A cosmic muons test bench for the characterisation of GRAiNITA

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on behalf of the GRAiNITA R&T members : S. Barsuk, D. Breton, I. Boyarintseva, A. Boyarintsev, A.M. Dubovik, B. Geoffroy, C.D. Goncalves, G. Hull, M. Imre, A. Kotenko, J. Lefrançois, M. Magne, B. Mathon, S. Monteil, S. Olmo, D. Picard, D. Reynet, M-H. Schune, N. Semkiv, I. Tupitsyna and M. Yeresko.

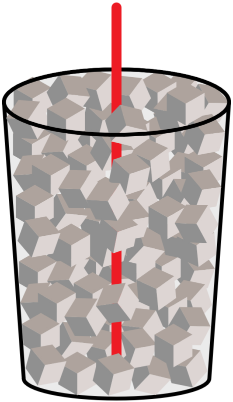
Introduction

GRAiNITA

- Demonstrator for a new generation calorimeter
- Adapted to the constrains FCC-ee
- Allows a fine digitization of the electromagnetic cascade thanks to light confinement (Inspired by the LiquidO detection technique[a])
- Reasonable cost

Collaboration

- ICJLab (Orsay-France)
- LPCA (Clermont-Ferrand-France)
- ISMA (Partner-Ukraine)

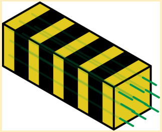


[a] A. Cabrera et al. LiquidO Commun Phys 4, 273 (2021)

Concept of GRAiNITA

Shashlik calorimeter

Alternated layer of scintillator and absorber

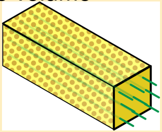


- High granularity
- Limited energy resolution :

$$\frac{\sigma_E}{E} \sim \frac{10\%}{\sqrt{E}}$$

GRAiNITA

Scintillator grain and absorber mixed in the same volume



- High granularity
- Expected energy resolution[1]:

$$\frac{\sigma_E}{E} \sim \frac{1\% \text{ to } 2\%}{\sqrt{E}}$$

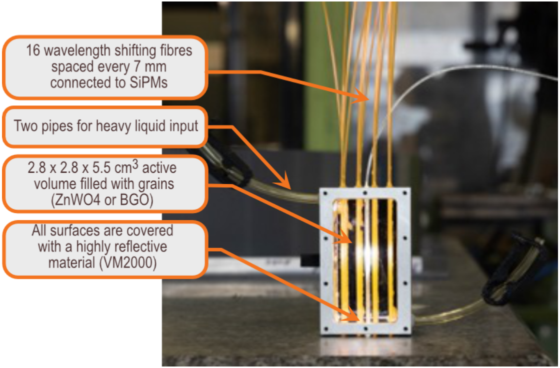
The energy resolution of a calorimeter can be written as :

$$\frac{\sigma_E}{E} \sim \frac{A}{\sqrt{E}} \oplus \frac{B}{E} \oplus C$$

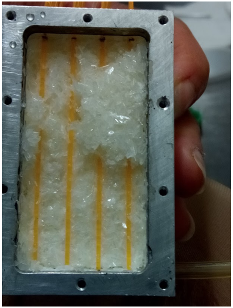
The determination of the C-term value is one of the challenges of the project.

[1] G4 simulation : Poster N-13-186 – Energy resolution of the GRAiNITA protoype detector

GRAiNITA prototype



Empty prototype



Grain filling (ZnWO4)

The GRAiNITA prototype is aimed at studying the performance of such a calorimeter :

- The number of photo-electrons per GeV
- The uniformity response (ex. close to a fiber or half-way)

Needs for a dedicated test bench

Cosmic muon test bench

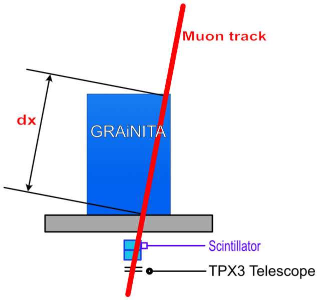
Objectives

- Design a muon tracker with a ± 1 mm resolution on the tracks
- Aimed at determining the performance of the GRAiNITA scintillators
- Can be used afterwards by any scintillator studies

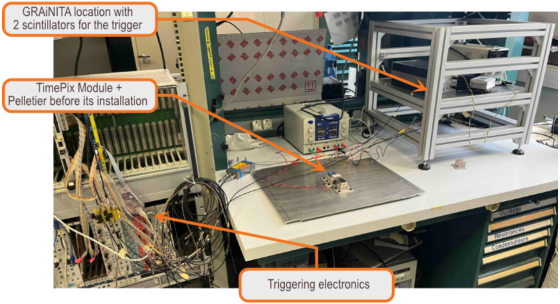
Working principle

Determine the dE/dx for each muons crossing GRAiNITA

- dE is measured by the GRAiNITA readout electronics
- dx has to be computed by the tracker



GRAINiTA cosmic test bench



Installation of the test bench

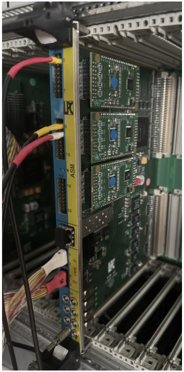
Checking the test bench geometry with a laser

- Test bench built Q4 2023
- Structure geometry checked, every angle bellow a few mrad

Fast acquisition system

Properties

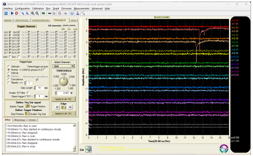
- Two available digitisers : ASM board and Wavecatcher
- Both based on a fast acquisition (> 1GHz) based on capacitor arrays
- 16 independent channels readout
- Allows single photon-electron (PE) counting during 25 μs
- Triggered by the 2 scintillators bellow the system



ASM board

Output

- Number of PE/channels for each event
- First μs acquired with the digitiser

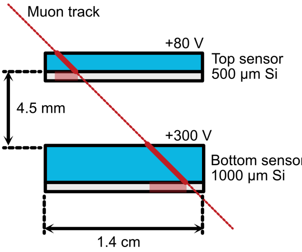


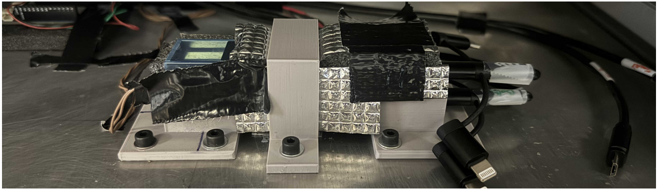
Acquisition software

The telescope

Properties

- Tracker based on a timepix3 telescope (TPX3 from the ADVACAM company)
- Hybrid pixel detector, matrix of 256x256 pixels (55 μm)
- Two detector separated by 4.5 mm
- Silicium Sensor 500 μm (top), 1000 μm (bottom)
- Expected resolution : 5.5 mrad
- Cooled by a Peletier element



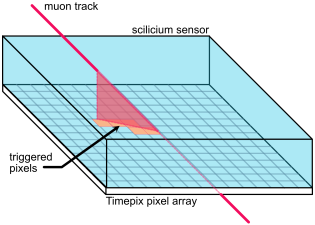


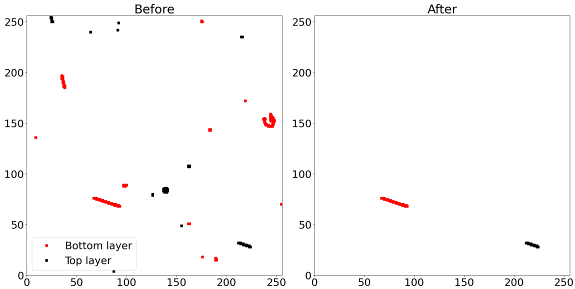
Muon track reconstruction

Algorithm

First step : Background rejection

- Each fired pixel is tagged with its energy deposits and a time stamp (1.56 ns resolution)
- Event with pixels in time-coincidence between two timepix layer are selected (350 ns windows)



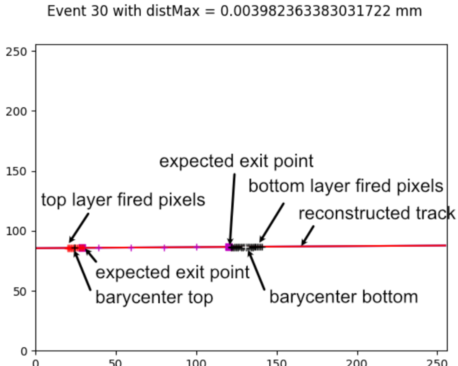


Muon track reconstruction

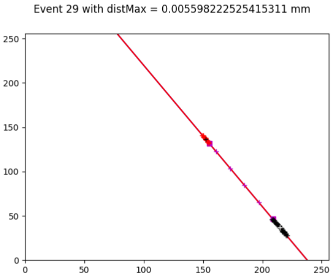
Algorithm

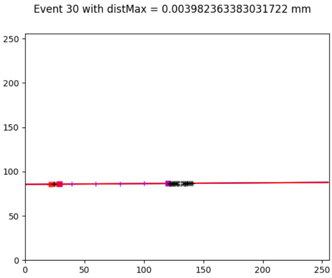
Second step : Track reconstruction

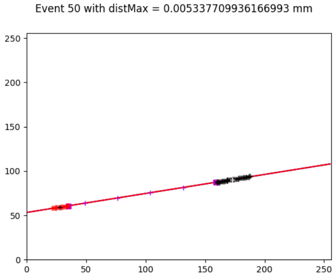
- Build the barycenter for each triggered pixels
- Line going thought the two barycenter is the reconstructed track
- The computation of the expected sensors exit point allows additional background rejection



Some examples







Tracking results

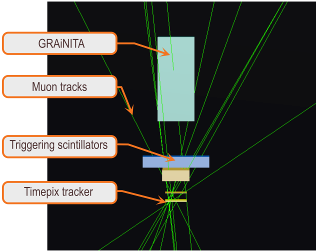
Validation

- Compare the acquired data with a model of the muon directionality :

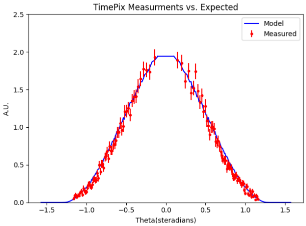
$$I(\theta) = I_0 \cos^{2.22}(\theta)\ \mathrm{m}^{-2}\mathrm{s}^{-1}\mathrm{sr}^{-1}$$

Results

- Agreement between the model and the data for an Advacam detector[2] and for our apparatus
- Event viewer in the root EVE framework



Event viewer



Data/model comparison

[2] C. Granja (Advacam) *et al.*, high-resolution mapping of secondary cosmic rays by miniaturized stacked pixel telescope, To be published

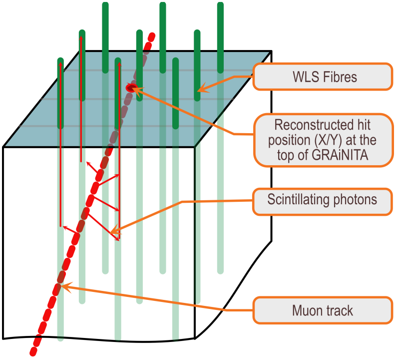
Application to GRAiNITA

Measurements

- 2 weeks of continuous data taking
- Acquired with the ASM readout
- ZnWO4 grains in air

Outputs

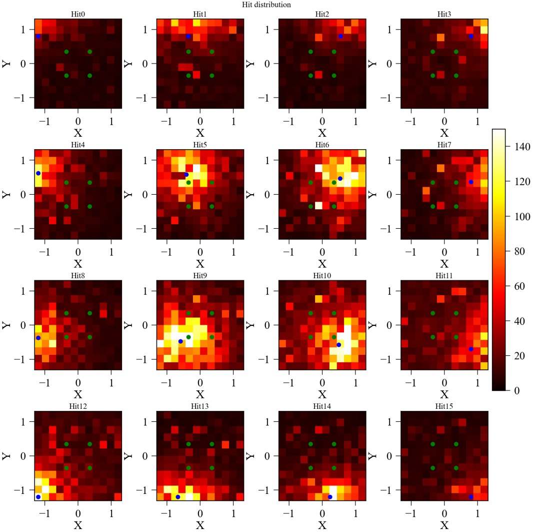
- Hit maps of the mean number of PE/fibres/muon position
- Histogram of the number of PE generated by cm (dN/dx) by the muon



Hit map

Results

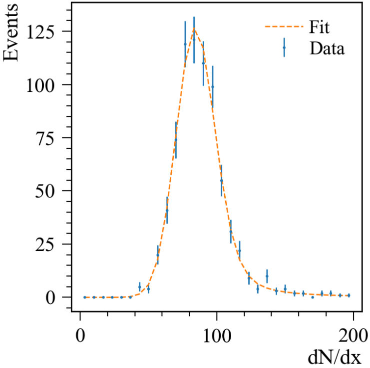
- View from the top of GRAiNITA
- For each fibre plot the mean number of PE received relatively to the reconstructed hit position
- Bins of 2 mm
- Light confinement can clearly be observed



dN/dx

Results

- Selecting only muons which cross GRAiNITA near its center (<1 cm)
- Fit with a Landau convoluted with a Gaussian (resolution)
- MPV of the Landau 84.3 PE/cm
- Muons deposits $\approx$ 40 MeV on 5.5 cm
- Gives a Light Yield (YD) of 9700 PE/GeV (dark noise removed)



Conclusion

- A test bench has been designed for the characterisation of the GRAiNITA prototype
- Its verstility allows to use it with any crystal studies
- Based on a Timepix tracker combined with a trigger
- Use track reconstruction of cosmics muons
- First performance studies were done with a few week of data acquisition
- Encouraging results were obtained and allowed to move to a charcaterization of the prototype in a test beam (June 2024)
- The same apparatus was used with an external wire chamber as tracker
- The experience acquired and the tools developed during this first step was of uttermost importance in its success
- Next step : add single photon timing in order to perform pulse shape analysis[3]

[3] M. Magne *et al.*, poster at TWEPP 2024

Test beam

Results

- Performed at CERN with muons and pions
- 0.2M high quality muons acquired in a few hours
- Very encouraging results for the future of this type of calorimeters
- Uniformity studies ongoing, soon to be published