International
MUON Collider
Collaboration

INFN
Istituto Nazionale di Fisica Nucleare

Crilin: crystal calorimeter with longitudinal information

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CRILIN
the semi-homogeneous crystal calorimeter

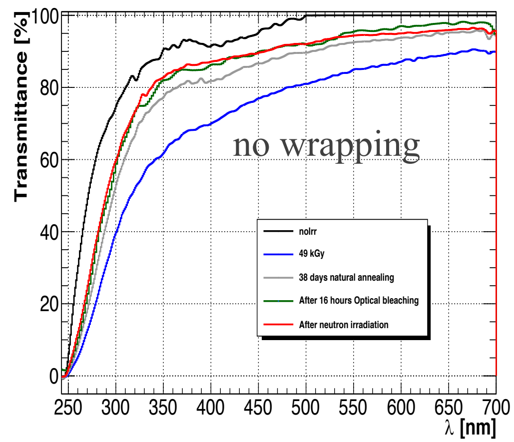
14 September 2021
Meeting con referees di RD_MUCOL

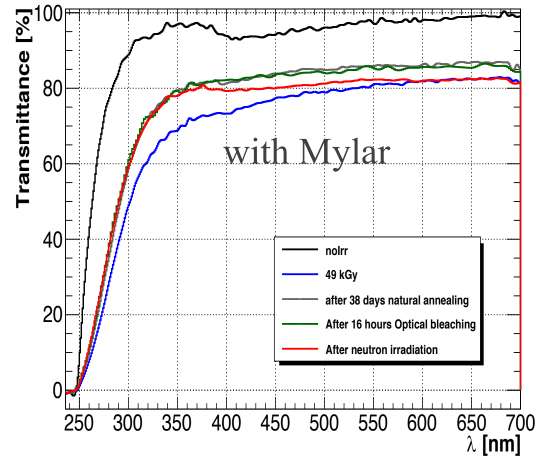
2021: Situazione a Giugno -1-

- Abbiamo testato dose e risposta ai neutroni delle singole componenti.

- Il test e i risultati mostrati di seguito sono stati ottenuti con cristalli di PbF_2 della SICCAS e SiPM S14160-4050HS della Hamamatsu:

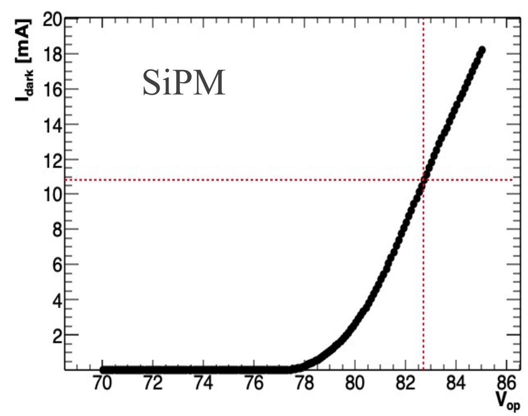
➢ Test di irraggiamento per dose a Calliope (Enea Casaccia) e fluenza di neutroni a FNG (Enea Frascati) su un cristallo "nudo" ed uno incartato con 100 um Mylar.





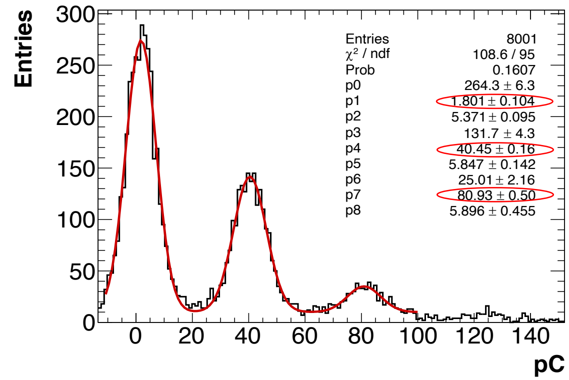
➢ A FNG abbiamo anche irraggiato la serie di 2 SiPM fino a 10^{12} n1MeVeq./cm^2

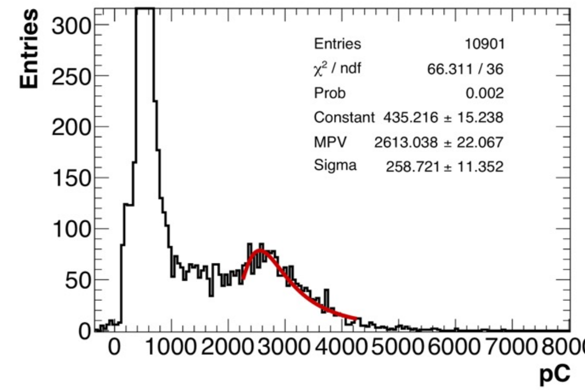
- Leakege current @ Vop ~ 11 mA [25 C], danno circa un fattore 2 inferiore rispetto ai SiPM di Mu2e.



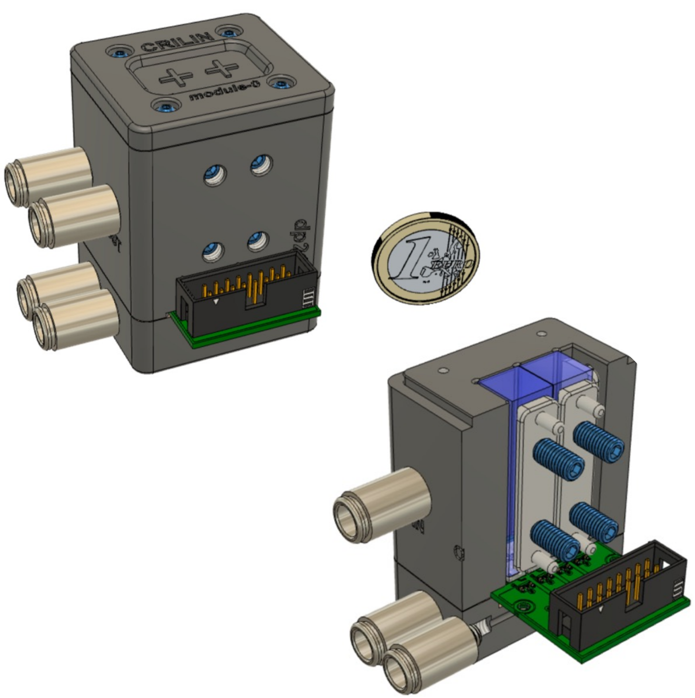
2021: situazione a Giugno -2-

- ➢ LY misurato con MIP → 6 p.e/MEV (ampli x250 gain, 100um Mylar e grasso ottico)

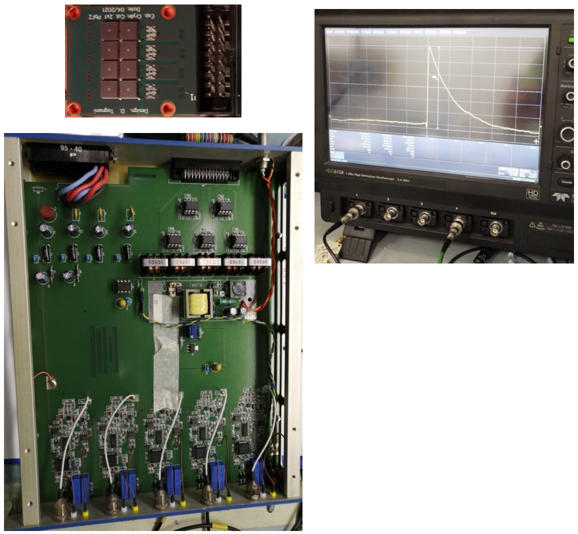




➢Modulo-0



- Due 10x10x40 mm³ cristalli di PbF2 incartati/verniciati con Mylar/EJ510 → 4 readout channels.
- Stampa 3D (FMD/ASA o PolyJet/VeroBlack)
- Integrato Sistema di cooling tramite flussaggio di gas freddo.
- Sistema di bloccaggio cristalli incororato.



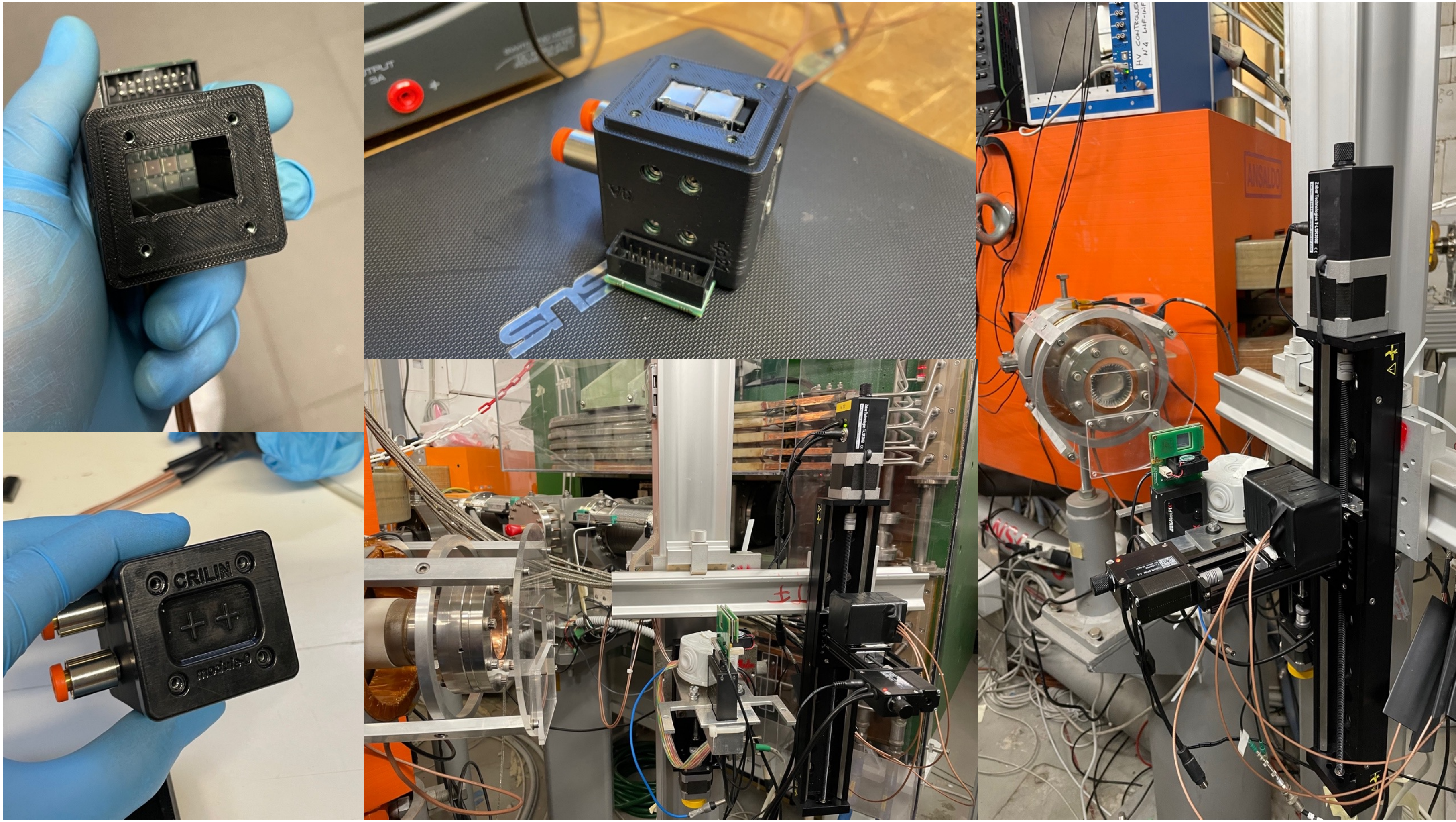
QCalT 4channels NIM module (2010) settled and adapted for Crilin FEE

2021: Collaborazione con Klever

- Klever vuole realizzare un calirimetro a piccolo angolo SAC della stessa tipologia;
- Abbiamo creato @LNF una collaborazione volta alla realizzazione dello stesso rivelatore:
  → ci aiuteranno con la logistica ed analisi dati;
  → test beam @BTF e @CERN in comune.

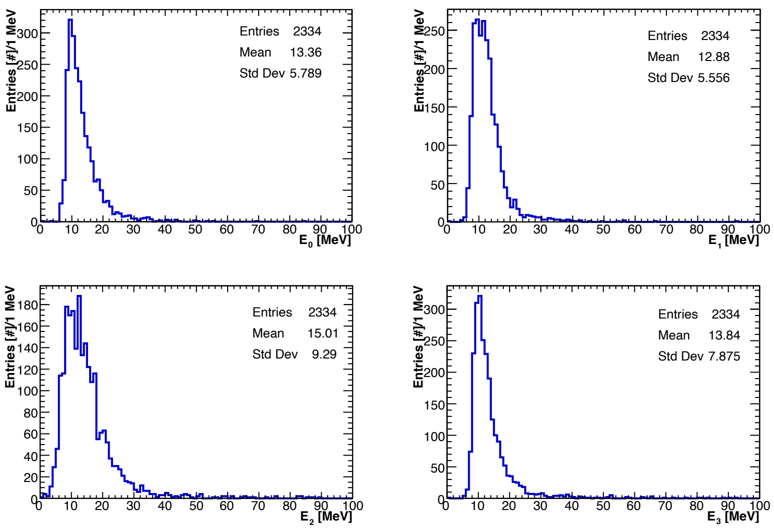
- **Continueremo noi lo sviluppo del rivelatore.**
- **Nessuna richiesta doppia è stata formulata tra le due sigle.**

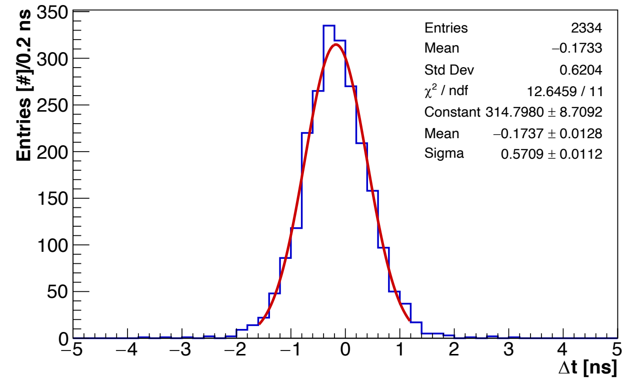
Luglio 2021: Test Beam a BTF



Luglio 2021: Test Beam a BTF

- *Guadagno Amplificatore regolabile 15 e 30*

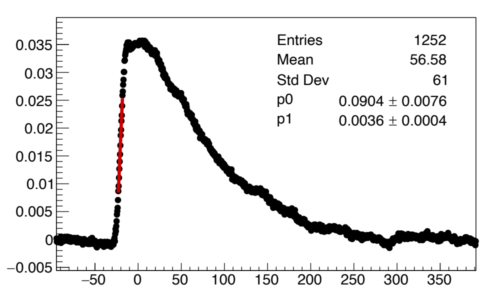




- Risoluzione temporale 570 ps @ 10 MeV, calcolata come la differenza dei tempi tra i 2 SiPM di ogni cristallo

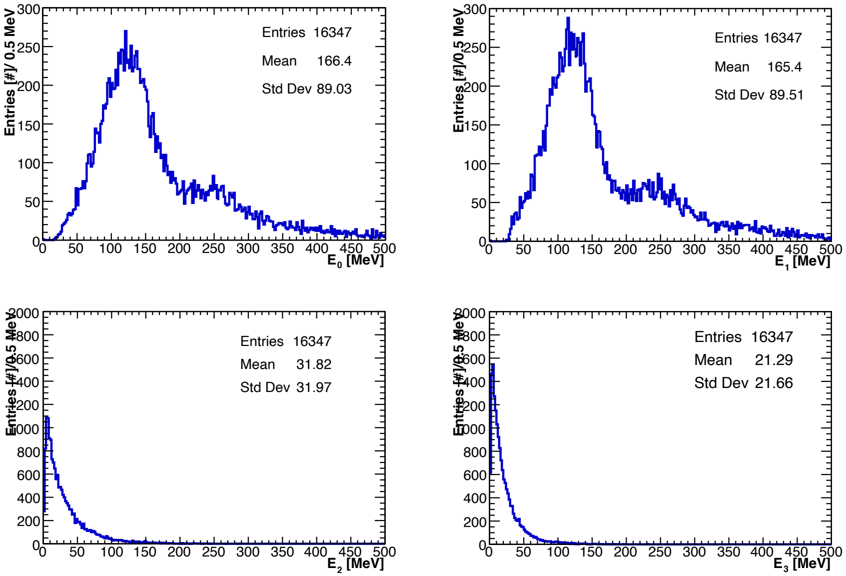
→ **$\sigma_t = \sigma_{measured} / 2 \approx$ 280 ps @ 10 MeV**

- Cosmic Rays – Fit temporale fatto con 2 threshold (80% e 20% del picco) e crossing a zero della retta interpolata.

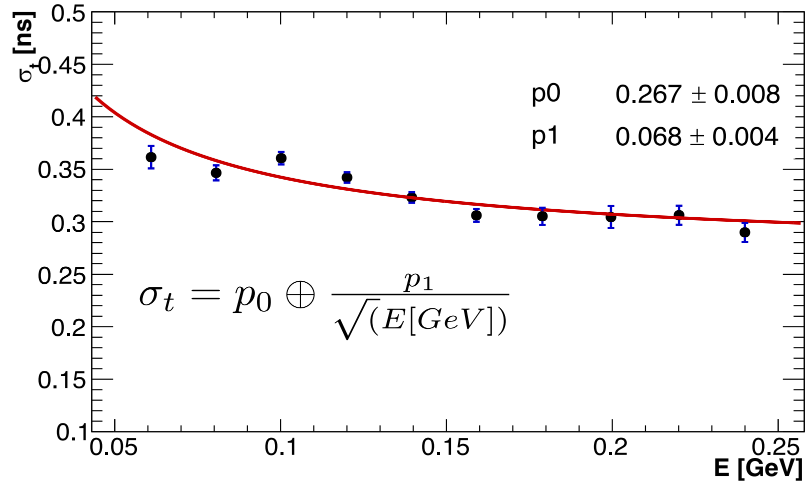


Luglio 2021: Test Beam a BTF

- Fascio centrato sul cristallo superiore.



- Carica divisa in slice da 10 MeV e risoluzione temporale calcolata come la differenza dei tempi tra i 2 SiPM di ogni cristallo .



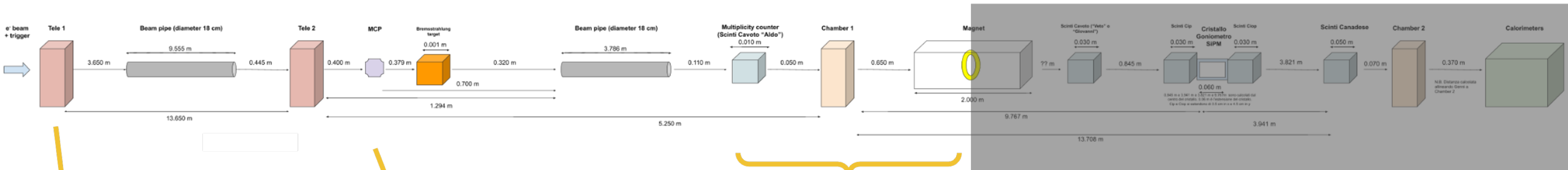
$$\sigma_t = p_0 \oplus \frac{p_1}{\sqrt{(E[GeV])}}$$

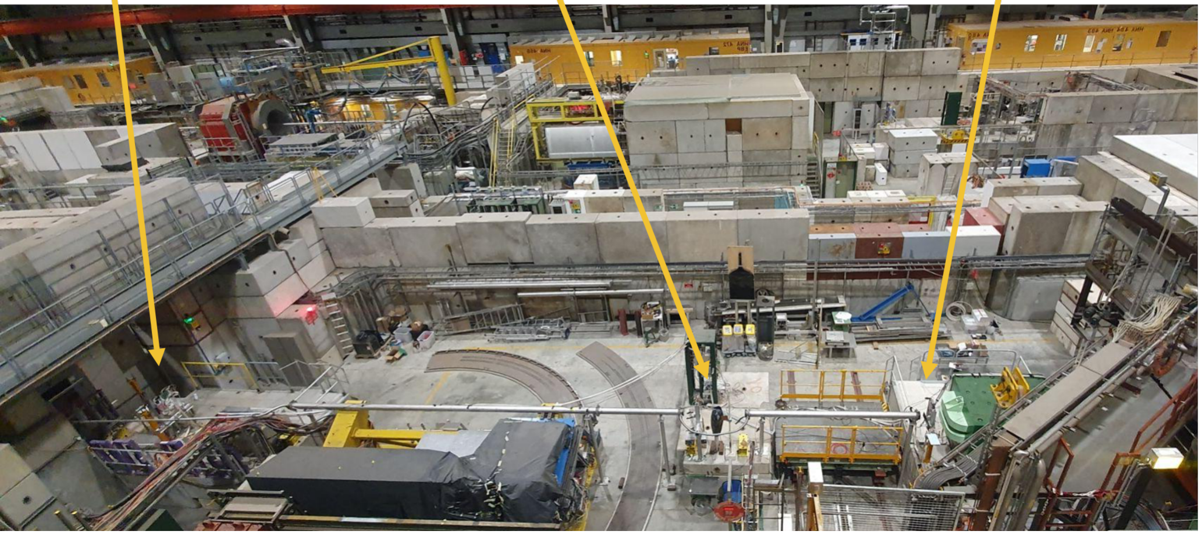
Risoluzione temporale < 300 ps per Edep>150 MeV
(da dividere per il fattore 2 dovuto ai due fotosensori)

→ P_0 derivante dall'elettronica ancora non ottimale

→ Termine stocastico incoraggiante <100 ps ad 1 GeV

Agosto 2021: Test Beam ad H2 (CERN)



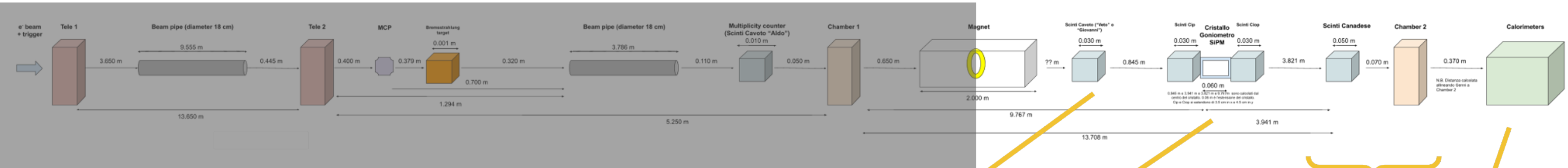


From the left:

- 1st input tracking station (Si micristrips, ~2×2cm^2, ~10um single-hit resolution)
- 2nd input tracking station (=1st), MCPs for high-precision timing (expected ~30ps resolution),

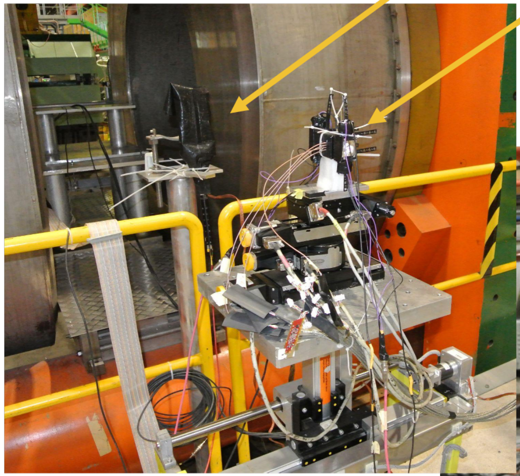
  Thanks to A. & M. Barnyakov
- charged multiplicity counters (~10×10cm2 Si microstrip pair & plastic scintillator), then dipole

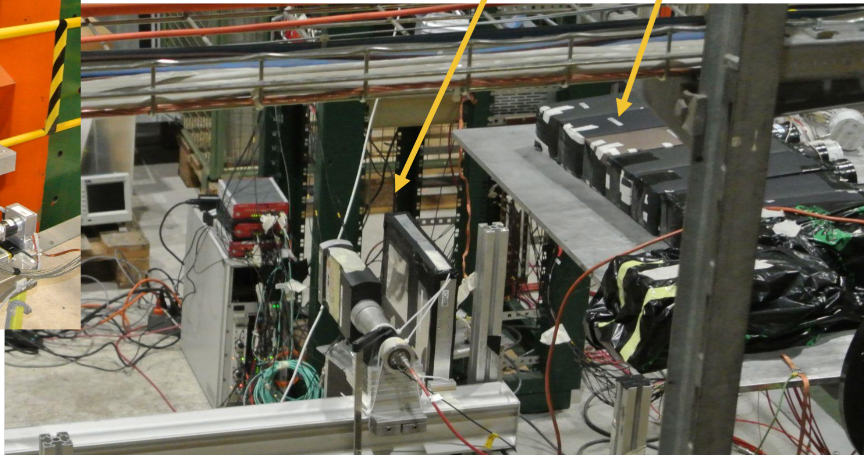
Agosto 2021: Test Beam ad H2 (CERN)



From the left:

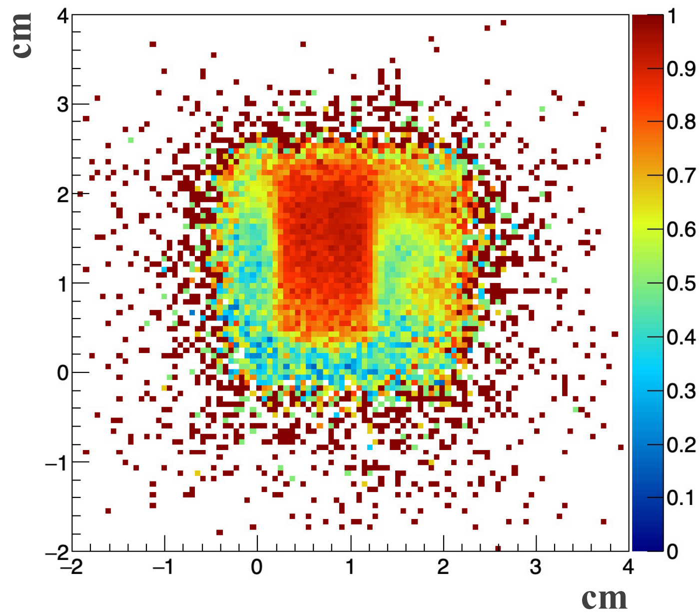
- scintillating charged veto
- high-precision goniometer with CRILIN
- sample output charged multiplicity counters (~10×10cm^2 Si micristrip pair & plastic scintillator)
- calorimeters…

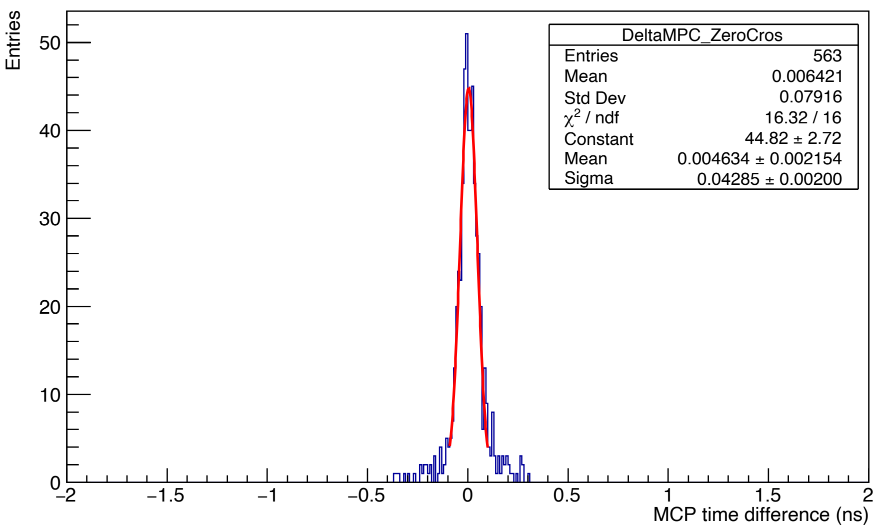




Agosto 2021: Test Beam ad H2 (CERN)

- Cristalli ricostruiti con i tracciatori prima e dopo (1 cluster prima e >6 cluster dopo il calo)
- Trigger tramite coppia di MCP (EKRAN-FEP) e radiatore di 6mm di plexiglass





$\sigma_t \sim 40$ps

Agosto 2021: Test Beam ad H2 (CERN)

Tre Giorni di Run, acquisiti:

- 150 GeV di Muoni
  → valutare la risposta a MIP passanti ~ 40 MeV

- 20, 40, 60, 80 e 120 GeV di Elettroni.
  → La risoluzione energetica è completamente "spalmata": i run saranno sommati insieme e la carica divisa in slice da 100 MeV

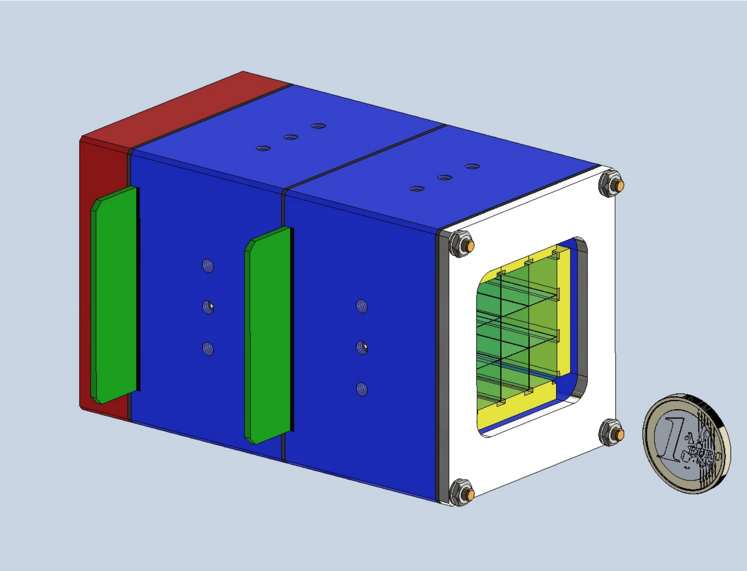
Workiong in progress

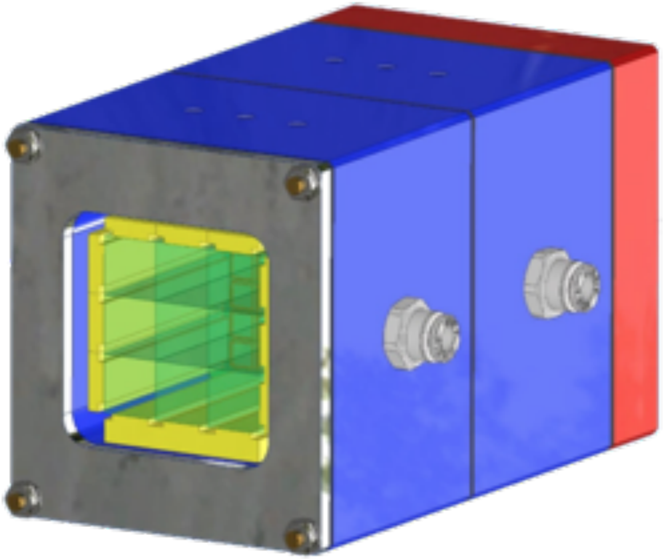
2022: Prototipo

Le richieste per il 2022 sono legate alla realizzazione e test di un prototipo composto da 2 layer di 3x3 cristalli di PbF_2 ognuno, operanti a 0 ℃

Crilin Prototype

- The prototype consists of two submodules, each composed of a 3-by-3 crystals matrix.
- The submodules are arranged in a series and assembled together by screws, resulting in a compact and small calorimeter





- Our design is capable of removing the heat load due to the increased photosensor currents after exposure to the expected 10^{12} n1MeV/cm^2 fluence, along with the power dissipated by the amplification circuitry. The total heat load was estimated as 350 mW per channel.
- The Crilin cooling system, which is based on conduction and forced convection of nitrogen, will provide the optimum operating temperature for the electronics and SiPMs at around 0 $^\circ$C.

Crilin Prototype - Richieste

- **Richieste 2022 → 33keuro** INVARIATE e NECESSARIE

- 2keuro meccanica:

  Costruzione prototipo + coinventazione + possibile uso della fibra di carbonio (guardando a Crilin)
- 15keuro elettronica:

  2+1 board da 18 canali (gain x2) + 4 cassetti NIM ricevitori da 10 canali ognuno (gain x4-5 settabile) per trasformare da differenziale a single endend e gestire l'HV + 1 crate di gestione (ad alimentazione lineare)
- 1keuro di metabolismo (spedizioni, cavi e accessori)

- 15keuro acquisizione fast CAEN 2.5 Gs/s per i 36 canali del prototipo.

- Possibile contributo da Dot.GR1 LNF
  - 5k chiesti anche da KLEVER

- in caso i contributi ci siano: restituire l'avanzo / usarlo per altro

- utilizzerei i residui per comprare SiPM SensL → fast output e prototipaggio

  Tot. 3k euro

SPARES

CRILIN

the semi-homogeneous crystal calorimeter

Considerations -1-

- The simulation shows the importance of the longitudinal segmentation. But, since many calorimeters also satisfy this feature, can a standard sampling calorimeter (at the same cost level) to be used for our purpose?

➢ Is difficult to obtain for high p_T muons an adequate time resolution (<100 ps):
  - i.e time resolution for MIP particle with the KLOE calorimeter (Fs, sampling ratio =Vscint/Vlead=1:1) is of 250 ps. The ATLAS liquid argon "accordion" case is even worser than this.

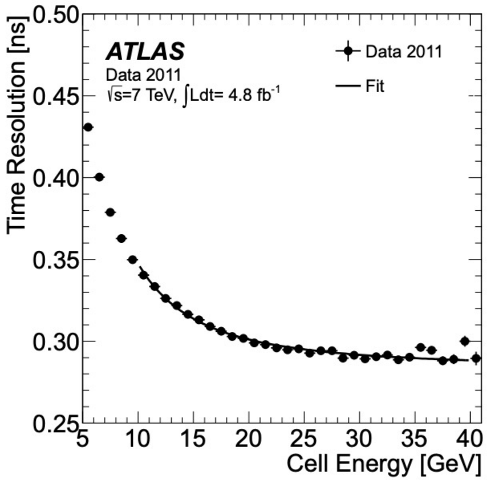


Fig. 14. Single cell time resolution energy dependence, for cells reconstructed in High gain, in the Middle layer of the LAr EM Barrel Calorimeter ($|\eta| < 1.4$). A fit with the expected energy dependence, comprising a so-called "noise term" and a "constant term", added in quadrature, is shown superimposed [14].

Considerations -2-

- Moreover, the BIB separation required an high time resolution in few cm of thickness. Our proposal allows to achieve an excellent time resolution for each sector individually, still maintaining a good linearity.
  - i.e assuming 30 GeV as our endpoint for e.m. shower where we intend to maintain good energy. Resolution and linearity, we estimate an energy deposition of roughly 5000 pe in a 5 cm long cells. Total Num of pixel 3600*9=32400 using the 50 um pixel size → 7% of not linearity in the worst case.

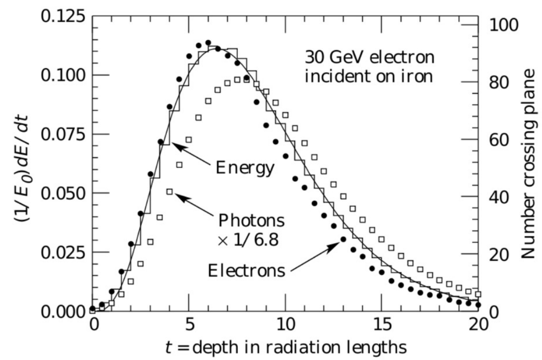


Figura 1.3: *Profilo longitudinale per il deposito di energia di uno sciame indotto da un e^- da 30 GeV in una simulazione di EGS4. L'istogramma mostra la frazione di energia depositata per lunghezza di radiazione. I cerchi indicano il numero di e^- con $E > 1.5\,MeV$ attraversanti piani posti a intervalli di $\frac{X_0}{2}$ (scala a destra) e i quadrati il numero di fotoni con $E > 1.5\,MeV$ attraversanti i medesimi piani (riscalati per avere la stessa area della distribuzione di elettroni). La curva è una funzione gamma che approssima molto bene la distribuzione.*

- Extending further the dynamic range is possible by proper choice of the pixel size. Producer have now available pixel size down to 15 um that will surely improve in this respect.

Example of application: Muon Collider Ecal

- The present Ecal in the simulation framework is based on 1.9 mm W + silicon pad layers:
  - 40 layers
  - 5x5 mm^2 cells
  - 22 X_0 + 1 λ_I
  - barrel (with dimension 4 m x 3 m) + 2 endcap

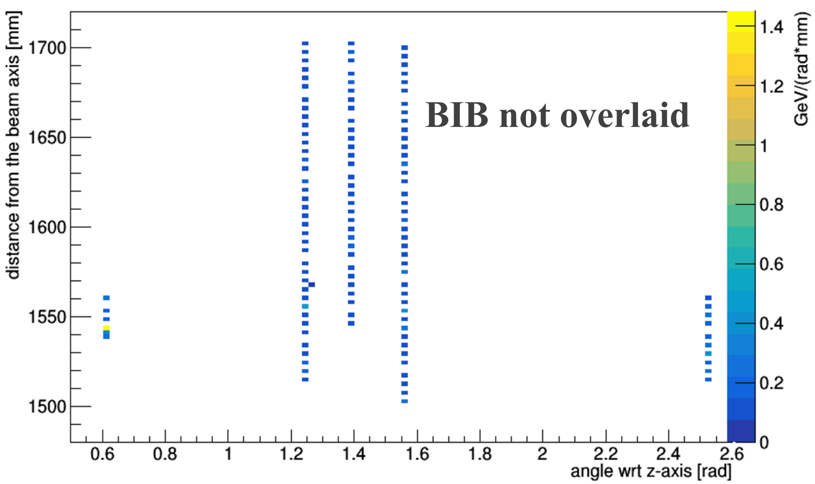
  ➢ Very expensive, huge amount of channels
  ➢ Low time resolution

- However, this high segmentation allows setting the requirement for the calorimeter

  → Lets see an example

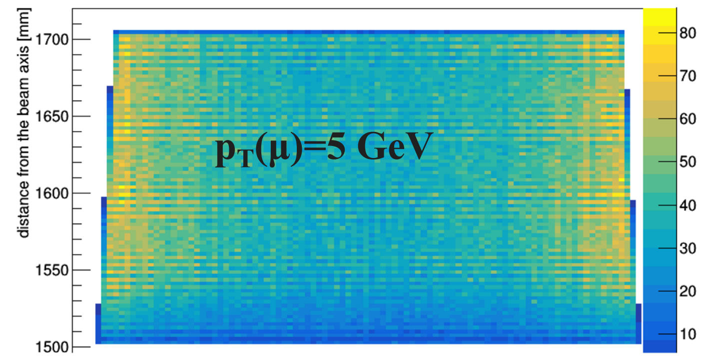
Muon ID with the calorimeter -1-

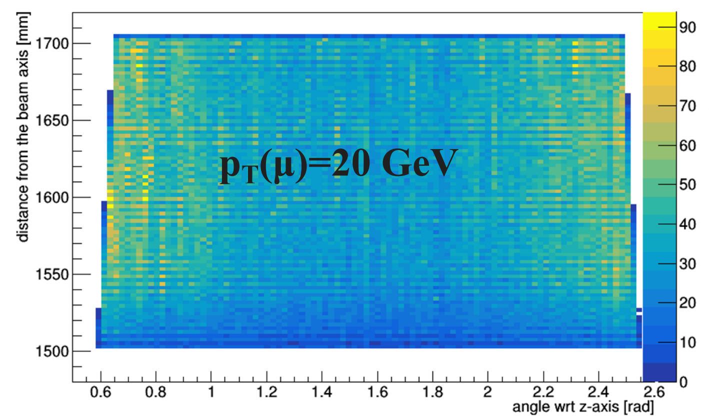
- The identification of high p_T muons could be difficult with just the Muon Detector → the calorimeter can be used to improve it.
- For such purpose, the longitudinal segmentation is important to reconstruct muon tracks in the calorimeter.



prompt muon tracks in ECAL barrel

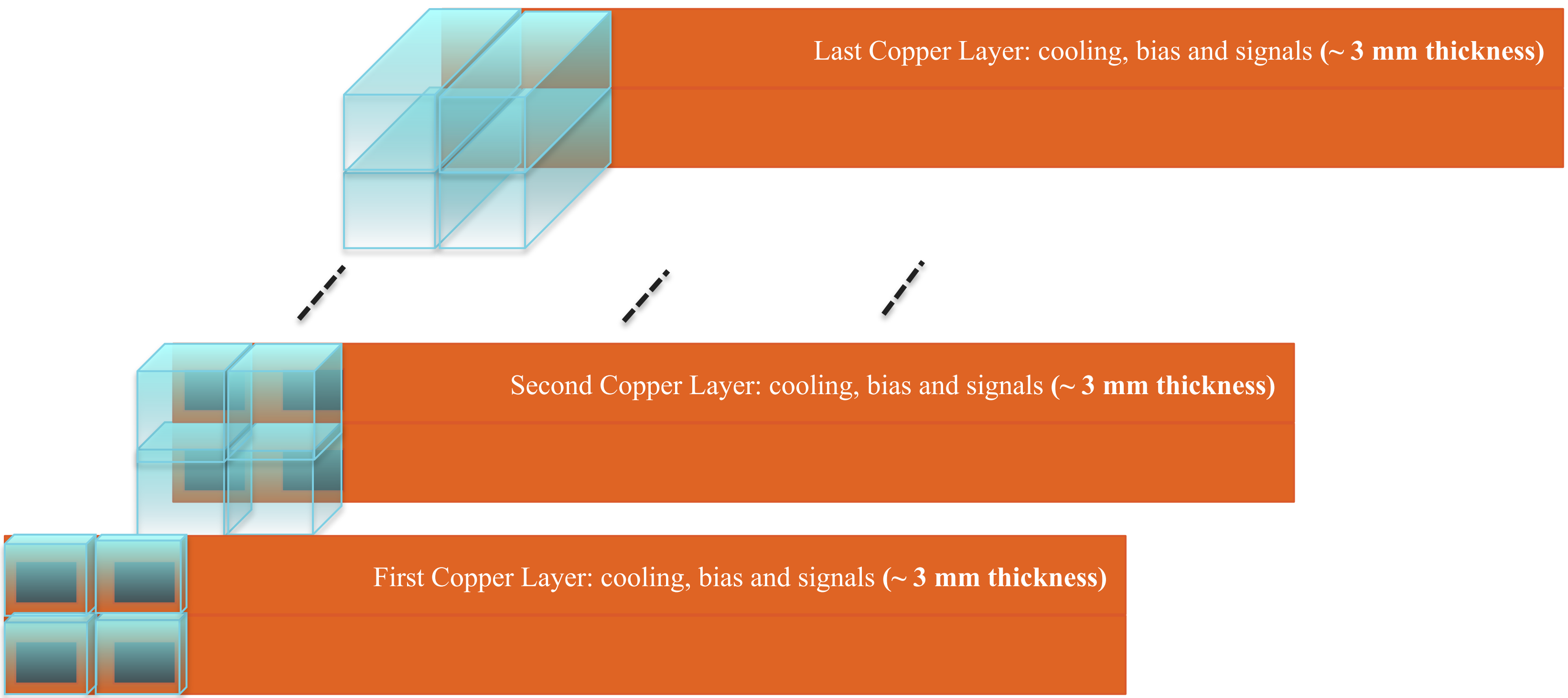
Energy released in ECAL barrel by uniformly distributed prompt muons in the (θ,φ) space





A Crystal Calorimeter with Longitudinal information

- Calorimeter Layout: **the calorimeter can be segmented longitudinally** as a function of the energy of the particles and the background level.



Timing resolution

- As far as timing resolution is concerned, in this configuration the stochastic term linked to PbF2 would be practically zero, while the dominant contribution would be linked to the rise time of the signal.

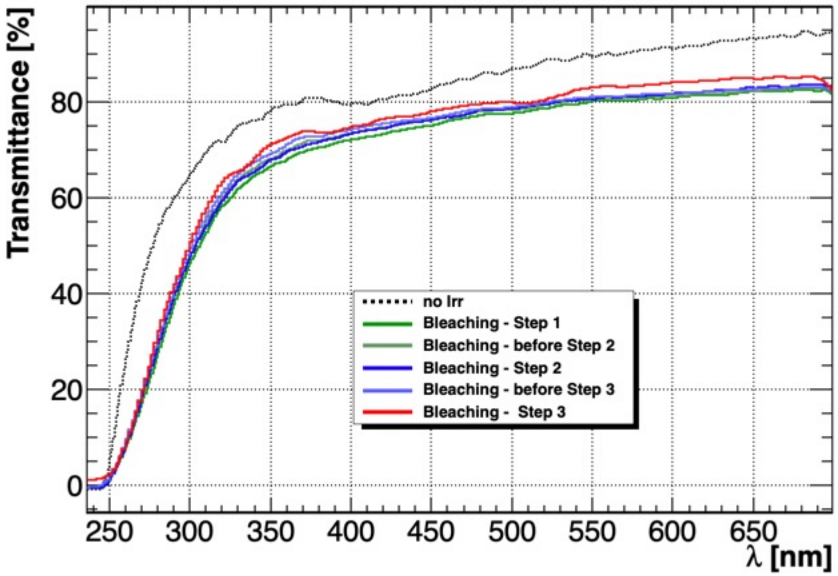
- The rise-time of SiPM pulses is in the order of the nanosecond, while the rise-time of the FEE depends on the choice of the amplifier.

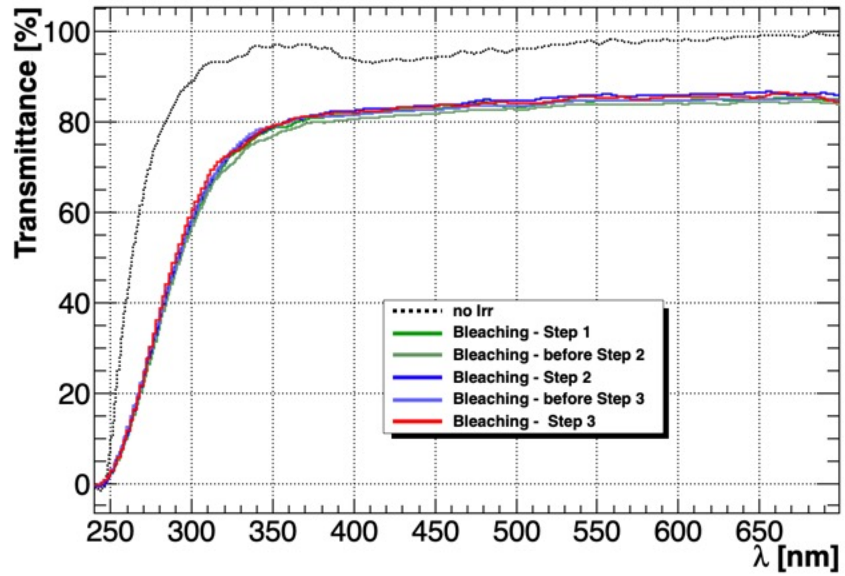
- Assuming a total rise-time of approximately 3-5 ns for the SiPM and FEE, the achievable time resolution would be of the order of 3-5 ns/sqrt(Np.e).

  This corresponds to 300 ps in the case of high impulse muons and up to 50 ps in the case of pions and jets. → will be measured with the module-0 (see later)

Optical Bleaching

- After 16 hours of optical bleaching, recovery of only a few percent on the transmittance spectrum was observed.
- This could indicate that the effect of the natural and induced annealing are quantitatively at the same amount. Bleaching seems to only speed up the natural annealing of the crystals.





- Step 1: six hours of bleaching
- Step 2: ten hours of bleaching
- Step 3: sixteen hours of bleaching

Crilin Prototype

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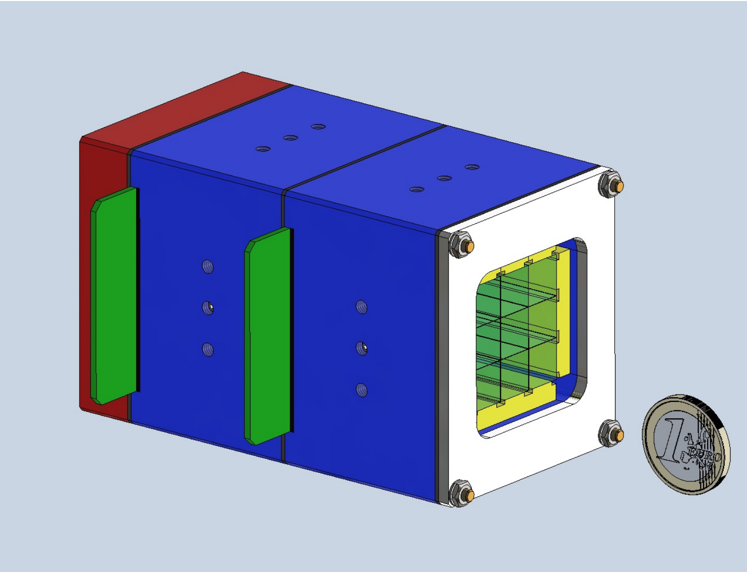
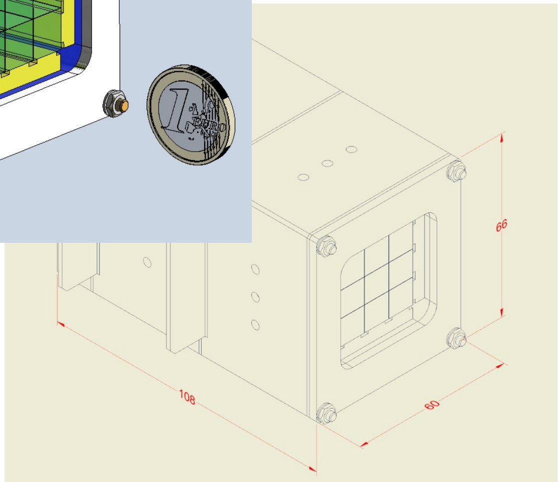
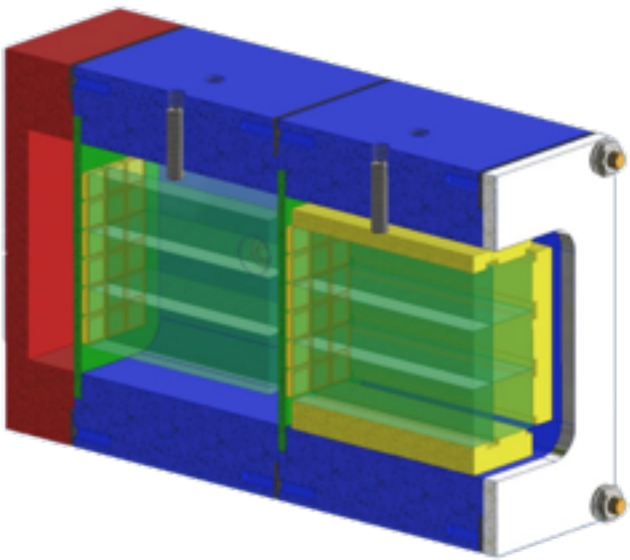
- The submodules are arranged in a series and assembled together by screws, resulting in a compact and small calorimeter



1. The cases, which house the crystal matrix and embed the front-end electronic boards. They are manufactured in aluminium alloy (EN AW 6082) and ABS to ensure the thermal insulation.

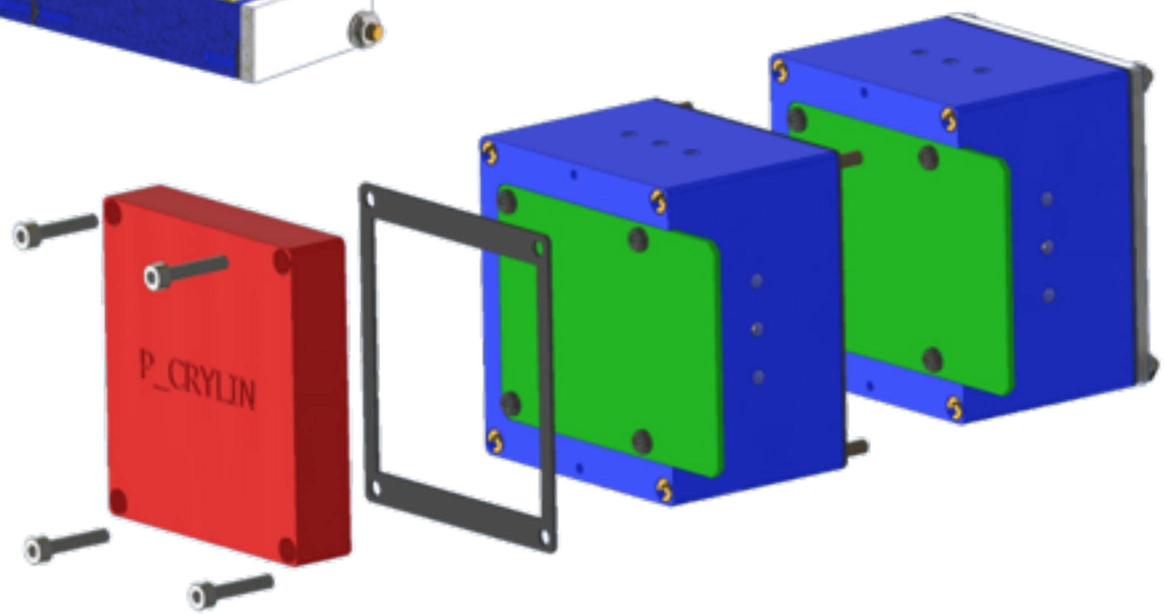


Crilin Prototype - 2 -



2. The locking plates, which ensure the positioning and the blocking of the crystals inside the case, are manufactured in ABS.

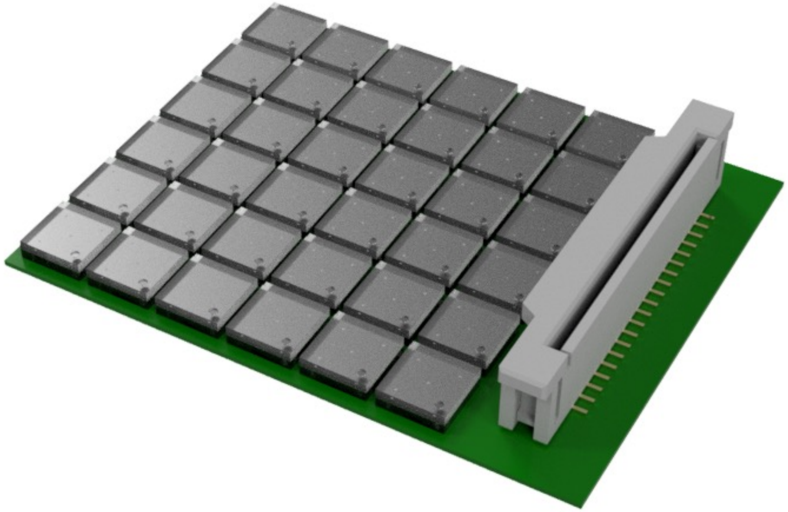
→ *This solution eases the assembling, positioning and locking of the crystals matrix.*



Crilin Prototype - Electronics

- The PCB layout was conceived so that, for each crystal, the amplification and bias distribution circuitry - mounted on the bottom side - could be contained in the footprint of the 4 photodetectors mounted on the top side.

- The chosen PCB solder mask for the final prototype is in black colour, an element which can be beneficial in preventing cross talk from happening at the SiPM-crystal interfaces.



- The differential outputs are back terminated with 50 Ω per side. The nominal transimpedance gain is 8 kΩ. In our case this corresponds to an overall charge **gain of about 2.**

- A control module will be developed in standard NIM format to provide the regulated bias supply voltages and perform the conversion of the differential pulses to a single ended, 50 Ω adapted voltage signal. **The NIM module also embeds an additional gain 5 stage.**