Calorimeter R&D: CRILIN

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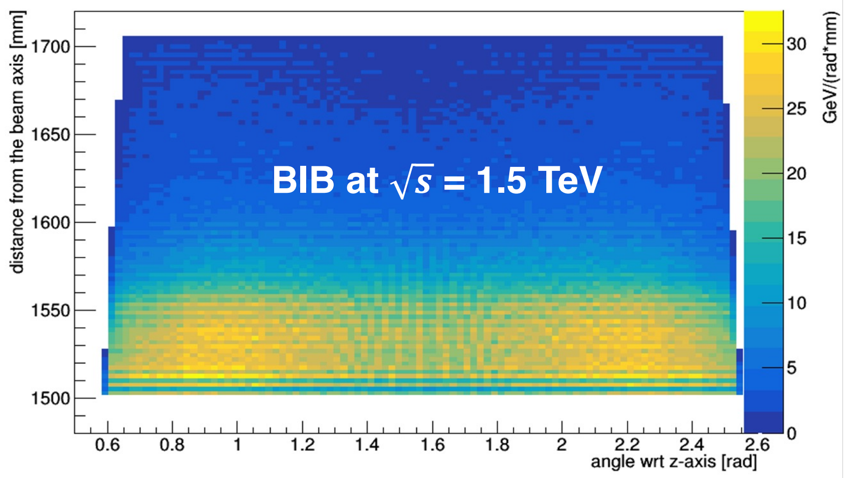
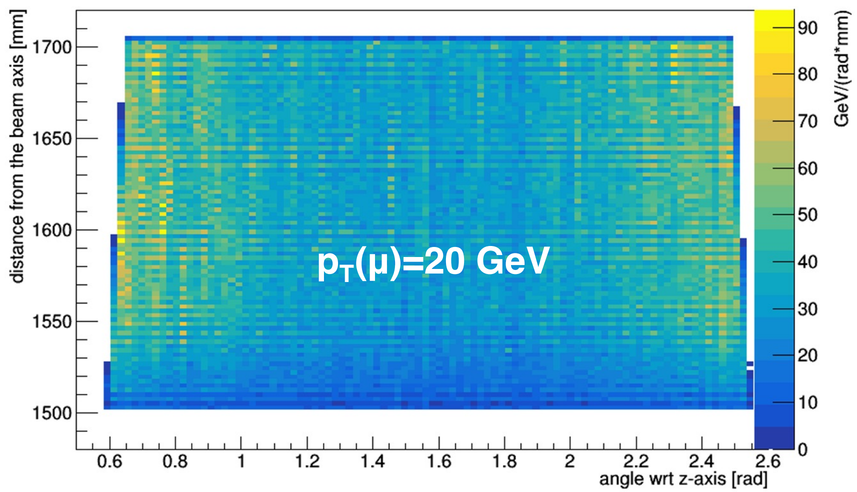
Beam Induced Background in ECAL

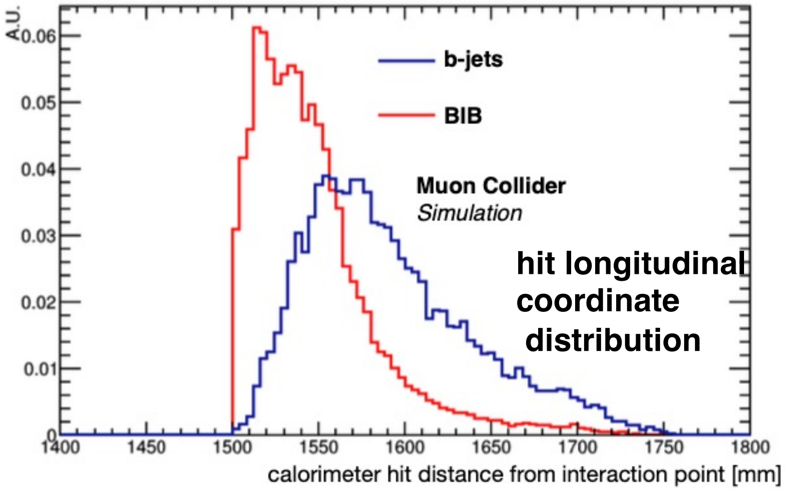
Energy released in ECAL barrel by one BIB bunch crossing

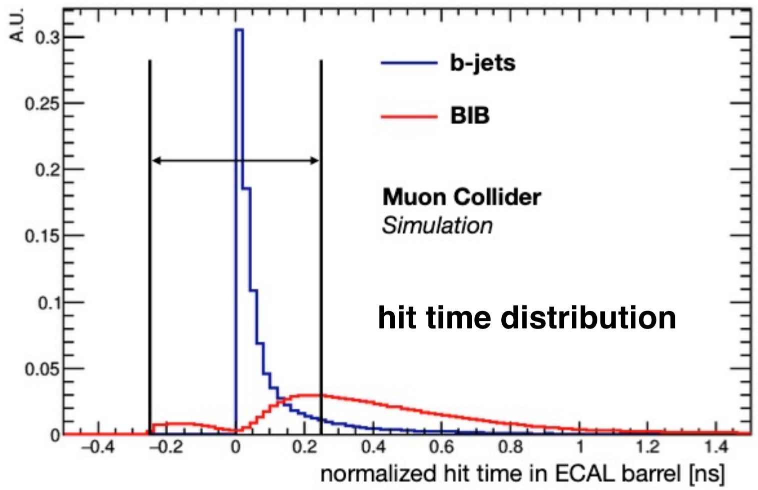


Energy released in ECAL barrel by uniformly distributed prompt muons in the (θ,ϕ) space



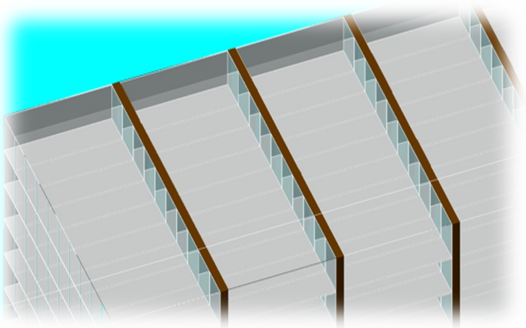
- Expected BIB on the ECAL barrel ~300 γ/cm^2 /event with E~1.7 MeV.
- BIB can be handled using information from energy releases in the ECAL.
- BIB produces most of the hits in the first few layers of the calorimeter while prompt muons produce a constant density of hits after the first calorimeter layers.
- Since BIB hits are out-of-time wrt the bunch crossing, a **measurement of the hit time performed cell-by-cell** can be used to **remove most of the BIB.**

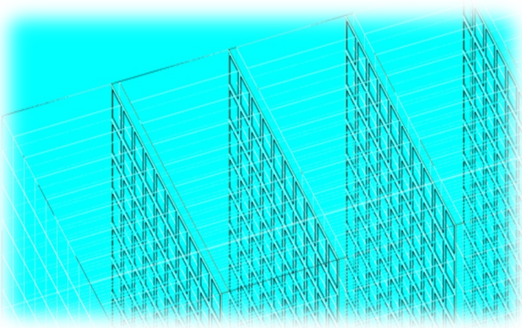


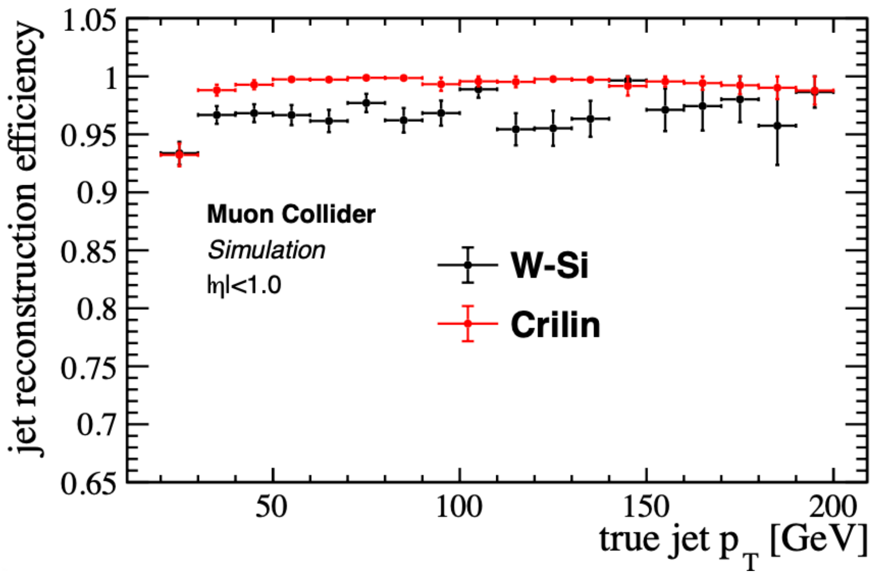


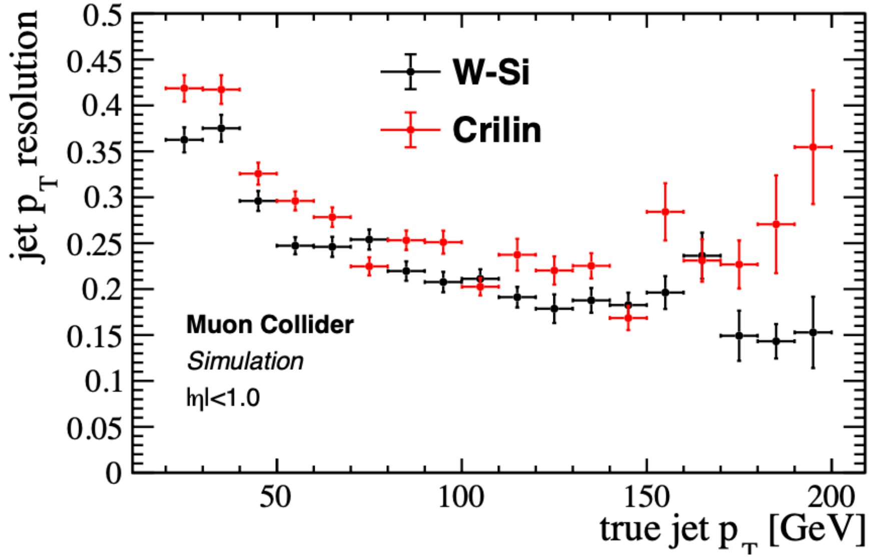
The Crilin calorimeter

- The goal is to build a crystals calorimeter that is fast, relatively cheap, with high granularity (both transversal and longitudinal), and radiation hard → optimized for muon collider characteristics.
- **Crilin** is a **semi-homogeneous** electromagnetic calorimeter made of **Lead Fluoride Crystals** (PbF_2) matrices where each crystal is readout by 2 series of 2 UV-extended surface mount **SiPMs.**
- **It represents a valid and cheaper alternative to the W-Si ECAL barrel**.
- Two prototype versions built and tested up to now: Proto-0 and Proto-1.







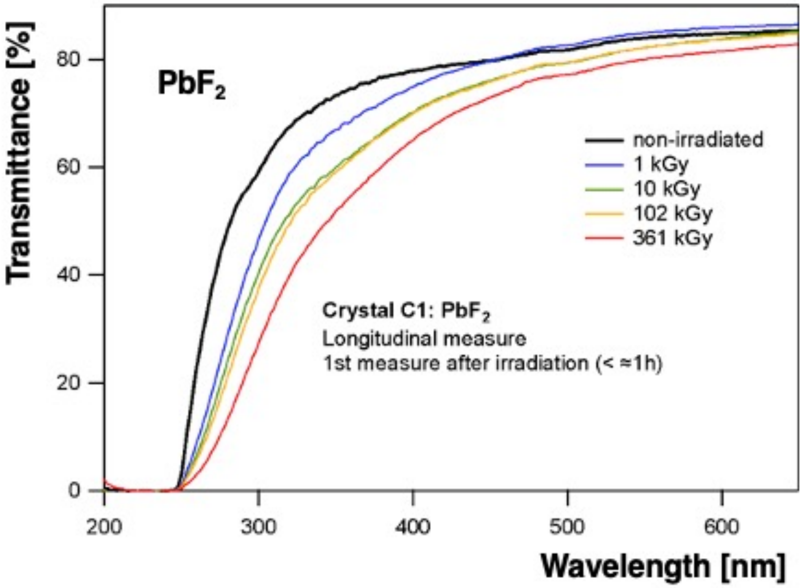


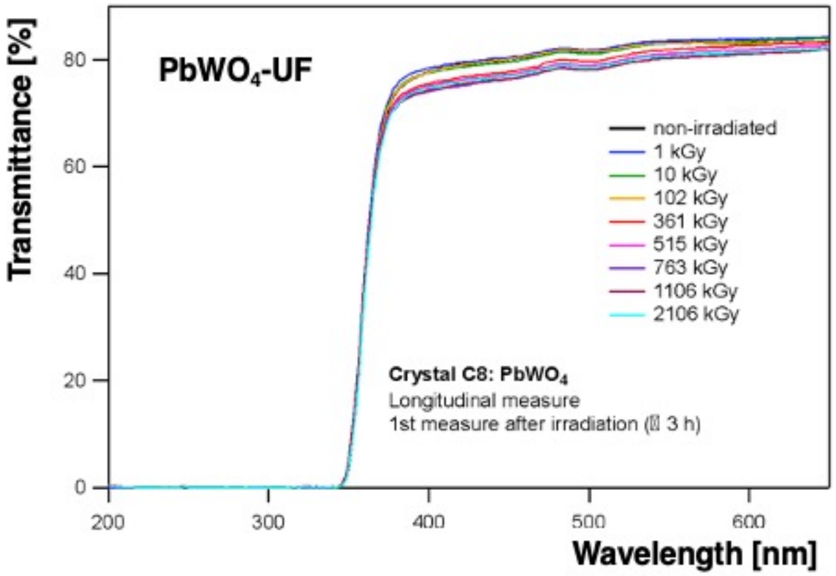
Radiation hardness: Crystals

Neutron fluence:~$10^{14} n_{1MeVeq}$**/cm²** **year** on ECAL **TID** ~ **100 krad/year** on ECAL.

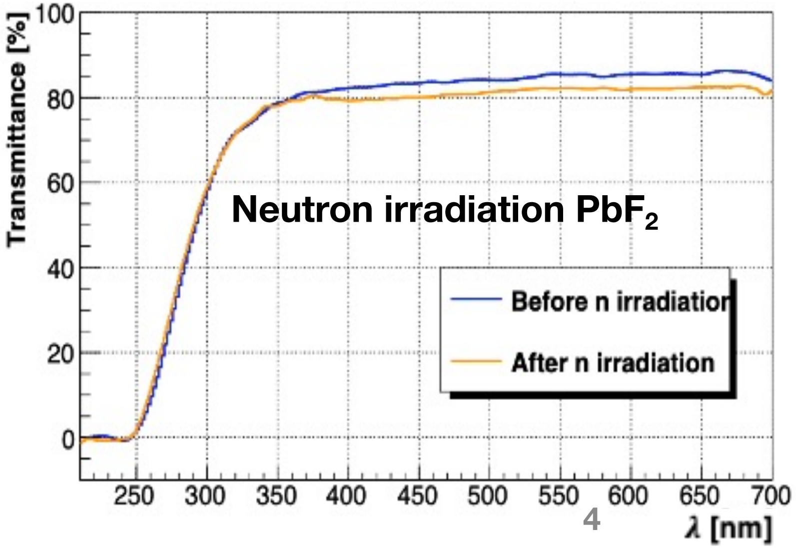
Radiation hardness of two PbF_2 and $PbWO_4$-UF crystals (10x10x40 mm³) checked for TID (up to **1 MGy** @ Calliope, Enea Casaccia) and neutrons (14 MeV neutrons from Frascati Neutron Generator, Enea Frascati, up to $\mathbf{10^{13}}$ **n/cm²**)

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





Crystal	PbF_2	PWO-UF
Density [g/cm³]	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



Radiation hardness: SiPMs

Neutrons irradiation:
14 MeV neutrons with a total fluence of 10^{14} n/cm^2 (@FNG) 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

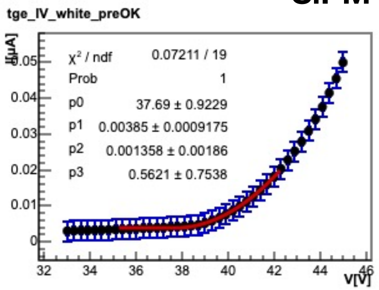
10 μm pixel-size

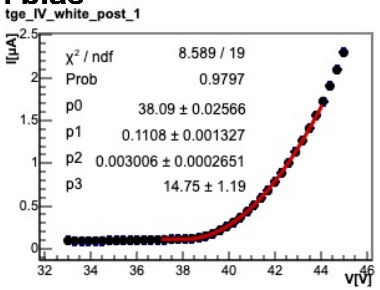
T [°C]	V_{br} [V]	I(V_{br}+4V) [mA]	I(V_{br}+6V) [mA]	I(V_{br}+8V) [mA]
-10 ± 1	76.76 ± 0.01	1.84 ± 0.01	6.82 ± 0.01	29.91 ± 0.01
-5 ± 1	77.23 ± 0.01	2.53 ± 0.01	9.66 ± 0.01	37.51 ± 0.01
0 ± 1	77.49 ± 0.01	2.99 ± 0.01	11.59 ± 0.01	38.48 ± 0.01

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

TID:
no significant amount of dark current up to 10 kGy (@Calliope).

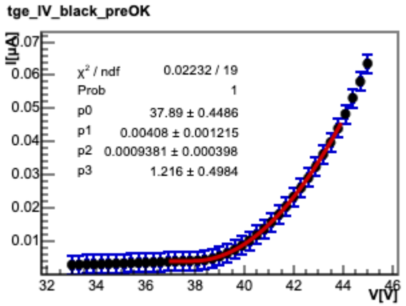
SiPM with bias

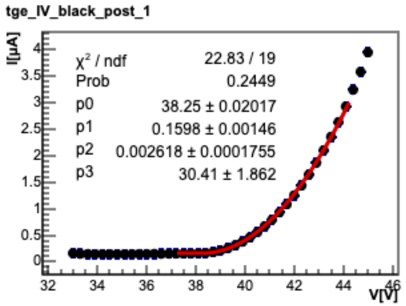




10 kGy dose

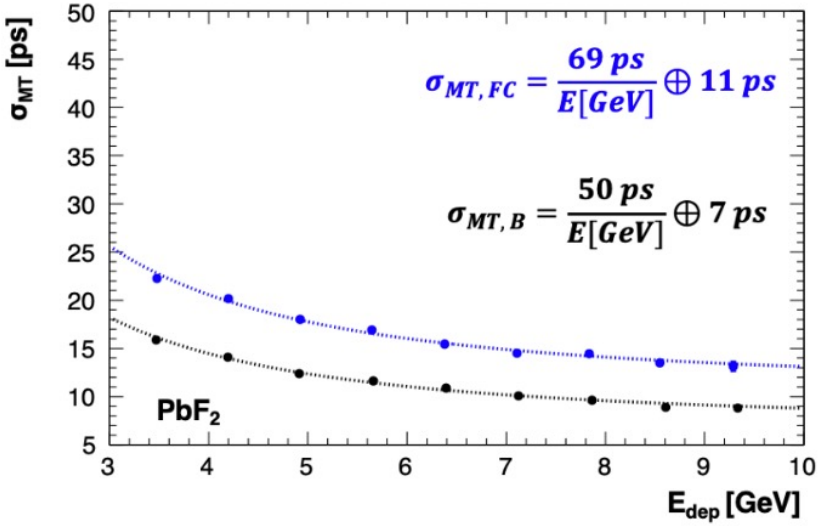
SiPM w/o bias

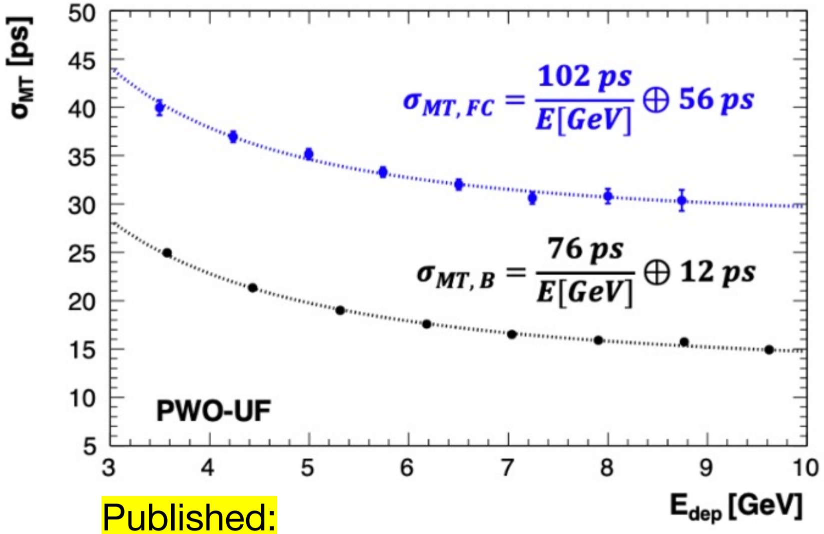


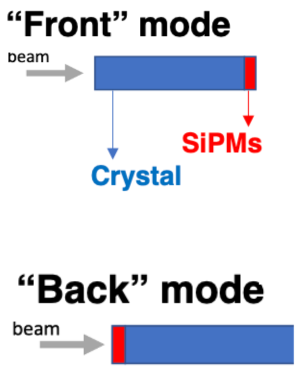


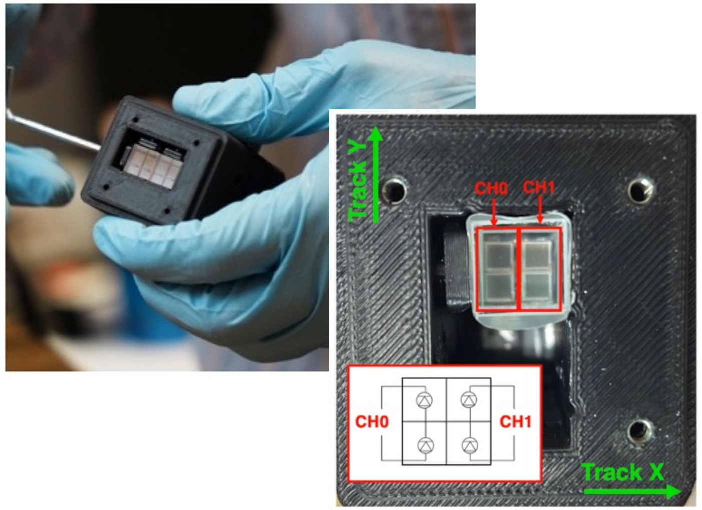
Test beam campaigns: Proto-0

- CERN SPS-H2→ 120 GeV e⁻ beam on a single crystal prototype
- Cherenkov systematics in the light propagation→ **FRONT** and **BACK** orientation tried
- The **BACK** run time resolution is better for both crystals.
- PbF_2 outperforms $PbWO_4$-UF despite its higher light output (purely Cherenkov)
- **PbF_2** → σ_{MT} < 25 ps worst-case for E_{dep} > 3 GeV
- **$PbWO_4$-UF** → σ_{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/MeV	~29.3	~35.6
NPE/MeV	~0.26	~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/MeV	~66.7	~76.9
NPE/MeV	~0.58	~0.67

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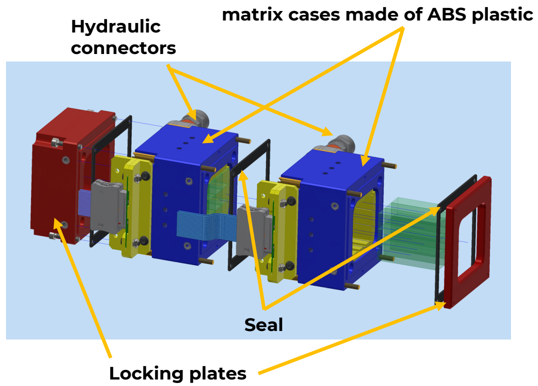
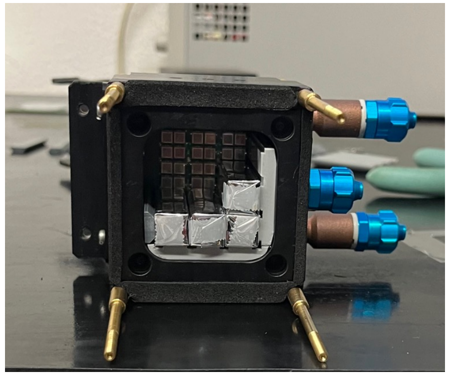
Frontiers in Physics, https://doi.org/10.3389/fphy.2023.1223183

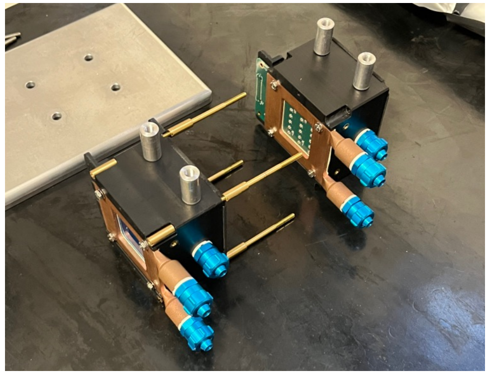
Proto-1: Mechanics and Electronics

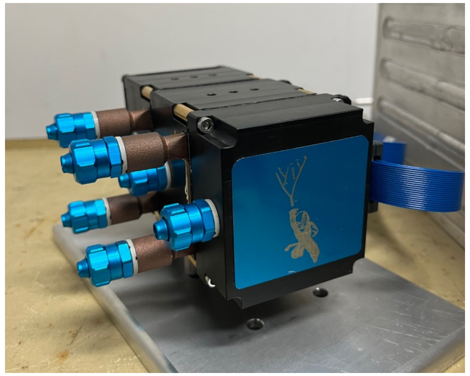
Mechanics:

- 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.



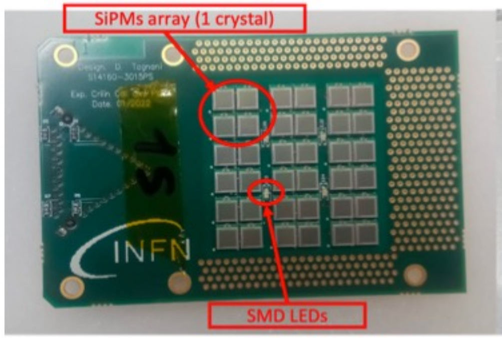


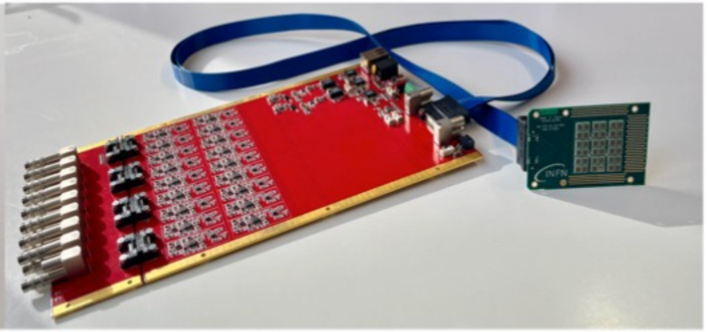




Electronics:

- **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





Test beam campaigns: Proto-1 BTF

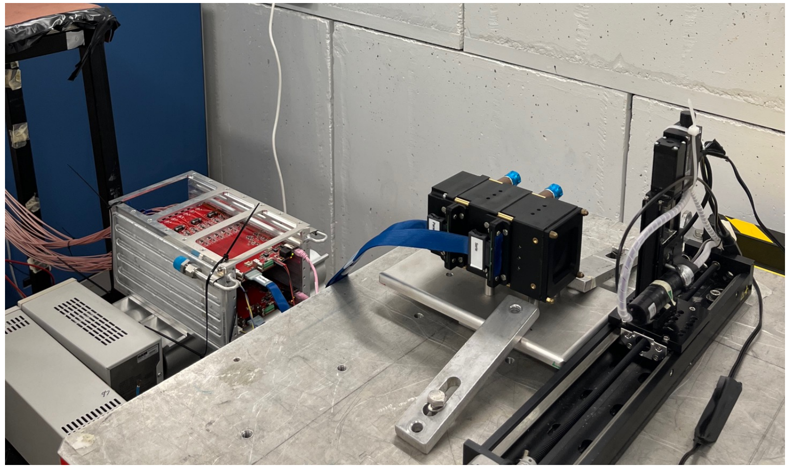
Aim:

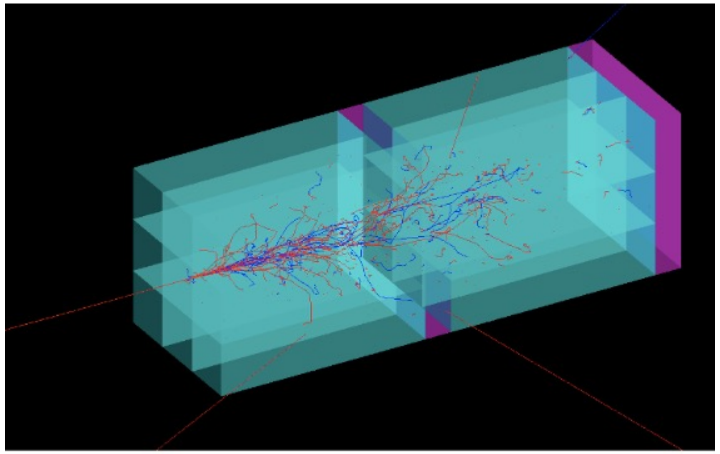
- Test CRILIN performances at low energies
- Study different wrappings and configurations
- First raw estimation of the energy resolution

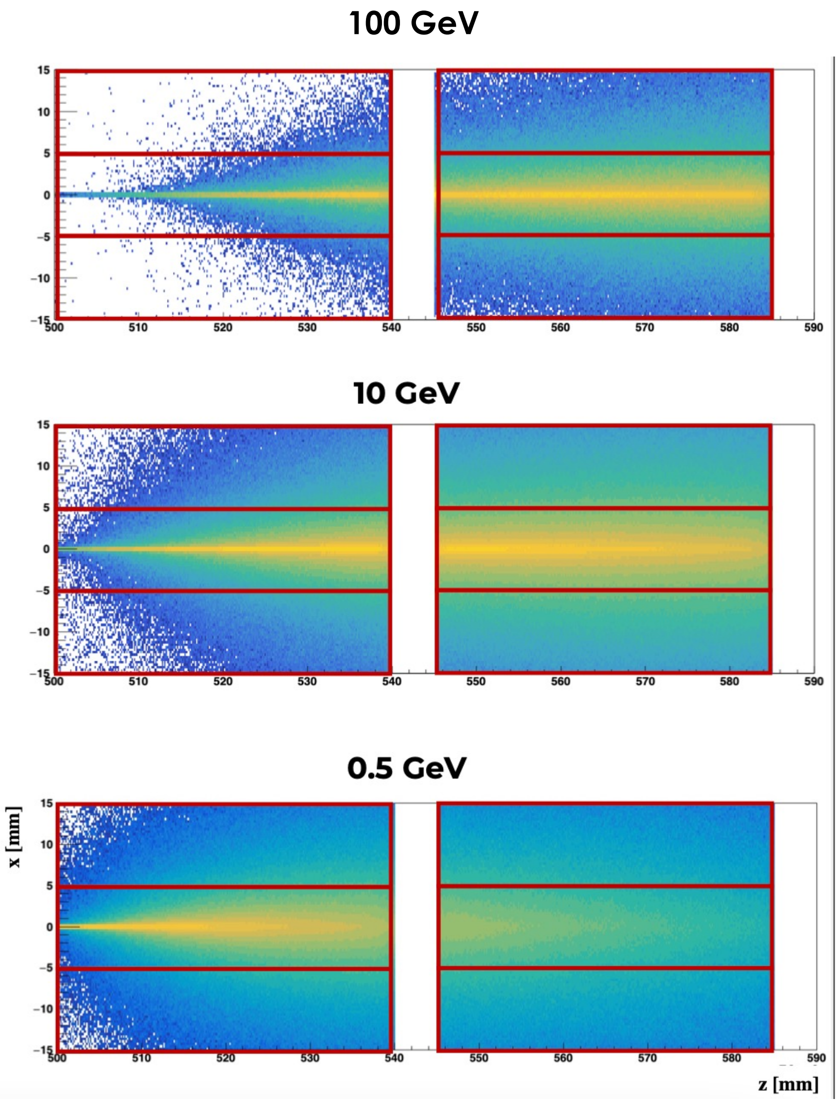
Beam: 450 MeV electrons in single particle mode

Proto-1:

- PbF_2 crystals → wrappings: Mylar and Teflon
- Readout: 10 μm pixel-size SiPMs, one layer with series connection, the other with parallel connection







Light output and timing - BTF

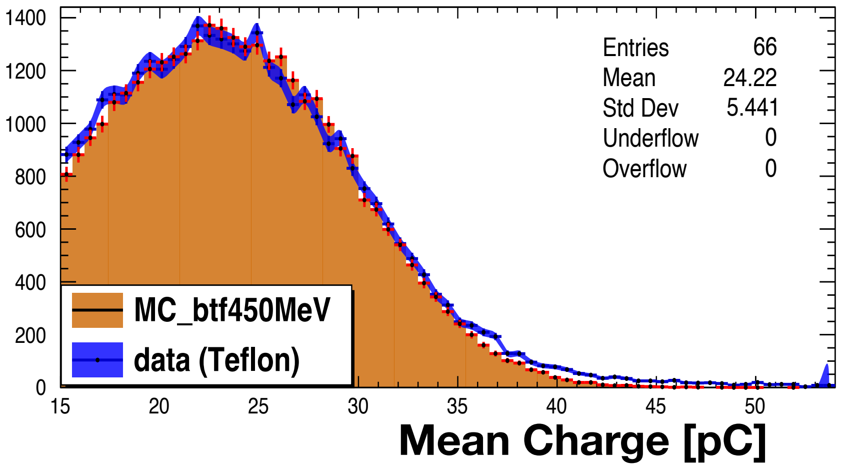
Light Yield:

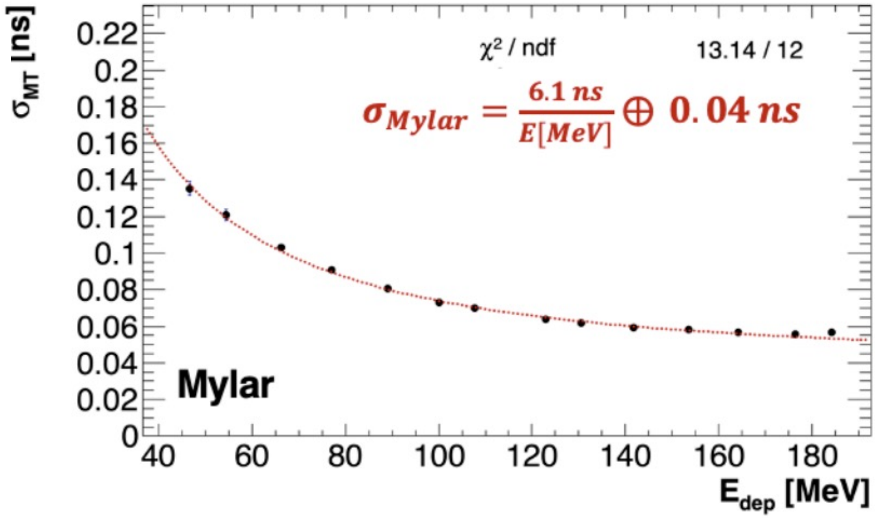
- ~ 0.13 pC/MeV response → Teflon
- ~ 0.32 PE/MeV @ V_{op} +2V→ Teflon
- ~ 0.25 PE/MEV @ V_{op} +2V→ Mylar

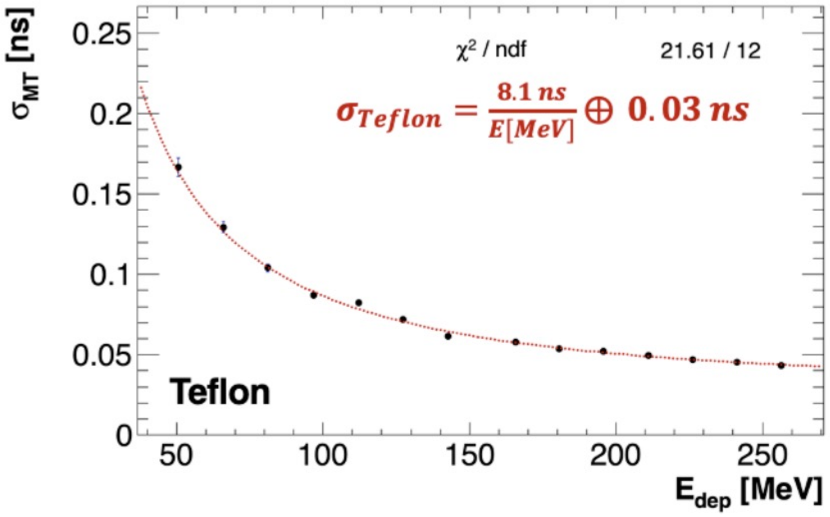
Timing:

- Time resolution of the central crystal for 15 energy slices fitted with: $\sigma_t = \frac{a}{E} \oplus b$
- Two wrappings compared → **Teflon outperforms Mylar**, higher amount of charge collected.
- Results are encouraging if we consider the very low light output

Submitted as article to IEEE

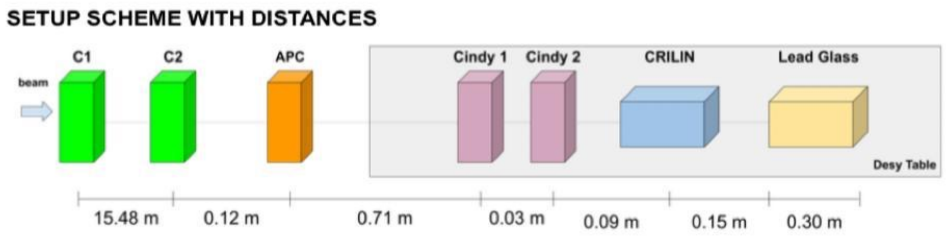


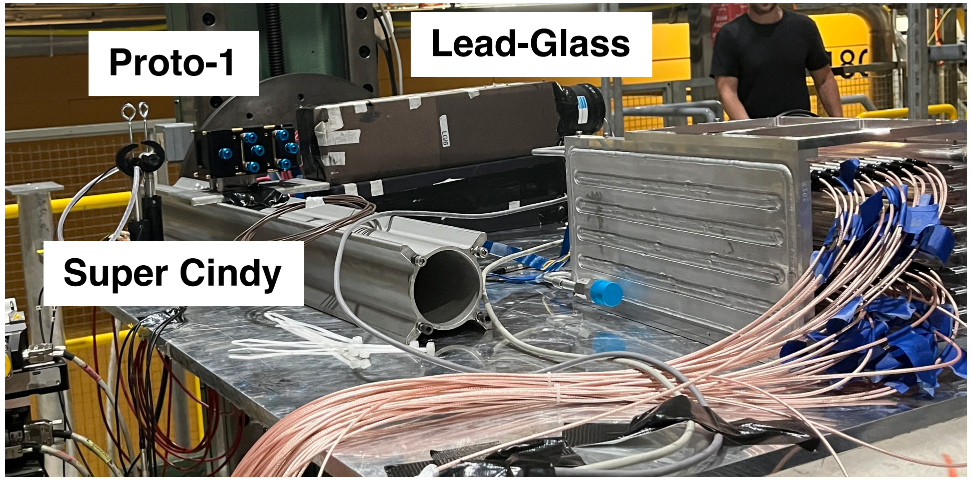


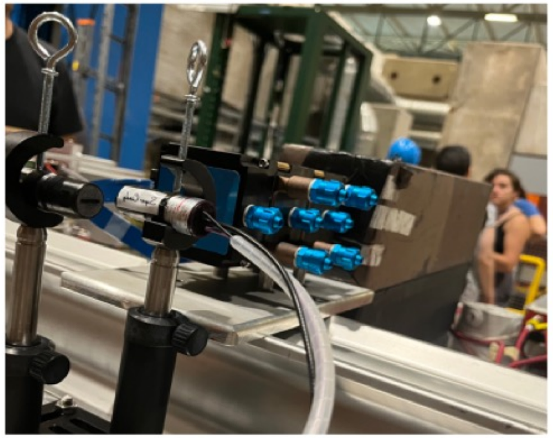


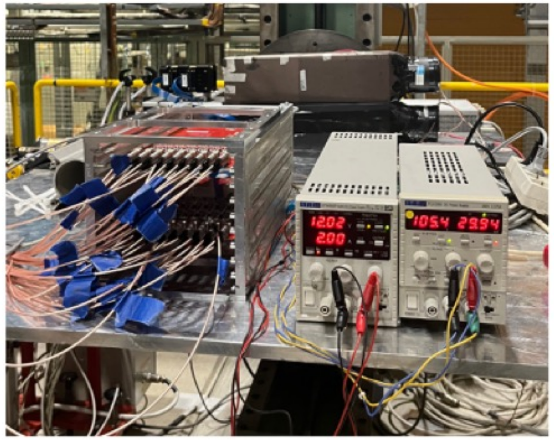
Test beam campaigns: Proto-1 H2

- CERN SPS-H2→ energy scan with electrons from 40 GeV to 150 GeV
- Aim: evaluation of energy and time resolution
- Beam reconstructed with 2 silicon strip telescopes
- Data acquisition with 2 CAEN V1742 (32 ch each) modified @ 2 Vpp
- 5 Gs/s sampling rate

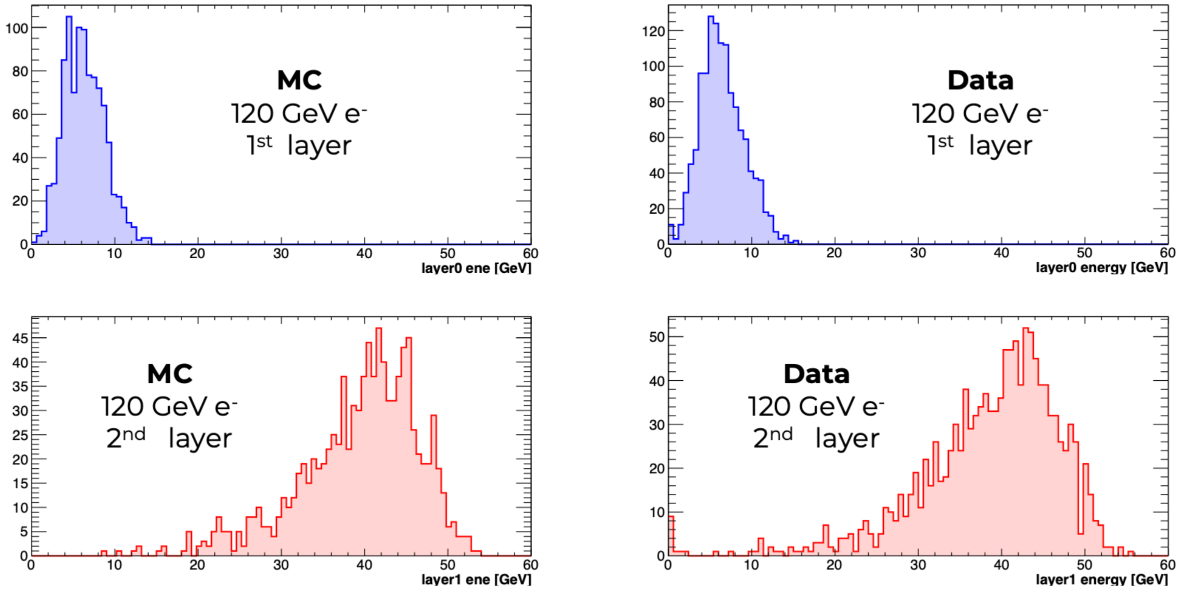








Data-MC agreement

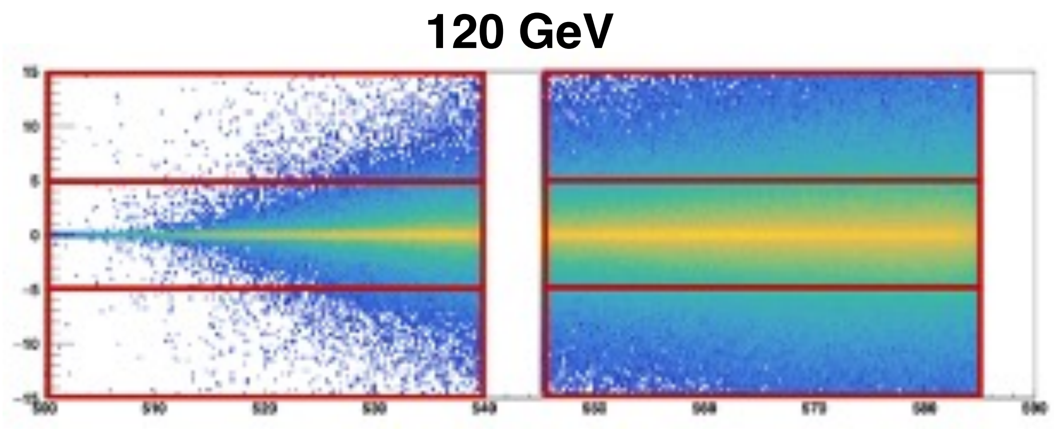


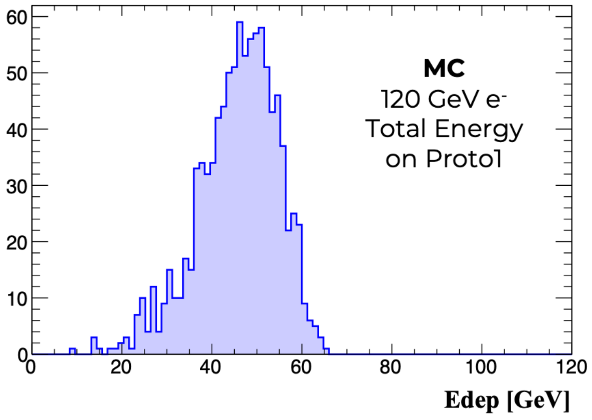
Geant-4 simulation of the prototype with a 120 e^- beam

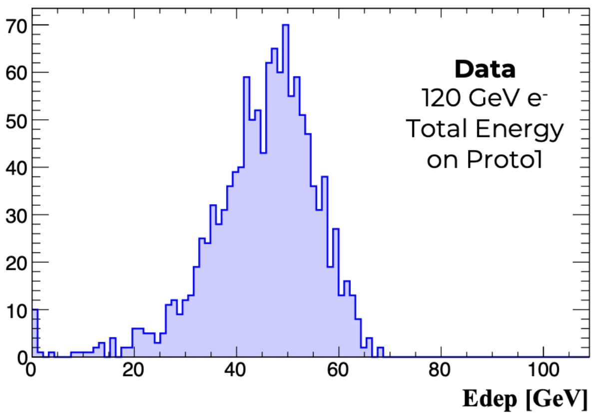
Energy deposit simulated:

- in the two layers
- In the whole prototype

Excellent agreement between data and MC for all configurations



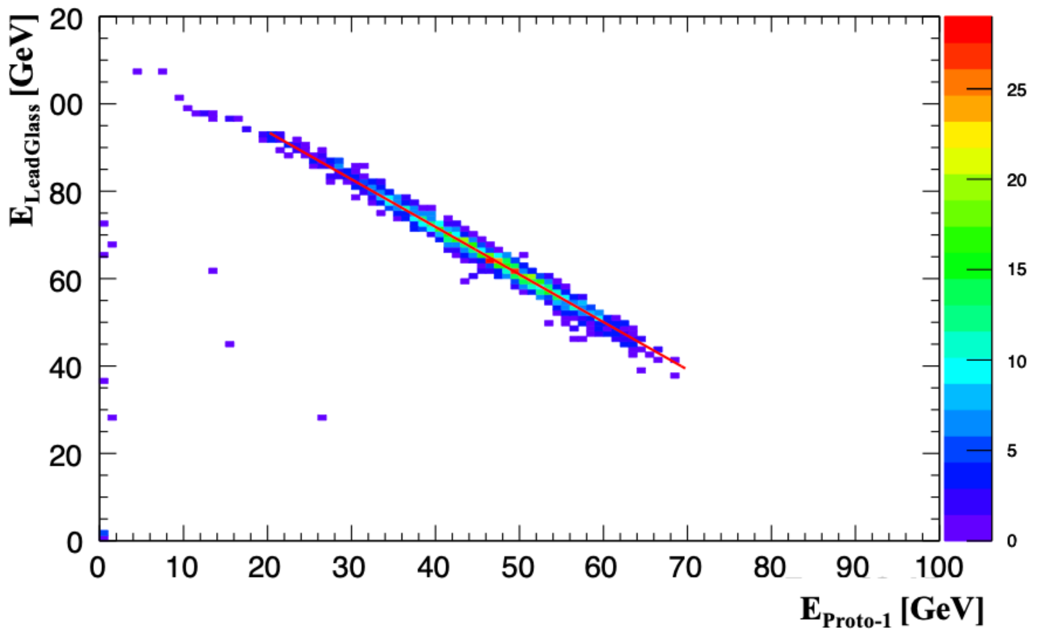


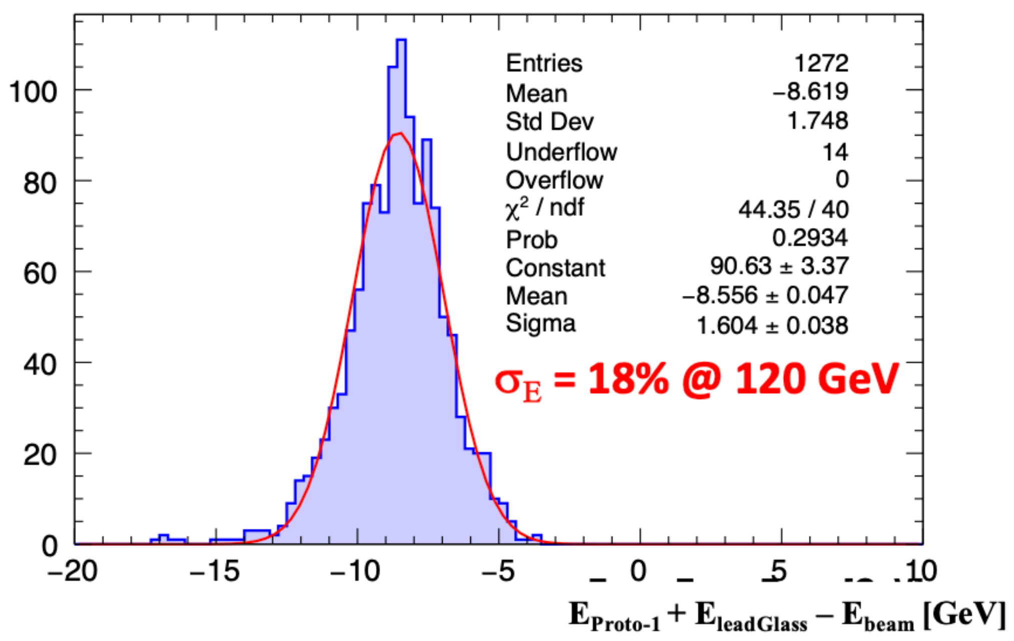


Proto-1 + Lead Glass

Energy resolution is dominated by leakage:

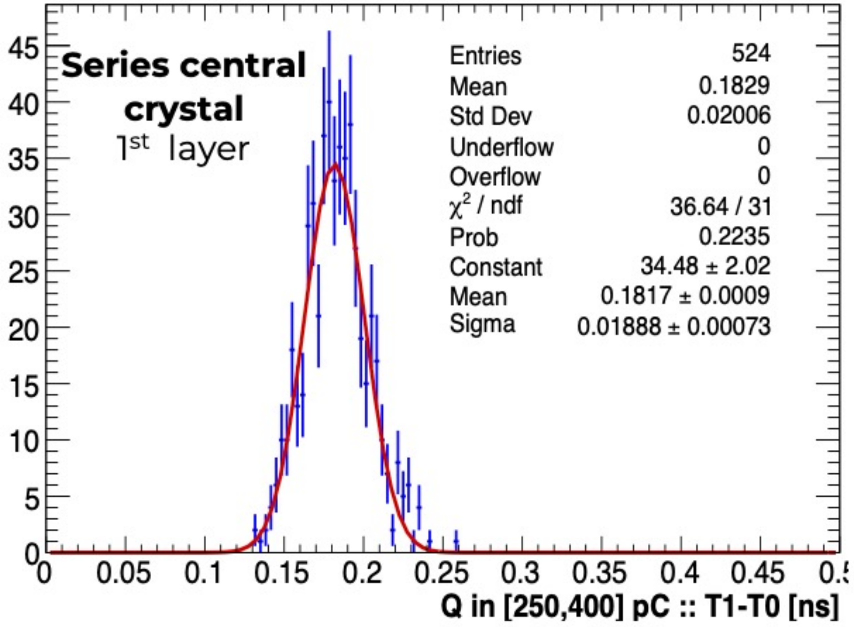
- A 24 X_0, ~2 M_R, lead glass crystal + PMT is used as tail catcher to recover the longitudinal leakage
- The energy resolution @ 120 GeV including the leadglass contribution→ Proto-1 apport is negligible, this is a good indication for the future large-scale prototypes.

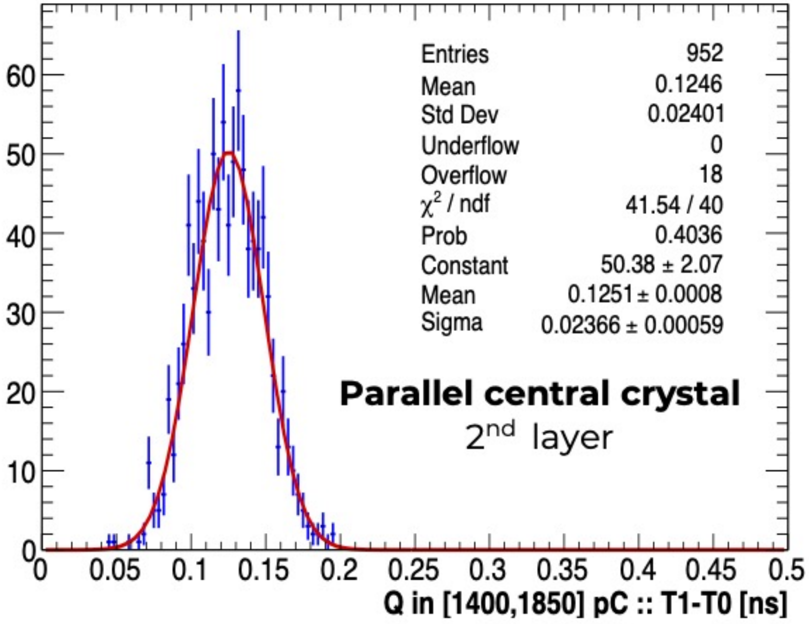


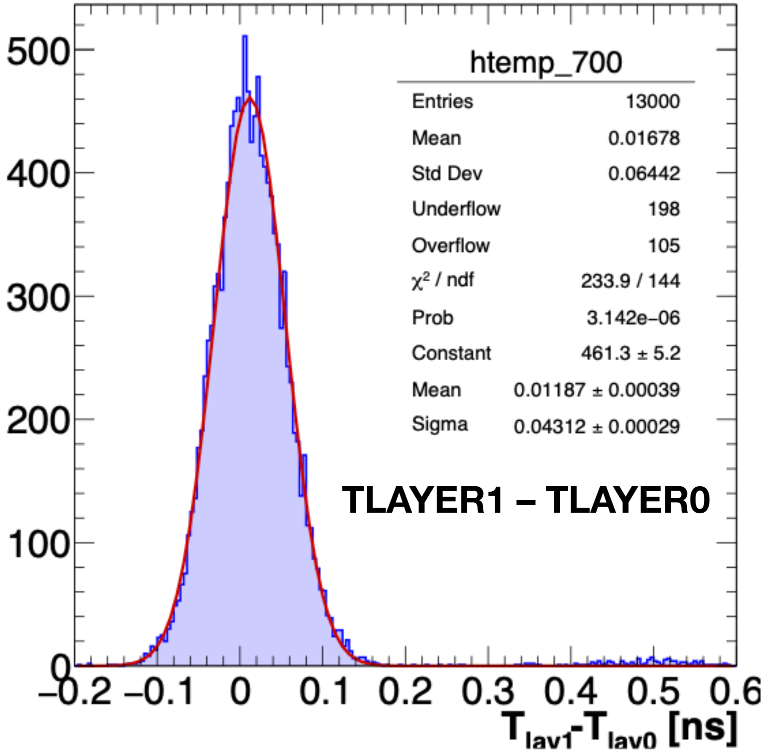


Time resolution

- Time Resolution @ 120 GeV is of **O(20 ps)** both in the series and in the parallel layers using the two channels time difference for the central crystals.
- Studies on using the layer mean time are still ongoing
- For TLAYER1 – TLAYER0 **σ(ΔT) ~ 40 ps** mainly dominated by synchronisation jitter estimated to be O(32ps)







Next steps

- Test beam at BTF within a short time from irradiation at Enea Casaccia
- Submitted and won a PRIN proposal for a 210 kEUR grant for the project CALORHINO: an innovative radiation-hard calorimeter proposal for a future Muon Collider Experiment.
- 120kEur has been assigned to develop a 5x5x4(layers) Crilin prototype.
- Submitted a DRD project to achieved a 2.5 M_R coverage