

# LhARA End Station Dose Modelling

Dose-depth profiles and dose rates at the *in-vitro* end stations

Matt Pereira

(matthew.pereira.2023@live.rhul.ac.uk)

01/08/25



ROYAL  
HOLLOWAY  
UNIVERSITY  
OF LONDON



# Stage 1 End Station

## Model and Method

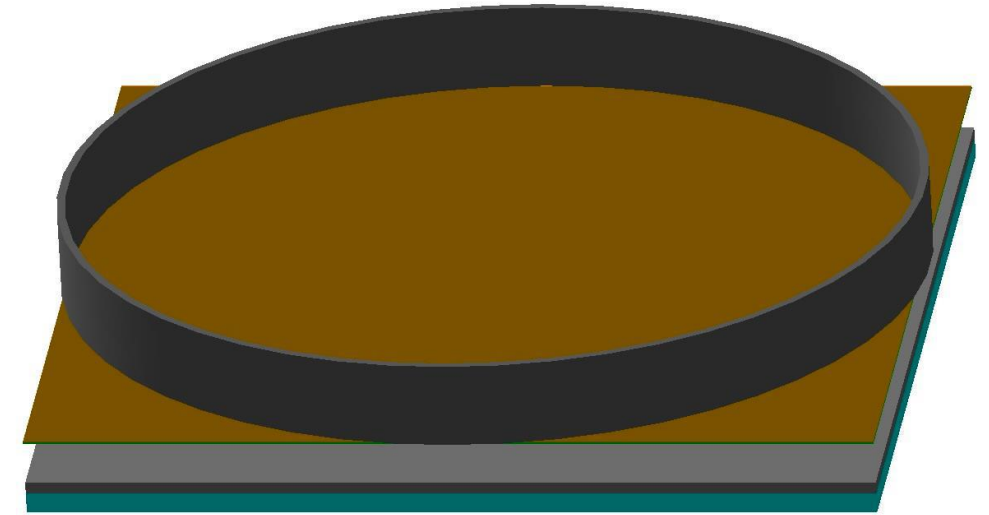
An idealised dose model gives theoretical maximum dose values that function as a 'gold standard' to compare to in start-to-end tracking.

### Beam

- 1.0 cm Gaussian beam of 10,000 Protons.
- 10, 12, 15 MeV beams both monoenergetic and with 2% energy spread
- Straight into the End Station model (parallel beam)

### Dose Calculation

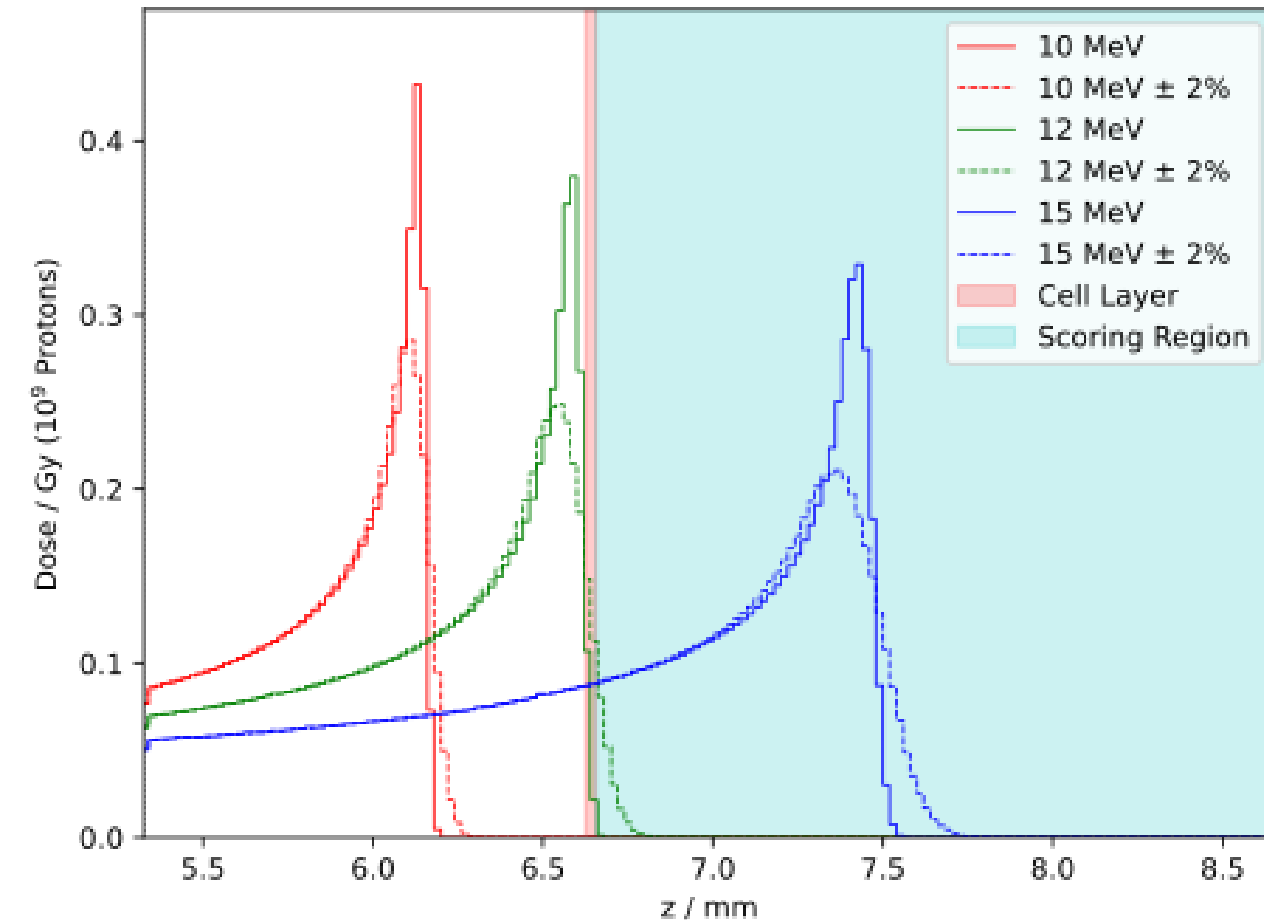
- "g4QGSP\_BIC\_EMZ" Physics list
- Scoring mesh within the water volume, flush to the surface with a 2 mm length in z.
- Radius of 2.65 mm to imitate a Markus Ion Chamber.
- Dose per proton scaled by  $10^{10}$  to represent the dose delivered by  $10^9$  protons at a 10 Hz repetition rate.



Component	Length (mm)	Material
Drift	10.0	Stainless Steel
Vacuum Window	0.075	Mylar
Scintillating Fibre	0.250	Polystyrene
Air Gap	5.0	Air
Sample Container	1.15	Polystyrene
Water	2.4	Water

# Stage 1 End Station

## Proton Bragg Peak Comparison and Dose Rate Calculation



Model region shown begins at the entrance to the sample container lid and ends 2 mm into the water volume.

Bragg peaks fall where expected by LhARA design:

- 10 MeV well before the cell layer
- 12 MeV just before the cell layer
- 15 MeV well beyond the cell layer but still within the water volume, cell layer sees the proximal edge where the dose is more uniform.

### Energy Spread

- Not previously included in dose modelling
- Broadens all Bragg peaks
- For 15 MeV, introducing energy spread has little effect as the scoring region captures the entire Bragg peak in both cases.
- Larger impact on 12 MeV dose as the higher energy particles deposit more within the scoring region.

Proton Energy [MeV]	Dose Rate [Gy / s]
12	$0.96 \pm 0.05$
$12 \pm 2\%$	$7.09 \pm 0.20$
15	$121.93 \pm 1.42$
$15 \pm 2\%$	$123.69 \pm 1.43$

# Stage 2 End Station

## Method and Models for 127 MeV Protons and 33 MeV/u Carbon

Up to the air gap, the Stage 2 in-vitro end station entrance is of the same material and dimensions as Stage 1.

**For Protons:** The region after the air gap is modelled after a PTW T41023 Water Phantom (pictured right)

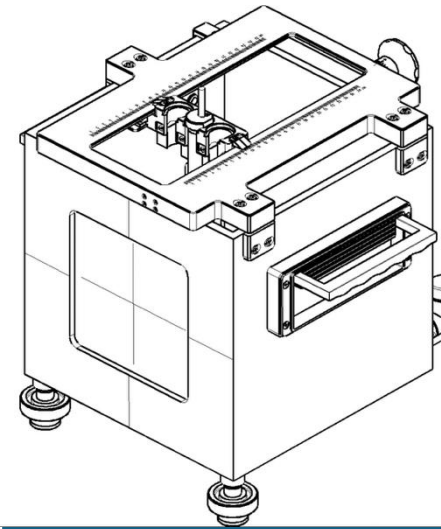
**For Carbon Ions:** The region after the air gap uses the stage 1 sample container model. If the full phantom model is used, no ions survive the phantom wall

### Beam

- 1.0 mm parallel Gaussian beam of 10,000 Protons.
- 127 MeV Proton and 33 MeV/u Carbon beams both monoenergetic and with 2% energy spread

### Dose Calculation

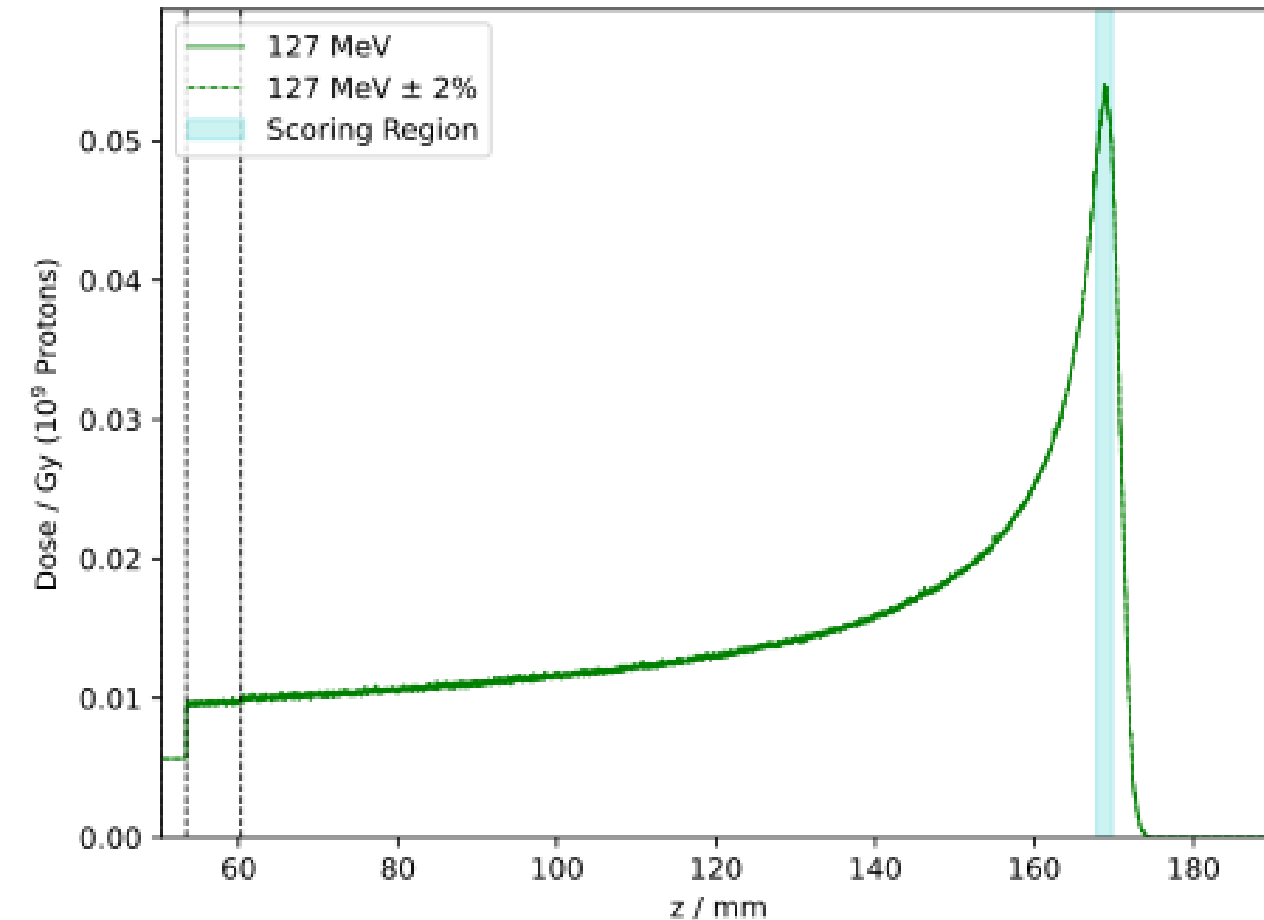
- Markus Ion Chamber scoring mesh (2mm length, radius of 2.65mm) is used again.
- For protons, the mesh is centred on the pristine Bragg peak depth. For carbon, the mesh is flush to the entrance of the water volume
- Dose per ion is scaled by the expected bunch ( $10^9$  for protons and  $8.3 \times 10^7$  for carbon) and to the 10 Hz repetition rate of the laser source.



Component	Length (mm)	Material
Drift	10.0	Stainless Steel
Vacuum Window	0.075	Mylar
Scintillating Fibre	0.250	Polystyrene
Air Gap	50.0	Air
Phantom Entrance Gap	3.05	Air
Phantom Entrance Wall	6.95	Plexiglass
Water	130	Water

# Stage 2 End Station

## Proton Bragg Peak and Dose Rate Calculation



Region shown above is from the start of the phantom wall gap through to the end of the water volume.

Scoring mesh placed to capture the **Pristine Bragg Peak**.

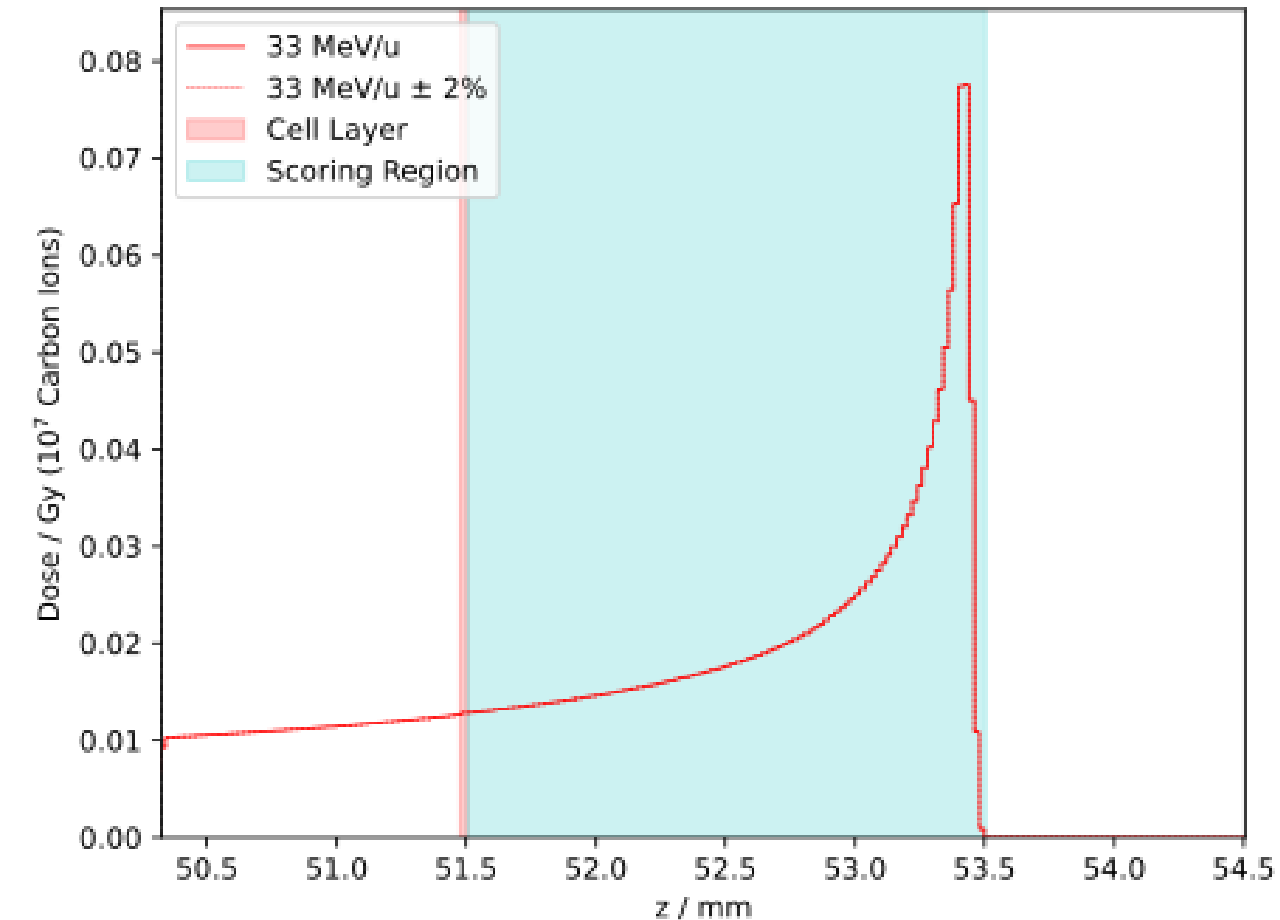
**Energy Spread** has no observable impact on the Bragg peak

**Calculated Dose rate:  $96.7 \pm 1.49 \text{ Gy / s}$**

- LhARA Documentation of previous modelling has a value of  $156 \text{ Gy / s}$  for the same end station setup
- The descriptions from documentation is the only information to compare to as the files for this model are lost.

# Stage 2 End Station

## Carbon Bragg Peak and Dose Rate Calculation



Model region shown begins at the entrance to the sample container lid and ends 3 mm into the water volume.

**Bragg peak** fully captured in the water volume and within the MIC scoring mesh, cell layer sees the proximal edge where the dose is more uniform.

**Energy Spread** has no observable impact on the Bragg peak

**Calculated Dose rate:**  $837 \pm 1.49 \text{ Gy / s}$

- LhARA Documentation of previous modelling has a value of  $730 \text{ Gy / s}$

# Summary

Dose modelling for LhARA Stage 1 and Stage 2 *in-vitro* end stations to provide “gold standard” profiles and dose rate calculations to compare with when complete source to end station tracking is carried out in future.

**Impact of nominal 2% energy spread** is limited to the stage 1 end station where the Bragg peak becomes broader, though dose scored in the mesh and the dose-depth profile at the cell layer are still comparable.

**Stage 1 Dose Rate Calculations** remain consistent with previous LhARA documentation.

**Stage 2 Dose Rate Calculations** are inconsistent with previous LhARA documentation but previous models to cross-validate with are unavailable.

**Immediate next steps** are to take the values from older documentation and try to find any scaling factors that are unaccounted for or were improperly applied.

# Thank You

Matt Pereira

[matthew.pereira.2023@live.rhul.ac.uk](mailto:matthew.pereira.2023@live.rhul.ac.uk)



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