Northern Illinois University

An Algorithm to Calculate WET Distributions of Proton Therapy Patients from DICOM Files

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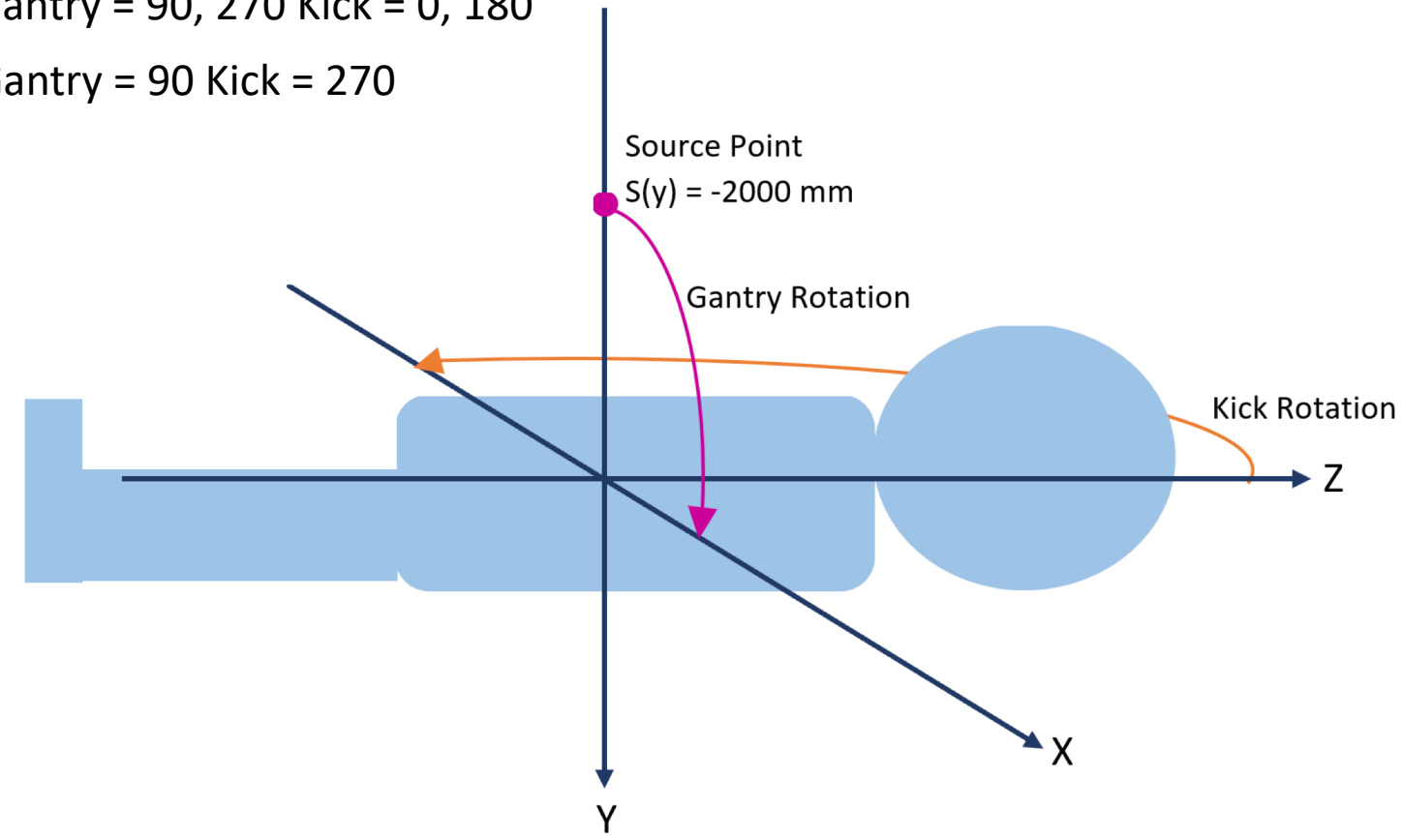
Motivation

- Proton imaging is limited by the energy of proton accelerators currently available in proton therapy clinics
- This study estimates the percent of patients that can be radiographed with a 230 MeV proton beam with 32 cm of water-equivalent range

Coordinate System

Lateral: Gantry = 90, 270 Kick = 0, 180

Vertex: Gantry = 90 Kick = 270



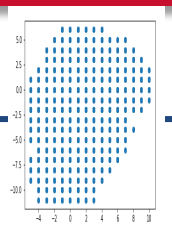
User defines SAD, HU to RSP conversion, input directory, output directory, step size.

Find all patients in input directory.

FOR EACH PATIENT

Read HU data, patient contour data, spot pattern data, isocenter

Calculated grid of 1 cm spaced points in spot pattern in BEV centered at isocenter.



FOR EACH TREATMENT BEAM

FOR EACH POINT, P(x,z), IN BEV GRID

Calculate divergent angles using Pythagorean theorem.

$$d_z = \tan^{-1}\frac{P_x}{SAD}$$

$$d_x = \tan^{-1}\frac{P_z}{SAD}$$

WHILE WITHIN PATIENT CONTOURS

Step

Euler rotate into divergent ray

$$R_{dx} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(d_x) & -\sin(d_x) \\ 0 & \sin(d_x) & \cos(d_x) \end{bmatrix}$$

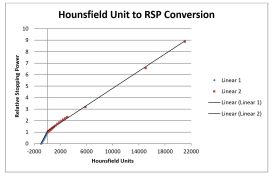
$$R_{dz} = \begin{bmatrix} \cos(d_z) & -\sin(d_z) & 0 \\ \sin(d_z) & \cos(d_z) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

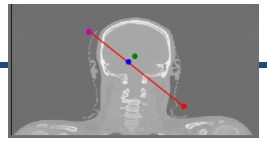
Euler rotate according to gantry and kick angles.

$$R_g = \begin{bmatrix} \cos(-g) & -\sin(-g) & 0 \\ \sin(-g) & \cos(-g) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$R_k = \begin{bmatrix} \cos(k) & 0 & \sin(k) \\ 0 & 1 & 0 \\ -\sin(k) & 0 & \cos(k) \end{bmatrix}$$

Pull HU at that point and convert to RSP

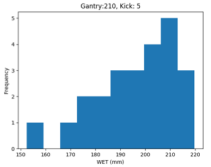




Multiply step size by RSP and sum over all steps along the ray to get WET value.

$$WET = \sum_{steps} RSP * StepSize$$

Collect WET for each point in BEV grid into histogram for analysis



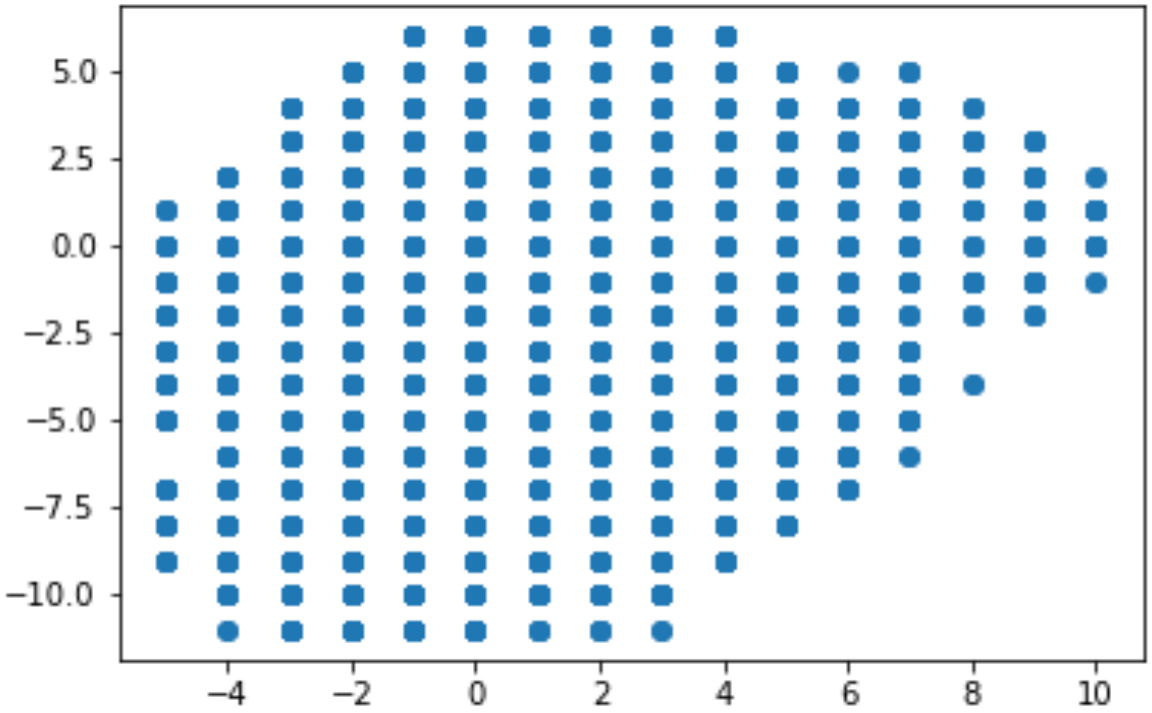
Algorithm - Input

- User defines:
  - Source axial distance
  - HU to RSP curve
  - Input directory
- Automatically loop through all directories and subdirectories in input directory

- From each patient CT file in input directory:
  - HU data
  - Patient contour data
  - Spot pattern or aperture data
  - Isocenter
  - Gantry angles
  - Patient couch (kick) angles
- No need to anonymize patient files

Algorithm – Spot data

- Calculate 1 cm spaced grid within extents of spot data (PBS) or aperture (Scanning beam) centered about isocenter in BEV.



Algorithm – Step and Rotate

- 5 steps per pixel
- Step along y axis then rotate to beam path with Euler matrices

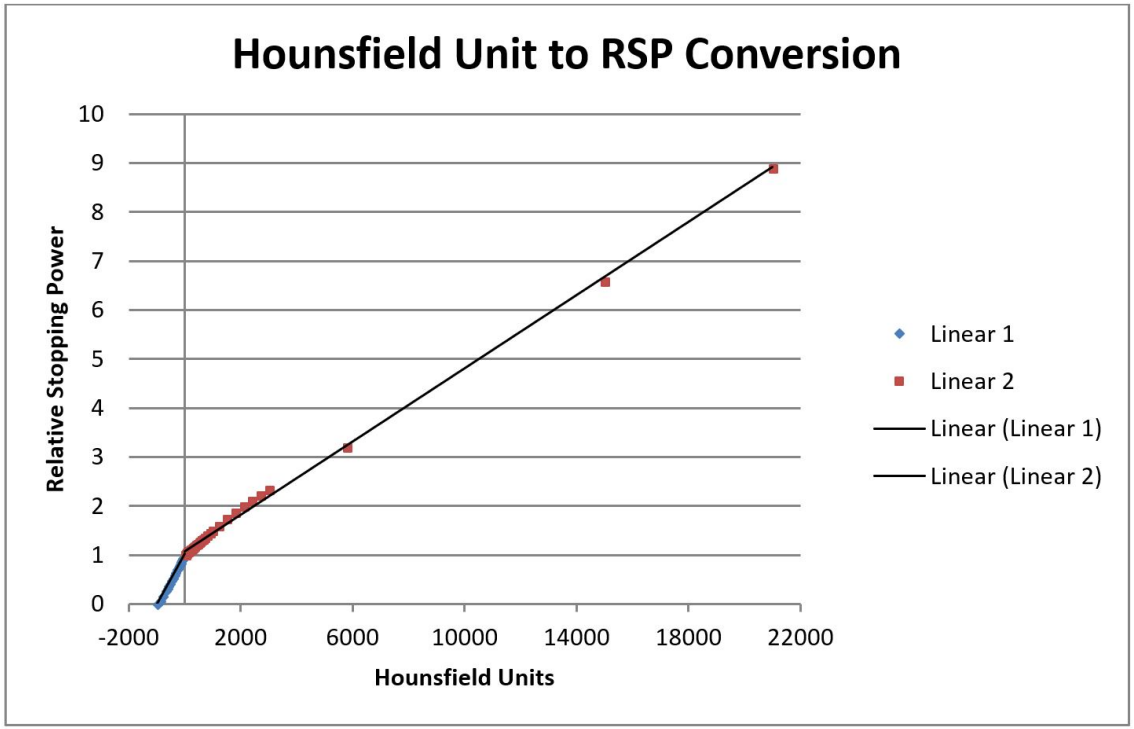
$$R_{dx} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(d_x) & -\sin(d_x) \\ 0 & \sin(d_x) & \cos(d_x) \end{bmatrix}$$

$$R_{dz} = \begin{bmatrix} \cos(d_z) & -\sin(d_z) & 0 \\ \sin(d_z) & \cos(d_z) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$R_g = \begin{bmatrix} \cos(-g) & -\sin(-g) & 0 \\ \sin(-g) & \cos(-g) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$R_k = \begin{bmatrix} \cos(k) & 0 & \sin(k) \\ 0 & 1 & 0 \\ -\sin(k) & 0 & \cos(k) \end{bmatrix}$$

Algorithm – HU to WET

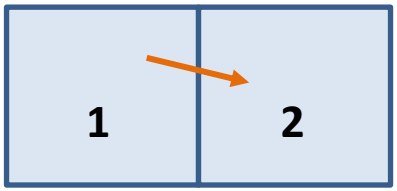


$$WET = \sum_i (RSP)_i \cdot L$$

$$L = 0.2 * \sqrt{(\cos(-g)\cos(k))^2 + (\sin(-g))^2 + (\cos(-g)\sin(k))^2}$$

Measurement Errors

- Stepping across pixel boundaries

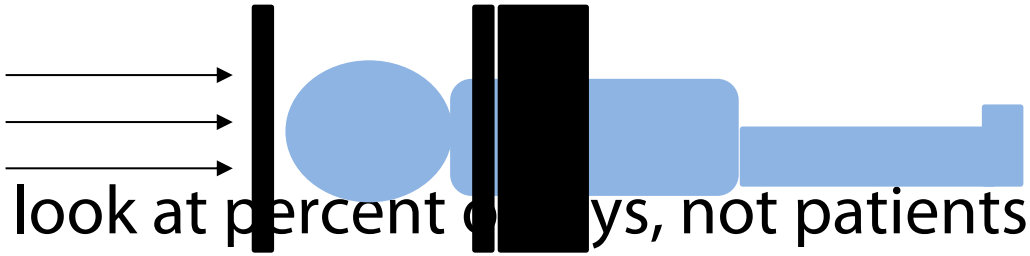


- HU to RSP curve is not perfect
- Scattering not taken into account

- Tests on a known cube showed all errors to be within 1 mm.

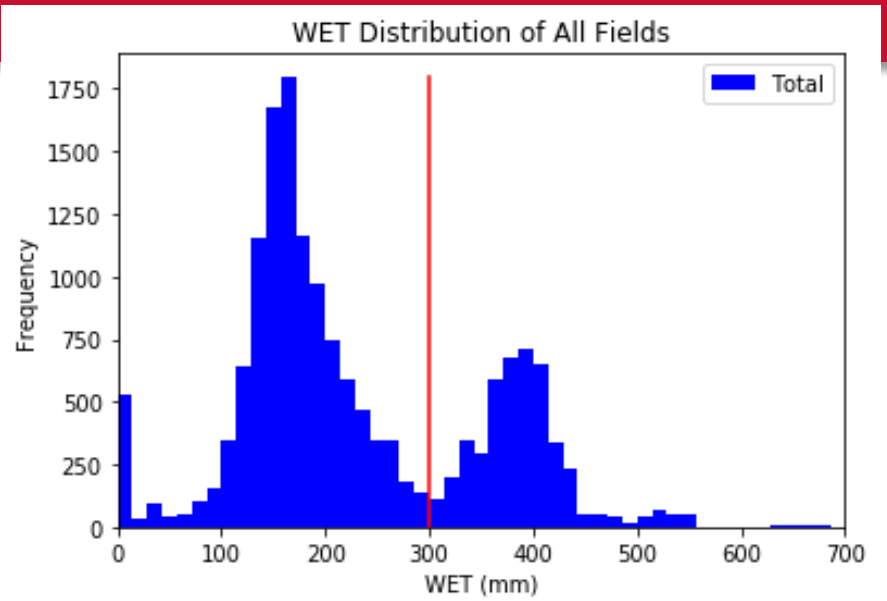
Biases

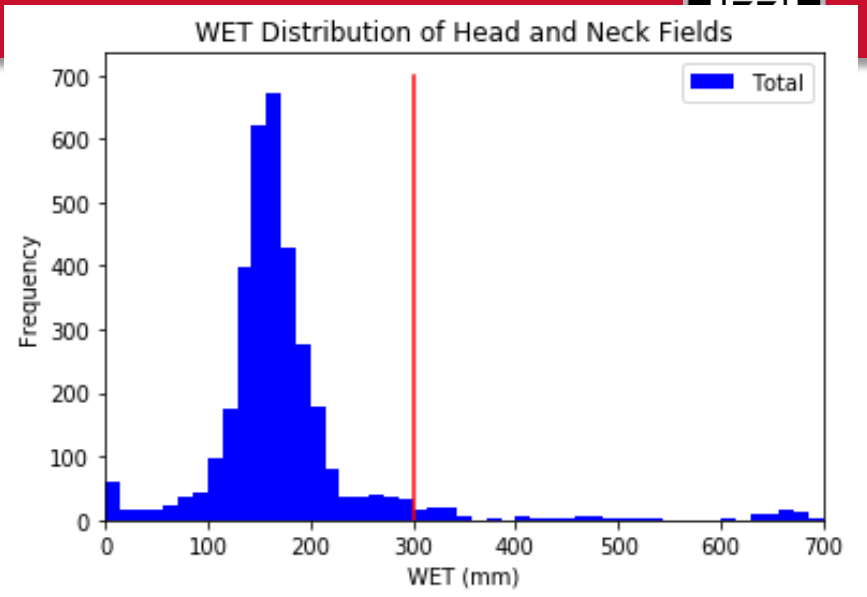
- All patients and treatment plans are from NWMCPC
  - May not be representative of full population
- Nothing in program for collision control

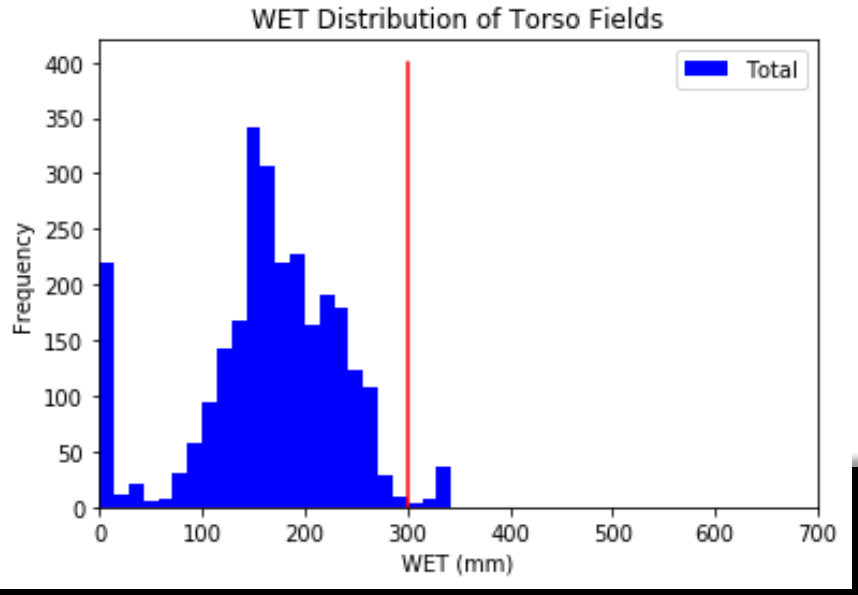


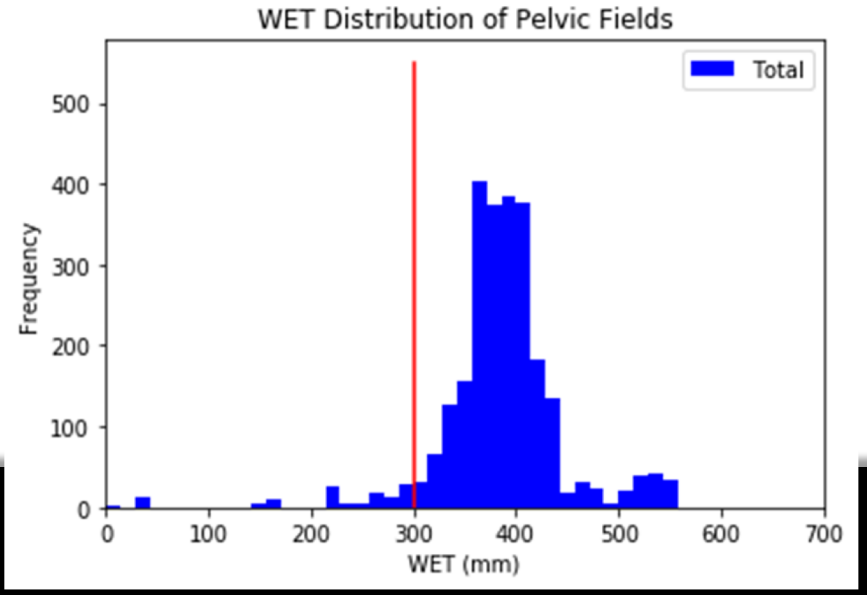
- We look at percent of days, not patients
- Cutoff at 30 cm
  - Possibly could image 30.5 cm

Results


WET Distribution of All Fields
Total
Frequency
WET (mm)
0
250
500
750
1000
1250
1500
1750
0
100
200
300
400
500
600
700

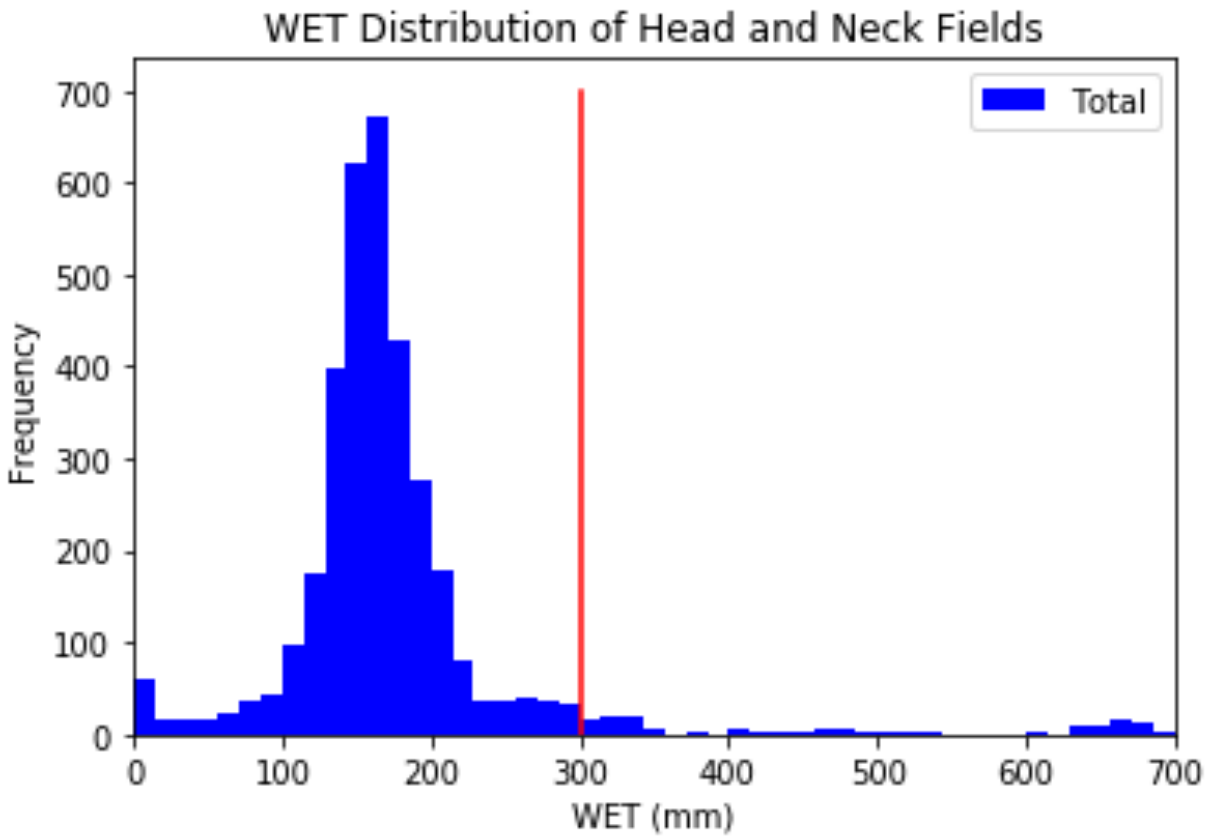

WET Distribution of Head and Neck Fields
Total
Frequency
WET (mm)
0
100
200
300
400
500
600
700
0
100
200
300
400
500
600
700


WET Distribution of Torso Fields
Total
Frequency
WET (mm)
0
50
100
150
200
250
300
350
400
0
100
200
300
400
500
600
700

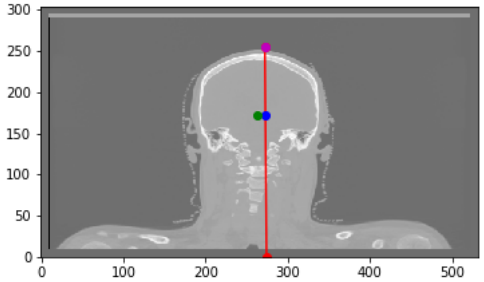

WET Distribution of Pelvic Fields
Total
Frequency
WET (mm)
0
100
200
300
400
500
0
100
200
300
400
500
600
700

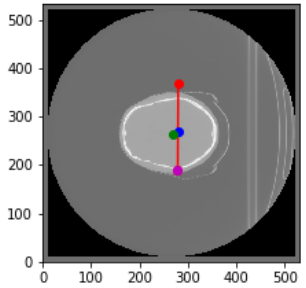
Results – Head and Neck

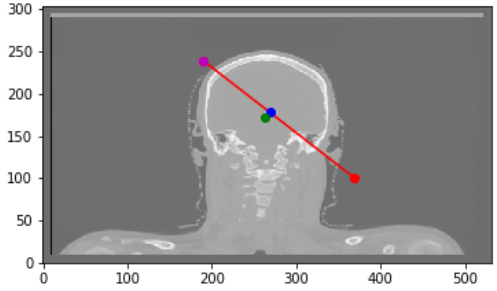
Patients: 229
Fields: 497
Total Rays: 3481
Imageable: 3322
Percent: 95.4%

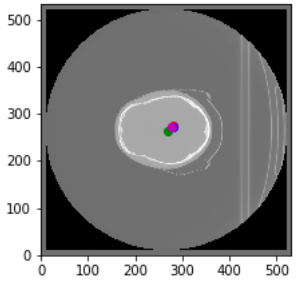


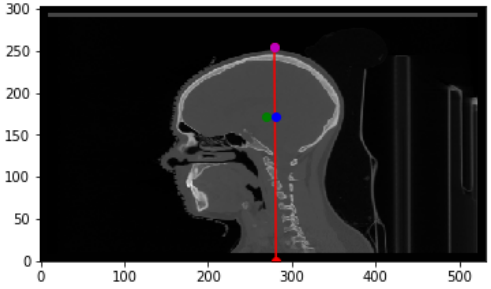
Collisions

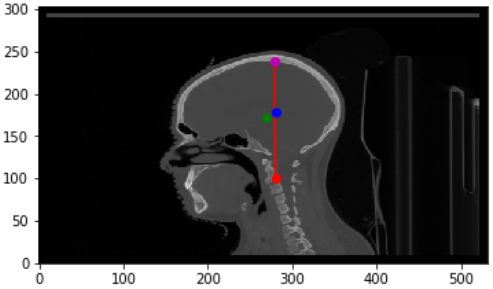

300
250
200
150
100
50
0
0
100
200
300
400
500

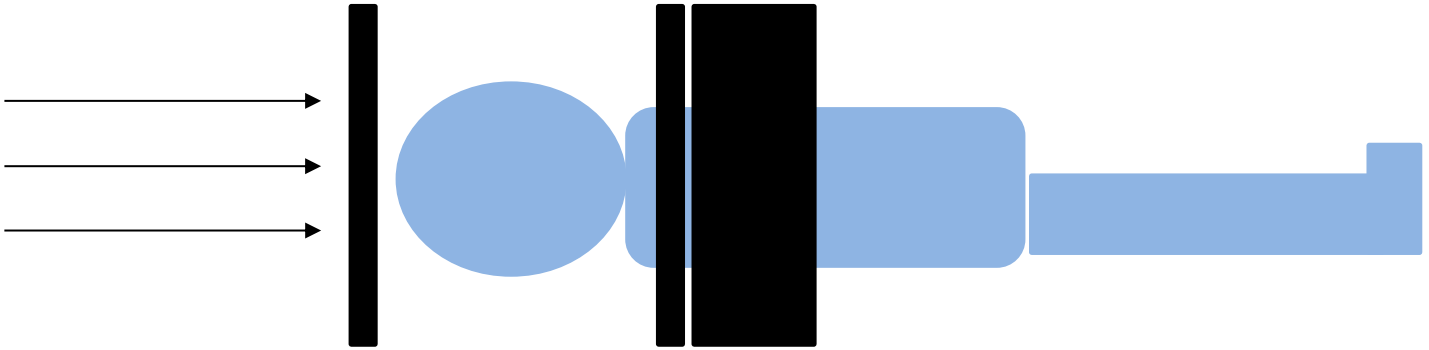

500
400
300
200
100
0
0
100
200
300
400
500


300
250
200
150
100
50
0
0
100
200
300
400
500


500
400
300
200
100
0
0
100
200
300
400
500

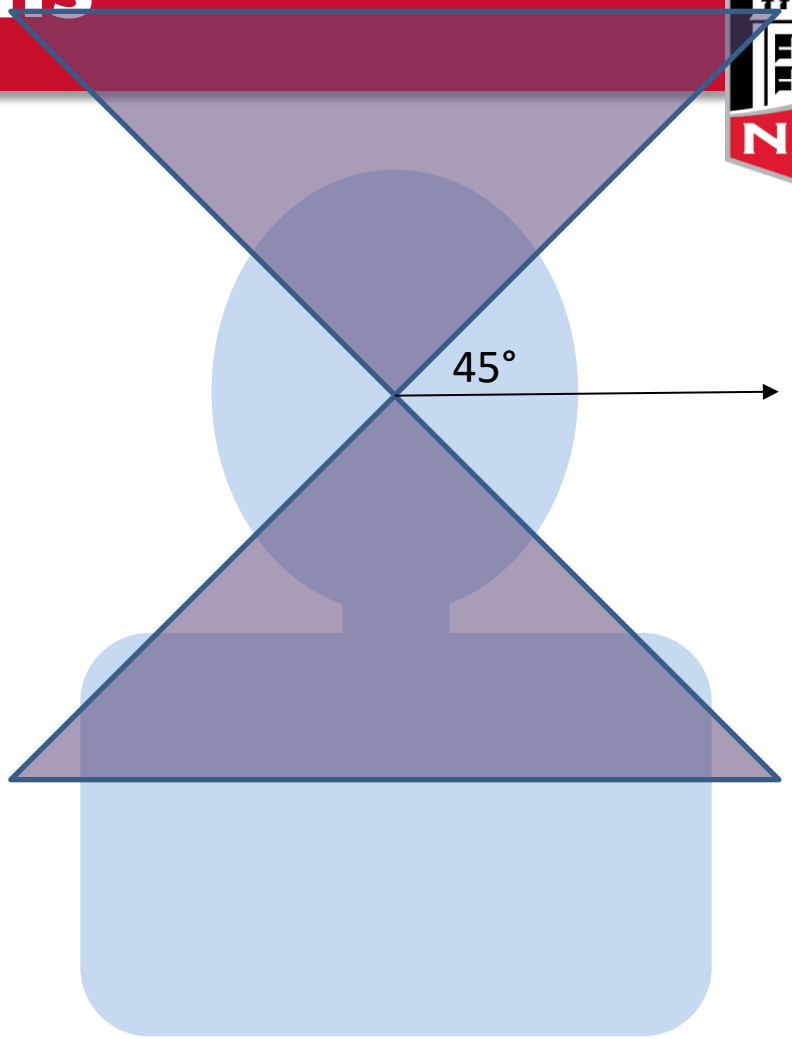

300
250
200
150
100
50
0
0
100
200
300
400
500


300
250
200
150
100
50
0
0
100
200
300
400
500



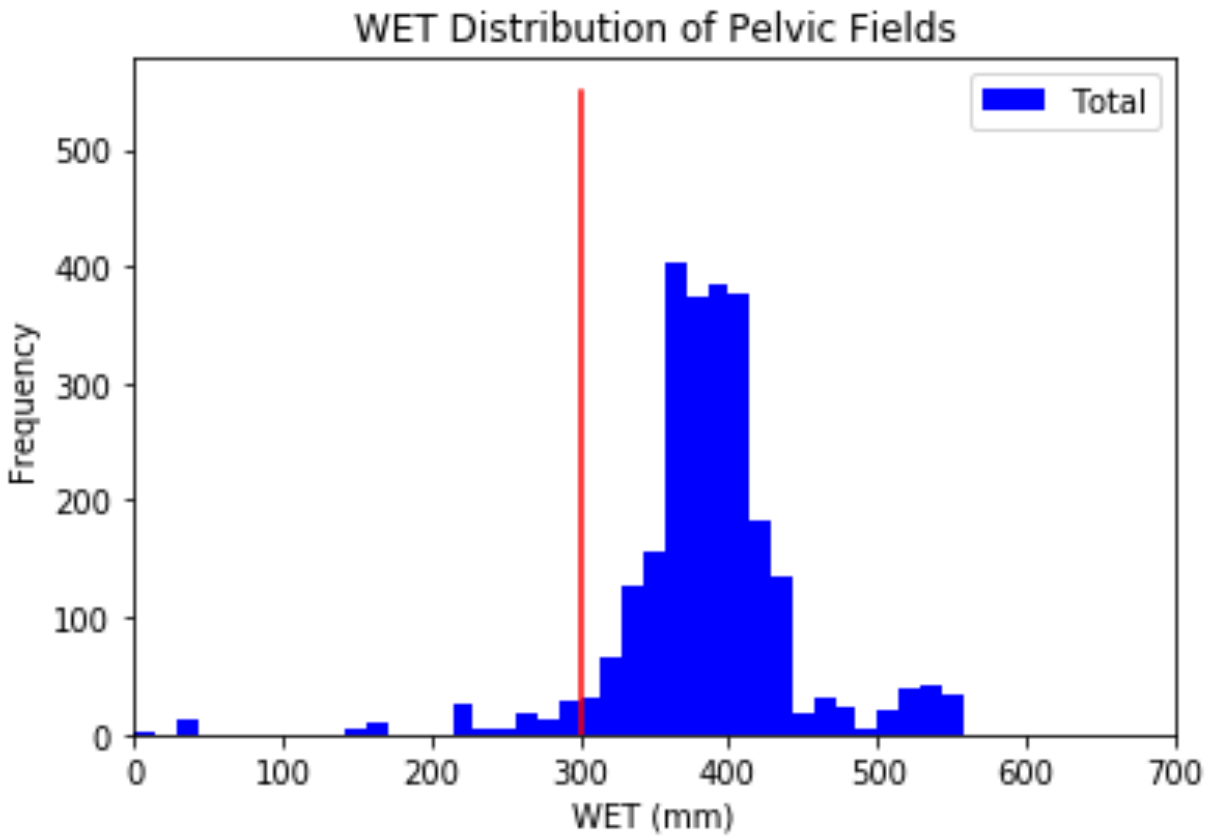
Head and Neck Fails

- G = 90, K = 225
- G = 90, K = 260
- G = 90, K = 265
- G = 90, K = 270
- G = 90, K = 275
- G = 90, K = 315
- G = 90, K = 325
- G = 270, K = 70



Results - Pelvic

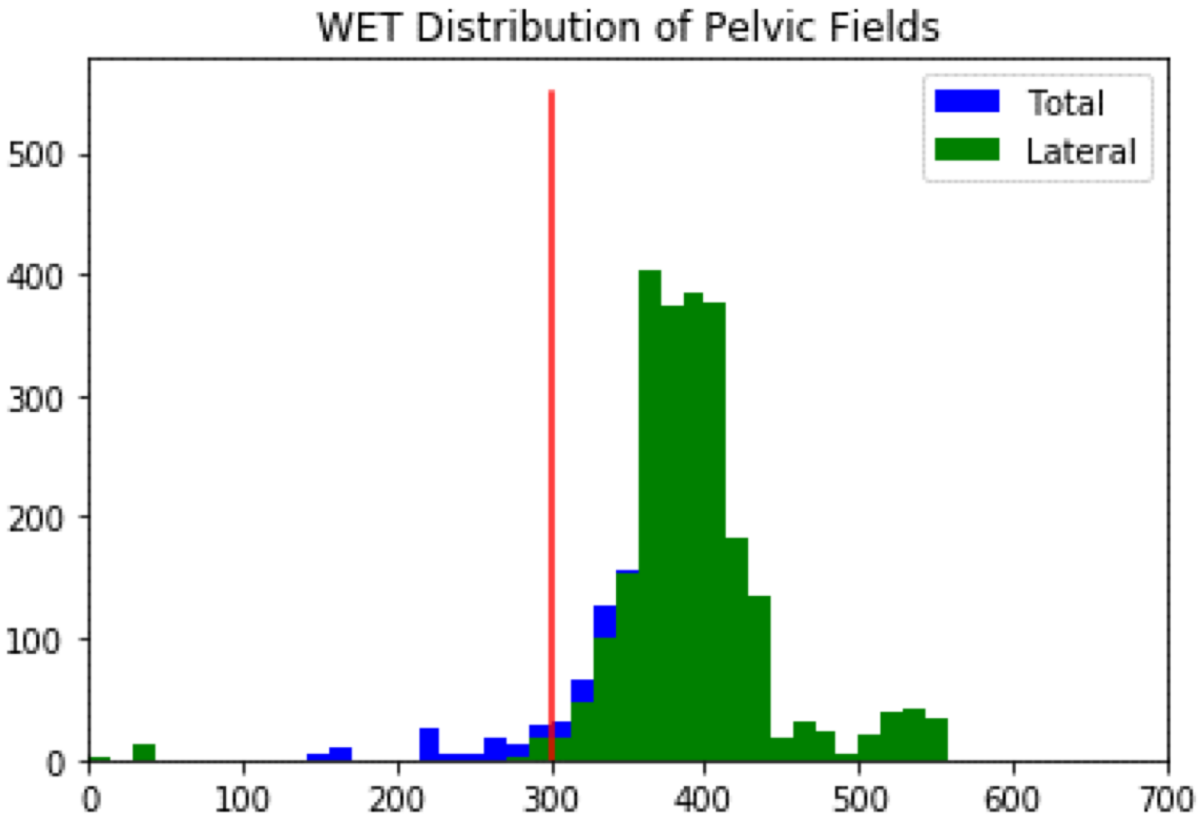
Patients: 208
Fields: 415
Total Rays: 2577
Imageable: 128
Percent: 5.0%



Results - Pelvic

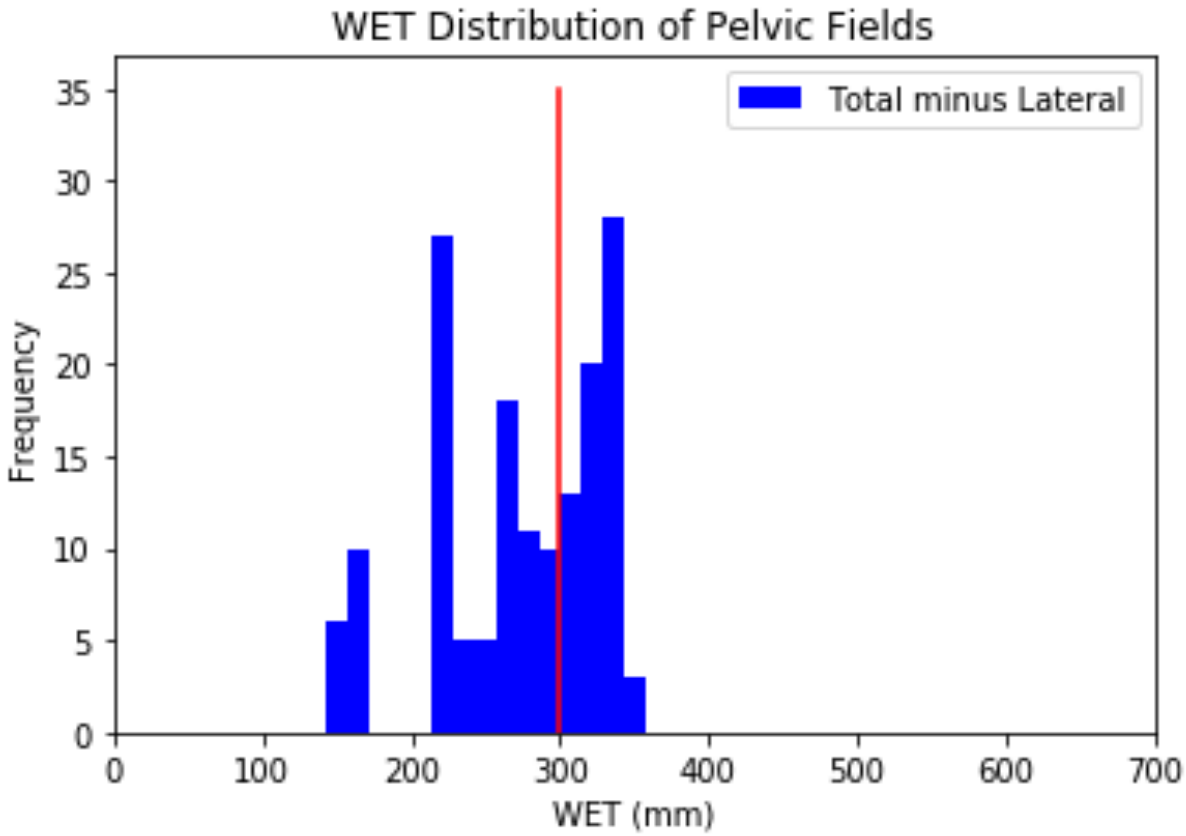
Patients: 208
Fields: 415
Total Rays: 2577
Imageable: 128
Percent: 5.0%

Lateral rays: 2421

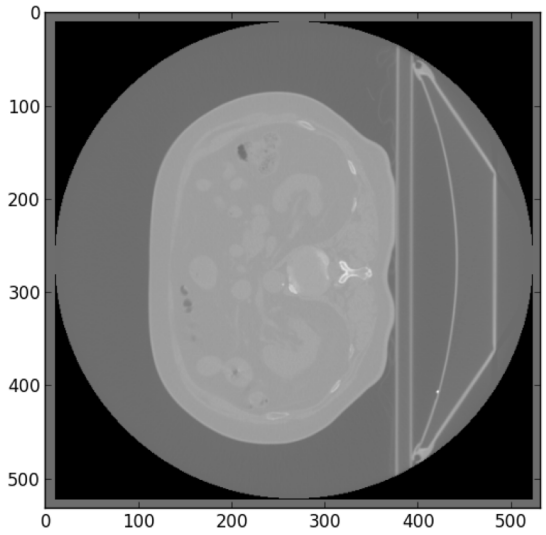


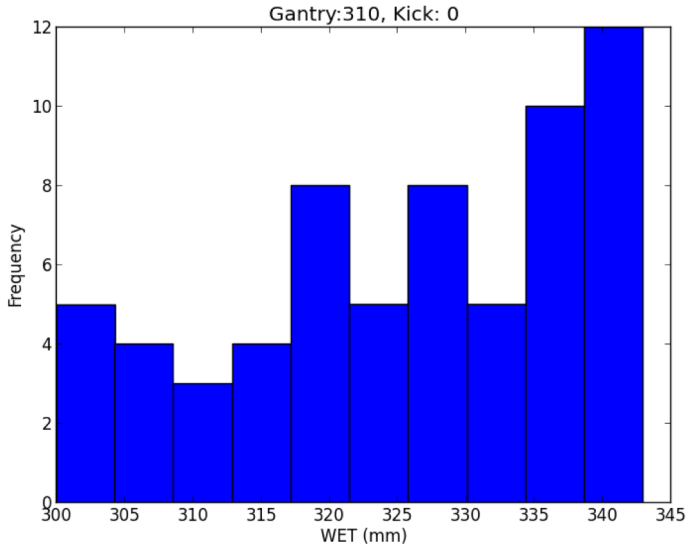
Results - Pelvic

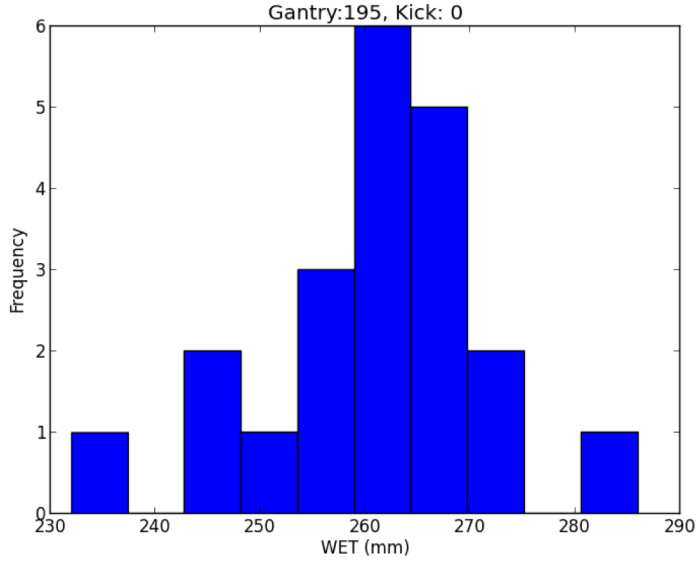
Total Rays: 156
Imageable: 92
Percent: 59.0%

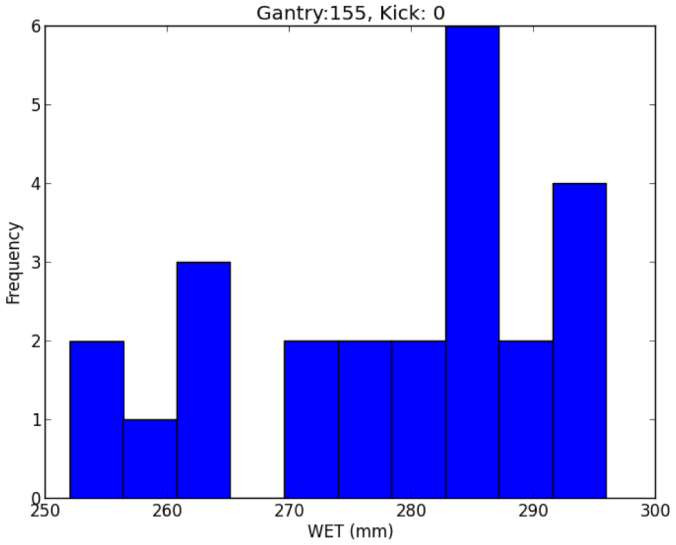


Lateral


0
100
200
300
400
500
0
100
200
300
400
500


Gantry:310, Kick: 0
Frequency
WET (mm)
0
2
4
6
8
10
12
300
305
310
315
320
325
330
335
340
345


Gantry:195, Kick: 0
Frequency
WET (mm)
0
1
2
3
4
5
6
230
240
250
260
270
280
290


Gantry:155, Kick: 0
Frequency
WET (mm)
0
1
2
3
4
5
6
250
260
270
280
290
300

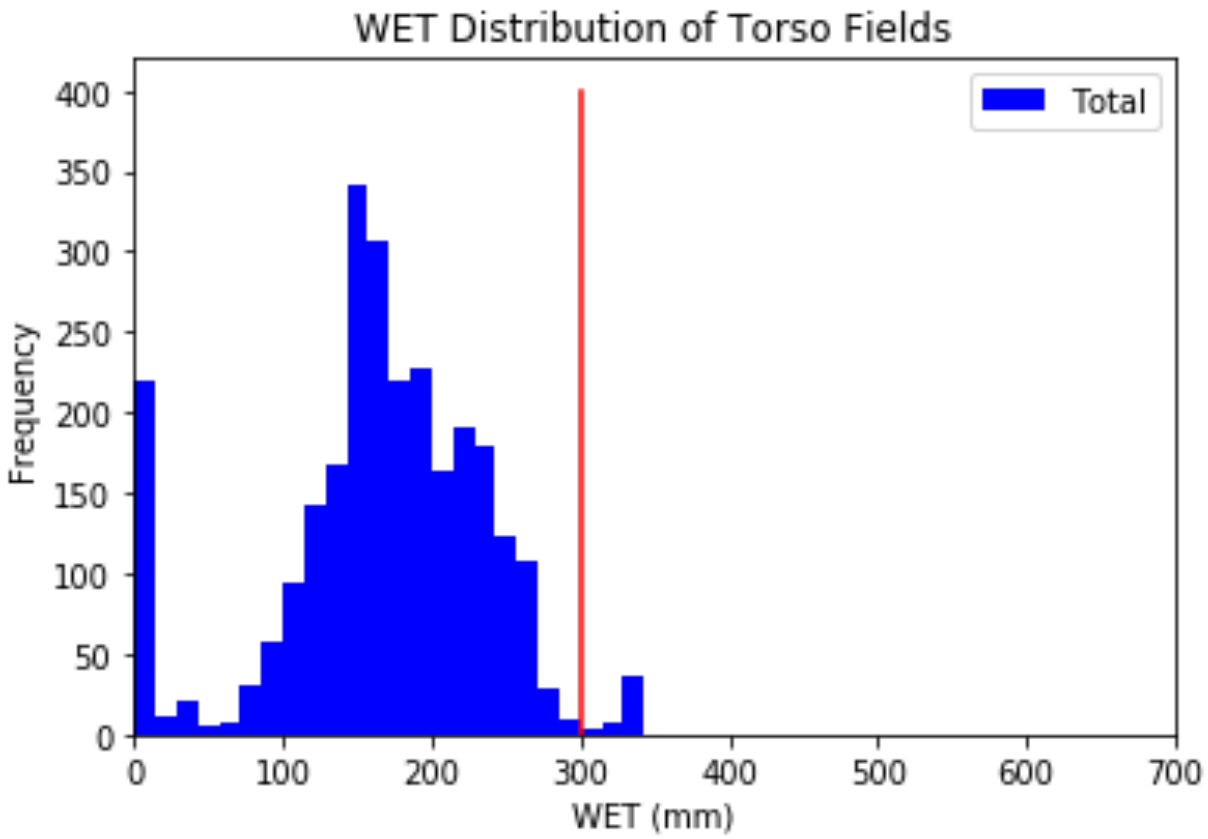
NWMCPC Patients

- Could be a preference for certain fields over others at NWMCPC
  - May not be the case for other centers

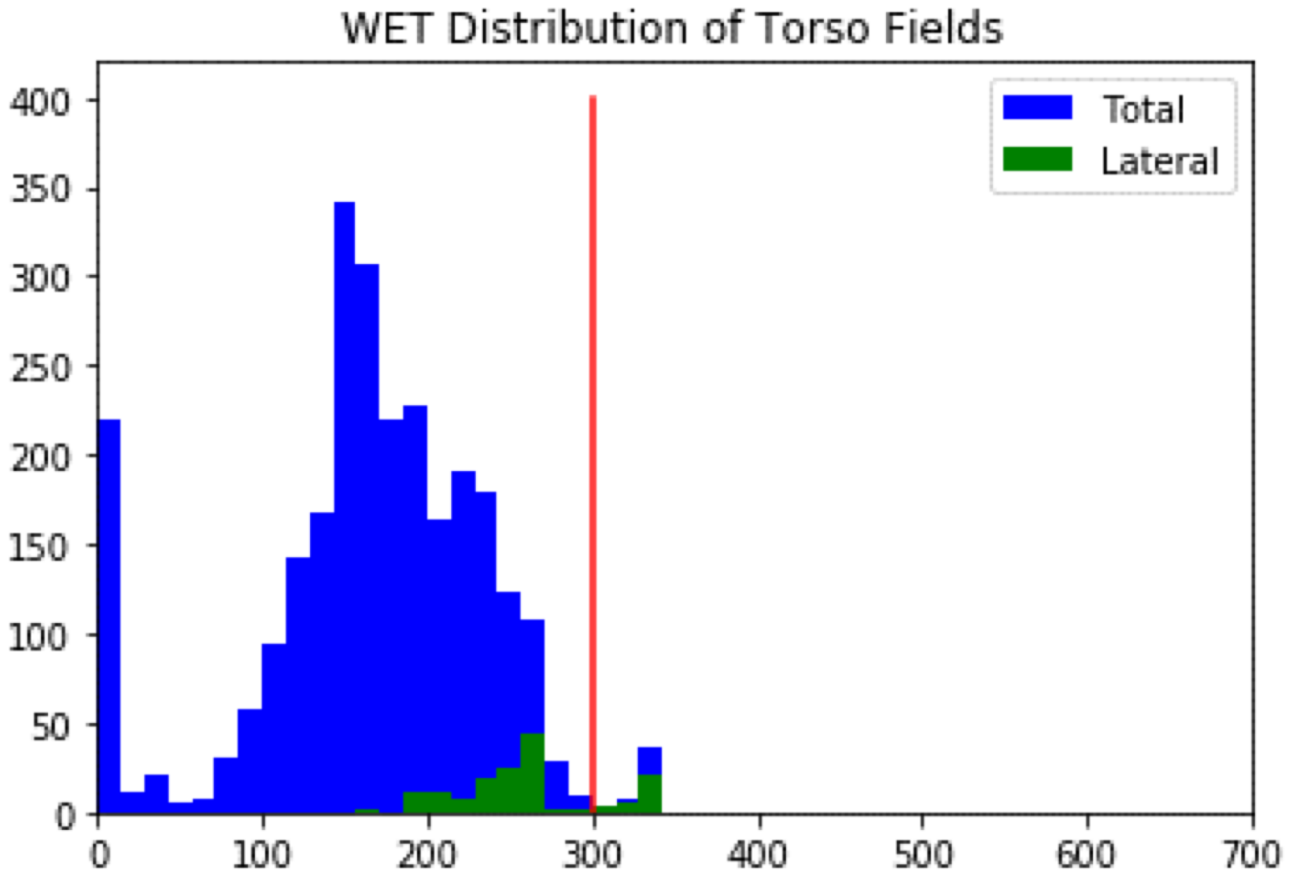
- **Call for help!**
  - If you would like to collaborate and share treatment plans with us, let me know.

Results - Torso

Patients: 117
Fields: 199
Total Rays: 2705
Imageable: 2659
Percent: 98.2%



Results - Torso



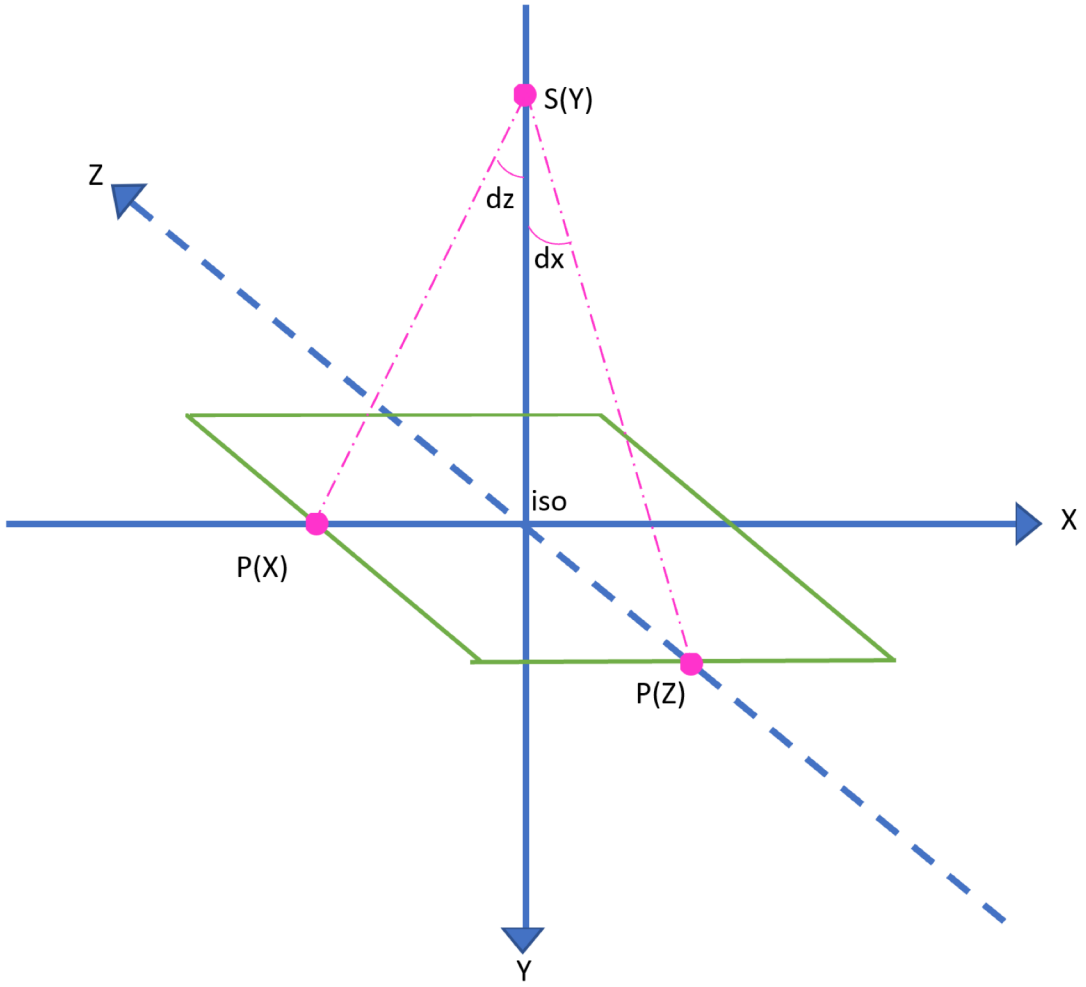
Conclusions and Future Work

- Overall, these results are promising
  - Head & Neck – 95%
    - Need to incorporate collision control
  - Pelvis – 5%
    - Jumps to >50% without lateral fields
  - Torso – 98%
- Future Work
  - Patients from other centers
  - Extend to pCT
  - Accelerator Plans for ProtonVDA detector

Acknowledgements

- Jake Ricci
- Mark Pankuch
- George Coutrakon
- Northwestern Medicine Chicago Proton Center
- Adit Panchal
- John Winans
- Rahul Kalle, Adam Maris, Gabrielle Franco

Additional Slides – Divergent Angles

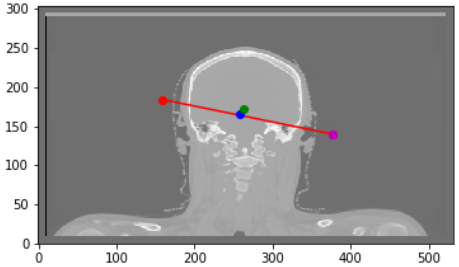
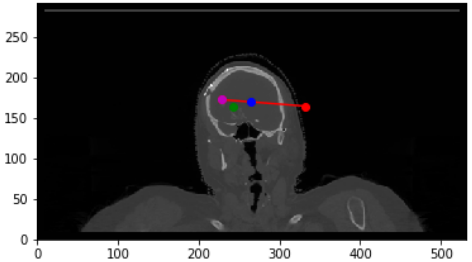
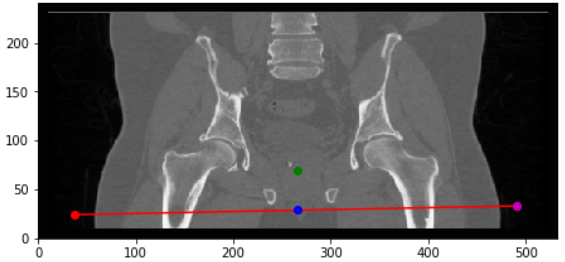
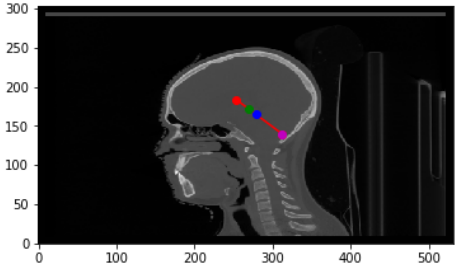
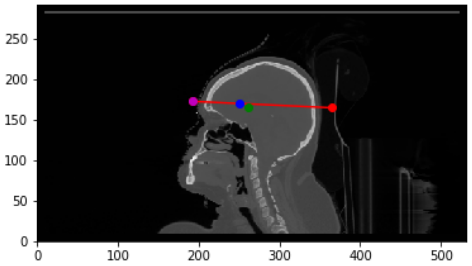
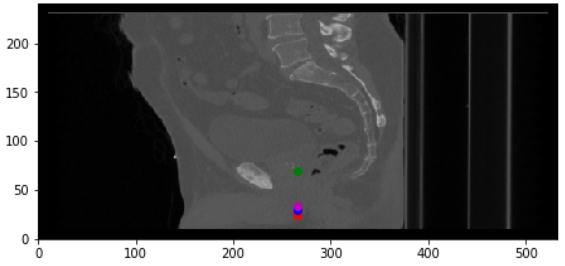
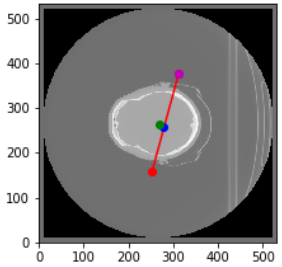
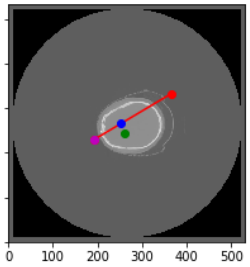
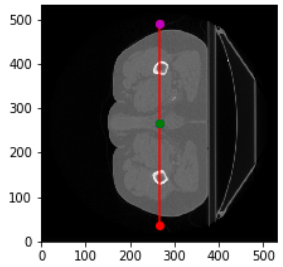


$$dx = \tan^{-1}\left(\frac{P(z)}{S(y)}\right)$$

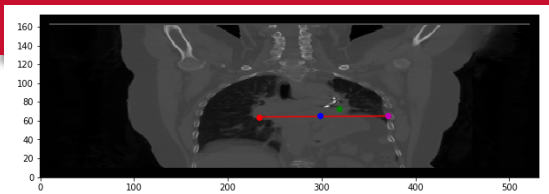
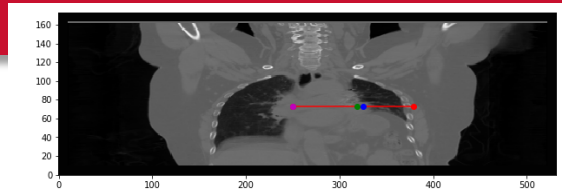
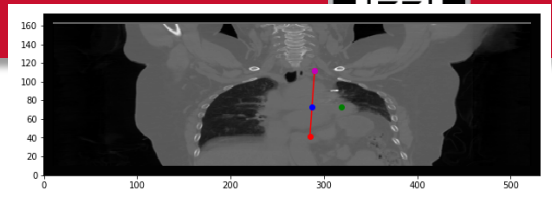
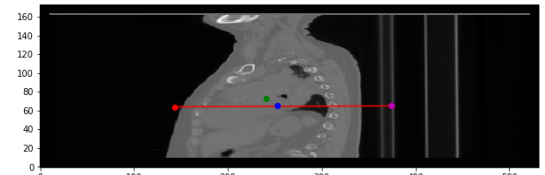
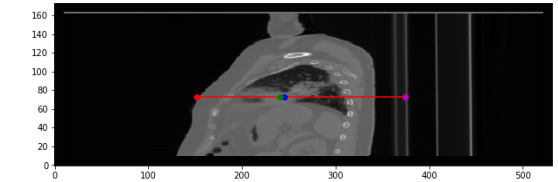
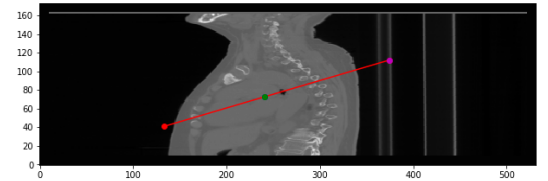
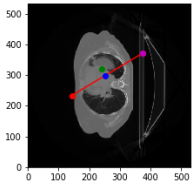
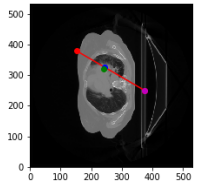
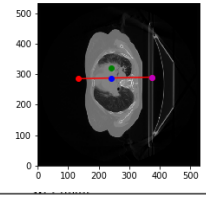
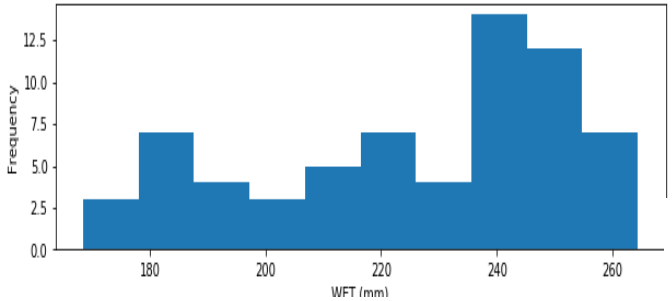
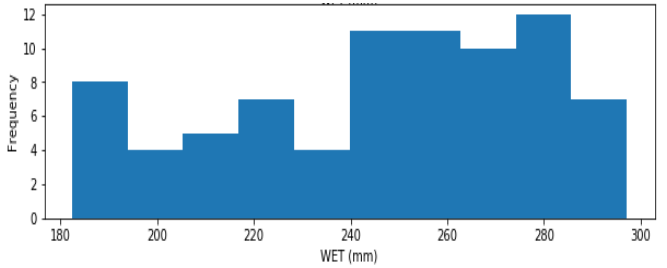
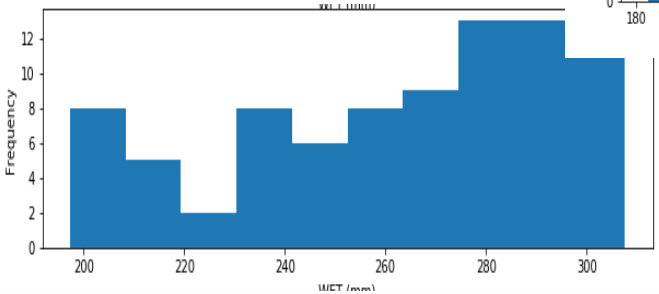
$$dz = \tan^{-1}\left(\frac{P(x)}{S(y)}\right)$$

Additional Slides - Algorithm - Contours

- Stops after 20 consecutive steps outside of the patient contours

Additional Slides – Rays v Patients

Lung Case: 230 total Rays, 94.7 % pass

Additional Slides - Flashovers