Recent activities of the Bonn Polarized Target Group

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POLARIZED TARGET BONN

Recent activities of the Bonn Polarized Target Group

Motivation

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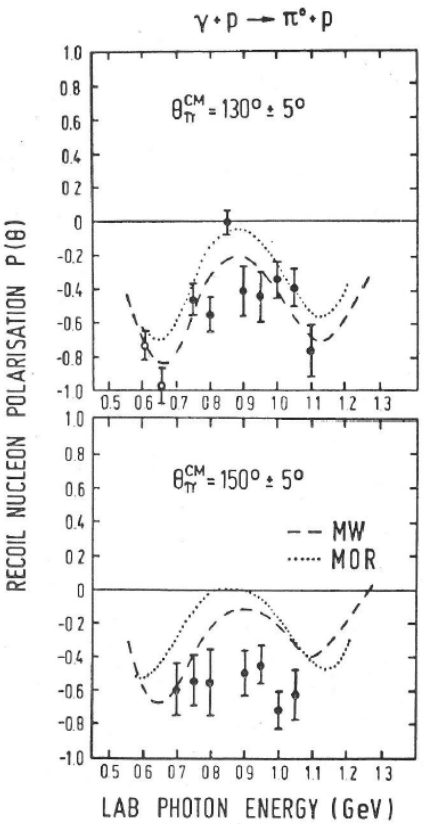
Opening (from recoil polarization to target polarization)



Recoil Nucleon Polarization

The polarization of the recoil particle is determined by measuring the left-right-asymmetry of the scattered particle. The analyzing power A depends on the particle energy and the scattering angle θ. Three different target-types have been used so far. Liquid helium is a good analyzer at lower energies and carbon and liquid hydrogen at high energies. The most important disadvantage of this method is the low efficiency. Only half a percent of the produced particles can be used for the analysis. A low counting rate and large statistical errors are typical. Another uncertainty is the influence of inelastic levels which mostly can not be separated. In spite of these difficulties this method was quite successful before polarized photons and targets were introduced in high energy photon physics.

[Althoff et al., Phys. Lett. 26B (1968)]

Why not using a polarized target? (W. Paul, spring 1968)

$$T = \frac{1}{f} \cdot \frac{1}{P_t} \cdot \frac{N\uparrow - N\downarrow}{N\uparrow + N\downarrow}$$

- suitable target material
- high magnetic field
- low temperatures

1968 Althoff, Herr, Hoffmann, Peschel met Borghini and Mango at CERN

17.09.2015 5

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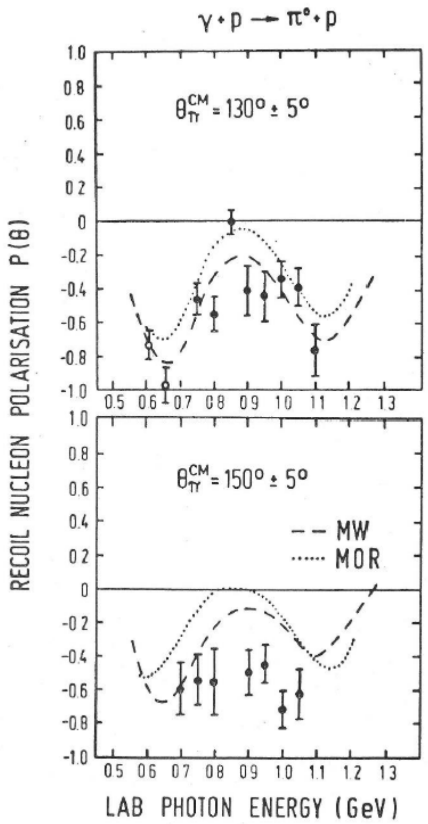

Recoil Nucleon Polarization

The polarization of the recoi
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Our goal since 50 years:
maximizing

'Figure of Merit': $FoM = n_T\, f^2\, P^2$

Luminosity: $\mathcal{L} = I\, n_T$

by optimizing the target ingredients for

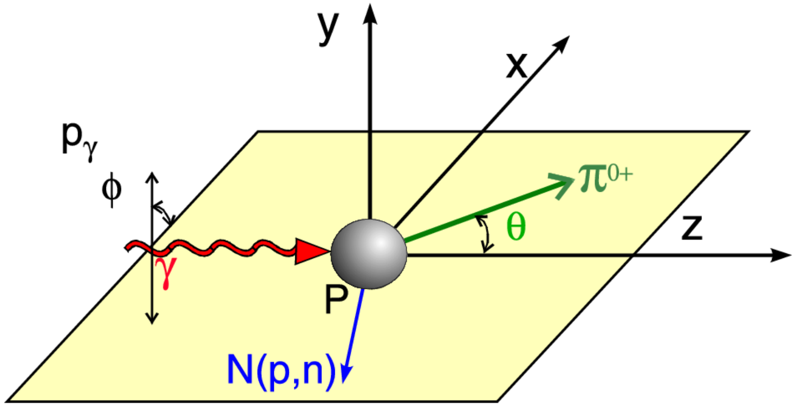
new and innovative polarization experiments

Recent activities of the Bonn Polarized Target Group

Motivation

Structure mapping @ ELSA and MAMI

→ Double polarization experiments
→ Modell independent partial wave analysis
→ Complete experiment



$$\frac{d\sigma}{d\Omega}(\Theta,\phi) = \frac{d\sigma}{d\Omega}(\Theta)\cdot\Big[1 - p_\gamma^{lin}\Sigma(\Theta)\cos(2\phi)$$
$$+ p_t^x\cdot\Big(-p_\gamma^{lin}H(\Theta)\sin(2\phi) + p_\gamma^{circ}F(\Theta)\Big)$$
$$- p_t^y\cdot\Big(+p_\gamma^{lin}P(\Theta)\cos(2\phi) - T(\Theta)\Big)$$
$$- p_t^z\cdot\Big(-p_\gamma^{lin}G(\Theta)\sin(2\phi) + p_\gamma^{circ}E(\Theta)\Big)\Big]$$

Photon		Target		
		x	y	z
unpolarized	σ	0	T	0
linear	(-Σ)	H	(-P)	(-G)
circularly	0	F	0	(-E)

Collaborative target group: Dubna/Mainz/Bochum/Bonn (2015 – 2019)
'Mainz/Dubna frozen spin target' + internal 'holding' coil(s)

Recent activities of the Bonn Polarized Target Group

Motivation

Run-time polarized target (cold cryostat)

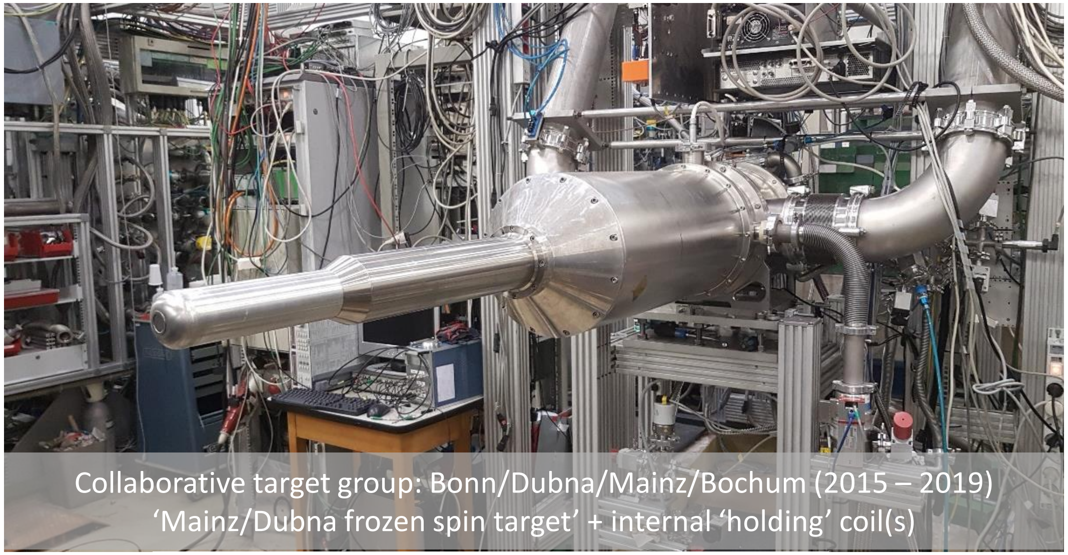
2017 (long. polarization) ~ 800h

- → max. pol: p_+ = 63 %, (butanol, TEMPO)
- → Relaxation time: $\tau \sim$ 1300h (@ 0.4 T, I ~ 10^8/s)
- → $\bar{P} \sim$ 56 %

2018 (transv. polarization) ~ 1000h

- → max. pol: p_+ = 83 %, p_- = 87 % (butanol, porphyrexide)
- → Relaxation time: $\tau \sim$ 500 h (@ 0.4 T, I ~ 10^8/s)
- → $\bar{P} \sim$ 78 %

Relaxation time without beam: 1800 h



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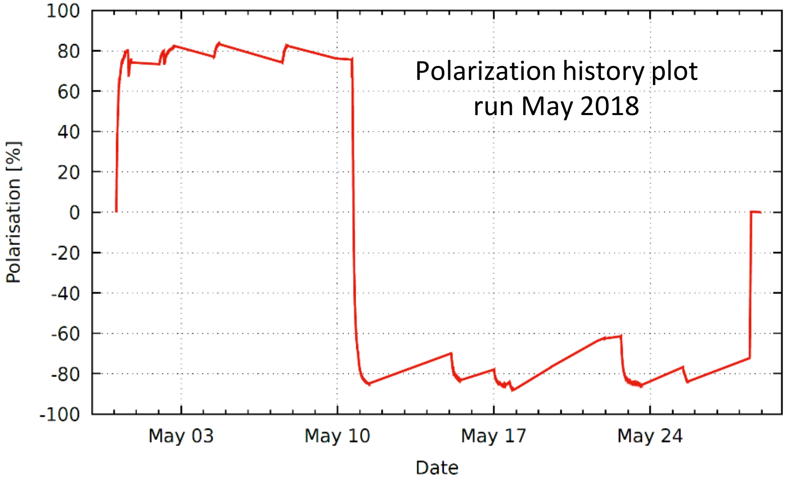

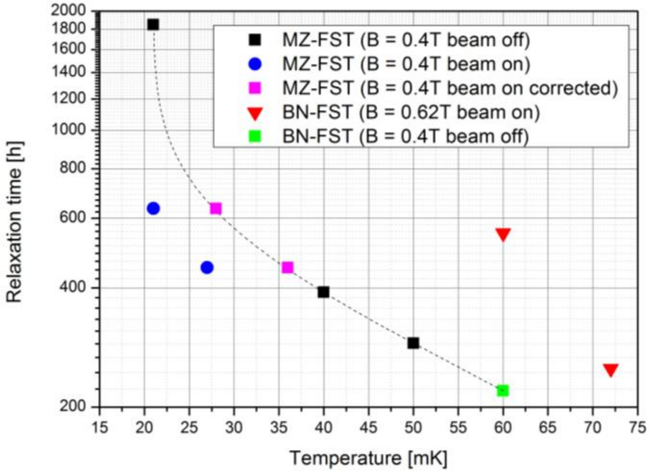

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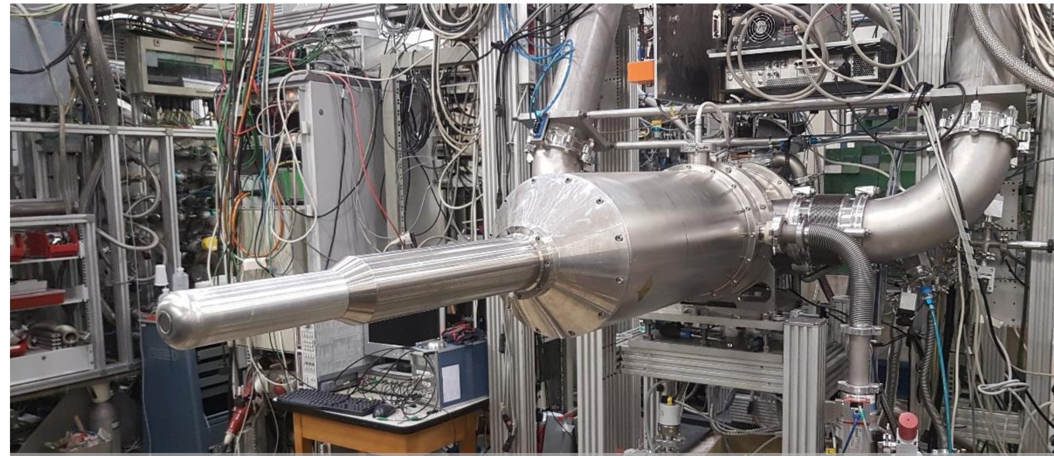

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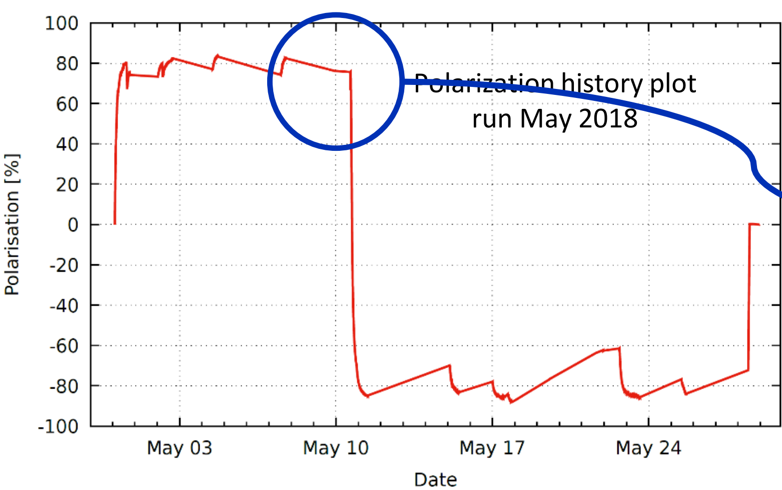

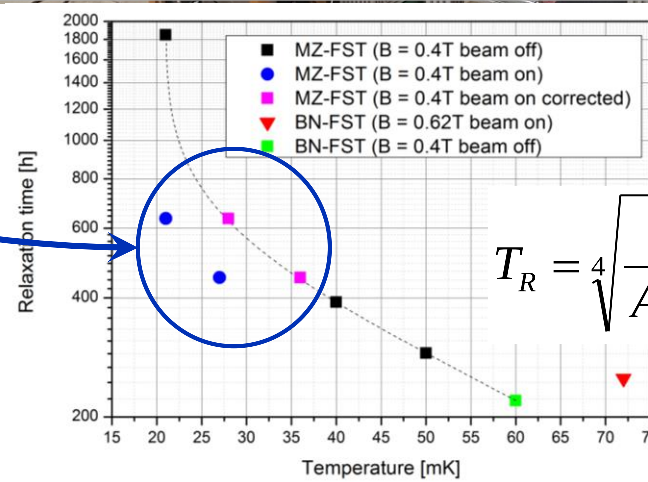

$$T_R = \sqrt[4]{\frac{\dot{Q}_v}{A_T \cdot \alpha} + T_{Bad}^4}$$

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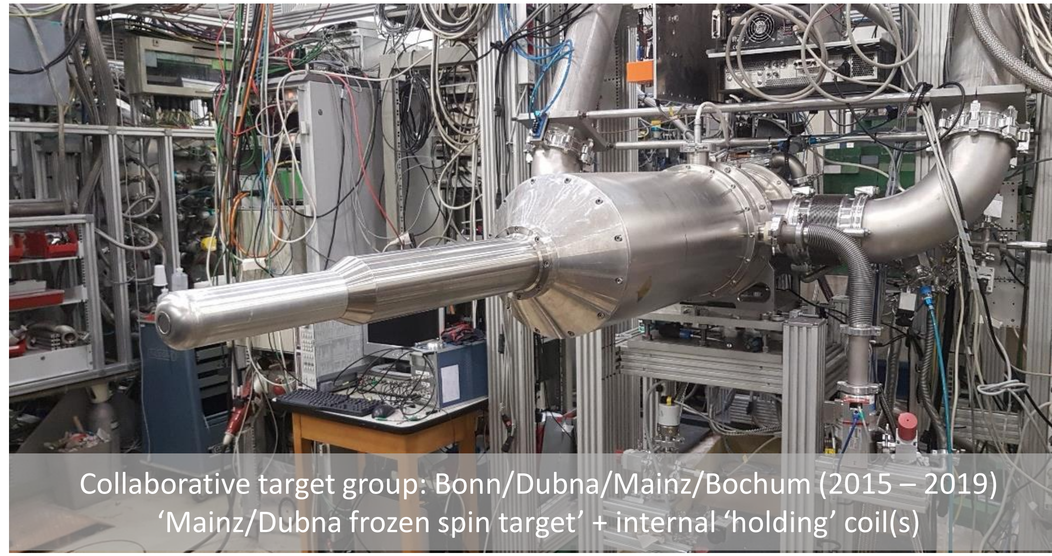


Collaborative target group: Bonn/Dubna/Mainz/Bochum (2015 – 2019)
'Mainz/Dubna frozen spin target' + internal 'holding' coil(s)

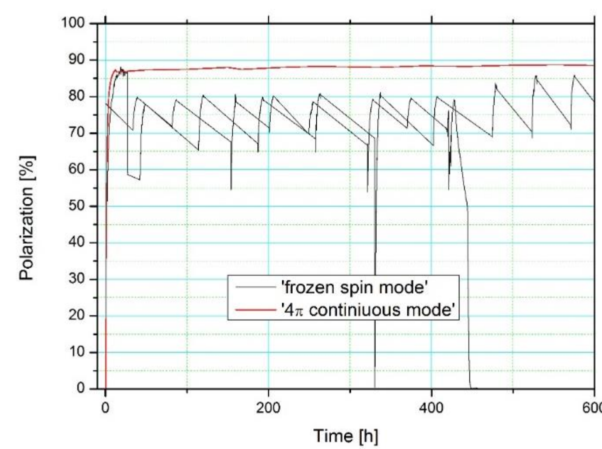
FSTechnique Limitations :

- Large acceptance target system requires dedicated railway system
- Beam time efficiency $\mathcal{F} \leq 0.8$
- $FoM = n_T\, f^2\, \bar{P}^2$ (relaxation τ)
- $\mathcal{L} = I\, n_T\ (I \leq 10^8/s)$

Combine advantages of the frozen spin technique with the advantages of a continuous polarization:

'4π continuous mode target'

replace the holding coil by an internal polarizing magnet!



Recent activities of the Bonn Polarized Target Group

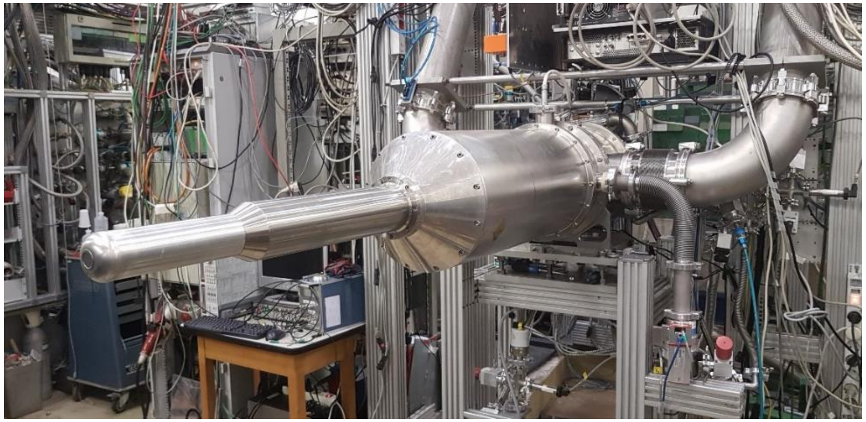
Research Objectives: horizontal dilution refrigerator for int. high field pol. magnets

New Bonn horizontal dilution refrigerator completed, tested in ^{4}He-mode.

→ Up to now non locatable super leak in the still region!!
→ No dilution operation in near future
→ Internal pol. coil testing in ^{4}He-mode

New, nearly identicaly, horizontal dilution refrigerator is under construction by the JINR Dubna group, delivery foreseen end of 2018

New internal magnets will be adapted to the Dubna design



New Bonn dilution refrigerator

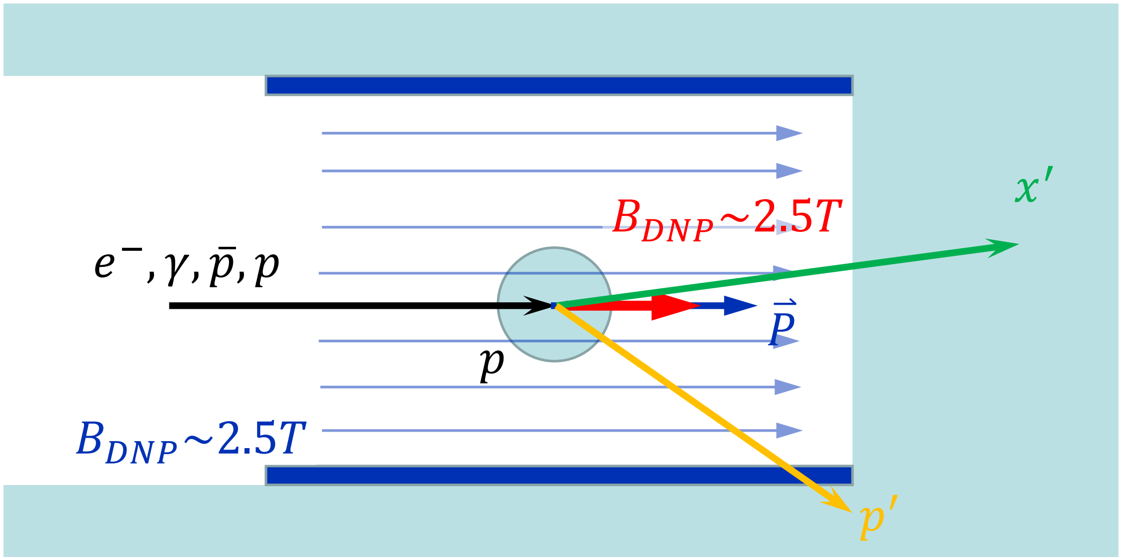
Collaborative target group: Dubna/Mainz/Bochum/Bonn (2015 – 202X)
'Dubna horizontal dilution refrigerator' + internal 'polarizing magnet'
Detailed information: Stefan Runkel „The Polarized Target at the CBELSA/TAPS Experiment"

Recent activities of the Bonn Polarized Target Group

Research Objectives: high field thin s.c. magnets

Polarized solid state target (DNP @ 0.2 – 0.3 K) (horizontal dilution refrigerator)

→ high mag. longitudinal field for DNP (B_{DNP} ~ 2.5 T)



4π – continuous mode target (what do we gain?):

- → good angular acceptance (~ 4π)
- → high luminosity L ~ $10^{33}/cm^2s^{-1}$ (N ≈ 10^{10}/s) [N < 10^8/s]
- → high mean polarization (P_p ~ 90%, P_d ~ 85%) [P_P ~ 75 %]
- → good beam time efficiency

Recent activities of the Bonn Polarized Target Group

Research Objectives: high field thin s.c. magnets

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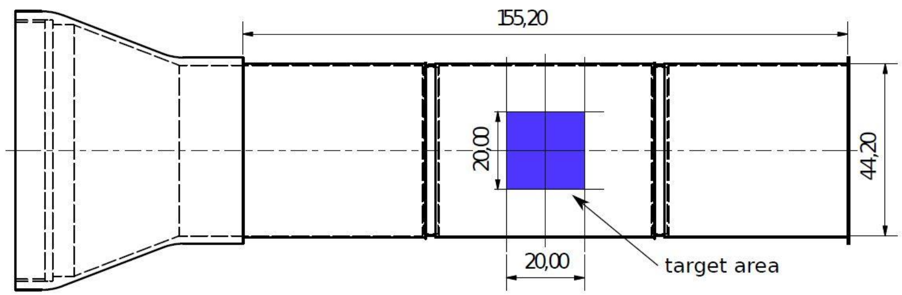
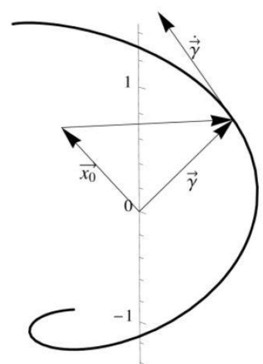
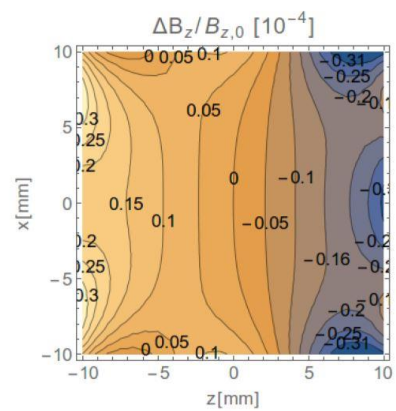
Internal polarisation magnet - Field calculation



Biot-Savart-Law:

$$\vec{B}(\vec{x_0}) = \frac{\mu_0}{4\pi} I \int \frac{(\vec{\gamma}(t) - \vec{x_0}) \times \frac{\dot{\vec{\gamma}}(t)}{|\dot{\vec{\gamma}}(t)|}}{|(\vec{\gamma}(t) - \vec{x_0})|^3} \mathrm{d}t$$





Loop parametrization:

$$\vec{\gamma} = (r\cos(t), r\sin(t), n \cdot d)$$

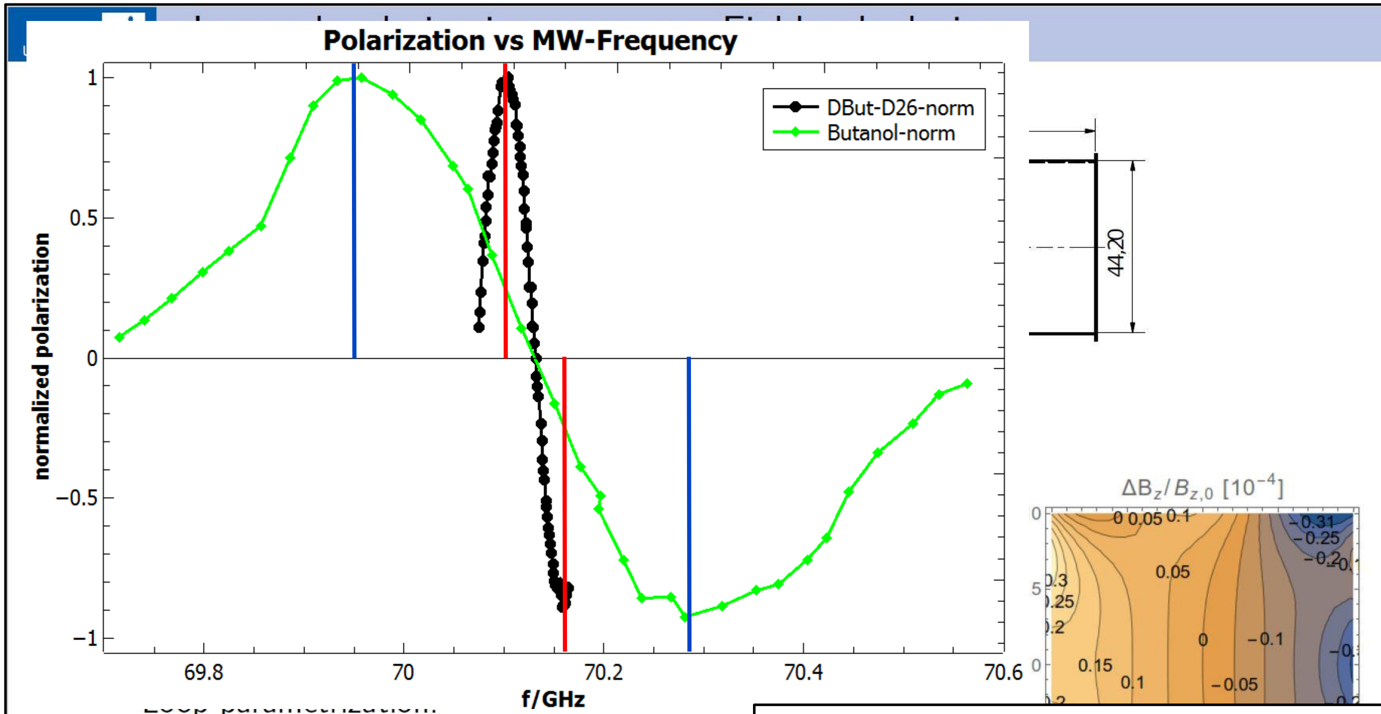
r: radius of each loop
$n \cdot d$: loop position
d: effective distance between 2 wires

DNP requires $\Delta B/B \leq 10^{-4}$

Internal magnet developments for polarized targets 7/14

Recent activities of the Bonn Polarized Target Group

Research Objectives: high field thin s.c. magnets



DNP requires $\Delta B/B \leq 10^{-4}$

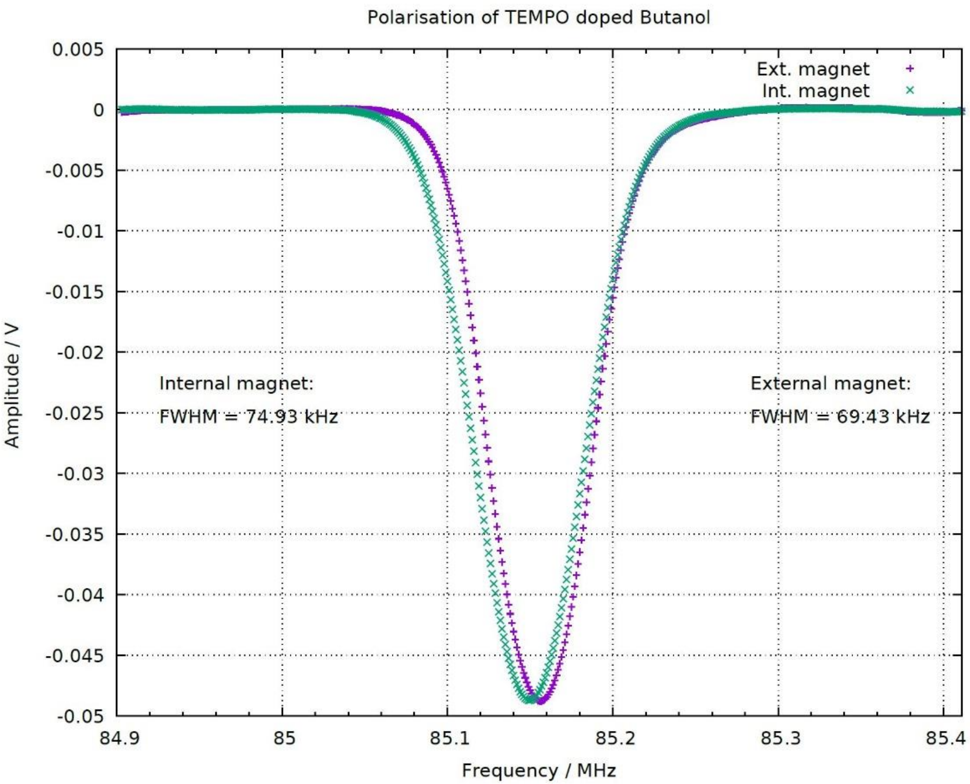
High precision winding technique to guarantee ‘orthozyclic winding’

Recent activities of the Bonn Polarized Target Group

Research Objectives: high field thin s.c. magnets

First DNP-signals in the **new internal thin s.c. polarizing magnet**

T_P = 1K!, B_P = 2 Tesla, $F_{\mu w}$ = 56 GHz !



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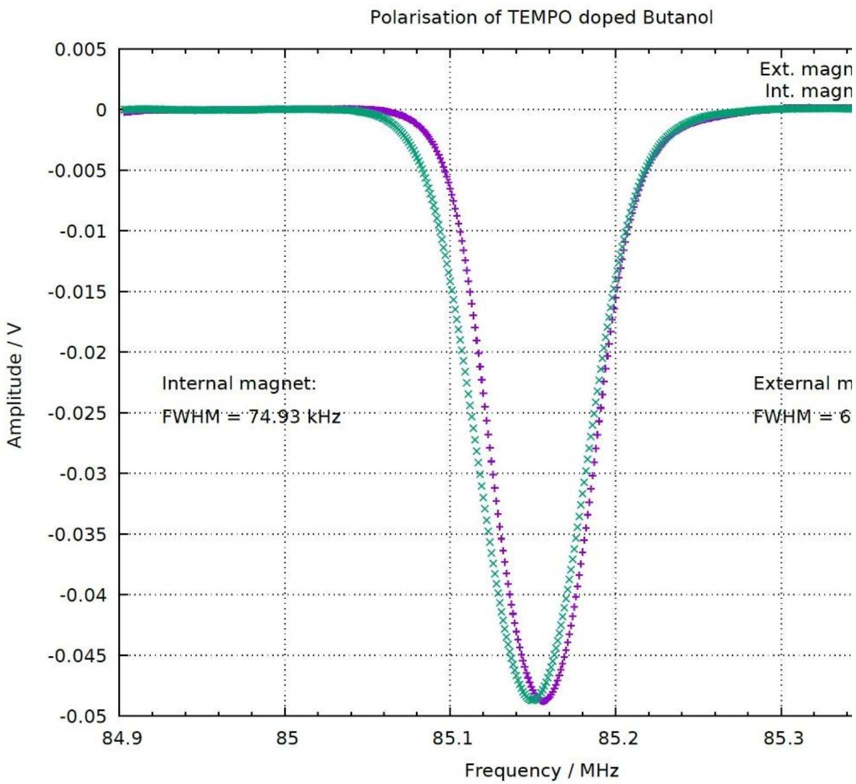

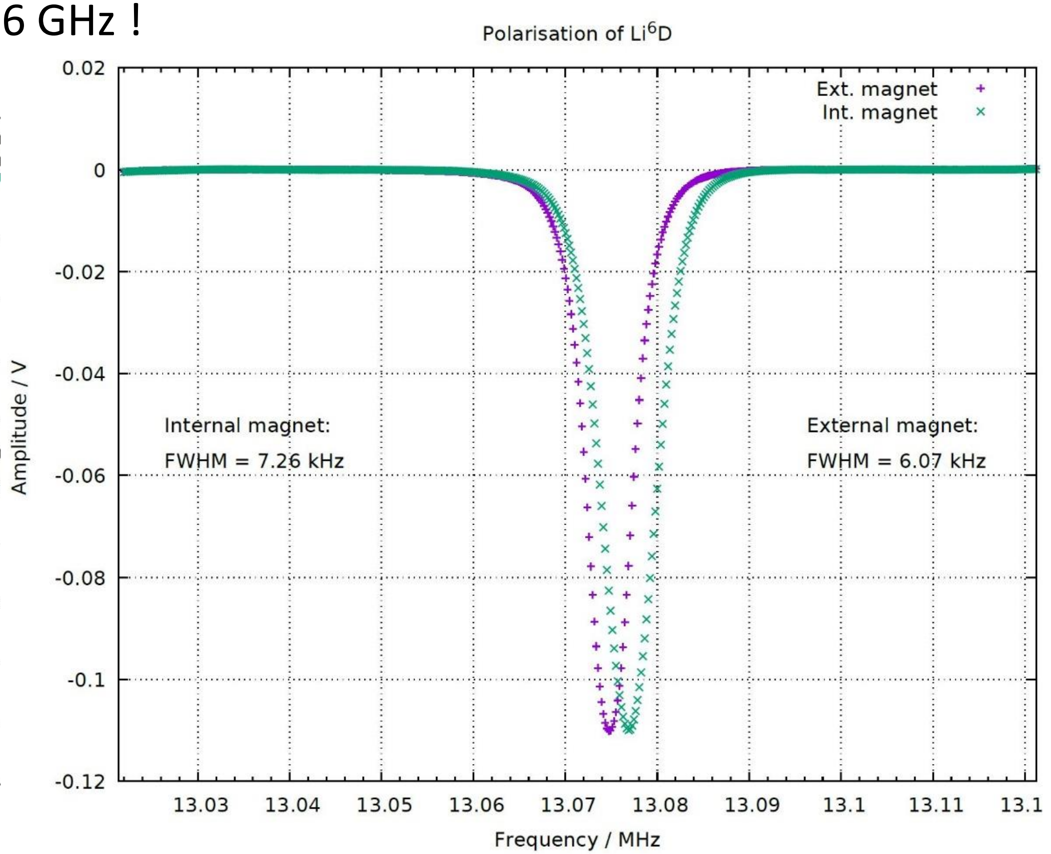

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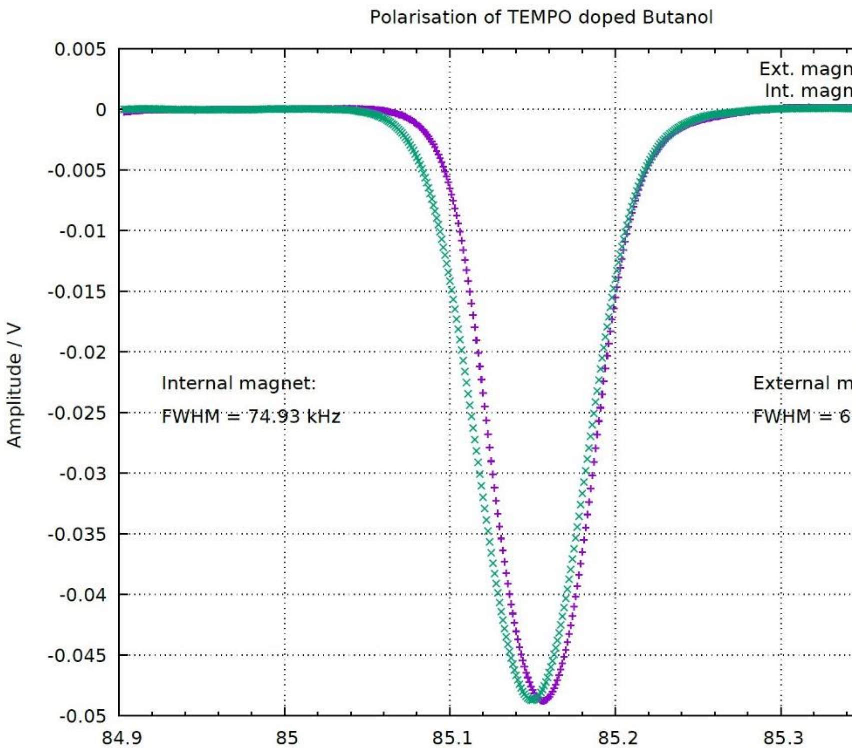
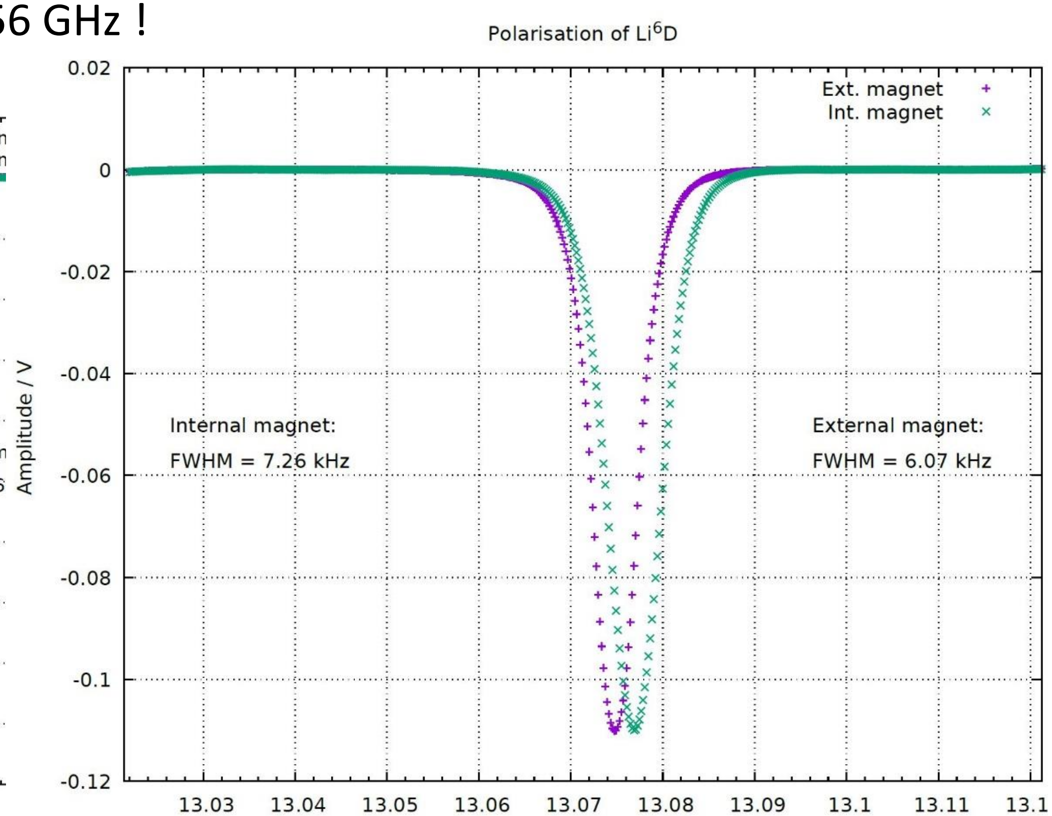




4π-continiuous mode scheme has been proven

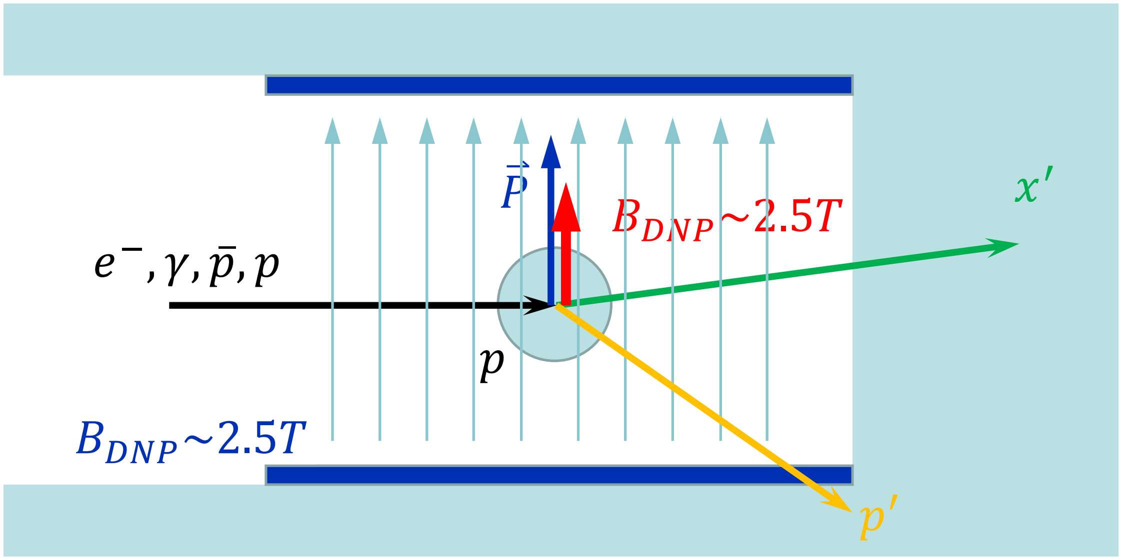
Next: 8-layers coil for the new refrigerator

more information next talk: Marcel Bornstein "Design and calculation of the 4π-Continuous-Mode-Target current leads"

Recent activities of the Bonn Polarized Target Group

Research Objectives: high field thin s.c. magnets

What's with high mag. transverse field for DNP (B_{DNP} ~ 2.5 T)



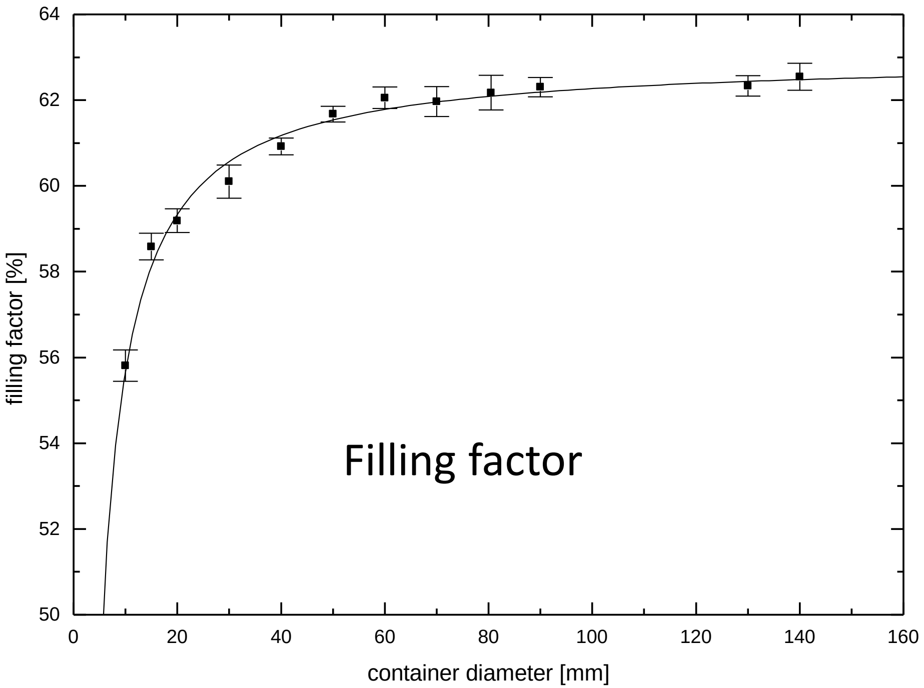
→ **CryPTA:ScM**:
Low mass, thin (< 4 mm) s.c. tilted solenoid (B ~ 2.5T, $\Delta B/B\ 10^{-4}$) for DNP comparable dimensions as the polarizing solenoid

→ Next generation of internal s.c. coils for transverse polarization

Recent activities of the Bonn Polarized Target Group

Research Objectives: Development and optimization of suitable target materials

Source of discussions (and uncertainties): filling factor κ and density distribution



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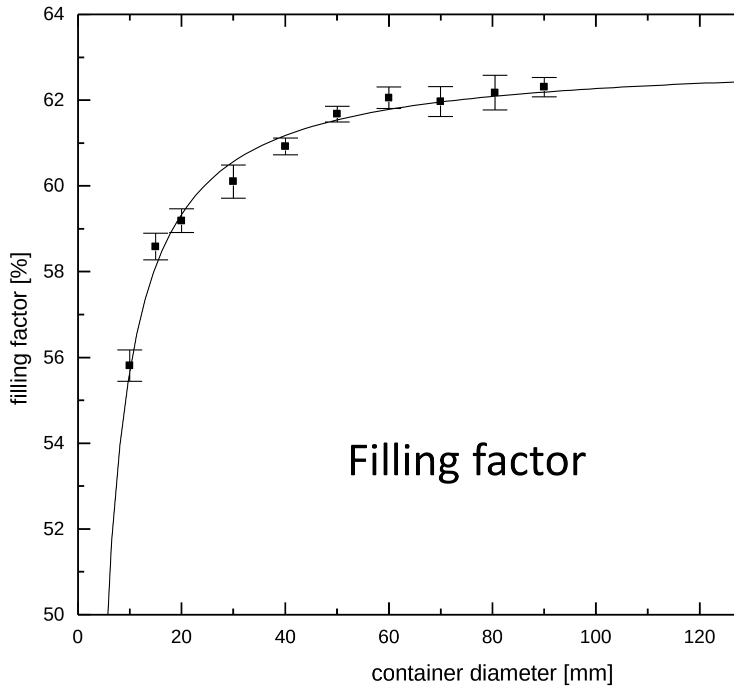

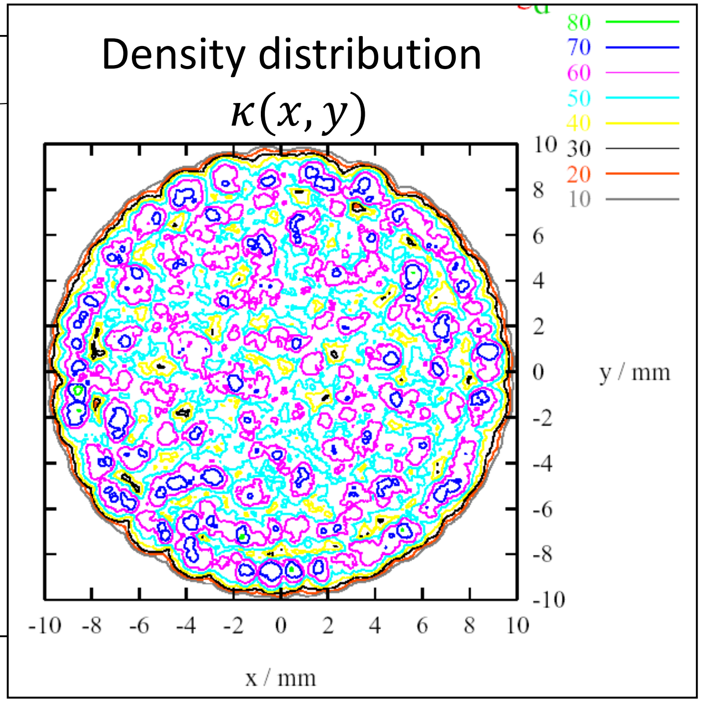

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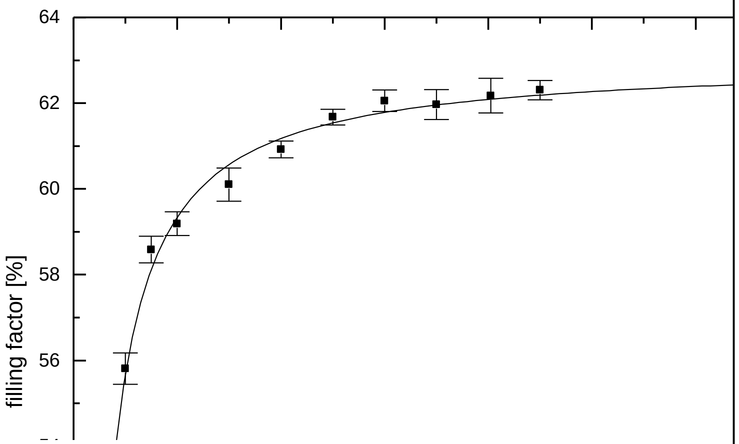
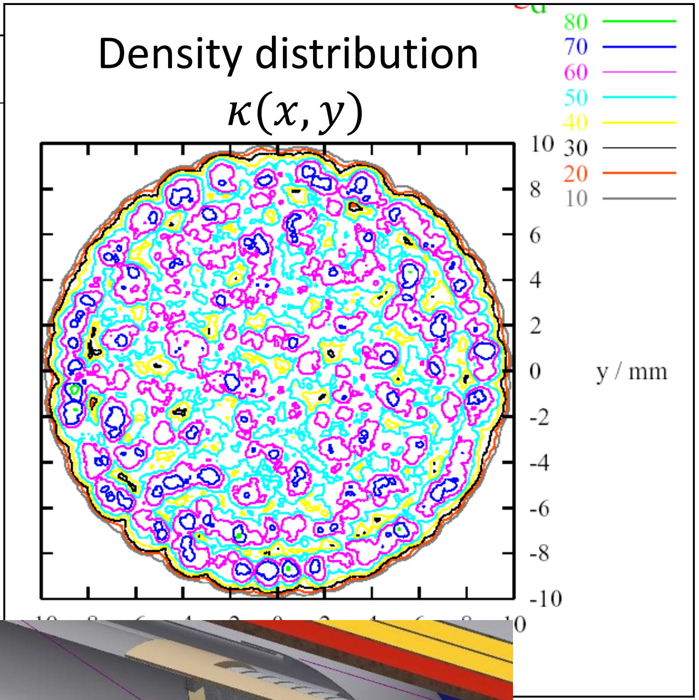
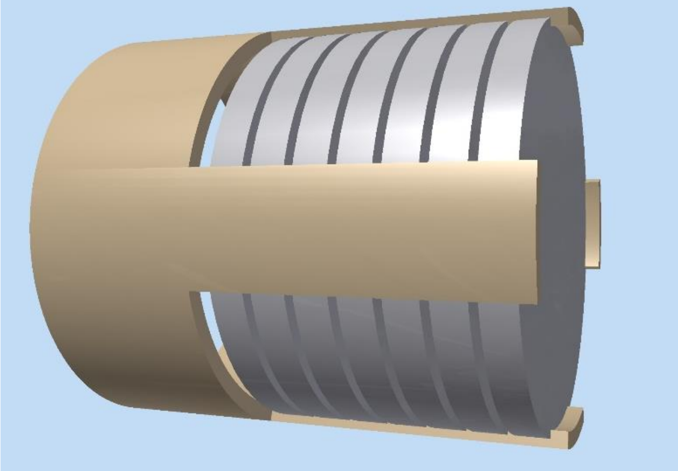
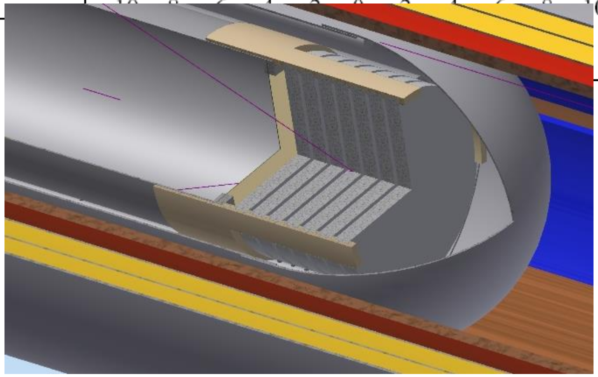




‘solid target material’: plastic plates (CH_2):



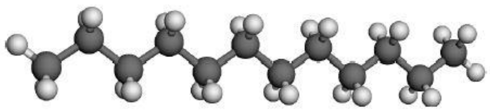


Recent activities of the Bonn Polarized Target Group

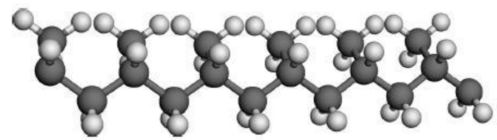
Research Objectives: Development and optimization of suitable target materials

Best choice: CH_2 – chain

Introduction - Polymers



Polyethylene $(CH_2)_n$



Polypropylene $(CH_2\text{-}CH\text{-}CH_3)_m$

Filling factor κ Samples can be formed to practically any geometry.

Density ρ Slightly higher than that of butanol.

Dilution factor f

material	f [%]
butanol	13.5
PE/PP	14.3

Polarisation P_t ???

Handling Samples are safe and stable at room temperature.

Background Signal background is purely carbon.

4/17

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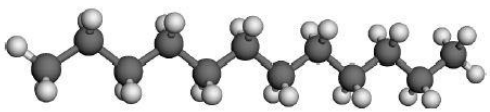
universitätbonn **Introduction - Polymers**



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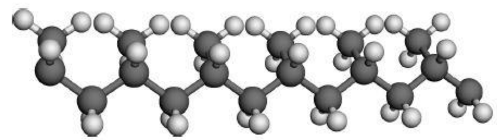

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Dilution factor f

- Irradiation of materials creates structural defects (hydrogen extraction, chain scisssions) that be used for DNP.
- ESR is an essential tool in the analysis of the structure of paramagnetic centres.
- The spin density of a paramagnetic sample can be determined by calibration.
- ESR gives us access to the spin density of the material, however it doesn't say anything about the spacial distribution of the radials within the material.

Polarisation P_t ???

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4/17

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Electron irradiation @ LINAC2 and pol. measurements @ 1K (Scott Reeve)

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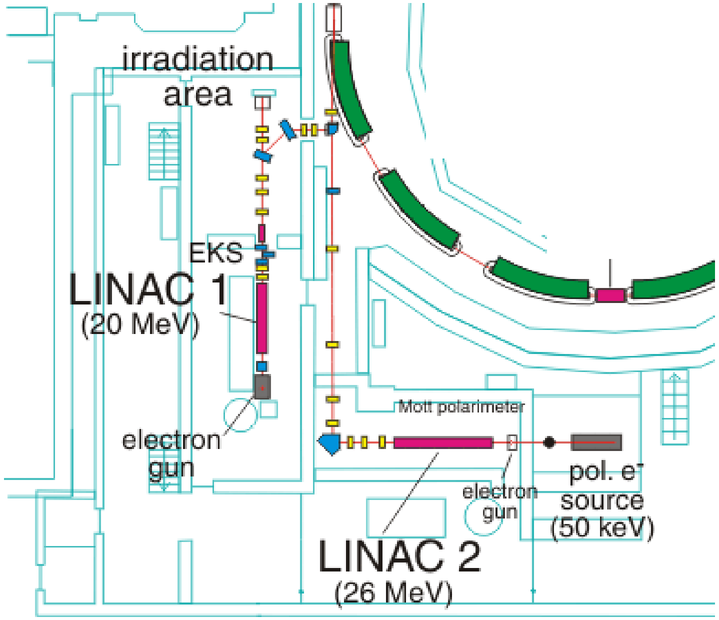
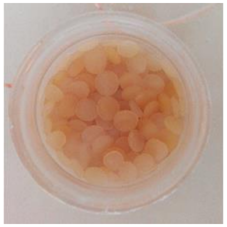
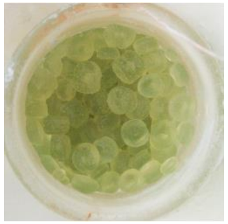
Electron Irradiations (LINAC2) - Cryostat and Ramping







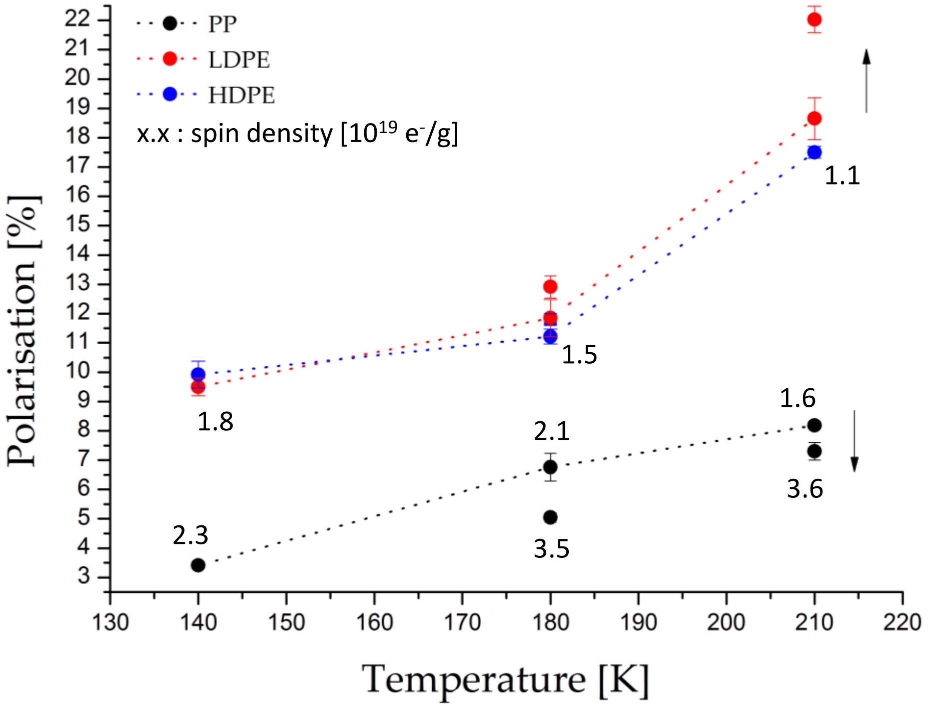
- Irradiations using wide range cryostat with range $90\,K < T < 300\,K$.
- Dual cycle system with a slow regulating LN_2 HE and fast regulating 1000 W heater.
- Temperature stable to within $\Delta T = \pm 1\,K$.
- Lower beam current of LINAC2 works in favour of stability of temperature.
- Irradiations are longer due to 20x lower current.

Recent activities of the Bonn Polarized Target Group

Research Objectives: Development and optimization of suitable target materials

Electron irradiation @ LINAC2 and pol. measurements @ 1K (Scott Reeve)

Polarization vs irradiation temperature



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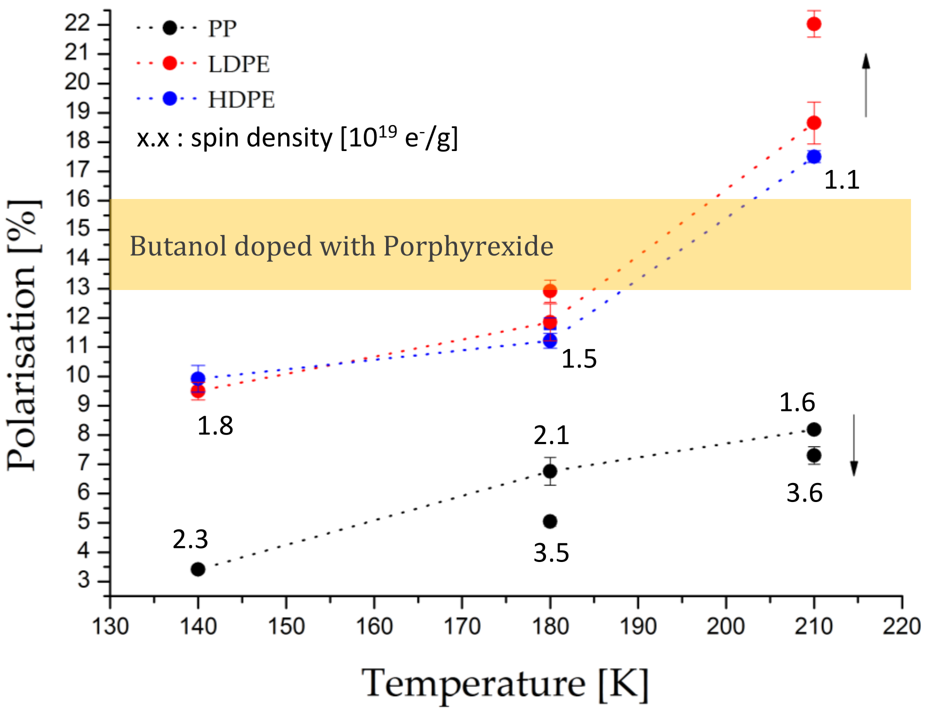

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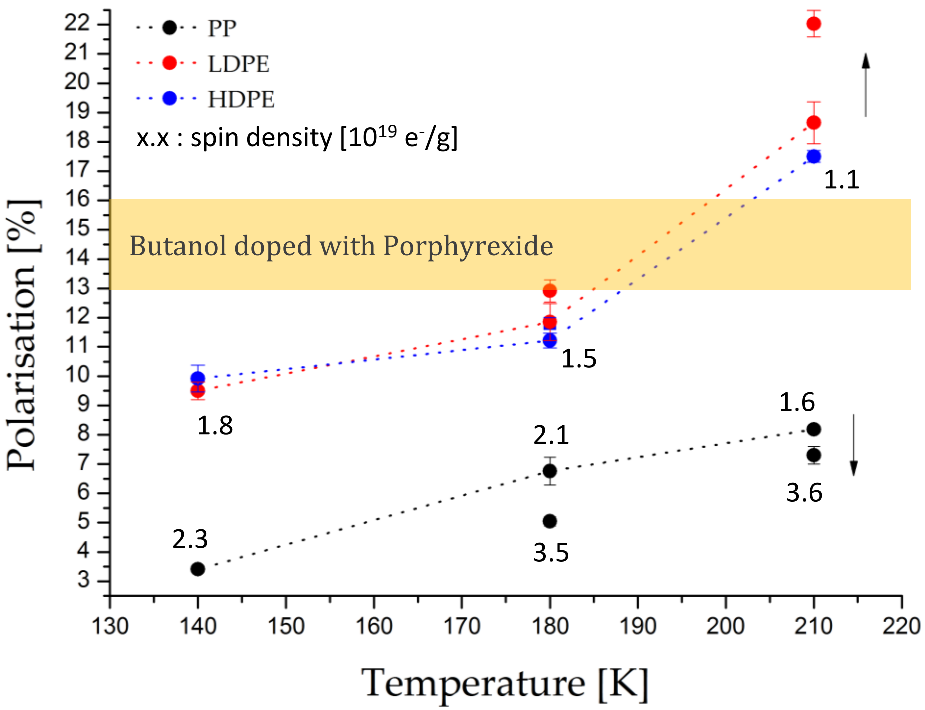
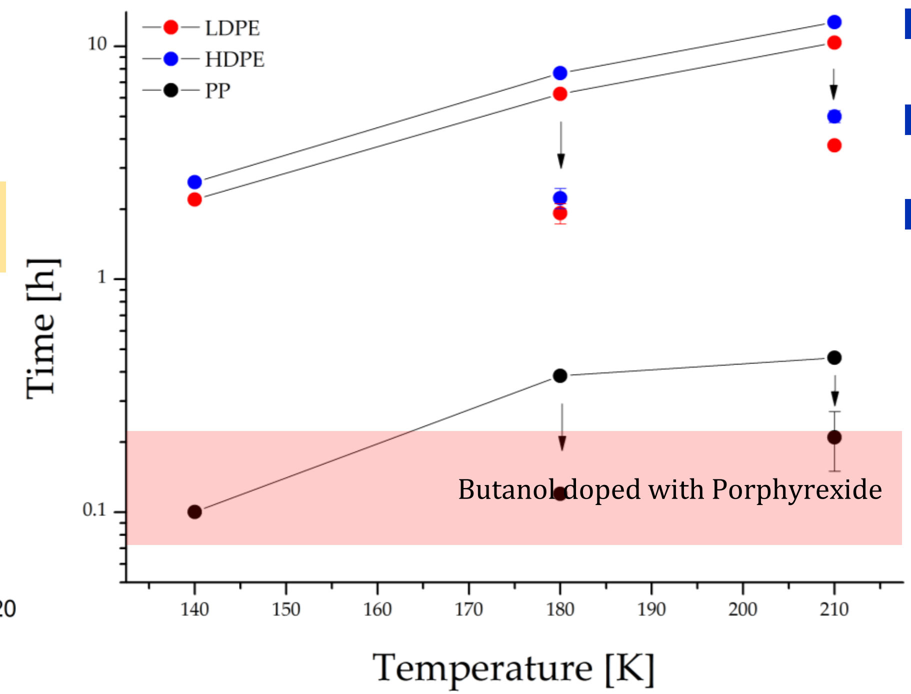


Relaxation times vs irradiation temperature

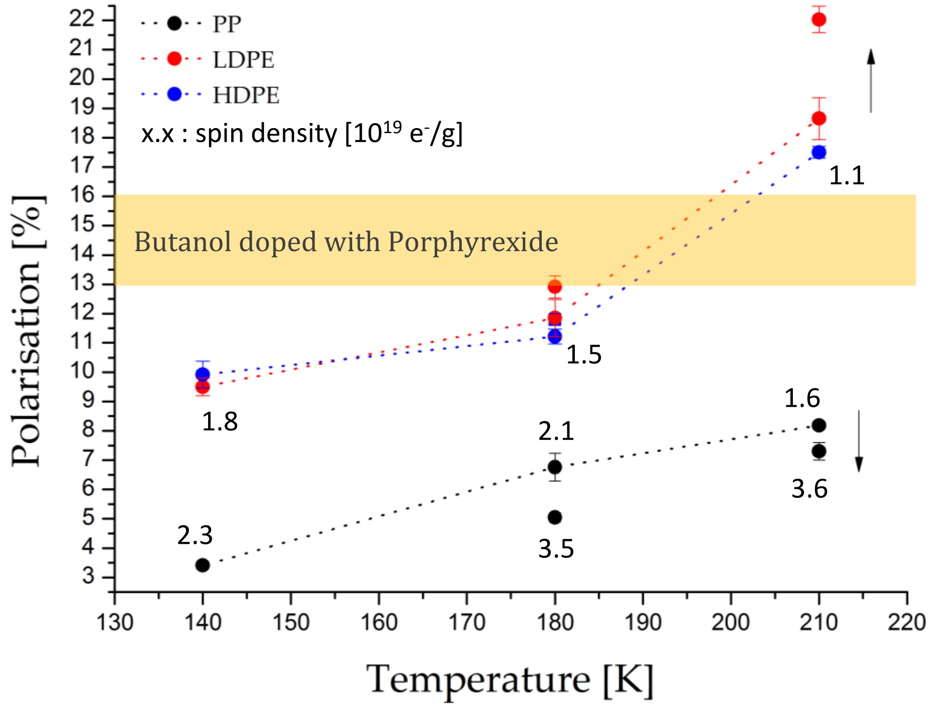


Recent activities of the Bonn Polarized Target Group

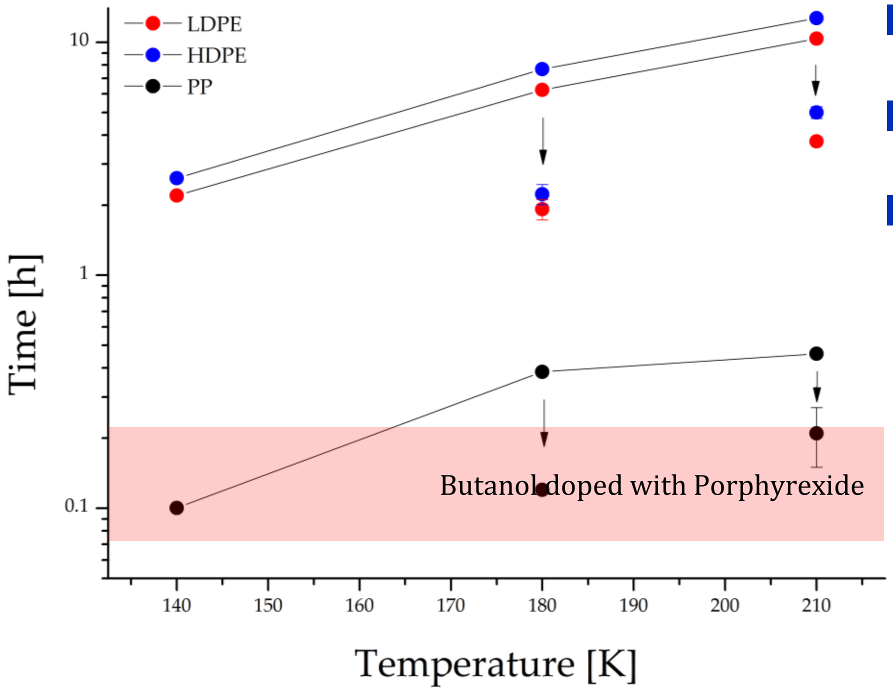
Research Objectives: Development and optimization of suitable target materials

Electron irradiation @ LINAC2 and pol. measurements @ 1K (Scott Reeve)

Polarization vs irradiation temperature



Relaxation times vs irradiation temperature



Promising results; low temperature data and polarizations needed

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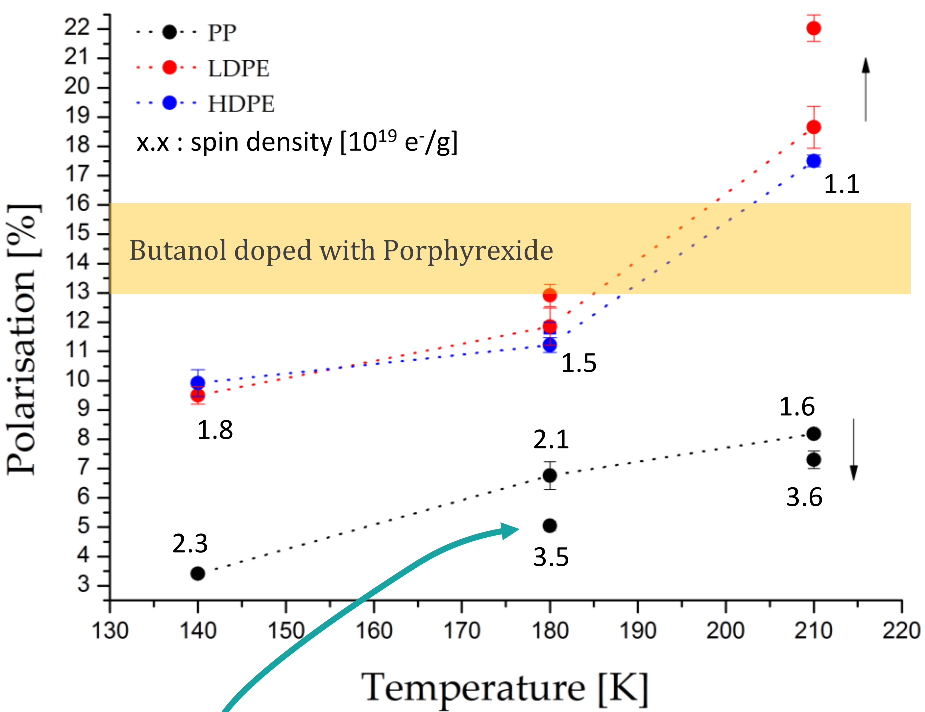

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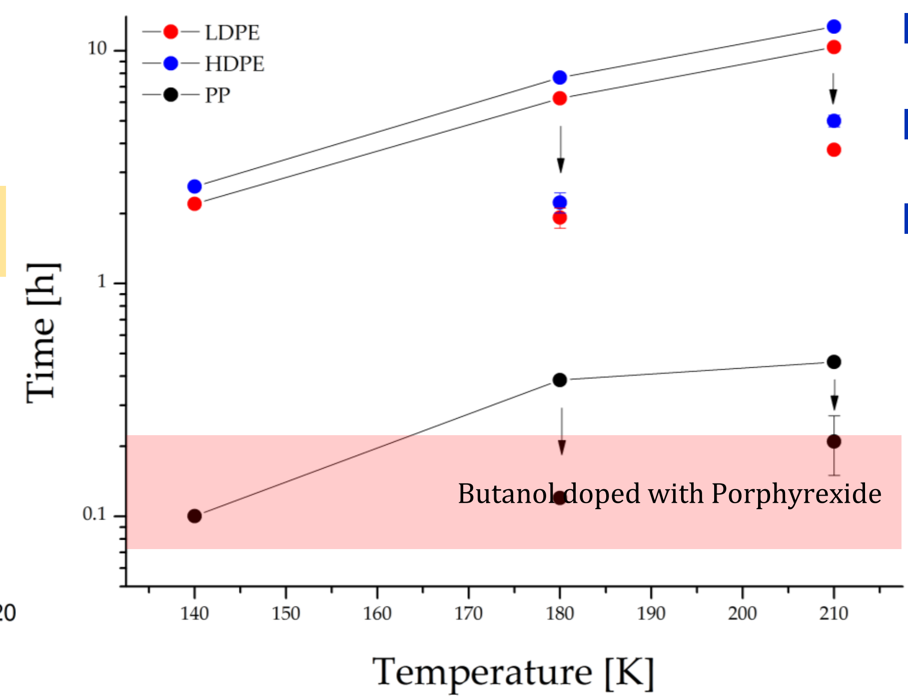


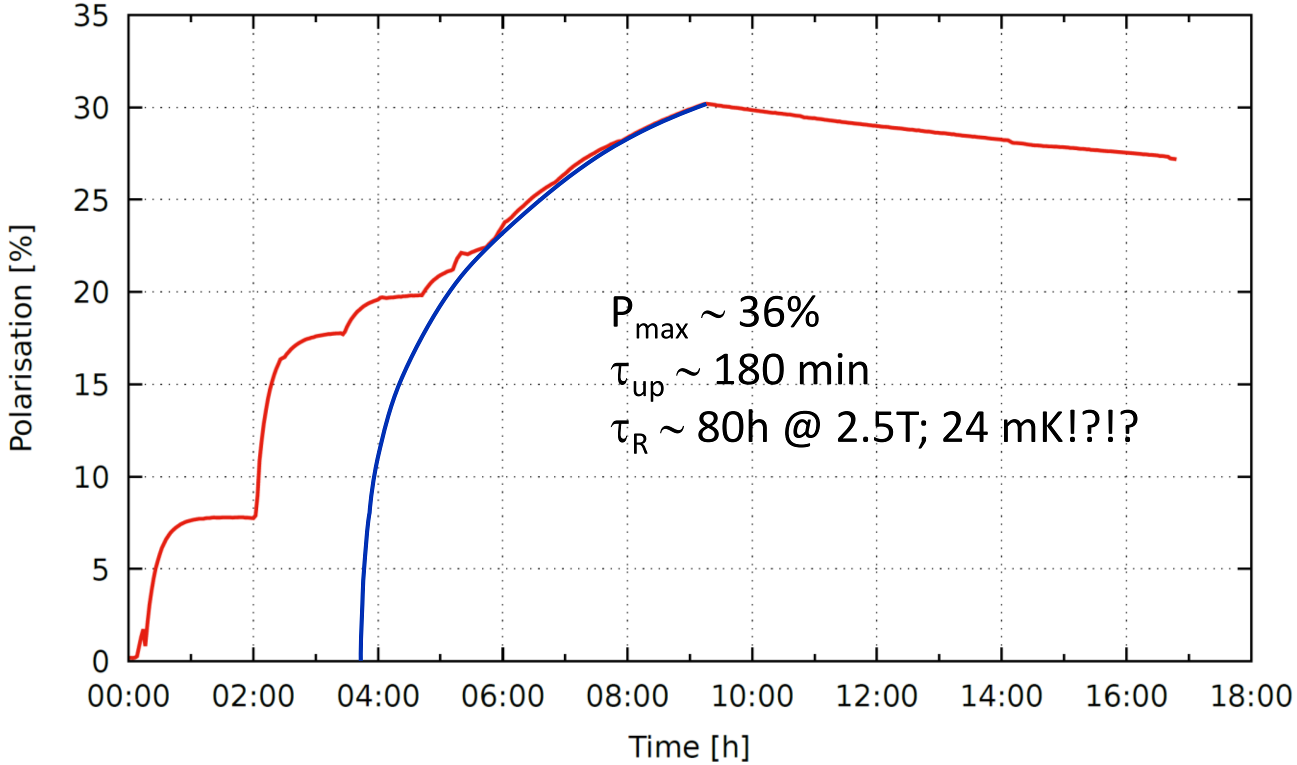
Promising results; low temperature data and polarizations needed

First attempt: pp (irradiated @ 180K, 5.6 mC, $3.5*10^{-19}$ e$^-$/g)

Recent activities of the Bonn Polarized Target Group

Research Objectives: Development and optimization of suitable target materials

Polarization measurements of pp (irradiated @ 180K, 5.6 mC) @ 200mK, 2.5T



pp (180K; $3.5*10^{-19}$ e^-/g) → (too) long build up times, low polarization, short relaxation times!

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Research Objectives: Development and optimization of suitable target materials

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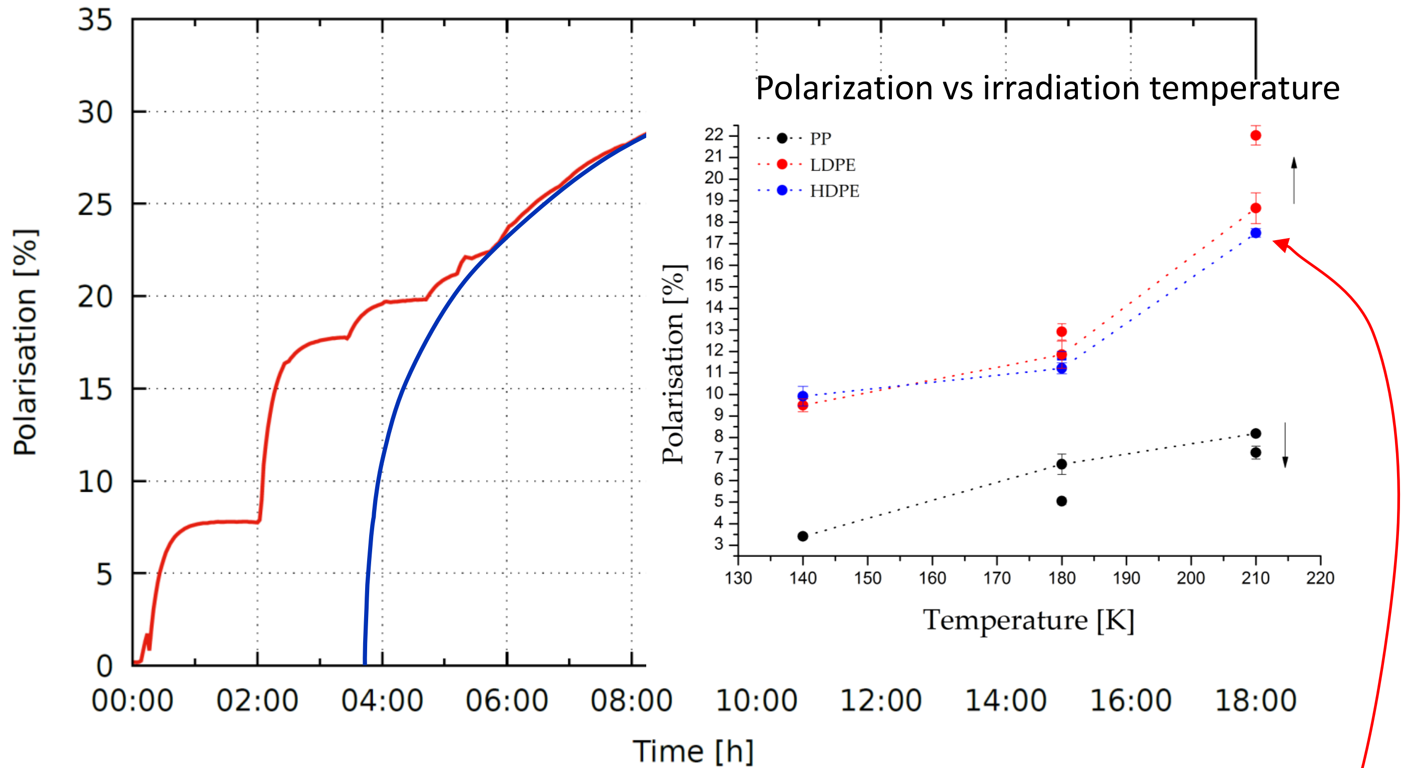

pp (180K; $3.5*10^{-19}$ e^-/g) → (too) long build up times, low polarization, short relaxation times!

next promising candidate HDPE (210K; $2.1*10^{-19}$ e^-/g)

more systematic low temperature studies needed!

Recent activities of the Bonn Polarized Target Group

Summary

The final goal is to provide low mass sc. magnets and new target materials for polarized targets operated in a 4π-detection system.

Key technology to improve the polarized target performance:

- increase the luminosity, FoM and availability
- gain to new polarization observables

Scheme has been proven @ 1K, 2 Tesla

With the new refrigerator and the cooperation with
Mainz/Dubna/Bochum PT-groups
we hope to realize the
'4π continuous mode target concept'
for real photon double polarization experiments at ELSA and MAMI
soon