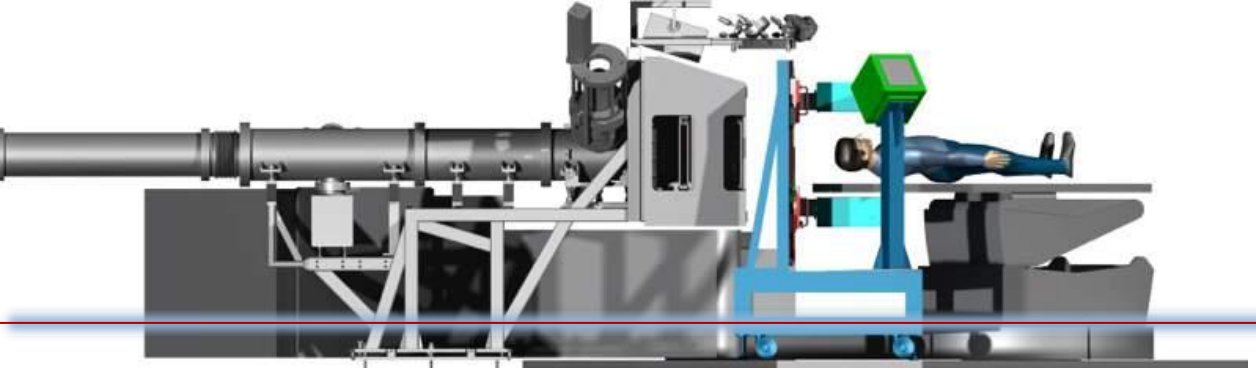

Real-Time Quality Assurance in Particle Therapy: simulation and DAQ challenges

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Outline

- Monitoring in HT
- The INSIDE experiment
- INSIDE DAQ system
- INSIDE data processing
- DAQ upgrades
- Monte Carlo Simulations for in-beam PET
  - treatment simulation
  - Detector simulation
- Simulation speed-up

Hadrontherapy monitoring

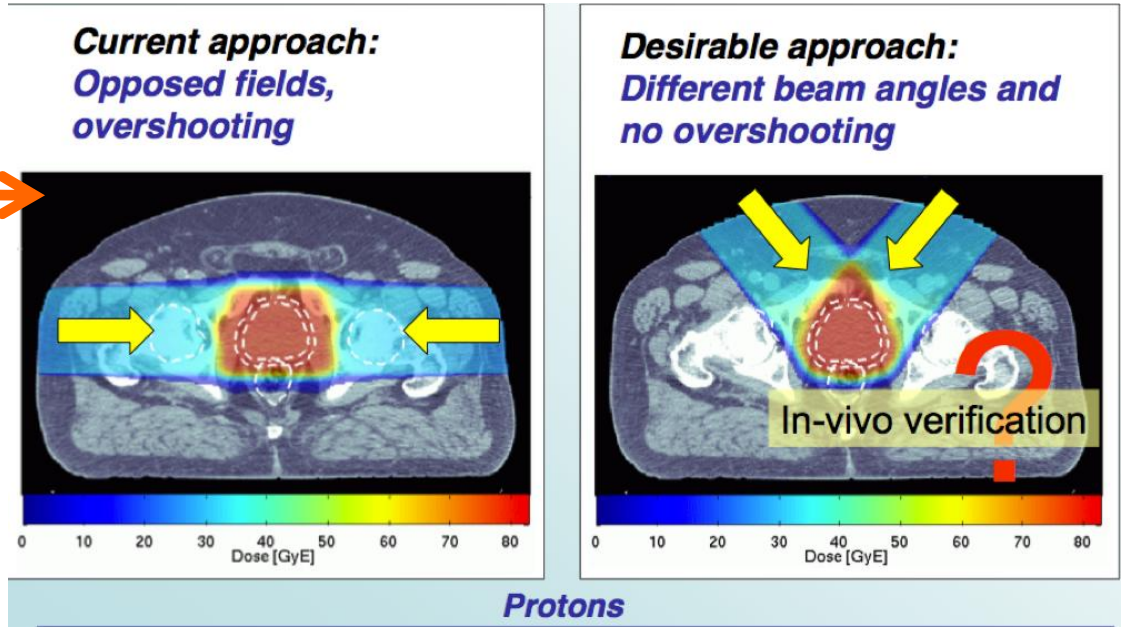
Why HT monitoring?

Uncertainty in particle range:

- validate the conformity actual dose delivery wrt treatment planning
  - Ensure treatment effectiveness
  - Healthy tissues sparing

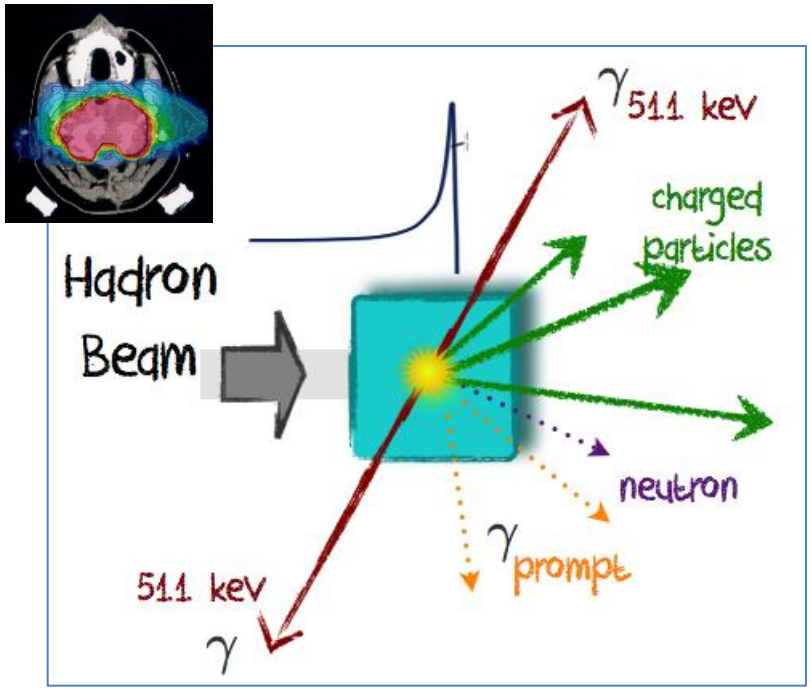
HT monitoring (possibly real-time) effects:

- More flexibility in HT treatment planning nearby critical organs
- Higher dose/fraction (hypofractioned plans):
  - More patients per day treated
  - Significant improvement in patient comfort

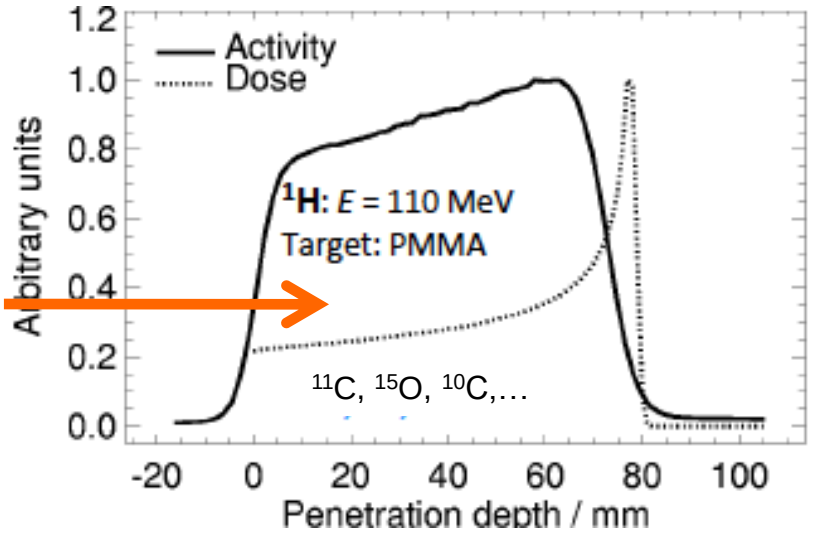


Hadrontherapy monitoring

Real time monitor of Bragg Peak depth with passive signals by secondary particles

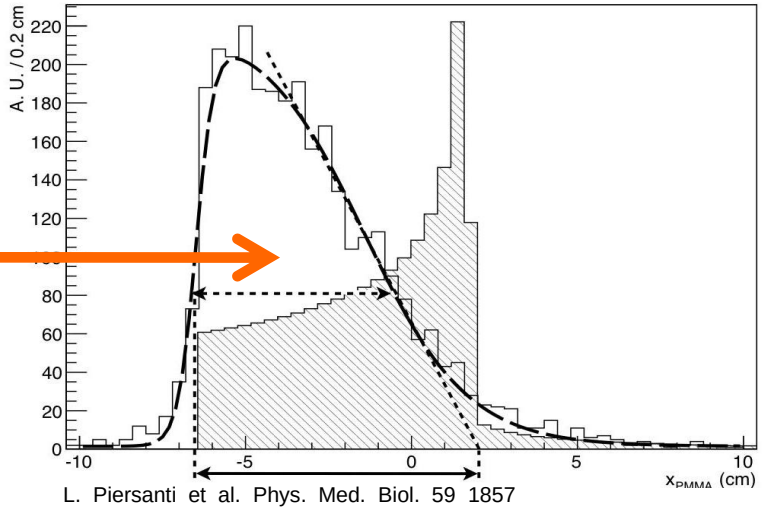


β⁺ activity distribution



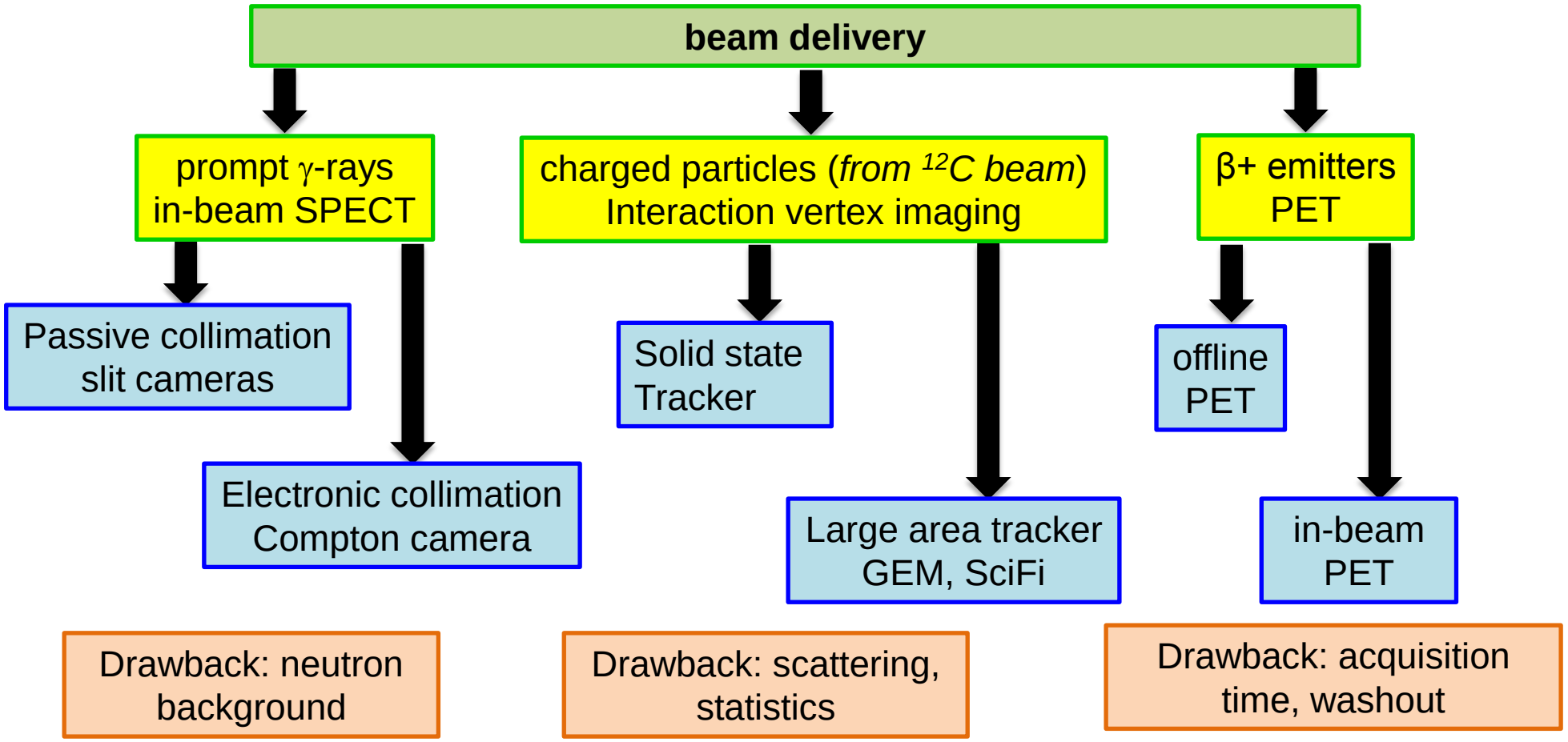
J Pawelke et al., Proceedings IBIBAM, 26.-29.09.2007, Heidelberg

prompt secondary particles emission

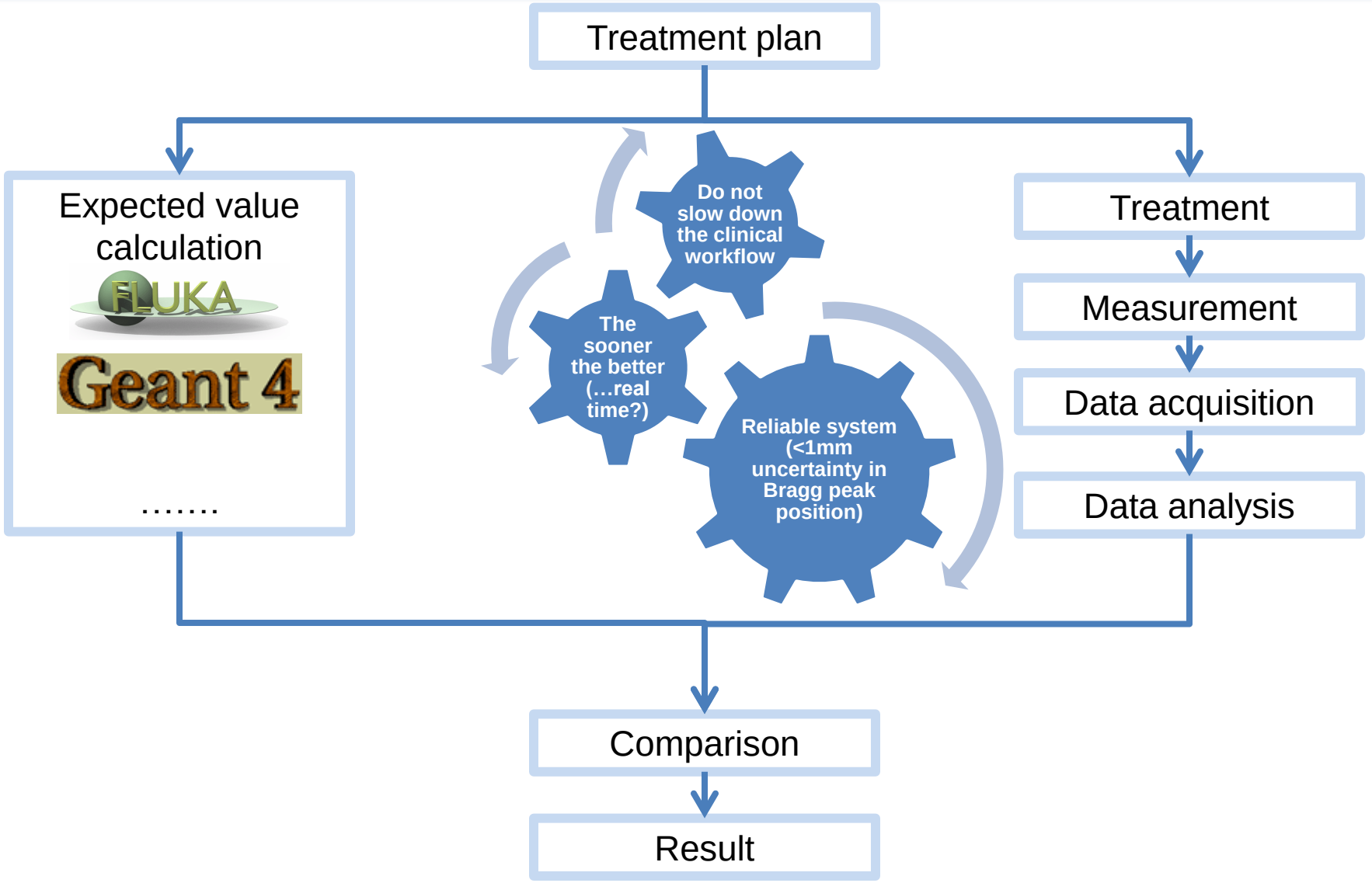


L. Piersanti et al. Phys. Med. Biol. 59 1857

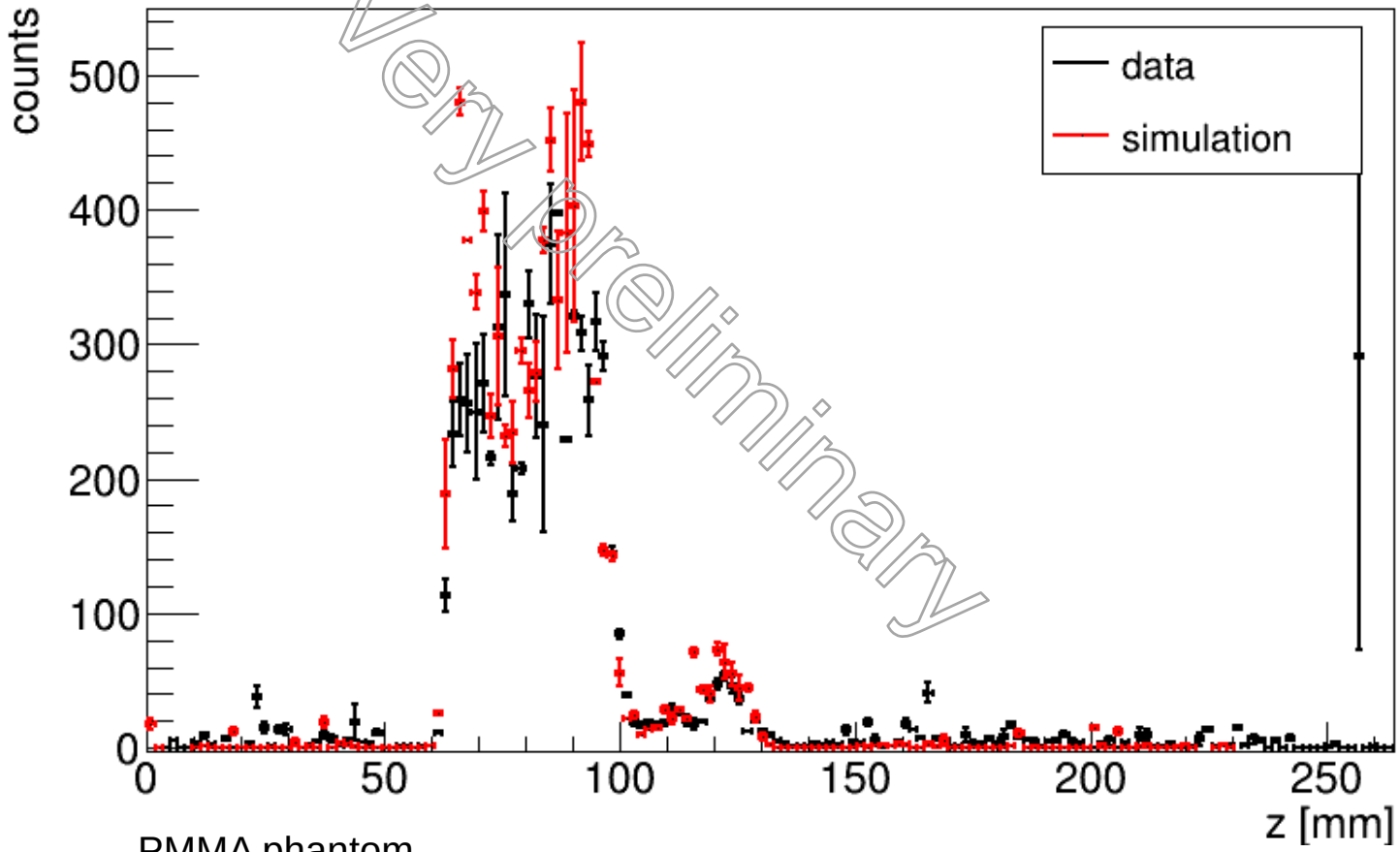
Secondary particles in HT and detectors



Monitoring in HT: Operating principle



Monitoring in HT: in-beam PET

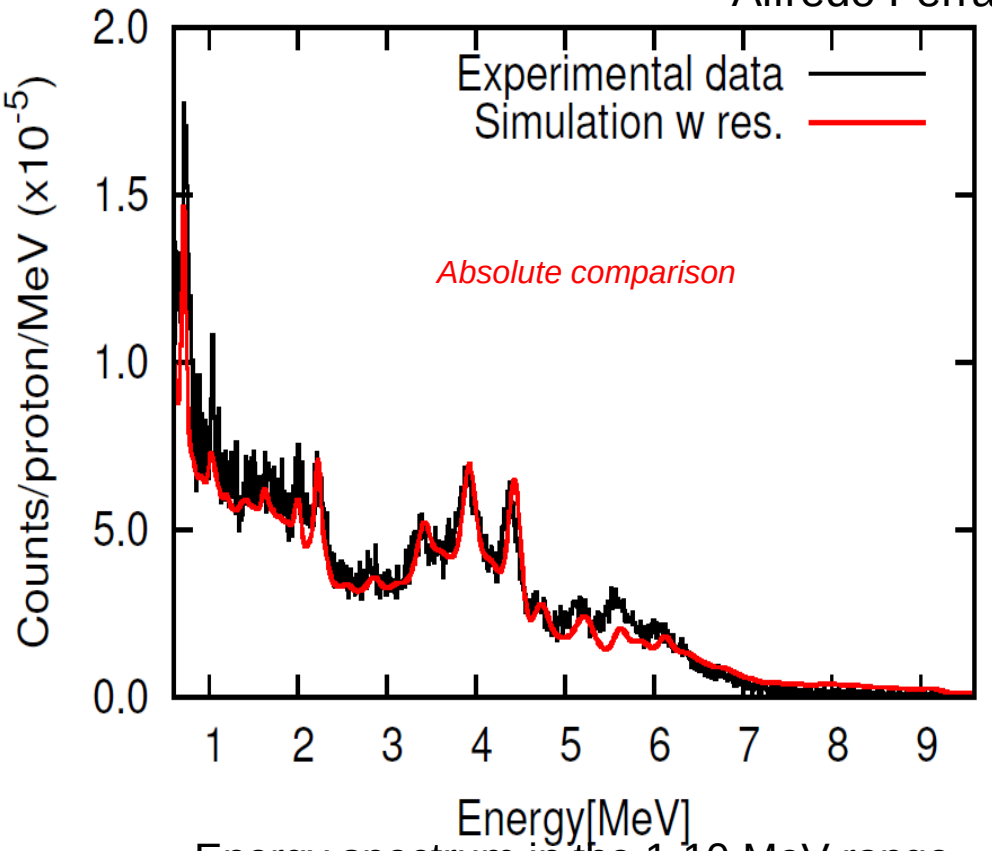


PMMA phantom
2 slices 2.7x2.7 cm^2 (E_1 = 77 MeV, E_2= 105 MeV)
Acquisition time = 254 s, absolute comparison (no normalization applied)

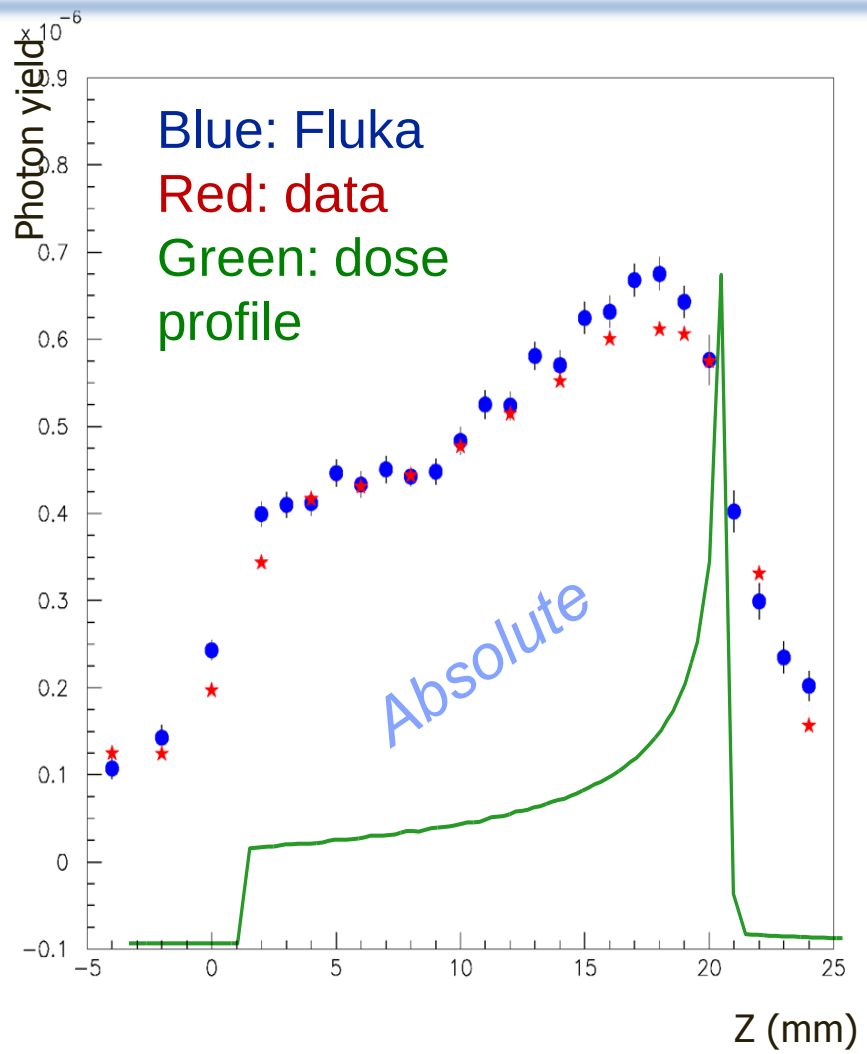
Monitoring in HT: prompt photons

160 MeV proton beam
Energy spectrum of prompt "photons"
(J.Smeets et al., IBA)

Courtesy
Alfredo Ferrari



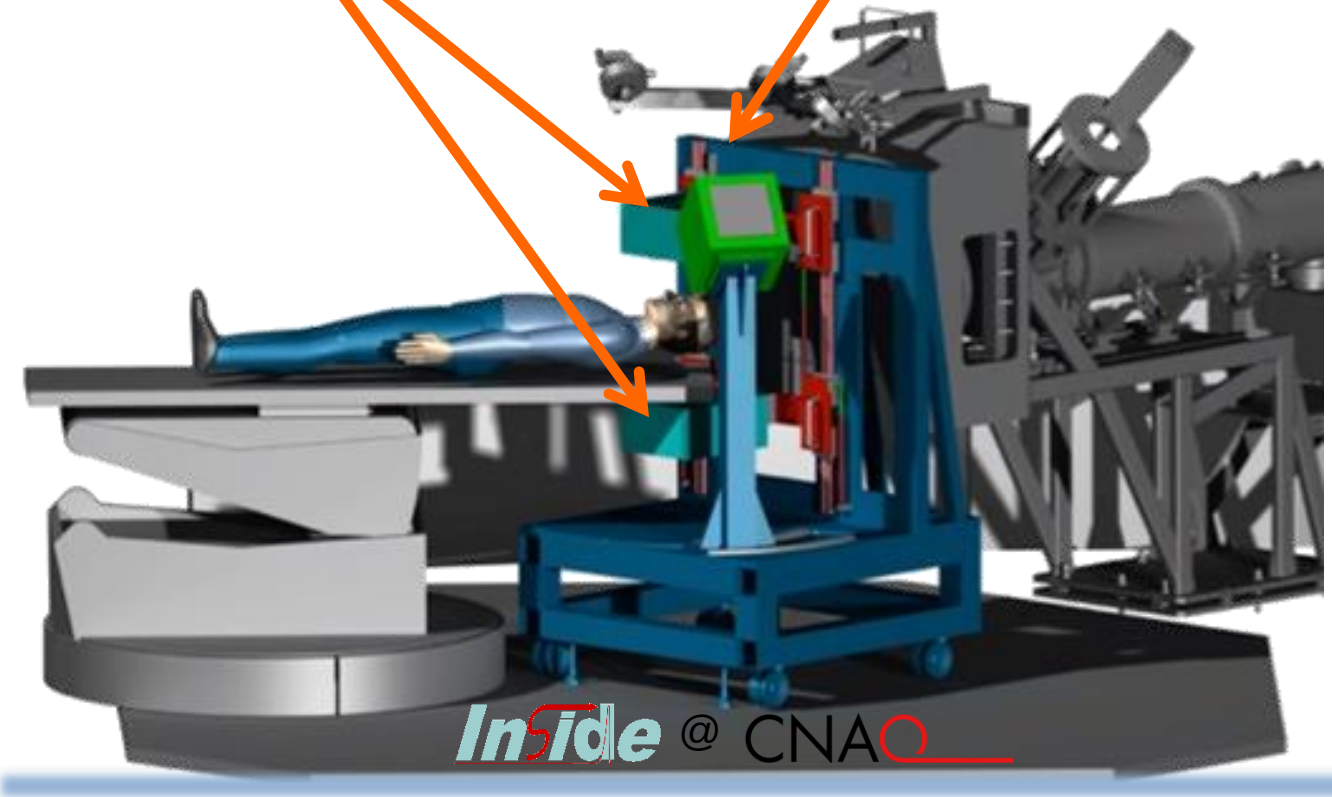
Energy spectrum in the 1-10 MeV range



The InSIDE Project

β^+ activity distribution
IN-BEAM PET HEADS

Prompt secondary particles emission
Tracker + Calorimeter = DOSE PROFILER



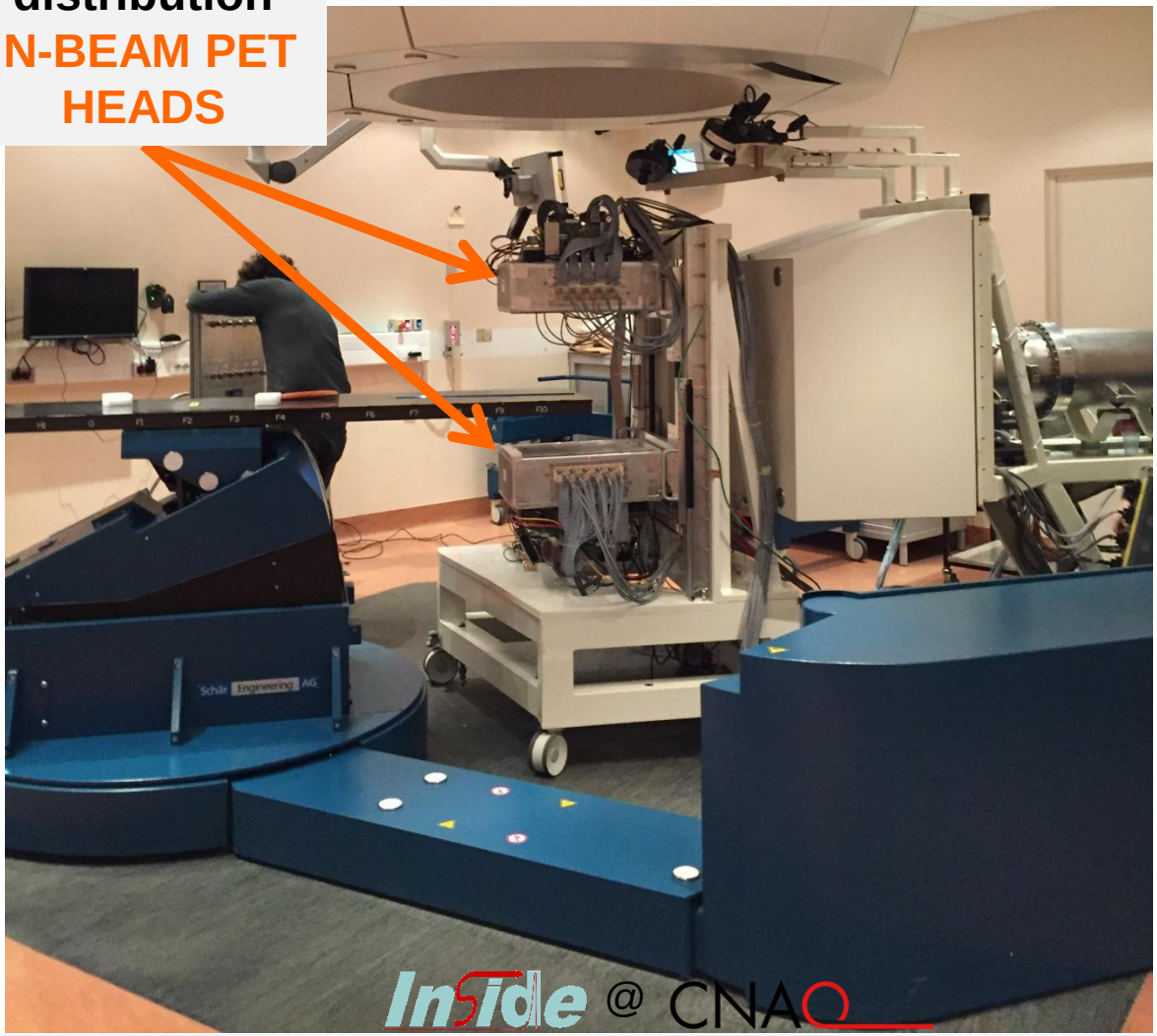
INnovative **S**olutions for **I**n-beam **D**osim**E**try in Hadrontherapy

Designed to:

- be integrated in the gantry
- be operated in-beam
- **provide an IMMEDIATE feedback on the particle range**

The InSIDE Project

β^+ activity distribution
IN-BEAM PET HEADS



INnovative **S**olutions for **I**n-beam **D**osim**E**try in Hadrontherapy

Designed to:

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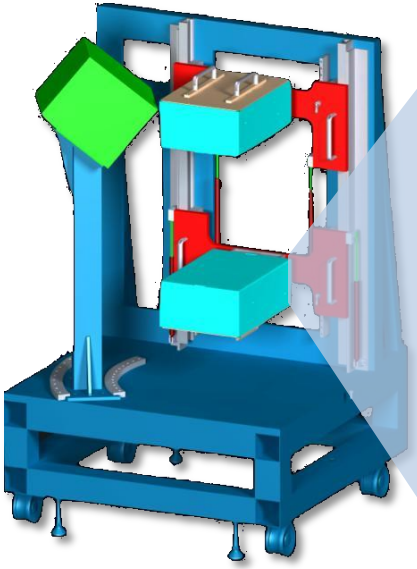
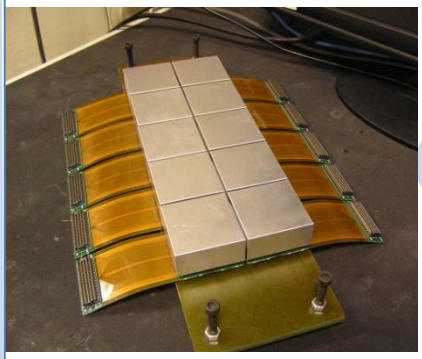
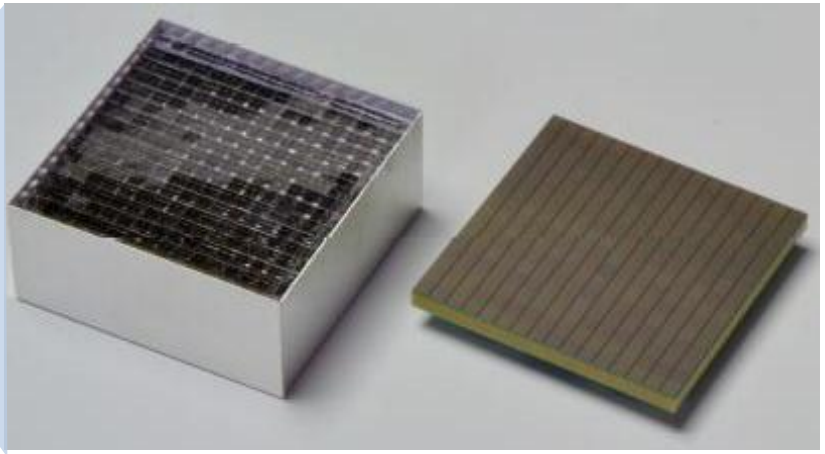
In-beam PET heads



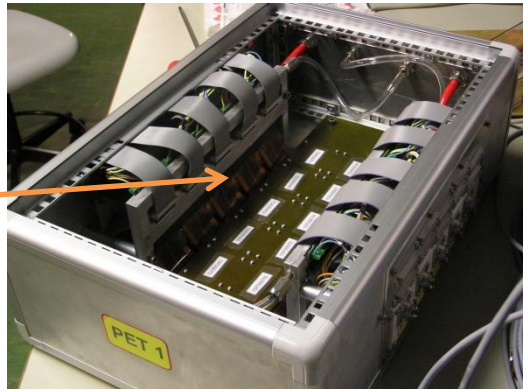


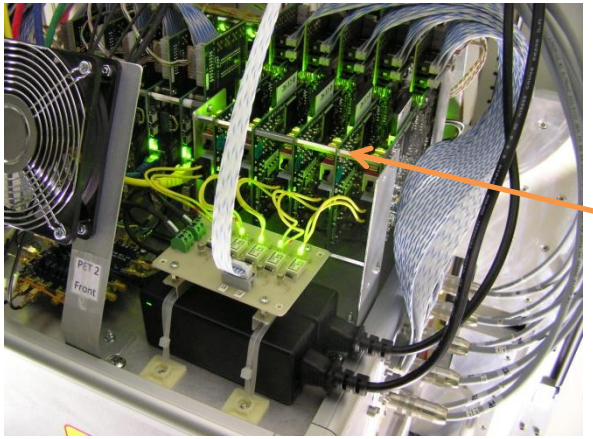
10x 25 x 5 cm^3
Distance from the isocenter=25 cm



256 LFS pixel crystals (3x3x20mm^3) coupled one to one to MPPCs (Multi Pixel Photon Counters, SiPMs).

20xFE board (4 Tofpet ASIC[1] each)





20xFPGA Xilinx Spartan6-SP605

[1] Work partly funded by the European Union 7th Framework Program (FP7/ 2007-2013) under Grant Agreement No. 256984 EndoTOFPET-US and supported by a Marie Curie Early Initial Training Network Fellowship of the European Union 7th Framework Program (PITN-GA-2011-289355-PicoSEC-MCNet).

Preliminary results

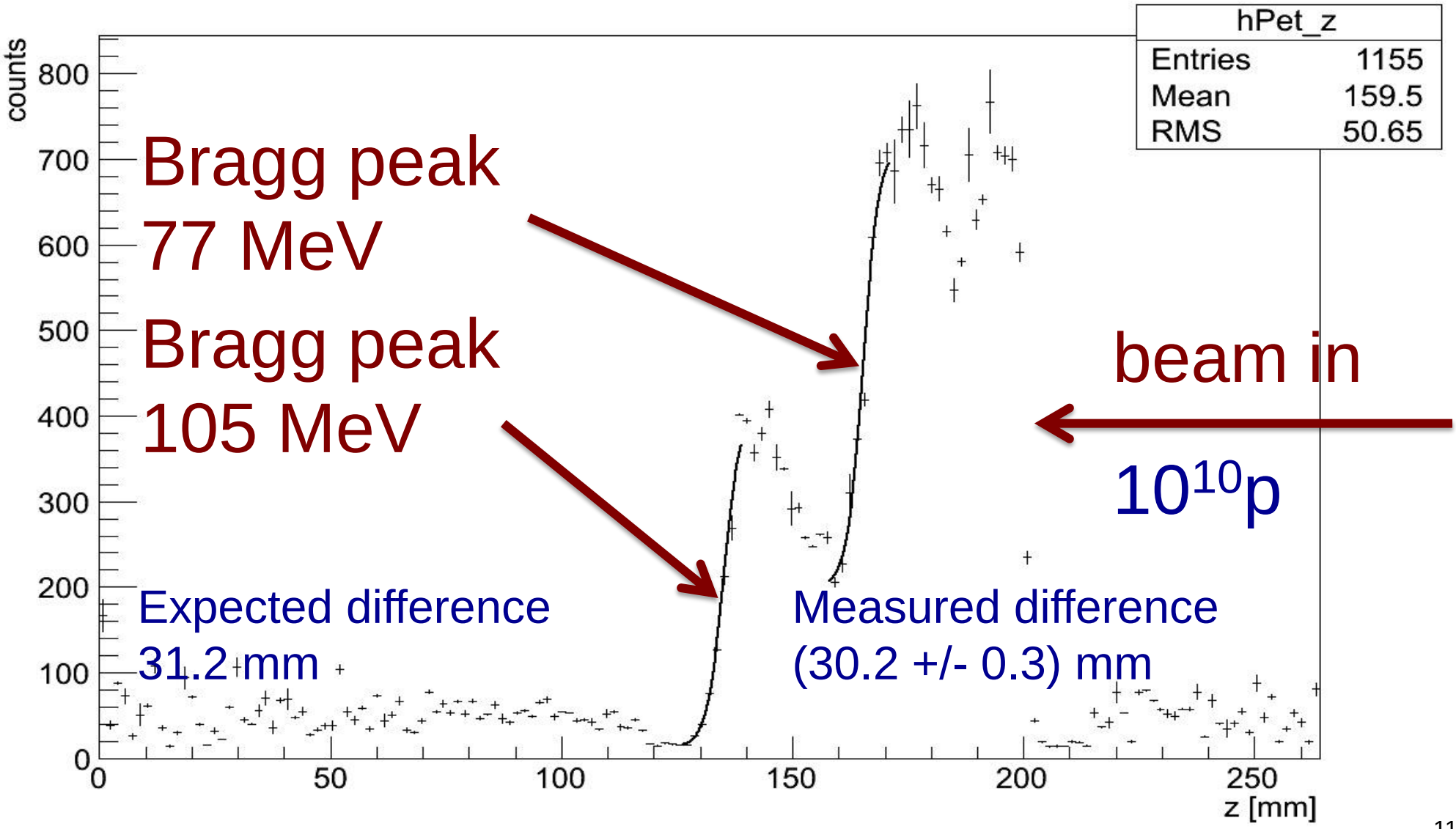
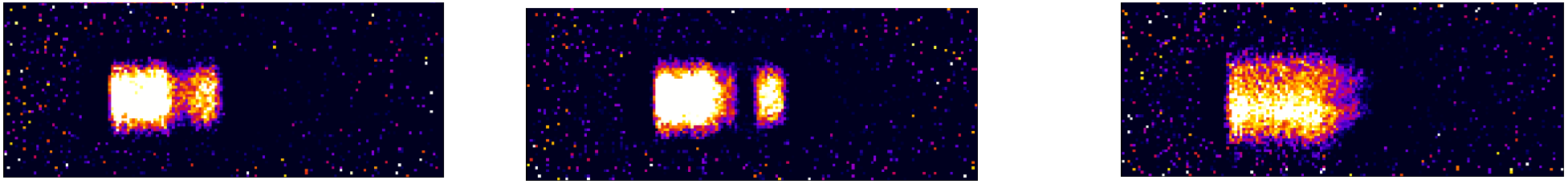


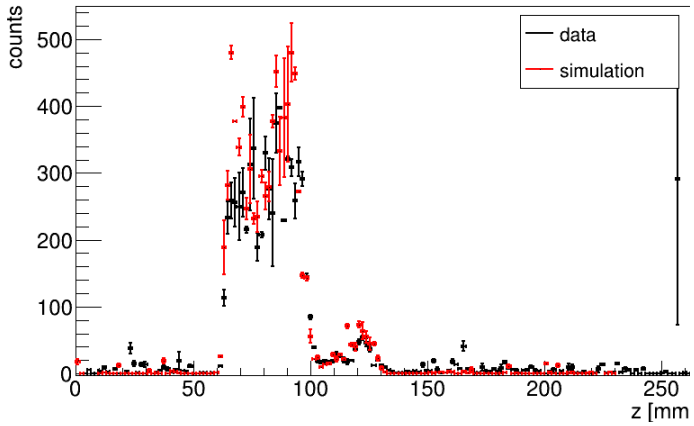
Image and profile reconstruction

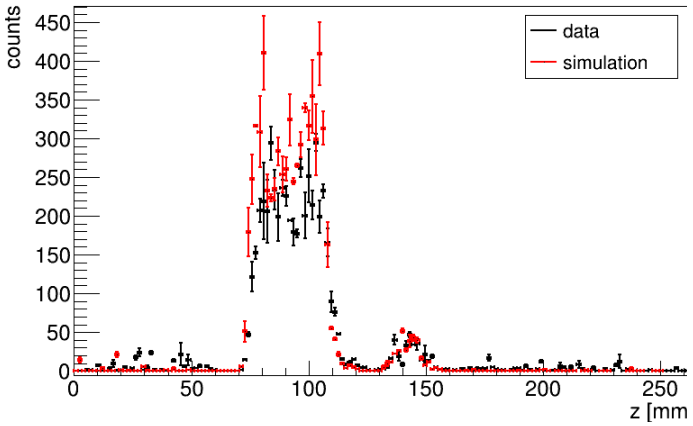
Preliminary – 25/02/2016
NO AFTER TREATMENT

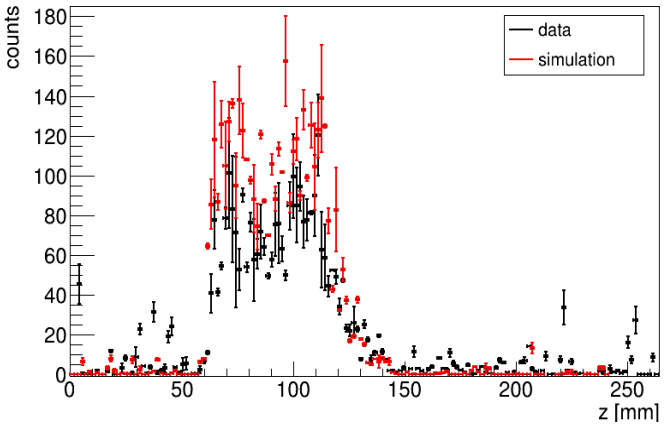
A B D



Data Simulation beam →





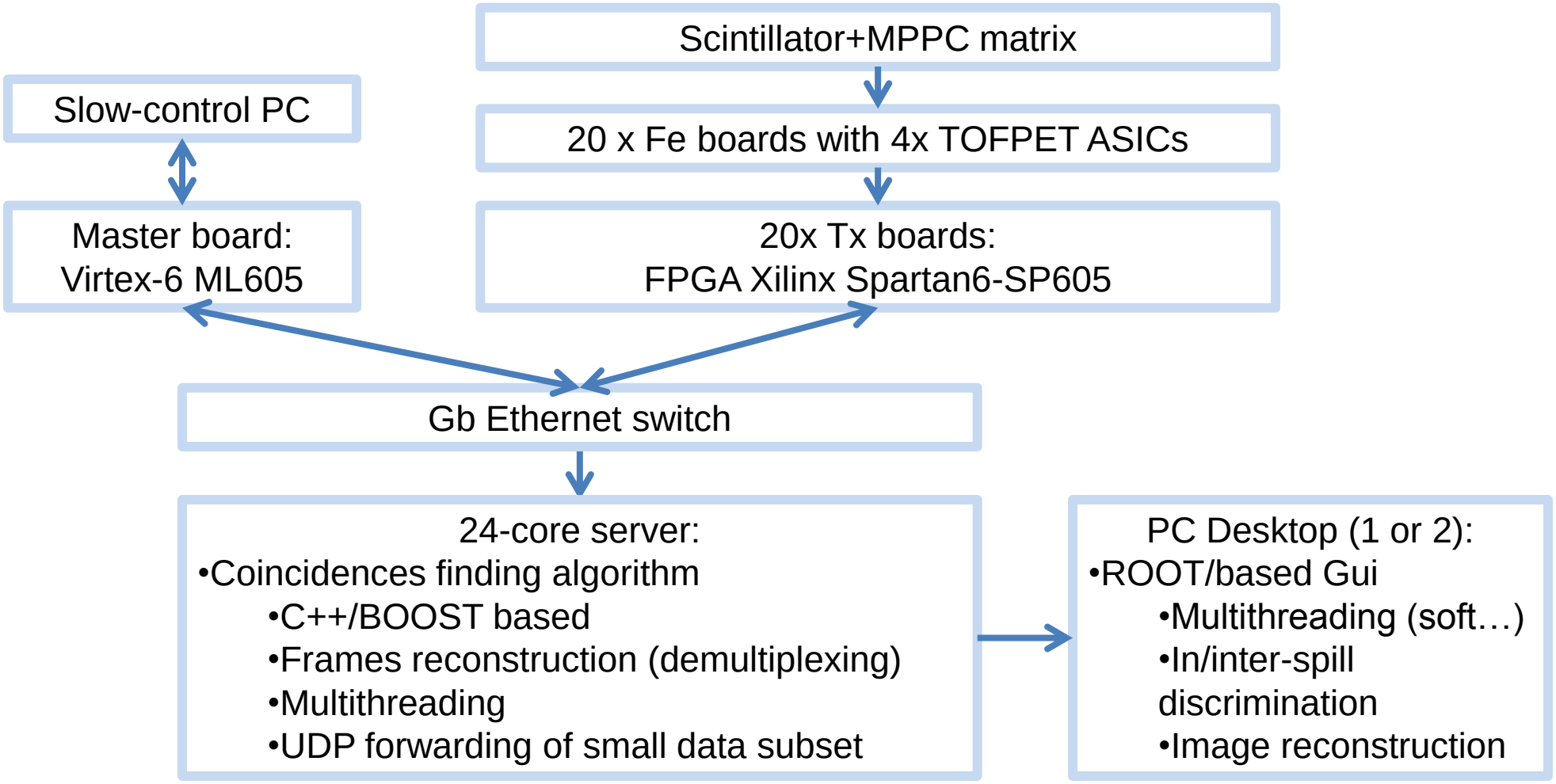


PMMA phantom
2 slices 2.7x2.7 cm^2 (E_1 = 77 MeV, E_2= 105 MeV)
Acquisition time = 254 s

PMMA phantom with hole
2 slices 2.7x2.7 cm^2 (E_1 = 77 MeV, E_2= 105 MeV)
Acquisition time = 155 s

PMMA phantom
Real treatment plan (E_{min}= 76.6 MeV, E_{max}= 124.5 MeV)
Acquisition time= 133 s

The INSIDE in-beam PET DAQ chain



Data processing

Tasks to performed online:

- Data quality monitoring (Gui)
- Energy threshold and **coincidences finding** (high performance dedicated machine and code)
- In-spill and inter-spill discrimination (if applicable)
- MLEM 3D image reconstruction – as soon as enough data is collected
- On-line comparison with expected image

DAQ development and upgrades

Software:

- Developed since project start
- Common C++ framework for analysis of simulation and data
  -> flexible and OO
- Crucial for system check and debug
- Feedback and new functionalities found and implemented on firmware

Firmware:

- Developed since project start
- Basic functions implemented first
- New functionalities added later (i.e. data decoding, calibration and energy threshold)
  ->lower data rate to be processed online by the coincidence finder

Future possible improvements:

- Next-gen (7) FPGA
- System-on-chip Rx layer
  - Fine TDC calibration LUT applicable (consequences: TOF)
- On-line accelerator information brought to DAQ -> finer data matching

In-beam PET simulations

STEP 1 (treatment): Beam simulation

About 1/1000 of primary hadrons, **custom simulation**

Time-tagged activity scoring

- Annihilation time and position (gold standard)
- Isotope production map

STEP 2 (detector): PET simulation

All positrons are simulated.

Detector simulation
(time and energy deposition)

1000x

digitization

Data analysis & PET image reconstruction

Same as real data:

- Line Of Response (LOR) list extraction
- Image reconstruction (MLEM algorithm, 5 iterations)

In-beam PET heads simulated geometry

- Simulation time: about 8 h (32-core)
- It is all about number of CPUs (low memory/disk requirements

In-beam PET simulations: future challenges

Goal: improve **simulation speed**

•Treatment is based on pencil-beams: **easy parallelization**

•Simulation simplification: **bias**, more aggressive energy cuts, simplified transport

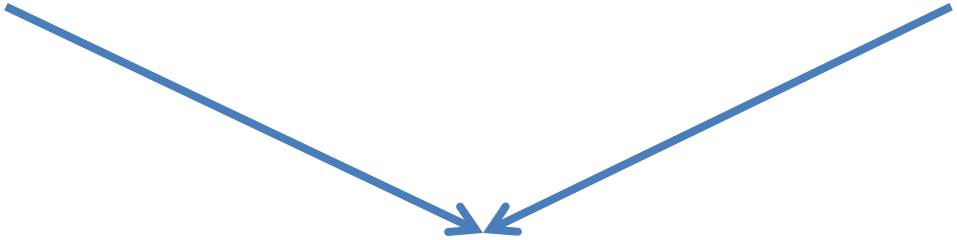
•Use of new non-standard tools (planIT?)

•GPU for image reconstruction

Goal: improve **simulation accuracy**

•More accurate reproduction of beam structure (i.e. beam delivery time may not be exactly known a priori)

•Accurate bias and simulation of significant processes other than beta+ decay



Ultimate Goal: fast detector response simulation

•On-line accurate monitoring for cyclotrons and fast duty cycle synchrotrons

•Easier deconvolution of data from background during beam delivery

Conclusions

- Real-time monitoring is a key to fully exploit hadrontherapy
- Different techniques with strengths and pitfalls
- All need reference data to be compared with
- Good preliminary indications from INSIDE in-beam PET test with phantoms
    - Data acquisition in-beam without modification of CNAO clinical workflow
    - Accurate range measurament
- Data acquisition and process require (ongoing) effort on features design
- Simulation validation and accuracy is crucial for HT monitoring
- Simulation speed is a key to extent its purposes

Acknowledgements

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