FOOT
FragmentatiOn Of Target

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

Particle therapy and Nuclear Physics

protons, light/mediium ions (^{4}He, ^{12}C, ^{16}O,...)

the development of **Particle Therapy** still requires fundamental contributions from Nuclear Physics:

- Physics modelling
- Exploitation of nuclear processes for Range and Dose Monitoring
- **Nuclear Fragmentation studies**

Different Z ➜ Different Radiobiological Effectiveness

More complex Planning

So far the attention was devoted to projectile fragmentation for ion therapy

Protons, at clinical practice, are approximated as ~photons, 10% more effective, although many experiments show that this in not true!! Why?

Relative Biological Effectivness (RBE) of Protons.

Cancers 2015,7 Tommasino & Durante

In clinical practice protons **RBE = 1.1**

BUT

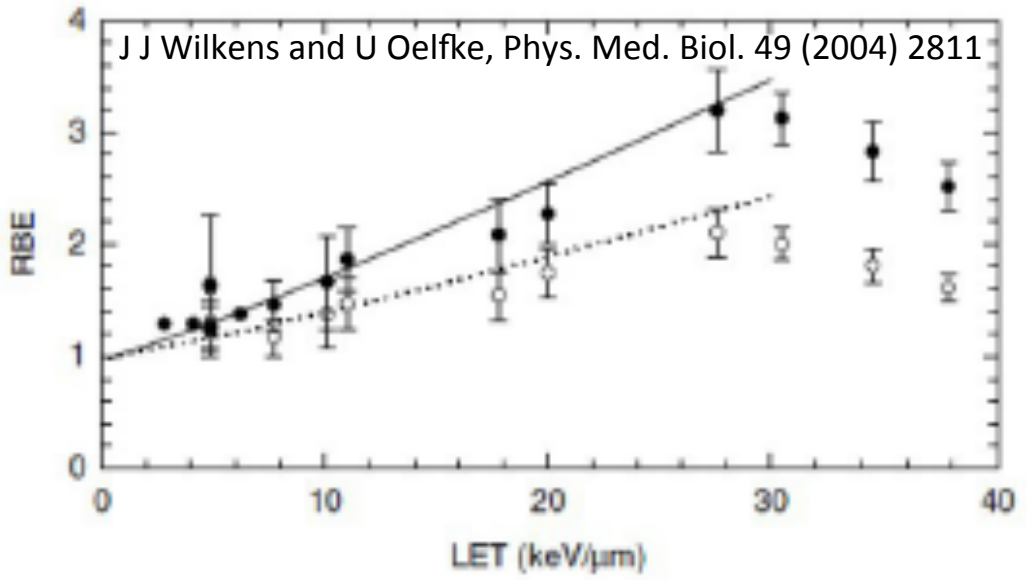
at the tissue-cellular-subcellular levels protons show **different physical and biological properties** wrt to gammas

→ **RBE ≠ 1.1**

(Girdhani2013, Tommasino2015)

risk of

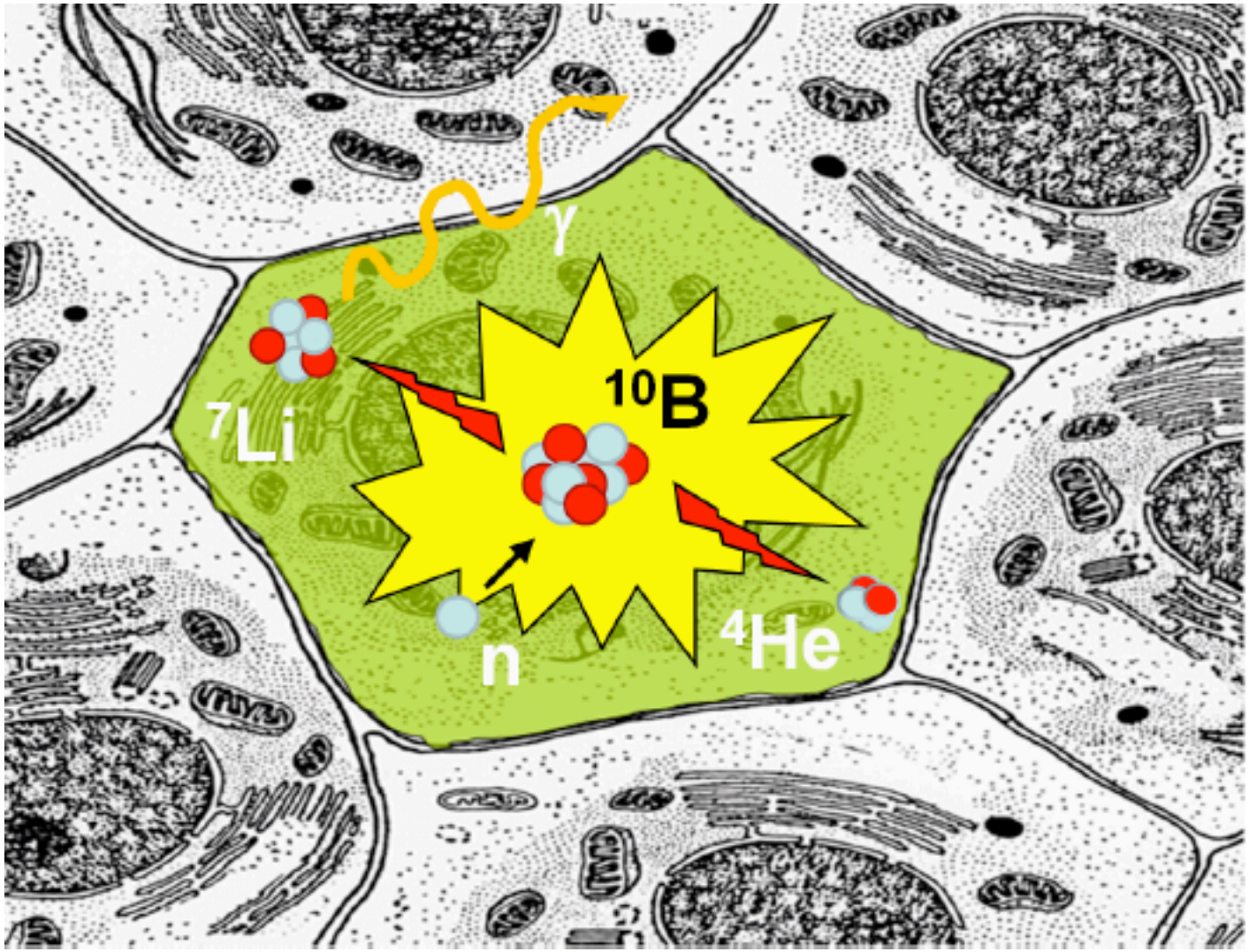
RBE>>1 in Organ At Risk



Is there a contribution due to nuclear physics?

Where?

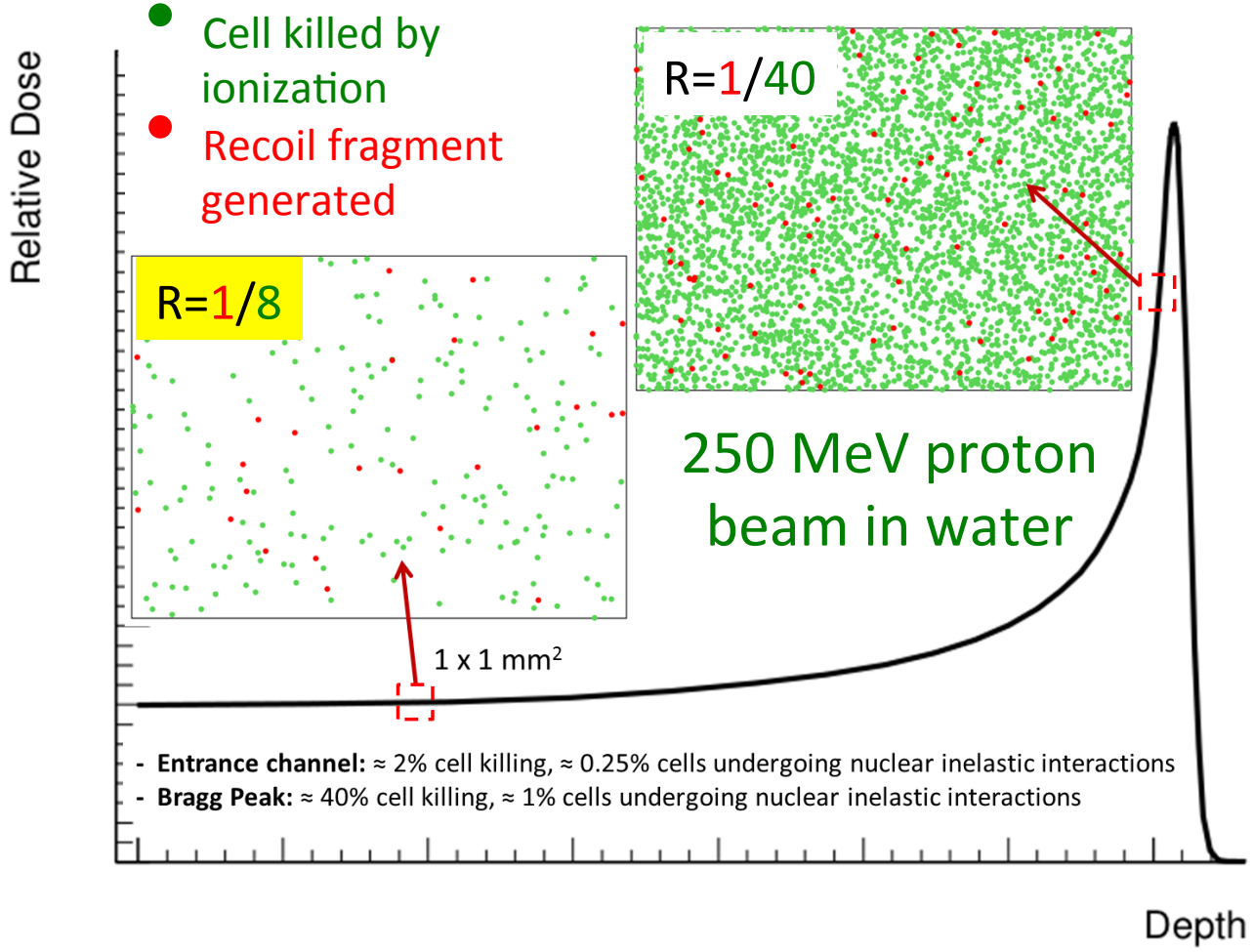
Target Fragmentation



Mechanim in action in Boron Neutron Capture Therapy

Target fragmentation & PT: where is an issue?

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



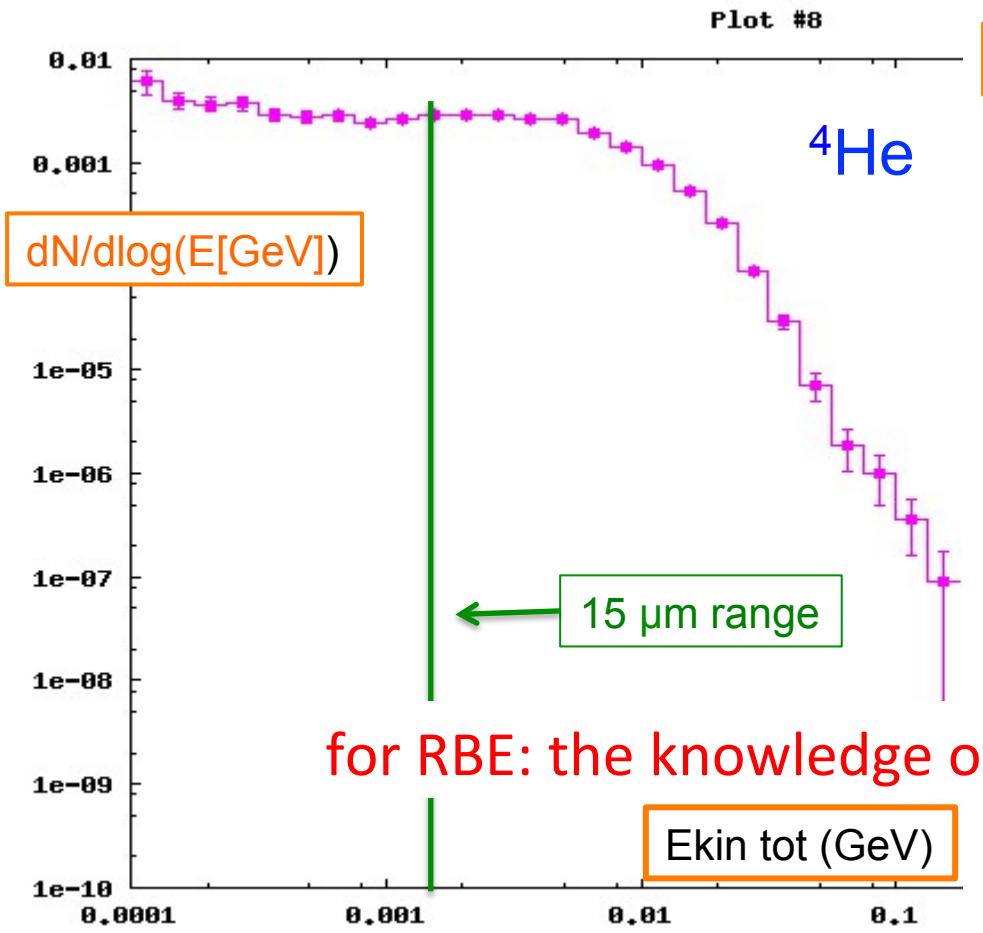
About 10% of biological effect in the entrance channel due to secondary fragments (Grun 2013)

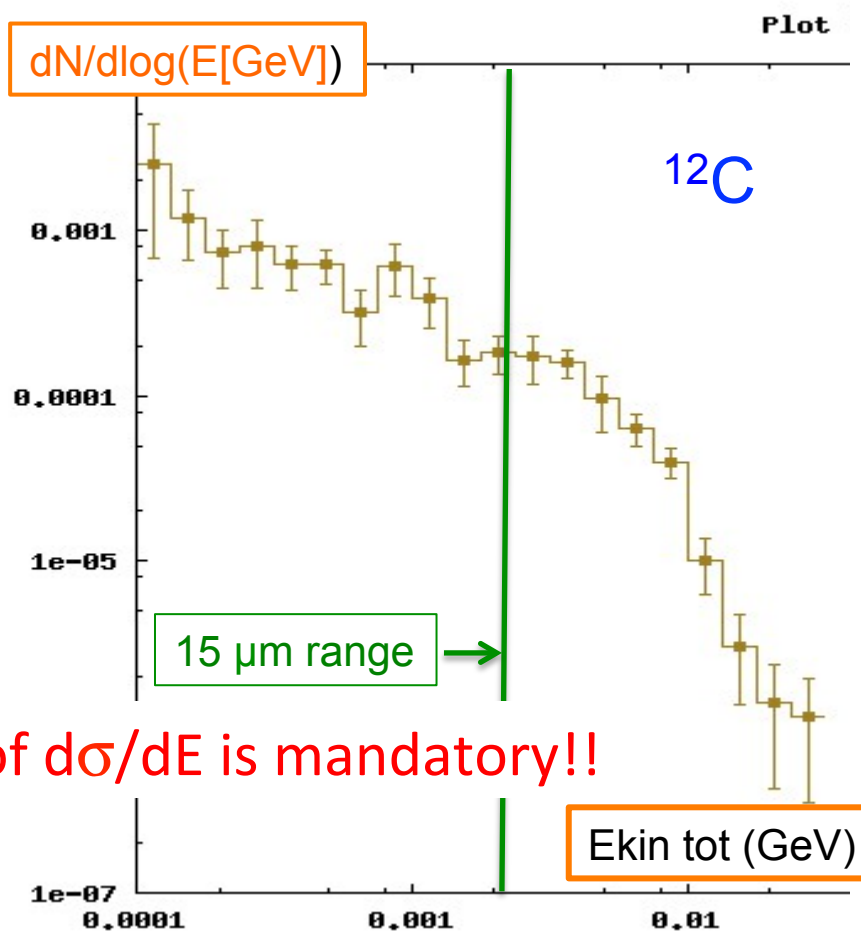
Largest contributions of recoil fragments expected from
He, C, Be, O, N
In particular on
Normal Tissue Complication Probability
See also :
- Paganetti 2002 PMB
- Grassberger 2011 PMB

p scattering on Brain tissue @200 MeV

"Heavy" (A≥4) fragment emission energy and angle largely unknown. Very low energy-short range fragments.

MC (FLUKA) prediction of production of heavy fragments for 200 MeV p on "BRAIN": production of He & C





for RBE: the knowledge of dσ/dE is mandatory!!

Inverse kinematic strategy

Target fragments travel few μm in the target-> difficult to directly detect them, even for very thin target (10 μm?)

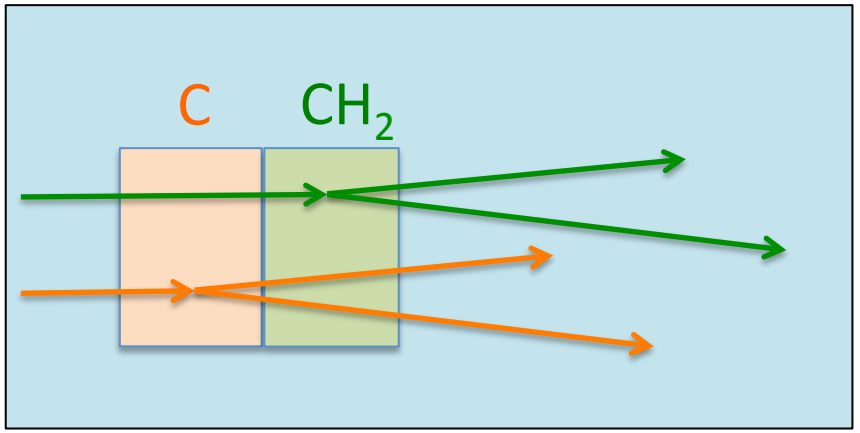
let's shoot a β=0.6 patient (C,O,N nuclei) on a proton at rest and measure how it fragments!!

Then if we measure the X-section, provided that we apply an inverse velocity transformation, the result should be the same.

- **Use (as patient) beams N, O, C ions with β= 0.6 ➔ Ekin=200 A MeV.**
- **The heavy fragment (all but p,d,t,He) has ~200 MeV/ nucleon kinetic energy and are forward peaked**

H target difficult!!

A possible solution is to use twin targets. The fragmentation cross section can be obtained by subtraction.



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. ds/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

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

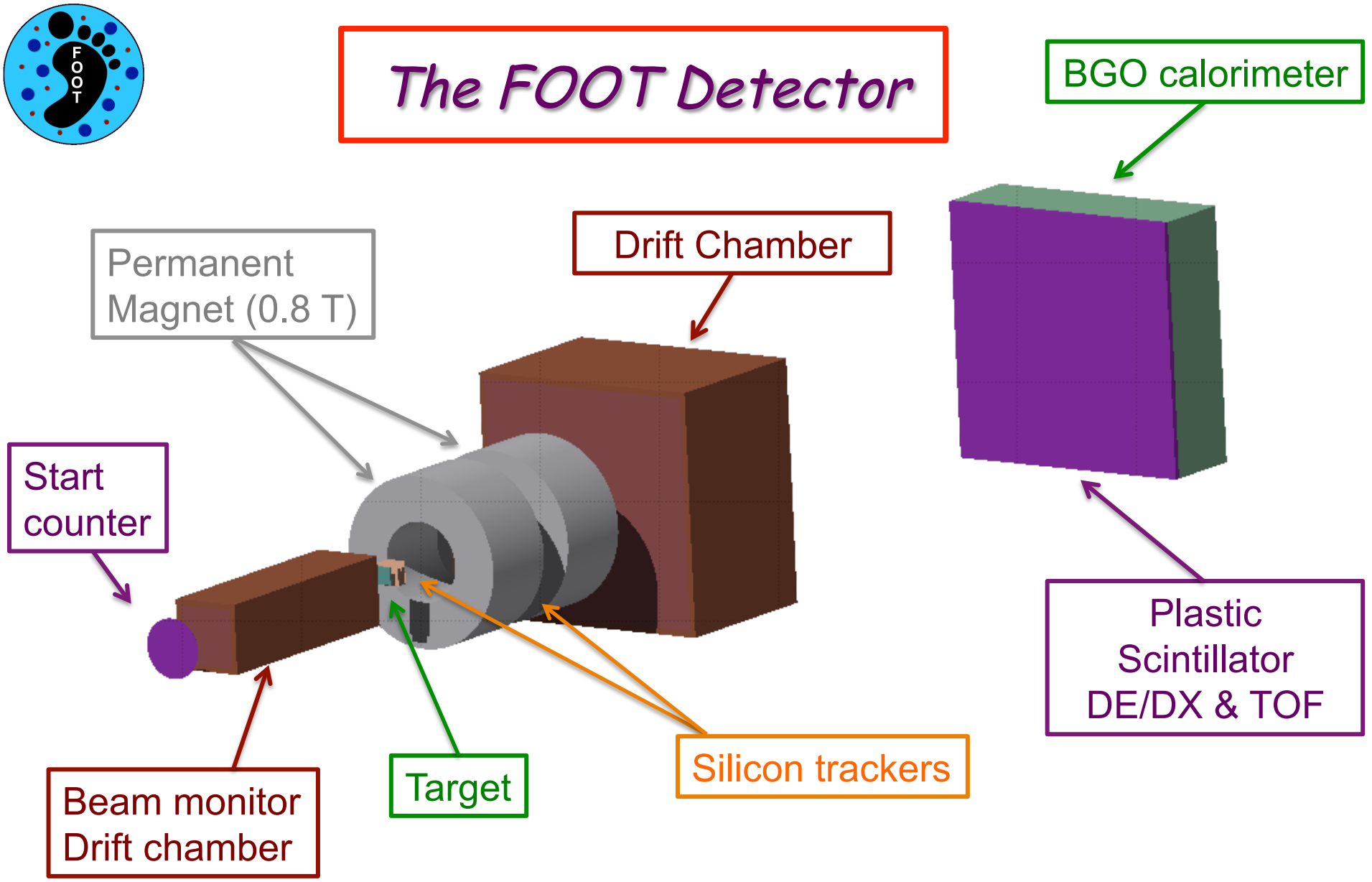
The measurement priority is on Z but we need to resolve A in order to have a correct evaluation of fragment range in the patient.

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

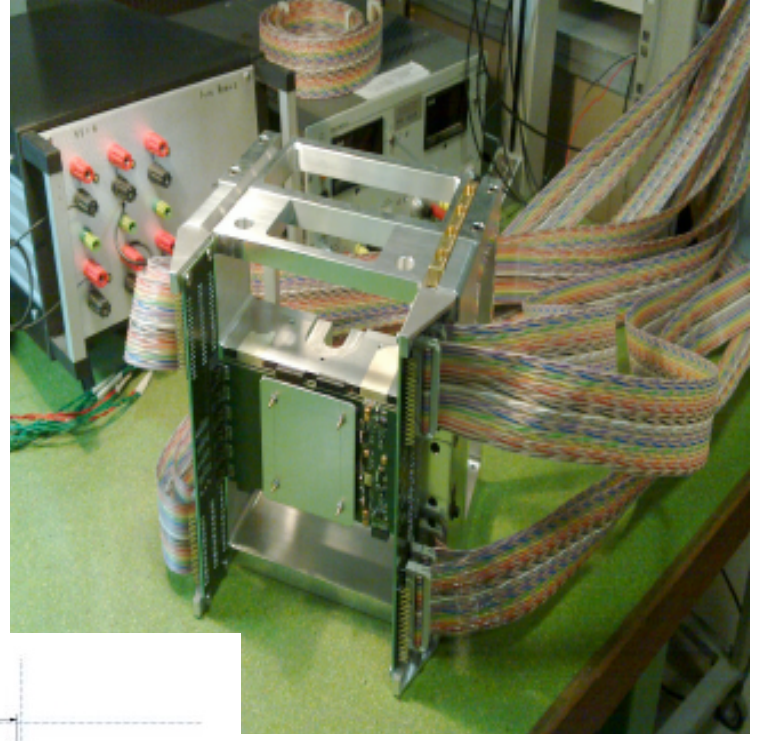


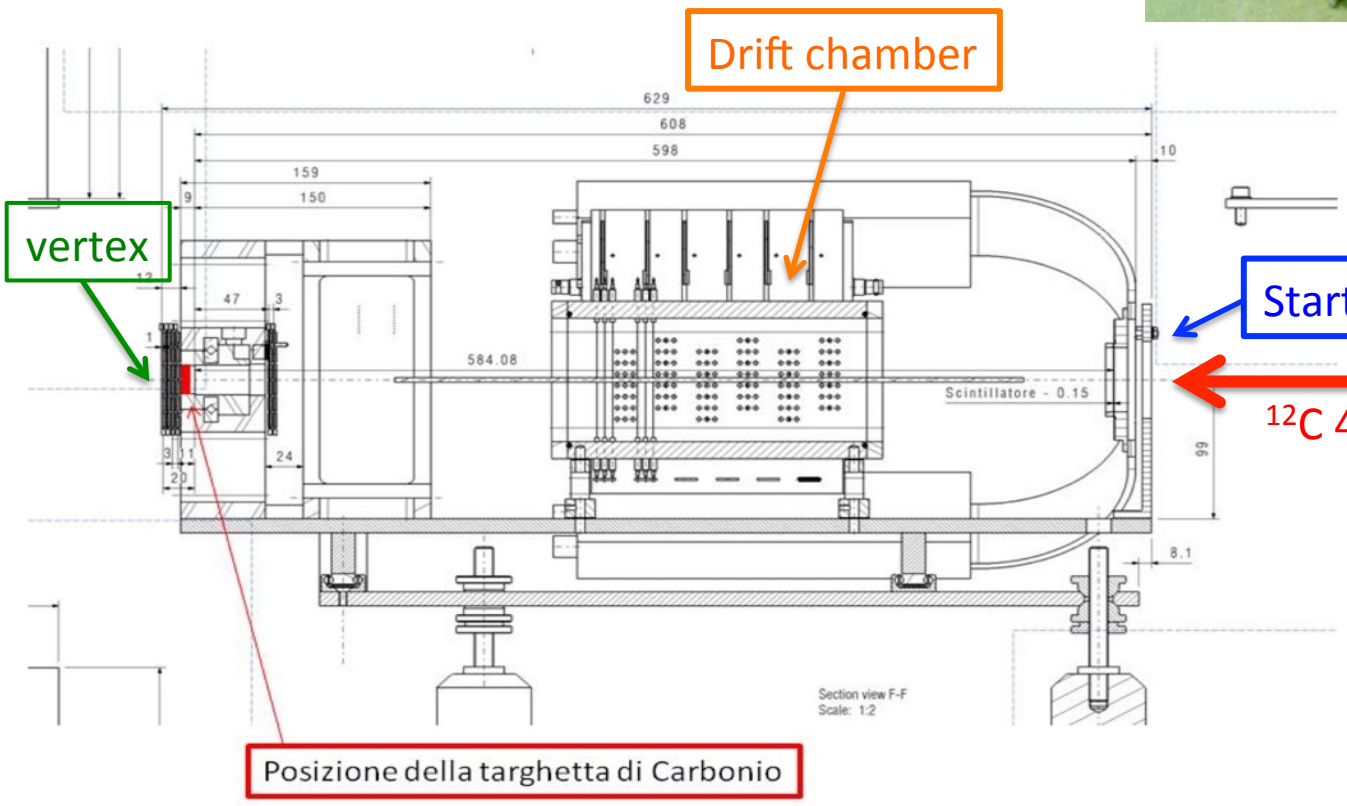
Combines magnetic, TOF and calorimetric measurements

The Int. reg. of FIRST exp.

Start counter optimized for C beam, drift chamber to monitor the beam direction

Vertex detector made of 4 planes of 2x2 cm^2 active area, each made of two MIMOSA 26 silicon pixel detectors (MAPS), 3mm spaced, 18.4 μm pitch. Hit resolution ~ 10μm





MAPS from Strasbourg: IPHC Strasbourg, http://www.iphc.cnrs.fr/-PICSEL-.html)

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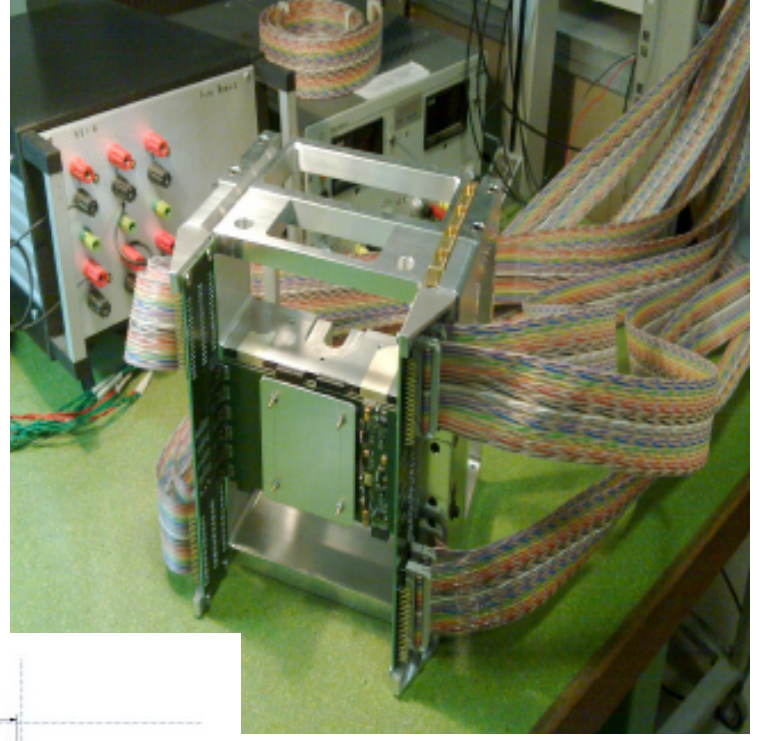
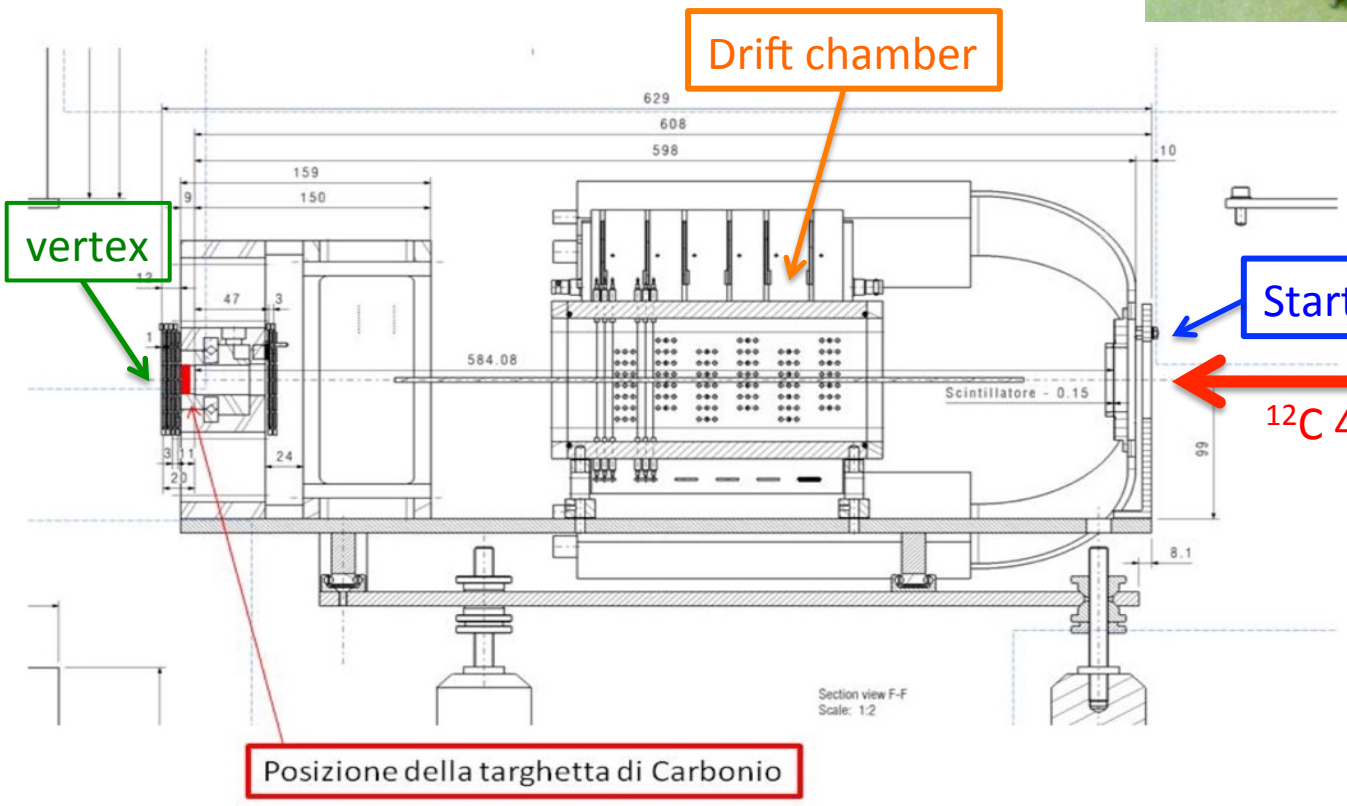


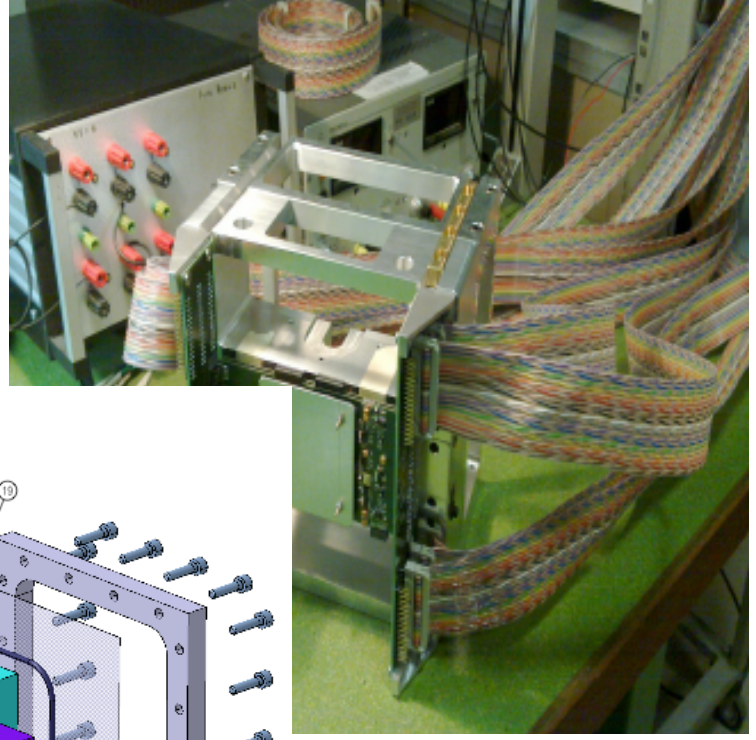


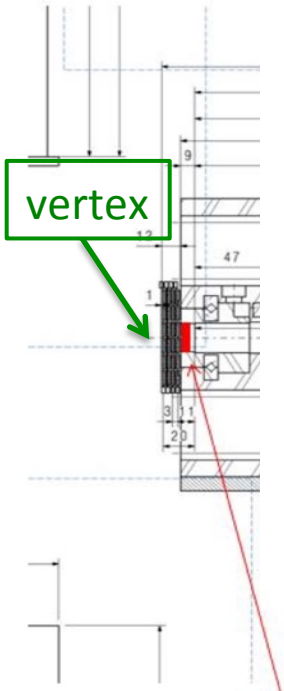
MAPS from Strasbourg: IPHC Strasbourg, http://www.iphc.cnrs.fr/-PICSEL-.html)

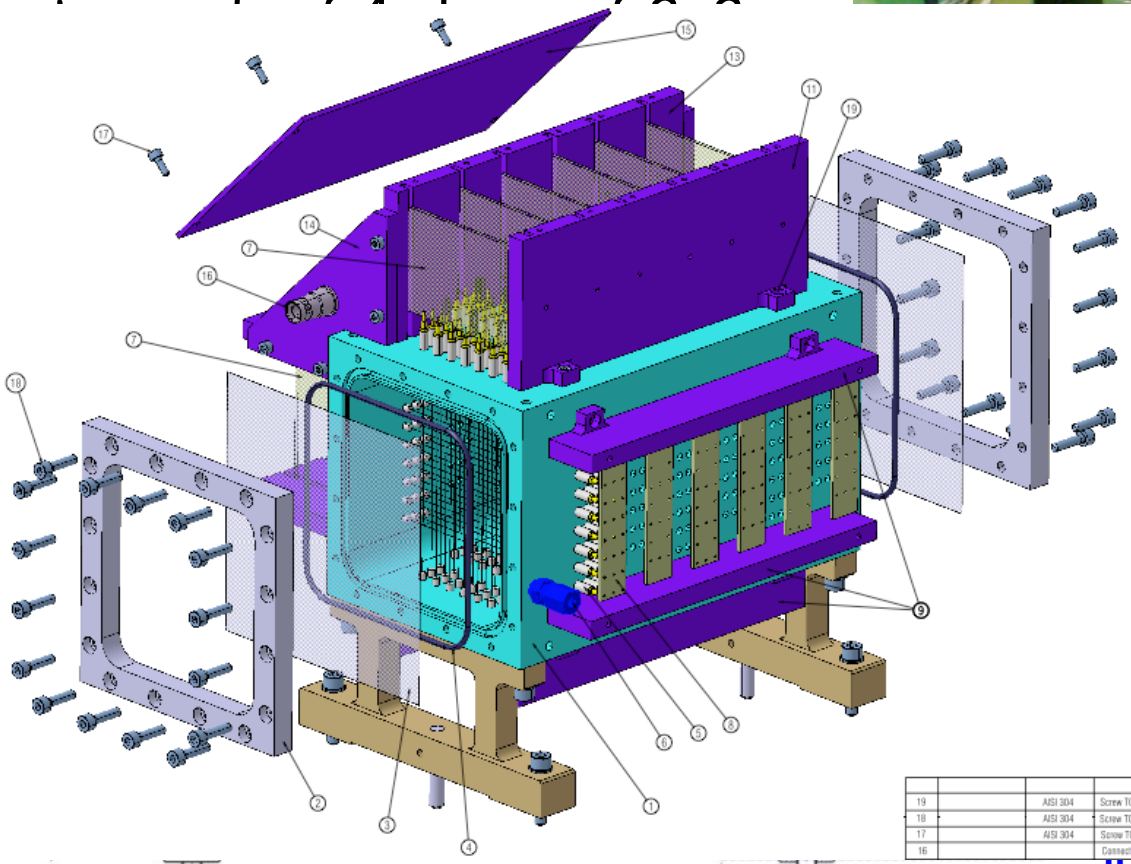
The Int. reg. of FIRST exp.

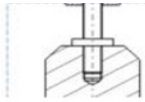
Start counter optimized for C beam, drift chamber to monitor the beam direction

Vertex de
cm² active
26 silicon
spaced, 18









Section view F-F
Scale: 1:2

Posizione della targhetta di Carbonio

ınter

MeV/nucl beam

APS from Strasbourg:
HC Strasbourg, http://
www.iphc.cnrs.fr/-
PICSEL-.html)

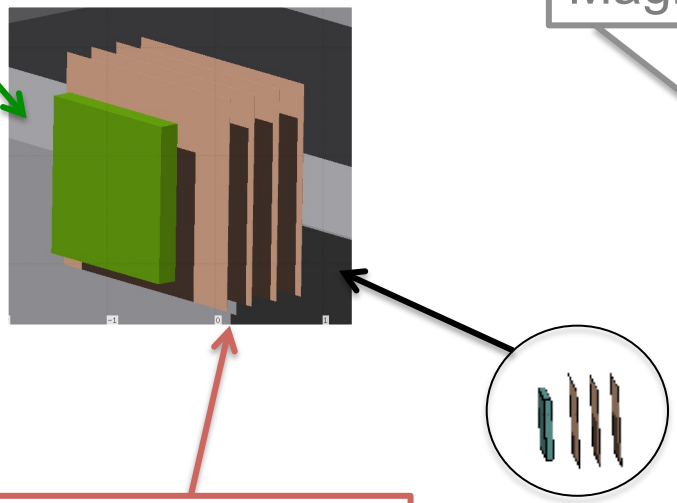
Interaction region

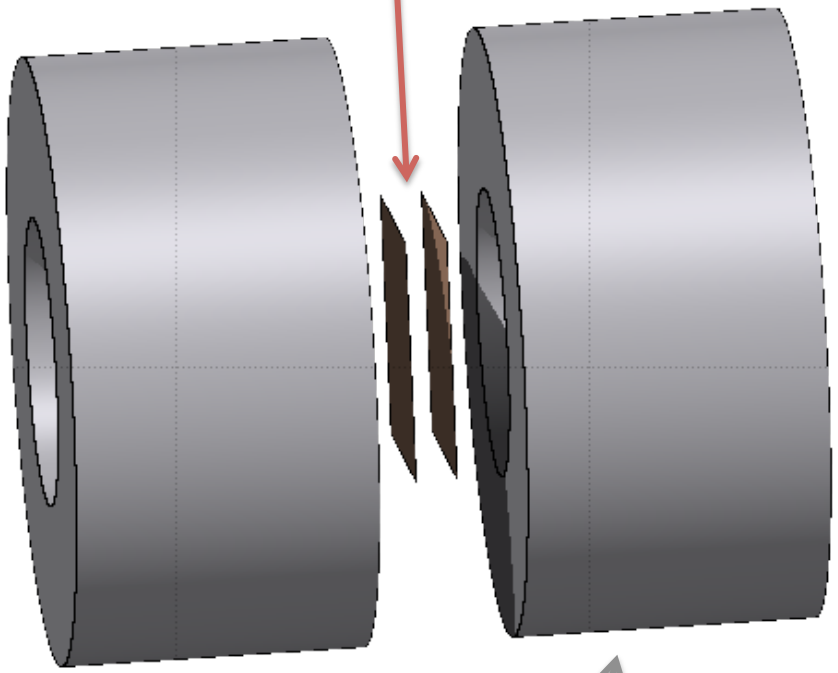
Target

Silicon Pixel Detector

Permanent Magnet (0.8 T)

Silicon Pixel Detector





Permanent Magnet (0.8 T)

Distance target-vertex= 0.5 cm

Distance inner tracker planes = 2 cm.

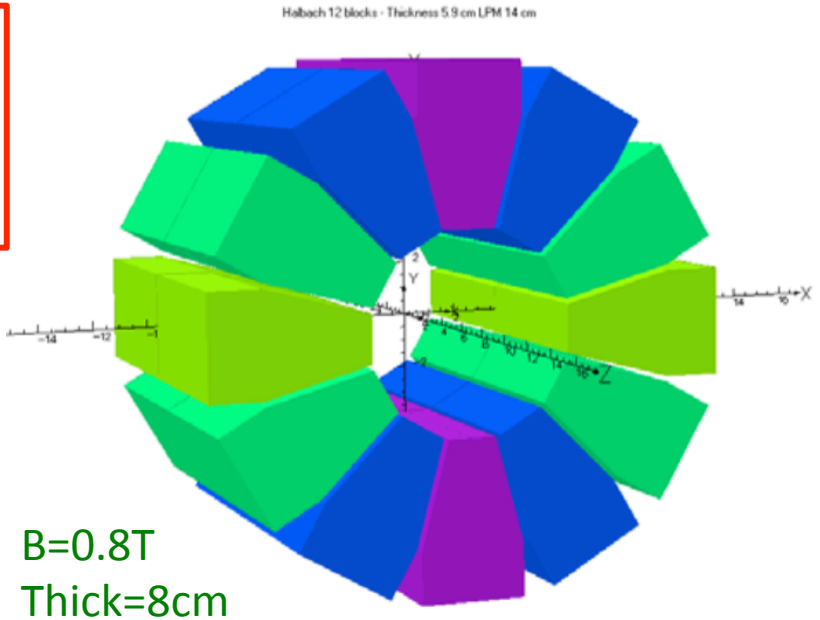
Distance between magnets = 4 cm.

Distance target- inner tracker = 14 cm

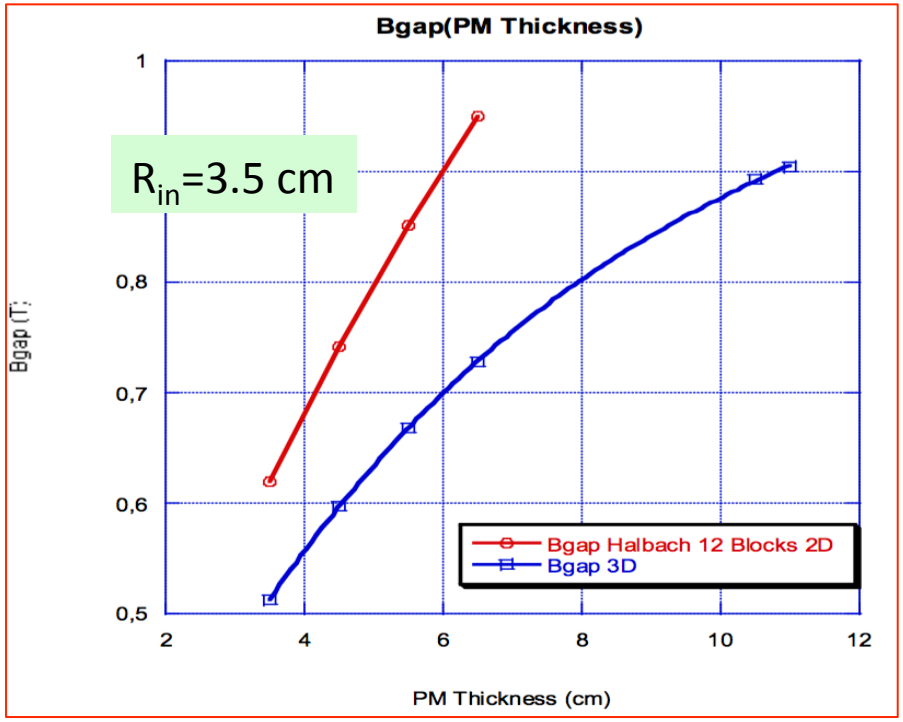
Pixel baseline: MIMOSA 28 chip: 2x2 cm^2 each
(MIMOSA can live in Tesla B field) with 20 mm pitch and 50 mm thickness

Halbach geometry for Magnet

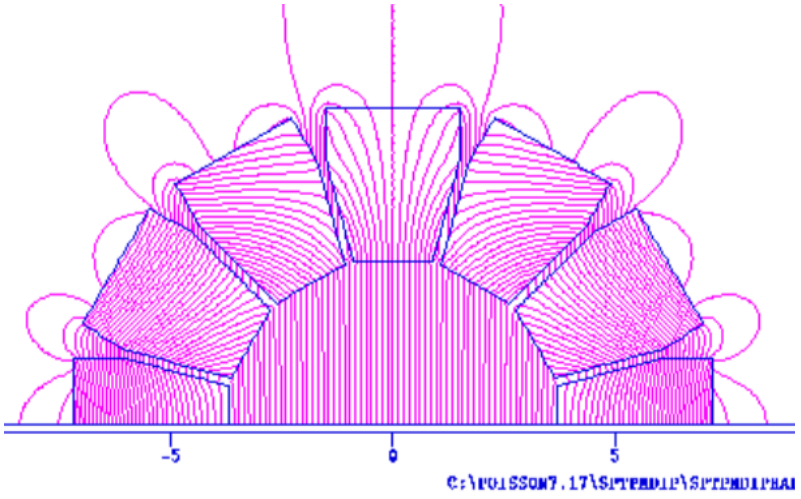
Halback geometry provides uniform transverse magnetic field in a cylindrical geometry: B field proportional to $\ln(R_{out}/R_{in})$



B=0.8T
Thick=8cm

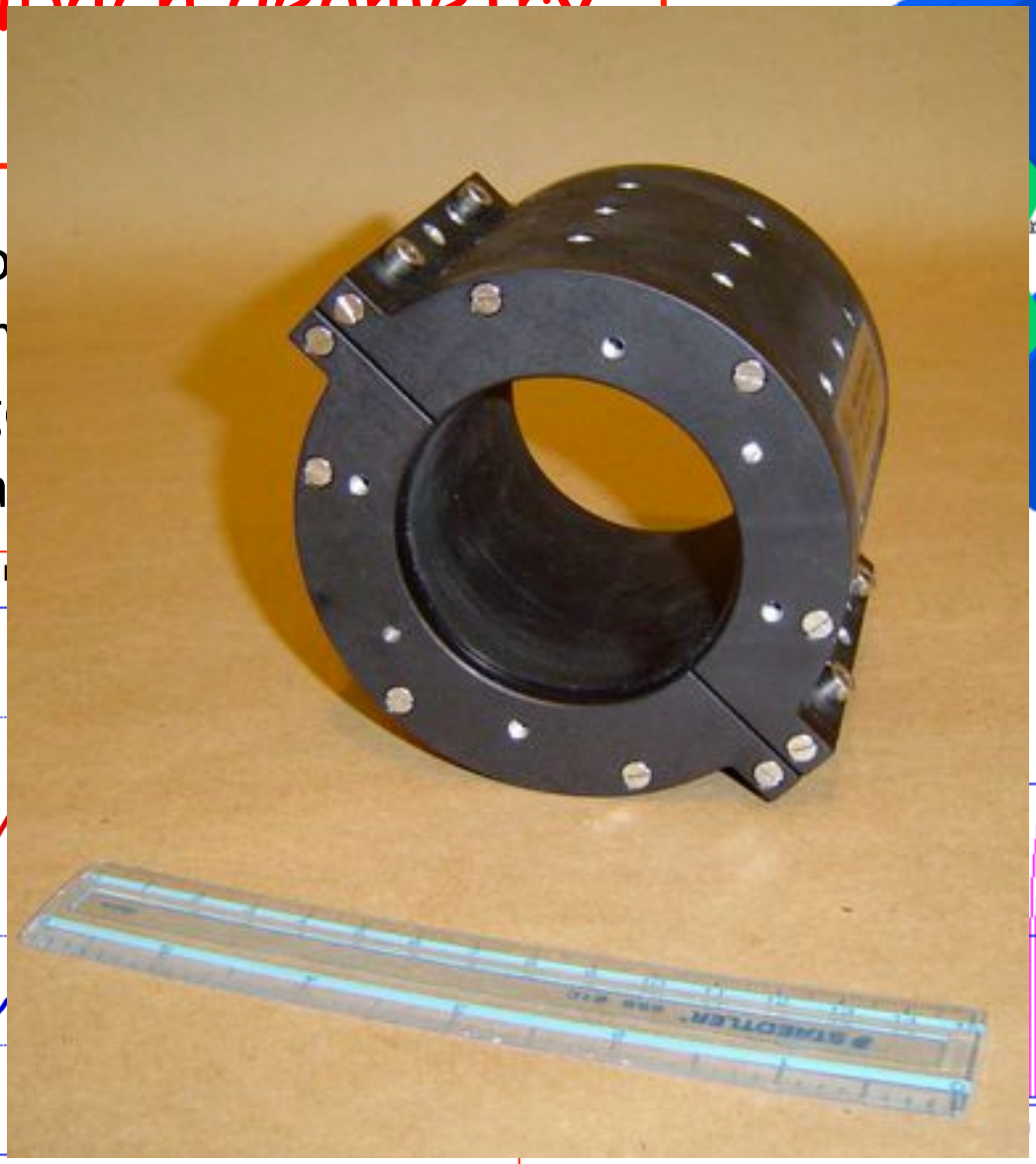


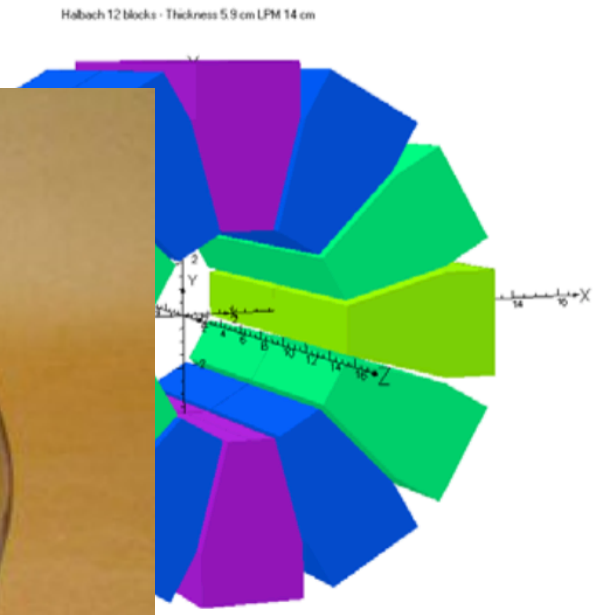
R_{in}=3.5 cm

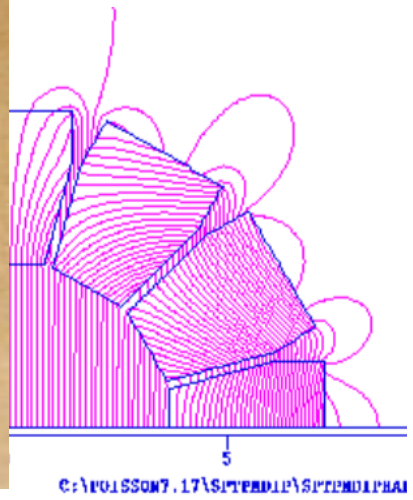


Halbach geometry

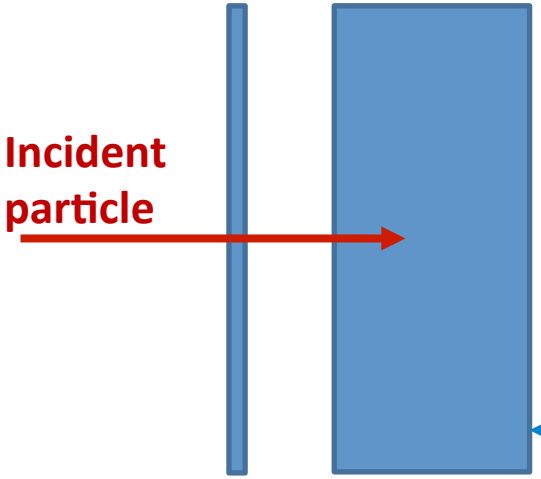
Halback geo
transverse r
cylindrical g
proportiona





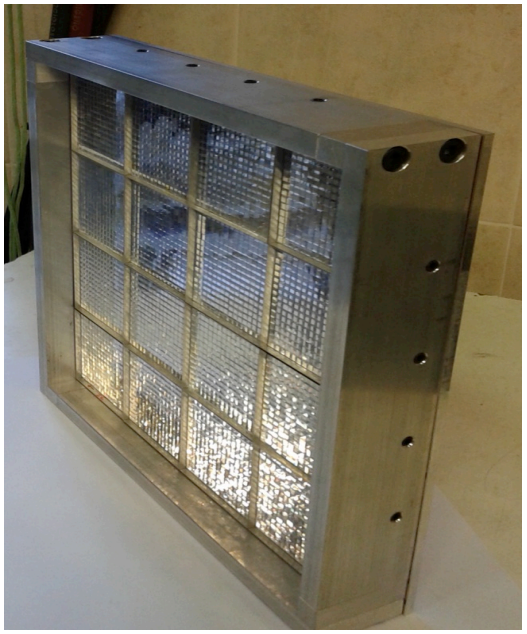


The ΔE – E measurement



$$\frac{\Delta E}{\Delta x} \sim \frac{mZ^2}{E} \ln \frac{E}{m}$$

The product ΔE x E sensitive to A,Z



Lyso Calorimeter (RDH-INSIDE)

«ΔE» Transmission detector
Segmentation needed

Thick «E» segmented calorimeter
Option: Inorganic Crystal
maybe BGO
thick enough to contain light fragments

Plastic scintillator of 5mm can obtain relative resolution on ΔE of ^{12}C beam at 400MeV/nucl of the order of 4%

$$\frac{\sigma_{\Delta E}}{\Delta E} \sim 2-3\%$$

Seems achievable

Additional Physics

- Projectile Fragmentation in direct kinematics:

- existing C-C, O-C measurements are not yet sufficient
➜improvement of treatment planning in ion therapy

- investigation of some other specific process useful for particle therapy: production of some specific β+ emitter species in view of range monitoring applications

- Cross sections useful for Radioprotection in Space

FOOT will have a counterpart in CSN5 for the connected radiobiological activities (mostly modelling): MoVe IT (call CSN5):
Modeling and **Ve**rification for **I**on beam **T**reatment planning

Where can we lay down the FOOT?

The wish-list for an experimental facility:

- C,O (N) beams in the 100-350 MeV/u 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 some β^+ emitters production (for instance ^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, G. Sartorelli, M. Selvi, R. Spighi, M. Villa, A. Zoccoli

LNF : 1.5 FTE
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

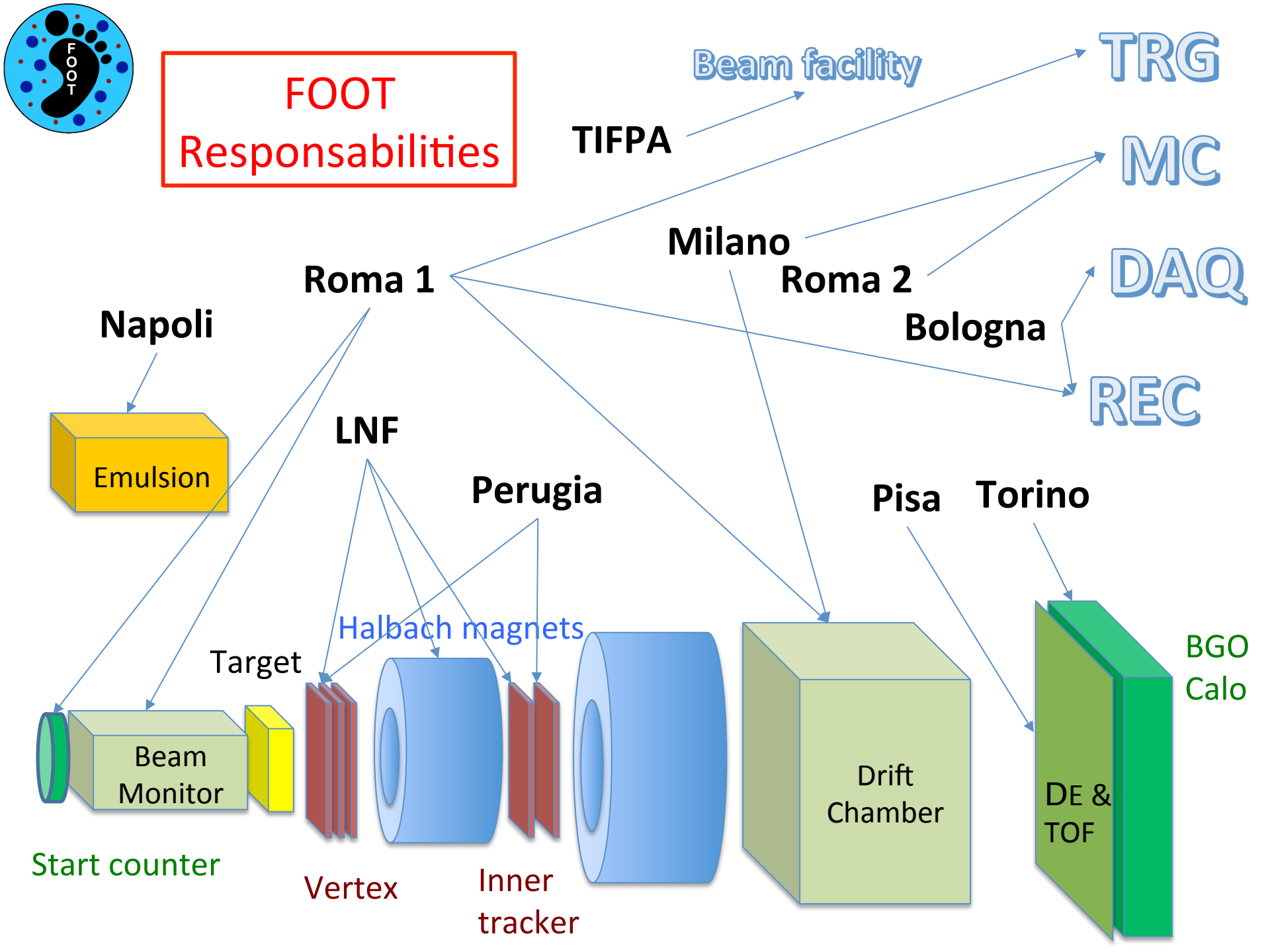
Roma1: 3.8 FTE
R. Faccini, F. Ferroni, V. Patera, R. Paramatti, A. Schiavi, A. Sciubba, G. Traini

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

FOOT Responsabilities



Profilo di spesa 2017-2020

	FTE		missioni	consumo	inventario	costr app	Totale	2017
Bologna	1,2		6	4	15		25	
Milano	2,9		7	5			12	
Napoli	3,0		15	5	21		41	
LNF	1,5		10	15	5	50	80	
Perugia	1,3							
Pisa	4,7		7	15			22	
Roma1	3,8		7	8			15	
Roma2	0,7		3				3	
TIFPA	1,8		5	10			15	
Torino	3,0		7	40			47	
FOOT	24,0		67	102	41	50	260	2017
			60	55	50	290	410	2018
			100	55	40	90	210	2019
			55	20	0	0	20	2020
Missioni : 282								
Apparato : 793			282	232	131	430	1075	2017-2020

FOOT@Mi: anagrafica & servizi 2017

	Posizione	Percentuale (%)
G. Battistoni	Ric	50
S. Muraro	Art. 2222	80
I.Mattei	Assegnista	80
S. Valle	Dottoranda	80

Coinvolgimento Milano:

- simulazionii MC
- software generale
- Lavoro congiunto con Rm1 su sviluppo parti detector

(inclusi Test Beams)

Richieste finanziarie:

Consumo 5 kEuro, Missioni 7 kEuro

Richieste servizi:

frazione del servizio elettronica

(S. Brambilla 10%)

Thanks……