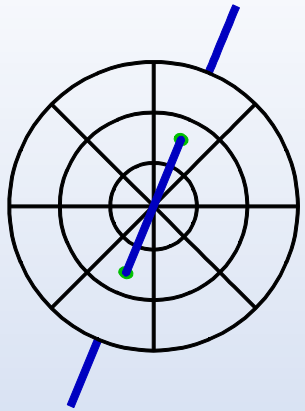
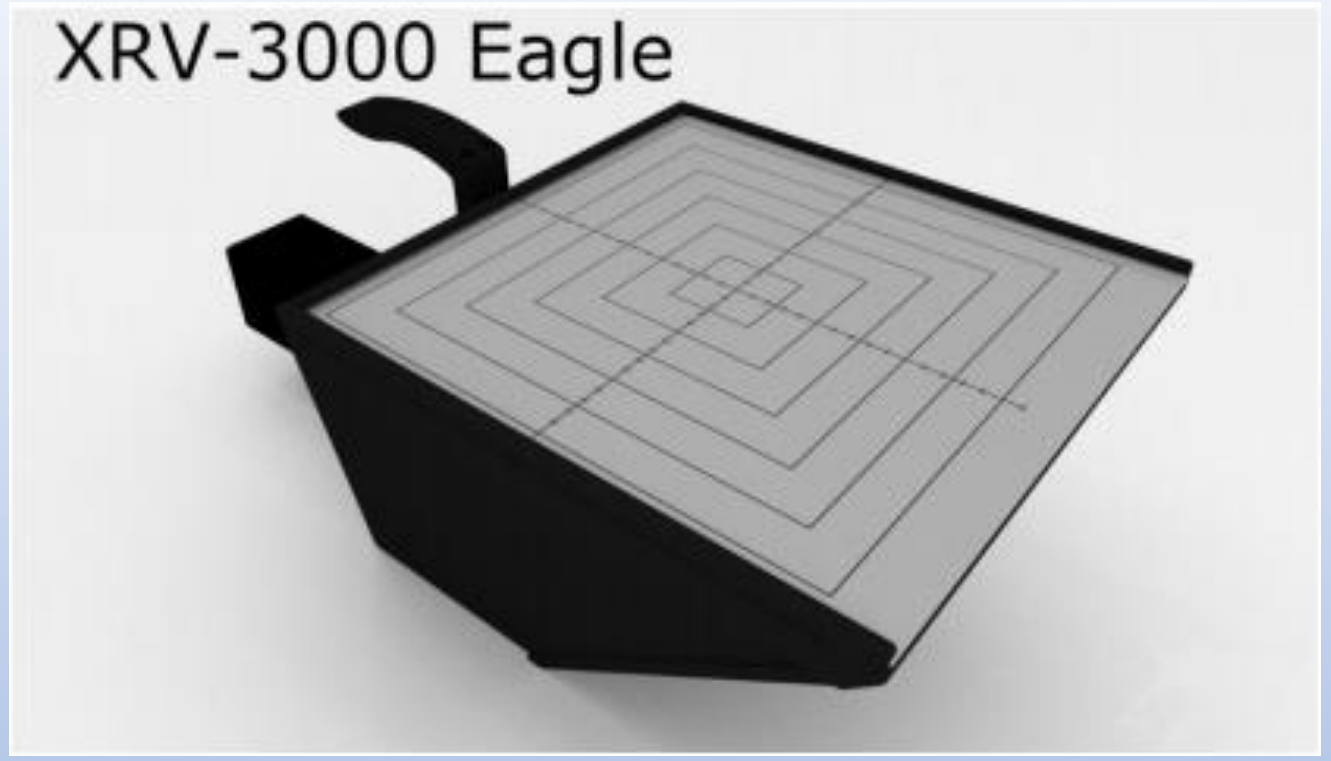
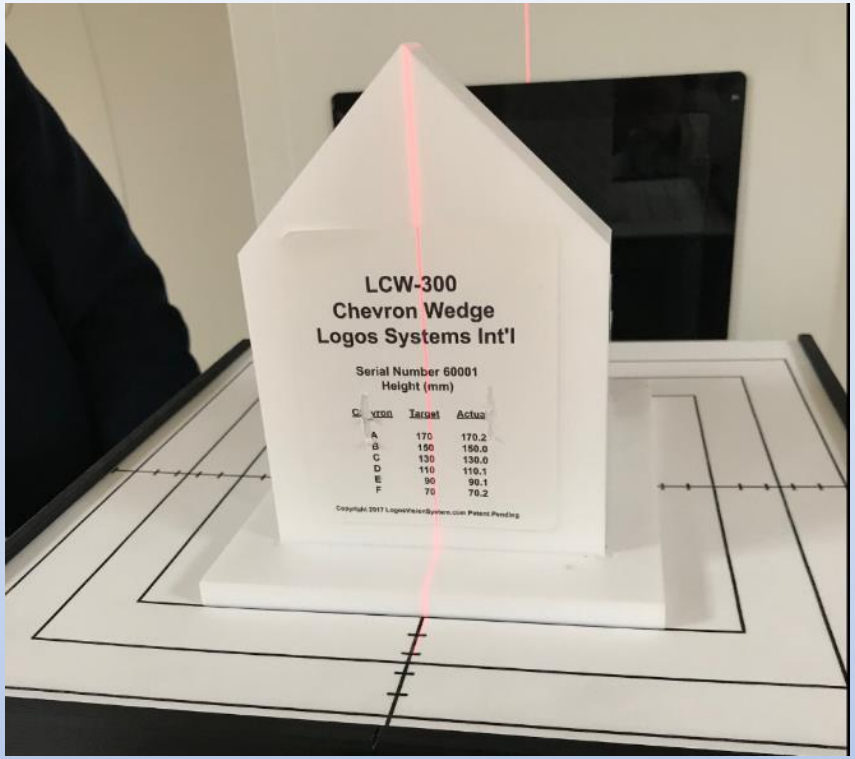


Logos Systems

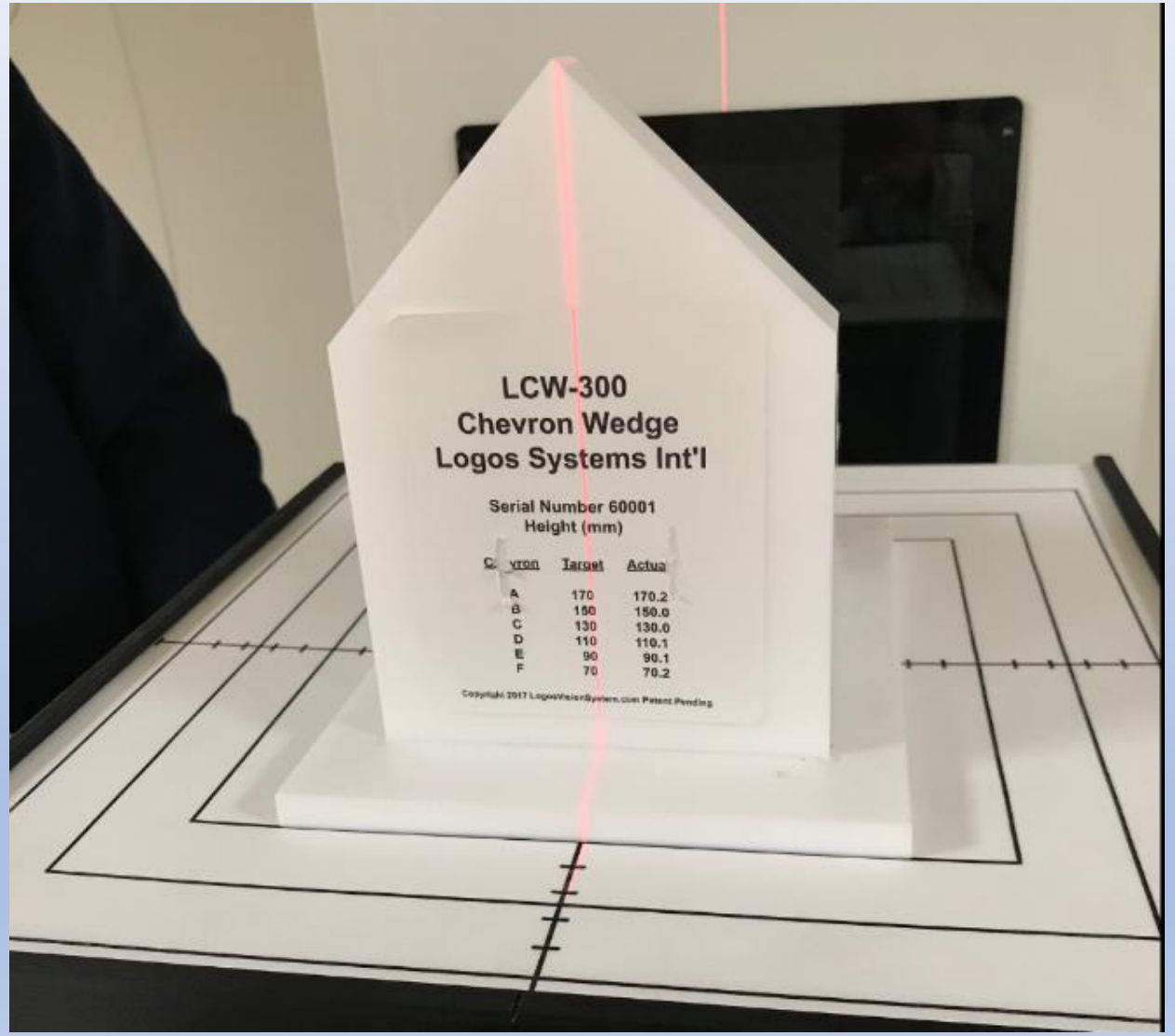
Capturing and Analyzing Bragg Peak Proton Range Data on the Mevion HyperScan





using the XRV-3000 Eagle and LCW-300 multi-chevron wedge

XRV-3000 Eagle Setup

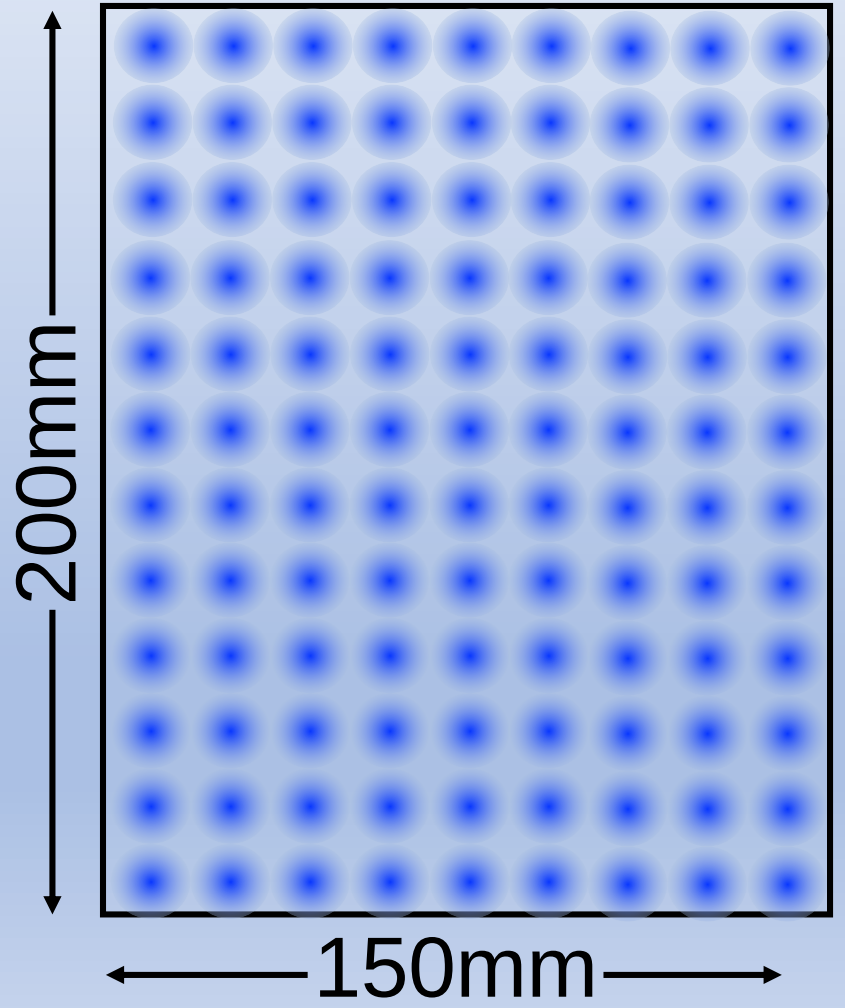


Tallest LCW-300 chevron should be located at the rear of the Eagle facing the handle

The LCW is centered on the target and the Eagle is aligned so the lasers hit the chevron peaks.

Mevion LCW-300 Delivery Plan

> 190 MeV,
9x12 - 15mm pitch



The grid pattern for each energy layer approximates a flat field

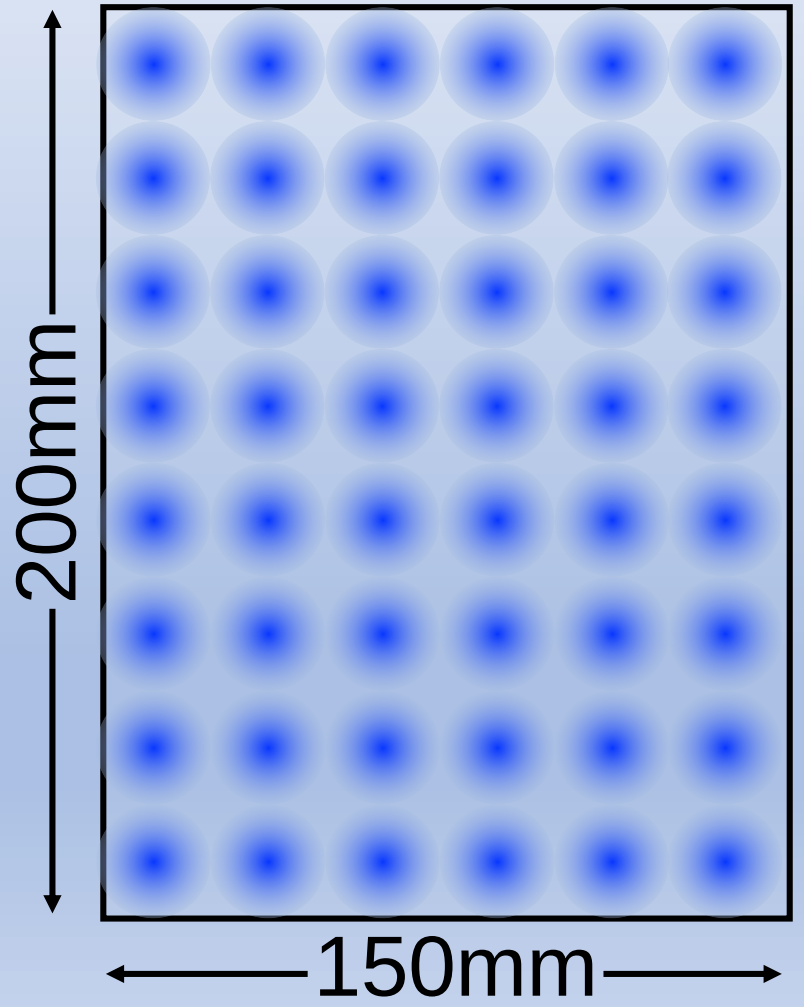
Dose for each spot is ~0.2 MU

There should be no beam activity in the capture ROI for ~1 second so the Logos software can detect the change in beam energy

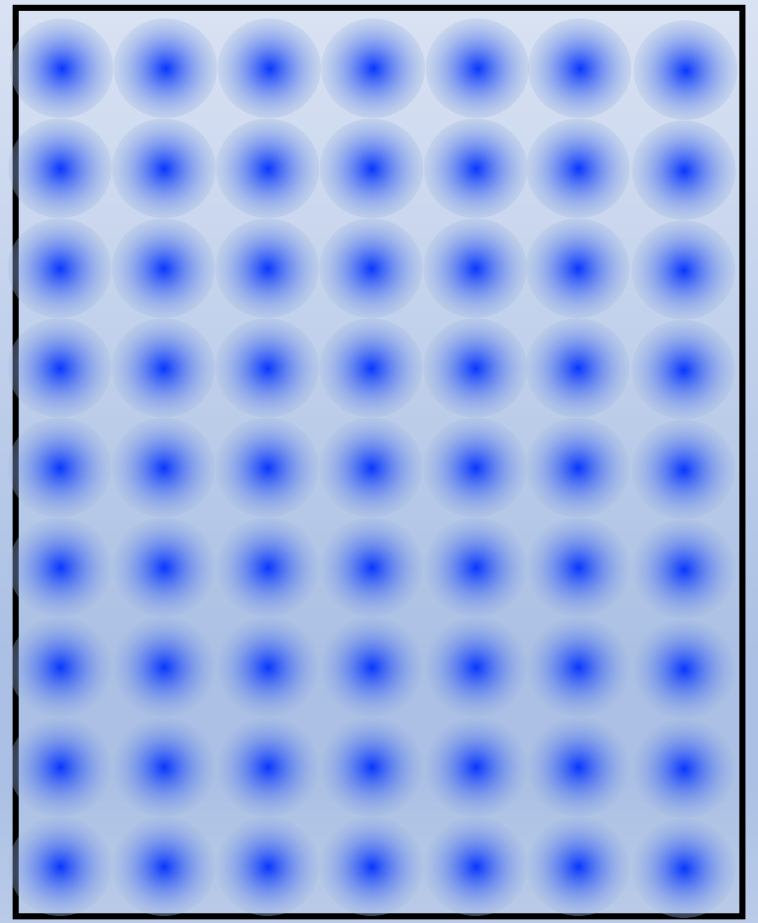
The standard spreadsheet analysis template allows for 35 energy levels

Mevion LCW-300 Delivery Plan

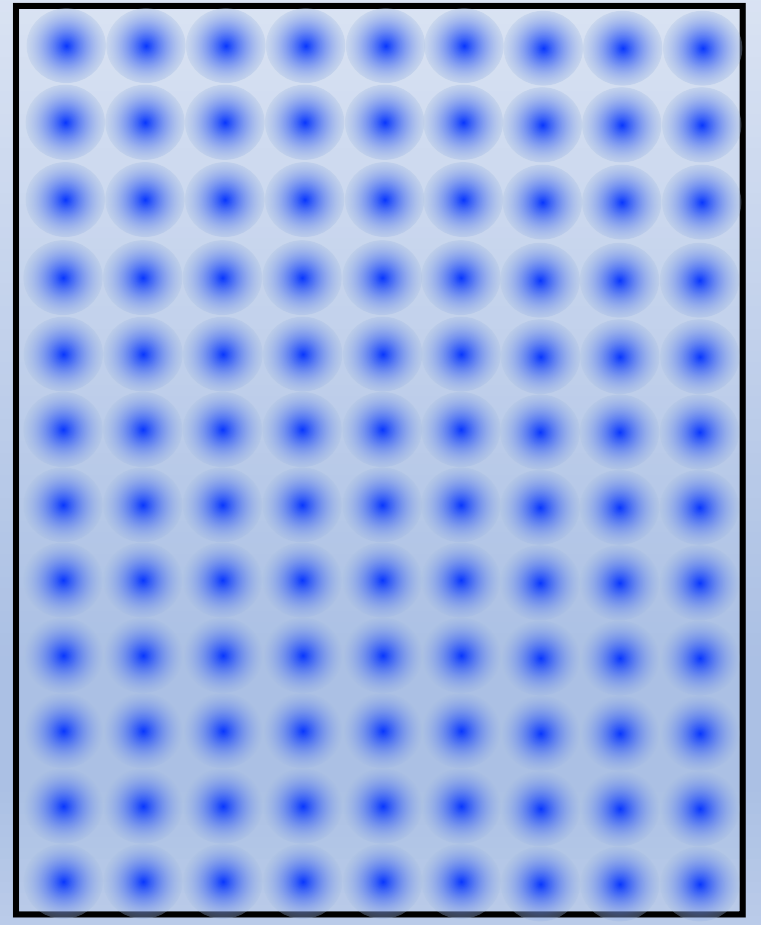
< 165 MeV,
6x8 - 25mm pitch



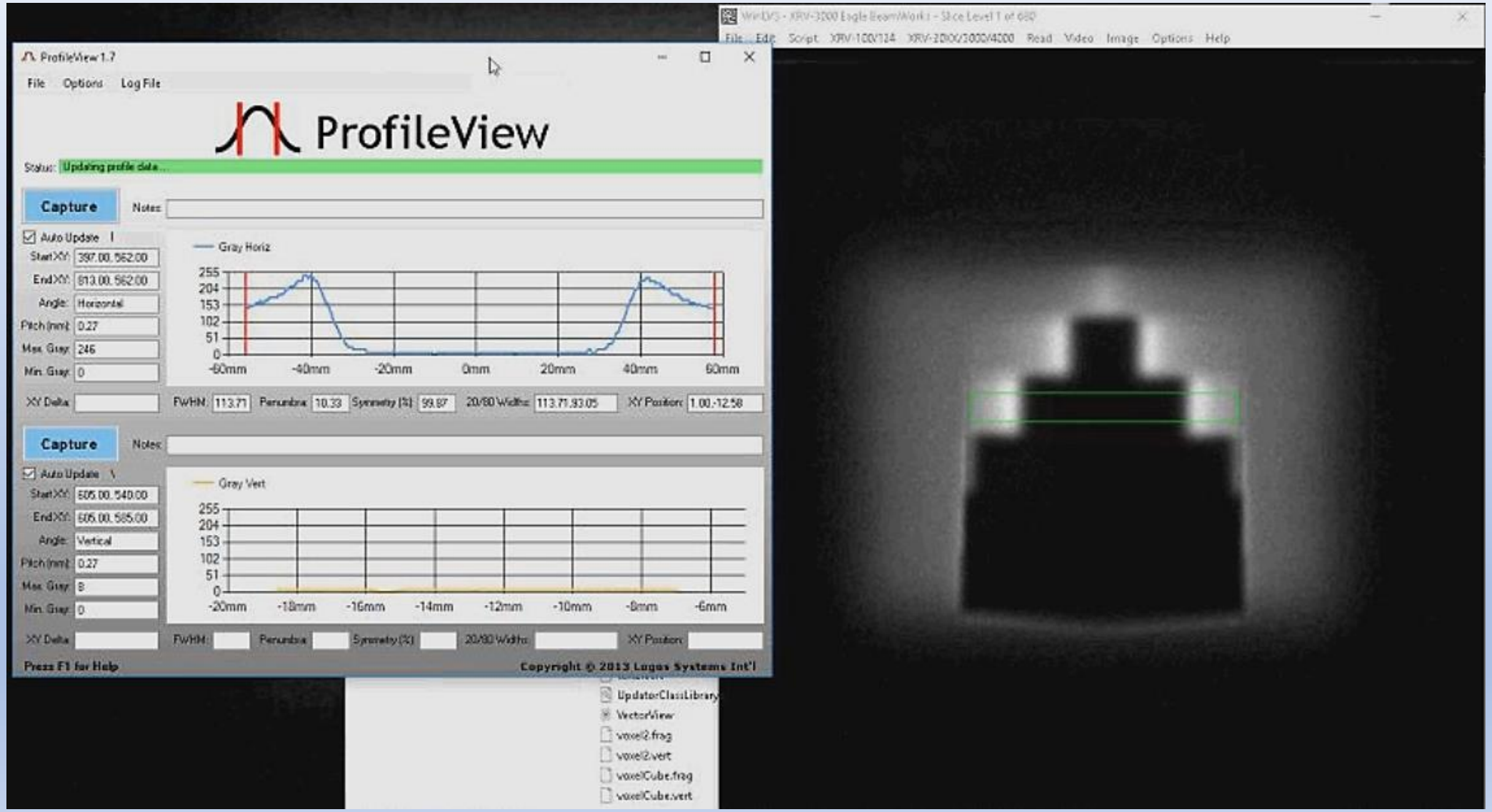
165 – 190 MeV,
7x9 - 20mm pitch

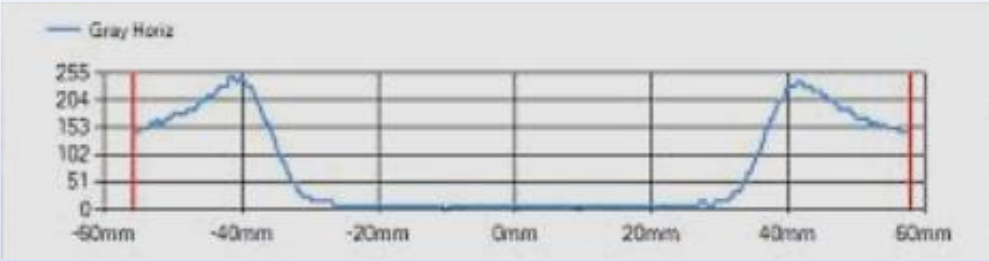


> 190 MeV,
9x12 - 15mm pitch



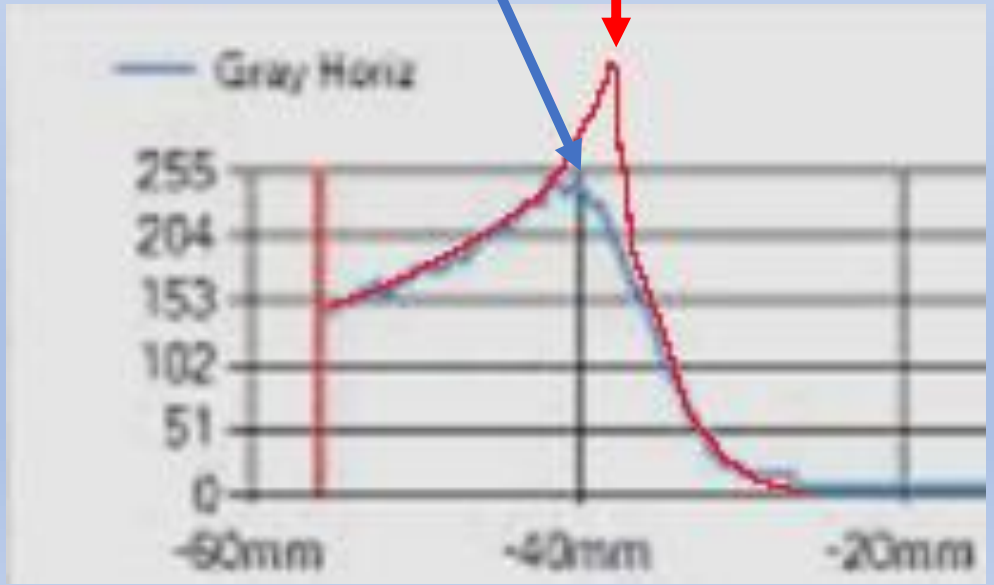
Each energy layer is captured as a proton radiograph allowing 2 peak-to-peak measurements





Pristine Bragg Peak

Quenched Bragg Peak

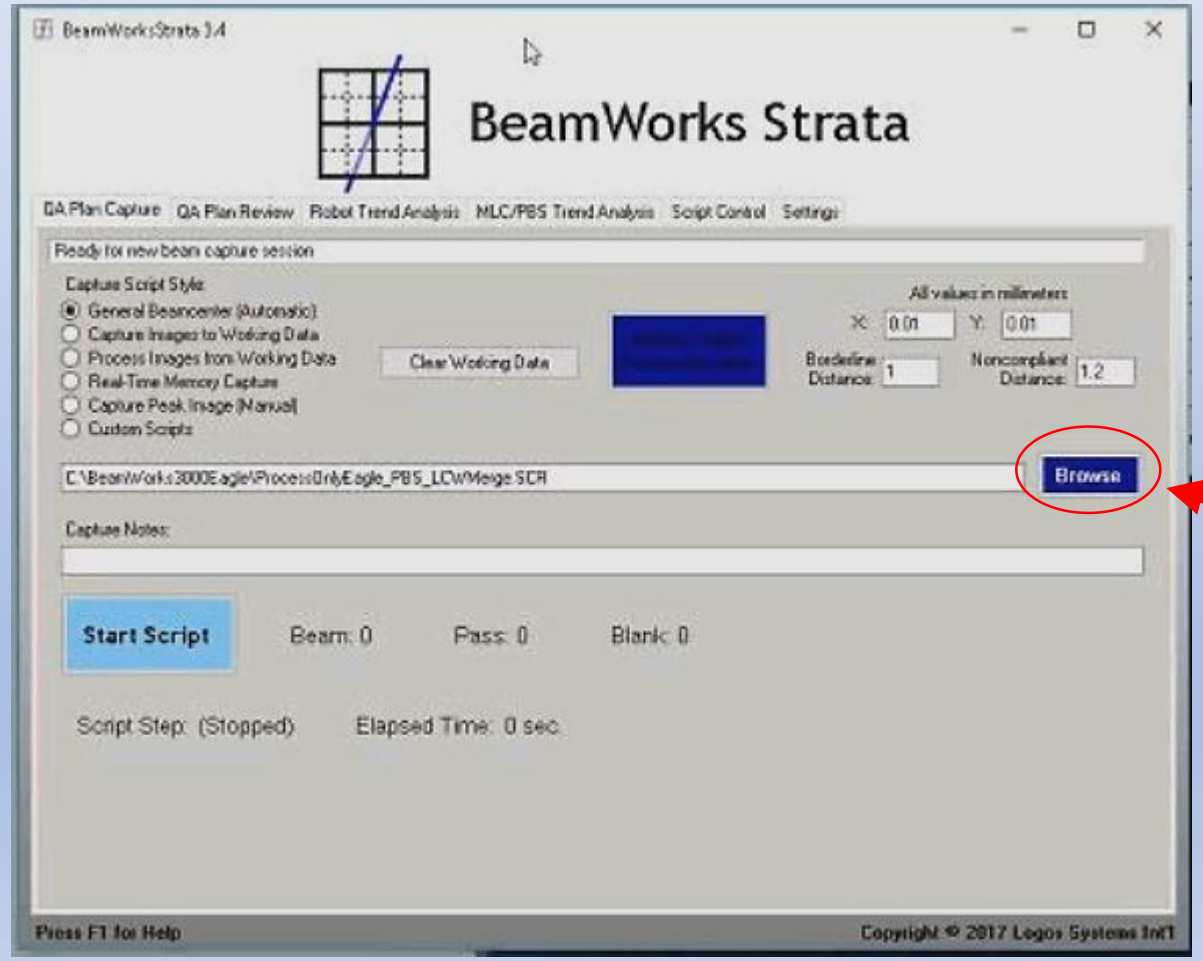


The pristine Bragg Peaks are “quenched” in the scintillator causing the peak-to-peak measurements to be skewed in the proximal direction.

It has been experimentally observed that acrylic and Teflon LCW measurements when adjusted for the WET, correspond closely to the proximal 80% range of protons in water.

Setting up BeamWorks Strata

Launch BeamWorks Strata



Select “Custom Scripts”

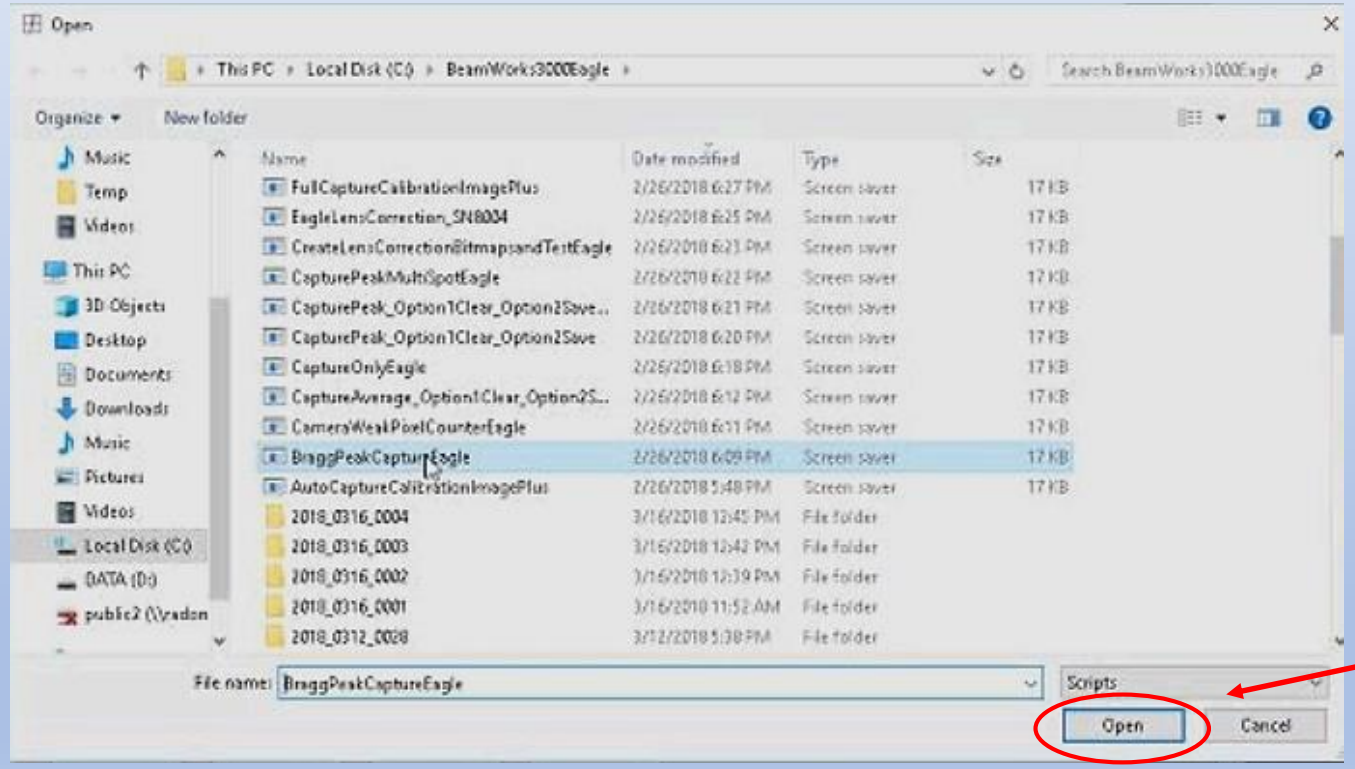
Capture Script Style:

- ○ Generate Beamcenter (Automatic)
- ○ Capture Images to Working Data
- ○ Process Images from Working Data
- ○ Real-Time Memory Capture
- ○ Capture Peak Image [Manual]
- ◉ Custom Scripts

Select “Browse”

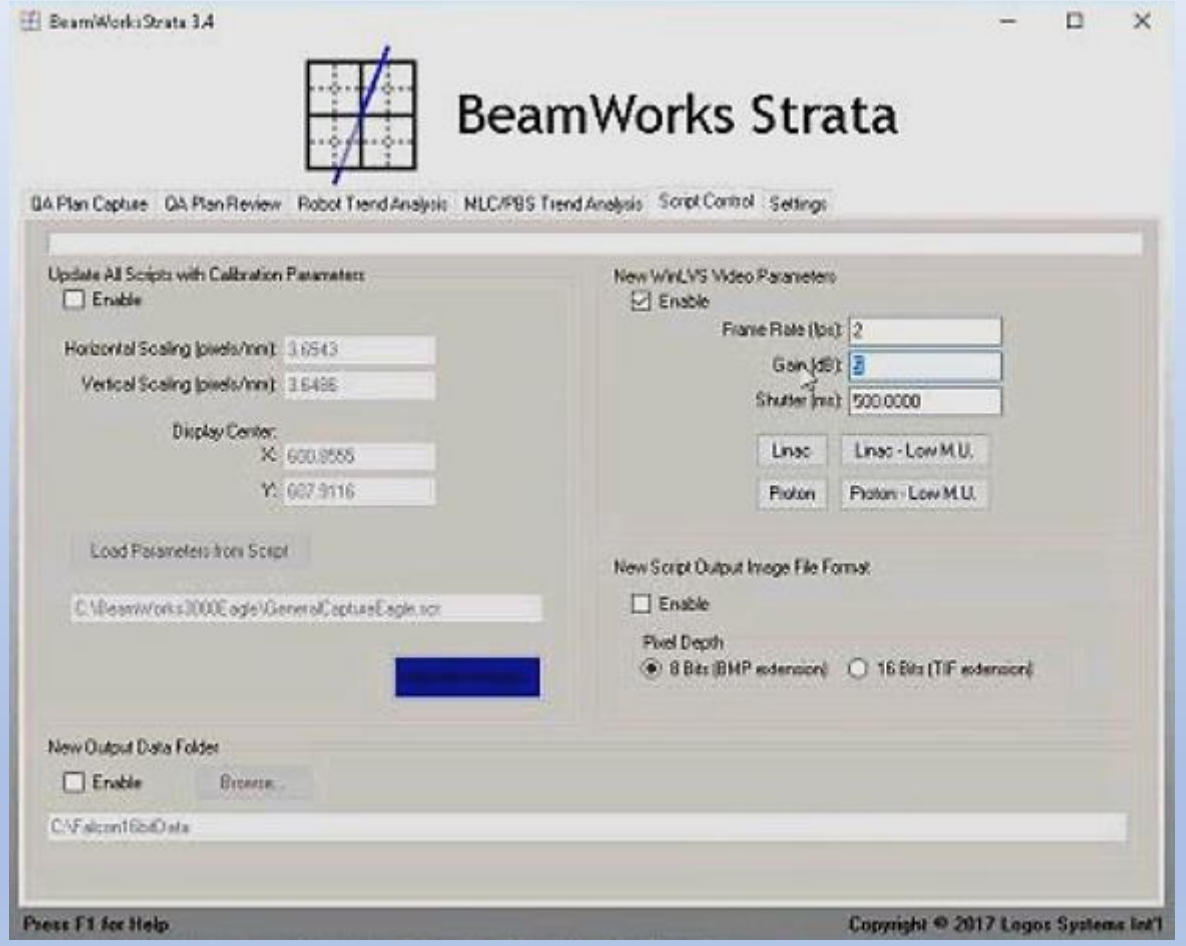
Setting up BeamWorks Strata

Load BraggPeakCaptureEagle script



Select “Open”

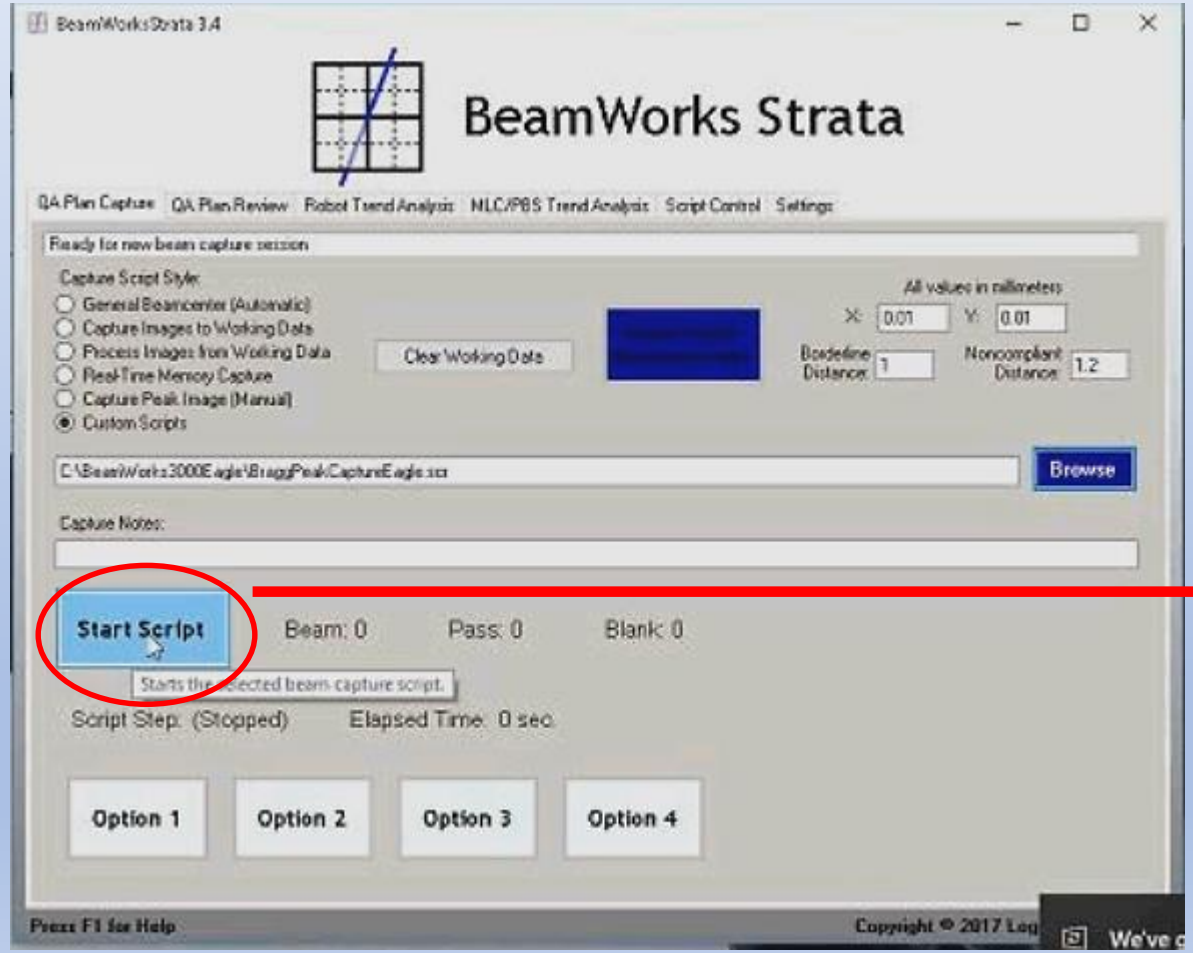
Setting up BeamWorks Strata

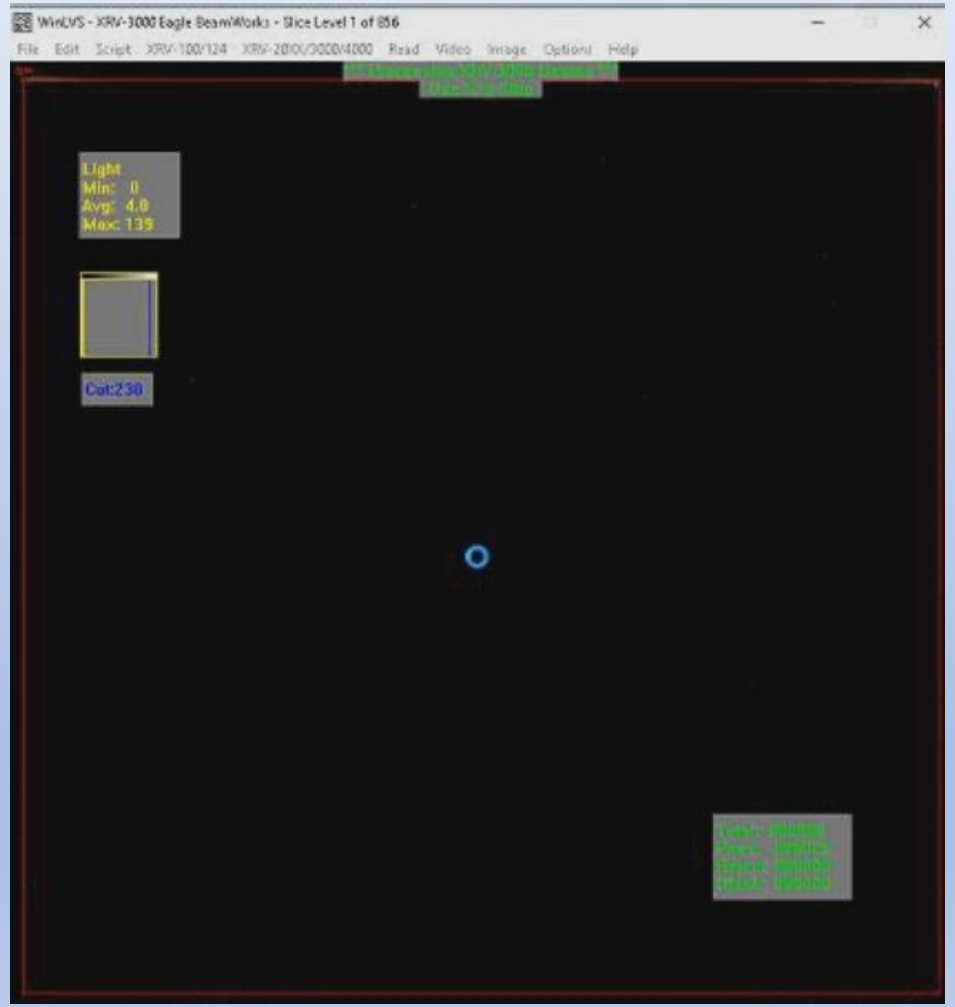


Set the Eagle camera Frame Rate to 2 frames per second and the Gain to 24 dB

Making Measurements

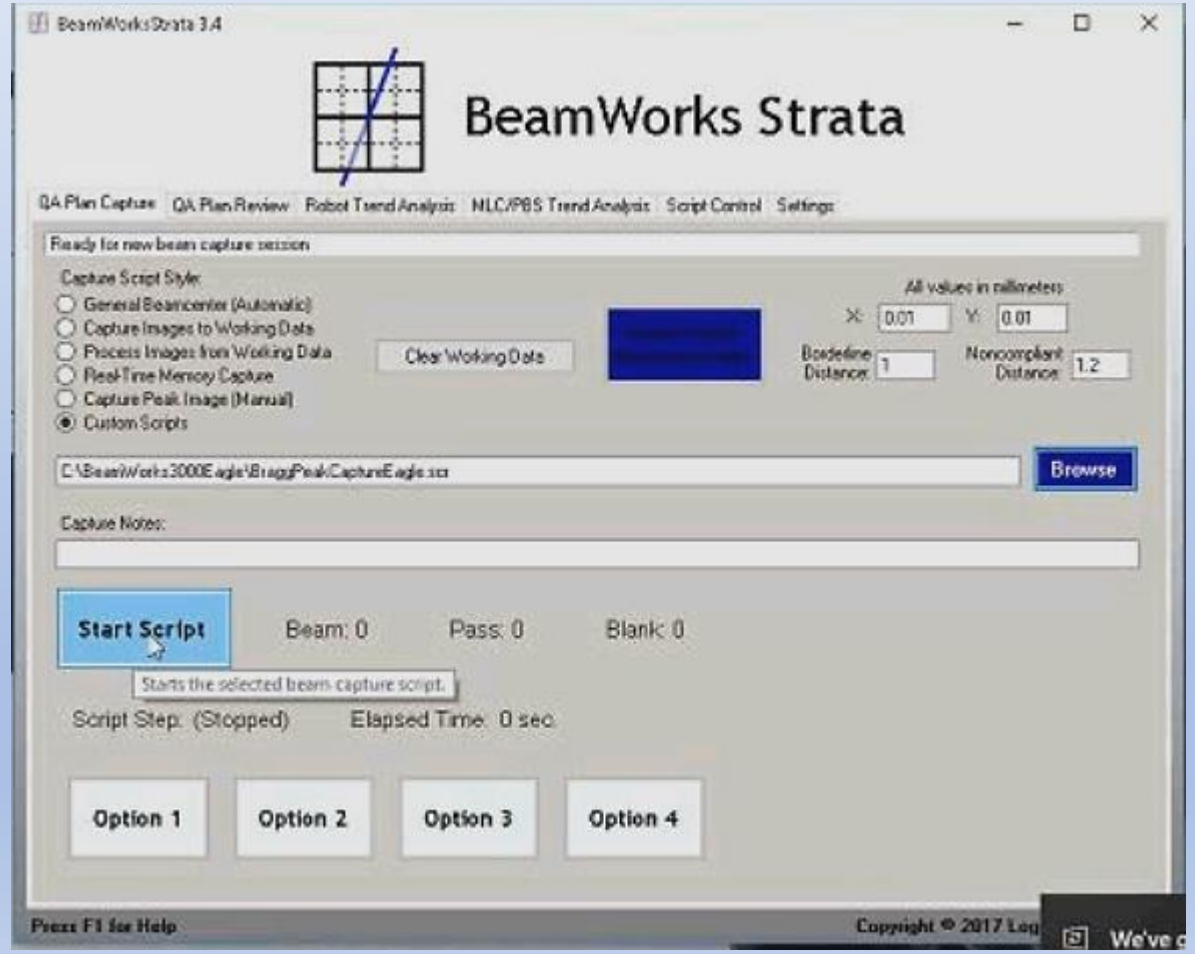
Click on Start Script to launch WinLVS

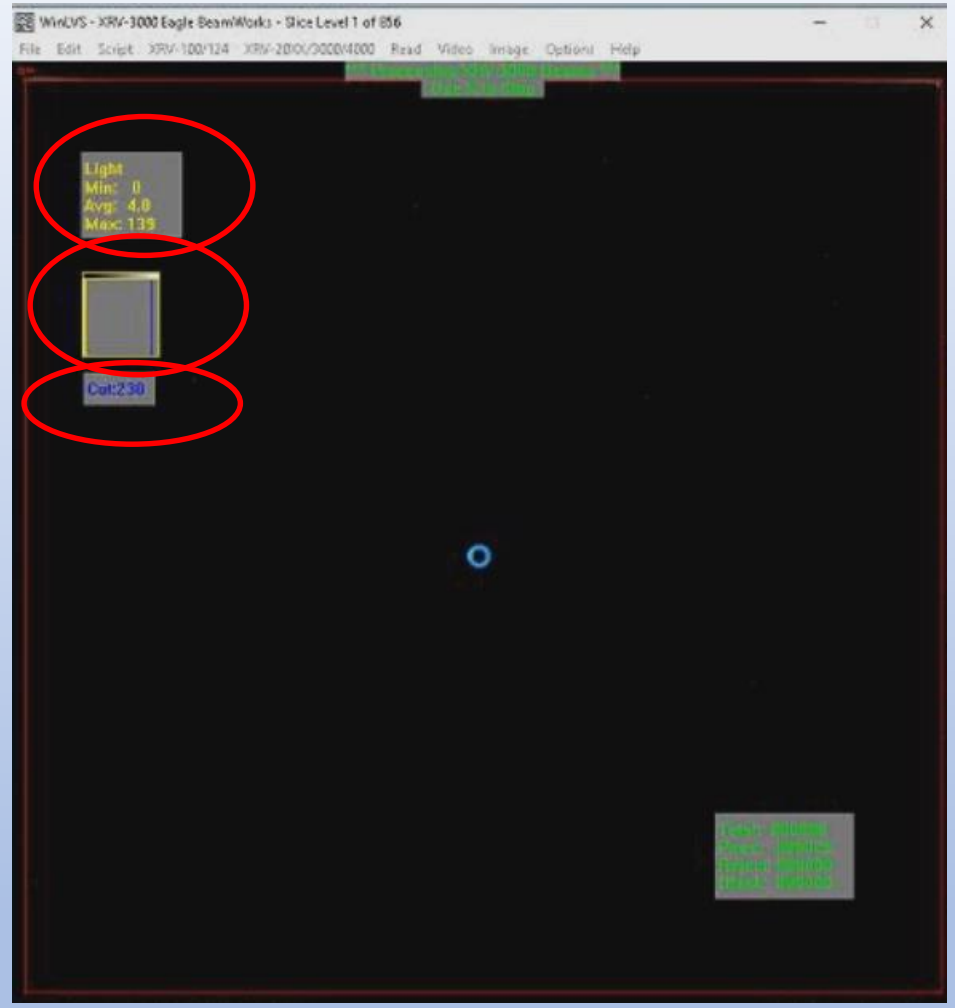




Making Measurements

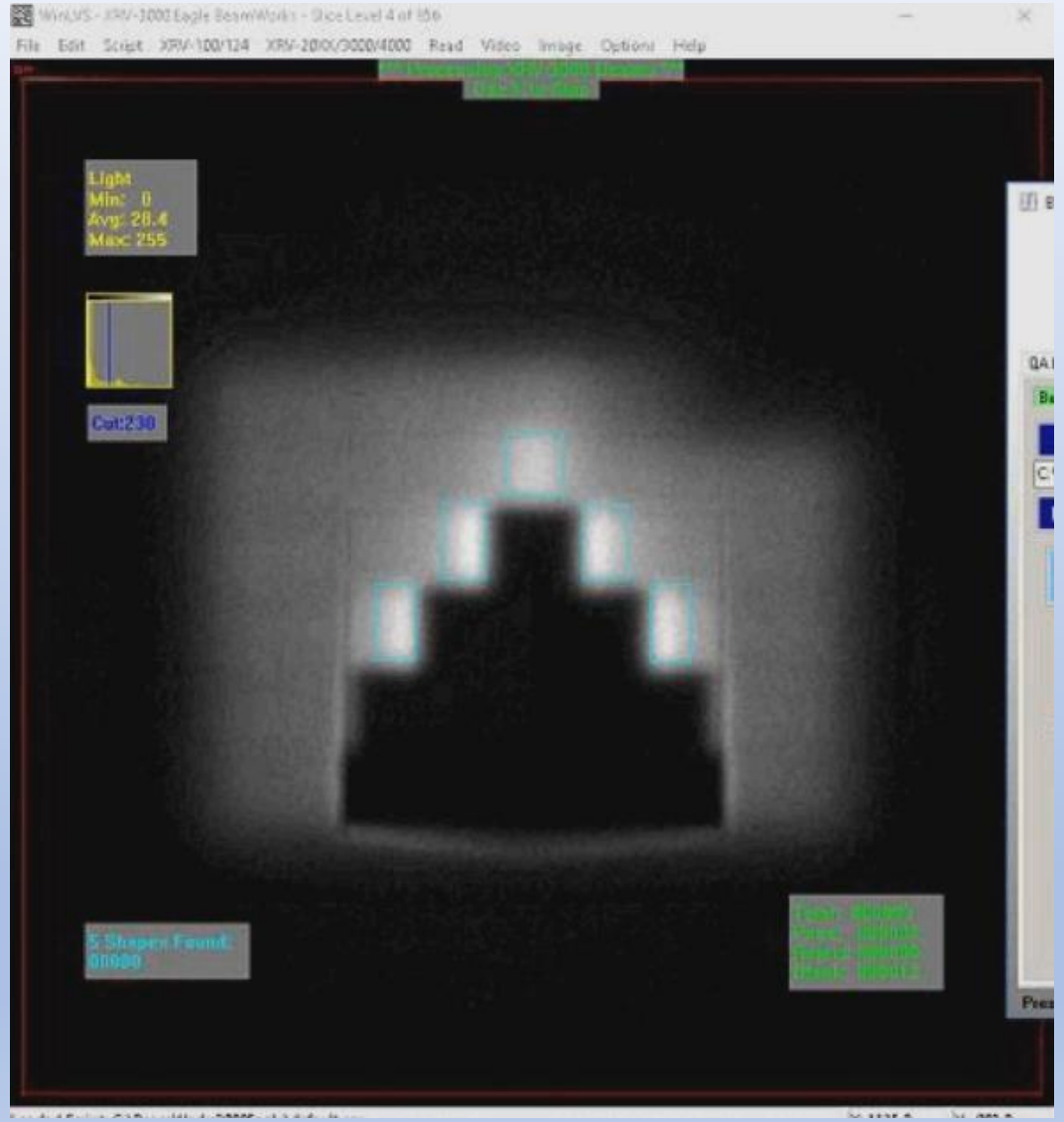
WinLVS captures images and saves measurements to disk



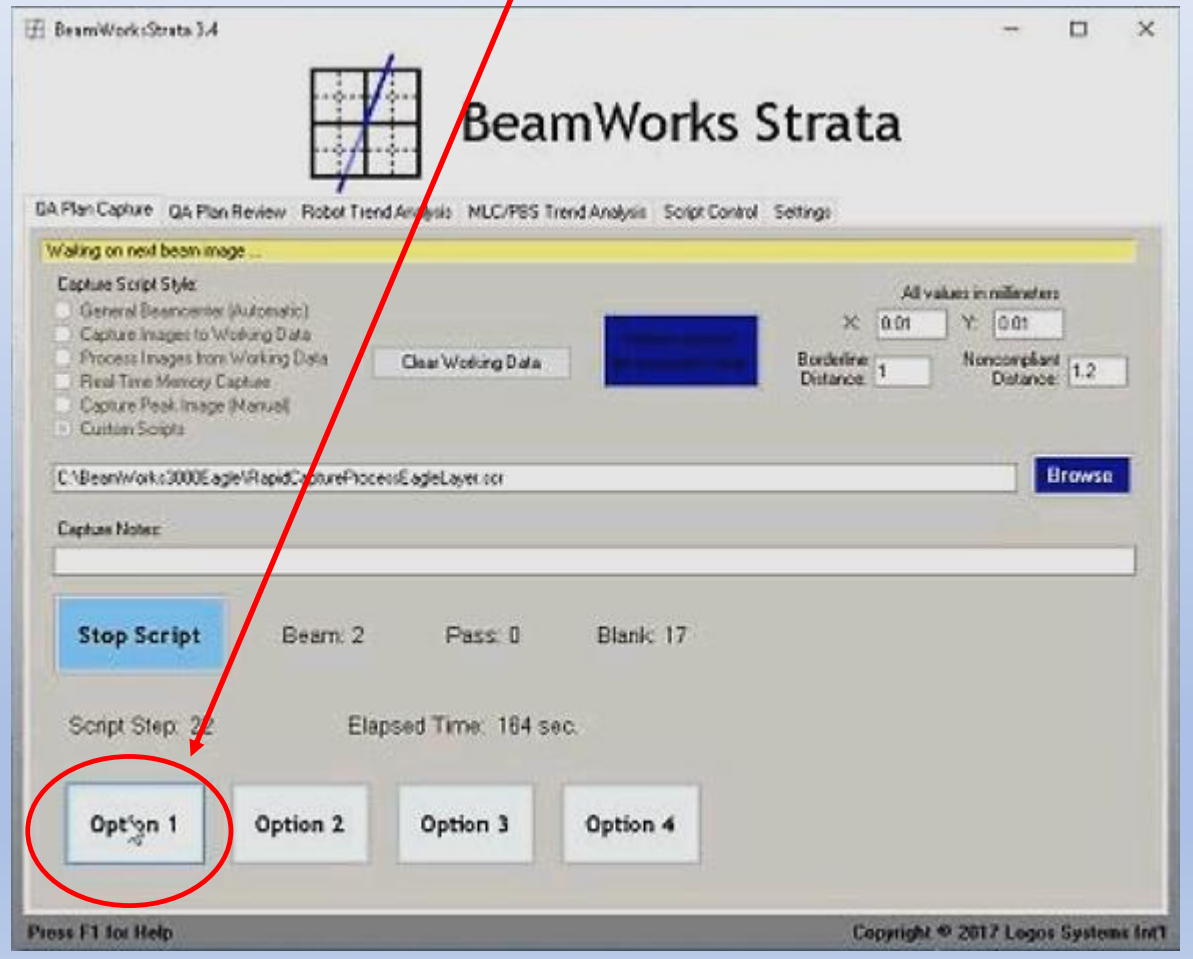


Tap spacebar to add information windows

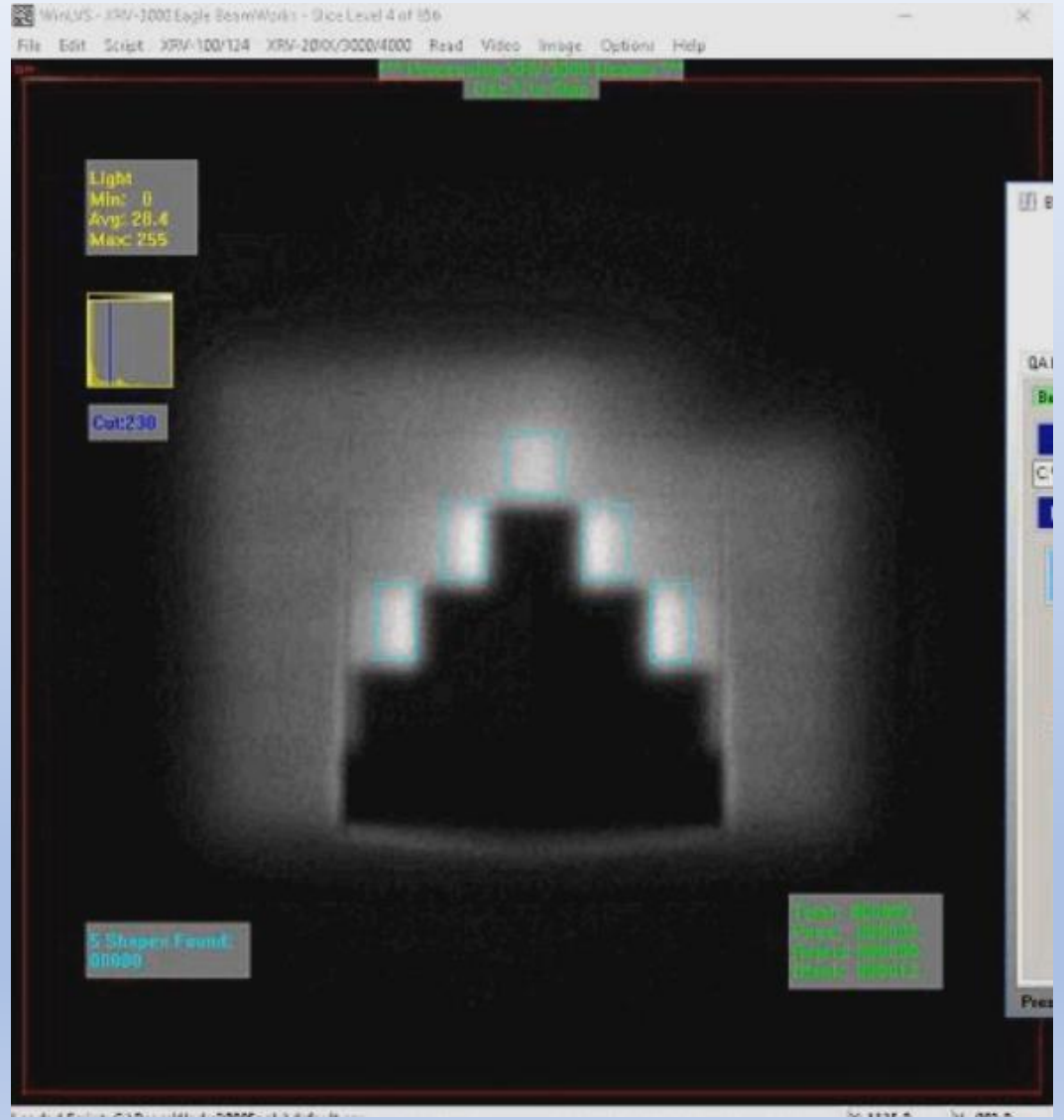
Deliver plan



Click “Option 1”



Making Measurements



Pressing the Option 1 button starts the process of detecting Bragg Peak regions in the captured images and writing peak-to-peak measurements to file in a CSV format that can be easily imported into the template spreadsheet for analysis.

Data is then pasted into the analysis spreadsheet in order to calculate the equivalent proton range in water

	A	B	C	D	E	F	G	H	I	J	K
10		Folder 0008						Layer Energy (MeV):		170.9	Snout Adj
11	1	LCW-200/300R		Center	Peak-to-Peak		Chevron Height		Target	Scint. Cove	Wedge
12	Image:	4		Dist (mm)	Dist (mm)		(mm)		(mm)	(mm)	WET
13	Chevron:	A		0	0		170.2		3.4	1.8	1.821
14	Chevron:	B		0	0		150		3.4	1.8	1.821
15	Chevron:	C		-12.462	62.3974		130		3.4	1.8	1.821
16	Chevron:	D		14.1868	16.9677		110.1		3.4	1.8	1.821
17	Chevron:	E		0	0		90.1		3.4	1.8	1.821
18	Chevron:	F		0	0		70.2		3.4	1.8	1.821
19											
20		Folder 0006				Delta (Me\	0	Layer Energy (MeV):		170.9	Snout Adj
21	2	LCW-200/300I		Center	Peak-to-Peak		Chevron Height		Target	Scint. Cove	Wedge
22	Image:	1		Dist (mm)	Dist (mm)		(mm)		(mm)	(mm)	WET
23	Chevron:	A		0	0		170.2		3.4	1.8	1.821
24	Chevron:	B		0	0		150		3.4	1.8	1.821
25	Chevron:	C		-11.9351	60.4817		130		3.4	1.8	1.821
26	Chevron:	D		13.7981	16.9677		110.1		3.4	1.8	1.821
27	Chevron:	E		0	0		90.1		3.4	1.8	1.821
28	Chevron:	F		0	0		70.2		3.4	1.8	1.821
29											
30		Folder 0008				Delta (Me\	10.5	Layer Energy (MeV):		160.4	Snout Adj
31	3	LCW-200/300I		Center	Peak-to-Peak		Chevron Height		Target	Scint. Cove	Wedge
32	Image:	3		Dist (mm)	Dist (mm)		(mm)		(mm)	(mm)	WET
33	Chevron:	A		0	0		170.2		3.4	1.8	1.821
34	Chevron:	B		0	0		150		3.4	1.8	1.821
35	Chevron:	C		-11.2606	82.3755		130		3.4	1.8	1.821
36	Chevron:	D		14.9266	40.5036		110.1		3.4	1.8	1.821
37	Chevron:	E		0	0		90.1		3.4	1.8	1.821
38	Chevron:	F		0	0		70.2		3.4	1.8	1.821

Peak-to-peak width

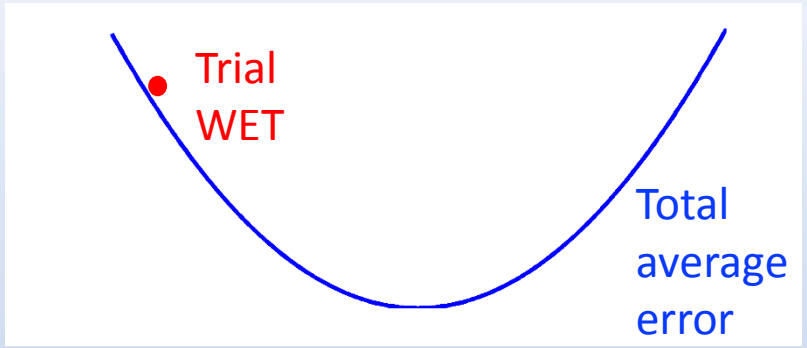
Delivery plan MeV values for each energy layer are entered into the spreadsheet

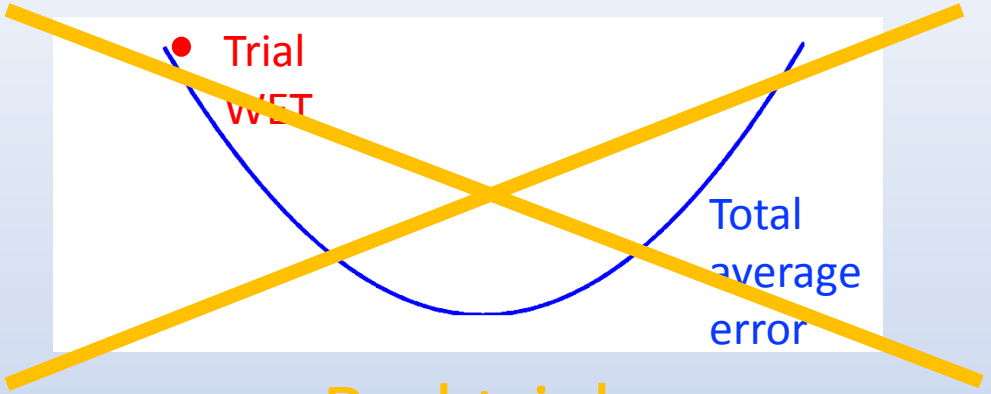
Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL
									LCW-300 Chevron Data Summary			
						Plan						
						Layer	Post Snout					
(SAD Y)	(SAD X)					Energy	Energy		Chevron		Avg. Energy	
cos(T)	cos(P)		Defined Energies		Layer	(MeV)	(MeV)	Delta	BPD (mm)	Delta	BPD (mm)	Delta
			170.9		1	170.9	167.8		189.8891		190.88674	
			170.9		2	170.9	167.8	0	190.728	0.8389	190.88674	0
0.999869	0.999977		160.4		3	160.4	157.3	-10.5	170.7299	-19.998	170.47672	-20.41
0.99999	0.999971		160.4		4	160.4	157.3	0	170.4918	-0.23816	170.47672	0
			150.5		5	150.5	147.4	-9.9	152.7851	-17.7067	152.14596	-18.3308
			140.1		6	140.1	137	-10.4	134.0345	-18.7506	133.86	-18.286
									Average	-11.1709		
									Std. Dev.	10.51008		
cos(T)	cos(P)											

Parameters for WET (Water Equivalent Thickness) entered into the spreadsheet:
1.821 for Teflon (LCW-300 Chevrons)
1.172 for Acrylic (Eagle support Target)

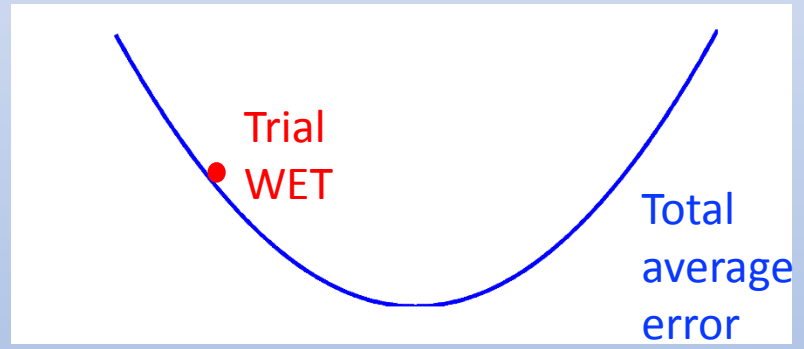
K	L	M	N	O	P	Q	R	S
		Global Input Values						
		XRV-3000 SAD X mm:		1850				
		XRV-3000 SAD Y mm:		1850				
		Snout Adj. MeV:		3.1				
		Nominal Wedge WET:		1.821				
00 Chevrons C and D.		Nominal TARGET WET		1.172				
proximately 20 mm more air to reach each lower Chevron.								
Snout Adj	3.1	Final MeV	167.8	Bragg Depth (mm):		PSI Equation for Proximal 80% F		
Wedge	PMMA	Trap. Scaling		Bragg Penetration			Adjusted BPD	
WET	WET	with SAD X		Depth in mm			(mm)	
1.821	1.172	0.939081						
1.821	1.172	0.95						
1.821	1.172	0.960811		188.238			188.209	
1.821	1.172	0.971568		191.5767			191.5691	
1.821	1.172	0.982378						
1.821	1.172	0.993135						

Optimization of WET values with the “Hill Climbing” method

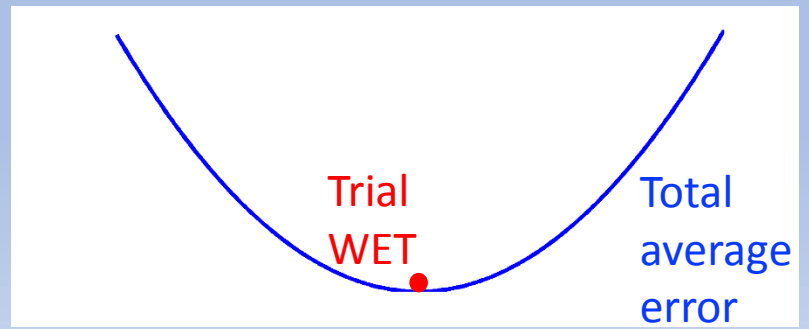




Bad trial

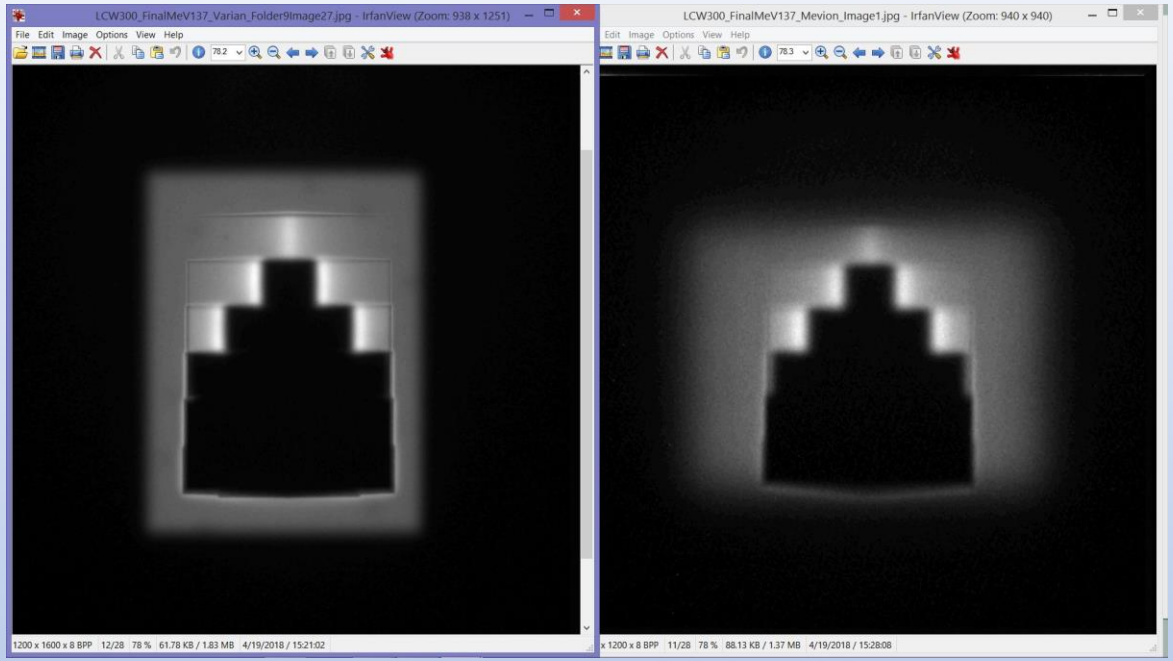


Good trial



Correct WET

Excellent agreement between Mevion and Varian energy layers



Delta (Me	2.3	Layer Energy (MeV):	139.1	Snout Adj	2.1	Final MeV	137	Bragg Depth (mm):	PSI Equation for Proximal 80% Penetration Depth:		133.86
eak	Chevron Height	Target	Scint. Cov	Wedge	PMMA	Trap. Scaling		Bragg Penetration		Adjusted BPD	
	(mm)	(mm)	(mm)	WET	WET	with SAD Y		Depth in mm		(mm)	
	170.7	3.4	1.8	1.821	1.172	0.946095					
	150.5	3.4	1.8	1.821	1.172	0.955714					
	130.4	3.4	1.8	1.821	1.172	0.965286					
	110.3	3.4	1.8	1.821	1.172	0.974857		133.8305		133.8284	
	90.2	3.4	1.8	1.821	1.172	0.984429		134.2768		134.2529	
	70.1	3.4	1.8	1.821	1.172	0.994					
							Average	134.0537	Average	134.0406	
/20/2018											
fps / 24 dB - approx 0.2 MU/spot											
ital											
Delta (Me	10.4	Layer Energy (MeV):	140.1	Snout Adj	3.1	Final MeV	137	Bragg Depth (mm):	PSI Equation for Proximal 80% Penetration Depth:		133.86
eak	Chevron Height	Target	Scint. Cov	Wedge	PMMA	Trap. Scaling		Bragg Penetration		Adjusted BPD	
	(mm)	(mm)	(mm)	WET	WET	with SAD X		Depth in mm		(mm)	
	170.2	3.4	1.8	1.821	1.172	0.939061					
	150	3.4	1.8	1.821	1.172	0.95					
	130	3.4	1.8	1.821	1.172	0.960811					
	110.1	3.4	1.8	1.821	1.172	0.971568		133.9582		133.9232	
	90.1	3.4	1.8	1.821	1.172	0.982378		134.1826		134.1458	
	70.2	3.4	1.8	1.821	1.172	0.993135					
							Average	134.0704	Average	134.0345	

Two different LCW units,
Two different XRV phantoms,
Two different proton delivery systems,
Two different facilities.
Excellent agreement!

Calculation for depth of 80% energy loss of beam in water converts MeV (black) to millimeters (red)

M	N	O	P	Q	R	S	T	U	V	W
Global Input Values										
XRV-3000 SAD X mm:		1850						The plan layer energies were de		
XRV-3000 SAD Y mm:		1850						The delivery was a grid pattern		
Snout Adj. MeV:		3.1						The PSI R80 depth equation cor		
Nominal Wedge WET:		1.821						Proximal edge R80 is used beca		
Nominal TARGET WET		1.172								
re air to reach each lower Chevron.										
Final MeV		167.8	Bragg Depth (mm):		PSI Equation for Proximal 80% Penetration Depth:				190.8867	
Trap. Scaling			Bragg Penetration		Adjusted BPD					
with SAD X			Depth in mm		(mm)					Y (mm)
0.939081										0
0.95										0
0.960811			188.238		188.209					29.97605
0.971568			191.5767		191.5691					8.242634
0.982378										0
0.993135										0
	Average		189.9073	Average	189.8891					
Final MeV		167.8	Bragg Depth (mm):		PSI Equation for Proximal 80% Penetration Depth:				190.8867	
Trap. Scaling			Bragg Penetration		Adjusted BPD					
with SAD X			Depth in mm		(mm)					Y (mm)
0.939081										0
0.95										0
0.960811			189.9139		189.8865					29.05574
0.971568			191.5767		191.5694					8.242634
0.982378										0
0.993135										0

PSI Equation

Proximal depth 80% of Bragg Peak formula (PSI):

$$D = 0.0244E^{1.75}$$

M	N	O	P	Q	R	S	T	U	V	W
Global Input Values										
XRV-3000 SAD X mm:		1850						The plan layer energies were de		
XRV-3000 SAD Y mm:		1850						The delivery was a grid pattern		
Snout Adj. MeV:		3.1						The PSI R80 depth equation cor		
Nominal Wedge WET:		1.821						Proximal edge R80 is used beca		
Nominal TARGET WET		1.172								
re air to reach each lower Chevron.										
Final MeV		167.8	Bragg Depth (mm):		PSI Equation for Proximal 80% Penetration Depth:				190.8867	
Trap. Scaling			Bragg Penetration		Adjusted BPD					
with SAD X			Depth in mm		(mm)					Y (mm)
0.939081										0
0.95										0
0.960811			188.238		188.209					29.97605
0.971568			191.5767		191.5691					8.242634
0.982378										0
0.993135										0
	Average		189.9073	Average	189.8891					
Final MeV		167.8	Bragg Depth (mm):		PSI Equation for Proximal 80% Penetration Depth:				190.8867	
Trap. Scaling			Bragg Penetration		Adjusted BPD					
with SAD X			Depth in mm		(mm)					Y (mm)
0.939081										0
0.95										0
0.960811			189.9139		189.8865					29.05574
0.971568			191.5767		191.5694					8.242634
0.982378										0
0.993135										0

PSI Equation

Calculate proton range in water from the LCW measurements using WET and other corrections

WET*[(Scaling ratio)*(Peak to peak)/2)+(Target thickness)]

M	N	O	P	Q	R	S	T	U	V	W
Global Input Values										
XRV-3000 SAD X mm:		1850						The plan layer energies were del		
XRV-3000 SAD Y mm:		1850						The delivery was a grid pattern o		
Snout Adj. MeV:		3.1						The PSI R80 depth equation conv		
Nominal Wedge WET:		1.821						Proximal edge R80 is used becau		
Nominal TARGET WET		1.172								
to reach each lower Chevron.										
Final MeV	167.8	Bragg Depth (mm):		PSI Equation for Proximal 80% Penetration Depth:					190.887	
Trap. Scaling		Bragg Penetration			Adjusted BPD					
with SAD X		Depth in mm			(mm)					Y (mm)
0.93908										0
0.95										0
0.96081		188.238			188.209					29.976
0.97157		191.577			191.569					8.24263
0.98238										0
0.99314										0
	Average	189.907		Average	189.889					
Final MeV	167.8	Bragg Depth (mm):		PSI Equation for Proximal 80% Penetration Depth:					190.887	
Trap. Scaling		Bragg Penetration			Adjusted BPD					
with SAD X		Depth in mm			(mm)					Y (mm)
0.93908										0
0.95										0
0.96081		189.914			189.887					29.0557
0.97157		191.577			191.569					8.24263
0.98238										0
0.99314										0
	Average	190.745		Average	190.728					

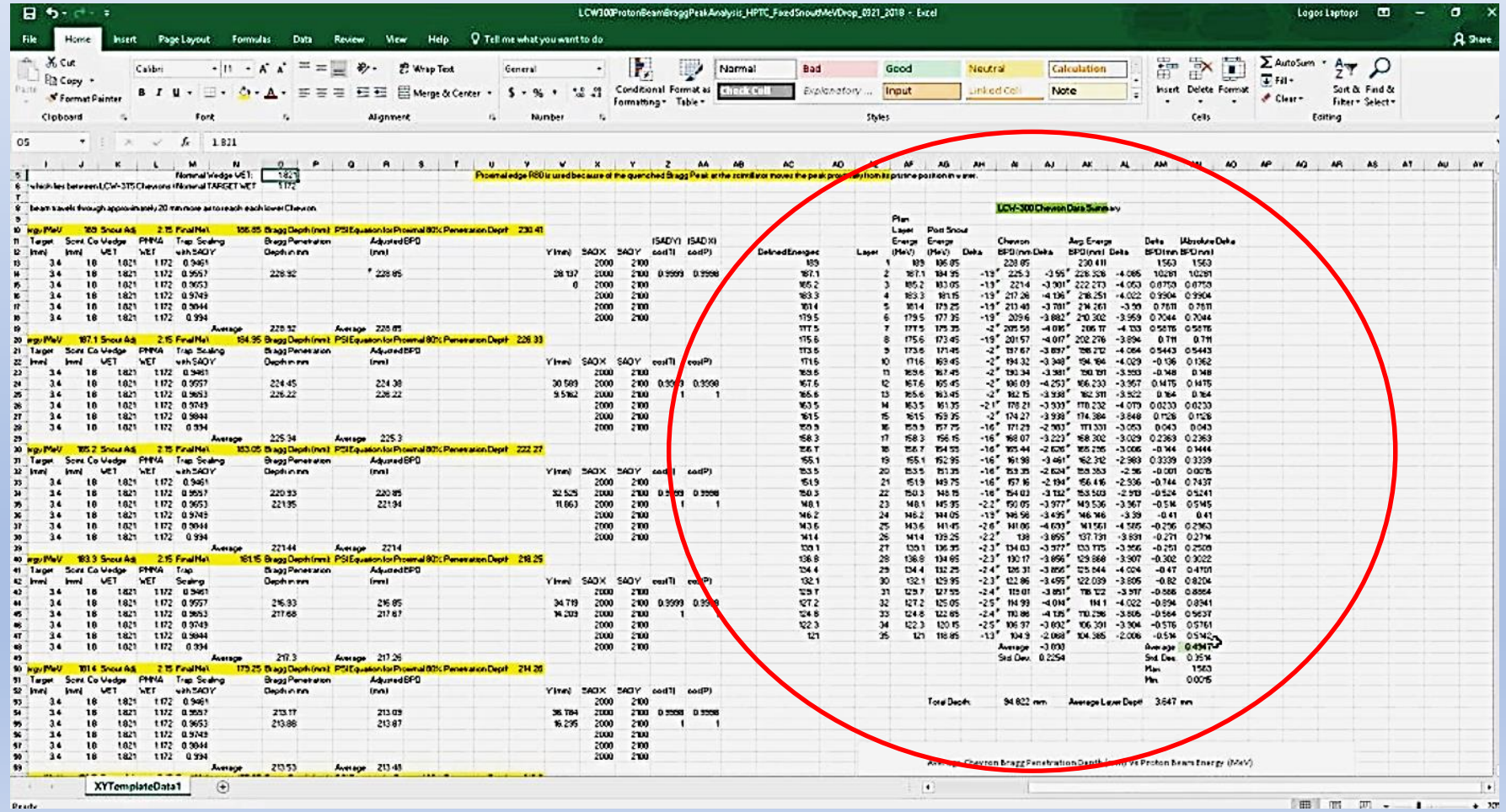
Comparing average measurement to equation gives a Δ for that energy layer

AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO
pristine position in water.										
				LCW-300 Chevron Data Summary						
	Plan									
	Layer	Post Snout								
	Energy	Energy		Chevron		Avg. Energy		Delta	(Absolute Delta	
Layer	(MeV)	(MeV)	Delta	BPD (mm)	Delta	BPD (mm)	Delta	BPD (mm)	BPD mm)	
1	170.9	167.8		189.889		190.88674		0.99765	0.99765	
2	170.9	167.8	0	190.728	0.8389	190.88674	0	0.15875	0.15875	
3	160.4	157.3	-10.5	170.73	-19.998	170.47672	-20.41	-0.25322	0.25322	
4	160.4	157.3	0	170.492	-0.23816	170.47672	0	-0.01507	0.01507	
5	150.5	147.4	-9.9	152.785	-17.7067	152.14596	-18.3308	-0.63912	0.63912	
6	140.1	137	-10.4	134.034	-18.7506	133.86	-18.286	-0.17448	0.17448	
				Average	-11.1709			Average	0.37305	
				Std. Dev.	10.5101			Std. Dev.	0.37116	
								Max.	0.99765	
								Min.	0.01507	

Find the average Δ for all energy layers

AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO
pristine position in water.										
				LCW-300 Chevron Data Summary						
	Plan									
	Layer	Post Snout								
	Energy	Energy		Chevron		Avg. Energy		Delta	(Absolute Delta	
Layer	(MeV)	(MeV)	Delta	BPD (mm)	Delta	BPD (mm)	Delta	BPD (mm)	BPD mm)	
1	170.9	167.8		189.889		190.88674		0.99765	0.99765	
2	170.9	167.8	0	190.728	0.8389	190.88674	0	0.15875	0.15875	
3	160.4	157.3	-10.5	170.73	-19.998	170.47672	-20.41	-0.25322	0.25322	
4	160.4	157.3	0	170.492	-0.23816	170.47672	0	-0.01507	0.01507	
5	150.5	147.4	-9.9	152.785	-17.7067	152.14596	-18.3308	-0.63912	0.63912	
6	140.1	137	-10.4	134.034	-18.7506	133.86	-18.286	-0.17448	0.17448	
				Average	-11.1709			Average	0.37305	
				Std. Dev.	10.5101			Std. Dev.	0.37116	
								Max.	0.99765	
								Min.	0.01507	

An automated treatment plan allows fast analysis of 35 energy layers as a proton range constancy check with an accuracy of about 0.5 mm



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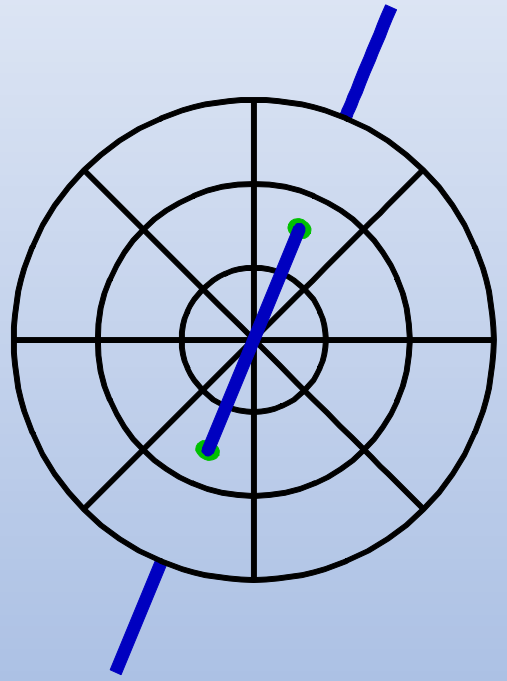

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