FOOT
FragmentatiOn Of Target

An experiment for the measurement of the nuclear fragmentation for Particle Therapy

(Slides mainly from V. Patera talk at Legnaro Comm. III meeting)

E. Spiriti

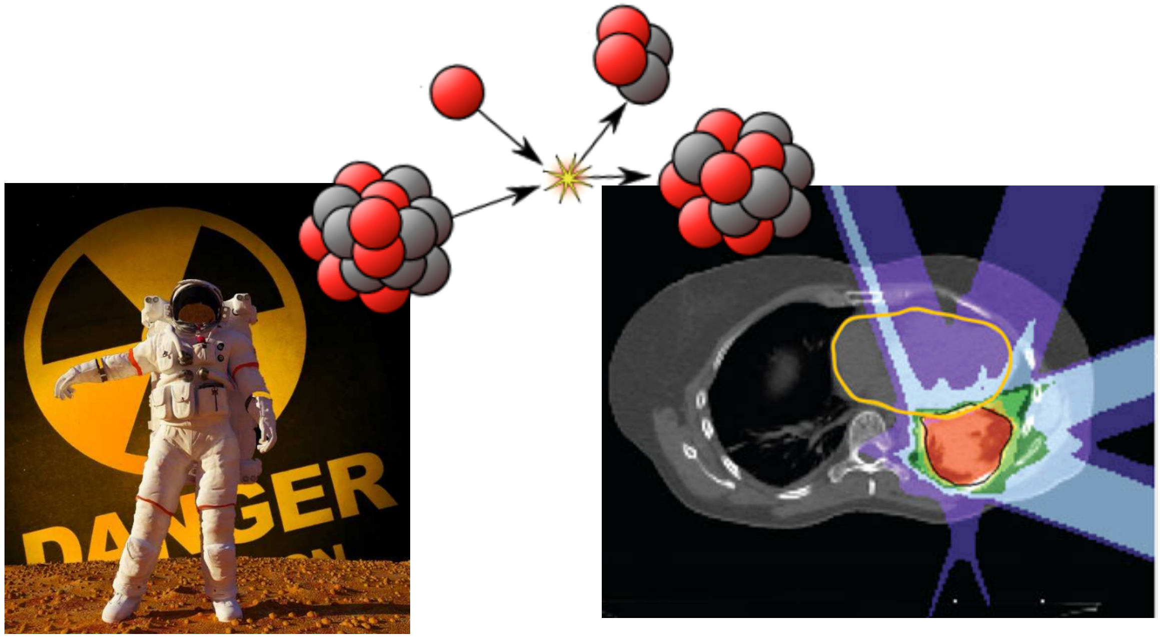
CdL LNF - 4 Luglio 2016

FOOT in pills

Sections/Labs: Bologna, Frascati, Milano, Napoli, Perugia, (Pavia), Pisa, Roma1, Roma2, Torino, Trento

People: ~50 researcher, ~24 FTE

DATA taking foreseen @ CNAO, TIFPA, LNS, BTF

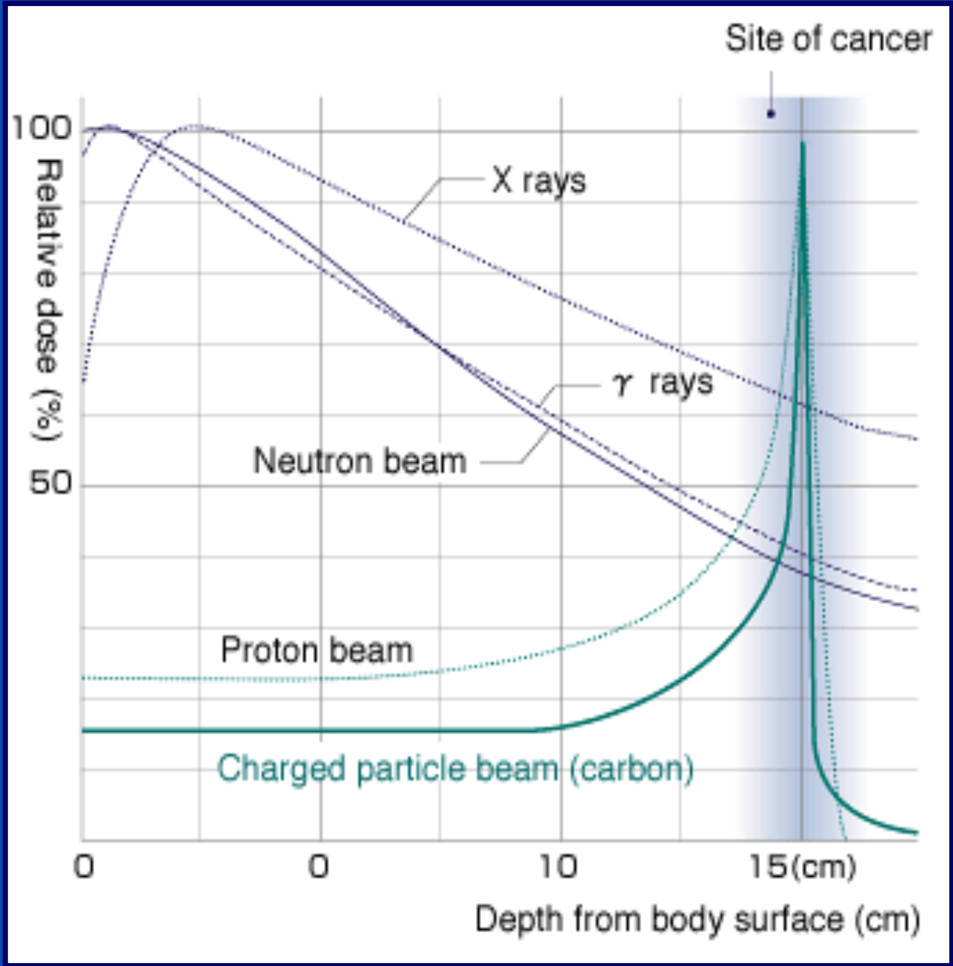


Experiment with translational approach: focus on nuclear physics, physics applied to medicine and radioprotection in space

Particle therapy & Nuclear Physics

Light ions advantages in radiation treatments of tumor wrt IMRT:

- ✓ Better Spatial selectivity in dose deposition: (p, ^{12}C but also ^{4}He, ^{16}O)
- ✓ Reduced lateral and longitudinal diffusion (^{4}He, ^{12}C, ^{16}O)
- ✓ High Biological effectiveness (RBE) for ^{12}C and ^{16}O beam

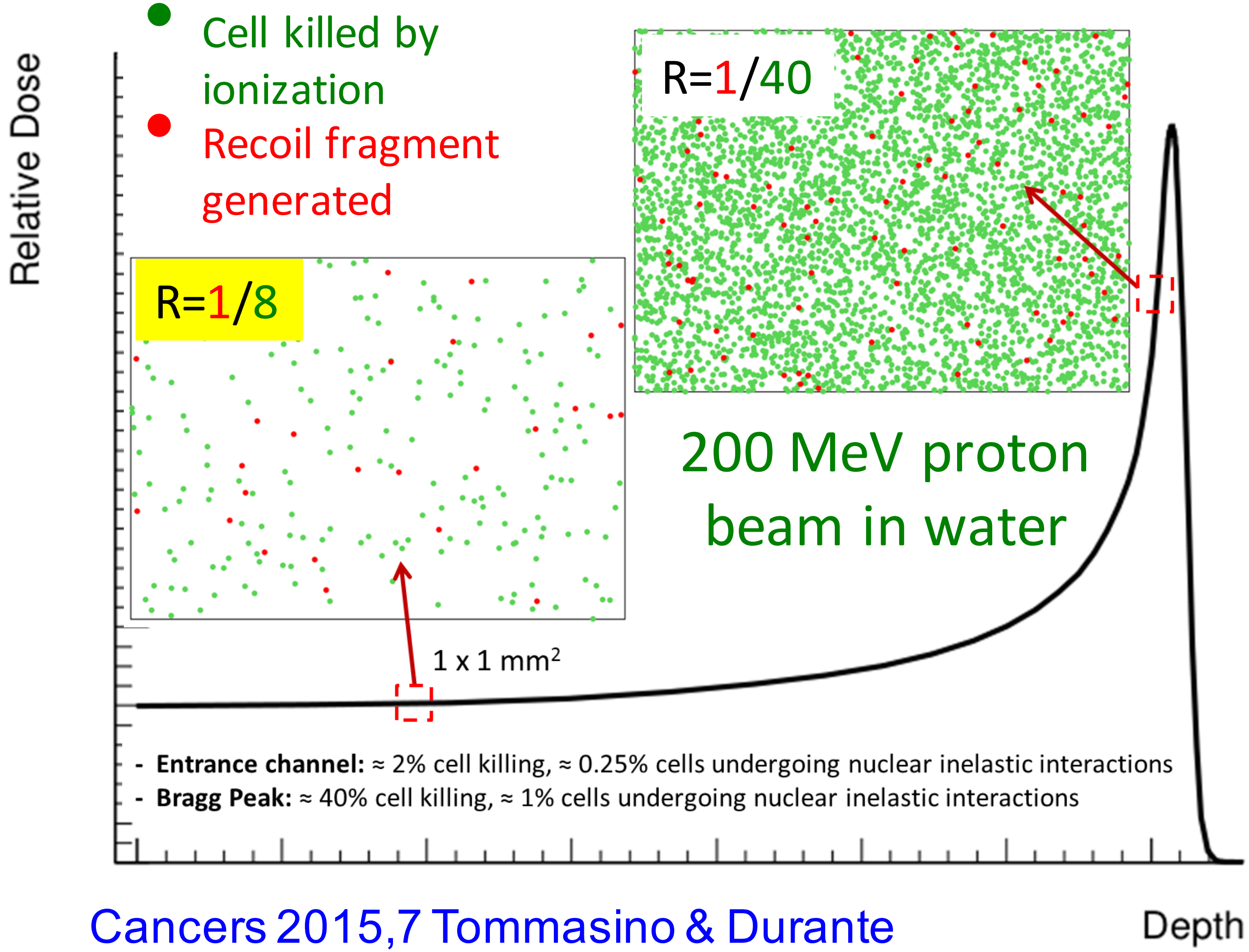


Treatment of highly radiation resistent tumours, sparing surrounding OAR

INFN has a long standing activity in this field, not only in beam facility realization (CNAO) but also in Treatment Planning System development (TPS INFN-IBA joint project)

Target (patient) fragmentation & PT

Target fragmentation in proton therapy: gives contribution also outside the tumor region!



Cancers 2015,7 Tommasino & Durante

About 10% of biological effect in the entrance channel due to secondary fragments (Grun 2013)

Largest contributions of recoil fragments expected from

He, C, Be, O, N

In particular on Normal Tissue Complication Probability

See also :

- Paganetti 2002 PMB
- Grassberger 2011 PMB

Target fragmentation & Radiobiology desiderata

To implement sound radiobiological models the requirements is to improve the knowledge of the p-> patient (p-> H,C,O) interaction, i.e. fragment production, at 100-200 MeV.

- Measure the heavy fragment (Z>2) production cross section with maximum uncertainty of 5%
- Measure the fragment energy spectrum (i.e. $d\sigma/dE$) with an energy resolution of the order of 1 MeV/u
- Charge ID at the level of 2-3%
- Isotopic ID at the level of 5%
- Not needed accurate angular measurement
- Study light ions production at large angle

p-> C, p->O scattering @200 MeV

The elastic interaction and the forward Z=1 fragment production (p,d,t) are quite well known. Large uncertainty on large angle Z=1,2 fragments.

Missing data on heavy fragments. Unreliable nuclear models

"Heavy" (A>4) fragment yields and emission energy ~ unknown

Very low energy-short range fragments.

MCs confirm this picture

Nuclear model & MC not reliable

Analitic model results on p->O @200 MeV

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

Cancers 2015,7 Tommasino & Durante

FOOT ➔ Inverse kinematic strategy

Since shooting a proton with a given β (for instance Ekin=200 MeV ➔ β=0.6) on a patient (i.e. at 98% a H,C,O nucleus) at rest gives little detection opportunity... let's shoot a β=0.6 patient (i.e. O,C beam) on a proton at rest and measure how it fragments..

A possible procedure would be:

- Use as beams the ions that are the constituents of the patient (mainly ^{16}O, ^{12}C) with Ekin/nucl in the 100-200MeV.
- Use twin targets made of C and polyethylene $(C_2H_4)_n$ and obtain the H target result from difference
- Apply the reverse boost with the well known β of the beam

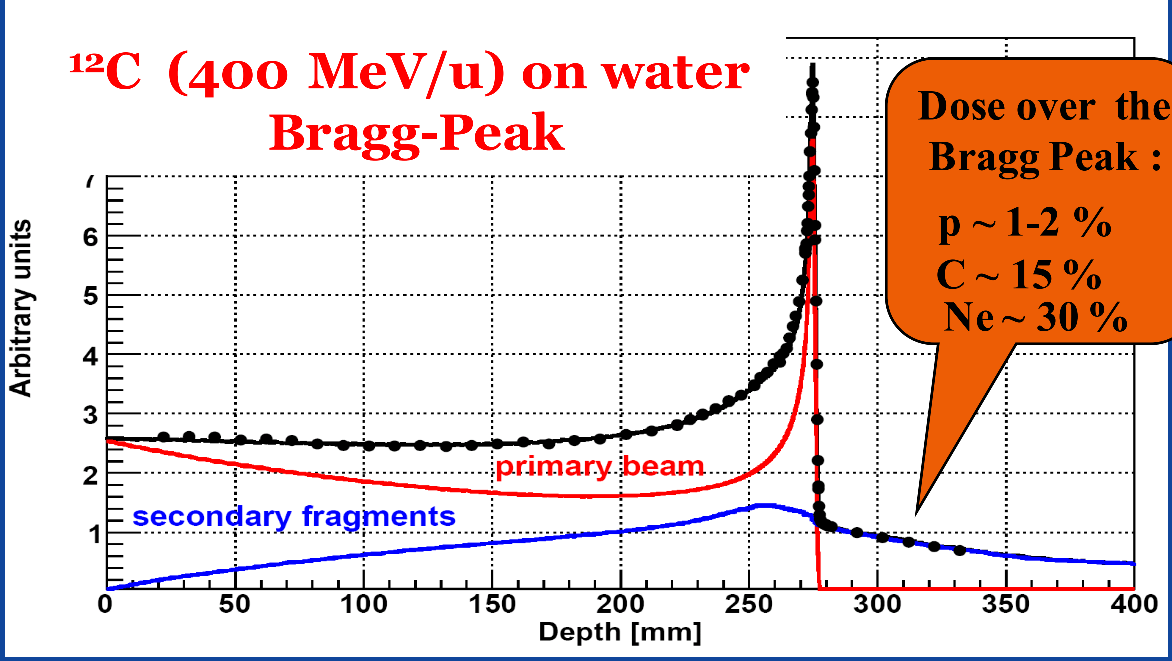
CAVEAT!: The fragment direction must be well measured in the Lab frame to obtain the correct energy in the Patient frame

FRAGMENTATION OF ^{12}C & ^{16}O in bio tissue

Dose release in healthy tissues in light ion treatments due to the beam (projectile) fragmentation. To be measured in the 100-400 MeV/nucl Ekin range. X-section needed for TPS

- Production of fragments with higher range and different direction vs primary ions
- Different biological effectiveness of the fragments

In the inverse kinematic strategy approach the FOOT experiment could also measure the ^{12}C and ^{16}O projectile fragmentation on C target @ 200-400 MeV/u



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

Courtesy of Andrea Mairani

Space radiation protection

The components of space radiation that are of concern are high energetic charged particles, especially protons from the Sun and heavier ions from galactic cosmic rays

(C2H4)n is foreseen to be used in spacecraft shielding..
Corresponding fragmentation cross sections are important for dose estimate to the astronauts

Energy:
100 MeV/n to 10 GeV/n

Projectiles:
H, He, C, O, Si and Fe

FOOT could explore He, C, O, Si beams @ 150-450 MeV/u

Norbury, J. W. et al. "Review of nuclear physics experimental data for space radiation." *Health physics* 103.5 (2012): 640-642.

Guide lines for the detector

- Main focus on Z>2 fragment yields & emission energy. Precise angle measurement are also needed to apply correct inverse boost transformation
- The fragment charge ID is the basis of the measurement.
- The fragment mass ID is a challenge and can be performed after a Z ID. An eventual wrong A assignment has an effect on the range evaluation-> less severe at high A
- Highly reliable PID achieved using E_{kin}, momentum and TOF measurement of fragment
- The fragmentation contribution of the detector material MUST be kept as low as possible and eventually subtracted
- Detector portability to different beams is an absolute need: size of the detector should be in the 2 meters range

Particle ID and analysis strategy

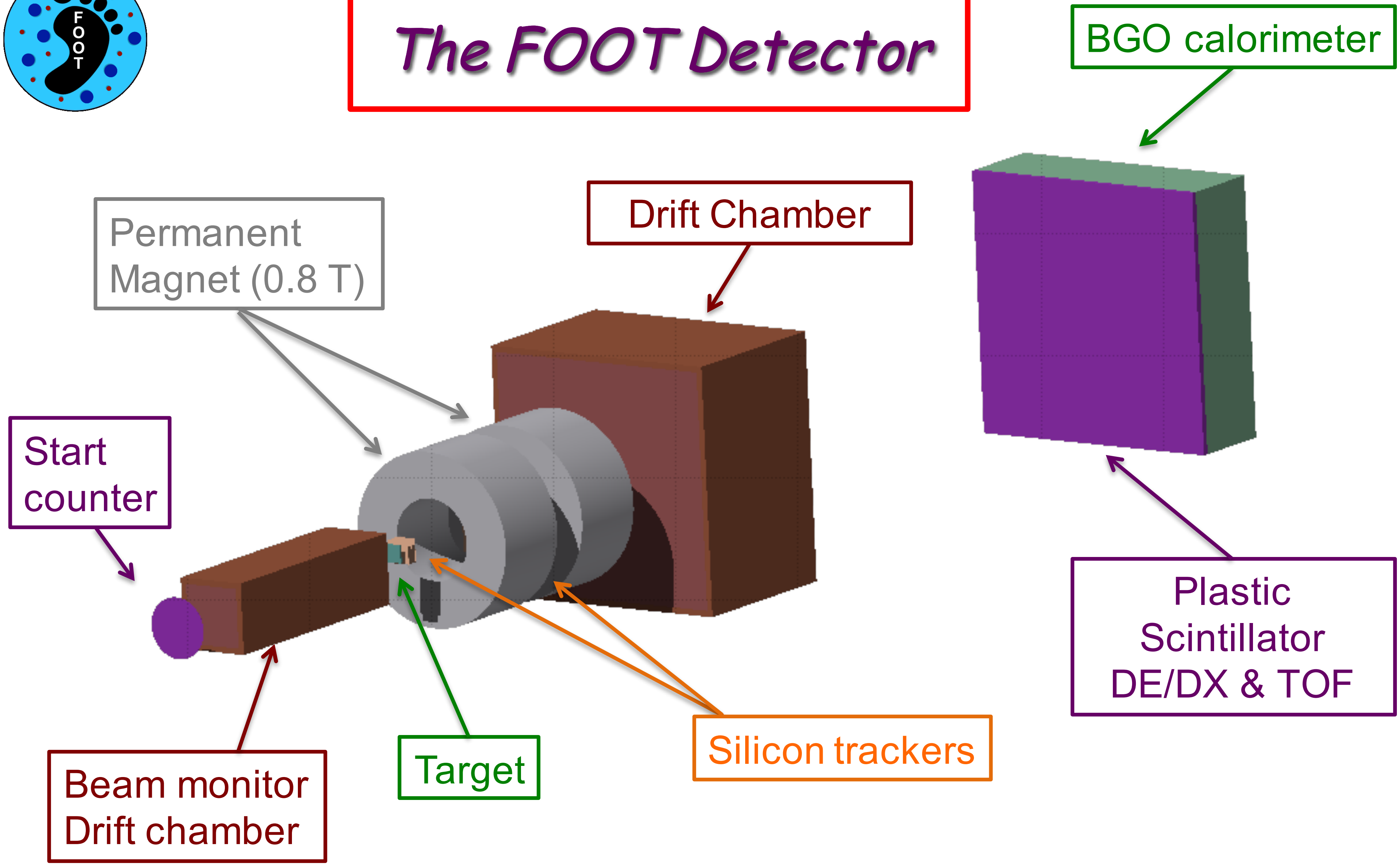
The measurement priority is on Z but we need to resolve A in order to have a correct evaluation of fragment range in the patient.

For each fragment we need Z, A and the 4-momentum to reconstruct the fragment energy in the patient frame

- E_{kin} is measured by a calorimeter
- p vector is measured by tracking in magnetic field
- Z ID achieved by means of ΔE–E_{kin} measurement
- A can be identified by p,E or p,β combinations
- Possibility of multivariate analysis on fragment ID and momentum is the figure of merit of the experiment

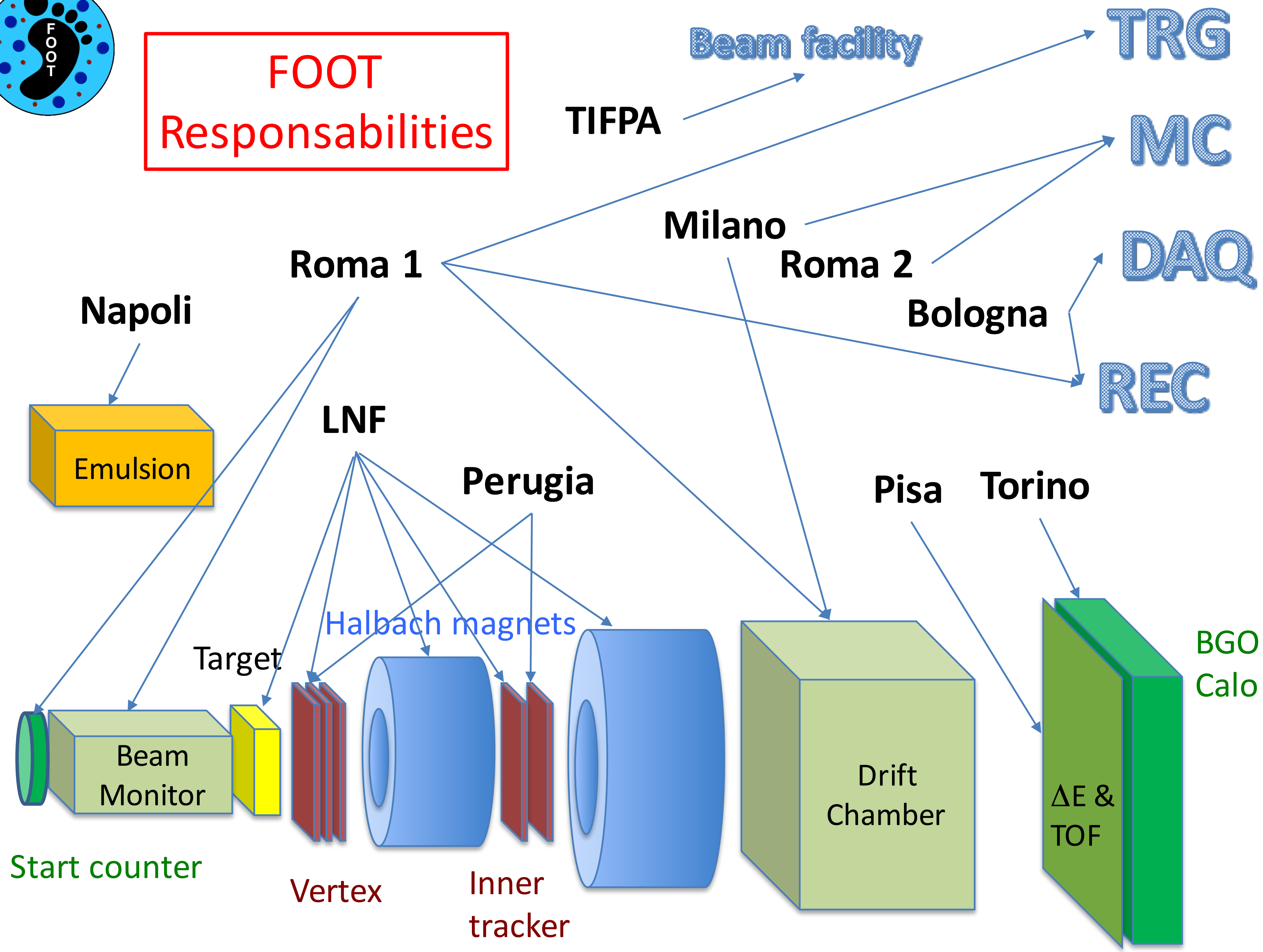
Indipendent multiple measurements of E and p are mandatory

The FOOT Detector

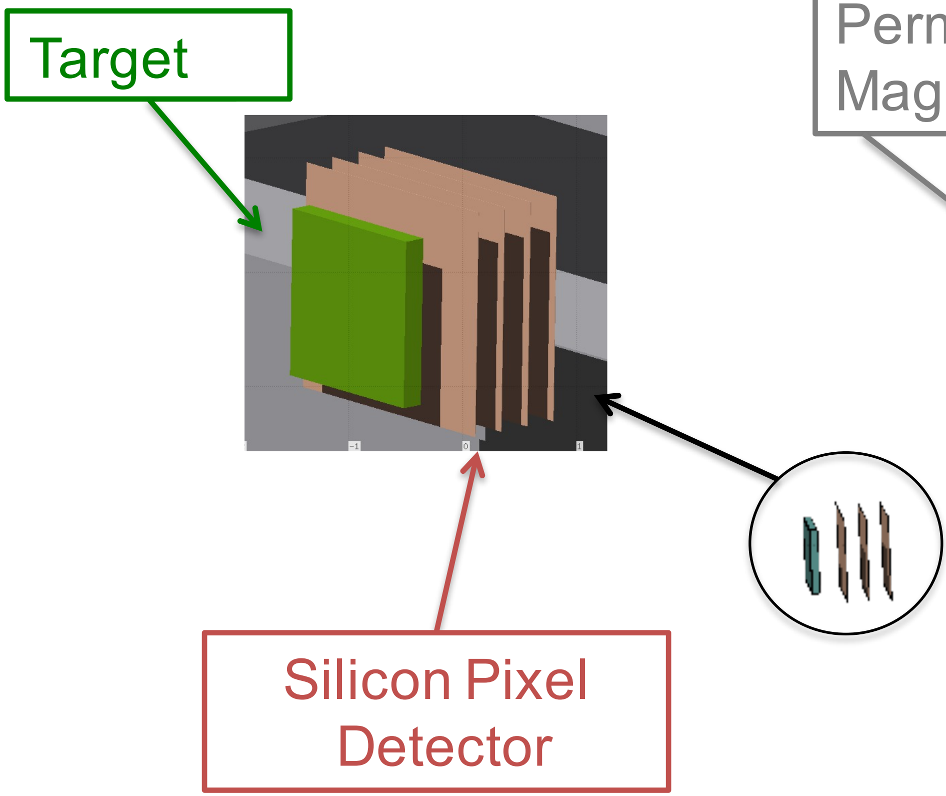


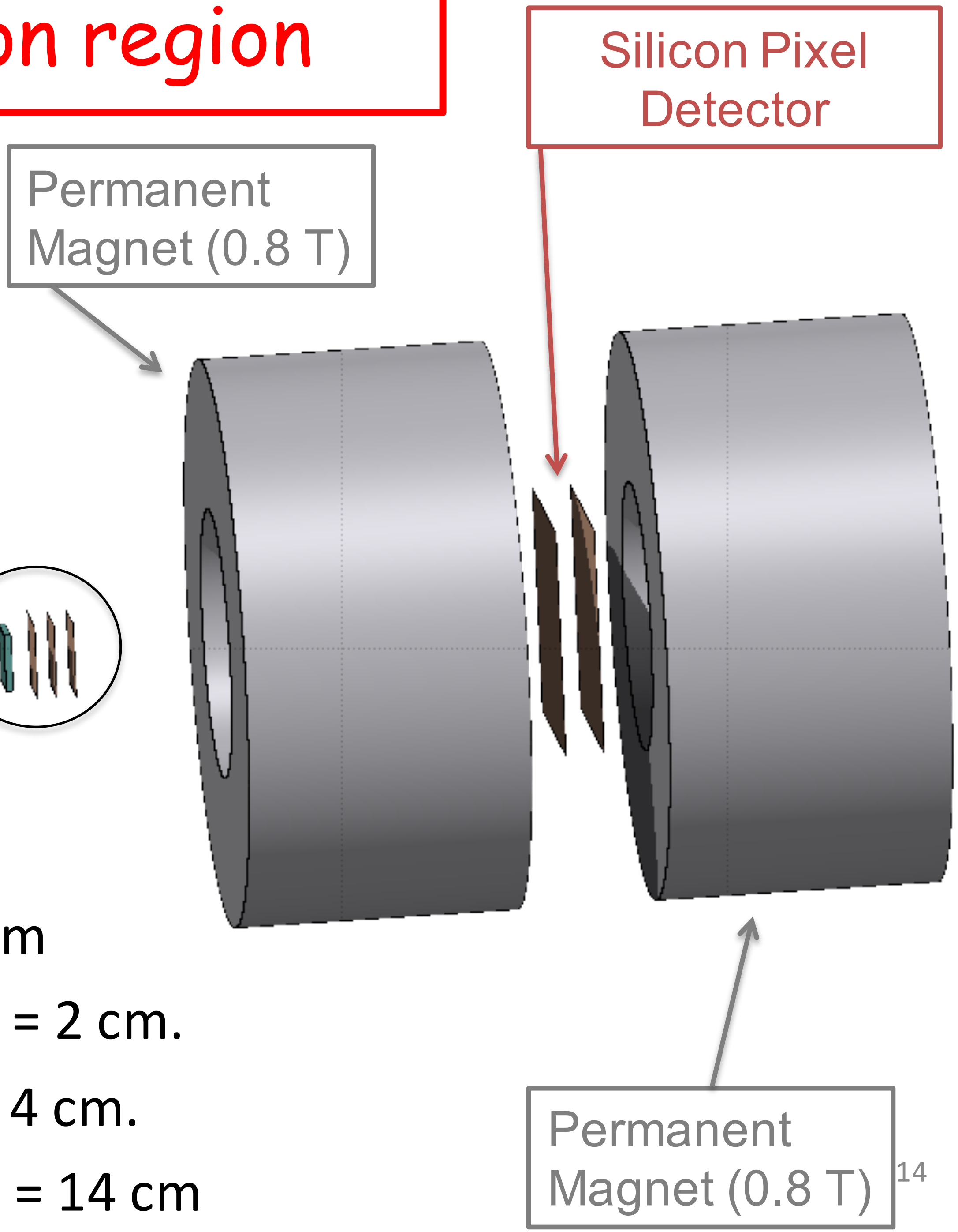
Combines magnetic, TOF and calorimetric measurements

FOOT Responsabilities



Interaction region





Distance target-vertex= 0.5 cm

Distance inner tracker planes = 2 cm.

Distance between magnets = 4 cm.

Distance target- inner tracker = 14 cm

Tracking system: baseline

- Setup for B field: 2 cylindrical magnets (KLOE dipole-like). Can be as high as B= 0.8 T with magnetic length DL~7 cm each.
- Acceptance: 10 deg angular semi-aperture
- Buiding block MIMOSA 28 chip: 2x2 cm^2 each (MIMOSA can live in Tesla B field) with 20 μm pitch and 50 μm thickness
- Scattering multiple is the driving issue. Both the MIMOSA material itself induces MS like the few cm air in between
- Drift chamber (6+6 XY planes) with a tracking active volume of 12x12x12 cm^3 and 150-200 μm of hit resolution detects the bending after last magnet up to MS >> hit resolution

D (cm)	R (cm)	Area (cm^2)	N MIMOSA CHIPS
14	2.5	25	9 + 9 +3

MS, resolution and all that

The Multiple Scattering has been evaluated with FLUKA, considering all material. The equivalent hit spread due to MS is

- Less then 10 μm on the vertex planes
- Order of 100-120 μm of the inner tracker
- From 200->260 μm on the DC ~ than the hit resolution

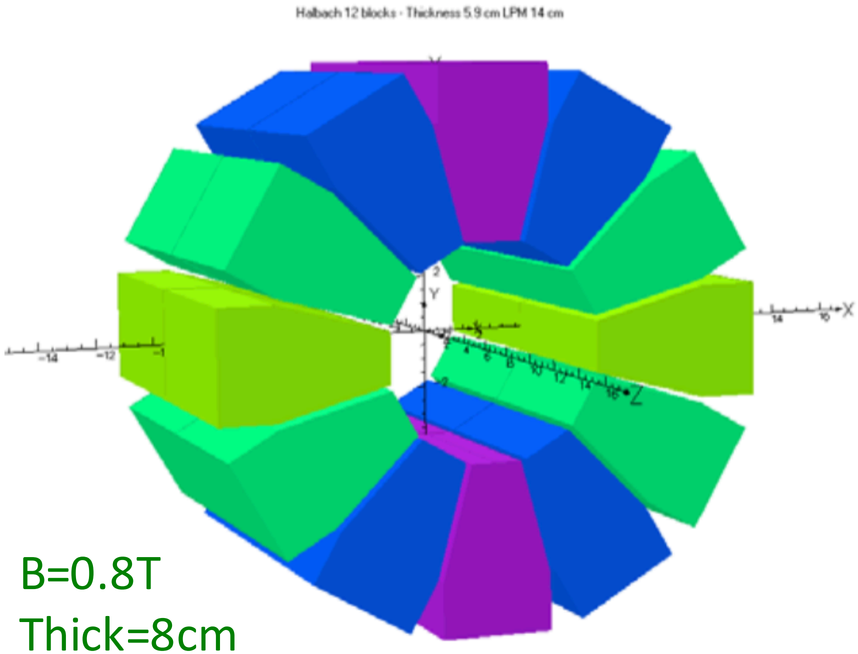
Using a simple tracking fit this system seems to provide a satisfactory σ_p/p = 3% - 5% for proton/oxy at 200 MeV/nucl.

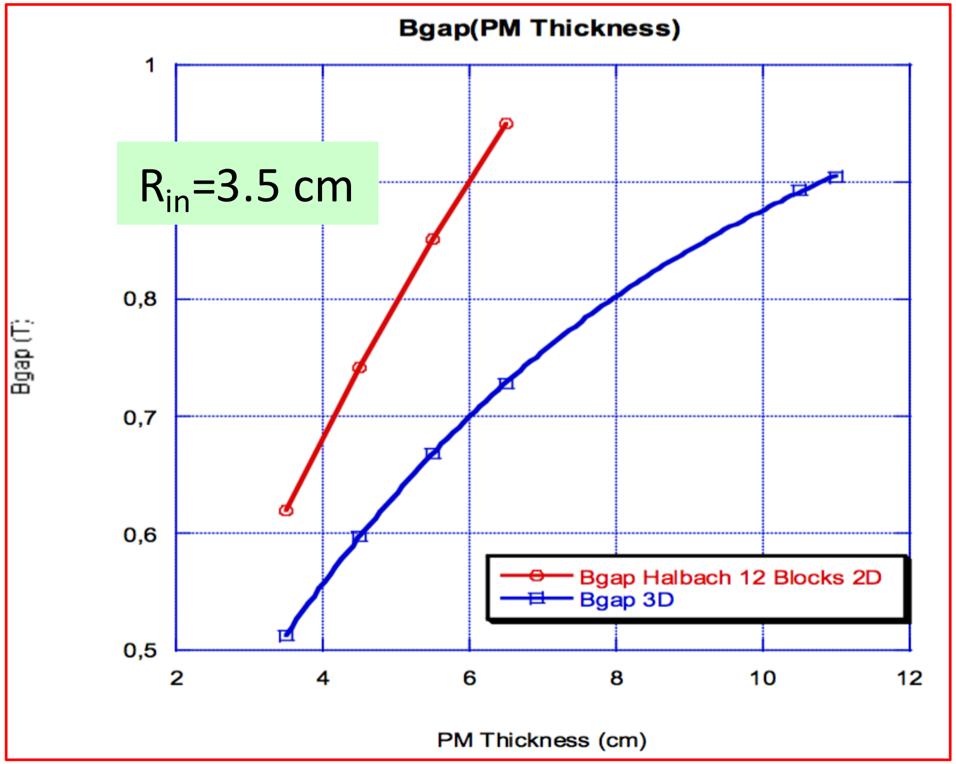
Comments:

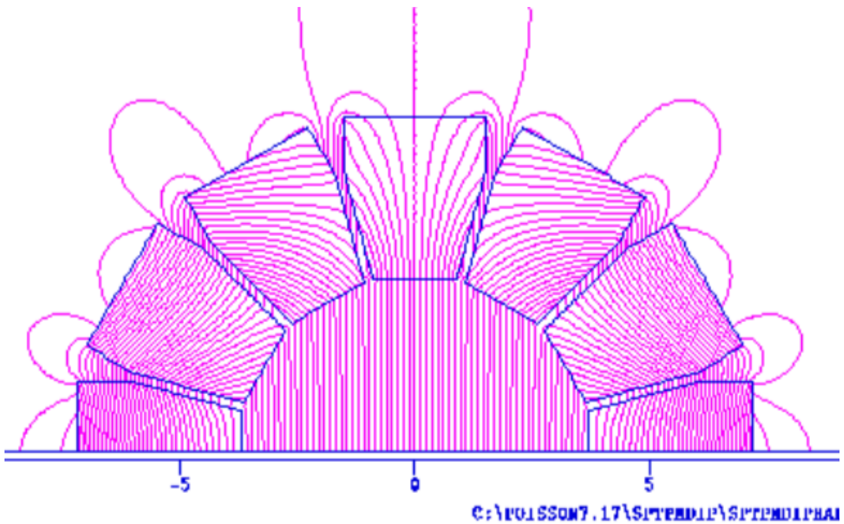
- The application of Kalman Filter will improve the resolution-> the inner tracker "erases" the effect of the previous MS.
- Up to 350 MeV/u the increase in the bending radius is compensate by MS decrease : σ_p/p almost flat on oxygen

Halbach geometry for Magnet

Halback geometry provides uniform transverse magnetic field in a cylindrical geometry: B field proportional to $\ln(R_{out}/R_{in})$







Where can we lay down the FOOT?

The wish-list for an experimental facility:

- C,O (N) beams in the 100-350 MeV/nucl available
- Possibility to mount and calibrate the experimental setup before data taking for "long" time (1-2 week?)
- Beam time availability in the week time range -> dedicated experimental hall
- Several data taking period possible, with safe time schedule to be known in advance

- CNAO Experimental room is our choice. Explicit interest and partecipation in the FOOT project. Exp. Hall times?
- HIT: possible, experimental room a bit small
- Trento and LNS are fundamental for calibration purpose

Timeline & measurements program

The "patient on proton" approach allows for a robust measurement program:

a) Target fragmentation of p on O,C @100-200 MeV/u
b) Projectile fragmentation of O on C @200-400 MeV/u
c) Projectile fragmentation of C on C @200-350 MeV/u
d) Evaluation of the β^+ emitters production (^8B production) from C,O on C @200-400 MeV/u
e) Fragmentation measurement of several beam on $(C2H4)_n$ of interest for radioprotection in space

In a realistic (moderately optimistic) schedule at least the a),b) measurements should starts by late 2019

FOOT Collaboration

10 Sections, 51 Researchers
~ 23.5 FTE

Bologna : 1.2 FTE
M. Franchini, A. Zoccoli, G. Sartorelli, M. Selvi, R. Spighi, M. Villa

LNF : 1.5 FTE
A. Clozza, C. Sanelli, A. Sarti, E. Spiriti, M. Toppi

Milano : 2.9 FTE
G.Battistoni, I. Mattei, S. Muraro, S. Valle

Napoli: 3 FTE
G. De Lellis, A. Lauria, A. Di Crescenzo, M.C. Montesi, V. Tioukov

Perugia : 1.3 FTE
L. Servoli, M. Salvatore

Pisa: 4.2 FTE
M.G. Bisogni, D. Barbosa, N. Belcari, N. Camarlinghi, M. Morrocchi, A. Retico, V. Rosso, G. Sportelli

Roma1: 3.8 FTE
R. Faccini, F. Ferroni, V. Patera, R. Paramatti, A. Schiavi, A. Sciubba, G. Traini

Roma2: 0.7 FTE
M.C. Morone

TIFPA: 1.8 FTE
M.Durante, F.Tommasino, S.Hild, M. Rovituso, P. Spinnato, E.Scifoni

Torino: 3 FTE
S. Argirò, P. Cerello, V. Ferrero, G.Giraudo, N. Pastrone, C. Peroni, L. Ramello, M. Sitta

Anagrafica/Attività LNF (2017)

- Alberto Clozza 20 %
- Claudio Sanelli 60 %
- Alessio Sarti 20 %
- Eleuterio Spiriti 50 %
- Assegno di ricerca (progetto MONOPIXEL del MAECI)

Richieste servizi:

SEA	3 mu
SPAS	3 mu
Off. Mecc.	1 mu

(richieste indicative)

MONOPIXEL: progetto finanziato dal MAECI (Affari Esteri)
Assegno di ricerca (bando in chiusura)
Titolo: “Sviluppo di tracciatori a pixel monolitici”
Trasversale ai due progetti ai LNF sui pixel monolitici: ALICE, FOOT.

Attività 2017 sul tracciatore a pixel (Frascati/Perugia)

- Acquisto e selezione dei sensori (Strasburgo)
- Disegno e realizzazione dei PCB ed FPC per Vertice/Tracciatore intermedio
- Sviluppo di sistemi di assemblaggio dei sensori (Jigs, incollaggio, bonding)
- Realizzazione dei sistemi di daq e test da laboratorio/fascio (BTF,LNS)
- Studio e “disegno” delle meccaniche di supporto: Vertice, Tracciatore, Magneti
- Studio di possibile sistema a vuoto per minimizzazione MS
- Studio sistemi di raffreddamento sensori a pixel in vuoto
- Studio di possibili nuovi sensori a pixel “analogici”

Thanks......