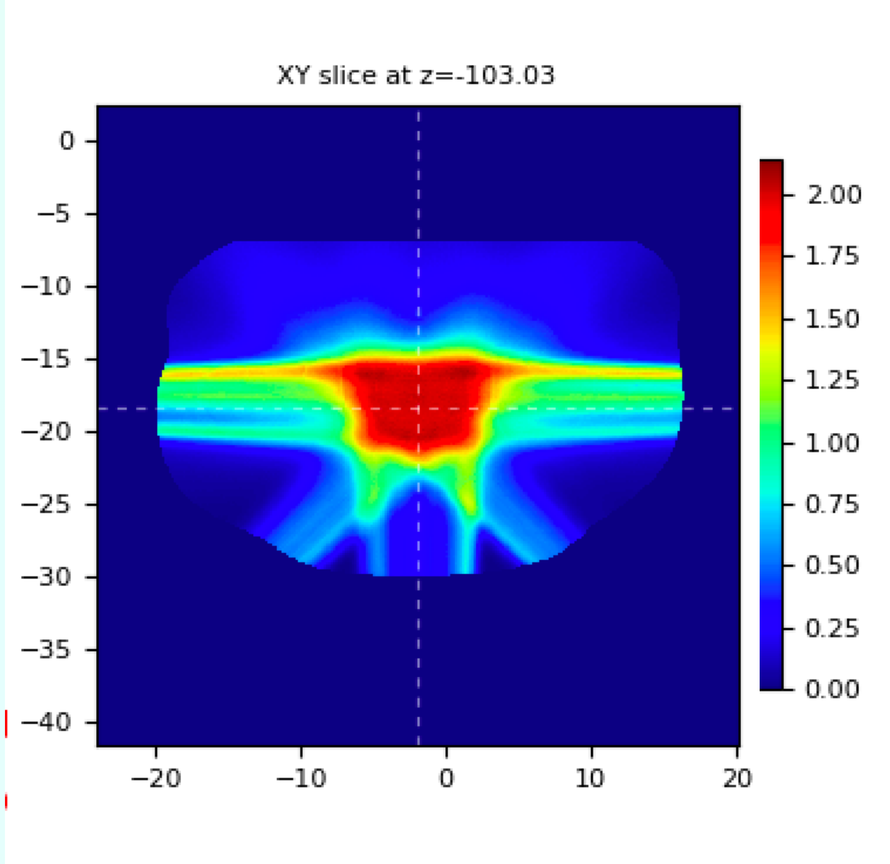
SPOT SPACING AND DOSE RATE FOR VHEE TREATMENT PLANS

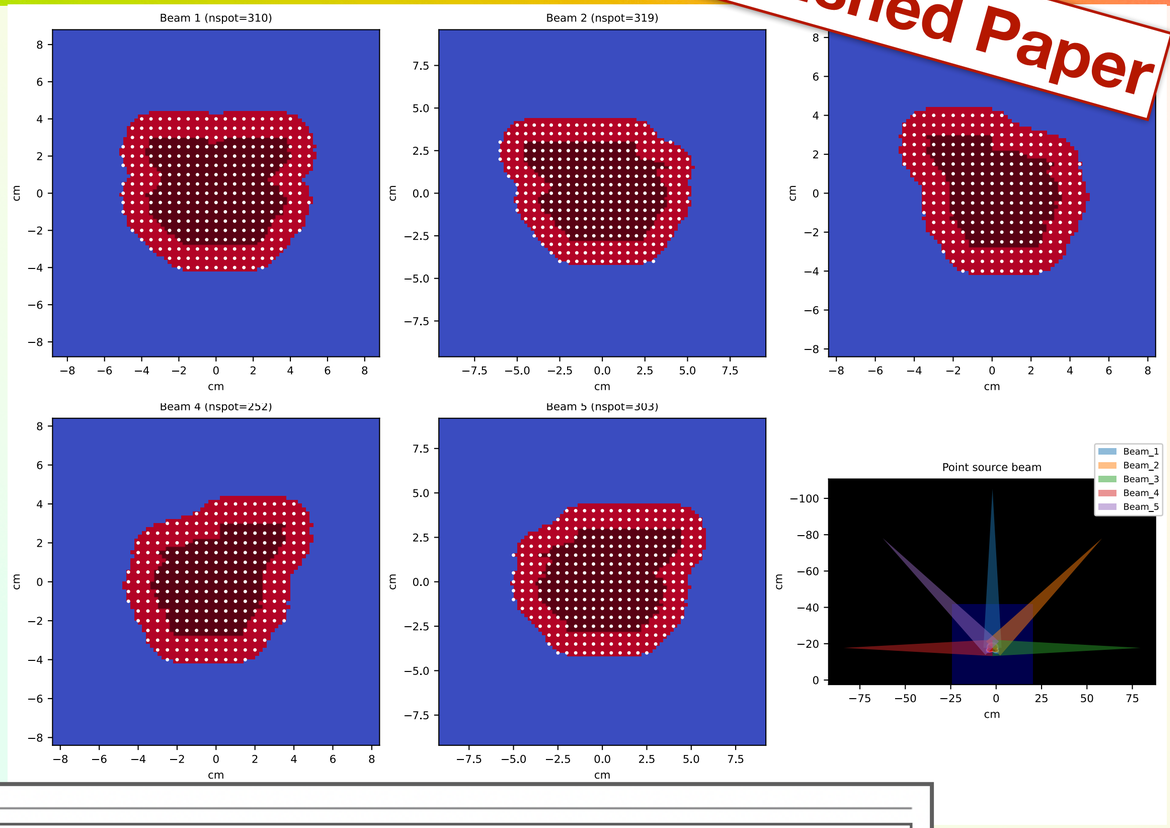
FRIDA GENERAL MEETING - WP4
ILARIA MATTEI ON BEHALF OF ROMA - MILANO COLLABORATION
27.09.2022

VHEE PLAN: PROSTATE CASE

Published Paper

- Prostate Patient (see Angelica's talk)
- 5 fields
- VHEE beam Ekin (MeV) = 70, 120, 130, 130, 120





costraint_ref

Organ	dosimetric constraints
Target volume	$V_{95\%} > 95\%$, never above 107%
Rectum	$V_{50} < 50\%$, $V_{60} < 35\%$, $V_{65} < 25\%$, $V_{70} < 20\%$, $V_{75} < 15\%$
Anus	$V_{30} < 50\%$
Bulbourethral Glands	$\bar{D} < 50$ Gy
Femurs	$\bar{D} < 52$ Gy, $V_{60} < 5\%$
Bladder	$\bar{D} < 65$ Gy, $V_{65} < 50\%$, $V_{70} < 35\%$, $V_{75} < 25\%$, $V_{80} < 15\%$

VHEE PLAN: PROSTATE CASE

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- Prostate Patient (see Angelica's talk)
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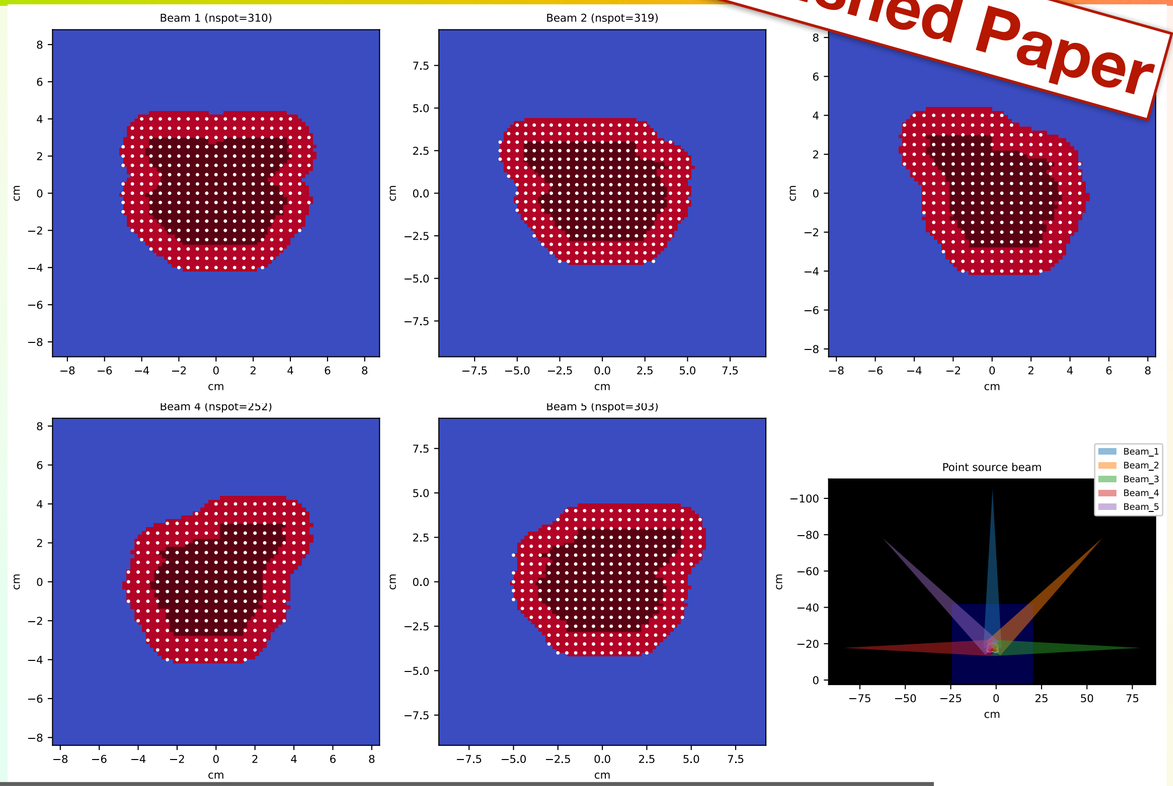
- VHEE beam Ekin (MeV) = 70, 120, 130, 130, 120

- Margins = 1.5 cm, Spot Spacing = 0.5 cm, FWHM = 1 cm
- # pencil beam / field = 310, 319, 253, 252, 303

PZ2	**DMF:**	**1**
PTV	$V_{95\%}$	95.7%
	$V_{105\%}$	0.29%
Rectum	V_{75}	0.8%
	V_{50}	20%
Anus	V_{30}	22.1%
Bulb	D_{50}	12.3 Gy
Femurs	D_{50}	26.8 Gy
Bladder	D_{50}	45Gy
	V_{70}	19.6%
	V_{65}	25.2%



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Organ	**dosimetric constraints**
Target volume	$V_{95\%} > 95_{\%}$, never above 107%
Rectum	V_{50} <50%, V_{60} <35%, V_{65} <25%, V_{70} <20%, V_{75} <15%
Anus	V_{30} <50%
Bulbourethral Glands	$\bar{D}$ <50 Gy
Femurs	$\bar{D}$ <52 Gy, V_{60} <5%
Bladder	$\bar{D}$ <65 Gy, V_{65} <50%, V_{70} <35%, V_{75} <25%, V_{80} <15%

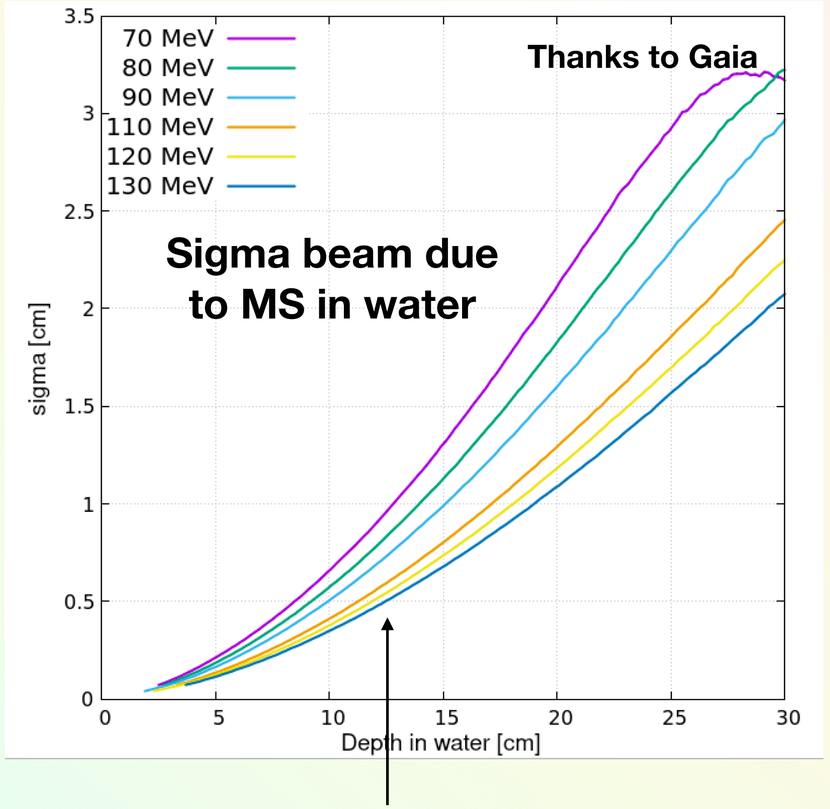
VHEE PLAN: REDUCING THE PROBLEM SIZE

- **Prostate Patient (see Angelica's talk)**
- **5 fields**
- **VHEE beam Ekin (MeV) = 70, 120, 130, 130, 120**

- Margins = 1.5 cm, **Spot Spacing = 0.75 cm, FWHM = 1.5 cm**
- **# pencil beam / field = 132, 137, 112, 112, 131 => ~ 2**

- Margins = 1.5 cm, **Spot Spacing = 0.75 cm, FWHM = 1 cm**

- Margins = 1.5 cm, **Spot Spacing = 1 cm, FWHM = 1 cm**
- **# pencil beam / field = 80, 85, 64, 64, 77 => ~ 4**

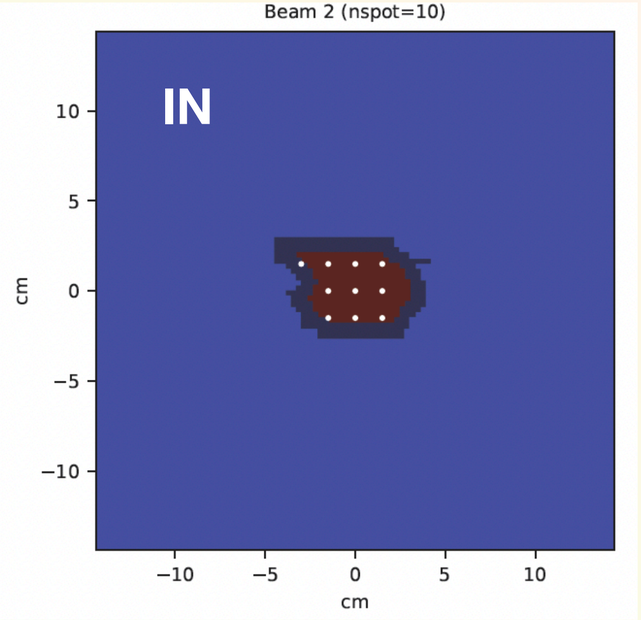


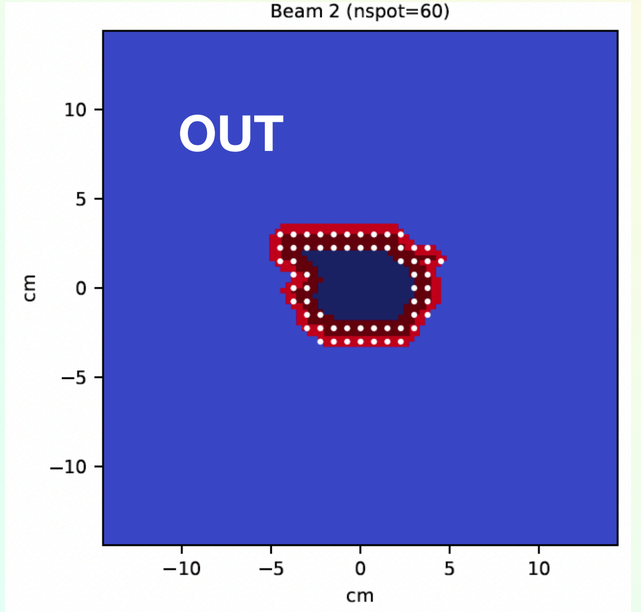
VHEE PLAN: REDUCING THE PROBLEM SIZE

- **Prostate Patient (see Angelica's talk)**
- **5 fields**
- **VHEE beam Ekin (MeV) = 70, 120, 130, 130, 120**

- **Margins = 1.5 cm**
  IN: 1 cm in PTV: ss = 1.5 cm, FWHM = 1.5 cm
  OUT: from 1 cm in PTV to MARGIN: ss = 0.5 cm, FWHM = 0.5 cm
- # pencil beam / field = 254, 255, 218, 219, 248

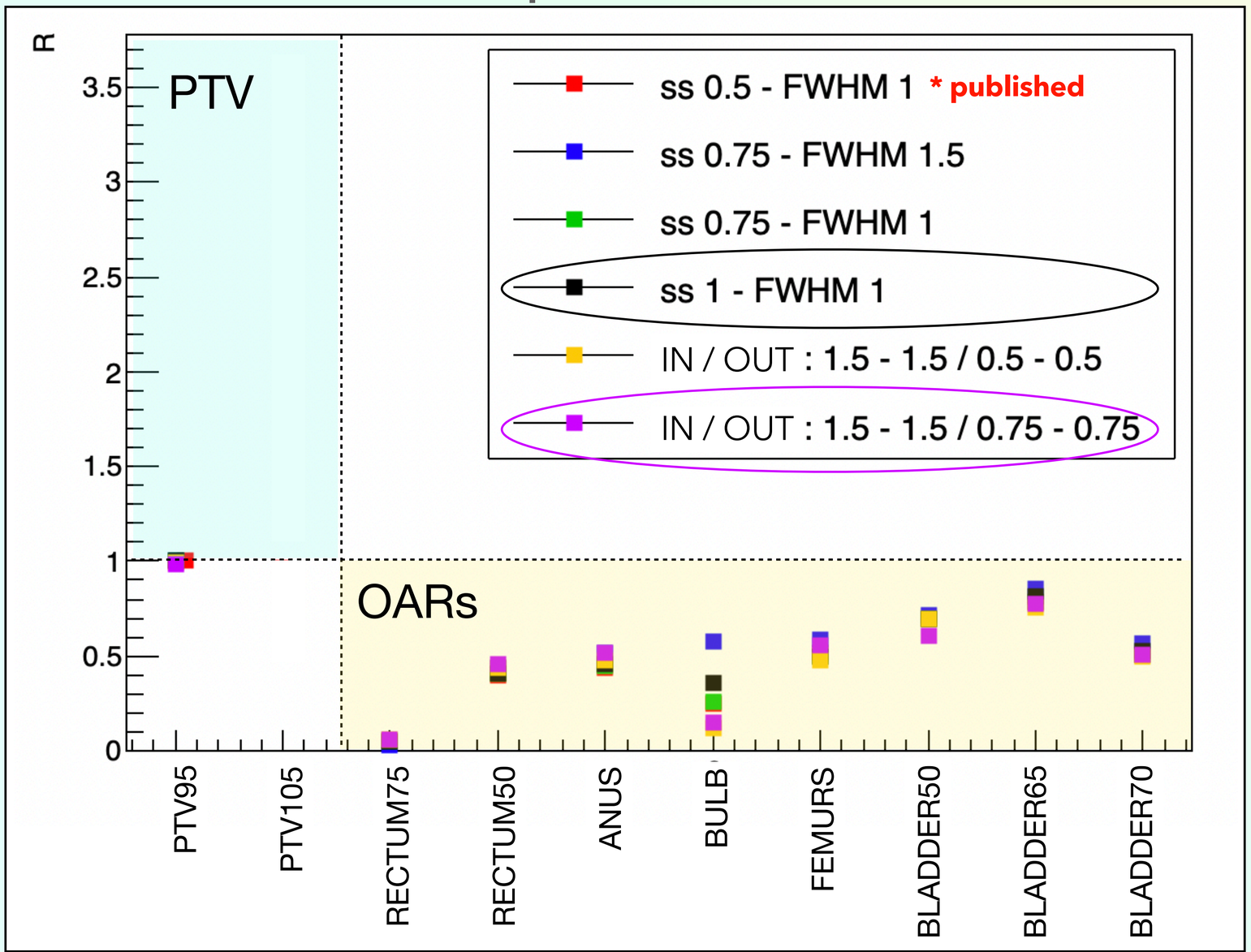
- **Margins = 1.0 cm**
  IN: 1 cm in PTV: ss = 1.5 cm, FWHM = 1.5 cm
  OUT: from 1 cm in PTV to MARGIN: ss = 0.75 cm, FWHM = 0.75 cm
- # pencil beam / field = 70, 70, 57, 58, 68 => ↓ ~ 4.5

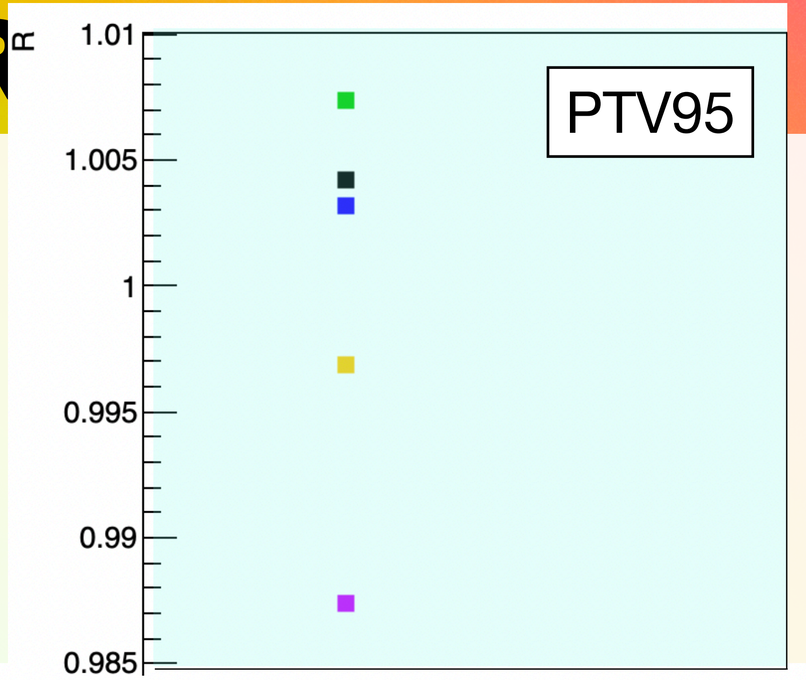


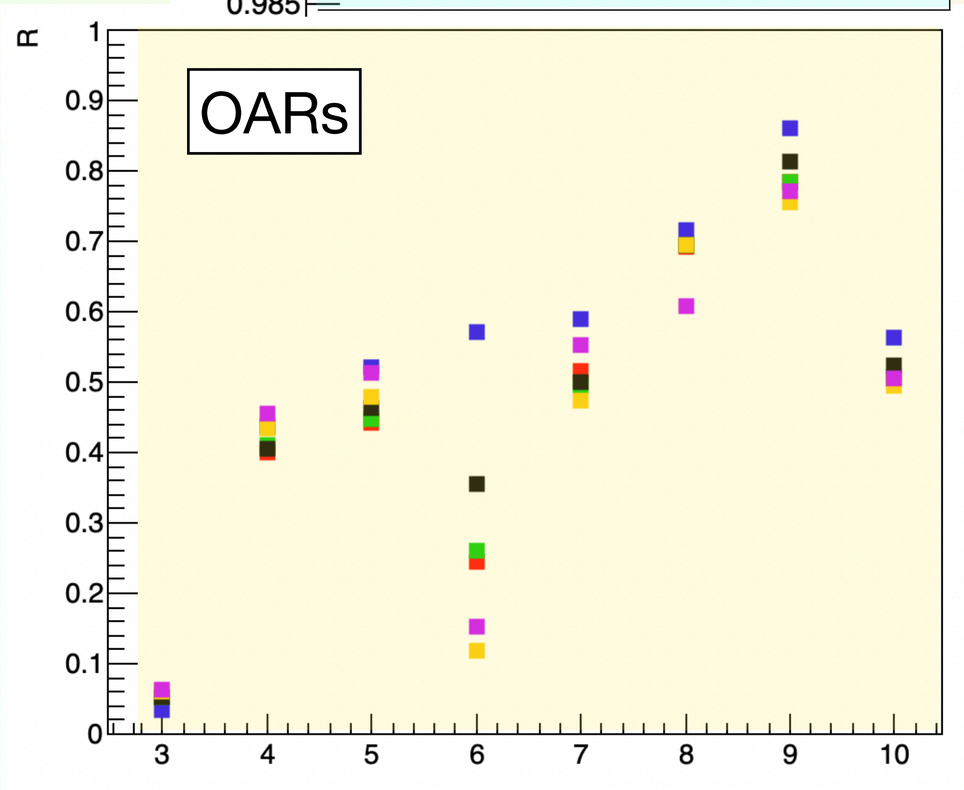


VHEE PLAN: REDUCING THE PR

- Constraints computed from each optimised plan
- **R = constraint from each plan / reference constraint**







AVERAGED DOSE RATE (ADR)

$$\dot{D}_j^{ADR} = \frac{D_j - 2d^*}{T_j}$$

where:

$$d_j(t_0) = d^*$$

$$d_j(t_1) = D_j - d^*$$

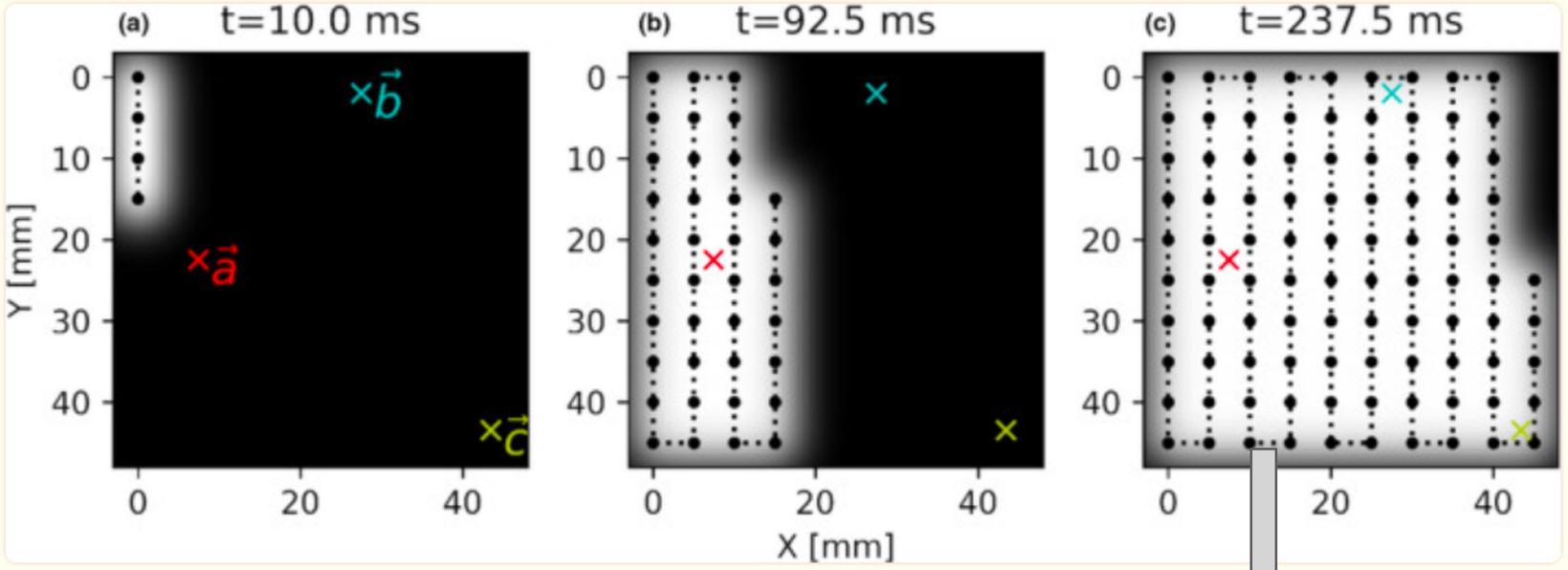
$$T_j = t_1 - t_0$$

d^* preset dose-threshold that determines the effective irradiation time

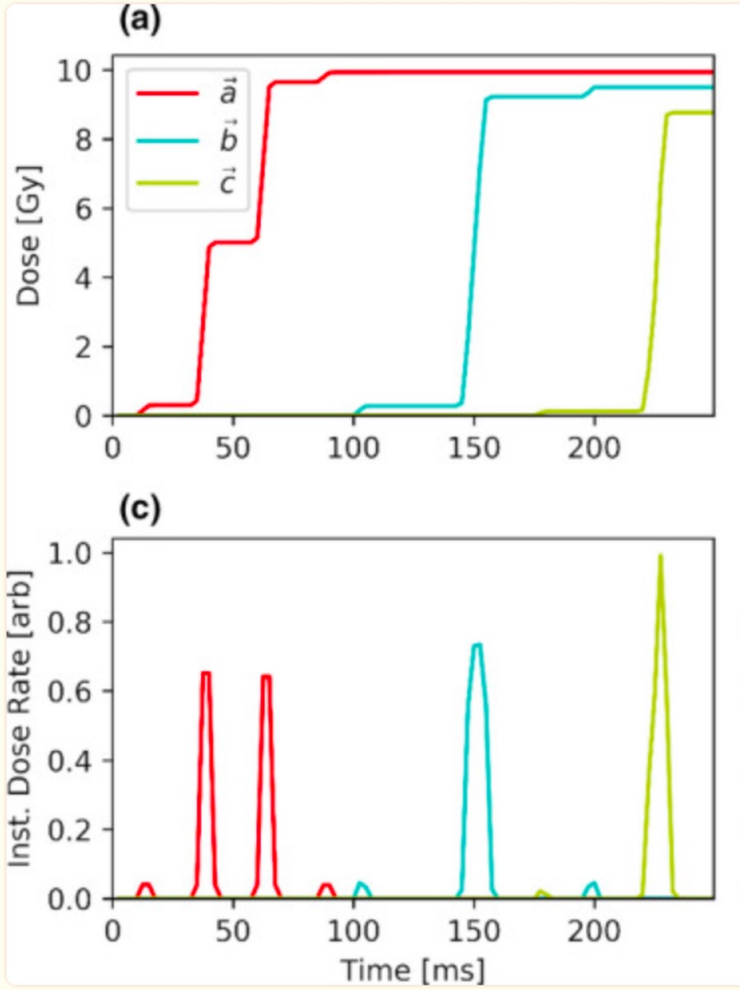
Both duration of individual PB delivery and scanning from one PB to the next are considered for the dose rate calculations.

SPOT SCANNING CONSIDERATIONS

Thanks to Angelo Schiavi and Andrei Paun



scanning pattern



SPOT SCANNING CONSIDERATIONS

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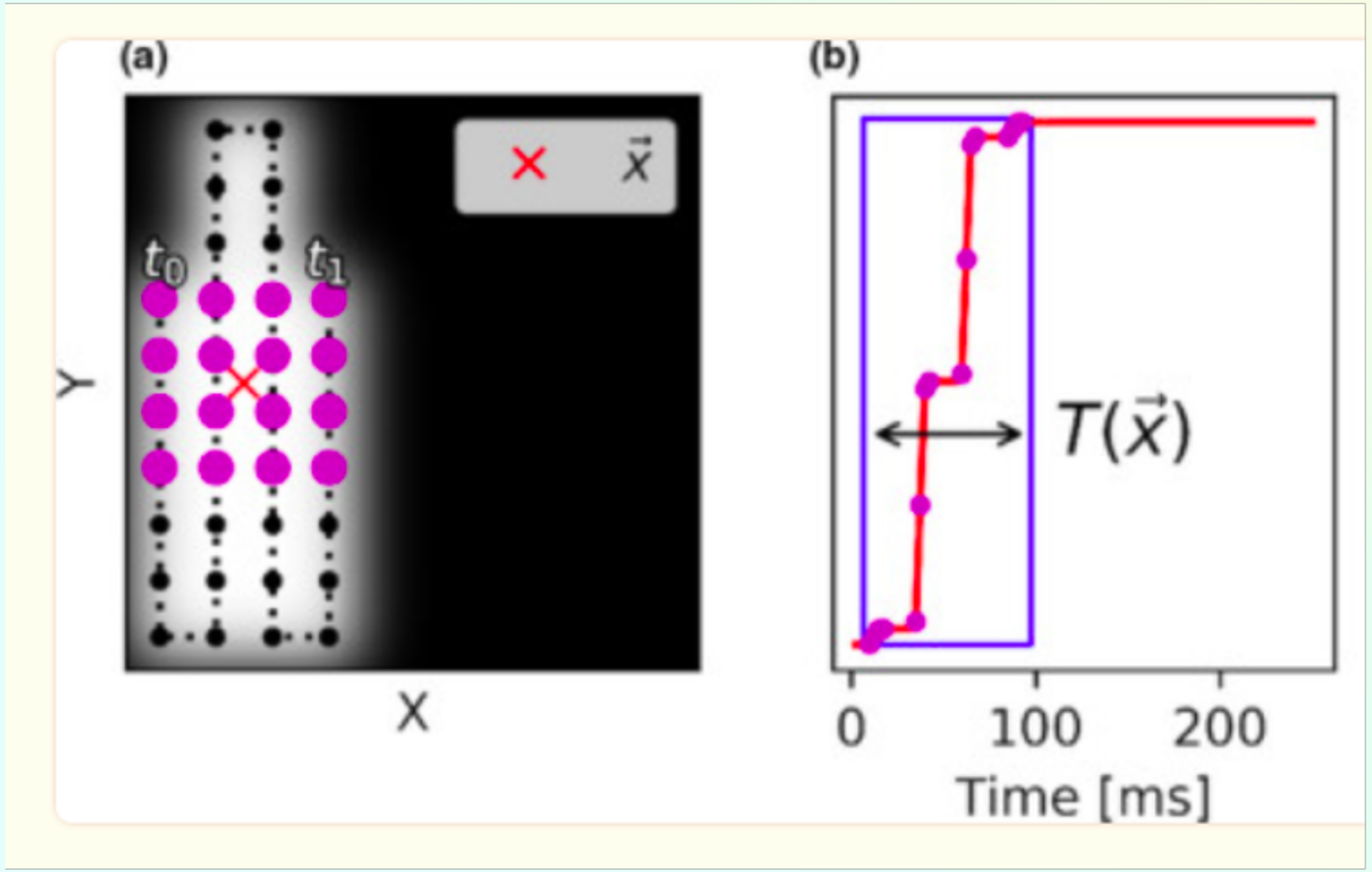


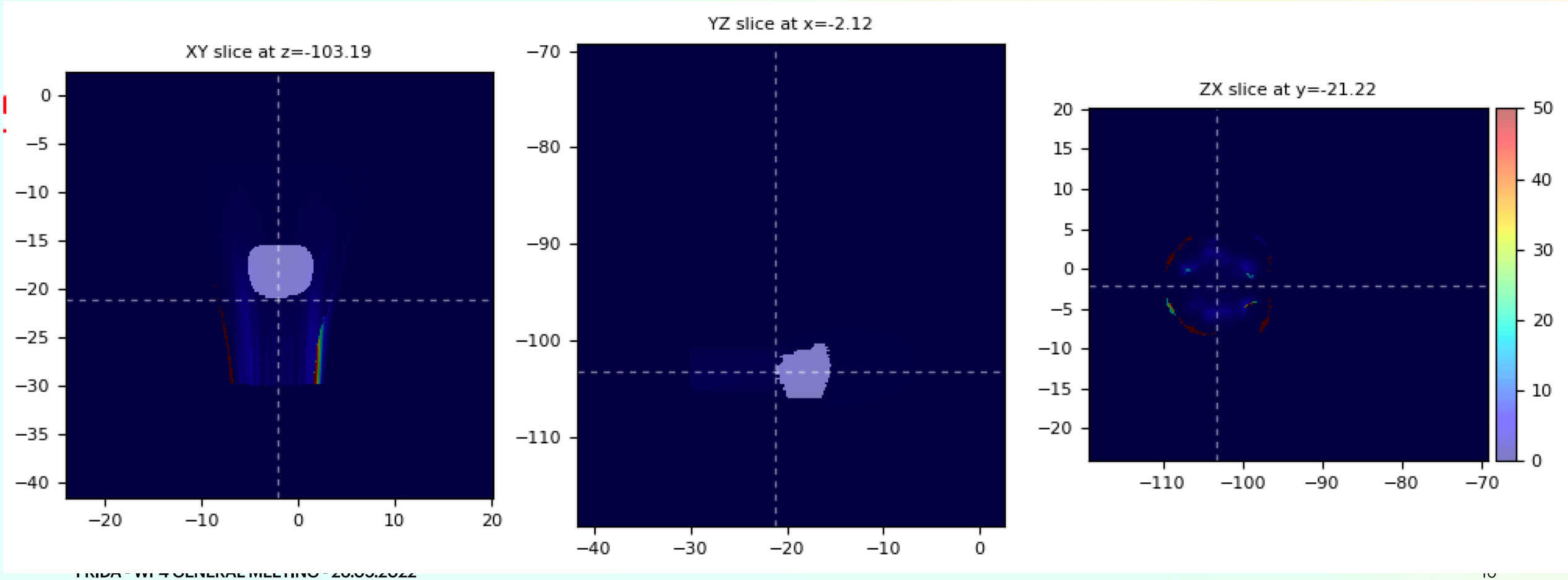
The time for a voxel to accumulate the max dose is a **fraction** of the total time of irradiation.

The dose accumulated depends on the **scanning pattern** and the **relative position** between the spots.

ADR MAP FIELD 1 ON PROSTATE BLACK CASE

- Hypothetic accelerator parameters:
  pulse time = 1 μs
  prf = 100 Hz (10 ms inter spot)
- d* = 5%
- Results for 1 single fraction

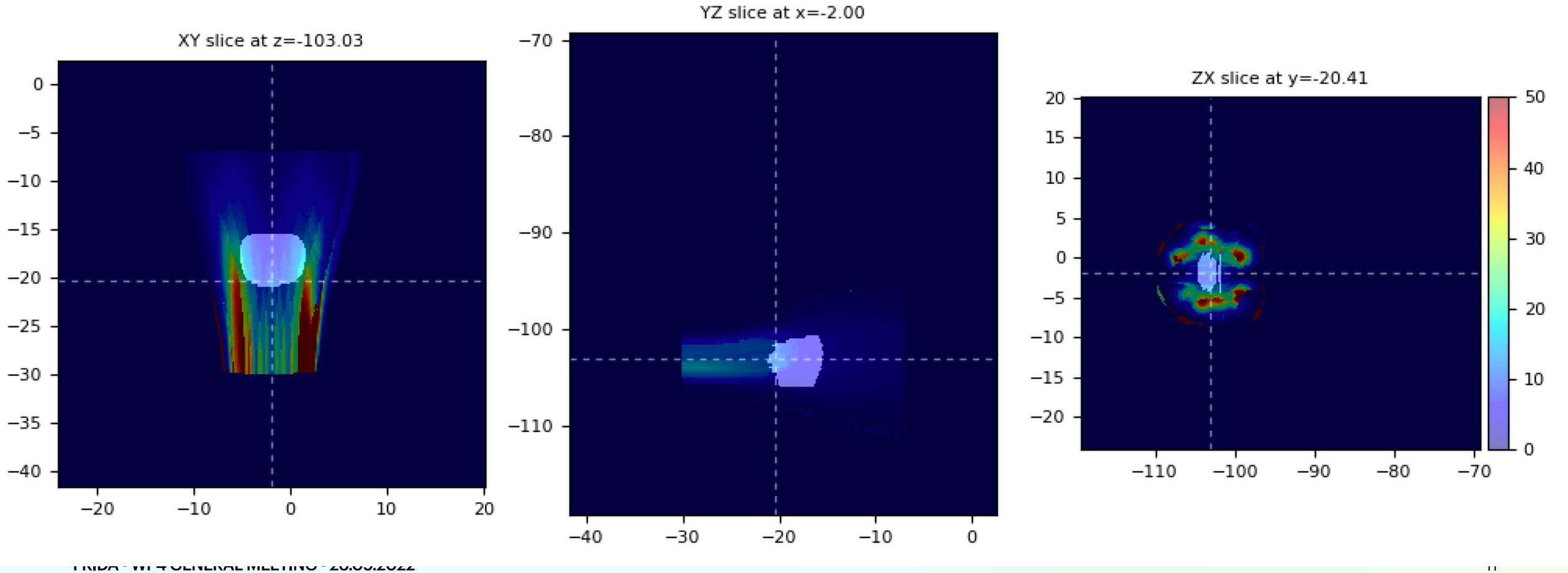
ADR < 20 Gy/s in the entry channel.
It could be optimised, optimising the pencil beam scanning sequence.



ADR MAP FIELD 1 ON PROSTATE BLACK CASE

- Hypothetic accelerator parameters:
  pulse time = 1 μs
  prf = 1 kHz (1 ms inter spot)
- d* = 5%
- Results for 1 single fraction

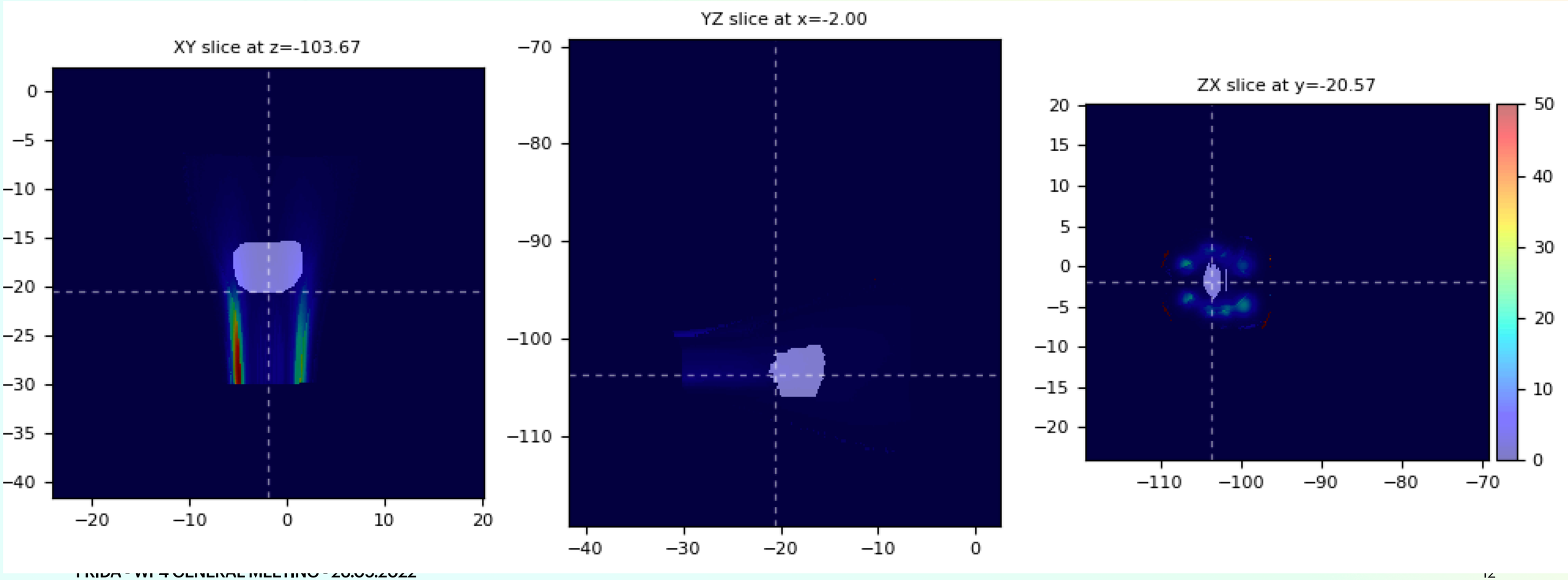
ADR > 40 Gy/s in the entry channel.
It could be optimised, optimising the pencil beam scanning sequence.



ADR MAP FIELD 1 ON PROSTATE PUBLISHED CASE

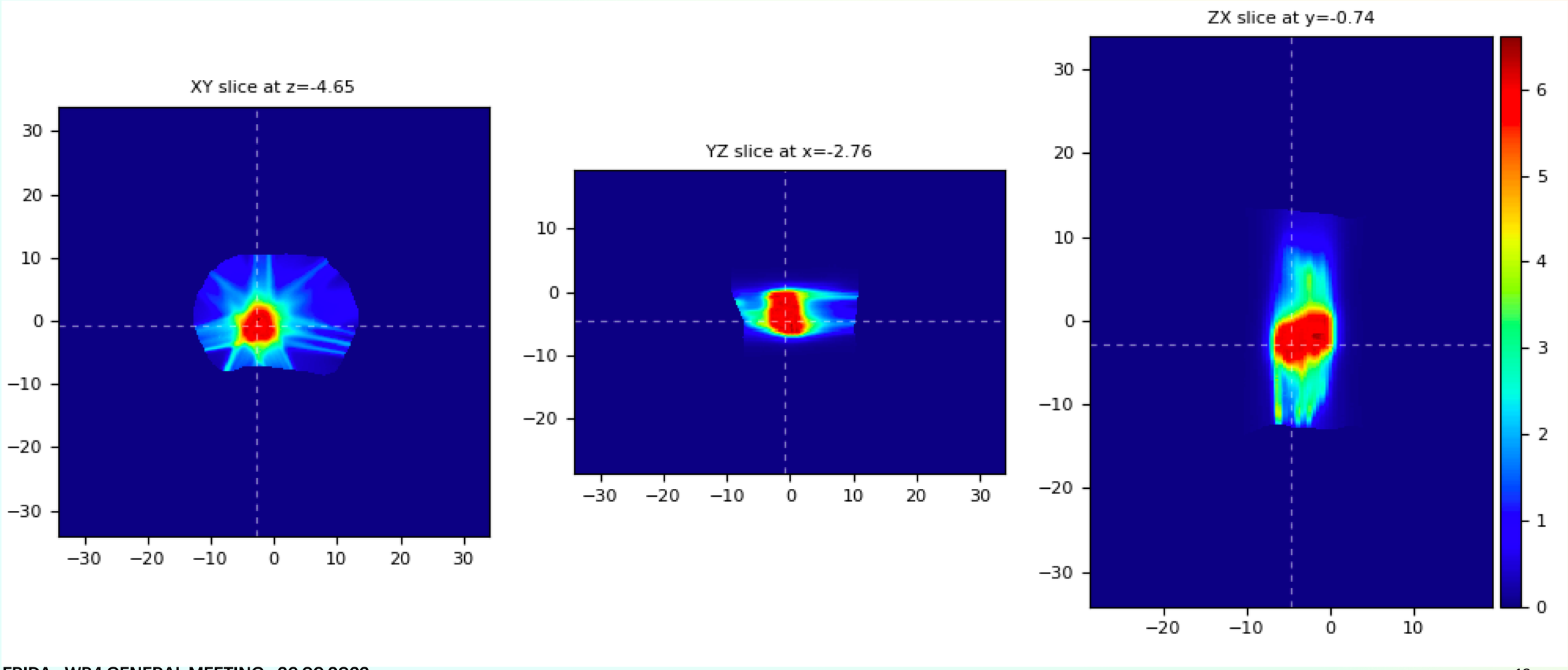
- Hypothetic accelerator parameters:
  pulse time = 1 μs
  prf = 1 kHz (1 ms inter spot)
- d* = 5%
- Results for 1 single fraction

ADR < 20 Gy/s in the entry channel with x4 PB per field



PANCREAS CASE: DOSE RATE STUDY

- Pancreas hypo fractionated treatment of a Roma BIO-CAMPUS patient
- TP with VHEE, 7 fields (see Annalisa's talk)



DOSE AVERAGED DOSE RATE (DADR)

$$DADR_j = \sum_{i=1}^{N} \frac{d_{ij}}{d_{totj}} \cdot \dot{D}_{ij} \tag{0.1}$$

dove i è l'i-esimo PB e j il j-esimo voxel.
Il DADR viene calcolato per ogni voxel. Per ogni voxel conosco quali PB lo toccano e quanta dose gli inviano. Ogni voxel è toccato da N PB e la dose totale che il voxel riceve è d_{totj}.
Quindi il DADR è calcolato come la somma degli N ratei di dose D_{ij} ciascuno PESATO per il valore di dose che esso eroga rispetto alla dose totale in quel voxel (rapporto d_{ij}/d_{totj}).
Il dose rate istantaneo D_{ij} relativo al singolo PB i-esimo sul voxel j è dato da:

$$\dot{D}_{ij} = \frac{d_{ij}}{T_i} \tag{0.2}$$

con T_i tempo di delivery del singolo PB, calcolato come:

$$T_i = \frac{\phi_i}{I_{acc}} \tag{0.3}$$

con ϕ_i fluenza del PB e $I_{acc} = 1.25e + 14$ corrente media dell'acceleratore

Sono inoltre presenti 2 valori di soglia :

- dose sul singolo voxel > 1e^-12 Gy
- fluenza del singolo PB > fluenza max x 1e^-4

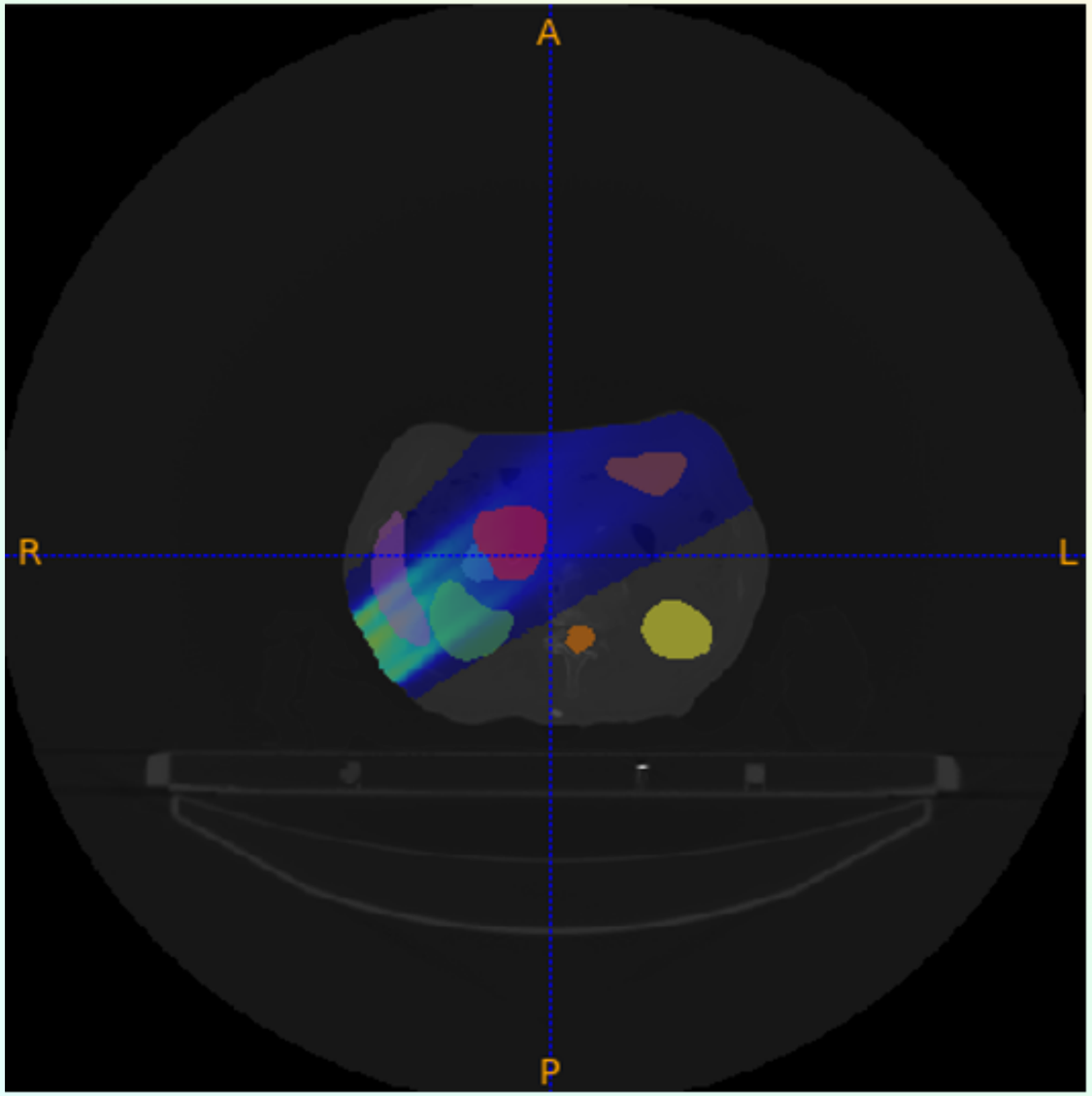
i voxel ed i PB che non superano tali valori non vengono considerati nel calcolo.

- Risultati per una singola frazione

Thanks to Angelo Schiavi and Andrei Paun

FIELD 1

Thanks to Angelo Schiavi and Andrei Paun



DADR MAP FIELD 1

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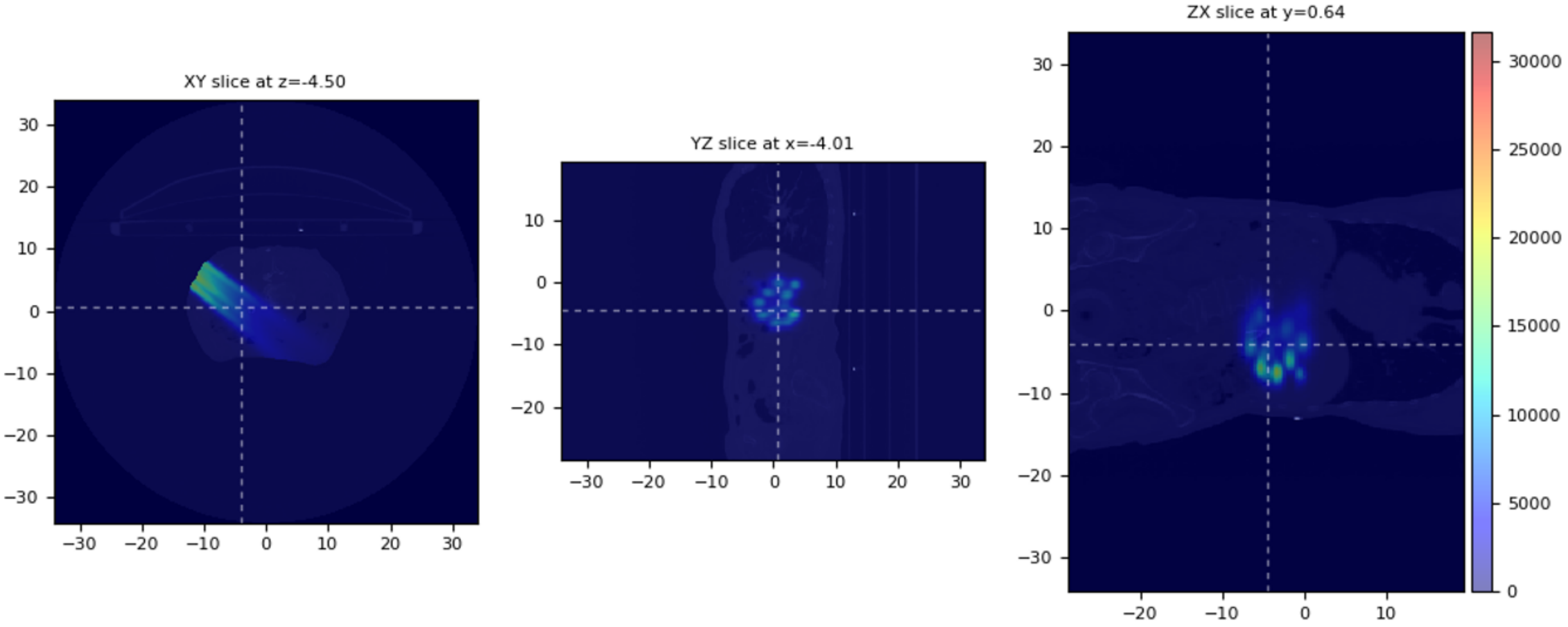

DADR MAP FIELD 1

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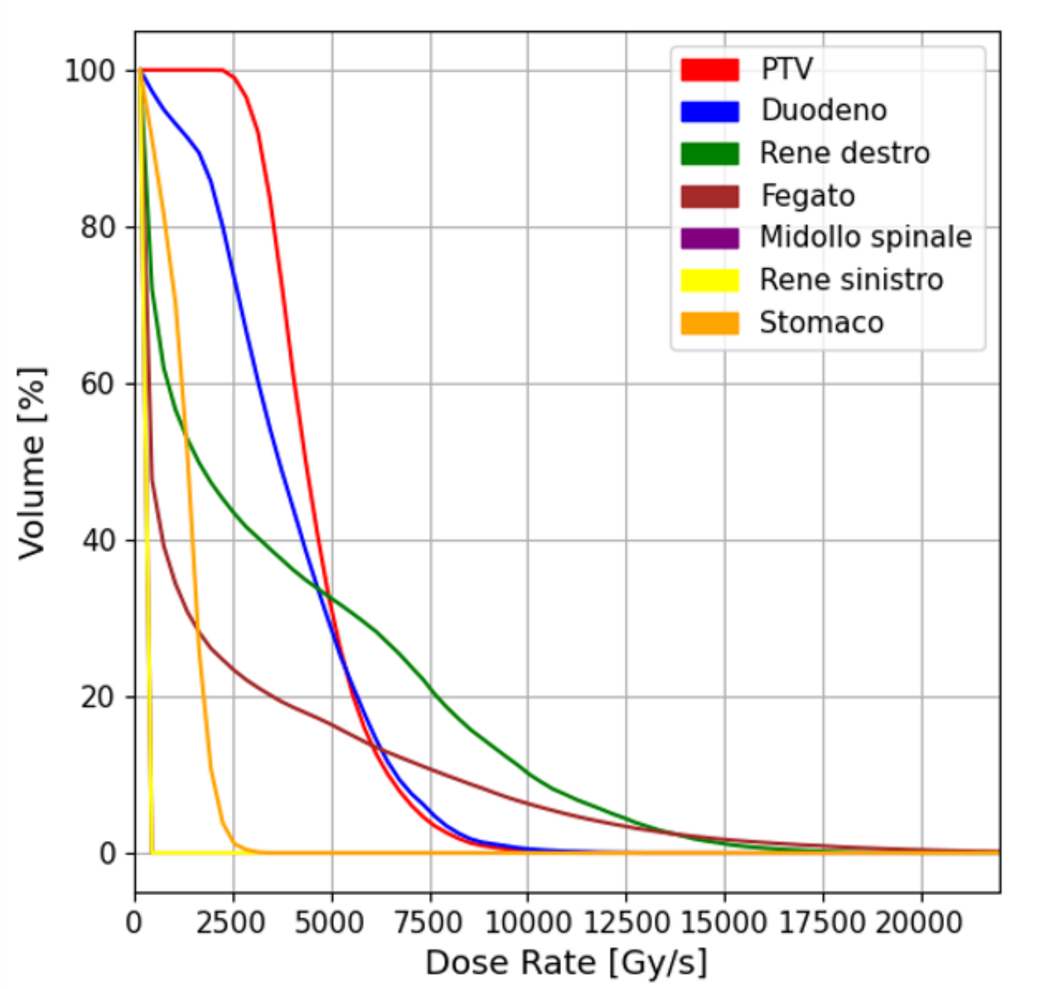

ROI	% DR > 40 Gy/s	% D > 4 Gy	D_max	D_mean
PTV	100%	0%	0.86 Gy	0.57 Gy
Duodeno	100%	0%	0.79 Gy	0.37 Gy
Rene_dx	93.09%	0%	1.20 Gy	0.24 Gy
Fegato	65.80%	0%	1.54 Gy	0.12 Gy
Midollo	0.01%	0%	0.01 Gy	0.00 Gy
Rene_sx	0%	0%	0.00 Gy	0.00 Gy
Stomaco	98.67%	0%	0.54 Gy	0.22 Gy

DR > 40 Gy/s in the entry channel
but no voxels with Total Dose per Field > 4 Gy.

ADR MAP FIELD 1

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- Hypothetic accelerator parameters:
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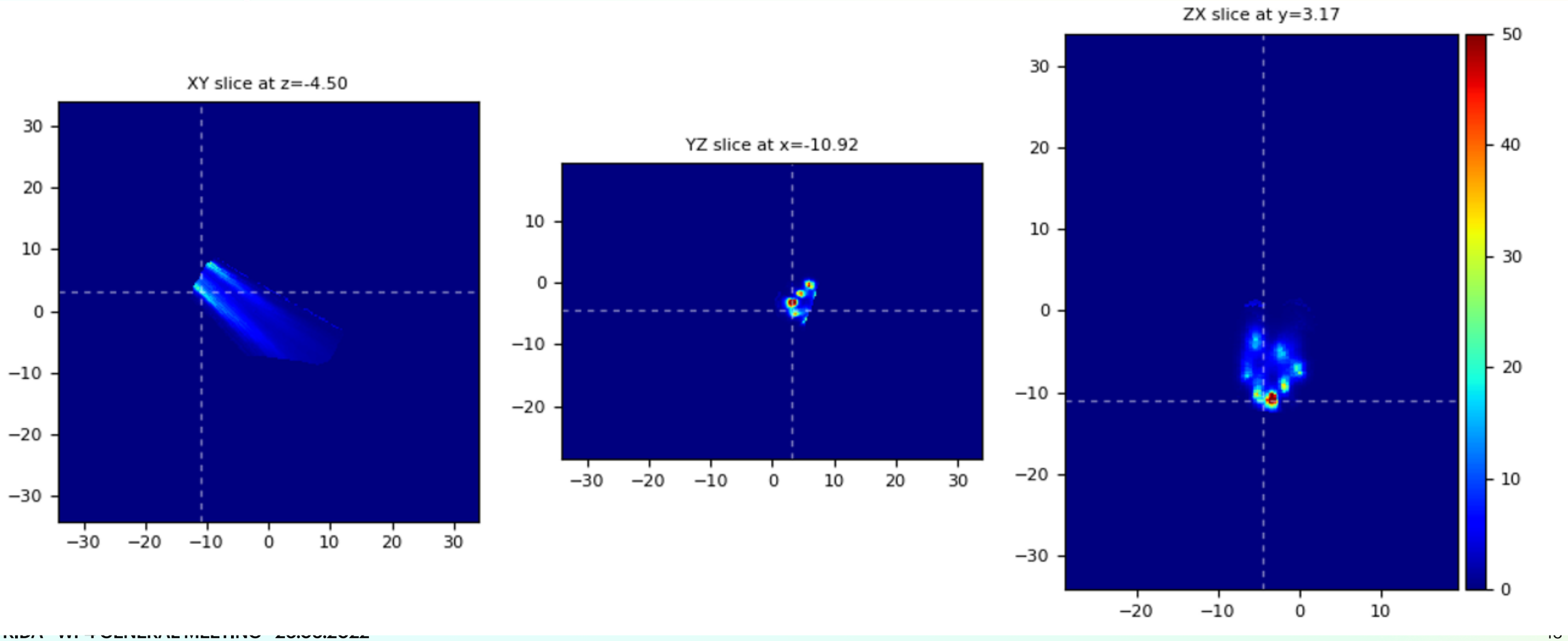
  prf = 1 kHz (1 ms inter spot)
- d* = 5%
- Results for 1 single fraction



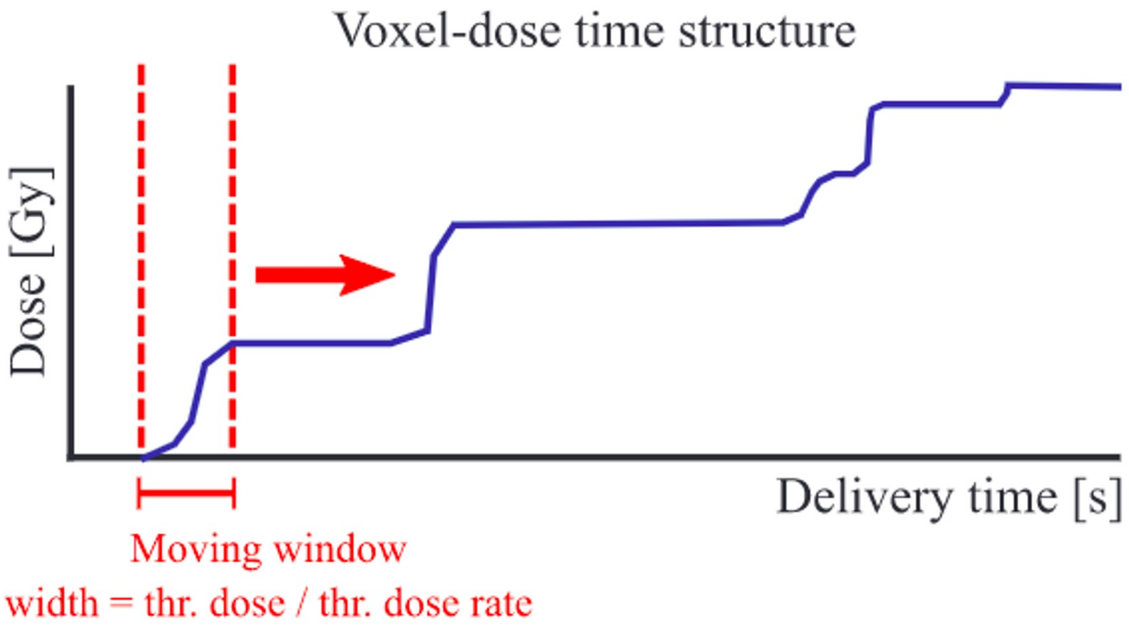
BACKUP

ADR MAP FIELD 1 PANCREAS

Thanks to Angelo Schiavi and Andrei Paun

ROI	D_max (Gy)	D_mean (Gy)	DADR_max (Gy/s)	DADR_mean (Gy/s)	ADR_max (Gy/s)	ADR_mean (Gy/s)
PTV	0.86	0.57	11190.22	4480.04	13.37	4.66
Duodeno	0.79	0.37	12715.31	3788.36	14.11	3.32
Rene_dx	1.20	0.24	20078.02	3606.20	53.36	3.47
Fegato	1.54	0.12	28725.59	2087.32	103.22	1.91
Midollo	0.01	0.00	125.51	0.01	0.00	0.00
Rene_sx	0.00	0.00	0.00	0.00	0.00	0.00
Stomaco	0.54	0.22	3244.23	1158.15	3.72	1.45

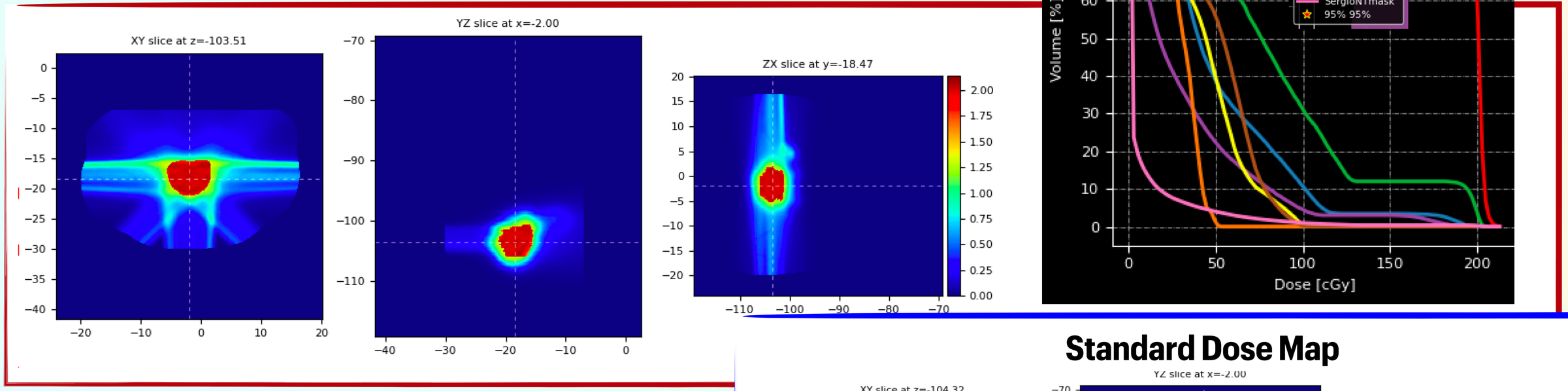
FLASH dose evaluation using a sliding window

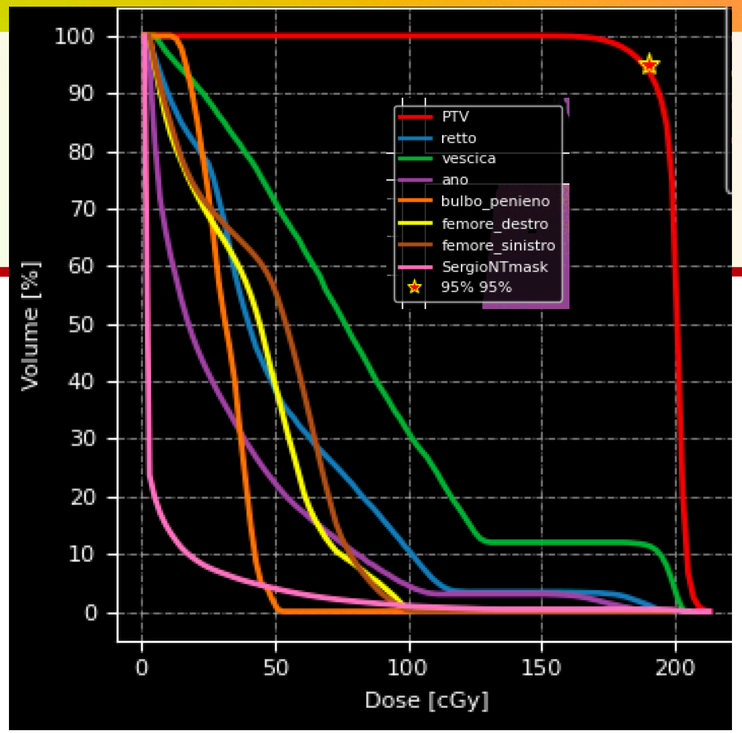


We assume that FLASH effect occurs whenever the dose delivered within the time window is larger than the dose threshold; in that case, all dose within the time window is considered as “FLASH dose” (i.e., no gradual building up of FLASH effect is hypothesized).

DOSE MAP WITH FMF: PROSTATE BLACK CASE

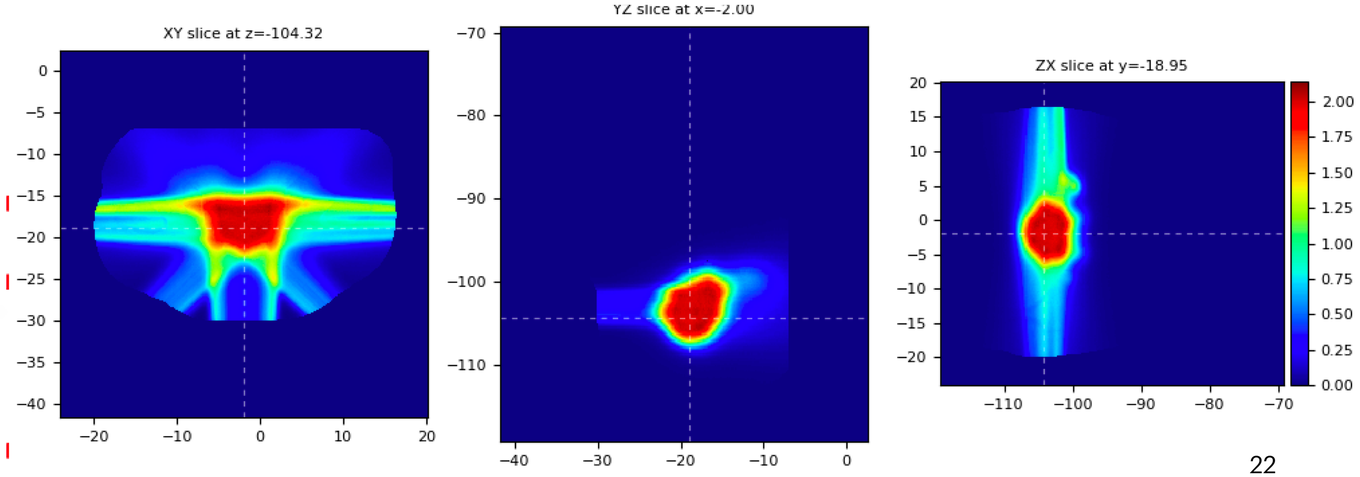
- FMF = FMF min = 0.65 (no dose tot per vxl threshold!)
- ADRthr> 40 Gy/s, prf 1kHz, 1 fraction (2Gy)





Dose in the entry channel reduced…

Standard Dose Map



DOSE MAP WITH FMF ON PROSTATE CASE

- Spot Spacing = 0.5 cm, FWHM = 1 cm
- # pencil beam / field = 310, 319, 253, 252, 303

PZ2	DMF:	1
PTV	$V_{95\%}$	95.7%
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Bladder	D_{50}	45Gy
	V_{70}	19.6%
	V_{65}	25.2%

- Spot Spacing = 1 cm, FWHM = 1 cm
- # pencil beam/field = 80, 85, 64, 64, 77

DMF1	DMF 0.65
94.65%	94.65 %
0.88%	0.88 %
0.51%	0.51 %
19.26%	3.39%
22.1%	11.30 %
18.21Gy	11.84 Gy
25.99Gy	17 Gy
44.87Gy	32.29 Gy
19.58%	12.01%
25.52%	12.01%

...indeed