

XVI FOOT General Meeting Napoli, 24-26 June 2024

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Collaboration



- **Collaboration by numbers:**
 - 93 Authors,
 - 33 Institutions
 - 5 countries (Italy, France, Germany, Japan, Cuba)
 - 3 continents (Europe, Asia, America)
 - 54% of women (highest in CSN3)

- **Still extending:**
 - A group from LNGS (emulsions)
 - Calicut University, India (?) (data analysis)



The FOOT Physics Program



Specific measurements related with Particle Therapy & Radioprotection in Space

- Using C, C₂H₄ → cross sections on C and H
- Using C, C₂H₄, PMMA → cross sections on C, O and H

PMMA is a combination of C,O,H.

Phys	Beam	Target	Energy (MeV/u)	Inv/direct
Target Frag. PT	¹² C	C, C ₂ H ₄	200	inv
Target Frag. PT	¹⁶ O	C, C ₂ H ₄	200	inv
Beam Frag. PT	¹² C	C, C ₂ H ₄ , PMMA	350	dir
Beam Frag. PT	¹⁶ O	C, C ₂ H ₄ , PMMA	400	dir
Beam Frag. PT	⁴ He	C, C ₂ H ₄ , PMMA	250	dir
Rad. Prot.space	⁴ He	C, C ₂ H ₄ , PMMA	700	dir
Rad. Prot.space	¹² C	C, C ₂ H ₄ , PMMA	700	dir
Rad. Prot.space	¹⁶ O	C, C ₂ H ₄ , PMMA	700	dir

open to other possible physics programs

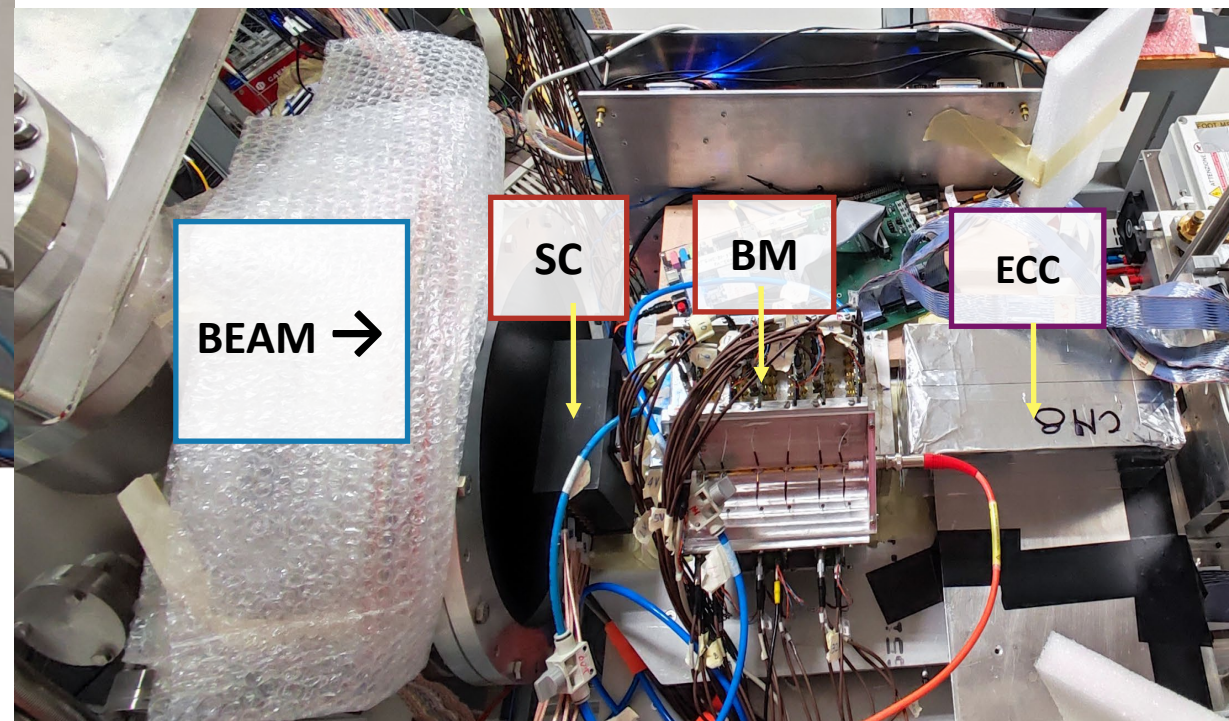
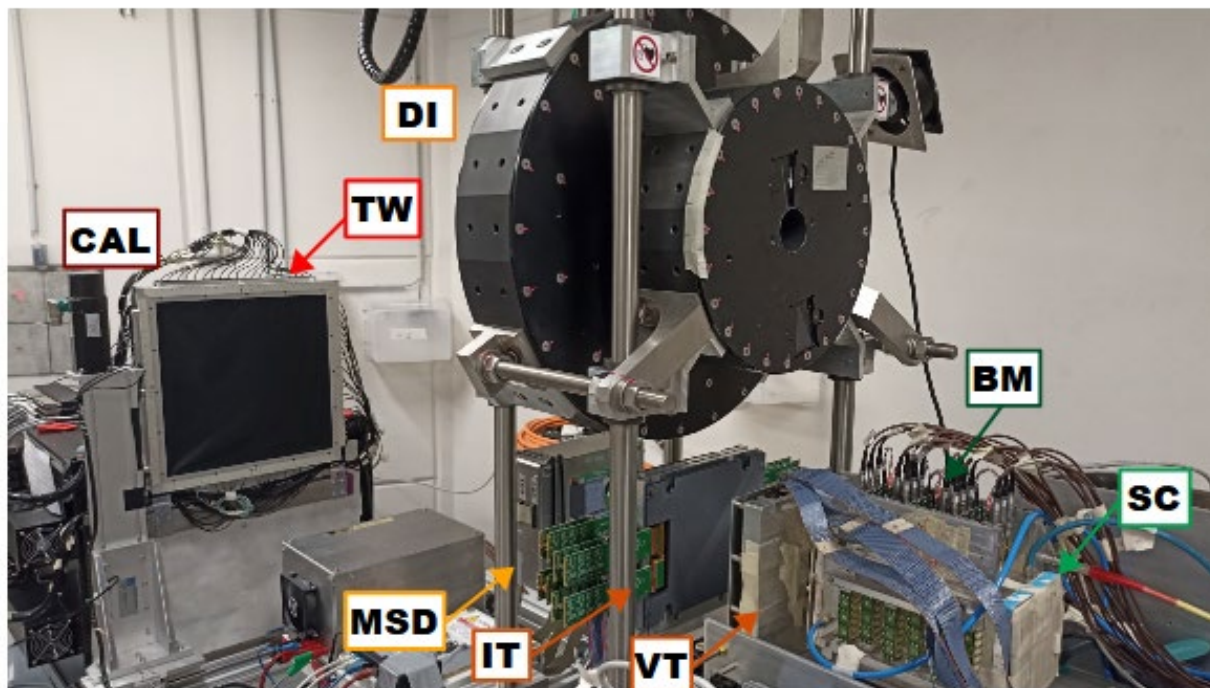
E.g. C + C → 3α + X

Physics data taking done up to now



Beam	Target	Energy MeV/u	Statistics (millions)	Integral Differential elemental	Integral Differential isotopic	direct	inverse	Emulsions	campaign
O	C C2H4	200 400	0.06	angle	NO	YES	NO	Yes Yes	GSI 2019 GSI 2020
O	C C2H4 C C2H4	200 200 400 400	14.2 12.2 5.5 6.5	angle	NO	YES	NO	Yes	GSI 2021
He	C	100 140 200 220	18.5 19.6 13.5 14.4	angle	NO	YES	NO	No	HEID 2022
C	C	200	4.1	angle	NO	YES	NO		CNAO 2022
C	C C2H4	200 200	3.2 2.0	Angle Energy	YES	YES	YES	Yes	CNAO 2023

Detectors from CNAO 2023



Tools



- **Monte Carlo:**
 - Continuously evolving and following the different set-ups used in data takings or contributing to the definition of the set-ups!
- **Trigger and Data Acquisition:**
 - Evolving with time and detectors on the beam line
 - More online controls; not yet finished!
- **Reconstruction software:**
 - Shoe: continuous development. Not at all an easy task!
 - Tuning at each data taking (alignment, noise, detectors on the beam line.....).
 - Emulsions: properly running. NIT reco ongoing

Tools are being used to get some physics!



Many calibration studies and analyses ongoing



- Really too many to mention!
- We'll get the details in this meeting

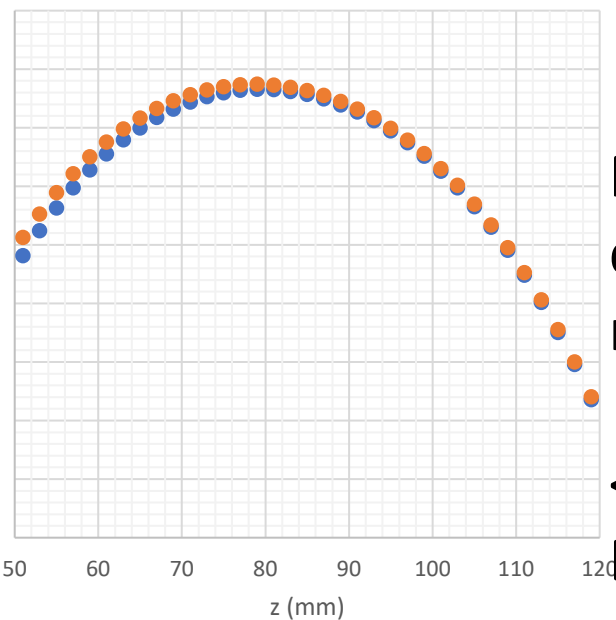
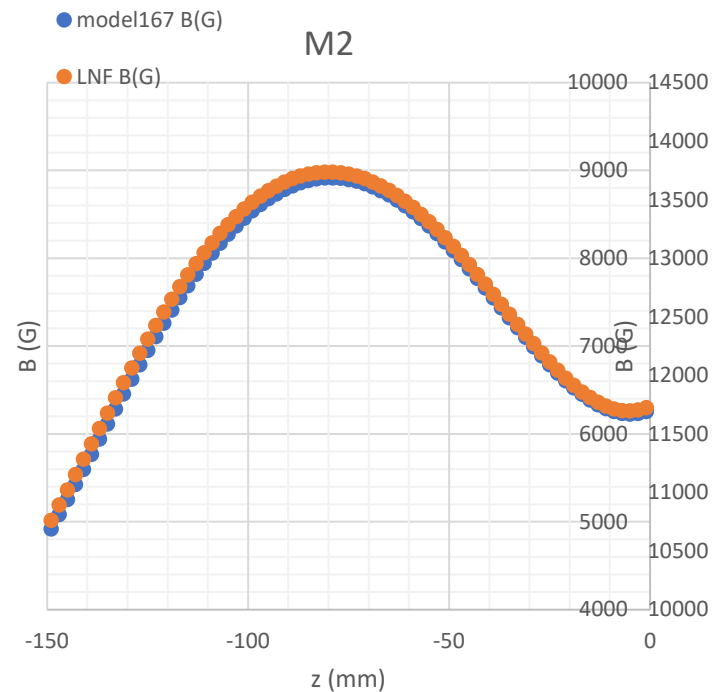
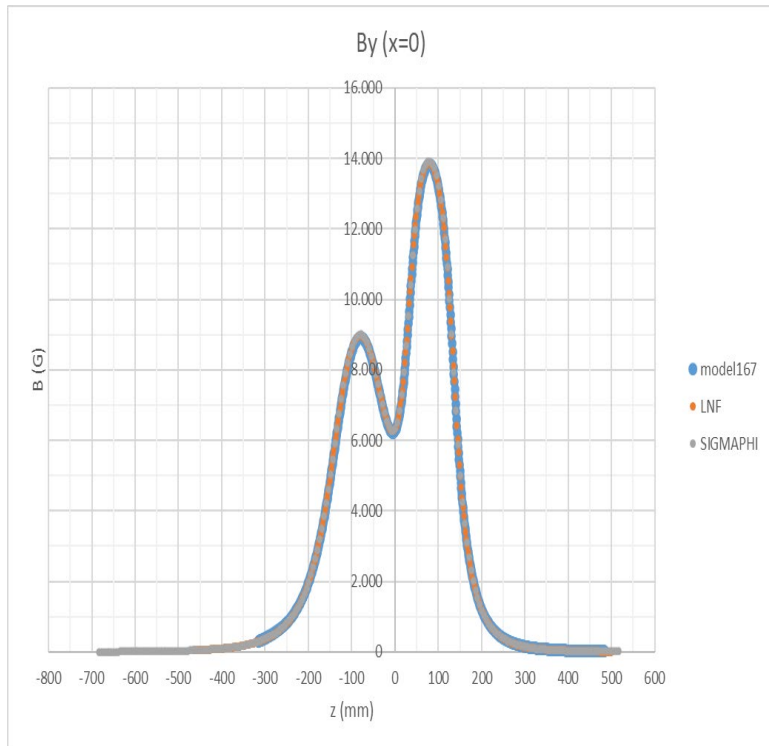
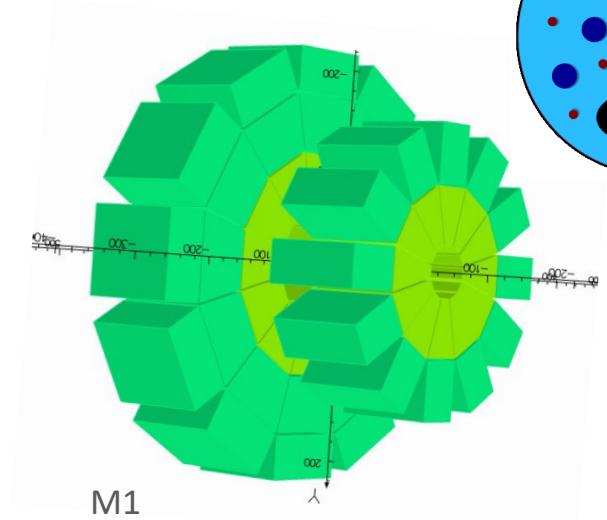
- Down here just a random selection

LNF measurements.

3D mechanical and magnetic model



- Needed several iteration to get the real «as built»
- Several tests for different «real positions» of M1 & M2
- Permanent magnets BH curves from producer.



Max 2%
disagree
ment.

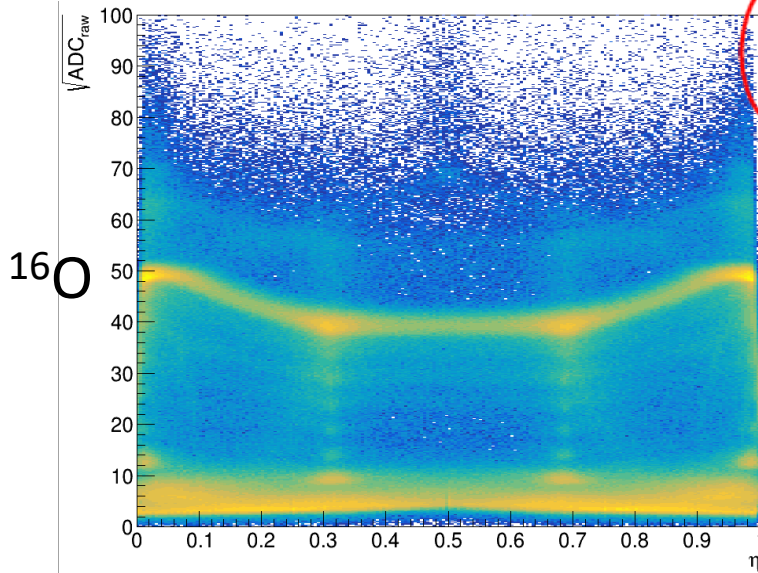
<0.5% at
B max

MSD: η correction applied to energy measurement!



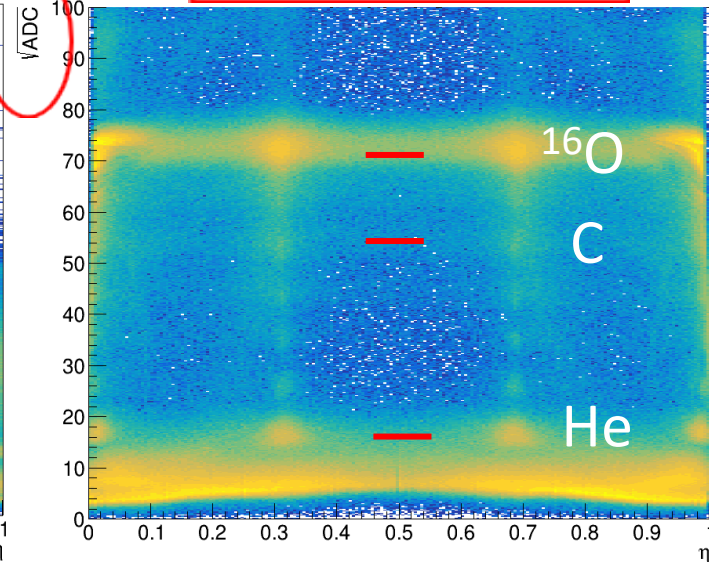
Apply η -correction \rightarrow Sensor response correctly flattened!!

Un-calibrated

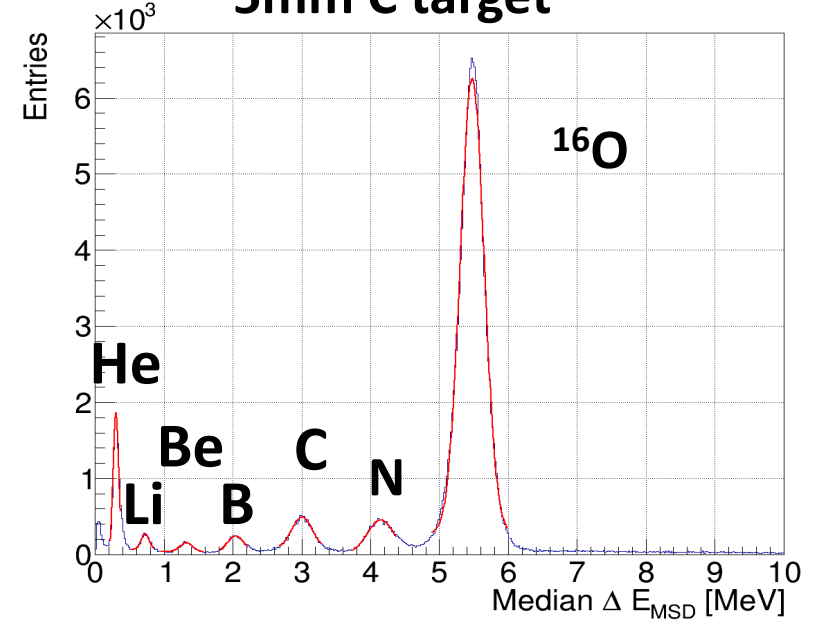


$$\sqrt{\Delta E (\text{keV})} \propto Q$$

η -calibrated



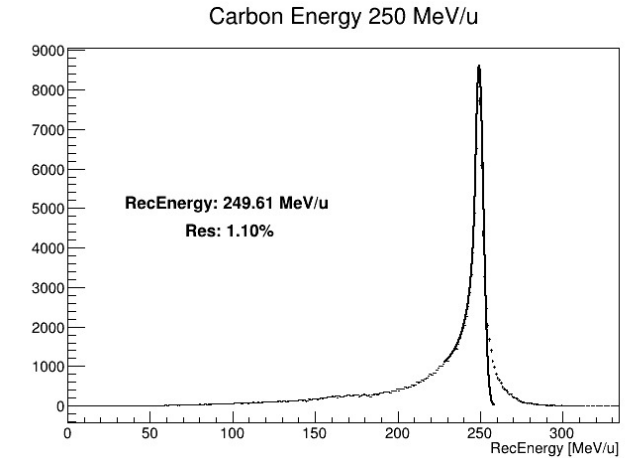
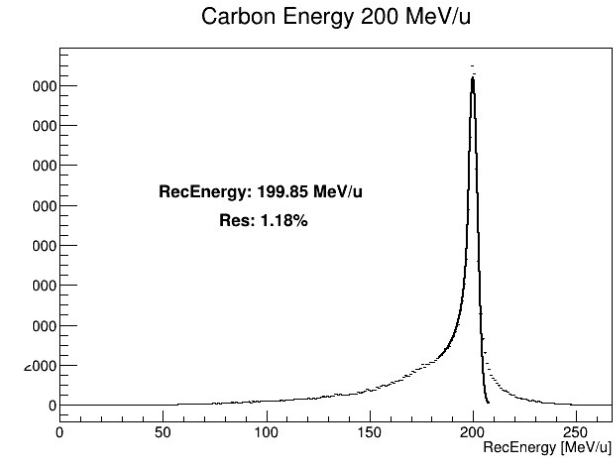
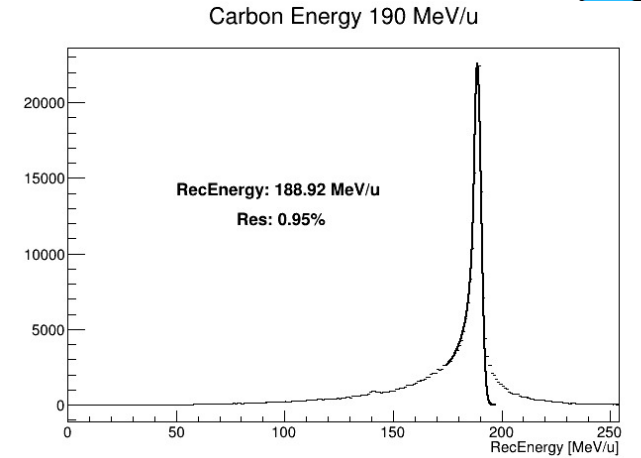
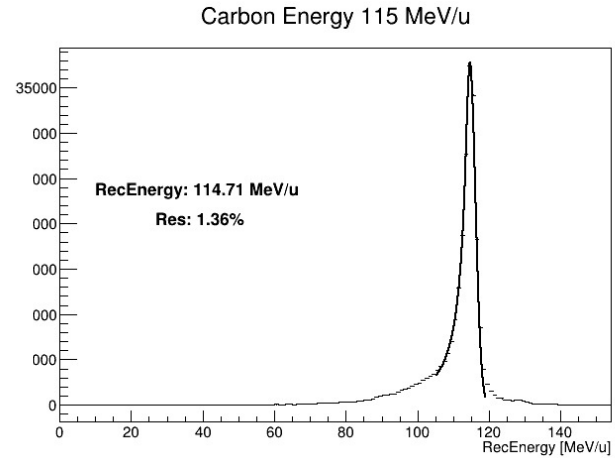
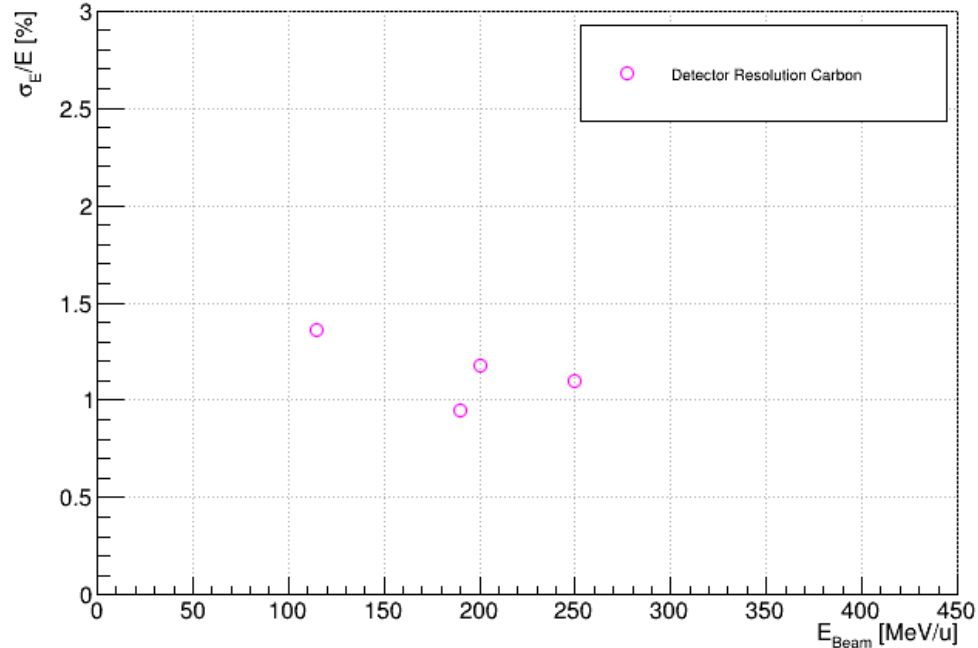
^{16}O @ 400 MeV/u
5mm C target



Median ΔE on a track

In-flight interactions can be well identified if they happens after MSD

Calorimeter Resolution



After equalization the integrated energy resolution is **~1%**

Monte Carlo tuning on data with magnet

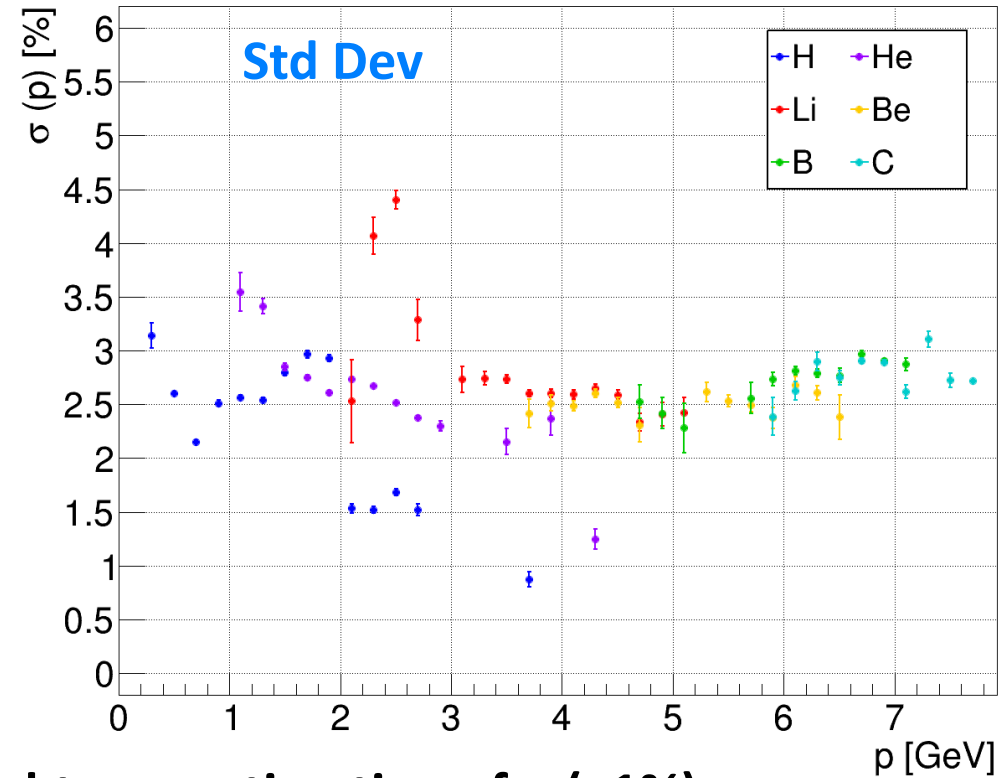
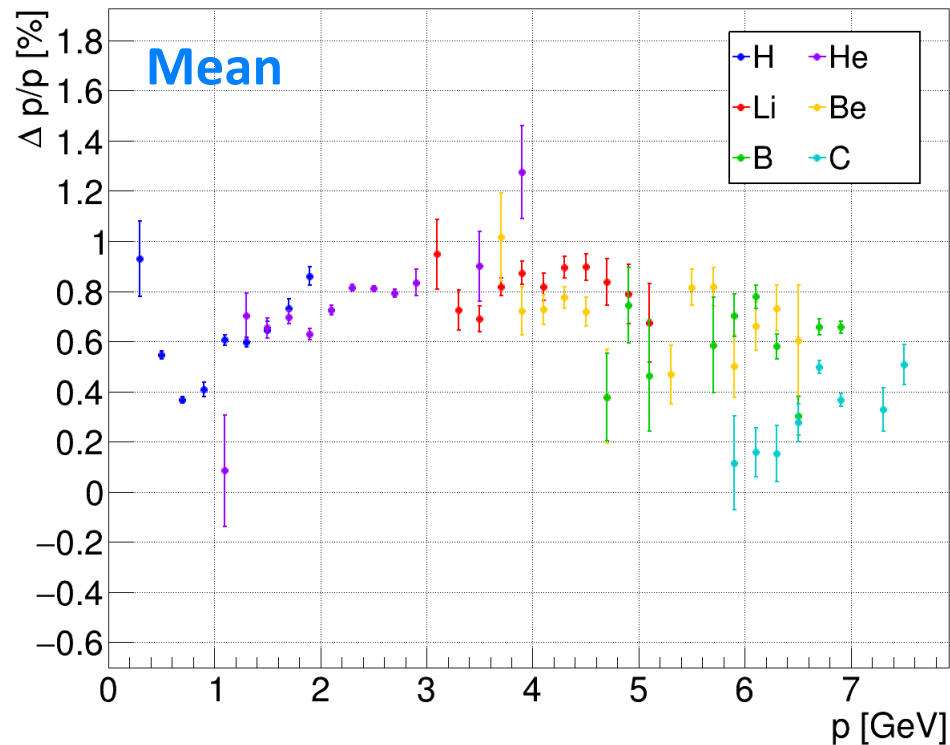


- A lot of effort to include all detectors in tracking.

A Runge-Kutta-Nystrom Kalman filtering fully implemented.

$$\frac{\Delta p}{p} = \frac{p_{preco} - p_{MC}}{p_{MC}}$$

Momentum resolution @ vertex

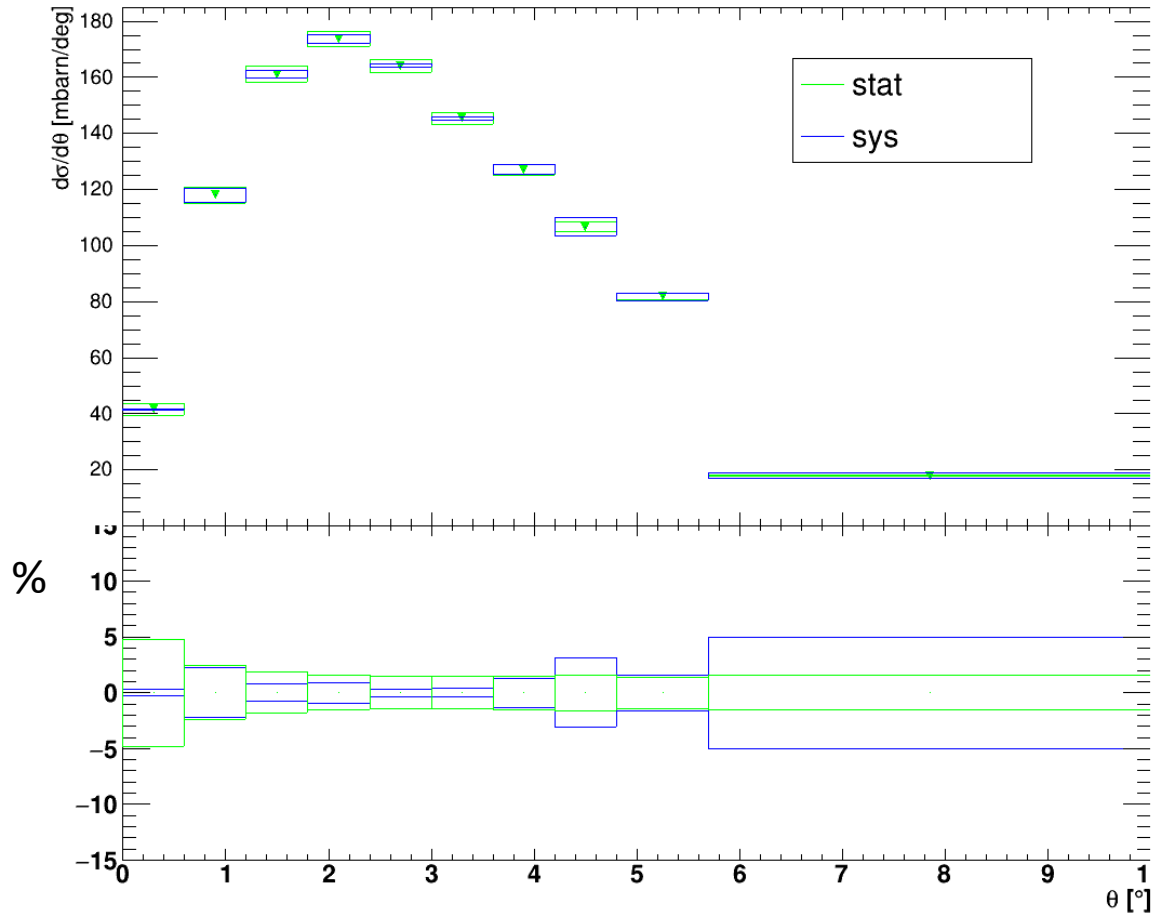


Slight overestimation of p (<1%)

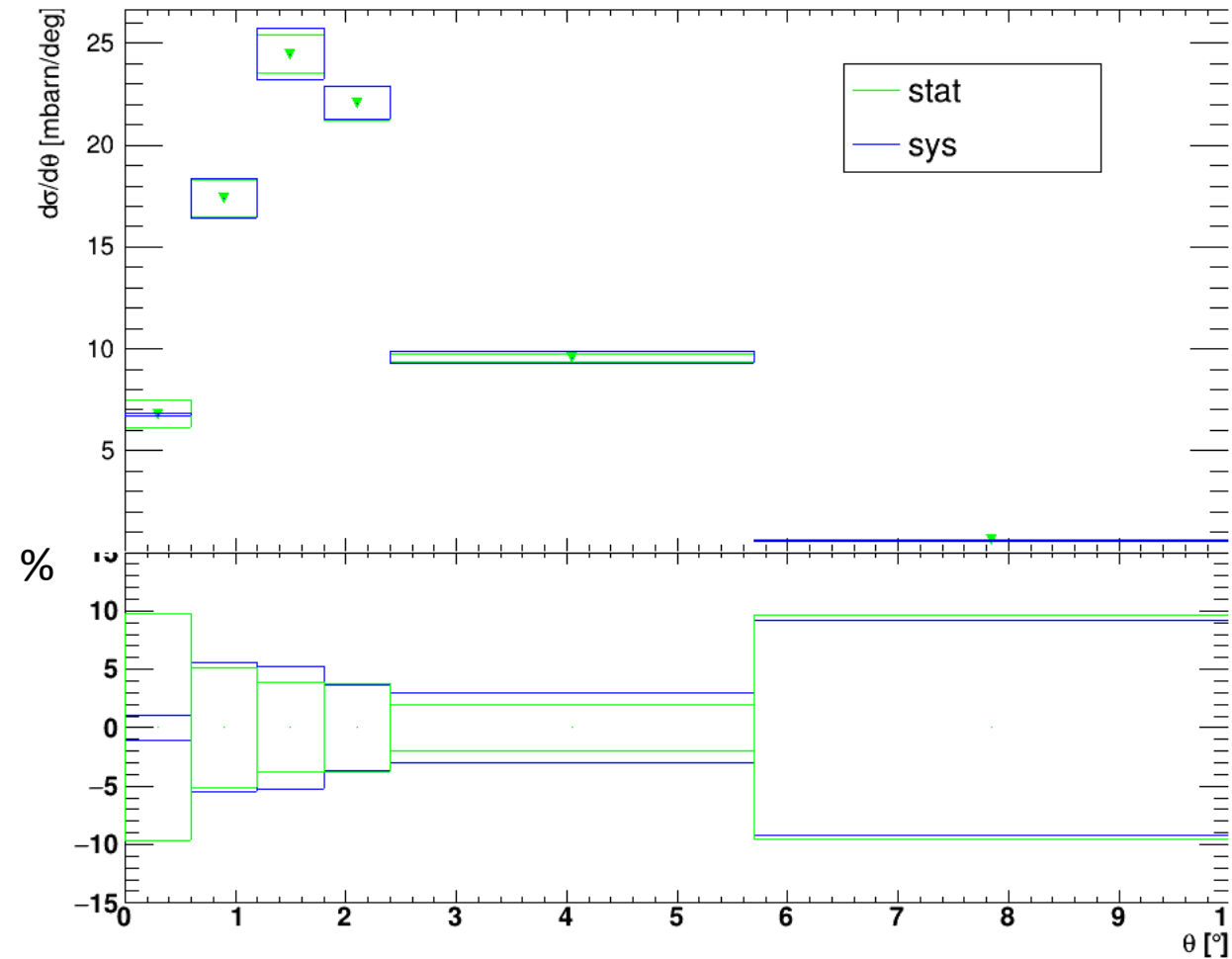
p resolution $\sim 2.5\%$ in the whole energy range (TDR goal: <4%)

Results on GSI 2021 O+C, 400 MeV/N $\sigma_{frag}(Z) \frac{d\sigma_{frag}(Z)}{d\theta} \quad Z < 8$

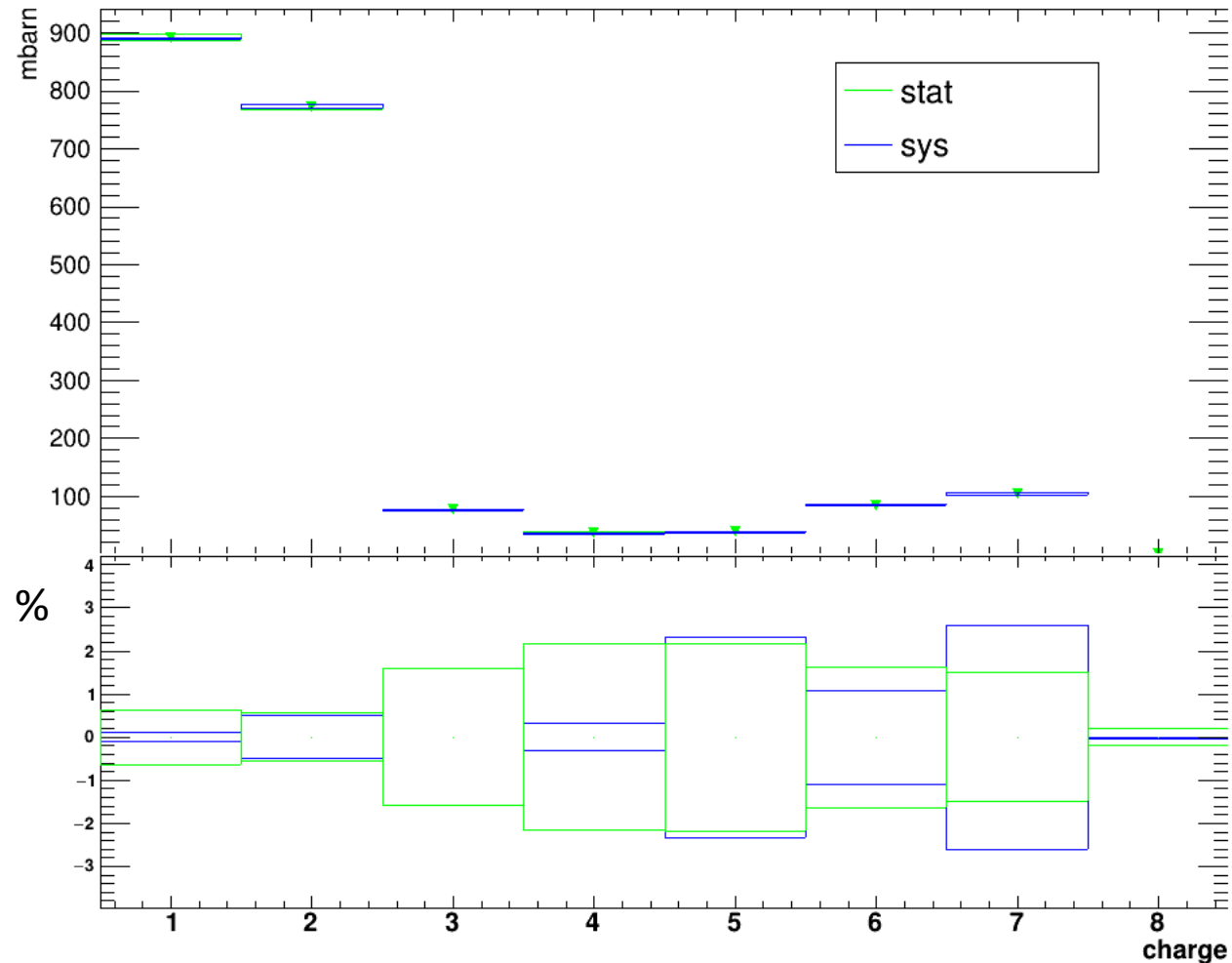
Z=2



Z=3



Integral cross section GSI 2021 – O+C 400 MeV

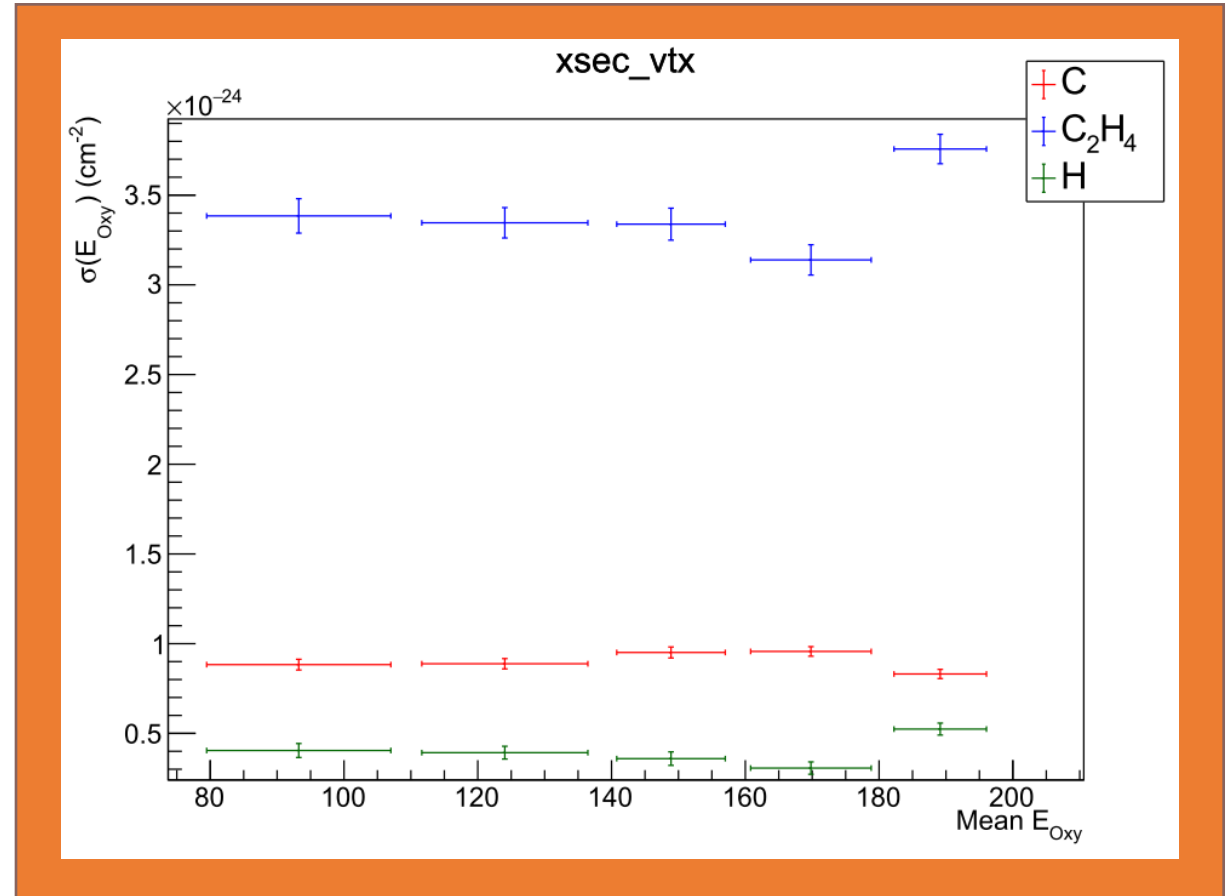


Paper in the writing stage
Uncertainties on cross sections
(much) lower than 5%

Analysis extension to the O+CH₂
And extraction of O+H cross section
Under way

Emulsions: data analysis and cross section measurement

- Analysis of ^{16}O @ 200 MeV/n on C and C_2H_4 targets almost completed:
 - Improvements in data-driven effects added on Monte Carlo reconstruction (background, misalignments, local distortion due to chemical development...)
 - Evaluation of total and reaction cross sections
- Paper on cross section measurements with ^{16}O at 200 MeV/n on C, C_2H_4 and H **in preparation**



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A general comment

- We have an abundance problem: too many data sets
- Still working on data from 2021 and earlier, while we have two samples in 2022 and one «engineering run» (good for physics) in 2023.
- I would welcome if more people decide to be involved in the analyses, but I also know duties and opportunities in other fields (i.e. calibration, prins, ...)
- The 2024 CNAO data taking will likely be detuned to be detector understanding only (or mostly). A physics data taking will come soon after.

CSN3 is asking us a three year plan ...



Beam	Target	Energy MeV/u	Integral Differential elemental	Integral Differential isotopic	direct	inverse	Emulsions	Campaign
O	C	500	Angle Energy	YES	YES	YES	YES	GSI 2025
C	C C2H4	100- 200	Angle Energy	YES	YES	YES	YES (NIT?)	CNAO 2025
C	C C2H4	200- 440	Angle Energy	YES	YES	YES	NIT	CNAO 2026
C	C C2H4	700	Angle Energy	YES	YES	YES	YES	GSI 2027



Foreseeable requests:

2025: 240 k€ - at GSI with part of MAECI funds

2026: 230 k€ - no external funding

2027: 270 k€ - no external funding





MAECI PROJECT: Measuring Oxygen Fragmentation For Improved Ion Therapy Strategies (MOFFIITS)

- Decided to measure cross sections in the «high» energy range:
 ^{16}O on C, CH_2 at 500 MeV/N, 32 h of beam
- Use of the Cave A – currently studying the optimal detector geometry
- MC generation will follow soon
- Foreseen data taking period: feb-jun 2025 (!) It might be early for new detectors (TW, New vertex)
- People: 3 Post doc bourses (12-18 months) opened in To, Na, Bo
(and still looking for a hardware-oriented person in LNF)

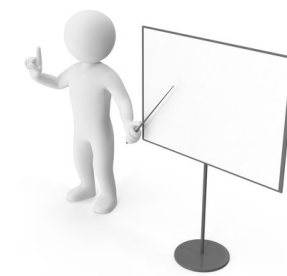
FOOT impact on the community



Activities ongoing on several fronts:

- Many are involved in PRIN 2022 (9!) activities and
 - in the MAECI Project
 - Detector calibration & understanding
 - Analyses
-
- Present at the Nuclear Physics Mid Term Plan & Sesto Incontro Nazionale di Fisica Nucleare (Trento)
 - Paper and conference proceedings
 - Proposal writing
 - No proposal in writing or in the waiting stage *at the moment*.
 - *Good: we're fully booked till 2026!!*

All these activities are signs of a healthy and active collaboration!



Time to start the meeting!



- Please stay in the allocated time
- Please upload your presentation as soon as possible
- Have a fruitfull meeting!