

Two, Three, Four: How Many Trackers Do We Really Need For Proton Imaging?

C.E. Ordoñez

Northern Illinois University

DeKalb, Illinois

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and Radiation Treatment Planning

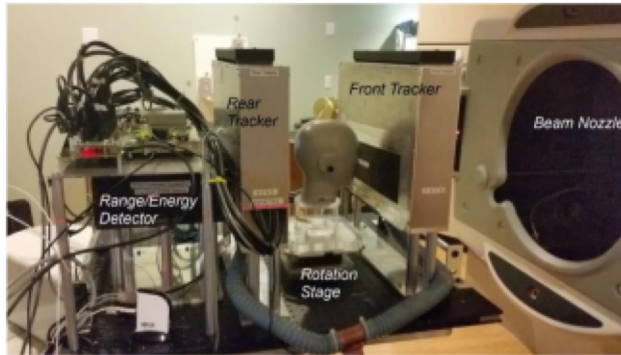
23 July 2019

Proton Imaging

LLUMC/UCSC

Proton Computed Tomography

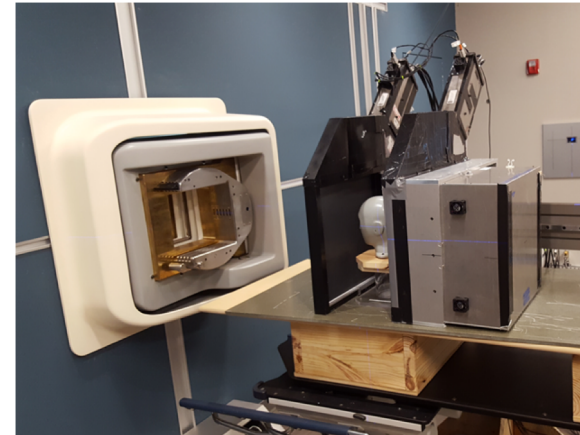
pCT



ProtonVDA

Proton Radiography

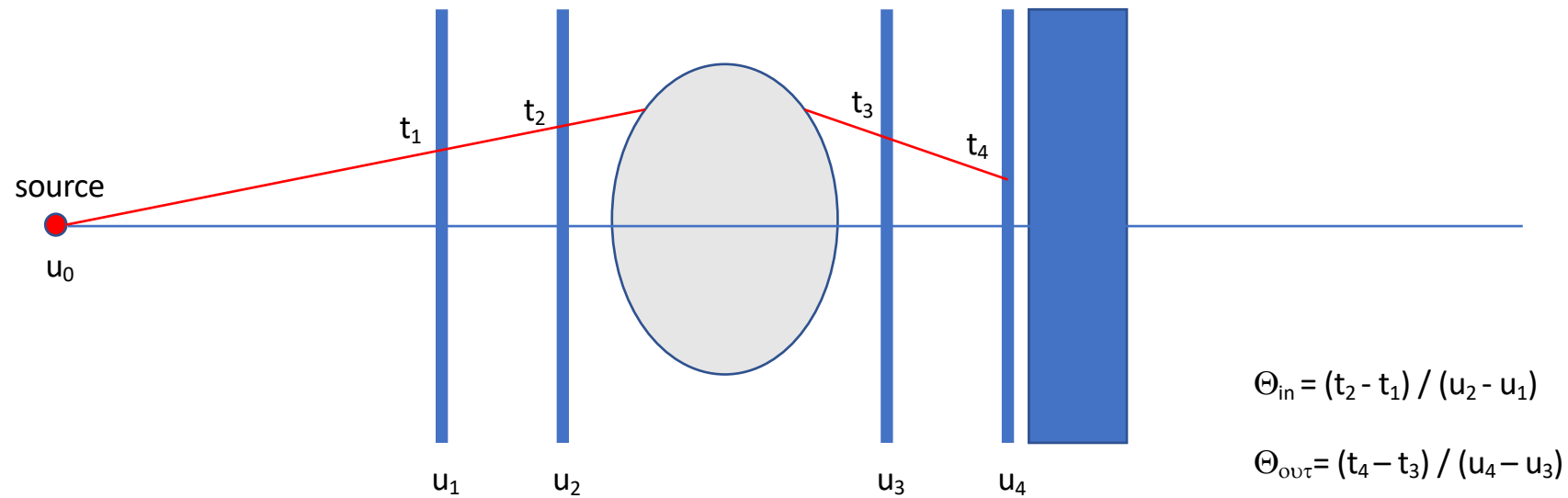
pRad



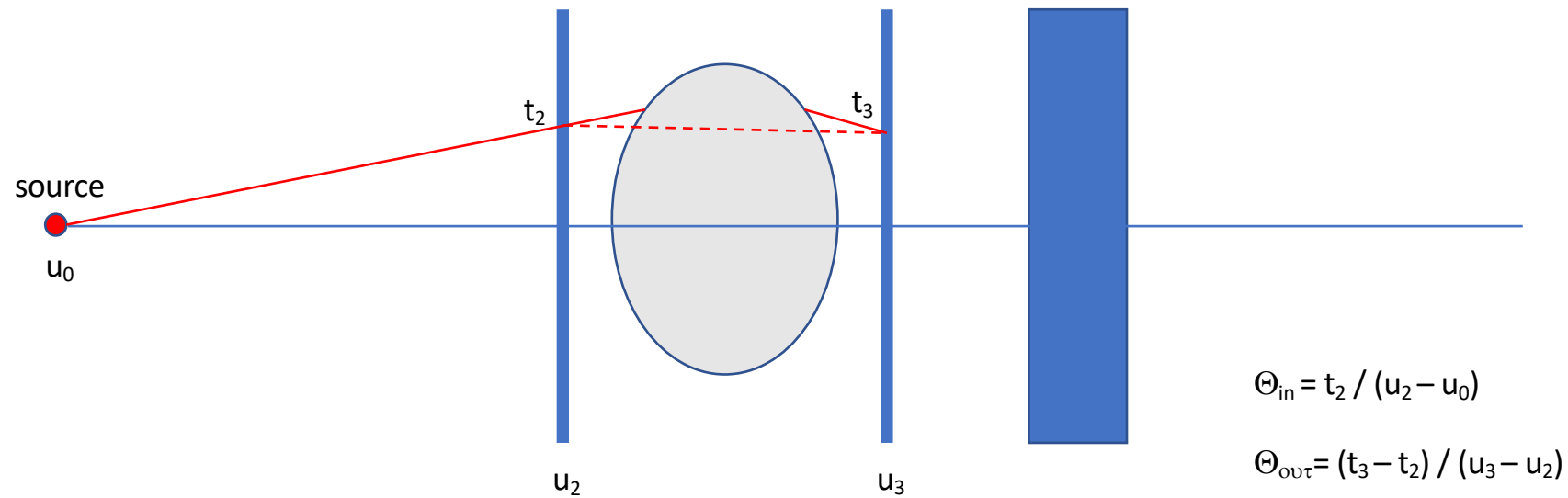
Imaging Problem

- $A\mathbf{X}=B$
 - A = most likely path (MLP)
 - B = measured water-equivalent path length (WEPL)
 - $\mathbf{X}$ = unknown 3D distribution of relative stopping power (RSP)
 - MLP = function of {detected proton positions/angles; energy; beam angle}
- pCT and pRad both solve for $\mathbf{X}$
 - pRad: one primary beam angle
 - pCT: multiple beam angles
- Radiograph
 - Collapse columns of $\mathbf{X}$ (RSP) along beam, weighted by pixel size
 - 2D distribution of water-equivalent thickness (WET)

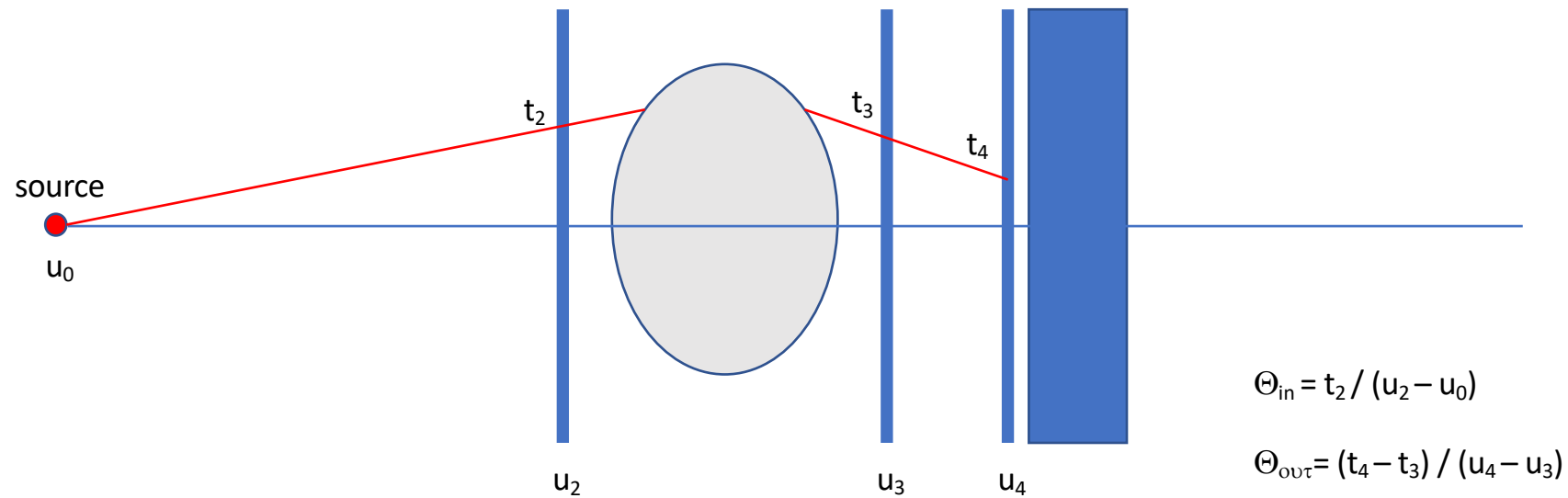
Four Trackers (2 upstream, 2 downstream) LLUMC / UCSC



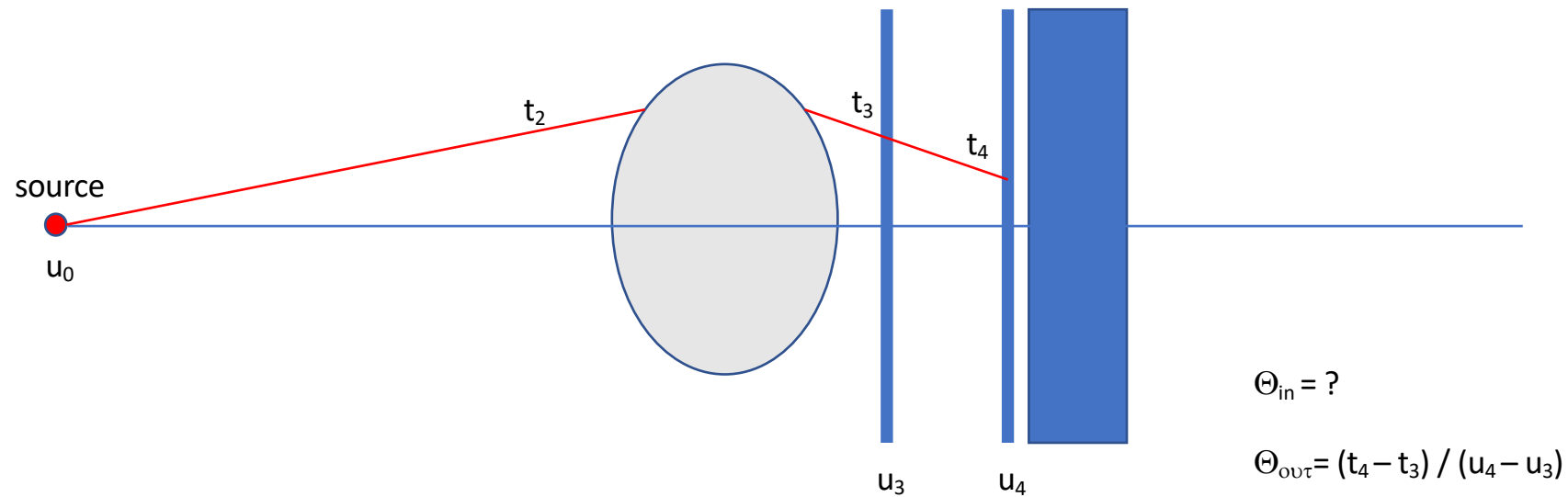
Two Trackers (1 upstream, 1 downstream) ProtonVDA



Three Trackers (1 upstream, 2 downstream) ?



No Front Tracker (0 upstream, 2 downstream) ?



NOT IN THIS TALK!

GOAL

Compare pCT and pRad Reconstructions with
Two, Three, and Four Trackers

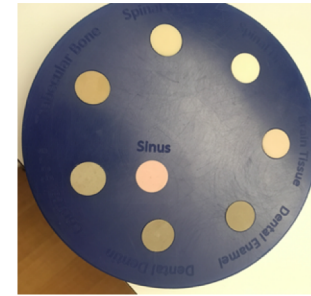
using real data

pCT/pRad Reconstruction

- Data from LLUMC/UCSC Phase II Detector
- Algorithm
 - pCT: DROP, TVS, effective chord length
 - pRad: DROP, no TVS, variable chord length
 - 20 iterations
 - 40 blocks
 - Relaxation parameter = 0.05
- Assumptions
 - Point source at $(u,t,v)=(-230,0,0)$ cm (BAD?)
 - Same WEPL for 2, 3, 4 trackers
- Modified NIU code (one CPU-core + one GPU)

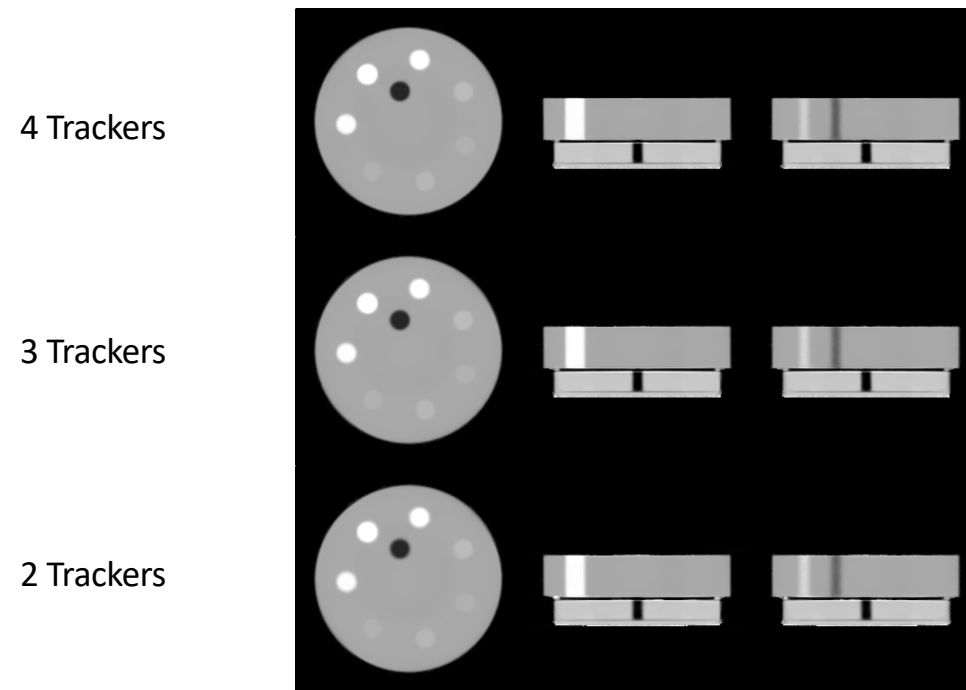
George Phantom

- NWMCPC Feb 2019
- Cylinder
 - wax
 - 18 cm diameter
 - 4 cm height
- 8 cylindrical inserts
 - 19 mm diameter
 - 4 cm height
- 275 million protons

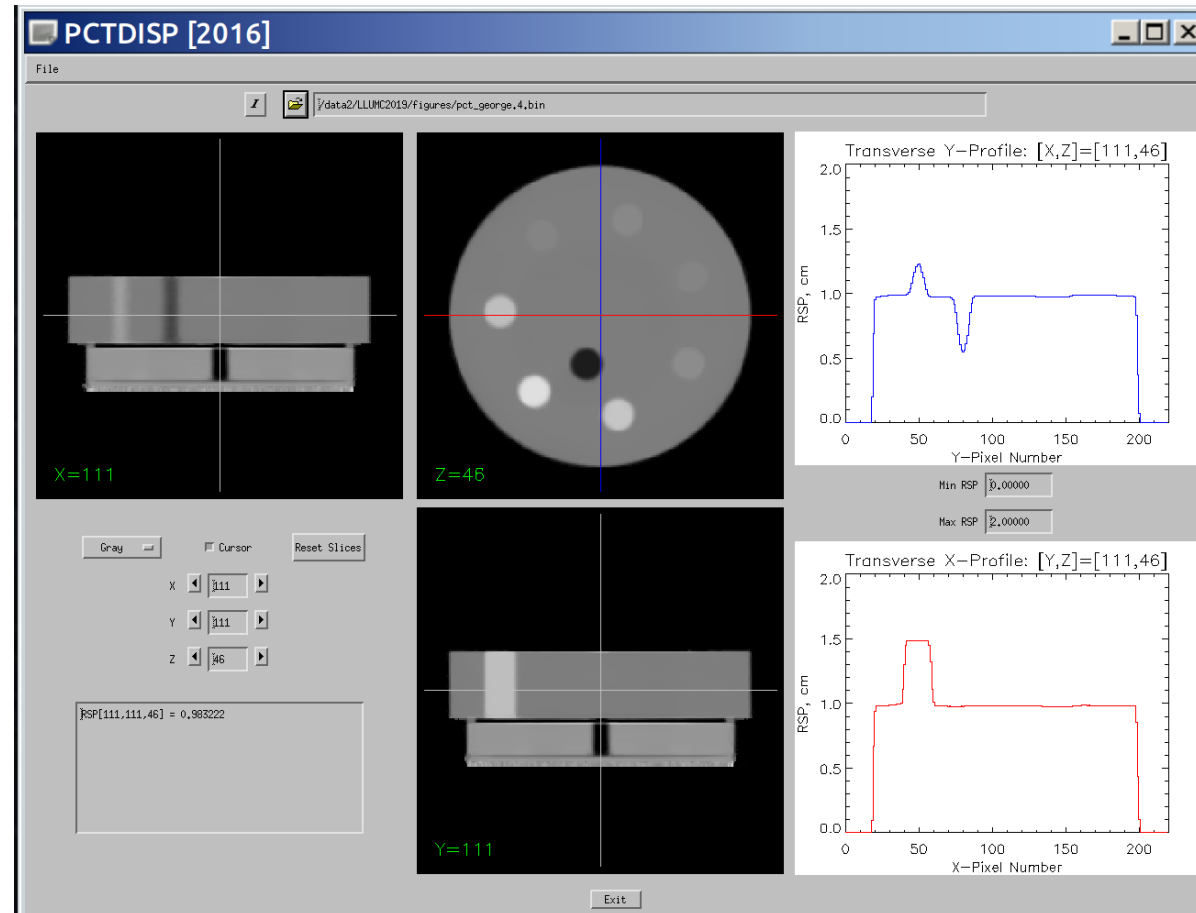


Material	RSP
Cortical Bone	1.555
Trabecular Bone	1.100
Brain Tissue	1.040
Dental Enamel	1.755
Dental Dentin	1.495
Spinal Cord	1.040
Spinal Disc	1.070
Sinus	0.220
Blue Wax	0.980

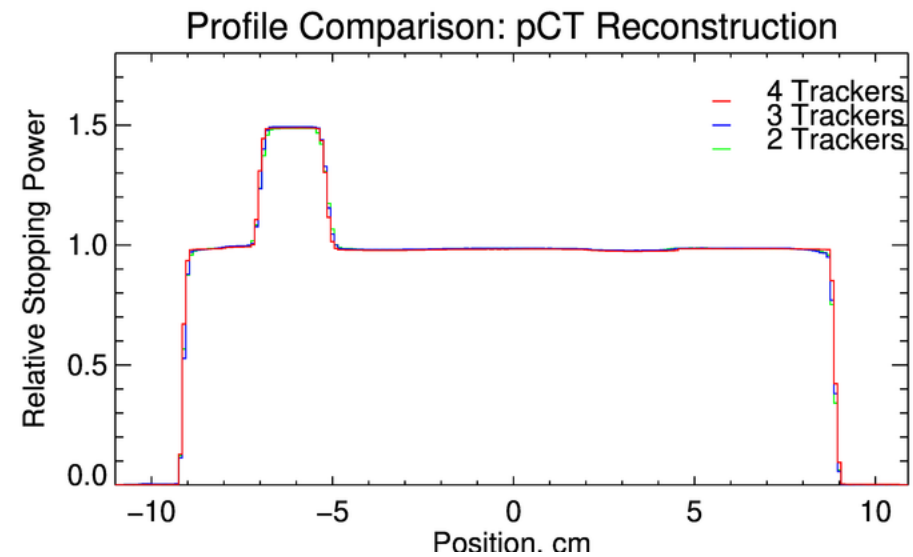
George Phantom pCT: Principal Slices



George Phantom pCT Reconstruction



George Phantom pCT: Profile Comparison



George Phantom pCT: Reconstructed RSPs

Material	Measured ^a	RSP from Reconstructed Image ^b		
		2 Trackers (1u + 1d)	3 Trackers (1u + 2d)	4 Trackers (2u + 2d)
Cortical Bone	1.555	1.544	1.552	1.548
Trabecular Bone	1.100	1.099	1.102	1.100
Brain Tissue	1.040	1.036	1.040	1.037
Dental Enamel	1.755	1.735	1.747	1.742
Dental Dentin	1.495	1.485	1.492	1.487
Spinal Cord	1.040	1.036	1.039	1.037
Spinal Disc	1.070	1.067	1.070	1.067
Sinus	0.200 / 0.220 ^c	0.226	0.224	0.222
Blue Wax	0.980	0.986	0.987	0.983

^aMark Pankuch, Northwestern Medicine Chicago Proton Center. Warrenville, IL

^bMean RSP inside cylindrical ROI (10mm diameter x 10 mm length)

^cCalculation by Valentina Giacometti

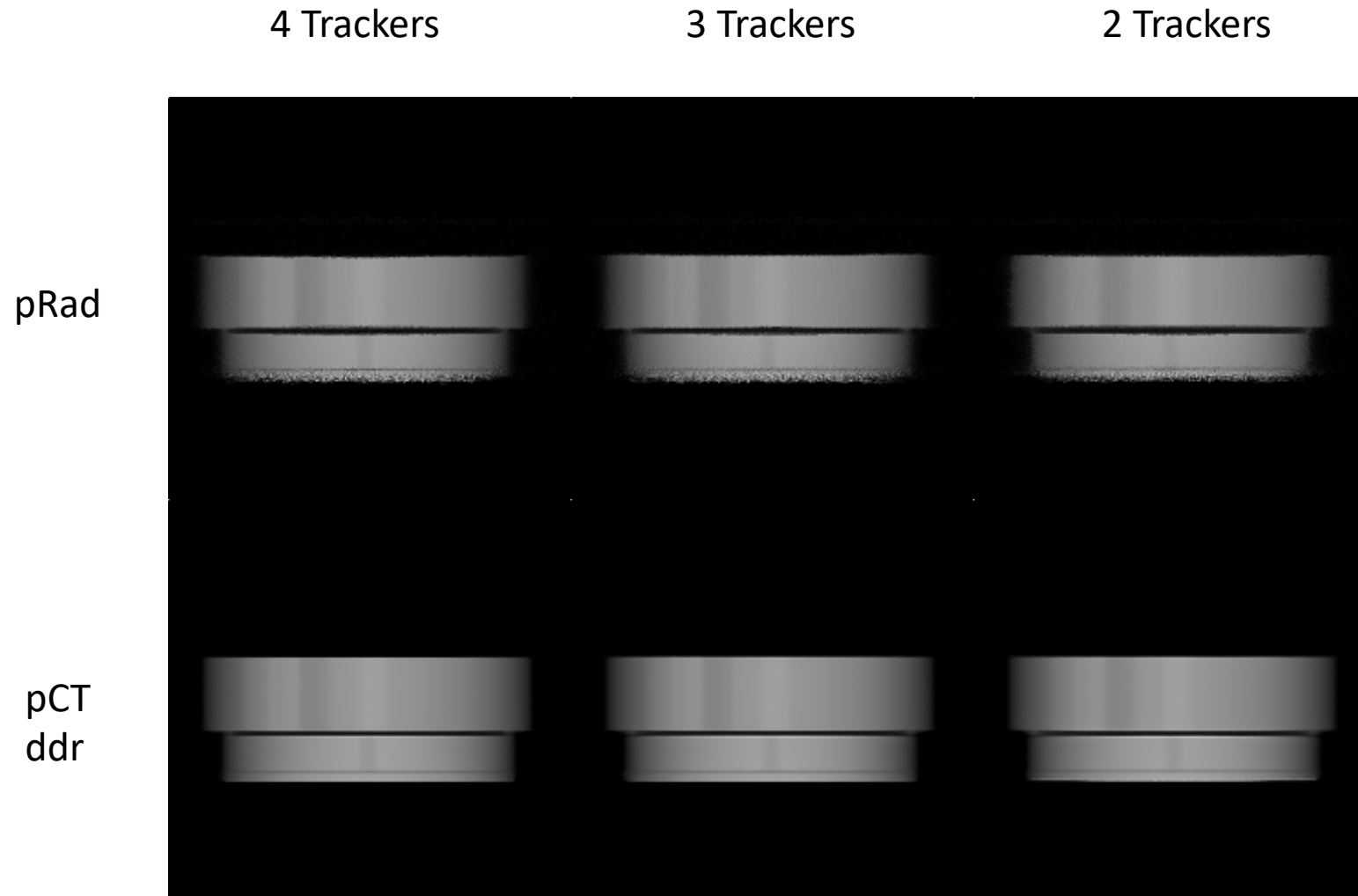
George Phantom pCT: Percent Difference of Reconstructed RSPs

Material	Measured ^a	Percent Difference from Measured RSP (%)		
		2 Trackers (1u + 1d)	3 Trackers (1u + 2d)	4 Trackers (2u + 2d)
Cortical Bone	1.555	-0.71	-0.19	-0.45
Trabecular Bone	1.100	-0.09	+0.18	0.00
Brain Tissue	1.040	-0.38	0.00	-0.29
Dental Enamel	1.755	-1.14	-0.46	-0.74
Dental Dentin	1.495	-0.67	-0.20	-0.54
Spinal Cord	1.040	-0.38	-0.10	-0.29
Spinal Disc	1.070	-0.28	0.00	-0.28
Sinus	0.200 / 0.220 ^b	13.0 / 2.73	12.0 / 1.82	11.0 / 0.91
Blue Wax	0.980	0.61	0.71	0.31

^aMark Pankuch, Northwestern Medicine Chicago Proton Center. Warrenville, IL

^bValentina Giacometti, calculated

George Phantom Radiographs



Pediatric Head Phantom Radiographs

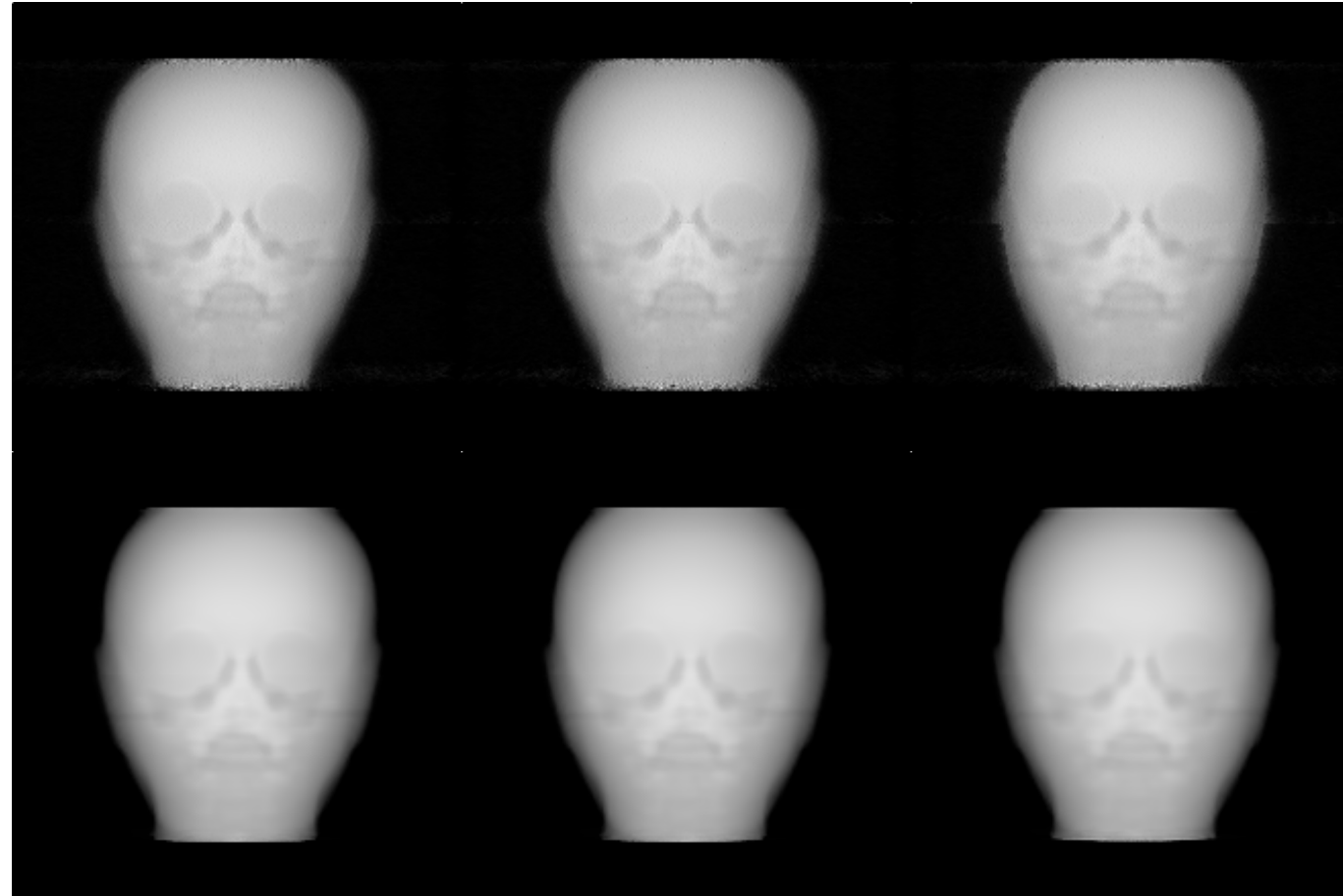
4 Trackers

3 Trackers

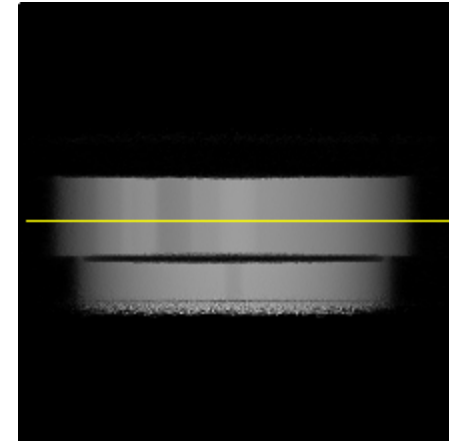
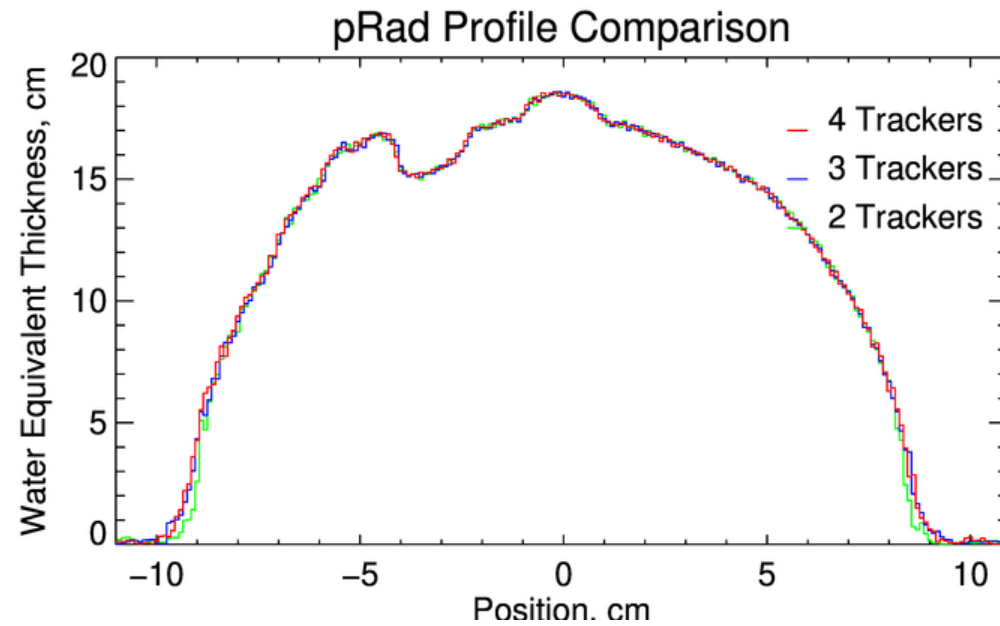
2 Trackers

pRad

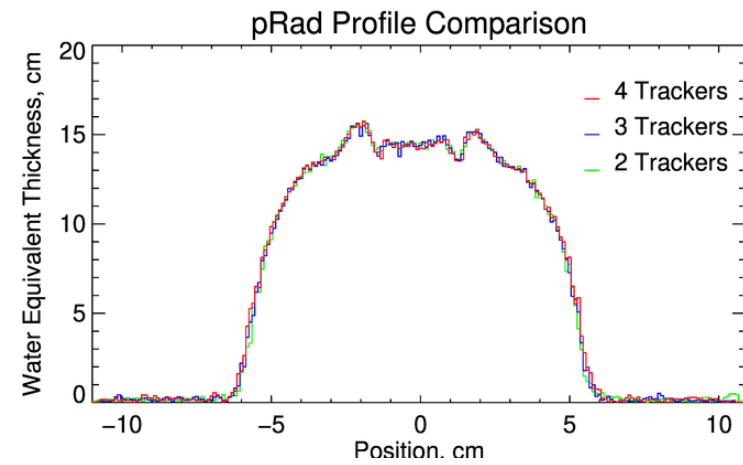
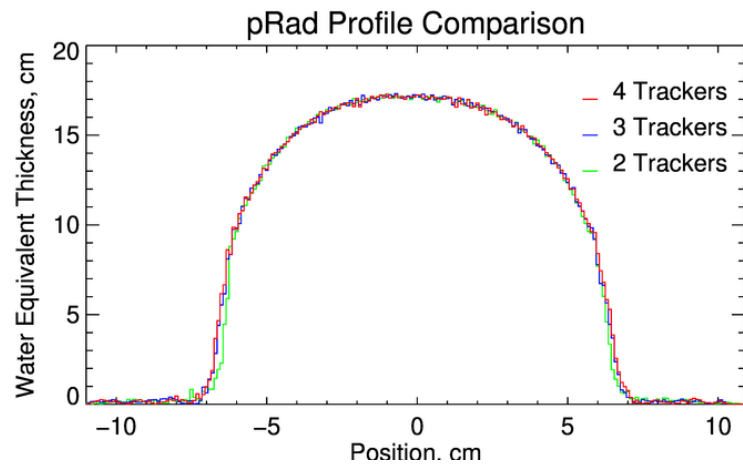
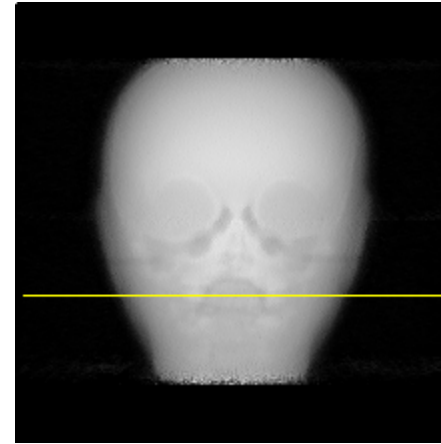
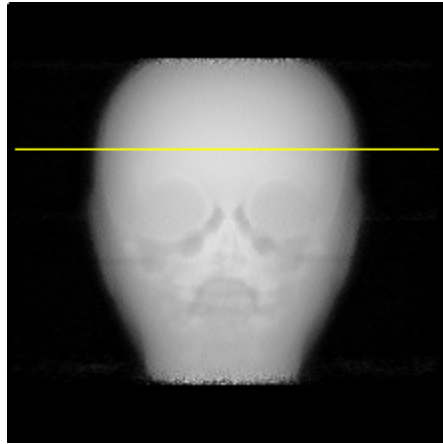
pCT
ddr



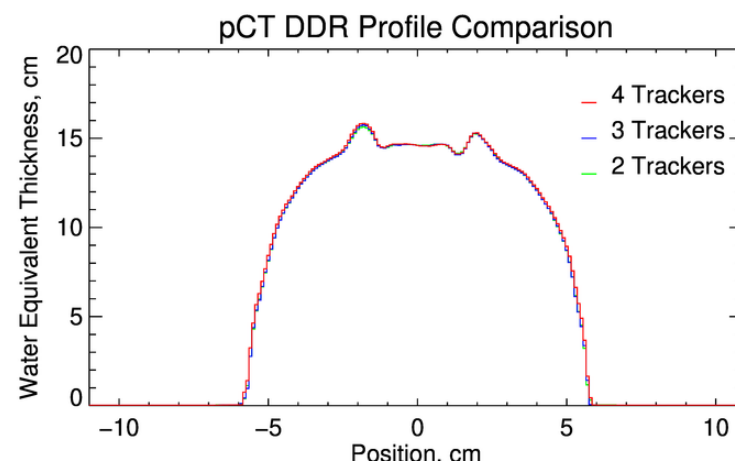
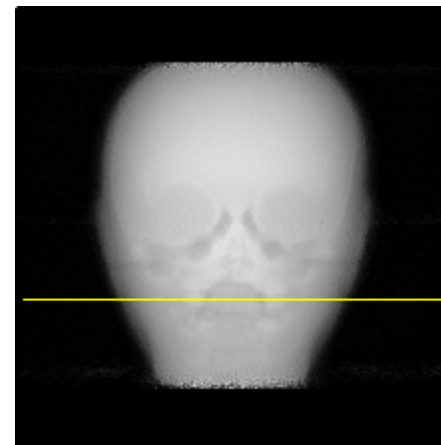
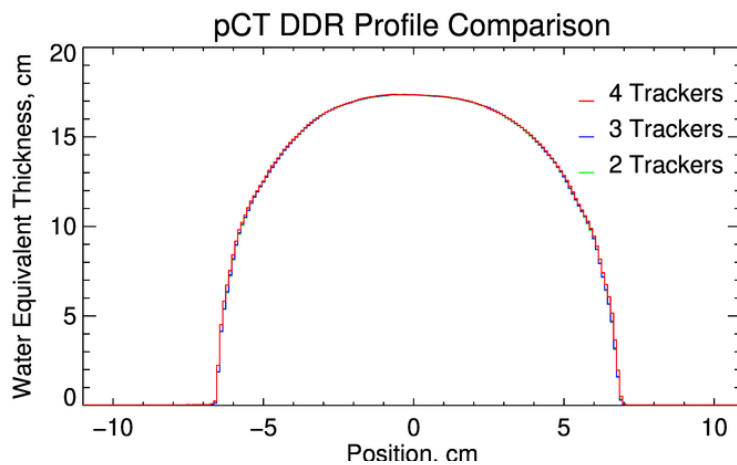
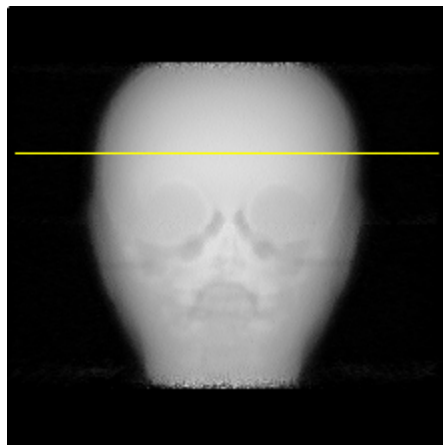
George Phantom pRad Profiles



Pediatric Head Phantom pRad Profiles

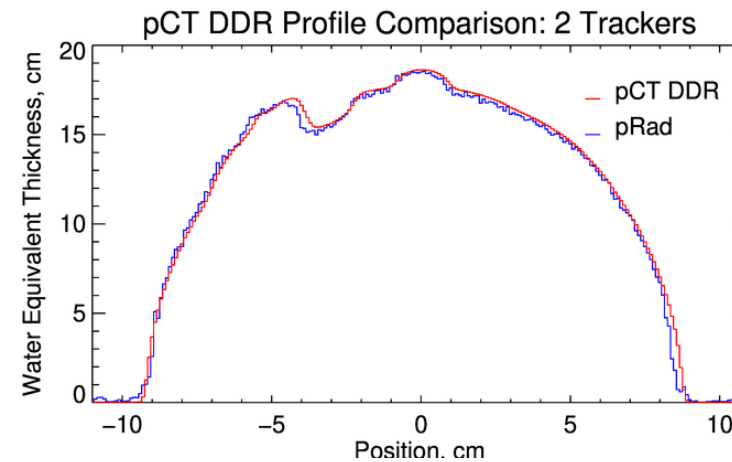
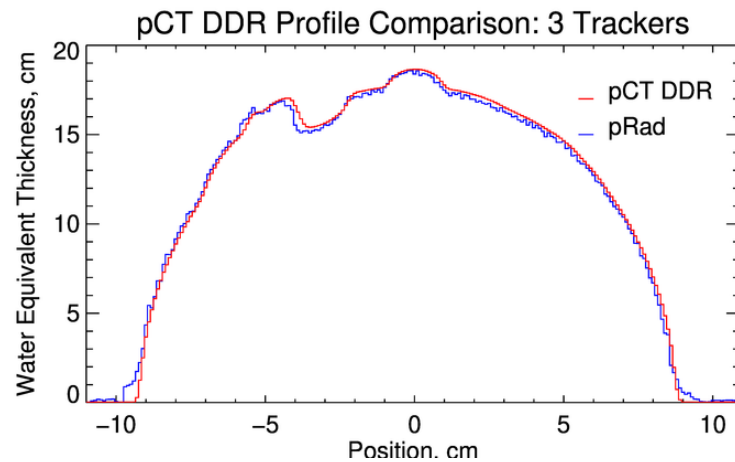
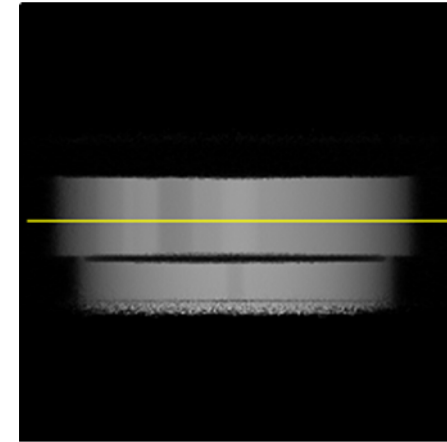
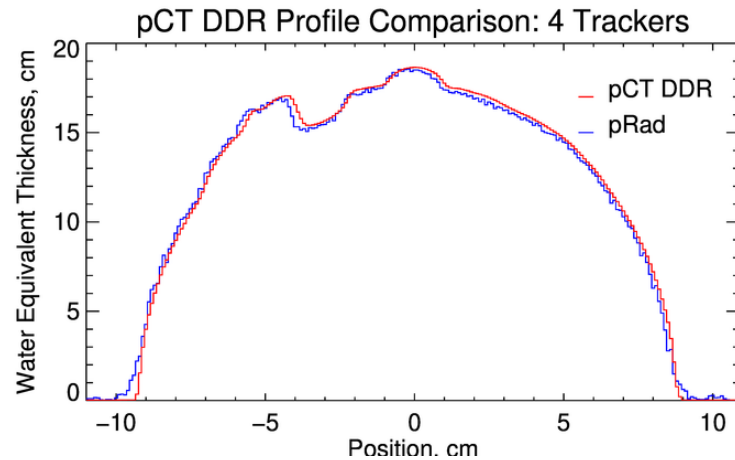


Pediatric Head Phantom pCT DRR* Profiles



*Digitally-Reconstructed Radiograph

George Phantom Profiles: pCT DDR* vs pRad



*Digitally-Reconstructed Radiograph

Summary and Conclusions

- pCT: reconstructed RSPs within less than 1% of measured values for 2, 3, 4 trackers
- pRad: reconstructed WETs very similar for 2, 3, 4 trackers
- Radiographs: pRad and pCT DDR show general agreement
- THIS IS WORK IN PROGRESS
 - Need more quantitative analysis
 - Simulations?