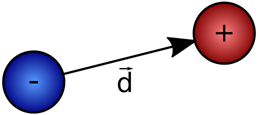
The EDM Polarimeter Development at COSY - Jülich

for the JEDI Collaboration | DPG Spring Meeting 2017

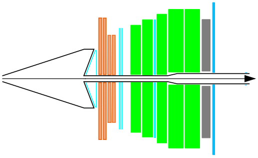
March 28, 2017 | Fabian Müller | IKP-2

Outline

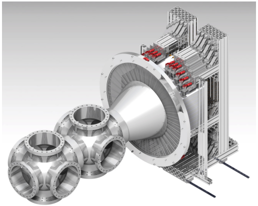
- Whats EDM & How to measure it?



- Measurement of Polarized Observables
  - Overview
  - Wasa Database Experiment

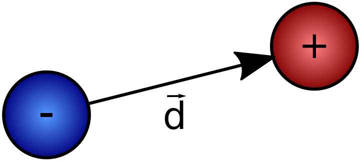


- The LYSO Polarimeter
  - Overview
  - LYSO Experiments



- Summary

Physics Institute III B — RWTH AACHEN UNIVERSITY — JEDI — JÜLICH FORSCHUNGSZENTRUM

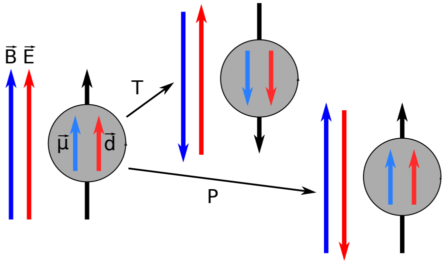


$$\vec{d} = q\vec{l}$$

In quantum mechanics, we can define EDM and MDM as follows:

$$\vec{d} = d\vec{S}$$

$$\vec{\mu} = \mu\vec{S}$$



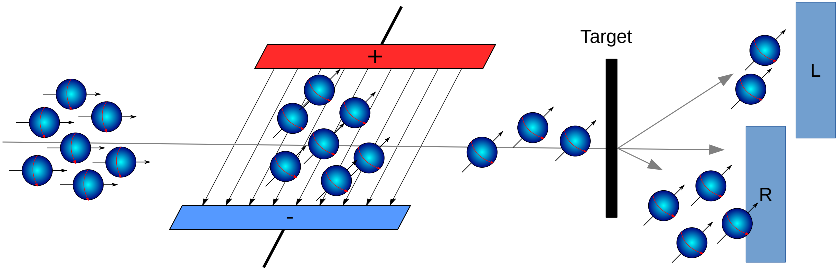
Hamiltonian of magnetic dipole moment (MDM) μ and electric dipole moment (EDM) d in external electric $\vec{E}$ and magnetic field $\vec{B}$:

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

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

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

$\rightarrow$ EDM violates both CP and P symmetry!



Simplified EDM measurement procedure

Polarimetry Fundamentals Using Asymmetries in Elastic Scattering

Polarized Cross Section:

$$\sigma_{pol}(\Theta) = \sigma_{unpol}(\Theta)[1+P_y A_y(\Theta)\cos(\Phi)]$$

Asymmetry ϵ:

$$\epsilon = P_y A_y = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} \text{ with } \sigma_{L,R} = \frac{\epsilon_{det}^{L,R} N_{L,R}}{L}$$

Full Cross Ratio ϵ_{CR}:

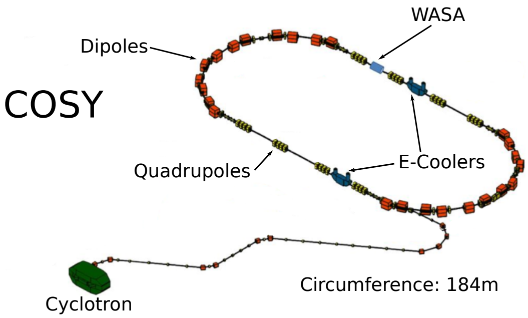
$$\epsilon_{CR} = \frac{r-1}{r+1} \text{ with } r^2 = \frac{N_L^{\uparrow} N_R^{\downarrow}}{N_L^{\downarrow} N_R^{\uparrow}}$$

Half Cross Ratio $\epsilon_{HCR}^{\uparrow,\downarrow}$:

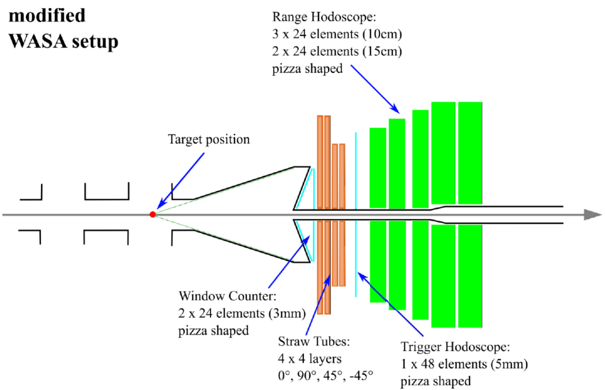
$$\epsilon_{HCR}^{\uparrow,\downarrow} = \frac{r-1}{r+1} \text{ with } r = \frac{N_L^{\uparrow,\downarrow} N_R^0}{N_R^{\uparrow,\downarrow} N_L^0}$$

Overview

- Motivation:
  - → realistic Monte Carlo simulations of detector responses for a polarimeter designed for EDM
- Goal: A_y, A_{yy}, $\frac{d\sigma}{d\Omega}$ for
  - → d-C elastic scattering
  - → main background reactions (deuteron breakup)
- Deuteron Beam:
  - → Energies: 170, 200, 235, 270, 300, 340, 380 MeV
  - → Targets: C and CH_2
  - → 5 Polarization States

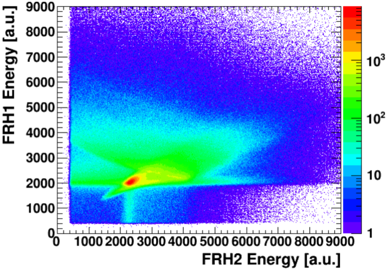


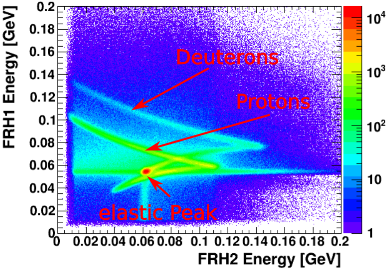
Measurement of polarized observables was performed using the WASA forward detector at COSY in Jülich → **WASA Database Experiment**



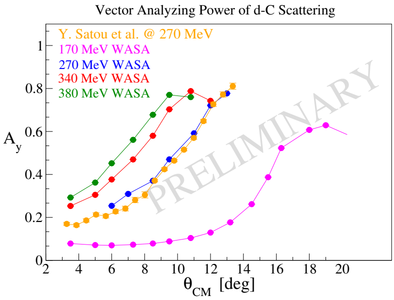
Key Features of the WASA Forward Detector

- Full Φ coverage, Θ: 4° to 17°
- High angular resolution with the straw tubes
- Large energy acceptance
- Full detector Monte-Carlo simulation





Left: uncalibrated. Right: calibrated using Monte-Carlo simulation

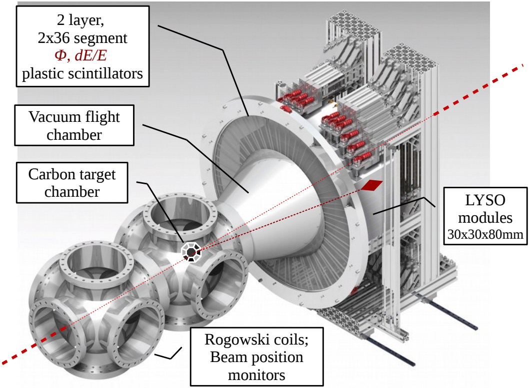


Status of WASA DB Analysis

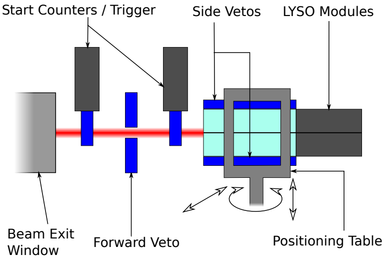
- ✓ Layer calibration
- ✓ Run dependent calibration
- → Kinematic reconstruction & PID
- → Vector and tensor analyzing power
- → Calculation of $\frac{d\sigma}{d\Omega}$

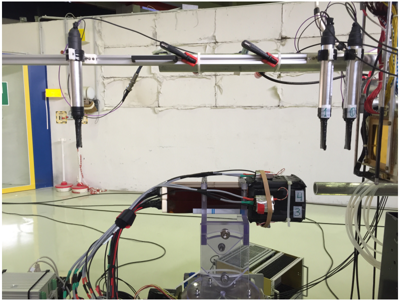
Advantages of the LYSO polarimeter

- Simple construction:
  - → No strong $\vec{E}$ and $\vec{B}$ fields
  - → Only two detection layers
- Modular setup:
  - → Modules can be easily rearranged
- Long term stability:
  - → LYSO is a radiation hard scintillator
- High accuracy:
  - → LYSO + SiPM modules have a high resolution

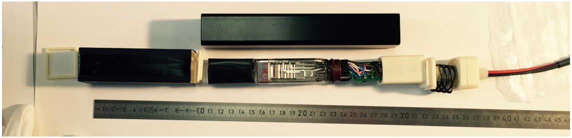


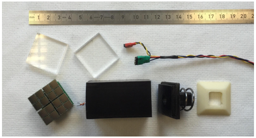
Model of the full EDM polarimeter built from LYSO detector modules



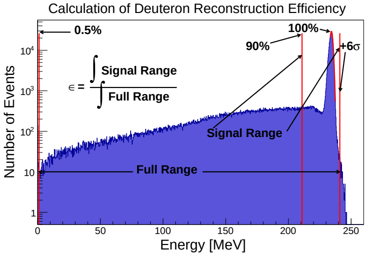


Experimental setup

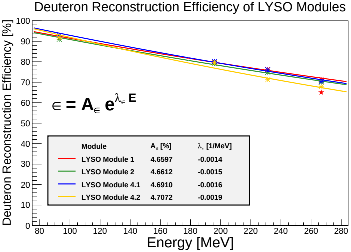




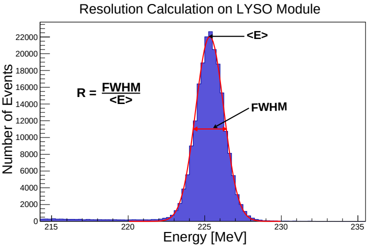
LYSO detector module, version I with PMT (left) and SiPM (right)



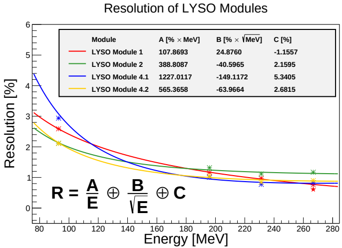
Calculation of Deuteron Reconstruction Efficiency
0.5%
100%
90%
+6σ
∈ = ∫ Signal Range / ∫ Full Range
Signal Range
Full Range
Number of Events
Energy [MeV]



Deuteron Reconstruction Efficiency of LYSO Modules
∈ = A∈ e^(λ∈ E)
Module | A∈ [%] | λ∈ [1/MeV]
LYSO Module 1 | 4.6597 | -0.0014
LYSO Module 2 | 4.6612 | -0.0015
LYSO Module 4.1 | 4.6910 | -0.0016
LYSO Module 4.2 | 4.7072 | -0.0019
Deuteron Reconstruction Efficiency [%]
Energy [MeV]



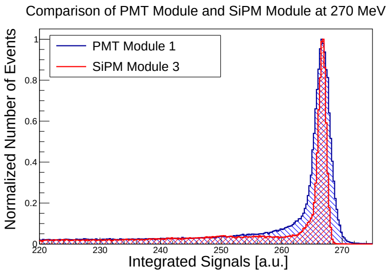
Resolution Calculation on LYSO Module
<E>
R = FWHM / <E>
FWHM
Number of Events
Energy [MeV]

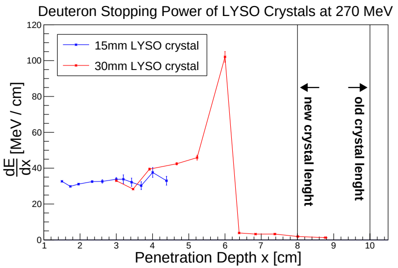


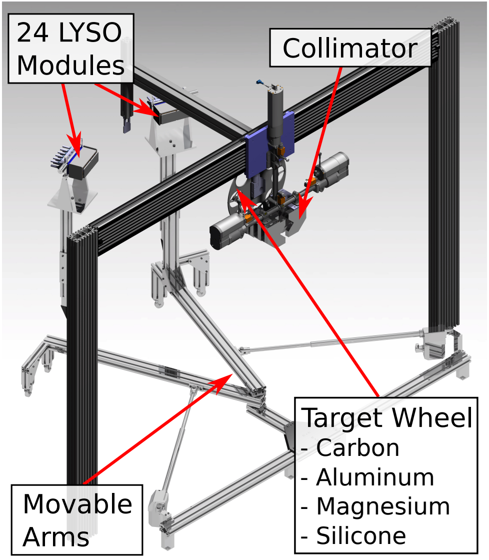
Resolution of LYSO Modules
Module | A [% × MeV] | B [% × √MeV] | C [%]
LYSO Module 1 | 107.8693 | 24.8760 | -1.1557
LYSO Module 2 | 388.8087 | -40.5965 | 2.1595
LYSO Module 4.1 | 1227.0117 | -149.1172 | 5.3405
LYSO Module 4.2 | 565.3658 | -63.9664 | 2.6815
R = A/E ⊕ B/√E ⊕ C
Resolution [%]
Energy [MeV]

Conclusions from LYSO I Experiment

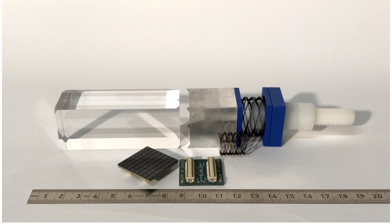
- Resolution of $< 1\%$ is achievable
- Deuteron reconstruction efficiency is $\sim 70\%$ for 270 MeV
- SiPM's can be chosen over PMT's
- 8cm LYSO crystals are long enough



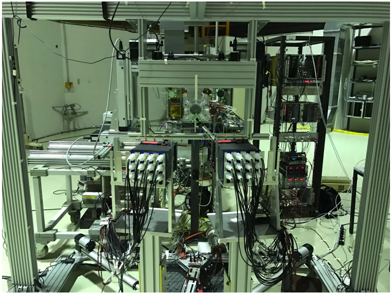


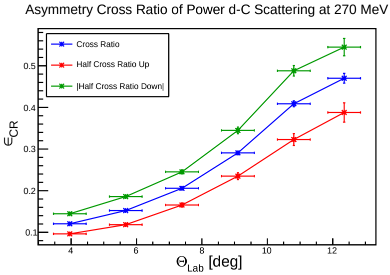


LYSO II experiment: model (left), setup (right)

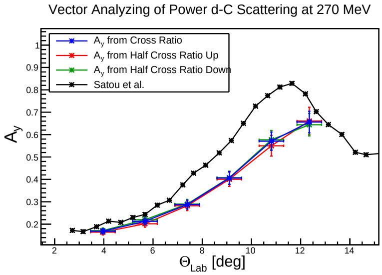


LYSO SiPM module V2

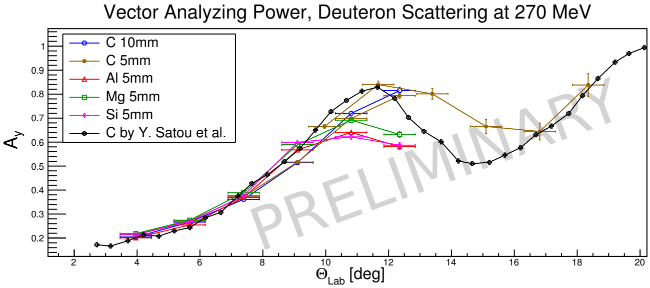




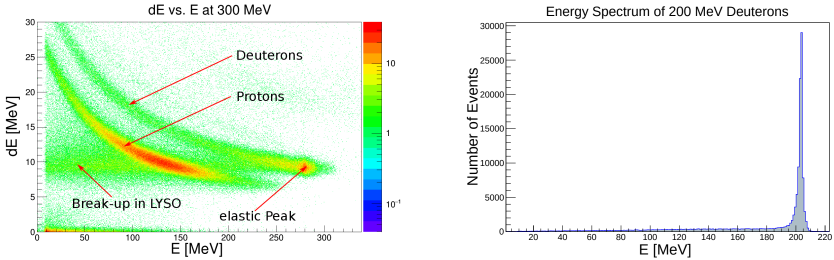
Asymmetry Cross Ratio of Power d-C Scattering at 270 MeV
Cross Ratio
Half Cross Ratio Up
|Half Cross Ratio Down|
ϵ_{CR}
Θ_{Lab} [deg]



Vector Analyzing of Power d-C Scattering at 270 MeV
A_y from Cross Ratio
A_y from Half Cross Ratio Up
A_y from Half Cross Ratio Down
Satou et al.
A_y
Θ_{Lab} [deg]



Vector Analyzing Power, Deuteron Scattering at 270 MeV
C 10mm
C 5mm
Al 5mm
Mg 5mm
Si 5mm
C by Y. Satou et al.
A_y
Θ_{Lab} [deg]
PRELIMINARY



Conclusions from LYSO II Experiment

- New LYSO SiPM modules work fine
- Promising results for vector analyzing power
- Targets other than carbon might be used for polarization measurement
- dE vs. E spectra allow a good particle identification

Summary

- Precise measurement of the polarization buildup is needed for EDM investigation
- Ongoing activities towards dedicated polarimeter development:
  - WASA experiment to create a database of polarized observables
  - Development of a new LYSO based polarimeter
- Variety of beam energies and target materials tested to find the optimum operation setting for a future polarimeter

Plans for the Future

- Building a 48 crystal LYSO polarimeter that will be installed in the COSY ring
- Measure the spin precession using WASA and the LYSO polarimeter simultaneously (see talk HK24.3 Martin Gaißer)