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Universita' and INFN Pisa
On behalf of the INSIDE collaboration

The INSIDE project

ENLIGHT Annual Meeting, June 13th, 2017
Aarhus University Hospital, Skejby



Rationale for in-vivo range monitoring

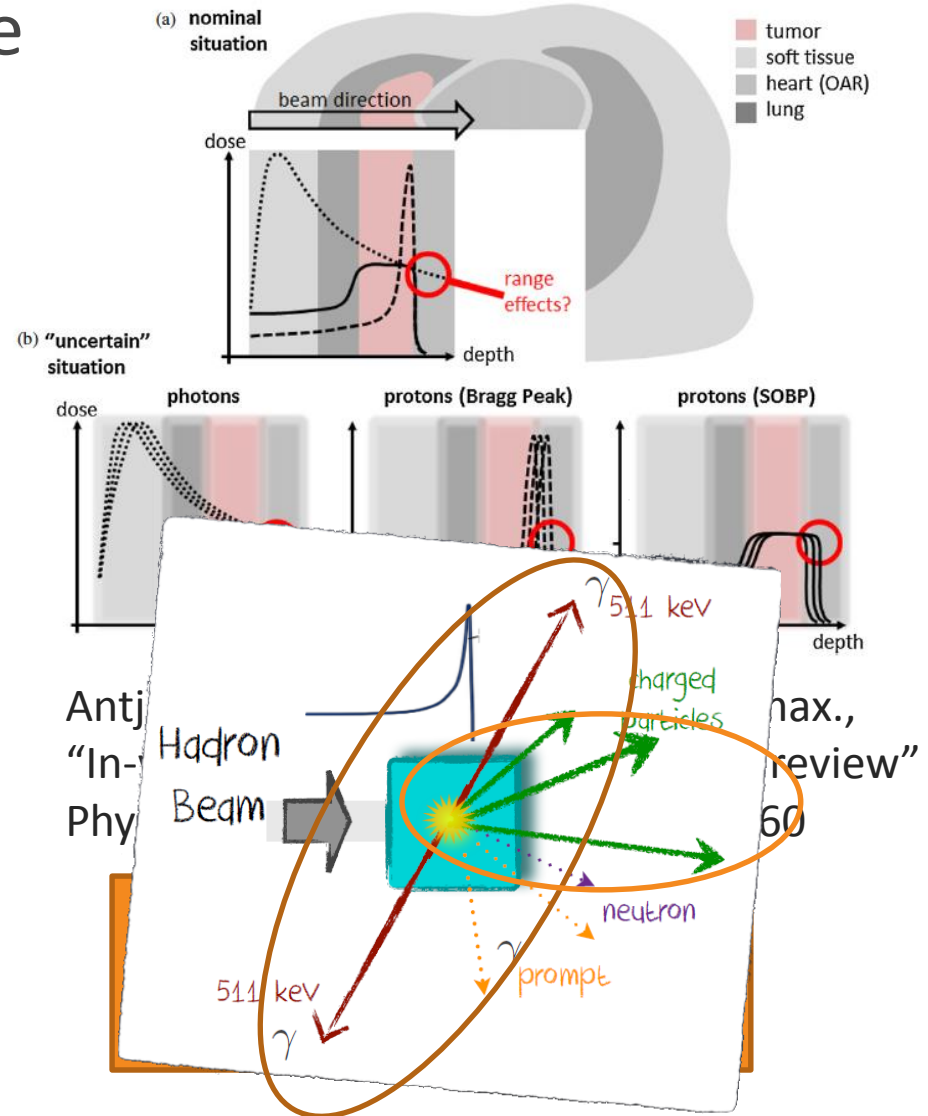
Ion therapy is highly sensitive to range uncertainties:

Planning

- Imaging artifacts
- Conversion CT HU to stopping power
- Biological models

Treatment

- Anatomical changes
- Patient positioning
- Inter/Intra-fractional Motion



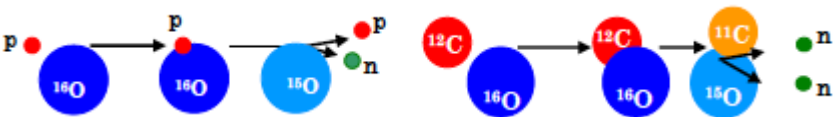
The *InSide* Project

DOSE PROFILER
Prompt secondary
particles imaging

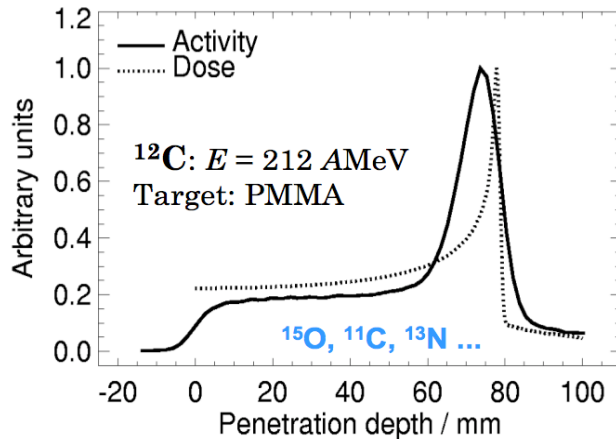
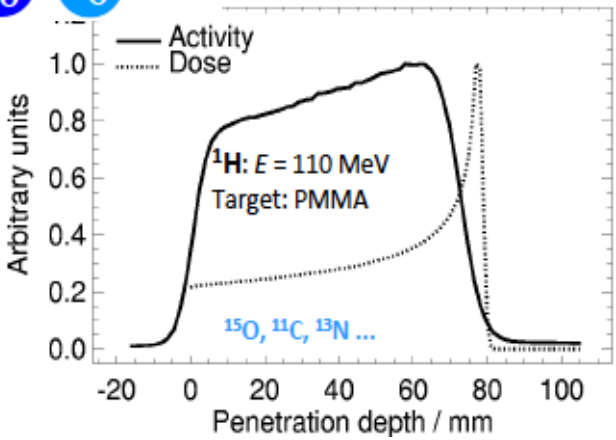
BI-MODAL IMAGING SYSTEM
for particle range monitoring and verification



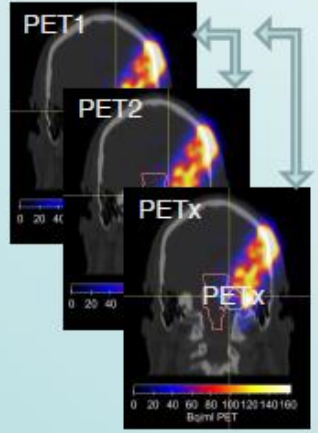
PET-based treatment verification



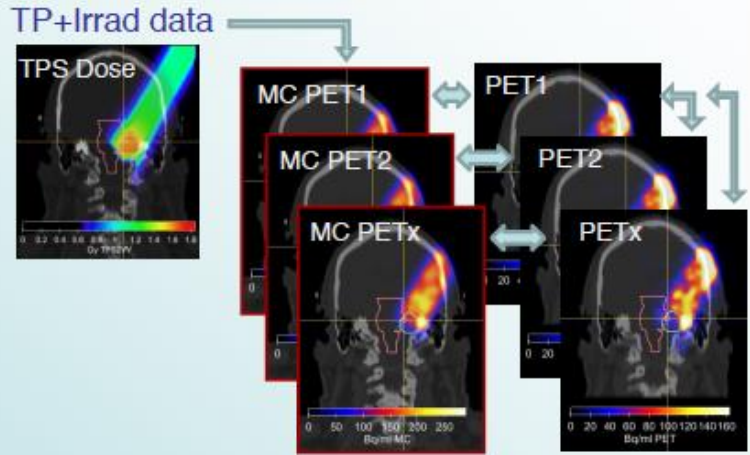
- Main contribution:
- ^{11}C ($T_{1/2} \approx 20.3$ min)
 - ^{10}C ($T_{1/2} \approx 19.3$ s)
 - ^{15}O ($T_{1/2} \approx 2.0$ min)
 - ^{13}N ($T_{1/2} \approx 10.0$ min)



Inter-fractional comparison:
 $\text{PET}_x - \text{PET}_1$
 → **Reproducibility**



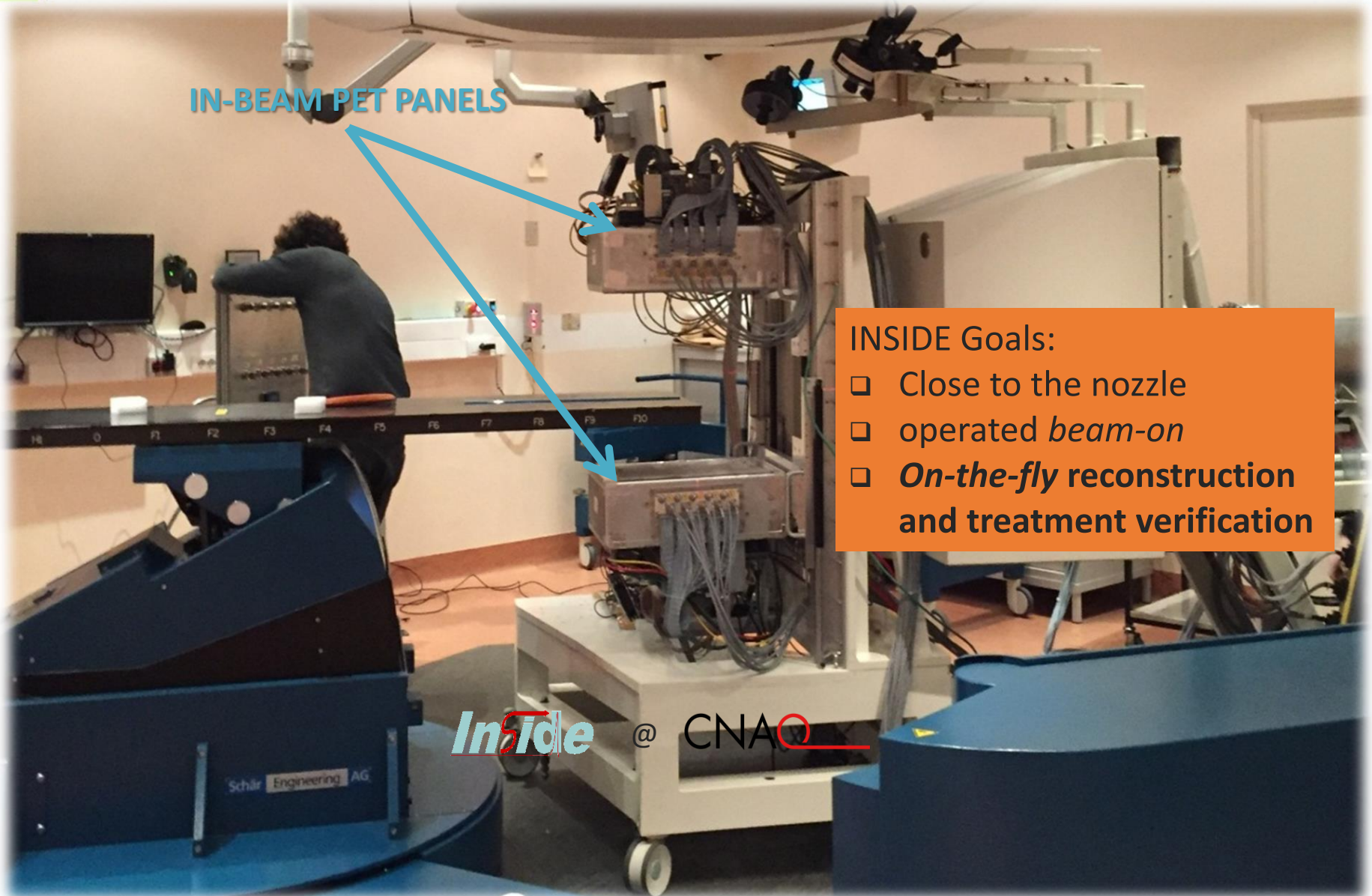
Comparison to expectation (MC):
 $\text{MCPET}_x - \text{PET}_x$
 → **Accuracy & Reproducibility**



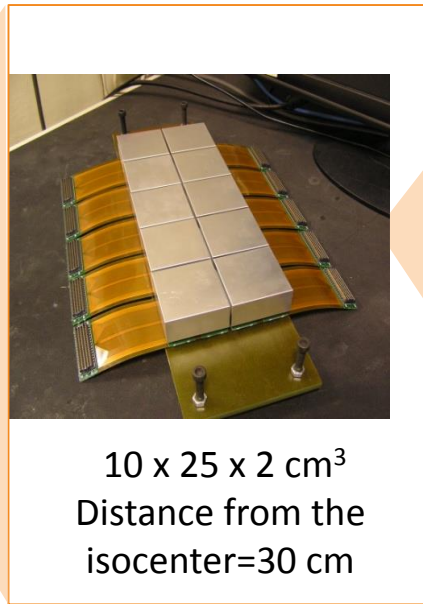
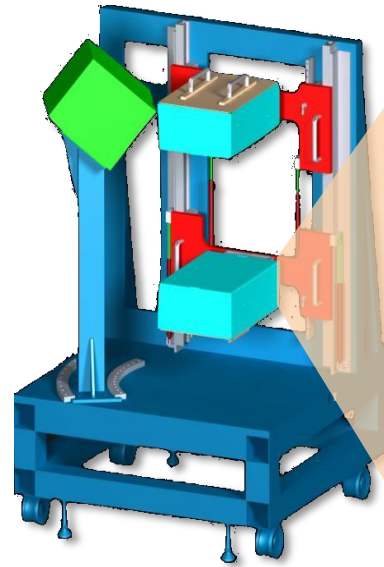
J Pawelke et al., Proceeding: Ion Beams in Biology and Medicine (IBIBAM), 26.-29.09.2007, Heidelberg, Germany

Courtesy of J. Bauer, HIT

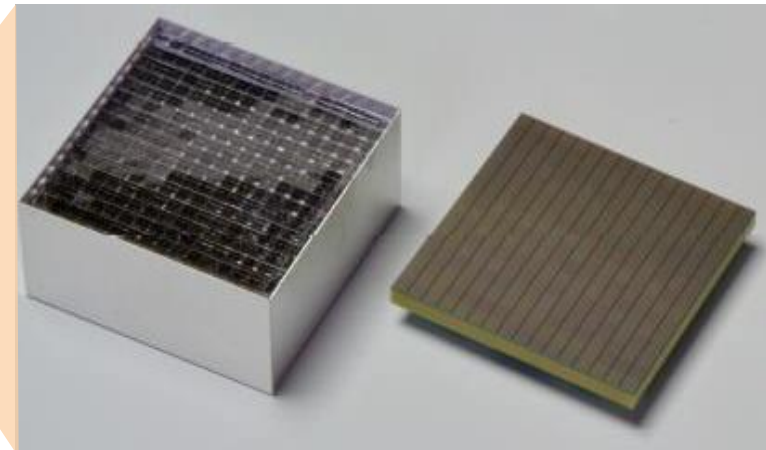
In-beam PET



In-beam PET Panels



10 x 25 x 2 cm³
Distance from the isocenter=30 cm



256 LFS pixel crystals (3x3x20mm³) coupled one to one to MPPCs (Multi Pixel Photon Counters, SiPMs).

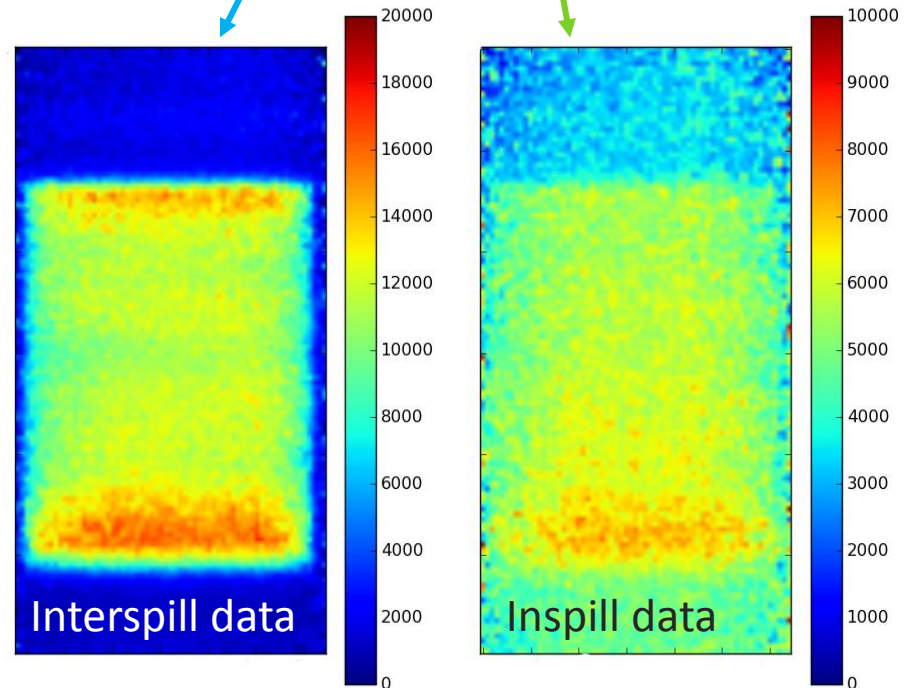
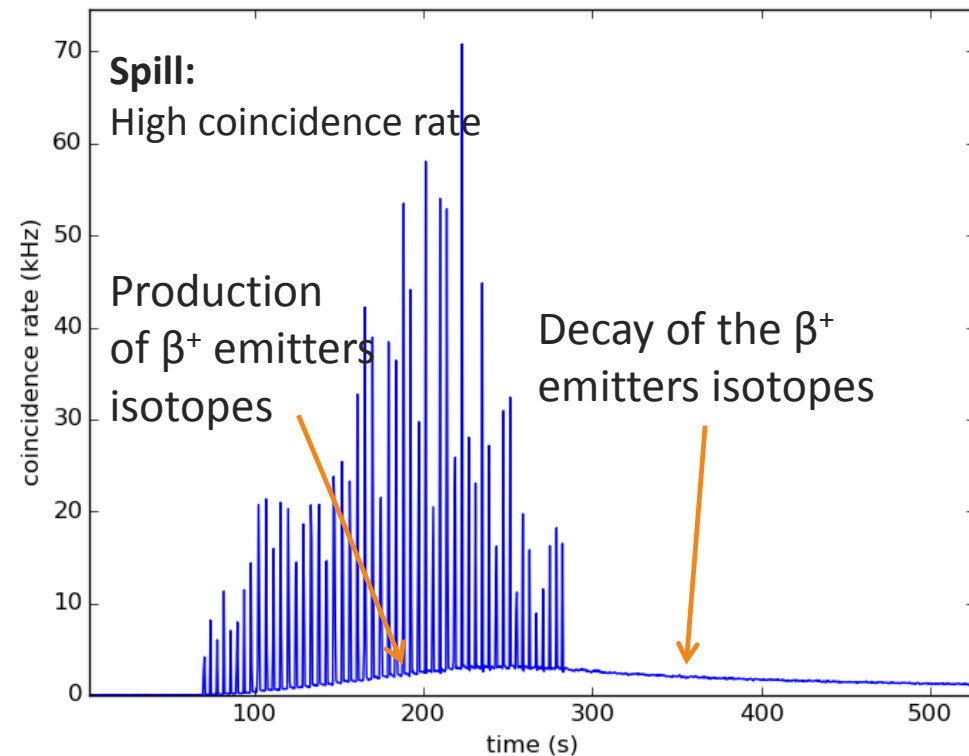
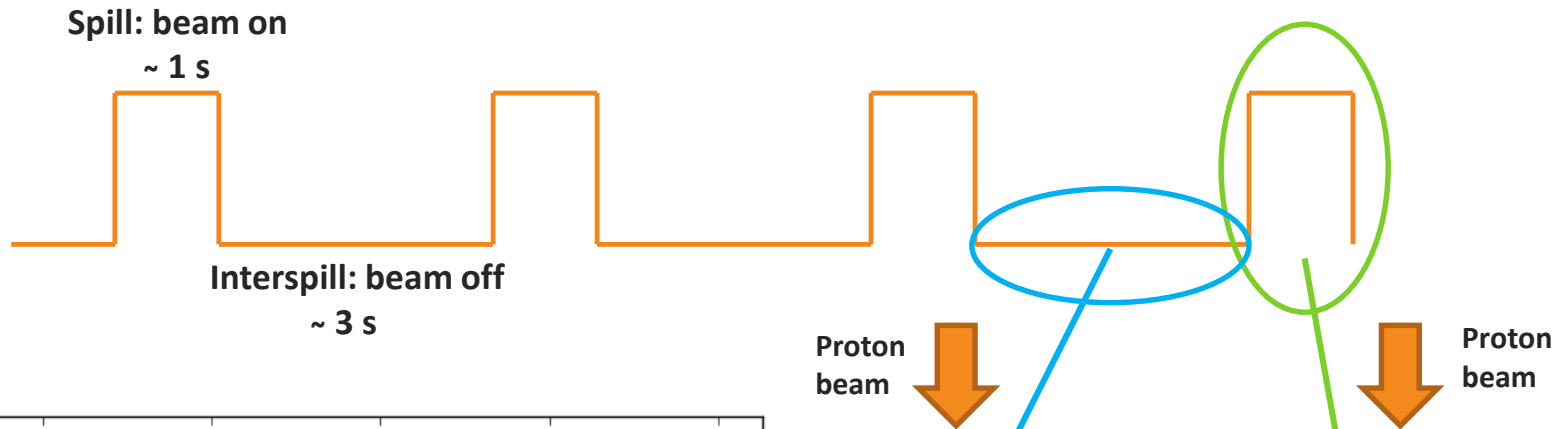
20xFE board
(4 Tofpet ASIC^[1] each)



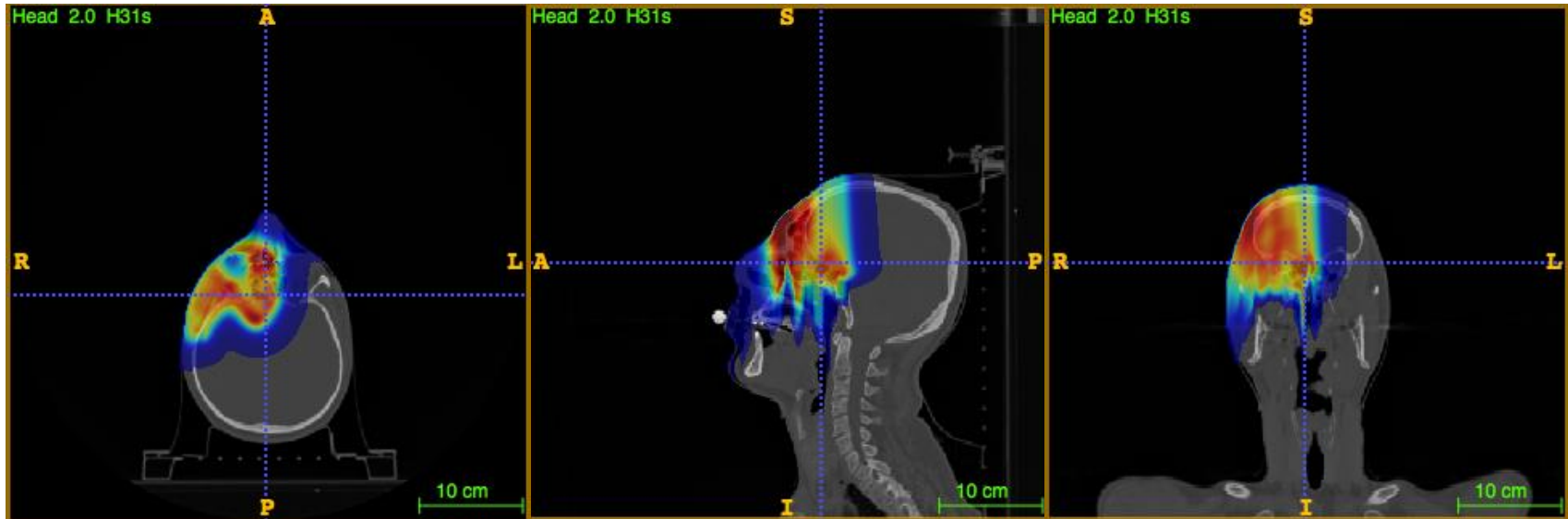
20xFPGA Xilinx
Spartan6-SP605

[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).

Data selection

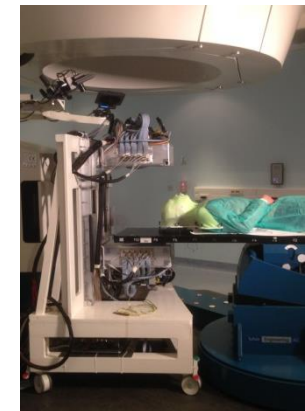


Planned dose



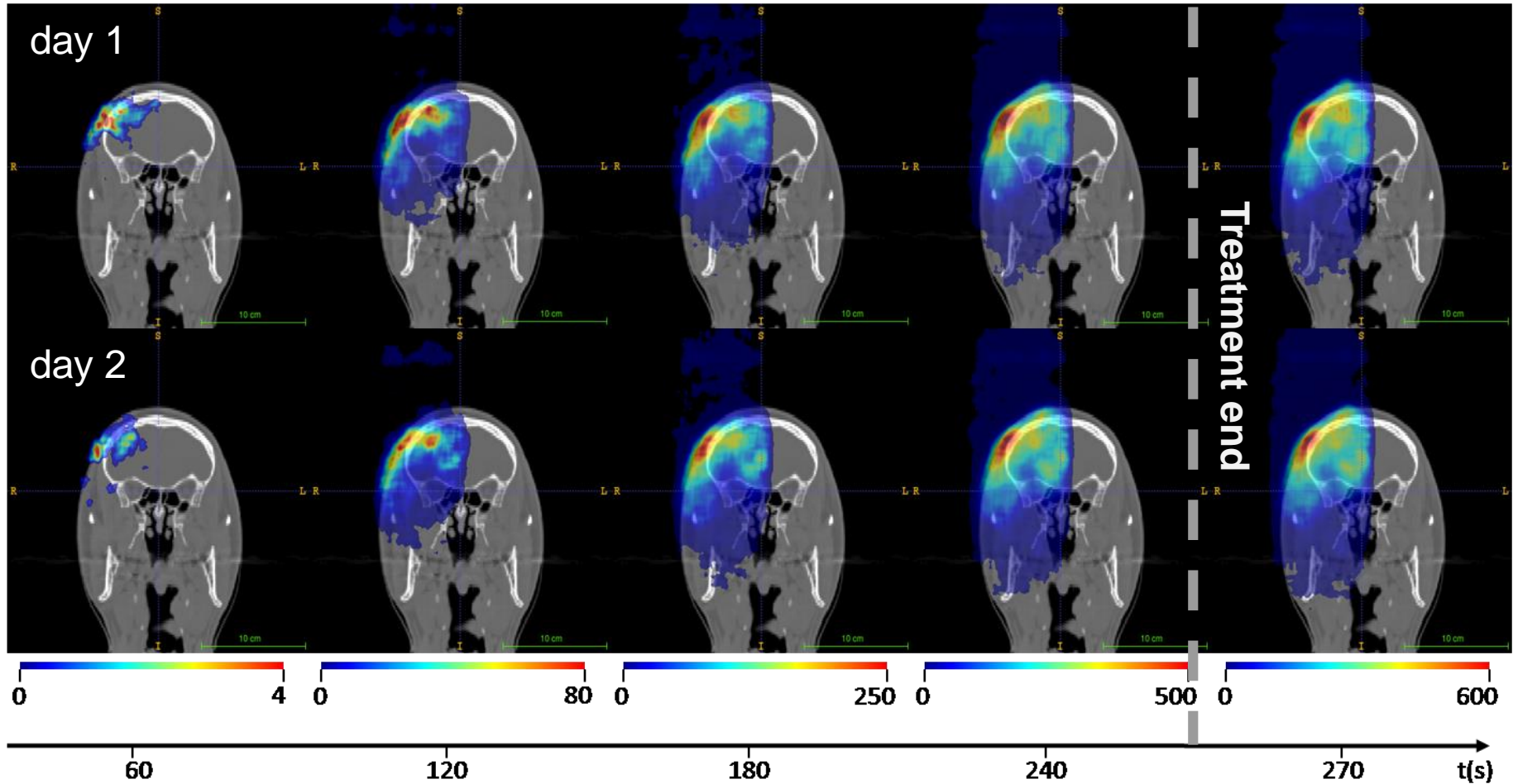
Carcinoma of the lacrimal gland
 $3.7 \cdot 10^{10}$ protons
[66.3, 144.4] MeV/u
(28-29)/30 fractions, 2.2 GyE
Vertex field

240 s treatment + 30 s
after-treatment of
data acquisition

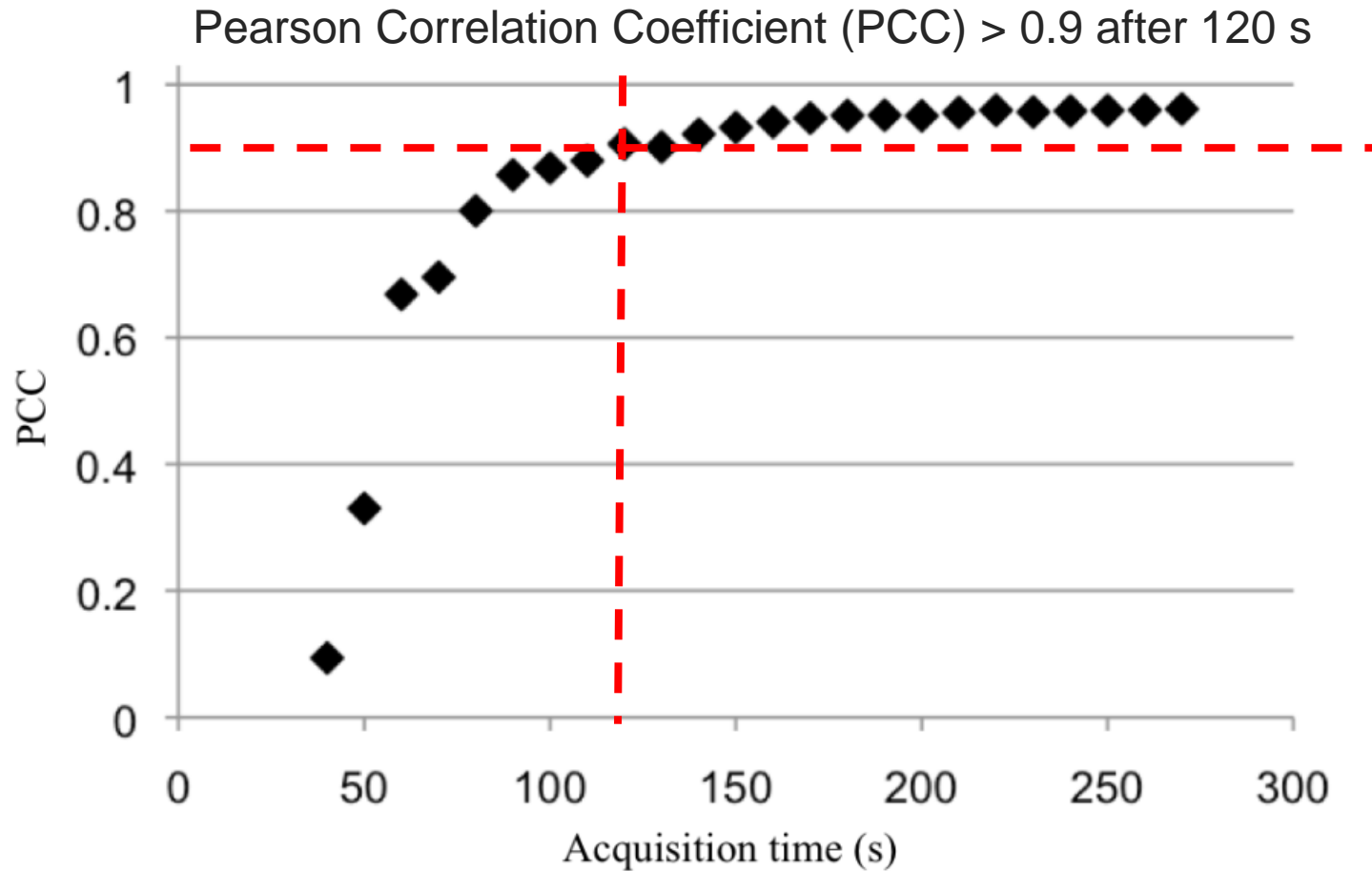


Time-resolved image reconstruction

Measured activity

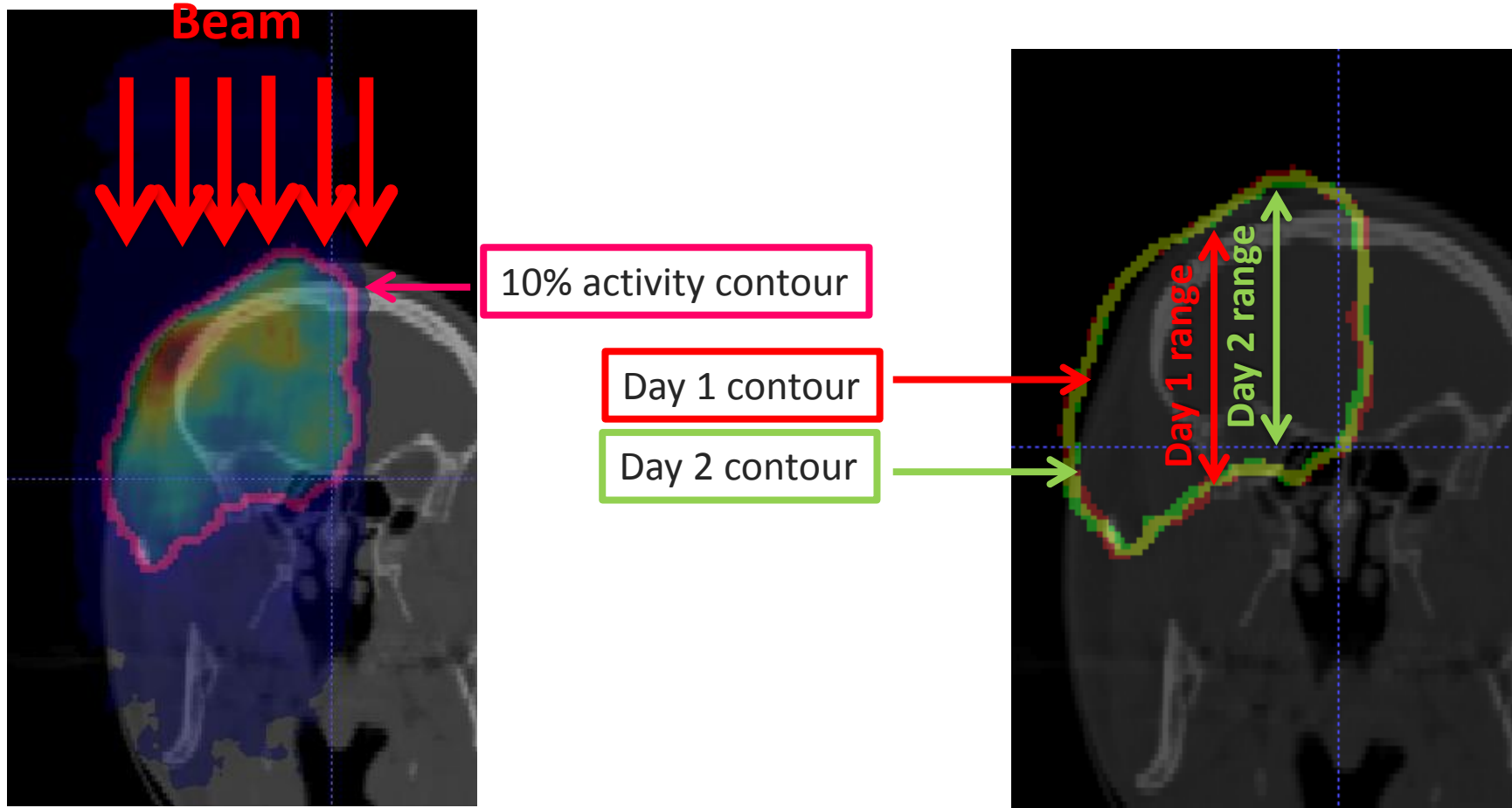


Quantitative comparison 1

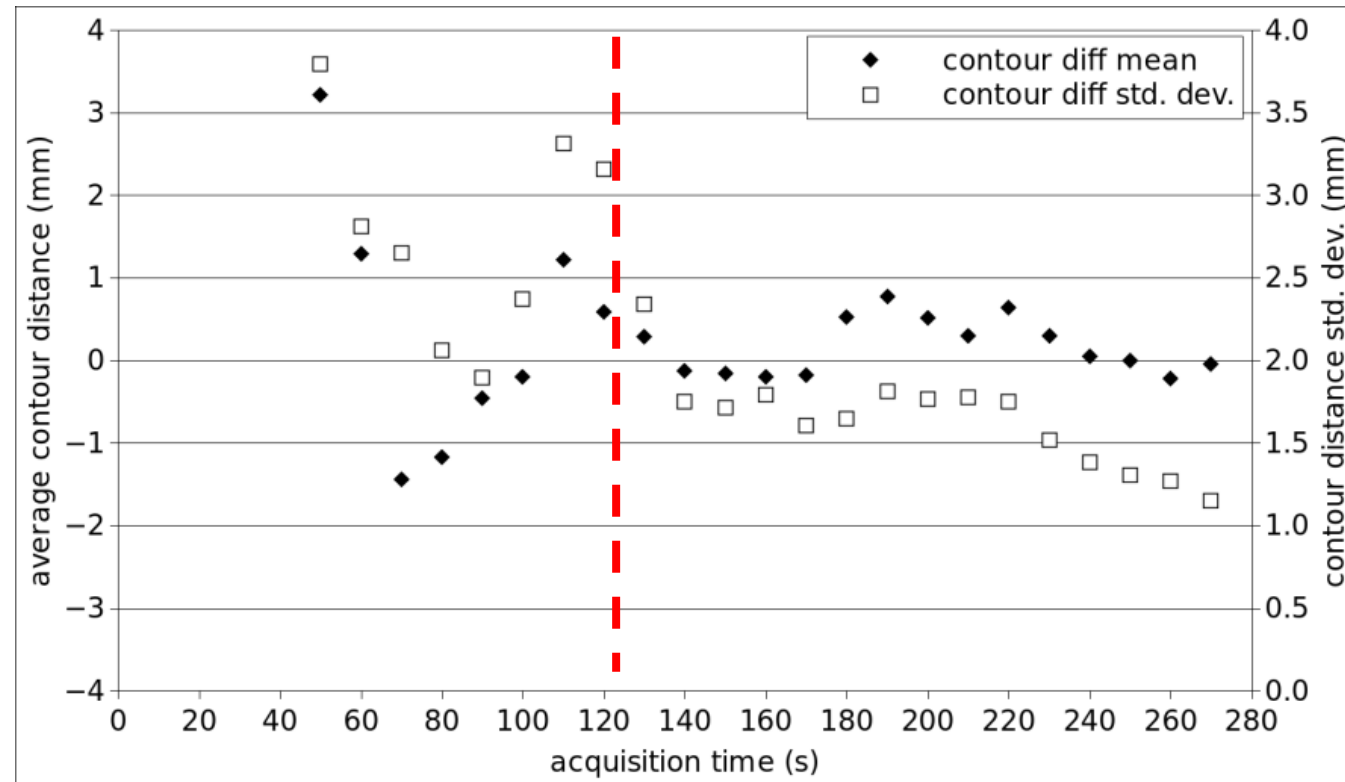
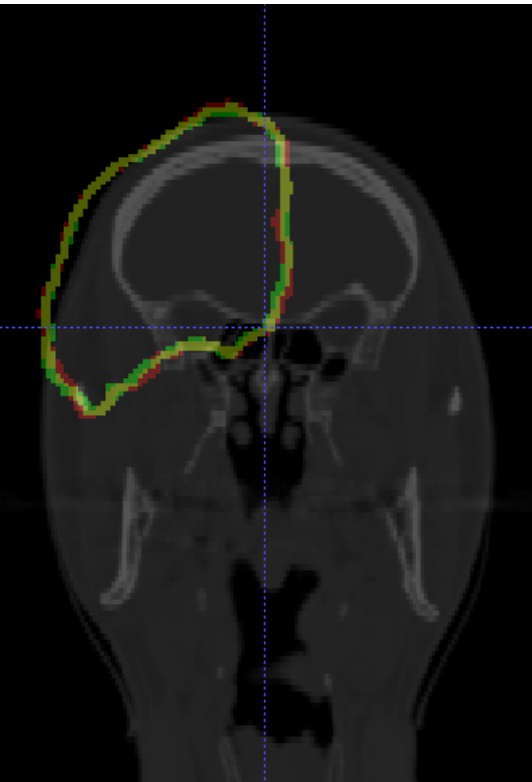


Kuess P, Birkfellner W, Enghardt W, Helmbrecht S, Fiedler F, Georg D. Using statistical measures for automated comparison of in-beam PET data. Med Phys. 2012 Oct;39(10):5874-81.

Quantitative comparison 2



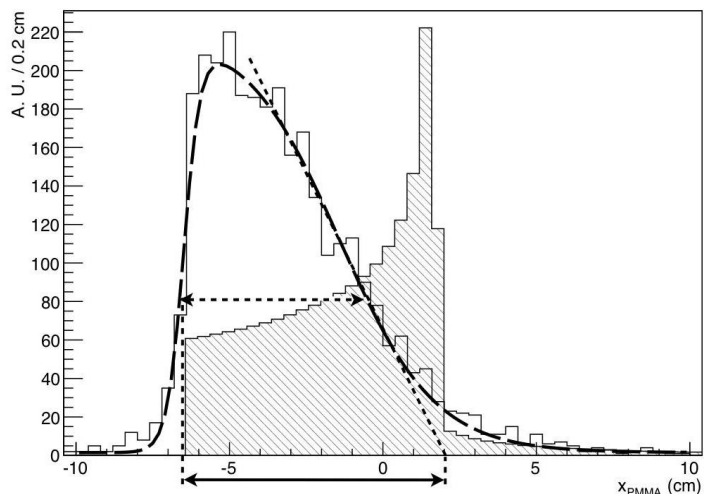
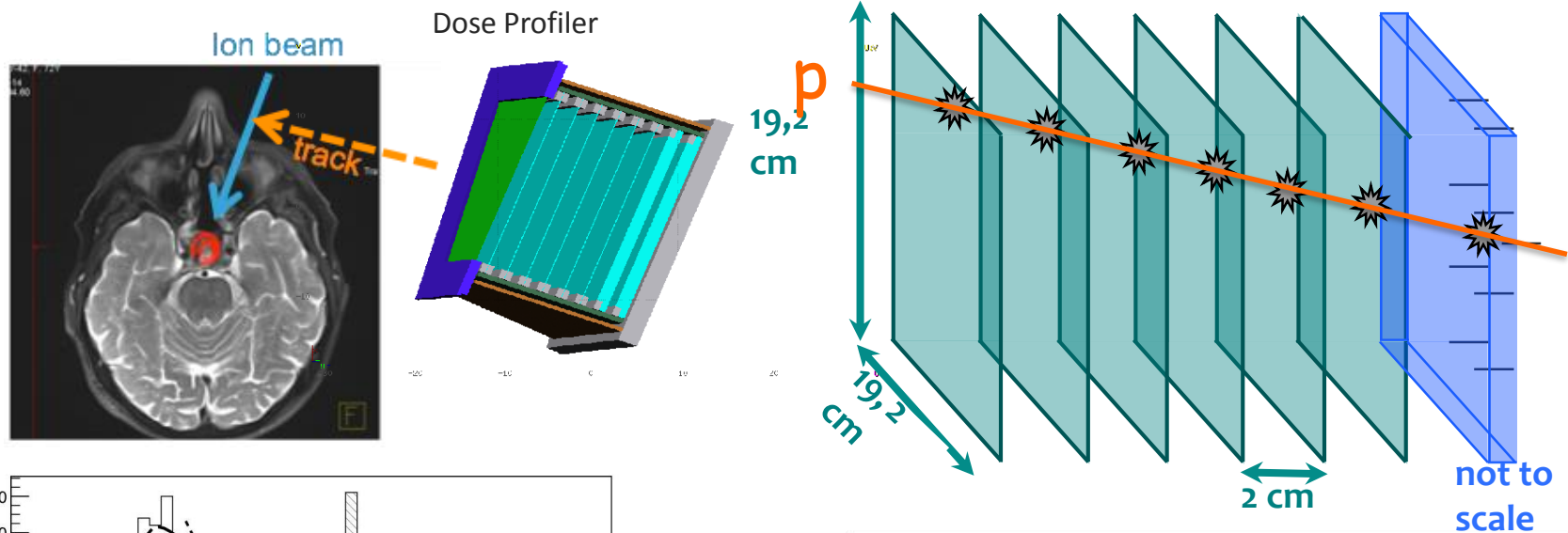
Quantitative comparison



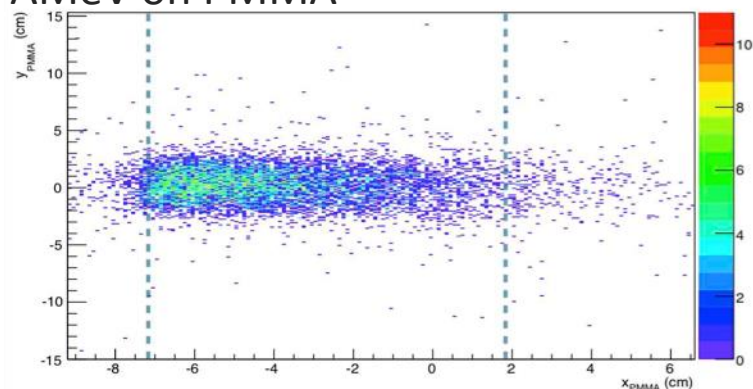
Comparison → after 120 s avg. contour distance < 1 mm

Dose profiler

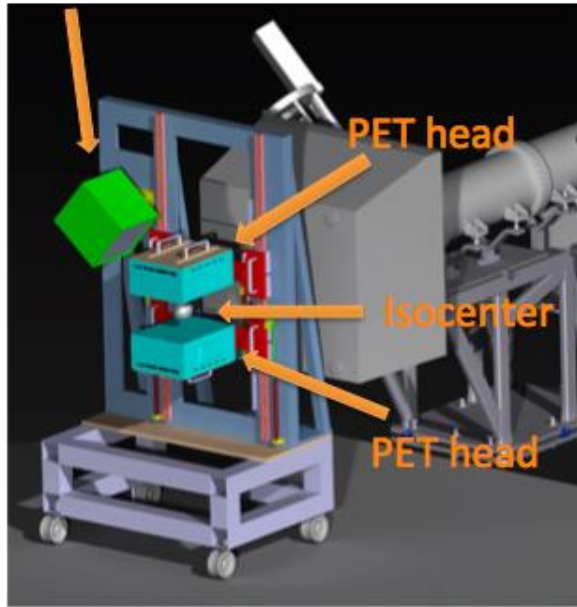
Charged fragments production is an high cross section process in the interactions of He, C and O beams and is hence particularly suited for monitoring applications of those beams.



C 220 AMeV on PMMA

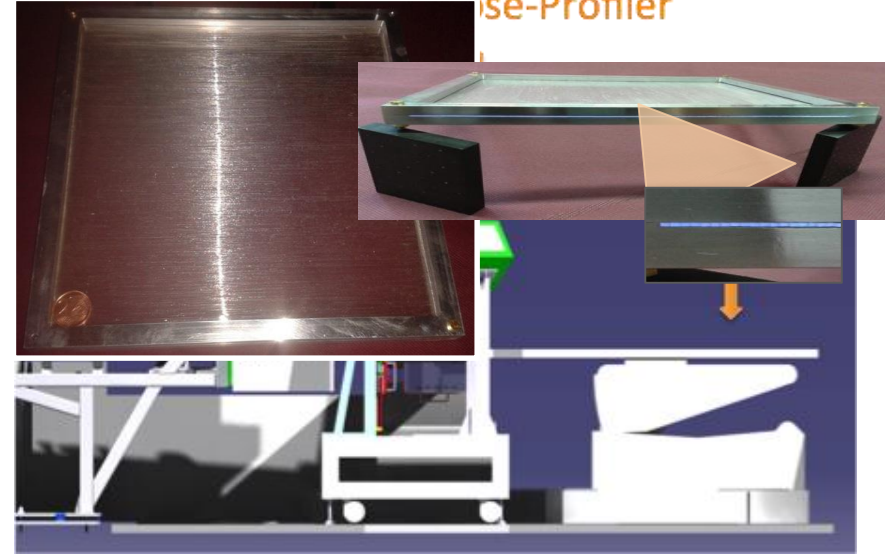


Dose-Profiler



Two independent XZ and YZ views (fibres layers), to be used for 3D tracking

Beam exit window



cooling aluminum plates



particles entrance window

Readout electronics (BASIC-32)

FPGAs cooling aluminum plates

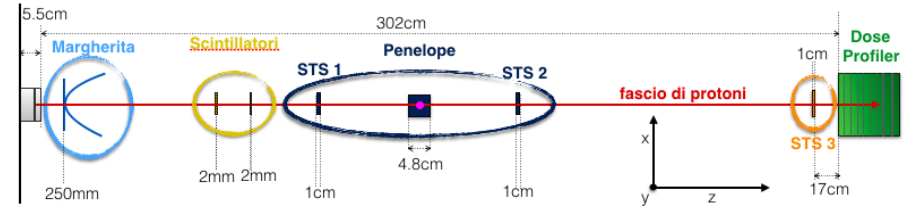
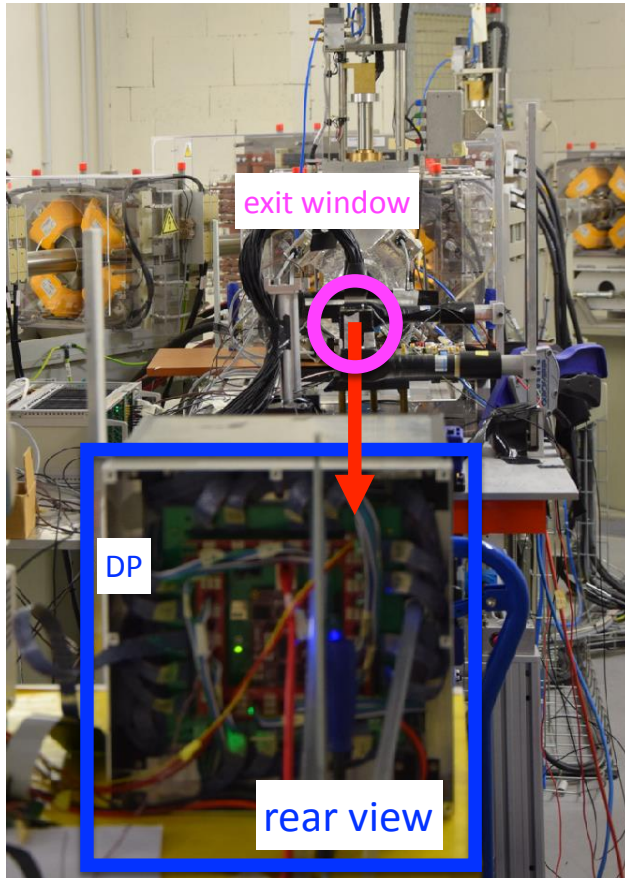


Global event collector (FPGA)

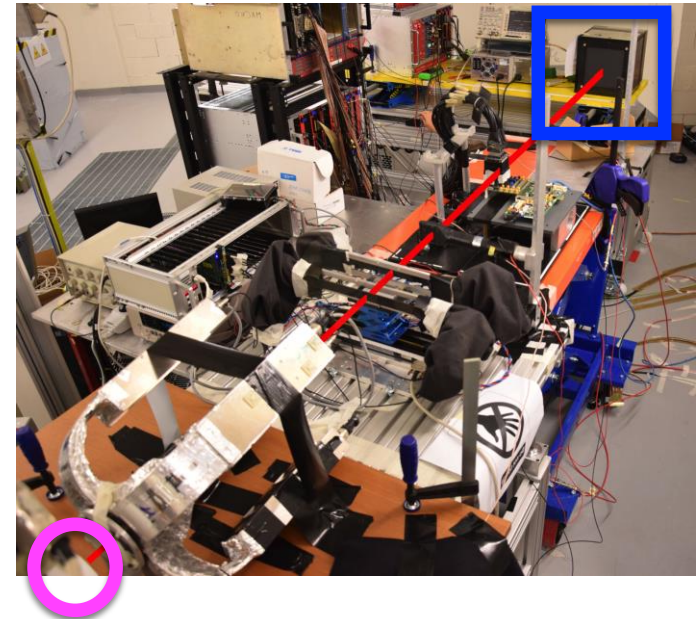
FPGAs (readout control)

Benchmarking the performances with protons

Trento Proton Therapy Center (CPT)

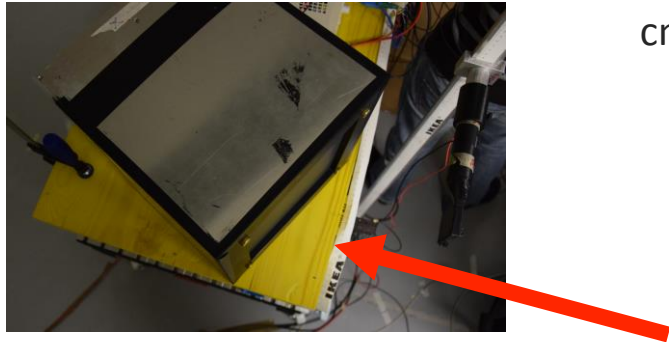


Beam direction from exit window towards DP

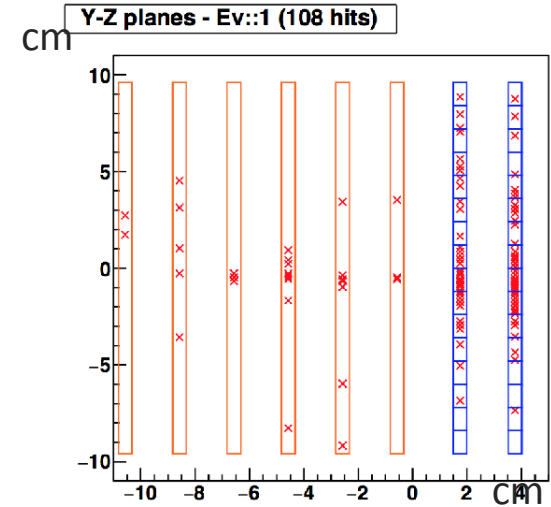
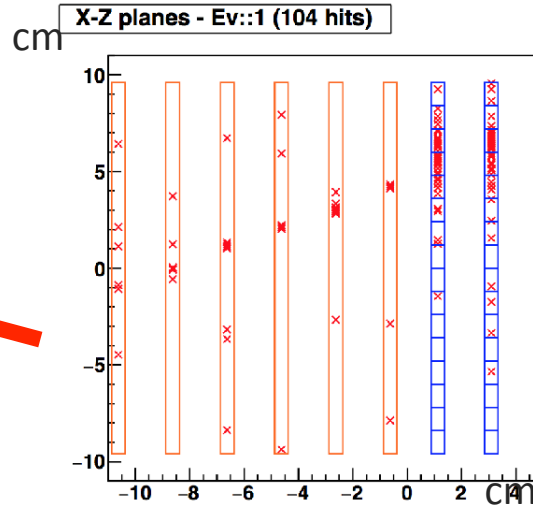


Courtesy of Alessio Sarti and Giacomo Traini, University of Rome "La Sapienza"

Track reconstruction



Events collected with DP tilted in XZ plane wrt beam direction

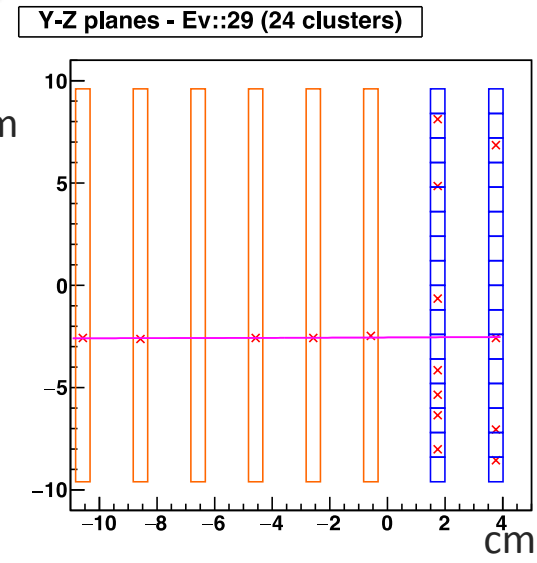
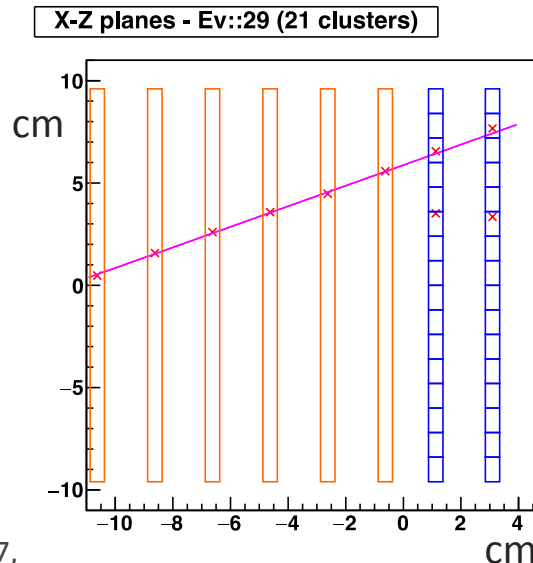


The hits relative to different fibres are clustered together using a proximity criterium, clusters that have a charge consistent with a proton release, are then identified and passed to the tracking algorithm (Hough transform) in the XZ and YZ views.

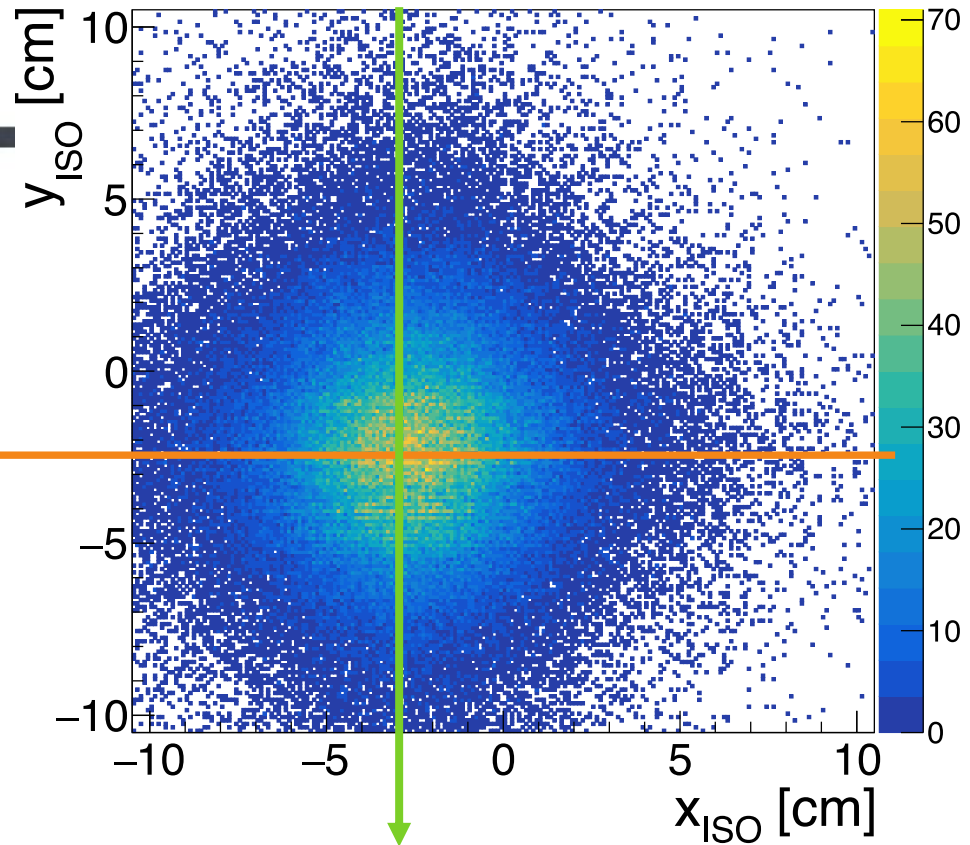
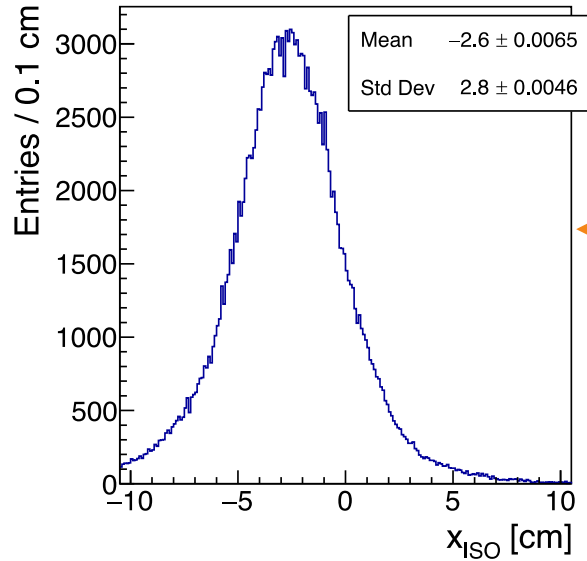
The optimisation of the noise reduction cuts is still ongoing



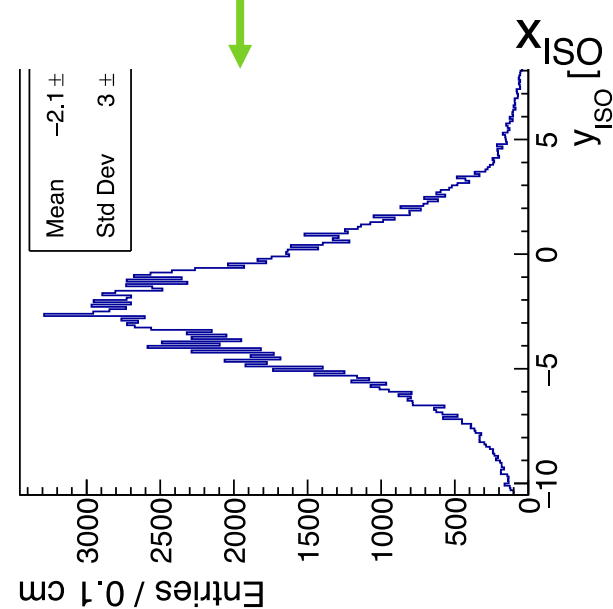
After clustering and noise reduction



Beam Spot



Beam spot reconstructed at
the beam isocenter
106 MeV protons
Recon SD 2.8-3 cm
Expected SD 0.7 cm
Multiple scattering in the
materials between nozzle and
DP



Conclusions

Bi-modal imaging system for range monitoring and verification

- **In-beam PET**

- performances assessed with protons
- **First measurement during patient treatment**
- **Time-resolved and on the fly reconstruction**

- **Dose profiler**

- Preliminary Performance tests w protons

- **Future steps:**

- Test with carbon beams
- Integration profiler-PET
- Integration with CNAO clinical workflow



INnovative Solutions for In-beam DosimEtry in Hadrontherapy

-Project supported by Ministero dell'Istruzione, dell'Università e della Ricerca of the Italian government under the program PRIN 2010-2011 project nr. 2010P98A75 – Principal Investigator **Maria Giuseppina Bisogni, University and INFN Pisa**

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Sandro Rossi, Guido Baroni, Mario Ciocca, Giuseppe Venchi, Francesca Valvo, Sara Tampellini, Franco Gerardi, Arianna Serra, Maria Vittoria Livraga

Thanks for your attention

