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Expected performance of the FOOT experiment

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Summary. — The main objective of the FOOT (FragmentatiOn of Target) experiment is to measure the double differential cross-sections with respect to the kinetic energy and the angle of emission of fragments produced in nuclear interactions with an accuracy of 5%. Measurements will use the inverse kinematics approach to study the interaction of heavy ions with proton-rich targets and will be performed in two energy regions, one up to 400 MeV/u, to assess the effects of nuclear fragmentation in hadrontherapy treatment with proton beams, and up to 700 MeV/u, to improve the knowledge of the fragmentation of ions on nuclei to help with the design of space vehicles shielding.

1. – Introduction

The FOOT experiment aims to precisely measure the double differential cross-sections of interest for both hadrontherapy and long-duration human future space missions.

In hadrontherapy, given the high energy of the beams in the input channel and the slowly changing low LET (Linear Energy Transfer), an RBE (Relative Biological Effectiveness) of about 1.0 is expected. A constant RBE value of 1.1 is currently assigned to protons in clinical practice. Radiobiological measurements however show a significant increase in RBE [1] that may be the result of nuclear interactions between the beam and the patient's tissues [2] that cause fragmentation of both the target and the projectile (in the case of heavier beam particles like carbon) [3].

Regarding space missions, there are three main sources of energetic particles: Solar Particle Events (SPE), Galactic Cosmic Beams (GCR) and geomagnetically trapped particles. Their energy spectrum ranges over ten orders of magnitude and they are able to inflict a lethal dose on astronauts. Double-differential cross-sections for light

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ions are particularly important, as these particles have a high penetrating power and a wide angular spread from the primary beam. Measurements for hydrogen targets are particularly necessary, as materials rich in hydrogen are among the best options for shielding spacecrafts [4].

2. – Design of FOOT experiment

The FOOT experiment will run using two different experimental setups: the first to study light fragments, based on emulsion chambers, due to the wide angular distribution, and the second one, an electronic setup based on active detectors [5], to study the heavier fragments ($Z > 2$) [6].

For the electronic setup it is possible to identify three different regions.

Target region: a thin plastic scintillator detector to provide trigger and the start of the Time Of Flight detector, a drift chamber with the purpose of measuring the beam direction and thin polyethylene and graphite targets.

Magnetic spectrometer: four layers of silicon pixel detector after the target as vertex detector, two permanent magnets with Halbach geometry with two layers of silicon pixel detector in-between and three layers of silicon microstrip detectors for xy-reconstruction, to perform the trajectory and momentum measurements.

Calorimeter region: $22 + 22$ plastic scintillator bars arranged in two orthogonal layers (to measure the energy deposited ($\mathrm{d}E/\mathrm{d}x$), give the stop to the TOF and an estimation of the fragment position) and a calorimeter composed by 360 elements of BGO crystal to measure the kinetic energy of the fragments.

3. – Expected results and performance

The preliminary study of the detector performances for charge measurements and on mass number resolution of the produced fragments has been carried out on the basis of FLUKA simulations using conservative values for the resolutions of the single detectors. The resolutions obtained for the charge of heavy fragments and the determination of the number of mass are respectively of about 2% and 3% [7], allowing a particle identification necessary for the final differential cross-sections measurements.

4. – Conclusions

The FOOT experiment will measure with great precision (better than 5%) the nuclear fragmentation cross-section of a ion beam with the ions most abundant in our body, for which there are no experimental measures at the energies used in treatments of hadrontherapy. The precision of theoretical models alone is not sufficient to guarantee satisfactory accuracy during the treatment of patients. The new values for these cross-sections will allow the design of more accurate Treatment Planning Systems (TPS) with consequent limitation of damage to healthy tissues.

Finally, the data provided by the FOOT experiment can be used to develop protection systems for cosmic radiation on board space shuttles for future missions.

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