Monte Carlo simulations for the JEDI polarimeter at COSY

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JEDI Collaboration | Physics Institute III B, RWTH Aachen University
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Outline

Introduction

Detector concept

Simulation studies

Summary & Outlook

Motivation

Where is the Antimatter in our Universe?

- One precondition for Baryogenesis: $\not{\mathcal{C}}\not{\mathcal{P}}$
- 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 $\not{\mathcal{C}}\not{\mathcal{P}}$ in Standard Modell

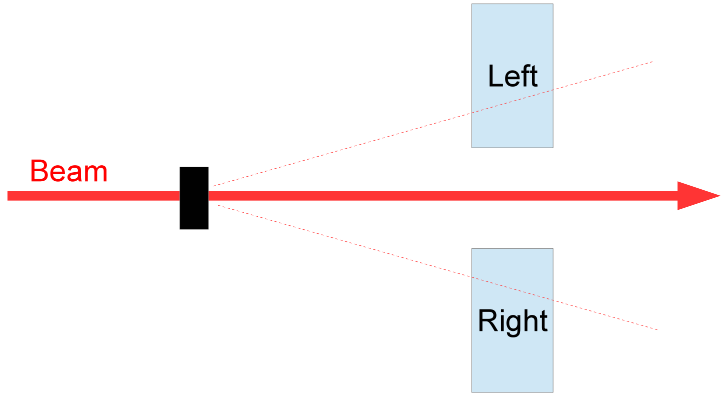
$$\mathcal{H} = -d\frac{\vec{S}}{S} \cdot \vec{E}$$
$$\mathcal{P}\colon \mathcal{H} = +d\frac{\vec{S}}{S} \cdot \vec{E} \qquad \boxed{d = EDM}$$
$$\mathcal{T}\colon \mathcal{H} = +d\frac{\vec{S}}{S} \cdot \vec{E}$$

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

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

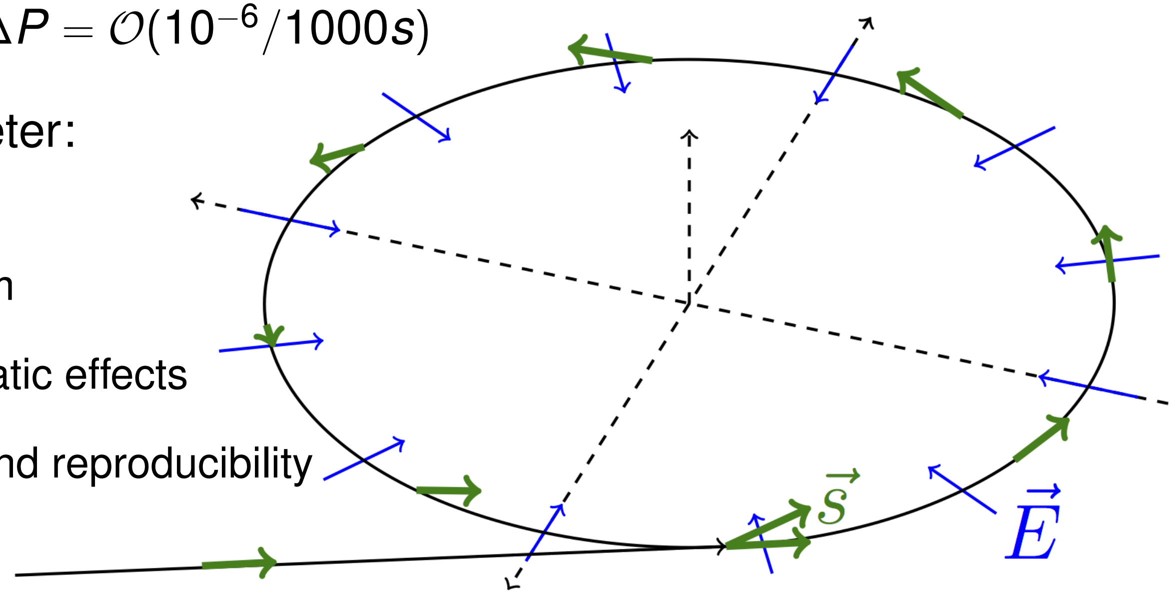
Nuclear scattering polarimetry

- 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

- EDM search in storage rings: Let EDM interact with fields, wait for polarization change: $\frac{d\vec{S}}{dt} \propto d\vec{E} \times \vec{S}$
- Current candidate method for EDM search implicates a linear buildup of polarization with time at $\Delta P = \mathcal{O}(10^{-6}/1000s)$
- Design goals for polarimeter:
  - Large FoM
  - Minimal influence on beam
  - High sensitivity to systematic effects
  - Good long term stability and reproducibility



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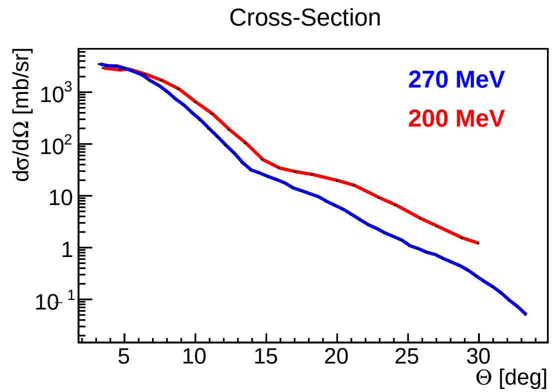
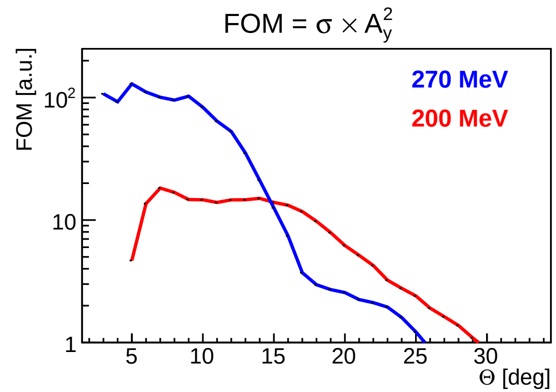
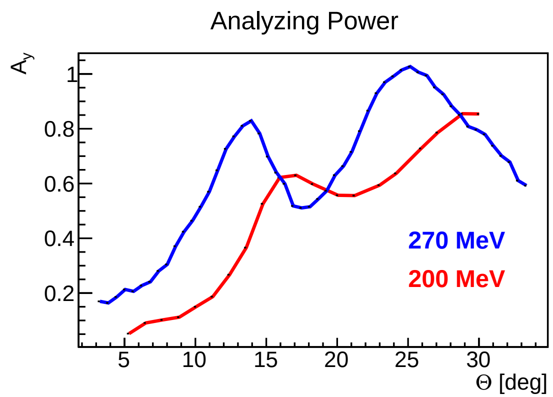
Target choice



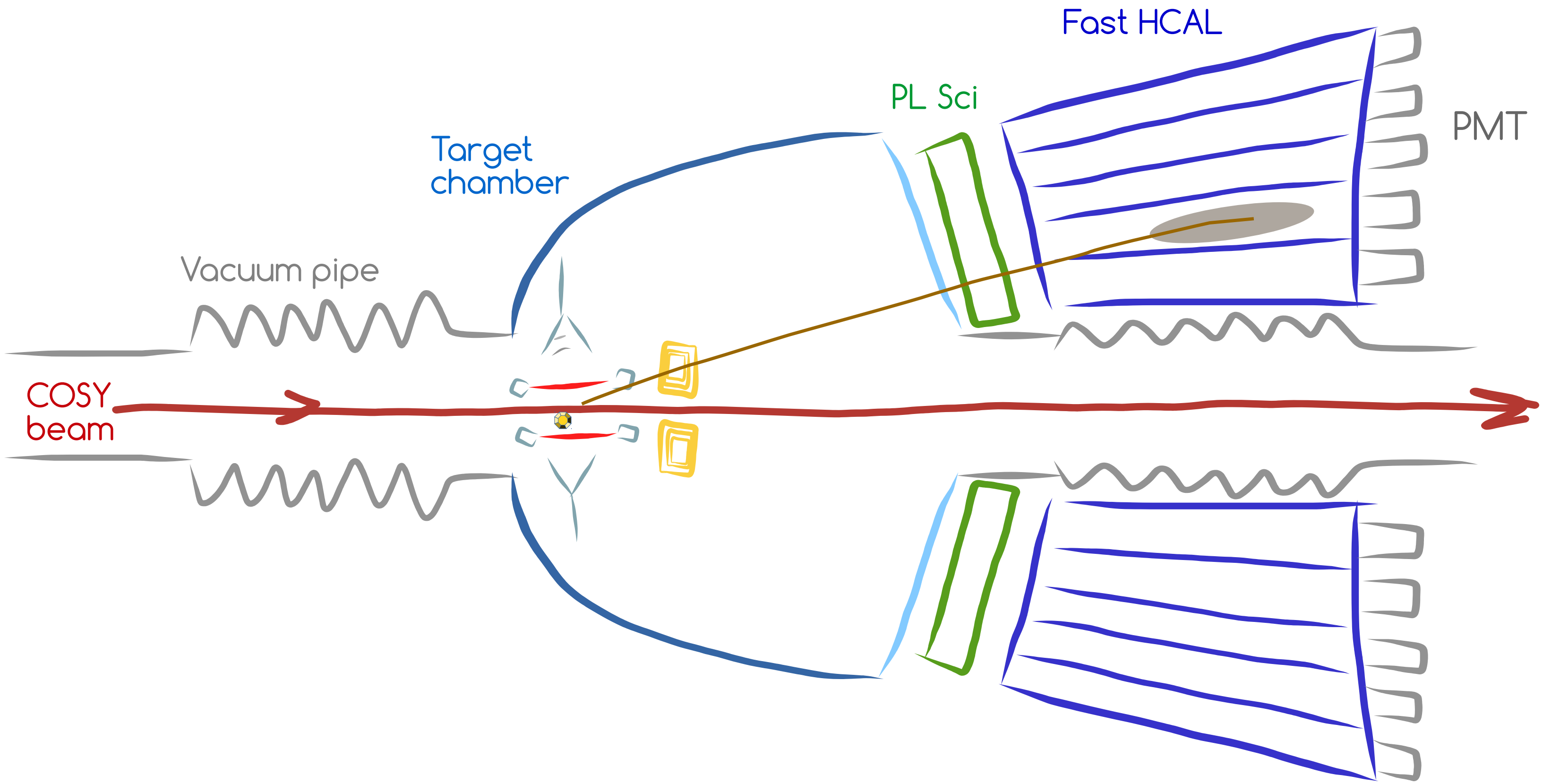




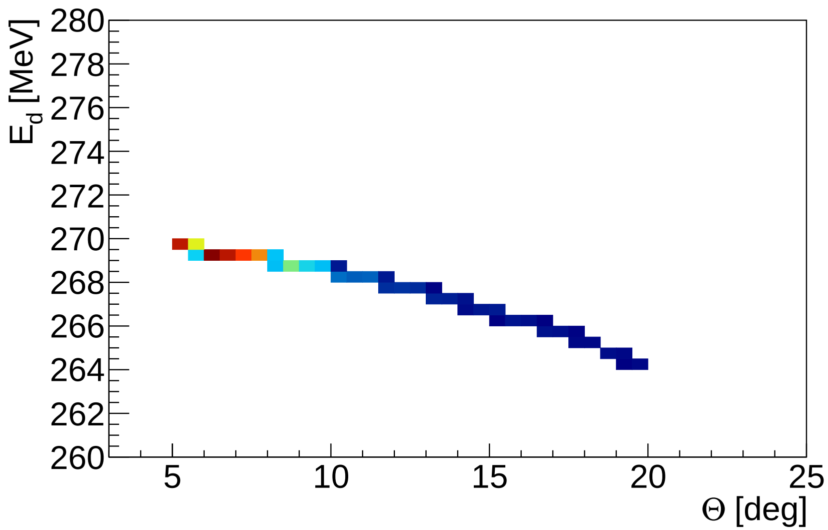
200 MeV: T. Kawabata et al. Phys. Rev. C 70, 034318
270 MeV: Y. Satou et al. Phys. Let. B 549, 307

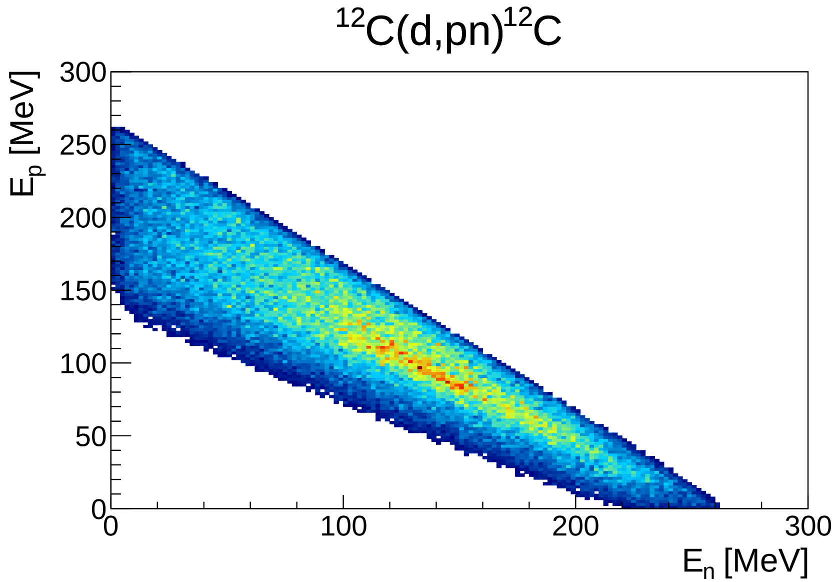
- Carbon was chosen as working choice
- Large analysing power, high elastic cross section
- FOM for Protons also concentrated in the forward region

Detector concept



Signal generation





- 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
  ⇒Complete stop of particles provides good signal separation
- Inelastic reactions carry some analysing power, so maybe keep these

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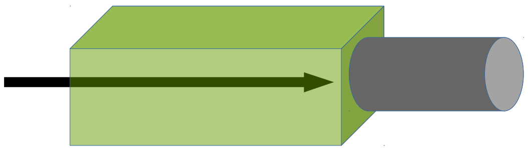
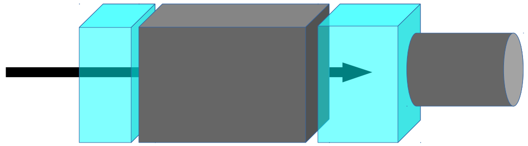
Candidate Materials: LYSO/Plastic Scintillator



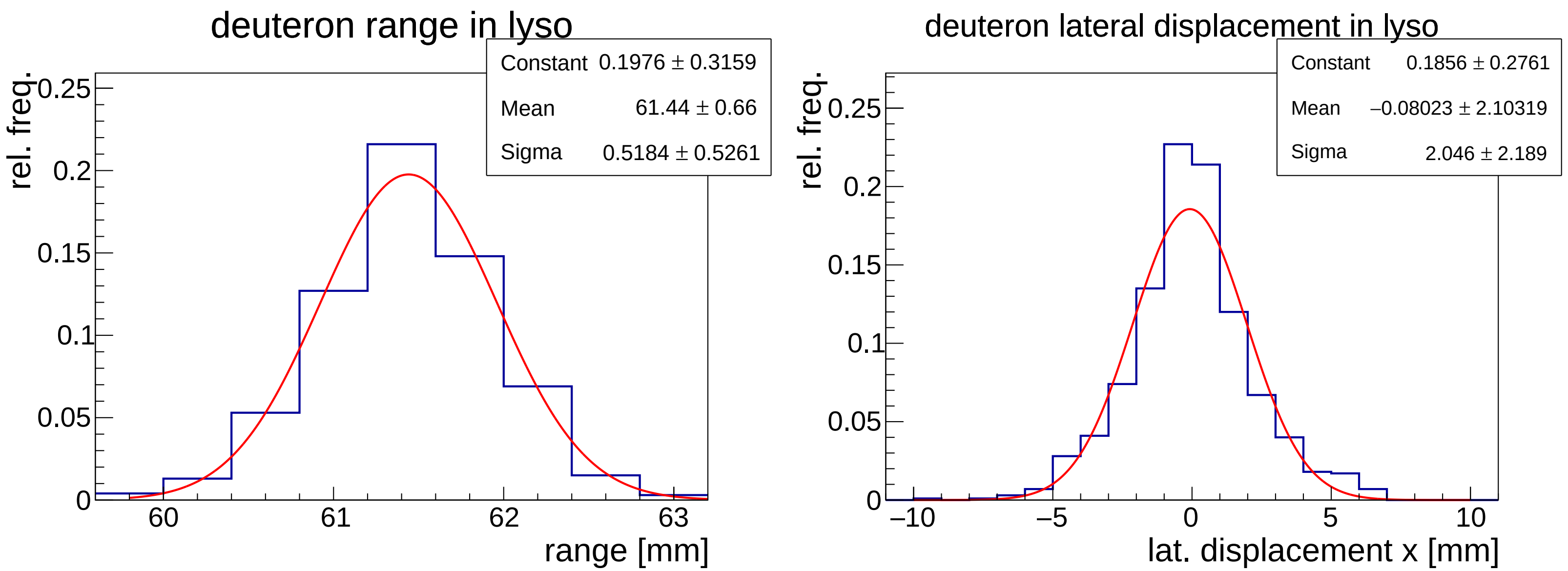


	LYSO	Plastic
Density [g/cm3]	7.3	1.05
Decay [ns]	40	2.4
L. Y. % NaI(Tl)	75	25
S. Peak [nm]	420	420
N ref.	1.82	1.58
Melt. [℃]	2050	75
Hygrosc.	No	No
Radioact	Yes	No

Simulation setup

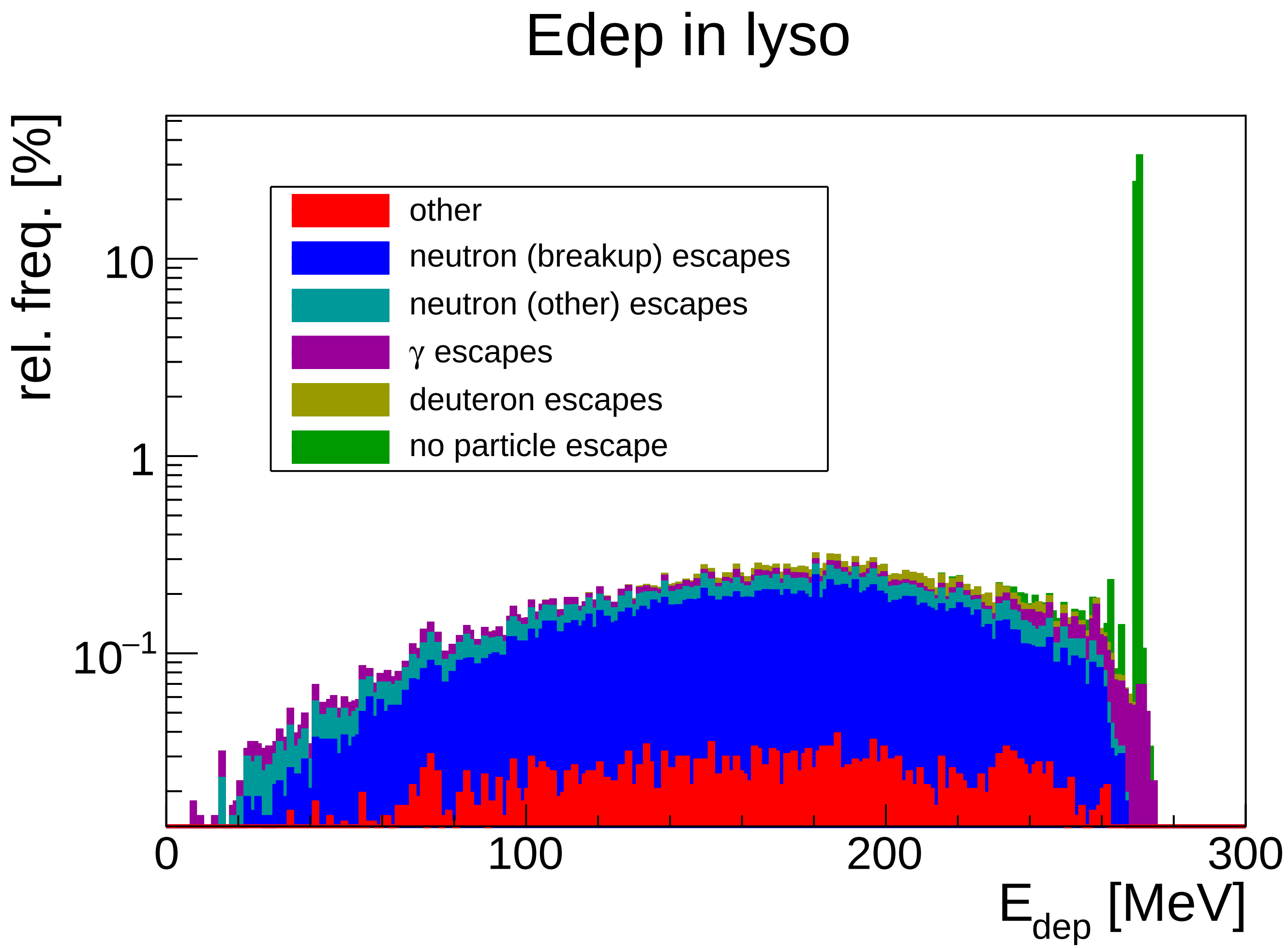
- Geometry: Single detector element
- Generated 100k events each at $T_d = 270\,\text{MeV}, 5^\circ < \Theta < 20^\circ$, $0^\circ < \phi < 360^\circ$
  - Signal: $^{12}C(d, d)^{12}C$
  - Background: $^{12}C(d, pn)^{12}C$
- $\mathcal{FOM} \propto (\sigma_{el}\epsilon_{el} + \sigma_{bg}\epsilon_{bg})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

Lyso scintillators



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

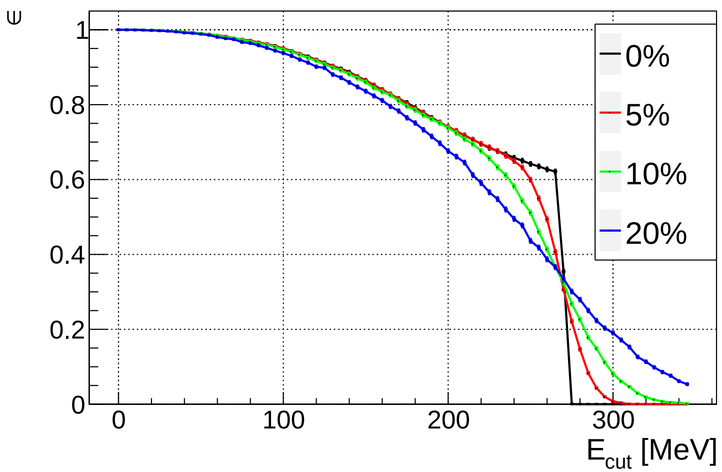
Detector response - lyso



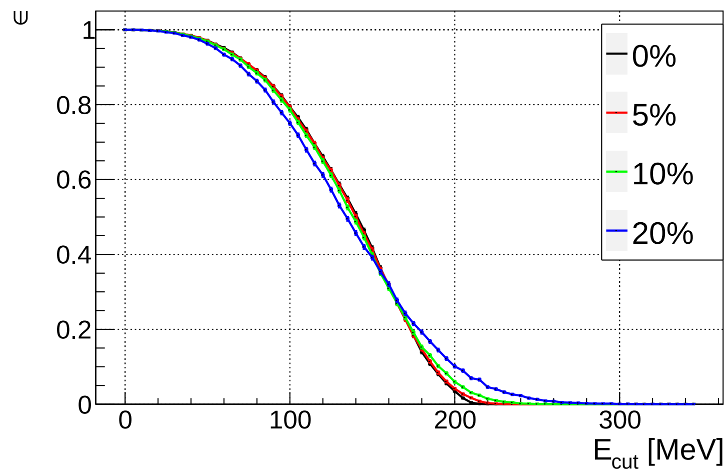
- Breakup is main cause of efficiency loss

Detection efficiencies (lyso)

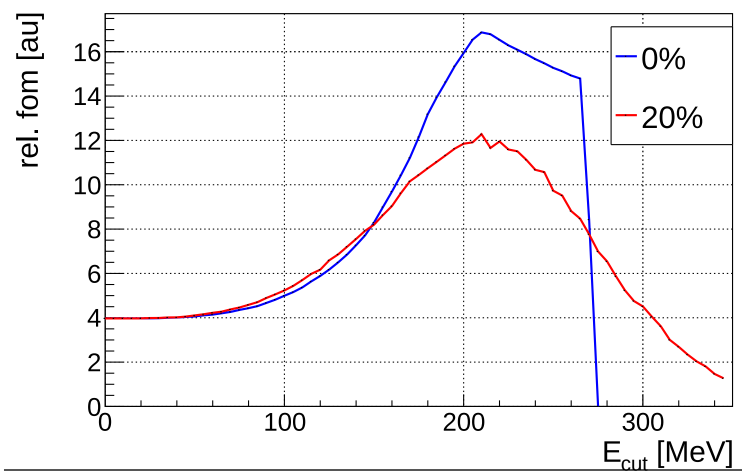
dcelastic detection efficiency in lyso



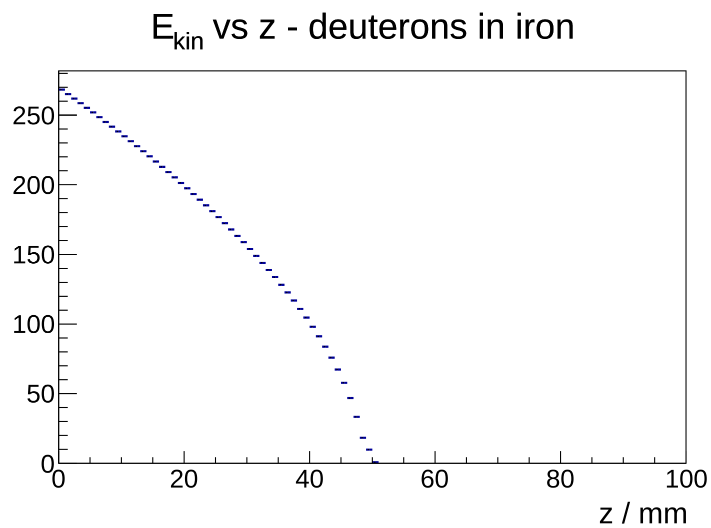
dcbreakup detection efficiency in lyso

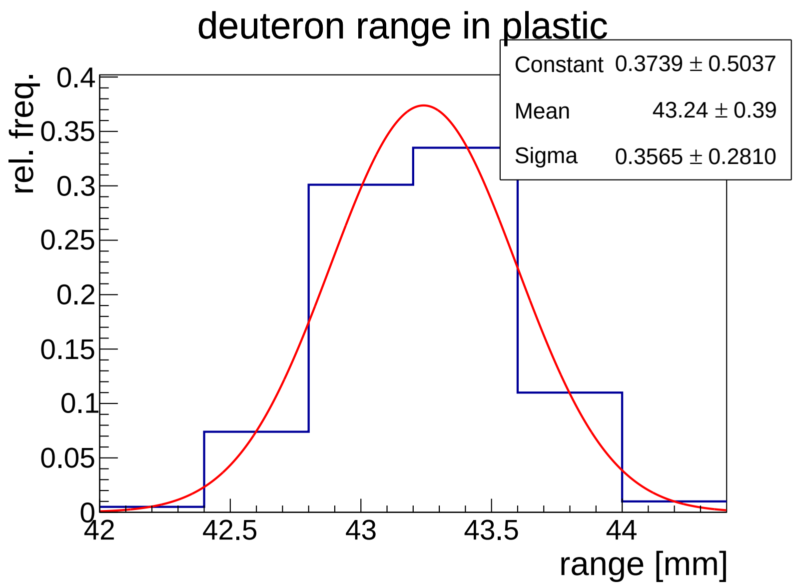


relative fom in lyso



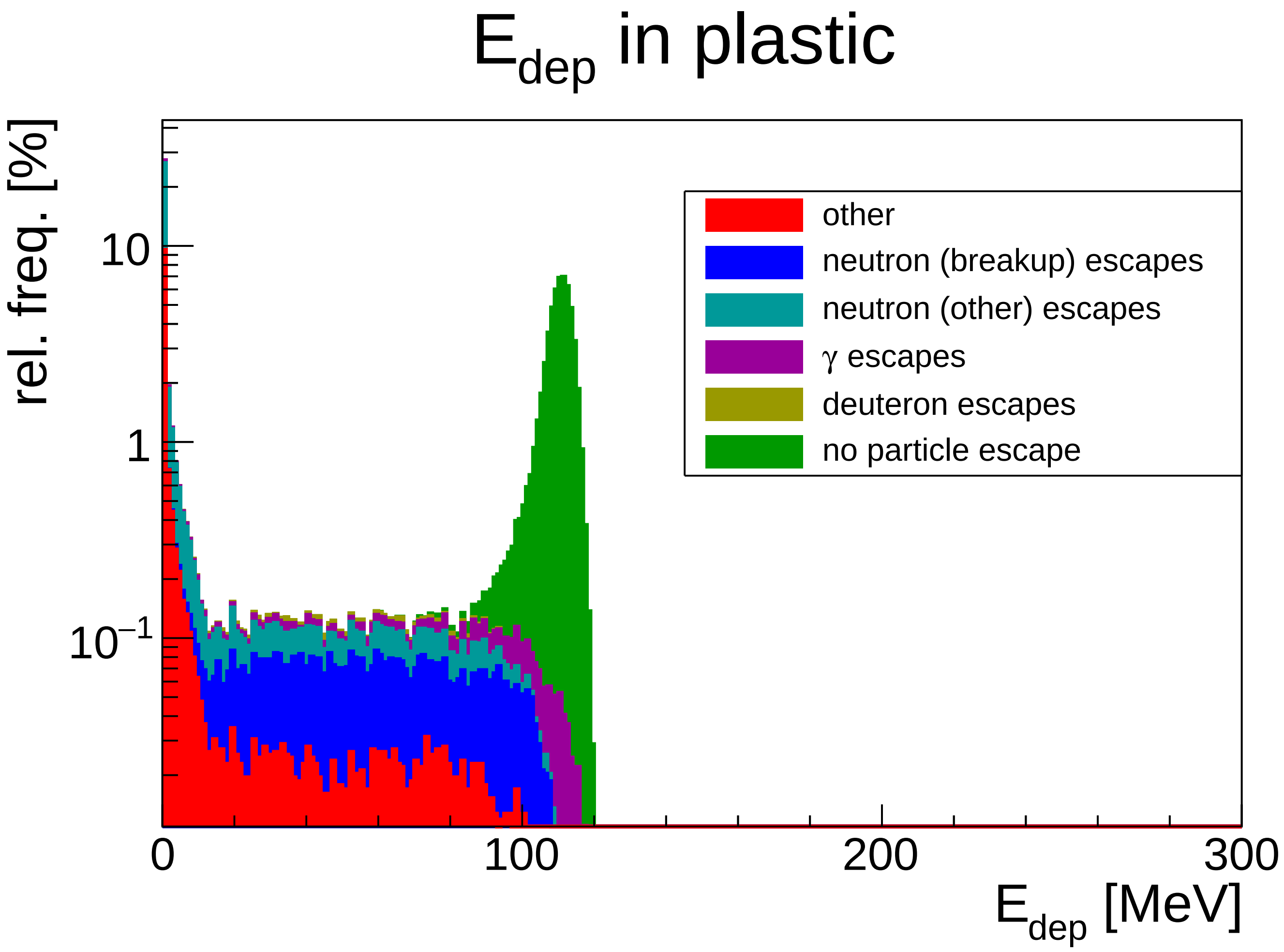
Plastic scintillators





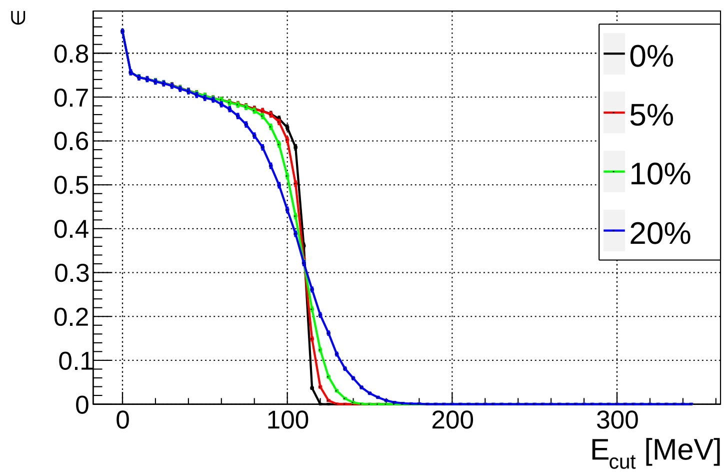
- Use degrader to suppress photon background and reduce length of plastic detector.
- $T_d = 270\,\mathrm{MeV}$
  - Absorber thickness $\approx 40\,\mathrm{mm}$
  - Scintillator thickness $\approx 50\ mm$

Detector response - plastic

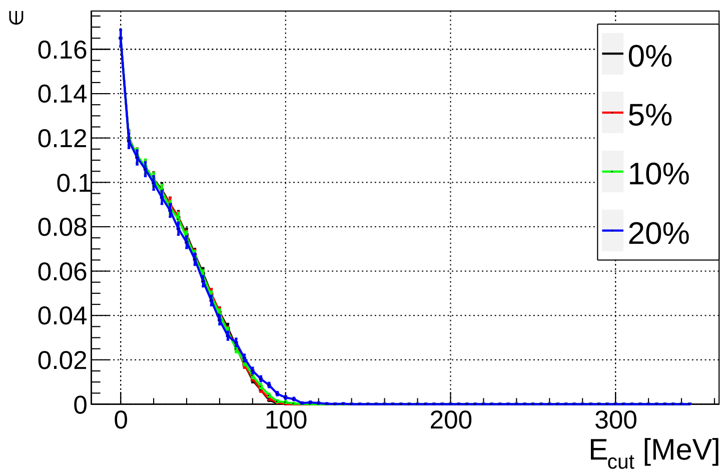


Detection efficiencies (plastic)

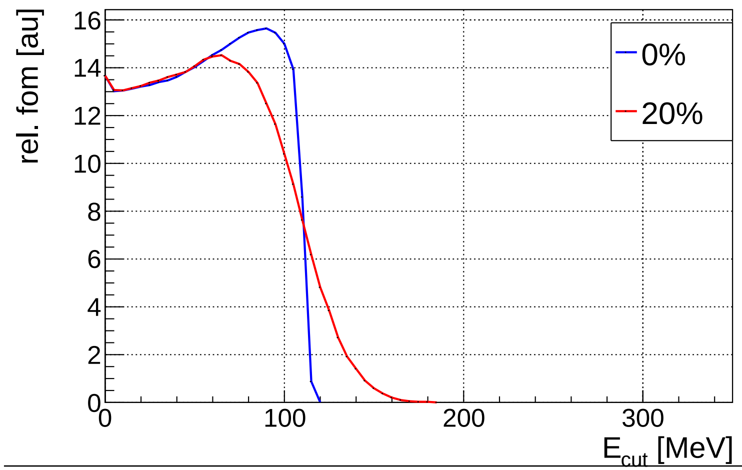
dcelastic detection efficiency in plastic



dcbreakup detection efficiency in plastic



relative fom in plastic



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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
- No strong dependence on energy resolution

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Summary & Outlook

- We have a candidate layout for JEDI polarimeter
- Simulations suggest promising performance
- Hardware tests with LYSO crystals are in progress
- Will include $\Delta E - E$ particle identification technique
- Will include inelastic scattering in simulation