DVH Revisited

Everything you (probably) already know
and maybe some things you don't (but should)

Ben Nelms, Ph.D.

August 14, 2017

Outline

1. History of the DVH: When? Why?
2. How to Calculate a DVH: Back to Basics
3. How to Calculate a DVH: A Deeper Dive
4. How to Validate a DVH Calculator (and Why)
5. Why Are We Talking About This Now?

History

When? Why?

History of the DVH: When?

- One if the first well-known publications

Dose-volume histograms.

Drzymala RE, Mohan R, Brewster L, Chu J, Goitein M, Harms W, Urie M.

Int J Radiat Oncol Biol Phys. **1991** May 15; 21(1):71-8.

The early 1990s marked a period of rapid growth for 3D conformal radiation therapy (3DCRT), catalyzed by: (1) increasing availability of CT imaging machines and (2) development of software to calculate and visualize dose in 3D.

History of the DVH: When?

- But the concept of the DVH goes farther back

Proton radiation as boost therapy for localized prostatic carcinoma.

Shipley WU, Tepper JE, Prout GR Jr, Verhey LJ, Mendiondo OA, Goitein M, Koehler AM, Suit HD.

JAMA. **1979** May 4; 241(18):1912-5..

History of the DVH: Why?

- 3D Dose + 3D Structures = Lots of information. How can we interpret efficiently?
  - View isodoses with structures in 2D views…
    - Requires scrolling through many slices.
    - Was every slice analyzed completely? If so, how long did it take?
    - Did you find ROI max and min, i.e. hot spots and cold spots?
    - Were objective stats (e.g. what volume of a structure received a threshold dose or higher) obvious?
  - View 3D dose with 3D structures…
    - Same problems as above.

History of the DVH: Why?

- DVH = graphical (and statistical) method that condenses the complicated 3D dose and structure data
  - Easy: Finding structure min and max dose
  - Easy: Assessing dose uniformity
  - Easy: Assessing coverage or sparing in terms of dose-at-volume or volume-at-dose
  - Easy: Comparing two treatment plans
  - But: You lose the spatial (positional) information

How to Calculate a DVH (Part 1)

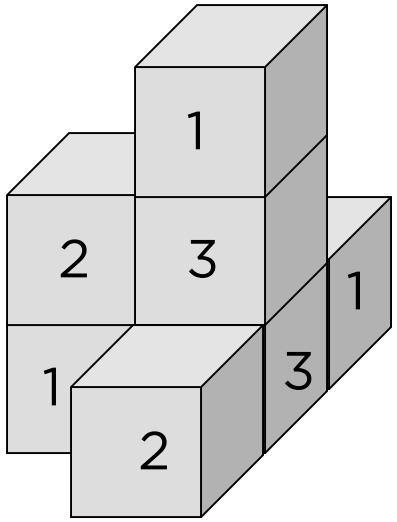
Back to Basics

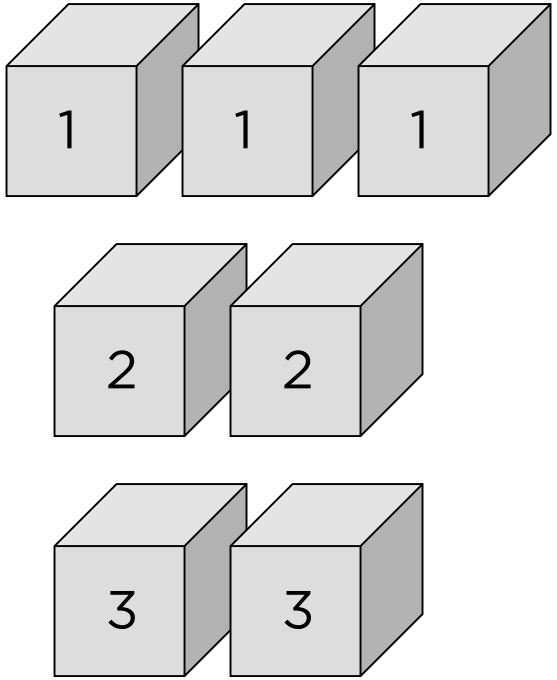
The Basics

1. Model 3D anatomy from the input 2D contours
   - Create “voxelized” structure volume.
   - For any given point XYZ, you can determine if it is “inside or outside” the structure.
2. Model 3D dose voxels from the input 3D dose grid
3. Go through the dose voxels:
   - For each XYZ voxel, ask: is it inside the structure?
   - If yes, then allocate the voxel’s volume into the appropriate dose bucket (i.e. bin)
   - Do for all applicable XYZ dose voxels

The Basics

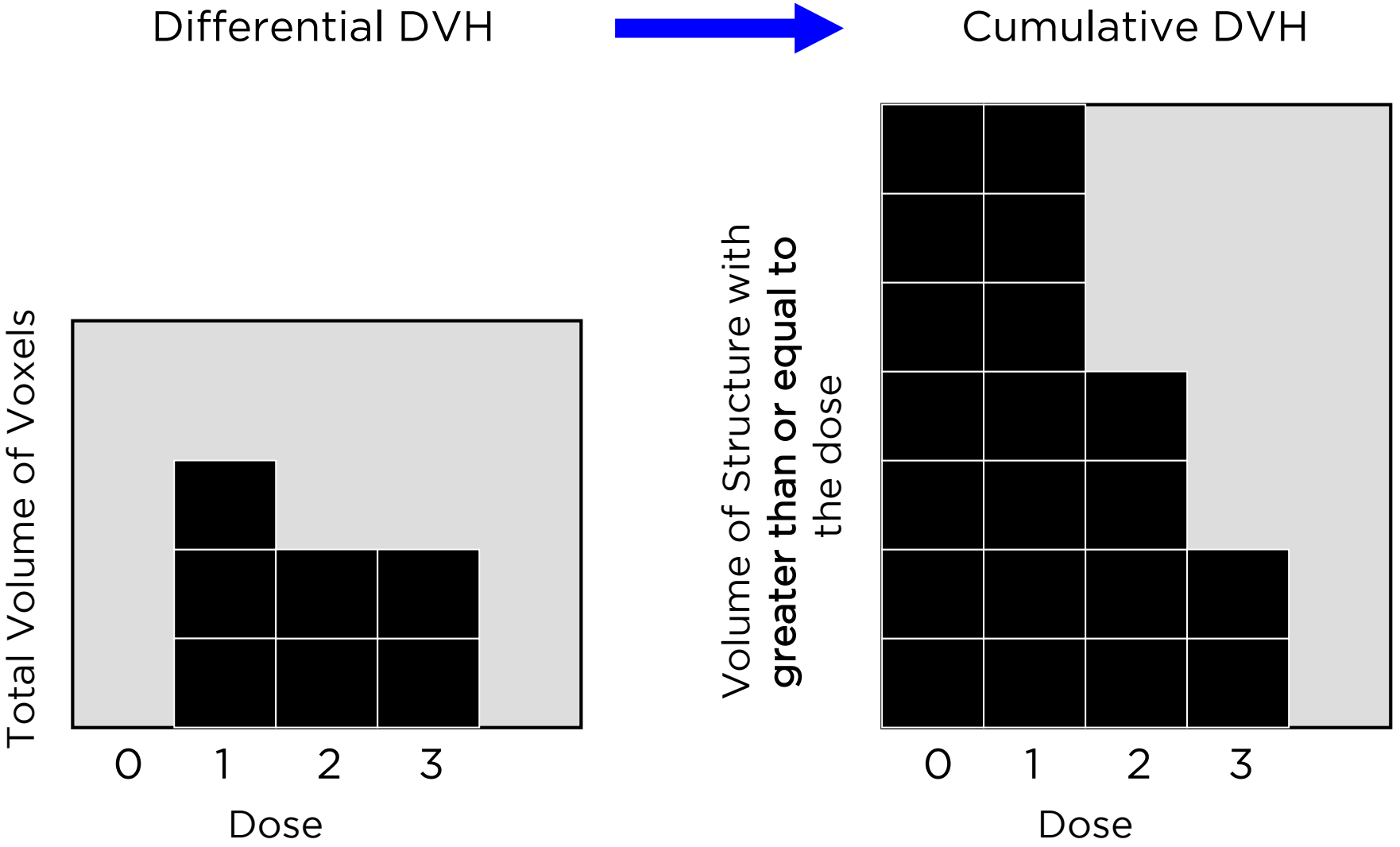
7 Voxels of Dose → "Bin" the Voxels → Assemble Histogram



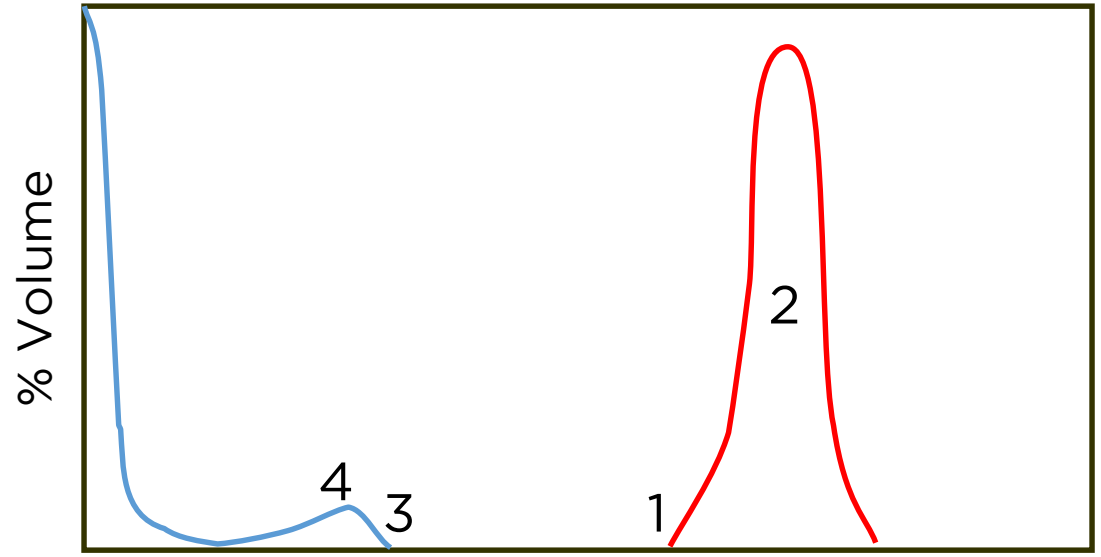


The Basics

Differential DVH → Cumulative DVH

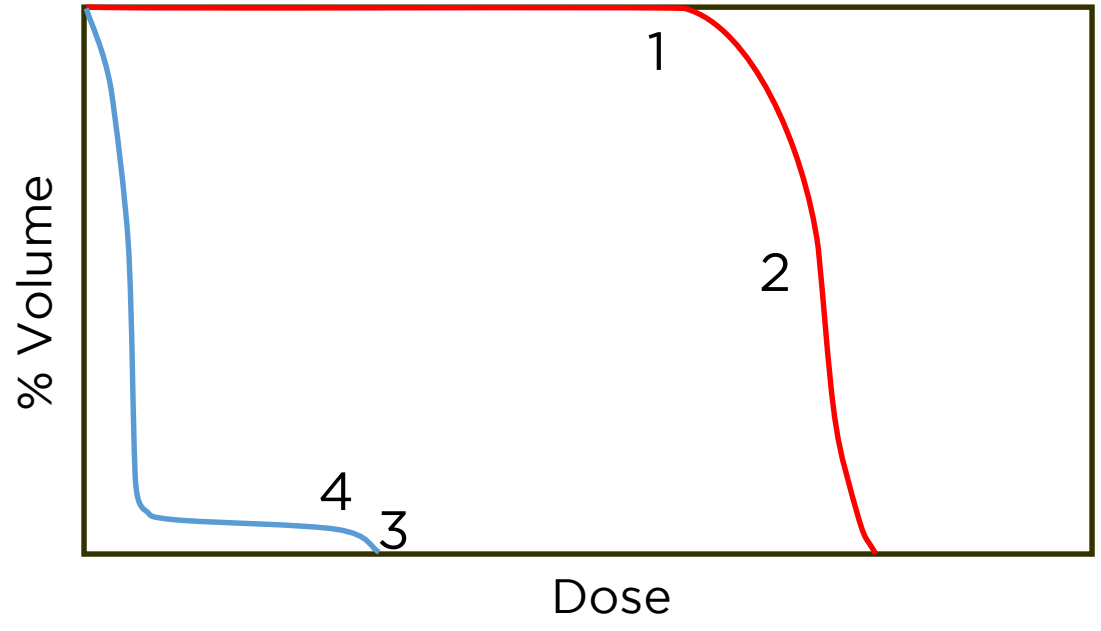


The Basics



Differential DVH

1. Min dose to tumor
2. Tumor dose uniformity
3. Max dose to organ
4. Sub-volume of organ receiving a range of dose



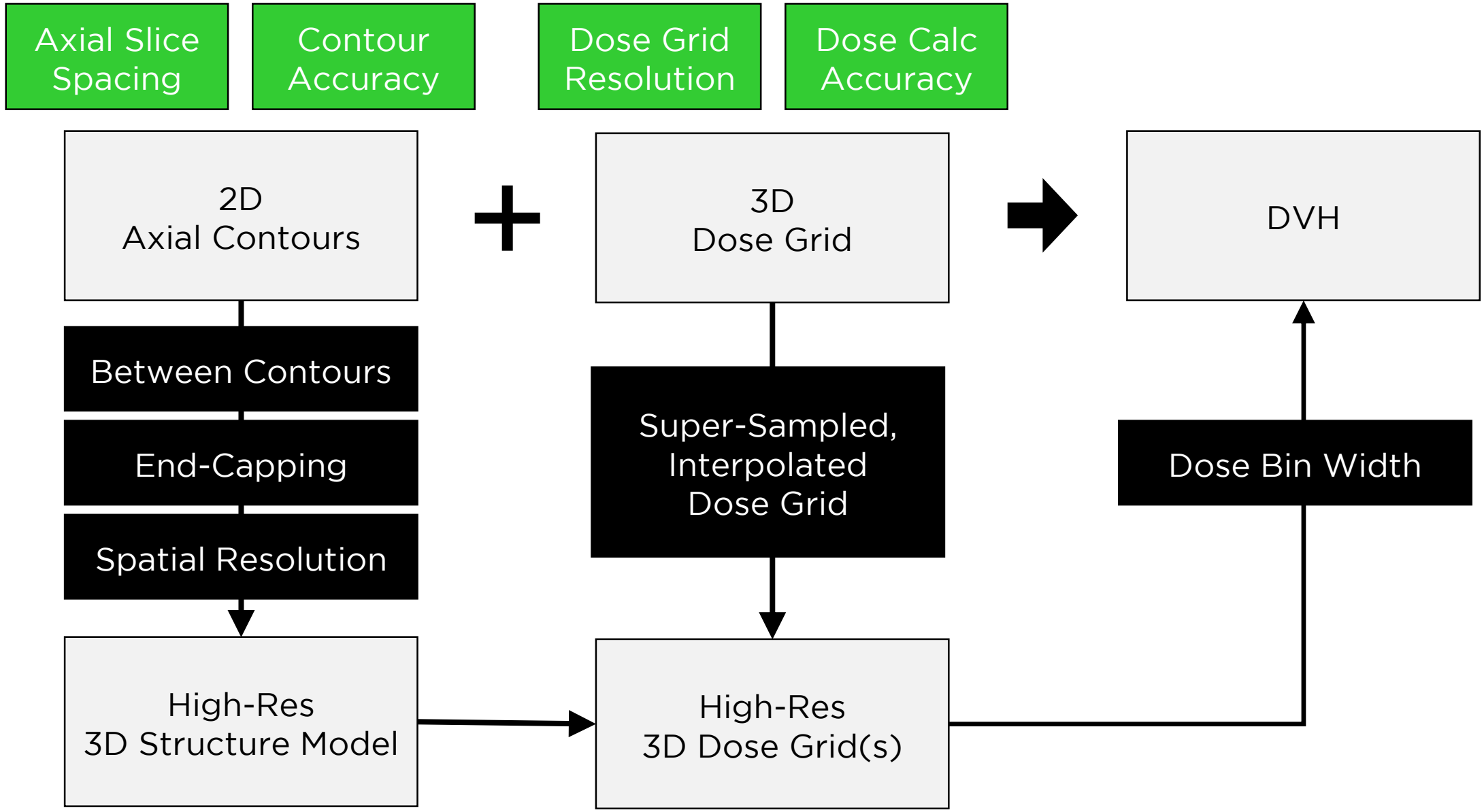
Cumulative DVH

1. Min dose to tumor
2. Tumor dose uniformity
3. Max dose to organ
4. Sub-volume of organ receiving a range of dose

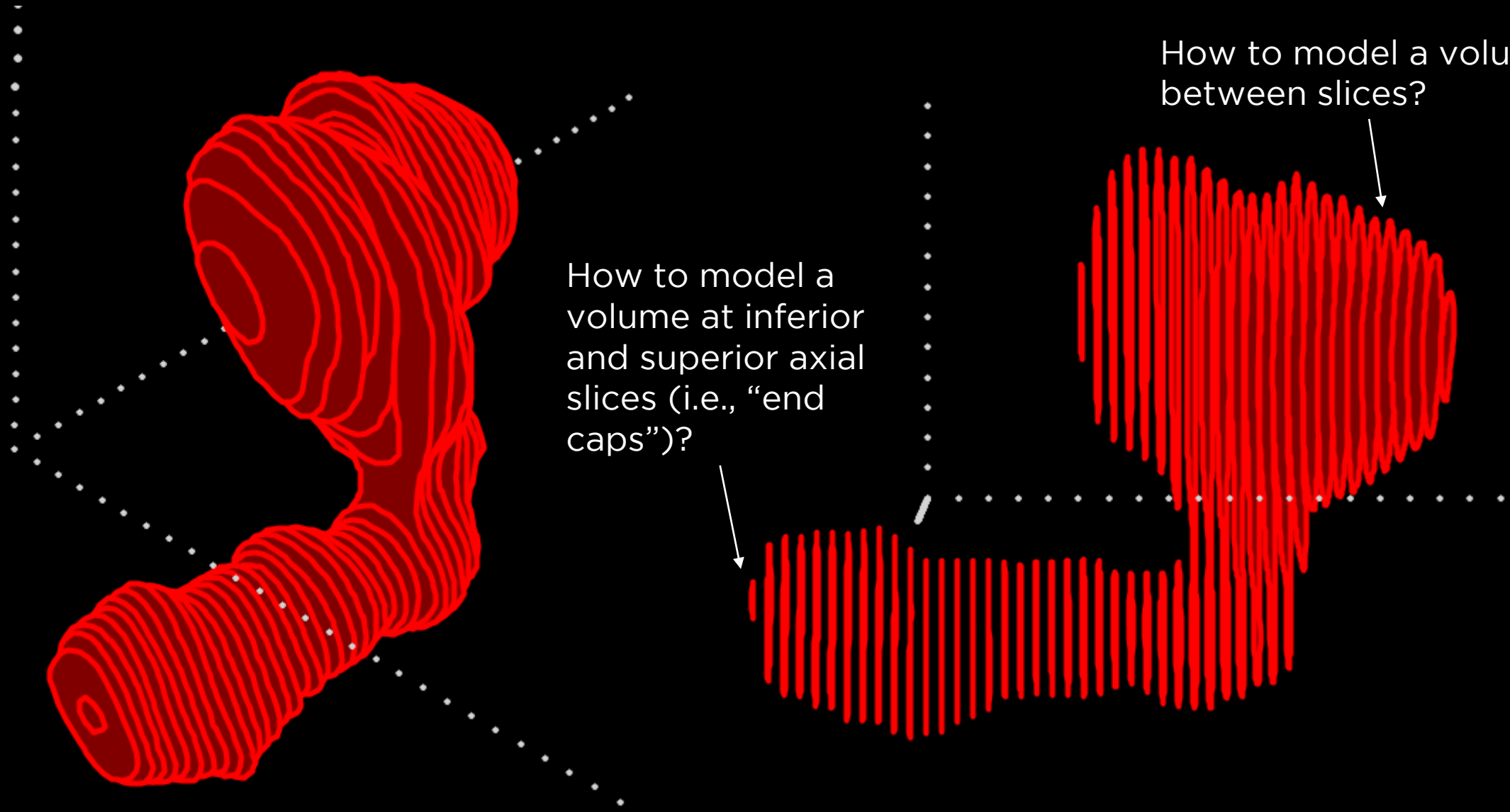
How to Calculate a DVH (Part 2)

A Deeper Dive

Deeper Dive


Axial Slice Spacing
Contour Accuracy
Dose Grid Resolution
Dose Calc Accuracy
2D Axial Contours
3D Dose Grid
DVH
Between Contours
End-Capping
Spatial Resolution
Super-Sampled, Interpolated Dose Grid
Dose Bin Width
High-Res 3D Structure Model
High-Res 3D Dose Grid(s)

Between Slices & End-Capping

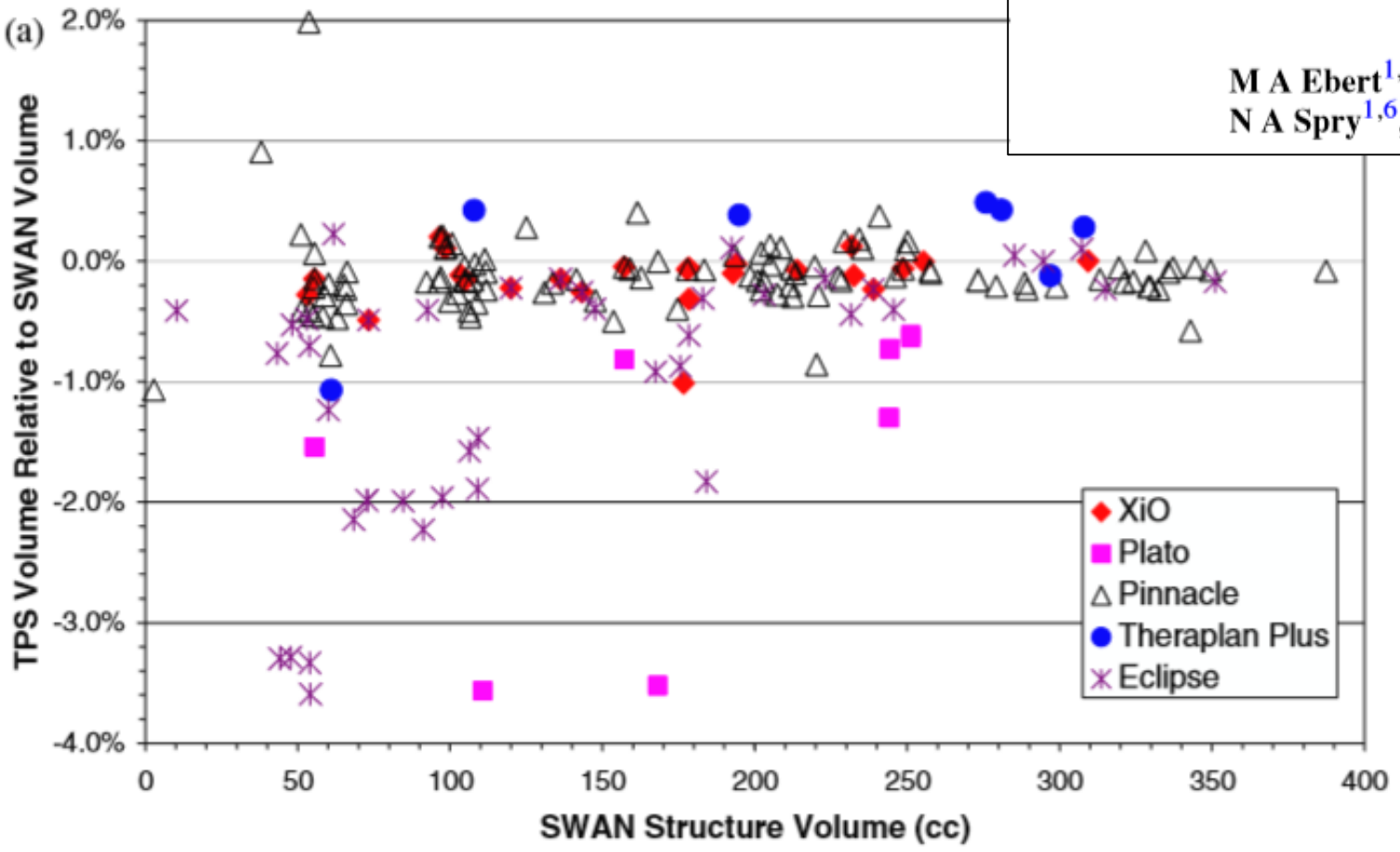


Different Software → Different Volumes!

Phys. Med. Biol. 55 (2010) N337–N346 doi:10.1088/0031-9155/55/11/N04

Comparison of DVH data from multiple radiotherapy treatment planning systems

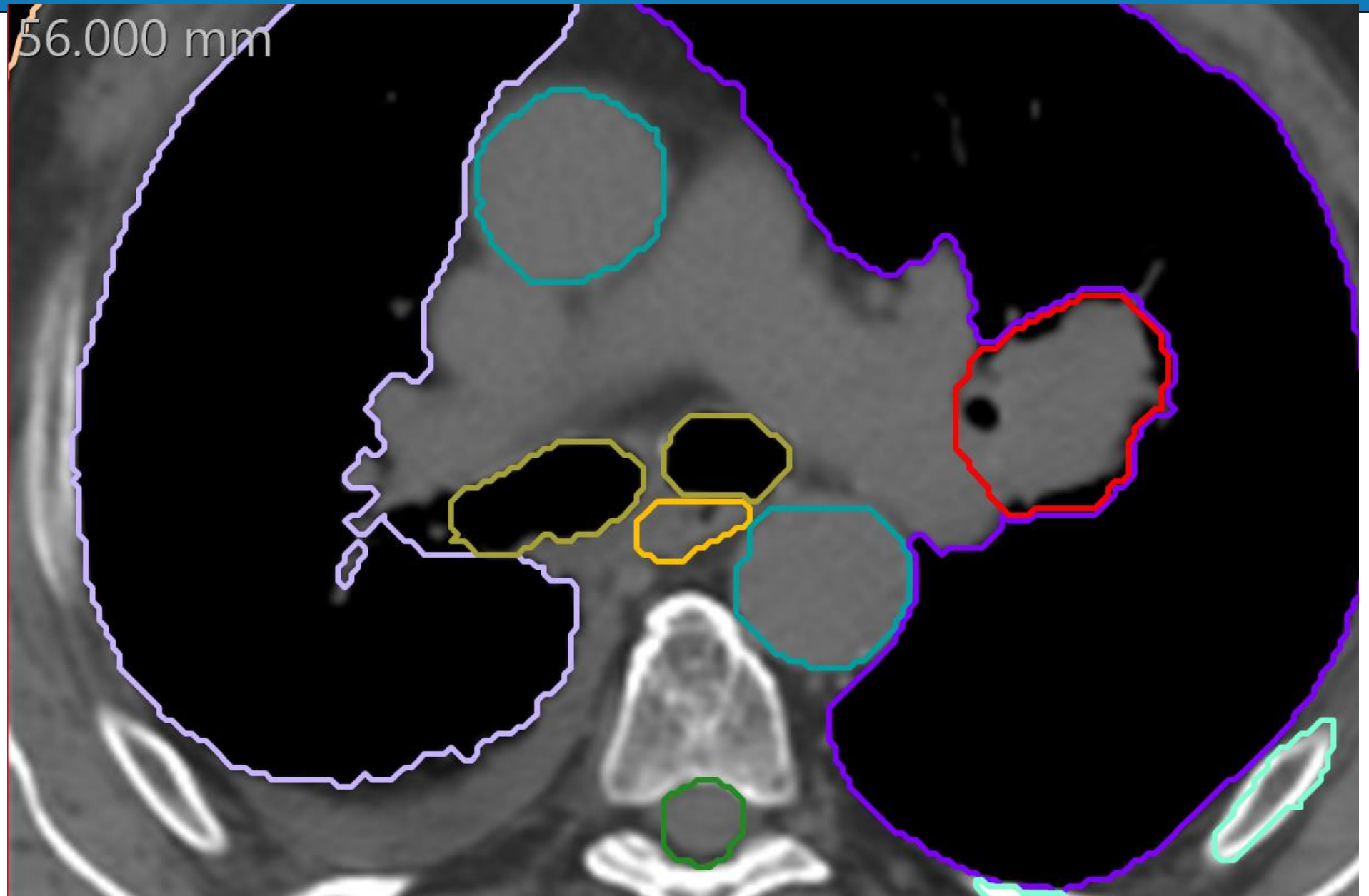
M A Ebert[1,2,8], A Haworth[3,4], R Kearvell[1], B Hooton[1], B Hug[5], N A Spry[1,6], S A Bydder[1,7] and D J Joseph[1,7]



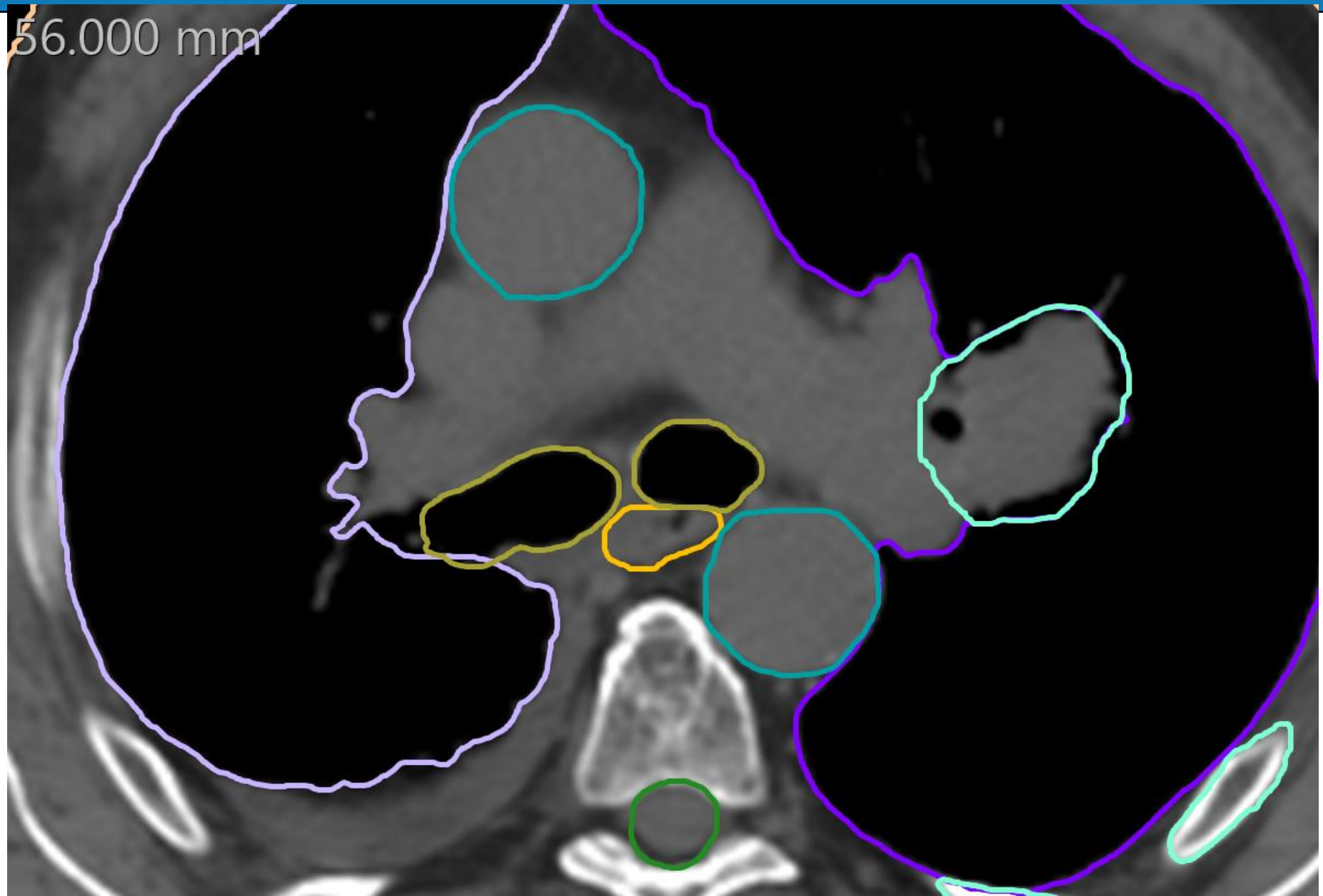
If different software applications render structure volumes differently…

…then they will definitely calculate different DVH curves and stats, too.

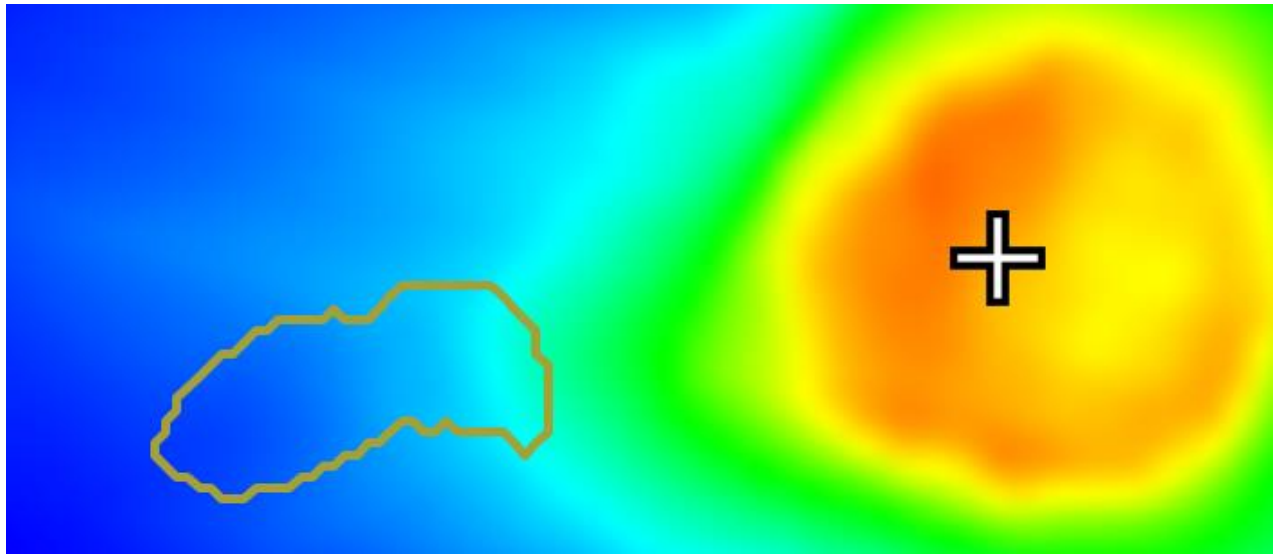
Beware of Low-Res Contours Like This



Because Normal Contours Look More Like This

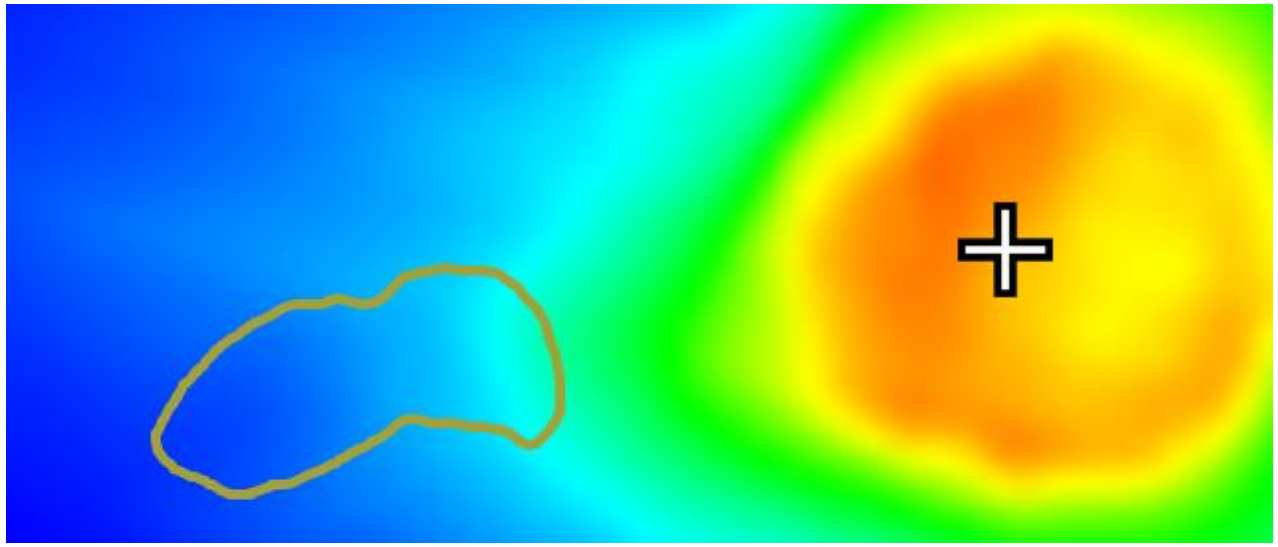


Avoid Blocky / Low-Res Axial Contours



“Blocky” Contours

- 36.2 cc structure volume
- 18.0 Gy mean dose
- 64.0 Gy max dose



Smooth Contours

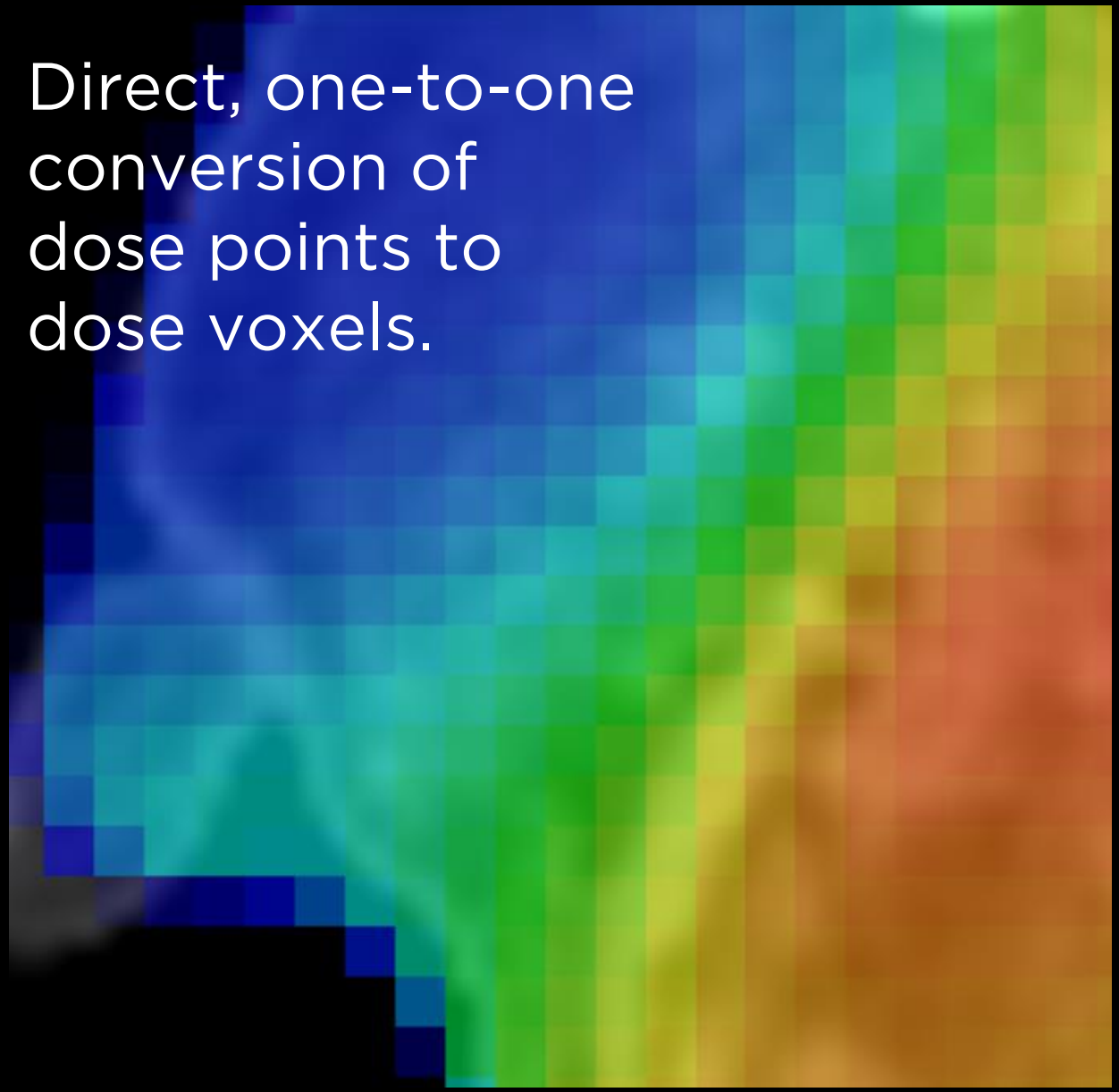
- 39.9 cc structure volume
- 17.8 Gy mean dose
- 64.3 Gy max dose

What About Dose Grids → Dose Voxels?

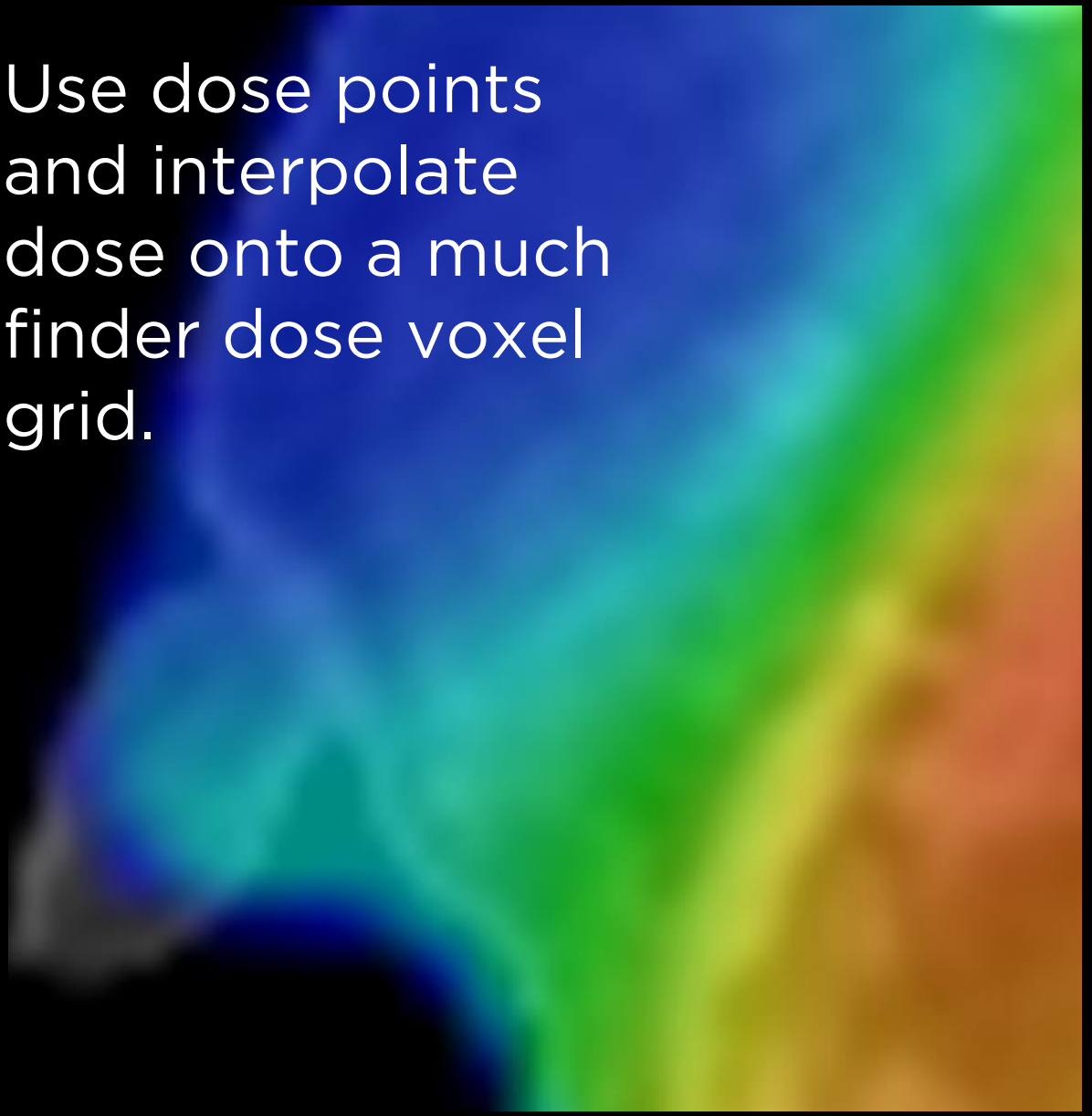
- Dose grids are (almost always) considered a grid of point doses.
- A point has no volume.
- Dose volume elements, or voxels, must be built from those points.
- The most basic approach is to consider each dose point in the grid to be a center of a voxel, and give that whole voxel a uniform dose equal to the point dose.
- This works ~okay for larger and simple structures.
- This does not work very well for small structures or for structures with complex surfaces.

What About Dose Grids → Dose Voxels?

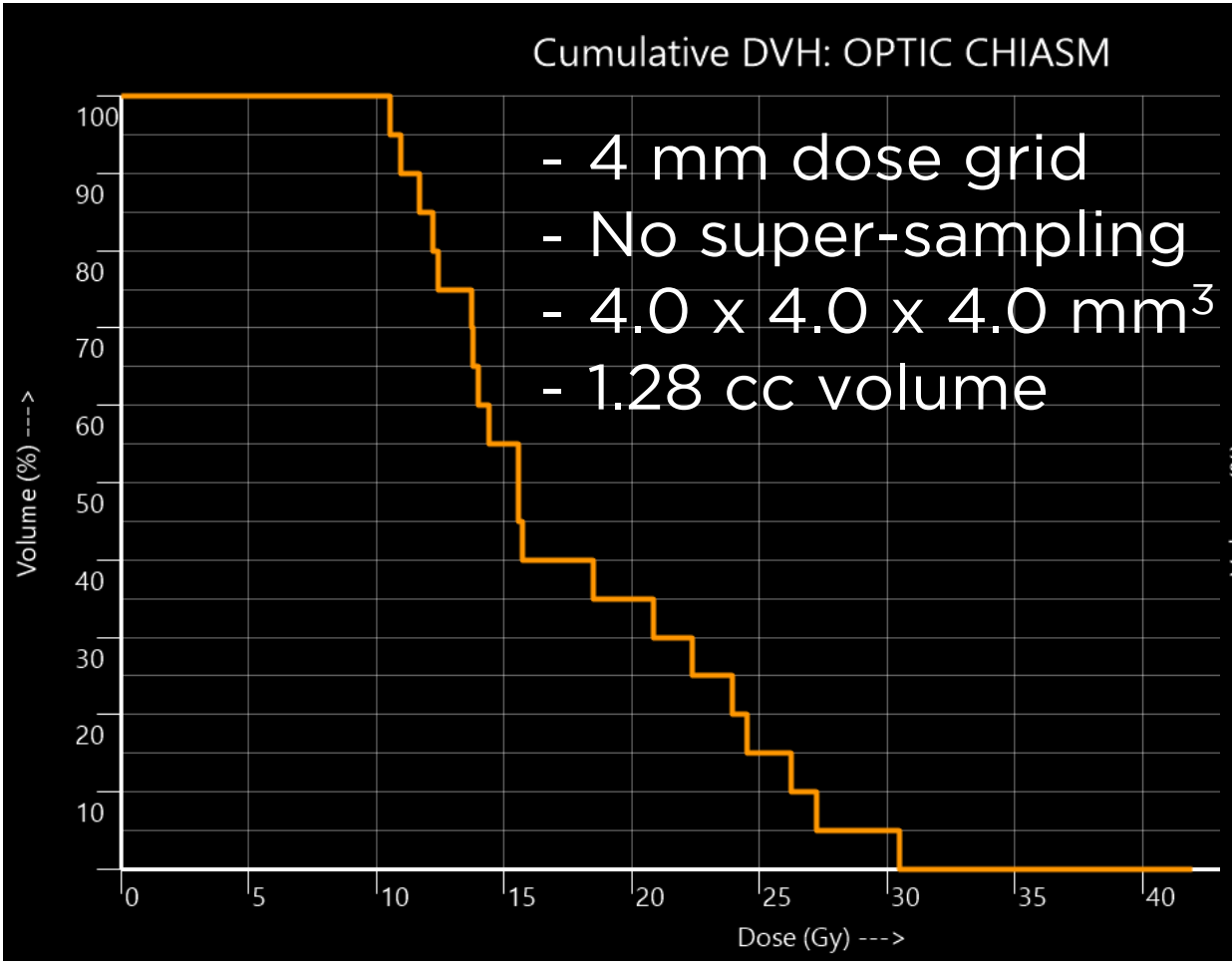
Direct, one-to-one conversion of dose points to dose voxels.

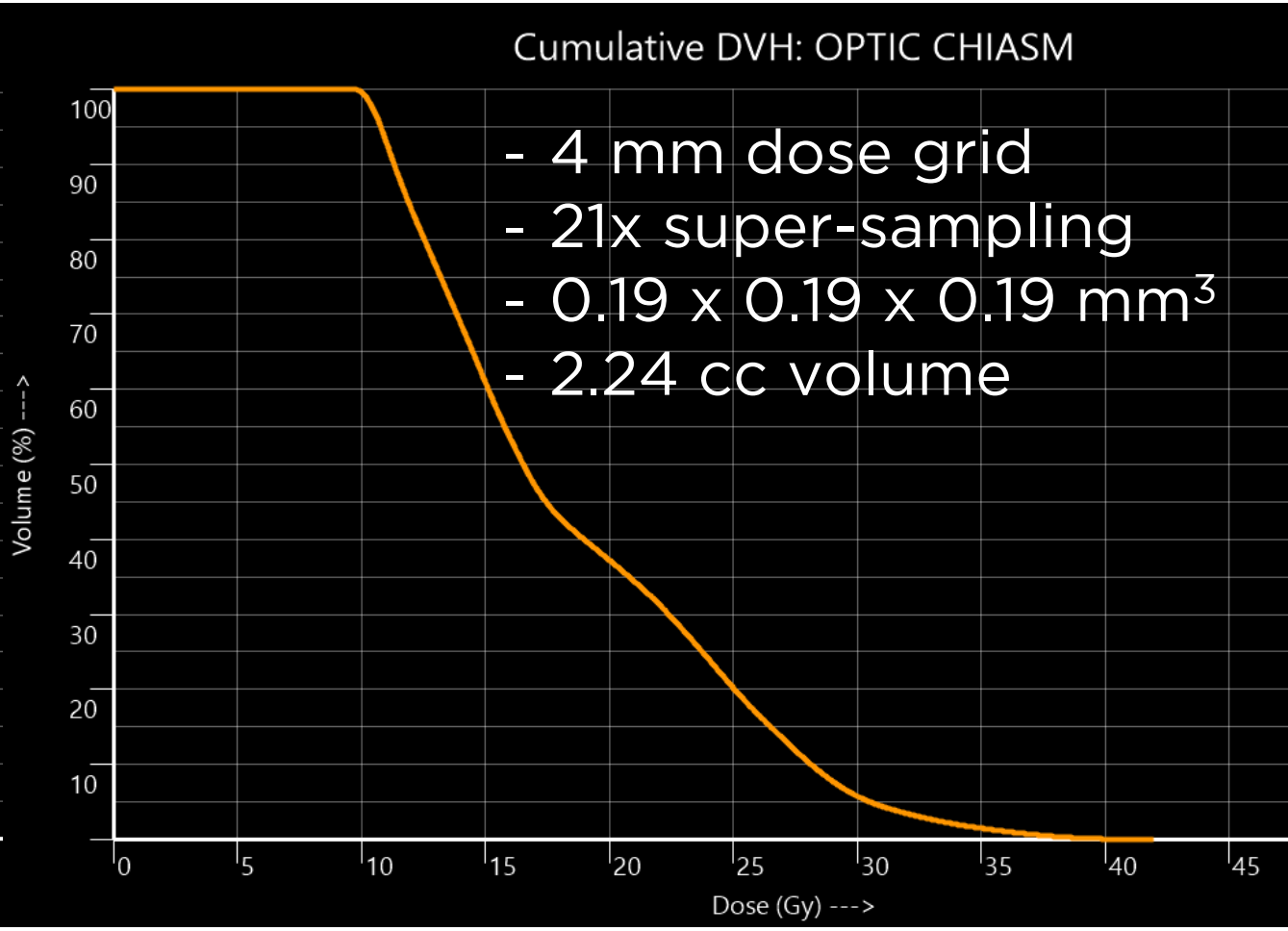


Use dose points and interpolate dose onto a much finder dose voxel grid.

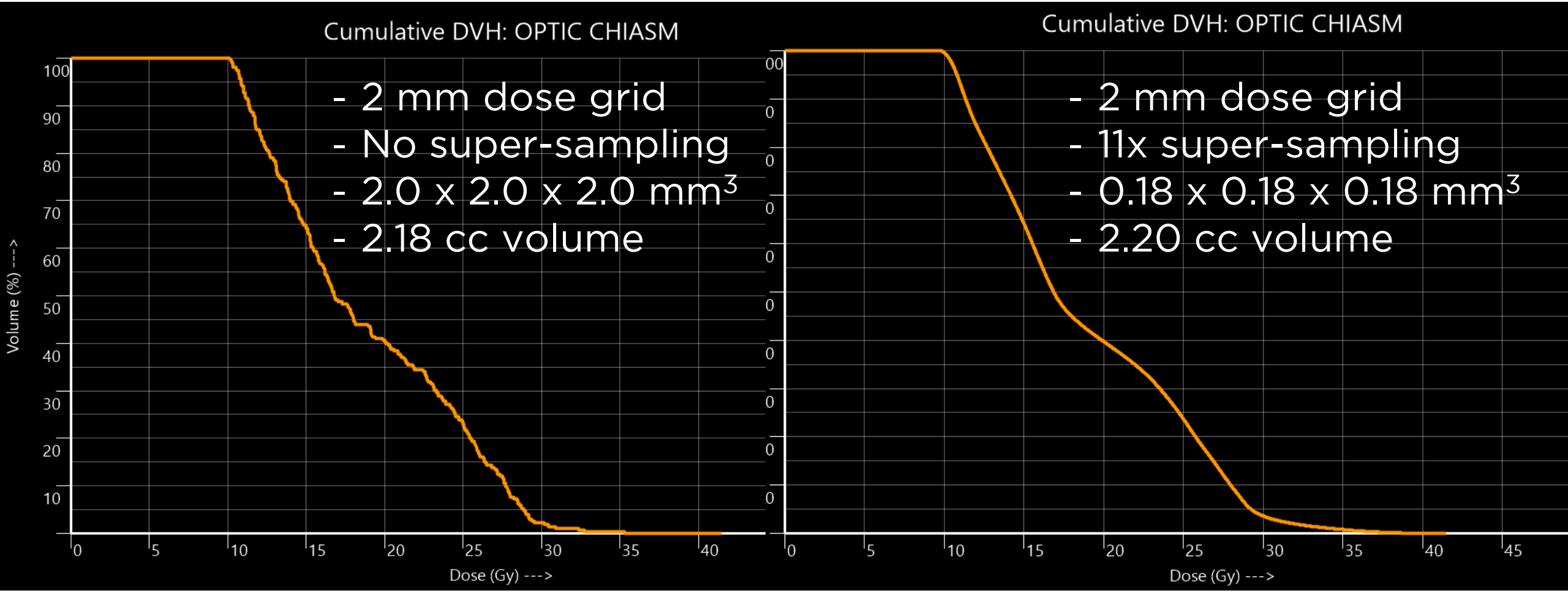


What About Dose Grids → Dose Voxels?





What About Dose Grids → Dose Voxels?



How to Validate a DVH Calculator

Don’t Assume Your Software’s DVH Calc is Perfect

(It Probably Isn’t)

DVH Validation Strategy

- How to validate DVH curves and statistics:
  - ***DO NOT*** validate your DVH calculations by comparing one software system (e.g. a new one) to another software system (e.g. an existing one).
  - ***DO*** validate your DVH calculations by comparing your software's results to trustworthy standards.
    - Fixed contours for known, geometric shapes
    - Pre-fabricated dose grids with dose patterns that are derived from known, continuous equations
    - Various CT slice spacings and dose grid resolutions
    - Compare to "ground truth" DVHs calculated analytically and not limited by data resolution

DVH Validation Strategy

Med. Phys. 42 (8), August 2015

Methods, software and datasets to verify DVH calculations against analytical values: Twenty years late(r)

Benjamin Nelms
Canis Lupus LLC, Merrimac, Wisconsin 53561

Cassandra Stambaugh
Department of Physics, University of South Florida, Tampa, Florida 33612

Dylan Hunt, Brian Tonner, Geoffrey Zhang, and Vladimir Feygelman[a)]
Department of Radiation Oncology, Moffitt Cancer Center, Tampa, Florida 33612

DVH Validation Strategy

- Nelms *et al.* **Med. Phys.** 42(8) August 2015
- This paper provides a complete kit:
  - **Contour Data**, provided as DICOM RT Structure Sets
  - **Dose Data**, provided as DICOM RT Dose
  - **Answer Key**, provided, analytically-derived DVH data
  - **Comparison Software**, to compare your DVH vs. truth
- It's free and available to everyone.
  - Physicists & dosimetrists can use it for software validation.
  - Vendors should use it for product validation.

Known Geometric Shapes

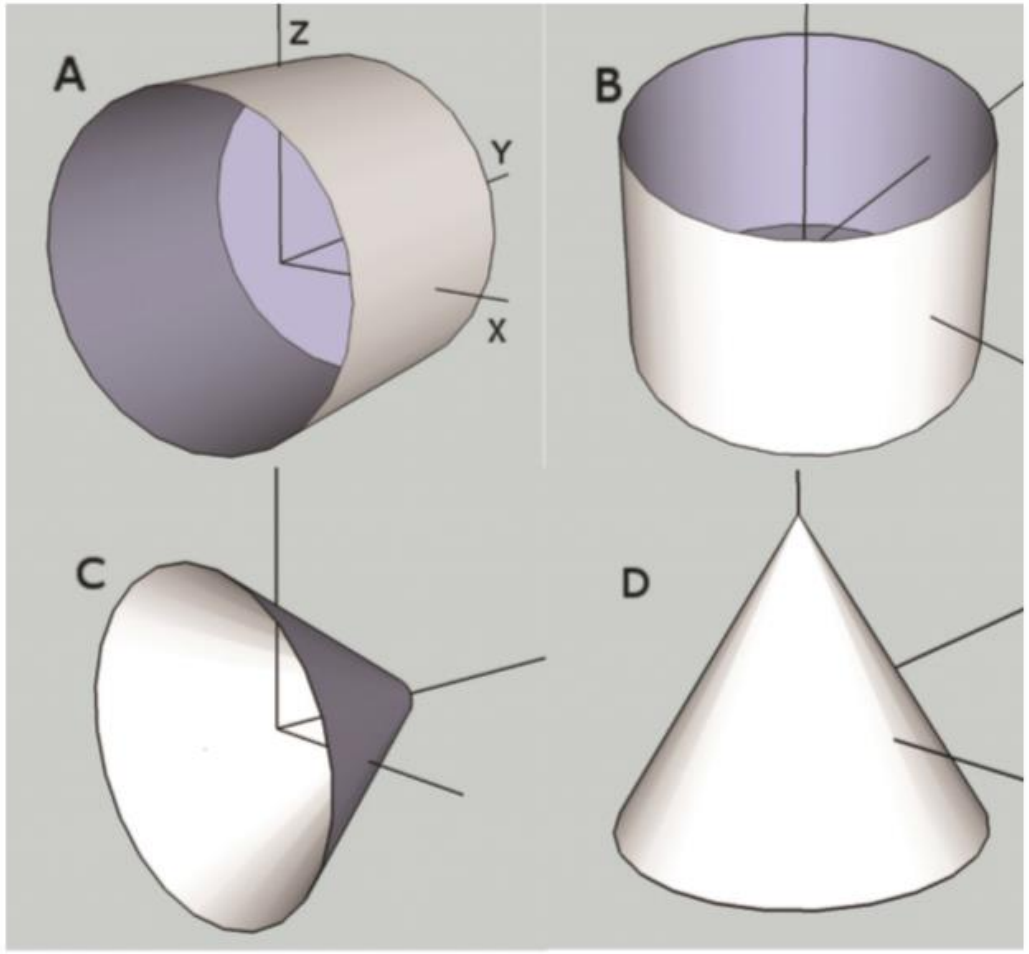
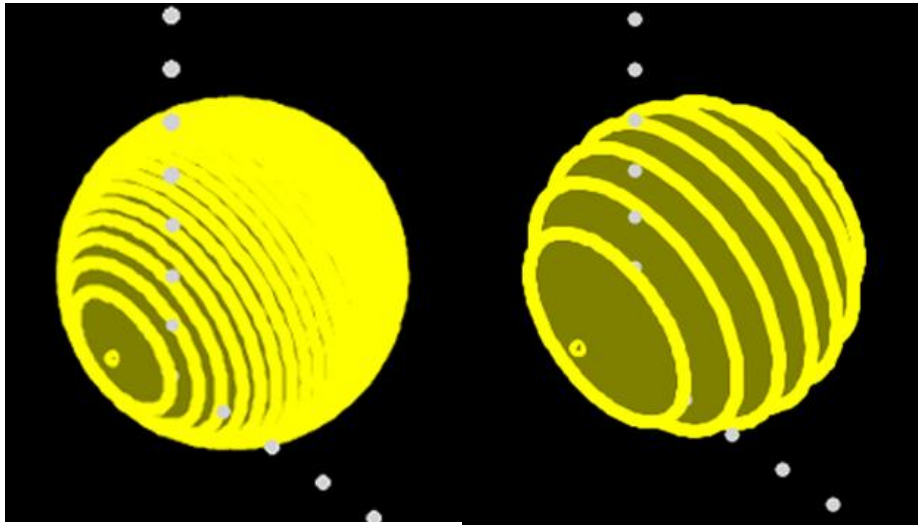
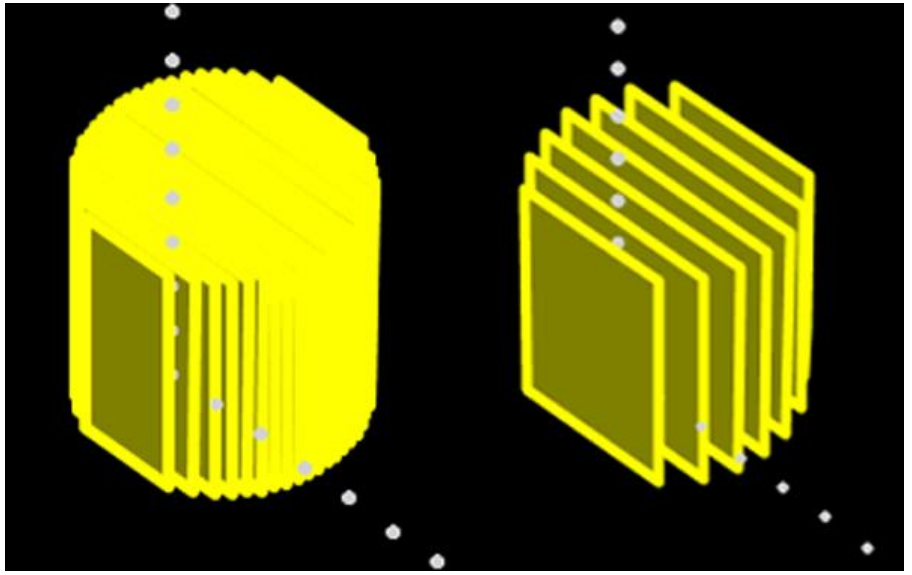


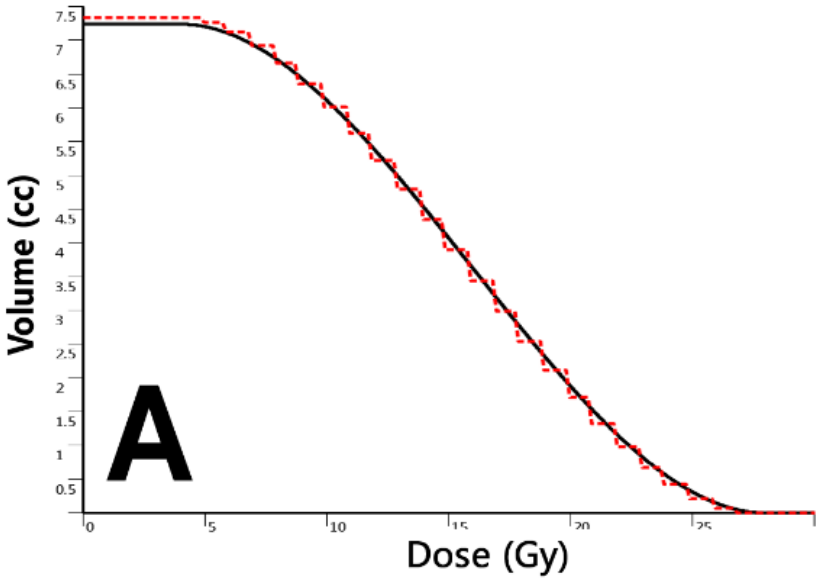
Fig. 2. Schematics of the structures in the IEC 1217 coordinate system. Axial (a) and rotated (b) cylinders. Axial (c) and Rotated (d) Cones.

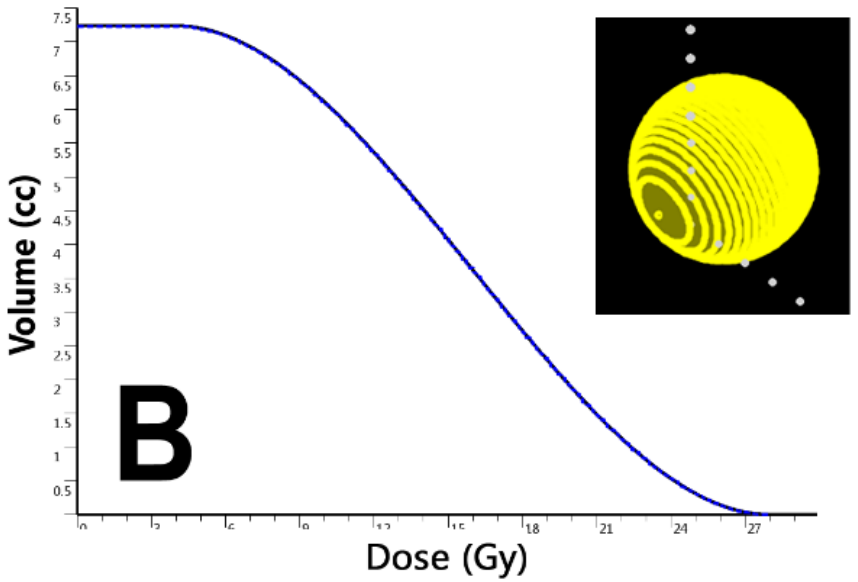


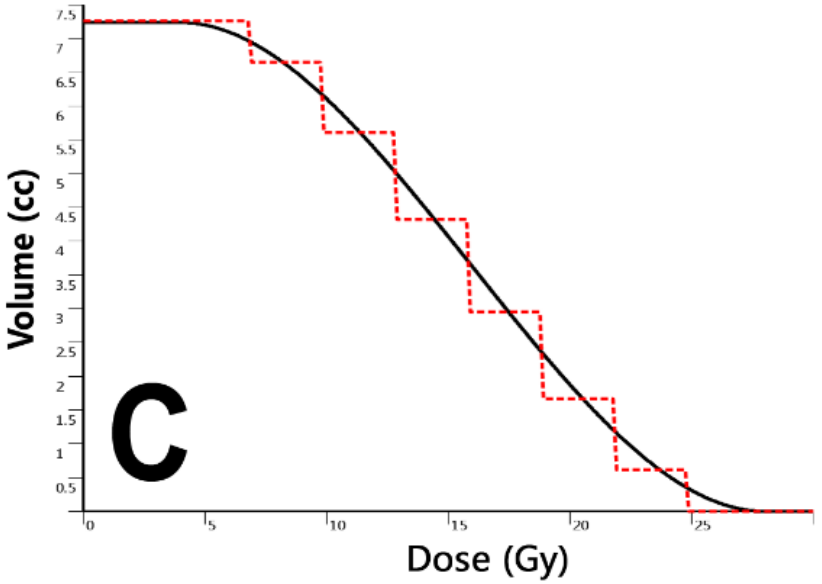


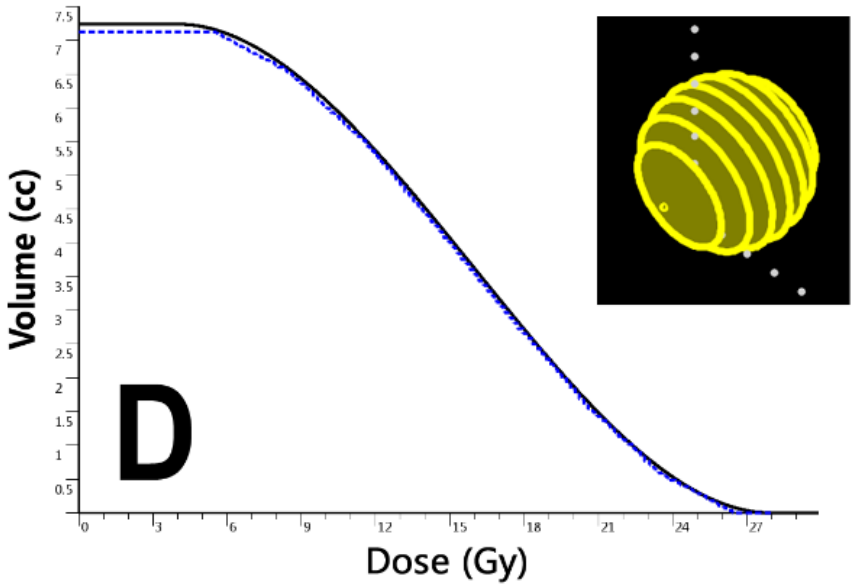
- Test the effect of CT slice spacing…
- for different shapes…
- and across dose grids of varying resolution.

Compare to "Ground Truth" DVH Curves







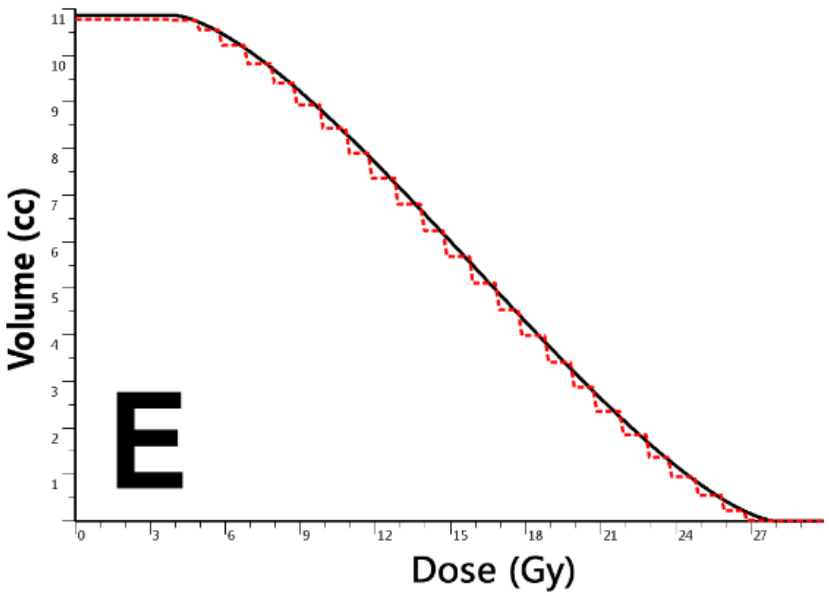


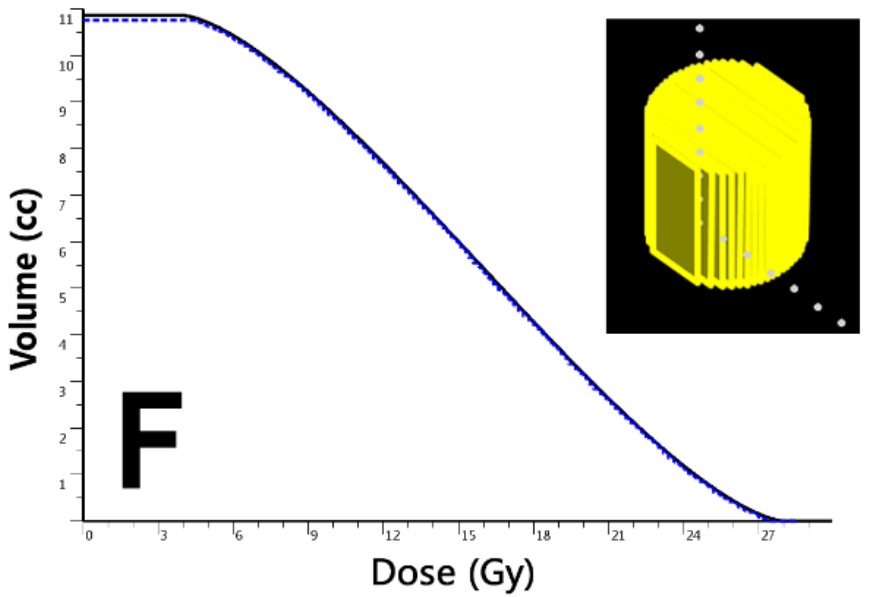
True DVH

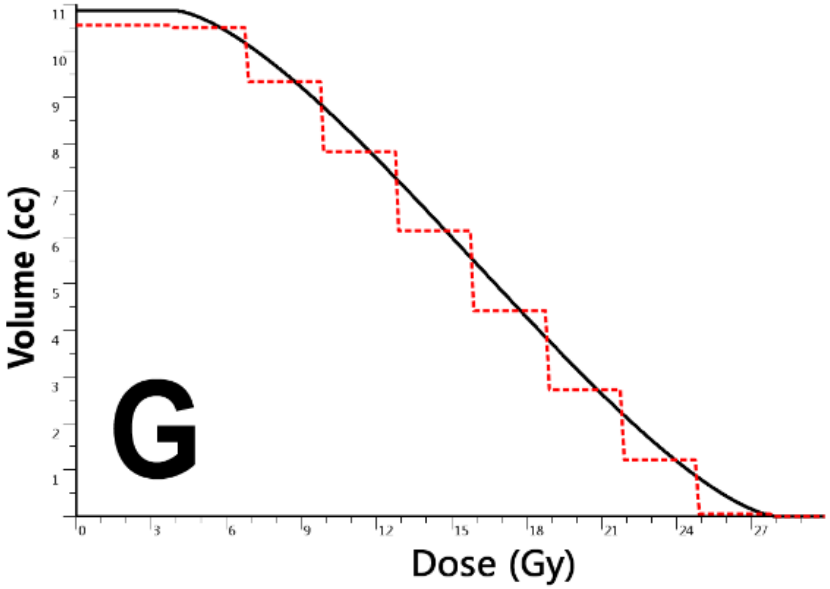
TPS

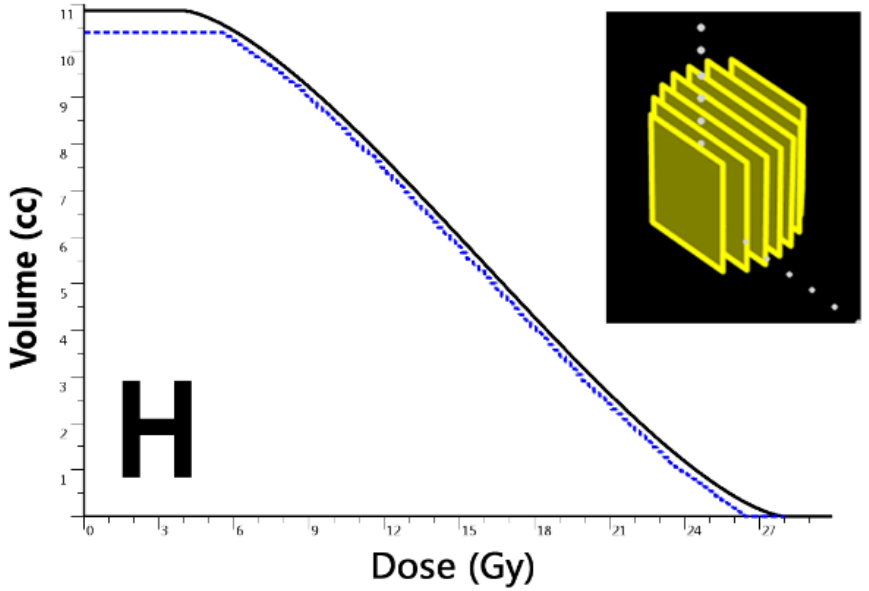
PlanIQ

Compare to "Ground Truth" DVH Curves









True DVH

TPS

PlanIQ

Why Are We Talking About This?

Lots of reasons. Here are three.

DVH Accuracy: Reason #1 to Care

- **Because it is the right thing to do**
  - For the industry as a whole, *variability in DVH methods* and results between different software systems (all else equal) *is a bad thing*.
  - DVH calculation imperfections are almost all avoidable. The user has some control to optimize accuracy, but that is not enough: the vendors must do the rest.
  - Just because DVHs became a common commercial tool 25 years ago doesn't mean they do not need to be scrutinized. *It is never to late to do the right thing*.

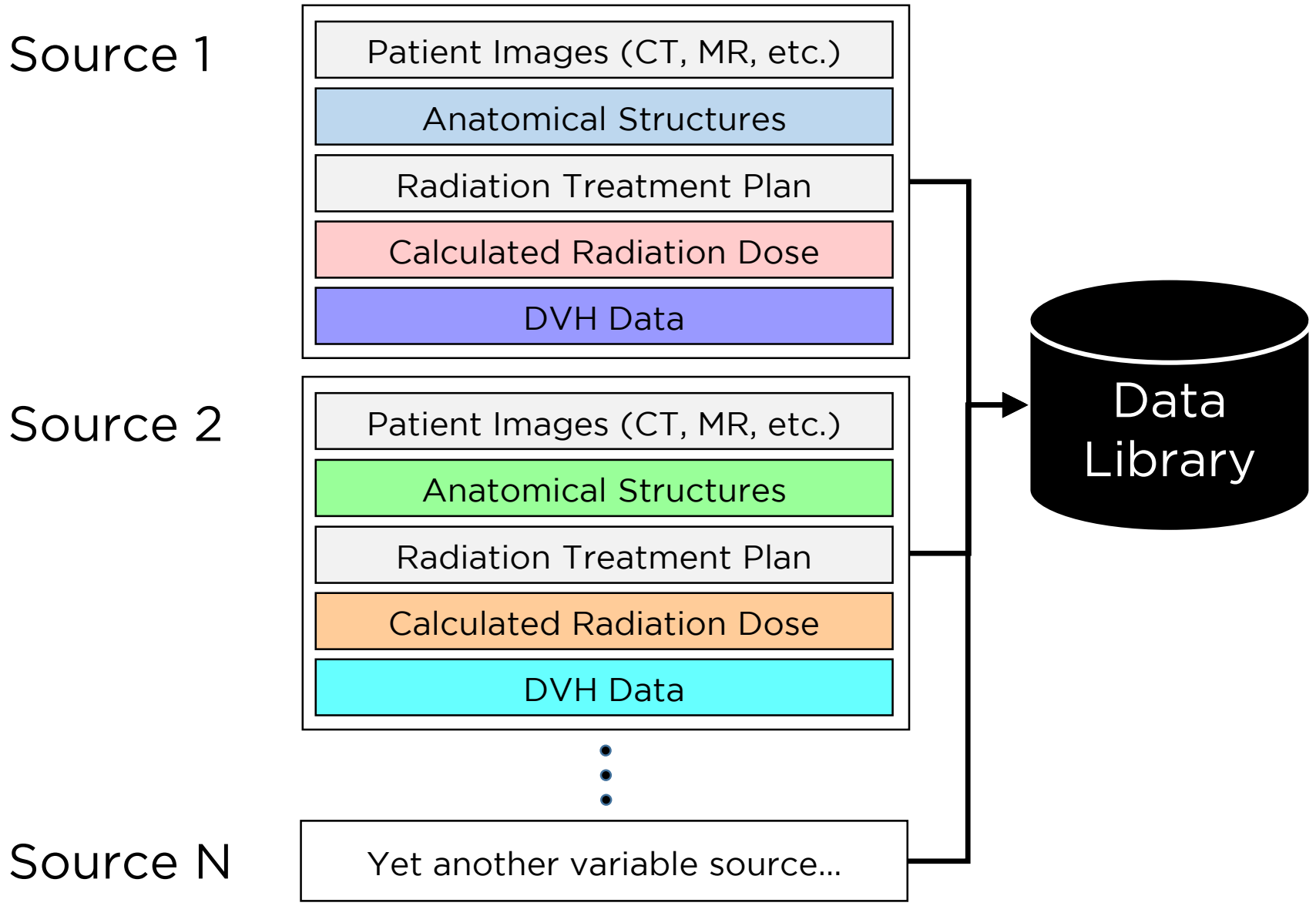
DVH Accuracy: Reason #2 to Care

- Because it is your job
  - The team of physicists and dosimetrists are responsible for the safety and accuracy of the TPS and other software.
  - Now that there is a test suite for DVHs (finally), this must be added to *TPS and software commissioning processes*.
  - Taking ownership of the testing will:
    - **Professional Development.** Improve your understanding of the underlying mechanisms.
    - **Risk Management.** Teach you limitations of your current system.
    - **Altruism.** Allow you to take up a good cause and work with your software vendor(s) to help them improve their system.

DVH Accuracy: Reason #3 to Care

- Prepare for big data and outcomes analyses
  - This is certain: expect to see more aggregation of patient data for outcomes analysis and big data analytics. DVH data will be a critical component.
  - Collecting data from different sources with variable DVH methods and lumping all of these together as if they are equivalent, is a bad practice.
  - It is essential, and may in fact someday be required, to *process all input data with a common DVH calculator* (one that is proven superior). Get ready for that.

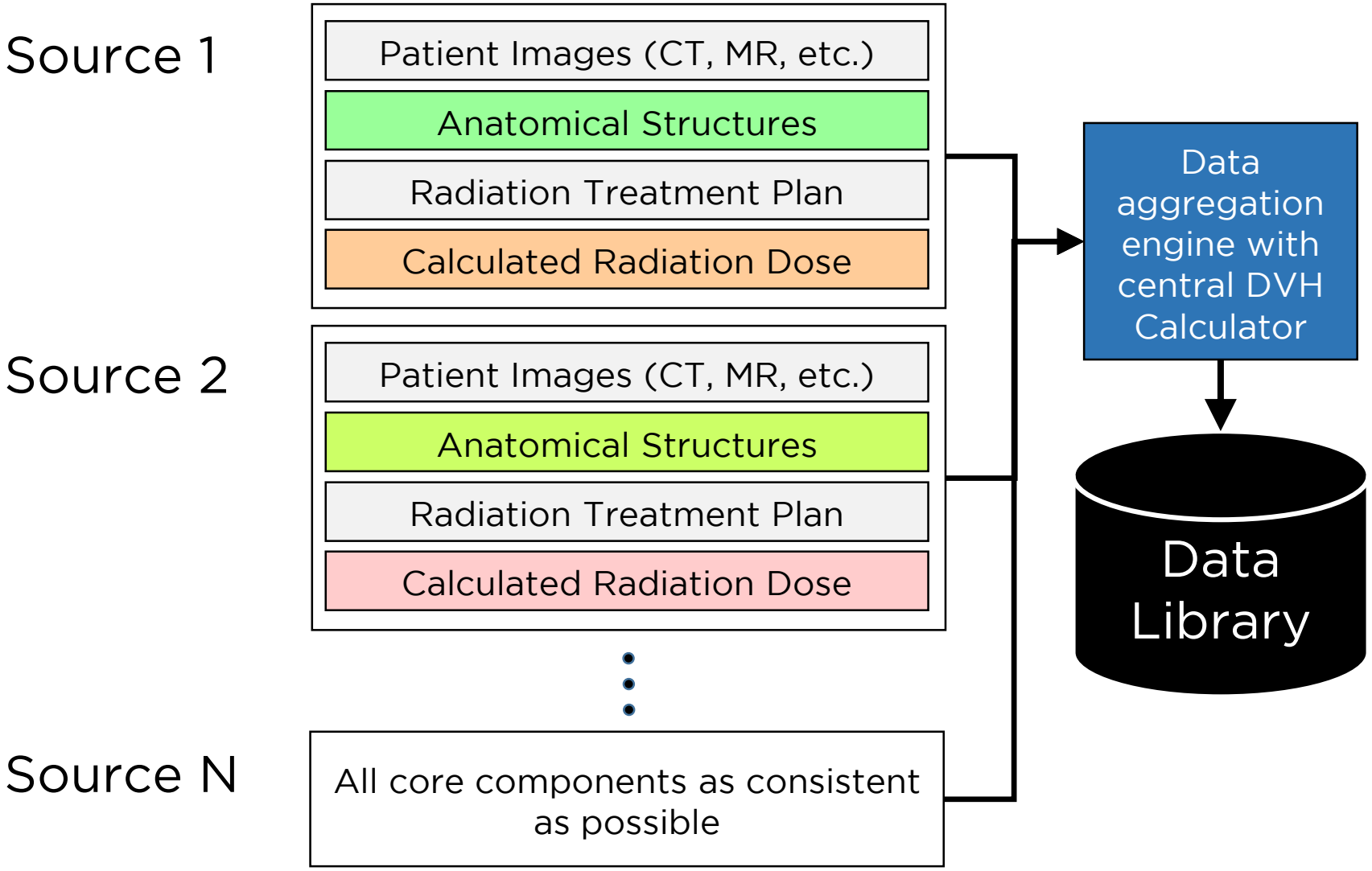
Data Aggregation



Bad Science:

- Anatomical contouring is not consistent and accurate
- Dose calculations are not consistent and accurate
- DVH calculations are not consistent and accurate

Data Aggregation



Better Science:

- Anatomical contouring is consistent and audited (with ability to edit, post-planning)
- Dose calculations are all consistent, or at least meeting the same, stringent requirements
- **DVH calculations are all performed with a common engine**