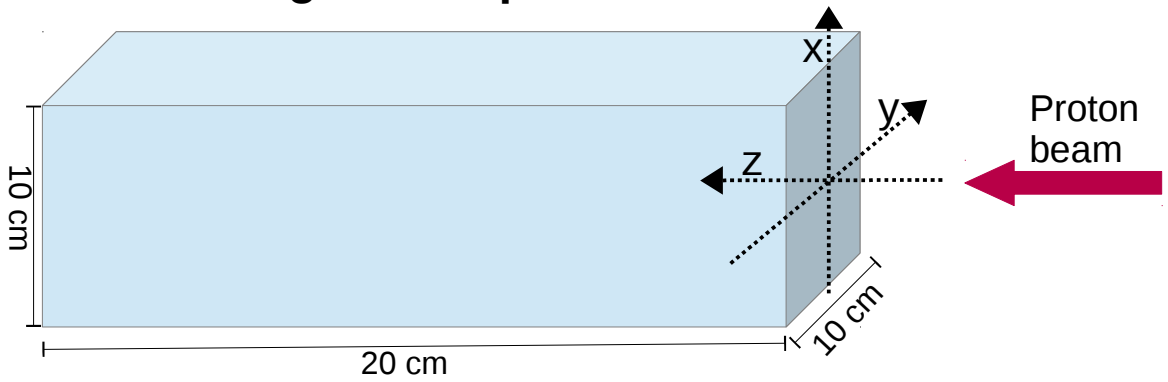
Performance measurements of the PET system: first experimental results on the homogeneity of response and reproducibility

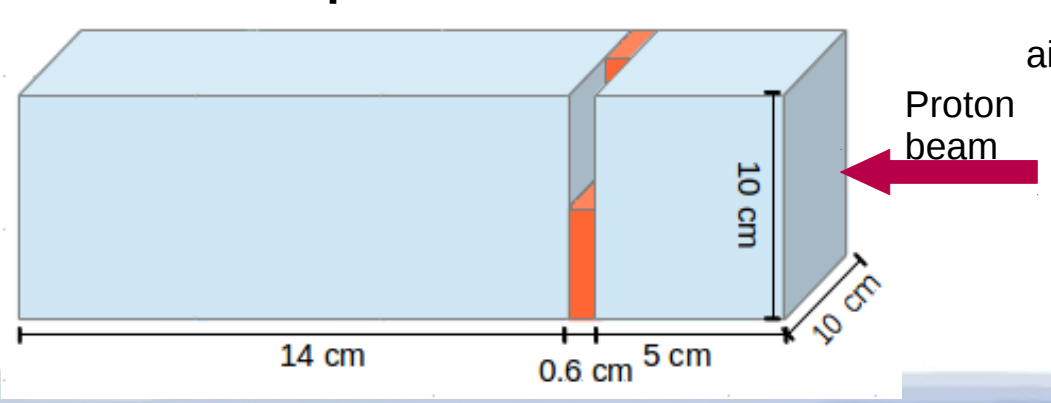
Homogeneity of response: measurements

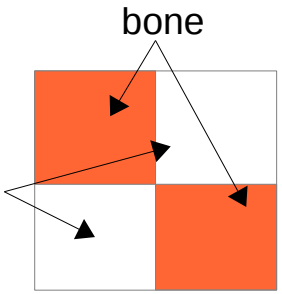
- Monoenergetic proton beam: 144 MeV
- Area irradiated: 9 cm X 9 cm (in the x-y plane), that is:
  from -4.5 cm to 4.5 cm along the y direction
  from -4.5 cm to 4.5 cm along the x direction

Homogeneous phantom

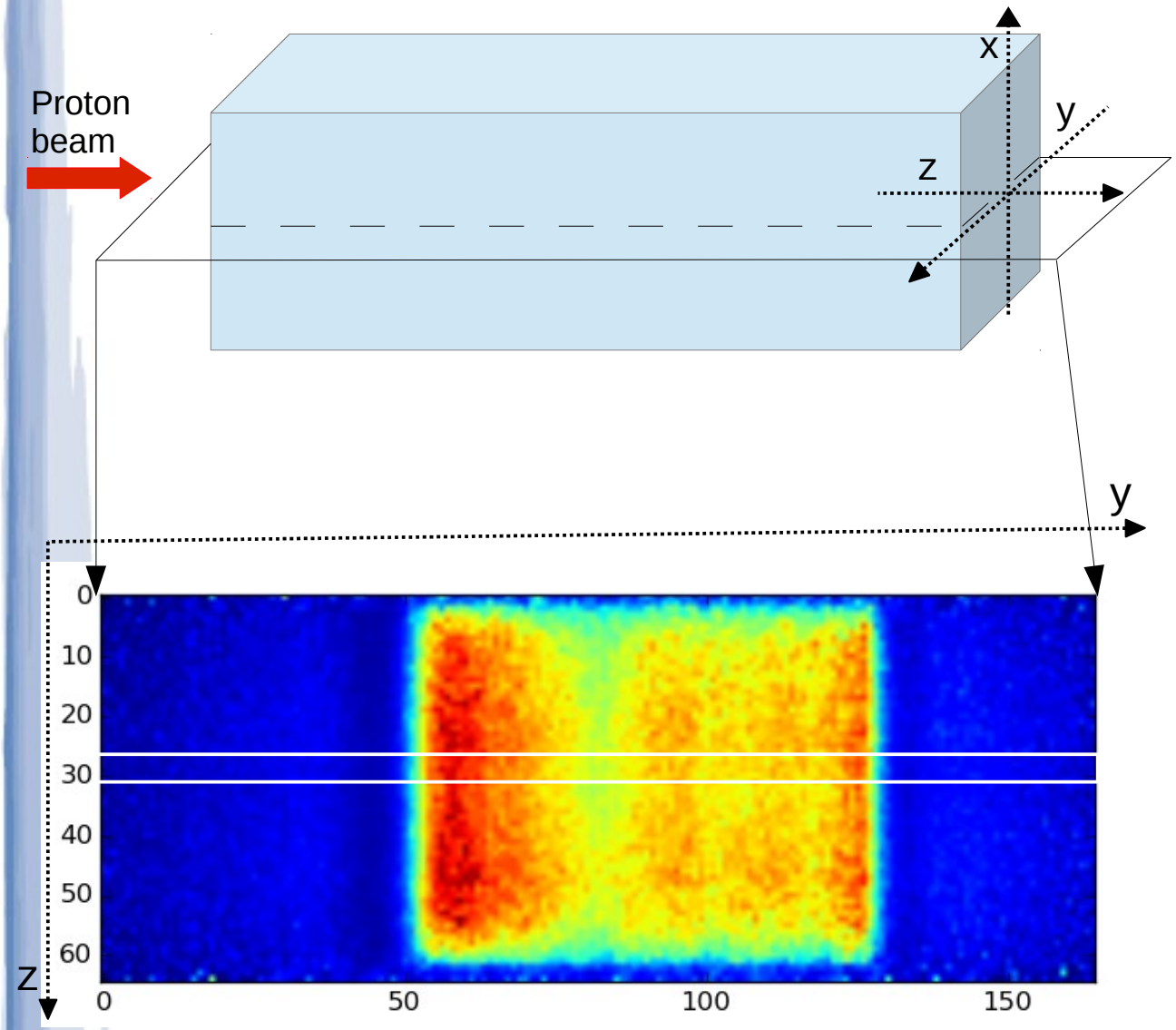


Air/bone phantom

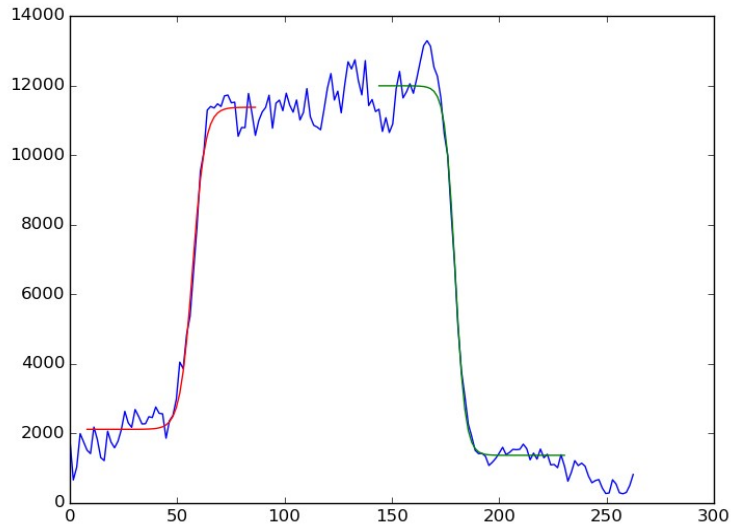




Homogeneity of response: data analysis



- Selection of the slice along the X direction
- Profile along the z direction
- Sigmoid fit at the beginning and at the end of the activity profile
- Evaluation of the inflection point of the two sigmoid curves

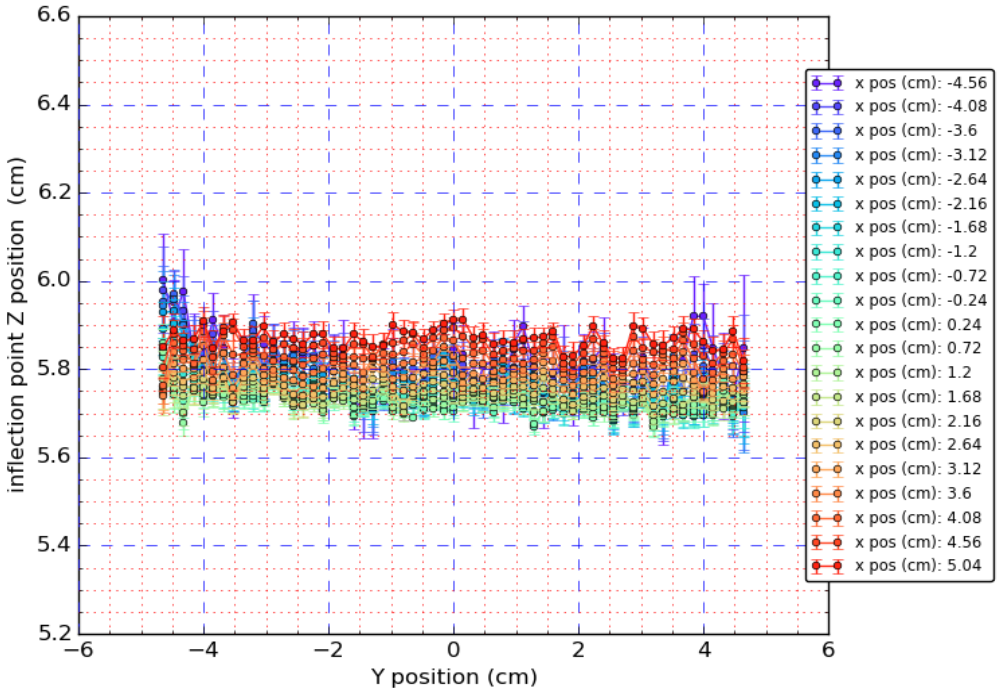


Beginning of the activity profile

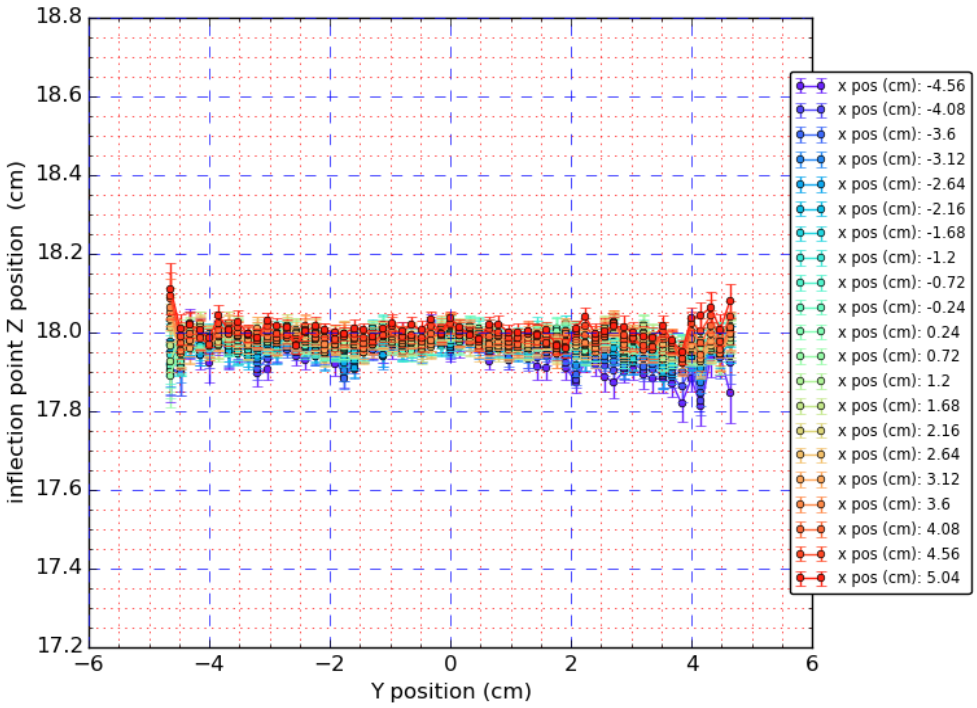
End of the activity profile

Homogeneity of response: results homogeneous phantom

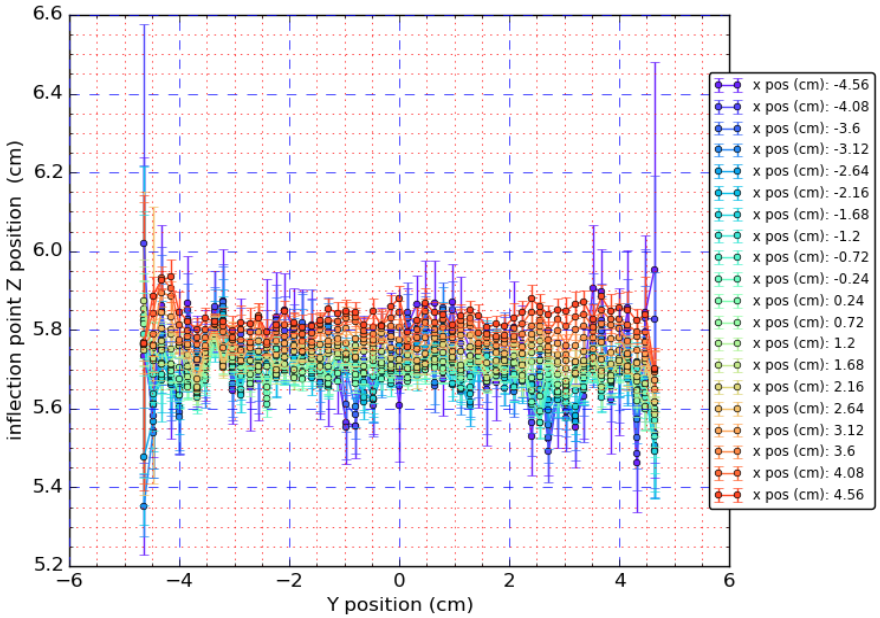
Start of the activity profile

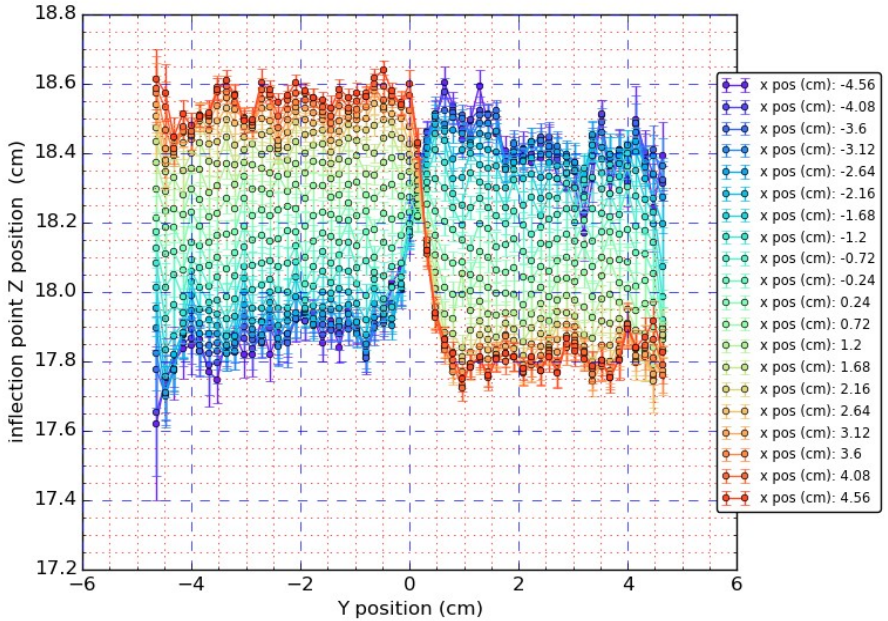


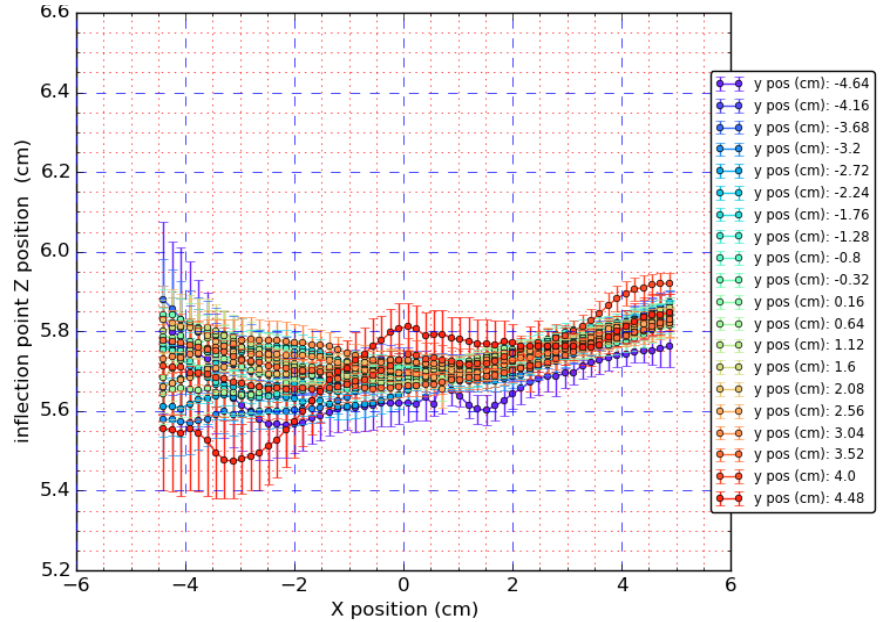
End of the activity profile

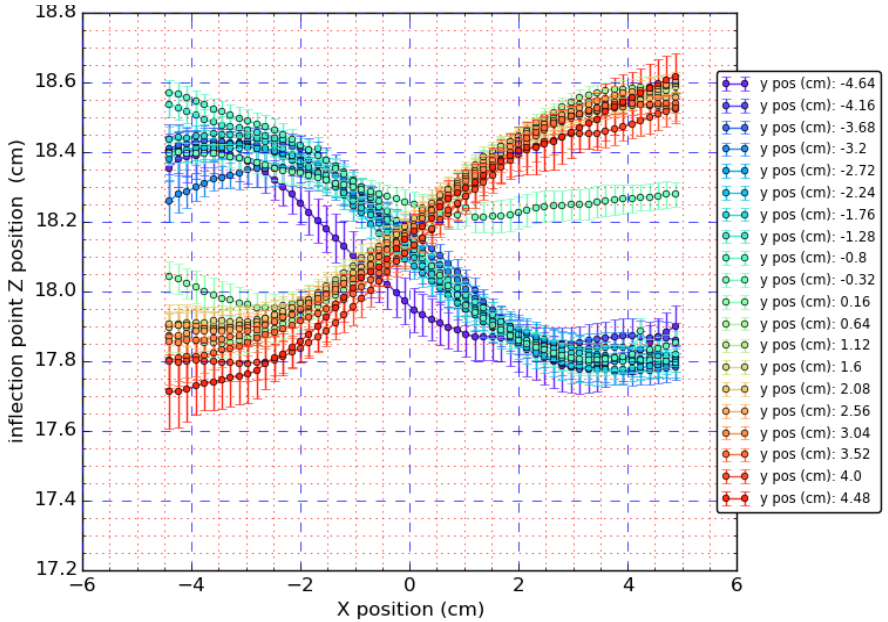


Homogeneity of response: results air-bone phantom

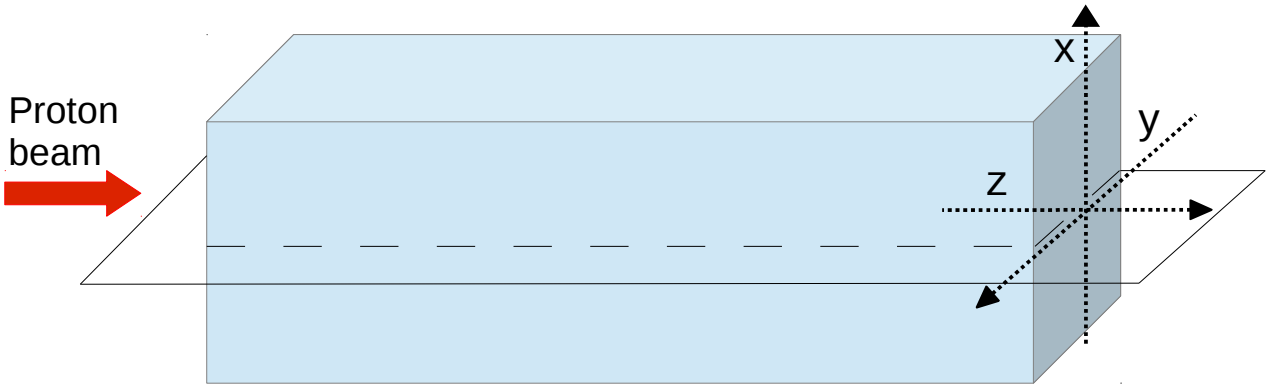








Reproducibility: measurements



- PMMA phantom: 15 cm X 15 cm X 20 cm
- Proton beam energies: from 129 MeV to 164 MeV
- Volume irradiated: 6 cm X 6 cm X 6 cm, in particular:
  from -3 cm to 3 cm along the y direction
  from 3 cm to 3 cm along the x direction
- 2 Gy within the cubic volume

Repeated 4 times

- 3D real treatment plan: two fields
- Proton beam energies: from 83 MeV to 150 MeV
- Dose of single fraction of the treatment (about 1 Gy)

Repeated twice for each field

Reproducibility: data analysis

How can we compare two activity distributions?

Gamma index method: a tool widely used in the radiotherapy field to compare the TP calculated and the measured dose distributions

$$\gamma(i) = \sqrt{\left(\frac{DD_i}{\Delta DD}\right)^2 + \left(\frac{DTA_i}{\Delta DTA}\right)^2}$$

- DD is the Dose Difference at point *i*
- DTA is the Distance To Agreement at point *i*
- ΔDD is the tolerance on the DD (in radiotherapy is usually 3%)
- ΔDTA is the tolerance on the DTA (in radiotherapy is usually 3 mm)

γ(i) < 1 pass the check; γ(i) > 1 fail the check

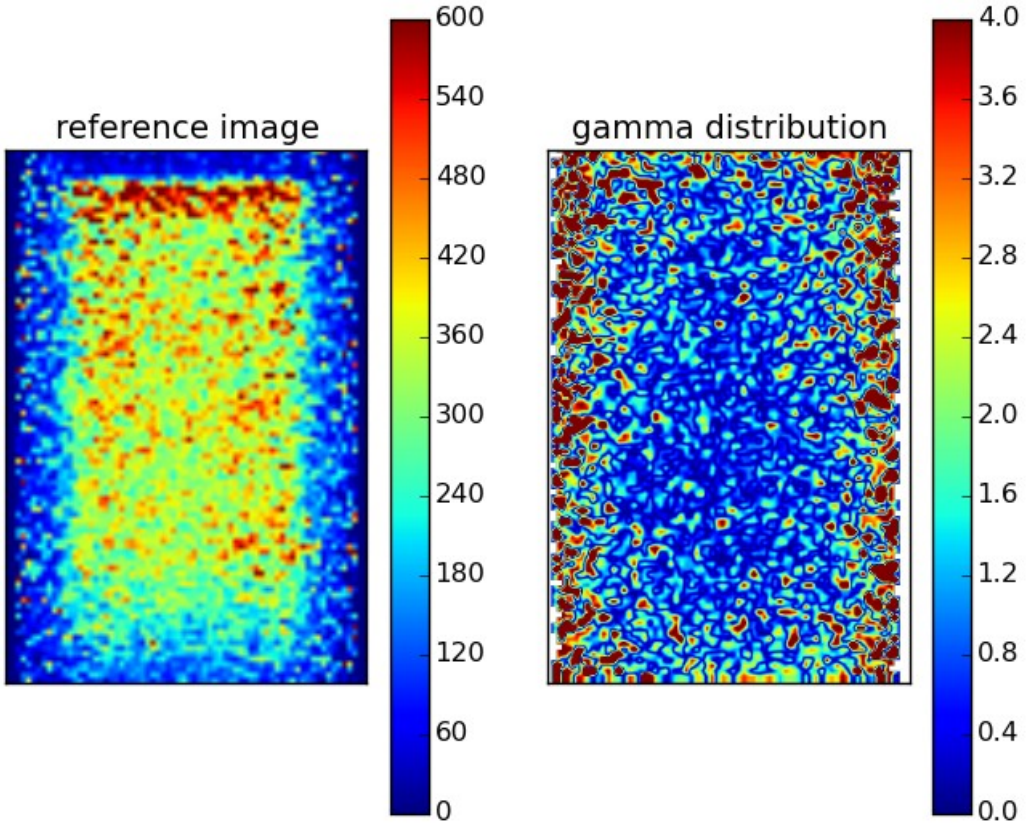
The comparison has a positive outcome if about 95% of the γs pass the check

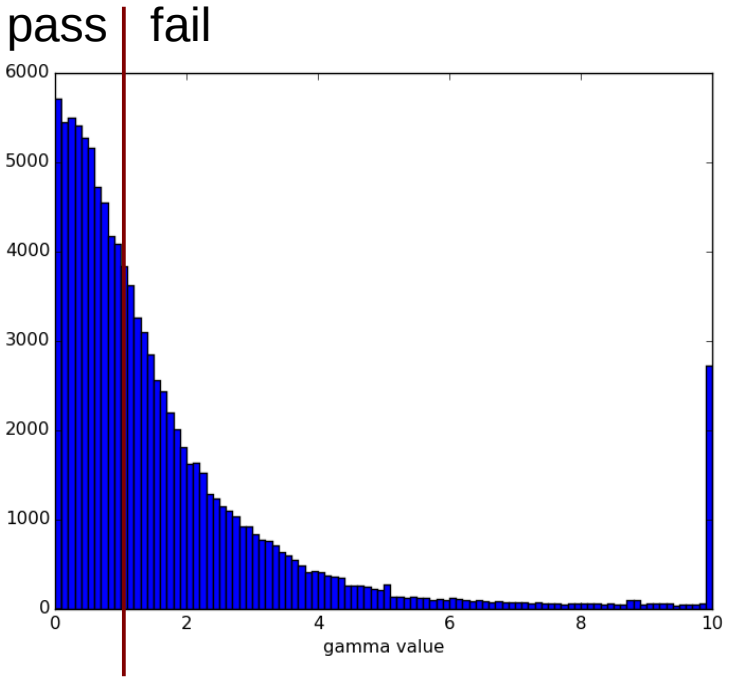
We have tried to apply the same method to compare the measured activity distributions. The gamma index method has been already used by the authors in reference [1]

[1] Knopf, Antje-Christin, et al. "Accuracy of proton beam range verification using post-treatment positron emission tomography/computed tomography as function of treatment site." International Journal of Radiation Oncology* Biology* Physics 79.1 (2011): 297-304.

Example 1 gamma index analysis

- First irradiation of a cubic volume
- Second irradiation of a cubic volume
- Selection of slice 70, center of the FOV
- Comparison between the two slices
  ΔDD= 20%
  ΔDTA= 0.5 mm





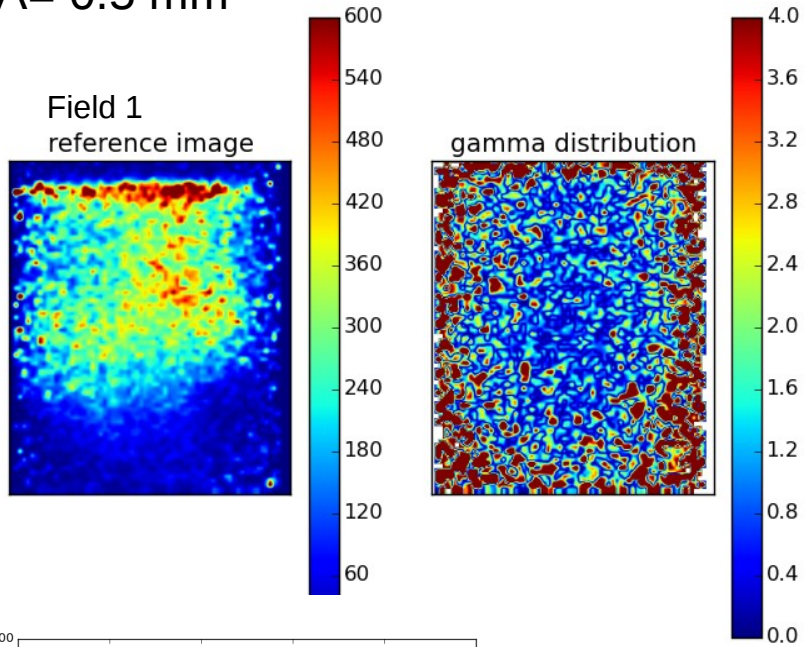
pass/total = 0.47

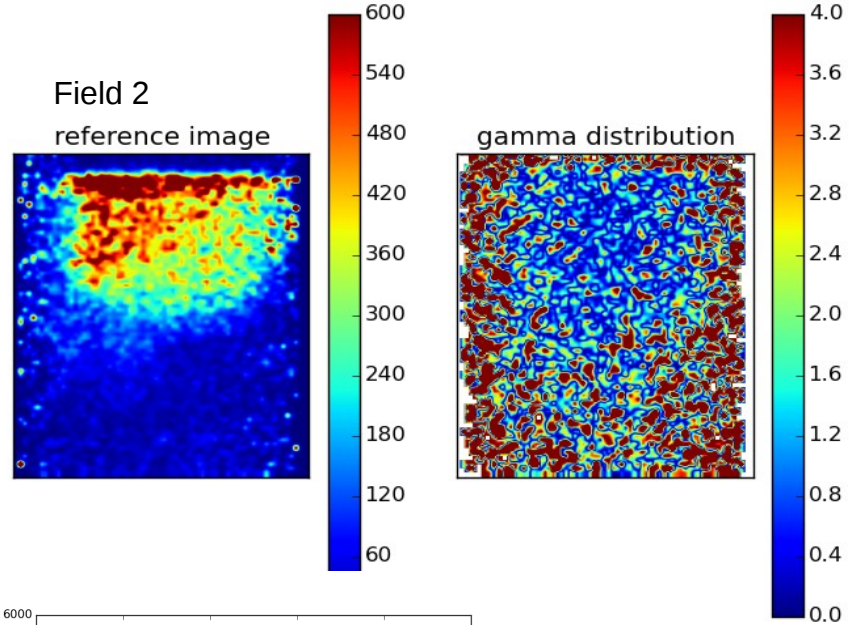
Example 2 gamma index analysis

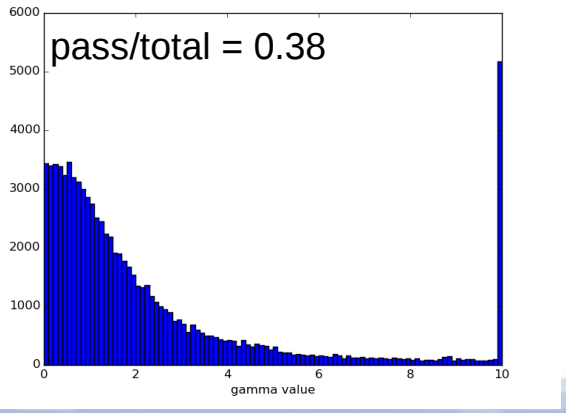
- First irradiation of one field of the treatment plan
- Second irradiation of one field of the treatment plan
- Selection of slice 70, center of the FOV
- Comparison between the two slices

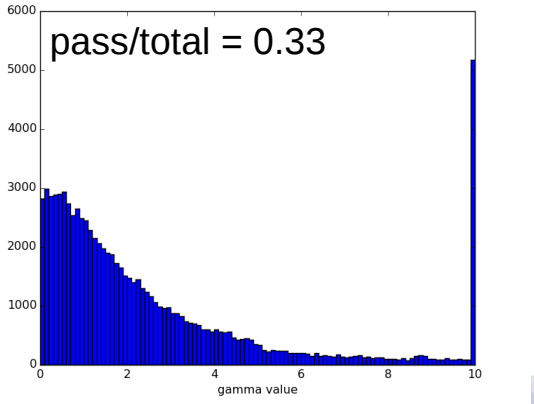
  ΔDD= 20%

  ΔDTA= 0.5 mm









Reproducibility: results (cube)

- Irradiation of the cubic volume
- Comparison between cube 2 and cube 1, cube 3 and cube 1, cube 4 and cube 1
- Evaluation of the gamma pass/total ratio for each slice
- Evaluation of the mean and standard deviation of the pass/total ratios

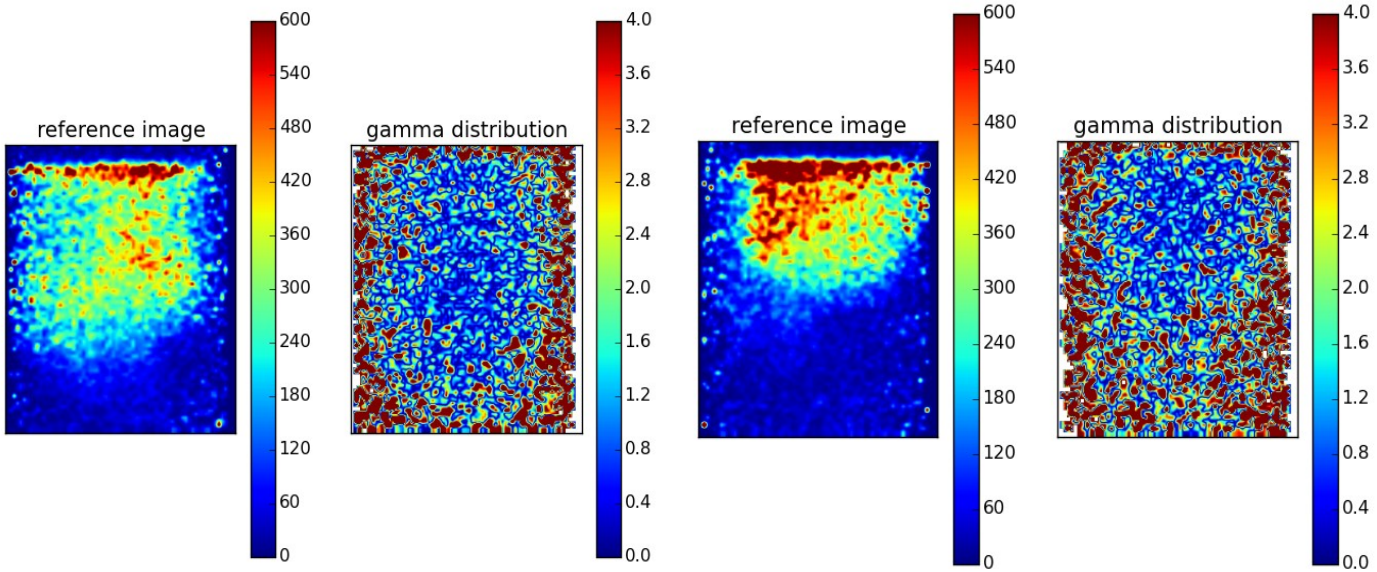
comparison	Mean ratio (over the slices)	Std ratio (over the slices)
2 ---> 1	0.49	0.01
3 ---> 1	0.50	0.01
4 ---> 1	0.47	0.01
2,3,4 ---> 1	0.49	0.01

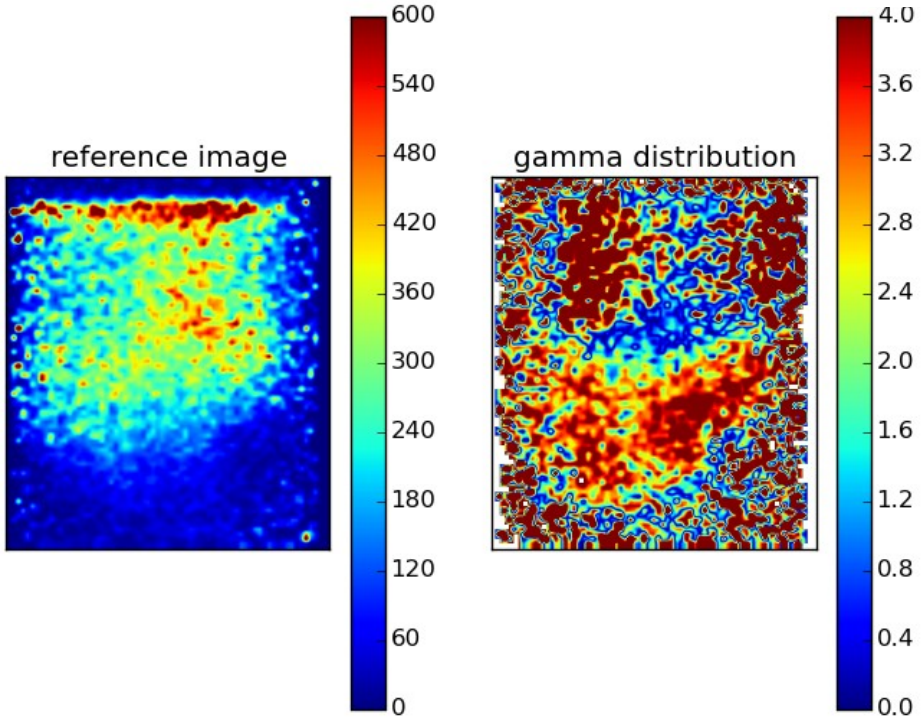
Reproducibility: results (treatment plan)

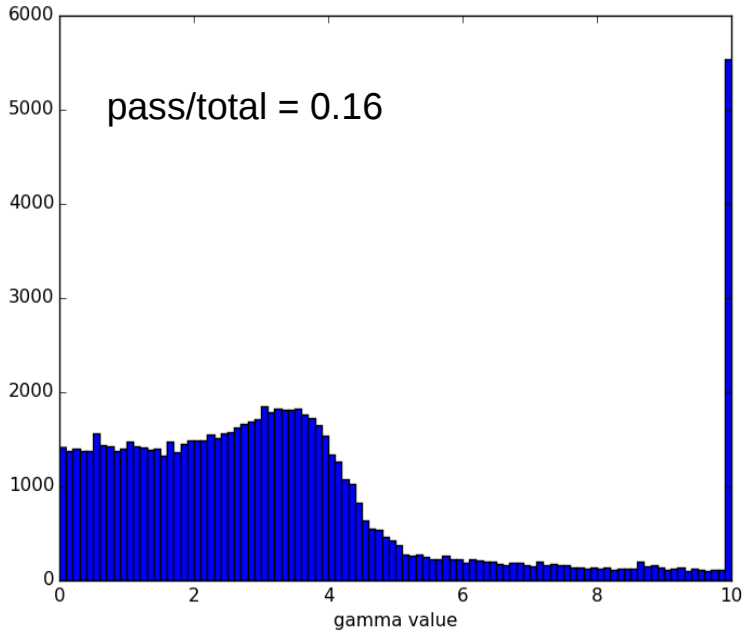
- Treatment plan with two fields
- Comparison between irradiation 1 (field 1) and irradiation 2 (field 1), irradiation 3 (field2) and irradiation 4 (field 2), irradiation 1 (field 1) and irradiation 3 (field 2)
- Evaluation of the gamma pass/total ratio for each slice
- Evaluation of the mean and standard deviation of the pass/total ratios

comparison	Mean ratio (over the slices)	Std ratio (over the slices)
2 ---> 1	0.38	<0.01
4 ---> 3	0.36	<0.01
3 ---> 1	0.23	0.04
4 ---> 1	0.23	0.04

Reproducibility: results (treatment plan)







Conclusions

- Measurements of the fall-off position of an homogeneous activity distribution is within 2 mm along the three directions
- The air and bone region along the Y direction can be unambiguously distinguished
- The air and bone region along the X direction are blurred (as expected)
- Different irradiation set ups could be distinguished from the same irradiation set up by using the gamma index method
- Need to explore the smallest change in the activity distribution which can be detected by the gamma index method