4.12.2019 *Rome, Italy*

Progress on the R&D of the FOOT calorimeter

FOOT Collaboration Meeting

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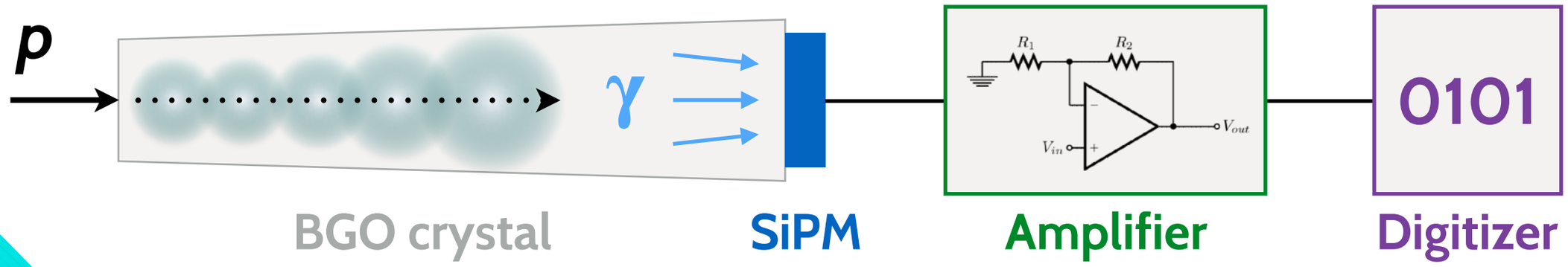
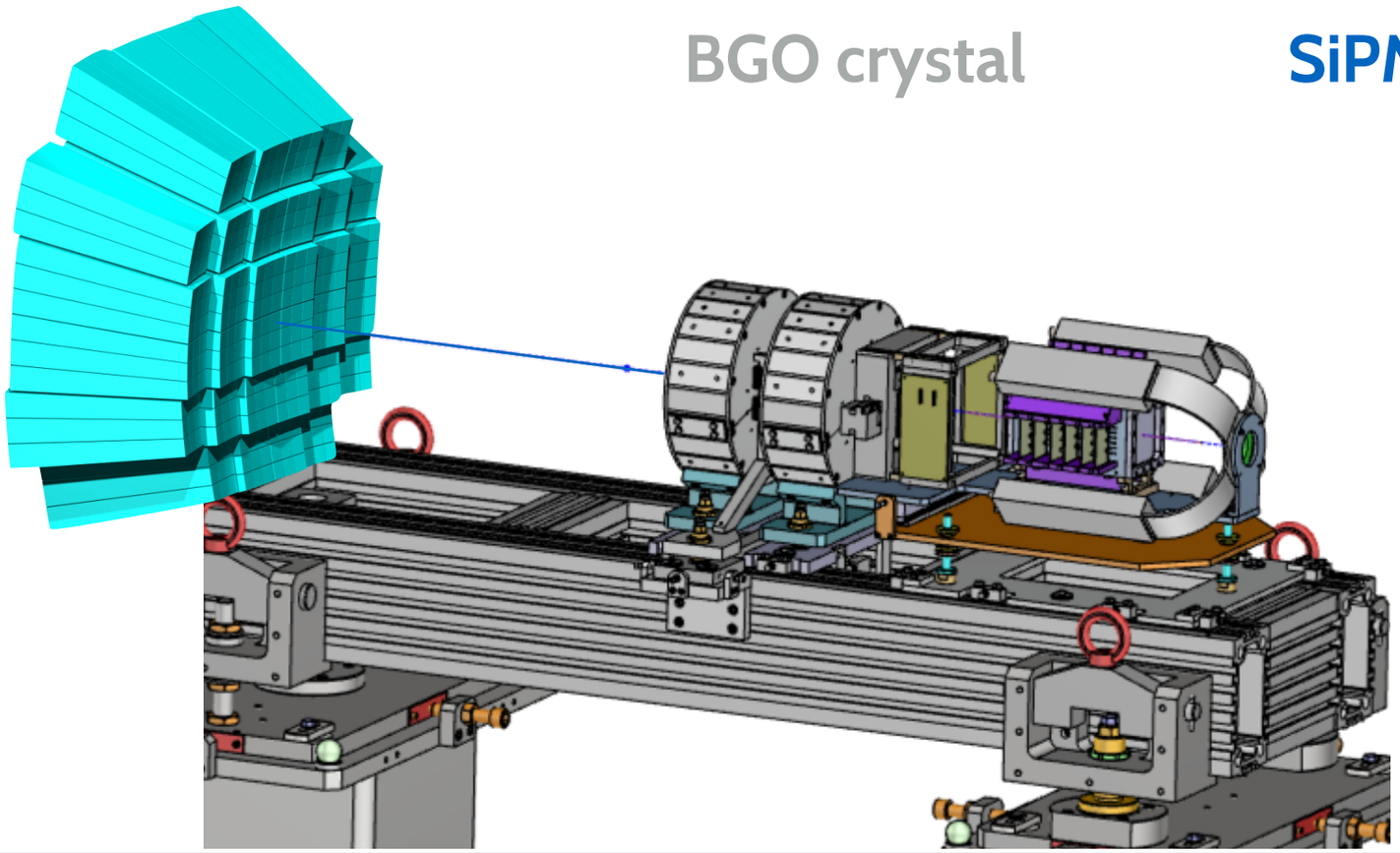
The goal

We are building the calorimeter to measure energy of the fragments

- high design energy resolution: ≤2%
- wide dynamic range: **100 MeV - 5 GeV**

It's a homogeneous calorimeter with BGO crystals as an active medium





We started from BGO crystals

Every other component has to be designed/conditioned/tested for our particular application

Status at the last meeting: June 2019

A number of testbeam campaigns have been carried out to converge on some crucial components of the FOOT calorimeter system:

- **BGO crystals as active volume:** *320 crystals available for the full assembly*
  - reflective layer required to achieve the design energy resolution
- **SiPM tiles as light detectors:** *FBK production | 15μm pitch | 25x25 mm²*
  - sufficient dynamic range and sensitivity for our purpose

Decisions on other components were yet to be made:

- **Readout circuit:** *single gain or two gains*
  - fitting the wide input dynamic range to a digitizer is not trivial
- **Digitizer:** ***CAEN V1742*** | *1Vpp* | 1GS/s | 32 channels
  - cheaper alternative: ***CAEN V1740*** | *2Vpp* | 62.5MS/s | 64 channels
  - low sampling rate might degrade the reconstructed resolution
- **Module assembly:** *main criteria for the mechanics have been established*
  - 3x3 crystal module, crystals holding from the back → ***to be tested***

Current status

A big step towards the final module design in the last 6 months:

- **Readout circuit**: *miniature readout board* | *size of a SiPM* | *single gain ×1*
  - designed and successfully tested at CNAO

more on results by Lorenzo

- **Digitizer**: ***CAEN V1740*** | *2Vpp* | 62.5MS/s | 64 channels
  - design resolution easily achieved (*by fitting the pulse shape*)
  - dynamic range matches perfectly the board output
- **Module assembly**: *first module prototype assembled and tested at CNAO*
  - design not final yet, but close to final

The last 2 testbeam campaigns were the most decisive:

- **October 2019**: *tested the new **SiPM** + **readout board** + **digitizer** combination*
- **November 2019**: *tested a prototype of the calorimeter module [3x3 crystals]*

➡ **Now to the more technical details...**

October 2019: testbeam setup

Towards a more compact readout design suitable for a calorimeter module

- 5x6 SiPM tiles *[15μm, 20μm]*
- old big readout board
  - reading 30 channels individually
  + sum of all 30 channels
- external trigger from PMTs
  - energy loss in the scintillators

Testing the new *SiPM* + *readout board* + *digitizer* combination

- 5x5 SiPM tile *[15μm]*
- compact readout board
  - reading only the sum
- internal trigger for the ultimate energy resolution measurement

October 2019: testbeam setup

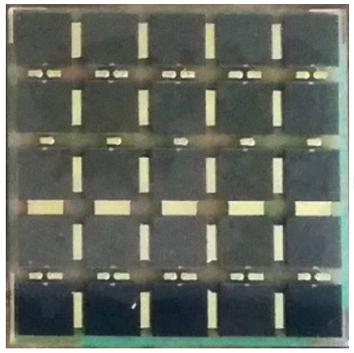
Crystal

BGO

Reflective layer

- White paint
- Mylar
- Tyvek

SiPM

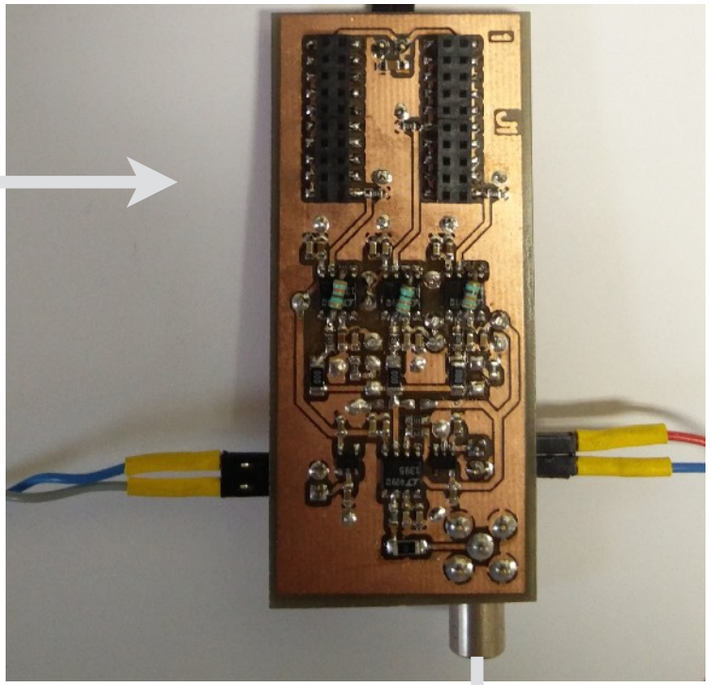


FBK 5×5 SiPMs

25×25 mm²

15µm pitch

Readout board



1 output: SUM

1 gain: ×1

Reading **only 15**/25 channels → output signals twice smaller

Digitizer

CAEN V1740

2Vpp 12bit

64 channels

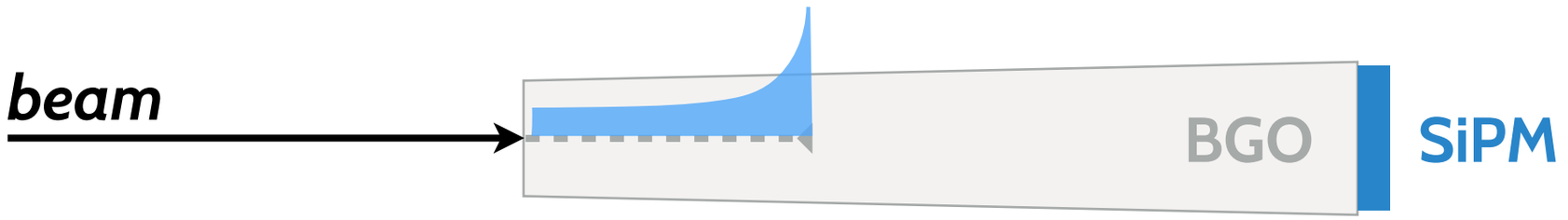
62.5 MS/s

↳ 192 points/pulse

Goals of the testbeam:

- validate the board design
  dynamic range, noise, pulse-shape quality
- *compare the different reflective layers*
  energy resolution, response linearity

October 2019: testbeam outcome



Performed energy scans with the *p* (70-220 MeV) **and *C*** (115-400 MeV/A) **beams**

- **the new readout board performs very well**
  - pulses have a smooth predictable shape
- **dynamic ranges of the board and digitizer match perfectly**
  - pulses from C at 400 MeV/A have amplitude of ~1V *(half of the digitizer input range)* when reading half of the SiPMs of the tile
- **design energy resolution is achieved with the CAEN V1740 digitizer**
  - fitting of the pulse is needed to maintain high resolution at lower energies
- **minor differences between reflective layers**, but nothing dramatic
  - price, fragility and the application process are of greater relevance

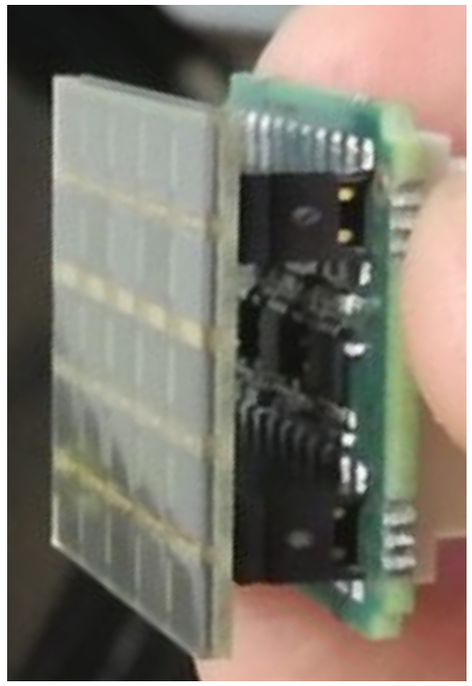
➡ **Now to a more real-life scenario: 3x3 module**

November 2019: testbeam setup

3x3 Module

SiPMs not attached to the crystals → bad optical coupling

SiPM + Readout board



× 9

1 output: SUM

1 gain: ×1

Reading **all 25** channels

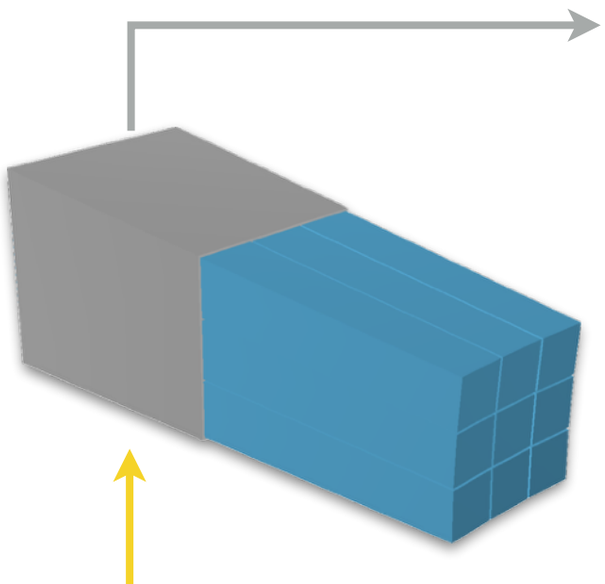
Digitizers

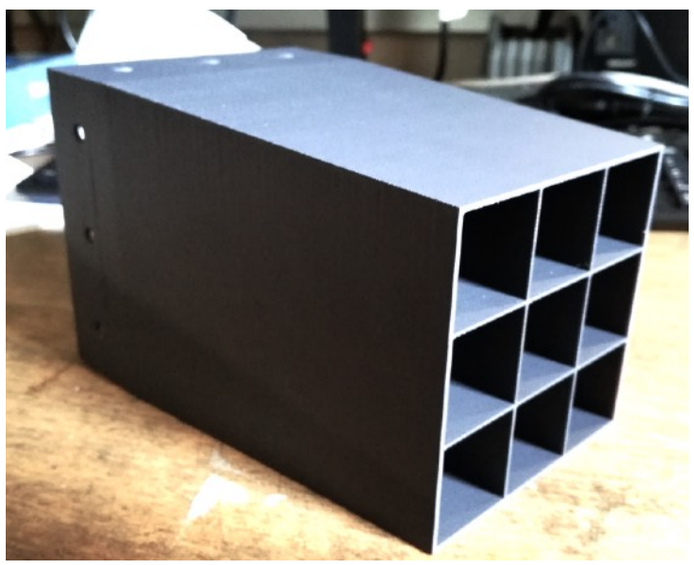
CAEN V1740	CAEN V1742
2Vpp	1Vpp
62.5 MS/s	1 GS/s

Goals of the testbeam:

- check energy resolution with the energy deposition spread across multiple crystals
- understand better the pulse-shape differences between particles and wrappings

November 2019: module setup





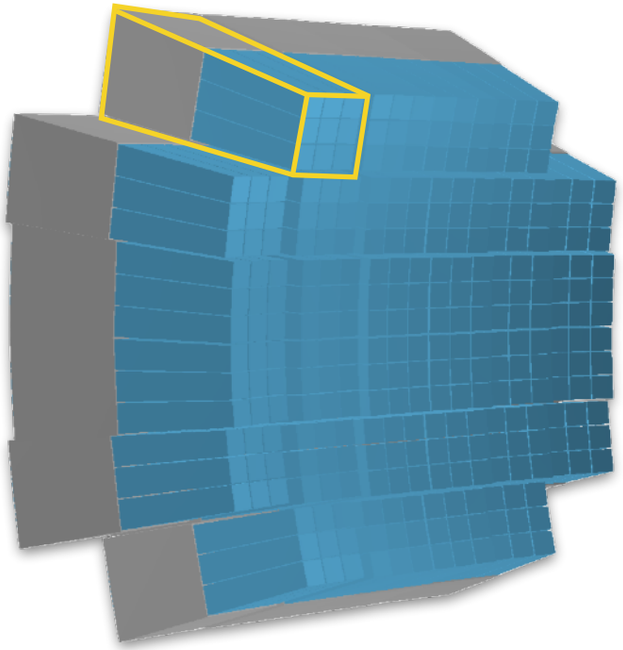
3D printed plastic structure
follows the crystal shape

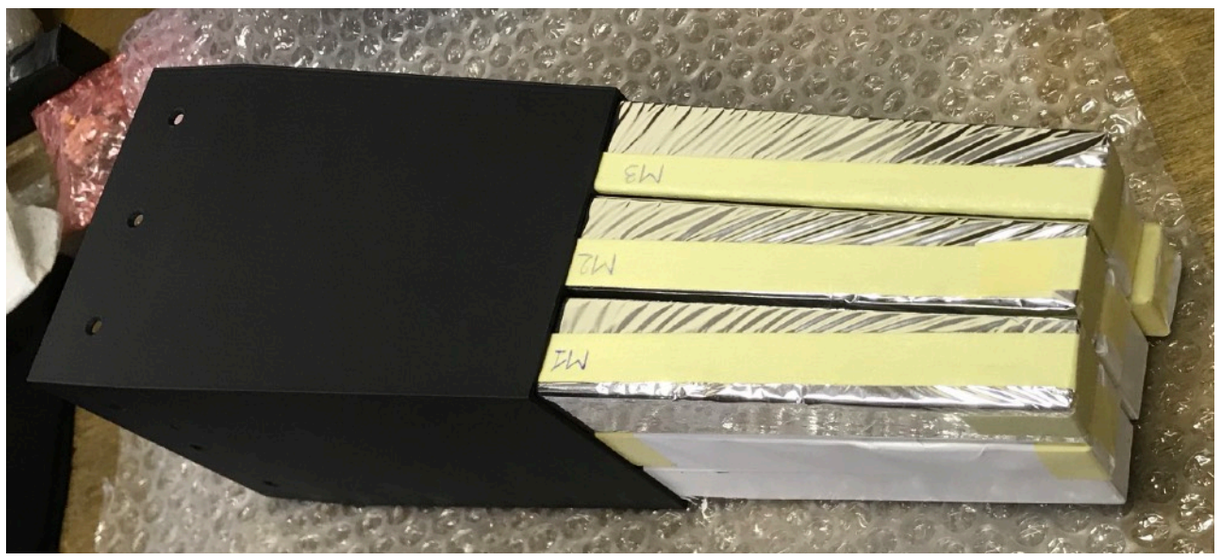
- crystals kept in place securely

SiPM + board kept in place very loosely

- SiPMs not coupled to crystals

↳ distance between crystal and SiPM **≤1 mm**
+ alignment **≤3 mm**

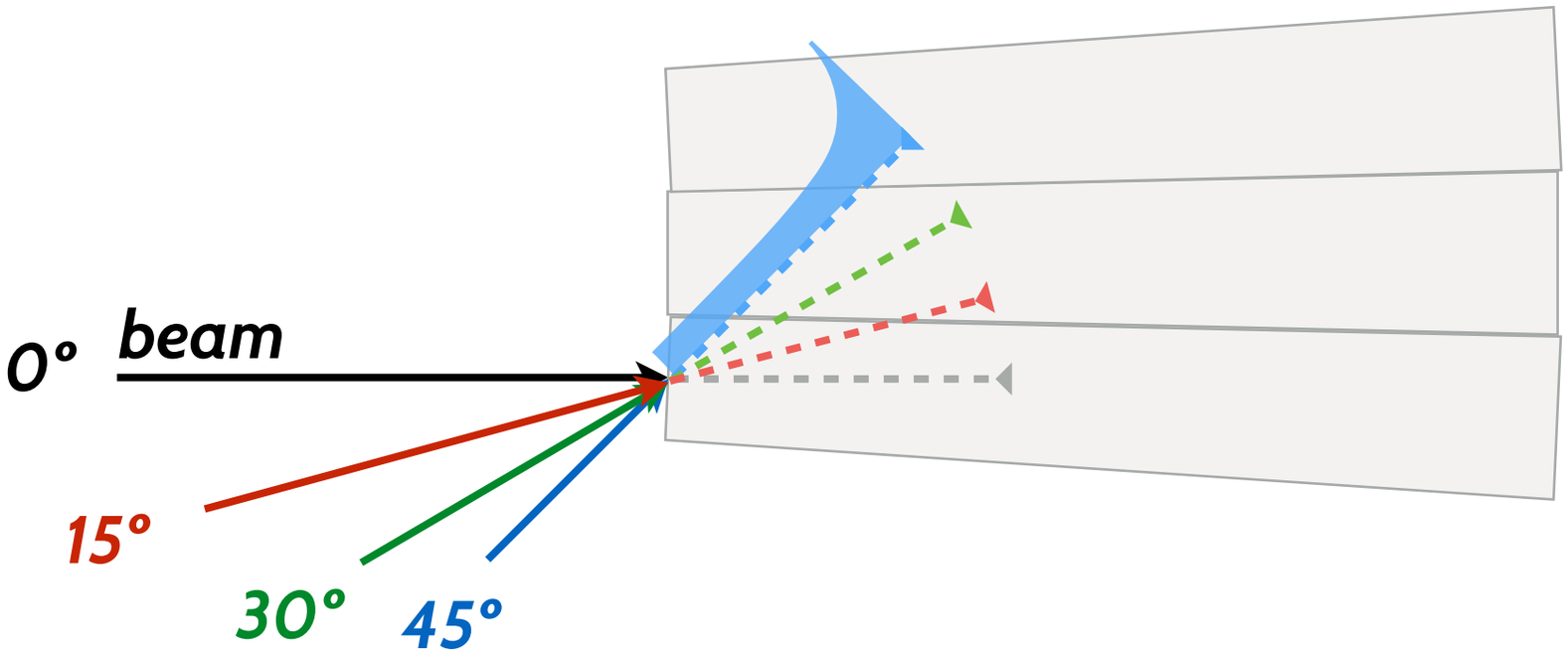




Crystals with 3 kinds of reflective layers were combined:

Mylar **Tyvek** **White paint**

November 2019: testbeam outcome



Only crystals with **Tyvek** wrapping used for the tilted beam

Performed energy scans with the *p* (70-220 MeV) **and *C*** (115-400 MeV/A) **beams at different angles between the beam and the module**

- **sufficient resolution obtained by summing signals from the 3 crystals**
  - effect of bad optical coupling is visible
  - further improvements to the analysis needed
- **differences in timing seen with the slower digitizer seem to be confirmed**
  - more careful pulse analysis is needed

➡ **More details in the talk by Lorenzo Scavarda**

Summary

A big progress towards the final Calorimeter design has been done recently

Crystal + SiPM + electronics chain is almost final

- a few options for the reflective layer and digitizer are still considered
- any option provides sufficient performance
- the decision is now about the convenience/cost/extra features

A bit more R&D time needed to evaluate the pros/cons of each option

Discrimination between particle types with the Calorimeter alone is possible

- a future testbeam at Heidelberg would be particularly interesting

Dedicated DAQ code for acquisition of subset of crystals (above threshold + neighbours) **has been developed**

- will be tested at one of the next testbeams

➡ **More on the future in the talk by Piergiorgio Cerello**