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Charge identification of fragments in FOOT experiment by nuclear emulsion detector

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Charged Particles Therapy (CPT) is a technique based on the use of charged particle beams for the treatment of deep-seated tumors. The advantages of CPT are due to the energy release occurring mainly at the end of the particles path, in the Bragg peak region, and to the enhanced biological effectiveness of hadron beams, measured in terms of the Relative Biological Effectiveness (RBE). Recent studies indicate the re-assessment of the proton RBE value due to secondary fragmentation as a crucial topic to improve the clinical treatment plans. The FOOT (FragmentatiOn Of Target) experiment is an international project aimed to measure the target fragmentation induced by a proton beam in the human tissues in the energy range relevant for therapeutic applications (150–250 MeV for protons and 200–400 MeV/n for carbon ions).
As fragments generated by a proton beam have few micrometers range, an inverse kinematic approach has been adopted in which a primary beam (carbon or oxygen) impinge on targets made of carbon and hydrogen-enriched carbon materials (C2H4). Therefore, the cross-section on hydrogen is derived from their linear combination.
The aim of the experiment is the measurement of the fragments production cross section in pA interactions with maximum uncertainty of 5%, the fragment energy spectra with an energy resolution of the order of 1–2 MeV/u, and the charge and isotopic identification with at the level of 3% and 5% uncertainty, respectively.
The detector was projected as a "table-top"one, so it could be easily moved and fitted in different experimental rooms where ion beams of therapeutic energies are available. The FOOT detector is based by two complementary setups: an electronic spectrometer, covering a polar angle acceptance up to about 10 degrees with respect to the beam axis, for fragments $Z > 3$, and an emulsion spectrometer, to measure light fragments ($Z < 3$) up to 70 degrees with respect to the beam axis.
The electronic setup is composed by a drift chamber, working as a beam monitor upstream of the target to measure the beam direction a magnetic spectrometer, based on silicon pixel and strip detectors, a scintillating crystal calorimeter to stop the heavier produced fragments, and a ΔE detector, with TOF capability, for the particle identification.
In this work we present the results obtained by the first data taking, occurred in 2019 at the GSI facility (Darmstadt, Germany), by exposing the emulsion detector to a 200 and 400 MeV/n oxygen ion beams. The charge identification of fragments and the cross section evaluation produced in interactions of the 16O beam with a C2H4 and C targets will be reported.
The emulsion spectrometers have been realized according the Emulsion Cloud Chamber (ECC) technique which consists of nuclear emulsion films alternated with passive material. Each emulsion spectrometer is composed of three sections: a first section for vertexing composed by alternated emulsion films and passive layers of C or C2H4 acting as target in which secondary fragments are originated; a second section dedicated to ion charge separation consisting of emulsion films underwent to controlled fading treatments; a third section composed by emulsion films alternated with passive materials of increasing density (plastic, lead and tungsten) to measure the particle range and momentum. For this analysis, the second Section has been considered as a stand-alone detector.
The method adopted for the analysis of the charge identification is based on thermal treatments inducing controlled fading of nuclear emulsion films to distinguish the charge of fragments generated by oxygen interactions and separate them from cosmic rays integrated during the detector lifetime.
The charge of the fragments was measured or assigned for more than 99% of tracks reconstructed in Section

II of the detector. Two complementary methods were adopted for the analysis: a cut-based analysis and the Principal Component Analysis

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