Energy/Time Resolution for an Array of LYSO Crystals

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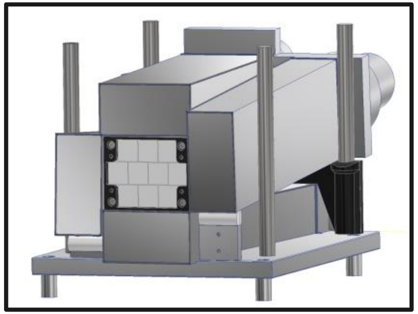
LYSO Testbeam Goals

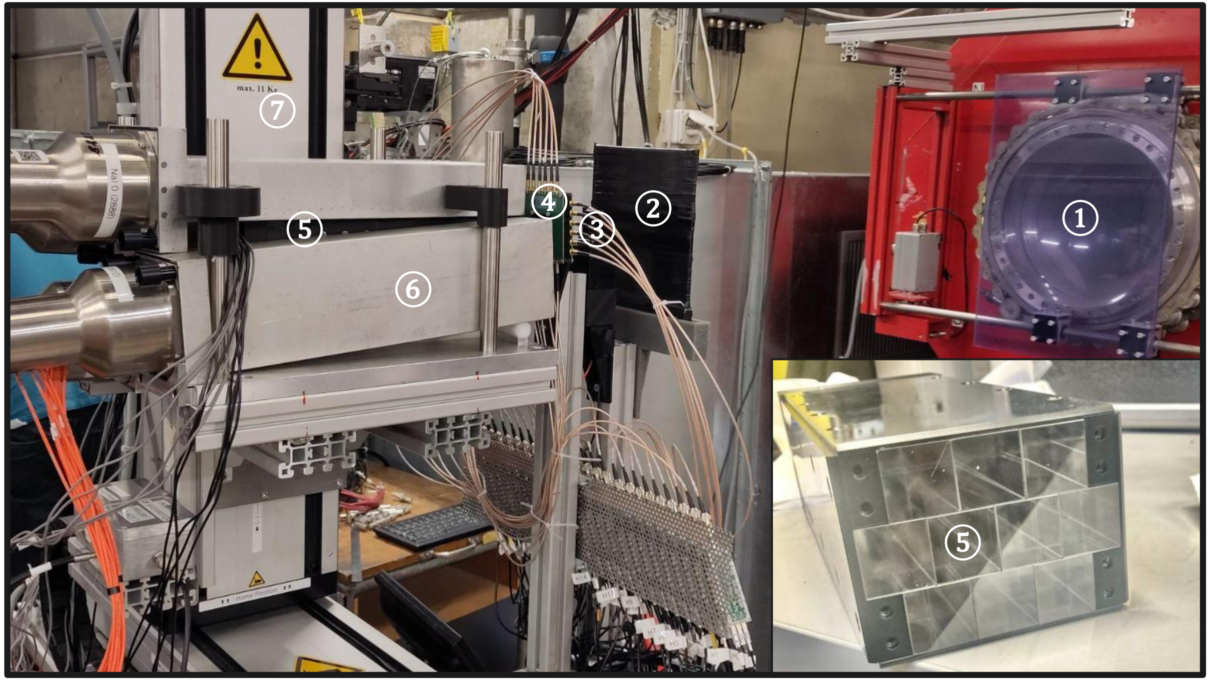
1. **Energy resolution measurement** – scan energies around 70 MeV
2. **Muon tomography** – determine longitudinal uniformity of LYSO crystals using a high energy muon beam
3. **Time resolution measurement -** determine crystal-crystal timing differences as a function of hit energy
4. **Fine position scans across front face of LYSO array** – determine losses at the boundaries of the crystals
5. **Position resolution measurements -** characterize ability of crystals to reconstruct hit position

Detector setup at PSI

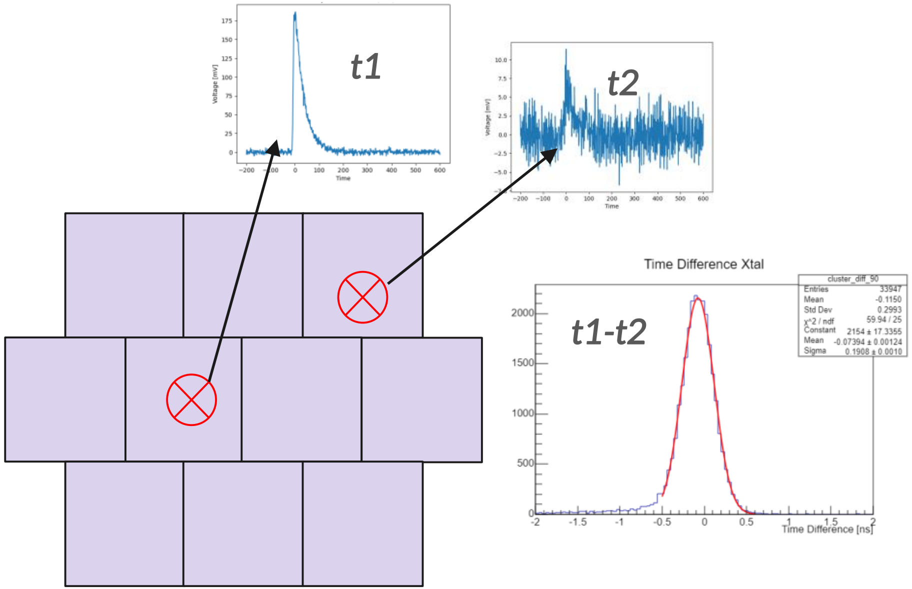
Detectors:

1. Positron beam exit
2. Veto detector
3. t0 detector
4. Beam hodoscope
5. LYSO array
6. NaI detectors
7. XY-table

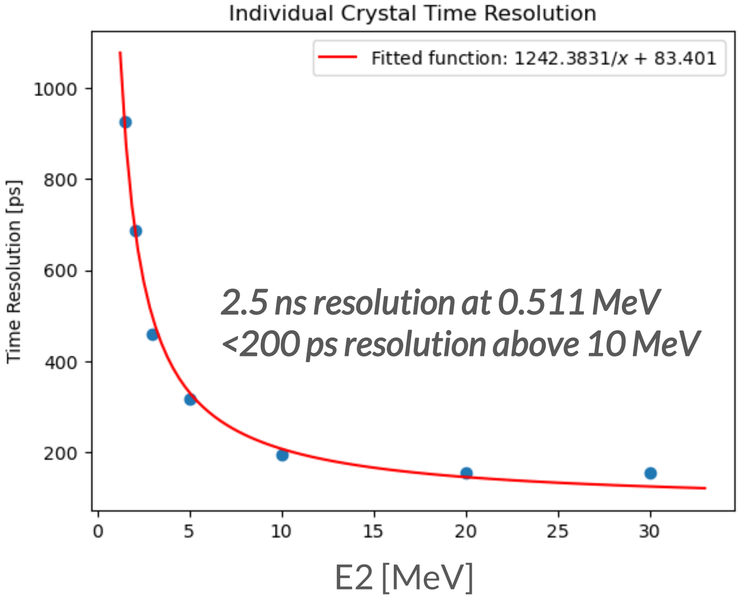




Time Resolution Results

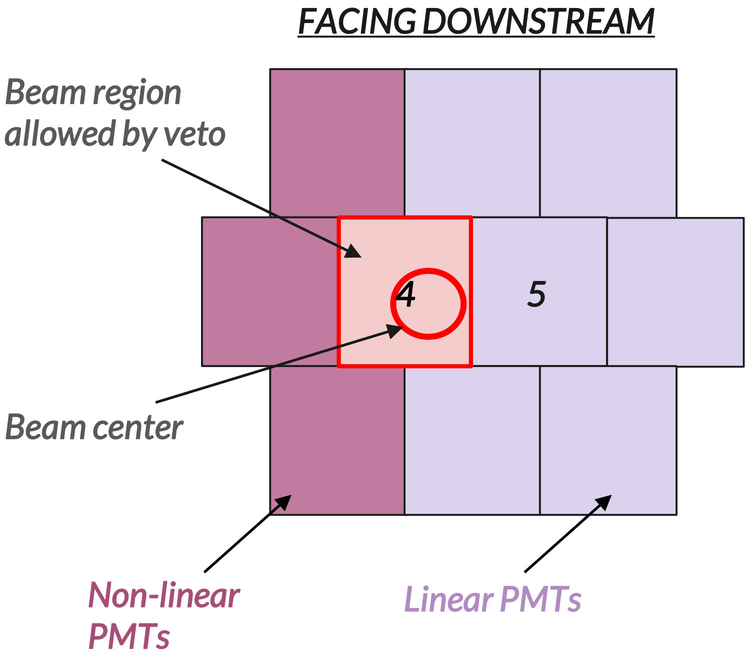


E1 > 10 MeV

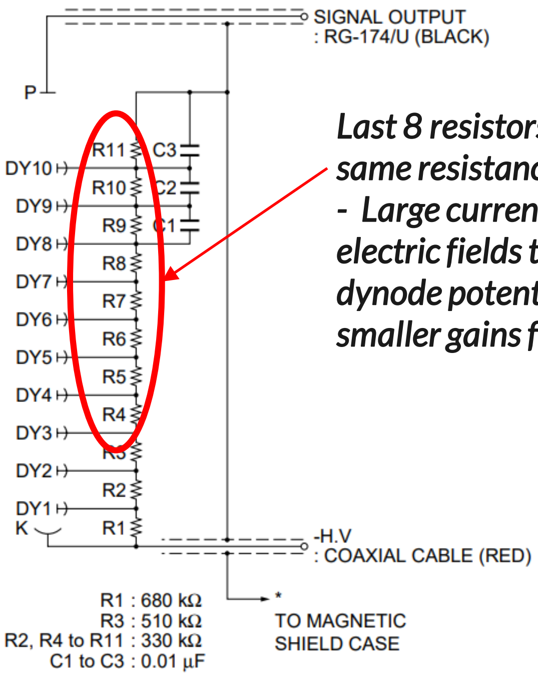


Nominal energy resolution configuration

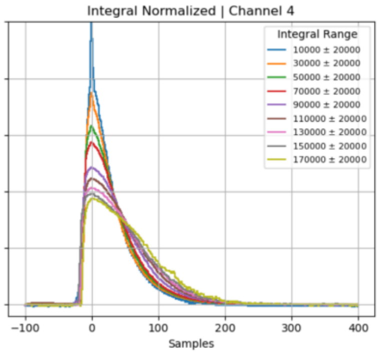
- Veto is centered on crystal 4 (outlined in red) so that only particles entering the array through crystal 4 can trigger the DAQ
- Crystal 4 used as the primary crystal due to a coupling issue with crystal 5
- Any energy deposit in a NaI detector results in the event being vetoed
- Non-linearity problem with 3 of the PMTs

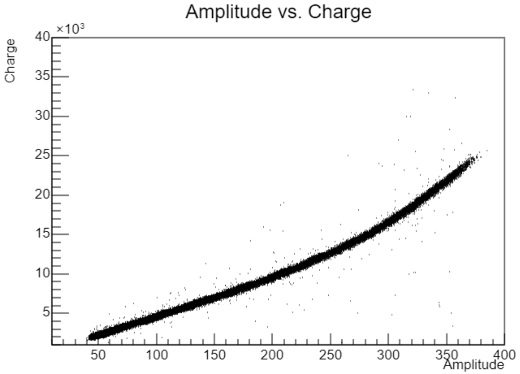


Hamamatsu R1450 and Non-Linearity Problems



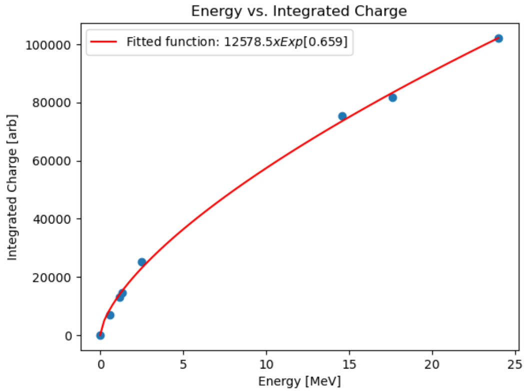
Last 8 resistors all have the same resistance:
- Large currents generate electric fields that oppose dynode potential and result in smaller gains for larger signals





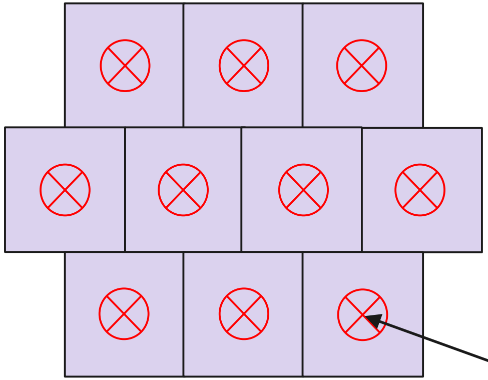
- Waveform shapes are energy dependent
- Energy is not proportional to charge

Run all PMTs at low voltages to minimize effects

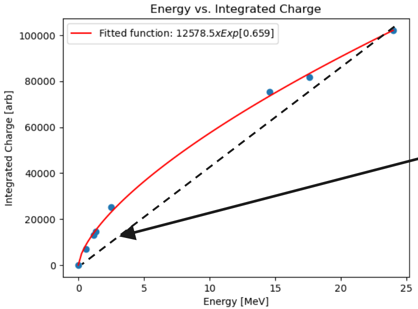


Crystal Calibrations and Timing Cuts

Before each data run at each energy, drive beam into the center of each LYSO xtal

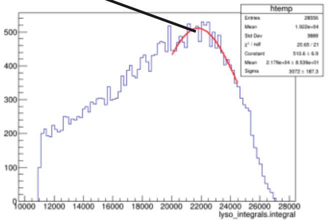


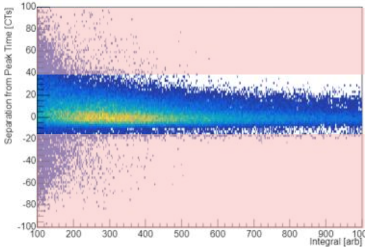
Additional suppression of low energy signals in non-linear PMTs is made (~10%)



We overestimate low-energy signals by calibrating on high energy signals

Fit e+ energy distribution to obtain intra crystal calibration constant – verified with μ+ from beam





Only consider pulses with peak within gate [t-15,t+35] of seed time *t*

Energy resolution results

~1.8% energy resolution at **70 MeV**

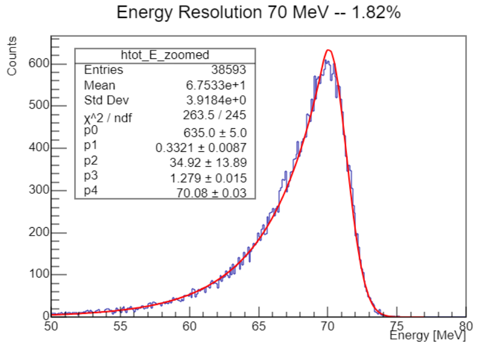
- NaI crystals used as vetos
- Momentum bite of beam (dp/p) < 0.6%

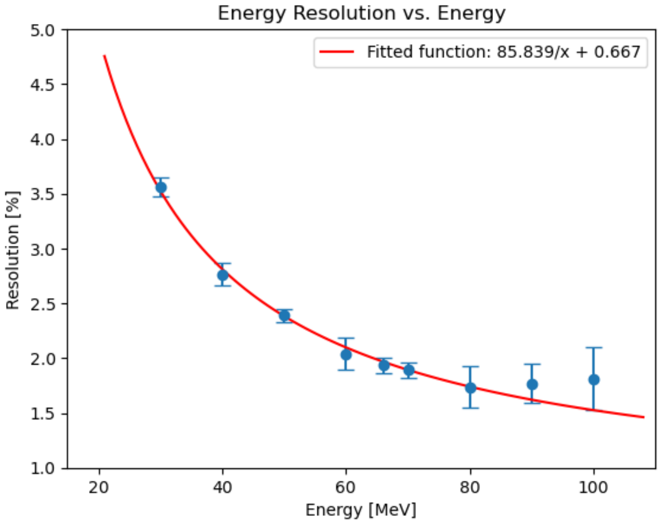
Energy resolution vs. energy fit:

$$\delta E/E = \cancelto{0}{a/\sqrt{E}} + \underbrace{b/E}_{\text{Noise}} + \underbrace{c}_{\text{Constant}}$$

Only noise term and constant term are non-zero in fit:

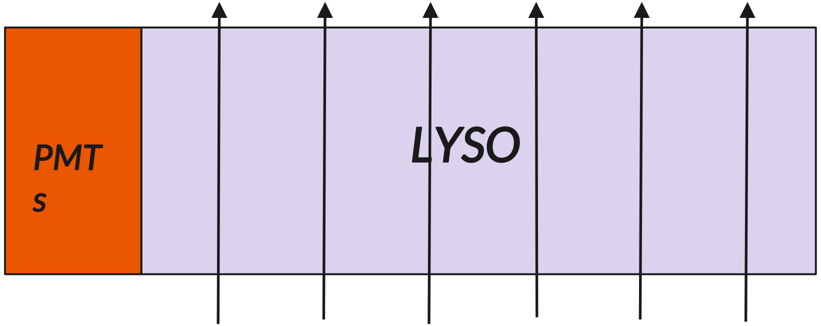
- Electronics noise (due to running the PMTs at low HV)
- Leakage from the array not picked up by NaI veto detectors
- Miscalibrations



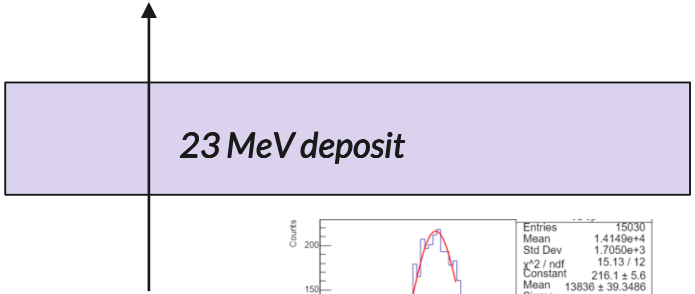


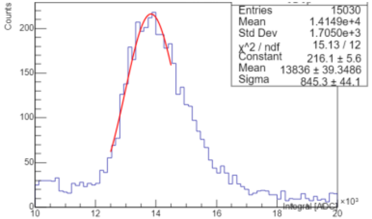
Muon Tomography Results

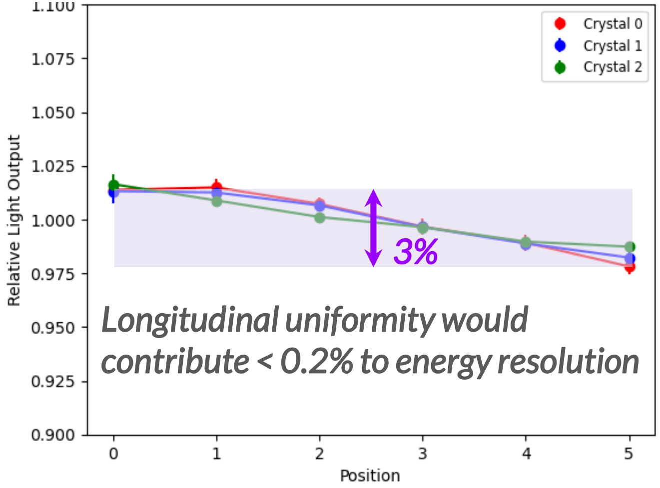
Detector rotated 90 degrees and NaI removed



Track light output across 6 positions along the long side of the crystals



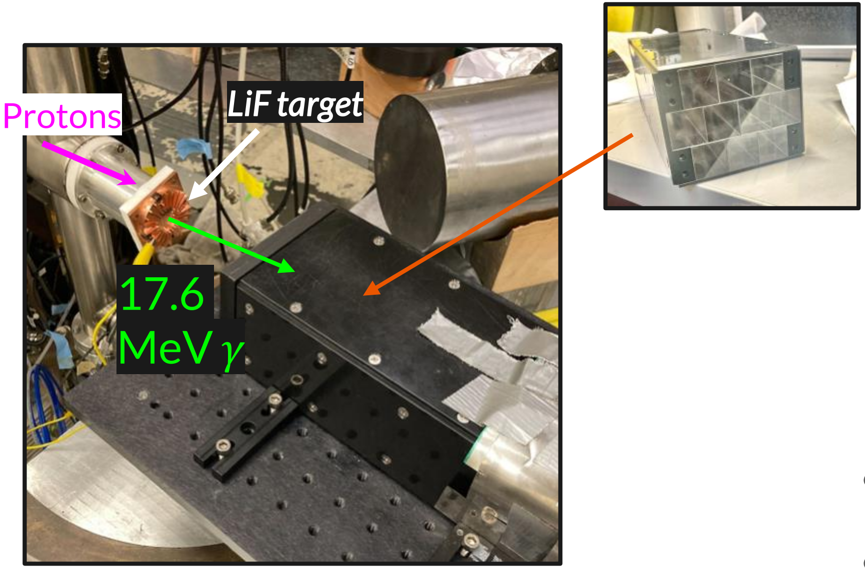


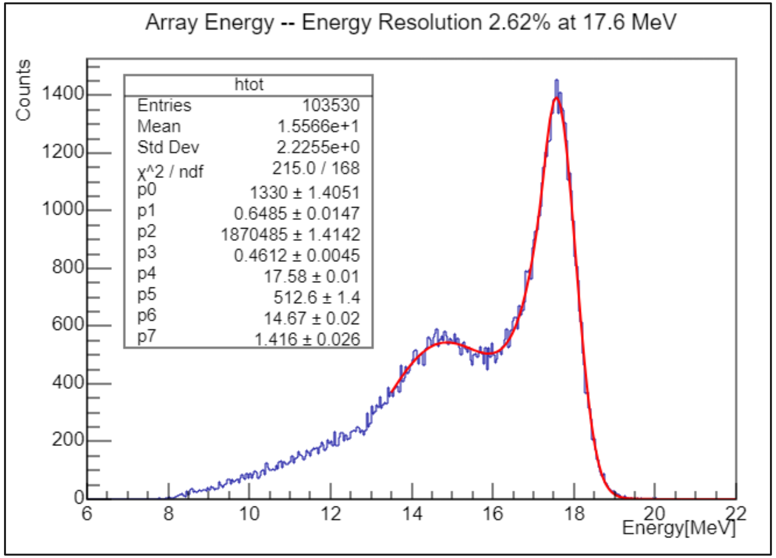


Longitudinal uniformity would contribute < 0.2% to energy resolution

Energy Resolution of a LYSO Array at 17.6 MeV

$$\text{Li-7} + p \rightarrow \text{Be-8} + \gamma, E_\gamma = 17.6\text{MeV}$$





- *2.62% energy resolution at 17.6 MeV – comparable to LXe detector*
- *Exact p-Li reaction could be used as a calibration in PIONEER – used by MEG II (also get ~2.6%)*

CENPA Beam Test Shows Significant Improvement

PMT bases were corrected to a tapered design

- Voltages were increased by about 300V on each PMT