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Measurements of 16O fragmentation cross sections on C target with the FOOT apparatus

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In Particle Therapy (PT), nuclear interactions of the beam with the patient's body causes fragmentation of both the projectile and target nuclei. In treatments with protons, target fragmentation generates short range secondary particles along the beam path, that may deposit a non-negligible dose especially in the entry channel. On the other hand, in treatments with heavy ions, such as C or other potential ions of interest, like He or O, the main concern is long range fragments produced by projectile fragmentation, that release the dose in the healthy tissues downstream of the tumor volume. Fragmentation processes need to be carefully taken into account when planning a treatment, in order to keep the dose accuracy within the recommended 3% of tolerance level. The assessment of the impact that these processes have on the released dose is currently limited from the lack of experimental data, especially for the relevant fragmentation cross sections. For this reason, treatment plans are not yet able to include the fragmentation contribution to the dose map with the required accuracy. The FOOT (FragmentatiOn Of Target) collaboration, funded by INFN (Istituto Nazionale di Fisica Nucleare, Italy) , designed an experiment to fill this gap in experimental data, aiming the measurement of the differential cross sections of interest with an accuracy better than 10%. The apparatus, shown in figure 1, is composed of several detectors that allow fragment identification in terms of charge, mass, energy and direction. Starting from the incident beam direction, the particles cross a plastic scintillator (Start Counter) and a drift chamber to measure the start for the Time Of flight and to monitor the primary beam respectively. Then the beam interacts with the magnetic spectrometer composed by two pixel detectors, a microstrip detector and a permanent magnet system that provides the required magnetic field in order to measure the fragments momentum. The last part of the FOOT electronic setup is composed by a plastic scintillator wall (ΔE-TOF detector) and a calorimeter that provide the fragments energy loss (ΔE) and the stop of the TOF measurements.The TOF system composed by the SC and after ~ 2 m the ΔE-TOF detector, plays a crucial role as the charge Z of fragments reaching the ΔE-TOF detector can be identified from the energy loss ΔE and the TOF information. The two detectors have been optimized in order to achieve a TOF resolution lower than 100 ps and an energy loss resolution $\sigma(\Delta E)/\Delta E \sim 5\%$. For this reason the SC thickness was carefully optimized looking for a good compromise between the out of target fragmentation probability, that called for the smallest possible thickness, and the time resolution, that is directly linked to the light yield requiring a thick detector. The final SC detector layout, that was optimized using MC simulations, foresees a squared EJ −228 plastic scintillator (5 × 5 cm2 active area) arranged in a set of four different thickness (ranging from 250 µm to 1 mm) used depending on the beam projectile and energy range. According to this geometrical proprieties the expected beam fragmentation inside the SC is about 5% of the incident ions. The plastic scintillator readout is performed by means of 48 3 × 3 mm2 SiPMs, 12 per side, bundled in eight electronic channels, each reading a chain of 6 SiPMs. The ΔE-TOF detector consists of a matrix of EJ-200 bars, 3mm thick, orthogonally arranged in two subsequent layers. The thickness of the bars is chosen as a trade-off between the amount of scintillation light produced in the bar (resulting in a better timing and energy resolution), which increases with the deposited energy and therefore with the bar thickness, and the systematic uncertainty induced on the ΔE- TOF measurement by secondary fragmentation in the bars that would worsen the particle identification and tracking. Each layer is composed of 20 bars that are 2 cm wide and 44 cm long, resulting into a 40 × 40 cm2 active area. The light produced in each bar is collected at both the extremities using to 4 SiPMs per side (3 × 3 mm2 active area) biased and read-out by a single electronic channel. The two detectors share the SiPM read-out system: the 88 output signals of the ΔE- ToF and the SC are digitized and recorded by using the

WaveDAQ system, capable of a 0.5–5 GS/s sampling speeds.The FOOT TOF system has been tested with 12C and 16O ion beams with energies ranging from 115 MeV/u to 400 MeV/u in March 2019 at the CNAO (Centro Nazionale di Adroterapia Oncologica) experimental room. The measured TOF resolution has matched the expectations (the average resolution σ(ToF) ranges between 55 ps and 80 ps as a function of the beam kinetic energy) and fulfilled the requirements needed for the fragment atomic mass discrimination level needed by the cross section measurement program of the FOOT experiment. In April 2019 a first data taking was done at GSI Laboratory using a 400 MeV 16O beam impinging on a graphite target with a partial FOOT experiment setup including the SC, the Beam Monitor and the ΔE-TOF detectors. In this contribution the two timing detectors and their performance tested at GSI are explained in detail. In addition, preliminary results of the charge changing cross sections for the production of fragments with Z between 2 and 7 for the case of 400 MeV/u 16O beam integrated in the ΔE-TOF detector acceptance will be presented

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