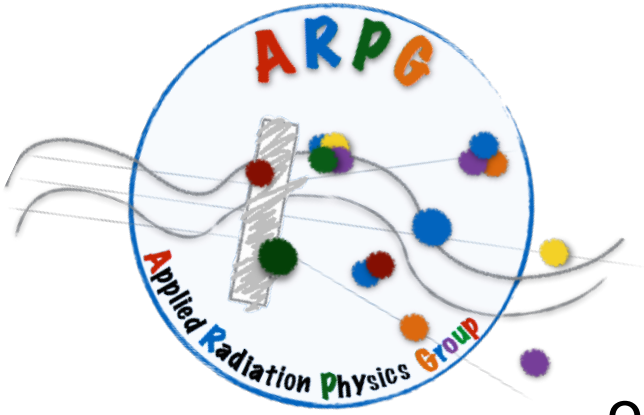
A novel dual-mode tracking device for online dose monitoring in hadron therapy



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on behalf of ARPG group

SAPIENZA
UNIVERSITÀ DI ROMA

53rd International Winter Meeting on Nuclear Physics

Bormio 26-30 January 2015

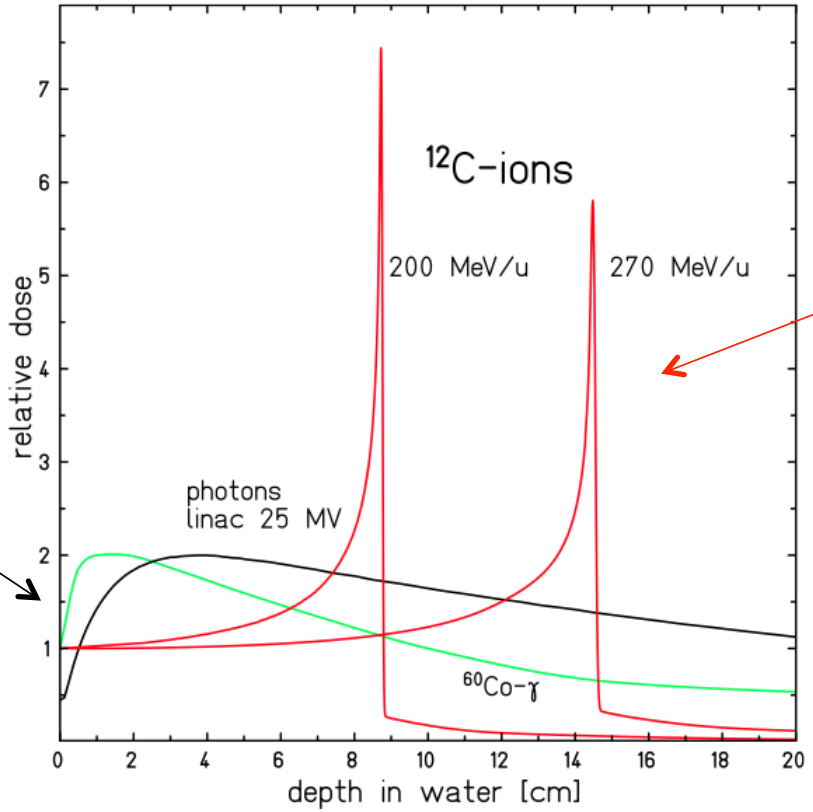
Tumor treatment with radiation/particle

Radiotherapy ➡ photons

Hadrontherapy ➡ protons, carbon ions...

Main difference is shape of dose release (dose=dE/dm)

maximum at 2-3cm depth then exponential decrease



Maximum at the end of the range: the Bragg peak

Radiotherapy vs Hadrontherapy

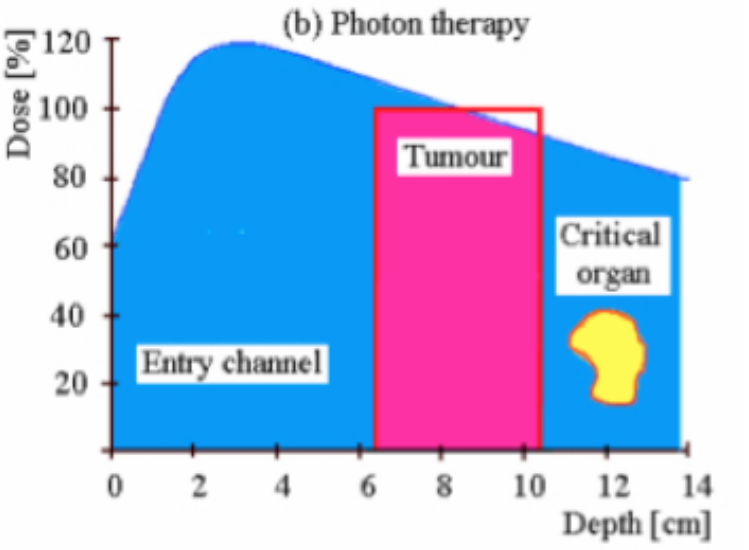
Radiotherapy

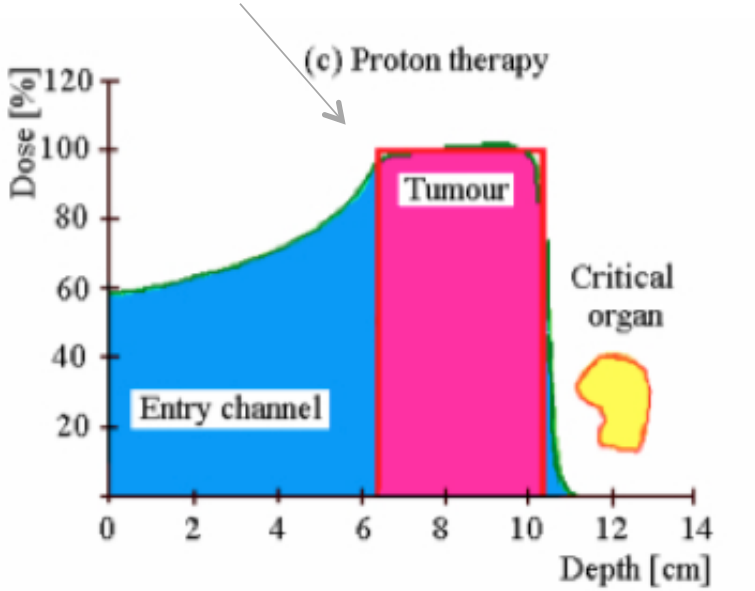
- Used for ~60% of patiens (also together with surgery)
- "Easy" but implies large doses to healty tissues
- Problems with radioresistent tumors and close to critical organs

Hadrontherapy

- Localized energy distribution spares healthy tissues
- Great efficiency in killing cells
- Needs more sophisticated facilities

Spread Out Bragg Peak (more beams combined)

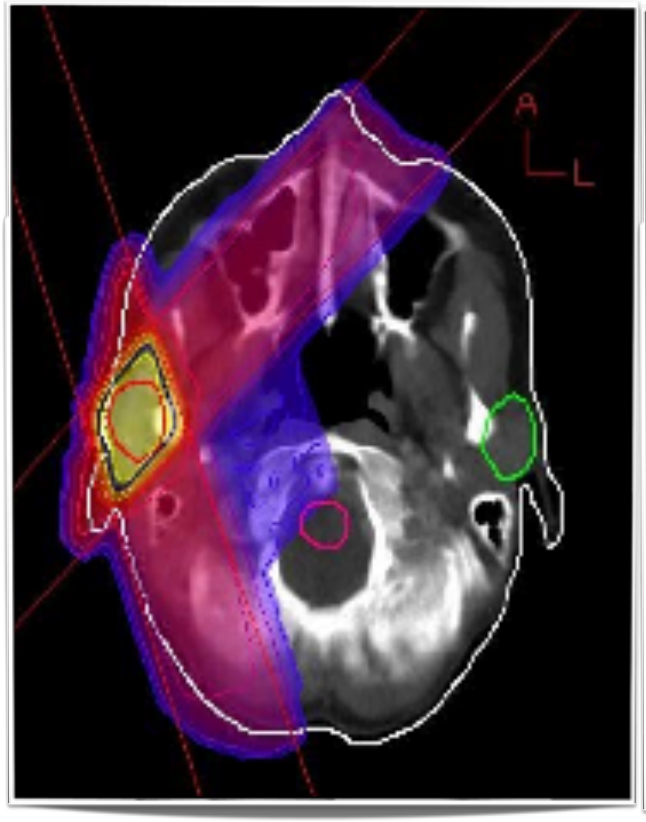




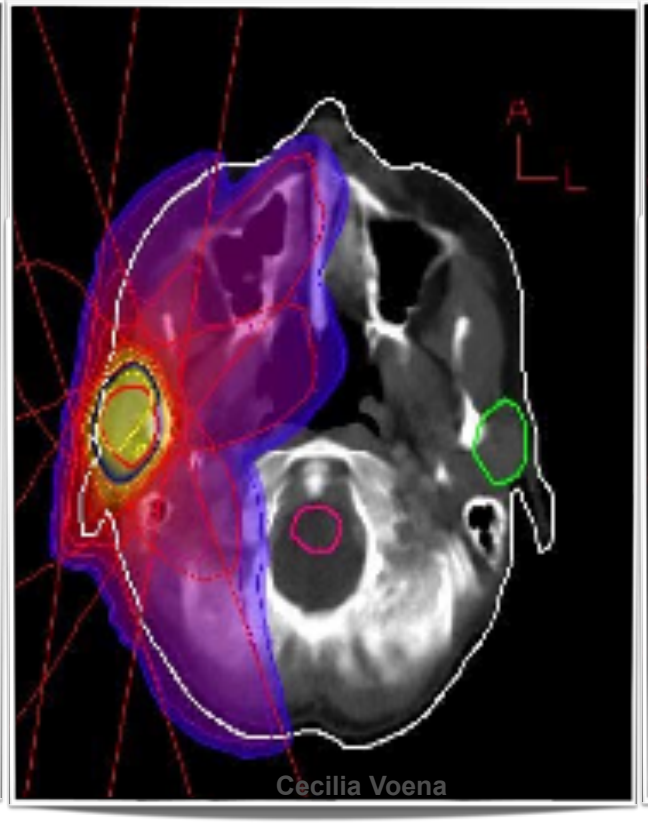
Radiotherapy vs Hadrontherapy

- Combination of many radiation fields allows improving the performances for localized tumors and preserve healty tissues
- The combination of few proton fields is extremely powerful in preserving healty tissues

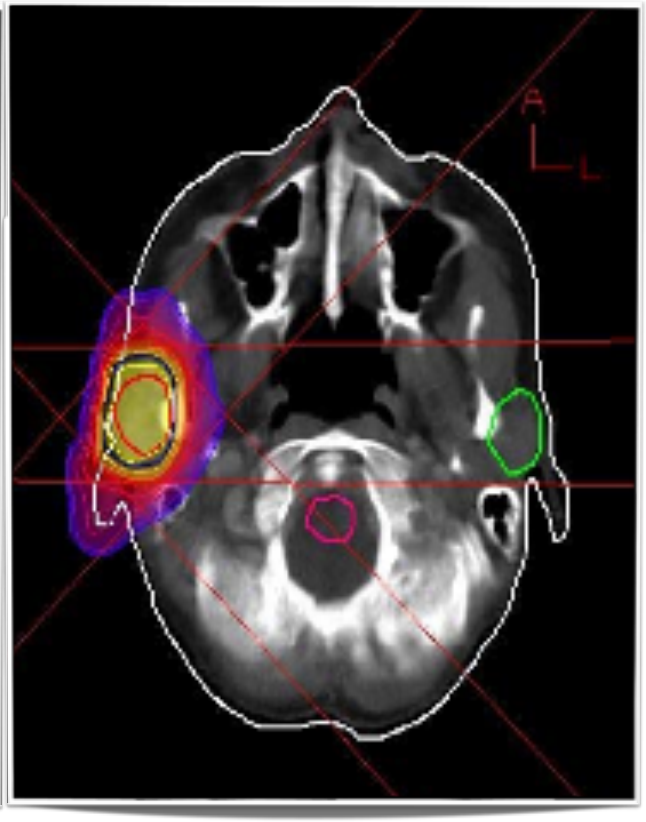
Photon 2 fields



Photon 5 fields



Proton 3 fields

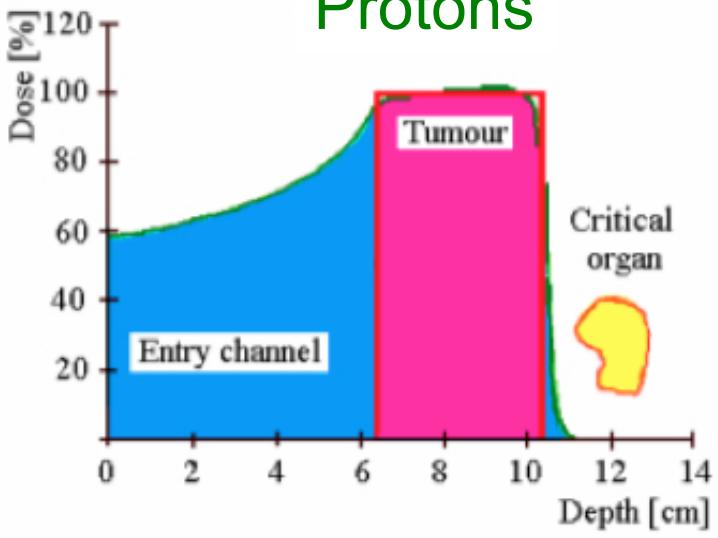


Proton vs Carbon beams

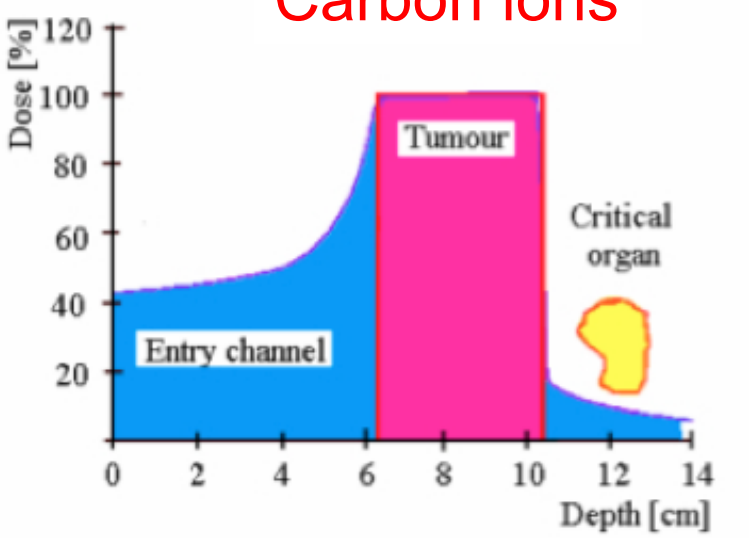
- Protons suffer more multiple scattering but are less affected by fragmentation

- Carbon ions have reduced multiple scattering but more fragmentation. More efficient in killing cells (higher ionization density), more effective in hypoxic tumors.
  Drawback: need bigger facilities

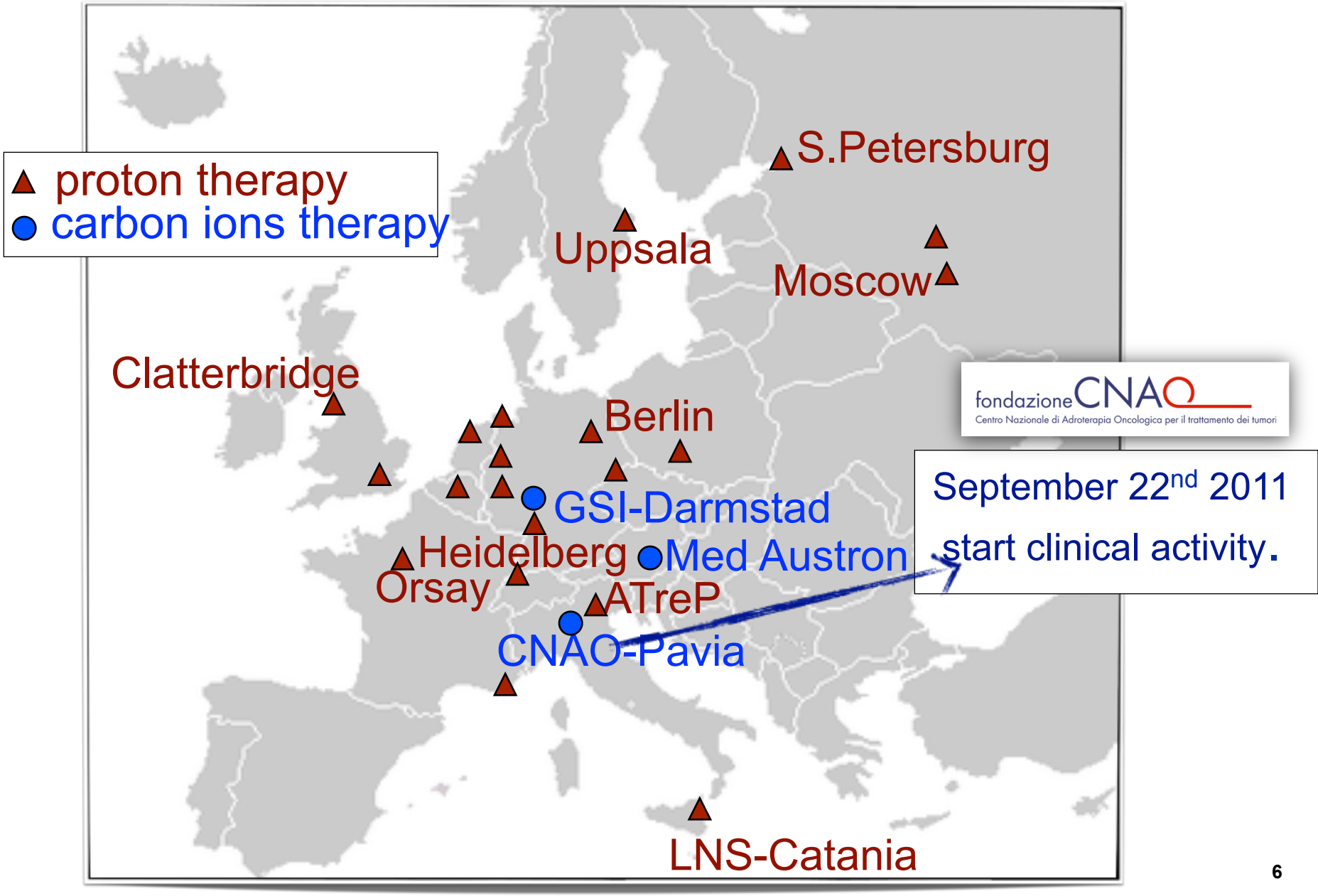
Protons



Carbon ions



Particle Theraphy in Europe



Dose monitoring in particle therapy

- Together with improving precision of hadrontherapy in tumor irradiation comes the necessity of new dose release monitoring technique:

- cannot exploit trasmitted beam as in radiotherapy

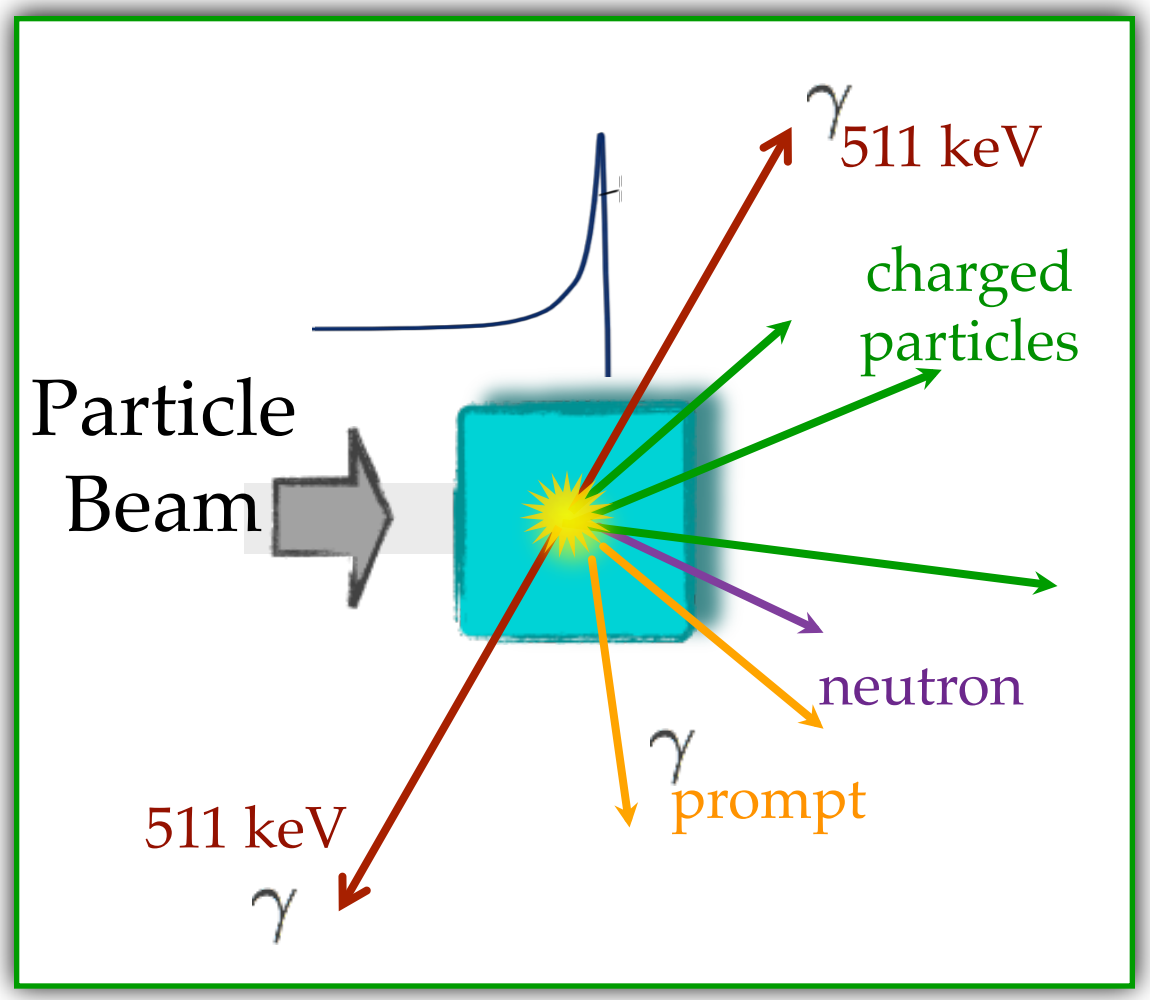
- can exploit secondary particles produced in the interactions of the beam within the patient

- stringent requirements due to space constraints in treatment room

- should provide feedback "on-line"

Dose monitoring in particle therapy

Point production is correlated with Bragg peak!



β^+ emitters results in 2 back-to-back photons with E=511 keV

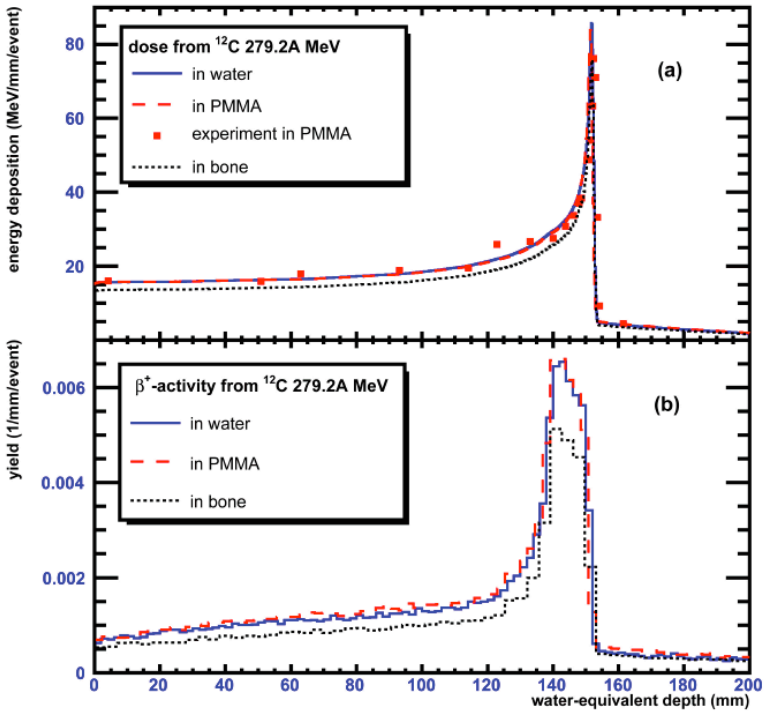
prompt photons emitted in nuclear de-excitation E<10 MeV

charged particles(p) produced in nuclear fragmentation E<200MeV

γ from β^+ emitters

- β^+ produced in de-excitation of isotopes (^{11}C,^{15}O..)
- Can use PET (Positron Emission Tomography) technique to detect the two photons

The activity emission shape is correlated with dose ditribution

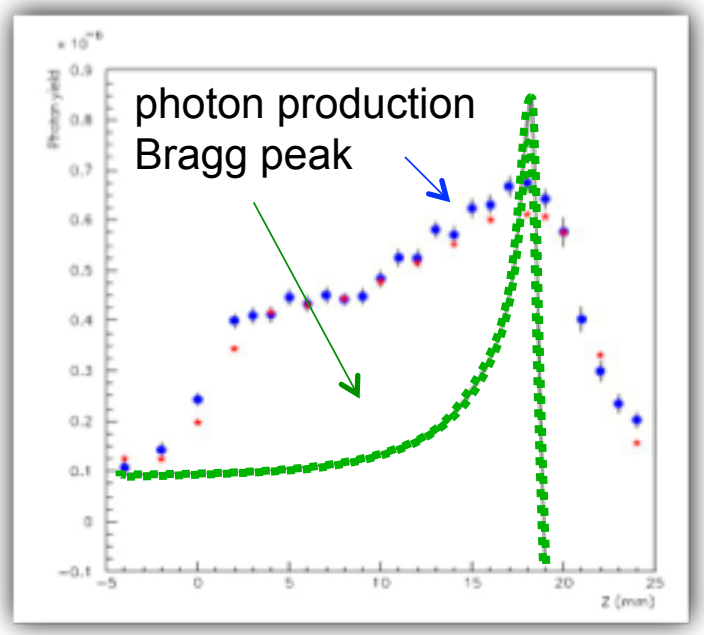


Geant simulation

- Spatial constraints in treatment room prevent standard PET
- Offline PET can be used, but metabolic wash out deteriorates resolution
- In-beam solutions under R&D

Prompt Photons

- Advantage: more abundant than other secondaries
- Disadvantages:
  - High background due to neutrons
  - Not easy back-pointing γ direction, can take profit by SPECT technique but energy range (1-10MeV) not favorable. R&D in progress



A.Ferrari and FLUKA collaboration
(73 MeV/u C ion)

- Flux and spectrum measured at different energy and angle e.g:
  200MeV/u ^{12}C beam (GSI, Germany)

$$\Phi^{\gamma}(E>2MeV@60^{o}) = (6.59 \pm 0.22_{stat} \pm 1.07_{syst}) \times 10^{-3}\, sr^{-1}$$

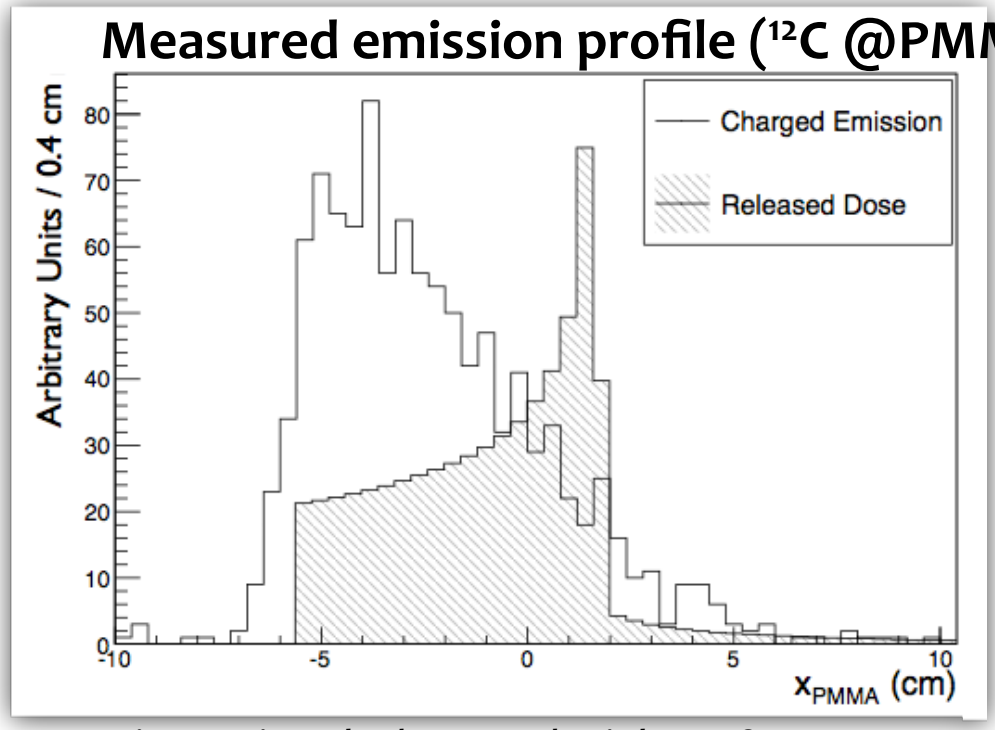
$$\Phi^{\gamma}(E>2MeV@90^{o}) = (7.39 \pm 0.38_{stat} \pm 1.27_{syst}) \times 10^{-3}\, sr^{-1}$$

$$\Phi^{\gamma}(E>2MeV@120^{o}) = (5.02 \pm 0.24_{stat} \pm 1.34_{syst}) \times 10^{-3}\, sr^{-1}$$

Under preparation: "Precise measurement of prompt photon emission from 220 MeV/u carbon ion beam irradiation"

Charged particles

- Protons, deutons, tritium...
- Advantages:
  Detection efficiency very high and can be easily backtracked
- Disadvantages: there is an escape threshold (50-100MeV)
  they are not so many especially for proton beams



L. Piersanti et al. Phys. Med. Biol. 59 1857

GSI measurement

$$\Phi^{p}(\Omega_{LYSO})_{\theta=60^{o}} = (8.78 \pm 0.07_{stat} \pm 0.64_{syst}) \times 10^{-3}\, sr^{-1}$$

$$\Phi^{d}(\Omega_{LYSO})_{\theta=60^{o}} = (3.71 \pm 0.04_{stat} \pm 0.37_{syst}) \times 10^{-3}\, sr^{-1}$$

$$\Phi^{t}(\Omega_{LYSO})_{\theta=60^{o}} = (0.91 \pm 0.01_{stat} \pm 0.21_{syst}) \times 10^{-3}\, sr^{-1}$$

$$\Phi^{p}(\Omega_{LYSO})_{\theta=90^{o}} = (1.83 \pm 0.02_{stat} \pm 0.14_{syst}) \times 10^{-3}\, sr^{-1}$$

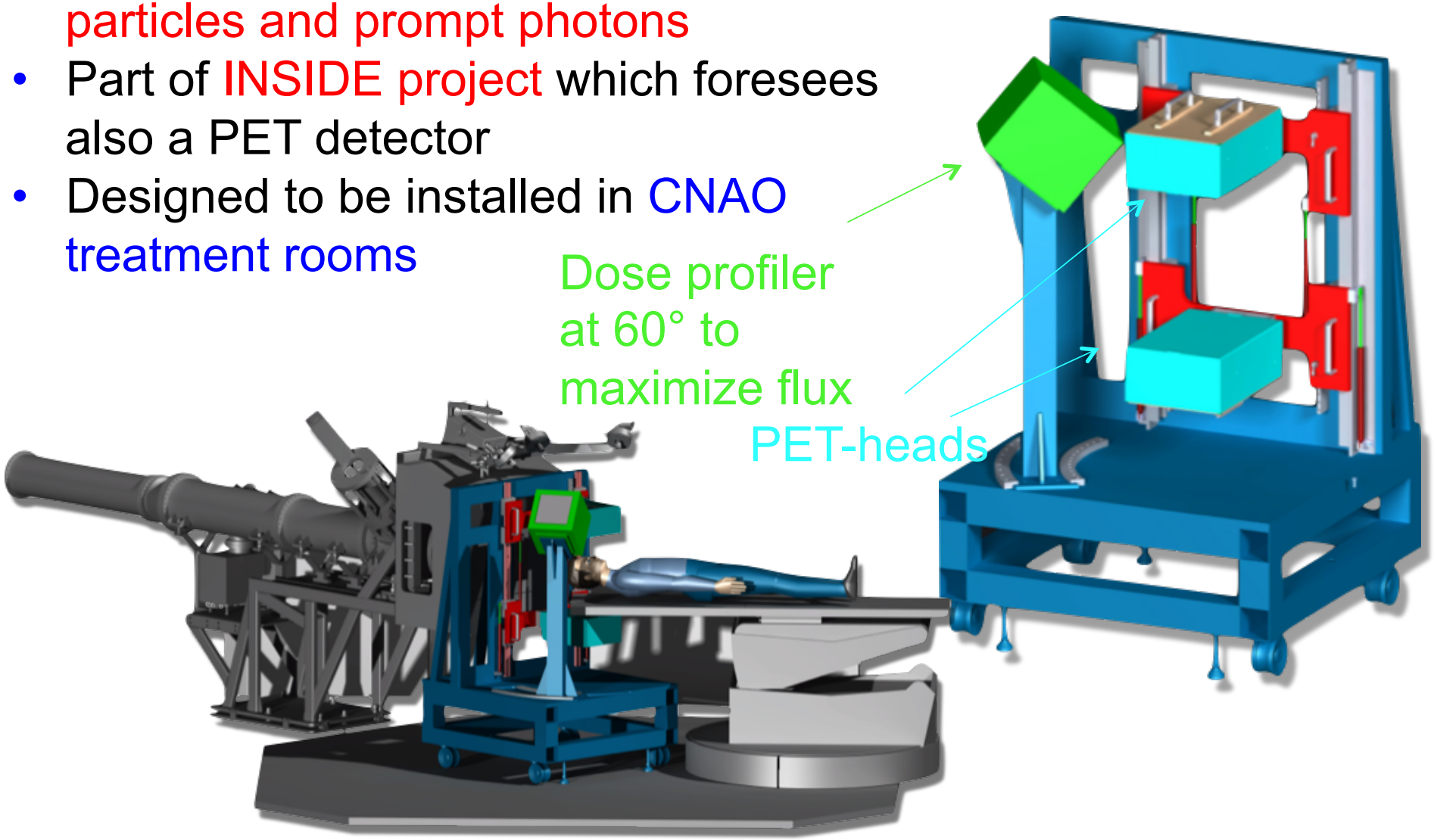
$$\Phi^{d}(\Omega_{LYSO})_{\theta=90^{o}} = (0.78 \pm 0.01_{stat} \pm 0.09_{syst}) \times 10^{-3}\, sr^{-1}$$

$$\Phi^{t}(\Omega_{LYSO})_{\theta=90^{o}} = (0.128 \pm 0.005_{stat} \pm 0.028_{syst}) \times 10^{-3}\, sr^{-1}$$

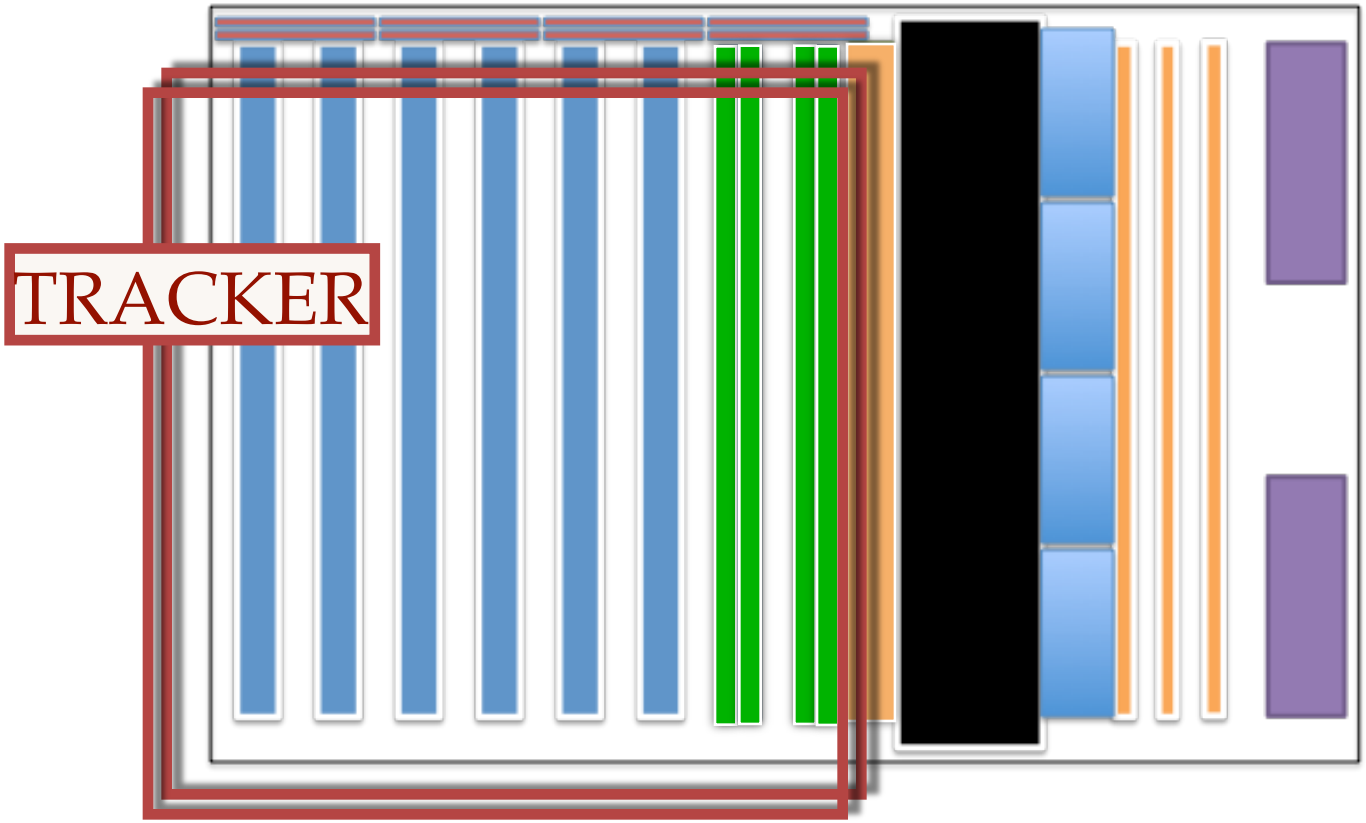
L.Piersanti et al. *"Measurement of charged particles yields from PMMA irradiated by 220 MeV/ u ^{12}C beam"* **PMB 59 (2014) 1857-1872**

The dose profiler project

- Dual-mode detector for measurement of both charged particles and prompt photons
- Part of INSIDE project which foresees also a PET detector
- Designed to be installed in CNAO treatment rooms

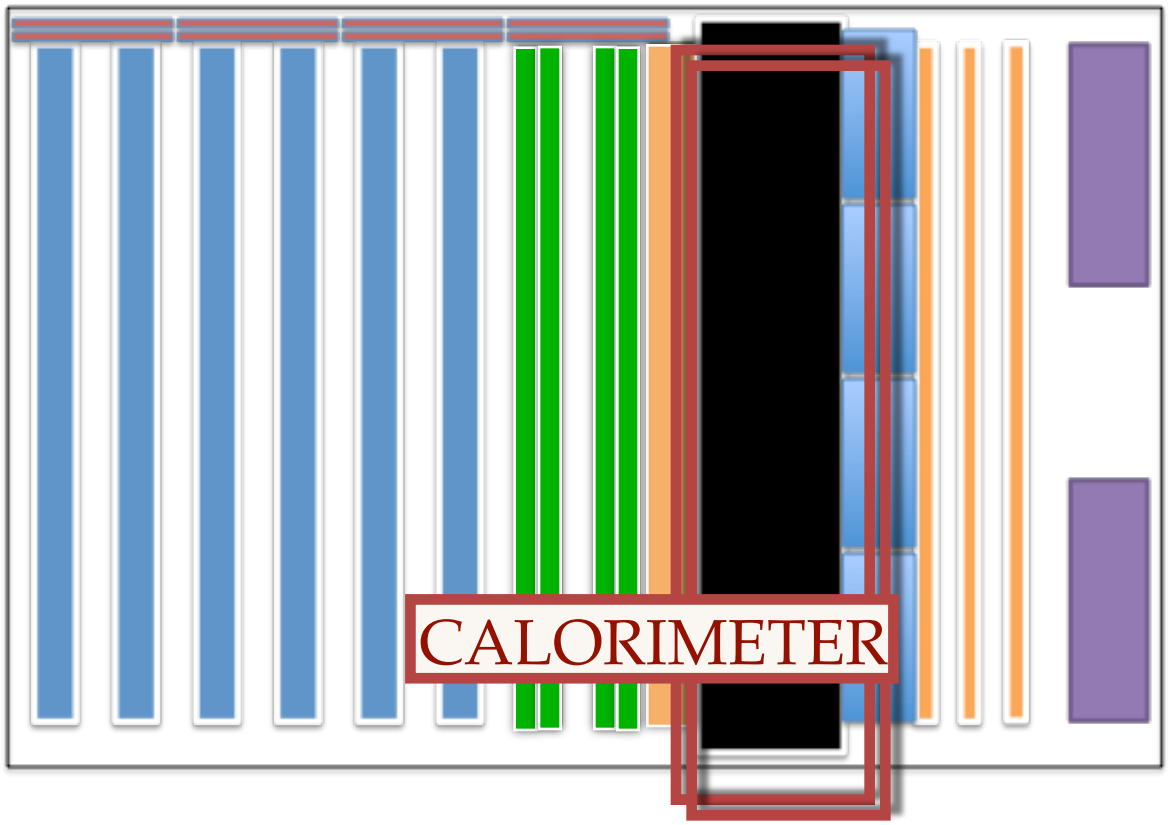


The dose profiler design



- 6 fiber planes X+Y BFC-12 scintillator 0.5mm thick with 2cm pitch, area of 19x19cm^2 , readout with SiPM
- 2 pairs of plastic scintillators (electron absorber) 6mm thick (each) with SiPM readout

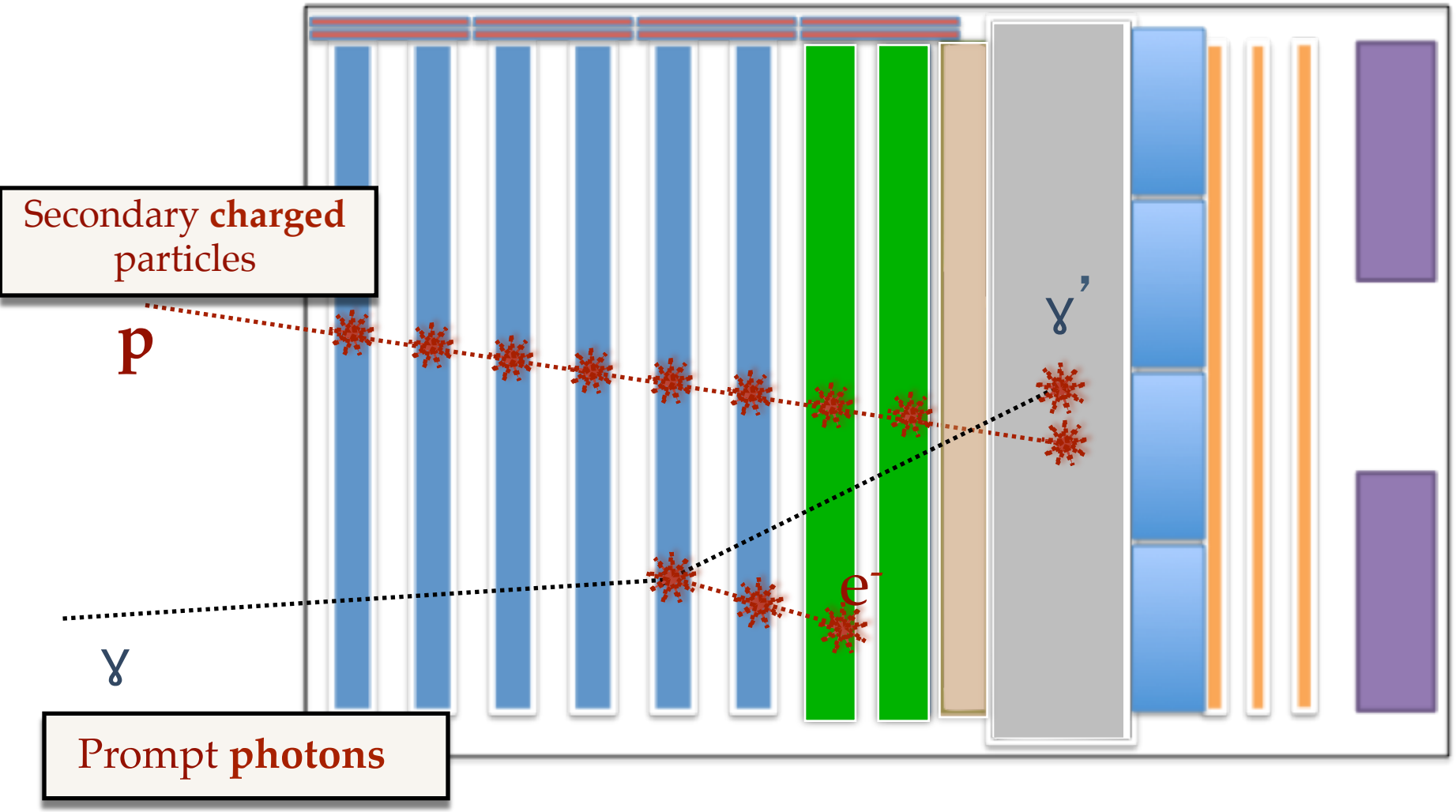
The dose profiler design



- 4x4 LYSO crystals matrices, 16x16 pixel (3mmx3mmx2cm) read out by multianode PMTs

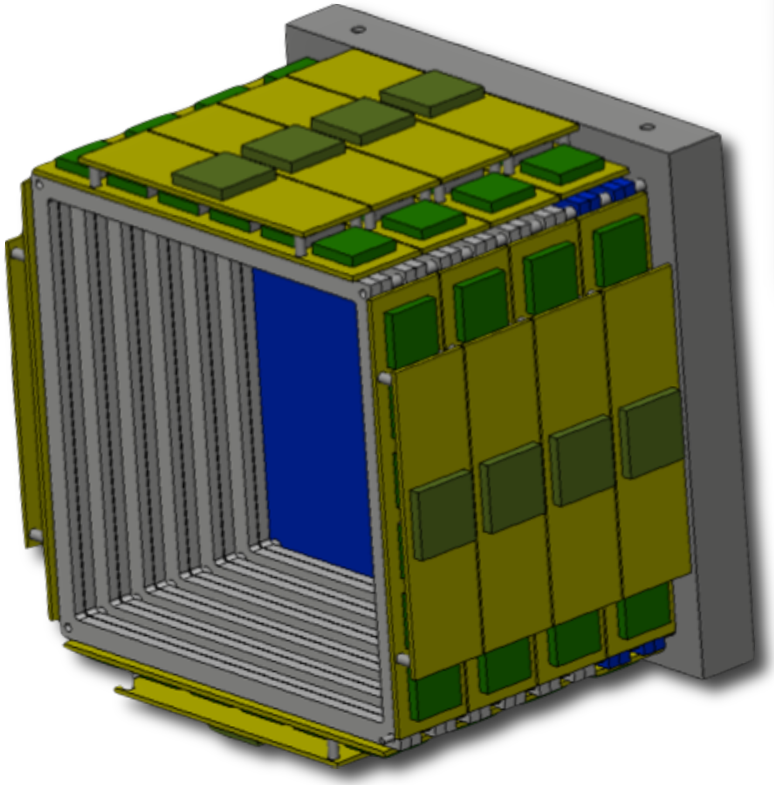
Dose profiler principle

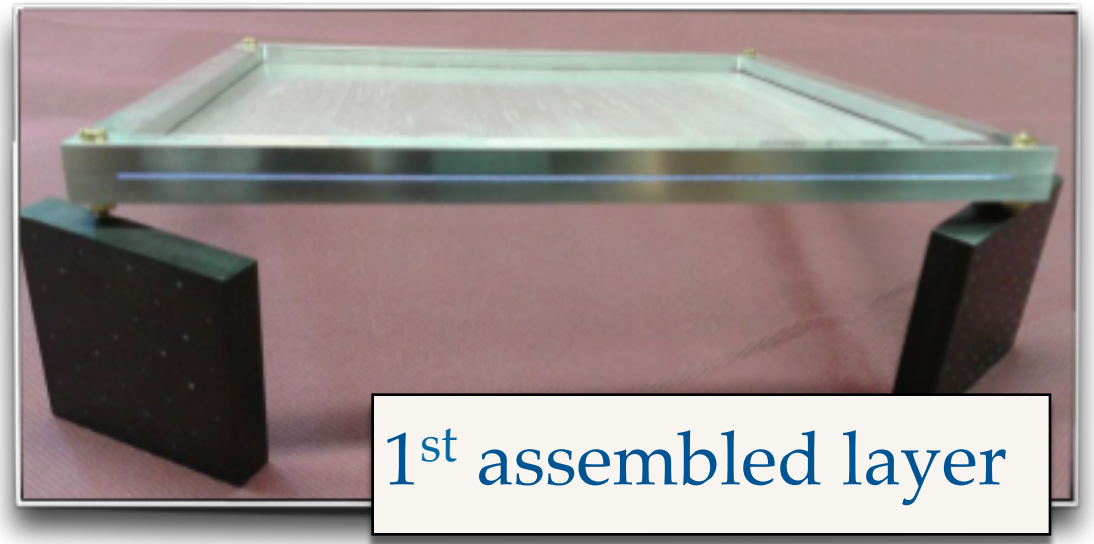
- Charged particles cross all layers
- Prompt photons back-traced by reconstructing Compton interaction



Dose profiler realization status

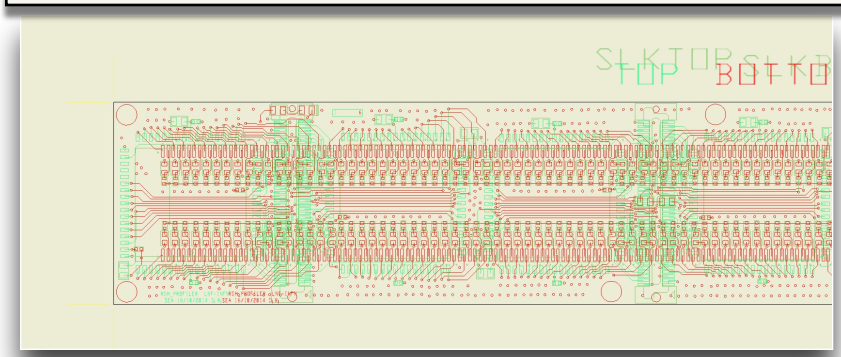
Mechanic structure





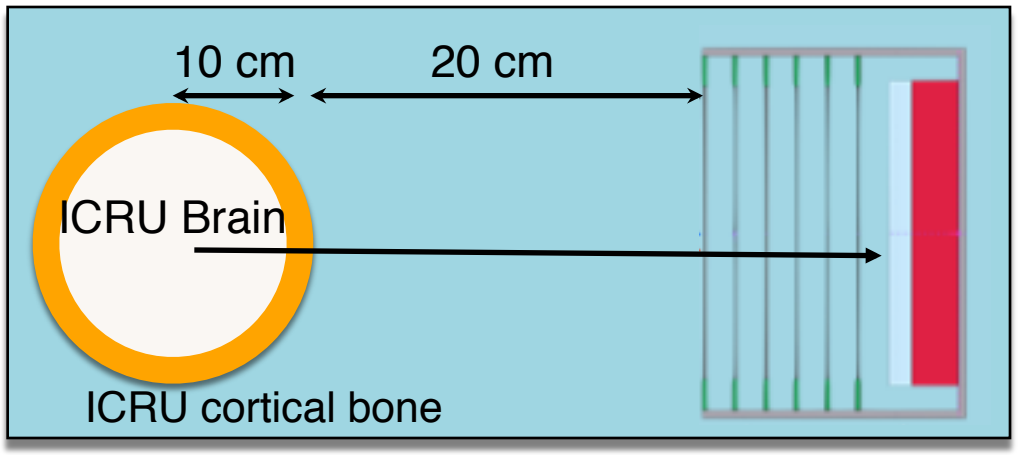
1st assembled layer

SiPM readout electronics



Complete simulation (FLUKA) and reconstruction software have been developed to optimize design and estimate perfomances

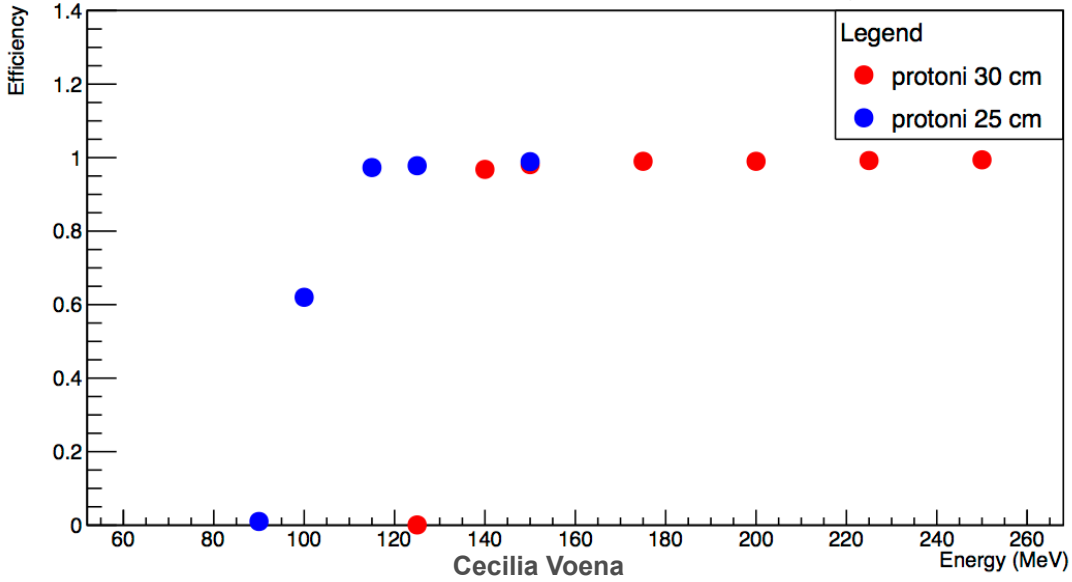
Charged particles reconstruction



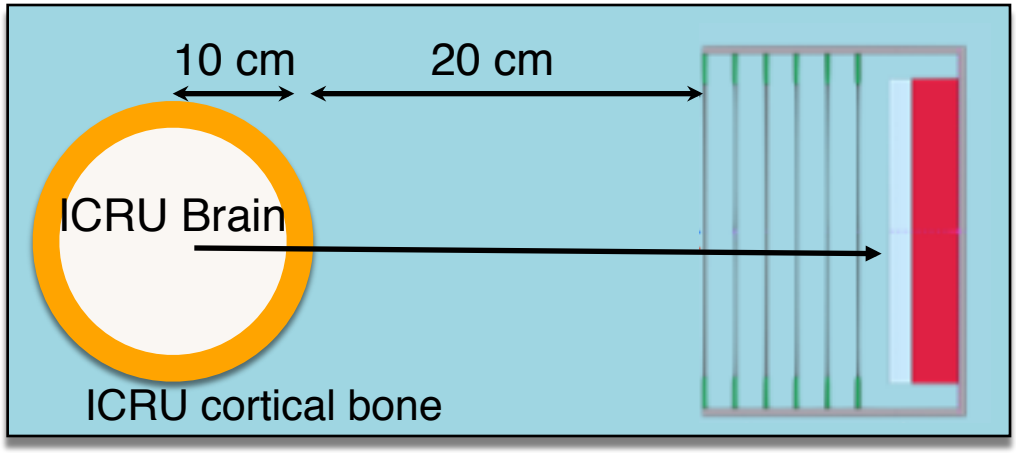
Simulation: protons of different energies and depths

E= 90-250 MeV
depth = 25cm or 30cm
from dose profiler

Reconstruction efficiency



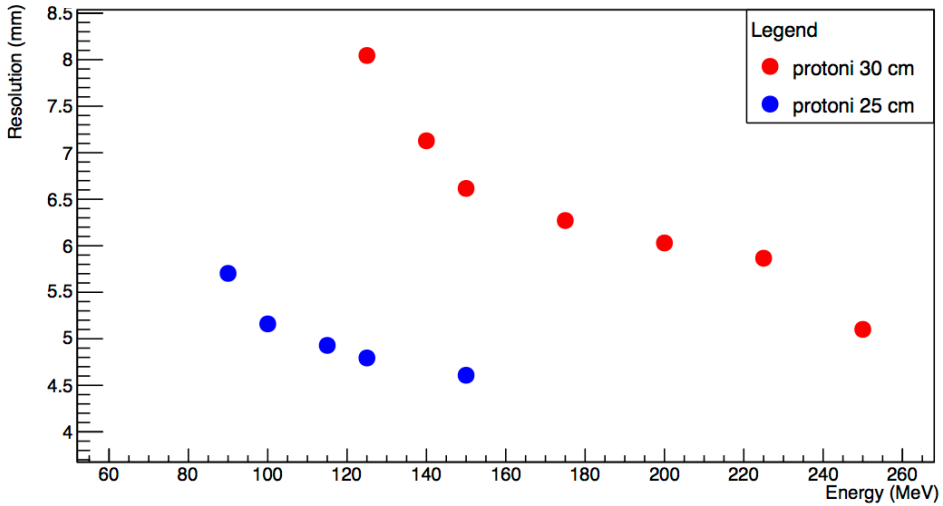
Charged particles reconstruction



Simulation: protons of different energies and depths

E= 90-250 MeV
depth = 25cm or 30cm
from dose profiler

Spatial resolution on point of origin
(single proton)

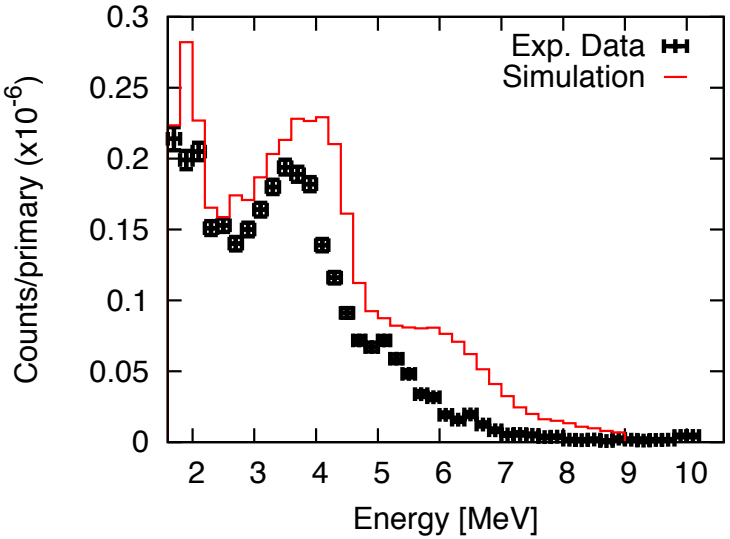


Preliminary

Extrapolating to a realistic treatement (for a single slice, dose= 2Gy/fraction) the expected global resolution is ~0.4mm

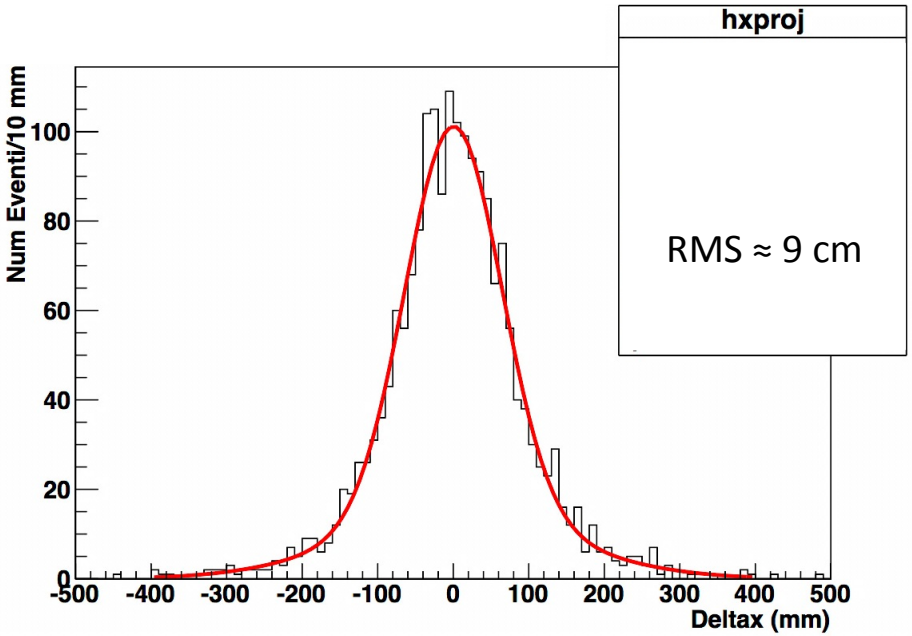
Prompt photon reconstruction

Simulation: prompt photons with measured spectrum isotropic in detector acceptance



Bellini et al. Nucl.Instrum.Meth. A745 (2014) 114-118

Spatial resolution on point of origin
(single photon)

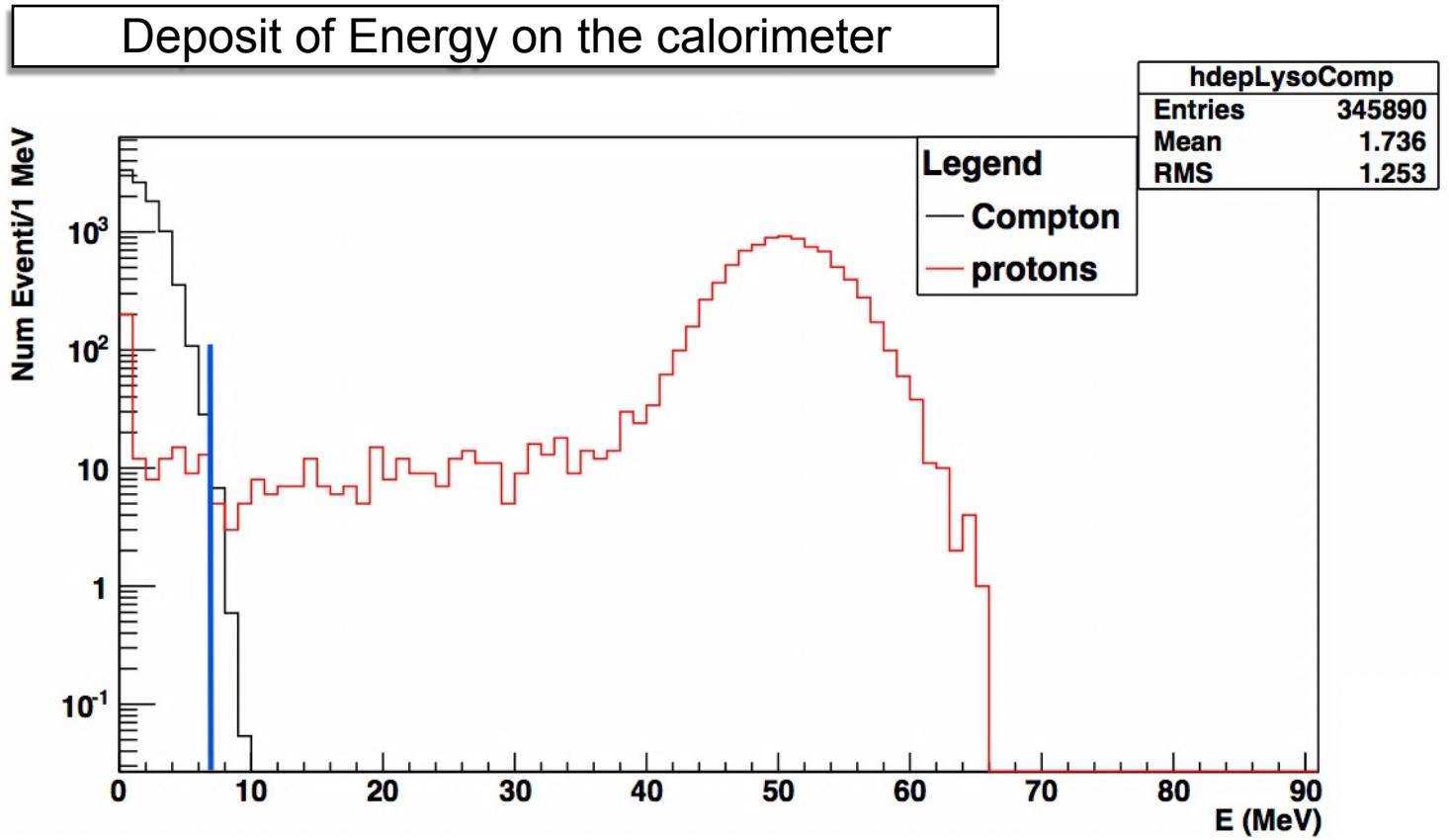


Preliminary

Expected resolution for a typical treatment ~8mm

Particle "identification"

- Exploit different energy release in the calorimeter



Conclusions

- Particle therapy is very effective in curing localized tumors (expecially radio-resistent tumors) preserving surrounding healty tissues
- On-line dose monitoring is curcial to improve performances:
- Secondary particles coming out from the patient can be exploited
- A dual-mode dose-profiler is under construction to detect prompt photons and charged particles (part of INSIDE project that includes also 2 PET heads)
- Test in treatment room at CNAO forseen end of 2016

Backup

Secondary particles: measurements

The **fluxes of secondary particles are largely unknown:**
MonteCarlo simulation not reliable => need of measurements

- PET Photons

  flux and profile for different energies:
  - 80 MeV/u ^{12}**C** beam
  - 102,125,144 MeV/u ^{4}**He** beam

- Prompt Photons

  flux and spectrum for different energies:
  - 80, 220 MeV/u ^{12}**C** beam
  - 50-300 MeV/u ^{16}**O** beam 60°, 90°,120°
  - 50-300 MeV/u ^{4}**He** beam

- Fragmentation (charged particles)

  flux and spectrum for different energies:
  - 80, 220 MeV/u ^{12}**C** beam 60°, 90°
  - 50-300 MeV/u ^{16}**O** beam 0°,5°,10°20°,30°
  - 50-300 MeV/u ^{4}**He** beam

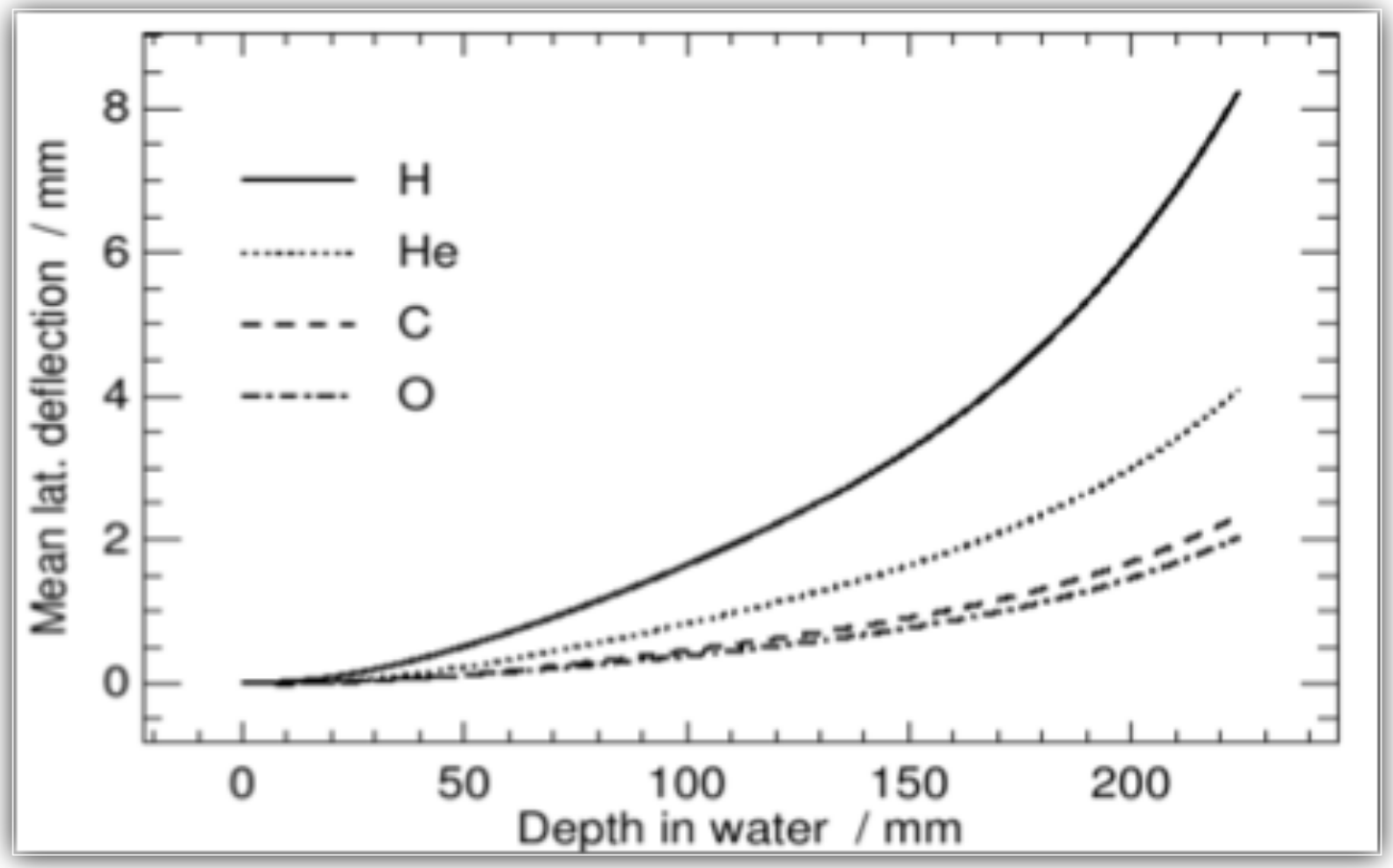
The INSIDE Project

PRIN MIUR
2010-2011
-2010P98A75

INFN RDH
project

Centro Fermi
project

INnovative Solutions for In-beam DosimEtry in Hadrontherapy


Mean lat. deflection / mm
8
6
4
2
0
H
He
C
O
0
50
100
150
200
Depth in water / mm