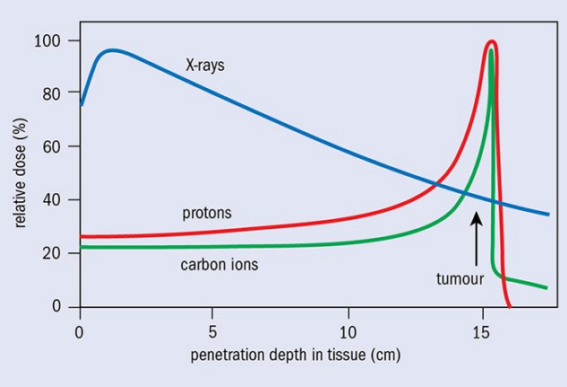
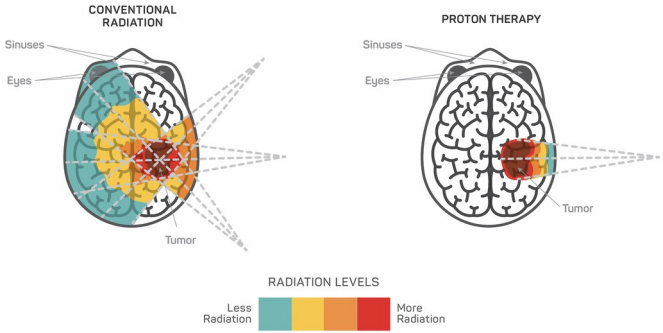
The FOOT experiment: nuclear fragmentation cross section measurements

Matilde Dondi

12 June 2025
XXII Seminar on Software for Nuclear, Subnuclear and Applied Physics

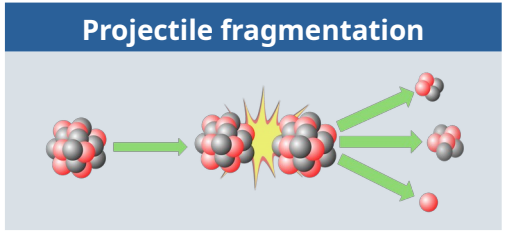
Hadron therapy





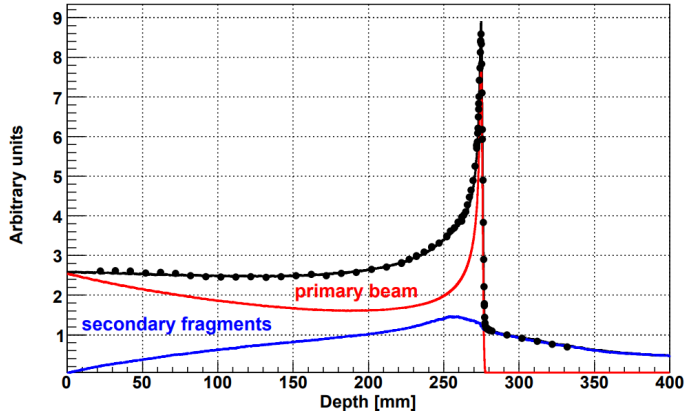
- Cancer treatment with charged particles (protons or ions)
- Main dose release in the **Bragg peak**
- Less damage to healthy tissues

Nuclear fragmentation



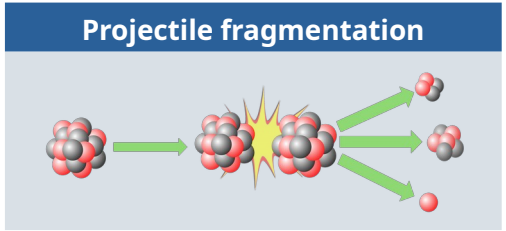
Long range fragments:

- dose release after the Bragg peak



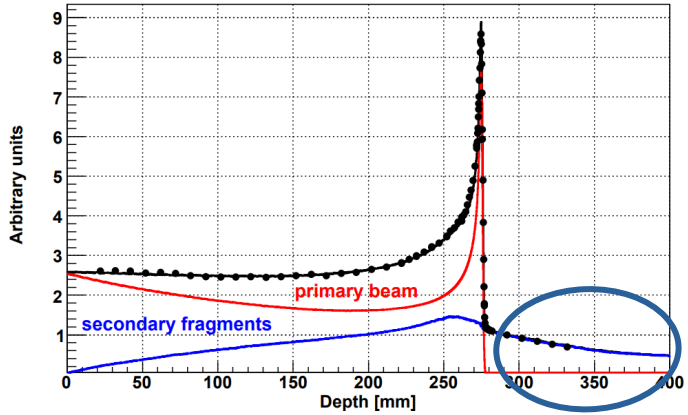
Durante M, Paganetti H. Nuclear physics in particle therapy: a review. Rep Prog Phys. 2016 Sep;79(9):096702. doi: 10.1088/0034-4885/79/9/096702.

Nuclear fragmentation



Long range fragments:

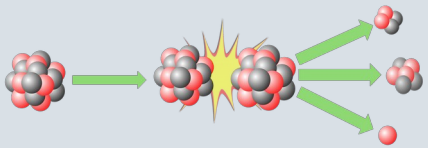
- dose release after the Bragg peak



Durante M, Paganetti H. Nuclear physics in particle therapy: a review. Rep Prog Phys. 2016 Sep;79(9):096702. doi: 10.1088/0034-4885/79/9/096702.

Nuclear fragmentation

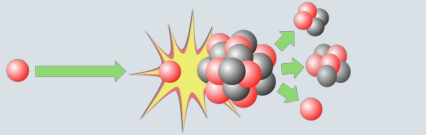
Projectile fragmentation



Long range fragments:

- dose release after the Bragg peak

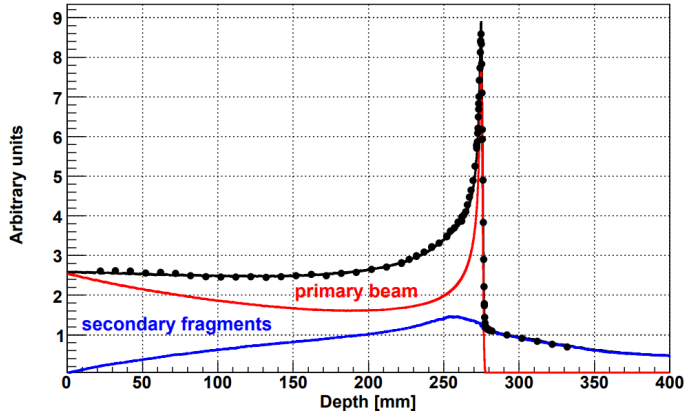
Target fragmentation



Low energy fragments, short range:

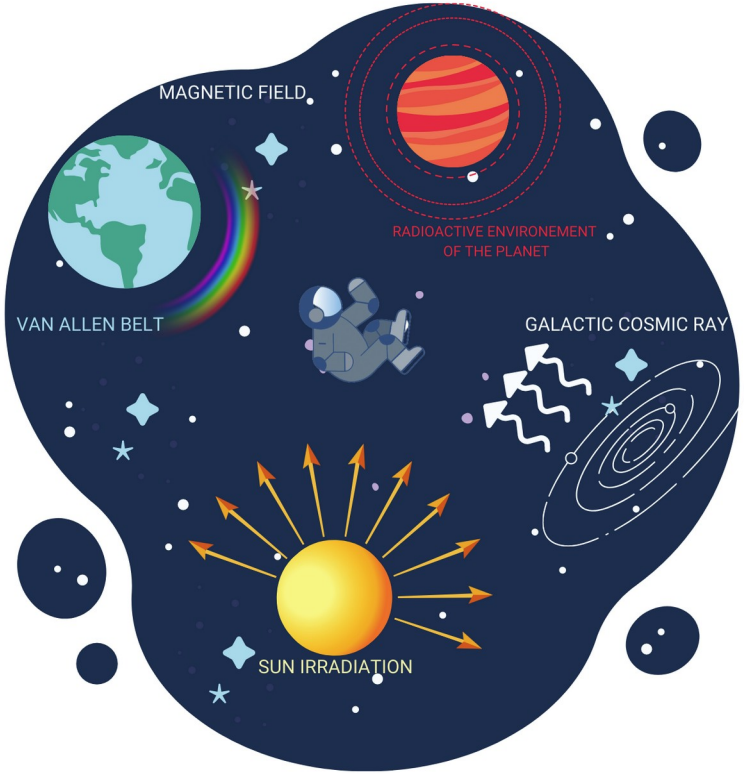
- impact in the entrance channel

difficult to detect



Durante M, Paganetti H. Nuclear physics in particle therapy: a review. Rep Prog Phys. 2016 Sep;79(9):096702. doi: 10.1088/0034-4885/79/9/096702.

Space radioprotection



Human missions in deep space:

- **Shielding** as primary method to reduce exposure
- Accurate **nuclear data** to ensure effective shielding

Durante, M., & Cucinotta, F. A. (2011). Physical basis of radiation protection in space travel. Reviews of Modern Physics, 83(4), 1245–1281. https://doi.org/10.1103/RevModPhys.83.1245

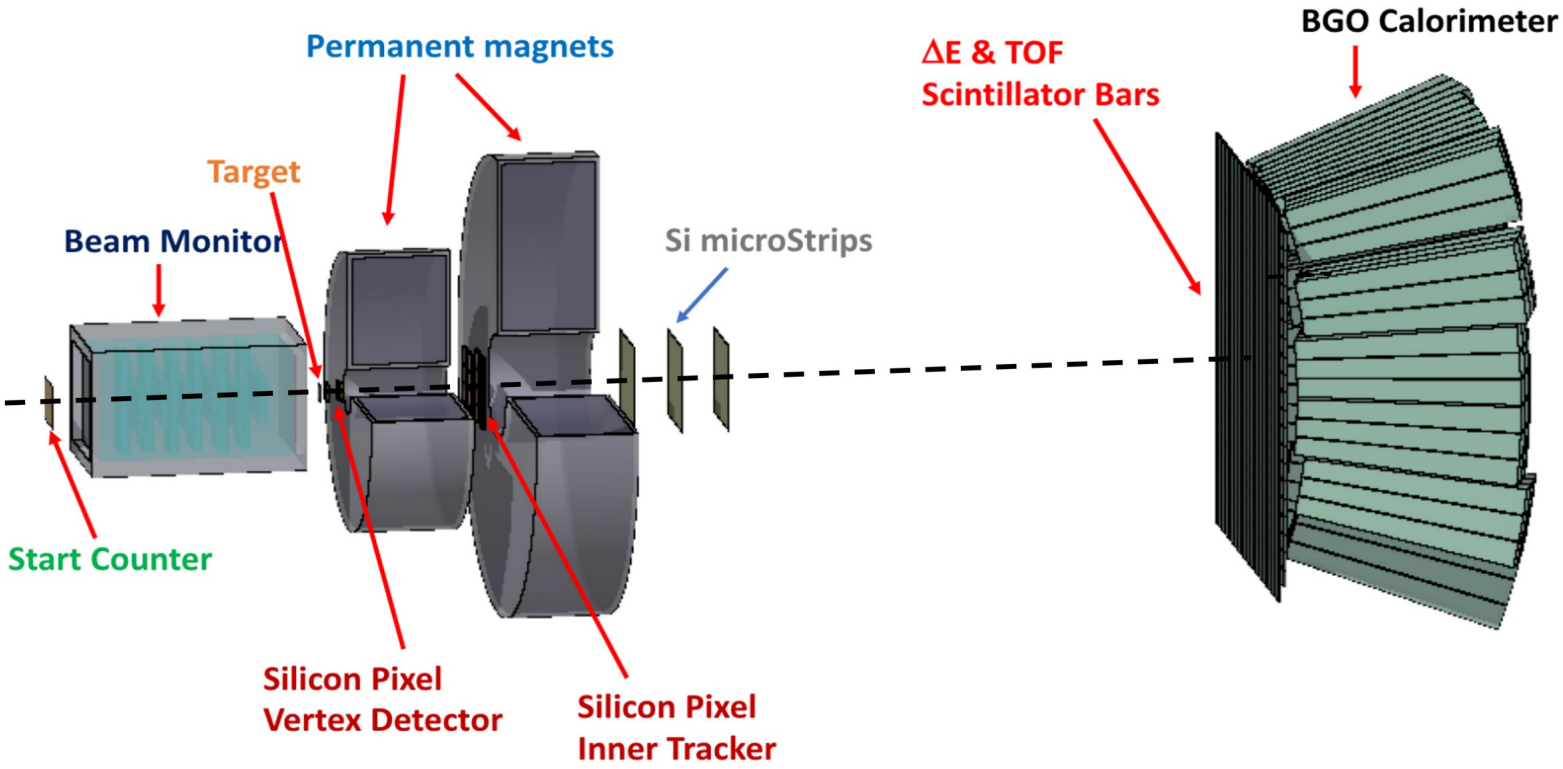
FOOT (FragmentatiOn Of Target) experiment

Double differential nuclear fragmentation cross section measurements:

- **Fixed target** experiment (C, C_2H_4 and PMMA targets)
- Light ion beams (like C and O) with energies 200 MeV/nucleon - 800 MeV/nucleon
- **Inverse kinematics** approach for target fragmentation
- Two setups: emulsion setup (low Z fragments) and **electronic setup**

Battistoni, G., Toppi, M., Patera, V., and The FOOT Collaboration. *Measuring the Impact of Nuclear Interaction in Particle Therapy and in Radio Protection in Space: the FOOT Experiment*. Frontiers in Physics, 8, 568242 (2020). DOI: 10.3389/fphy.2020.568242

FOOT: electronic setup

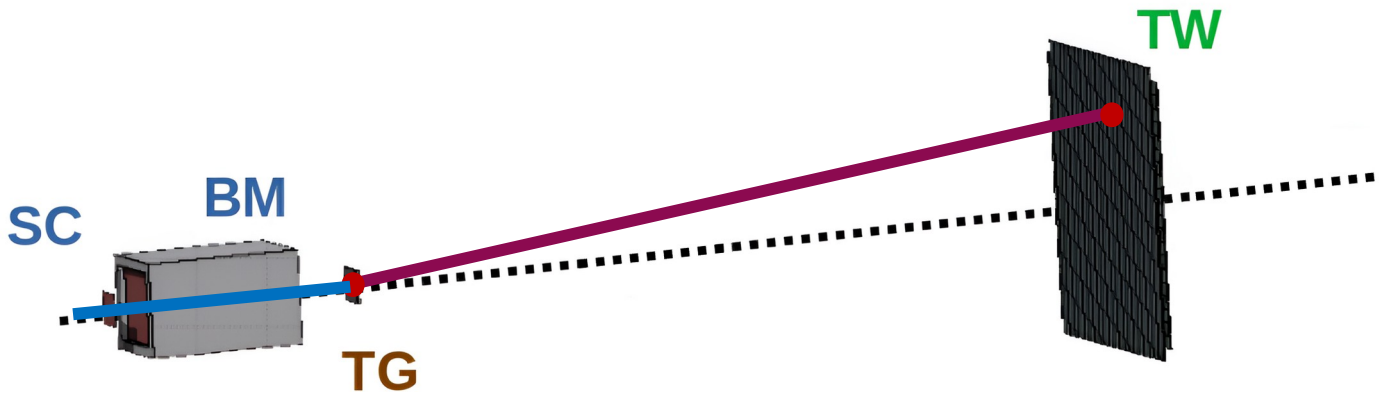


GSI2021 data analysis

Elemental and angular differential cross section:

400 MeV/nucleon ^{16}O beam on C and C_2H_4 targets

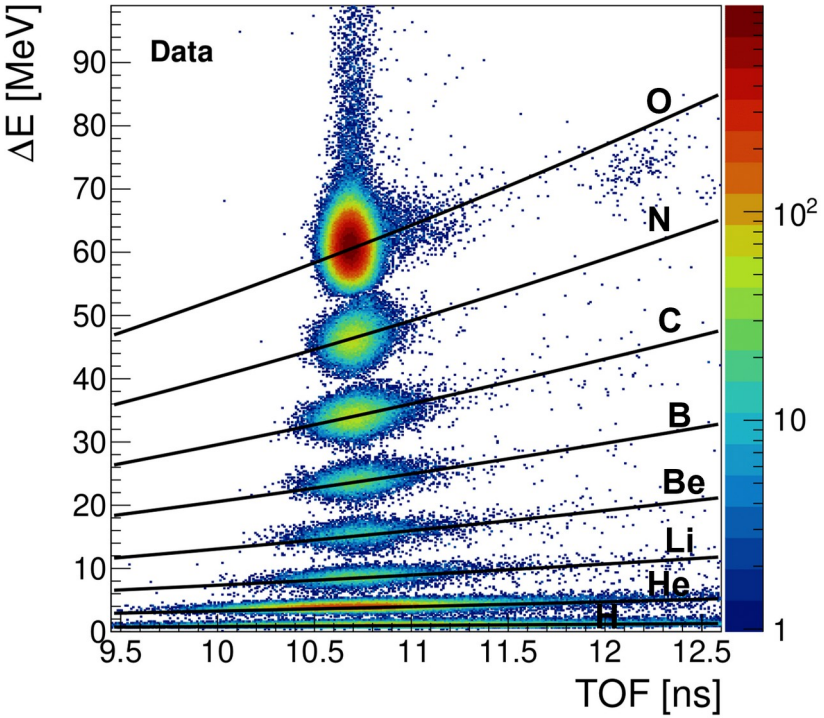
$$\frac{d\sigma}{d\Omega}(Z) = \frac{Y(Z,\theta)}{N_{prim} N_{TG} \mathcal{E}(Z,\theta) \Delta\Omega}$$



GSI2021 data analysis

Elemental and angular differential cross section:

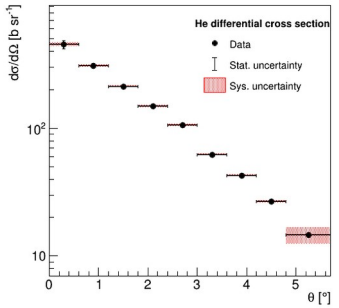
400 MeV/nucleon ^{16}O beam on C and C_2H_4 targets

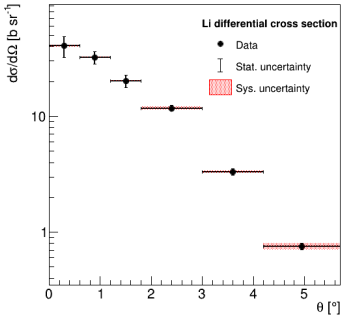


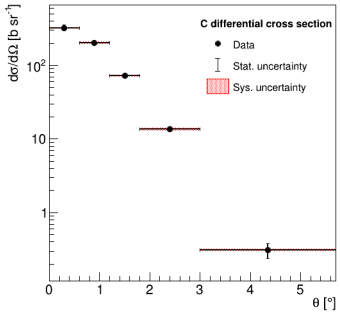
GSI2021 data analysis: results

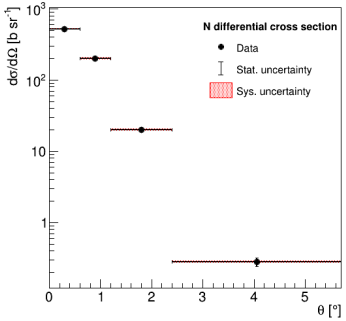
$^{16}O + C_2H_4$ cross sections

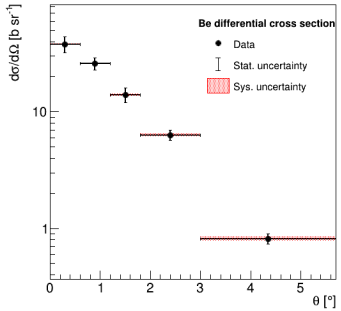
Angular cross sections for different Z

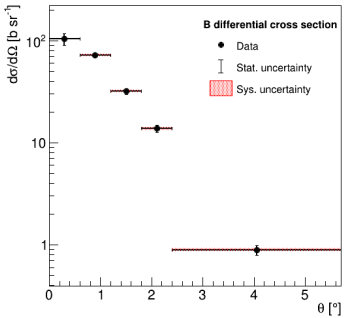








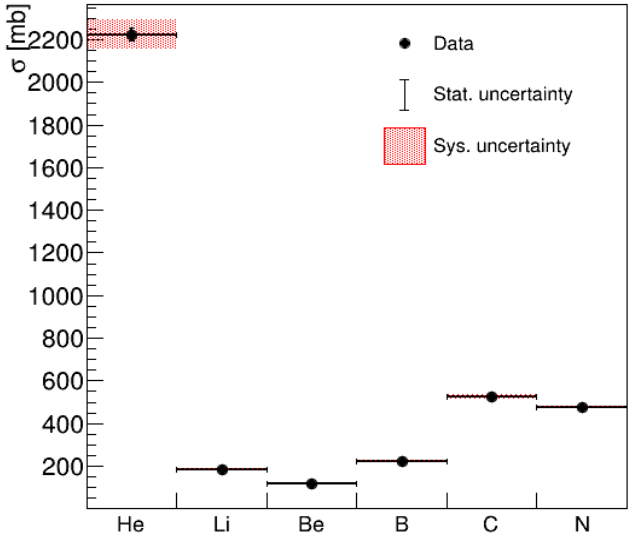




GSI2021 data analysis: results

$^{16}O + C_2H_4$ cross sections

Elemental integral cross section



GSI2021 data analysis: results

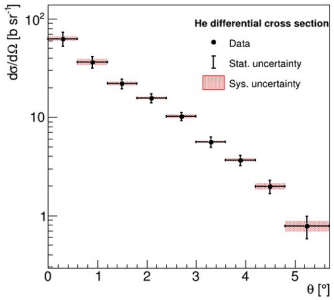
^{16}O + H cross sections obtained via subtraction between C_2H_4 and C:

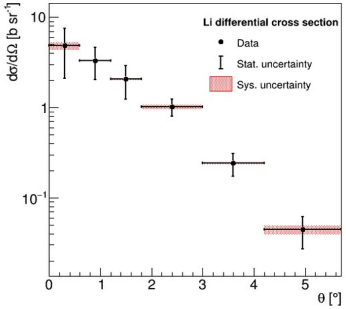
$$\sigma[\mathrm{p}] = \frac{\sigma[\mathrm{C_2H_4}] - 2\sigma[\mathrm{C}]}{4}$$

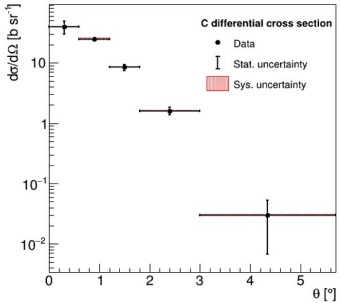
GSI2021 data analysis: results

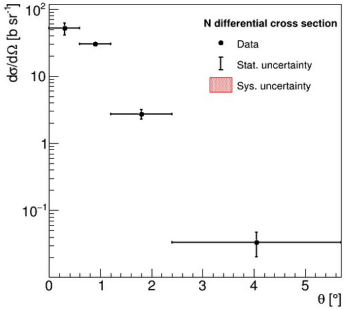
O + H cross sections

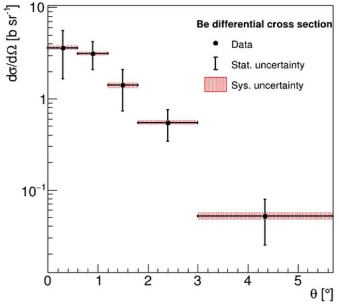
Angular cross sections for different Z

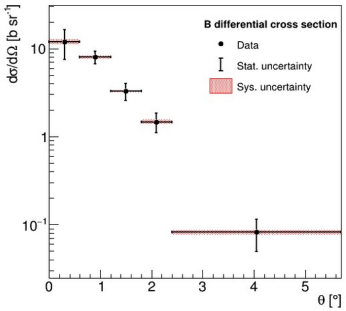




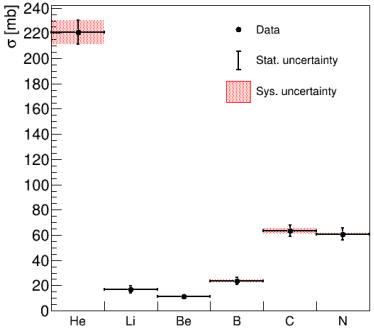








Elemental cross section



Conclusions

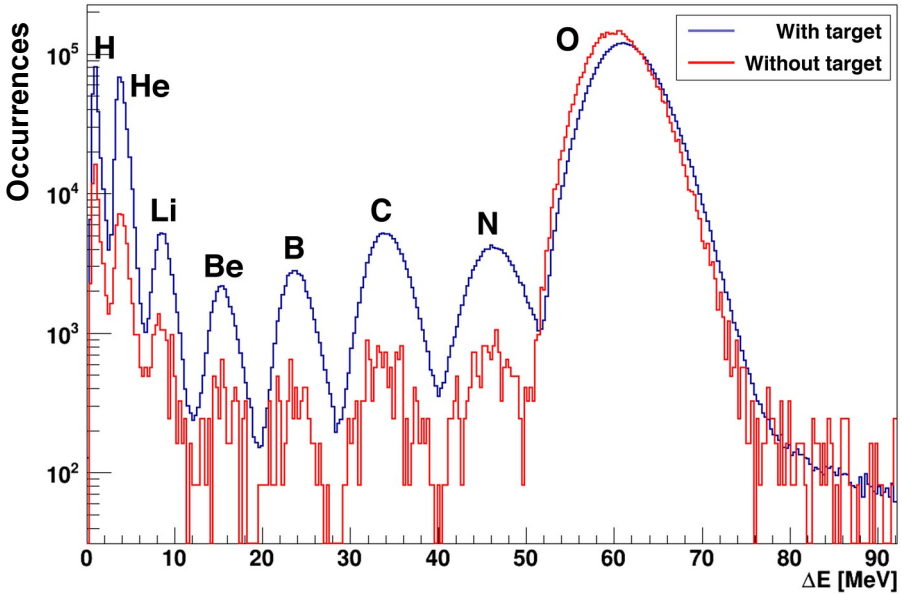
- **Nuclear fragmentation cross section** measurements for hadron therapy and space radioprotection applications
- Very promising results of **elemental and angular cross sections**
- Ongoing analysis on **new campaigns** with the complete setup: **isotopic cross sections** + **inverse kinematics**
- New data taking foreseen

Thank you for the attention!

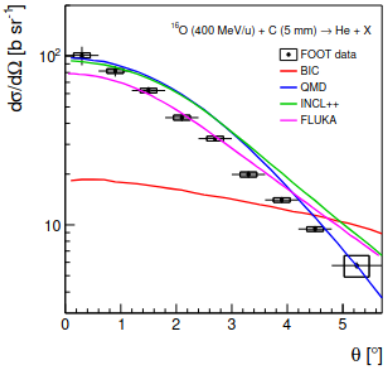
GSI2021 data analysis

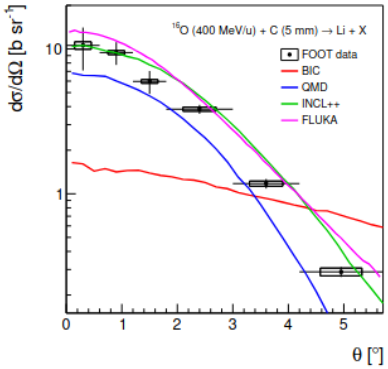
Elemental and angular differential cross section:

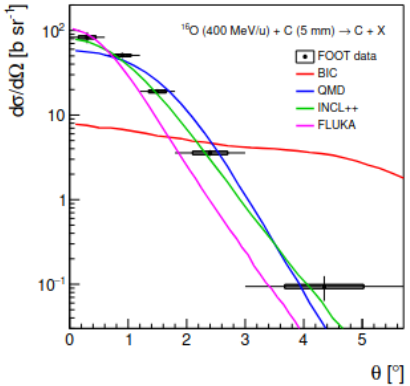
400 MeV/nucleon ^{16}O beam on C and C_2H_4 targets

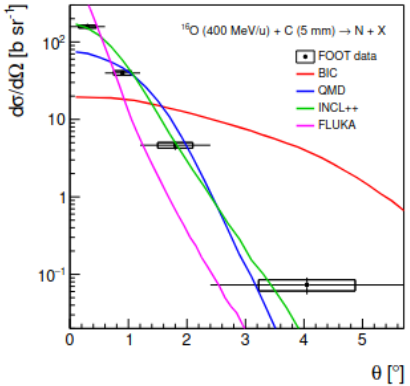


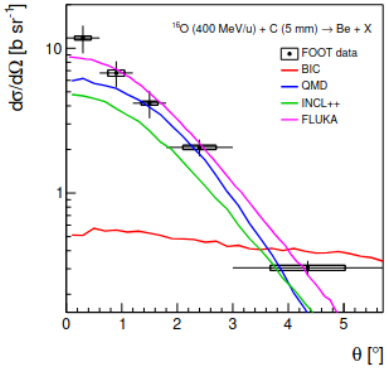
Comparison with models

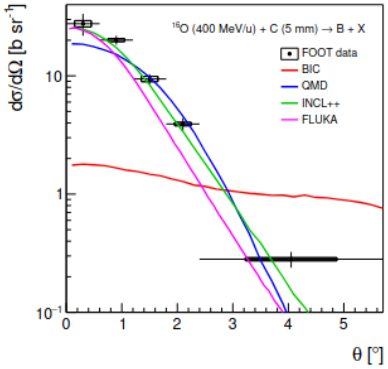












- FLUKA
- Geant4 hadronic models:
  - Binary Ion Cascade (BIC)
  - Quantum Molecular Dynamics (QMD)
  - Liège Intranuclear Cascade (INCL++)