DoPET: an in-treatment monitoring system for particle therapy

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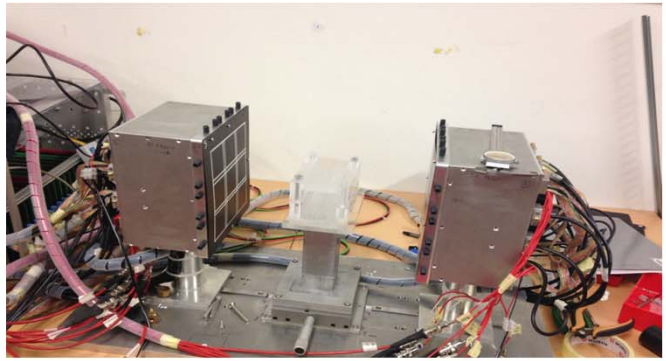
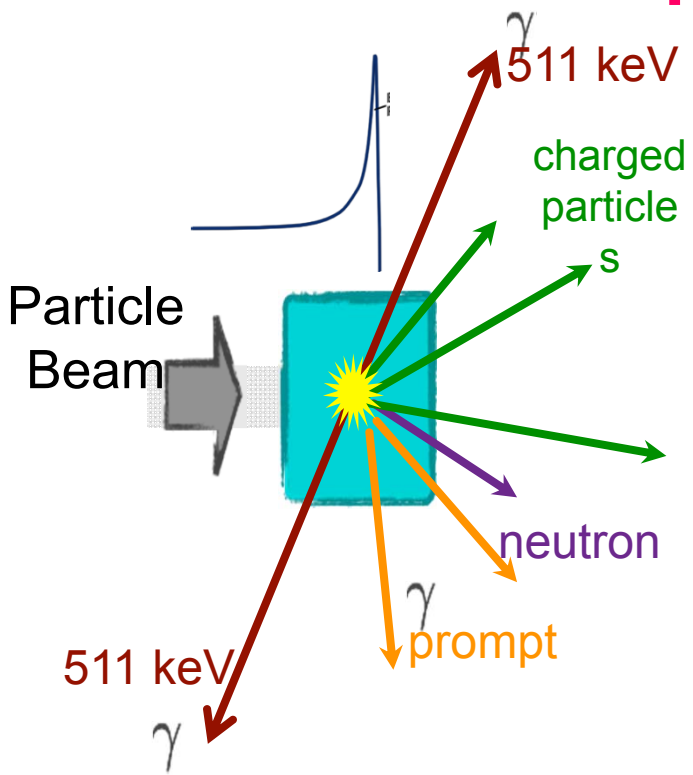


ICTR-PHE 2016

Proton therapy monitoring using PET



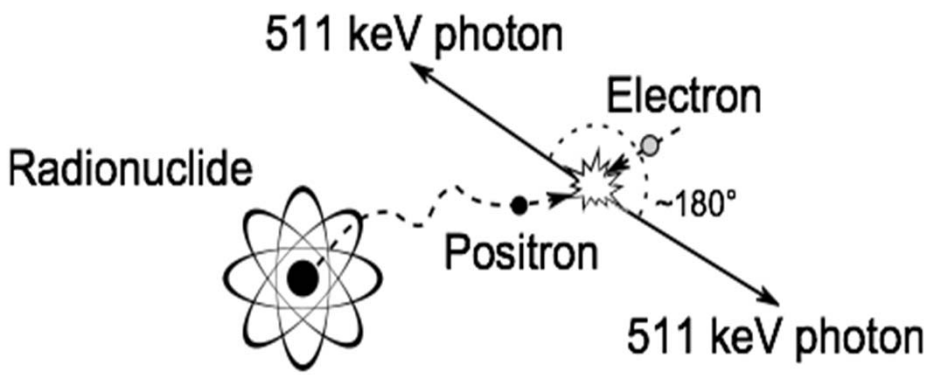
Proton as a projectile

Fragmentation of the target:

$^{16}O\ (p,n)\ ^{15}O$ $\qquad$ $^{12}C\ (p,n)\ ^{11}C$

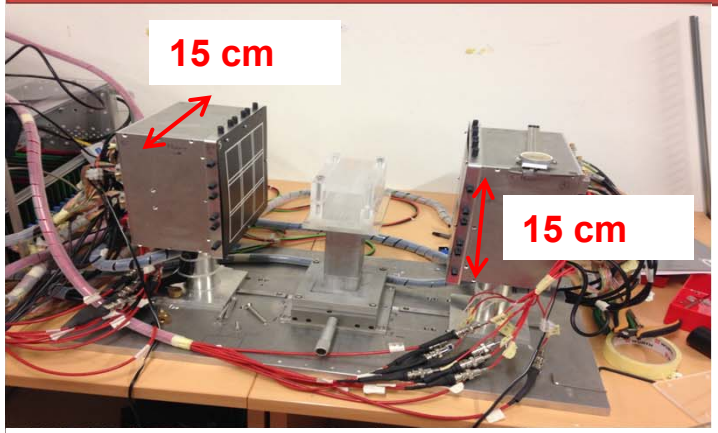
$\tau_{15\text{-}O}$=121.8 s $\qquad$ $\tau_{11\text{-}C}$=1222.8 s

[15-20 MeV threshold for p-induced nuclear reactions]

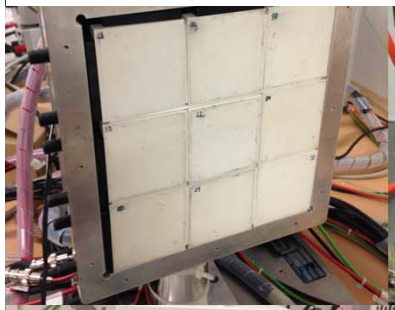


Measuring the β^+ activated volume we monitor the treatment

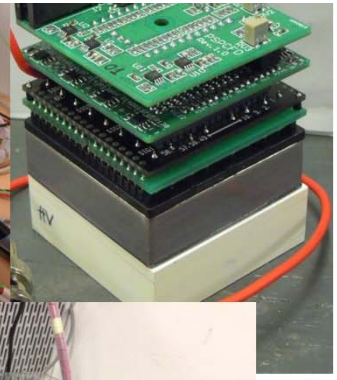
DoPET: 15 cm x 15 cm prototype

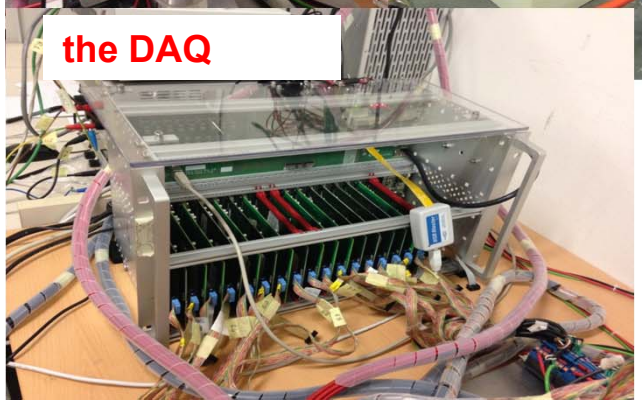


9 detecting modules



the single module





Detecting module 5cm x 5cm

- LYSO matrices, each 23 x 23 crystals, 2mm pitch)
- PS-PMT 8500 Hamamatsu
- Dedicated front-end electronics

- Modularized acquisition electronics
  - FPGA based acquisition and coincidence processing
  - Coincidence time window ~5 ns

➢3D-activity distribution is reconstructed with Maximum Likelihood Estimation Maximization (MLEM) Iterative algorithm

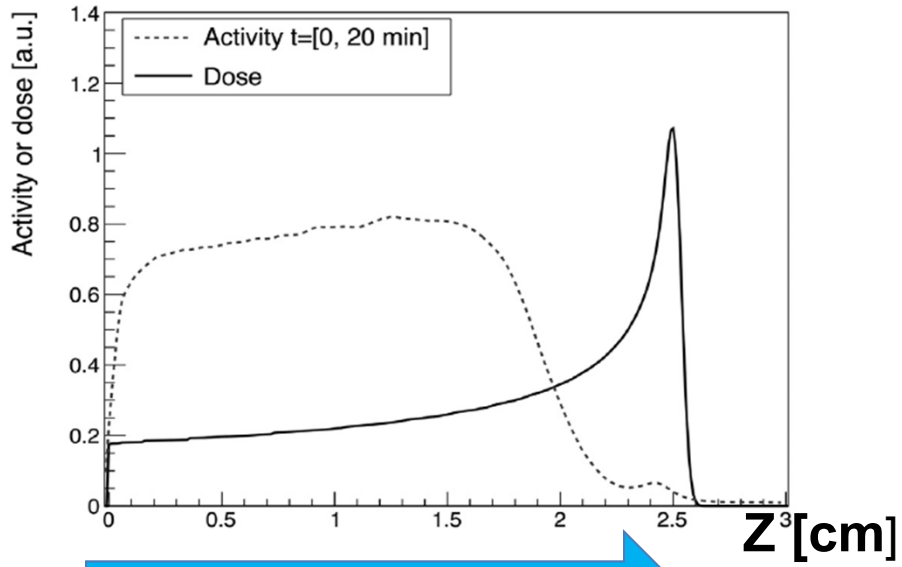
The reconstruction is performed in less than 1 minute (8 core Intel Xeon e5620 @2.4 GHz)

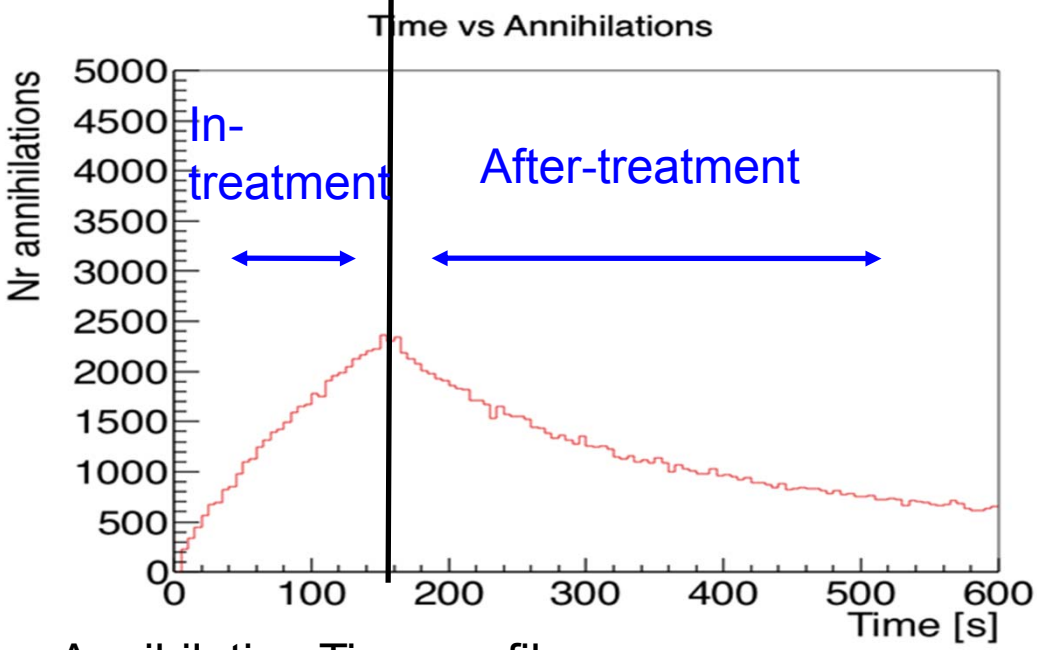
S. Vecchio et al., IEEE Trans. Nucl. Science 56 (2009) 51-56
G. Sportelli et al., IEEE Trans. Nucl. Science 58 (2011) 695-702
N. Camarlinghi et al., JINST 9 (2014) C04005 1-12

CATANA: expected activity profile (FLUKA MC)

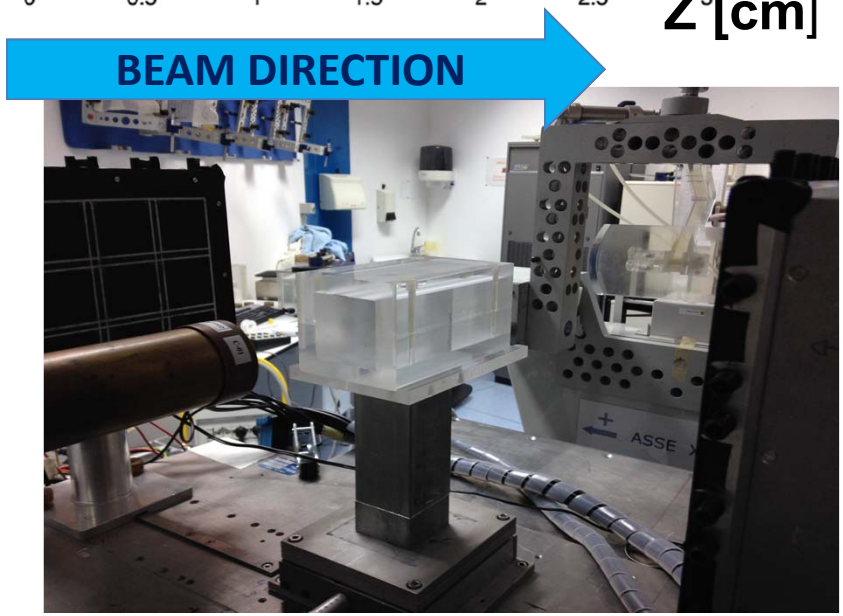
- **58 MeV protons on PMMA (ocular melanoma)**
- **collimator: ∅ 30mm**
- **D= 15 Gy**
- in-treatment: 0-158s (5.7 Gy/min)
- after-treatment: 158s-300s

❖ Simulations with FLUKA
http://www.fluka.org

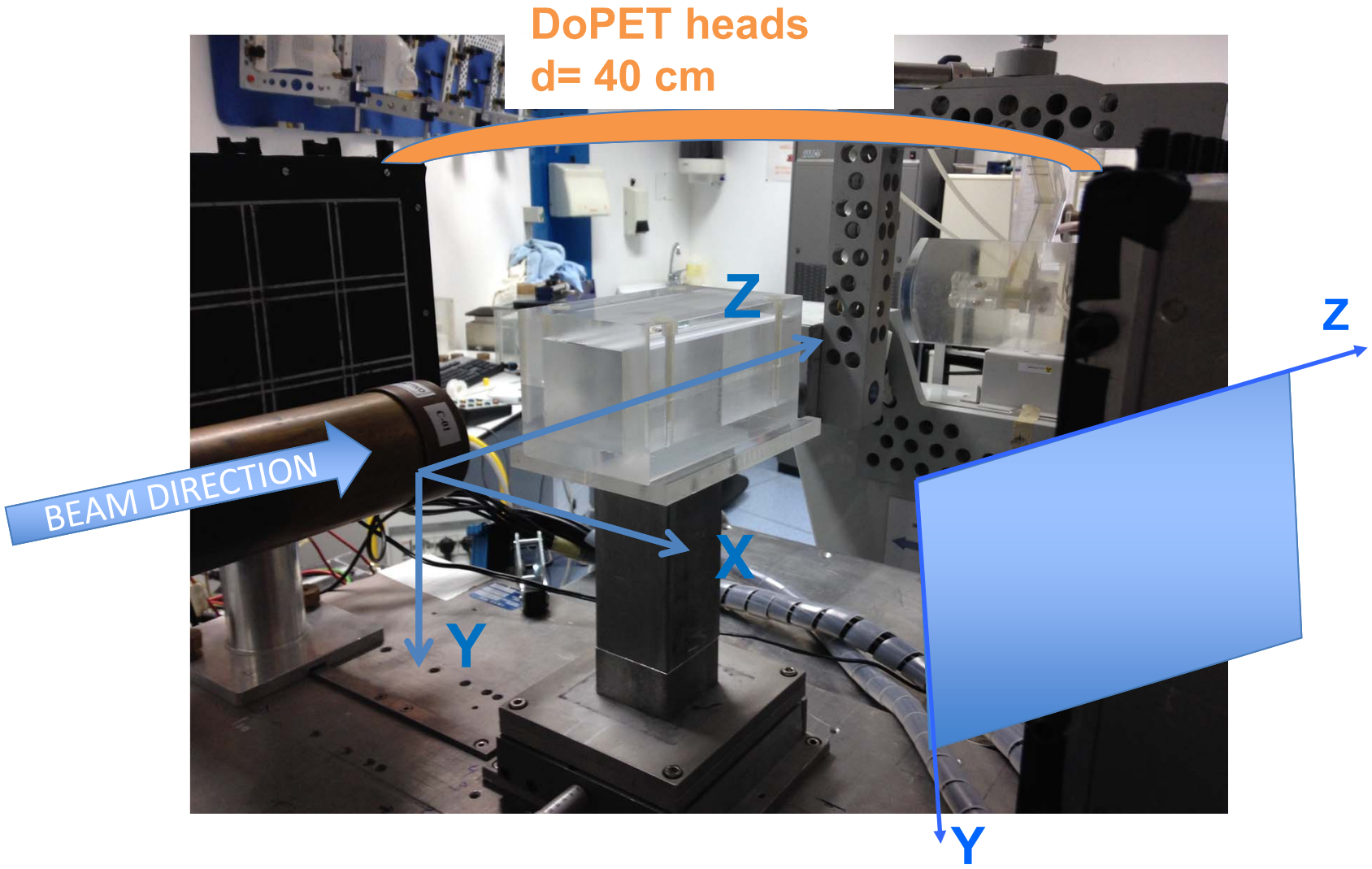




Annihilation Time profile



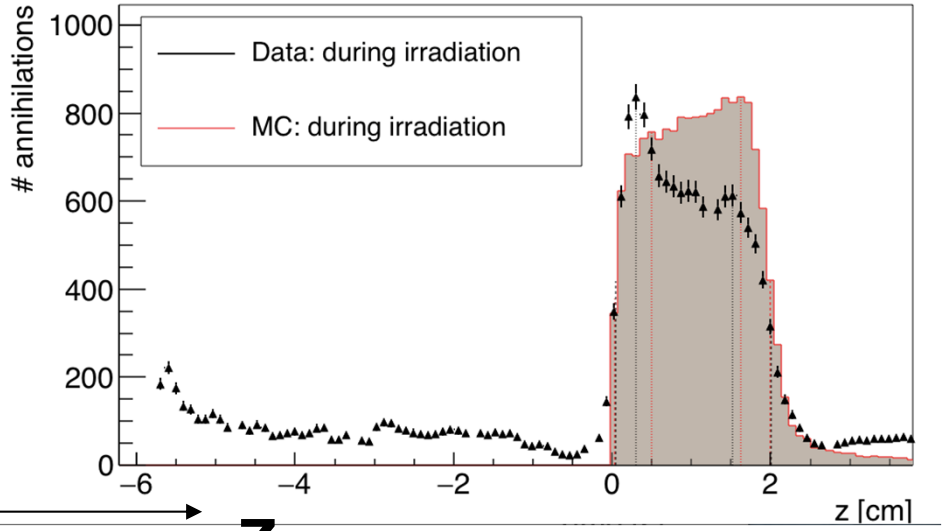
CATANA: set-up



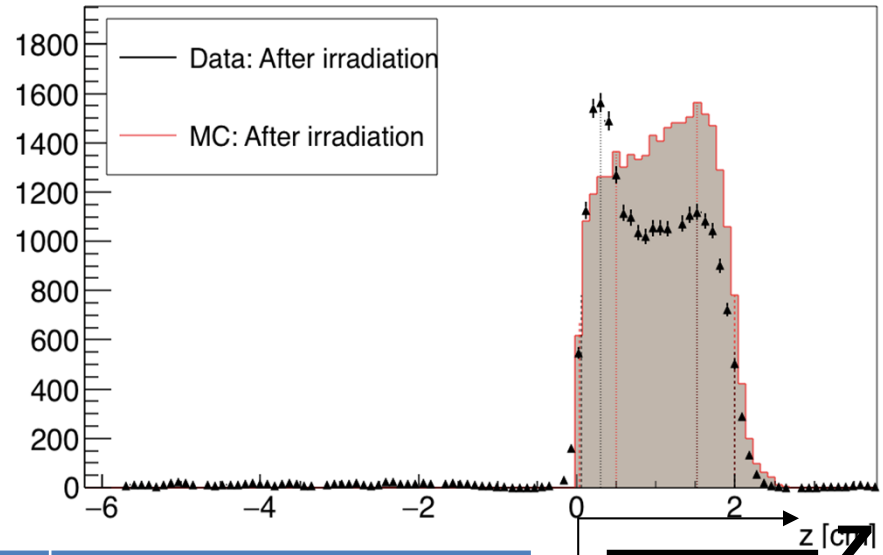
CATANA: comparison between simulated and experimental data

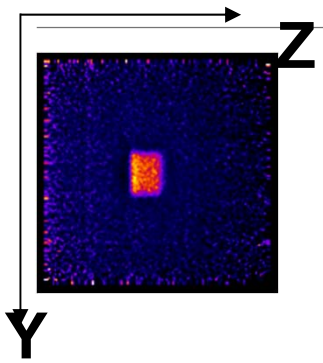
- 58 MeV protons on PMMA
- collimator: ∅ 30mm
- D= 15 Gy (5.7 Gy/min)

z-profile
In-treatment: t< 158 s

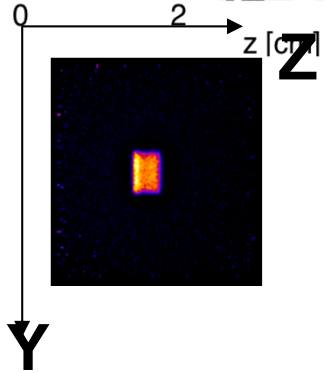


z-profile
After treatment: 158s-280 s



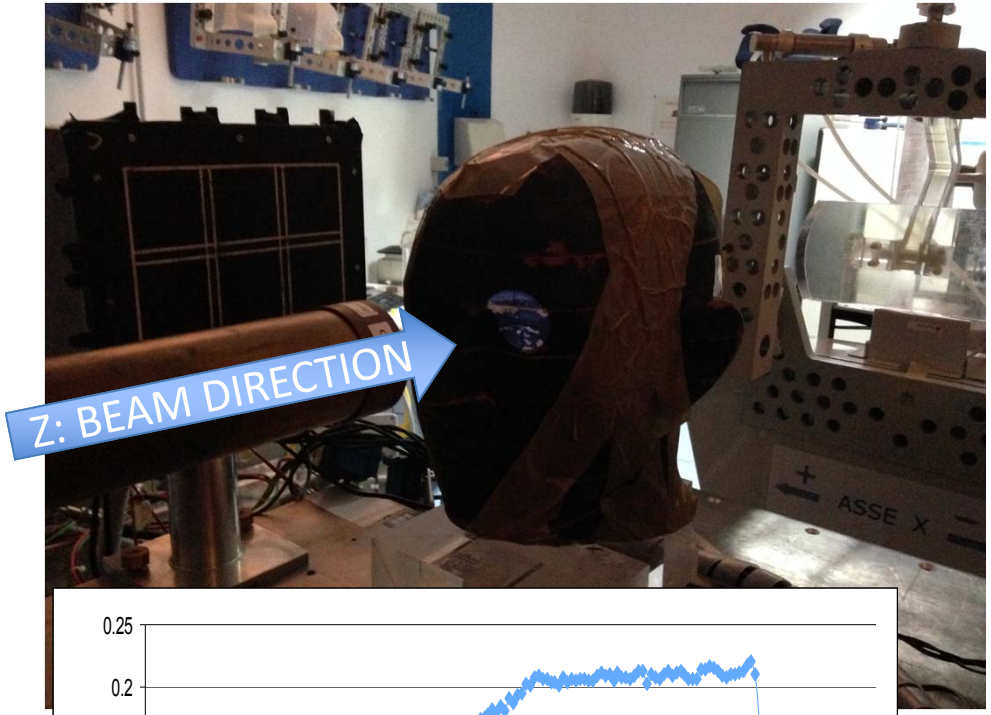


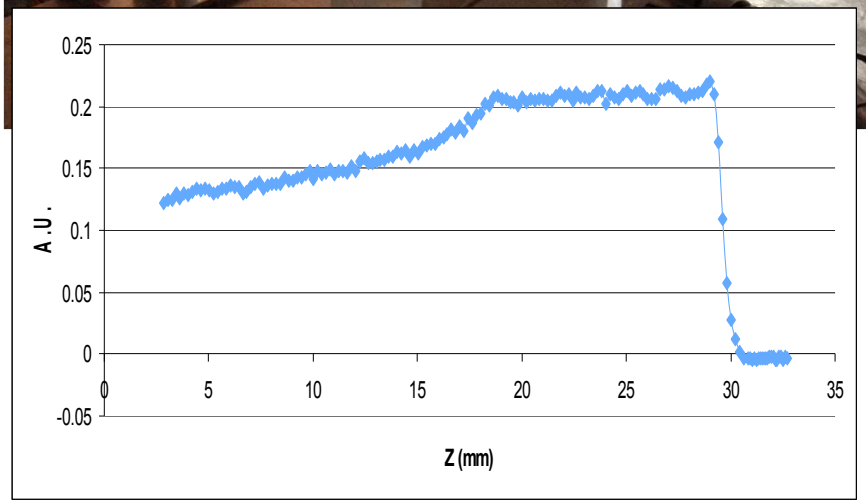
Δw50%	in-treatment [cm]	after-treatment [cm]
MC	1.96	1.96
data	1.95 ± 0.03	1.93 ± 0.03

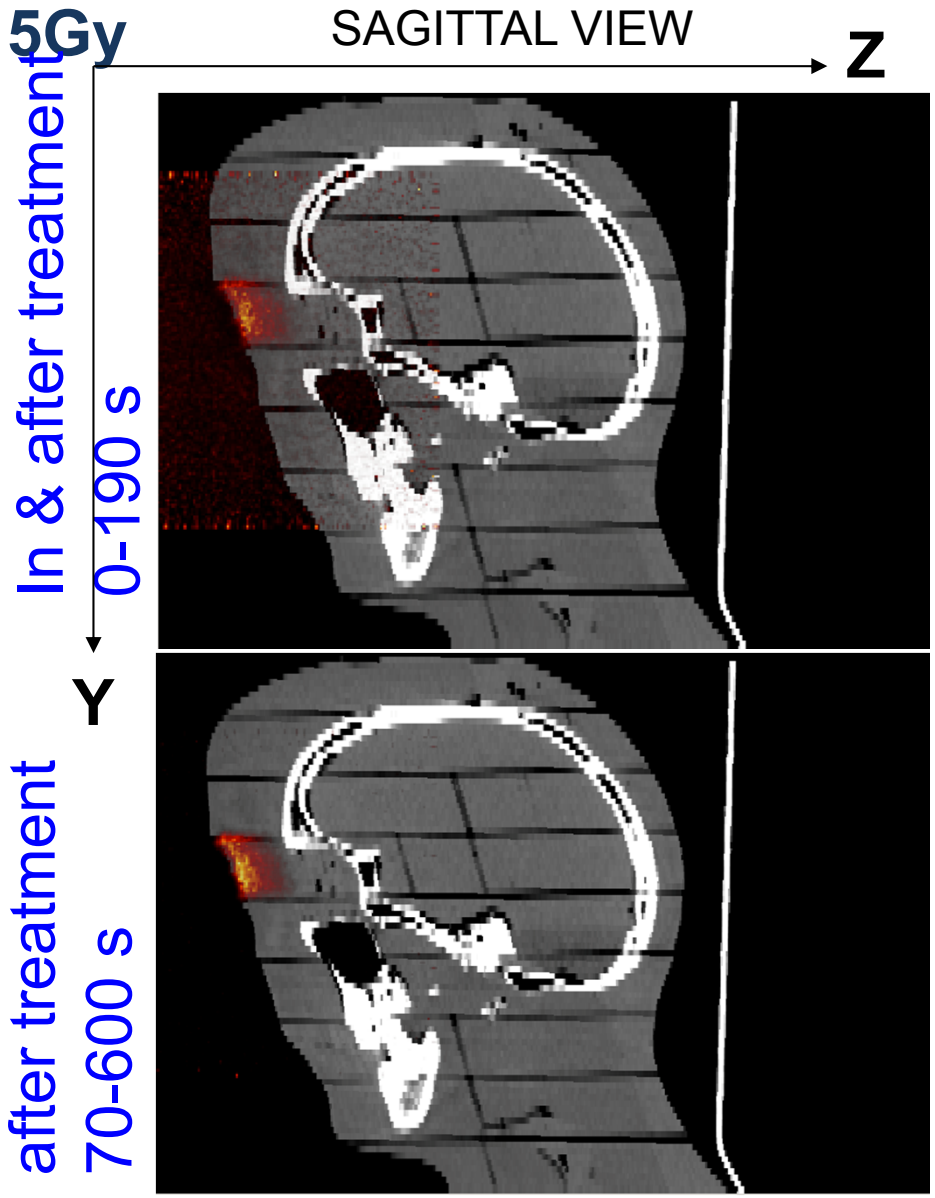


CATANA: an example of an antropomorphic phantom irradiation

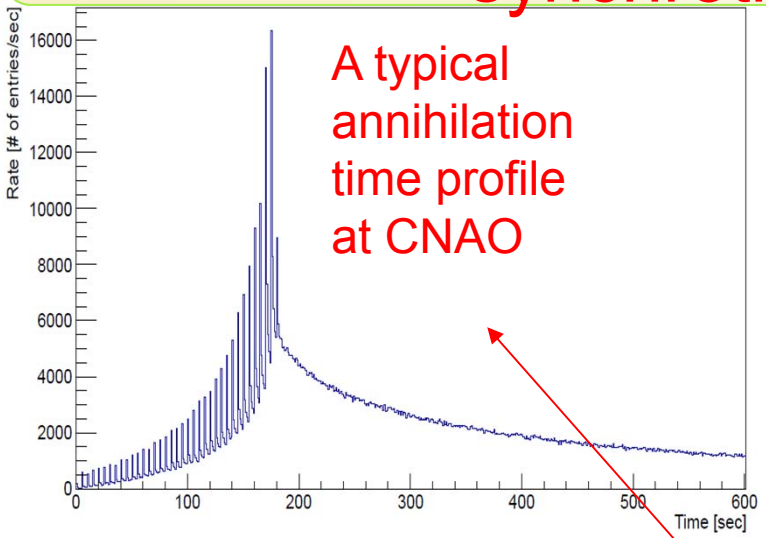
SOBP, collimator: Ø 3 cm, D= 15Gy
Δt in-treatment= 70s





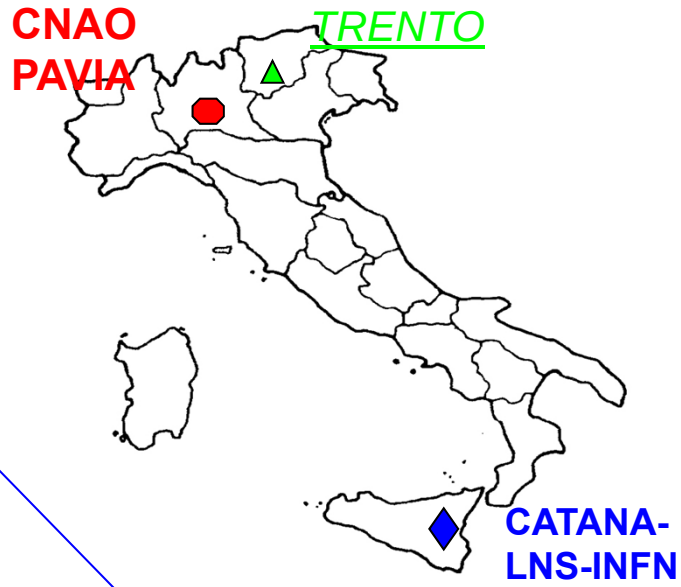


CNAO vs CATANA
synchrotron vs cyclotron

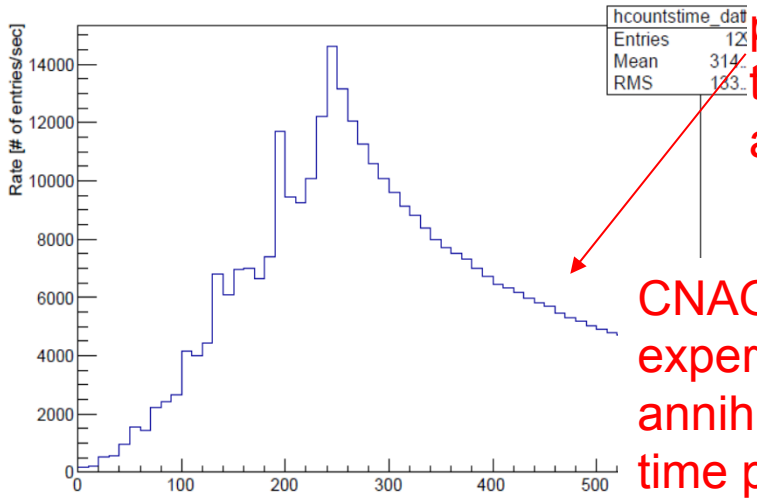


A typical annihilation time profile at CNAO

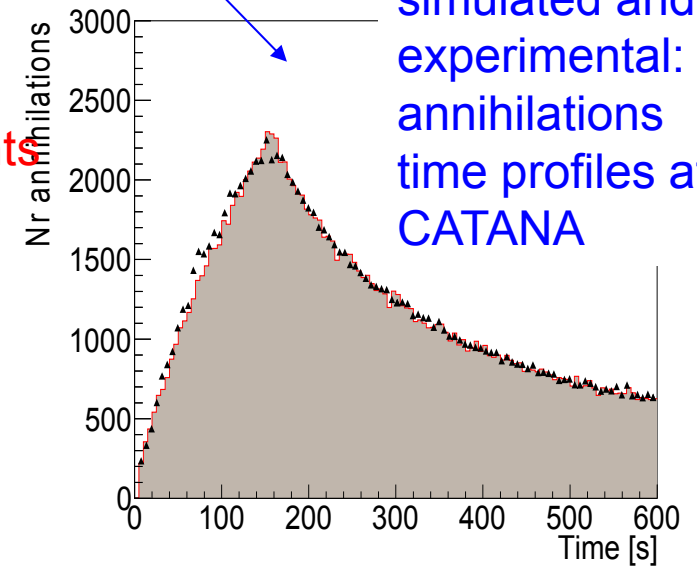
DoPET acquired continuously at CATANA in-treatment and off-treatment



at CNAO is partially paralized during the spills, and cannot profit of all the in treatment annihilations events



CNAO: experimental annihilation time profile for protons

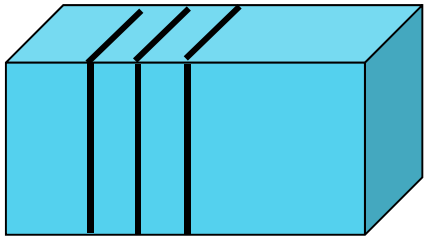


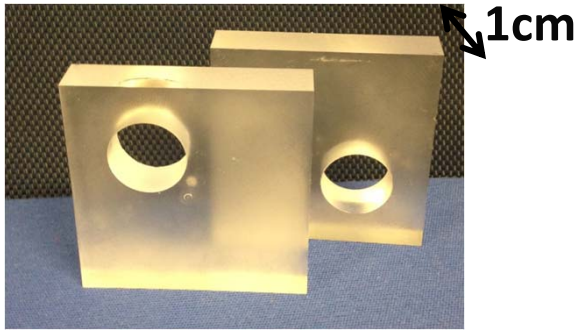
simulated and experimental: annihilations time profiles at CATANA

CNAO:PMMA phantom with 2 air cavities

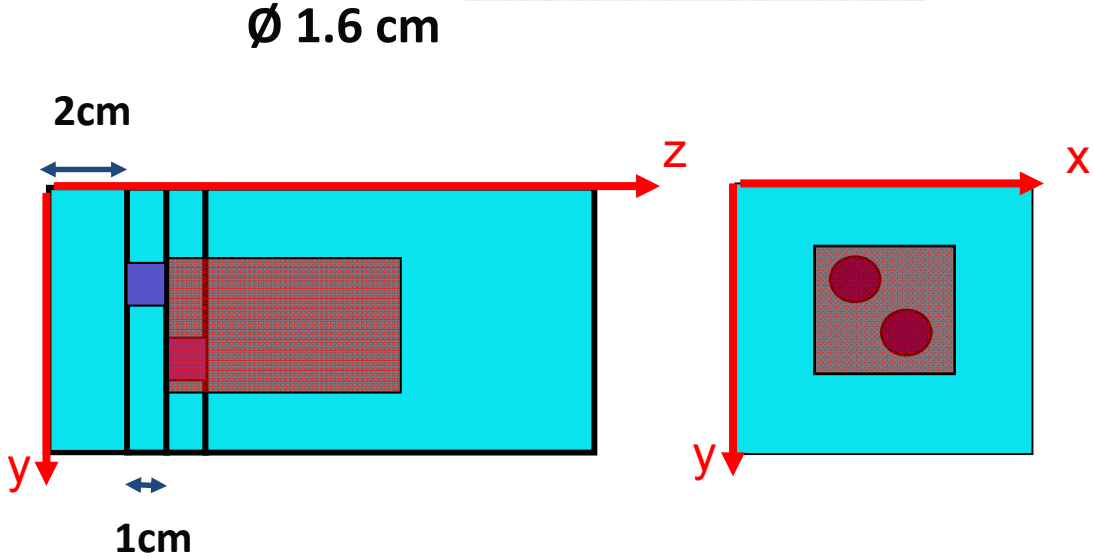
TPS: Syngo PT Planning VC12, Siemens

- protons
- **2Gy** on PTV: 4x4x6 cm^3 (z: 3-9 cm)
- 62.3 MeV - 116 MeV (35 EL)





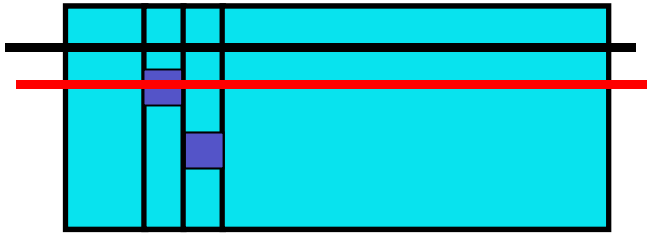
- PMMA phantom: 8x8x14 cm3
- 2 cavities: z=1cm Ø=1.6cm

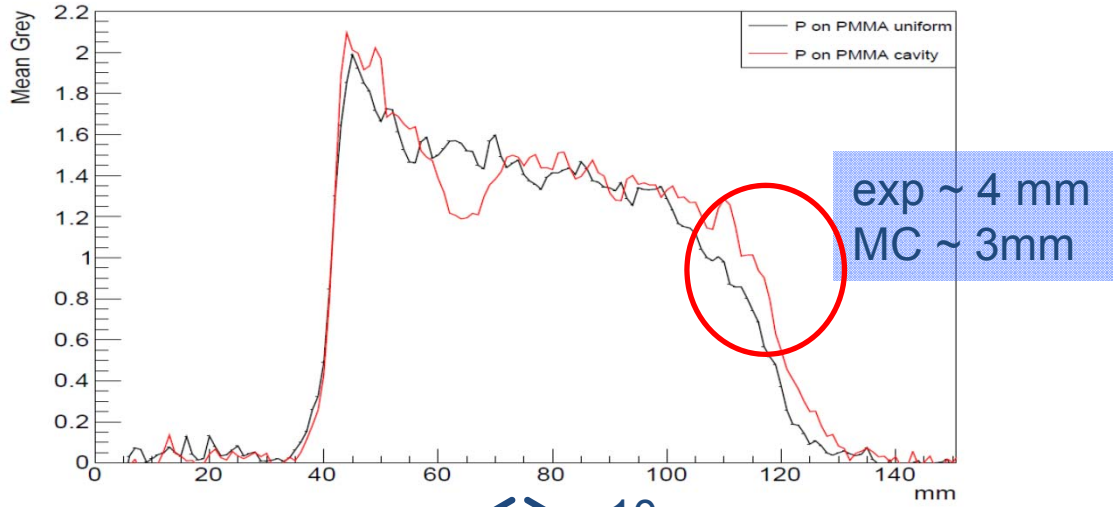


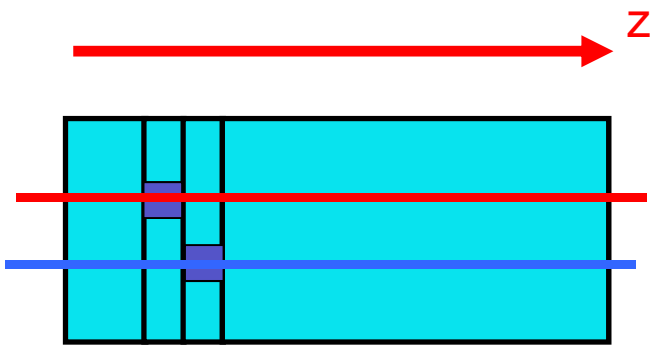
CNAO: 2 cavities profiles

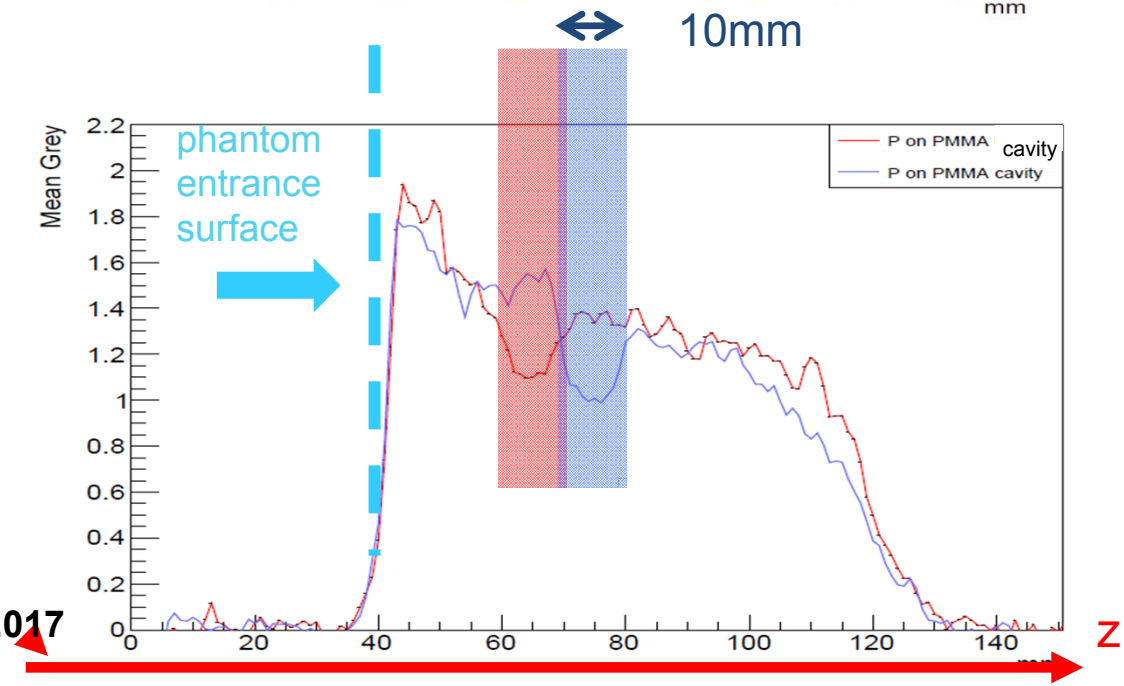
D= 2Gy

Acquisition time [0, 600 s]
TP delivered in 230 s
Activity: z profile



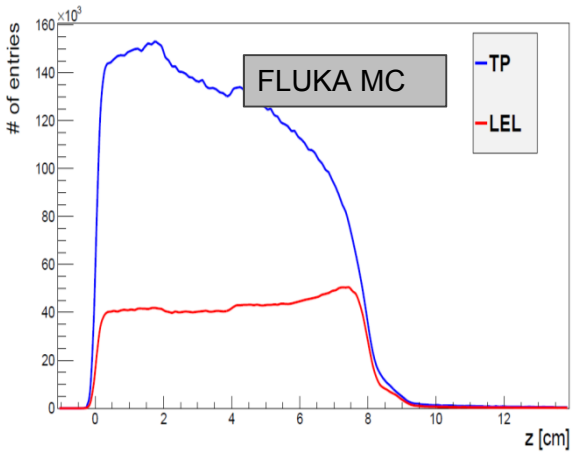






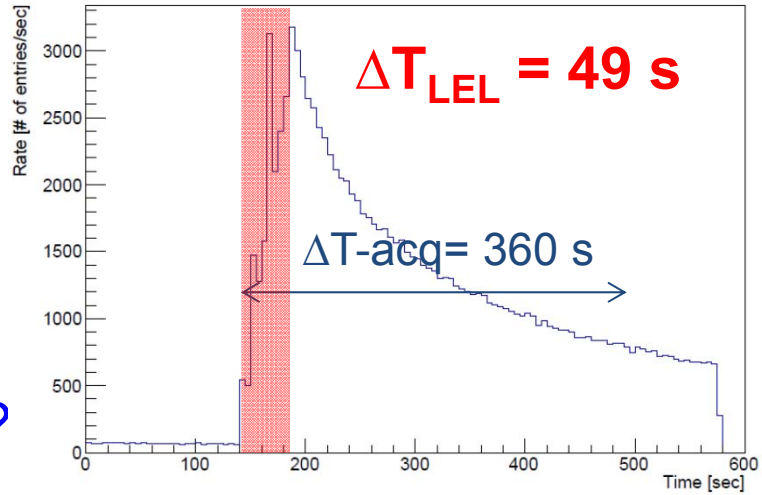
V. Rosso et al.,
http://dx.doi.org/10.1016/j.nima.2015.11.017

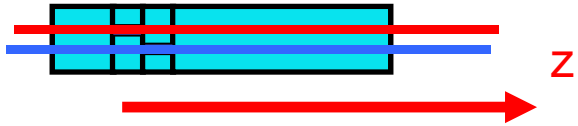
CNAO: Last Energy Layer



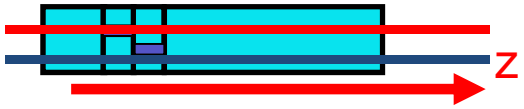
only LEL protons

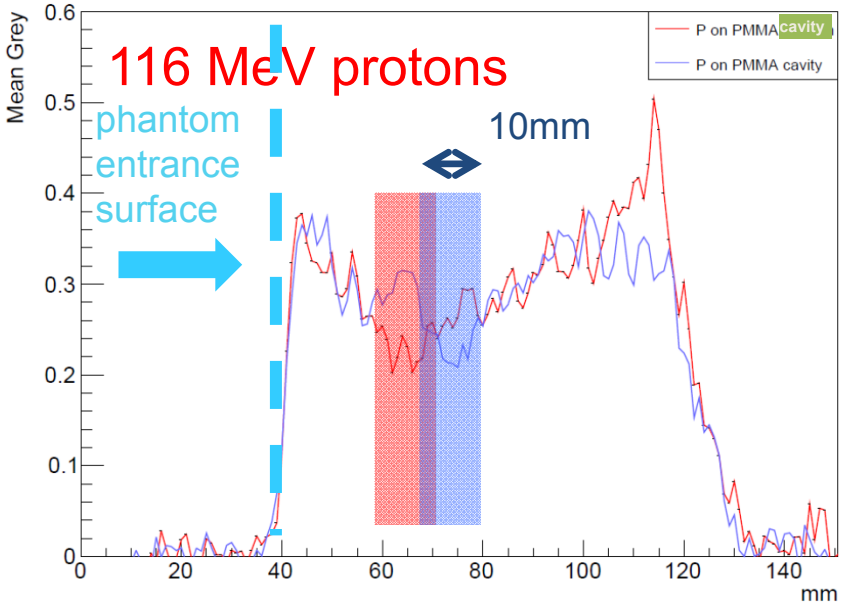
The same information with a smaller dose: helpful for hypofractionation?

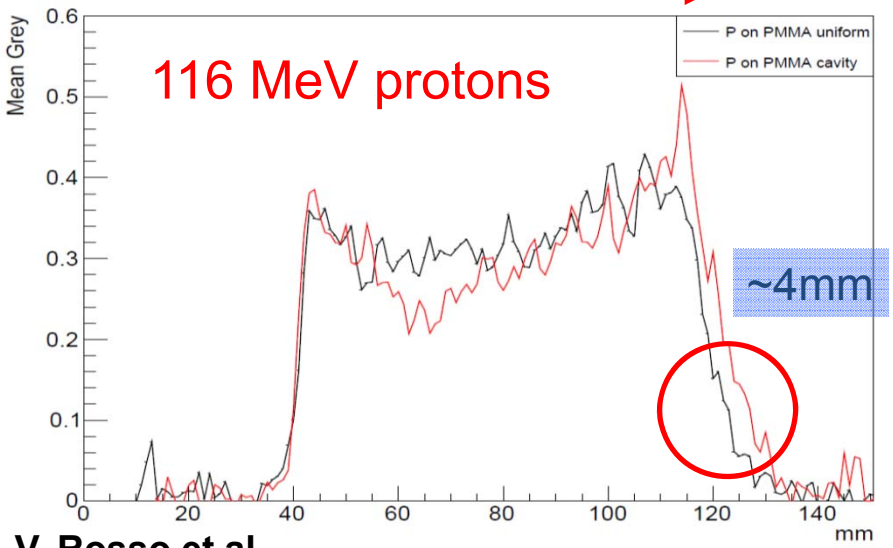




ΔT-acq= 360 s





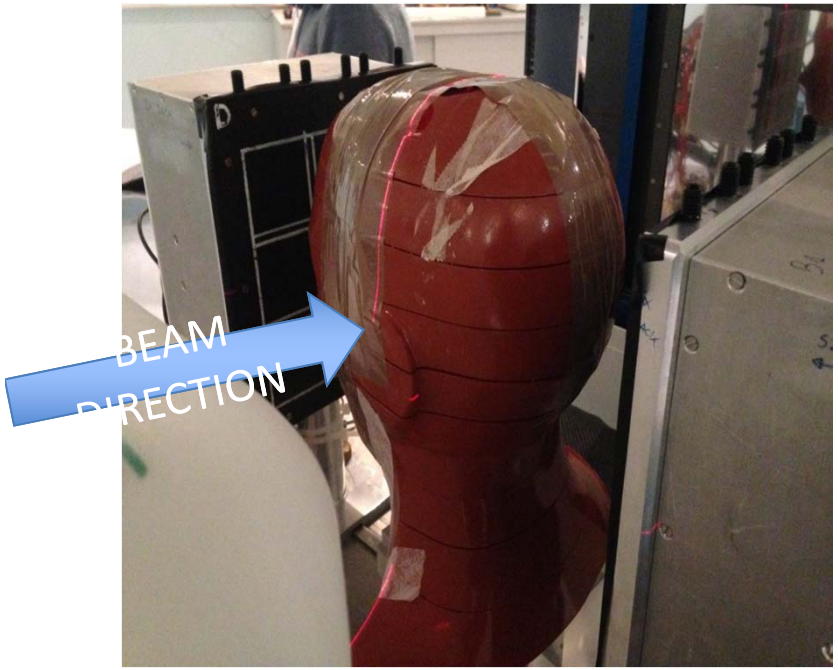


V. Rosso et al.,
http://dx.doi.org/10.1016/j.nima.2015.11.017

CNAO: an example of an antropomorphic phantom irradiation

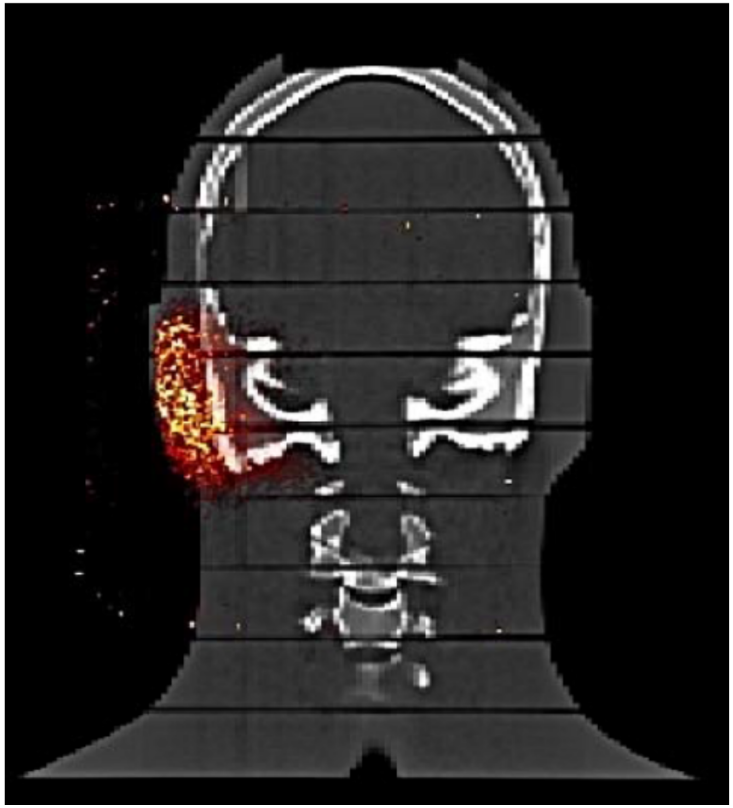
2 Gy on PTV: 5x5x6 cm^3 (z: 1-7 cm)

Δt in-treatment= 287s



Acquisition time [0, 600 s]

coronal view



Conclusions

The first tests with the enlarged DoPET prototype, 15 cm x15 cm, confermed the usefulness of the in-tratment data.

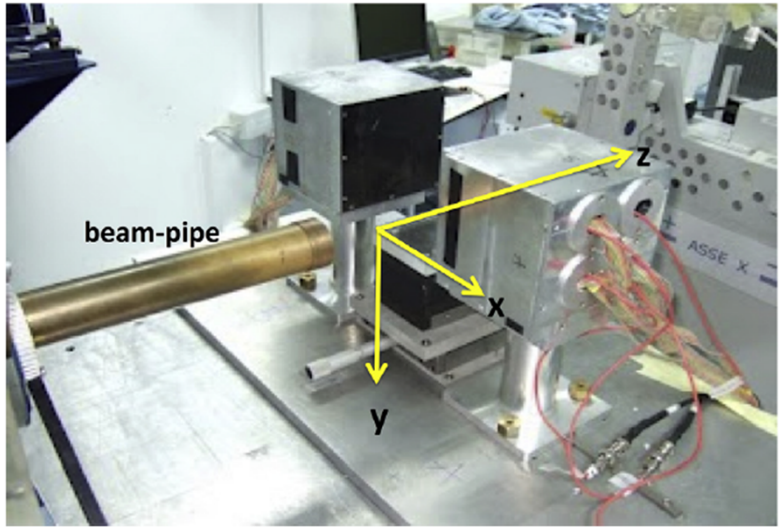
- along the beam direction capability to detect millimetric change of RS in-treatment and after-treatment (also small cavities)

  - in-treatment works properly up to 16.9 Gy/min

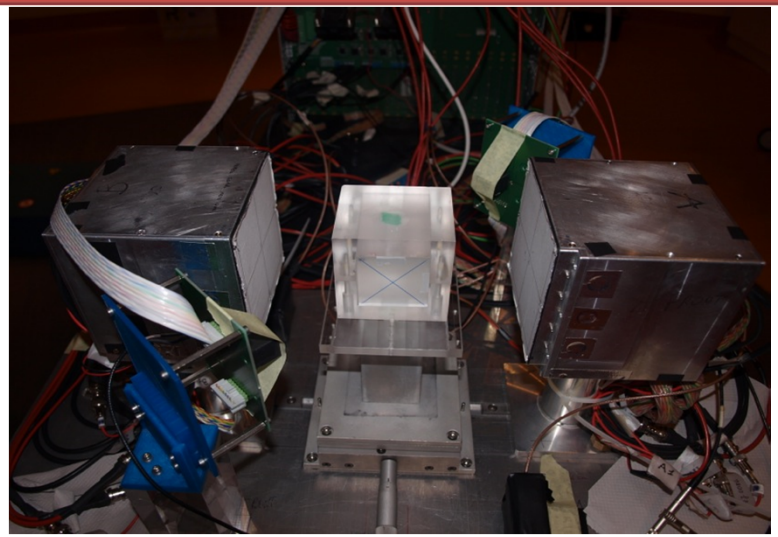
- a limited time is necessary to perform monitoring of TP delivered on antropomorphic phantoms
- using only LEL protons is advantageous for the monitoring

❖ we plan to test DoPET in other proton cyclotron based centers

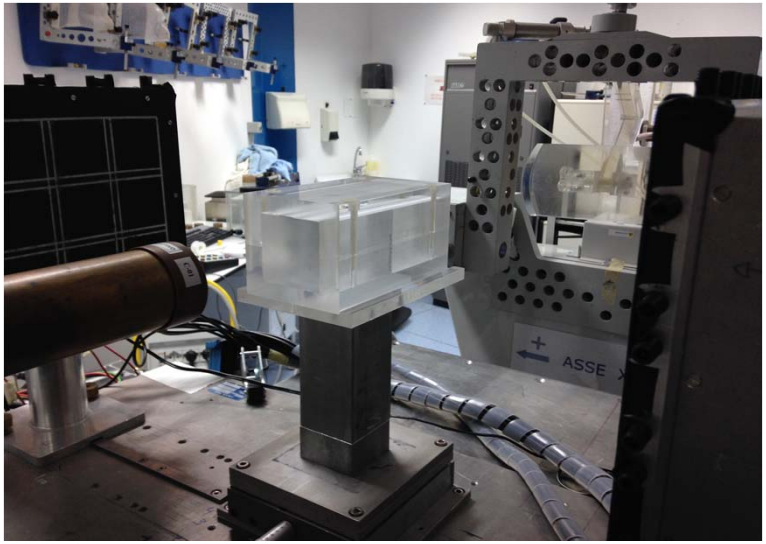
Several data taking were already performed at CATANA and at CNAO

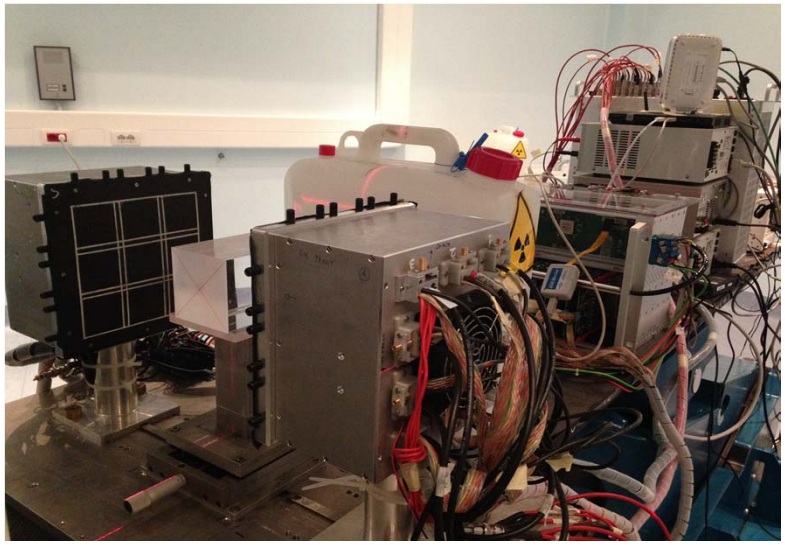


A. Kraan et al., Physica Medica 30 (2014) 559-569



A. Kraan et al., NIMA 786 (2015) 120-126





V. Rosso et al.,
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