Summary of Activities During the First Year of PhD

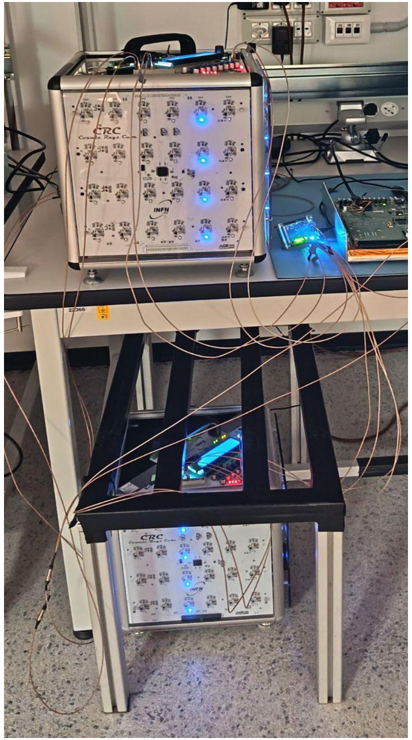
Space-based cosmic-radiation detection with the Zirè instrument.

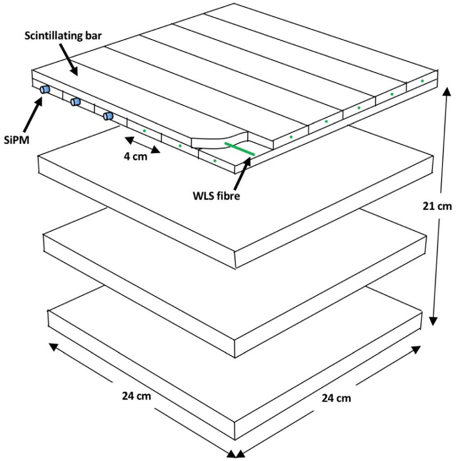
Supervisor: Adriano Di Giovanni
co supervisors: NUSES collaboration
Sindor Ashurov

Outline

1. MCT software
2. Investigation of the scintillator materials and SiPMs
3. GEANT4 project on Heavy-Metal Oxide Glass shielding
4. CR muon data analysis with ACS
5. Study activities

Prepared the muon track reconstruction software for MCT
Under review by Pierpaolo Savina





Distance between the cubes - 88 cm

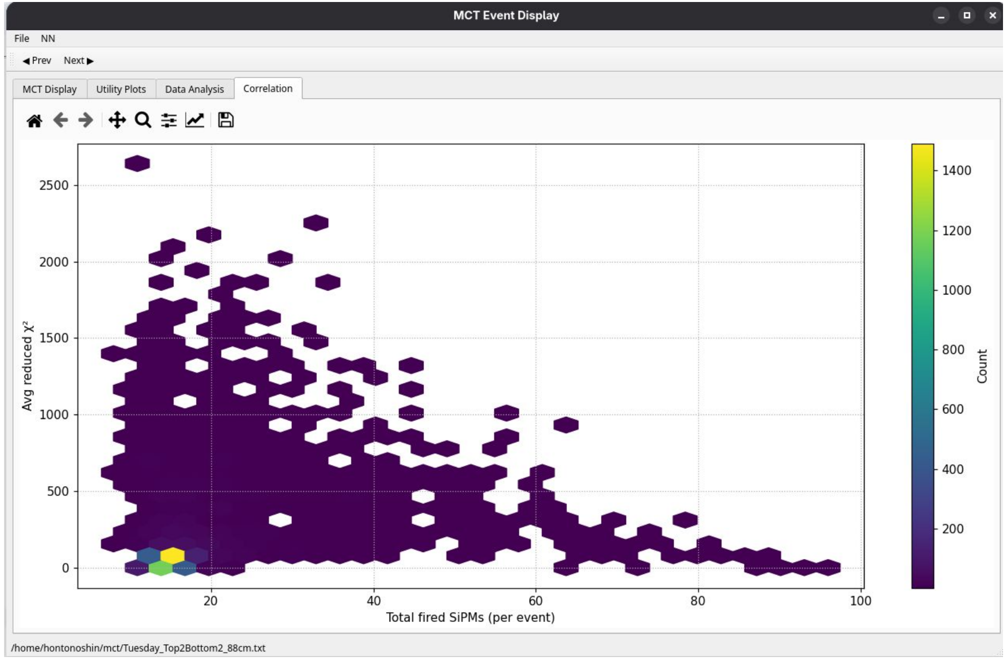
each cube contains 4 layers, by 2 sublayers in each layers and by 6 bars in each sublayers.

MCT Event Display app

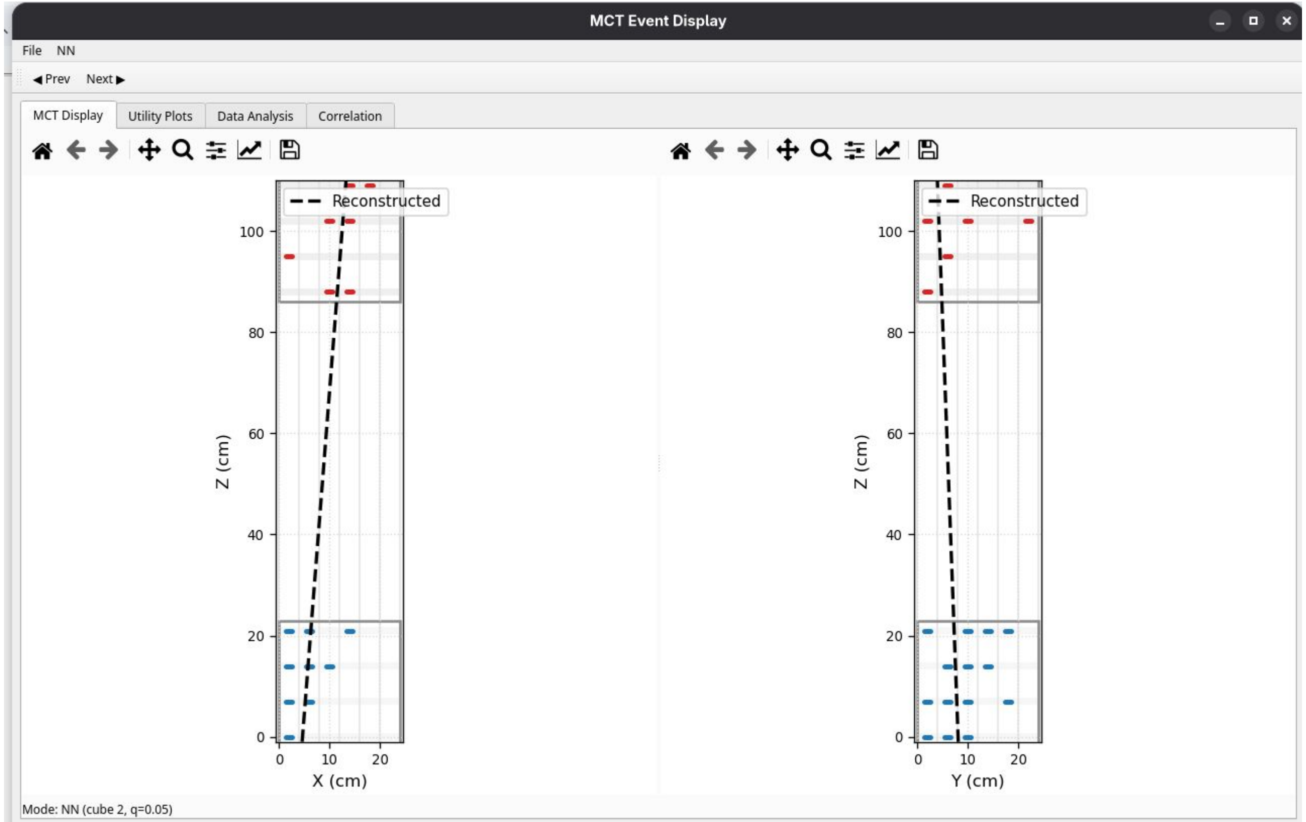
Developed software for muon track reconstruction for the MCT.

Implemented 2D linear fits in the x–z and y–z planes(θ, φ).

Added event display module with χ^2 analysis and angular distribution plots.



Using NN for track reconstruction

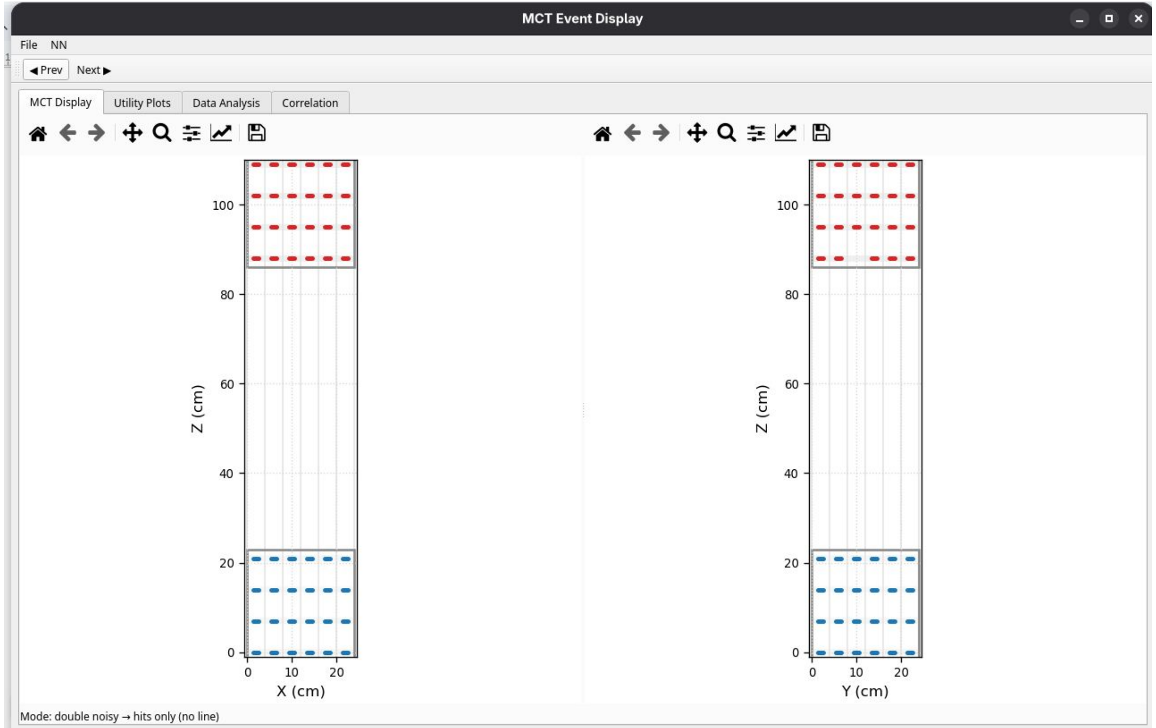


If one cube is noisy and second one is “clearer” we can use NN for predict the particle track

(NN trained with “pure” events, by saving the plot parameters data to csv file)

q is the probability of cube being noisy

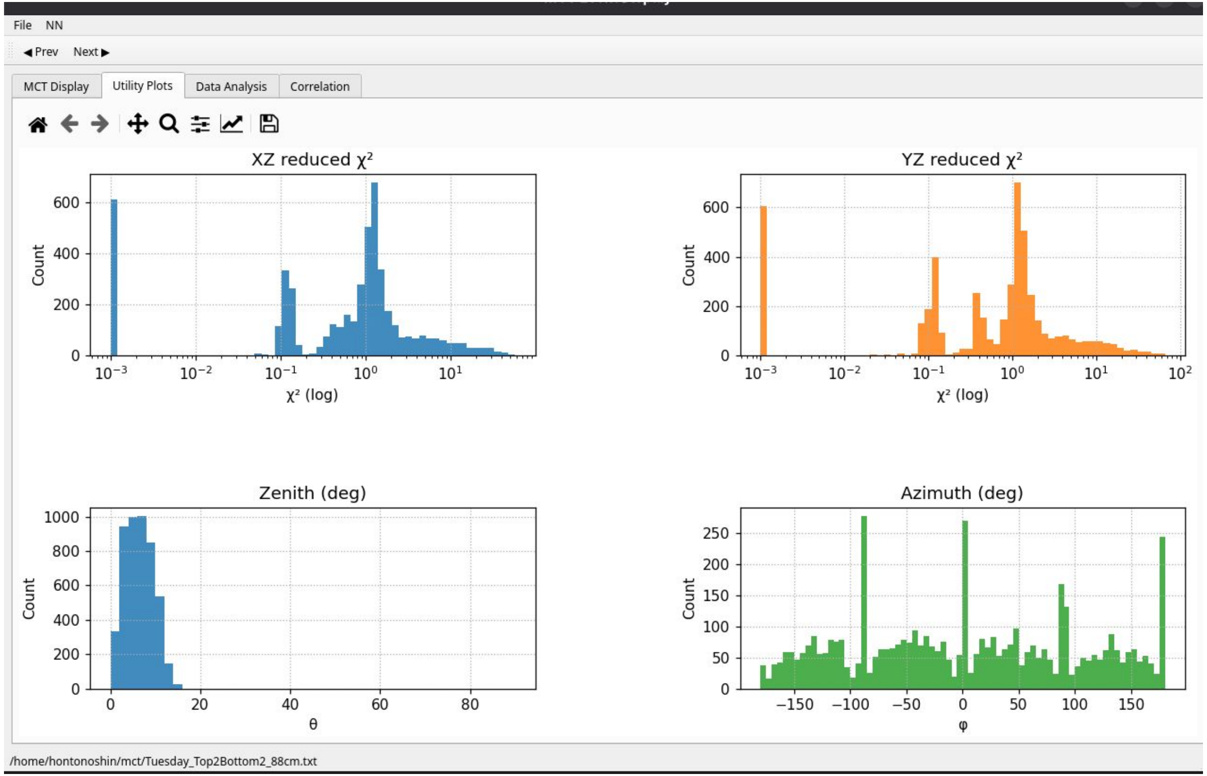
“Double noisy” case



When we have very high energetic particle, or because of side events, all bars will fire.

And in this case we cannot reconstruct the track and just lose the event.

Utility plots and MCT_Display tabs



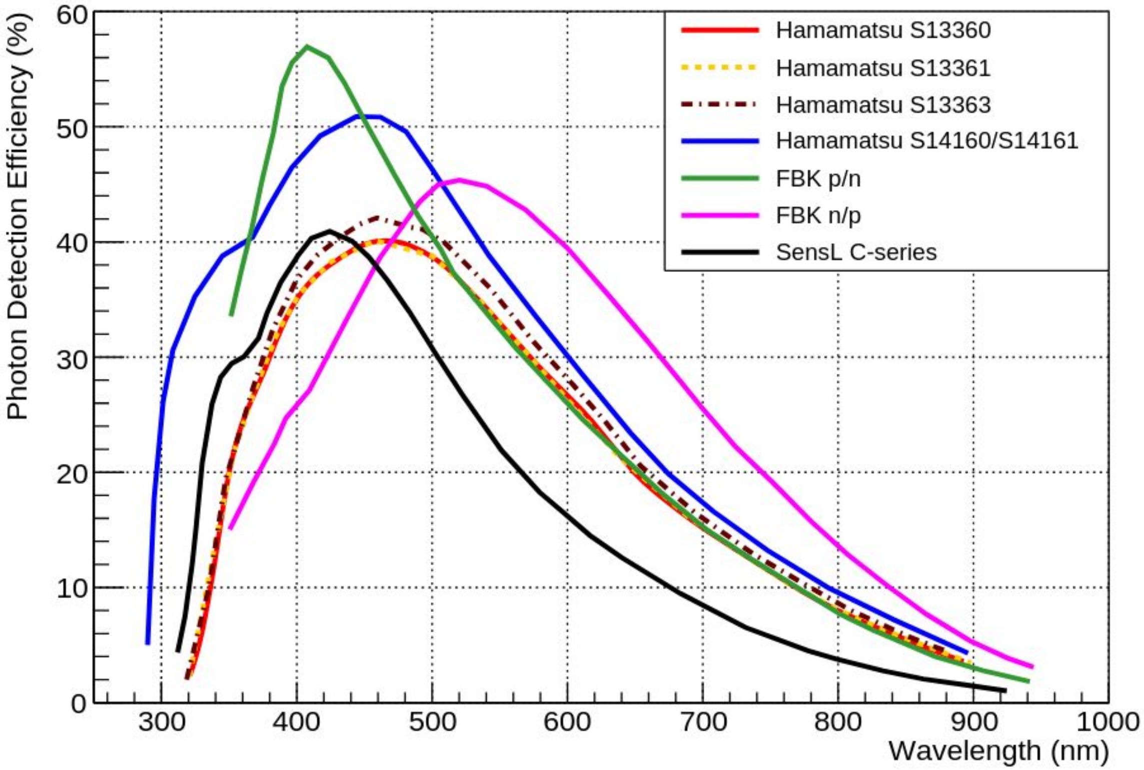
angular distribution and chi^2 plots

Investigated the scintillator materials for space applications (with Diptiranjan Pattanaik and Sara Fogliacco)

Crystal	BGO	GAGG	LYSO	NaI(Tl)	CsI(Tl)	$LaBr_3$ (Ce)	Plastic (BC-440)
Density (g/cm^3)	7.13	6.63	7.1	3.67	4.51	5.2	1.03
Emiss. Peak (nm)	480	520	420	415	550	380	430
Rad. Length (cm)	1.18	(1.7–2)[a]	1.1	2.6	1.86	1.881	$\sim$ 43
Light Yield (ph/keV)	8–10	40–60	25	55	54	63	$\sim$10
Melting Pt. (°C)	1050	1850	2050	651	621	1116	$\sim$135-300
Decay Time (ns)	300	50–150	40	230	900	25	2–3
Hygroscopic	No	No	No	High	Slight	High	No
Intrinsic ER[b]	12	5.2	8	6.6	6	2.6	–
d(LY)/dT [c]	-0.9	-0.2 to -0.3	-0.2 to -2	-0.2	0.4	–	–
Refractive Index	1.90–2.15	$\approx$ 1.85	1.81–1.83[d]	1.85	1.79	1.9	$\sim$ 1.5

[a] Approximate, based on various references (e.g., advatech-uk.co.uk).
[b] % at 662 keV
[c] At room temperature, linear approximation in 15–25°C range (see Mao et al.).
[d] Varies with wavelength (405–546 nm).

PDE for different SiPMs



GEANT4 project on Heavy-Metal Oxide Glass shielding

Simulated a lead-free gamma-ray shielding material with high attenuation, low toxicity, and optical transparency.

Material: Bi_2O_3–MoO_3–B_2O_3 heavy-metal oxide glass (density ≈ 5.2 g/cm³).

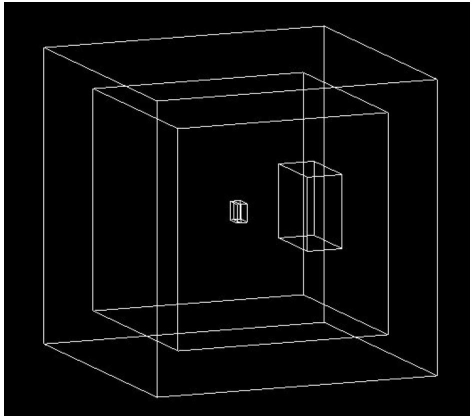
E (keV)	μ/ρ (Geant4)	μ/ρ (Exp *)	μ/ρ (FLUKA**)
100	0.82	$0.83 \pm 0.02^{*}$	0.81^{**}
200	0.67	$0.66 \pm 0.01^{*}$	0.66^{**}
300	0.55	$0.56 \pm 0.01^{*}$	0.55^{**}
500	0.42	$0.43 \pm 0.02^{*}$	0.42^{**}

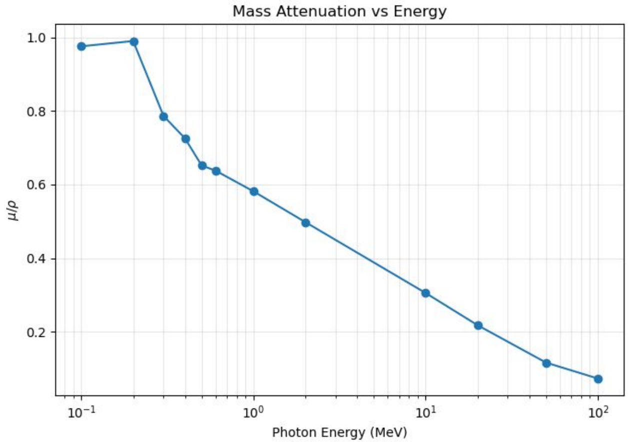
* Sharma S. et al., “Experimental evaluation of Bi-based glass for gamma shielding”, Radiat. Phys. Chem. 200 (2023) 110312.

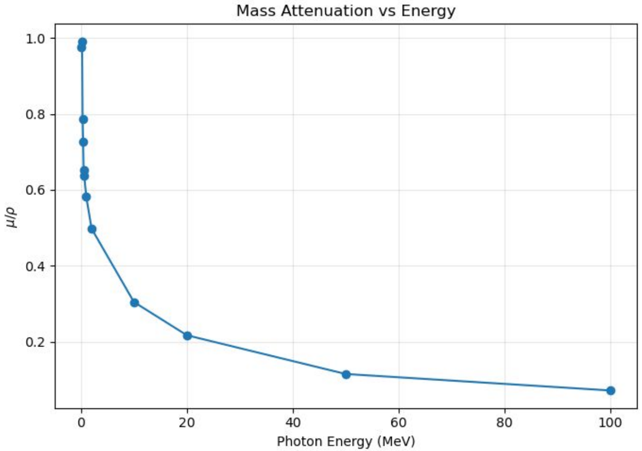
** Böhlen T.T. et al., “The FLUKA Code: Developments and Benchmarking”, Nucl. Data Sheets 120 (2014) 211–214.

Geometry visualization and Mass attenuation

A 20 × 20 × 2 cm³ plate of Bi-Mo glas





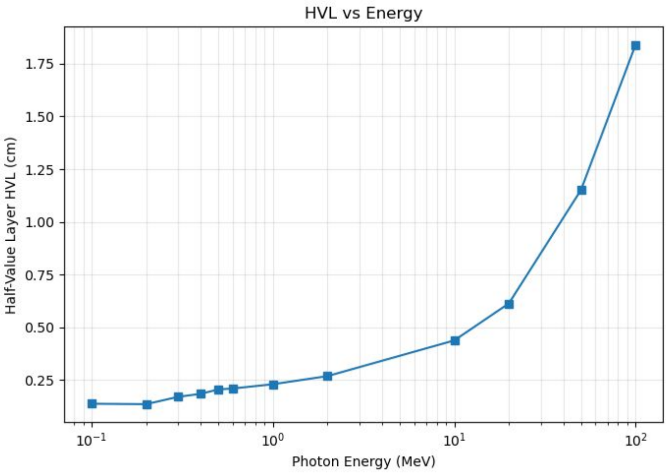


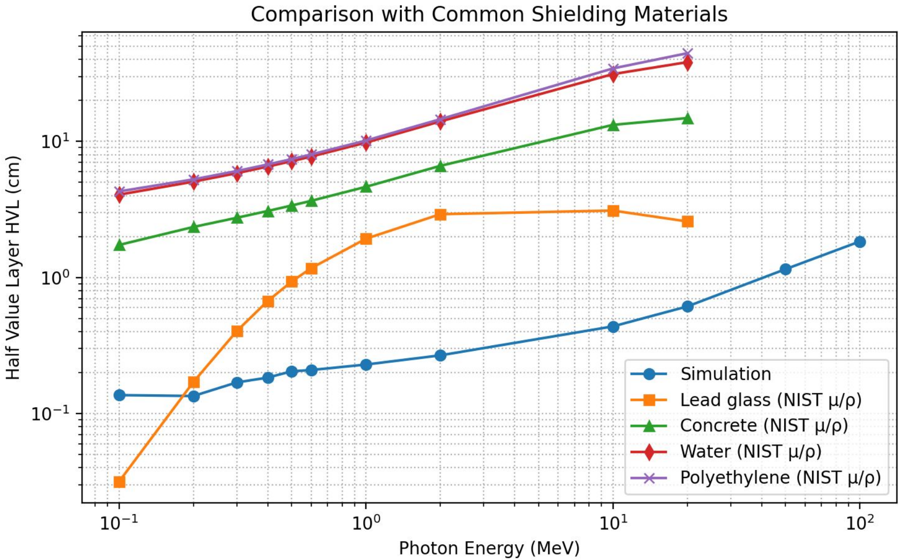
At low energies (<0.3 MeV), attenuation is dominated by the **photoelectric effect**, leading to large μ/ρ values.

In the intermediate range (0.3–3 MeV), the **Compton scattering** region shows a gradual decrease.

Above 1.022 MeV, **pair production** becomes relevant, but the total attenuation continues to decrease with energy.

Half Value Layer





HVL represents the material thickness required to attenuate the incident photon intensity by 50%.

Chosen PhD thesis topic

Space-based cosmic-radiation detection with the Zirè instrument.

The Zirè experiment on board the NUSES space mission Mateo Fernandez Alonso

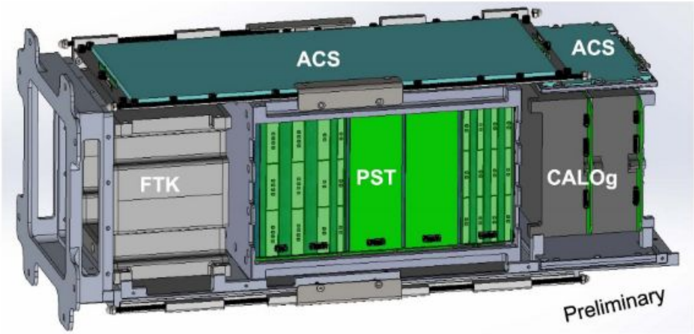


Figure 2: Preliminary mechanical design of the Zirè detector. Charged particles will reach the detector from the left through a dedicated thin window, crossing the FTK, PST and then the CALOg (see text). Low energy gamma-ray measurements will be done using two additional windows placed close to the CALOg (right and top side in the image, corresponding to horizontal (H) and zenith (V) direction respectively). The LEM sub-detector is not shown in this figure.

https://doi.org/10.22323/1.444.0139

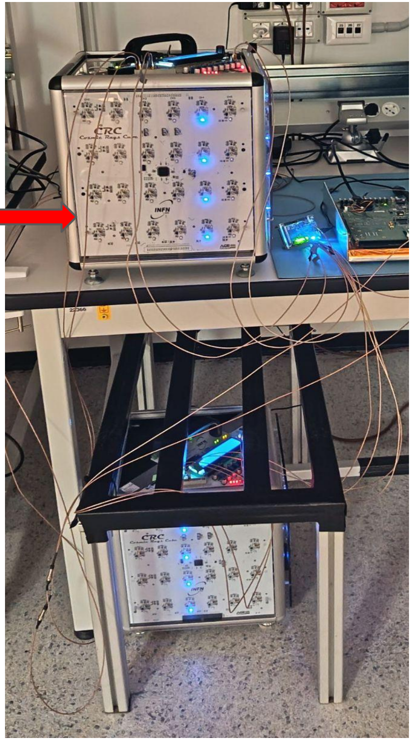
Altitude: 550 km (LEO)

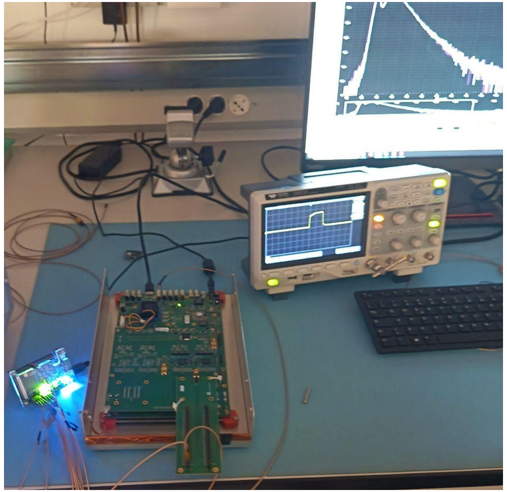
Inclination: 97.8°

Purpose: Detect cosmic rays (a few to hundreds of MeV) to study their energy spectra and testing new materials (scintillators, sipms etc).

CR muon data analysis with ACS (triggered by the MCT) under review by Dimitrios Kyratzis

here



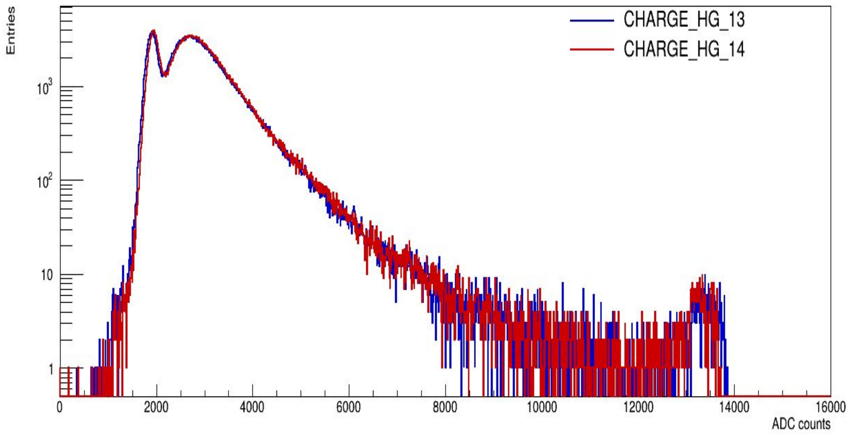


Signals from MCT used as an external trigger

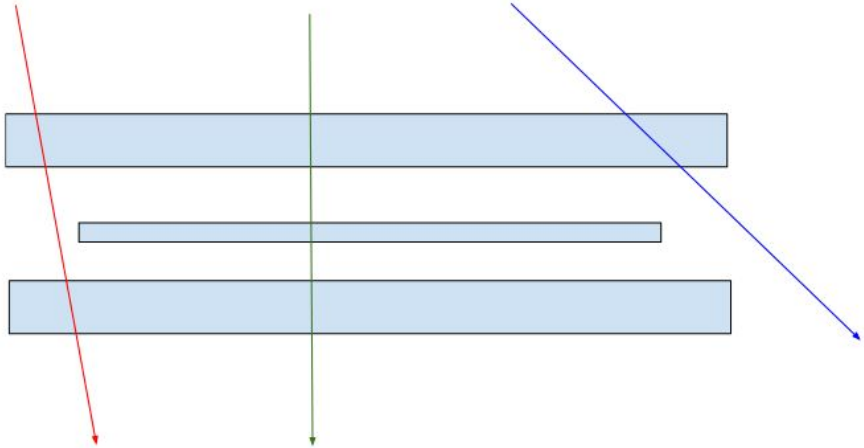
ACS tile placed between the 3rd and 4th layers of the top cube and counted the # of particles that would pass through these two MCT layers, and then determined how many of them would pass through the ACS panel, which is located between these two panels.

CRC panels: 26x26x2 cm

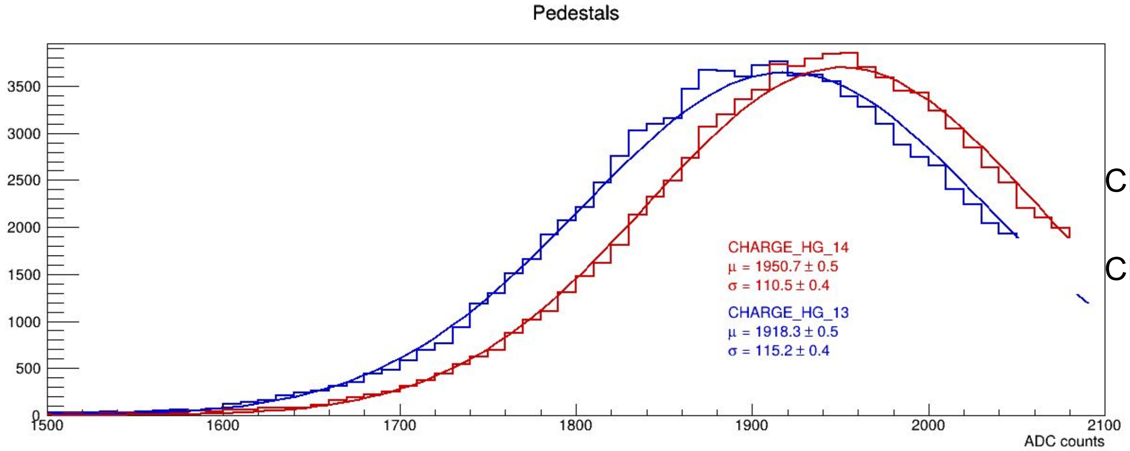
ACS tile: 26.5x15.5x0.5 cm



Full spectrum (Pedestals + Signal)



We need to find the fraction of green events to red events

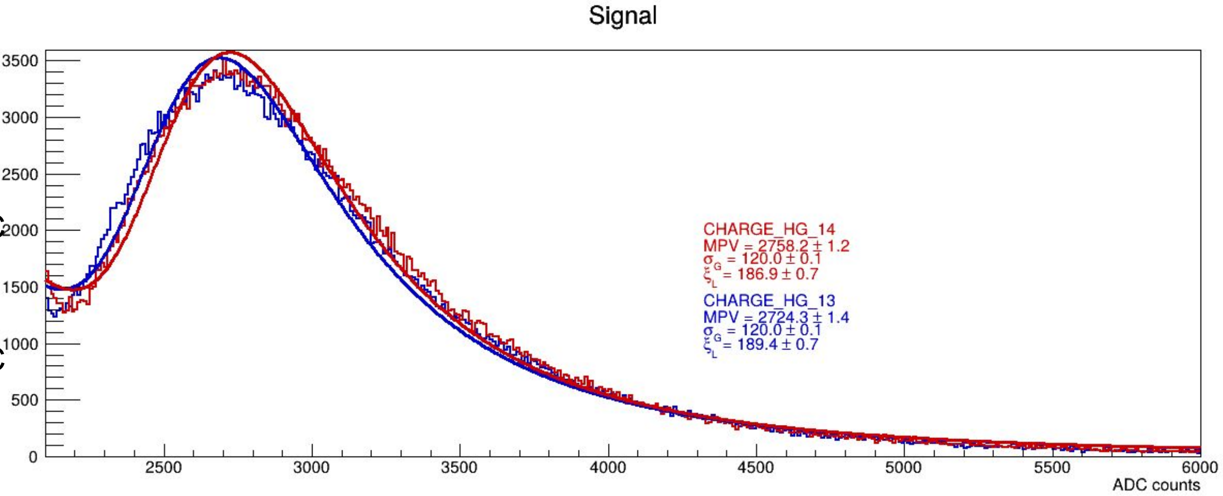


CHARGE_HG_13 μ ≈ 1918.3, σ ≈ 115.2 +/- 0.4

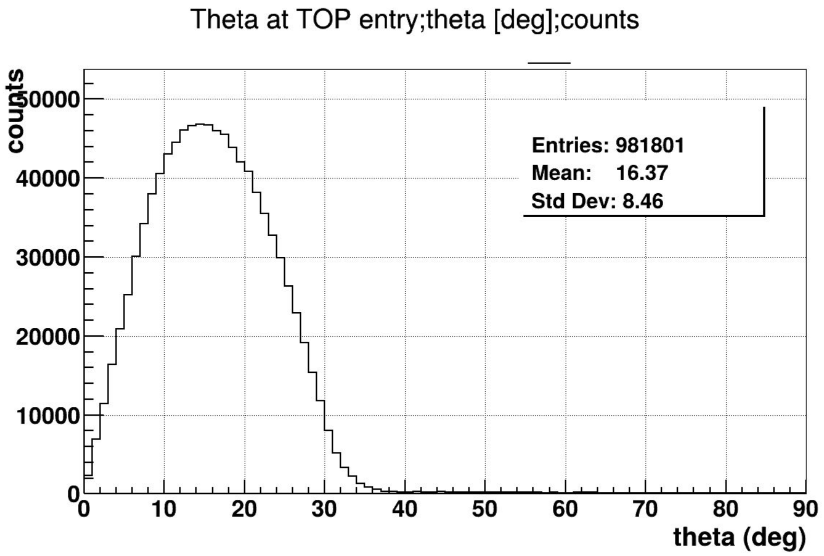
CHARGE_HG_14 μ ≈ 1950.7, σ ≈ 110.5 +/- 0.5

CHARGE_HG_13 MPV ≈ 2724.3 +/- 0.7 ADC
σ ≈ 120.0 +/- 0.1

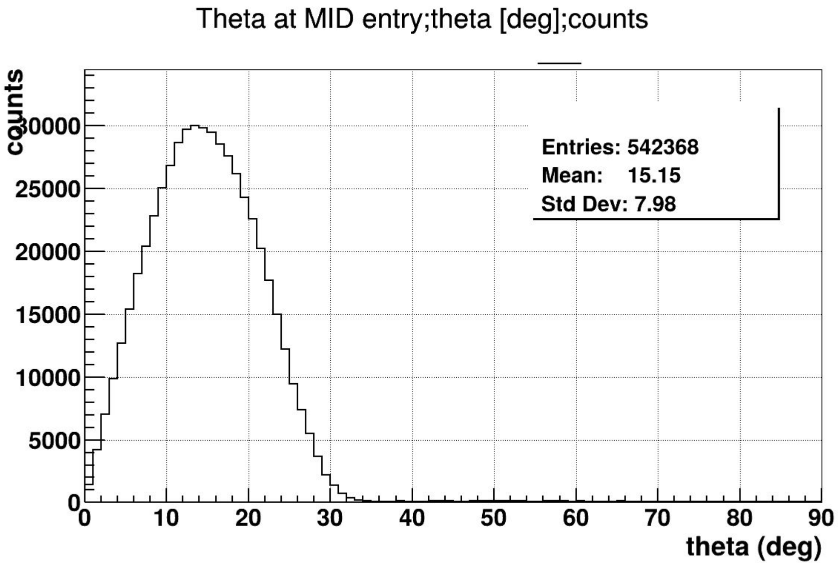
CHARGE_HG_14 MPV ≈ 2758.2 +/- 0.7 ADC
σ ≈ 120 +/- 0.1



GEANT4 simulation of the setup



# of muons which crossed top + bottom panels



# of muons which crossed top +ACS tile + bottom panels

12 000 000 generated muons, 981801 are passed through top/bottom panels, and only 542368 are passed through top/mid/bottom panels

Analytical calculations and comparisons

With top at z=0, middle at z=d_1 = 2cm, bottom at z = *l* = 4.5 cm, and using the dimensions for the top/bottom 26x26x2 cm^3, for the middle 26.5x15.5x0.5 cm^3

$$G_{13} = \int\int \frac{X_{13}Y_{13}}{(1+t_x^2+t_y^2)^3} dt_x dt_y \qquad X_{13} = (26 - 4.5|t_x|) \qquad Y_{13} = (26 - 4.5|t_y|)$$

$$G_{123} = \int\int \frac{X_{123}Y_{123}}{(1+t_x^2+t_y^2)^3} dt_x dt_y \qquad X_{12} = (26.25 - 2|t_x|) \qquad Y_{12} = (20.75 - 2|t_y|)$$

$$X_{123} = X_{13}$$

G_{13} = 888.12 cm^2 sr
G_{123} = 736.99 cm^2 sr

G_{123} / G_{13} = 0.829

t_x and t_y are in the range 26/4.5 = 5.777

Sullivan, John D.. "GEOMETRICAL FACTOR AND DIRECTIONAL RESPONSE OF SINGLE AND MULTI-ELEMENT PARTICLE TELESCOPES." *Nuclear Instruments and Methods* 95 (1971): 5-11.

	Total #of events	**#of events**	
Experiment	512751	280465	54.69%
GEANT4	981801	542368	55.24%
Analytical			83%

Overall

- ❑ Gained broad research experience through GSSI and INFN activities — from detector simulation and track-reconstruction software to radiation-safety.
- ❑ Developed functional tools such as MCT track reconstruction, ML-based event analysis, and Bi_2O_3–MoO_3–B_2O_3 γ-shield simulations
- ❑ The shielding study showed that heavy-metal oxide glass can serve as a compact, lead-free alternative with excellent attenuation below 2 MeV.

TO DO:

- Integration of the ZIRE database for unified data storage and visualization,
- Automation of electronic measurements for SiPM characterization
- Upcoming radiation tests of ZIRE tiles and bars.

Courses taken

1. Introduction to nuclear and particle physics
2. Introduction to radiation detection techniques
3. HE-EXP
4. Front-end electronics and daq systems for radiation detection
5. Cosmic radiations and radiation hardness assessments
6. Numerical Modelling of space structures
7. Project management
8. Finite-element models and analyses
9. The governance of space

Workshops and schools attended

1. ISAPP 2025 – Astroparticle Physics School – Lecce

Participated in the international school “From cosmic rays to multi-messenger astrophysics.”

CORSIKA, GEANT4, ML for particle track reconstruction

2. 14th Young Researchers Meeting (YRM 2025), GSSI
3. Hidden Structures in Dynamical Systems Workshop, GSSI

Gained insights into nonlinear modeling and data-driven reconstruction and also physics informed NN

4. Frontiers of X-ray Polarimetry School, GSSI

Learned simulation of astrophysical sources using IXPEOBSSIM

5. Radiation Safety Course, LNGS

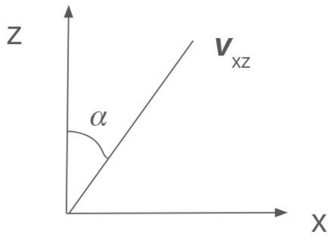
Certified training in radiation protection procedures and dose assessment inside underground laboratories.

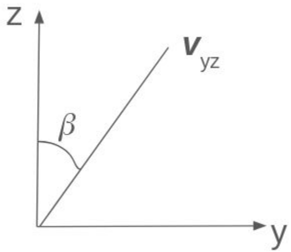
Backup slides

Zenith and Azimuth calculation

We define separate direction vectors in each plane:

$$\vec{v}_{xz} = (\sin\alpha,\ 0,\ \cos\alpha), \quad \vec{v}_{yz} = (0,\ \sin\beta,\ \cos\beta)$$





We represent the full 3D track with spherical coordinates:

$$\vec{v} = (\sin\theta\ \cos\phi,\ \sin\theta\ \sin\phi,\ \cos\theta).$$

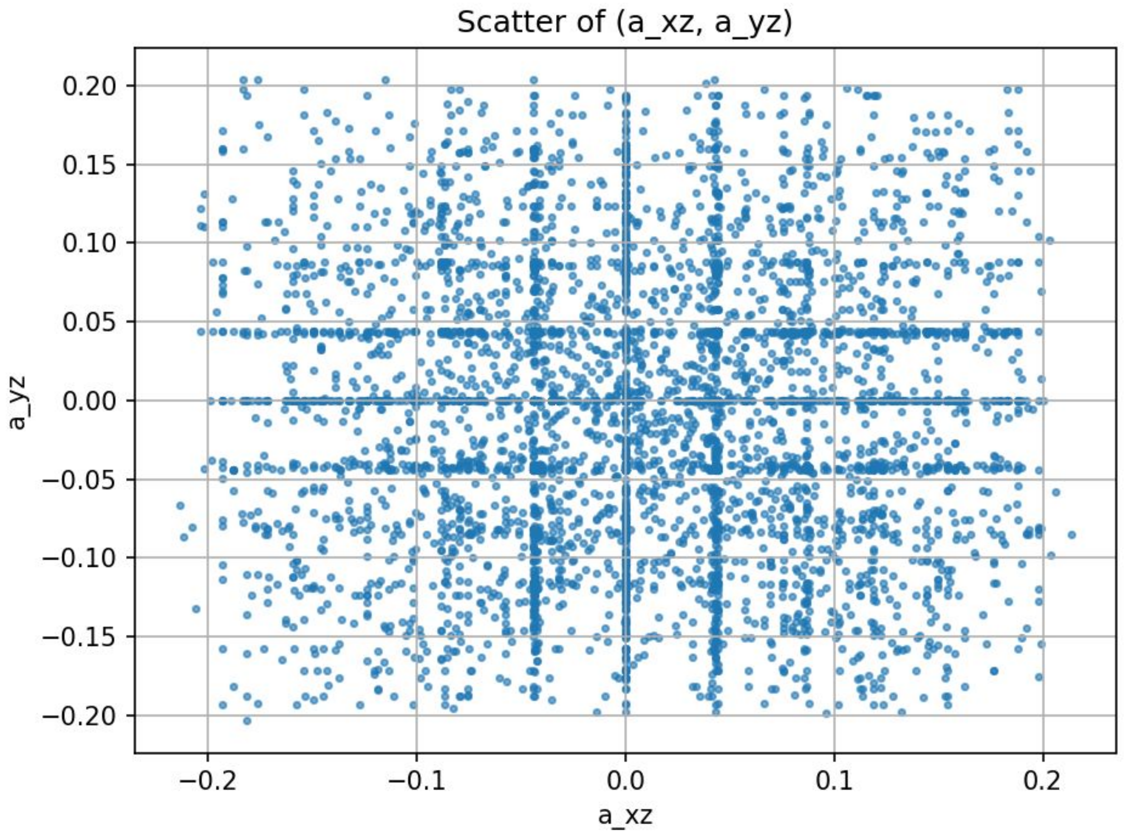
Then we relate them via:

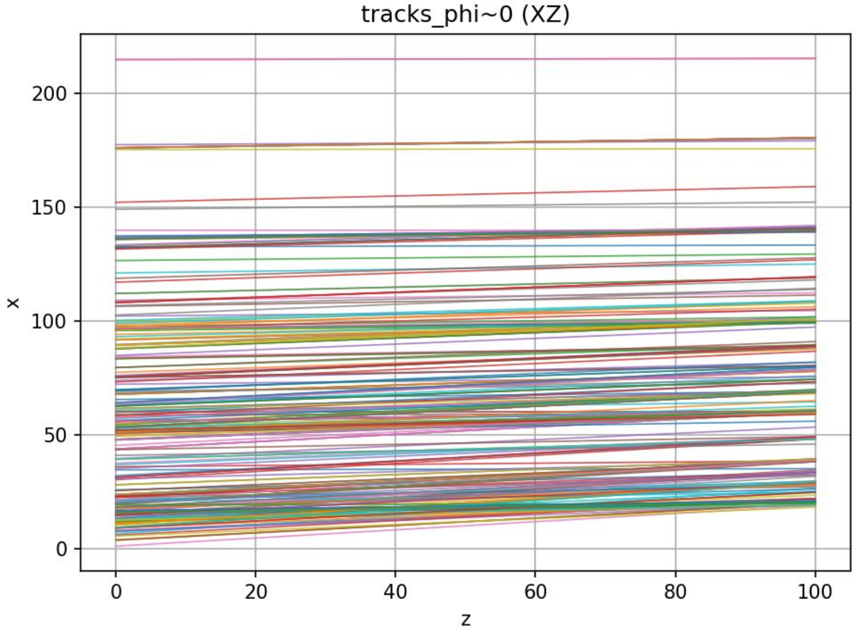
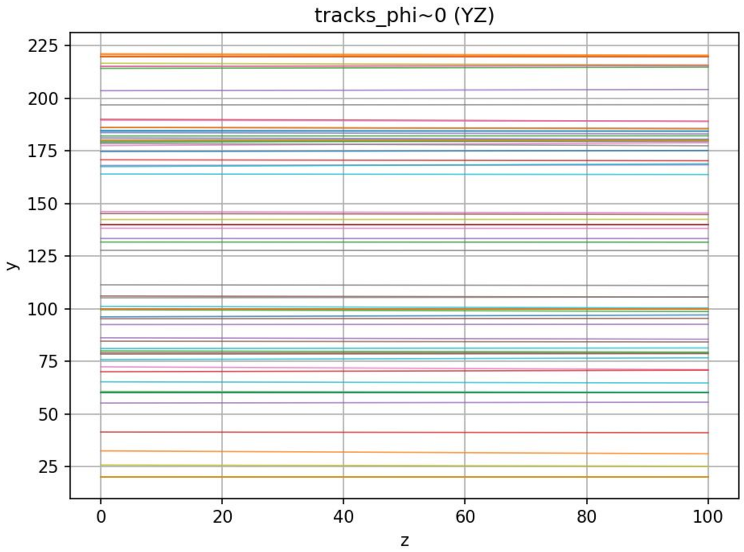
$$\tan\alpha = \tan\theta\cos\phi$$

$$\tan\beta = \tan\theta\sin\phi$$

```
phi = np.arctan(a_yz / a_xz)
theta = np.arctan(a_xz / np.cos(phi))
```

$$\begin{cases} \tan\theta = \dfrac{\tan\alpha}{\cos\phi} \\ \tan\beta = \tan\theta\tan\phi \end{cases} \Rightarrow \begin{cases} \tan\phi = \dfrac{\tan\beta}{\tan\alpha} \\ \tan\theta = \dfrac{\tan\alpha}{\cos(\arctan\phi)} \end{cases}$$


Scatter of (a_xz, a_yz)
0.20
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
−0.20
a_yz
−0.2
−0.1
0.0
0.1
0.2
a_xz


tracks_phi~0 (XZ)
x
z
0
50
100
150
200
0
20
40
60
80
100

tracks_phi~0 (YZ)
y
z
25
50
75
100
125
150
175
200
225
0
20
40
60
80
100