Report on activity of Rome: planning with electrons

G.Traini on behalf of Rome group

Activity of WP4

- Study of cases of interest with the current version of TPS:
  - **head and neck** (2 cases, ~concluded);
  - **pancreas** (provided by Campus Biomedico, started);
  - **whole brain** (provided by Stefano Ursino, going to start);

  Group/people involved:

  Angelica De Gregorio, Gaia Franciosini (Ph.D.), Annalisa Muscato (Scuola di Specializzazione in Fisica Medica), Valentina Romaniello, Andrei Paun (Undergraduating students), Alessio Sarti

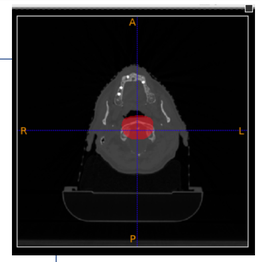
- Planning optimisation and new possible strategies
  - Preliminary study of the impact of the spot size;
  - Simulated annealing

  Group/people involved:

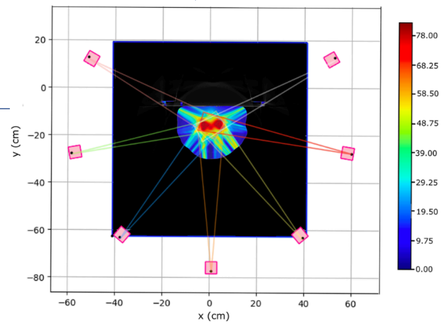
  Angelica De Gregorio (Ph.D.), Carmela Truscelli, (Undergraduating student), Ilaria Mattei (Researcher), Vincenzo Patera

VHEE planning: workflow

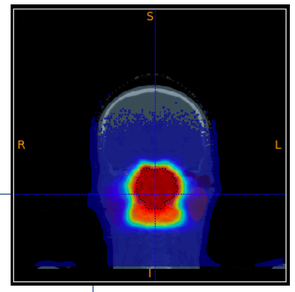
Choice of the pathology and acquisition of the CT scans and constraints



Fix the geometry treatment and the beam energies

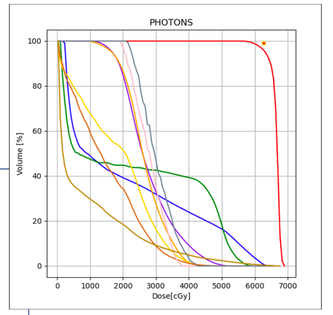


D_{ij} evaluation with Monte Carlo simulations



Optimisation of beam fluences

Recalculation and DVHs creation



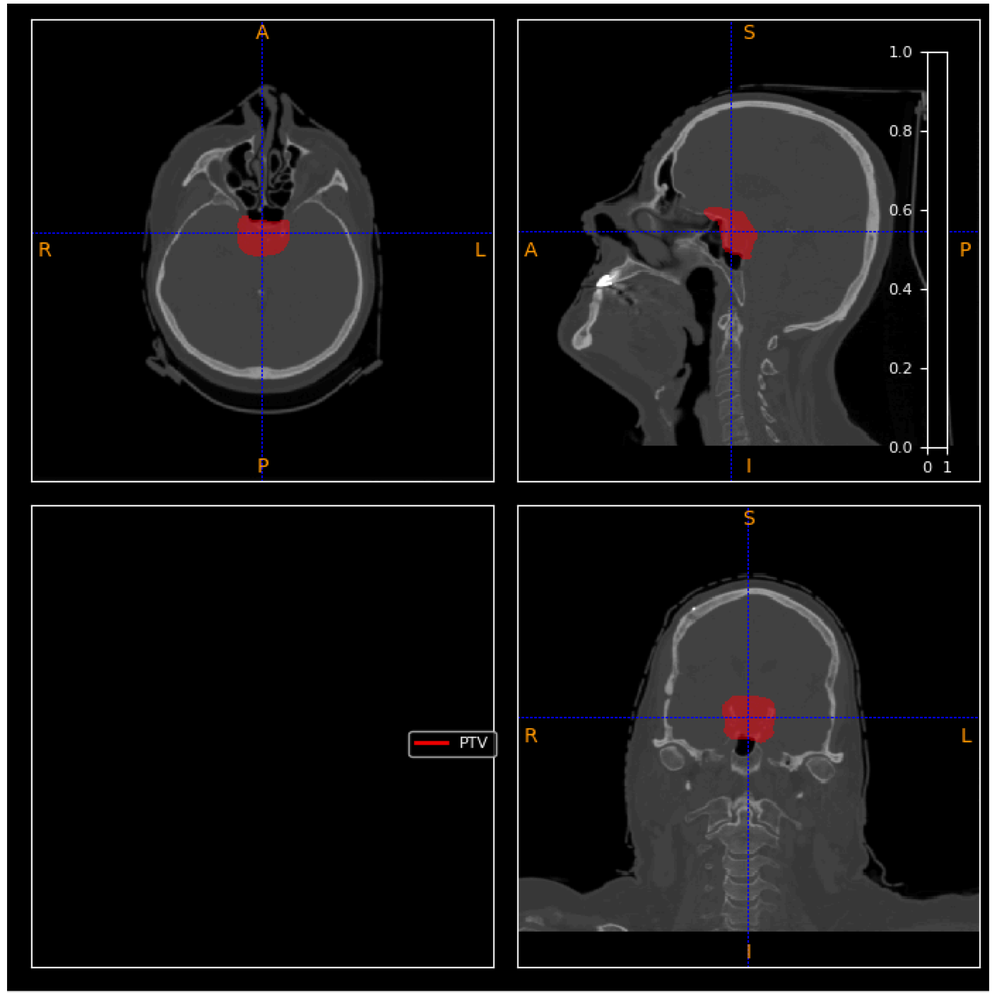
Comparison with photons, protons

Head and neck (M1)

- Prescription: 54 gyRBE in 27 fractions

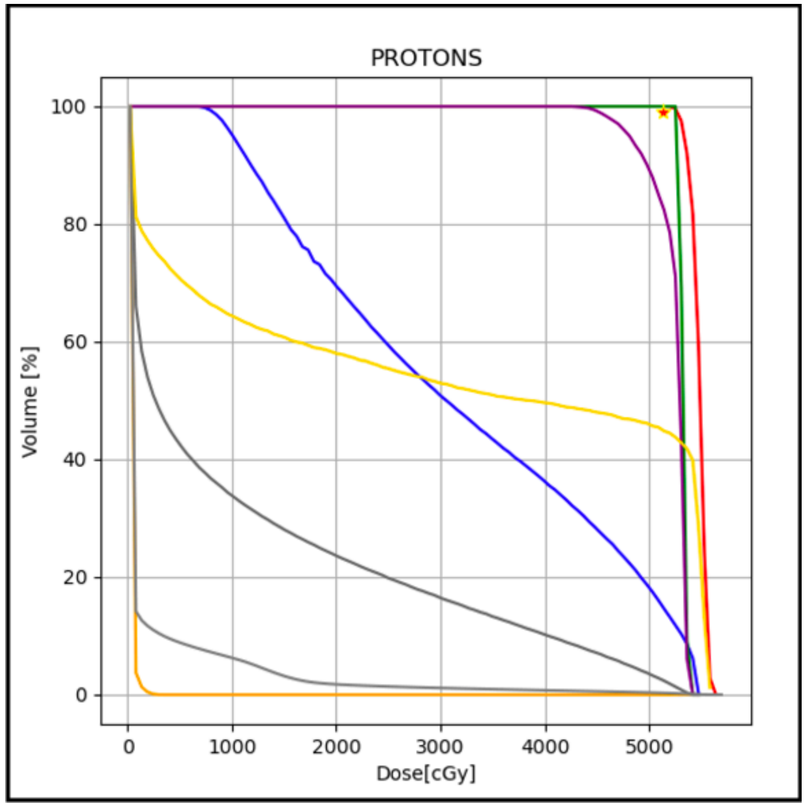
- 3 different RT plan
  - Protons (3 fields, provided by Marco)
  - VHEE (3 & 7 fields)
  - Photons (7 fields, provided by Policlinico Umberto I **)

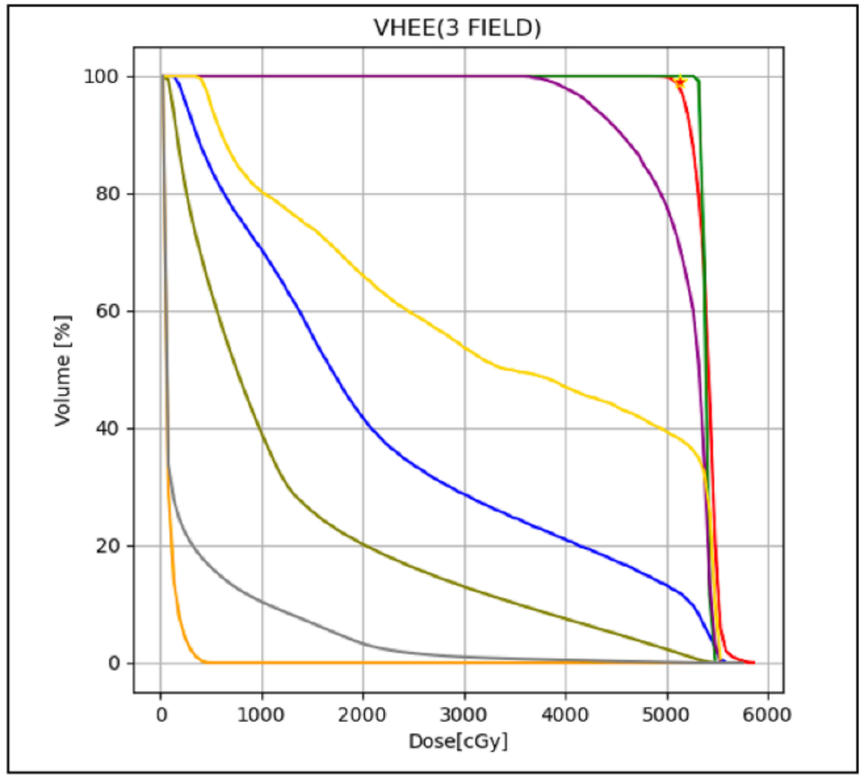
Organo	Constraints
PTV	$V_{95} > 99\%$, mai oltre il 105%
Nervi Ottici	$D_1 \leq 54$ GyRBE
Chiasma	$D_1 \leq 54$ GyRBE
Vie Ottiche Posteriori	$D_1 \leq 54$ GyRBE
Occhi	$D_1 \leq 40$ GyRBE
Tronco Encefalico	$D_1 \leq 54$ GyRBE
Carotidi	No hot spots ($< 105\%$ dose di prescrizione)

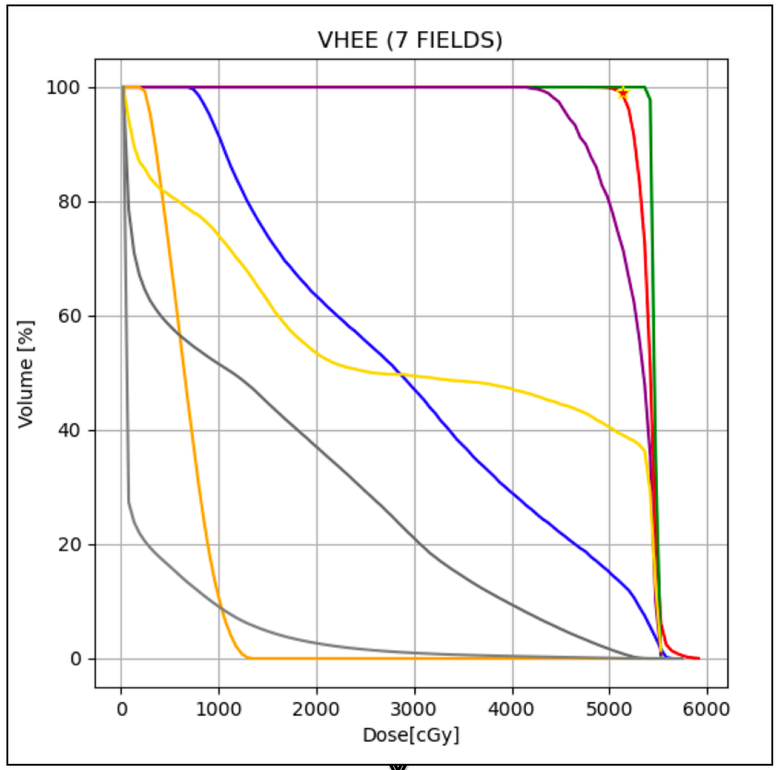


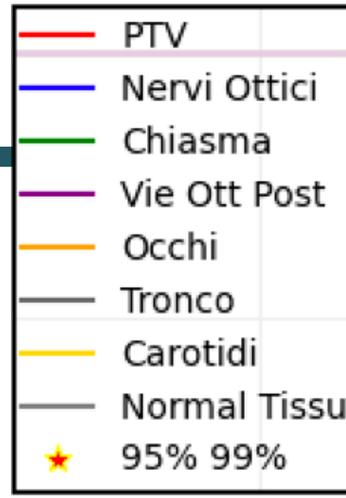
DVH comparison

- We got promising results for both the configuration
- DMF=1 (No flash effect)







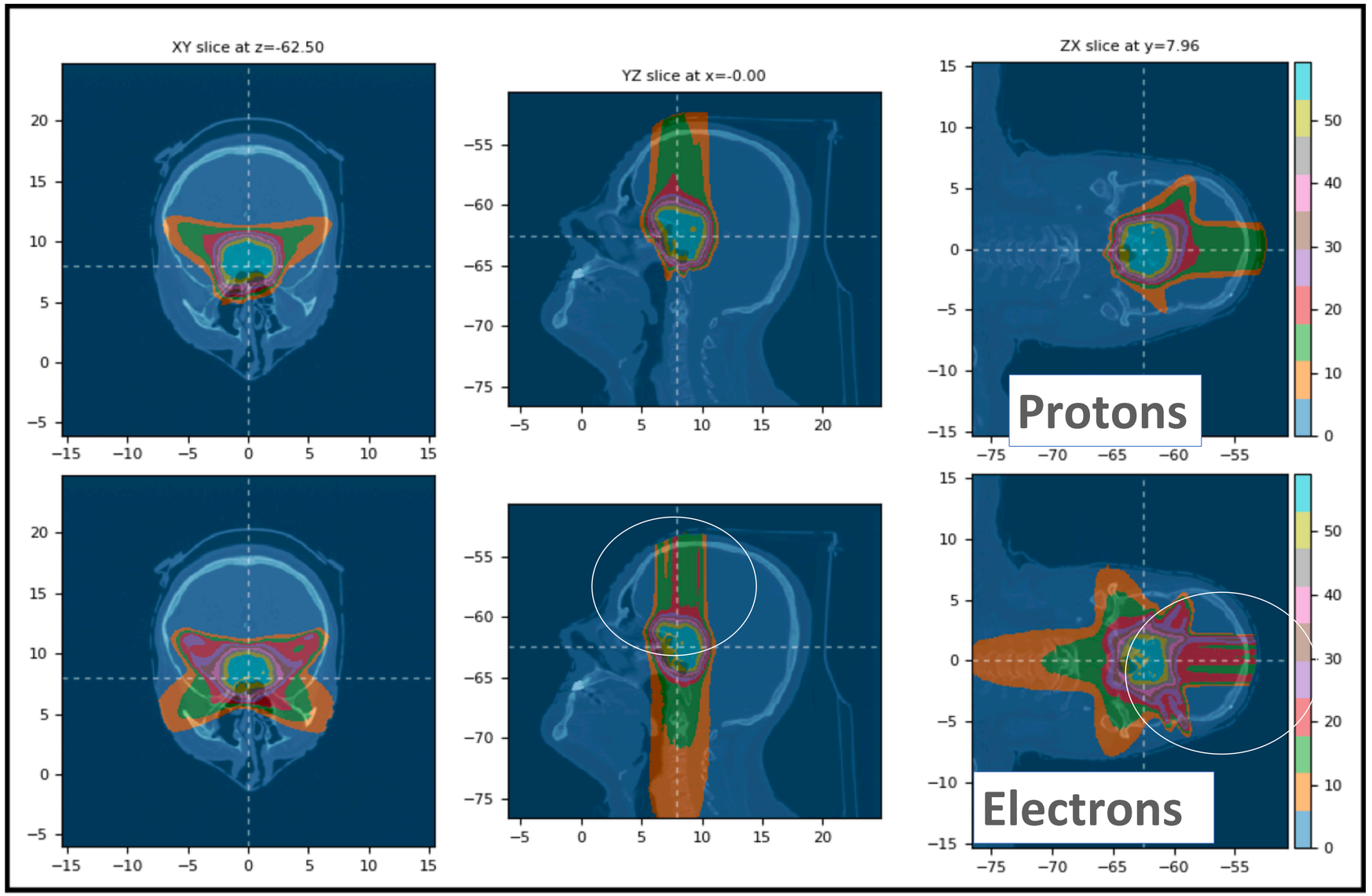


Head and Neck results (M1)

- Plan rationale: sacrify OARs to optimize the PTV coverage
- VHEE: results not so far from protons, better sparing of brain stem in case of 7 fields

Organ	Constraint	Protoni	VHEE	VHEE
PTV	$V_{95\%}$ $V_{100\%}$ $V_{105\%}$	100% 90.62% 0.01%	99.44% 67.41% 1.16%	99.18% 69.75% 1.30%
PRV Nervi Ottici	D_{max}	53.52 GyRBE	55.61 GyRBE	56.10 GyRBE
PRV Chiasma	D_{max}	53.60 GyRBE	54.59 GyRBE	55.08 GyRBE
PRV Vie Ottiche	D_{mean}	53.81 GyRBE	55.13 GyRBE	55.26 GyRBE
Occhio	D_{mean}	2.82 GyRBE	4.76 GyRBE	13.10 GyRBE
Tronco	D_{mean}	54.26 GyRBE	54.73 GyRBE	53.69 GyRBE
Arterie Carotidi	$V_{105\%}$	0.03%	0.19%	0.85%

Dose map comparison



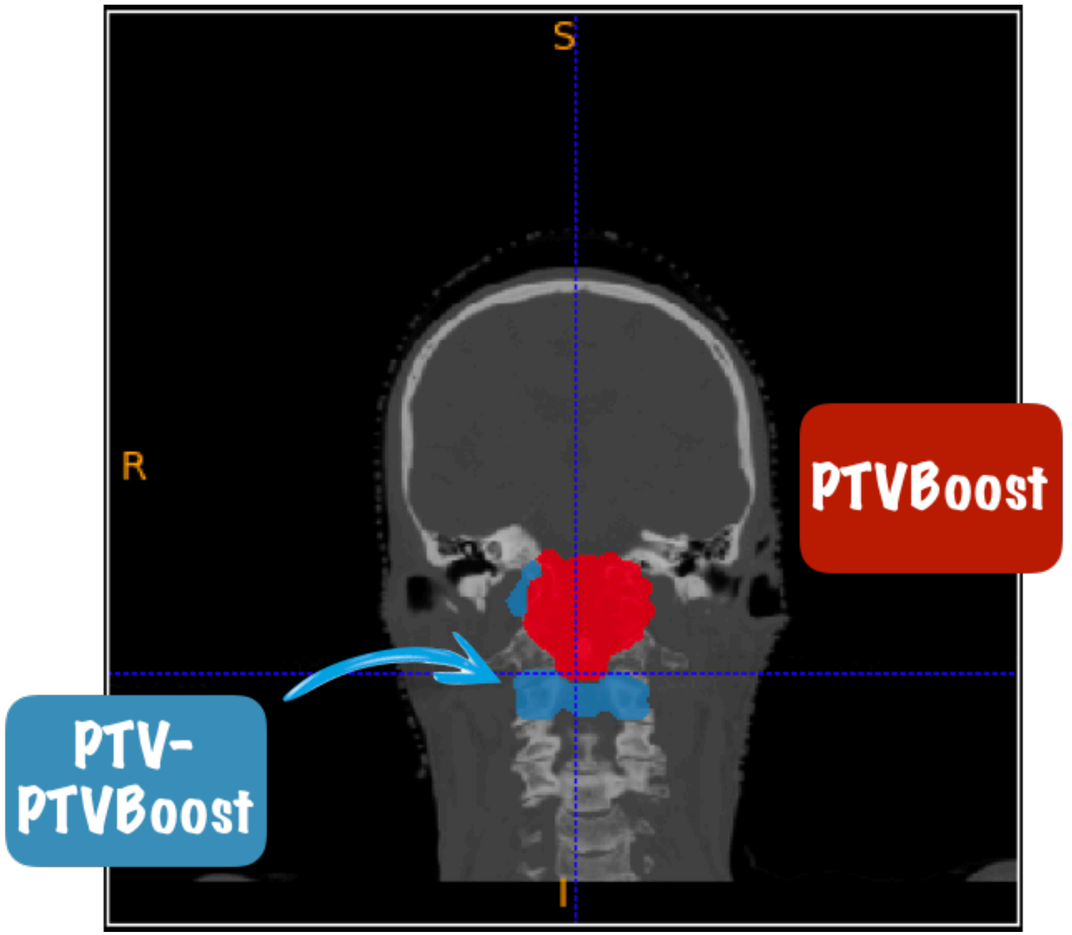
- We observe some “artefacts” in the isodose curves that has to be still understood
- Work in progress…

Head and neck (C1)

- **PTV**: **54 GyRBE** in 30 frazioni da 1.8 GyRBE;
- **PTV Boost**: **66 GyRBE** in 33 frazioni da 2 GyRBE, di cui le prime 30 sono erogate in SIB, le ultime 3 in sequenziale.

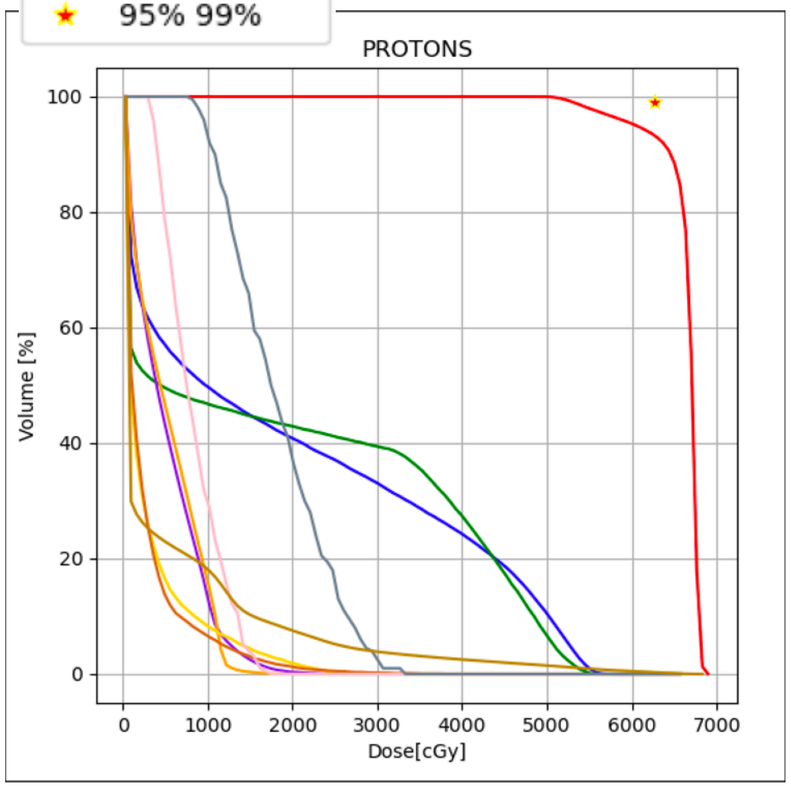
- 3 different RT plan
  - Photons (7 fields, provided by Policlinico Umberto I **)
  - Protons (3 fields, provided by Marco)
  - VHEE (3 & 7 fields)

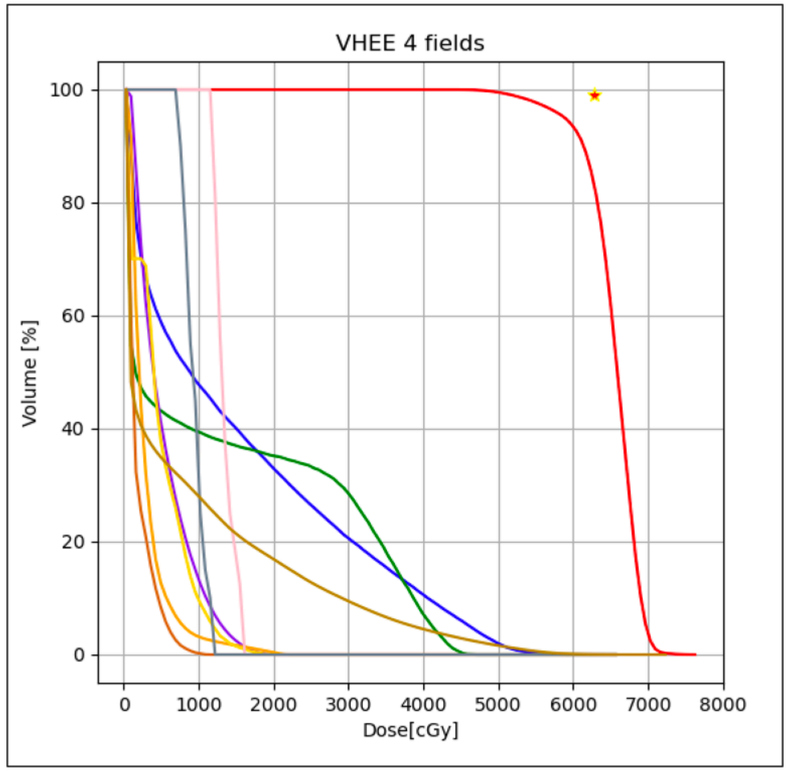
Organo	Constraints
PTV e PTV Boost	$V_{95} > 99\%$, mai oltre il 107%
Tronco Encefalico	$D_1 \leq 55$ GyRBE
Midollo Spinale	$D_1 \leq 54$ GyRBE
Parotidi	$D_{mean} \leq 26$ GyRBE
Canali Uditivi	$D_{mean} \leq 30$ GyRBE
Coclee	$D_{mean} \leq 35$ GyRBE

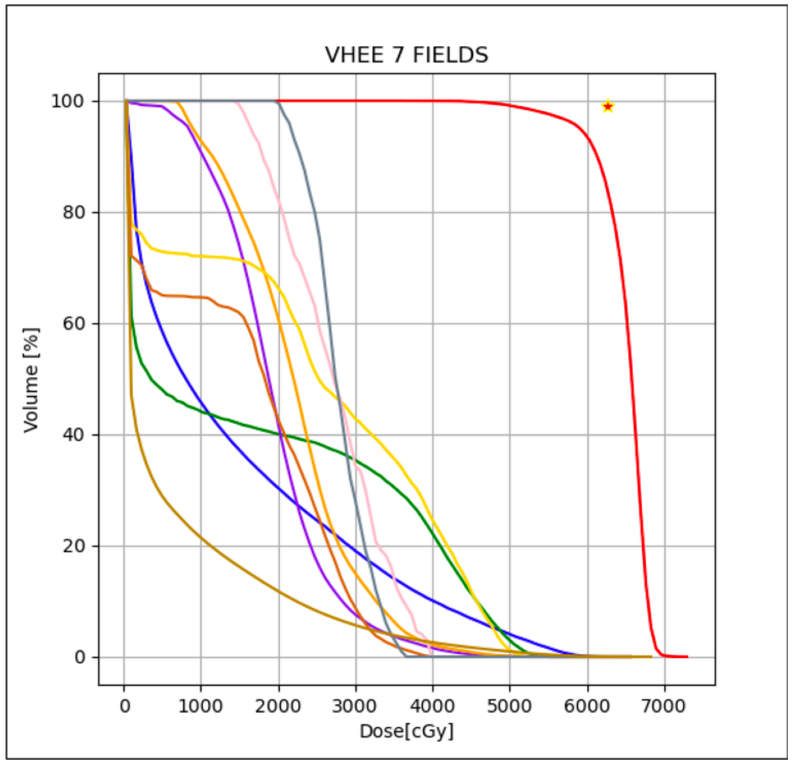


DVH comparison

- Plan rationale: sacrify PTV coverage to better spare the OARs
- VHEE: very good sparing of OARs (4 field)







Constraints check

PTV Boost

Organ	Constraint	Protoni	VHEE 7 fields	VHEE 4 fields
PTV	$V_{95\%}$ $V_{100\%}$ $V_{105\%}$ $V_{107\%}$	93.51% 84.77% 0.02% 0.02%	93.42% 61.90% 2.37% 0.25%	85.67% 53.02% 10.55% 2.43%
Tronco	D_{max}	57.84 GyRBE	58.06 GyRBE	58.47 GyRBE
Midollo Spinale	D_{max}	56.49 GyRBE	51.01 GyRBE	46.30 GyRBE
Parotide destra	D_{mean}	4.73 GyRBE	18.83 GyRBE	4.91 GyRBE
Parotide sinistra	D_{mean}	4.78 GyRBE	21.84 GyRBE	2.64 GyRBE
Can Uditivo Dx	D_{mean}	2.64 GyRBE	23.51 GyRBE	4.28 GyRBE
Can Uditivo Sx	D_{mean}	2.41GyRBE	13.27 GyRBE	1.42 GyRBE
Coclea Dx	D_{mean}	7.88 GyRBE	25.82 GyRBE	13.13 GyRBE
Coclea Sx	D_{mean}	17.80 GyRBE	28.45 GyRBE	8.97 GyRBE

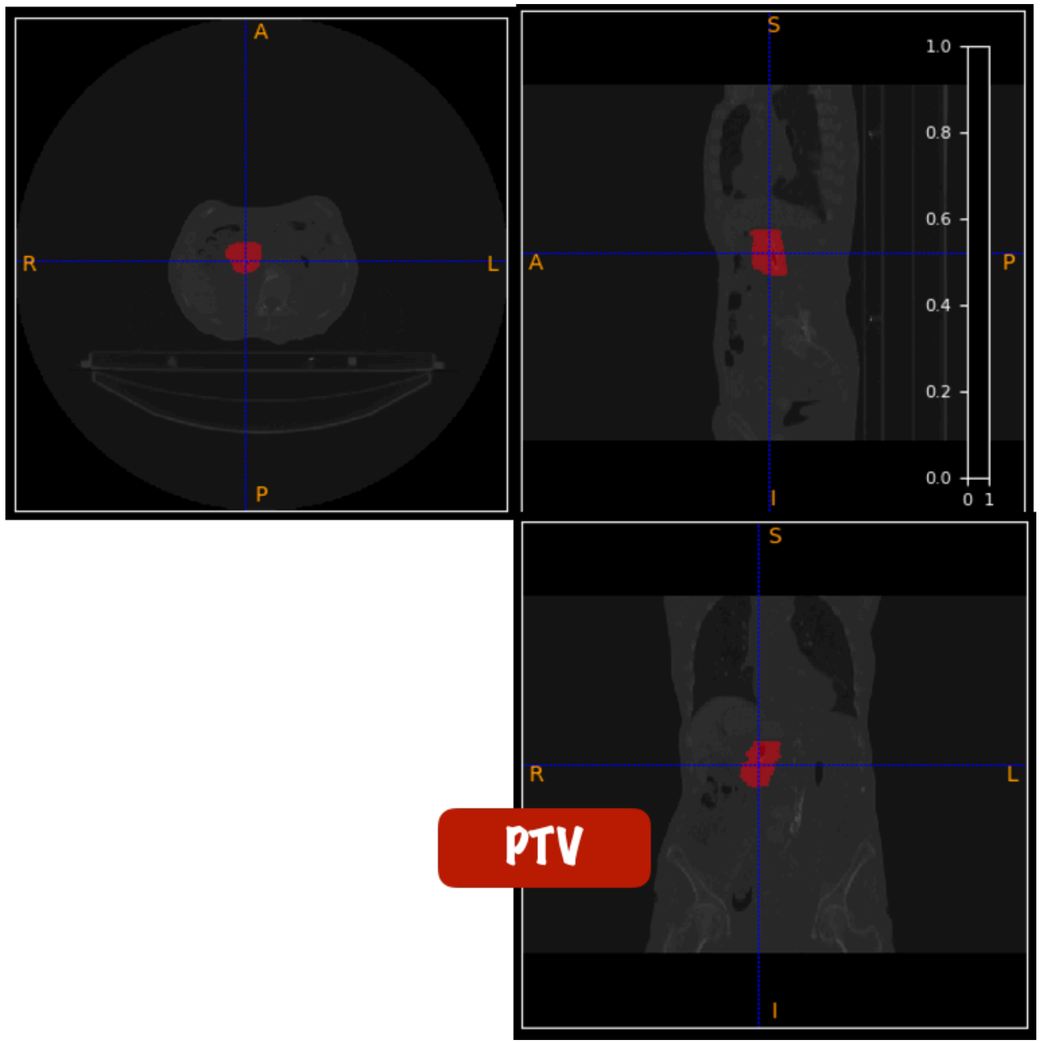
- Larger the number of field, higher the coverage of the PTV
- Spinal chord dose lower in both cases
- Reminder: a lot of parameters can be still optimised.. (geometry, energy-fluence) and flash effect not included

Pancreas

- Prescription: 30 GyRBE in 5 fractions

- (at present) 3 different plans:
  - IMRT (7 field)
  - Stereotactic radiotherapy
  - VHEE (starting)

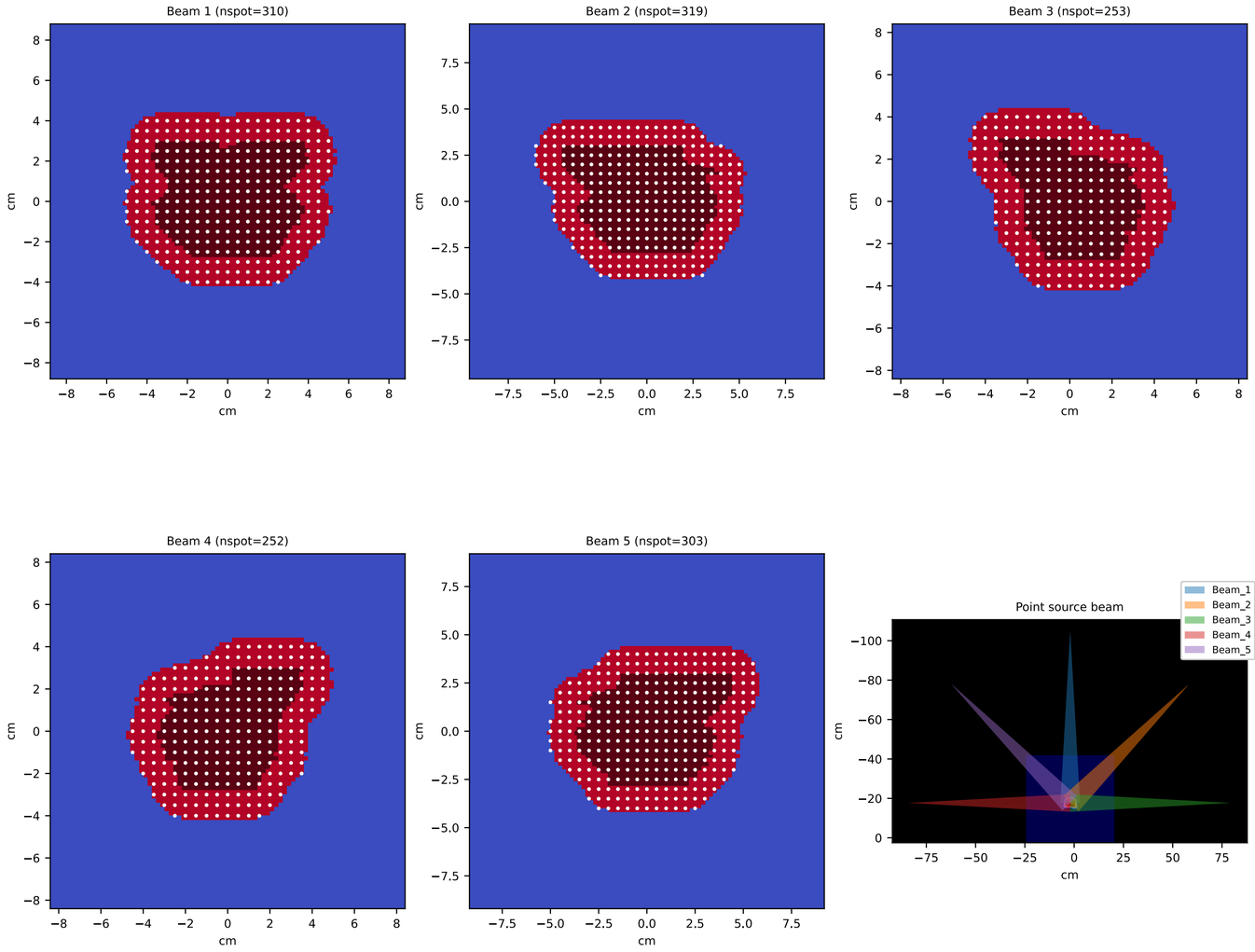
- Question: how to make a fair comparison with Stereotactic radiotherapy? We can not deal with a too large number of PB with different energy and directions… → smart choice of field



Optimisation strategy: impact of the beam transverse size

- Motivation: reduce the degree of freedom in the optimisation process while keeping the same outcome

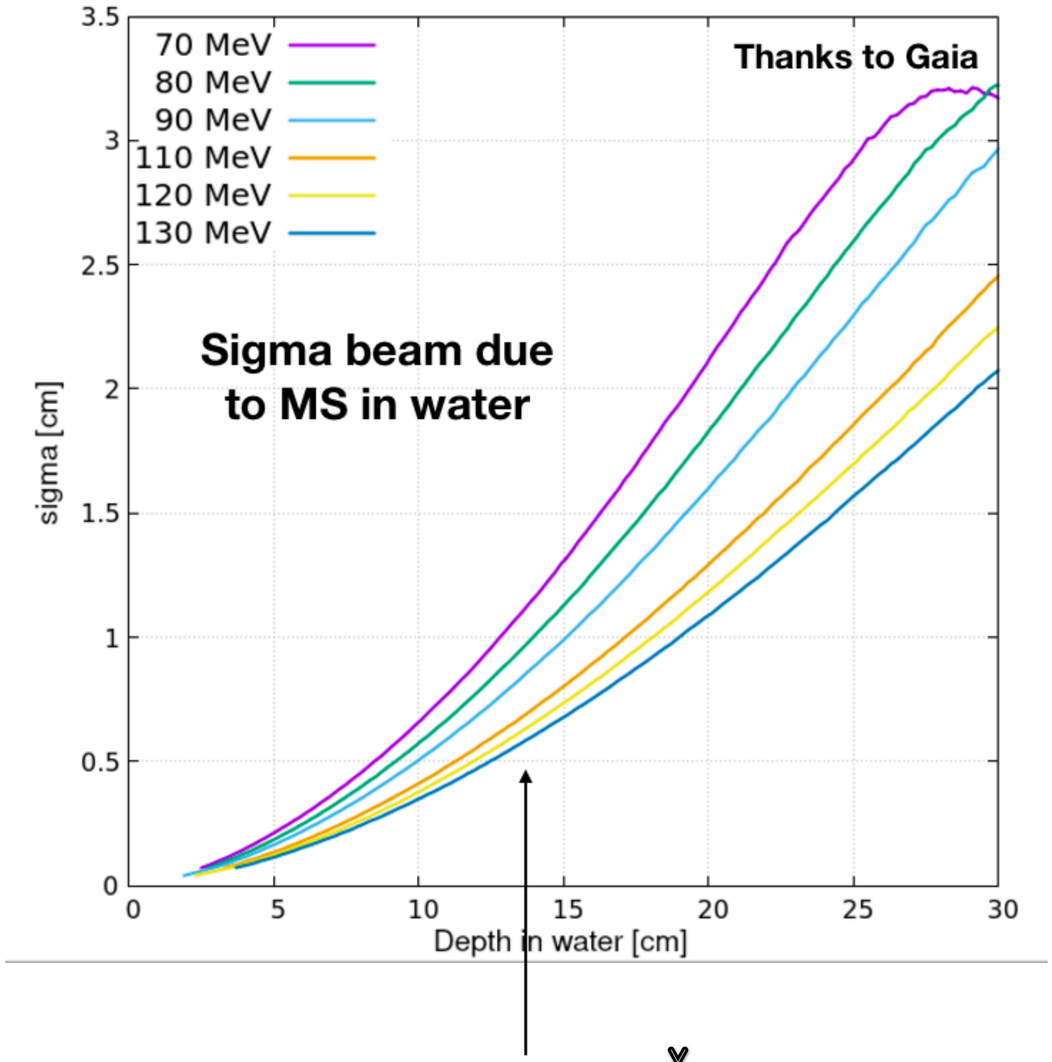
- In principle a larger number PB having a small transverse size may help in improve dose conformity, at expense of:
  - Robustness of optimisation
  - Possible losing of flash effect?



Optimisation strategy: impact of the beam transverse size

- Motivation: reduce the degree of freedom in the optimisazion process while keeping the same outcome

- In principle a larger number of small transverse size may help in improve dose conformity, at expense of:
  - Robustness of optimisazion
  - Possible losing of flash effect?
  - Intrinsic limitation from physics: **multiple scattering**



Preliminary study: case of prostate

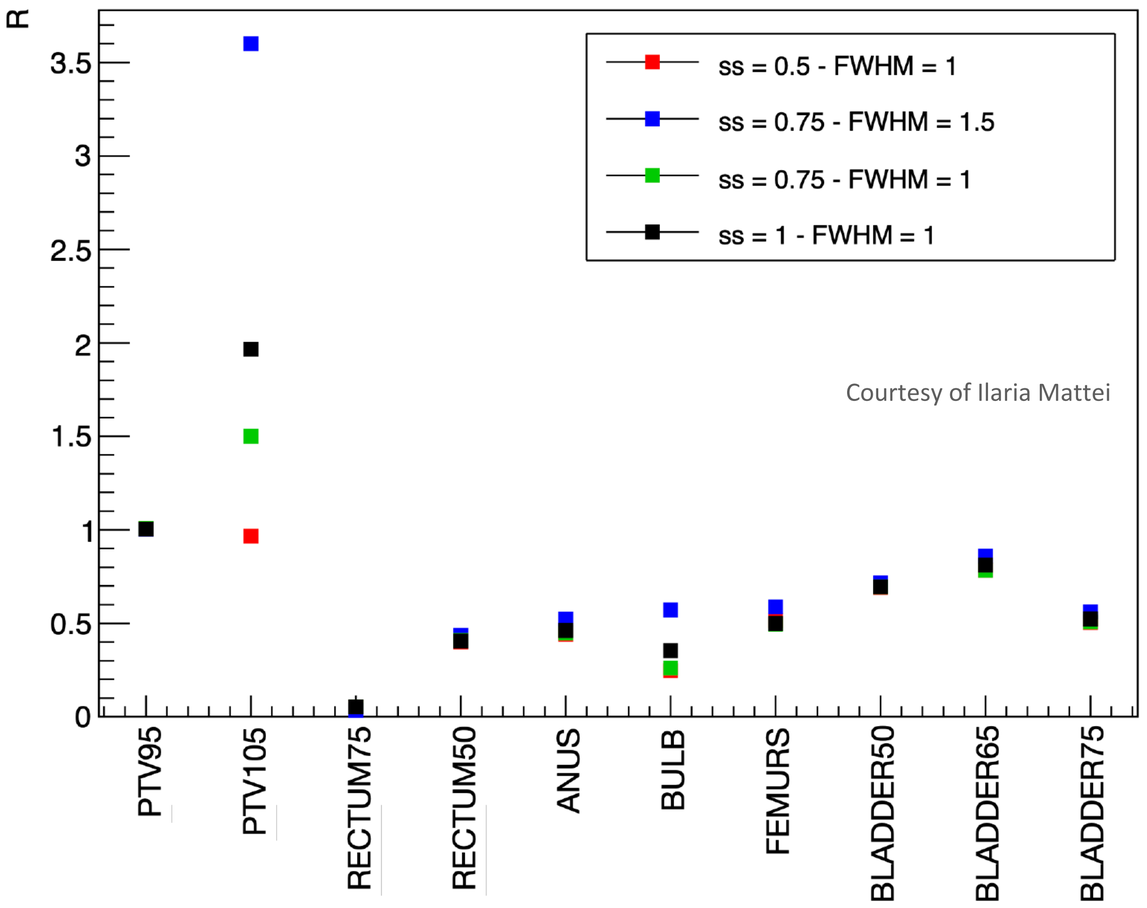
- As a starting exercise we investigated the case of prostate cancer already published in 10.3389/fonc.2021.777852

Reference: Spacing 0.5 cm, spot size 1.0 cm FWHM

Case1: Spacing 0.75 cm, spot size 1.5 cm FWHM (reduction 33%)

Case2:Spacing 0.75 cm, spot size 1.0 cm FWHM (reduction 33%)

Case3:Spacing 1.0 cm, spot size 1.0 cm FWHM (reduction 25%)



Courtesy of Ilaria Mattei

Simulated annealing

- Simulated annealing is a probabilistic technique for approximating the global optimum of a given function. Specifically, it is a metaheuristic to approximate global optimization in a large search space for an optimization problem. (Wiki)

- For problems where finding an approximate global optimum is more important than finding a precise local optimum in a fixed amount of time, simulated annealing may be preferable to exact algorithms such as gradient descent or branch and bound.

- In our application: correlated optimisation of energy and fluence!

- At moment, the dose is calculated with an analytical model in water-equivalent approximation. Open issue: dose directly from MC? Challenging from the computational point of view… (smart rebinning?)

- We started…

The next future

- Study of new cases and/with introduction of flash effect (threshold, dose rate)

- **Optimisation algorithm improvement**:
  - Explore new strategy for planning (volume based approach..)
  - FLASH effect embedding (Dose rate, threshold)