JEDI Polarimetry

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Physics
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Outline

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Detector concept

Simulation studies

R&D Beam time @ COSY: First results

Summary & Outlook

Introduction

Where is the Antimatter in our Universe?

- One precondition for Baryogenesis: $\cancel{\mathcal{CP}}$
- Standard Model prediction: $\frac{n_B - n_{\bar{B}}}{n_\gamma} \approx 10^{-18}$
- WMAP and COBE (2012): $\frac{n_B - n_{\bar{B}}}{n_\gamma} \approx 10^{-10}$

$\Rightarrow$Not enough $\cancel{\mathcal{CP}}$ in Standard Modell

$$\mathcal{H} = -d\frac{\vec{S}}{S} \cdot \vec{E}$$
$$\mathcal{P}: \mathcal{H} = +d\frac{\vec{S}}{S} \cdot \vec{E} \qquad \boxed{d = EDM}$$
$$\mathcal{T}: \mathcal{H} = +d\frac{\vec{S}}{S} \cdot \vec{E}$$

$\Rightarrow$Electric Dipole Moments violate $\mathcal{CP}$ (assuming $\mathcal{CPT}$)

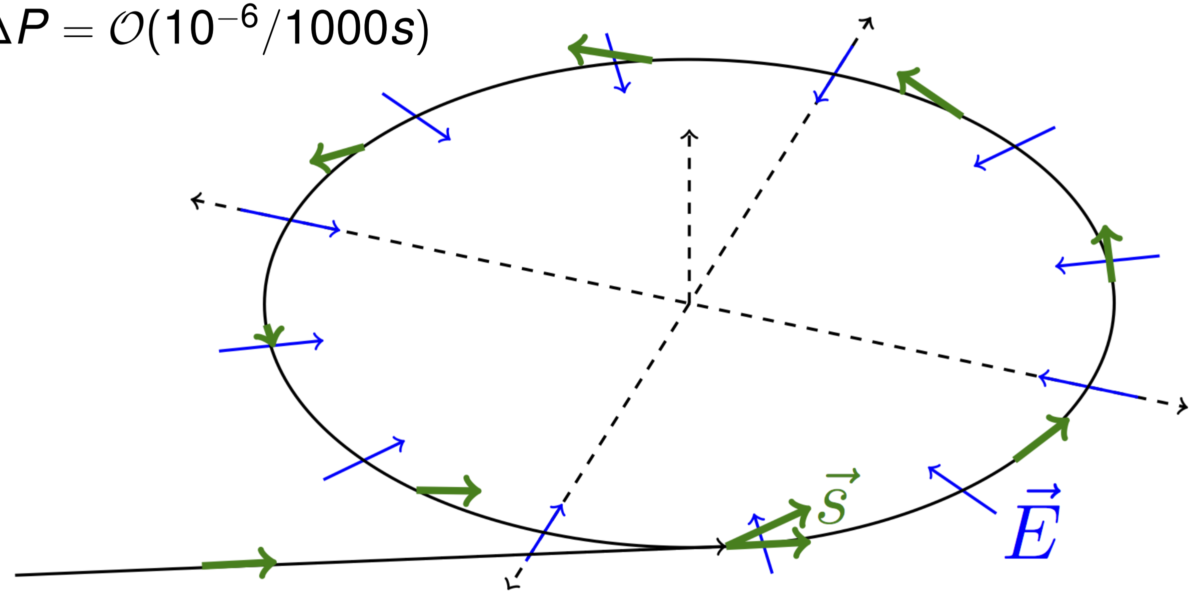
$\Rightarrow$Probe into the physics of the early universe

Charged particle EDM

- Most EDM searches measure neutron EDM. Current limit $\approx 10^{-25} e\mathrm{cm}$
- No limits for charged hadrons exist.
- Hadron EDM experiments have potentially better sensitivity.
  - Better lifetime
  - More particles
- To disentangle EDM sources, more than one measurement needed!

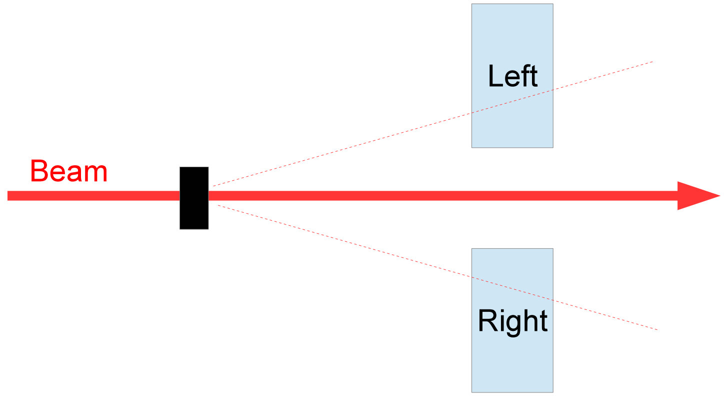
EDM search in storage rings

- All EDM experiments measure interaction between $\vec{d}$ and electric field $\vec{E}$
  - $\frac{d\vec{S}}{dt} \propto d\vec{E} \times \vec{S}$
- EDM search in storage rings: Let EDM interact with fields, wait for polarization change:
- Current candidate method for EDM search implicates a linear buildup of polarization with time at $\Delta P = \mathcal{O}(10^{-6}/1000s)$



Nuclear scattering polarimetry

- Nuclear scattering cross section for scattering of polarized particles:
  $\sigma(\theta, \phi) = \sigma_0(\theta) \cdot \left(1 + P_y A_y(\theta) \cdot \cos(\phi)\right)$
- Measure left-right asymmetries in cross section: $P_y = \frac{1}{A_y} \frac{L-R}{L+R}$
- May need to also include up, down to account for tensor polarization
- Currently using elastic deuteron-carbon scattering

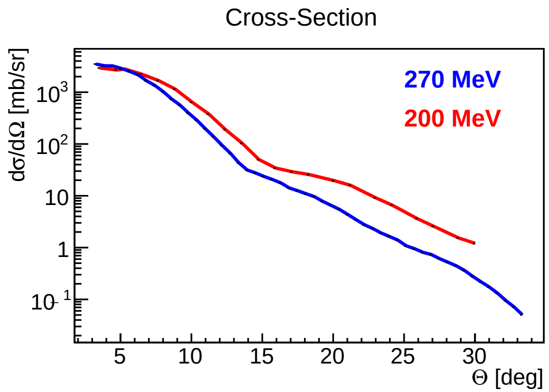


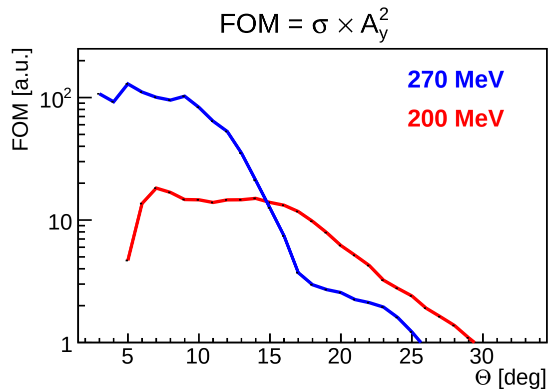
Design goals for an EDM polarimeter

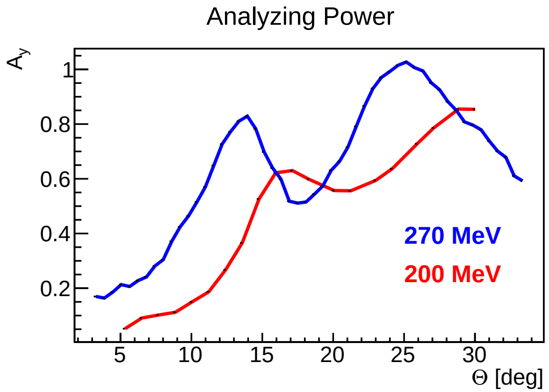
- Design goals for polarimeter:
  - Large FoM
  - Minimal influence on beam
  - High sensitivity to systematic effects
  - Good long term stability and reproducibility

Detector concept

Target choice



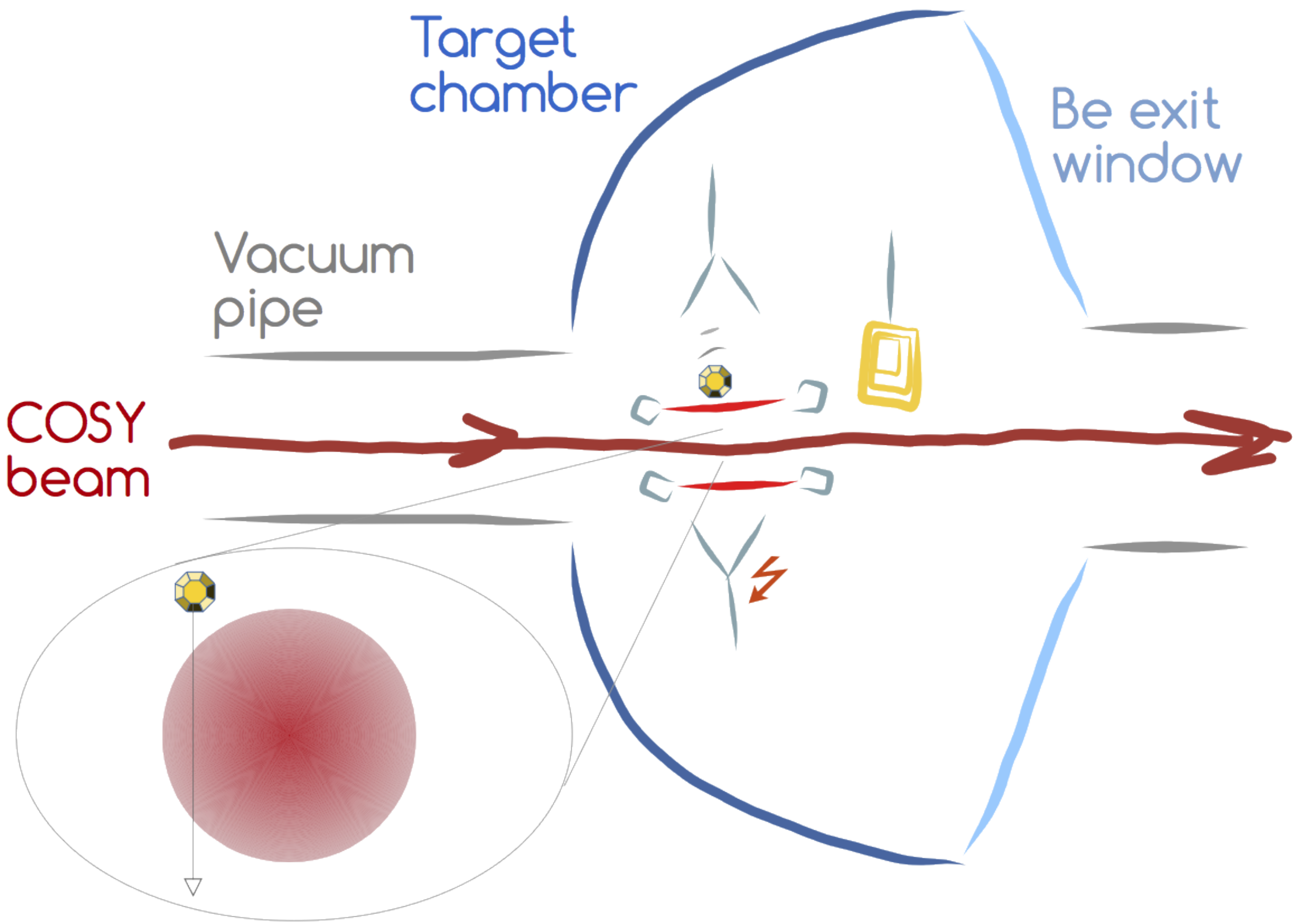




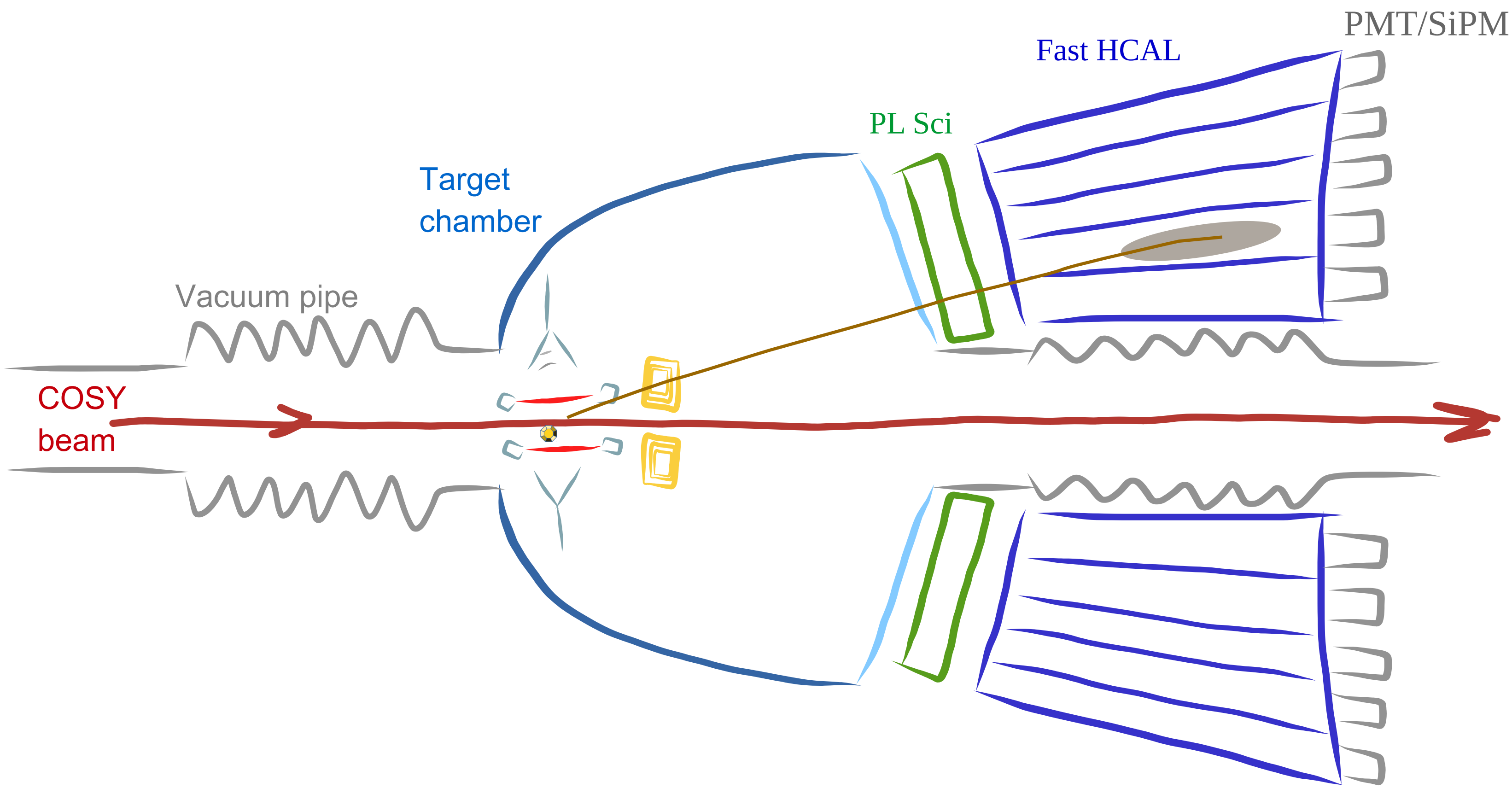
200 MeV: T. Kawabata et al. Phys. Rev. C 70, 034318
270 MeV: Y. Satou et al. Phys. Let. B 549, 307

- Carbon was chosen as working choice
- Large analysing power, high elastic cross section
- FOM for Protons also concentrated in the forward region

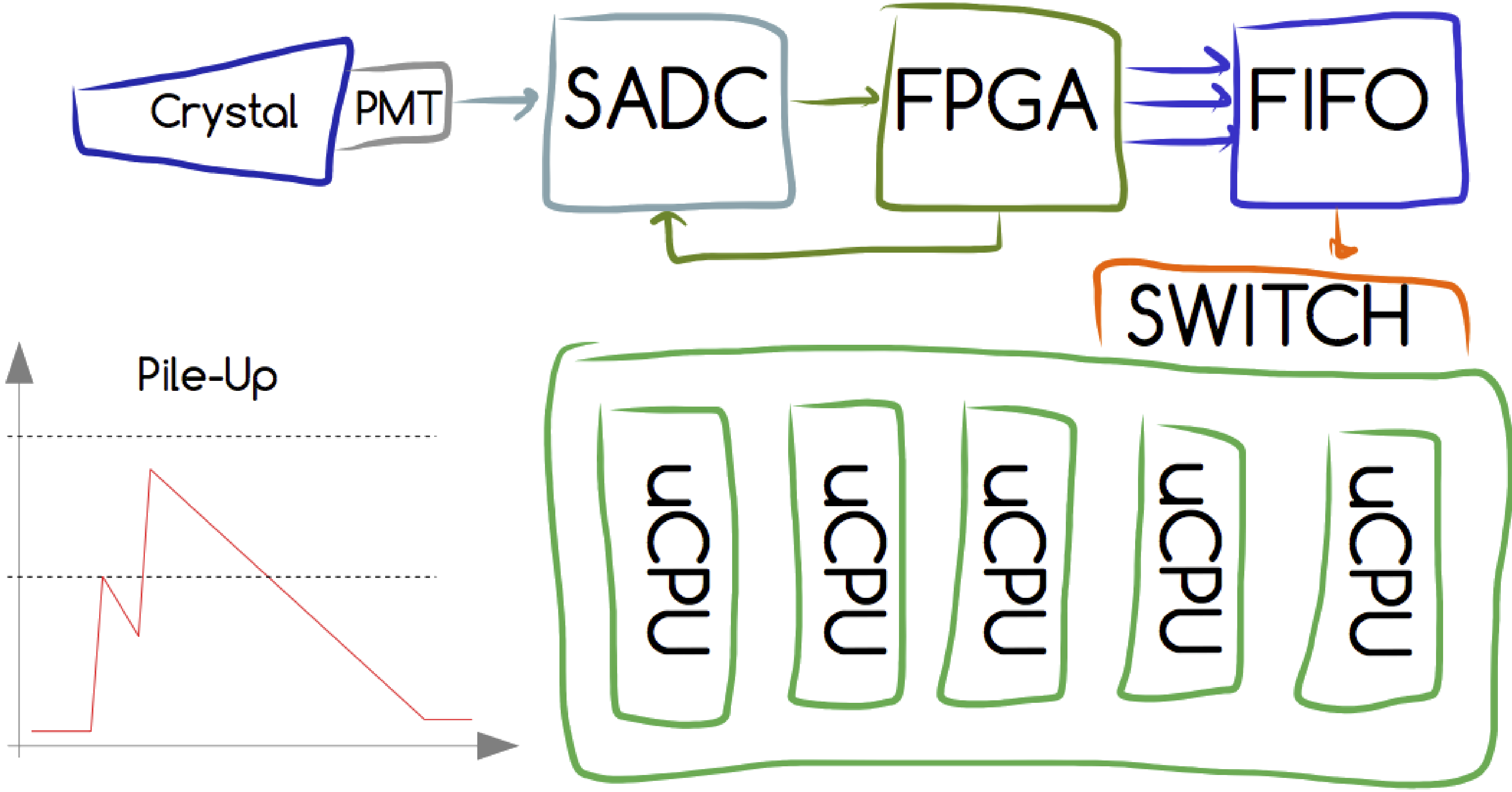
Target concept



Detector concept



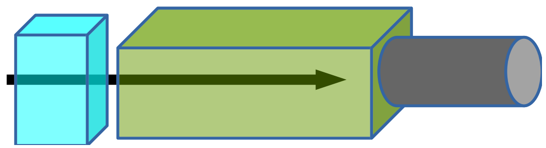
Readout concept



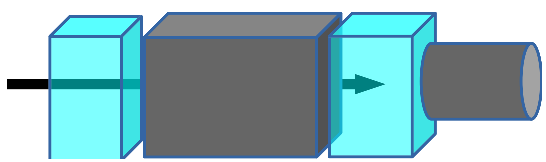
Simulation studies

HCal Candidate Materials: LYSO/Plastic Scintillator

Pl. + LYSO

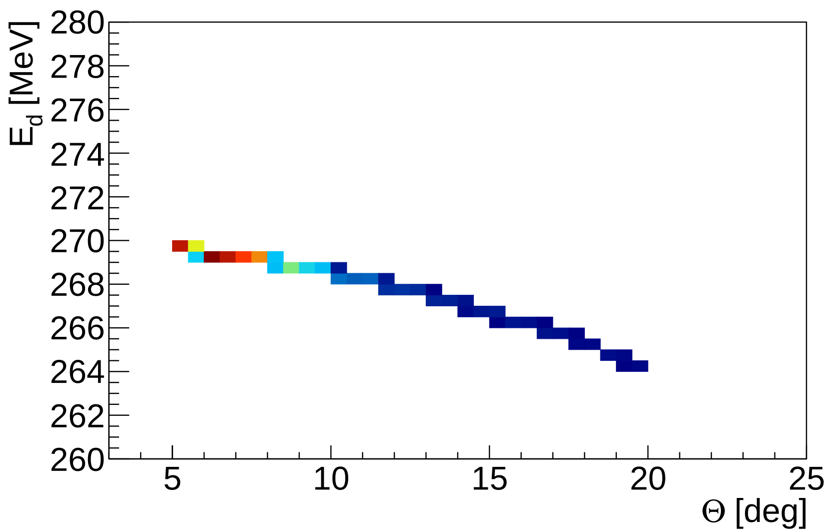


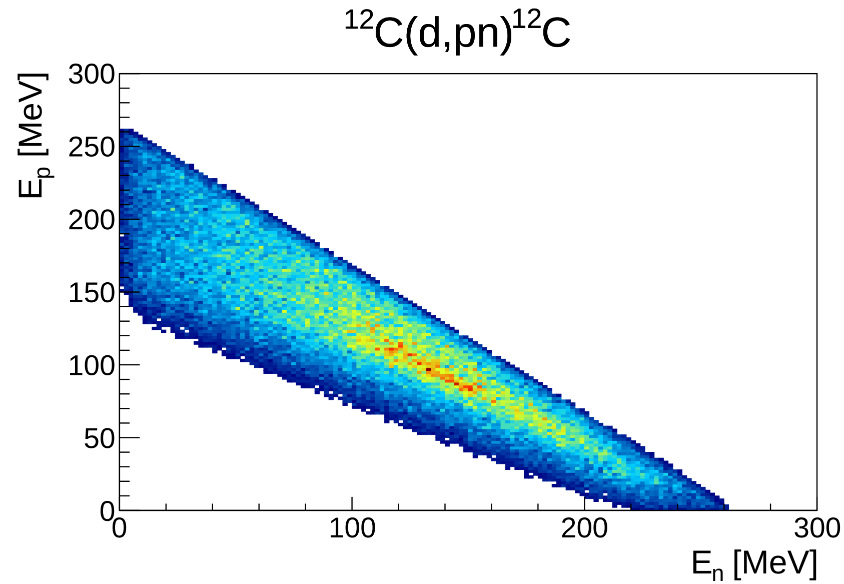
Pl. +W + Pl.



	LYSO	Plastic
Density [g/cm3]	7.3	1.05
Decay [ns]	40	2.4
L. Y. % NaI(Tl)	75	25
S. Peak [nm]	420	420
N ref.	1.82	1.58
Melt. [řC]	2050	75
Hygrosc.	No	No
Radioact	Yes	No
Cheap	No	Yes

Signal and Background





- Elastically scattered deuterons retain almost complete beam energy.
- Break-up has almost no analyzing power, so discard it
- Protons and neutrons from break-up are energetically well separated
  $\Rightarrow$Complete stop of particles provides good signal separation
- No reliable model for inelastic reactions available
  - Qualitative experiments: Inelastic reactions carry some analysing power, so maybe keep these

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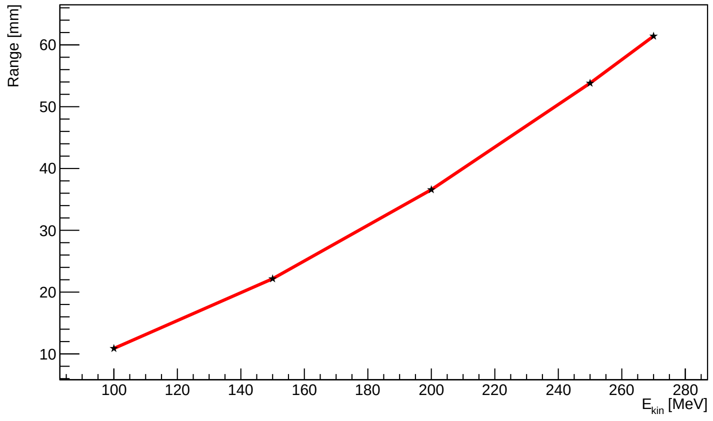
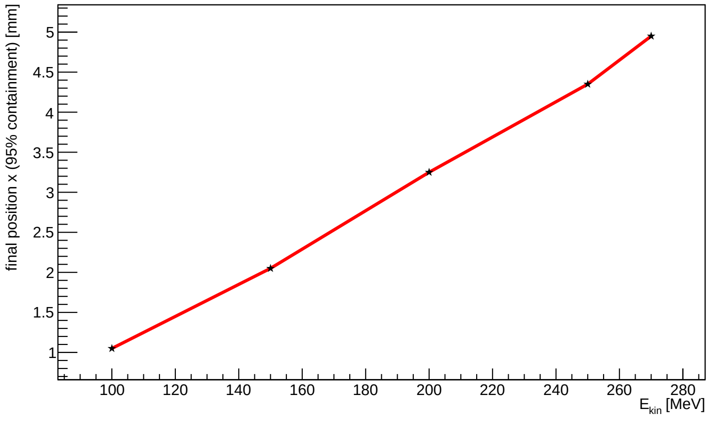
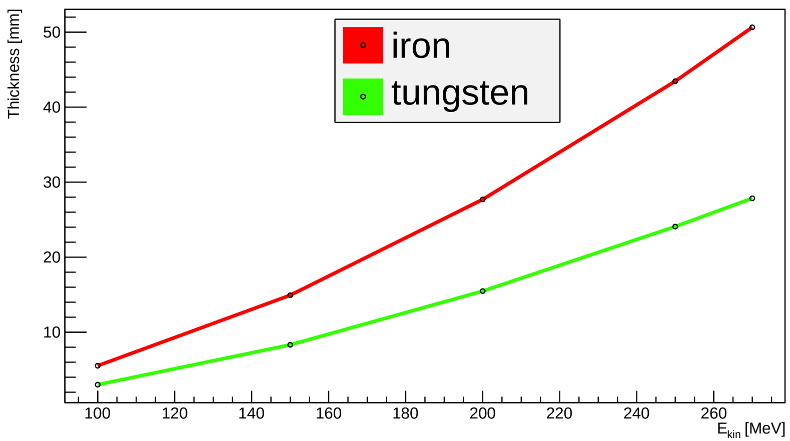
LYSO module

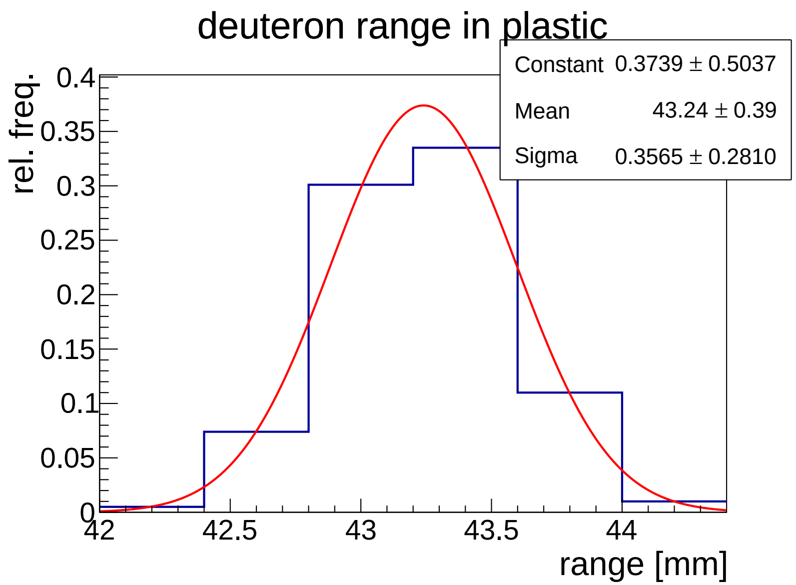




- Chosen detector size of $3 \times 3 \times 10\,\mathrm{cm}^3$as starting value

Plastic scintillators



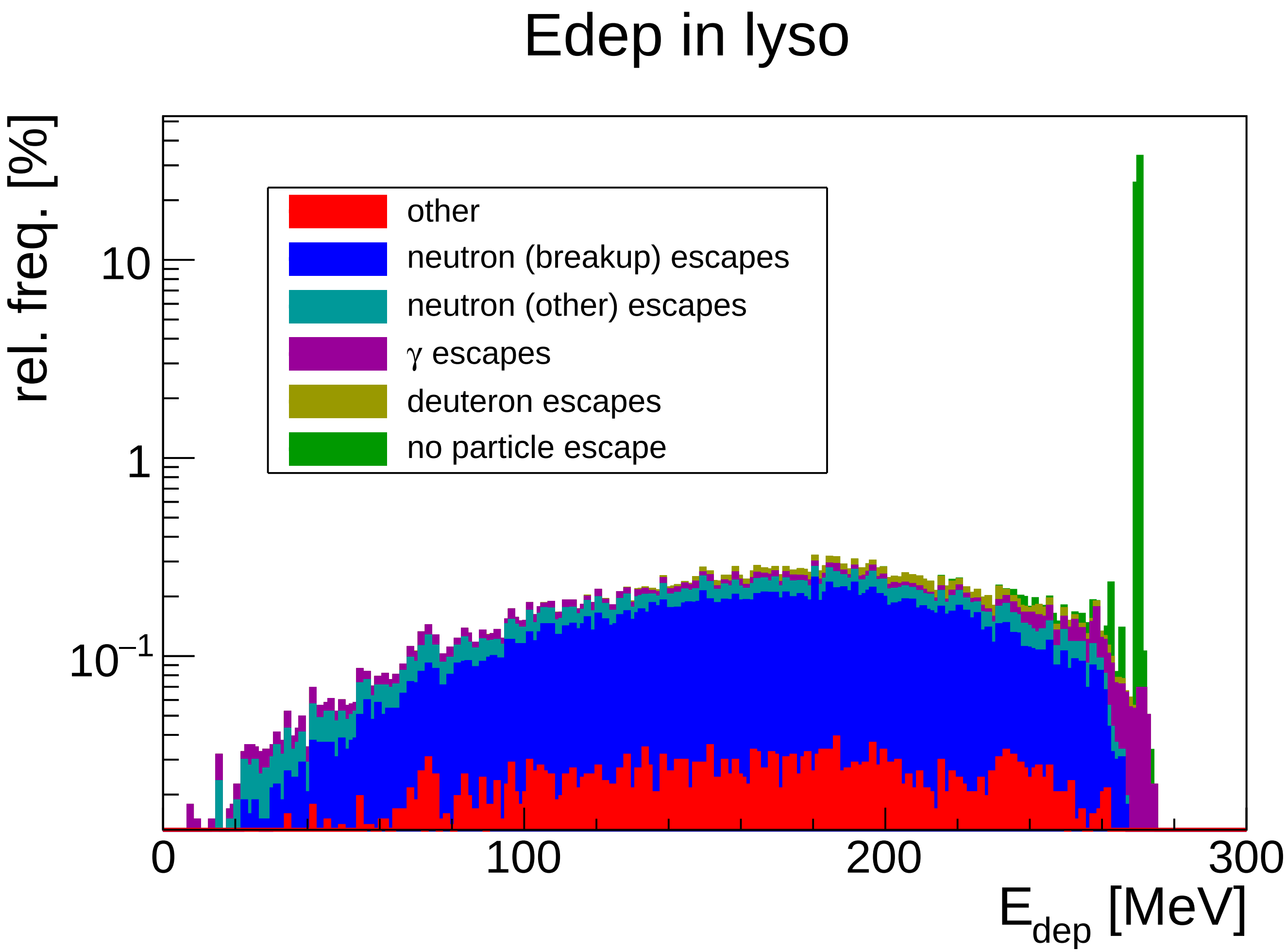


- Use absorber to suppress proton background and reduce length of plastic detector.
- Arbitrarily chosen 50 MeV as working point for calorimeter element
  - Tune thickness of absorber so that $E_{entry} = 100$ MeVfor every beam energy

Simulation setup

- Geometry: Single detector element
- Generated 100k events each at $T_d = 270\,\text{MeV}, 5^\circ < \Theta < 20^\circ$, $0^\circ < \phi < 360^\circ$
  - Signal: $^{12}C(d,d)^{12}C$
  - Background: $^{12}C(d,pn)^{12}C$
- $\mathcal{FOM} \propto \sigma_{eff} \times < A_y >^2 = (\sigma_{el}\epsilon_{el} + \sigma_{bg}\epsilon_{bg}) \times \left(\frac{A_{y,el}\sigma_{el}\epsilon_{el} + \sigma_{bg}\epsilon_{bg}A_{y,bg}}{(\sigma_{el}\epsilon_{el} + \sigma_{bg}\epsilon_{bg})}\right)^2$

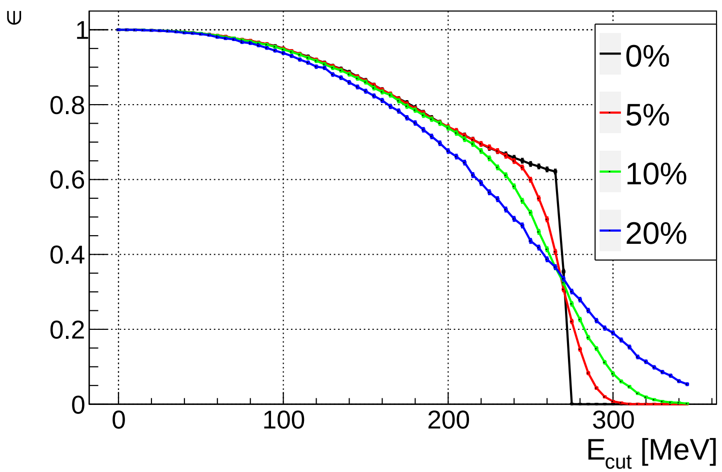
Detector response - lyso



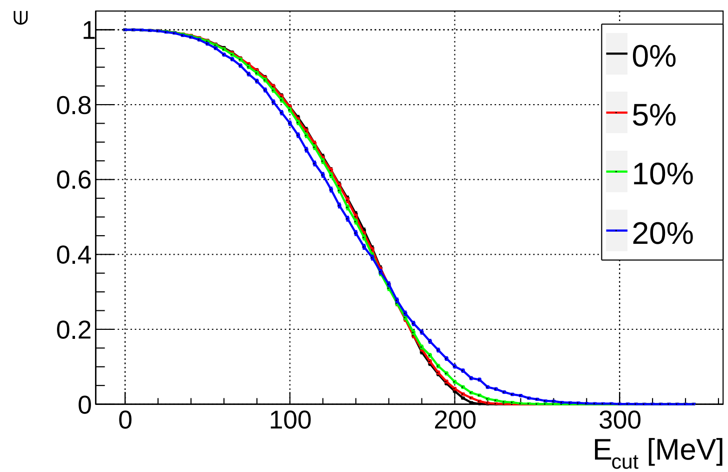
- Breakup in detector element is main cause of efficiency loss.

Detection efficiencies (lyso)

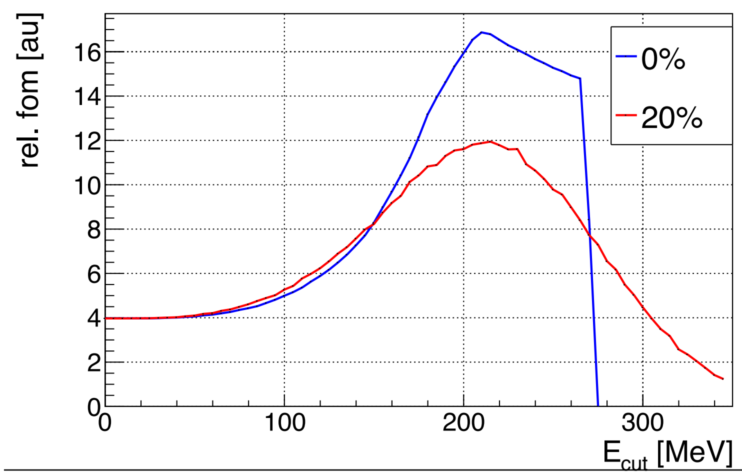
dcelastic detection efficiency in lyso



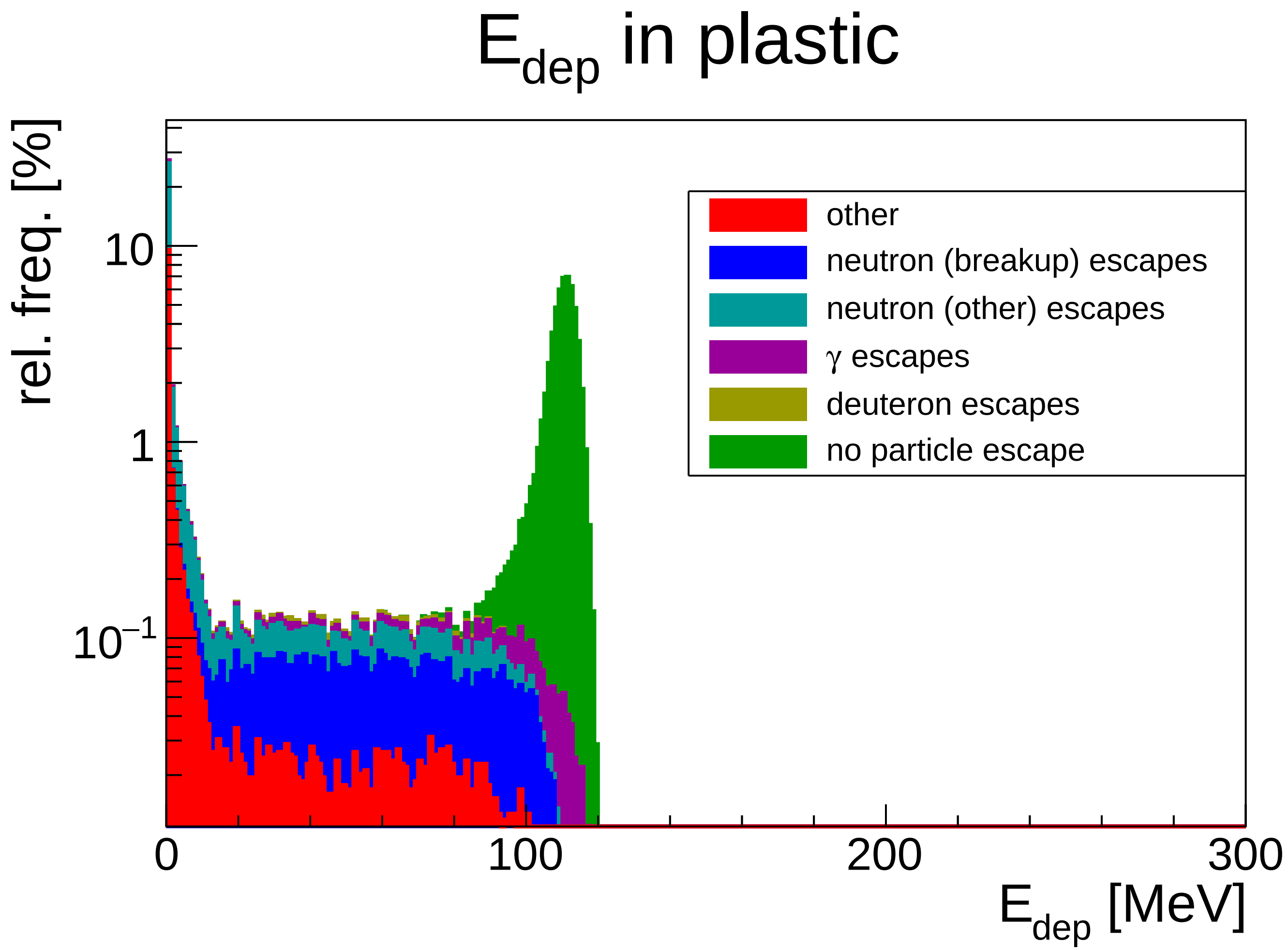
dcbreakup detection efficiency in lyso



relative fom in lyso

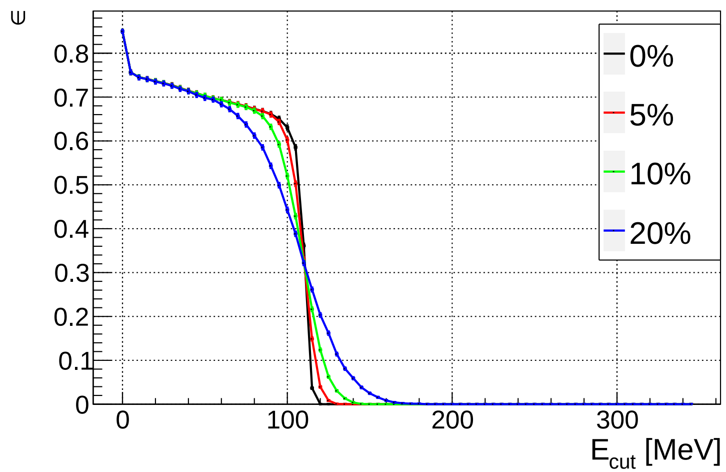


Detector response - plastic

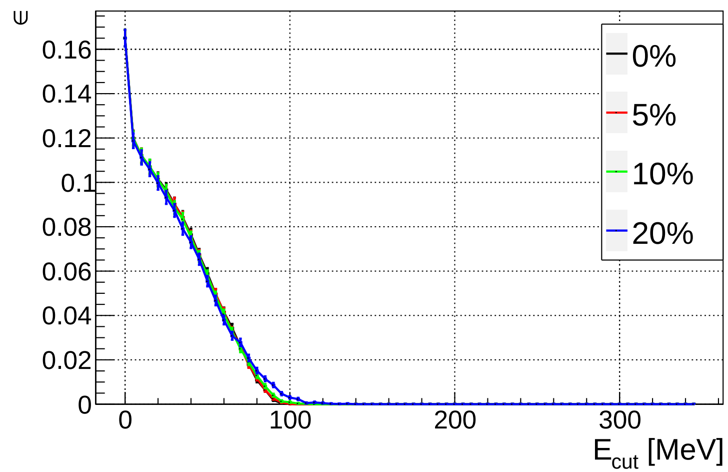


Detection efficiencies (plastic)

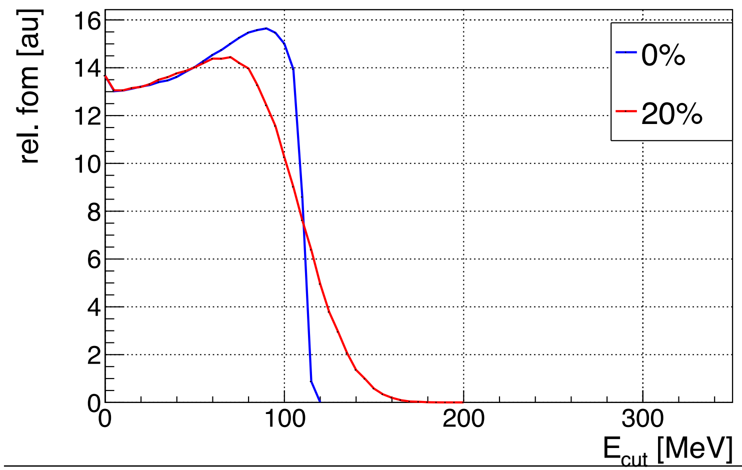
dcelastic detection efficiency in plastic



dcbreakup detection efficiency in plastic



relative fom in plastic



Simulation Results

- Main cause of efficiency loss is breakup in detector
- Maximum relative FOM:

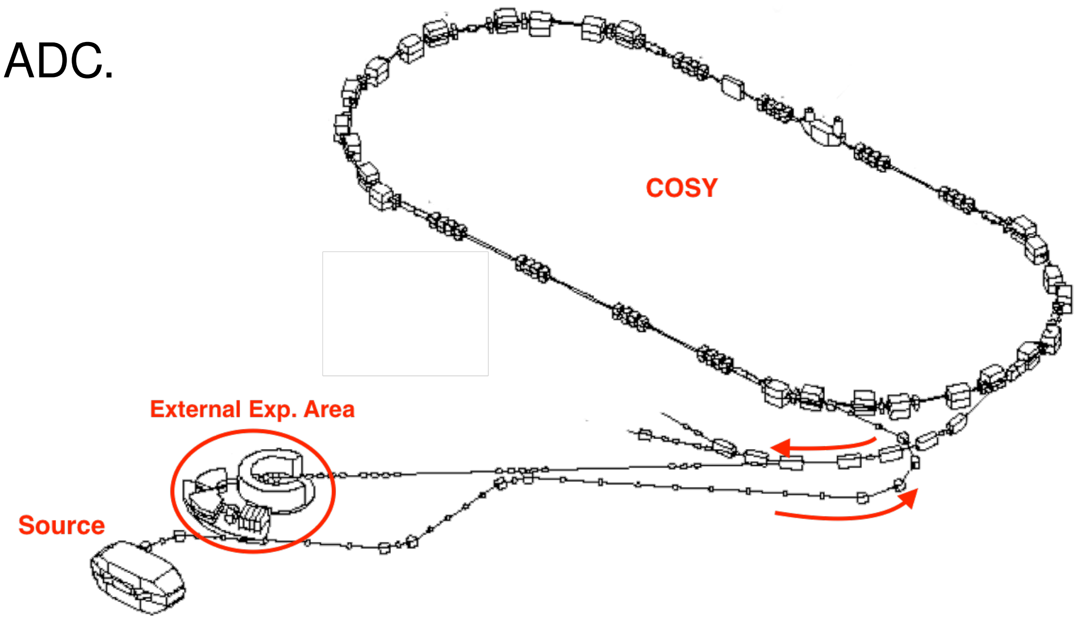
	0%	20%
Plastic	15.5	14.5
LYSO	17	12

- LYSO and plastic scintillators provide comparable performance
- Plastic scintillator performance exhibits no strong dependence on energy resolution

R&D Beam time @ COSY: First results

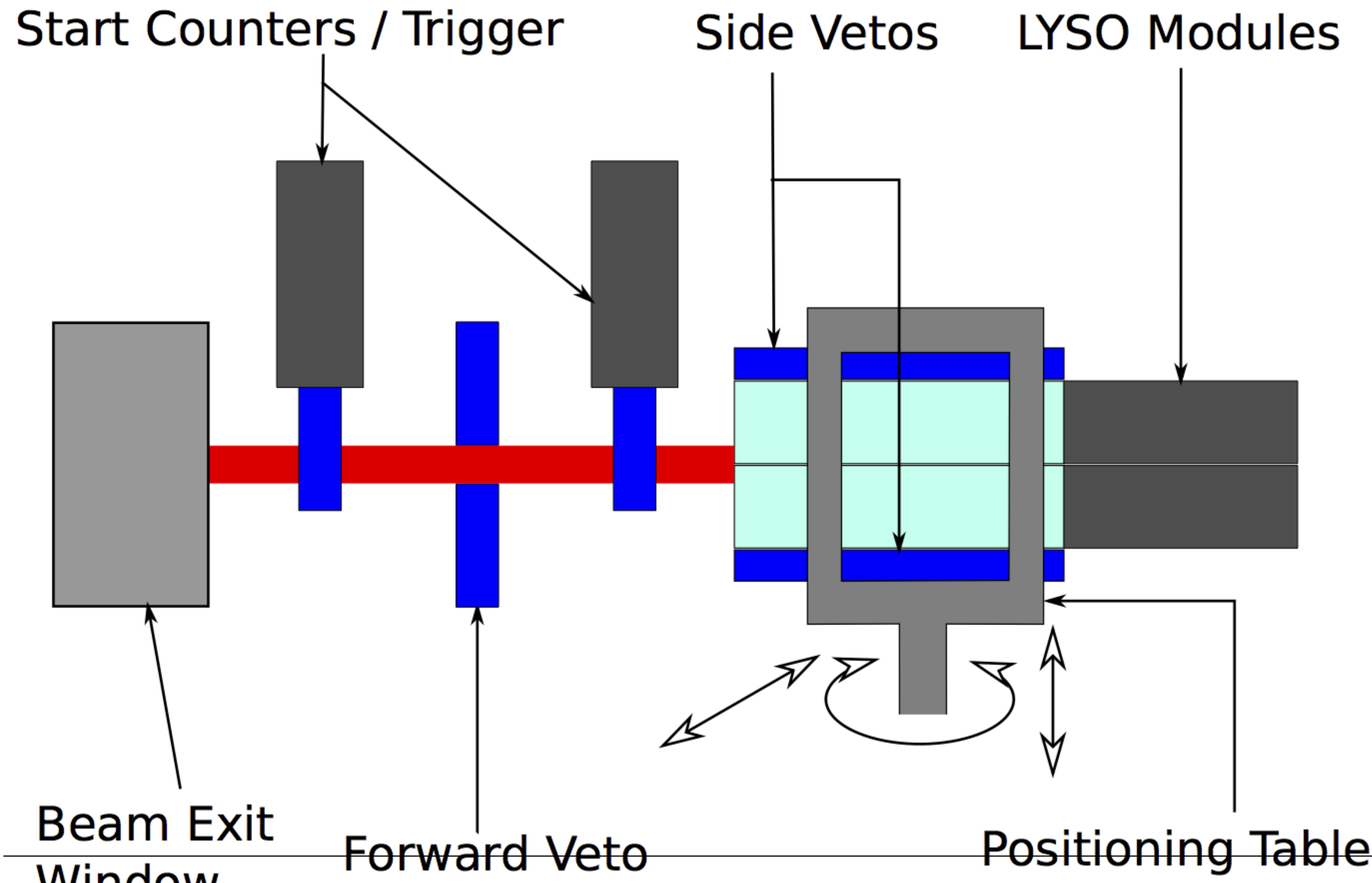
Beam time Spring 2016

- External beam at COSY in Jülich
- LYSO crystals from two different manufacturers
- PMT and Silicon Photomultiplier (SiPM).
- Deuteron beam @ 100MeV, 150MeV, 200MeV, 235MeV and 270MeV
- Struck 14 bit, 250 MS/s Flash ADC.



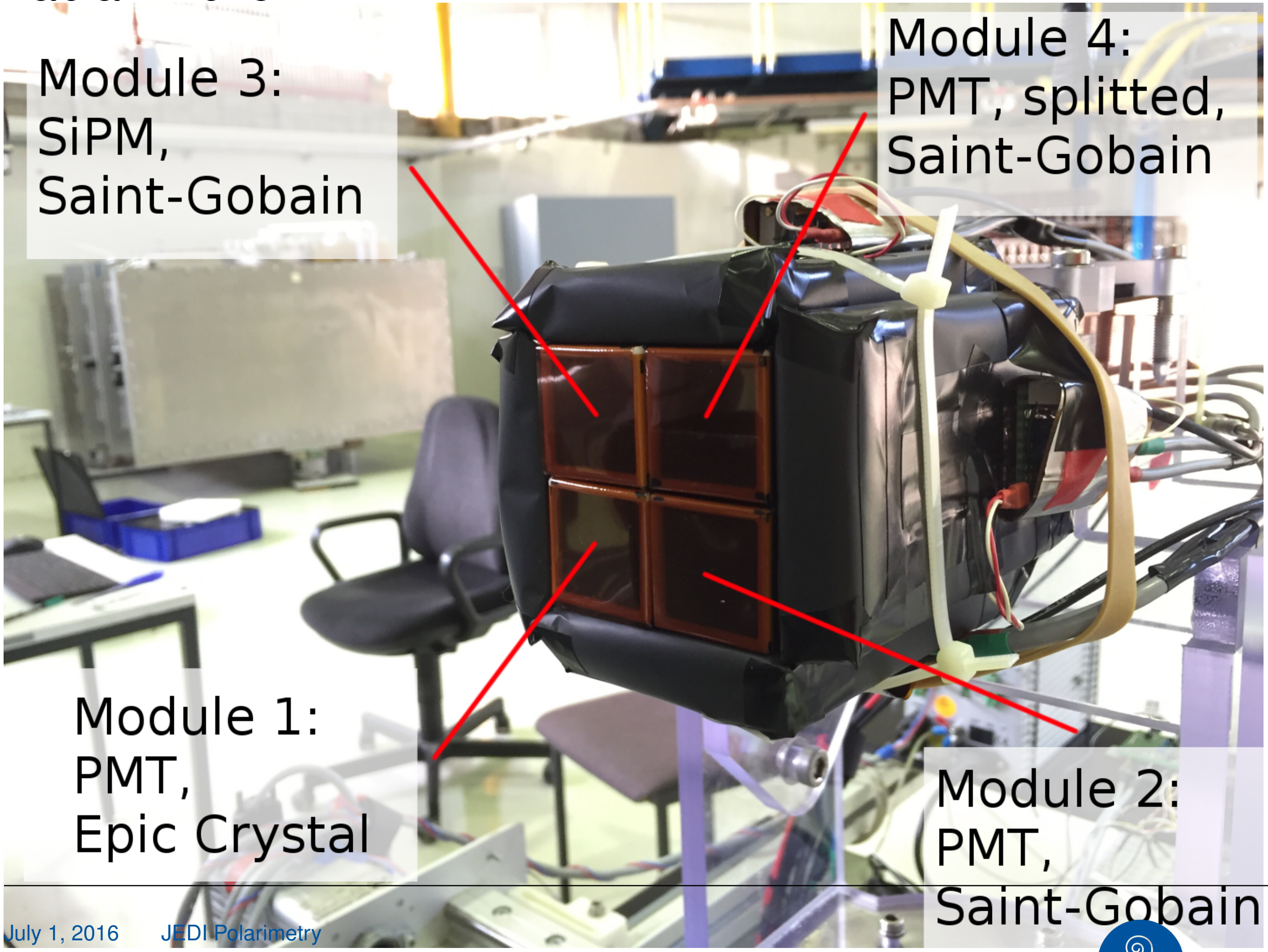
Measurement setup

Fabian Müller

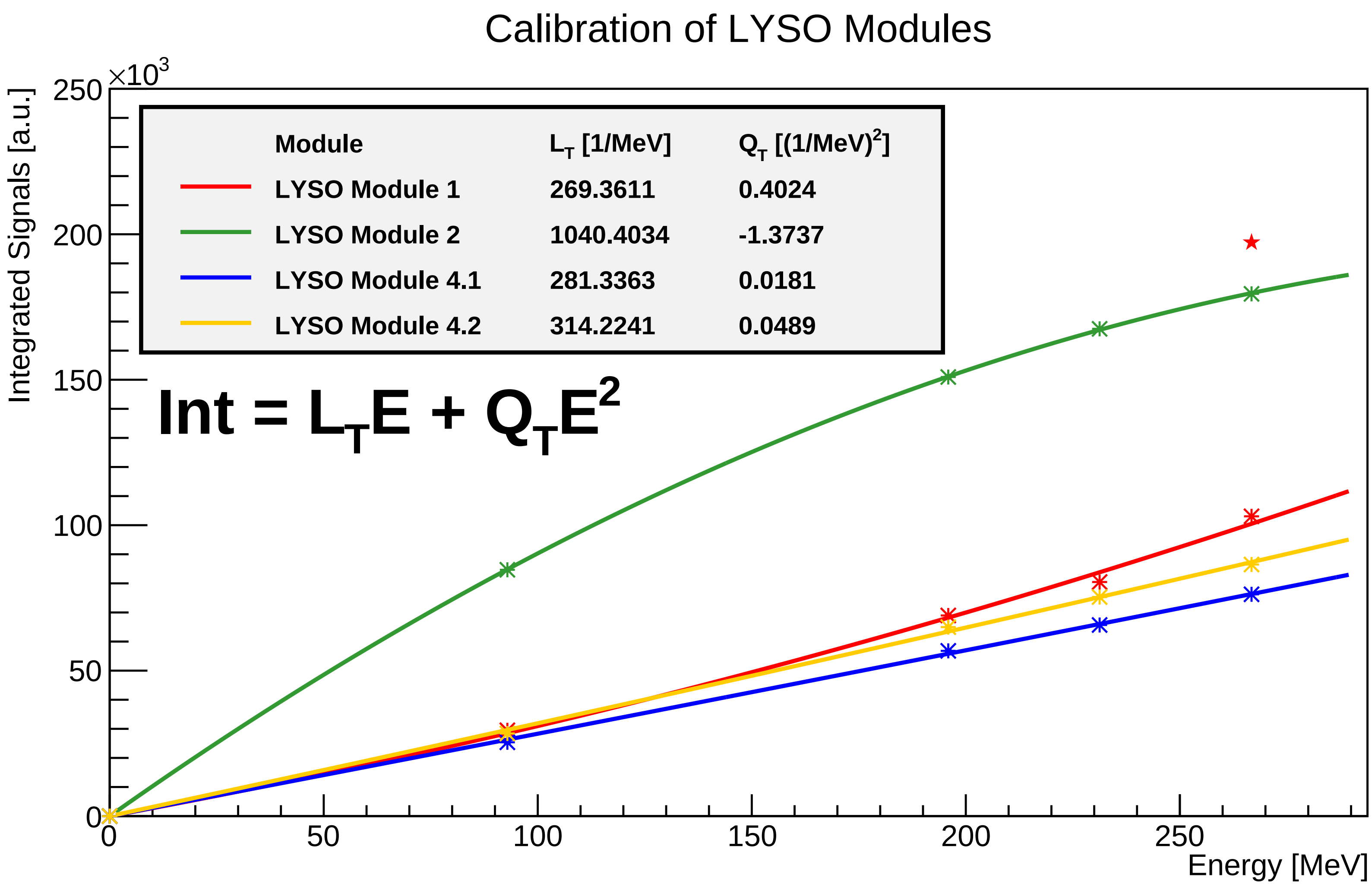


Measurement setup (cont'd)

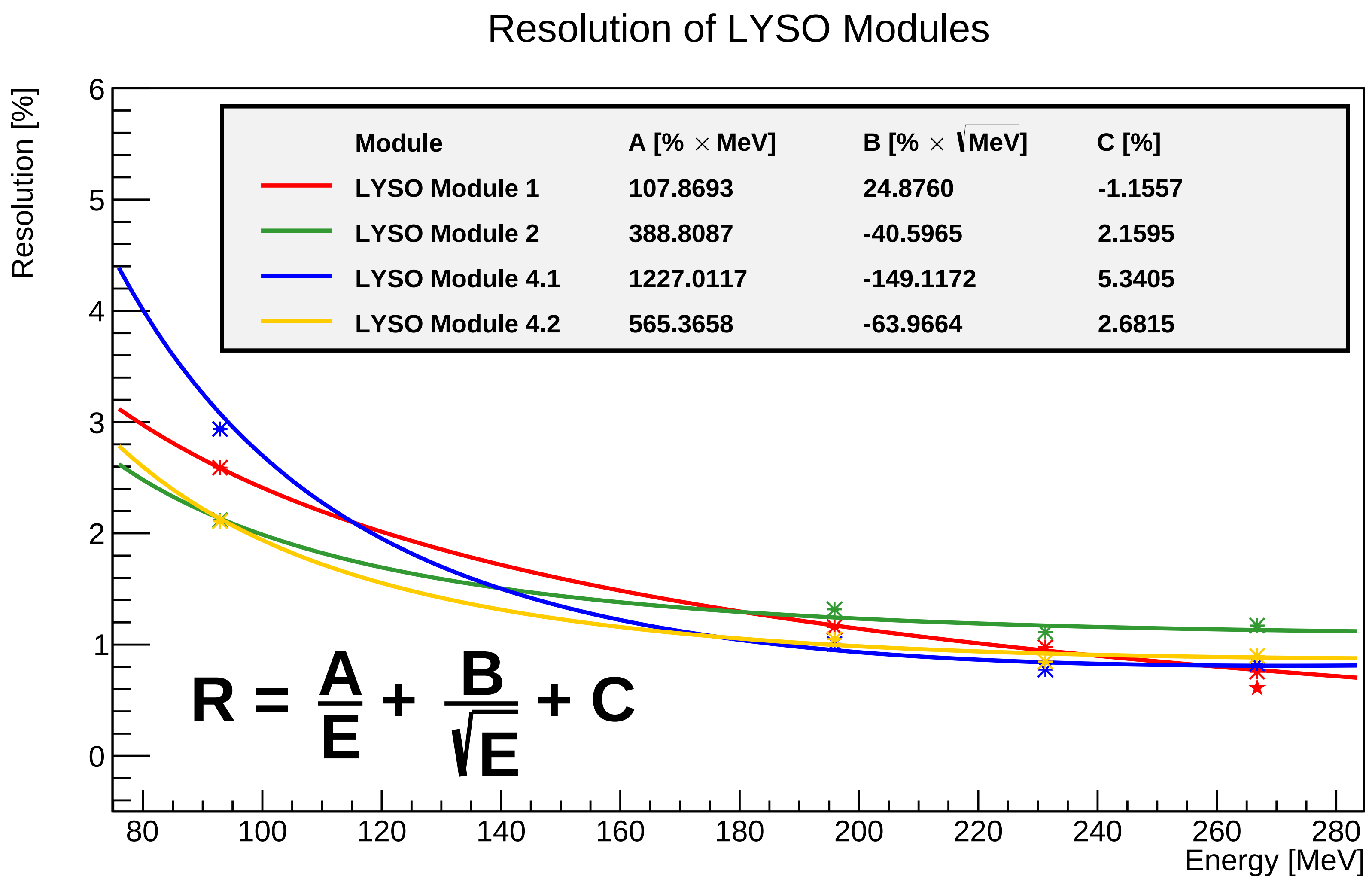
Fabian Müller



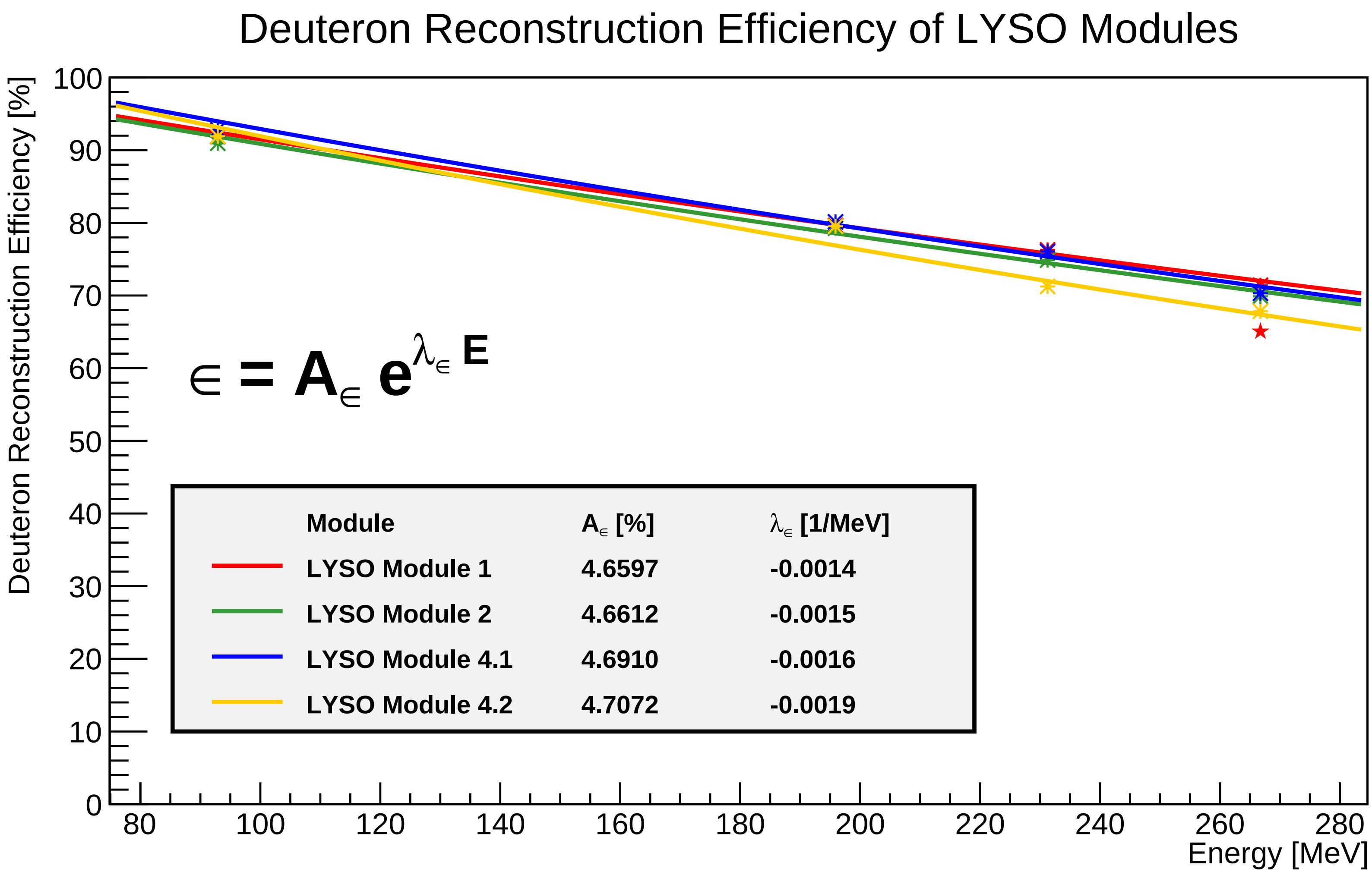
Energy calibration



Energy resolution



Efficiency



Deuteron Reconstruction Efficiency of LYSO Modules
Deuteron Reconstruction Efficiency [%]
Energy [MeV]
0
10
20
30
40
50
60
70
80
90
100
80
100
120
140
160
180
200
220
240
260
280
$\epsilon = A_\epsilon \, e^{\lambda_\epsilon E}$
Module
A_ϵ [%]
λ_ϵ [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

Measurement Results

- 5 LYSO modules succesfully commissioned, PMT and SiPM readout tested
- Calibration curve exhibits considerable nonlinearity
- Energy resolution between 1% and 4%
- Deuteron reconstruction efficiency above 70%

Summary & Outlook

Summary

- We have a candidate layout for JEDI polarimeter
- Simulations suggest promising performance
- A deuteron beam with five different energies up to 270MeV was used to examine the prototype LYSO modules
- The resolution of the LYSO modules was better than 3%
- A deuteron reconstruction efficiency over 65% have been achieved in the whole energy spectrum
- The SiPM readout promises good results without the need for an active amplification circuit and high voltage

Outlook

- Theoretical calculations for signal and background cross sections and analyzing powers are under progress and will be included in simulation.
- Next beamtime will include a greater number of crystals and test polarization measurements