ICTR-PHE 2014

Simulation* of Hadrontherapy in-beam monitoring at CNAO with the INSIDE detector

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on behalf of the INSIDE Collaboration

*** and comparison with preliminary beam test data**

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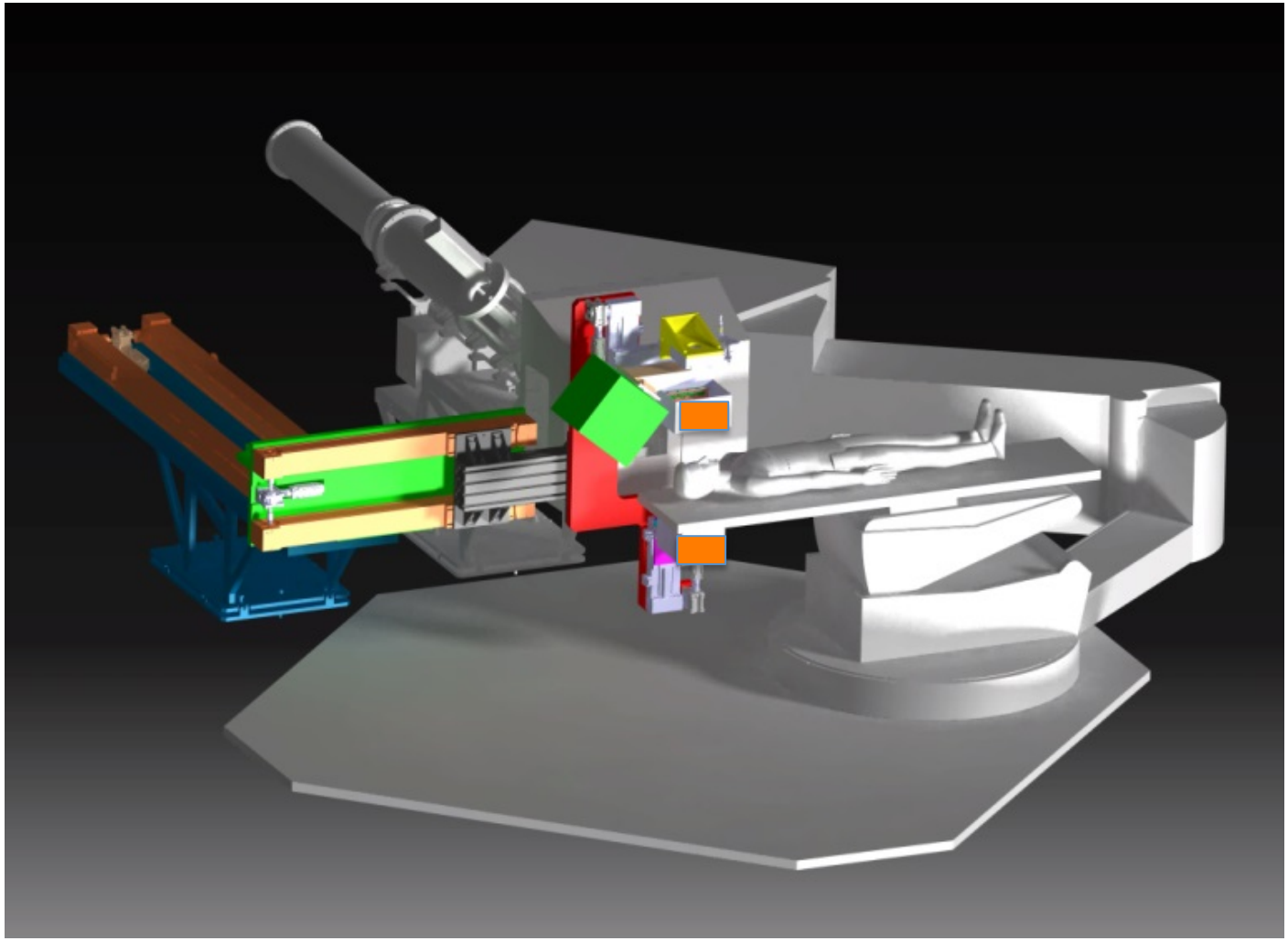
INFN Istituto Nazionale di Fisica Nucleare

INSIDE: Innovative Solutions for In-beam Dosimetry in Hadrontherapy



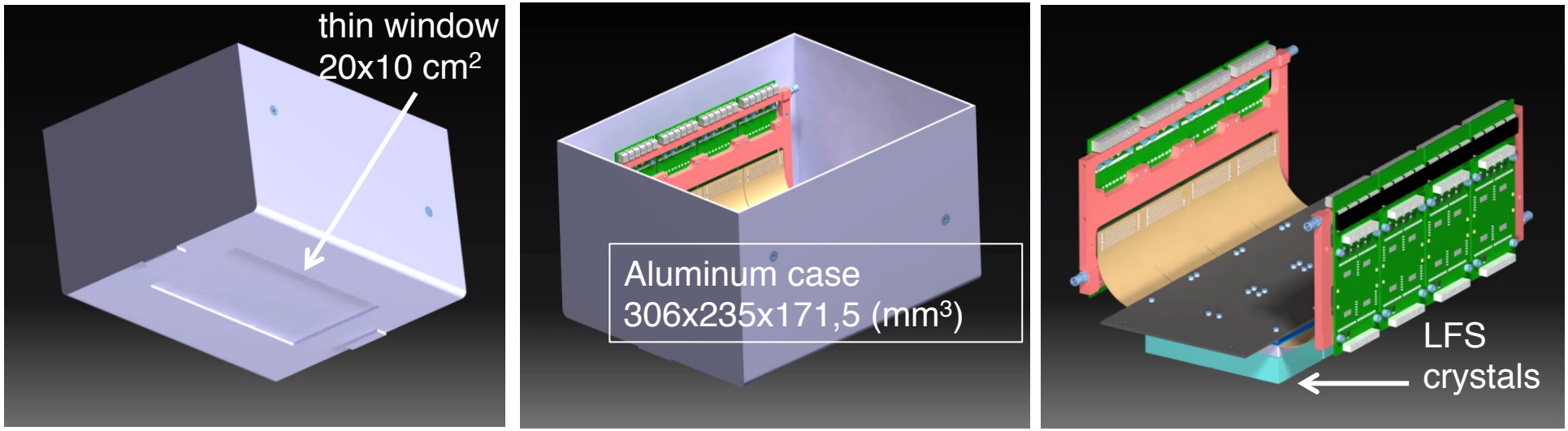
in-beam, multimodal dose profiler for hadron-therapy at CNAO

detection of

- **β+ decaying isotopes (PET)**
- **charged secondaries & (?) prompt photons (Tracker)**

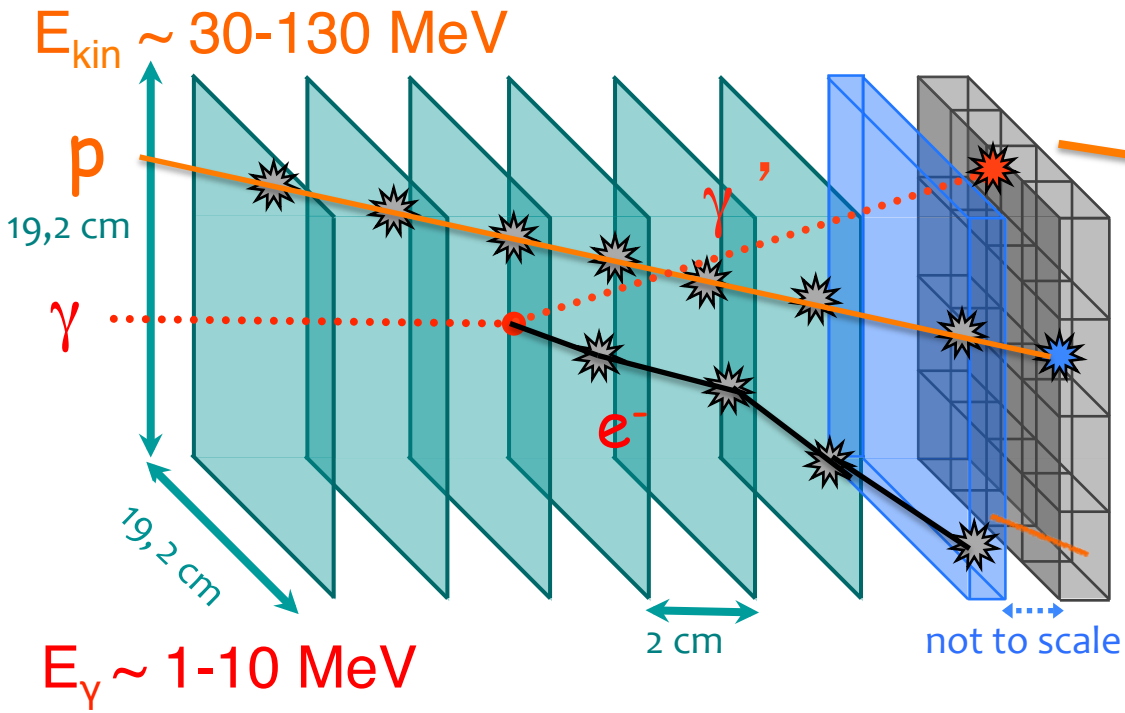
the PET detector

^{15}O, ^{11}C

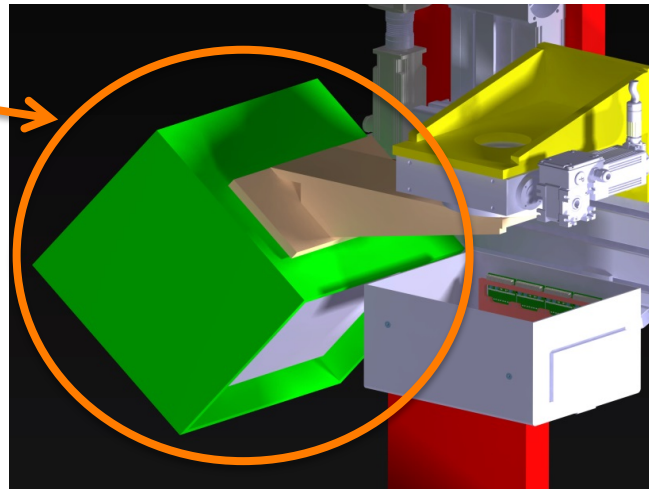


- 2 planar panels 10 cm x 20 cm^2 , each made by 2 x 4 detection modules
- Each module is composed of a 16 x 16 pixelated LYSO (or LFS) scintillator matrix (3x3 mm^2 crystals, 3.1 mm pitch, for a total sensitive area of 5x5 cm^2) coupled to a SiPM array

the Tracker



prompt γ, p

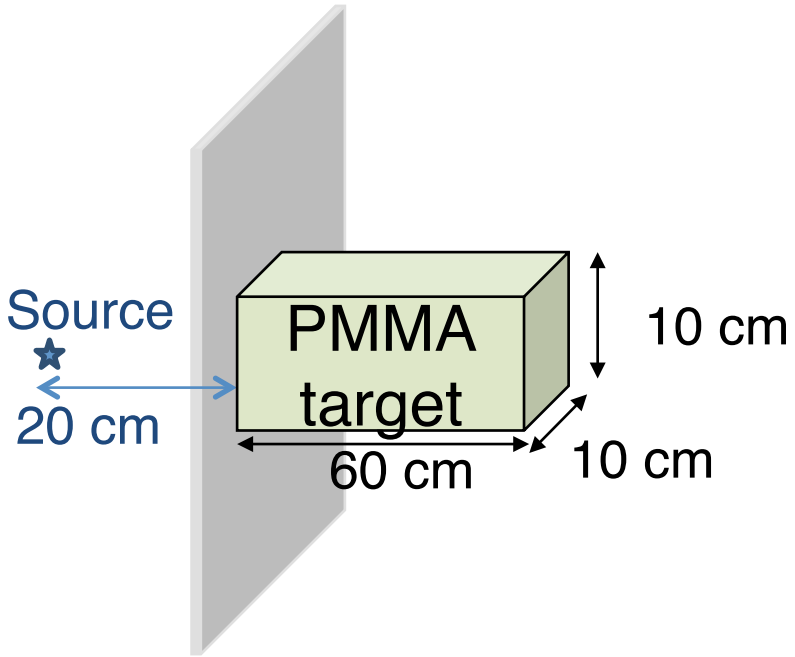


- 6 XY planes, with 2 cm spacing, made of 2 stereo layers of 192 0.5x0.5 mm^2 square scintillating fibers, read out by Hamamatsu 1mm^2 SiPM : S12571-050P
- 1 pad with 4x4 LYSO pixelated crystals (50 x 50 x 16 mm^3), with 1.5 cm thick Plastic absorber in front to screen electrons, read out by 64 ch Hamamatsu MultiAnode

Simulations

- based on FLUKA + ROOT
  - Detailed detector description
  - Signal generation and reconstruction with readout features
  - Geometry and material description (electronic board, mechanical structures)
- extensively used for the detector design optimization
- **now being exploited for further optimization and beam test validation**
- will be used on INFN-cloud computing facilities to provide input to optimize the reconstruction and analysis

Primaries: 10^8 protons
Energy: 134 MeV
Time: **2 ms beam on**, 300 s beam off
Rate: $5*10^{10}$ pps, scaled down to $5*10^9$ pps



Detector requirements

- sustain single channel trigger rate
- sustain overall coincidence and DAQ rate
- provide an adequate performance (spatial and energy resolution)
- provide an adequate number of integrated events (coincidences or prompt) on a “typical” treatment plan

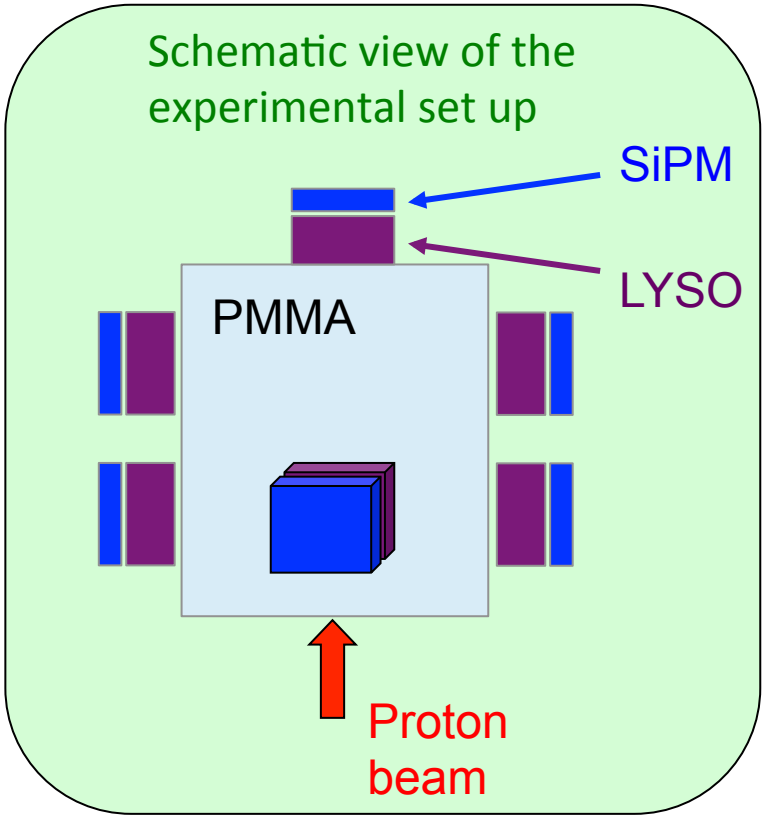
Let’s take a look at PET and Tracker simulations vs beam test…

Test of PET system “prototype”

- ✓ LYSO crystal 3 x 3 x 10 mm^3
- ✓ RGB SiPM from AdvanSid 3x3 mm^2
- ✓ Front-end ASIC: TOFPET from

  LIP Lisbon/INFN Torino

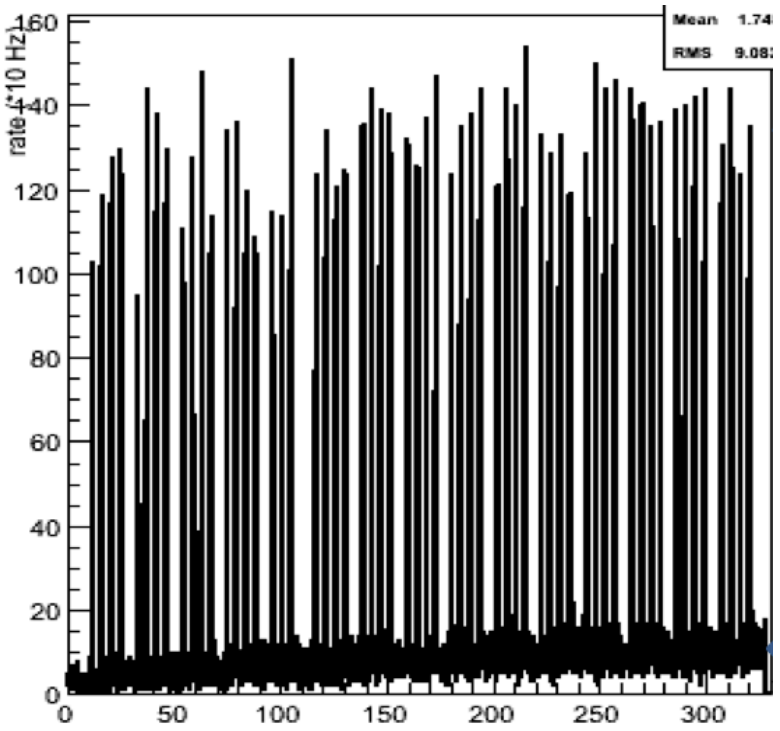
  - 64 input channels
  - 100 kHz/chn
  - Dyn range 200 pC
  - SNR 20 dB
  - Time resolution 500ps FWHM
  - Power consumption 10 mW/chn



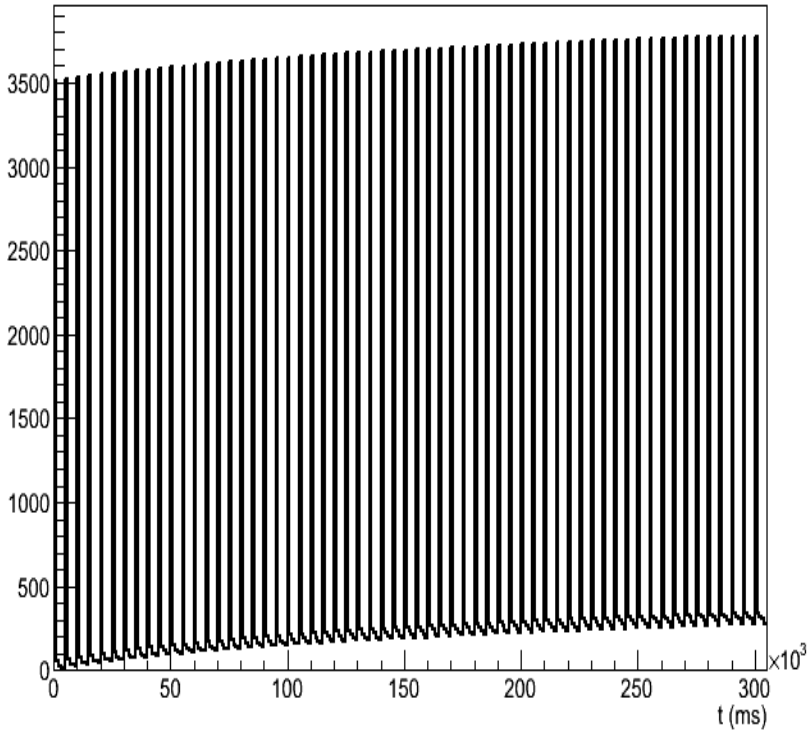
The LYSO crystal on top of PMMA phantom (5 x 5 x 7 cm^3)

PET Single Trigger Rate

Raw Data



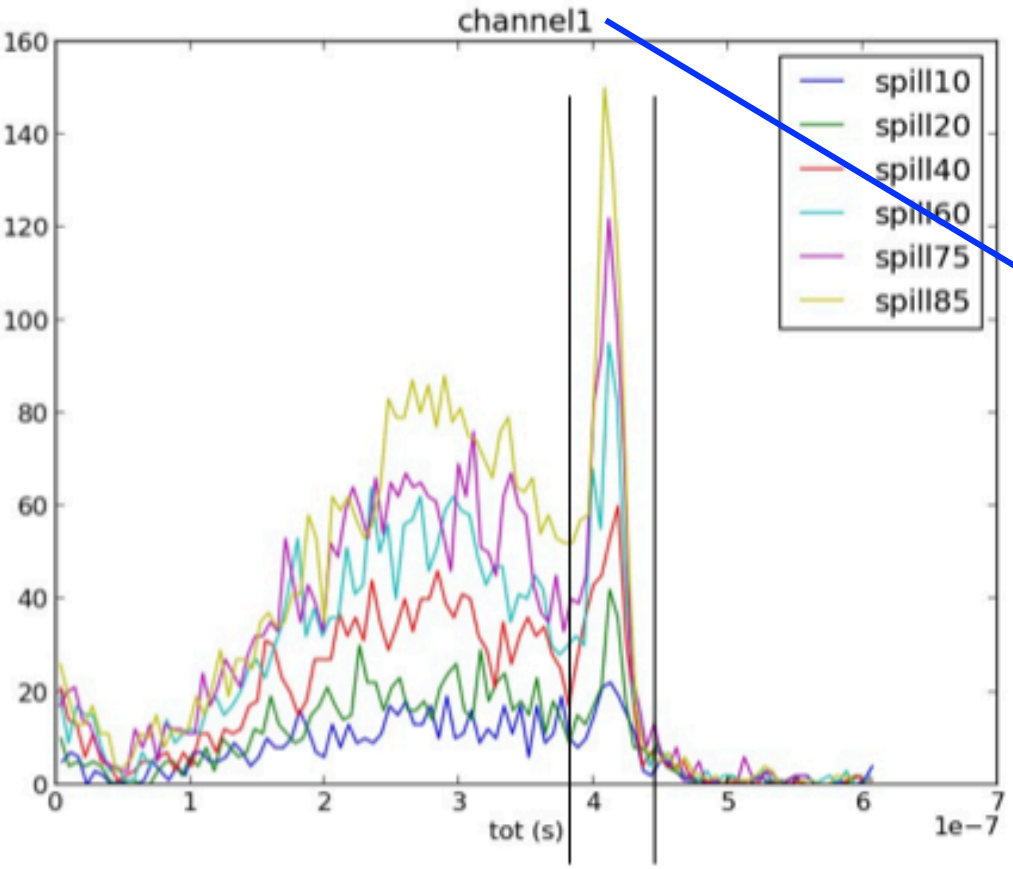
Simulation



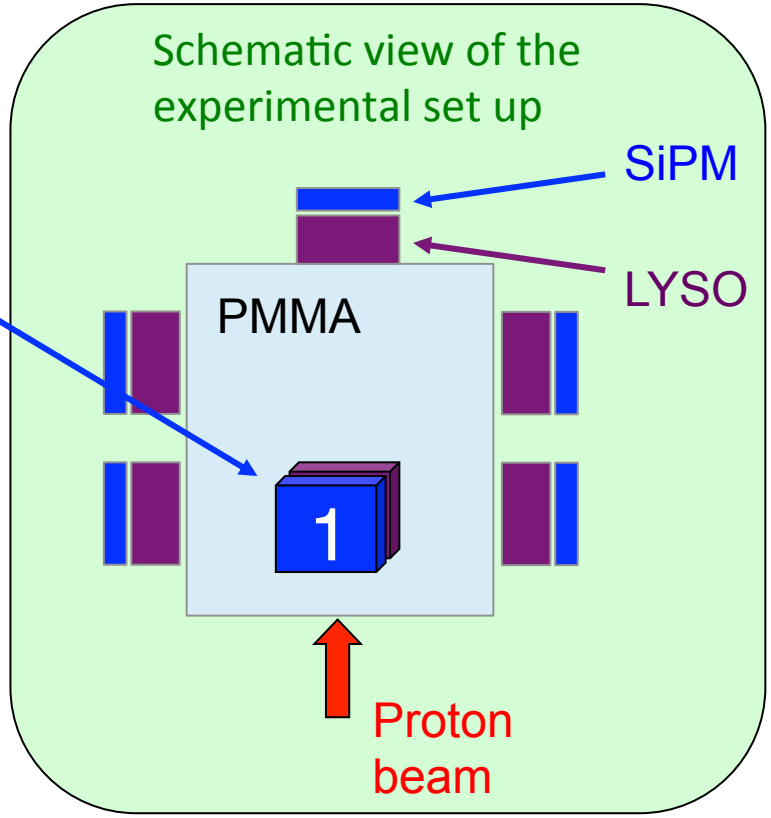
Peak to valley: ~ 15 (Raw Data), ~ 16 (Simulation)

DAQ Rate and full beam/in beam structure under control

Photopeak position (on singles!)

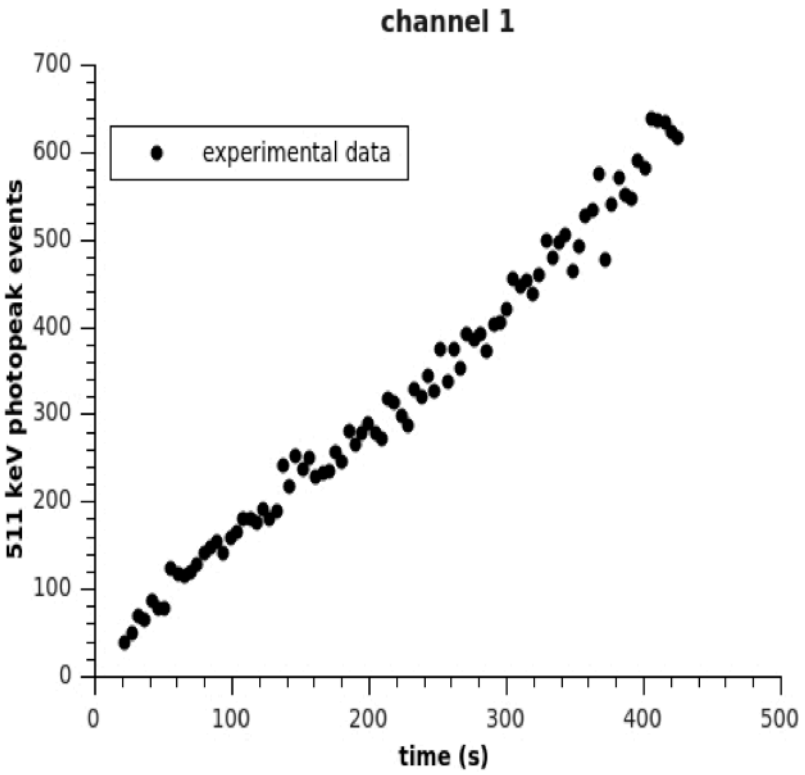


511 keV photopeak events

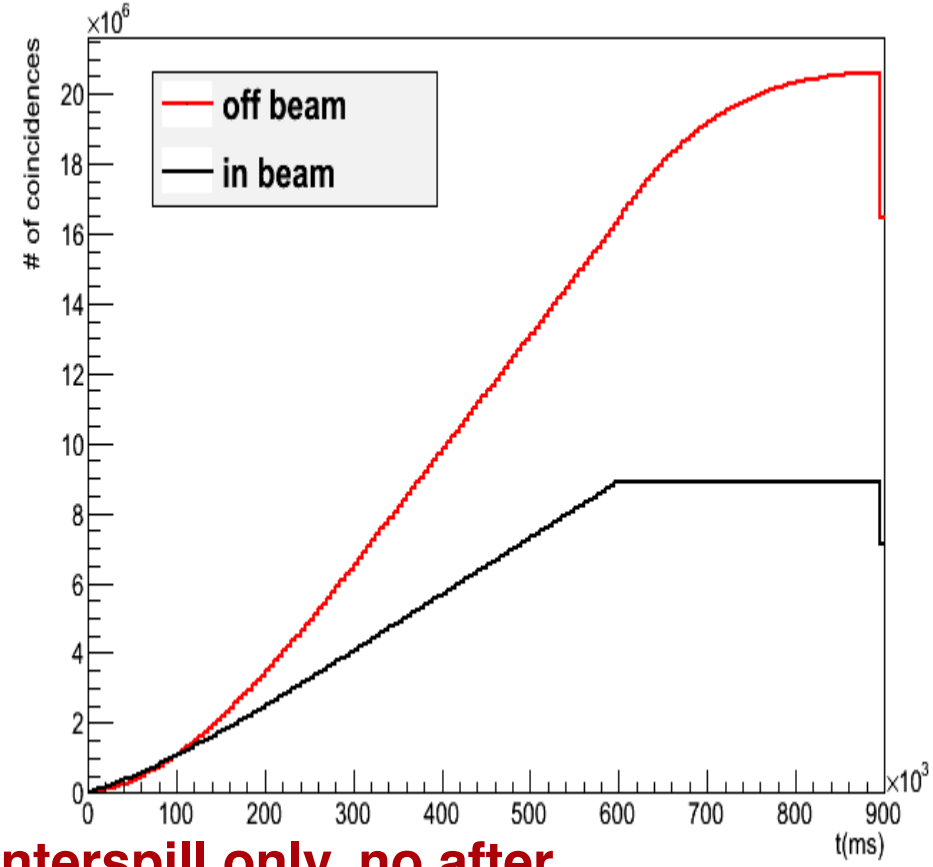


PET: Number of events

Integrated “single” photopeak triggers on channel 1 during beam test



Total number of coincidences with beam on and off, $5*10^9$ pps, 10 min treatment + 300 s post-treatment

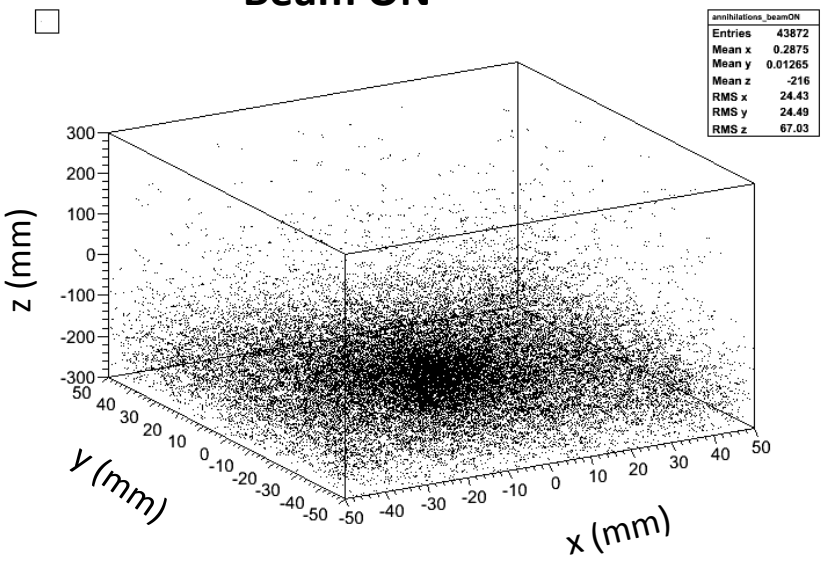


Expected number of **coincidences** (**interspill only, no after treatment acquisition**) evaluated on an **input treatment plan**, taking the detector acceptance/efficiency into account: **$3.09*10^5$**

Annihilation position distribution

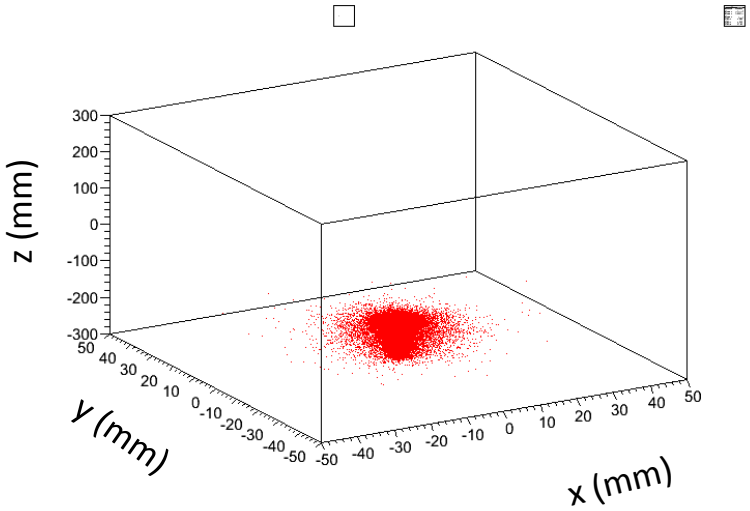
- Analysis of the annihilation position :
  - "original" data used (no pile-up to build spills): 2 ms beam on + 300 s beam off
  - Plot of the **(known!!!)** annihilation positions with beam on (black) and off (red)

Beam ON



prompt annihilations & β^+ decays

Beam OFF



β^+ decays only

Annihilation position distribution

- Analysis of the annihilation position :
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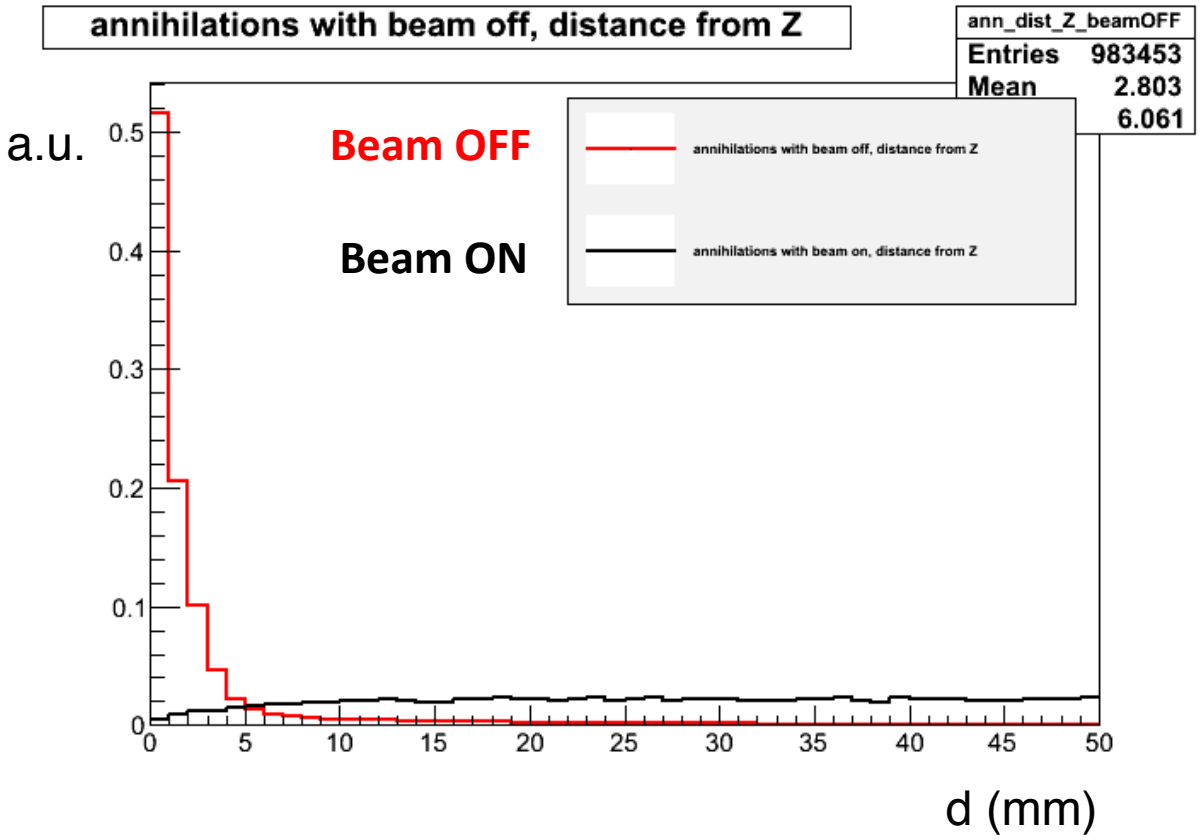


Tracker Simulations

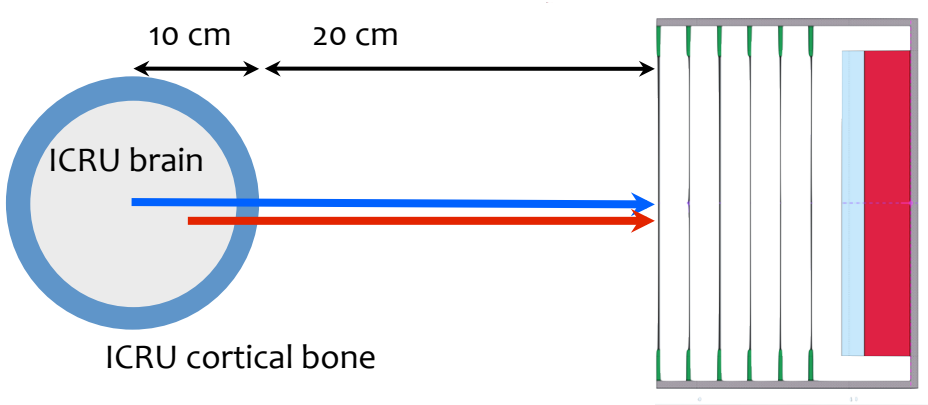
Simulation of a "spherical patient" with ICRU materials, with proton source placed at different depths:

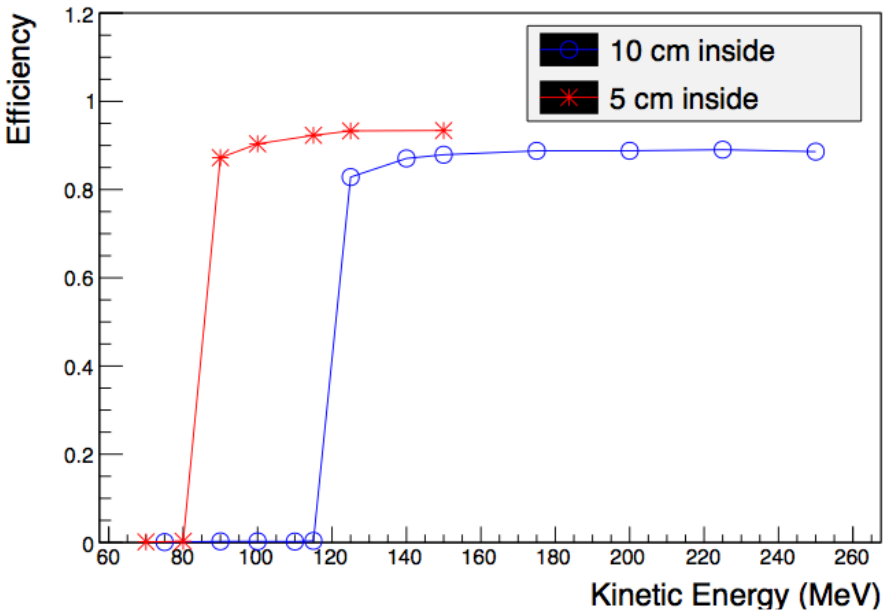
10 cm and 5 cm

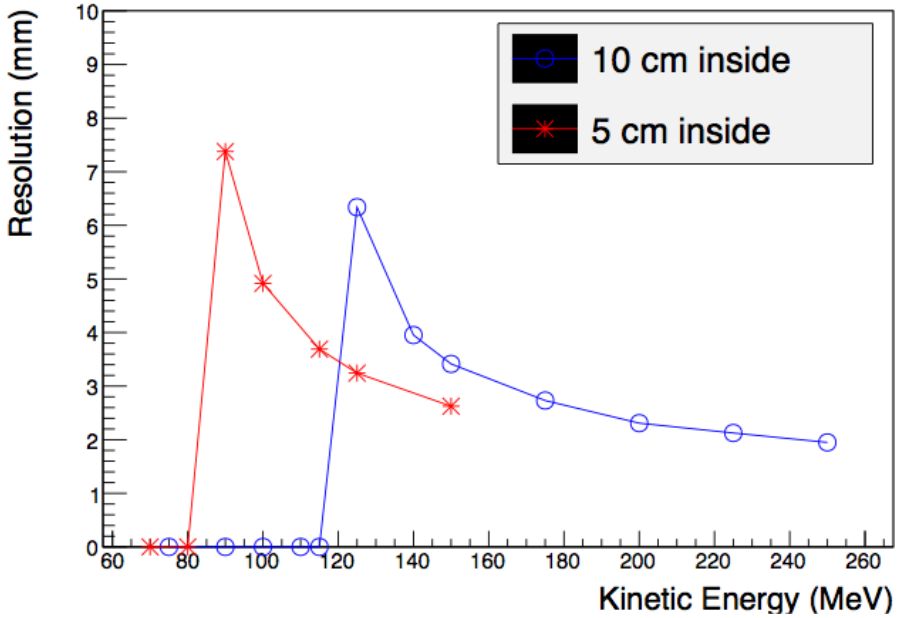
Energy Threshold

Single Track Spatial Resolution

~ few mm



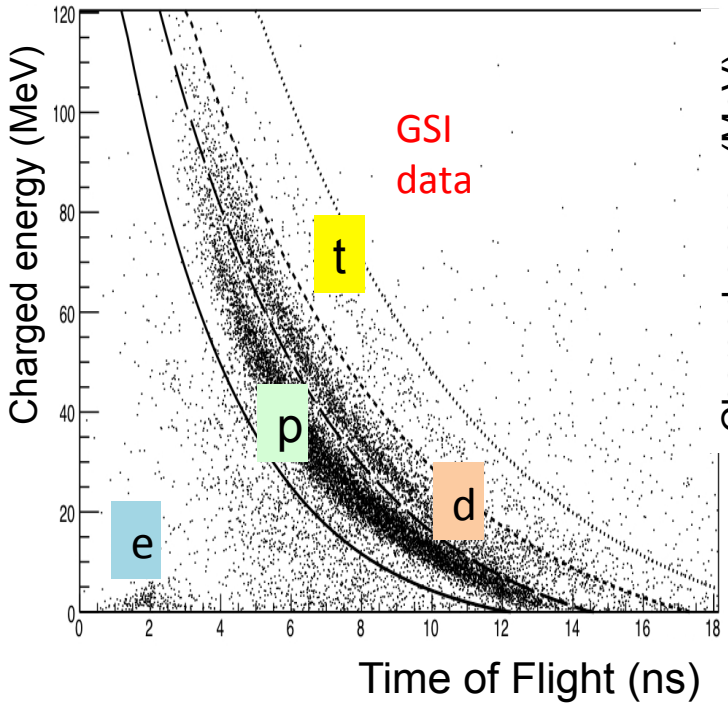


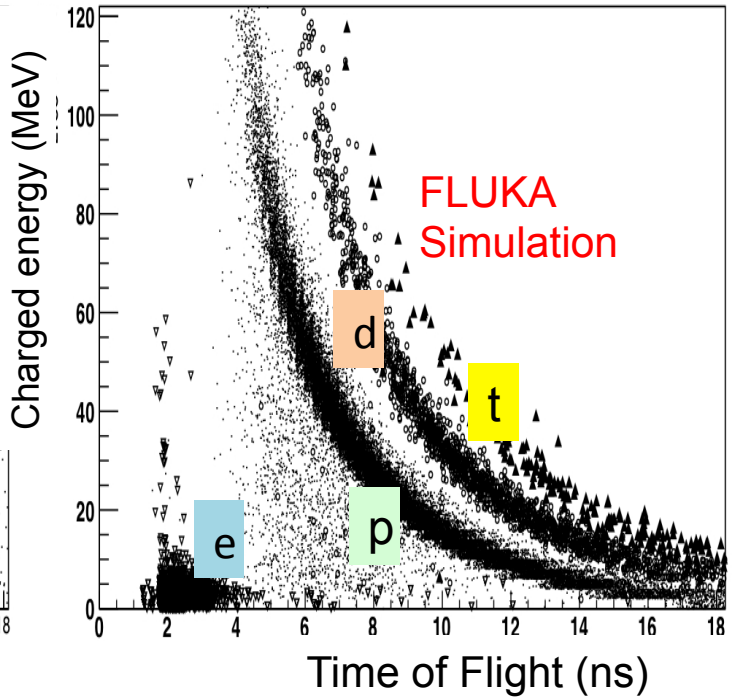


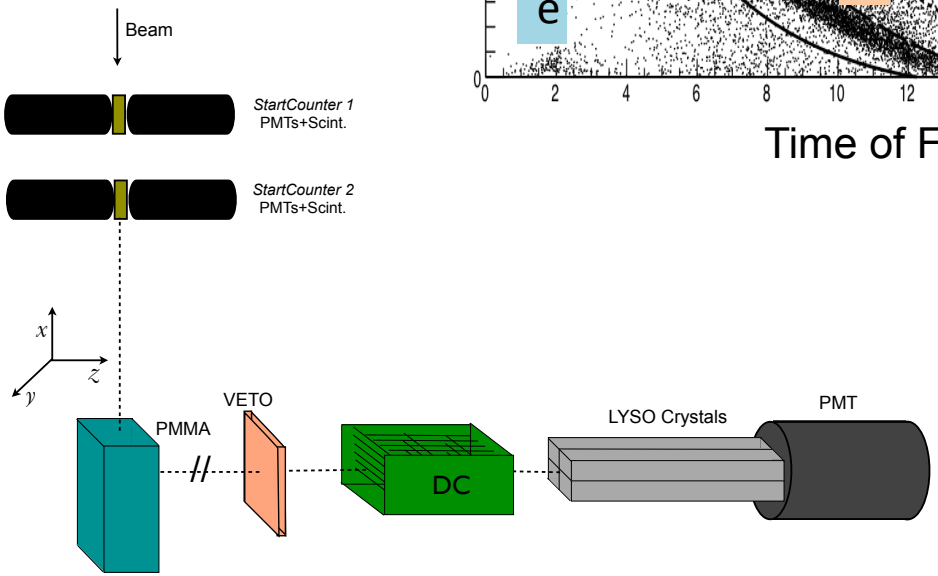
Tracker Prototype Testing

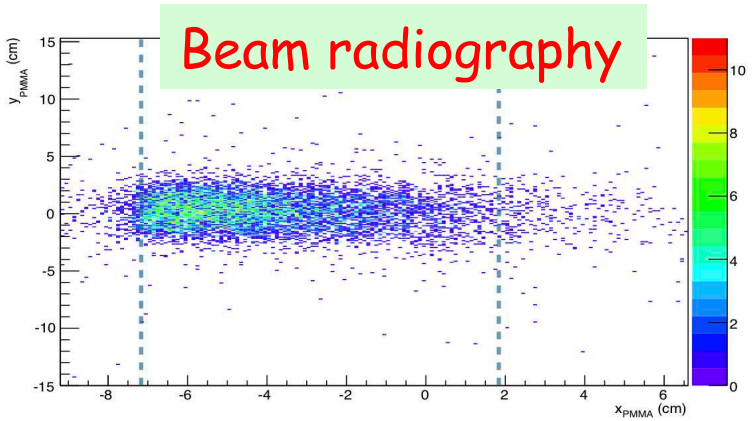
L.Piersanti et al. Submitted to PMB

Charged secondaries produced at 90^0 wrt the beam from PMMA target on 220 AMeV ^{12}C beam at GSI









Conclusions (to date)

FLUKA-based simulations were validated on CNAO and GSI test data

PET

- the PET detector can operate full beam/in beam
- single Channel Trigger rate under control
- photopeak well identified, even on single channel triggers
- O(10^5) expected coincidences on a typical treatment plan
  - **simulations suggest avoiding full beam acquisition (i.e., only inter-spill coincidences in the analysis) will provide better data quality**

Tracker

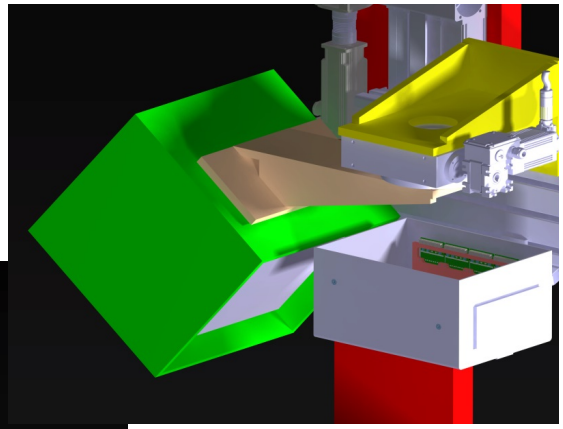
- the Tracker can operate full beam
  - It must to do so, as it exploits information from prompt events!
- GSI testing confirms the expected spatial resolution

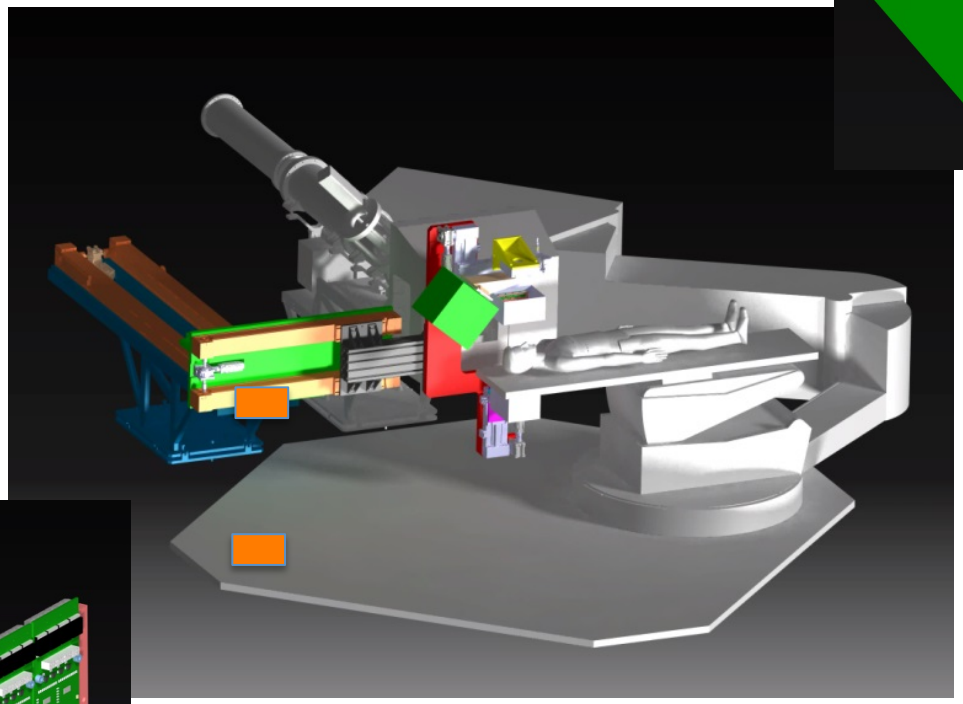
Concerns

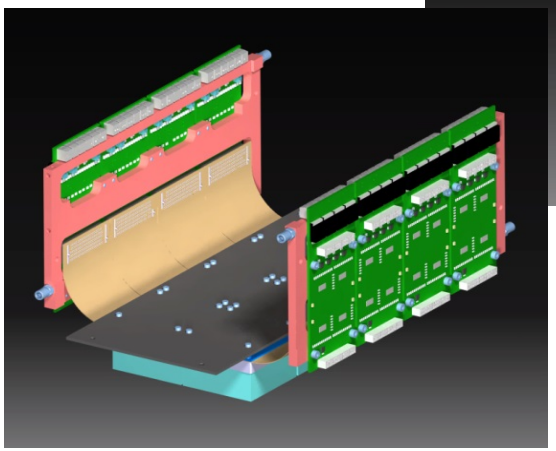
- If the distal part of the treatment comes last, it will correspond to the less precise measurement (because of low statistics) and might require a post-treatment acquisition
- We will evaluate the possibility to deconvolve contributions corresponding to different beam energies

INSIDE

2014 construction







2015 commissioning

Opportunity: correlate PET and Tracker information in the data analysis