Trento Institute for Fundamental Physics and Applications

Istituto Nazionale di Fisica Nucleare

Fragmentation Measurements in Particle Therapy: status and plans of the FOOT experiment

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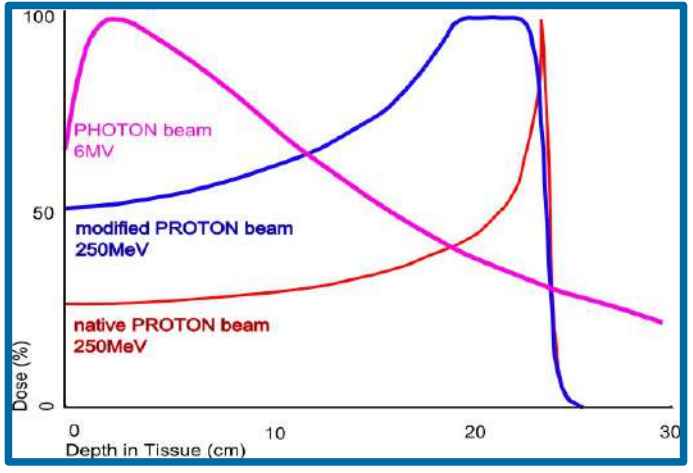
Talk Outline:

- Hadrontherapy
- The FOOT experiment
- Foot Electronic Configuration and sub-detectors elements
- Foot Emulsion Configuration
- Data taking plans
- Conclusion
- Documentation

Hadrontherapy: protons and ions for cancer treatment

Hadrontherapy is the medical use of protons and ions to treat cancer.
In conventional radiation therapy, beams of X rays (high energy photons) are delivered to the patient to destroy tumor cells.
When the irradiating beams are made by protons and other ions (such as carbon), radiation therapy is called hadrontherapy.

The strength of hadrontherapy lies in the fact that proton and ions can penetrate the tissues with little diffusion and deposit the maximum energy just before stopping allowing a more precise definition of the region to be irradiated.
The peaked shape of the hadron energy deposition is called Bragg peak.



Picture from: wikipedia/Bragg peak

Trento Proton Therapy Center (Italy):
One of the two patient hadrontherapy treatment room (gantry)

FOOT: the FragmentatiOn Of Target experiment

The main purpose of the FOOT experiment (FragmentatiOn Of Target) is to improve the hadrontherapy tumor treatments by studying the **nuclear fragments** produced during therapy applications in the **Interactions** of the **particle beams** with the **nuclei** constituting the **human tissues**.

The **nuclear fragments** are an important **source of biological damage**, both for cancer cells and for nearby healthy tissues, and it is of fundamental importance to have a **deep knowledge of this process** in order to make the most **effective and safe medical treatment**.

FOOT: the Fragmentati**O**n **O**f **T**arget experiment

In hadrontherapy treatment many fragments can be created: from the **fragmentation of the target** cell nuclei (mainly composed by carbon, oxygen or hydrogen atoms), or from the **fragmentation of the beam elements** (mainly carbon, under studying oxygen and helium) when ions are used for the treatment.

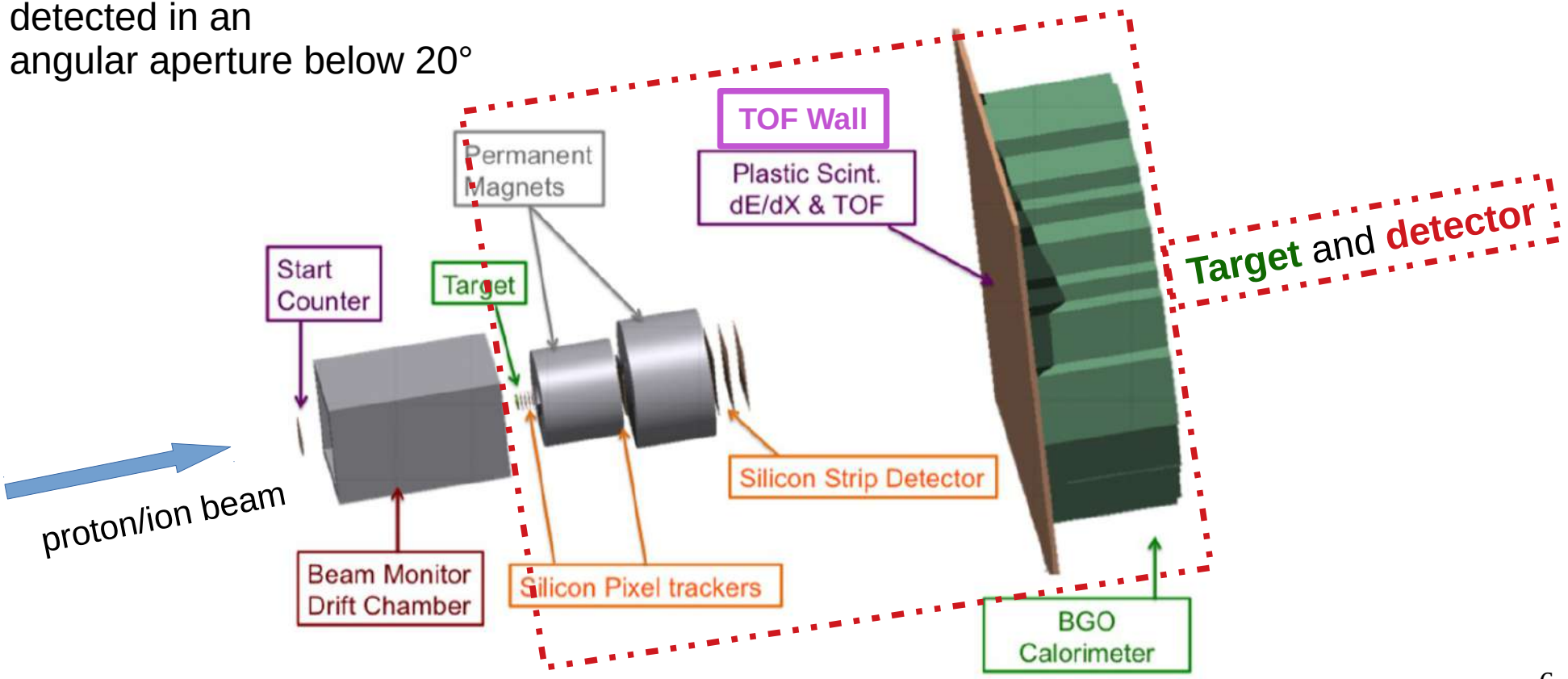
Foot will realize these precise cross-section fragmentation measurements using the ***reverse kinematic technique:*** the measurements will be realized using carbon, helium and oxygen beams on **C** and **CH targets.**

In order to perform precise cross-section measurements, two different configurations will be used:

- The ***Electronic Configuration,*** for the cross-section measurements of heavy fragments (Z>2) mainly produced in a small angle below 20deg.)
- The ***Emulsion Configuration***, for the cross-section measurements of light fragments (Z<=2) mainly produced in a large angle, up to 70deg.)

FOOT: *"electronic"* configuration

Heavy Fragments detection (Z >2)
detected in an
angular aperture below 20°

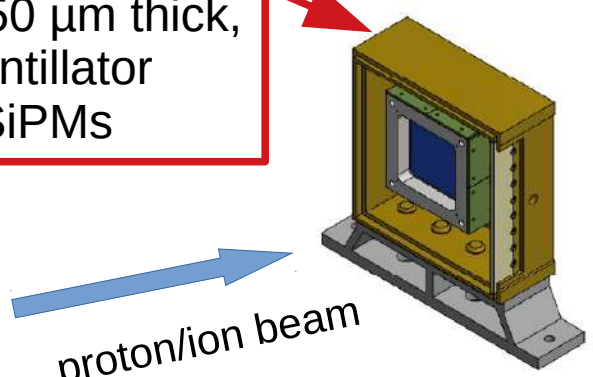


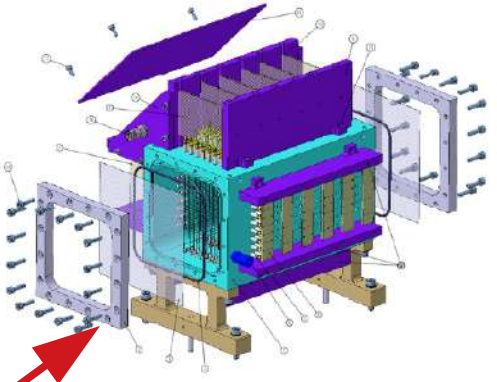
FOOT: *"electronic"* configuration

Start Counter and Beam Monitor

START COUNTER (SC):
EJ-228 plastic scintillator 250 μm thick, the light produced in the scintillator is collected laterally by 48 SiPMs

The SC provides an event trigger and a time reference for TOF measurements

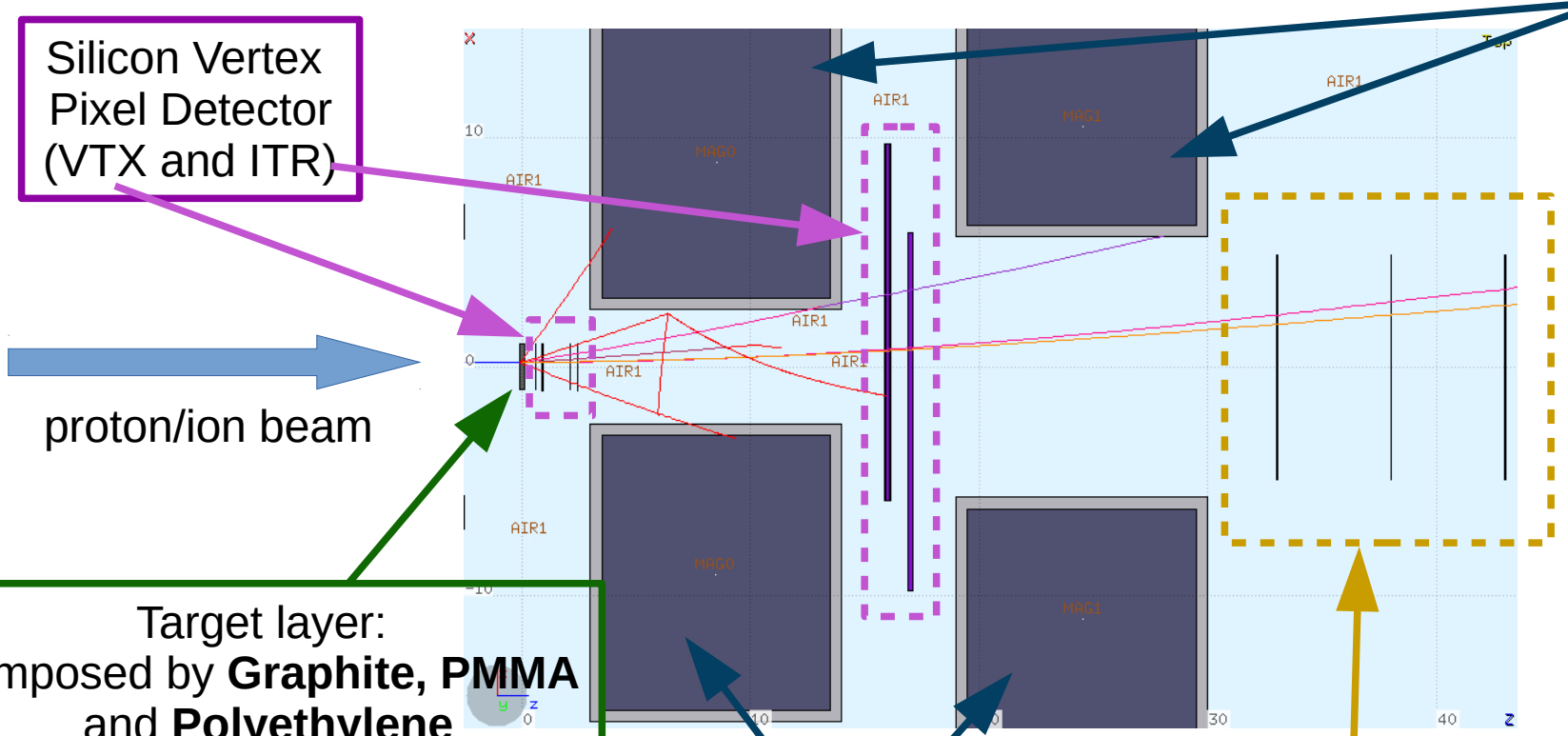




BEAM MONITOR CHAMBER (BM):
Drift Chamber composed by 12 layers. Used for precise measurement of the beam profile after the interaction with the start counter foil.
The same chamber is also used in the emulsion configuration

FOOT: *"electronic"* configuration

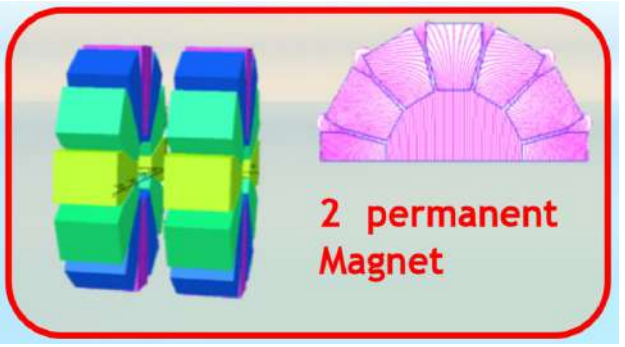
Overview of the tracking system in the x-z plane



FOOT: *"electronic"* configuration

Overview of the tracking system

PERMANENT MAGNETS:
two cylindrical Halbach arrays of permanent magnets.
maximum intensity of 1.4 T and 0.9 T along the y axis
in the internal cylindrical hole.



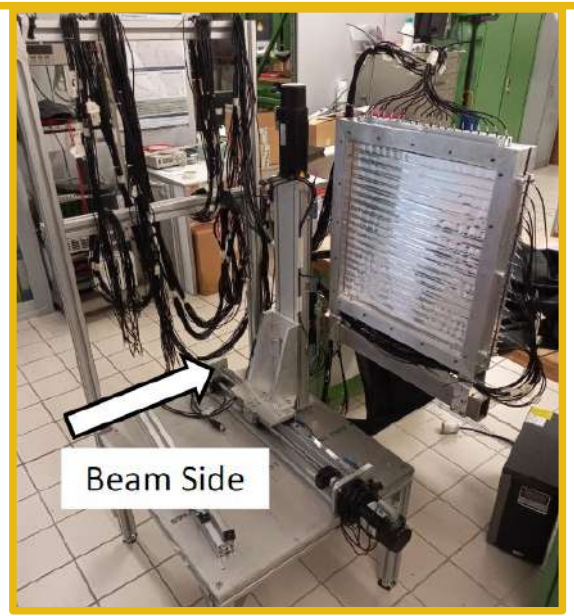
VTX and ITR:
Respectively four and two planes of MAPS Silicon Pixels sensors Mimosa28 assembled in two different ladders geometry. Pixel pitch: 18.4 μm.

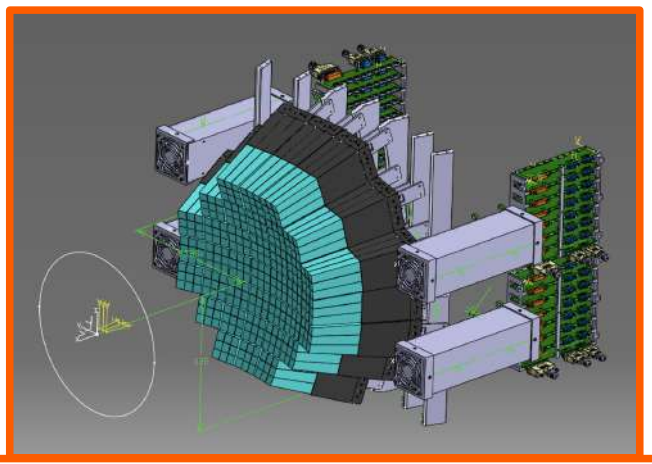
Microstrip Silicon Detector MSD: 3 planes, each plane is composed by two perpendicular Single-Sided Silicon Detector (SSSD) sensors thinned down to 150 μm with analog read-out. Expected space resolution of 40 μm.

FOOT: *"electronic"* configuration

TOF Wall and Calorimeter

TOF Wall: two layers of 20 plastic scintillator bars (EJ-200) orthogonally arranged with SiPMs and fast digitizers read-out. Used, together with the SC, for TOF measurements with time resolution below 100 ps, and for energy loss measurements with σ(ΔE)/ΔE ~ 4-5%.

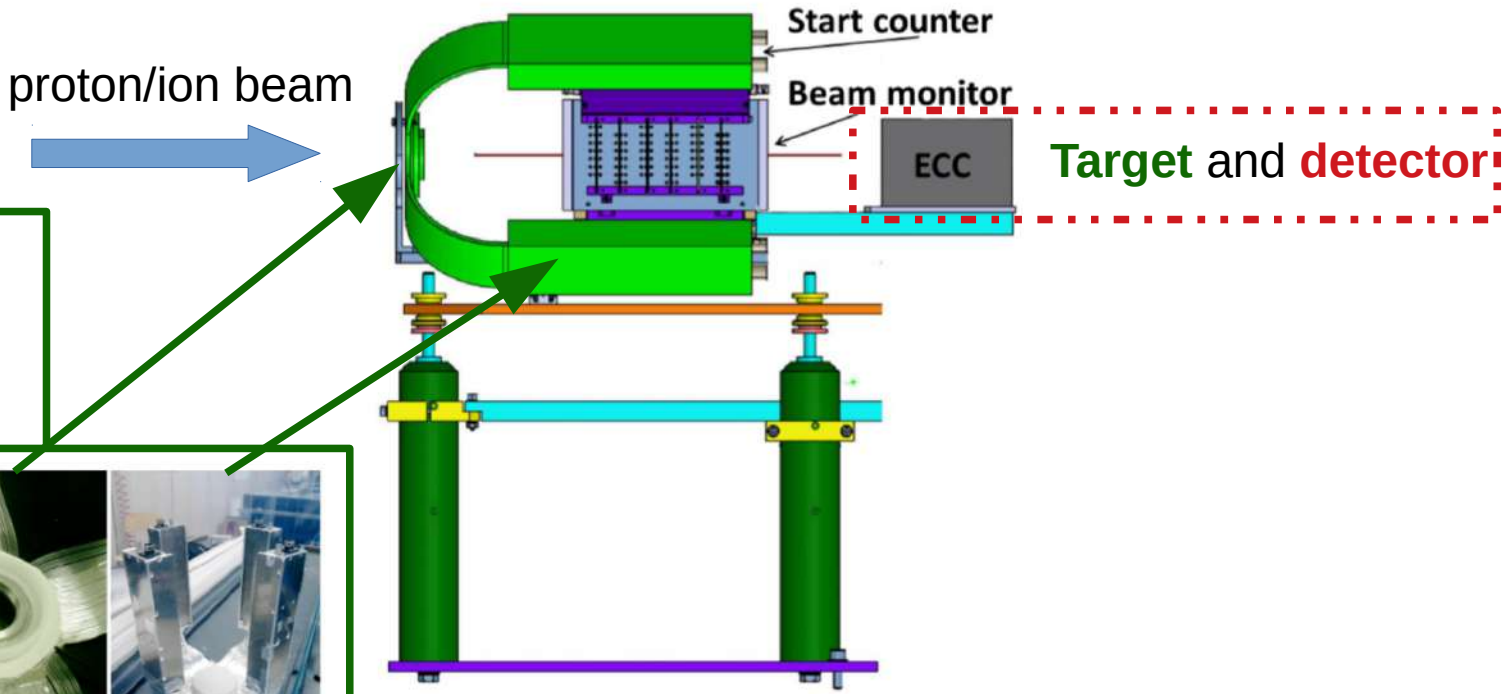




BGO Calorimeter: 320 BGO crystals with SiPM readout. Energy resolution σ(Ekin)/Ekin below 2%.

FOOT: *"emulsion"* configuration

Light Fragments detection (Z <=2)
detected in an angular aperture up to 70°



START COUNTER:
Composed by a thin plastic scintillator with readout fibers and four PM.

FOOT: *"emulsion"* configuration

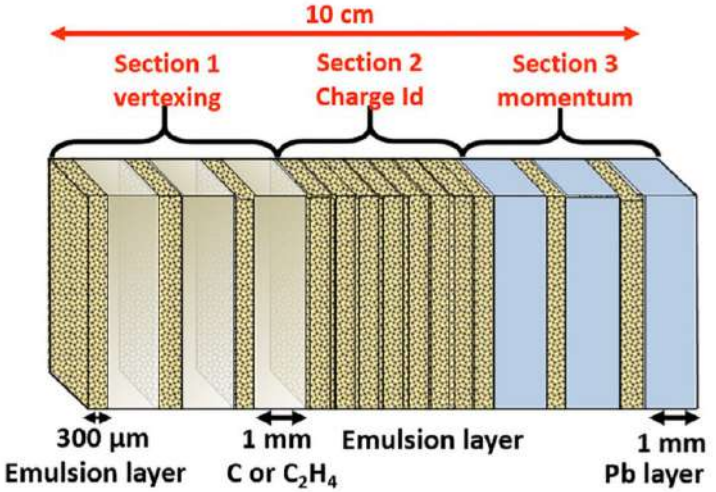
Used for measurements of tracks from light fragments with very short path and large angle spread.

The emulsion configuration is composed by a sandwich of **emulsion layers** and other materials organized in 3 sections:

Vertexing section:
target layers and emulsions.

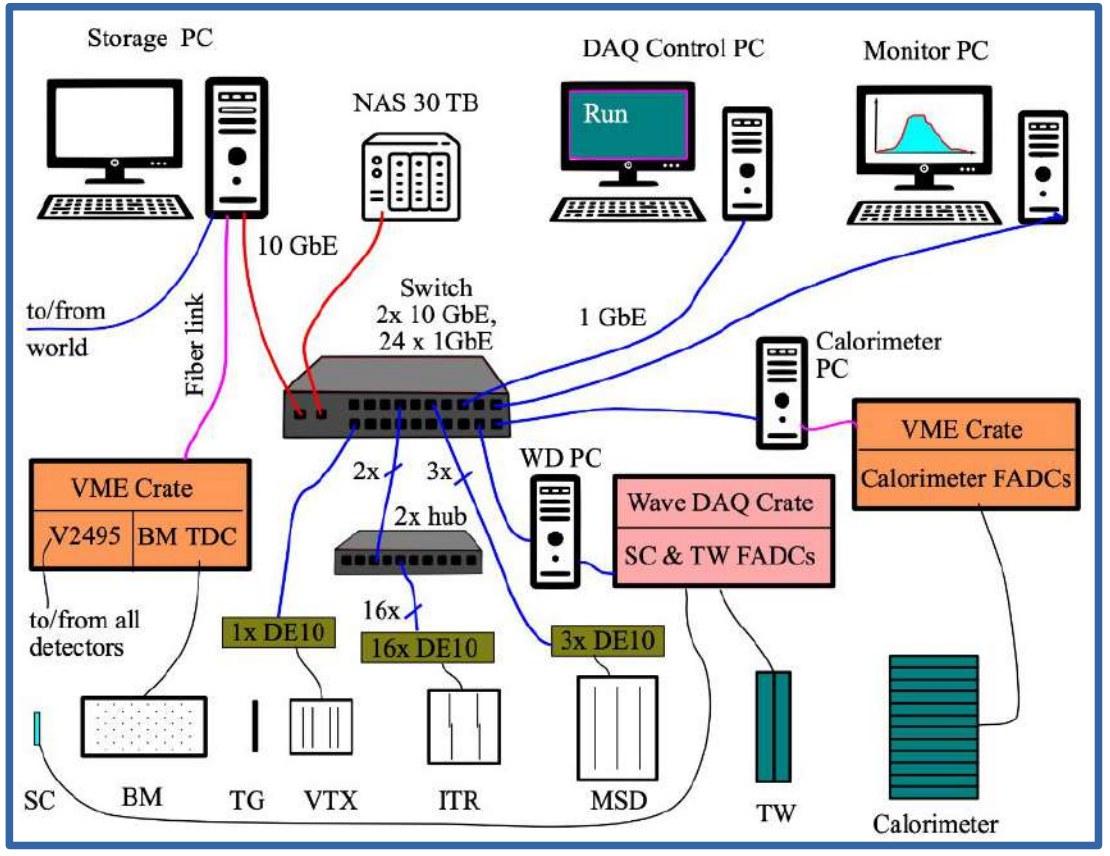
Charge identification section:
only emulsion layers.

Momentum measurements section:
lead and emulsion layers.



The *emulsion detector technique* was developed and successfully used in tau neutrino detection experiments.

FOOT: DAQ structure



The FOOT detector will be equipped with a DAQ system designed to acquire the largest sample size with high accuracy in a controlled and online-monitored environment.

Designed DAQ rate:
1 kHz event rate at 50 KB/event.

Data taking

FOOT scientific program started using the **Emulsion Configuration** at **GSI** (Darmstadt, Germany), in 2019 with ^{16}O ions at 200 and 400 MeV/nucleon on C and C_2H_4 targets, and in 2020 with ^{12}C ions at 700 MeV/nucleon, on the same targets. Data analysis is still in progress.

The **Electronic Configuration** setup is under completion, tests and data taking are being scheduled at the GSI with a ^{16}O beam and at the **CNAO** (Pavia, Italy), using ^{12}C ions at 200 MeV/nucleon.

Conclusions

The **FOOT Experiment** has been designed to perform measurements of differential cross sections for the production of charged fragments in the nuclear interaction between ion beams (p, ^{4}He, ^{12}C, ^{16}O) and targets (H, C, O) of interest for charged Particle Therapy and space radioprotection.

The same apparatus will be used to investigate the double differential cross sections of the projectile fragmentation process for beams of ^{4}He, ^{12}C and ^{16}O impinging on graphite, polyethylene and PMMA targets up to 500 MeV/nucleon for charged PT and up to 800 MeV/nucleon for space radioprotection studies.

The construction of the detector is being finalized and several beam tests have already been performed for calibration purposes.
The experiment started its scientific program in 2020, data analysis is ongoing.

Two data taking are planned in 2021 with both the two experiment configurations: at GSI in July with a Oxygen beam and at CNAO in Fall with a Carbon beam.

Documentation

See also the following posters at the present TIPP 2021 conference:

TIPP2021: #309

Nazar Bartosik et al.

High-precision energy measurement of medium-light ions with the FOOT calorimeter

https://indico.cern.ch/event/981823/contributions/4295546

TIPP2021: #603

Gianluigi Silvestre et al.

Test of a prototype Microstrip Silicon Detector for the FOOT experiment

https://indico.cern.ch/event/981823/contributions/4295385

OTHER DOCUMENTS:

Battistoni Giuseppe, Toppi Marco, Patera Vincenzo, The FOOT Collaboration

Measuring the Impact of Nuclear Interaction in Particle Therapy and in Radio Protection in Space: the FOOT Experiment

Front. Phys., 08 February 2021

https://doi.org/10.3389/fphy.2020.568242

FOOT Experiment official web page:

https://web.infn.it/foot/en/home

Thanks for your attention!

And fell free to contact me for other questions!
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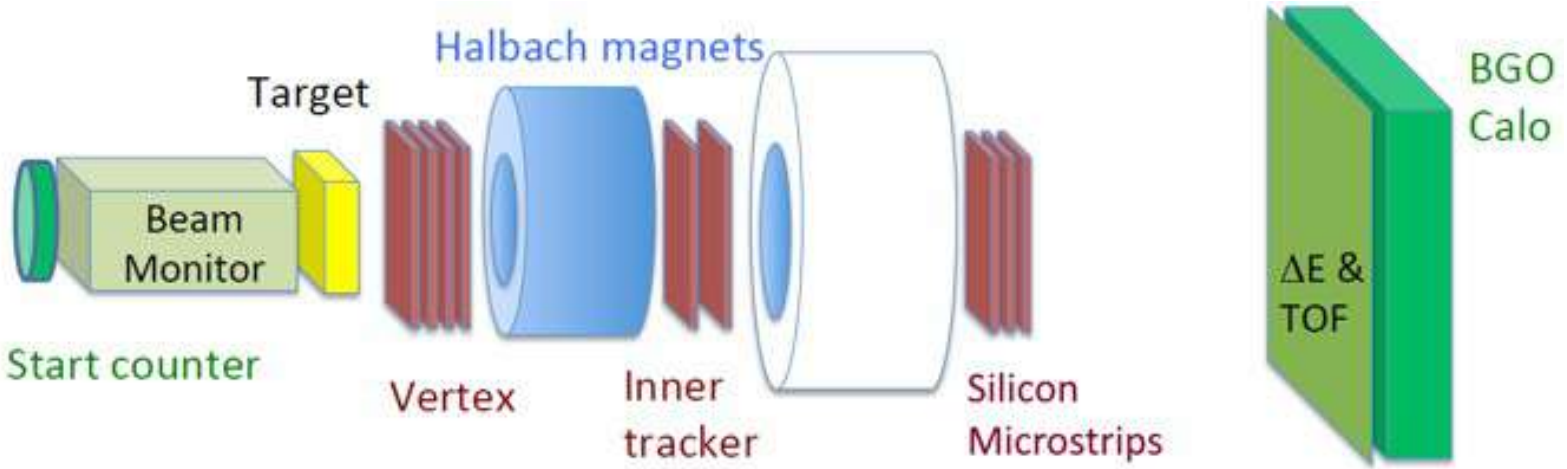
Back-up slides

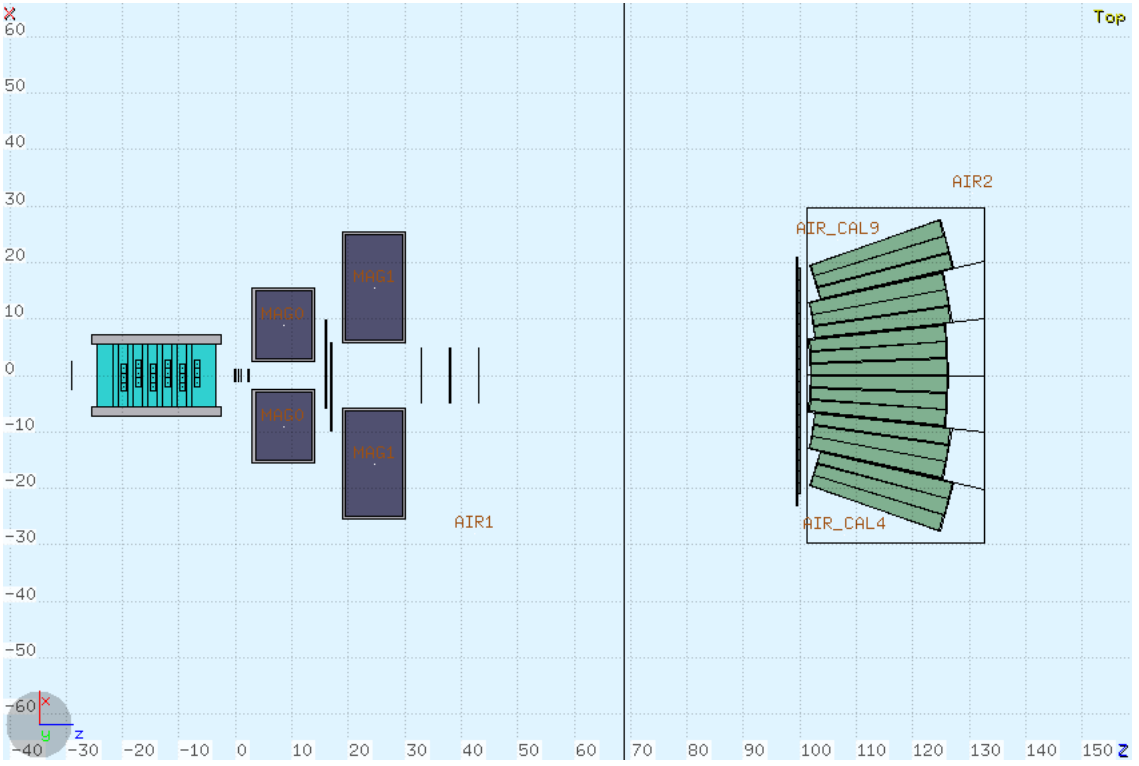
Abstract:

Due to the advantageous characteristics of charged particles' energy deposition in matter, protons in the energy range of 70-230 MeV or ^{12}C beams with energy up to 400 MeV/u are used in hadrontherapy to treat deep-seated solid tumors. Using these beams, the maximum of the dose is released to the tumor tissues at the end of the beam range. In this process nevertheless, fragmentation of both projectile and target nuclei can occur in the nuclear interactions of the beam with the patient tissues and needs to be carefully taken into account.
The goal of the FOOT (FragmentatiOn Of Target) experiment is to estimate target and beam fragmentation cross sections in the energy range of interest for hadrontherapy, in order to provide new data for medical physicists, radio-biologists and to improve the new generation of Treatment Planning Systems.
In this talk the project, the status of the different sub-systems construction and the plans for the final experiment assembling will be presented.

FOOT Electronic configuration overview



One of the design used for MC simulations



Magnetic field simulation (electronic configuration)

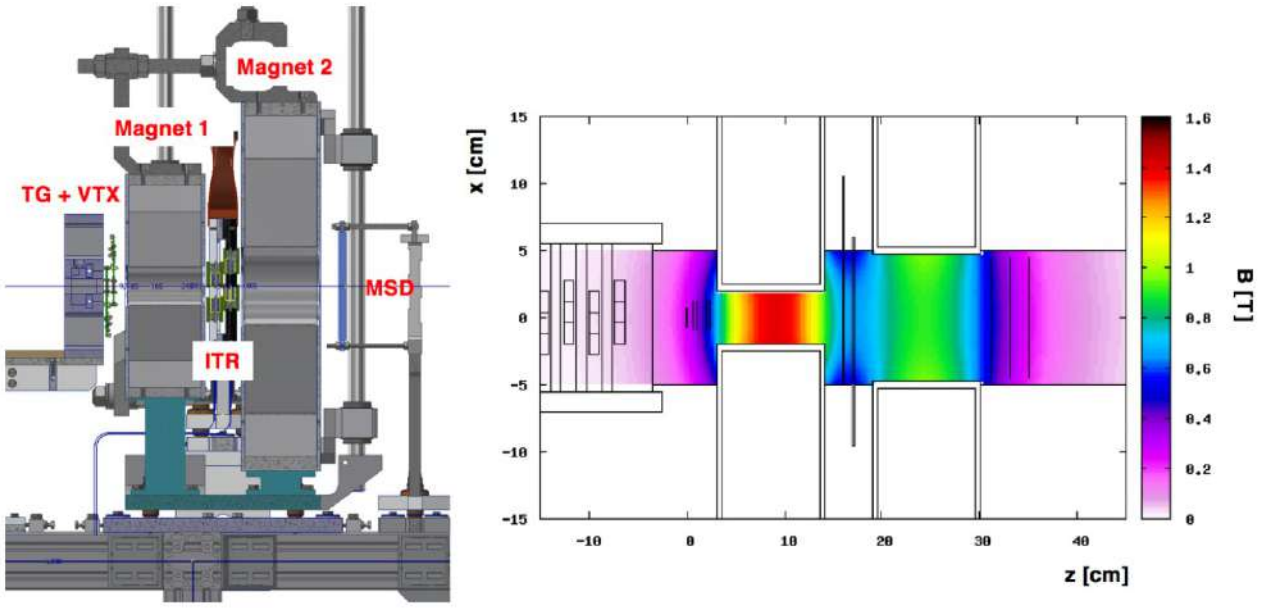
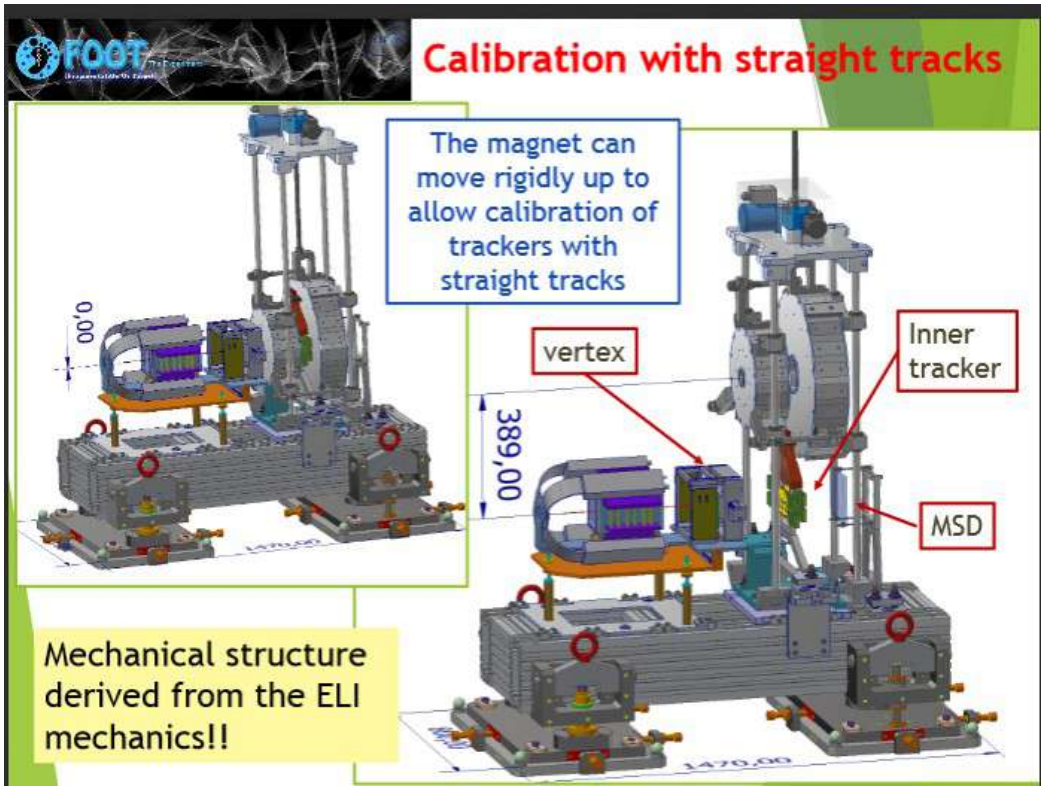


Figure 4. (Left) Technical design of the interaction and tracking region. (Right) Computed magnetic field map produced by the FOOT magnets in Halbach configuration.

Overview of the beam monitor and tracking elements of the electronic configuration



NOTE: this representation contains a obsolete version of the the start counter used in the electronic configuration.