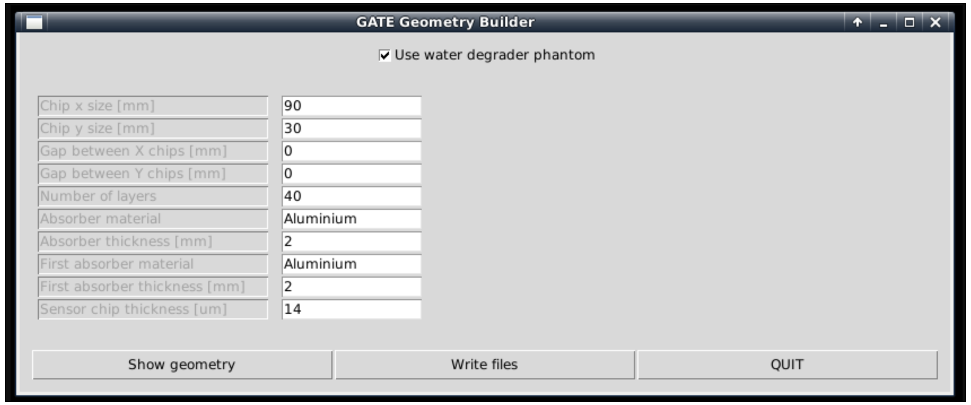
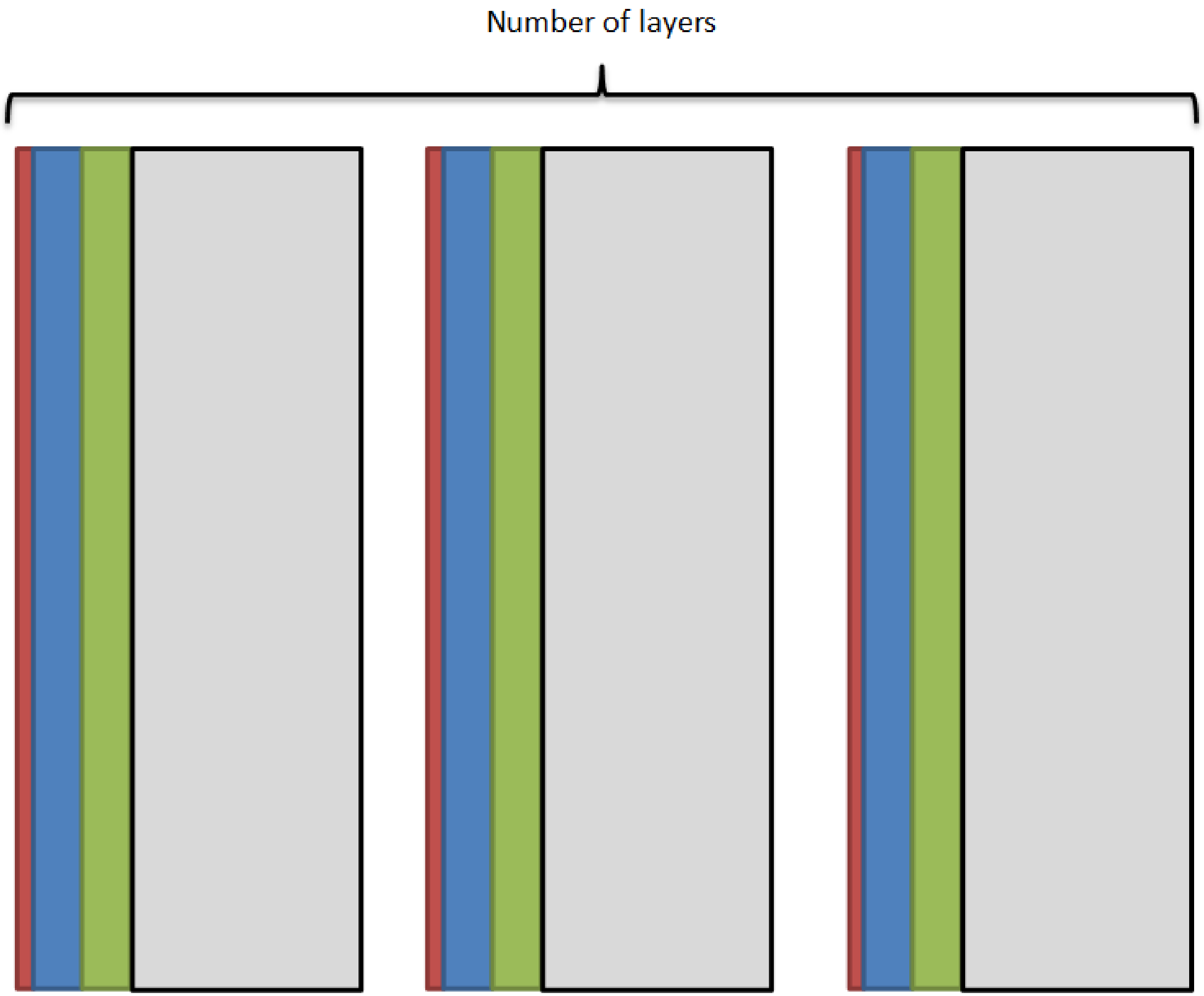
Update on DTC design optimization



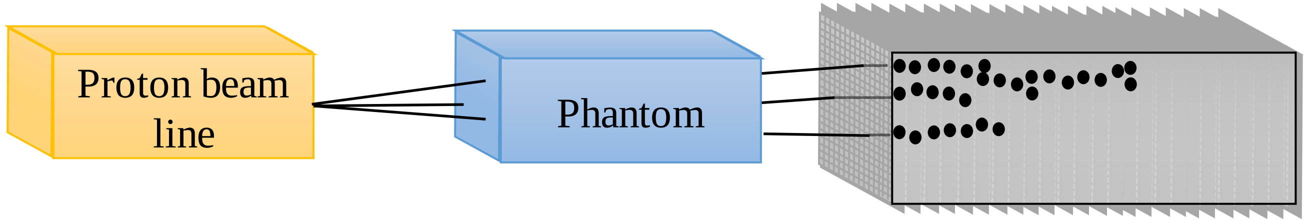


Material	Thickness	$t/\sqrt{12}$ WEPL	Layers for 230 MeV + 5σ
Al	2 mm	1.5 mm	67
Al	3 mm	2.1 mm	48
Al	4 mm	2.7 mm	39
Al	5 mm	3.3 mm	32
Al	6 mm	3.9 mm	27
Al	7 mm	4.5 mm	23

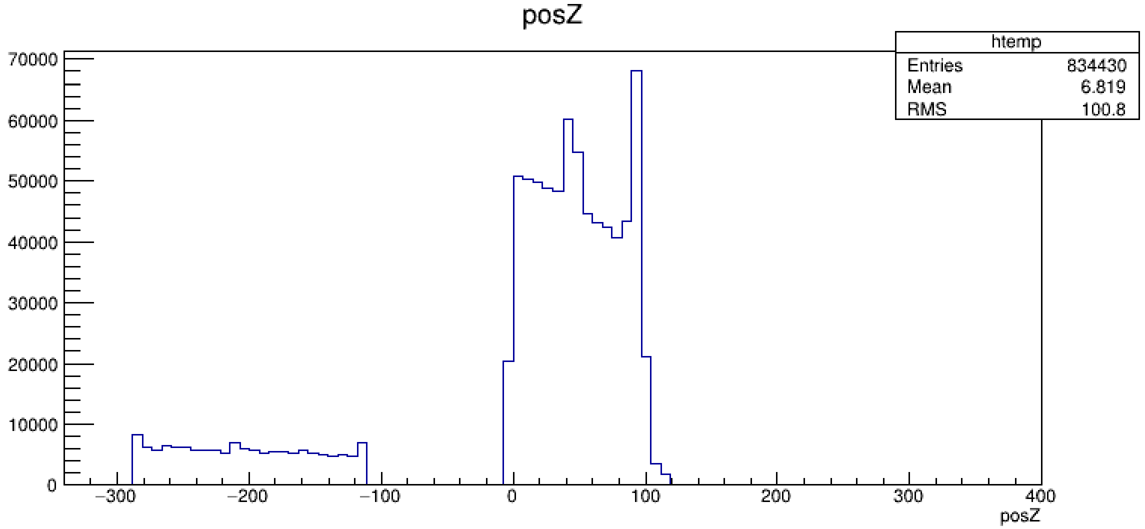
telescope. For the discretization uncertainty to be sub-dominant to range straggling, we would require $\Delta/\sqrt{12} < 3$ mm (Table 4).

Poludniowski, G., Allinson, N.M., Evans, P.M., 2015. Proton radiography and tomography with application to proton therapy. The British Journal of Radiology 88, 20150134. doi:10.1259/bjr.20150134

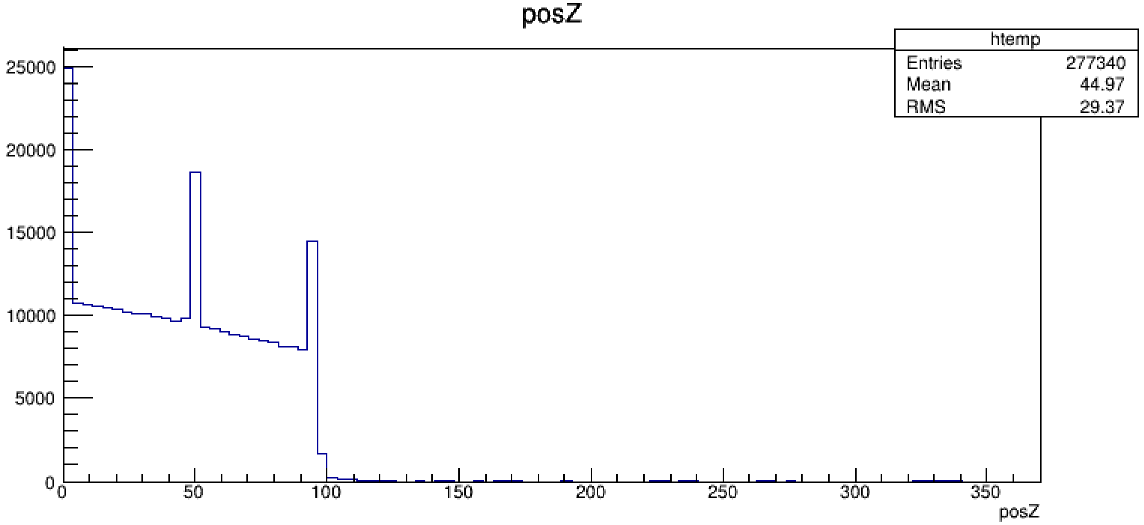
Monte Carlo simulations



Full simulation: Record everything: 5’ primaries/energy



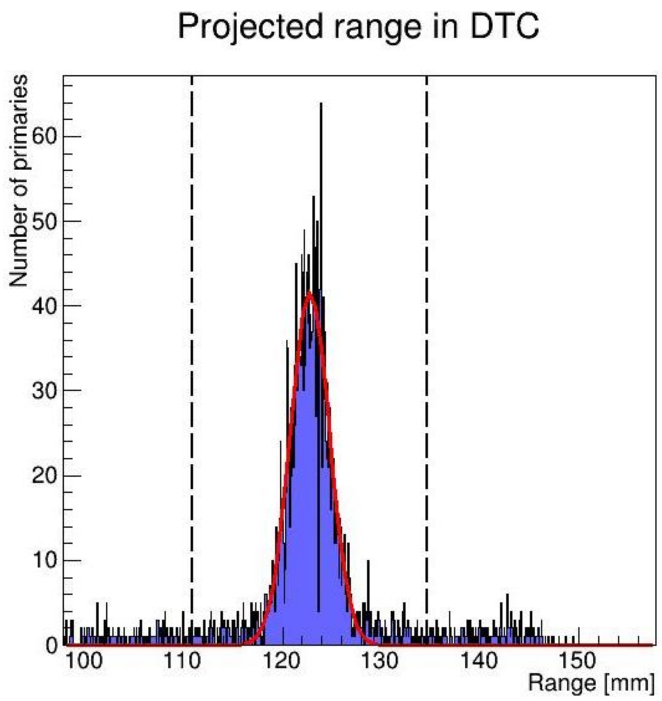
Chip simulation: Record only events in sensors: 15’ primaries/energy

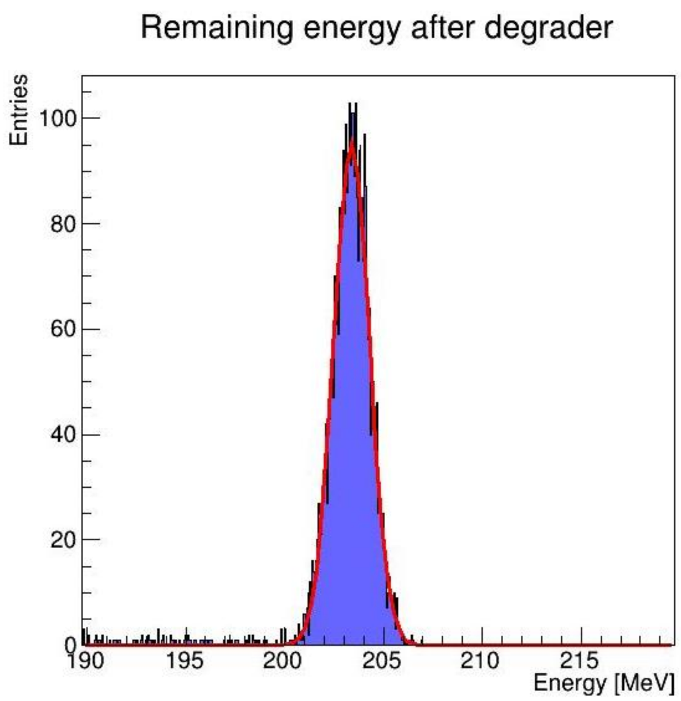


Full MC simulations

The «Gold standard» in this context

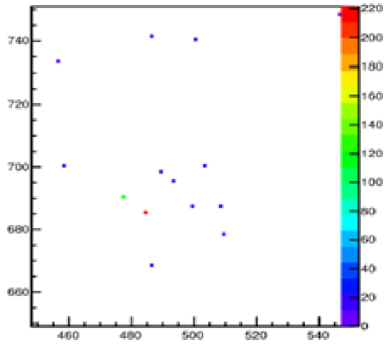
1. Range for each water phantom thickness and geometry configuration
2. Range straggling
3. Energy spread distal to DTC

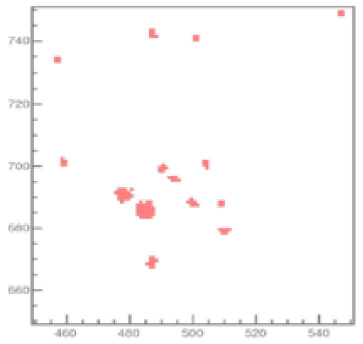


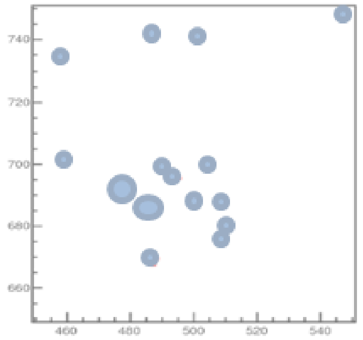


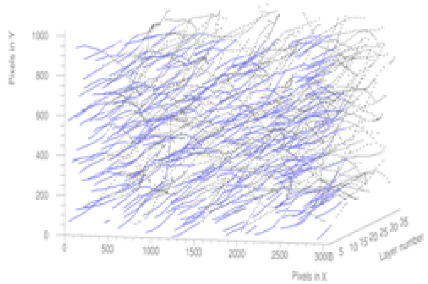
May be skipped in «simplified» analysis

Data readout MC, MC + truth, exp. → **Pixel diffusion modelling (MC only)** → **Cluster identification** → **Proton track reconstruction**

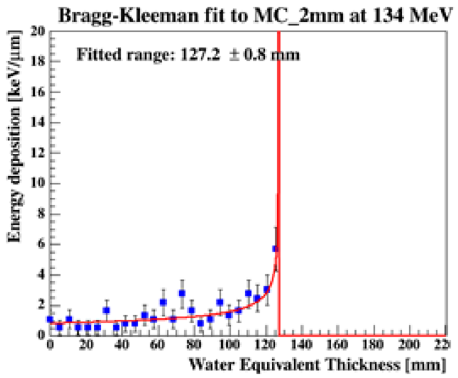


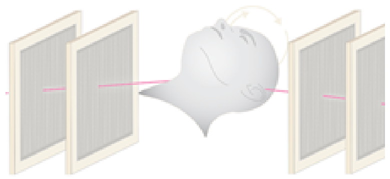


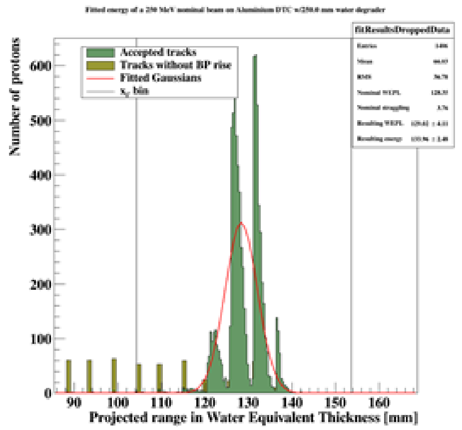


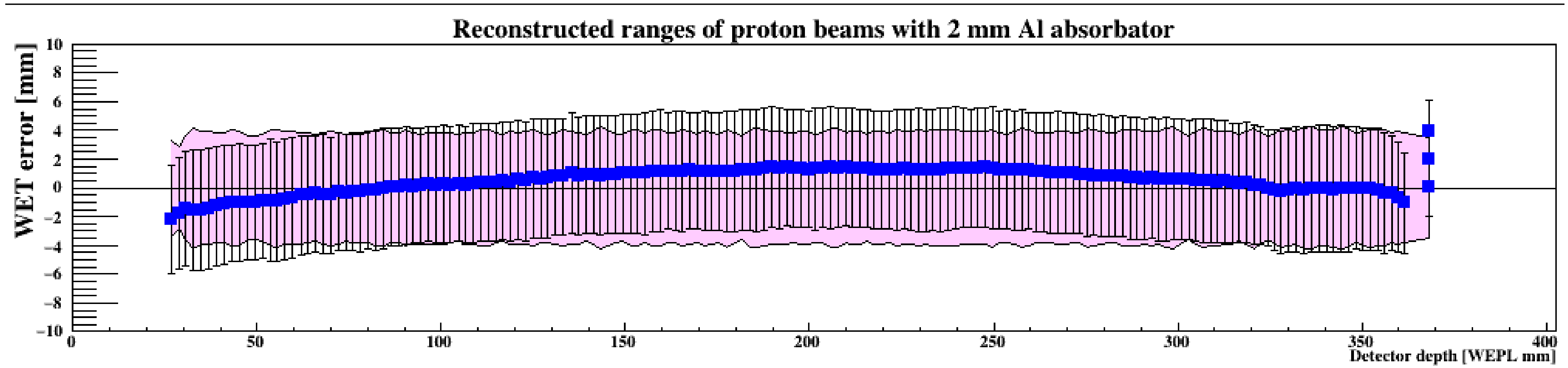


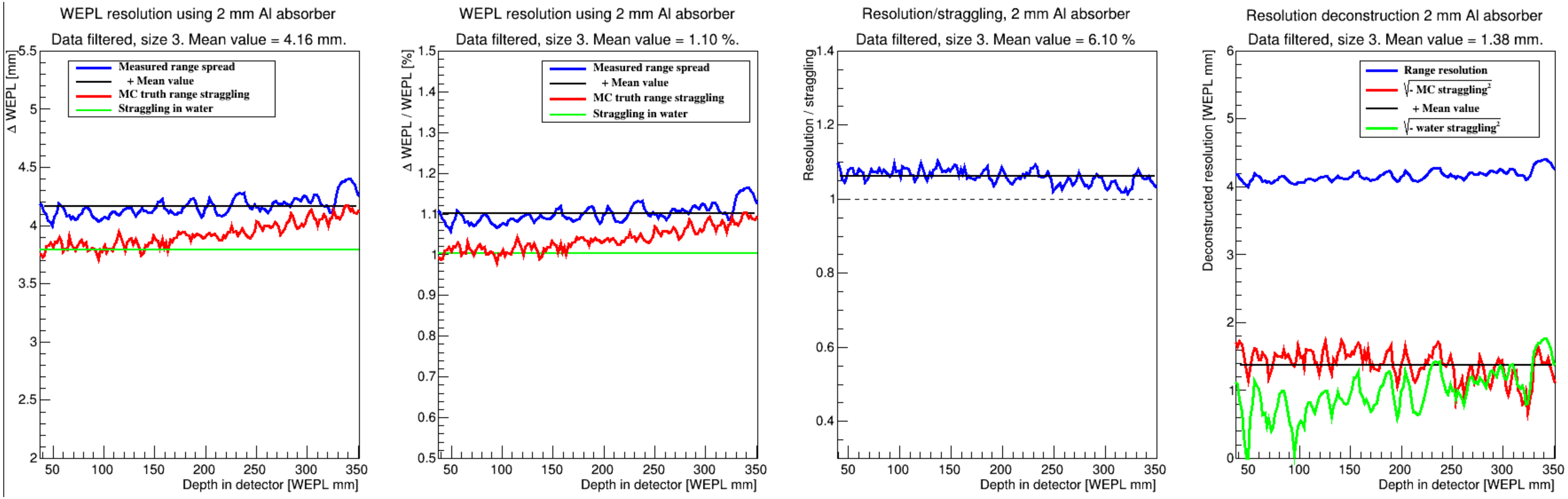
Individual track – energy loss fitting → **If 3D reconstruction: MLP estimation** → **Residual range calculation**

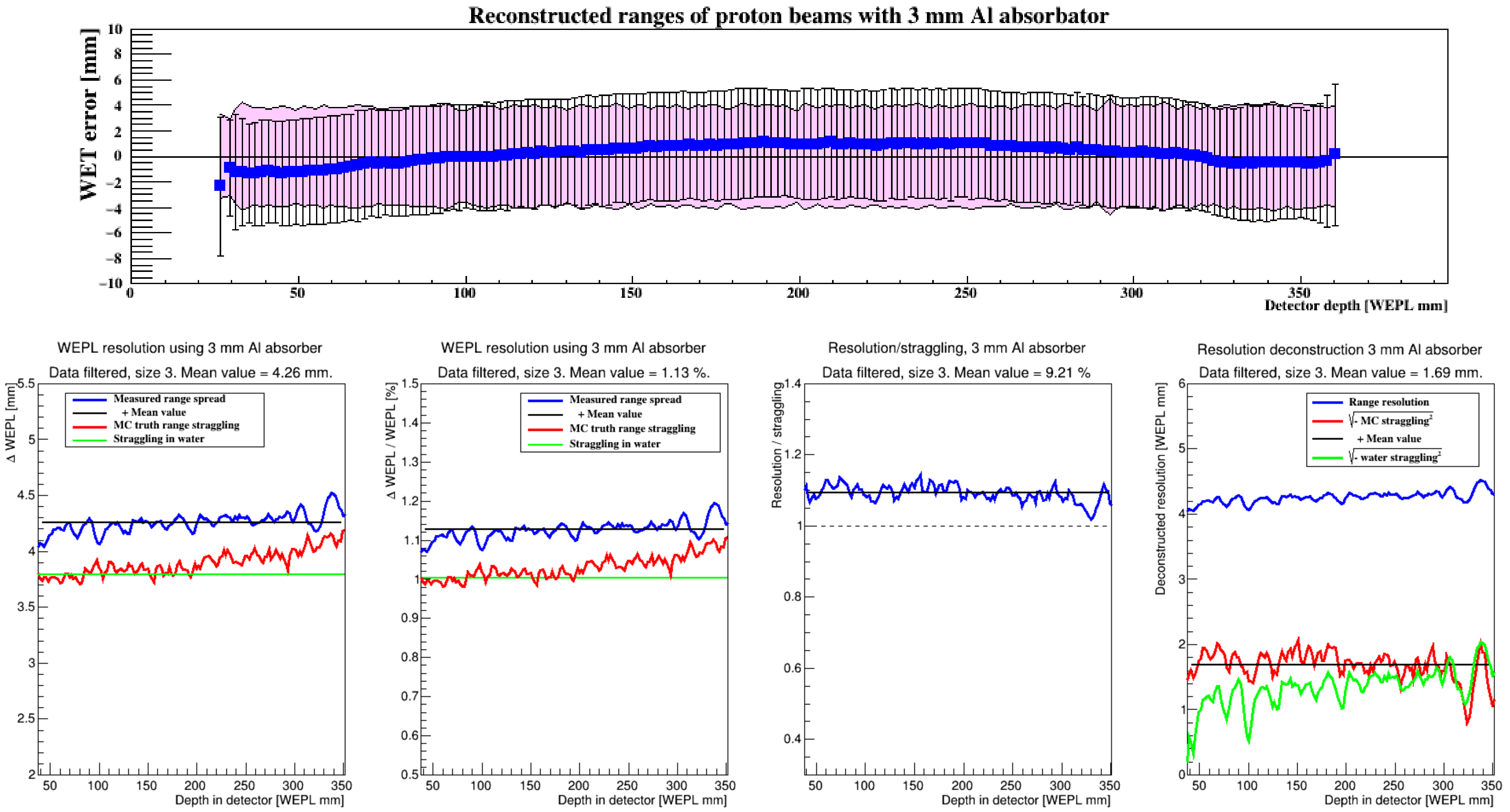




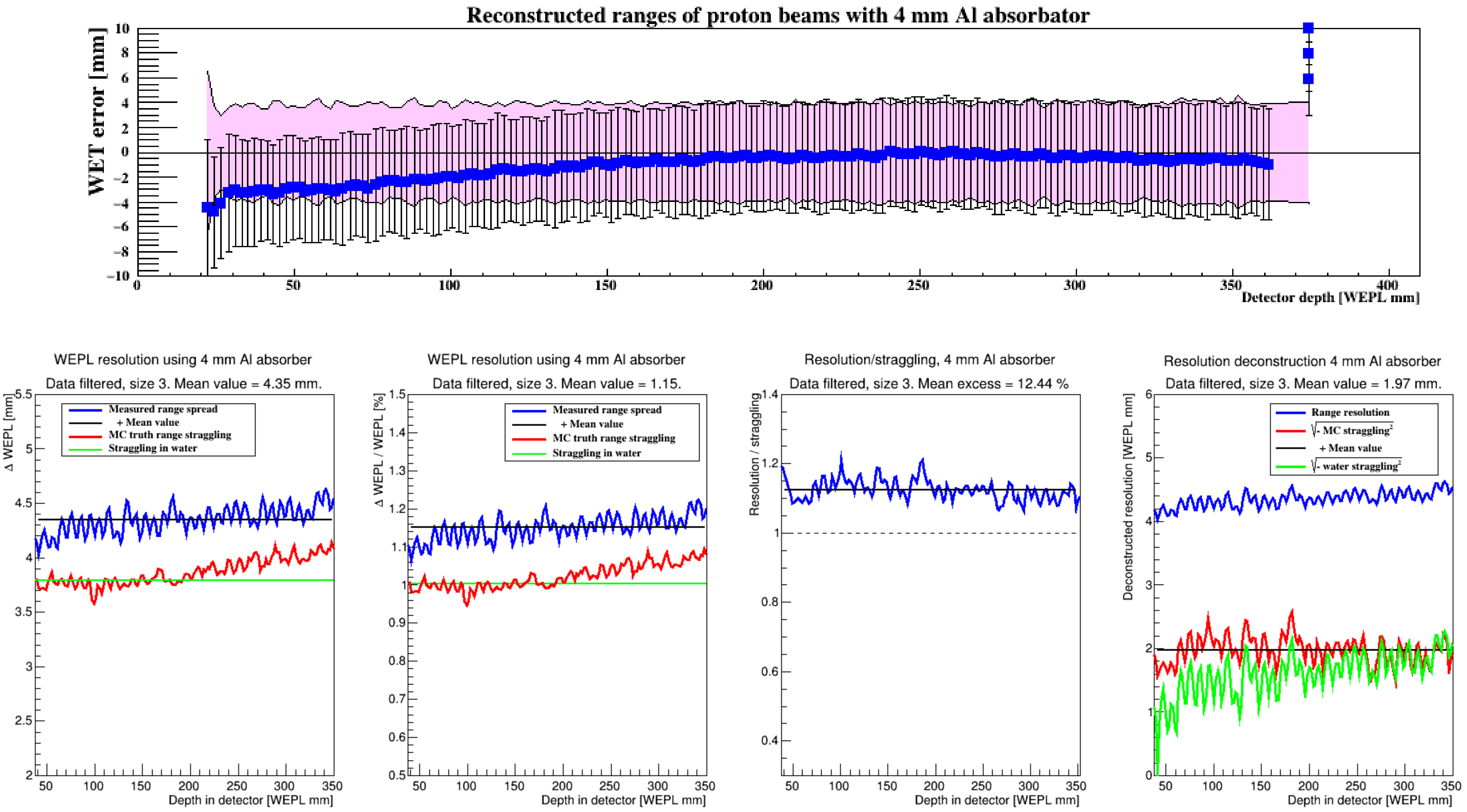



Reconstructed ranges of proton beams with 2 mm Al absorbator
WET error [mm]
Detector depth [WEPL mm]

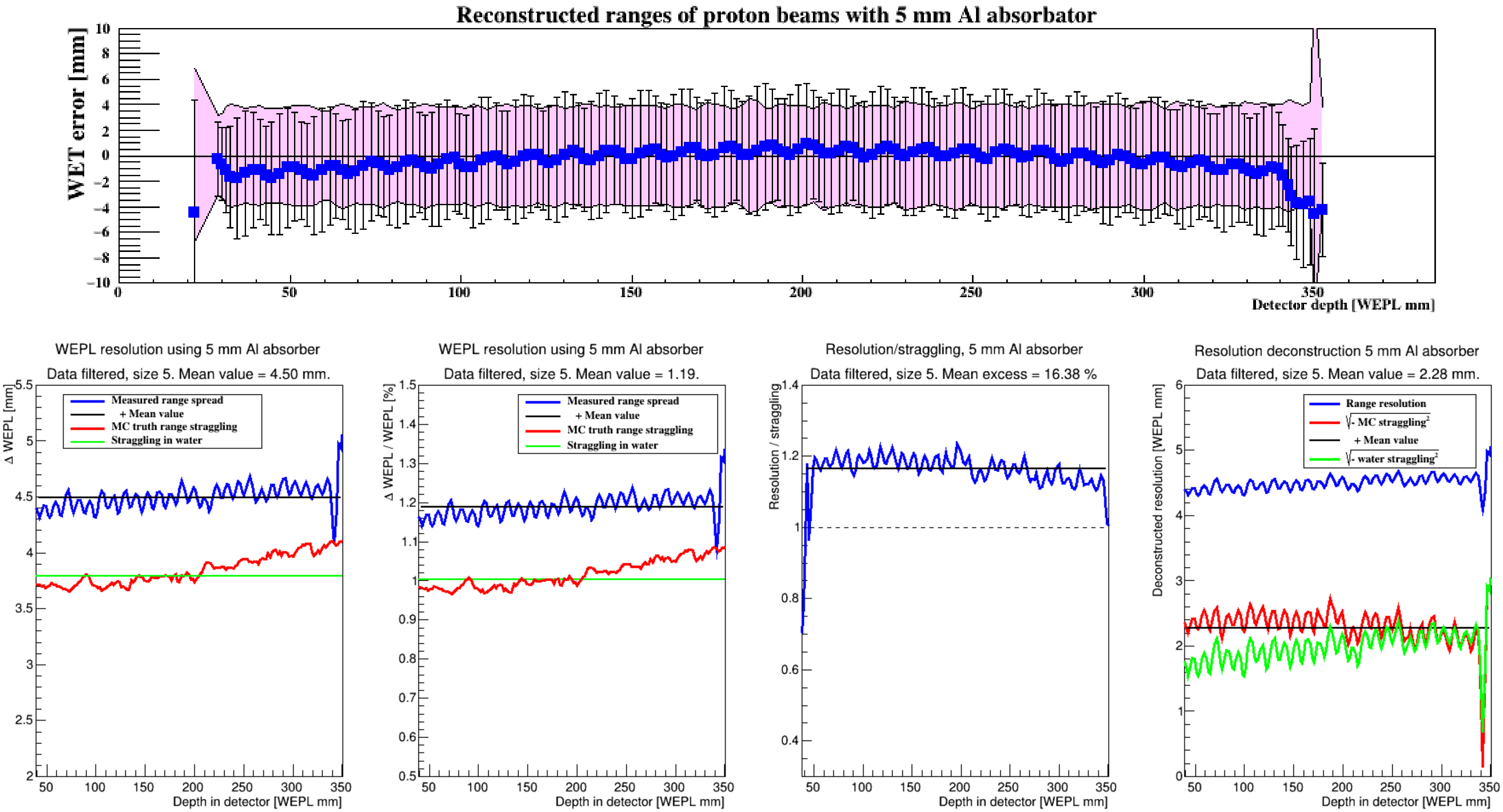

WEPL resolution using 2 mm Al absorber
Data filtered, size 3. Mean value = 4.16 mm.
Δ WEPL [mm]
Measured range spread
+ Mean value
MC truth range straggling
Straggling in water
Depth in detector [WEPL mm]
WEPL resolution using 2 mm Al absorber
Data filtered, size 3. Mean value = 1.10 %.
Δ WEPL / WEPL [%]
Measured range spread
+ Mean value
MC truth range straggling
Straggling in water
Depth in detector [WEPL mm]
Resolution/straggling, 2 mm Al absorber
Data filtered, size 3. Mean value = 6.10 %
Resolution / straggling
Depth in detector [WEPL mm]
Resolution deconstruction 2 mm Al absorber
Data filtered, size 3. Mean value = 1.38 mm.
Deconstructed resolution [WEPL mm]
Range resolution
√- MC straggling²
+ Mean value
√- water straggling²
Depth in detector [WEPL mm]



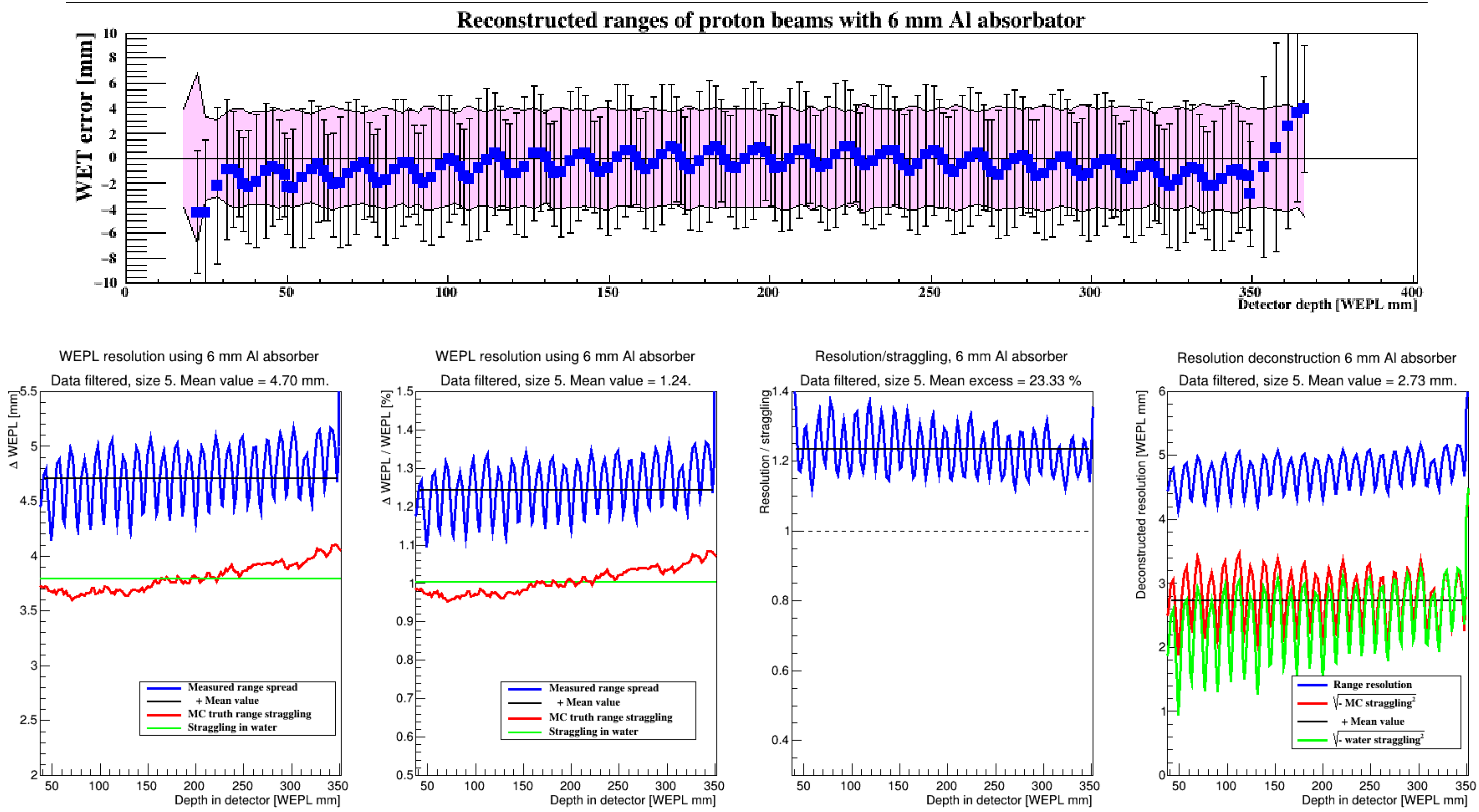
Reconstructed ranges of proton beams with 3 mm Al absorbator
WET error [mm]
Detector depth [WEPL mm]
WEPL resolution using 3 mm Al absorber
Data filtered, size 3. Mean value = 4.26 mm.
Δ WEPL [mm]
Measured range spread
+ Mean value
MC truth range straggling
Straggling in water
Depth in detector [WEPL mm]
WEPL resolution using 3 mm Al absorber
Data filtered, size 3. Mean value = 1.13 %.
Δ WEPL / WEPL [%]
Measured range spread
+ Mean value
MC truth range straggling
Straggling in water
Depth in detector [WEPL mm]
Resolution/straggling, 3 mm Al absorber
Data filtered, size 3. Mean value = 9.21 %
Resolution / straggling
Depth in detector [WEPL mm]
Resolution deconstruction 3 mm Al absorber
Data filtered, size 3. Mean value = 1.69 mm.
Deconstructed resolution [WEPL mm]
Range resolution
√- MC straggling²
+ Mean value
√- water straggling²
Depth in detector [WEPL mm]



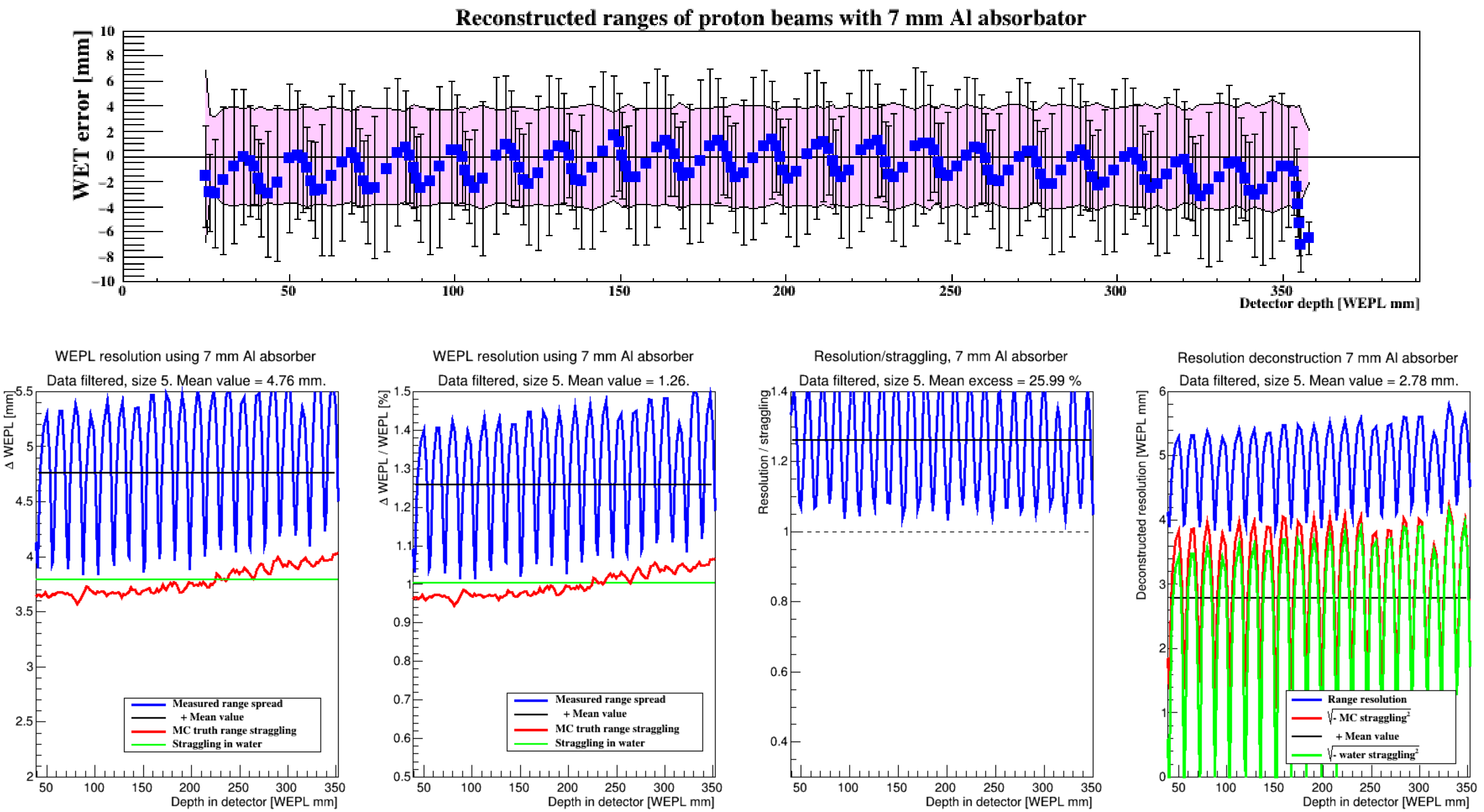
Reconstructed ranges of proton beams with 4 mm Al absorbator
WET error [mm]
Detector depth [WEPL mm]
WEPL resolution using 4 mm Al absorber
Data filtered, size 3. Mean value = 4.35 mm.
Δ WEPL [mm]
Measured range spread
+ Mean value
MC truth range straggling
Straggling in water
Depth in detector [WEPL mm]
WEPL resolution using 4 mm Al absorber
Data filtered, size 3. Mean value = 1.15.
Δ WEPL / WEPL [%]
Measured range spread
+ Mean value
MC truth range straggling
Straggling in water
Depth in detector [WEPL mm]
Resolution/straggling, 4 mm Al absorber
Data filtered, size 3. Mean excess = 12.44 %
Resolution / straggling
Depth in detector [WEPL mm]
Resolution deconstruction 4 mm Al absorber
Data filtered, size 3. Mean value = 1.97 mm.
Deconstructed resolution [WEPL mm]
Range resolution
√- MC straggling²
+ Mean value
√- water straggling²
Depth in detector [WEPL mm]



Reconstructed ranges of proton beams with 5 mm Al absorbator
WET error [mm]
Detector depth [WEPL mm]
WEPL resolution using 5 mm Al absorber
Data filtered, size 5. Mean value = 4.50 mm.
Δ WEPL [mm]
Measured range spread
+ Mean value
MC truth range straggling
Straggling in water
Depth in detector [WEPL mm]
WEPL resolution using 5 mm Al absorber
Data filtered, size 5. Mean value = 1.19.
Δ WEPL / WEPL [%]
Measured range spread
+ Mean value
MC truth range straggling
Straggling in water
Depth in detector [WEPL mm]
Resolution/straggling, 5 mm Al absorber
Data filtered, size 5. Mean excess = 16.38 %
Resolution / straggling
Depth in detector [WEPL mm]
Resolution deconstruction 5 mm Al absorber
Data filtered, size 5. Mean value = 2.28 mm.
Deconstructed resolution [WEPL mm]
Range resolution
√- MC straggling²
+ Mean value
√- water straggling²
Depth in detector [WEPL mm]



Reconstructed ranges of proton beams with 6 mm Al absorbator
WET error [mm]
Detector depth [WEPL mm]
WEPL resolution using 6 mm Al absorber
Data filtered, size 5. Mean value = 4.70 mm.
Δ WEPL [mm]
Measured range spread
+ Mean value
MC truth range straggling
Straggling in water
Depth in detector [WEPL mm]
WEPL resolution using 6 mm Al absorber
Data filtered, size 5. Mean value = 1.24.
Δ WEPL / WEPL [%]
Measured range spread
+ Mean value
MC truth range straggling
Straggling in water
Depth in detector [WEPL mm]
Resolution/straggling, 6 mm Al absorber
Data filtered, size 5. Mean excess = 23.33 %
Resolution / straggling
Depth in detector [WEPL mm]
Resolution deconstruction 6 mm Al absorber
Data filtered, size 5. Mean value = 2.73 mm.
Deconstructed resolution [WEPL mm]
Range resolution
√- MC straggling²
+ Mean value
√- water straggling²
Depth in detector [WEPL mm]



Reconstructed ranges of proton beams with 7 mm Al absorbator
WET error [mm]
Detector depth [WEPL mm]
WEPL resolution using 7 mm Al absorber
Data filtered, size 5. Mean value = 4.76 mm.
Δ WEPL [mm]
Measured range spread
+ Mean value
MC truth range straggling
Straggling in water
Depth in detector [WEPL mm]
WEPL resolution using 7 mm Al absorber
Data filtered, size 5. Mean value = 1.26.
Δ WEPL / WEPL [%]
Measured range spread
+ Mean value
MC truth range straggling
Straggling in water
Depth in detector [WEPL mm]
Resolution/straggling, 7 mm Al absorber
Data filtered, size 5. Mean excess = 25.99 %
Resolution / straggling
Depth in detector [WEPL mm]
Resolution deconstruction 7 mm Al absorber
Data filtered, size 5. Mean value = 2.78 mm.
Deconstructed resolution [WEPL mm]
Range resolution
√- MC straggling²
+ Mean value
√- water straggling²
Depth in detector [WEPL mm]

Material	Thickness	$t/\sqrt{12}$ WEPL	Resolution	Excess straggling	Pre-straggling resolution	Layers for 230 MeV + 5σ
Al	2 mm	1.5 mm	4.16 mm	6.1%	1.38 mm	67
Al	3 mm	2.1 mm	4.26 mm	9.2%	1.69 mm	48
Al	4 mm	2.7 mm	4.35 mm	12.4%	1.97 mm	39
Al	5 mm	3.3 mm	4.50 mm	16.4%	2.28 mm	32
Al	6 mm	3.9 mm	4.70 mm	23.3%	2.73 mm	27
Al	7 mm	4.5 mm	4.76 mm	26.0%	2.78 mm	23
Loma Linda	N/A	N/A	4.1 mm*	N/A	N/A	N/A
FOCAL	32 mm	9.2 mm	15.6 mm**	N/A	N/A	11

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* At 200 MeV. Scintillator measurements, res. does not scale linearly with depth.
** Resolution scaled to 230 MeV from 188 MeV
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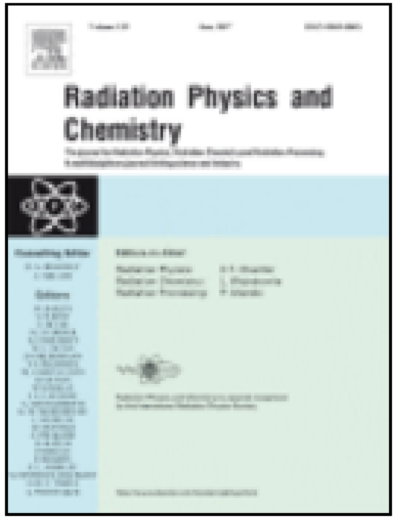
Next software tutorial

- Matthias suggested next Monday (the 3rd) to get him going
- We've made the software compatible with ROOT 5, ROOT 6 & up to C++11

Accuracy of parameterized proton range models; a comparison

H. E. S. Pettersen[a,b*], I. Meric[c], O. H. Odland[a], J. R. Sølie[c], D. Röhrich[b]



Abstract

An accurate calculation of proton ranges in phantoms or detector geometries is crucial for decision making in proton therapy and proton imaging. To this end, several parameterizations of the range-energy relationship exist, with different levels of complexity and accuracy. In this study we compare the accuracy four different parameterizations models: Two analytical models derived from the Bethe equation, and two different interpolation schemes applied to range-energy tables. In conclusion, a spline interpolation scheme yields the highest reproduction accuracy, while the shape of the energy loss-curve is best reproduced with the differentiated Bragg-Kleeman equation.