The Crilin calorimeter: a highly granular, segmented crystal calorimeter for future colliders

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On behalf of the Crilin calorimeter group

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The Crilin calorimeter

Crilin is a **semi-homogeneous** electromagnetic calorimeter made of **crystal matrices** interspaced and readout by **SiPMs.** Each crystal is independently read by 2 channels, each consisting of 2 SiPMs in series.

Key Features:

Excellent timing: (<100 ps) to reject the out- of-time components and for good pileup capability.

Longitudinal segmentation: allows to recognize fake showers from beam bkg.

Fine granularity: reduced hit density in a single cell, distinguish beam bkg hits from the signal.

Good resistance to radiation: good reliability during the experiment

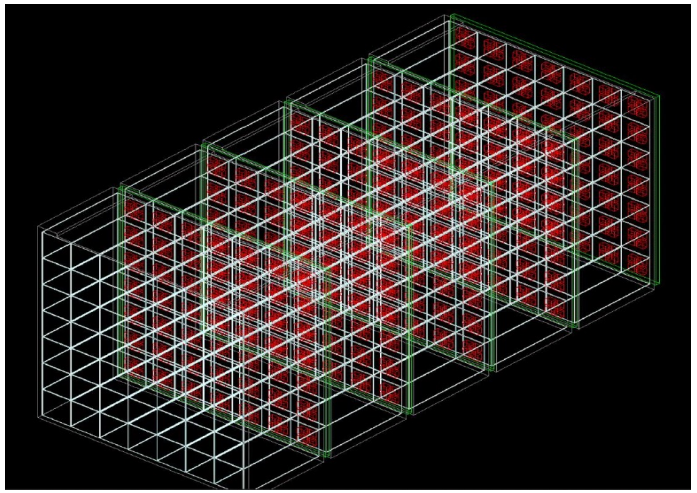
Perfectly suitable for ~any future collider!

Crystal choice:

High-density crystal: selected to balance the need for increased layer numbers with space constraints

Speed response: Cherenkov/fast crystals, ensuring accurate and timely particle detection

→ **PbF2, $PbWO_4$-UF, LYSO…**



Differentiation:

Semi-homogeneous : strategically between homogeneous and sampling calorimeters → able to exploit the strengths of both kinds

Flexibility: able to modulate energy deposition for each cell and adjust crystal size for tailored solutions

Compactness: Unlike segmented or high granularity calorimeters CRILIN can optimize energy detection while staying compact

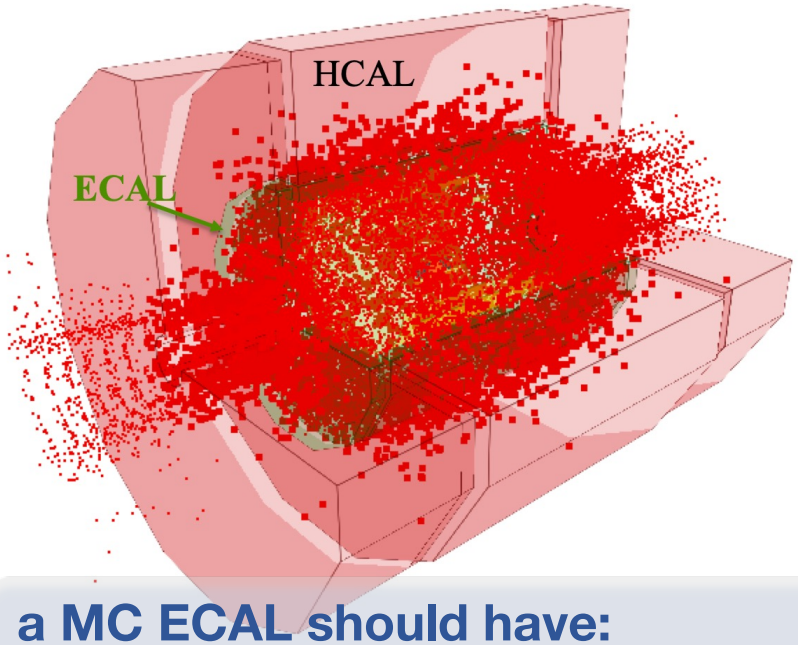
*S. Ceravolo et al 2022 JINST **17** P09033*

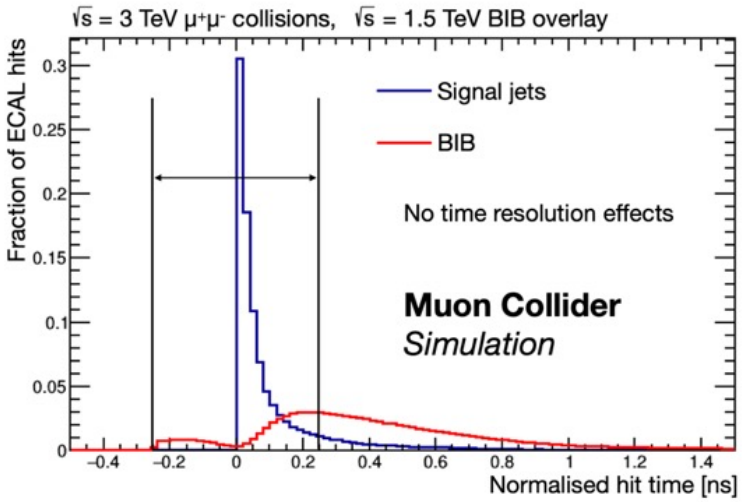
Muon collider requirements

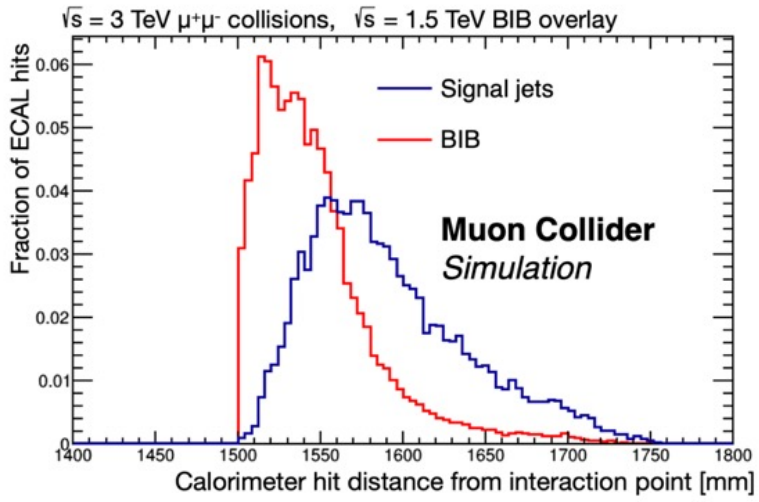
BIB in the ECAL region (after nozzles and tracking system):

- Flux of 300 particles per cm^2 through the ECAL surface mainly γ (96%) and n (4%), average photon energy 1.7 MeV
- **Time of arrival flatter** throughout the bunch crossing → can exclude most of BIB with an acquisition window of ~240 ps
- Different **hit longitudinal profile** wrt signal
- **Total Ionising Dose**: ~1 kGy/year
- **Neutron fluence**: 10^{14} $n_{1MeVneq}/cm^2$ / year

BIB hits in the calorimeters







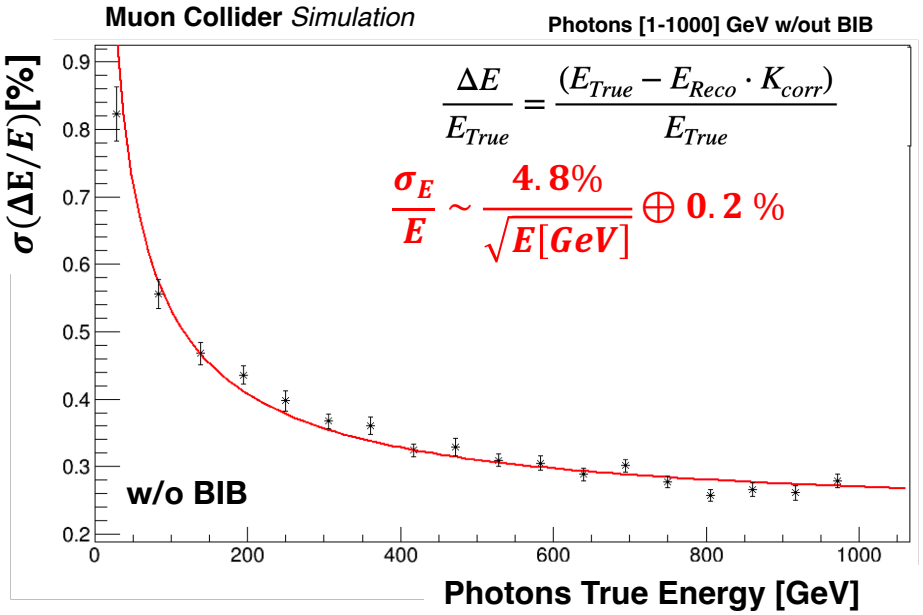
a MC ECAL should have:

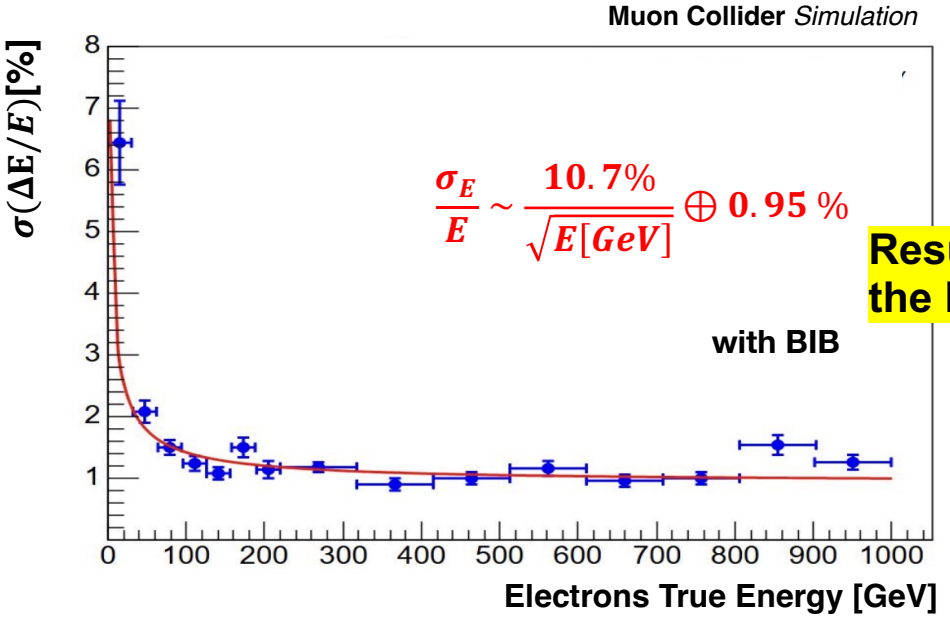
- σ_t ~ 80 ps
- longitudinal segmentation
- fine granularity to distinguish BIB and signal
- radiation resistance
- $\sigma_E/E \sim 10\%/\sqrt{E}$

CRILIN is now the baseline solution for the MUSIC MC detector

Simulated performances

- The ECAL barrel with Crilin technology has been implemented in the Muon Collider simulation framework
  - ➢ 6 layers of 45 mm length, 10 X 10 mm^2 cell area → **25 X_0**
  - ➢ **In each cell:** 40 mm PbF_2 + 3 mm SiPM + 1 mm electronics + 1 mm air
- Design optimized for BIB mitigation: having thicker layers, the BIB energy is integrated in large volumes → reduced statistical fluctuations of the average energy
- 6 layers wrt to 40 layers of the W-Si calorimeter → **factor 10 less in cost (6 vs 64 Mchannels)**





Results in agreement with the ECAL requirements!

Towards the real detector

Prototype versions

- Proto-0 (2 crystals → 4 channels)
- Proto-1 (3x3 crystals x 2 layers → 36 channels
- Proto 2 3x3x1 layers→ 9 channels, new mechanics
- Large area module 7x7x5 layers → 225 channels

Front-end electronics and mechanical designs

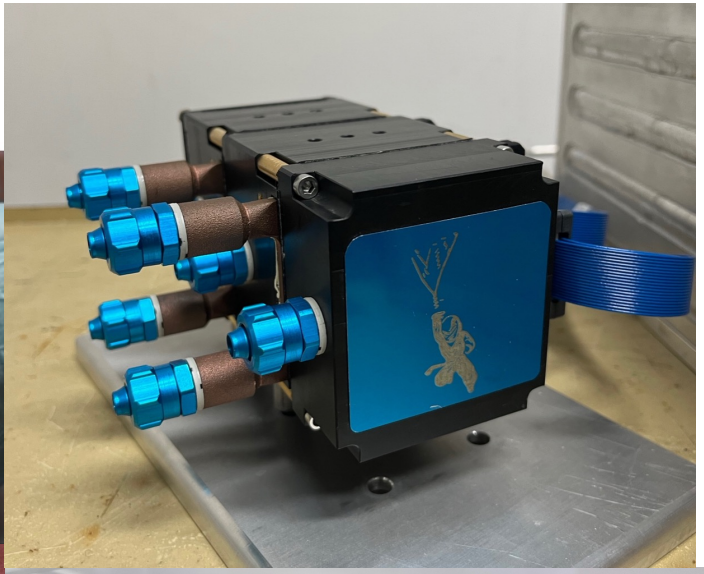
Radiation hardness campaigns

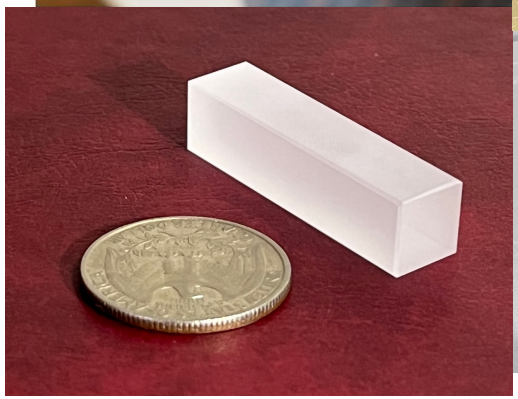
Beam test campaigns

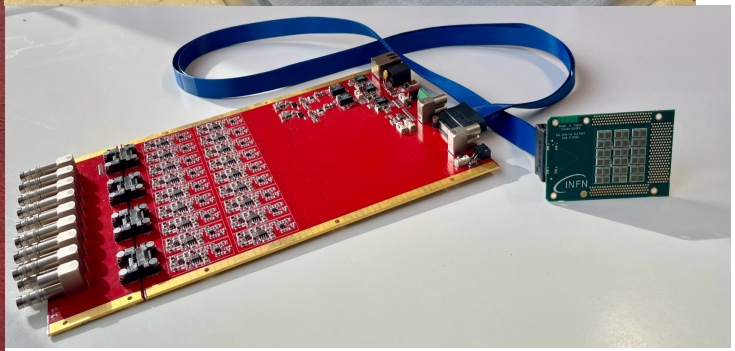
- Proto-0 at CERN H2 (August 2022) *Front. Phys. 11:1223183*
- Proto-1 at LNF-BTF and CERN H2 (July 2023-August 2023 - April 2024) *doi:10.1109/TNS.2024.3364771*
- Proto-2 at and CERN (October 2025), final choices validation
- Final module at CERN H2 (End of June 2026) 2026 JINST 21 P09015

Studies on software hadronic compensation → towards FCCee (under review arXiv:2606.05111)







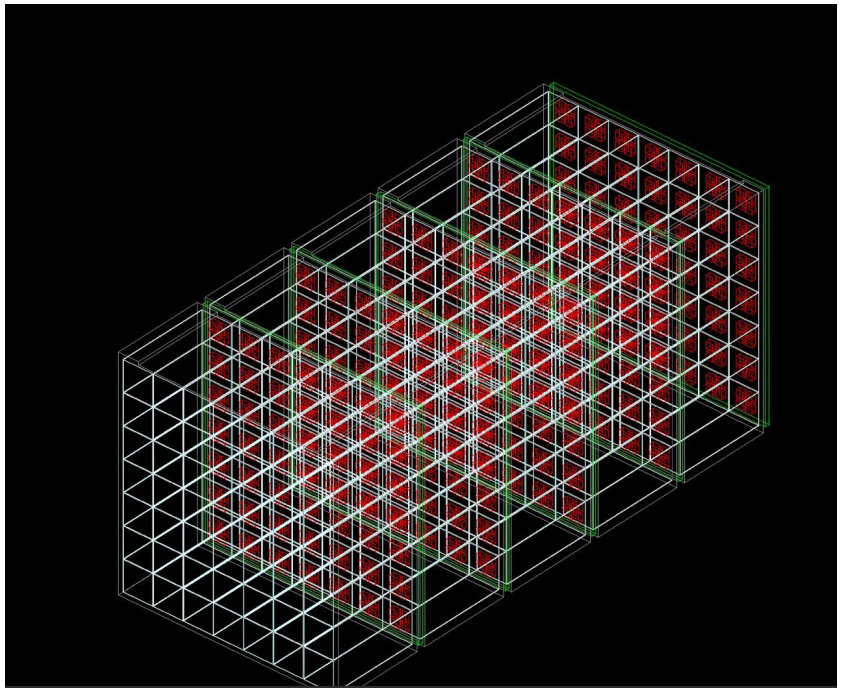


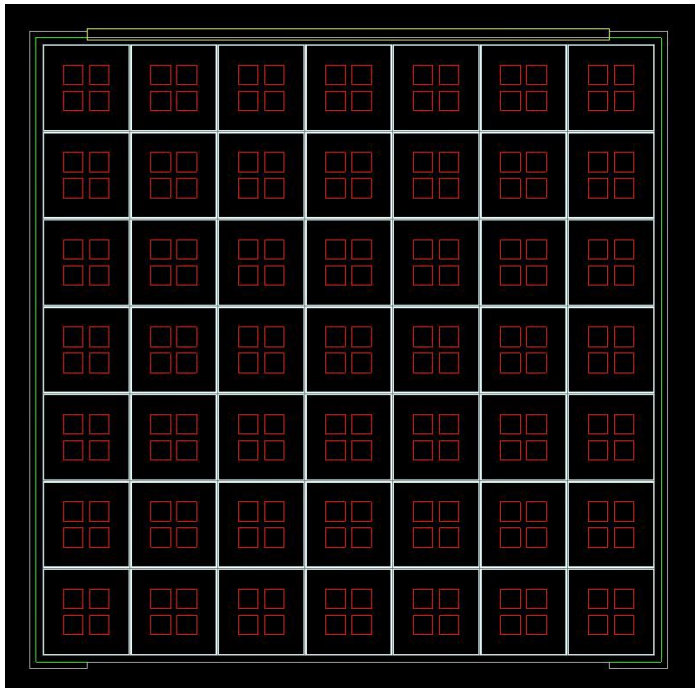
Final module

New 7x7 module

New 7x7 crystals, 5 layers CRILIN module has been designed and studied using simulations

- **$2M_R$ and 22 X_0**
- PbF_2 Crystal dimensions 13x13x40 mm^3
- 4 SiPM per crystal
- 15 μm SiPM for higher light yield (looking towards FCCee)
- **Design almost experiment-ready!**







Mechanics

Aluminium alveolar matrix support

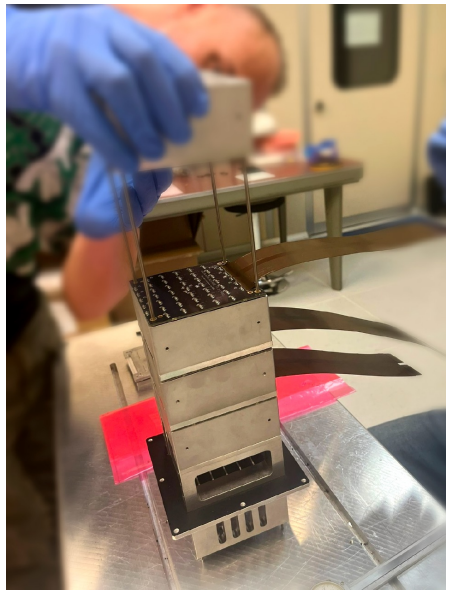
→ max 200μm inter-crystal thickness

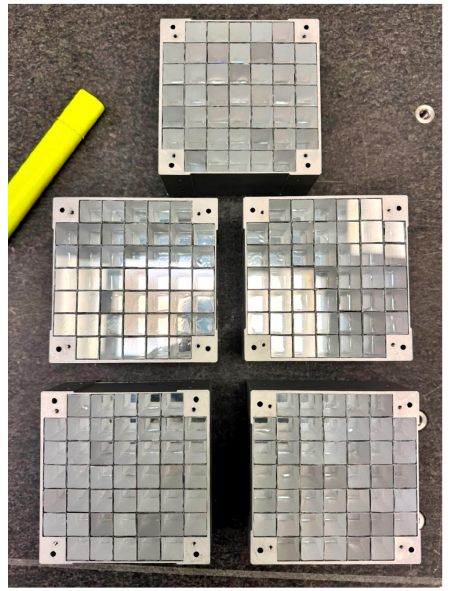
→ ***max 2mm external envelope thickness***

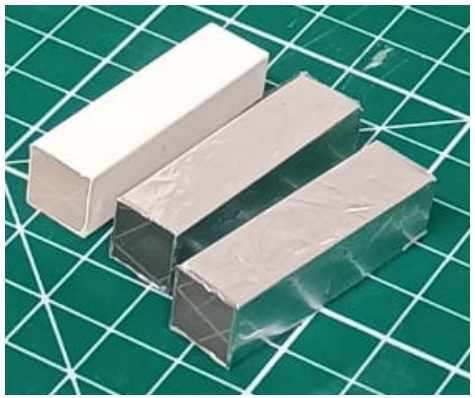
→max 5mm between layers

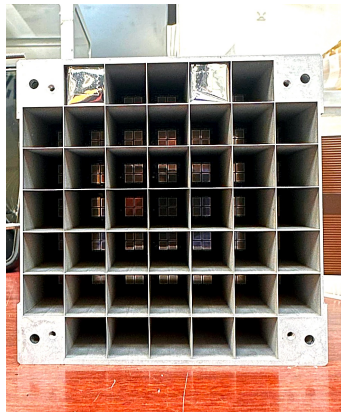
PbF_2 Crystals: wrapping in LNF all crystals + spares, 4 layers of 50um Mylar + Aluminium tape

External 3D printed mechanics for light isolation

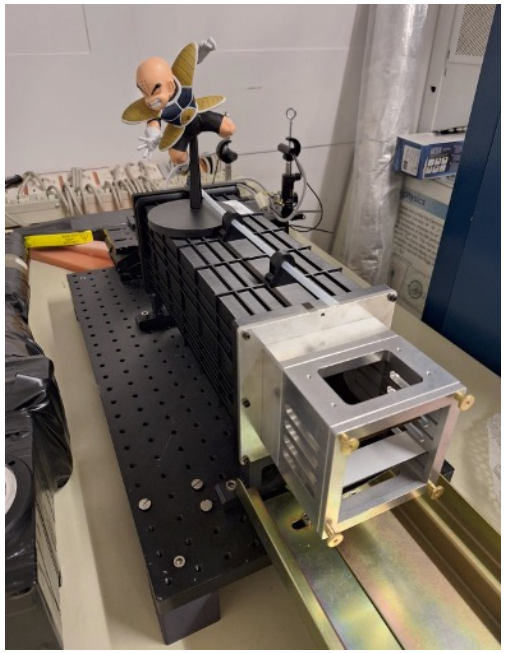








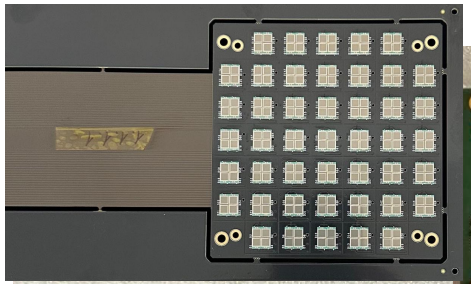


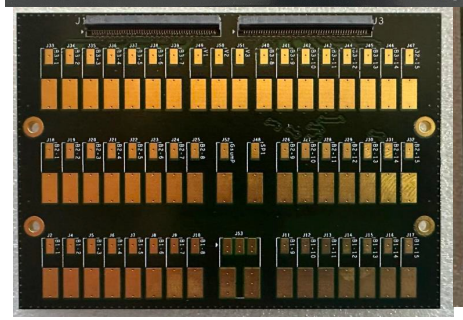


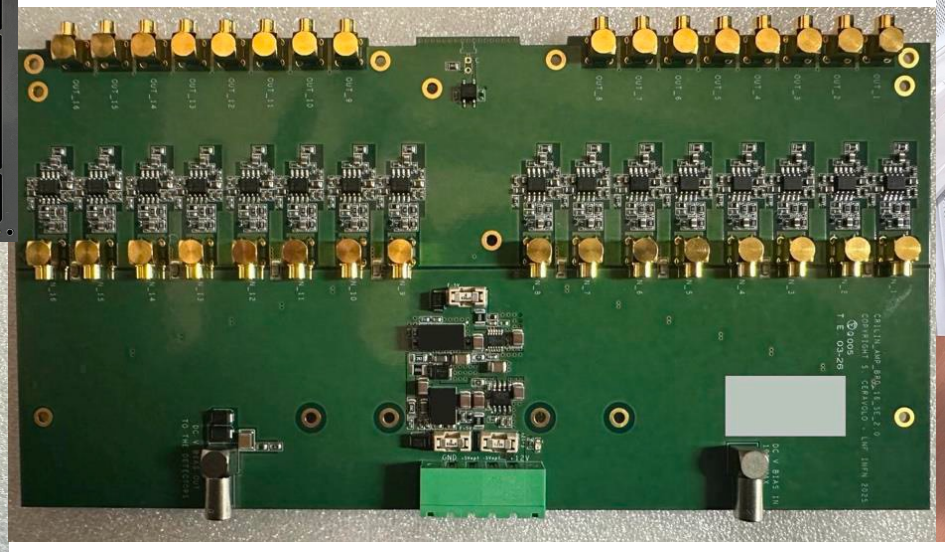
Electronics and DAQ

Module readout divided in 3 stages:

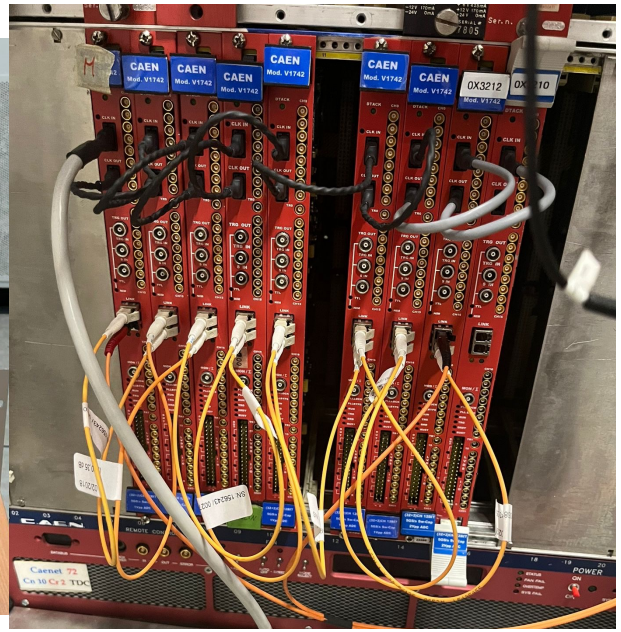
- 5 **SiPMs boards** (15um pixel size): signal pickup and biasing provided by Kapton strips
- 5 **Kapton connector patch panel**: 1 for each layer → signal passes from the Kapton connector to MCX cables
- 16 **Front End Electronics boards**→ each one handling 16 channels amplification and biasing. Gain tuned following the layer served (G: 4-1-1-4-6)
- 8 **CAEN V1742 + Trigger board** → one with 2V dynamics for central crystals
- 15um SiPM used for higher light yield (looking towards FCCee)





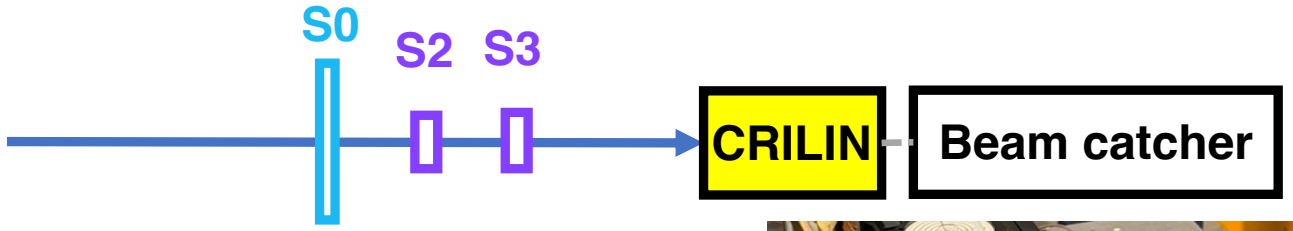




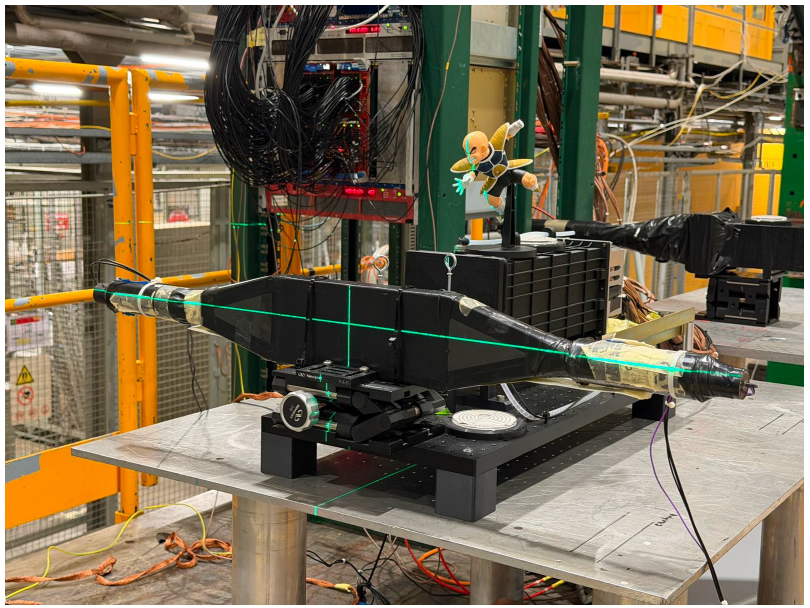


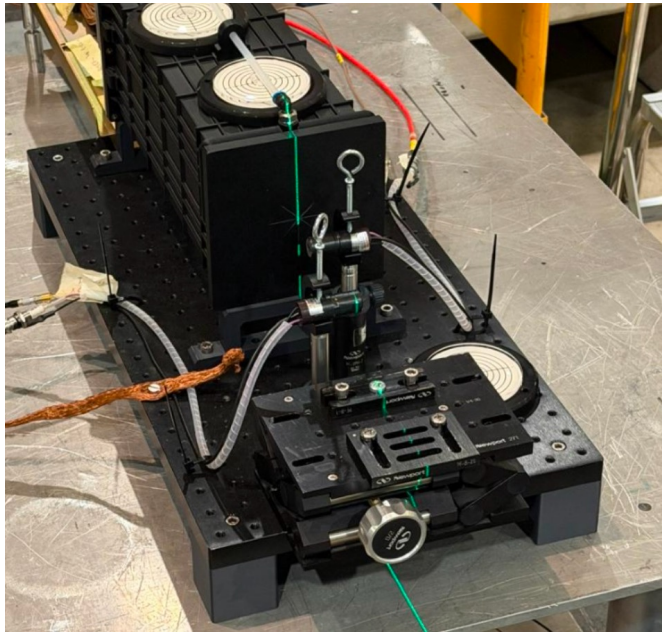
Test beam setup and data-taking

- 4 days data taking in SPS-H2: 26-29 June
- Setup optimized for alignment and trigger selection
- Large plastic-scintillator paddle followed by 2 optically aligned 5x5mm^2 fast scintillators→ automatically centred to CRILIN → trigger cuts directly on the centroid
- Good beam for 2 days → estimate of the BES evaluated thanks to the beamline scientist
- Last 2 days→ beam full of pions



p_{nominal} [GeV/c]	$C6$ [mm]	$C12$ [mm]	$\Delta p/p$ [%]
10	16	16	0.24
20	16	16	0.24
34	16	16	0.24
52	20	16	0.27
65	30	16	0.36
74	30	16	0.36
99	50	16	0.56
120	70	16	0.77



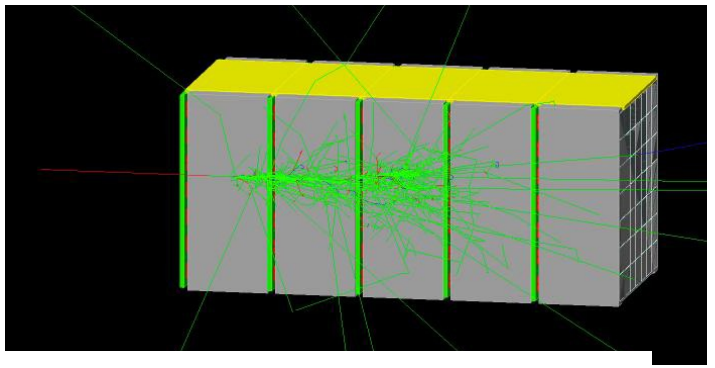


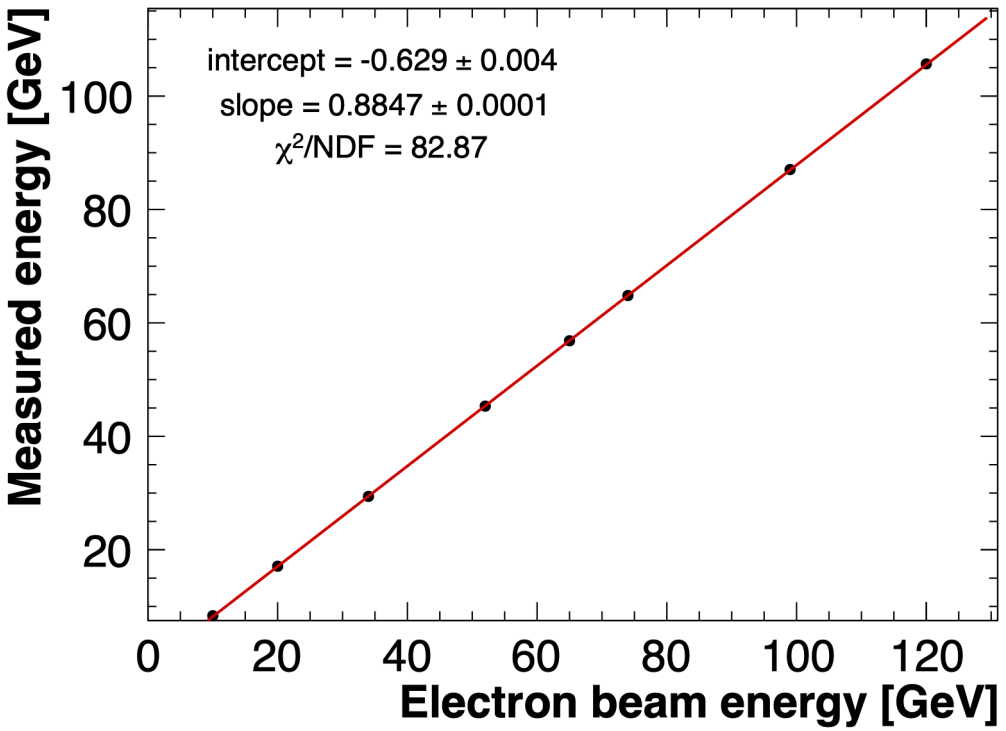
MC Simulation

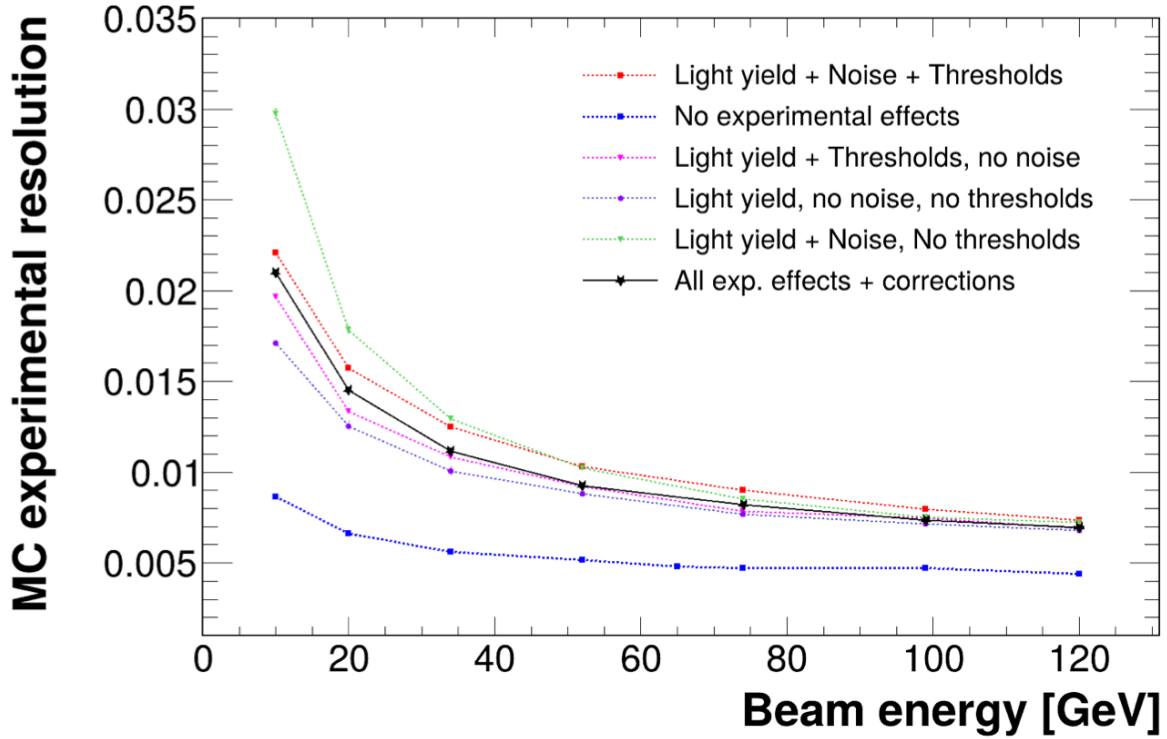
Finely tuned to reproduce the test beam setup and to systematically study possible improvements

- ~0.6 p.e./MeV per crystal (15um SiPM, 4 50um Mylar layers + 100 um Al wrapping)
- Gaussian noise (to mimic electronic noise and digitizers)
- Threshold per crystal tuned following the layer gain and dynamics

Simulation results on linearity and energy resolution confirm expectations!

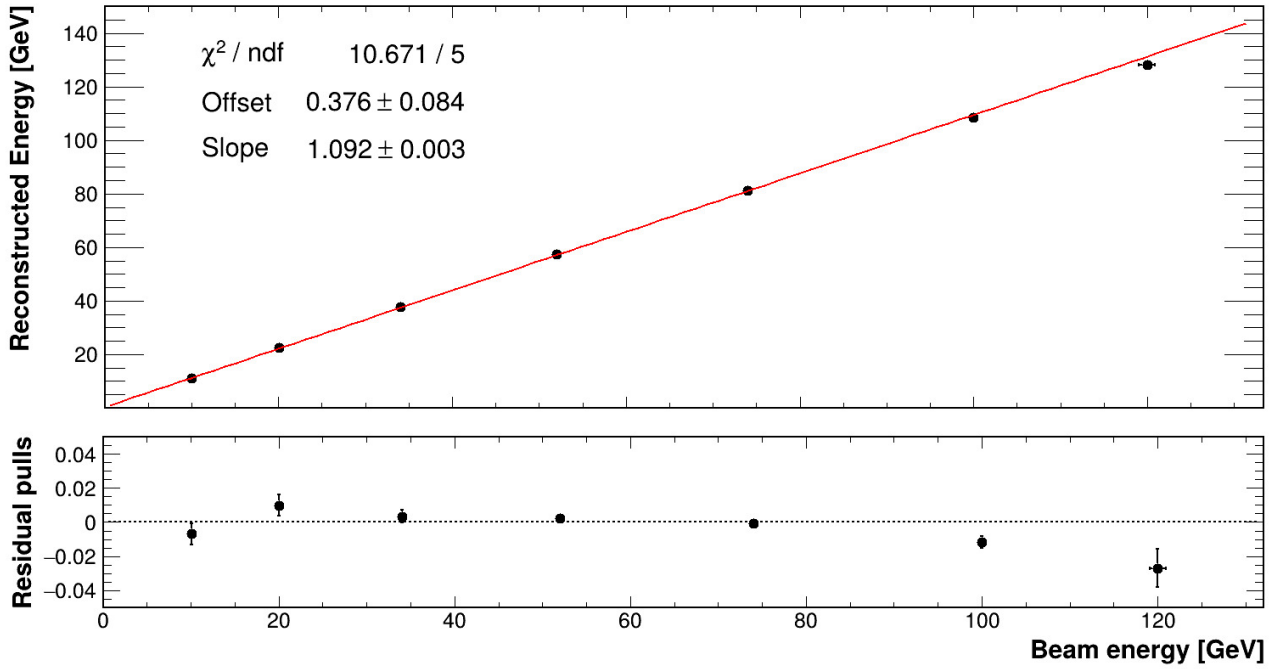


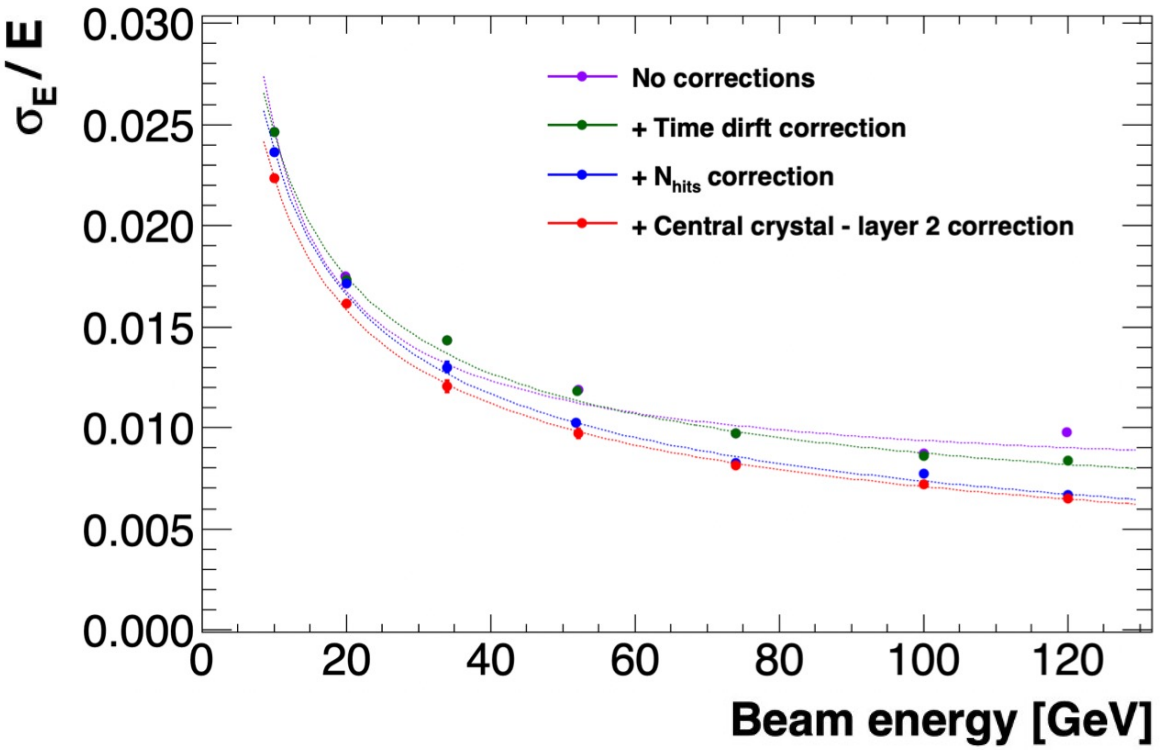




Results: linearity and energy resolution

- Intercalibration plays a crucial role → ~20% relative variation
- MIPs only visible with gain at 4, impossible to calibrate all 225 channels together for now
- Set of corrections applied to data → digitizer different offsets event-by-event, drift in time, dependence from shower shape (calibration driven) both transverse and longitudinal
- Good linearity and **best energy resolution for a high-granularity calorimeter up to now!**

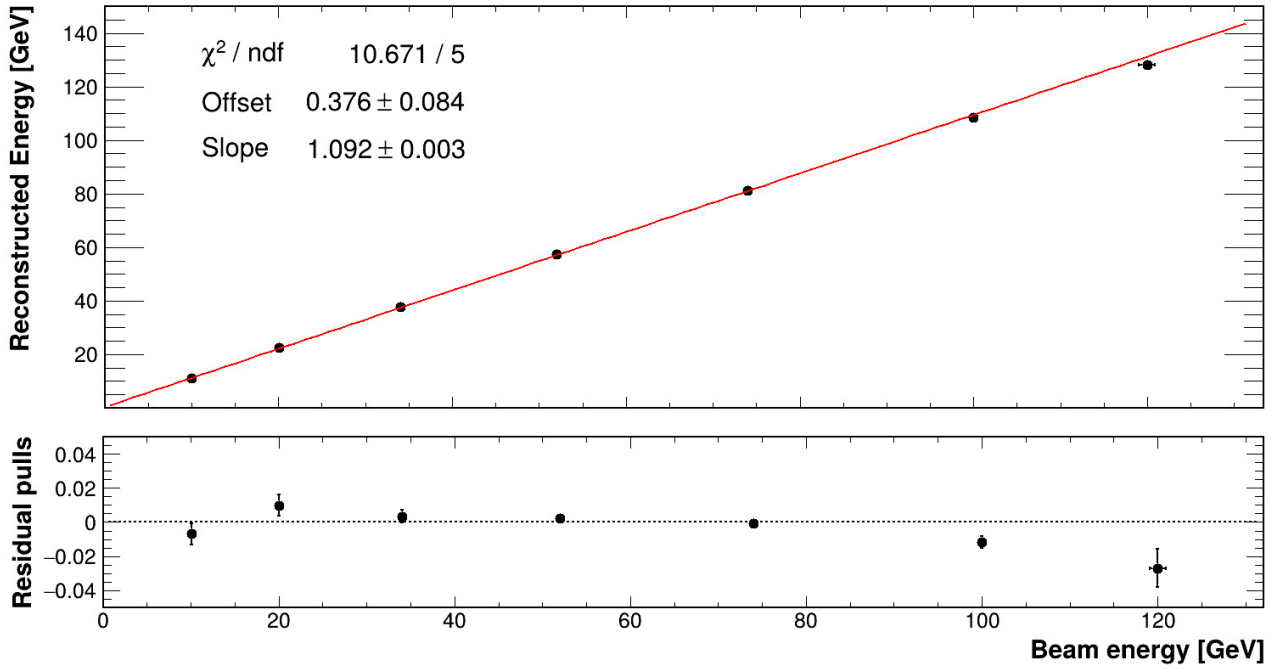


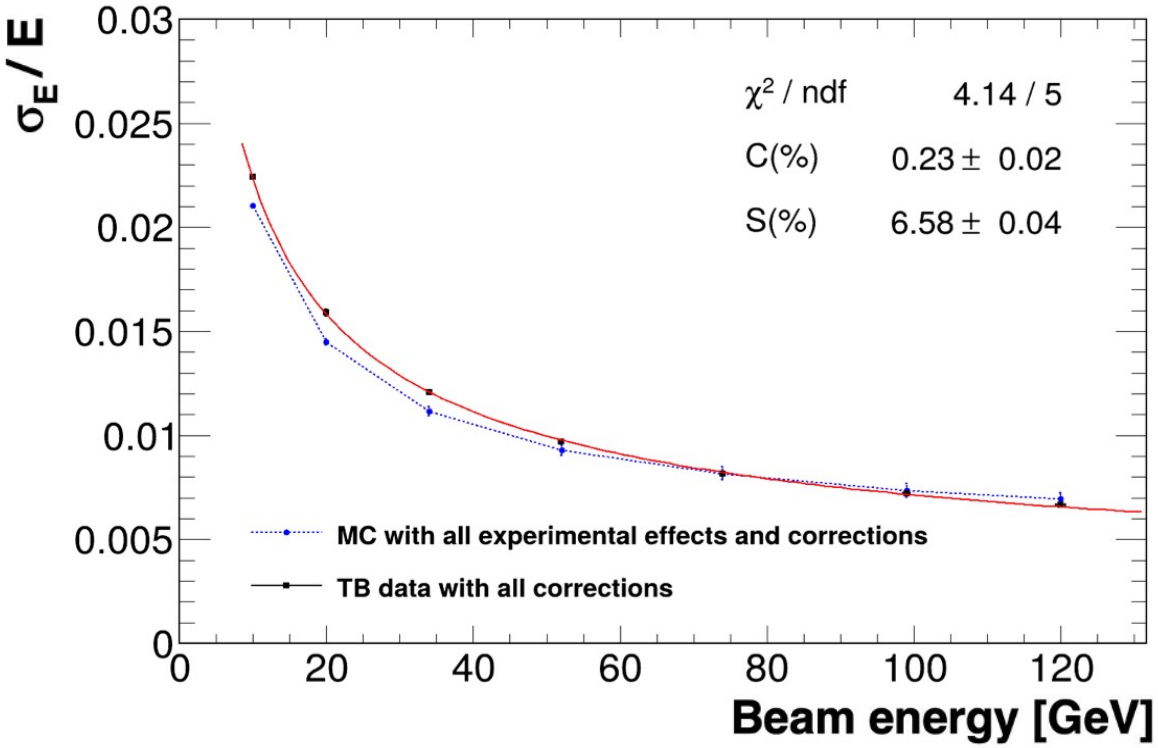


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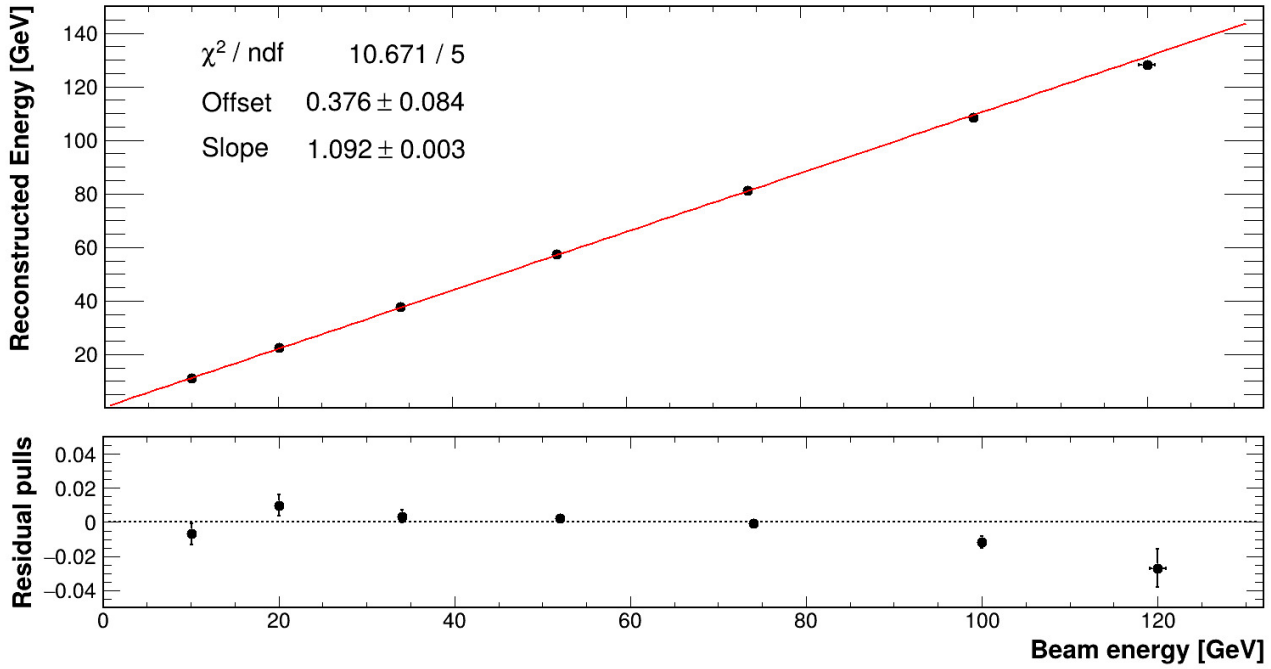


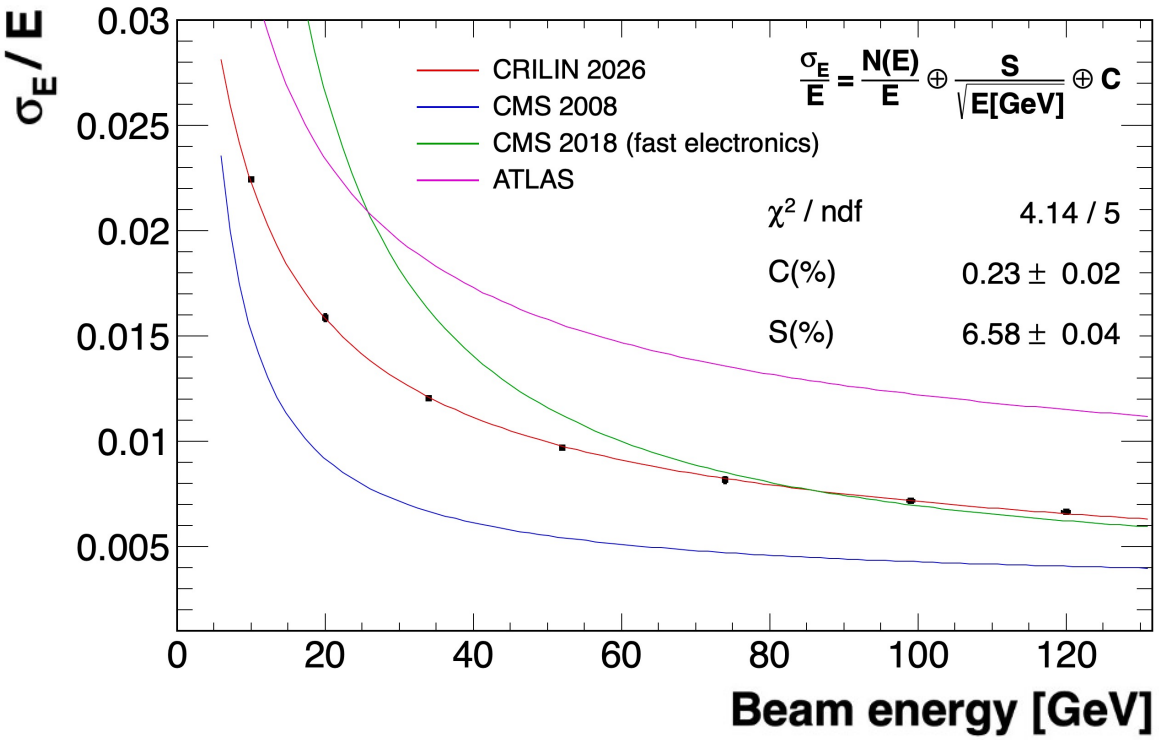


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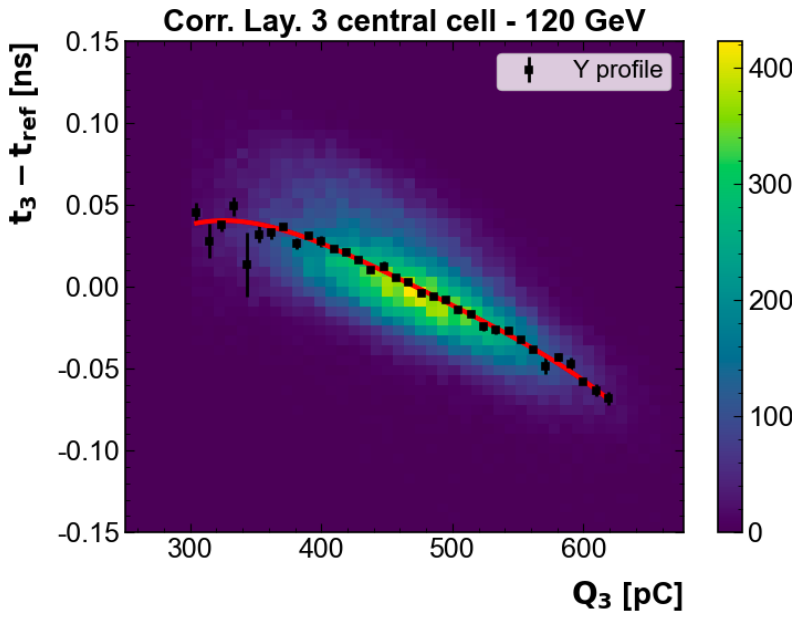


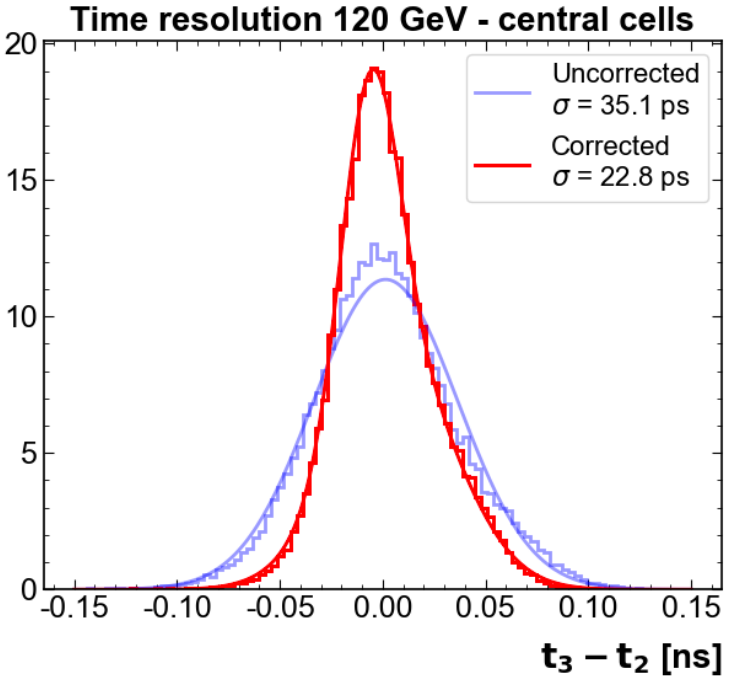


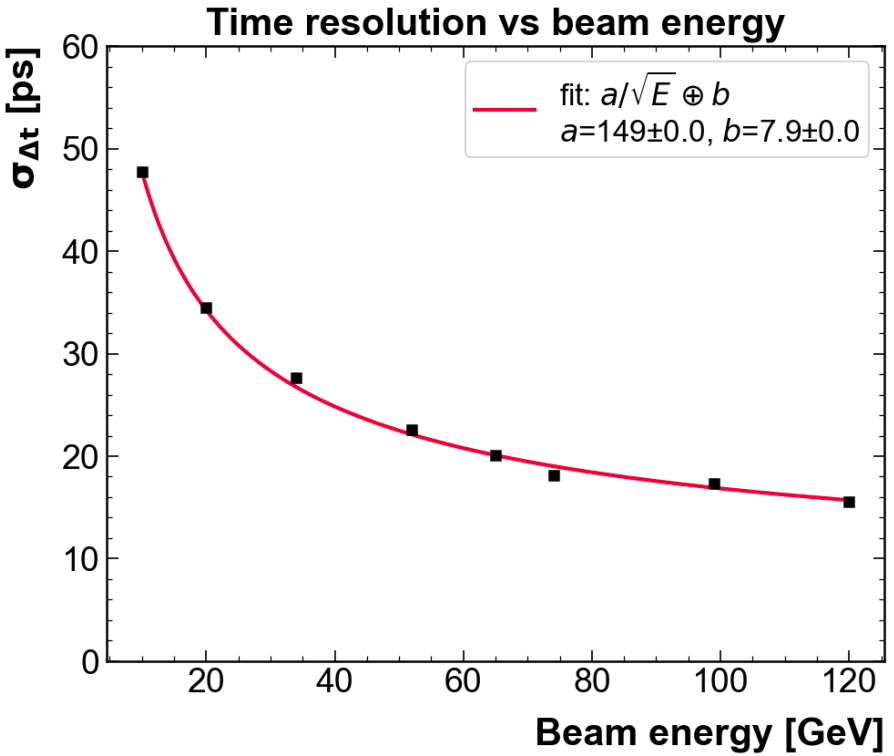
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Results: Timing performaces

- Some slewing observed, corrected using information coming from the fast trigger scintillators→ used as time reference
- Time resolution then evaluated on the difference between the two most energetic crystals for each energies
- Below 50 ps for a 10 GeV beam → strictly depending on the energy deposit on the cells
- **Well within any time resolution request for an ECAL**





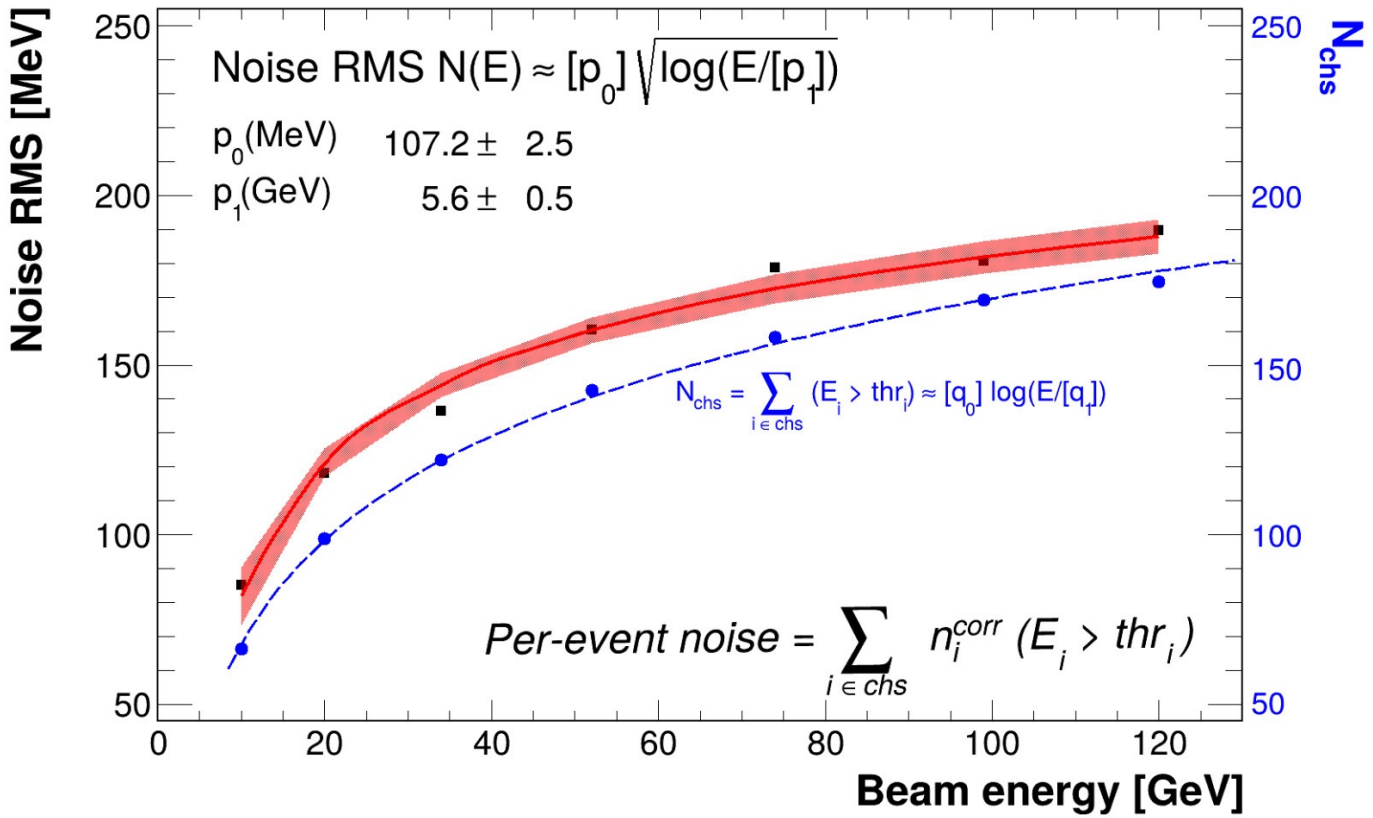


Limiting factors → noise & LY

- Noise term fixed from data observation
- Lots of channels entering in our clusters → all with their noise (and different for each layer)
- Wrt a classical crystal calorimeter that use 3x3 or 5x5 clustering in our setup the minimum number of fired channels is 60 and growing up to 170 at 120 GeV, each bringing their noise
- **Noise and thresholds must be reduced to improve the result**
- This **coupled to an increase of the light collection efficiency** should help going below $5\%/\sqrt{E}$

Thresholds set to 3.5 ADC

Layer	Conversion (MeV/ADC), 1 V digitizers	Conversion (MeV/ADC), 2 V digitizer
Layer 1 (Gain 4)	2.38	4.76
Layer 2 (Gain 1)	9.72	19.44
Layer 3 (Gain 1)	9.72	19.44
Layer 4 (Gain 4)	2.38	4.76
Layer 5 (Gain 6)	1.60	3.20



Conclusions and next steps



Crilin is a crystal calorimeter suited for any future collider with a measured energy resolution at the level of $6.58\%/\sqrt{E}$ and time resolution below 50 ps for a 10 GeV beam.

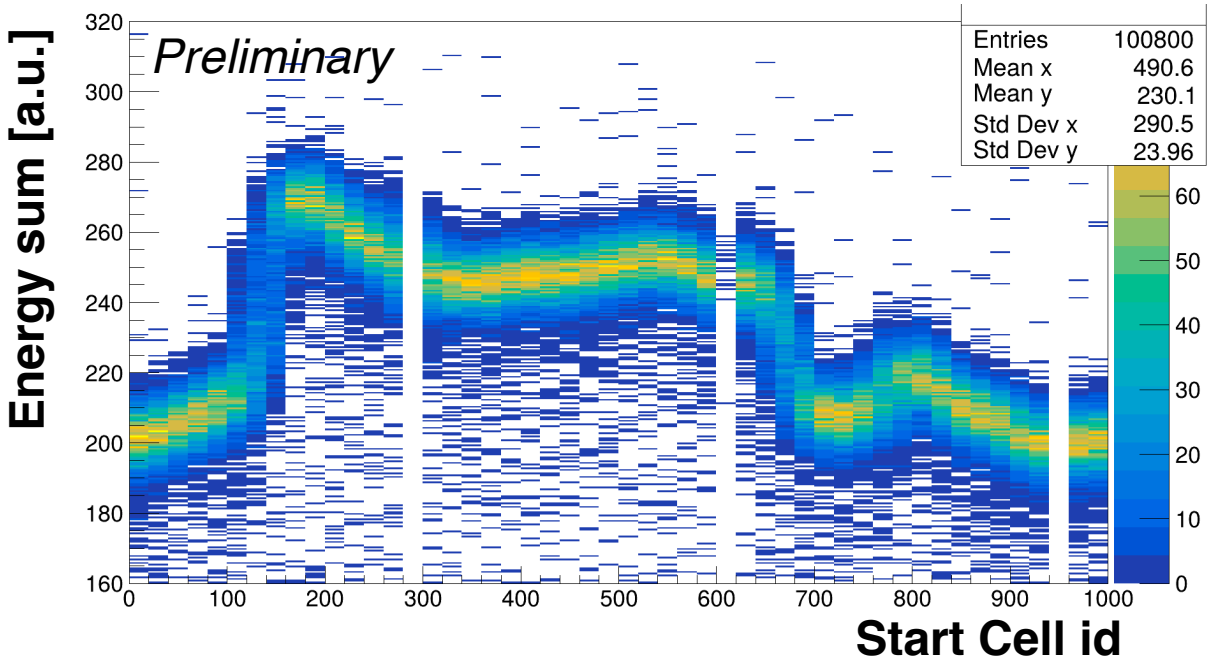
- **Several improvements foreseen in the next three years with the aim to reach the level of 5%/ $\sqrt{E}$**
  - **Electronics and data-acquisition systems:** new front-end electronics with a 0–4 V dynamic range and reduced noise, and 2 CAEN VX2730 digitizers.
  - **Laser monitoring and micro-cooling systems:** essential for the stability of the prototype
  - **New CRILIN prototype** including new matrices with six SiPMs per crystal, Kapton interconnections, and the integration of the FEE, laser-monitoring, and micro-cooling systems.

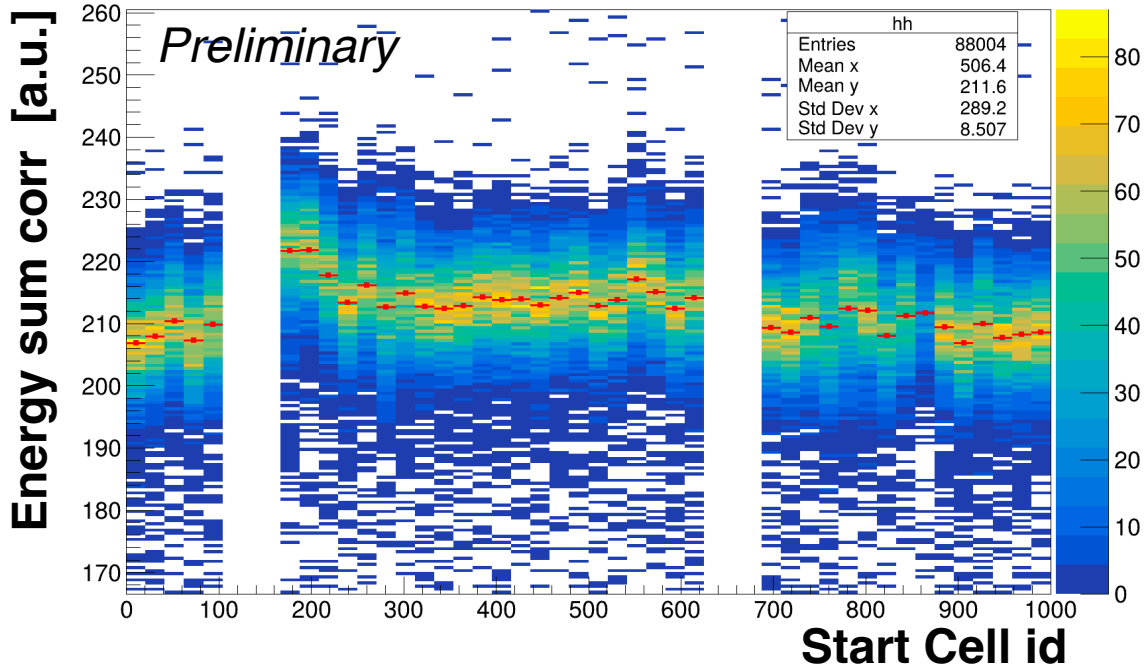
International MUON Collider Collaboration

Backup slides

Improving the noise -1

- FEE electronics noise @ 3 mV level→ we start seeing the other components
- V1742 switch capacitor→ very useful to digitize the waveforms at this level of R&D <u>but:</u>
  - Dynamics limited at 2V maximum (only 32 channels, 1V for the others)
  - Low acquisition rate → with 8 board max 150 Hz
  - Strong event–by-event dependence from the capacitor that initiate the acquisition
- Corrections are possible using the pedestal events, but some remaining effect was directly corrected on data → still plays a role in the resolution





Improving the noise -2

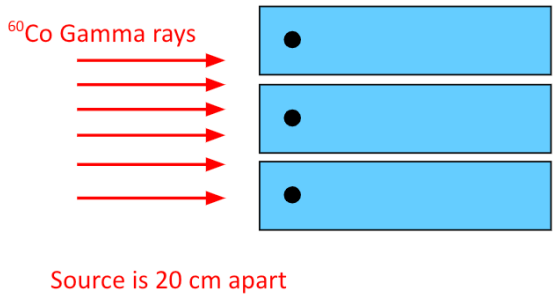
- Limited dynamics of FEE and digitizer made us trying optimize the gain over the layer
- Having different gain on the layers:
  - does not allow us to evaluate the MIPs in the central layers → need at least gain 4 while to avoid FEE and digitizer saturation those are set to 1
  - Force us to have different thresholds for different gains → significantly higher in the central layers
- Essential to have all the layers with gain 4 but without saturating → our solution:
  - Produce a new version of the FEE just for the central layers with 3.8 V dynamics instead of the 1.6 V one that we have now
  - Increase also the dynamical range for the acquisition step as well as fixing the intrinsic switch capacitor issue → proposed solution CAEN VX2730B 14-bit flashADC, 4V dynamics to be used at least on the core of the central layers' crystals

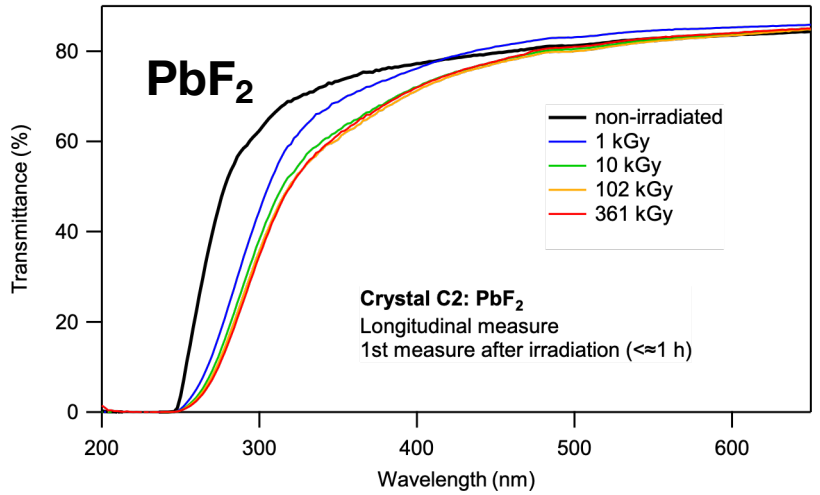
Radiation hardness studies

Crystal radiation hardness

Neutron fluence: $\sim 10^{14} n_{1MeVeq}/cm^2$ **year** on ECAL **TID:** ~ **1 kGy/ year** on ECAL.

Radiation hardness of two PbF_2 and $PbWO_4$-UF crystals (10x10x40 mm^3) checked for TID (up to 100 Mrad @ Calliope, Enea Casaccia) and neutrons (14 MeV neutrons from Frascati Neutron Generator, Enea Frascati, up to 10^{13} n/cm^2)

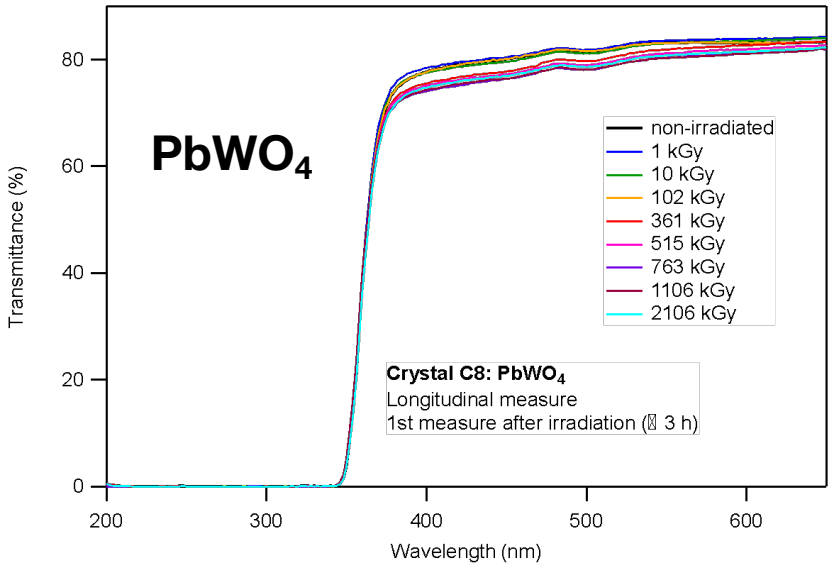




- **For PbF_2:**
  - **after a TID > 350 kGy no significant decrease** in transmittance observed.
  - Transmittance after neutron irradiation showed no deterioration
- **For $PbWO_4$-UF:**
  - **after a TID > 2 MGy no significant decrease** in transmittance observed.

Crystal	PbF_2	PWO-UF
Density [g/cm^3]	7.77	8.27
Radiation length [cm]	0.93	0.89
Molière radius [cm]	2.2	2.0
Decay constant [ns]	-	0.64
Refractive index at 450 nm	1.8	2.2
Manufacturer	SICCAS	Crytur

PWO-UF (ultra-fast):
Dominant emission with $\tau < 0.7$ ns
M. Korzhik et al., NIMA 1034 (2022) 166781



SiPMs radiation hardness

Neutron fluence: $\sim 10^{14} n_{1MeVeq}/cm^2$ **year** on ECAL **TID:** ~ **1 kGy/ year** on ECAL.

Neutrons irradiation: 14 MeV neutrons with a total fluence of 10^{14} n/cm^2 for 80 hours on a series of two SiPMs (10 and 15 μm pixel-size).

Extrapolated from I-V curves at 3 different temperatures:

- Currents at different operational voltages.
- Breakdown voltages;

15 μm pixel-size

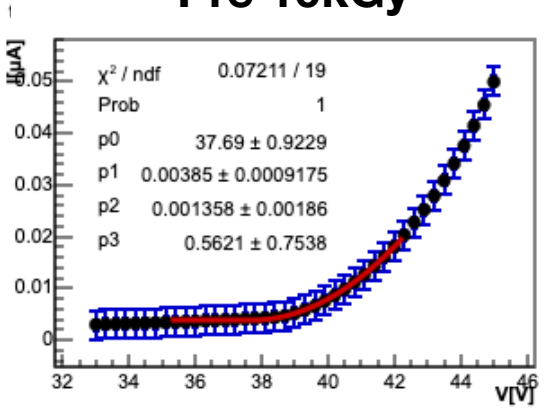
T [°C]	V_{br} [V]	I(V_{br}+4V) [mA]	I(V_{br}+6V) [mA]	I(V_{br}+8V) [mA]
-10 ± 1	75.29 ± 0.01	12.56 ± 0.01	30.45 ± 0.01	46.76 ± 0.01
-5 ± 1	75.81 ± 0.01	14.89 ± 0.01	32.12 ± 0.01	46.77 ± 0.01
0 ± 1	76.27 ± 0.01	17.38 ± 0.01	33.93 ± 0.01	47.47 ± 0.01

10 μm pixel-size

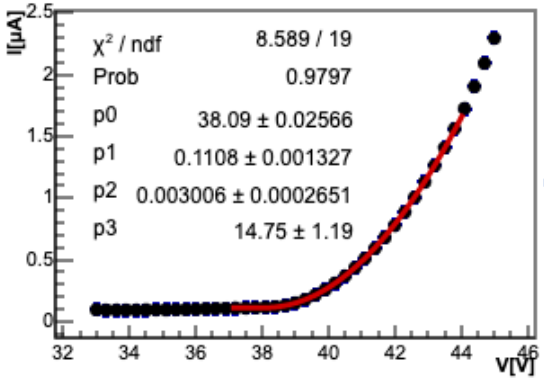
T [°C]	V_{br} [V]	I(V_{br}+4V) [mA]	I(V_{br}+6V) [mA]	I(V_{br}+8V) [mA]
-10 ± 1	76.76 ± 0.01	1.84 ± 0.01	6.82 ± 0.01	29.91 ± 0.01
-5 ± 1	77.23 ± 0.01	2.53 ± 0.01	9.66 ± 0.01	37.51 ± 0.01
0 ± 1	77.49 ± 0.01	2.99 ± 0.01	11.59 ± 0.01	38.48 ± 0.01

For the expected radiation level, **the best SiPMs choice are the 10 μm ones** for their minor dark current contribution.

Pre 10kGy



Post 10kGy

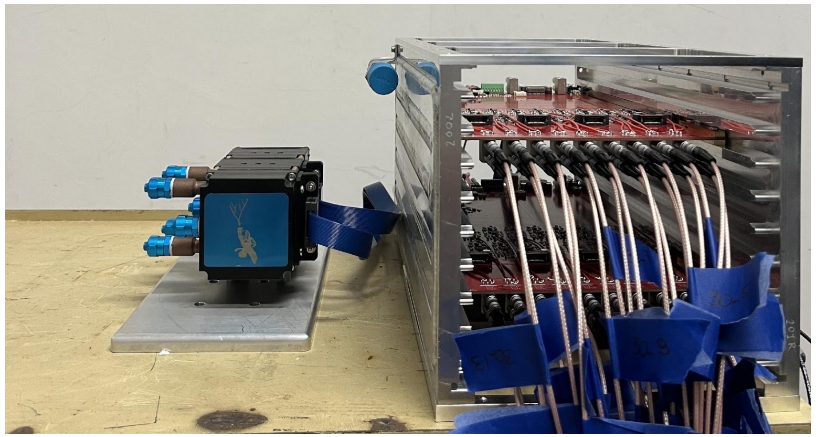


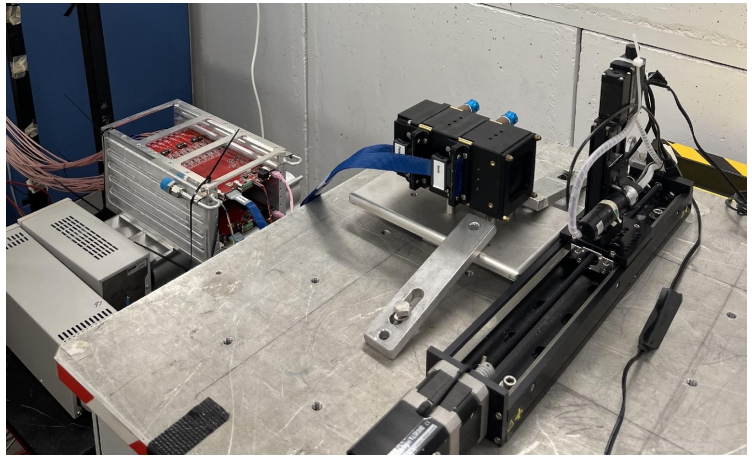
Dark current @ V_{op} goes from 12 nA to 600 nA

LY loss evaluation @ BTF

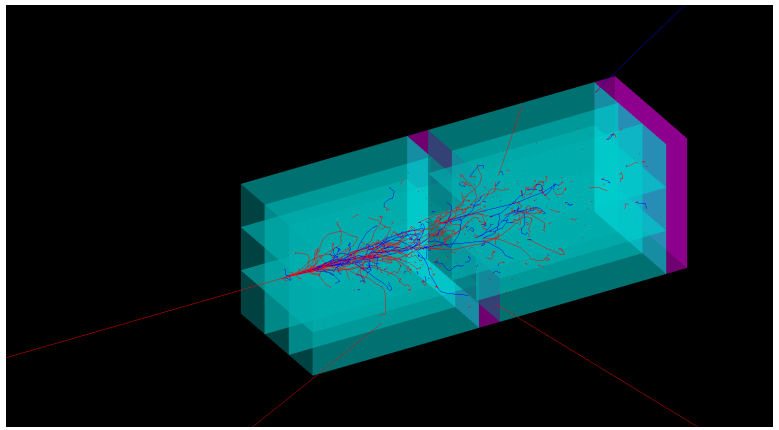
BTF, April 2024

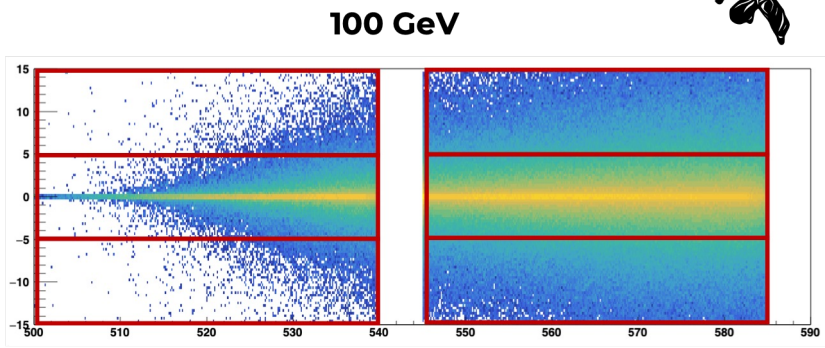
- Study of the LY loss of one layer of Proto-1 after Gamma ray irradiation
- Beam: 450 MeV electrons with multiplicity set to 1
- Beam centered on a different crystal at each run

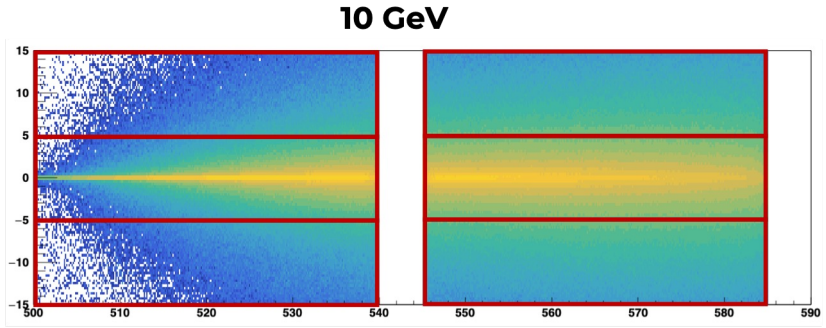


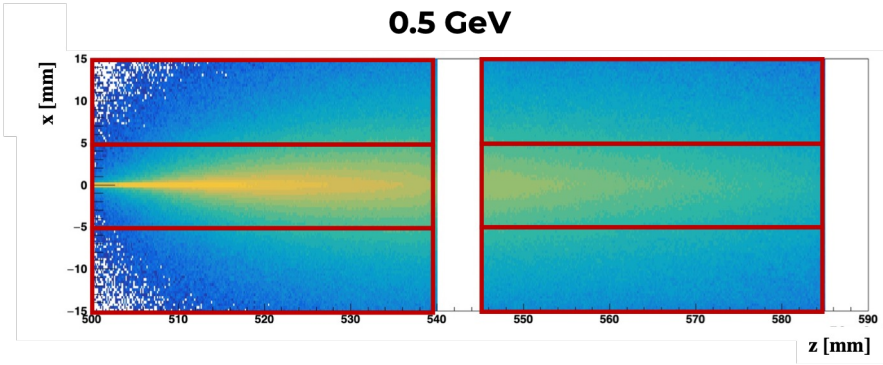


Monte Carlo







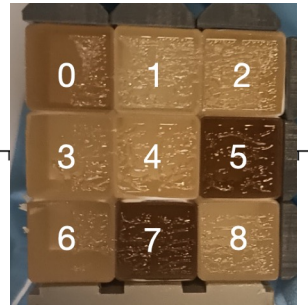


Beam test @ BTF: crystals

- Crystals tested with two different wrapping, Teflon and Mylar, up to 80 kGy
- LY loss evaluated through variation in charge and number of photo-electrons

Telfon wrapping

Npe values of PbF_2 pre and post 80 kGy irradiation



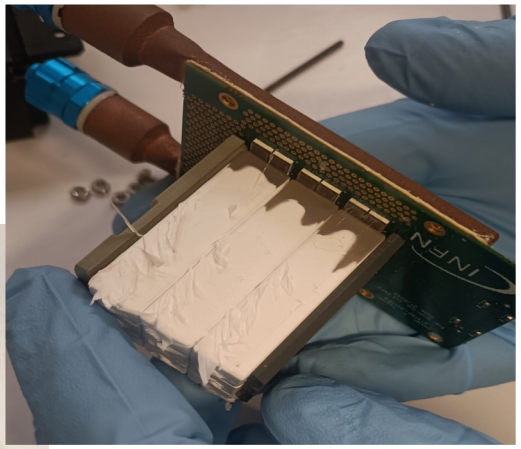
Mylar wrapping

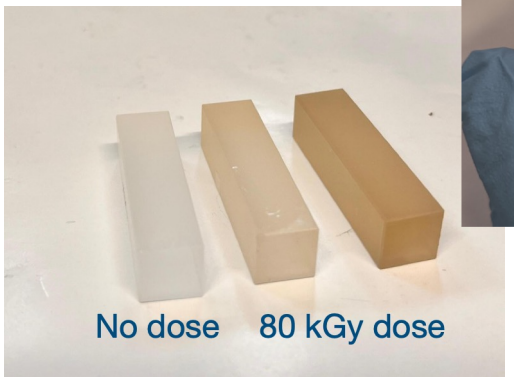
Npe values of PbF_2 pre, after 10 kGy and after 80 kGy irradiation

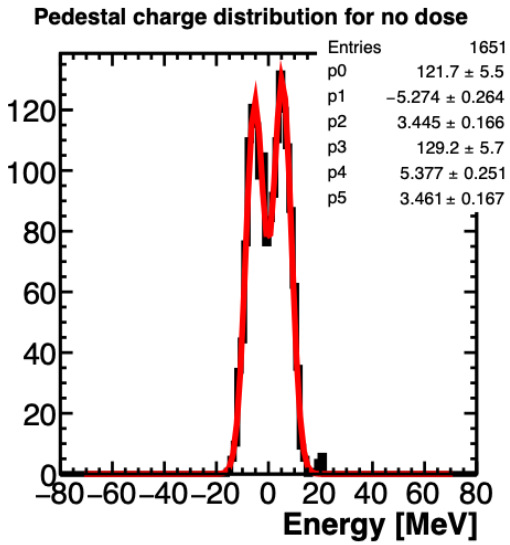


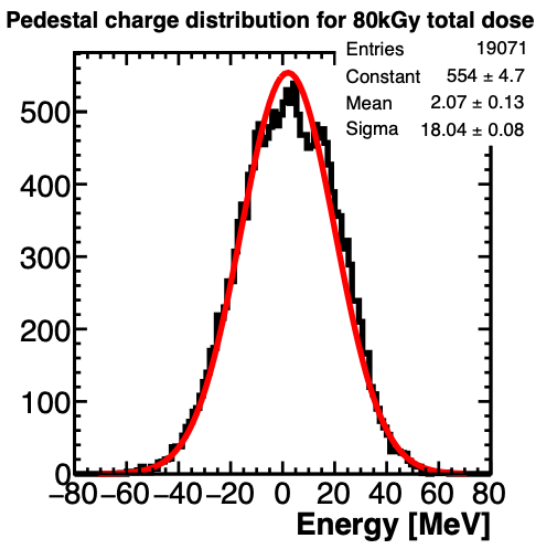
Beam test @ BTF: considerations

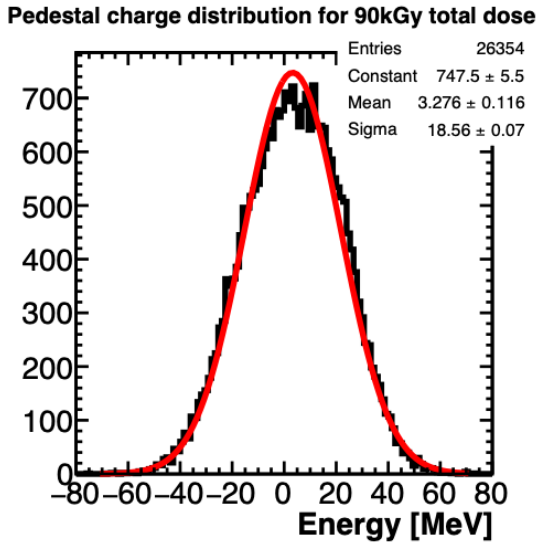
- Considerable variability in crystals' response to radiation, despite SICCAS claiming use of high-purity (>99.9%) PbF_2 powder for crystal growth
- **Crystals evident loss of transparency**, uniform along the longitudinal axis
- Teflon was damaged and brittle → **Mylar is the best choice**
- SiPM dark counts increases significantly with the absorbed dose
- New tests planned to evaluate SiPMs PDE loss

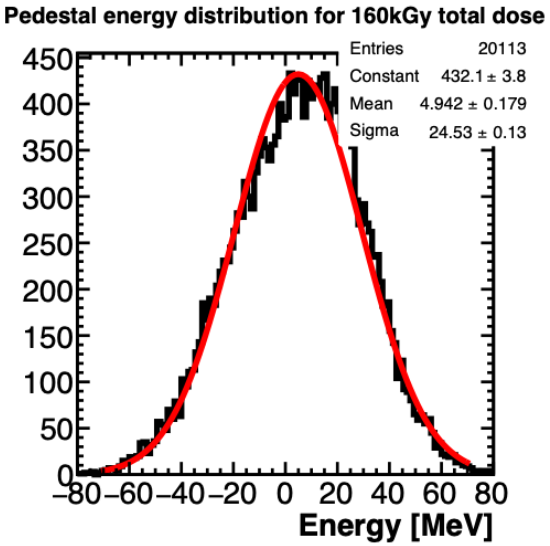










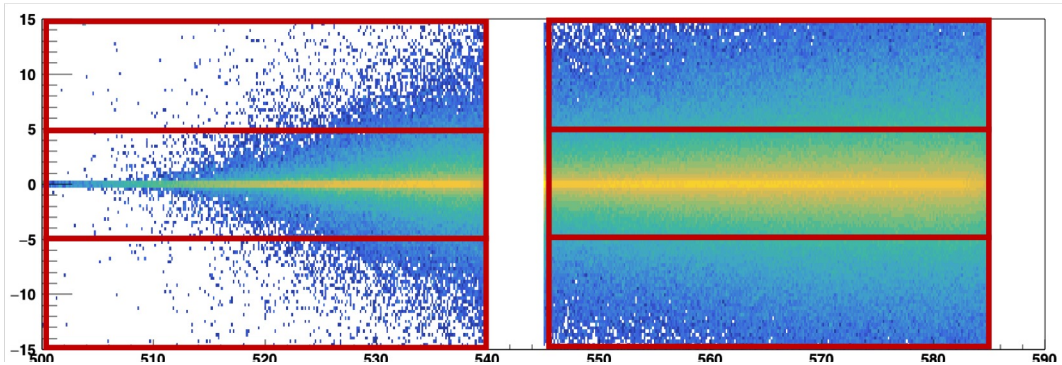


Proto 1 Timing performances

Beam test @ CERN: MC agreement

- **Electron beam from 40 GeV up to 150 GeV**
- **Proto-1** (2 crystal layers totalling **8.5 X_0**) is not deep enough to fully contain the electromagnetic shower, making energy resolution studies unfeasible.

MC
120 GeV e^-

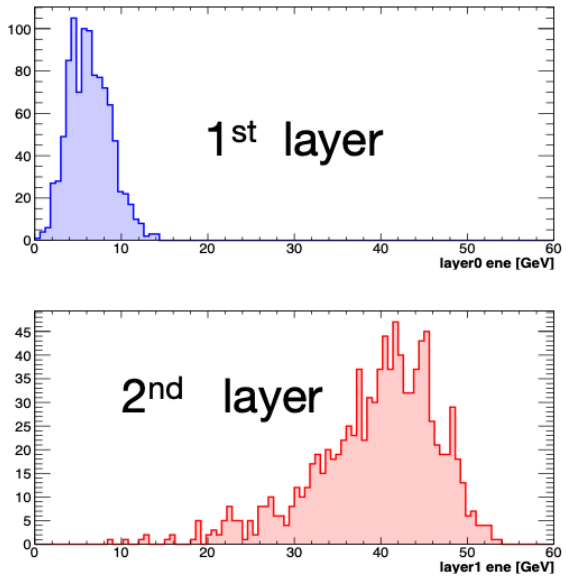


Will be possible with new larger prototype, now under construction

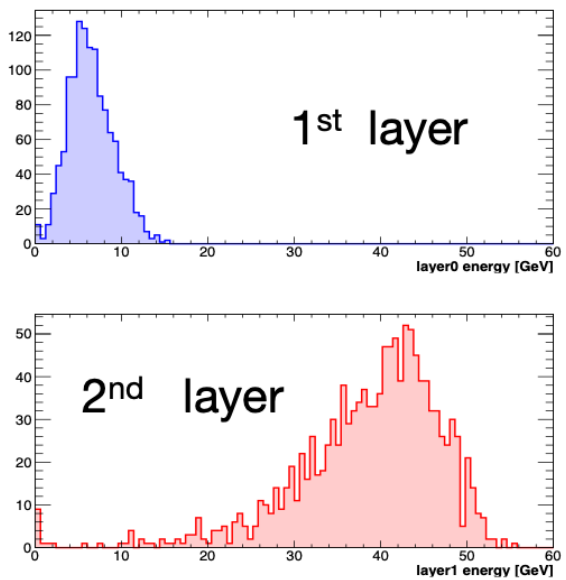
- Great agreement between **MC simulation studies** and **experimental data** from the test beam on the energy deposited in the prototype.

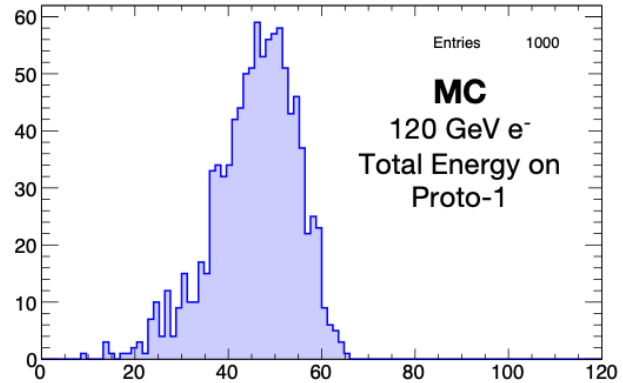
- Validation of the **simulation model**.

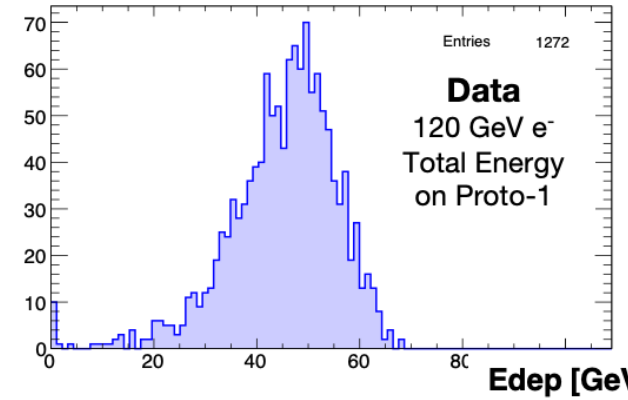
MC
120 GeV e^-



DATA
120 GeV e^-



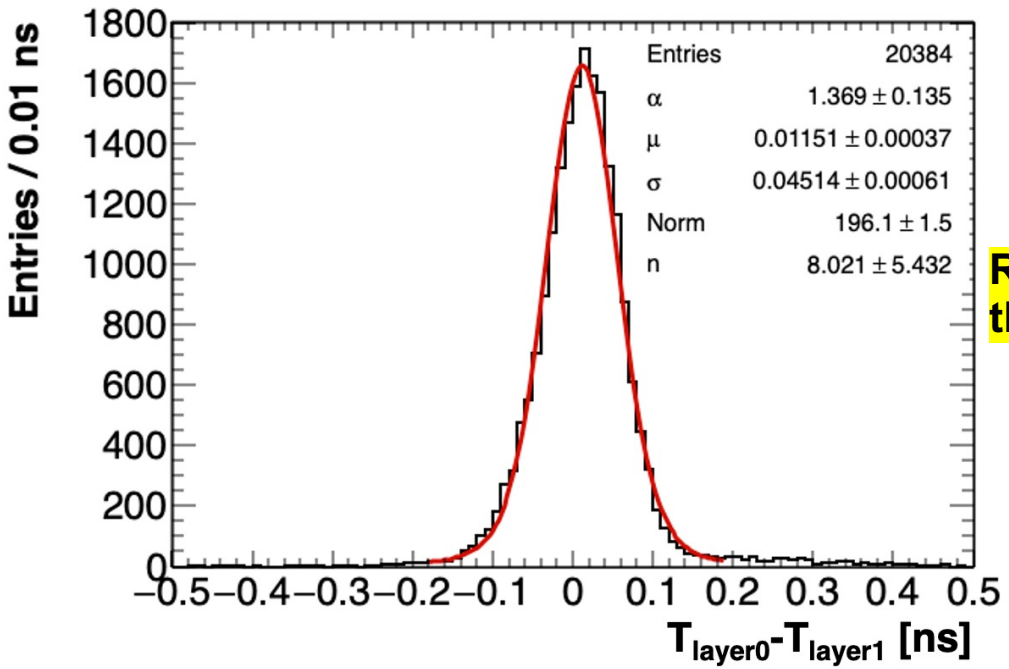




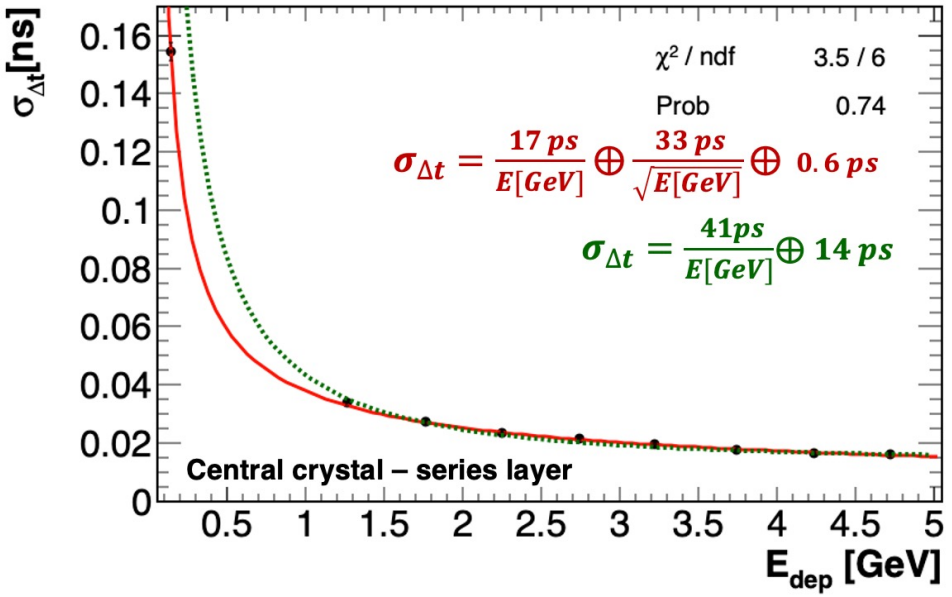
Beam test @ CERN: Timing

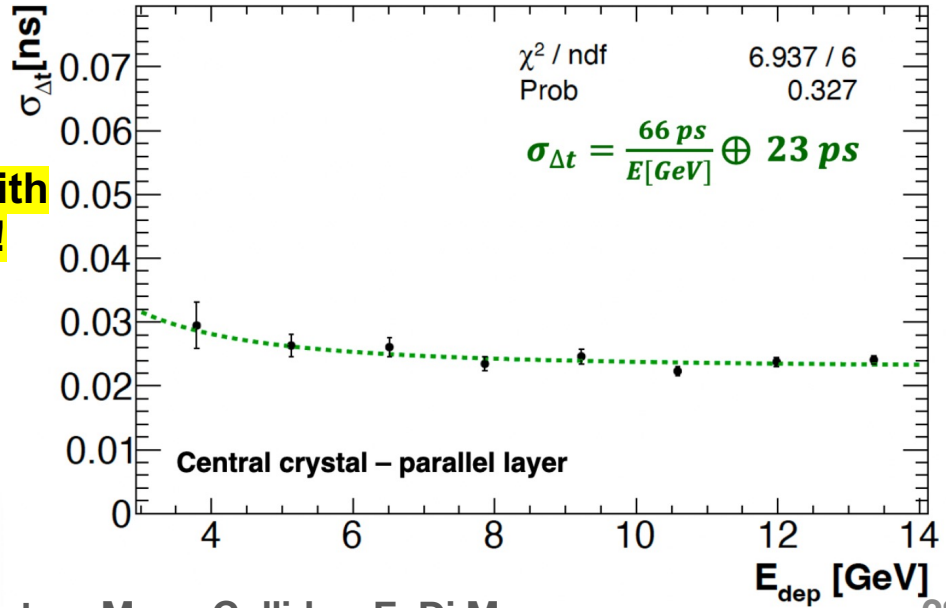
- Time Resolution of **O(20 ps)** both in the series and in the parallel layers using the SiPMs time difference of the central crystals

- Excellent results using most energetic crystal of different layers. **Time resolution dominated by the 2 boards synchronisation jitter** O(32ps)



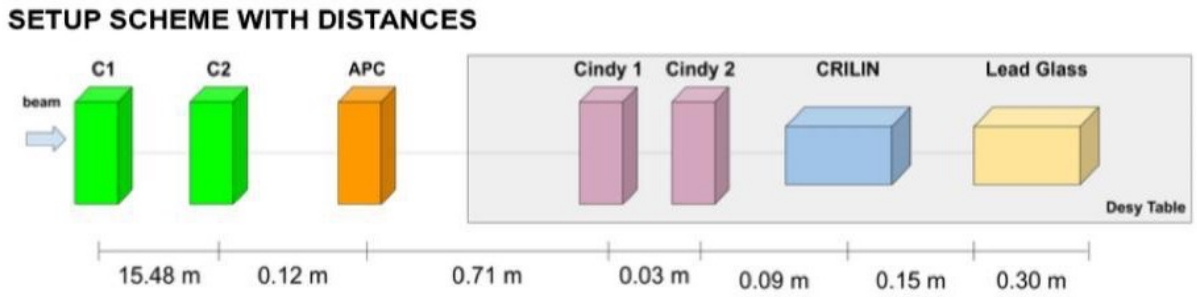
Results in agreement with the ECAL requirements!

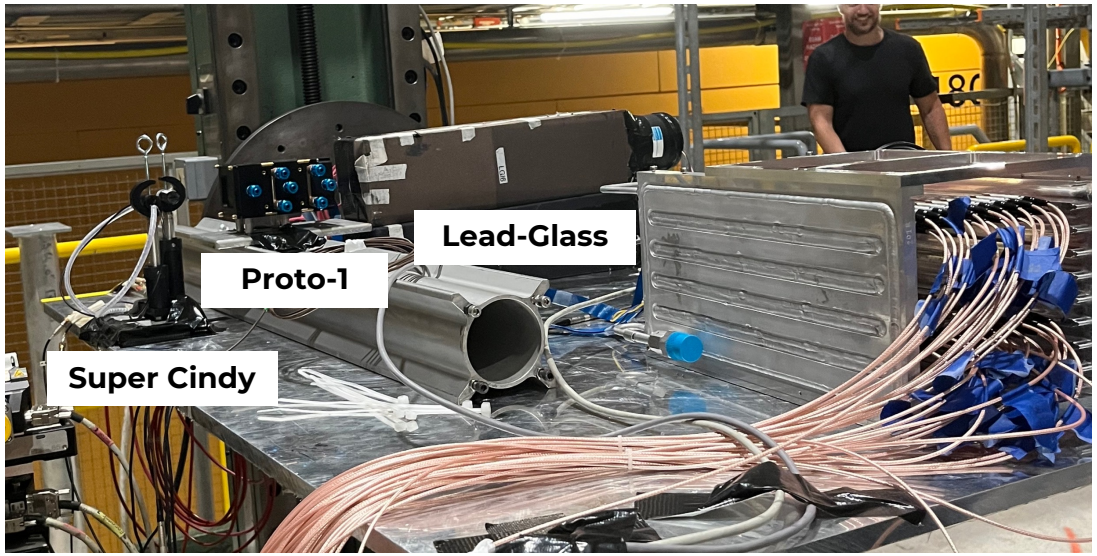




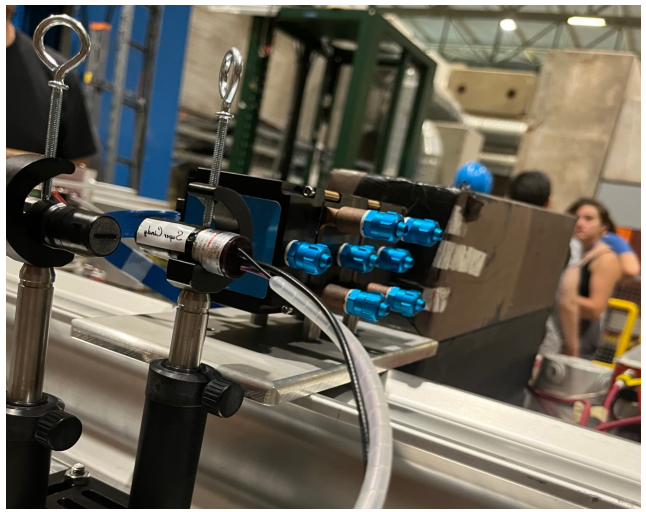
Beam test @ CERN

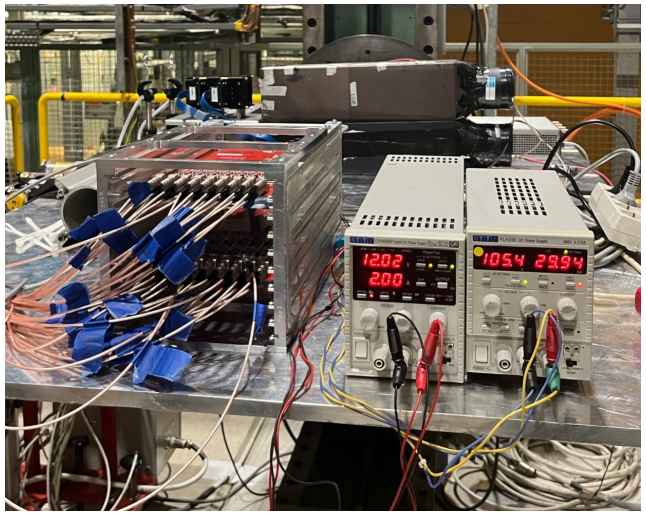
H2-SPS-CERN, August 2023





- Electron beam from 40 GeV up to 150 GeV
- Beam reconstructed with 2 silicon strip telescopes
- Data acquisition with 2 CAEN V1742 (32 ch each) modified @ 2 Vpp
- 5 Gs/s sampling rate

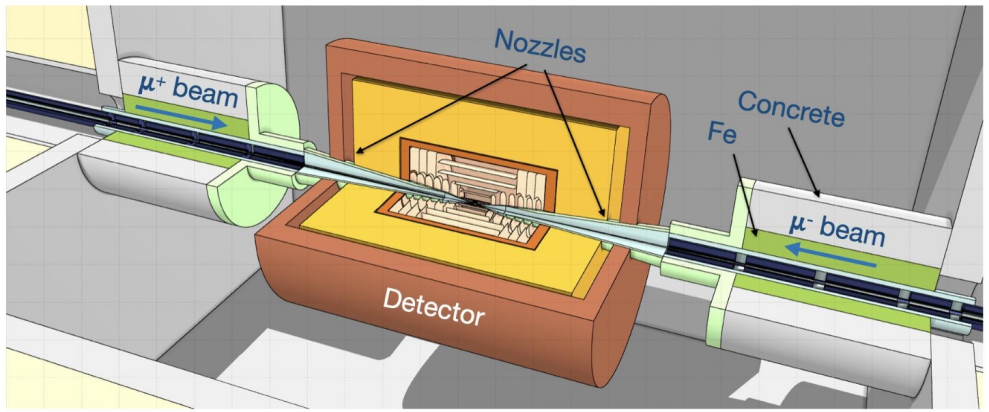


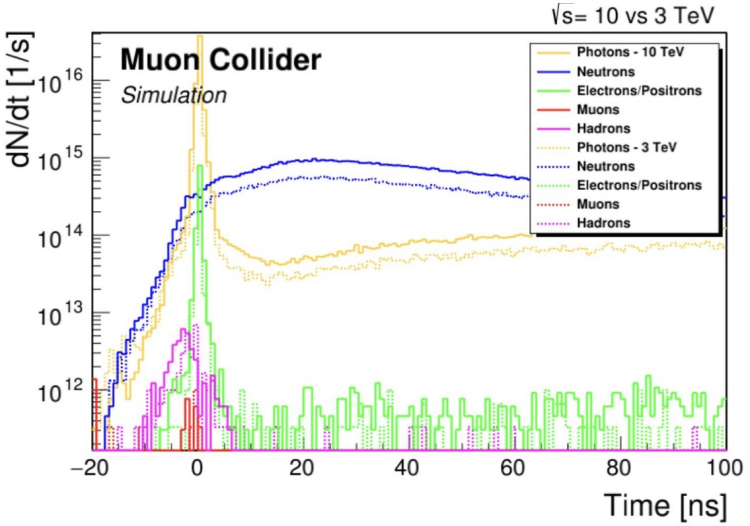


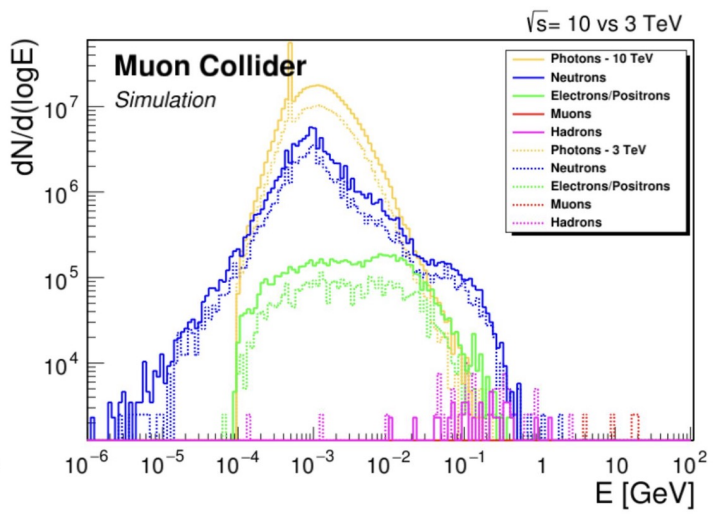
Beam Induced Background

The decay of muons in flight along the accelerator ring produces high-momentum secondary particles, which interact with the machine's materials, and generate an **intense flux of tertiary particles** entering the detector region→ Beam-Induced Background (BIB)

- MDI optimized to reduce this contribution throughout a pair of Tungsten conical-shape absorber (**nozzles**) in the forward region on the detector.
- **Residual component** characterized by **low energy and broad arrival time distributions.**
- For $\sqrt{s}$=10 TeV, also the **incoherent pair production** process is an important source of high-energy background particles in time with the signal.



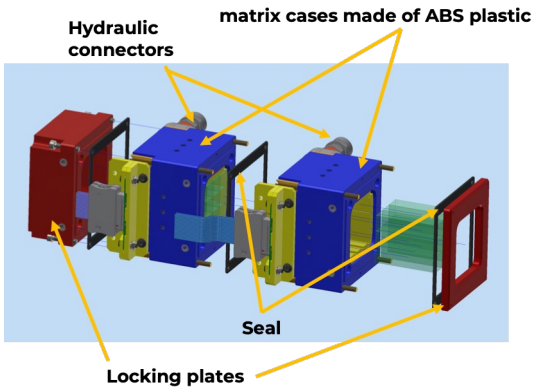


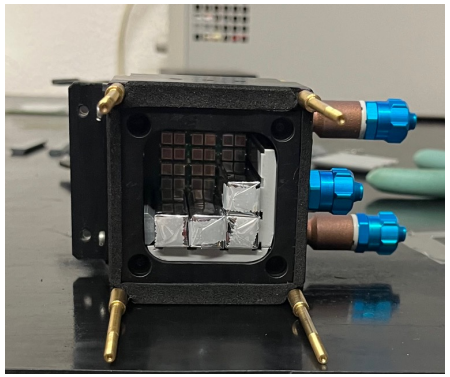


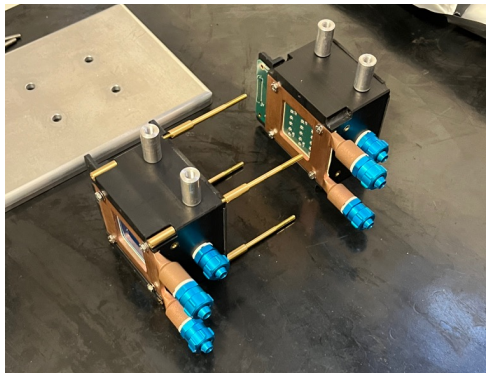
Proto-1: Mechanics and Electronics

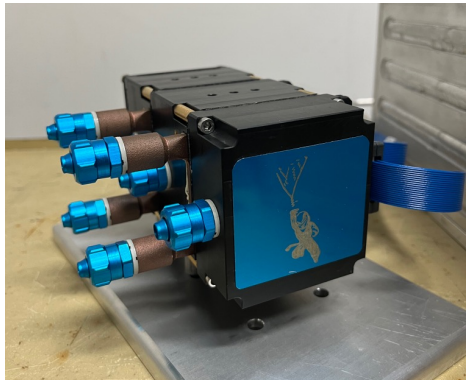
Mechanics:

- Two stackable and interchangeable submodules assembled by bolting, each composed of 3x3 crystals+36 SiPMs (2 channel per crystal)
- light-tight case which also embeds the front-end electronic boards and the heat exchanger needed to cool down the SiPMs.



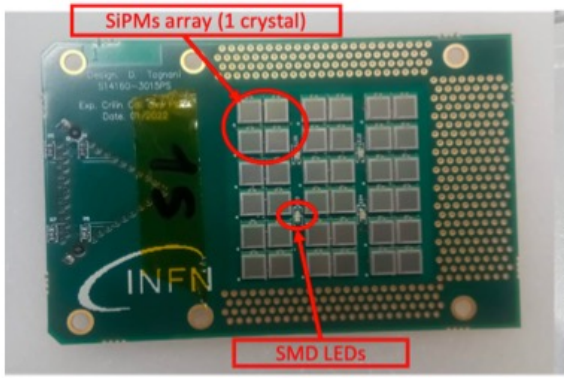


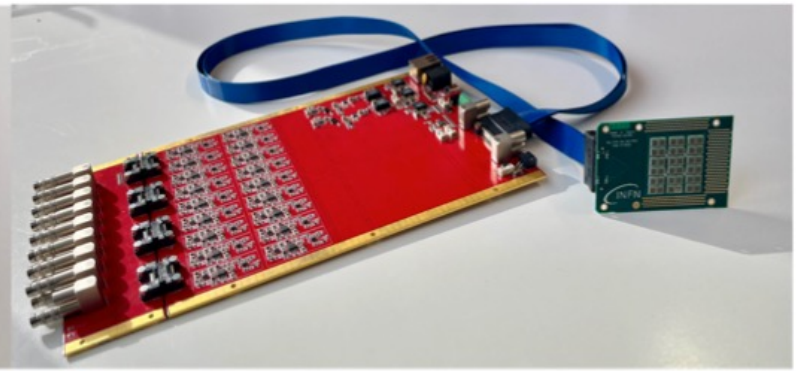




Electronics:

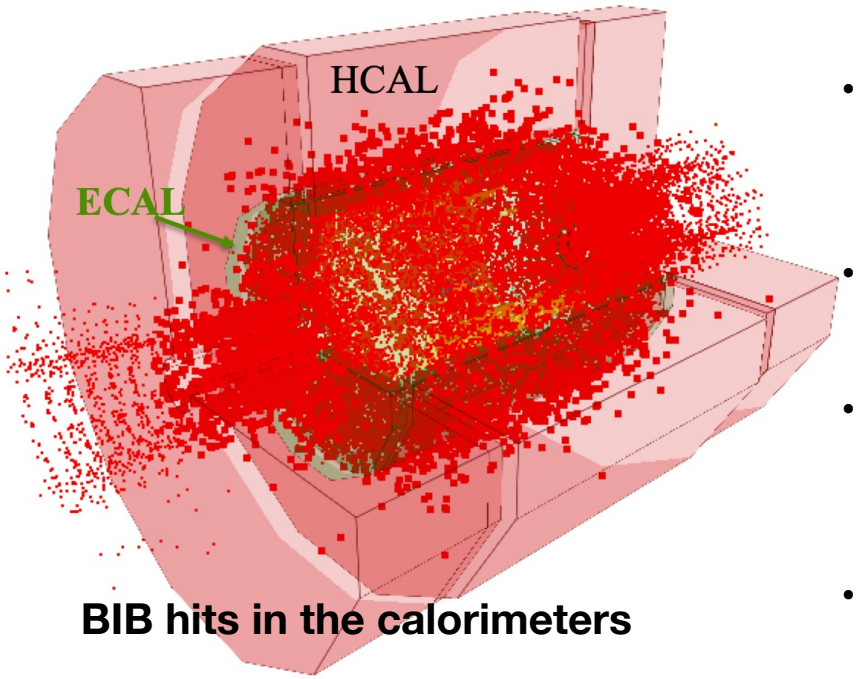
- **SiPMs board:** custom SiPM array board 36x10 μm Hamamatsu SMD SiPMs
- **Mezzanine board:** 18x readout channels → amplification, shaping and individual bias regulation, slow control routines





Beam Induced Background

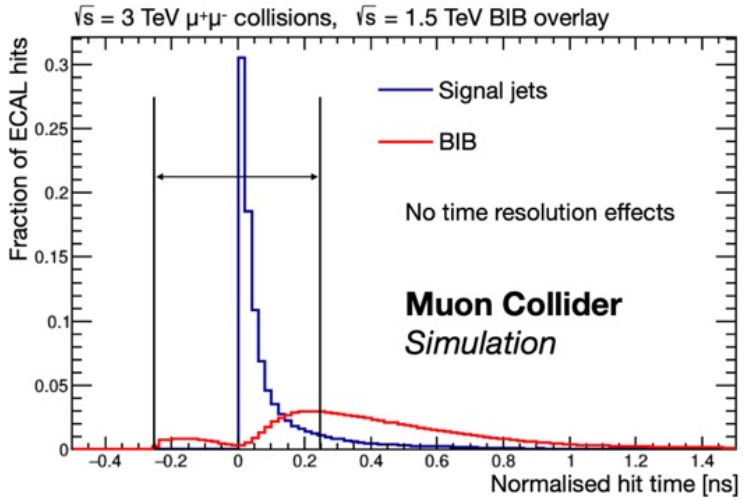
- **The beam-induced background (BIB)** poses the main challenge for the detector development at the Muon Collider
- Produced by muons decay in the beams, and subsequent interactions with the machine
- The BIB produces a flux of 300 particles per cm^2 through the ECAL surface
- 96% photons and 4% neutrons, average photon energy 1.7 MeV

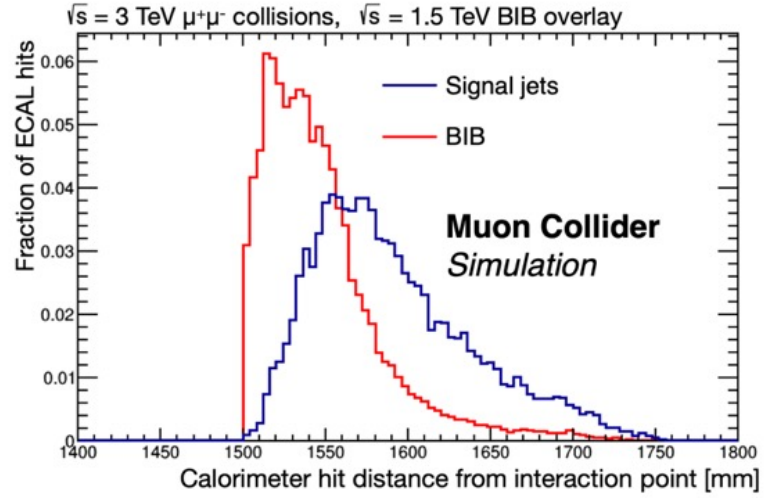


BIB hits in the calorimeters

Key features:

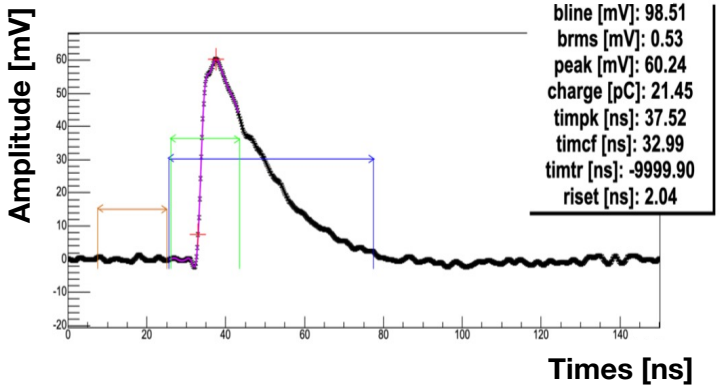
- **Timing**: BIB hits are out-of-time, a resolution in the order of 100 ps is needed
- **Longitudinal segmentation**: different profile for signal and BIB
- **Granularity**: helps in separating BIB particles from signal, avoiding overlaps in the same cell
- **Energy resolution:** target $\frac{\Delta E}{E} \simeq \frac{10\%}{\sqrt{E[\mathrm{GeV}]}}$



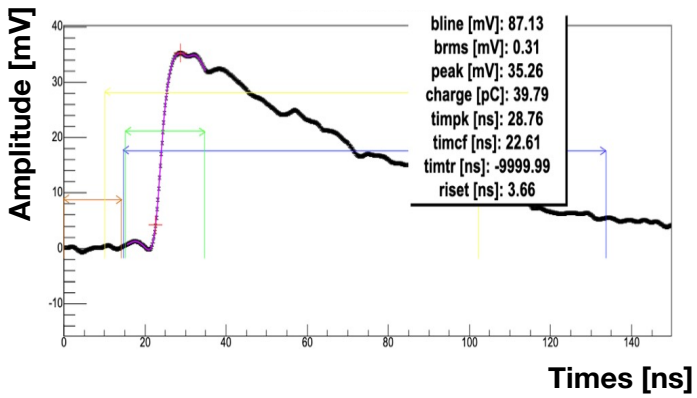


Beam test @ CERN: Configuration

1st layer: SiPMs series



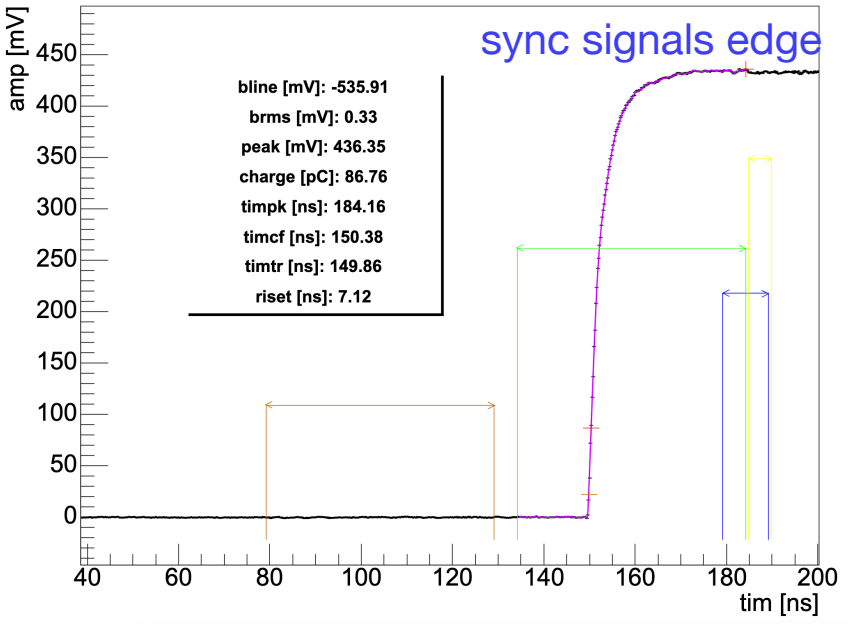
2nd layer: SiPMs parallel



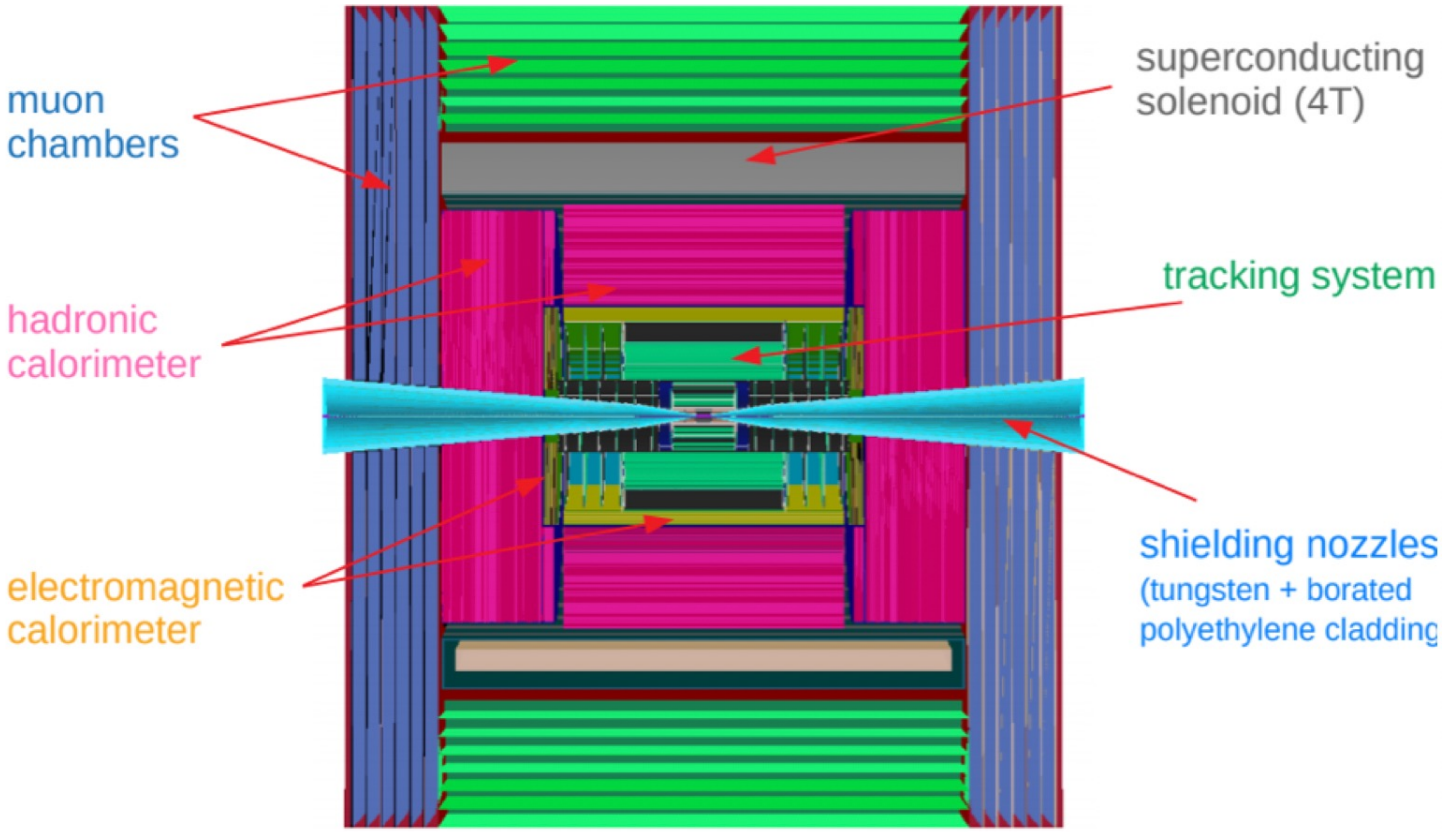
- **Two different connection in the two layers:** series and parallel
- **Low pass filtering** (Bessel 2nd order) cutoff_parallel ~ 2* cutoff_series.
- Cut-off frequency based on two parameters: baseline RMS and risetime (10-90%)
- Wave quality flag based on baseline RMS, peak, and risetime to discard bad waves
- **Processing cuts:** peak > 2 mV

Syncronisation pulses reconstruction:

- **O(10 ps) ch-to-ch in the same chip**
- **O(30 ps) board-to-board jitter**



Muon Collider



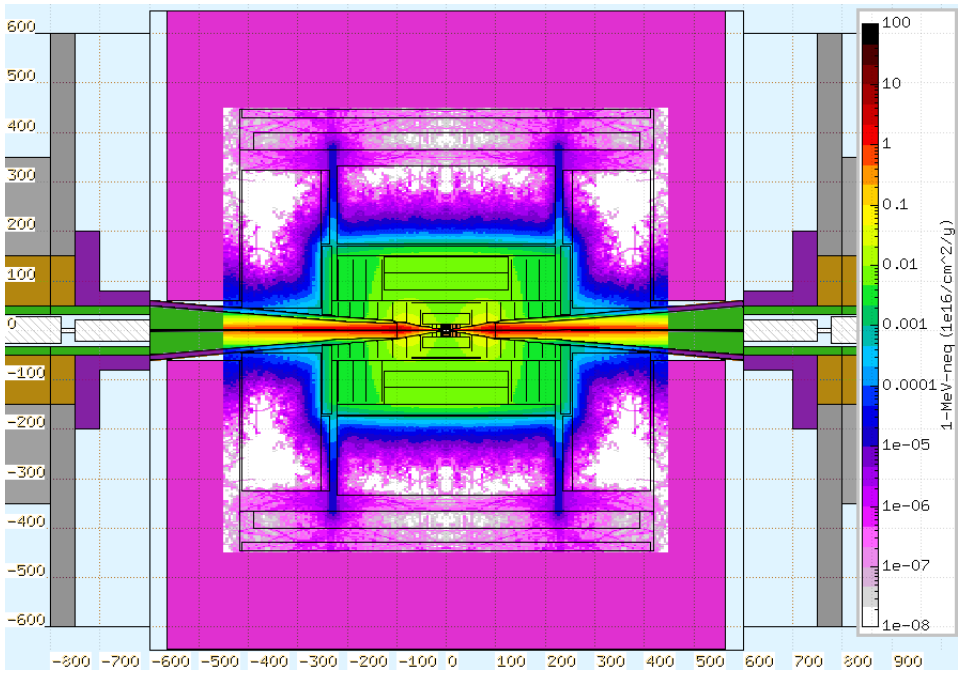
Main issues: BIB and radiation damage

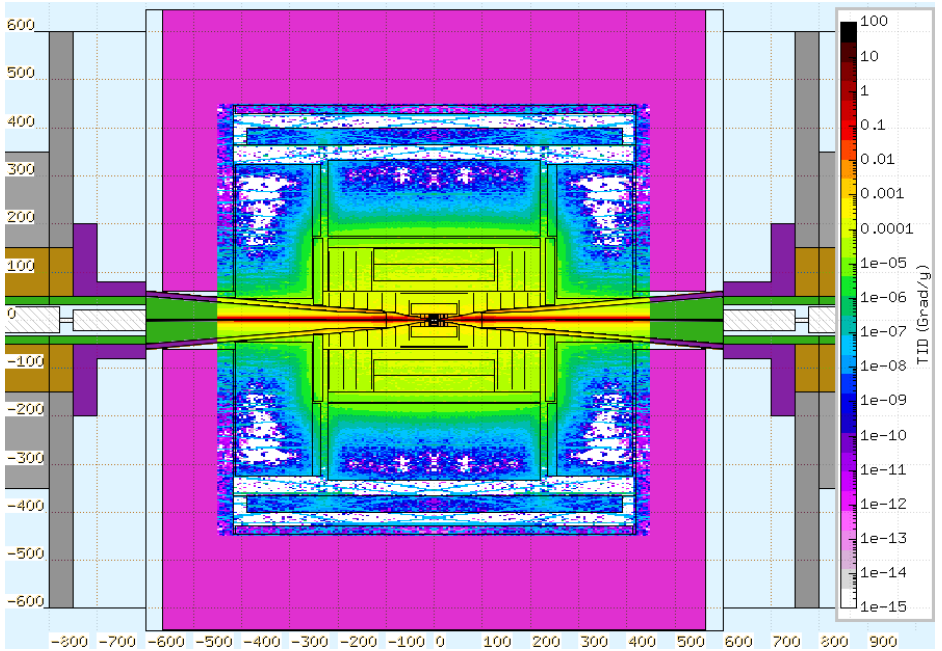
Optimized detector interface:

- Based on CLIC detector, with modification for BIB suppression.
- Dedicated shielding (nozzle) to protect magnets/detector near interaction region.

Radiation enviroment

FLUKA simulation for the BIB at $\sqrt{s}$=1.5 TeV



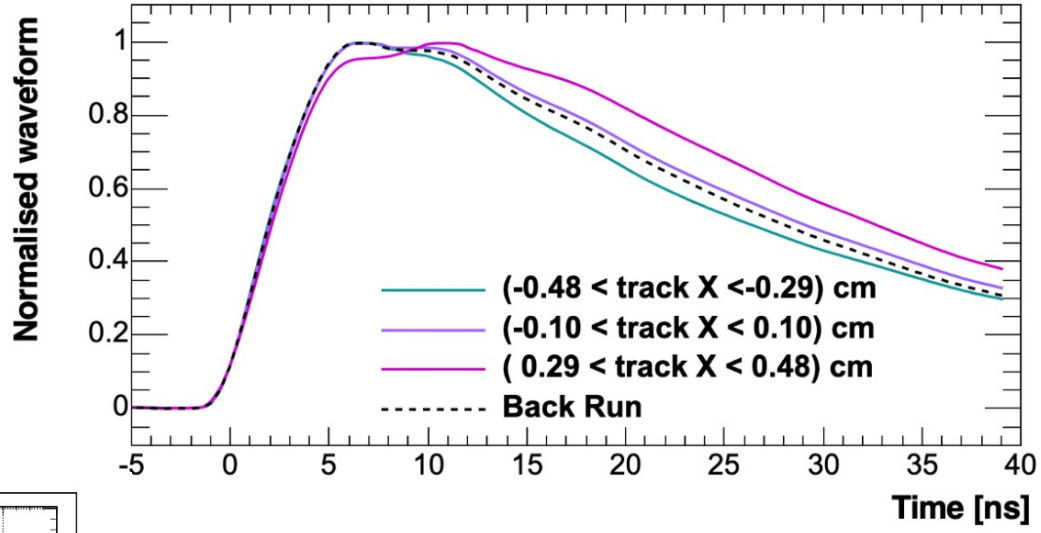


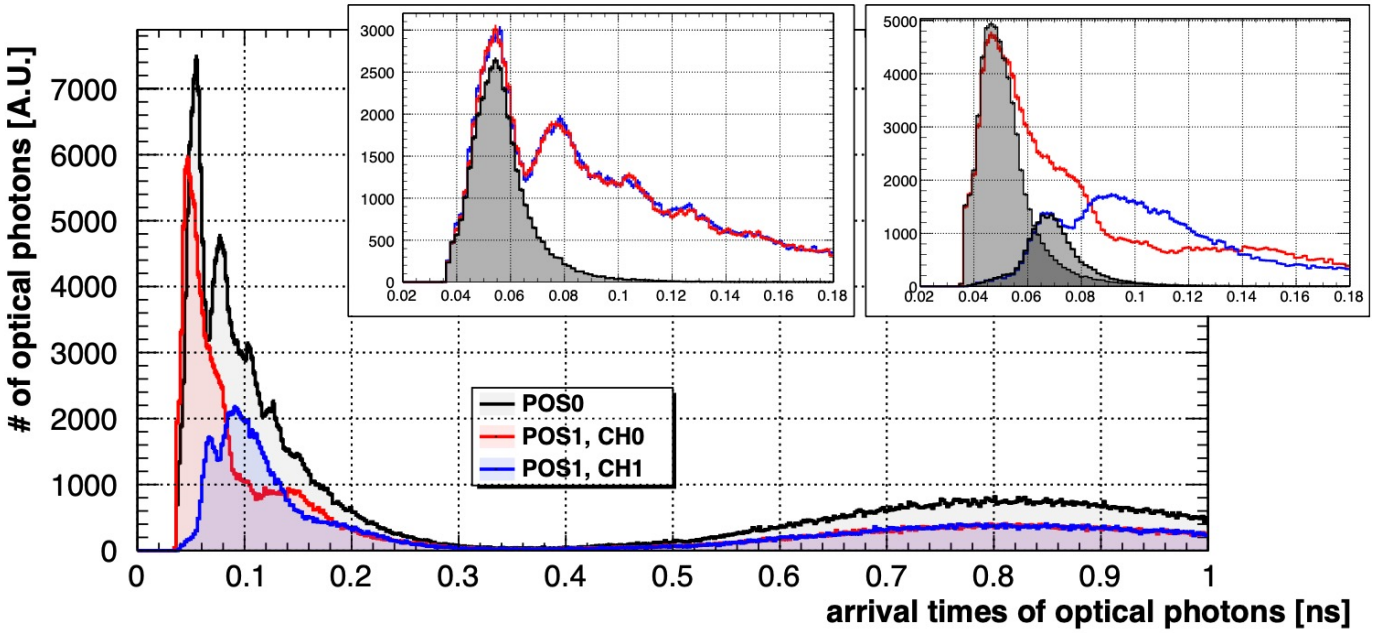
- **Neutron fluence** $\sim 10^{14} n_{1MeVeq}/cm^2$**year** on ECAL.
- **TID ~1 kGy/year** on ECAL.

Positional effects: waveshapes

Effects on waveforms (data)

- Pulse shape modification as a function of impact position selected with different fiducial cuts
- Green → particle incident directly on SiPM pair giving signal
- Magenta → particle incident on opposite SiPM pair
- Purple → particle incident between SiPM pairs
- Dashed line → signal shape for back runs



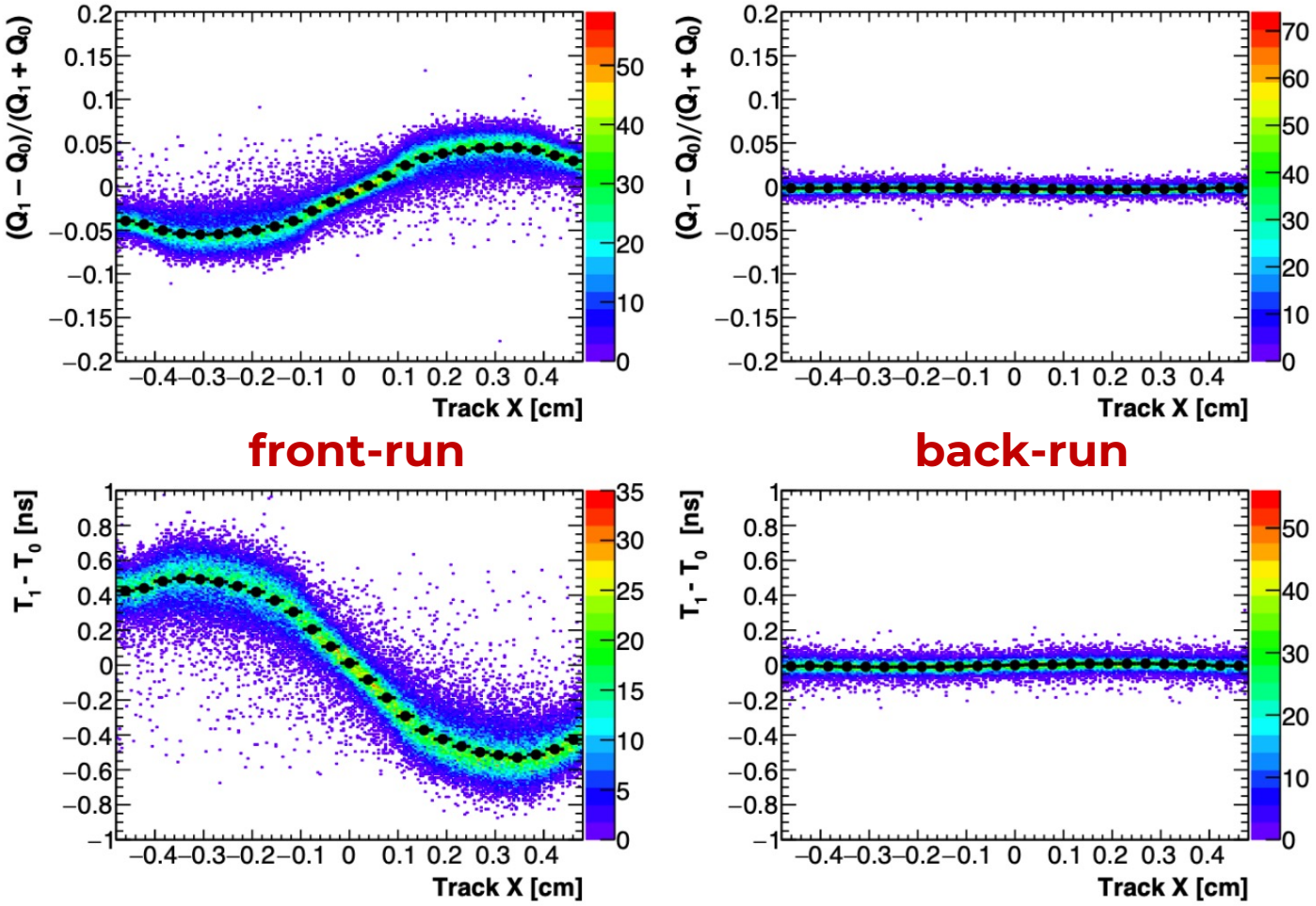


Optical simulation

- Simulated time distributions for optical photons arrival on the photosensors, for two beam positions
- POS0: centred beam the crystal
- POS1: 3 mm beam offset (towards CH0)
- shaded areas → contributions due to light reaching the photosensors directly (i.e., with zero or one reflections)

Positional effects: charge and timing

PbF2 DATA



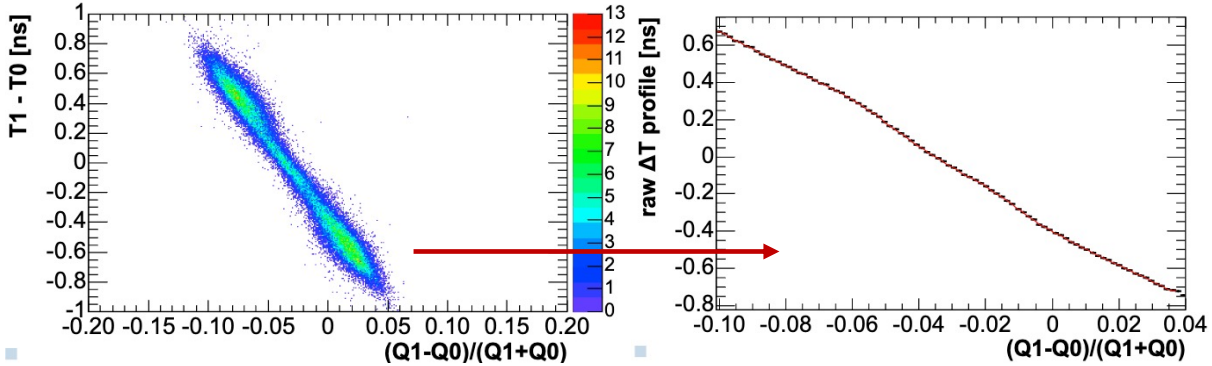
- +/- 10 % maximum imbalance in light collection
- anticorrelated effect on timing (T1-T0)

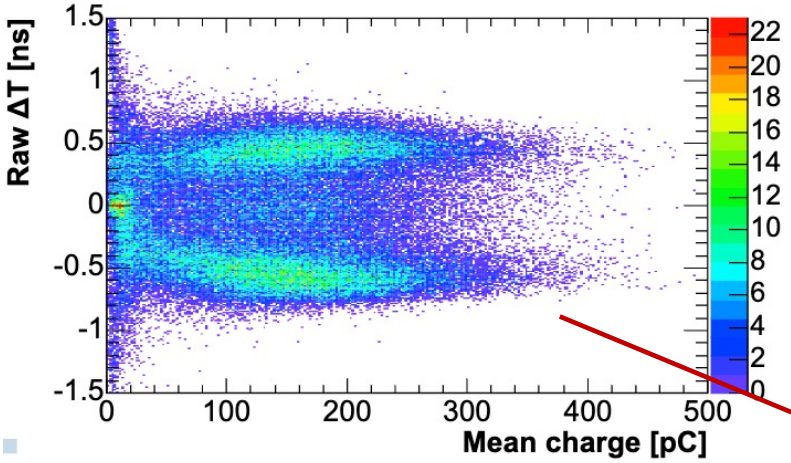
- No significant effects for back-runs
- Similar effects for PbWO4-UF

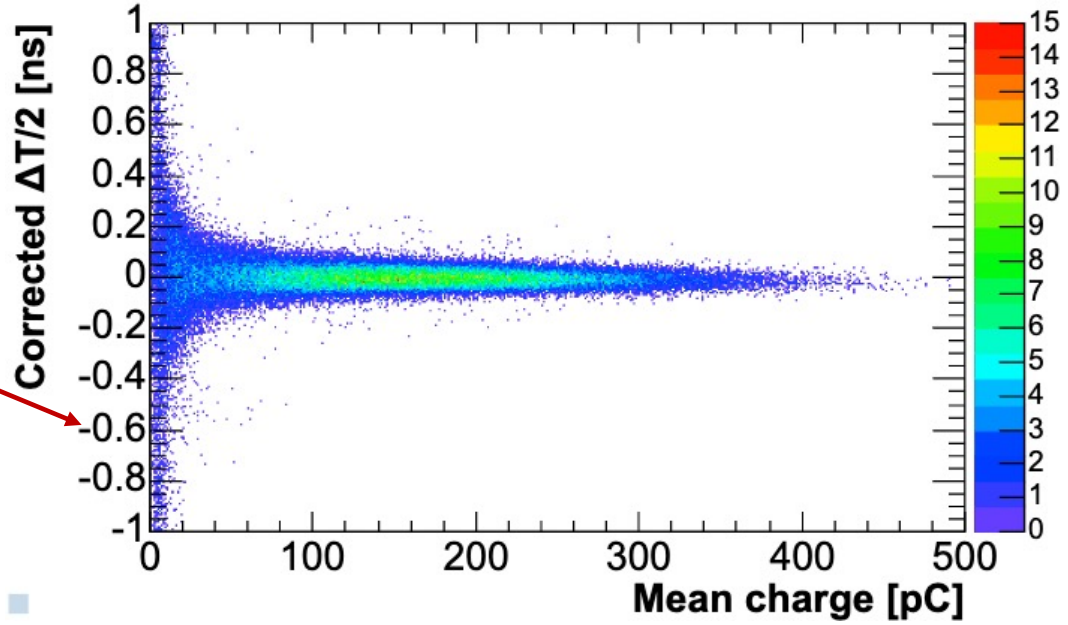
- Light propagated indirectly is more strongly attenuated due to the longer total path length traversed and the multiple reflections
- earlier arrival times for photons arriving directly

Correction process

- The front mode shows a peculiar distribution both in time time difference and charge sharing:
  - the relationship between this two quantities can be used as correction function
  - Negligible effect in back runs

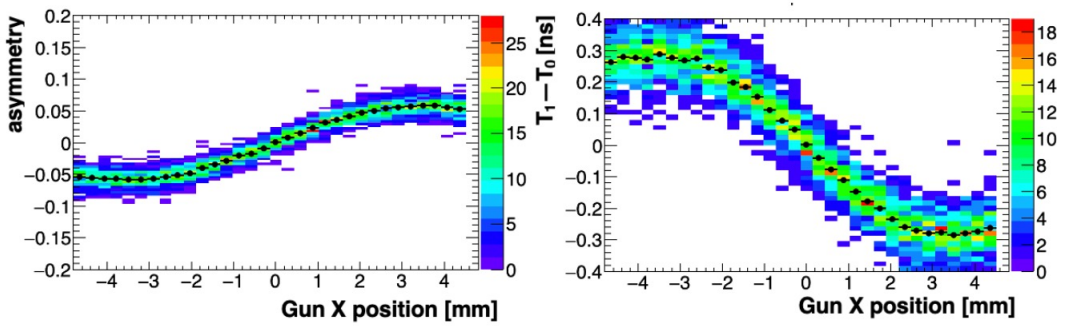


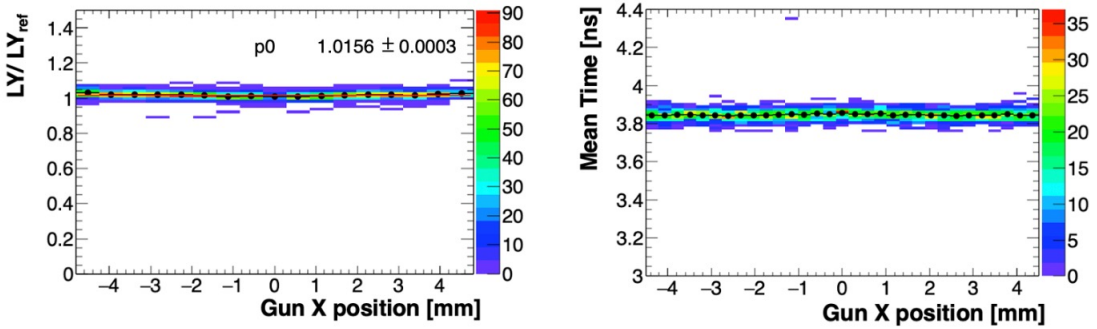


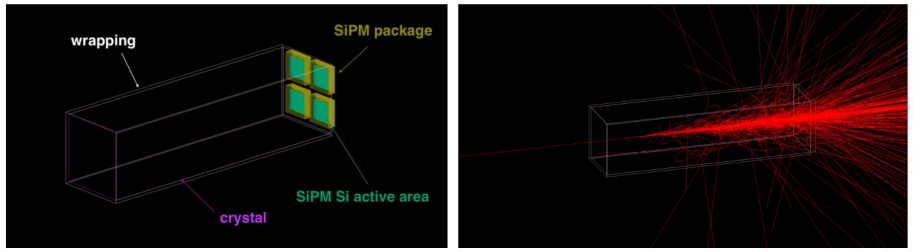


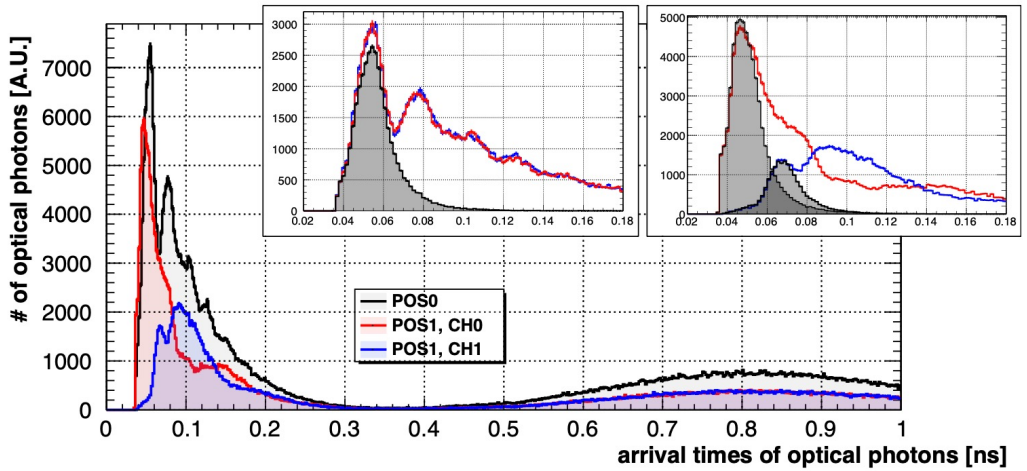
MC validation: optical simulation

- Simulated time distributions for optical photons arrival on the photosensors, for two beam positions
- POS0: centred beam the crystal
- POS1: 3 mm beam offset (towards CH0)
- shaded areas → contributions due to light reaching the photosensors directly (i.e., with zero or one reflections)









- Confirmation of the positional effects
- Charge asymmetry matched within 20 %
- Smaller timing offsets in simulation wrt data
- mean-time and mean-energy information are always well behaved

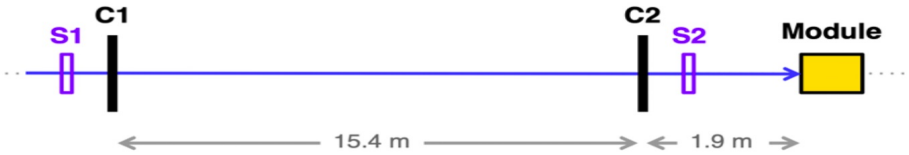
Proto-0: Single crystal beam test

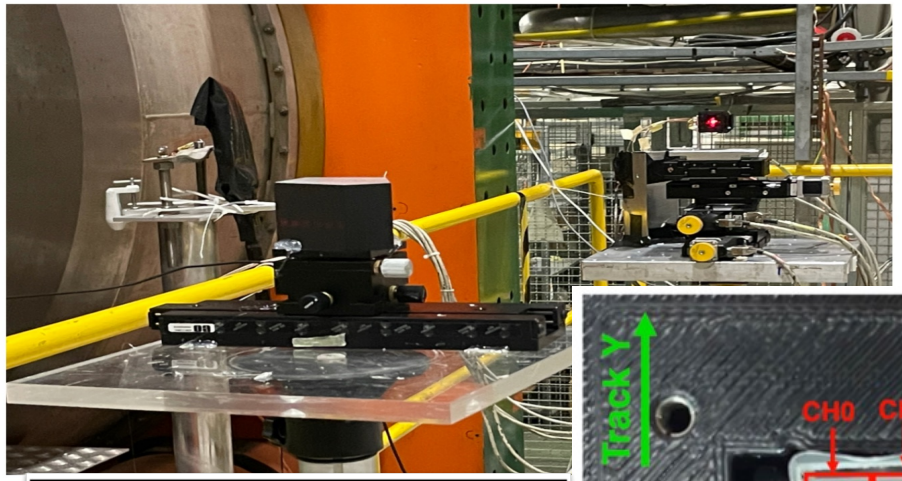
Beam test on Proto-0 in a single crystal configuration in fall 2022:

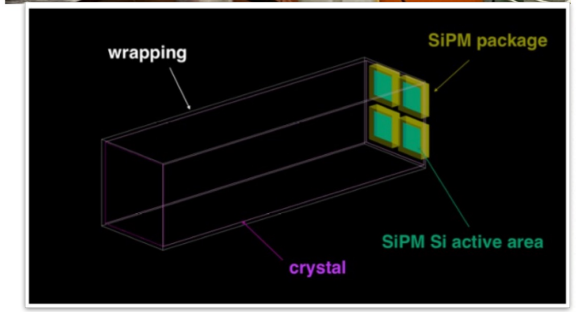
- 10 × 10 × 40 mm^3 single crystal → 2 options: **PbF_2** (4.3 X_0) **$PbWO_4$-UF** (4.5 X_0).
- Four 3x3 mm^2, 10 μm pixel size SiPMs for two independent readout channels (SiPM pairs connected in series).
- Mylar wrapping - No optical grease.

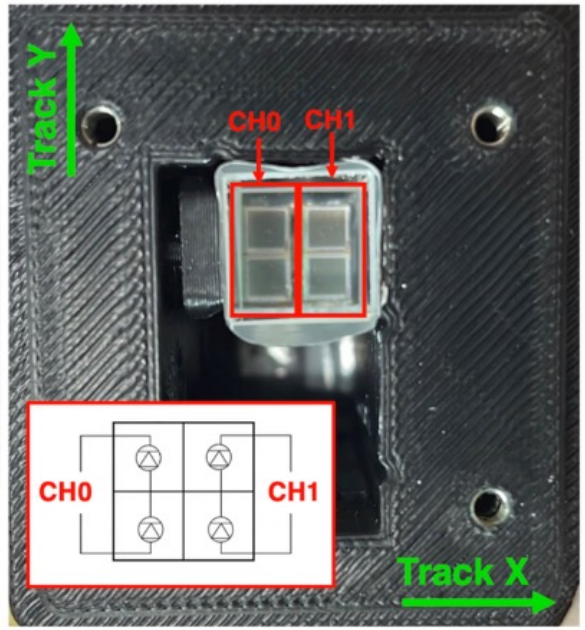
Aim:

• Validate CRILIN new readout electronics and readout scheme.
• Study systematics of light collection in small crystals with high *n*.
• Measure time resolution achievable with different crystal choices.









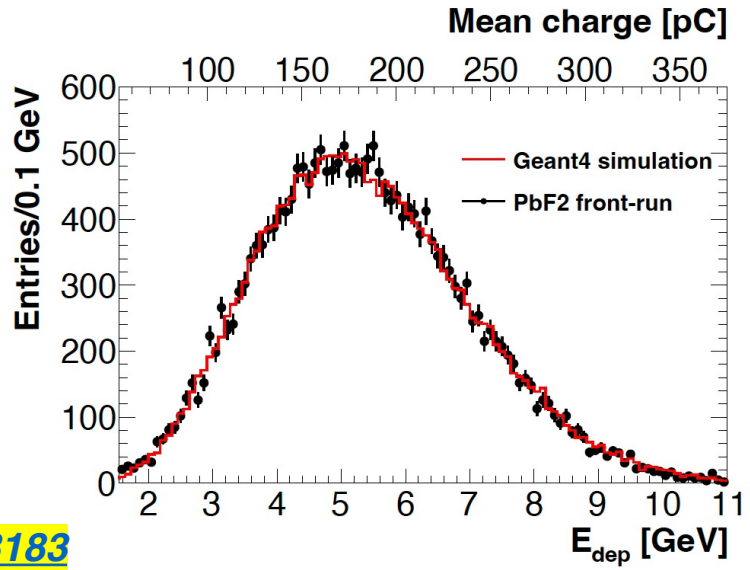
Results

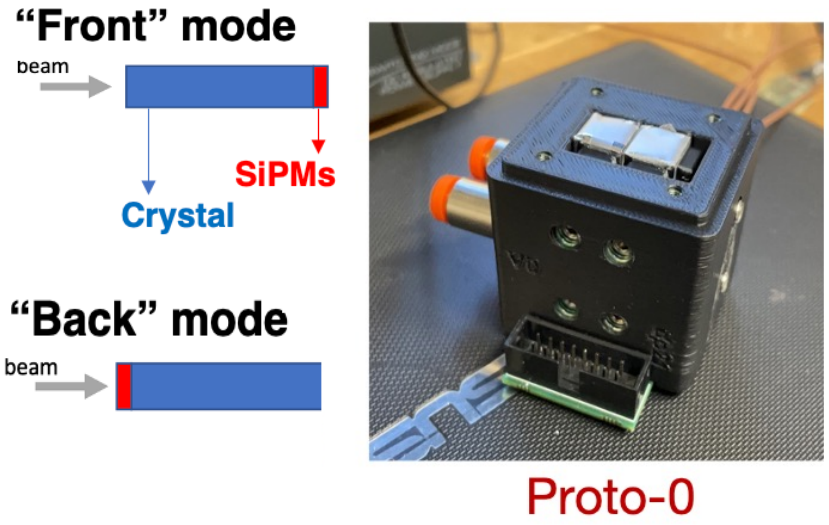
Two different orientation were tested → **FRONT** and **BACK:**

- The BACK run time resolution is better, even after correction, for both crystals.
- PbF_2 outperforms $PbWO_4$-UF despite its higher light output (purely Cherenkov)
- **PbF_2** → $\sigma_{MT} < 25$ ps worst-case for $E_{dep} > 3$ GeV
- **$PbWO_4$-UF** → $\sigma_{MT} < 45$ ps worst-case for $E_{dep} > 3$ GeV

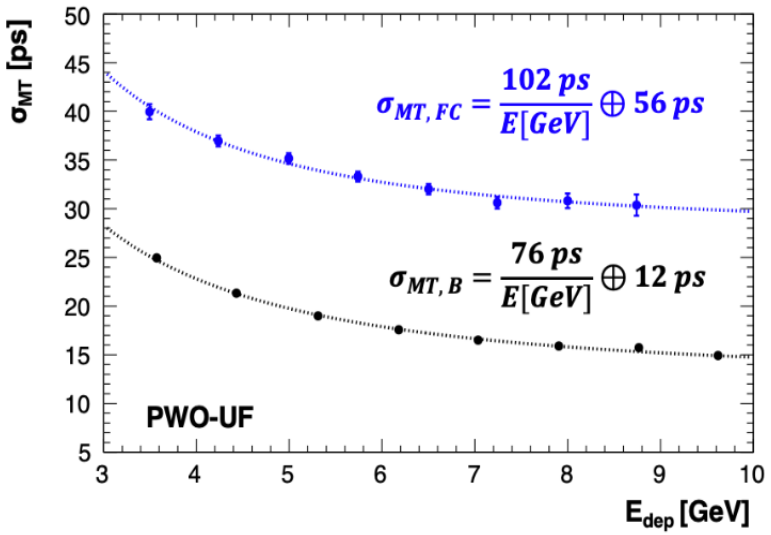
PbF_2	back-run	front-run
E_{dep} MPV [GeV]	4.26 ± 0.01	4.81 ± 0.03
E_{dep} sigma [GeV]	1.35 ± 0.01	1.46 ± 0.02
pC/GeV	~29.3	~35.6
NPE/MeV	~0.30	~0.30

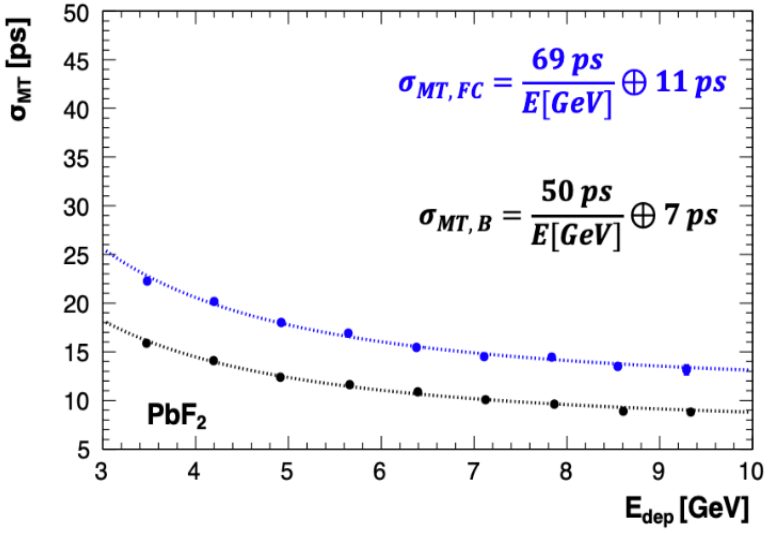
PWO-UF	back-run	front-run
E_{dep} MPV [GeV]	6.39 ± 0.01	6.88 ± 0.01
E_{dep} sigma [GeV]	1.83 ± 0.01	1.99 ± 0.01
pC/GeV	~66.7	~76.9
NPE/MeV	~0.11	~0.13





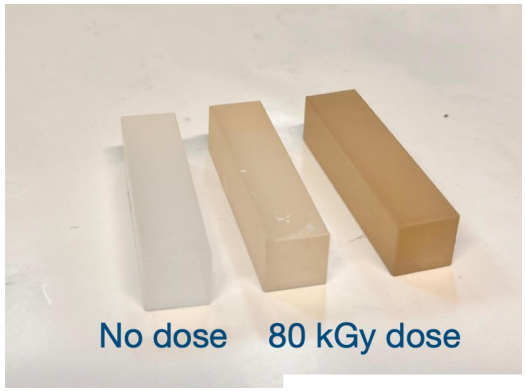
[C. Cantone et al. 2023 Front. Phys. 11:1223183]

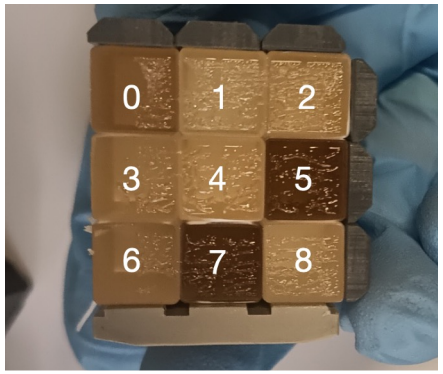


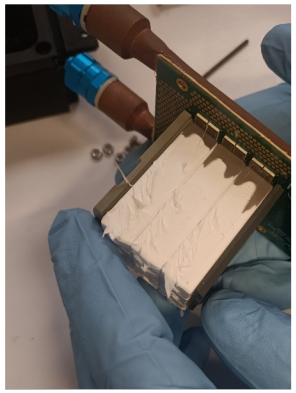


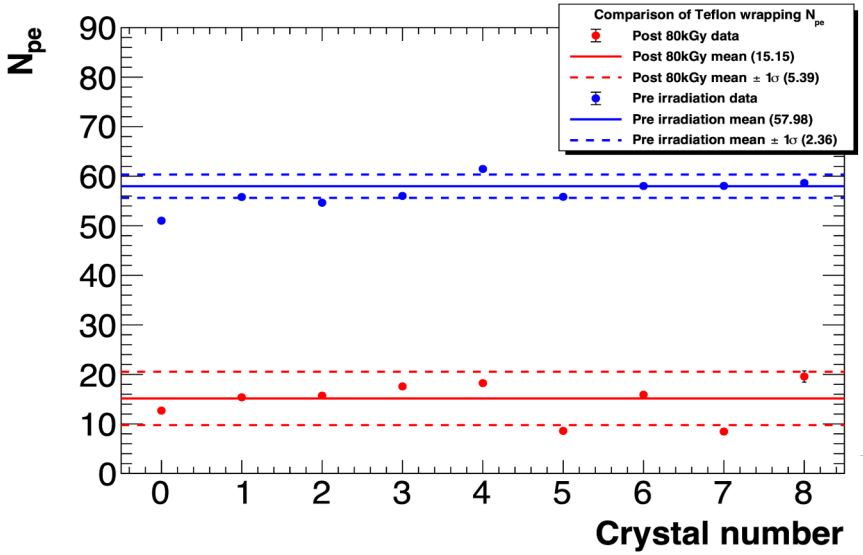
Beam test @ BTF: Teflon wrapping

After 80 kGy (8 Mrad) irradiation
- Teflon was damaged and brittle
- Crystals evident loss of transparency

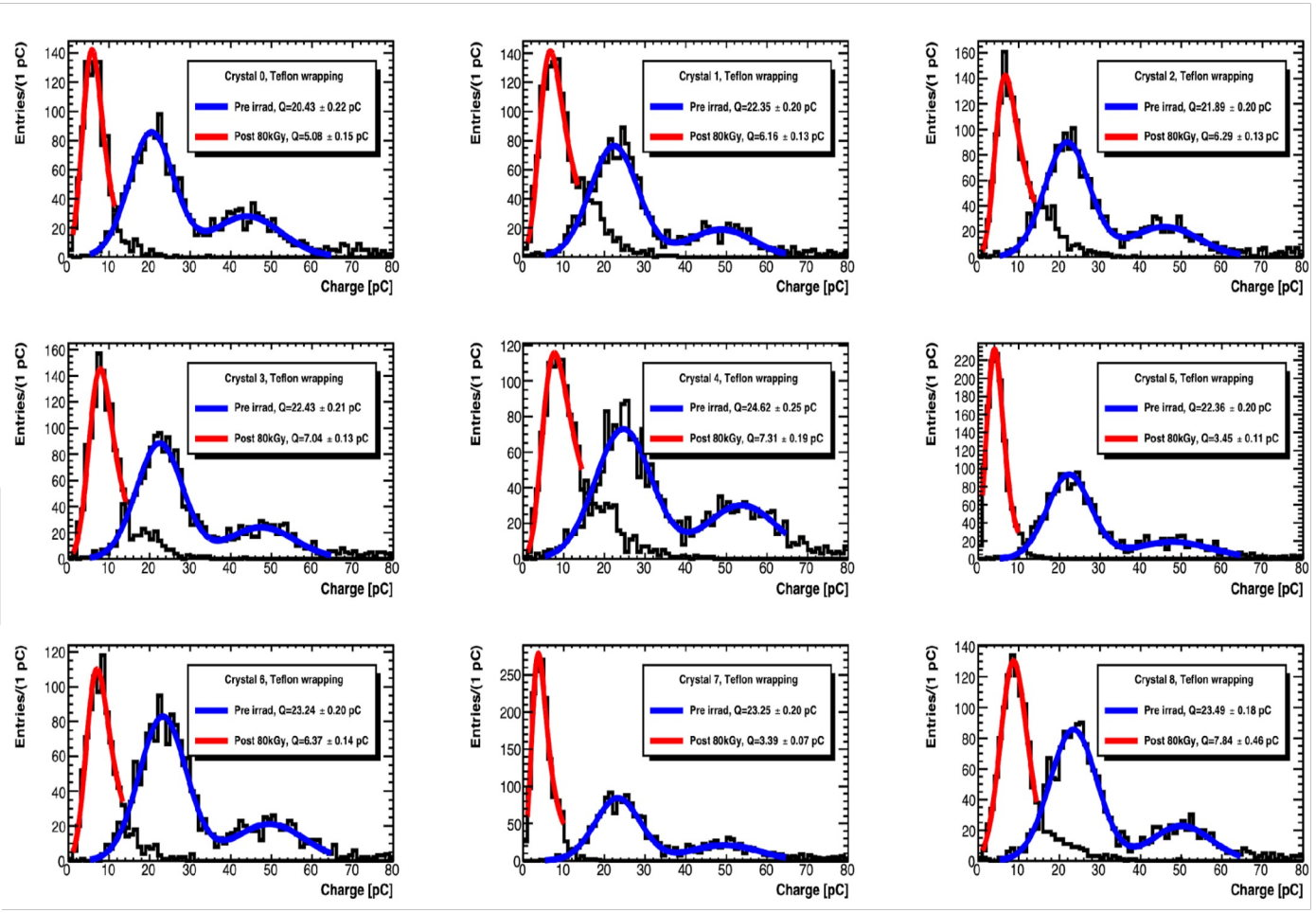






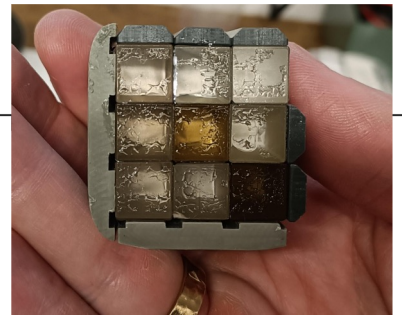


Charge distribution of PbF_2 pre and post irradiation



Beam test @ BTF: Mylar wrapping

- Test repeated with a Mylar wrapping
- **No annealing after 48h and 60h observed**
- New test planned to evaluate SiPMs PDE loss and optical grease degradation



Charge distribution of PbF_2 pre, after 10 kGy and after 80 kGy irradiation

