ICTR-PHE 2014

The INSIDE project

An integrated monitoring system for the on-line assessment of particle therapy treatment accuracy

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Geneve – 12th February 2014

The INSIDE project @CNAO

the INSIDE (Innovative Solutions for In-beam DosimEtry in hadrontherapy) project has the aim to build an in-beam, multimodal dose profiler for Hadrontherapy.

Mechanics and operation is optimized to be inserted in the CNAO work-flow-> realistic environment

The monitoring is based on the detection of different signal produced by the beam:

- Annihilation gammas from β^+ emitters (PET)
- Prompt charged secondaries (mainly protons)

Universita' di Pisa, Bari Politecnico, Universita' di Roma La Sapienza, Universita' di Torino, INFN -> 40 researchers

Duration 3 years from February 1st, 2013

INSIDE Project: synergies

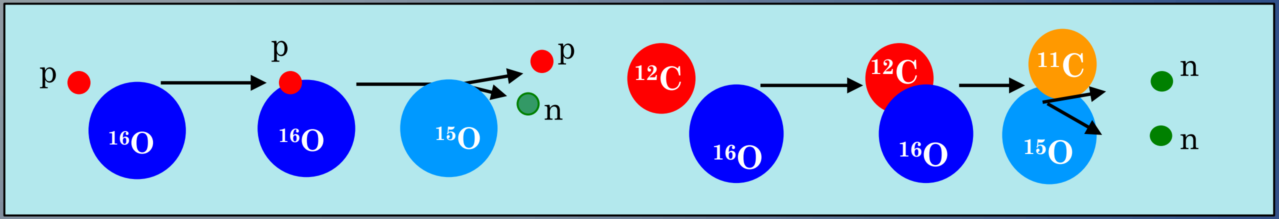
PRIN INSIDE project:
INnovative Solutions for In-beam DosimEtry in Hadrontherapy

CNAO

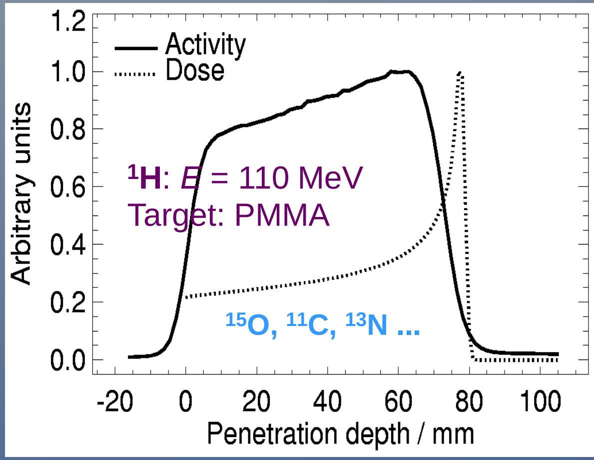
INFN RDH project:
Research & Developments for Hadrontherapy

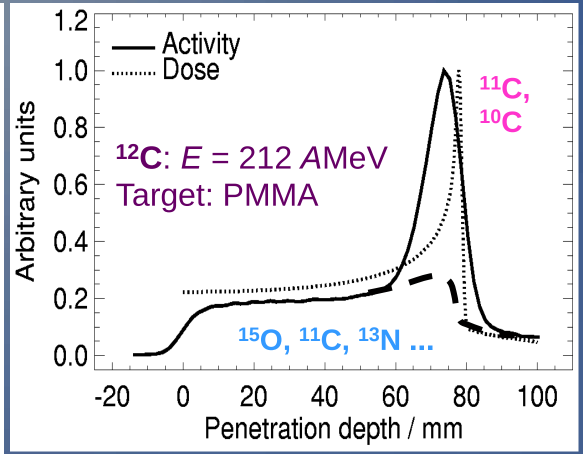
Centro Fermi project:
Innovative Non Invasive Imaging of Dose Release in Hadrontherapy

In-beam PET monitoring



J Pawelke et al., Proceeding: Ion Beams in Biology and Medicine (IBIBAM), 26.-29.09.2007, Heidelberg, Germany





A possible method for the control of the geometrical accuracy of the treatment is PET imaging

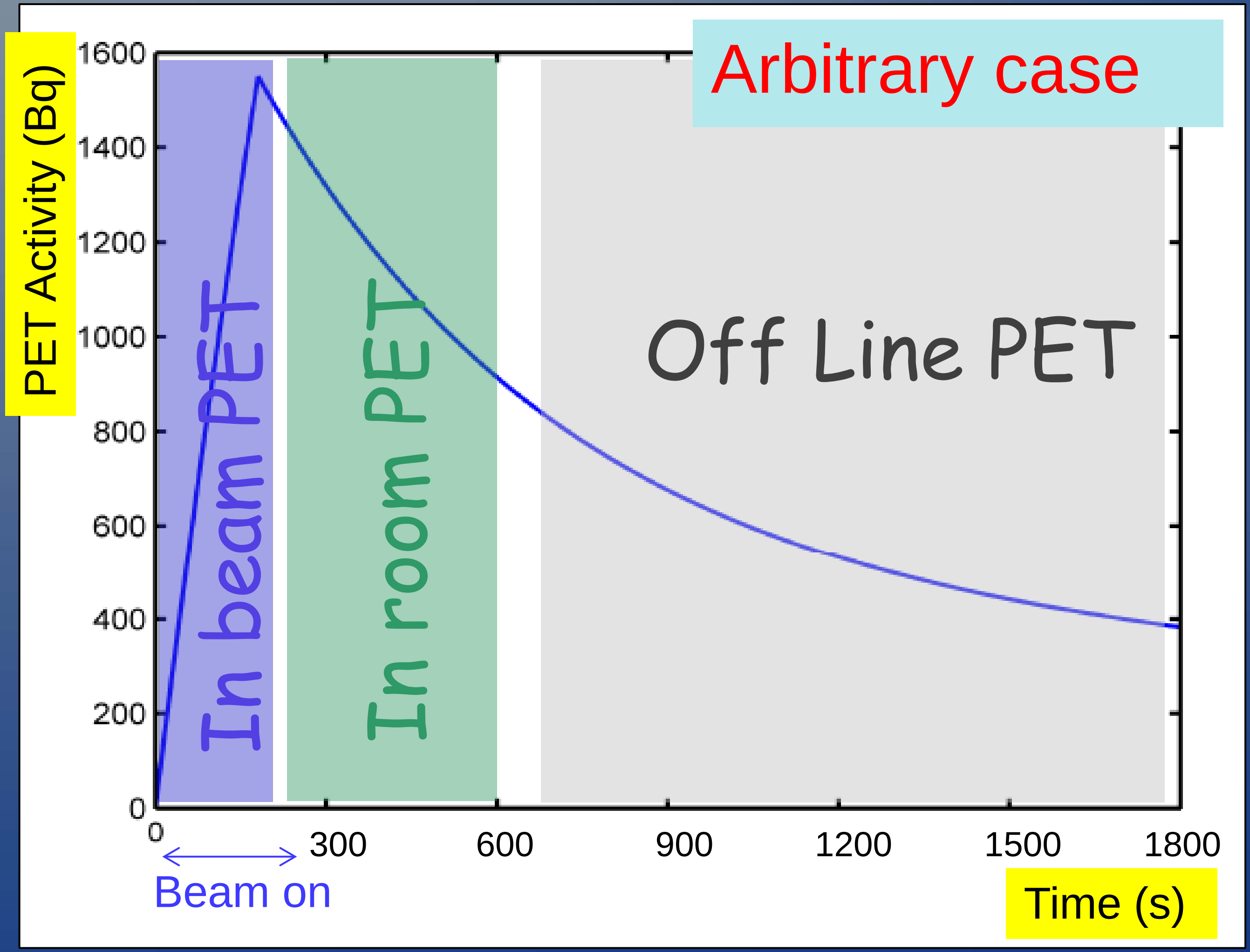
- ✓ Nuclear inelastic reactions between the hadron beam (both p & ^{12}C) and nuclei in tissue
- ✓ β^+ emitting isotopes are produced with short half-lives like
  - ^{11}C (20.3 min),
  - ^{13}N (9.97 min),
  - ^{15}O (2.03 min).

In-beam/in-room dedicated instruments are necessary to:

- Avoid data loss of very short living isotopes
- Avoid metabolic wash-out
- Avoid patient re-positioning

PET-based monitoring timing and specs

In-beam (& In room) PET data taking time is highly dependent from patient, number of fields, beam features, treatment center work-flow...



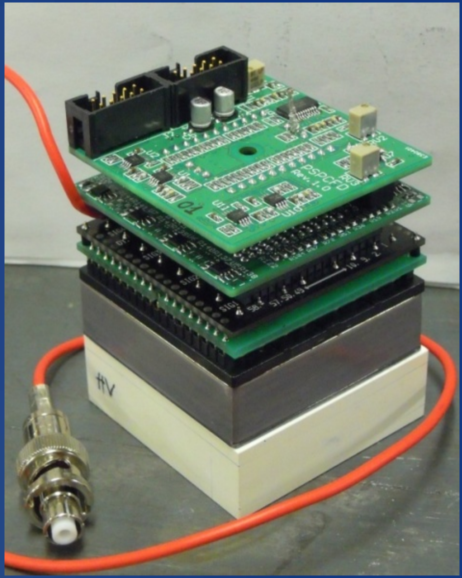
Detector acceptance should be such to collect enough statistics in the beam-on time

DAQ must sustain the beam background rate (at least inter-spill)

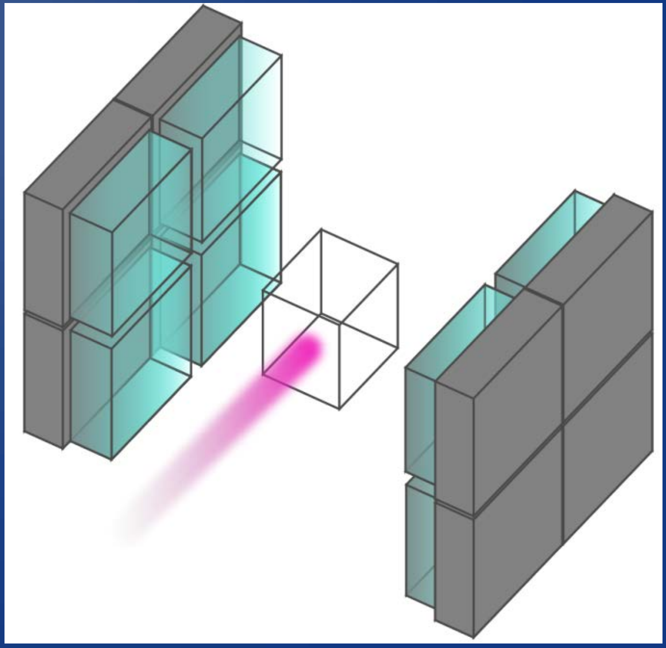
Reconstruction must not have biases from beam background

INSIDE PET System: Prototype and experiments

- DO-PET INFN monitoring system
- Two PET heads, each one 2x2 squared MA-PMT H8500 coupled to matrices of the same size of LYSO:Ce scintillating crystals ($2 \times 2 \times 18$ mm^3 pixel dimensions).
- One head total active area is 98x98 mm^2
- Maximum Likelihood Expectation Maximization reconstruction



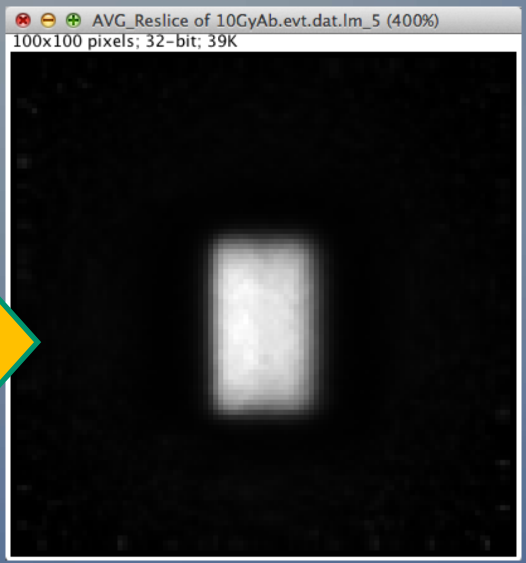
- Test on p and ^{12}C (LNS & CNAO)
- Different phantoms irradiated
- Dose tested from 1 to 20 Gy
- In-beam vs off-beam tests
- Activity determination
- Comparison with FLUKA

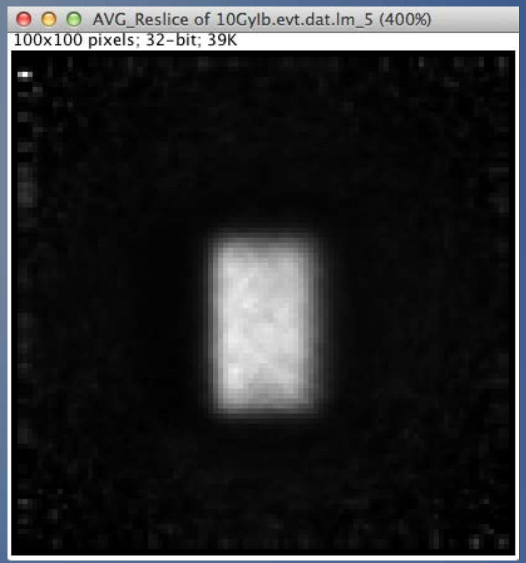


In-beam vs off-beam β^+ activity

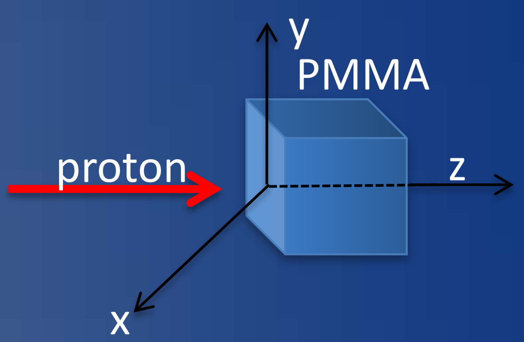
Off-beam: 12’

In-beam: 3’

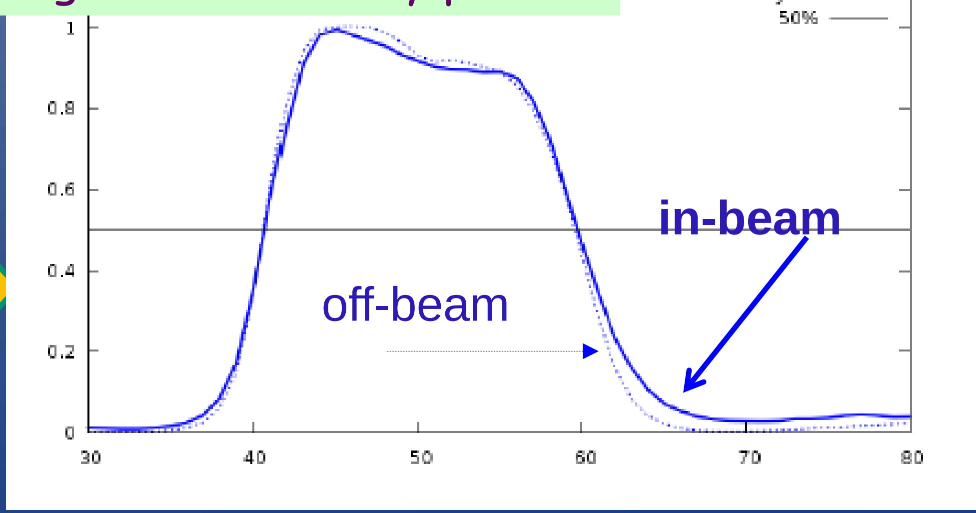




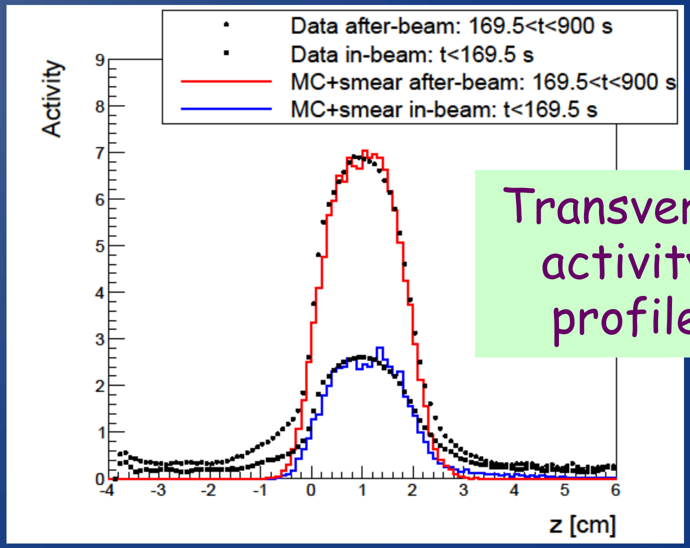
CATANA: 62 MeV proton beam on PMMA off-beam and in-beam acquisition



Longitudinal activity profile



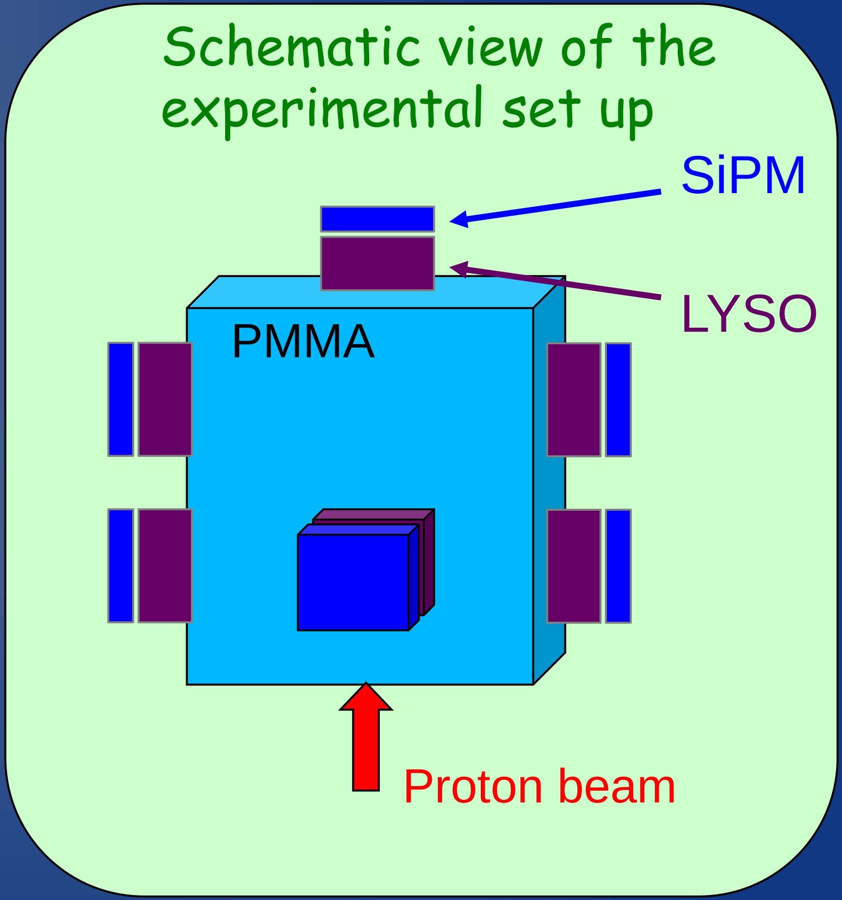
Transverse activity profile



In-beam test of PET DAQ prototype

INSIDE is designed to exploit single crystal trigger (β^+ coincidences made at 2nd level). We tested the DAQ operation at the irradiation condition rate.

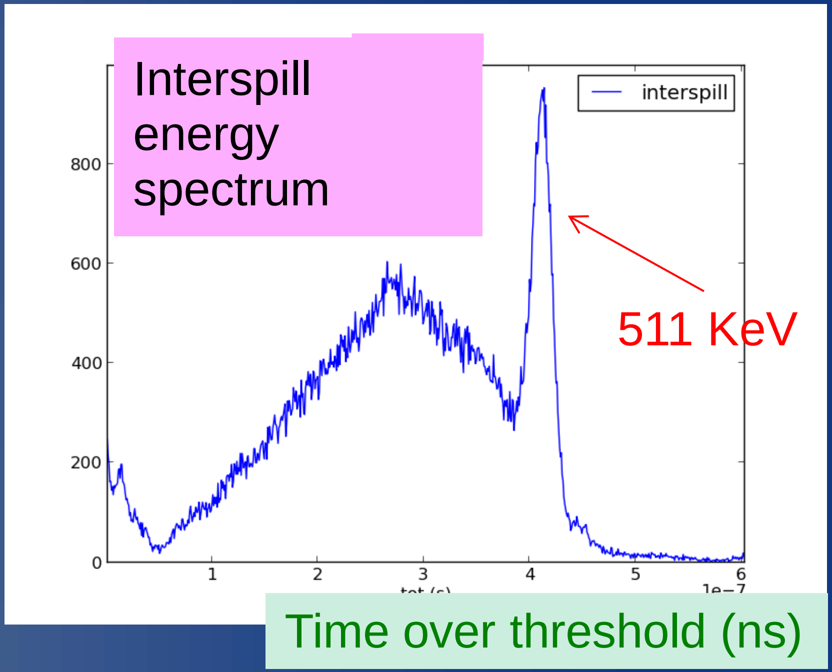
- ✓ LYSO crystal 3 x 3 x 10 mm^3
- ✓ RGB SiPM from AdvanSid 3x3 mm^2
- ✓ Front-end ASIC:TOFPET from LIP Portugal/INFN Torino, developed within FP7 ENDOTOFPET e PICOSEC
  - 64 input channels
  - 100 kHz/chn
  - Dyn range 200 pC
  - SNR 20 dB
  - Time resolution 500ps FWHM
  - Power consumption 10 mW/chn

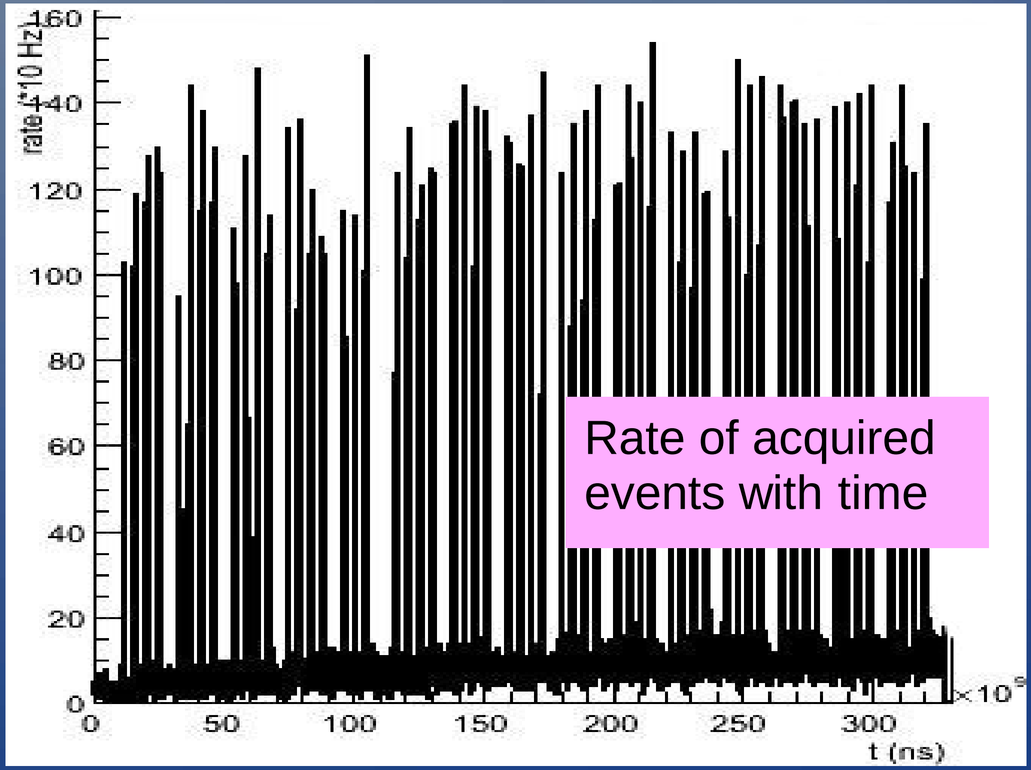


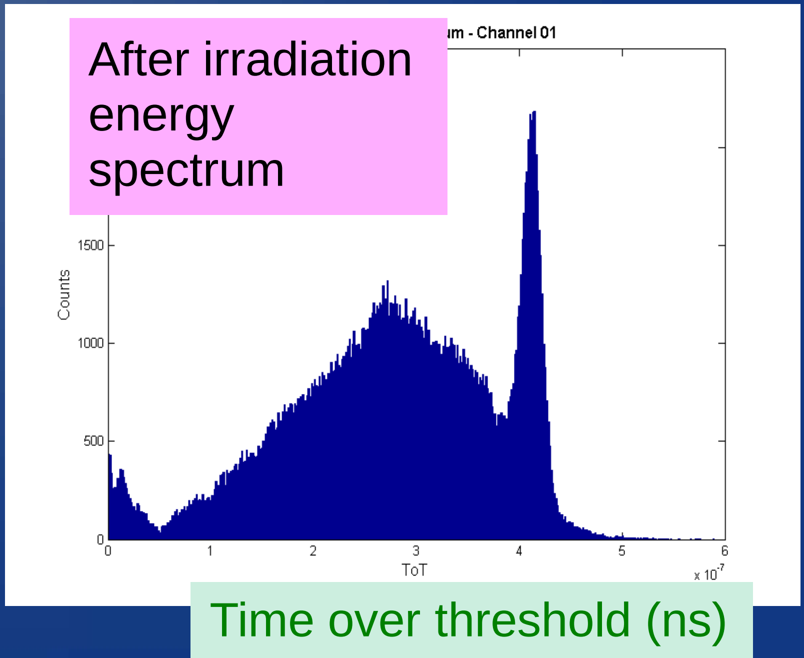
The LYSO crystals in contact with PMMA phantom (5 x 5 x 7 cm^3)

DAQ rate and single rate spectrum

- ✓ No dead time saturation observed during the spill
- ✓ No energy spectrum distortion observed off-beam vs inter-spill







HT monitoring vs charged particles

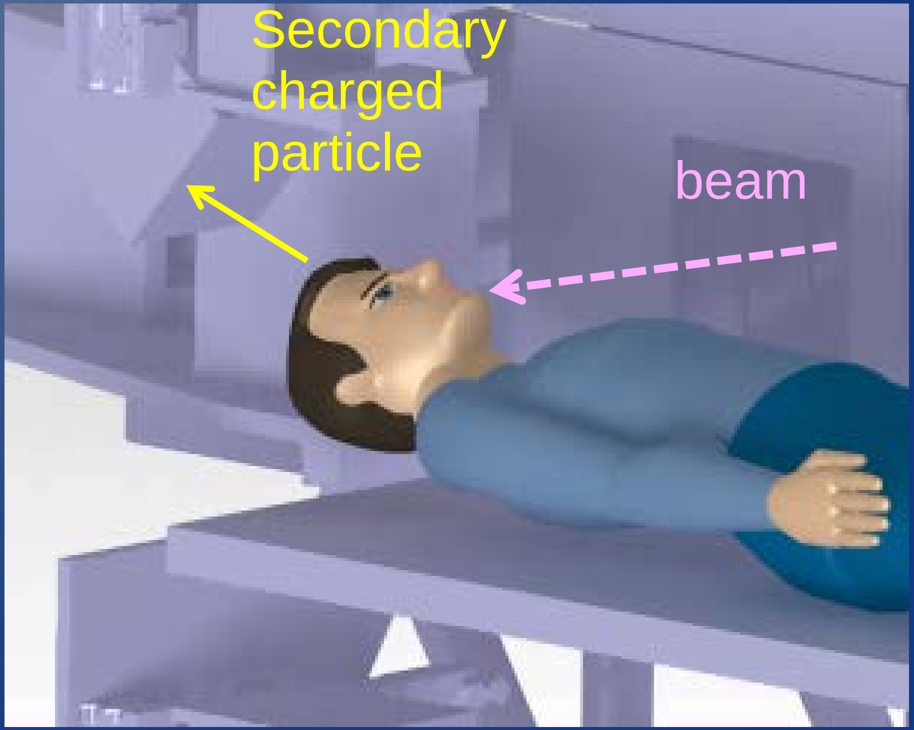
Agodi *et al* 2012
PMB **57** 5667
Gwosch et al2013
PMB ***58*** 3755

Secondary charged particles produced by the beam and escaping the patient (mainly protons) have several nice features:

- The detection efficiency is almost one
- Can be easily back-tracked to the emission point-> can be correlated to the dose release profile & Bragg Peak position

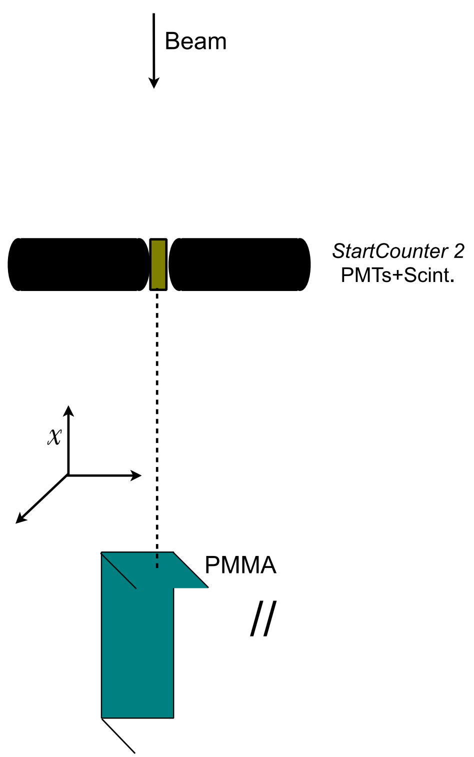
BUT…

- They are not so many for ^{12}C, few for protons, in particular at large angle wrt the beam direction.
- Energy threshold to escape ~ 100 MeV
- They suffer multiple scattering inside the patient

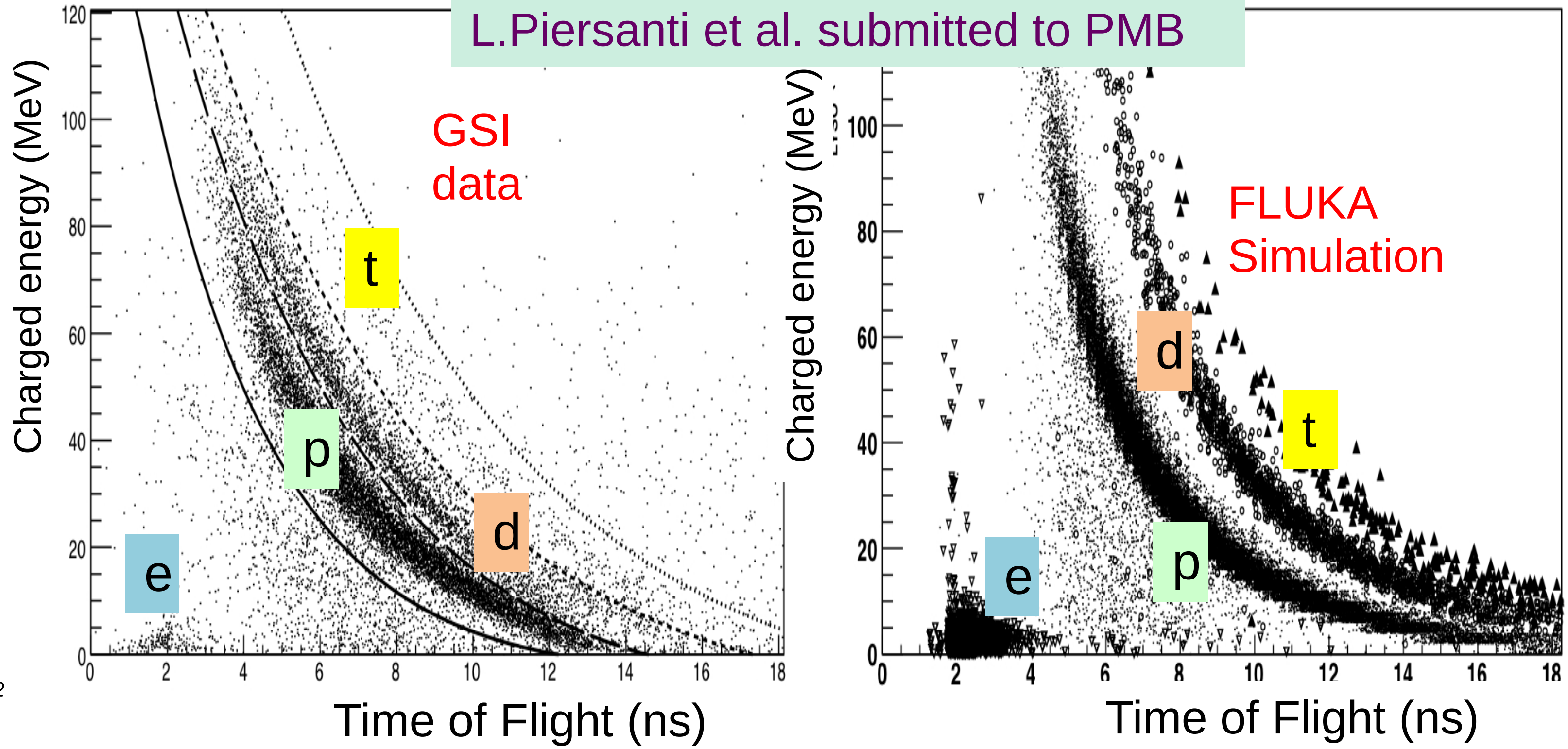


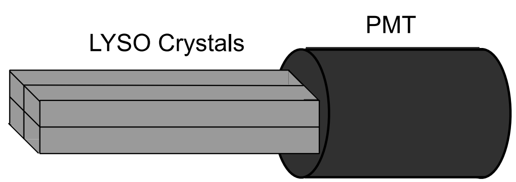
Charged secondaries at 90^0 from ^{12}C beam

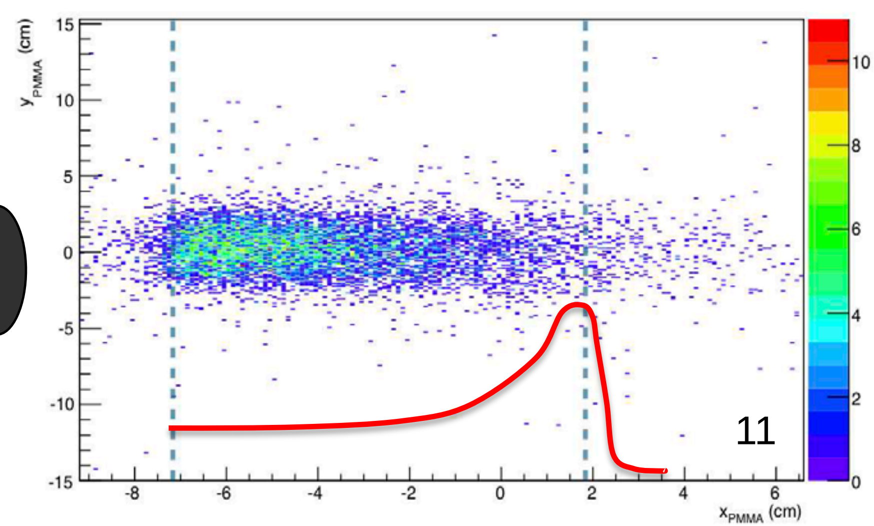
Charged secondaries from PMMA target on 220 AMeV ^{12}C beam at GSI. Flux measured at 90^0 wrt beam



L.Piersanti et al. submitted to PMB





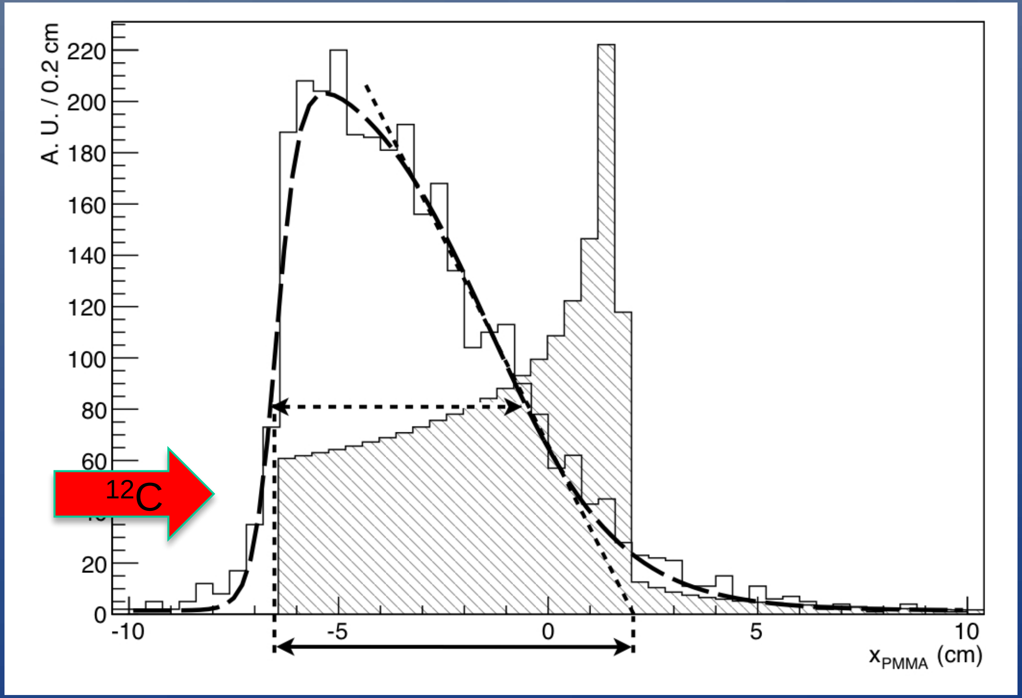


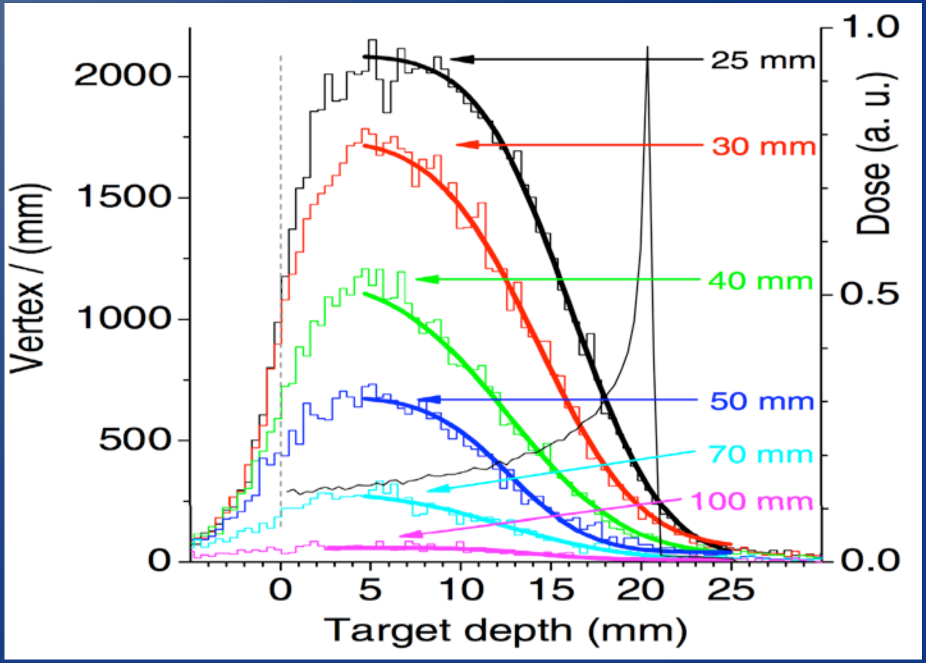
Fragmentation & dose monitoring

The emission point distribution of 100-150 MeV secondary protons provides info on the BP position. In particular this can be exploited for ^{12}C beam

Measured emission distribution shape of protons as detected outside a 5 cm thick PMMA at 90^0 wrt the direction of 220 AMeV ^{12}C beam
L. Piersanti et al submitted to Phys. Med. Biol

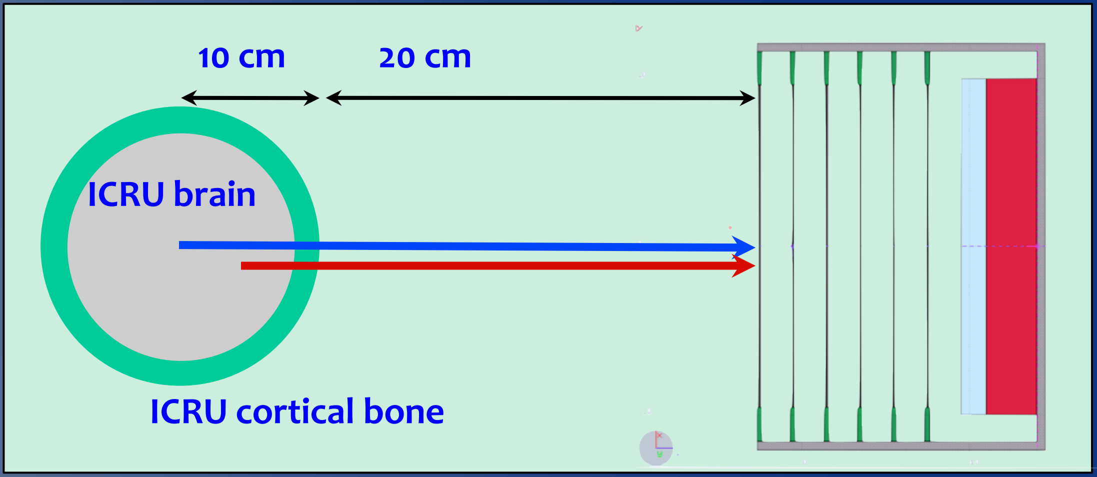
Simulated emission distribution shape of protons as detected ouside different PMMA thickness at 30^0 wrt the direction of 95 AMeV ^{12}C beam
E. Testa et al Phys. Med. Biol. 57 4655





Efficiency and resolution on emitted protons

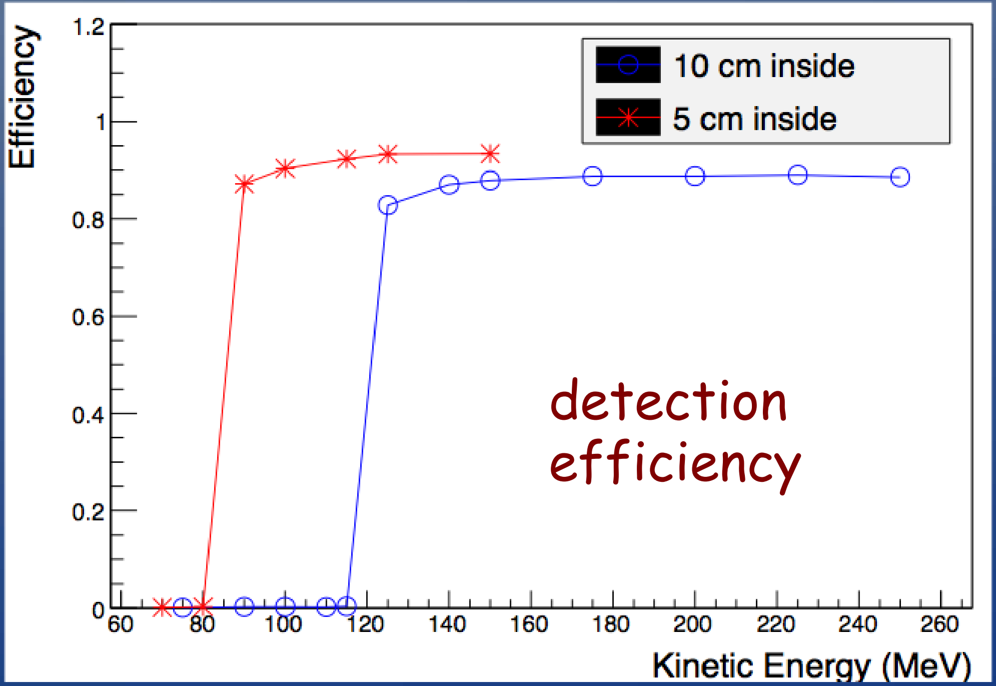
Simulation of a "spherical head" with ICRU materials, with proton source placed at different depths: 10 cm and 5 cm

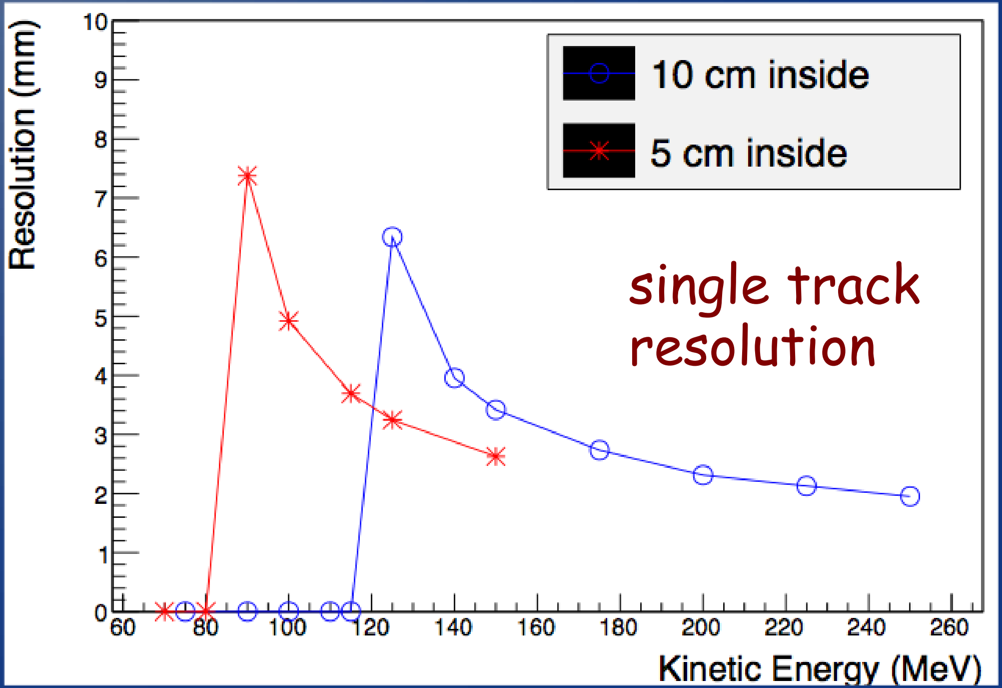


Low detection eff for emission near BP (low energy protons)

M.S. in the patient rules out need for high resolution devices

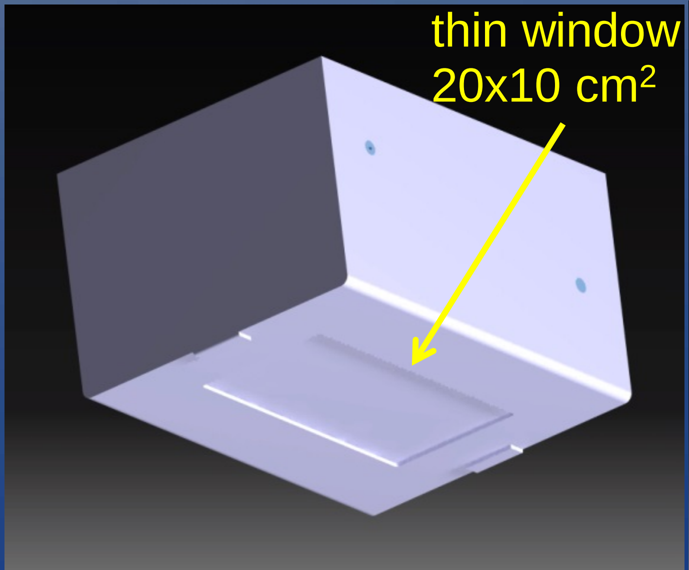
FLUKA sim. of tracker made of 6 planes of 500 μm XY sci fi

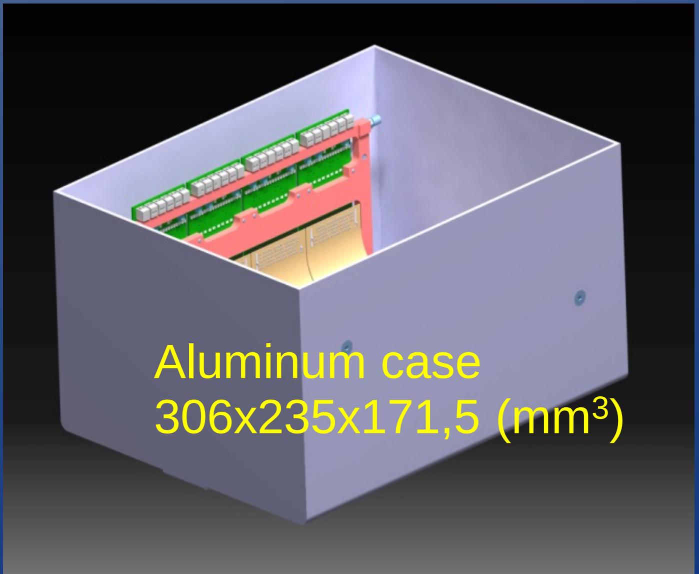


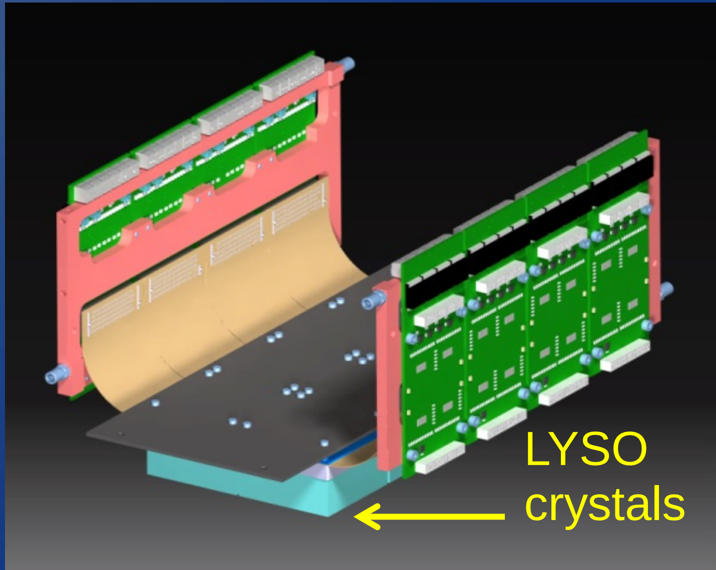


The INSIDE PET detectors

- Two planar panels each 10 cm x 20 cm^2 wide. Each panel will be made by 2 x 4 detection modules (scalable)
- Each module is composed of a pixelated LYSO scintillator matrix 16 x 16 pixels, 3x3 mm^2 crystals, 3.1 mm pitch, for a total sensitive area of 5x5 cm^2
- One SiPM array (16x16 pixels) is coupled one-to-one to each LYSO matrix
- DAQ sustains annihilation and prompt photon rates during the beam irradiation, Each crystal acquired as single trigger

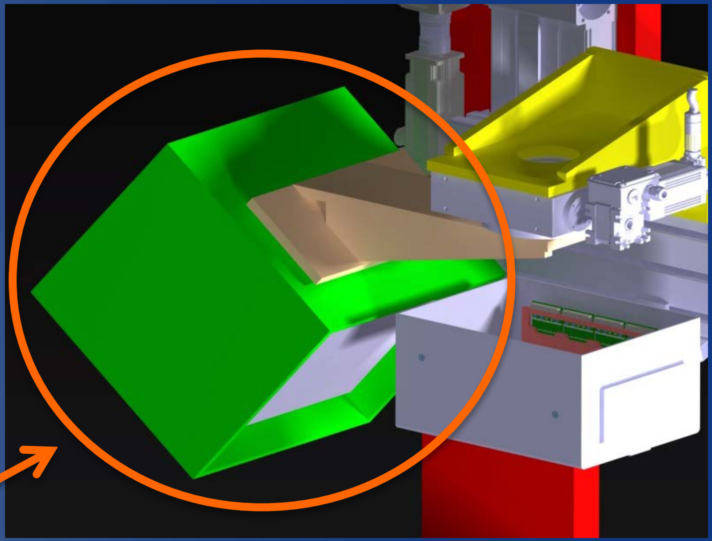


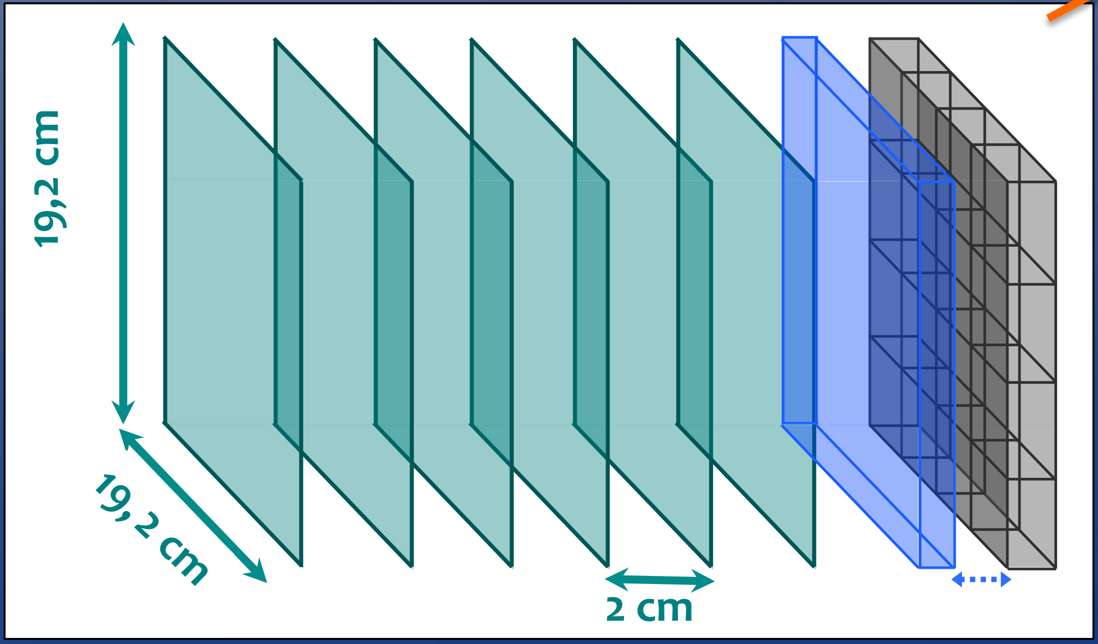




The INSIDE charged tracker

- ✓ 6 XY planes with 2 cm spacing. Each plane made of 2 stereo layers of 192 0.5x0.5 mm^2 square scintillating fibers
- ✓ 2x0.5 mm squared fibers read out by Hamamatsu 1mm^2 SiPM : S12571-050P
- ✓ 32 SiPM feed a 32 ch ASIC BASIC32

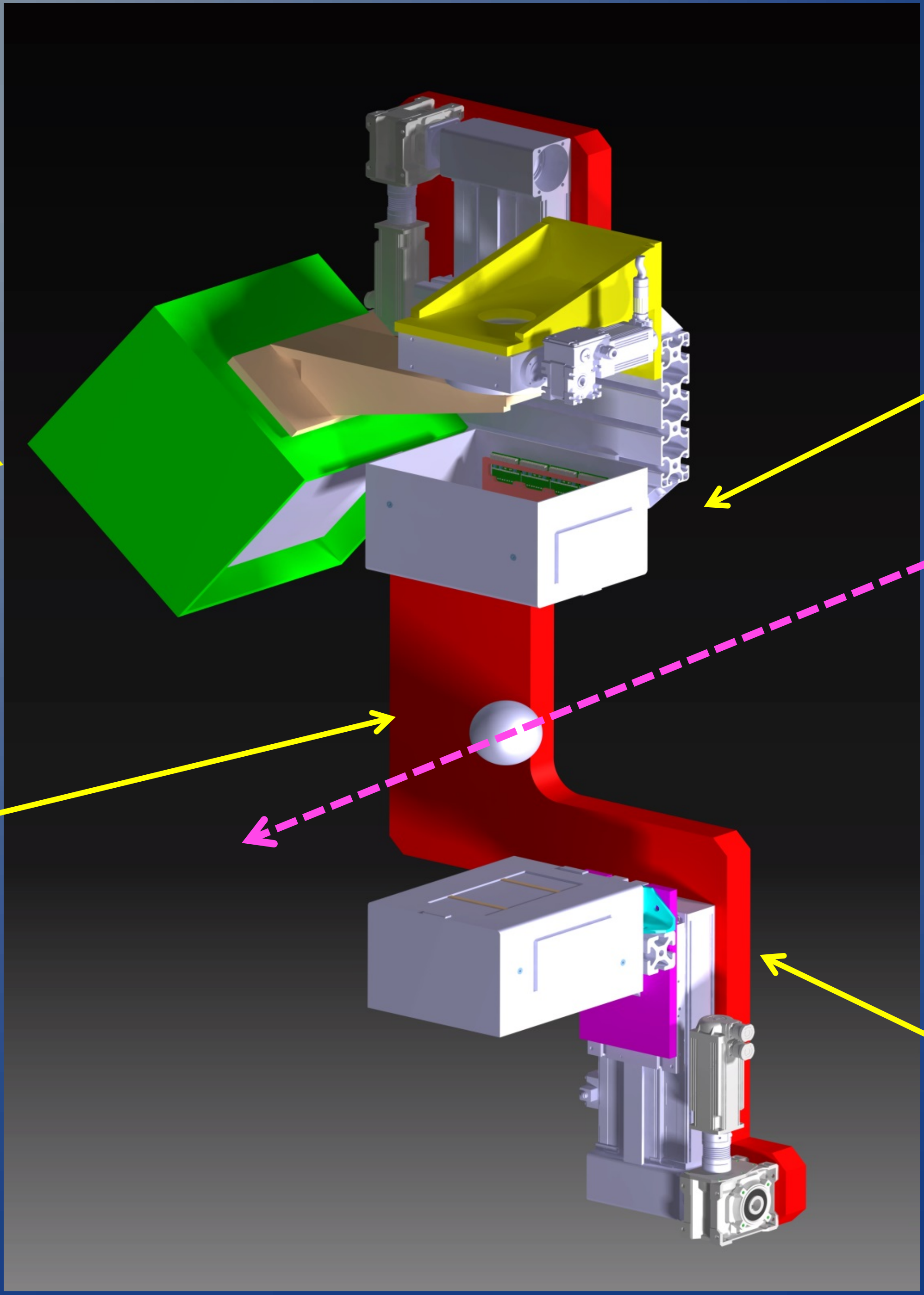




- ✓ 4x4 LYSO pixellated crystals. Each one: 50 x 50 x 16 mm^3
- ✓ Plastic absorber 1.5 cm thick in front of LYSO to screen electrons
- ✓ Crystals read out by 64 ch Hamamatsu MultiAnode

The INSIDE mechanics

Charged tracker box: 90^0-60^0 wrt the beam



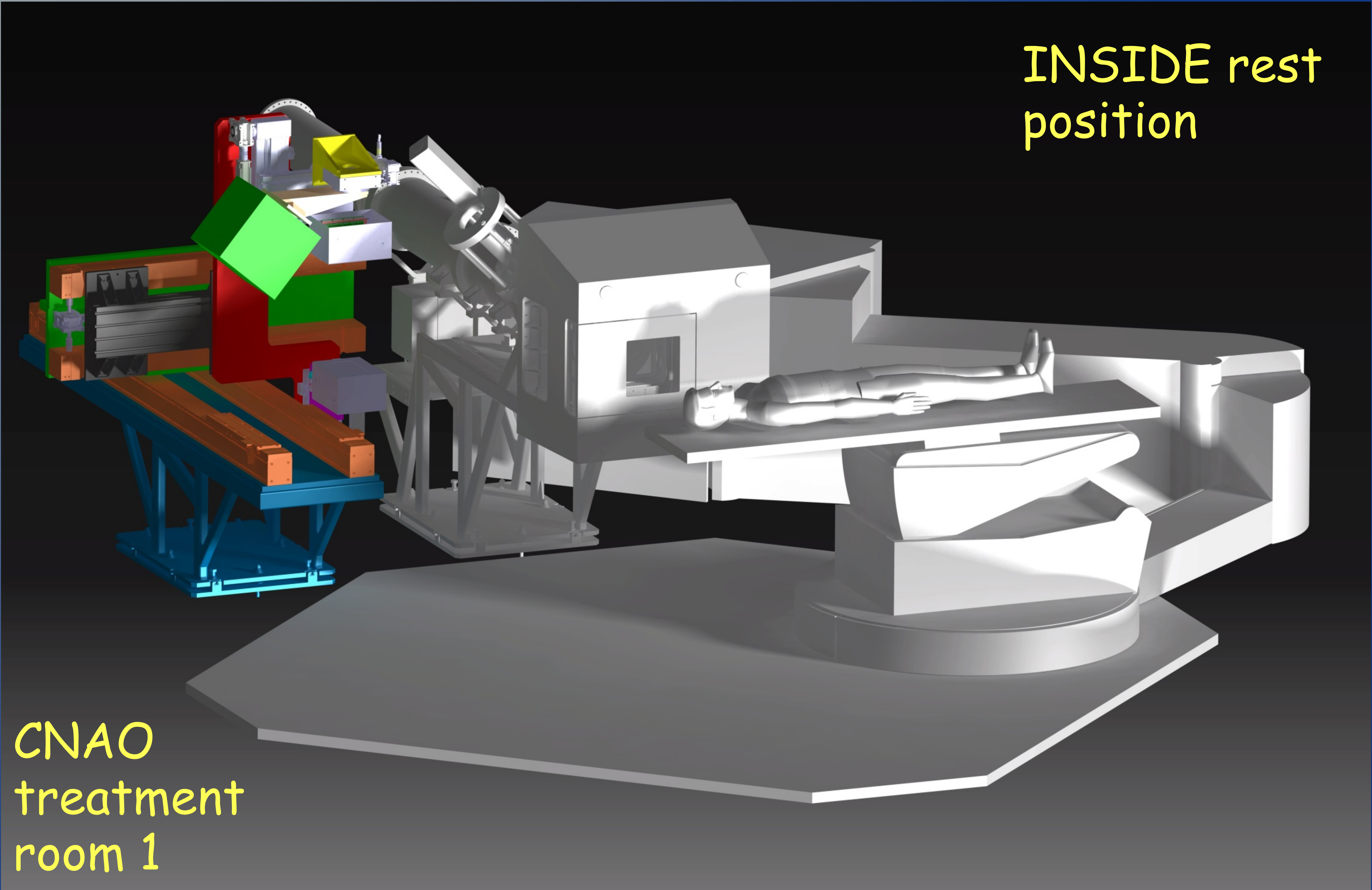
Sliding PET Head located above the couch

Beam

Tilting and sliding arm

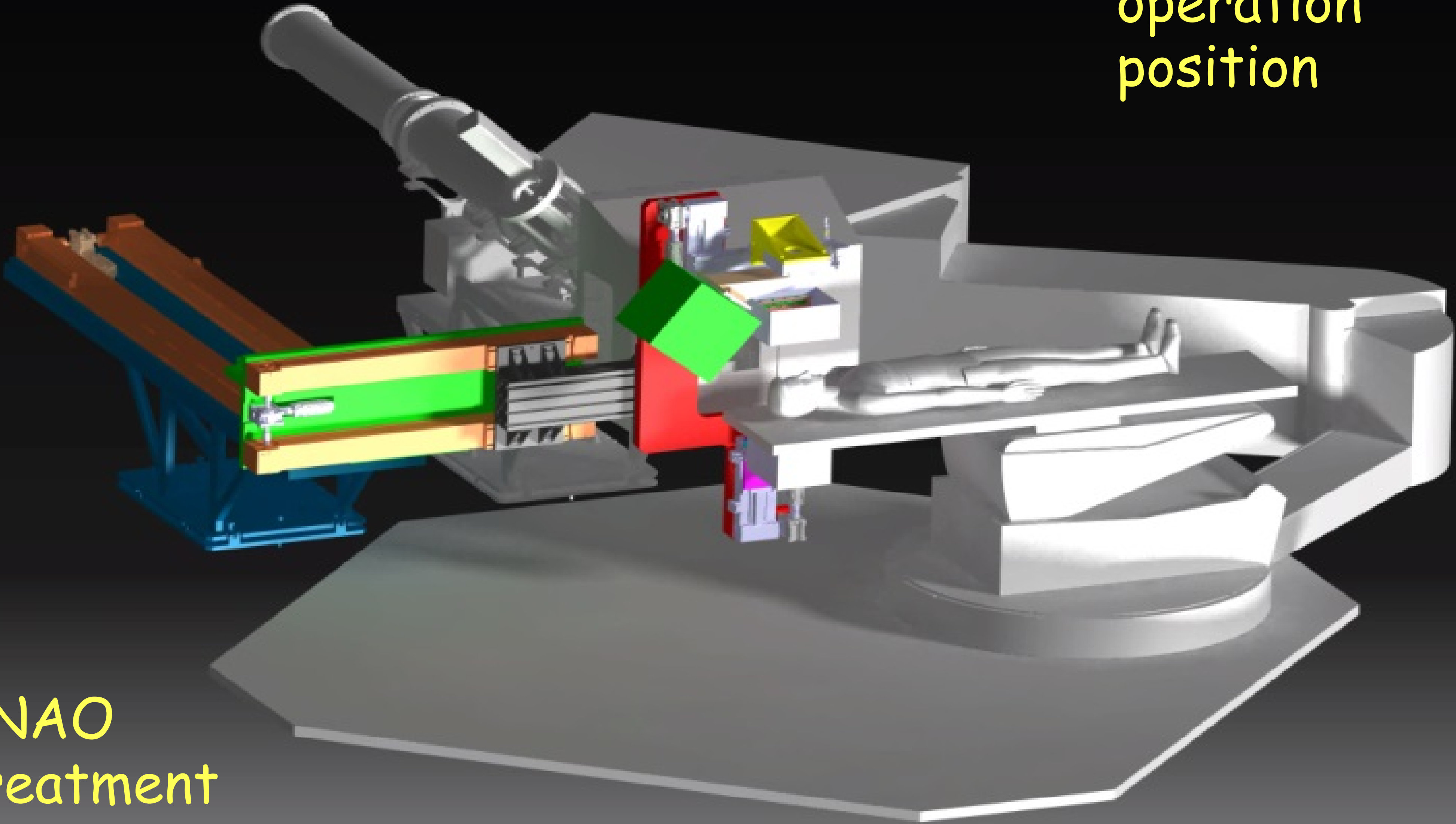
Sliding PET Head located below the couch

INSIDE @ CNAO



INSIDE @ CNAO

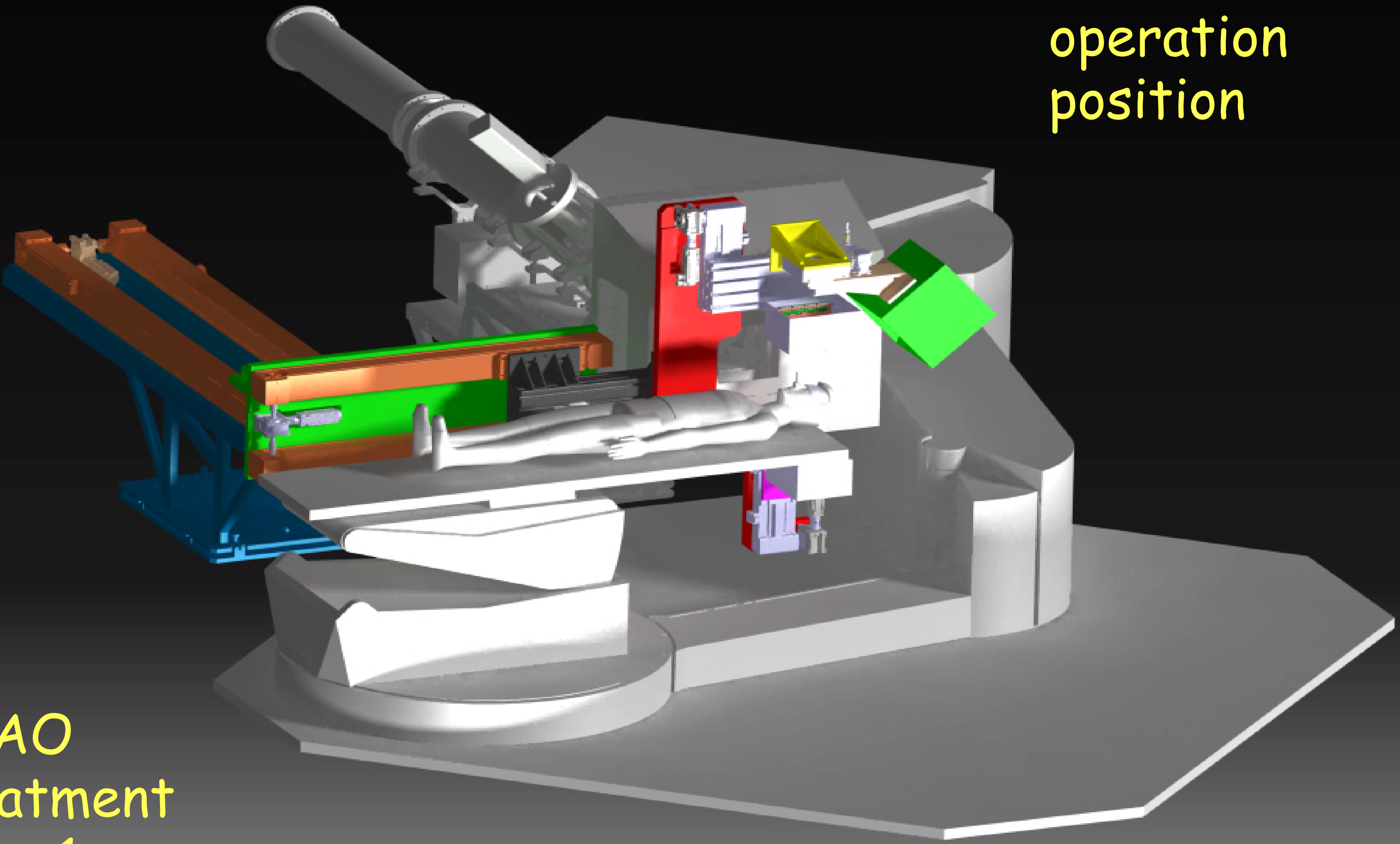
INSIDE
operation
position



CNAO
treatment
room 1

INSIDE @ CNAO

INSIDE operation position



CNAO treatment room 1

Summary & conclusions

The INSIDE collaboration aims to develop an in-beam monitoring device for hadrontherapy that exploits the joint information from PET photons & prompt charged particle detection

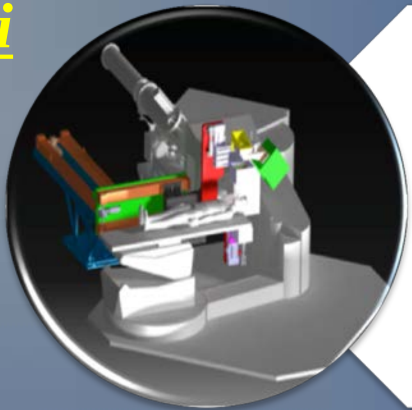
The system is designed to be put in operation in the CNAO treatment room and should be ready in early 2016

The twofold detected emission will be compared with TPS info and embedded in the general information system of CNAO.

For INSIDE software and MC related features, see also the talk from P.Cerello on Wednesday 12th

CNAO

The INSIDE collaboration: Alberto Del Guerra (University of Pisa)



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