Estimating the actual dose delivered by intravascular coronary brachytherapy using geometrically correct 3-D modeling

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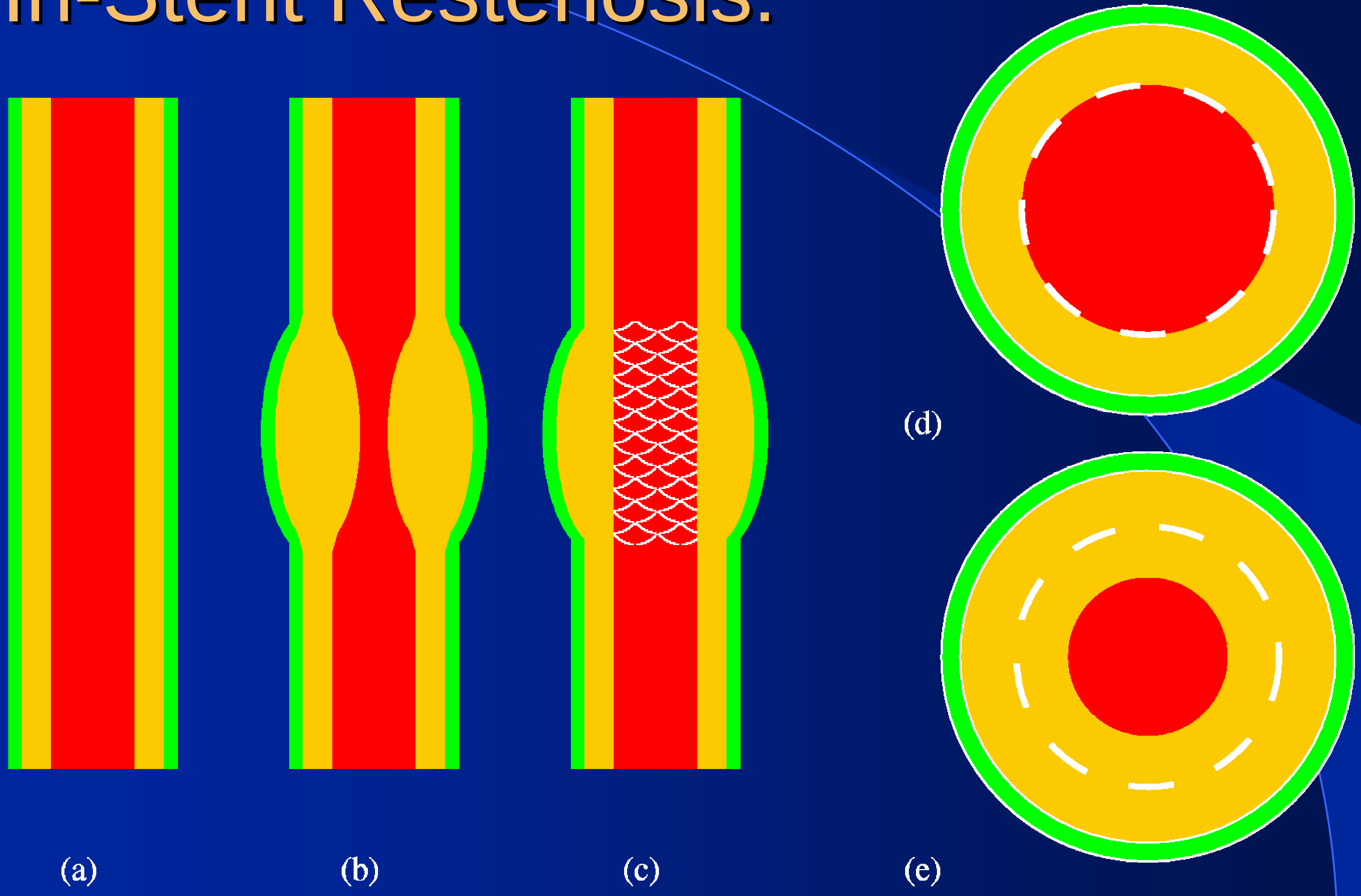
Motivation

- Coronary arteries tend to develop new plaque accumulation after balloon angioplasty and stenting ***(in-stent restenosis)***
- Irradiating the restenosed vessel segment decrease recurrent restenosis rate by 40-60%
- Common dose models for intravascular brachytherapy do not consider vessel curvature and eccentricity of catheter

In-Stent Restenosis:

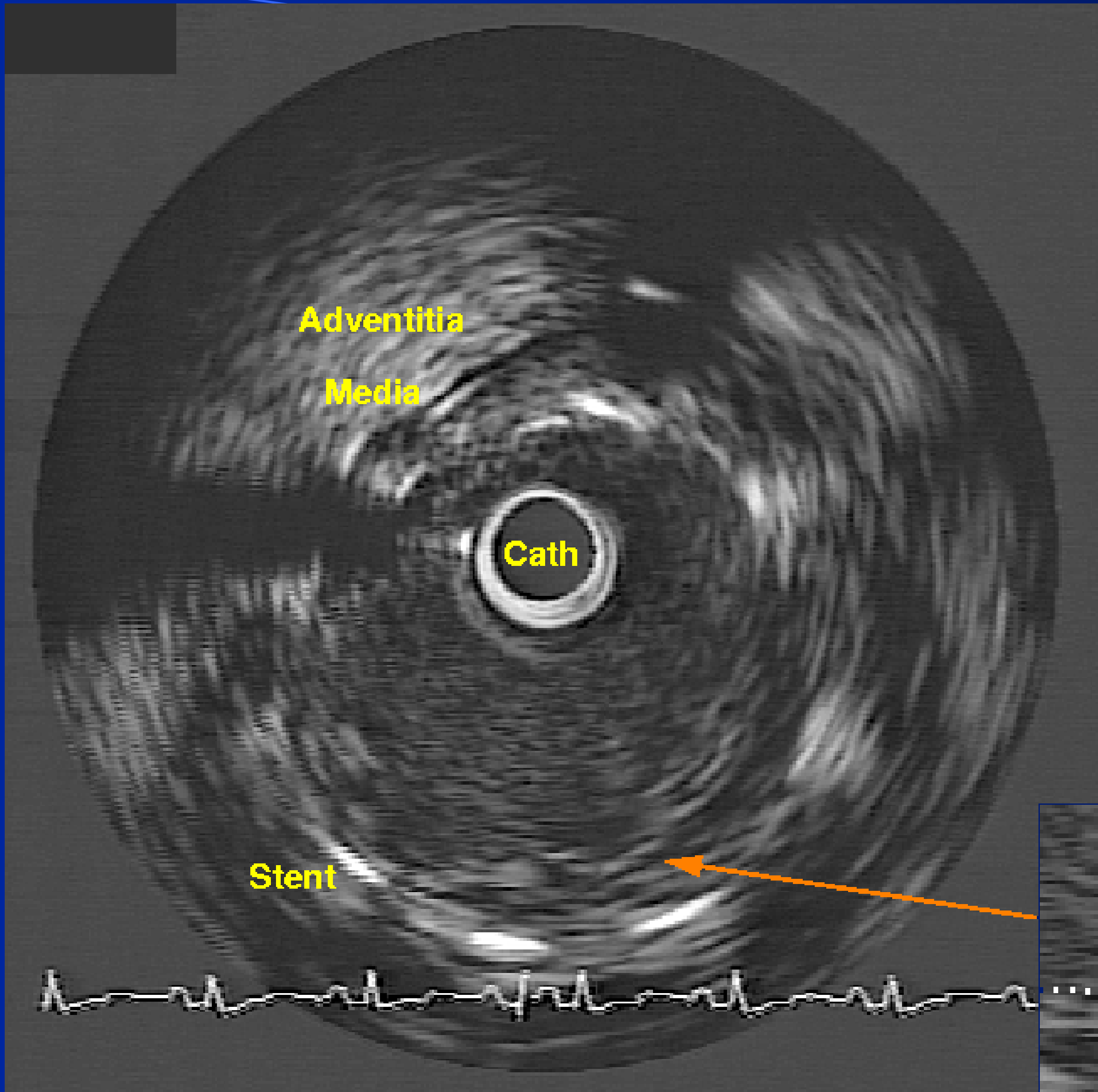


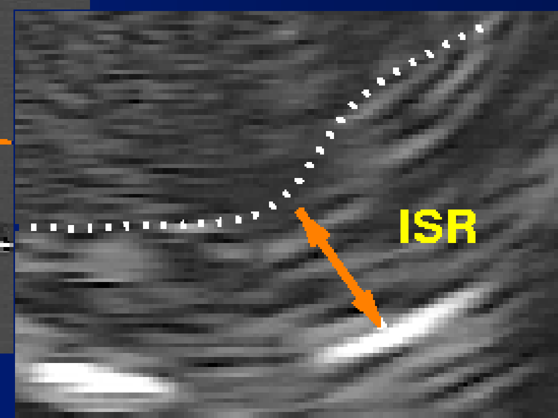
In-Stent Restenosis (angio)

RAO

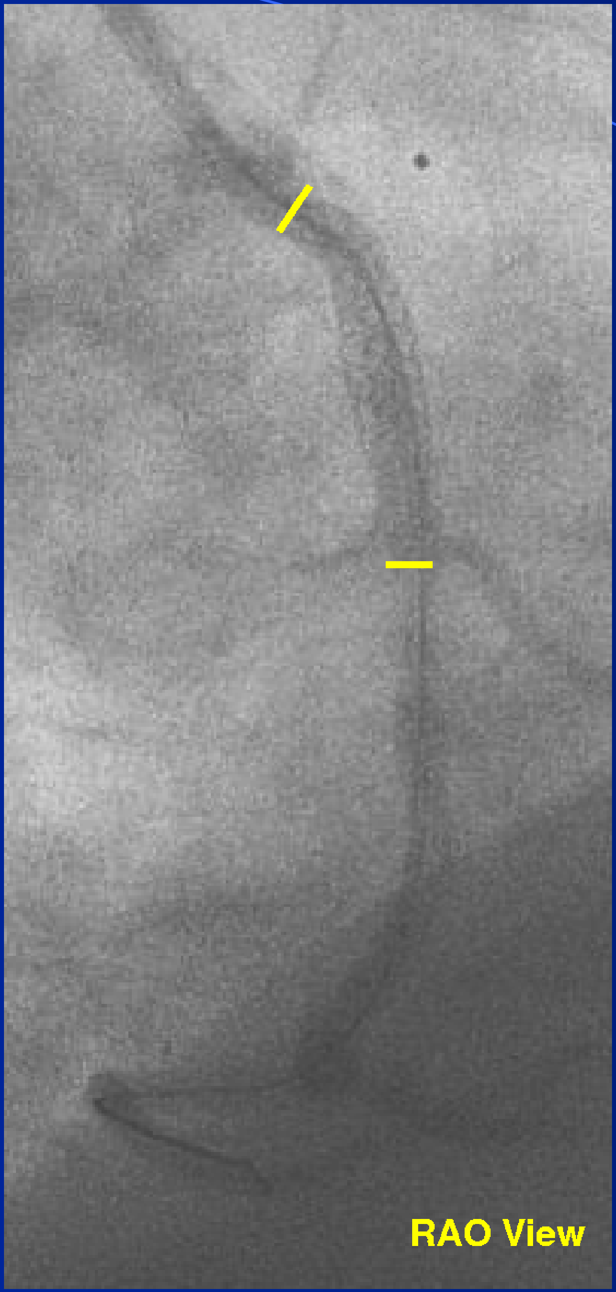
LAO

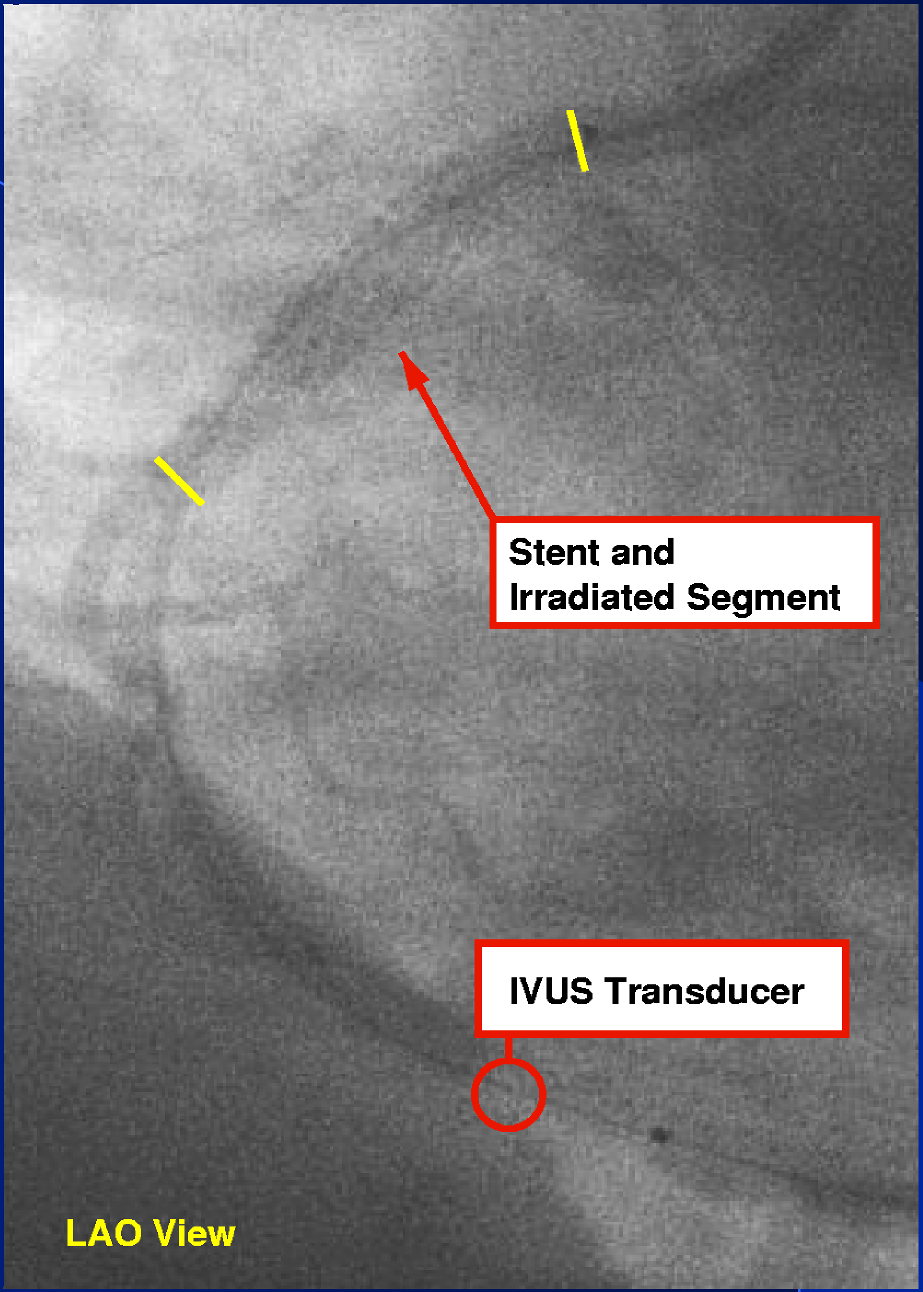
In-Stent Restenosis (IVUS)





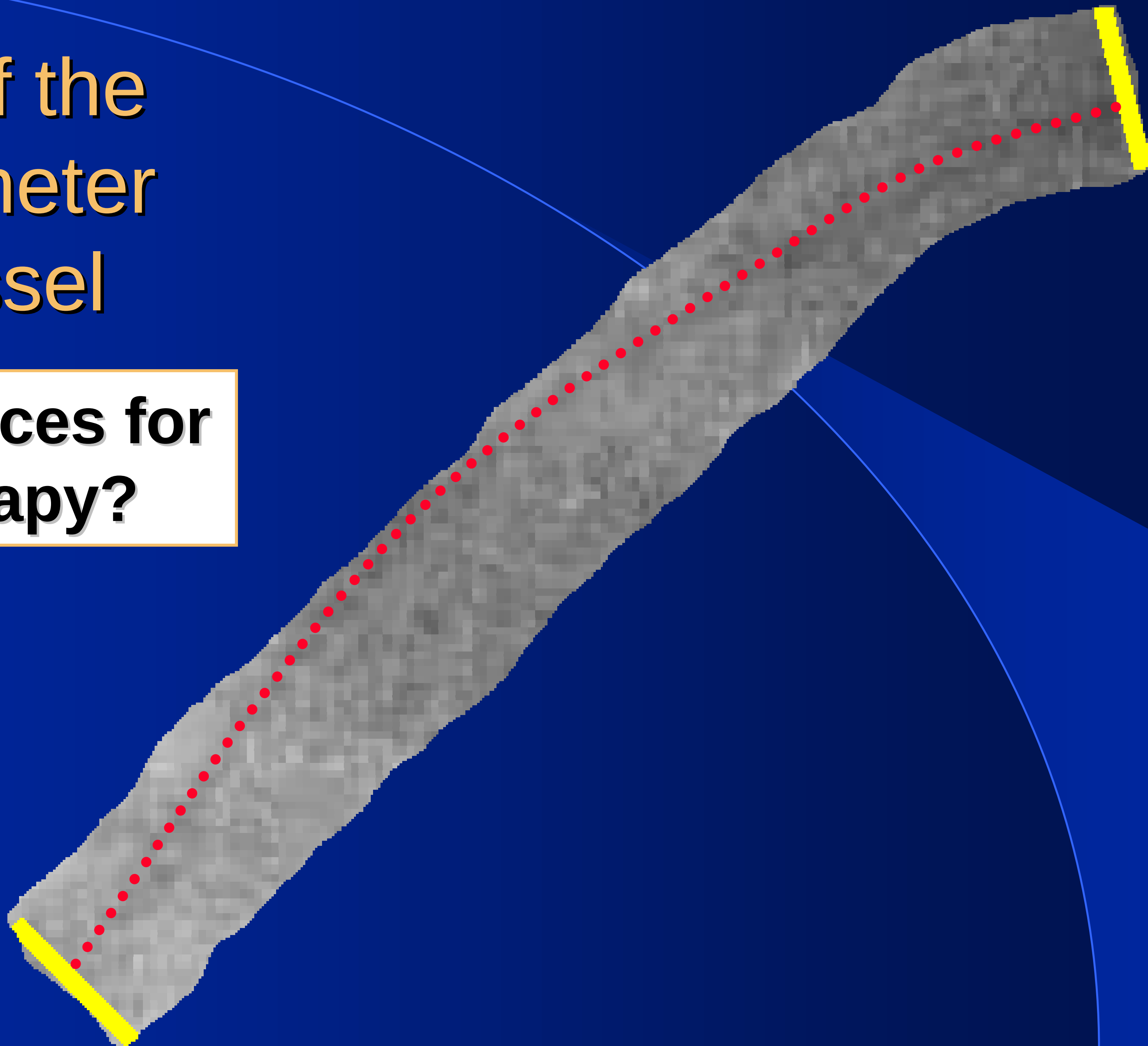
Angio-graphy and IVUS





Position of the IVUS Catheter within Vessel

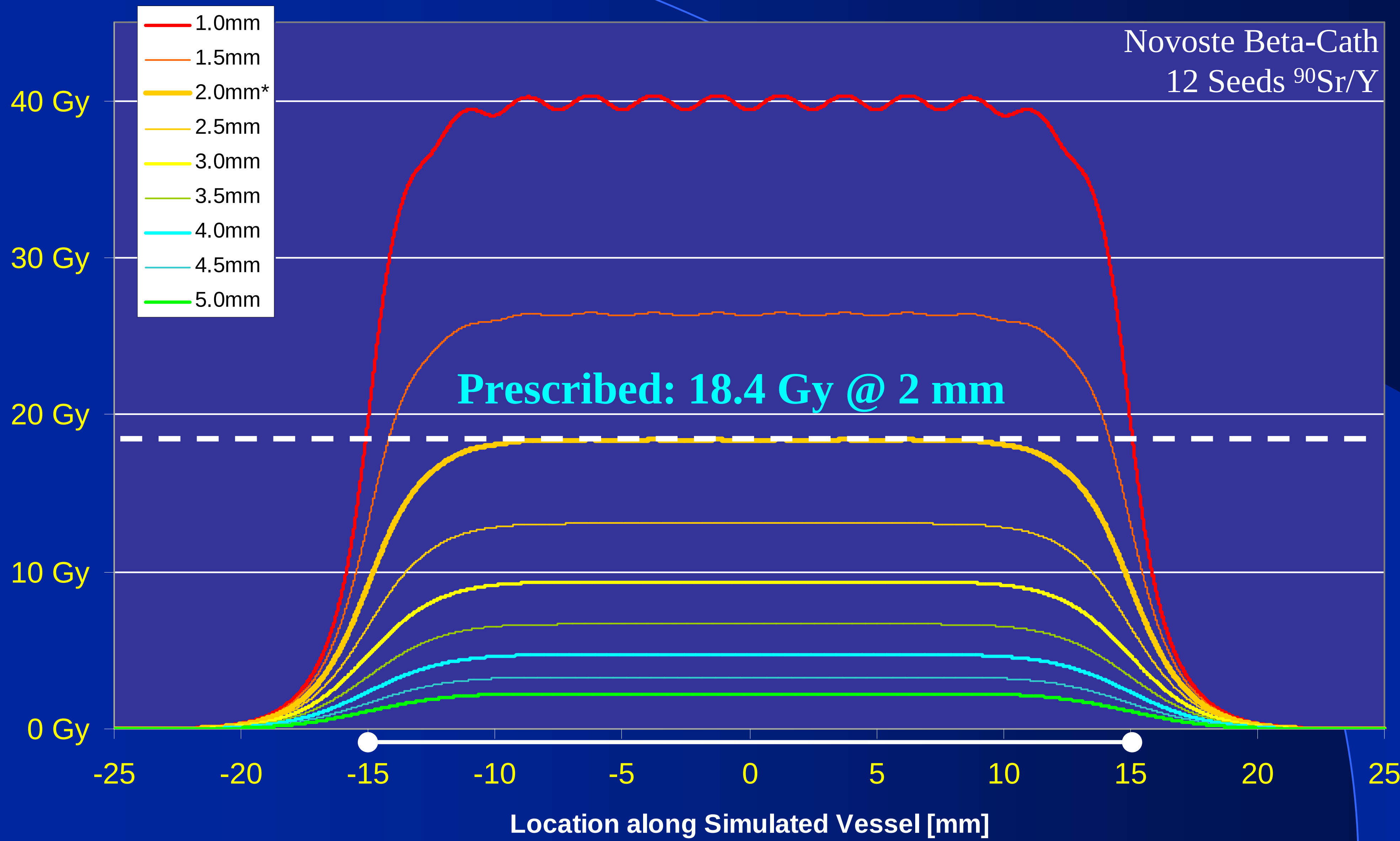
Consequences for Brachytherapy?



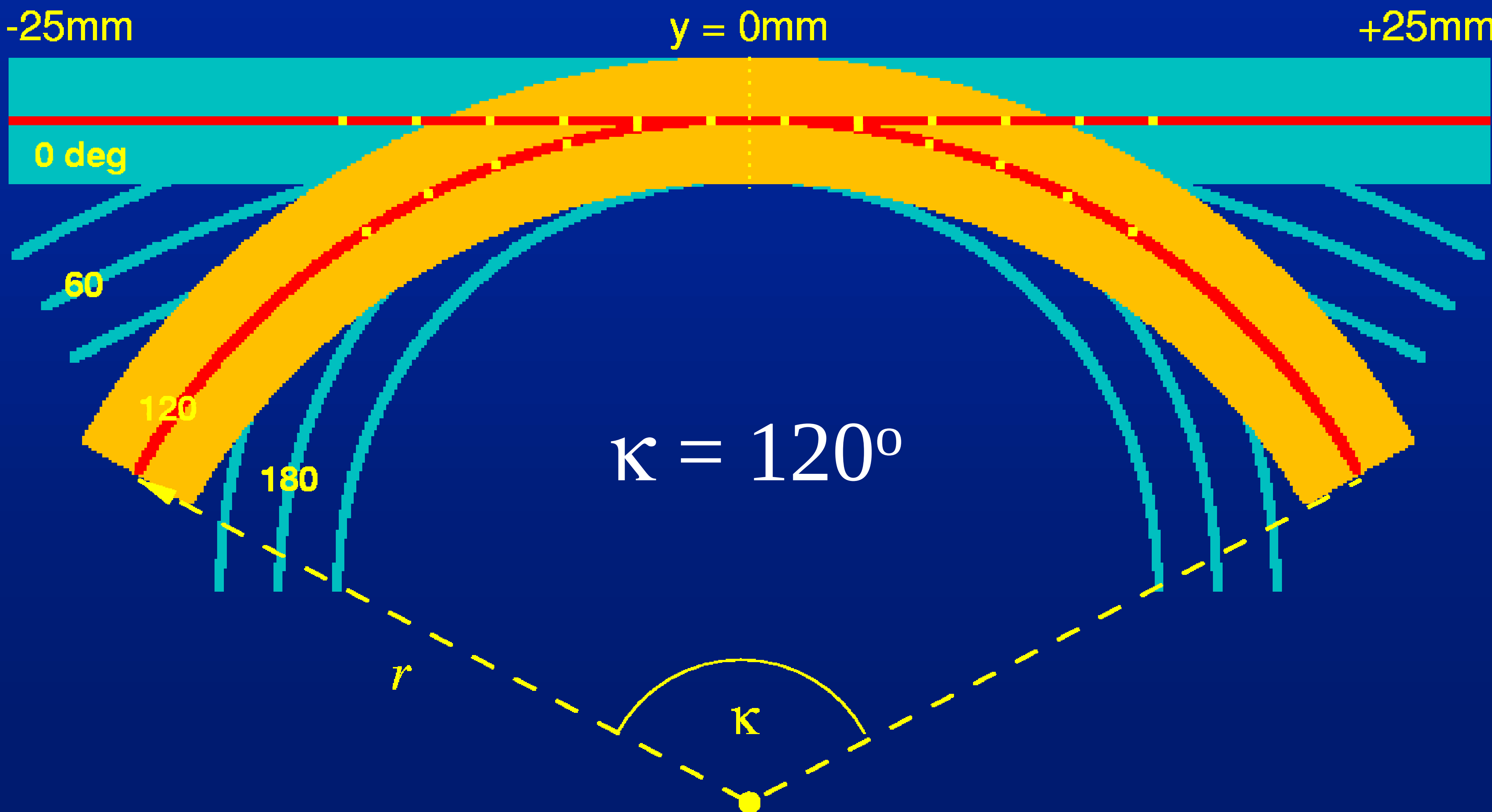
Questions:

- What is the impact of the vessel ***curvature*** on dose distribution?
- What is the impact of catheter ***eccentricity*** on dose distribution

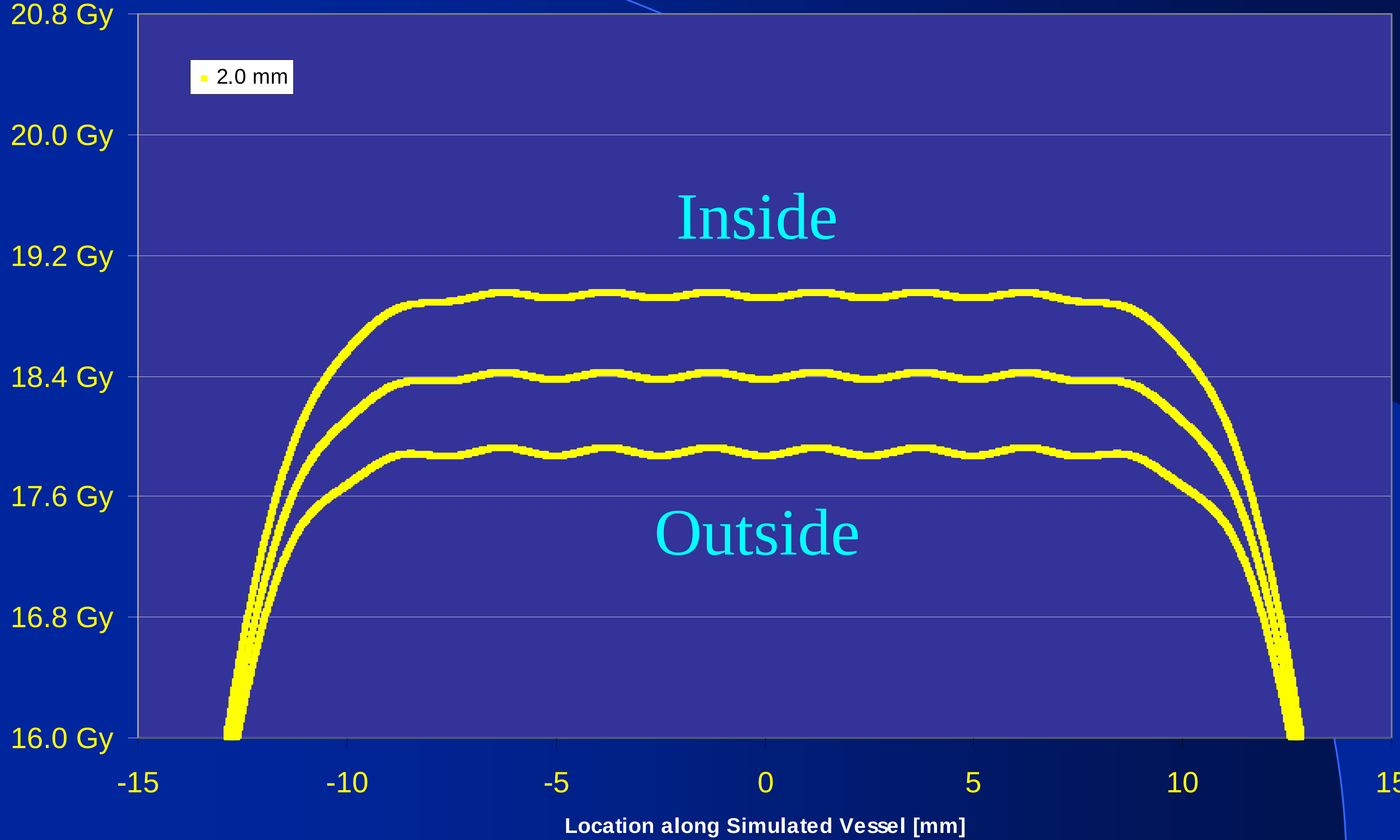
Dose Distribution in 0.5-mm Layers



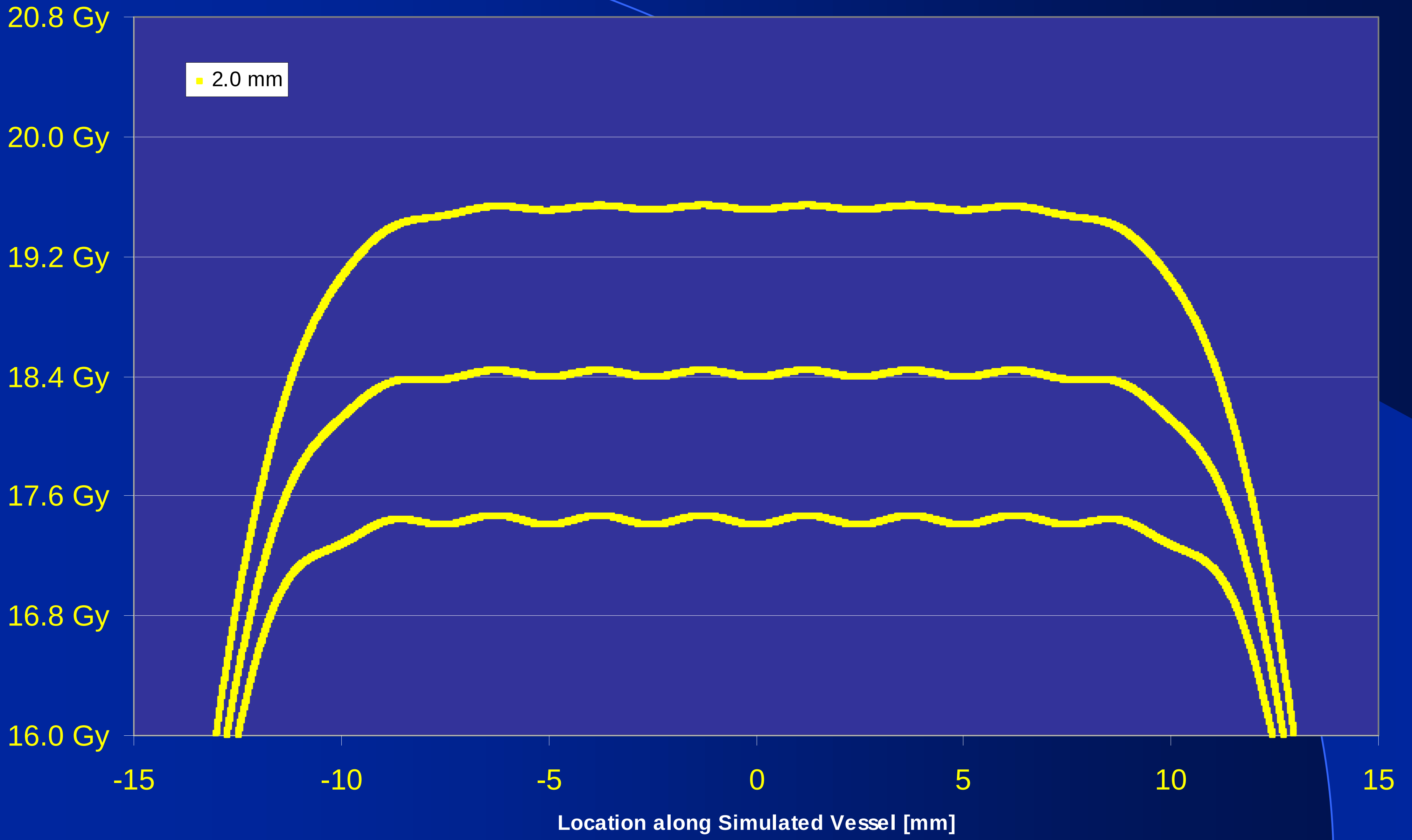
Simulation: 60-180° Torus



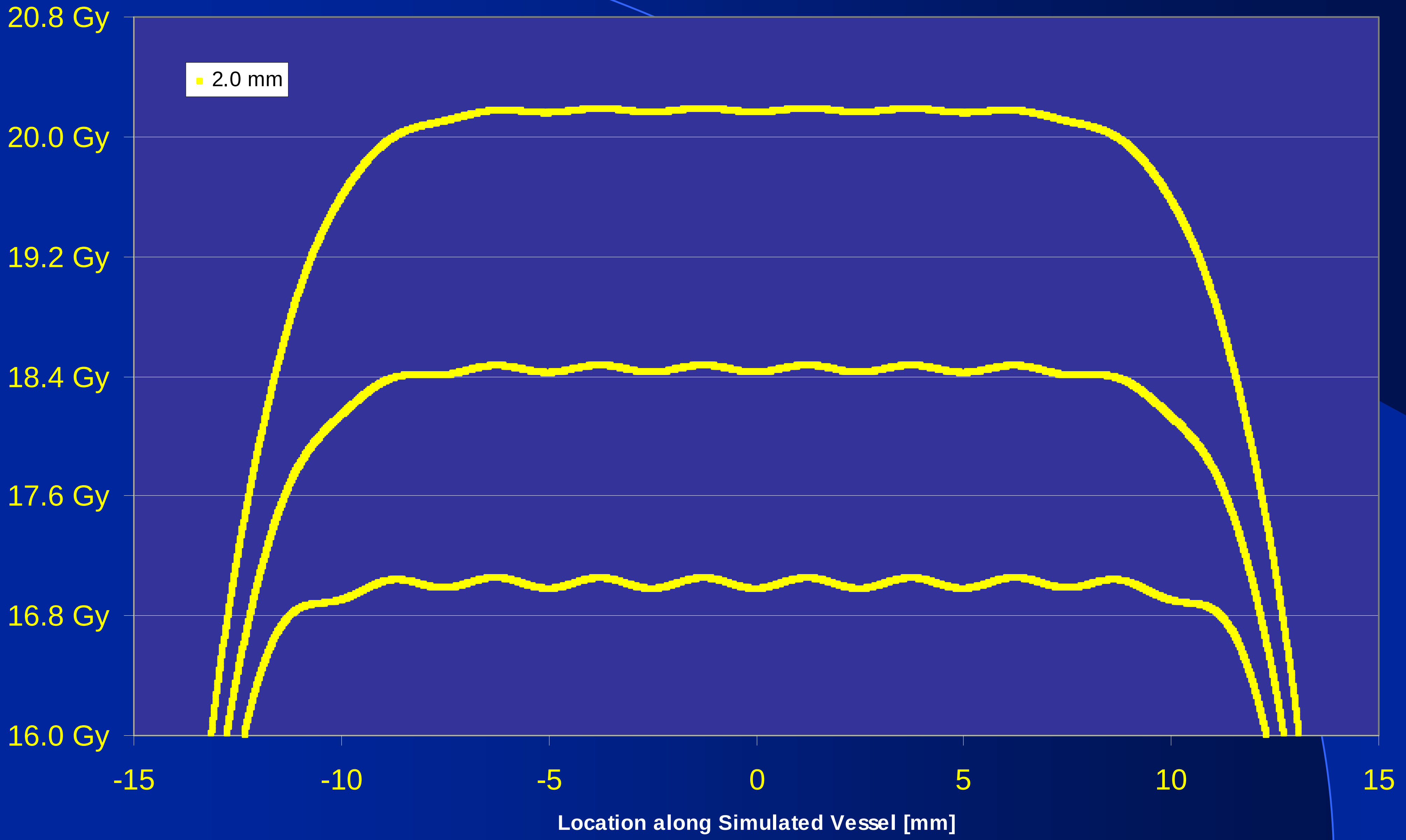
Dose Distribution 60º Torus



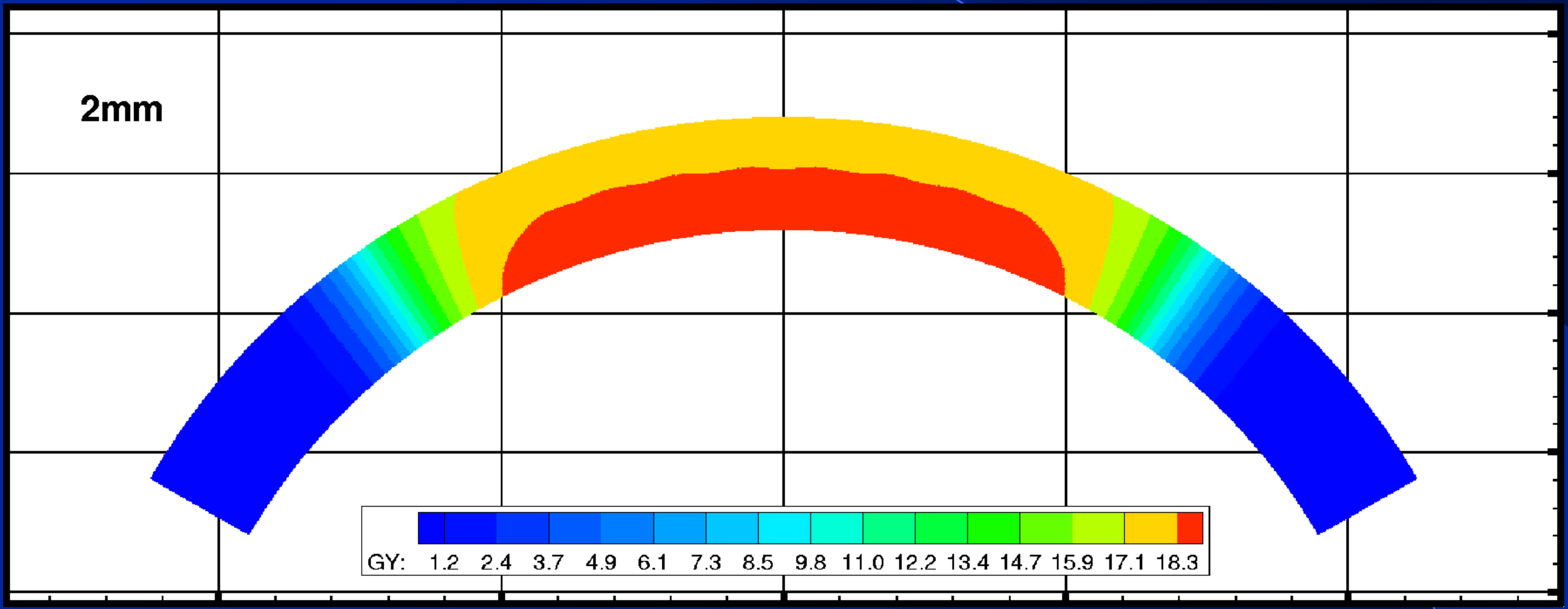
Dose Distribution 120º Torus



Dose Distribution 180º Torus

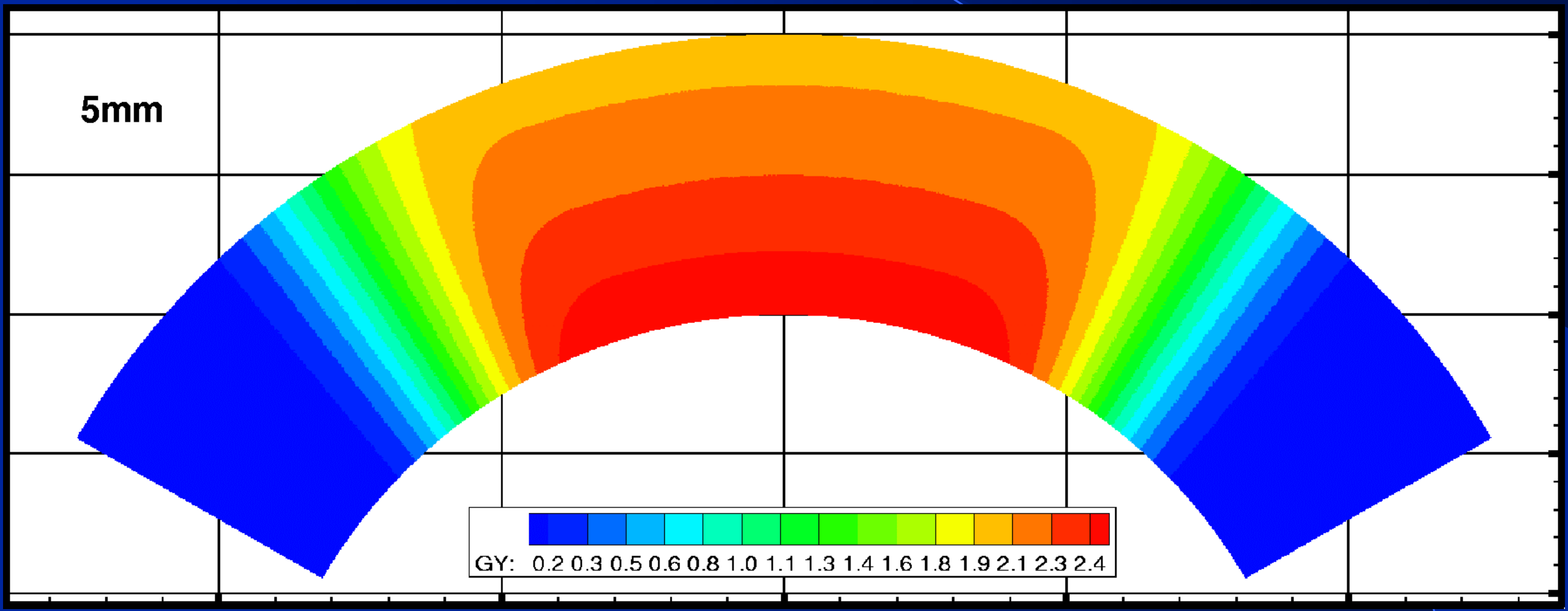


Results 120° Torus

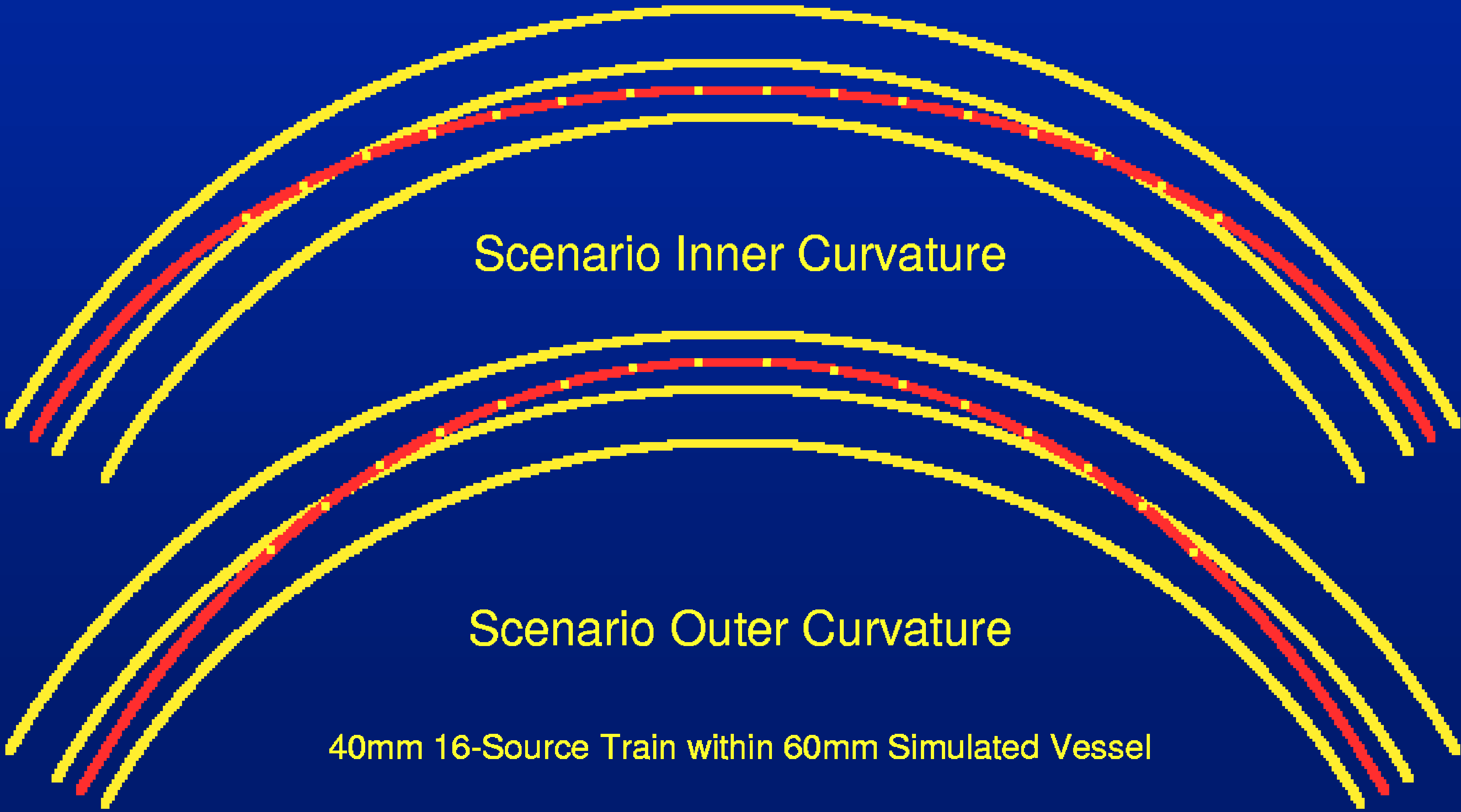


Prescribed dose: 18.4 Gy

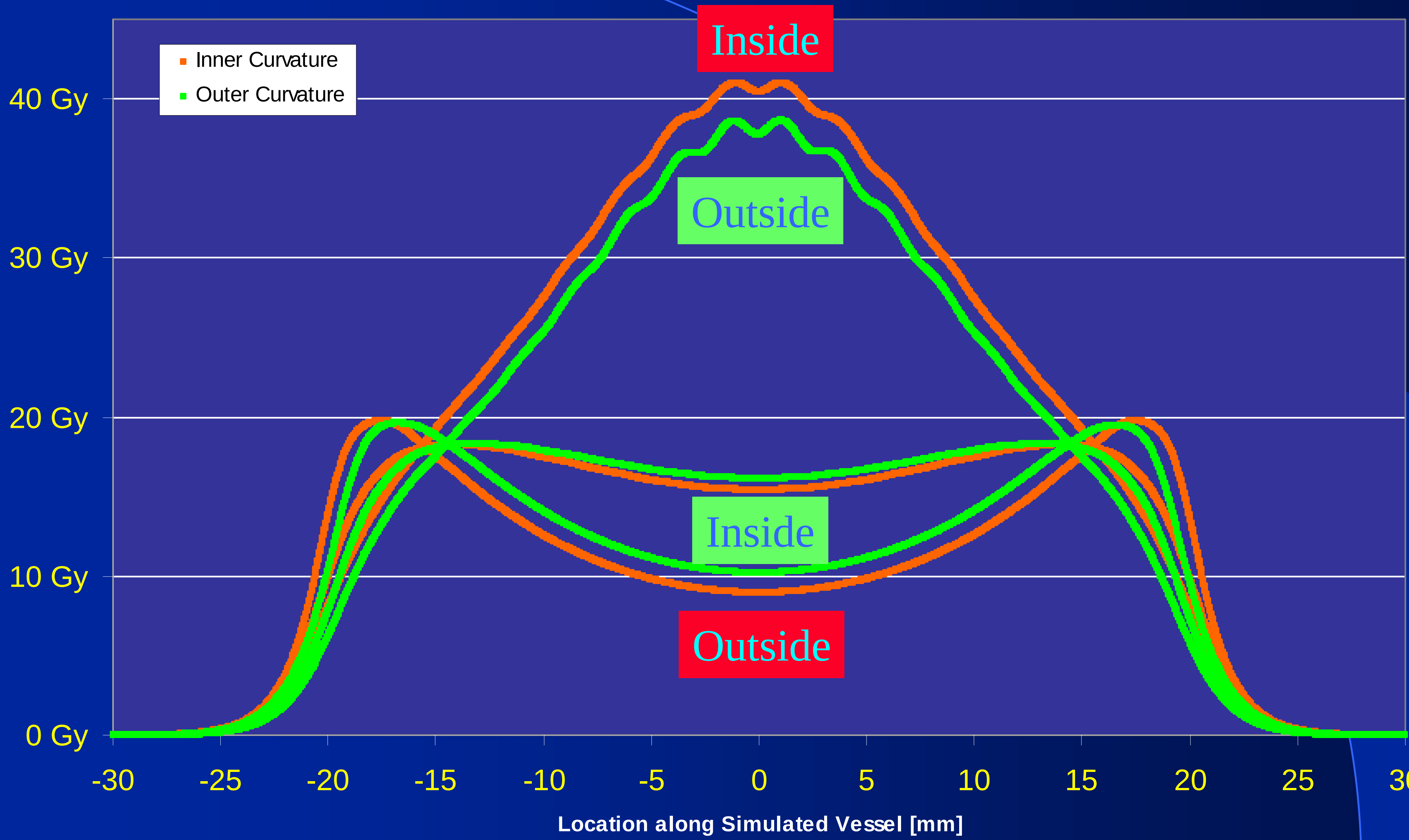
Results 120^{o} Torus



Eccentricity of the Catheter



120-degree Curved Vessel with Eccentric Catheter



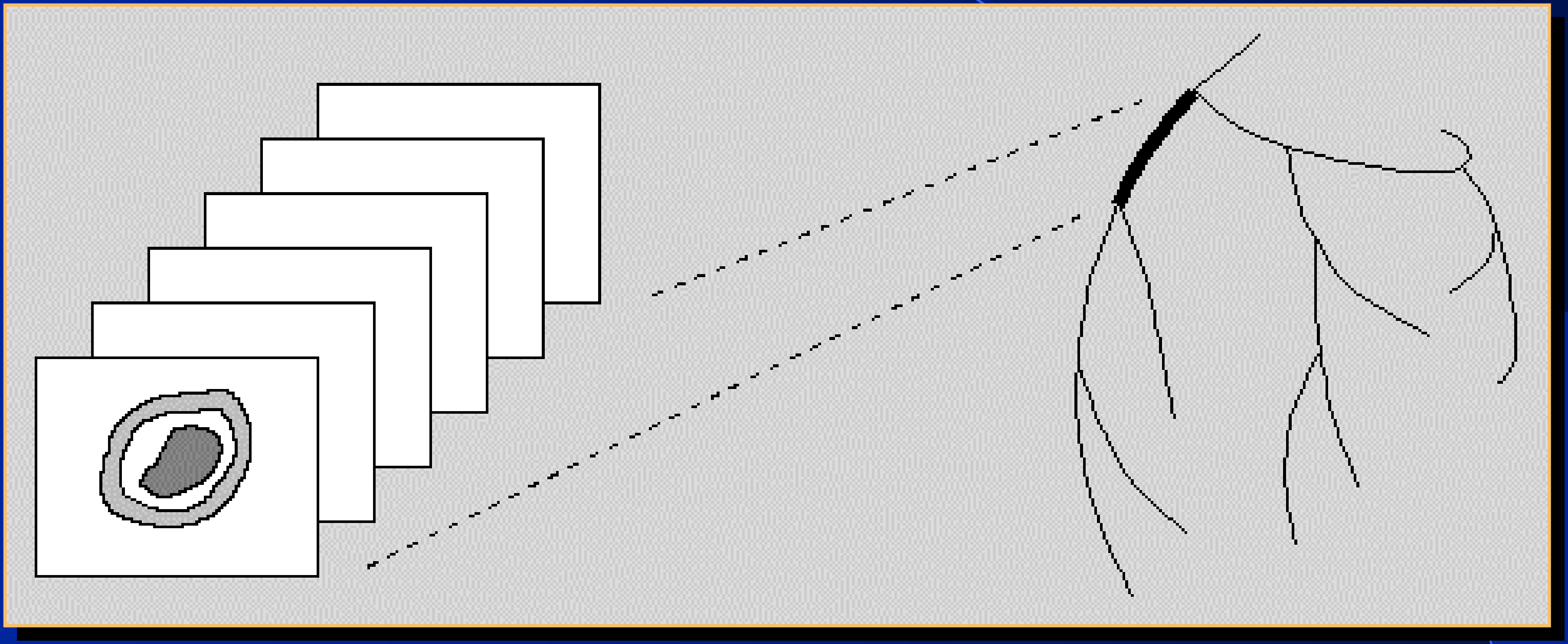
Simulation Results:

- Vessel ***curvature*** increases the doses delivered to the inner bend
- Catheter ***eccentricity*** biases dose distribution towards closer wall
- Effects may partially offset each other if catheter is at outer bend

Questions (2):

- Impact ***in-vivo***?
- How to generate an accurate 3-D model of the vessel segment?
- Angiography-IVUS Fusion

Principle of Data Fusion



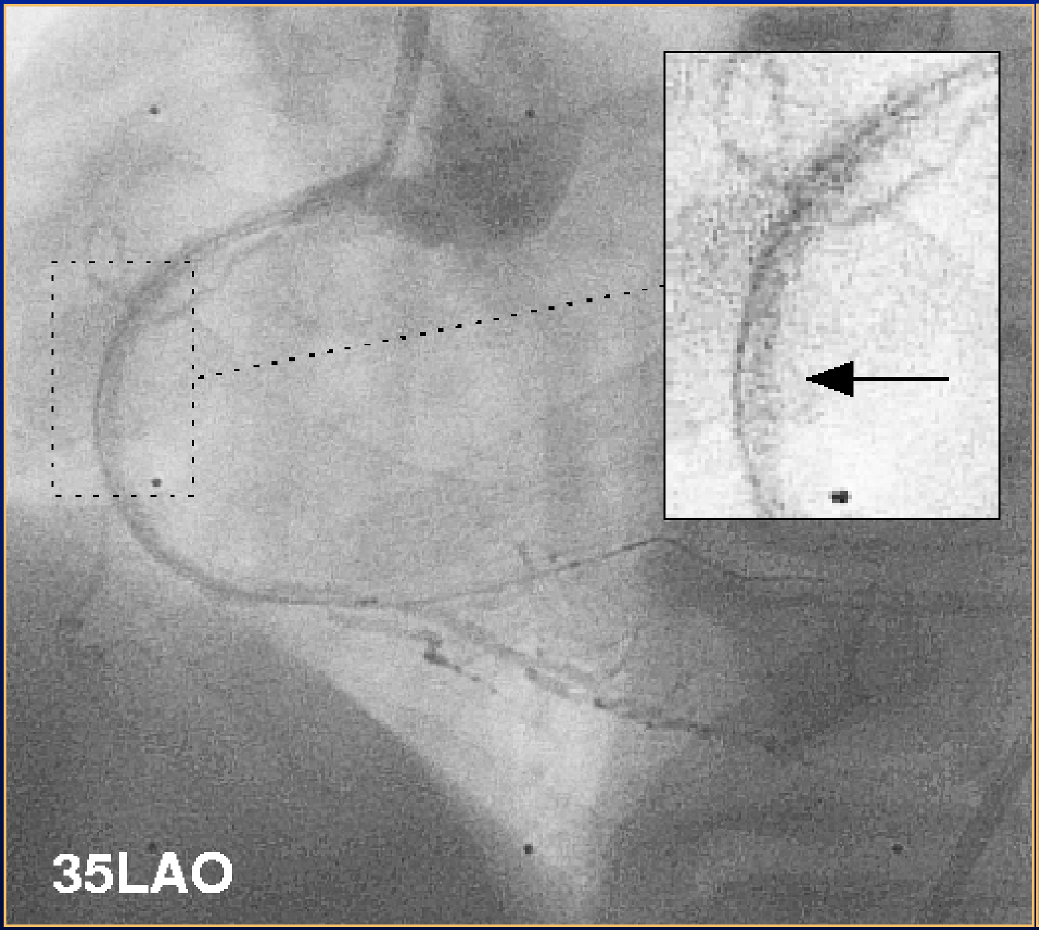
IVUS

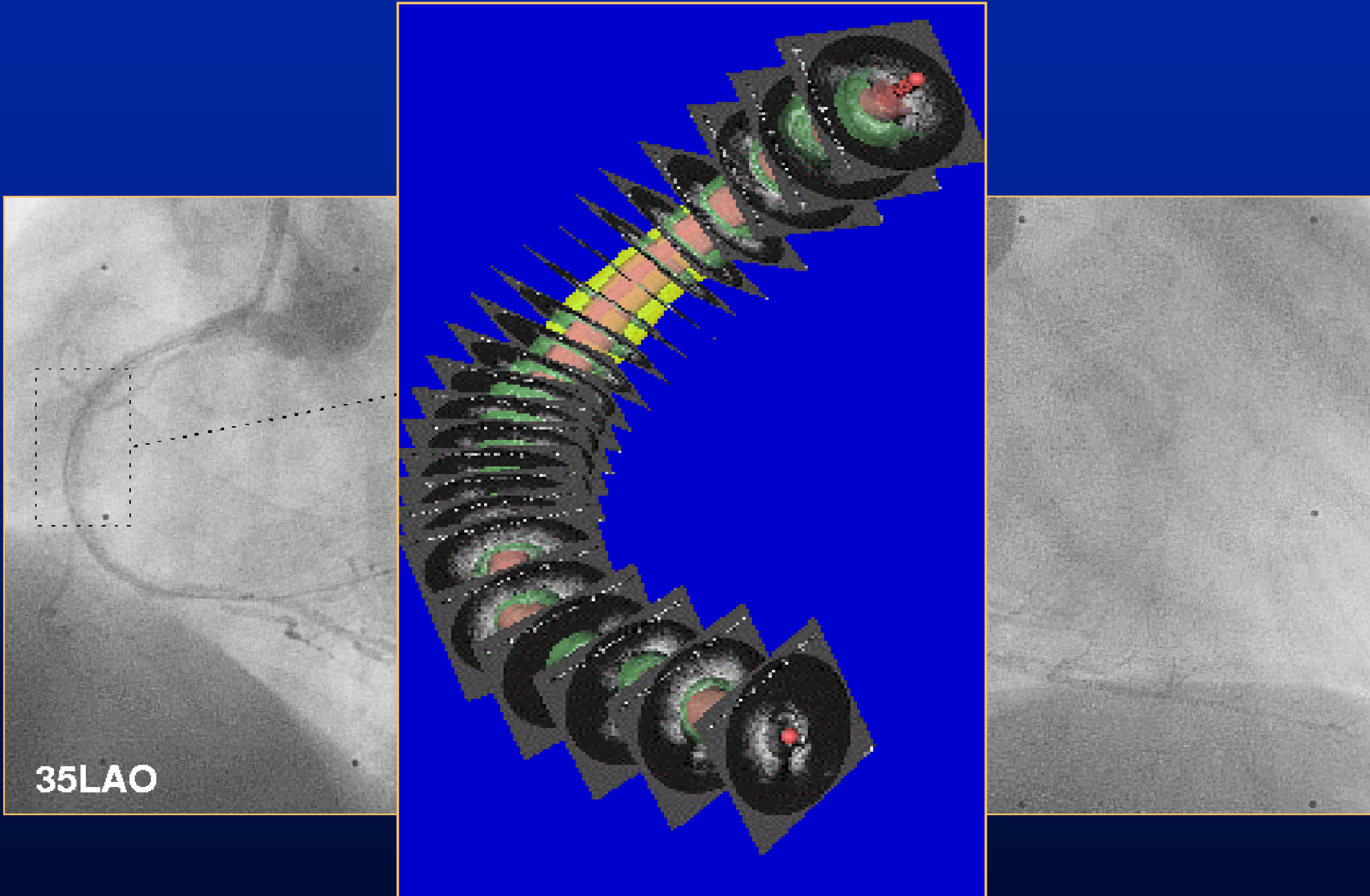
Angiography

Fusion Outline

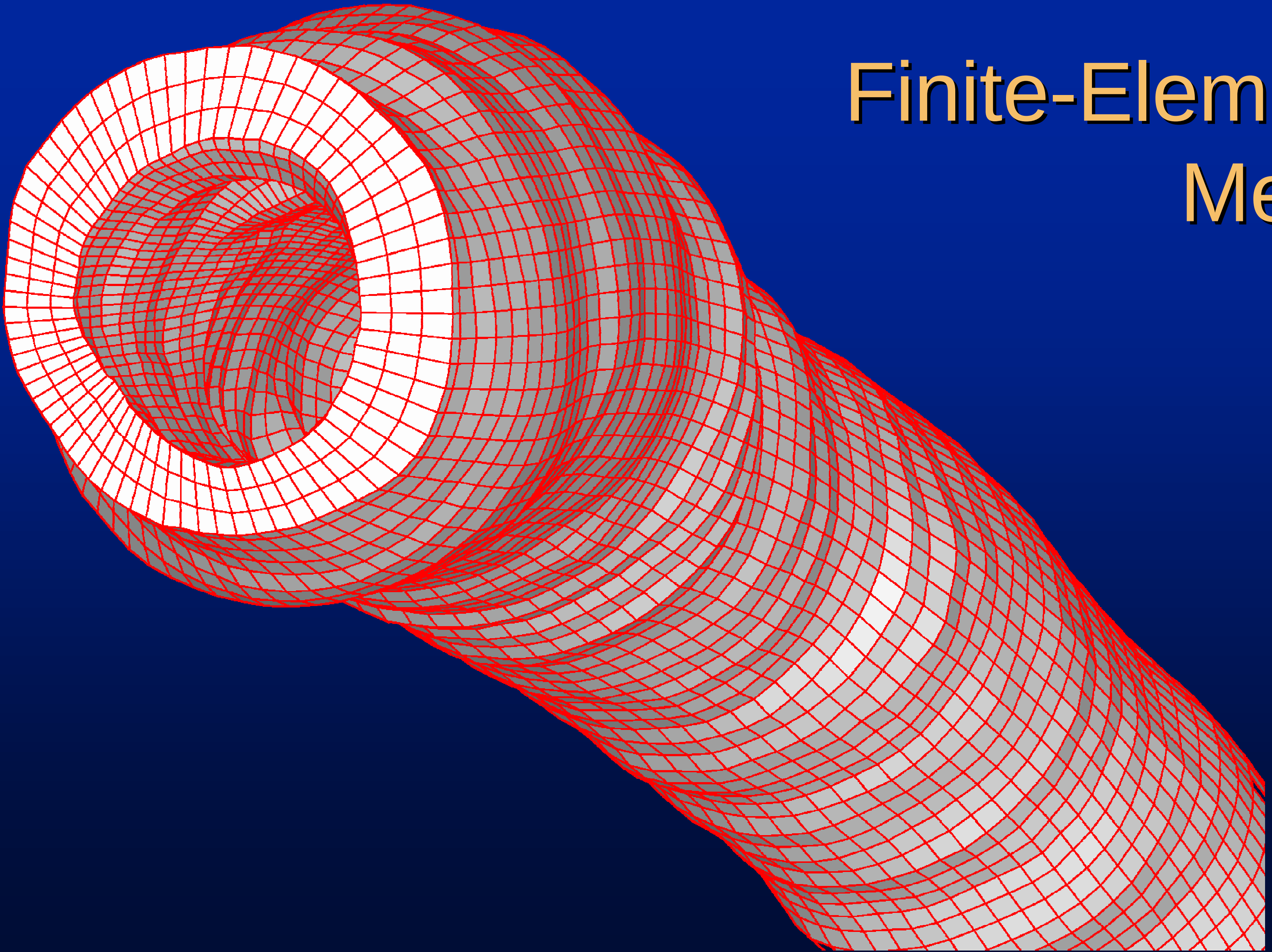
- Matching of IVUS frames on 3-D path
  – Constant pullback speed
- Determination of absolute orientation
  – Differential geometry
  – Using IVUS catheter as landmark
- Mapping of pixel and contour data

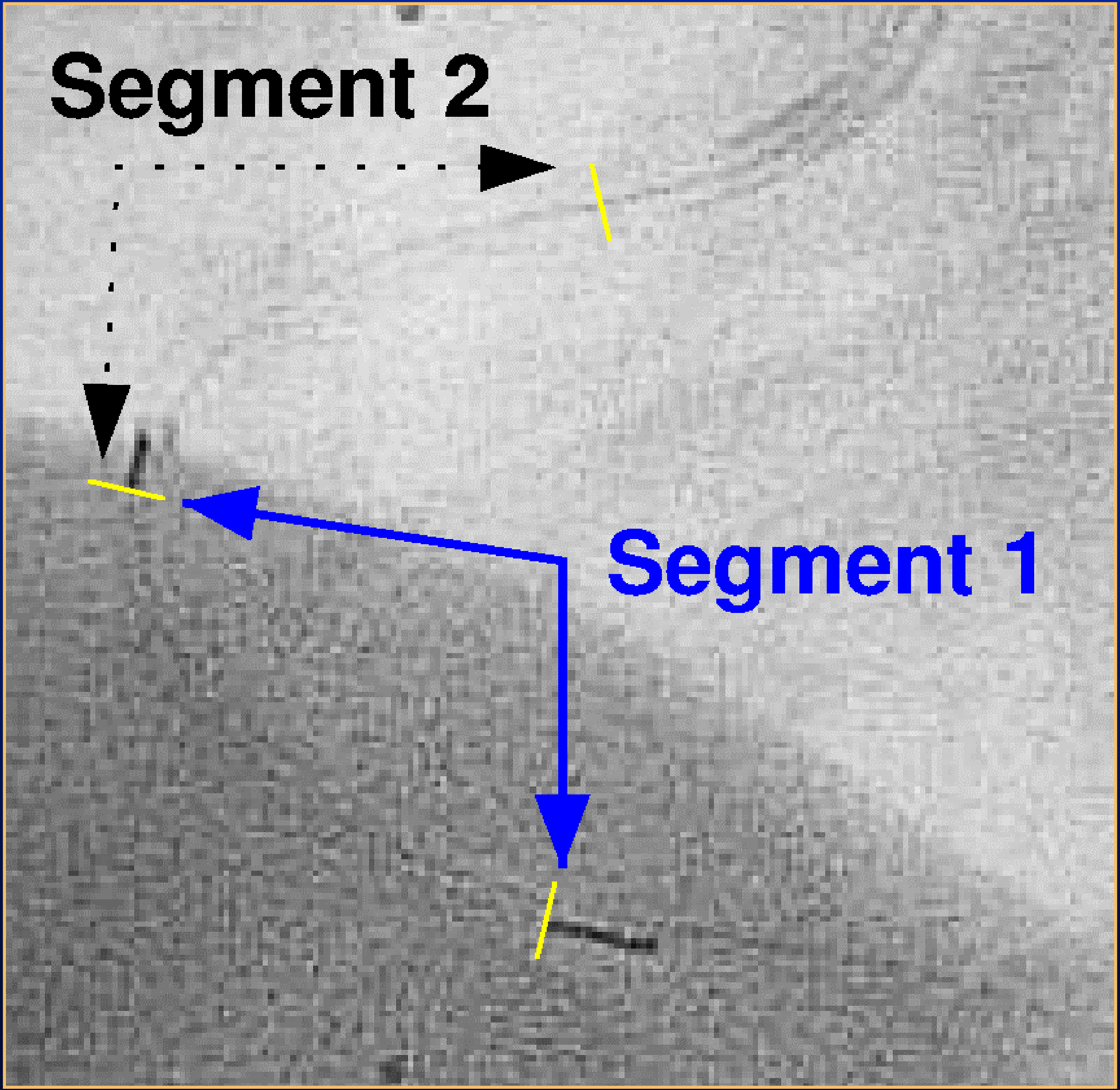
In-Vivo Example




35LAO

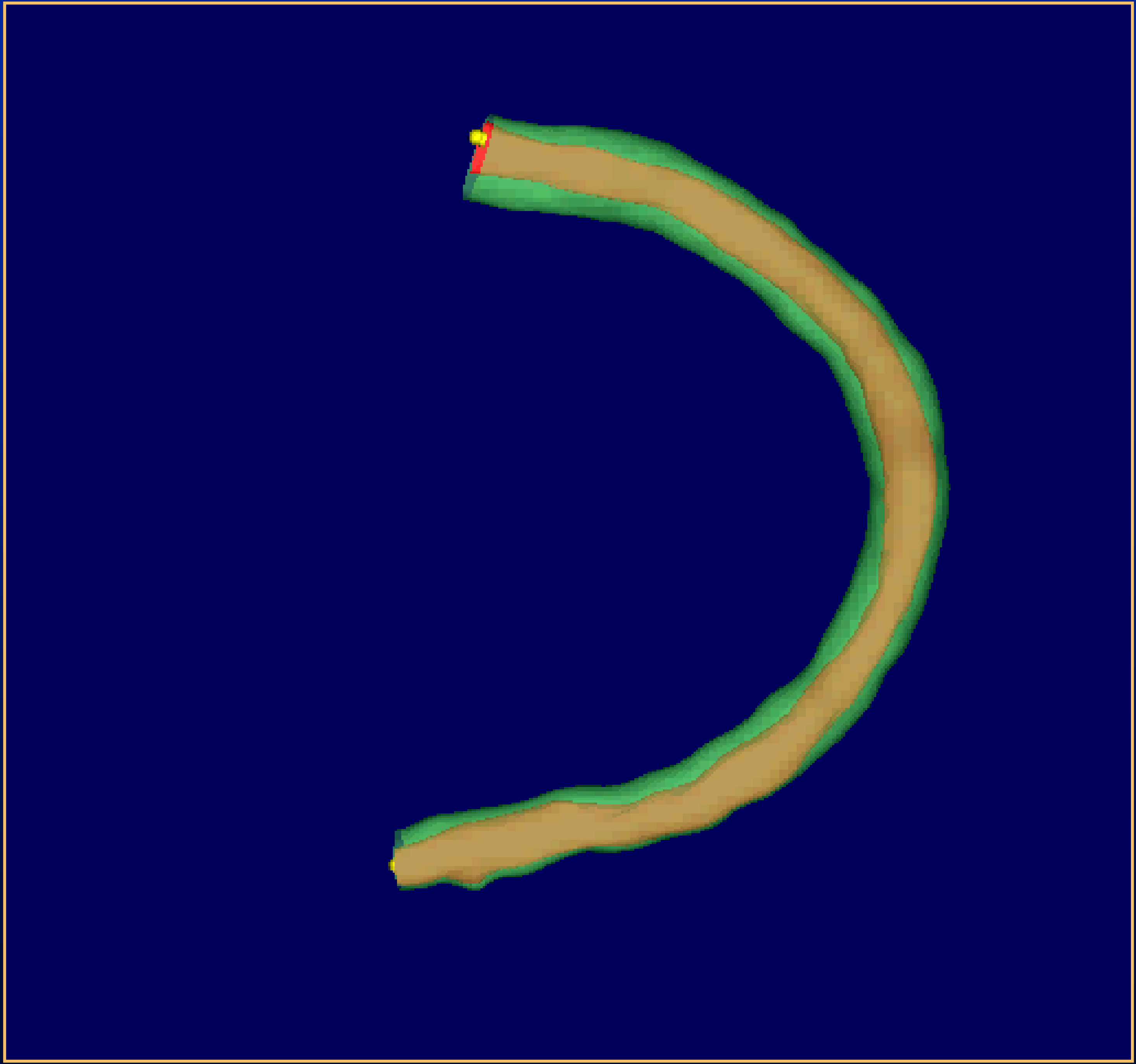
Finite-Element Mesh





Simulation

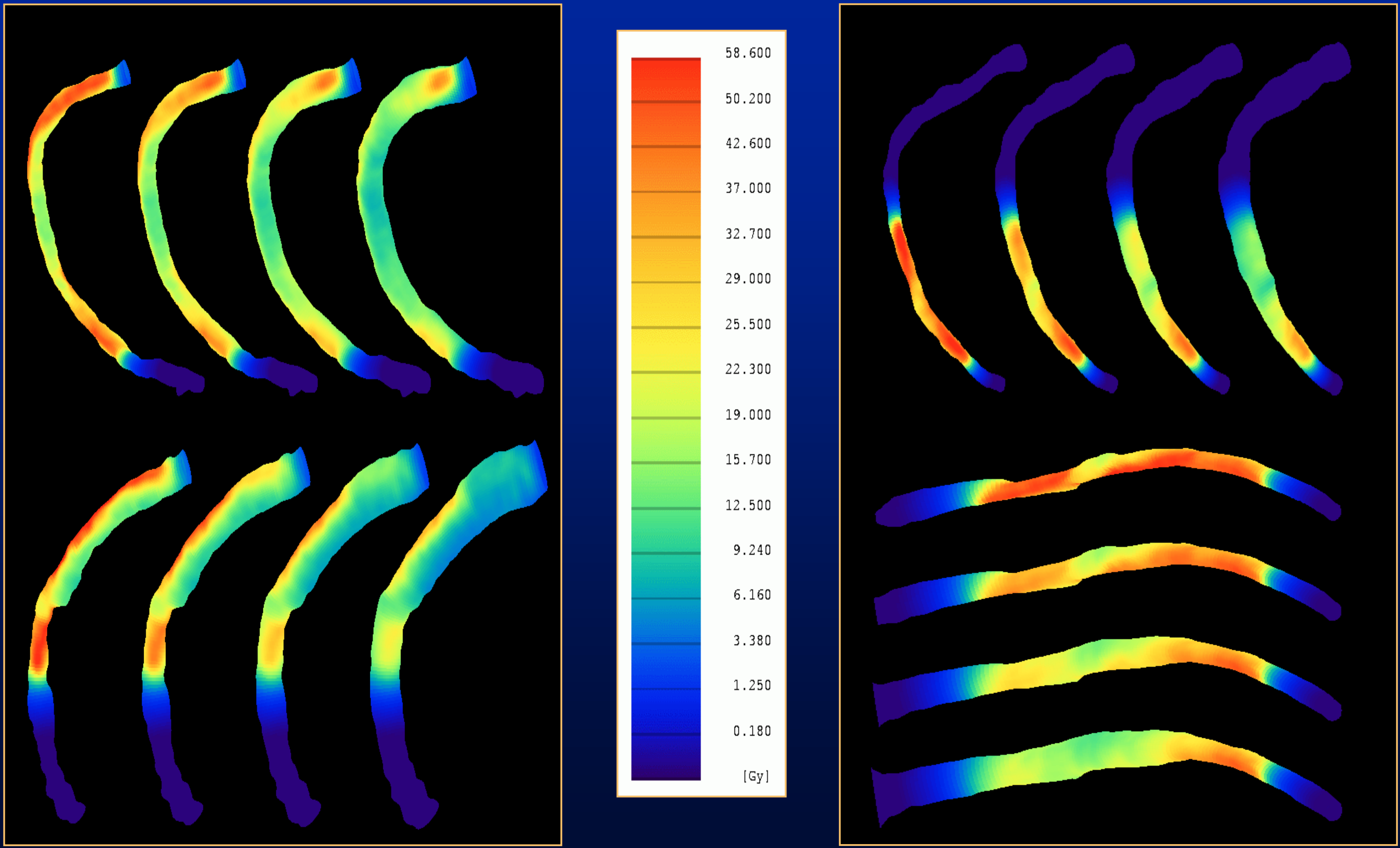
2 Segments
30mm train

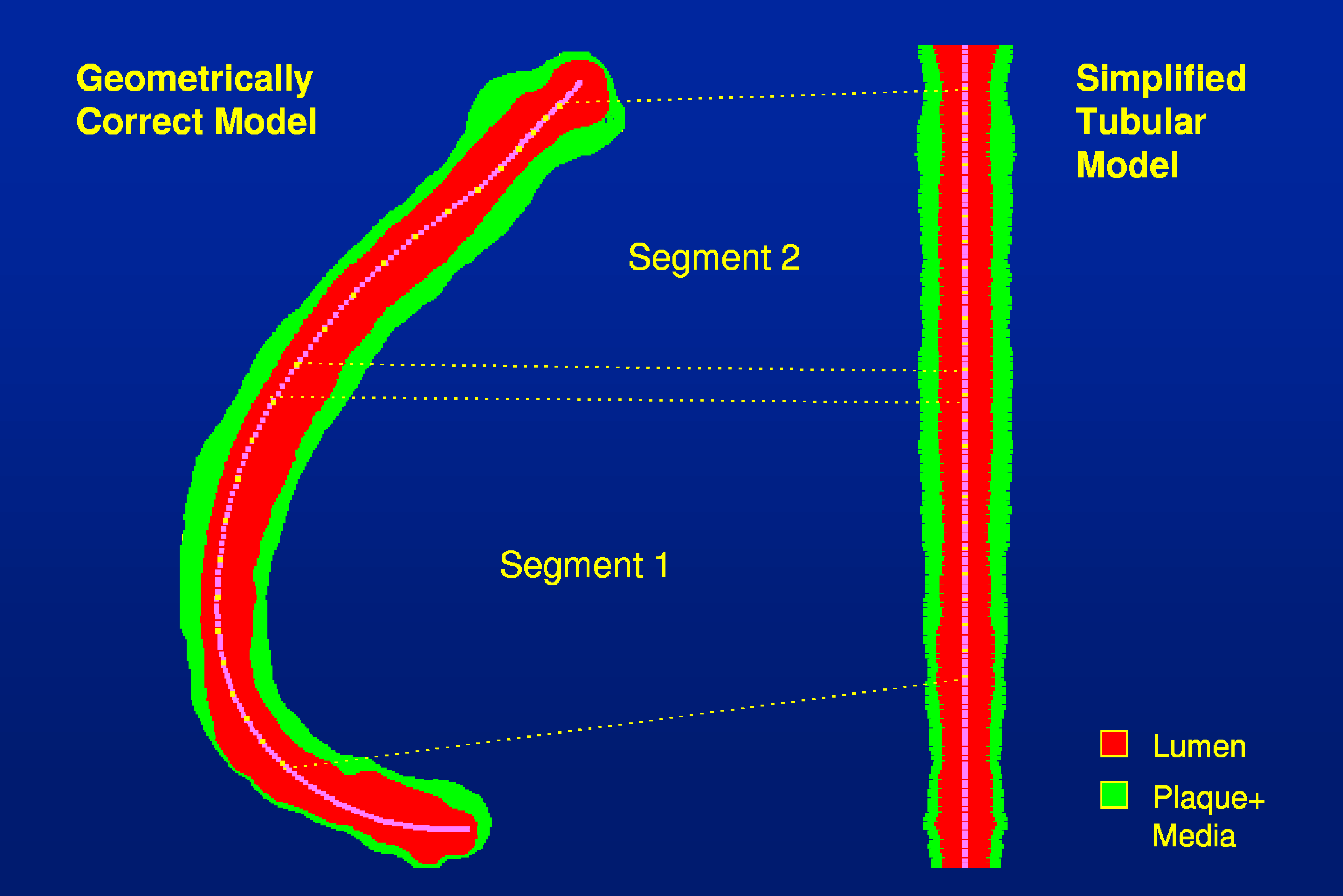


Doses

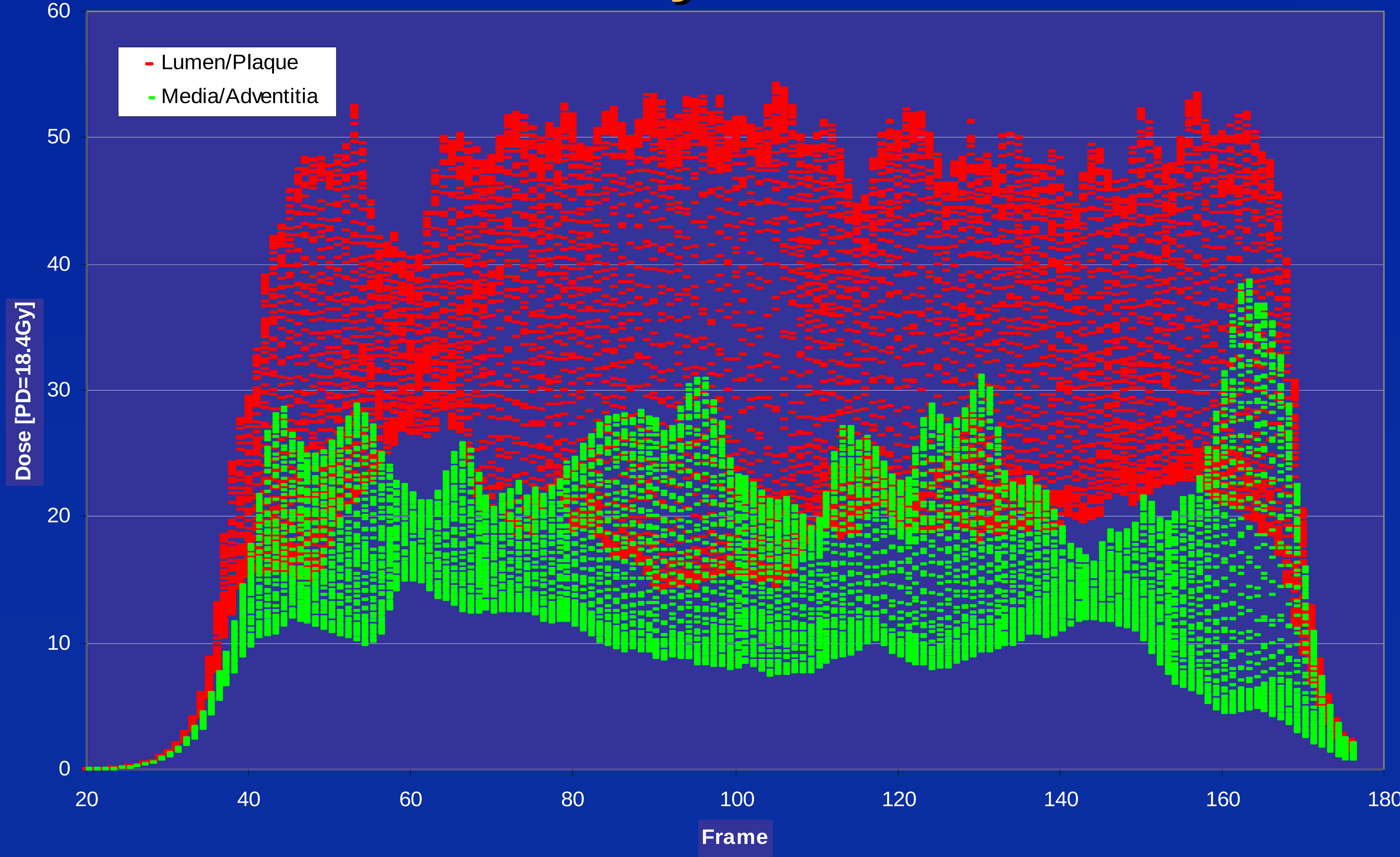
1. Adventitia
2. Lumen

Visualization

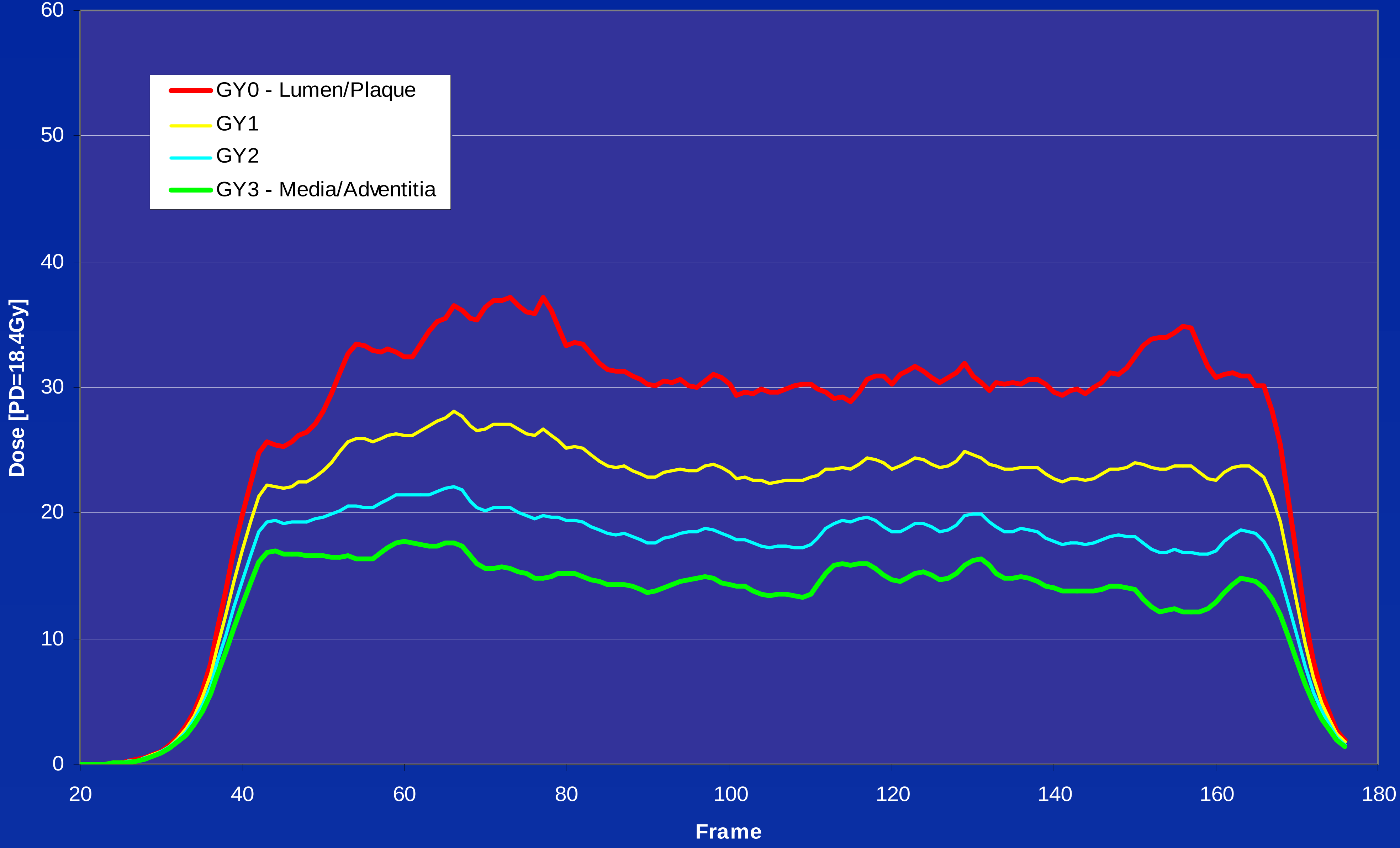



Geometrically
Correct Model
Simplified
Tubular
Model
Segment 2
Segment 1
Lumen
Plaque+
Media

Geometrically Correct Model



Simplified Tubular Model



In-Vivo Results

Layer	GCM [Gy] (mean±SD)	STM [Gy] (mean±SD)	Difference means [%GCM] All	LAD	LCX	RCA
	$n = 10$	$n = 10$	$n = 10$	$n = 3$	$n = 2$	$n = 5$
Lumen/Plaque	34.70 ± 11.93	31.66 ± 5.11	8.76	6.54	7.62	10.44
Intermediate 1	26.71 ± 8.76	24.85 ± 4.14	6.96	4.77	6.58	8.38
Intermediate 2	21.28 ± 7.41	19.92 ± 3.84	6.39	3.95	6.70	7.74
Media/Adven.	17.31 ± 6.72	16.18 ± 3.71	6.52	3.82	7.35	7.86

Discussion

- Vessel curvature and catheter eccentricity influence dose distribution of beta emitters
- Simplified models underestimate average doses as well as dose variability as compared to geometrically correct 3-D models
- No gold standard available
- However, tendencies shown in this study should prevail regardless of absolute values

Discussion

- Future extensions:
  - Plaque characterization
  - Monte-Carlo simulation
  - 4-D model by ECG sorting
  - ...

Conclusions

- Dose-delivery models for intravascular brachytherapy should consider vessel curvature and eccentricity of catheter
- Centering of the catheter of major interest to ensure prescribed dose is actually delivered homogeneously
- Our method may help improving both dosing models and delivery systems