

**PET analysis status: a preliminary  
statistics study and proton patients  
analysis**

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# Patients analysed

## Proton treatment plan

- P002 (mening.)
  - P003 (mening.)
  - P006 (ACC)
  - simulated pz (not included in the trial)
- results submitted to Frontiers



## Carbon ion treatment plan

- C004 (ACC)
- C006 (ITAC)

- P001 (SCC)
- P004 (mening.)
- P005 (clivus)

no changes

moderate variations (no replan)

significant variations (replanned)

troublesome patients

p statistics study

12C statistics study

# Statistics study - P001: SCC

54 Gy in 27 frazioni										
volume irraggiato (RTDOSE)		590,792 cm <sup>3</sup> (B2 - 0°)								
		649,08 cm <sup>3</sup> (B1 - 270°)								
<b>001 P</b>										
fract	t_start	t_end	t_reconstruction	field	coinc	coinc/vol	coinc/tempo	coinc/tempo/vol		
13	941,9	1108,3	166,400	B1 - 270°	57246	88,1956	344,0264	0,5300		
16	194,6	297,8	103,200	B2 - 0°	29533	49,9888	286,1725	0,4844		
17	398,2	493,9	95,700	B2 - 0°	30094	50,9384	314,4619	0,5323		
22	482,4	586,1	103,700	B2 - 0°	31032	52,5261	299,2478	0,5065		
23	617,2	731,6	114,400	B2 - 0°	36115	61,1298	315,6906	0,5344		
24	316,7	427,6	110,900	B2 - 0°	35022	59,2797	315,7980	0,5345		
25	410,9	505,5	94,600	B2 - 0°	31540	53,3860	333,4038	0,5643		
27	428,3	539,3	111,000	B2 - 0°	34324	58,0983	309,2252	0,5234		
			t_mean							
			104,786							
					coinc/vol = 55 coinc/cm <sup>-3</sup>					
					average irradiation time = 105 s					
patient ID	measured angles	angle	N particles	N_p/vol	angle	N particles	N_p/vol			
1	all	B2 - 0°	2,22E+10	3,76E+07	B1 - 270°	2,33E+10	3,59E+07			
				no RS					RS	

# Statistics study - P003: meningioma

54 Gy in 27 frazioni

volume irraggiato (RTDOSE)

574,56 cm<sup>3</sup> (B2 - 235°)

003 P

AAA

AAA

fract	t_start	t_end	t_reconstruction	field	coinc	coinc/vol	coinc/tempo	coinc/tempo/vol
2	99,586	250,5	150,914	B2 - 235°	66678	116,0505	441,8271	0,7690
3	115,803	215,179	99,376	B2 - 235°	51086	88,9133	514,0662	0,8947
4	336,543	488,623	152,080	B2 - 235°	67538	117,5473	444,0949	0,7729
6	315,205	467,933	152,729	B2 - 235°	68879	119,8813	450,9892	0,7849
7	110,886	260,404	149,517	B2 - 235°	67496	117,4742	451,4263	0,7857
11	521,140	672,731	151,591	B2 - 235°	66349	115,4779	437,6837	0,7618
15	425,667	577,736	152,069	B2 - 235°	68903	119,9231	453,1038	0,7886
17	manca			B2 - 235°				
19	85,790	239,399	153,609	B2 - 235°	66843	116,3377	435,1505	0,7574
25	641,616	803,405	161,789	B2 - 235°	65969	114,8166	407,7466	0,7097
26	529,847	683,546	153,699	B2 - 235°	66436	115,6294	432,2480	0,7523

t\_mean

147,737 AAA frac 3??

coinc/vol = 114 coinc/cm<sup>3</sup>  
average irradiation time = 148 s

patient ID	measured angles	angle	N particles	N_p/vol	angle	N particles	N_p/vol
3	all	B1 - 180°	2,64E+10		B2 - 235°	2,21E+10	3,85E+07

RS

RS

# Statistics study - P006: ACC

70 Gy in 35 frazioni

volume irraggiato (RTDOSE)

958,118 cm<sup>3</sup> (B2 - 175°)

1269,25 ---> se non si considera FOV inside

006 P

fract	t start	t end	t reconstruction	field	coinc	coinc/vol	coinc/tempo	coinc/tempo/vol
2	859	1096,4	237,40	B2 - 175°	126419	131,9451	532,5147	0,5558
3	212,0	432,0	220,00	B2 - 175°	132461	138,2512	602,0955	0,6284
7	62,3	267,9	205,60	B2 - 175°	131052	136,7806	637,4125	0,6653
11	546,6	820,8	274,20	B2 - 175°	155414	162,2076	566,7907	0,5916
17	375,3	619,2	243,90	B2 - 175°	140217	146,3463	574,8954	0,6000
21	248,5	481,7	233,20	B2 - 175°	127075	132,6298	544,9185	0,5687
22	482,0	721,0	239,00	B2 - 175°	125509	130,9953	525,1423	0,5481
25	758,9	970,7	211,80	B2 - 175°	127233	132,7947	600,7224	0,6270
26	457,6	686,4	228,80	B2 - 175°	135771	141,7059	593,4047	0,6193
31	386,3	634,3	248,00	B2 - 175°	135591	141,5181	546,7379	0,5706
33	422,3	673,5	251,20	B2 - 175°	143731	150,0139	572,1775	0,5972
34	618,6	882,5	263,90	B2 - 175°	130965	136,6898	496,2675	0,5180

t\_mean 1T

238,08

**coinc/vol = 140 coinc/cm<sup>3</sup>**

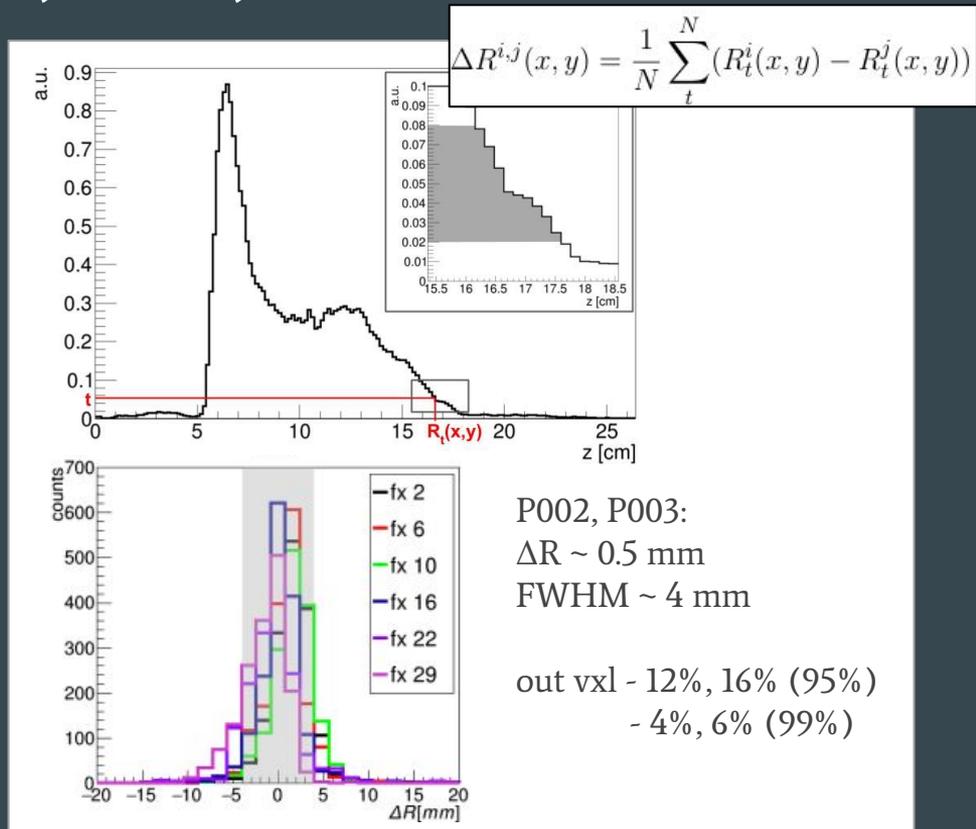
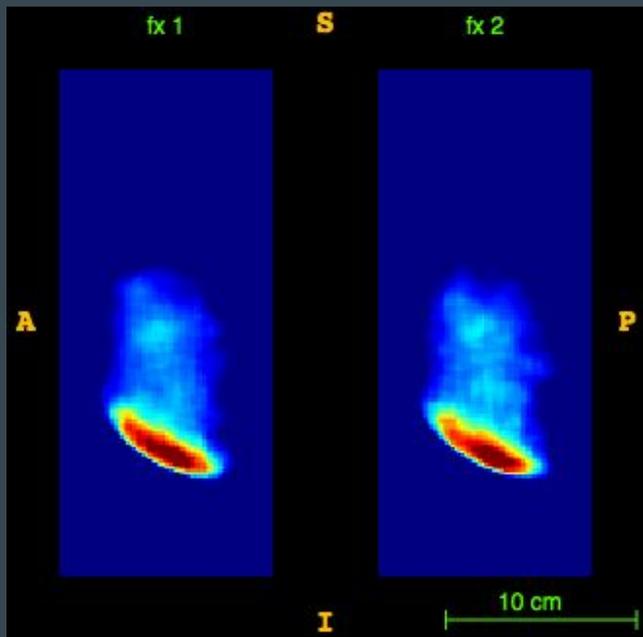
**average irradiation time = 238 s**

patient ID	measured angles	angle	N particles	N_p/vol	angle	N particles	N_p/vol
6	175 only	B1 - 15°	3,72E+10	/	B2 - 175°	5,64E+10	4,44E+07

non compatibile

# Proton patients analysis: P002, P003, P006

Multi-threshold analysis: measured fractions



Results submitted to Frontiers in Physics

# Proton patients analysis: P002, P003, P006

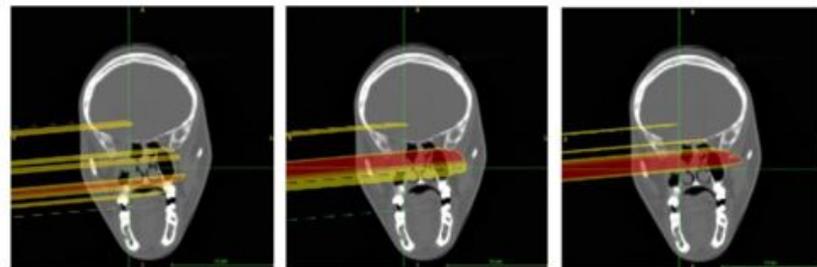
Planning CT



Control CT



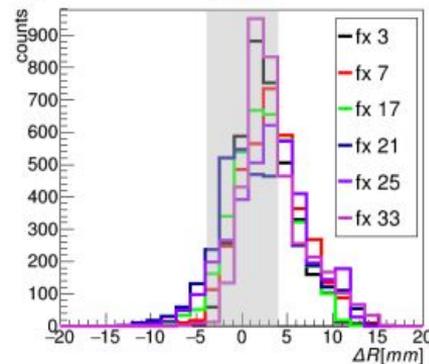
Measurements



fx 2 vs fx 3

fx 2 vs fx 21

fx 2 vs fx 33



P006:

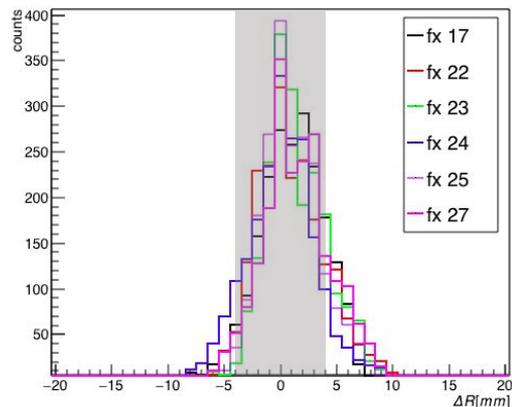
$\Delta R \sim 2.7$  mm

FWHM  $\sim 7$  mm

out vxl - 39% (95%)

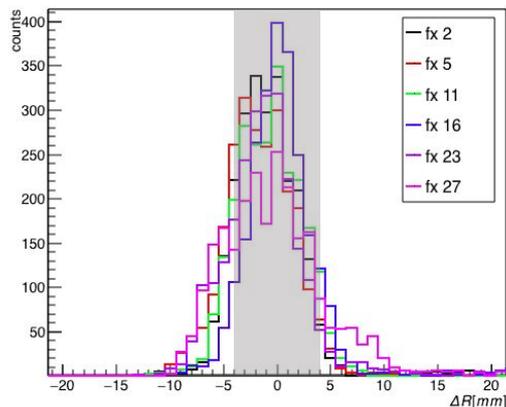
- 20% (99%)

# Proton patients analysis: P001, P004, P005



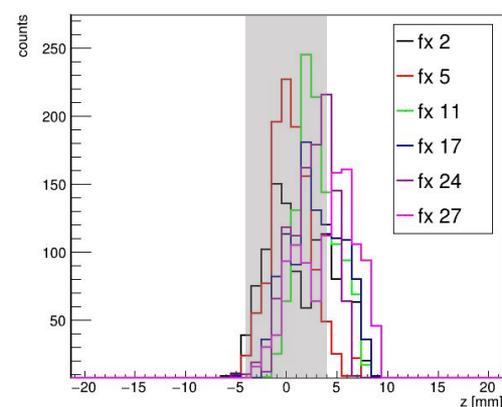
P001 (SCC):  
 $\Delta R \sim 1.3$  mm  
FWHM  $\sim 5.6$  mm

out vxl - 20% (95%)  
- 7% (99%)



P004 (mening.):  
 $\Delta R \sim 0.04$  mm  
FWHM  $\sim 7.5$  mm

out vxl - 29% (95%)  
- 13% (99%)



P005 (clivus):  
 $\Delta R \sim 1.9$  mm  
FWHM  $\sim 6.4$  mm

out vxl - 27% (95%)  
- 10% (99%)

# Proton patients analysis: P001, P004, P005

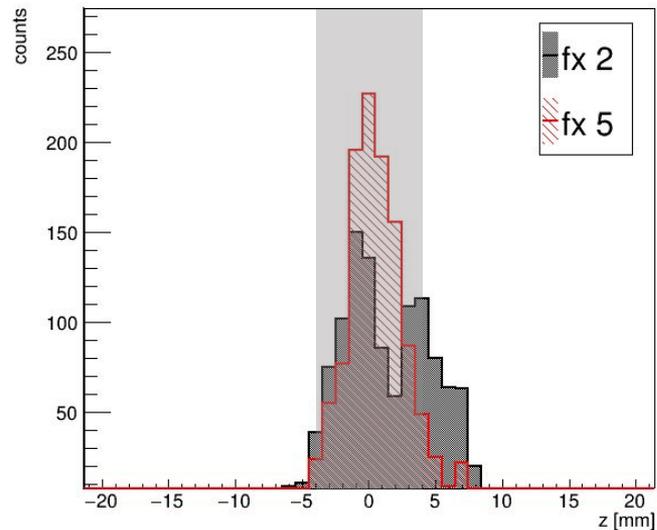
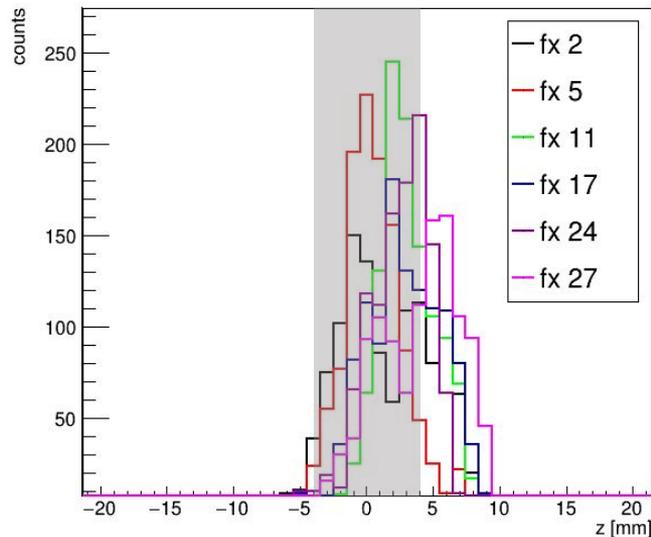
P005 (clivus):

$\Delta R \sim 1.9$  mm

FWHM  $\sim 6.4$  mm

out vxl - 27% (95%)

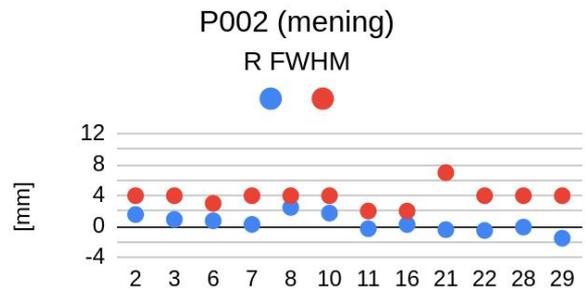
- 10% (99%)



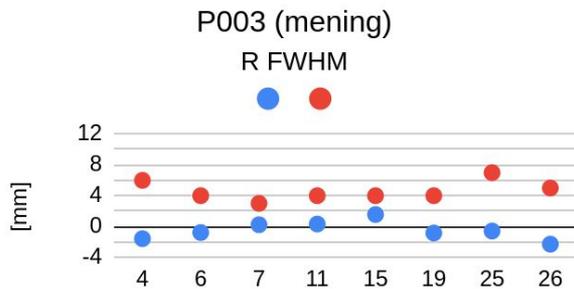
fx 2 - 2 peaks!!

....results depend on the day

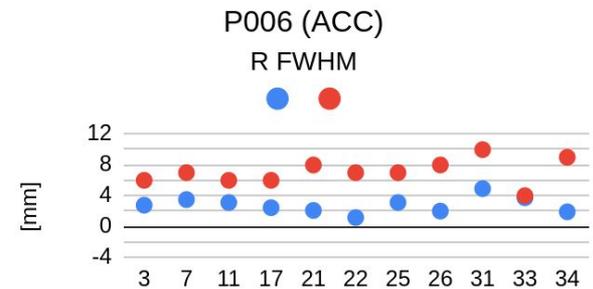
# Proton patients analysis: P001, P004, P005



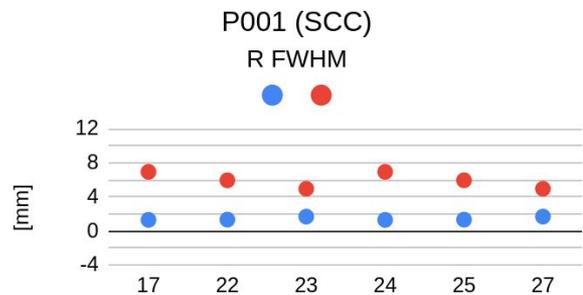
0.4 [-1.5,1.7] mm, 4.1 [1.9,6.9] mm



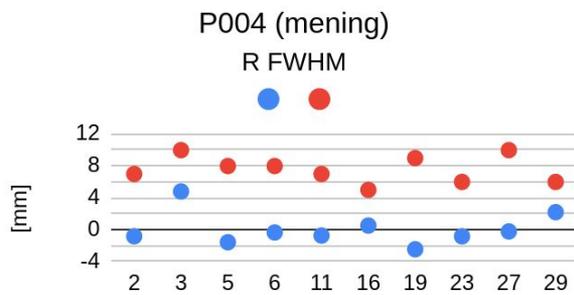
-0.5 [-2.3,1.5] mm, 5.2 [2.9,6.9] mm



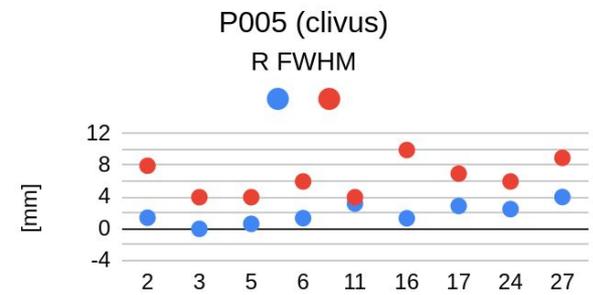
2.7 [1.1,4.8] mm, 7 [3.9,9.9] mm



1.3 [0.5,1.8] mm, 5.6 [4.9,6.9] mm

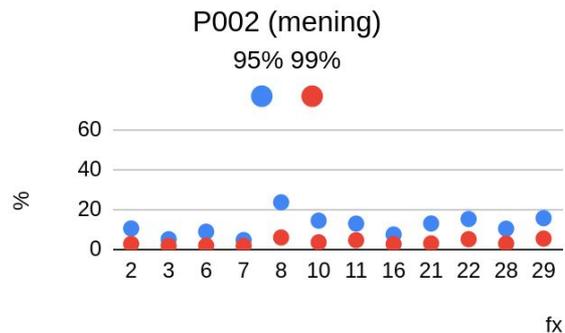


0.04 [-2.4,4.8] mm, 7.5 [4.9,9.9] mm

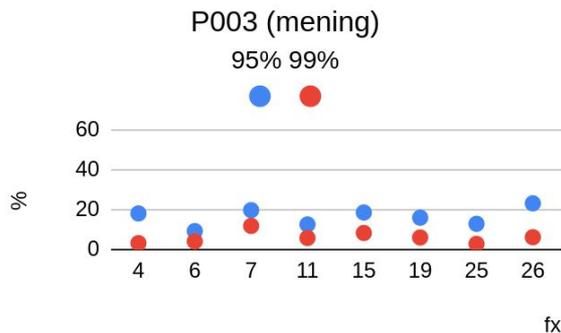


1.9 [-0.02,3.99] mm, 6.4 [3.9,8.9] mm

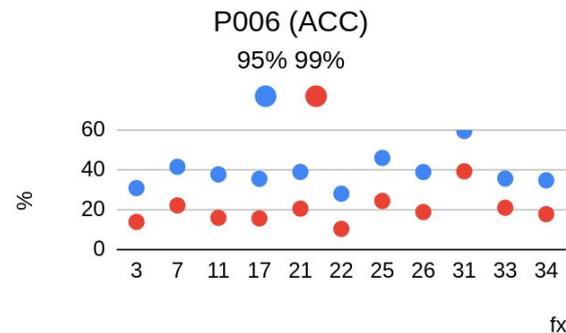
# Proton patients analysis: P001, P004, P005



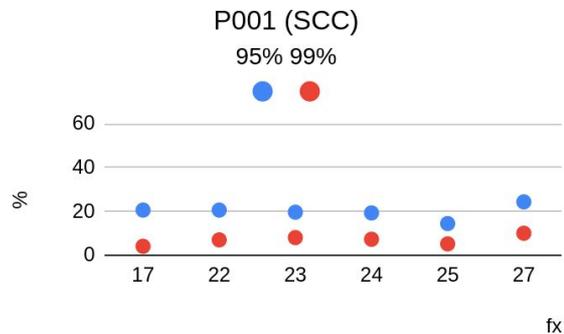
~12% [5,23], ~4% [2,6]



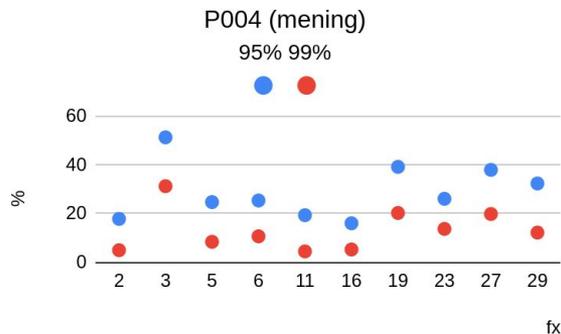
~16% [10,23], ~6% [3,11]



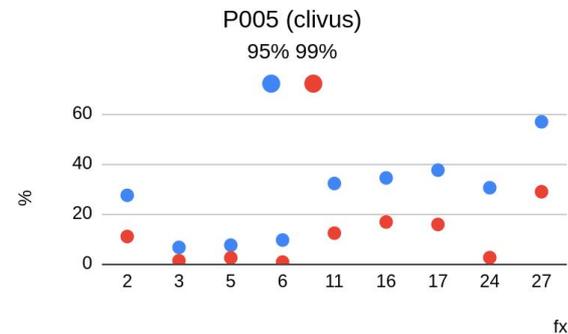
~39% [28,46], ~20% [10,39]



~20% [15,24], ~7% [4,10]



~29% [16,51], ~13% [5,31]



~27% [7,57], ~10% [0.7,29]

**PET analysis status: simulation  
and carbon ion patients analysis**

**...**

# Simulation status

- **proton patients**

completed: 002P, 003P, 006P, 008P

missing simulation on control CT: 001P, 007P

not done yet: 004P, 005P, 009P

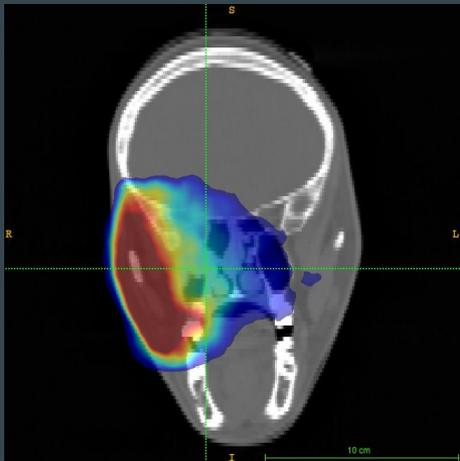
- **MCP: SCC replanned patient (article submitted to Frontiers)**

- **carbon ion patients**

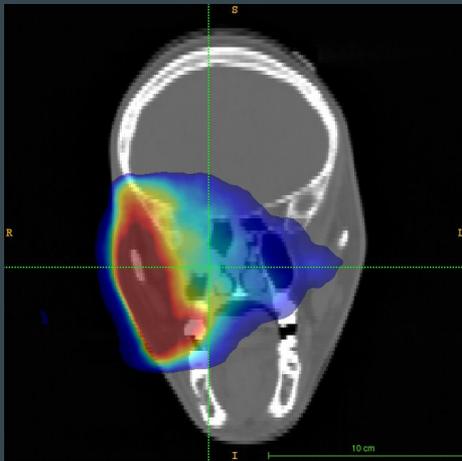
004C: moderate morphological changes analysed in DP article SciRep

006C: replanning due to tumor growing (before treatment begin?)

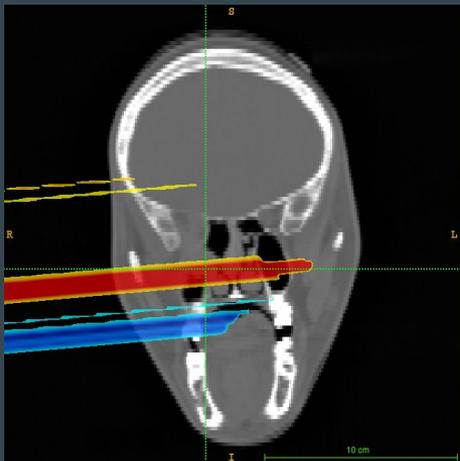
Planning CT



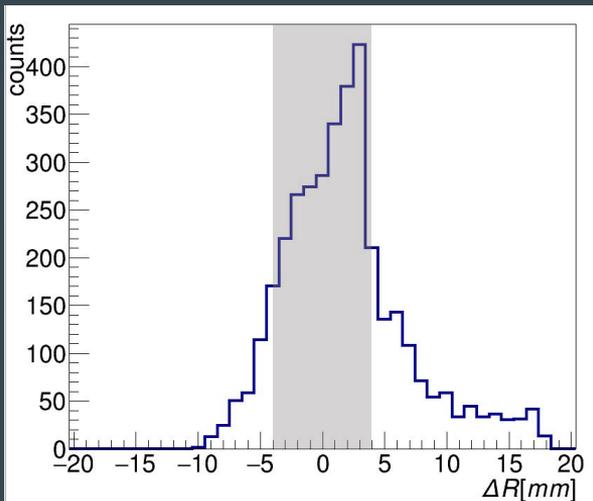
Control CT



Compliance map



# Proton patient simulation analysis 006P: ACC

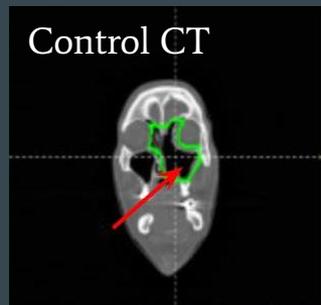
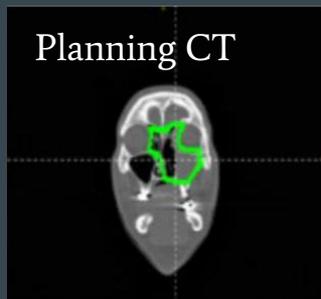


$\Delta R \sim 2$  mm (exp 2.7 mm)  
FWHM  $\sim 7$  mm (exp 7 mm)

percentage of voxels outside  
the 95% confidence interval: 34% (exp 39%)

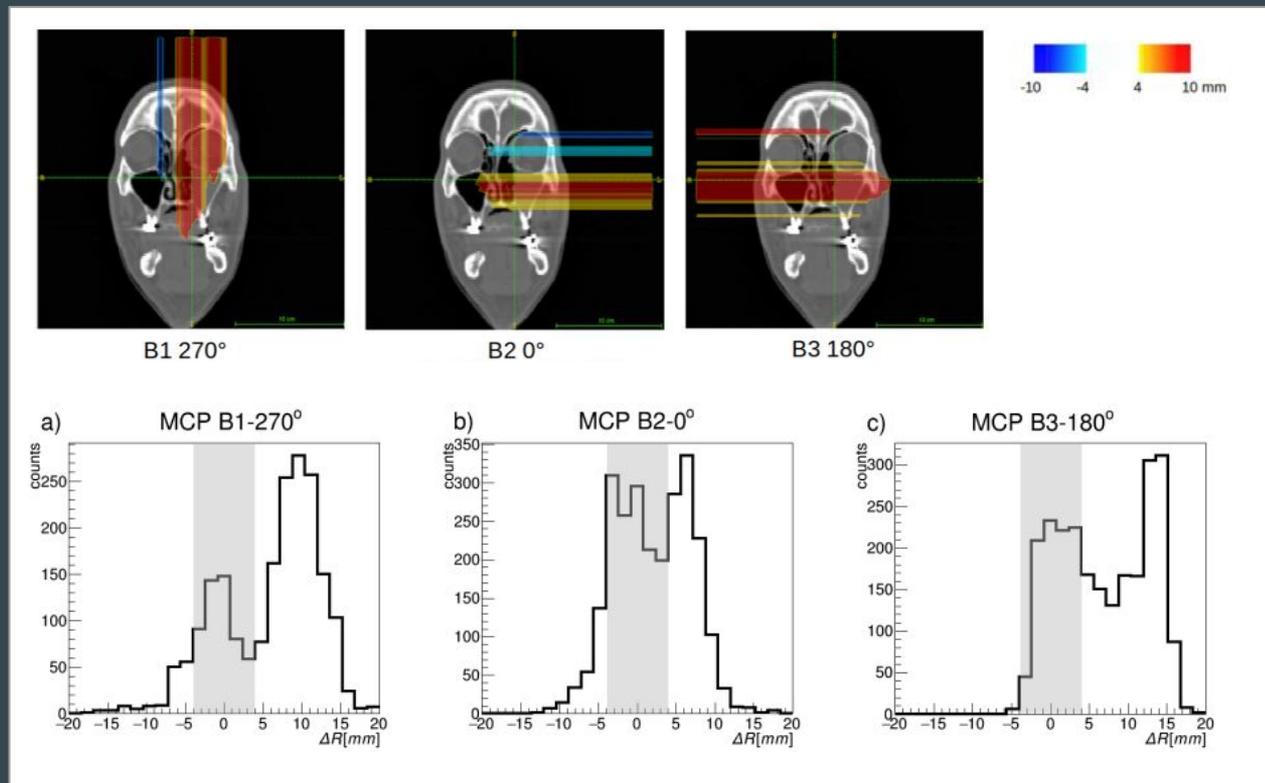
percentage of voxels outside  
the 99% confidence interval: 20% (exp 20%)

# MCP: SCC - Replanned proton patient (not included in the clinical trial)



out vxl:

- 73%(B1)-49%(B2)-62%(B3) (95%)
- 64%(B1)-29%(B2)-53%(B3) (99%)



Results submitted to Frontiers in Physics

# Statistics study - 004C: ACC

39,6+28,7 GyE in 9+7 frazioni					
volume irraggiato (RTDOSE1T)	874,776 cm <sup>3</sup> (B2 - 0°)	926,2	--> se non si considera FOV inside		
(RTDOSE2T)	689,272 cm <sup>3</sup> (B4 - 0°)	690,28			

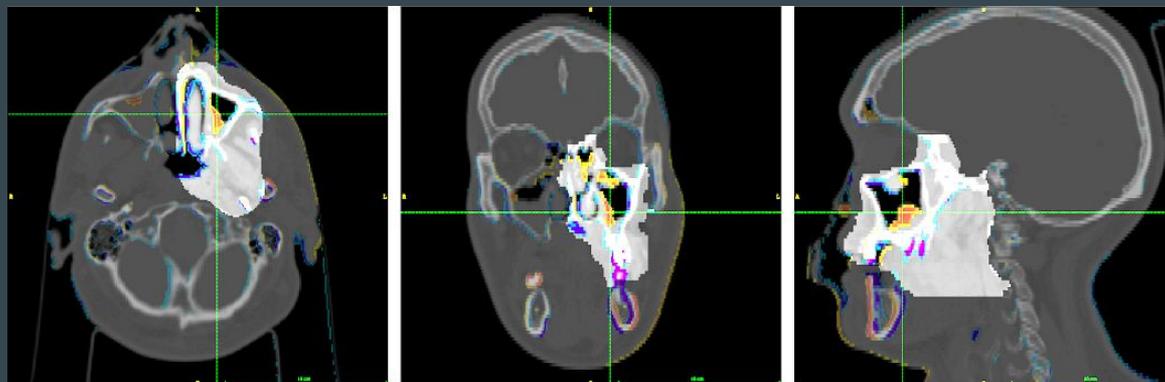
004 C recon times									
fract	DDS	t_start	t_end	t_reconstruction	field	coinc	coinc/vol	coinc/tempo	coinc/tempo/vol
1	B2 - B1	43,700	203,700	160,0000	B2 - 0°	10221	11,684134	63,88125	0,073026
2	B2 - B1	976,000	1132,400	156,4000	B2 - 0°	10250	11,717285	65,53708	0,074919
3	B2 - B1	152,600	314,800	162,2000	B2 - 0°	10004	11,436070	61,67694	0,070506
5	B2 - B1	177,000	336,700	159,7000	B2 - 0°	10352	11,833887	64,82154	0,074101
6	B2 - B1	529,300	690,200	160,9000	B2 - 0°	10186	11,644124	63,30640	0,072369
9	B2 - B1	61,400	227,600	166,2000	B2 - 0°	9904	11,321756	59,59085	0,068121
1_2T	B4 - B3	456,400	617,400	161,0000	B4 - 0°	6061	8,793336	37,64596	0,054617
4_2T	B4 - B3	239,500	399,500	160,0000	B4 - 0°	6152	8,925359	38,45000	0,055783
5_2T	B4 - B3	51,800	207,100	155,3000	B4 - 0°	5883	8,535092	37,88152	0,054959
7_2T	B4 - B3	385,600	549,400	163,8000	B4 - 0°	6079	8,819450	37,11233	0,053843

t_mean 1T	160,9000
t_mean 2T	160,0250

**coinc/vol = 11 cm<sup>-3</sup>**  
**average irradiation time = 161 s**

patient ID	measured angles	angle	N particles	N_p/vol	angle	N particles	N_p/vol
4	1T: all	B2 - 0°	2,20E+09	2,38E+06	B1 - 310°	1,77E+09	
		RS			RS		
	2T: all	B4 - 0°	1,25E+09	1,81E+06	B3 - 310°	1,61E+09	
		RS			RS		

# Morphological changes identification - 004C: ACC



HU differences btw the planning and control CTs with highlighted CTV

red - there is a reduction of HU in the control CT

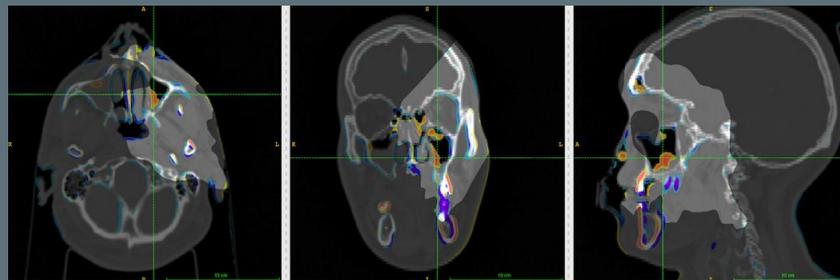
blue - there is an increasing of HU in the control CT

## Field contributions B2 vs B1 → evaluation by considering RTdose

B2 - 0° IEC



B1 - 310° IEC - analysed in DP article SciRep



# Compliance maps - 004C: ACC

considering subsequent fractions to increase statistics... fx 5-6 vs fx 1-2



threshold 0.19 - 0.25

same CLUT used for  
proton patients

## MC simulation



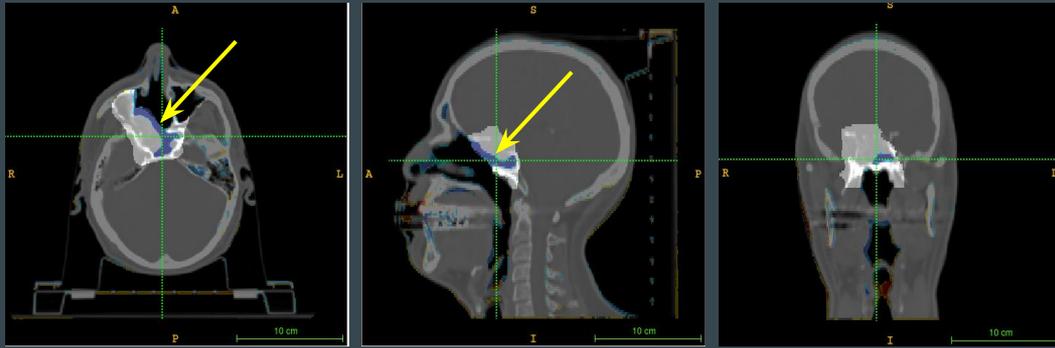
work in progress:  
understanding  
differences between  
simulated and acquired  
images



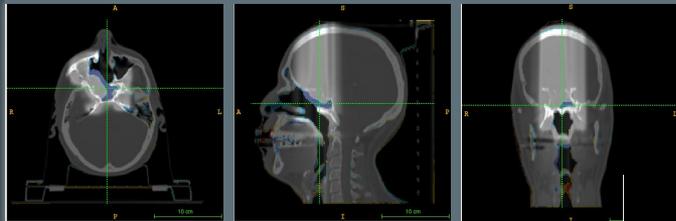
# Morphological changes identification - 006C: ACC

HU differences btw the planning and control CTs with highlighted CTV

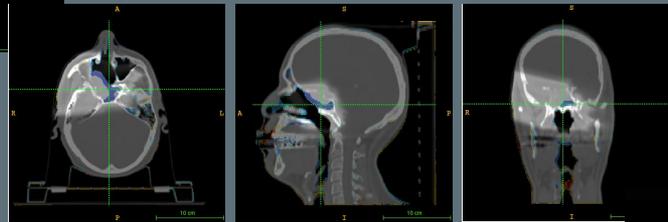
red - there is a reduction of HU in the control CT  
blue - there is an increasing of HU in the control CT



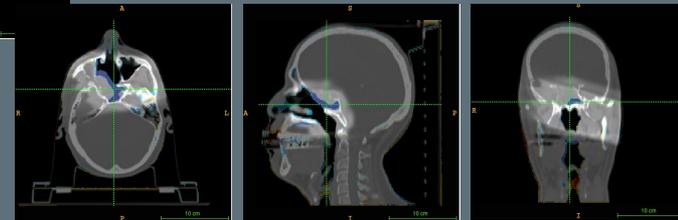
## Field contributions B3 vs B2 vs B1 → evaluation by considering RTdose



B3 - 270° IEC



B2 - 195° IEC



B1 - 15° IEC

work in progress: how to sum all field contributions?



# Statistics study - P004: meningioma

56 Gy in 31 frazioni									
volume irraggiato (RTDOSE)		737,856 cm <sup>3</sup> (B2 - 245°)							
<b>004 P</b>									
fract	t start	t end	t reconstruction	field	coinc	coinc/vol	coinc/tempo	coinc/tempo/vol	
1	84,181	223,722	139,541	B2 - 245°	47805	64,7891	342,5873	0,4643	
2	54,686	195,370	140,684	B2 - 245°	49006	66,4168	348,3415	0,4721	
3	177,177	336,716	159,539	B2 - 245°	79791	108,1390	500,1357	0,6778	
5	95,078	234,806	139,728	B2 - 245°	49213	66,6973	352,2049	0,4773	
6	72,309	212,717	140,408	B2 - 245°	48839	66,1904	347,8356	0,4714	
11	685,436	829,035	143,599	B2 - 245°	48952	66,3436	340,8940	0,4620	
16	697,446	840,815	143,368	B2 - 245°	49506	67,0944	345,3065	0,4680	
19	687,991	830,010	142,019	B2 - 245°	47628	64,5492	335,3638	0,4545	
23	358,181	531,514	173,334	B2 - 245°	54202	73,4588	312,7032	0,4238	
27	259,308	411,942	152,634	B2 - 245°	52311	70,8959	342,7229	0,4645	
29	229,842	446,009	216,167	B2 - 245°	62087	84,1451	287,2178	0,3893	
			t_mean						
			153,729						
				<p><b>coinc/vol = 73 coinc/cm<sup>3</sup></b>  <b>average irradiation time = 154 s</b></p>					
patient ID	measured angles	angle	N particles	N_p/vol	angle	N particles	N_p/vol		
4	all	B1 - 180°	2,07E+10		B2 - 245°	2,57E+10	3,48E+07		
				RS			RS		

# Statistics study - P005: clivus

54+20 Gy in 27+10 frazioni									
volume irraggiato (RTDOSE - 1T)		459,864 cm <sup>3</sup> (B2 - 5°)							
<b>005 P</b>									
fract	t_start	t_end	t_reconstruction	field	coinc	coinc/vol	coinc/tempo	coinc/tempo/vol	
1	70,024	162,132	92,108	B2 - 5°	31519	68,5398	342,1963	0,7441	
2	70,963	160,553	89,590	B2 - 5°	31130	67,6939	347,4703	0,7556	
3	130,926	221,651	90,724	B2 - 5°	32324	70,2903	356,2882	0,7748	
5	75,003	166,544	91,541	B2 - 5°	32413	70,4839	354,0831	0,7700	
6	73,312	162,800	89,489	B2 - 5°	32979	71,7147	368,5273	0,8014	
11	287,673	378,752	91,079	B2 - 5°	32767	71,2537	359,7646	0,7823	
16	1655,822	1745,901	90,079	B2 - 5°	30774	66,9198	341,6335	0,7429	
17	296,773	386,427	89,654	B2 - 5°	32519	70,7144	362,7150	0,7887	
24	227,383	319,909	92,526	B2 - 5°	31461	68,4137	340,0222	0,7394	
27	404,254	496,810	92,556	B2 - 5°	33311	72,4366	359,9003	0,7826	
002_2T	33,5	114,1	80,600	B4 - 0°					
007_2T	1308,9	1383,1	74,200	B4 - 0°					
008_2T	656,8	736,8	80,000	B4 - 0°					
			t_mean 1T						
			90,935						
					<p><b>coinc/vol = 70 coinc/cm<sup>3</sup></b>  <b>average irradiation time = 91 s</b></p>				
patient ID	measured angles	angle	N particles	N_p/vol	angle	N particles	N_p/vol		
5	1T: 5 only	B2 - 5°	1,33E+10	2,89E+07	B1 - 185°	1,35E+10			