Available online at www.sciencedirect.com

SciVerse ScienceDirect

Physics Procedia 37 (2012) 1466 – 1472

Physics Procedia

TIPP 2011 - Technology and Instrumentation in Particle Physics 2011

The Upstream Detectors of the FIRST Experiment at GSI

A. Paoloni[a,*], M. Anelli[a], E. Iarocci[a,b], V. Patera[a,b], L. Piersanti[a,b], A. Sarti[a,b], A. Sciubba[a,b]

[a]*Istituto Nazionale di Fisica Nucleare - Laboratori Nazionali di Frascati, Italy*
[b]*Dipartimento di Scienze di Base e Applicate per l'Ingegneria, Università di Roma "La Sapienza", Italy*

Abstract

FIRST (Fragmentation of Ions Relevant for Space and Therapy) is an experiment devoted to a precise measurement of ion fragmentation for space radiation protection and hadron therapy applications. A first run dedicated to the fragmentation of fully stripped ^{12}C ions on a thin graphite target has been already performed during August 2011 at GSI. The experiment is composed of already existing detectors complemented by a newly designed interaction region, including the so - called Upstream Detectors: a Start Counter and a Beam Monitor. The Start Counter is used to trigger the beam and to give a precise time reference for time of flight measurements, while the Beam Monitor is needed to track ions before their interaction in the target. In this paper we present their description and the results of the tests performed on different beams to validate their performances before the installation at GSI.

Keywords: Hadron therapy, Fragmentation, Nuclear physics, Elementary particle and nuclear physics experimental methods and instrumentation.

1. Introduction

Carbon ions are used in hadron therapy because of their high biological effectiveness and better spatial selectivity in dose deposition with respect to protons ([1] and [2]). Unlike protons, carbon ions may undergo fragmentation as a consequence of interaction with matter. The produced fragments have a higher range and a different direction with respect to the primary ion and therefore release a consistent fraction of the dose beyond the nominal Bragg peak. A precise knowledge of the fragmentation processes is therefore desirable for the optimization of the treatment planning.

The FIRST (Fragmentation of Ions Relevant for Space and Therapy) experiment is devoted to measure ion fragmentation on selected targets measuring type, energy and direction of the fragments. A first run has been already performed for 400 AMeV ^{12}C fully stripped ions on a thin (5 mm) graphite target at SIS accelerator of GSI laboratory in Darmstadt. Future runs dedicated to fragmentation studies of interest for hadron therapy and space radiation protection applications will be considered.

A simplified scheme of the experiment is sketched in figure 1.

The Start Counter is a 250 μm thick plastic scintillator used for trigger and timing purposes, while the Beam Monitor is a drift chamber for tracking beam ions before the target. They constitute the Upstream Detectors.

*Corresponding author. E-mail: alessandro.paoloni@lnf.infn.it

1875-3892 © 2012 Published by Elsevier B.V. Selection and/or peer review under responsibility of the organizing committee for TIPP 11. Open access under CC BY-NC-ND license. doi:10.1016/j.phpro.2012.03.745

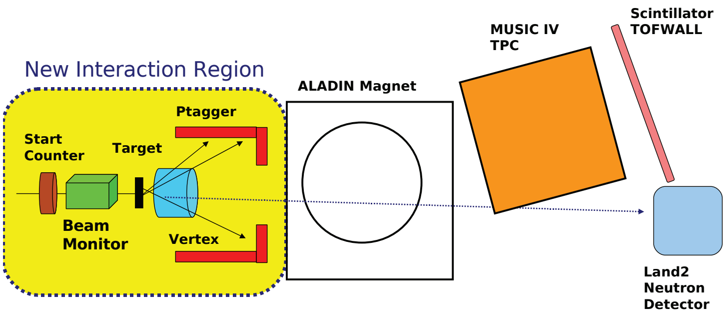

Figure 1. Simplified scheme of the FIRST experiment at GSI. Not to scale.

The vertex detector is composed by four Si pixel layers at a distance of 3 mm one from the other along the beam direction. Each layer is made of two MIMOSA26 [3] pixel sensors for a total sensitive area of 2×2 cm^2 and a pitch of 18.4 μm. The angular acceptance of the vertex detector is 40^o.

Forward emitted ($< 5^o$) fragments enter the ALADIN dipole magnet and are detected by the MUSIC IV TPC [4] and by the scintillator TOFWALL. The fragment mass is determined by combining the deflection inside the magnetic field, the time of flight between the TOFWALL and the Start Counter, the ionization measured in the TPC and the light yield in the TOFWALL.

A scintillator VETO counter, of area 6×6 cm^2, is placed beyond the TOFWALL along the path of the carbon ions not interacting in the target.

The Large Area Neutron Detector (LAND2) [5] is designed for neutron detection. It has an active area of ($2{\times}2$ m^2) and is made of alternated iron and plastic scintillator layers.

Fragments emitted at high angles (protons and He nuclei) are detected by the proton tagger. The detector has a cylindrical shape and it is made of plastic scintillator modules for measuring the arrival time and sampling the light yield. At high polar angles ($> 40^o$) the proton tagger is complemented by scintillating fibers bent to form circles orthogonal to the beam direction.

The experiment is designed to obtain a fragment mass resolution ΔM/M $<$ 20% and it is composed by detectors already exisiting at GSI (the ALADIN dipole magnet, the MUSIC IV TPC, the TOFWALL and LAND2) complemented by a newly designed Interaction Region. A detailed description of each single detector is beyond the aim of this paper, dedicated to the upstream detectors and to the results of the tests performed to validate their performances.

2. The Beam Monitor

As beam monitor we employ a drift chamber with 12 consecutive layers made of alternated horizontal and vertical wire planes. Each layer is composed by three drift cells, for a total of 36 sense wires. In each view two consecutive layers are staggered by half a cell to avoid ambiguities in track reconstruction. A scheme and a picture of the Beam Monitor are shown in figure 2. The dimensions of a single drift cell is 1.6×1.0 cm^2, designed to contain the GSI beam ($\sim$ 5 mm wide) inside one half of the cell in order to minimize beam interactions with the wires. Front - End boards, designed by the LNF electronics workshop (SEA), are embedded in the detector, amplifying the signals by a factor of 10.

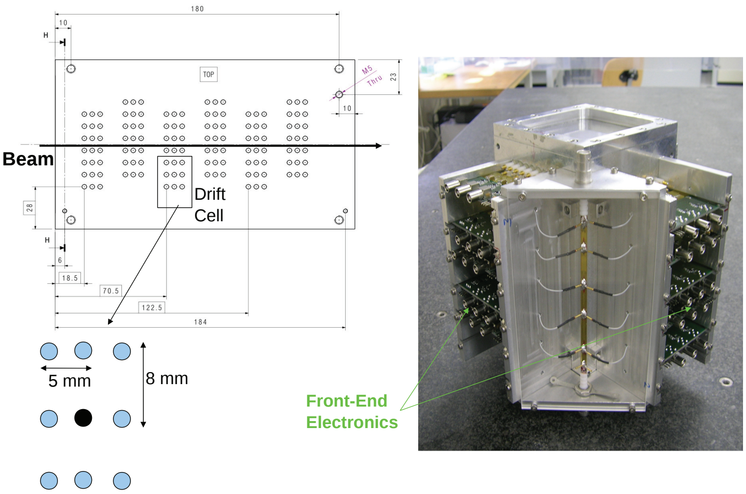

Figure 2. Beam Monitor wire scheme and picture.

We have tested the Beam Monitor with 500 MeV electrons at the LNF (INFN Frascati National Laboratories) BTF (Beam Test Facility) in order to study its performances with different gas mixtures (Ar/CO_2 and Ar/CH_4, also known as P10). A scheme of the experimental set - up is depicted in figure 3. The trigger was given by the accelerator radiofrequency and single electron events were selected by means of a lead glass calorimeter used as a beam dump and as a time reference for the drift chamber under test.

The layer efficiency has been estimated by considering events with three consecutive fired wires in even (odd) layers and then looking for the presence of hits in the odd (even) ones. The measured efficiency values are then averaged. In figure 4 the efficiencies are shown for the tested gas mixtures. Unless stated otherwise, signals have been discriminated at 15 mV.

Comparing the measured efficiency values for Ar/CO_2 mixtures, operating voltages are lower for decreasing CO_2 quantities: a 250 V difference is observed between 10% and 20% CO_2 concentration. Using P10, the operating voltage is 50 V lower than with Ar/CO_2=90/10.

In figure 5 the corresponding space resolutions are also shown. For all the considered mixtures a resolution better than 100 μm is obtained; the same is true also for P10 at 45 mV threshold.

At the LNS (INFN Southern National Laboratories in Catania) facility we have verified the performances on 80 AMeV protons and ^{12}C ions, respectively less and more ionizing than the 400 AMeV ^{12}C ions at GSI. The experimental set-up is also sketched in figure 3. The trigger was given by the plastic scintillator beam dump. The FIRST vertex detector was also present in the test. The measured efficiencies and space resolutions are reported in figures 6 and 7 respectively.

The operating voltages for protons are similar to those observed for electrons, while on ^{12}C ions the chamber is operated 300 V lower. For ^{12}C ion beam, as well as for the electron one, a 300 V shift is observed between the operating voltages with P10 and Ar/CO_2=80/20. Single layer space resolutions better than 100 μm at full efficiency are obtained on electrons and protons. On ^{12}C ions space resolutions get worse for increasing voltages and with Ar/CO_2=80/20 values around 300 μm are measured at full efficiency. Better space resolutions are obtained with P10.

3. The Start Counter

The Start Counter is a 250 μm thick scintillator (EJ - 228, pilot U) disc of 4.6 cm diameter. The light is collected through radial optical fibers, as shown in figure 8. The fibers are collected into 4 bundles, each connected to a

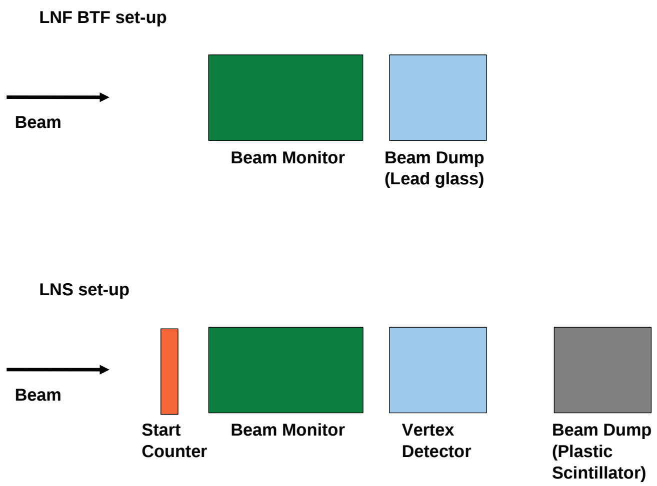

Figure 3. Experimental set-up schemes of Frascati (top) and Catania (bottom) test beam facilities.

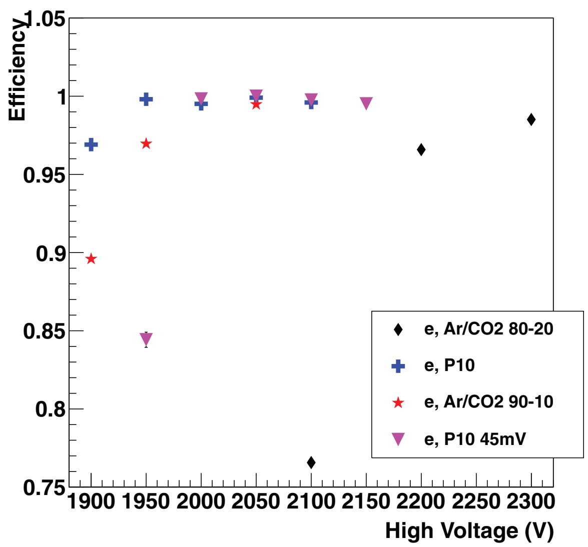

Figure 4. Single layer efficiencies measured on the electron beam at the BTF facility.

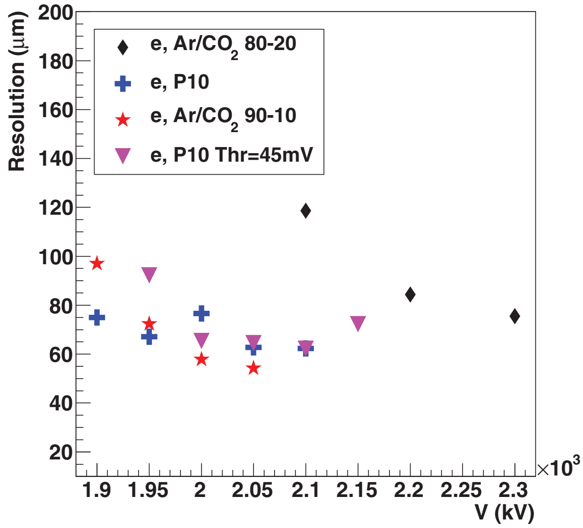

Figure 5. Single layer space resolutions measured on the electron beam at the BTF facility.

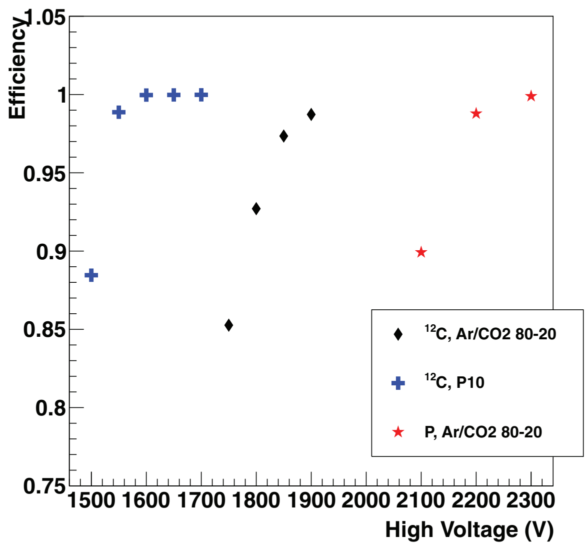

Figure 6. Single layer efficiencies measured at the LNS facility on proton and ^{12}C ion beams.

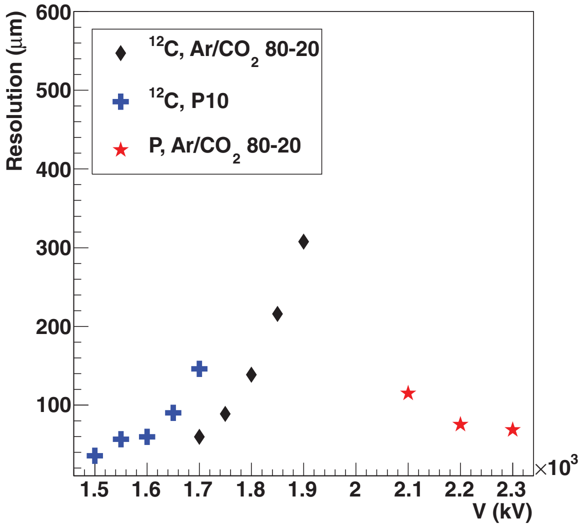

Figure 7. Single layer space resolutions measured at the LNS facility on proton and ^{12}C ion beams.

photomultiplier (Hamamatsu UBA H10721 - 201). The photomultipliers output signals are amplified by a factor of 20 with custom boards designed by the LNF electronics workshop and embedded in the detector.

The Start Counter has been tested at the LNS facilities with 80 AMeV protons and ^{12}C ions. The efficiency is defined as the fraction of events with at least three fired photomultipliers out of four. The time resolution is estimated by means of a gaussian fit on the distribution of the time difference between the first fired photomultiplier and the beam dump time (for a description of the set-up see figure 3). In figure 9 efficiencies and time resolutions are shown for different thresholds.

Efficiency and time resolution on protons are dependent on the applied threshold: at 15 mV the efficiency is $\sim$ 97% and the time resolution is $\sim$ 275 ps. For ^{12}C ions, given the high amplitude signals, the results are almost threshold independent, with efficiency $\sim$ 100% and time resolution $\sim$ 130 (100) ps without (with) time slewing correction at 60 mV threshold.

4. Conclusions

FIRST is an experiment devoted to ion fragmentation studies for hadron therapy and space radiation protection applications. The first run has been performed during August 2011 at GSI and it was dedicated to the study of ^{12}C fragmentation on a thin graphite target. In this paper we present the description of the upstream detectors used to trigger and to track the incoming ion beam as well as their performances on test beams. They consist of a thin scintillator, the Start Counter, showing high efficiency and time resolution $\sim$ 100 ps on low energy carbon ions and of a drift chamber, the Beam Monitor, with a single layer space resolution between 100 μm and 300 μm. These performances fulfill the requirements of our experiment.

5. References

References

[1] M. Durante and J.S. Loeffler, Nat. Rev. Clin. Oncol. 7 (2010) 37
[2] O. Jakel et al., Med. Phys. 35 (2008) 5653
[3] G. Deptuch et al., NIM A512 (2003) 299.
[4] G. Bauer et al., NIM A386 (1997) 249.
[5] T. Blaich et al., NIM A314 (1992) 136.

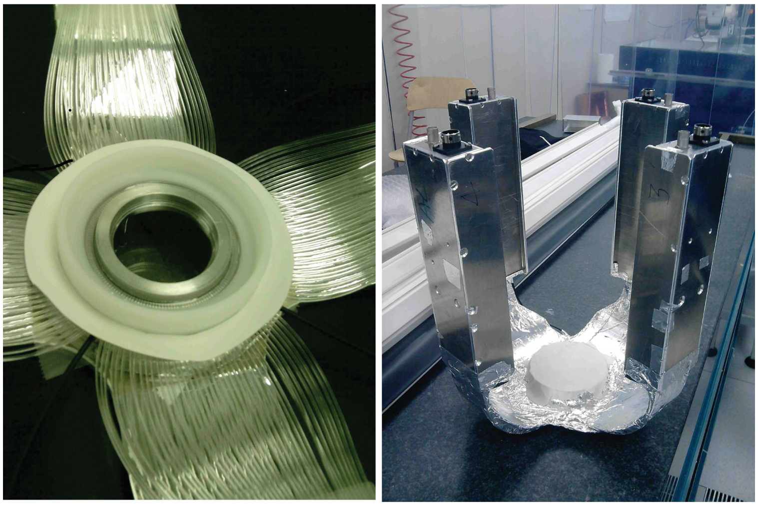

Figure 8. The Start Counter. In the left picture the optical fibers connected to the scintillator disc are shown. The picture at right shows the assembled detector.

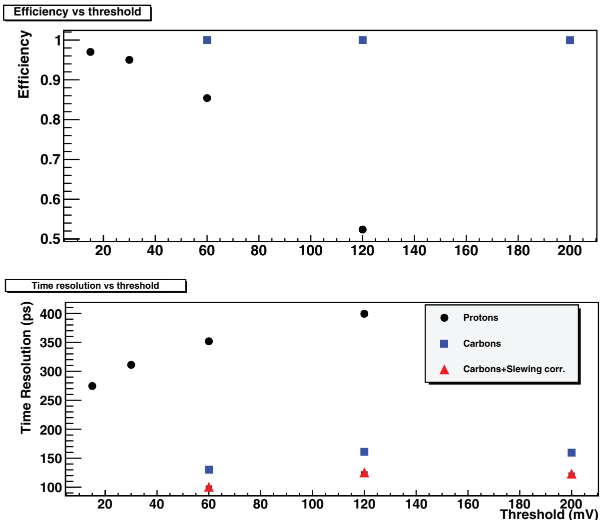

Figure 9. Start Counter test beam results: efficiencies (upper plot) and time resolutions (lower plot).