The Upstream Detectors of the FIRST Experiment at GSI

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TIPP 2011
Technology and Instrumentation in Particle Physics 2011
Instrumentation for Medical, Biological and Materials Research
Chicago, 10 June 2011
Acknowledgements

Detectors realization:
R. Rosellini, G. Corradi, D. Tagnani, E. Dane', S. Cerioni (LNF)

BTF tests:
A. Mengucci, B. Buonomo, L. Foggetta (LNF)

LNS tests:
C. Agodi, F. Romano (LNS)
Hadrontherapy with 12C ions

Light ions advantages in radiation treatments of tumor with IMRT:
Better Spatial selectivity in dose deposition
Reduced lateral and longitudinal diffusion
High Biological effectiveness
Fragmentation of 12C ions

Production of fragments with higher range and different direction wrt to primary ions;
Attenuation of the primary beam;
Different biological effectiveness of the fragments wrt to 12C ions.

12C (400 MeV/u) on water

Bragg-Peak

Dose over the Bragg Peak:
- p ~ 1-2%
- C ~ 15%
- Ne ~ 30%

Exp. Data (points) from Haettner et al, Rad. Prot. Dos. 2006

A lot of measurements on thin targets, but very few with fragment angular and energy distributions, in the energy range of interest for hadrontherapy.....
Fluka MC Simulation

Protons are by far the most abundant fragments with a wide velocity range (0<\( \beta < 0.6 \)) with a wide angular distribution.

Z=2 fragments are emitted within 10° around the projectile direction.

Z>2 fragments approximately have the same velocity of 12C beam projectiles and are collimated in the forward direction.

The dE/dX of the fragments spans from \(~2\) to \(~100\) m.i.p.
First Experiment at GSI

New Interaction Region

Start Counter

Target

Beam Monitor

Vertex

Ptagger

ALADIN Magnet

MUSIC IV TPC

Scintillator TOF

Land2 Neutron Detector

Run 2011: 12C @ 200-400 MeV/nucleon on carbon target
The FIRST experiment is designed to identify all the fragments (0<Z<6) and to measure their energy and direction.
Scintillator Start Counter: Trigger and T0 for TPC and TOF wall
Beam Monitor: Beam direction and impact point on target
Si pixel vertex detector: fragments emission angle
TPC: Z/p, θ, φ after bending, dE/dX ∼ (Z/β)^2
Scintillator TOF wall: TOF=f(Z,p,θ,φ)/β
Ptagger calorimeter:p(He) detection/discrimination through TOF and dE/dX
BEAM MONITOR

Rectangular Drift Cell (8 mm drift space)

Six staggered planes/view

Less beam interaction with the wires
Less border effect in the space-time relations
Tracking redundancy

Front-End Electronics (Gain=10)
250 micron thick scintillator disc (5 cm diameter)
Optical fibers for light transmission
Fibers collected in 4 bundles

Scintillator: EJ-228 (Pilot U)
PMTs: Hamamatsu UBA H10721-201
500 MeV electrons: 10 ns spills at 25 Hz. 
$<N_e>=1$, Poisson statistics $\rightarrow$ Calorimeter for single electron selection.
Dedicated to Beam Monitor gas mixture studies

BTF Test Beam at LNF
LNS Test Beam @ Catania

Protons and Carbons @ 80 MeV/nucleon ; Rate ~ 1 MHz
Final test of the detectors in GSI-like conditions (high ionization)

\[ \frac{dE}{dx} (\text{p @ 80 MeV/N}) \approx 6 \frac{dE}{dx} (\text{mip}) \]
\[ \frac{dE}{dx} (^{12}\text{C @ 400 MeV/N}) \approx 40 \frac{dE}{dx} (\text{mip}) \]
\[ \frac{dE}{dx} (^{12}\text{C @ 200 MeV/N}) \approx 80 \frac{dE}{dx} (\text{mip}) \]
\[ \frac{dE}{dx} (^{12}\text{C @ 80 MeV/N}) \approx 200 \frac{dE}{dx} (\text{mip}) \]
Start Counter Test Beam Results

Efficiency: fraction of events with at least 3 fired petals.

Time resolution estimation: Gaussian fit on first petal time wrt to Beam Dump (Trigger) time.

Time Resolution ~ 100 psec on Carbons, after Time Slewing correction.
Time Slewing correction

Carbon ions @ 80 MeV/nucleon
Threshold = 60 mV

\[ T = p_0 + \frac{p_2}{(Q-p_1)^2} \]
Beam Monitor Test Beam Results

Carbons @ 1.8 kV
Ar/CO2=80/20
Threshold = 15 mV (unless stated otherwise)

Ar/CO$_2$ mixtures: lower operating voltages at higher Ar concentrations
P10 ($\text{Ar}/\text{CH}_4 = 90/10$) operating voltage similar to Ar/CO$_2 = 90/10$
Operating voltage on LNS protons similar to BTF electrons
Operating voltage on LNS carbons ~ 300 V lower than on protons.
A cleaner tracking seems to be obtained with P10 mixture (higher quenching power). Ar/CO\textsubscript{2} mixtures are preferable from a safety point of view. Due to redundancy, the Beam Monitor can be indeed operated at lower (by few %) cell efficiency, fixing the average occupancy.
Threshold = 15 mV (unless stated otherwise).
R vs t relation parametrized through splines.
Average on all cells. Systematic studies for separate cells to be done.

Average Space resolutions better than 100 μm can be obtained for all mixtures and beams.
Beam Monitor Test Beam Results: Resolution

LNS protons @2.3 kV

\[
\begin{align*}
k_1 & = 3.847e+04 \pm 9.338e+01 \\
\mu & = -0.006618 \pm 0.000013 \\
\sigma & = 0.006856 \pm 0.000014 \\
k_2 & = 1809 \pm 17.4 \\
\mu_2 & = 0.01301 \pm 0.00022 \\
\sigma_2 & = 0.04058 \pm 0.00023
\end{align*}
\]

LNS
Beam Monitor Test Beam Results: Resolution vs Position

Electrons @2.2 kV
Ar/CO$_2$=80/20

Protons @2.2 kV
Ar/CO$_2$=80/20
FIRST Schedule

5 May 2011: Interaction region assembly test in Rome3 University

Si Vertex tracker
Beam Monitor
Start Counter

Installation at GSI: July 2011
Data taking: first two weeks of August
Conclusions

The FIRST experiment has been designed to measure the fragmentation of ions relevant for space and hadron-therapy applications.

The 2011 run is dedicated to the study of the fragmentation of $^{12}$C ions on a C target.

The experiment is made of detectors already existing at GSI integrated with a newly designed interaction region.

The Beam Monitor and the Start Counter have been completed and tested at LNF and LNS beam facilities.

The analysis of the Test Beams data confirms the good performances of the detectors on $^{12}$C ions:
Beam monitor space resolution $\sim 100 \, \mu m$
Start Counter time resolution $\sim 100 \, ps$