Meeting with referees

30 Mar 2026

Progetto sottomesso all'ESA-PAC

Setting FOOT on Mars:
Cross-Section Measurements for Space Radioprotection

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for the FOOT Collaboration

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Abstract

The FOOT collaboration is conducting experimental campaigns to measure double-differential fragmentation cross sections relevant to Particle Therapy (PT) and Space Radiation Protection (SRP). This proposal aims to take advantage of the unique capabilities of the GSI accelerator complex to measure missing cross sections, relevant for SRP research.

The FOOT experiment has the capability to perform measurements close to the peak of the spectrum of Galactic Cosmic Rays. Therefore, by using a ^{12}C beam at 0.7 GeV/u and at 1.5 GeV/u, incident on carbon, polyethylene, and aluminum targets, we propose to measure: a) double-differential cross sections for C, C_2H_4, Al, and H (the latest using a subtraction technique); b) differential fragmentation cross sections of protons on C via an inverse kinematic approach.

Both sets of measurements are essential for improving and validating the radioprotection codes used to calculate shielding and to assess astronaut exposure to proton and carbon ions from Galactic Cosmic Rays in deep space.

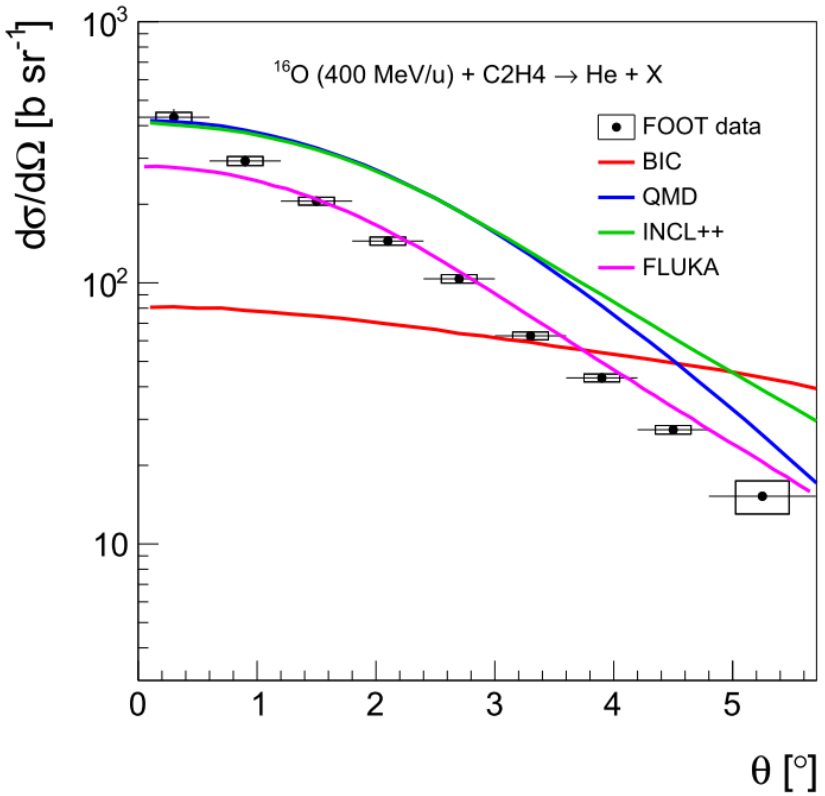
- Progetto per 2 gg di fascio al GSI finanziato dall'ESA nell'ambito della radioprotezione spaziale.
- Finanziano solo il fascio.
- Accettato dall'ESA; presentato al GSI il 1/12/25
- Schedulato per l'autunno 2026
- Posticipato sine die per l'incendio al GSI.

→ la collaborazione ha deciso di prendere dati nel 2026 al CNAO. Seconda metà dell'anno, date esatte entro giugno.

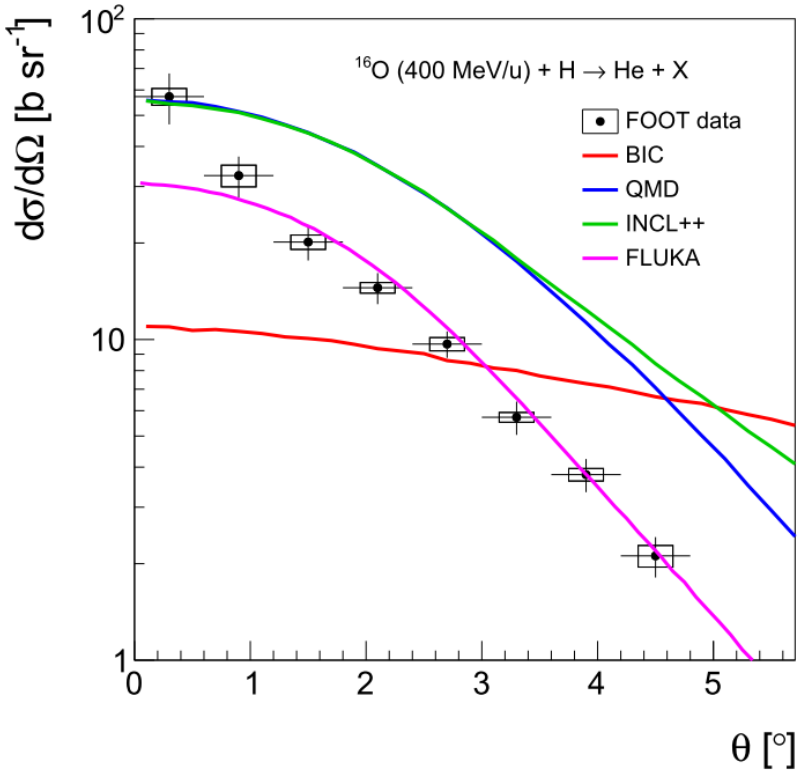
Nuclear fragmentation cross section measurements for a 400 MeV/nucleon ^{16}O beam on polyethylene and Hydrogen targets with the FOOT experiment

Matilde Dondi,[1,2] Riccardo Ridolfi,[1,2] Marco Toppi,[3,4] Alberto Mengarelli,[1] Andrey Alexandrov,[5] Behcet Alpat,[6]

Dati GSI 2021; Ossigeno su polietilene

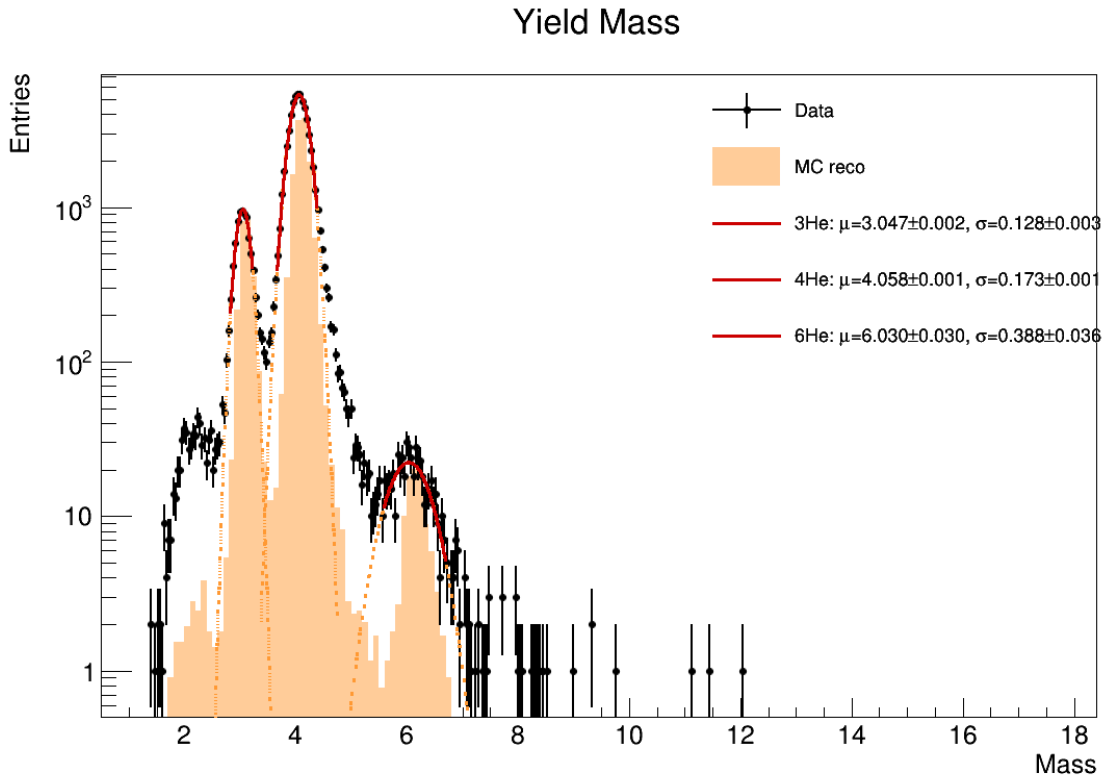


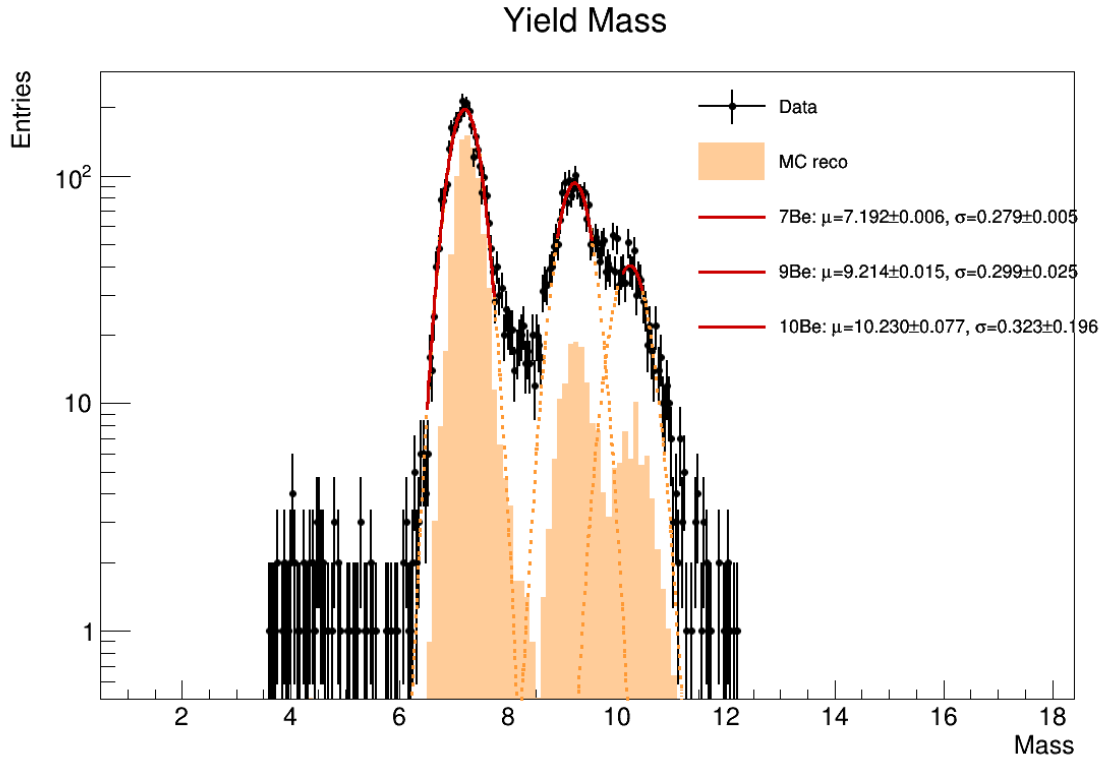
Ossigeno su idrogeno; da sottrazione O+C



Sottomesso a PRC il 16/02/2026

Ricostruzione delle masse: p & Tof





- Dati CNAO 2025
- Ricostruzione delle masse fondamentali per la cinematica inversa

Prime misure di sezione d'urto differenziali per isotopi

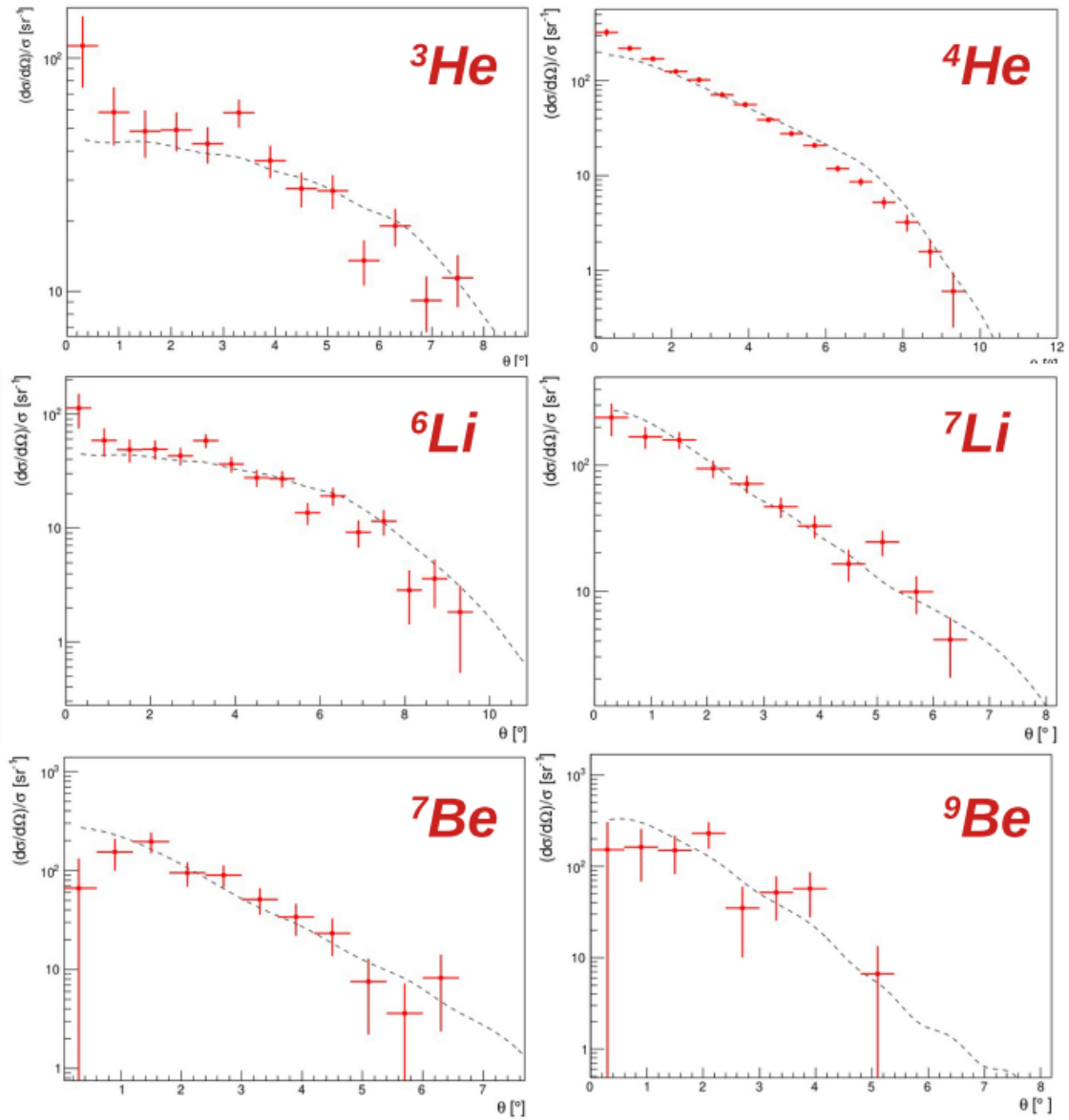
Experimental results of
CNAO 2024 data taking of
Isotopic differential cross section results, normalized to total elemental cross section

$$\frac{d\sigma}{d\theta}(Z,\theta) = \frac{Y(Z,\theta)}{N_{beam}\ N_{target}\ \Omega_\theta\ \epsilon(Z,\theta)}$$

$$\sigma(Z) = \int_{\theta_i}^{\theta_f} \frac{d\sigma}{d\theta}(Z,\theta)\, d\theta$$

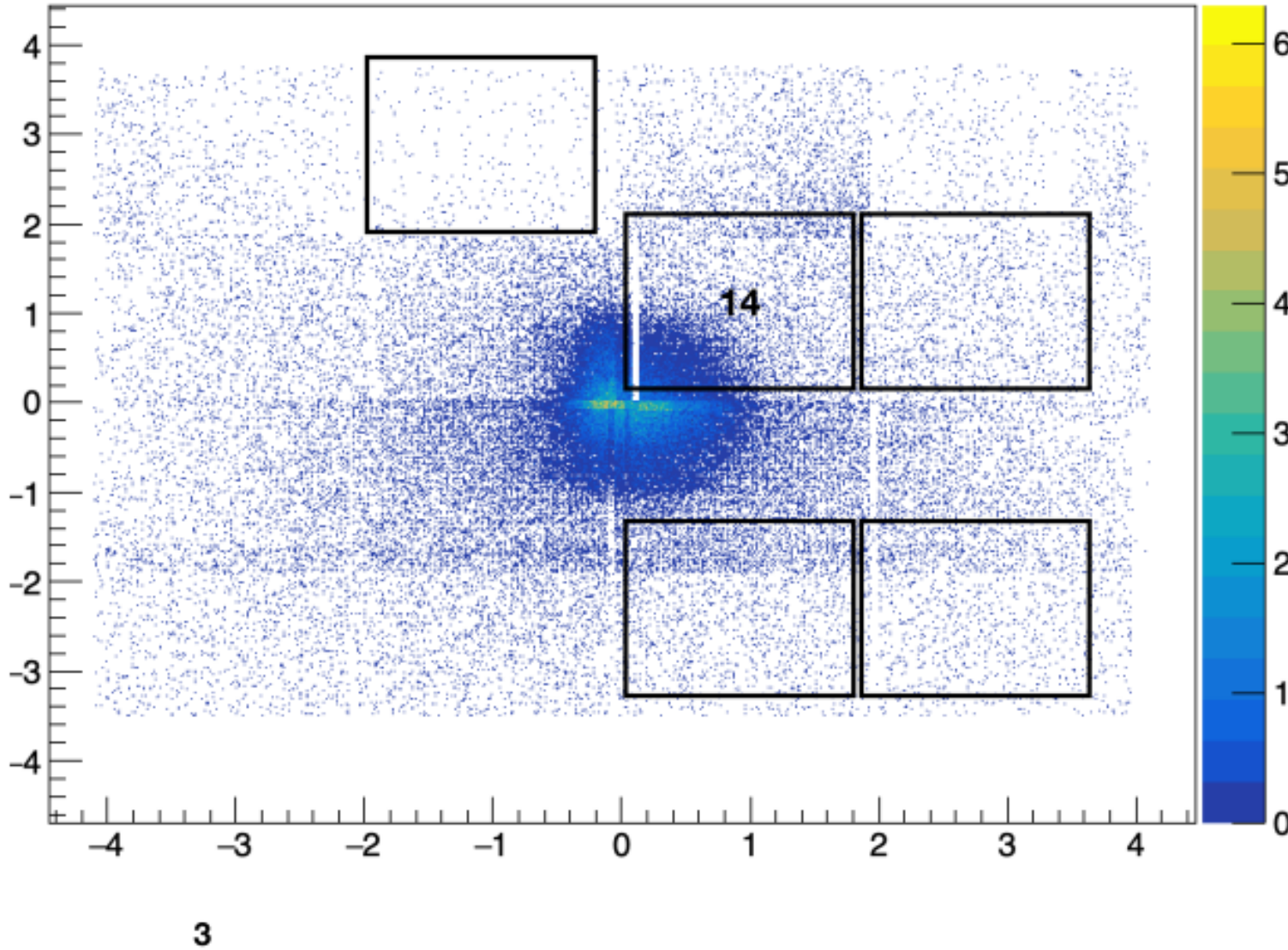
First results of 200 MeV/u ^{12}C on C, with FOOT full setup, in B field for isotopes of He, Li, Be

Following the same procedure
as for elemental x.s.,
from cuts to closure tests.



IT Broken Sensors

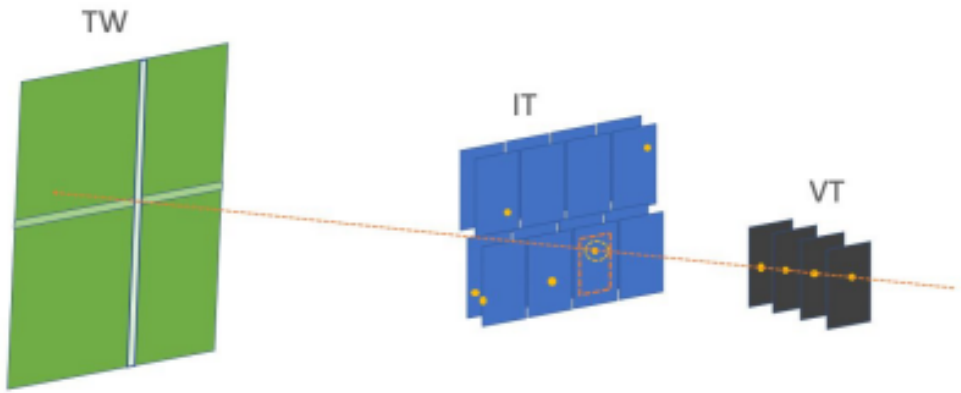
- **Detector Status:**
  - During the data taking, **5 sensors** were identified as non-operational (broken):
    - **IDs: 5, 6, 13, 27**, and **14**.
- **Cluster Map Analysis:**
  - A distinct "hole" (loss of acceptance) is visible in the center of the IT occupancy map.
  - **Root Cause:** Failure of the central **Sensor 14**.
- **Geometrical Explanation:**
  - The Inner Tracker consists of **4 layers** of sensors.
  - However, there are physical **geometrical gaps** between adjacent sensors on each layer.
  - Due to this layout, the specific central region corresponding to the hole was covered **exclusively** by Sensor 14.

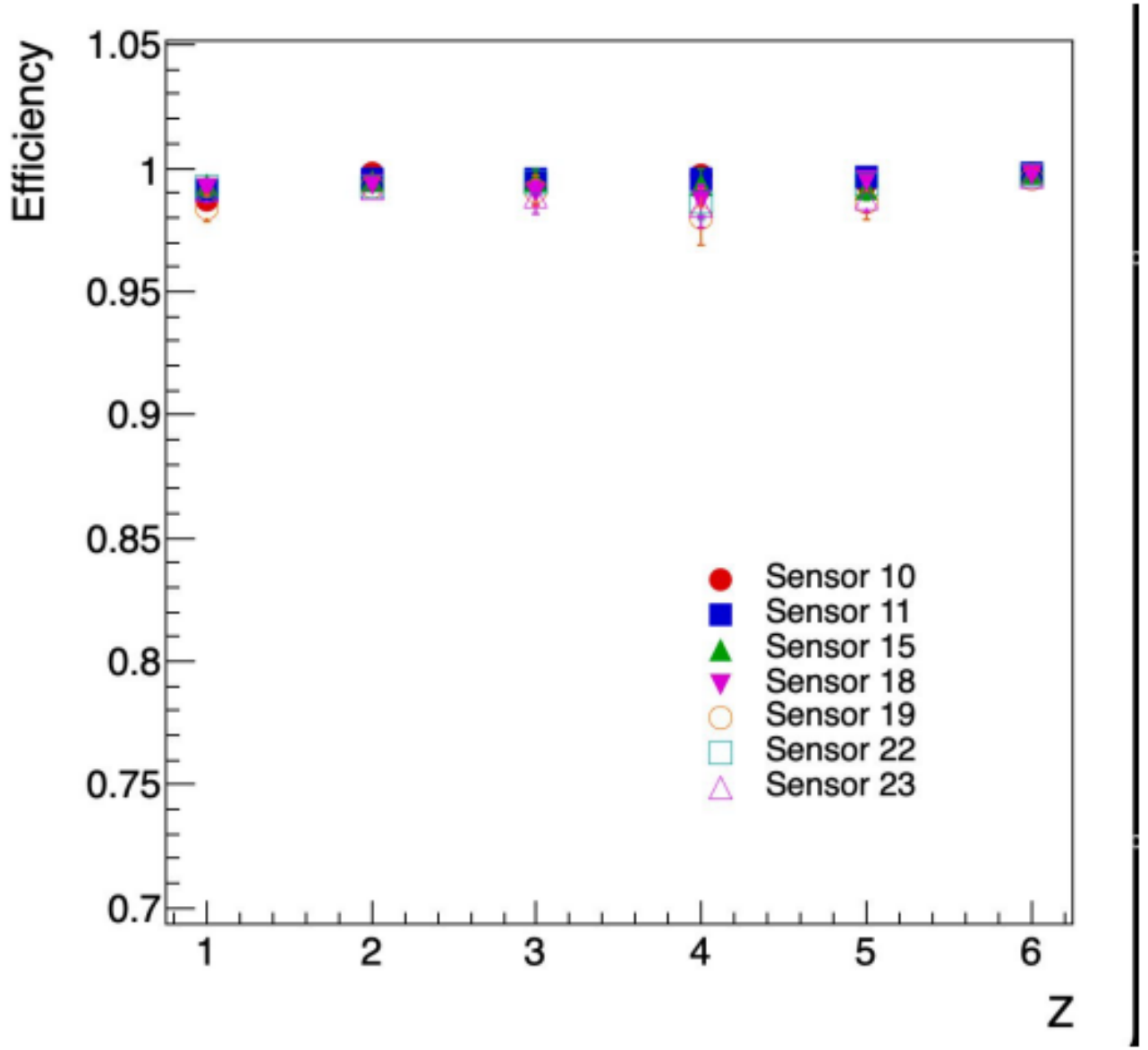


Inner Tracker Efficiency vs Z

Efficiency Evaluation Method:

- **Sample Selection:**
  - Reconstructed vertices matched with ToF Wall.
- **Procedure:**
  - **Extrapolation:** VT tracks projected onto IT planes.
  - **Geometrical Acceptance:** Check if track projection falls inside the sensor area.
  - **Cluster Matching:** Search for clusters within a defined distance cut (ROI) from the projected point.





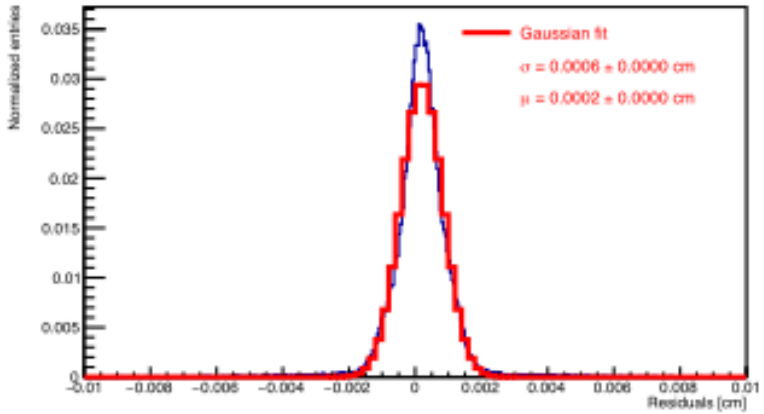
- Efficiency remains **flat around 99%** across Z=1…6. This confirms the IT sensors operate reliably.

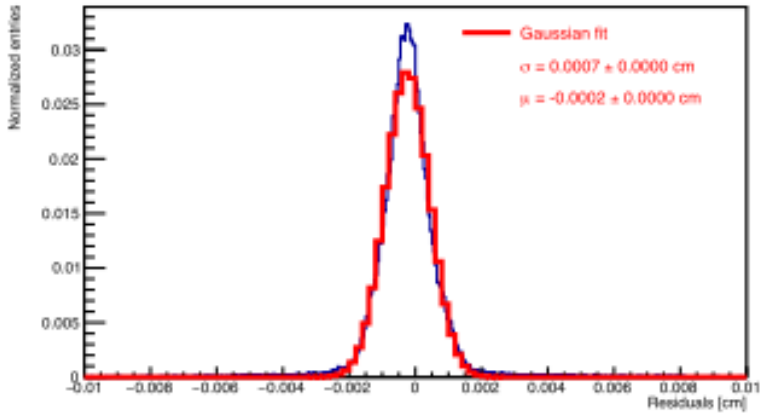
VTX residuals: Observations

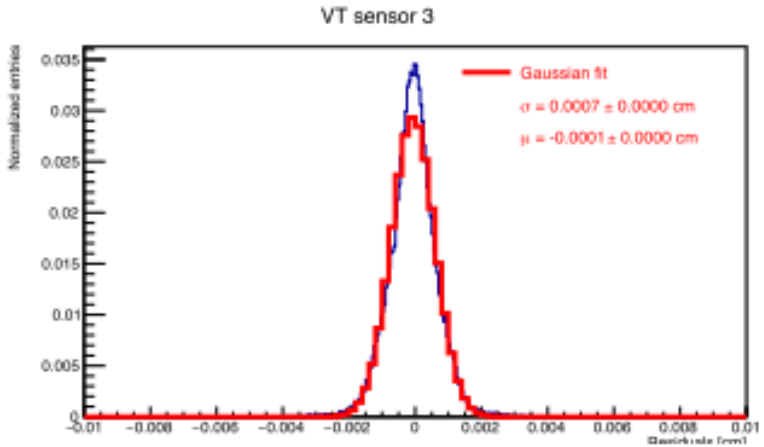
Difference between IT and Vertex Tracker residuals

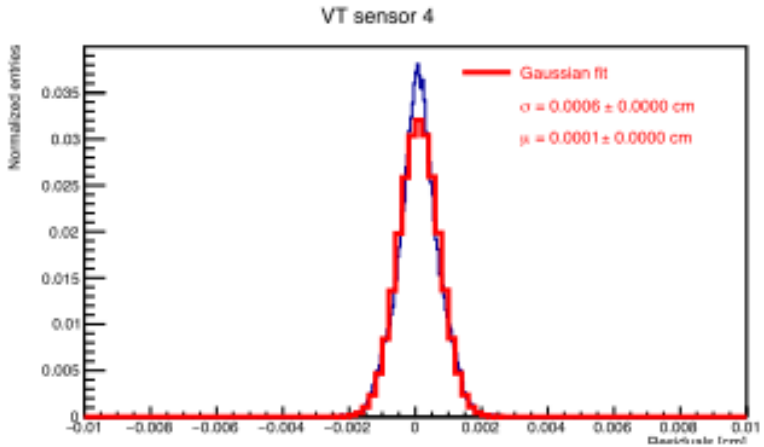
- Residuals defined as distance between the **cluster** and the **projected track of the BM**.
- σ ≈ 6/7 μm

Residuals are dominated by the intrinsic sensor resolution.





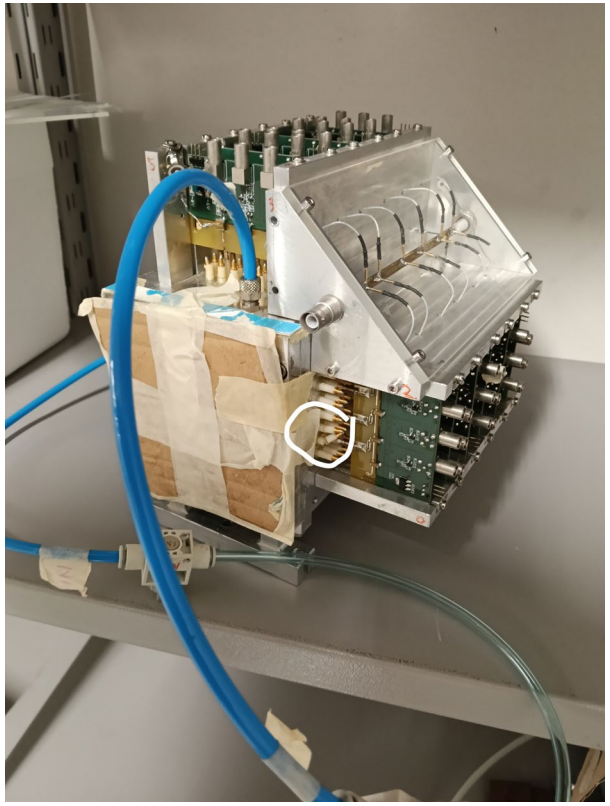


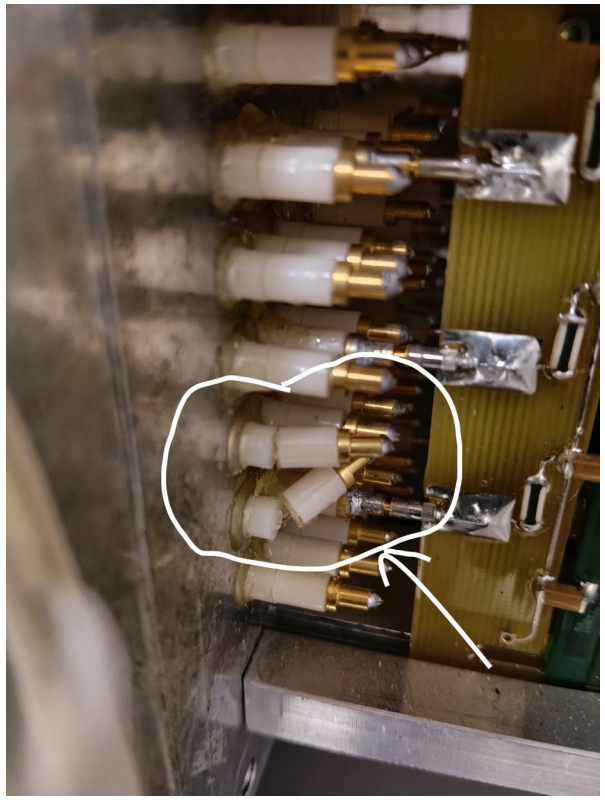


Recupero IT

- L’Inner Tracker richiede ancora uno sviluppo
- 5 sensori su 32 funzionano male o non funzionano
- Rientro a LNF programmato per Dicembre, bloccato dalla radioprotezione CNAO, sbloccato a Gennaio.
- Bloccato dal cantiere al CNAO, si tenta un recupero dopo Pasqua

Danno al Beam Monitor presso il CNAO





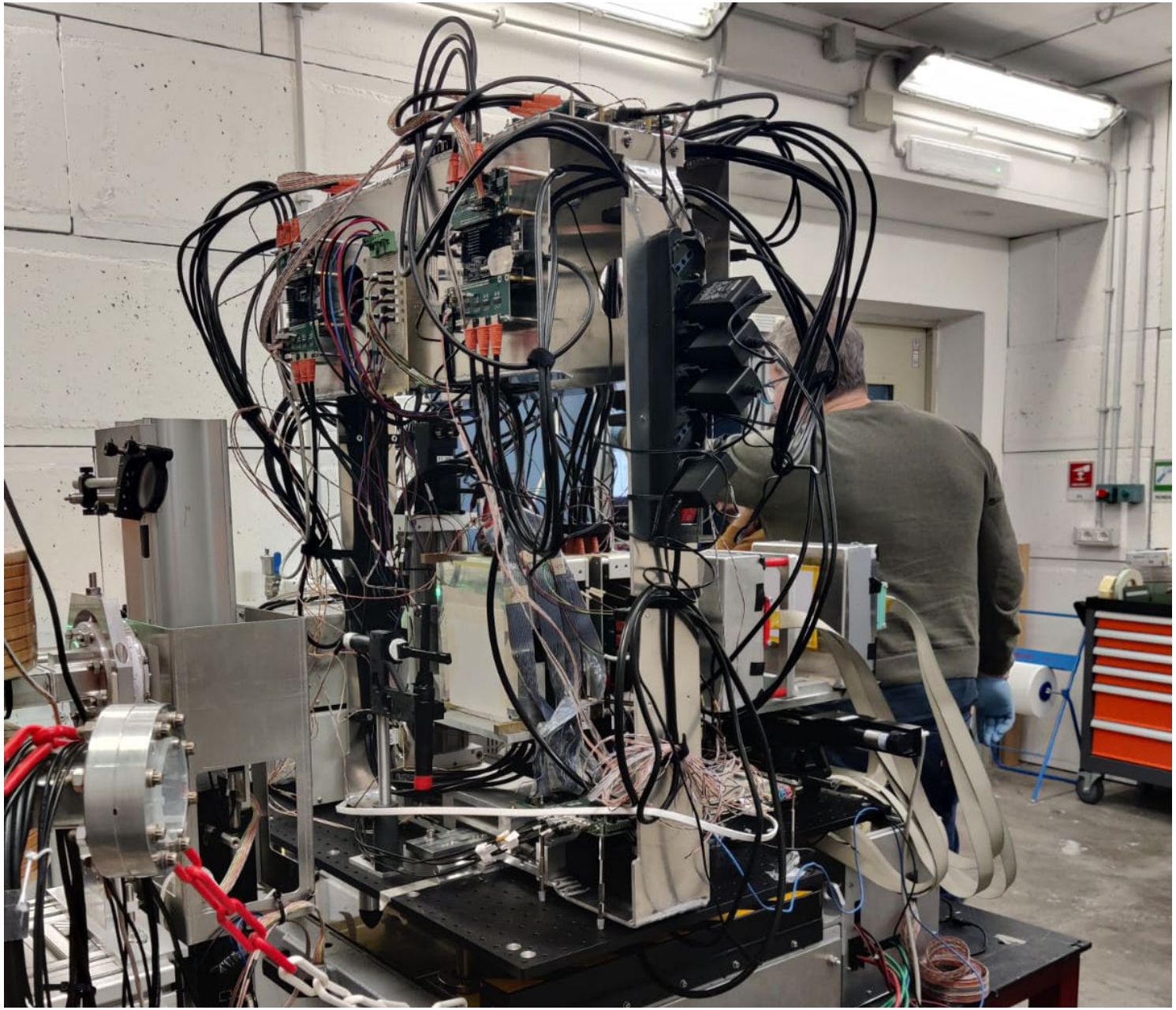
- Danno prodotto durante la permanenza del BM al CNAO.
- Richiede un intervento a Roma

→3 missioni non previste

(recupero BM al CNAO, consegna e recupero BM a Roma)

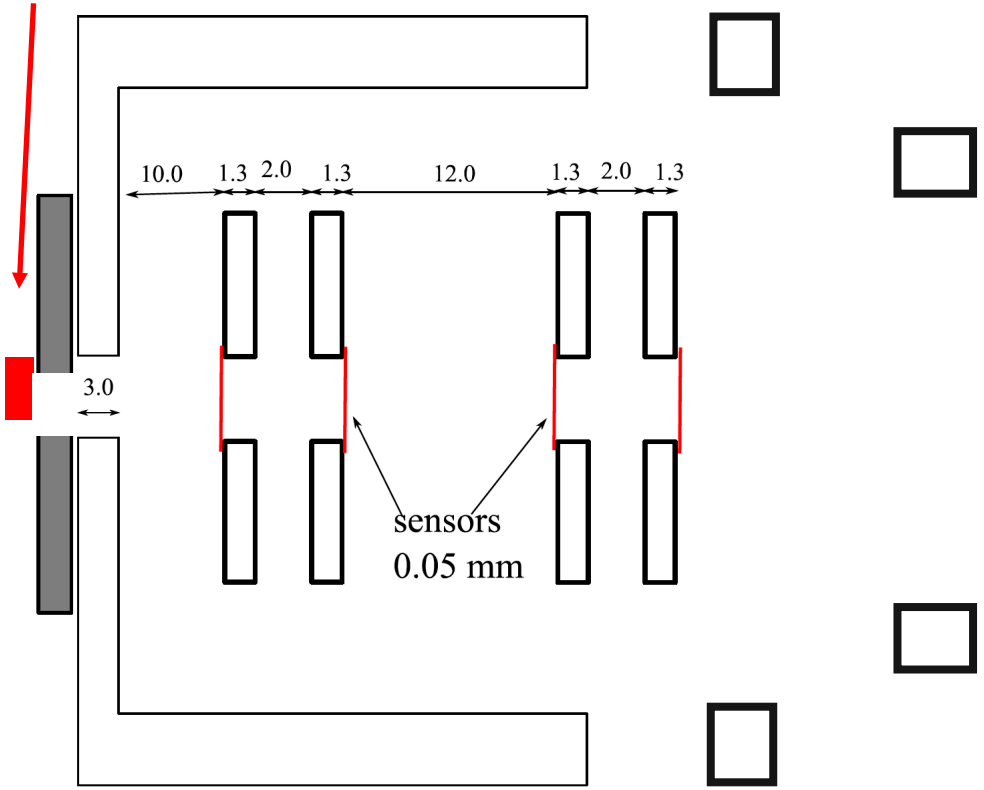
Test beam @ BTF

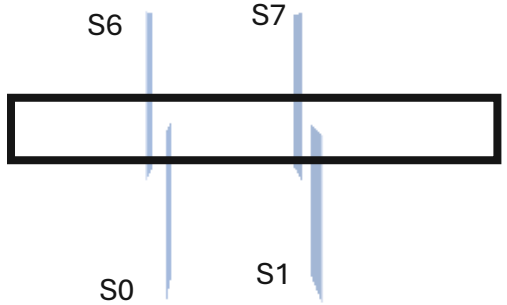
- Richiesta 1 settimana → date 2
- Test omnicomprensivo per
  - OLD Vertex
    → 4 sensori
  - New Vertex sensors
    → 12 sensori
  - MSD
    →12 piani singoli
- Elettroni a 450 MeV → MIP equivalent



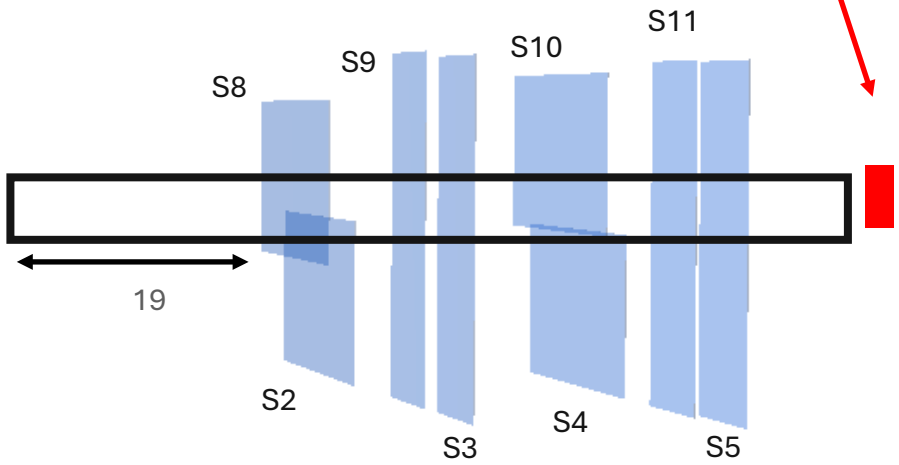
VTX- VTI geometry @ BTF

Couple of thin plastic scintillators 1x1 cm²





Couple of thin plastic scintillators 1x1 cm²

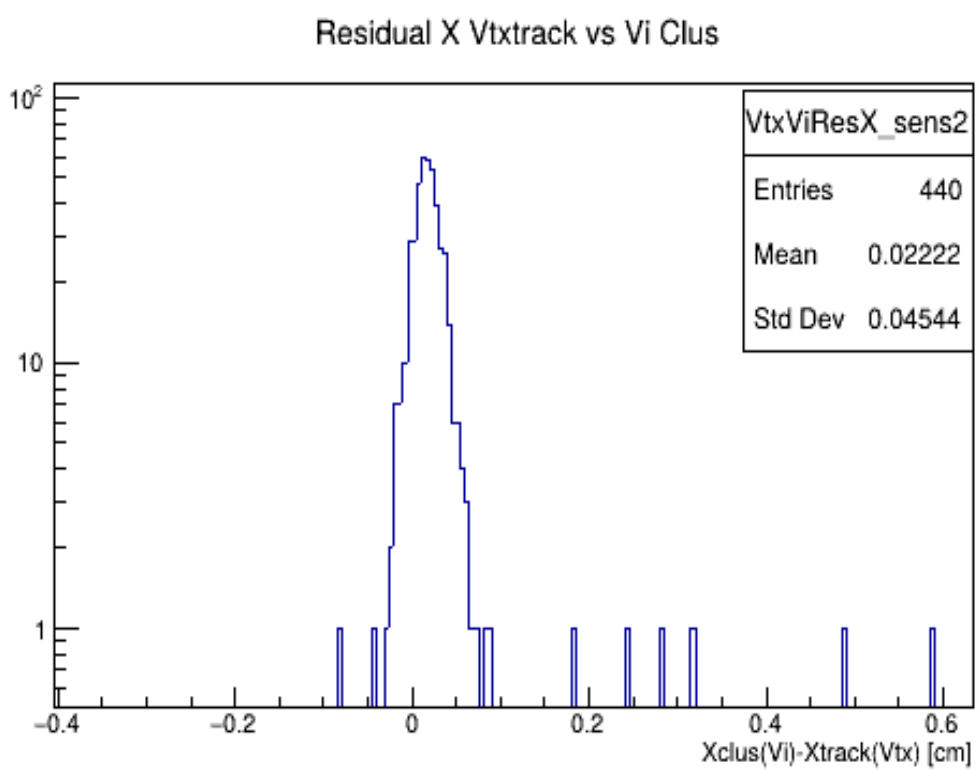


Old VTX (MIMOSA28)

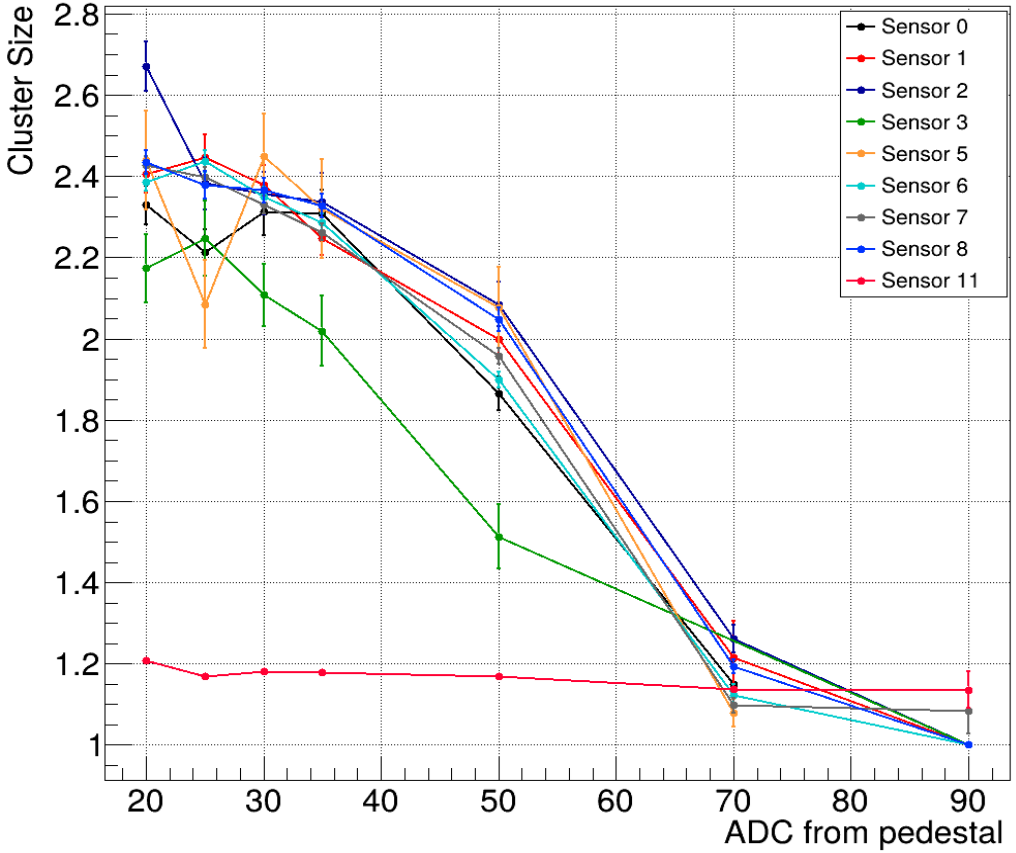
New VTX (MIMOSIS)

New Vertex sensors

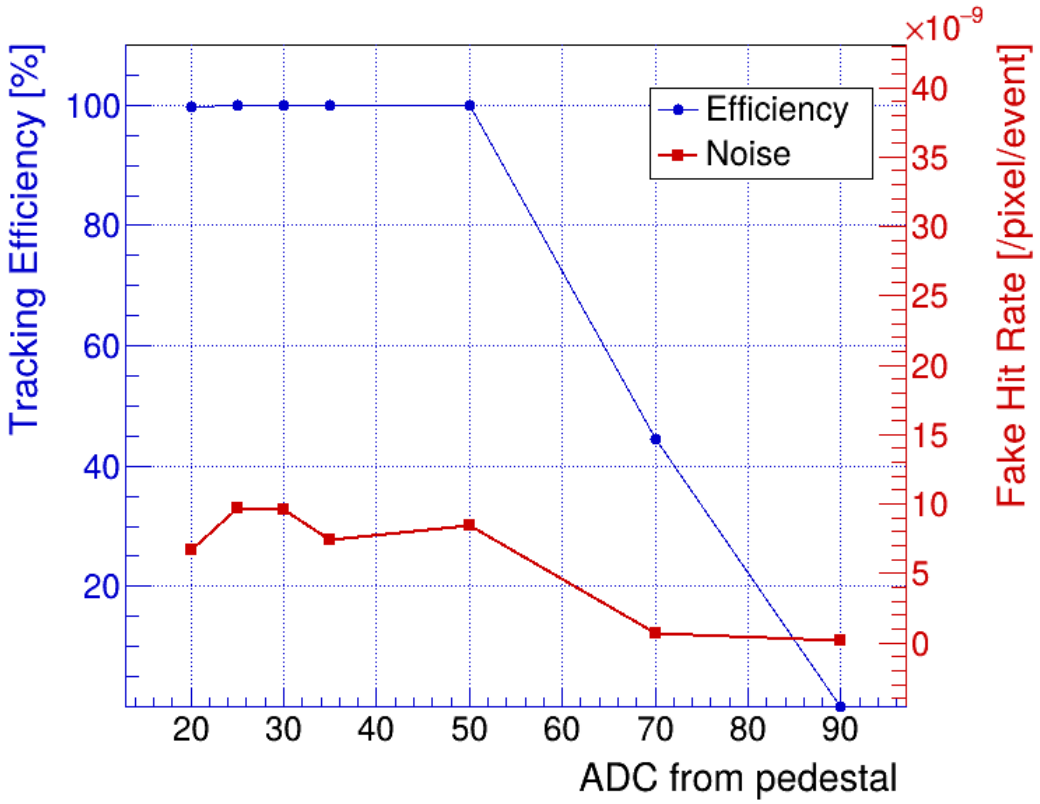
- 9 out of 12 working properly. 2 damaged, 1 recovered after BTF tests



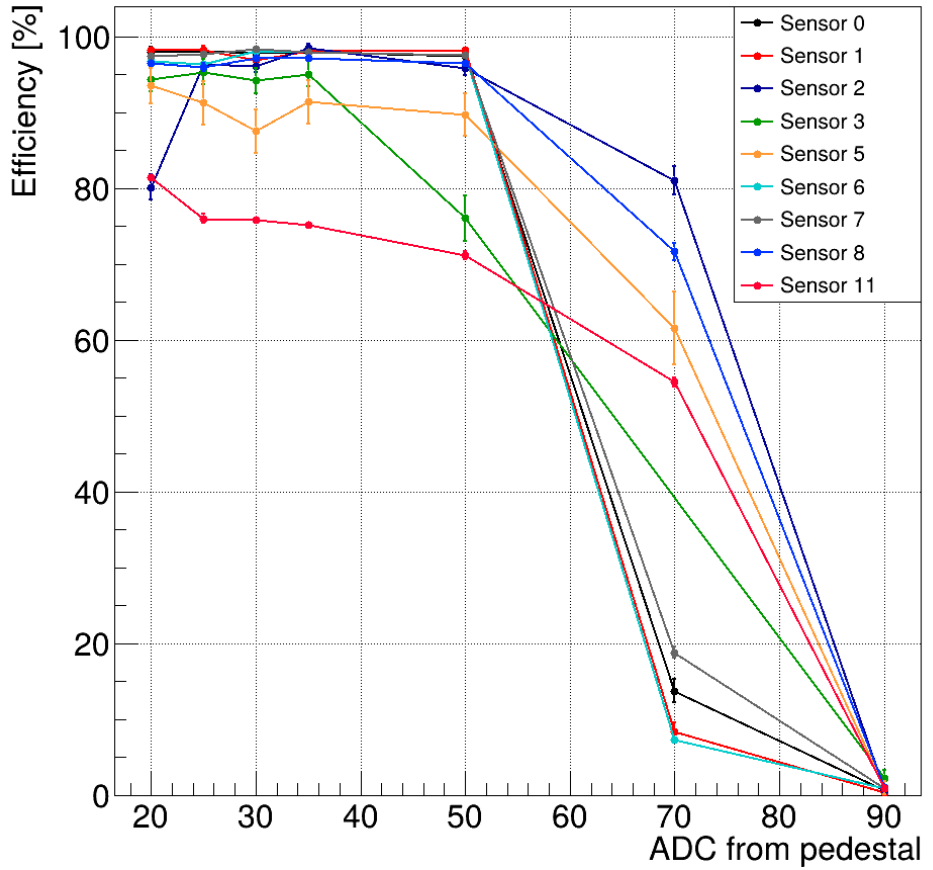
Residuals very low;
dominated by multiple scattering



New vertex tracking efficiency

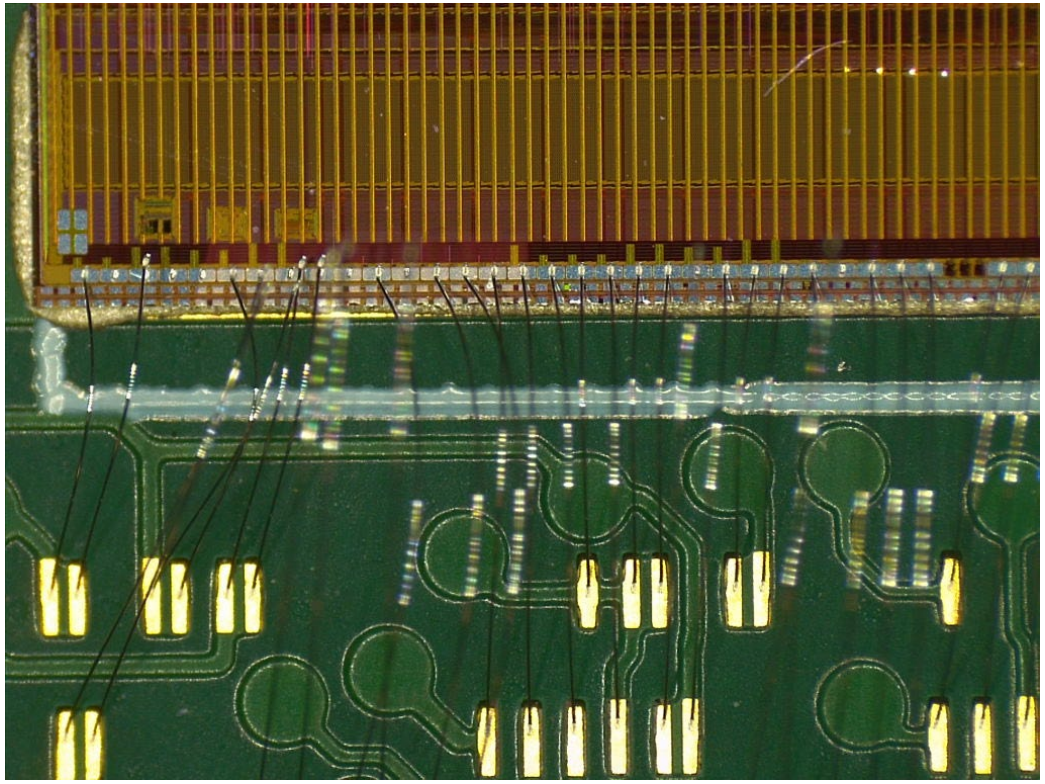


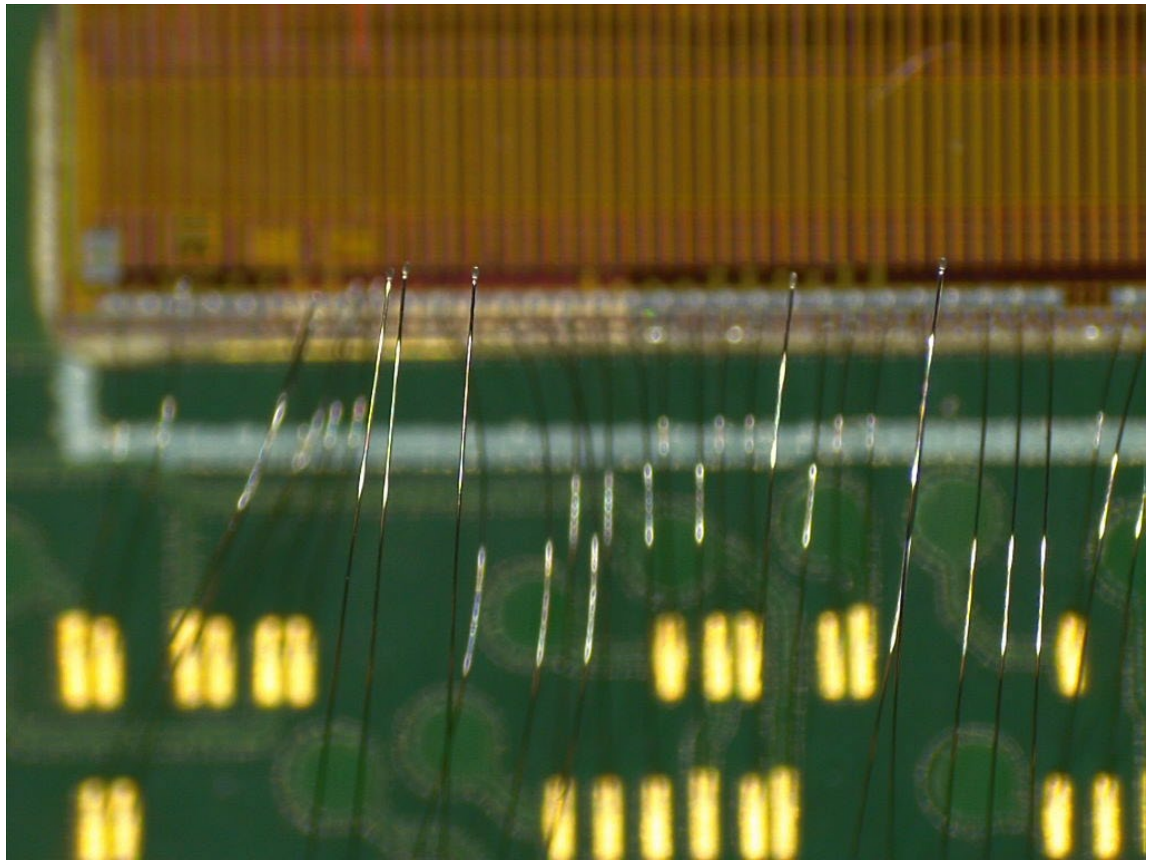
Tracking and fake rate in the new vertex



Hit finding probability in Mimosis sensors using tracks from old vertex

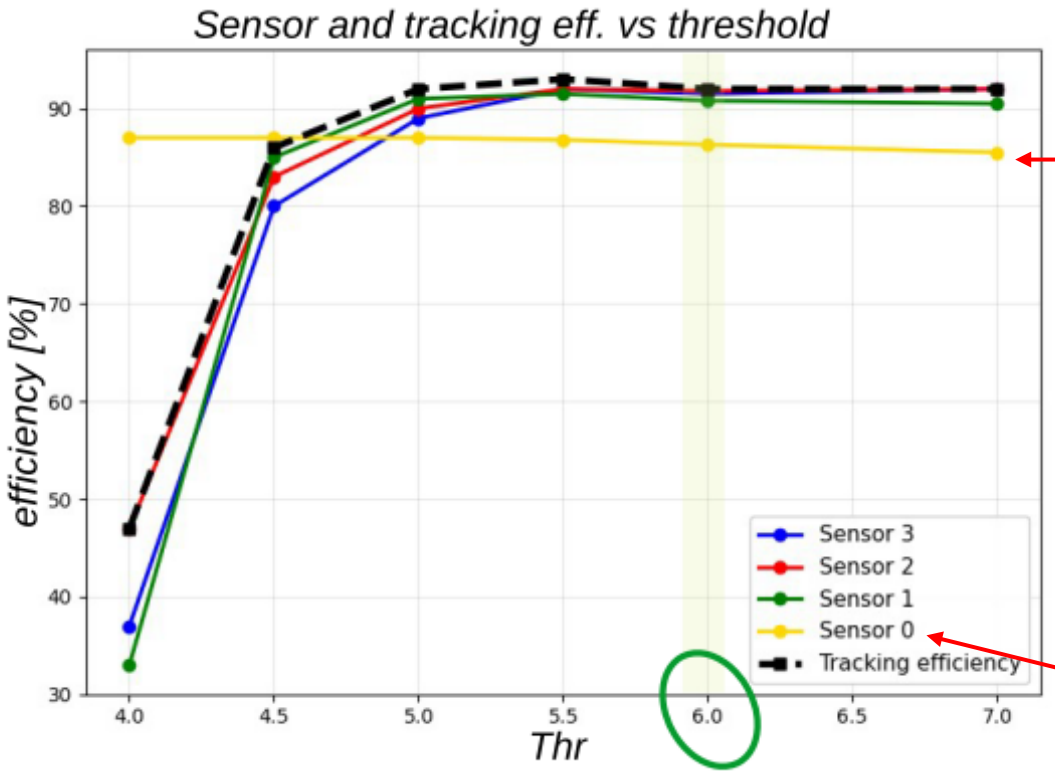
Two broken sensors



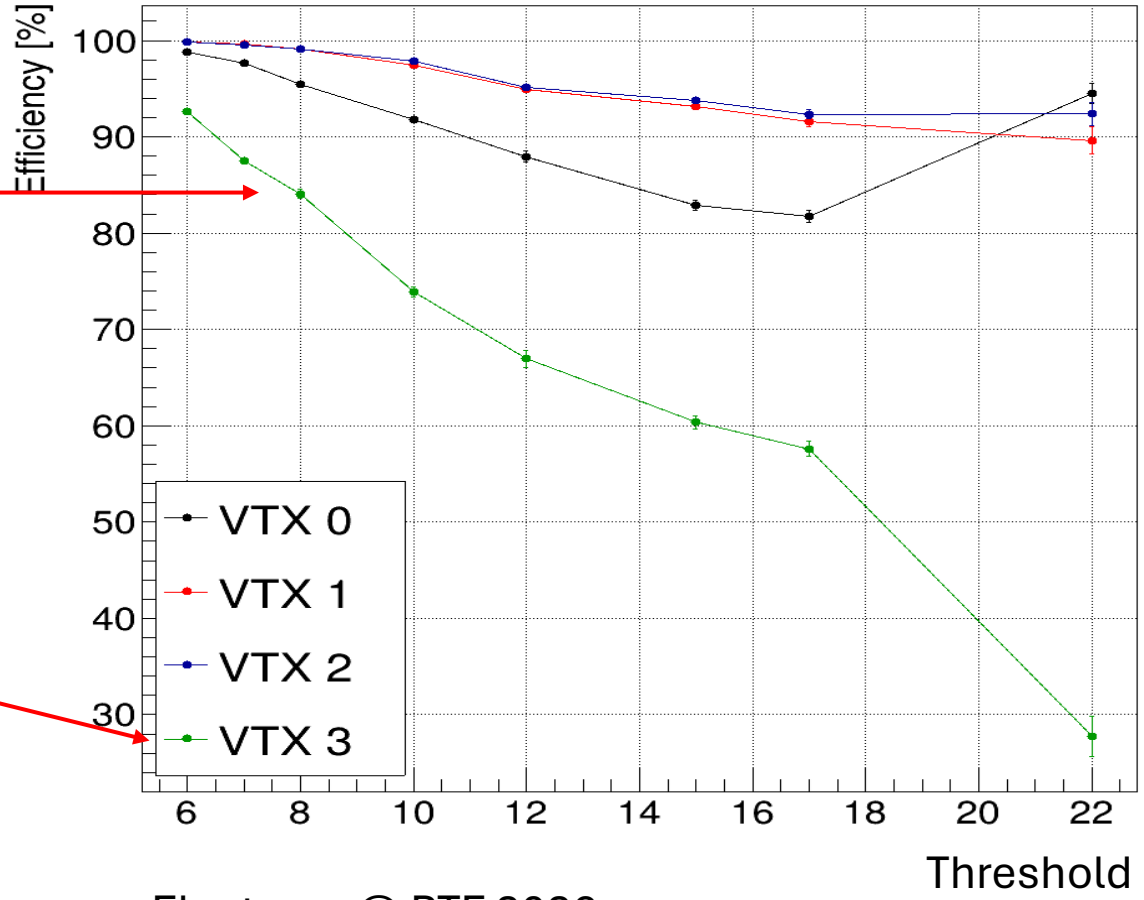


- Sent to Strasbourg for repair; expected in Pisa in 3 weeks

Old Vertex



Protons @ CNAO 2025



Electrons @ BTF 2026

Sensor 3 has more noise and smaller cluster sizes. No spares available.

- Ordinati 5 sensori spare nell'ambito del progetto MAECI
- Problemi di comprensione tra le burocrazie IPHC e INFN
- Tentato l'acquisto su fondi PRIN in scadenza → deadline passata
- I sensori servono e sono pronti per la spedizione da luglio 2025.

IPHC
Institut Pluridisciplinaire Hubert CURIEN
STRASBOURG

Strasbourg, February 9, 2026

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Maura VILLA - SEZIONE DI BOLOGNA
Viale Berti Pichat 6/2
40127 BOLOGNA
C.F 84001850589
ITALIA

Our reference : Quote n° 110-2025 - Period of validity: 1 year in the date of issue

Designation	Quantity	Unit price Euro	Total price Euro
5 Capteurs CMOS MIMOSA-28/ULTIMATE for project 202295SHW3 High performance DMAPS for Hadrontherapy CUP I53D23000990006	1	8 328,12	8 328,12

SUBTOTAL	8 328,12 €
TOTAL	8 328,12 €

Financial contact :
Mickael PUERTO
☎ (+33) 88 10 64 72
mickael.puerto@iphc.cnrs.fr

Emulsioni

Submitted to PRC on 17/02/26

Measurement of 80-200 MeV/n ^{16}O nuclear cross-section on Carbon and Polyethylene targets with the nuclear emulsion detector of the FOOT experiment

G. Galati,[1,2] V. Boccia,[3,4] A. Alexandrov,[4] B. Alpat,[5] G. Ambrosi,[5] S. Argirò,[6,7] M. Barbanera,[5] N. Bartosik,[7]

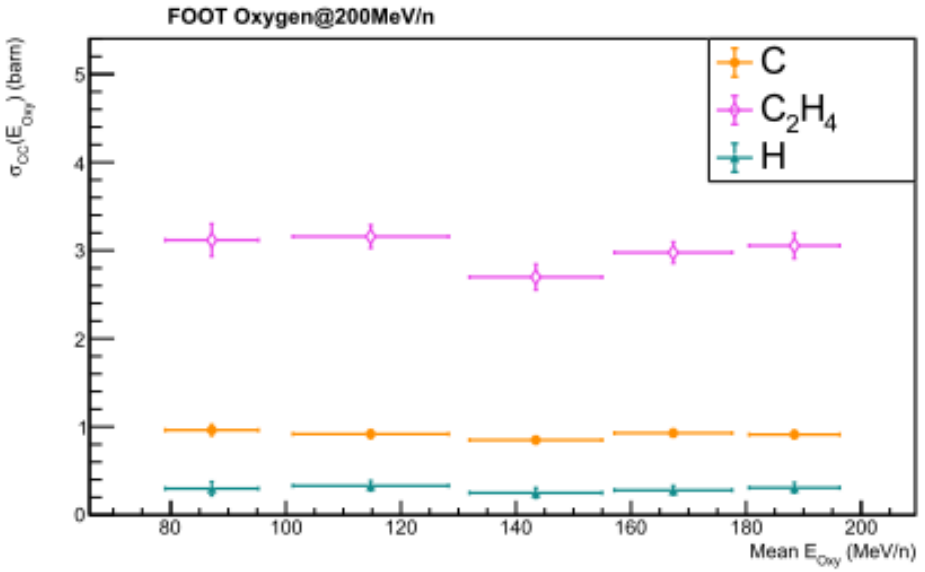


FIG. 11. Total charge-changing cross-sections on C, C_2H_4 and H as a function of energy.

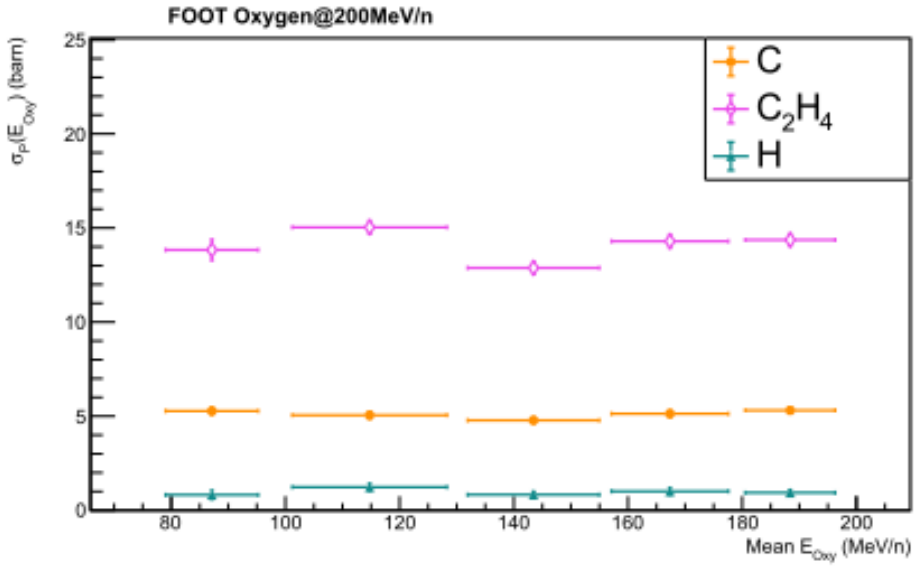
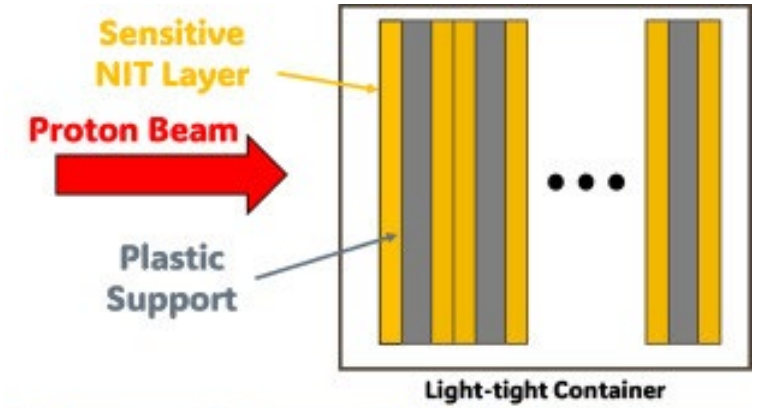
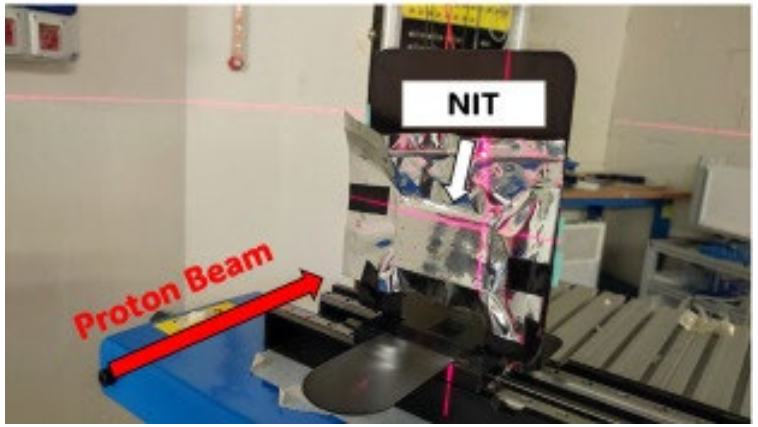
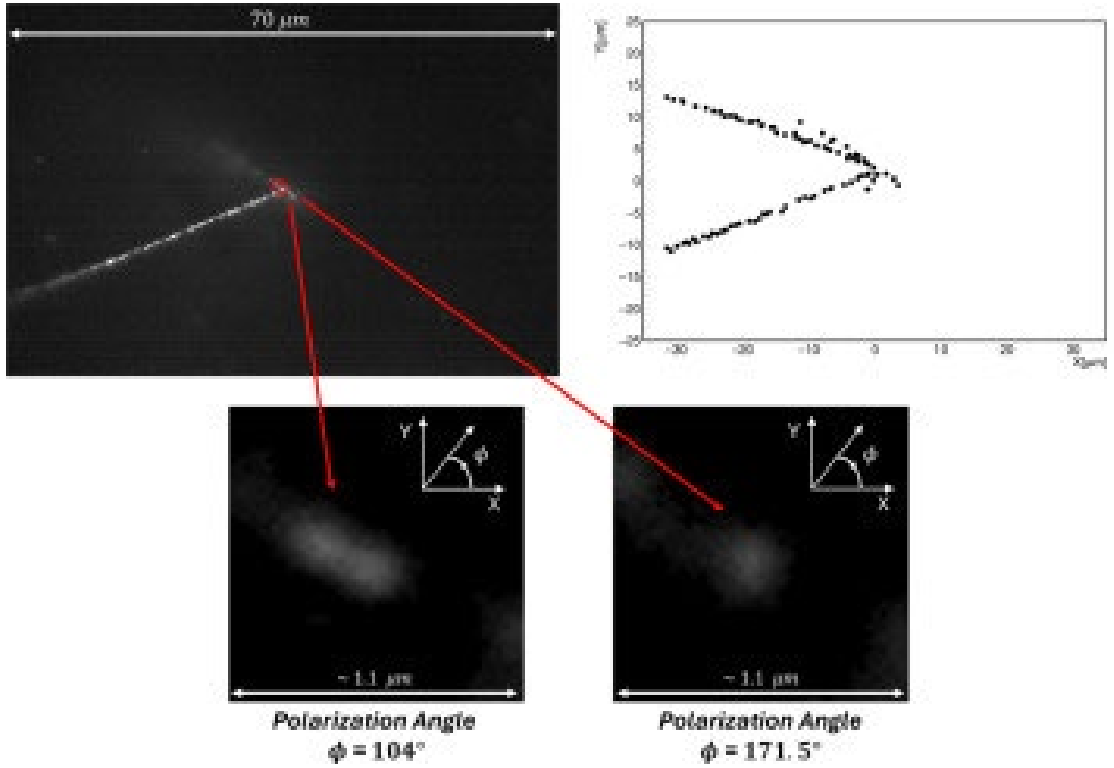


FIG. 12. Fragment production cross-sections on C, C_2H_4 and H as a function of energy.

NIT







From dark matter searches to proton therapy: Measuring target fragmentation with nanometric nuclear emulsions

Nuclear Instruments and Methods in Physics Research A 1070 (2025) 170006

MC Montesi @ PTCOG63 e G Galati @ IFD 2025

Instrumentation paper

Prepared for submission to JINST

The FOOT apparatus for nuclear fragmentation measurement

- Parti 1-5 «quasi» pronte
- Parte 6 da completare
- Conclusioni e abstract da scrivere

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Situazioni Milestones

- Preliminary CNAO 2023 electronic set-up results – (100%) --> 100%
- Preliminary 2023 emulsion results – (70%) --> 70%
- New vertex detector beam test – (50%) --> 100% raggiunto con i test alla BTF a feb 2026
- Prototype TOF-Wall beam test – (100%) --> 100%
- Instrumentation paper submission – (50%) --> 75%, l'articolo non è ancora stato sottomesso e si sta lavorando sulle ultime sezioni
- NIT R&D publication – (70%) --> 100%, vedi MC Montesi @ PTCOG63 e G Galati @ IFD 2025

Richieste per la riunione di CSN3 di aprile

- Spese extra per la partecipazione al test BTF (tranne dottorandi)

- Bologna: 6 k€ (spese effettive BTF; faremo un supplemento di test a maggio per i sensori che non hanno funzionato)
- Milano: 1k€ (BTF + missioni BM)
- Perugia: 4 k€ (3k€+1k€ per supplemento di test ad aprile)

- Nuova richiesta:

  Fondi per acquisto sensori M28 spare: 10 k€