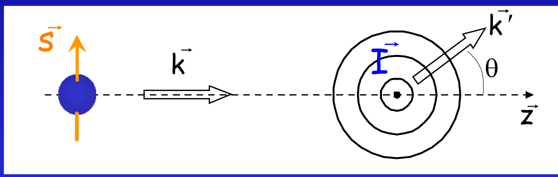
Neutron Scattering Length

Cold neutrons 4 Å (≈ 5 meV) ⟶ s-wave scattering
scattering amplitude f constant



$$\psi = e^{i\vec{k}\cdot\vec{r}} - f(\theta)\frac{e^{ikr}}{r}$$
$$\rightarrow e^{i\vec{k}\cdot\vec{r}} - a\frac{e^{ikr}}{r}$$

free scattering length [fm]

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

coherent (spin independent) — "incoherent" (spin dependent)

$$\vec{J} = \vec{s} + \vec{I}$$ (Deuteron I = 1)

$$a_2 = a_{c,d} - \sqrt{2}\, a_{i,d} \quad (J = 1/2\text{ , doublet})$$
$$a_4 = a_{c,d} + \frac{1}{\sqrt{2}}\, a_{i,d} \quad (J = 3/2\text{ , quartet})$$

actually not a new idea ...

Volume [illegible], Number 2 — PHYSICAL REVIEW LETTERS — 8 July 1974

Systematic Pseudomagnetic Measurements of the Spin-Dependent Scattering Length of Slow Neutrons with Atomic Nuclei

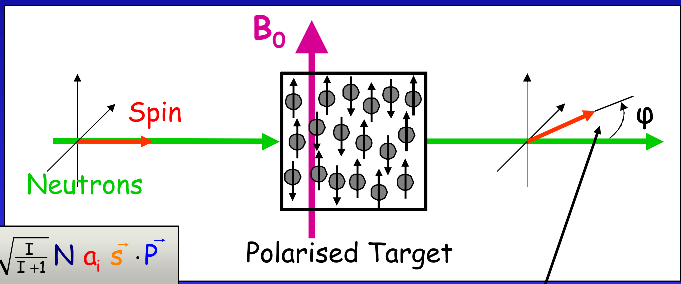
P. Roubeau, A. Abragam, G. L. Bacchella, H. Glättli, A. Malinovski,* P. Mériel, J. Piesvaux, and M. Pinot
Service de Physique du Solide et de Résonance Magnétique, Centre d'Etudes Nucléaires de Saclay, 91190 Gif-sur-Yvette, France
(Received 21 May 1974)

The authors (who are not nuclear physicists) would be grateful for suggestions of nuclei of particular interest. Is O^{17} of sufficient special interest to be investigated in spite of its very small isotopic abundance? Is an *accurate* measurement of μ^* for the deuteron of interest to specialists of the three-body problem? What about magic nuclei plus or minus a nucleon? For many isotopes differing by two neutrons, spins are identical and magnetic moments very near. Is the ratio of their pseudomagnetic moments worth investigating, etc.? We welcome suggestions.

Method: Pseudomagnetic Precession

[V. Barychevsky, M. Podgoretsky, JETP **20** (1965) 704]

[A. Abragam, G.L. Bachella, H. Glättli et al., PRL **31** (1973) 776]



$$V_{eff}^{s.d.} = \frac{4\pi\hbar}{m}\sqrt{\frac{I}{I+1}}\, N\, a_i\, \vec{s}\cdot\vec{P}$$

with $\vec{\mu}_n = \gamma\hbar\vec{s}$

$$V_{eff}^{s.d.} = -\vec{\mu}_n\cdot\vec{H}^* = \vec{\mu}_n\cdot\underbrace{\left[\frac{4\pi\hbar}{\gamma m}\sqrt{\frac{I}{I+1}}\, N\, a_i\, \vec{P}\right]}_{-H^*}$$

$$\varphi^* = \gamma H^* t = 2\sqrt{\frac{I}{I+1}}\lambda\, d\, N\, P\, a_i$$

Pseudomagnetic Precession $\omega_L = -\gamma_n\left(H_0 + H^*\right)$

strong interaction

relative measurement

$$a_i \propto \frac{\varphi^*}{\lambda\, d\, \left(\frac{N}{V}\right)\, P}$$

impossible to measure all quantities with the desired absolute accuracy

Idea: measure $a_{i,d}$ relative to $a_{i,p}$, which is very well known (2.4×10^{-4})

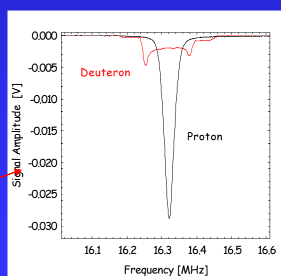
$$a_{i,d}/a_{i,p} \propto \frac{\lambda\, d\, \varphi_d^*\left(\frac{N_p}{V}\right) P_p}{\lambda\, d\, \varphi_p^*\left(\frac{N_d}{V}\right) P_d}$$

sample containing protons & deuterons

$$a_{i,d}/a_{i,p} \propto \frac{\varphi_d^* N_p\, P_p}{\varphi_p^* N_d\, P_d}$$

Ramsey's method

NMR



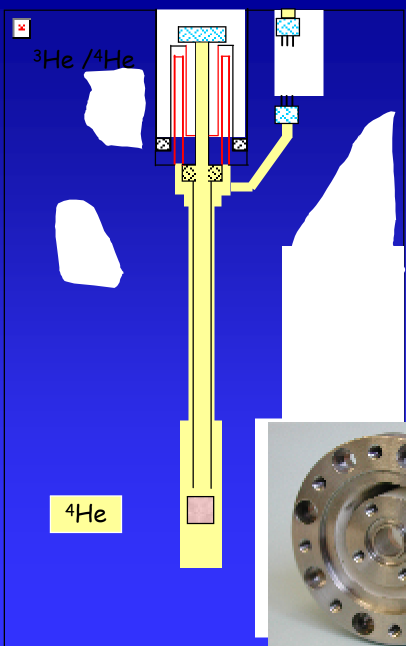
Frozen Spin Polarised Target for a cold neutron beam

Requirements:

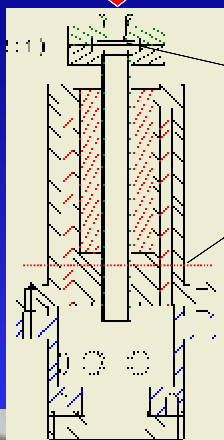
- Measure NMR signals of Protons and Deuterons with same Q-meter circuit at different Field (B = 2.5 T and 0.34 T)
- No ^3He on the beam path

Solution:

- Dilution refrigerator for frozen spin mode operation
- Target cell separate from DR mixing chamber
- Target samples solid at room temperature



Microwaves

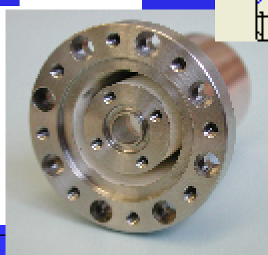


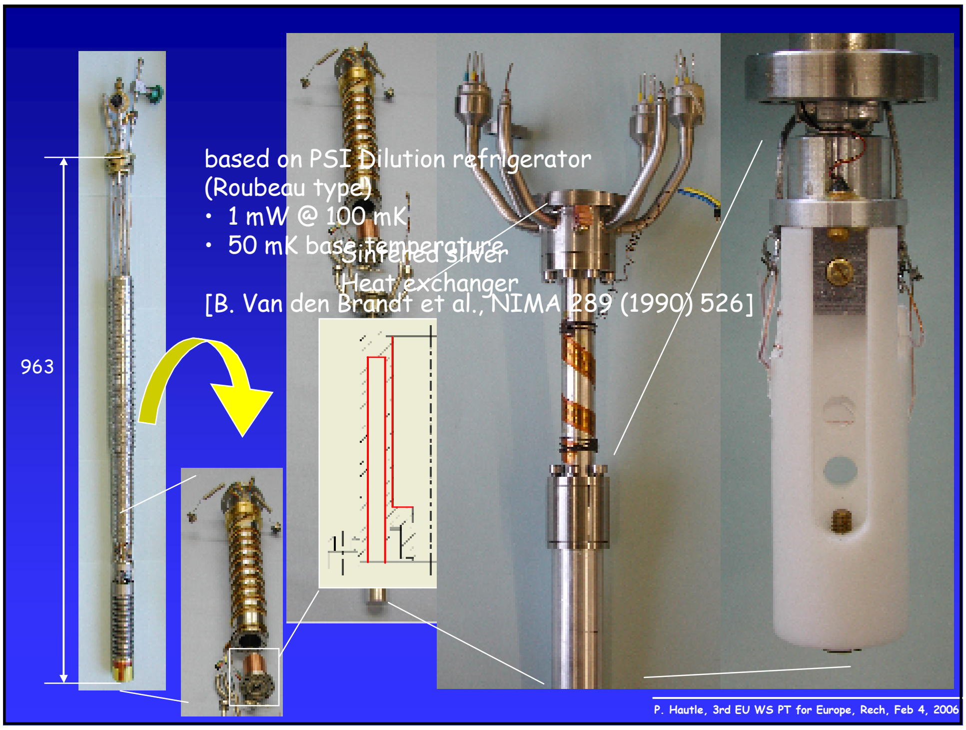
Saphire Window

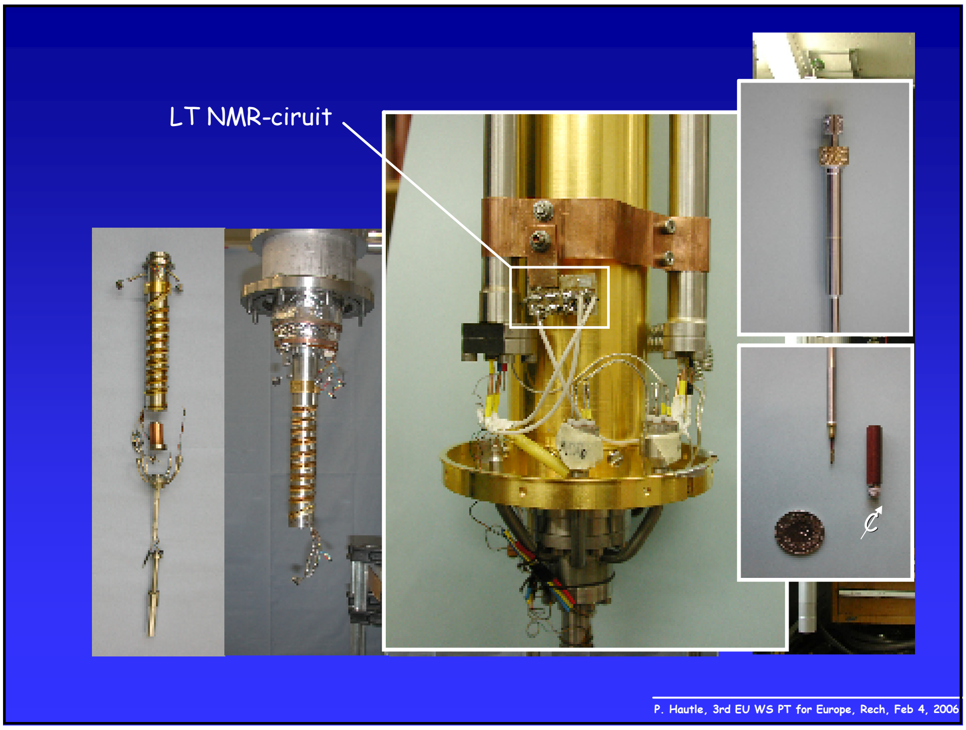
Copper

Friction Weld

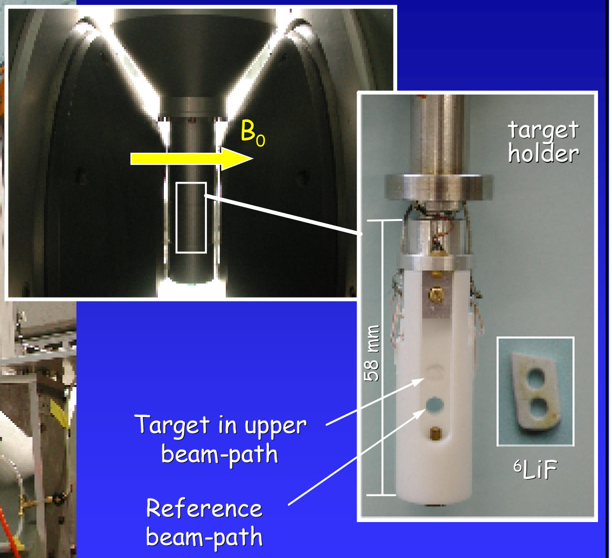
Stainless Steel



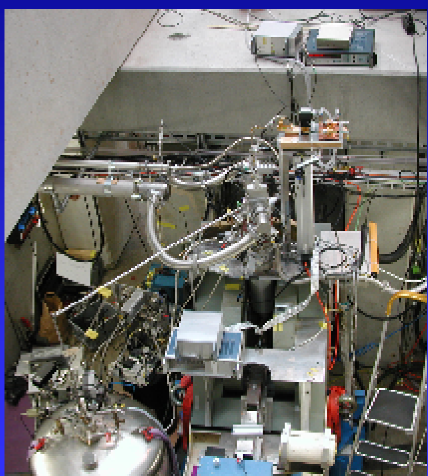

963
based on PSI Dilution refrigerator
(Roubeau type)
• 1 mW @ 100 mK
• 50 mK base temperature
Sintered silver
Heat exchanger
[B. Van den Brandt et al., NIMA 289 (1990) 526]
P. Hautle, 3rd EU WS PT for Europe, Rech, Feb 4, 2006


LT NMR-ciruit
P. Hautle, 3rd EU WS PT for Europe, Rech, Feb 4, 2006

cryostat, magnet & target



Summary, Performance of the Cryostat



- Design & construction realised in ½ year
- 3 Month operation on cold neutron beam (July – August 2005)
- Base temperatures:
  - Mixing chamer : T = 70 mK
  - Target cell : T = 80 mK
- Heat conductivity of ^{4}He is responsible for the temperature gradient not the heat exchanger