Treatment Planning for Skull Base Tumors PTCOG 52, June 2013

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Chordomas and Chondrosarcomas Prescription and Constraints

Dose in Gy(RBE)

- Chondrosarcomas

  Rx: GTV – 70; CTV – 50
- Chordomas

  Rx: GTV – 72 to 78; CTV – 50
- Constraints:

  Optic structures – 60 to 62

  Brainstem/spinal cord – center 53 to 55

  surface 64 to 67 (or max dose)

  Cochlea – <60 (unless tumor abutts)

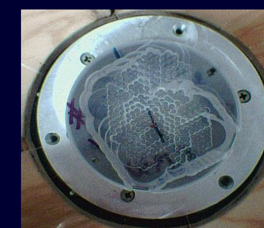
Planning considerations

- CTV & GTV
  - Size, shape, and location
- Beam Arrangement
  - Paired beams
  - Matching
  - Patching
- Rx dose versus constraints
  - Penumbra considerations
  - When to design aperture ‘off’ critical structures

Planning Basics for SOBP

- Lateral coverage by aperture edge
- Lateral penumbra
- Targeting uncertainty (<3mm, mostly random)

volume guided



- Distal coverage by compensator
- Sharper distal penumbra
- Range uncertainty (3.5% of range, mostly systematic)

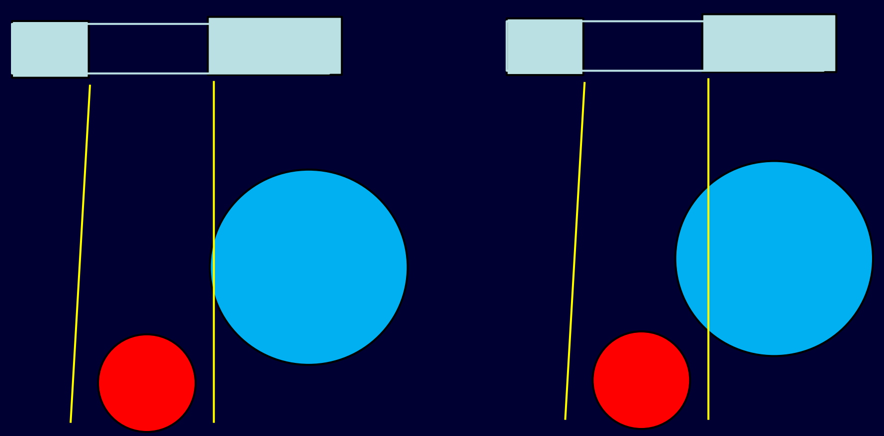
Must move around

Staying 'Off' Critical Structures

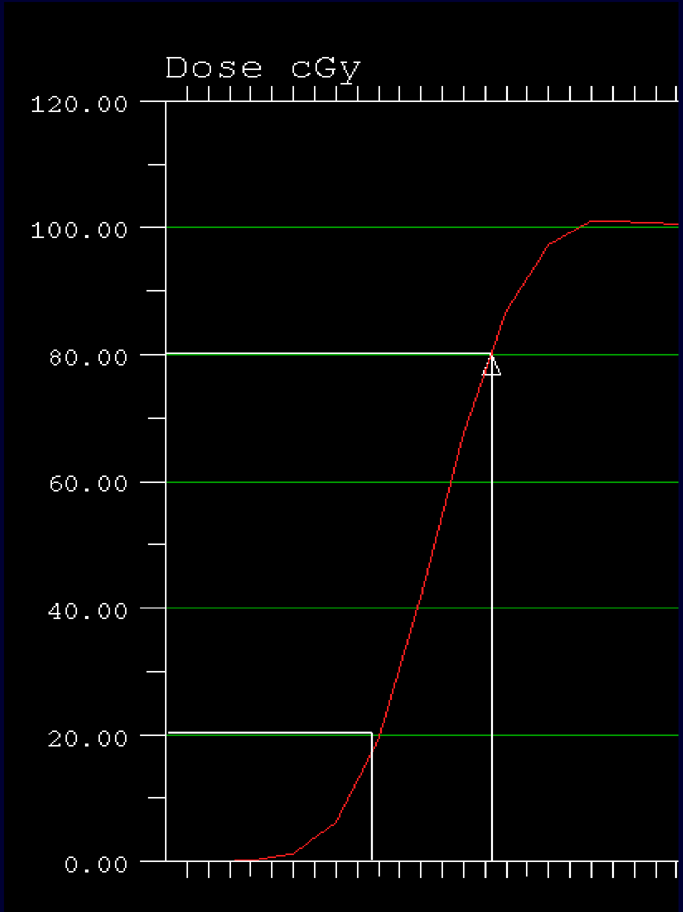
Aperture edge is more reliable

Rule of thumb for dose gradient for ranges up to 16 cm:

1mm = 10% of dose across 20-80%



On edge → 50%   2 mm → 70%



Lateral Penumbra

MGH Standard Approach

Photon component to 20 Gy

IMRT or 3D conformal

CTV/GTV beam arrangement to 60 Gy

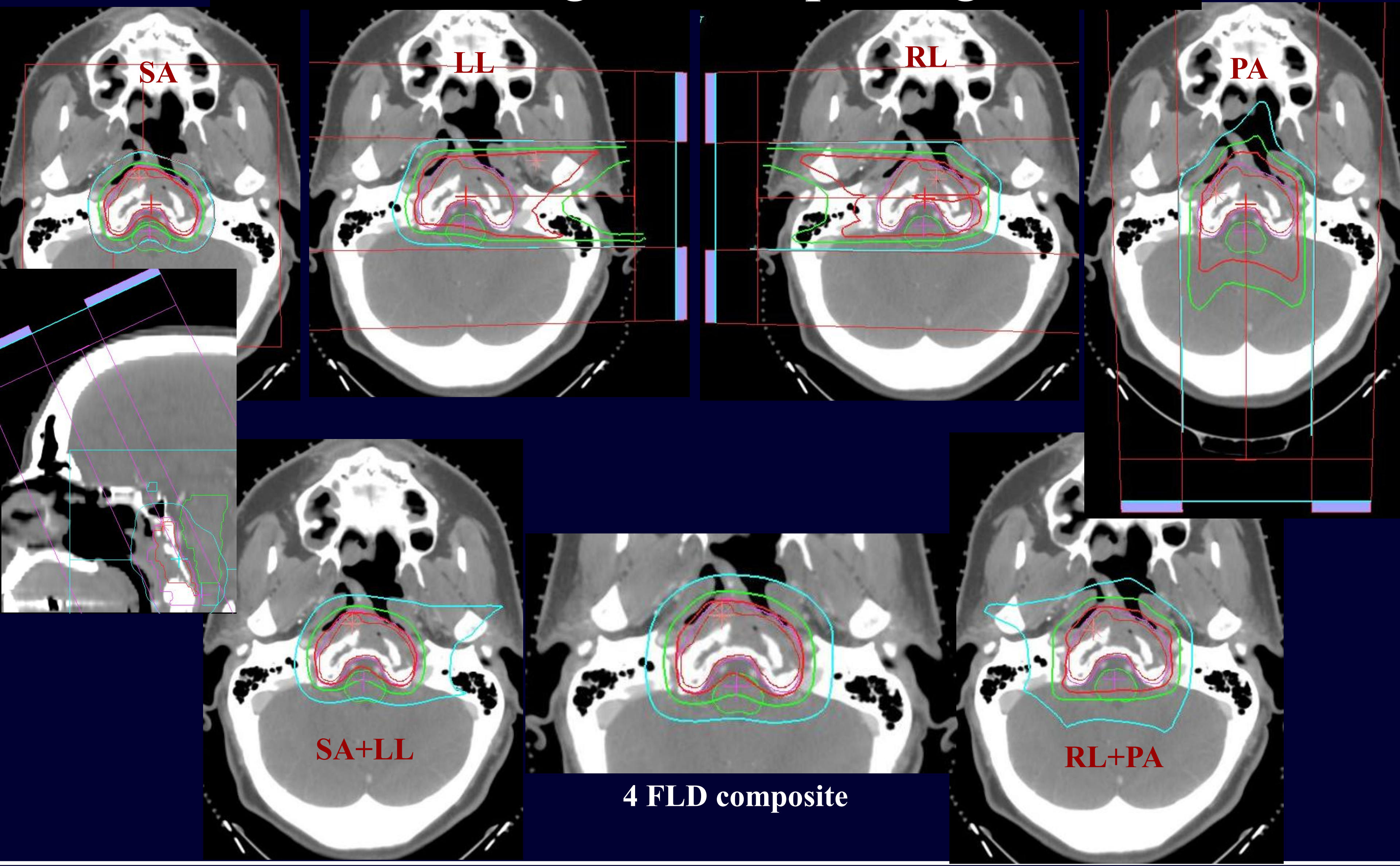
Paired split dose fields:

PA – 14 Gy
R (RL, RAO, RP)) – 8 Gy
L (LL, LAO, LP)) – 8 Gy
SAO – 10 Gy (aperture to GTV, RC to CTV)

GTV to 70Gy (chondrosarcoma) and 72-78Gy (chordomas)

'off critical structures'
split-dose fields, matching fields or patch combos

Field Arrangement – pairing fields



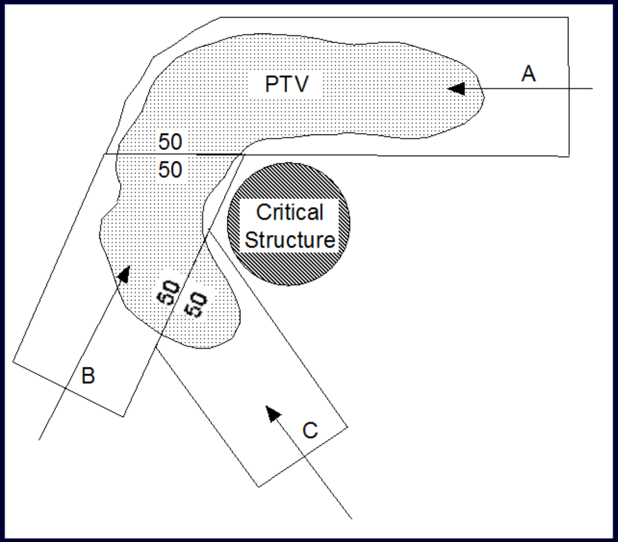
4 FLD composite

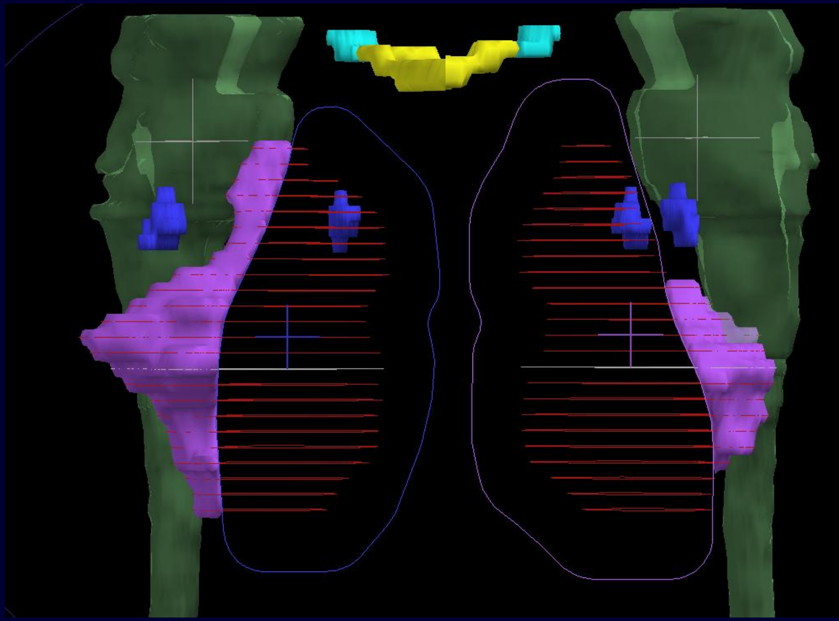
Matching Technique

- Not unique to proton therapy
- Changing target volume geometry
- Target volume(s) segmented into separate volumes (commonly superior and inferior components)
- Fields abutt

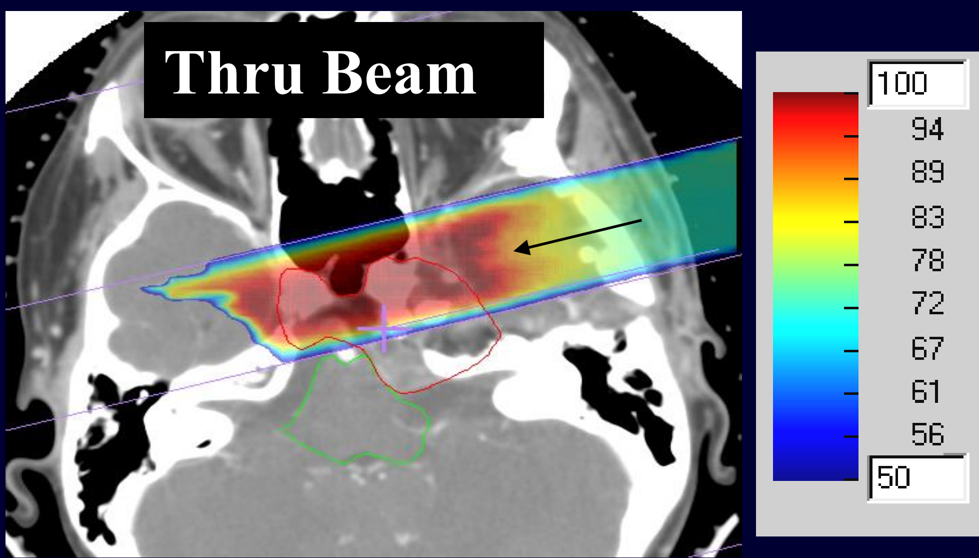
Field Patching

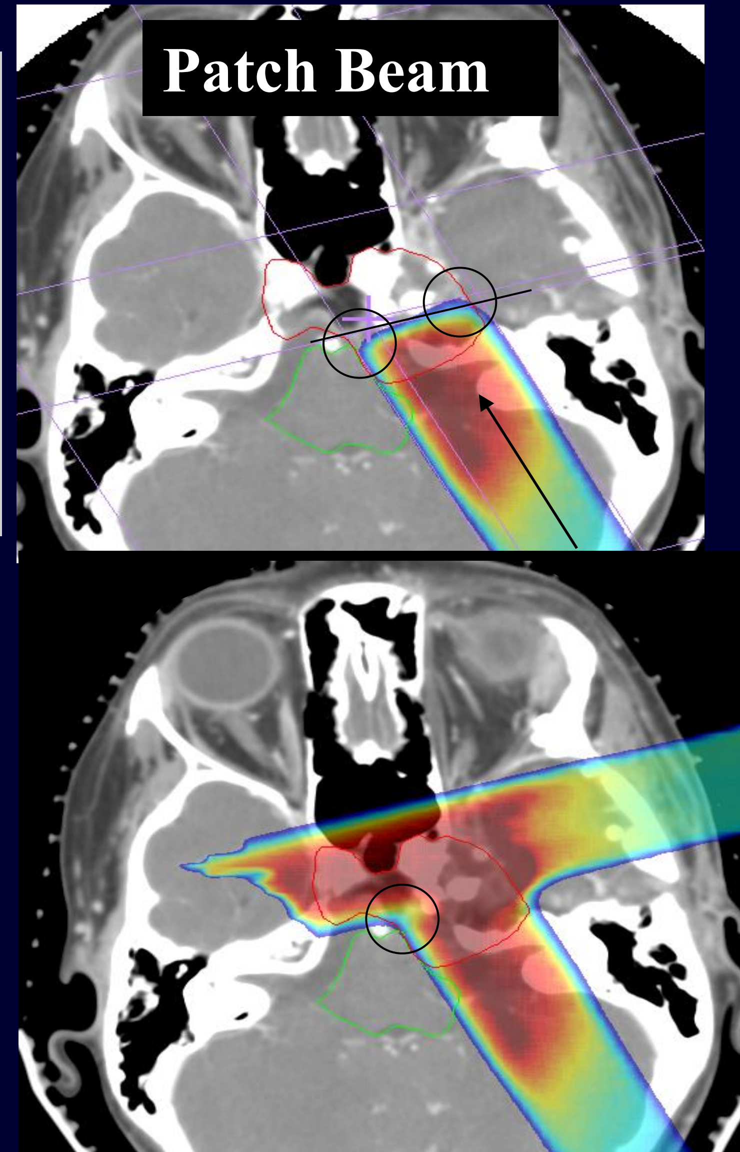
- Patching is a hierarchical sequence of proton fields.
  - "THROUGH" Field A: Achieved distal conformation to TV with the Range Compensator.
  - PATCH Field B: Achieve matching of distal edge of B with the Range Compensator at the lateral (50%) field edge of A
  - PATCH Field C: Match at 50% isodose, lateral + distal, levels





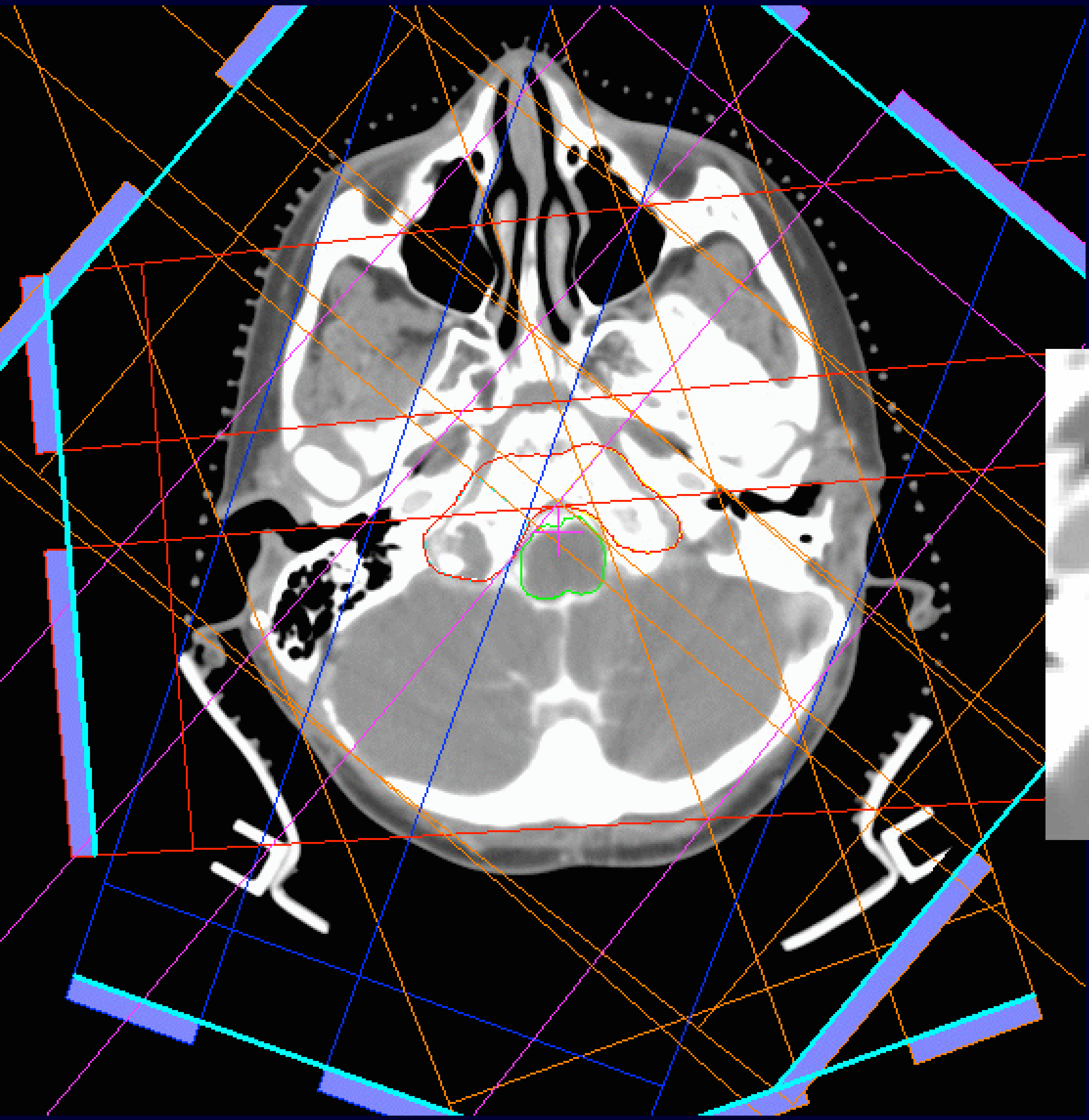
Patch Technique



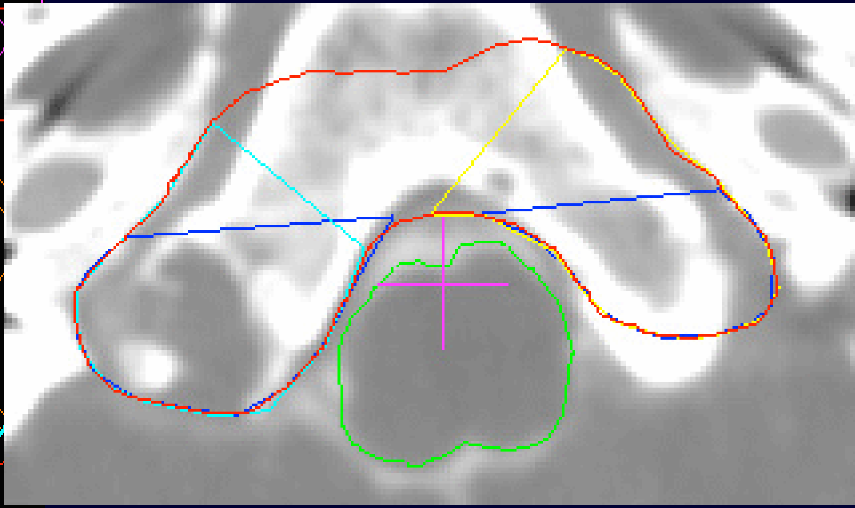


- Multiple (2 or 3) patch combinations usually required
  - move around hot and cold regions
  (hot at patchline, cold triangle at aperture intersections)

Patch Combinations



Patch Lines



Overall hot/cold spots less than 10%

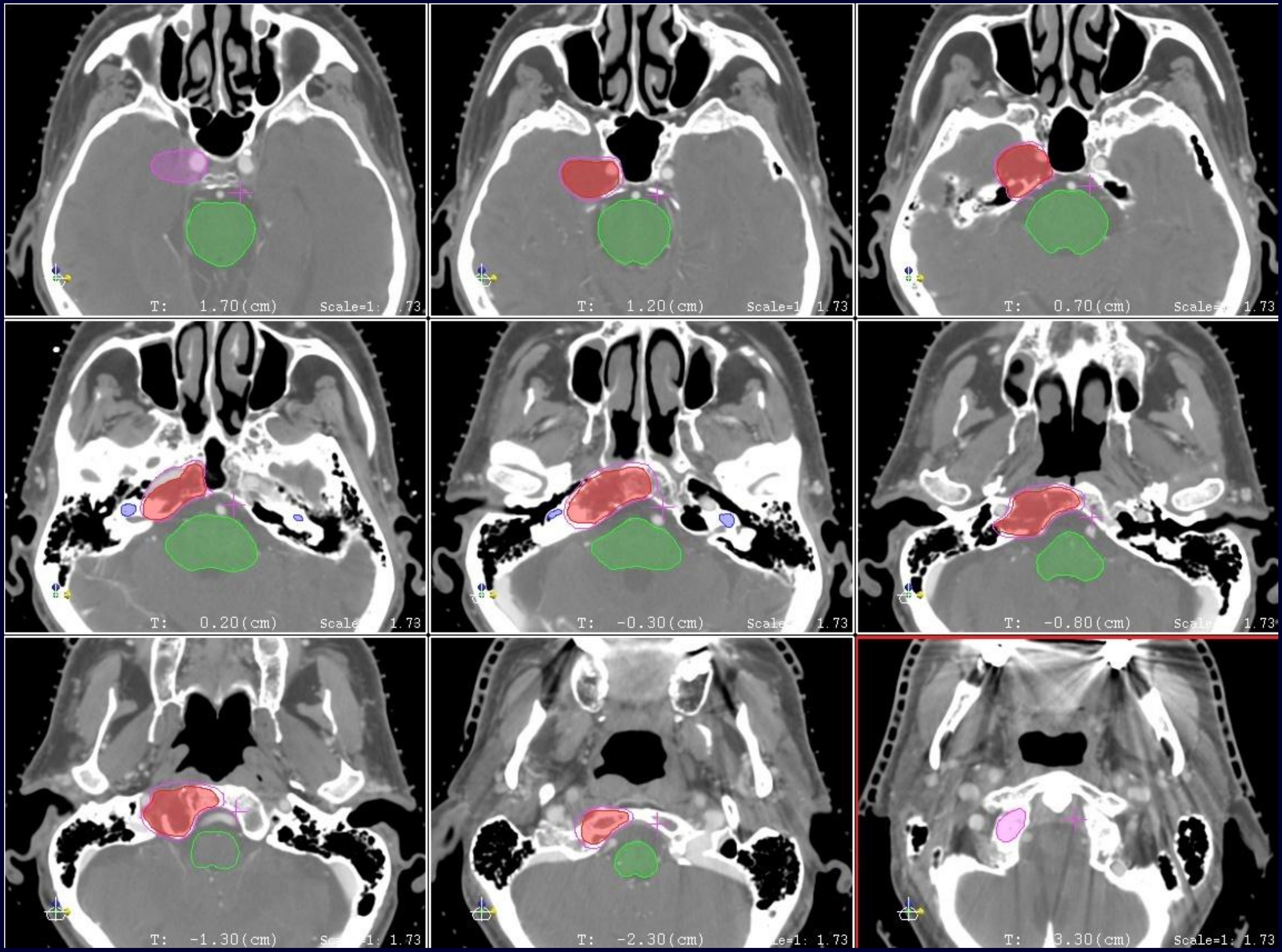
Case 1: Chondrosarcoma
(proton dose in Gy (RBE))

Right petroclival junction tumor

Rx: GTV – 70 Gy; CTV – 50 Gy
(CTV received 20Gy with IMRT, 5 flds)

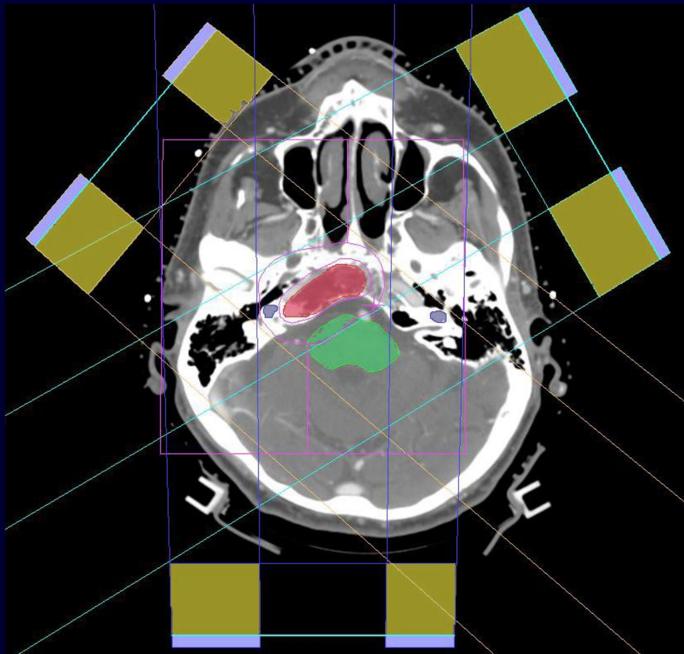
Constraints: BS, SC – 55/67 Gy, center/surface
Cochlea <60 Gy

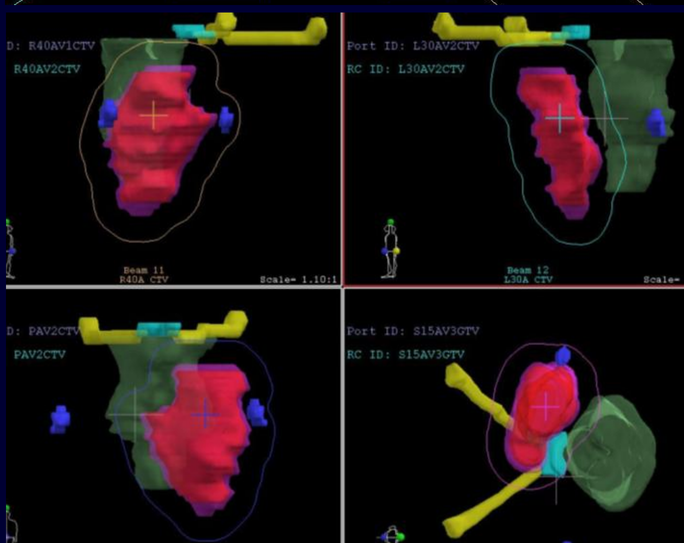
Proton field arrangement and dose:
CTV: PA – 14 Gy, R40A – 8 Gy, L30A – 8 Gy
GTV: S15A – 10 Gy, R30P – 5 Gy, L30A – 5 Gy



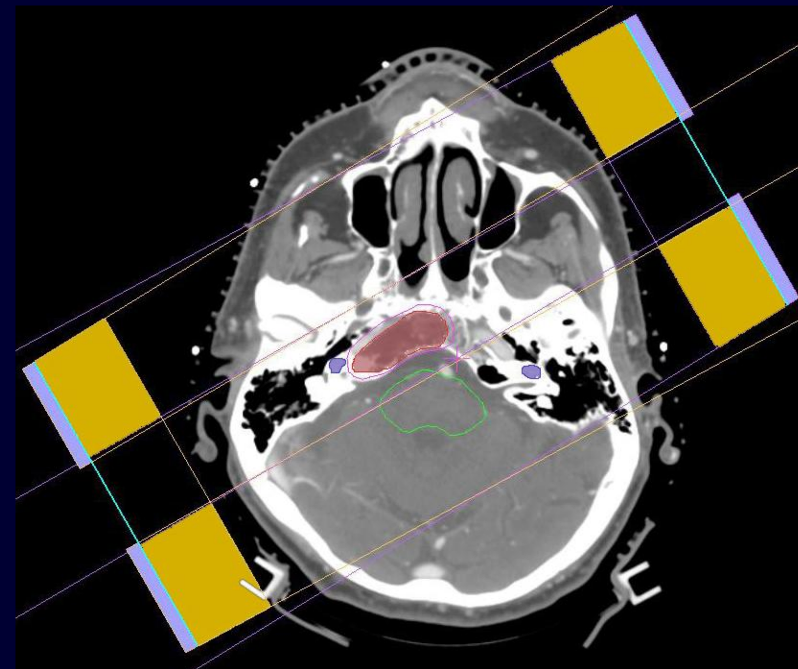
Scan with contrast important for target and critical structures

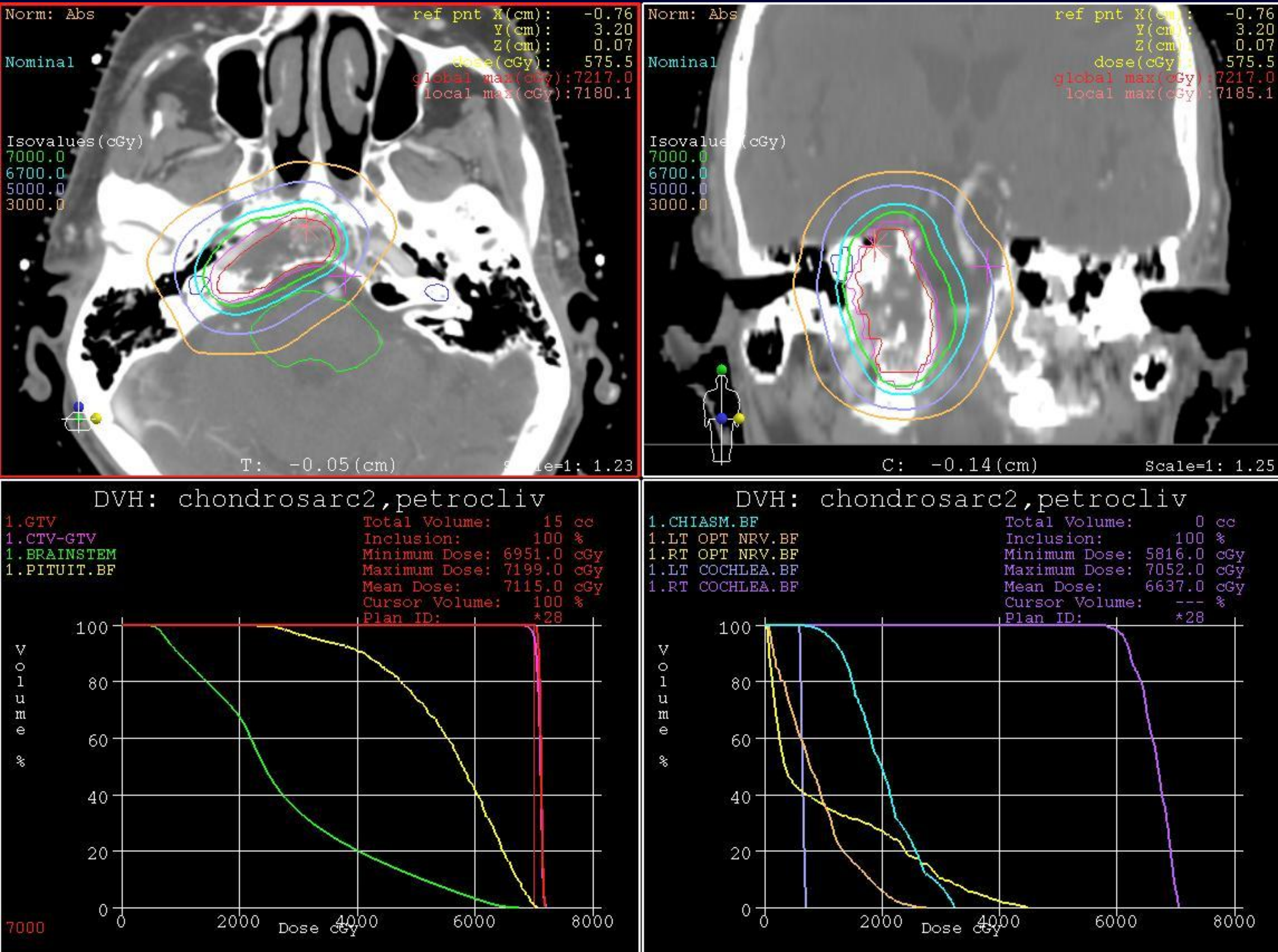
RAO paired with SAO, PA paired with LAO





GTV (boost) fields 70% to brainstem surface




Norm: Abs
Nominal
ref pnt X(cm): -0.76
Y(cm): 3.20
Z(cm): 0.07
dose(cGy): 575.5
global max(cGy):7217.0
local max(cGy):7180.1
Isovalues(cGy)
7000.0
6700.0
5000.0
3000.0
T: -0.05(cm)
Norm: Abs
Nominal
ref pnt X(cm): -0.76
Y(cm): 3.20
Z(cm): 0.07
dose(cGy): 575.5
global max(cGy):7217.0
local max(cGy):7185.1
Isovalues(cGy)
7000.0
6700.0
5000.0
3000.0
C: -0.14(cm)
Scale=1: 1.25
DVH: chondrosarc2,petrocliv
1.GTV
1.CTV-GTV
1.BRAINSTEM
1.PITUIT.BF
Total Volume: 15 cc
Inclusion: 100 %
Minimum Dose: 6951.0 cGy
Maximum Dose: 7199.0 cGy
Mean Dose: 7115.0 cGy
Cursor Volume: 100 %
Plan ID: *28
Volume %
Dose cGy
7000
DVH: chondrosarc2,petrocliv
1.CHIASM.BF
1.LT OPT NRV.BF
1.RT OPT NRV.BF
1.LT COCHLEA.BF
1.RT COCHLEA.BF
Total Volume: 0 cc
Inclusion: 100 %
Minimum Dose: 5816.0 cGy
Maximum Dose: 7052.0 cGy
Mean Dose: 6637.0 cGy
Cursor Volume: --- %
Plan ID: *28
Volume %
Dose cGy

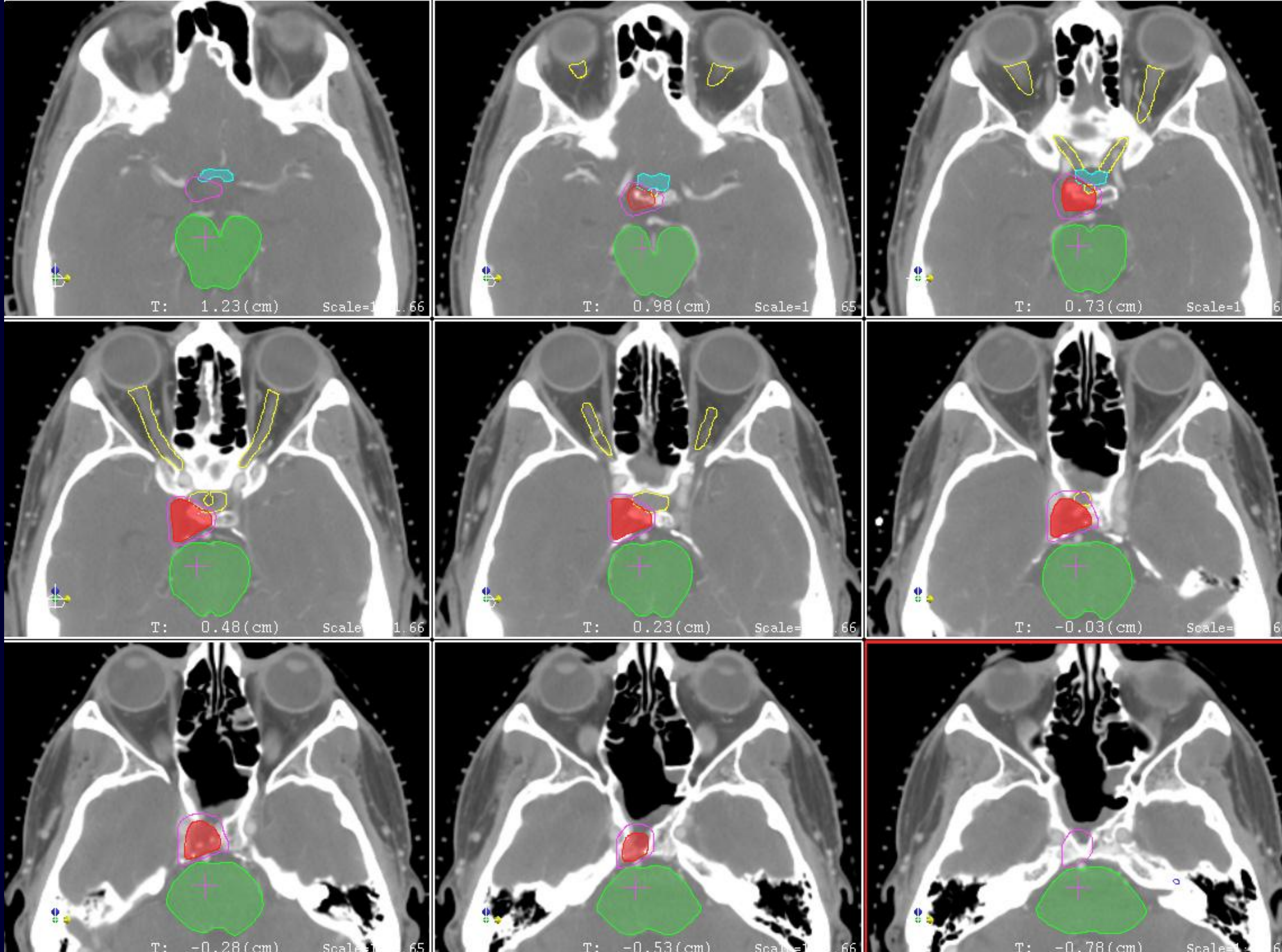
Case 2: Chordoma
(proton dose in Gy (RBE))

Small upper clival tumor

Rx: *GTV – 72 Gy; CTV – 50 Gy
(CTV – 20Gy, 3 field, 3D photons)
*76 to 78 Gy not achievable due to tumor size and location

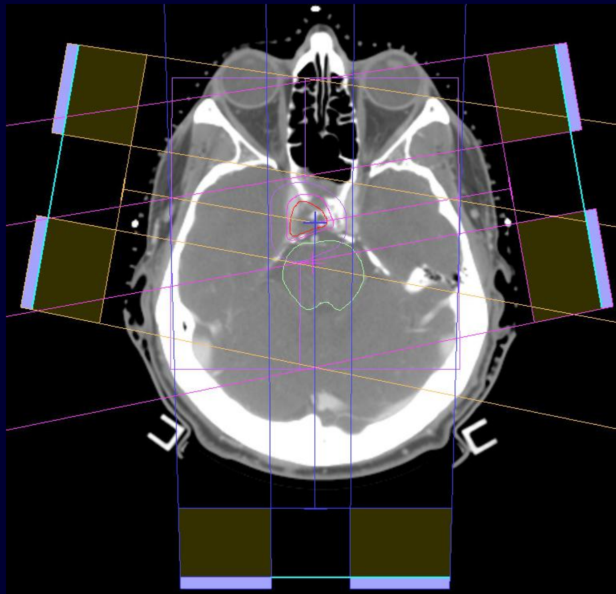
Constraints: BS, SC – 55/67 Gy, center/surface
Cochlea <60 Gy

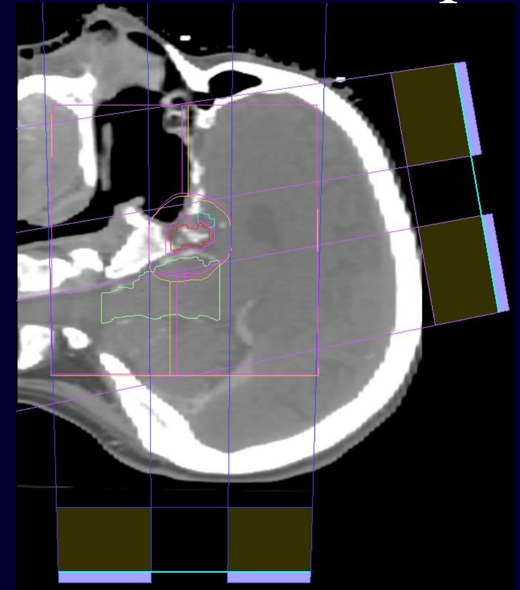
Proton field arrangement and dose:
CTV: PA – 10 Gy, R20A – 9 Gy, L20A – 9 Gy
GTV: S10A – 10 Gy, R15S – 6 Gy, L15I – 6 Gy

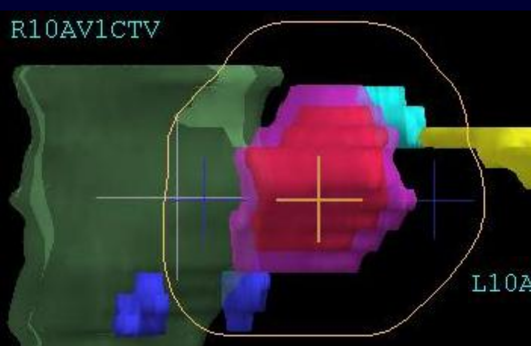


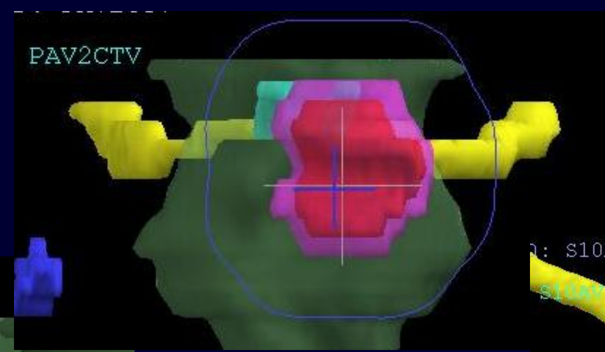
T: 1.23(cm)
T: 0.98(cm)
T: 0.73(cm)
T: 0.48(cm)
T: 0.23(cm)
T: -0.03(cm)
T: -0.28(cm)
T: -0.53(cm)
T: -0.78(cm)

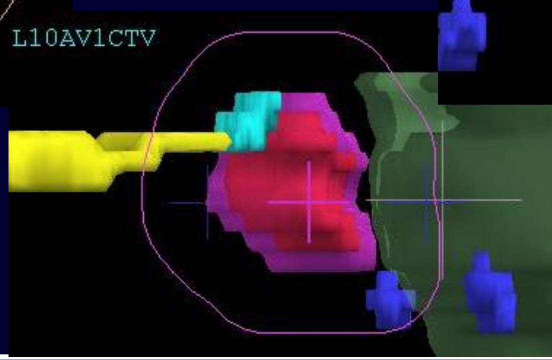
Combinations of RAO, LAO, PA, SAO - 2 fields per day

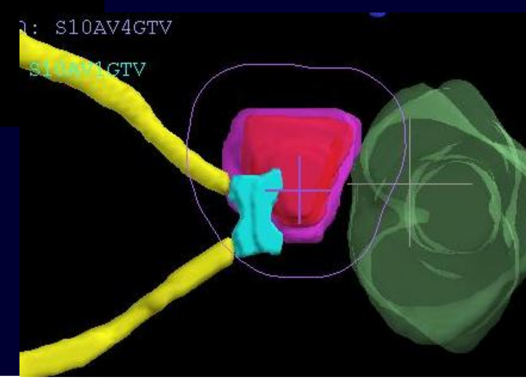




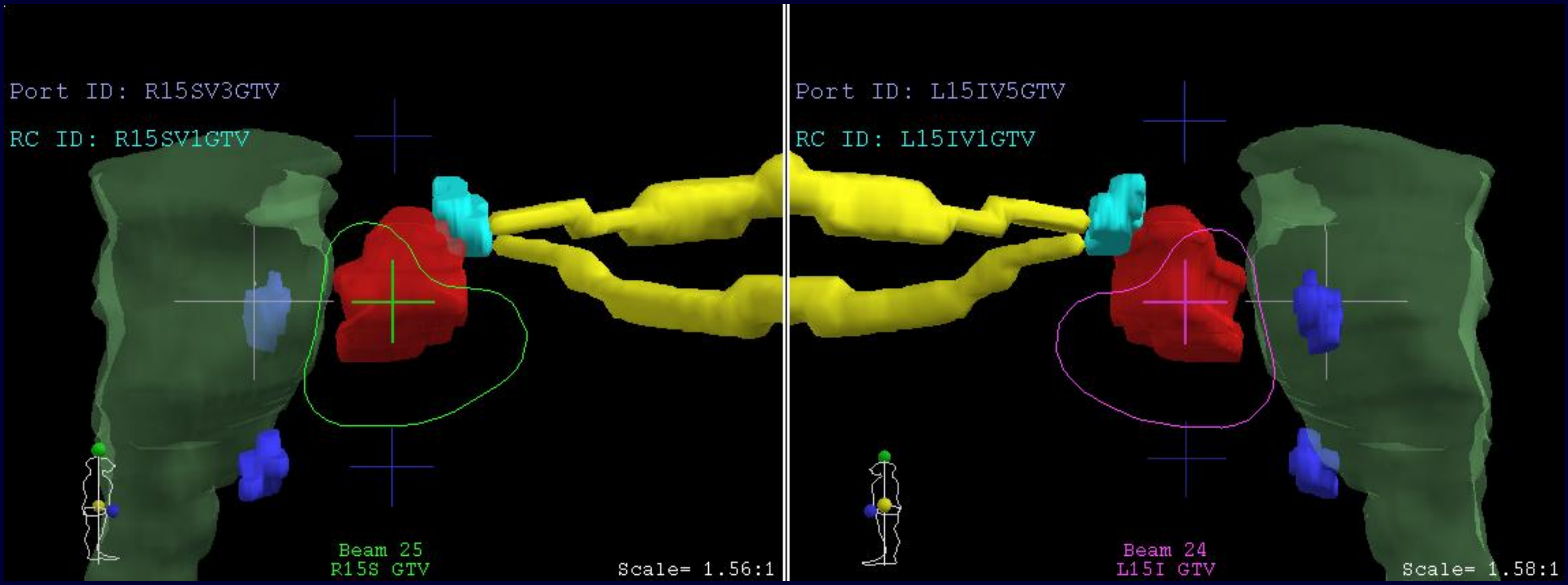






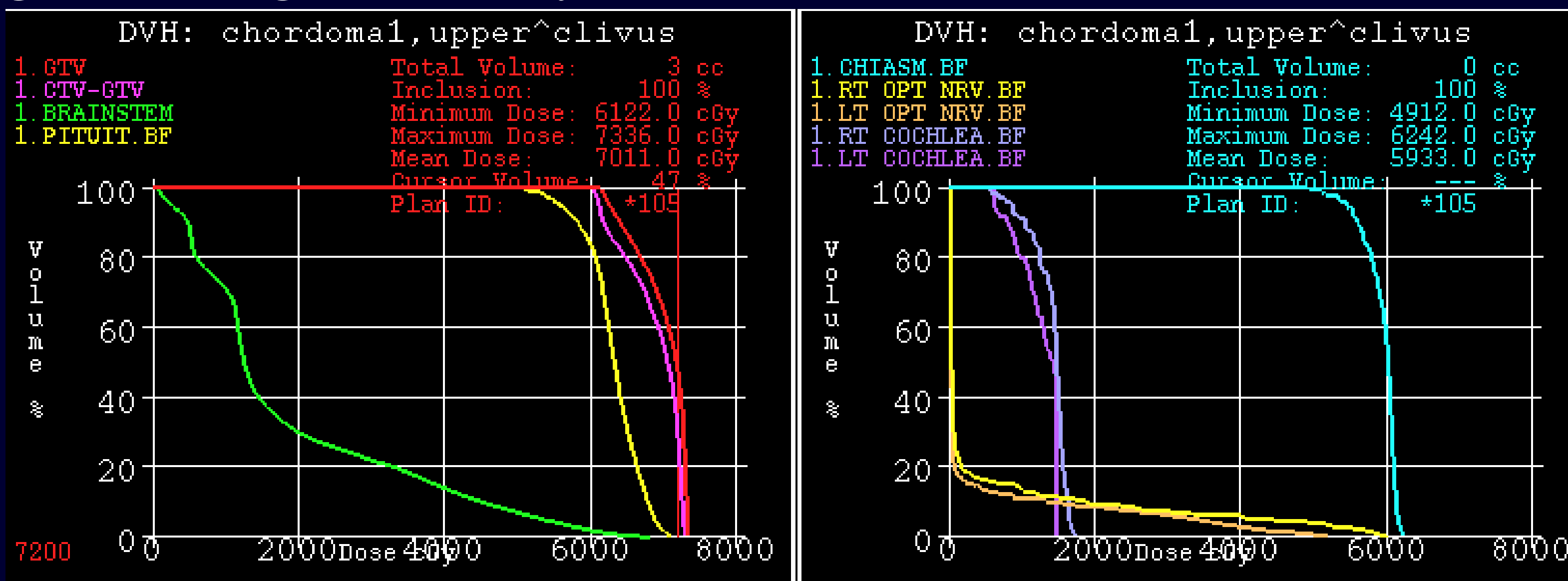


RSO + LIO to undercut optic structures, 60% to brainstem surface



Composite to 72Gy(RBE)

Target coverage driven by chiasm and brainstem surface constriant

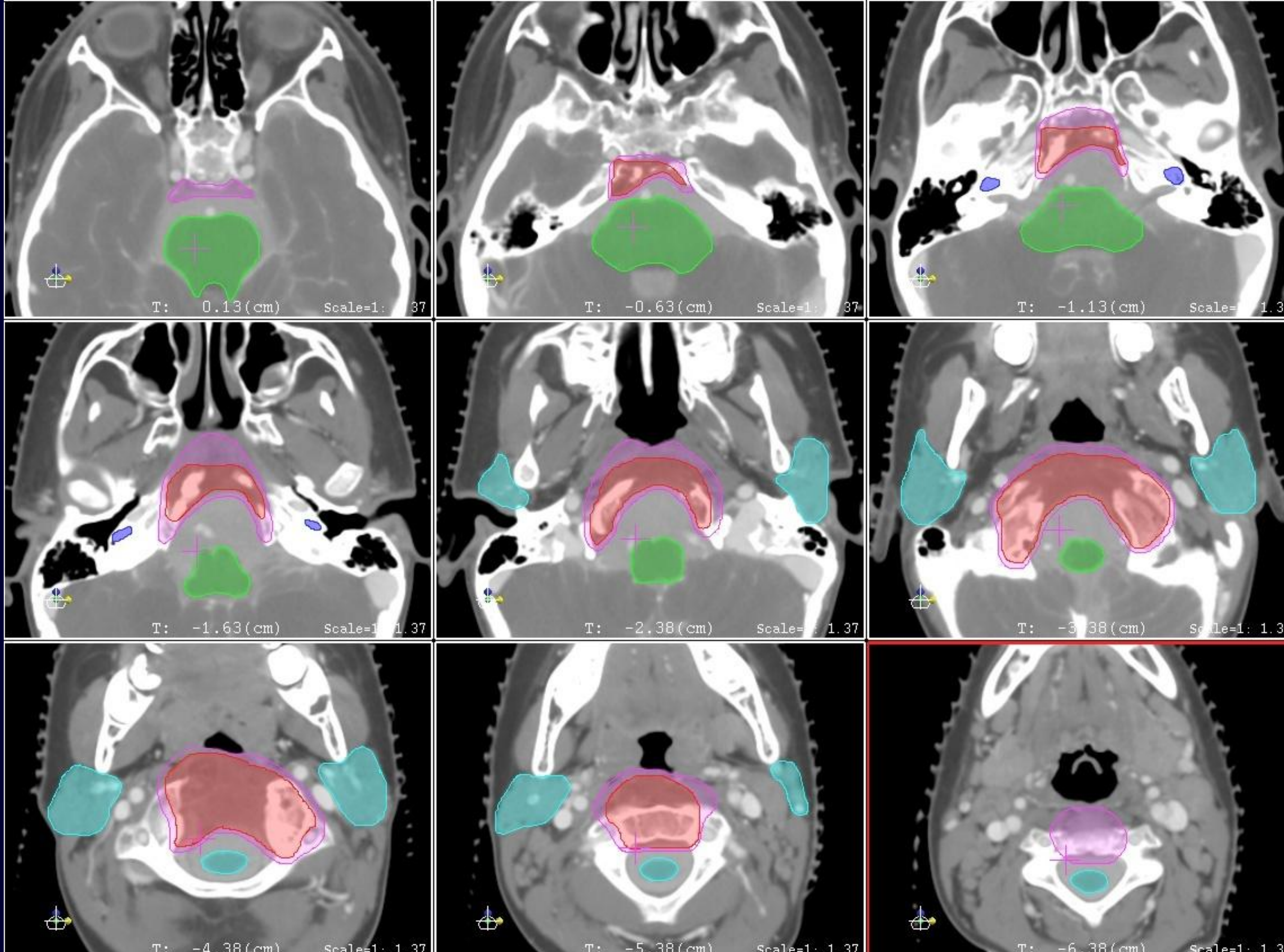


Case 3: Chordoma
(proton dose in Gy (RBE))

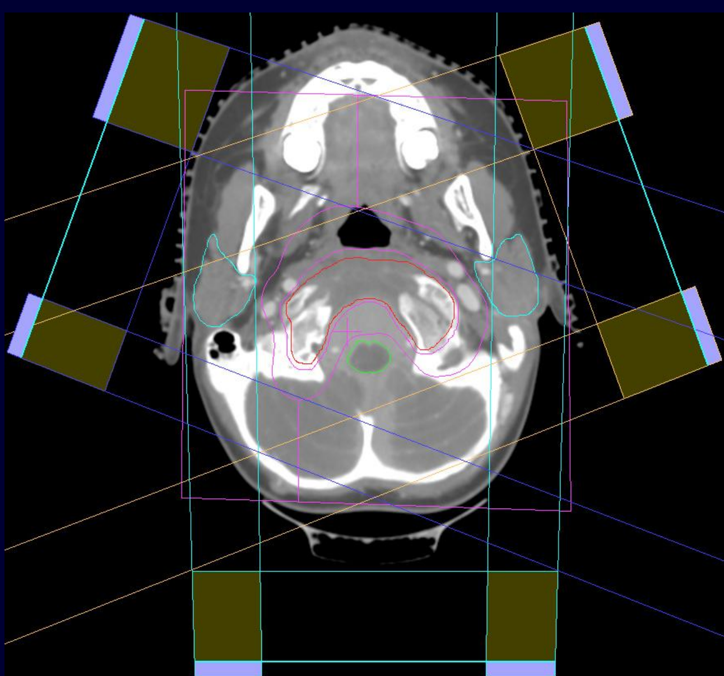
Large lower clival tumor
Rx: GTV – 78 Gy; CTV – 48 Gy
(CTV – 20Gy, 5 field IMRT)

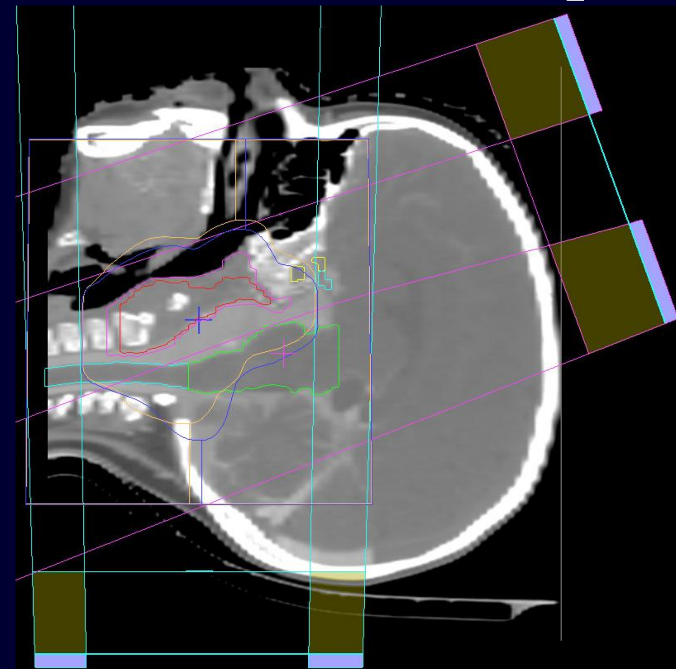
Constraints: BS, SC – 53/64 Gy, center/surface
Cochlea <60 Gy
Parotids – as low as possible

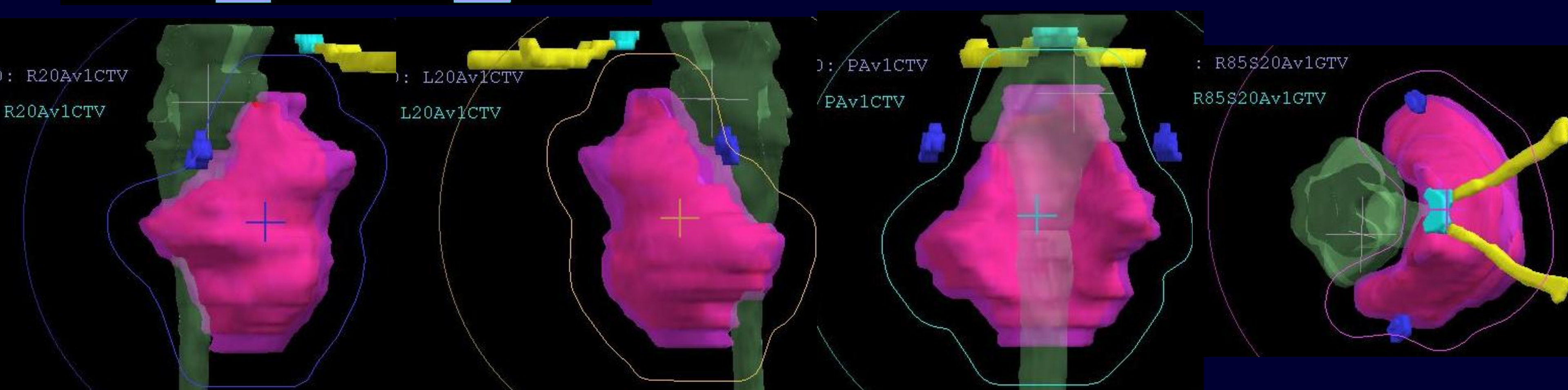
Proton field arrangement and dose:
CTV: PA – 10 Gy, R20A – 9 Gy, L20A – 9 Gy
GTV: R85S20A – 8 Gy
L10A thru + RT PA,LT PA patch combo - 12 Gy
R25A thru + R55P patch combo – 10 Gy

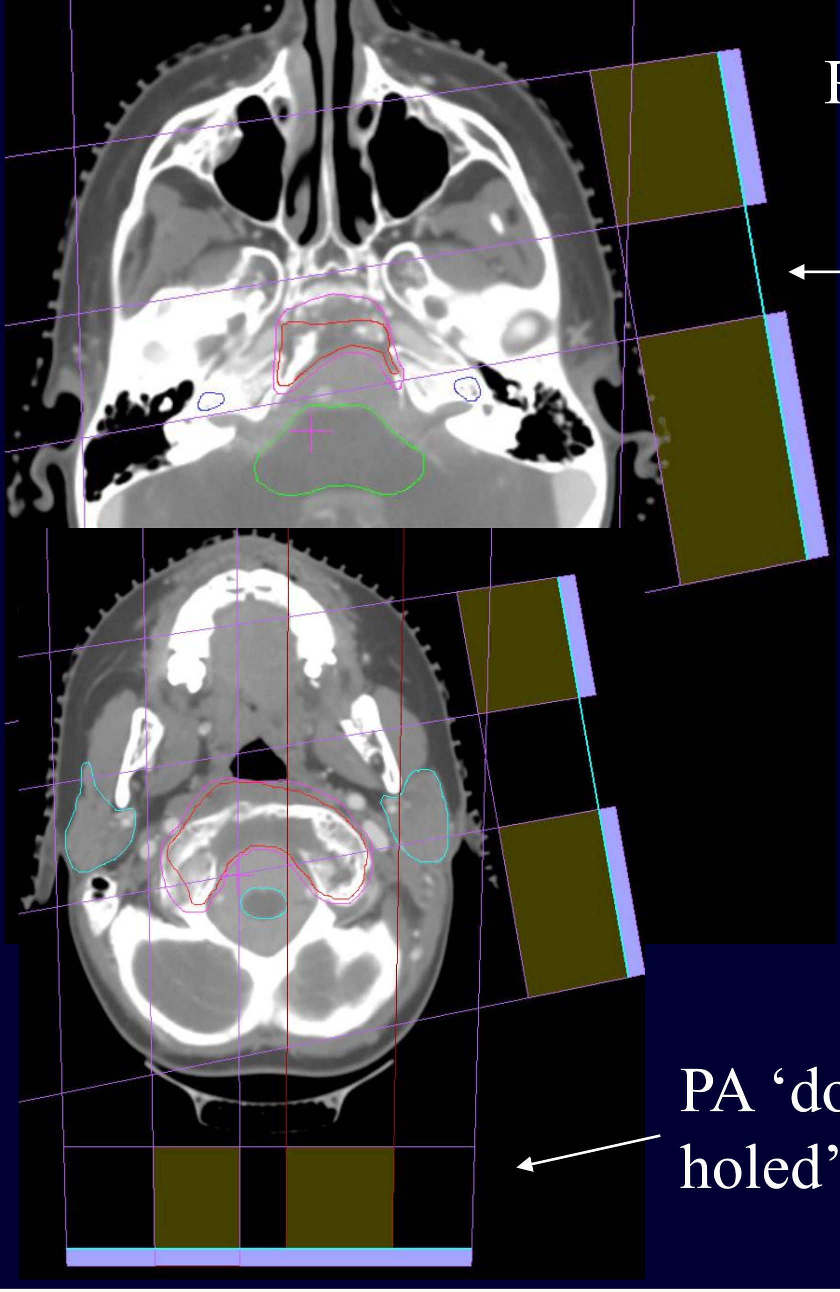

T: 0.13(cm)
T: -0.63(cm)
T: -1.13(cm)
T: -1.63(cm)
T: -2.38(cm)
T: -4.38(cm) Scale=1: 1.37
T: -5.38(cm) Scale=1: 1.37
T: -6.38(cm) Scale=1: 1.37

Combinations of RAO, LAO, PA, SAO - 2 fields per day





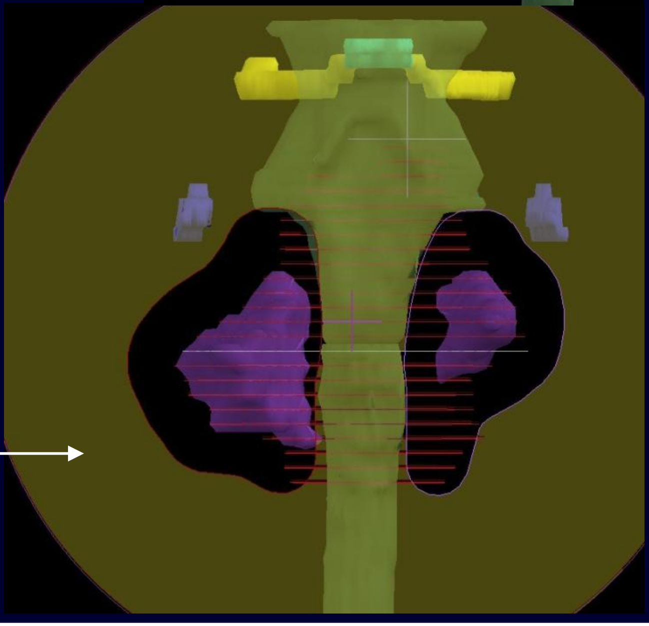




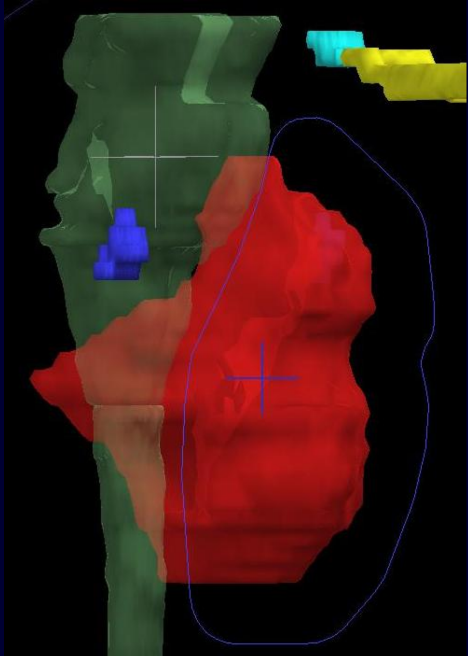
Patch combo 1

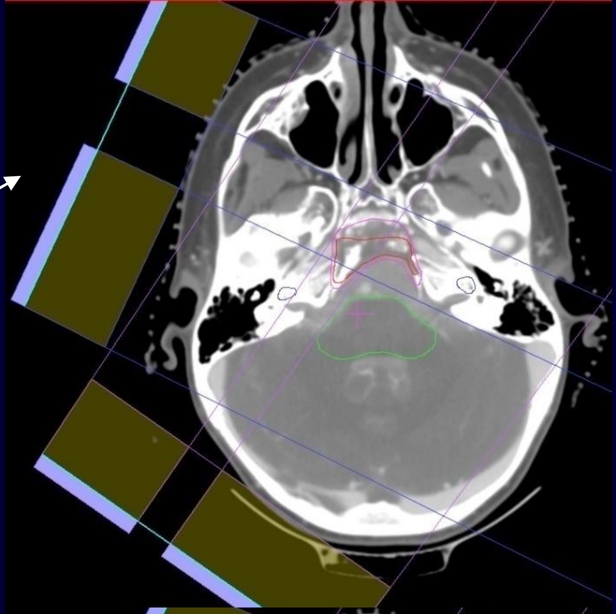
← LAO thru →

PA 'double-holed' patch

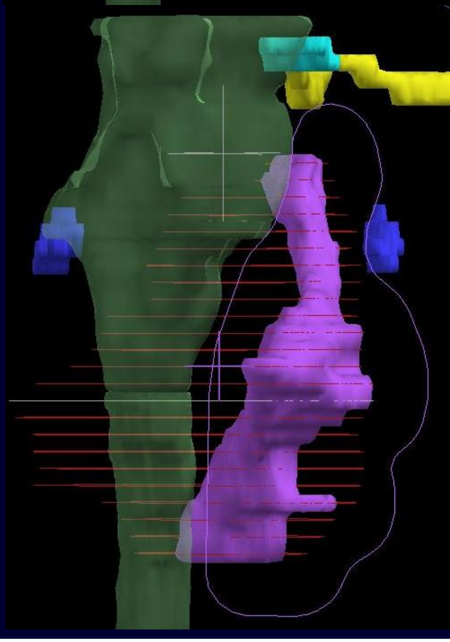


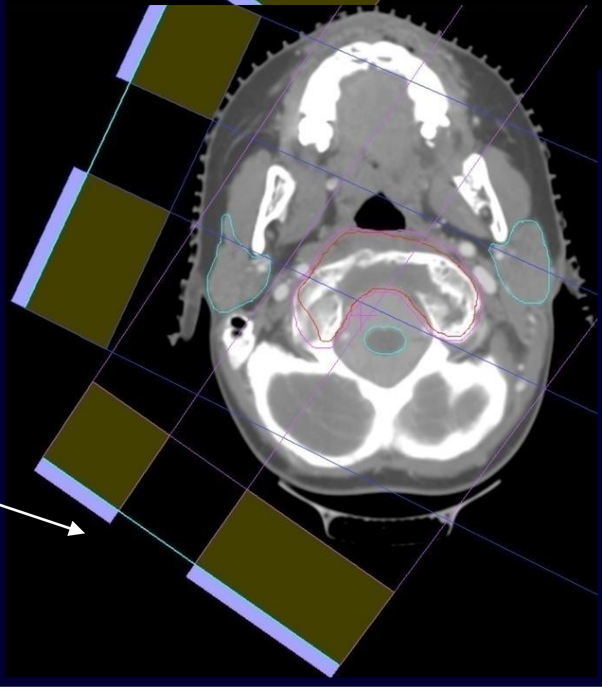
Patch combo 2





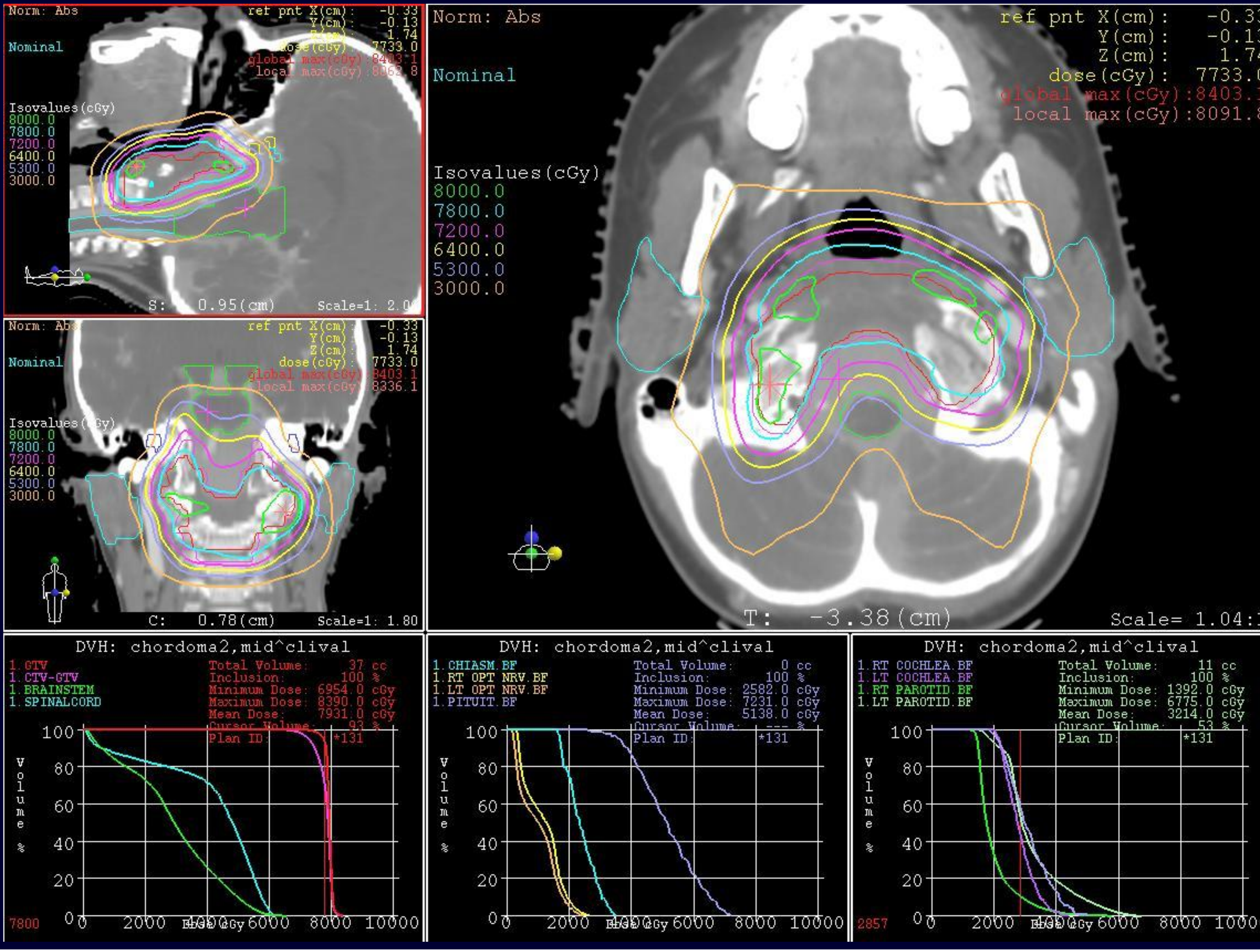
← RAO thru →





← RPO patch →

Composite to 78Gy(RBE)

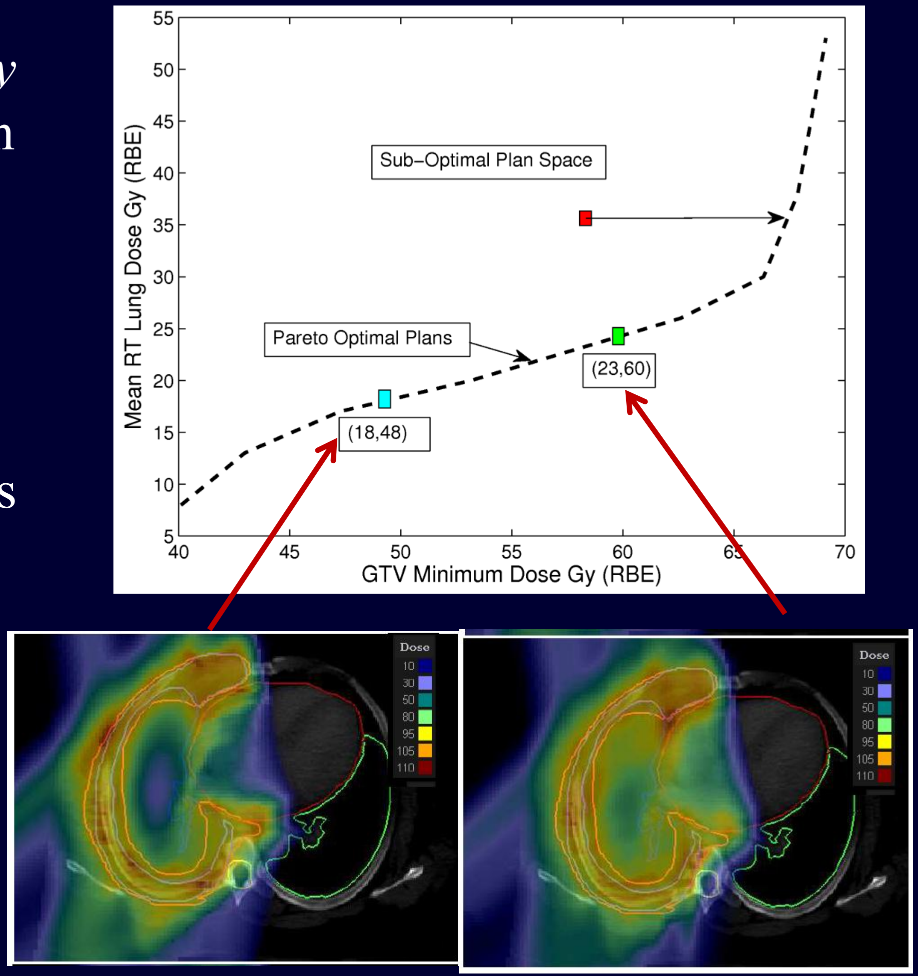


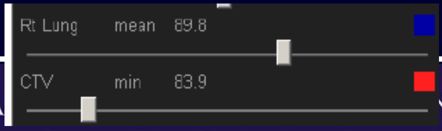
PBS for Skull Base

- Same beam arrangements
  - SOBP fields are proven in terms of geometric and dosimetric accuracies
  - Uncertainties EXCLUDE use of distal range for dose shaping
- PBS optimization for “patch” equivalents offers efficiencies
  - Partly because patching is not well supported in any TPS!
- Apertures may still offer benefit in penumbra (R<10 cm) and edge certainty vis-à-vis critical structure
- Management of uncertainties in range and setup
  - Inherent in SOBP for range and setup
  - PBS doesn’t provide (yet) the proper set of tools
    - … and will require significant computational support

Multi-Criteria Optimization

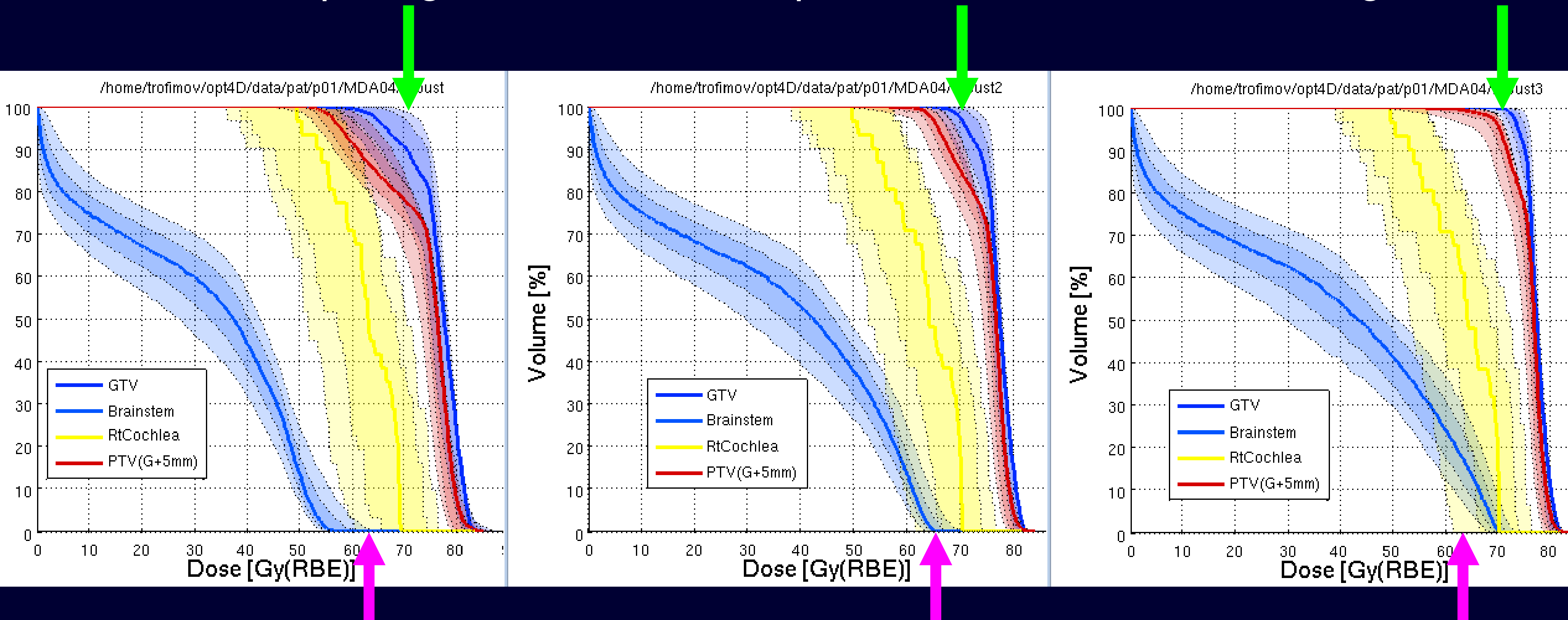
- Large # of spots means
  - Constraint-based optimization *only* will not yield clinically "best" plan
  - Opportunity for healthy tissue dose trade-off analysis greater compared to IMRT
- MCO vs "One-Plan Only"
  - Minimal set of absolute constraints
    - D(GTV) > 50 Gy(RBE)
  - Specify competing objectives –
    - "minimize max brainstem dose" vs "maximize min GTV dose"





The need for MCO in robust planning

Robust OAR sparing | Balanced plan | Robust Target dose



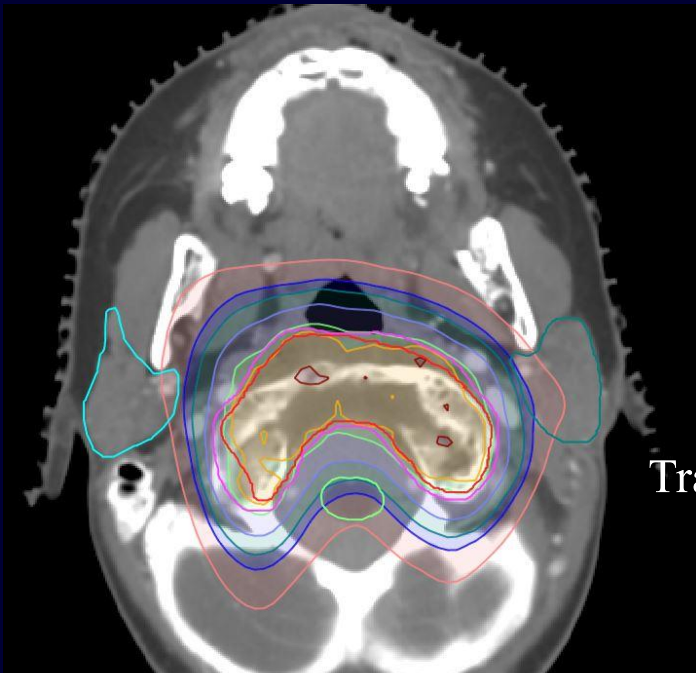
OAR dose stable at expense of TV

Robust Trade-off

TV dose stable at expense of OAR

Trofimov – Probabilistic Planning

PBS – MCO



Absolute Constraints

Optimization

Constraints

structure	type	dose (Gy (RBE))
patient	MAX	84
AntBSSC	MAX	64
PostBSSC	MAX	53
RT COCHLEA.BF	MAX	50
LT COCHLEA.BF	MAX	50

Objectives

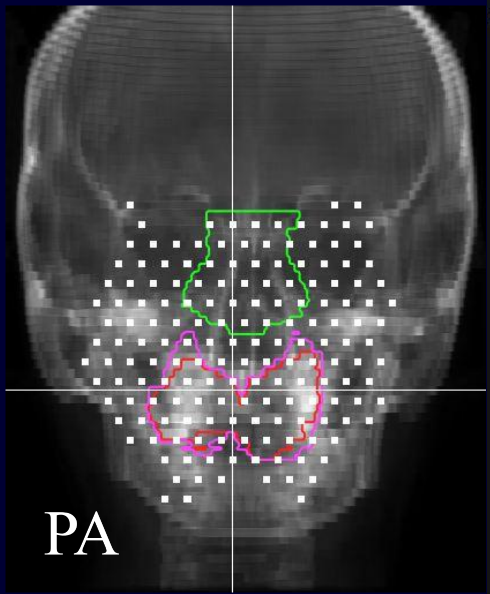
structure	objective	dose (Gy (RBE))
GTV	MIN MAX	
GTV	MAX MIN	
GTV	MAX MEAN	
GTV	MIN UNDERDOSE	78
CTV	MIN MAX	
CTV	MIN UNDERDOSE	50
BRAINSTEM	MIN MAX	
BRAINSTEM	MIN MEAN	
SPINALCORD	MIN MAX	
SPINALCORD	MIN MEAN	
RT COCHLEA.BF	MIN MAX	
RT COCHLEA.BF	MIN MEAN	
LT COCHLEA.BF	MIN MAX	
LT COCHLEA.BF	MIN MEAN	
RT PAROTID.BF	MIN MAX	
RT PAROTID.BF	MIN MEAN	
LT PAROTID.BF	MIN MAX	
LT PAROTID.BF	MIN MEAN	

Trade-off Objectives

	structure	objective	value	range min	range max
2	GTV	MAX	[illegible] < 82.6	71.3	83.9
2	GTV	MIN	70.6 > 68.2	68.2	76.4
2	GTV	MEAN	79.6 > 79.6	70.2	81.8
2	GTV	UNDERDOSE	0.1 < 1.8	0	7.8
3	CTV	MAX	81.8 < 83.9	71.3	83.9
3	CTV	UNDERDOSE	0.0 < 0.0	0	0
12	BRAINSTEM	MAX	64.2 < 70.1	59	70.1
12	BRAINSTEM	MEAN	23.1 < 32.3	10	32.3
13	SPINALCORD	MAX	60.9 < 63.9	51.1	63.9
13	SPINALCORD	MEAN	36.1 < 42.9	22.6	42.9
7	RT COCHLEA.BF	MAX	40.5 < 40.5	18.7	50
7	RT COCHLEA.BF	MEAN	27.9 < 41.1	9.3	41.1
8	LT COCHLEA.BF	MAX	35.0 < 39.3	9.8	48.6
8	LT COCHLEA.BF	MEAN	26.8 < 41.3	5.2	41.3
10	RT PAROTID.BF	MAX	49.8 < 60.1	19.4	60.1
10	RT PAROTID.BF	MEAN	17.8 < 27.5	2.9	27.5
11	LT PAROTID.BF	MAX	54.7 < 68.1	31.6	68.1

Fraction Groups		# fractions
1	RA+PA	15
2	LA+SA	15
3	LA+PA	9
		39

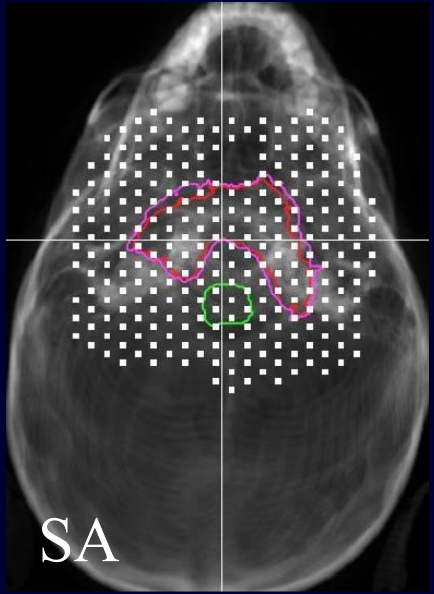
Simultaneous optimization
Astroid – 10 min



Spot Controls

Energy Layer

164 MeV
160 MeV
157 MeV
153 MeV
149 MeV
146 MeV
142 MeV
138 MeV
133 MeV
130 MeV
126 MeV
121 MeV
116 MeV
113 MeV
108 MeV
102 MeV
99 MeV



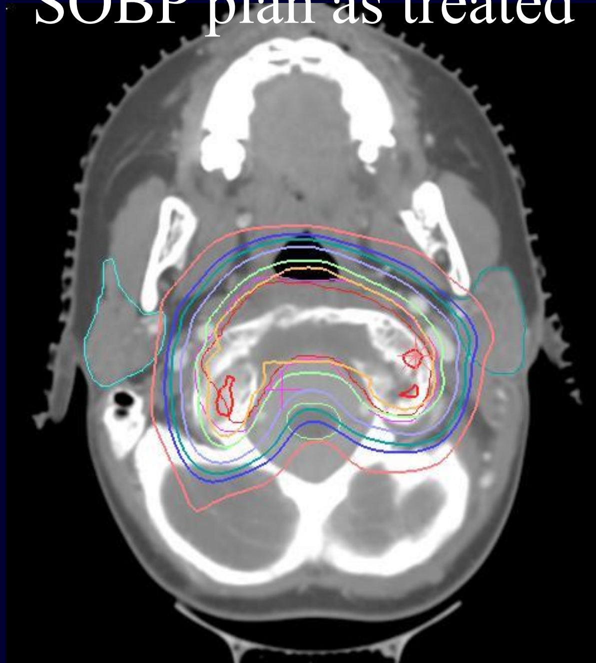
Spot Controls

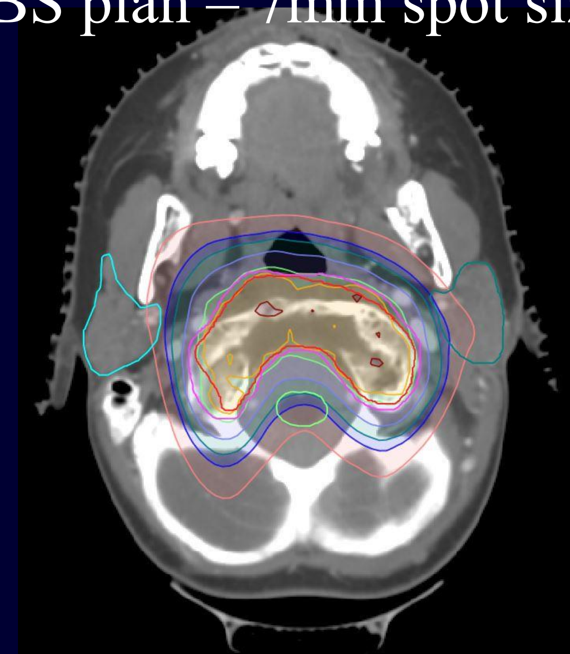
Energy Layer

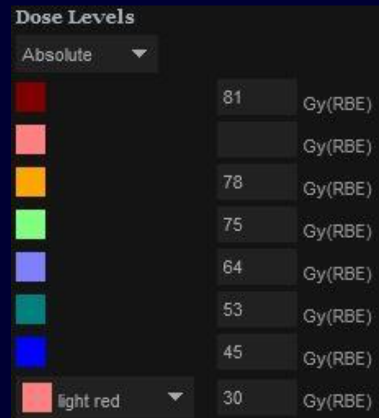
187 MeV
183 MeV
180 MeV
175 MeV
171 MeV
168 MeV
164 MeV
158 MeV
155 MeV
150 MeV
145 MeV
141 MeV
136 MeV
132 MeV
126 MeV

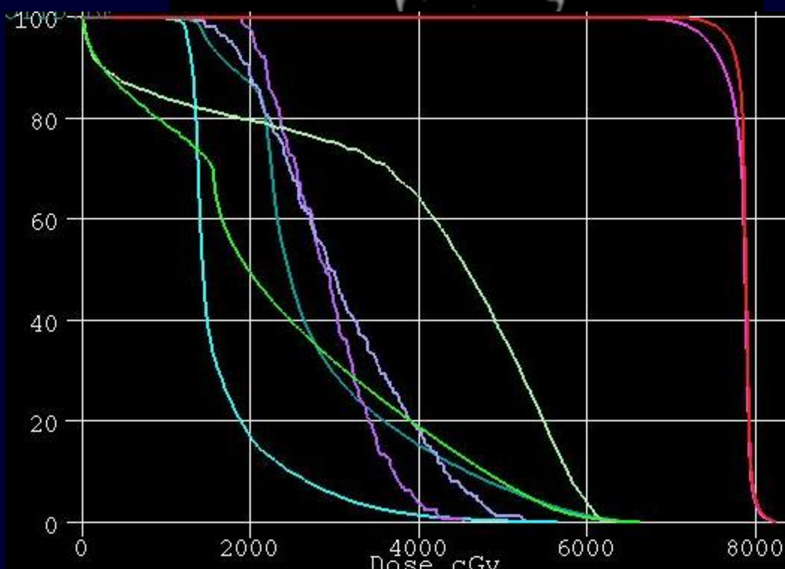
SOBP plan as treated

PBS plan – 7mm spot size









GTV
CTV
BRAINSTEM
SPINALCORD
RT COCHLEA
LT COCHLEA
RT PAROTID
LT PAROTID

Summary

- p for skull base tumors was the first modality to prove that precision and dose escalation can cure disease
- SOBP dosimetry outperforms IMRT
  - Albeit at significant effort
    - Poor TPS support necessitates manual operations
- PBS may not always improve dosimetry but does improve planning efficiency
  - Use same SOBP field arrangements
  - MCO greatly improves treatment plan
  - Robustness must be managed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HARD WORK NEVER KILLED ANYBODY,
BUT WHY TAKE A CHANCE?
Edgar Bergen