Recent activities of the Bonn Polarized Target Group

Edward Bickmann, Marcel Bornstein, Hartmut Dutz, Stefan Goertz, Sascha Heinz, Stefan Runkel

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Recent activities of the Bonn Polarized Target Group

Motivation

Opening (from recoil polarization to target polarization)

- Reciprocal nucleon polarization
  - Polarity of the recoil particle depends on the left-right asymmetry of the scattered particle.
  - Analyzing power $A$ depends on the particle energy and the scattering angle $\theta$.
  - Three different target types have been used so far.
  - Liquid bismuth is a good analyzer at lower energies and carbon and liquid hydrogen at higher 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 cannot 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)

- Suitable target material
- High magnetic field
- Low temperatures

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

Our goal since 50 years: maximizing

‘Figure of Merit’: \( \text{FoM} = n_T f^2 P^2 \)

Luminosity: \( \mathcal{L} = I n_T \)

Why not using a polarized target

by optimizing the target ingredients for new and innovative polarization experiments

- suitable target material
- high magnetic field
- low temperatures

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Motivation

Structure mapping @ ELSA and MAMI
→ Double polarization experiments
→ Modell independent partial wave analysis
→ Complete experiment

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

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) \( \sim 800 \) h
- max. pol: \( p_+ = 63 \% \), (butanol, TEMPO)
- Relaxation time: \( \tau \sim 1300 \) h (\( @ 0.4 \, T \), \( I \sim 10^8 / s \))
- \( \bar{P} \sim 56 \% \)

2018 (transv. polarization) \( \sim 1000 \) h
- max. pol: \( p_+ = 83 \% \), \( p_- = 87 \% \) (butanol, porphyrexide)
- Relaxation time: \( \tau \sim 500 \) h (\( @ 0.4 \, T \), \( I \sim 10^8 / s \))
- \( \bar{P} \sim 78 \% \)

Relaxation time without beam: 1800 h

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FSTechnique Limitations:

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

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

‘4\pi 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 $^4\text{He}$-mode.

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

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“
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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}/cm²s^{-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

\[ \frac{\Delta B}{B} \leq 10^{-4} \]

Biot-Savart-Law:

\[ \vec{B}(x_0) = \frac{\mu_0}{4\pi} \int \frac{\vec{\gamma}(t) - \vec{x}_0}{|\vec{\gamma}(t) - \vec{x}_0|^3} \times \frac{\vec{\gamma}(t)}{|\vec{\gamma}(t)|} \, dt \]

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
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Research Objectives: high field thin s.c. magnets

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

High precision winding technique to guarantee ‘orthozyclic winding’
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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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Research Objectives: high field thin s.c. magnets

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

\[ T_P = 1 \text{K}, \quad B_P = 2 \text{Tesla}, \quad F_{\mu W} = 56 \text{GHz} \]

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\[ 4\pi\text{-continuous mode scheme has been proven} \]

Next: 8-layers coil for the new refrigerator

more information next talk: Marcel Bornstein “Design and calculation of the 4\pi-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 ($B_{DNP} \sim 2.5$ T)

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

→ Next generation of internal s.c. coils for transverse polarization
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Research Objectives: Development and optimization of suitable target materials

Source of discussions (and uncertainties): filling factor $\kappa$ and density distribution
Recent activities of the Bonn Polarized Target Group

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Source of discussions (and uncertainties): filling factor $\kappa$ and density distribution

![Graph showing filling factor and density distribution](image-url)
Recent activities of the Bonn Polarized Target Group

Research Objectives: Development and optimization of suitable target materials

Source of discussions (and uncertainties): filling factor $\kappa$ and density distribution

'Solid target material': plastic plates (CH$_2$):
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Research Objectives: Development and optimization of suitable target materials

Best choice: CH$_2$ – chain

Introduction - Polymers

Polyethylene (CH$_2$)$_n$

Polypropylene (CH$_2$–CH–CH$_3$)$_m$

Filling factor $\kappa$: Samples can be formed to practically any geometry.
Density $\rho$: Slightly higher than that of butanol.
Dilution factor $f$

<table>
<thead>
<tr>
<th>material</th>
<th>f [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>butanol</td>
<td>13.5</td>
</tr>
<tr>
<td>PE/PP</td>
<td>14.3</td>
</tr>
</tbody>
</table>

Polarisation $P_t$ ???

Handling: Samples are safe and stable at room temperature.
Background: Signal background is purely carbon.
Recent activities of the Bonn Polarized Target Group

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Dilution factor $f$

- Irradiation of materials creates structural defects (hydrogen extraction, chain scississions) 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.

Handling: Samples are safe and stable at room temperature.
Background: Signal background is purely carbon.
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)

Electron Irradiations (LINAC2) - Cryostat and Ramping

- Irradiations using wide range cryostat with range $90\,\text{K} < T < 300\,\text{K}$.
- Dual cycle system with a slow regulating LN$_2$ HE and fast regulating 1000W heater.
- Temperature stable to within $\Delta T = \pm 1\,\text{K}$.
- Lower beam current of LINAC2 works in favour of stability of temperature.
- Irradiations are longer due to 20x lower current.
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Research Objectives: Development and optimization of suitable target materials

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

Polarization vs irradiation temperature

- PP
- LDPE
- HDPE

x.x : spin density $[10^{19} \, \text{e}/\text{g}]$

![Graph showing polarization vs irradiation temperature]
Recent activities of the Bonn Polarized Target Group

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Butanol doped with Porphyrexide
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Polarization vs irradiation temperature

Relaxation times vs irradiation temperature

Butanol doped with Porphyrexide

![Graphs showing polarization and relaxation times vs temperature]
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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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Research Objectives: Development and optimization of suitable target materials

Promising results; low temperature data and polarizations needed

First attempt: pp (irradiated @ 180K, 5.6 mC, 3.5*10^{-19} e^-/g)
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Research Objectives: Development and optimization of suitable target materials

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

P_{max} \sim 36\%

\tau_{up} \sim 180\ min

\tau_{R} \sim 80h @ 2.5T; 24\ mK!?!?

pp (180K; 3.5*10^{-19}\ e^-/g) \rightarrow \text{(too) long build up times, low polarization, short relaxation times!}
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Polarization measurements of pp (irradiated @ 180K, 5.6 mC) @ 200mK, 2.5T

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

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

more systematic low temperature studies needed!
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Summary

The final goal is to provide low mass sc. magnets and new target materials for polarized targets operated in a $4\pi$-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 ‘$4\pi$ continuous mode target concept’ for real photon double polarization experiments at ELSA and MAMI soon