A first attempt to evaluate some numerology to be used as reference for INSIDE

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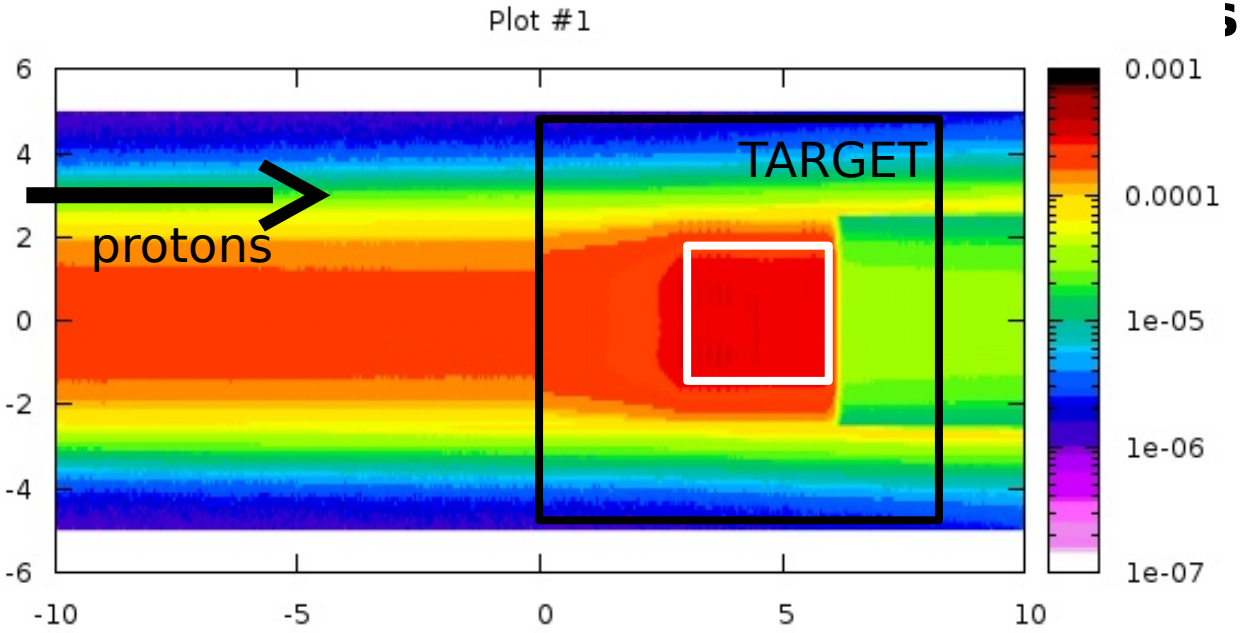
In a typical treatment fraction:

- How many annihillations do we expect in a typical treatment fraction?
- How many useful particles enter in the acceptance area of the Profiler?

Connected topic:
Developments in progress for Profiler simulation

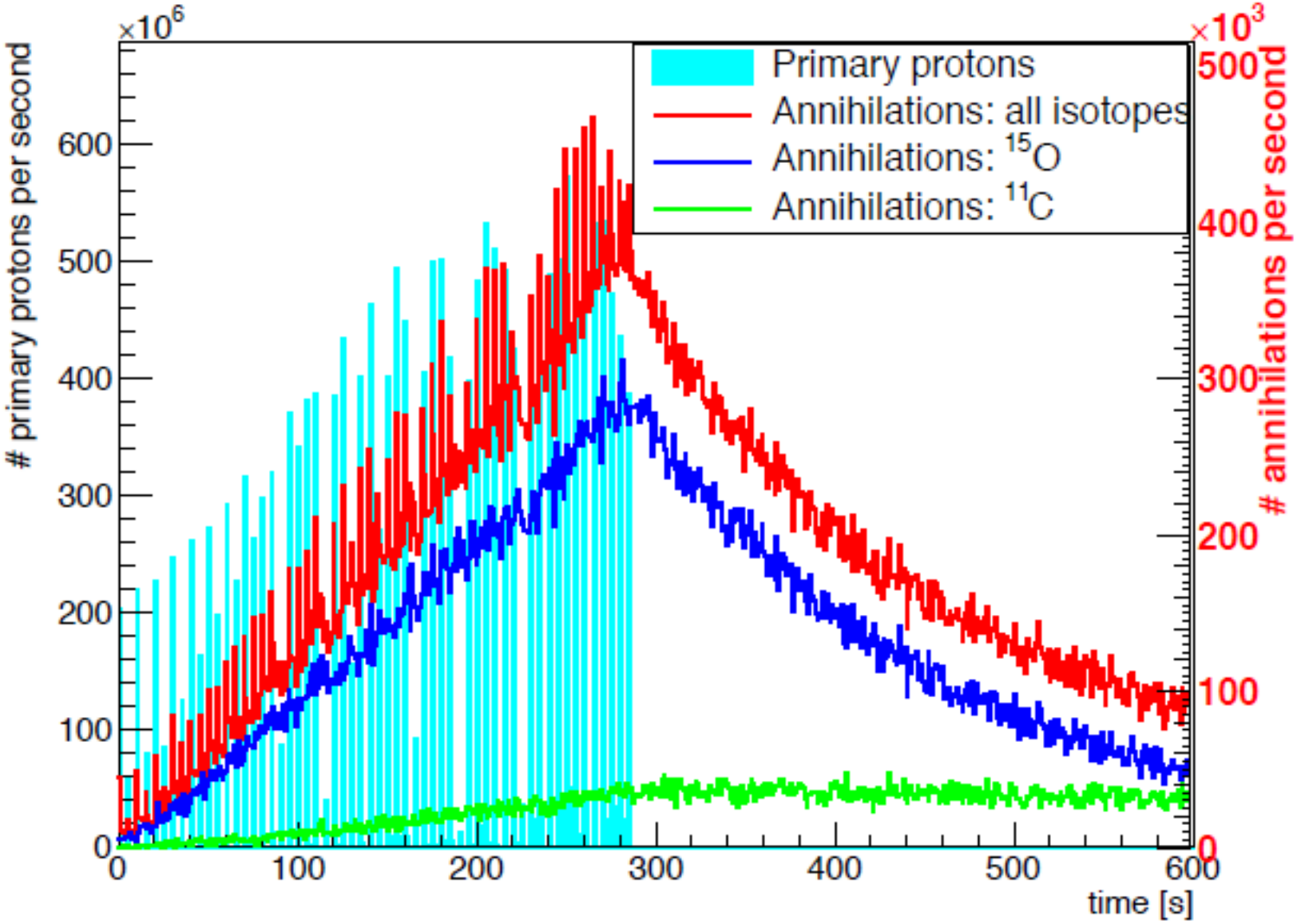
a) β^+ activity in proton therapy (A. Kraan)

- FLUKA simulation: treatment plan delivering 2 Gy on a 3x3x3 cm^3 “tumor” (box) located at z=3 until z=6 cm
- Plan: 2 Gy plan from Silvia Molinelli (CNAO): 2 10^{10} protons
  - Target: 5x5x8 cm^3 block of brain, (composition from Brain ICRP)
  - Number of primaries 4 10^7 (simulation time was couple of hours)
  - Irradiation time was 4.5 minutes which is rather long (low beam intensity)
- **scaled by 2 10^{10}/4$10^7$=**

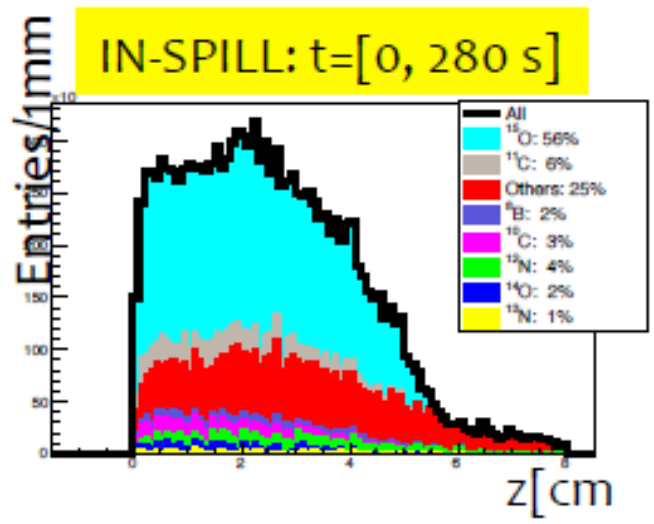


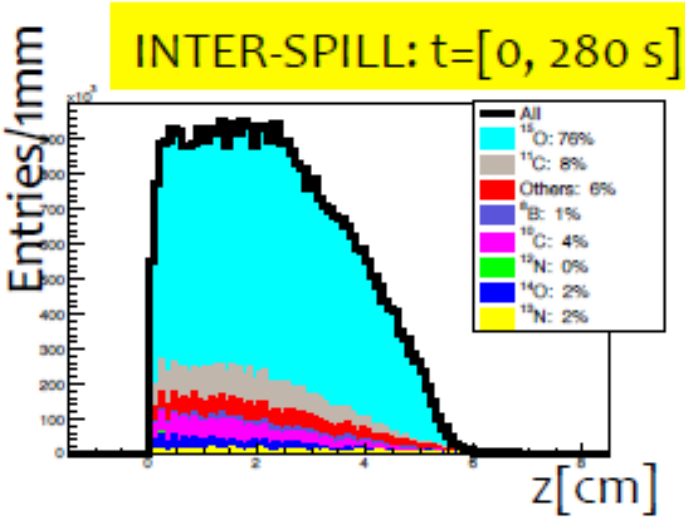
DOSE from flair

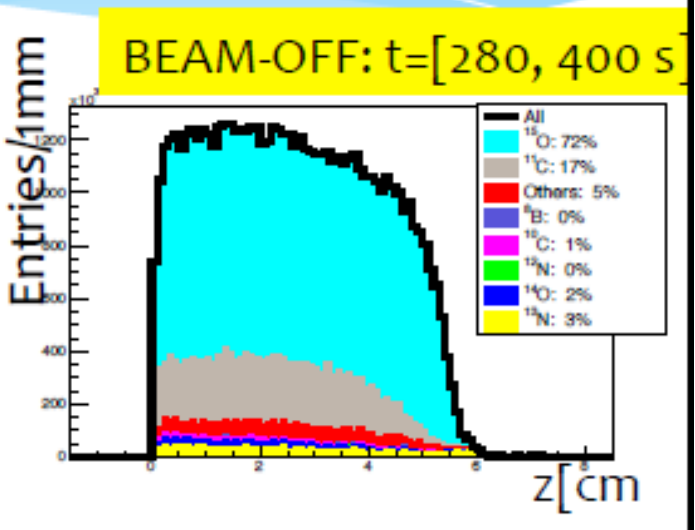
Annihilations vs time



MC truth







- **Brain irradiation: if focusing on short acquisition times, activity generated mostly by ^{15}O (roughly 75% for inter-spill+beam-off)**

Truly generated beta+ annihilation events in the target in this setup in 4 π phasespace:

- total in-spill in [0, 280 s] = **1.3 10^7**
- total inter-spil in [0, 280 s] = **3.8 10^7**
- total beam-off in [280, 400 s] = **3.5 10^7**
- total inter-spill+2 min beam-off [0, 400 s] = **7.4 10^7**
- total inter-spill+5 min beam-off [0, 580 s] = **9.9e 10^7**
-

NO geometrical efficiency, detector effects, attenuation effects, etc etc

Typical H&N tumors

But total numbers do not say much. What matters is more the 'density' of activity. Reconstructed profiles will depend among many other things on

- Beam directions. Here 2 Gy given from 1 direction. Usually more than 1 direction used, so per beam direction the statistics would be smaller and activity in target would be mixed from more directions.
- Tumor volume (no. of β^+ annihilations $\propto$ no. of impinging protons $\propto$ tumor volume)

Typical H&N tumor sizes: (here size was 27 cm^3)

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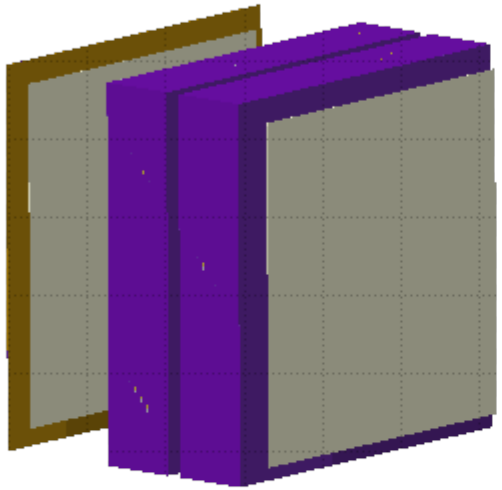
Patient	Site	TNM staging	Planning CT: Volume CTV66Gy (cm^3)	Planning CT: Volume CTV54Gy (cm^3)	Repeat CT: Volume CTV66Gy (cm^3)	Repeat CT: Volume CTV54Gy (cm^3)	Average defor-mation* (mm)
1	Base of tongue	T1N2c	106	199	82	176	4.2
2	Base of tongue	T3N2a	99	313	73	268	3.3
3	Tonsil	T2N1	43	165	37	156	2.5
4	Tonsil	T2N0	11	77	9	75	3.1
5	Soft palate	T2N0	14	72	10	67	2.4
6	Base of tongue	T3N2a	68	221	47	191	6.6
7	Tonsil	T2N0	5	67	5	72	2.3
8	Tonsil	T1N1	41	95	35	87	2.5
9	Base of tongue	T3N3	178	343	132	296	6.6
10	Base of tongue	T1N2c	70	294	63	252	4.5
Patient average			63	185	49	164	3.8

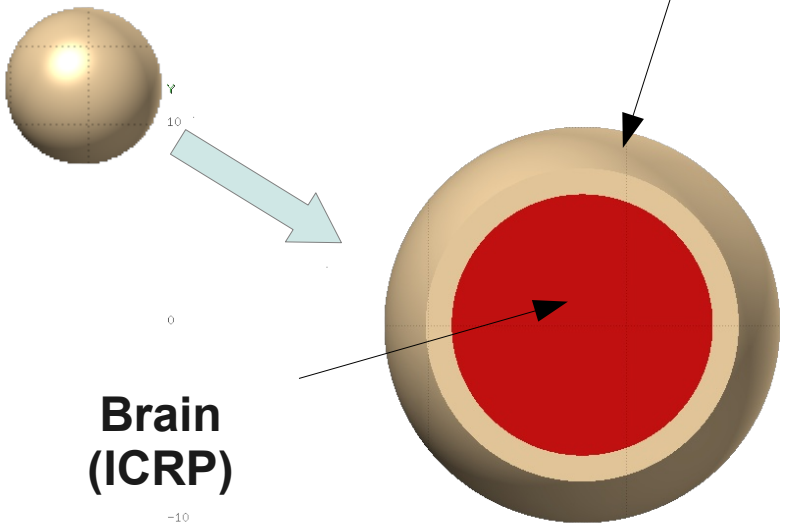
From: Kraan et al, Int J Radiat Oncol Biol Phys. 2013 Dec 1;87(5):888-96

B) Emission of γ and protons in Carbon Therapy

CNAO Nozzle



Simulation Setup: the "Mental Ball"

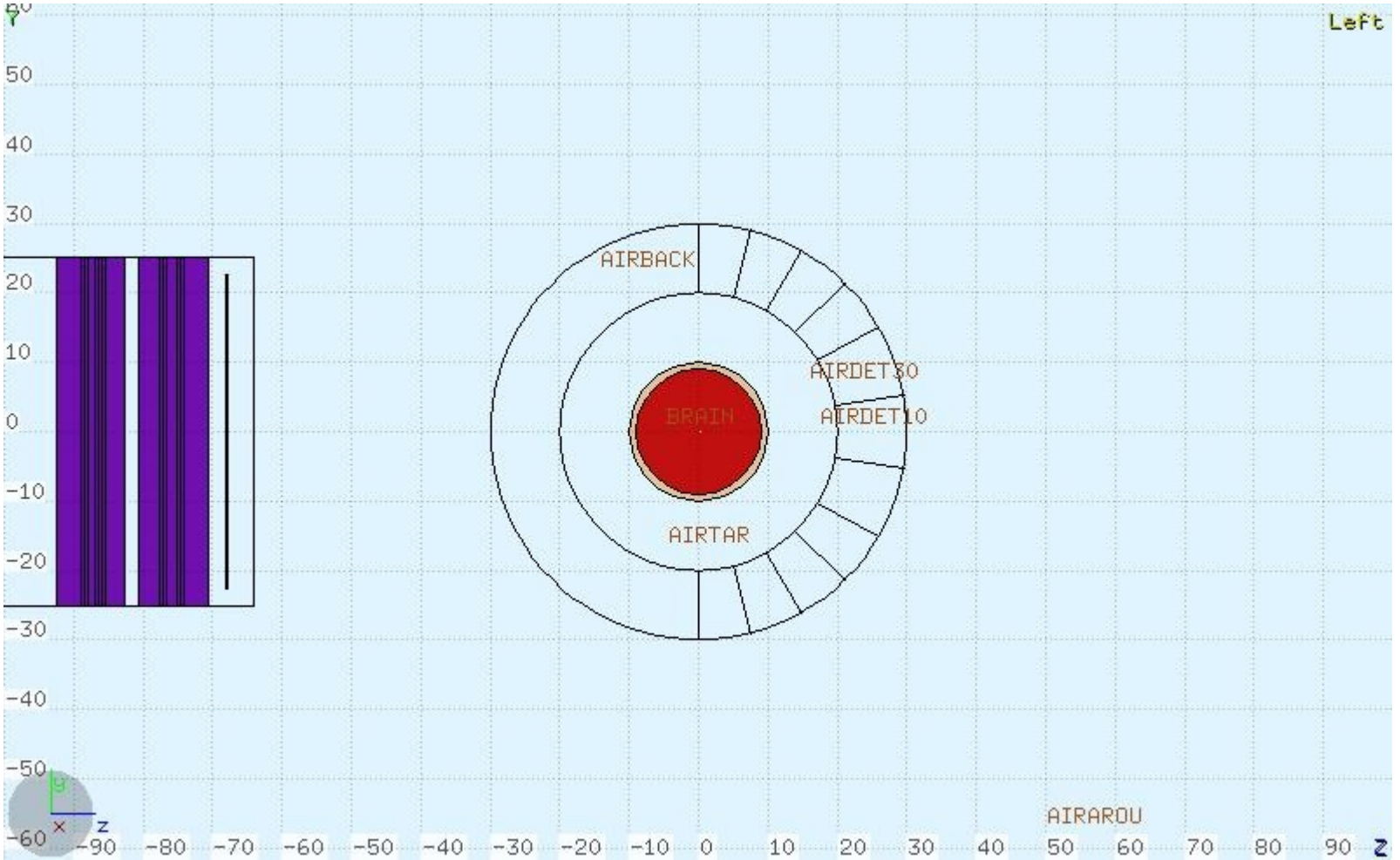


Cortical Bone (ICRP)

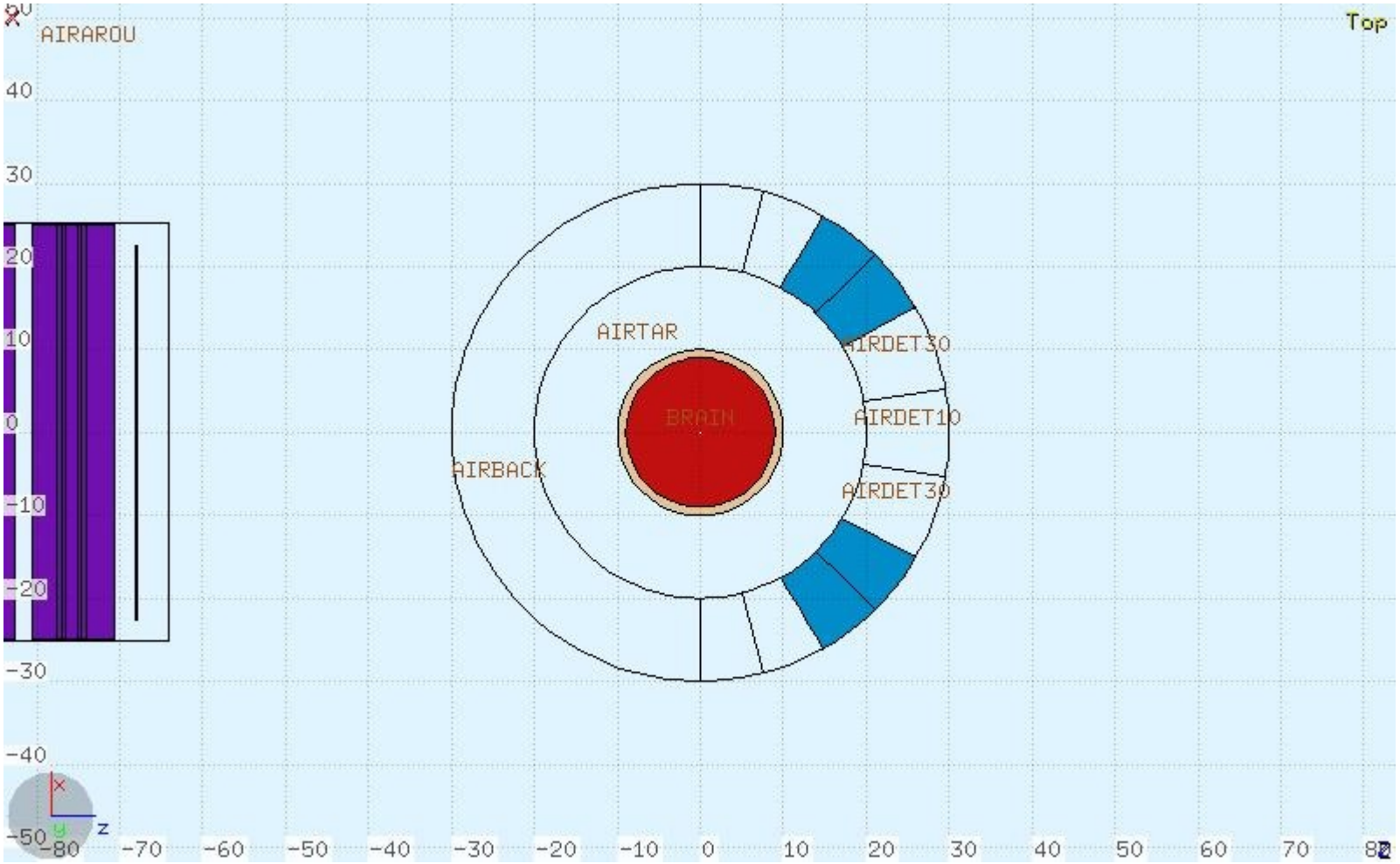
Brain (ICRP)

10 cm radius
1 cm of bone

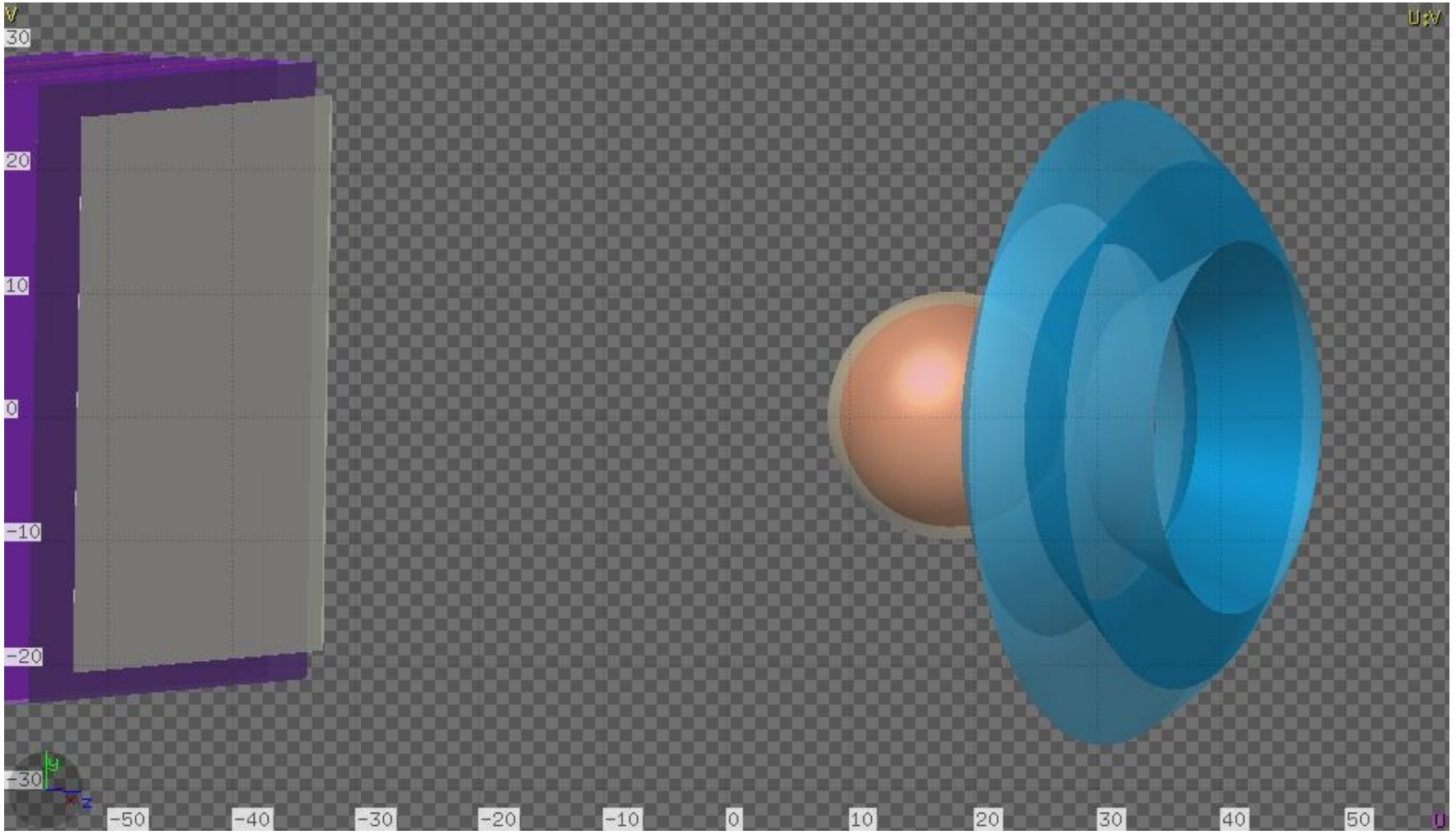
Regions to detect outgoing particles



Detector area

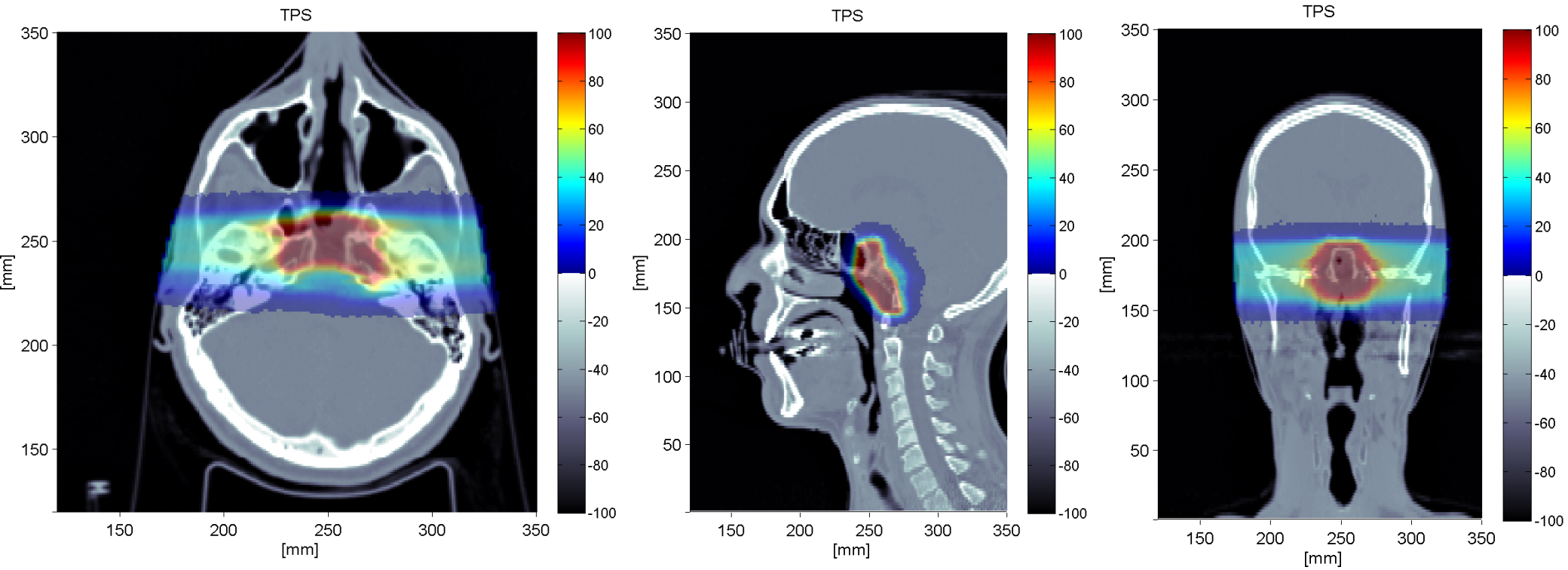


Detector Area (~7 times Profiler)



Same patient case as presented in March: now all energies of the plan have been considered. ONLY 1 BEAM

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



Dose prescription as calculated by Syngo TPS

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

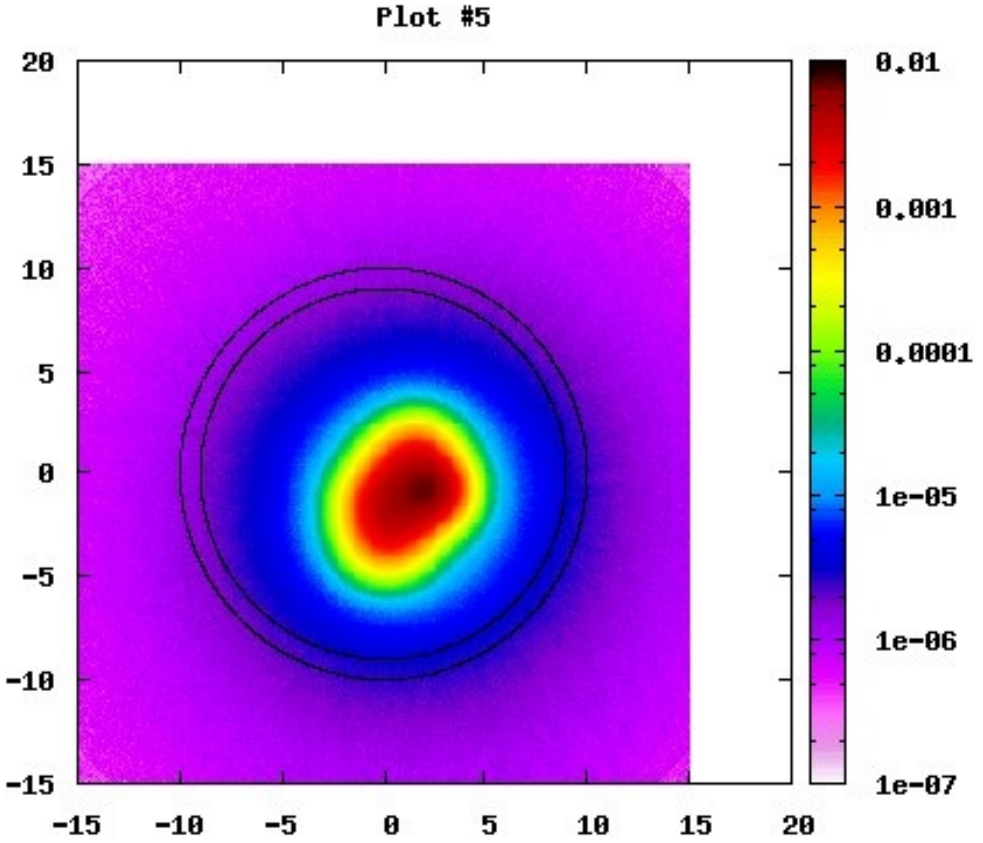
Treatment Description: Beam 1

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

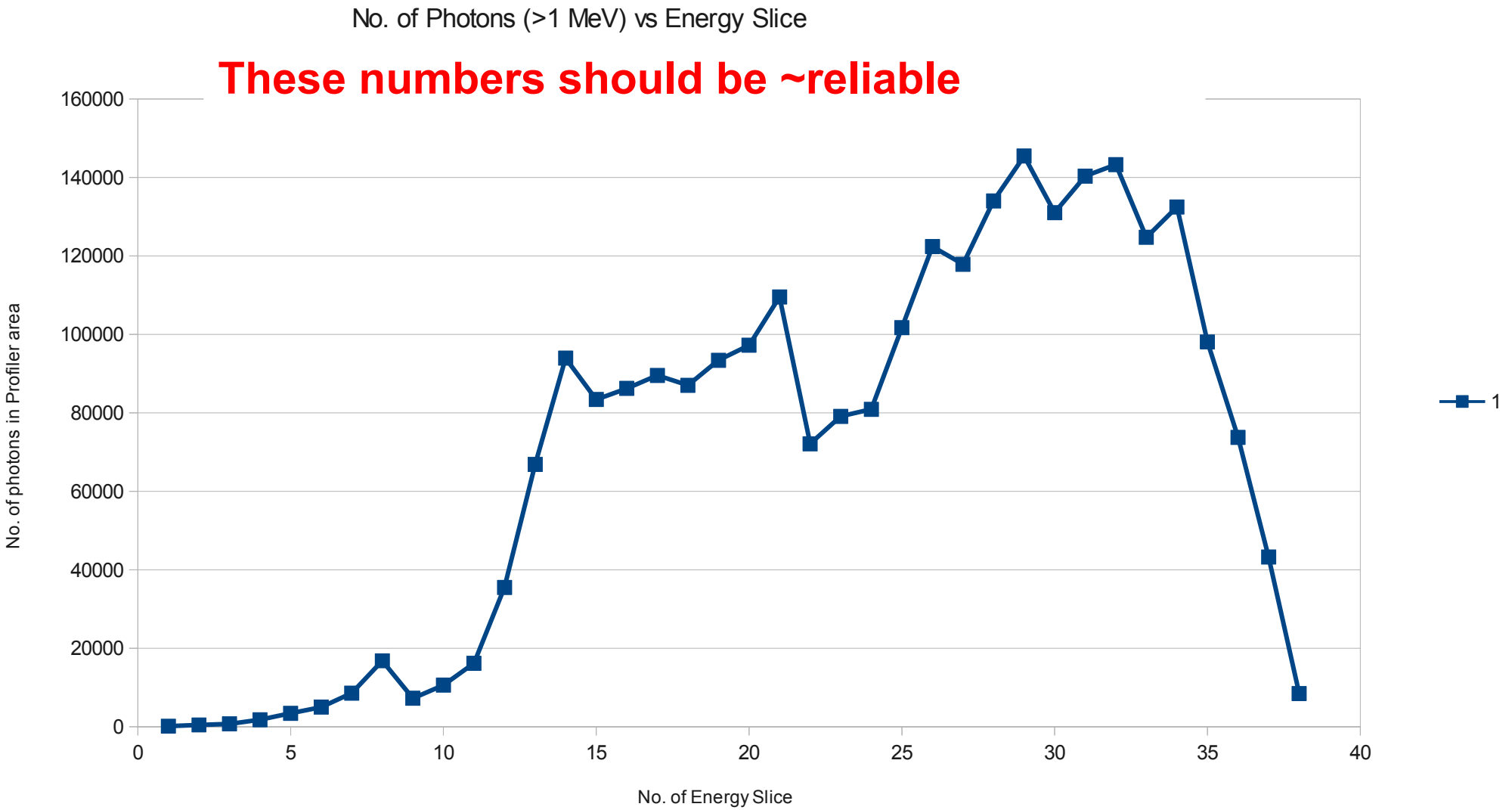
Slice [n] [n]:	Energy [MeV/u]	Slice
21	197.91	232
22	200.61	228
23	203.29	193
24	205.95	181
25	208.58	174
26	211.19	186
27	213.79	180
28	216.36	172
29	218.91	166
30	221.45	154
31	223.96	135
32	226.46	123
33	228.94	105
34	231.34	88
35	233.79	72
36	236.22	49
37	238.63	33
38	241.03	14
39	243.42	4

Total no. of spots: 4542

Dose map in Mental Ball for the whole TP (Beam 1) with ^{12}C



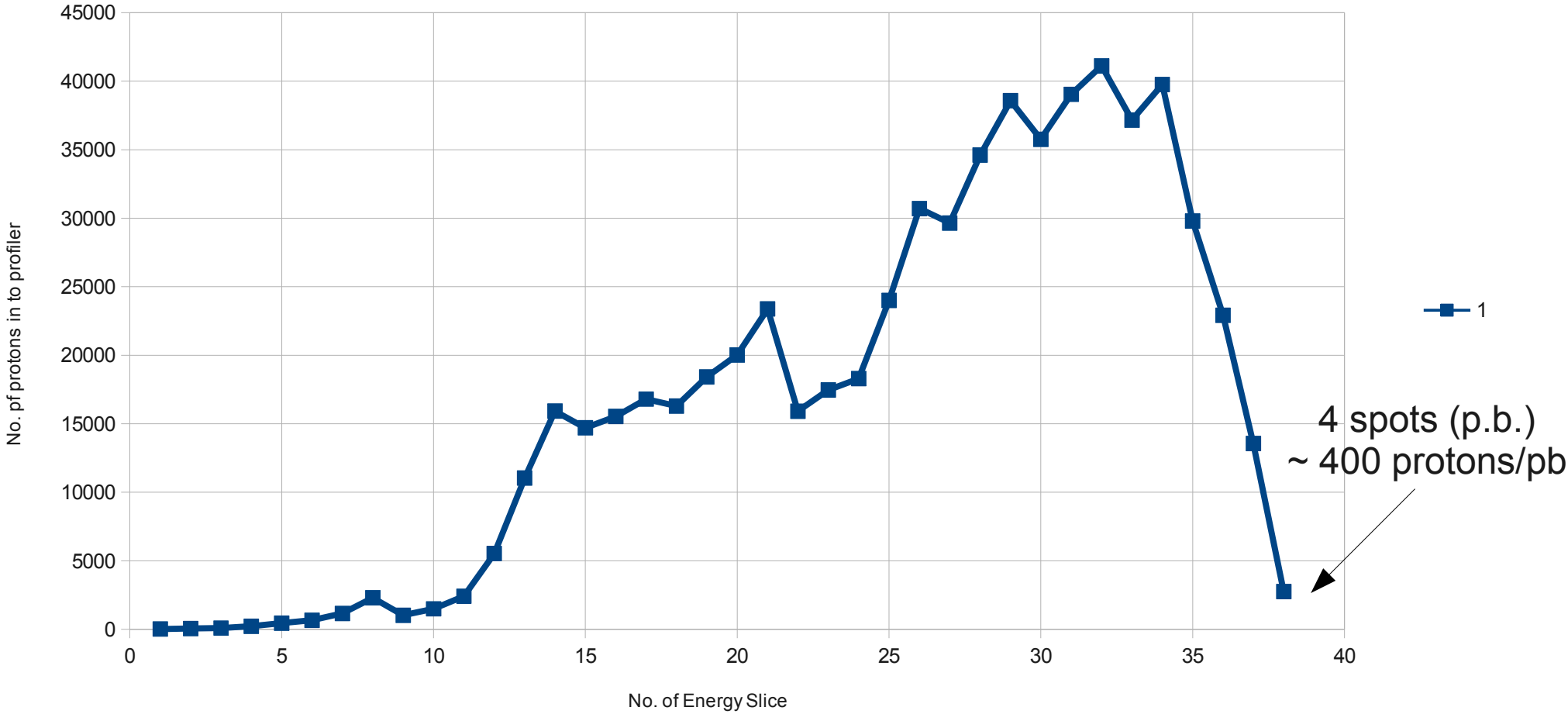
Photons (E>1 MeV) vs Slice Number inside Profiler APPROXIMATE equivalent area in a single fraction at 60º



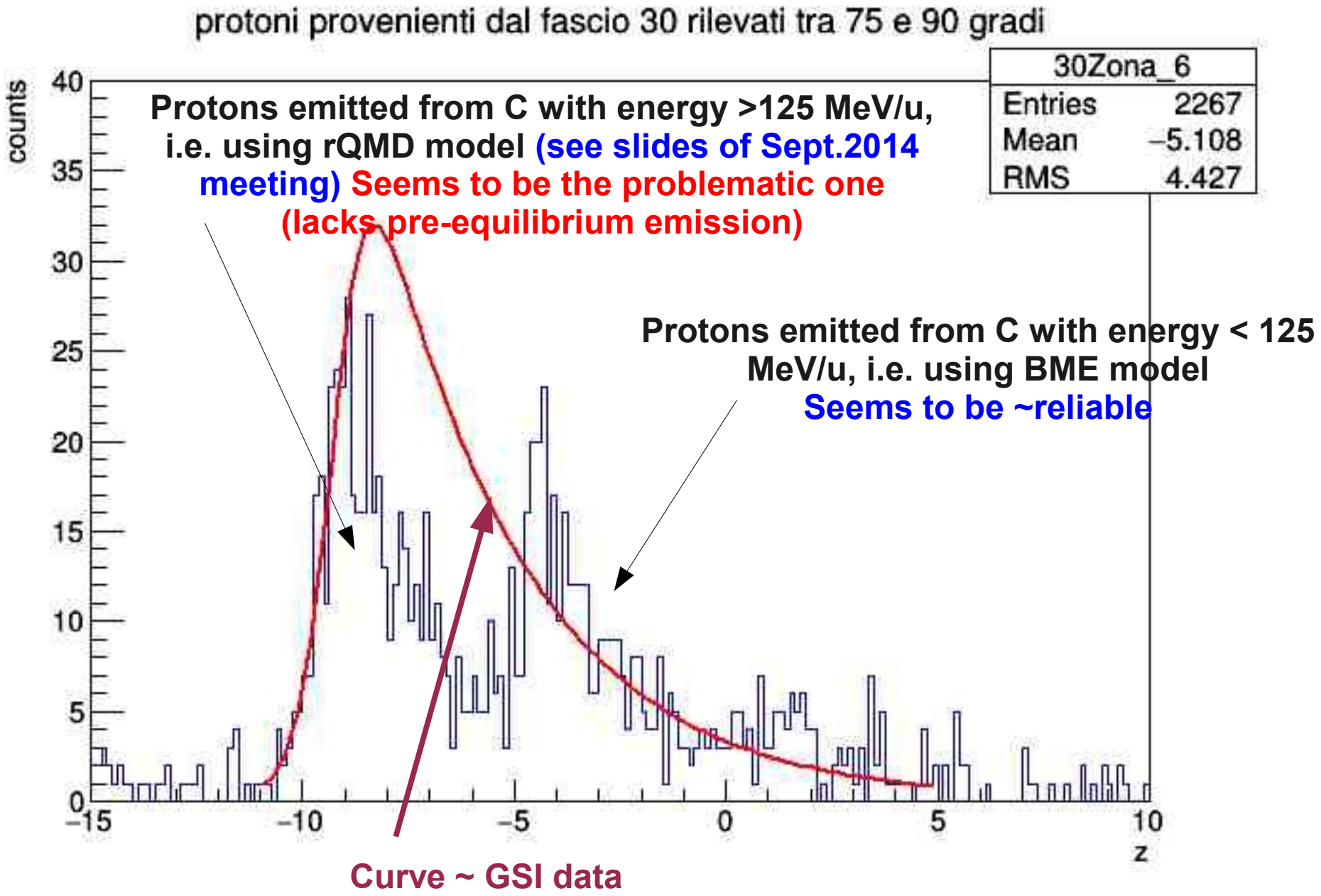
Total no. of Photons (>1 MeV): 2.66 10^6

Protons (E>20 MeV, 60o) vs Slice Number inside Profiler approx. equivalent area in a single fraction

Very probably underestimated by ~30% - 50% because of cotninuity failure in interaction models at about 125 MeV/u

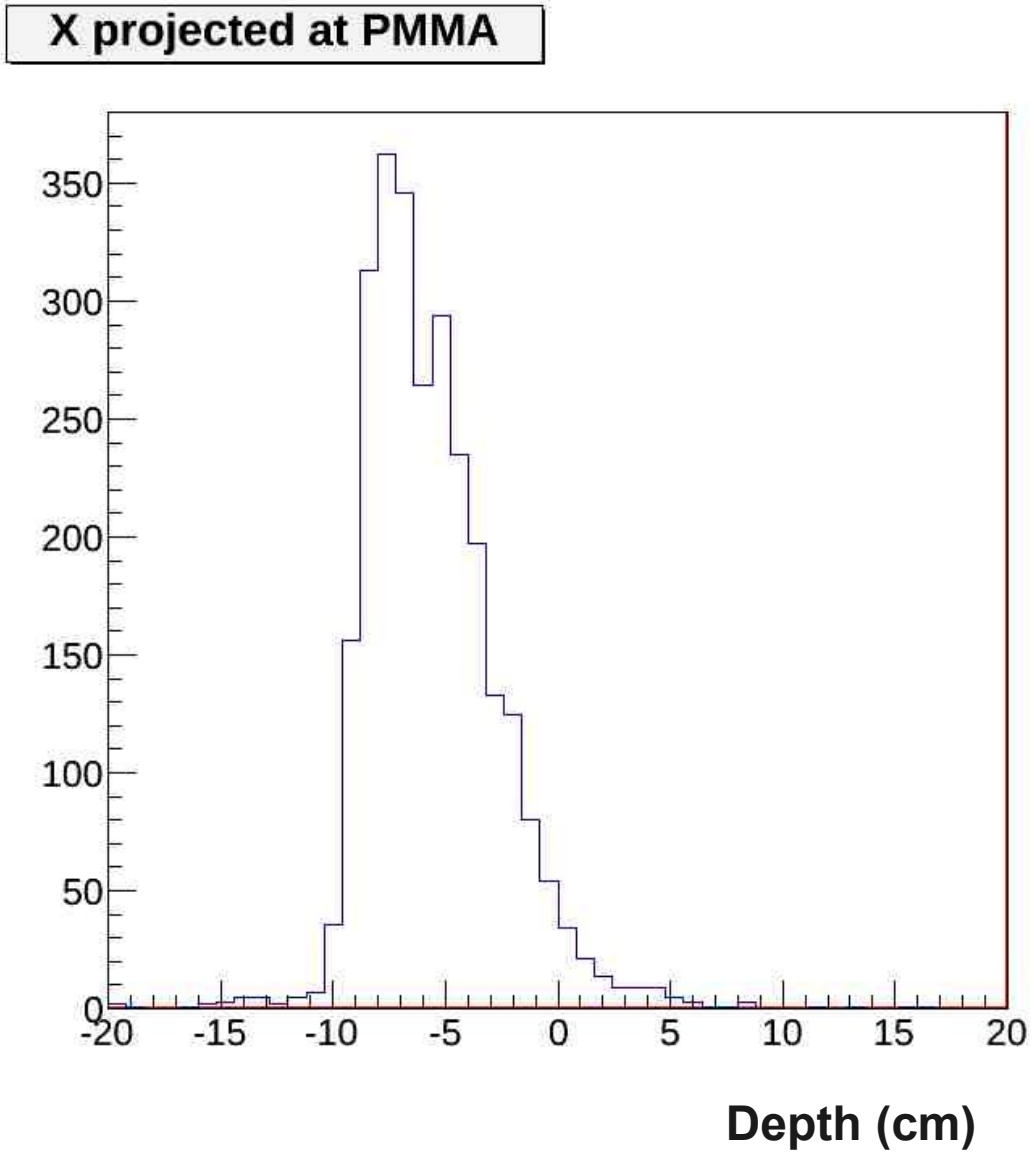


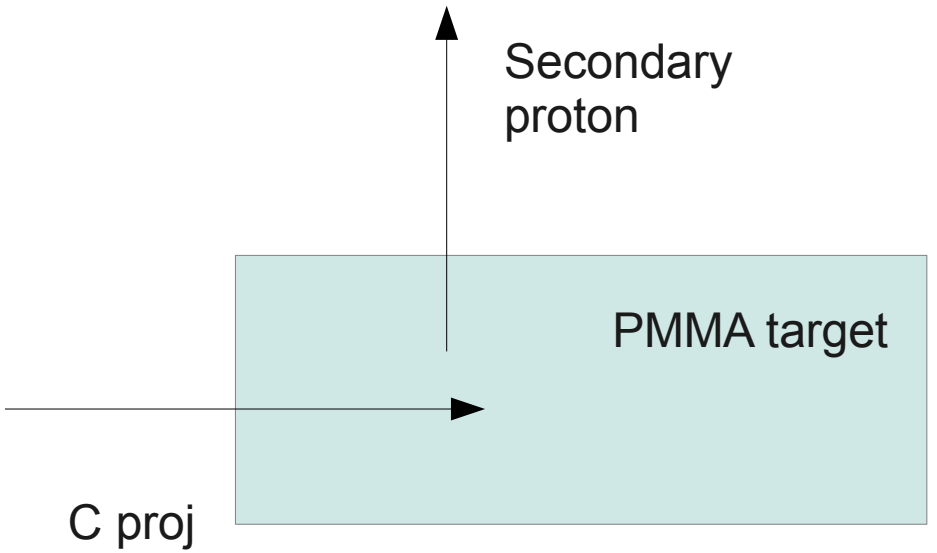
Total no. of protons (>20 MeV): 6.39 10^5



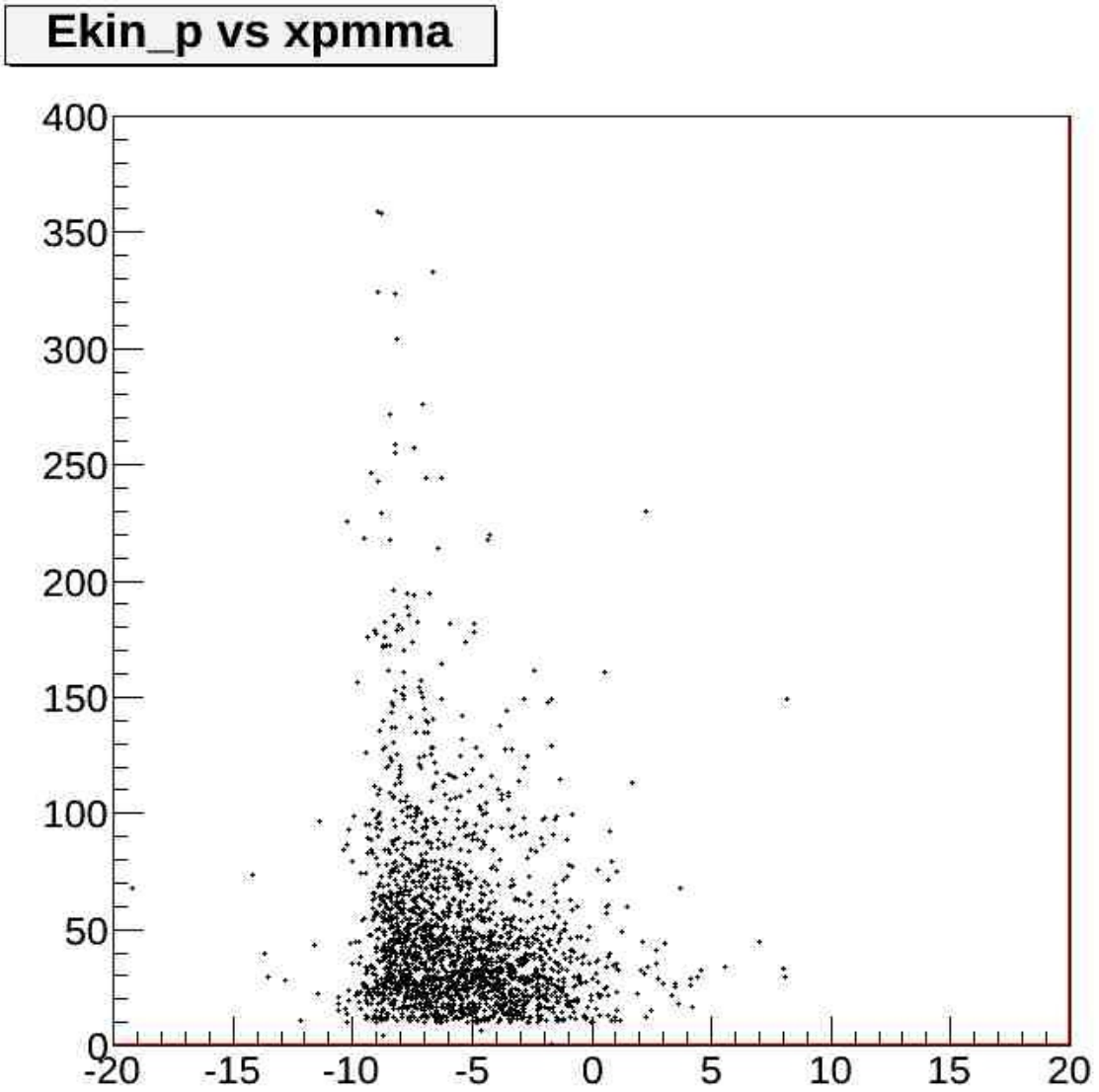
FLUKA group is officially in charge of solving the problem: to be solved before next release. Not easy...

In the meanwhile: let's use existing data from C at 220 MeV/u to sample E_{proton} (at 90°) as a function of depth





Ekin reconstr. of detected protons vs Depth



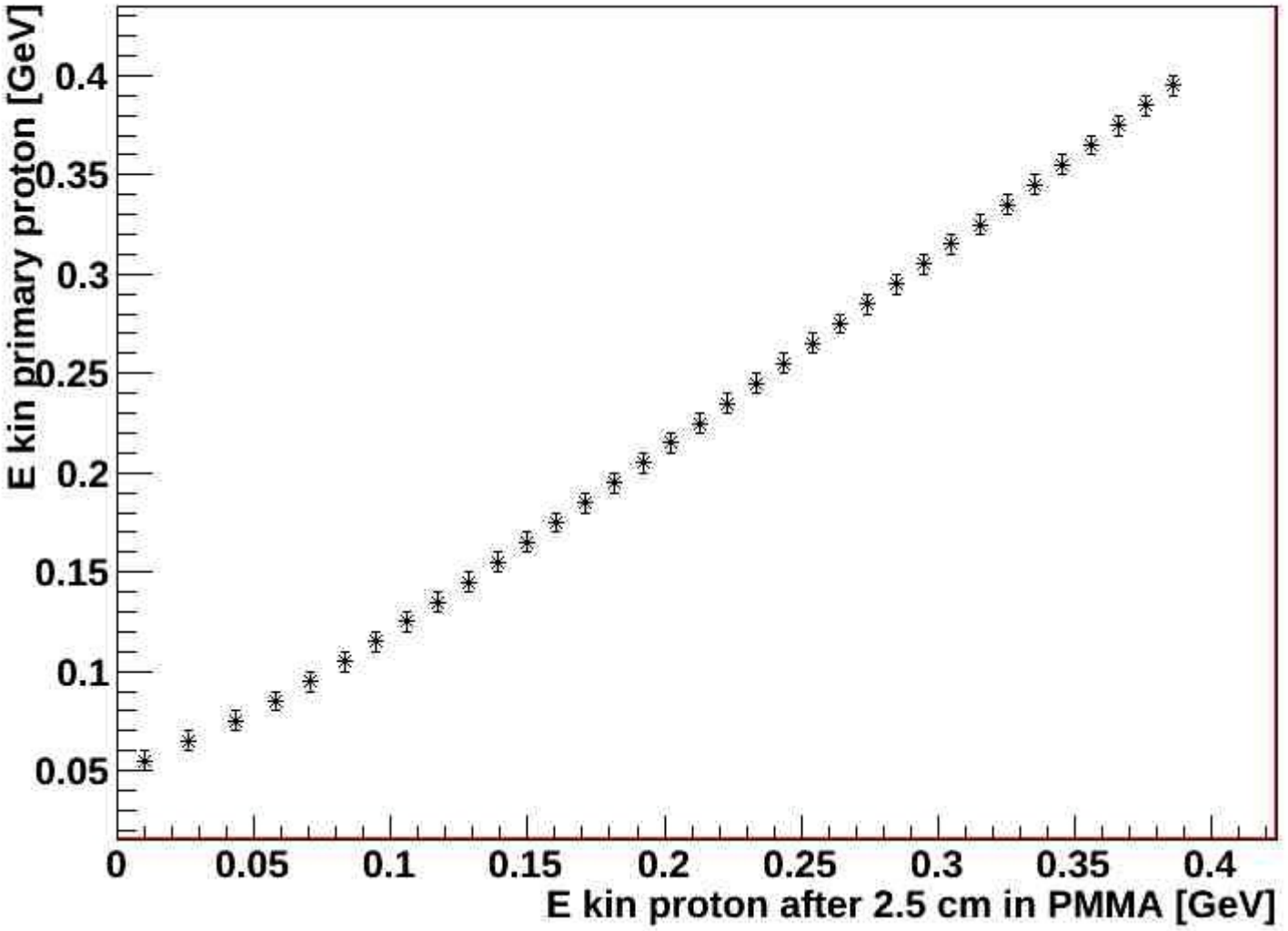
Proposed method:
a) Foreach bin in energy take depth distribution

b) energy value is corrected to account for the energy loss in the target so to get (in average) original energy value

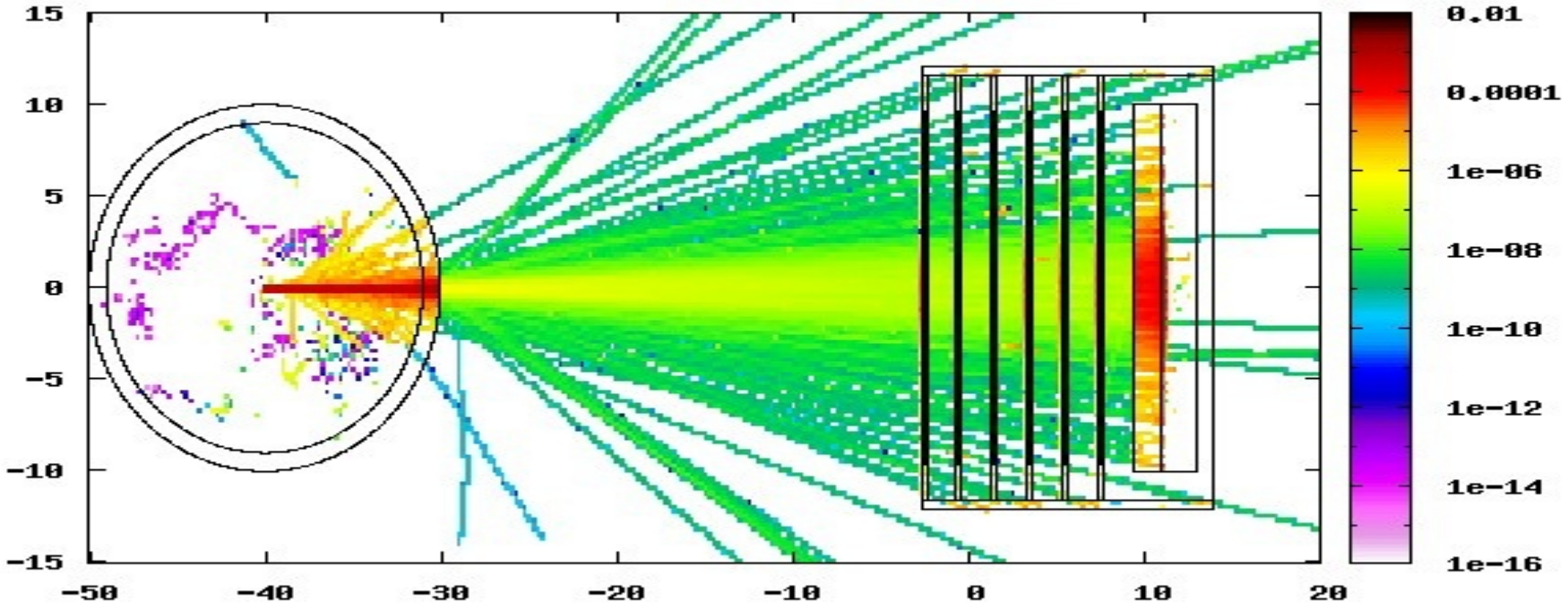
c) Fit depth distriution to build a function to sample event

d) take into account the different populations of different energy bins

Average energy correction for protons



New developments in Profiler simulation are in progress



To match reconstruction and analysis needs:

a) new powerful routine to record on event by event basis the tree of generated particles

b) effort to build a full working chain of simulation + reconstruction software

with Erika De Lucia & Cecilia Voena