Towards particle treatment planning with Ionization Detail

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Contents of the presentation

- *From Ionization Detail to Cluster dose*

  Mathematical model
  Why is it important?

- *My PhD project*

  The main idea
  Starting point: protons

- *Future outlook*

  Heavier ions
  Treatment planning

Cluster Dose

What is cluster dose? Analogy with the physical dose

Dose

- Energy deposited per unit mass;
- Biological models are necessary to study the effect of the deposited dose;
- Biological model depends on the source particle, and also several models exist for the same source;

Cluster Dose

- Number of ionizations per unit mass;
- Physical model describing the distribution of ionization clusters;
- Related to the number of DSB (double strand breaks) in the DNA, expected same biological effect in volumes with same cluster dose value;

Cluster Dose

Mathematical model

1. Frequency ICSD (ionization cluster size distribution)

   Number of clusters of size *v*

   $$f(\nu)$$

2. Ionization parameter

   Condensed ID information

   $$I_p$$

3. Cluster dose

   Generalized I_p per unit mass

   $$g_j^{I_p}$$

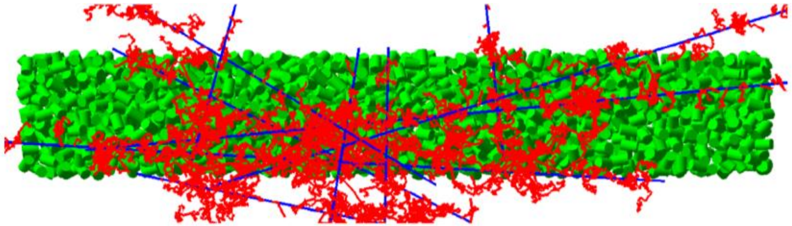

Illustration taken from Ramos-Mendez et al. 2018

The ICSD describes the Ionization Detail (ID), i.e. the spatial distribution of ionization along a particle track

Cluster Dose

Mathematical model

1. Frequency ICSD (ionization cluster size distribution)

   Number of clusters of size ν

   $f(\nu)$

2. Ionization parameter

   Condensed ID information

   I_p

3. Cluster dose

   Generalized I_p per unit mass

   $g_j^{I_p}$

Number of ionizations: N_k

$$N_k^c = \sum_{\nu=k}^{\infty} \nu f^c(\nu)$$

Number of clusters: F_k

$$F_k^c = \sum_{\nu=k}^{\infty} f^c(\nu)$$

Ionization parameter I_p

$$G_p : f^c(\nu) \rightarrow I_p^c$$

Cluster Dose

Mathematical model

1. Frequency ICSD (ionization cluster size distribution)

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3. Cluster dose

   Generalized I_p per unit mass

   $$g_j^{I_p}$$

The cluster dose is the fluence-weighted sum of the I_p in a macroscopic bin.

$$g_j^{(I_p)} = \frac{1}{\rho_0 V_j} \sum_{c \in C_j} t_j^c \; I_p^c$$

$$\Phi_j^c = \frac{t_j^c}{V_j}$$

$$g_j^{(I_p)} = \frac{1}{\rho_0} \sum_{c \in C_j} \Phi_j^c \; I_p^c$$

Cluster Dose

Mathematical model

1. Frequency ICSD (ionization cluster size distribution)

   Number of clusters of size *v*

   $f(\nu)$

2. Ionization parameter

   Condensed ID information

   I_p

3. Cluster dose

   Generalized Ip per unit mass

   $g_j^{I_p}$

$$f^c(\nu)$$

$$\downarrow G_p$$

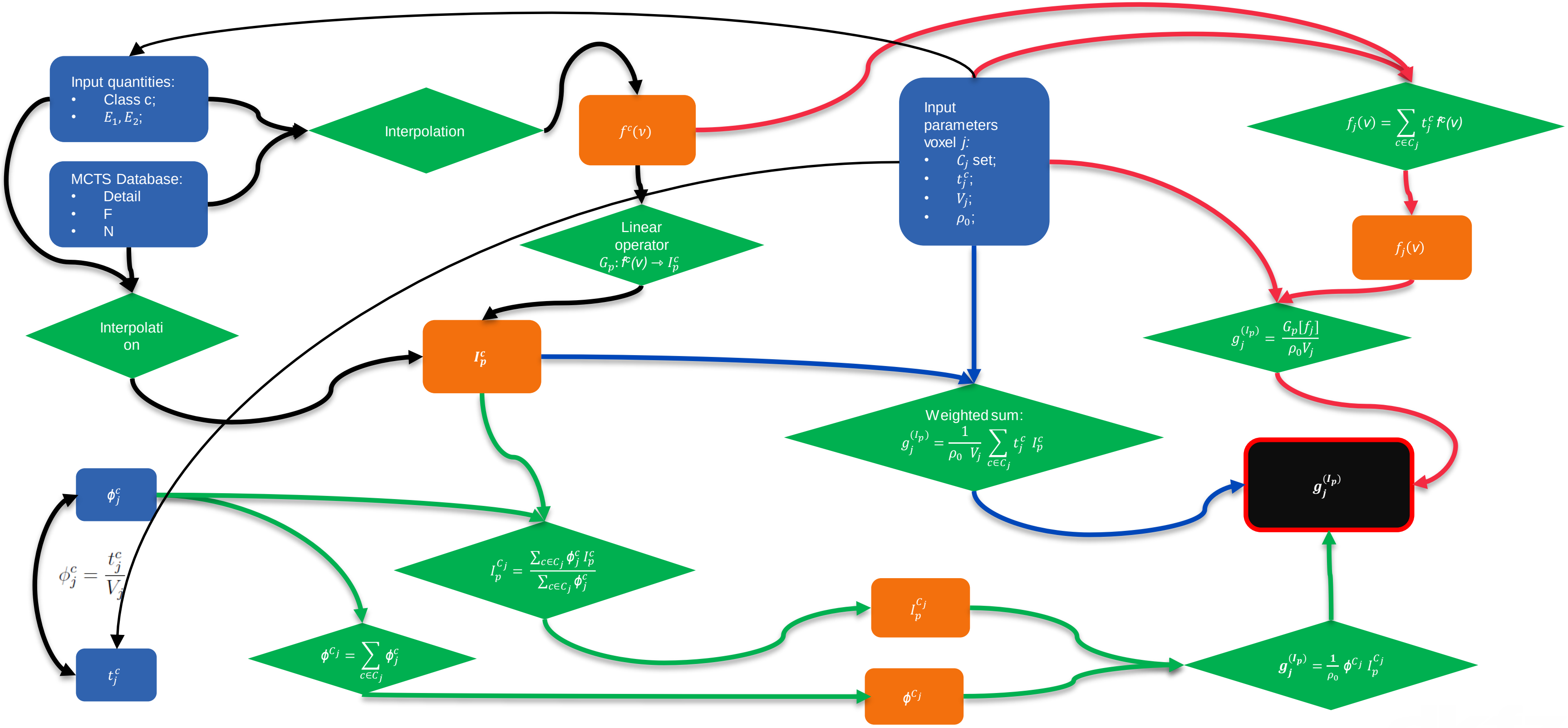
$$I_p^c = G_p[f^c(\nu)]$$

$$\downarrow \sum$$

$$g_j^{(I_p)} = \frac{1}{\rho_0 V_j} \sum_{c \in C_j} t_j^c \; I_p^c$$

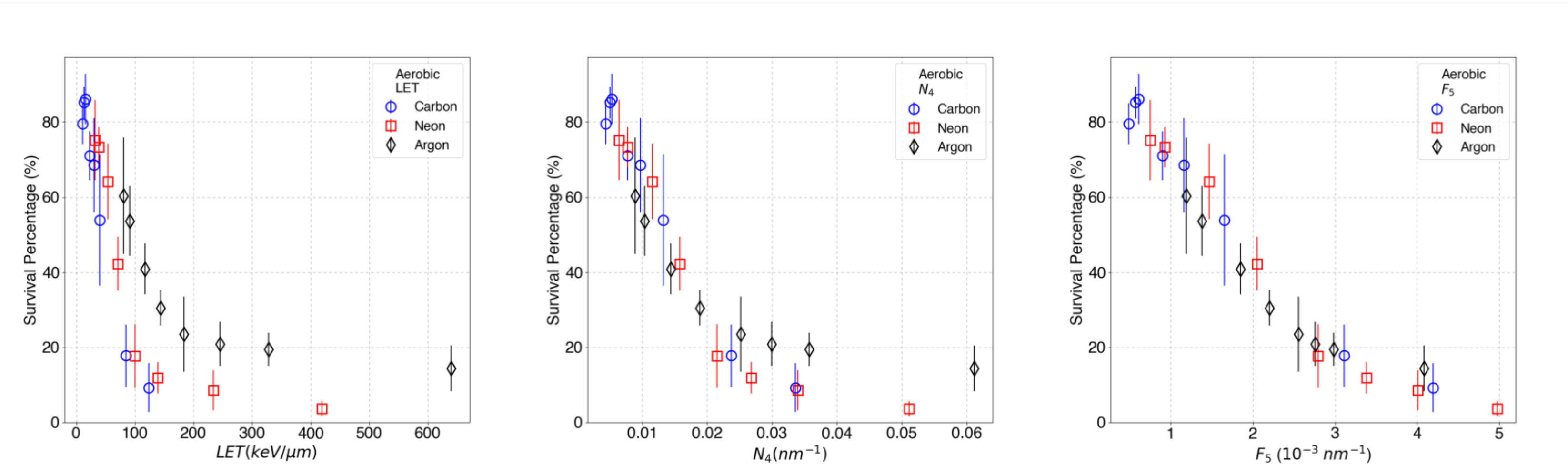
Cluster Dose

Mathematical model: the overview



Cluster Dose

Why is cluster dose remarkable?

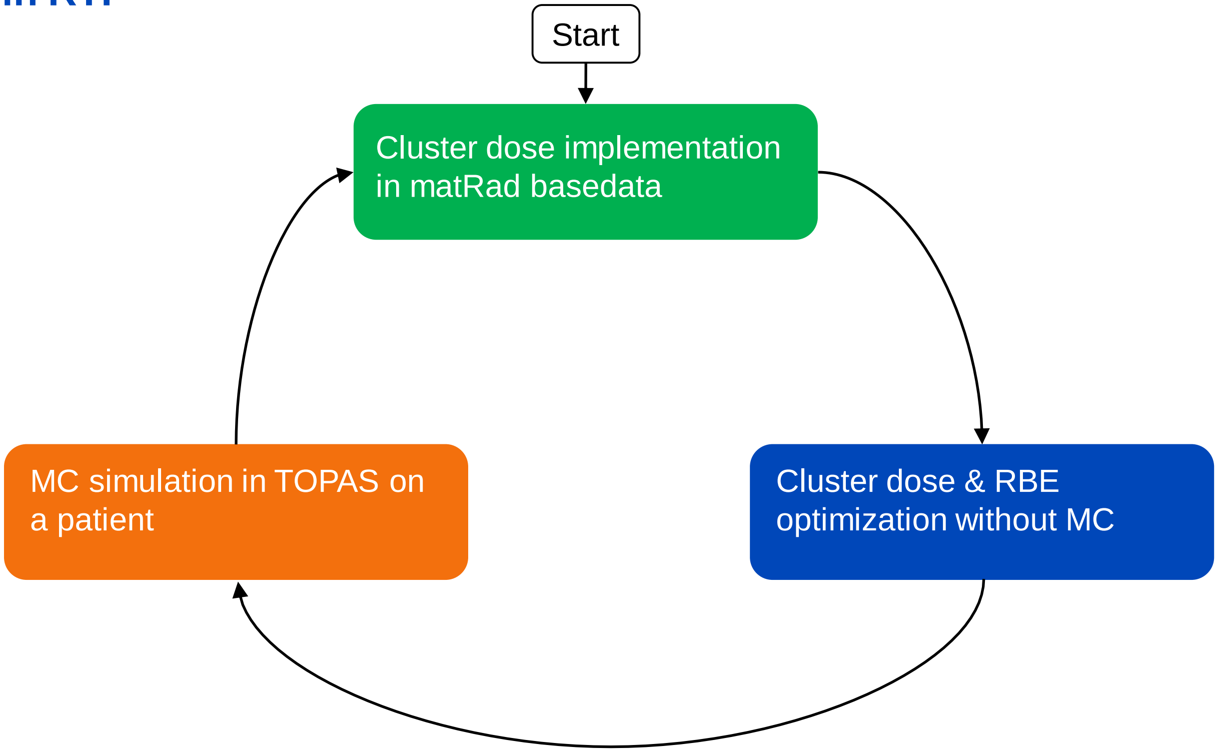


The association of cell survival measured under aerobic conditions with LET (left), N4 (middle) and F5 (right).
Taken from "*Ionization detail parameters and cluster dose: A mathematical model for selection of nanodosimetric quantities for use in treatment planning in charged particle radiotherapy*" Faddegon et al. 2023 (accepted PMB)

My PhD project

Research for a Life without Cancer

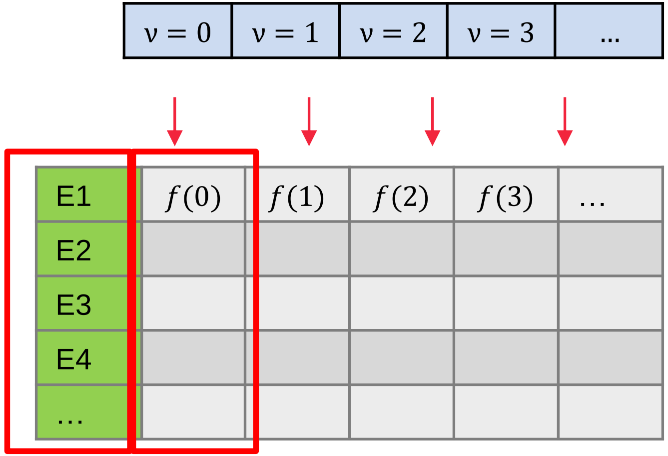
The main idea: Introducing the Cluster Dose optimization in RTP

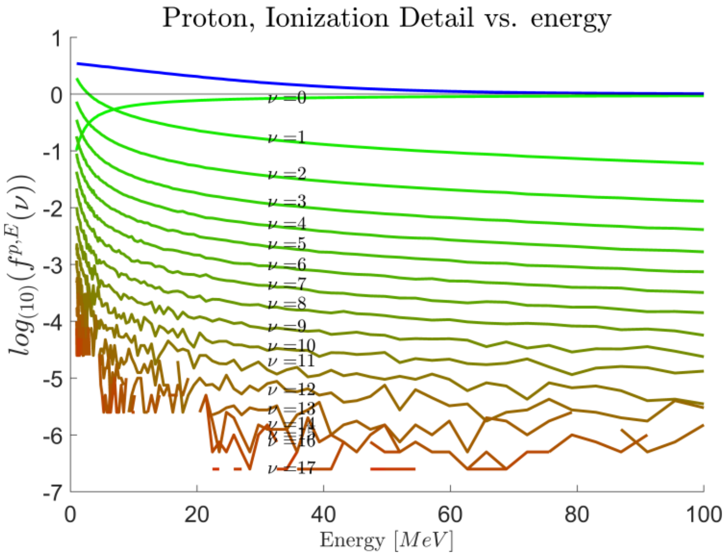


My PhD project

How can I compute the cluster dose?

- MCTS UCSF database format

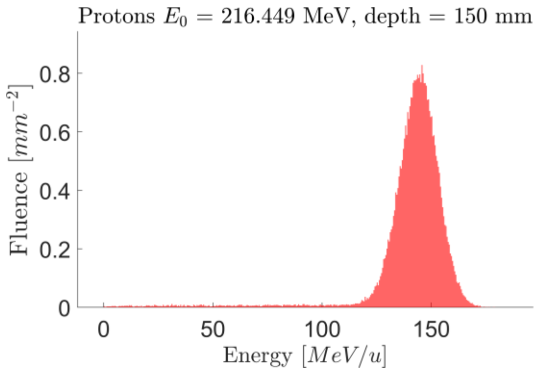


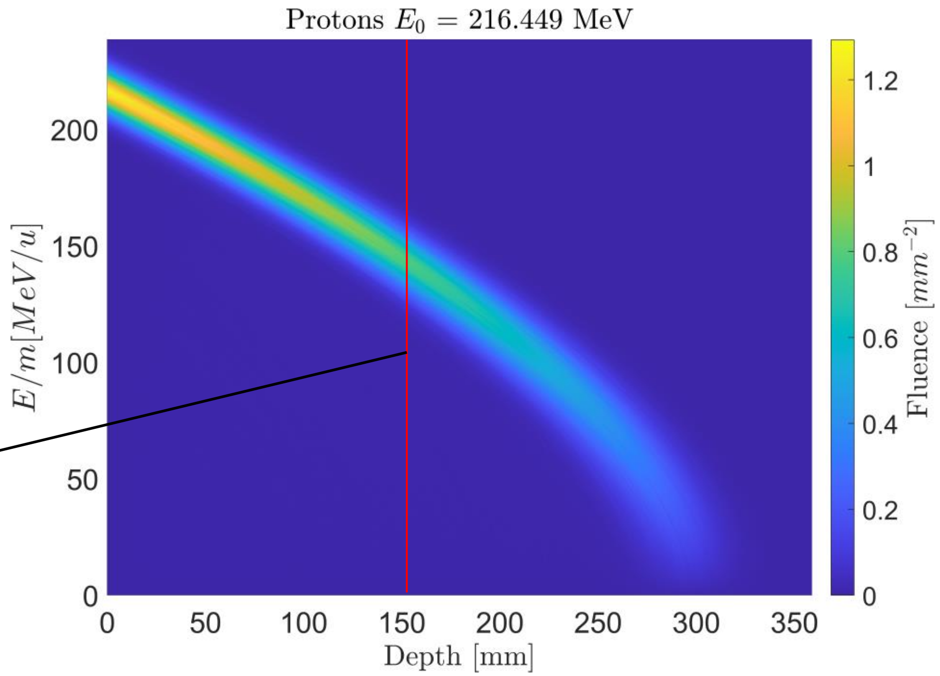


My PhD project

How can I compute the cluster dose?

- MCTS UCSF database;
- TOPAS simulations:
  Fluence matrix scoring;

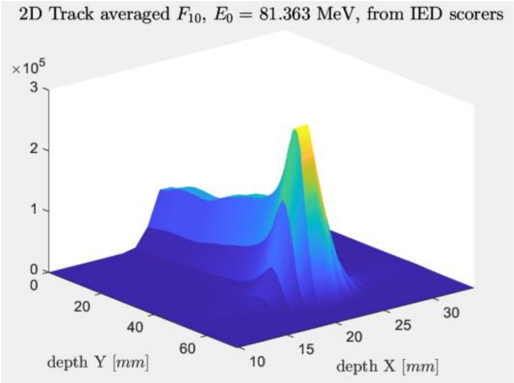




My PhD project

How can I compute the cluster dose?

- MCTS UCSF database;
- TOPAS simulations:
  Fluence matrix scoring;
- TOPAS IED scorers: score the track weighted sum of I_p for each particle, and for each voxel;



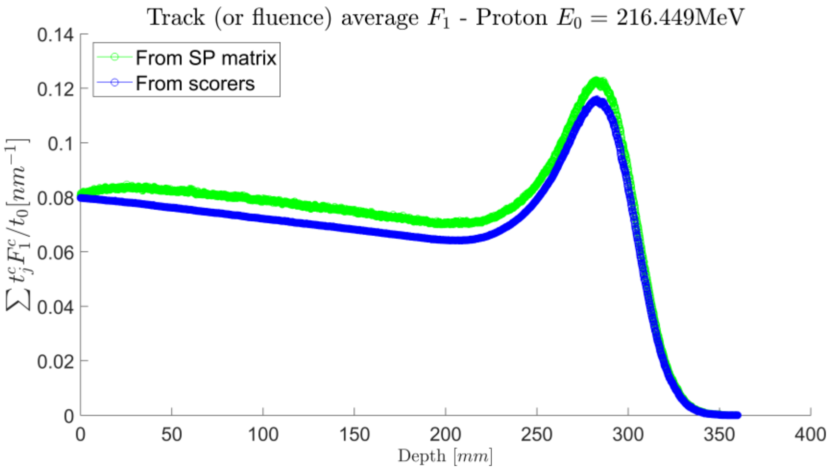
Weight Accumulation	Ionization Detail	IonizationIDsF and IonizationIDsM	
$\sum_{c\,\in C j} t_j^c$	$\sum_{c\,\in C j} t_j^c\, f^c(\nu)$	$\sum_{c\,\in C j} t_j^c F_k^c$	$\sum_{c\,\in C j} t_j^c N_k^c$

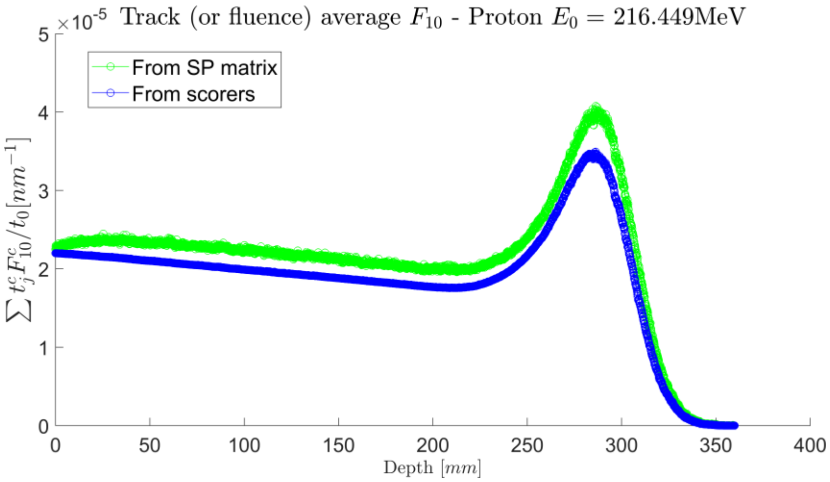
Total, primary, secondary

My PhD project

Starting point: protons

matRad cluster dose implementation based on fluence-energy kernels in water



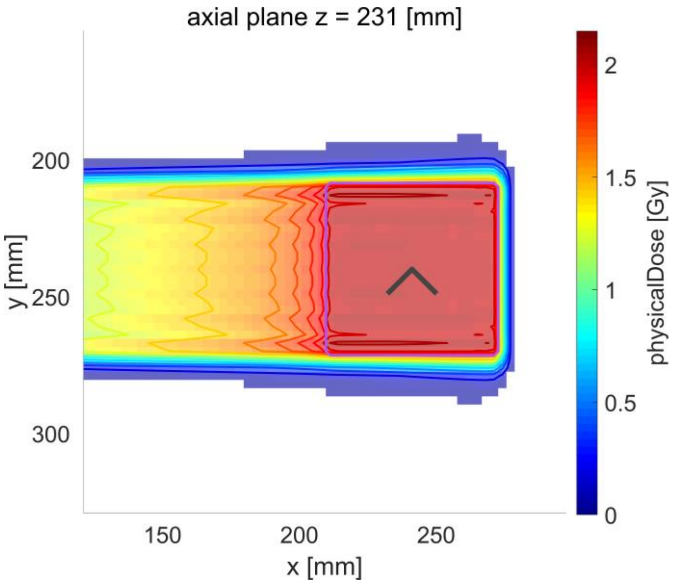


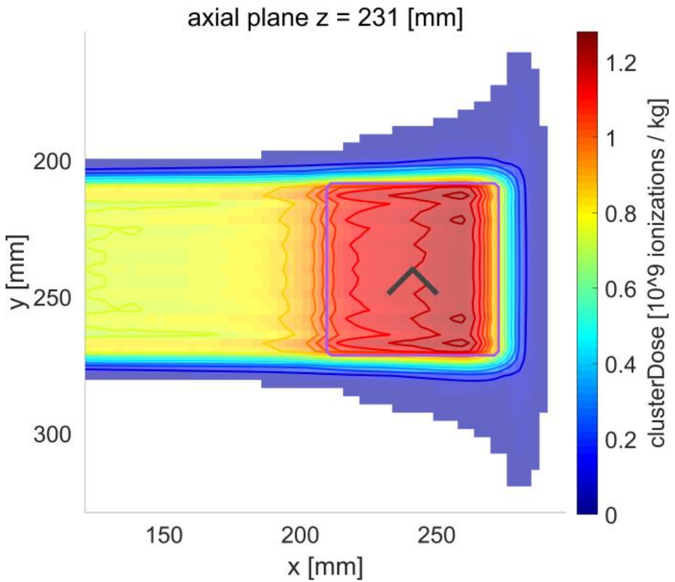
My PhD project

Starting point: protons

What I can do with the basedata:

- **Physical dose optimization in a box phantom;**
- Cluster dose and physical dose optimization in a box phantom;



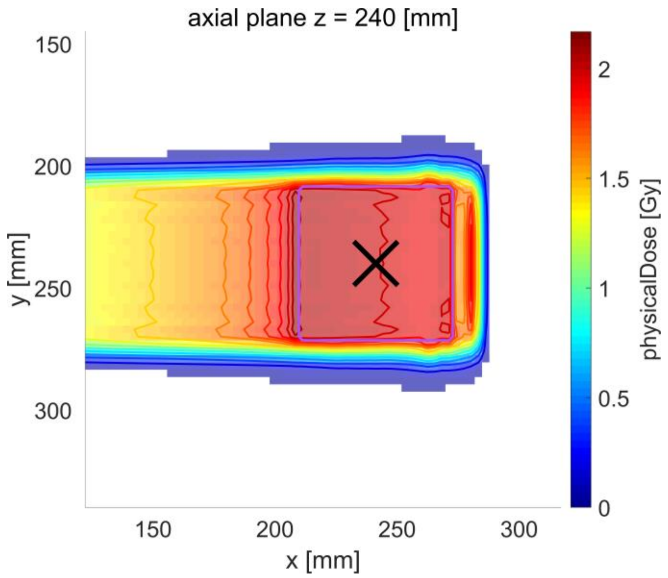


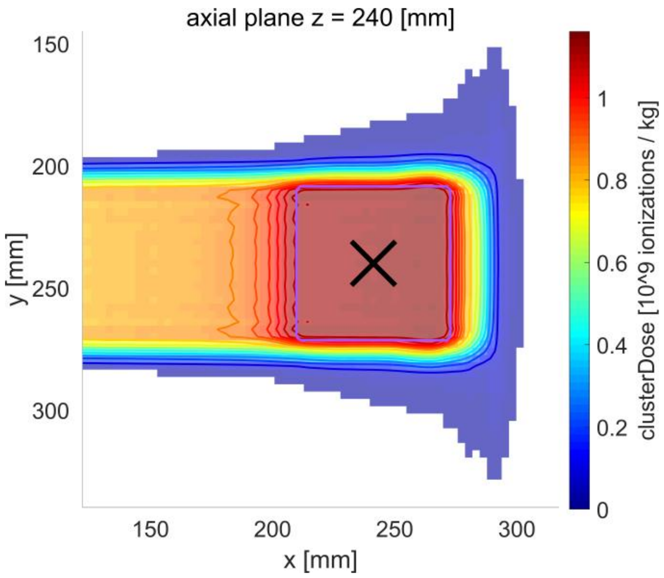
My PhD project

Starting point: protons

What I can do with the basedata:

- Physical dose optimization in a box phantom;
- **Cluster dose and physical dose optimization in a box phantom;** New



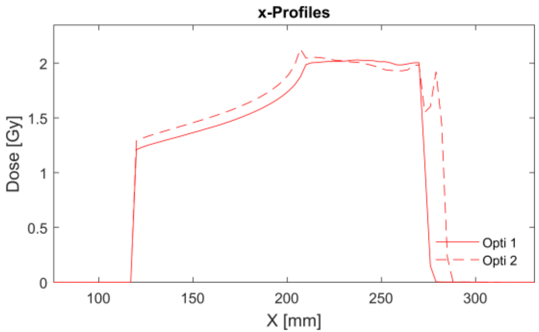


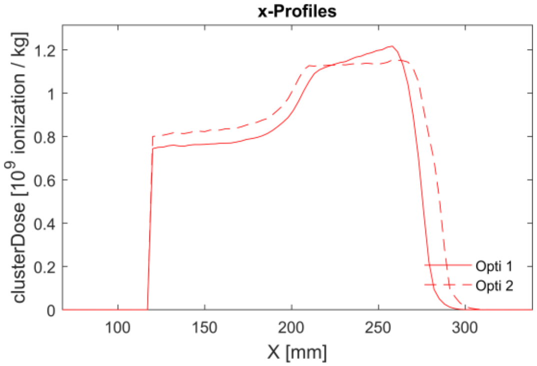
My PhD project

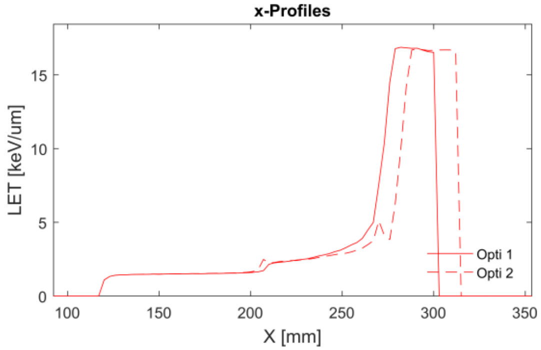
dkfz.
Research for a Life without Cancer

Starting point: protons

Results compared
Opti 1: Physical dose optimization;
Opti 2: Cluster dose and physical dose optimization;







My PhD project

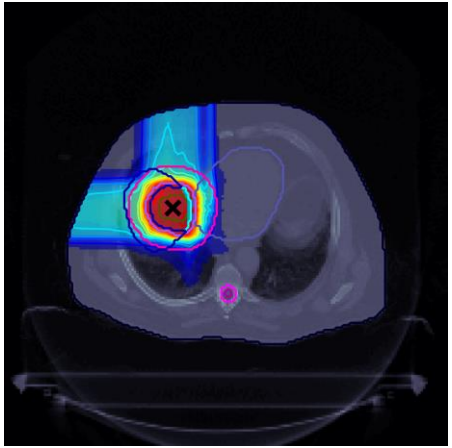
Summary

- Cluster dose vs. depth curve with fluence kernel in water;
- Comparison with scored 3D cluster dose;
- Cluster dose implemented in dose computation in matRad;
- Cluster dose objective implemented and optimization on a boxphantom;

My PhD project

Future outlook

- Extend the cluster dose computation to heavier ions and fragments;
- Extend the basedata for cluster dose – depth and lateral profiles;
- Implement new objectives and constraints in cluster dose optimization with matRad;
- Patient RTP with RBE and cluster dose combined optimization;



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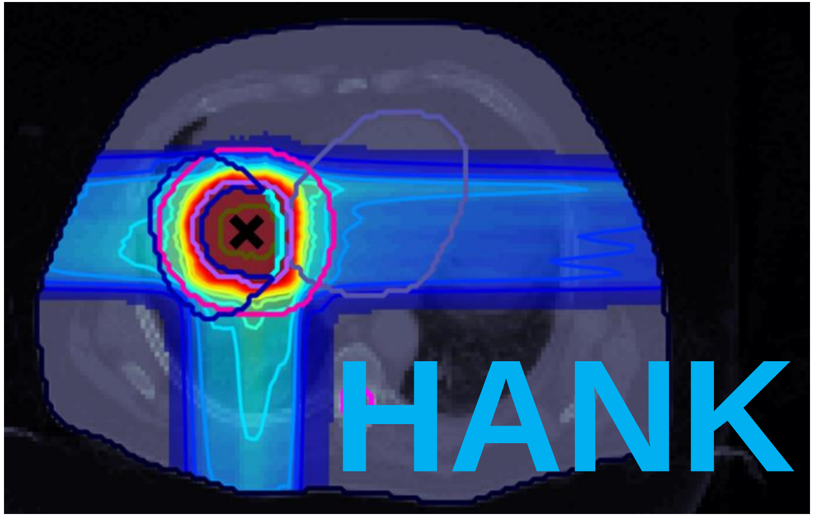
The end (for now).



HANK YOU.