Northern Illinois University

Range Verification of xCT- and pCT-based Treatment Plans

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Introduction

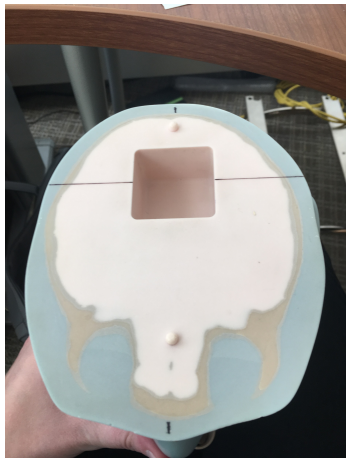
- Proton radiation therapy treatment plans are currently done on xCT images
- Errors arise due to:
  - HU-to-RSP conversion
  - Streak artefacts from metallic implants
- pCT could improve treatment plans and reduce error margins around the CTV

Goal

- Determine the error in proton range in a phantom by comparing the dose distribution on a stack of radiochromic film to the dose distribution predicted by treatment plans created on an xCT and pCT image.

Phantom and Films

- Customized CIRS 715HN Pediatric Head Phantom
- EBT3 Gafchromic® radiochromic film
  - Stack of 36
  - Dimensions: 1.5 cm x 3 cm
  - Thickness: 0.27 mm
  - RSP: 1.27



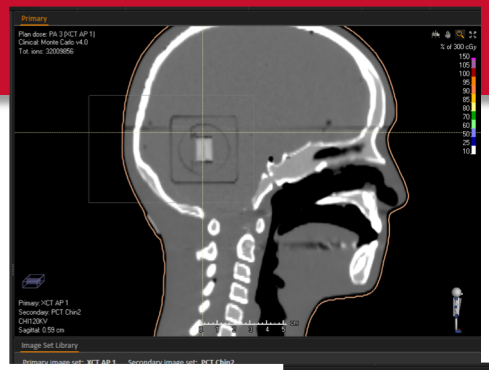
Proton Computed Tomography

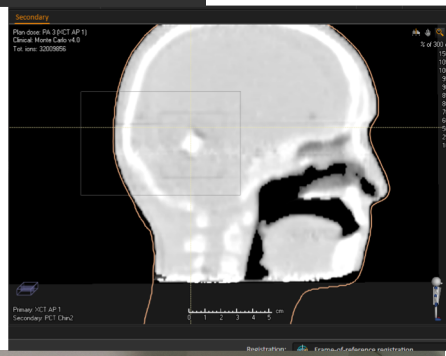
- System:
  - Low intensity protons
  - Total eight tracking planes, two x and two y both upstream and downstream
  - Five-stage scintillating energy detector
  - Rotating stage

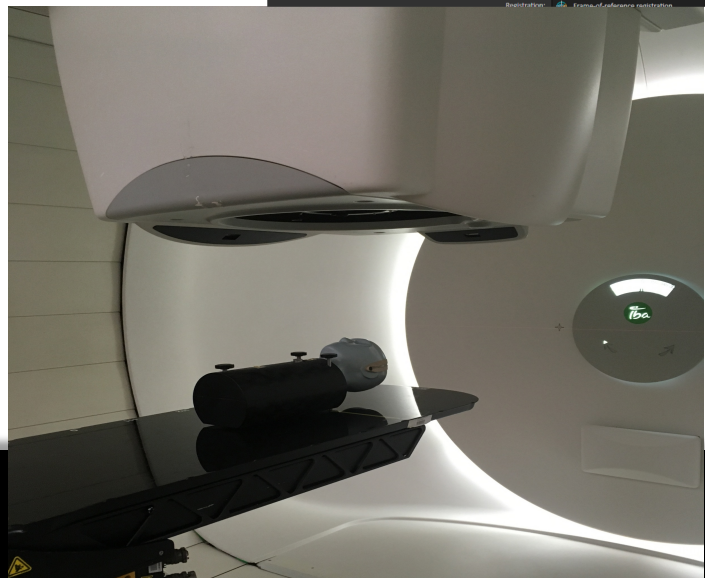
- Image Reconstruction
  - Preprocessing
  - Filtered back projection
  - Most Likely Path algorithm
  - Iterative Reconstruction
  - Final image is an RSP map

Treatment Planning

- Import xCT and pCT images into RayStation treatment planning system
- pCT images are registered to xCT
- Treatment plan is created and optimized on xCT
- Identical beam parameters are applied to pCT image and the dose map is calculated.
- The same beam parameters are delivered to phantom with film in place







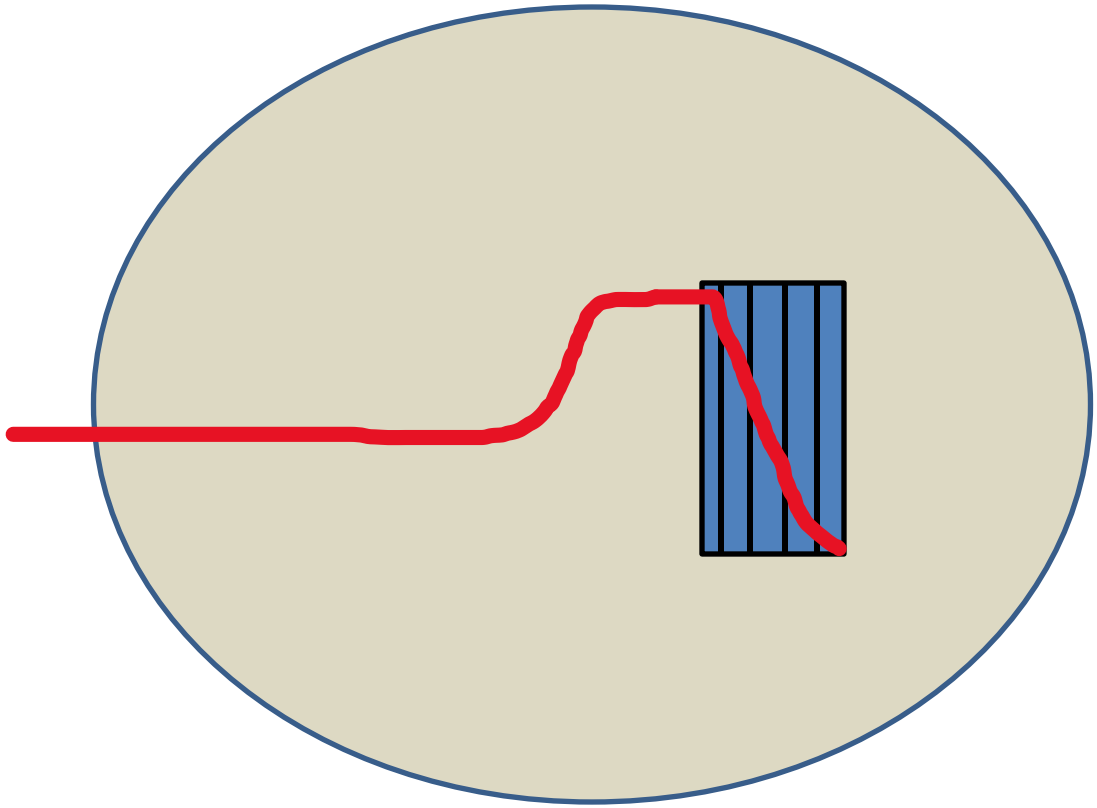
Gamma Analysis

- Gamma is defined by:

$$\Gamma = \sqrt{\left(\frac{\%\,\boldsymbol{Dose}}{\boldsymbol{3\%}}\right)^2 + \left(\frac{\boldsymbol{DTA}}{\boldsymbol{3\ mm}}\right)^2}$$

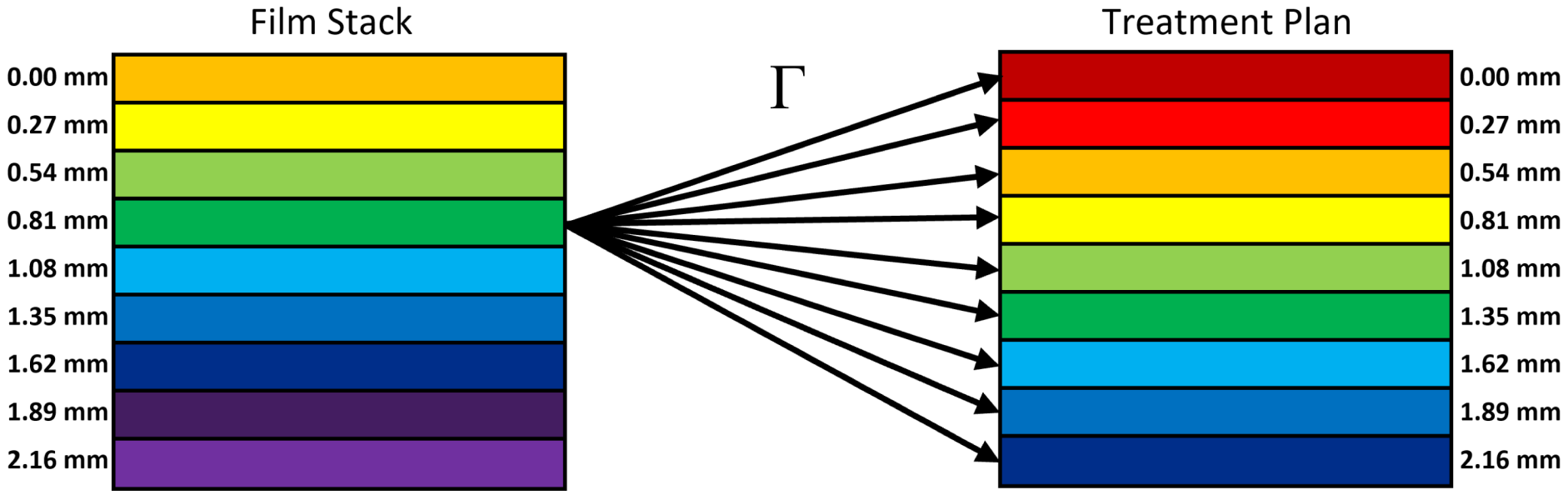
- Gamma score is the percent of pixels with $\Gamma < 1$
- Where % Dose is the percent difference between the dose in a given pixel on one plane with a nearby pixel in a different plane and DTA is the distance to agreement.
- Note, this is a 2D analysis technique

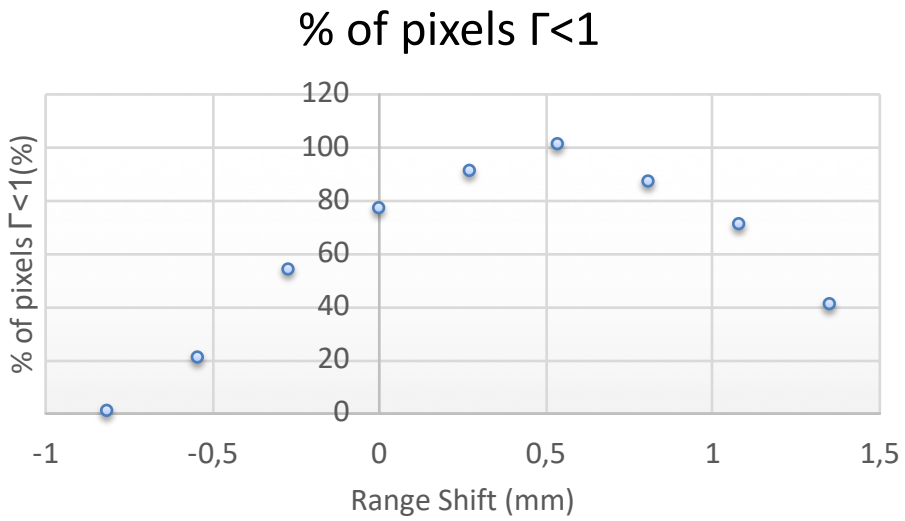
Determination of Range Error



- Stack of film is placed normal to the incident beam
- Fall-off of SOBP is over the range of the stack

Determination of Range Error



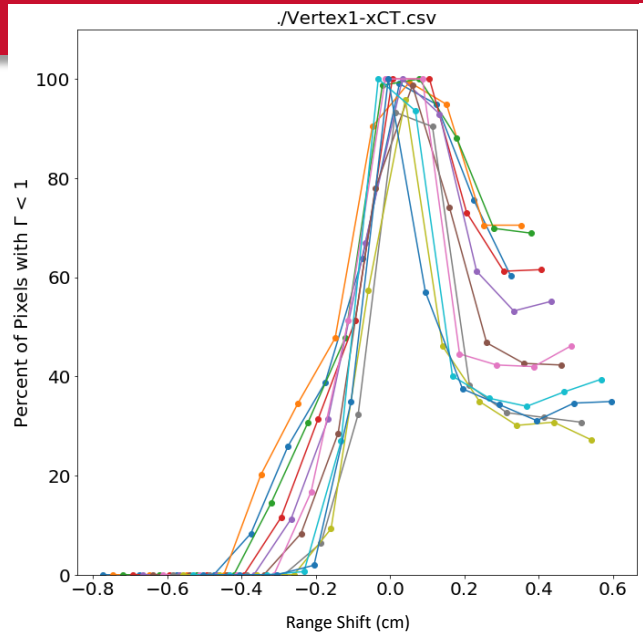


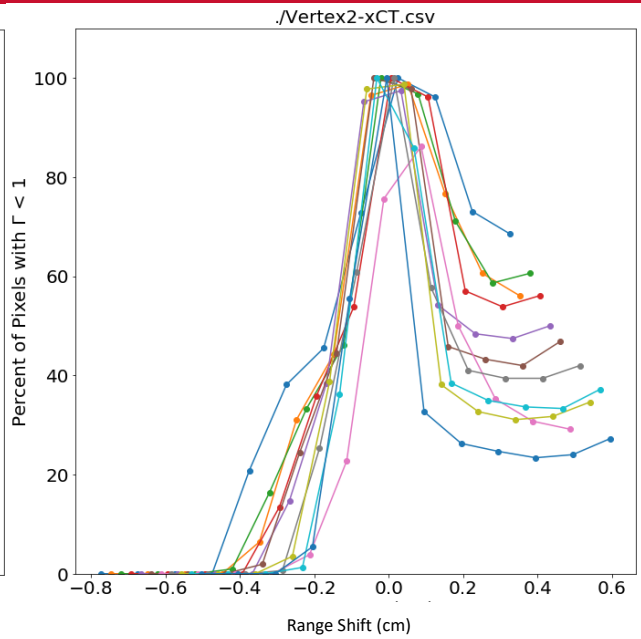
- Range Error = Treatment Plan depth – film depth
- Positive value implies protons undershot the predicted range

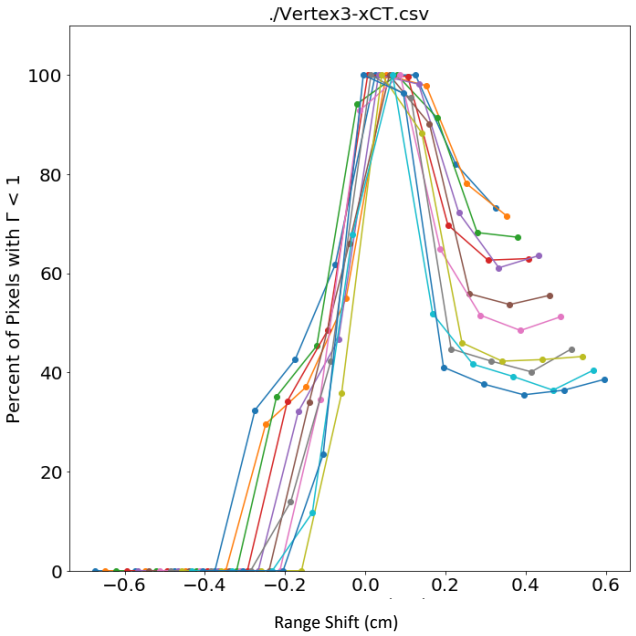
Fields

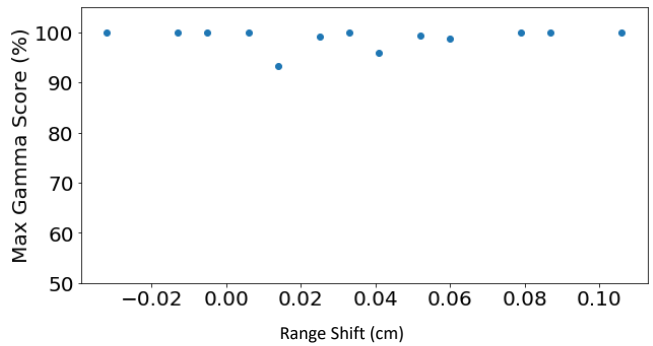
- Two fields were tested: Vertex and AP
  - Vertex: homogenous field
  - AP: heterogenous field
- Each film dose distribution was compared to the predicted dose distribution from xCT- and pCT-based treatment plans
- Three trials for each field

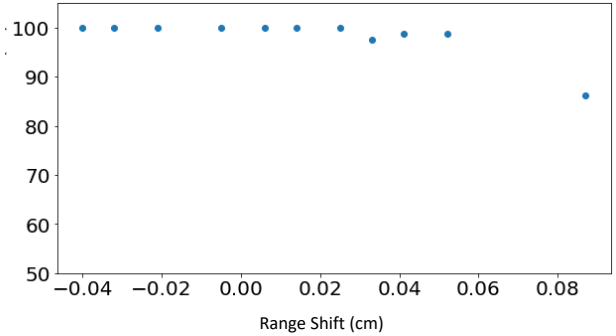
Vertex xCT Results

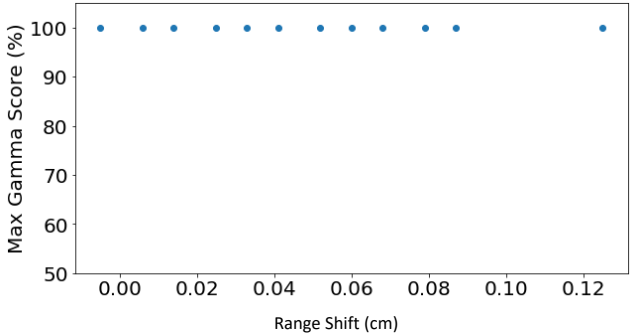










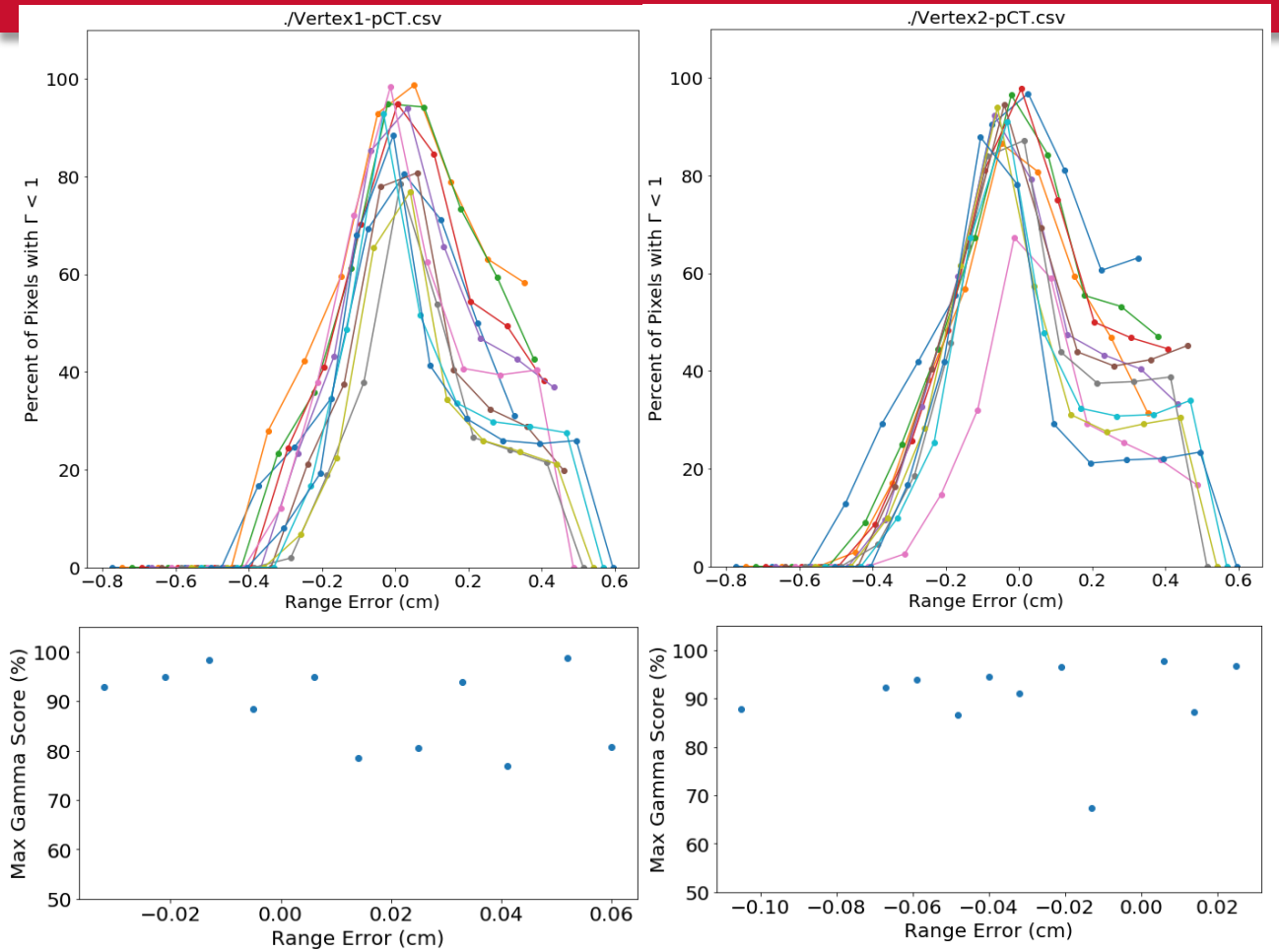


Range Error: 0.035 +/- 0.04 cm
Gamma Ave: 98.94 +/- 1.98 %

Range Error: 0.015 +/- 0.037 cm
Gamma Ave: 98.28 +/- 3.9 %

Range Error: 0.049 +/- 0.036 cm
Gamma Ave: 100.0 +/- 0.0 %

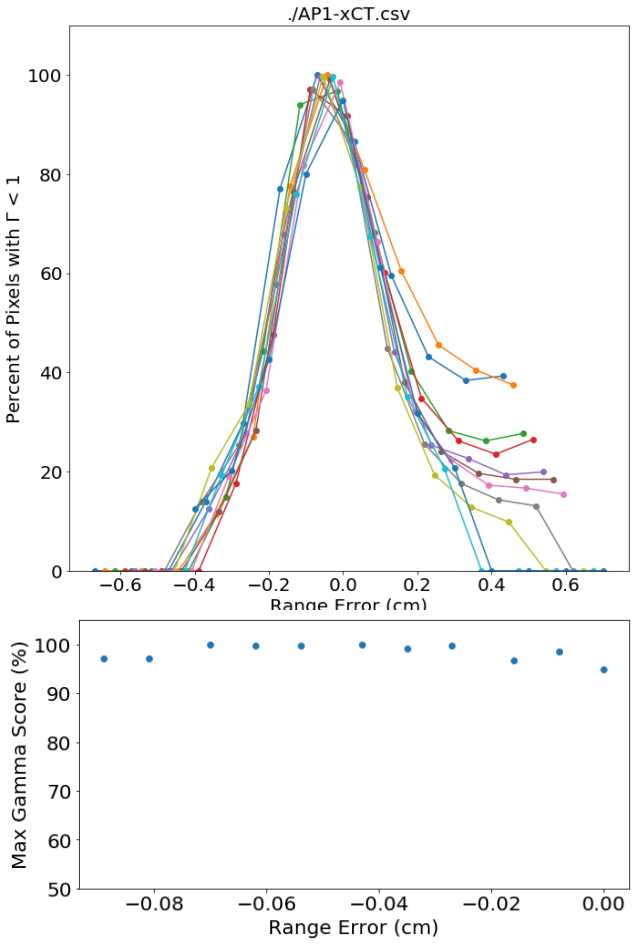
Vertex pCT Results

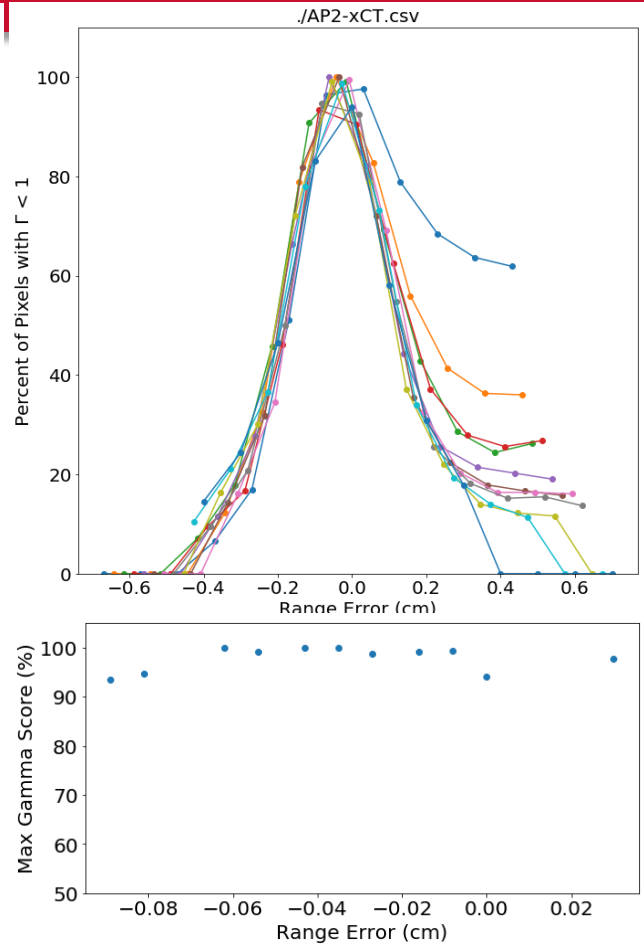


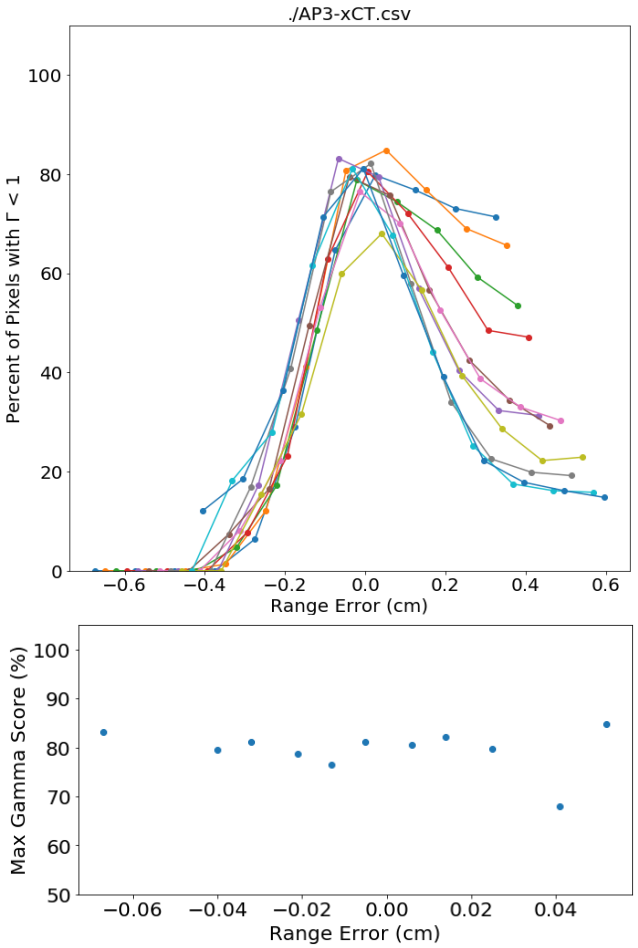
Range Error: 0.015 +/- 0.029 cm
Gamma Ave: 88.99 +/- 7.91 %

Range Error: -0.031 +/- 0.037 cm
Gamma Ave: 90.15 +/- 8.15 %

AP xCT Results





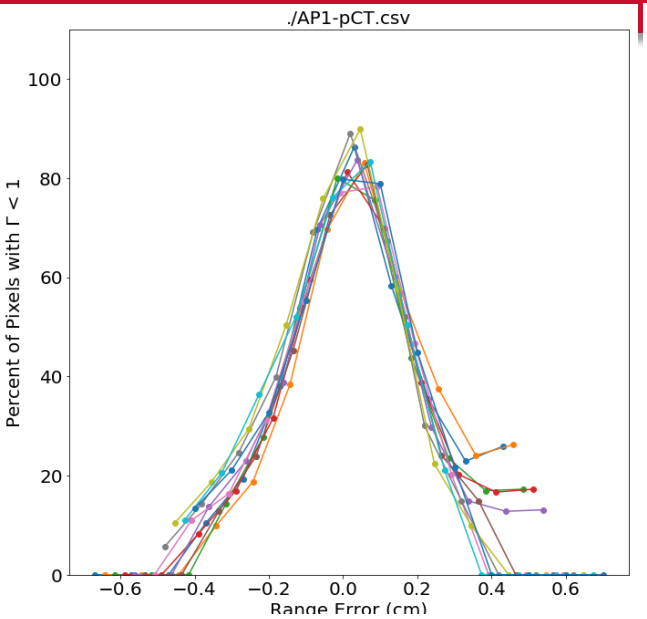


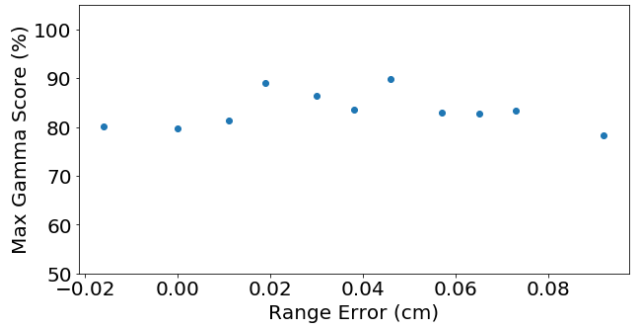
Range Error: -0.044 +/- 0.028 cm
Gamma Ave: 98.4 +/- 1.63 %

Range Error: -0.035 +/- 0.034 cm
Gamma Ave: 97.84 +/- 2.42 %

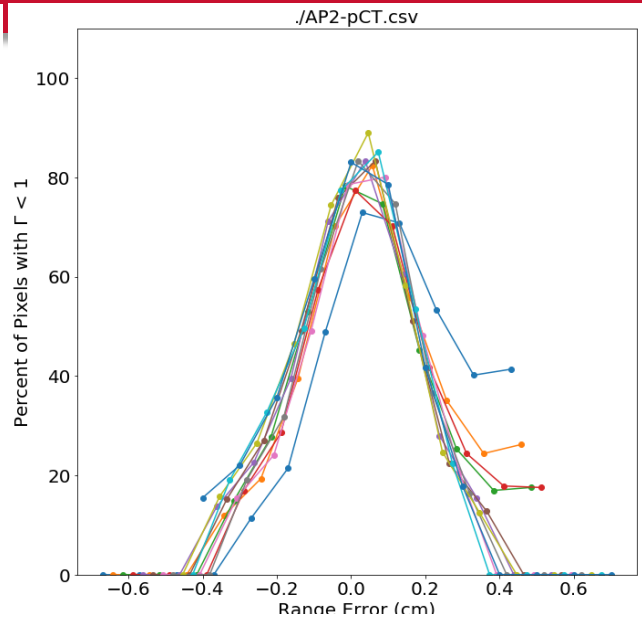
Range Error: -0.004 +/- 0.034 cm
Gamma Ave: 79.58 +/- 4.24 %

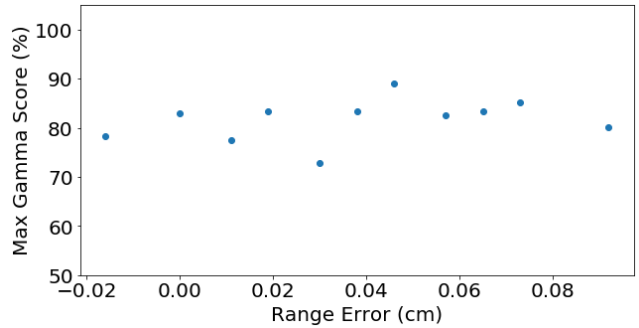
AP pCT Results



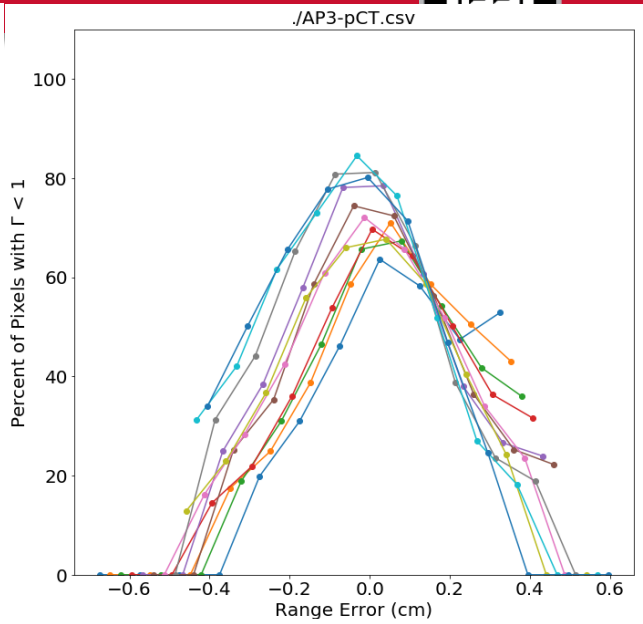


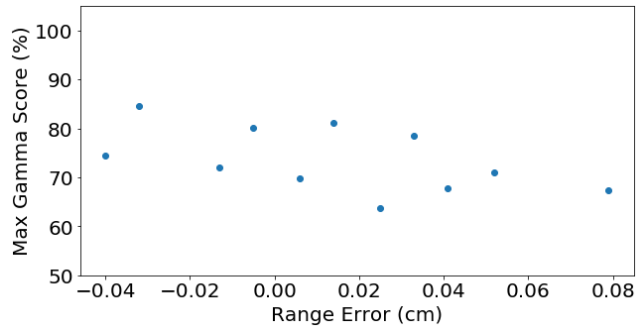
Range Error: 0.038 +/- 0.031 cm
Gamma Ave: 83.39 +/- 3.54 %





Range Error: 0.038 +/- 0.031 cm
Gamma Ave: 81.66 +/- 4.1 %





Range Error: 0.015 +/- 0.034 cm
Gamma Ave: 73.64 +/- 6.33 %

Results Overview

Vertex		
	Range Error (cm)	Gamma Score (%)
xCT	0.033 ± 0.023	99.07 ± 1.46
pCT	-0.008 ± 0.024	89.57 ± 5.68
AP		
	Range Error (cm)	Gamma Score (%)
xCT	-0.028 ± 0.019	91.94 ± 1.72
pCT	0.030 ± 0.018	79.56 ± 2.78

Conclusions & Future Work

- Proton range prediction from pCT- and xCT-based treatment plans are accurate to within 0.5 mm for two fields
- Phantom is tissue equivalent and therefore is biased towards a correct HU-to-RSP conversion

- Future Work:
  - Irradiate an AIO field through a region with a gold dental crown in or near the treatment field

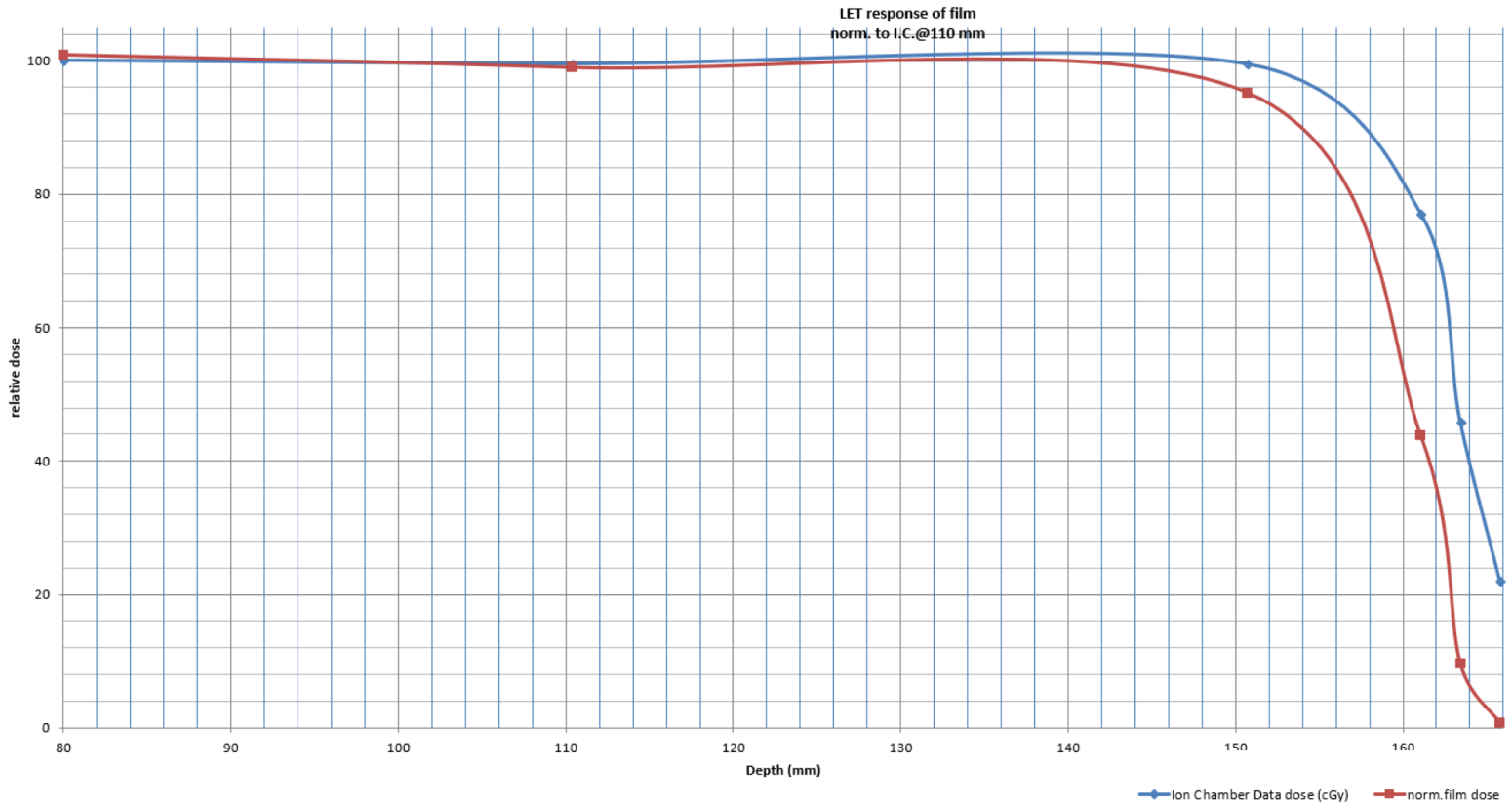
Acknowledgements

- Northwestern Medicine Chicago Proton Center: Mark Pankuch, Adit Panchal, Ming Gao
- Northern Illinois University: Mike Figora
- This work was supported by funding from Ion Beam Applications.

Thank you

Additional Slides

LET Response



LET Correction to Film