Measurement of $dC$ Vector Analyzing Power and Cross Section at COSY for srEDM Polarimetry

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OUTLINE

- Short EDM Introduction / Motivation
- WASA Forward Detector
- dC Vector Analyzing Power
- Elastic dC Cross Section
- Summary / Conclusion
EDM

Introduction / Motivation

Electric Dipole Moment (EDM): \( \vec{d} = d \vec{S} \)

Magnetic Dipole Moment (MDM): \( \vec{\mu} = \mu \vec{S} \)

\[
H = -d \vec{S} \cdot \vec{E} - \mu \vec{S} \cdot \vec{B}
\]

\[
T : H = +d \vec{S} \cdot \vec{E} - \mu \vec{S} \cdot \vec{B}
\]

\[
P : H = +d \vec{S} \cdot \vec{E} - \mu \vec{S} \cdot \vec{B}
\]

→ EDM violates both CP and P symmetry!

Simplified EDM measurement procedure:

- Use horizontally polarize deuterons
- Horizontal E-field creates spin build-up along y
- Elastic scattering creates asymmetry proportional to polarization along y
- EDM is proportional to polarization build-up
MOTIVATION

Research and development towards a first proof-of-principle EDM experiment within the JEDI (Jülich Electric Dipole Investigation) Collaboration

http://collaborations.fz-juelich.de/ikp/jedi/

- Plans for first storage ring based EDM measurements on protons and deuterons
  → Overview talk given by Dr. Frank Rathmann: *Electric dipole moment searches using storage rings*

- Development of a dedicated polarimeter based on LYSO crystals
  → Detailed talk given by Dito Shergelashvili: *Development of LYSO detector modules for a charge-particle EDM polarimeter*

→ Measurement of deuteron analyzing power and elastic cross section will be used to find optimal polarimeter configuration
Installed in the COSY (COoler SYncrotron) accelerator at the research center in Jülich
Detector is remnant of former WASA
Multi layer design
Large acceptance: 2° - 17° in Θ, full coverage in Φ
Two strip targets installed: Carbon (Diamond) and Polyethylene (CH2)
VECToR ANALYZING POWER

Elastic Scattering of Polarized Deuterons - Overview

Deuteron spin-1 factor

\[ \sigma_{dC}^{\text{pol}}(\Theta, \Phi) = \sigma_{dC}^{\text{unpol}}(\Theta) [1 + \frac{3}{2} P_y A_y(\Theta) \cos(\Phi)] \]

Asymmetry \( \epsilon \) → first topic of the talk

Polarized elastic cross section

Unpolarized elastic cross section

→ second topic of the talk

Vector polarization

Vector analyzing power
VECTOR ANALYZING POWER

Measurement Principle – One Asymmetry, Two Methods

Asymmetry
→ can be extracted from data

\[ \epsilon = \frac{3}{2} P_y A_y = \begin{cases} \frac{N_{\uparrow} - N_{\downarrow}}{N_{\uparrow} + N_{\downarrow}} = \frac{N_L - N_R}{N_L + N_R} \\ \frac{\sqrt{N_{\downarrow}^L N_R^L} - \sqrt{N_{\uparrow}^L N_R^L}}{\sqrt{N_{\downarrow}^L N_R^L} + \sqrt{N_{\uparrow}^L N_R^L}} \end{cases} \]

Asymmetry Method:
• Either, one detector and two polarization states
• Or, two detectors and one polarization state
• Left/right detector acceptance must be equal

Cross Ratio Method:
• Uses both polarization states and detector sides simultaneously
• Different acceptances in left/right detector cancels
→ This method was used in this work

→ Important for polarimetry:
Polarization can be calculated from asymmetry if the analyzing power is known!
Extracting the analyzing power from the asymmetries:
1. Absolute beam polarization was not known → using reference $A_y$ from Satou et al.
VECTOR ANALYZING POWER

Results

Extracting the analyzing power from the asymmetries:
1. Absolute beam polarization was not known → using reference $A_y$ from Satou et al
2. Fitting asymmetry for 270 MeV to reference → got polarization value of 0.434
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1. Absolute beam polarization was not known → using reference $A_y$ from Satou et al
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3. Using this polarization to scale asymmetries for other energies (assuming same polarization)

Statistical errors shown
Results will be used for an optimal EDM polarimeter development
ELASTIC DC CROSS SECTION

Approach for Cross Section Extraction

\[ \sigma_{dC} = \frac{N_{el}^{d}}{\varepsilon_{dC} L_{int}^{dC}} \]

Number of elastically scattered deuterons → extracted from measured data

Integrated luminosity for dC scattering
→ proportional to the beam current
→ no direct measurement in storage ring experiment

Detector acceptance for dC scattering
→ from Monte-Carlo simulation

→ Luminosity cannot be extracted from dC scattering only
ELASTIC DC CROSS SECTION

Approach for Cross Section Extraction

Solution:
- Measure dp elastic scattering off CH$_2$
- Extract luminosity by comparison to dp reference data
- Scale luminosity for CH$_2$ to C target

\[ \frac{\mathcal{L}_{\text{int}}}{dC} = \frac{1}{2} \frac{\mathcal{L}_{\text{int}}^{dp}}{\eta_{\text{CH}_2 \rightarrow \text{C}}} \]

Detector acceptance for pd scattering → from Monte-Carlo simulation

\[ \text{Elastic pd cross section } \rightarrow \text{from reference data} \]

\[ \Rightarrow \sigma_{\text{dC}} = 2\sigma_{\text{pd}} \frac{N_{d}^{el}}{N_{p}^{el}} \frac{\epsilon_{pd}}{\epsilon_{dC}} \eta_{\text{CH}_2 \rightarrow \text{C}} \]

Number of elastically scattered protons → extracted from data

Scaling factor H$_2$ to C in CH$_2$ target

Scaling factor CH$_2$ to C target

→ Fitting CH$_2$ to C spectra
Proton Extraction from CH$_2$ Data

Steps done for each energy and each $\Theta$-bin:
1. Graphical cut around the elastic proton peak
2. Subtracted C contribution from CH$_2$ data
3. Fitted elastic peak and background

$\rightarrow$ Number of elastically scattered protons from peak integral
ELASTIC DC CROSS SECTION

Elastic $dC$ Cross Sections & Reference $pd$ Cross Sections

Elastic $dC$ cross section:
- Calculated using experimental data and MC
- Scaled using reference data for elastic $pd$ scattering
- Statistic error bars are shown
- Available reference data for elastic $pd$ scattering shows some deviations among different publications → Careful ponder on the choice of reference is needed

dC Cross Sections:

270 MeV

- This work
- Satou et al.
  PLB 549, 307

200 MeV

- This work
- Kawabata et al.
  PRC 70, 034318

Preliminary

dp Cross Sections for 270 MeV:

- Ermish et al.
  PRC 71, 064004
- Hatanaka et al.
  Private communication
- Sekiguchi et al.
  PRC 65, 034003
- Sakamoto et al.
  PLB 367, 60

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SUMMARY / CONCLUSION

Summary:
● Non-zero EDM violates both, P and CP symmetry
● High precision asymmetry measurements are needed to access EDMs
● The WASA Database Experiment aims to provide the necessary tools for an optimal polarimeter development
● First results of the vector analyzing are very promising and show good agreement with published references
● Preliminary results for the elastic cross section extraction are compatible with experiments done by Satou et al. and Kawabata et al.

Outlook:
● Extraction of the cross section for the energies between 170 MeV and 380 MeV → Work in progress but not ready to be presented yet
● Investigation on the polarization stability during the beam time
● Estimation of the systematic errors of the experiment
BACKUP
ELASTIC DC CROSS SECTION

Deuteron Extraction from Carbon Data

Steps done for each energy and each $\Theta$-bin:
1. Graphical cuts around the deuteron band for all layers
2. Spectra for summed for all layers
3. Fit the elastic peak and the background

→ Number of elastically scattered deuterons from peak integral
ELASTIC DC CROSS SECTION

Acceptance from Monte-Carlo Simulation

Generated elastic events → Isotropically distributed:
\( \Phi \in [0^\circ, 360^\circ], \ \Theta \in [3^\circ, 16^\circ] \)

Detector acceptance

\[ \epsilon = \frac{N_{gen}}{N_{det}} \]

Detected events from Geant3 MC → includes detector geometry → includes nuclear reactions in the scintillators → cut on particle bands
ELASTIC DC CROSS SECTION

C to CH$_2$ Scaling

- Apply same band cuts on C and CH$_2$ data
- Simultaneous fitting histogram on histogram in all $\Theta$-bins