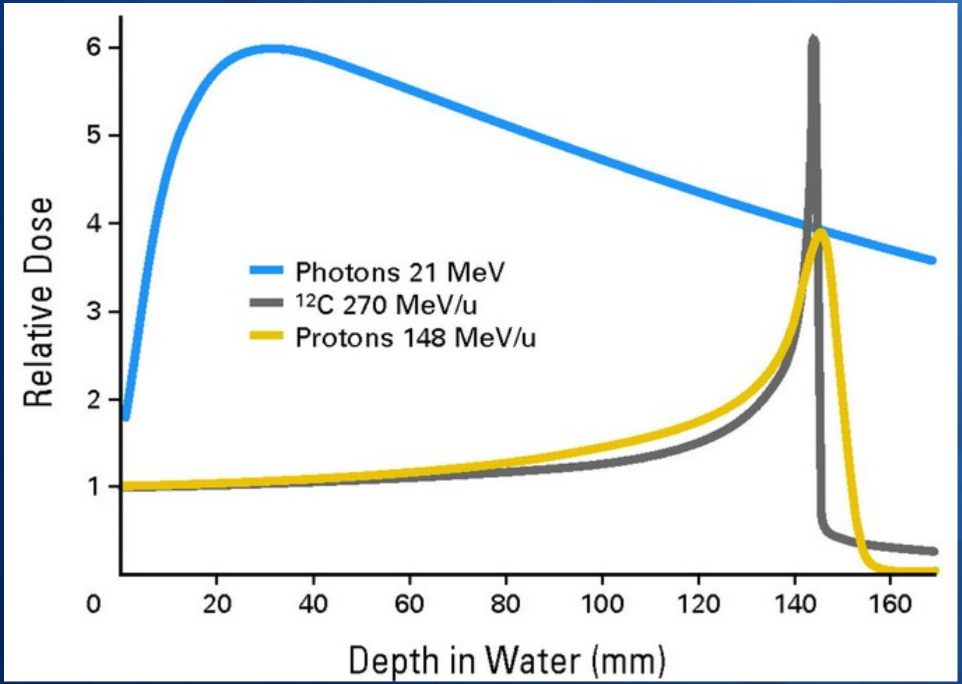
Characterization, performance assessment and data analysis of a drift chamber in the FOOT experiment

Yunsheng Dong

09-10-2018

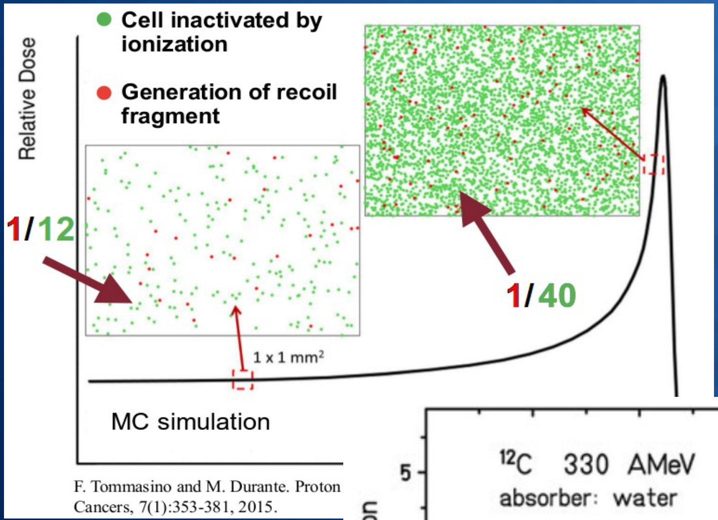
Ph.D. workshop @ Università degli studi di Milano Statale

Hadrontherapy

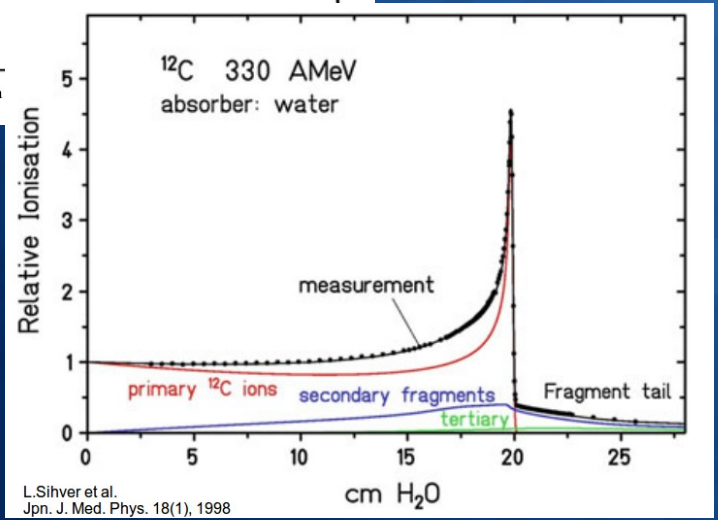


- Max dose release in the Bragg peak
- Better dose conformation on the tumor volume, minimizing the damage in the healthy tissues
- Enhanced biological effectiveness for heavy ion therapy (Z>1)
- 71 Proton, 11 C-ion facilities (2018)
174512 patients (1954-2016)

Nuclear interactions



F. Tommasino and M. Durante. Proton Cancers, 7(1):353-381, 2015.



L.Sihver et al.
Jpn. J. Med. Phys. 18(1), 1998

- **Proton therapy** (50-250 MeV): higher dose release in the entrance channel due to the target fragmentation
- **Heavy ion therapy** (Z>1; 50-400 MeV/u): dose release beyond the Bragg peak due to the projectile fragmentation
- Difficulties to include these effects in the Treatment Planning Systems due to a lack of experimental data e.g.: Ganil (Carbon ions at 50 and 95 MeV/u, 2011)

FOOT: FragmentatiOn Of Target
(Financed by INFN)

FOOT goals

Cross section measurements to improve the current Treatment Planning Sistems:

- Projectile Fragmentation:
  C, O beams at 200~400 MeV/u on C, C_2H_4 targets
  (direct kinematic)
- Target Fragmentation:
  protons at 60~250 MeV
  on C, C_2H_4 targets
  (inverse kinematic)

Radioprotection in space

- Fragmentation cross section measurements to design and optimize the spacecraft shielding:
  p, He, Li, C, O beams
  at ~ 700MeV/u on C, C_2H_4 targets

Radiobiological desiderata

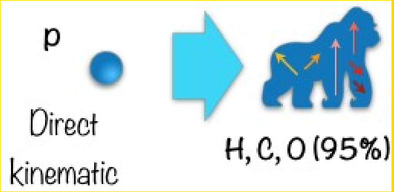
- $\sigma(Z>2)$ ~ 5%
- $d\sigma/dE$ ~ 5%
- Z ~ 3% ; A ~ 5%

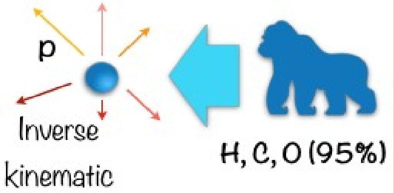
Measurement strategy

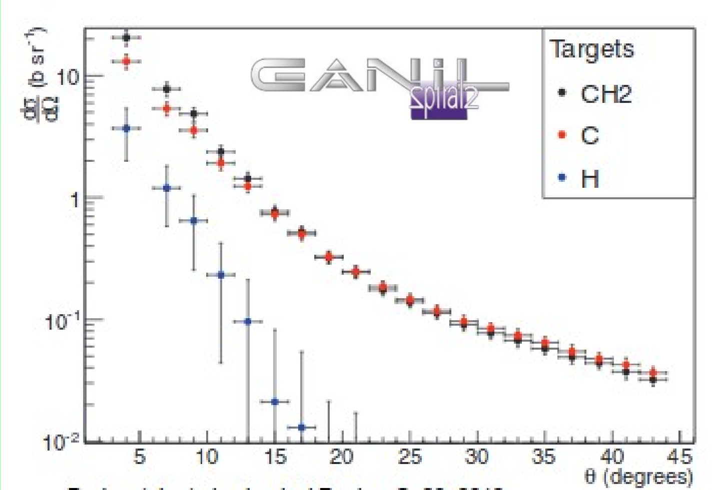
Expected average physical parameters for target fragments produced in water by a 180 MeV proton beam

Fragment	E (MeV)	LET (keV/μm)	Range (μm)
^{15}O	1.0	983	2.3
^{15}N	1.0	925	2.5
^{14}N	2.0	1137	3.6
^{13}C	3.0	951	5.4
^{12}C	3.8	912	6.2
^{11}C	4.6	878	7.0
^{10}B	5.4	643	9.9
^{8}Be	6.4	400	15.7
^{6}Li	6.8	215	26.7
^{4}He	6.0	77	48.5
^{3}He	4.7	89	38.8
^{2}H	2.5	14	68.9

GoodHead D.T., Radiation protection dosimetry, 122, 2006







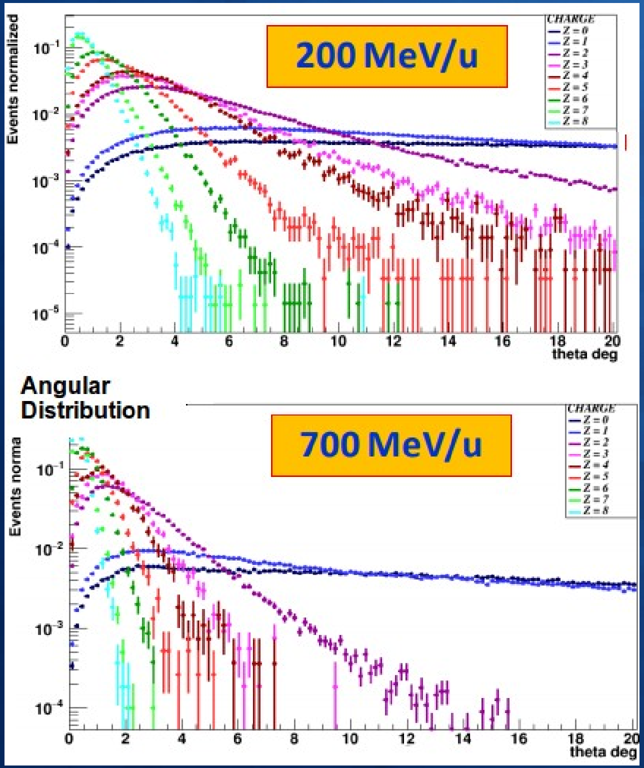
Dudouet J. et al., physical Review C, 88, 2013

Inverse kinematic approach
Target fragments ranges are too short.
Must adopt an inverse kinematic approach (patient → p)

Target material
A pure hydrogen target is difficult to handle.
Subtraction of cross sections method

$\sigma(H) = [\ \sigma(C_2H_4) - 2\sigma(C)\ ] / 4$

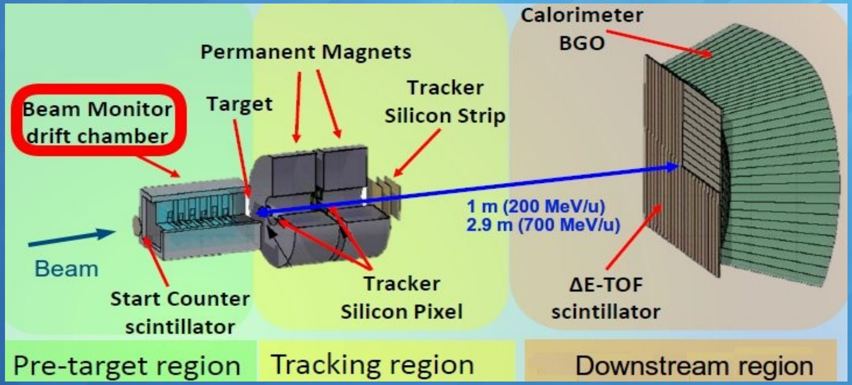
Experimental setup

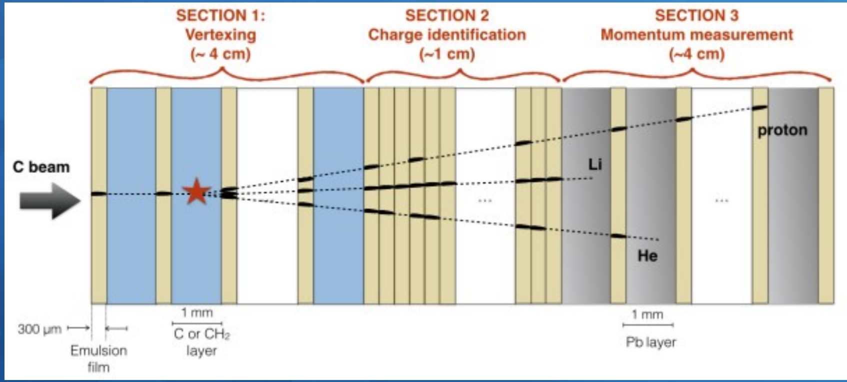


Two experimental setup:

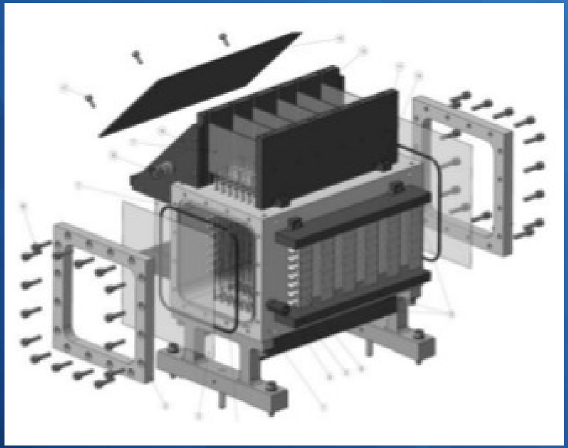
- Electronic setup: fragments with Z≥3 and θ<10°

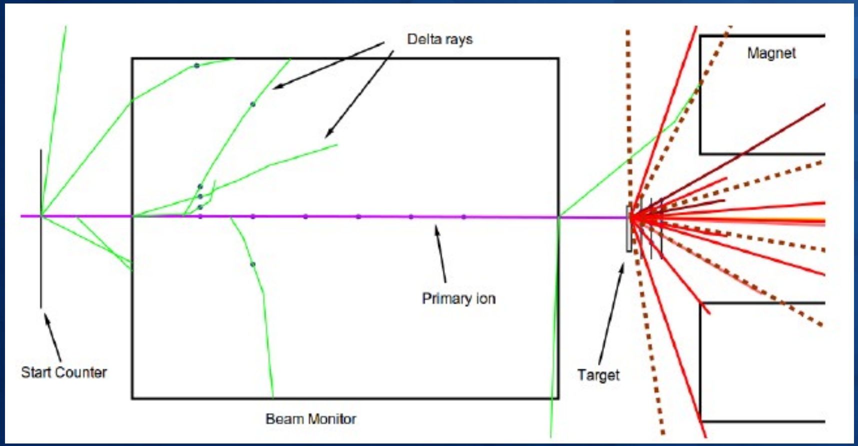
- Nuclear Emulsion (Emulsion Cloud Chamber): fragments with Z≤3 and θ≤75°





FOOT Drift Chamber

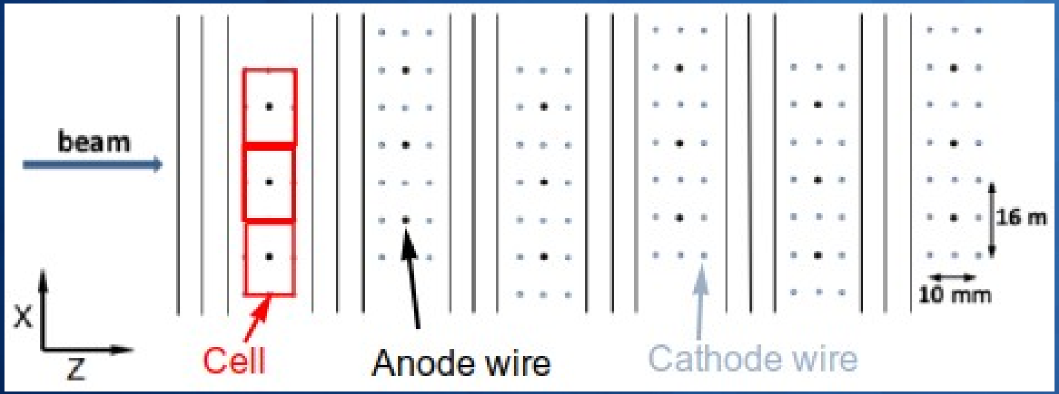


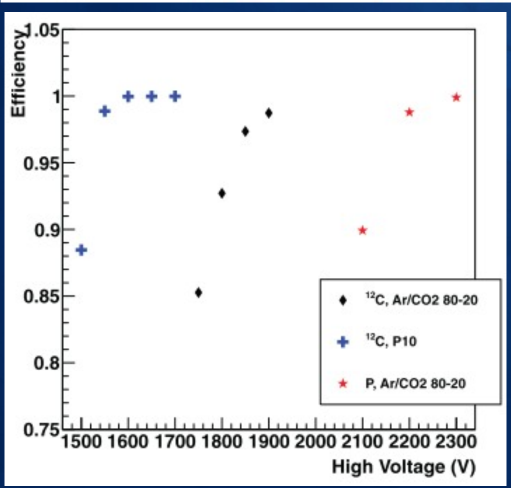


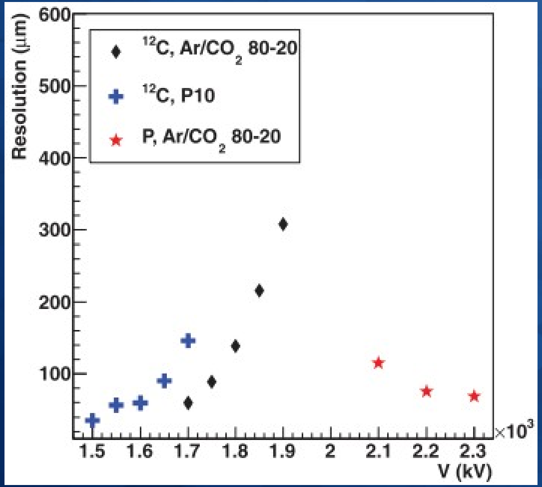
Beam monitor goals:

- Detect and reject the events in which the primary particle undergoes a nuclear interaction before the target
- Beam direction measurement
- Reconstruction of the interaction vertex in the target material with the tracking region detectors

FOOT Drift Chamber

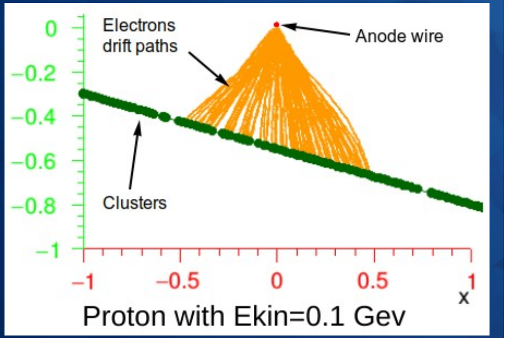


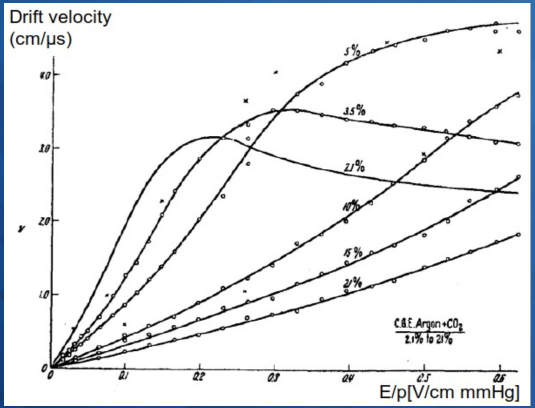


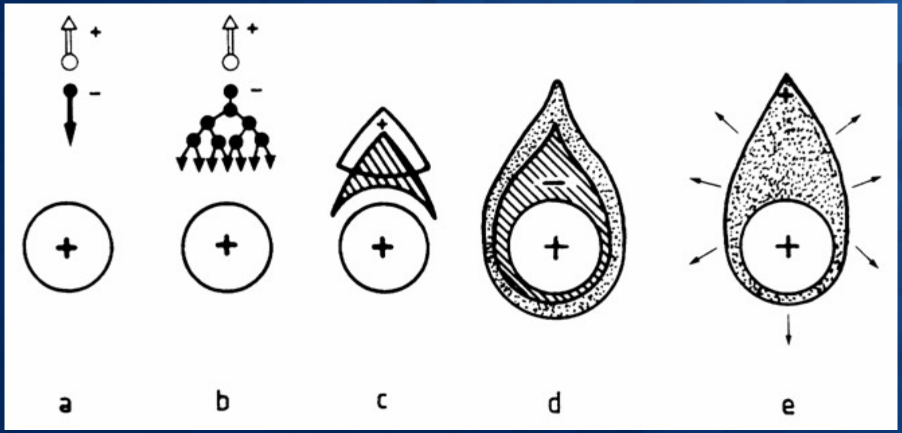


- Drift chamber with 6 planes of cells for each view (X-Y), 3 cells of 1.8x1 cm^2 for each layer.
  Dimensions: 11 cm x 11 cm x 20 cm
- Ar/CO2 at 80/20%
- Inherited from FIRST exp. (GSI, 2011)
- Spatial resolution ~ 200 μm
- Reconstruction algorithm and fragmentation studies performed in 2016-2017

Drift chamber: principle of operation





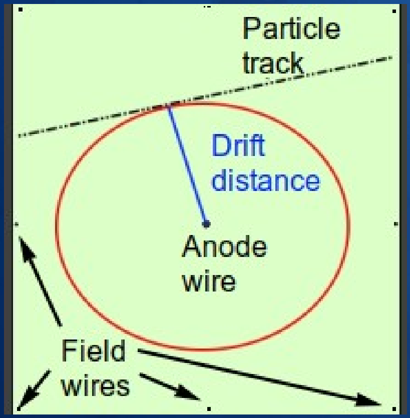


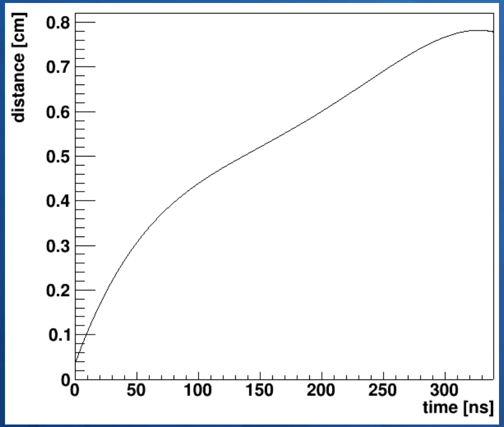
- **Ionization:** the incident particle looses its energy in the detector material by ionization.
  $p + X \rightarrow p + X^* + e^-$ $dE/dx \sim z^2/\beta^2$

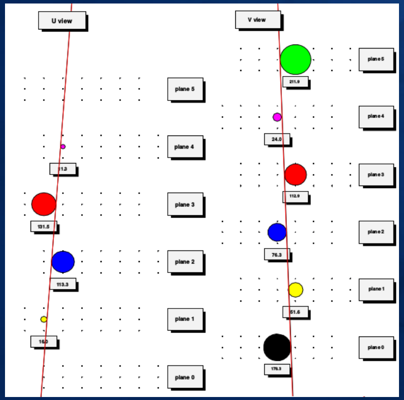
- **Transport:** the electrons drift towards the anode wire driven by the electric field ($\overline{E}$) shaped by the field wires.
  $v_d \sim f(p,\overline{E},gas)$

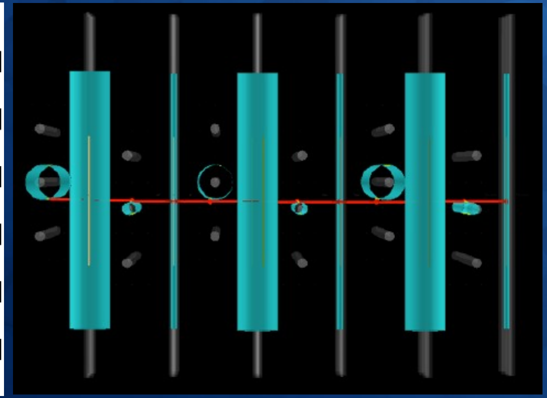
- **Multiplication:** the increasing $\overline{E}$ field close to the anode wire (~10^5 kV/cm) multiply the e^- (Gain ~ $10^3 - 10^5$) and a signal can be detected.

Drift chamber: principle of operation



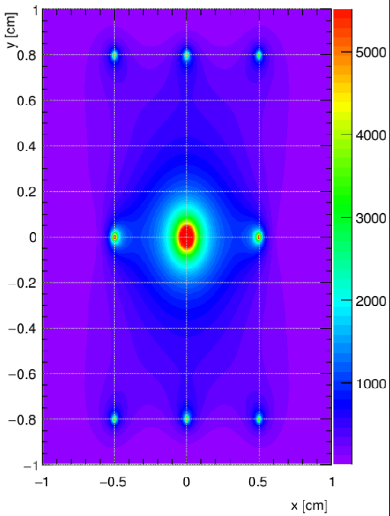


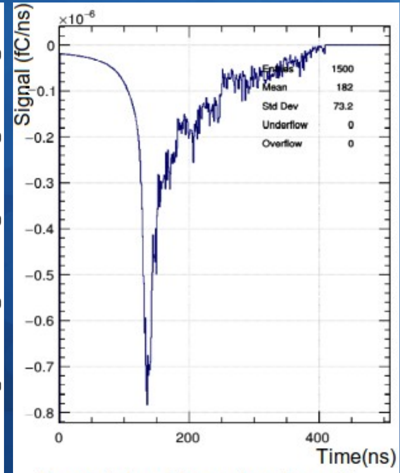




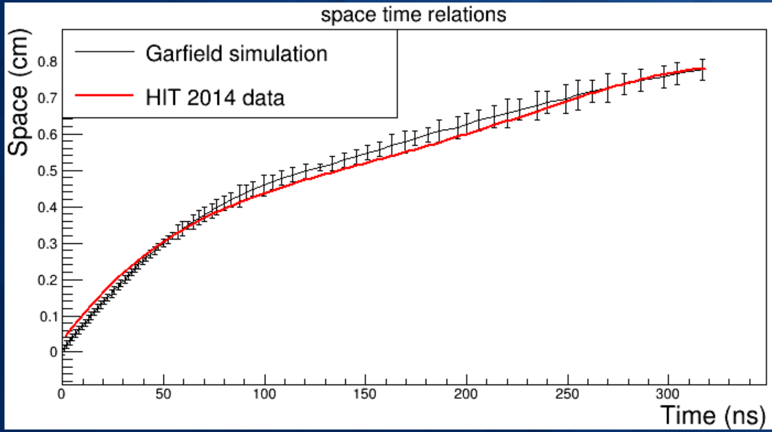
- A TDC (Time to Digital Converter) read the time difference between the anode wire signal and an external fast detector signal
- With the space-time relations one can convert the time measurement in a space measurement
- A tracking algorithm fits the drift distances to reconstruct the trajectory

Garfield++ studies





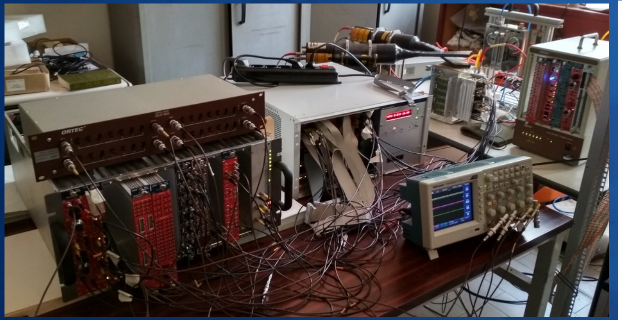
Current signal for carbon ion with Ekin=3.2 Gev

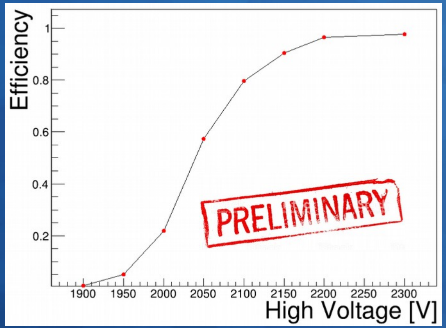


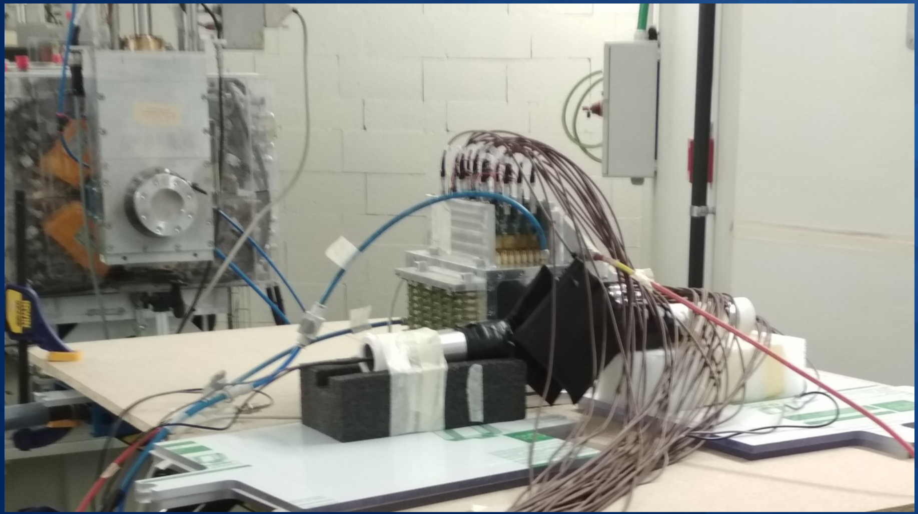
Garfield++ is a toolkit for the simulation of gaseous and semiconductor based detectors

- Calculation of the electric field map for a given anode HV
- Simulation of the charged particle passage and the current signal on the sense wire
- Estimation of the drift velocity and space time relations for different parameters (gas choice, HV, etc..)

Experimental development and tests

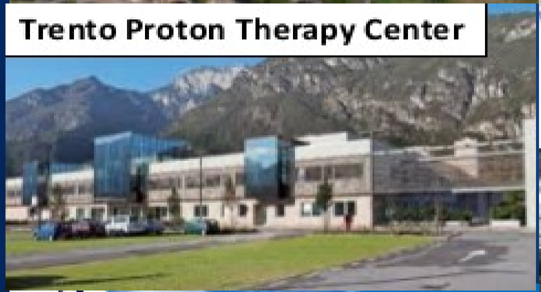


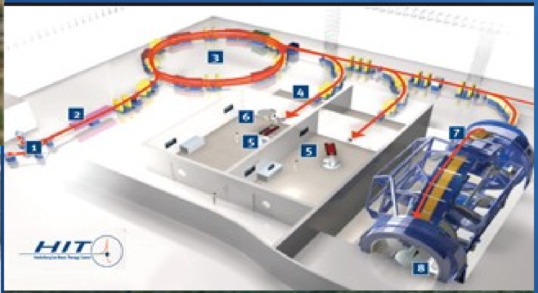




- Gas distribution system setup
- Acquisition and analysis software development
- Beam Monitor experimental setup and acquisition software test @ Milan (7/2018): cosmic rays detection
- Efficiency measurement test @ Trento with protons at 70 Mev – 220 MeV last week (10/2018)

Future perspective





- 2018-2019: Electronic setup detectors finalizing test beam
  Beam monitor space time relations calibration test @ Trento
- 03/2019: **ECC first data taking @ GSI with the Beam Monitor**
- 12/2019: Electronic setup first data taking with almost complete apparatus @ GSI
- 2020-2021: Data taking with the complete apparatus

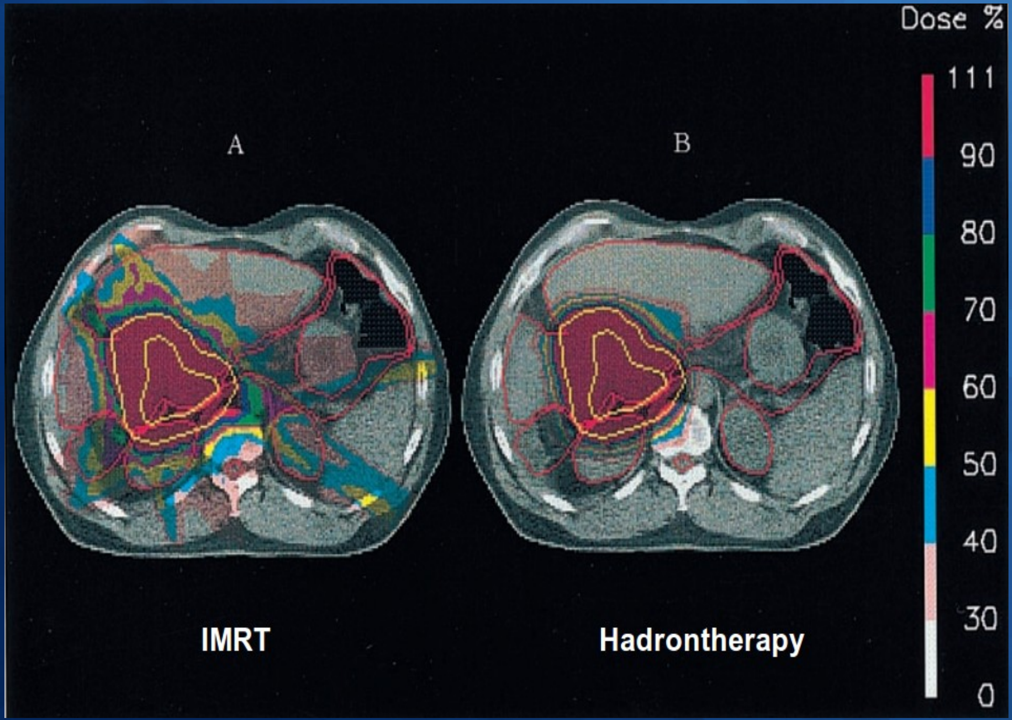
FOOT collaboration

- 92 members (60% staff)
- 12 INFN Sections/Italian university
- 6 laboratories: Frascati, CNAO, Trento, LNS, GSI (Heidelberg), IPHC (Strasbourg)
- Centro Fermi
- University of Aachen (Ger)
- University of Nagoya (Jap)

Thank you

Back up

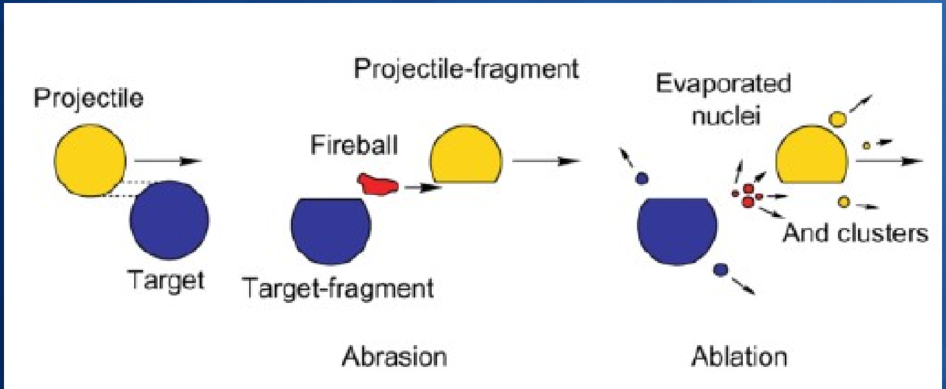
Hadrontherapy vs radiotherapy



Pancreatic tumor treatment planning

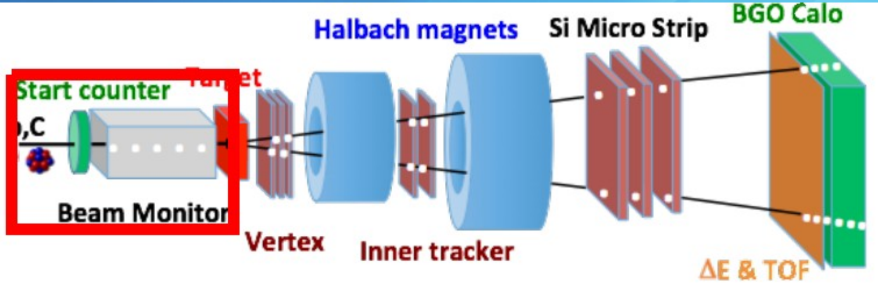
- A: Intensity modulated coplanar photon beam (9 beams)
- B: Coplanar proton beam (4 beams)

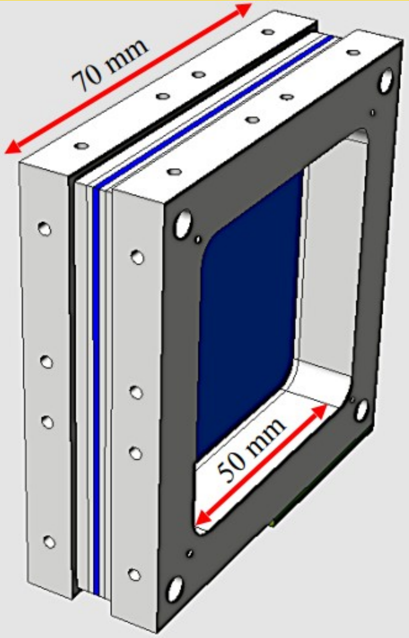
Abrasion – Ablation model



- A nucleus-nucleus collision model adopted in MC simulations
- Abrasion (10^{-23} s):
  formation of excited projectile fragments (fireball) following the initial trajectory without change of velocity
- Ablation(10^{-16} ~10^{-21} s):
  -Nuclear evaporation: light fragment with Ekin of few MeV
  -Fission ($Z \geq 65$)
  -Fermi breakup ($A \leq 17$)
  -Photon emission

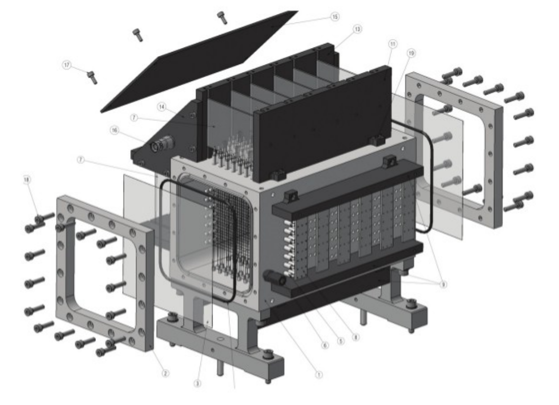
Foot electronic setup: pre-target region

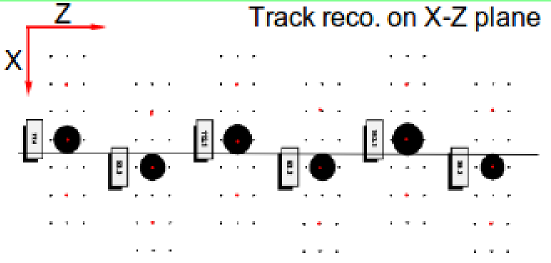




Start Counter

- **Trigger and TOF measurement**
- 250 μm-1mm thick plastic scintillator
- Readout with SiPM
- **ΔTOF: < 80 ps**
- Rebuilt from FIRST exp. (GSI, 2011)

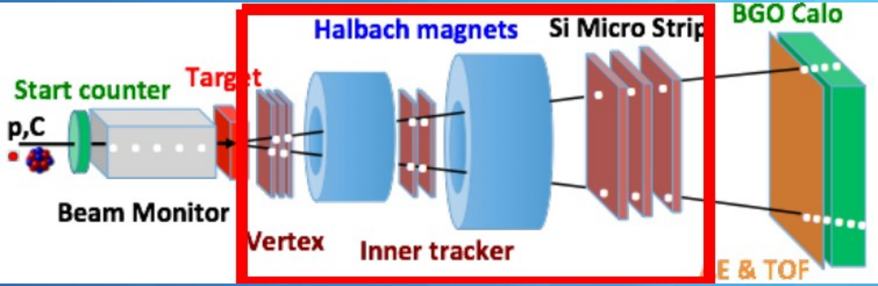




Beam Monitor

- **Beam direction meas.**
- Drift chamber with 6 planes of cells for each view (X-Y), 3 cells of (1.8x1 cm^2) for each layer
- Ar/CO2 ~ 80/20%
- **Spatial res. ~ 200 μm**
- Inherited from FIRST exp. (GSI, 2011)

Foot electronic setup: tracking region (momentum measurement)



Vertex

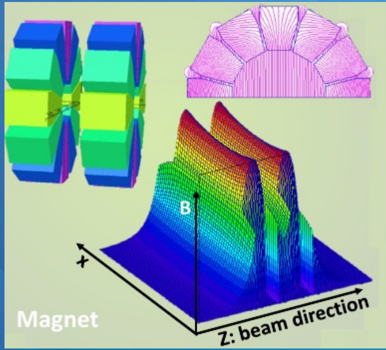
- 4 layers of pixeled silicon detector (20x20 μm)
- Spatial resolution: 10μm (X-Y direction); 60μm (Z direction)

Inner tracker

- 2 layers of pixeled detector as the vertex

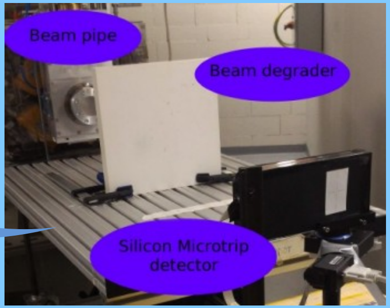
Kalman filter

- Track reconstruction
- P evaluation



Halbach magnets

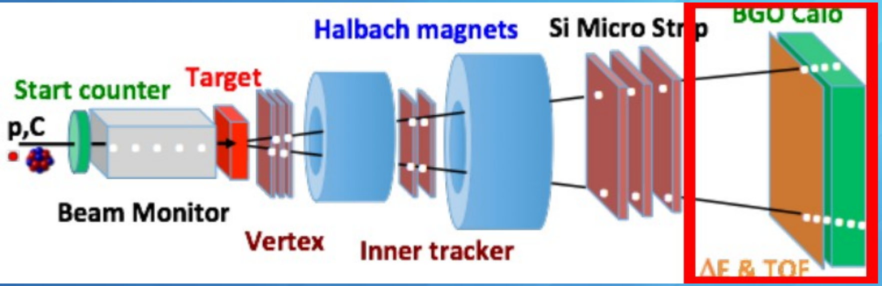
- 2 permanent magnets
- B field in Y direction (max ~ 0.8T)

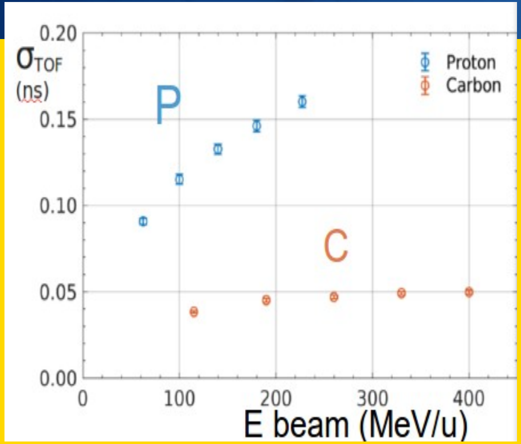


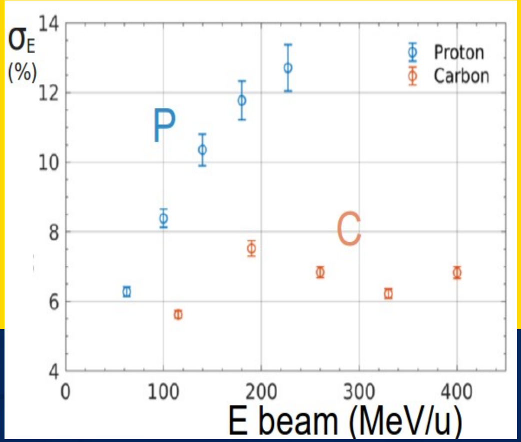
Microstrip Silicon Detector (MSD)

- 3 layers of silicon microstrip detector (120μm x 9 cm)
- Test ongoing

Foot electronic setup: downstream region

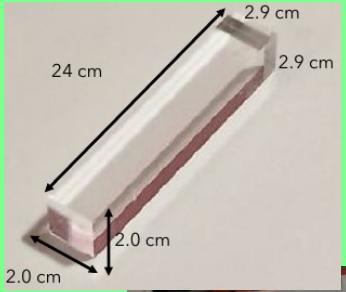


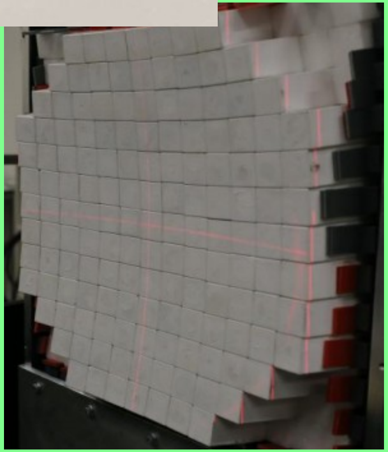




Scintillator

- **ΔE and TOF measurement**
- 2 layers of 20 bars of plastic scintillator (400x20x3 mm^3)
- Readout with SiPM
- **ΔTOF ~ 40 ps for C**
- **ΔE/E ~ 7%**

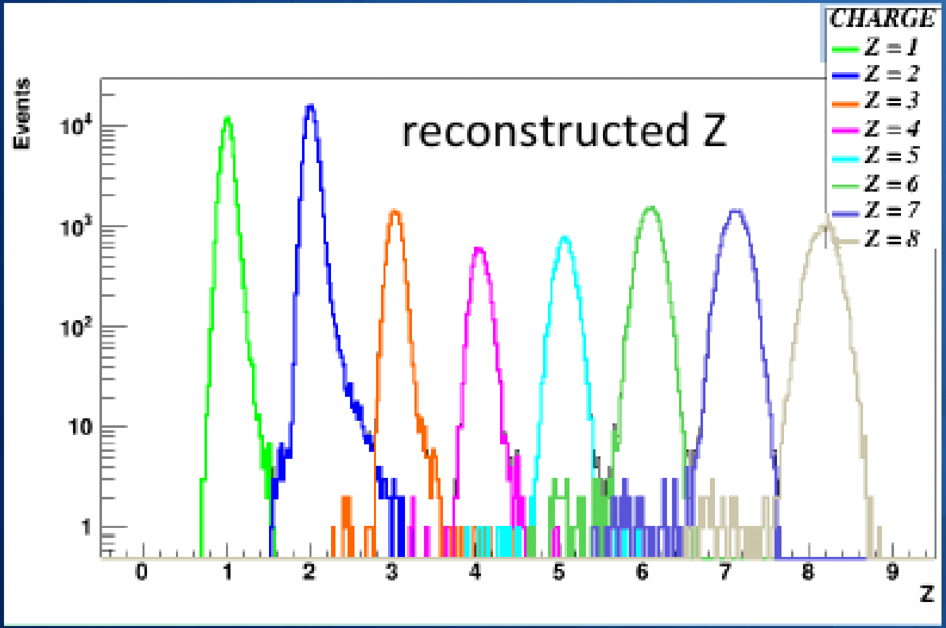




Calorimeter

- BGO inorganic scintillator (2x3x24cm^3)
- 145 crystals read by SiPM (50x50μm^2)
- Tested at HIT (Aachen Univ.) with C at 200-400 MeV/u
- **Ekin res ~ 1-2% for C**
- To be tested at CNAO

Charge reconstruction

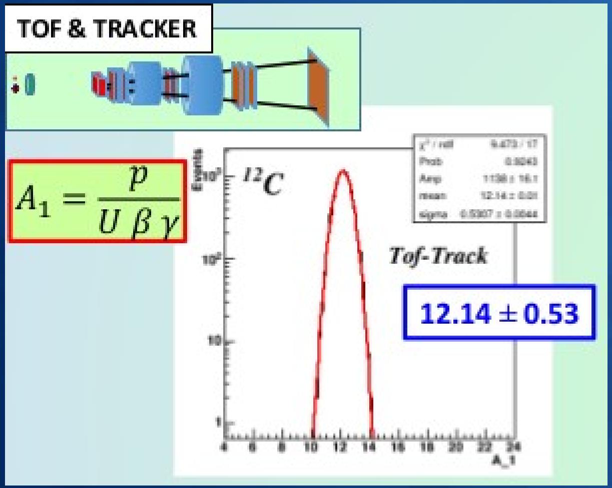


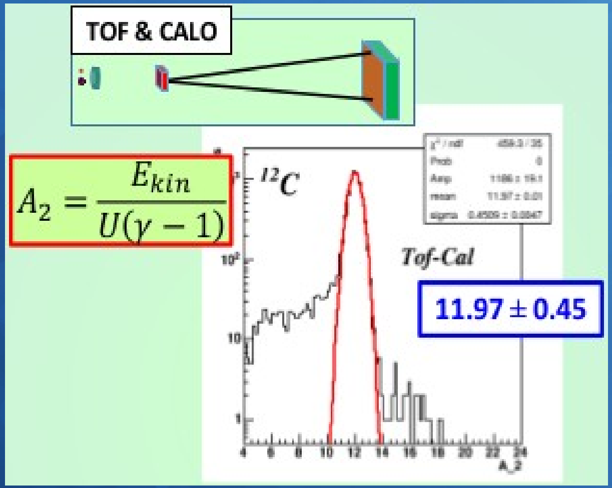
- **Z reconstruction study based on FLUKA simulation:** ^{16}O at 200MeV/u on C_2H_4

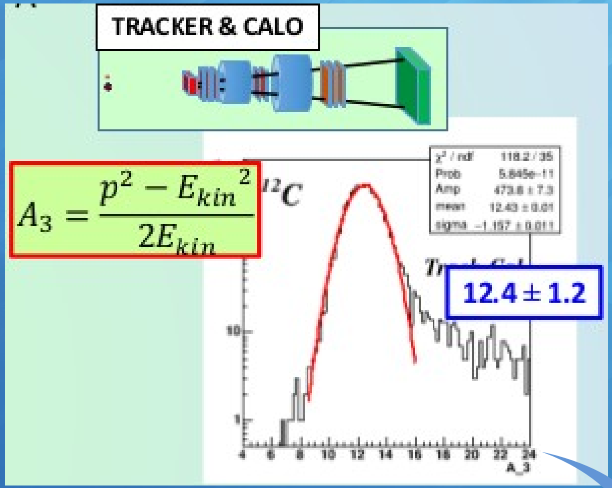
$$-\frac{dE}{dx} \propto \frac{z^2}{\beta^2}$$

- Scintillator ~ dE/dx; TOF ~ β
- ^{1}H~9.0% ^{4}He~3.0%
  ^{7}Li~2.7% ^{9}Be~2.2%
  ^{11}B~2.0% ^{12}C~2.0%
  ^{14}N~2.0% ^{16}O~2.0%
- **Charge misidentification < 1%**

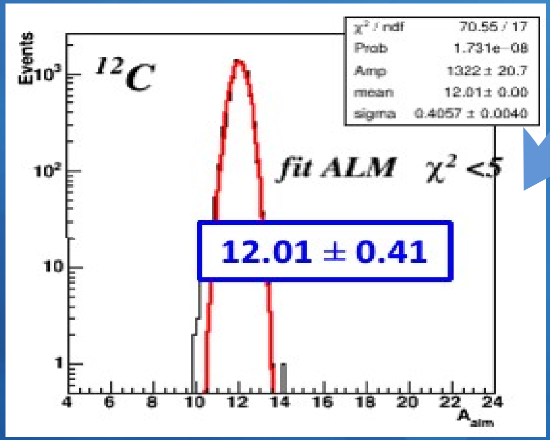
Mass identification



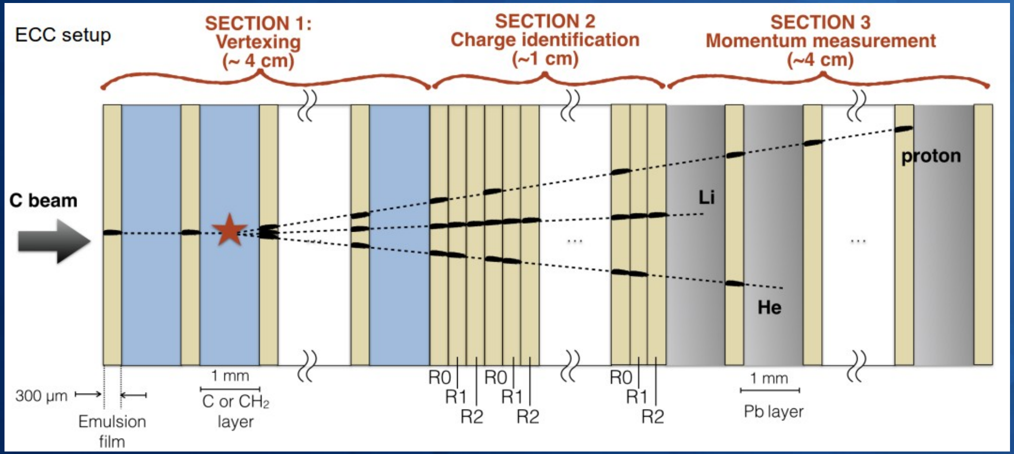




- Redundant measurement
- **σ(A)/A ~ 3-4%**
- Isotope separation under study



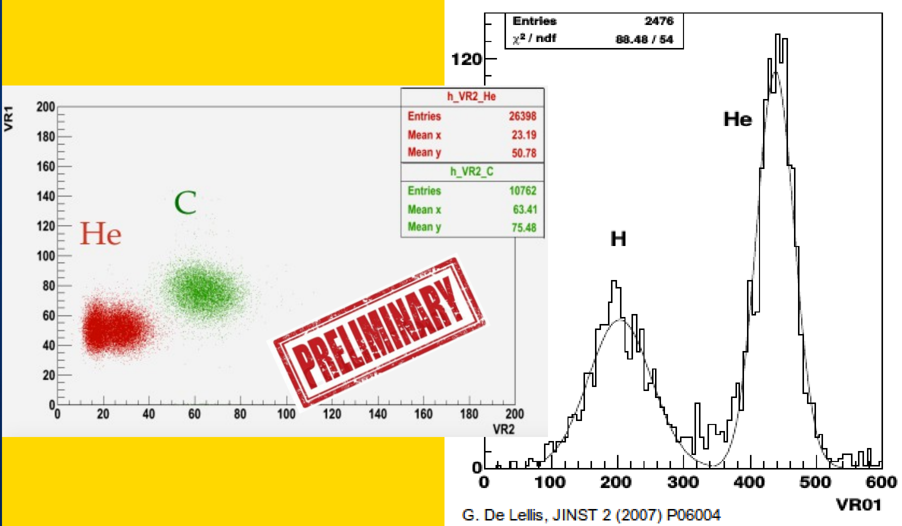
Emulsion cloud chamber



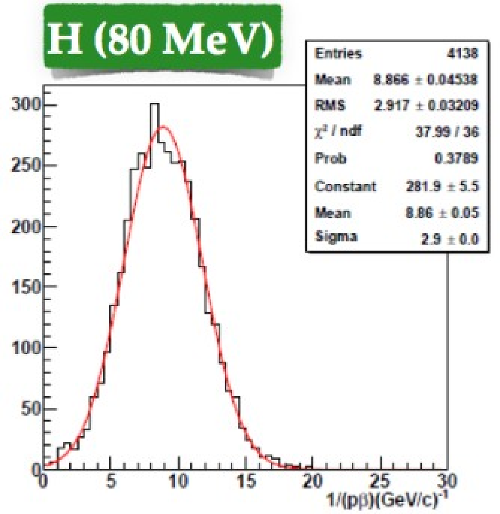
- Z≤3; θ≤75°
- Three sections:

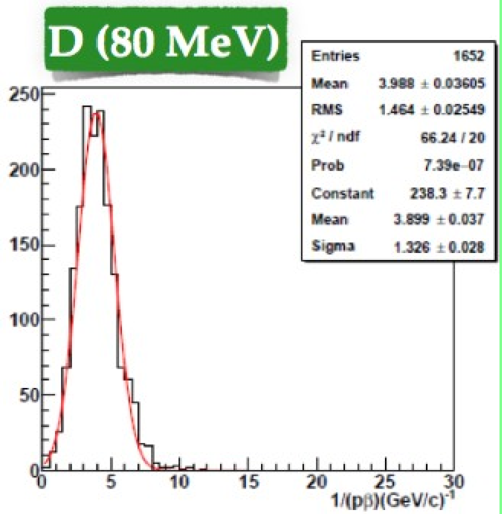
  -**charged particle tracking:** layers of emulsion films and target (C/C2H4)
  -**charge id.**: emulsion films only
  -**momentum meas.**:layers of emulsion films and passive material(Lead/Steel)
- ECC system tested at HIMAC (Japan) with C at 400 MeV/u for Z id.
- Tested at INFN-LNS (Catania) and Trento with new emulsion films from Nagoya Univ.

ECC performances



G. De Lellis, JINST 2 (2007) P06004





Charge separation

Z ∝dE/dx ∝ grain density ∝ track volume

Charge identification efficiency ~ 99%

Isotope separation (preliminary study)

Particle range and multiple coulomb scattering measurements could provide a isotope identification