Characterization and Irradiation study for the Crilin Electromagnetic Calorimeter

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International
MUON Collider
Collaboration

Crilin and the Muon Collider

Crilin (crystal calorimeter with longitudinal information): ECAL R&D for the future Muon Collider, which is being considered as an option for a next generation facility; studies for 3 and 10 TeV designs are being carried out

Muon Collider pros:

- **m_μ>>me** (negligible synchrotron radiation)
- **point-like particle:** all $\sqrt{s}$ is available in collisions
- perfect for **direct search of heavy states**

Muon Collider cons:

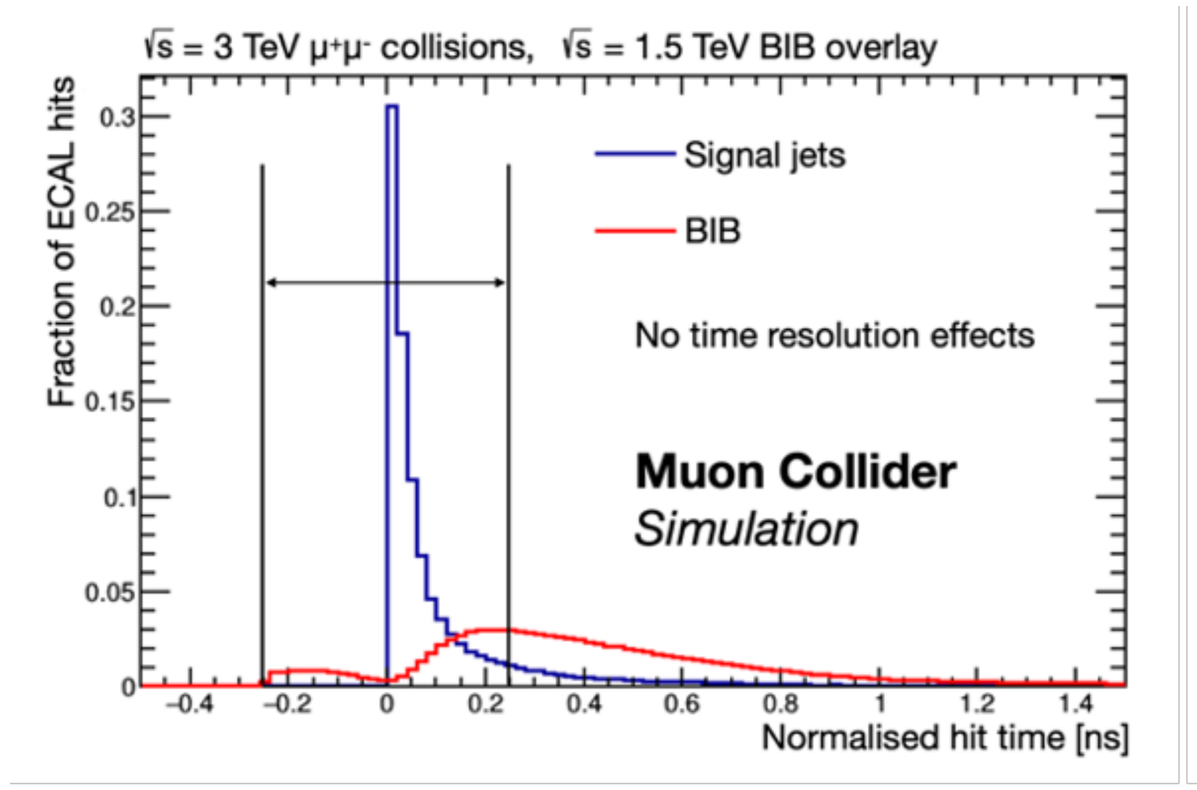
- τ_0**= 2.2μs :** very fast cooling and fast-ramping magnet system needed
- μ decay + interaction with machine: **beam-induced background (BIB)**, partially shielded by nozzles

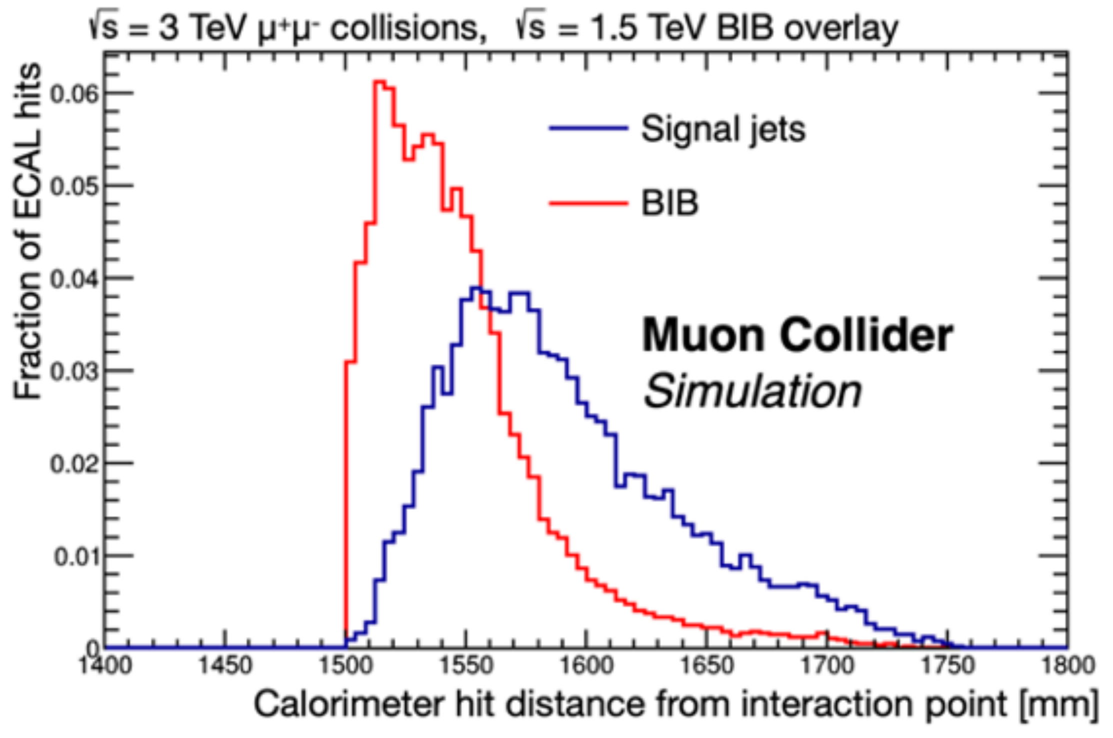
→ detectors must be able to cope with the BIB and to have good physics performances

Muon Collider ECAL requirements

BIB in the ECAL region (after nozzles and tracking system):

- mainly γ (96%, <E> = 1.7 MeV) and n (4%)
- different **hit longitudinal profile** wrt signal
- **time of arrival flatter** wrt bunch crossing → can exclude most of BIB with an acquisition window of ~240 ps
- total ionising dose: ~1 kGy / year
- total neutron fluence: 10^{14} $n_{1MeVneq}$ / cm^2 / year





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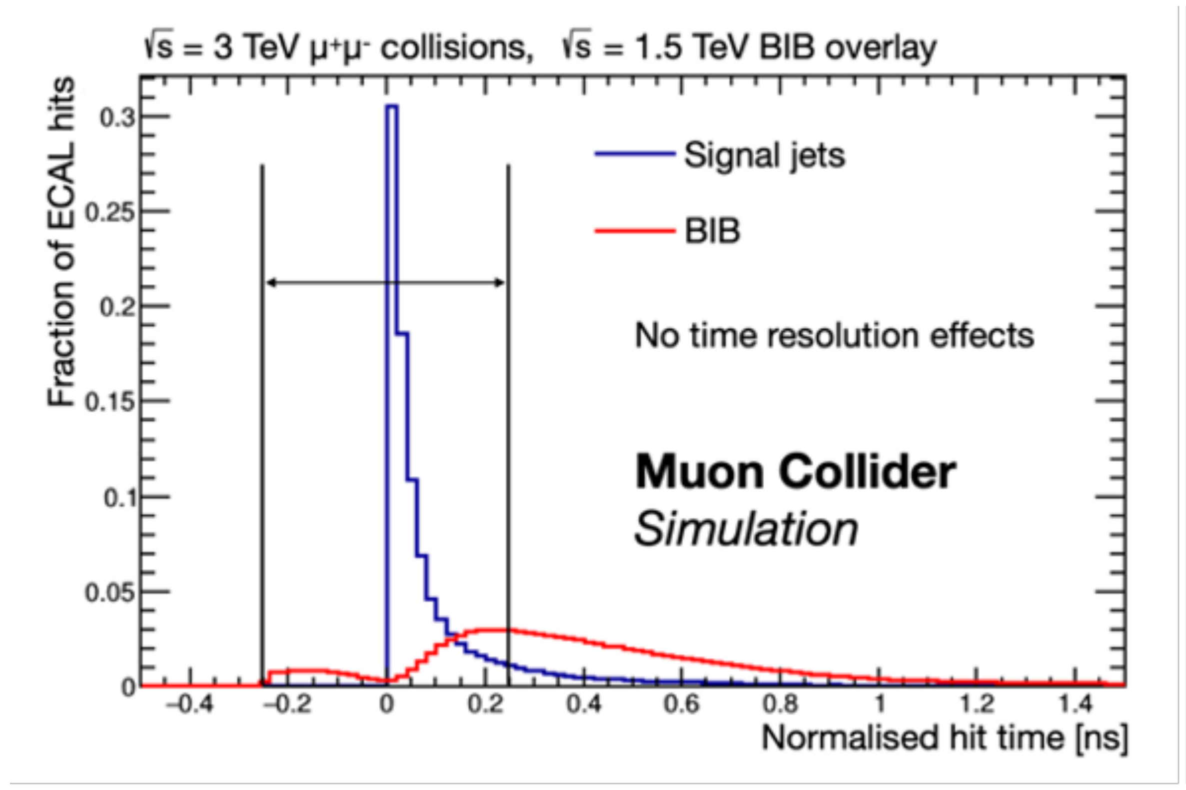
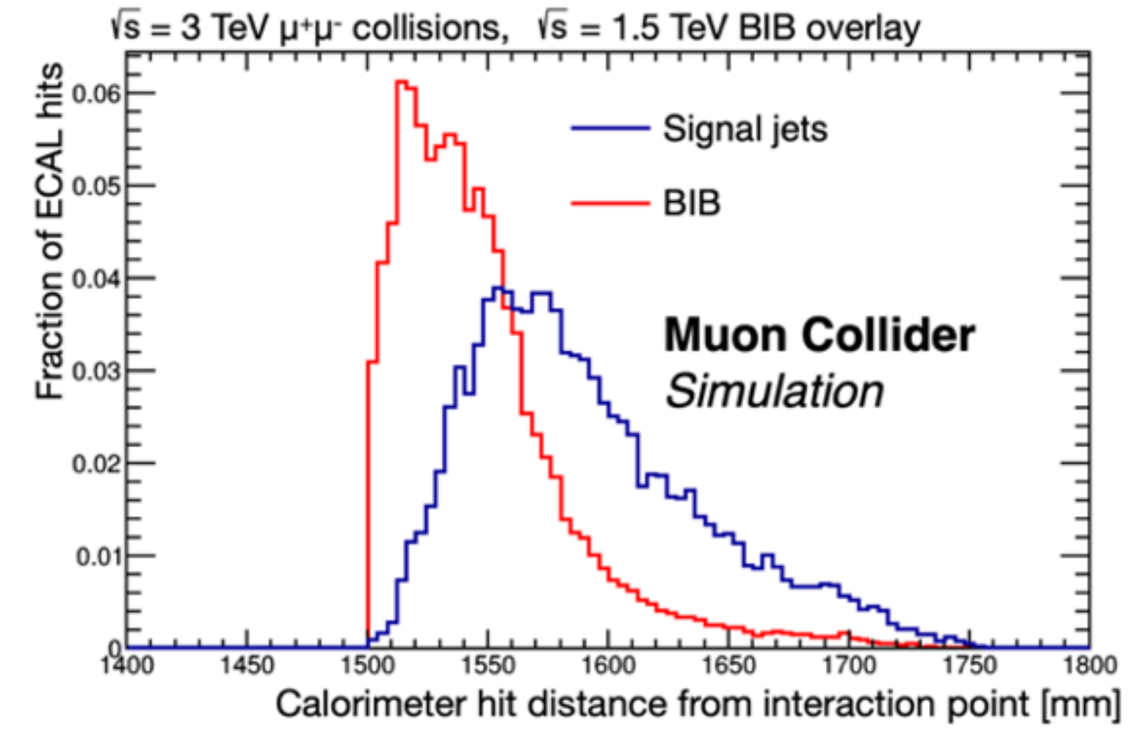




→ a Muon Collider ECAL should have:

- σ_t ~ 80 ps
- longitudinal segmentation
- fine granularity to distinguish BIB and signal
- radiation resistance
- $\sigma_E/E \sim 10\%/\sqrt{E}$

→ **Crilin is a good ECAL candidate**, and a competitive option wrt the W-Si sampling calorimeter

Why Crilin?

Semi-homogeneous calorimeter

Modular architecture made of stackable and interchangeable submodules ➝ **longitudinal segmentation**

One layer: matrix of **PbF_2** crystals, each read out by 2 series of 2 UV-extended **SiPMs**

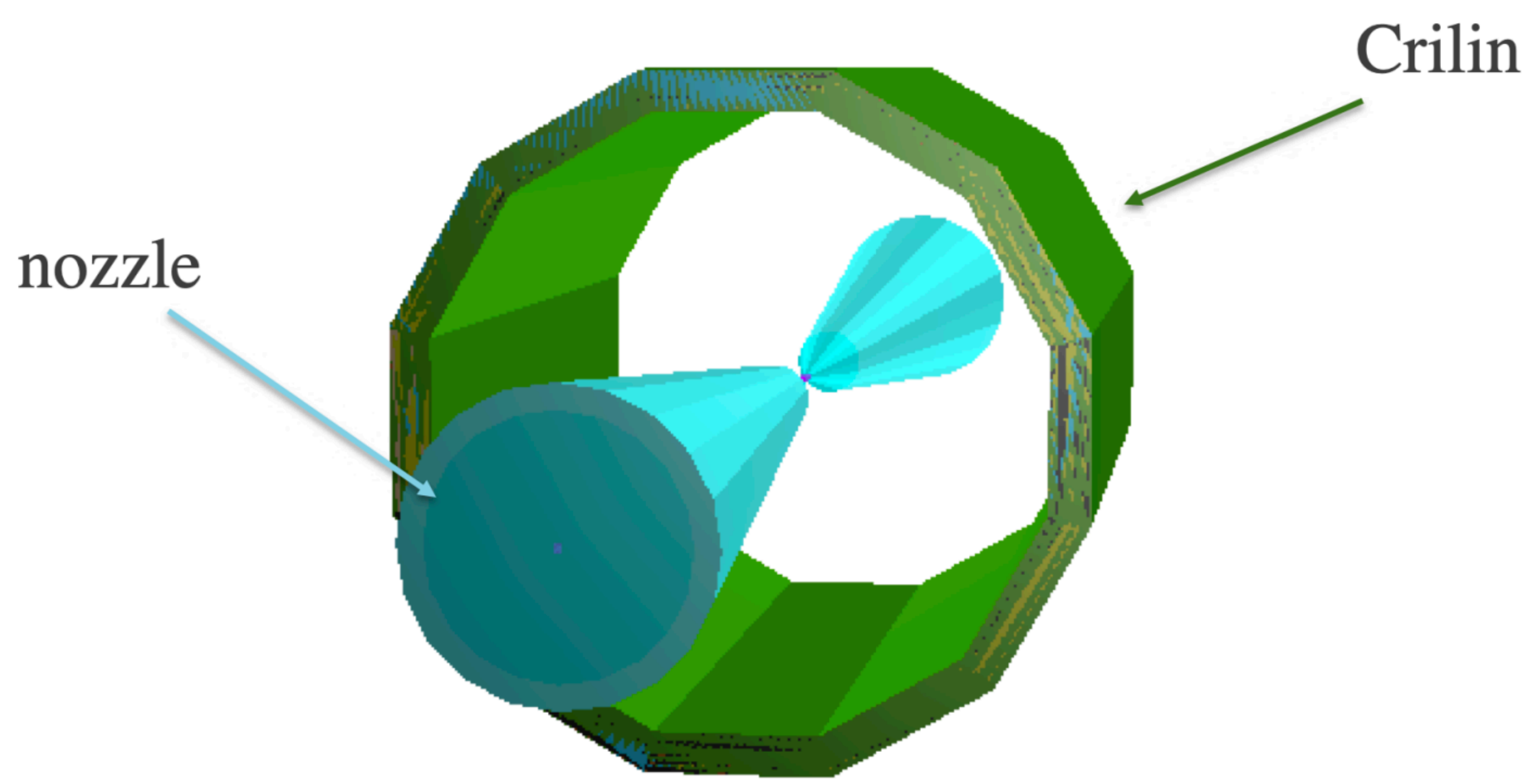
PbF_2: dense, high n, low λ, Cherenkov light ➝ high light response speed, no significant transmittance loss up to 350 kGy

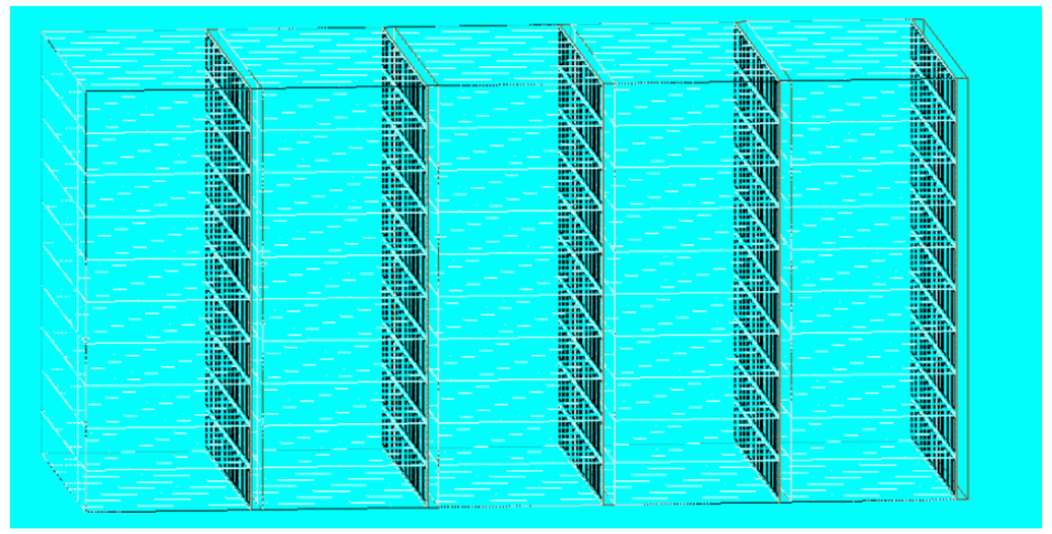
good timing resolution, sufficient resistance to radiation

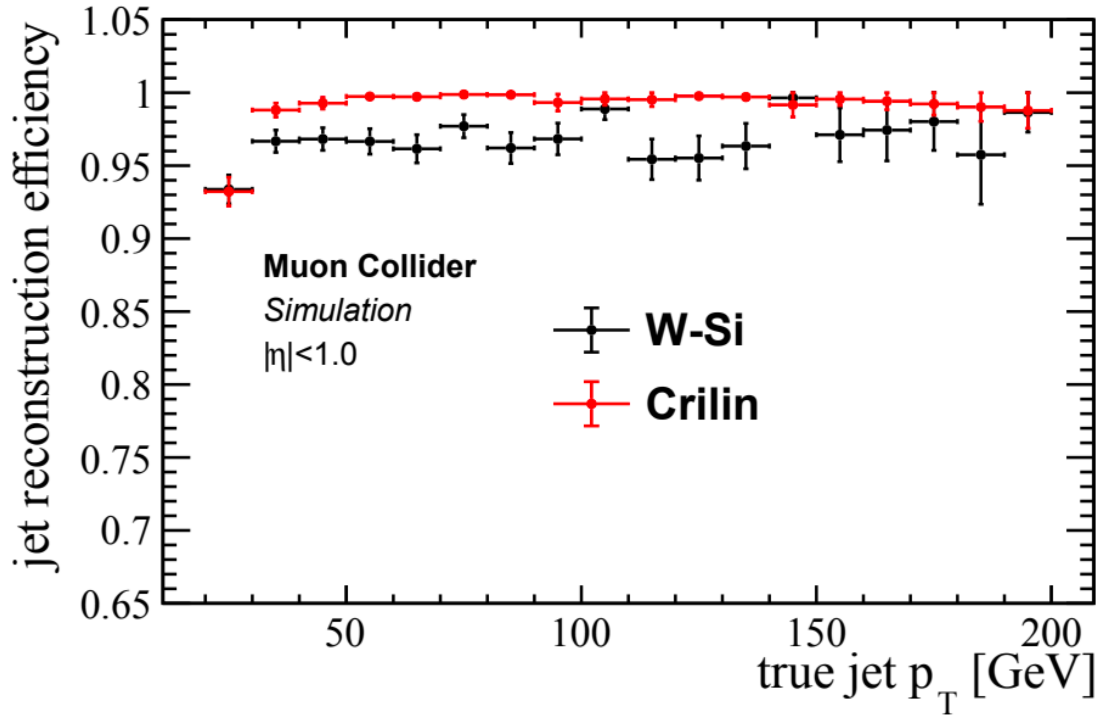
Small SiPM pixels ➝ **fine granularity**

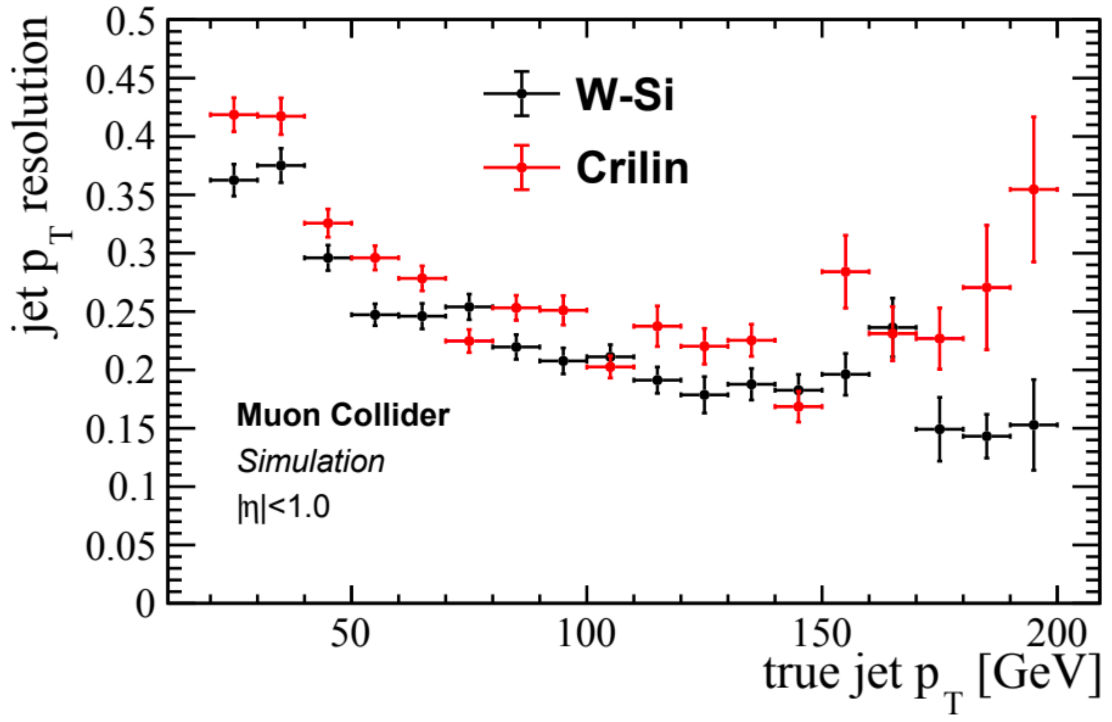
Good light collection ➝ **good energy resolution**

5 layers with a dodecahedra geometry
➝ **manageable number of readout channels, affordable**







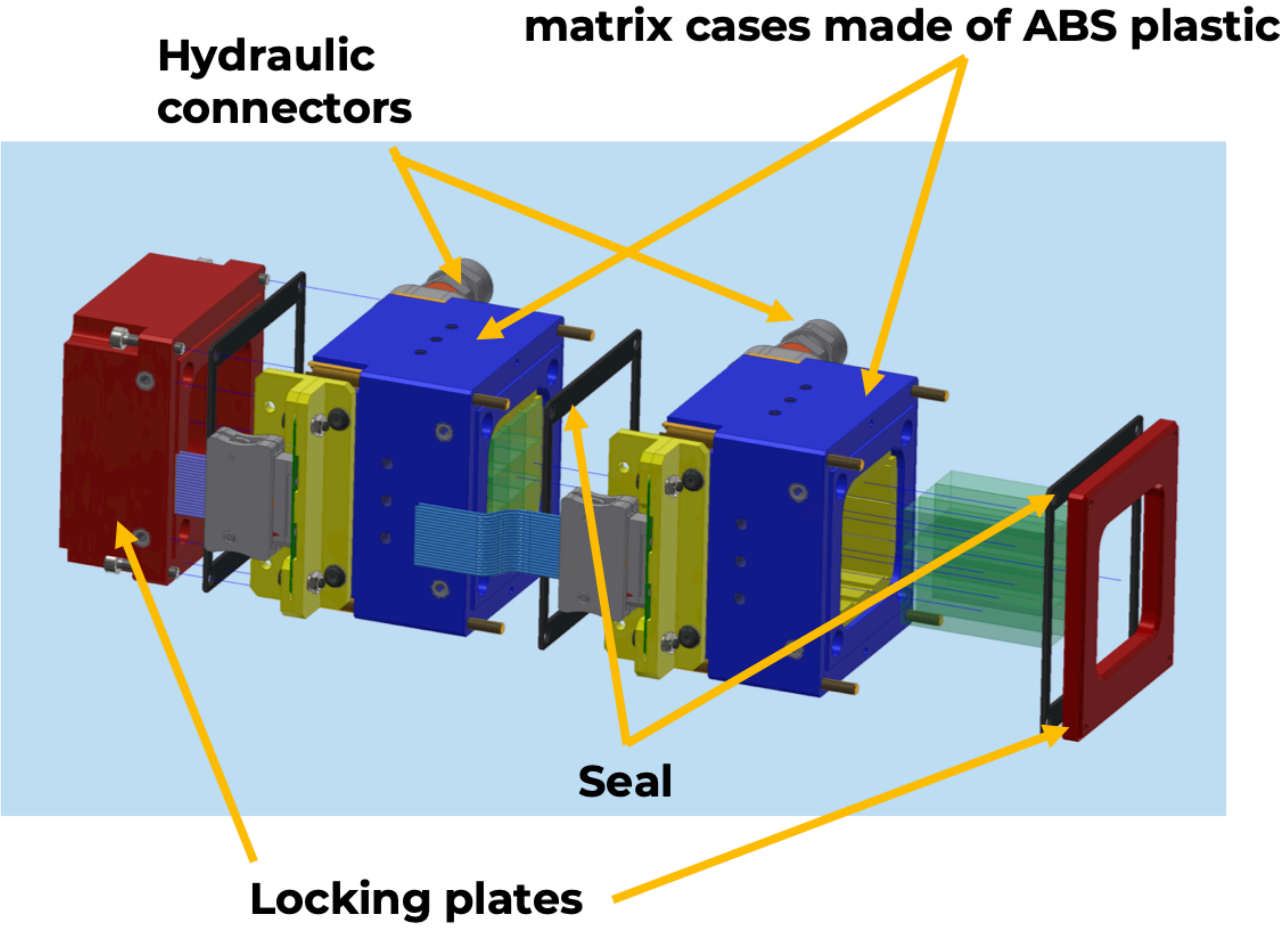


Proto-1

Two stackable, interchangeable **layers**
Each layer has 3x3 10x10x40 mm^3 PbF$_2$ crystals

SiPMs: Hamamatsu S14160-3010PS (3x3 mm^2 each, 10 μm pixels)
Copper cold plates to exchange heat with the SiPM electronic board

Performances tested at LNF BTF and at CERN H2-SPS

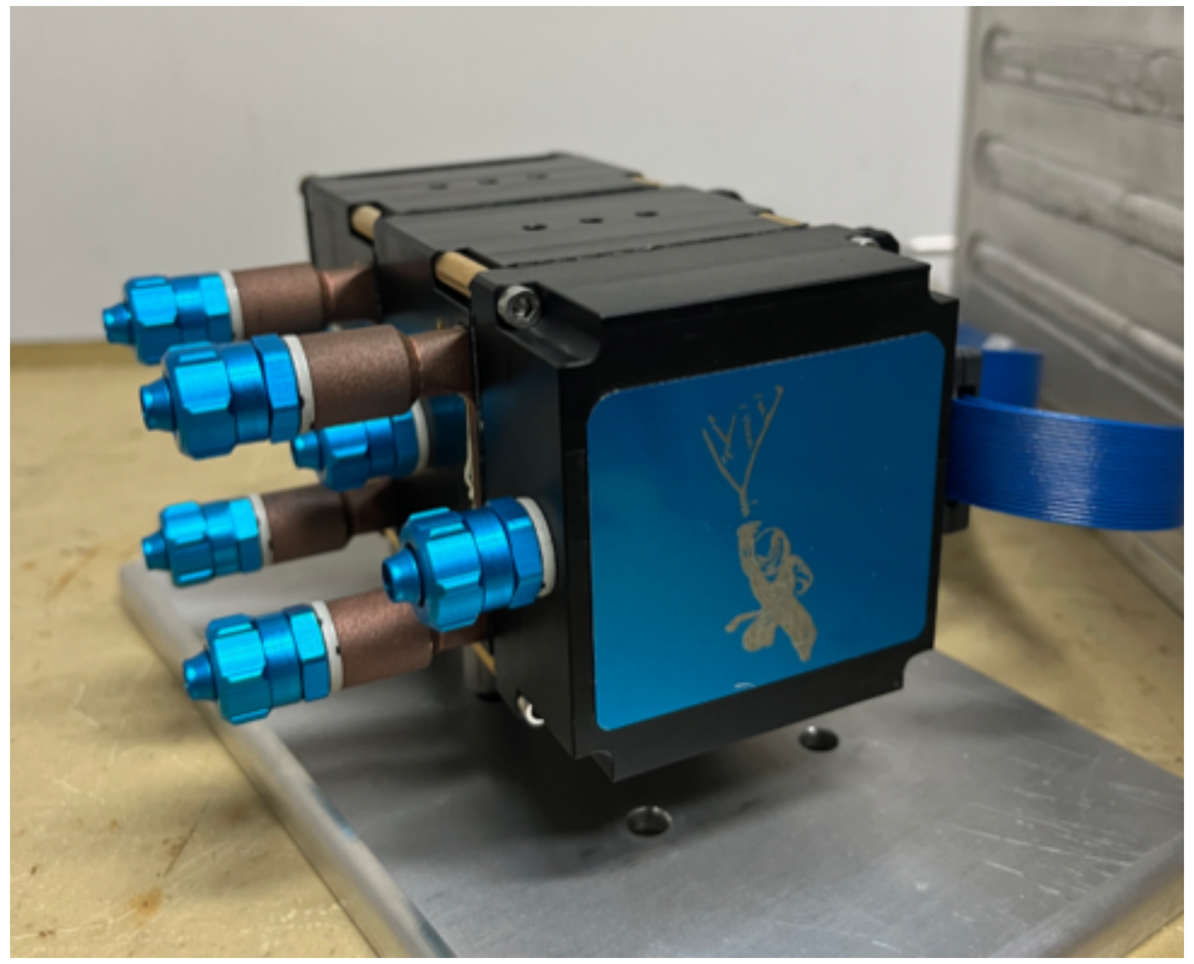


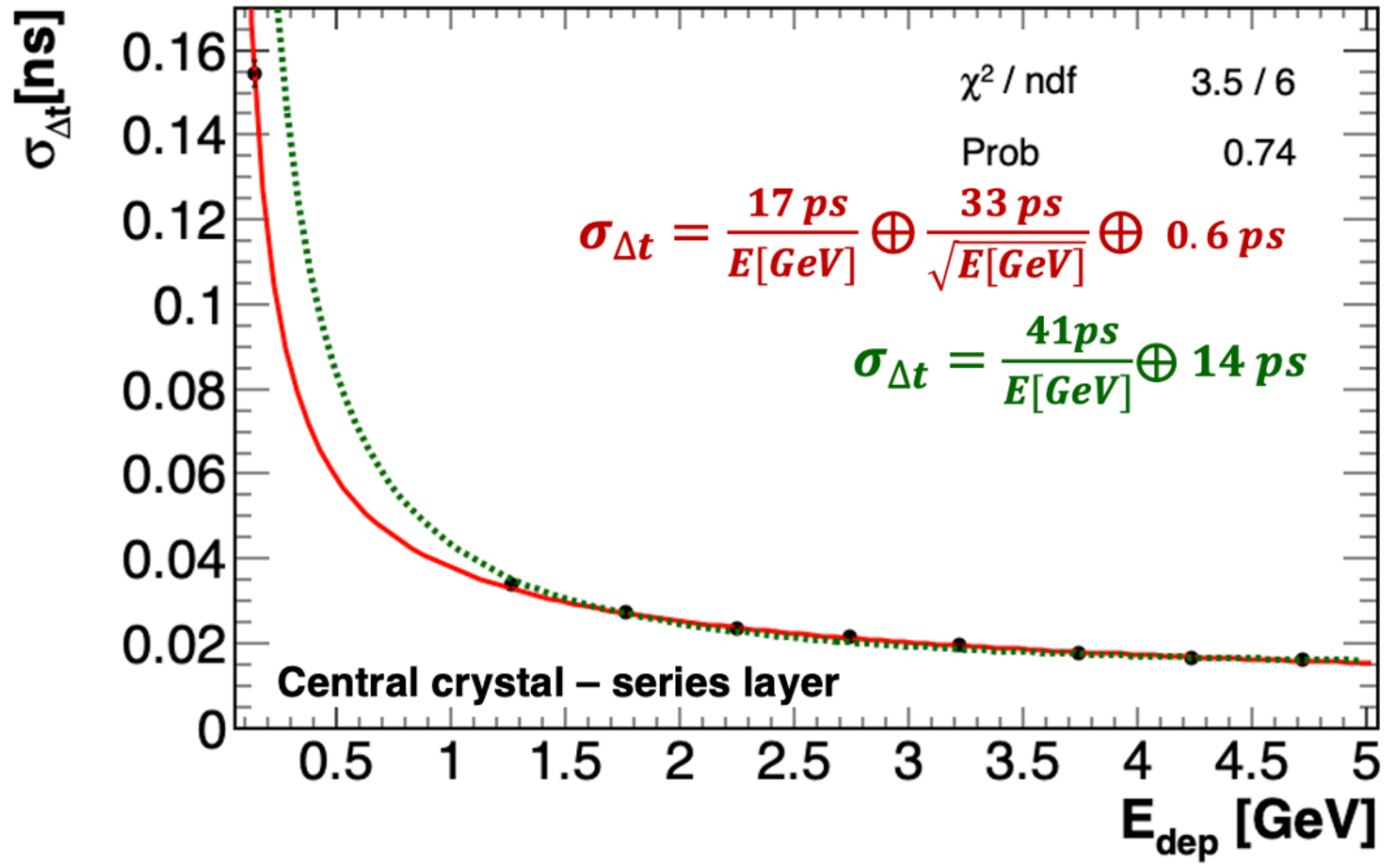
Hydraulic connectors

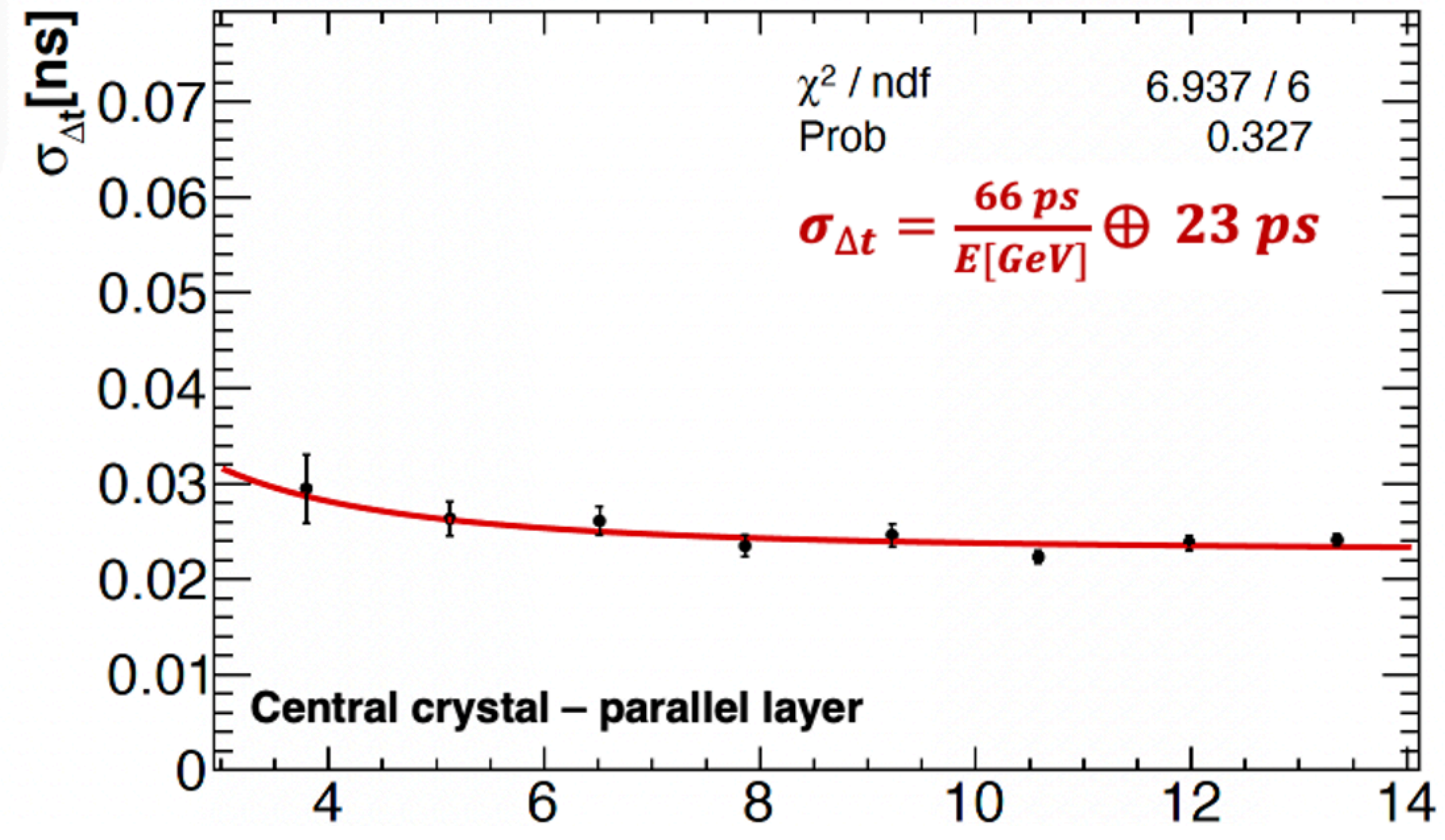
matrix cases made of ABS plastic

Seal

Locking plates







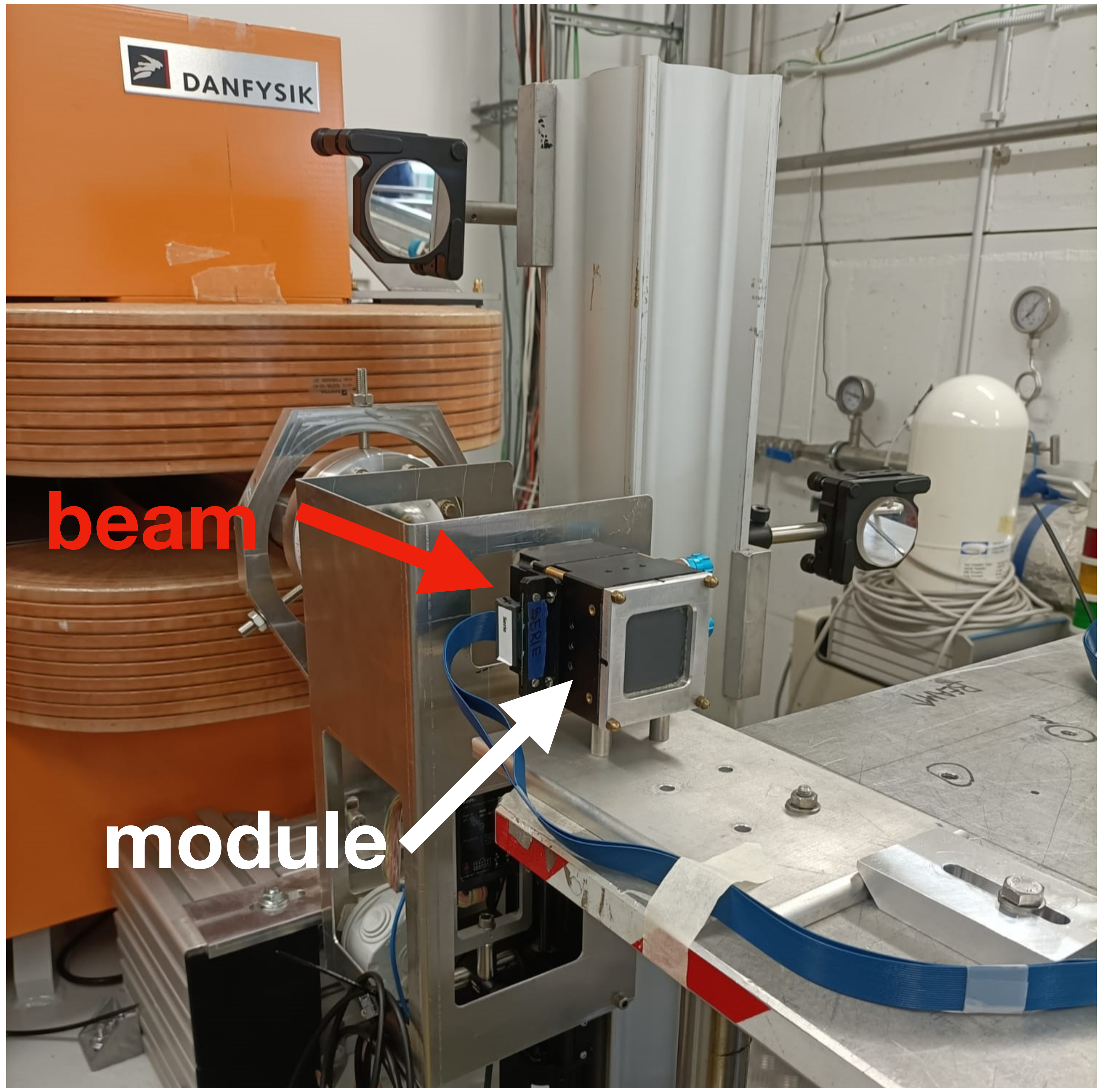
Irradiation study: March 2024 Test Beam

Goal: study the LY loss of one layer of Proto-1 after γ ray irradiation (**80 kGy** dose) for different wrappings

Irradiation at Calliope (Enea Casaccia), ^{60}Co γ source, $E_\gamma = 1.25$ MeV

TB carried out at LNF BTF using e^- beam with multiplicity 1 and **E = 450 MeV**

Beam centred on each crystal at each run, to study charge deposition in each crystal



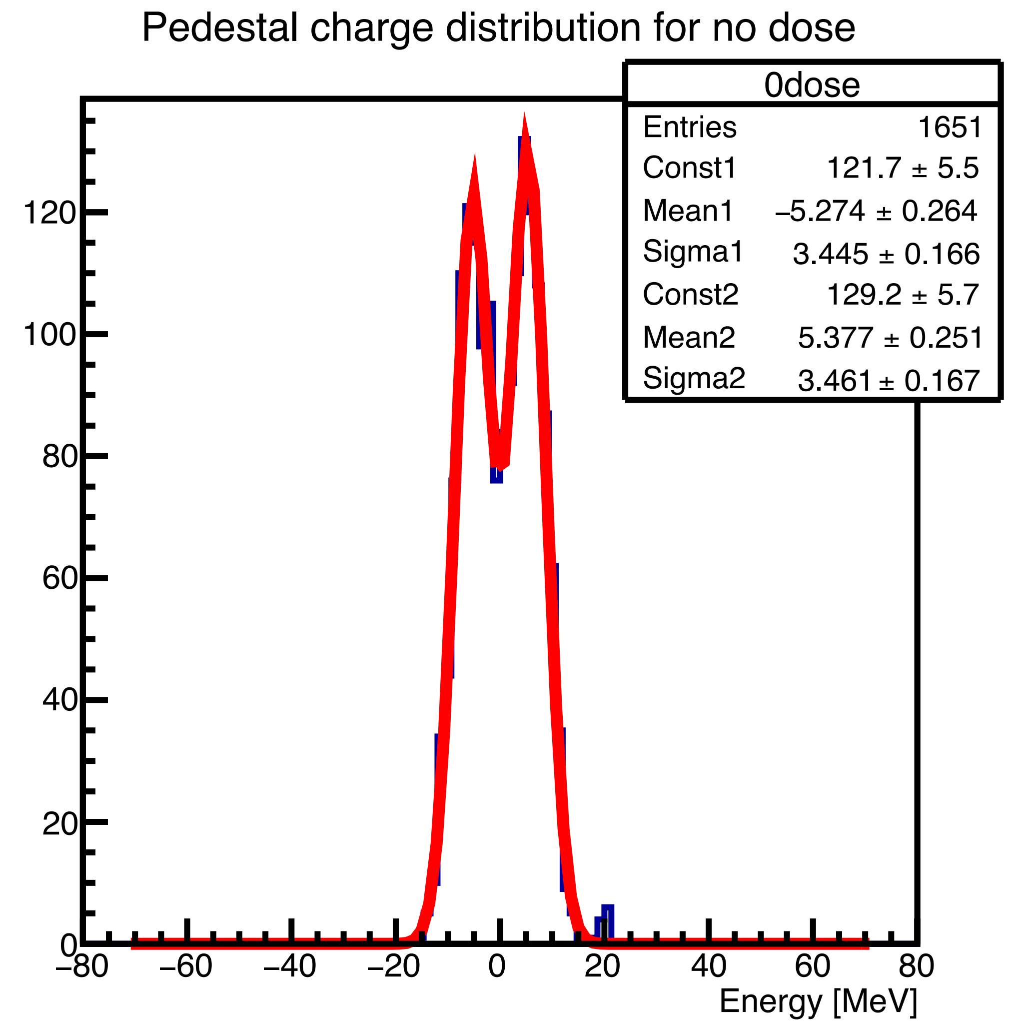
TB timeline:
→ non irradiated module, **Teflon** wrapping + optical grease
→ same setup after 80 kGy dose
→ new crystals, **Mylar** wrapping + optical grease
→ same setup after 10 kGy dose
→ same setup after additional 70 kGy dose (80 kGy on crystals)
→ same setup after 48h and 60h from irradiation

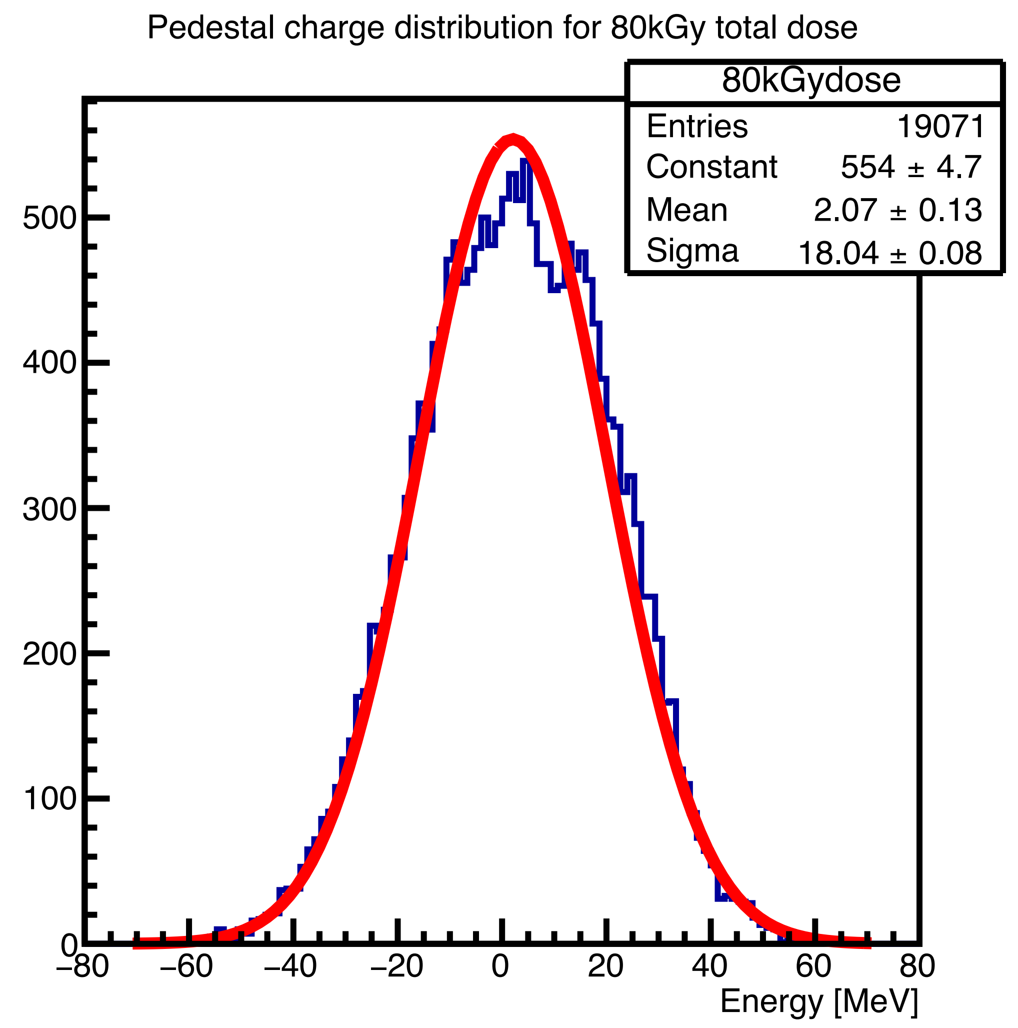
Signal study: pedestals

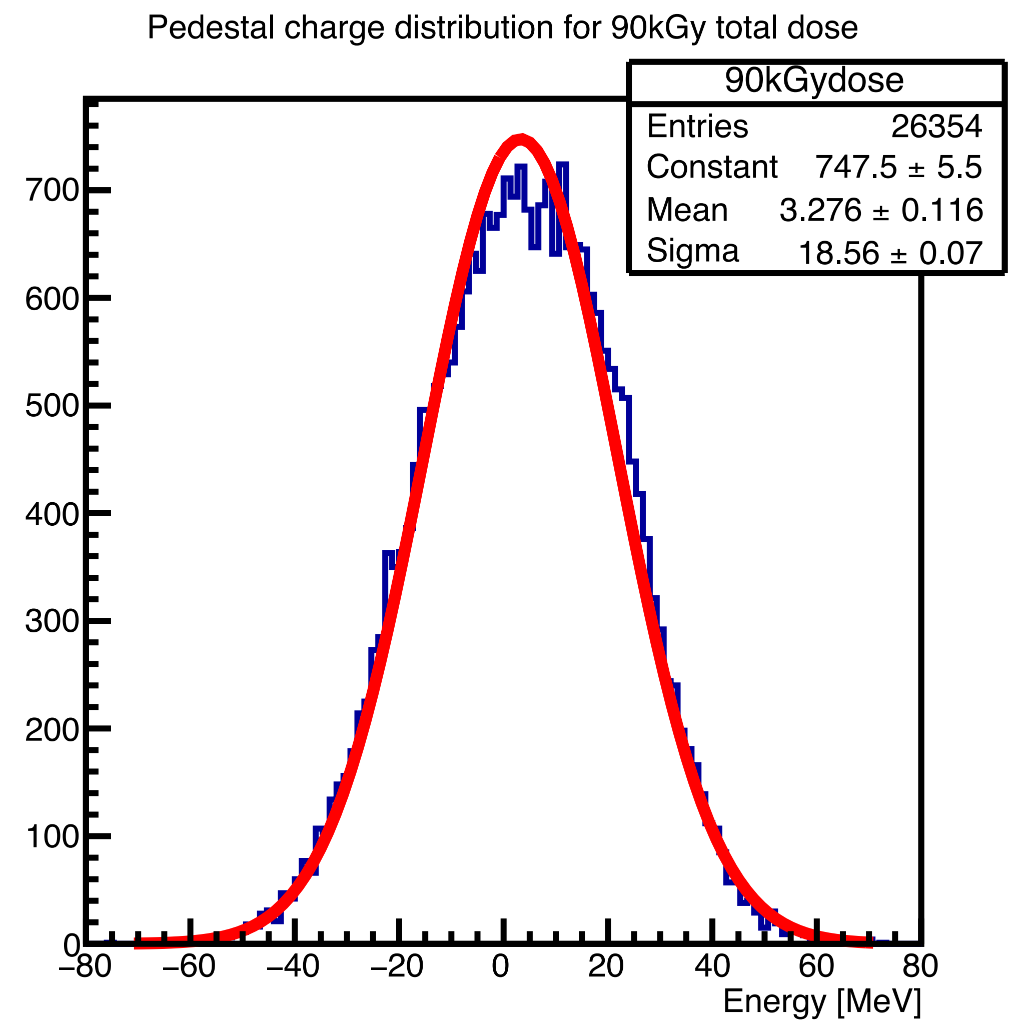
Waveform integration to get charge deposition

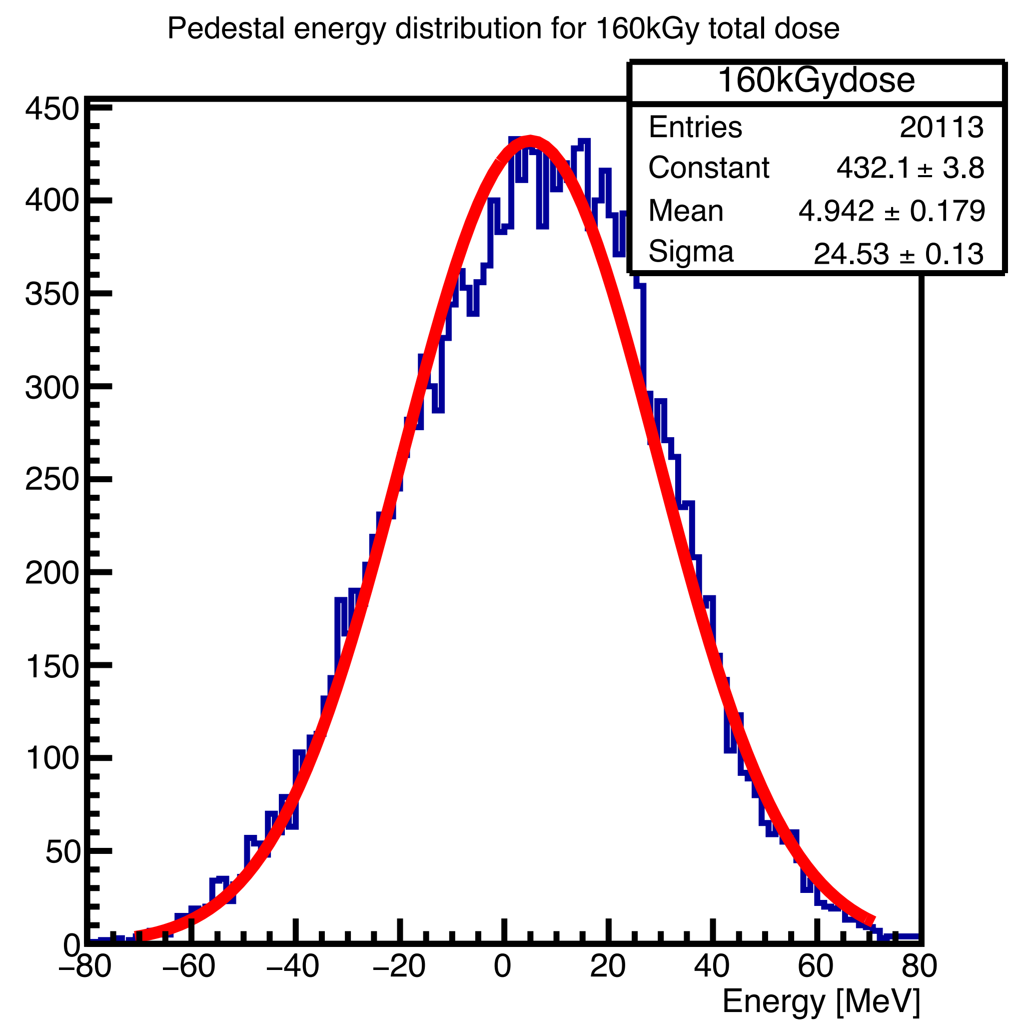
Pedestal charge is selected using random triggers and empty events, and is fit to a Gaussian
(pre dose double Gaussian distribution is due to the DAQ board characteristics)

Sigma increases with dose → cannot use a constant cut on the deposited charge to exclude the pedestal
→use the BTF lead glass calorimeter (behind Crilin) to perform the pedestal cut


Pedestal charge distribution for no dose


Pedestal charge distribution for 80kGy total dose

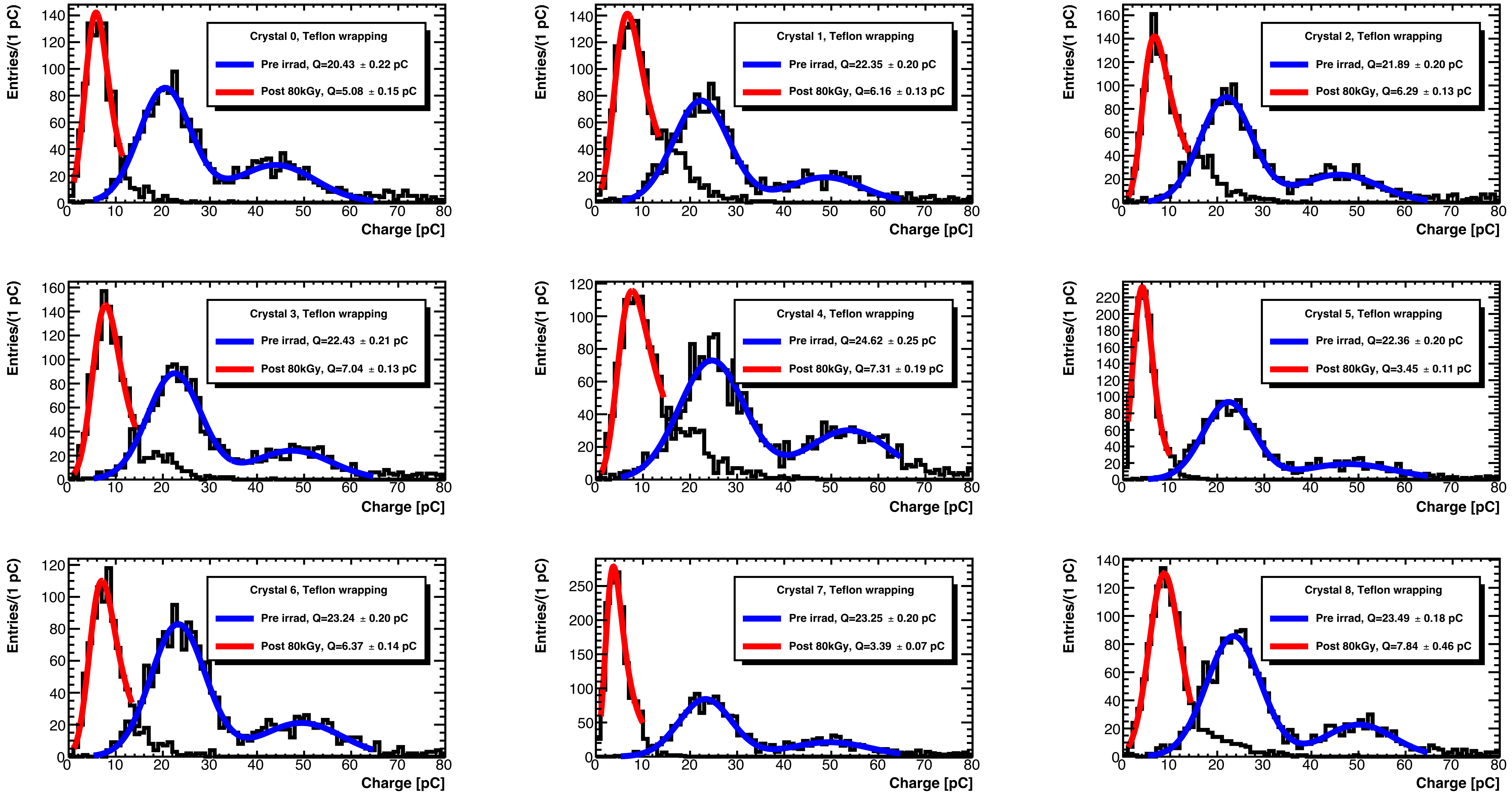

Pedestal charge distribution for 90kGy total dose


Pedestal energy distribution for 160kGy total dose

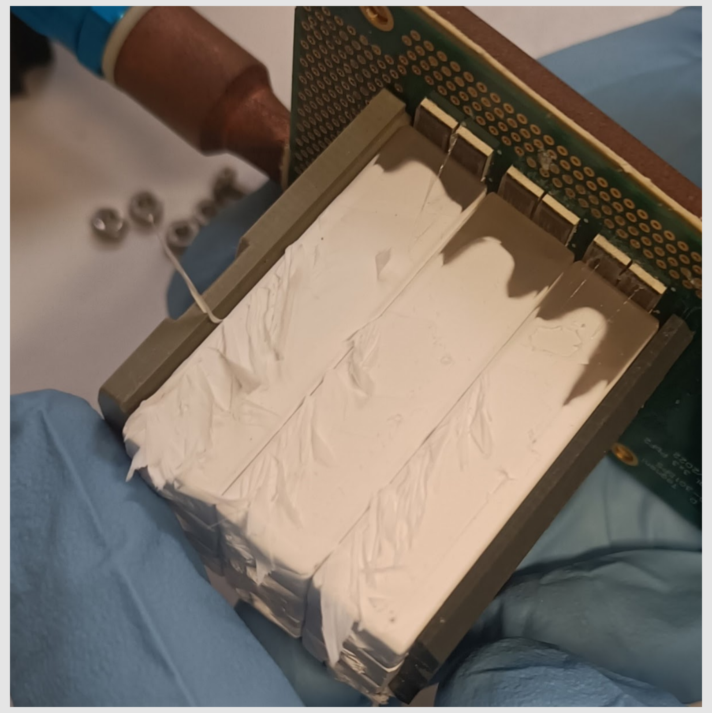
example: readout channel 11

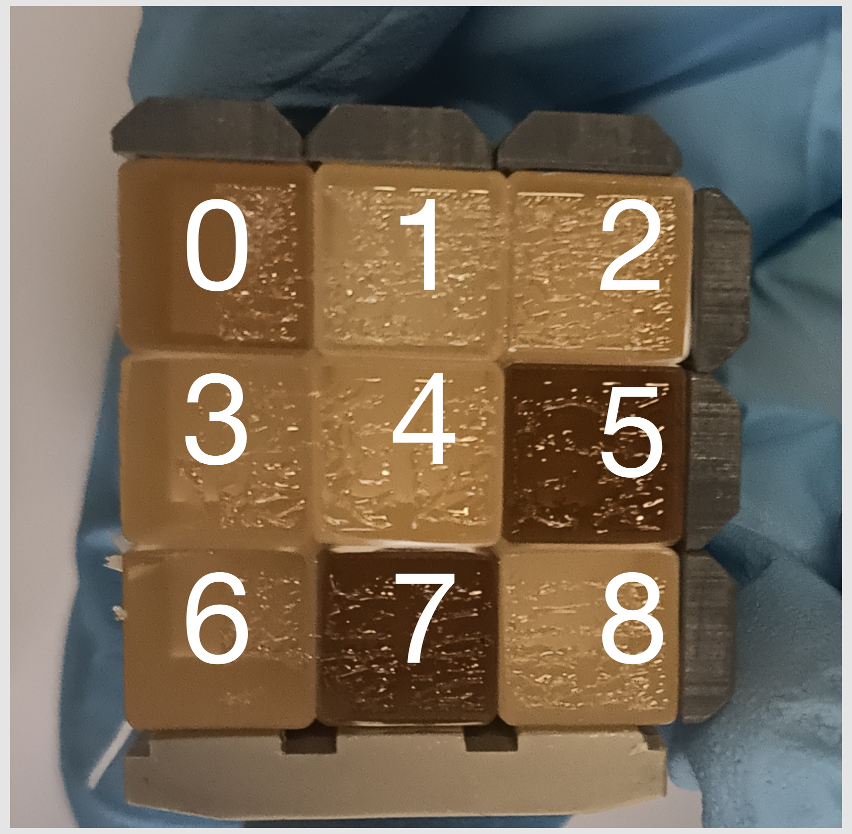
Charge distribution, Teflon wrapping

Pedestal cut: charge deposition in the BTF calorimeter [5, 10] pC



After irradiation: teflon was damaged and brittle, **crystals lost transparency**



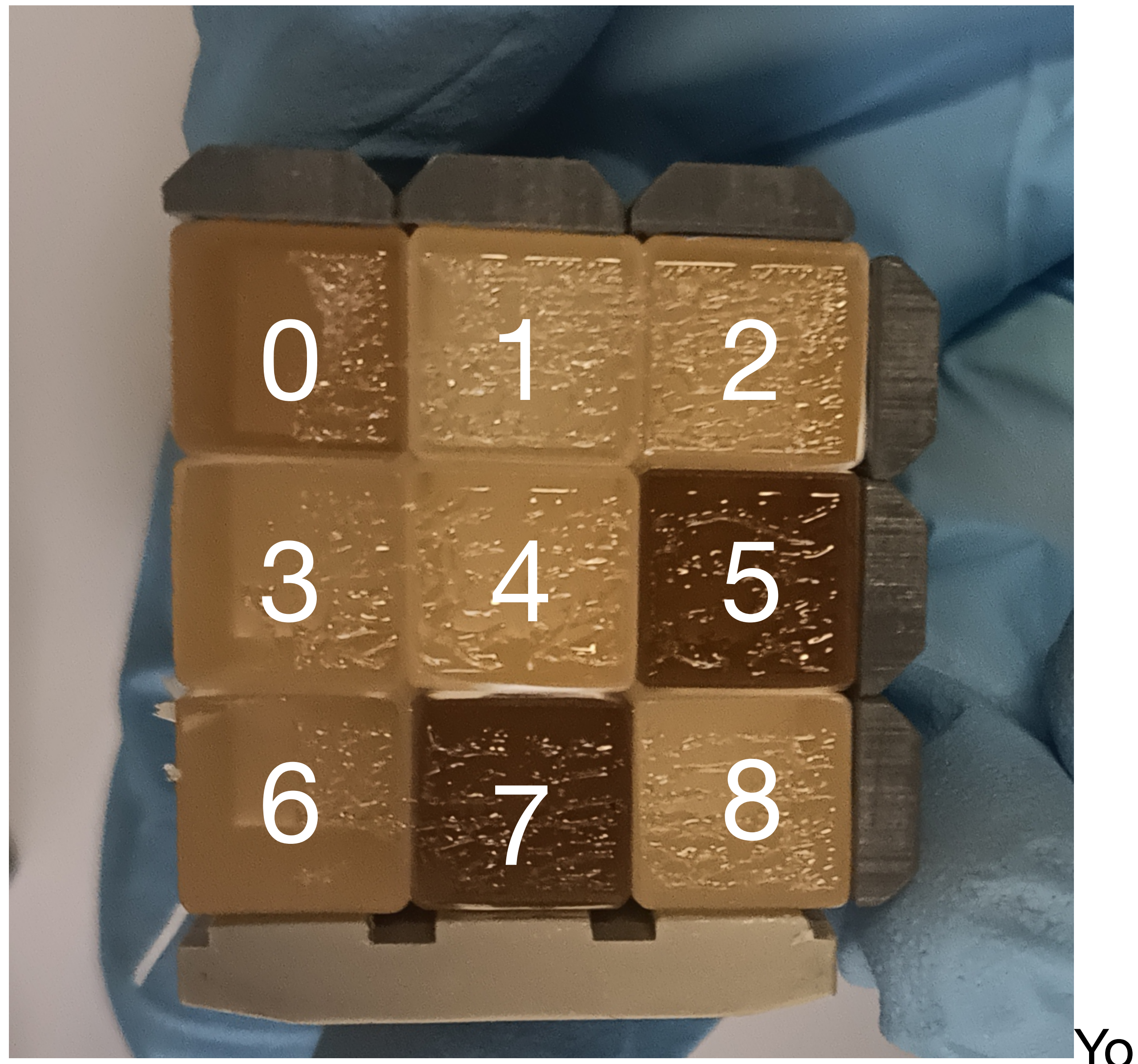


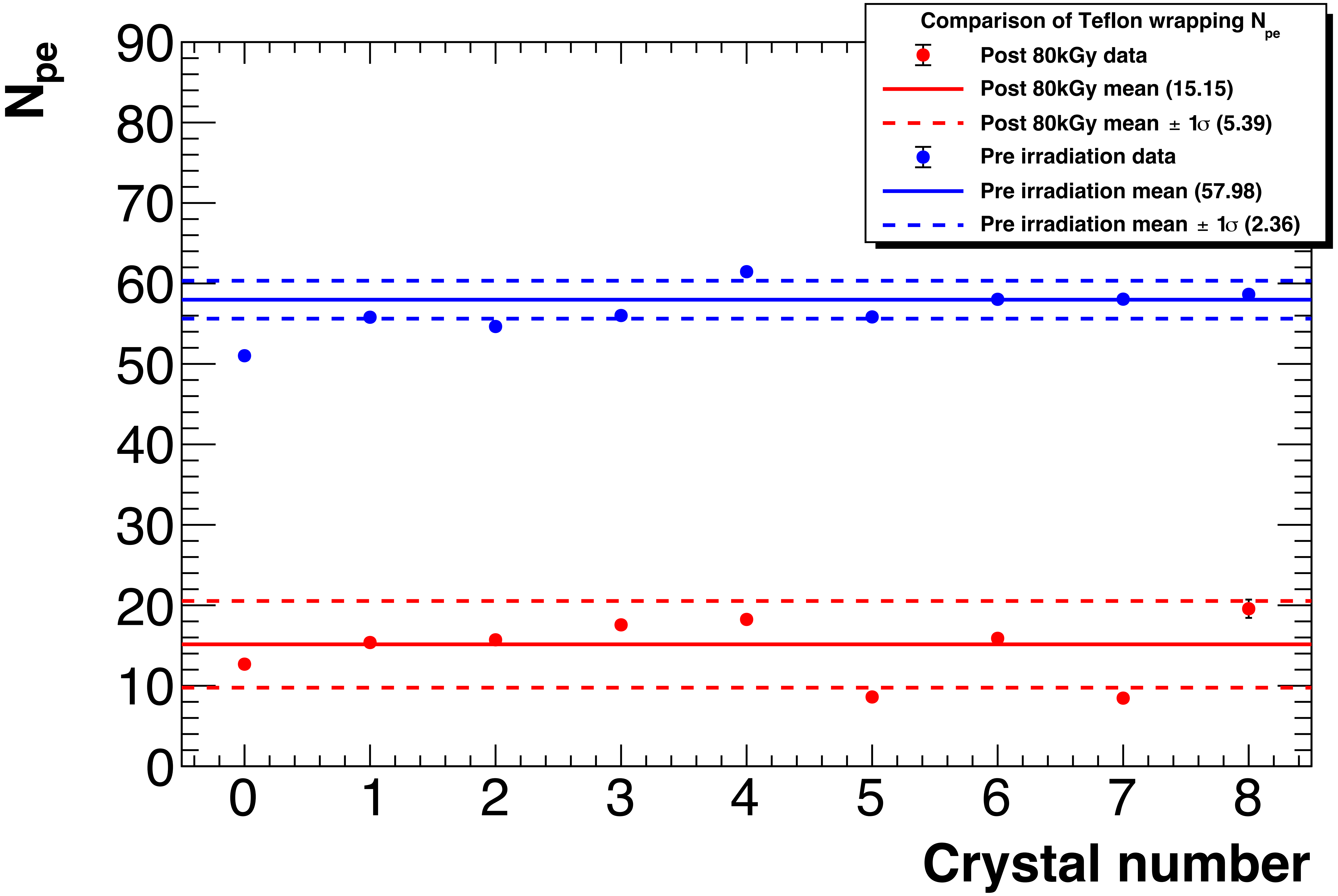
Number of photoelectrons, Teflon wrapping

The number of photoelectrons (N_{pe}) is computed using:

$$N_{pe} = \frac{Q}{e \cdot G_{FEE} \cdot G_{SiPM}}$$

where $G_{FEE} = 10$, $G_{SiPM} = 2.5 \cdot 10^5$ at $V_{bias} = 91$ V

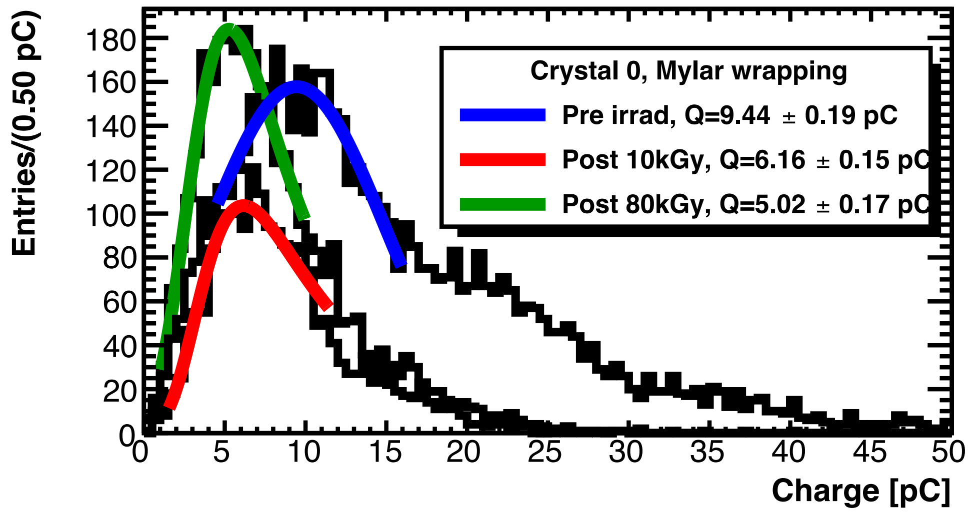


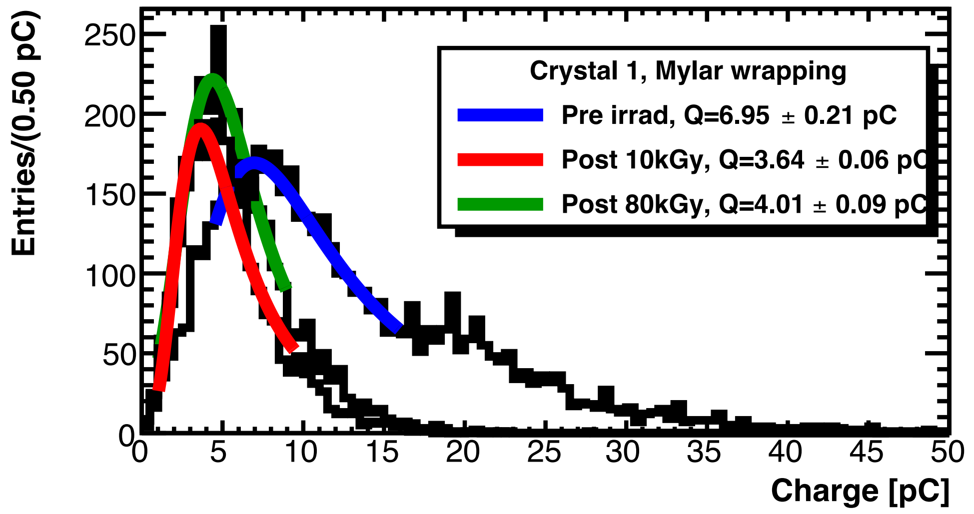


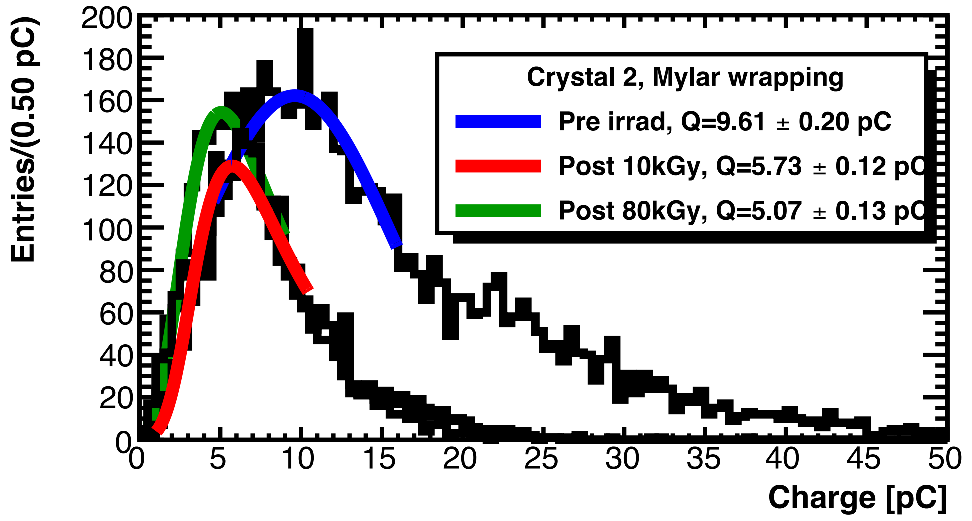
Darker crystals give lower N_{pe} after irradiation

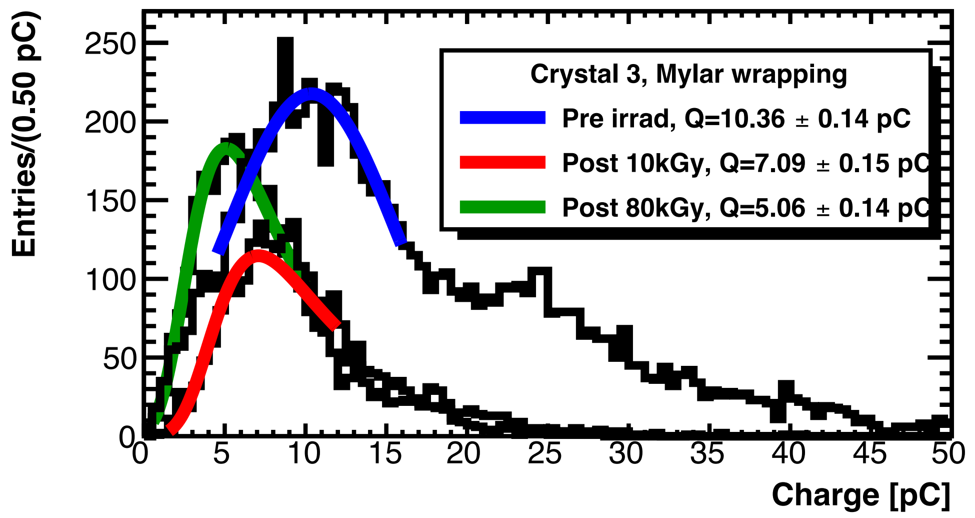
Charge distribution, Mylar wrapping

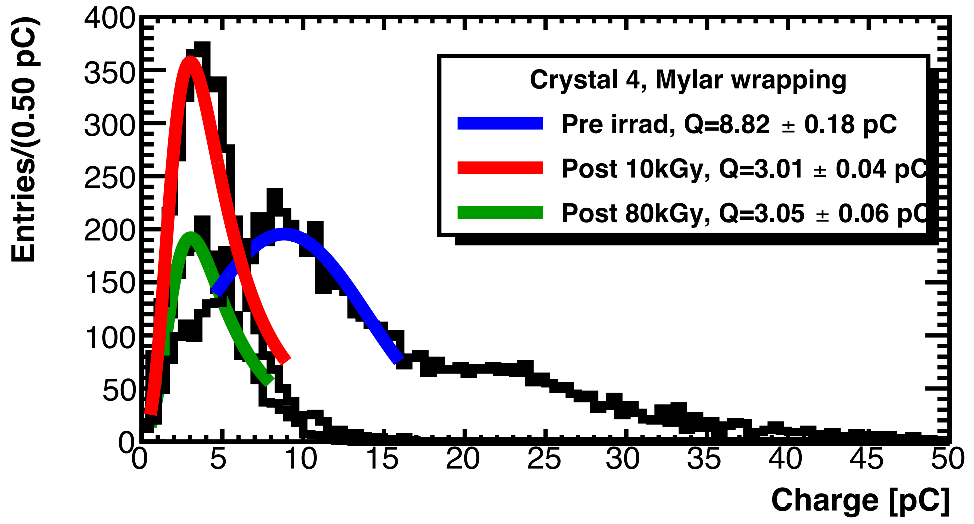
Pedestal cut: charge deposition in the BTF calorimeter > 5pC before 10kGy irradiation, [3, 8] pC after

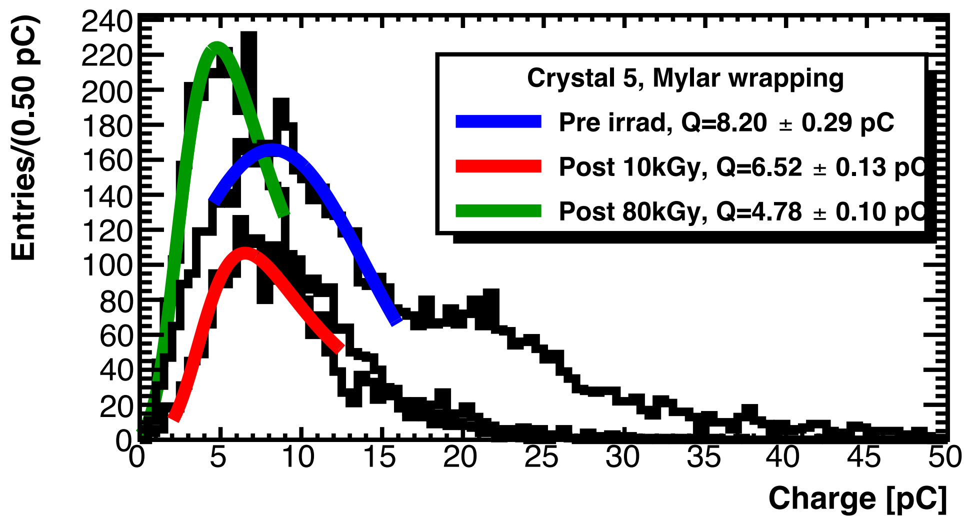


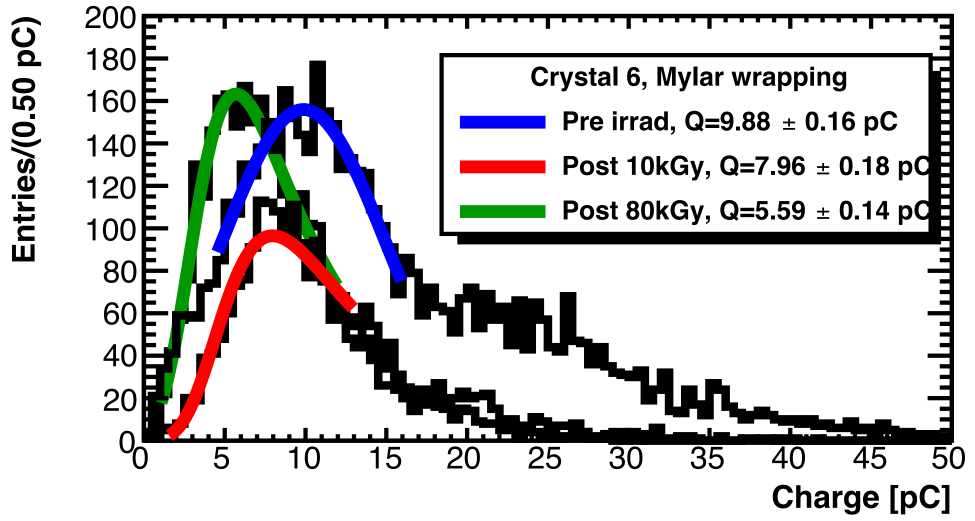


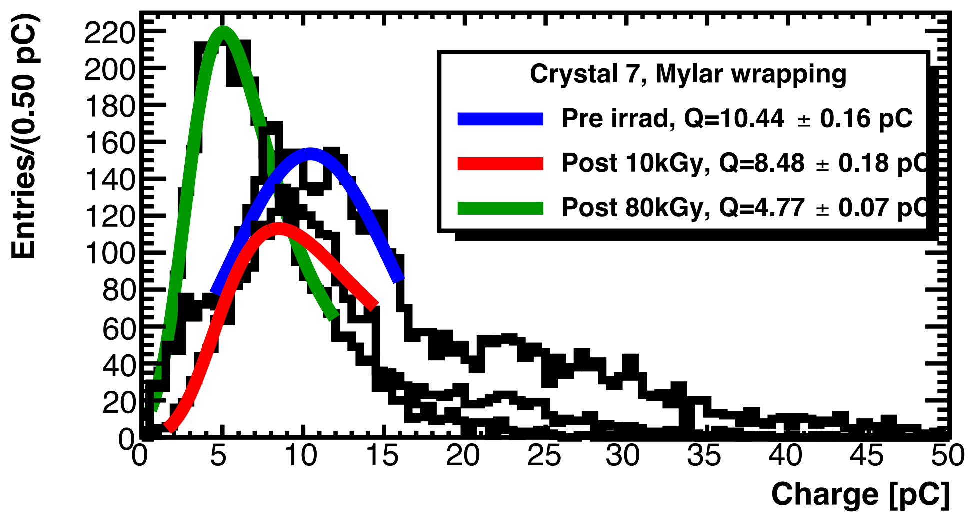


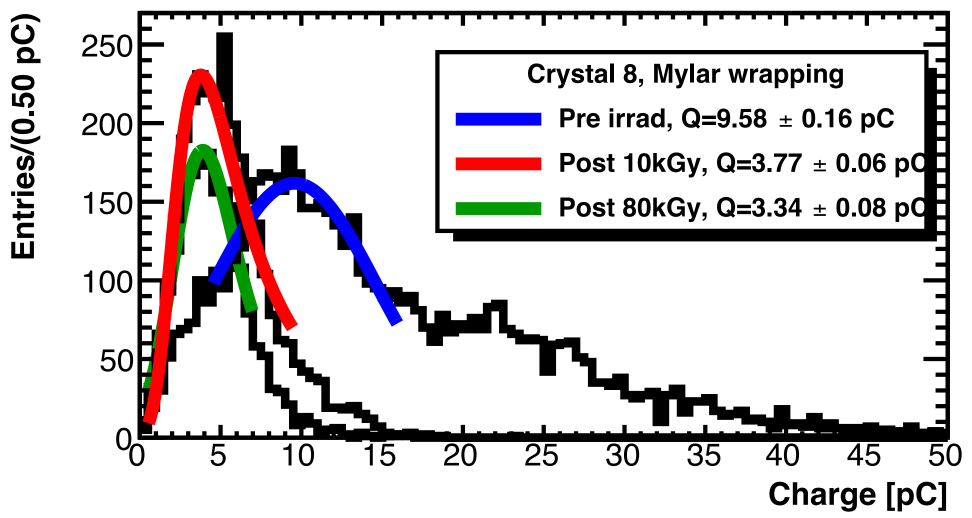




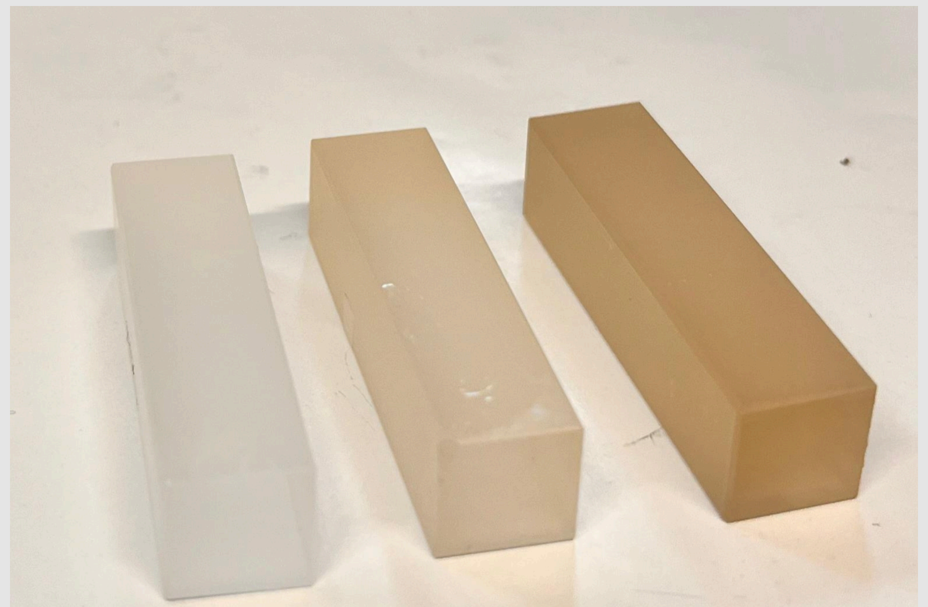








Similar crystal status after irradiation, **transparency loss was uniform length-wise in the crystals**

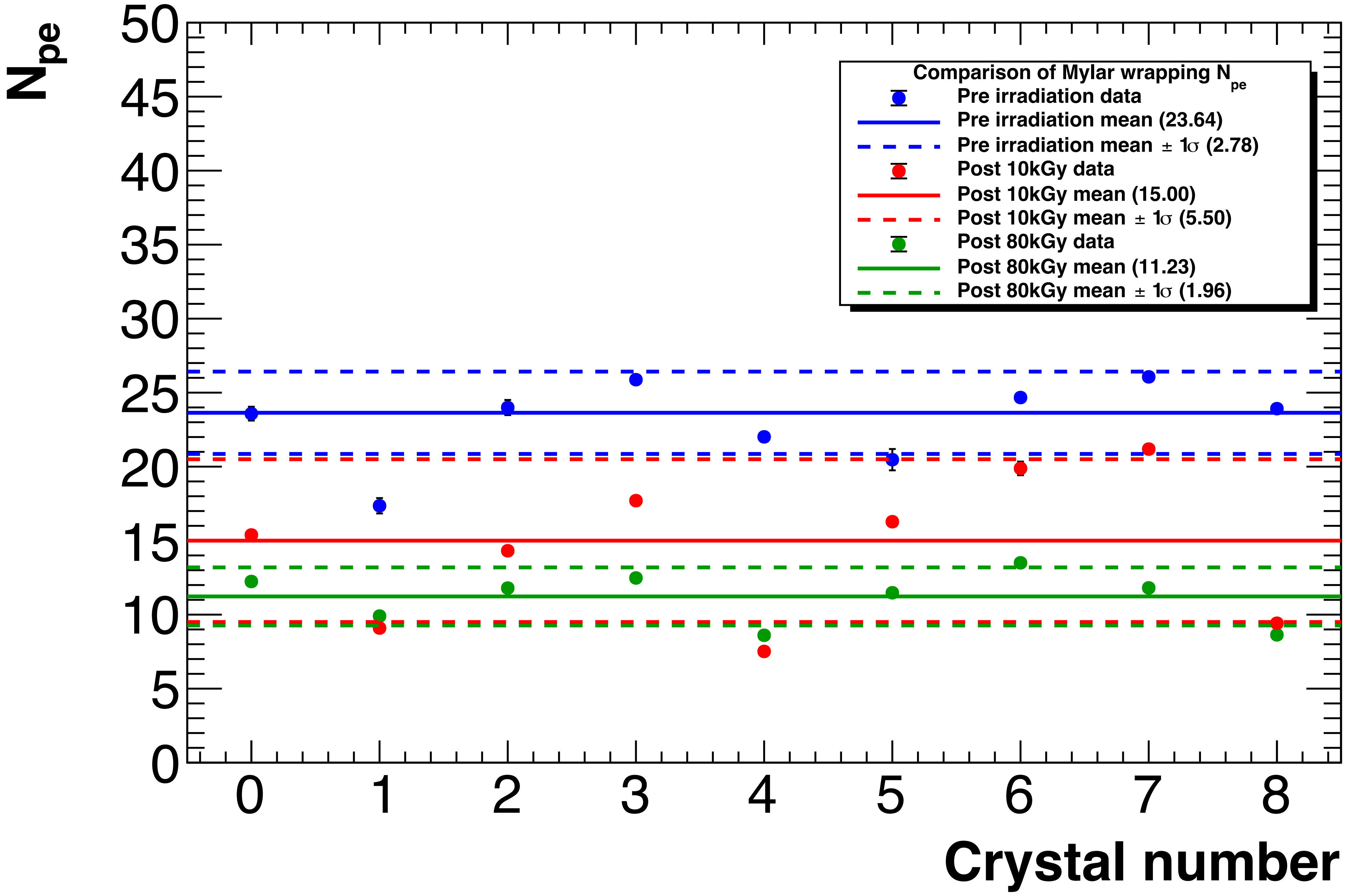


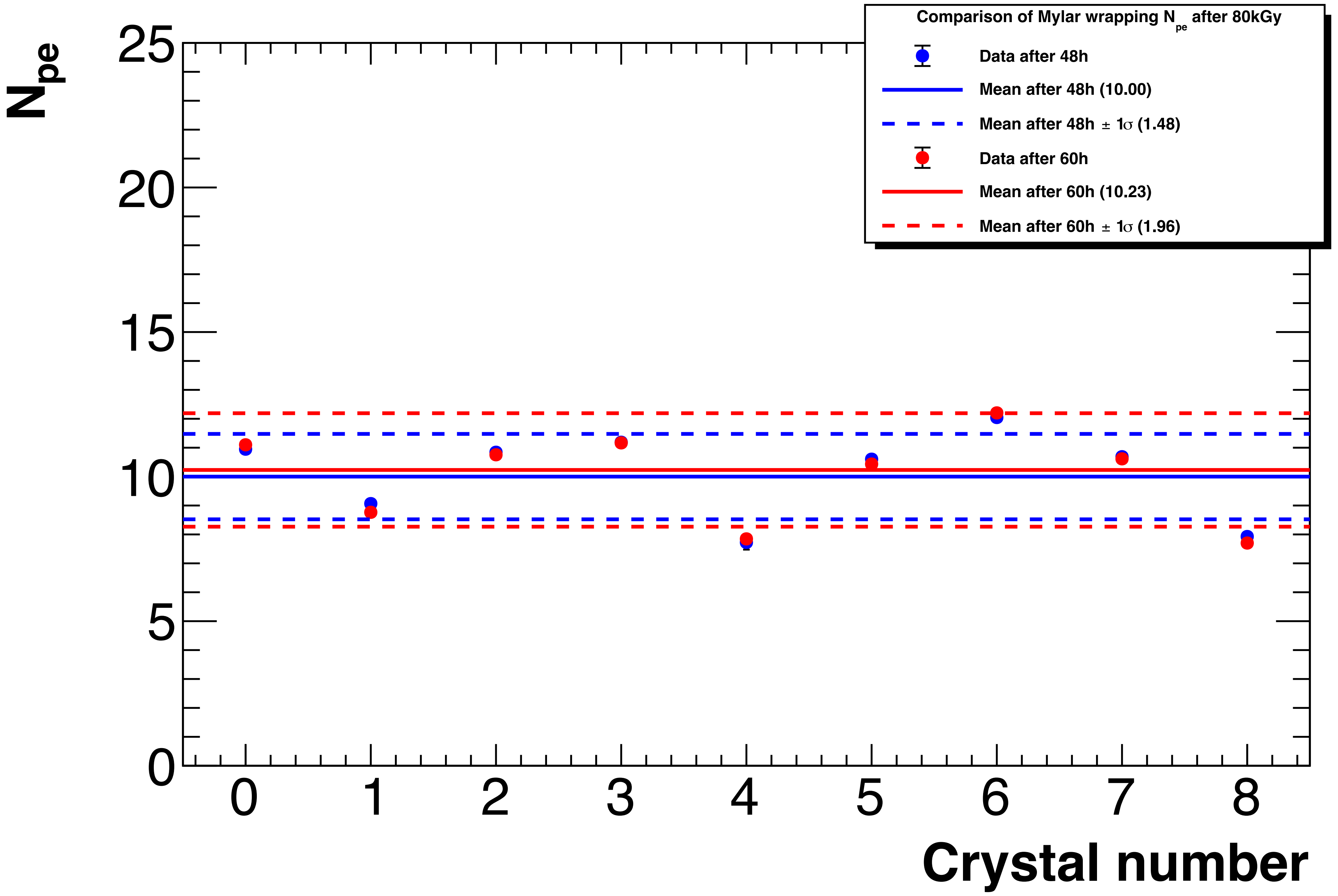
no dose **80 kGy dose**

N_{pe} for Mylar wrapping, + annealing

Post irradiation data shows a lower number of photoelectrons

After 48h and 60h, the charge distribution remains the same, and the N_{pe} estimate remains compatible with the one **right after the 80kGy irradiation**





Summary and next steps

- There was considerable **variability in the crystals' response** to radiation, despite the predictor's claim to have used >99.9% pure PbF_2 powder for crystal growth
- **New tests** have been planned to evaluate SiPMs PDE loss and optical grease degradation
- Next step would be to test the **SiPMs response** without irradiating the crystals, and conduct new irradiation tests monitoring the **Cherenkov light variations** using a blue laser
- An idea for future optimisation is using **$PbWO_4$-UF** crystals in the first ECAL layer (stable up to 2 MGy)

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Next steps:
Won a PRIN proposal for a grant partly assigned to develop a **5x5 x4 layers** prototype (1 M_R, ~16.8 X_0)

Plan for 2025:
Expand the prototype to a **9x9 x5 layers** module (2 M_R, ~22 X_0)