Integrating knowledge in inverse treatment planning

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Disclosures

- Vumc has a research collaboration with Varian Medical Systems

IMRT (VMAT)

Inverse optimization

- Allows to create complex plans
- Irregular dose distributions
- Sparing of OAR

But

- Requires new knowledge
- Many parameters to set
- Which leads to optimal plans?
- How optimal is needed?
  - Pareto optimal?
  - Very optimal: for comparison with IMPT

Knowledge in inverse treatment planning

- Knowledge of patient anatomy
  - locations of OAR – PTV
  - PTV size
- Knowledge of past treatment plans, DVHs
  - Library of plans accroding to institutional standard
  - General correlations between OAR and PTV
- Knowledge of what should be achieved, for clinical relevance
- Knowledge of the optimizer
  - Avoid trial and error in optimization
  - Improve planning efficiency

What is a good IMRT plan?

- Differences in Treatment planning systems
- Differences in optimizer versions
  - Eclipse: v10 versus v8.9, continute previous opt. (cpo)
- Depends on experience of planner
- Depends on institutional clinical protocol
  - PTV minimum dose coverage
    - RTOG: >95% should receive PD
    - EORTC: >95% should receive 95% of PD
  - PTV dose homogeneity (Dmax?)
- Depends on physician's experience
  - Who decides on OAR dose for a specific patient?
  - Or pareto-optimal?

Head and Neck: typical example

- Large PTVs
- Many OAR, parallel and serial
- Often 2-3 PTV dose levels
- Sequential boost versus SIB. SIB:
  - One plan for all, but different dose levels
  - Radiobiological conversion of lower PTV_E dose fractions

    Take into account overall treatment time

    (46Gy in 23fr or 54.25Gy in 35fr)
  - Entry and exit dose of boost can be used for lower dose levels.
  - How to deal with transition zones between PTVs

IMRT - VMAT

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Static IMRT:

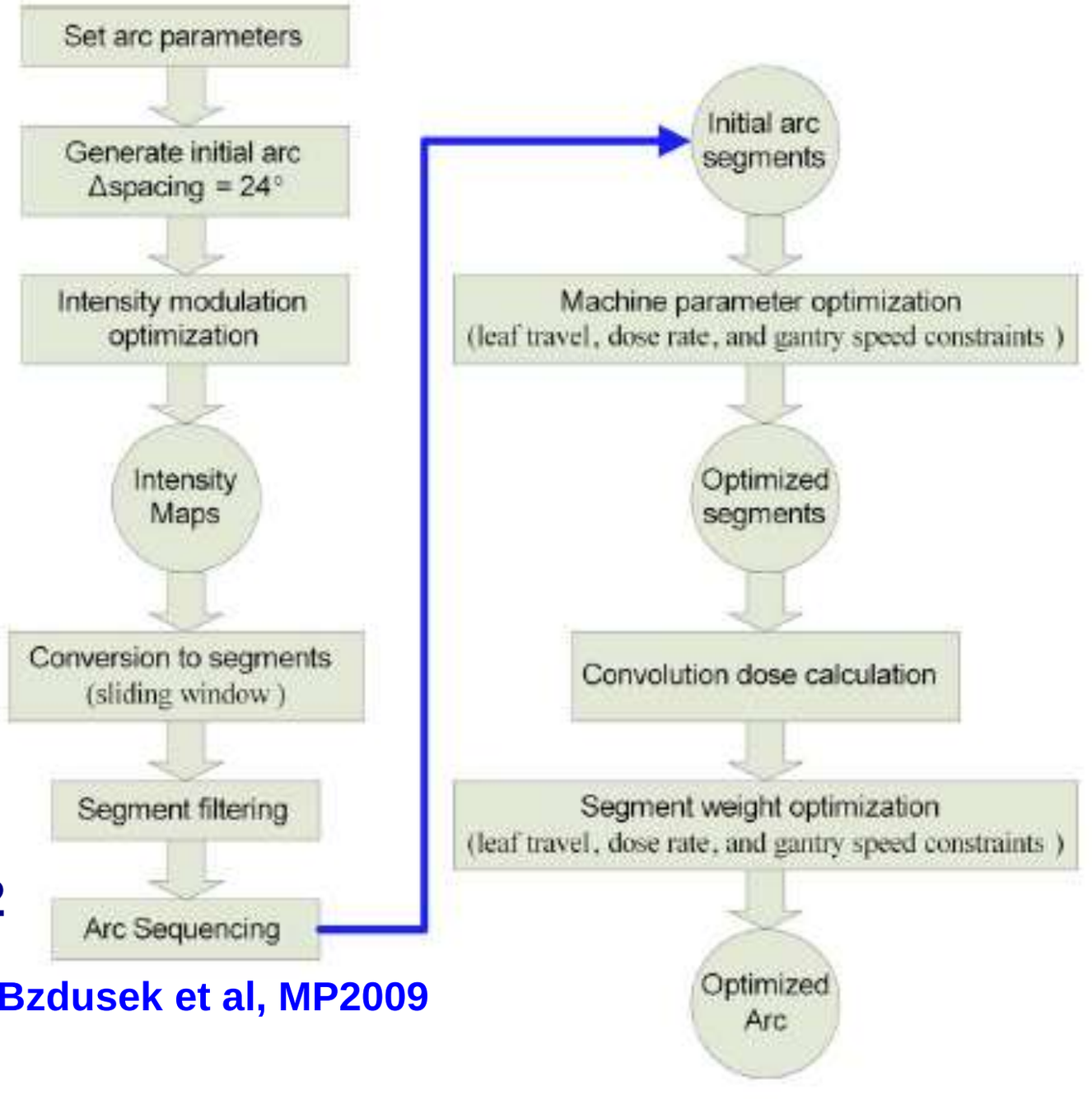
- multiple fields, high modulation per field
- Longer delivery times
- Step and shoot versus sliding window

VMAT:

- Rotational IMRT
- Continuous modulation of leaves
- Mostly no higher modulation from preferred directions
- Short delivery times
- More variation between vendors in optimization algorithm
- Interactive – non-interactive optimization

SmartArc (Pinnacle, Philips) optimization scheme

- 15 field IMRT optimization
- 3 segments, then discard 1
- Distribute 30 segm. over arc
- Interpolate to 46 segments
- Further optimization
- Dose calculation for 92 segments



Bzdusek et al, MP2009

RapidArc optimization

K.Otto, MedPhys 2008

- Different optimization strategies between versions
- Arc optimization by progressively increasing control points (up to 177)
  - start optimization (direct aperture) for few control points
  - As optimization progresses, new beams are inserted into the plan
- Dose (rate) and leaf positions are optimized at each control point;
- Sliding window interpolation
- Optimization by
  - DVH constraints
  - MU objective
  - Max leaf speed 2.5 cm/s ➔ 0.5 cm per degree

Different VMATs

- Different optimization strategies:
  - Direct aperture optimization (RapidArc)
  - Segmented IMRT optimization, followed by further optimization (SmartArc)
- RapidArc: no gantry slow down for more modulation
- No interactive optimization possible:
  - Start with initial guess of OAR sparing
  - Often multiple optimizations necessary
    - Can be automated
- Interactive optimization possible:
  - Find trade-off between OAR sparing and PTV coverage while optimizing
  - Adapt objectives accordingly

VOLUMETRIC INTENSITY-MODULATED ARC THERAPY VS. CONVENTIONAL IMRT IN HEAD-AND-NECK CANCER: A COMPARATIVE PLANNING AND DOSIMETRIC STUDY

IJROBP 2009; 74: 252-9

WILKO F. A. R. VERBAKEL, PH.D.,* JOHAN P. CUIJPERS, PH.D.,* DAAN HOFFMANS, B.SC.,* MICHAEL BIEKER, M.D., PH.D.,* BEN J. SLOTMAN, M.D., PH.D.,* AND SURESH SENAN, M.R.C.P., F.R.C.R., PH.D.*

- **12 patients treated with 7-field sliding window IMRT**
- **Compare with RapidArc plans using 1and 2 arcs**
- **Film dosimetry in 3-5 coronal planes of QA phantom**

⇨ **60% reduction in MU achieved (1108 to 439 MU)**

⇨ **comparable or better sparing of the organs at risk**

⇨ **double arc plans improved dose homogeneity to PTVs**

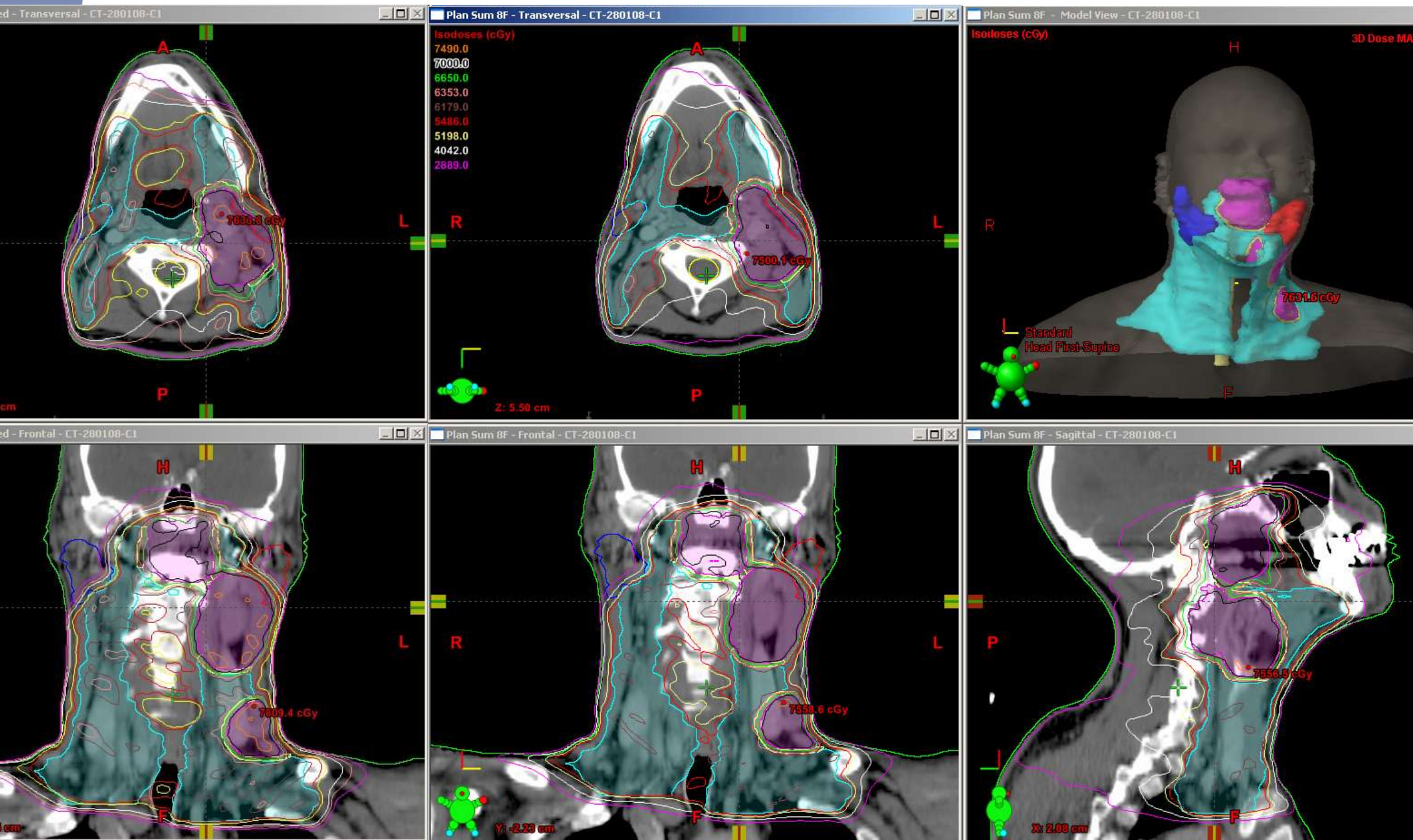
– **V95 =99.4% (IMRT: 98.8%), V107 = 0.2% (IMRT: 0.8%)**

⇨ **film measurements showed good agreement**

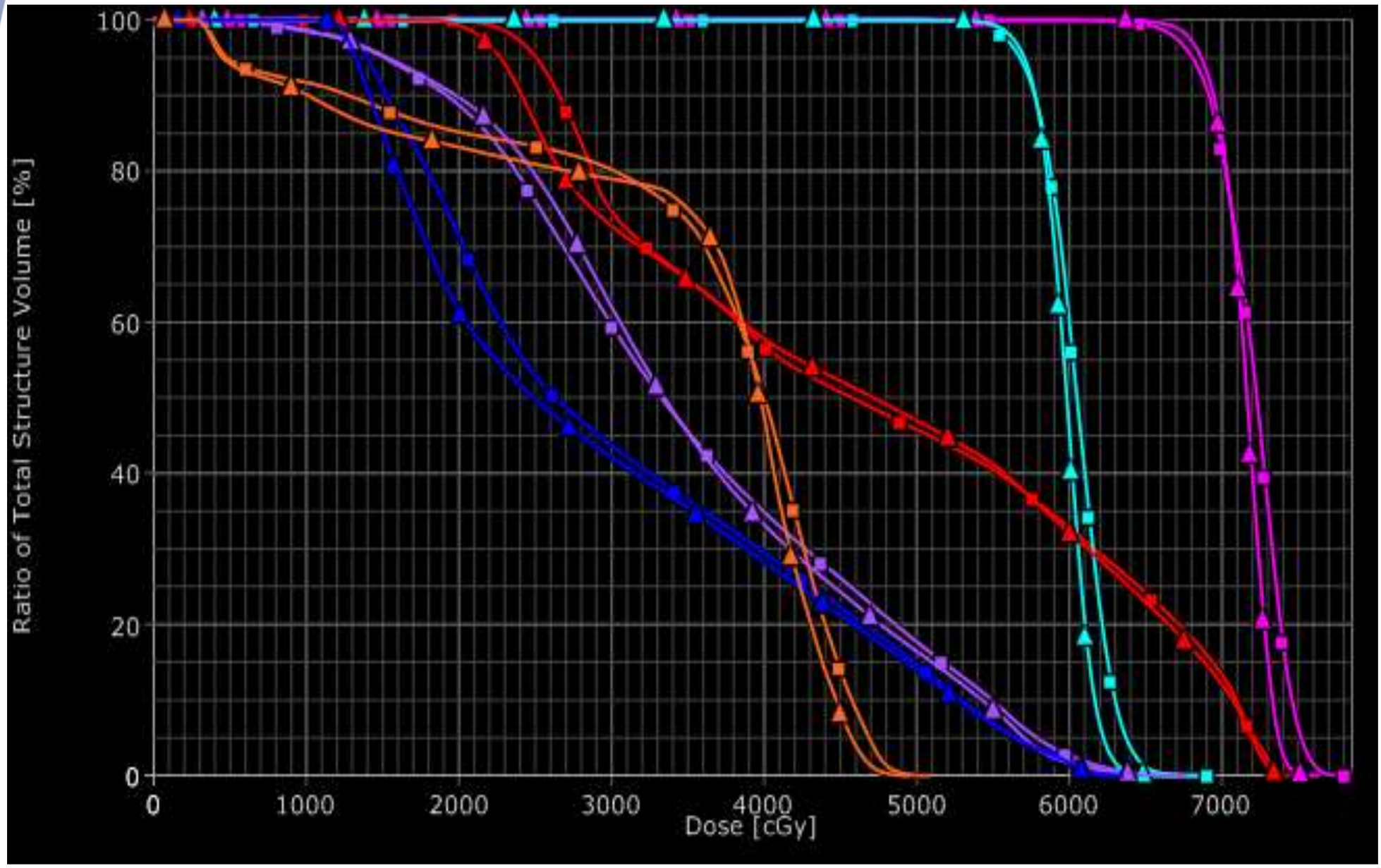
- **Better than for IMRT**

⇨ **delivery time 73 seconds per arc**

1 arc versus 2 arc RA: dose homogeneity improves



DVH: single arc versus double



- 2 arcs RA higher dose homogeneity in PTV
- Slightly better sparing of OAR

VMAT for H&N

- In 2008 at Vumc: large variation between 8 planners
- Individual preferences of different planners
- Often replanning needed

➔ Systematic evaluation of optimal optimization:

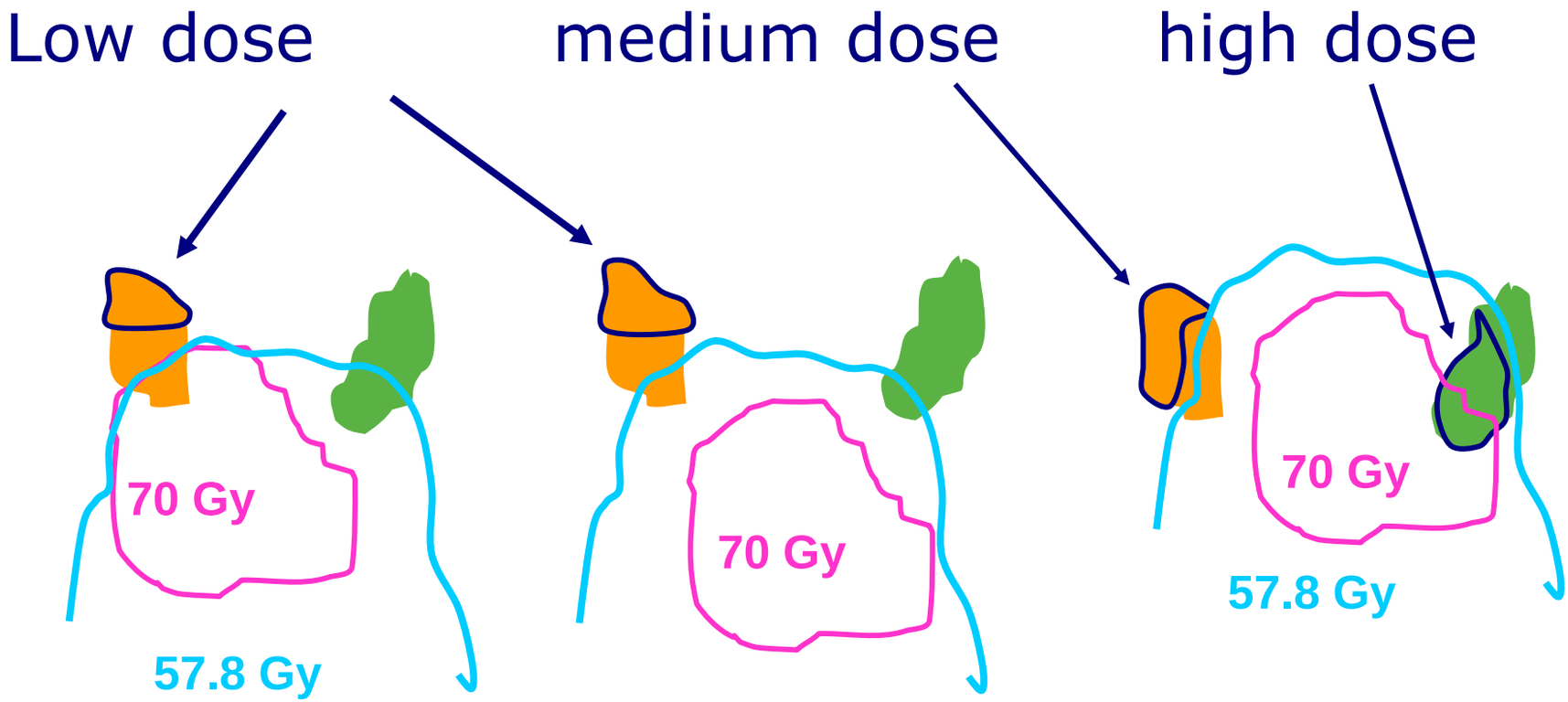
➔ How to get (close to) pareto optimal plans

- Standardization of optimization
  - Choice of location and number of objectives
  - Priorities
  - How to deal with overlap
  - How to deal with different PTV doses
- Original time investment pays back in clinical cases

➔ Knowledge of VMAT optimizer

Knowledge of OAR position

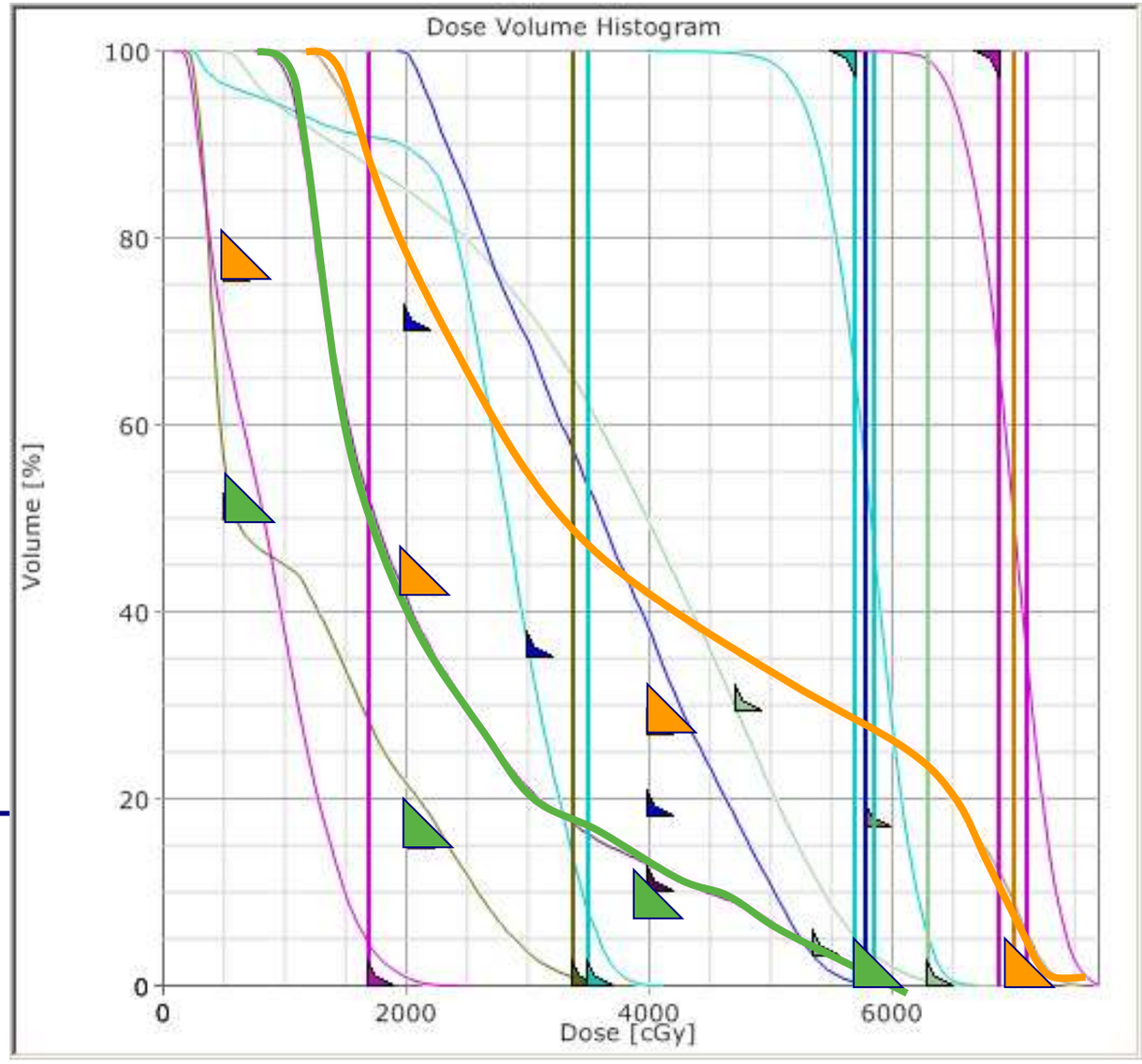
- Example: parotid glands
- Where to put objectives?
- Potentially, calculate overlapping parts: above PTV, inside boost PTV, inside elective PTV



"Standard" constraint set

- PTVb: 69 / 71 Gy (p=130)
- PTVe: 57 / 58.5 Gy (p=130)
- Standard ring
- SC/brainstem (p=120)
- Shoulders
- PG-IL, PG-CL: (p=75)
- Adapt PG during first few minutes
- PG always tighter than DVH

- Exact location of OAR objectives not so important



PG objectives not tight enough

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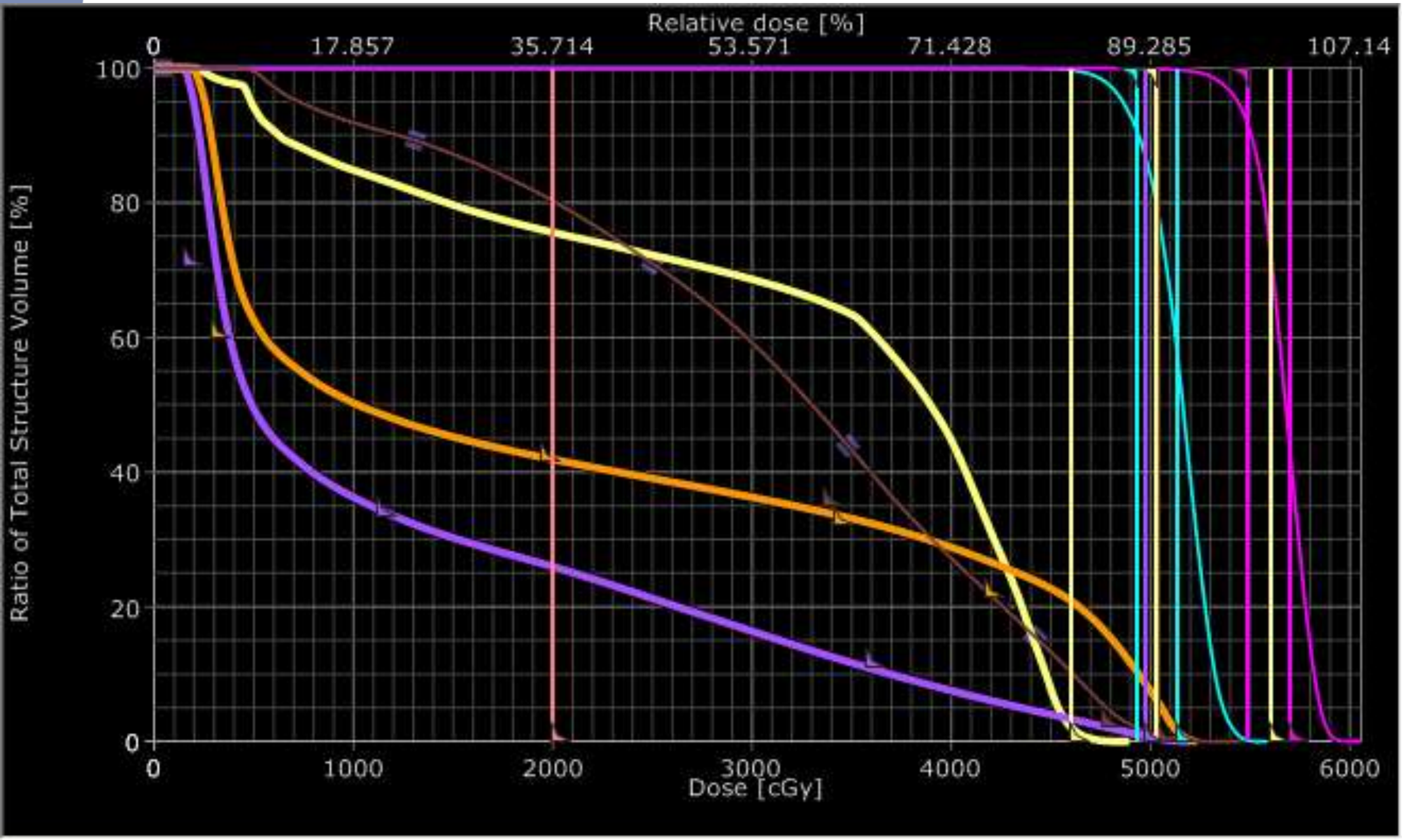
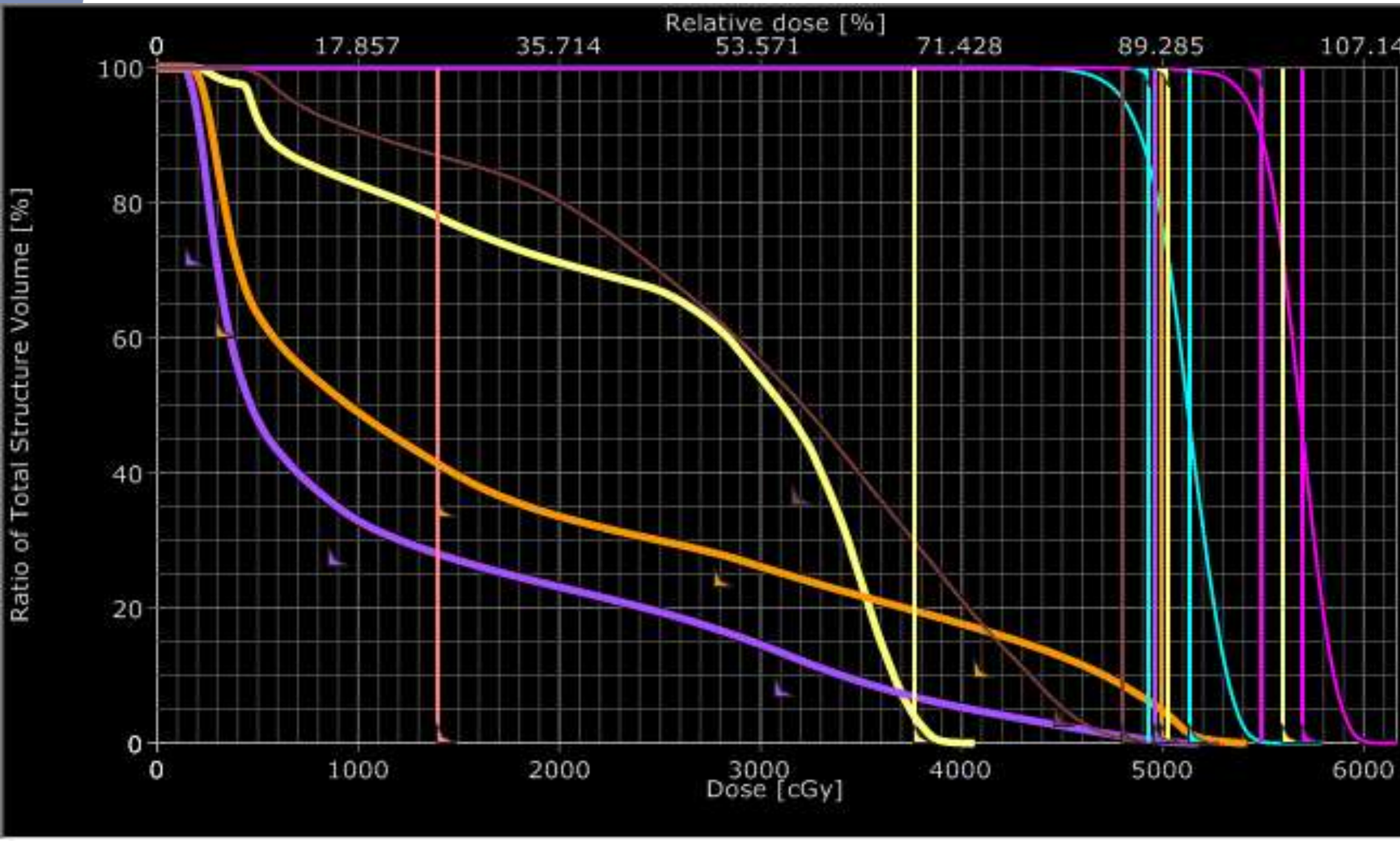
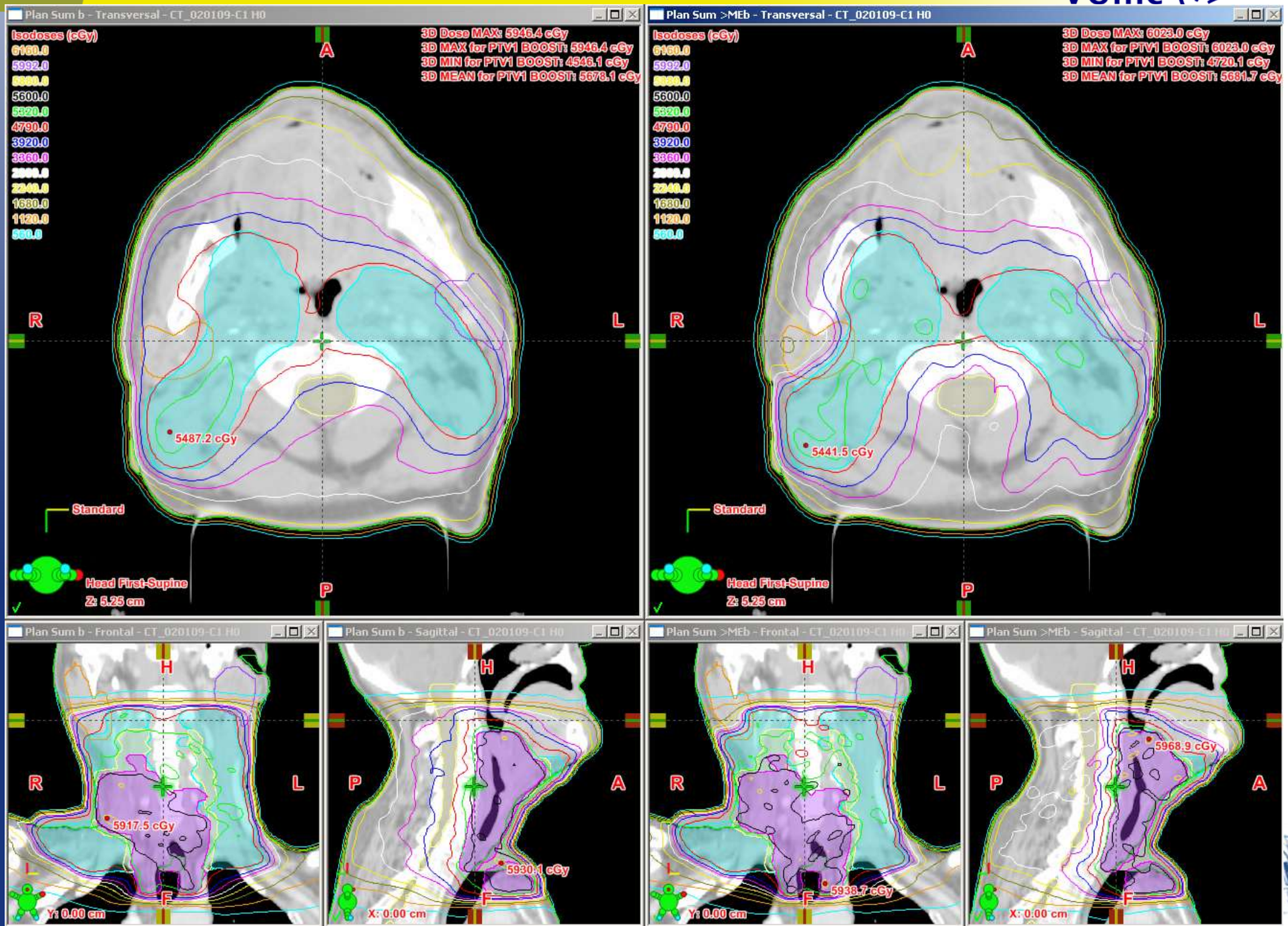


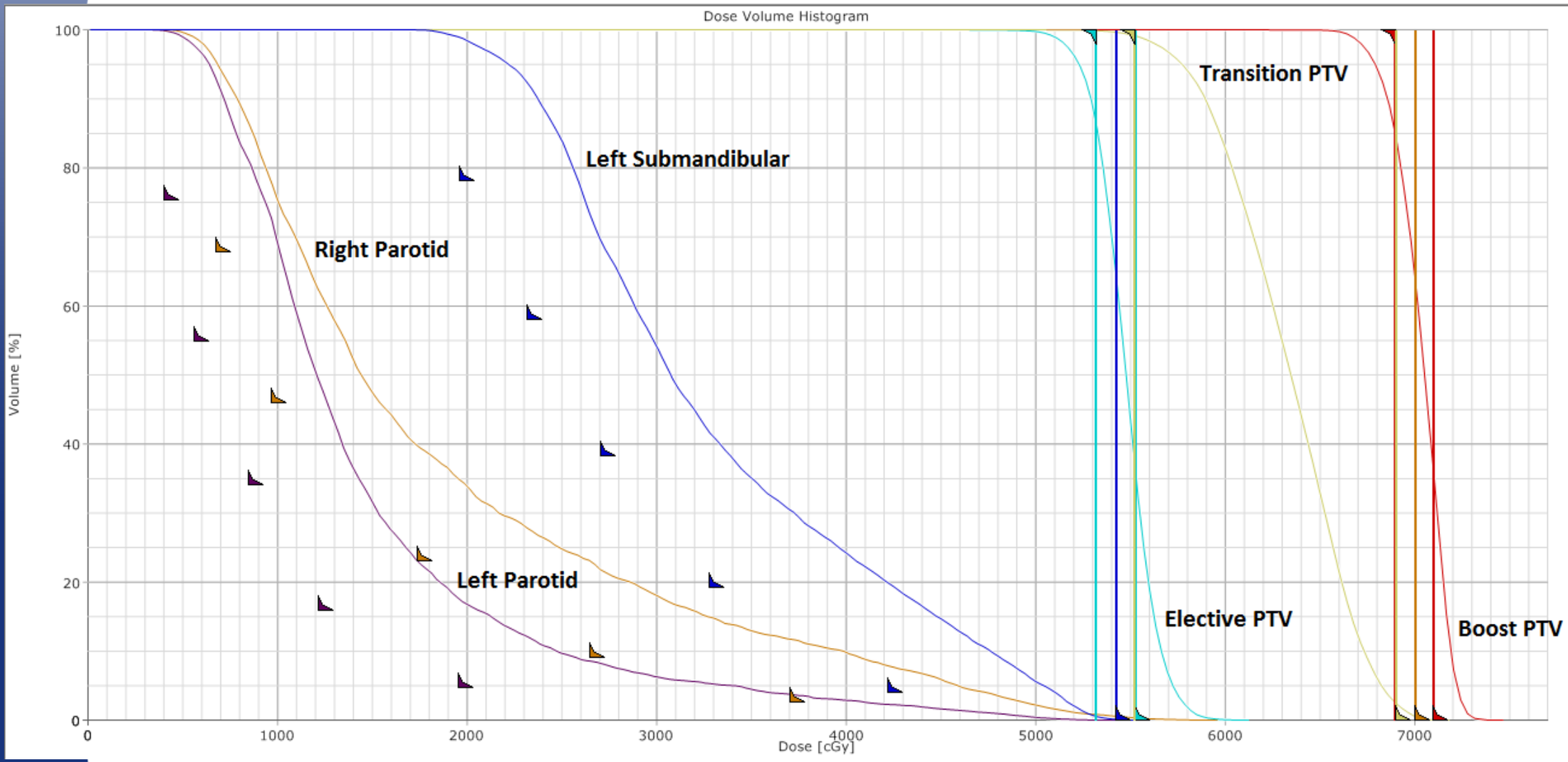
Tighter constraints, more PG +SC sparing



More PG and SC sparing (right)



Optimization objectives



Introduction of more OAR

- 2008: parotid glands (+spinal cord, brainstem)
  - Oral cavity and other OAR by general ring structures
- 2009: sparing of Submandibular glands
- 2009: lower spinal cord dose if possible
- 2011: sparing of swallowing structures

- Sparing is possible
- Sometimes small underdosage of PTV locally
- Influence sparing new OAR on "old" OAR?
- "Dose dumping" elsewhere?

SMG-sparing versus non-sparing

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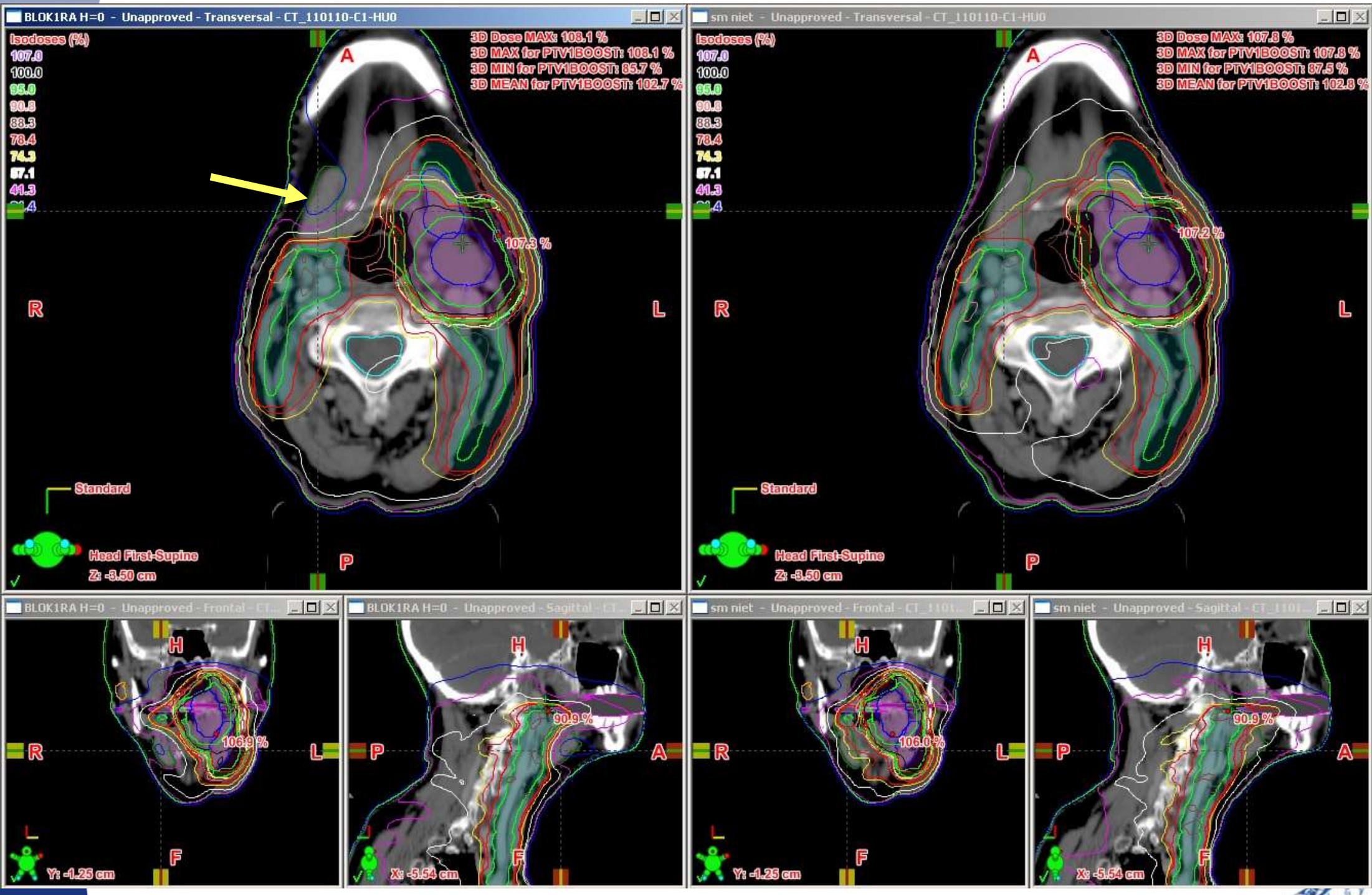
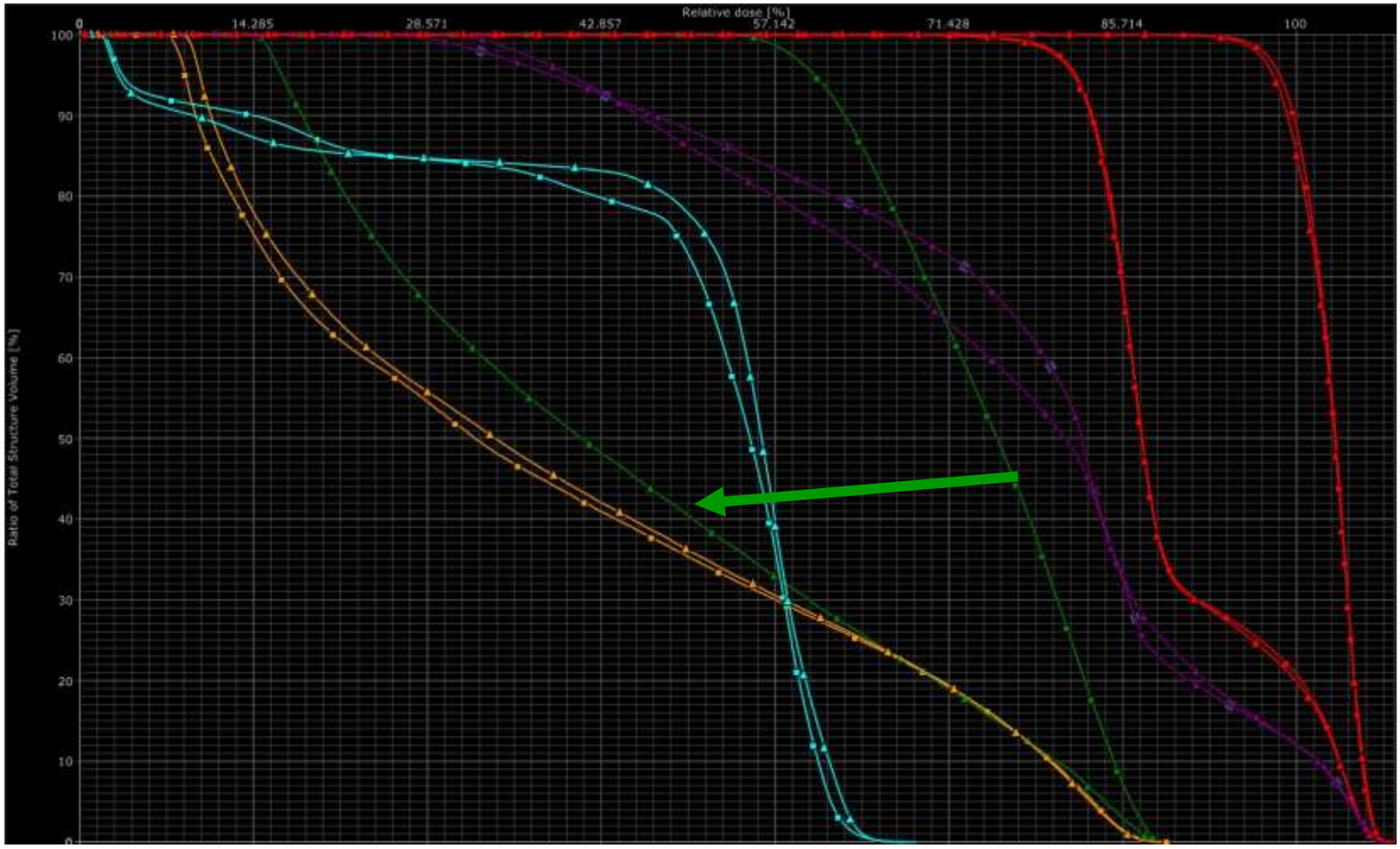


SMG-sparing versus non-sparing



▲ clinical plan ■ non-sparing plan

➔ Now also sparing of swallowing structures
Acceptance of more dose spread to posterior neck
Locally PTV underdosage

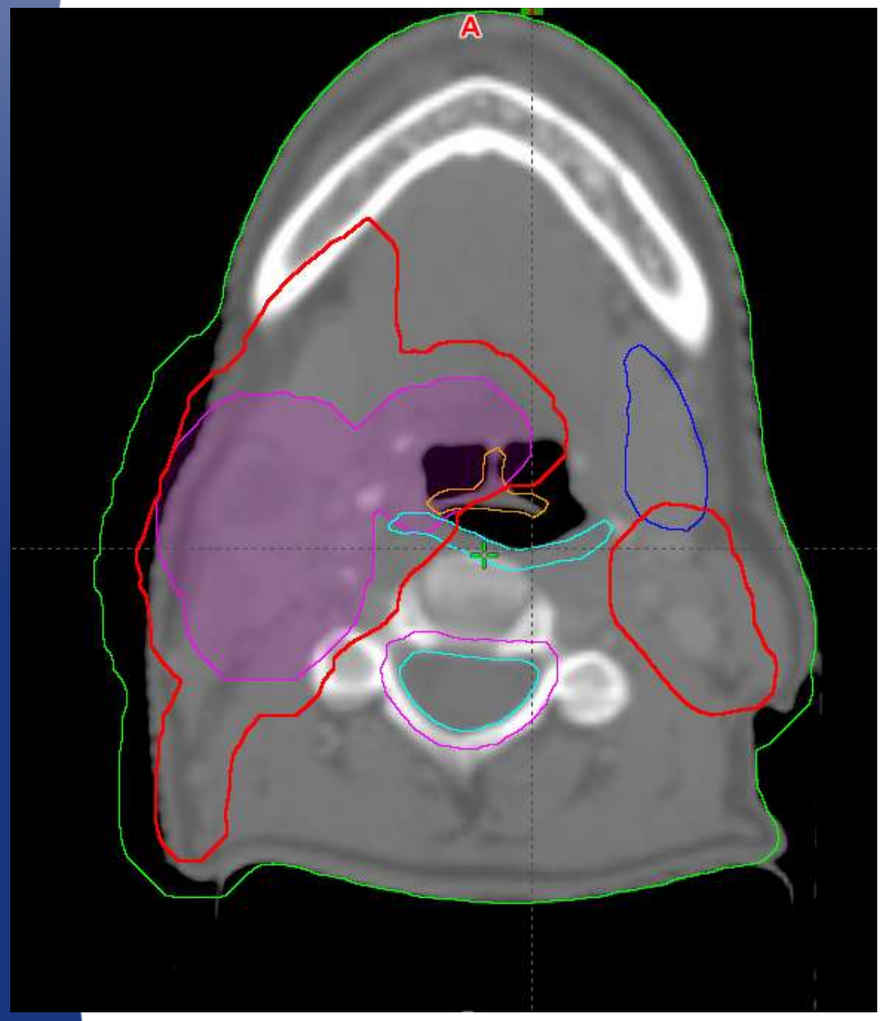
Local PTV underdosage

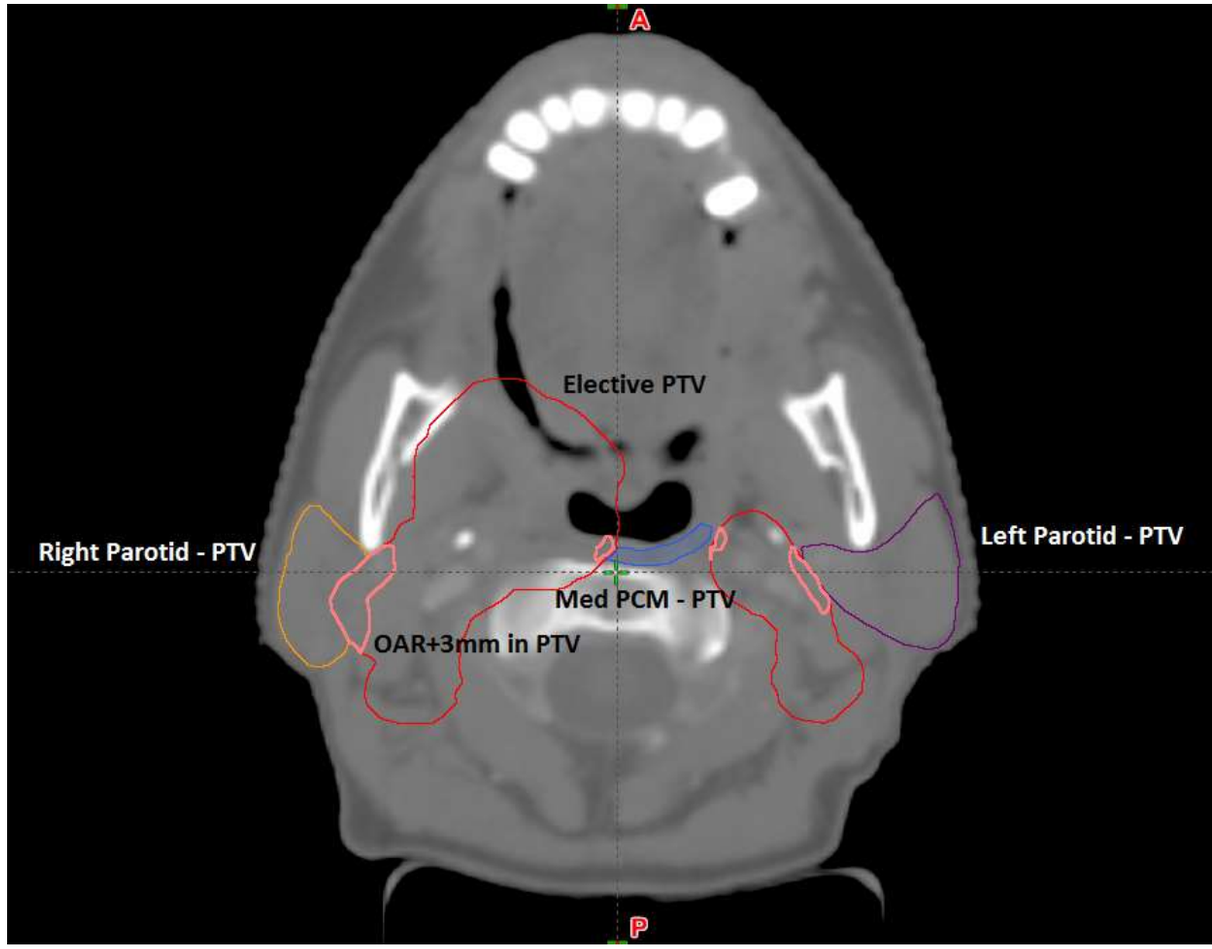
- Not always visible in DVH
- More OAR, more sparing ➔ more underdosage

Solutions

- Local PTV expansion (+2mm)
  - Also results in slightly higher OAR dose
- Extra local separate PTV in optimization:
  - PTV near OAR (OAR + 5mm expansion)
  - Extra minimum dose objective

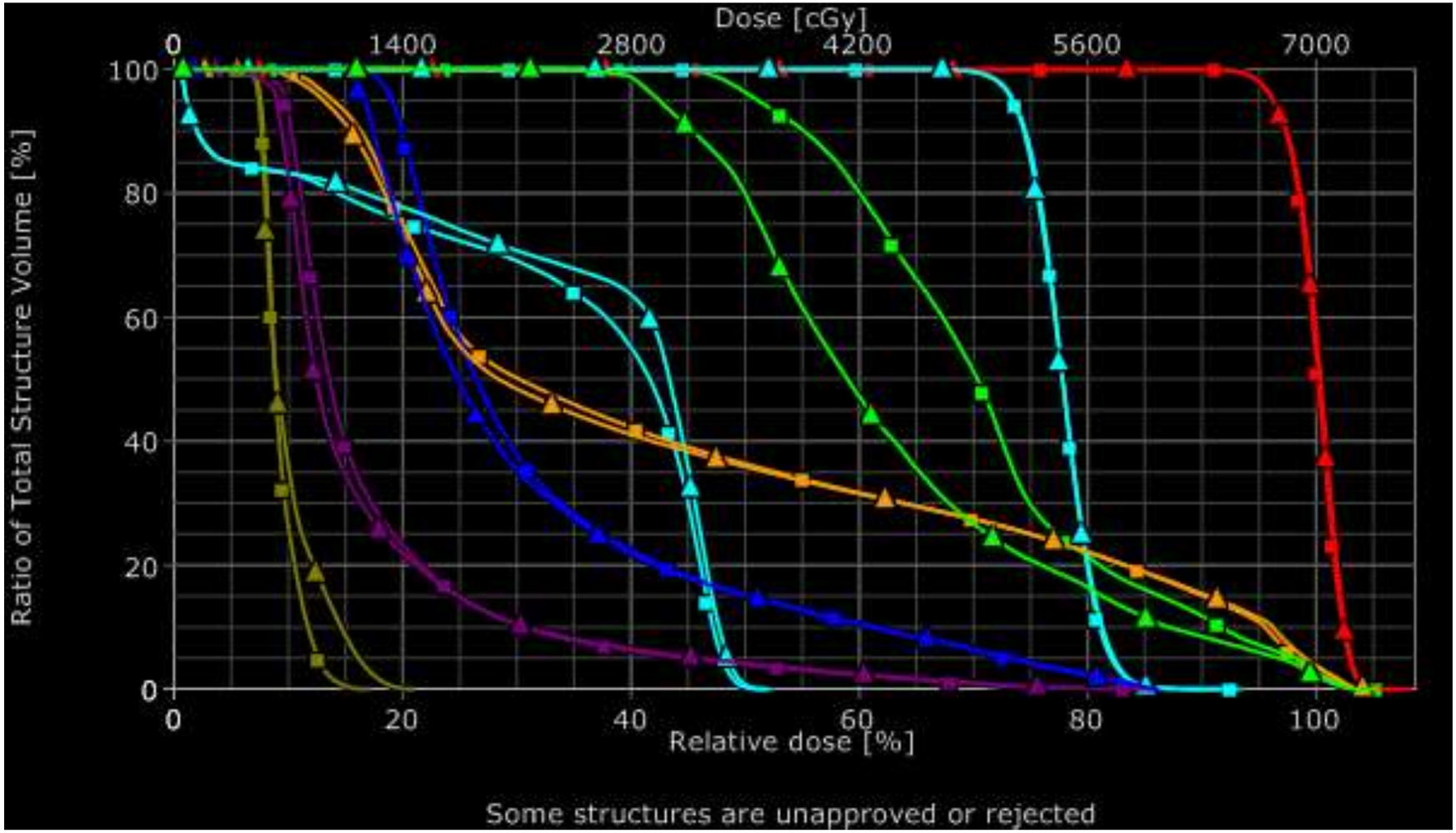
Avoid local PTV underdosage



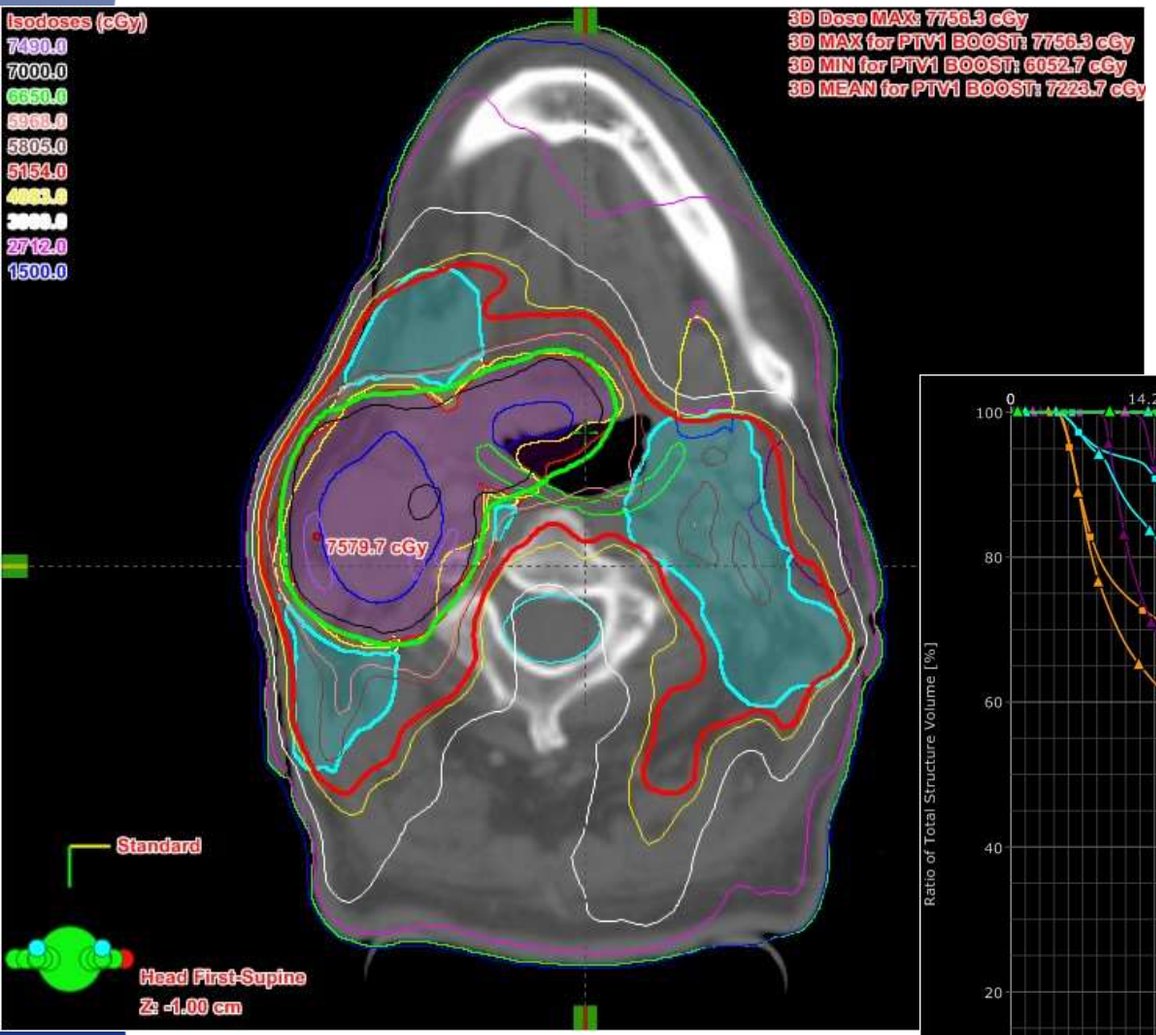


Effect of more OAR sparing

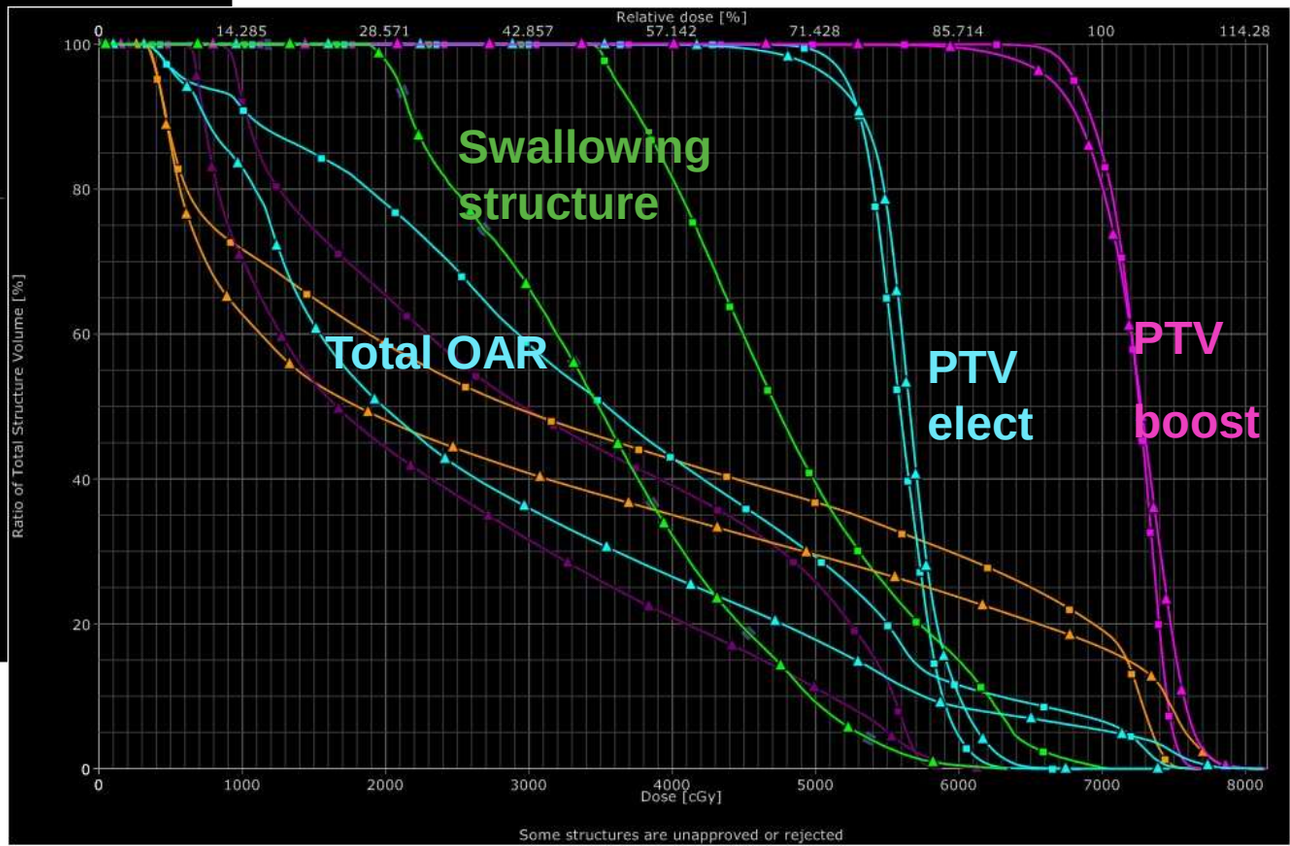
- No dose increase for other OAR (PG, SMG)



More sparing of OAR: loss of PTV coverage



- Sparing of SC, PG, SMG and swallowing structures
- Which underdose is acceptable?



Knowledge of past plans

- Library of good plans
- Relationship of geometry and achievable OAR dose
- Match new patient with model
- What about Pareto-optimality of library plans?
- Aim for best plans in library
- Differences in plan acceptance:
  - V95: from 95-99% of PD, or D95 = PD
  - Which maximum dose in PTV (V107, D2)
  - Between centers, between clinical studies: RTOG, EORTC, …
- How does dose homogeneity to PTV influence OAR sparing?

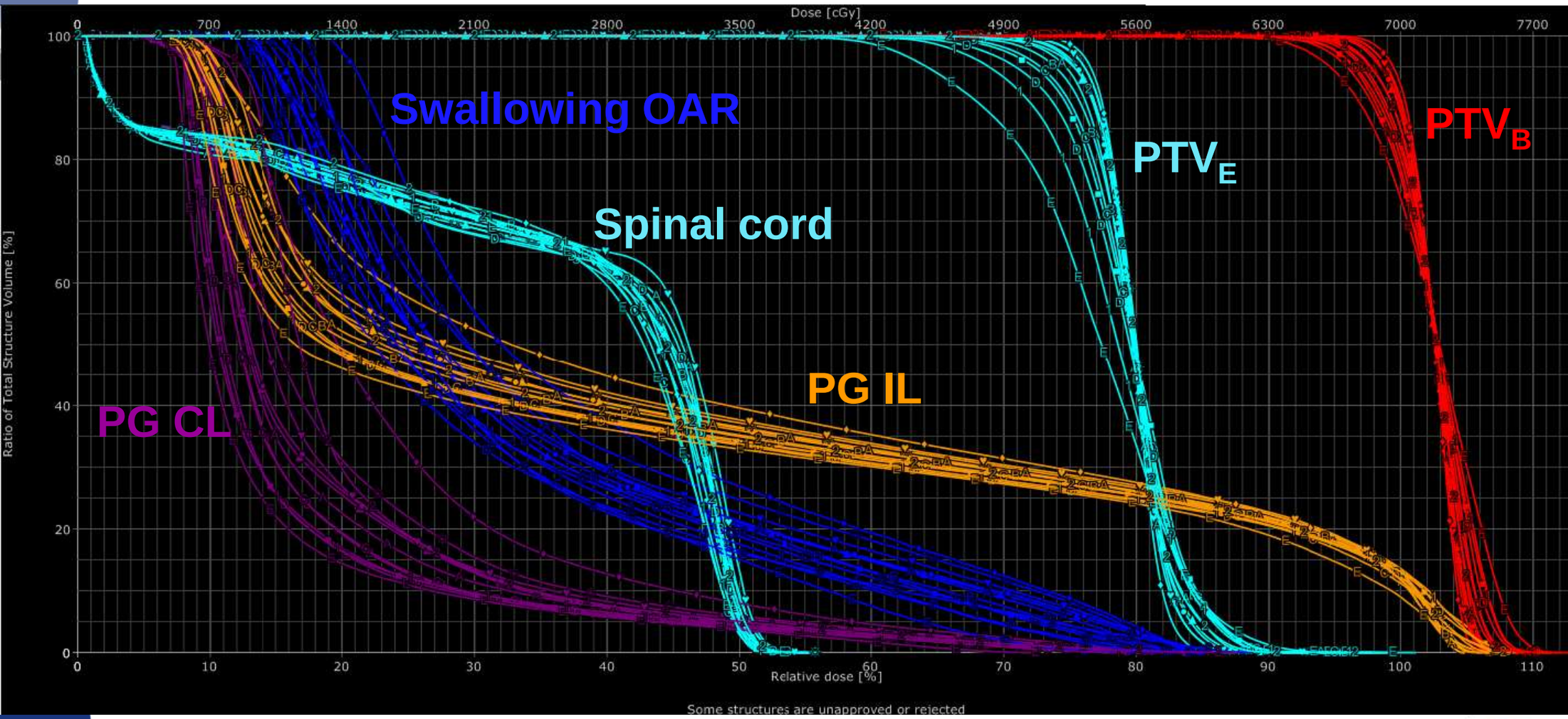
Trade-off between PTV – OAR dose

VUmc

- 10 H&N patients (54.25Gy with SIB to 70Gy)
- RapidArc (Eclipse v10), 2arcs
- All plans CPO (continue previous optimization)
  - Proven to improve PTV dose homogeneity
- Multiple plans (13) per patient
- Spinal cord and brainstem +PRV Dmax < 48Gy
- Decreasing PTV priority (200-80)
- OAR priority constant 85, institutional interactive optimization
- Salivary OAR (PG, SMG, if mostly outside PTV)
- Swallowing OAR (indicated by clinician)
- D_{mean} to salivary and to swallowing OAR

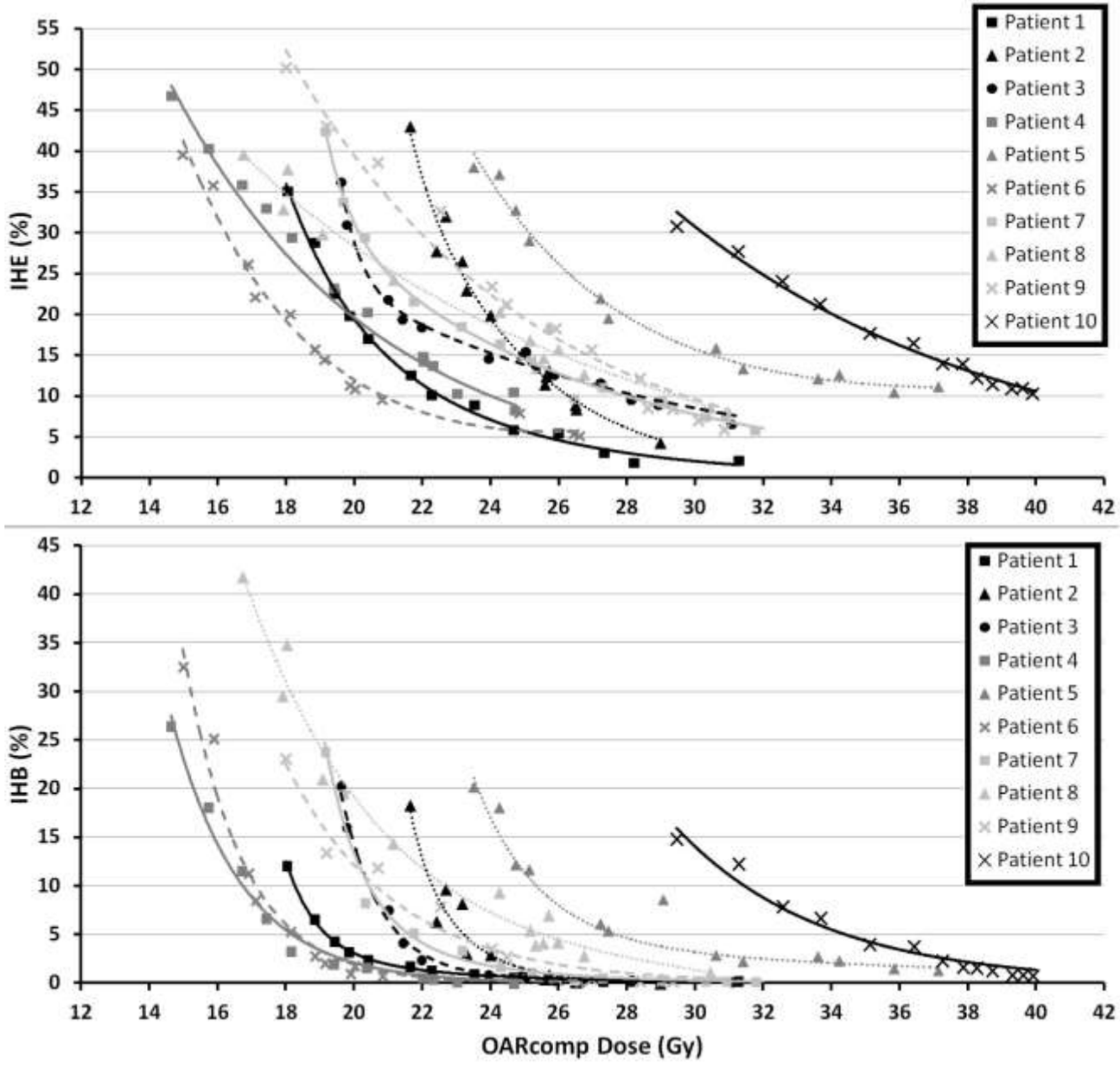
Trade-off between PTV – OAR dose

- Example of increased OAR sparing



Trade-off between PTV – OAR dose

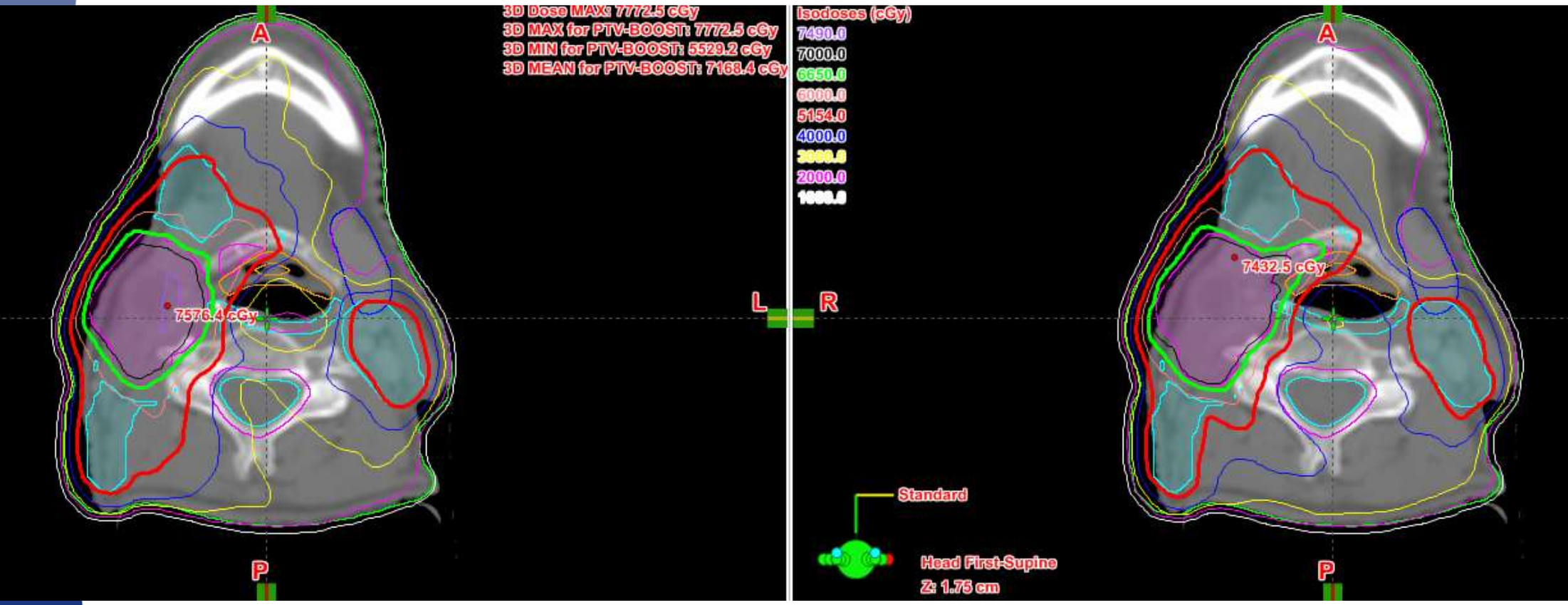
- PTV dose homogeneity = 1 – V95 + V107
- Average D_{mean} swallowing and D_{mean} salivary



Effect of PTV dose homogeneity

IH_B <5%

IH_B<1%

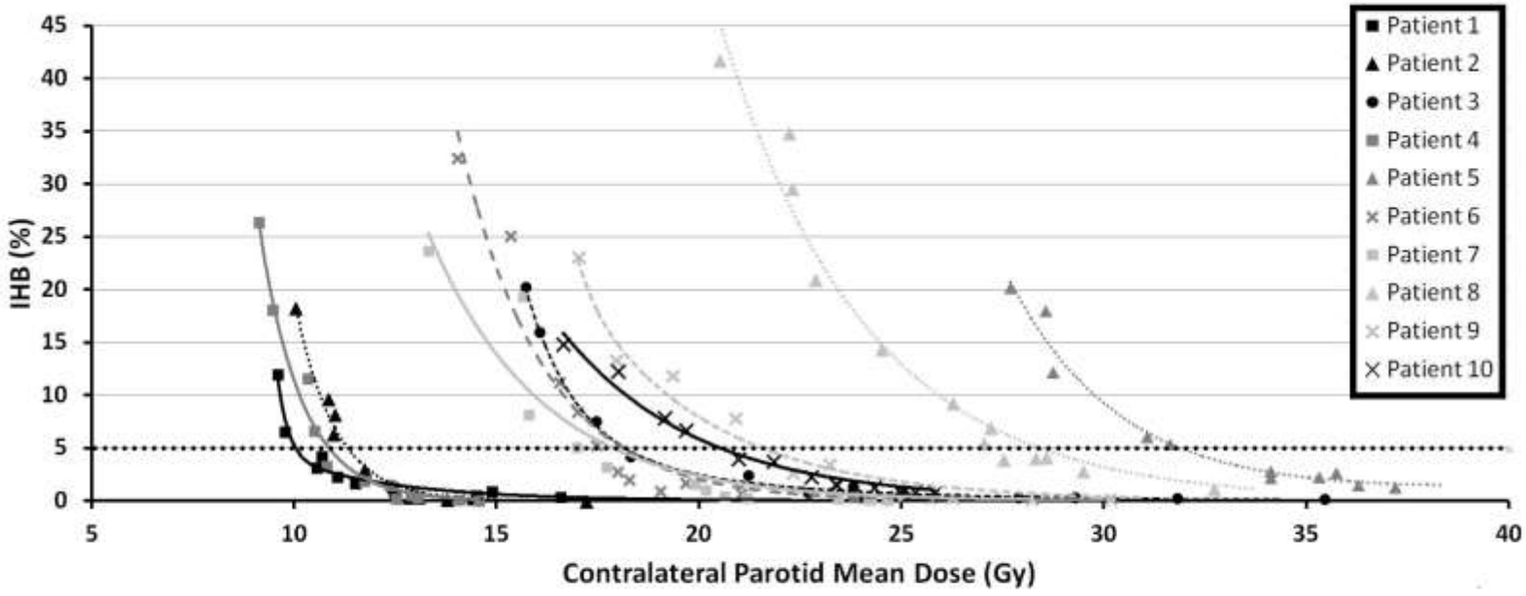


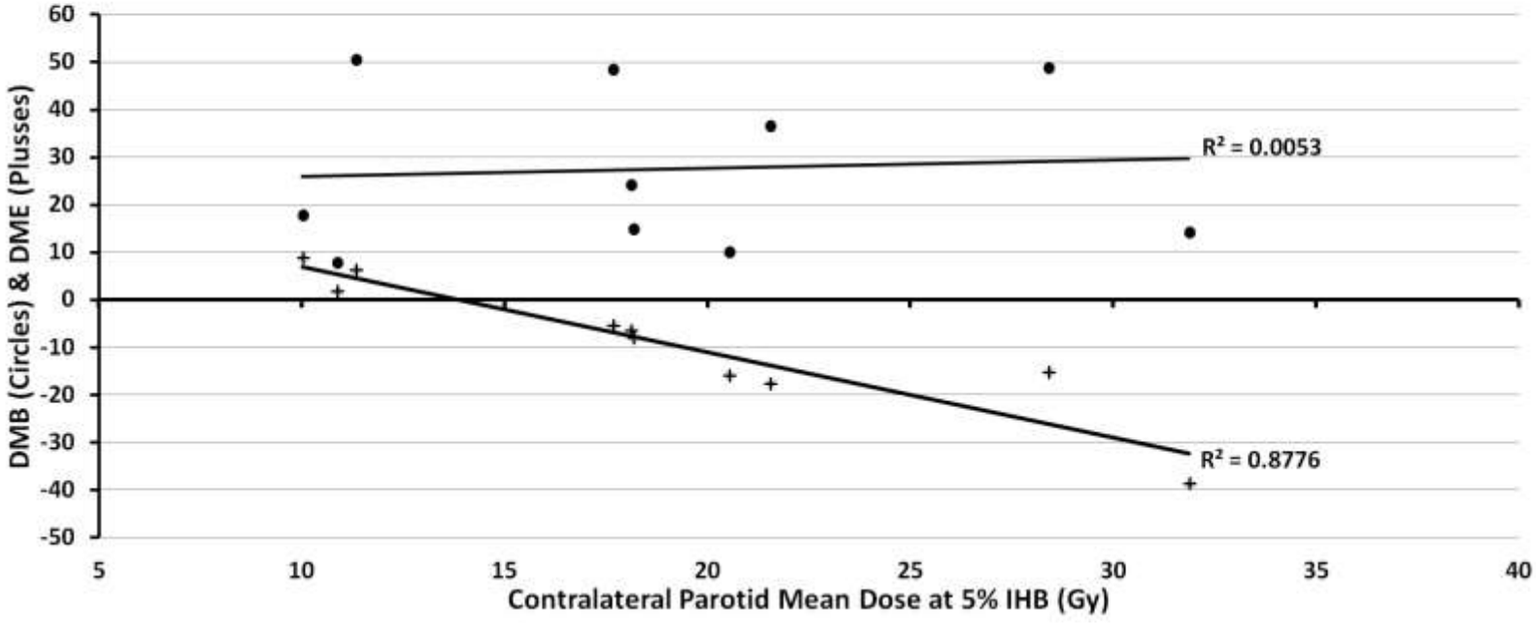
Distance measure – OAR dose at IH_B=5%

VUmc

DM= adapted Euclidean distance OAR-PTV

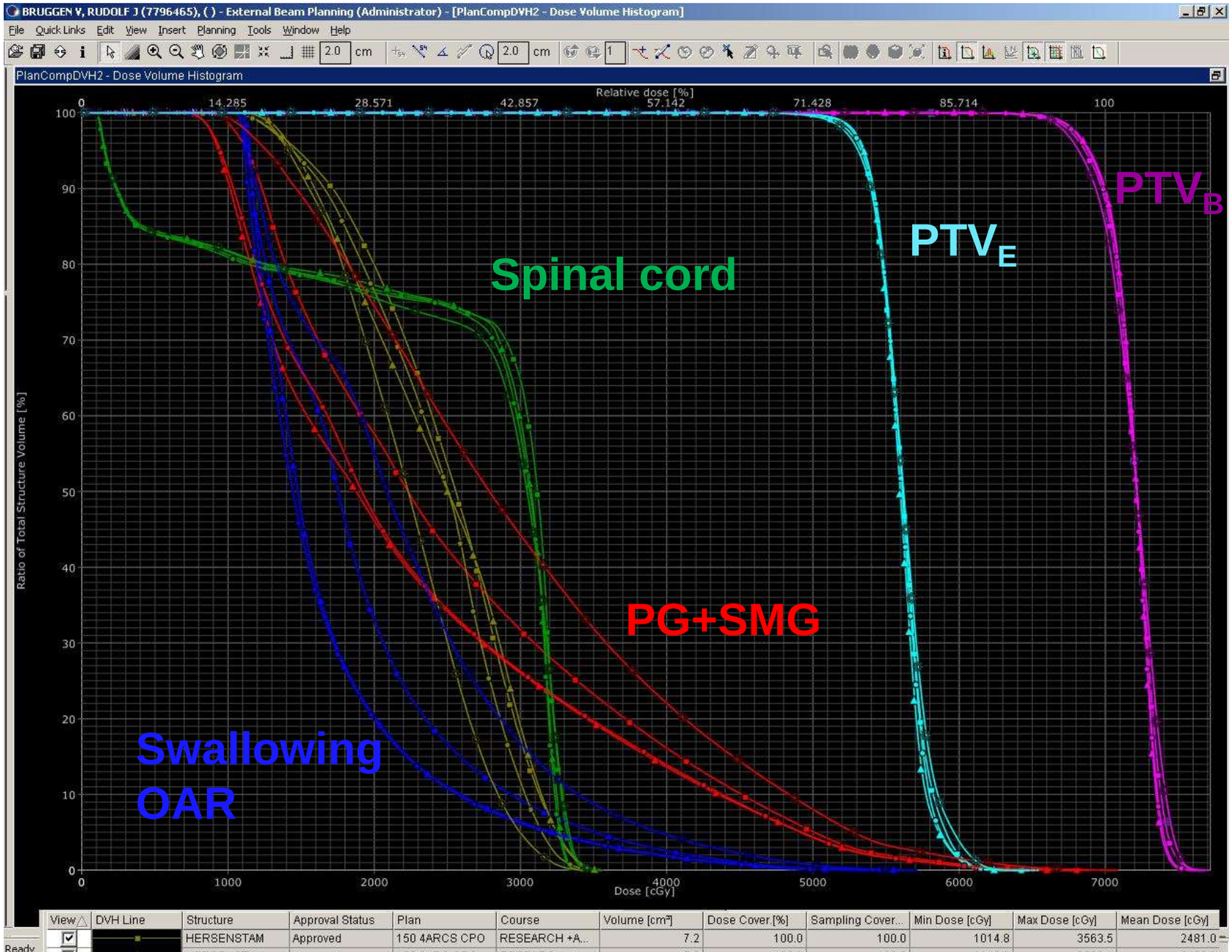
➔ Predict achievable OAR sparing at certain IH_B





Further improving VMAT

- Effect of more arcs (2, 4, 6, 8)



Knowledge for automated planning

VUmc

- Effect of choosing very homogeneous PTV dose

➔ Choose priorities accordingly

- Distance measure of OAR-PTV
  - Works for PG IL, PG CL, SMG, swallowing OAR separately
- For chosen PTV dose homogeneity, predict possible OAR doses

➔ Not needed to have a library of good plans, but library of plans exploring all trade-offs

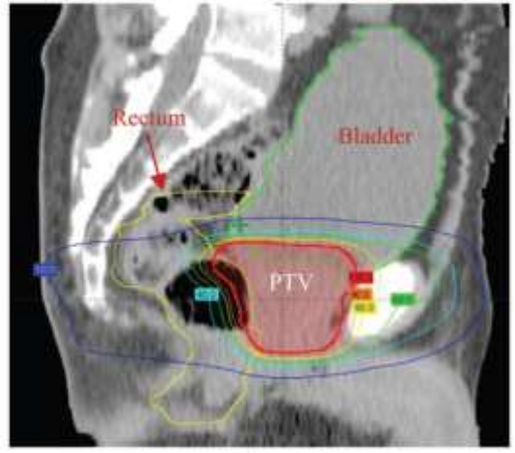
Automatic planning strategies

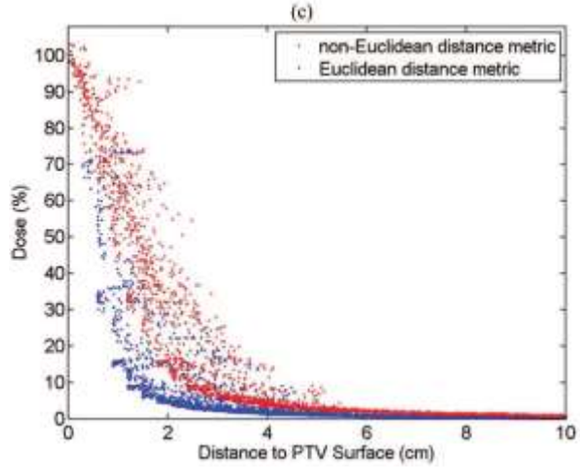
- Using prior knowledge of patients
- Iteratively running optimizations, increasingly sparing OAR
- Theoretical work on smart multi-criteria optimization

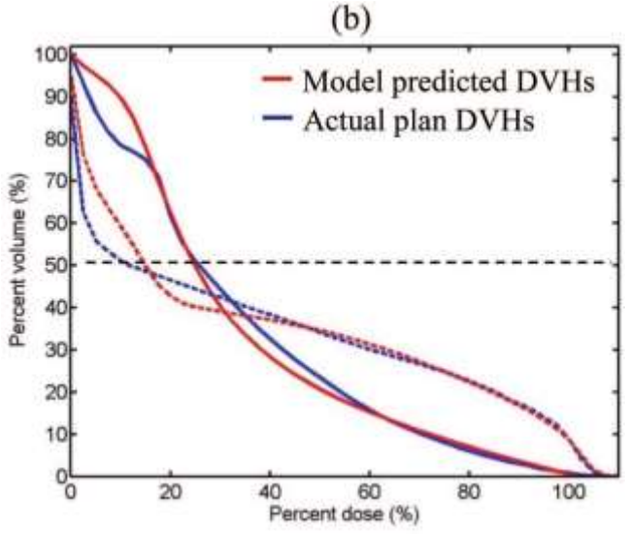
Yuan L, Med Phys 2012

- Duke University mc, USA
- Automate VMAT or IMRT for H&N
- Library of previous patients: distance to target histogram
- Correlation between OAR-PTV geometry and OAR DVH
- For prostate and H&N IMRT
- Prediction of OAR DVH
- Use to set objectives in optimizer

- Requires library of **optimal** plans







Voet PWJ, IJROBP 2012

- Erasmus mc, Netherlands
- Automated multicriteria IMRT plan generation for H&N
- iCycle: beam angle and fluence profile optimization
- Create Pareto-optimal plans by first satisfying most important objective, then next, etc. stopping when deteriorating a more important objective

Table 2 Applied wish list for first dose interval of each patient, containing hard constraints, and prioritized objectives

Constraints			
	Volume	Type	Limit
	PTV	Maximum	107% of prescribed dose
	Spinal cord	Maximum	48 Gy*
	Unspecified tissue	Maximum	107% of prescribed dose
Objectives			
Priority	Volume	Type	Goal
1	PTV	↓LTCP	1
2	Parotid/SMG	↓Mean	39 Gy
3	Parotid/SMG	↓Mean	20 Gy
4	Oral cavity	↓Mean	39 Gy
5	Spinal cord/brain stem	↓Maximum	30 Gy
6	External ring†	↓Maximum	90% of prescribed dose
7	Larynx + swallowing muscles	↓Mean	75% of prescribed dose
8	PTV shell 1 cm‡	↓Maximum	75% of prescribed dose
9	Parotid/SMG	↓Mean	10 Gy
10	PTV shell 4 cm‡	↓Maximum	40% of prescribed dose
11	Parotid/SMG	↓Mean	2 Gy

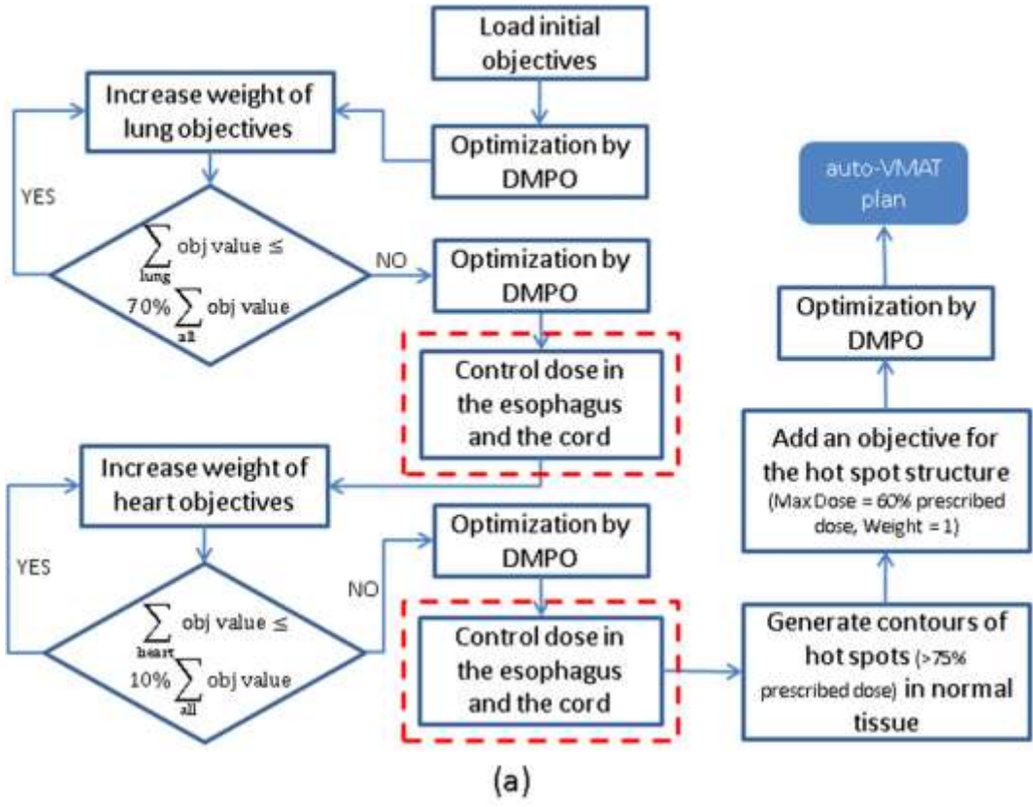
- Final step: optimization by Monaco (for IMRT / VMAT)

Wu B, Med Phys 2013

- Johns Hopkins, USA
- Automate VMAT or IMRT for H&N
- Model based automated planning. Requires database of previous patients to determine location of optimization objectives for new pt
- Overlap Volume Histogram for 3D spatial relationship between OARs and PTVs
- Pinnacle + C++ subroutines
- Generate objectives for VMAT optimization

Quan EM, IJROBP 2012

- MD Anderson, USA
- Automated VMAT for st III lung cancer
- Uses Smartarc module (Pinnacle)
- Multiple optimizations necessary, progressively increasing OAR weights
- Long planning times



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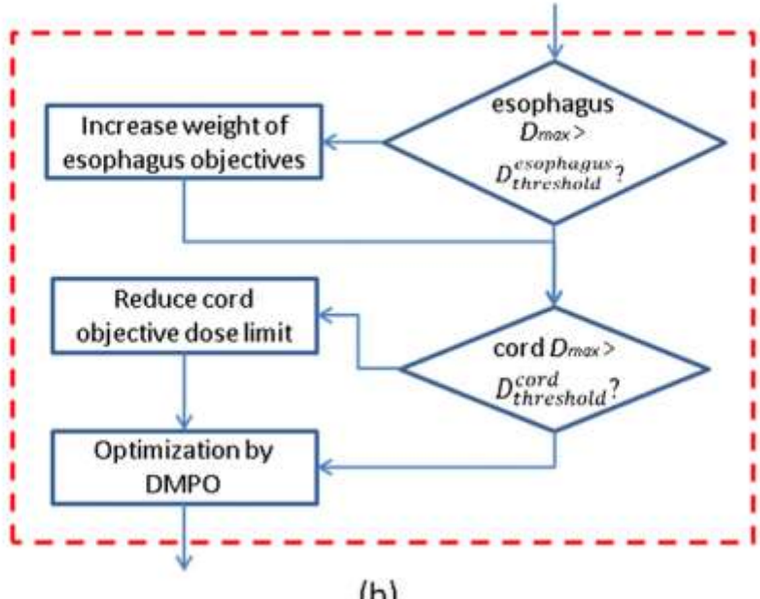

(b)

Acknowledgement

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- Duke university: Jackie Wu