AdS 28/3/2022

FOOT (FragmentatiOn Of Target):

Adroterapia e Radioprotezione Spaziale in un esperimento

spighi@bo.infn.it

FOOT Collaboration

September 2017: approved experiment in CSN3

101 members (60% staff):

- 10 INFN Sections
- 5 laboratories:
  - Frascati, CNAO, Trento, GSI,IPHC (Strasbourg)
- 12 Italian Universities
- 3 foreign Universities: Aachen, Nagoya, Strasbourg
- Centro Fermi

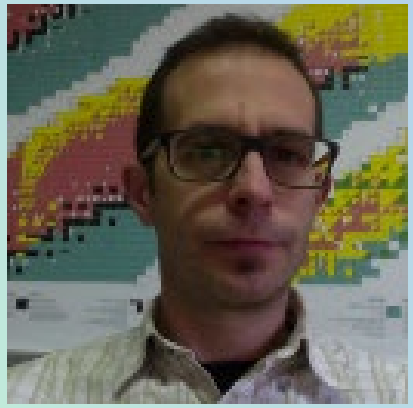
Graziano

Sofia

Matteo

Alice

Cristian



Riccardo

FOOT – BOLOGNA
12 membri (5.6 RE)

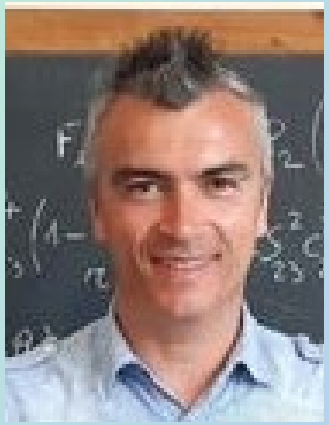
- **Spokesperson**
- **Physics coordinator**
- **DAQ and Trigger coordinator**

Antonio

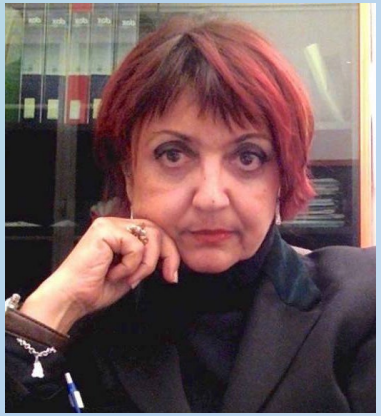
Roberto

Mauro

Roberto



Marco

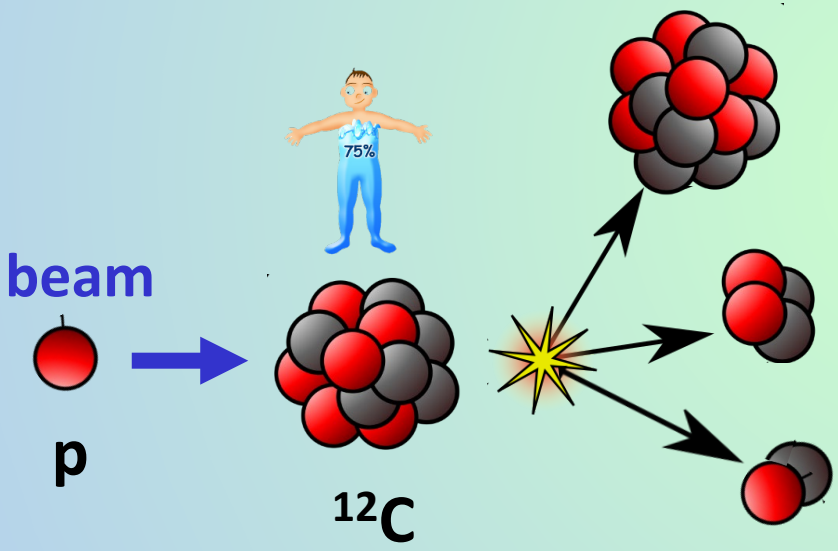


Gabriella

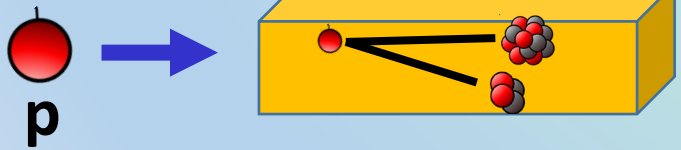
Hadrontherapy vs Radiotherapy

Pros and contra

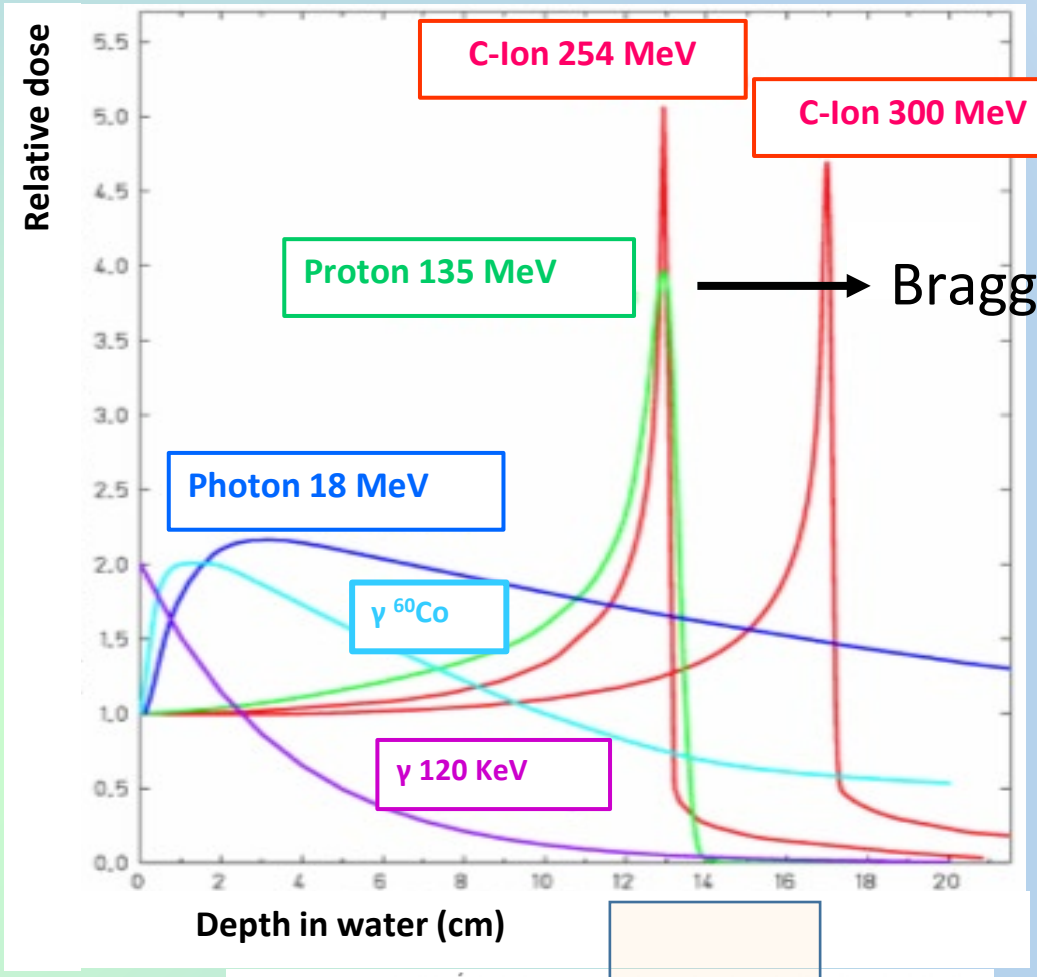
- Better dose profile from hadrons
- Penetration depends on energy
- MORE expensive than γ
- Nuclear effect not completely known

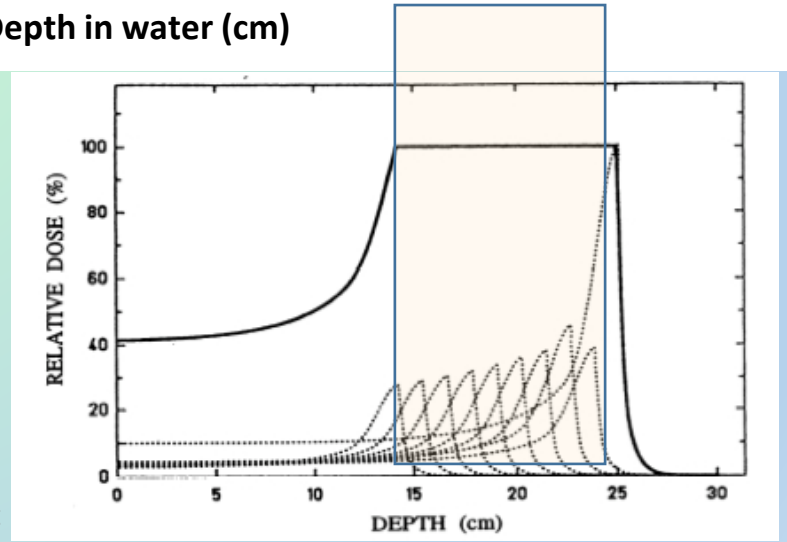


Target Fragmentation



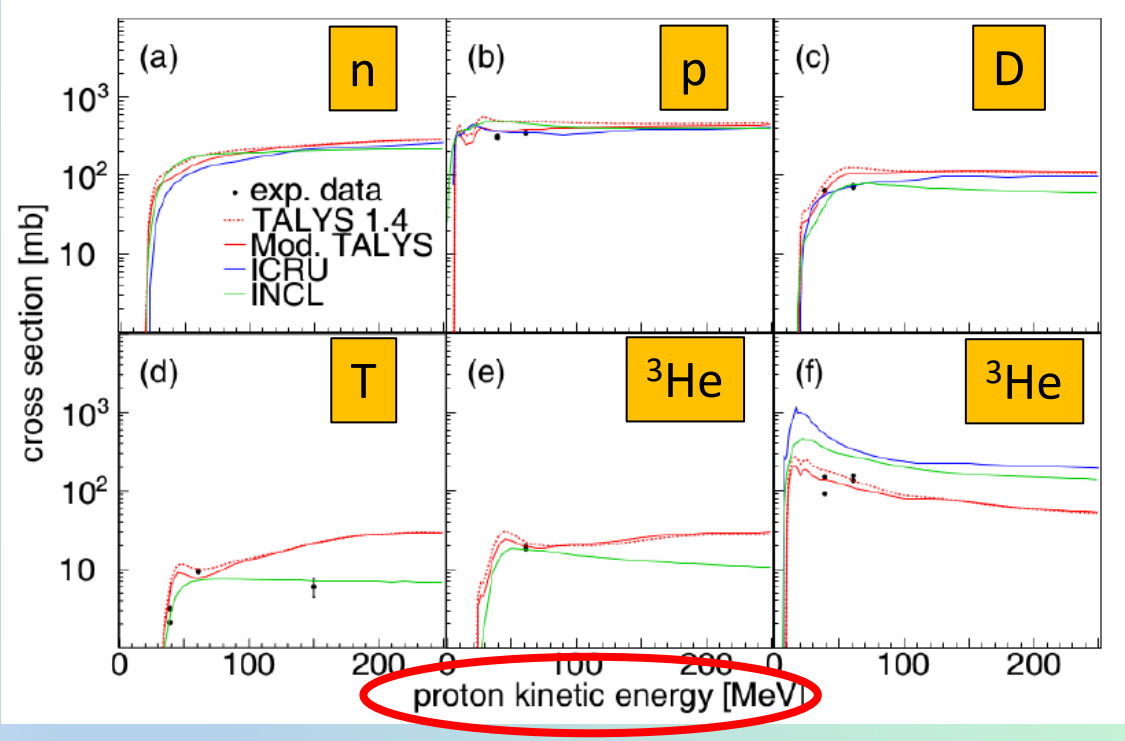
Do not leave the target

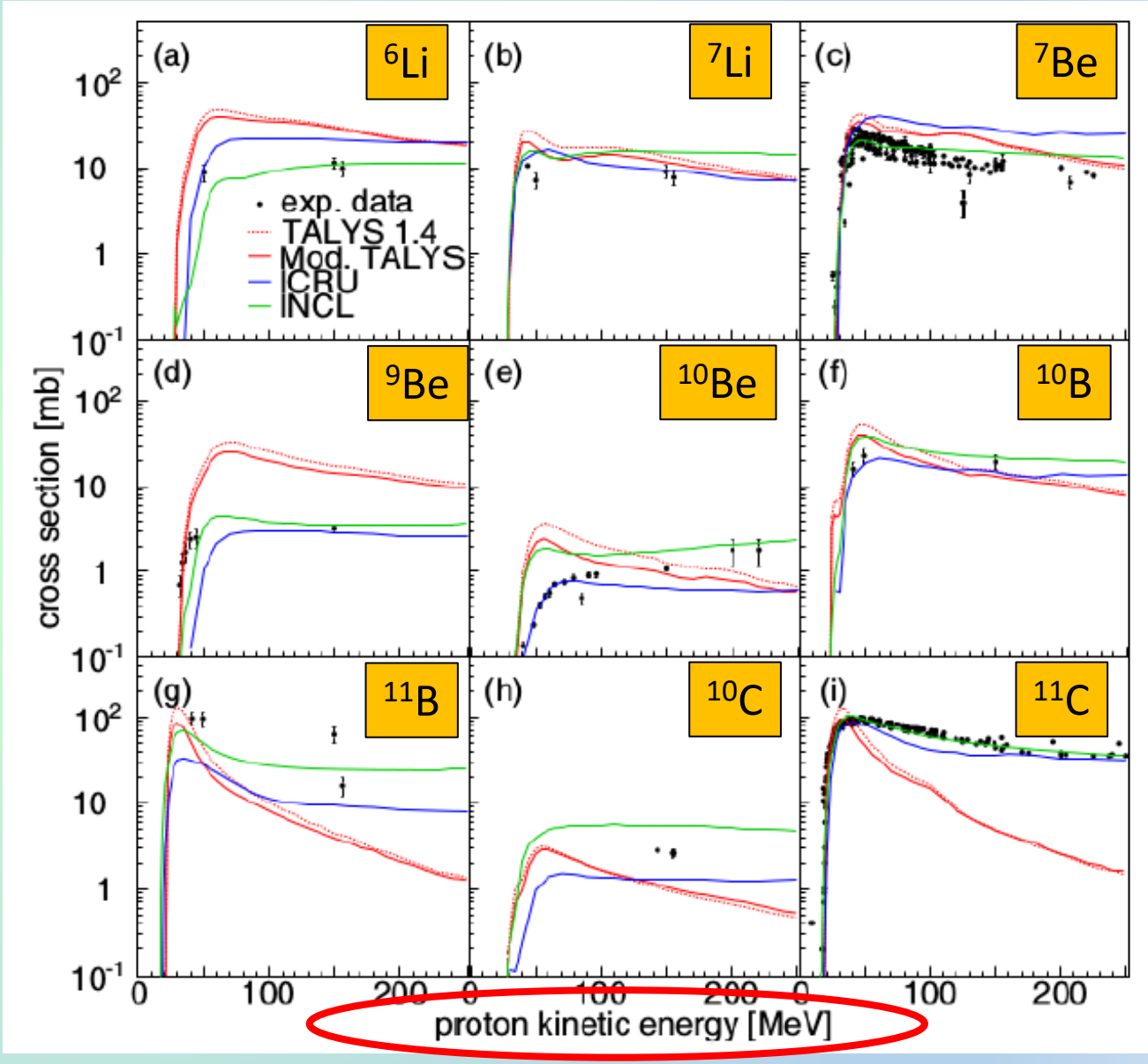




Experimental Nuclear proton cross section: p + ^{12}C → X: target fragmentation

Production of different fragment



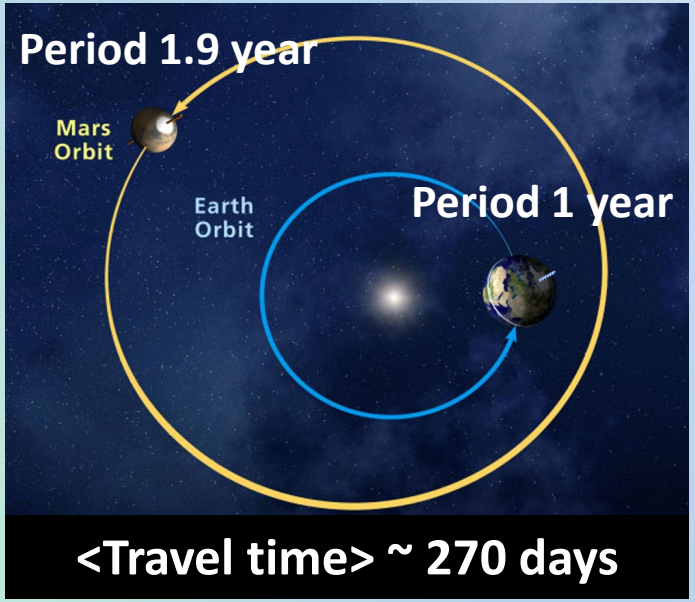


Useful to measure σ of each produced fragment wrt its energy (not beam energy)

Lack of measurements → FOOT

Mars mission: radio protection in space

Mars: NO magnetosphere and very thin atmosphere → **no protection from GCR and SPE**



<Travel time> ~ 270 days

Radiation (measured by MSL):

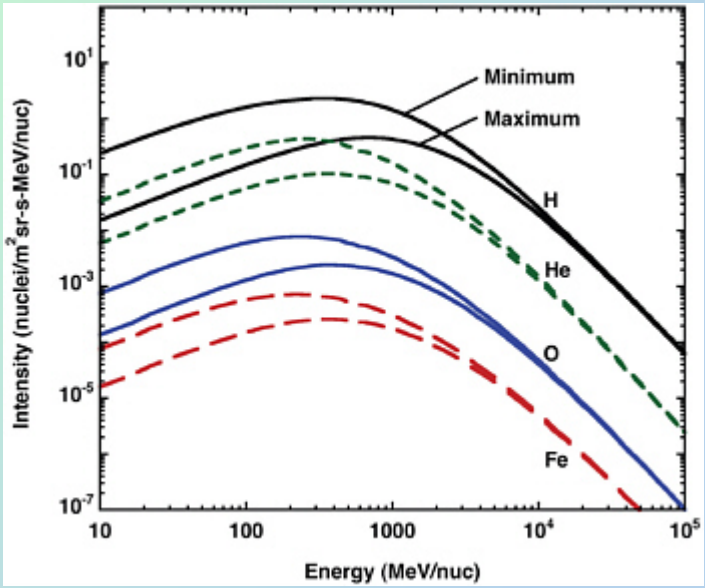
- **Travel: 700 mSv/year (GCR + SPE)**
- **On Mars: 200 mSv/year**

→ $\frac{Rad\ on\ Mars}{Rad\ on\ Earth} = \sim 300$

- **On earth: 2 mSv/year**

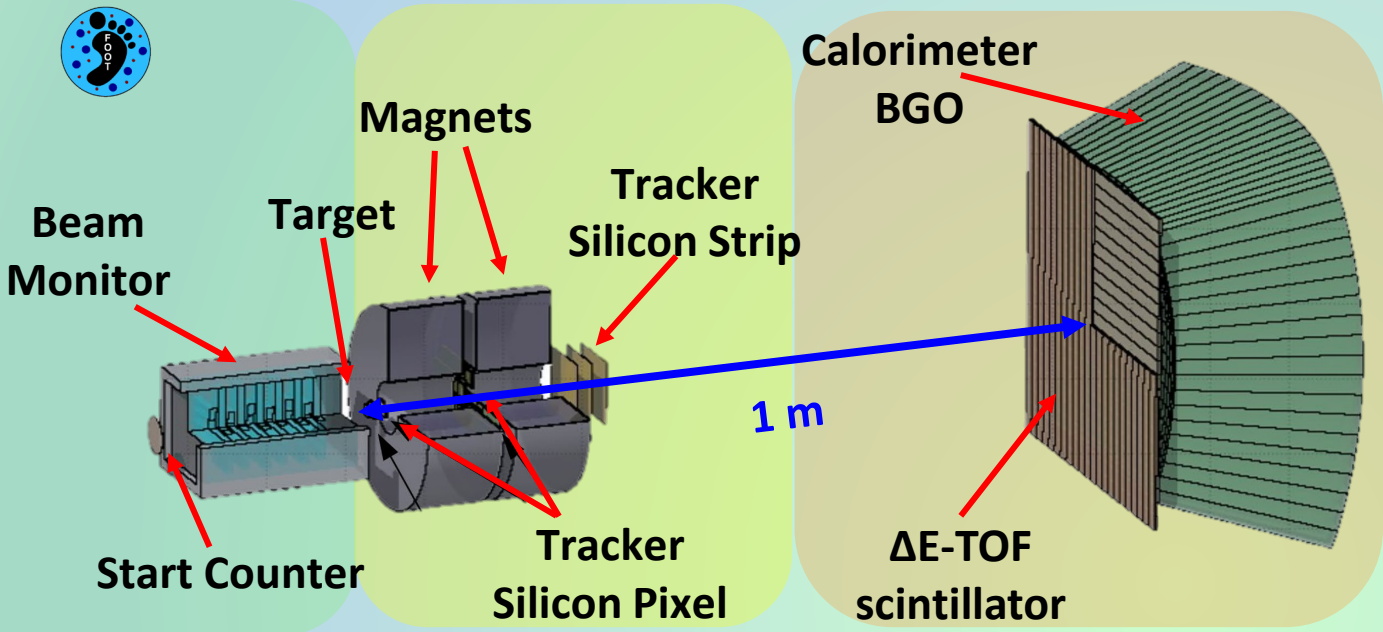
↓

shielding is needed (interaction on it?)



Electronic Setup

FOOT Detector

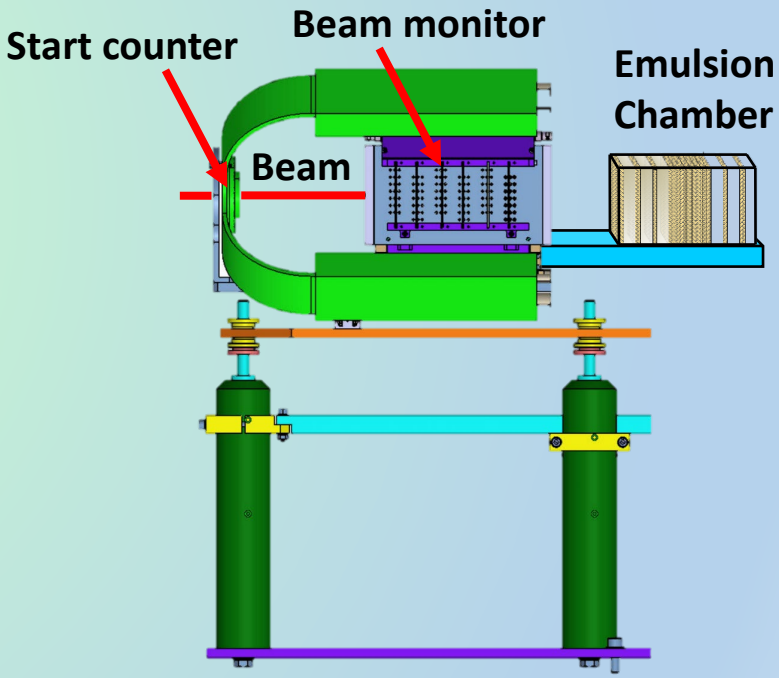


Pre-target region | **Tracking region** | **downstream region**

- STC
- BM
- VTX
- ITR
- MSD
- MAGNET
- TOF-WALL
- CAL
- TDAQ

DESIGNED AND DEVELOPED BY BOLOGNA GROUP

Emulsion Chamber Setup

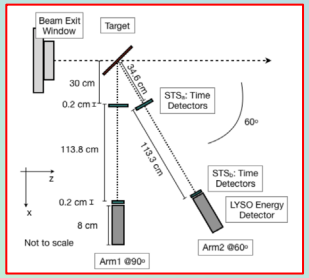


COMPLETED

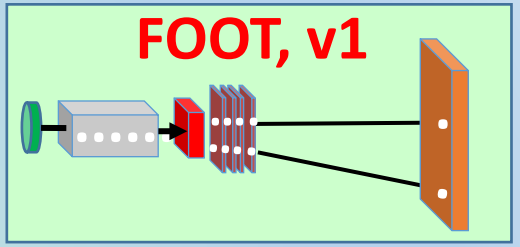
Acquired Data (for physics)

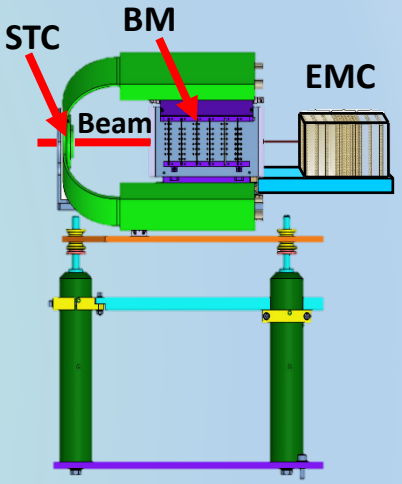
- **CNAO 2017**
  - **FOOT prototype:** ^{12}C (≠ energies) on C, O, H
- **GSI 2019**
  - **Electronic Setup:** ^{16}O(400 MeV/u) on C ~60k min bias evts
  - **Emulsion chamber:** ^{16}O(200 & 400 MeV/u) on C, C_2H_4 ~300K interacting evts
- **GSI 2020**
  - **Emulsion chamber:** ^{12}C(700 MeV/u) on C, C_2H_4 ~$300 \cdot 10^3$ interacting evts
- **GSI 2021**
  - **Electronic Setup:** ^{16}O(200 & 400 MeV/u) on C, C_2H_4 ~ $41 \cdot 10^6$ mb&trig evts
  - **Neutron Setup :** ^{16}O(200 & 400 MeV/u) on C, C_2H_4 ~$20 \cdot 10^3$ mb&trig evts
- **CNAO 2021**
  - **STC, TW, CALO:** ^{12}C(200 MeV/u) on C, C_2H_4 ~$10 \cdot 10^6$ mb & trig evts
- **HEIDELBERG: june 2022, ^4He**
- **CNAO: winter 2022**

FOOT, v0

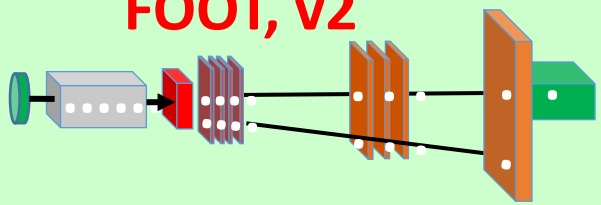


FOOT, v1

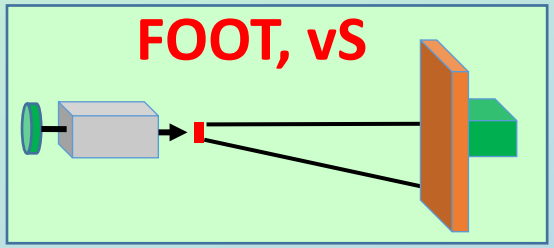


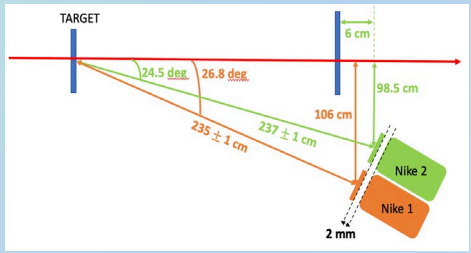


FOOT, v2

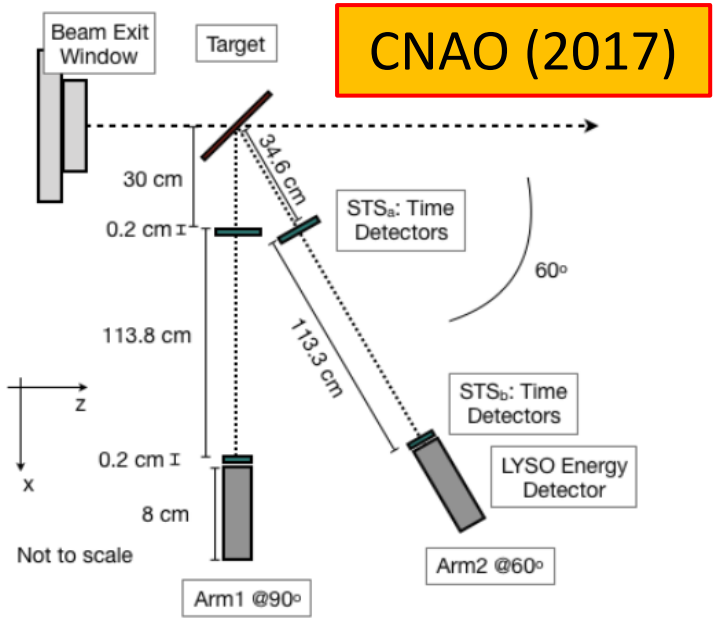


FOOT, vS



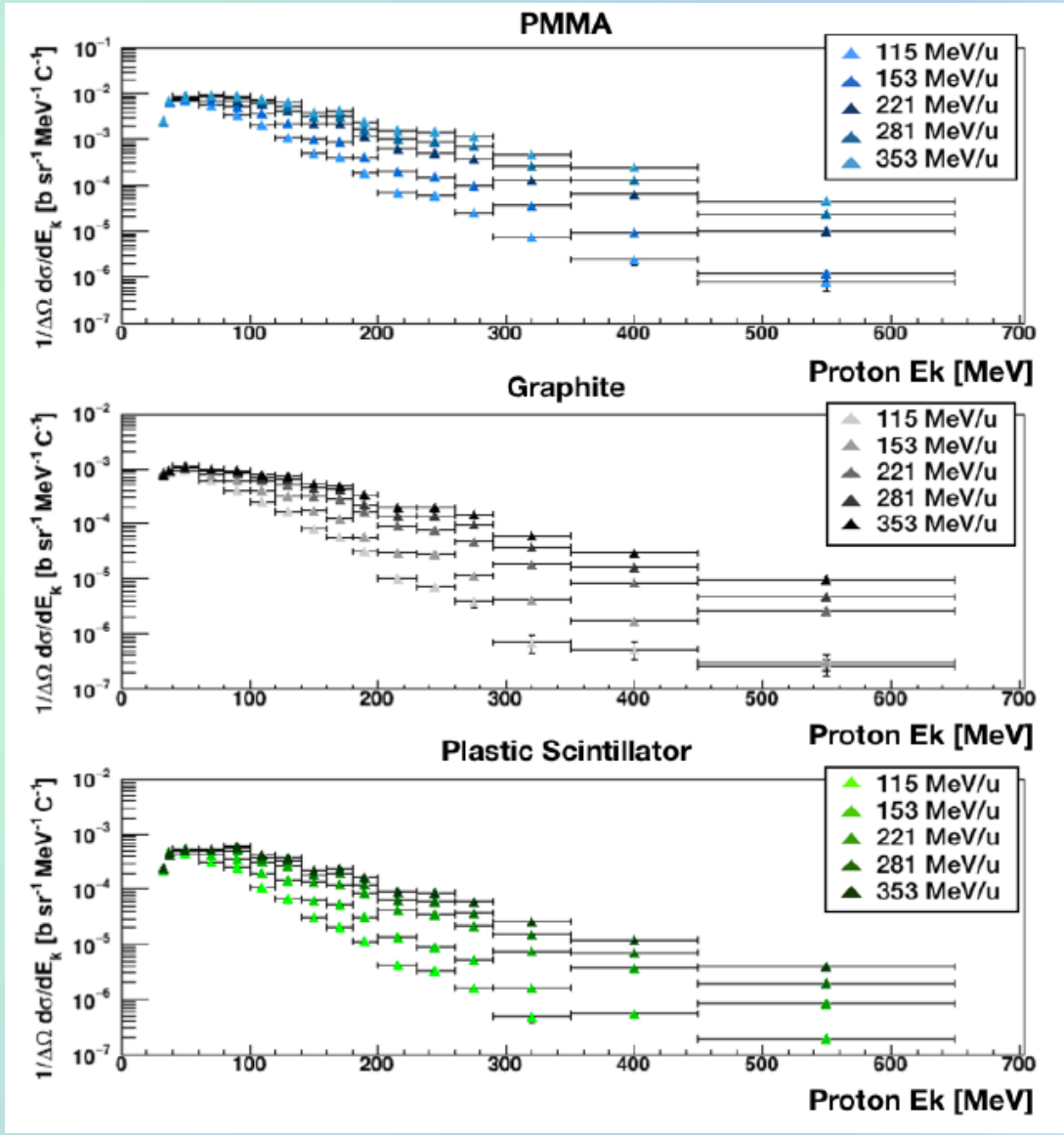


Cross sections measurements



diff Xsec for *p, d, T*
@ 60 and 90° in C,O,H

Differential Cross Section for *p production*



This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/TRPMS.2020.2972197, IEEE Transactions on Radiation and Plasma Medical Sciences

Measurement of ^{12}C Fragmentation Cross Sections on C, O and H in the Energy Range of interest for Particle Therapy Applications.

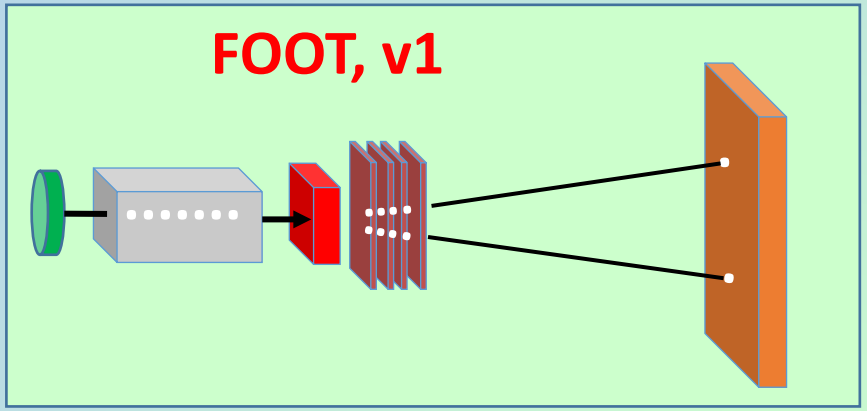
I. Mattei[1], A. Alexandrov[6], L. Alunni Solestizi[21,7], G. Ambrosi[7], S. Argirò[8,9], N. Bartosik [8], G. Battistoni [1], [13], M.G. Bisogni[10,11], G. Bruni[12], N. Camarlinghi[10,11], P. Carra[10,11], E. Catanzani Cerello[8], A. Clozza[14], S. Colombi[15,16], G. De Lellis[6,17,32], A. Del Guerra[10,11], [17,6], M. Donetti[18,8], Y. Dong[1,19], M. Durante[15], A. Embriaco[1], M. Emde[20],

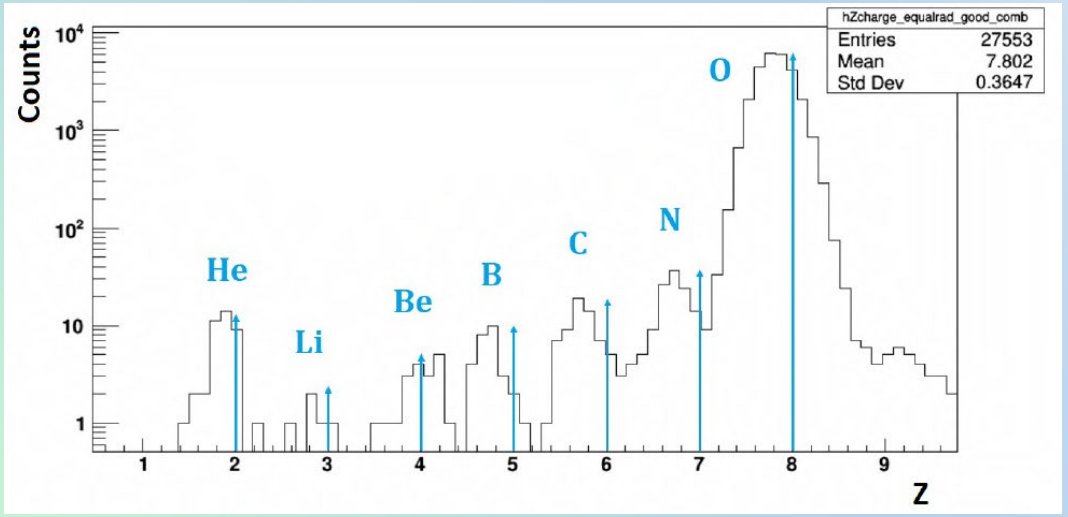
Pub: 2020

Transaction on Radiation and Plasma Medical Science

Elemental Cross Sections measurements

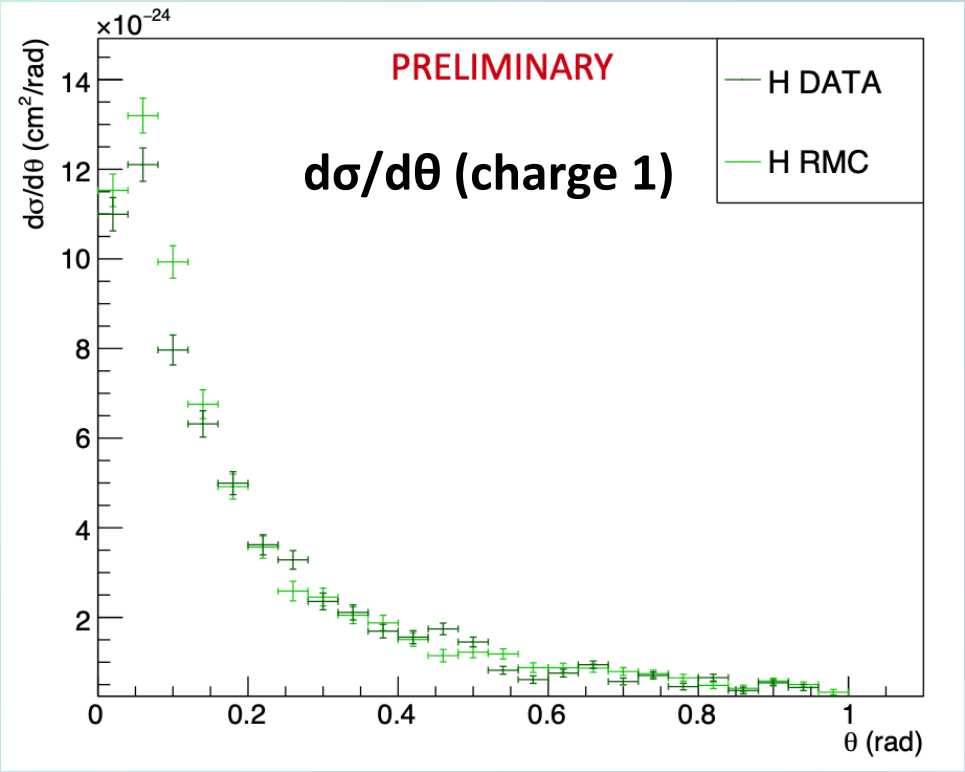
GSI 2019





Integral & differential Elemental Xsec

Element	$\sigma_{frag} \pm \Delta_{stat} \pm \Delta_{sys} [mbarn]$	$\Delta_{stat}/\sigma_{frag}$	$\Delta_{sys}/\sigma_{frag}$
He	$625 \pm 22 \pm 21$	3.6%	3.6%
Li	$85 \pm 10 \pm 5$	11.9%	5.6%
Be	$31 \pm 10 \pm 3$	31.8%	8.8%
B	$70 \pm 10 \pm 5$	14.9%	7.3%
C	$113 \pm 12 \pm 3$	10.9%	2.7%
N	$101 \pm 14 \pm 5$	13.7%	4.8%



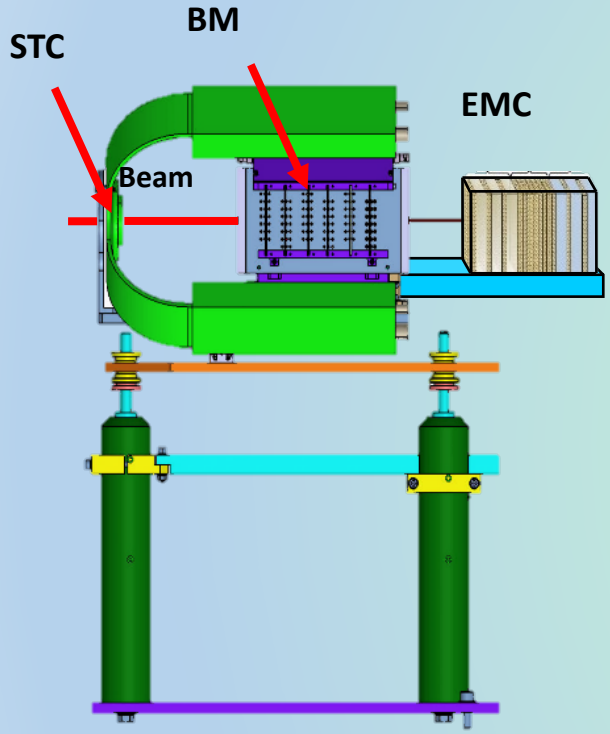
Poor statistics due to problem at the accelerator

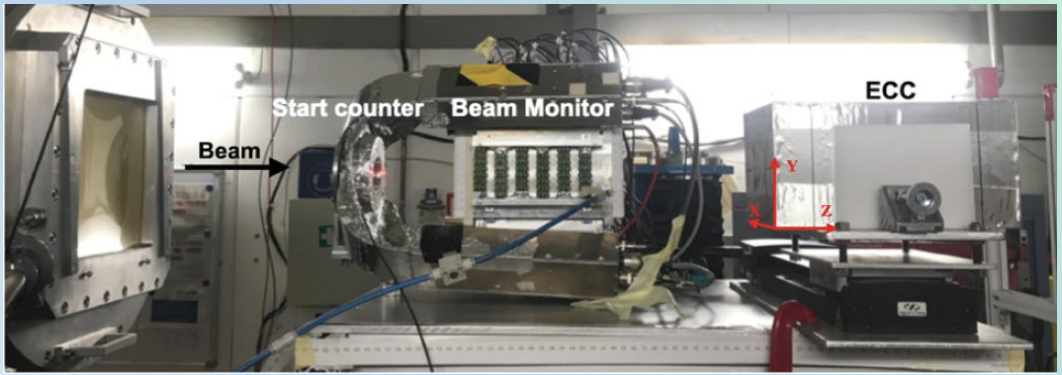
Paper in submission phase

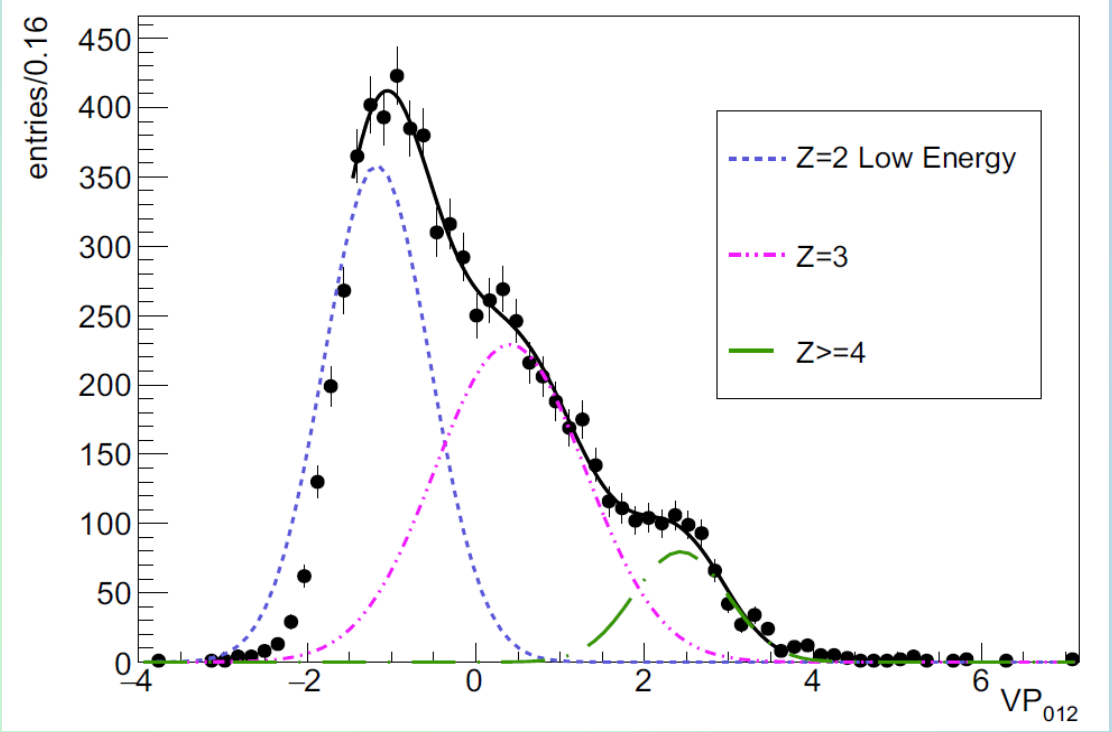
Light Fragment Identification

GSI 2019

EMULSION CHAMBERS







Marco Toppi, Giacomo Traini, Serena Marta Valle, Marie Vanstalle, Mauro Villa, Ulrich Weber, Roberto Zarrella, Antonio Zoccoli, and Giovanni De Lellis

Charge identification of fragments with the emulsion spectrometer of the FOOT experiment

https://doi.org/10.1515/phys-2021-0032
received December 03, 2020; accepted April 21, 2021

Abstract: The FOOT (FragmentatiOn Of Target) experi- … project designed to carry out … tional measurements relevant for charged particle therapy (CPT), a technique based on the use of charged particle beams for the treatment of deep-seated tumors. The FOOT detector consists of an electronic setup for the identification of $Z \geq 3$ fragments and an emulsion spectrometer for $Z \leq 3$ fragments. The first data taking was performed in 2019 at the GSI facility

Pub: 2021

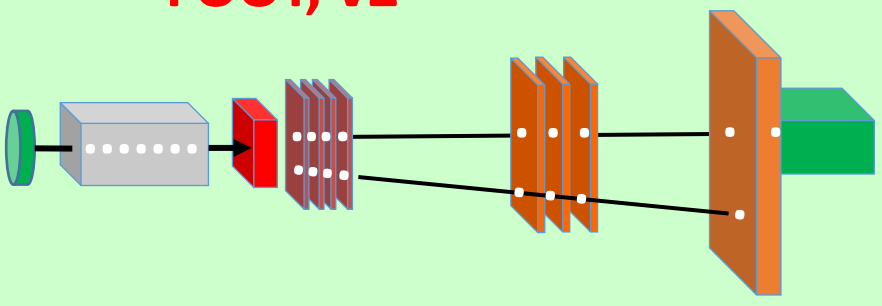
Open Physics

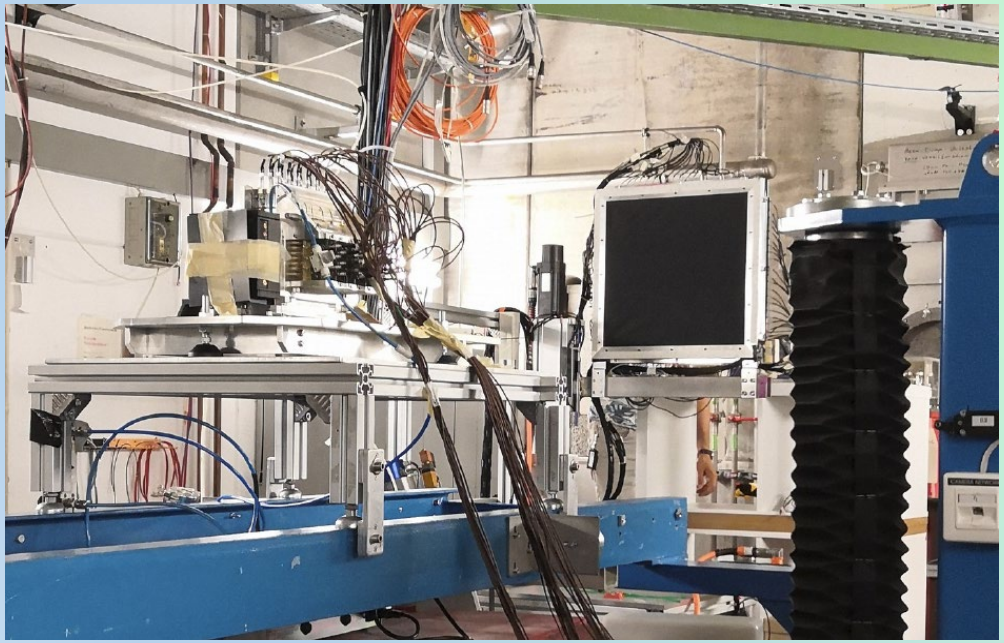
Ongoing Xsect of 2019-20 samples

Charged Fragment Identification

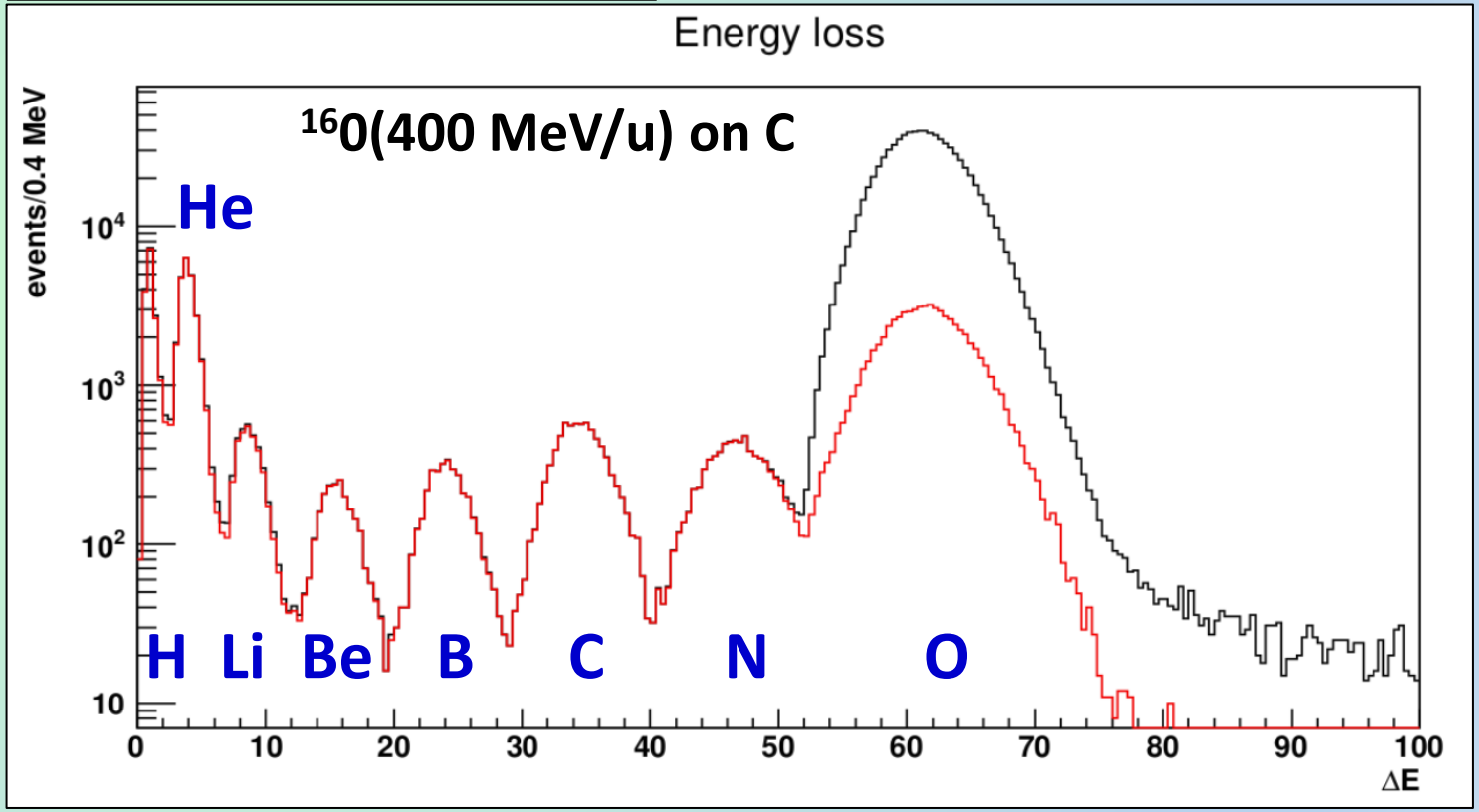
GSI 2021

FOOT, v2





Charge Identification



ANALYSIS PERFORMED BY BOLOGNA GROUP

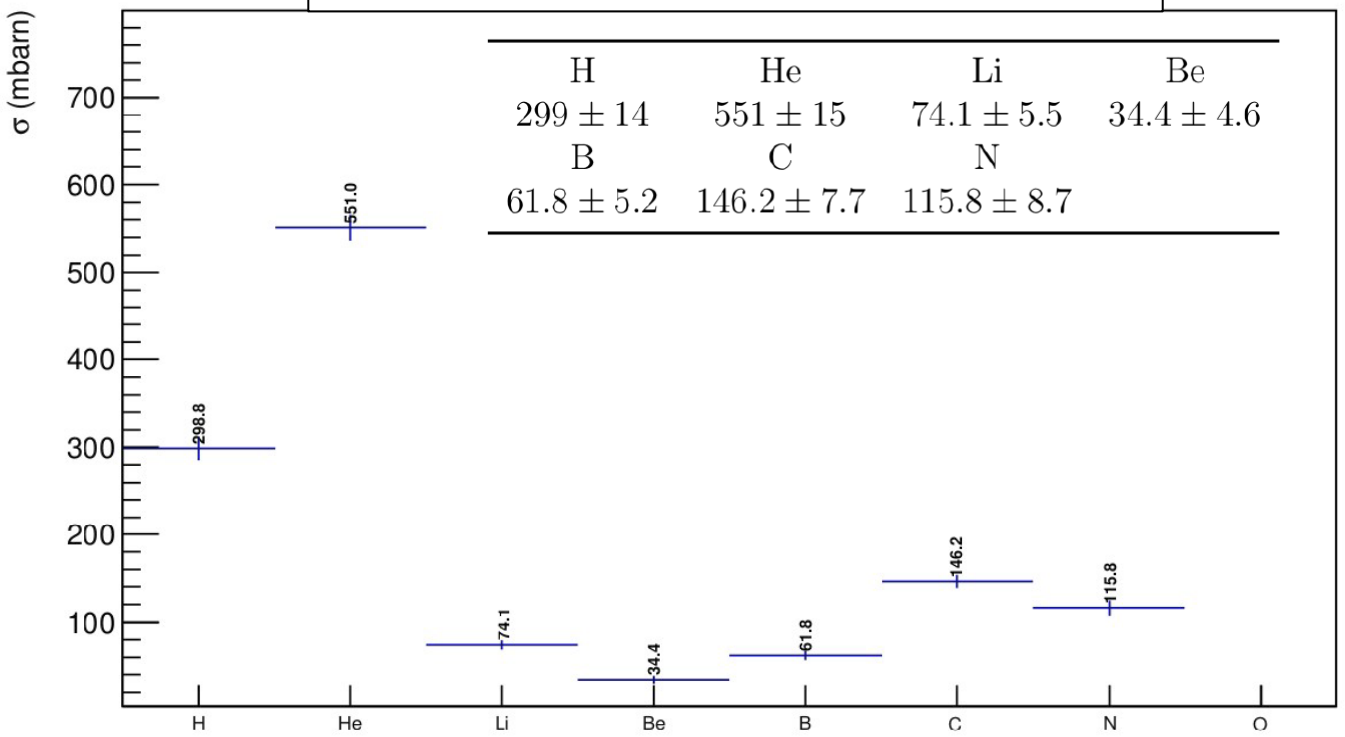
Elemental Intergral & Differential Cross Sections

GSI 2021

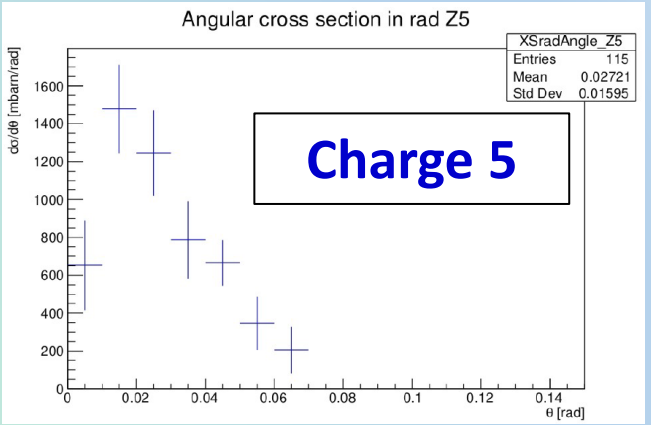
^{16}O(400 MeV/u) on C

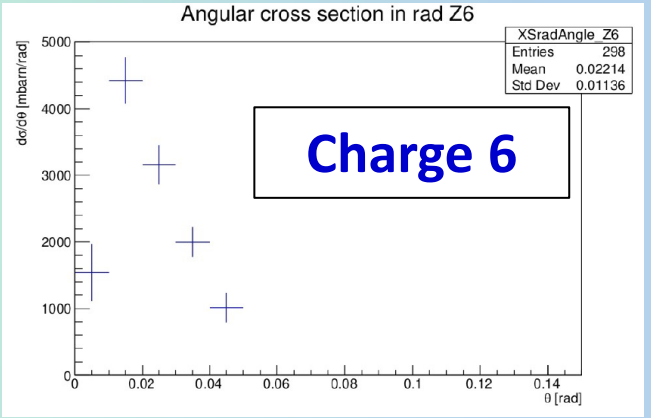
Integral Elemental Cross Section

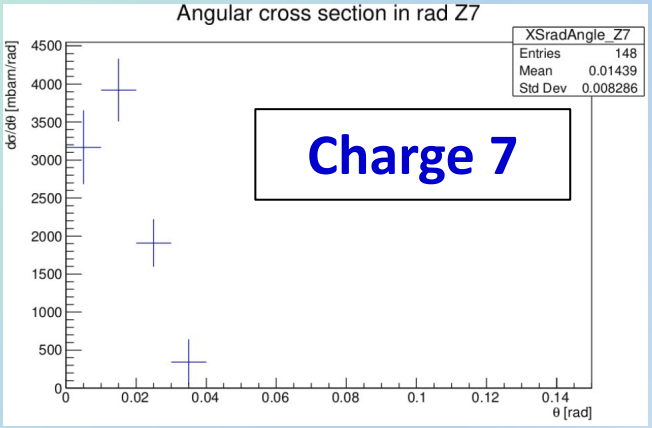
H	He	Li	Be
299 ± 14	551 ± 15	74.1 ± 5.5	34.4 ± 4.6
B	C	N	
61.8 ± 5.2	146.2 ± 7.7	115.8 ± 8.7	



Differential Angular Elemental Cross Section







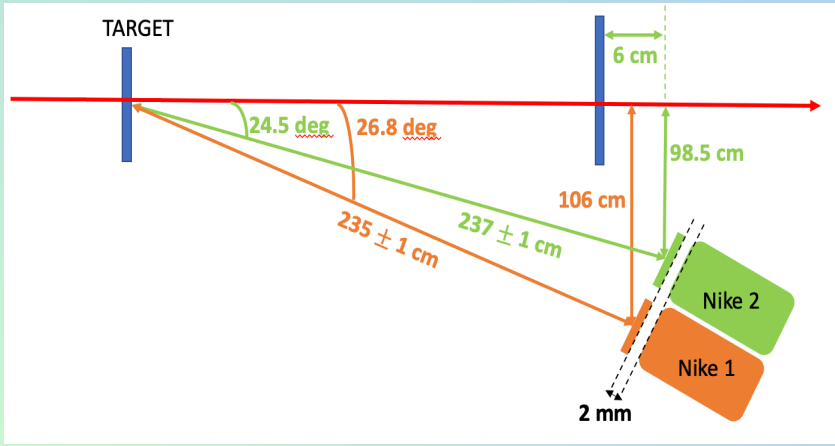
Ongoing:

- ^{16}O(400 MeV/u) on C_2H_4
- ^{16}O(200 MeV/u) on C & C_2H_4
- Isotope cross section

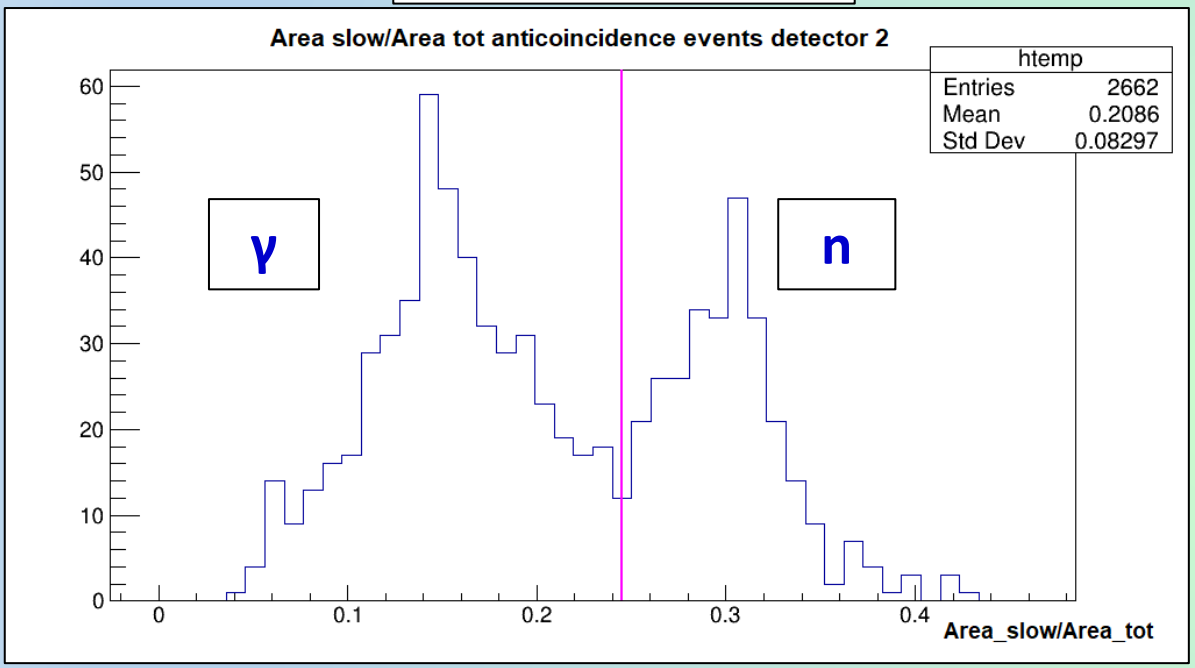
ANALYSIS PERFORMED BY BOLOGNA GROUP

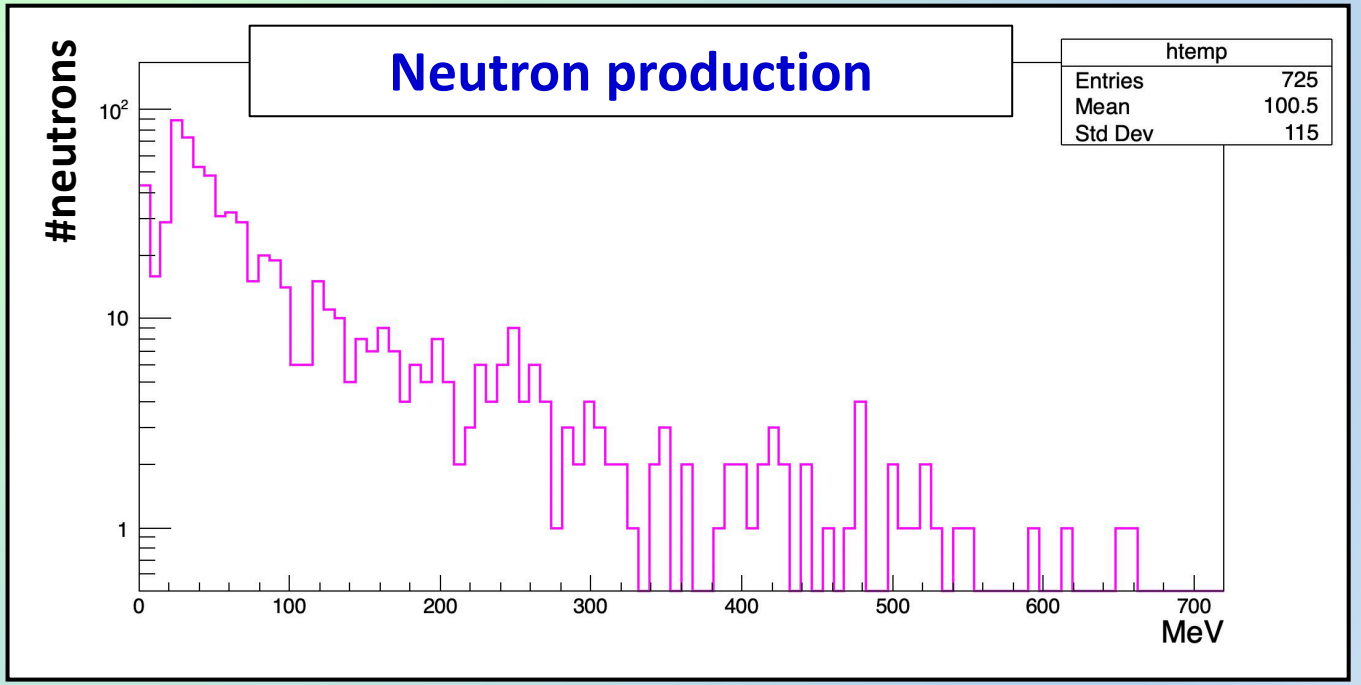
First acquisition for neutron detection

GSI 2021



n – γ separation



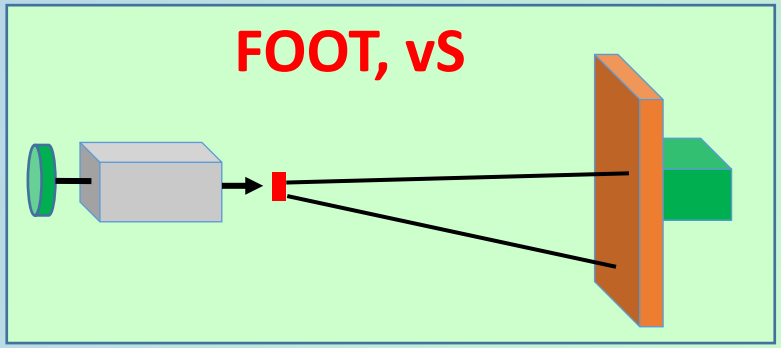


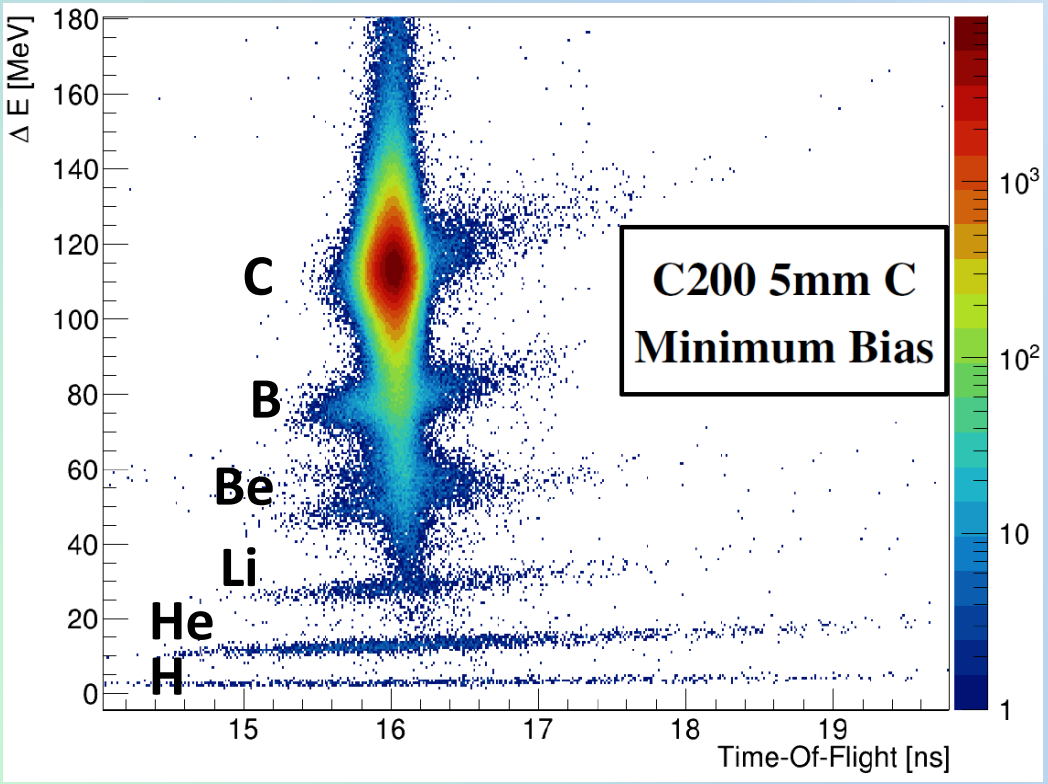
ANALYSIS PERFORMED BY BOLOGNA GROUP

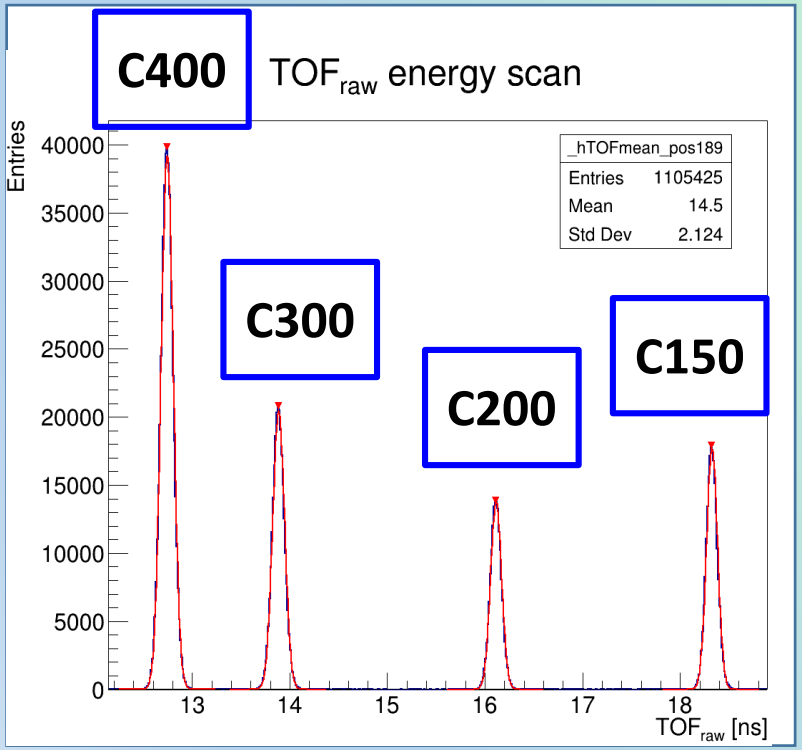
Strong collaboration with n_TOF: neutron detectors @ CERN to be calibrated

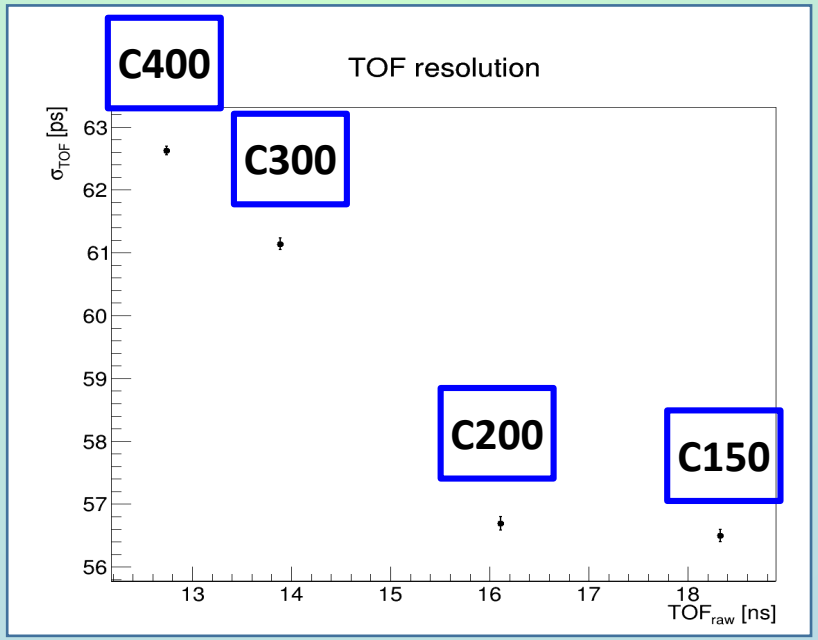
Ongoing analysis on data taking @CNAO 2021

^{12}C(200 MeV/u) on C, C_2H_4









ANALYSIS PERFORMED BY BOLOGNA GROUP

Students are interested in these topics

Theses 2021:

- Bachelor Physics degree: 6
- Bachelor Engineering degree: 2
- Master Physics degree: 1
- PhD Thesis: 1 (2022)
- **TOTAL: 10**

Theses :

- 2017: 4
- 2018: 4
- 2019: 10
- 2020: 4
- 2021: 10
- **2022: 3 (+14 programmati)**
- **TOTAL: 49**

Contatti per fare tesi in sedi esterne

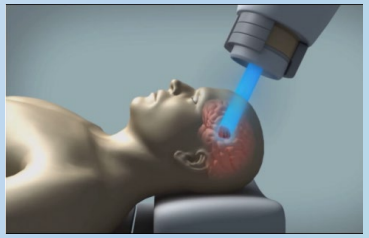
- **CNAO**
  - **Marco Pullia:** Responsible of the R&D department of
  - CNAO & Accelerator Coordinator
  - **Mario Ciocca** Responsible of the Medical Physics Units at
  - CNAO & Professor at UniMi of Specialization in Medical Physics

- **SANT'ORSOLA**
  - **Lidia Strigari:** Direttore, UOC Fisica Sanitaria IRCCS Azienda Ospedaliero-Universitaria di Bologna
  - **Gianfranco Cicoria:** Dirigente Fisico, UOC Fisica Sanitaria IRCCS Azienda Ospedaliero-Universitaria di Bologna

- **LINEARBEAM srl (Bari)**
  - **Ing. Raffaele Andrea Prisco:** Responsabile delle simulazioni MC per la radioprotezione lungo la linea di fascio

Conclusion

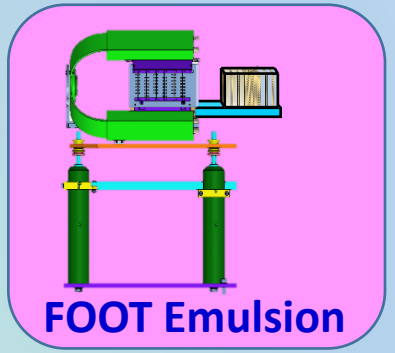
- **Wide physics panorama**
  - Hadrontherapy
  - Radioprotection in space

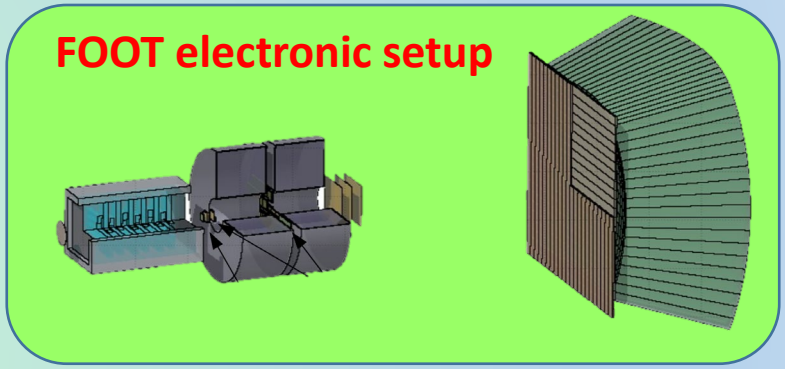


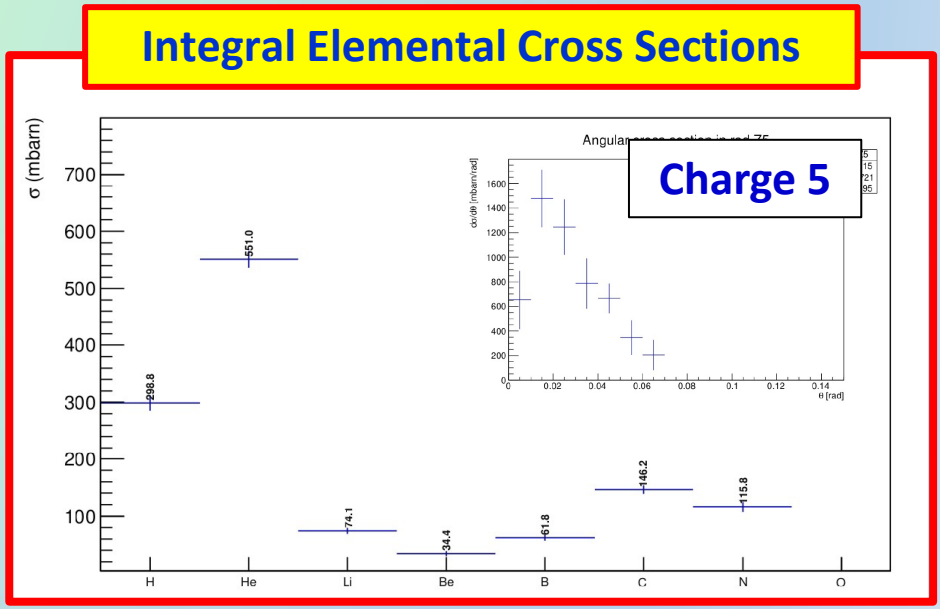
- **Detector Status:**
  - tests beam on subdetectors
  - Performances are as expected
  - Magnet is a problem

- **Preliminary Results**
  - Integral & Diff Elemental Cross Section (^{16}O + C)
  - First analysis of neutron identification
  - 6 published papers
  - 80 conferences (> 50 proceedings)

- **Future perspective**
  - Data taking @HEIDELBERG & CNAO
  - 3 submitted papers





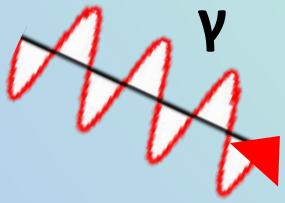


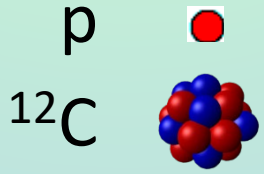
Backup slide

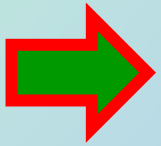
hadrontherapy

We don’t know what cancer is → we cannot prevent → we can only try to remove

Radiotherapy **Hadrontherapy (PT)**







H, C, O (>95%)