Measurement of nuclear fragmentation cross sections for particle therapy and radioprotection in space: the FOOT experiment

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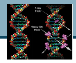
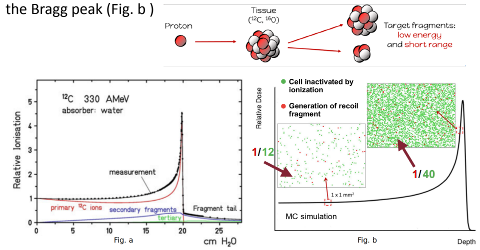
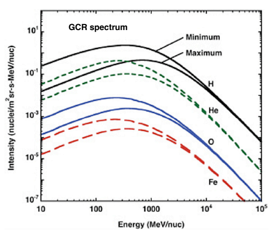


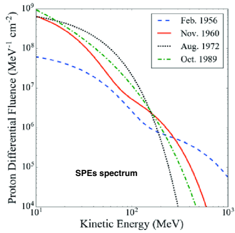
The importance of nuclear fragmentation

In **particle therapy** nuclear inelastic interactions results in the fragmentation of the target nuclei, producing fragments with low energy and high Linear Energy Transfer (LET) which may alter the estimated local dose deposition, especially in the entry region (Fig. a) nuclear inelastic interactions of the incident beam with the patient tissues lead also to the break-up of the incident ion The produced fragments of projectile have a longer range with respect to the primaries and lead to an undesirable dose deposition beyond the Bragg peak (Fig. b)



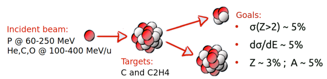
Solar Particle Events (SPEs) Galactic Cosmic Rays (GCRs) are the most critical hazard for humans during deep **space exploration**. In fact, they can interact with the spaceship hull producing lighter and highly penetrating radiation able to inflict a lethal dose and affect the stability of electronic devices. Experimental data investigating the fragments production for beam-target combinations relevant in **space radiation applications** will be of great help to select innovative shielding materials and provide recommendations on space radioprotection for different mission scenarios.

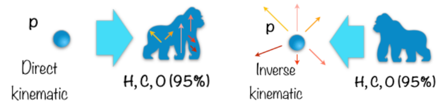




The FOOT experiment: goals and strategies

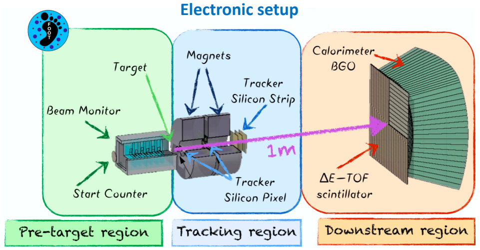
The main goal of the **FOOT (FragmentatiOn Of Target) [3]** experiment is to measure the double differential cross sections with respect to kinetic energy and emission angle of fragments produced in nuclear interactions of particles with energies relevant for hadrontherapy. The data will be exploited to benchmark the MC simulation tools and will be to develop a new generation of high quality **treatment planning systems.**





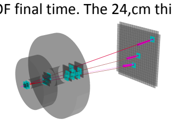
To study target fragmentation, an **inverse kinematic approach** is applied to overcome the difficulties given by the short fragments range (μm). The final cross sections on Hydrogen is obtained with the technique of cross sections subtruction, adopting a double target separately made of C and C2H4,.

Electronic setup

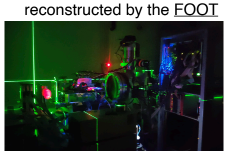


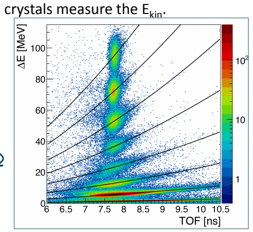
Detect fragments with Z>=3 with angular acceptance θ<10°

- **Pre-target**: a plastic scintillator provides the trigger and the start time of the TOF. A drift chamber measures the beam direction and position.
- **Tracking**: 4+2 layers of silicon pixel trackers placed beyond the target and between 2 permanent magnet (max ~1T). Together with 3 layers of silicon microstrip detectors measure the fragments momentum (p).
- **Downstream**: 2 planes of plastic scintillator strips provide the ΔE and the TOF final time. The 24,cm thick BGO crystals measure the E_{kin}.



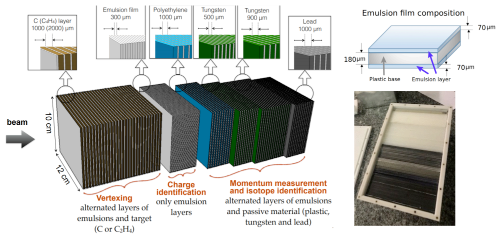
Event display collected and reconstructed by the FOOT



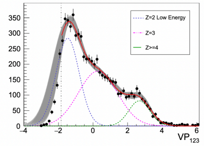


Fragment identification from ^{16}O beam @ 400 MeV/u impinging on graphite target @ GSI

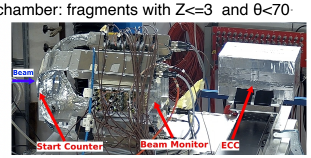
Emulsion setup



Nuclear emulsion cloud chamber: fragments with Z<=3 and θ<70°



Charge identification with 16° beam @ 200 MeV/u



^{16}O beam at 200-400 MeV/u @ GSI (2020), next data taking @ CNAO (October 2023)

References

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[3] Battistoni G, Toppi M, Patera V and The FOOT Collaboration (2021) Measuring the Impact of Nuclear Interaction in Particle Therapy and in Radio Protection in Space: the FOOT Experiment. *Front. Phys.* **8**:568242. doi: 10.3389/fphy.2020.568242

[4] Toppi M et al, (2022) Elemental fragmentation cross sections for a ^{16}O beam of 400 MeV/u kinetic energy interacting with a graphite target using the FOOT ΔE-TOF detectors. *Front. Phys.* 10:979229. doi: 10.3389/fphy.2022.979229

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