The lateral edge of proton therapy beams: Clinical relevance and current developments

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PPRIG
December 2016

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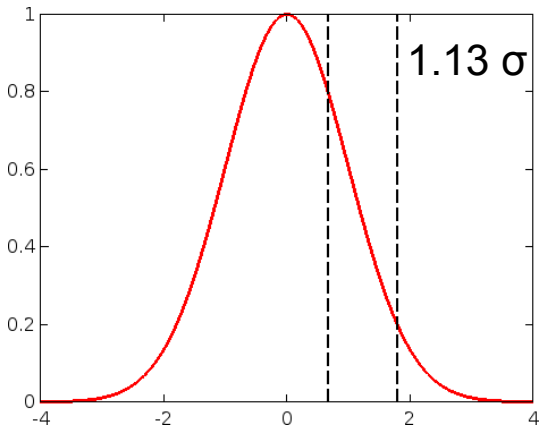
Motivation

Having OARs immediately distal to the target may be risky due to:

- High weighting of distal spots (esp. in SFUD)
- Range uncertainty
- Increased LET / RBE at end of proton range

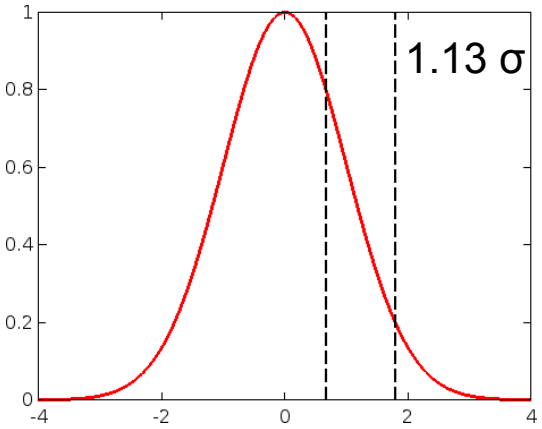
- Use of lateral edge to deliver dose to these areas may be preferable

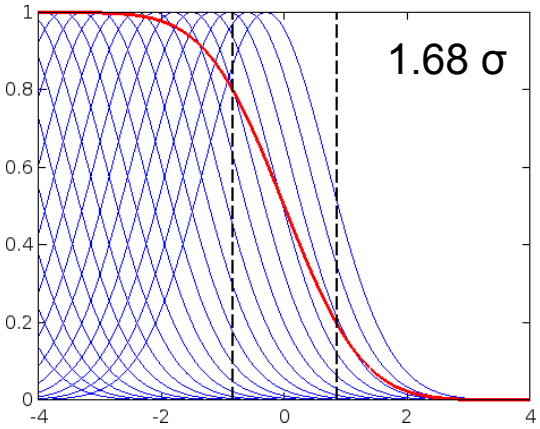
Lateral penumbra (80%-20%) in 1D



1. For a single spot: LP ≈ 1.13 σ

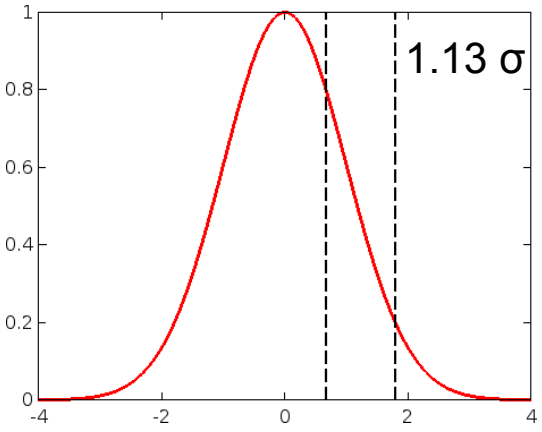
Lateral penumbra (80%-20%) in 1D

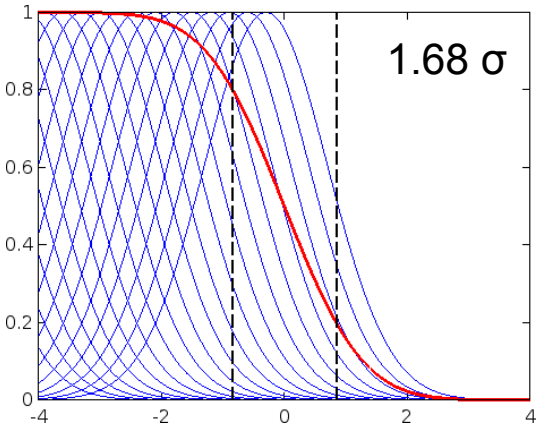


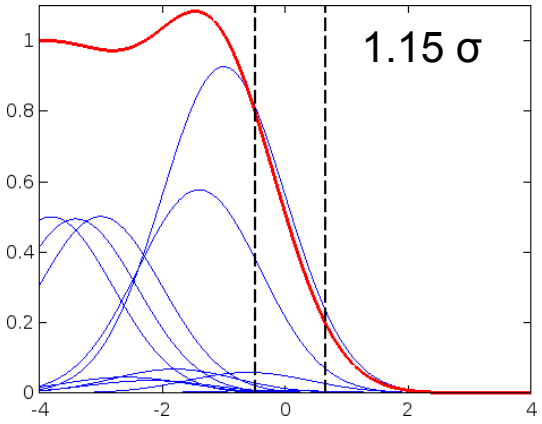


1. For a single spot: LP ≈ 1.13 σ
2. For equally weighted spots: LP ≈ 1.68 σ

Lateral penumbra (80%-20%) in 1D

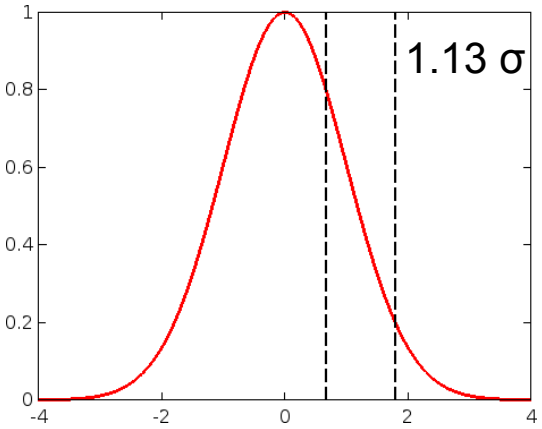


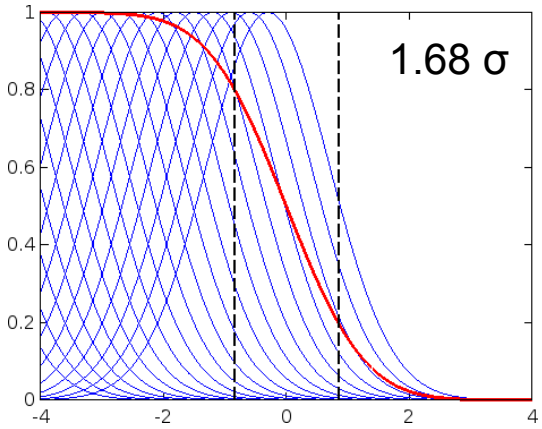


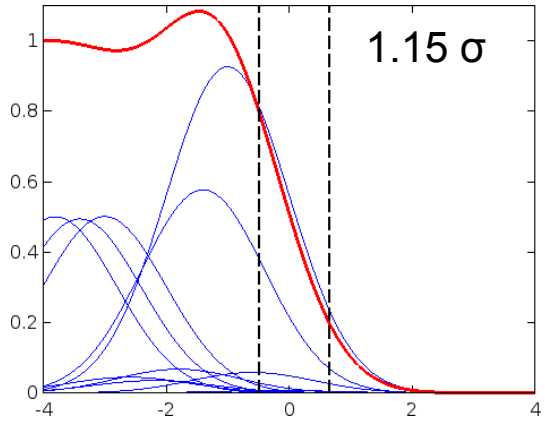


1. For a single spot: LP ≈ 1.13 σ
2. For equally weighted spots: LP ≈ 1.68 σ
3. Weights can be adjusted to recover sharpness, at the expense of uniformity: LP ≈ 1.15 σ

Lateral penumbra (80%-20%) in 1D







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- See:

Lateral dose profile characterization in scanning particle therapy

Christian Bäumer[a)] and Jonathan B. Farr

Westdeutsches Protonentherapiezentrum Essen gGmbH, 45147 Essen, Germany

Med. Phys. 38 (6), June 2011

Scanning spot size

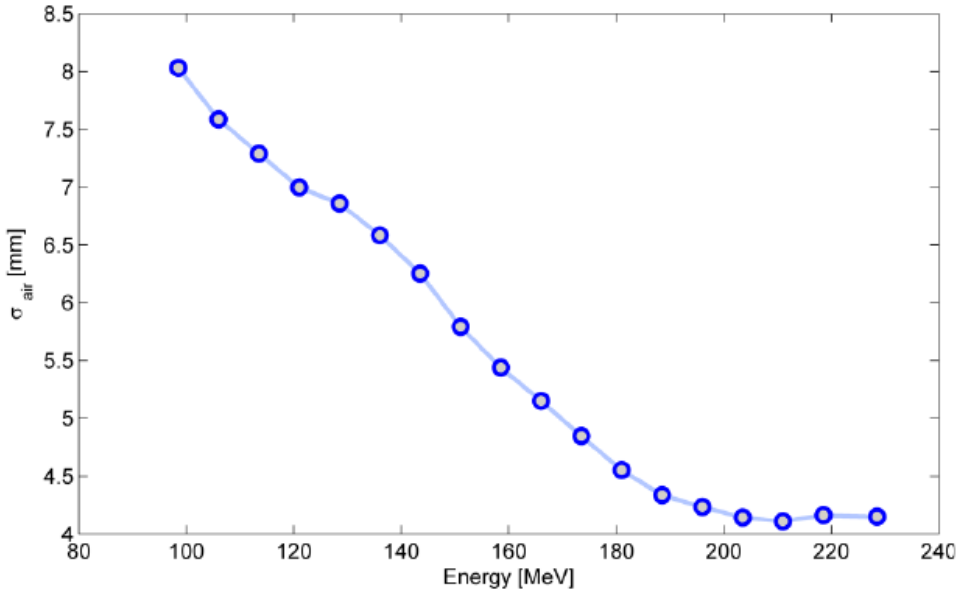

FIG. 2. Energy dependent spatial sigma for the IBA Universal Nozzle at CDH Proton Center. The same energy dependence was used for the Monte Carlo simulations.

A method for modeling laterally asymmetric proton beamlets resulting from collimation

Edgar Gelover[a] and Dongxu Wang
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Daniel E. Hyer
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Med. Phys. 42 (3), March 2015

Scanning spot size

Scanning

Scattering

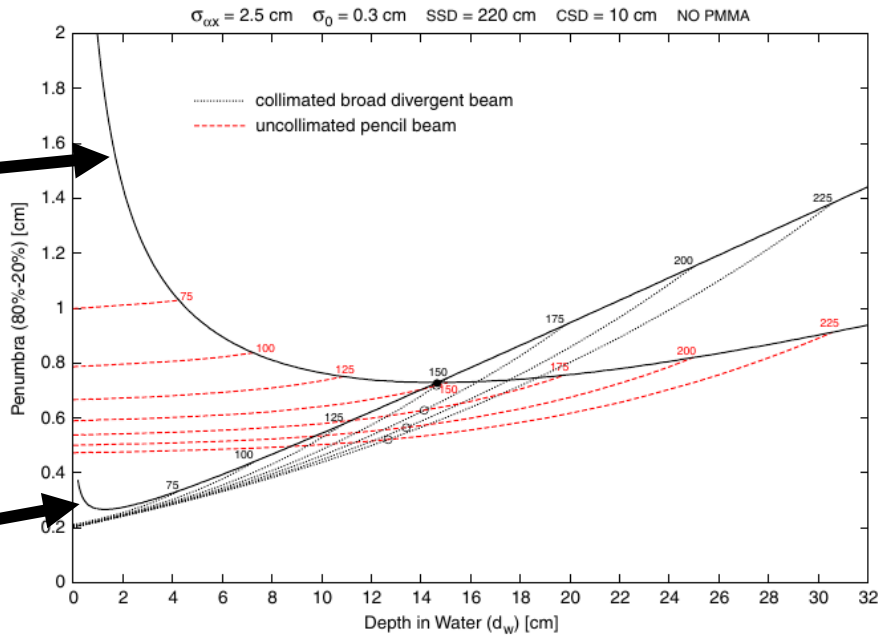


Figure 5. Penumbra as a function of depth in water (d_w) for different beam energies (expressed in MeV) for a collimated broad divergent beam and for an uncollimated pencil beam.

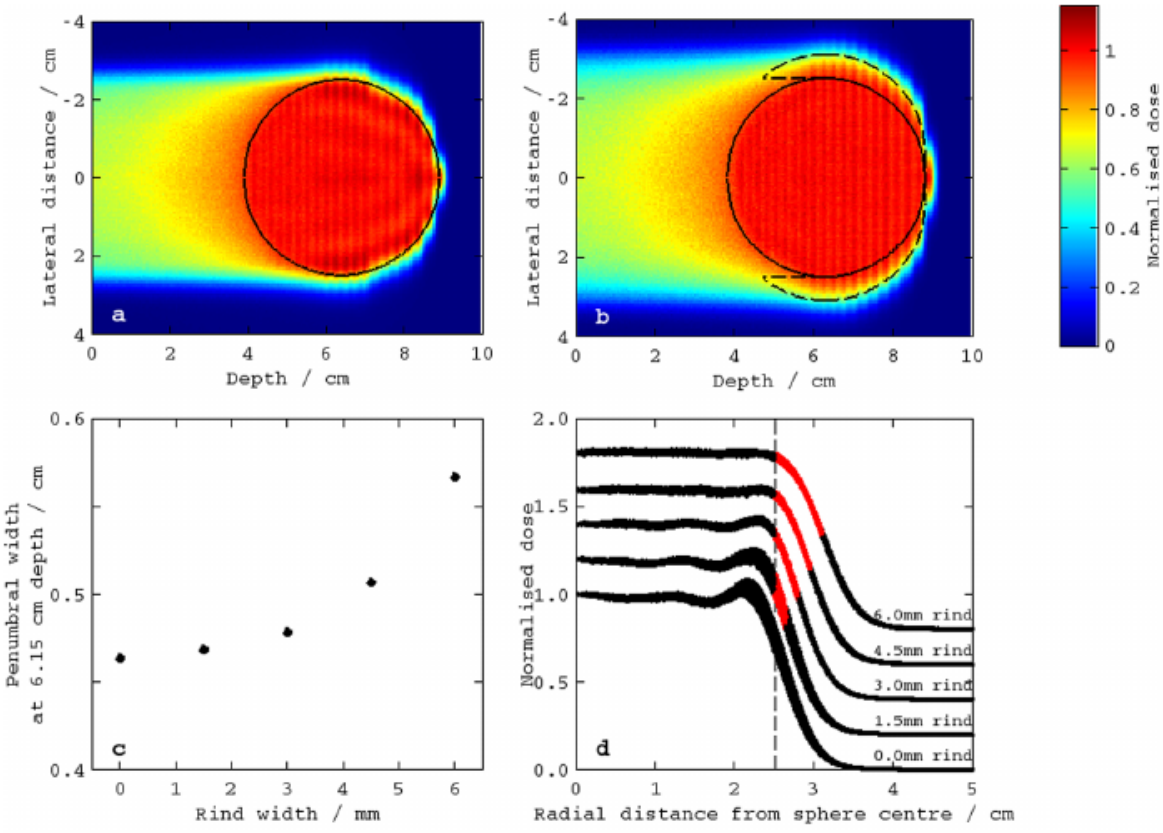
Phys. Med. Biol. **53** (2008) 1729–1750 doi:10.1088/0031-9155/53/6/016

Comparison between the lateral penumbra of a collimated double-scattered beam and uncollimated scanning beam in proton radiotherapy

Sairos Safai, Thomas Bortfeld and Martijn Engelsman

Francis H Burr Proton Therapy Center, Massachusetts General Hospital, 30 Fruit Street, Boston, MA 02474, USA

Lateral penumbra (80%-20%) in 3D

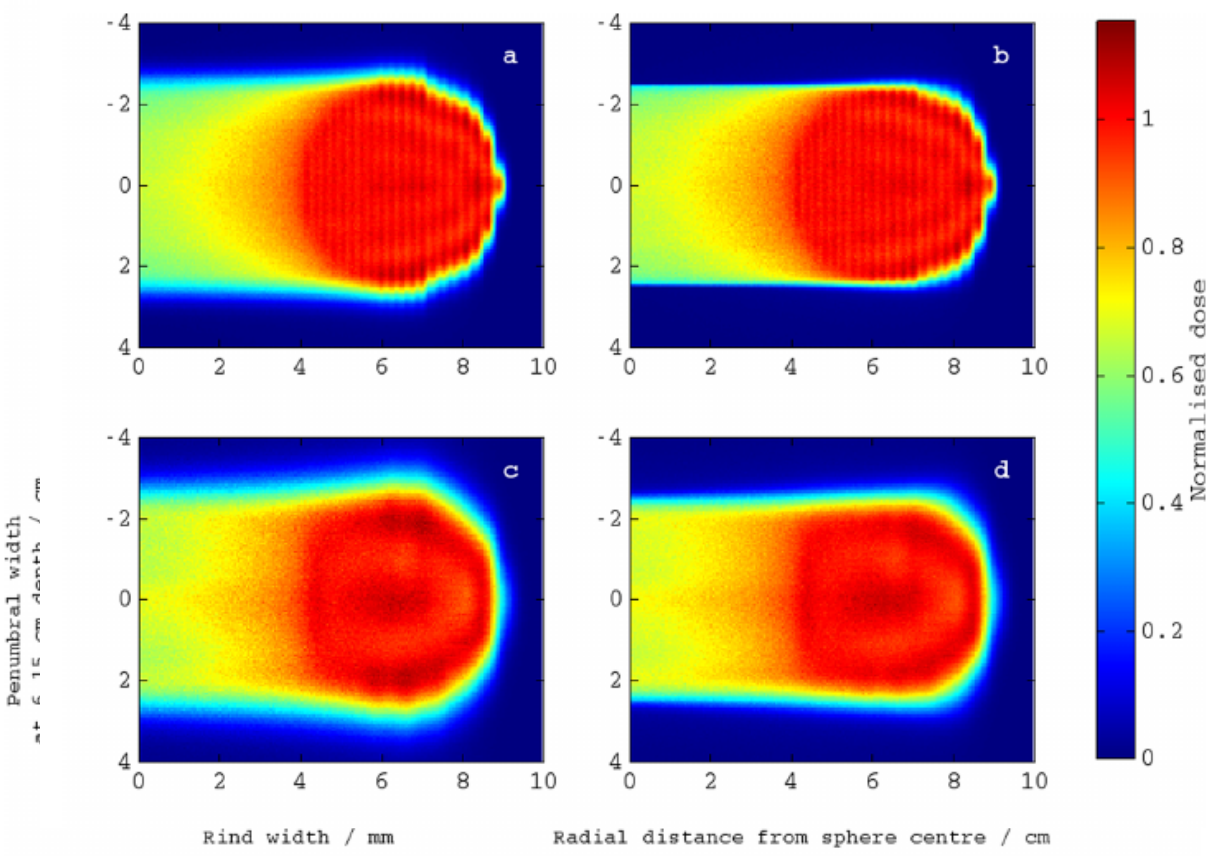


A Monte Carlo study on the collimation of pencil beam scanning proton therapy beams

Frances C. Charlwood, Adam H. Aitkenhead,[a)] and Ranald I. Mackay

Med. Phys. 43 (3), March 2016

Collimation of 3D volumes



A Monte Carlo study on the collimation of pencil beam scanning proton therapy beams

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Collimator implementation: Physical design

Phys. Med. Biol. **59** (2014) N187–N196 doi:10.1088/0031-9155/59/22/N187

Note

Effects of spot size and spot spacing on lateral penumbra reduction when using a dynamic collimation system for spot scanning proton therapy

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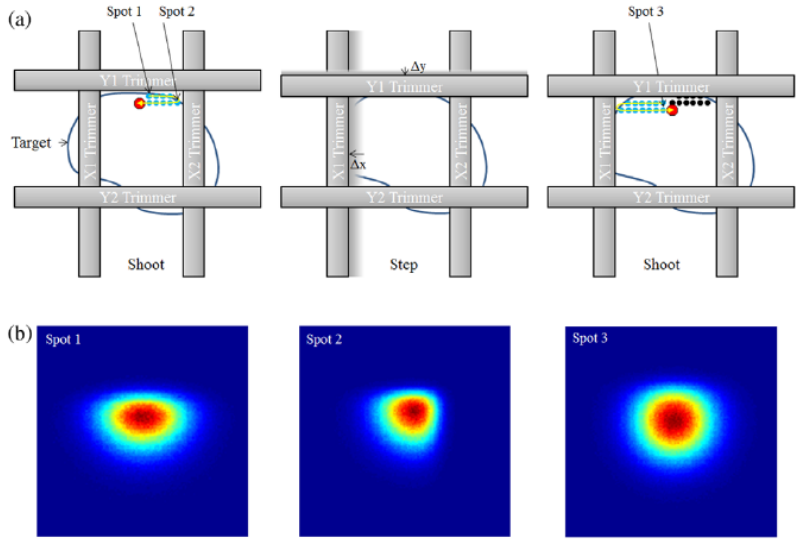

Figure 2. (*a*) A beam's eye view diagram illustrating the step-and-shoot delivery technique for positioning the trimmer blades to intercept the beam when it arrives at the edges of the target and (*b*) selected spot dose distributions qualitatively illustrating the effect of the trimmers on a single spot.

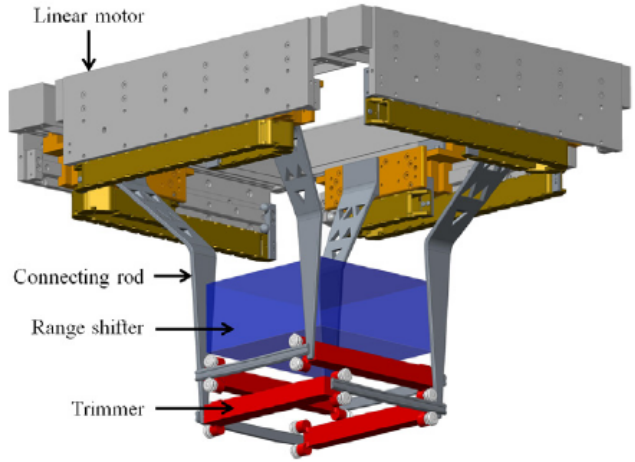

Figure 1. Major DCS components. The position of each trimmer is individually controlled by a linear motor that is connected to the trimmer via a connecting rod. A range shifter is also mounted just upstream of the trimmers. A support frame and housing surrounding the components is not shown.

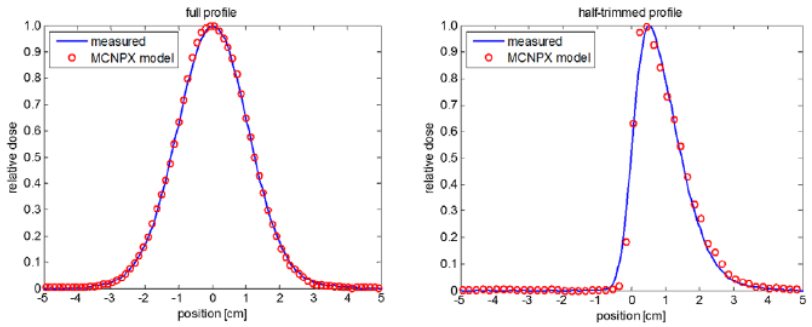

Figure 4. Experimental measurements of an untrimmed and half-trimmed profile to validate the Monte Carlo model.

Collimator implementation: Analytical dose models

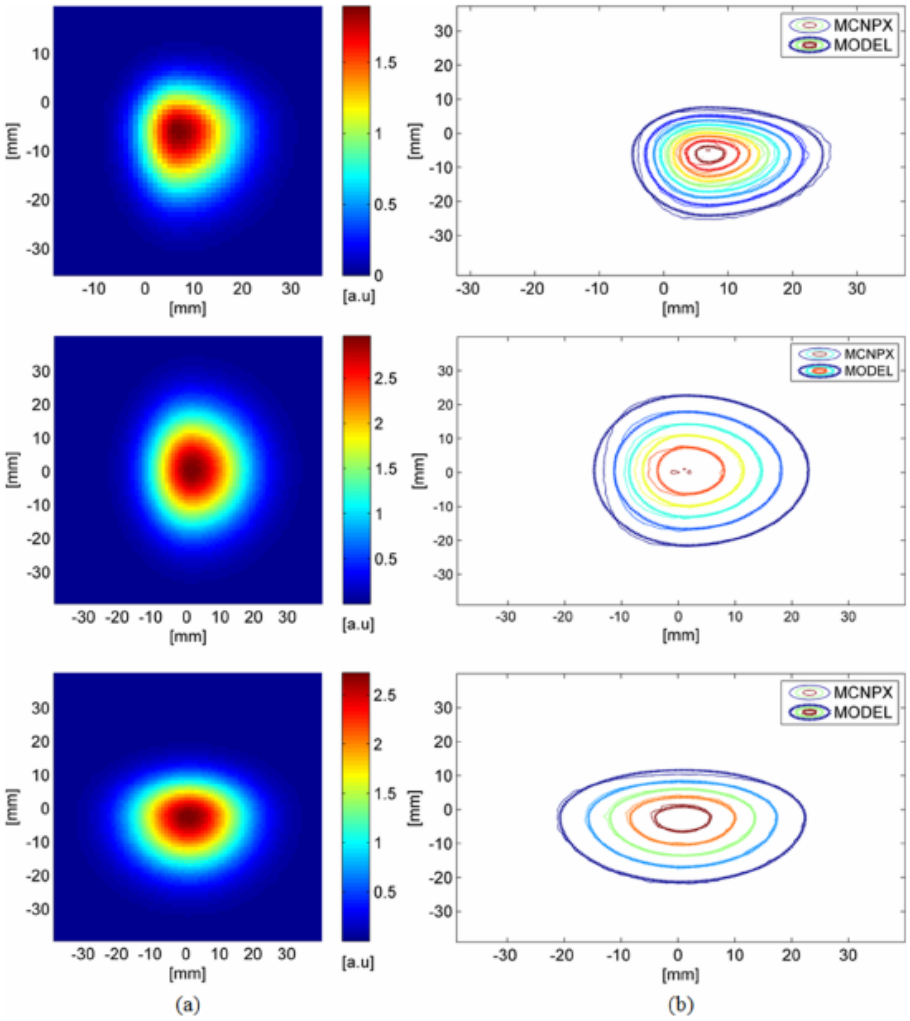

Fig. 6. (a) Examples of three modeled lateral dose distributions at the depth of the Bragg peak (5 cm) for the 128.0 MeV beam. (b) Isodose comparison with MCNPX in the beam's eye view. The trimmer configurations shown are identical to those in Fig. 5.

A method for modeling laterally asymmetric proton beamlets resulting from collimation

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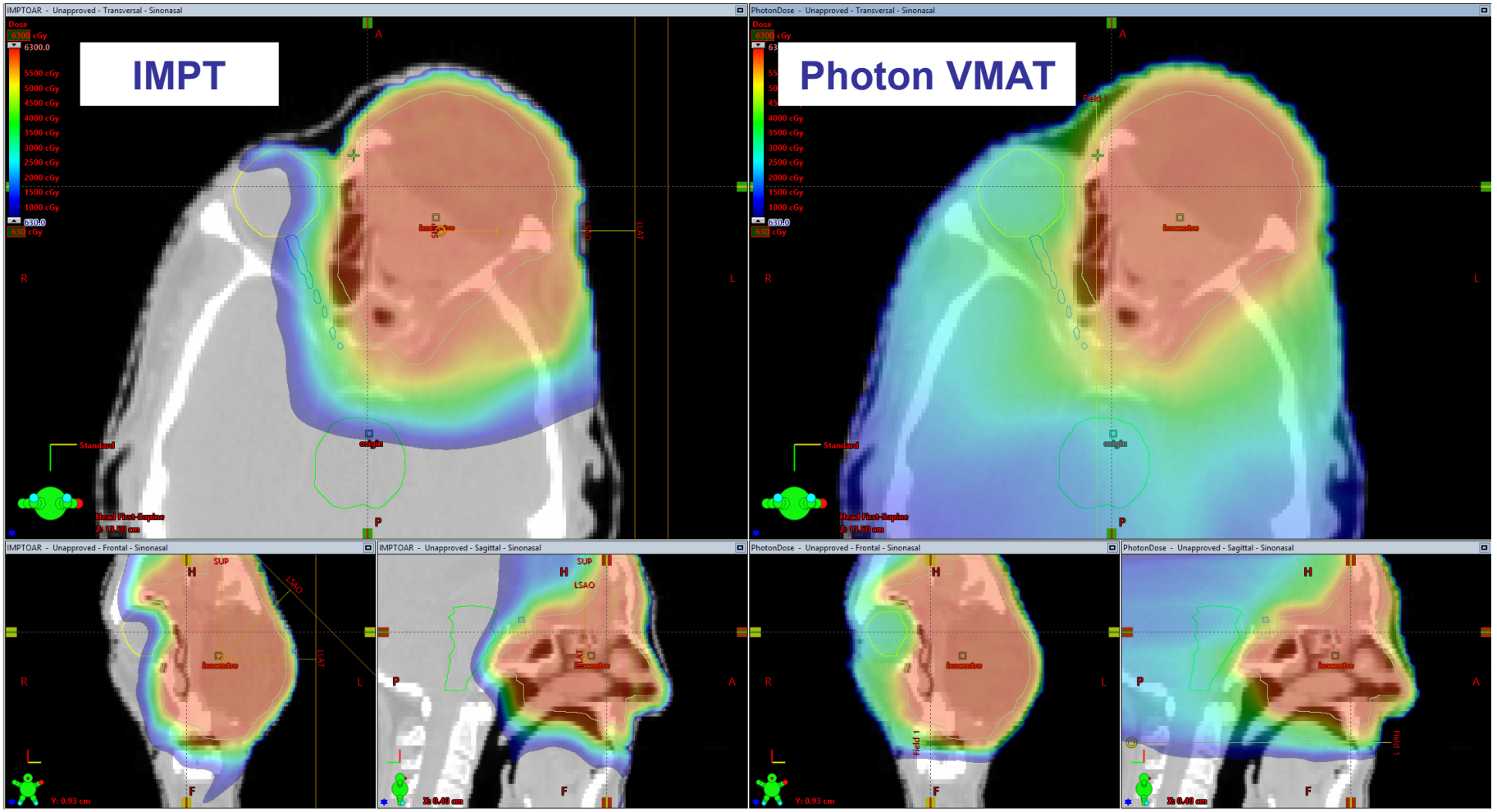
Clinical case studies

Is collimation needed?

- Case 1: Nasal cavity – Photon VMAT
- Case 2: Ewing sarcoma of cheek – Passive scattered protons
- Case 3: Chordoma – Photon IMRT
- Case 4: Nasopharynx – Photon VMAT

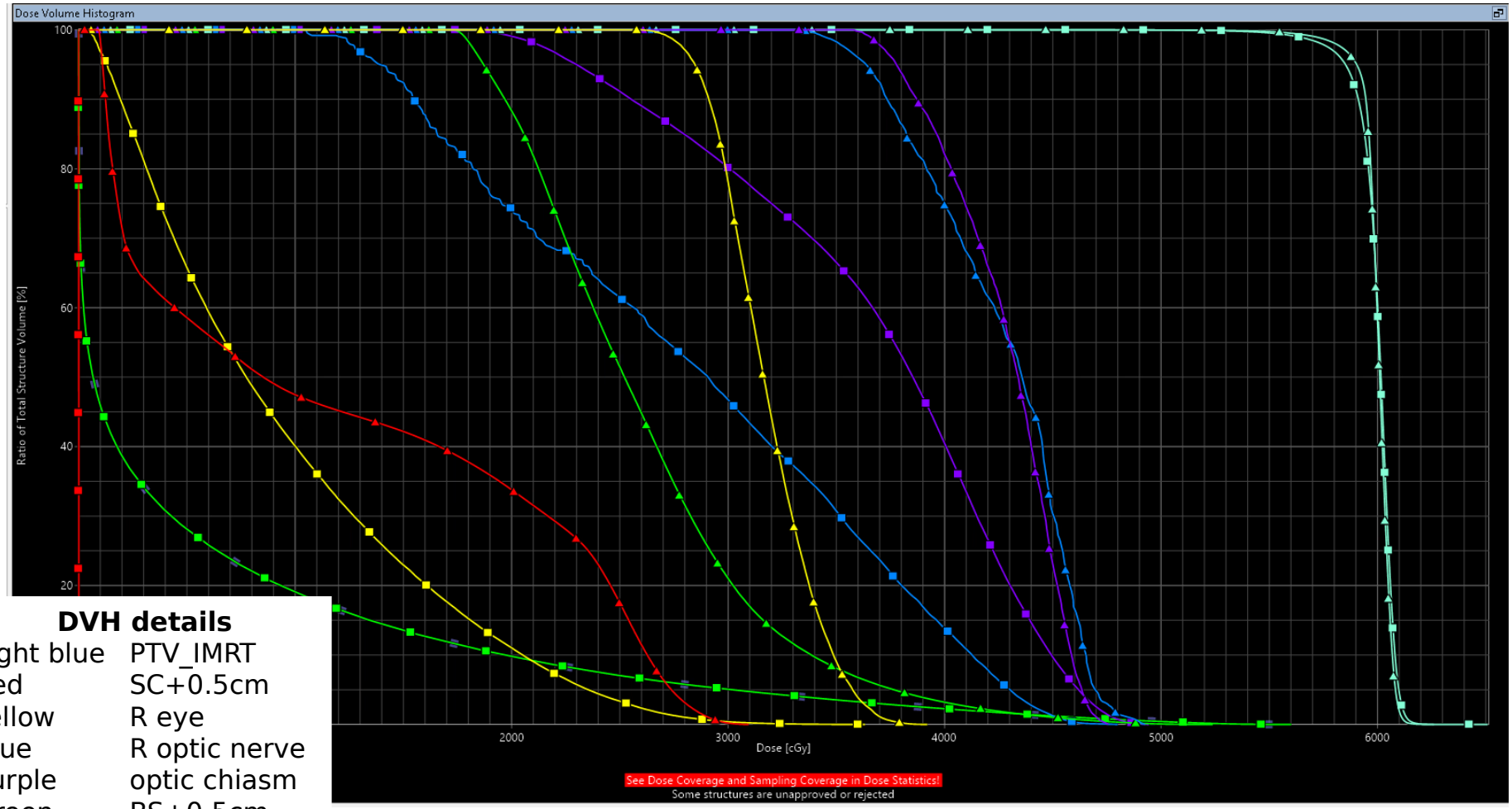
Clinical case 1: Nasal cavity

- Target is superficial and close to optics
- Locally advanced adenoid cystic carcinoma of the right sino-nasal anterior skull base region, treated by left partial maxillectomy
- Dose: 60 Gy



Clinical case 1: Nasal cavity

- IMPT sparing of contra-lateral optics is improved compared to photons.
- IMPT target coverage is comparable to photons.



DVH details

Light blue	PTV_IMRT
Red	SC+0.5cm
Yellow	R eye
Blue	R optic nerve
Purple	optic chiasm
Green	BS+0.5cm
Squares	IMPT
Triangles	Photons

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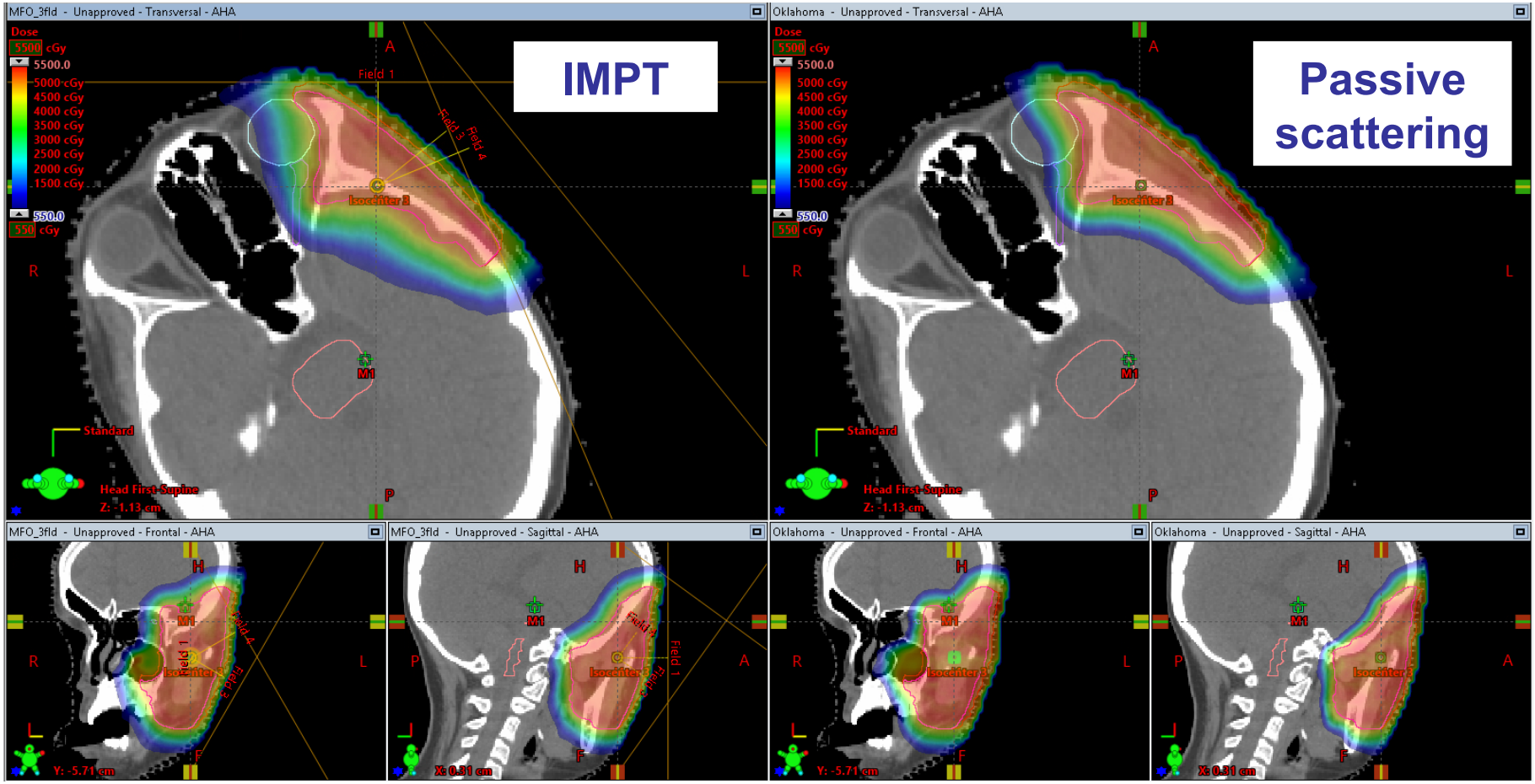
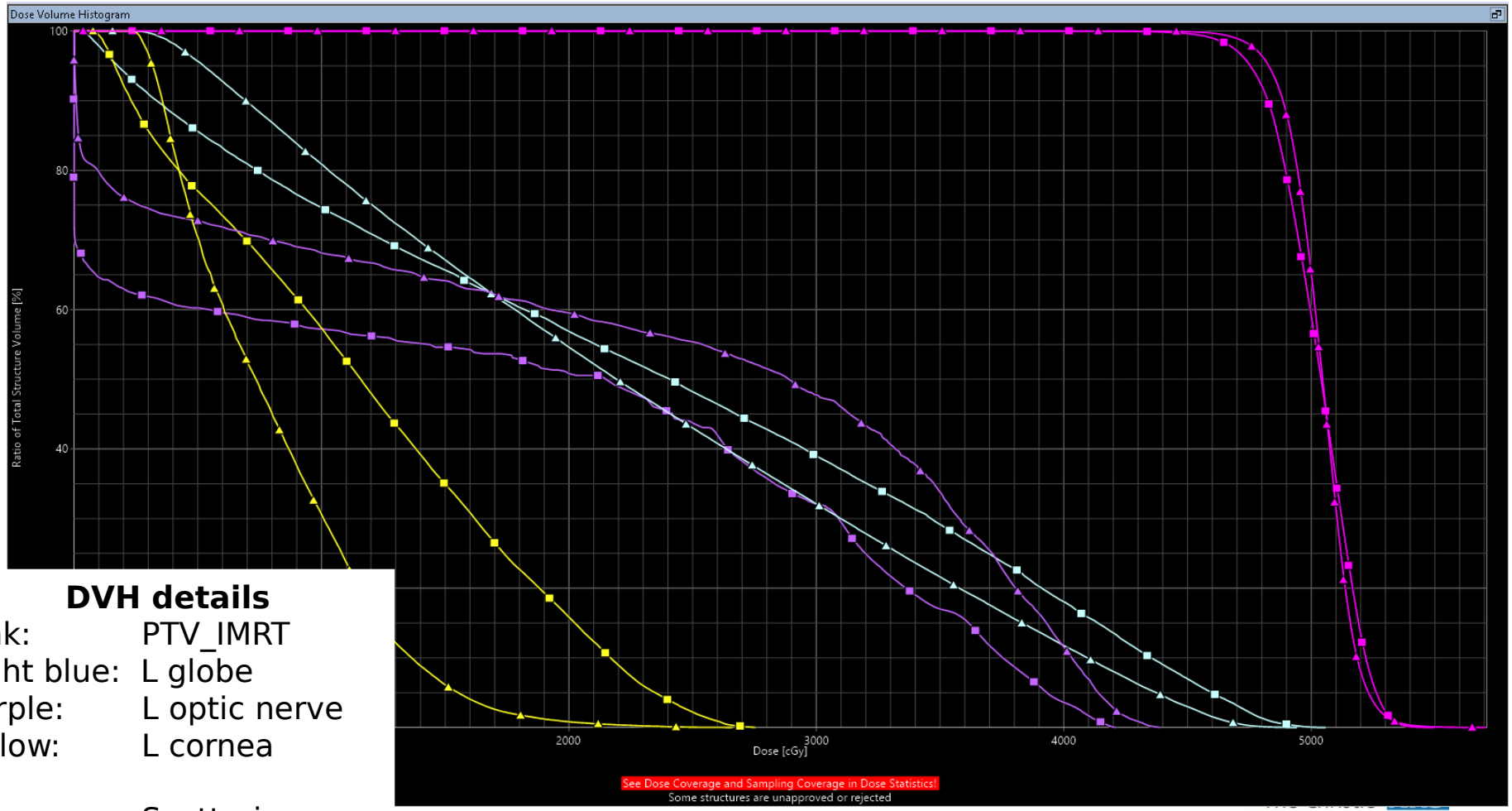
Clinical case 2: Ewing sarcoma

- Target is superficial and close to optics.
- 50.4 Gy



Clinical case 2: Ewing sarcoma

- IMPT target coverage is comparable to passive scattering.
- IMPT dose fall-off is less sharp around target.
- IMPT optic nerve dose is higher.

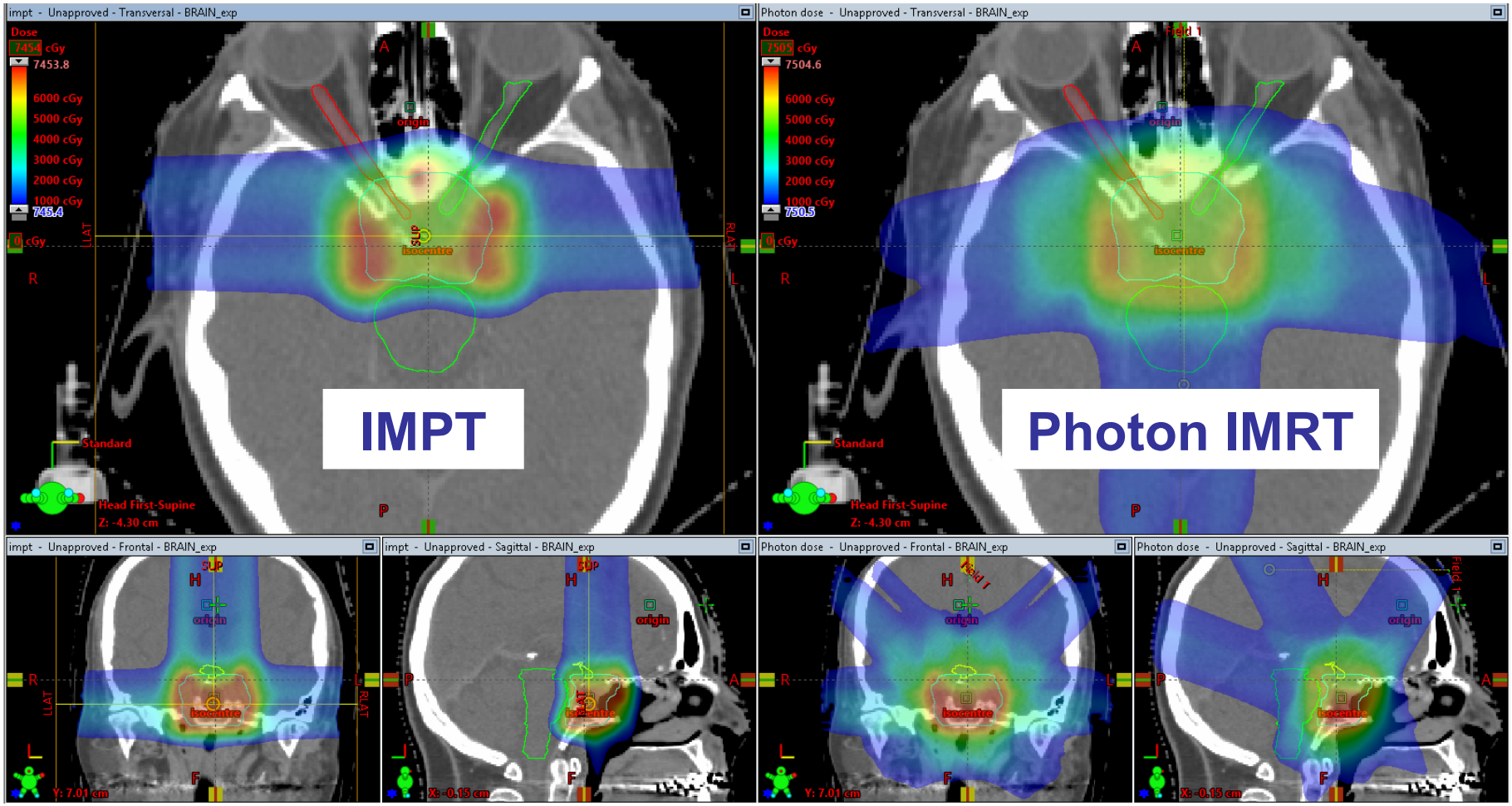


DVH details

Pink:	PTV_IMRT
Light blue:	L globe
Purple:	L optic nerve
Yellow:	L cornea
Squares:	Scattering
Triangles:	IMPT

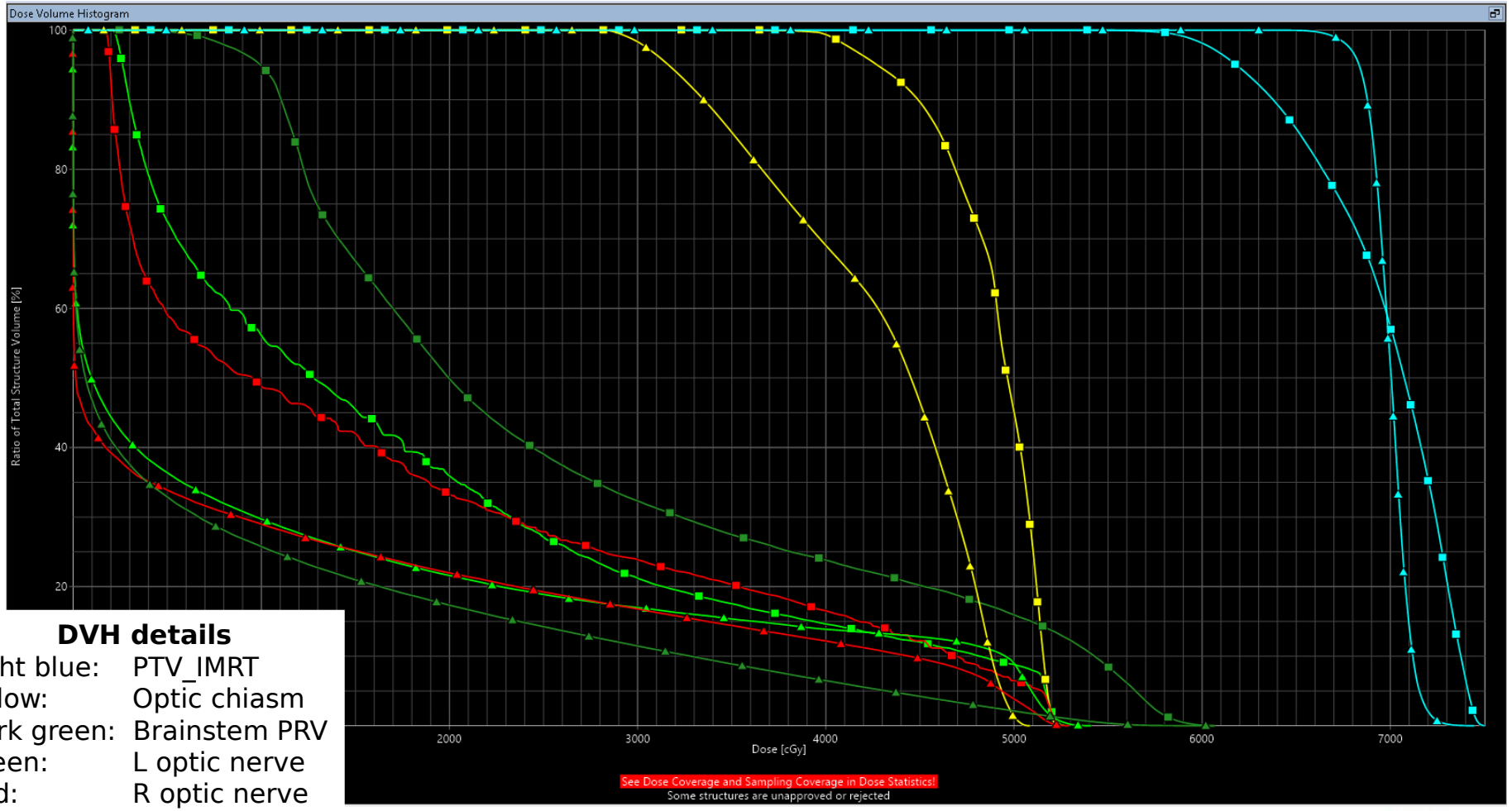
Clinical case 3: Chordoma

- Clinicians initially thought this case might be unsuitable for protons due to proximity of brainstem to target.
- 70 Gy.



Clinical case 3: Chordoma

- Control of dose to target is as good as (or better than) photons.
- IMPT sparing of OARs is improved compared to photons.



DVH details

Light blue:	PTV_IMRT
Yellow:	Optic chiasm
Dark green:	Brainstem PRV
Green:	L optic nerve
Red:	R optic nerve
Squares:	Photons
Triangles:	IMPT

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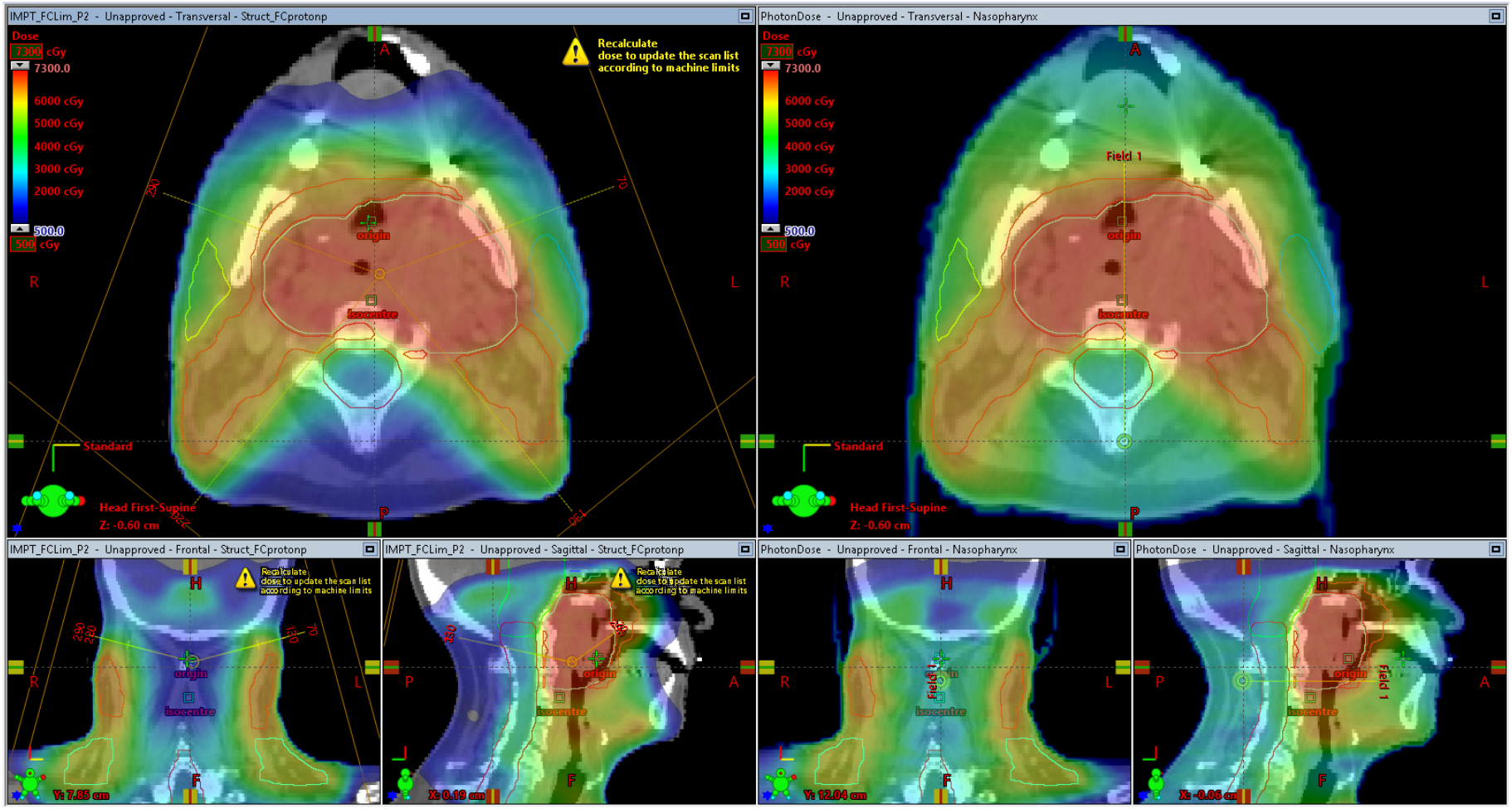
Clinical case 4: Nasopharynx



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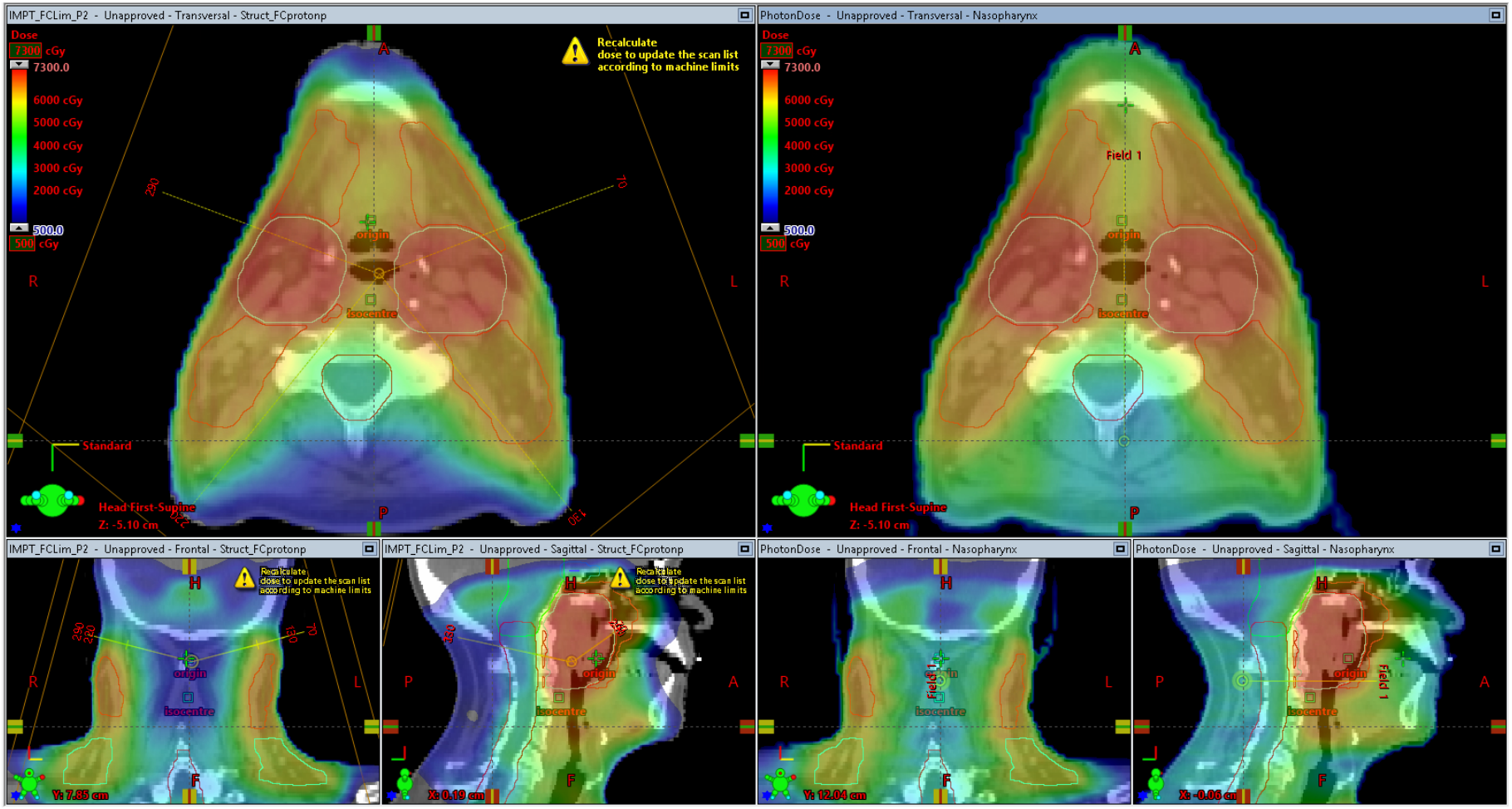
Clinical case 4: Nasopharynx



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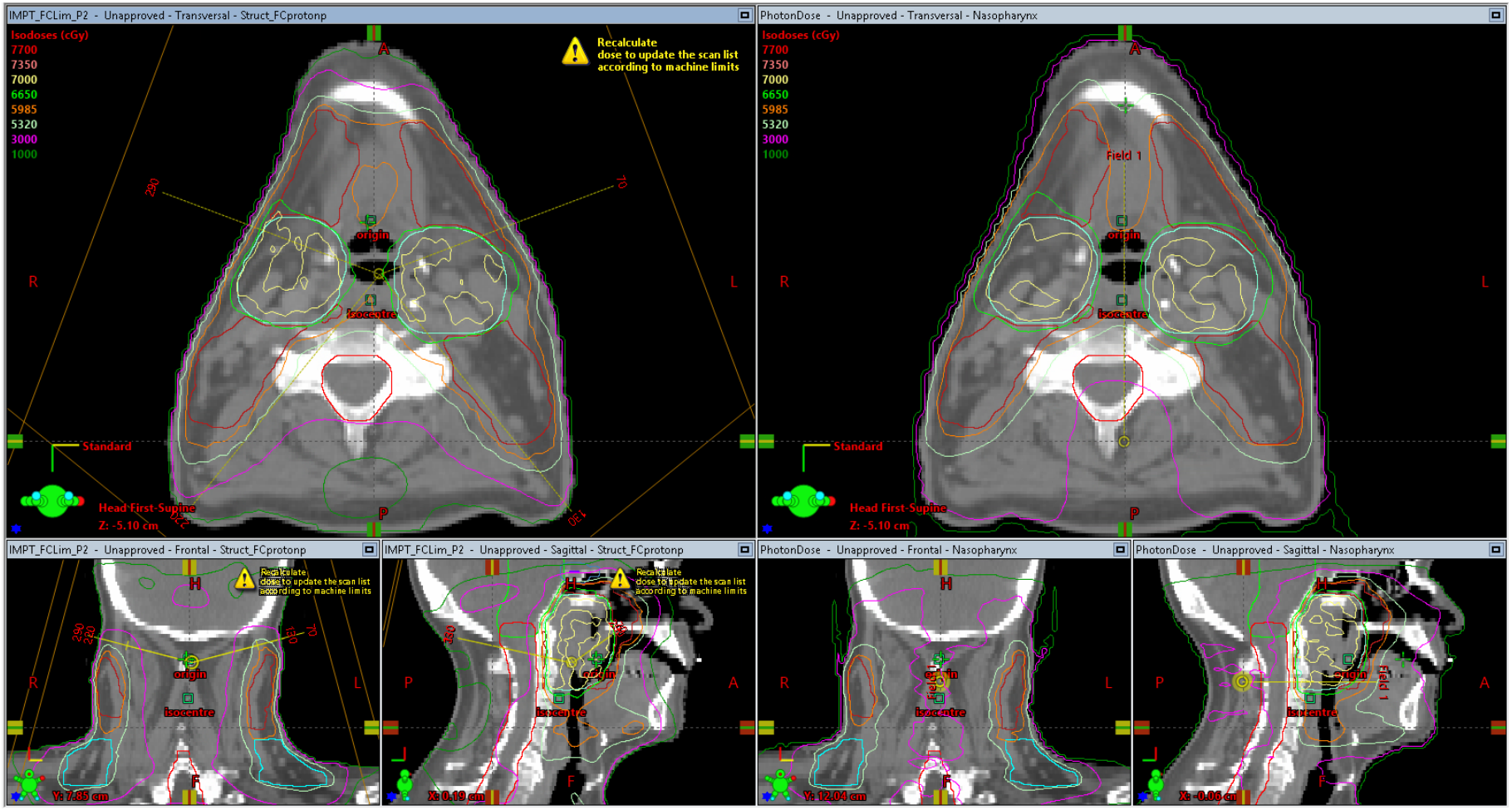
Clinical case 4: Nasopharynx



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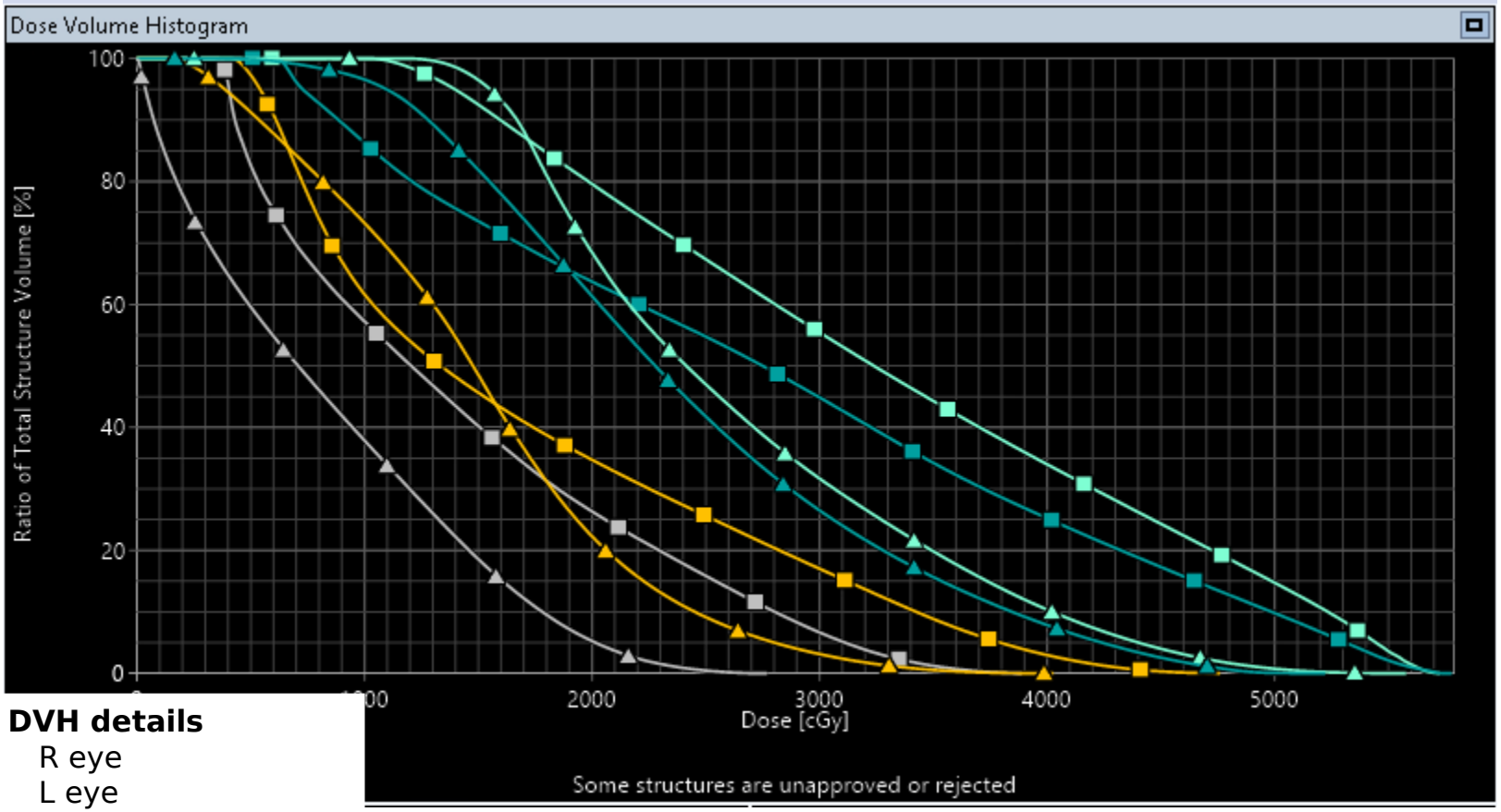
Clinical case 4: Nasopharynx

- Optics: IMPT reduced dose



DVH details

Lilac:	R eye
Orange	L eye
Blue:	R optic nerve PRV
Cyan:	L optic nerve PRV
Grey:	Optic chiasm
Squares:	Photons
Triangles:	IMPT

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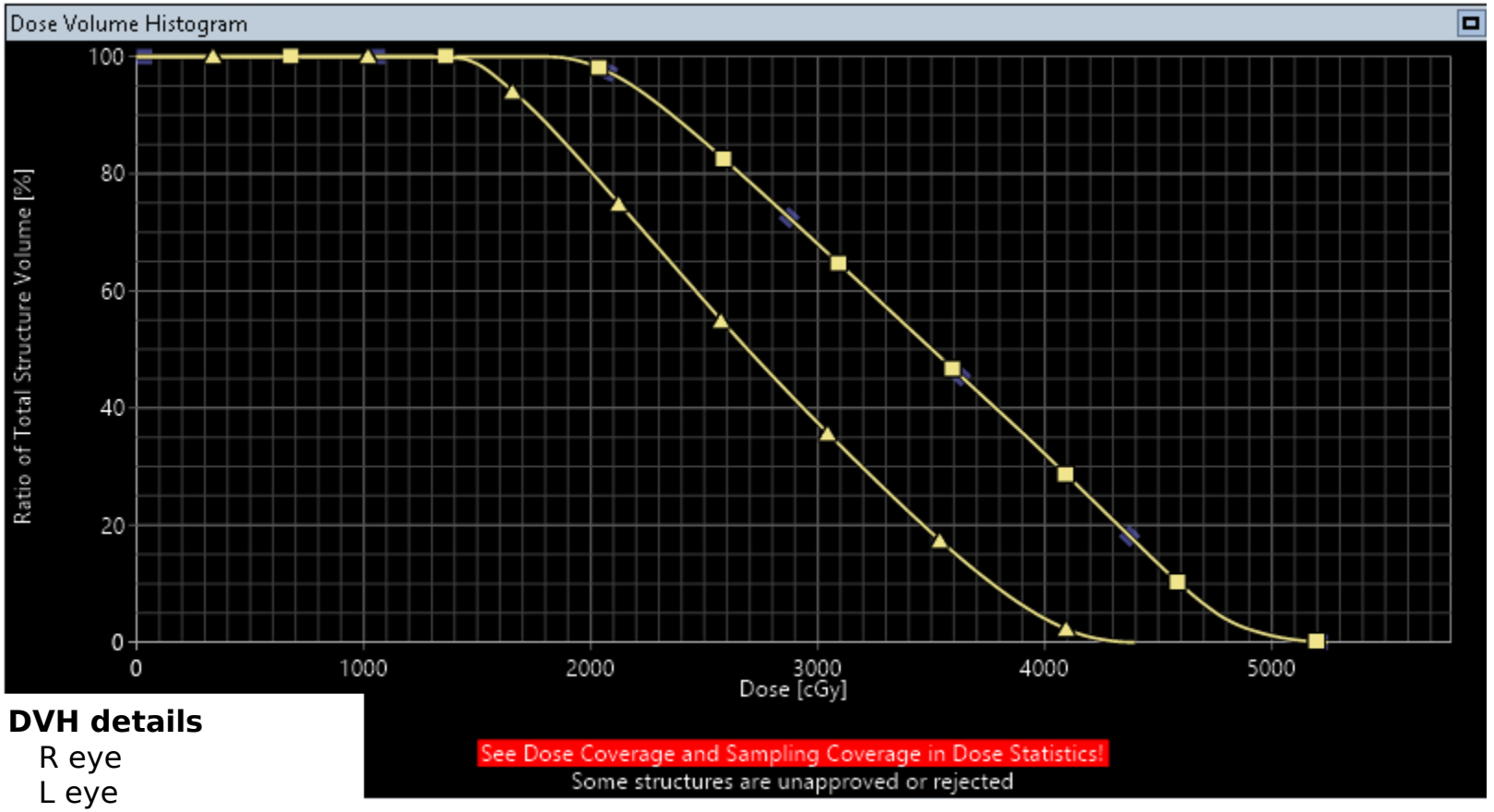
Clinical case 4: Nasopharynx

- Optic chiasm: IMPT reduced dose



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Lilac:	R eye
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Blue:	R optic nerve PRV
Cyan:	L optic nerve PRV
Grey:	Optic chiasm
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Triangles:	IMPT

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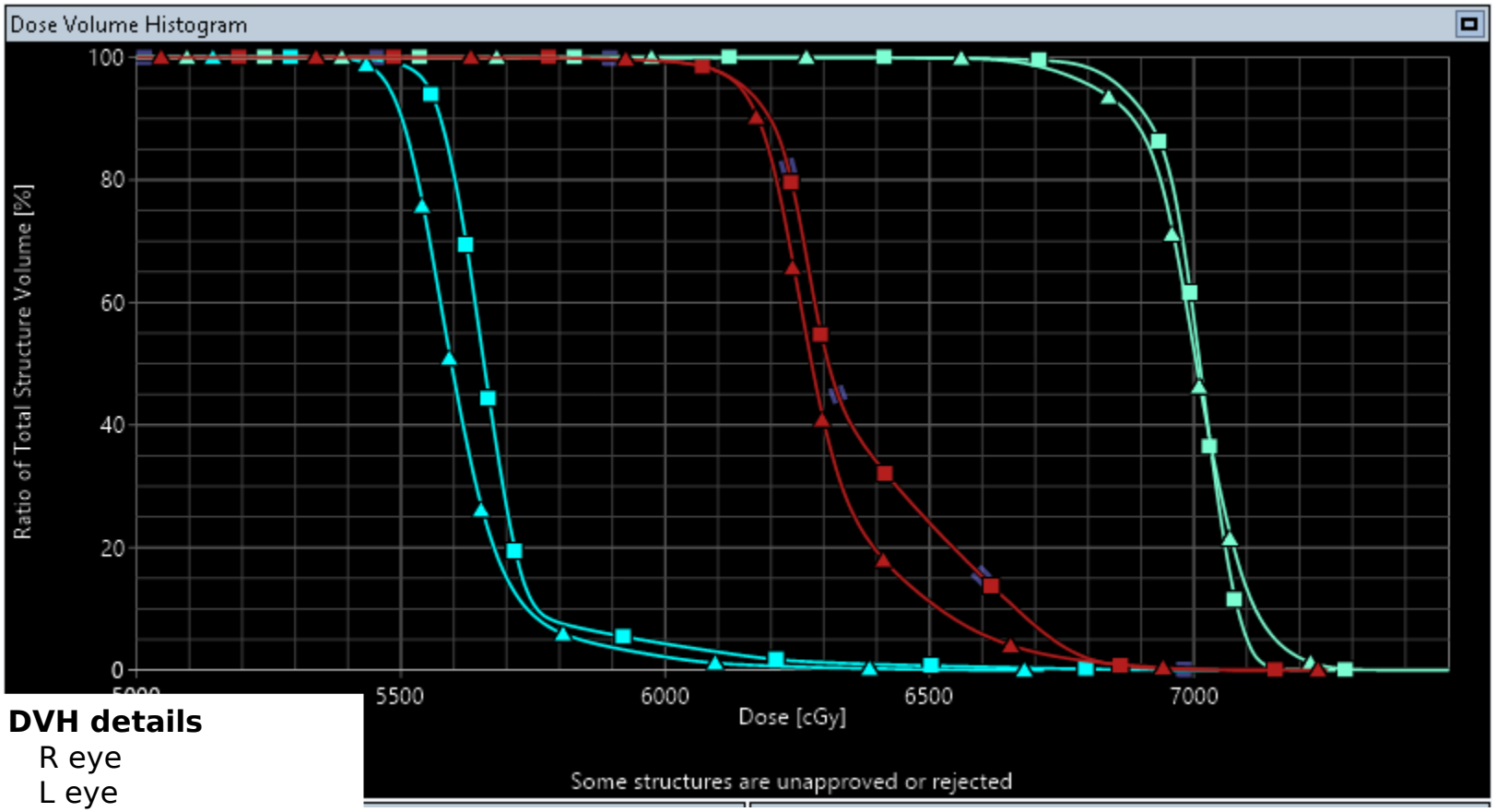
Clinical case 4: Nasopharynx

- Targets: 70, 63, 56 Gy
- IMPT showed poorer uniformity



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Orange	L eye
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Cyan:	L optic nerve PRV
Grey:	Optic chiasm
Squares:	Photons
Triangles:	IMPT

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Summary

- Lateral penumbra is between 1.13 – 1.68 σ
- The optimizer can adjust spot weights to sharpen an edge at the cost of poorer uniformity (hot and cold spots).

- Current PBS technology is capable of producing similar plan quality as VMAT photons for the cases investigated here.

Potential for improvement:

- Collimation
- Reduced spot sizes
- Avoiding use of range shifter where possible

Thank you