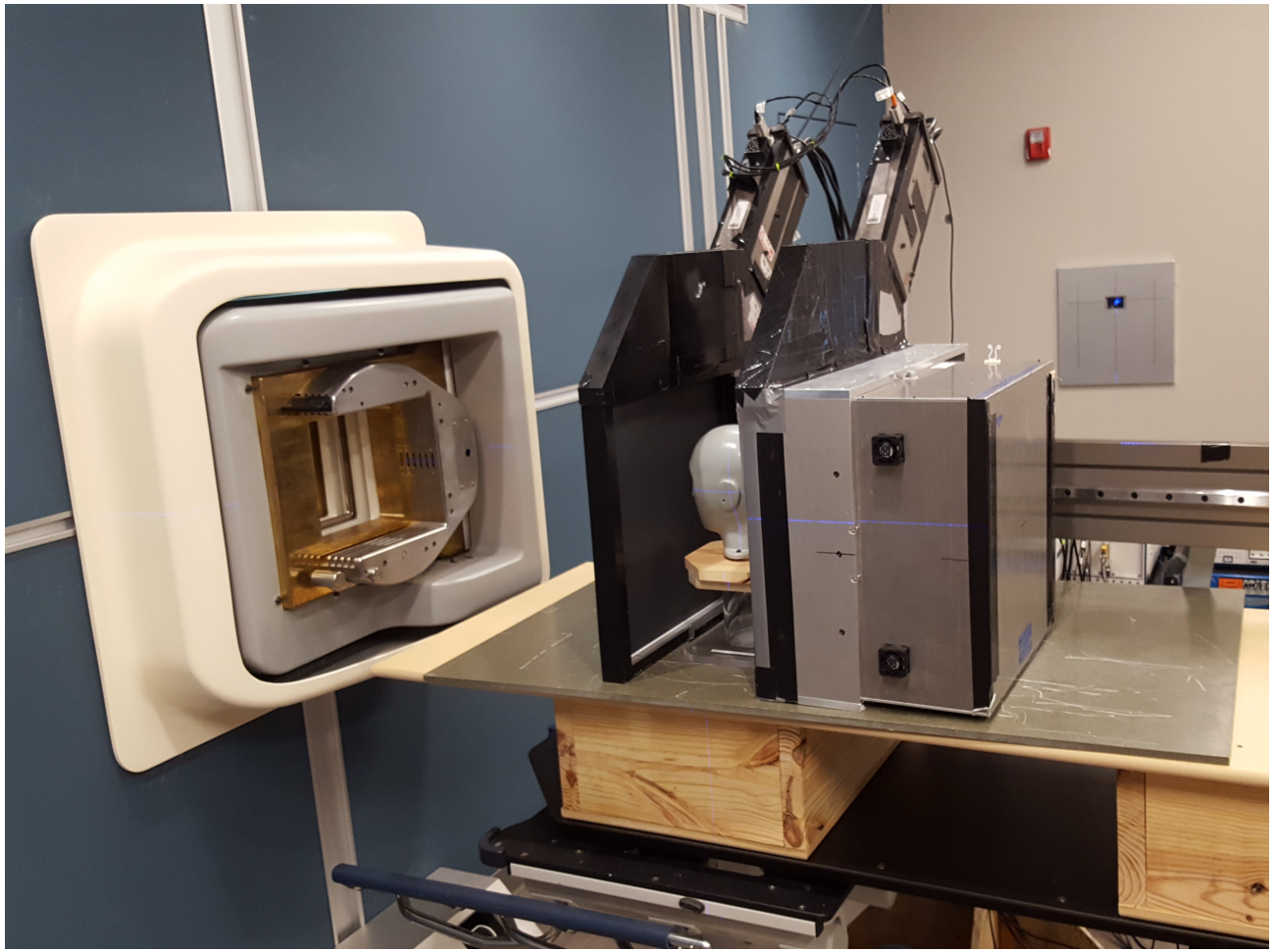
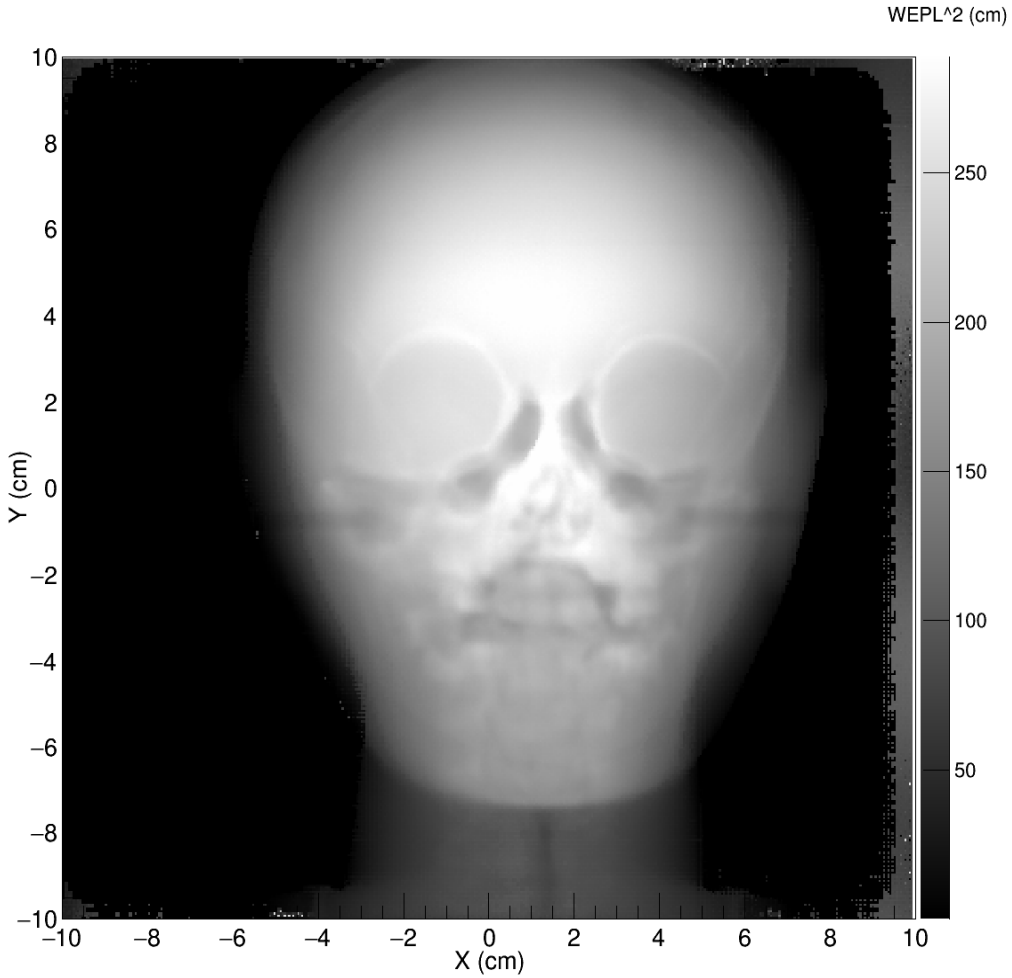
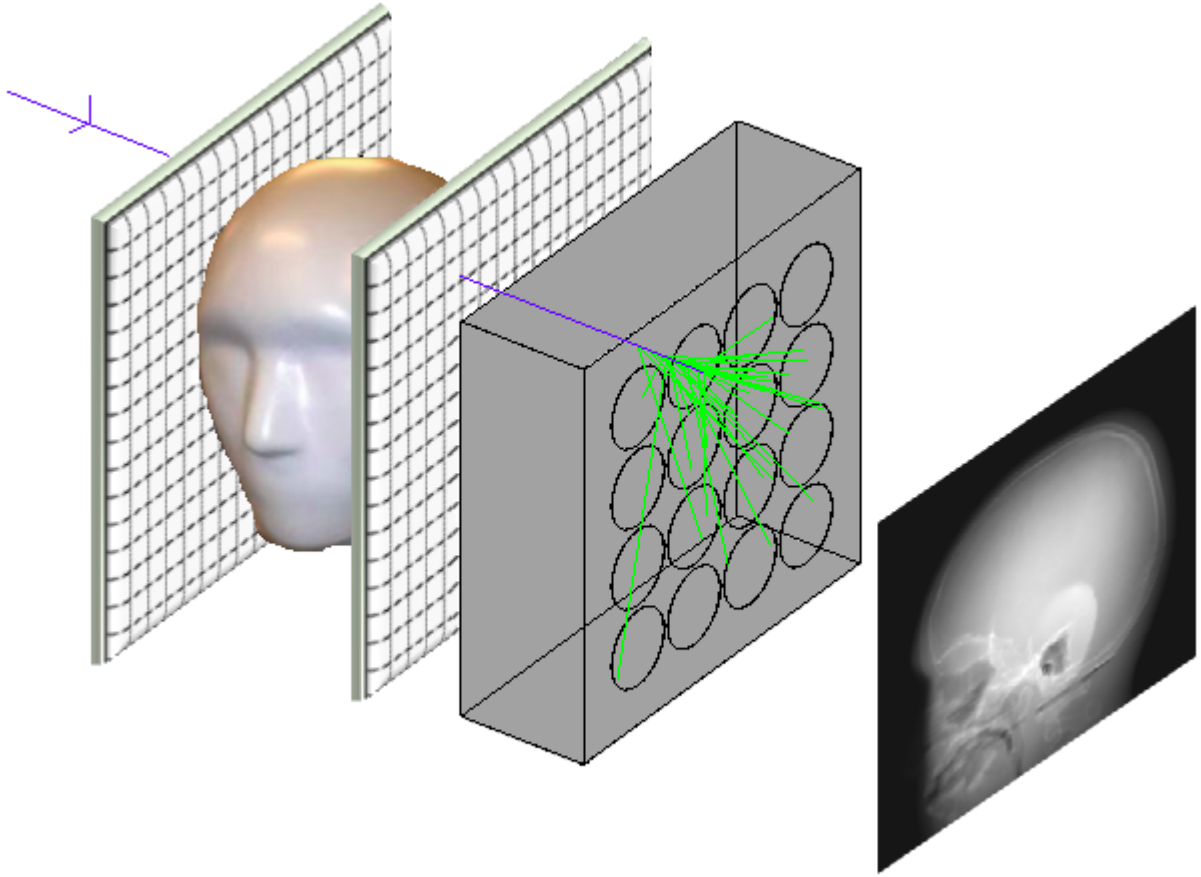
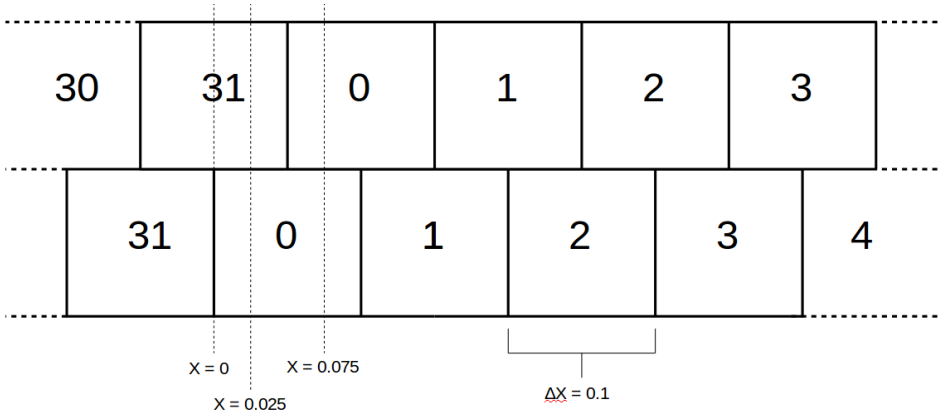
ProtonVDA Radiography Results







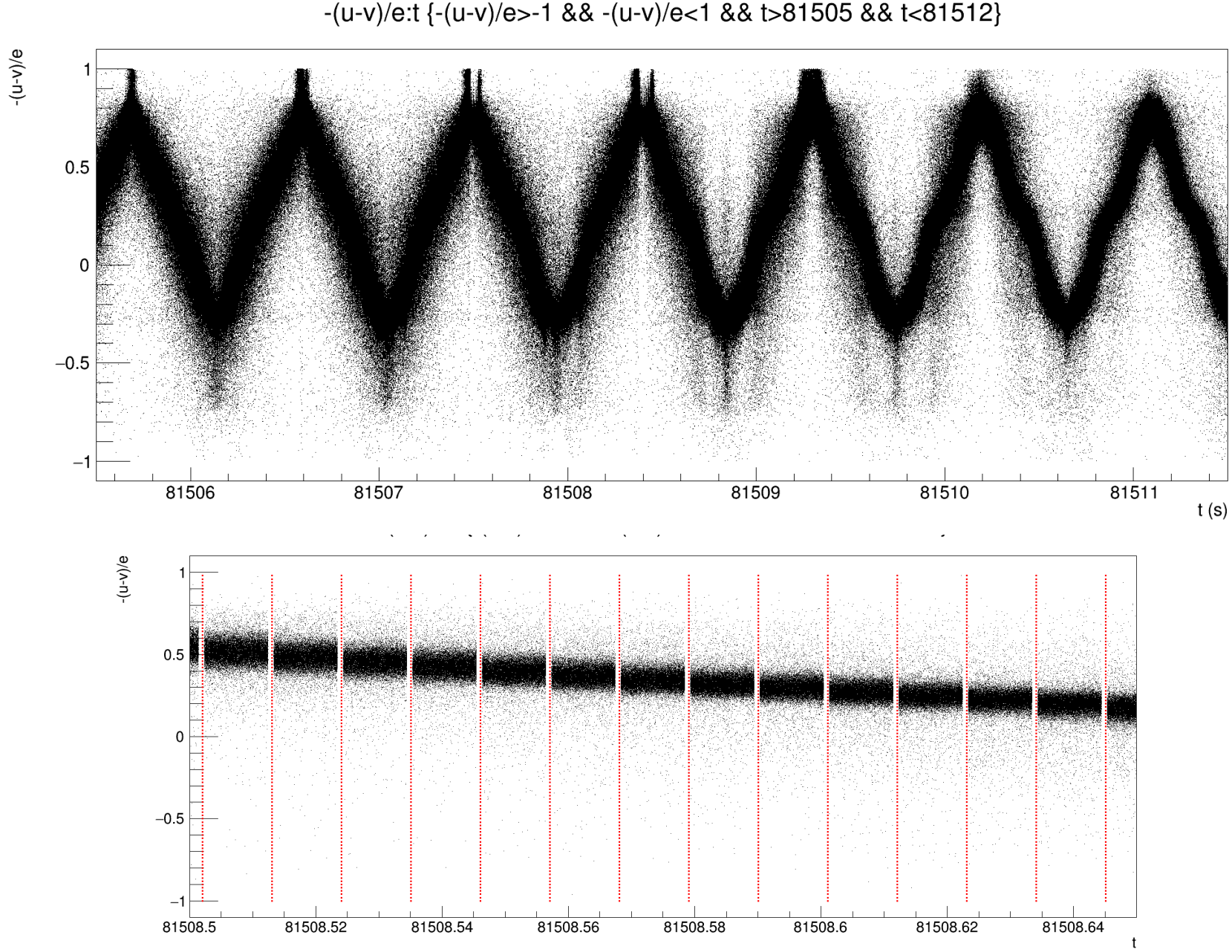


- X-Y tracking planes upstream and downstream – two layers of 1 mm scintillating fibers, offset for 0.5 mm granularity

- Multiplexed fiber readout
  – 32 channels per plane
  - fibers divided into 12 strips

- 40 x 40 x 13 cm block of scintillator for range detector
  - 4 x 4 array of PMTs
  - Output digitized into four channels: E, U, V,C

- Individual protons tracked at up 10 MHz
- > 99% tracking efficiency
- WEPL resolution ~ 3 mm per proton
- 40 x 40 cm image field size
- Fast (<1 min) image reconstruction for radiograph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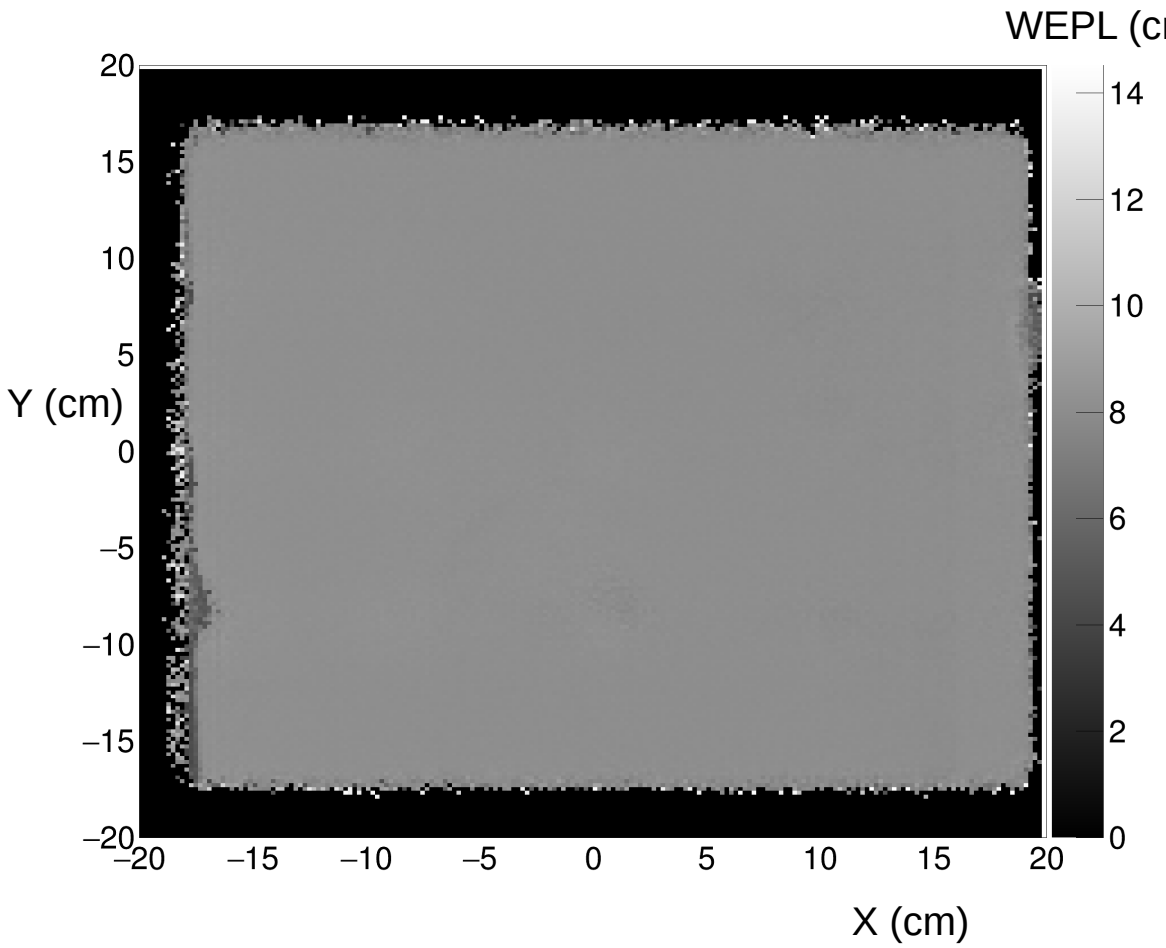
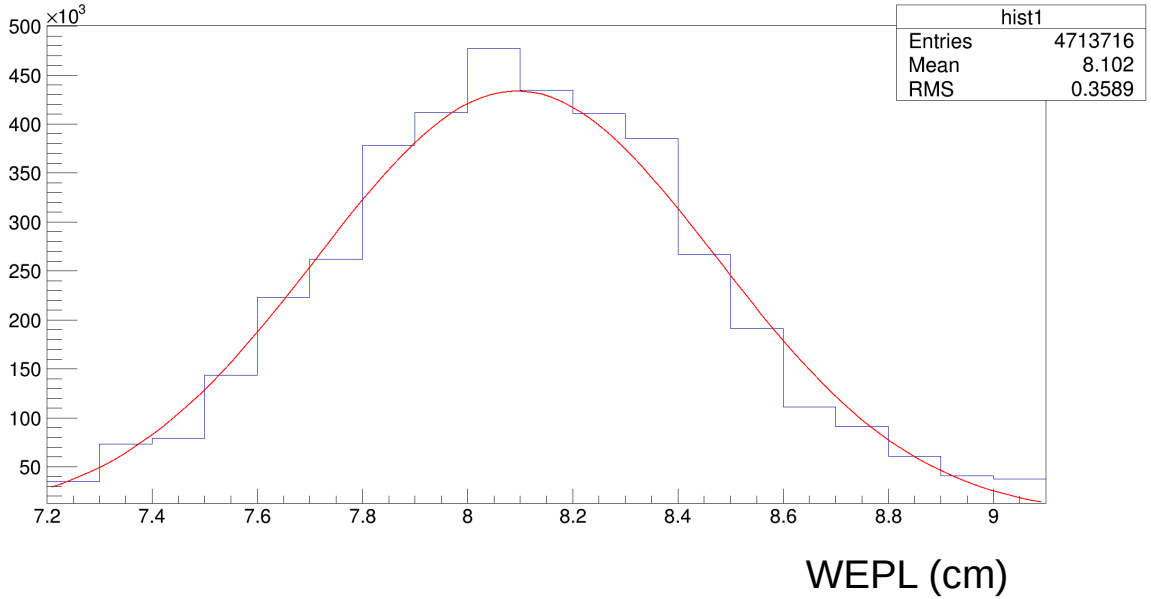
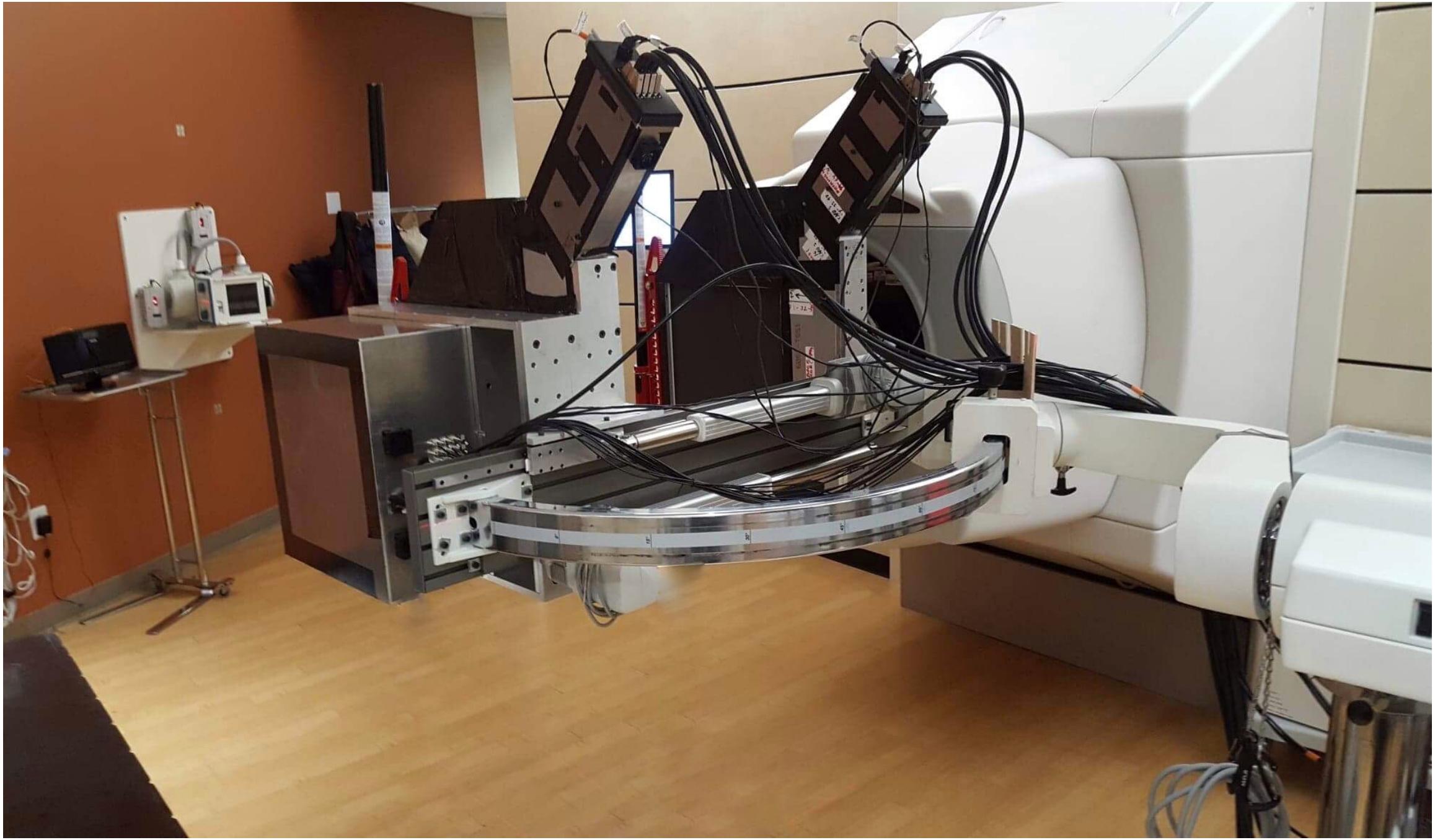
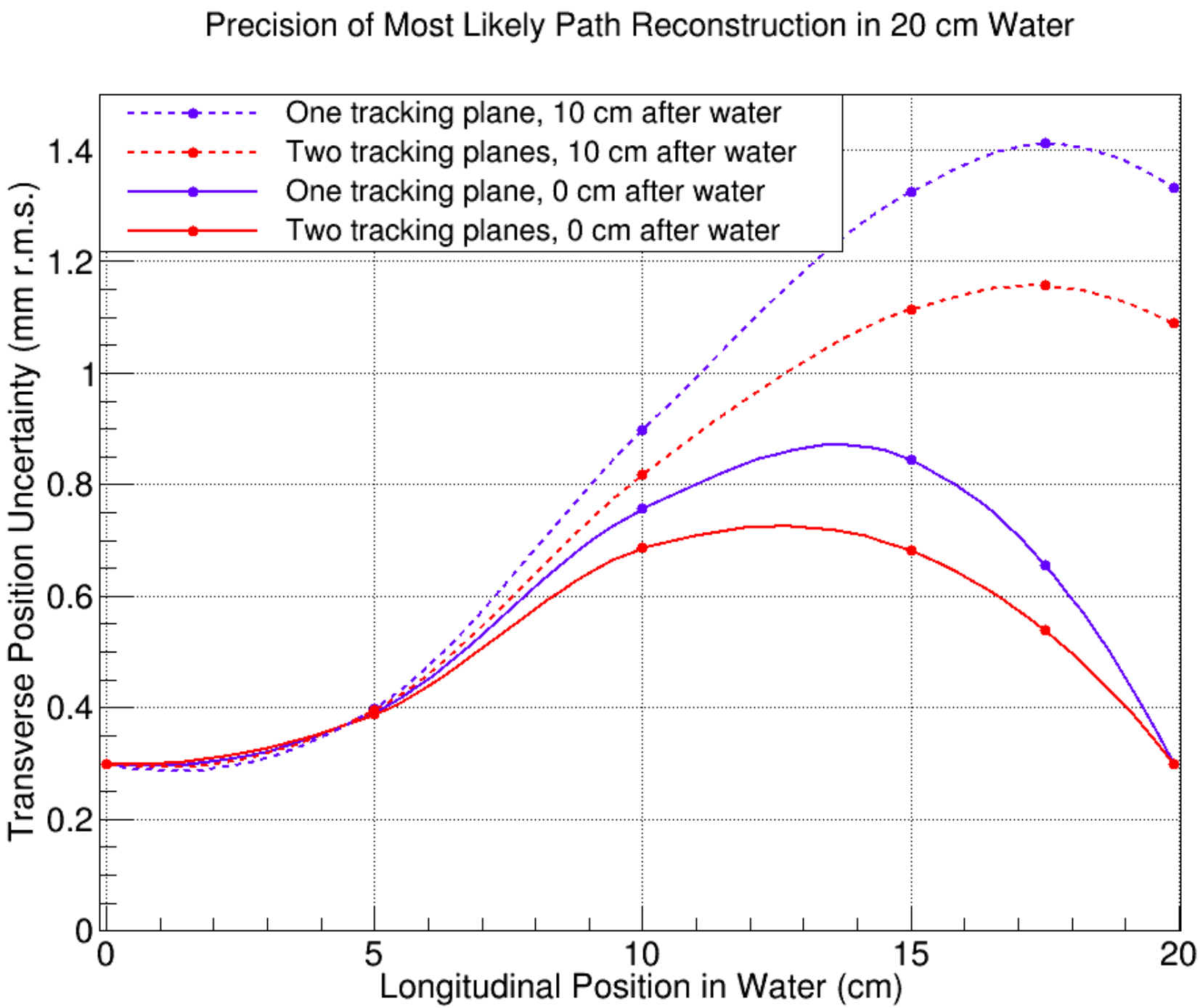
-(u-v)/e
1
0.5
0
−0.5
−1
81506
81507
81508
81509
81510
81511
t (s)
-(u-v)/e
1
0.5
0
−0.5
−1
81508.5
81508.52
81508.54
81508.56
81508.58
81508.6
81508.62
81508.64
t

151 MeV scan through 8.1 cm block of water

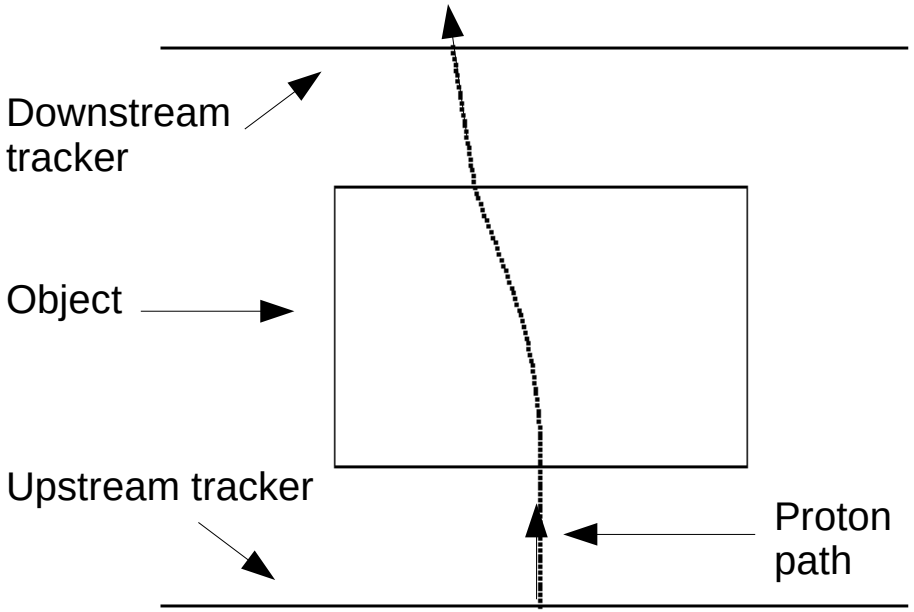




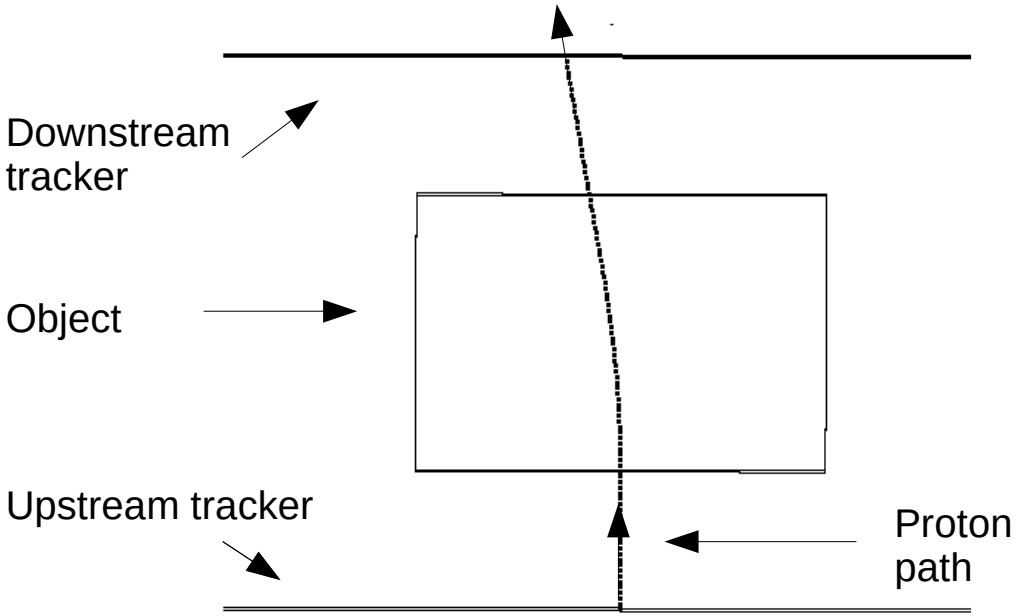



Precision of Most Likely Path Reconstruction in 20 cm Water
One tracking plane, 10 cm after water
Two tracking planes, 10 cm after water
One tracking plane, 0 cm after water
Two tracking planes, 0 cm after water
Transverse Position Uncertainty (mm r.m.s.)
Longitudinal Position in Water (cm)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
0
5
10
15
20

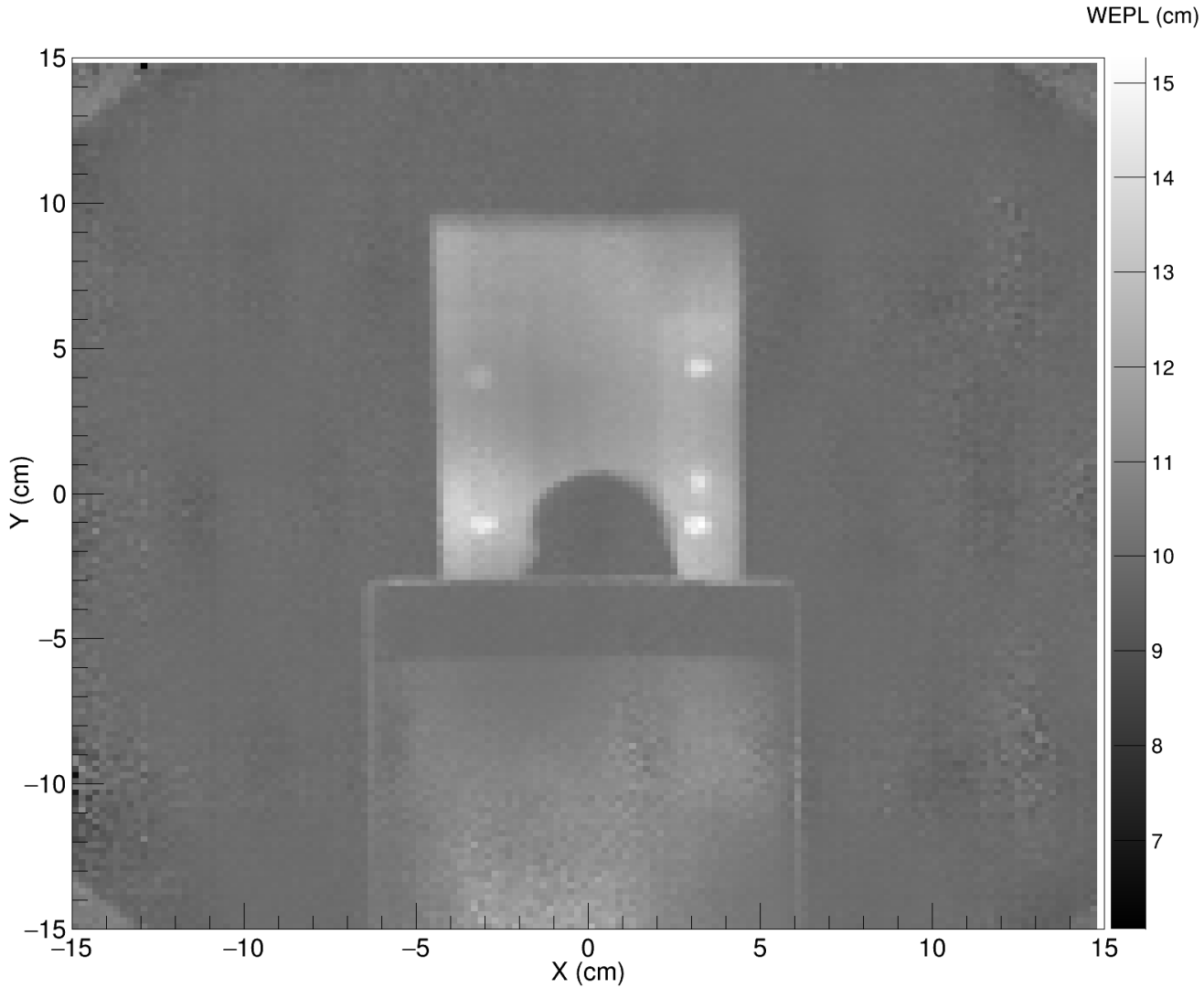
Hull exit point from straight line approximation

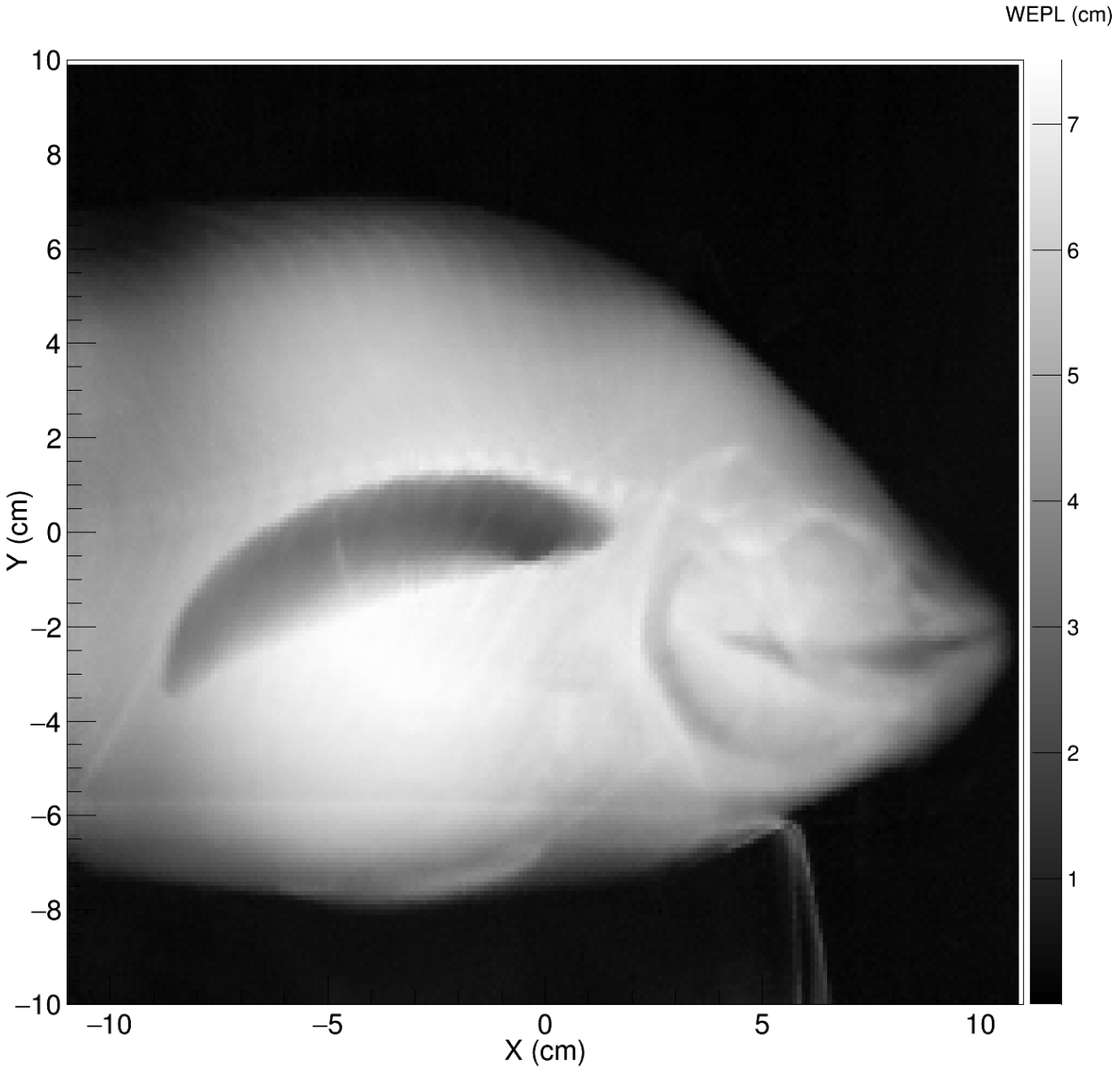


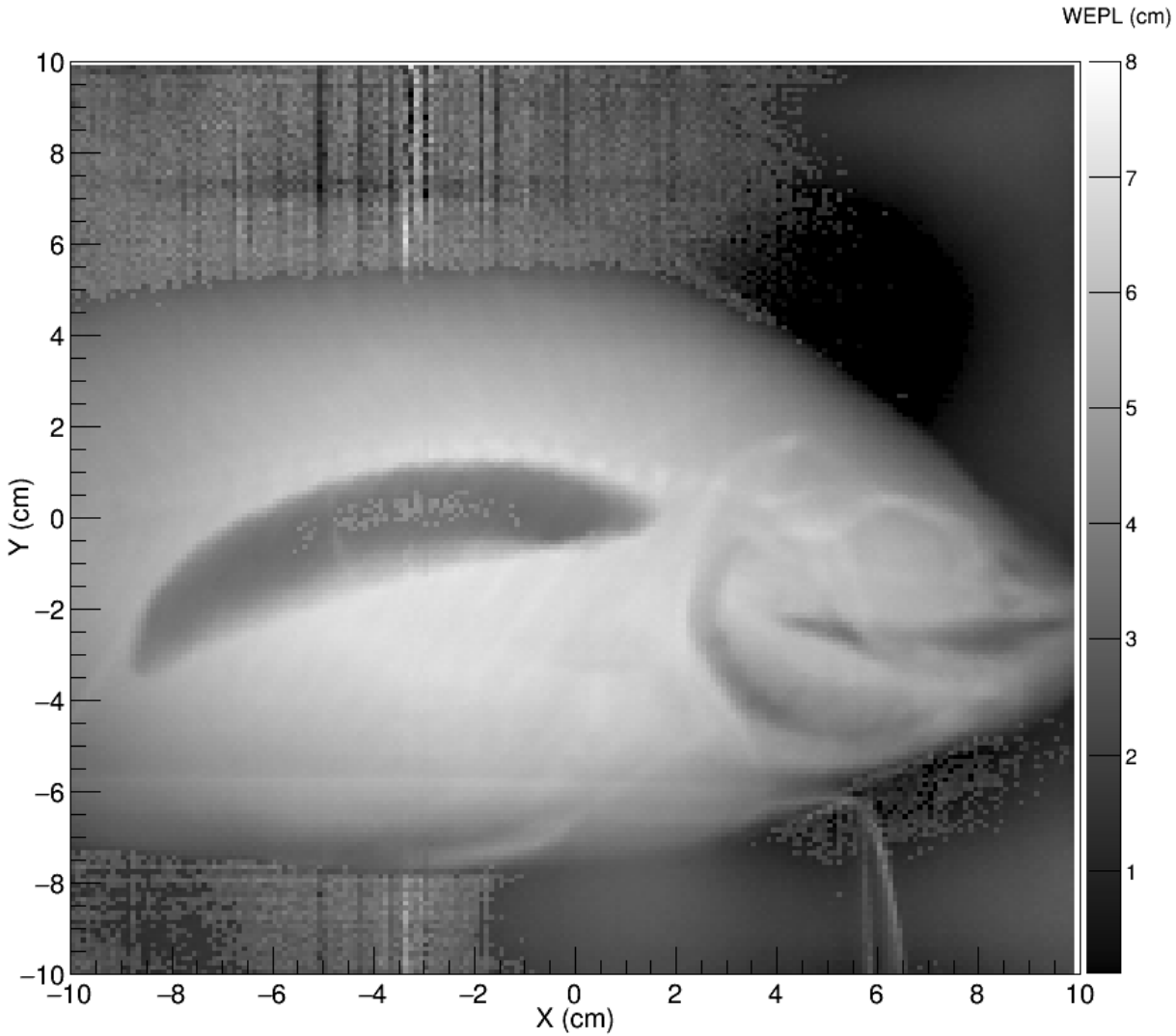
Hull exit point from Most Likely Intersection method

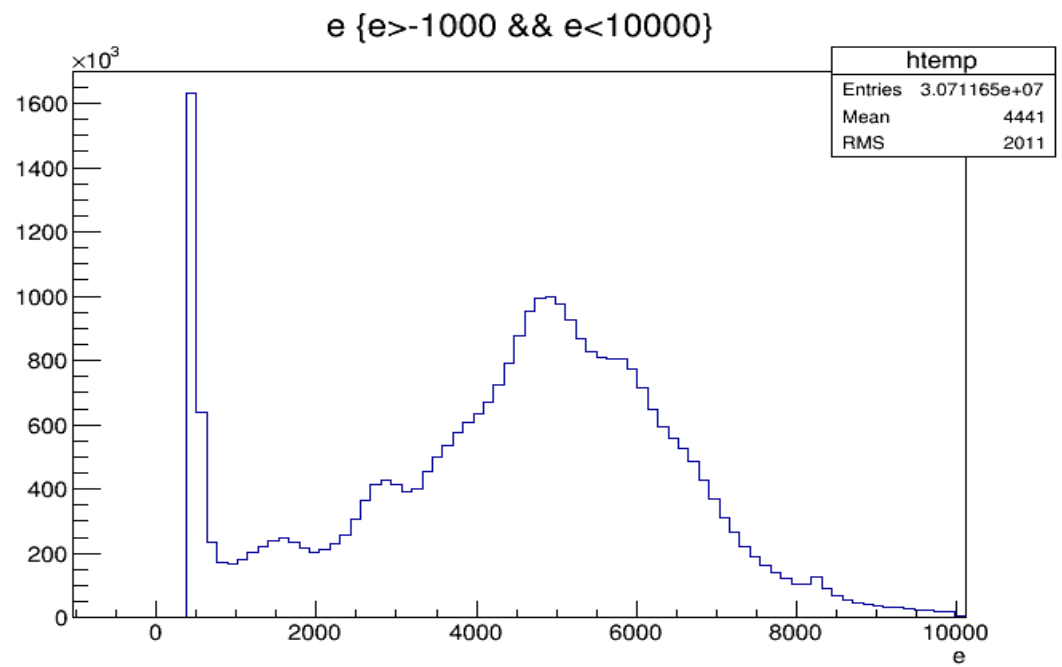


Our first real image – block of wood with screws

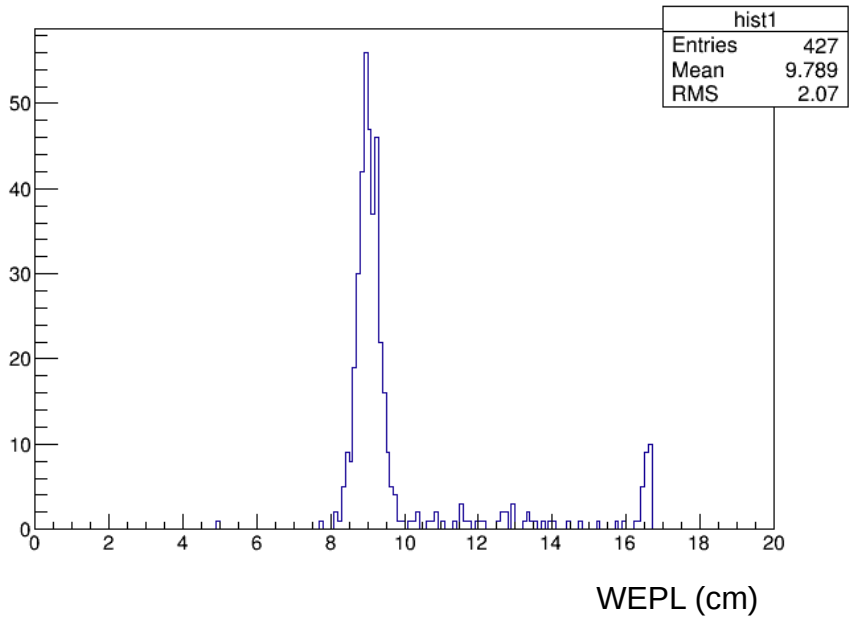



WEPL (cm)
10
8
6
4
2
0
−2
−4
−6
−8
−10
Y (cm)
−10
−5
0
5
10
X (cm)
7
6
5
4
3
2
1

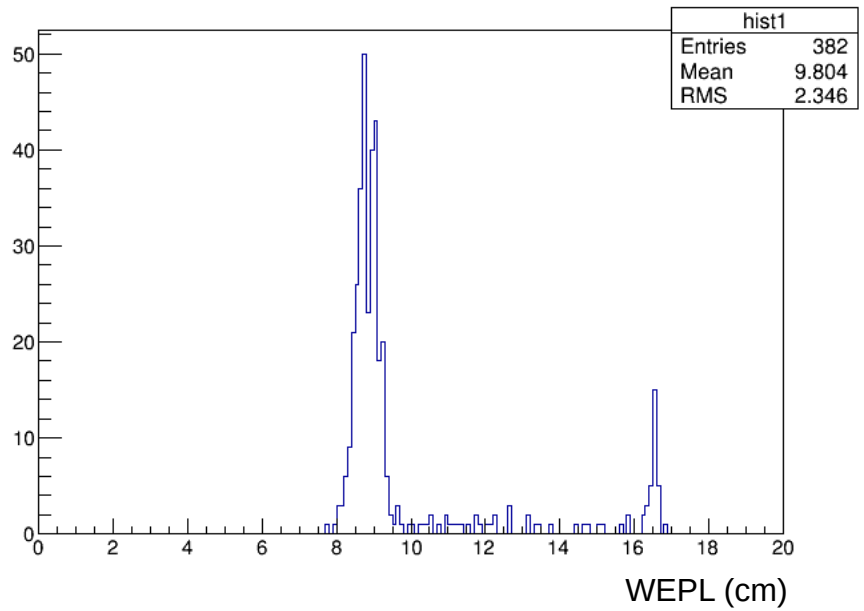

WEPL (cm)
Y (cm)
X (cm)
10
8
6
4
2
0
−2
−4
−6
−8
−10
−10
−8
−6
−4
−2
0
2
4
6
8
10
8
7
6
5
4
3
2
1


e {e>-1000 && e<10000}
htemp
Entries 3.071165e+07
Mean 4441
RMS 2011
×10^3
1600
1400
1200
1000
800
600
400
200
0
0
2000
4000
6000
8000
10000
e

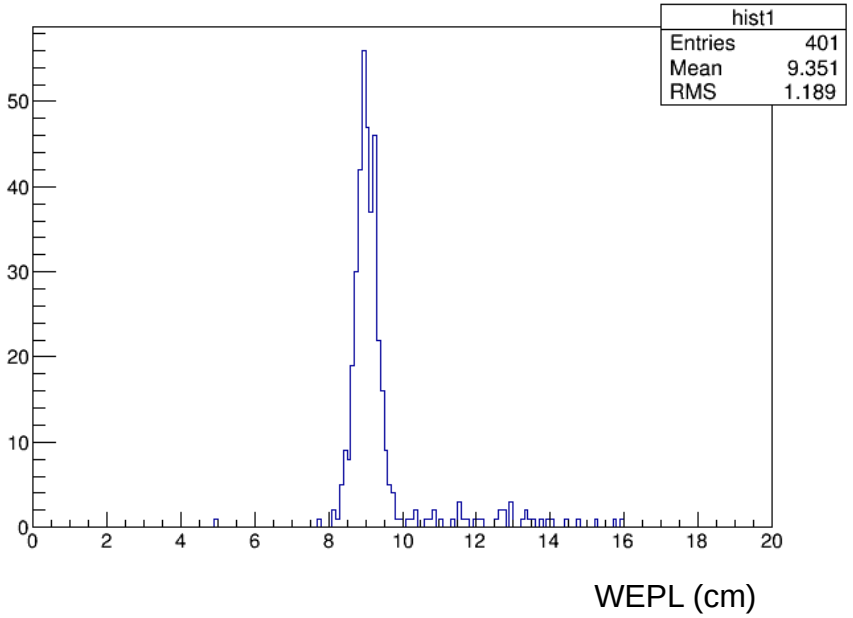
Pixel 1



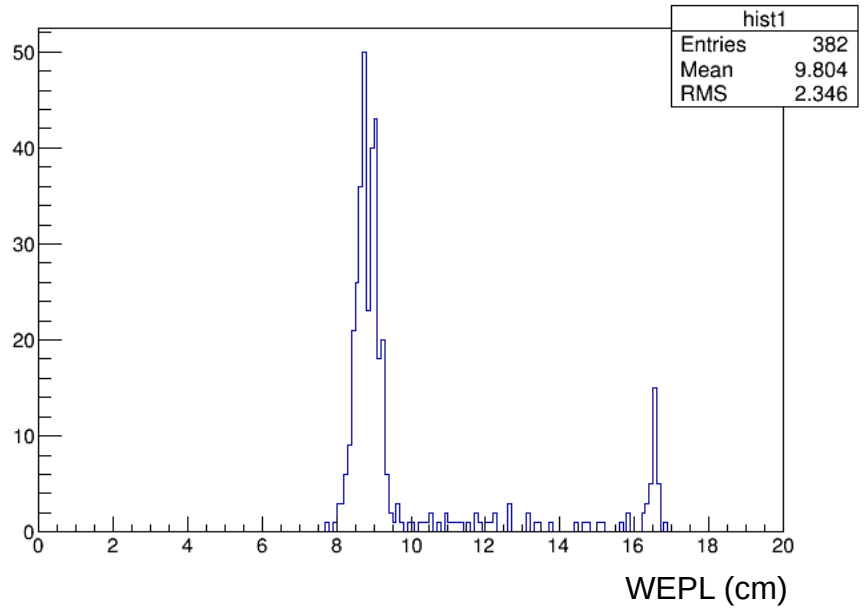
Pixel 2



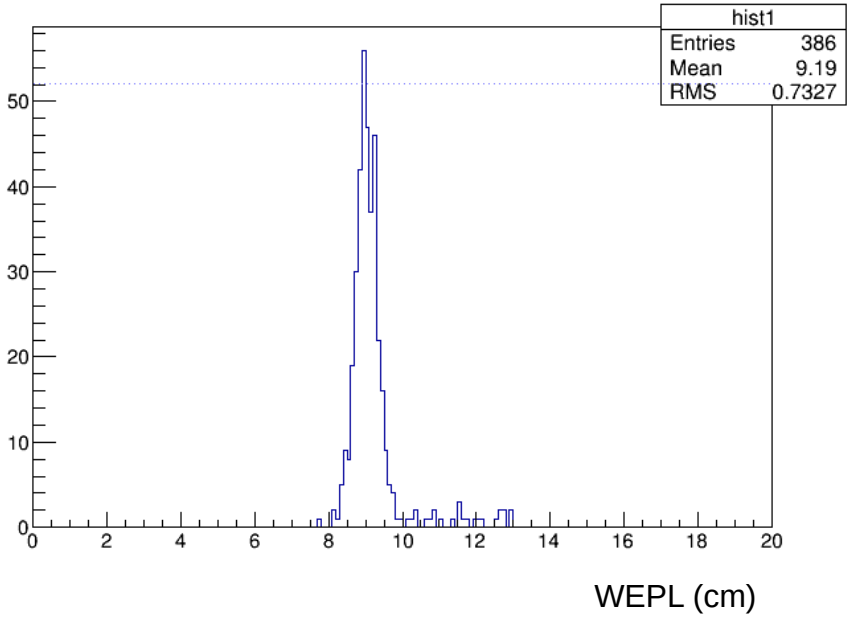
Pixel 1



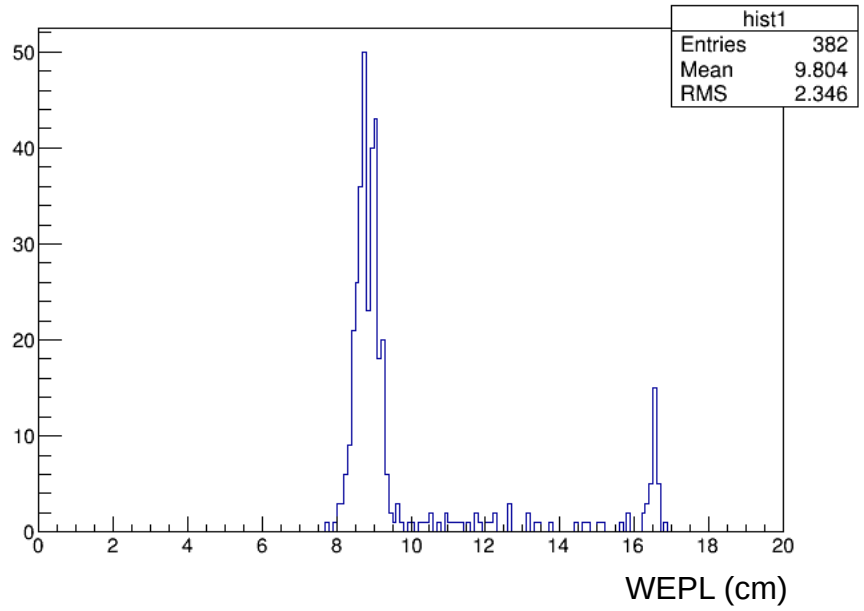
Pixel 2



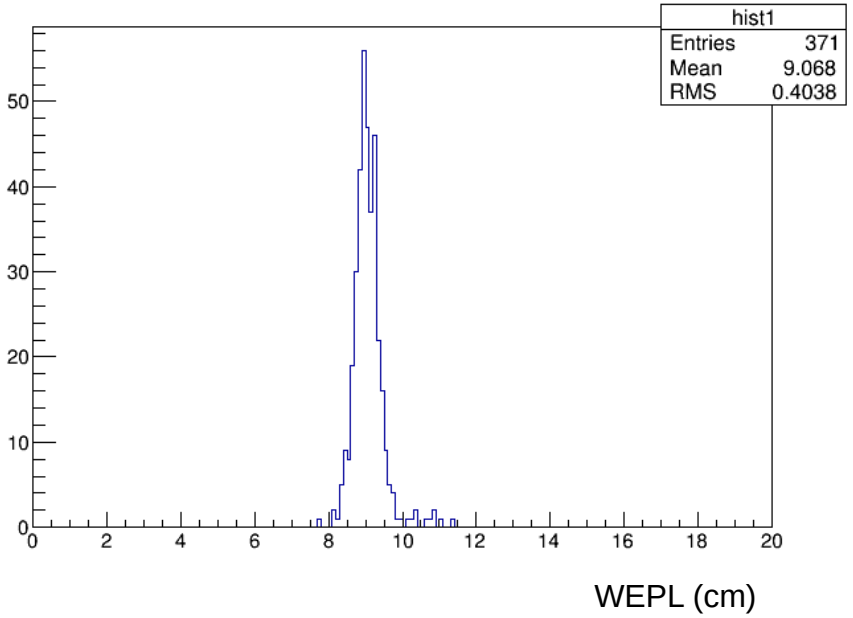
Pixel 1



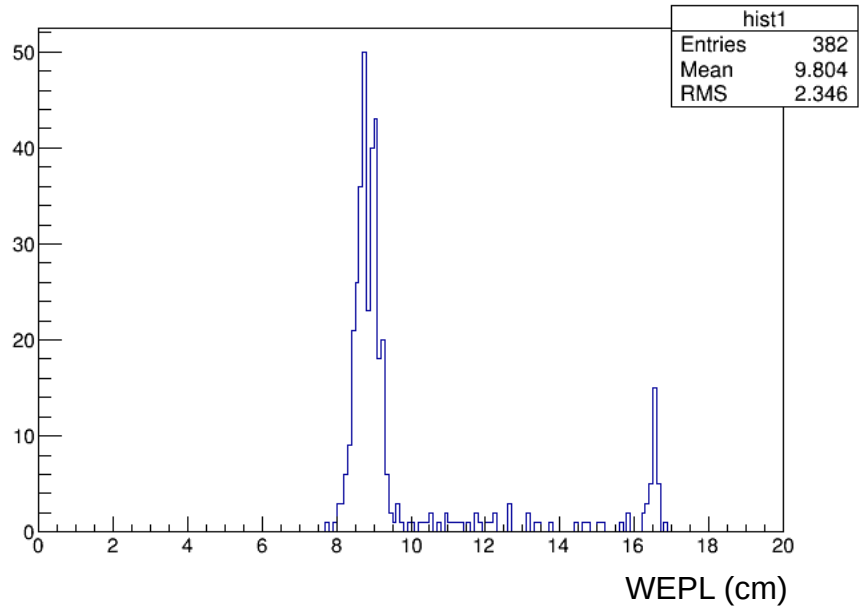
Pixel 2



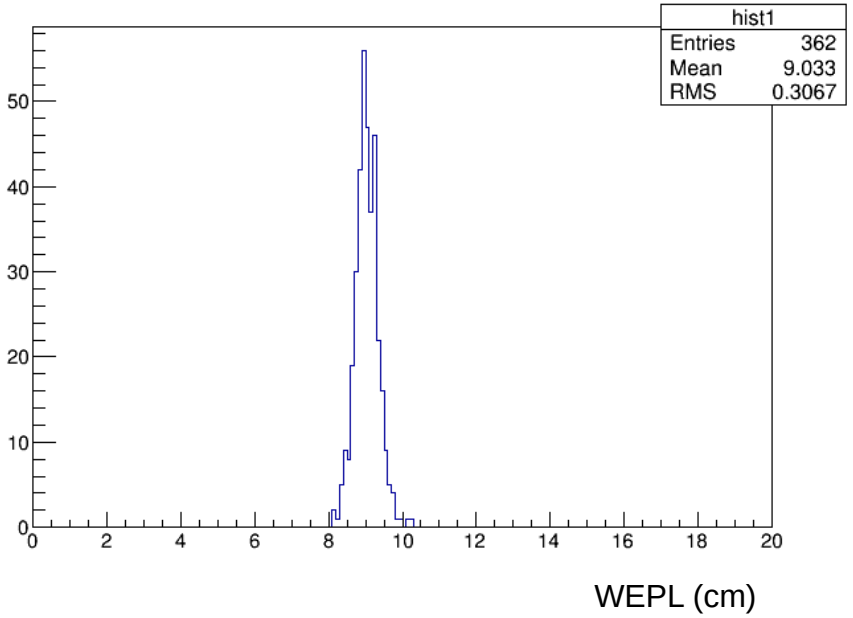
Pixel 1



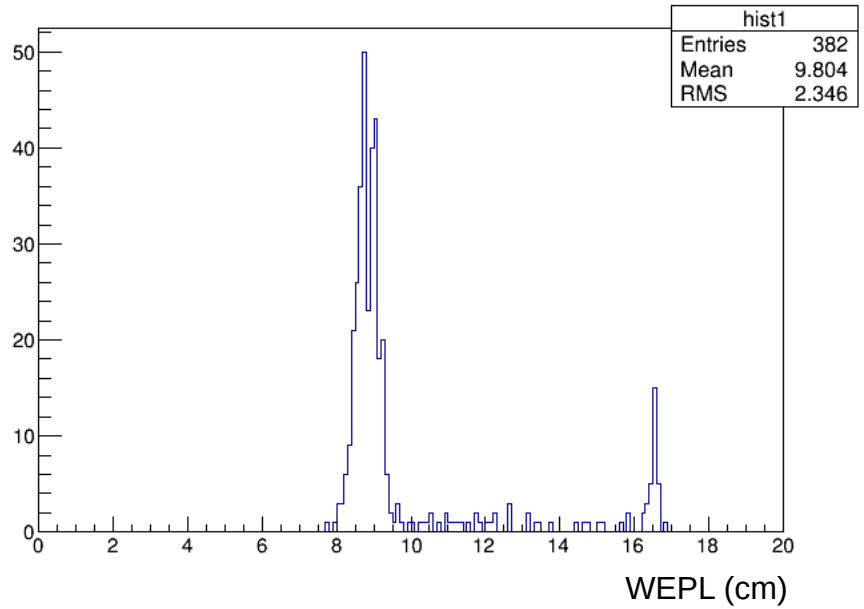
Pixel 2



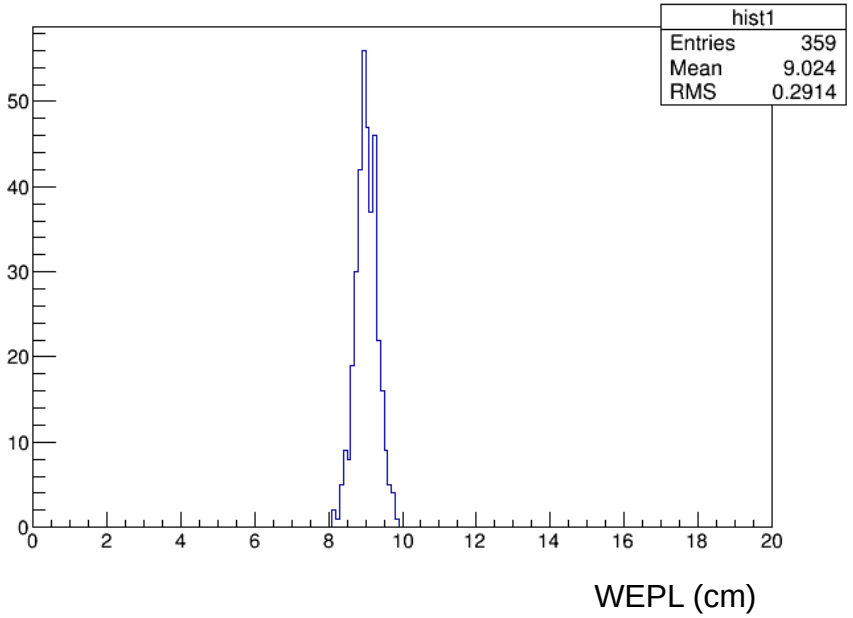
Pixel 1



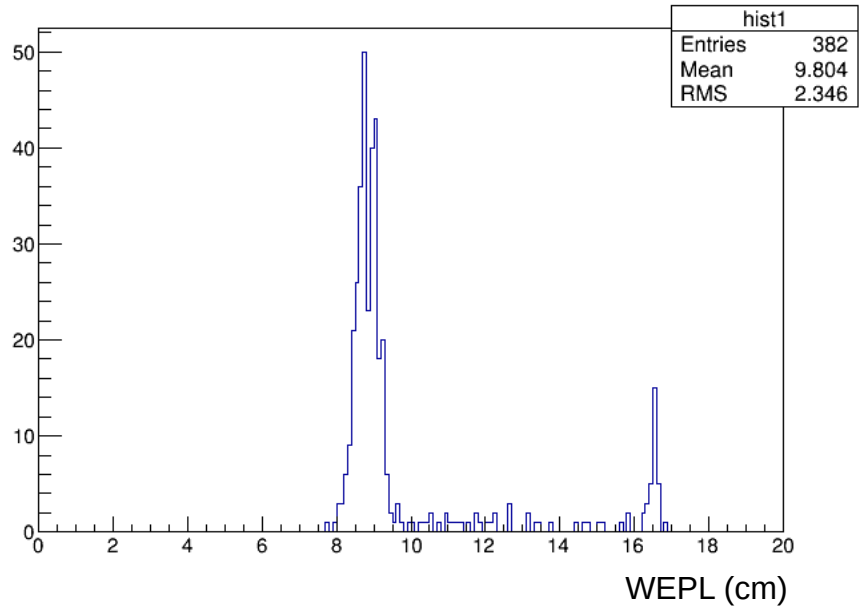
Pixel 2



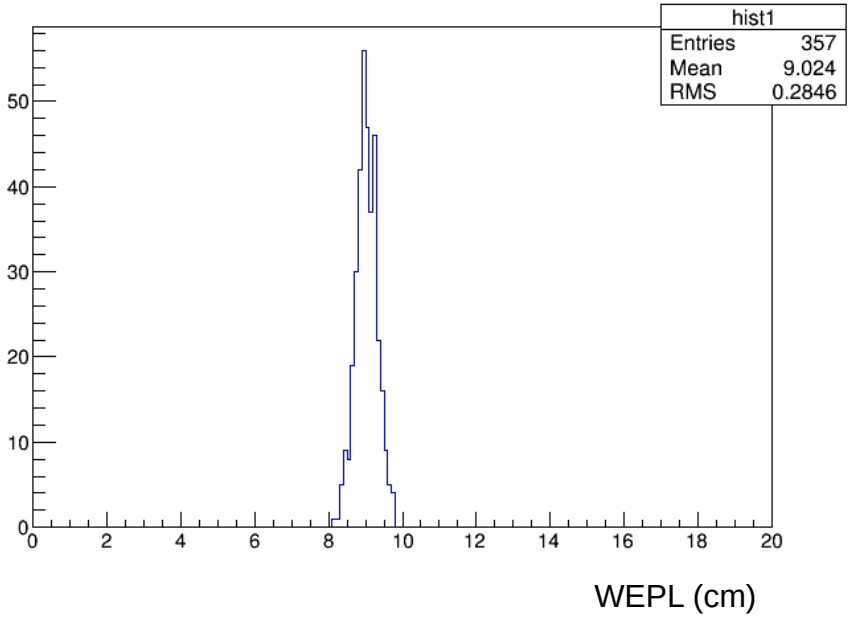
Pixel 1



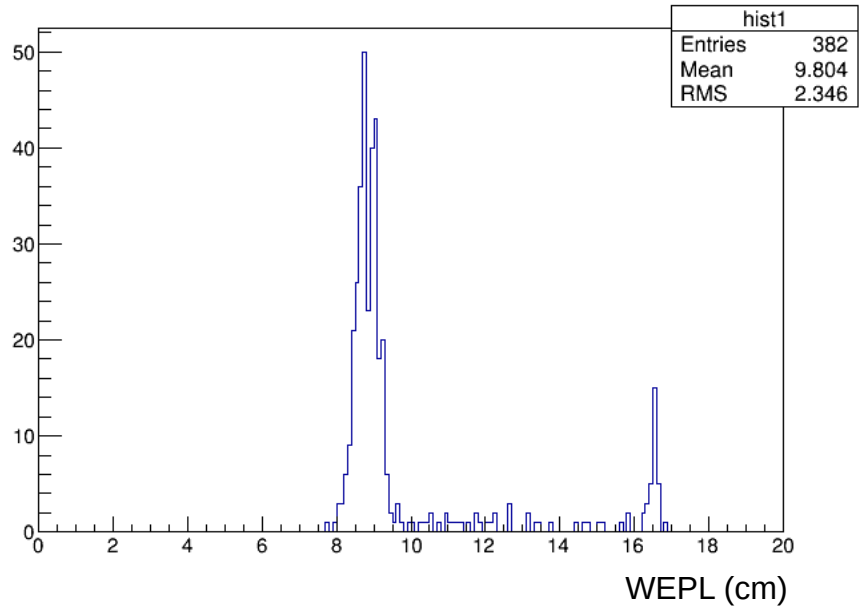
Pixel 2

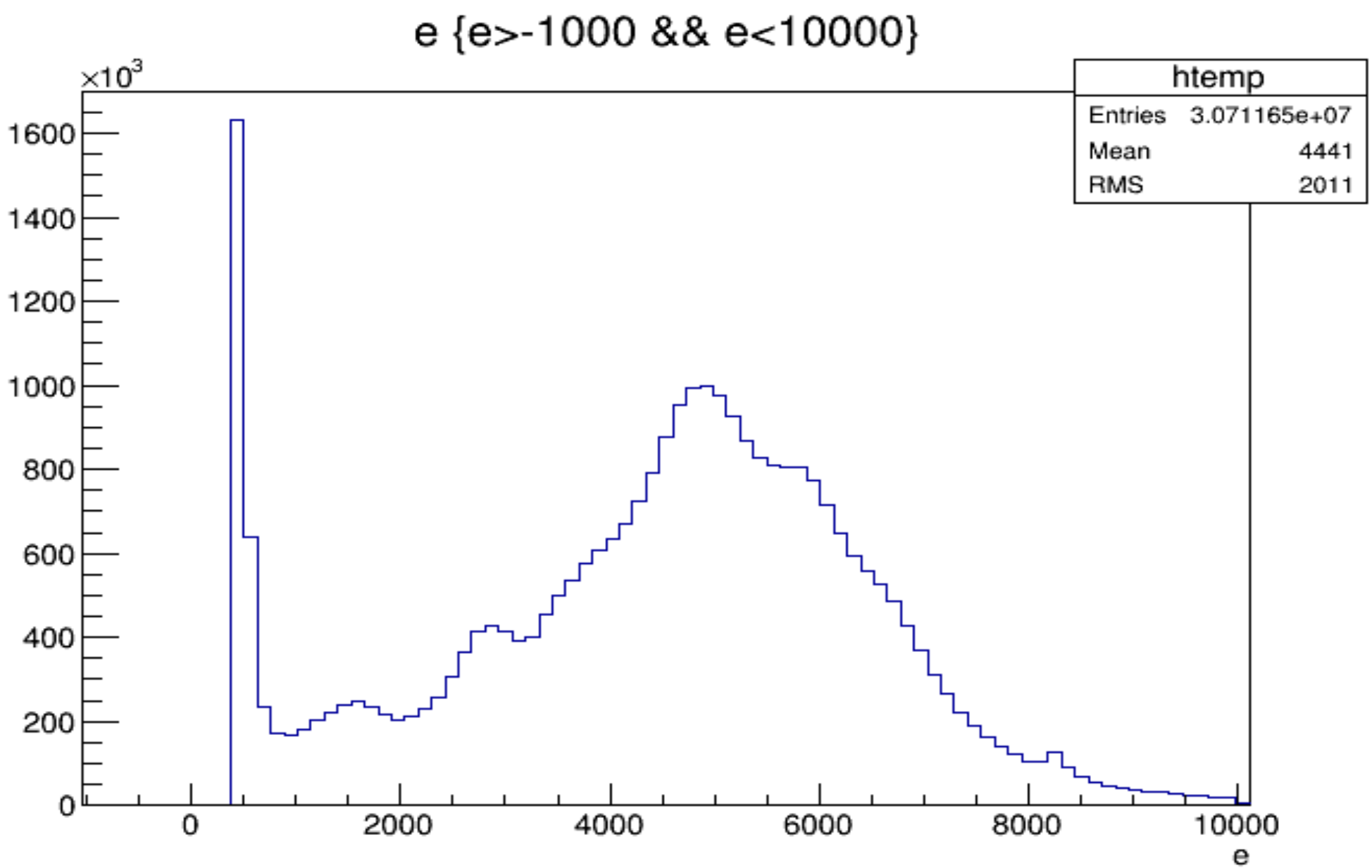


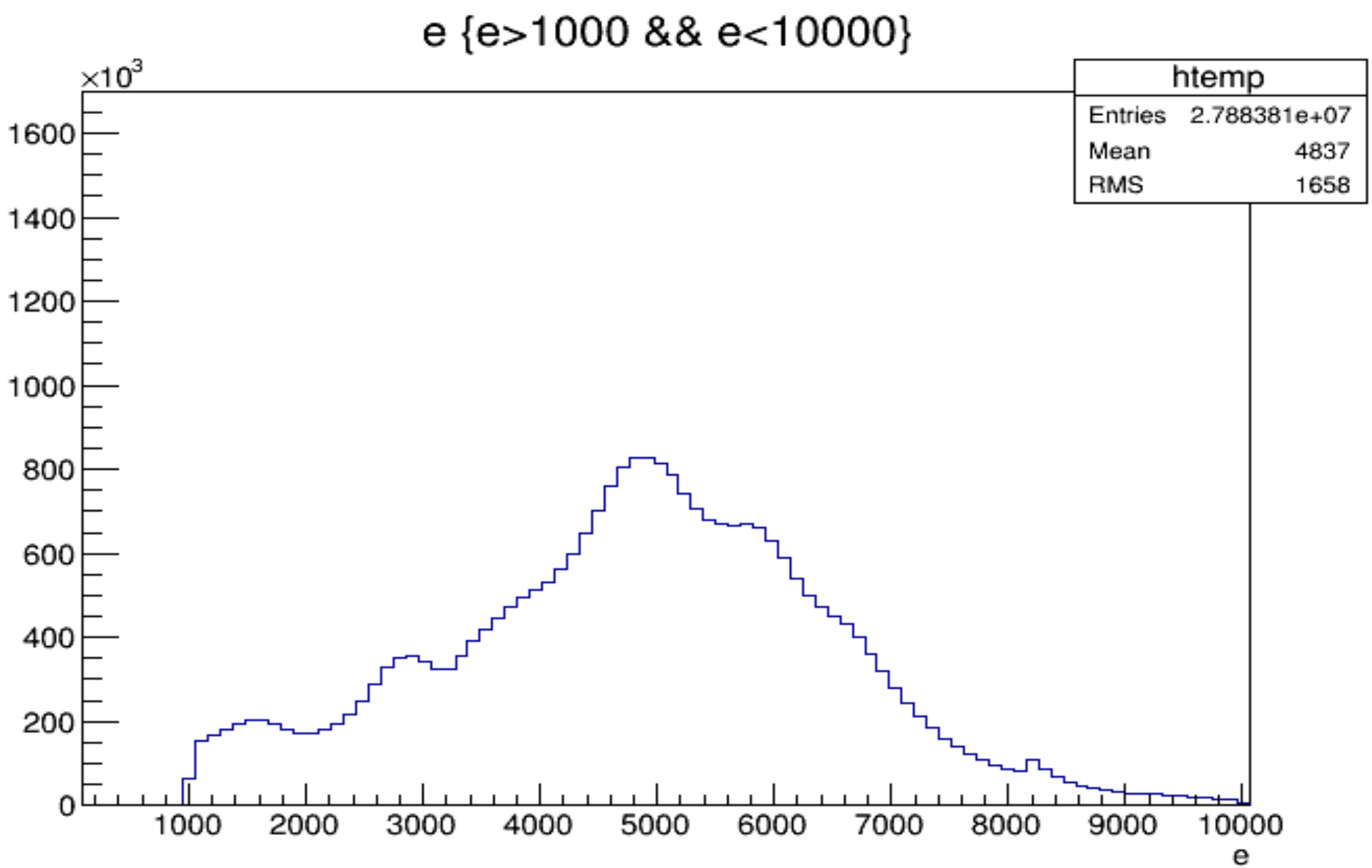
Pixel 1



Pixel 2




e {e>-1000 && e<10000}
htemp
Entries 3.071165e+07
Mean 4441
RMS 2011
×10^3
1600
1400
1200
1000
800
600
400
200
0
0
2000
4000
6000
8000
10000
e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Entries 2.788381e+07
Mean 4837
RMS 1658
×10^3
1600
1400
1200
1000
800
600
400
200
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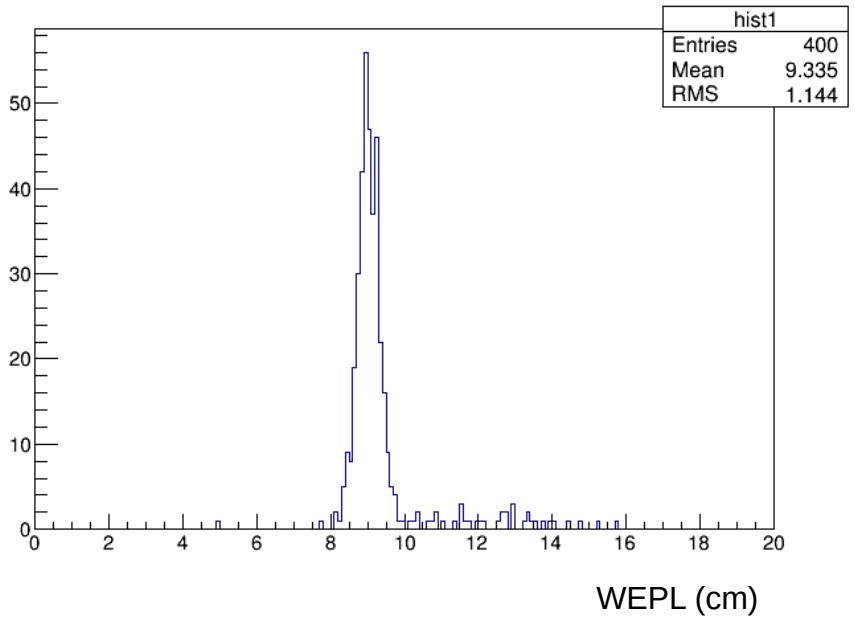
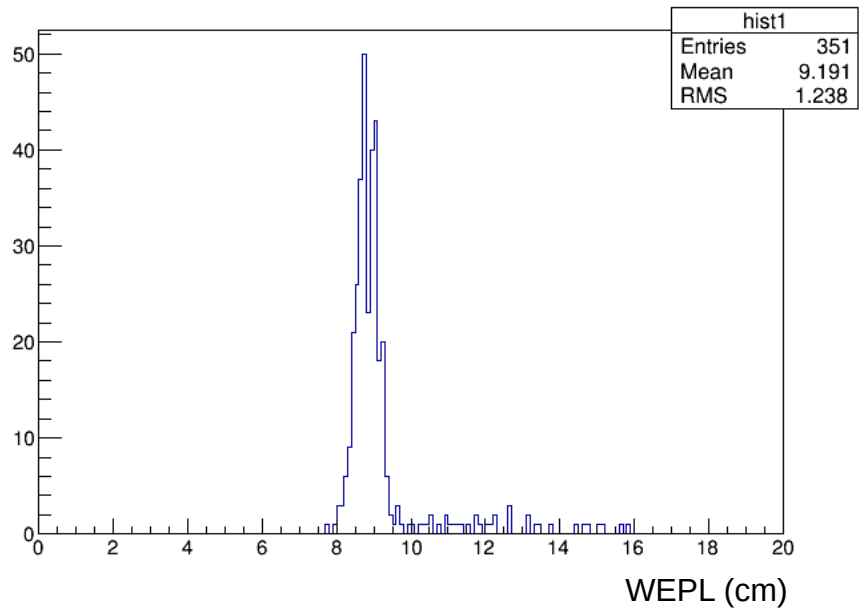
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
e

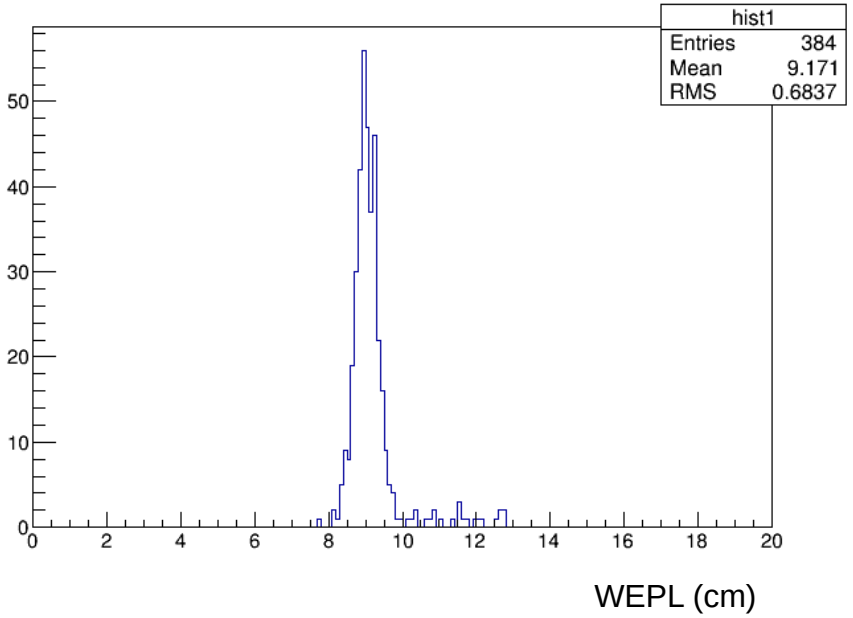
Pixel 1



Pixel 2



Pixel 1



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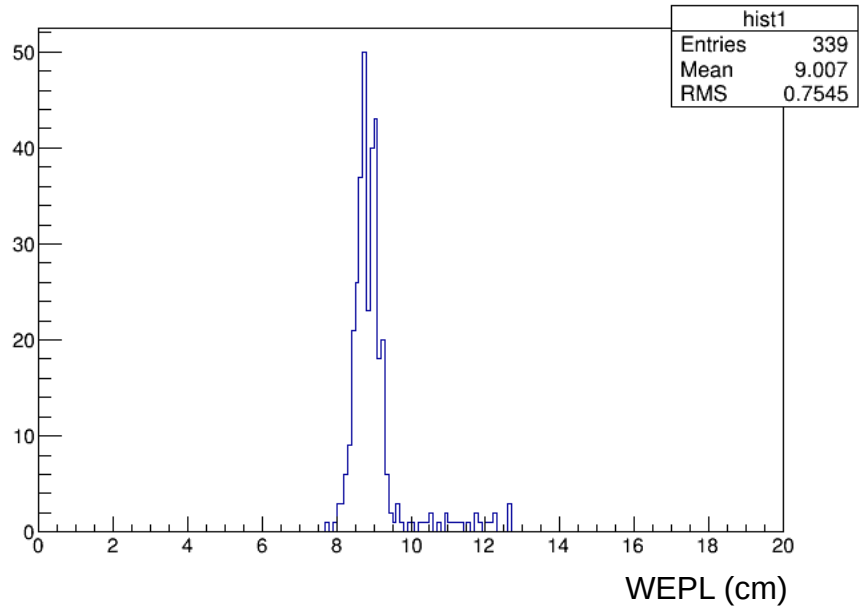
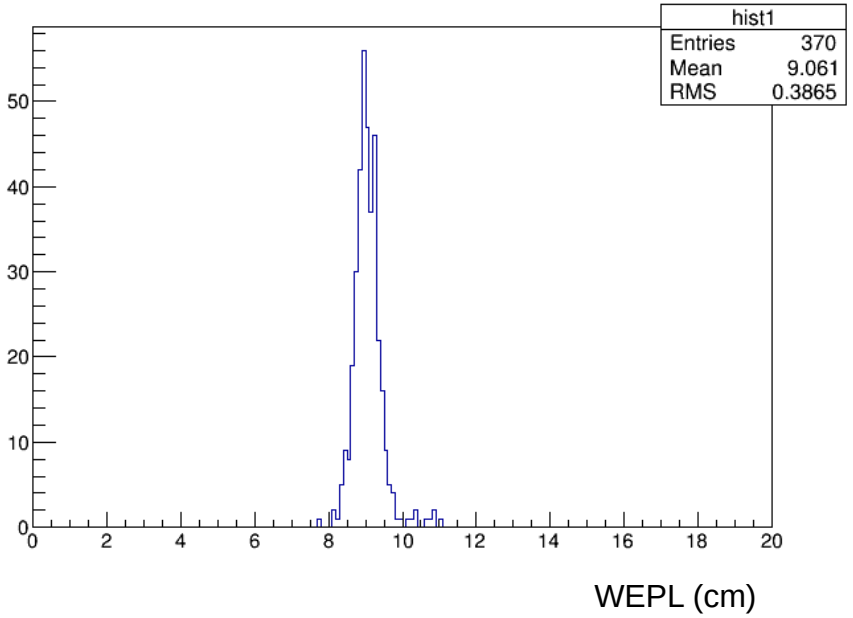
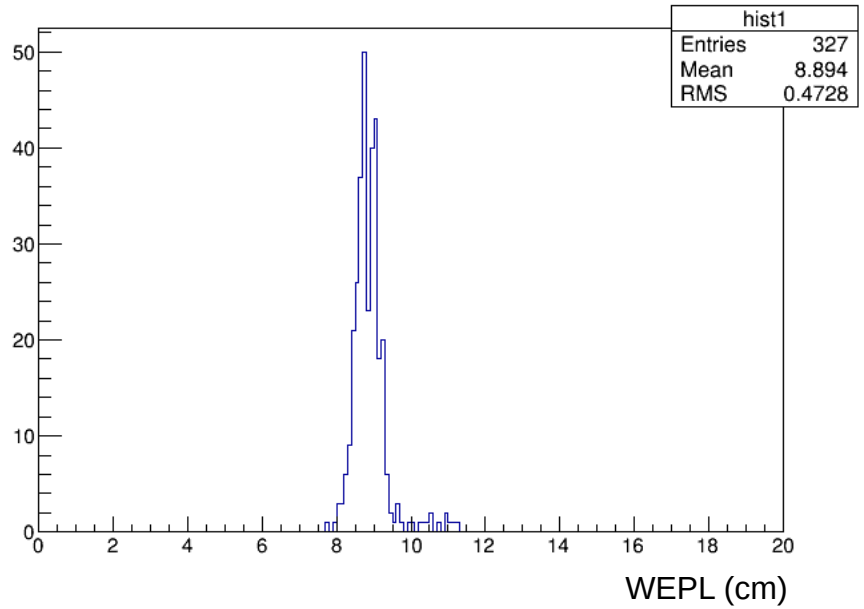


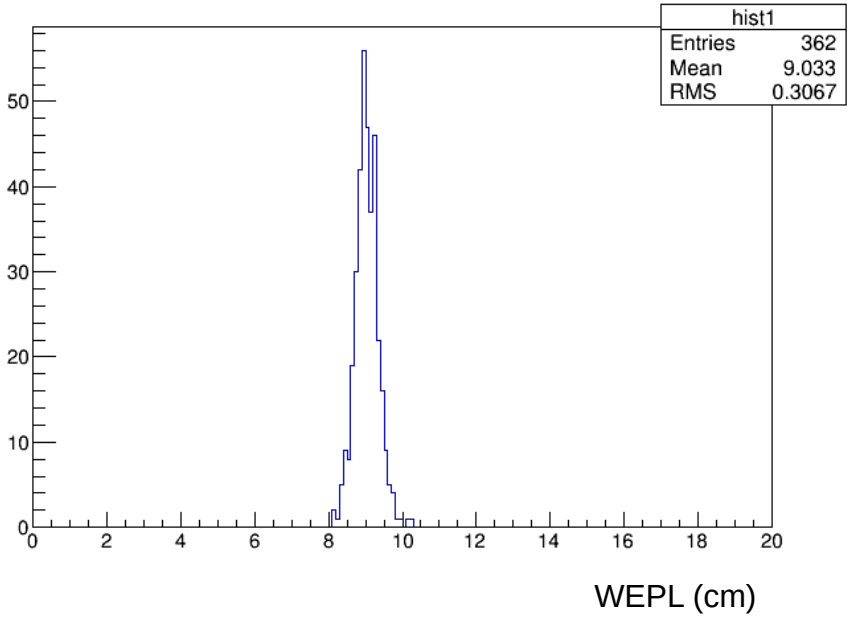
Pixel 1



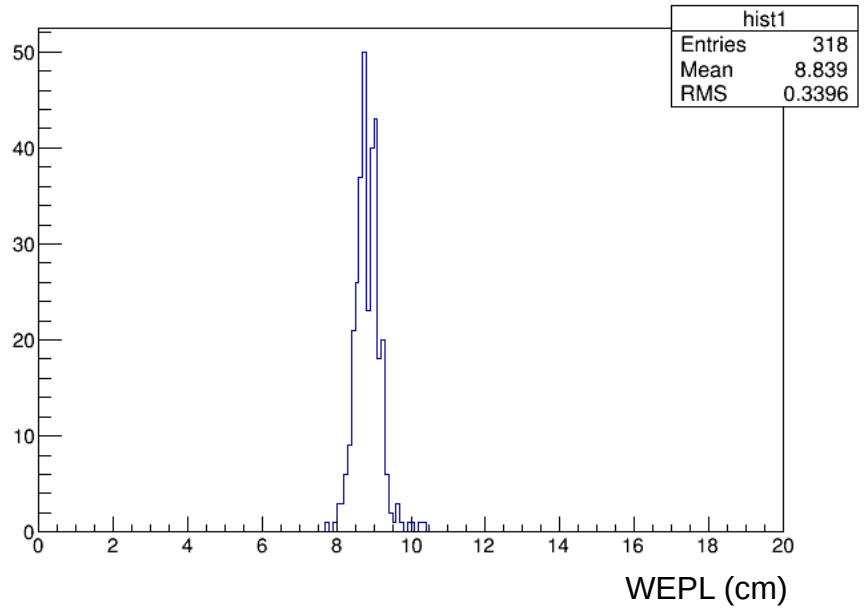
Pixel 2



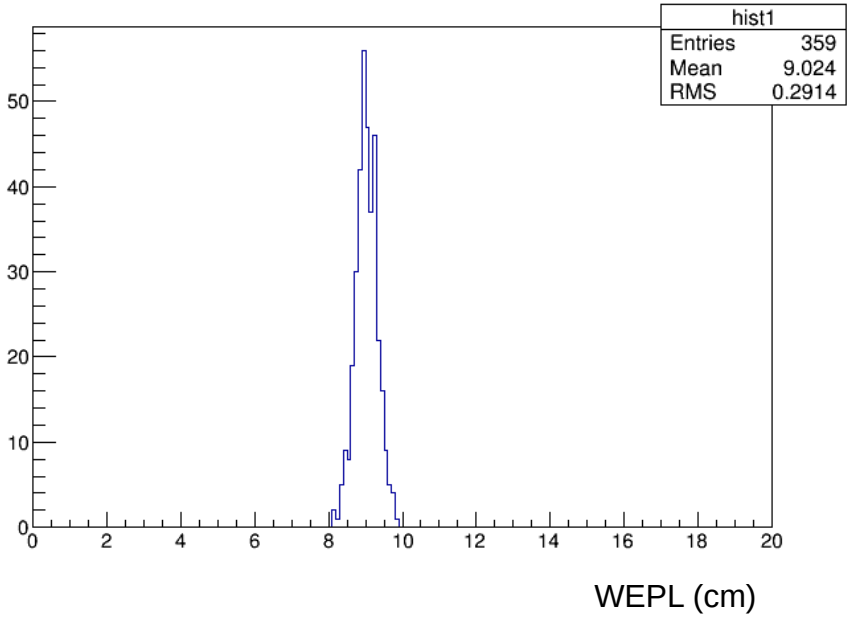
Pixel 1



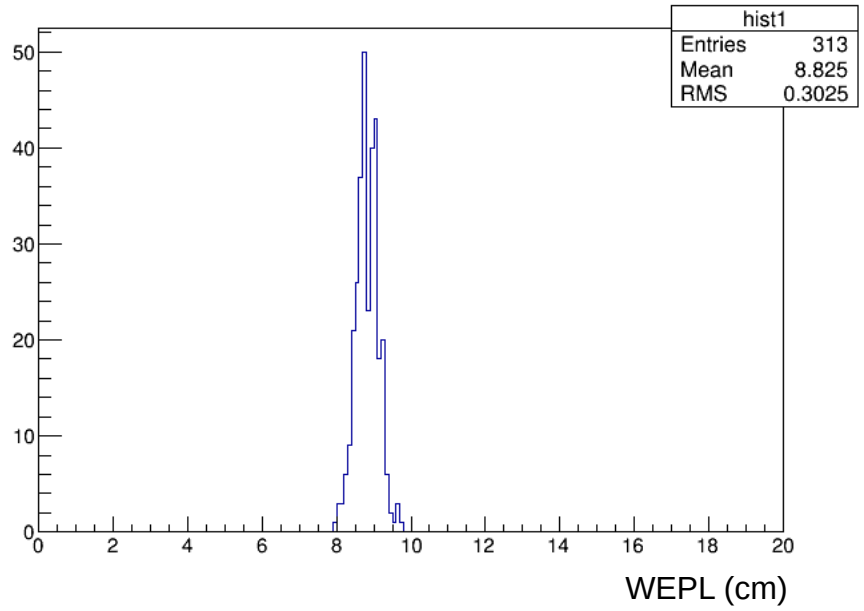
Pixel 2



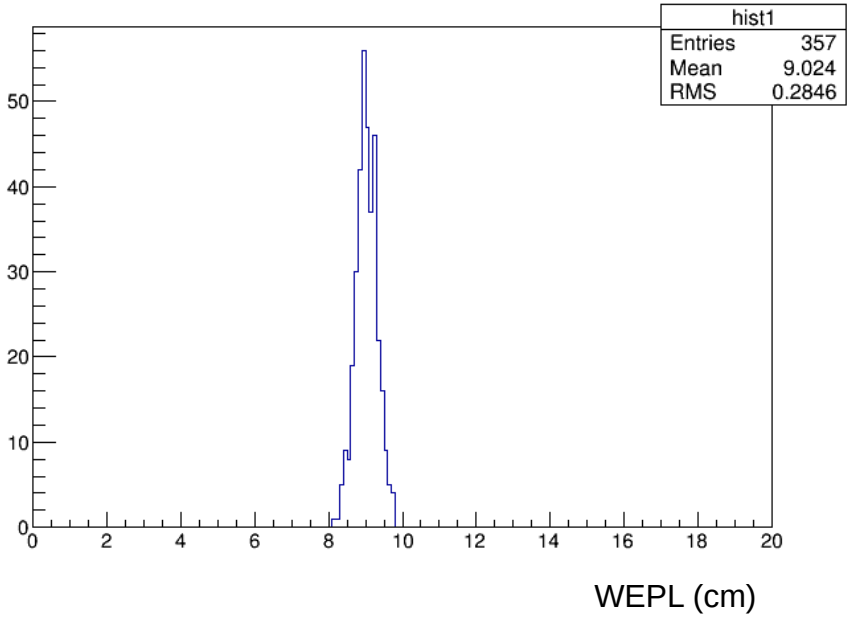
Pixel 1



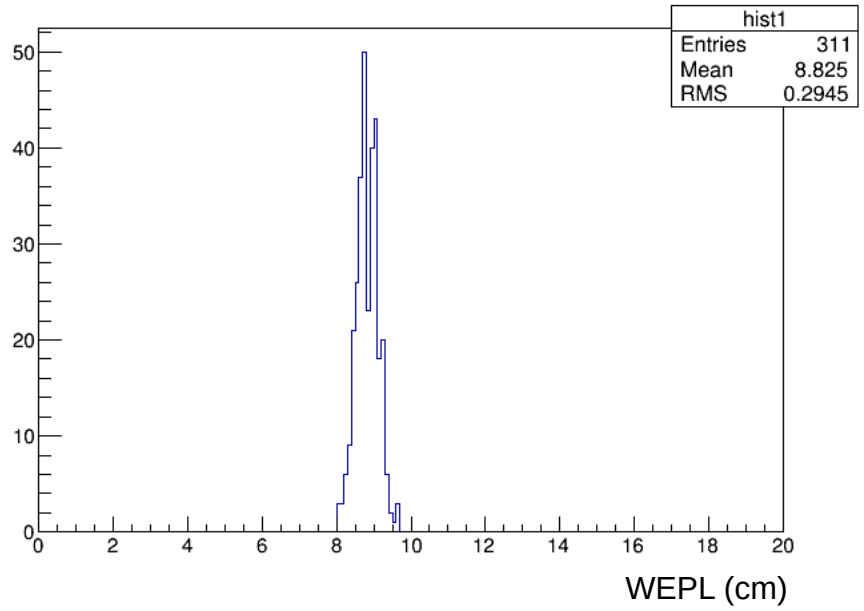
Pixel 2

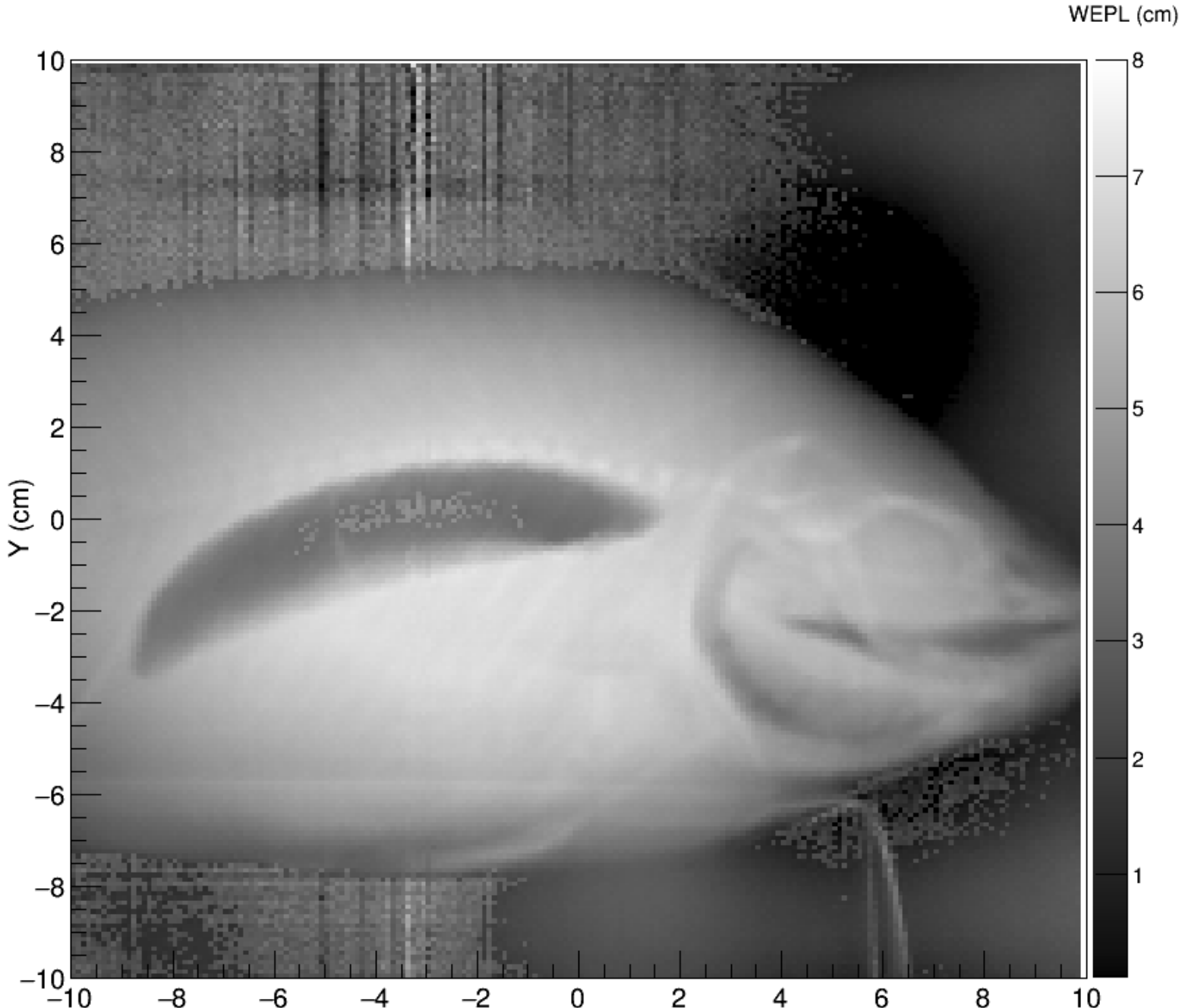


Pixel 1



Pixel 2




WEPL (cm)
Y (cm)
10
8
6
4
2
0
−2
−4
−6
−8
−10
−10
−8
−6
−4
−2
0
2
4
6
8
10
8
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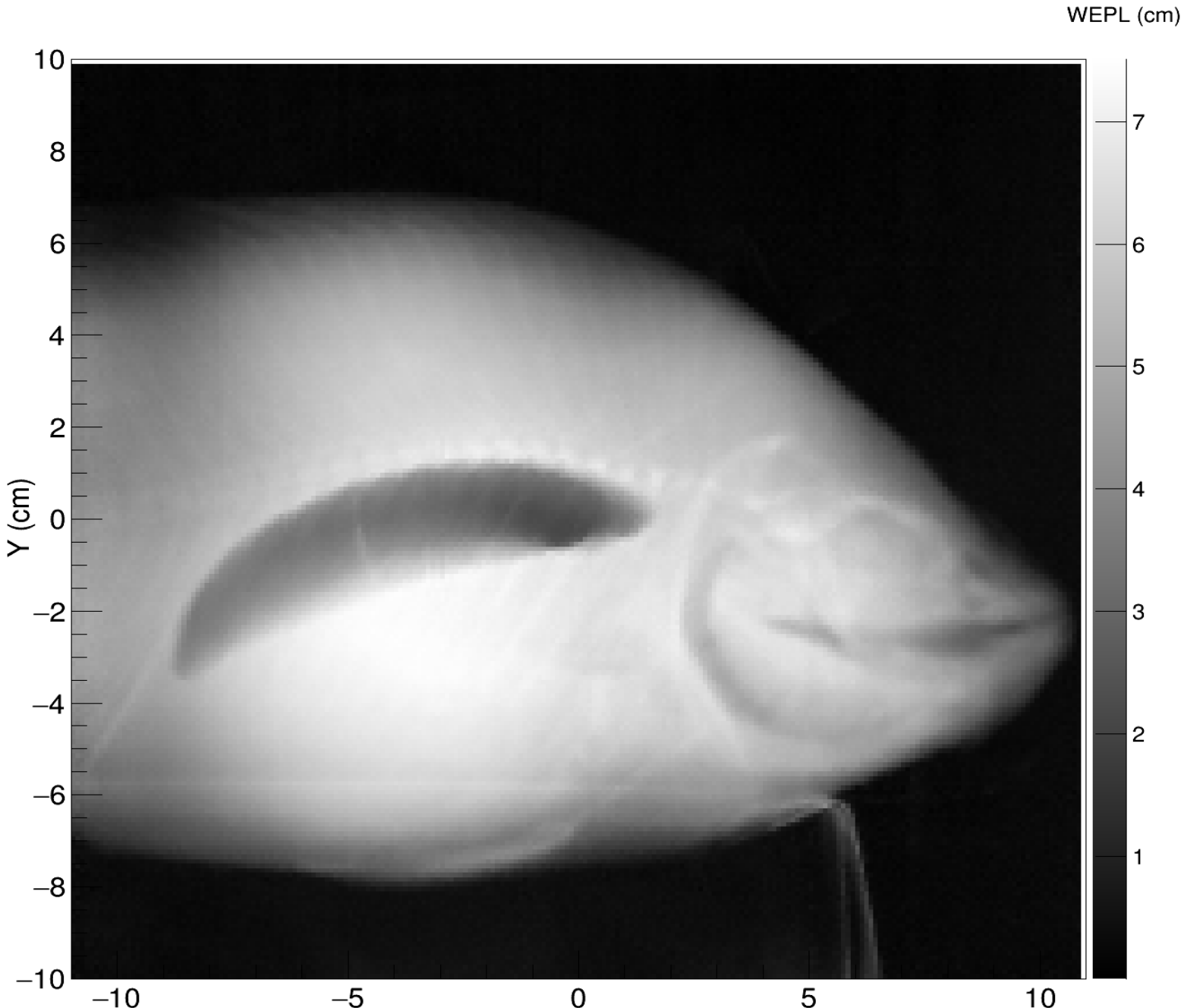
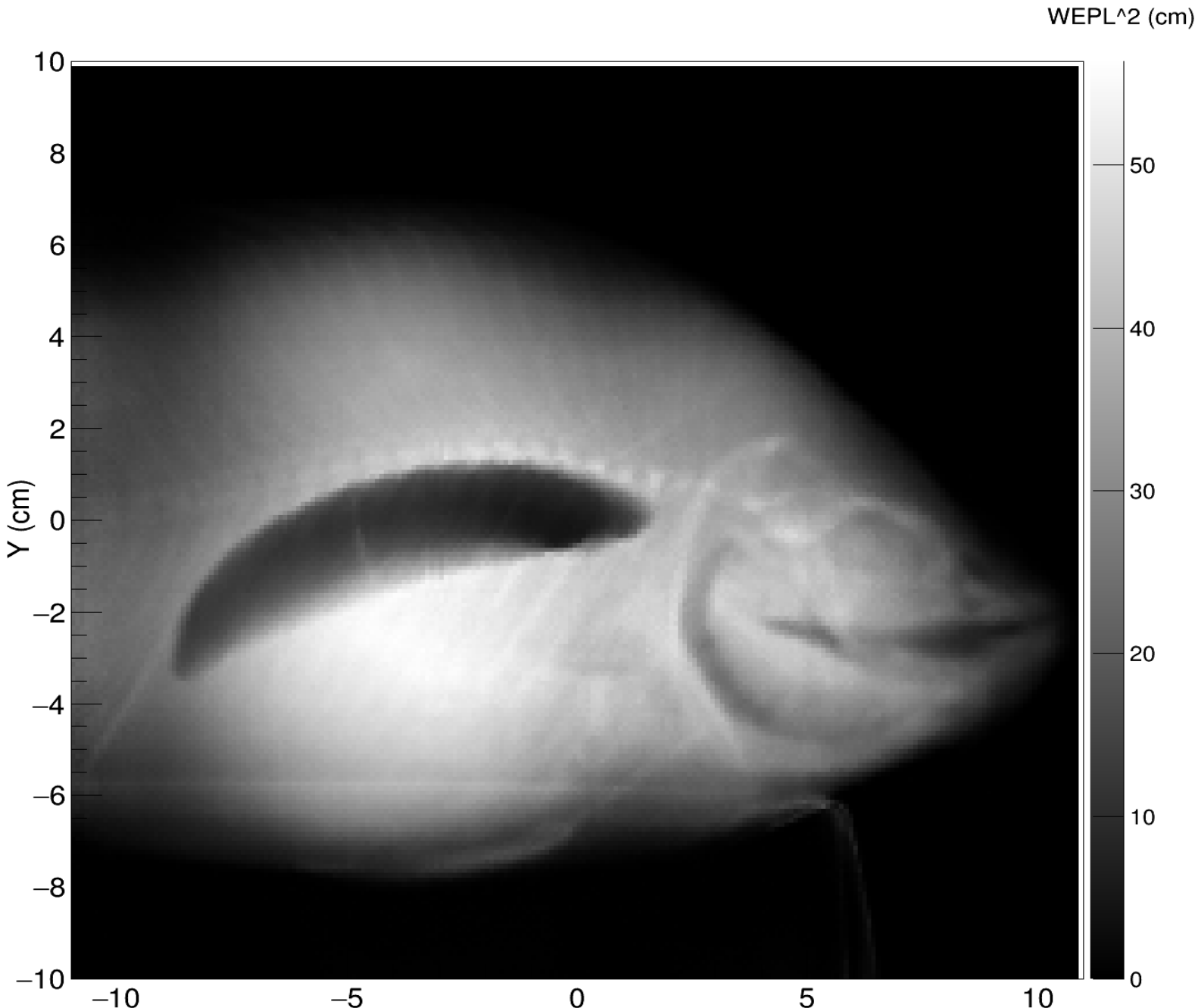
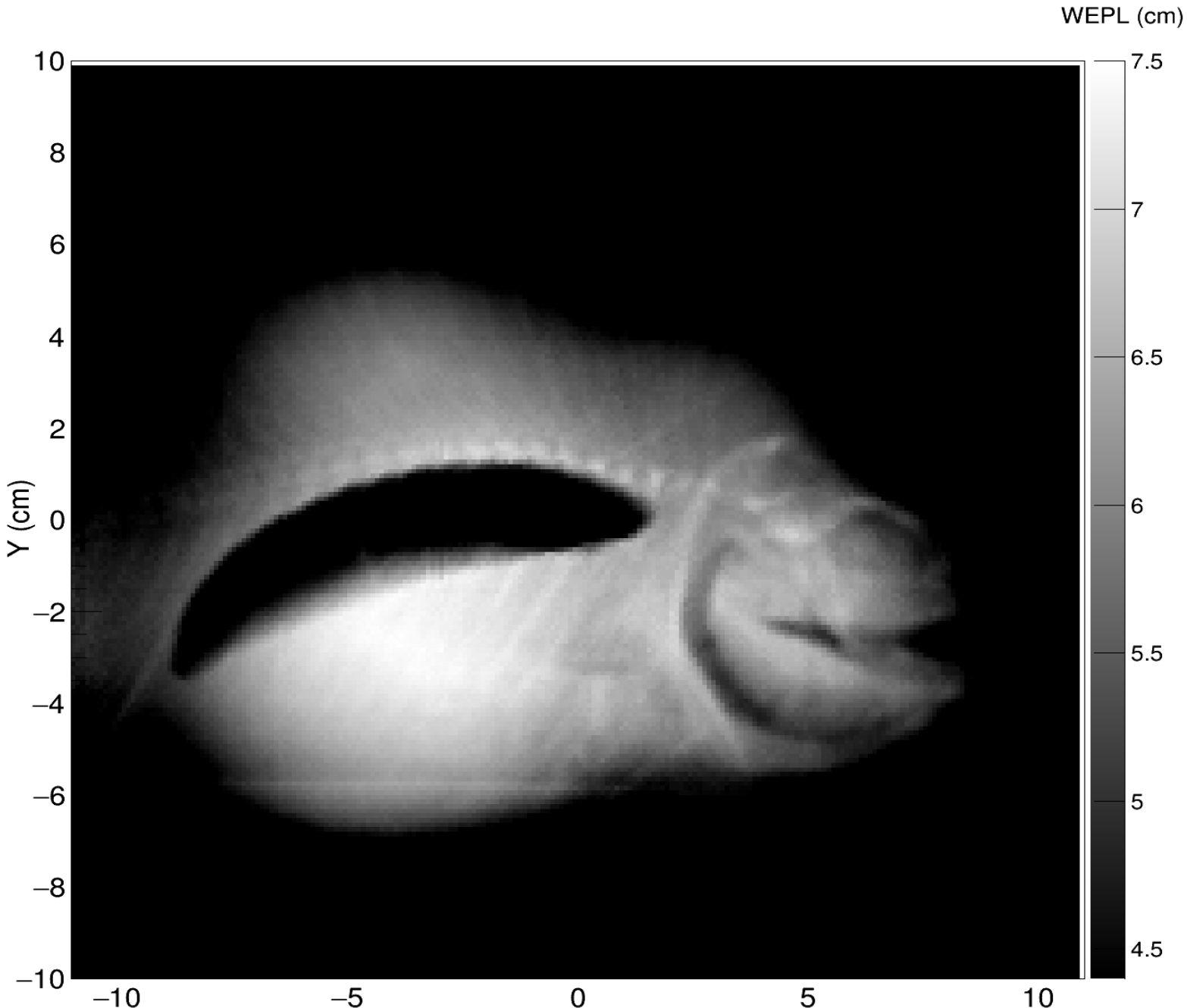
6
5
4
3
2
1


WEPL (cm)
7
6
5
4
3
2
1
Y (cm)
10
8
6
4
2
0
−2
−4
−6
−8
−10
−10
−5
0
5
10

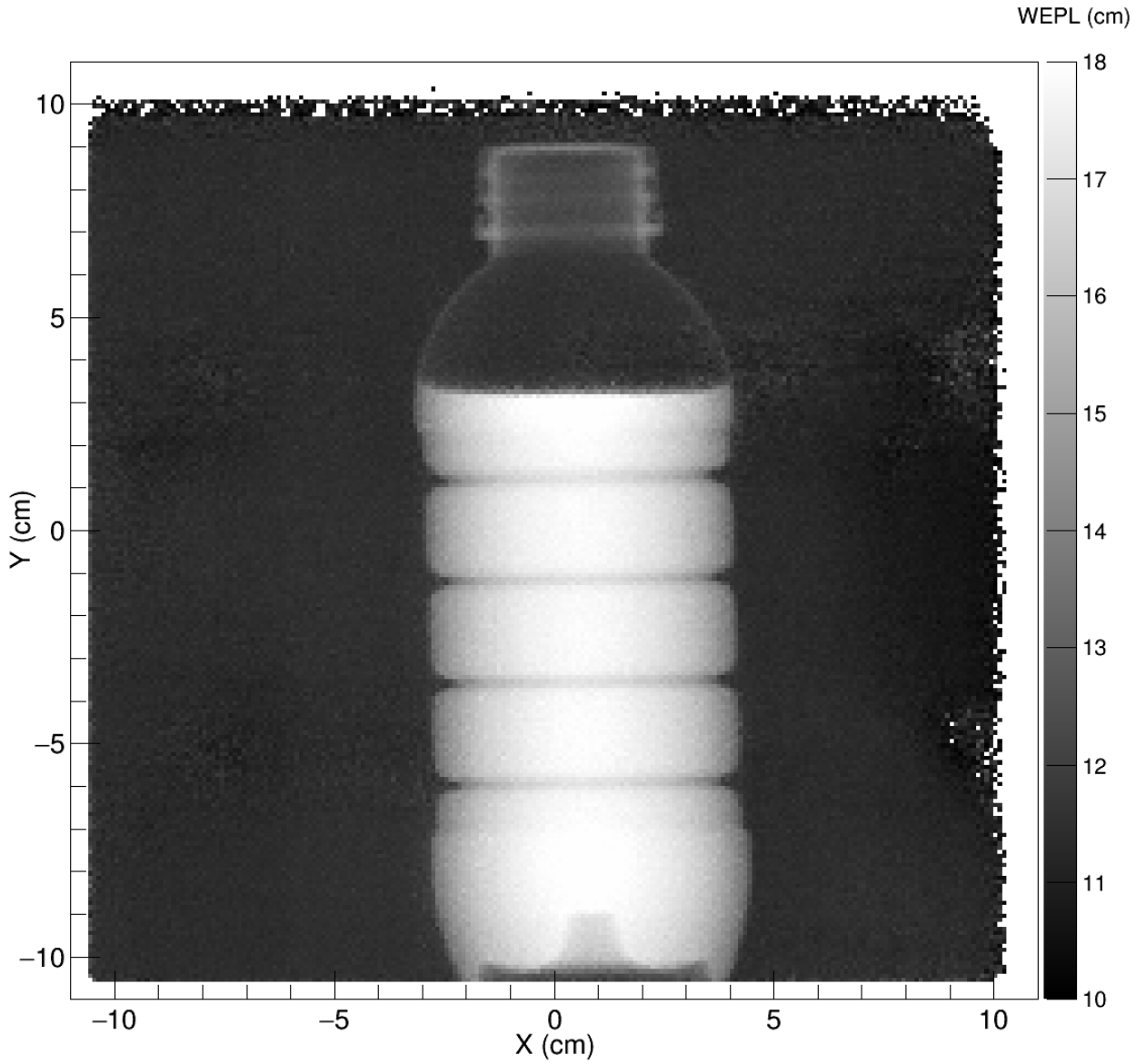

WEPL^2 (cm)
Y (cm)
10
8
6
4
2
0
−2
−4
−6
−8
−10
−10
−5
0
5
10
50
40
30
20
10
0

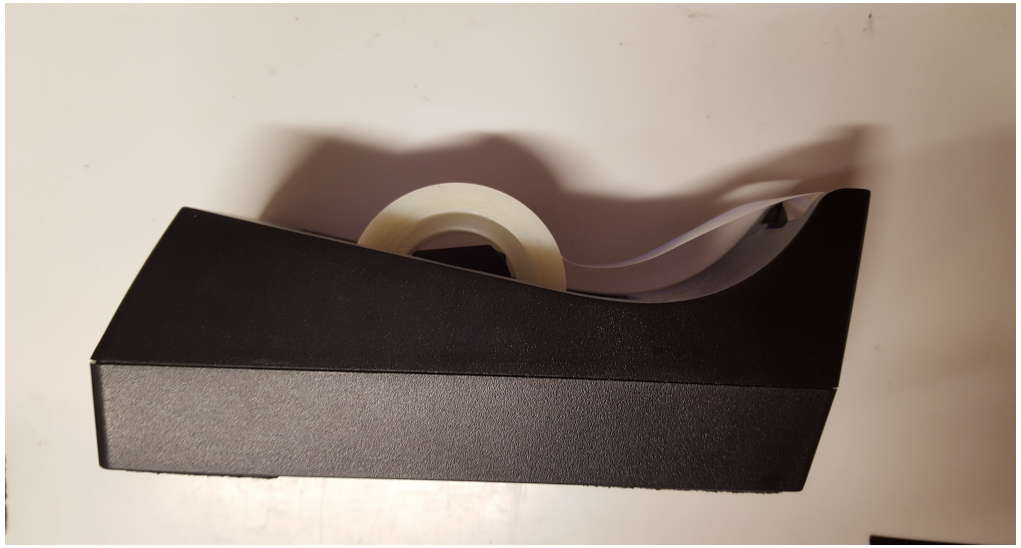

WEPL (cm)
7.5
7
6.5
6
5.5
5
4.5
Y (cm)
10
8
6
4
2
0
−2
−4
−6
−8
−10
−10
−5
0
5
10

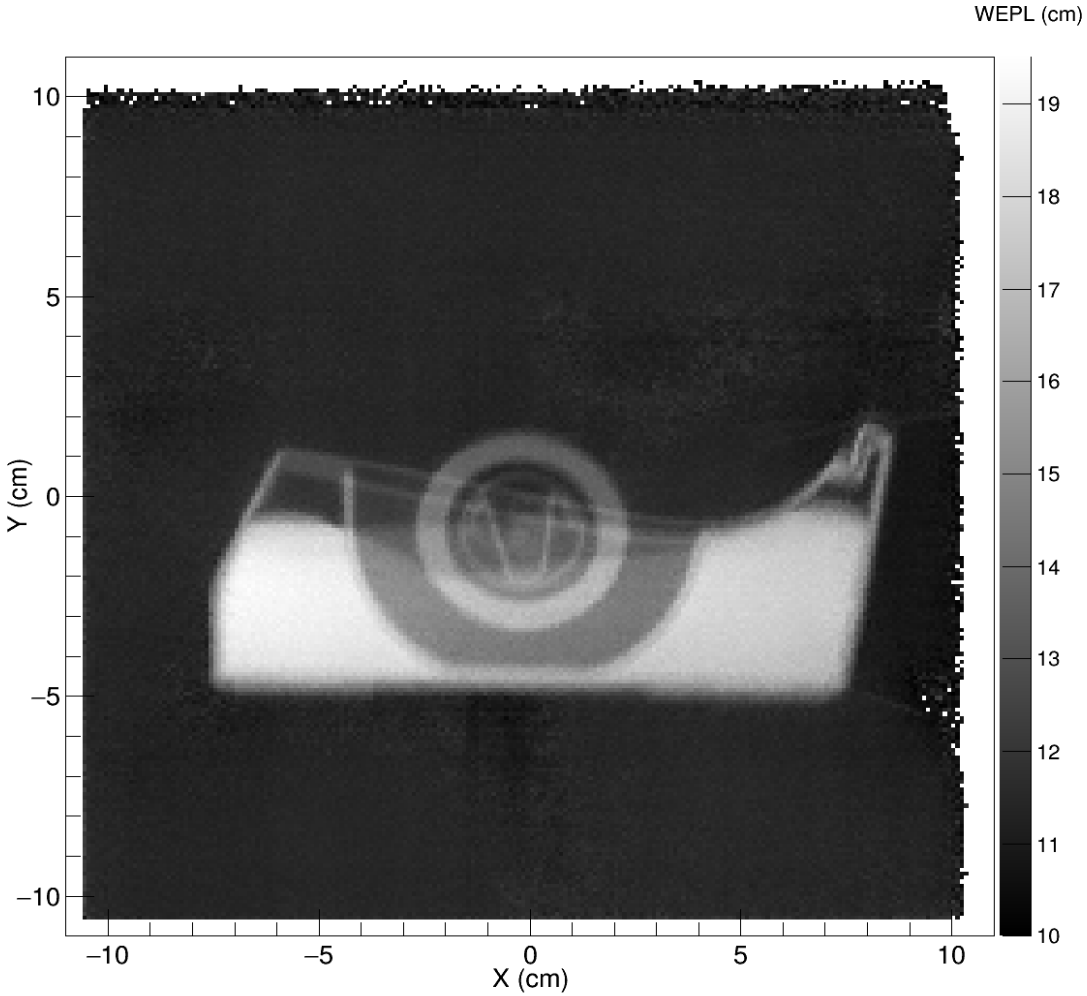
Test with ProtonVDA pRad system and ProNova Knoxville system

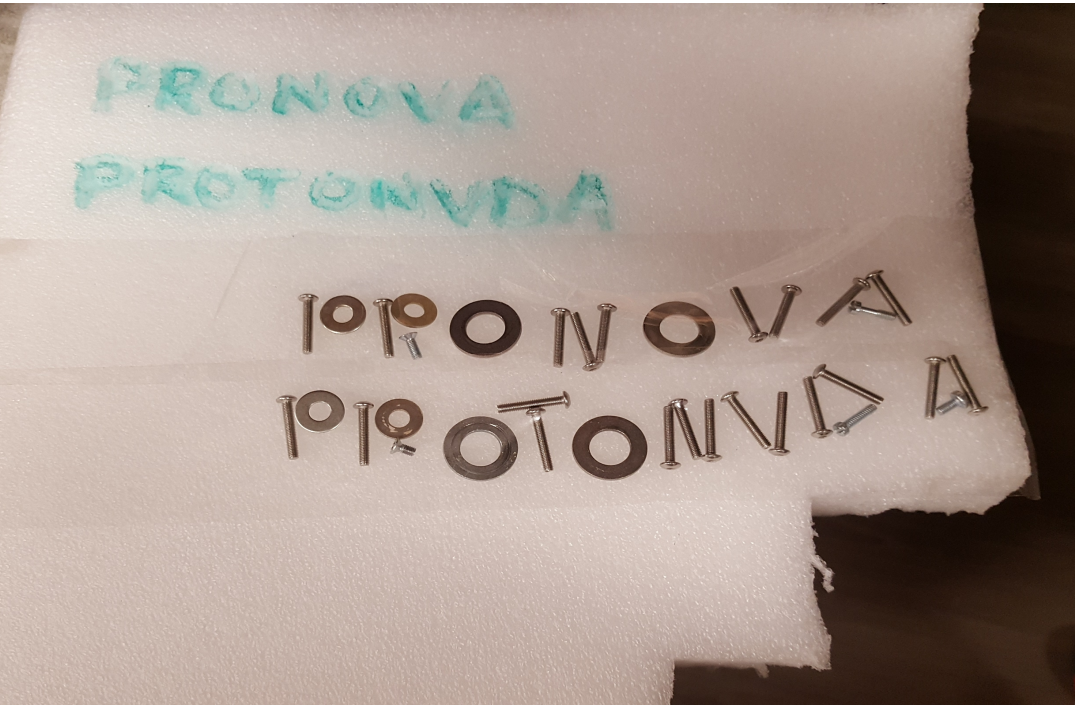
July 26 and 27 2018

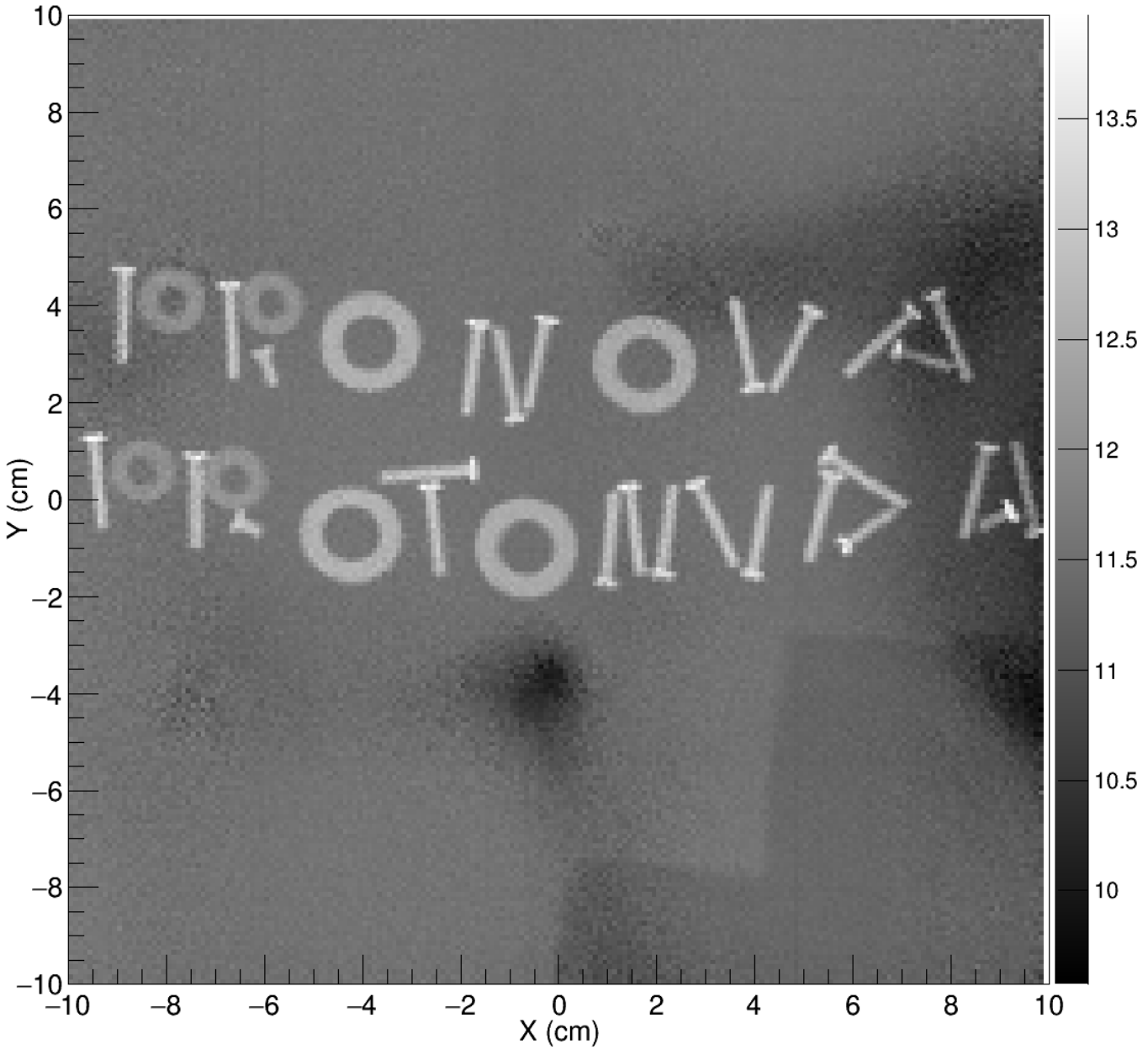
Fast (~ 1 min) online image reconstruction



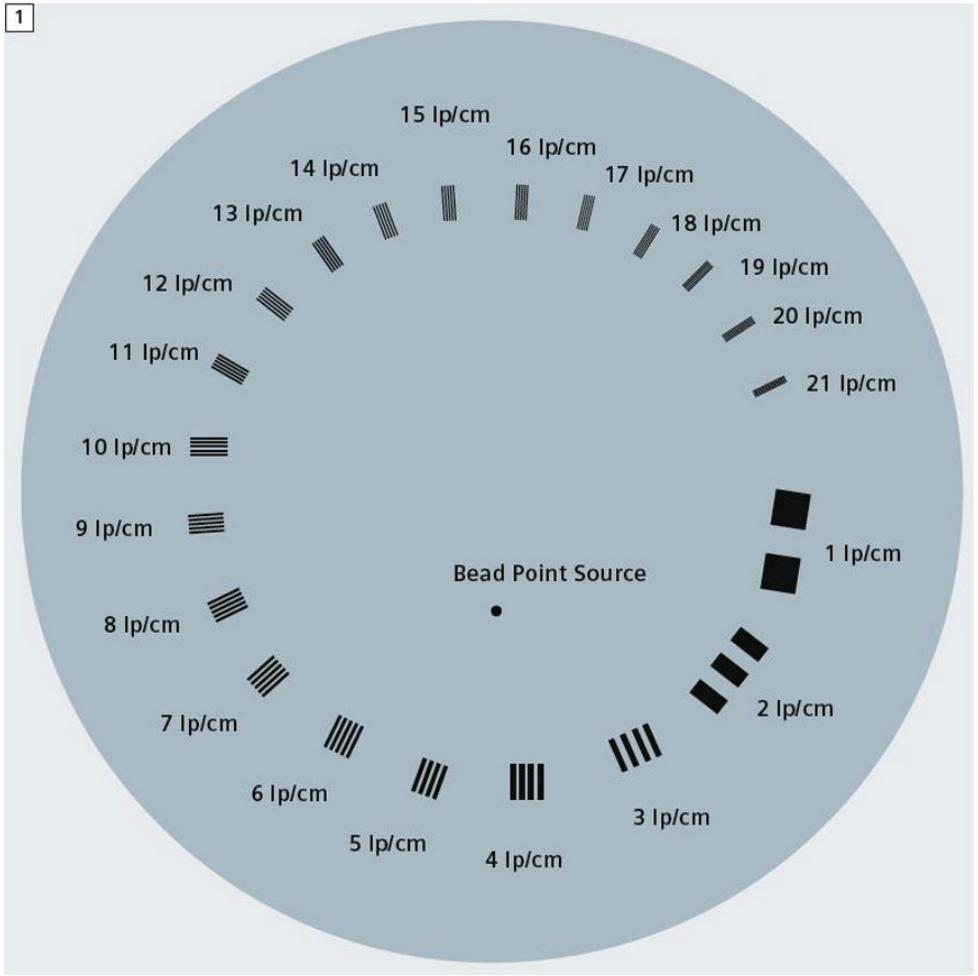



WEPL (cm)
19
18
17
16
15
14
13
12
11
10
Y (cm)
10
5
0
−5
−10
−10
−5
0
5
10
X (cm)


PRONOVA
PROTONVDA

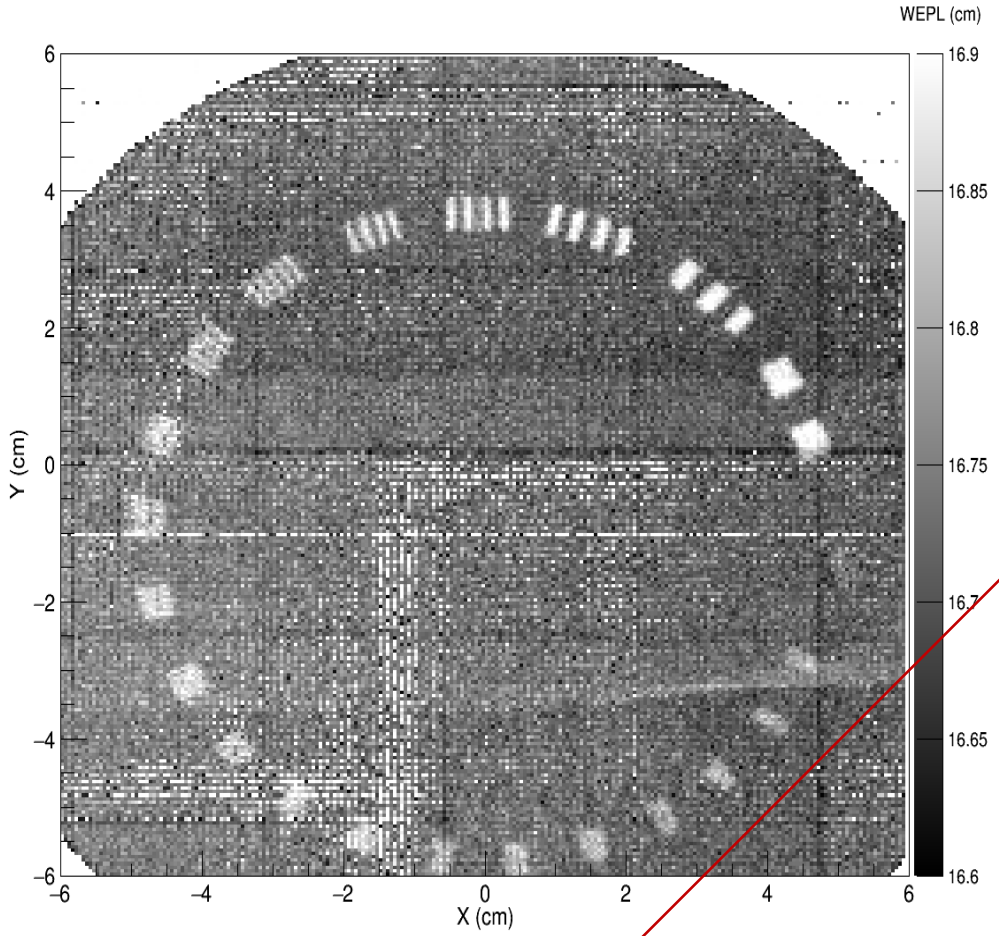

WEPL (cm)
Y (cm)
X (cm)
10
8
6
4
2
0
−2
−4
−6
−8
−10
13.5
13
12.5
12
11.5
11
10.5
10

CATPHAN Line Pair Phantom

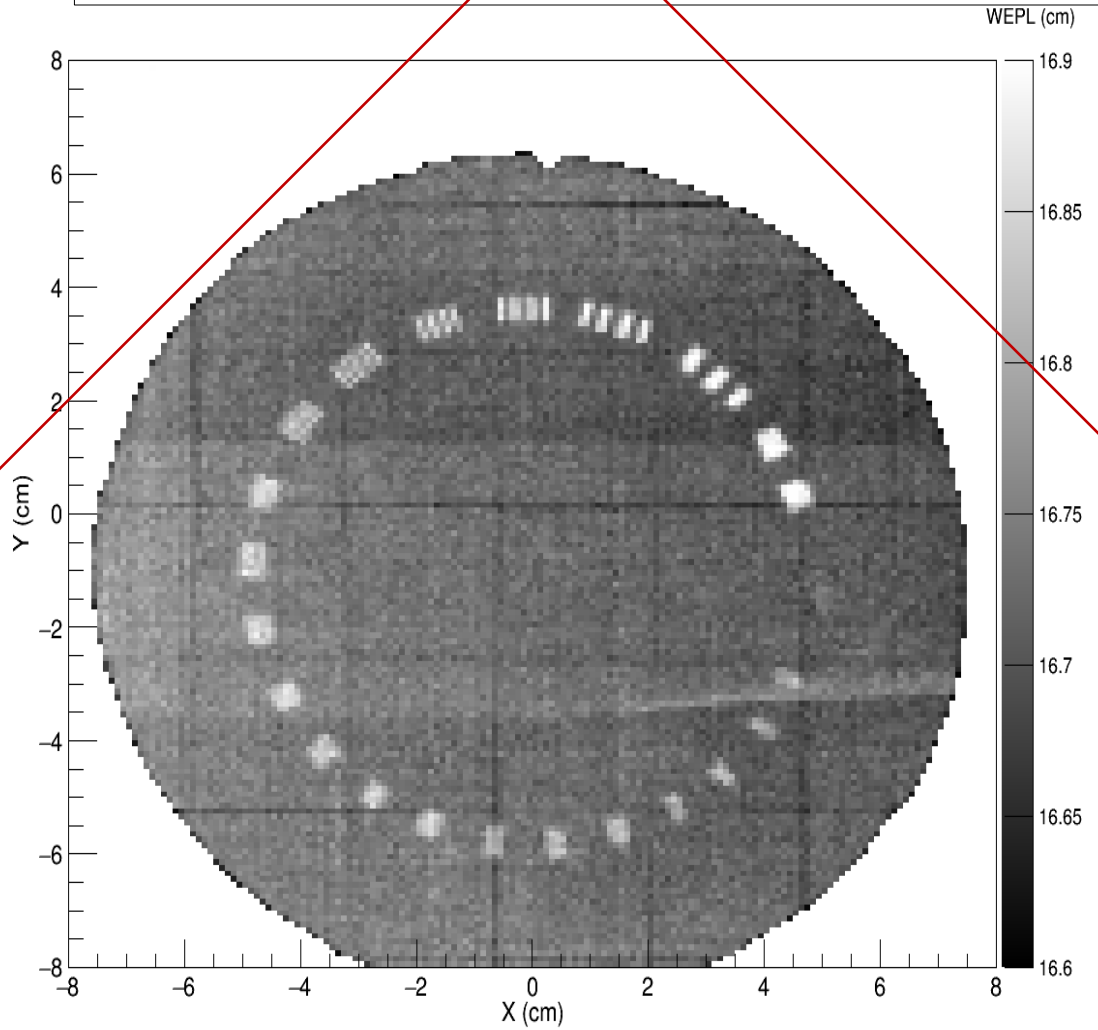


Offline reconstruction
Note: grey scale range only 3 mm!

As to range sensitivity.. We clearly see the 0.2 mm tape supporting the phantom. The density of this tape is slightly above water density.

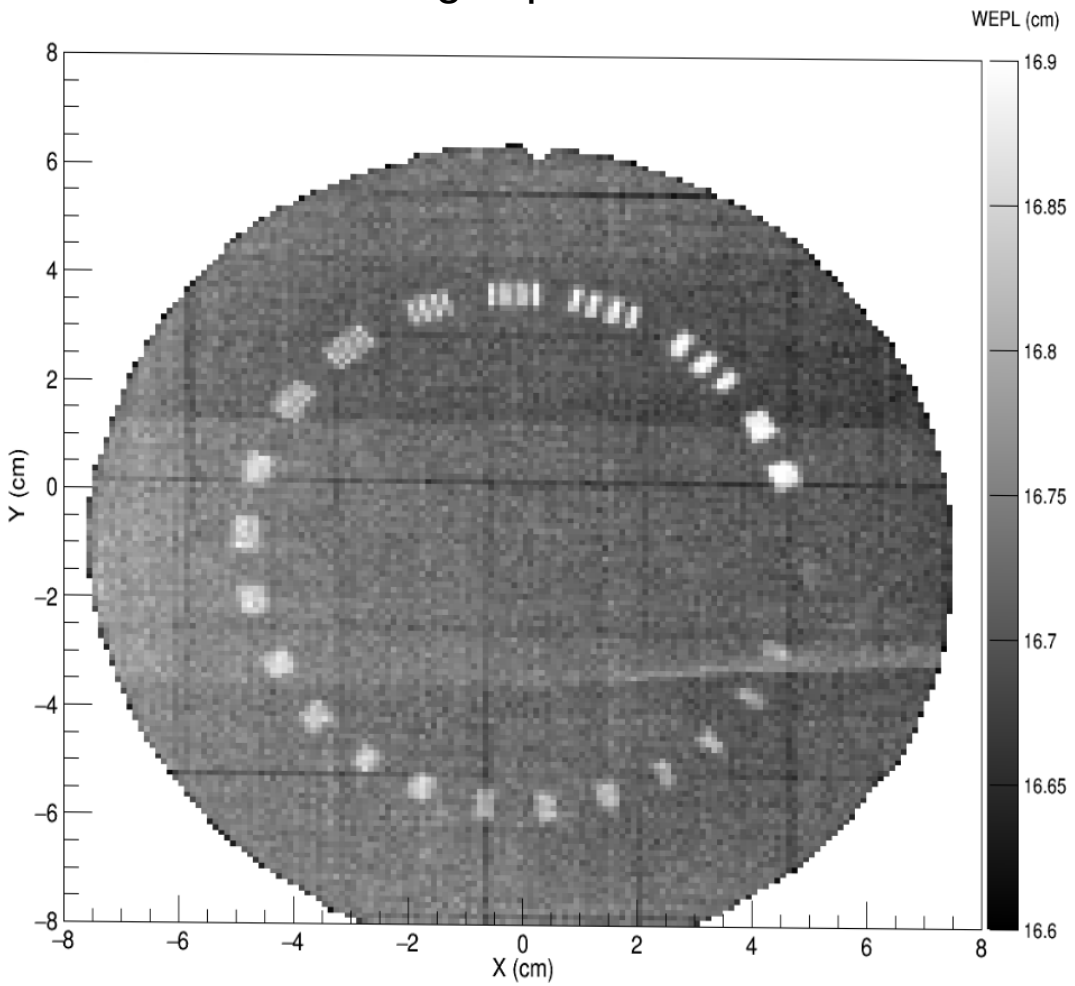


We see 7 line pairs/cm with 0.5 mm pixel size

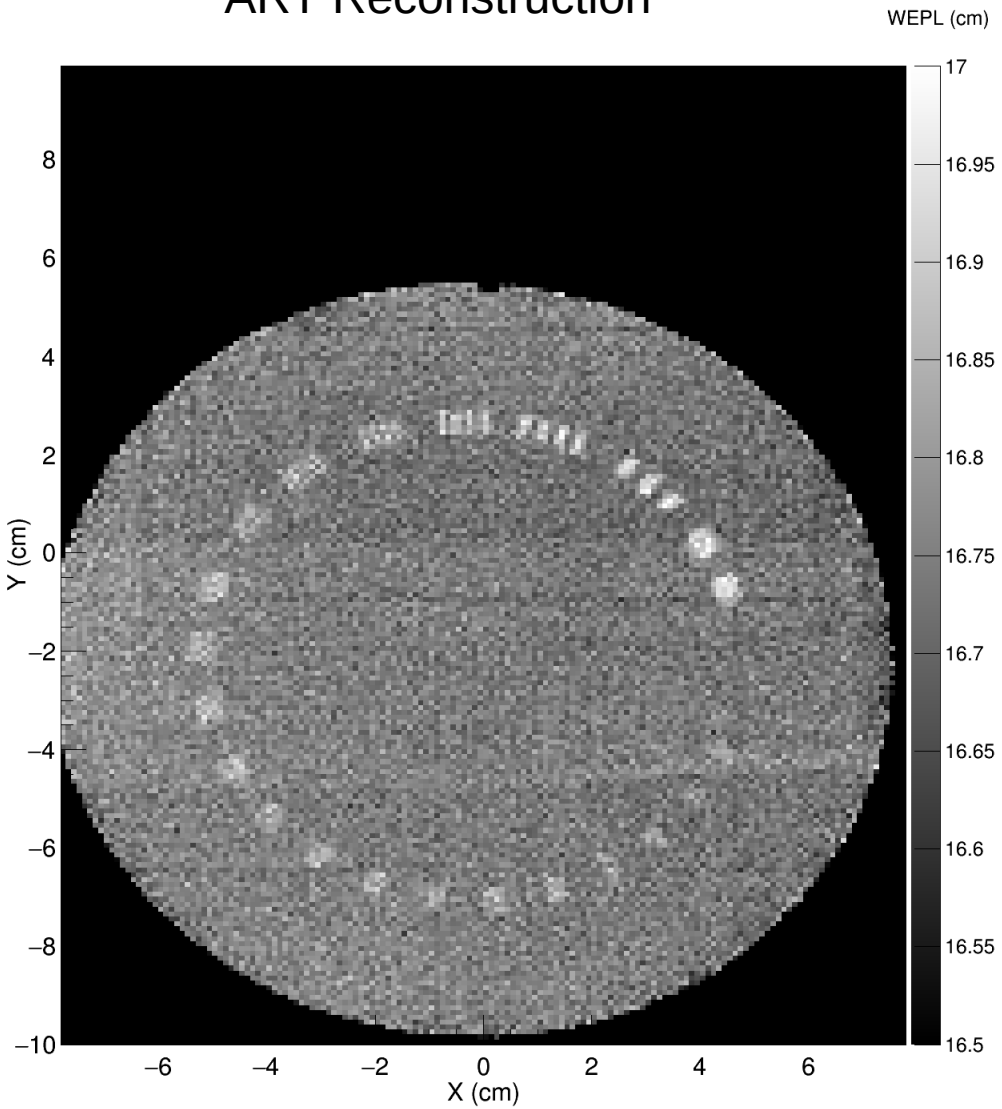


We see 6 line pairs/cm with 1 mm pixel size

2-D Binning in plane of inserts



ART Reconstruction



Loma Linda pCT reconstructed image (offline) of the same line-pair phantom

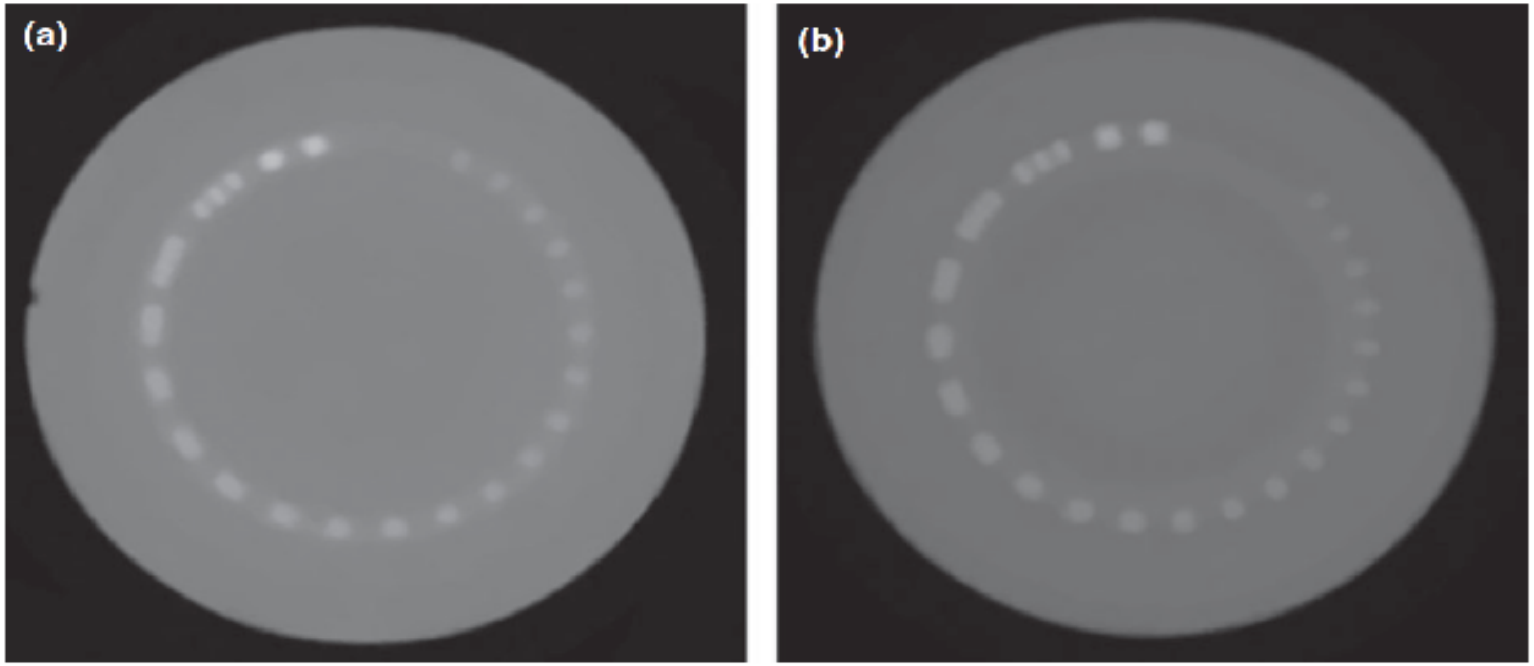
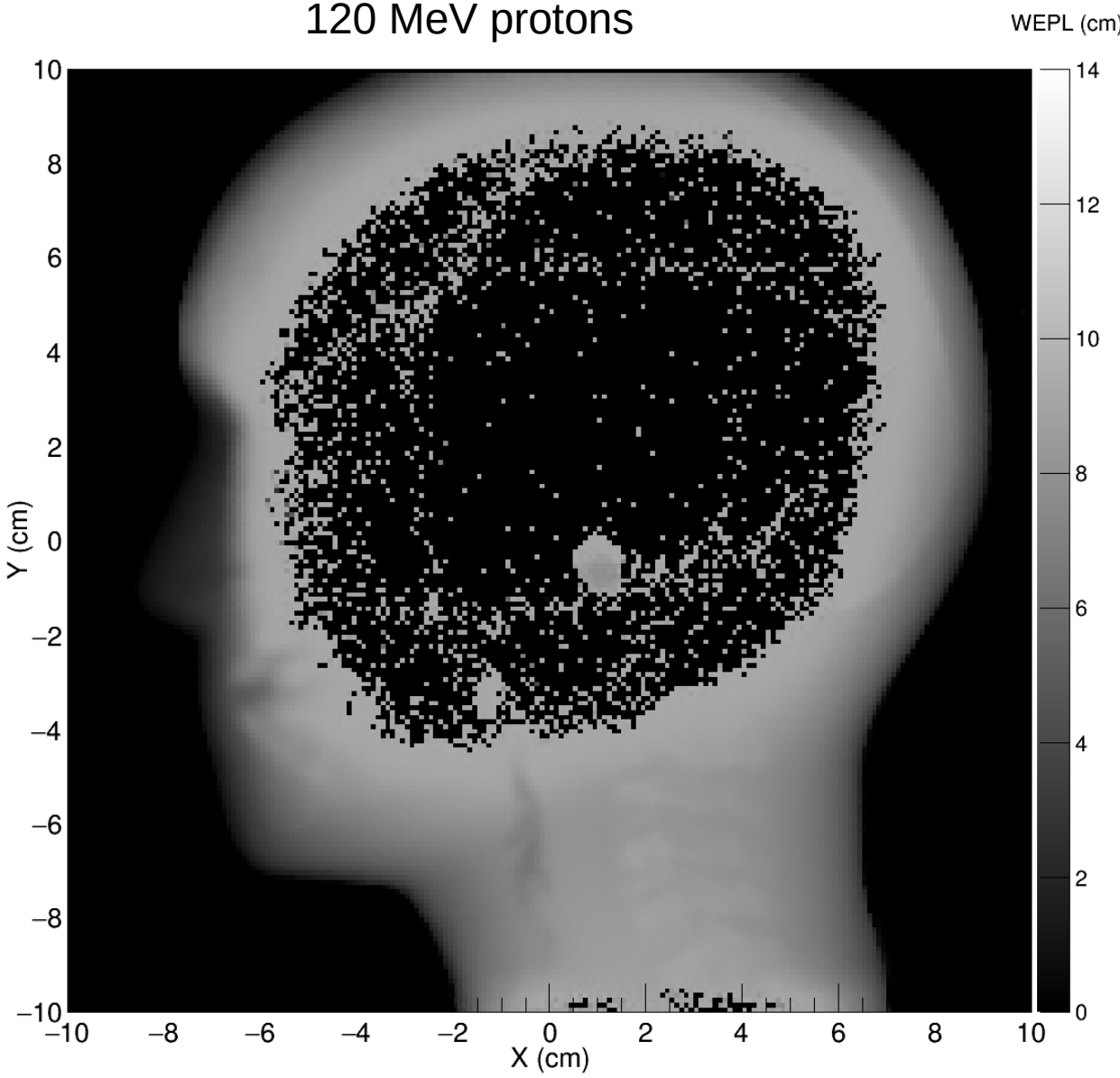


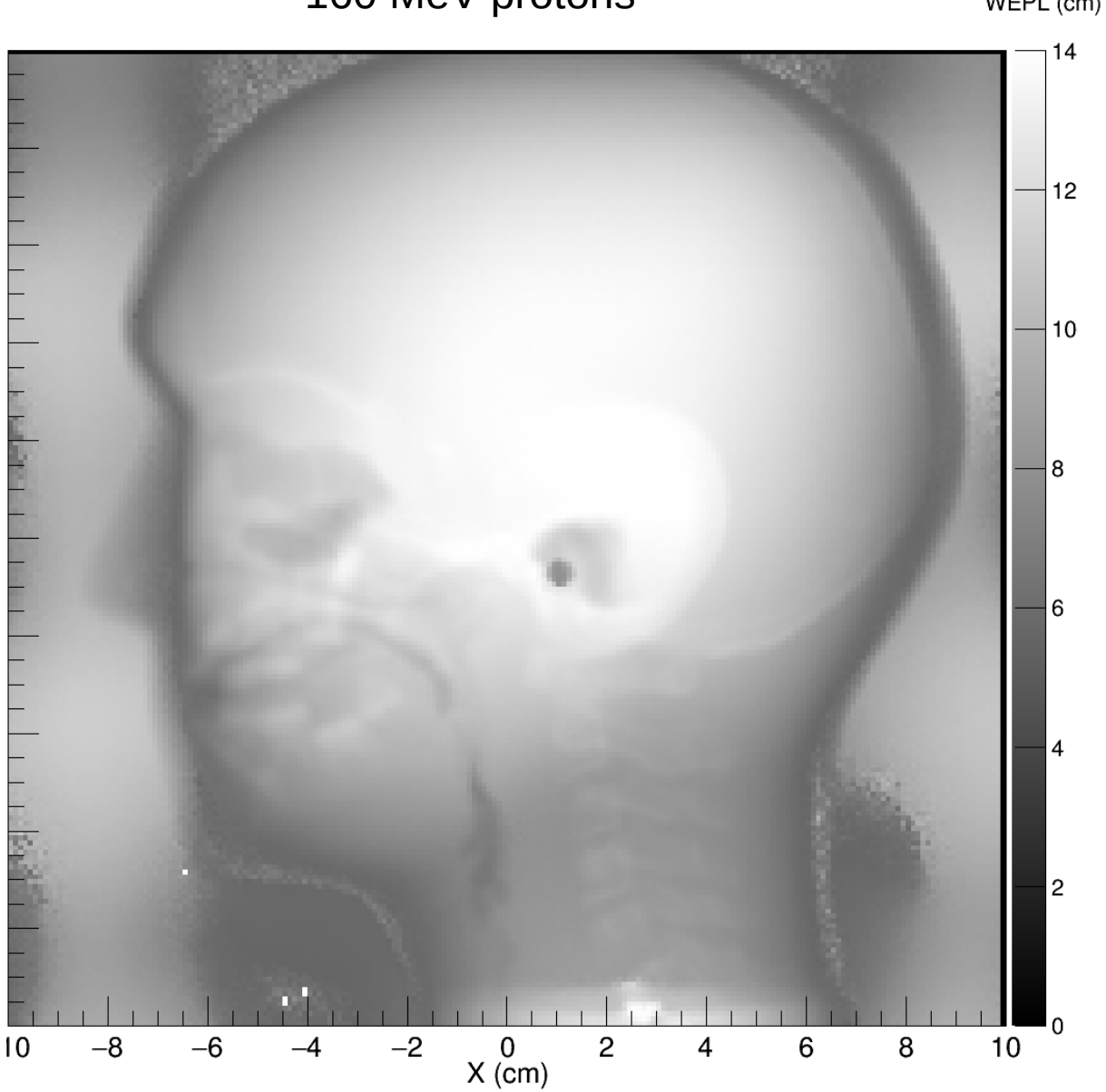
FIG. 13. Catphan©60 Line pair module pCT reconstruction using experimental (a) and simulated (b) data.

Pediatric head phantom

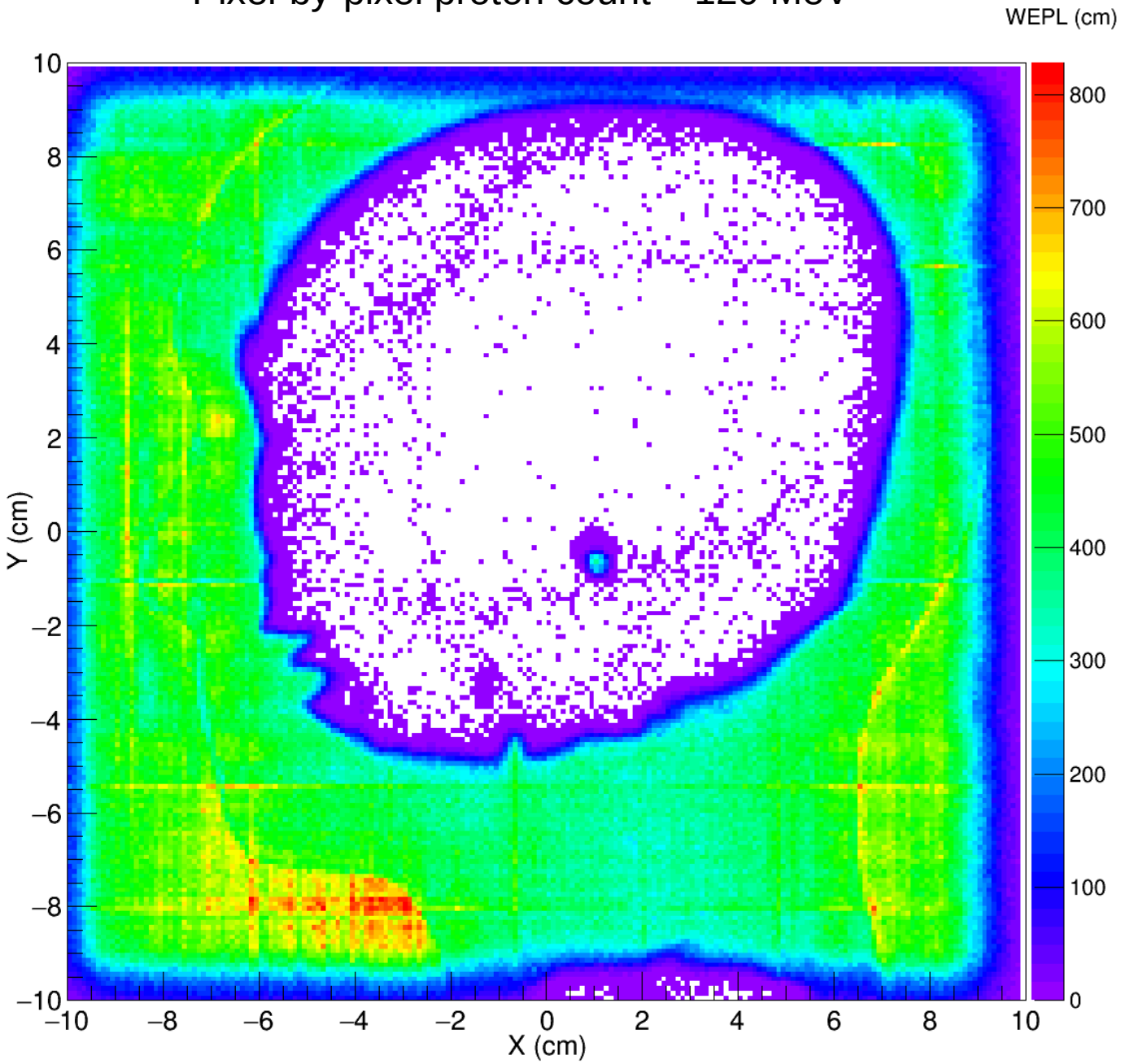
120 MeV protons



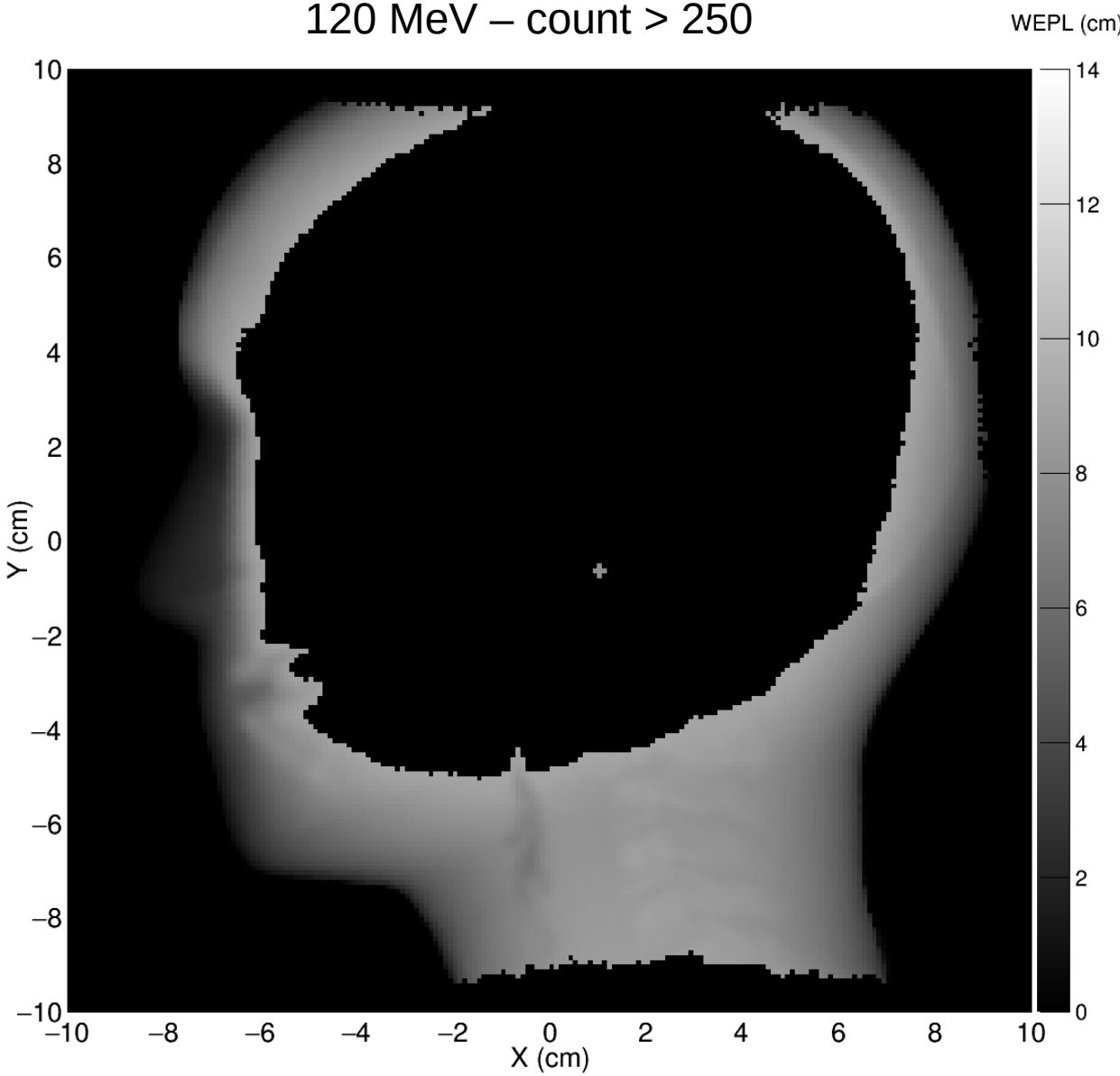
160 MeV protons



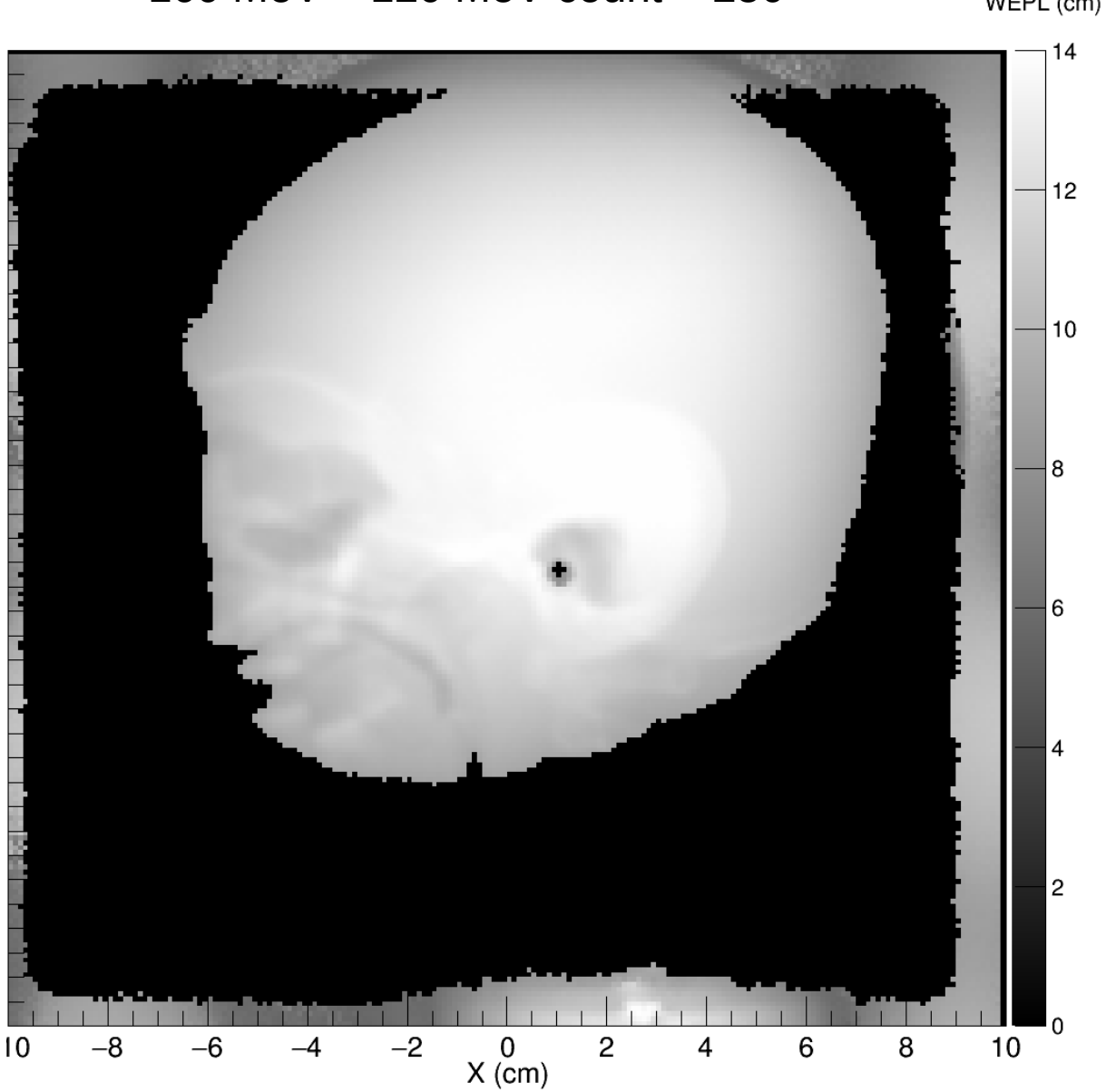
Pixel-by-pixel proton count – 120 MeV

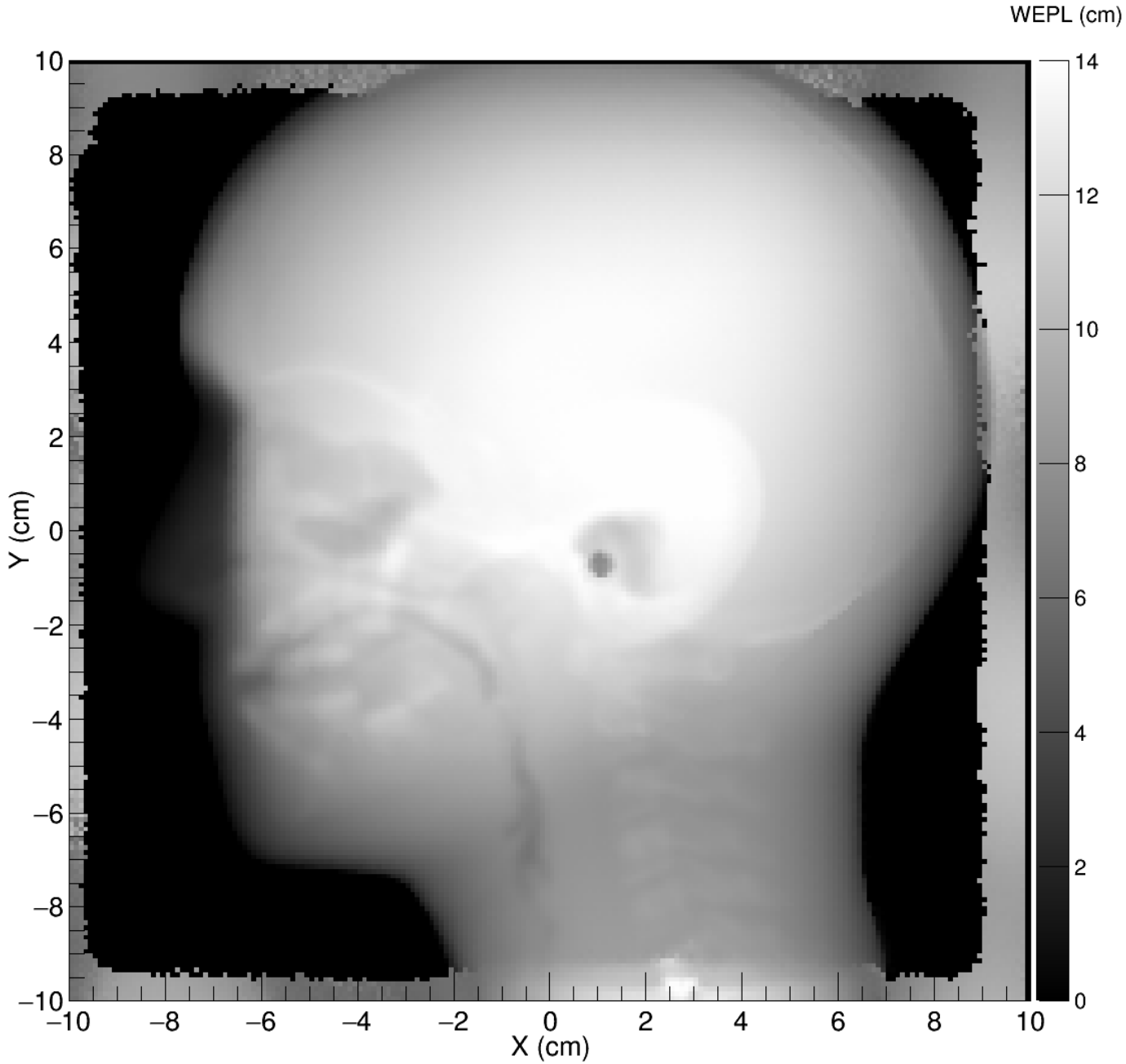


120 MeV – count > 250



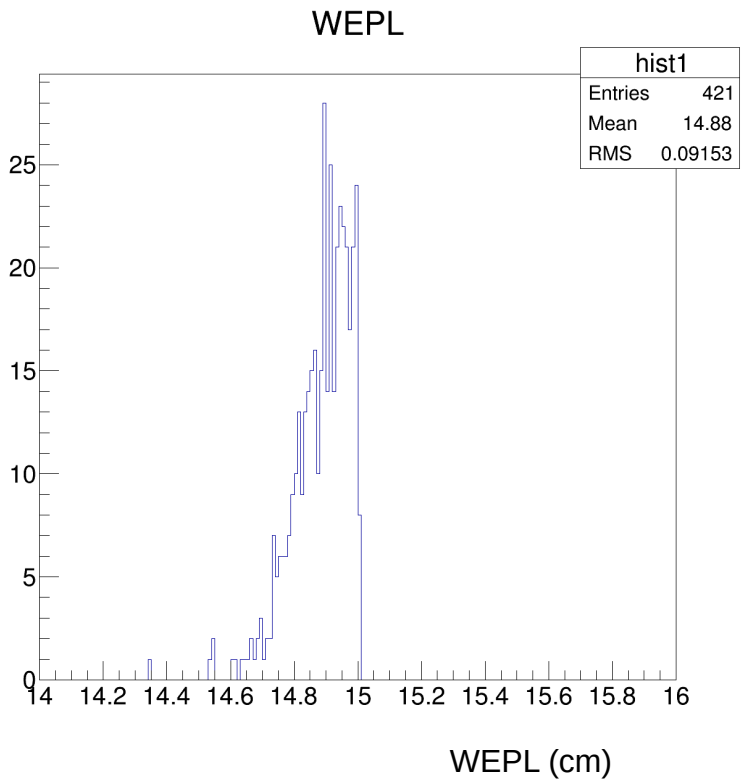
160 MeV – 120 MeV count < 250



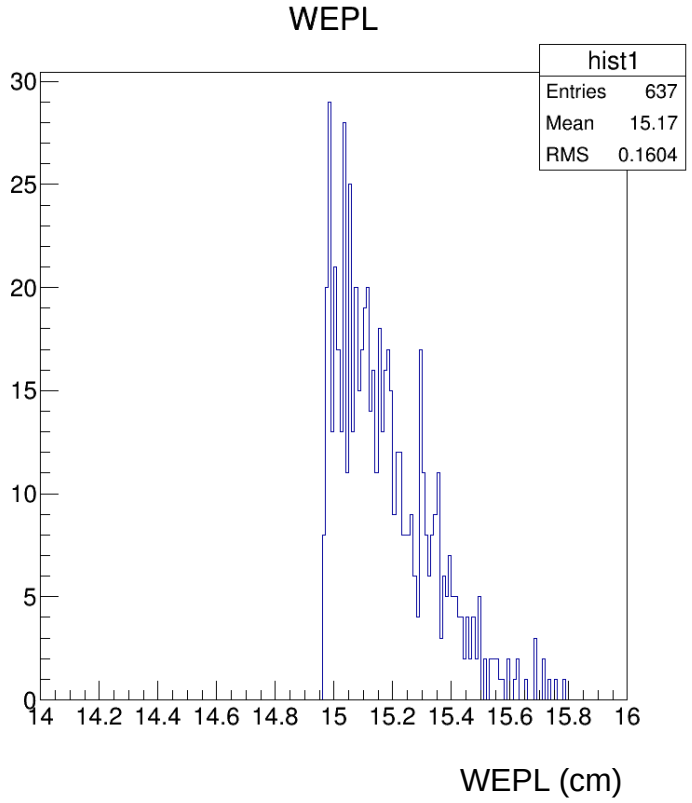

WEPL (cm)
14
12
10
8
6
4
2
0
Y (cm)
10
8
6
4
2
0
−2
−4
−6
−8
−10
−10
−8
−6
−4
−2
0
2
4
6
8
10
X (cm)

Energy Boundary Artifacts

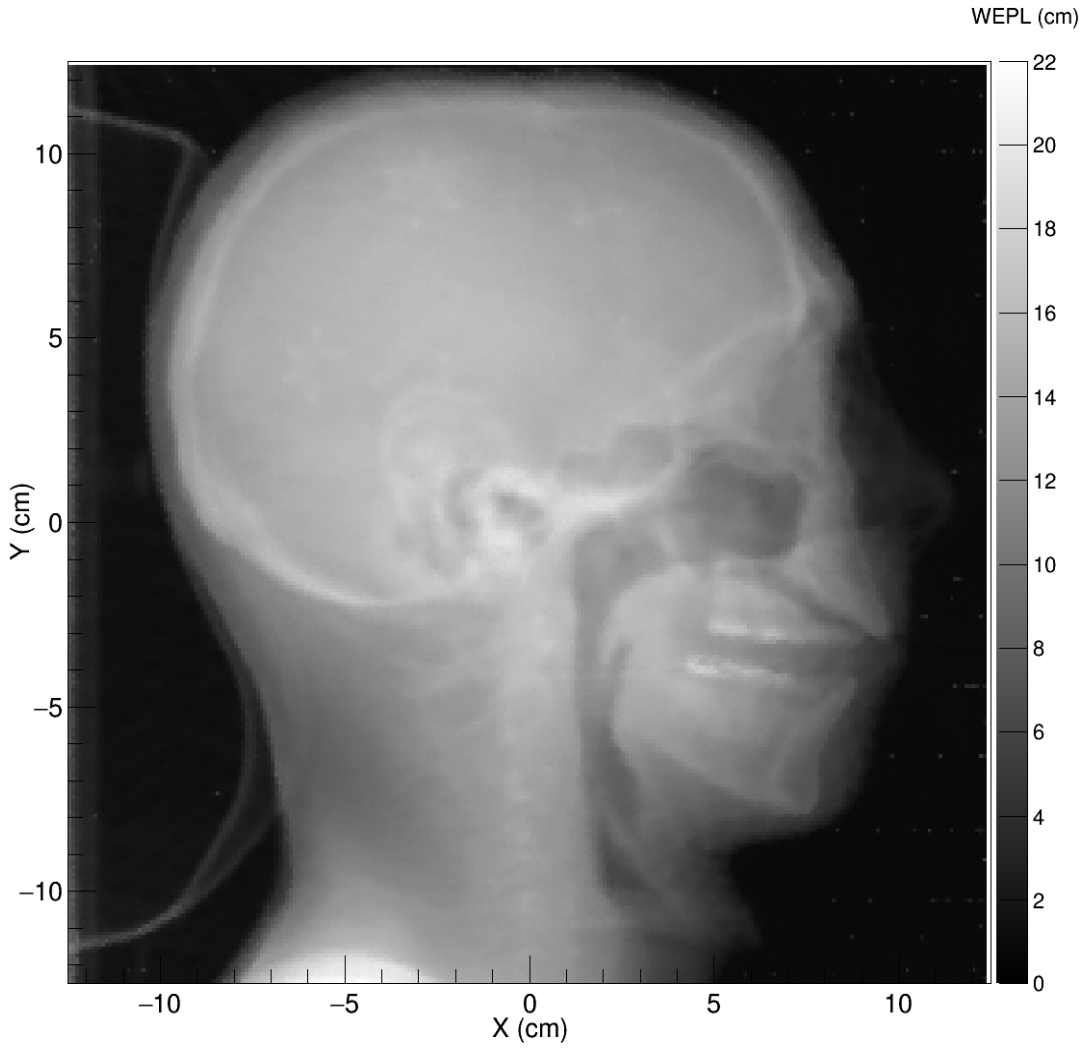
16 cm range beam through 15 cm water:

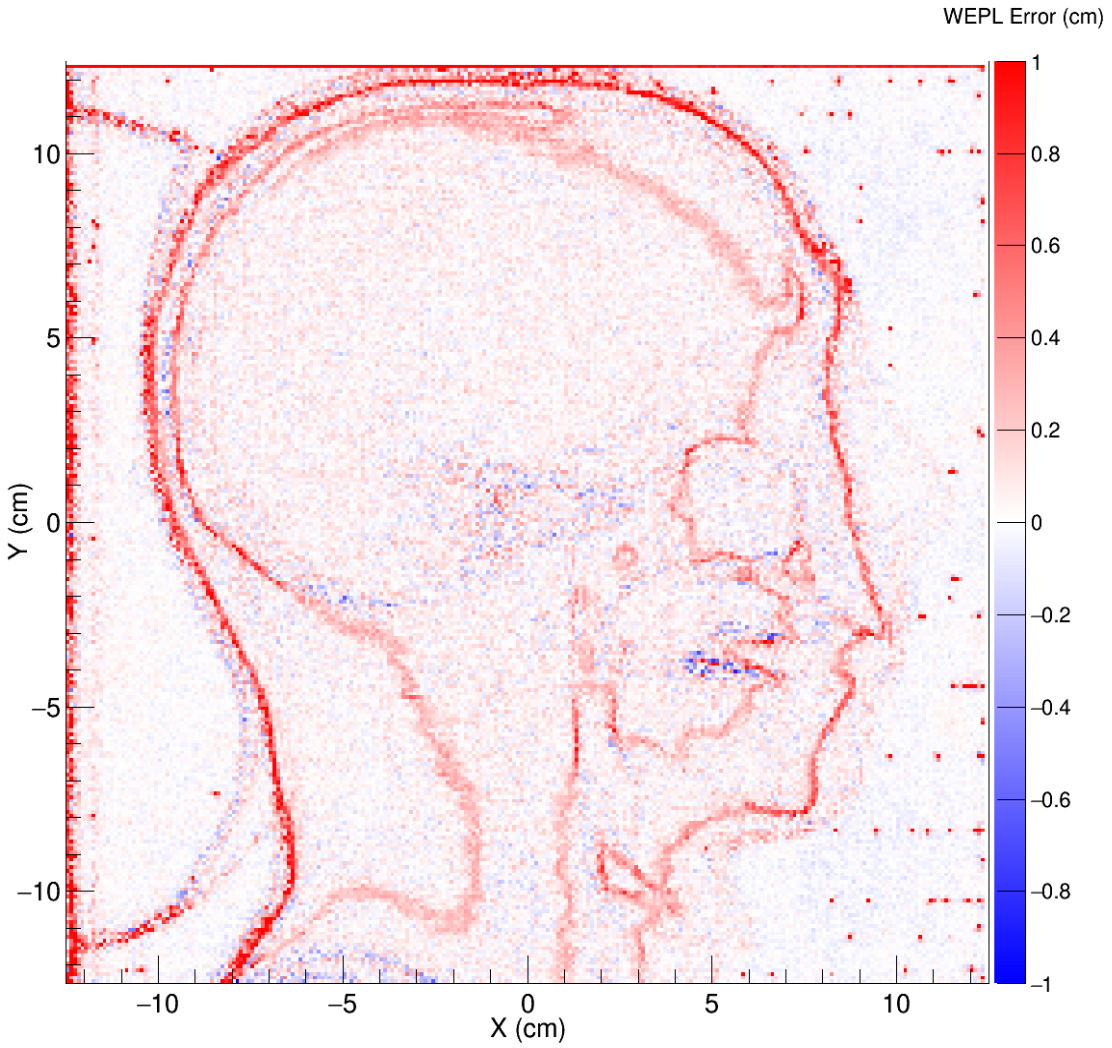


26 cm range beam through 15 cm water:

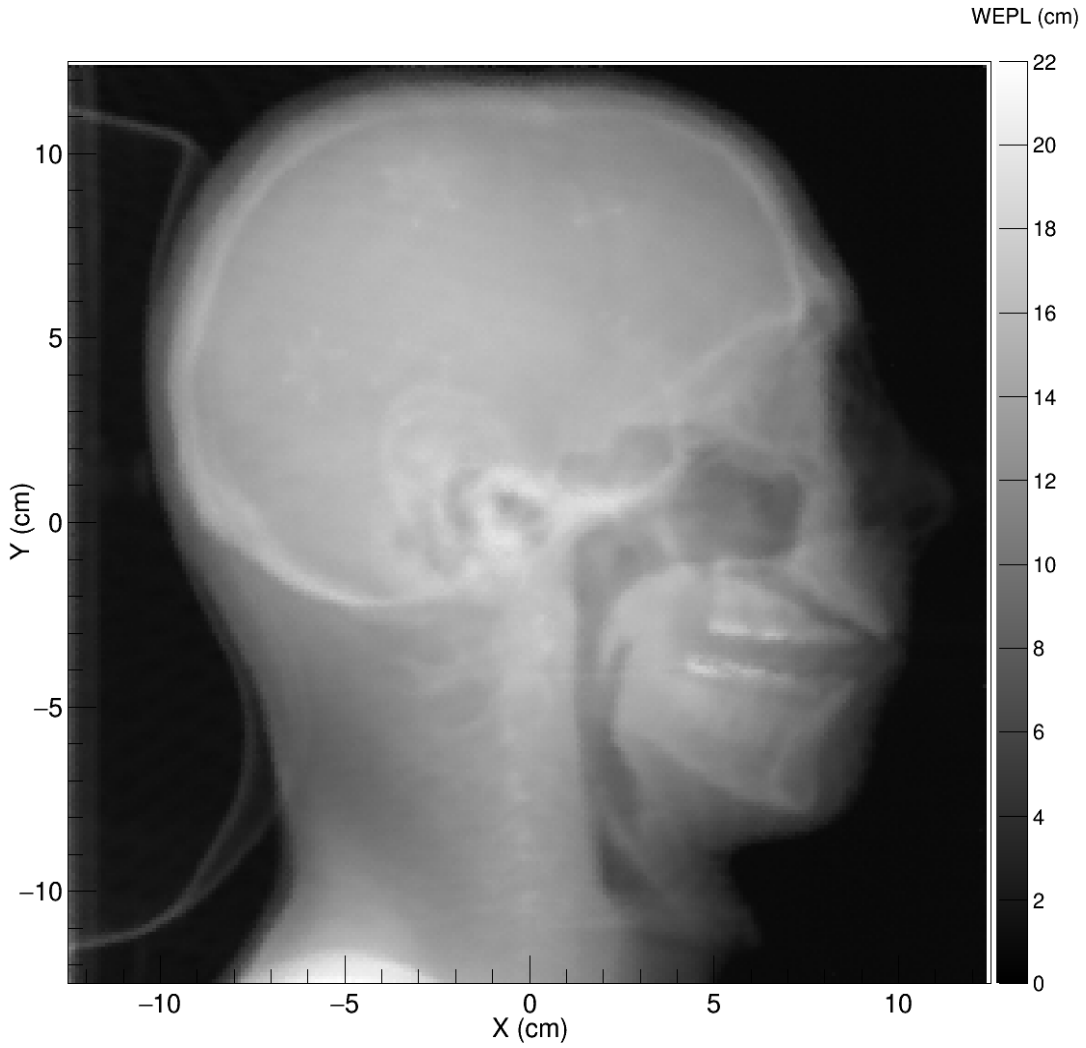


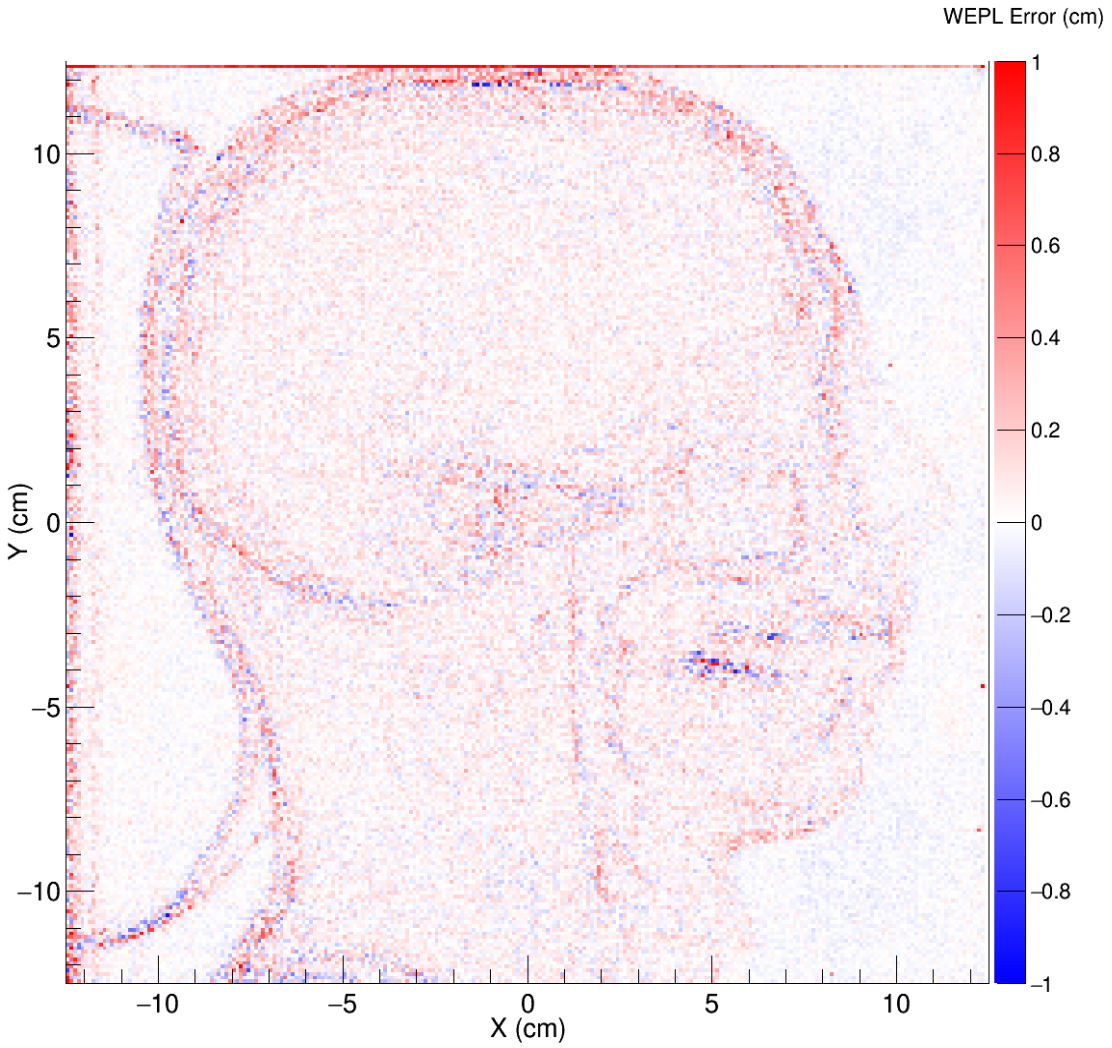
No Energy Boundary Cuts



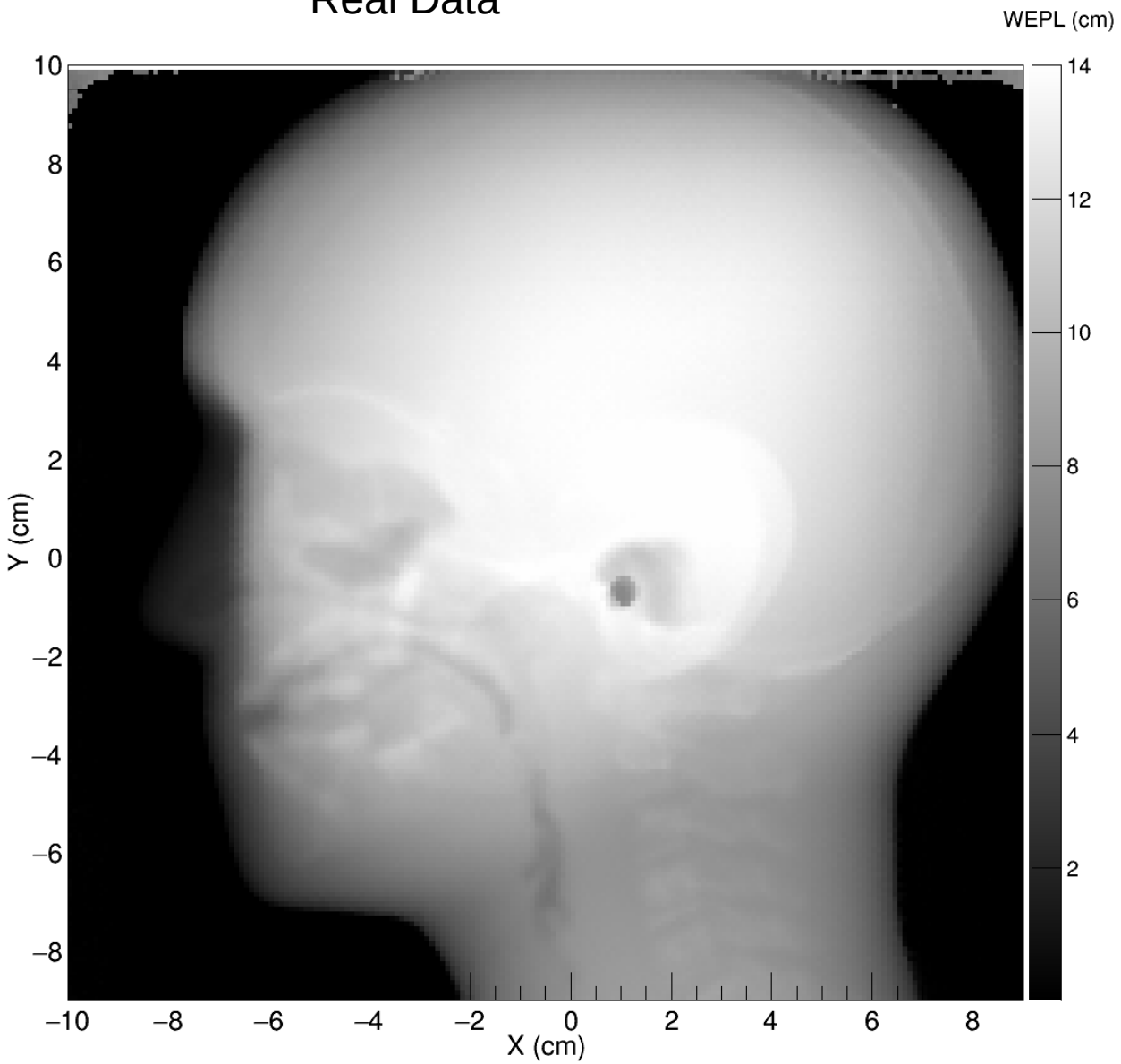


With Energy Boundary Cuts

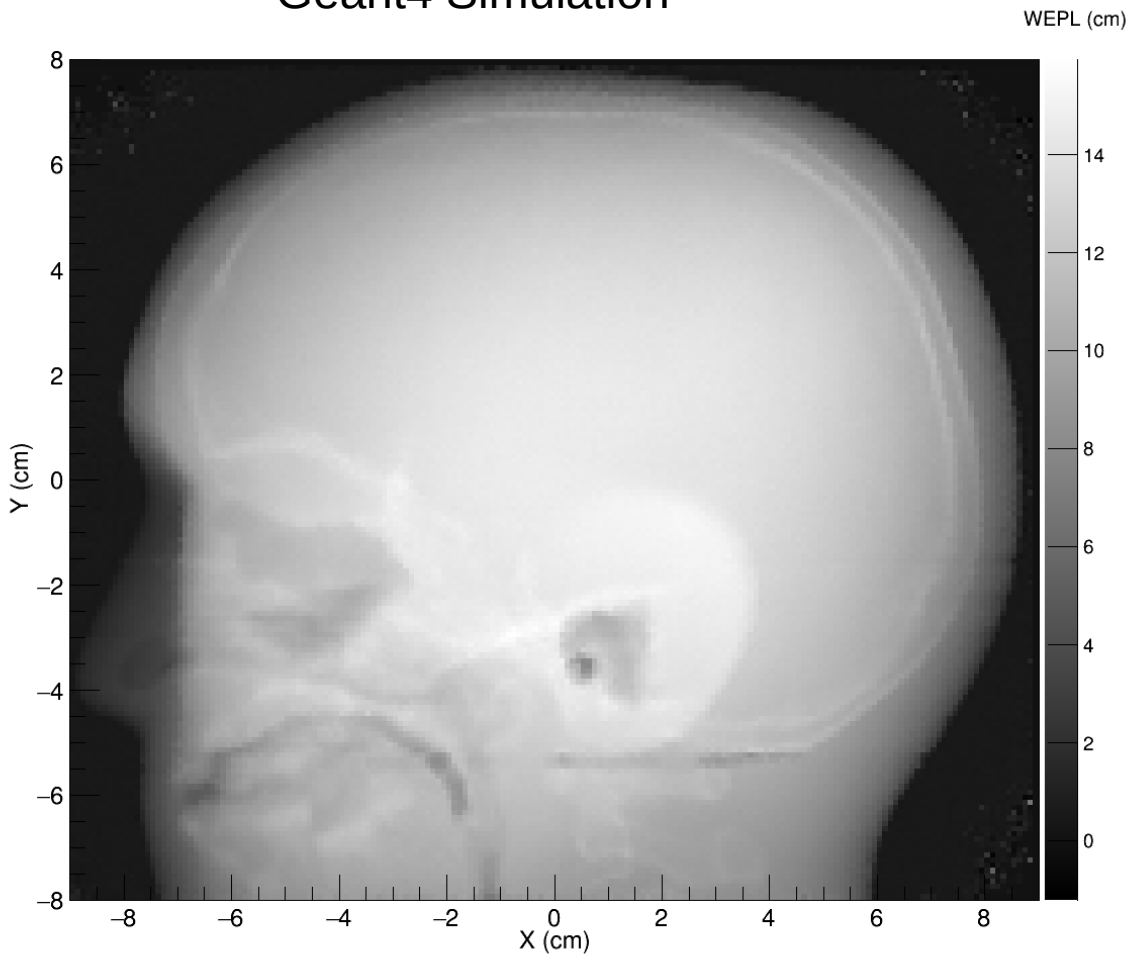




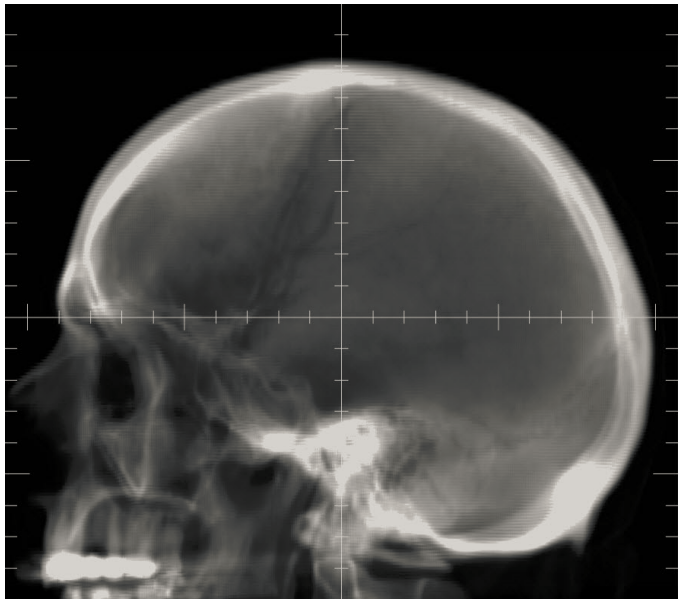
Real Data



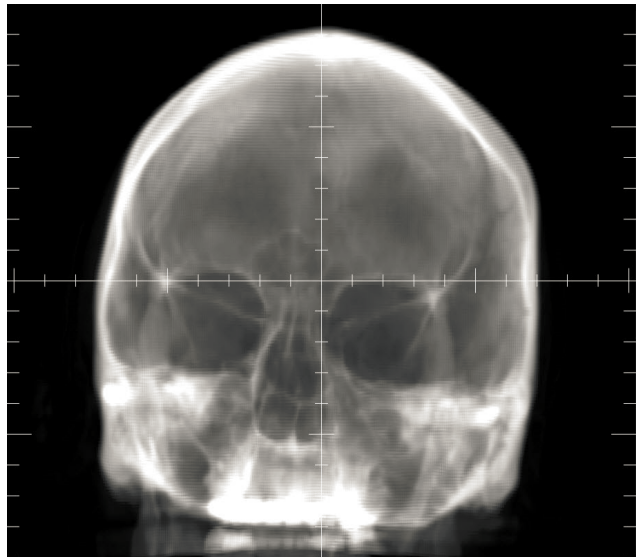
Geant4 Simulation

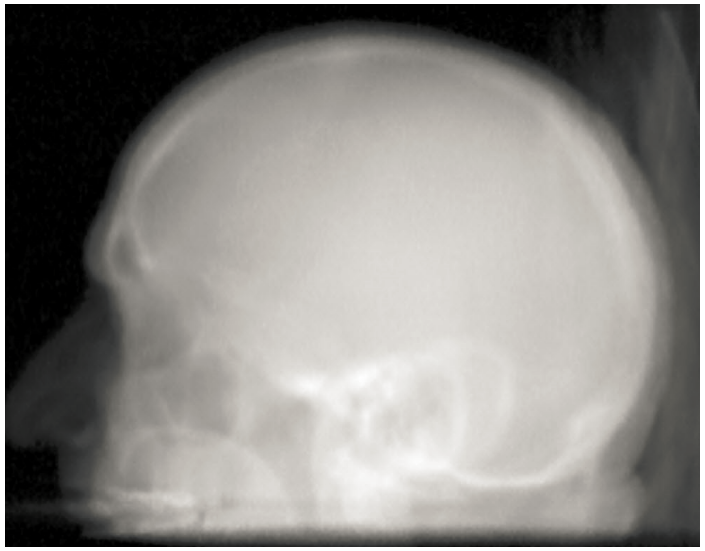


Are these images good enough to align the patient??

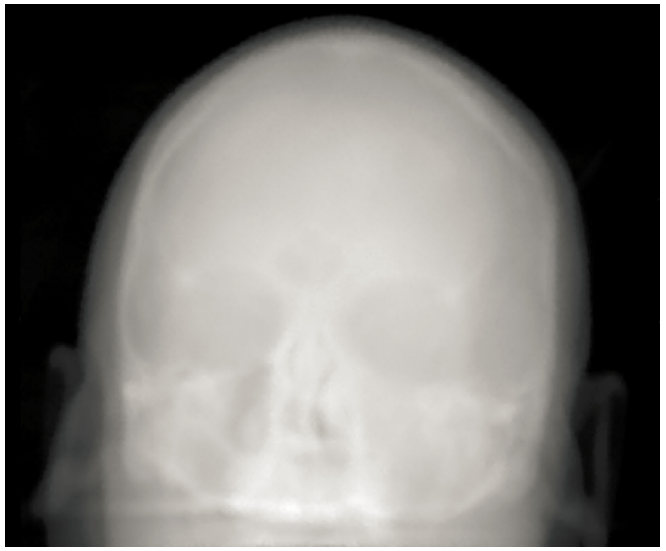


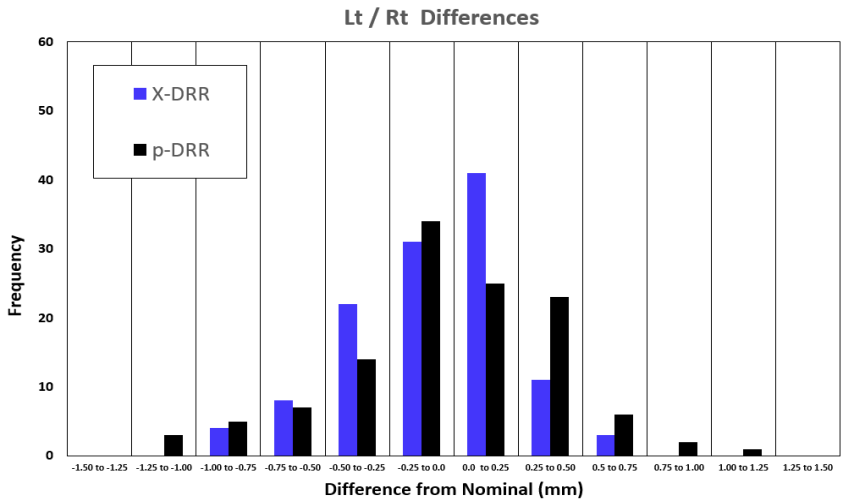
X-DRR

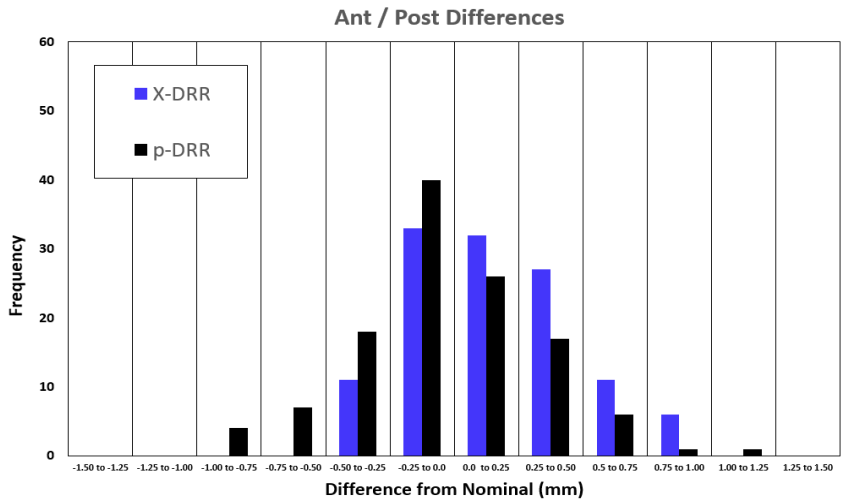




p-DRR

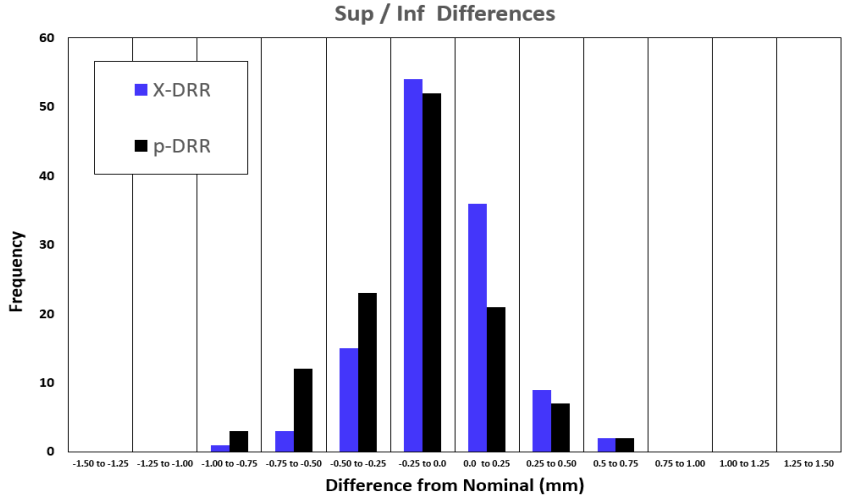


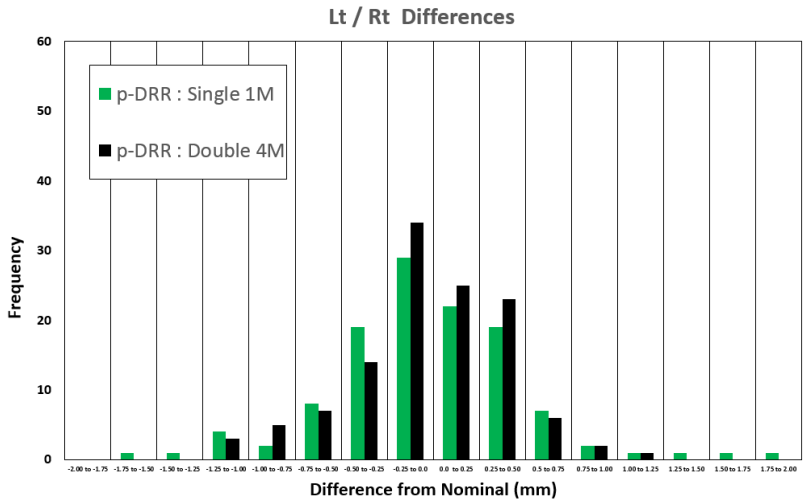


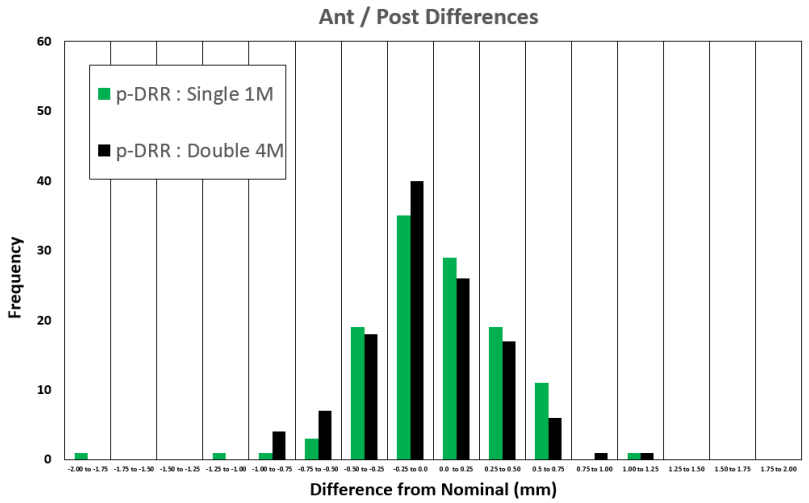


Average Difference (mm)			
	Lt / Rt	Ant/Post	Sup/Inf
X-DRR	-0.1	0.2	0.0
p-DRR	0.0	0.0	-0.1

Standard Deviation (mm)			
	Lt / Rt	Ant/Post	Sup/Inf
X-DRR	0.3	0.3	0.2
p-DRR	0.4	0.4	0.3

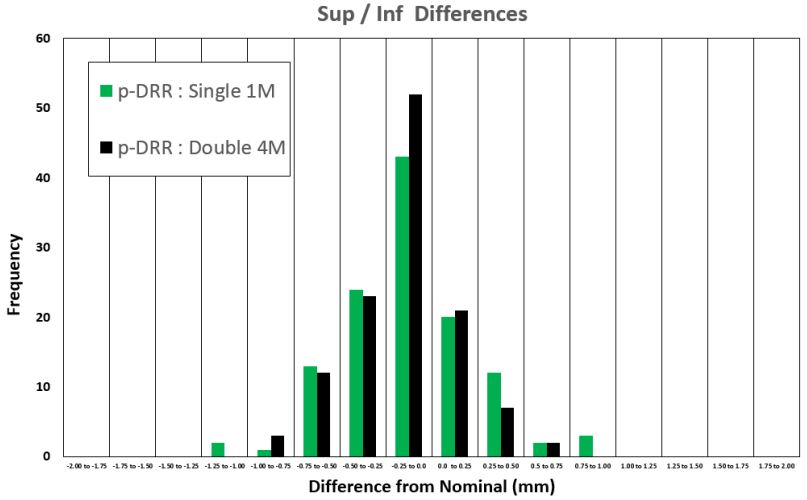


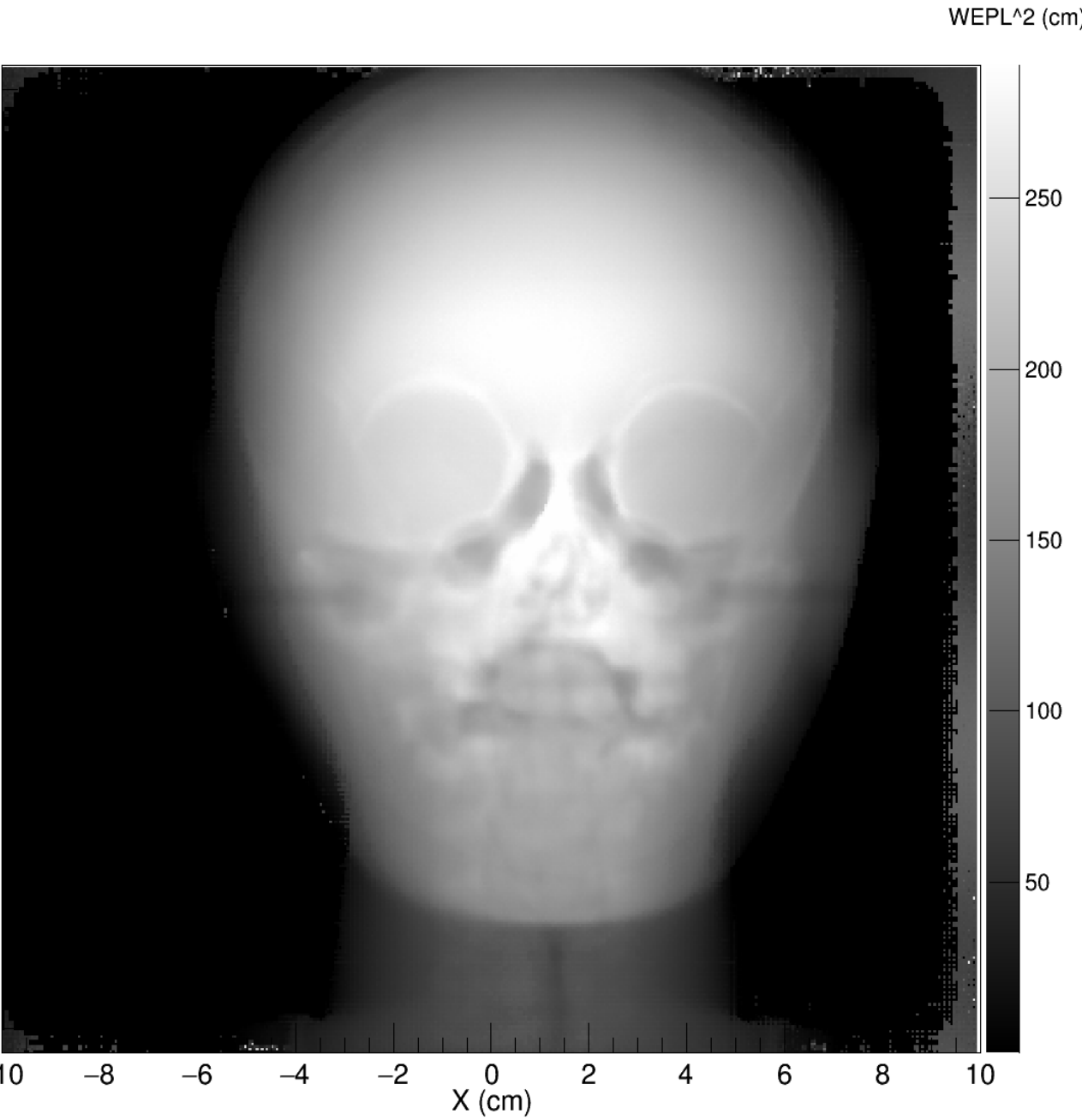


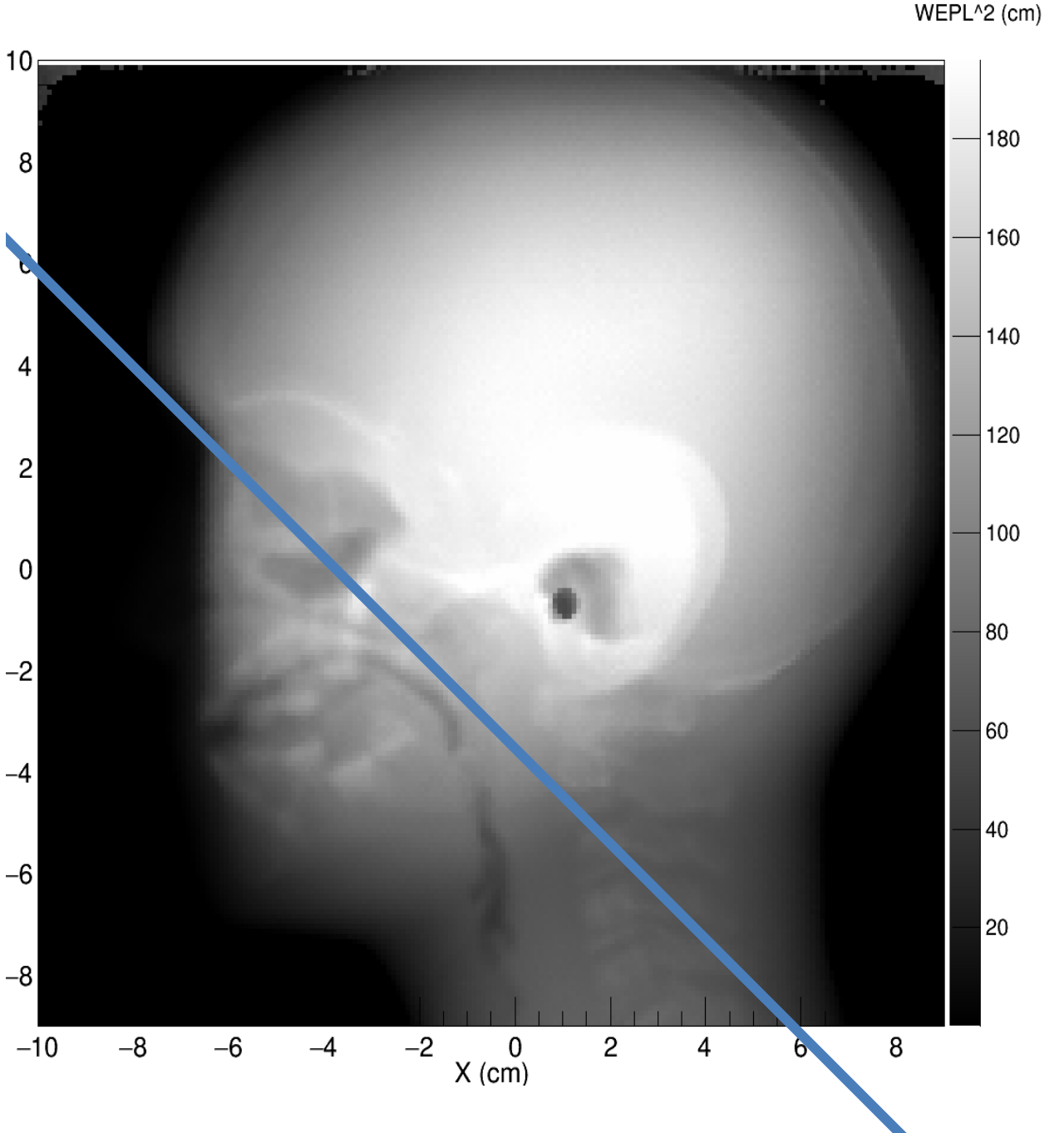


Average Difference (mm)			
	Lt / Rt	Ant/Post	Sup/Inf
p-DRR1	-0.1	0.0	-0.1
p-DRR4	0.0	0.0	-0.1

Standard Deviation (mm)			
	Lt / Rt	Ant/Post	Sup/Inf
p-DRR1	0.6	0.4	0.4
p-DRR4	0.4	0.4	0.3




WEPL^2 (cm)
250
200
150
100
50
10
−8
−6
−4
−2
0
2
4
6
8
10
X (cm)


WEPL^2 (cm)
180
160
140
120
100
80
60
40
20
10
8
4
2
0
−2
−4
−6
−8
−10
−8
−6
−4
−2
0
2
4
6
8
X (cm)