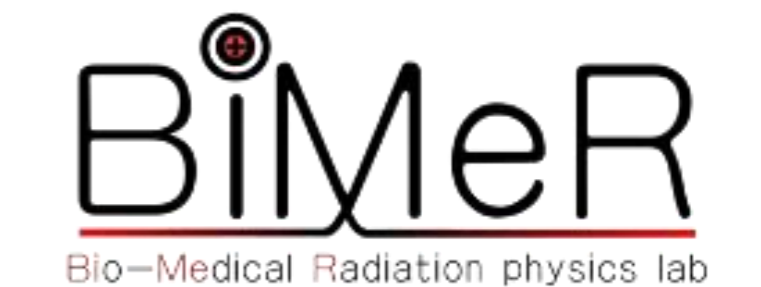


MC based Optimization of 3DRM for UHDR p+ therapy

Update on the FRIDA activity



A. Taffelli - FRIDA GM - 04-03-2026



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Provincia Autonoma di Trento*

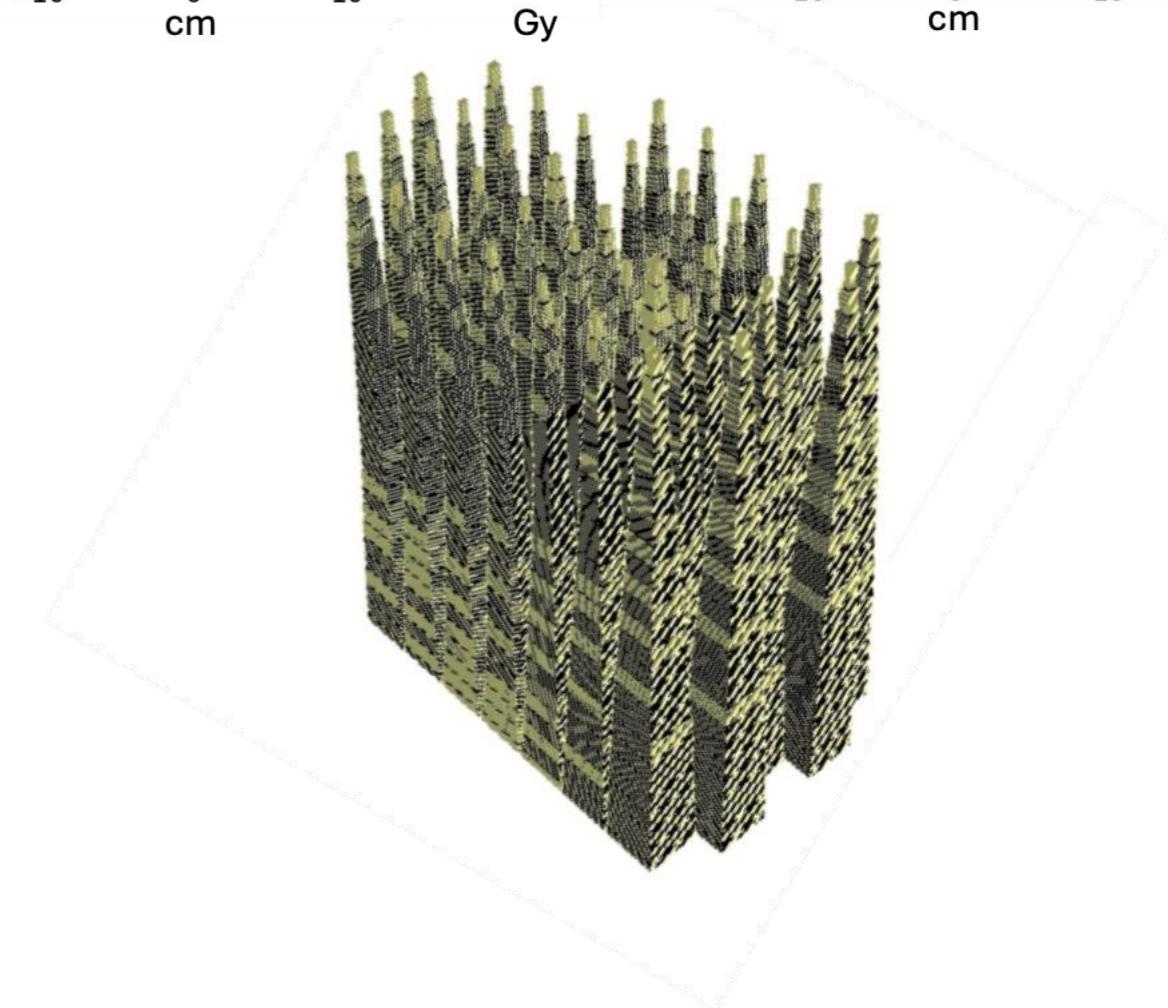
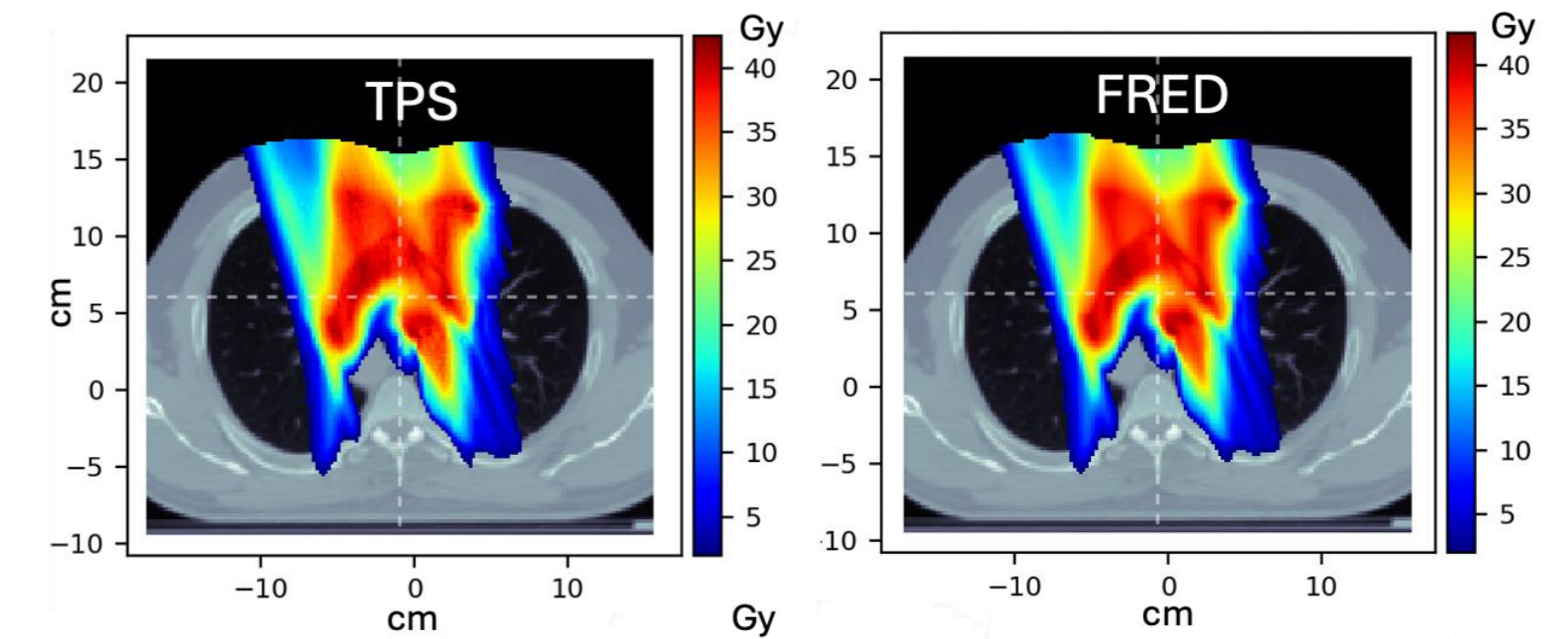
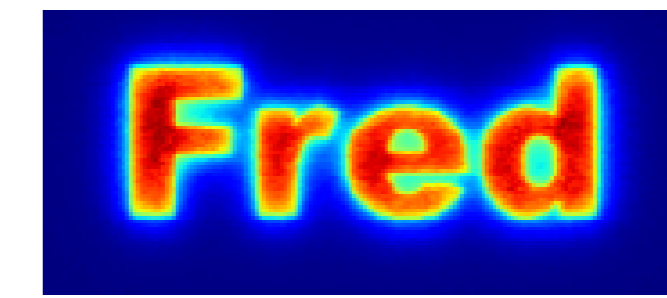


FRIDA WP4 at Trento:



FLASH Radiotherapy with high
Dose-rate particle beams

- 1) Commissioning of a Fast Monte Carlo code for treatment plan recalculation (concluded)
- 2) Development of 3D Range modulators for Ultra-high dose rate (UHDR) p+ therapy based on MC simulations



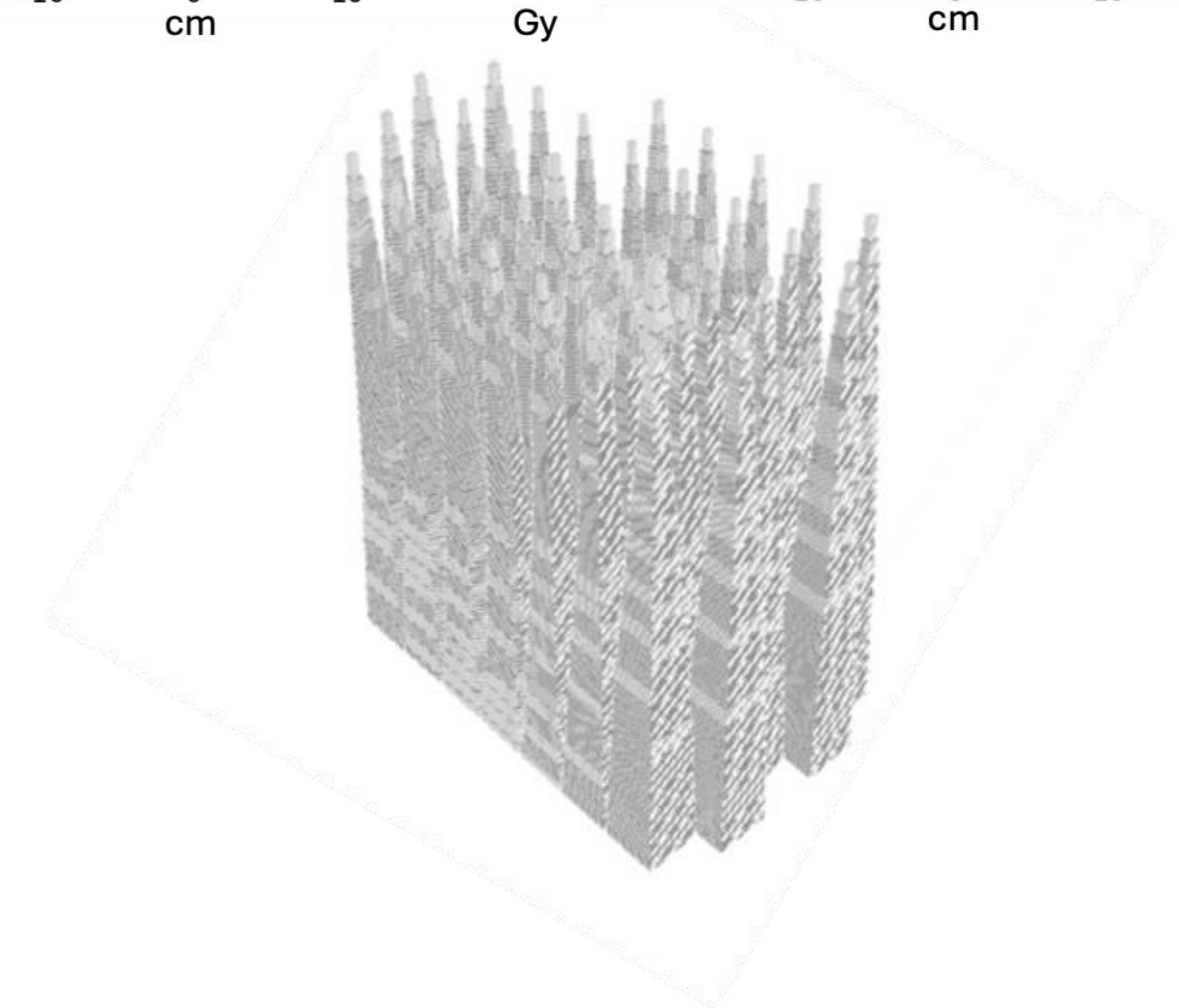
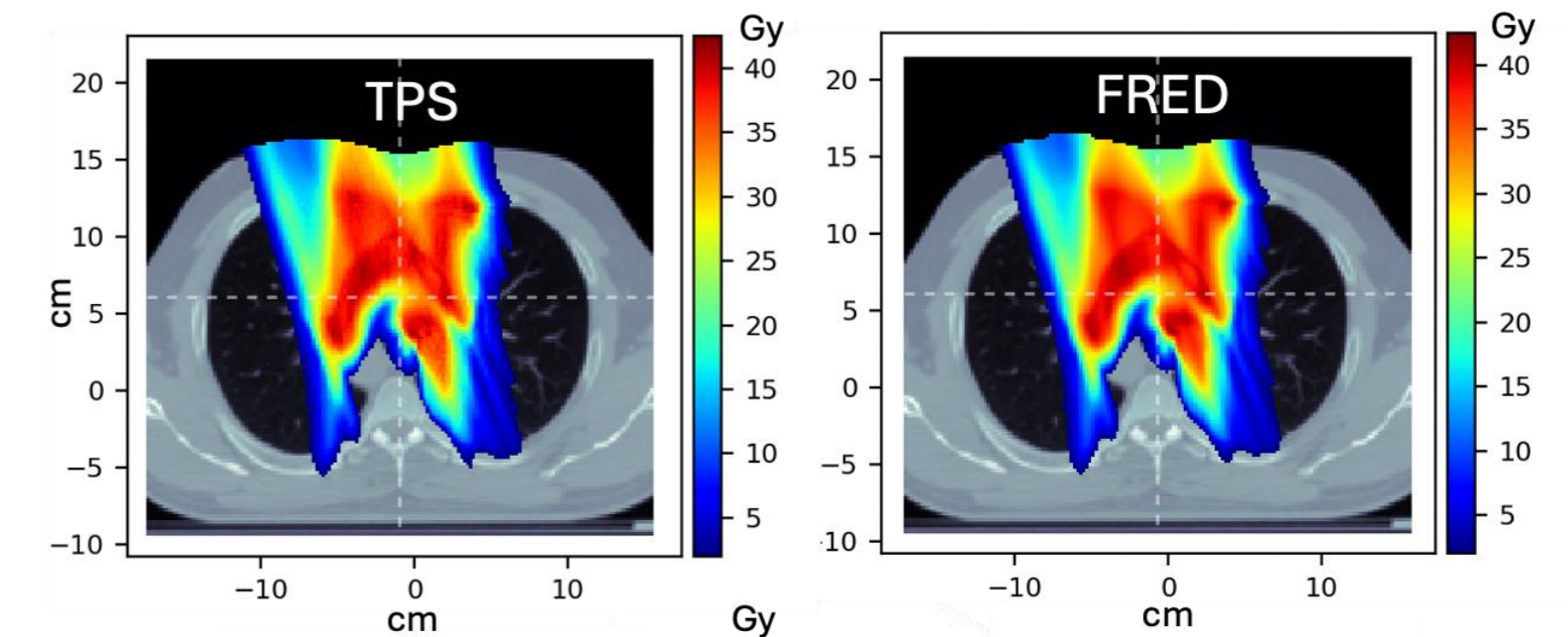
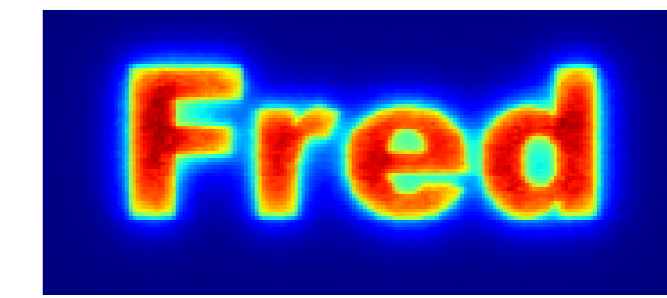
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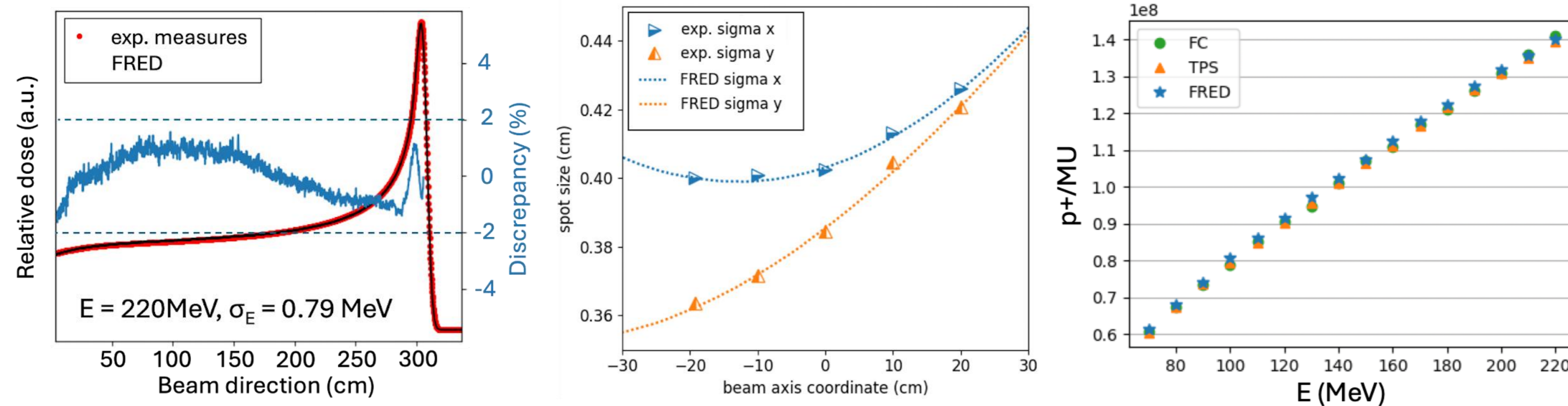


1) Commissioning of a Fast MC code for proton plan recalculation

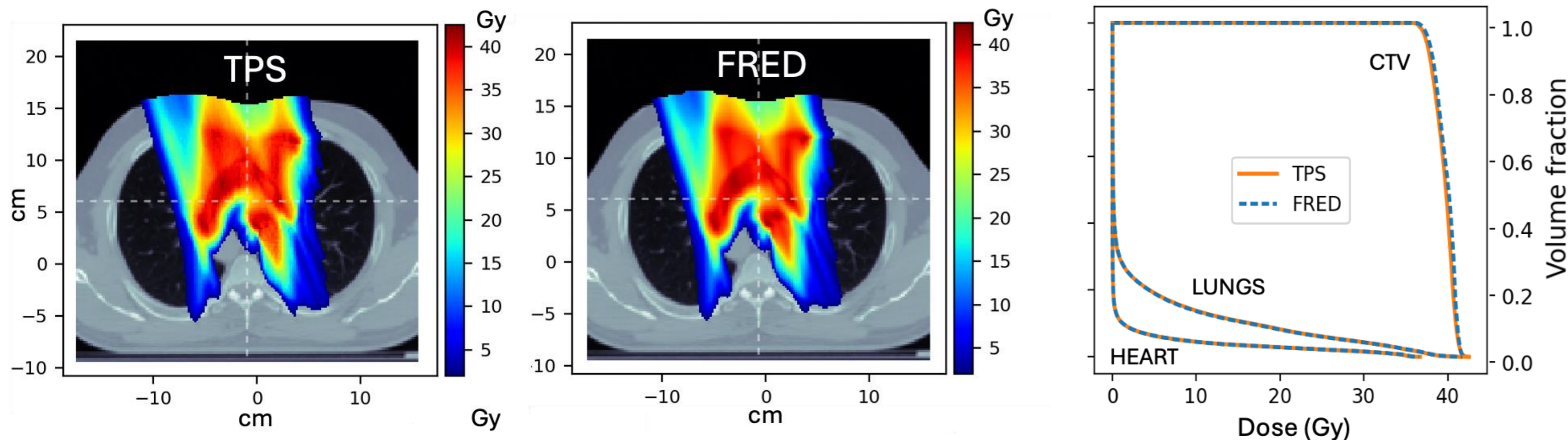


FLASH Radiotherapy with high
Dose-rate particle beams

Implementation of the Trento gantry proton beam model in FRED:



Validation against a series of patients:



7 patients, 13 fields tot:

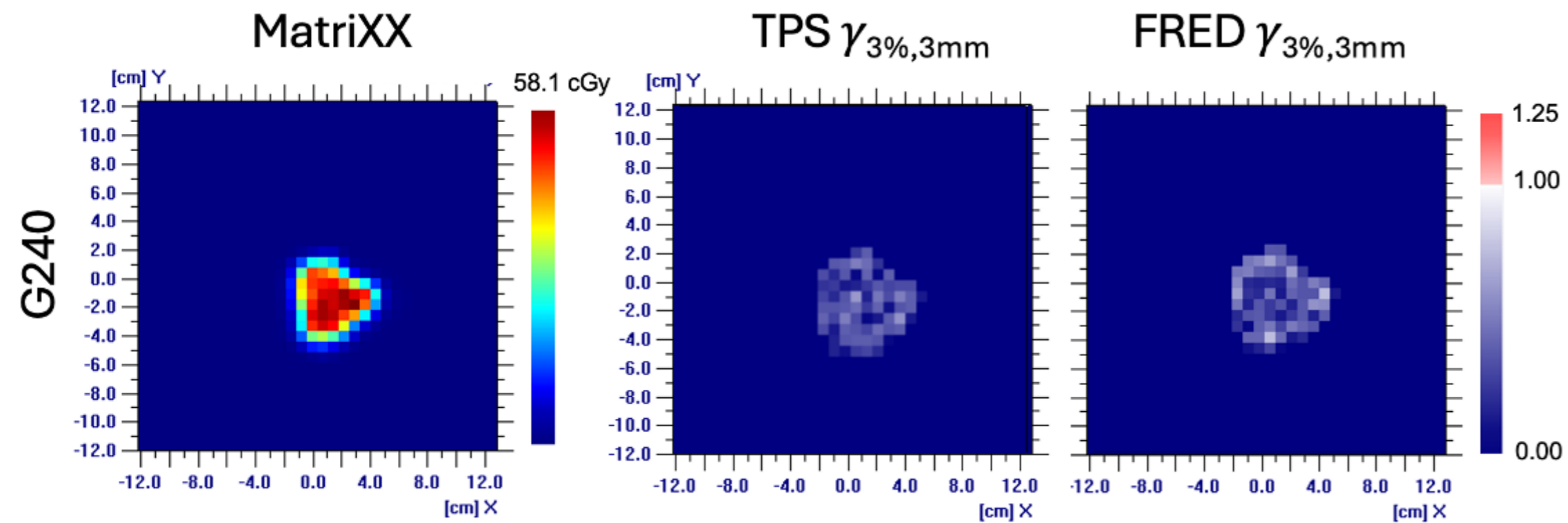
- Gamma 3%-3mm > 98%
- Sim. times < 2h

1) Commissioning of a Fast MC code for proton plan recalculation

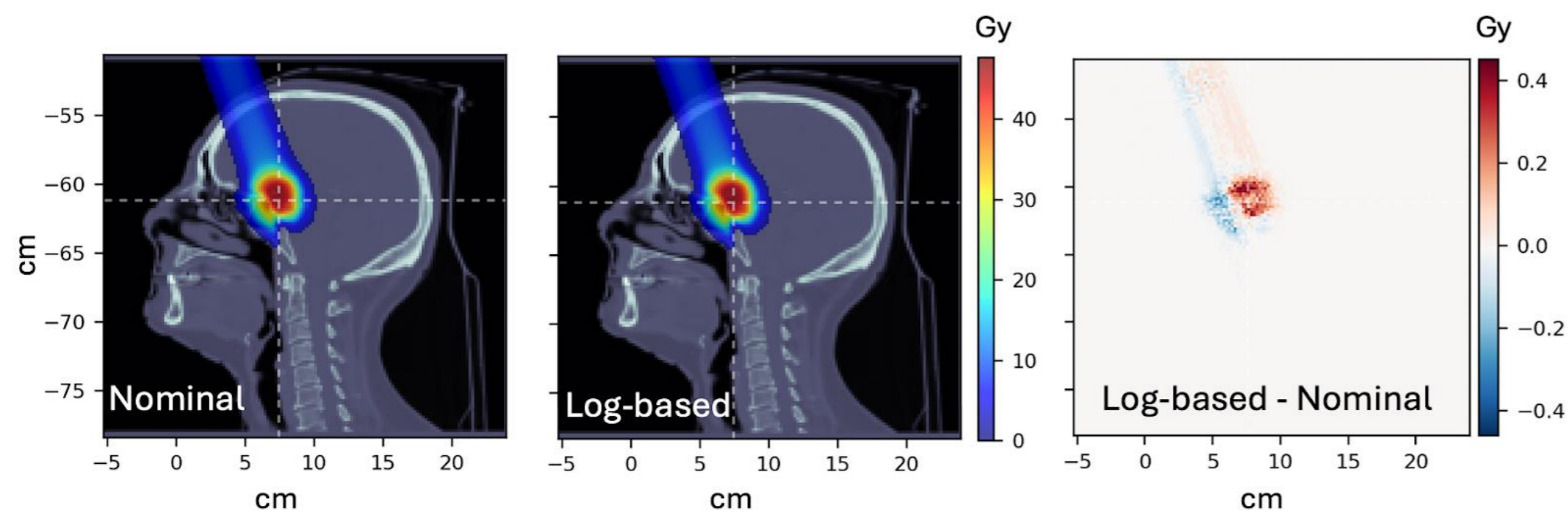


FLASH Radiotherapy with high
Dose-rate particle beams

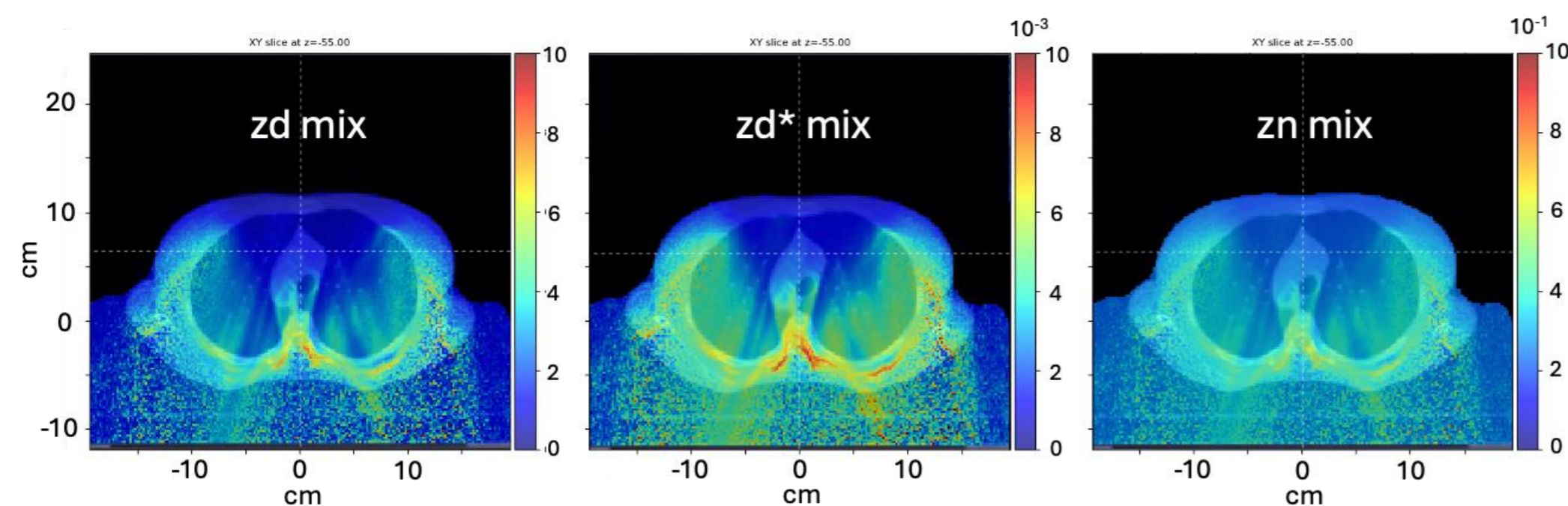
Independent MC tool for several applications:



Patient-Specific Quality Assurance



Simulation of **log-based** plans to assess
dose rate metrics



Simulate and assess **microdosimetric**
information for **RBE** evaluation

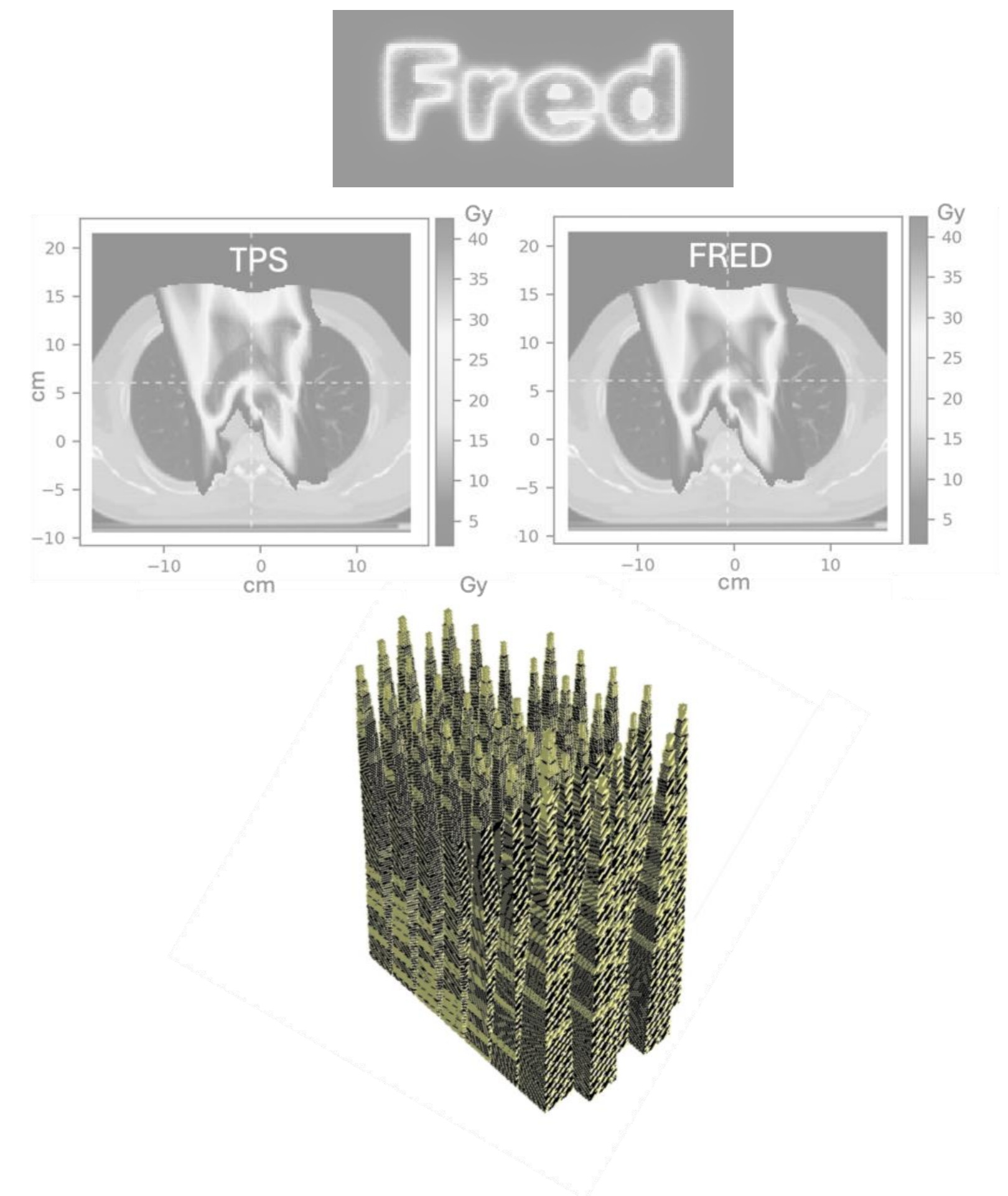
FRIDA WP4 at Trento:



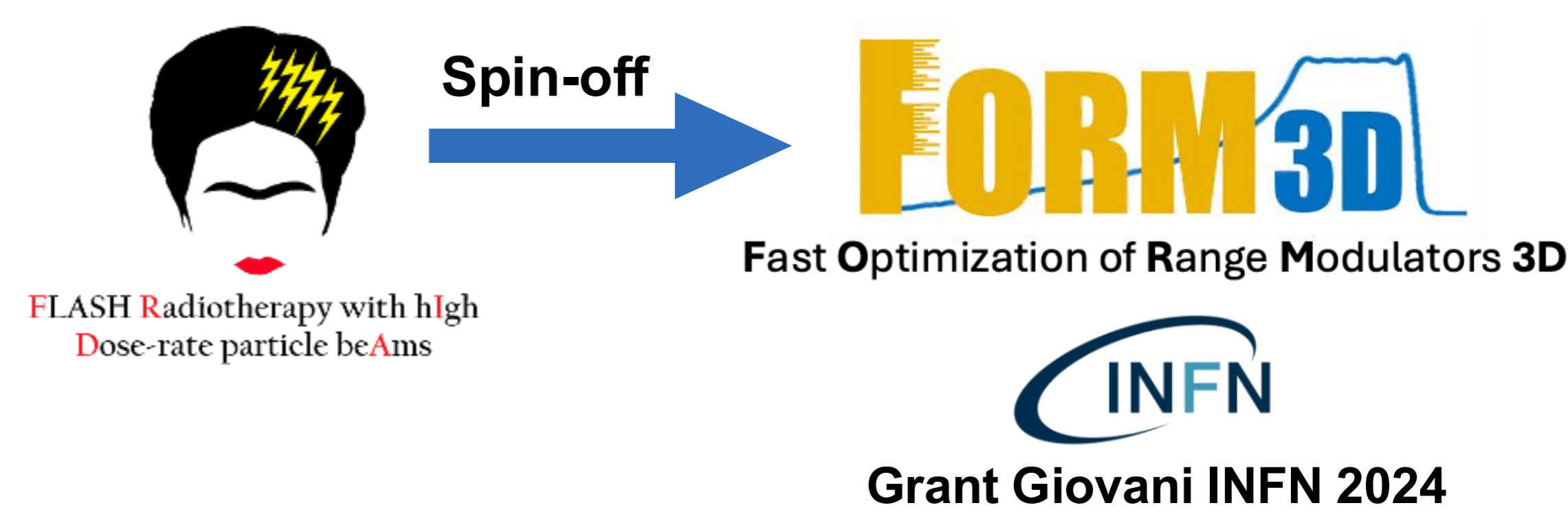
FLASH Radiotherapy with high
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1) Commissioning of a Fast Monte Carlo code for treatment plan recalculation (concluded)

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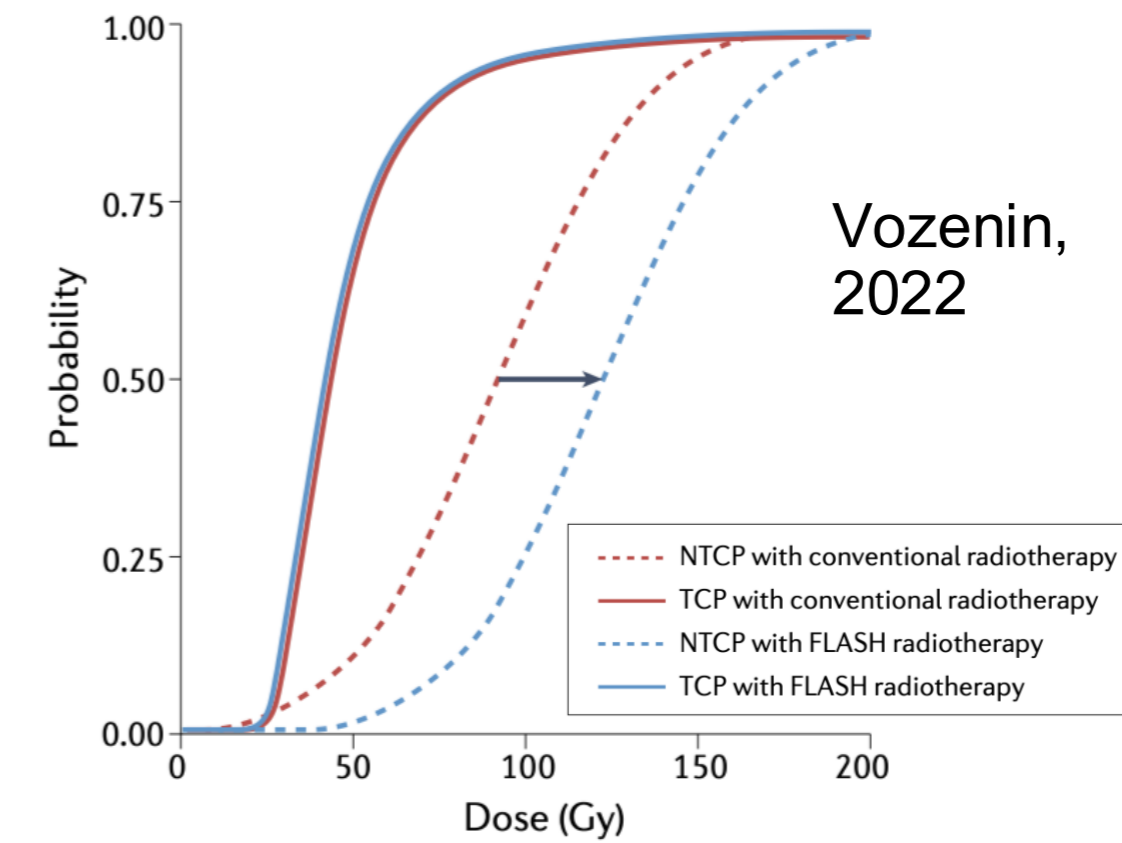
2) 3DRM for UHDR proton therapy



Why UHDR:

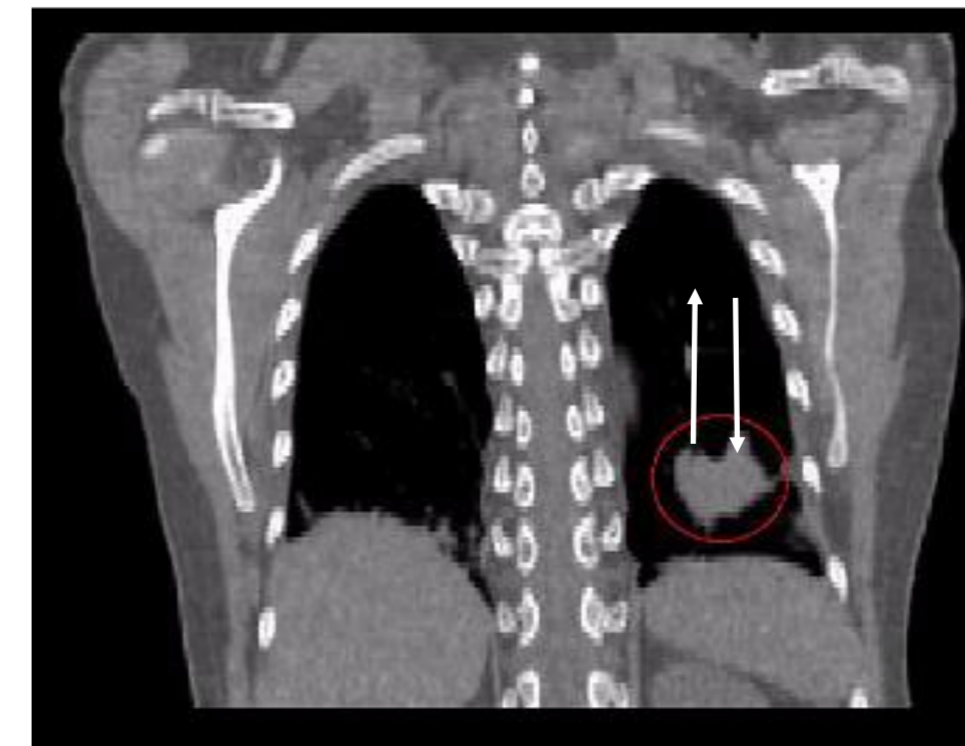
Reason 1: FLASH EFFECT

- In RT = increase the **therapeutic window**

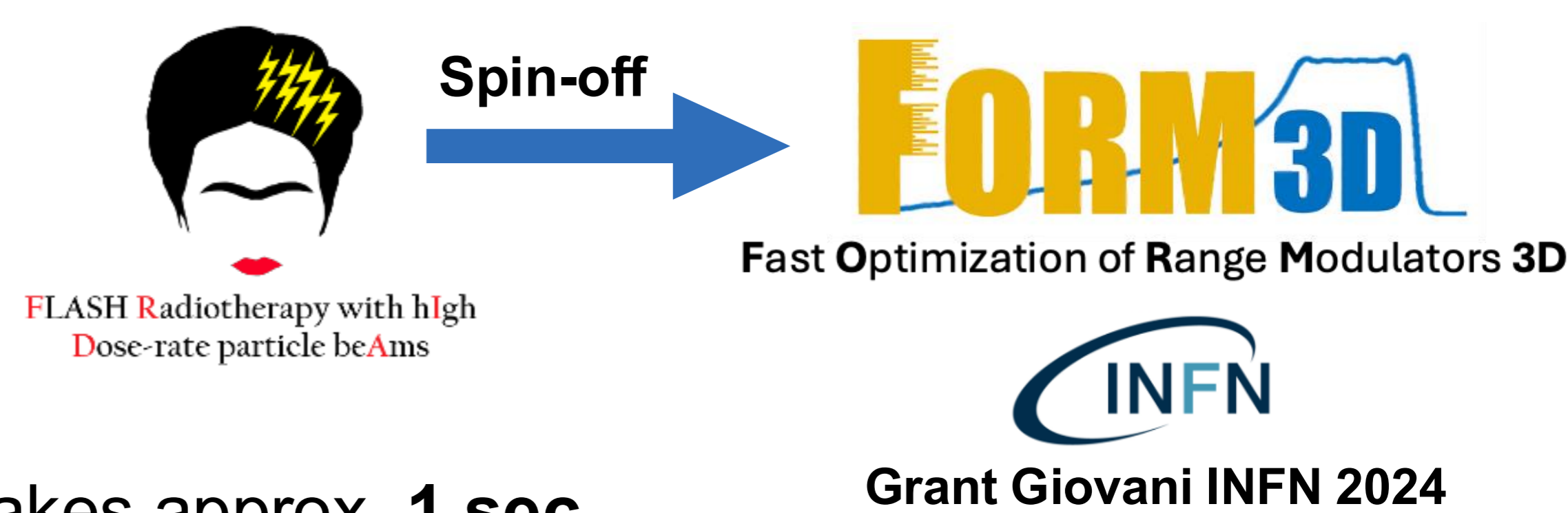


Reason 2: SPEED UP THE TREATMENTS

- Organ motion mitigation (ms treatment)



2) 3DRM for UHDR proton therapy

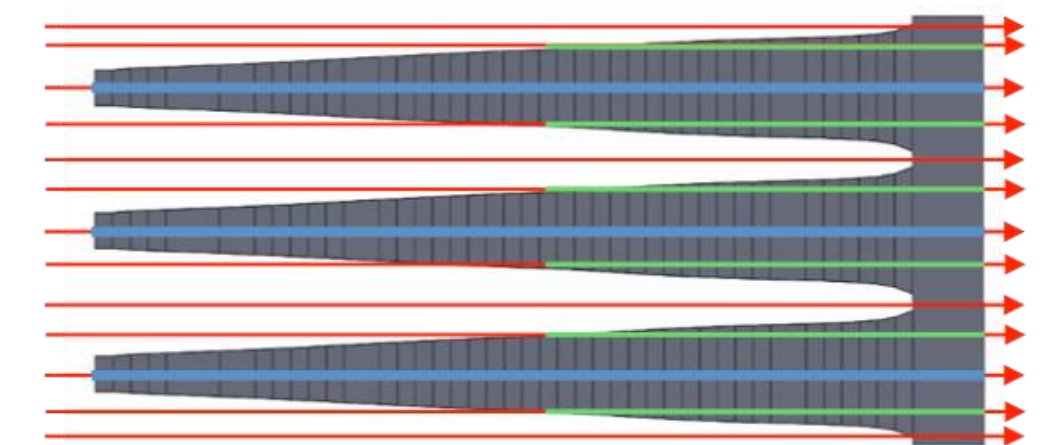
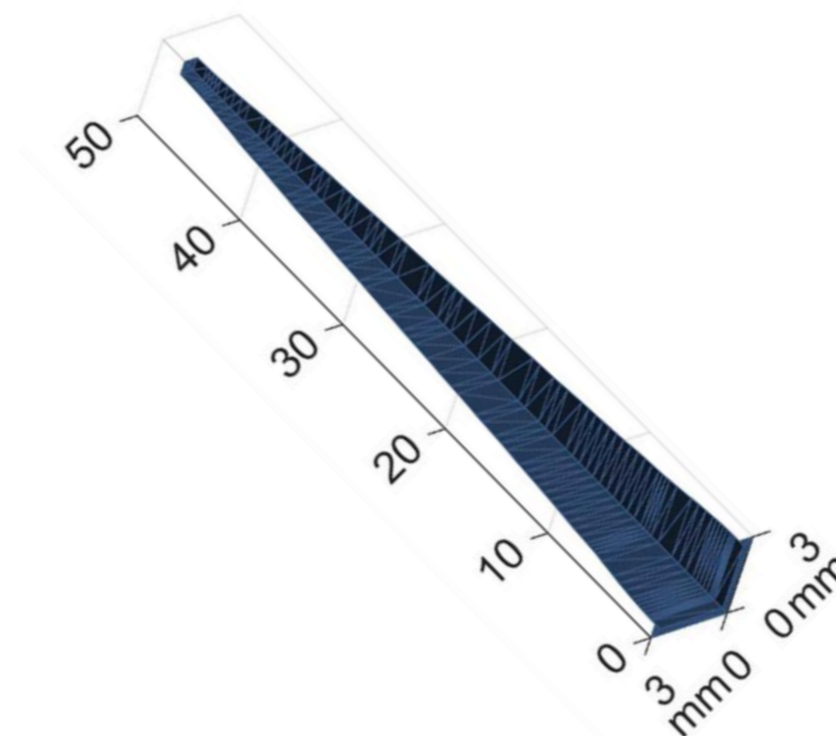
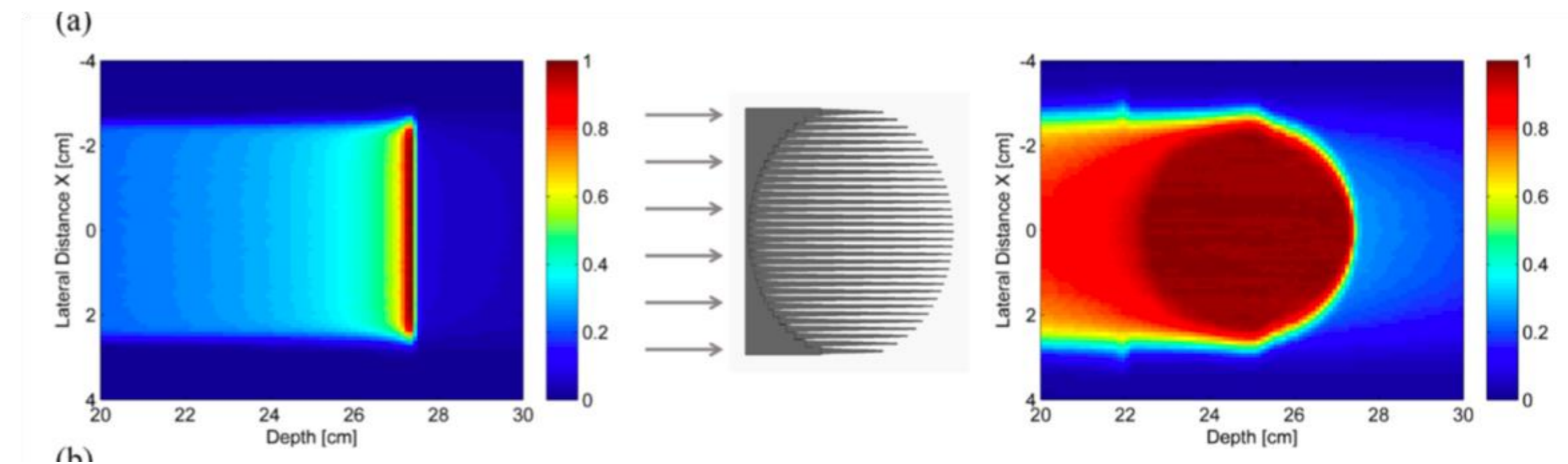


Main problem with UHDR: Cyclotron energy switching takes approx. **1 sec**

➔ We cannot achieve high dose rates and the overall **FLASH effect is lost**

Solution: Passive energy modulation

- Hedgehog or 3D range modulator
- Pins are used to passively modulate the proton energy
- Optimize the pins to reproduce the objective dose distribution



2) 3DRM for UHDR proton therapy



FLASH Radiotherapy with high
Dose-rate particle beams

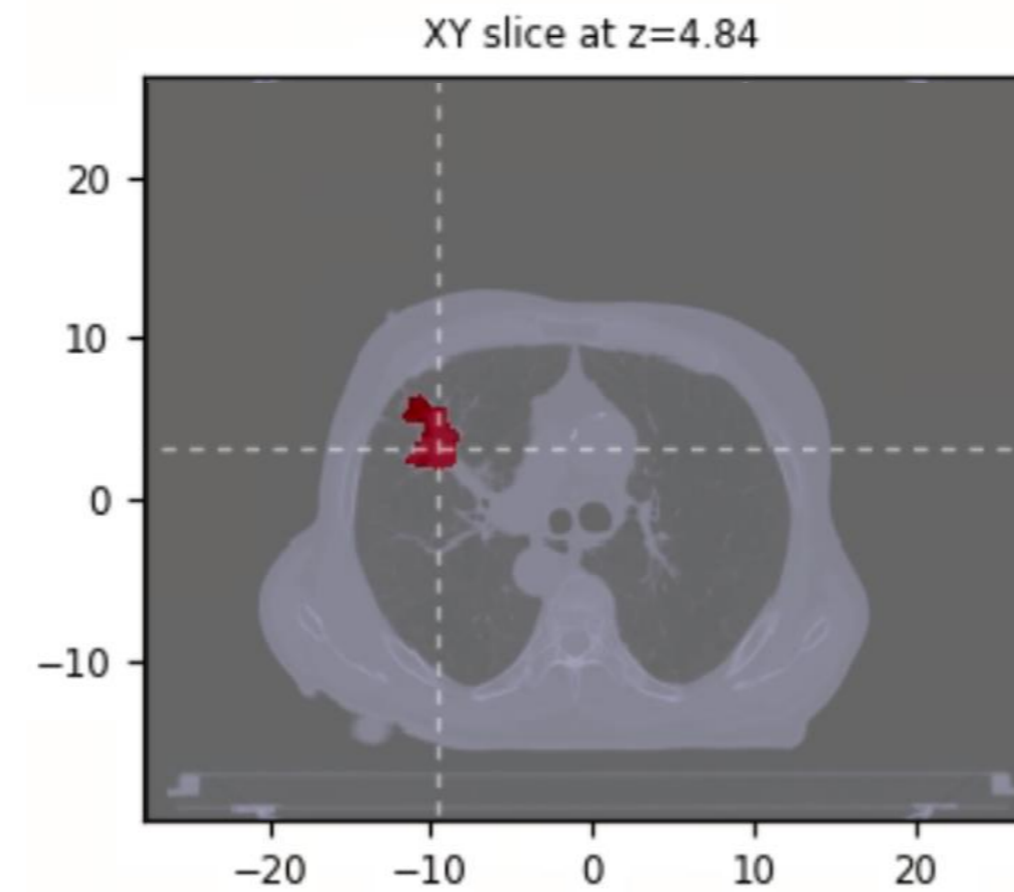


Fast Optimization of Range Modulators 3D

Clinical cases:

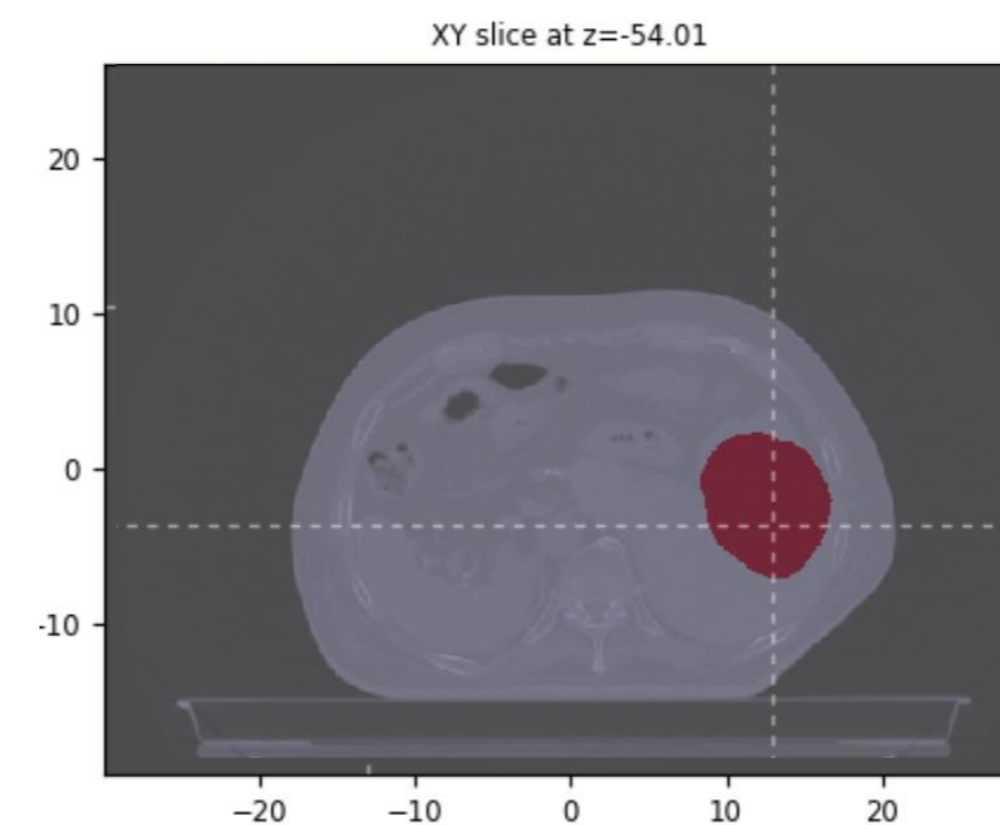
Case1: Lung Cancer

- Small volume
- Heterogeneous medium



Case2: Liver Cancer (ongoing)

- Large volume
- Homogeneous medium



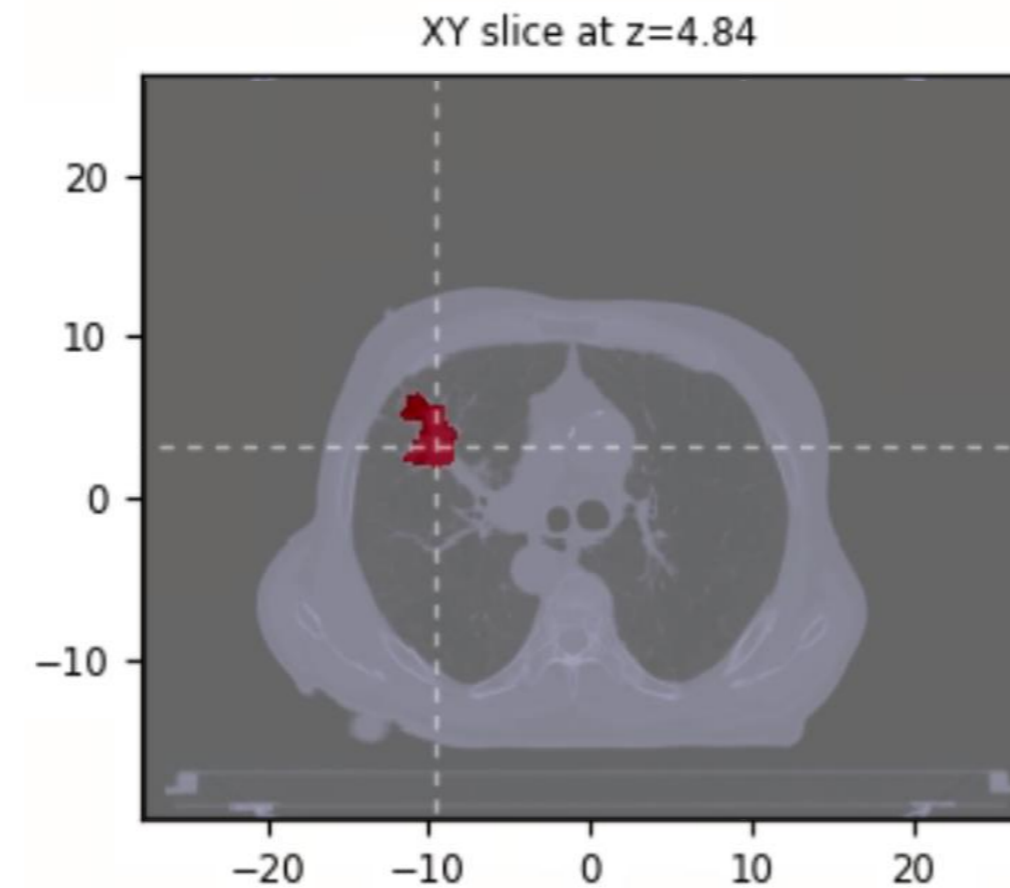
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Provincia Autonoma di Trento*

2) 3DRM for UHDR proton therapy



Case1: Lung Cancer

- Small volume
- Heterogeneous medium



1 Single field considered

Active case:

- Energy: 106.0-142.2 MeV
- Npb = 54
- Range shifter



Passive case:

- Only max energy 142.2 MeV
- Npb = 36
- Range shifter

2) 3DRM for UHDR proton therapy



FLASH Radiotherapy with High Dose-rate particle beams

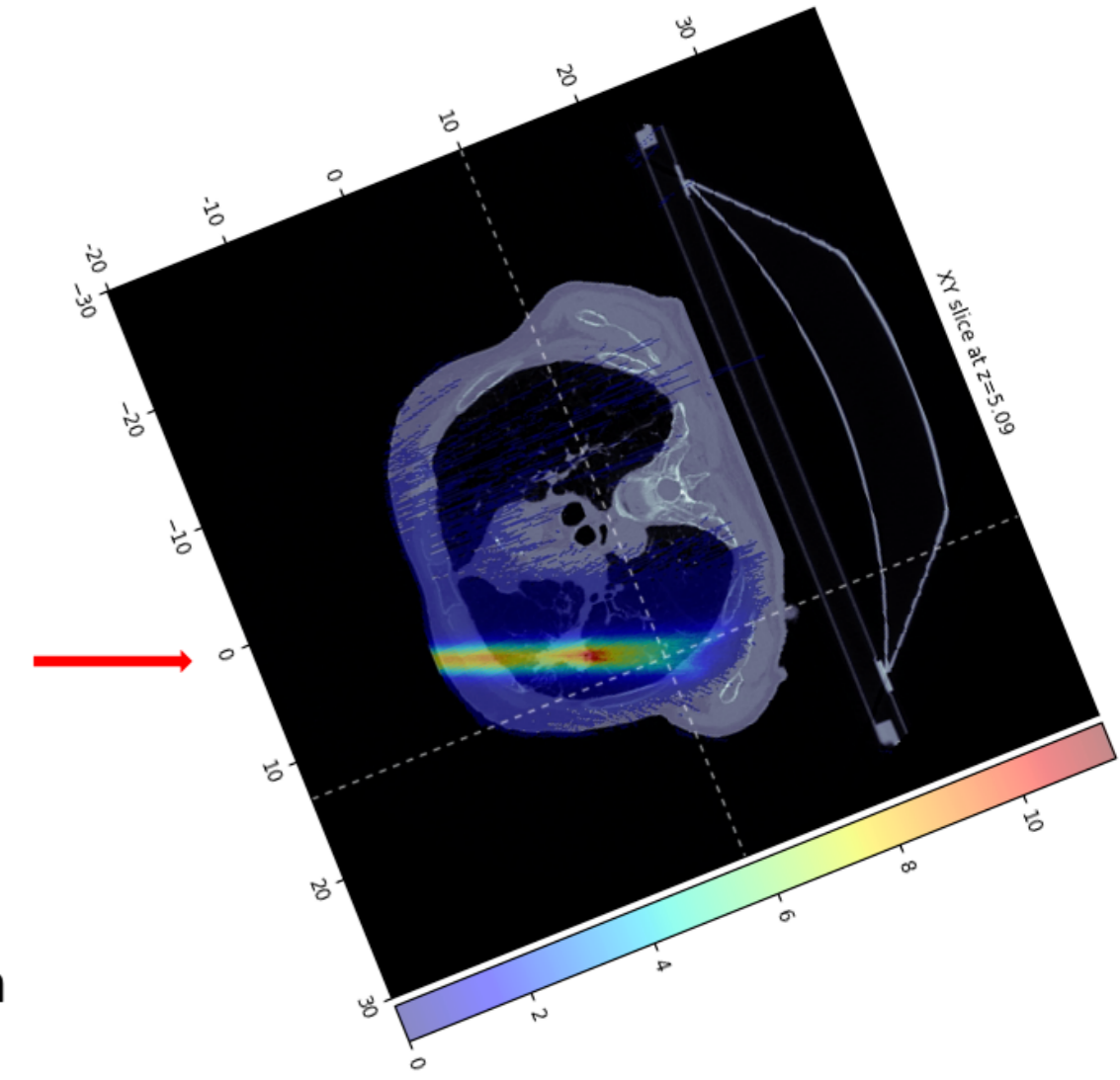
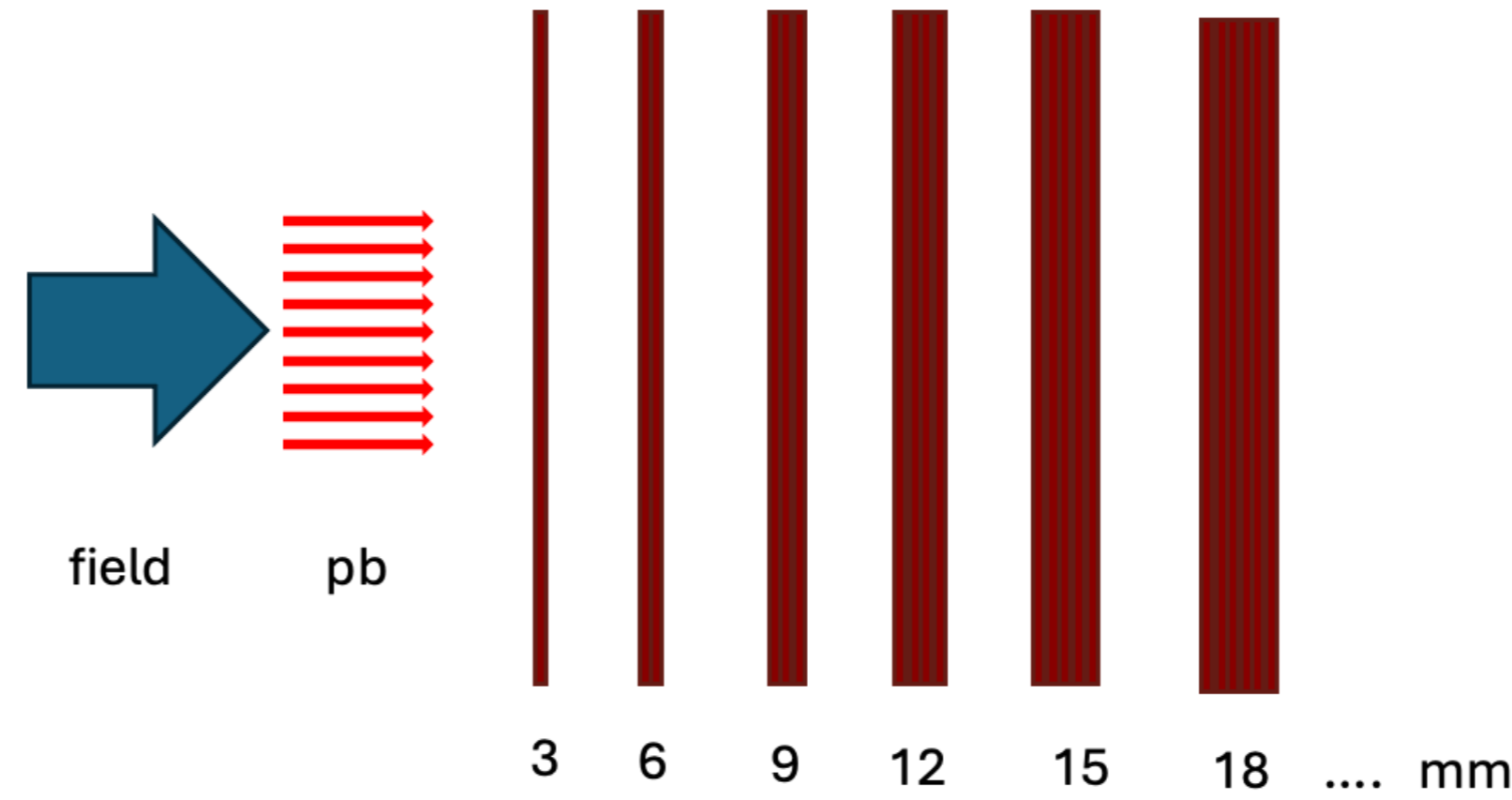


Fast Optimization of Range Modulators 3D

Case1: Lung Cancer

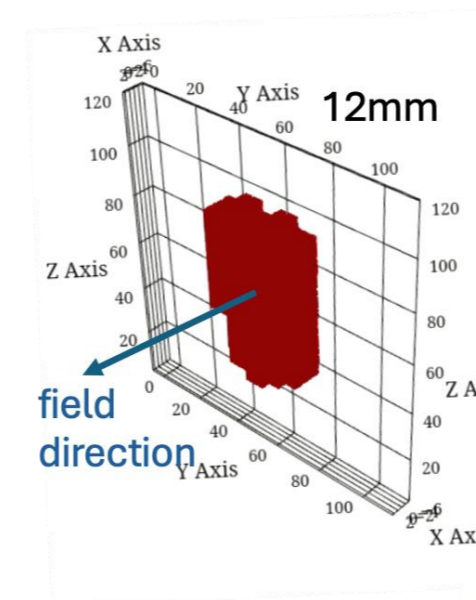
- Creation of Look Up Tables (LUTs) of dose distributions with **Fred**
- Opposed to standard analytical methods

for each pb we simulate with FRED a dose map for increasing thickness of the attenuator



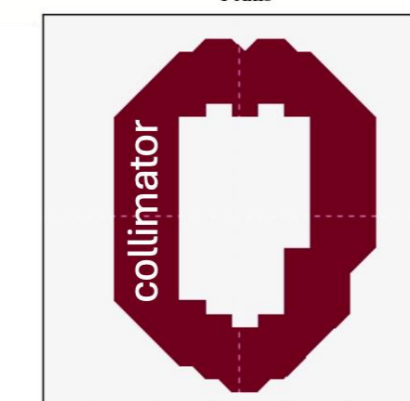
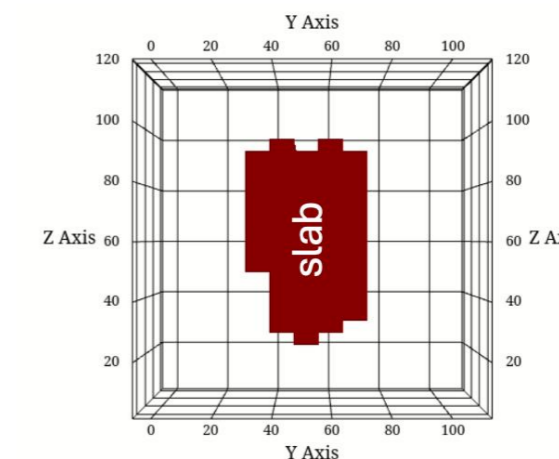
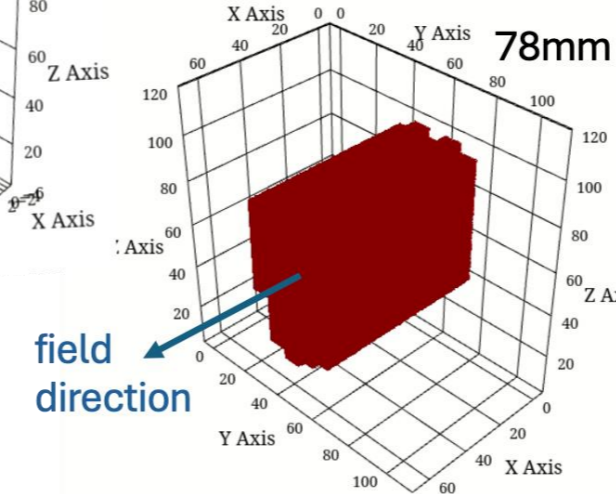
attenuator

Dose map for #pb and #thickness



the slab of the attenuator is shaped as the modulator

a collimator 2cm large is considered around the slab



computational time for the production of all the LUT: 20 minutes

2) 3DRM for UHDR proton therapy



Case1: Lung Cancer

- Optimization of the pb fluence associated to the thickness

Constraints: ITV and Ring

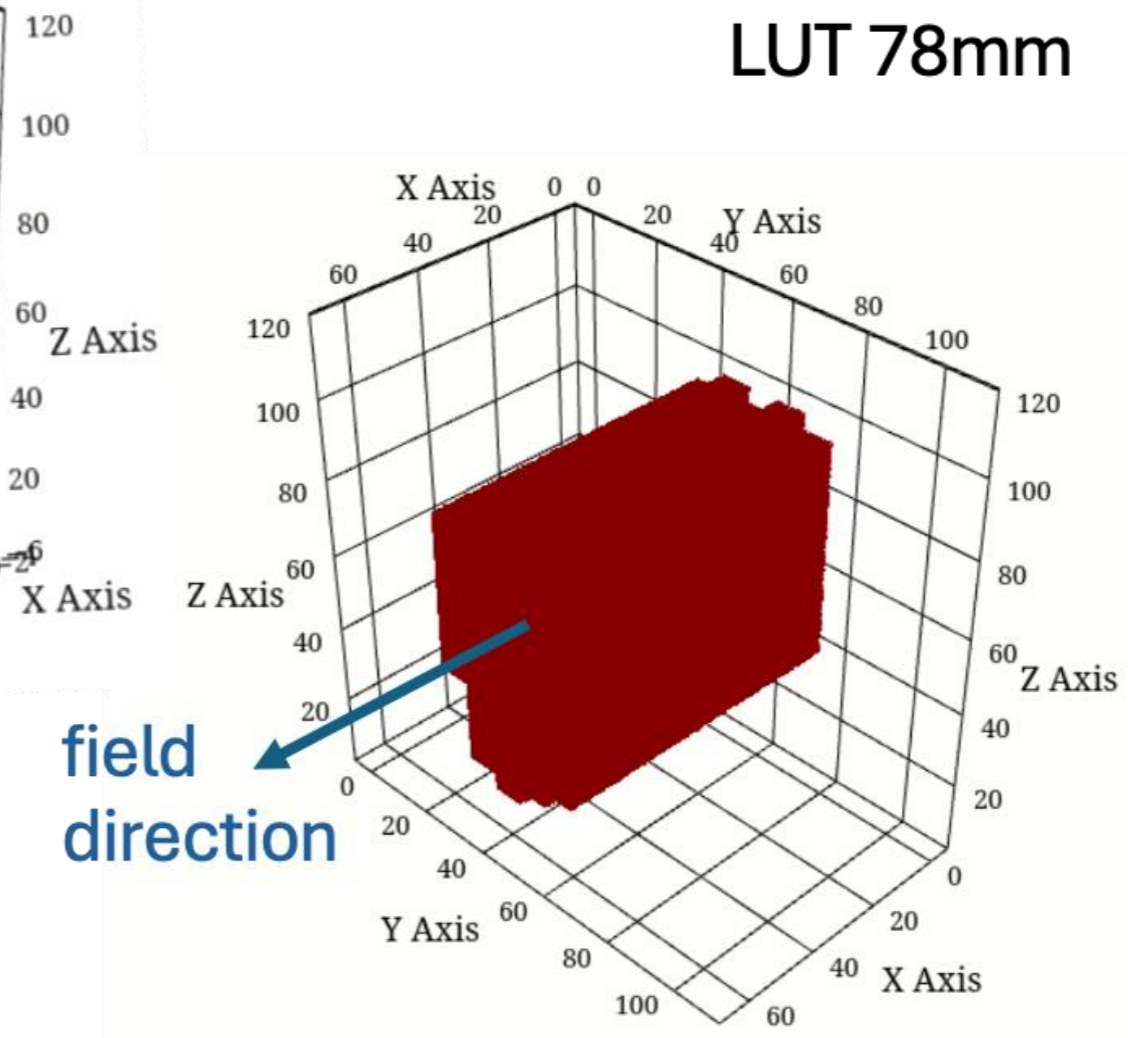
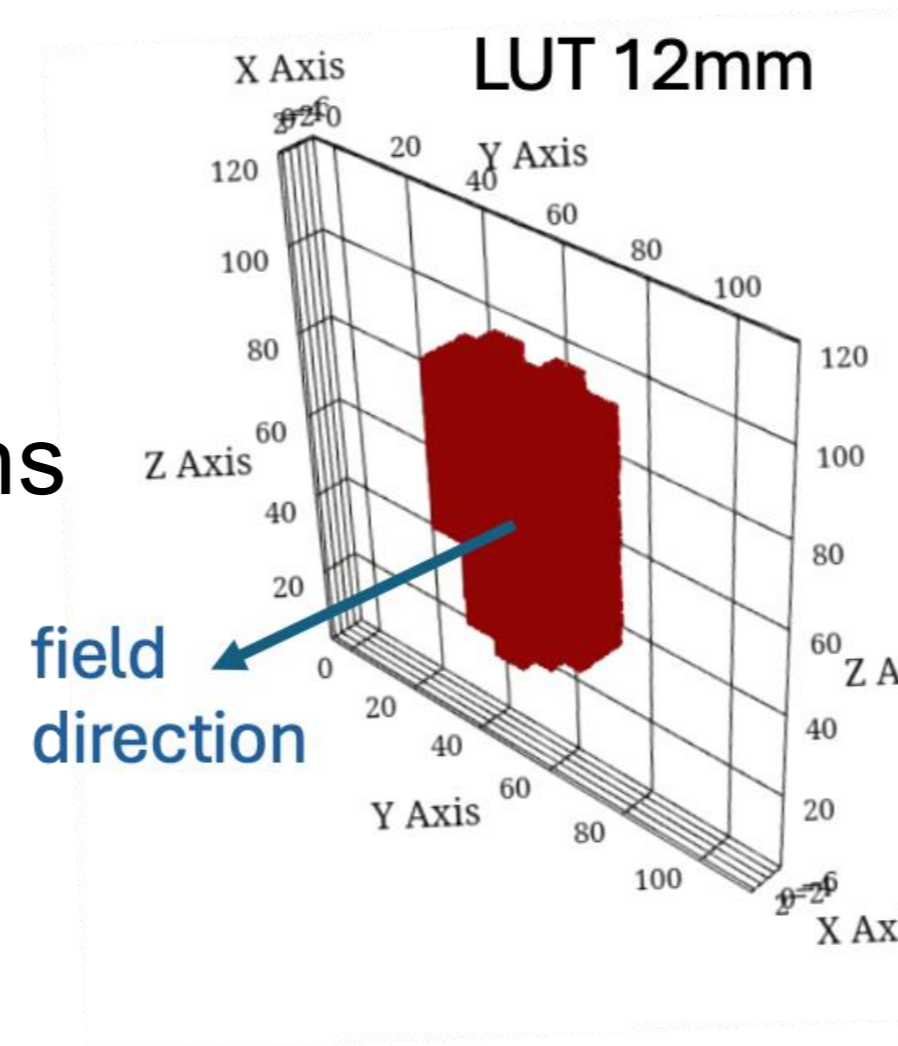
ITV target dose: 62Gy

Ring: max dose 52Gy (to 70% volume)

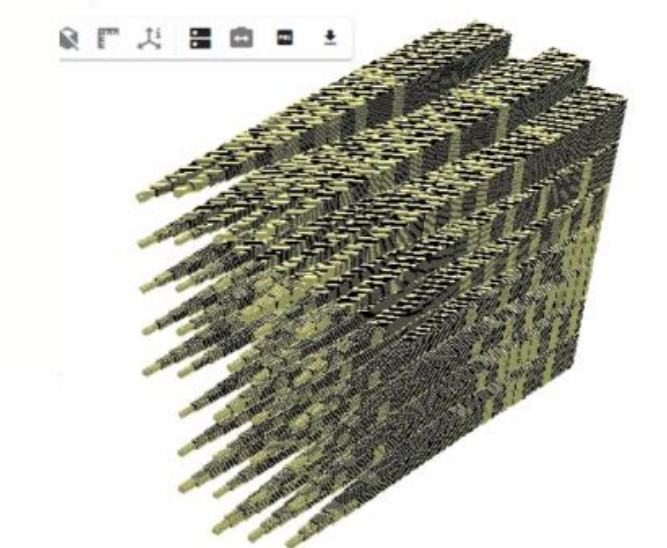
- Conversion of optimized weights into pin lengths

pb	mm	weight	pin length (res 0.1mm)
1	0.0	2.369	0.80 cm
1	3.0	2.318	0.79 cm
1	6.0	2.430	0.77 cm
1	9.0	2.390	0.75 cm
1	12.0	2.448	0.74 cm
1	15.0	2.560	0.72 cm
...
2	0.0
...

New LUTs



Optimized 3DRM shape



Thanks to P. Aklaghi

2) 3DRM for UHDR proton therapy



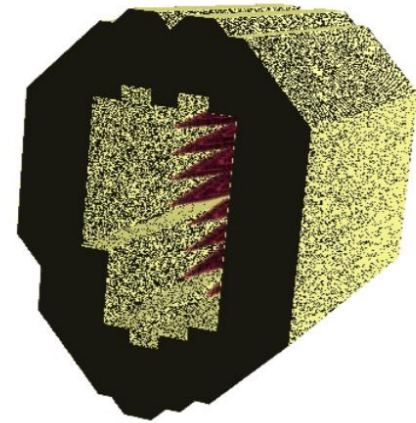
FLASH Radiotherapy with high
Dose-rate particle beams



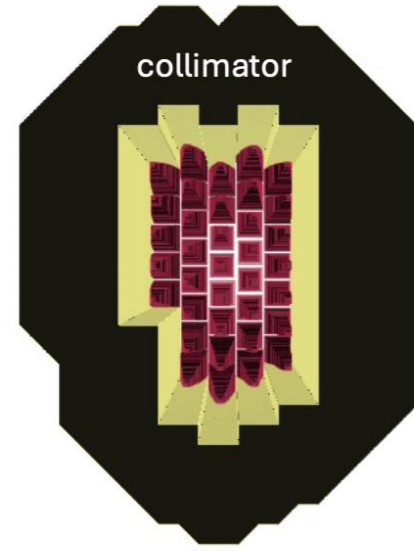
Fast Optimization of Range Modulators 3D

Case1: Lung Cancer

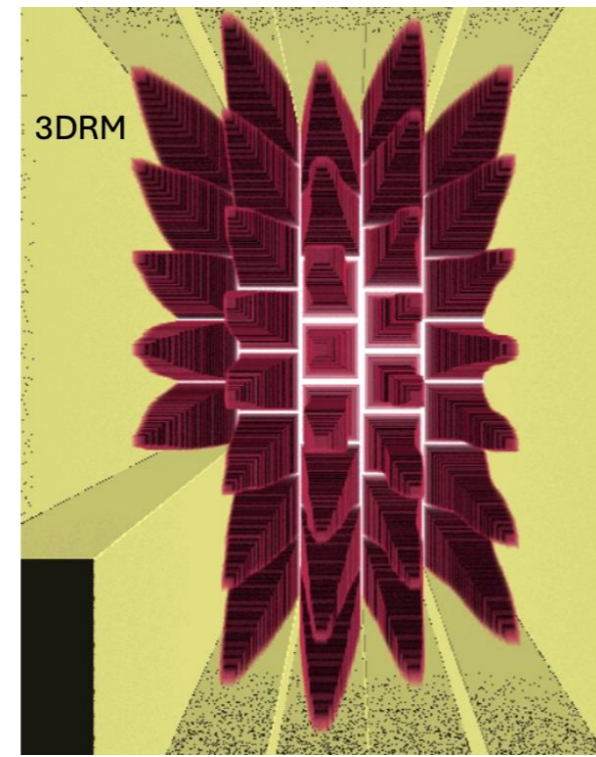
collimator + 3DRM



collimator

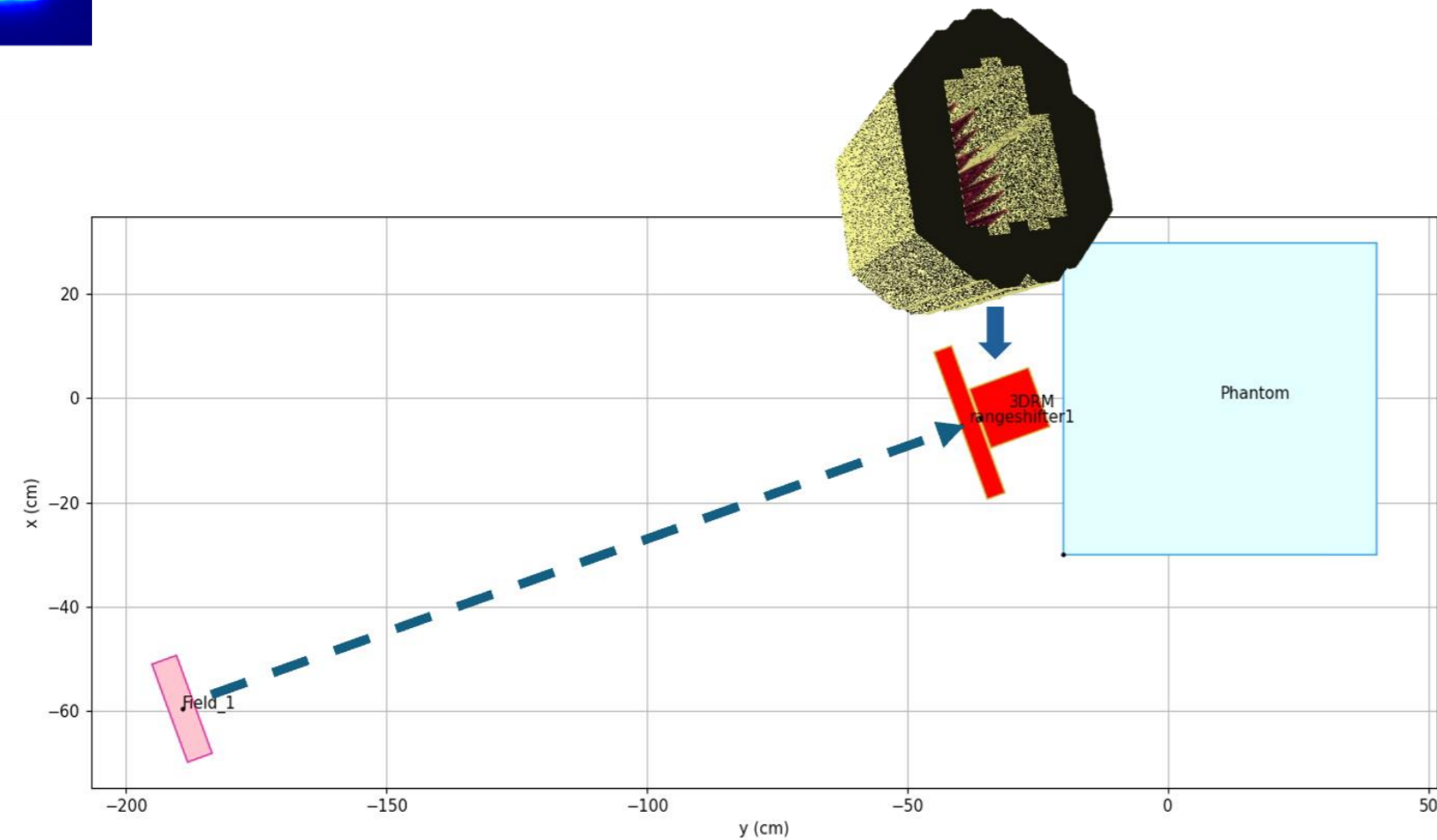


3DRM

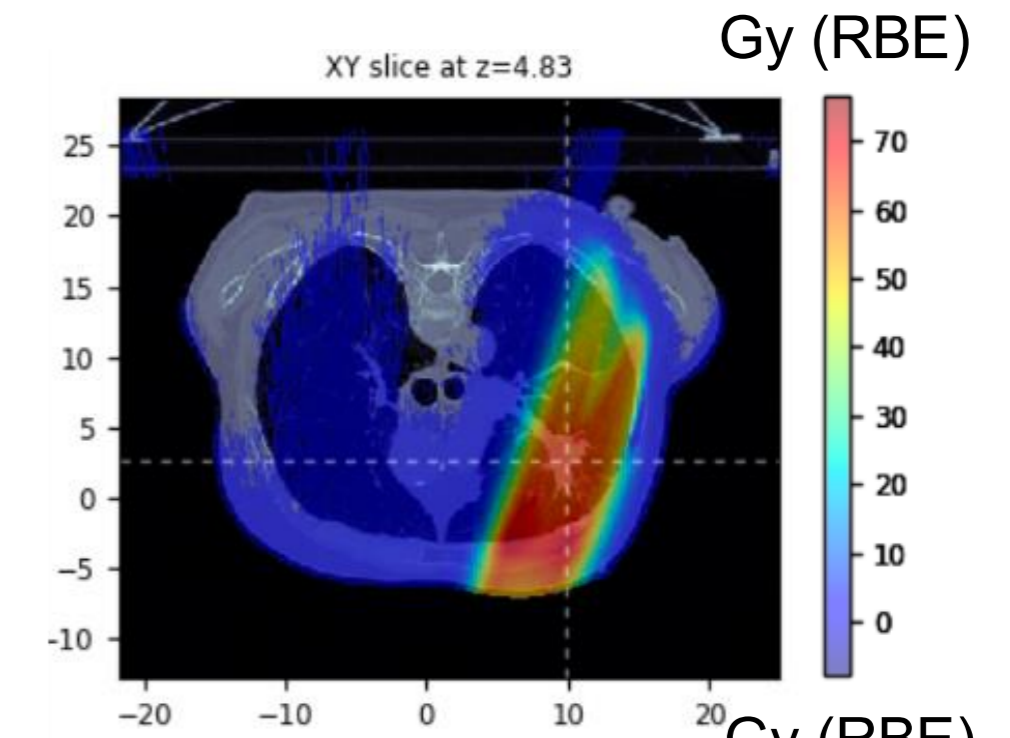


Fred

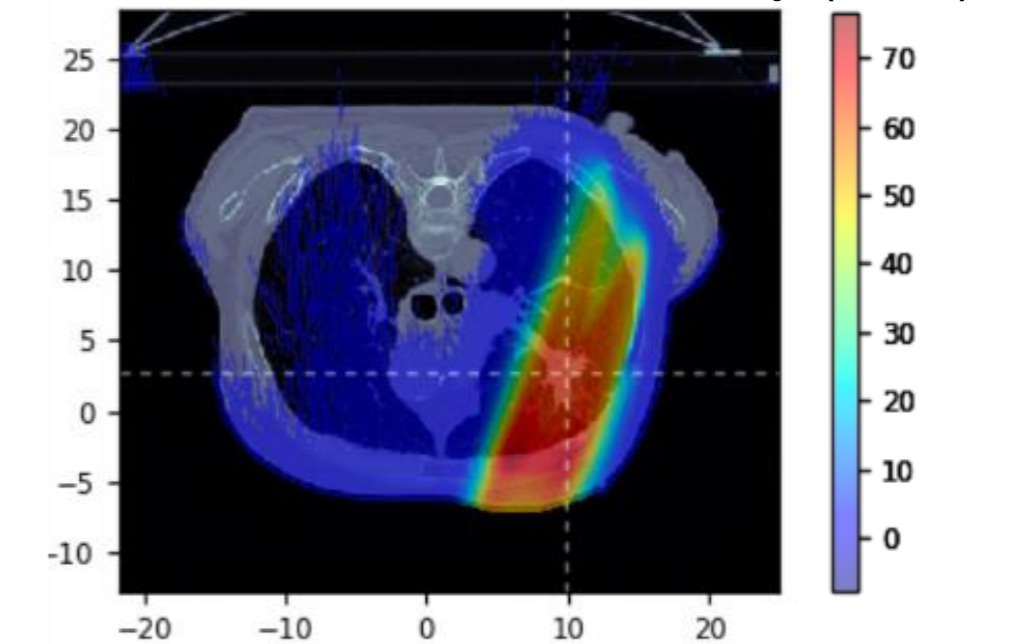
simulation with the derived 3DRM



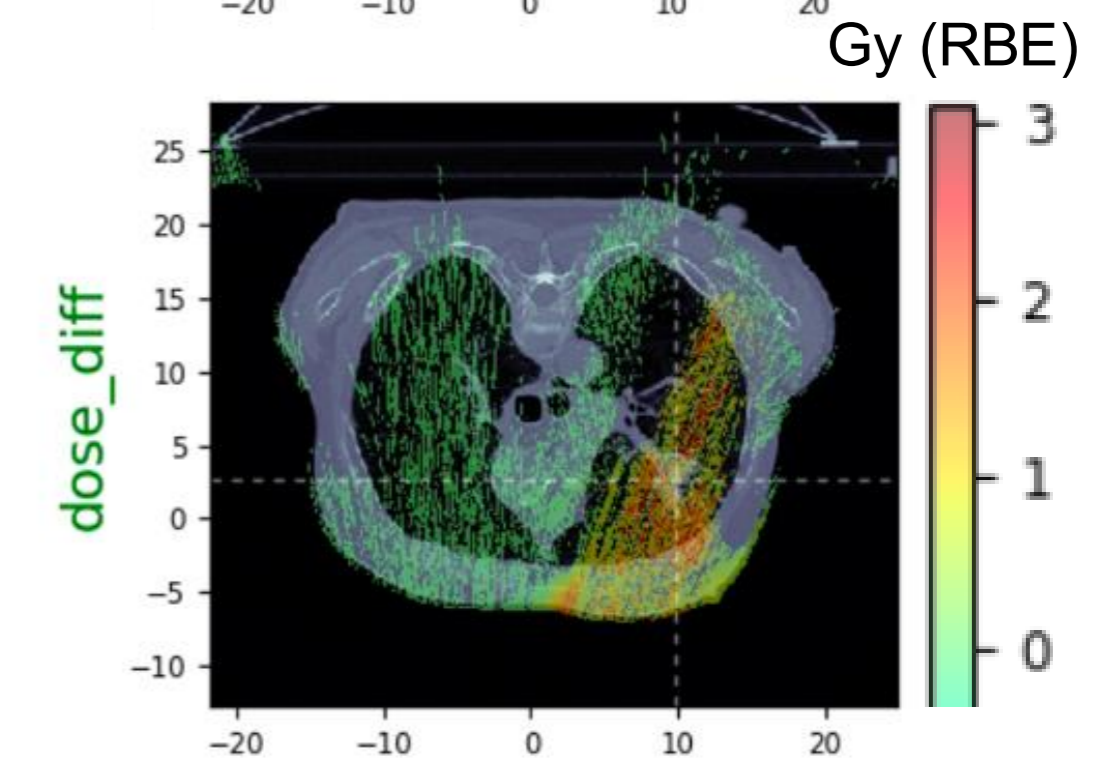
Optimal dose



3DRM dose



3DRM - Optimal



2) 3DRM for UHDR proton therapy



FLASH Radiotherapy with High
Dose-rate particle beams



Fast Optimization of Range Modulators 3D

Case1: Lung Cancer

Comparison with the active case:

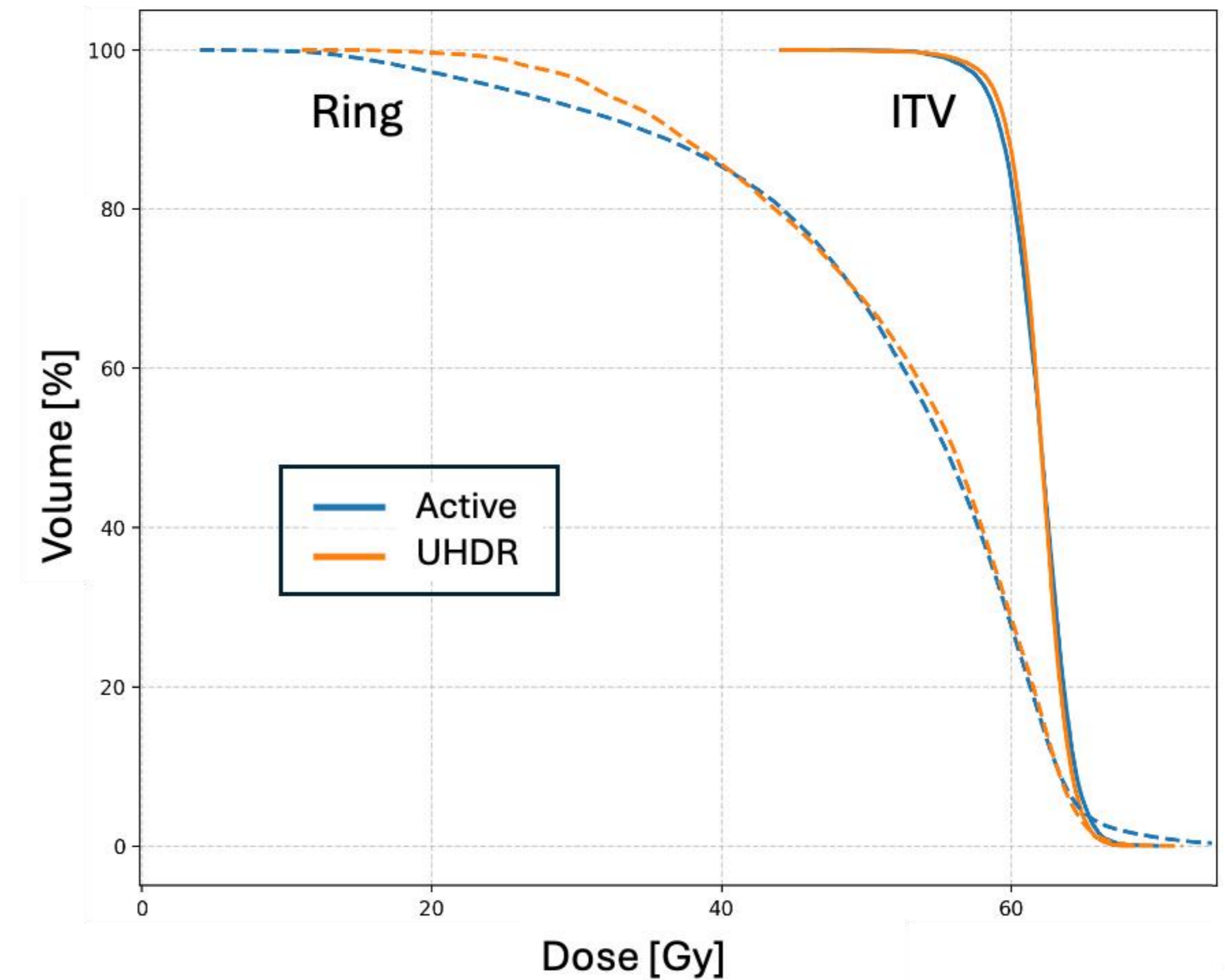
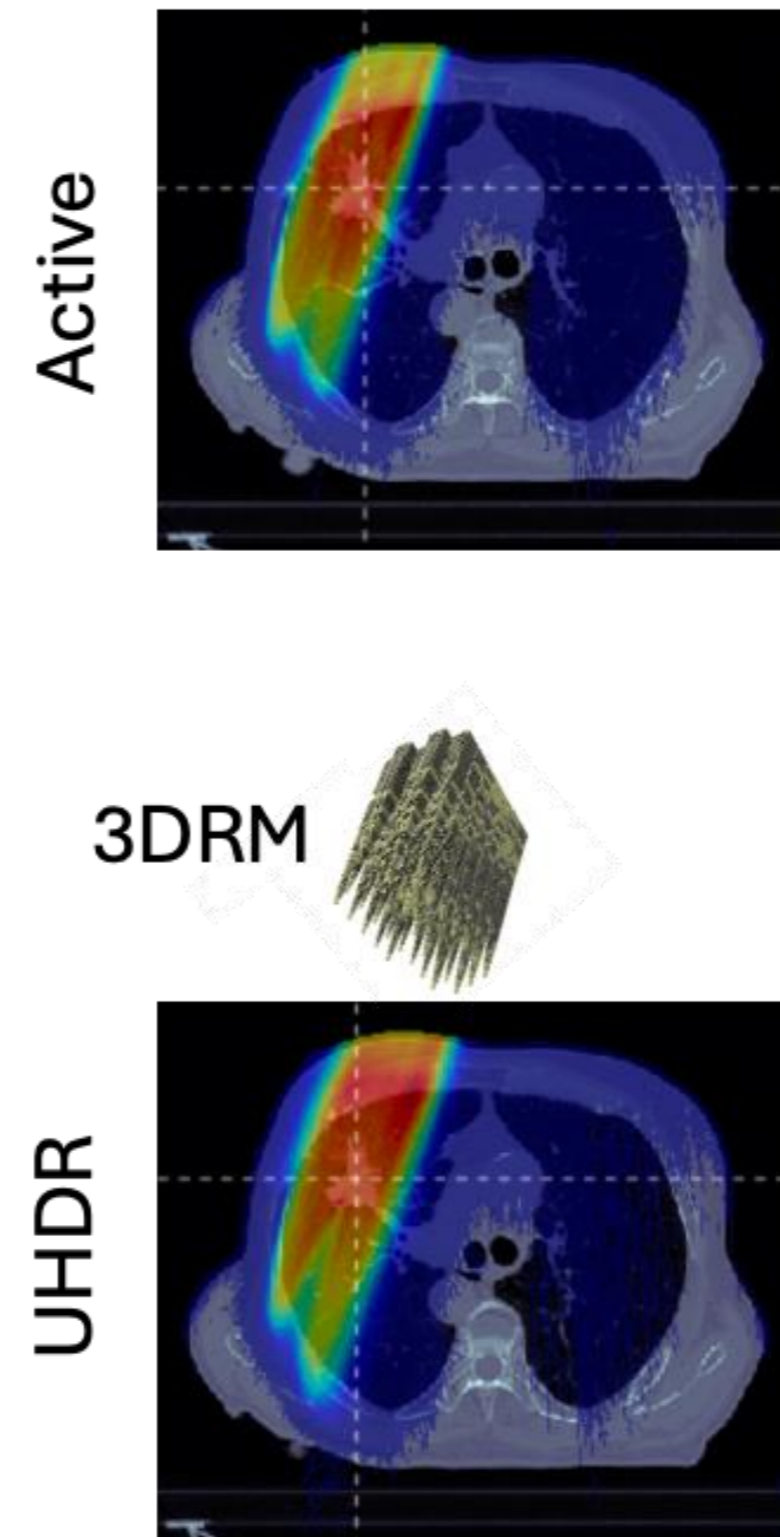


Fig.1: Dose distribution for the active plan and passive (UHDR) plan (left), and corresponding DVHs for the ITV and Ring structures (right).

2) 3DRM for UHDR proton therapy



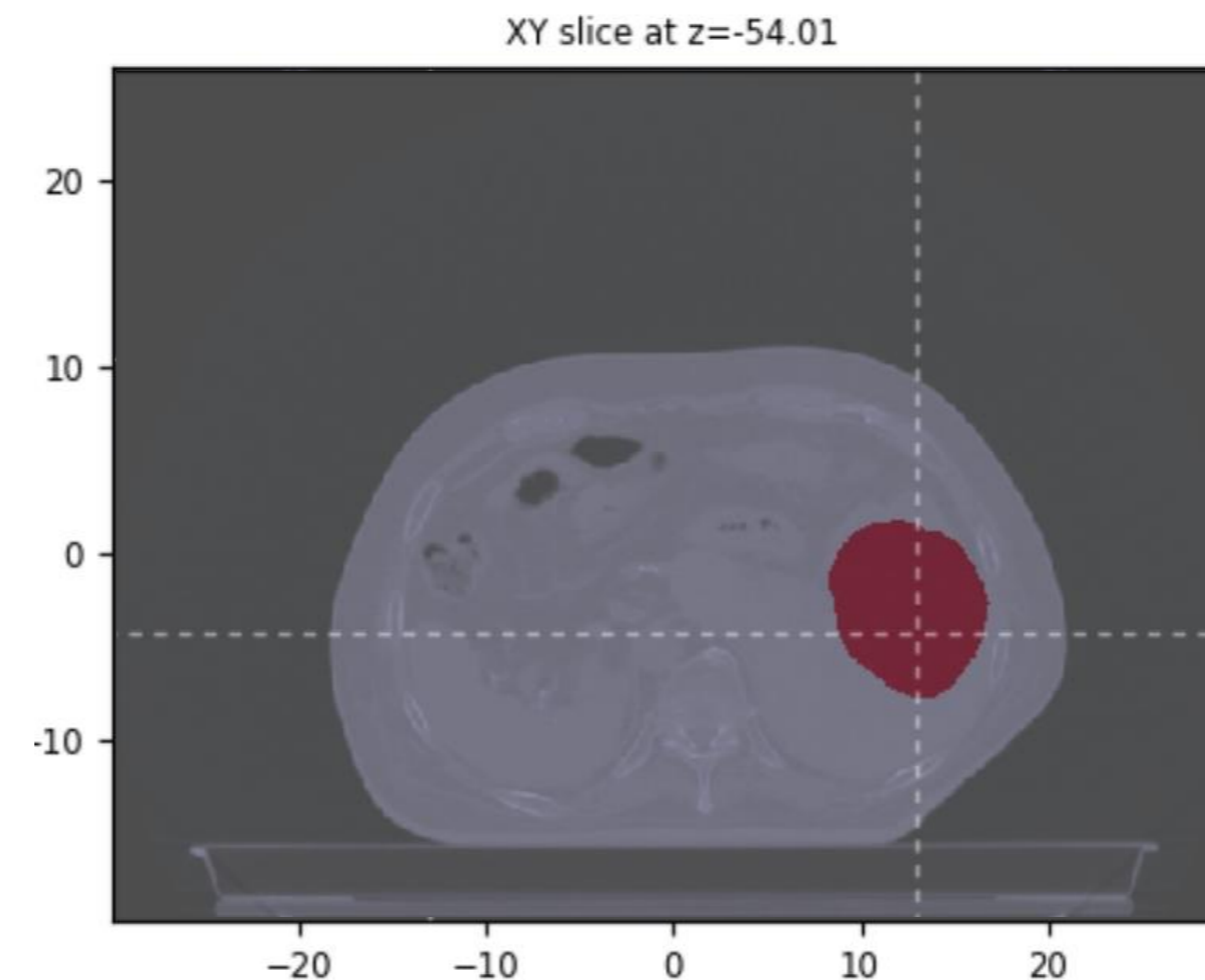
FLASH Radiotherapy with high
Dose-rate particle beams



Fast Optimization of Range Modulators 3D

Case2: **Liver Cancer**

- Large volume
- Homogeneous medium



1 Single field considered

Active case:

- Energy: 70.0-146.1 MeV
- Npb = 5142
- No range shifter



Passive case:

- Only max energy 146.1 MeV
- Npb = 369
- No range shifter

2) 3DRM for UHDR proton therapy



FLASH Radiotherapy with High
Dose-rate particle beams



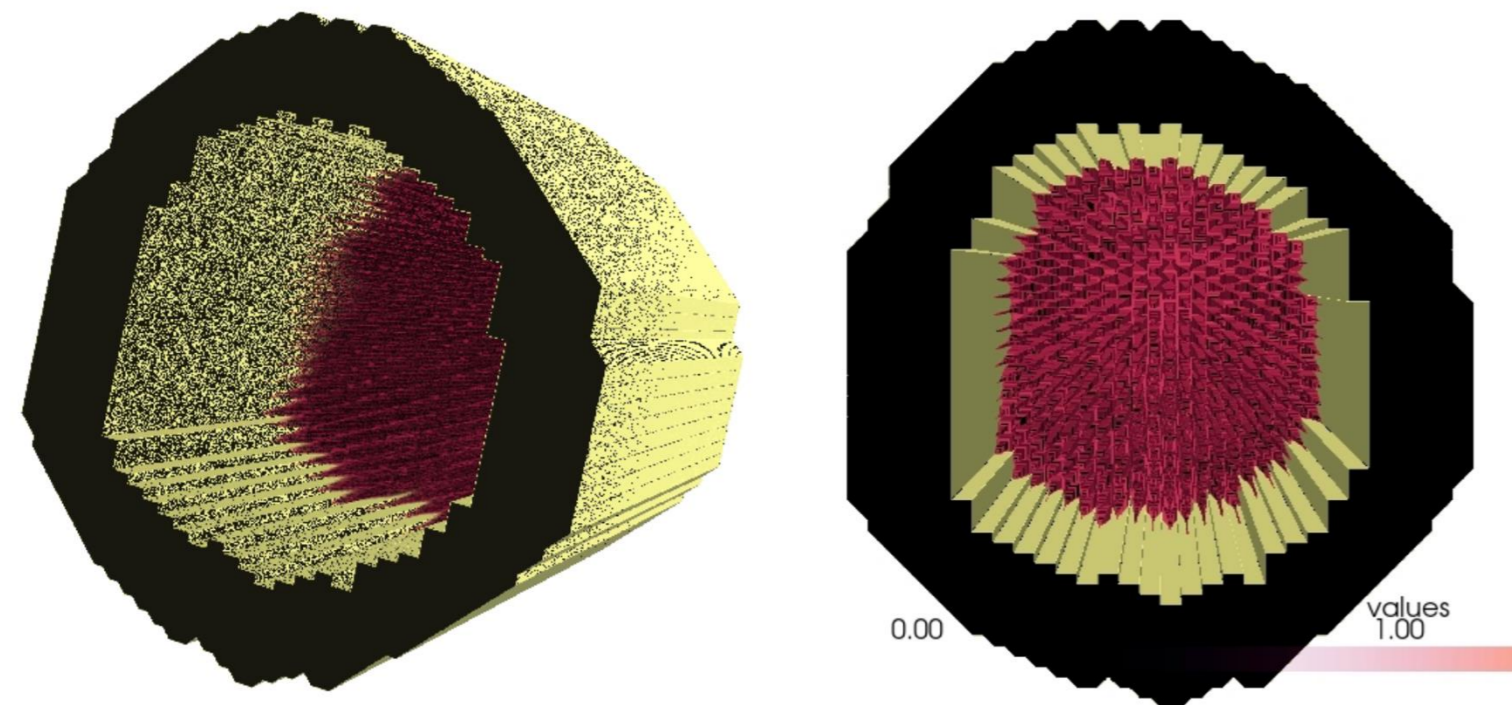
Fast Optimization of Range Modulators 3D

Case1: **Liver Cancer**

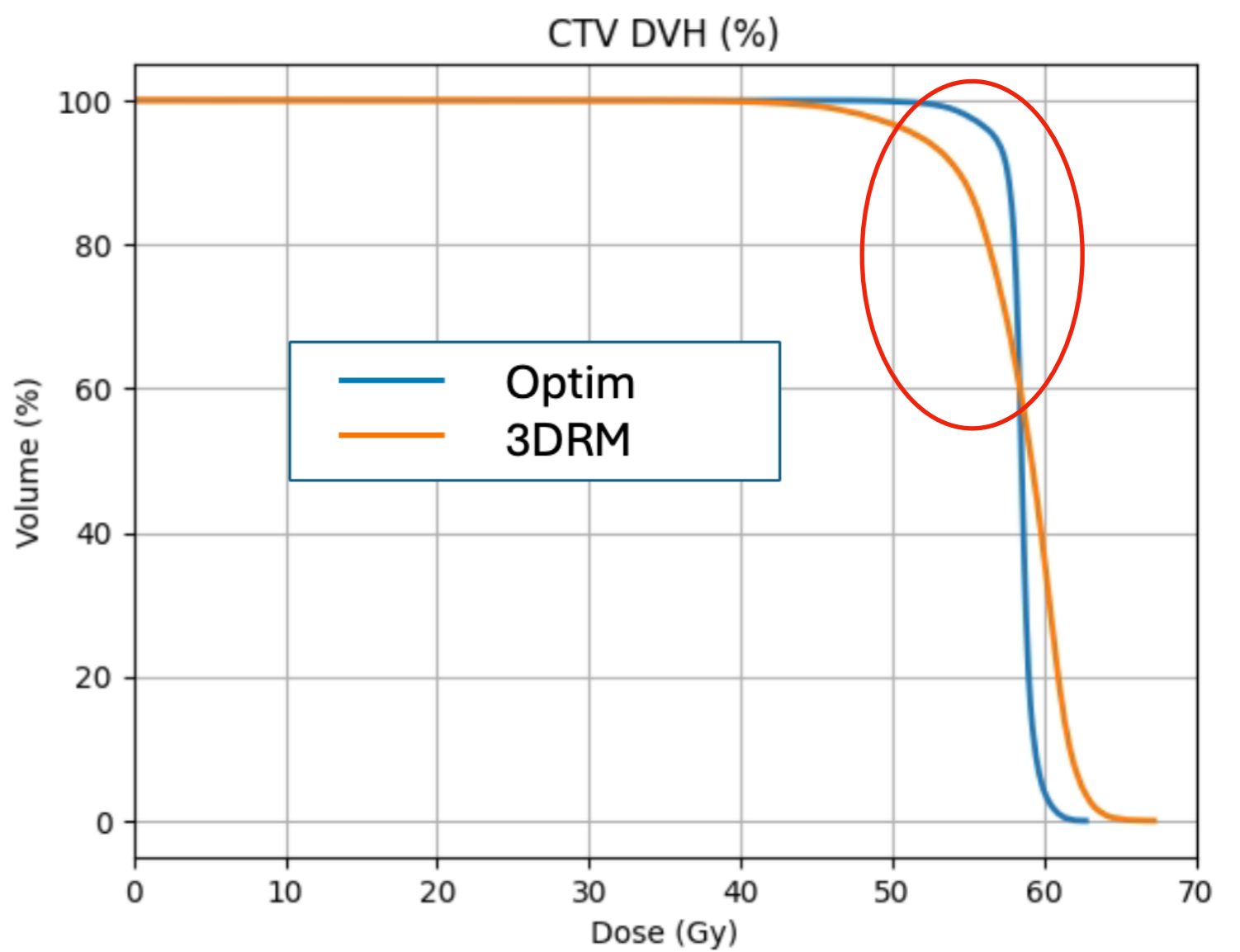
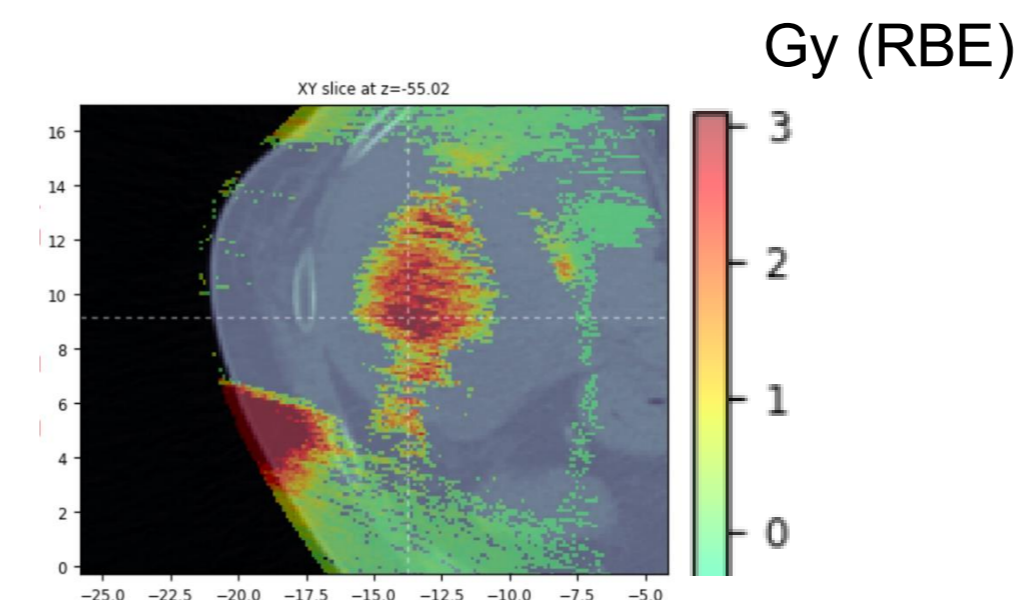
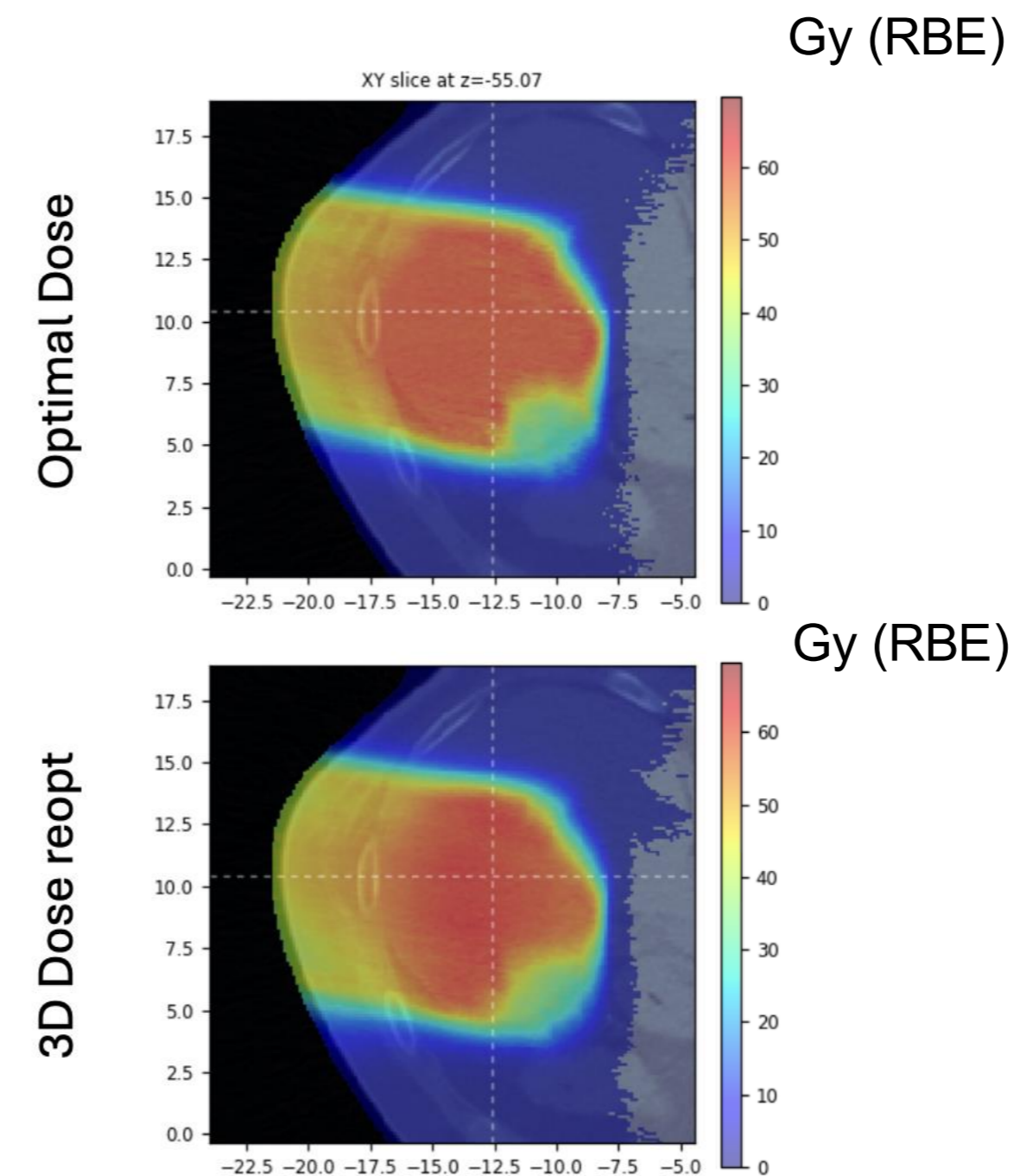
Constraints: CTV and Ring

CTV target dose: 62Gy

Ring max dose: 52Gy (to 70% volume)



4mm base pins



We lose conformity compared to the opt:

- Error in the simulation setup with the 3DRM?
- Implementation beam fluence in the opt algorithm
- Model the beam divergence

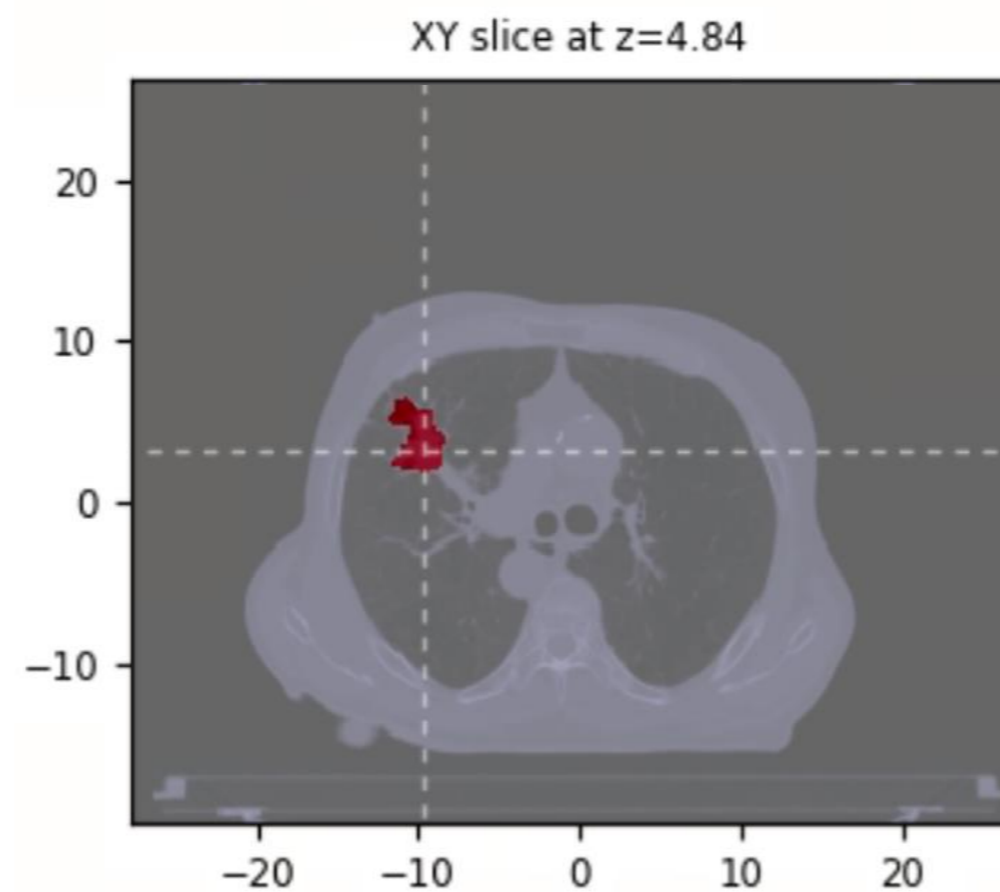
Next steps: Modelling



Clinical cases:

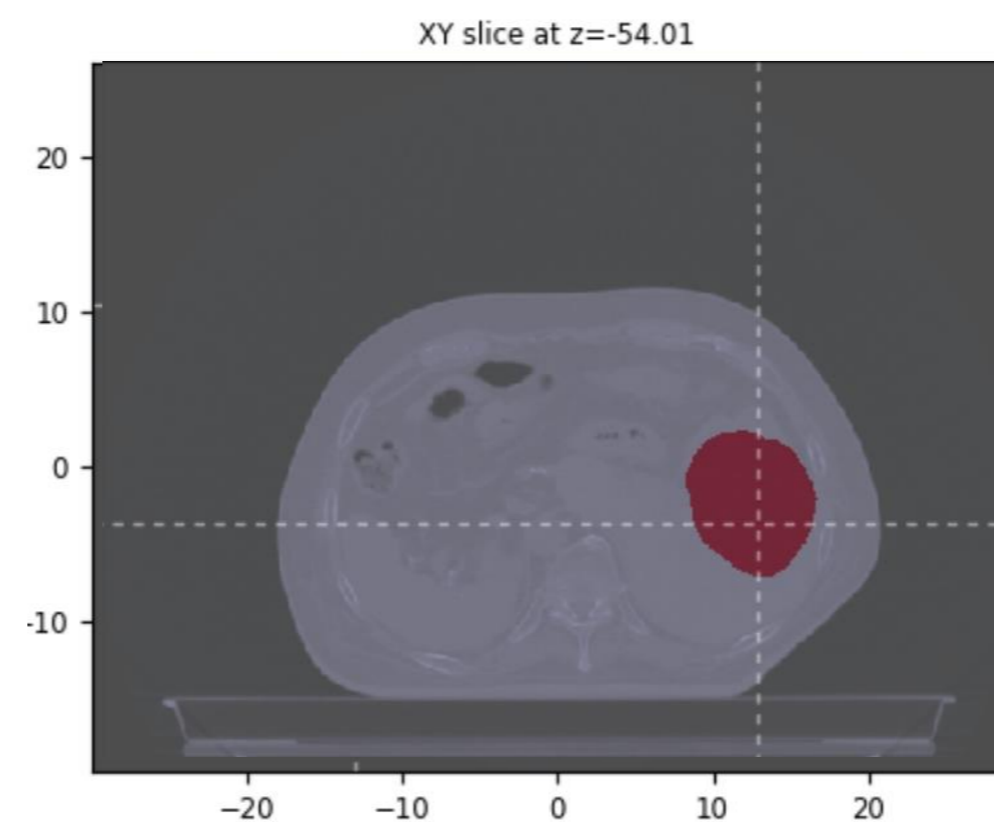
Case1: Lung Cancer

- Small volume
- Heterogeneous medium



Case2: Liver Cancer (ongoing)

- Large volume
- Homogeneous medium



Move to the simulation of the FLASH setup:

- Maximum available energy (226MeV)
- Larger Range Shifter
- Larger beam spotsize

Next steps: Printing and testing



FLASH Radiotherapy with High
Dose-rate particle beams



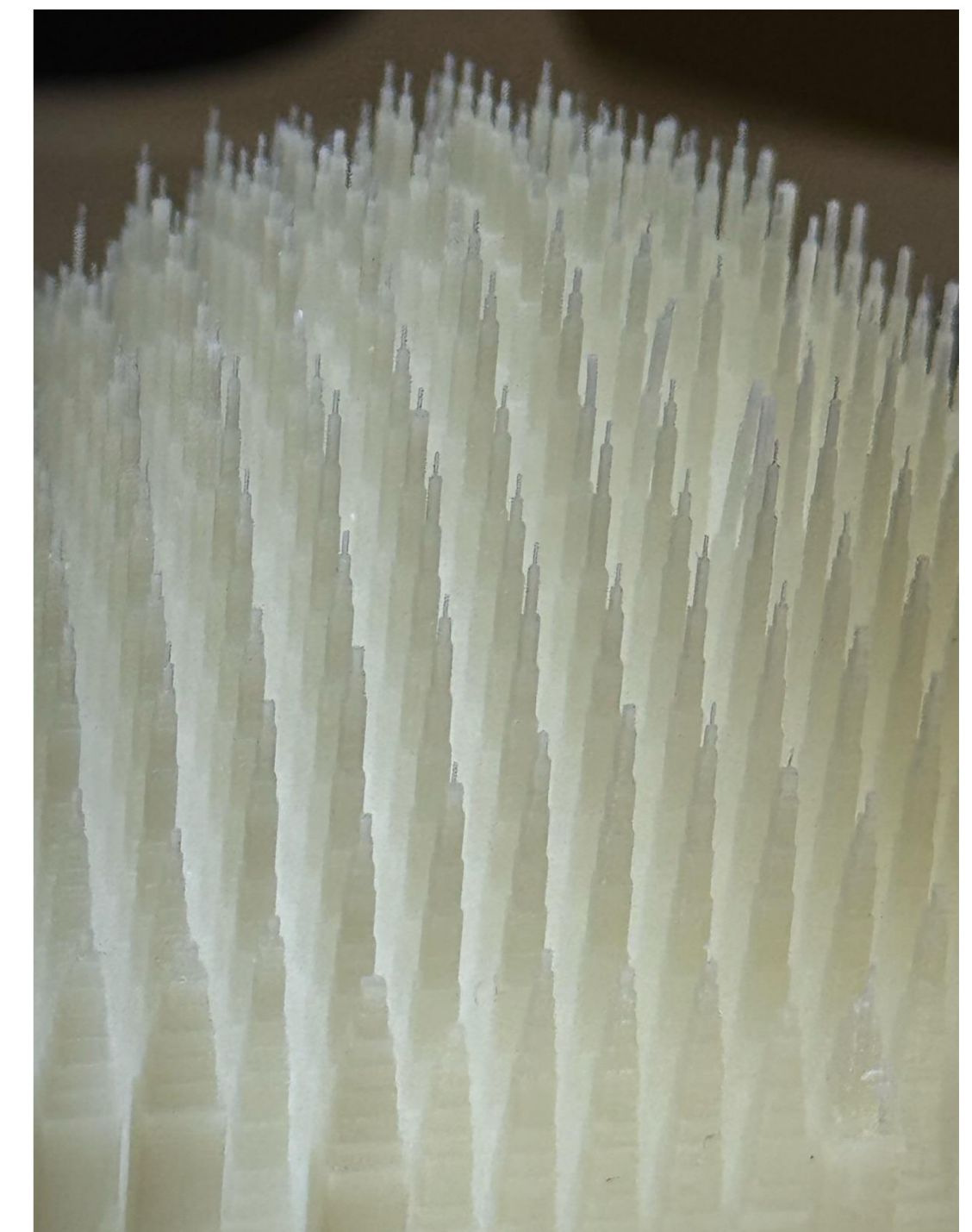
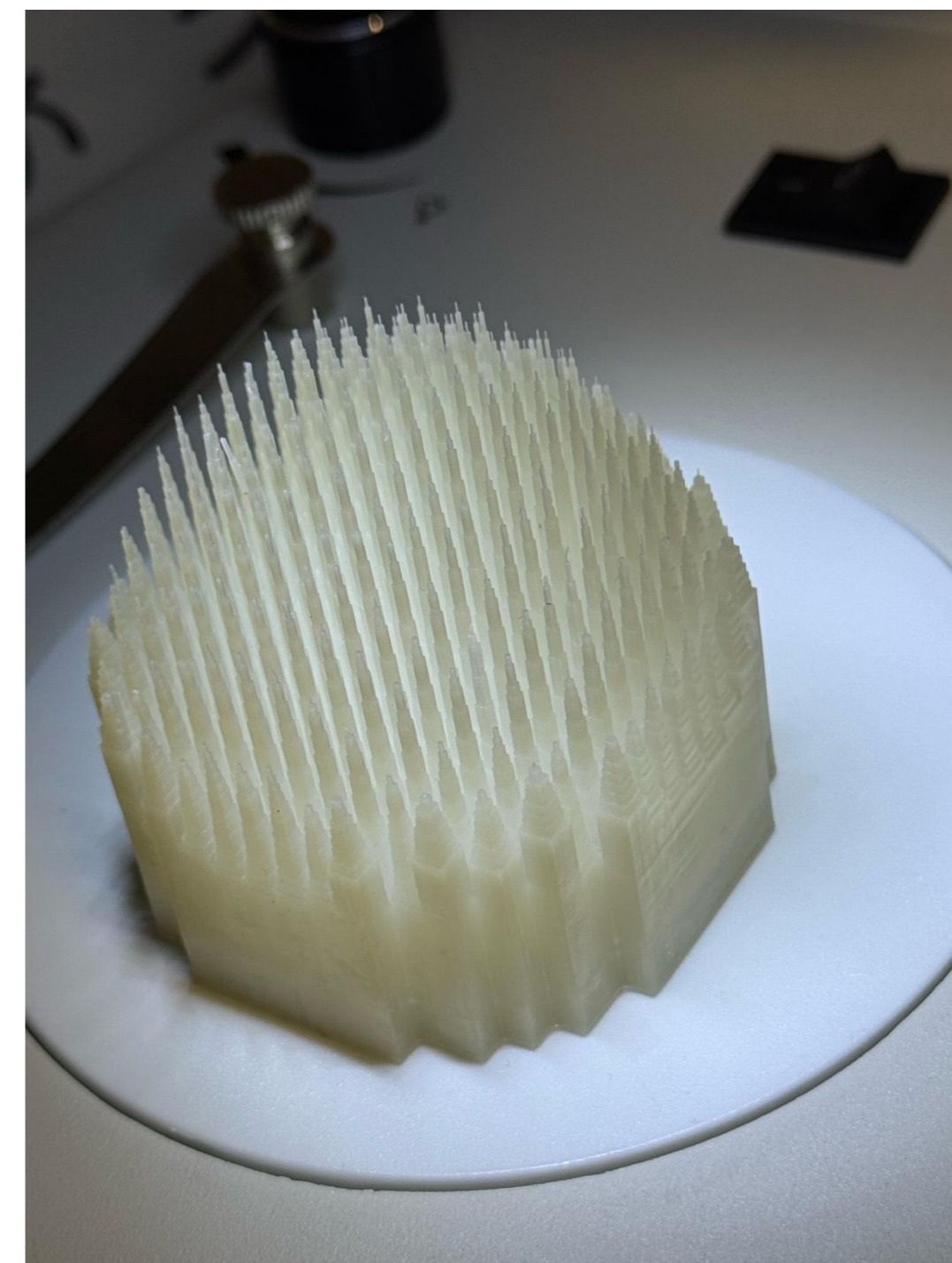
Fast Optimization of Range Modulators 3D

- First feasibility test of printing with a stereolithographic printer (Duplicator 7, Wahnao)
- Standard white resin
- 100 um resolution



Test 2DRM in the exp room

Test of 3DRM in the gantry



CONCLUSIONS



FLASH Radiotherapy with High
Dose-rate particle beams

Commissioning of a fast MC code (FRED) for the APSS of Trento

Successful implementation of FRED as a tool for further studies

Development of an algorithm based on MC to design 3DRM

First results on clinical cases are promising

Printing and testing of 3DRM

Ongoing feasibility study



Fast Optimization of Range Modulators 3D



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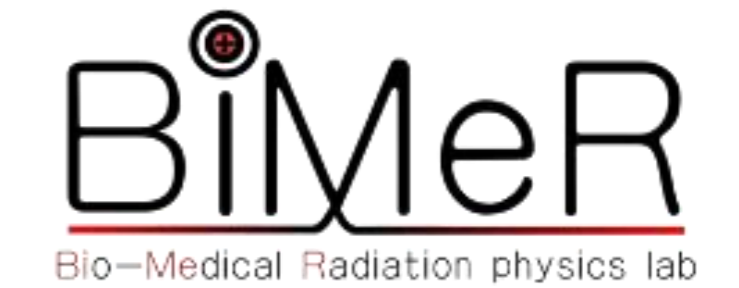


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Fast Optimization of Range Modulators 3D



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THANK YOU



FLASH Radiotherapy with high
Dose-rate particle beams

Thanks to:

- F. Tommasino, E.Scifoni
- A. Attili, P. Aklaghi
- A. Schiavi
- F. Fracchiolla, S.Lorentini