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Interactive Dose Modification

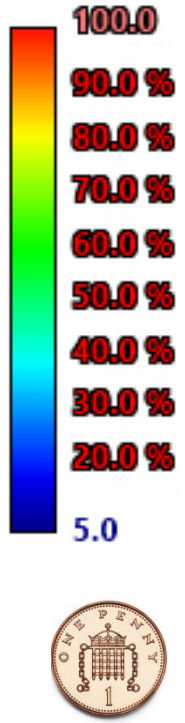
a novel approach to proton therapy treatment planning

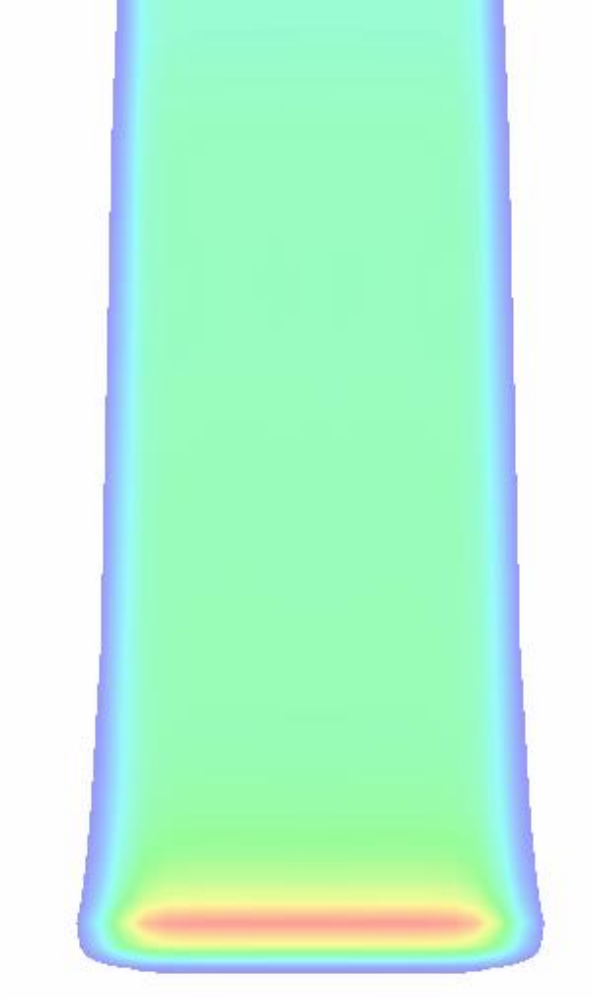
Matthew Lowe | Matthew.Lowe11@nhs.net

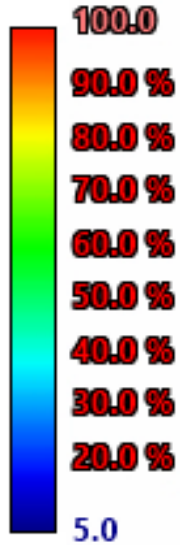
But first...

what does proton treatment planning look like?

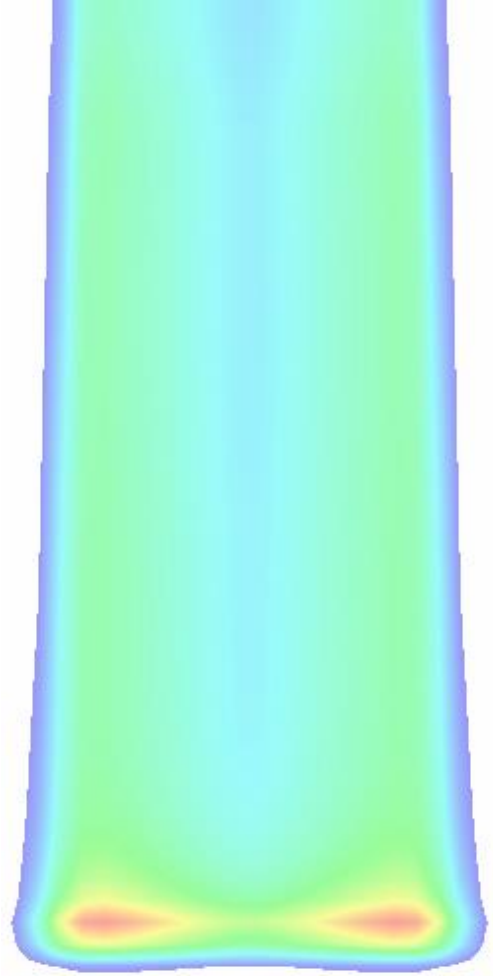
Pencil beam or '*Spot*'

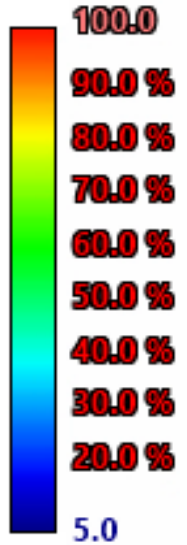




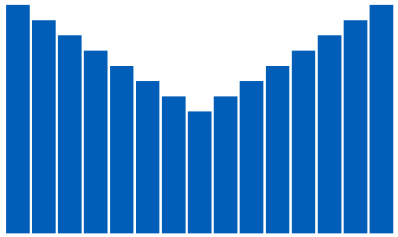


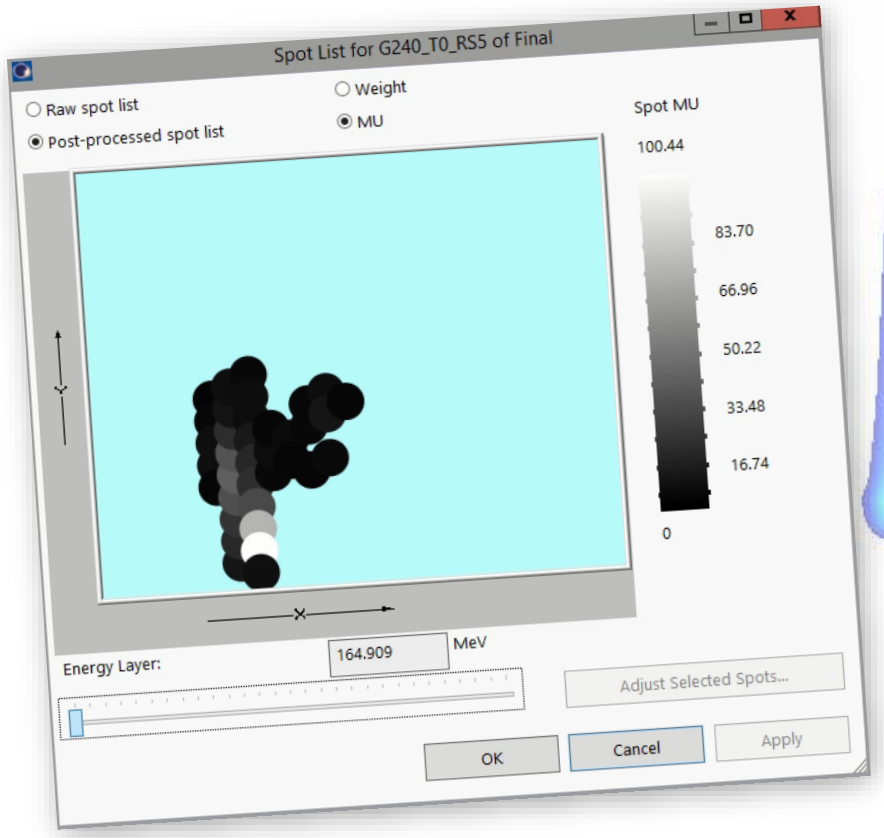
Spot weights, ω

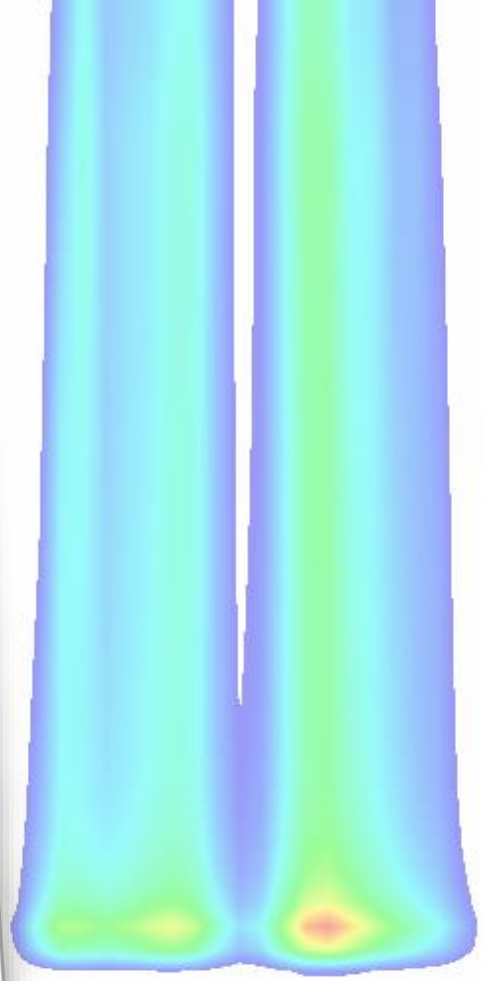


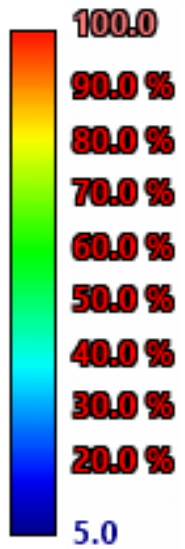


Spot weights, ω

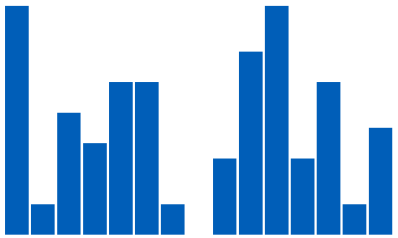




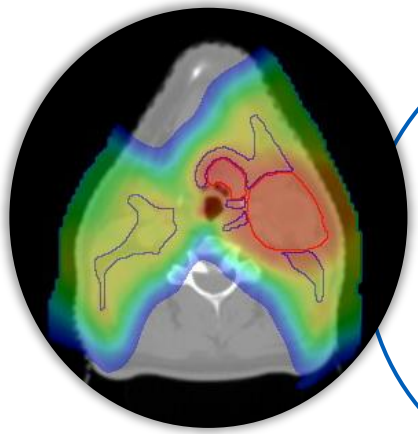




Spot weights, ω

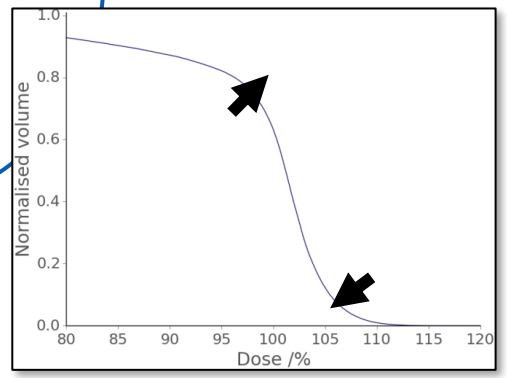



Plan Information
ID/Type
cm³
Lower
CTV1
Upper
Lower
Lower
Target
CTV2
Upp
Lo
[S]C
[S]L
[S]Pa
Upp
Upper
Fields
Perturbations
Normal Tissue Objective
Settings
Automatic Optimization Mode
Optimize Us
Multi Field Optimization: NUPO
Isodoses...
7700 cGy
7350 cGy
6650 cGy
880 cGy
0 cGy
cGy
114.3
00 cm
10.00 cm
Open Log...
OK
Cancel
22.8 100.0 7000 5650
108.6
Upper 0.0 0.0 7000 7968 150
Lower 108.6 100.0 7000 6639 240
Lower 107.5 99.0 7000 6804 200
Target gEUD 7000 6987 100 1.0
CTV2 333.2
Upper 3.3 1.0 7000 7273 100
Lower 333.2 100.0 5600 4679 100
Lower 329.9 99.0 5600 5402 200
[S]Cavity_Oral 45.8
Upper gEUD 700 1094 100 1.0
[S]Larynx_SG 0.3
Upper gEUD 2000 2971 0 1.0
[S]Parotid_L 24.0
Upper 4.8 20.0 1300 1495 110
2.4 10.0 2000 2025 100
14.4 60.0 100 294

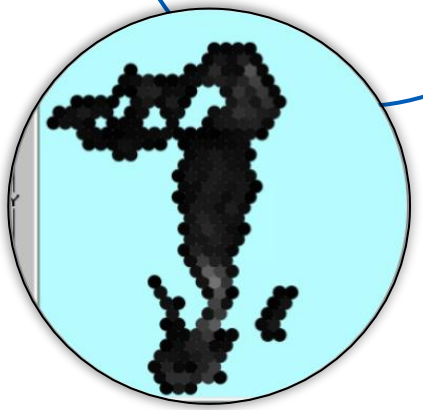


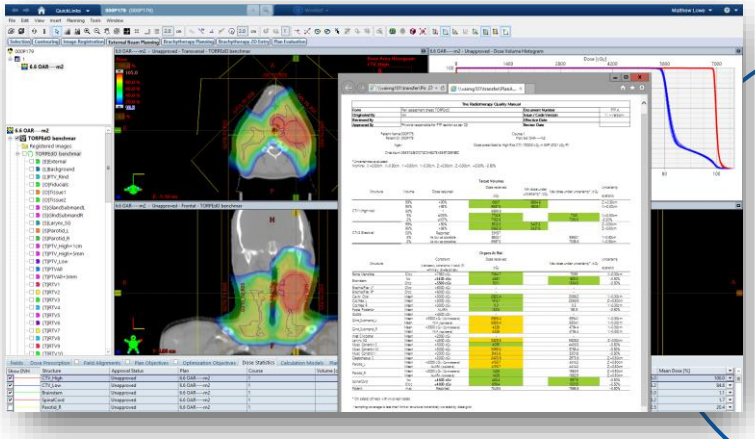
Calculate dose distribution

Compare with objectives

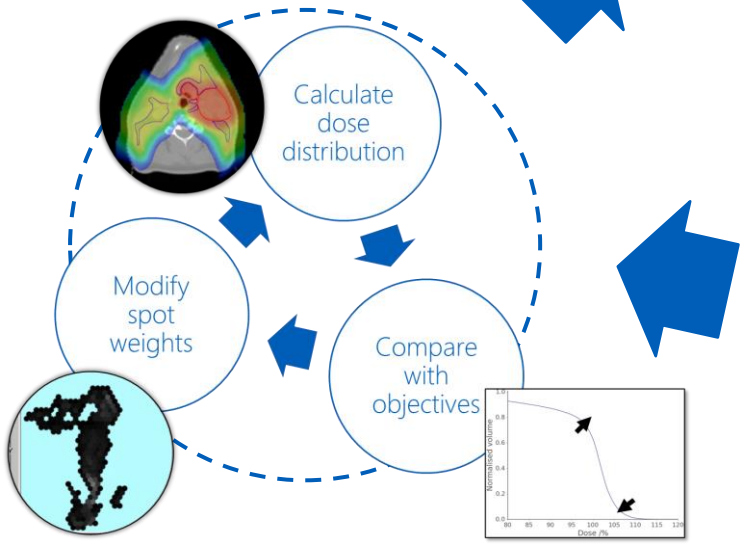


Modify spot weights

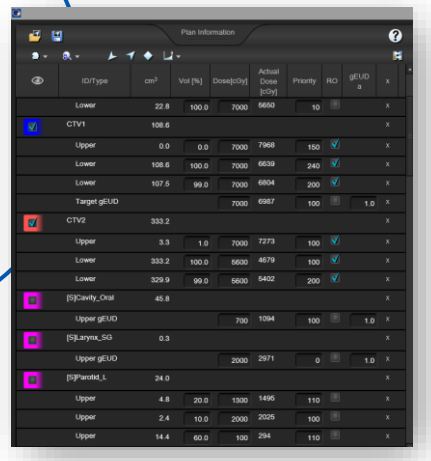


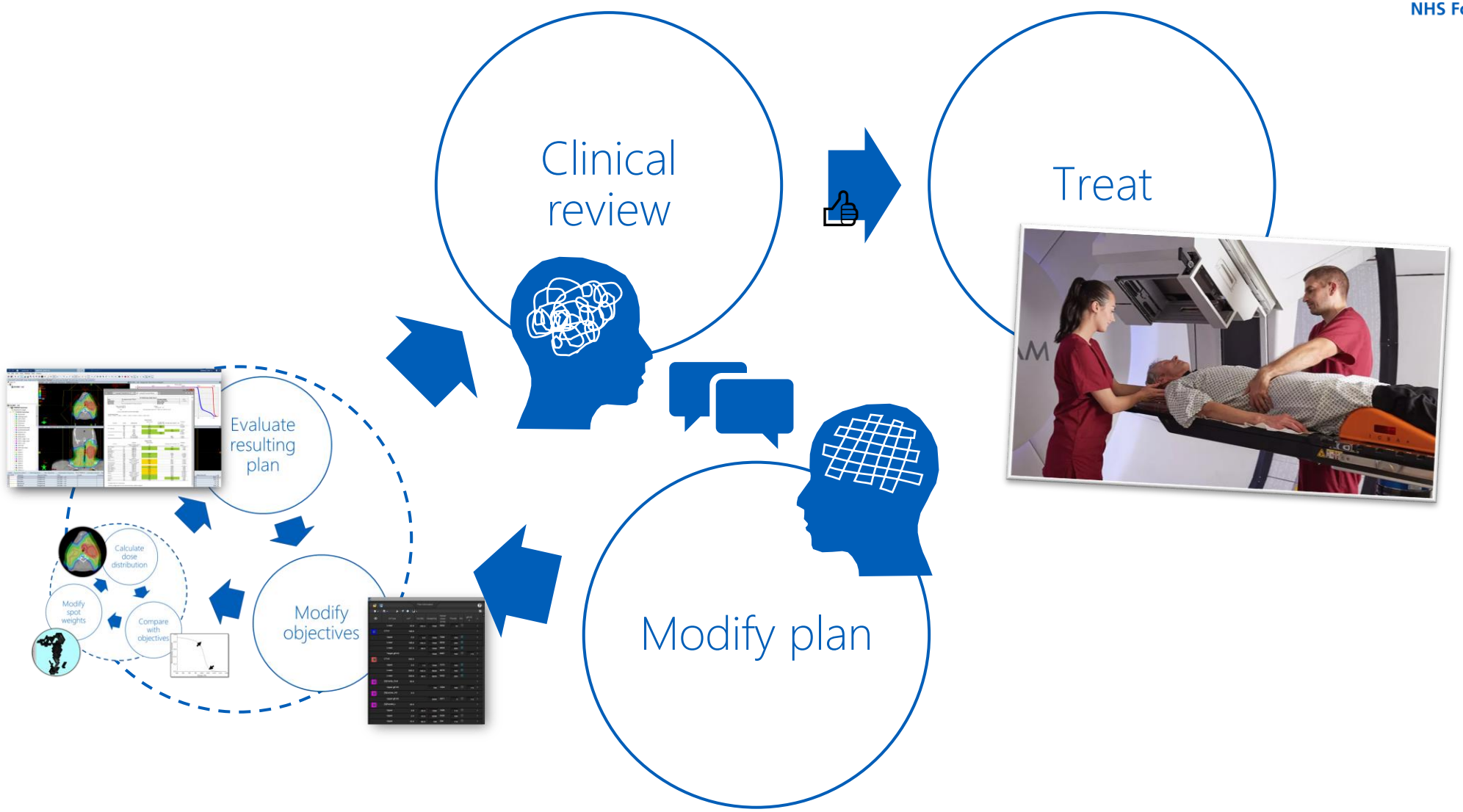


Evaluate resulting plan



Modify objectives




Clinical review
Treat
Modify plan
Evaluate resulting plan
Modify objectives
Calculate dose distribution
Compare with objectives
Modify spot weights


Interactive Dose Modification v0.42
Interactive
Dose
Modification
v0.42

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Treatment Planning System

Contouring
Planning

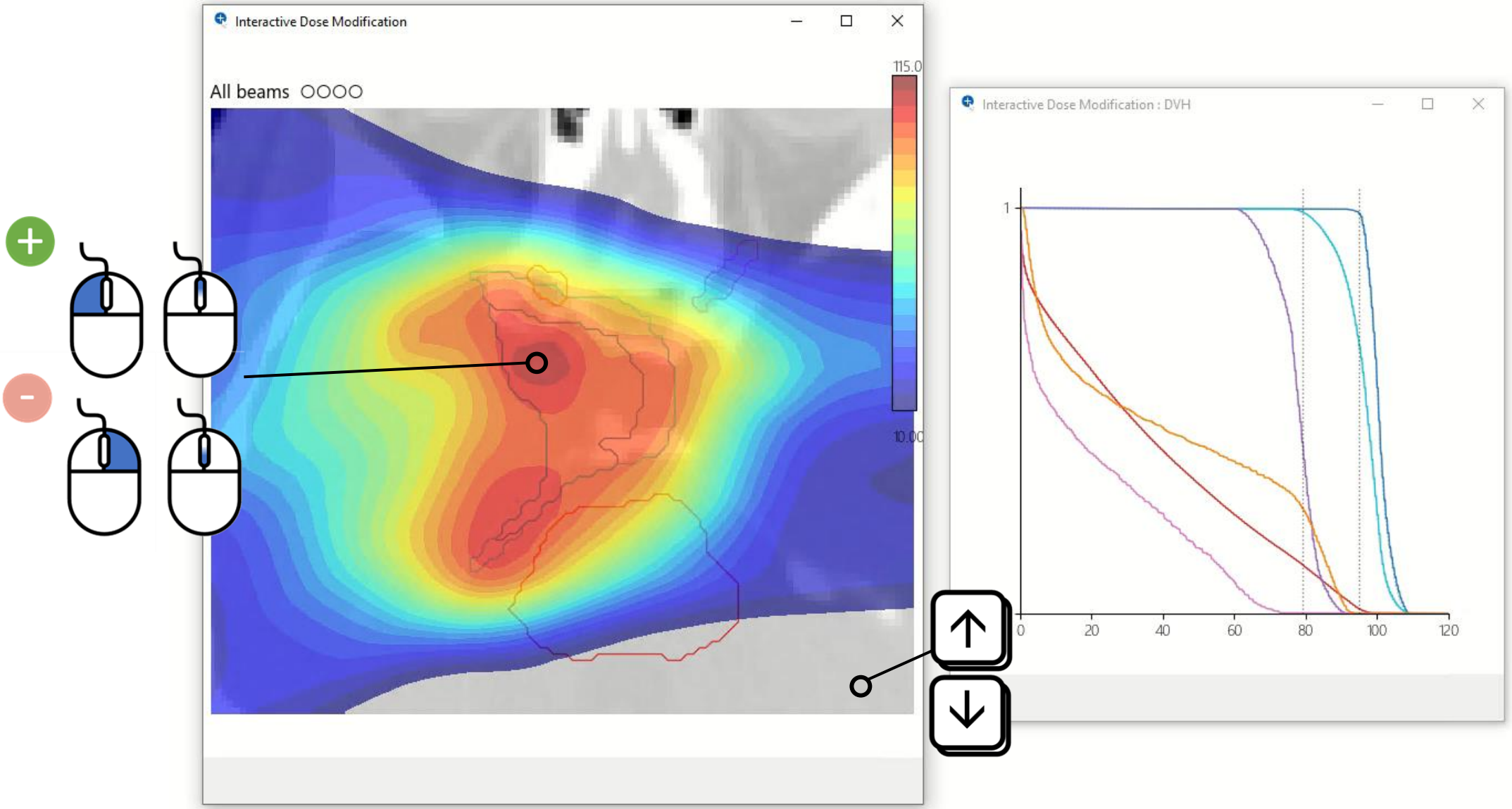
DICOM:
CT
Structures
Dose
Plan

Scripting:
Spot weights
Influence matrix

Spot weights

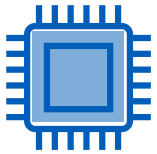
Treatment Planning System

Treatment Delivery

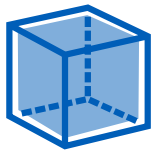

Interactive Dose Modification
All beams
115.0
10.00
Interactive Dose Modification : DVH
1
0
20
40
60
80
100
120

Response time:
~0.2 s

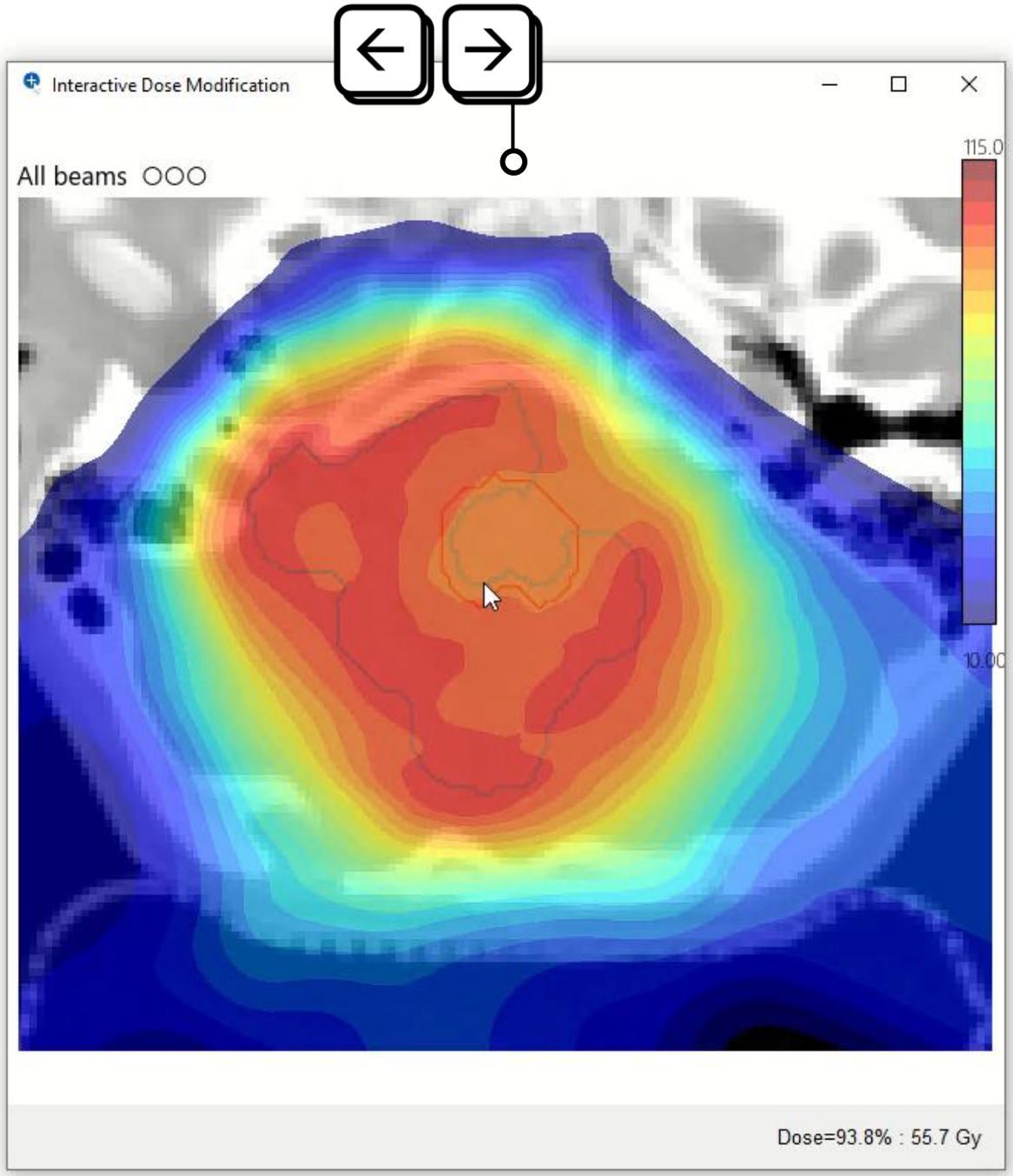
Minimum spot weights accounted for in real-time



Demonstrated using an Intel Xeon CPU E5-2680 v3 @ 2.50GHz



Resolution:
0.98 x 0.98 x 1 mm



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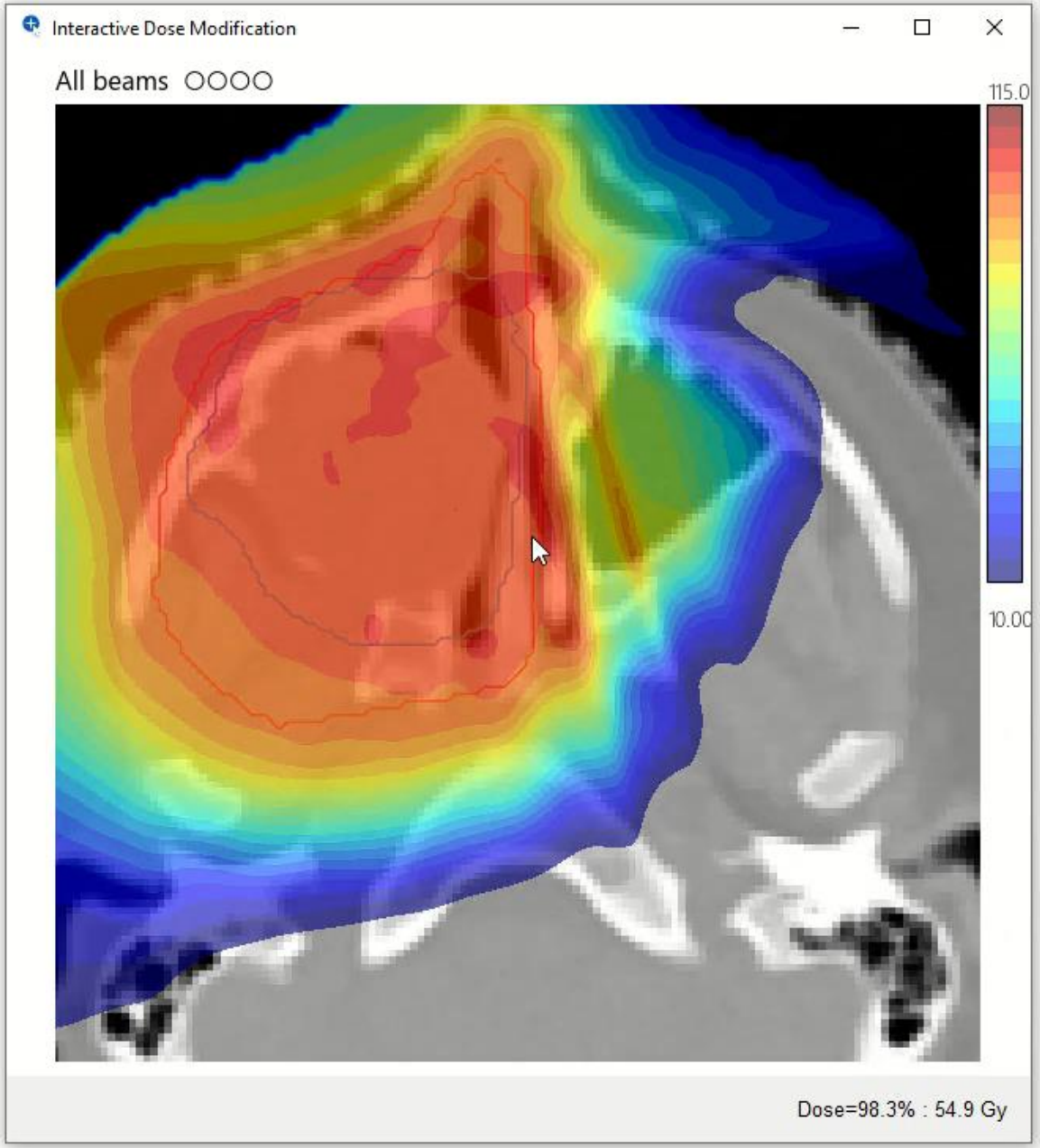
View and modify fields individually

Lock beams, preventing further changes

L Lock/unlock beam

S Show spot positions

P Place pin



View spot positions and weights

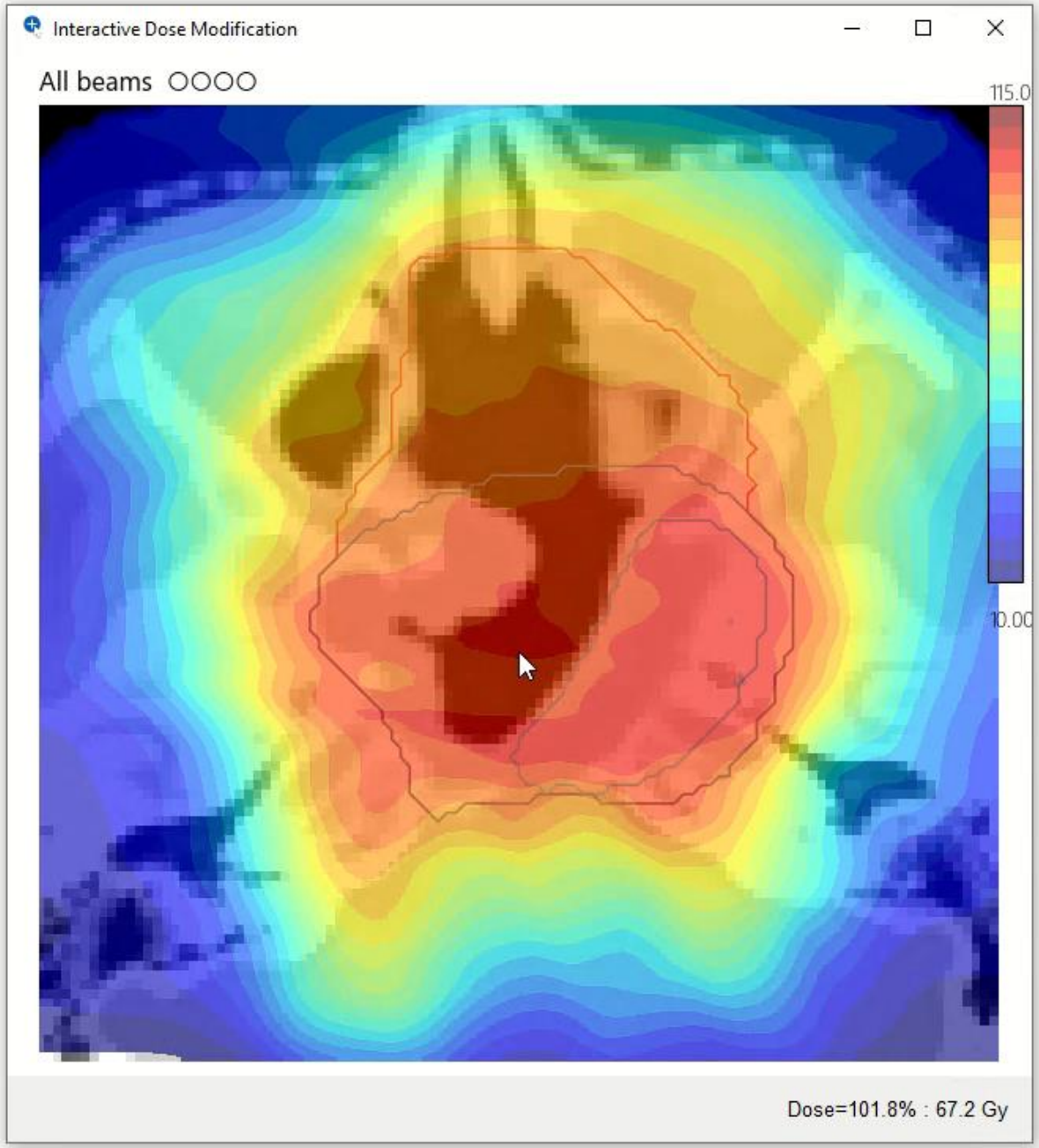
Pin dose to minimise change at a given point

Ctrl + Z

Ctrl + 1

1

0



Undo & bookmark to save progress

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Click or **scroll** to change dose

Shift ×2

Ctrl ×5

Holding **Shift** and/or **Ctrl** will increase effect

Cycle through individual beam doses

Bookmarks:

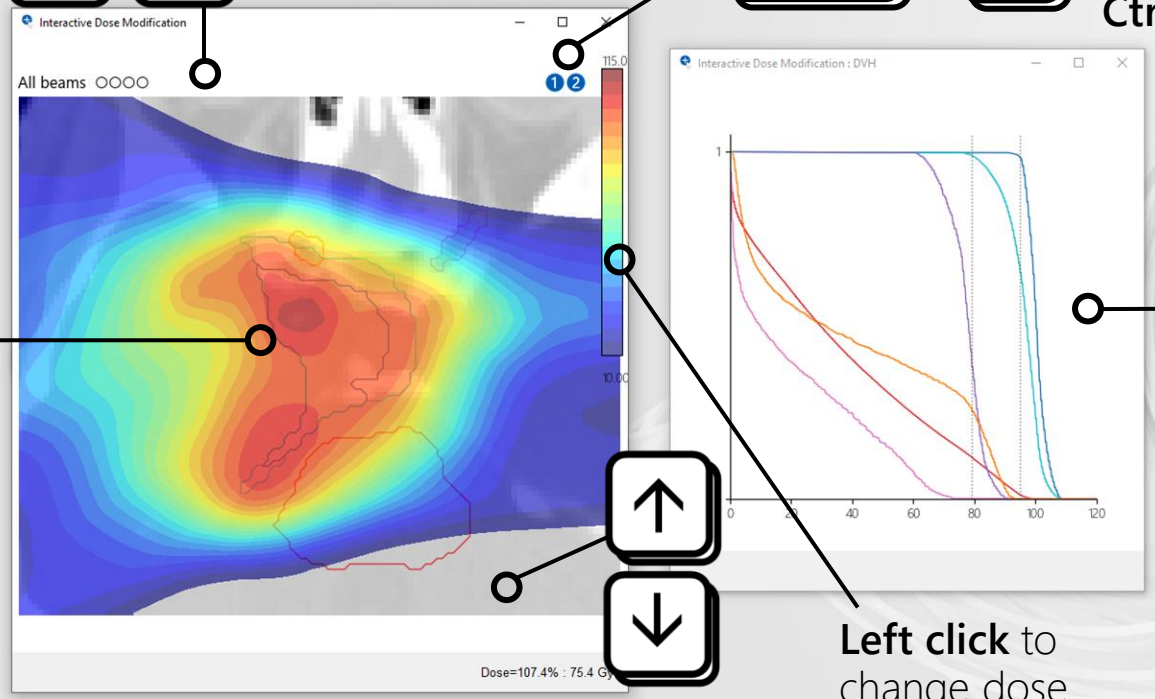
Ctrl + 1

Ctrl and **any number** to store weights

Ctrl + Z to undo

1

Number to restore (0 to restore initial weights)

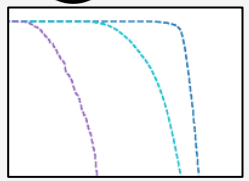


Scroll through slices

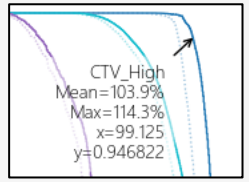
Left click to change dose display

Right click to switch between absolute and relative dose

Hover or **Left click** to recalculate DVHs



Dashed: DVHs outdated



Transparent dotted: Original DVHs

Hover to see DVH statistics

Right click to reselect ROIs

I Show isodose labels

S Show spot positions

P Place pin

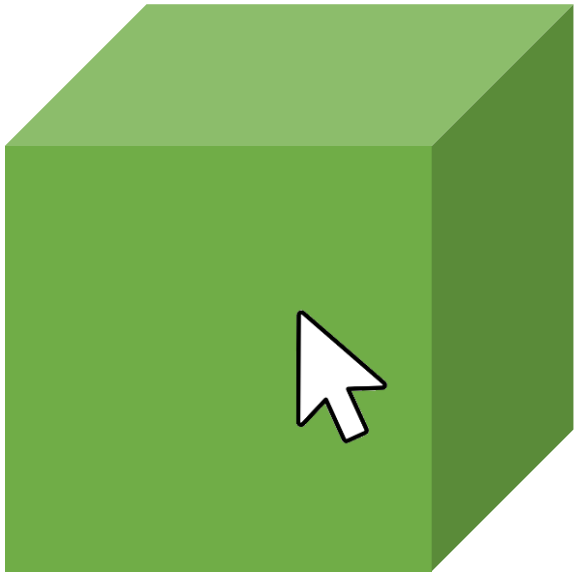
[Remove pins

R Renormalise

L Lock/unlock beam

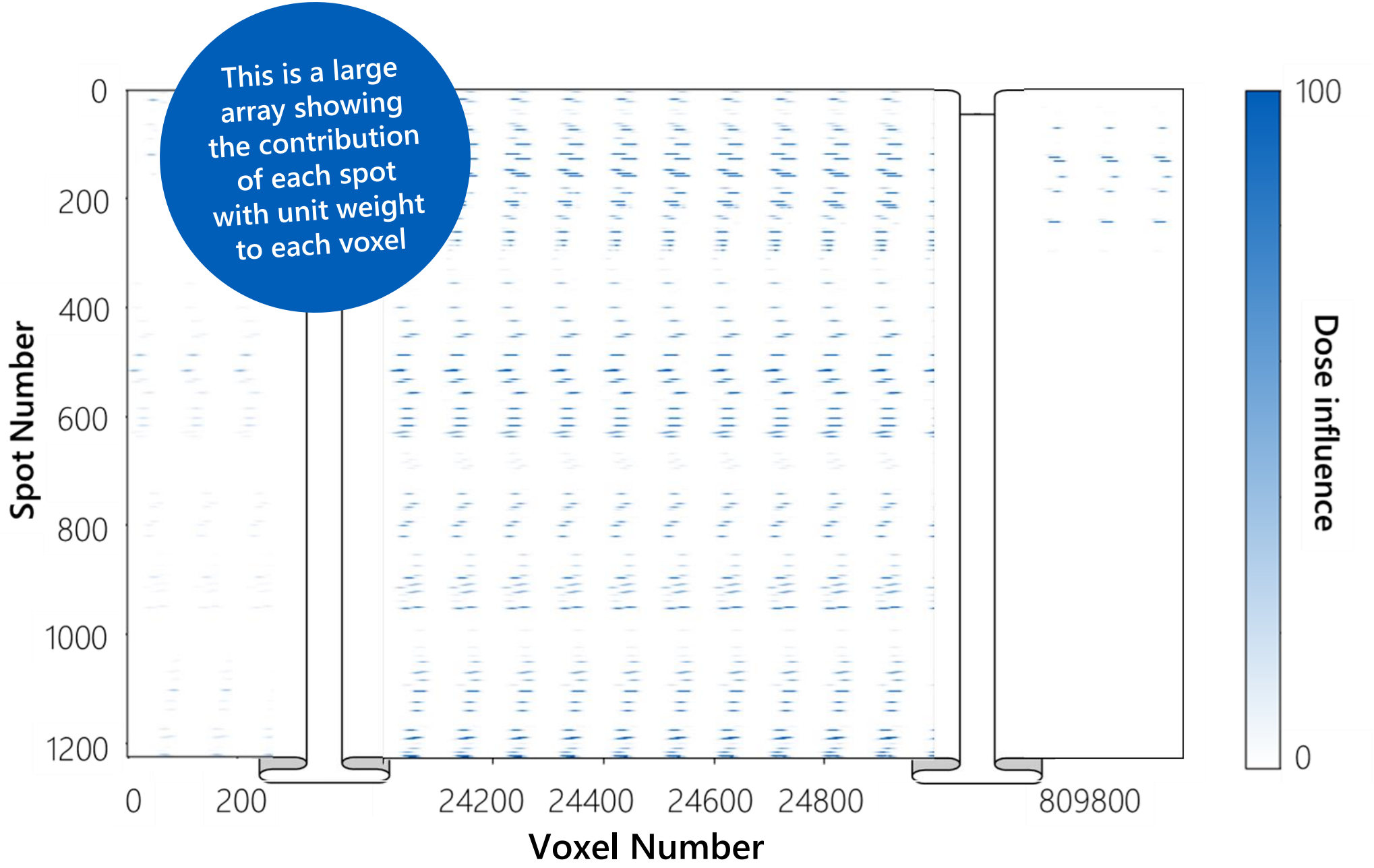
X Export to TPS

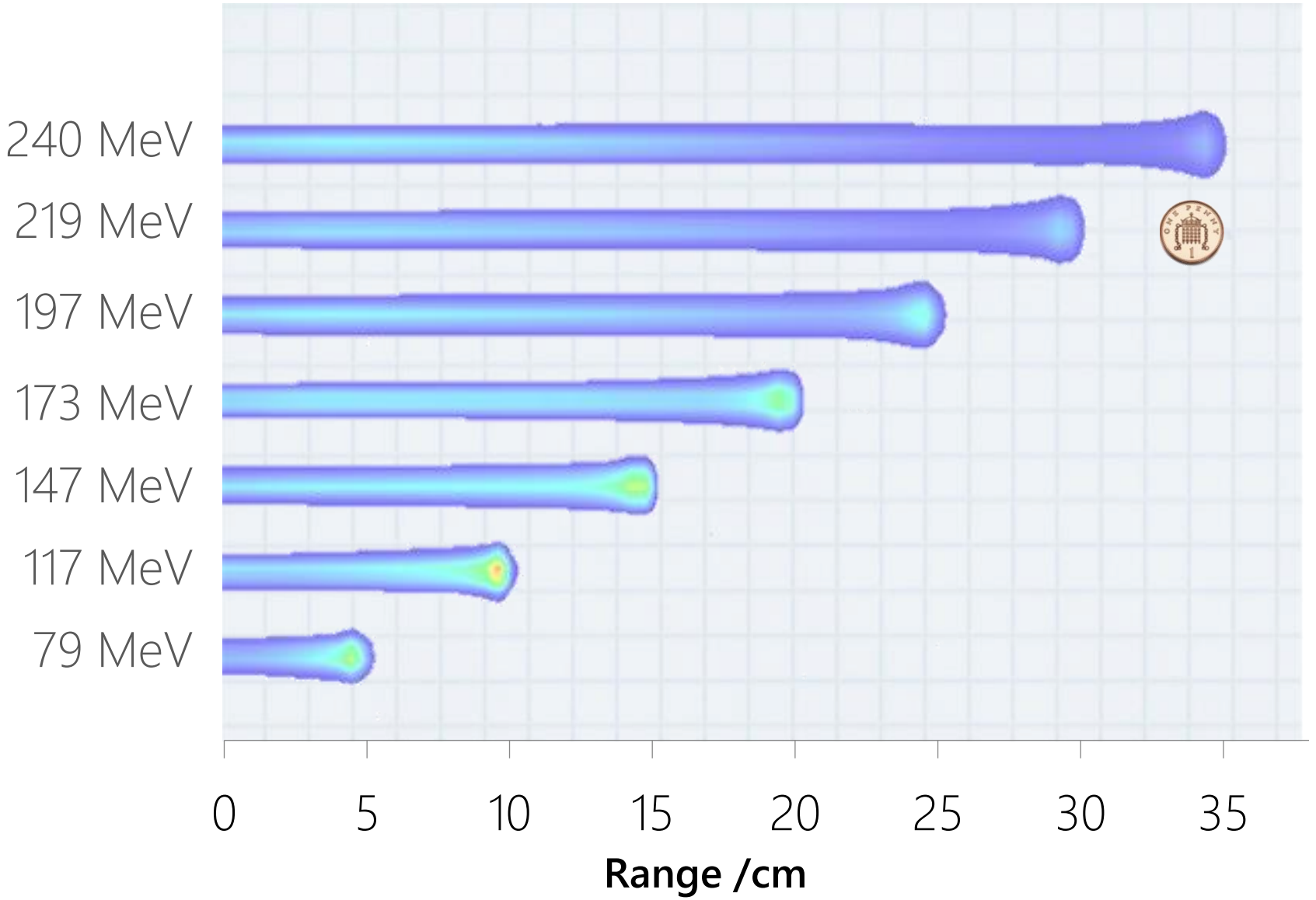
Method

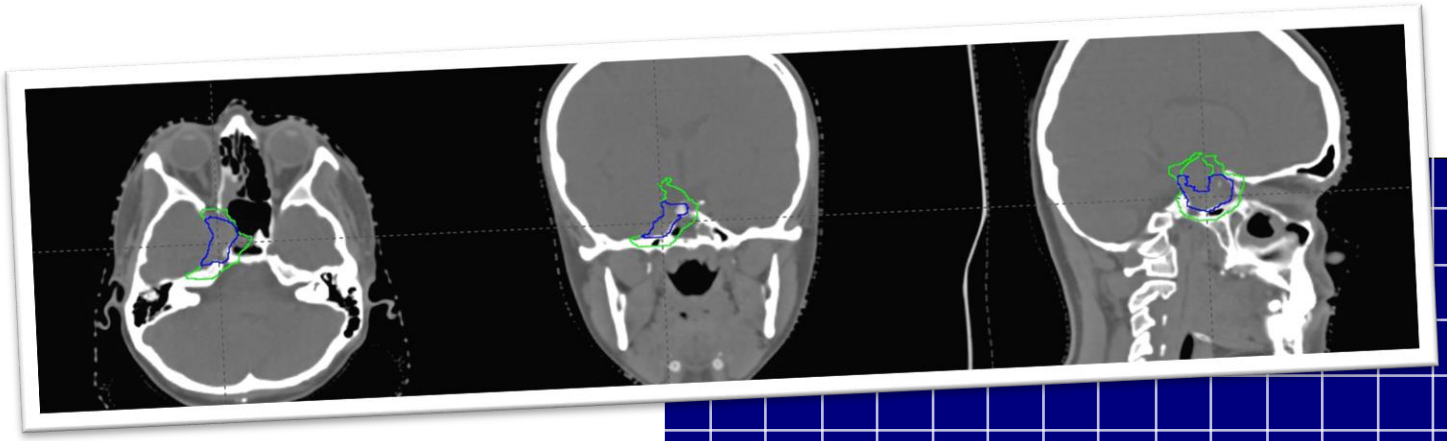


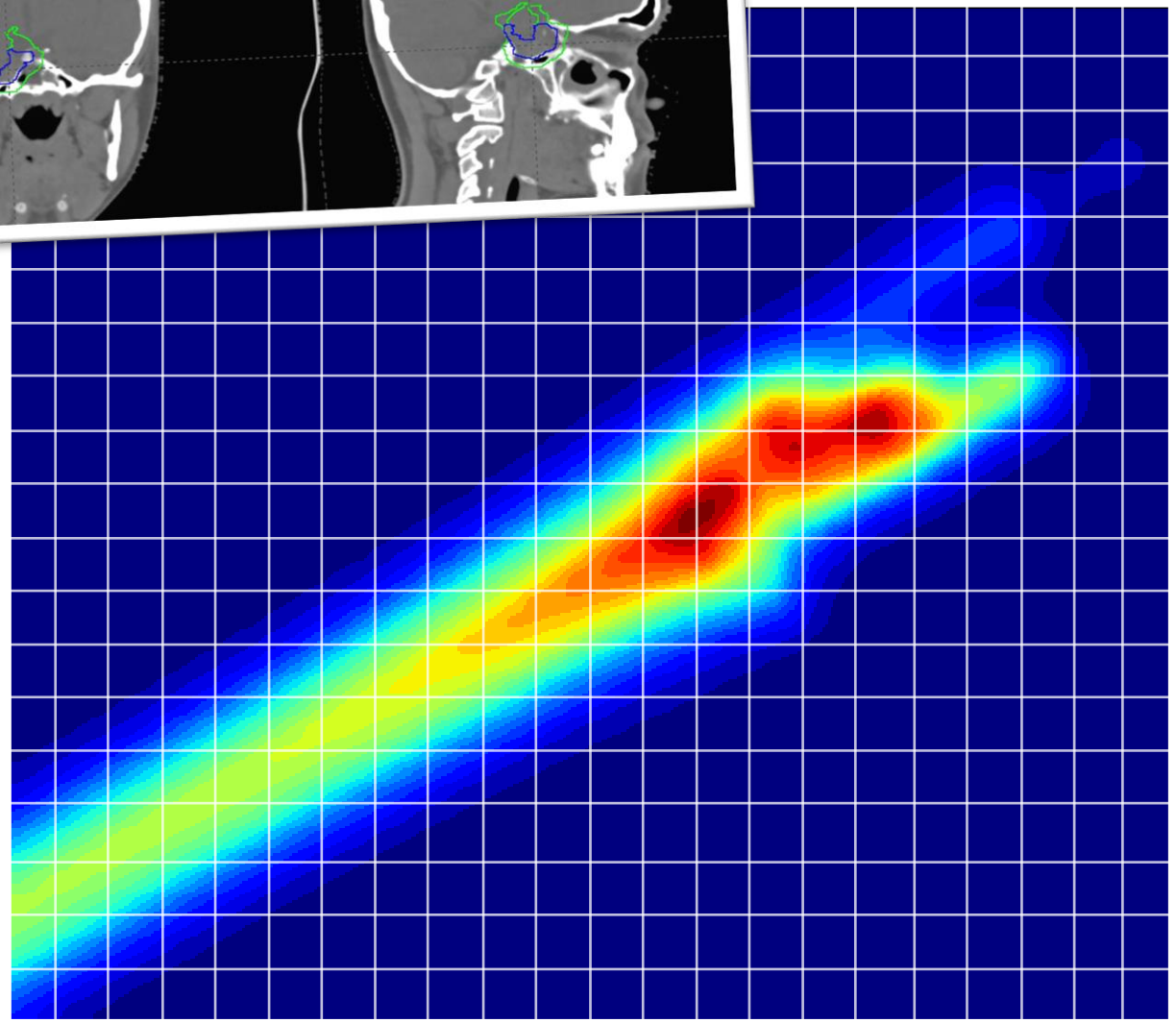
To change the dose at a point we need to know which spots contribute to that point.

This is done using an **influence matrix**

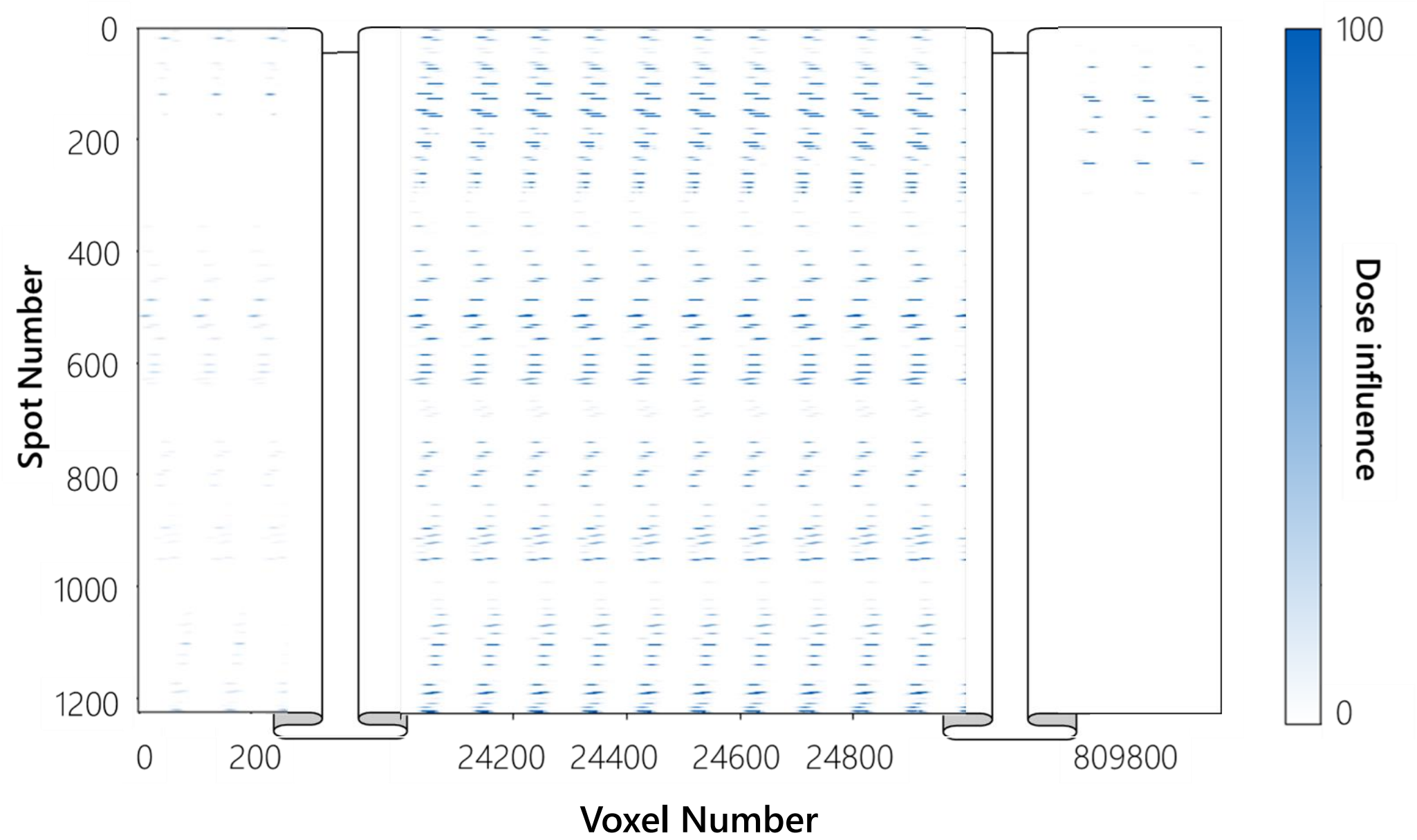

This is a large array showing the contribution of each spot with unit weight to each voxel
Spot Number
0
200
400
600
800
1000
1200
Voxel Number
0
200
24200
24400
24600
24800
809800
Dose influence
100
0

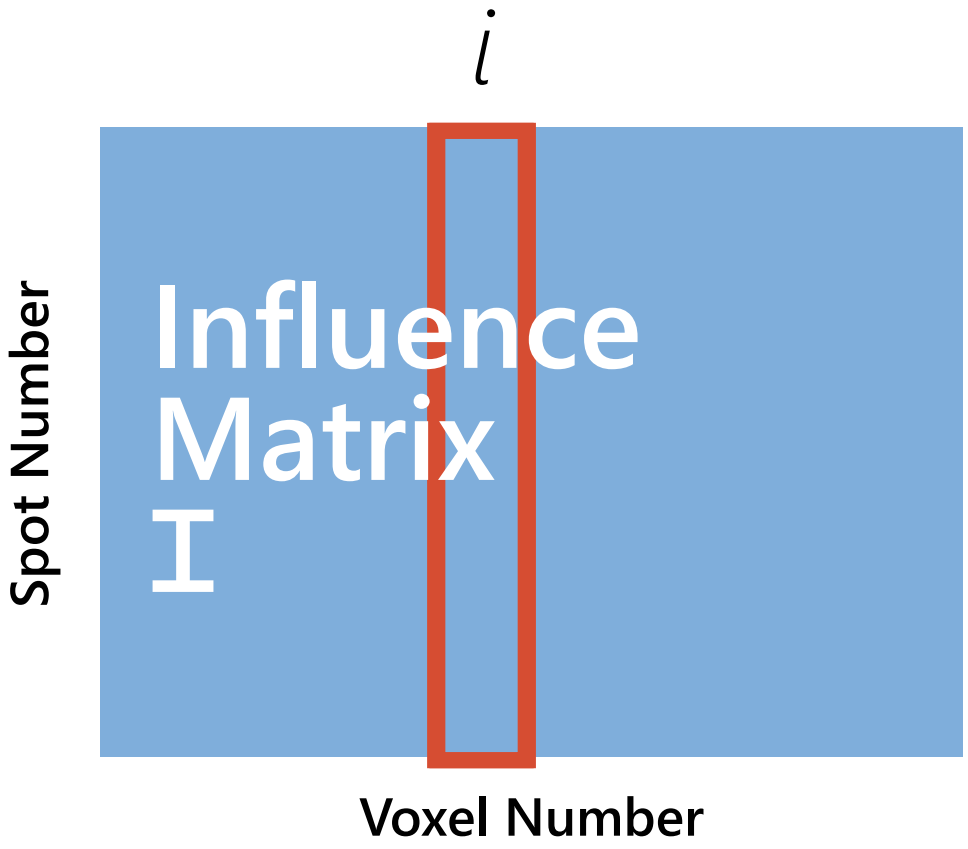

240 MeV
219 MeV
197 MeV
173 MeV
147 MeV
117 MeV
79 MeV
0
5
10
15
20
25
30
35
Range /cm



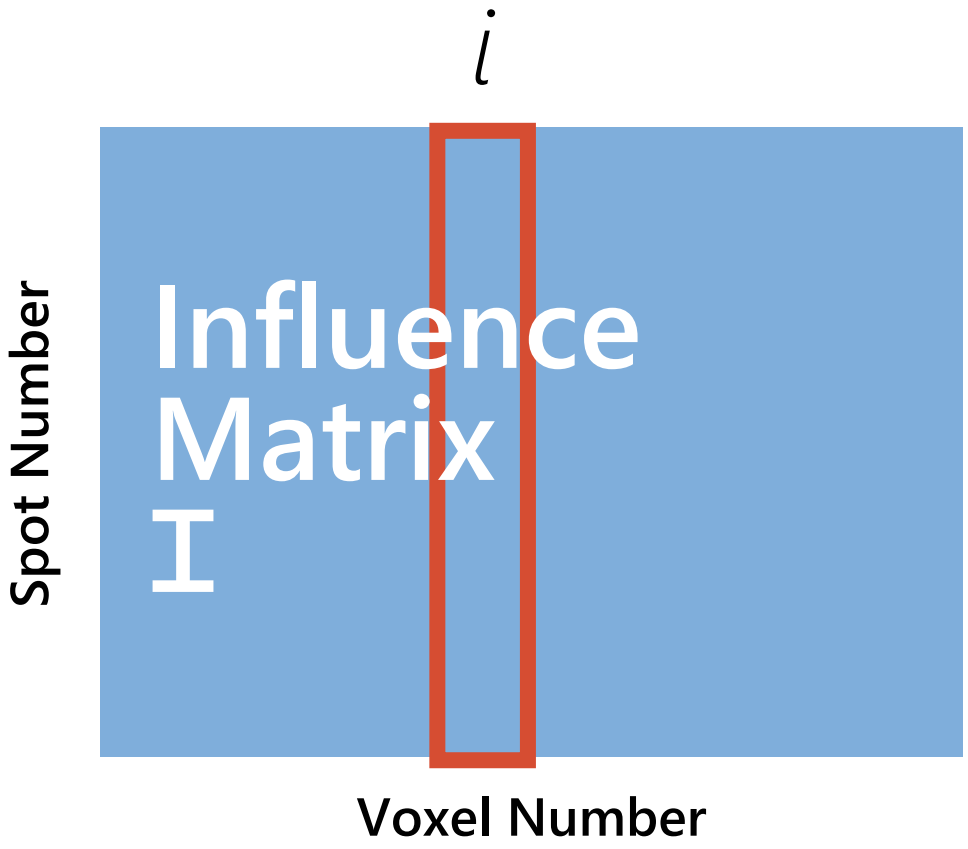


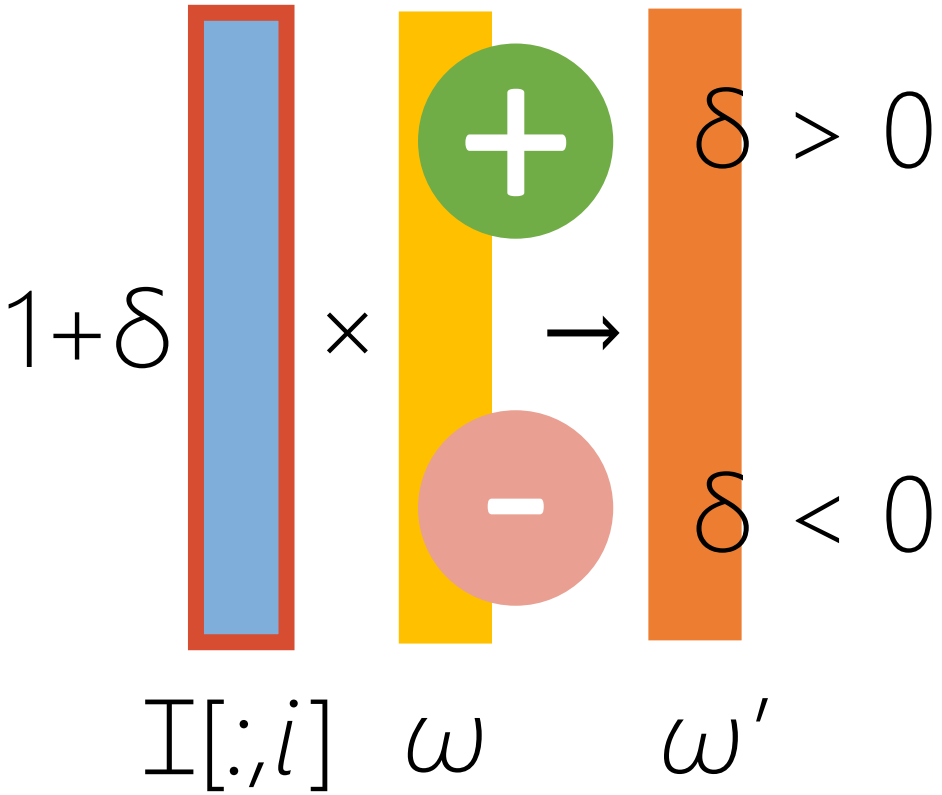
*actual voxels are ~5 times smaller than this…

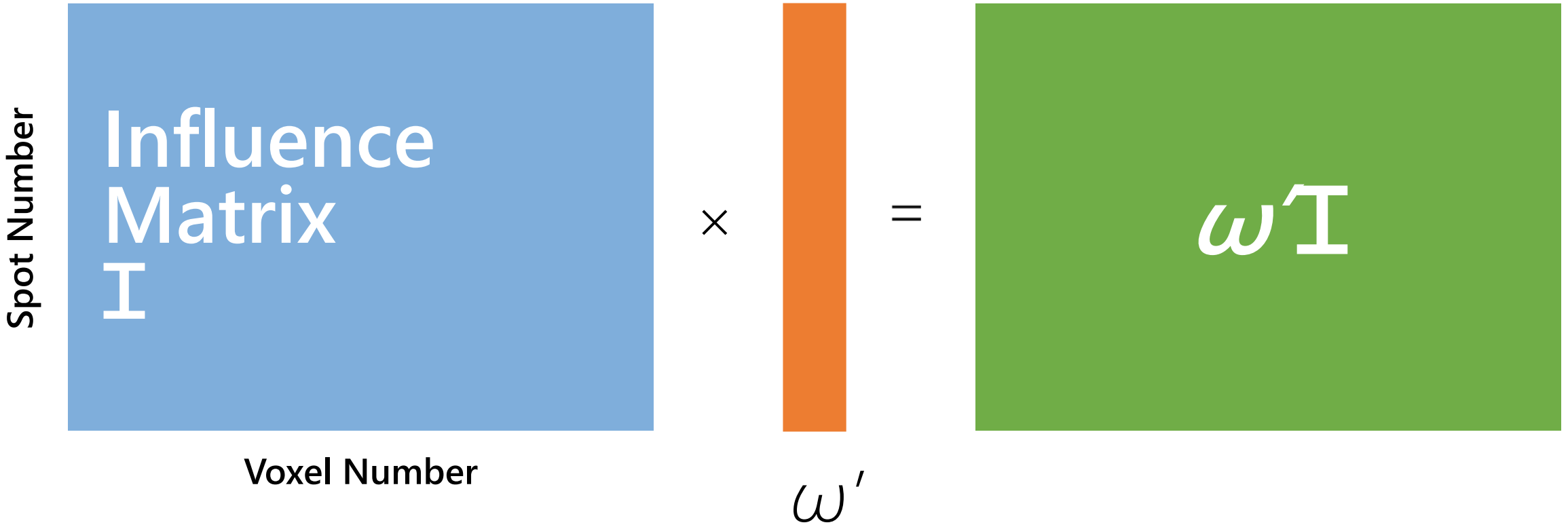

Spot Number
0
200
400
600
800
1000
1200
0
200
24200
24400
24600
24800
809800
Voxel Number
100
0
Dose influence



Dose
Distribution
D


i
Influence
Matrix
I
Spot Number
Voxel Number


1+δ
×
→
δ > 0
δ < 0
I[:,i]
ω
ω′


Spot Number
Influence Matrix
I
Voxel Number
×
ω′
=
ωI

$$\sum_{\text{spots}} \omega I$$

$$\sum_{\text{spots}} \omega I$$

$$\text{Voxel Number}$$

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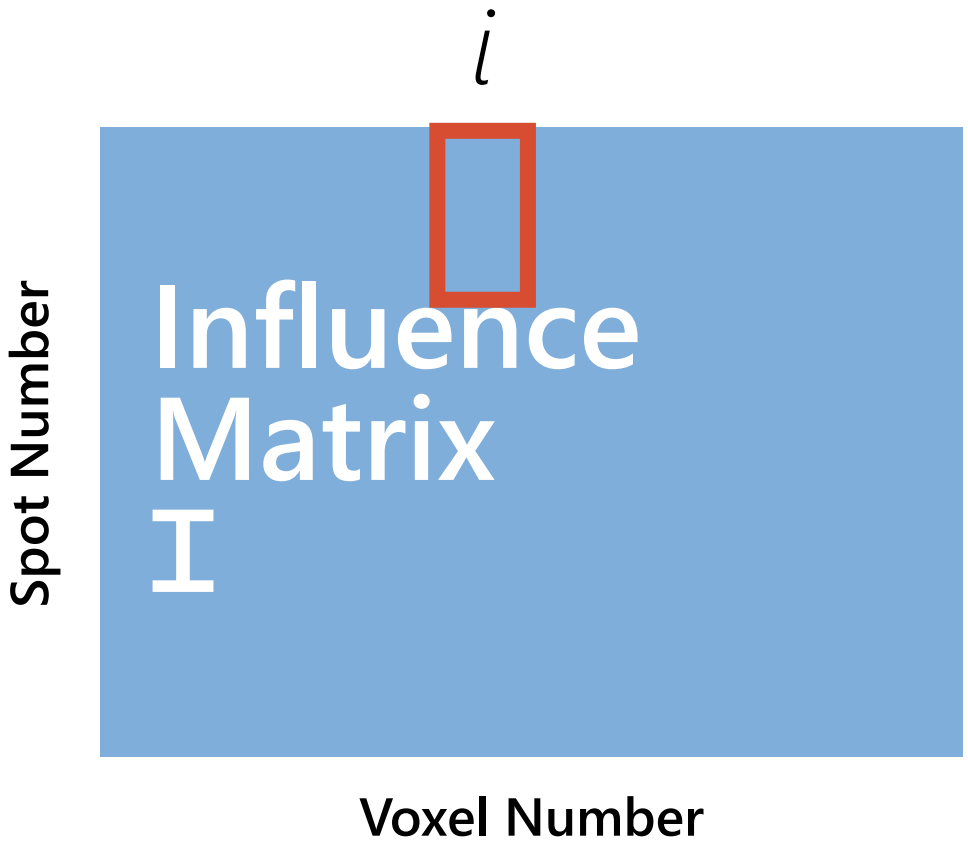
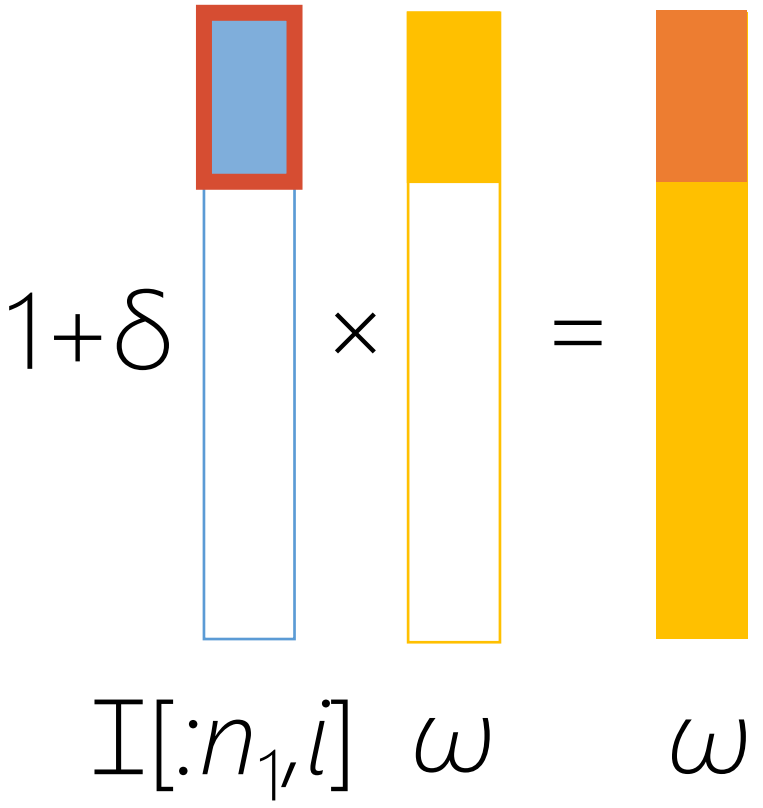
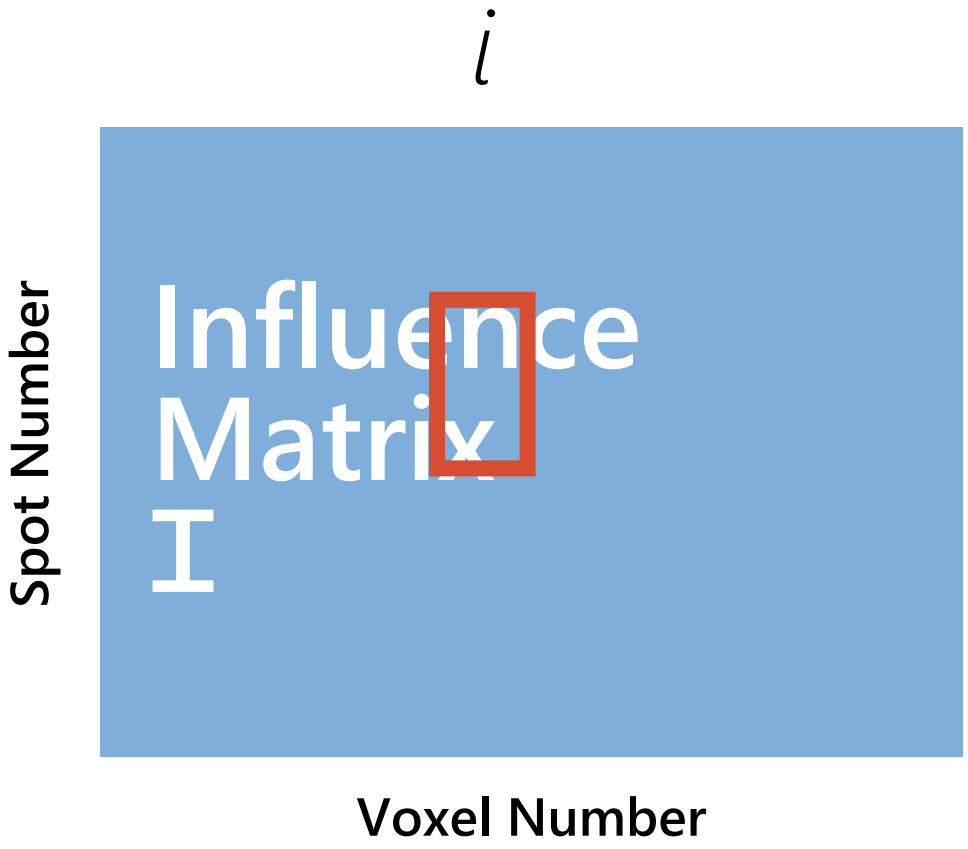
Dose Distribution D’

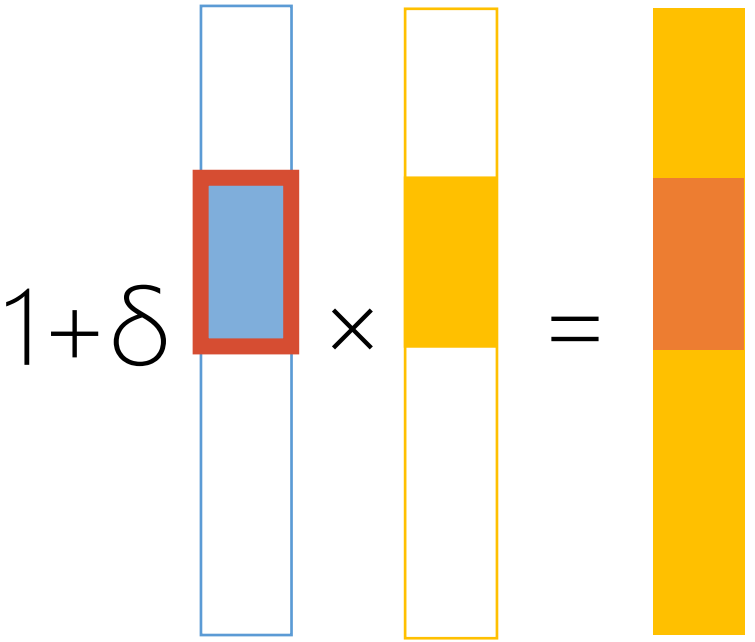
Method: field-only modification



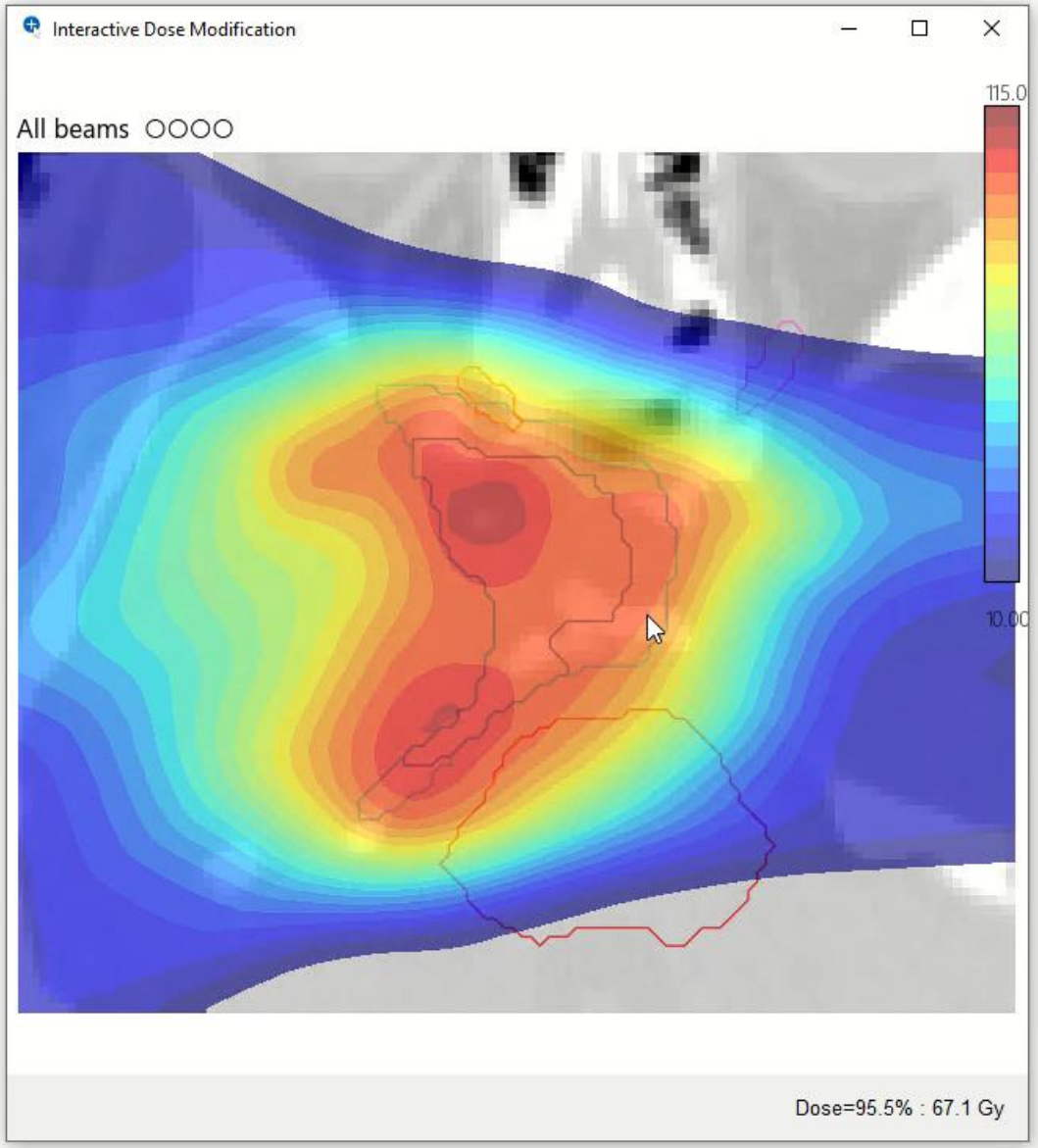


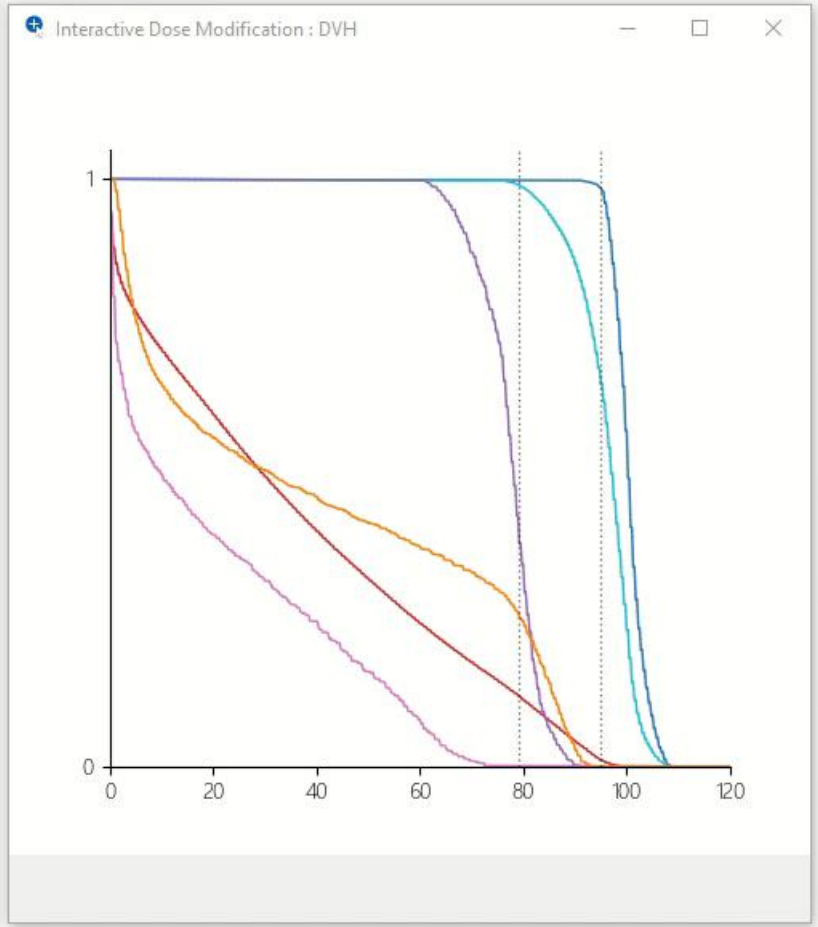
Method: field-only modification

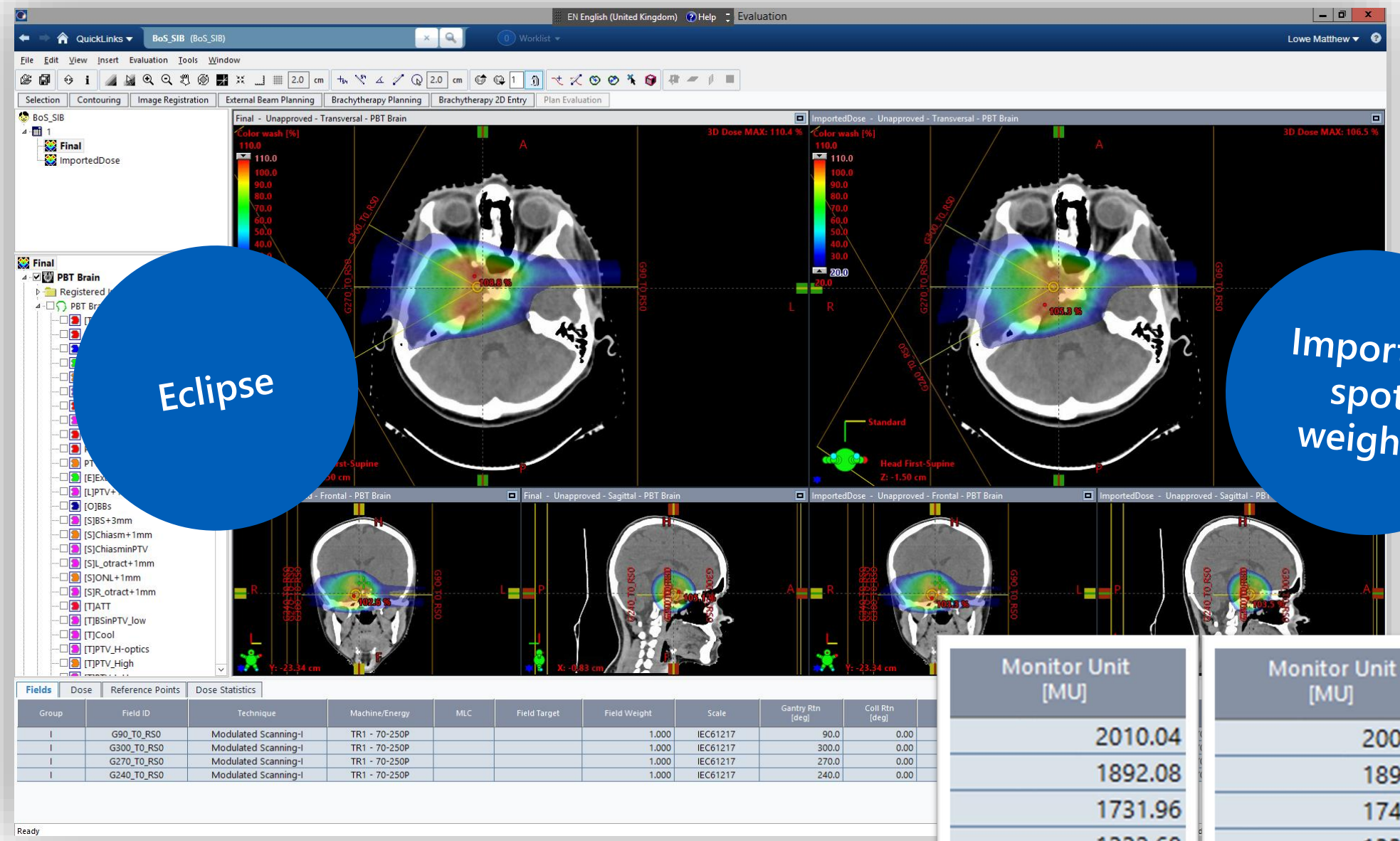




$I[n_1{:}n_2, i]\ \omega \qquad \omega'$


Interactive Dose Modification
All beams
115.0
10.00
Dose=95.5% : 67.1 Gy


Interactive Dose Modification : DVH
1
0
0
20
40
60
80
100
120



Monitor Unit [MU]
2010.04
1892.08
1731.96
1332.68

Monitor Unit [MU]
2003.87
1899.52
1743.41
1339.07

Method: minimum deliverable MU constraints

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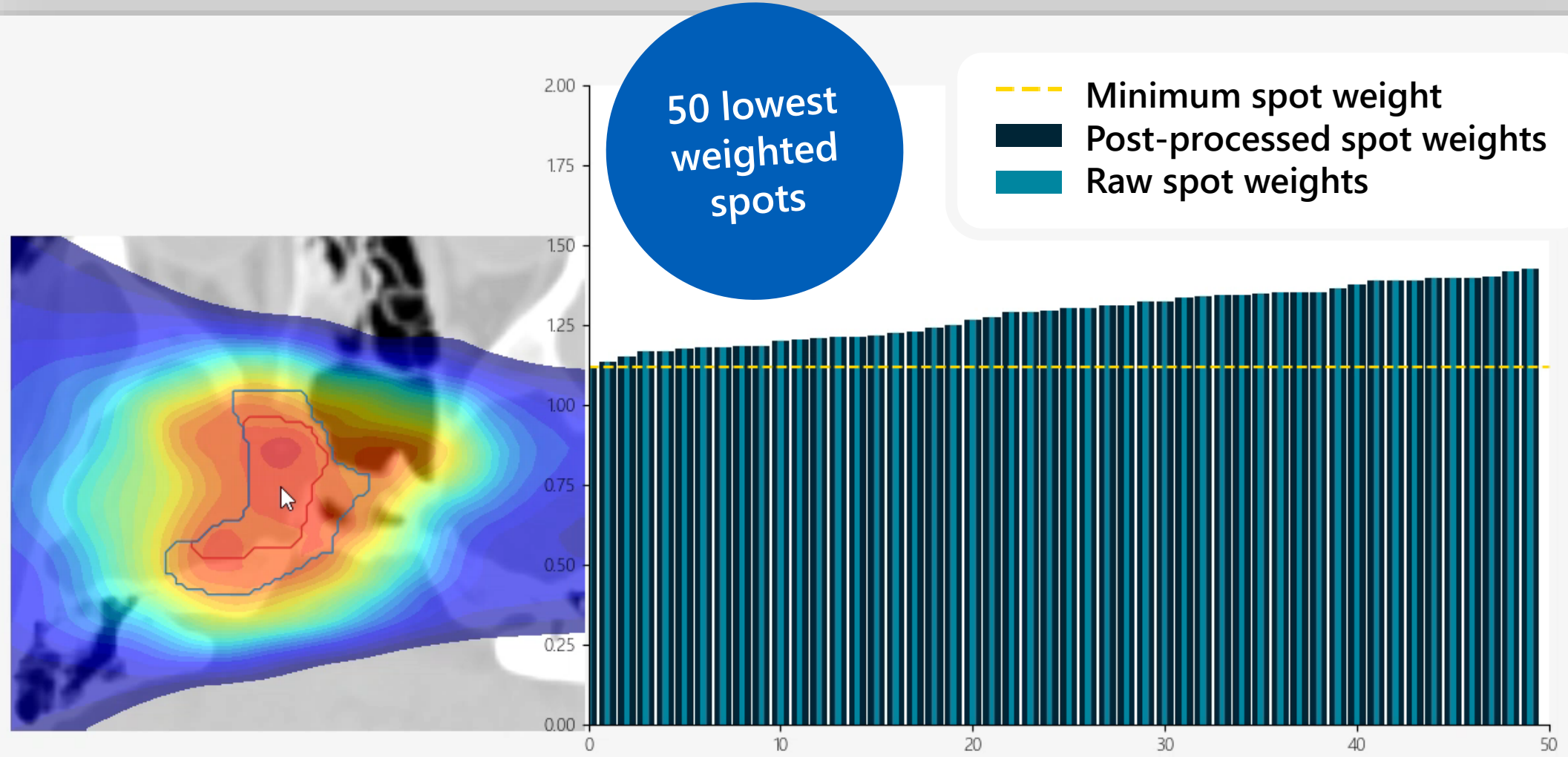
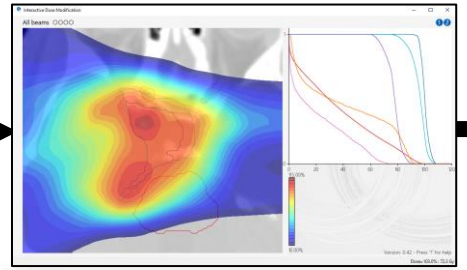


Treatment Planning System

Contouring
Planning

DICOM:
CT
Structures
Dose
Plan

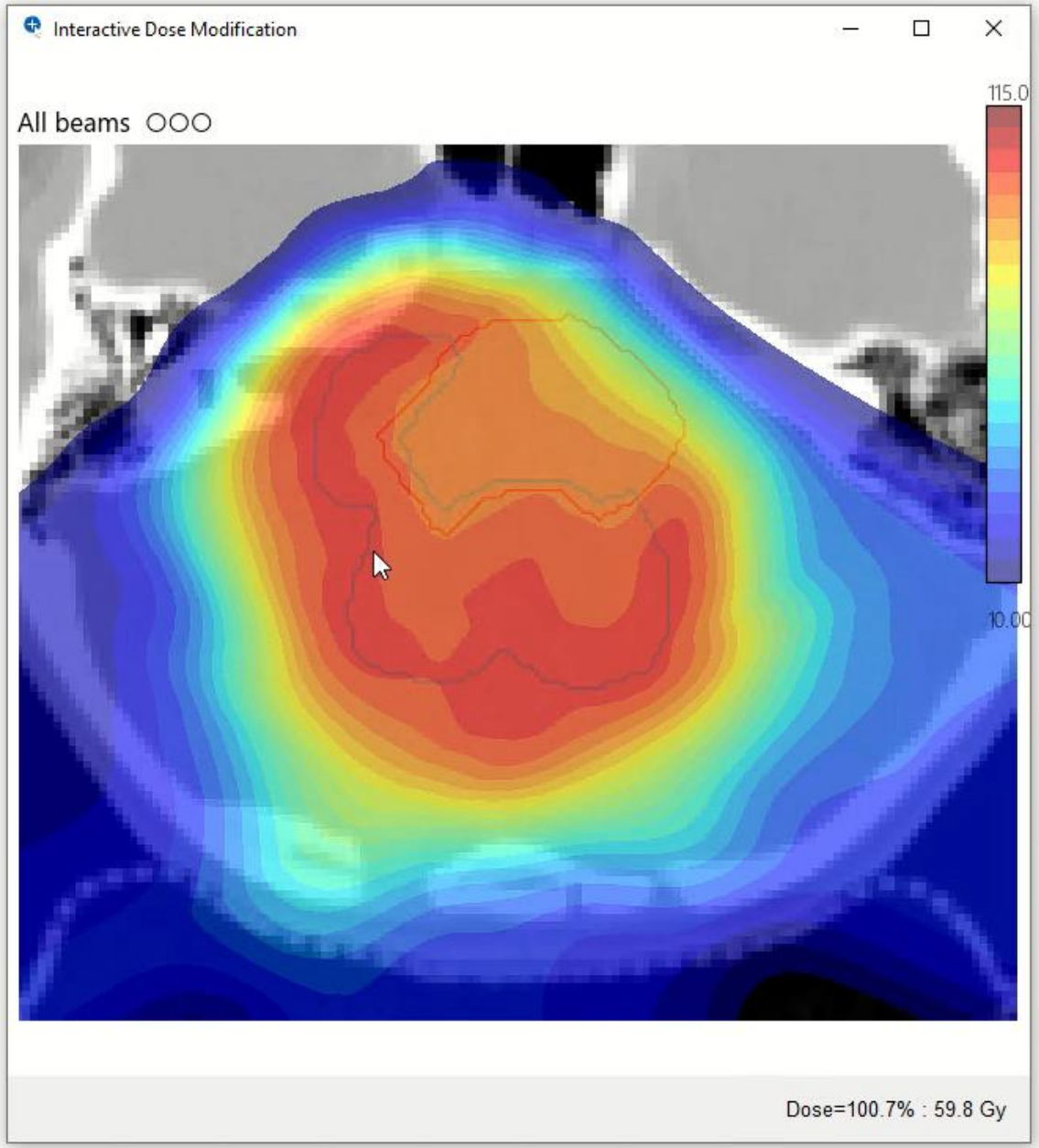


Spot weights

Treatment Planning System

Treatment Delivery

Scripting:
Spot weights
Influence matrix



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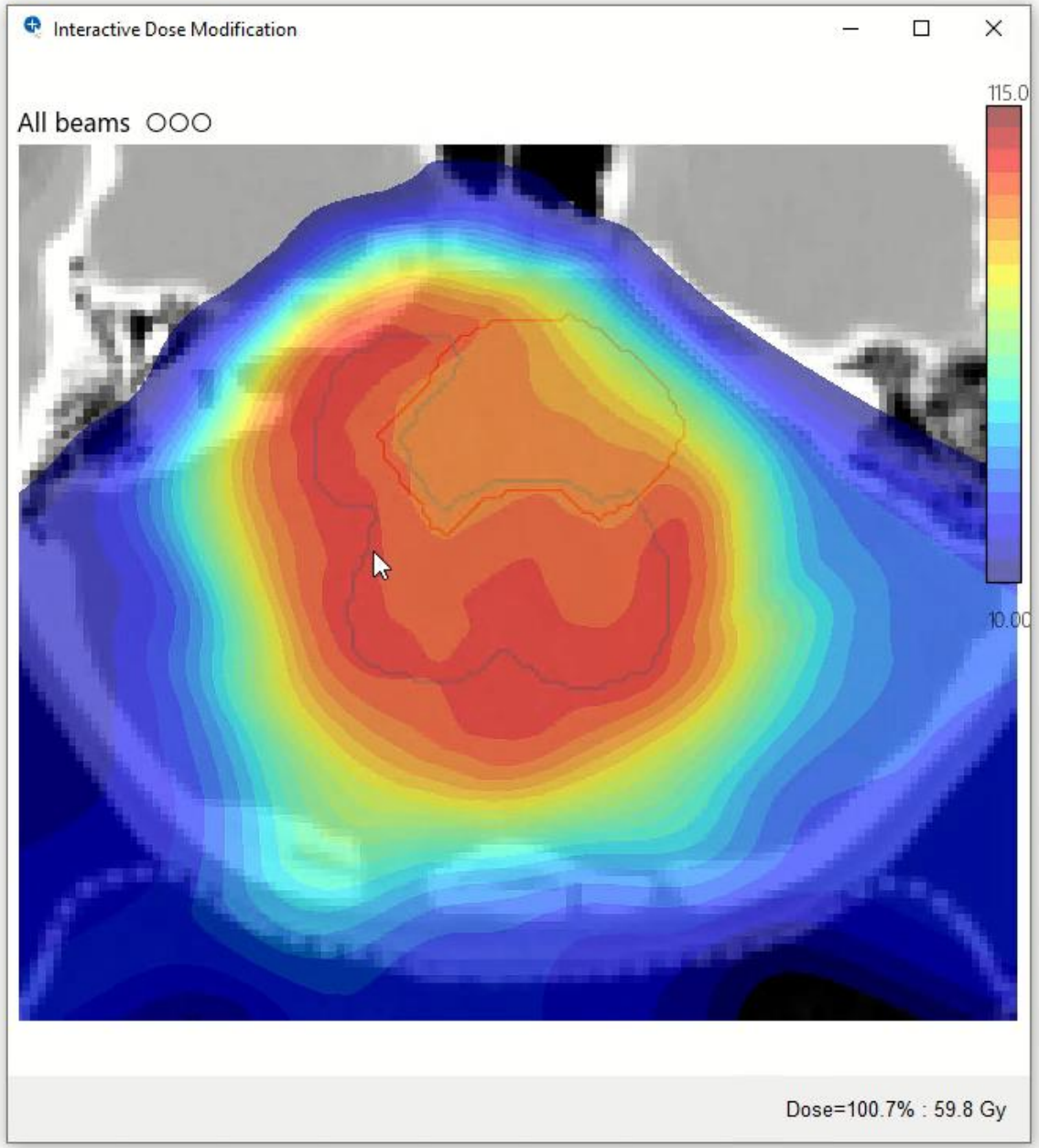
Advantages

- Can get a distribution you want without knowing how to describe it with optimisation objectives.
- Reduces the expertise needed to produce or modify plans for both treatment planners and physicians.



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Advantages

- Planning trade-offs are immediately apparent.
- Can complement existing automated planning approaches to fine tune plans and simplify the planning process.

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Thank you for listening