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Needs for Treatment Planning and Quality Assurance in Proton Spot Scanning Therapy

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PTV Doesn't Work for Protons

- Single volume doesn't describe necessary dose coverage for all beams
- Need to prescribe dose to CTV, with defined positional and range uncertainties
  - Evaluate CTV and OAR including uncertainties
- Optimization algorithm needs to consider these uncertainties when determining spot weights
  - Range uncertainties
  - Setup variations
  - Intra-fractional motion

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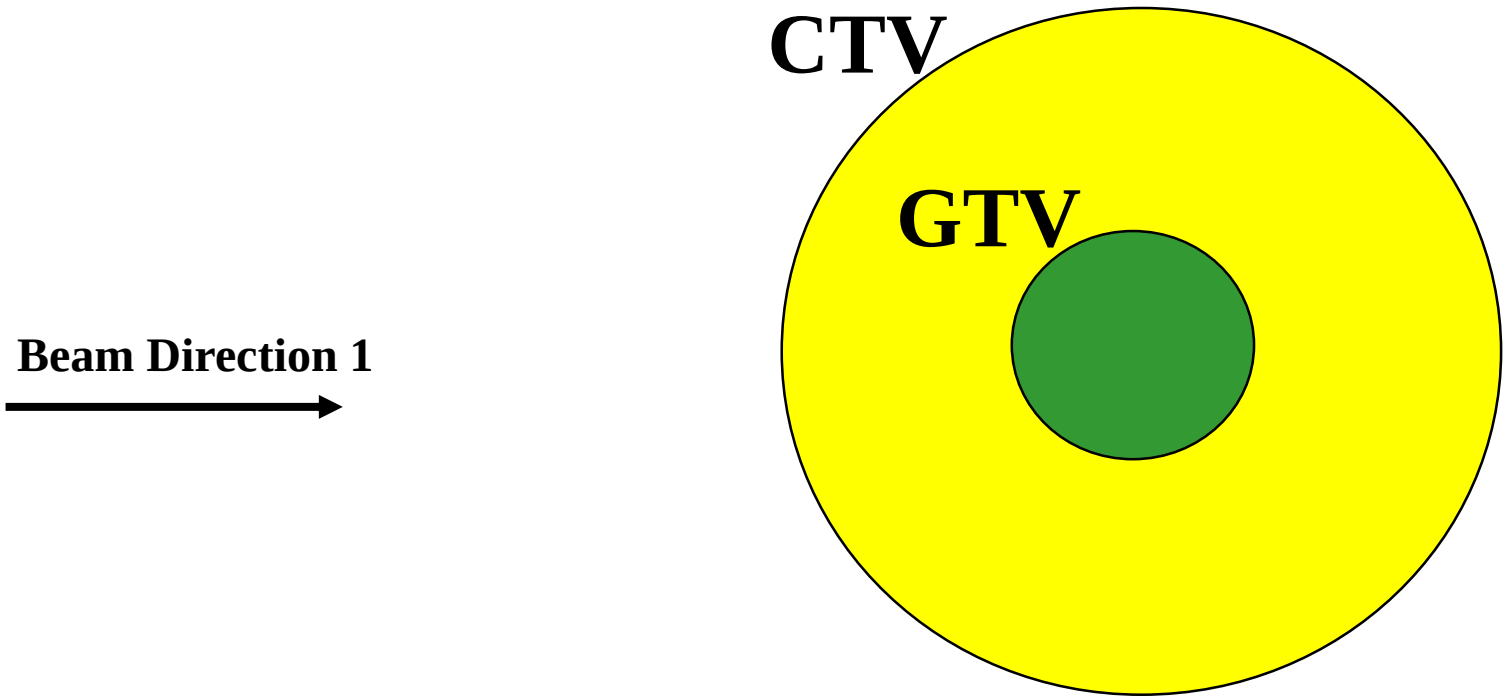
PTV for Protons



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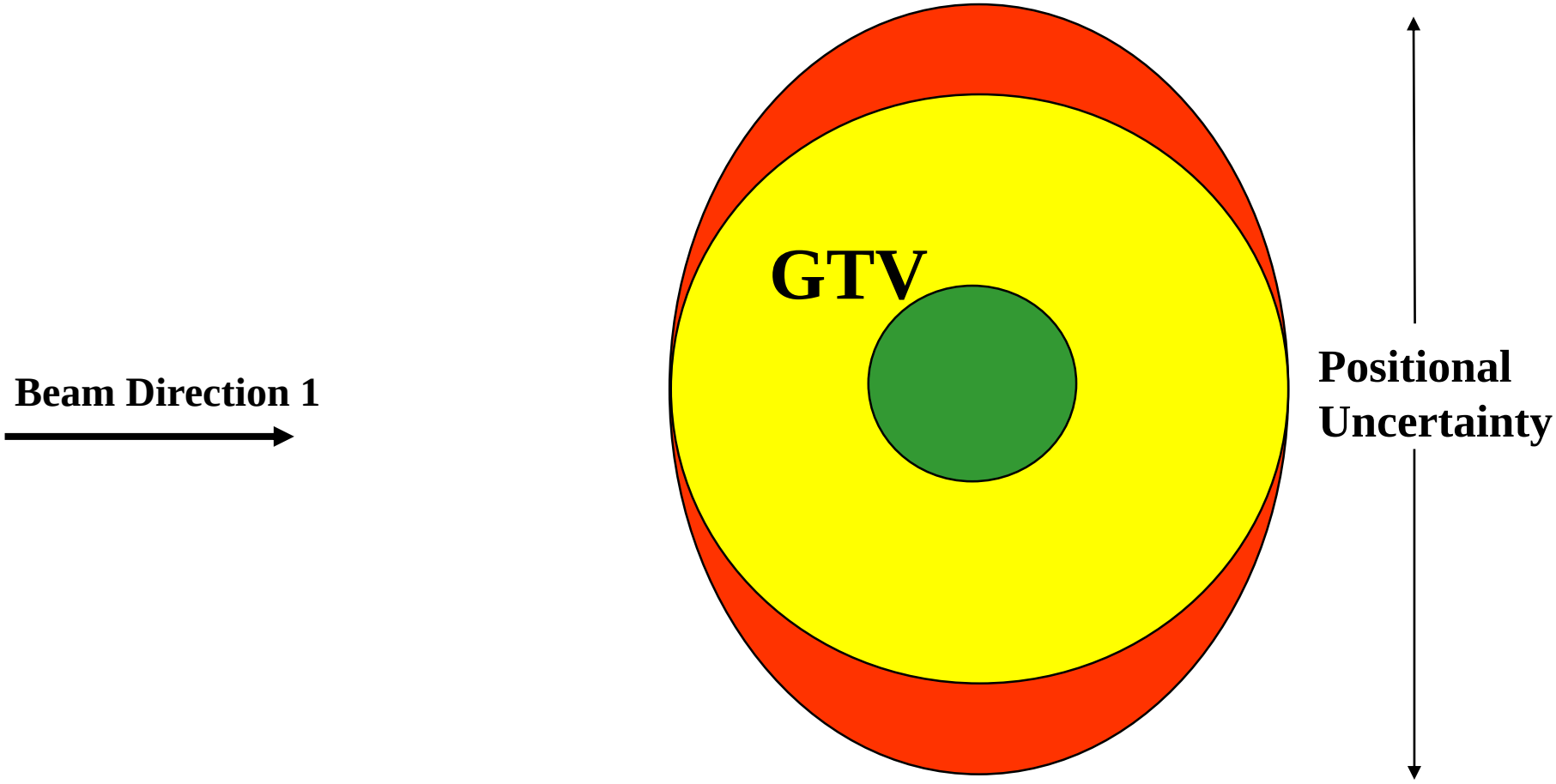
Back to the PTV



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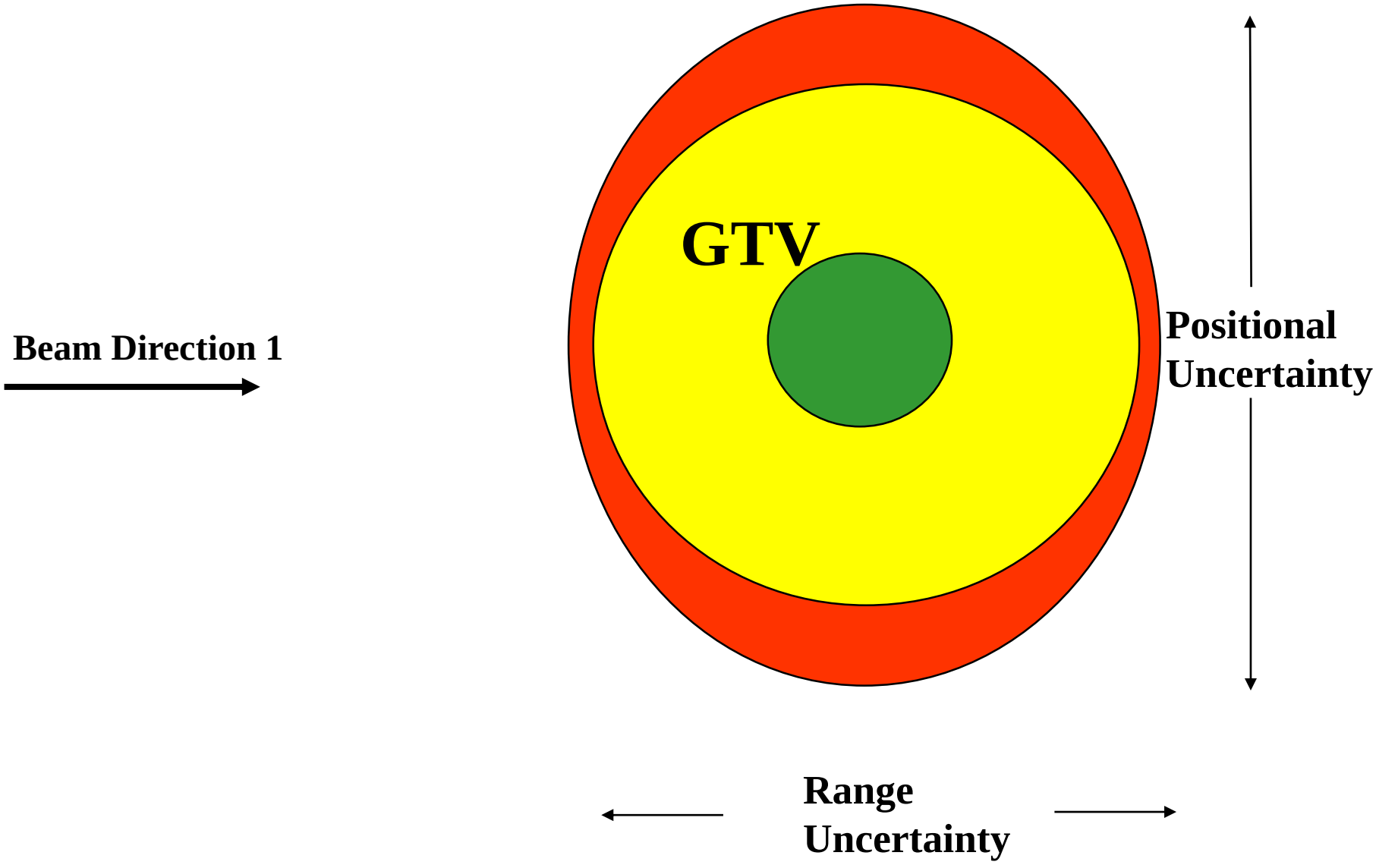
Back to the PTV



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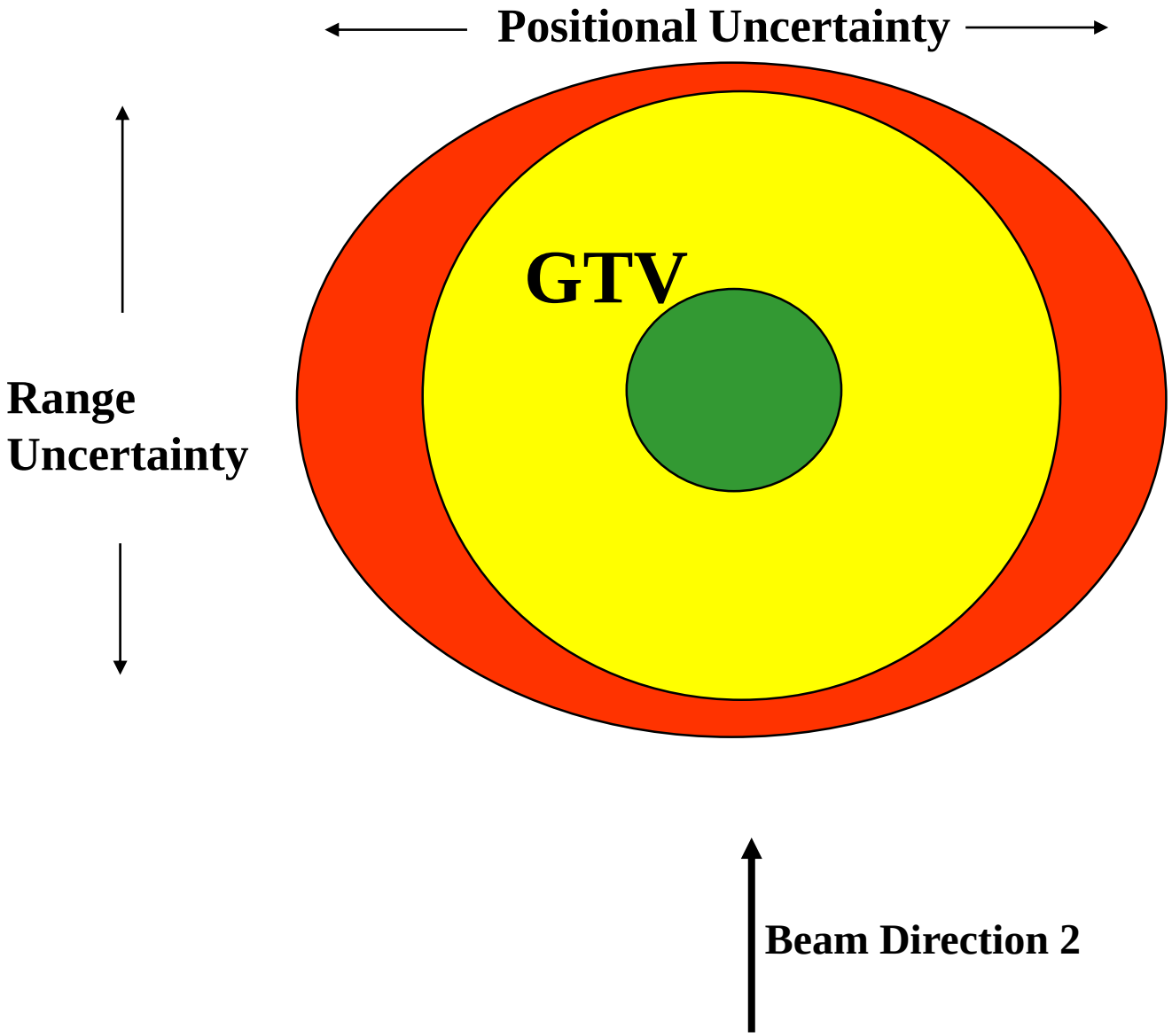
Back to the PTV



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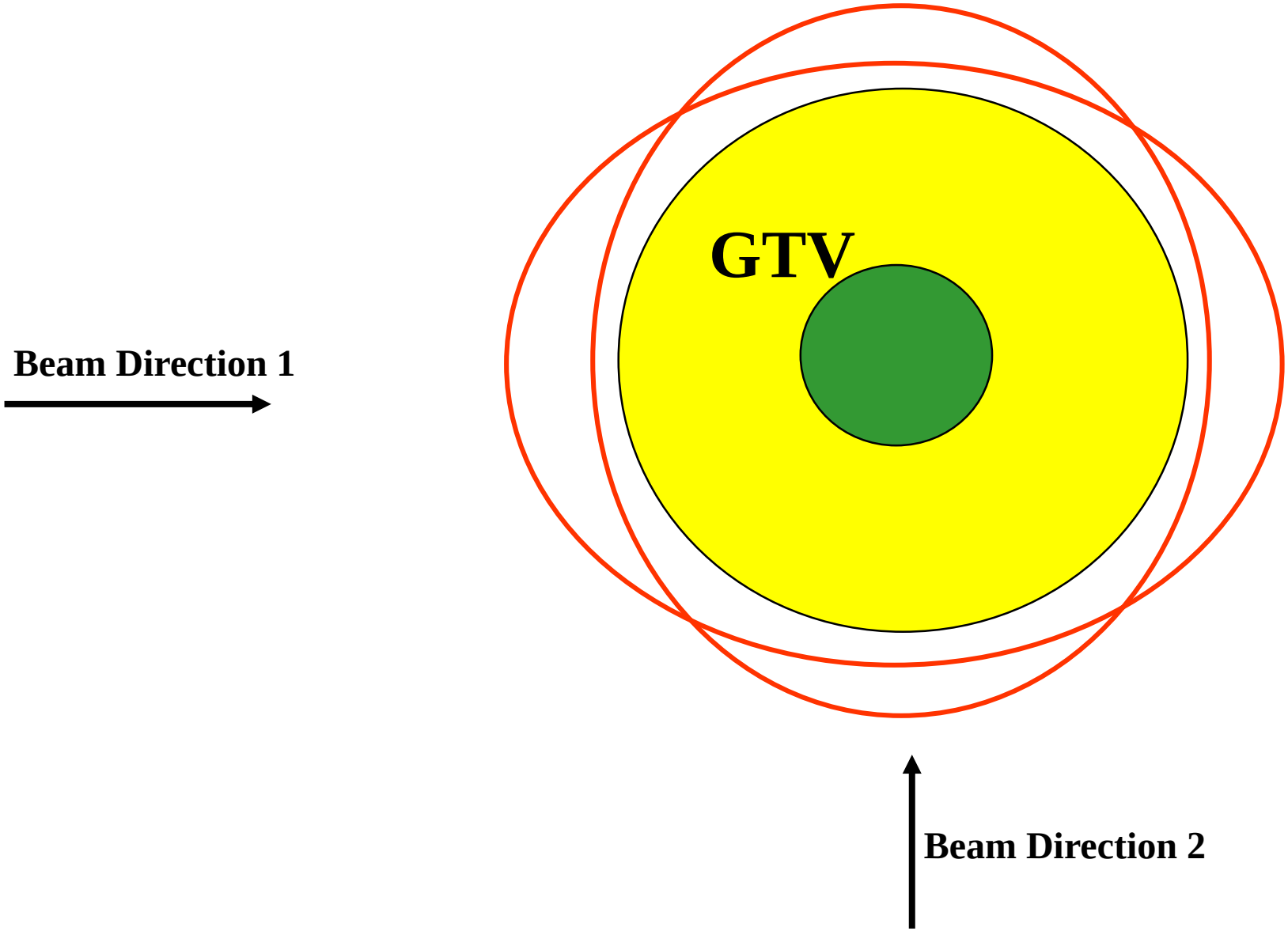
Proton PTVs Different for Each Beam



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Evaluate DVH "band", not just curve

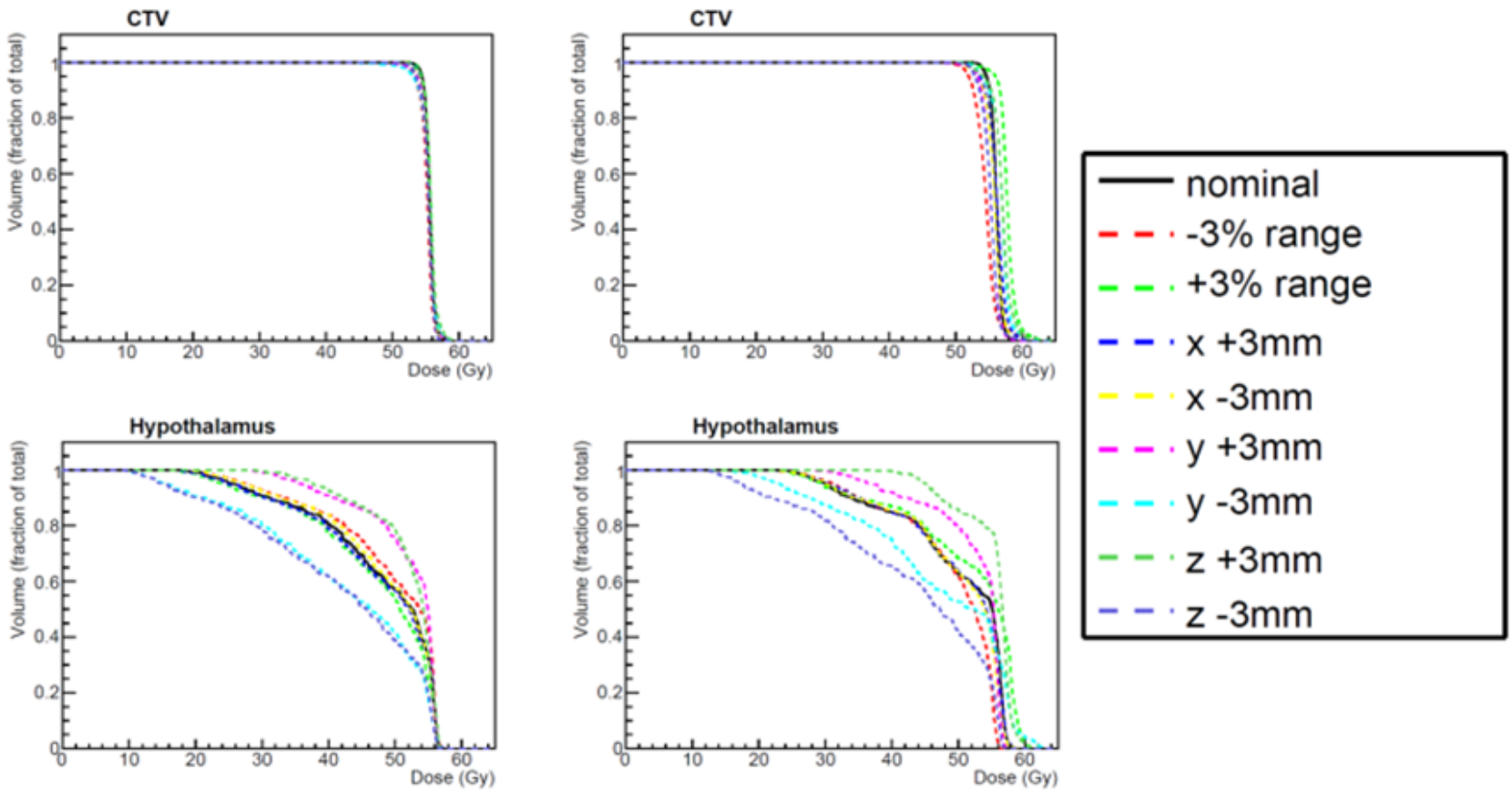

Fig. 1. Comparison of the robust IMPT optimization method and the OTV-based method: DVHs of CTV and hypothalamus in a pediatric brain case. The DVHs for the nominal scenario and eight uncertainty scenarios are plotted in each panel. The result of the robust optimization is on the left, and the result of the OTV-based IMPT optimization is on the right.

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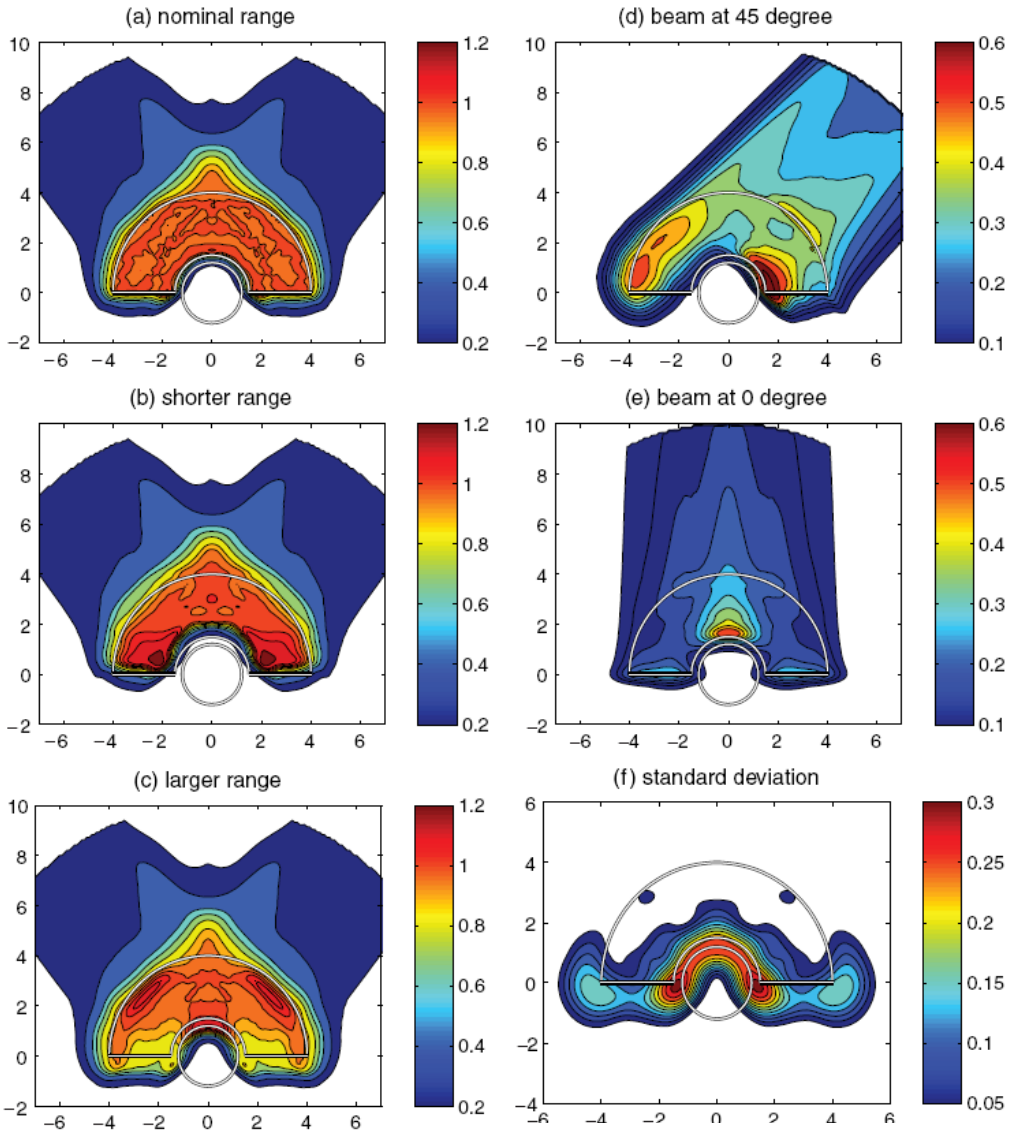
Standard Optimization



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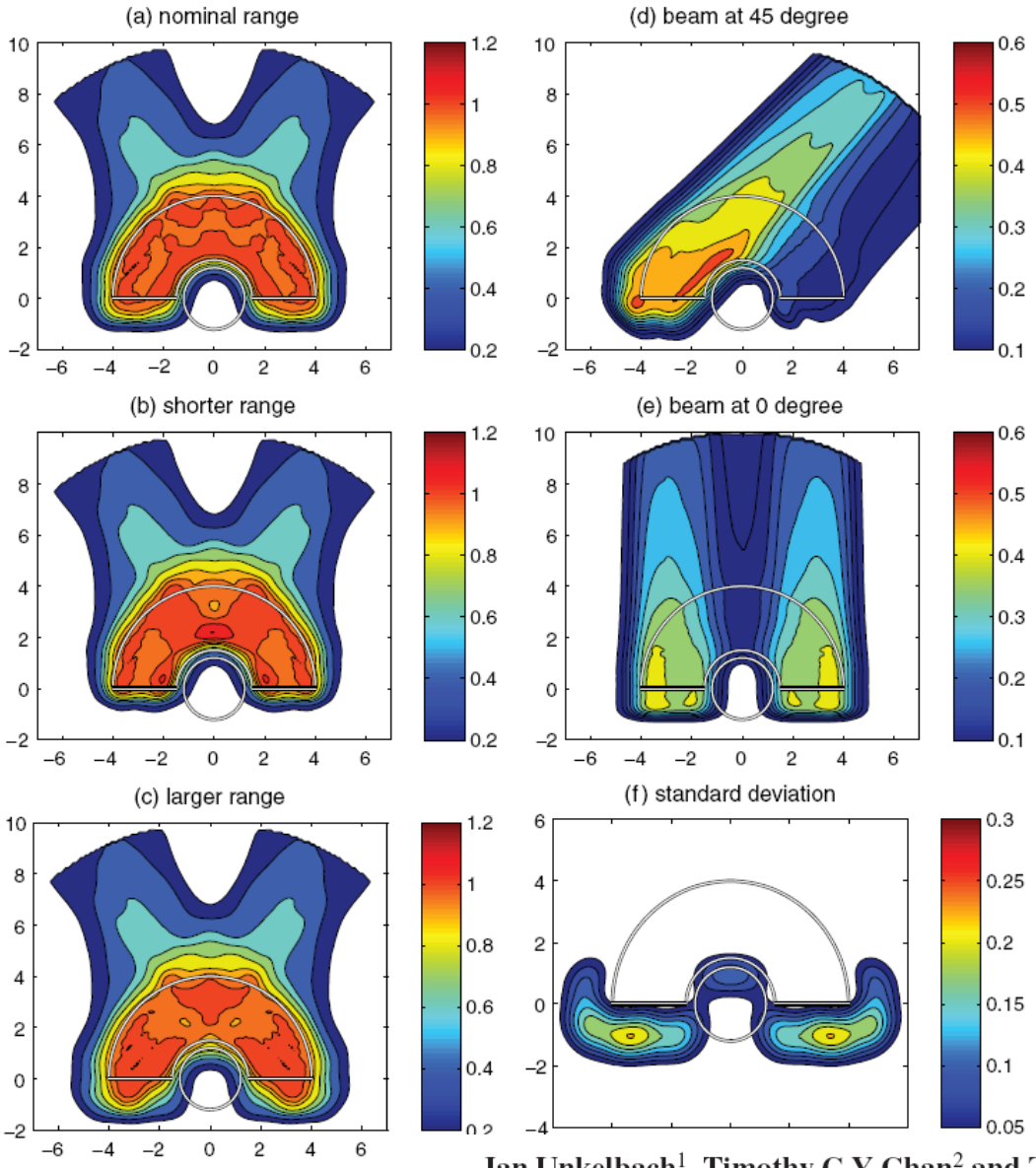
Range Uncertainty Optimization



Jan Unkelbach[1], Timothy C Y Chan[2] and Thomas Bortfeld[1]

Dose Calculation

- It has been well published that current pencil beam calculation algorithms have notable limitations
- It has been recommended to use Monte Carlo calculations

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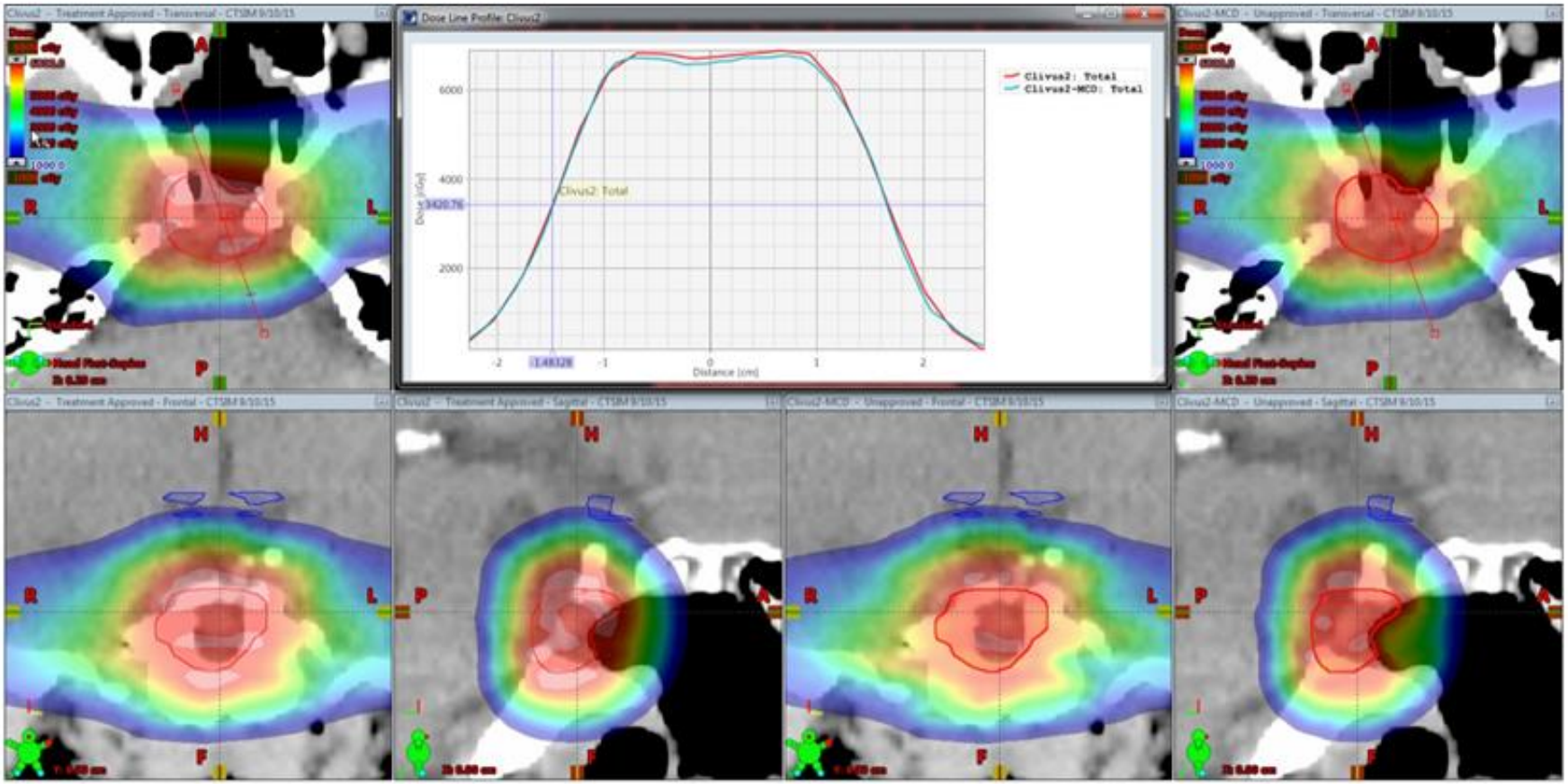

Figure 5. Above are the dose colorwash of the TPS generated distribution (left) and the Monte Carlo generated dose distribution (right) for a central brain tumor with a CTV (red) that is approximately 2cm in diameter. The graph in the center displays the dose profile through the center of the CTV. Note that the MC dose distribution is 2.2% lower than that from the TPS. This difference is attributed to the small target size and the complex heterogeneous surroundings. This plan would be suitable for renormalization.

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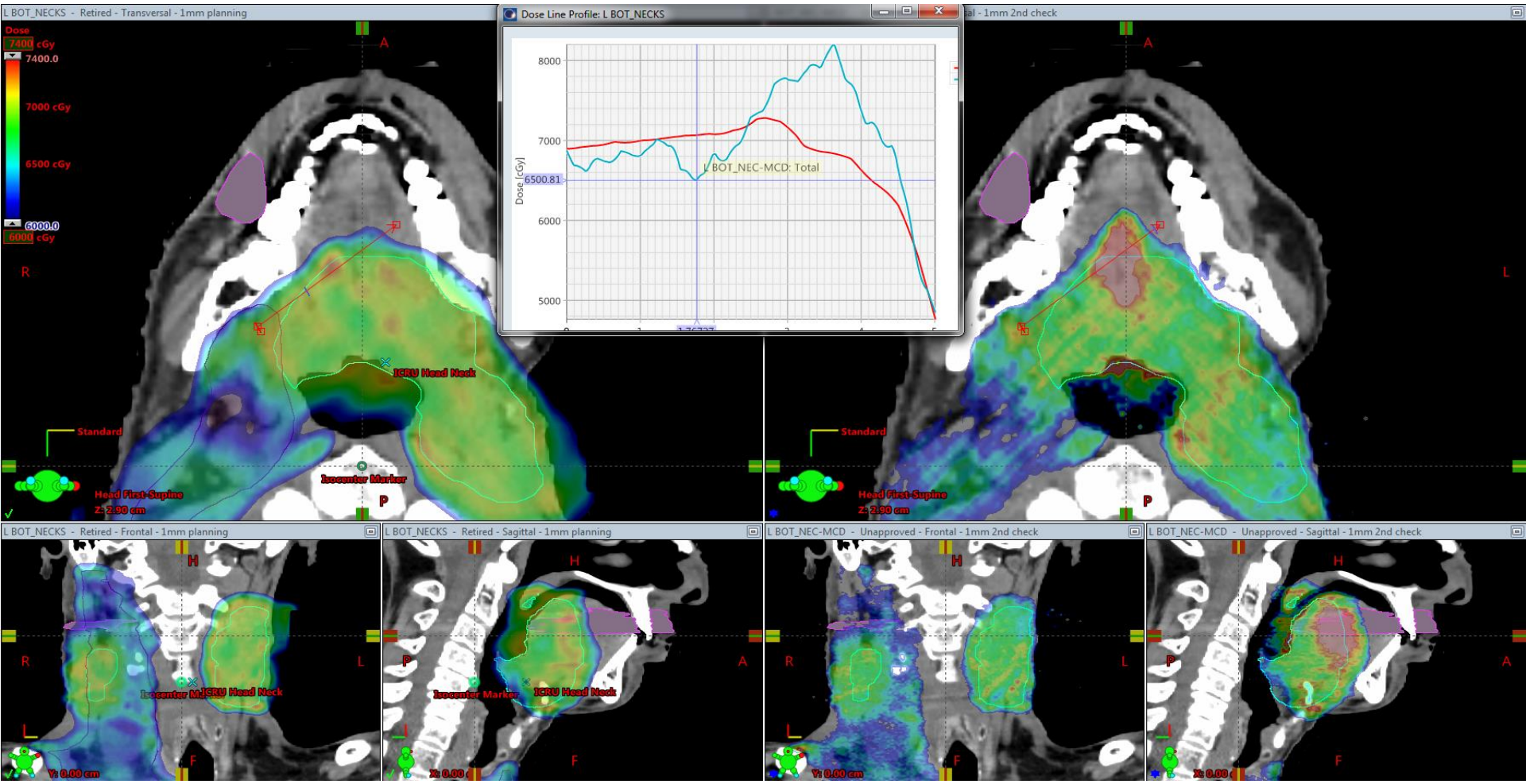
TPS on Left

MC on Right



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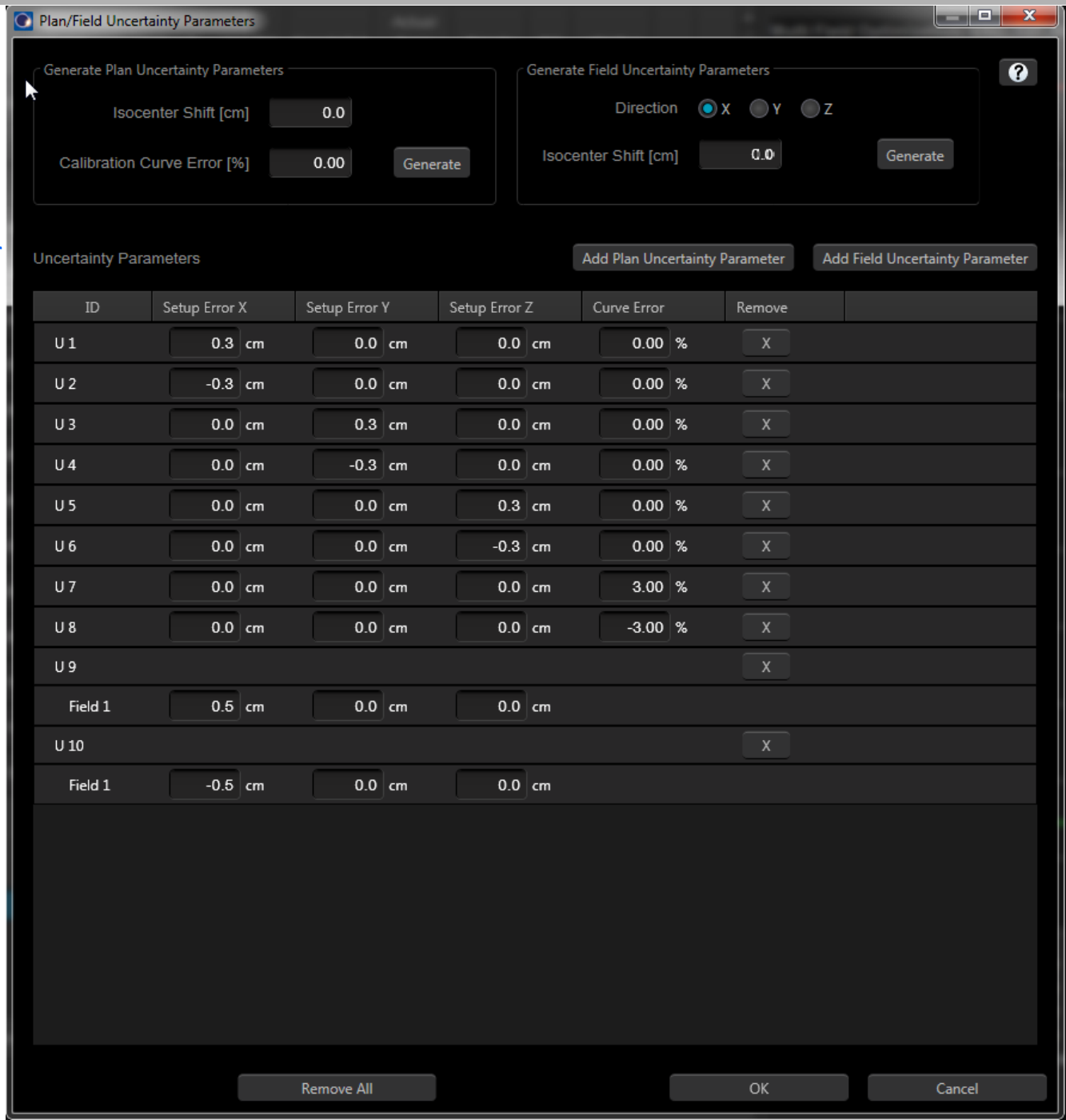
Robust Optimization



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Biological Considerations

- It has been well published that the Relative Biological effectiveness of Proton therapy is larger that 1.1 near the Bragg Peak
- Notable side effects, such as Brainstem necrosis in pediatric cases have been reported

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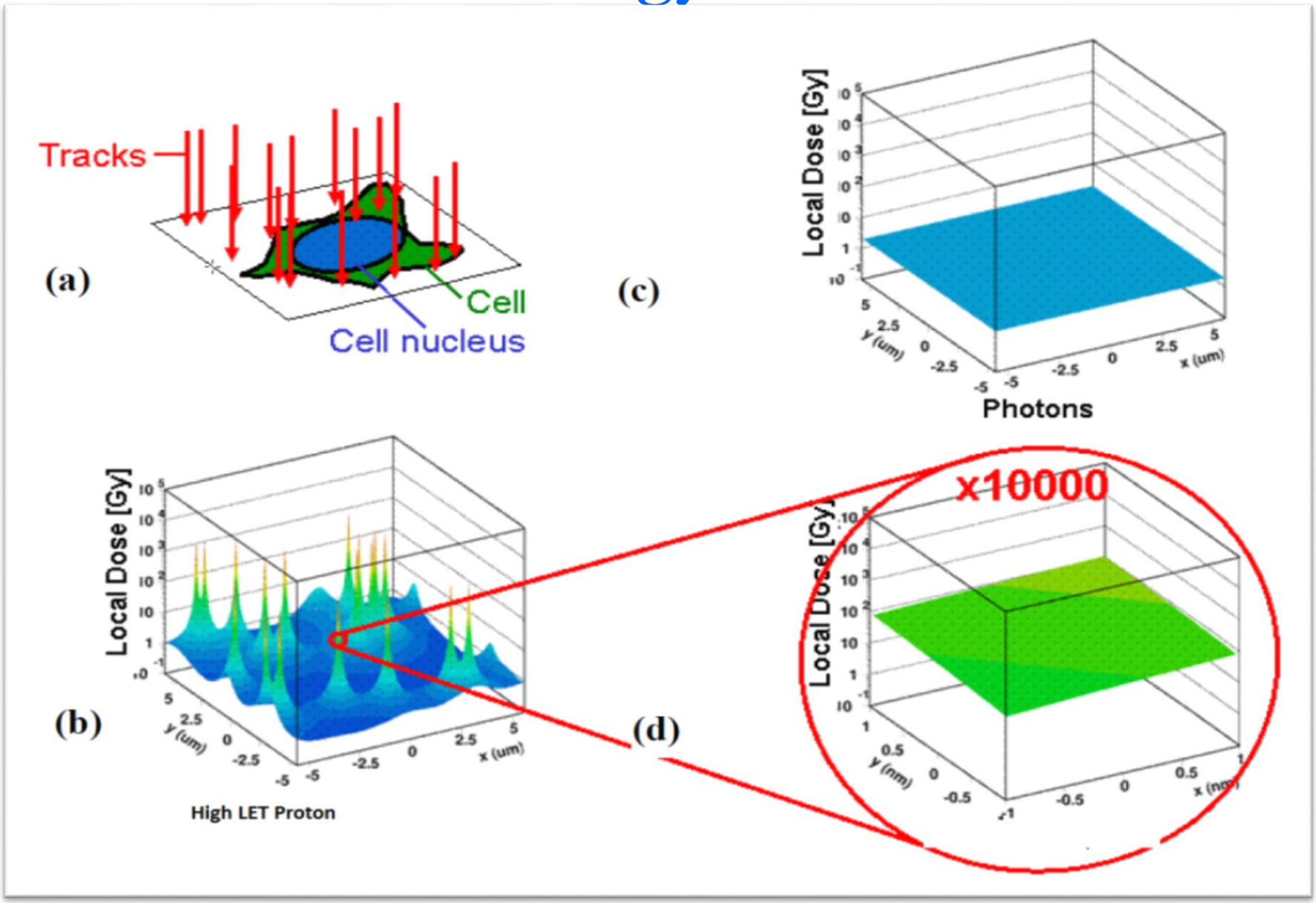
Linear Energy Transfer



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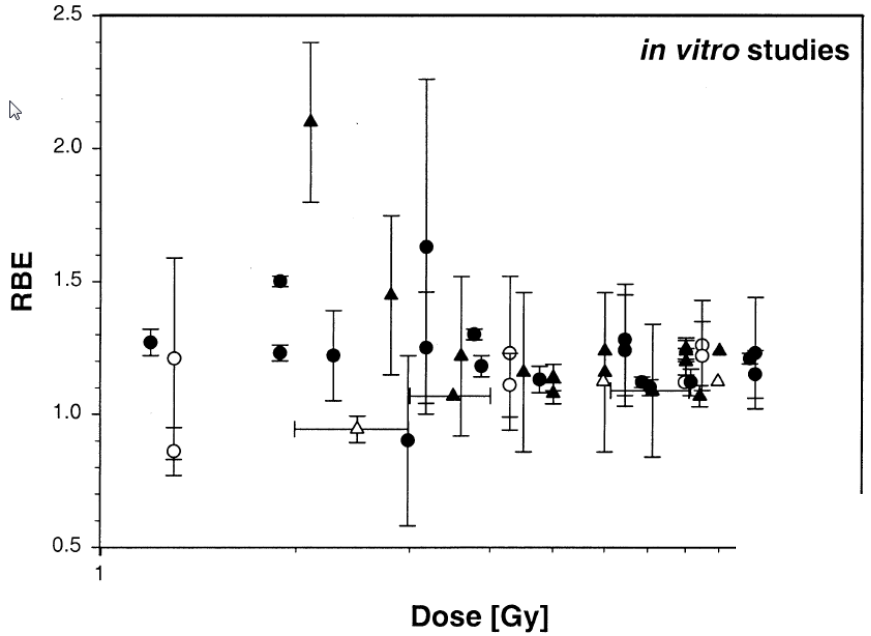

Fig. 1. Experimental proton RBE values (relative to ^{60}Co) as a function of dose/fraction for c
in vitro in the center of a SOBP. Closed symbols show measurements using Chinese Hamster
stand for other cell lines. Circles represent RBEs for <100-MeV beams and triangles for >1

BIOLOGY CONTRIBUTION

RELATIVE BIOLOGICAL EFFECTIVENESS (RBE) VALUES FOR PROTON BEAM THERAPY

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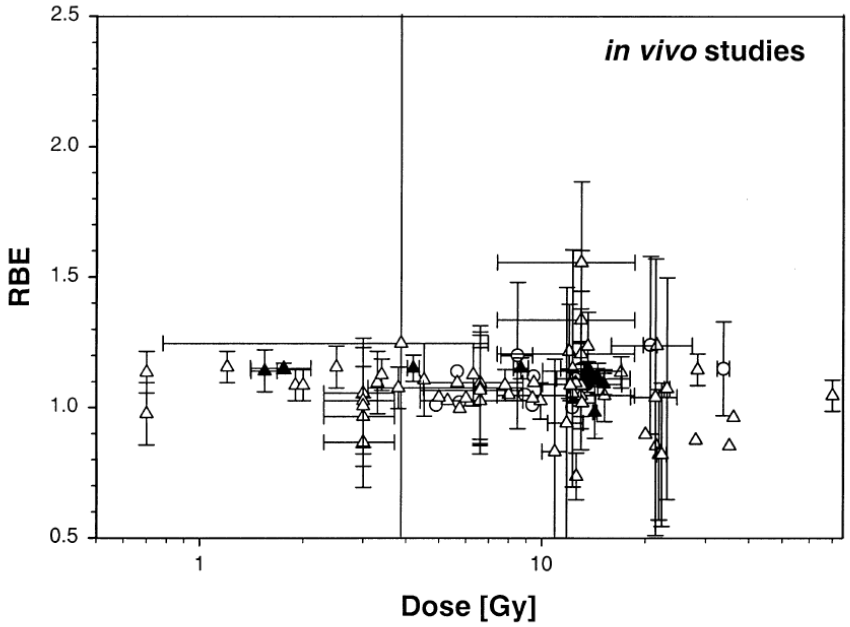

Fig. 2. Experimental proton RBE values (relative to ^{60}Co) as a function of dose/fraction measured *in vivo* in the center of a SOBP. Closed symbols show RBE values for jejunal crypt cells, open symbols stand for RBEs for all other tissues. Circles represent RBEs for <100-MeV beams and triangles for >100-MeV beams.

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Relative biological effectiveness (RBE) values for proton beam therapy. Variations as a function of biological endpoint, dose, and linear energy transfer

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Received 2 July 2014, revised 18 September 2014
Accepted for publication 29 September 2014
Published 31 October 2014

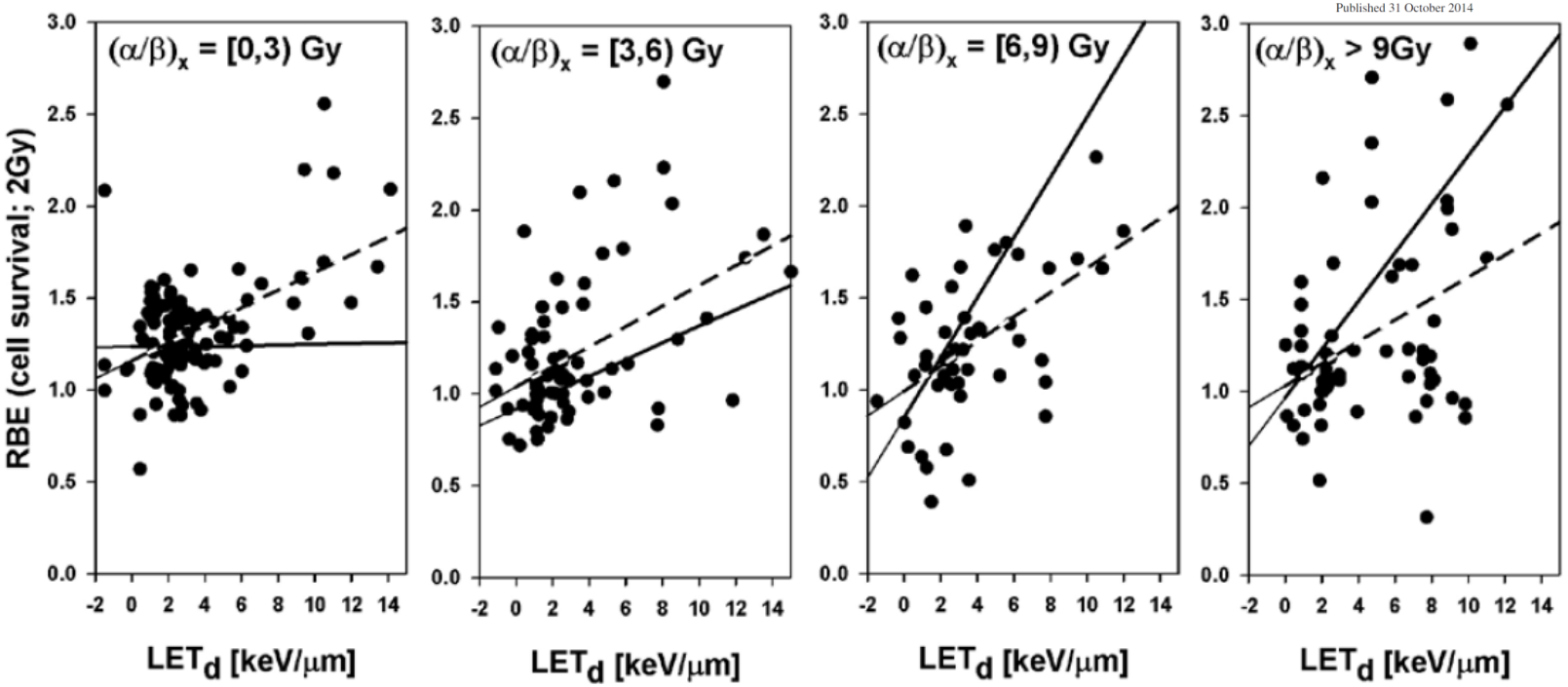

Figure 6. RBE for cell survival as a function of LET_d at a proton dose of 2 Gy (from left to right: $(\alpha/\beta)_x$ between 0 Gy and 3 Gy, between 3 Gy and 6 Gy, between 6 Gy and 9 Gy, and above 9 Gy). The upper row shows all data points included in the analysis. The lower row includes only data with LET_d values ≤15 keV μm^{-1}, the area most clinically relevant. LET_d values are given relative to the reference photon radiation. The solid lines are fits through the data included in each plot considering the published uncertainties. The dashed lines show the fit results without considering individual uncertainties.

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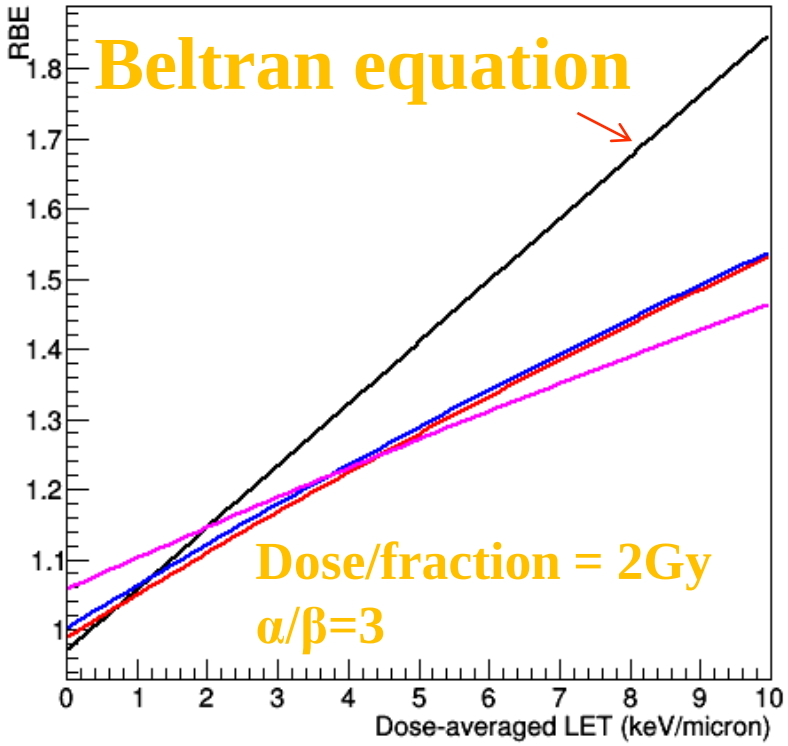
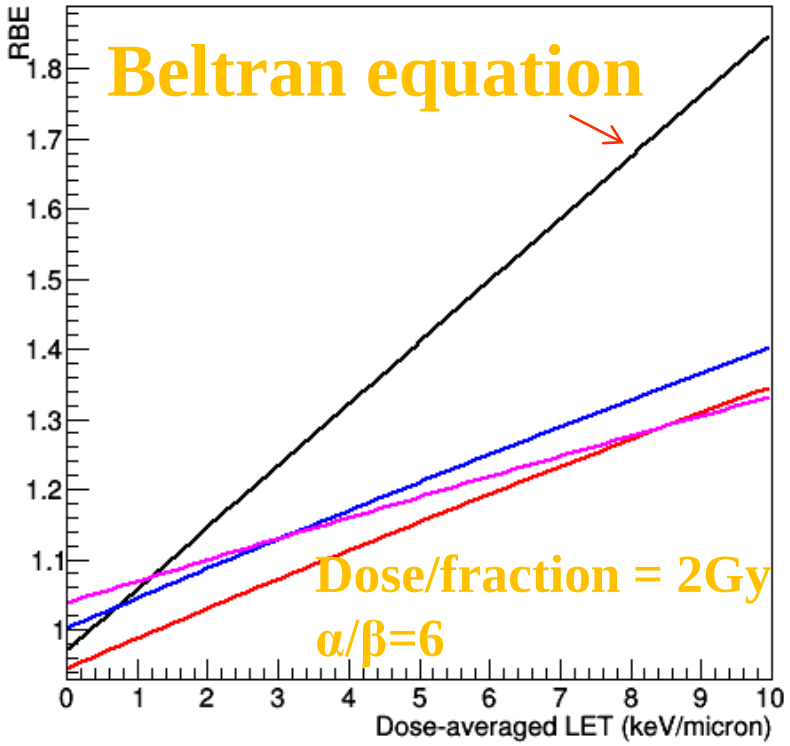
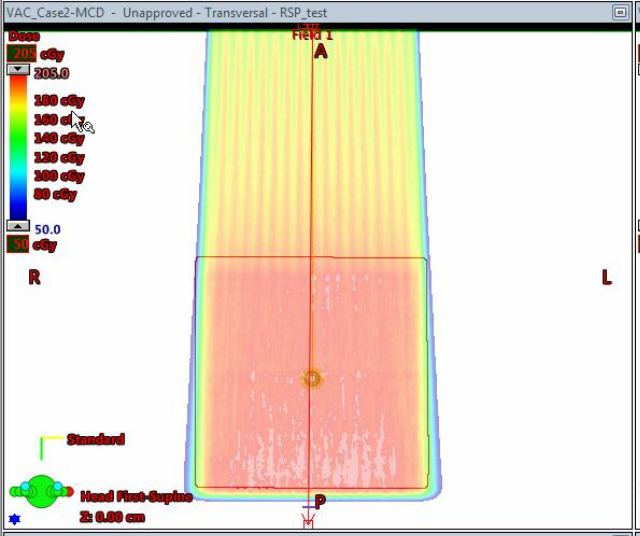
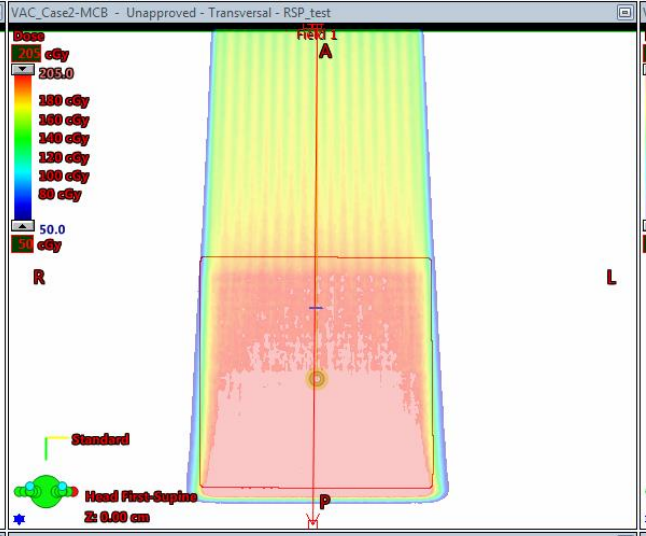
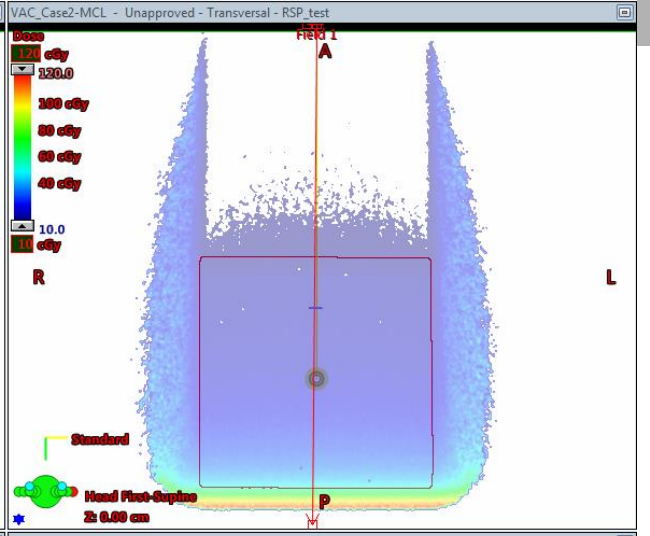
Previously published LQ RBE models (Carabe, Wedenberg, McNamara) described in Phys. Med. Biol. 60 (2015) 8399

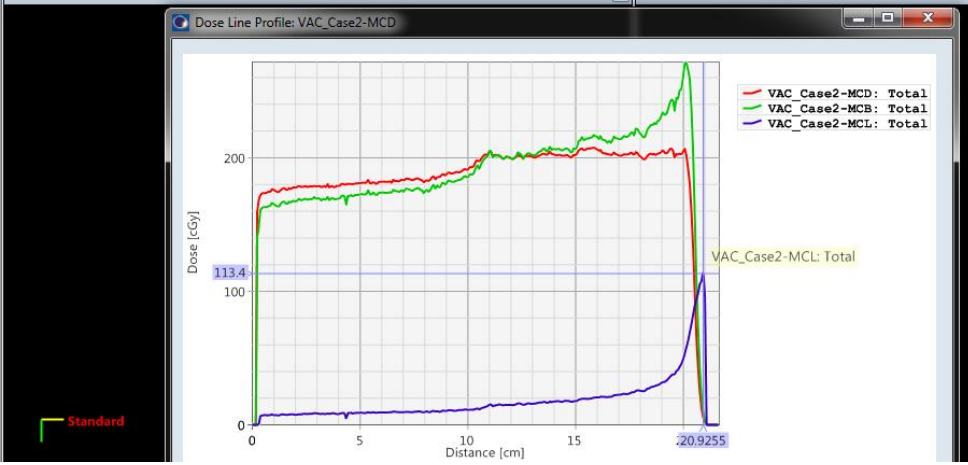


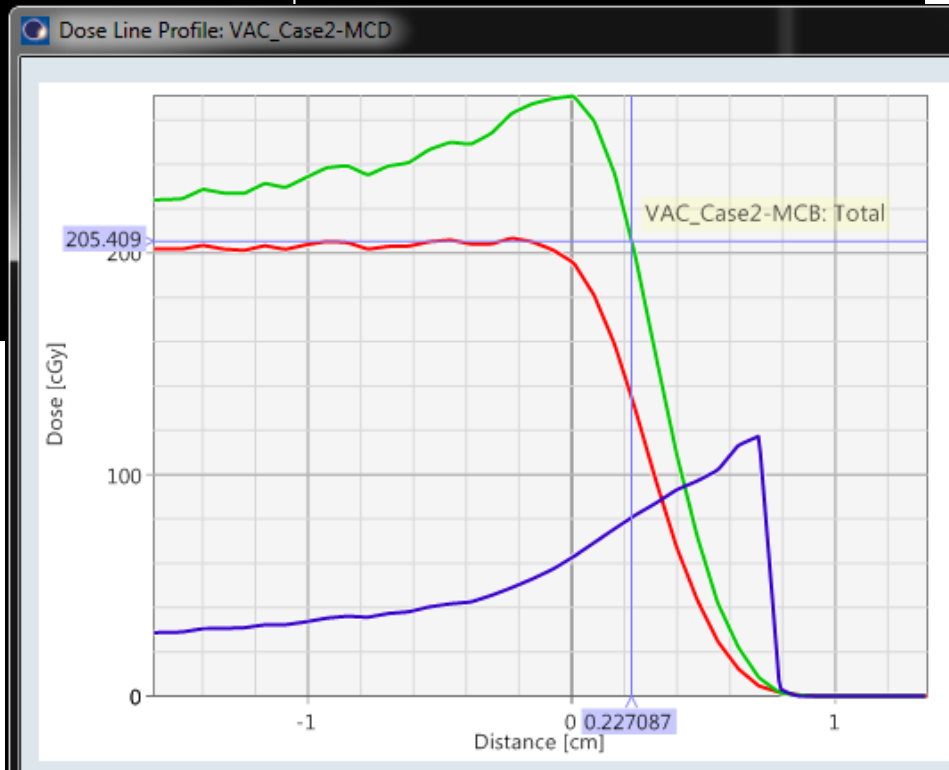



VAC_Case2-MCD - Unapproved - Transversal - RSP_test
Dose
205.0
180 cGy
160 cGy
140 cGy
120 cGy
100 cGy
80 cGy
50.0
50 cGy
Field 1
A
R
L
P
Standard
Head First-Supine


VAC_Case2-MCB - Unapproved - Transversal - RSP_test
Dose
205.0
180 cGy
160 cGy
140 cGy
120 cGy
100 cGy
80 cGy
50.0
50 cGy
Field 1
A
R
L
P
Standard
Head First-Supine


VAC_Case2-MCL - Unapproved - Transversal - RSP_test
Dose
120.0
100 cGy
80 cGy
60 cGy
40 cGy
10.0
10 cGy
Field 1
A
R
L
P
Standard
Head First-Supine


Dose Line Profile: VAC_Case2-MCD
VAC_Case2-MCD: Total
VAC_Case2-MCB: Total
VAC_Case2-MCL: Total
200
113.4
100
0
Dose [cGy]
VAC_Case2-MCL: Total
0
5
10
15
20.9255
Distance [cm]
Standard


Dose Line Profile: VAC_Case2-MCD
205.409
200
VAC_Case2-MCB: Total
Dose [cGy]
100
0
-1
0
0.227087
1
Distance [cm]

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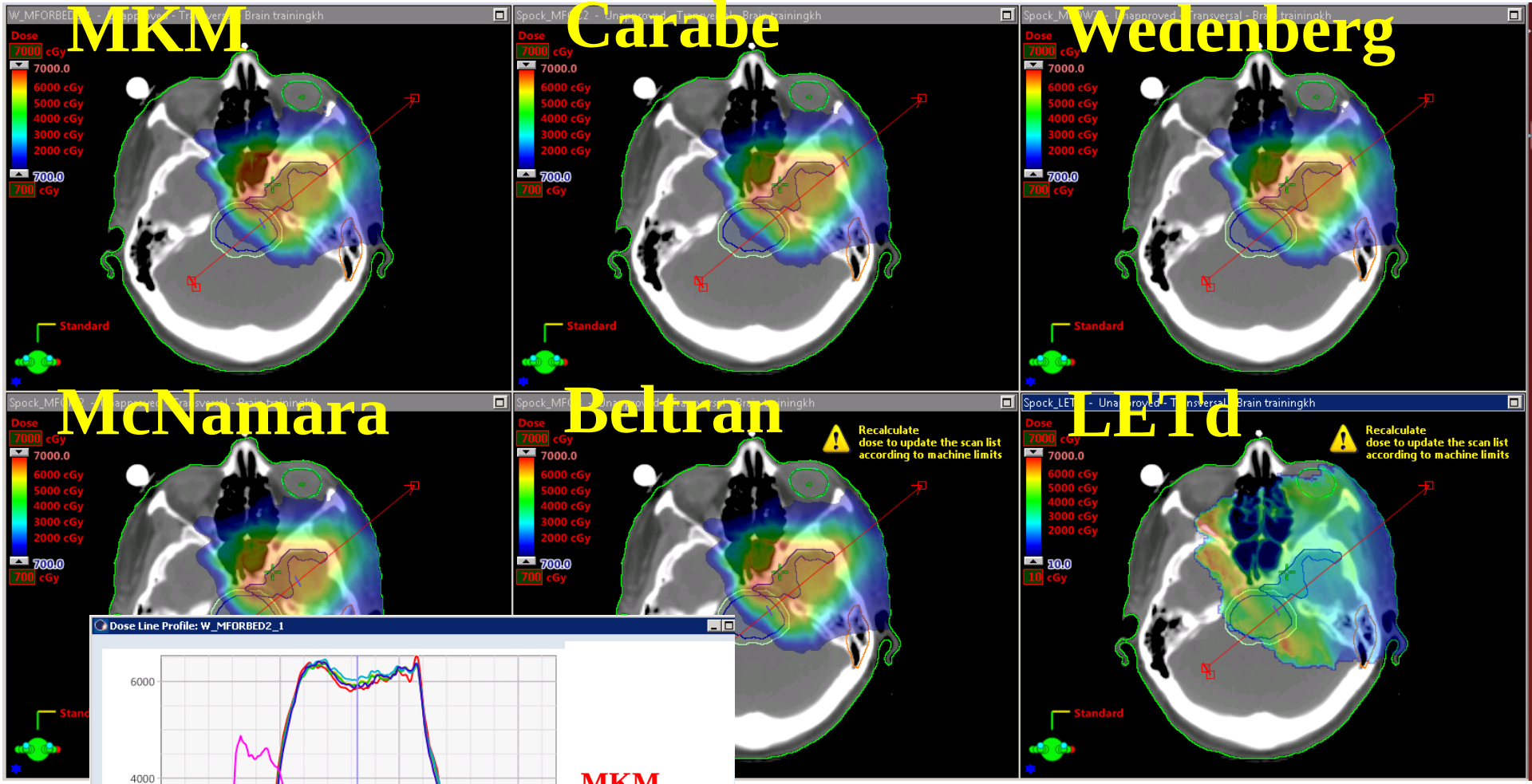
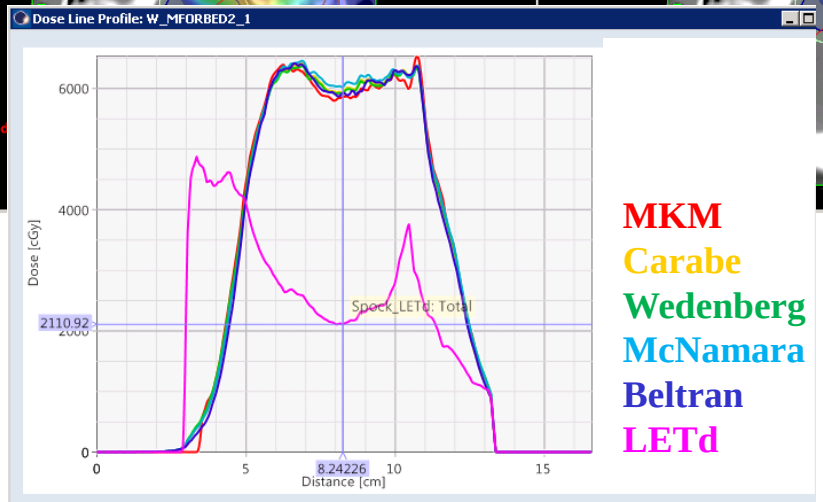
H&N α/β=2 Biodose





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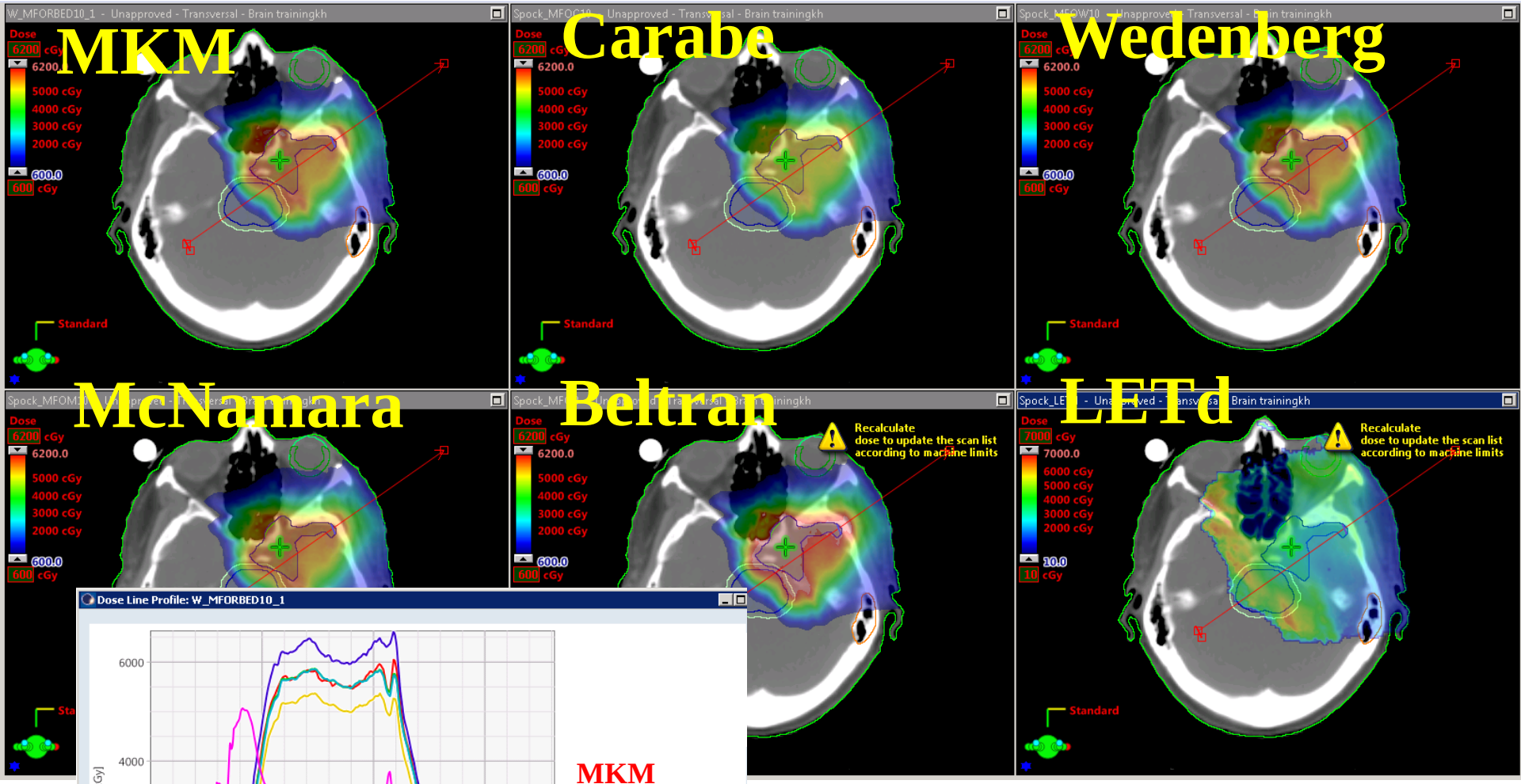
H&N α/β=10 Biodose



For large a/b and large dose/fraction, maybe biological = physical dose

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Modify the Treatment Plan based on biological considerations

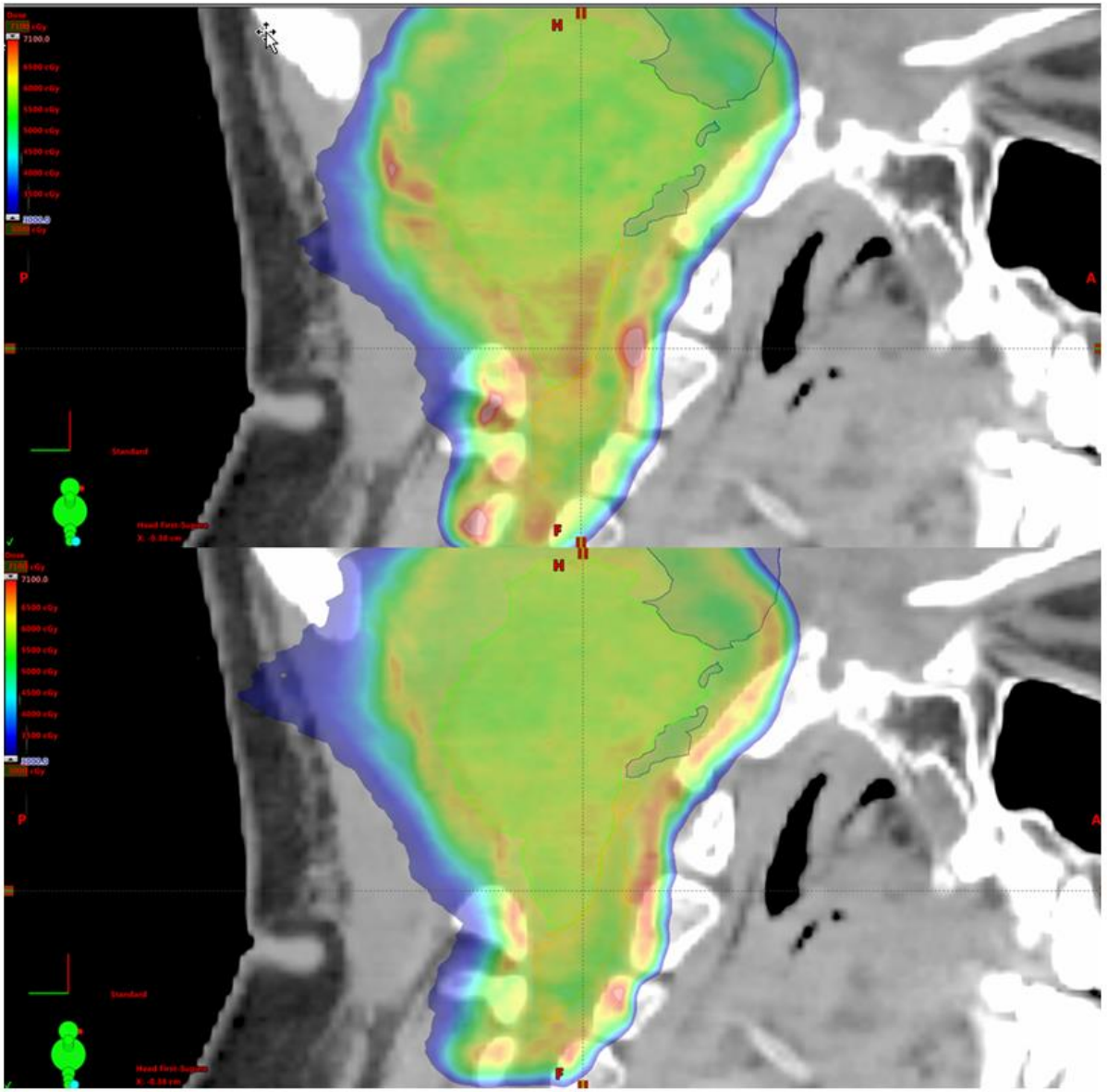

Figure 6. Above are the dose colorwash for the LETd weighted biological dose calculation, (top) initial plan and (bottom) after mitigation for high biological dose. In the region of the biological hot spots, the physical dose of the initial plan is 2% higher than the modified plan, but the biological dose is ~10% different. Small modifications of margin and gantry angle resulted in an improved biologic dose profile in critical location such as the brainstem and spinal cord.

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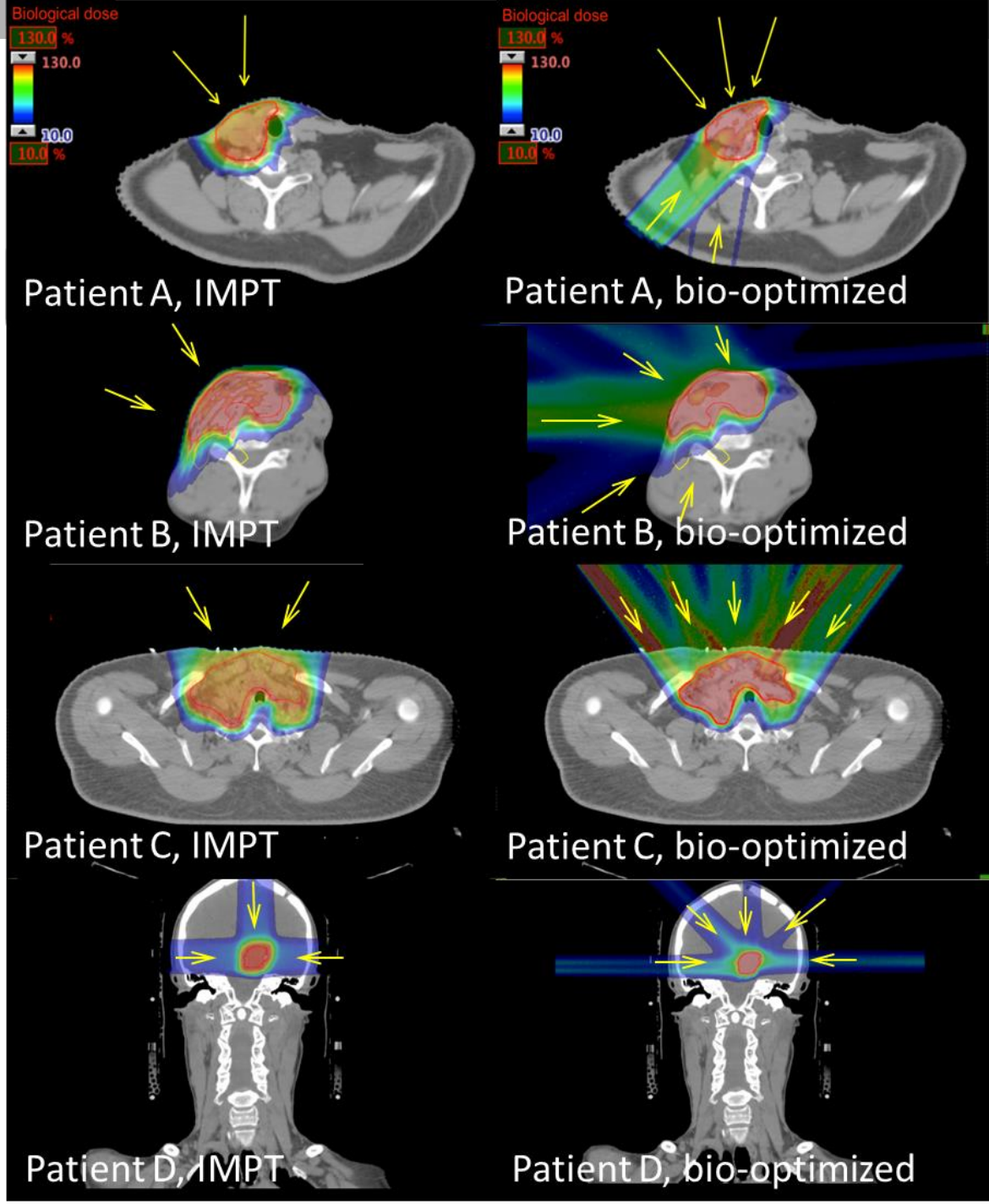
Biological based Treatment Planning



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Quality Assurance

- For future Clinical trials involving spot scanning proton therapy,
  - Monte Carlo calculations are needed
  - Robust evaluation of the plans are needed
    - *Ideally robust optimization*
  - Biological considerations are needed
- For routine clinical QA
  - True Failure Mode Analysis is needed
  - There is not time to measure everything
  - May give a false sense of "quality"

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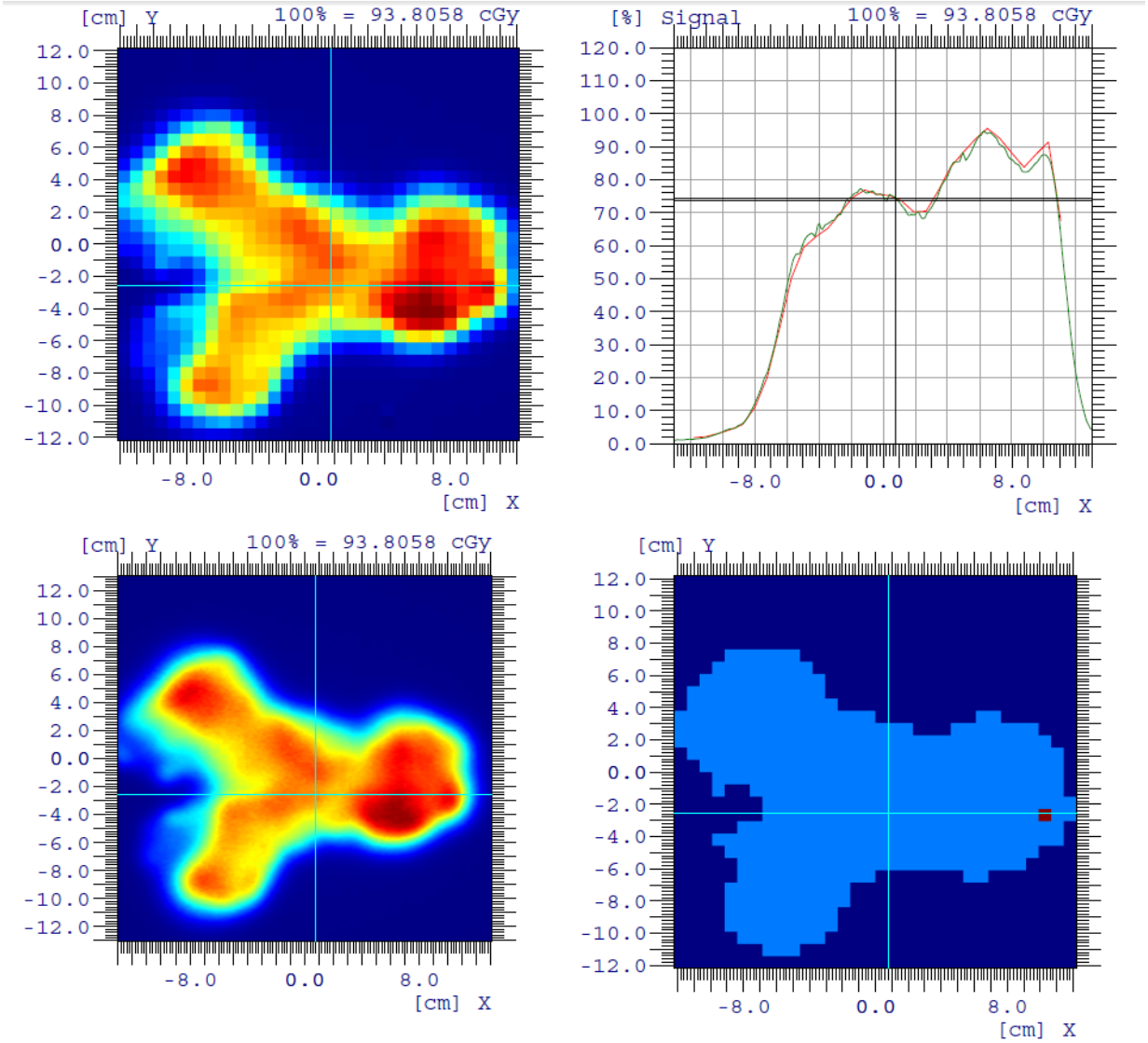
Patient Specific QA with time consuming "flat water phantom" measurements



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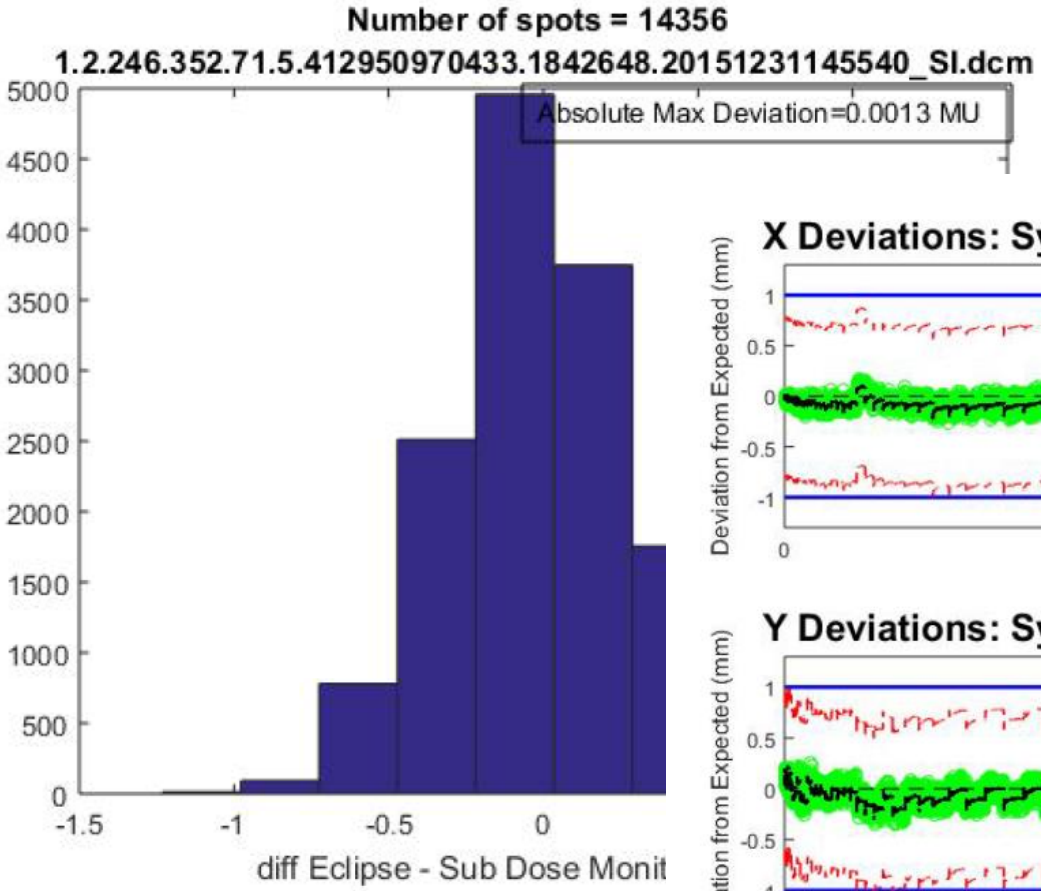
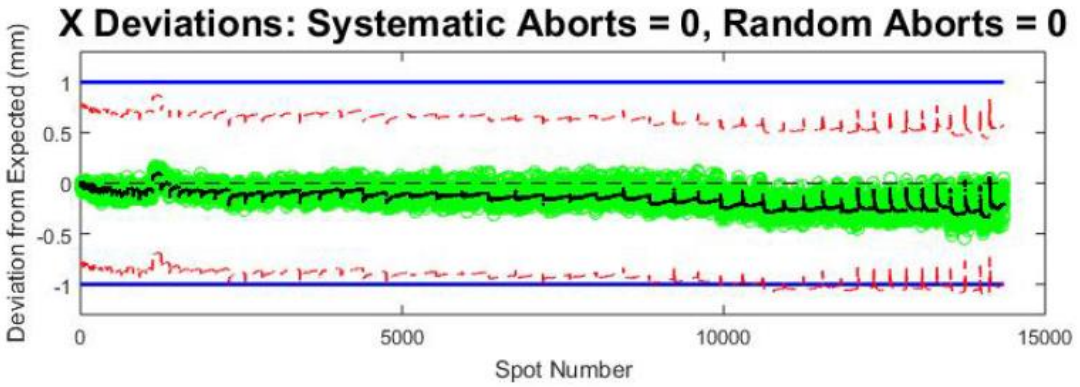
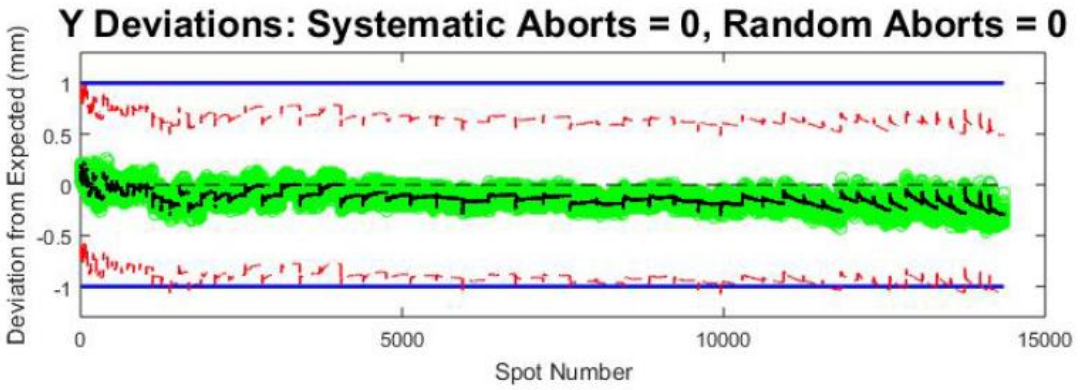
Moved to more efficient and meaningful Patient Specific QA

G30T0







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Thank you for your time

- **QUESTIONS**