The FOOT experiment: status and first experimental results

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On Behalf of the FOOT collaboration

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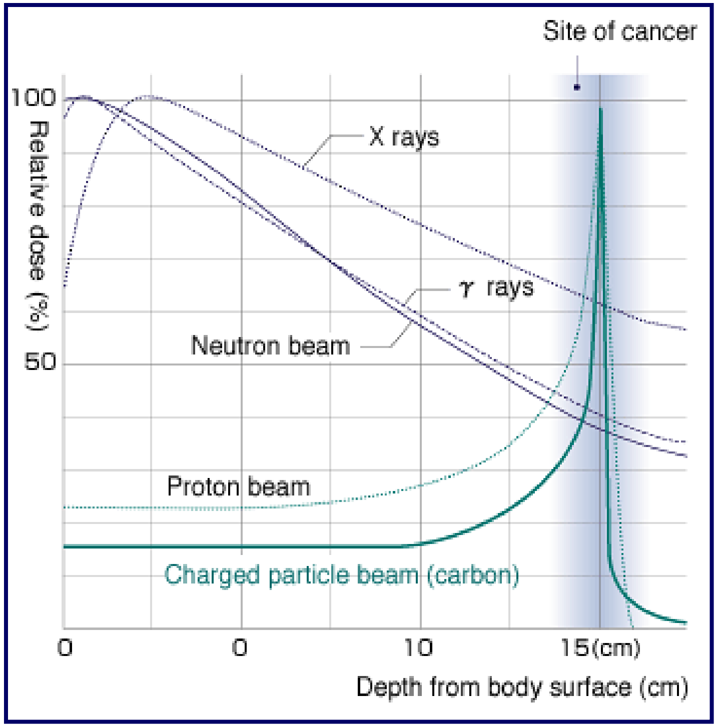
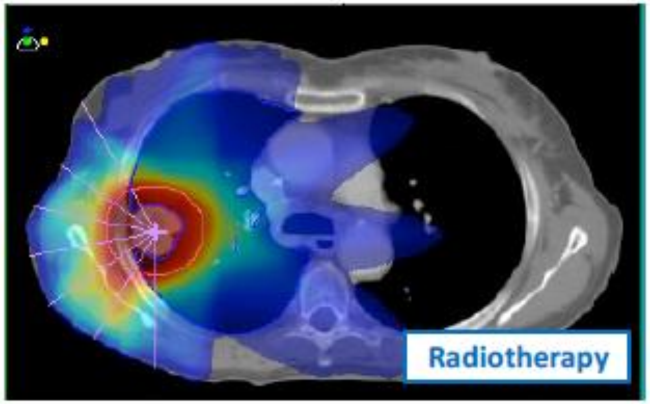
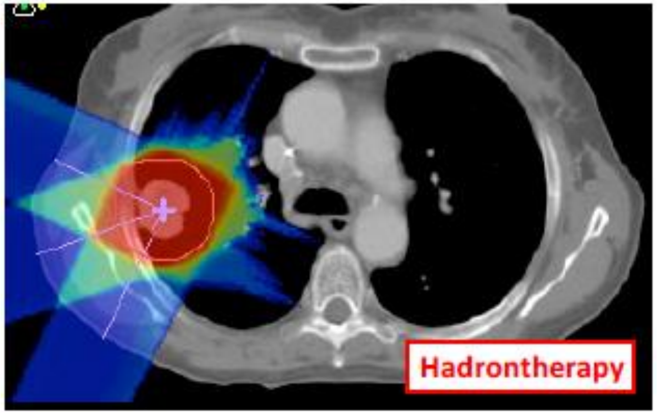
Hadrontherapy

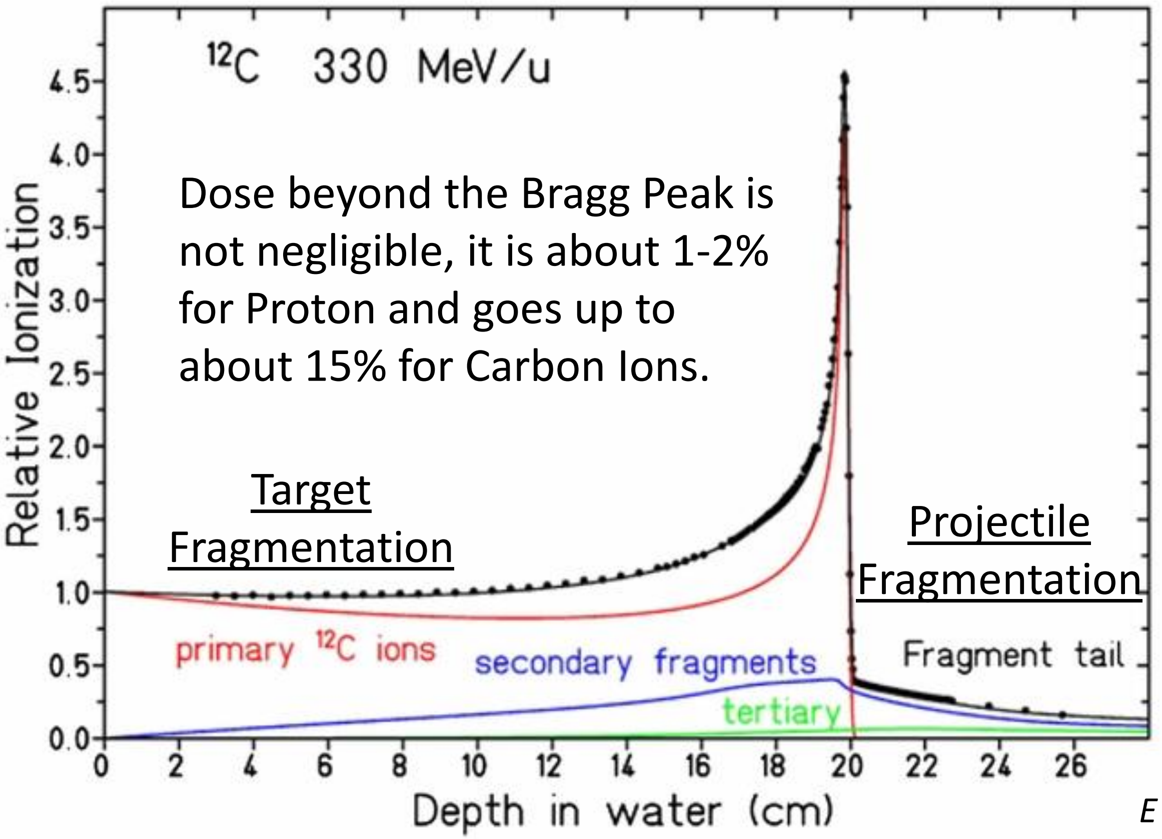
Dose delivery of an Hadron beam is mainly concentrated on the Bragg-peak.

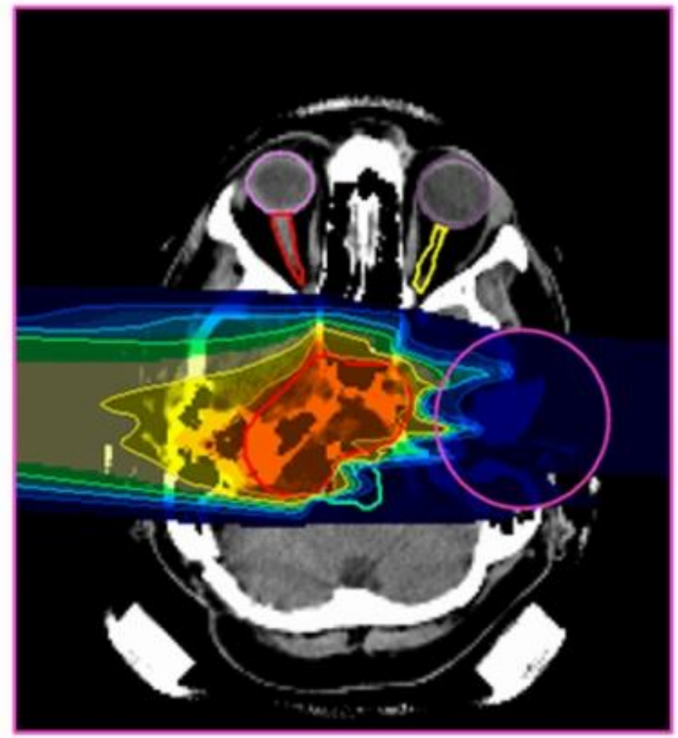






FOOT Motivations

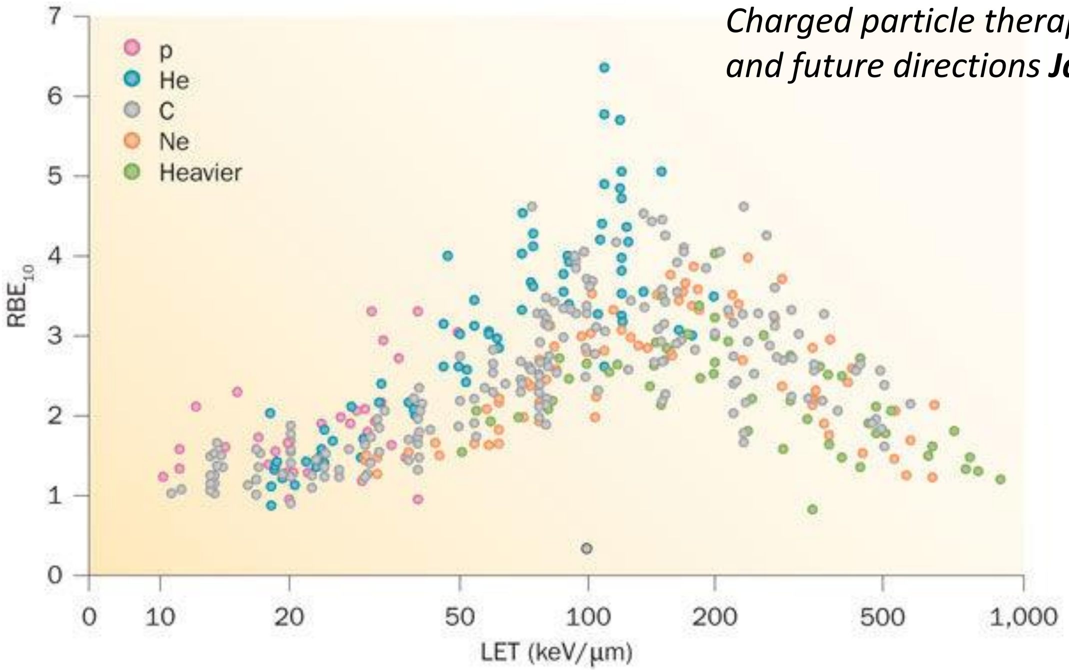




E Haettner et al 2013 Phys. Med. Biol. 58 8265

Exp. Data (points) from Haettner et al, Rad. Prot. Dos. 2006
Simulation: A. Mairani PhD Thesis, 2007, Nuovo Cimento C, 31, 2008

FOOT Motivations



Charged particle therapy—optimization, challenges and future directions ***Jay S. Loeffler & Marco Durante***

The creation of fragments gives a change in the dose release that is reflected in a different <u>Biological Effectiveness</u>.

An accurate model of the fragmentation needs to be taken into account in the treatment planning. But <u>a precise set of cross sections</u> at clinical energies is still missing!

The Experiment

Measure the double differential cross-section using inverse kinematic

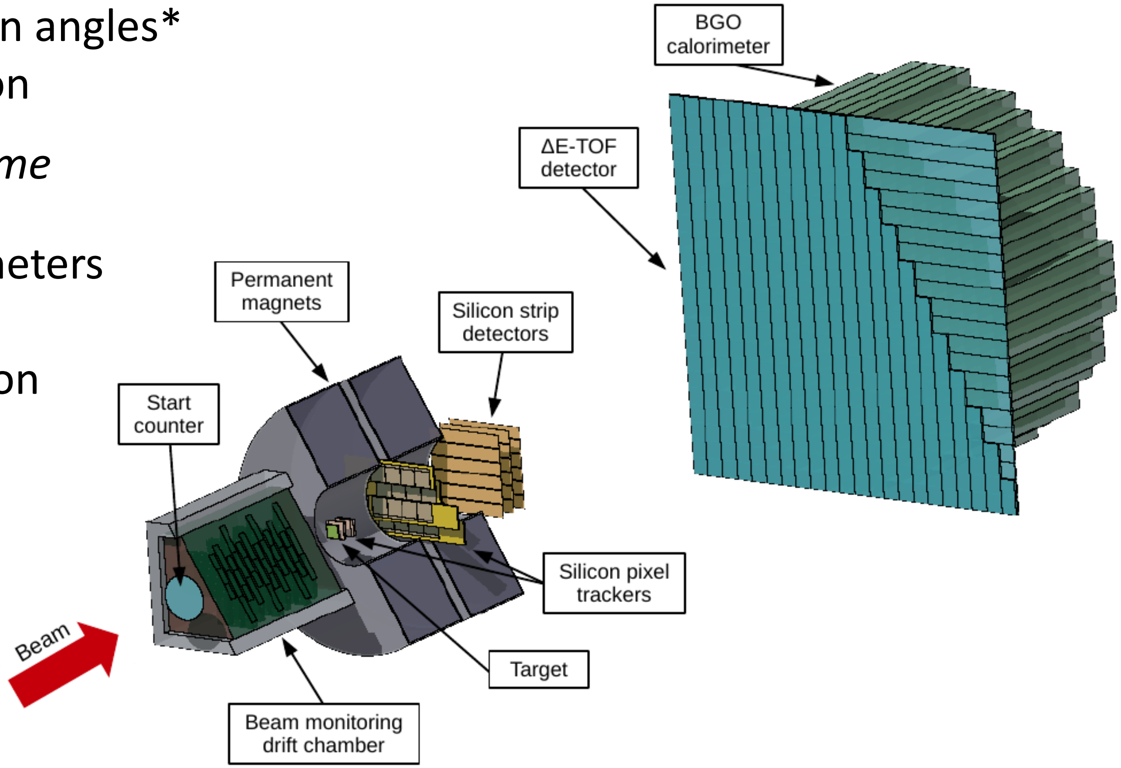
- 5% uncertainty for 200MeV ions for various ion (H, He, C, O…) impinging on different targets (C, C_2H_4,PMMA)*
- 1-2MeV/u resolution in the fragment energy*
- ~10 mrad accuracy in angles*
- isotopic identification

** In the "patient" reference frame*

Overall dimension of about 2 meters

Capability to move the system on different facilities

Working at rate of few kHz

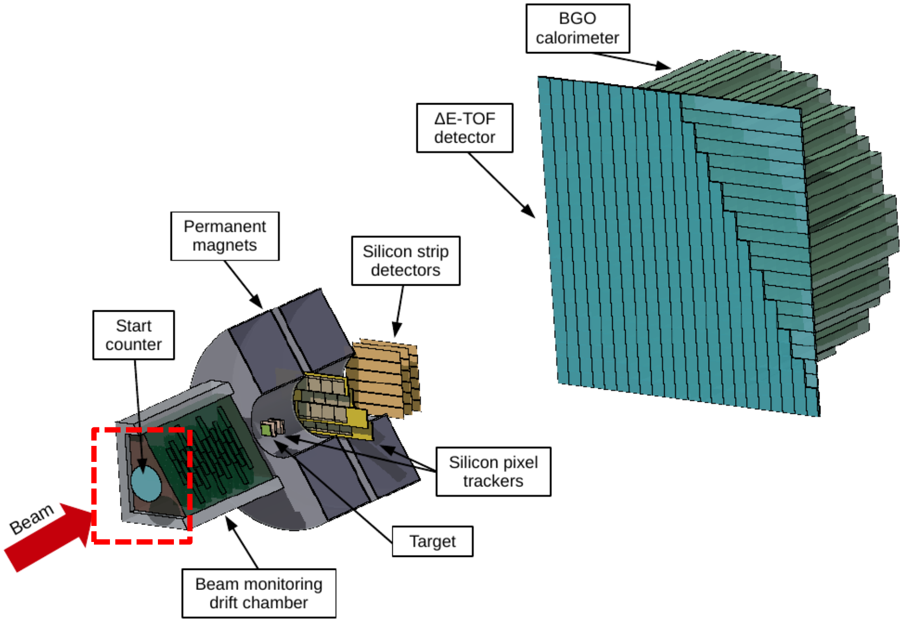


Start Counter

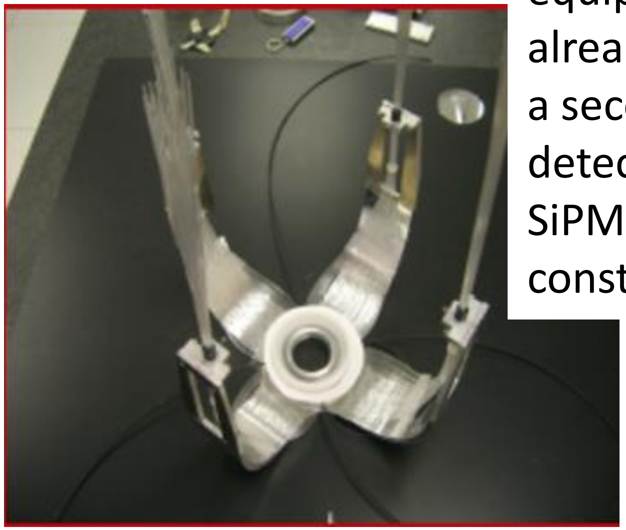
Thin plastic scintillator layer (about 250 μm) with side read-out

PROVIDES:

- First time-stamp for the Time of Flight measurement
- Incoming ion counter



A first prototype equipping PMTs already running, a second detector with SiPMs is under construction

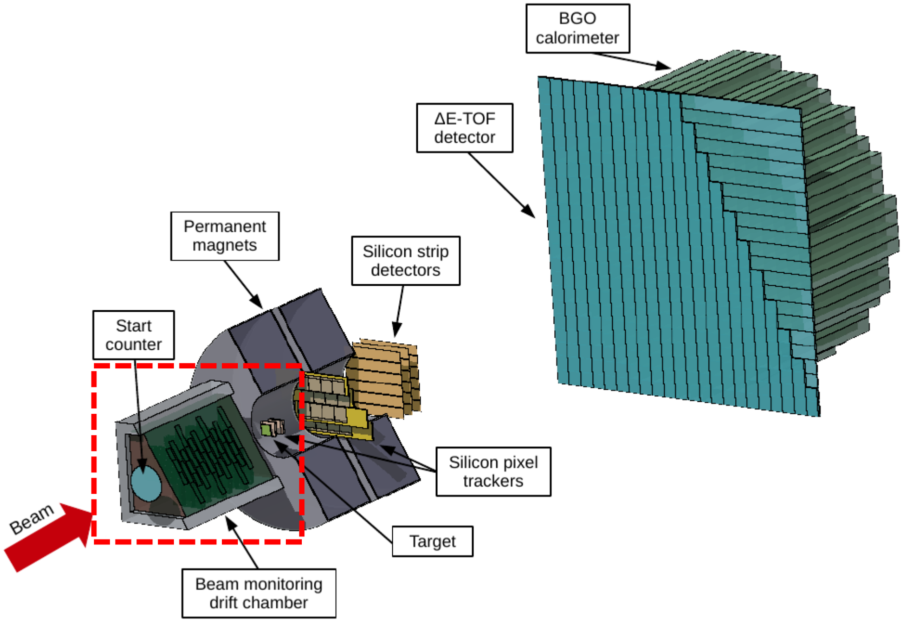


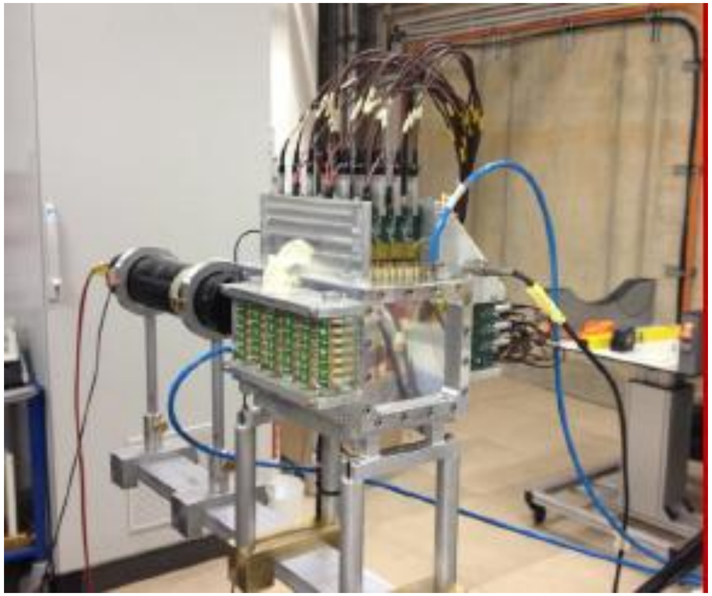
Beam Monitoring

Drift chamber of 11 cm x 11 cm x 20 cm dimension composed of 12 orthogonal layers of wires.

PROVIDES:

- Position and the direction of the primary particle, essential to apply inverse kinematic with the required resolution



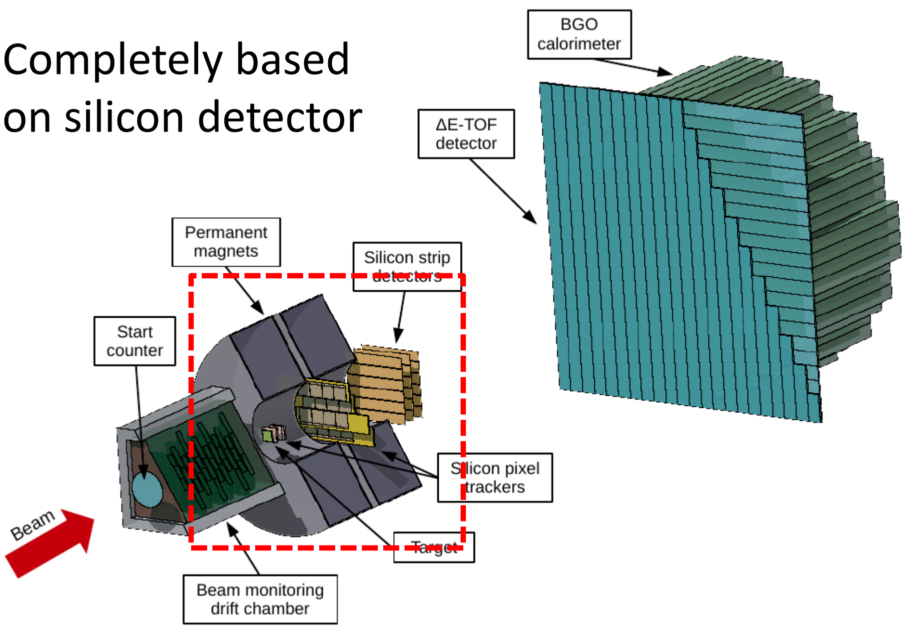


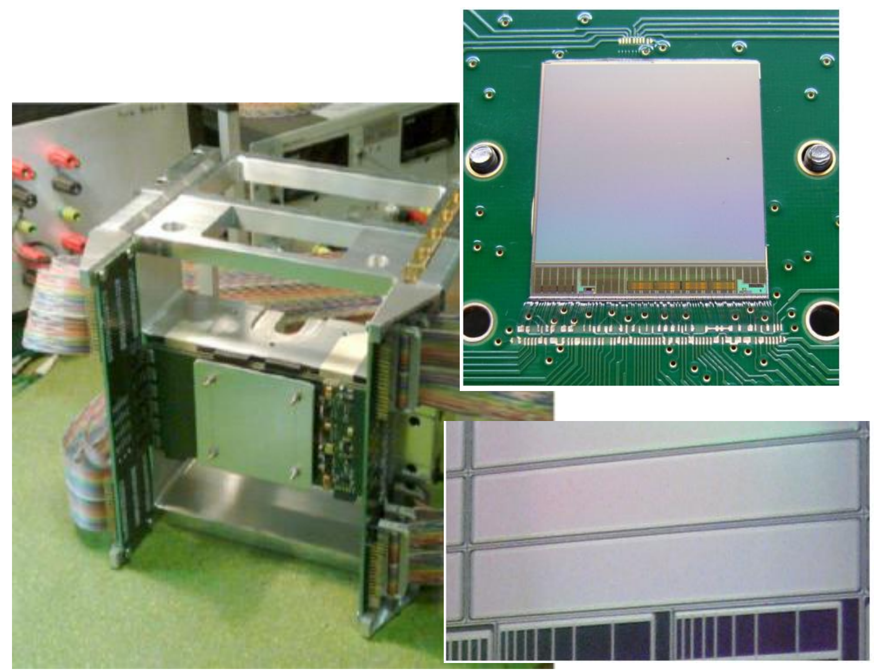
Magnetic Spectrometer

•**Vertex tracker**: 4 tracking layers of M28 MAPS, 20.7 μm pitch and 50 μm thickness
• **Inner Tracker**: 2 layers of M28 sensors
•**Downstream Tracking**: 3 layers of x-y silicon strips, 100-150 um width and 9 x 9 cm^2 area

PROVIDES:
• The track of the fragment before and inside the magnet
• The dE/dx in the strips with a large dynamic range

Completely based on silicon detector



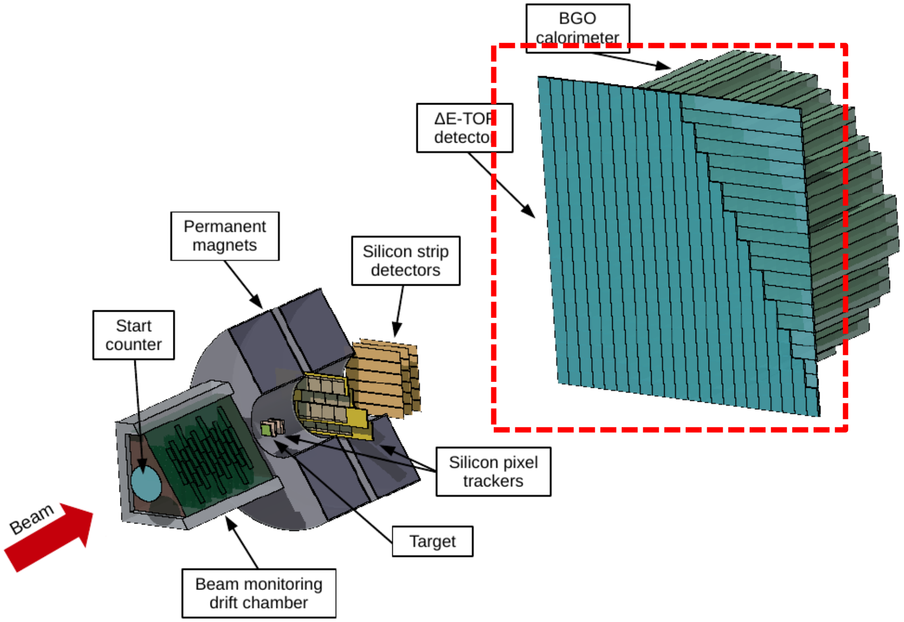


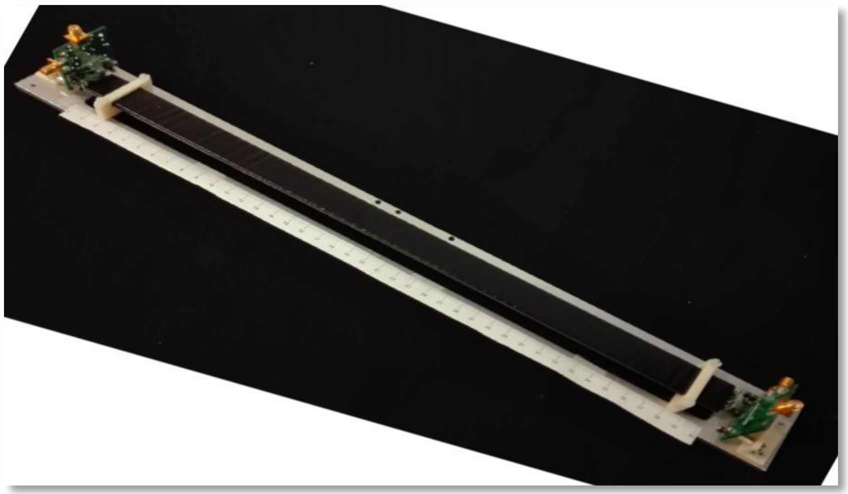
ΔE-TOF Detector

Plastic scintillator wall composed of two layers of bars read-out by SiPMs

PROVIDES:

- Second time-stamp for the TOF measurement
- dE/dx information



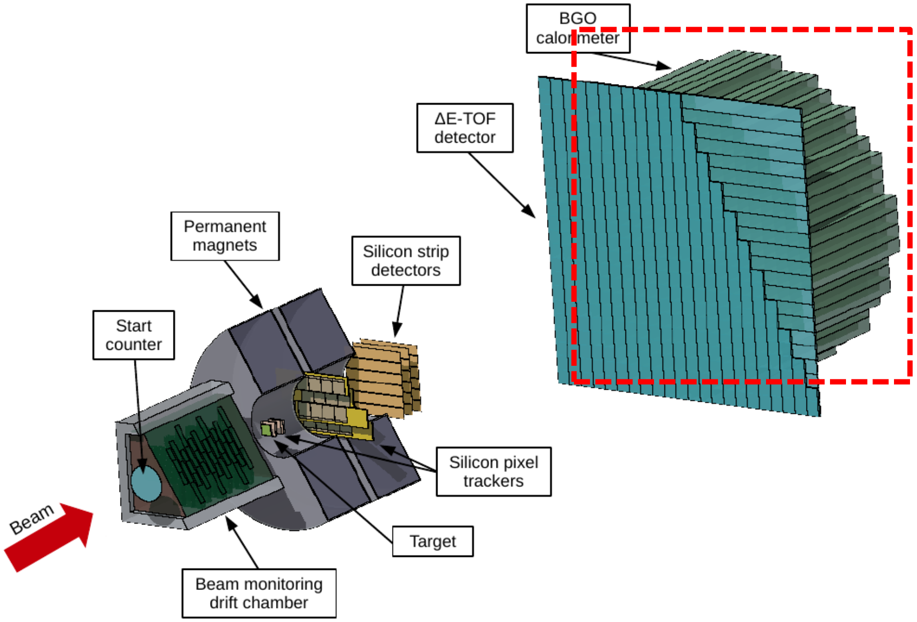


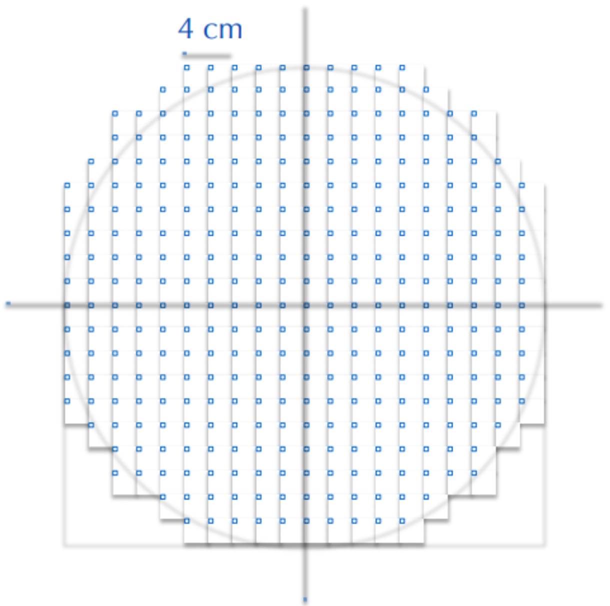
Calorimeter

BGO calorimeter with 20 cm radius (344 pixels)
2 x 2 cm pitch (same as the ΔE/TOF).

PROVIDES:

- The kinetic energy of the particle
- Interaction position





Some ΔE-TOF details

Using the TOF information and the energy released in the scintillator, the atomic number (z) of the fragment can be evaluated according to the Bethe-Block formula:

$$-\frac{dE}{dx} = \frac{\rho \cdot Z}{A} \frac{4\pi N_A m_e c^2}{M_U} \left(\frac{e^2}{4\pi\epsilon_0 m_e c^2} \right)^2 \frac{z^2}{\beta^2} \left[\ln \left(\frac{2 m_e c^2 \beta^2}{I \cdot (1-\beta^2)} \right) - \beta^2 \right]$$

Scintillator Properties

Particle Properties

REQUIREMENTS ⇒

- 70 ps time resolution
- 2-3% energy resolution for heavy fragments
- few kHz sustainable data rate
- spatial resolution of few centimeters

Some ΔE-TOF details

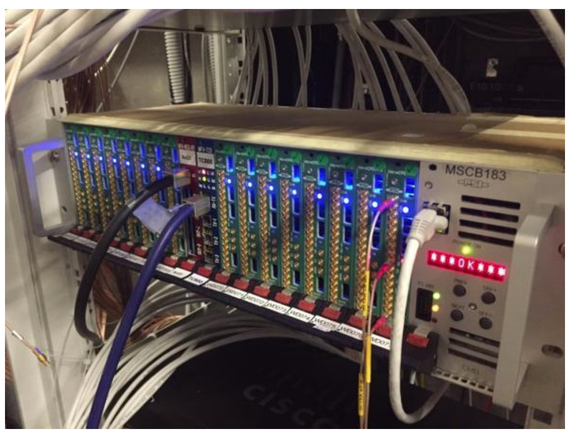
STRUCTURE

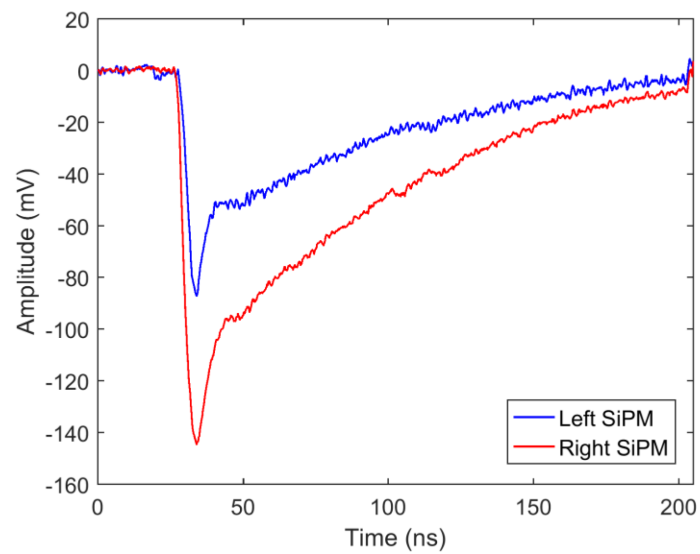
- 2 layers of plastic scintillators, 20+20 bars, each of 40 x 2 x 0.3 cm^3
- SiPM read-out on both side, up to 4 SiPM connected in series on each side

Scintillator thickness and SiPM arrangement are still under investigation

DATA ACQUISITION

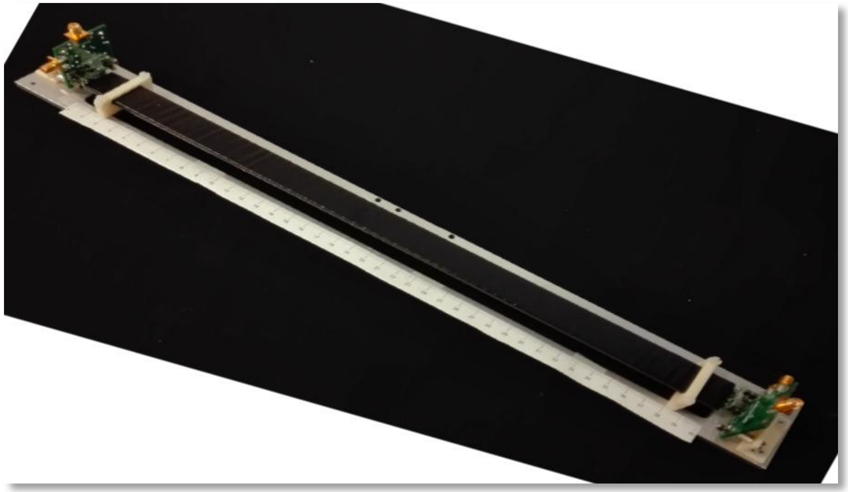
MEG DAQ based on the DRS ASIC*. Waveform can be sampled at 5 Gs/s.

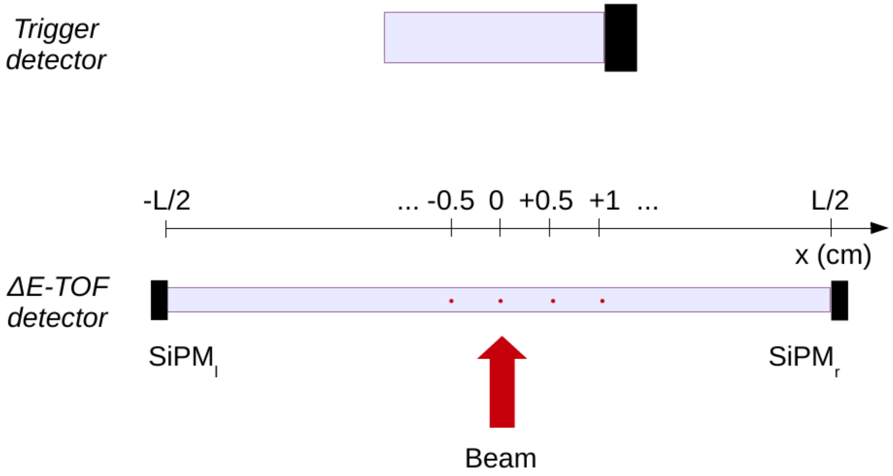




** The DRS chip: Cheap waveform digitizing in the GHz range, S. Ritt, NIM-A 518 (1) 2004*

First tests on a demonstrator





Tests with proton beam of a first 20 cm x 2 cm x 0.2 cm scintillator bar coupled to 2 + 2 SiPMs

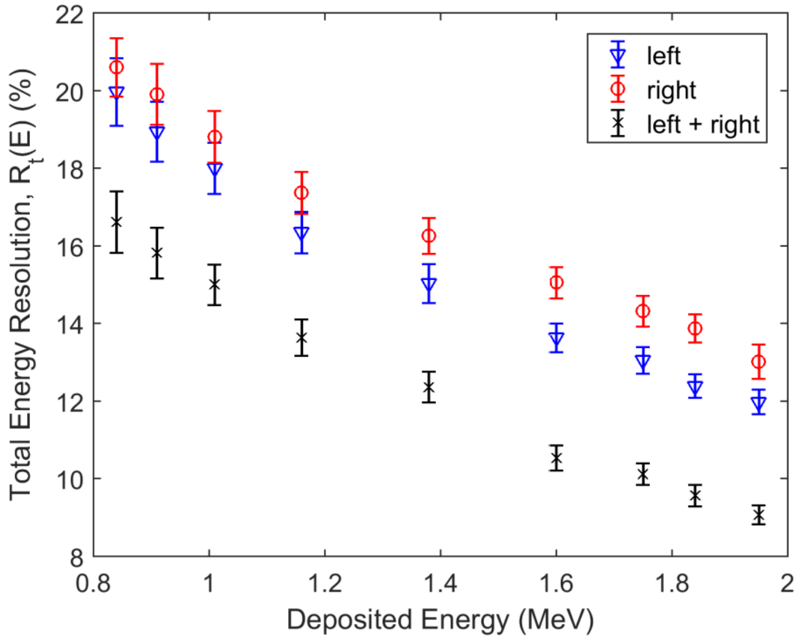
<u>Measurement at Centro di Protonterapia di Trento</u>

Type of scan	**Beam position x (cm)**	**Beam energy E_b (MeV)**
Beam position x	[-7,+7], 0.5 cm steps	170
Beam energy E_b	0	[70-230], variable steps

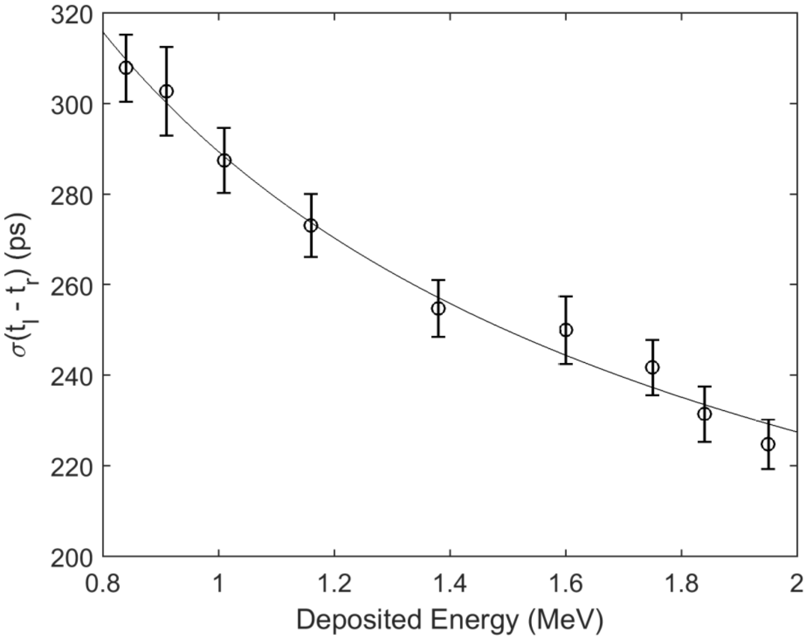
Beam Energy E_b (MeV)	**Deposited energy E_{dep} (MeV)**
70	1.95
75	1.84
80	1.75
90	1.60
110	1.38
140	1.16
170	1.01
200	0.91
230	0.84

Energy and Timing Resolution

The Energy resolution (σ/μ) has been evaluated

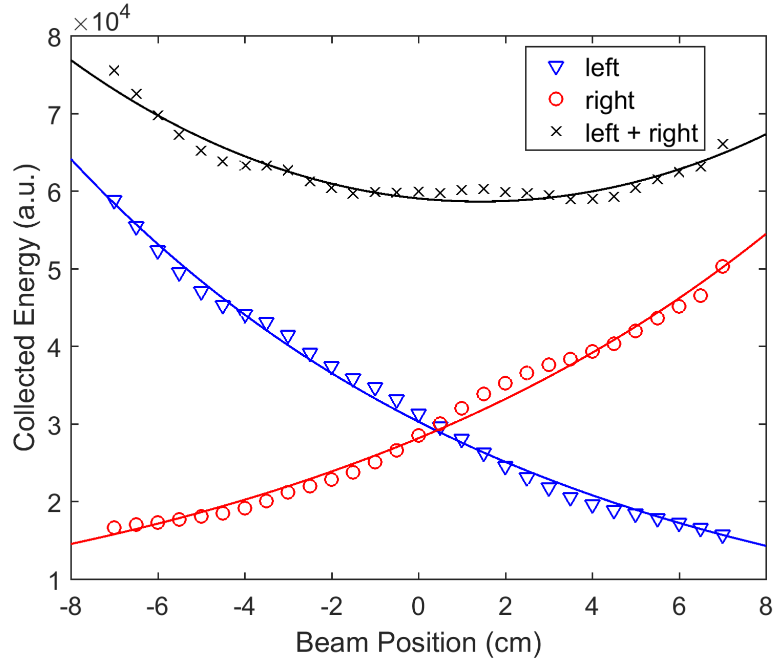


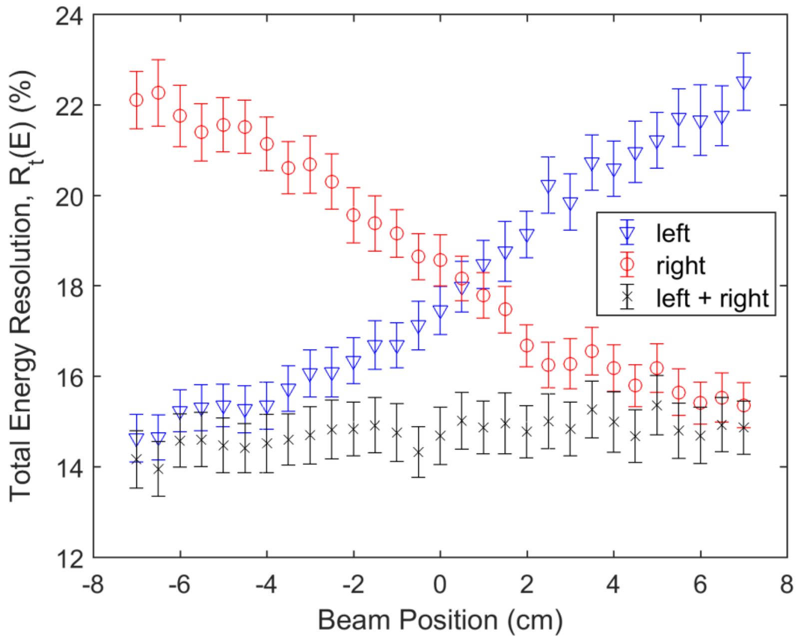
Time resolution between the two ends of the bars was evaluated
A coincidence time resolution between the two end of about 140 ps can be extrapolated at high energies (corresponding to 70 ps for the detector)



Light attenuation in the bar

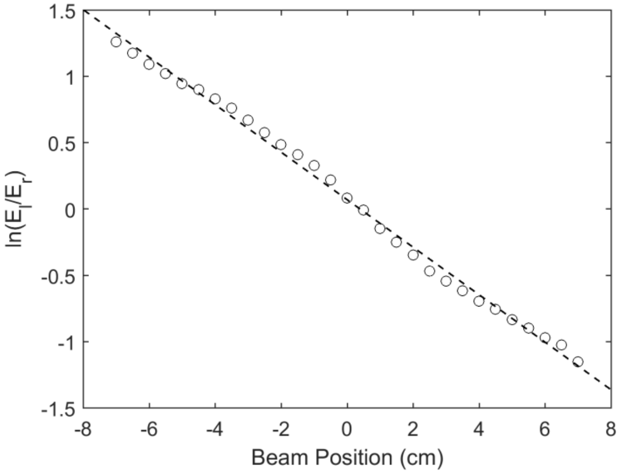
The collected signal as a function of the proton interaction position was evaluated and modeled with an exponential attenuation.

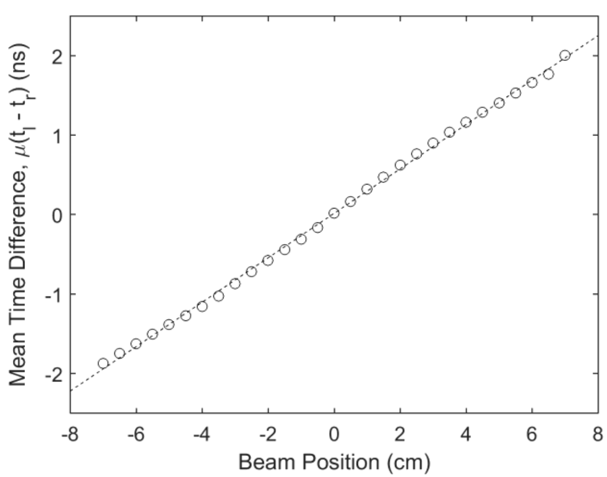




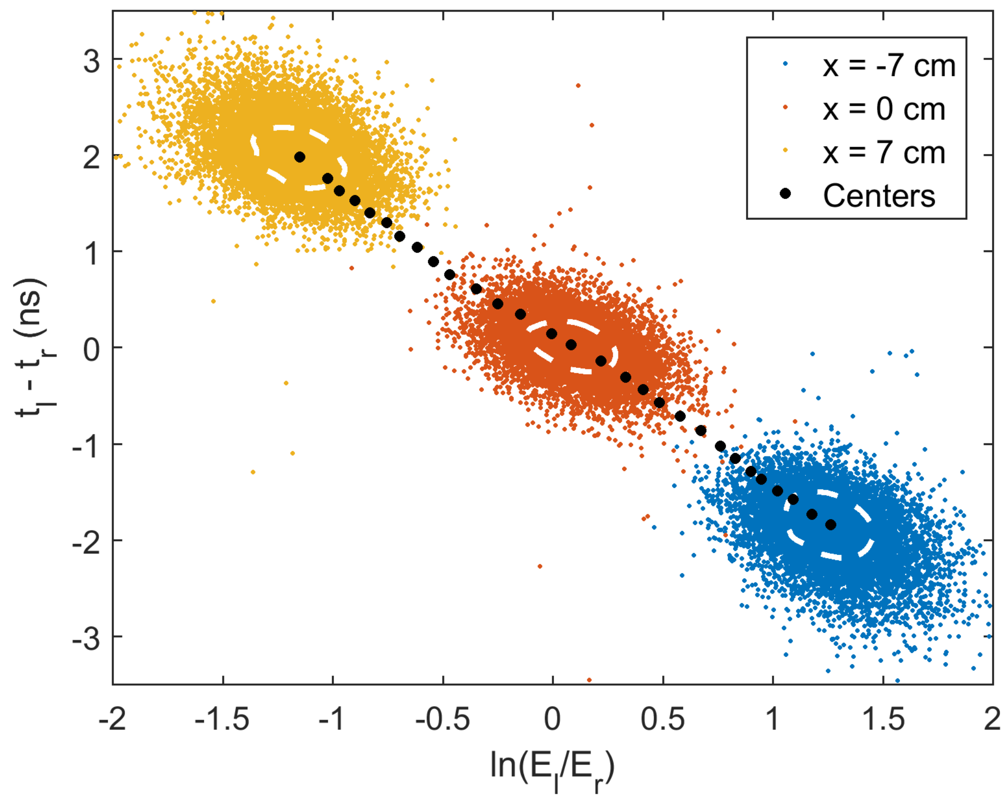
Total Energy resolution constant along the bar

Signal dependence on position



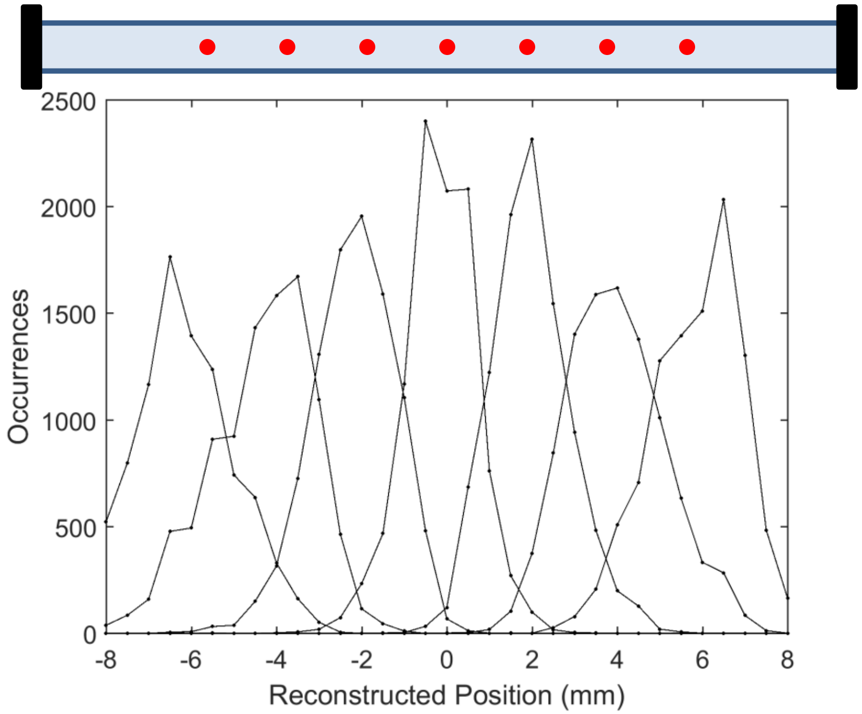


Amplitude of the signal at each side and propagation delay both depends on interaction position



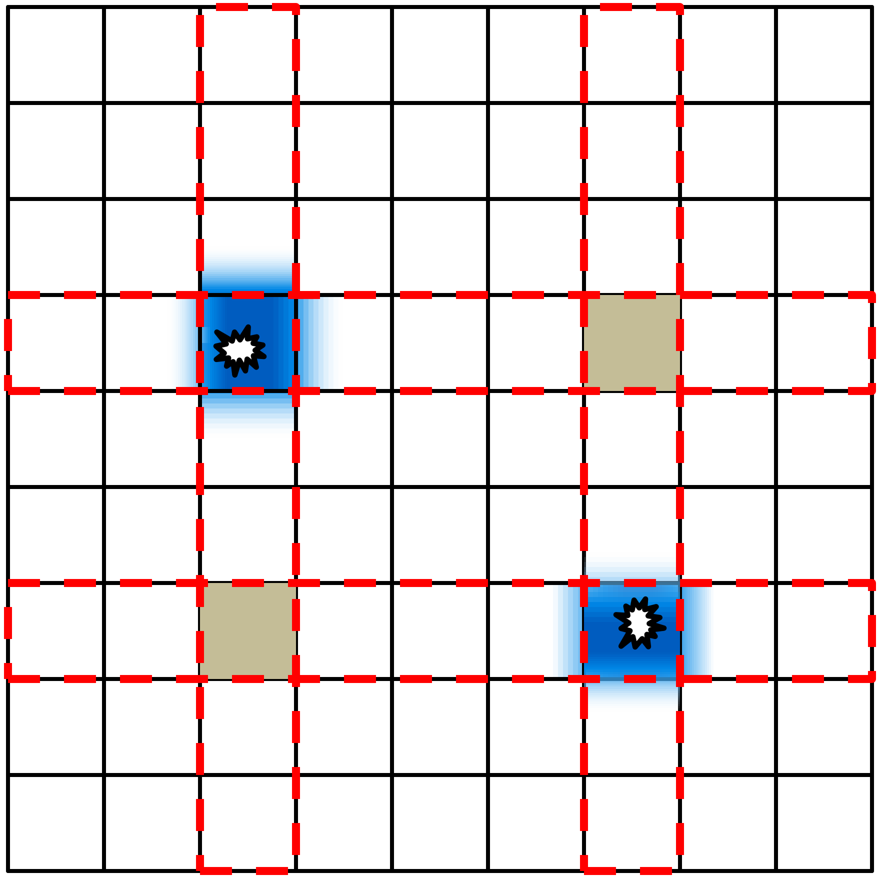
Signal dependence on position

Interaction position can be reconstructed with a resolution of about 2 cm.



Profiles reconstructed according to the two parameters above irradiating the bars at 2 cm steps.

→ Multiple fragments can be identified in the same event.



Conclusions and Outlook

- The FOOT experiment is under development, simulations and test beams are ongoing for each detector
- Results obtained with a ΔE-TOF demonstrator were shown
  - Time resolution (70 ps) fits with the experimental requirements
  - Energy resolution (9%) can be improved with a better wrapping and by increasing the number of SiPMs at each side
  - Spatial resolution (2 cm) is comparable with the granularity of the detector

<u>OUTLOOK</u>

- Tests with heavier ions are necessary to fully assess the performances
- A second demonstrator is under development, with 40 cm length and 4 SiPMs on each side (various configurations available)
- Tests of different thickness: high signal with a limited fragmentation probability in the bar
- The system is expected to be ready for data taking at the end of 2019

Thank you!

9 INFN sections + 4 laboratories (CNAO, TIFPA, LNS, LNF)

International collaboration:

- Nagoya University (Japan)
- GSI (Germany)
- Aachen University (Germany)
- IPHC Strasbourg (France)

Back-up slides

FOOT Motivations

Radioprotection in space

- Risk assessment for astronauts in view of long duration space missions

- Design and optimization of spacecraft shielding

- $(C_2H_4)n$ is foreseen to be used in spacecraft shielding.

Corresponding fragmentation cross sections are important for the estimation of the dose absorbed by the astronauts

There is a shared interest of ion species and energy range between hadrontherapy and space radioprotection
- protons, alpha particles, heavier ions like C, Si and Fe
- 100 MeV/n to 1 GeV/n energy range

Emulsion Spectrometer

Emulsion layer after the beam monitor can be used as an alternative to the previous design

- Good separation of low mass isotopes
- Large angular acceptance due to high compactness (about 70 degrees)