INSIDE Meeting

Software status overview

Contributions by:

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Milano, March, 25th, 2014

Summary

- Status of implemented functionality
  - **Beam + patient: Fabrizio, Giuseppe**
  - PET simulation: Francesco, Aafke, Ben
  - PET reconstruction: Nicolo'
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    - Discussion
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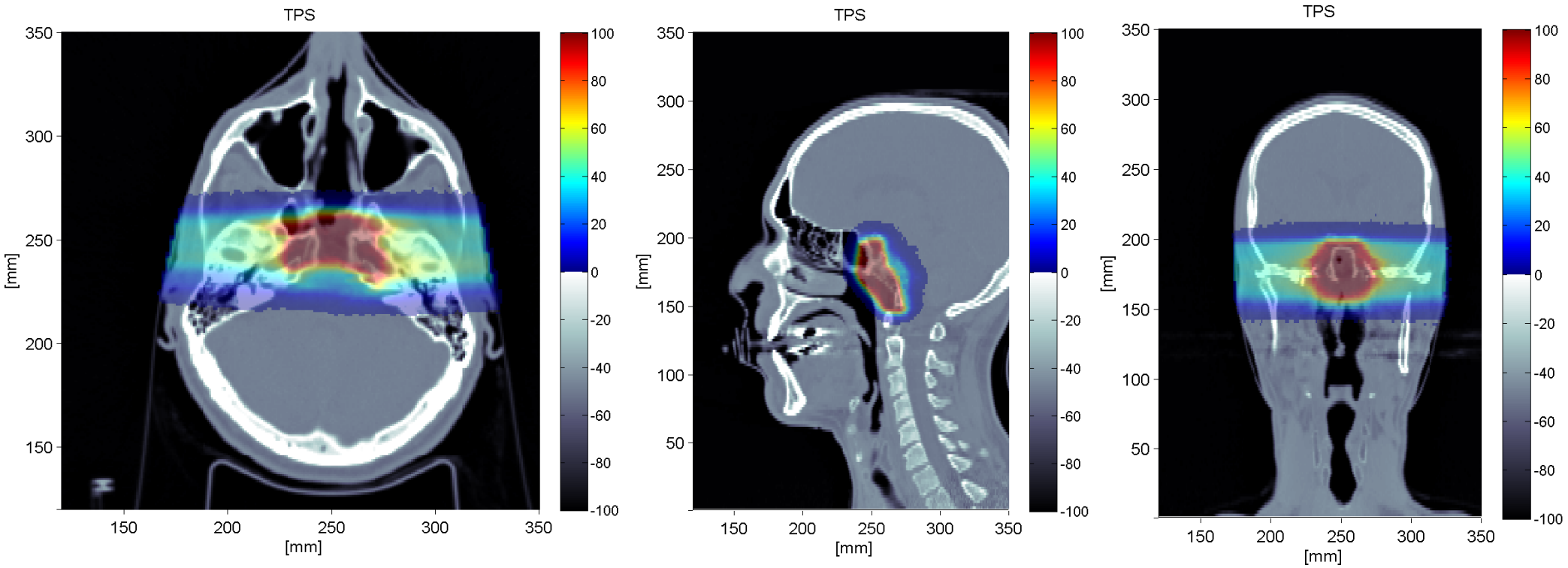
Treatment Description

The complete plan is composed by 2 opposed fields, ^{12}C.



Dose prescription as calculated by Syngo TPS

Beam1 = 272 571 648 particles
Beam2 = 239 598 608 particles

Treatment Description: Beam 1

Energy Slice [n]	Nominal Beam Energy [MeV/u]	Spots per Slice [n]:
1	137.28	2
2	140.72	2
3	144.10	3
4	147.43	3
5	150.71	5
6	153.94	7
7	157.12	8
8	160.26	10
9	163.35	15
10	166.41	28
11	169.43	71
12	172.41	103
13	175.37	163
14	178.28	219
15	181.17	249
16	184.03	236
17	186.86	234
18	189.66	235
19	192.43	231
20	195.18	229
21	197.91	232
22	200.61	228
23	203.29	193
24	205.95	181
25	208.58	174
26	211.19	186
27	213.79	180
28	216.36	172
29	218.91	166
30	221.45	154
31	223.96	135
32	226.46	123
33	**228.94**	**105**
34	231.34	88
35	233.79	72
36	236.22	49
37	238.63	33
38	241.03	14
39	243.42	4

Total no. of spots: 4542

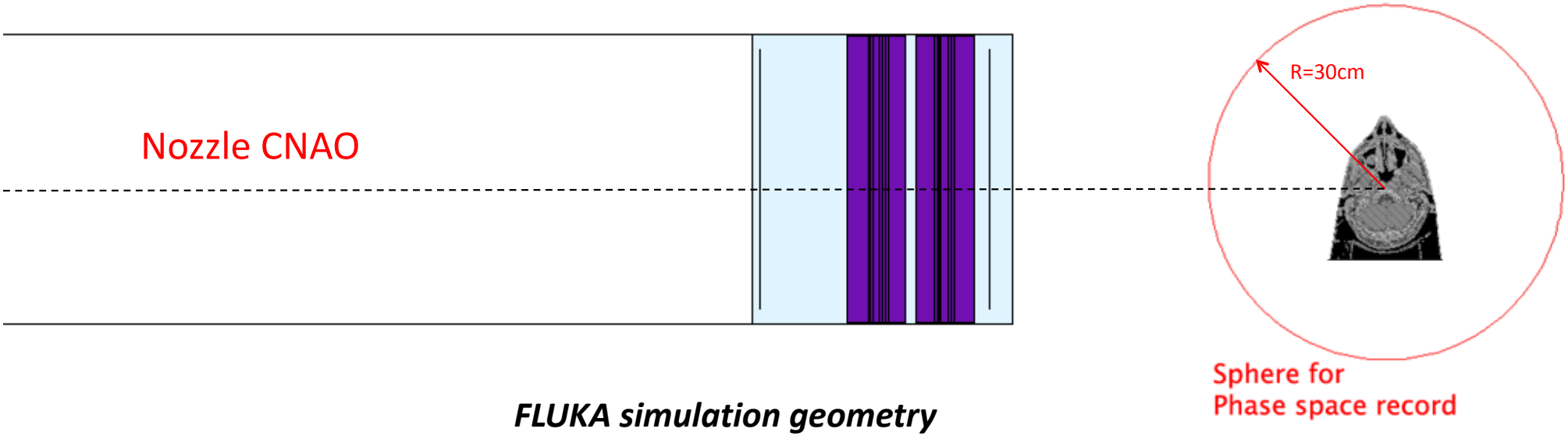
Giving some numbers….

TPS calculation set for slice 33, beam 1, about 12×10^6 particles, i.e. ≈1/20 (5%) of the total planned number (for Beam1).

We implemented a simulation with 5×10^5 particles, (≈ 4% of the total slice parrticles) performing an uniform sampling on the 105 available spots.

Total time for the simulation was 8h on a single core.

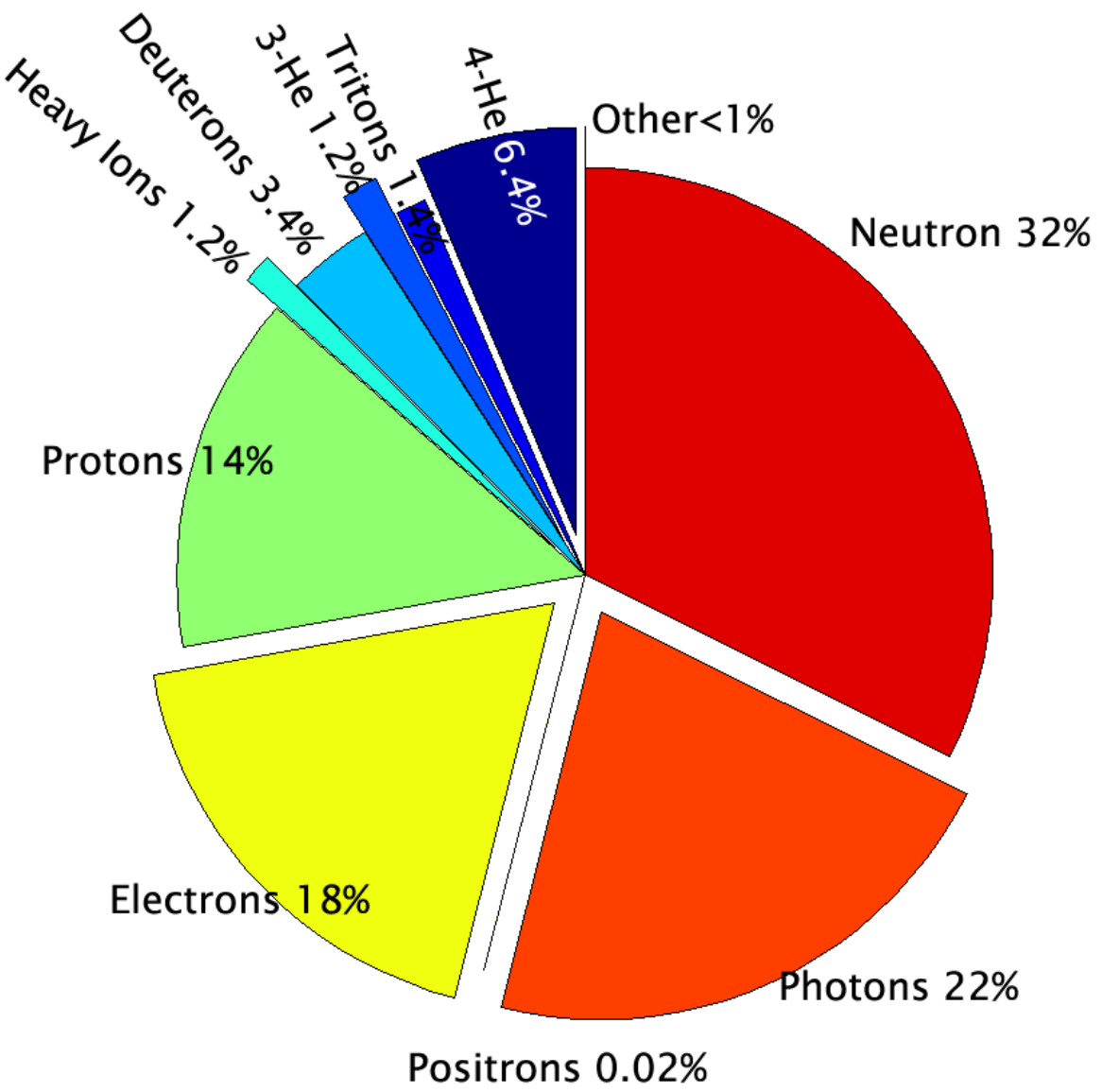
A simulation of the total particles of the plan ($\approx 5 \times 10^8$) require roughly 20 days , for example, on a 24-cores-cluster.



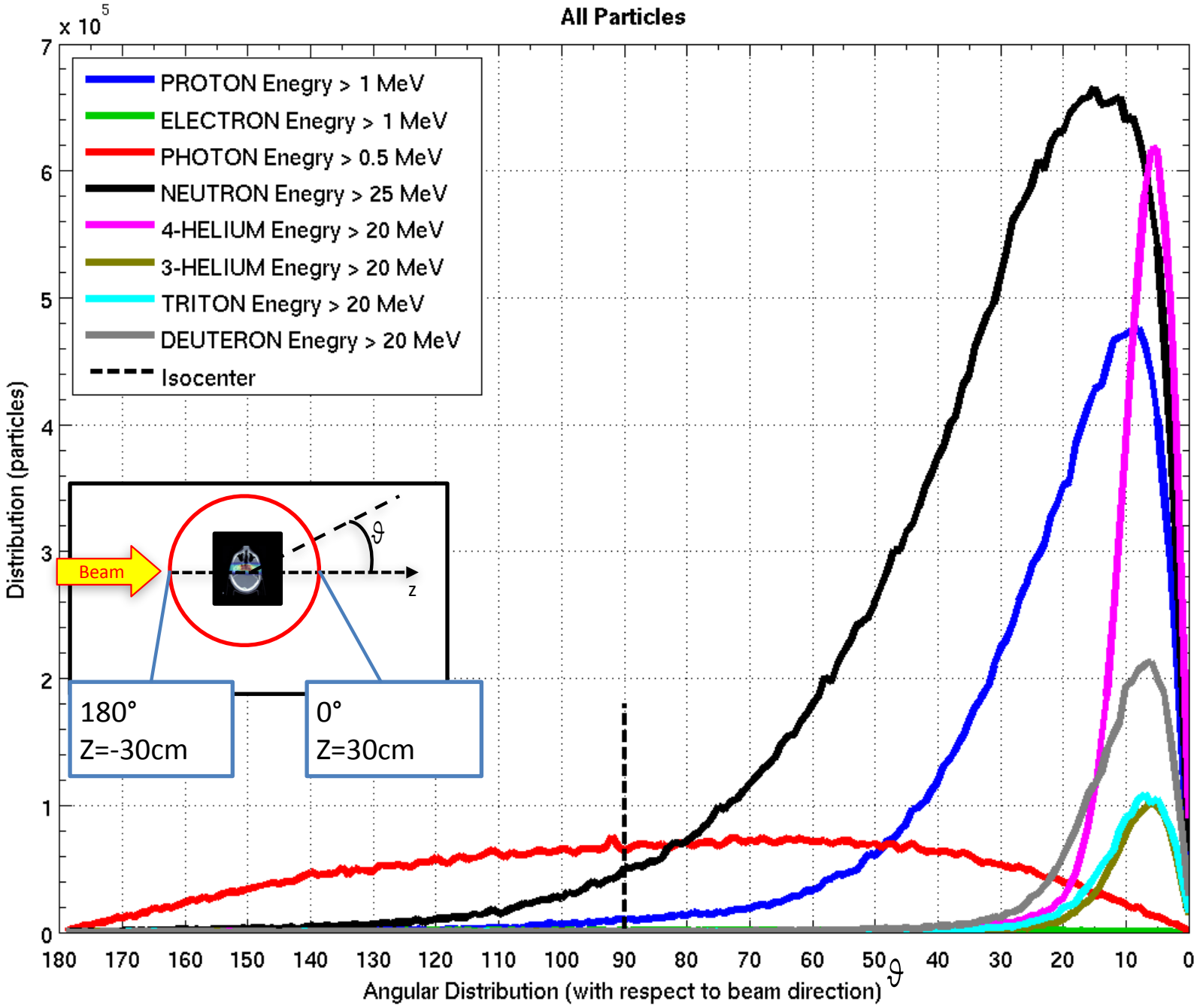
FLUKA simulation geometry

Emitted Radiation Flavor (1 slice = 1 energy)

Number of crossing particles	Particle name	Percentage
6e+06	4-HELIUM	6 %
1e+06	3-HELIUM	1 %
1e+06	TRITON	1 %
3e+06	DEUTERON	3 %
1e+06	HEAVYION	1 %
1e+07	PROTON	10 %
2e+07	ELECTRON	20 %
2e+04	POSITRON	0.02 %
2e+07	PHOTON	20 %
3e+07	NEUTRON	30 %
2e+02	MUON+	0.0002 %
3e+02	MUON-	0.0003 %
3e+03	PION+	0.002 %
2e+03	PION-	0.002 %

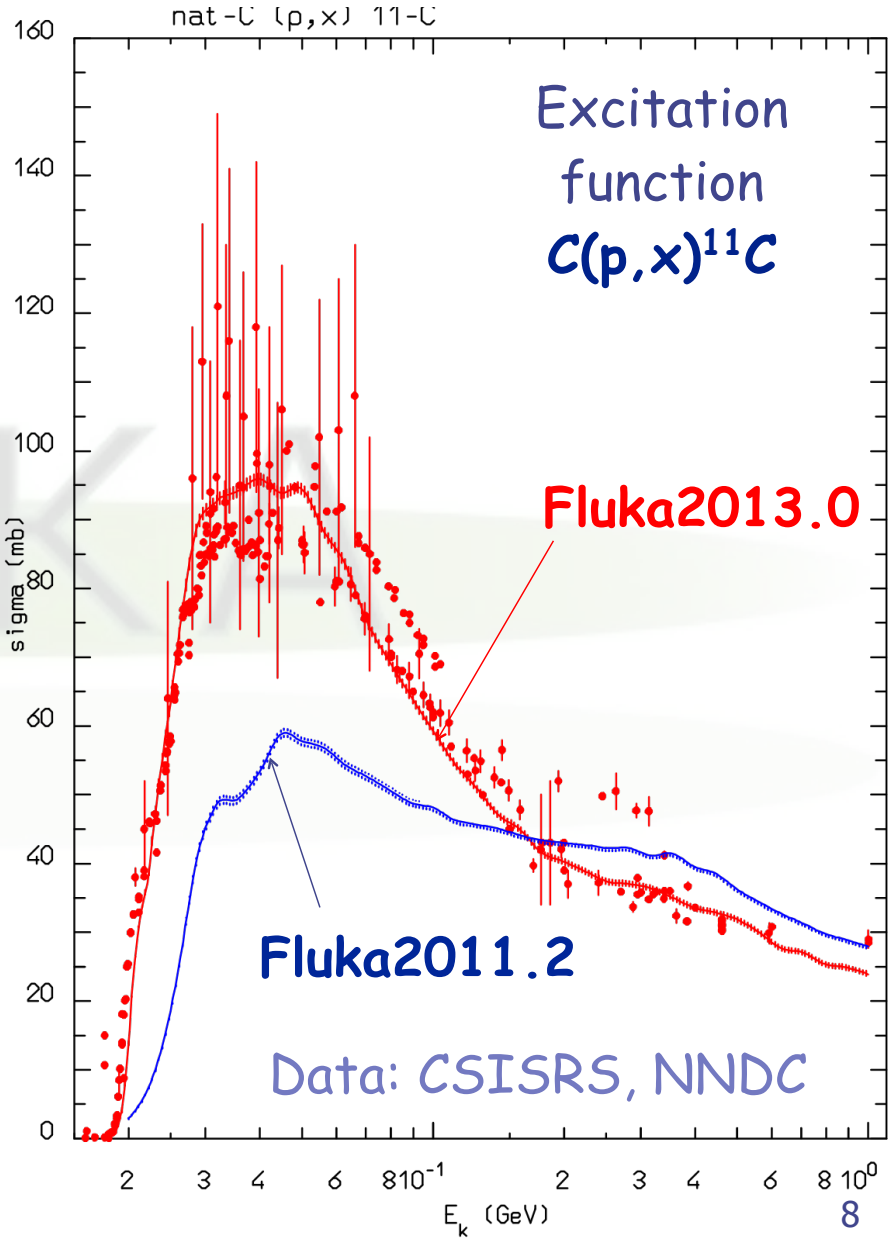


Angular Distribution (azimuthally integrated)



Improvements to β-emitters production → PET

- Radioactive isotopes produced as residuals of nuclear interactions
- Prediction strongly dependent on low-energy and/or low excitation reaction models
- Evidences for bad reproduction of deuteron emission at low E
- A **direct deuteron formation** mechanism at the first **pn** elementary step in the cascade or pre-equilibrium stage has been introduced in **FLUKA** in addition to the standard **coalescence**



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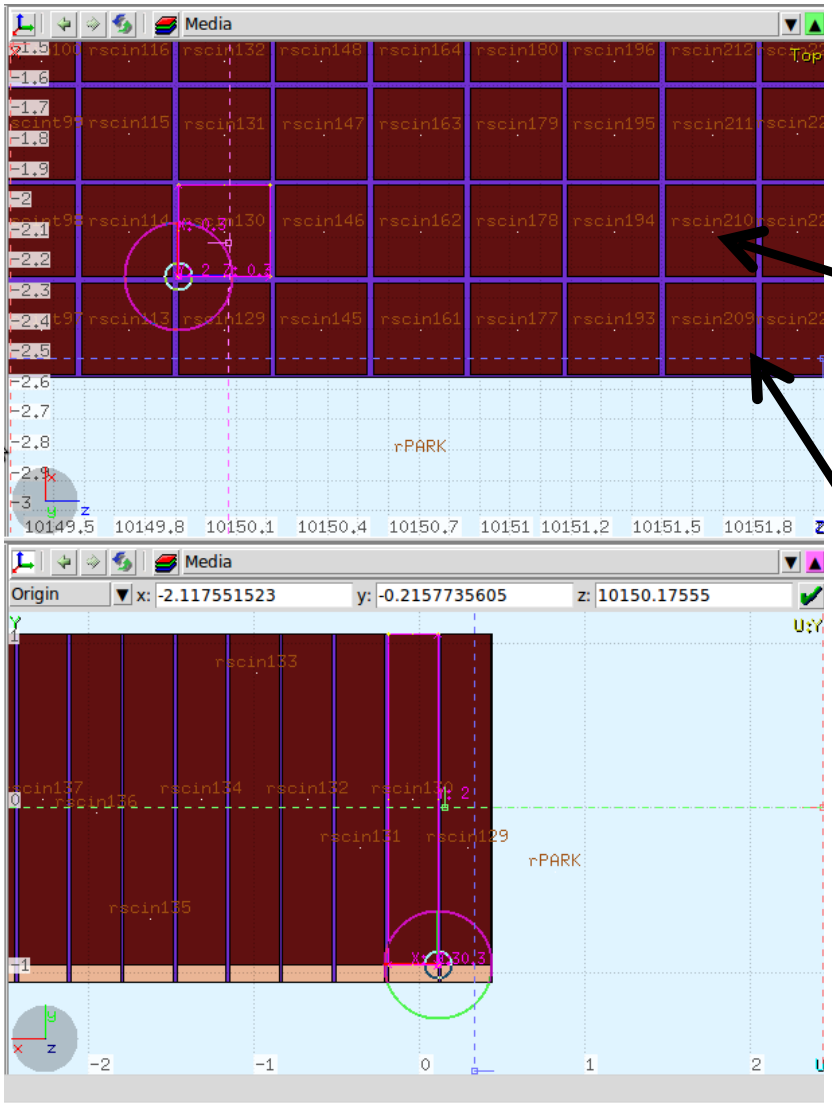
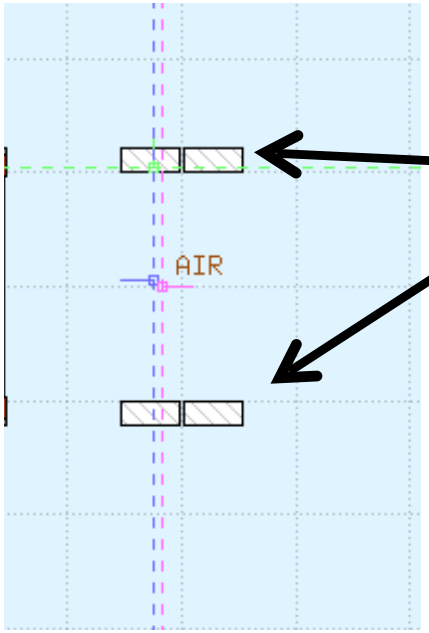
FLUKA geometry(1)



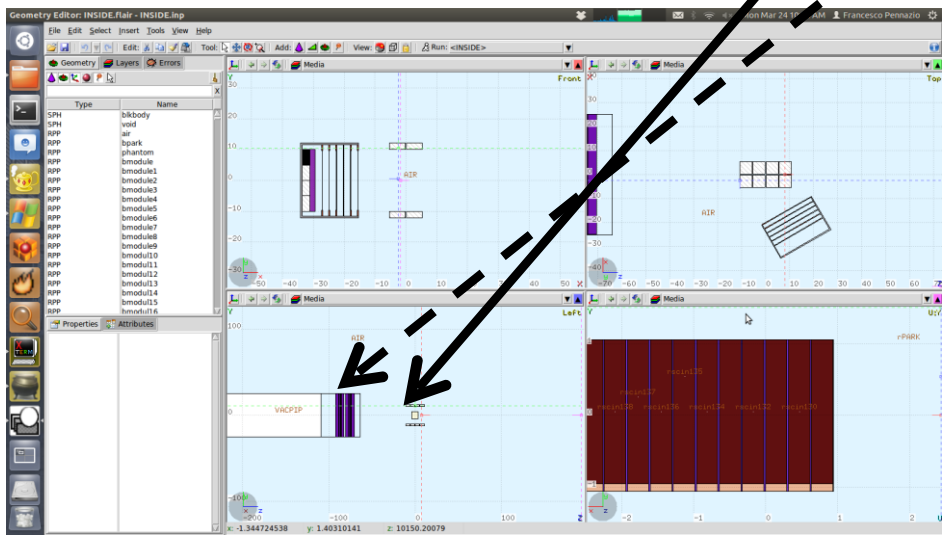
- 16*16 channels per module
- Scintillator elements of $3*3*20\ mm^3$
- 3.2 mm pitch
- $BaSO_4$ container
- Lattice – based geometry (replica of a detailed block in park region)

FLUKA geometry (2)



Head distance = 60 cm (variable)

- 4*2 modules per head
- PMMA phantom
- CNAO beam pipe inherited from dott. Mairani



PET simulated detector output

- Text file (at the moment)

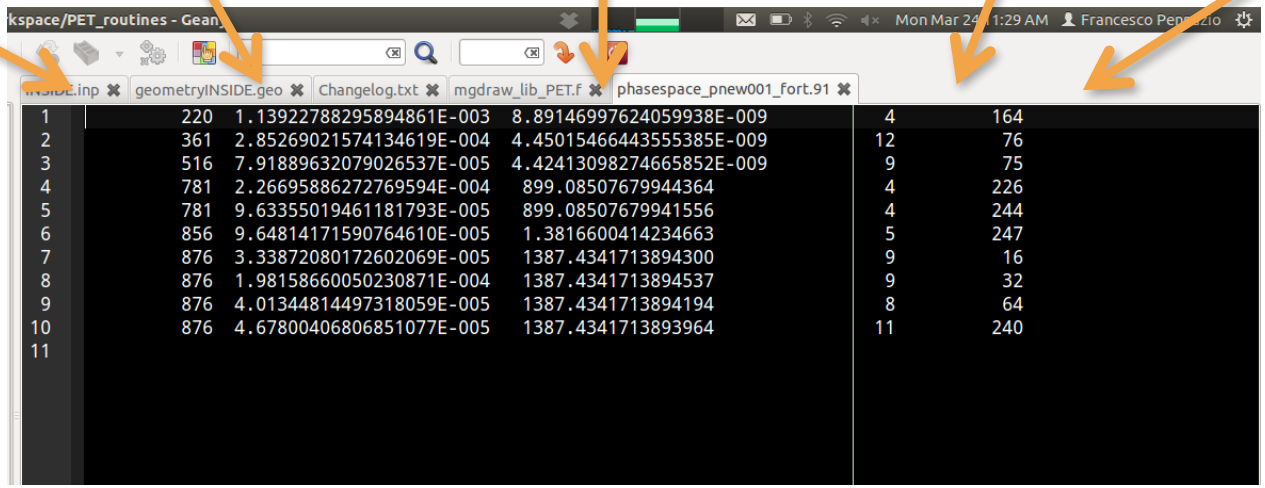
Event number

Energy deposited

Last energy deposition time in the detector

Block

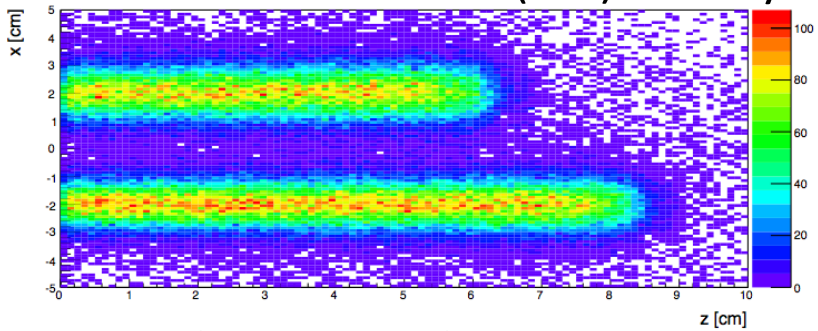
Element



Example distributions

Simulation 2 spots

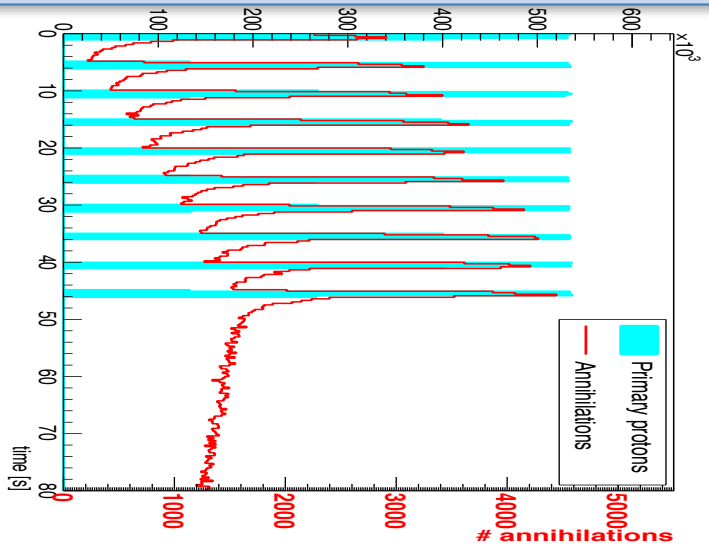
2-D distribution of total (int.) activity



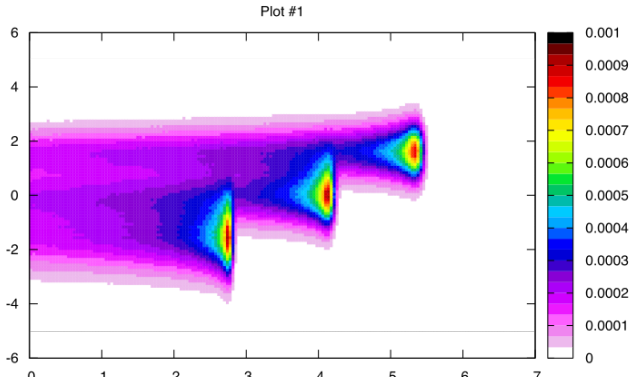
Activity for spot 1 of treatment plan

Activity for spot 2

- CNAO time structure included (Roberto N)
- CNAO beam-line included (Mairani, Battistoni)
- Treatment plan simulation included
- CT scans can be imported (see 10-11)
- You can sum up contributions from spots, energies, etc.



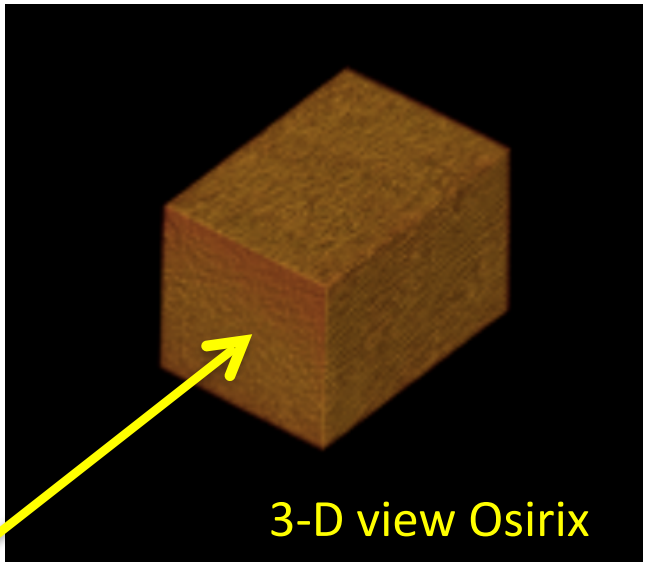
"Plan" with 10 spills: timestructure of annihilations

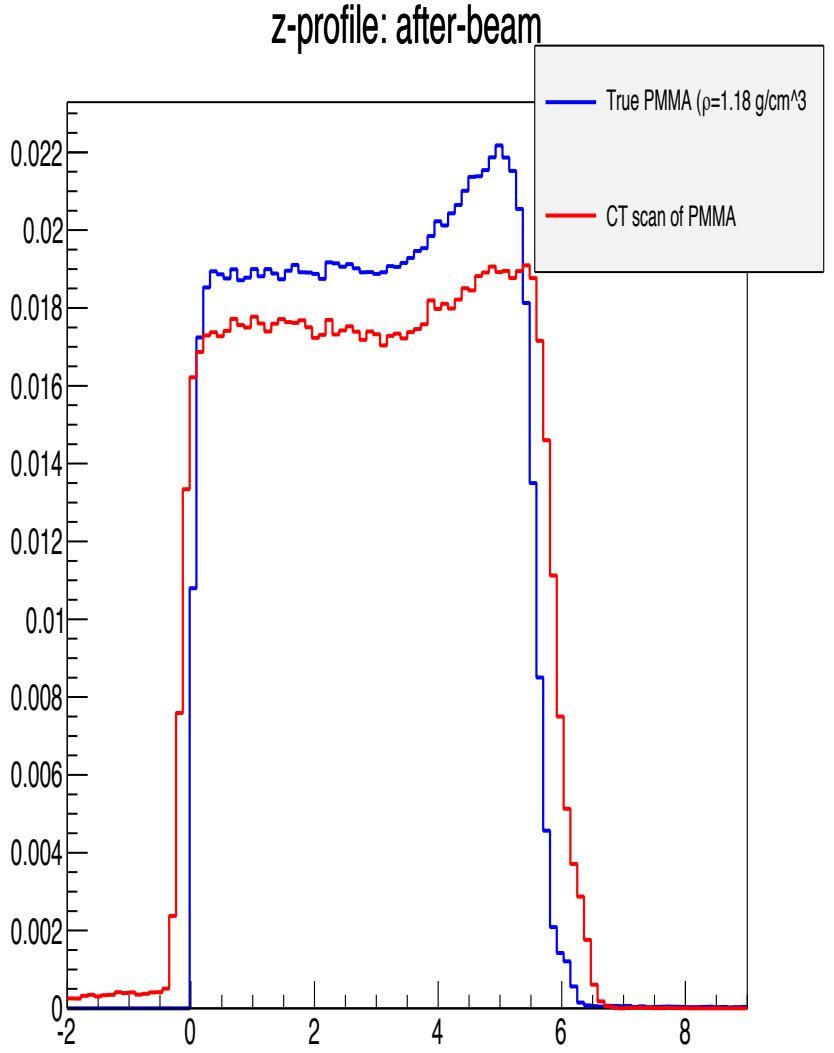


Dose of "plan" with 3 spots

First test on CT scan (PMMA)

- Mono-energetic beam of 97.5 MeV
- CT imported in FLUKA (thanks to Fabrizio)





- Profile and fall-off not quite the same

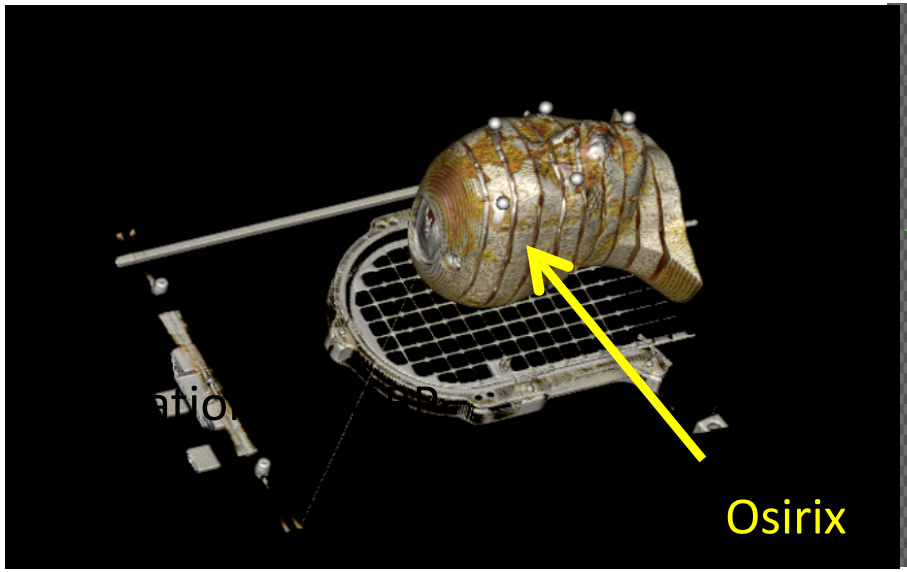
Work in progress…

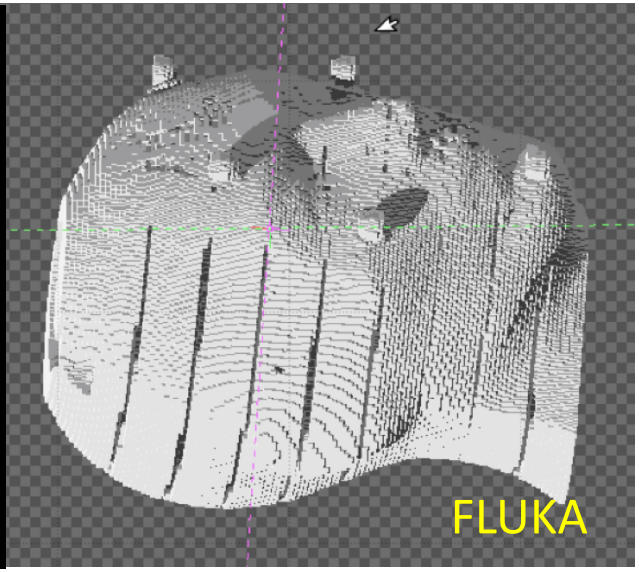
First test on CT of anthropomorphic phantom

Treatment plan from CNAO (Molinelli, Mairani, Ciocca)

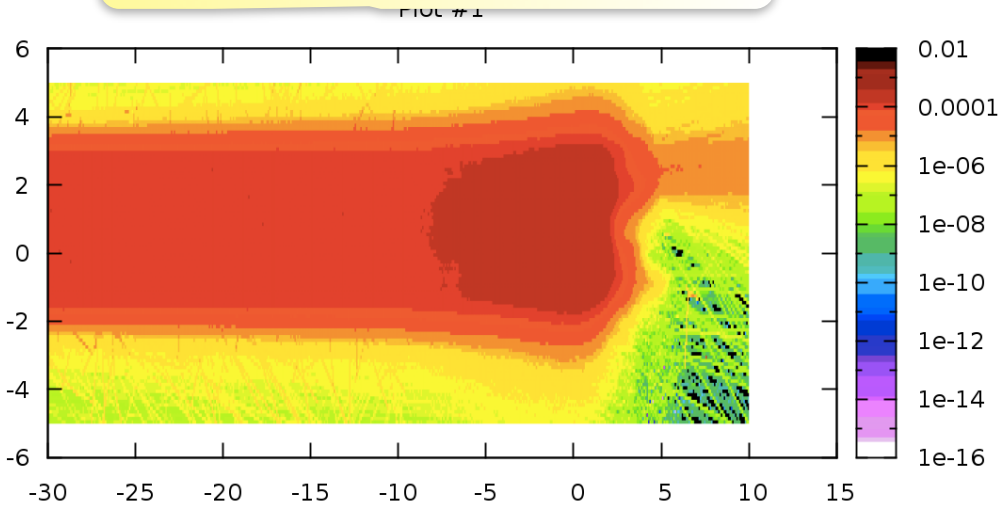
- Tumor ~5x3x3 cm^3
- 34 energy layers
- 2958 spots
- Nr protons: 2E10

FLUKA:
2E6 primaries
(factor 1E4 too little)

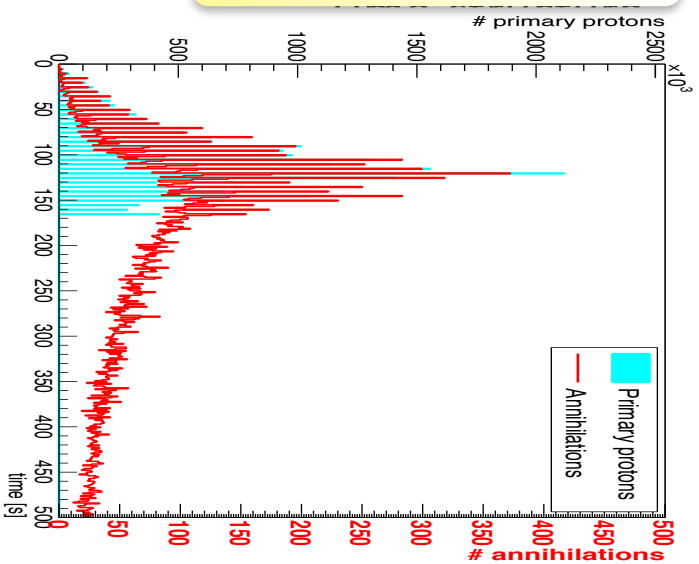




2-D dose distribution FLUKA

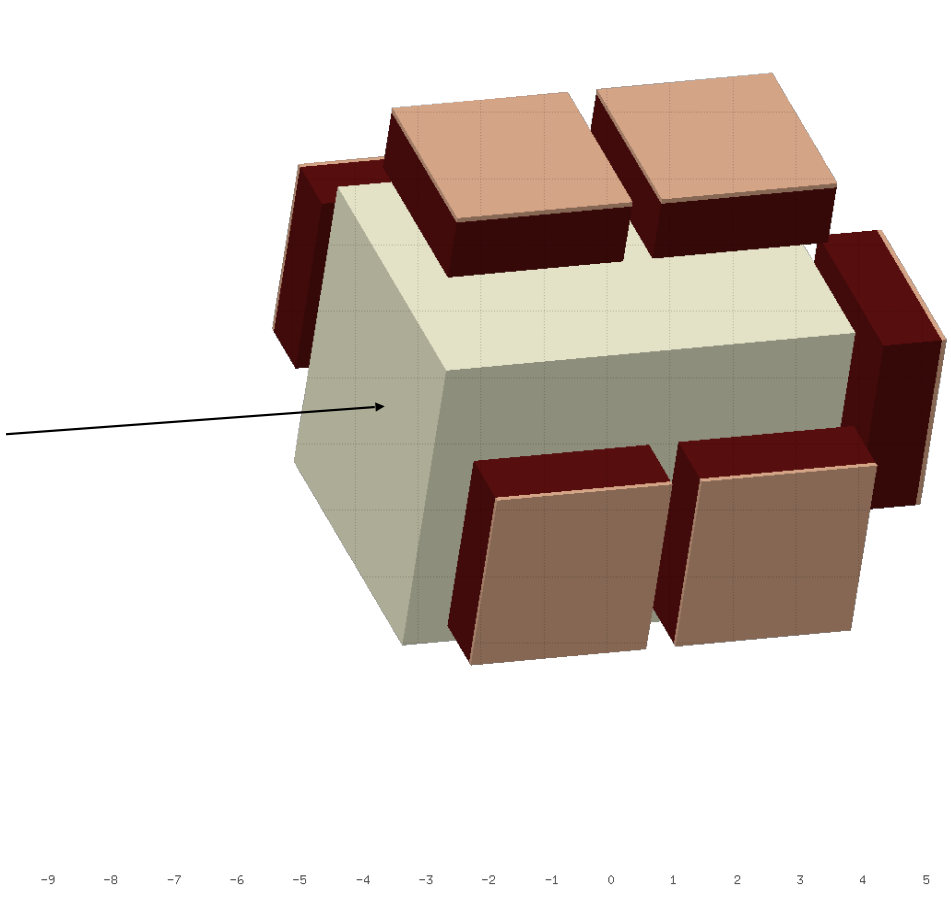


Time-structure



Nr primaries increases here with delivery time

Beam Test Geometry setup

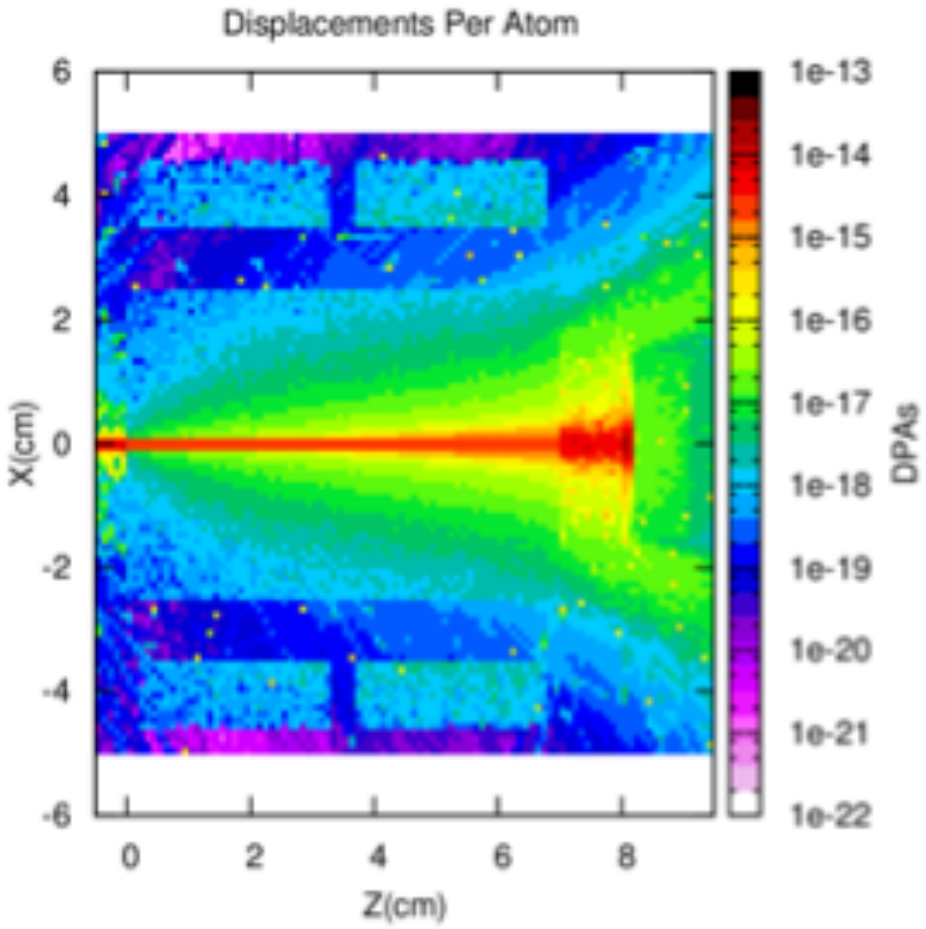


95 MeV proton beam with time structure (see next slide);

PMMA phantom with dimension 5cm*5cm*7cm;

7 LYSO+SiPM combined detectors is located vertically(6 detectors) and paralleled (1 detector);

LYSO size: 3cm*3cm*1cm, increasing the size for statistics.



Radiation damage is scored by DPA.
The detector placed back side is mostly damaged by hadrons.

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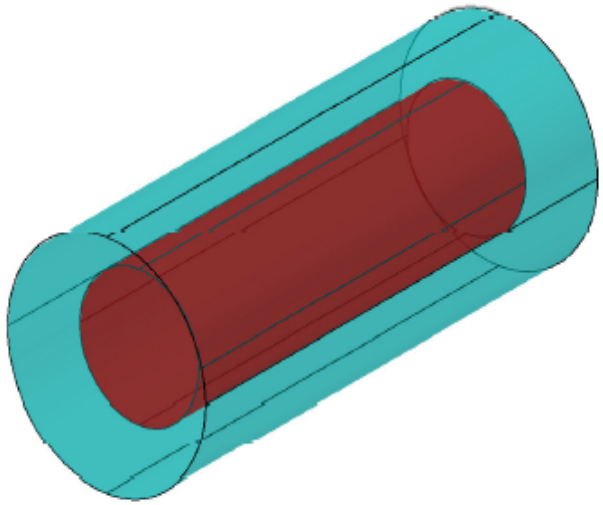
Cylinder simulation setup

Hot region

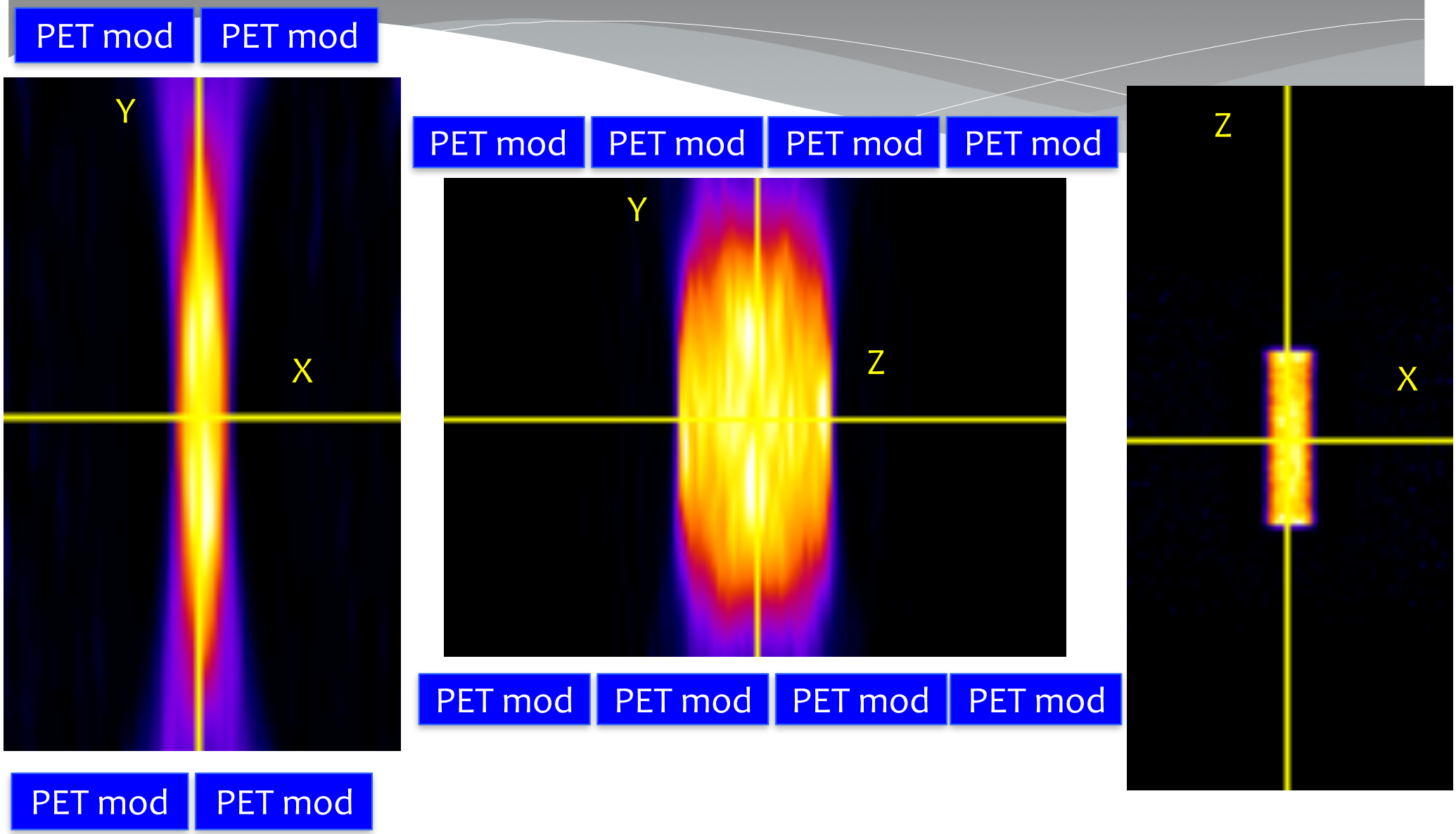
* Cylinder filled with F-18 (half life 108 min) dimension 15 mm diameter, 50 m height
* Initial activity 5 mCi (185 MBq)

Phantom

* PMMA cylinder diameter 25 mm and 6 mm height
* Aligned along the Z axis
* Posed in the center of the FOV
* Acquisition time: 3600 sec



Reconstructed cylinder



Results: reconstruction time

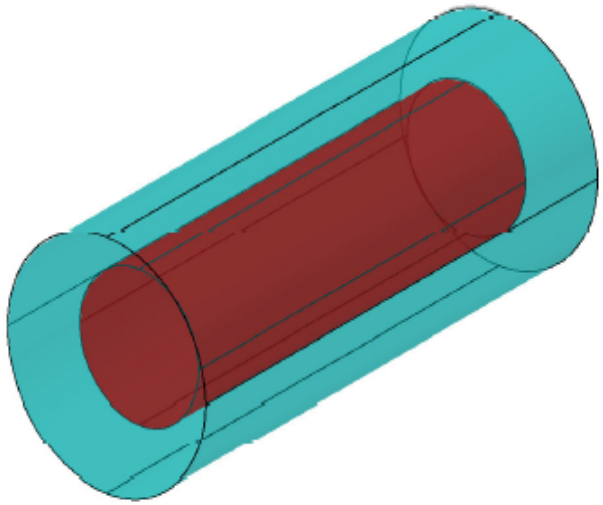
* **600 K coincidences detected in the energy window [350,650] keV**
* **All inclusive reconstruction time 2min 40 sec on a quad core (core duo Q9400 2.6Ghz)**
* Iteration time 5 sec
* 5 iterations performed

Sensitivity at the FOV center

* Spherical F-18 point source of radius 0.25 mm in a PMMA cubic phantom 5mm size
* Source activity 10MBq
* ***Sensitivity at the FOV center 0.2 %***

Test of Single slice Analysis

* thin cylinder sources (as thin as the expected fixed energy beams) will be reconstructed and superimposed to test the actual TP conditions



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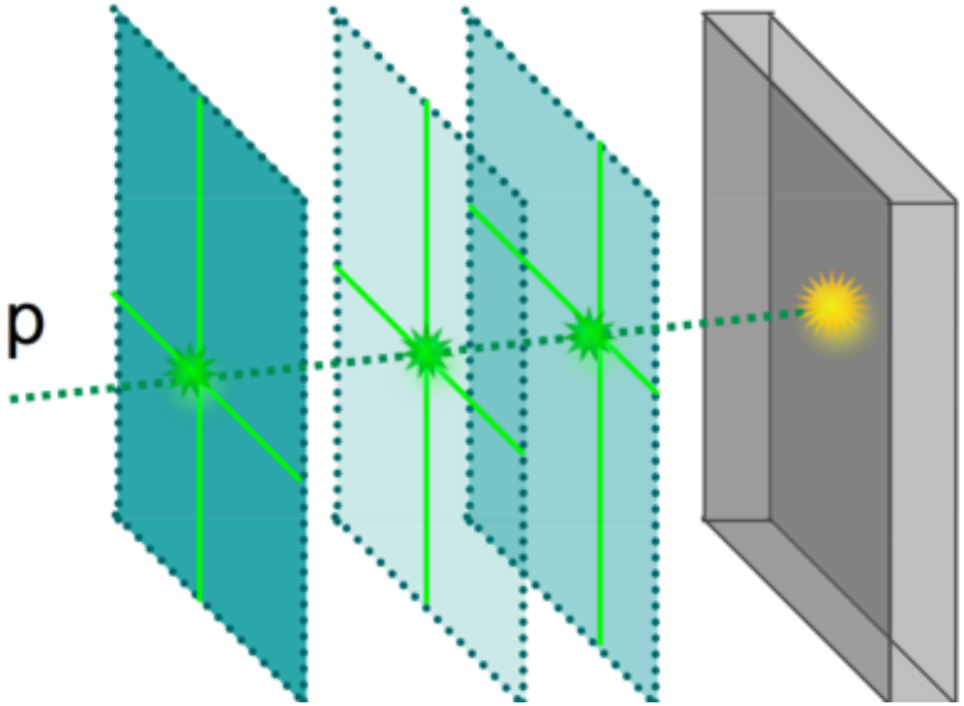


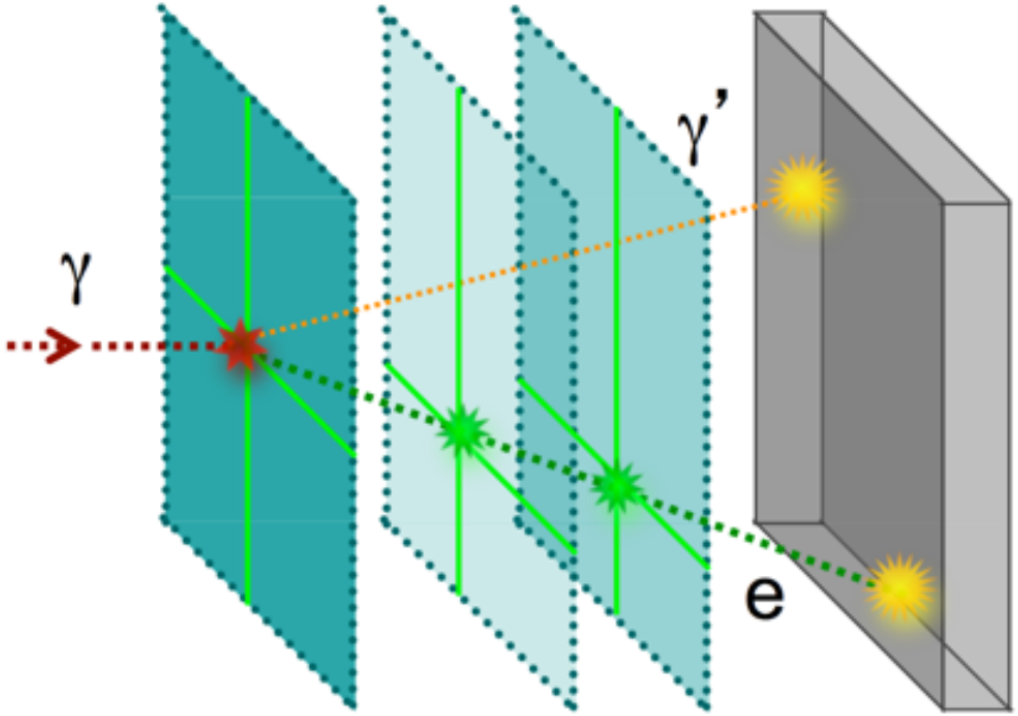
Event Selection:

- 3 Tracker planes hit
- LYSO Deposit w E> 100 keV

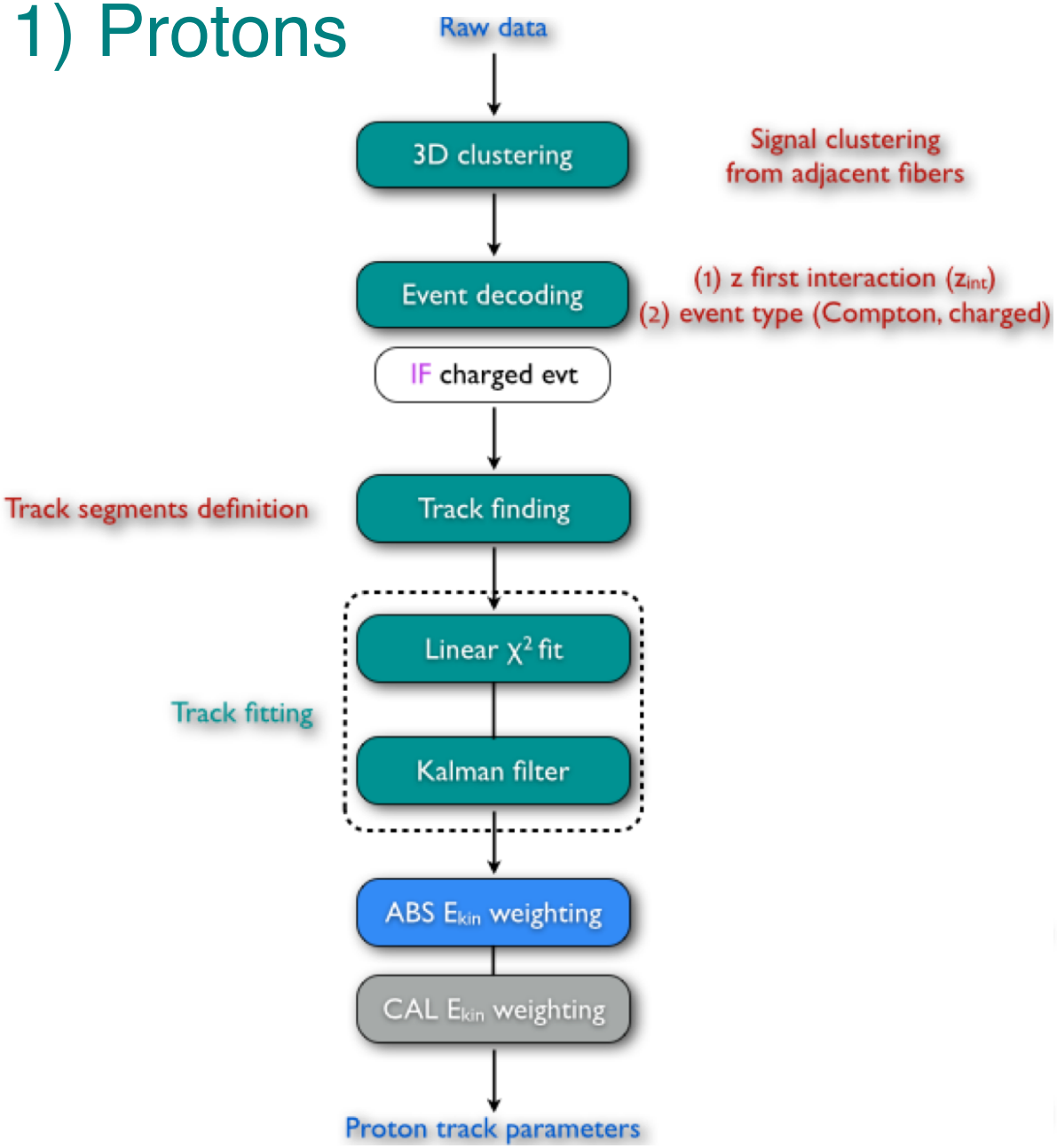
1) Protons

2) Prompt photon:

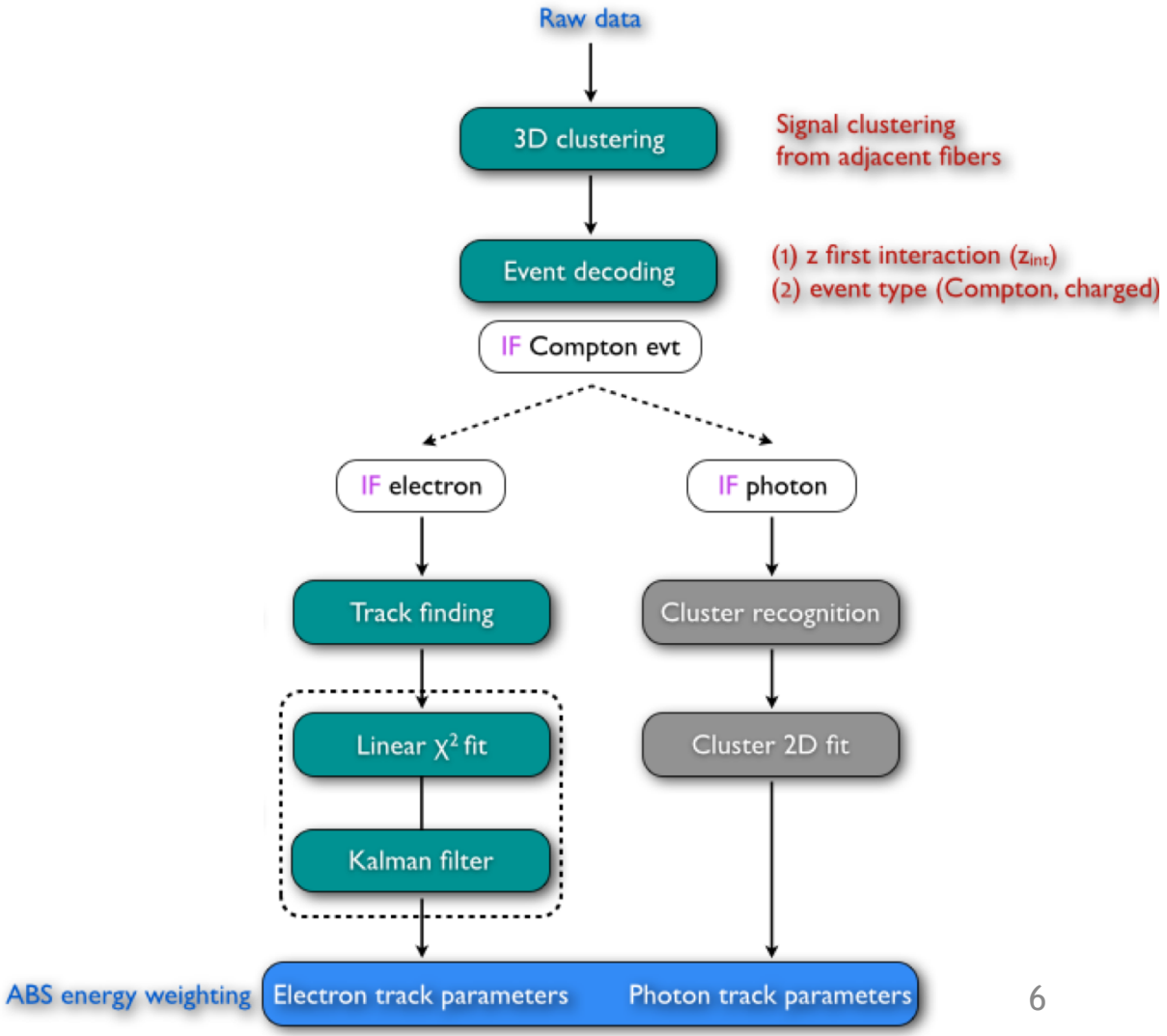
Compton scattering



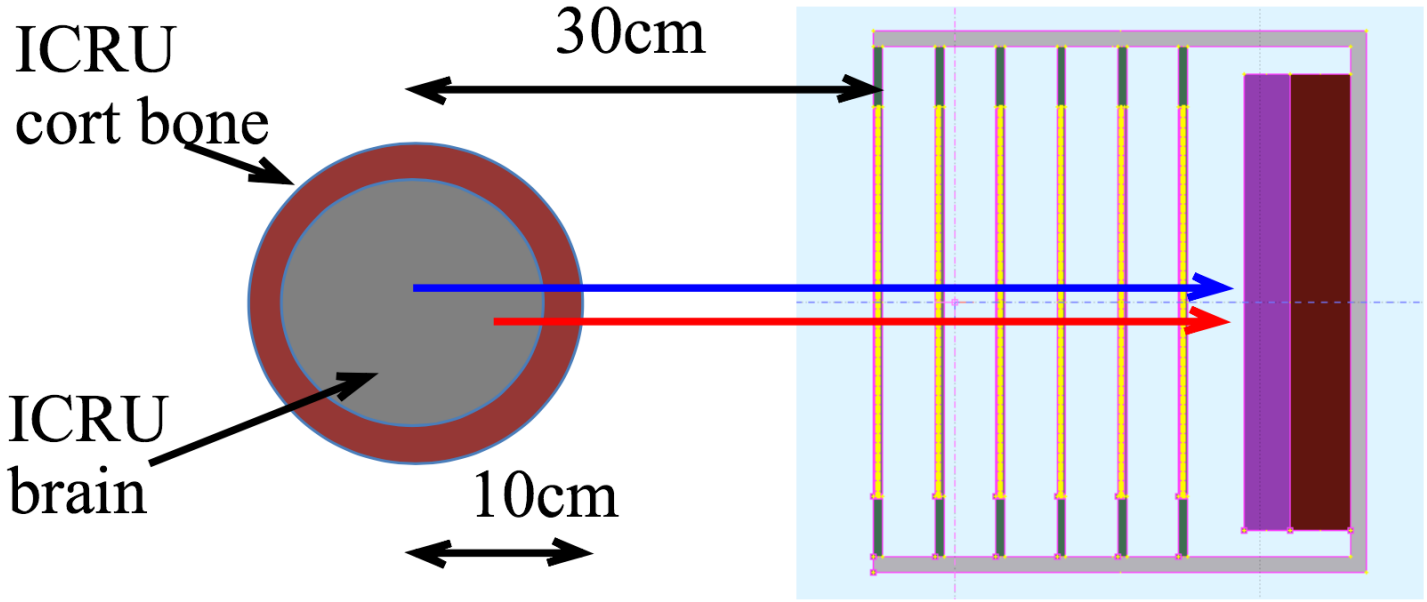
1) Protons

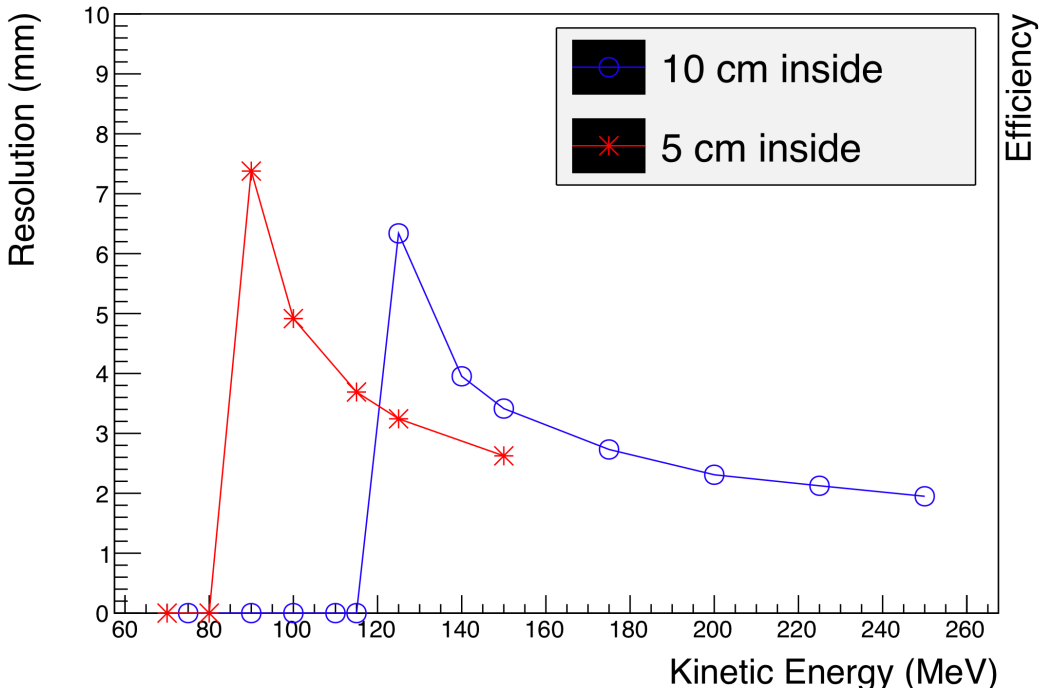


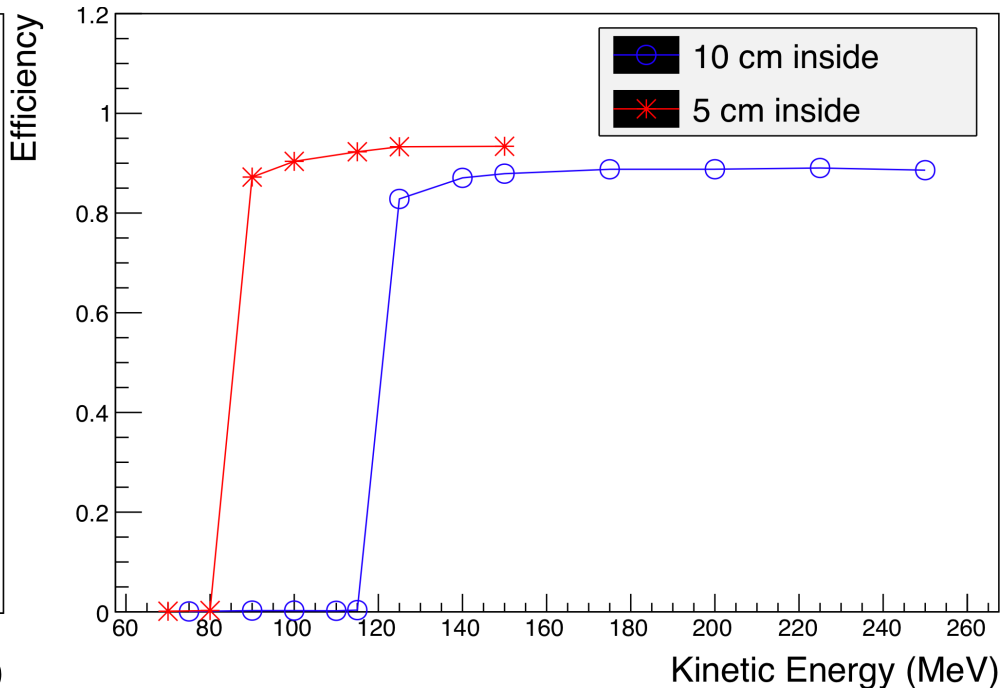
2) Prompt photon: Compton scattering



Tracking: resolution with protons



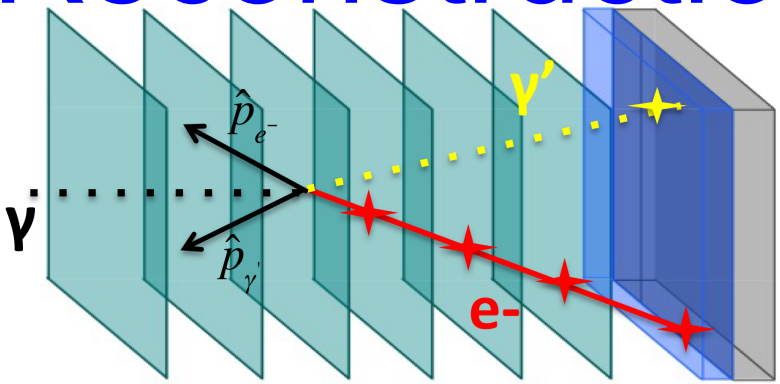




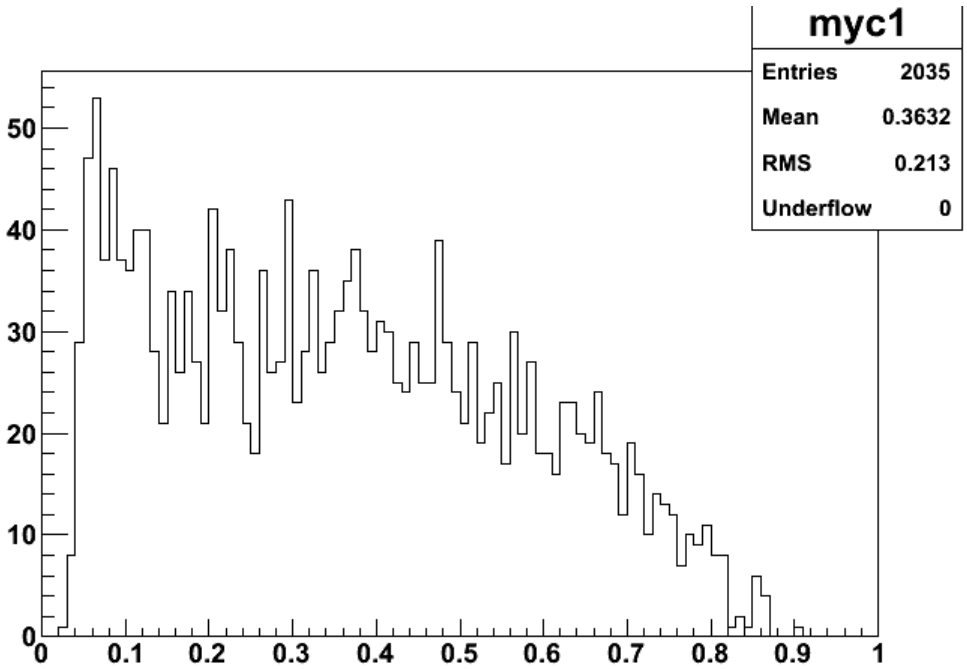
Primary Photon Reconstruction

$$\hat{p}_\gamma = c_1^{MC}\,\hat{p}_{\gamma'} + c_2^{MC}\,\hat{p}_{e^-}$$

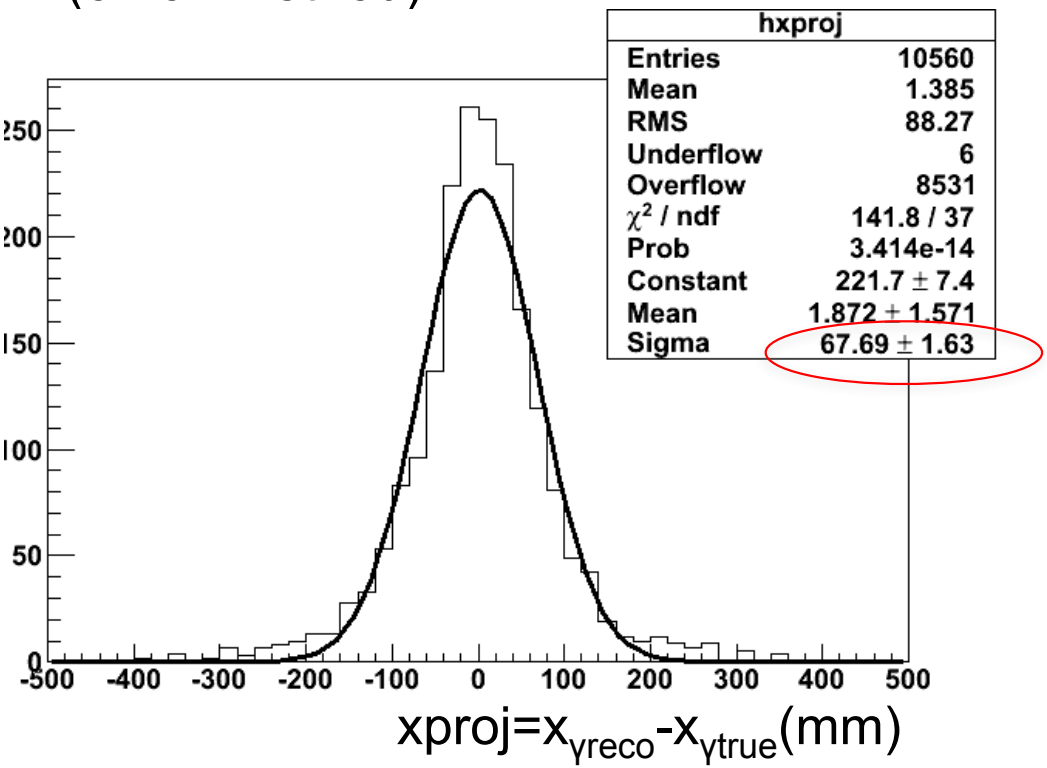
$$c_1 = \frac{|p_{\gamma'}|}{|p_\gamma|} \qquad c_2 = \frac{|p_{e^-}|}{|p_\gamma|}$$



- Recomputed c1 coefficient



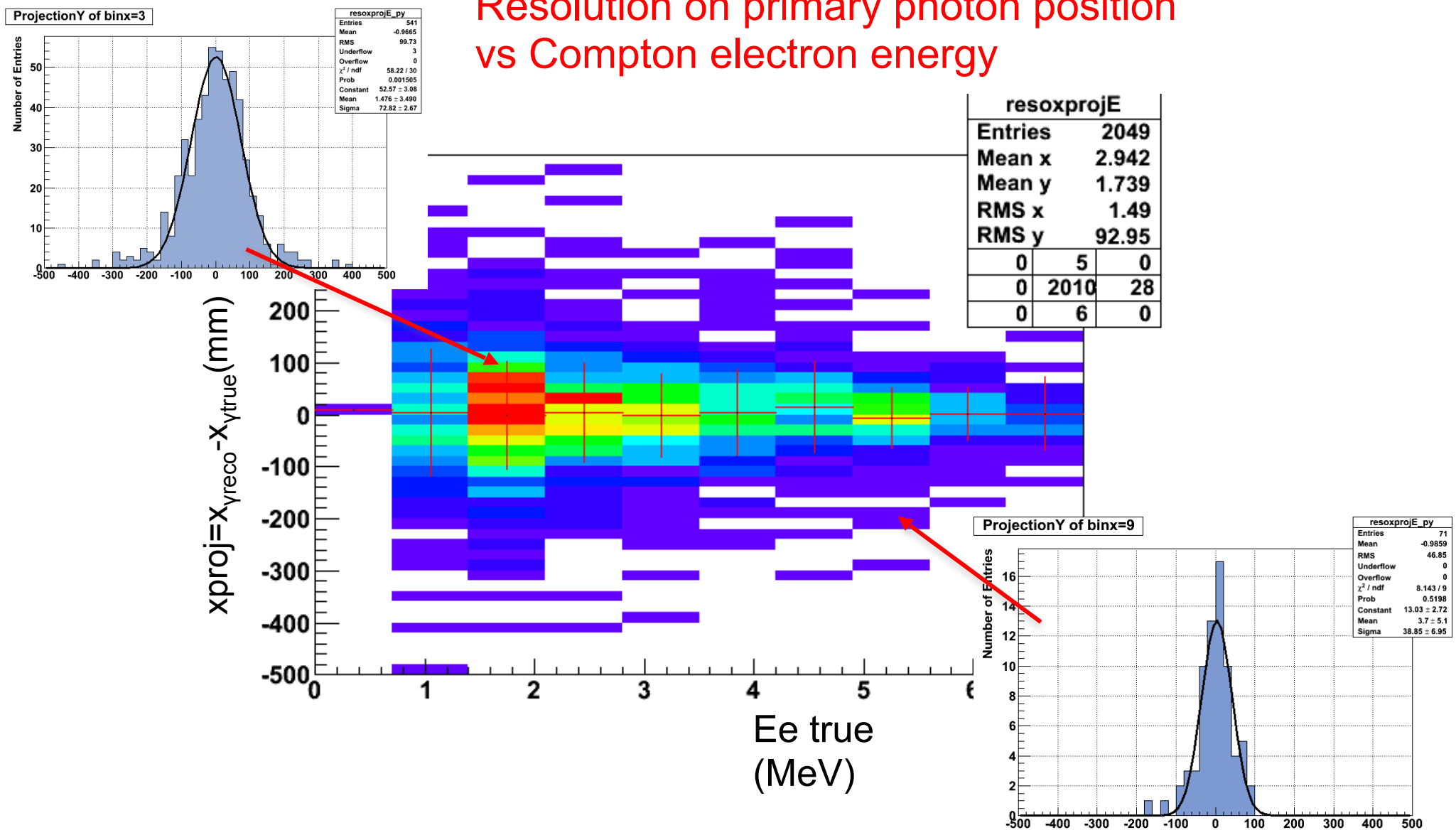
- Resolution on primary photon position (c1-c2 method)



Resolution with 1 M of events: 68/sqrt(2023) =1.5mm

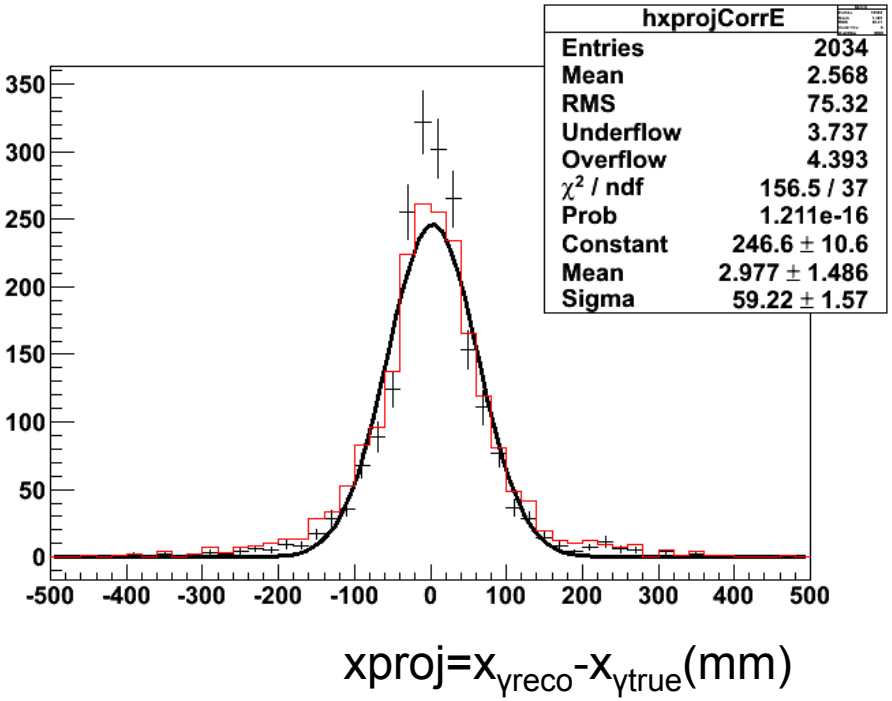
Possible improvement on primary photon resolution

Resolution on primary photon position vs Compton electron energy



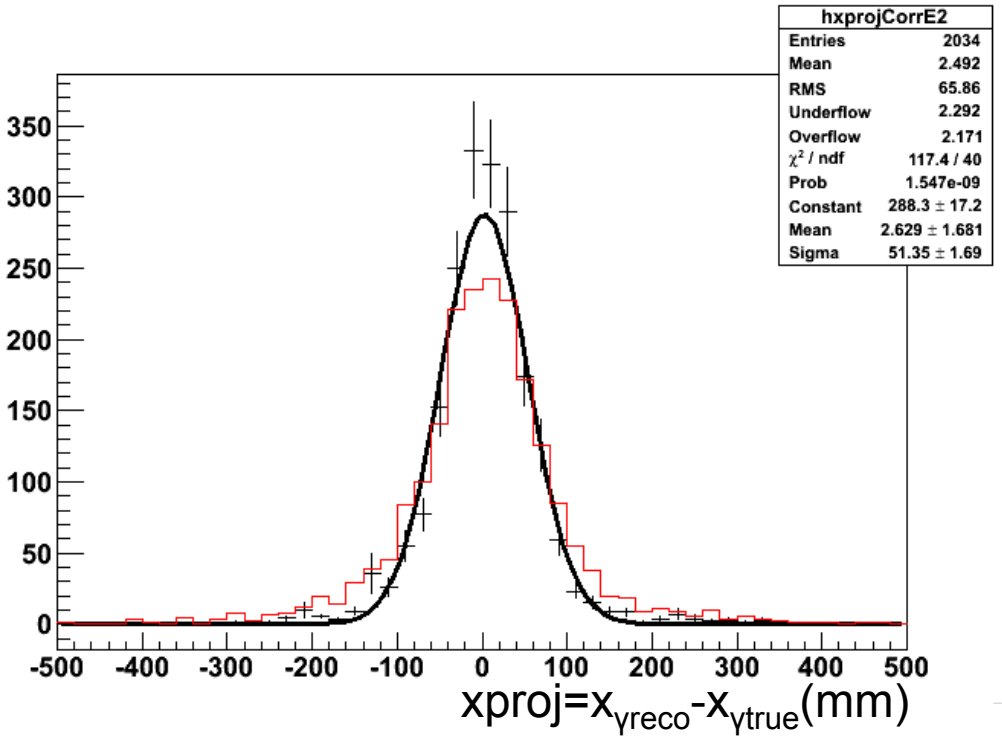
Weighting resolution with 20%-smeared electron energy

black (fit): resolution weighted with Ee
red: no correction



xproj=$x_{\gamma reco}$-$x_{\gamma true}$(mm)

black (fit): resolution weighted with Ee^2
red: no correction



xproj=$x_{\gamma reco}$-$x_{\gamma true}$(mm)

Resolution with 1 M of events: 50/sqrt(2023) =1.1mm

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How to combine the PET and Profiler information in the data analysis?

- High-level reconstruction should be envisaged: the PET, charged and neutral info should be merged to exploit the maximum information on the treatment.
- Joint MC run will be produced to have all secondary reconstructed for the same treatment situation
- CPU power is an issue: we will use LHC (cloud) facilities to simulate a “full” treatment session
  - one pencil beam (x,y,E,n) = one job
  - time offset and merging
- **Profiler information as input to the PET deconvolution procedure?**

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What to integrate (1)

- Geometry:
  - Source
  - Profiler model
  - PET model
  - Phantom / CT
- User routine:
  - Profiler
  - PET
  - Activity distribution analysis
- Simulation physics
  - DEFAULTS PRECISIO
    EMFCUT -0.0001 0.0001 @LASTREG
    EMFCUT -0.0001 0.0001 1. @LASTMAT PROD-CUT

Work in progress

Done

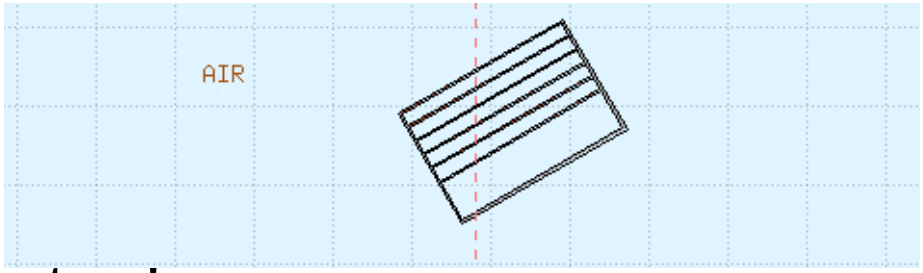
What to integrate (2)

- Post-processing:
  - PET (ROOT/C++)
  - Profiler (Root, Matlab?)
- Reconstruction
  - PET
  - Profiler
- User manual
- Installation script
- Repository (presently Dropbox shared folder)

Geometry integration (1)

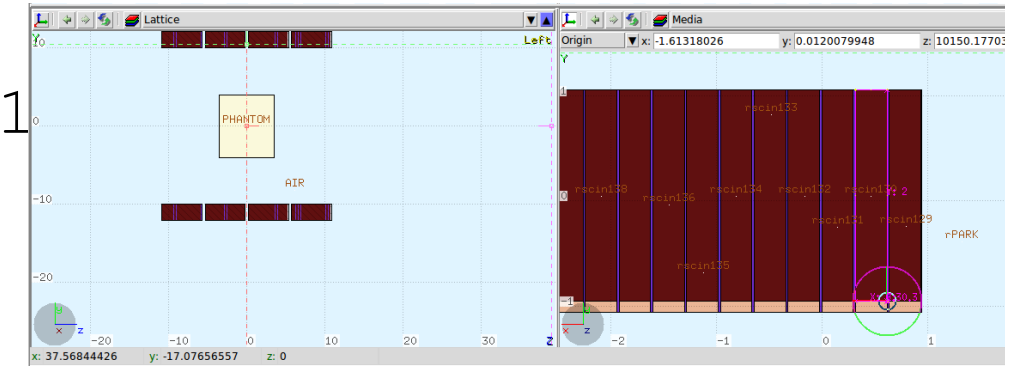
- Tracker
  - freely rotating in the *x* – *z* plane around *y* axis

```
#define trk_ang 60.
#define trk_dist 20.
```



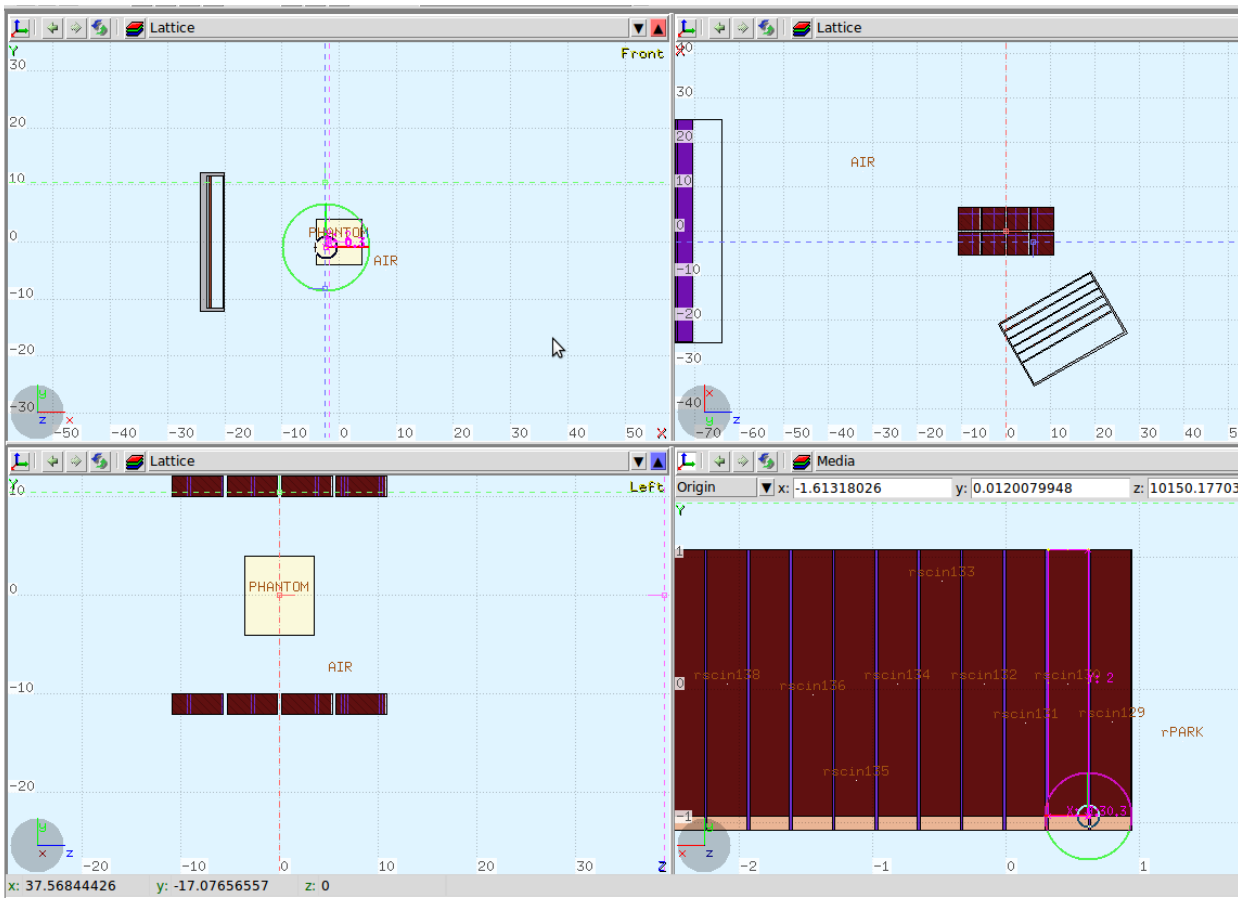
  - Lattice seems to correctly rotate too!
- PET position free along *x*,*y*,*z*

```
#define head_z 22.08
#define head_c_x 0
#define head_dist 1
```



Geometry integration (2)

- Tracker and PET on the same model



Next steps

- Selection of Profiler and/or PET or phantom
- CT integration
- Improve PET data with father and grandfather information (STUPRF)
- Speed up the simulation
  - Bias
  - Activity based-generator
  - Cloud-computing
  - -> in any case work on code is needed (to set up the bias and the correct analysis, to write the generator user routine, to divide and merge the simulation cores)
- Simulations
- Complete treatment simulation (at least for PET)
- Information about integrated signal on both detectors

... and test ...

Summary

- SW functionality almost all in place (detector calibration missing)
- Integration effort started
- Simulation (beam + phantom & beam + patient) with FLUKA will be provided as input for PET and Profiler simulation & reconstruction
- DAQ interface: buffer structure required to start the implementation
- Data Analysis strategy
  - at least 3 “full” adjacent slices (i.e., beam energy values) required
  - for PET: likely required a “full” Treatment simulation before the data taking (to be compared with data)
- Access to INFN-Cloud will be implemented (first meeting soon at CNAF)

Goals

- Short / medium term
  - The PET analysis must be based on iterative subtraction of convolved contributions
  - Expected number of events for a full treatment session
    - ~ 3 x 10^5
    - 30 – 50 energy values
    - ~ 10^4 events / energy
    - 10^3 for the integration at the initial energy value
      - Can we extract a realistic fit to model contributions that mix up with higher energy values?
  - To test that we need a full treatment simulation for at least 3 energy values
    - How much computing time?
    - What model?
  - Profiler: …

Goals

- “Long” term
  - Fully integrated software release to be built on INFN cloud computing facilities
    - Capability to simulate a full treatment (or a statistically significant fraction) in a “short” time (1 – 2 days)
  - Fast reconstruction and data analysis software
    - We need information “during” the treatment
    - Can it be done on a “standalone” machine?
  - What information to integrate with the CNAO workflow? How?