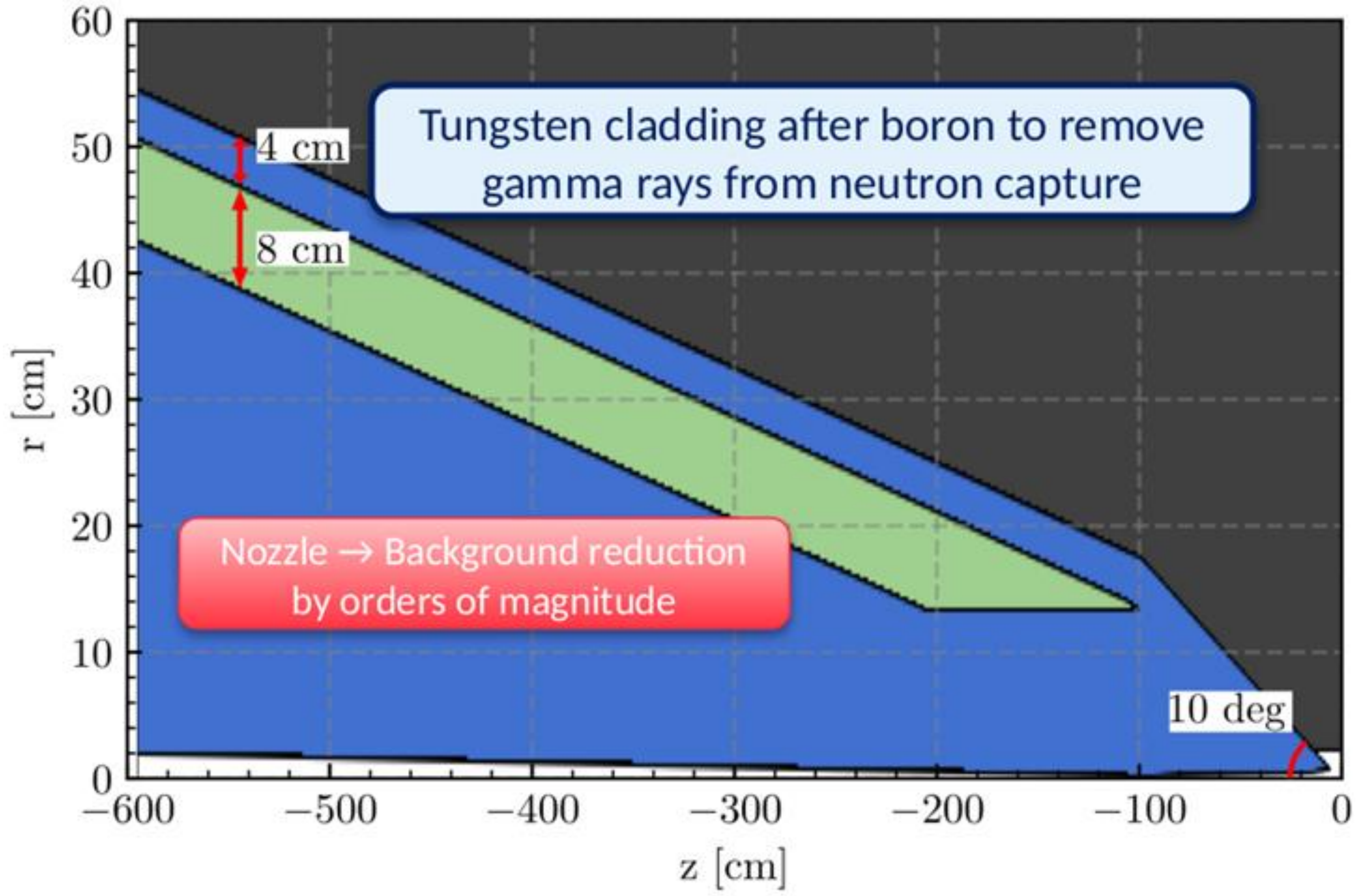
RD_Mucol @ LNF

Machine-Detector Interface

- **All activities are now oriented towards the preparation for the Update of the European Strategy for Particle Physics (submission of contributions is due by March 26, 2025).**

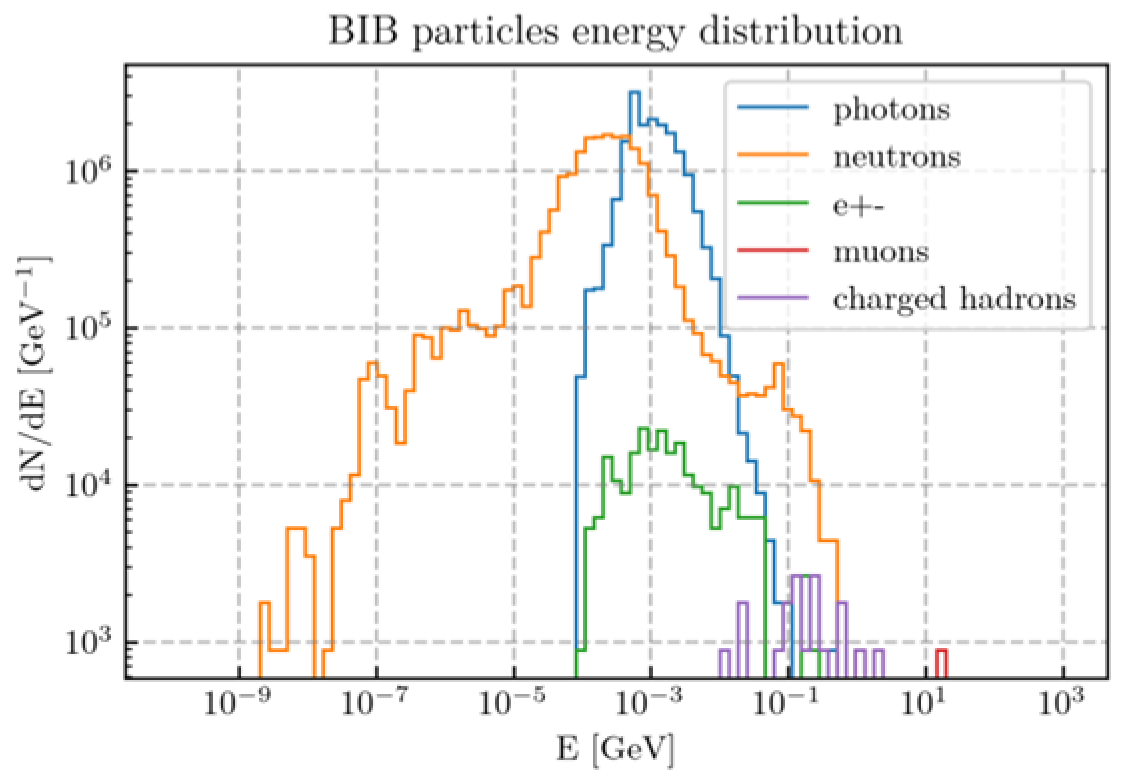
New nozzle design for 10 TeV

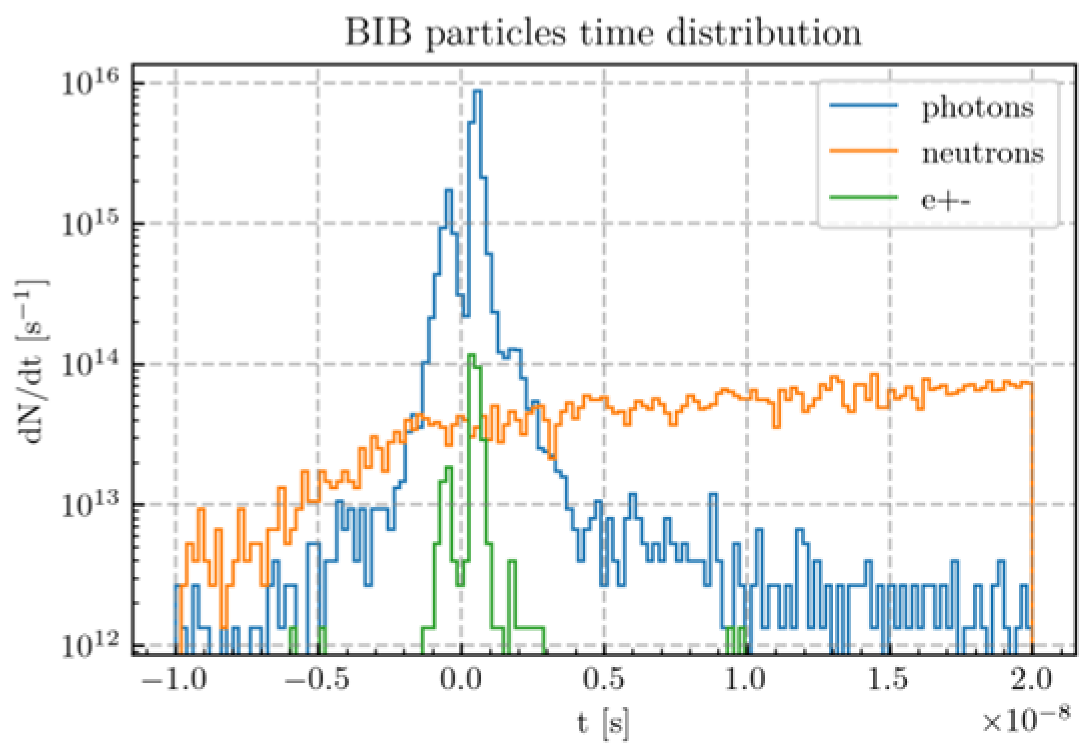


Realistic material composition

Component	Density [g/cm3]	Element	Atomic Fraction (mass fraction if negative)
EM Shower Absorber	18	W	-0.95
		Ni	-0.035
		Cu	-0.015
Neutron Absorber	0.918	H	0.5
		C	0.25
		B	0.25

Available high-statistics BIB sample with the new nozzles.



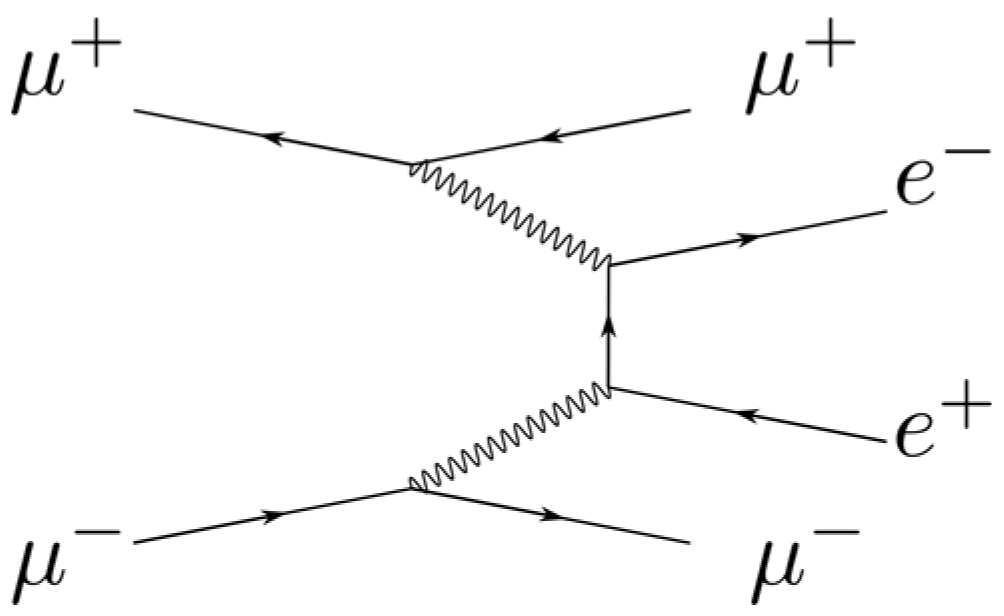


MAP's 1.5 TeV nozzle — new 10 TeV nozzle

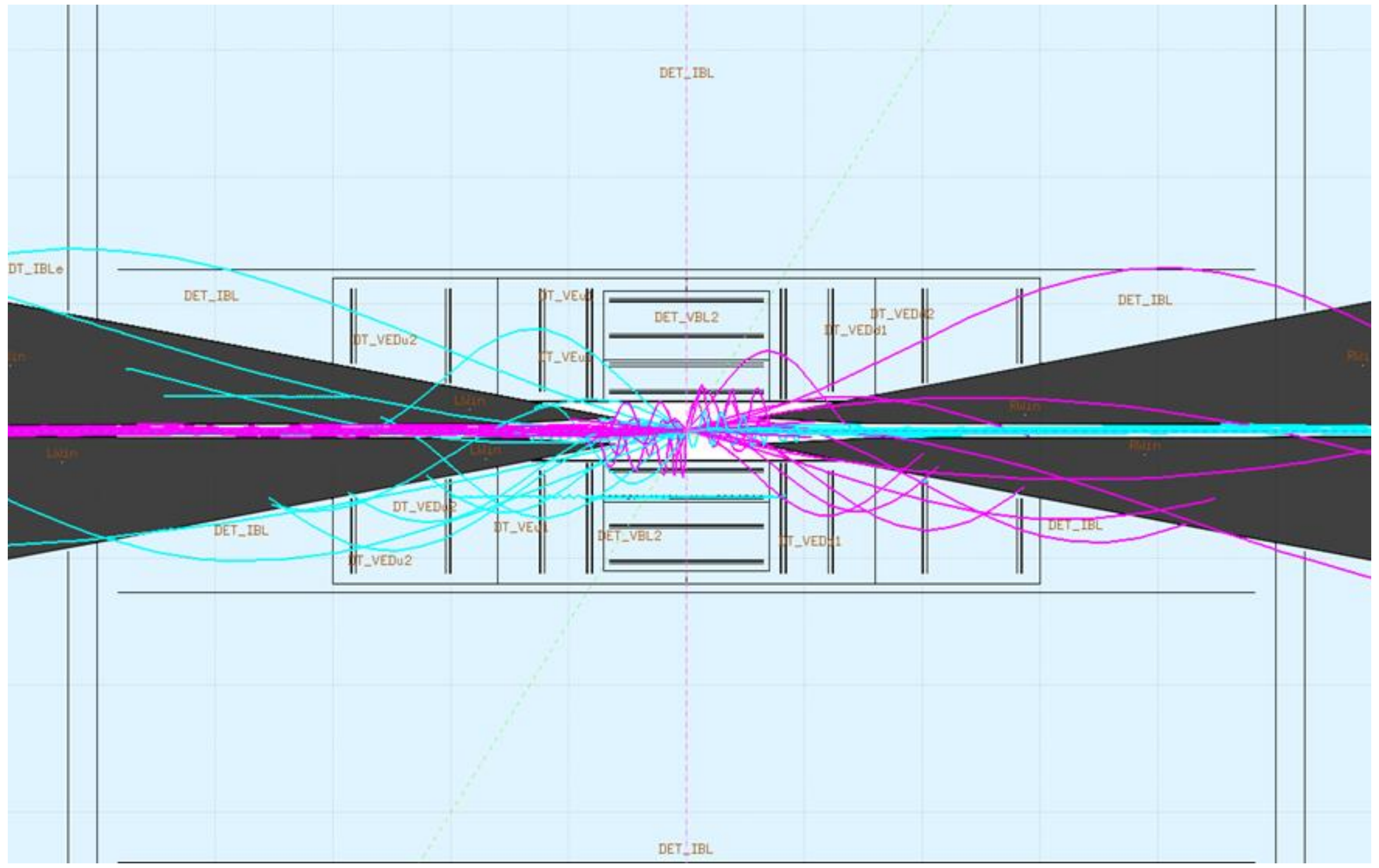
Collider energy	1.5 TeV	3 TeV	10 TeV (v 0.8)	10 TeV (EU24*)
Photons	7.1E+07	9.6E+07	1.6E+08	9.9E+07
Neutron	4.7E+07	5.8E+07	1.4E+08	1.1E+08
e+/e-	7.1E+05	9.3E+05	8.9E+05	1.2E+06
Ch. hadrons	1.7E+04	2.0E+04	5.2E+04	4.2E+04
Muons	3.1E+03	3.3E+03	3.3E+03	9.6E+03

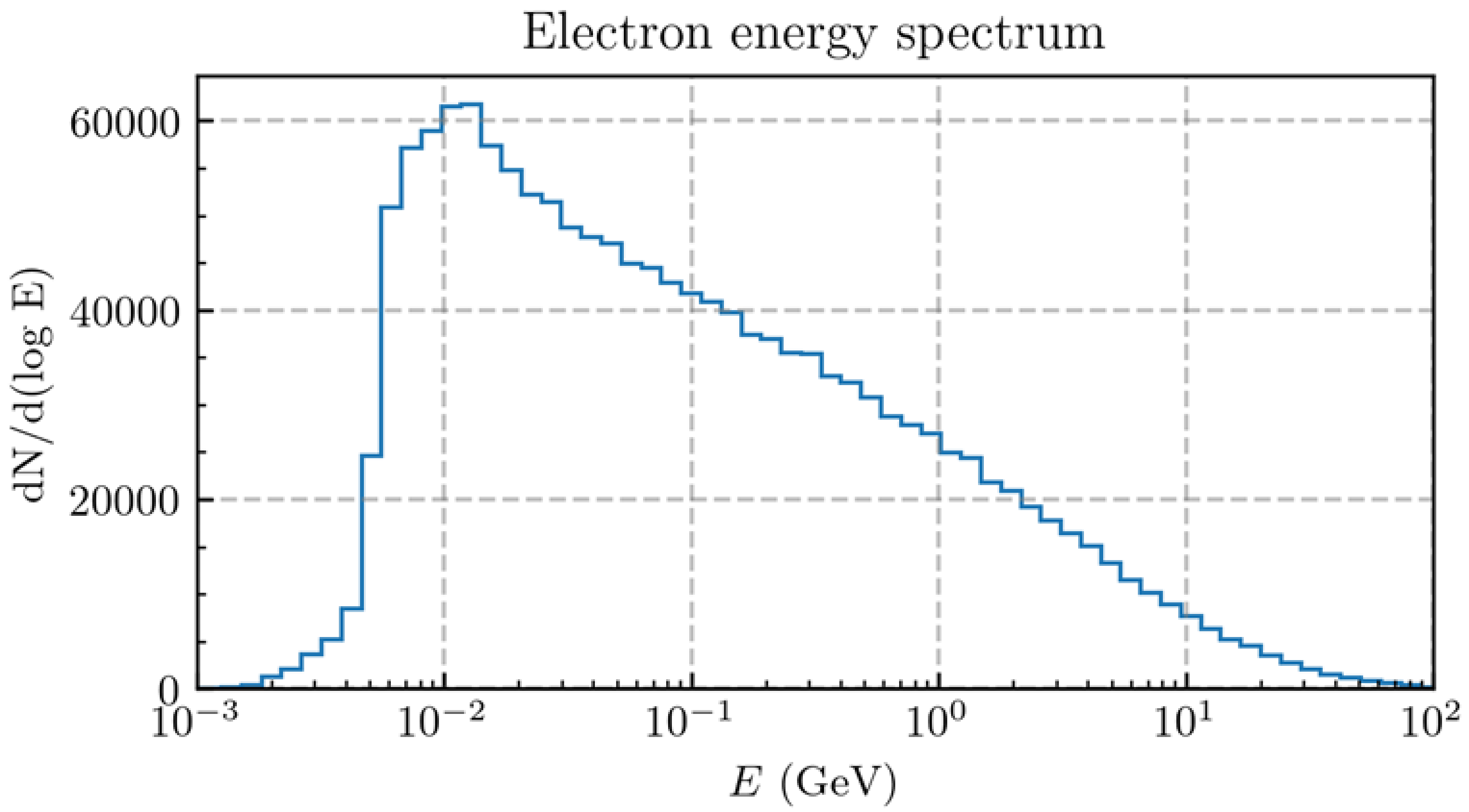
Incoherent e^+e^- pair production

- Additional significant background from incoherent e^+e^- pairs produced at bunch crossing is now taken into account:



- relatively high-energy $e^{+/-}$ enter the detector at the interaction point **in time with the bunch crossing**;
- the solenoidal B field confines most of the $e^{+/-}$ in the innermost region close to the beampipe;
- mainly the vertex detector and the inner tracker layers are affected.





10 TeV	BIB	e^+e^- pairs
Photons	9.9E+07	4.0E+06
Neutron	1.1E+08	1.3E+05
e+/e-	1.2E+06	2.1E+05

New detector concept for 10 TeV

- The requirements for the detector specifications from physics are similar to those of other multi-TeV machines to reconstruct:

- boosted low-pT physics objects from Standard Model processes;
- central energetic physics objects from decays of possible new massive states;
- less conventional experimental signatures: disappearing tracks, displaced leptons,
- displaced photons or jets, ...

- Constraints from the machine design: final focusing quadrupoles at ±6 m from the interaction point.

Ultimately, the detector design, the technological choices, and the development of the event reconstruction algorithms will be driven by the high levels of machine-induced background.

The MuSIC detector concept

The MuSIC detector (Muon Smasher for Interesting Collisions)

fully integrated in MuonColliderSoft

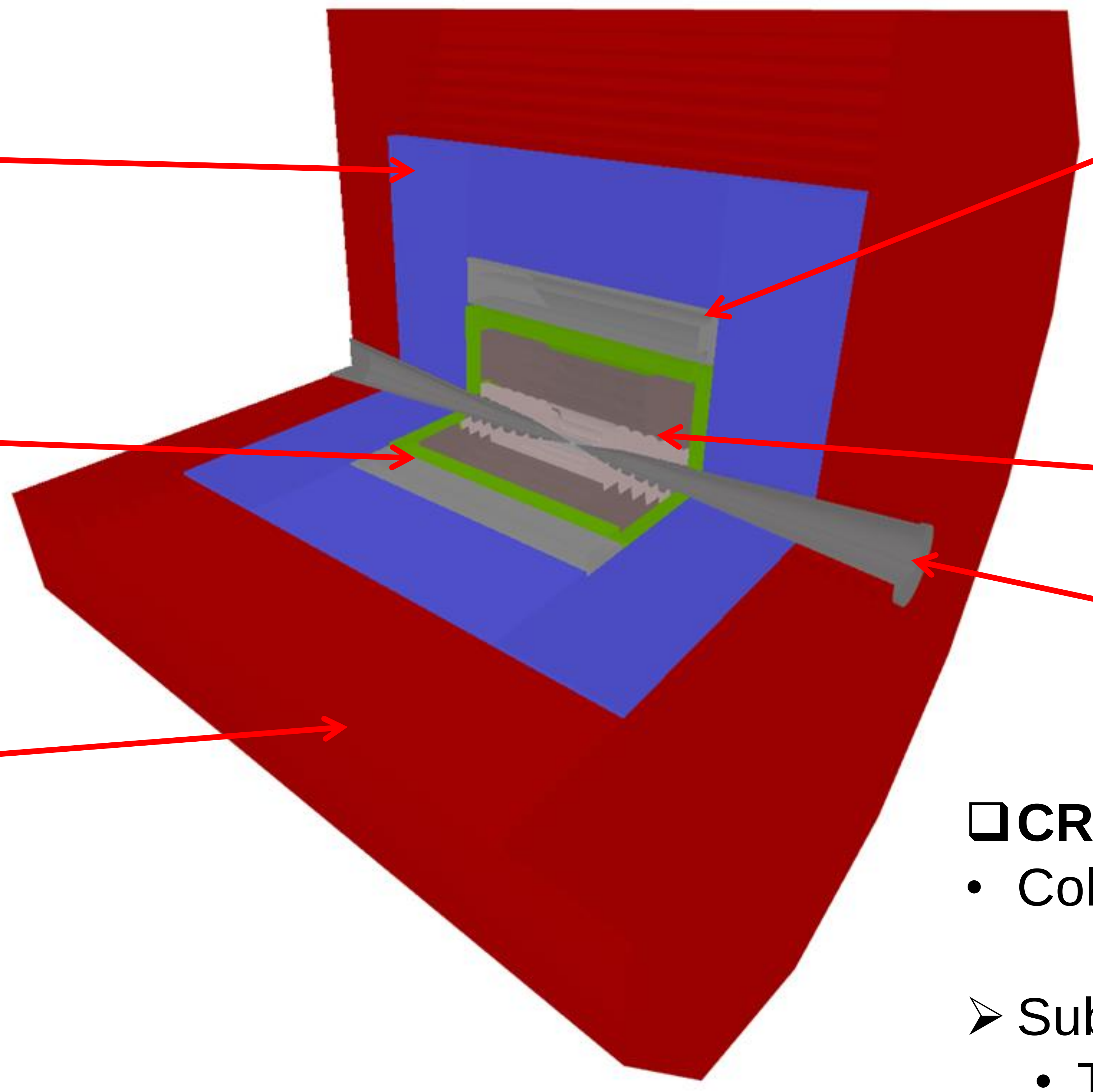
hadronic calorimeter:

- ✓ Fe-scintillator;
- ✓ Fe absorber serves as
- ✓ B-field flux return.

electromagnetic calorimeter:

- ✓ CRILIN (6 layers).

muon detectors



superconducting solenoid:
B = 5 T.

vertex detector and tracking system:
Full-silicon (pixels and macro pixels).

new 10-TeV nozzles

- ❑ **CRILIN** was conceived and is led by **LNF**
- • Collaboration with teams from **Padova, Trieste, and Torino**

➢ Submitted a **FIS-2 project** for:

- • The **electromagnetic calorimeter** (CRILIN) and an innovative **hadronic calorimeter**

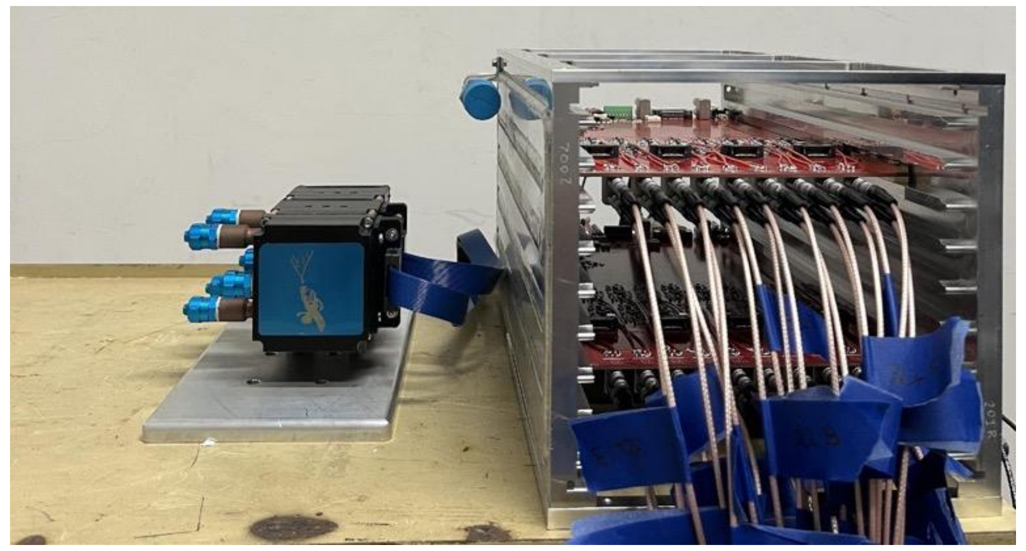
→ **MITICO** (MultI TeV Colliders CalOrimeter)

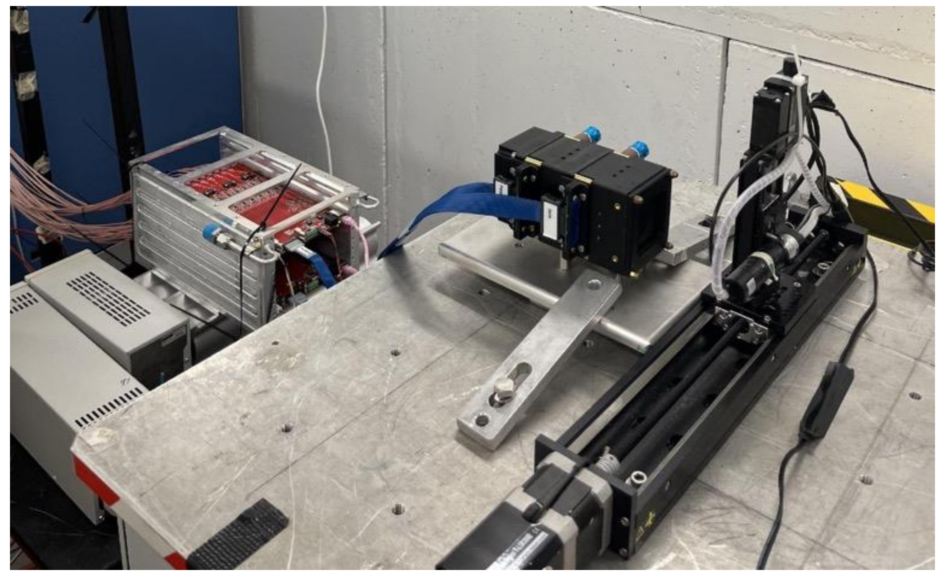
CRILIN
a CRystal calorImeter with Longitudinal Information for the future Muon Colliders

- **Irradiation Studies:** Irradiation studies with the designated dose have been concluded.

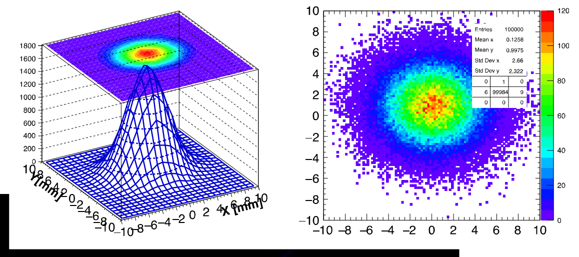
BTF, April 2024

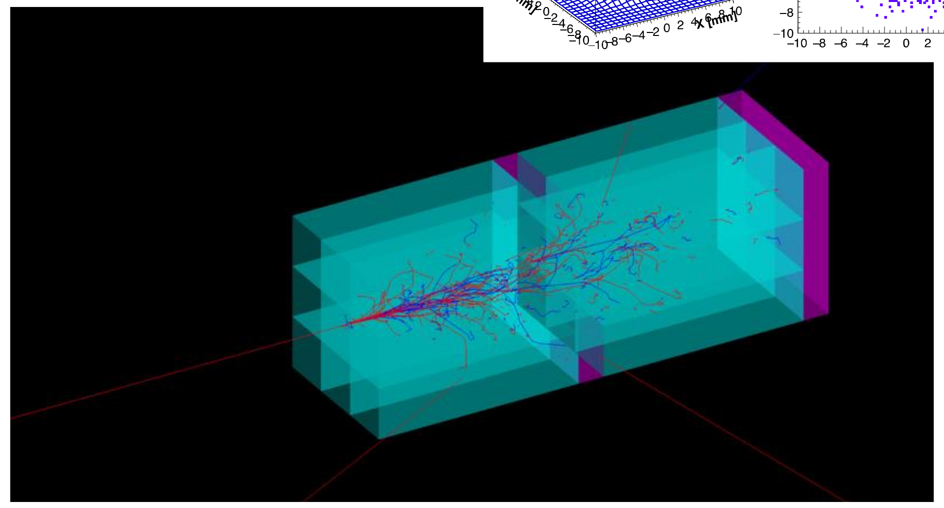
- Study of the LY loss of one layer of Proto-1 after Gamma ray irradiation
- Beam: 450 MeV electrons with multiplicity 1
- Beam centered on a different crystal at each run





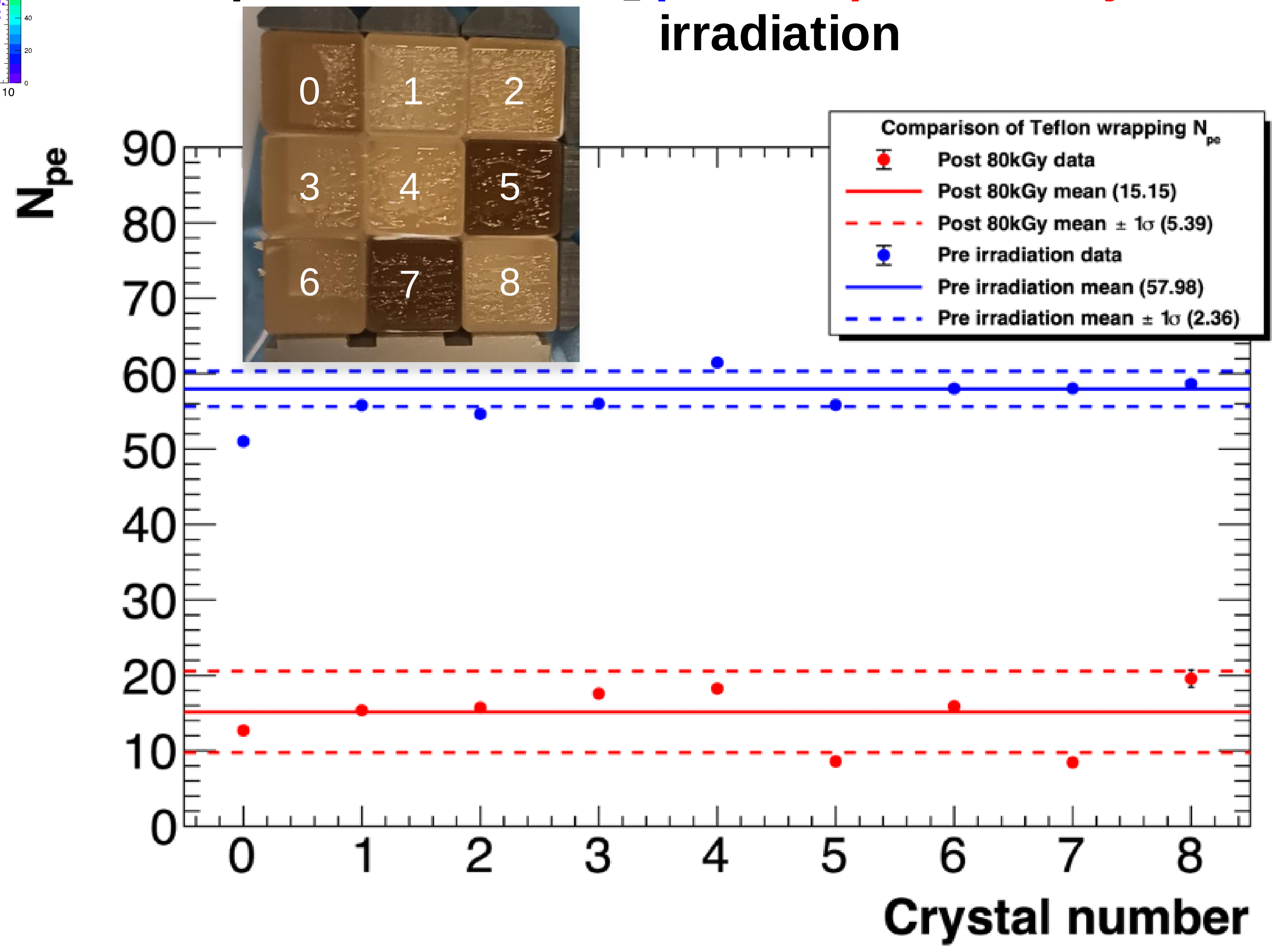
Monte Carlo





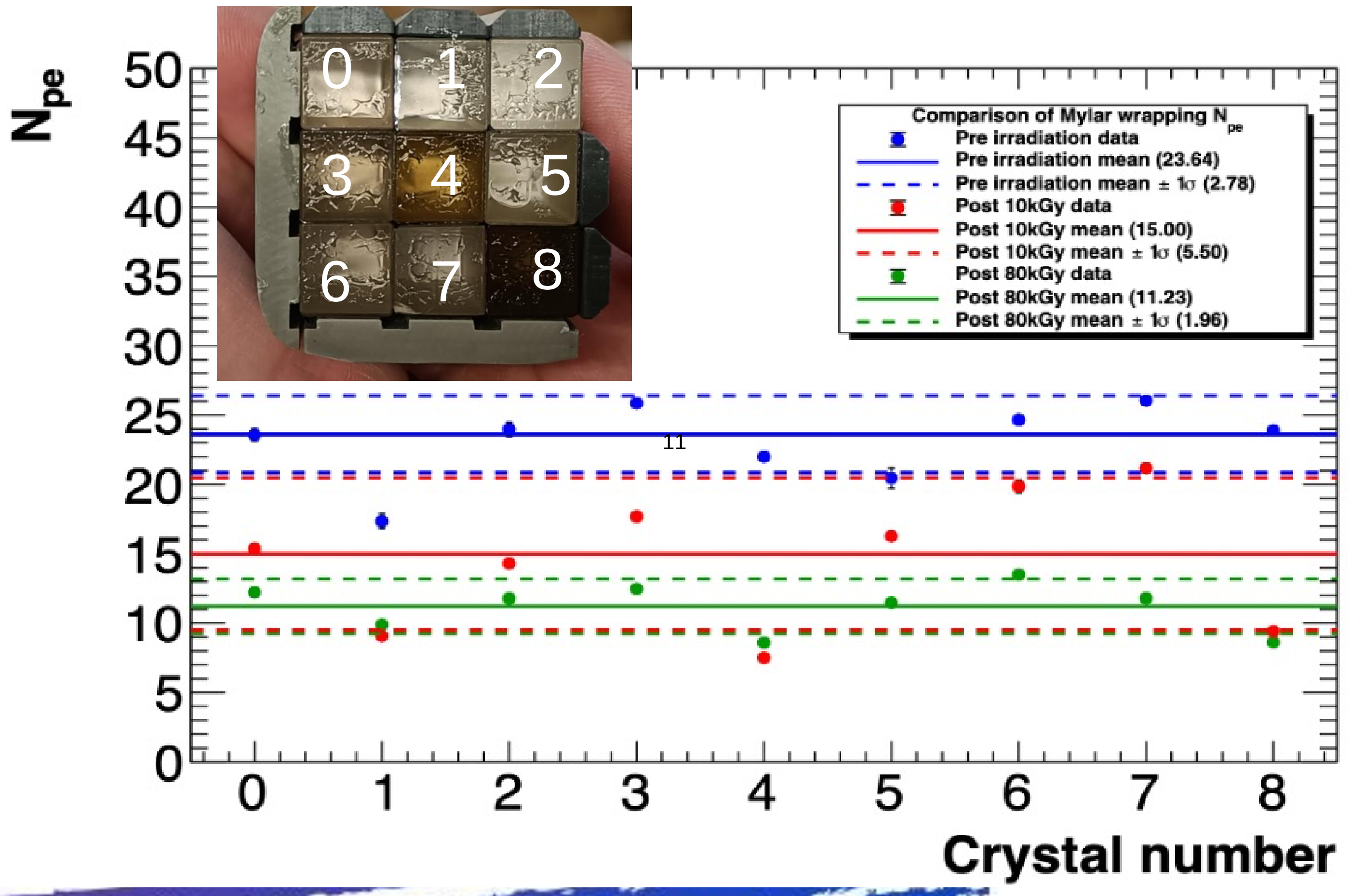
Teflon wrapping

Npe values of PbF_2 pre and post 80 kGy irradiation



Mylar wrapping

Npe values of PbF_2 pre, after 10 kGy and after 80 kGy irradiation



Building a large-scale prototype

- **SiPMs Procurement:** A total of 800 SiPMs (3x3 mm^2 with 10 μm pixel size) have been acquired, sufficient for 400 crystals (with 2 SiPMs in series per channel).
- **Mechanical Design:** The first design of the new mechanical envelope is complete, and the prototype matrix for 3x3 crystals is currently in fabrication.
- **Electronics:** The design of the electronics has been finalized.
- **MC Design:** The design of the Crilin full scale prototype in the Monte Carlo simulation has been completed.

DRD 6 Task 3: Deliverables Status

- We are almost on schedule.

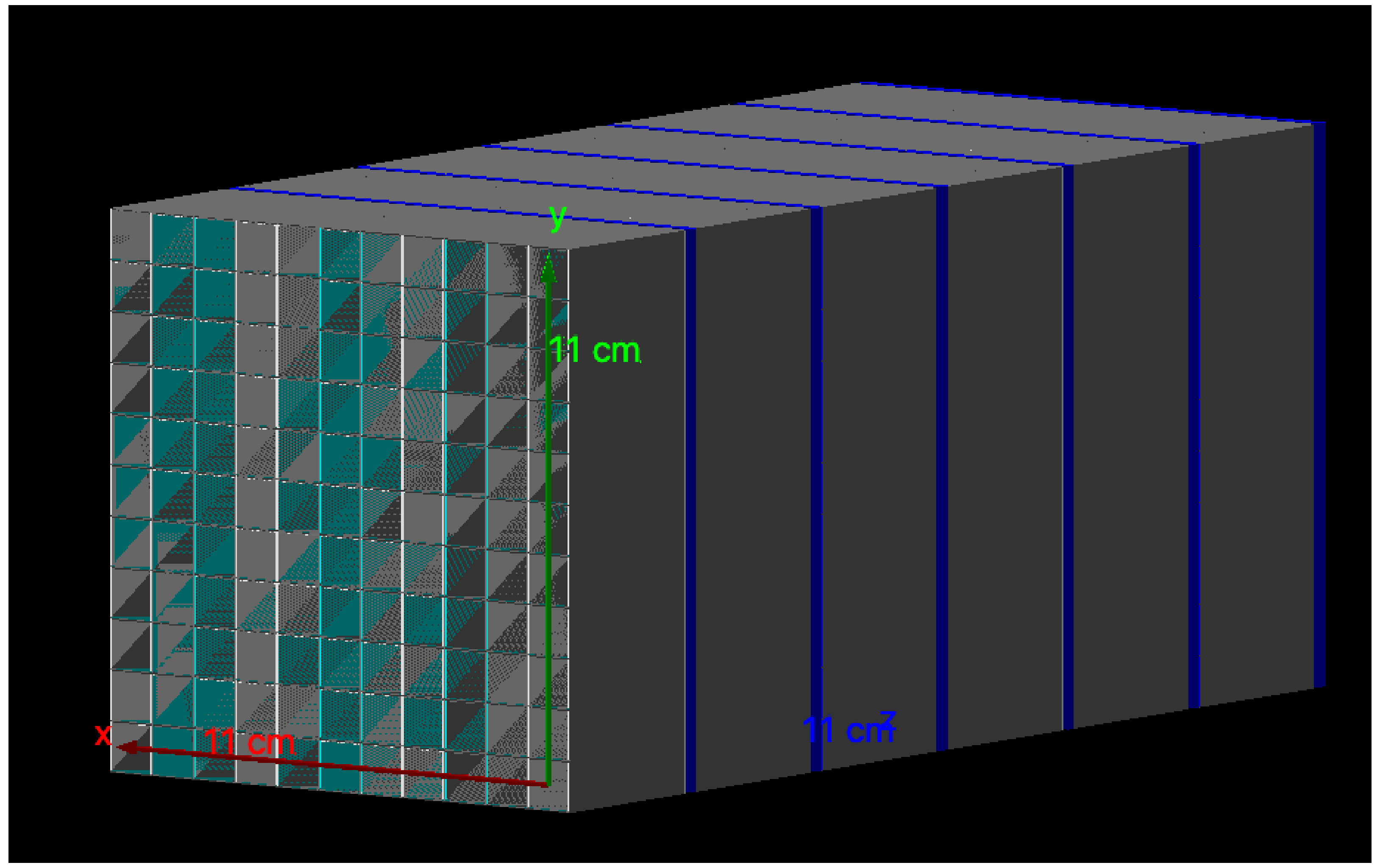
•We won an Italian grant for a small-scale prototype (5x5x5 layers).

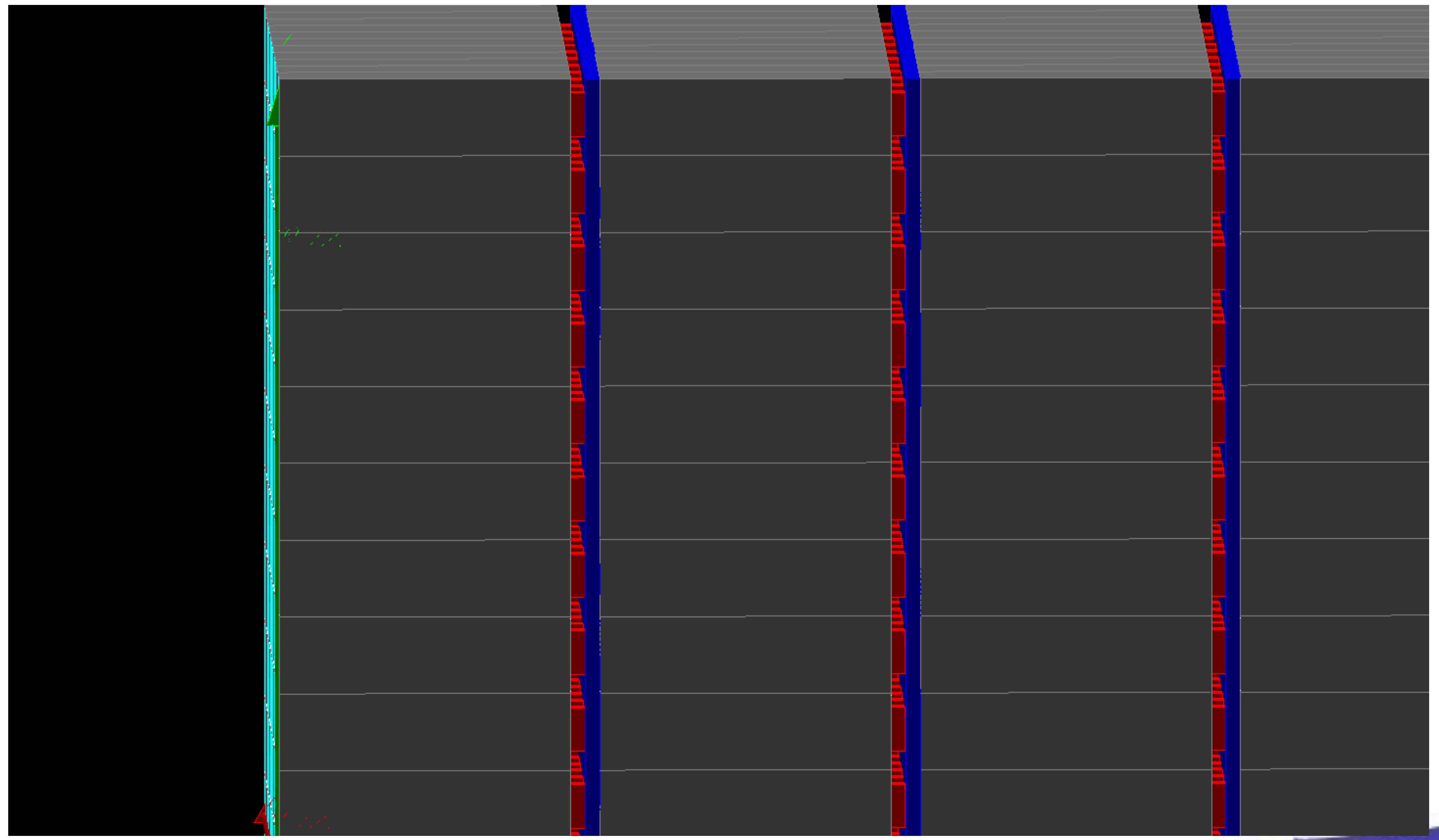
•Funding from the agency is still delayed until 2025, which may cause potential issues with the readout of the full-scale prototype
(details to follow).

	Milestone	Deliverable	Description	Due date
		D3.4	Acquisition and tests of crystals and SiPMs; design and production of electronics boards; design and production of the mechanical components	2024
Crilin		D3.5	Calorimeter fully assembled	2025
	M3.8		Beam test characterisation of a full containment EM calorimeter prototype	2025
	M3.9		Report on testbeam results	2026

Geant4 simulation of the new prototype

- Initial proposal **11x11 x6 layer** (crystals 10x10x40 mm^2 each) → **2.5 R_M – 26 X_0**
- Crystals wrapped in 150 um Mylar foils and placed a 150 um aluminum honeycomb
- 2 SiPMs 3x3 mm^2 per cystal, 2 mm thick, per layer
- 2 mm thck PcB, per layer
- Photostatistics and noise measured during beam tests : Poisson 0.3 p.e./MeV, Gauss 5 MeV

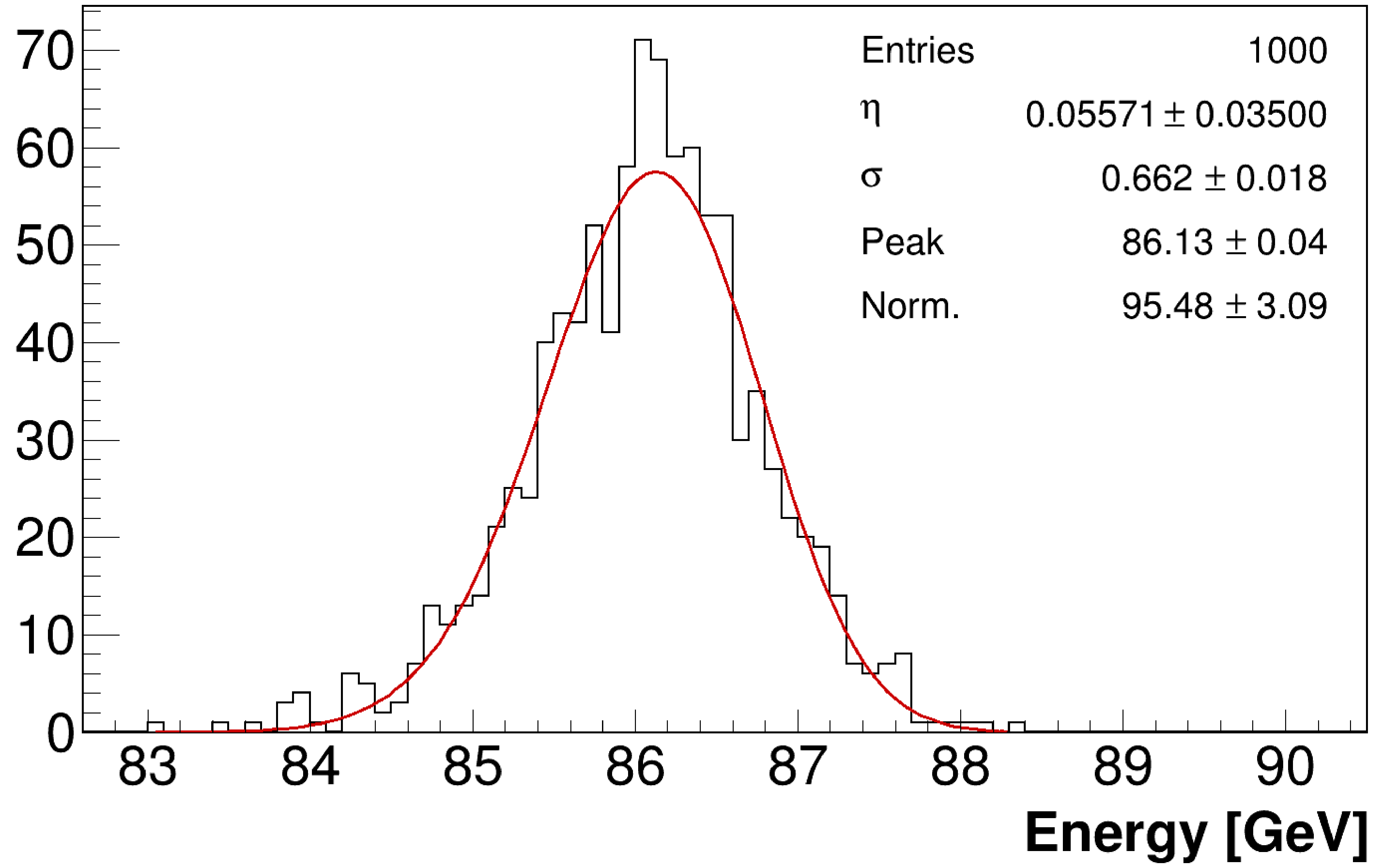


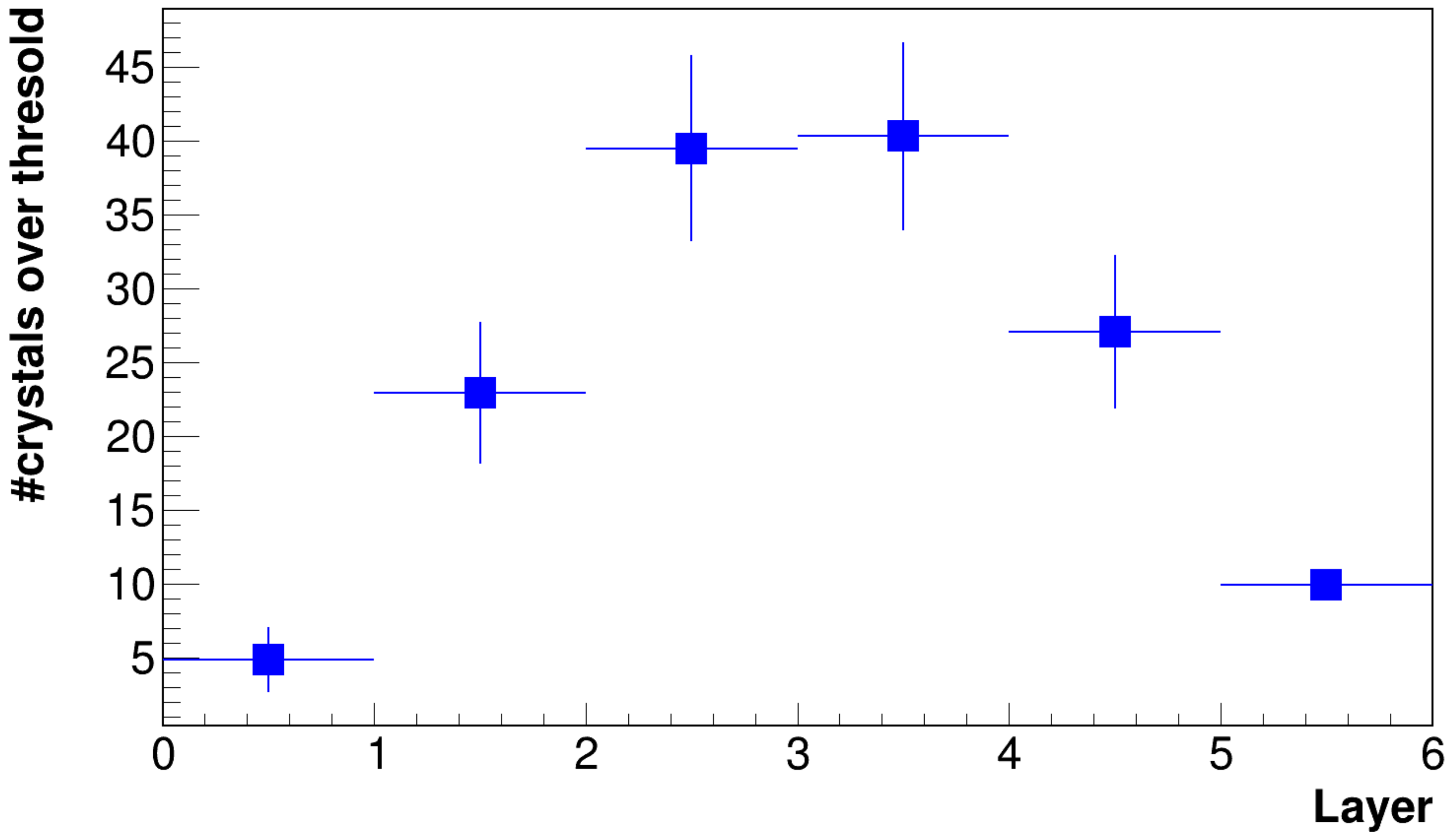


Number of crystals optimization

- By setting a threshold similar to that expected for the Muon Collider (i.e. 40 MeV) per crystal, we optimized the number of crystals, with the goal of minimizing the energy resolution loss

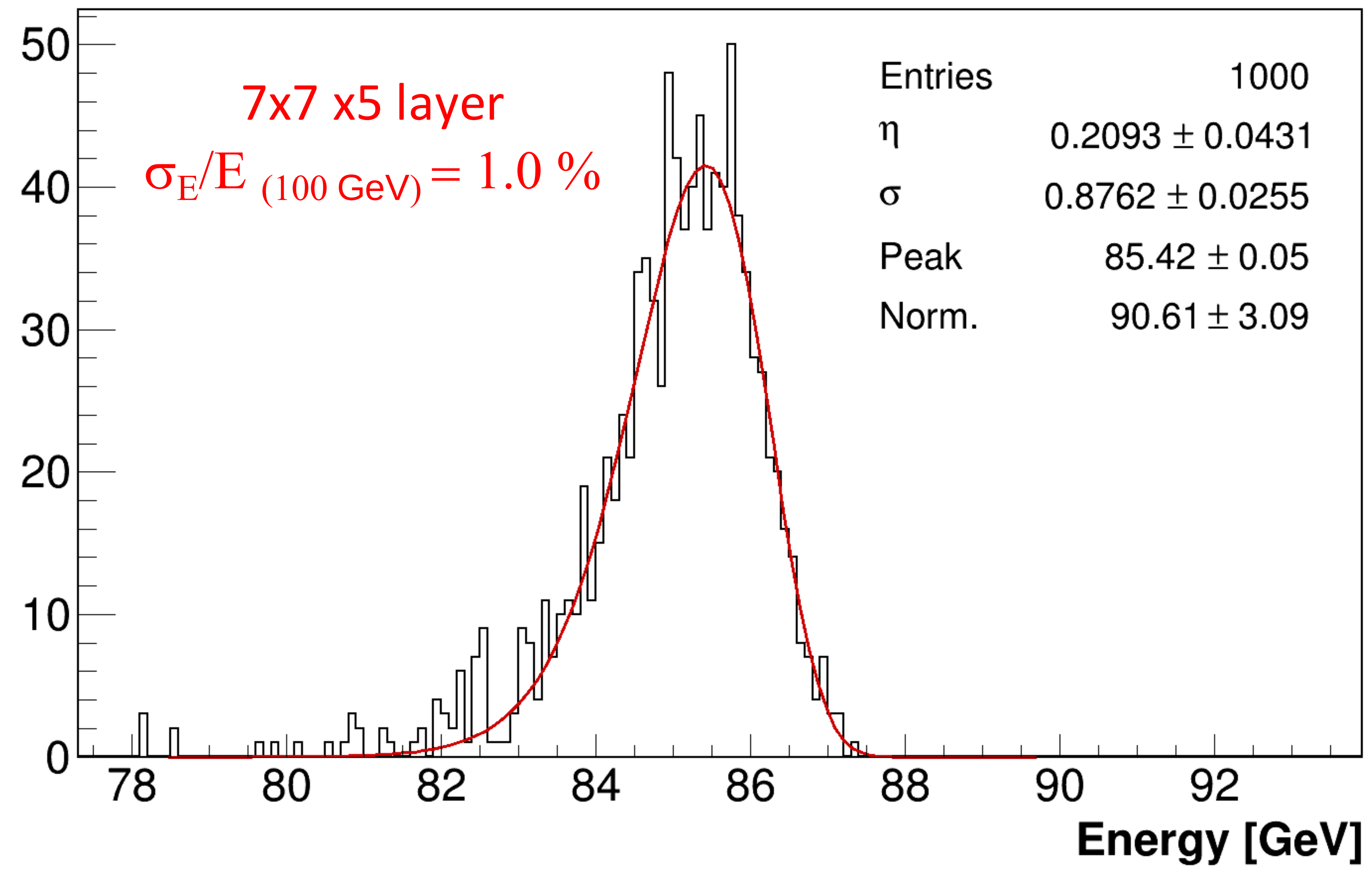
→ optimization performed for an electron beam with 100 GeV of energy.

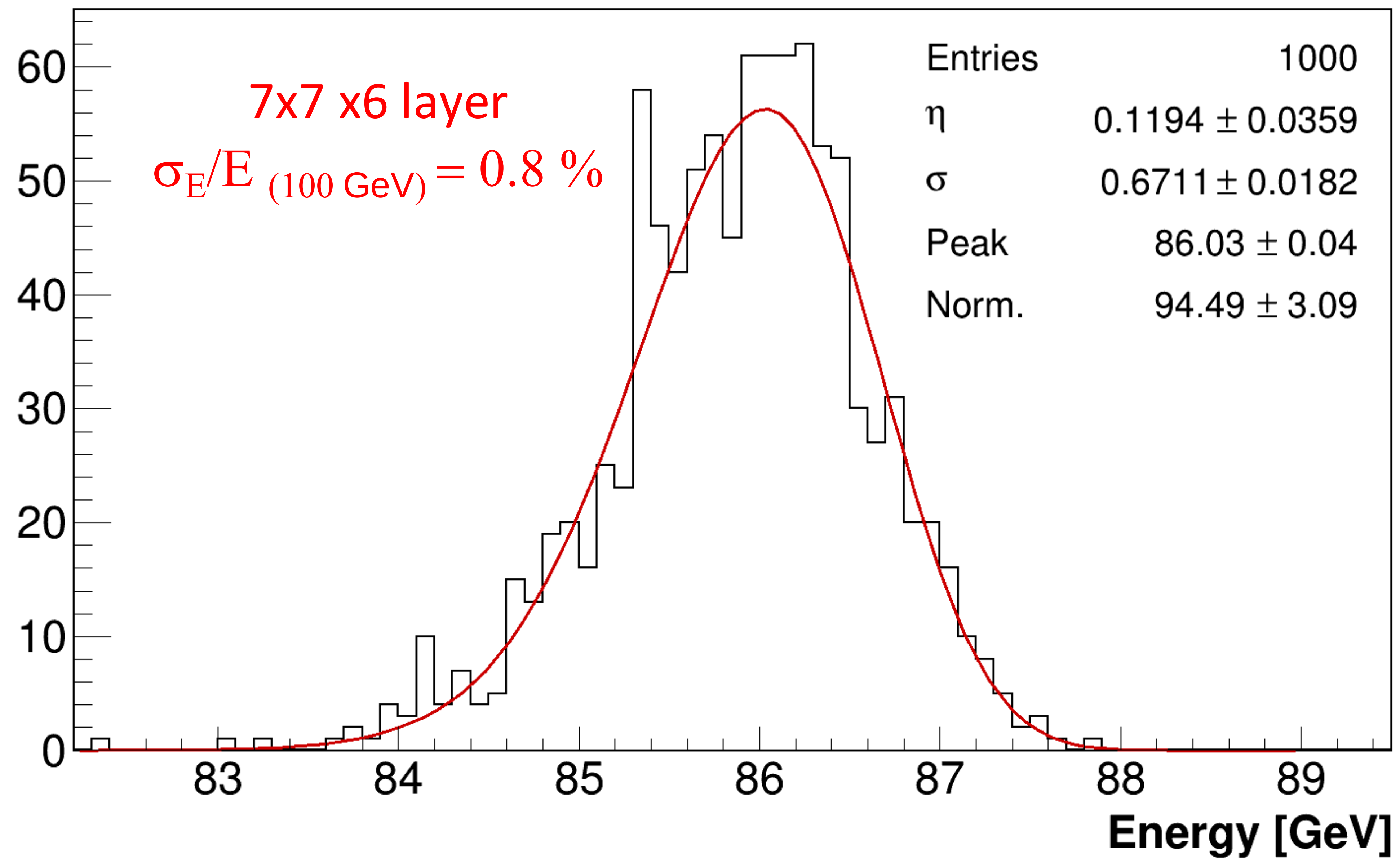




Number of layers optimization – 1

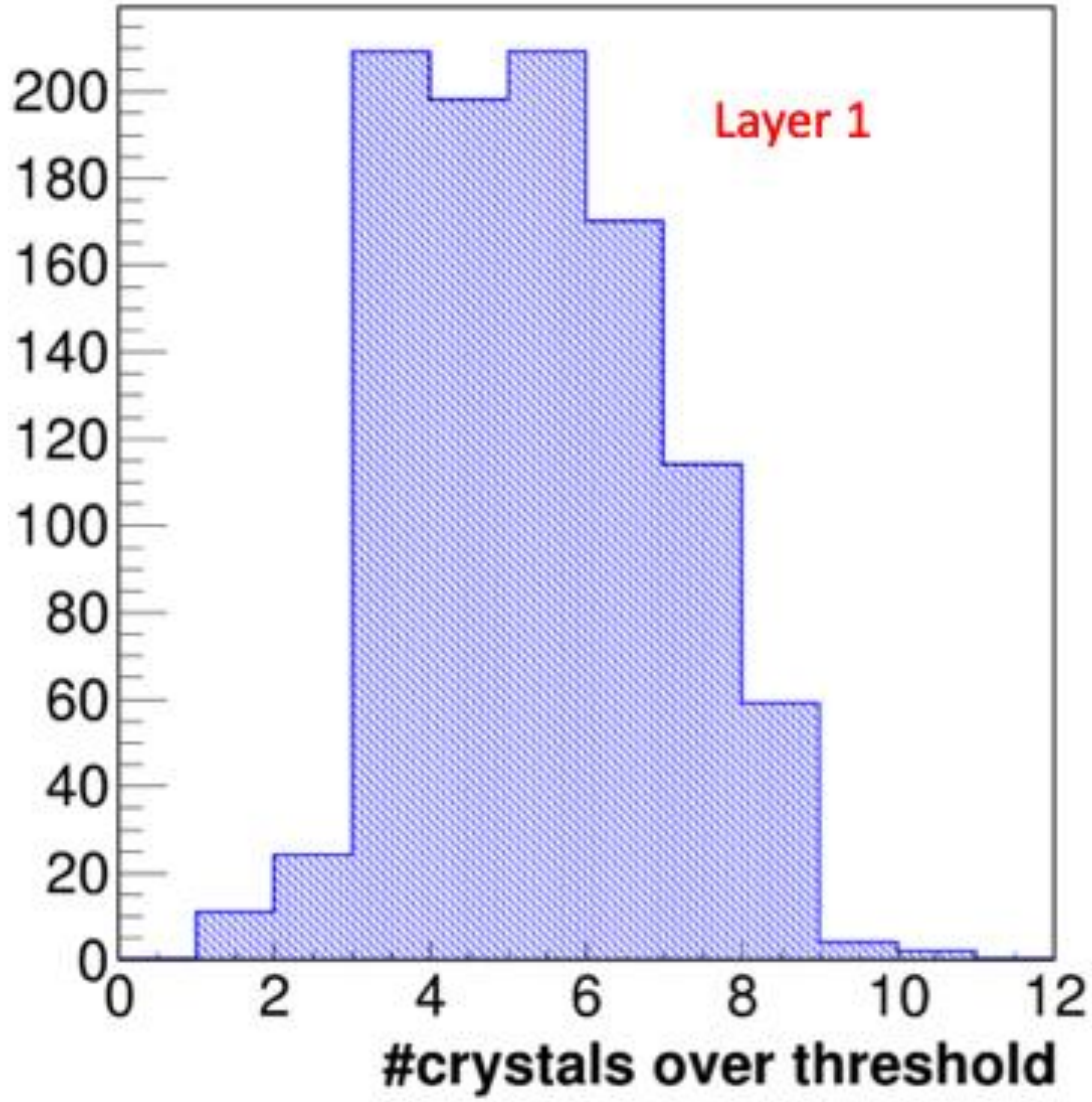
- The average number of crystals triggered above the threshold leads to a 7x7 configuration for layers 2, 3, 4, and 5.
- **The sixth layer is crucial for maximizing energy resolution**→ longitudinal leakage creates a much larger energy fluctuation compared to lateral leakage (for the same amount of leakage).

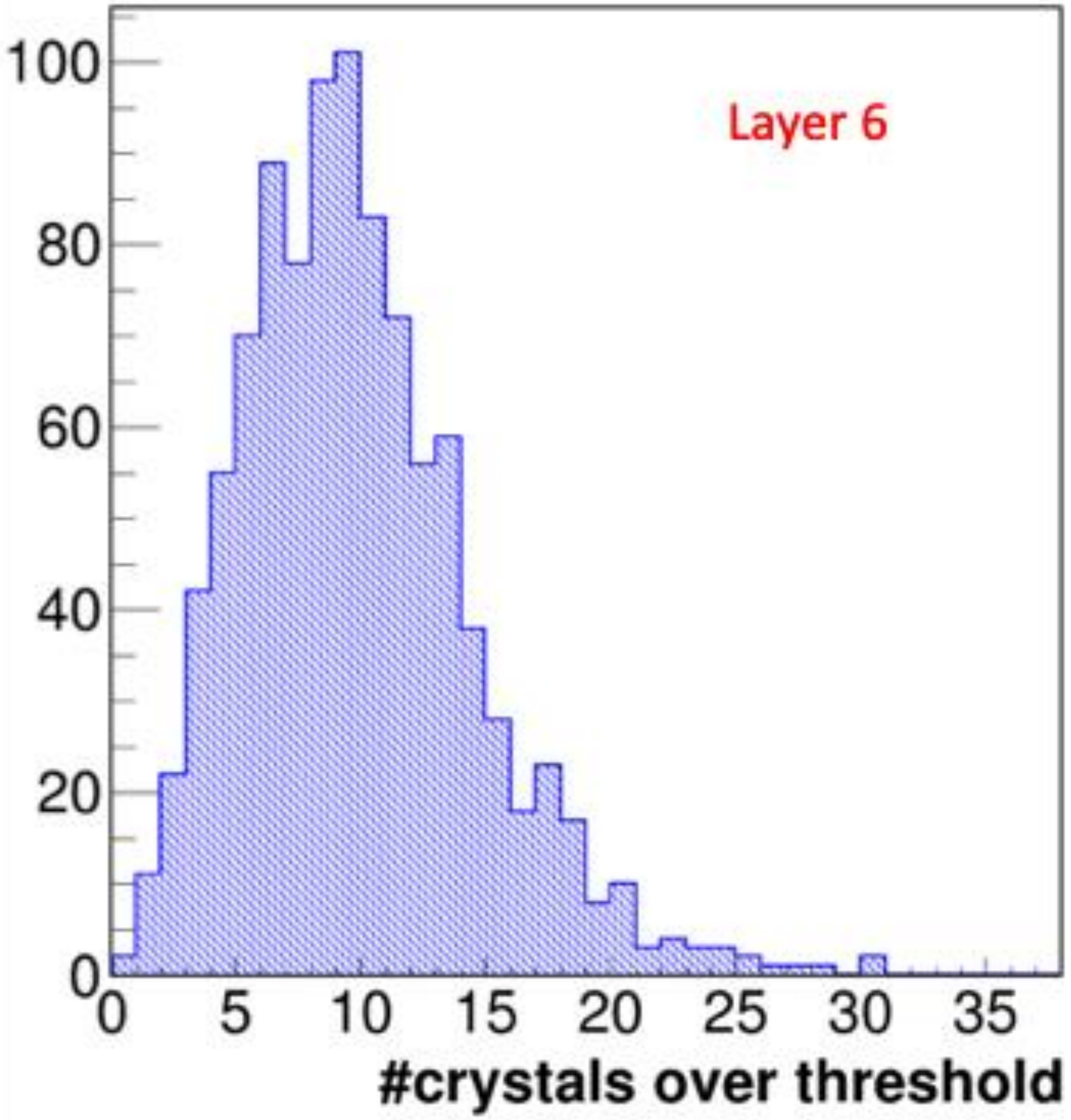




Number of layers optimization – 2

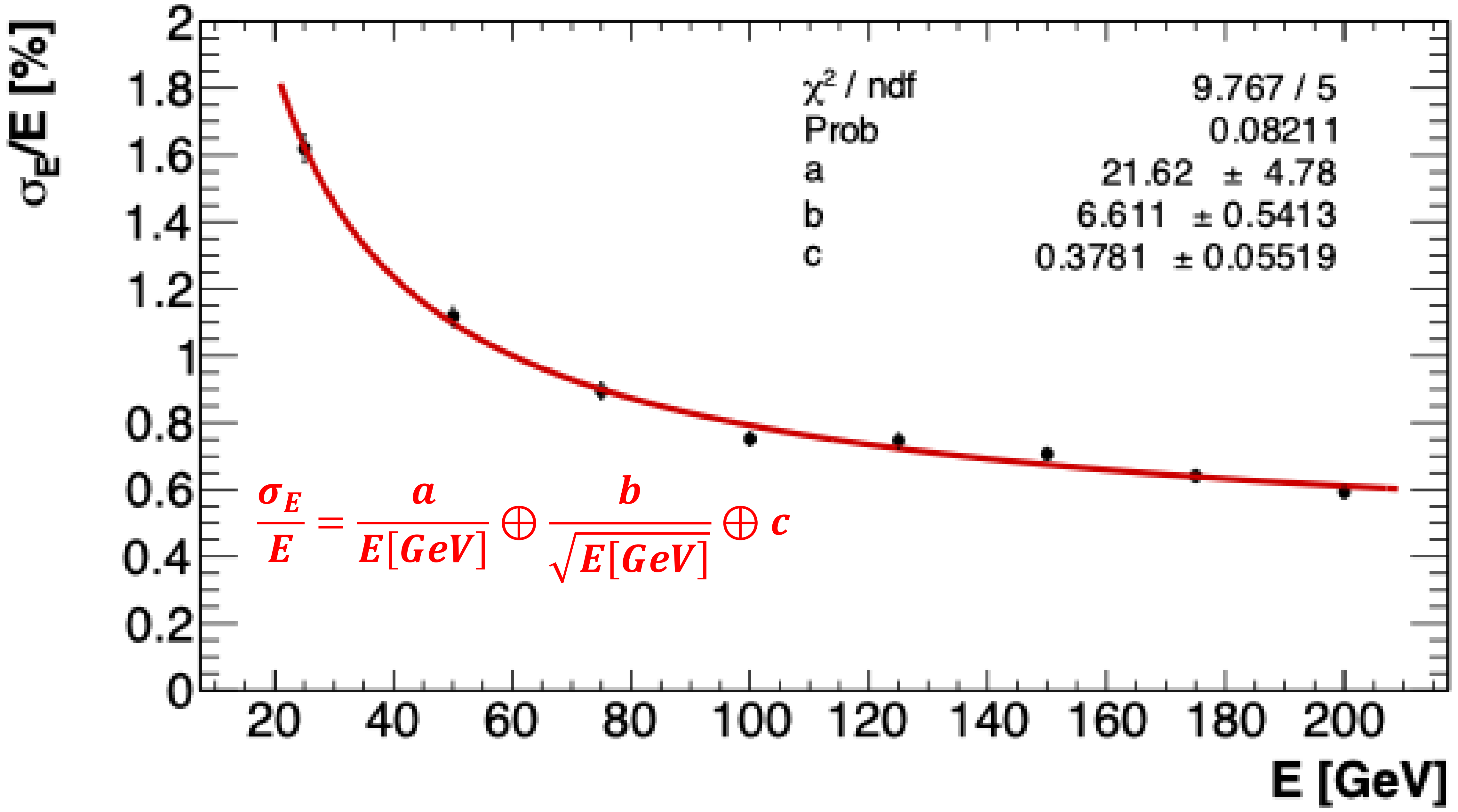
- The average number of crystals triggered above the threshold leads us to a 5x5 configuration for layers 1 and 6.

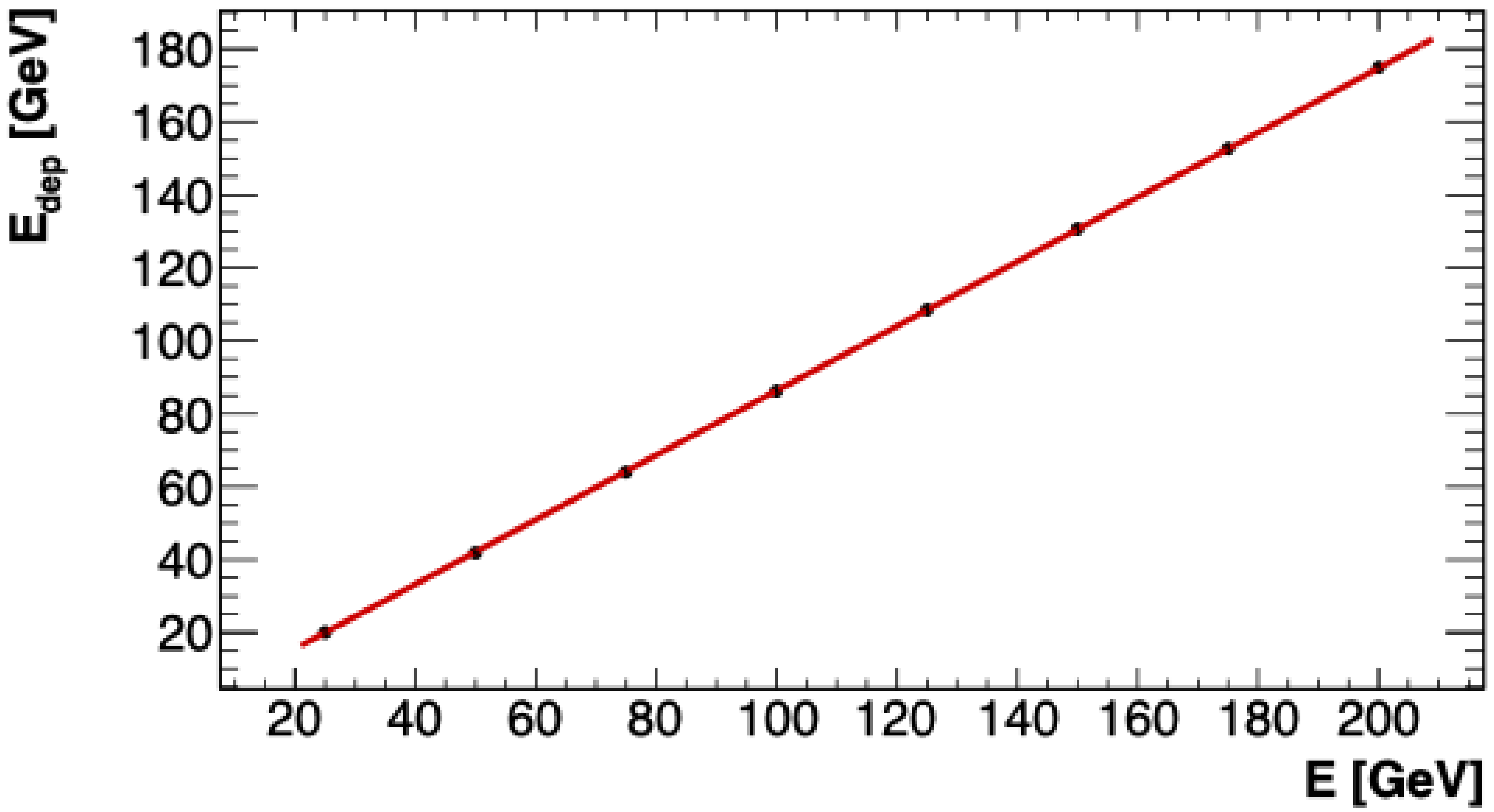




Energy resolution

- Energy Resolution and Linearity as a function of E for the reduced matrix:
- 7x7 in layers 2, 3, 4, and 5, and 5x5 in layers 1 and 6 → ~ 250 crystals in total.





International MUON Collider Collaboration

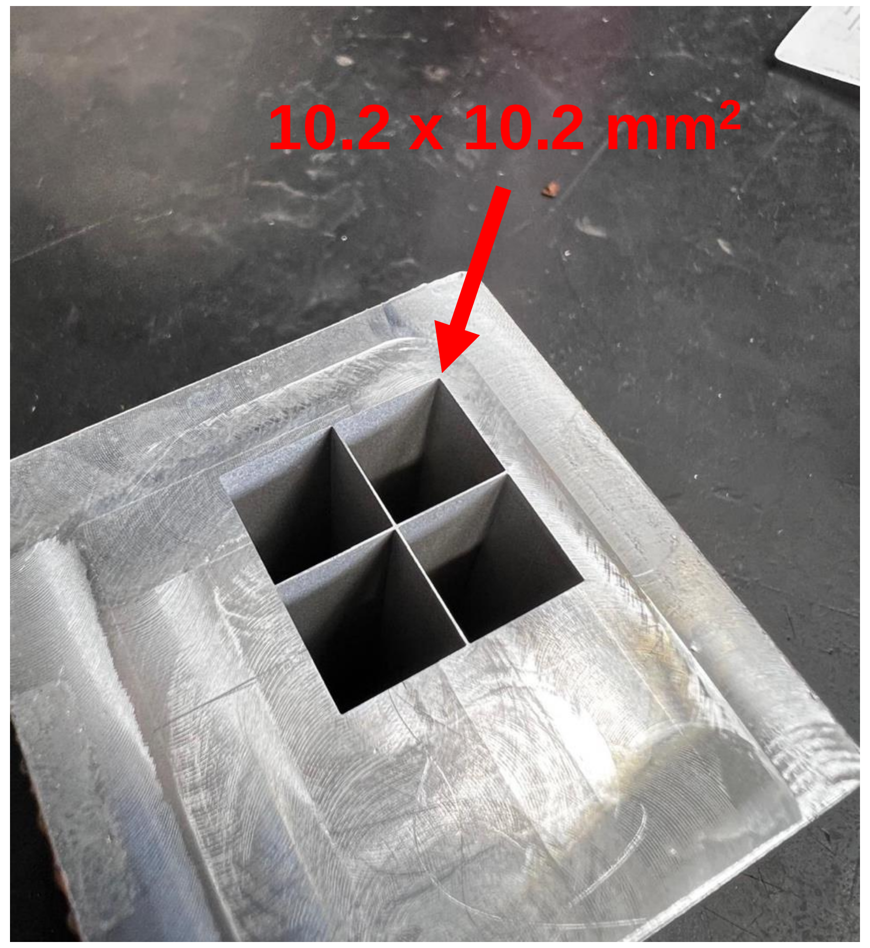
2024: Prototype Development for Mechanics and Data Acquisition

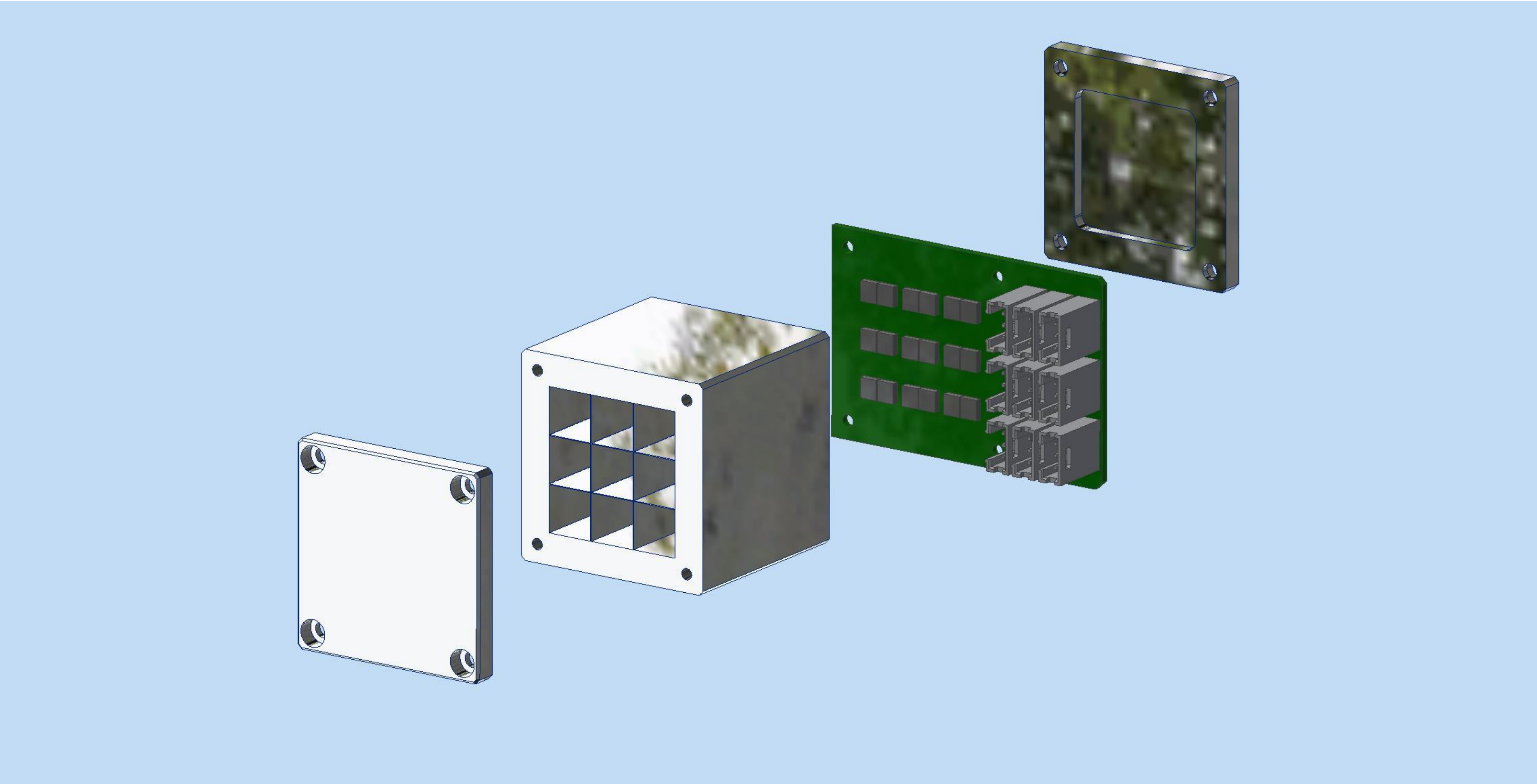
For the acquisition of the required 250 channels, we have two options:

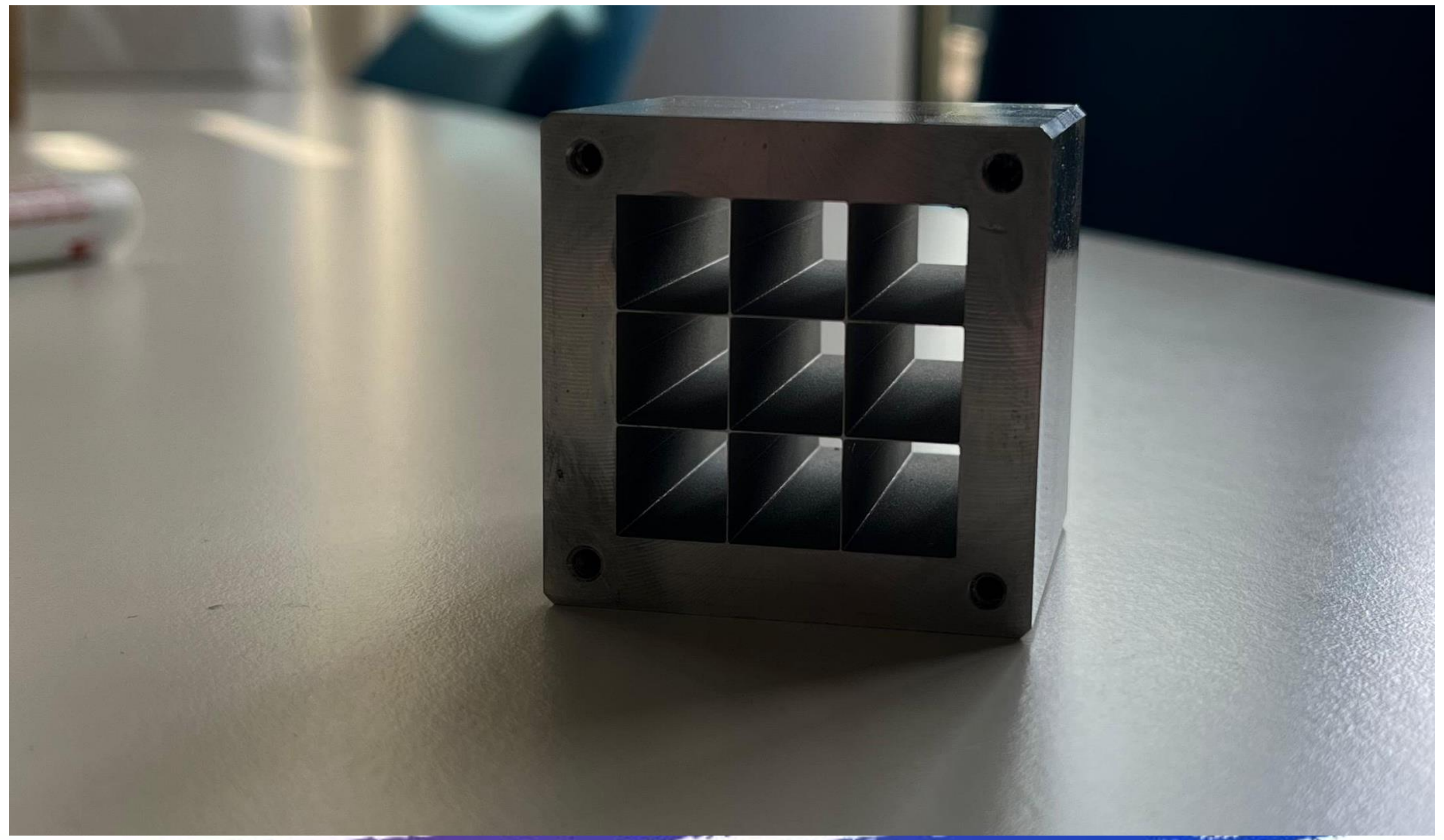
- **Custom front-end electronics paired with CAEN V1742 flash ADC digitizers** (cost ~ 40+80k EUR needed)
- **CAEN A5204 board** with integrated amplification electronics, based on the 64-channel Radioroc unit for FERS-5200 and Pico TDC (total cost for 250 channels ~ 60k EUR needed)

➢ We are developing a 3x3 prototype compatible with both solutions and will assess the effectiveness of the CAEN board in a dedicated test beam at the beginning of 2025.

➢ The first solution (custom electronics and flash ADC) has already been proven effective in previous Proto-1 tests, achieving timing O(20 ps) for deposited energies >1 GeV.







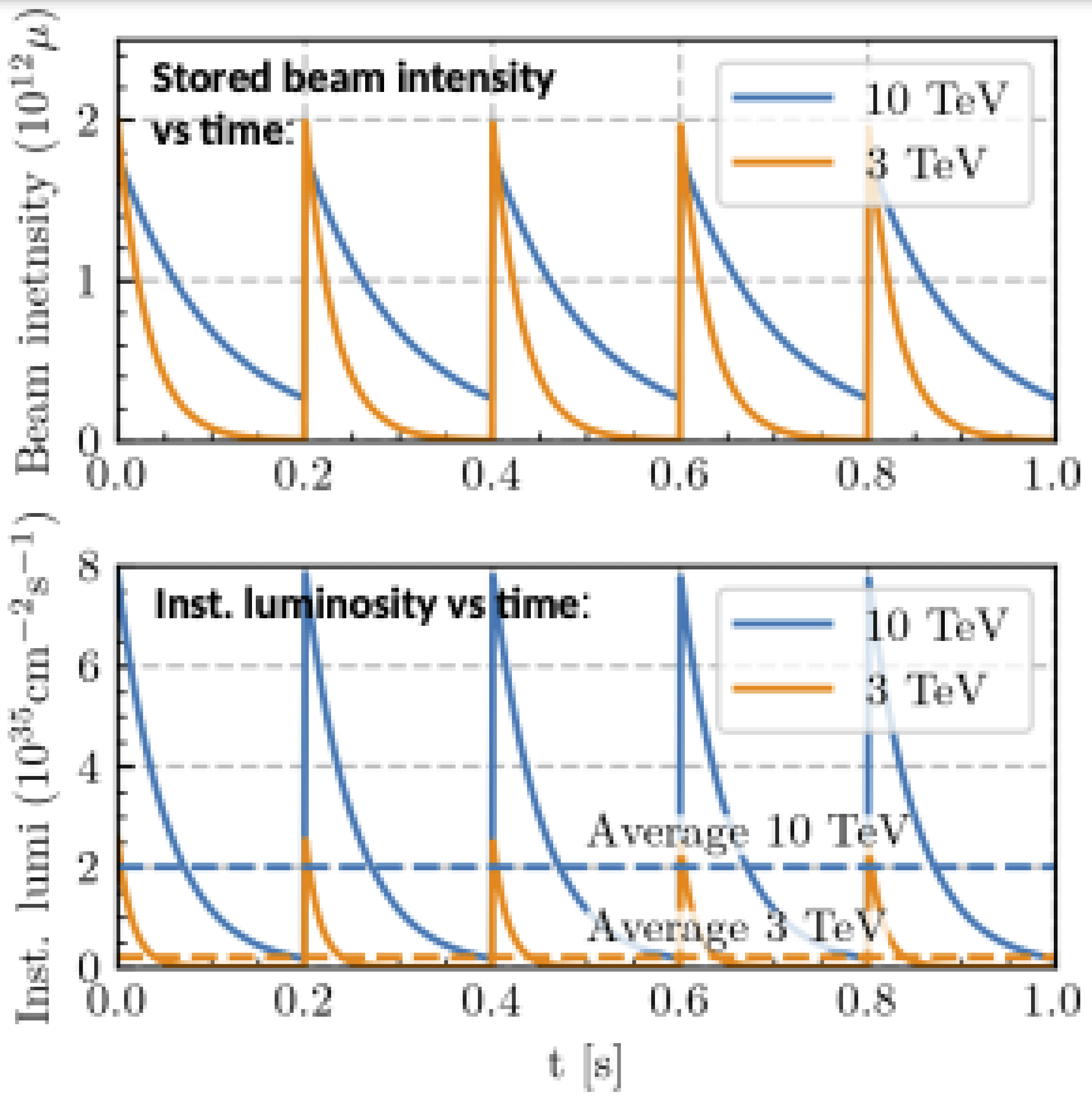
SPARES

Example as discussion basis numbers will change

	=3 TeV	=10 TeV
Beam parameters		
Muon energy	1.5 TeV	5 TeV
Bunches/beam	1	
Bunch intensity (at injection)	2.2×10^{12}	1.8×10^{12}
Norm. transverse emittance	25 µm	
Repetition rate (inj. rate)	5 Hz	
Collider ring specs		
Circumference	4.5 km	10 km
Revolution time	15.0 µs	33.4 µs
Luminosity		
Target integrated luminosity	1 ab^{-1}	10 ab^{-1}
Average instantaneous luminosity (5/10 yrs of op.)	2×10^{34} $cm^{-2}s^{-1}$ / 1×10^{34} $cm^{-2}s^{-1}$	1×10^{35} $cm^{-2}s^{-1}$ / 2×10^{35} $cm^{-2}s^{-1}$

$\tau = 2.2\times10^{-6}$ s

Muon decay	=3 TeV	=10 TeV
Mean muon lifetime in lab system ($\gamma\tau$)	0.031 s	0.104 s
Luminosity lifetime	1039 turns	1558 turns



See also parameter doc: https://cernbox.cern.ch/s/NraNbczzBSXctQ9