The FOOT Experiment : Physics Motivation and VTX Testing

Laura Rocchetti XLI cycle

FramentatiOn Of Target

Supervisor : Maria Cristina Morone
Supervisor CREF : Angela Bracco
Cosupervisor : Marco Toppi

The FOOT Experiment

FOOT (FragmentatiOn Of Target) experiment measures nuclear fragmentation cross section differential in angle and energy.

The FOOT Collaboration (2025)

R. Ridolfi,[1,2,*] M. Toppi,[3,4] A. Mengarelli,[1] M. Dondi,[1,2] A. Alexandrov,[5] B. Alpat,[6] G. Ambrosi,[6] S. Argirò,[7,8] M. Barbanera,[6] N. Bartosik,[8] G. Battistoni,[9] M.G. Bisogni,[10,11] V. Boccia,[12,5] F. Cavanna,[8] P. Cerello,[8] E. Ciarrocchi,[10,11] A. De Gregorio,[13,4] G. De Lellis,[12,5] A. Di Crescenzo,[12,5] B. Di Ruzza,[14,15] M. Donetti,[16,8] Y. Dong,[9] M. Durante,[12,17] R. Faccini,[13,4] V. Ferrero,[8] C. Finck,[18] E. Fiorina,[8] M. Francesconi,[5] M. Franchini,[1,2] G. Franciosini,[3,4] G. Galati,[19,15] L. Galli,[11] M. Ionica,[6] A. Iuliano,[12,5] K. Kanxheri,[6,20] A.C. Kraan,[11] C. La Tessa,[21,22] A. Lauria,[12,5] E. Lopez Torres,[23,8] M. Magi,[3,4] A. Manna,[1,2] M. Marafini,[24,4] M. Massa,[11] C. Massimi,[1,2] I. Mattei,[9] A. Mereghetti,[16] T. Minniti,[25,26] A. Moggi,[11] M.C. Montesi,[5,27] M.C. Morone,[25,26] M. Morrocchi,[10,11] S. Muraro,[9] N. Pastrone,[8] V. Patera,[3,4] F. Peverini,[6,20] F. Pennazio,[8] C. Pisanti,[1,2] P. Placidi,[6,28] M. Pullia,[16] L. Ramello,[8,29] C. Reidel,[17] L. Sabatini,[30] L. Salvi,[6,20] C. Sanelli,[30] A. Sarti,[3,4] O. Sato,[31] S. Savazzi,[16] L. Scavarda,[32] A. Schiavi,[3,4] C. Schuy,[17] E. Scifoni,[22] L. Servoli,[6] G. Silvestre,[6] M. Sitta,[8,33] R. Spighi,[1] E. Spiriti,[30] L. Testa,[4,13] V. Tioukov,[5] S. Tomassini,[30] F. Tommasino,[34,22] A. Trigilio,[30] G. Traini,[4] G. Ubaldi,[1,2] S. Valentinetti,[1,2] A. Valetti,[7,8] M. Vanstalle,[18] U. Weber,[17] R. Zarrella,[1,2] A. Zoccoli,[1,2] and M. Villa[1,2]
(The FOOT Collaboration)

INFN:

12 units (Ba, Bo, LNF, LNGS, Mi, Na, Pg, Pi, Rm1, Rm2, TIFPA, To)

64 researchers & 12 technologists

29.8 FTE (26.6 res., 3.2 tech.)

99 Authors (+6)

35 Institutions (+2)

Italy, France, Germany, India, Japan, Cuba

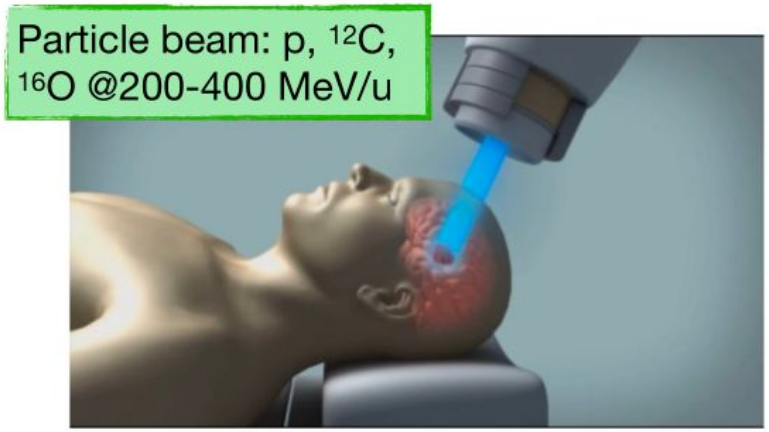
3 Continents (Europe, Asia, America)

54% women

The FOOT Experiment

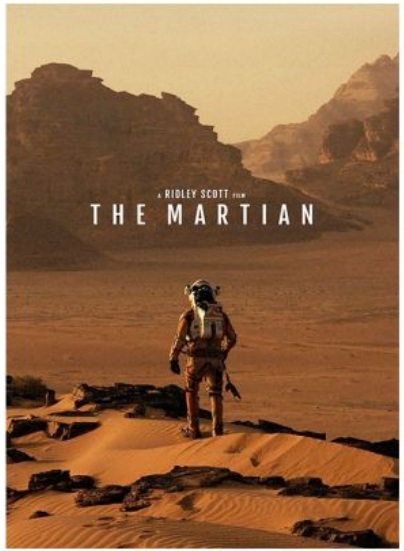
Application

Hadrontherapy



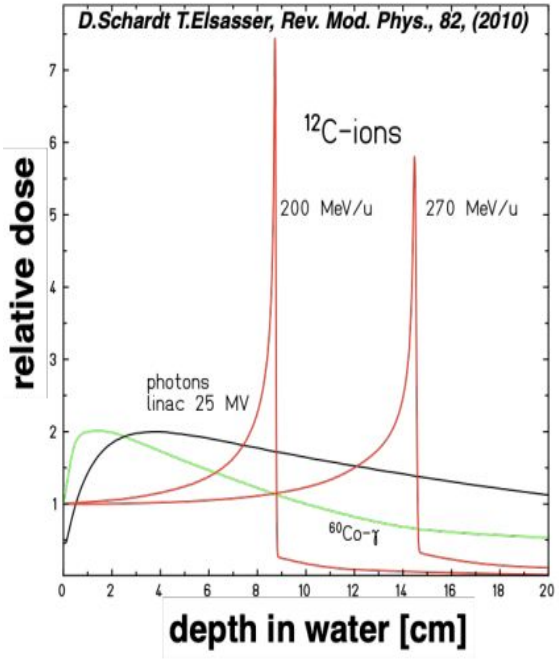
Particle Therapy: improve accuracy of Treatment Planning Systems to reduce dose uncertainties

Radiation protection in space



- Optimize the shielding for human mission in space
- **p - ^{56}Fe** beams in the energy range **400 - 1000 MeV/u** interacting with **hydrogen-rich targets**

Particle Therapy



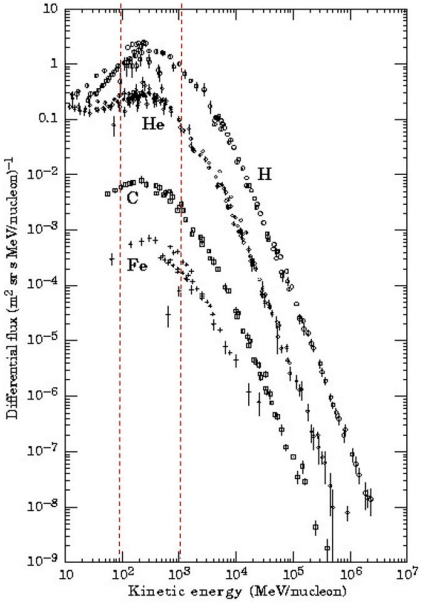
- Bragg curve
- penetration depends on energy
- lower dose outside the tumor
- Higher biological effectiveness

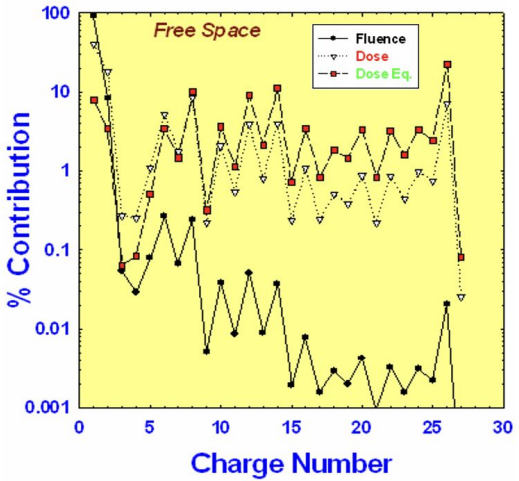
- More complex infrastructures
- **Nuclear fragmentation**

As protons or ions traverse matter, they produce secondary fragments through nuclear fragmentation. These particles can be scattered at various angles, resulting in unwanted dose delivery to areas surrounding or distant from the targeted tumor.

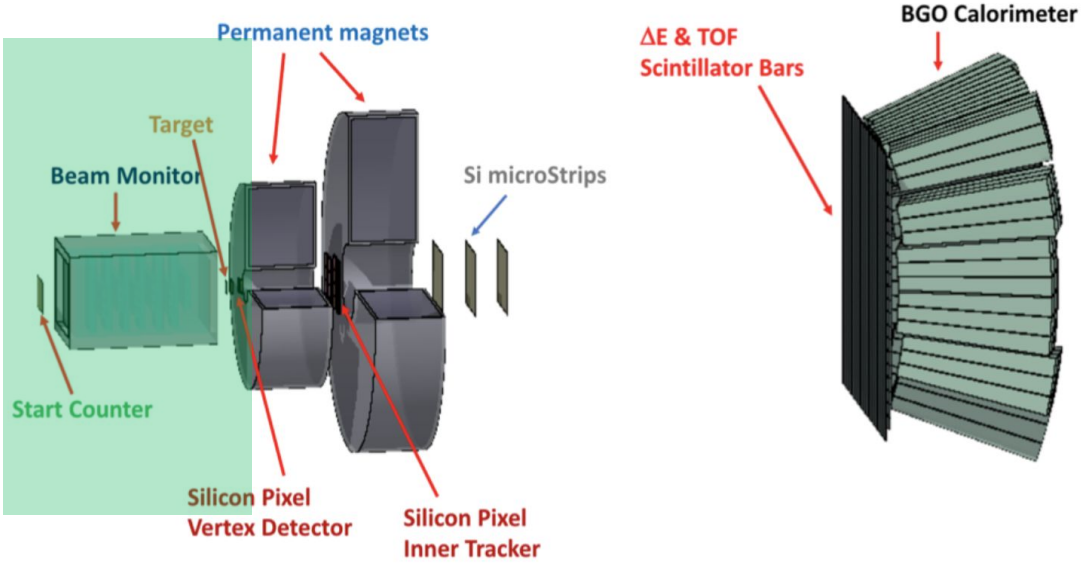
Radiation protection in space

- Radiation is the main hindrance to safe human space exploration
- **Overall objective**: To allow exploration of the Solar system with acceptable risk from space radiation exposure
- Radiation Protection in Space (RPS): astronauts are exposed to high level of radiation, necessitating precise **models for shielding optimization**
- The interaction of space radiation with the spacecraft hull and internal material produce fragments
- Primary cosmic ray flux has its maximum in a range of energies similar to the ones of interest for PT (100 MeV/u < Ekin < 1 GeV/u)
- Study fragmentation with beams of interest for RPS up to ^{56}Fe





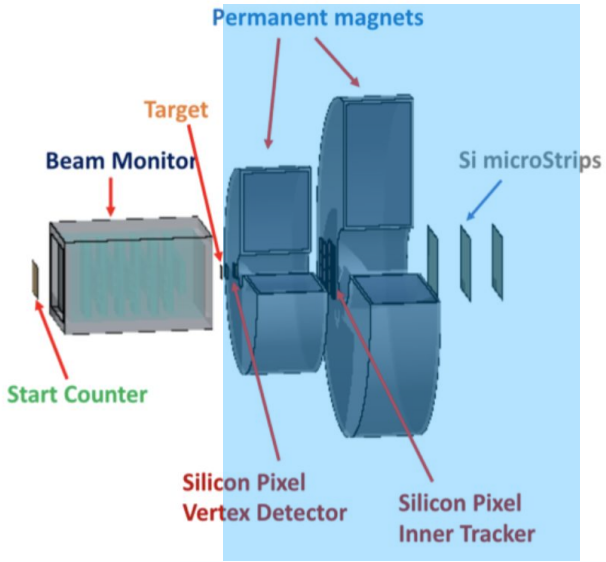
FOOT detector

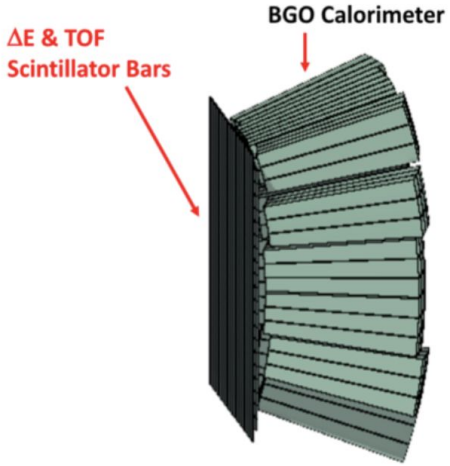


Pre-target region

- Very thin plastic scintillator (250 μm) for TOF measurement and trigger
- Drift chamber (12 xy wire layers) for the beam direction and position measurement

FOOT detector

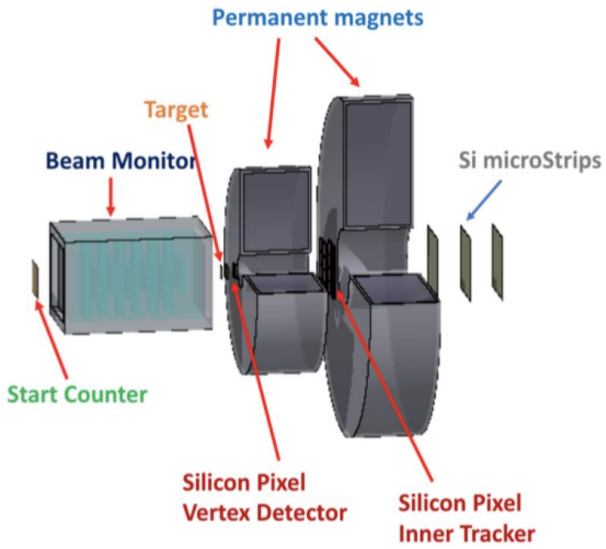


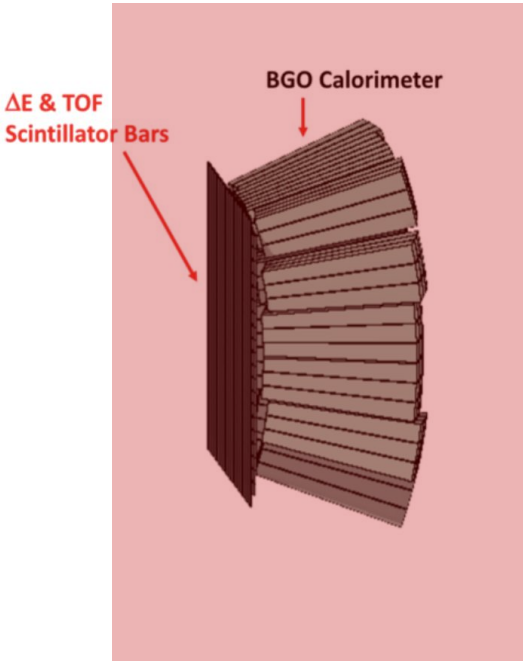


Tracking and magnetic region

- Permanent magnet in Halbach configuration B_{MAX}~ 1.4 T
- MAPS (M-28) and micro strip silicon detector (MSD) for tracking and momenum reconstruction

FOOT detector

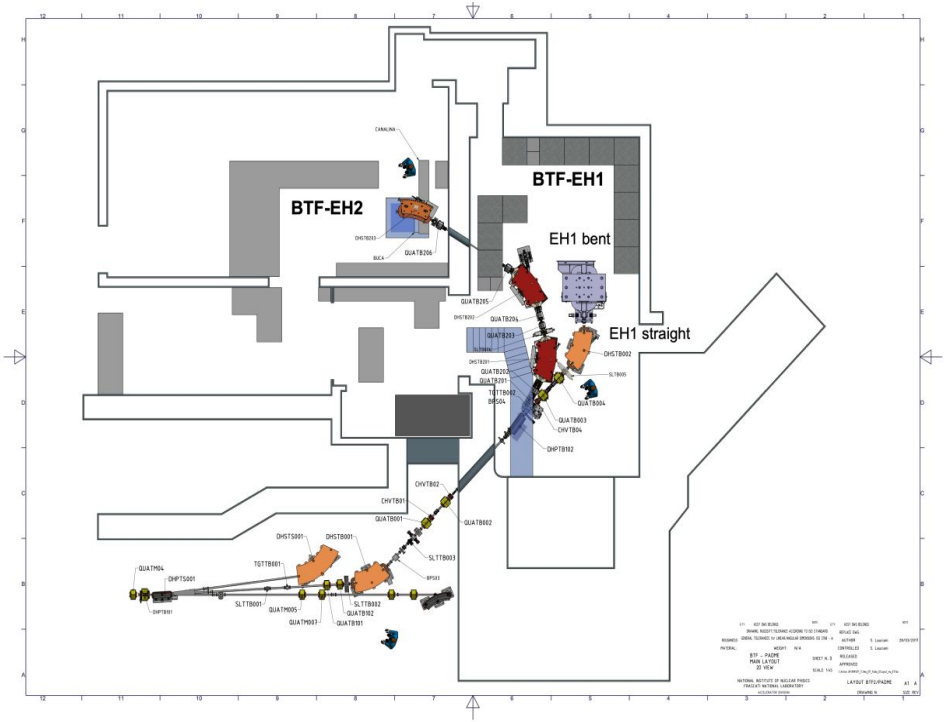


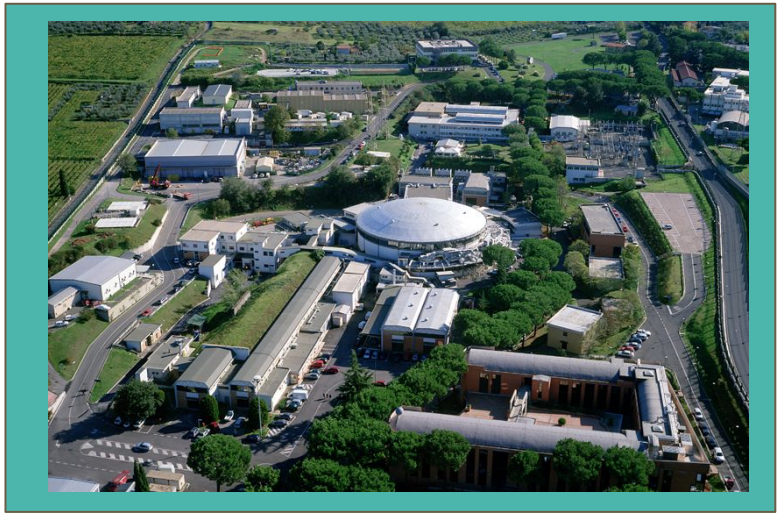


Mass and charge identification region

- Two layers xy of plastic scintillator bars for Z identification through dE/dx and TOF
- BGO calorimeter for the E_{kin} measurement

BTF data-taking

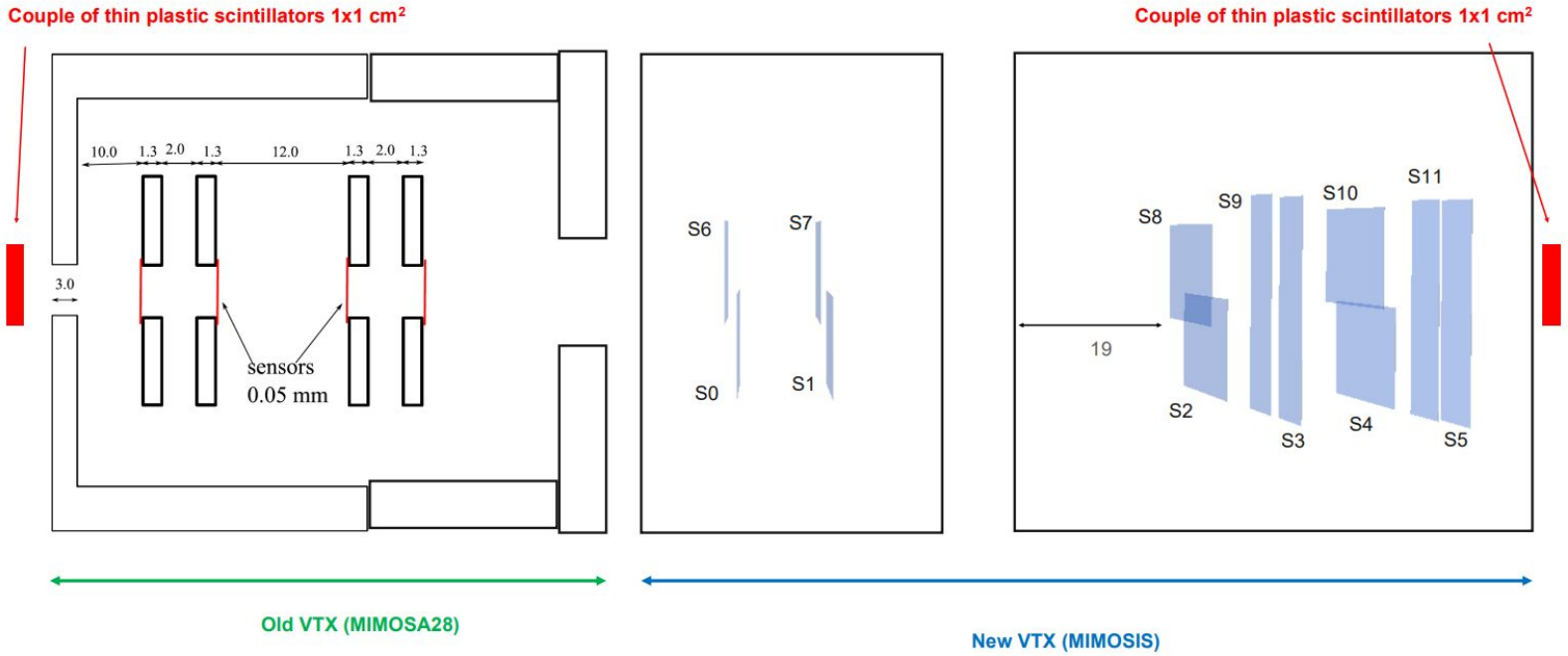




Vertex detector beam tests were conducted at the Frascati BTF from February 2nd to 16th.

Geometrical Setup

The experimental apparatus integrates both the new (**VI**) and old (**VTX**) vertex detector, complemented by pair of scintillators for triggering, and a calorimeter

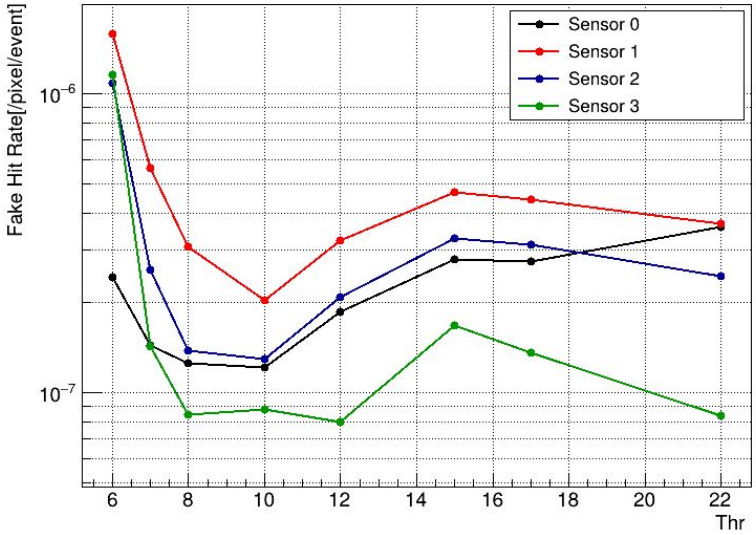


Old VTX (MIMOSA28)

- 4 layers of Si pixels
- Active Area: ~ 3.8 cm^2
- Very close to the target
- **Read out time of 1 pixel matrix : 185.6 µs**

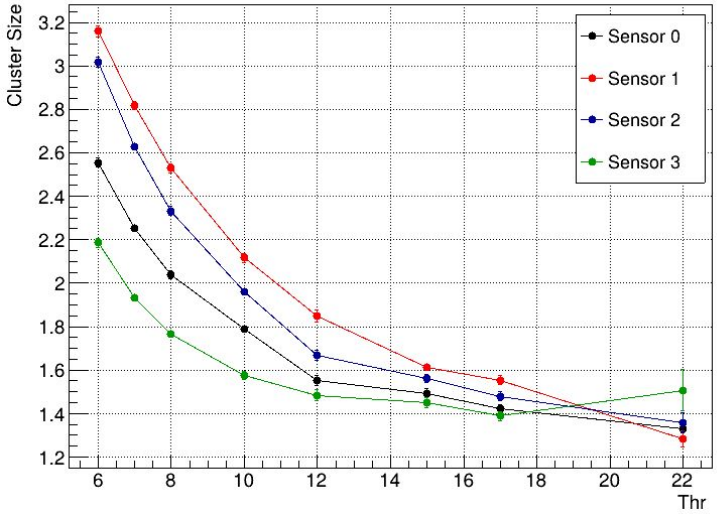
Noise analysis and Cluster Size

Characterization of noise through beam runs by evaluating non-track-related clusters



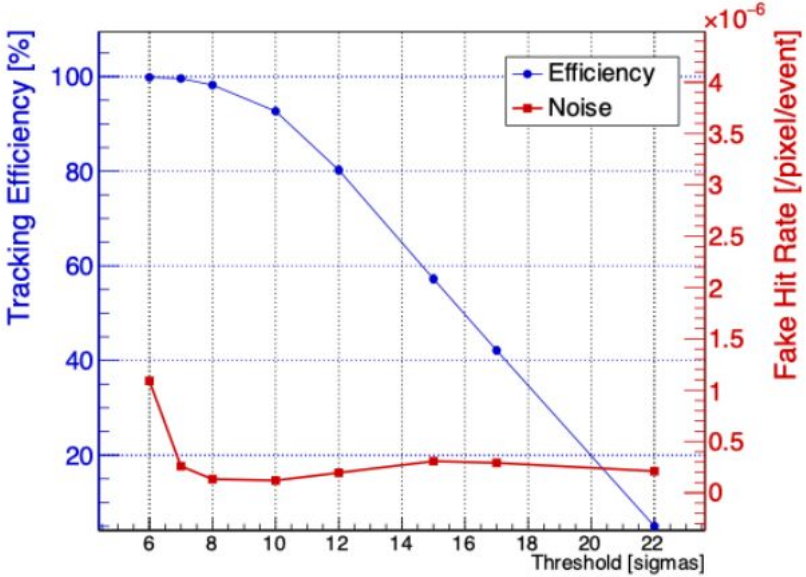
The **Fake Hit Rate** is defined as the average number of noise-induced hits per event, normalized by the total number of pixels in the sensor.

Cluster size of track-associated cluster



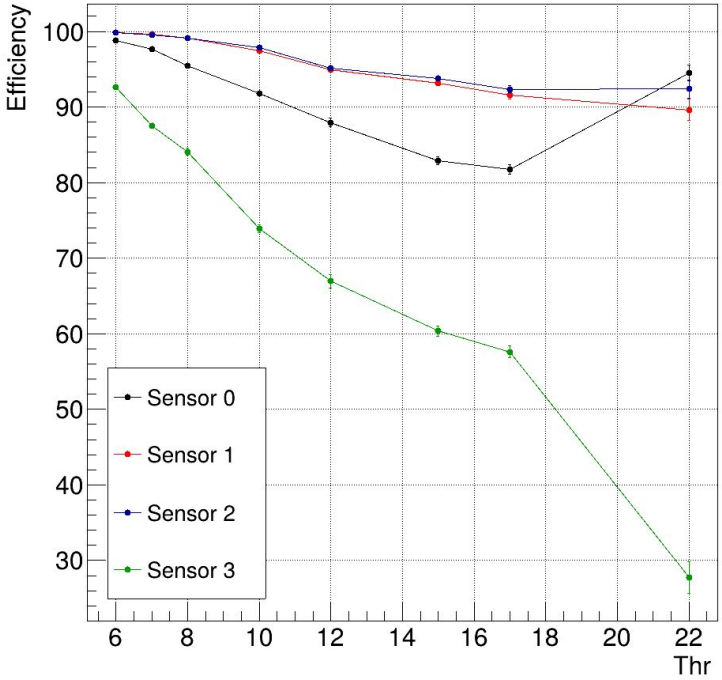
Tracking efficiency

Request: 1 track in VTX when the AND of the four scintillator is true together with a request of one single particle in BTF calorimeter.



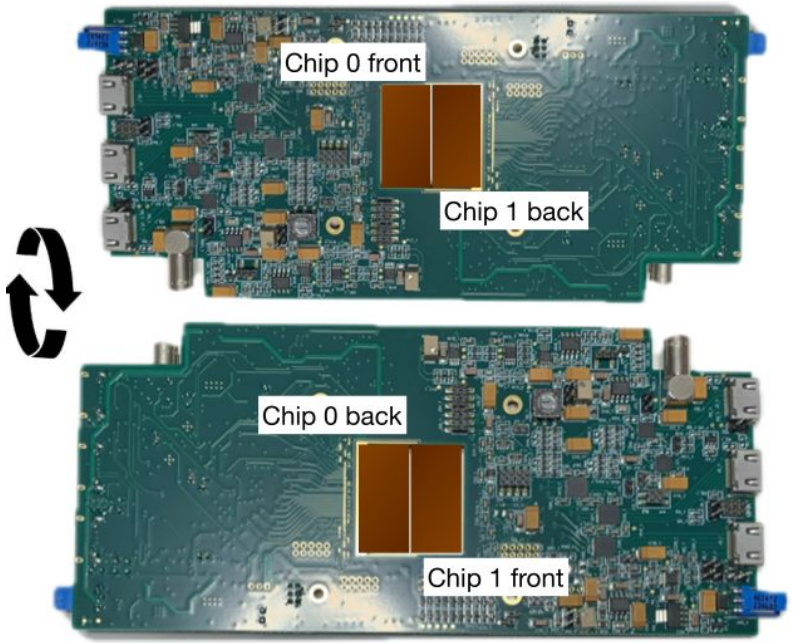
tracking efficiency > 99% to MIPs in the threshold region (7 sigma) where FOOT worked at CNAO2024 and CNAO2025

Sensor tracking participation probability



Probability of a sensor participating in a track. A track occurs when there are three clusters across three different sensors

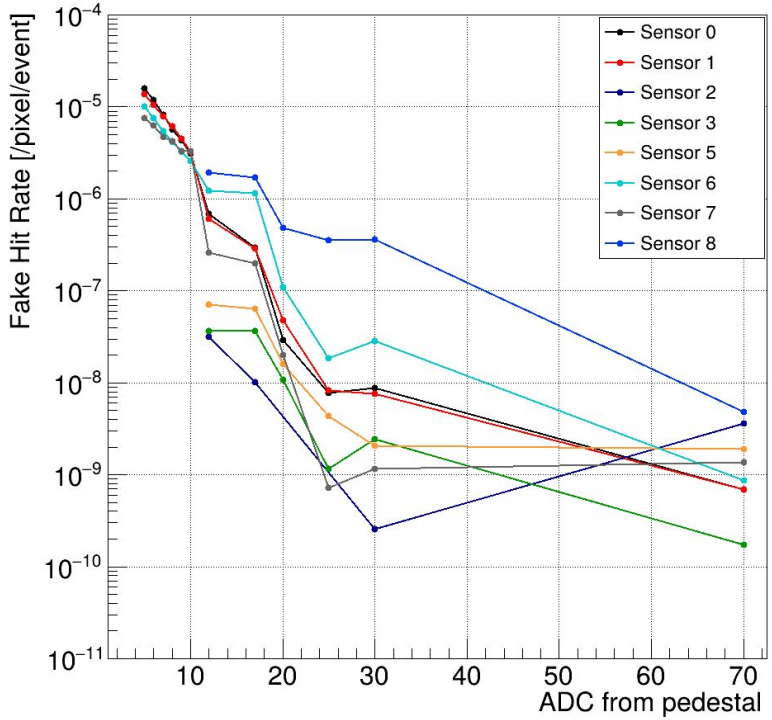
New VT (MIMOSIS)



- 2 chip for layer
- 6 layer
- **Time resolution : 5 μs** → it will help to achieve a better Rate

Noise analysis from pedestal runs

Pedestal runs were performed to identify and analyze noisy pixels.

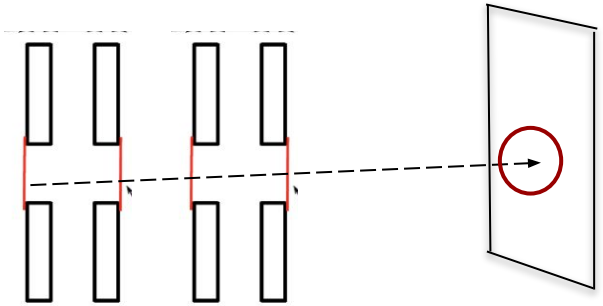


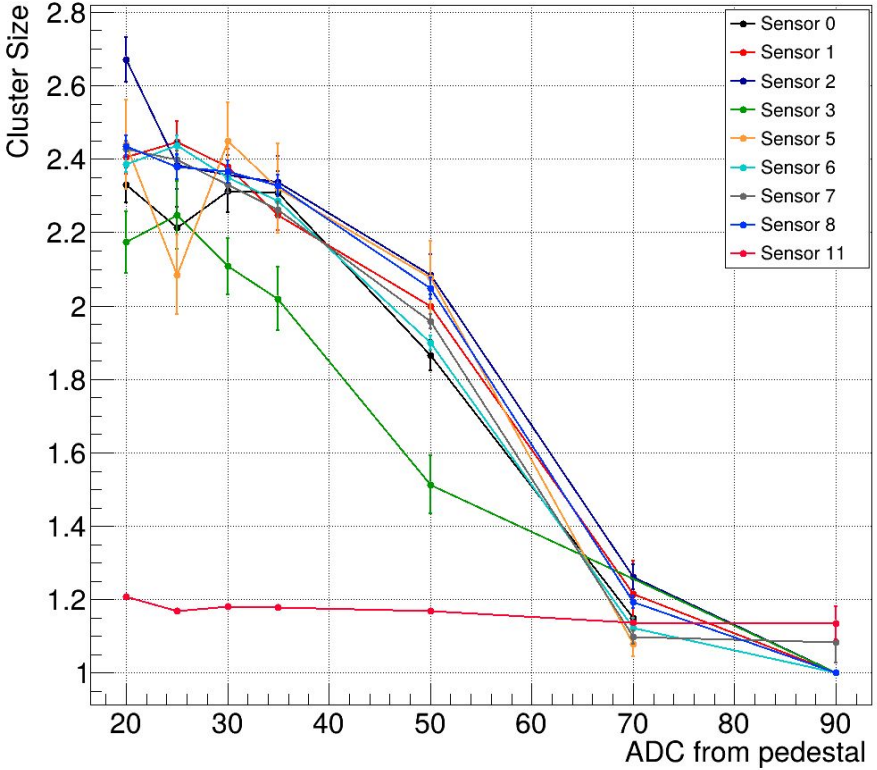
Sensors 4, 9, and 10 were consistently **inactive** throughout the data-taking period.

Cluster Size Analysis

These measurements were performed using a 450 MeV electron beam with the table in its nominal position to evaluate cluster size and efficiency.

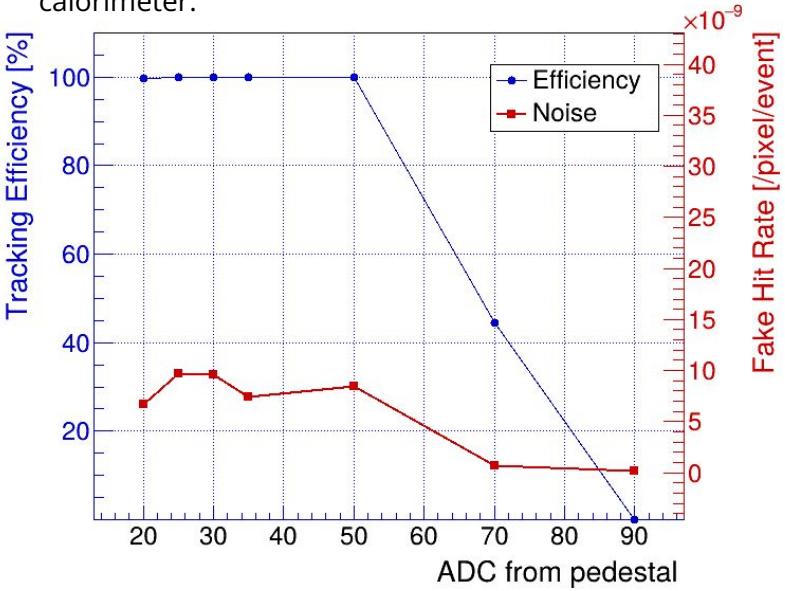
Selection Cuts -> a track originating from the old vertex is projected onto the sensor plane of the new vertex; only clusters within a 1 mm radius are selected as good for the analysis

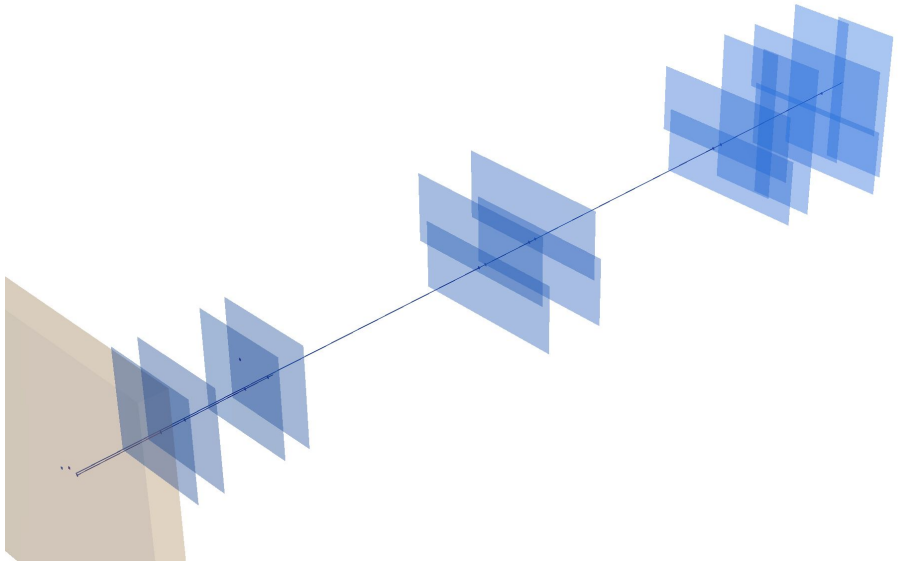




Tracking efficiency

Request: 1 track in VI when the AND of the four scintillator is true together with a request of one single particle in BTF calorimeter.





tracking efficiency > 99% in the threshold region from 20 to 50 ADC

Conclusions

- The **old vertex** achieved a tracking efficiency exceeding 99 % at relevant physics thresholds

- The **new vertex** achieved a tracking efficiency exceeding 99 % from 20 to 50 ADC

- New data taking Autumn 2026

Thank you