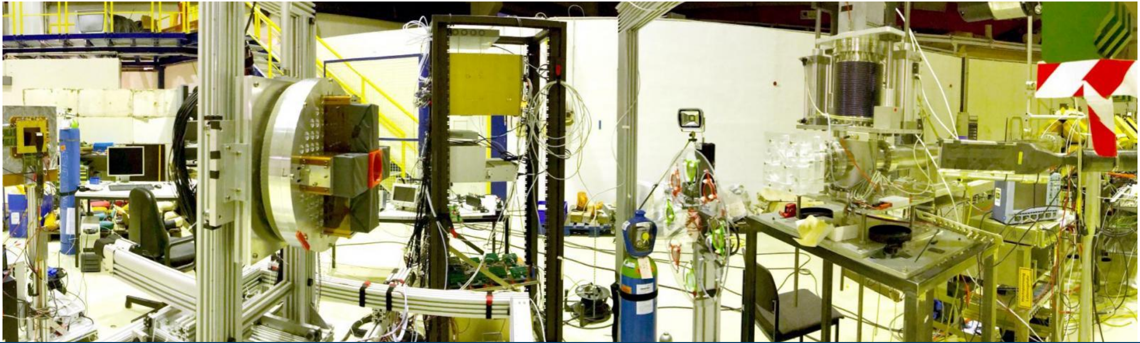


EDM POLARIMETER DEVELOPMENT AT COSY

for the JEDI Collaboration

23th August 2018, GGSWBS'18 | Fabian Müller | IKP 2

ELECTRIC DIPOLE MOMENT

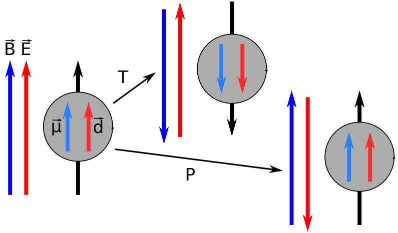
Electric **D**ipole **M**oment (EDM): $\vec{d} = d\vec{S}$
Magnetic **D**ipole **M**oment (MDM): $\vec{\mu} = \mu\vec{S}$

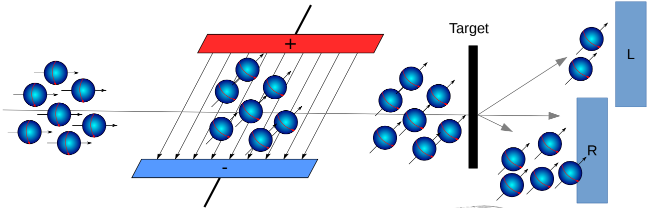
$$H = -d\vec{S}\cdot\vec{E} - \mu\vec{S}\cdot\vec{B}$$

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

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

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





Simplified EDM measurement procedure

- Horizontally polarize deuteron
- Horizontal $\vec{E}$-Field creates vertical spin build-up
- Elastic scattering creates asymmetry proportional to vertical polarization
- EDM is proportional to polarization build-up

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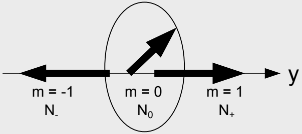
POLARIZATION

Definition

Polarization: statistical measure for the spin distribution



- Deuteron is a Spin-1 particle
  → Three spin states possible: N_-, N_0 and N_+
- Vector Polarization:

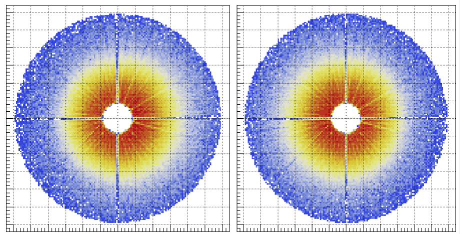
$$P_y = \frac{N_+ - N_-}{N_+ + N_0 + N_-} = p_+ - p_-$$

- Tensor Polarization:

$$P_{yy} = \frac{N_+ - 2N_0 + N_-}{N_+ + N_0 + N_-} = 1 - 3p_0$$

Definition

Analyzing Power: property of a target material (e.g. carbon) that describes the asymmetric pattern in a elastic scattering experiment.



dC scattering at 270 MeV, left pol-up, right pol-down

POLARIMETER CONCEPTS

Fundamental Polarimetry Concept

Measure Asymmetry ϵ of elastic scattering $\rightarrow$ with known Analyzing Power A_y calculate Polarization P_y

Polarimetery Basic Principle

- Polarized Cross Section:

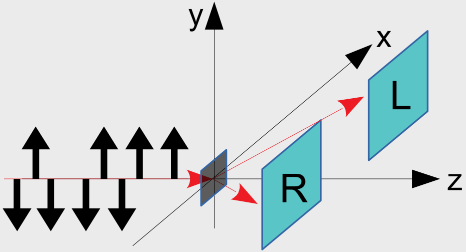
$$\sigma_{pol}(\Theta) = \sigma_{unpol}(\Theta)[1 + \frac{3}{2}P_y A_y(\Theta)\cos(\Phi)]$$

- Asymmetry ϵ:

$$\epsilon = \frac{3}{2}P_y A_y$$

$$\epsilon = \frac{N_+ - N_-}{N_+ + N_-} = \frac{N_L - N_R}{N_L + N_R}$$

Asymmetry Measurement

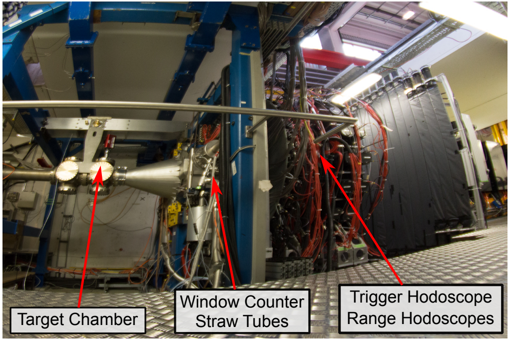


Asymmetry measurement scheme

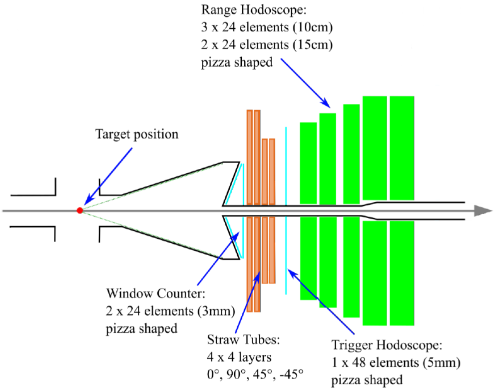
MEASURE ANALYZING POWER WITH WASA

Analyzing Power

Knowledge of the Analyzing Power A_y for the energies of interest is the key for polarimetry!

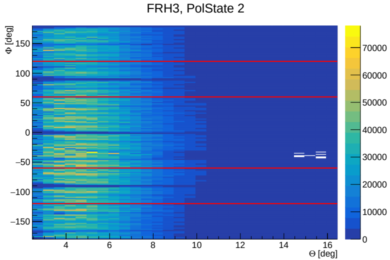


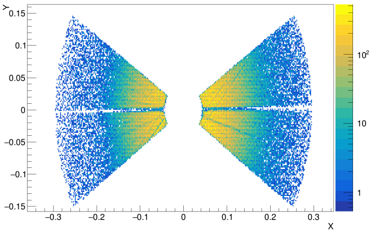
WASA forward detector at COSY



WASA detector scheme

MEASURE ANALYZING POWER WITH WASA





Event distribution of 270 MeV deuterons off dC scattering for spin-state 2 = spin-down

Asymmetry vs. Cross Ratio

- $\epsilon = \frac{3}{2} P_y A_y$
- Asymmetry method:
  - $\epsilon = \frac{N_+ - N_-}{N_+ + N_-}$

  $\rightarrow$ Can be used if the acceptance is the same in both sides of the detector
- Cross Ratio ϵ_{CR}:
  - $\epsilon_{CR} = \frac{\sqrt{N_-^L N_+^R} - \sqrt{N_+^L N_-^R}}{\sqrt{N_-^L N_+^R} + \sqrt{N_+^L N_-^R}}$

  $\rightarrow$ Since acceptance cancels out, can be used for “non-perfect” detector
- $N_{+,-}^{L,R}$: Integrated number of counts in the left/right detector side for spin-up/spin-down polarization, respectively
- Each event is weighted by its ϕ angle

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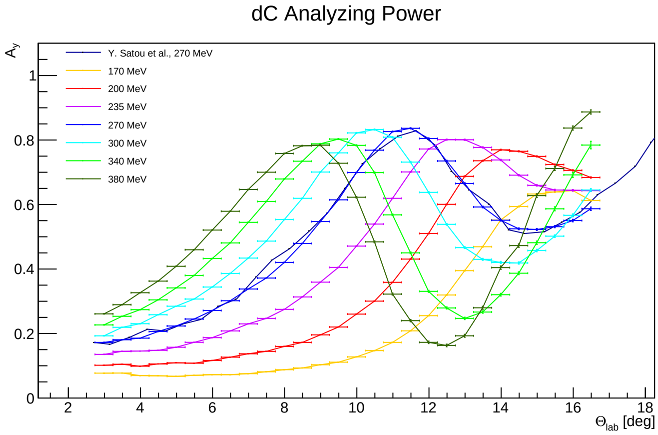
MEASURE ANALYZING POWER WITH WASA

WASA Database Experiment

- Deuteron beam for 7 energies (170 MeV - 380 MeV)
- 3 Polarization states for vector polarization (up, down and unpolarized)
- Carbon and CH_2 target
- Measured the dC asymmetry for all energies
- Normalized using measurement by Satou et. al

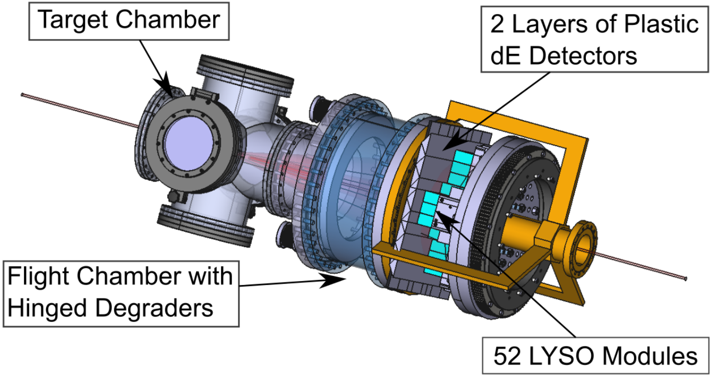


Analyzing power for beam energies from 170 MeV to 380 MeV

LYSO BASED POLARIMETER DEVELOPMENT

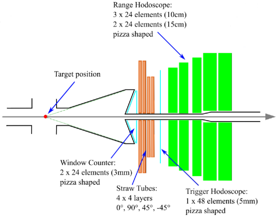
Advantages of the LYSO polarimeter

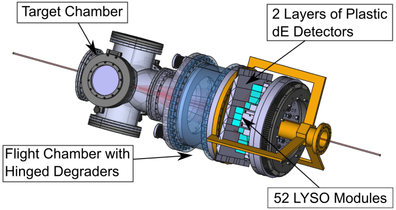
- Simple construction:
  - → No strong $\vec{E}$ and $\vec{B}$ fields
  - → Only two detection layers
- Modular setup:
  - → Modules can be easily rearranged
- Long term stability:
  - → LYSO is a radiation hard scintillator
- High accuracy:
  - → LYSO + SiPM modules have a high resolution
  - → Plastic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



Model of the full EDM polarimeter built from LYSO detector modules

POLARIMETER COMPARISON





WASA detector

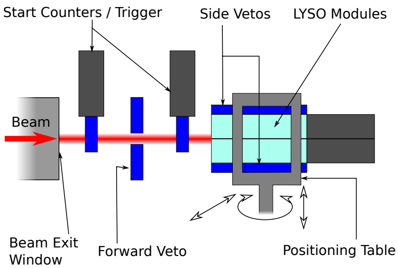
- ⊕ Know & well served machine
- ⊕ Monte-Carlo simulation available
- ⊕ Large Θ-acceptance angle ($2^\circ - 20^\circ$)
- ⊖ Multi-layer structure renders analysis complicated
- ⊖ Dead (non-scintillating) material reduces acceptance & resolution
- ⊖ Detector was not designed to be a polarimeter

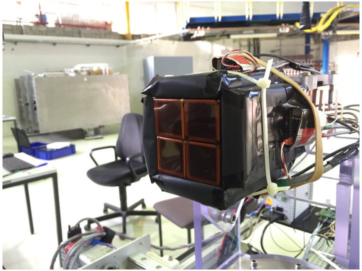
LYSO polarimeter

- ⊕ Designated Polarimeter
- ⊕ Two-layer only design
- ⊕ Modular & compact
- ⊕ Minimal amount of dead material ($<$ 1mm wrapping of the modules)
- ⊖ Monte-Carlo simulation not fully available (yet)

HISTORY OF LYSO POLARIMETER DEVELOPMENT

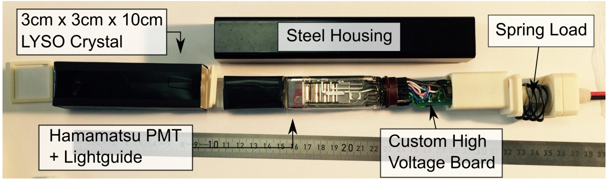
1^{st} Iteration



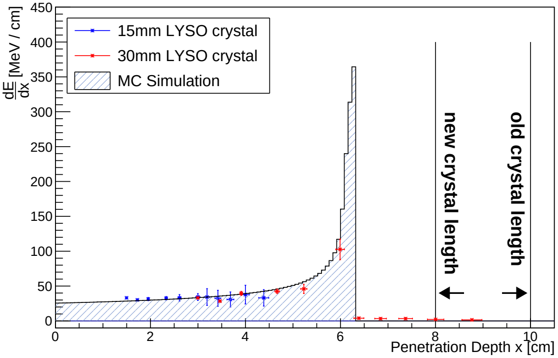


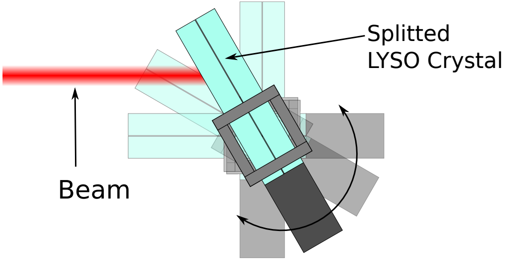
1^{st} Iteration

- 4 Modules were tested
- PMTs + 10cm LYSO crystals were used
- First experiment with SiPMs



RESULTS I



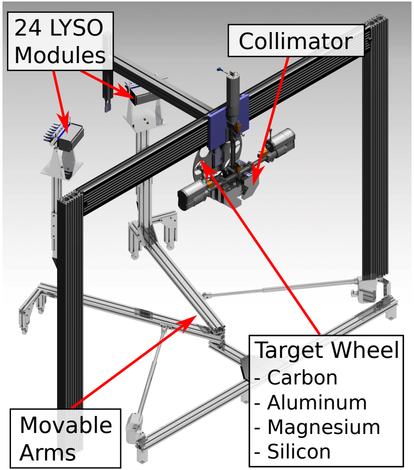


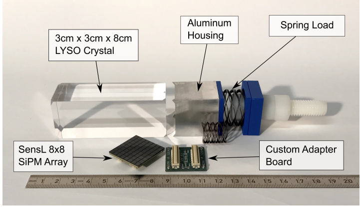
Bragg Peak at 270 MeV

- Rotating split LYSO crystal $\rightarrow$ dE as a function of the penetration depth x_n
- $\frac{dE}{dx} = \frac{dE_{x_n} - dE_{x_{n-1}}}{x_n - x_{n-1}}$
- Measurement is in alignment with the simulation
- 8 cm of LYSO crystal is enough to stop 270 MeV deuterons

HISTORY OF LYSO POLARIMETER DEVELOPMENT

2^{nd} Iteration

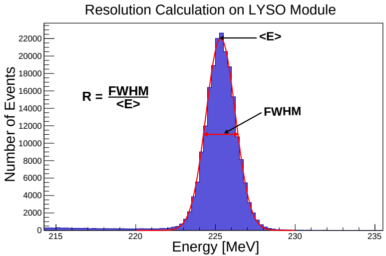


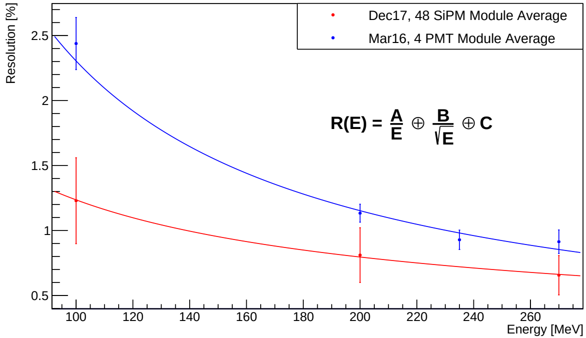


2^{nd} Iteration

- 24 Modules were tested
- SiPMs + 8cm LYSO crystals were used
- 4 different target material were tested
- Plastic scintillators in front of the modules for dE vs E plots
- Custom voltage supply for the SiPMs

RESULTS II

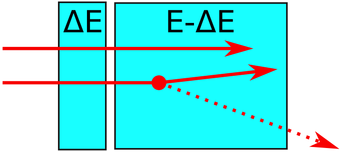


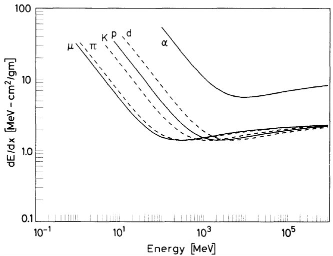


Module Resolution for Deuteron

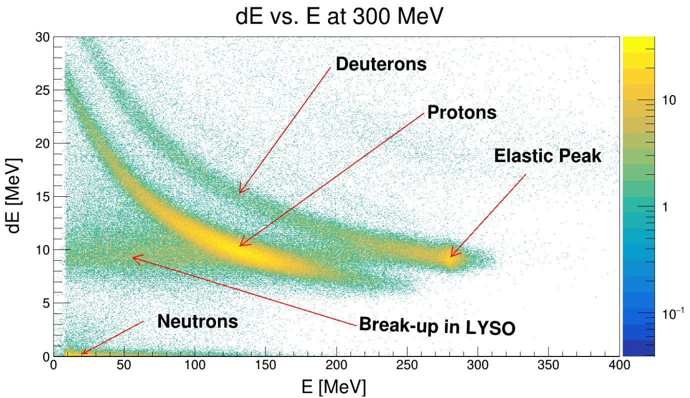
- Higher resolution $\rightarrow$ Cleaner identification of elastically scattered deuterons
- Resolution below $\sim$ 1.5% for the whole energy range
- Resolution of SiPM modules is superior to PMT modules

RESULTS II





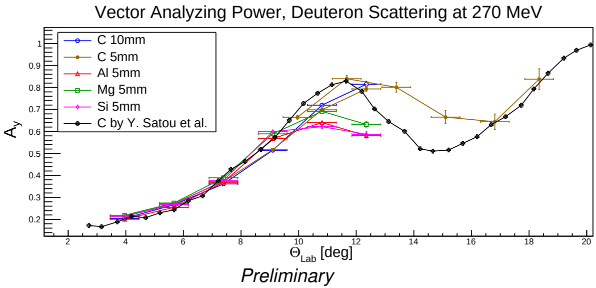
Bethe-Bloch-Plot; taken from W. R. Leo, Thechniques for Nuclear and Particle Physics Experiments

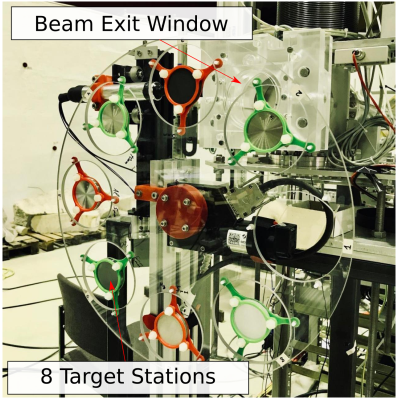


ΔE vs E plot

Particle species specific energy deposition in the each layer allows for the creation of a *Particle Identification Plot* (PID)

RESULTS II



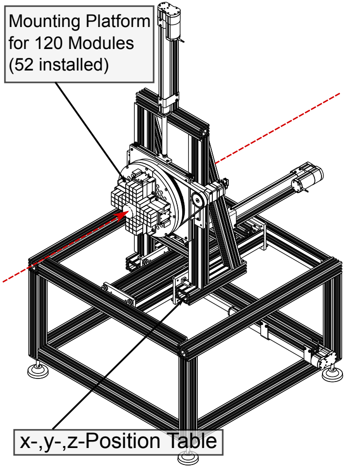


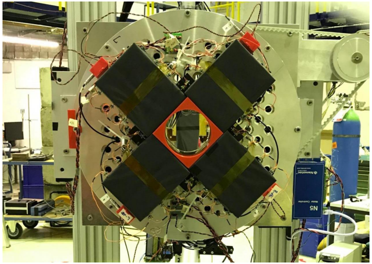
Vector Analyzing Power

- Cross ratio measured for different target materials
- Large angle coverage for dC scattering obtained by moving detector arms to different angles
- Vector analyzing power calculated using polarization measured by the *low energy polarimeter*

HISTORY OF LYSO POLARIMETER DEVELOPMENT

3^{rd} Iteration

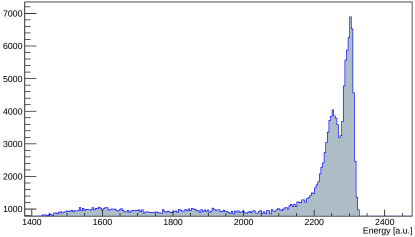




3^{rd} Iteration

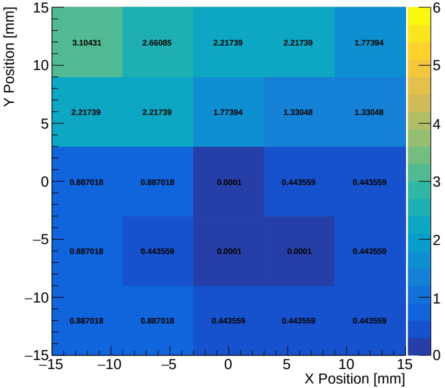
- 52 Modules were examined
- 2 types of SiPM array (SensL and KETEK)
- First tests with triangular dE scintillators
- Final mounting platform was tested

RESULTS III



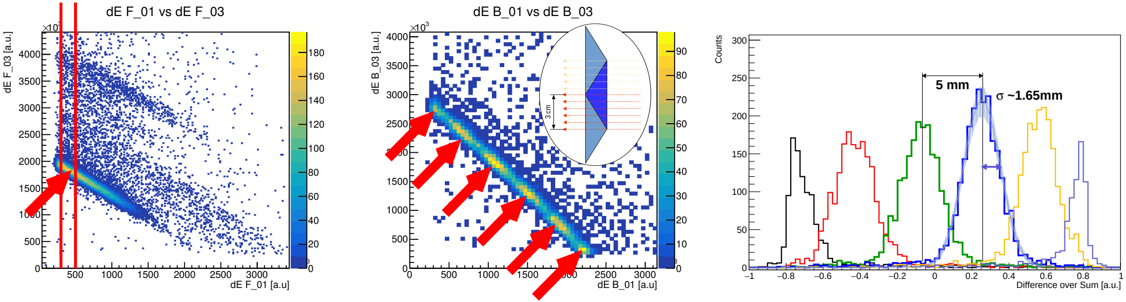
Double Peak Investigation

- Starting from 1st beamtime, a double-peak structure in the elastic peak was visible
- Behavior was not reproducible but did erratically occur
- In the latest beamtime, the double-peak spectra could be explained by inhomogeneities in the light-yield of the LYSO scintillators
- Peak position map was created for each LYSO crystal face



Relative deviation from the maximum peak position. Obtained by directing a pencil-like beam onto 25 different position of the LYSO crystal face

RESULTS III



Triangular dE Detector

- Two layers of orthogonally arranged triangular plastic scintillators will form the dE detector in front of the LYSO crystals
- Each bar is connected to a SiPM mounted on a designated pre-amp board
- position information extracted using *difference over sum*: position $\sim \frac{E_{\Delta 1} - E_{\Delta 2}}{E_{\Delta 1} + E_{\Delta 2}}$
- This detector will deliver dE information as well as the position of the particle entering the detector
- First test: spacial resolution of $\sim 5mm \rightarrow$ mayor improvement compared to the $\sim 30mm$ resolution provided by the LYSO modules

SUMMARY AND OUTLOOK

Summary

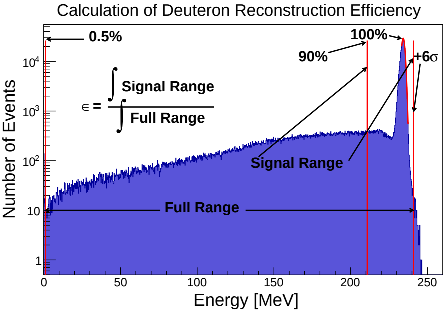
- Precise measurement of the polarization build-up is needed for EDM investigation
- Measurements of the vector analyzing power using the WASA detector provide the data to be used for the future LYSO polarimeter
- A designated LYSO based polarimeter for EDM measurement is under development
- Tests of 52 LYSO based detection modules and a polarimetry setup were performed and show promising results
- First tests on a combined position and dE detector were conducted

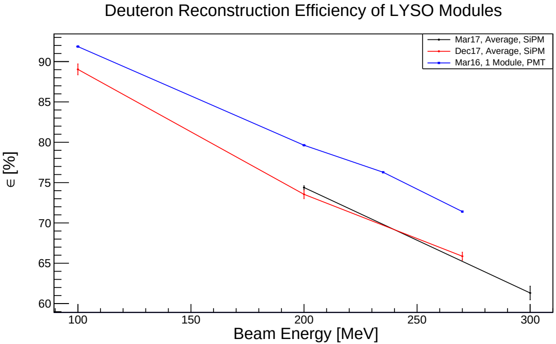
Outlook

- Further analysis of the WASA database experiment data to extract dC cross sections
- Final assembly of triangular plastic scintillator array for improved angular resolution
- Assembly of full polarimeter including target- and flight vacuum chamber
- Installation and test of the polarimeter inside of the COSY accelerator ring

BACKUP

RESULTS VI

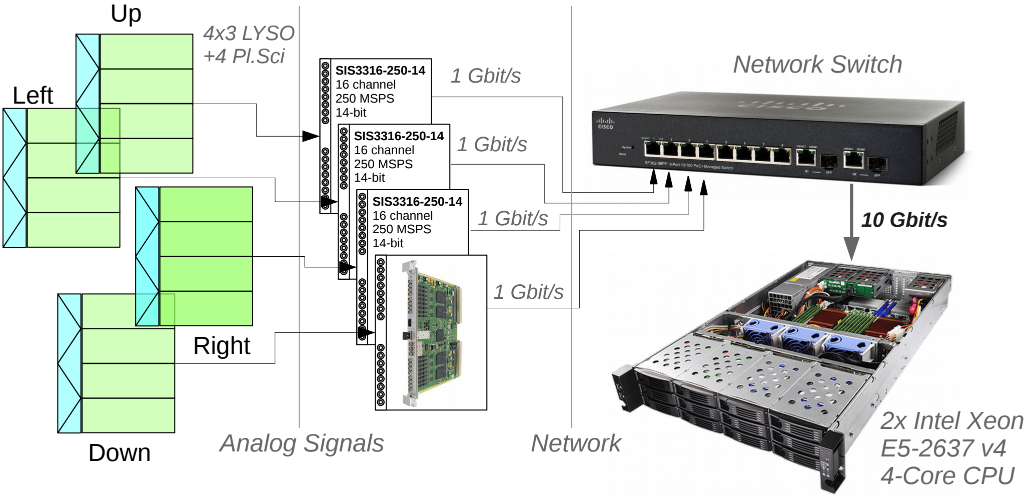




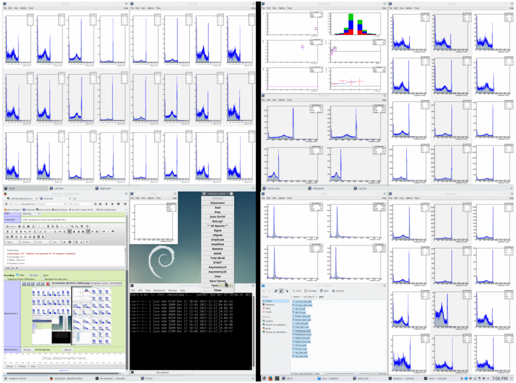
Deuteron Reconstruction Efficiency

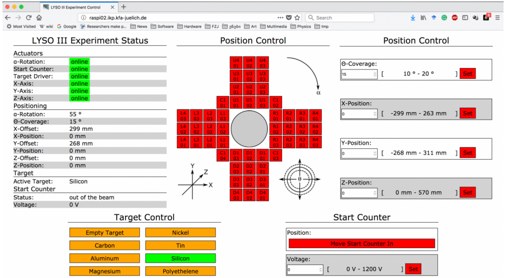
- Deuterons can break-up inside the LYSO crystal into protons + neutrons
- As they entered the scintillator as a deuteron → Can be used for asymmetry calculation
- *Deuteron Reconstruction Efficiency* describes what fraction of deuterons broke-up

DAQ SYSTEM


Up
4x3 LYSO
+4 Pl.Sci
Left
Right
Down
SIS3316-250-14
16 channel
250 MSPS
14-bit
SIS3316-250-14
16 channel
250 MSPS
14-bit
SIS3316-250-14
16 channel
250 MSPS
14-bit
1 Gbit/s
1 Gbit/s
1 Gbit/s
1 Gbit/s
Network Switch
10 Gbit/s
Analog Signals
Network
2x Intel Xeon
E5-2637 v4
4-Core CPU

DAQ SYSTEM





Slow Control & Online Analysis

- Spectra of all 52 module can be monitored online
- Online calculation of asymmetry and cross ratio
- Web interface for the slow control of the whole detector