Energy Spread Effects

Stage 1 Beam Profile and Updated Dose Calculations

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ROYAL HOLLOWAY UNIVERSITY OF LONDON

LhARA Laser-hybrid Accelerator for Radiobiological Applications

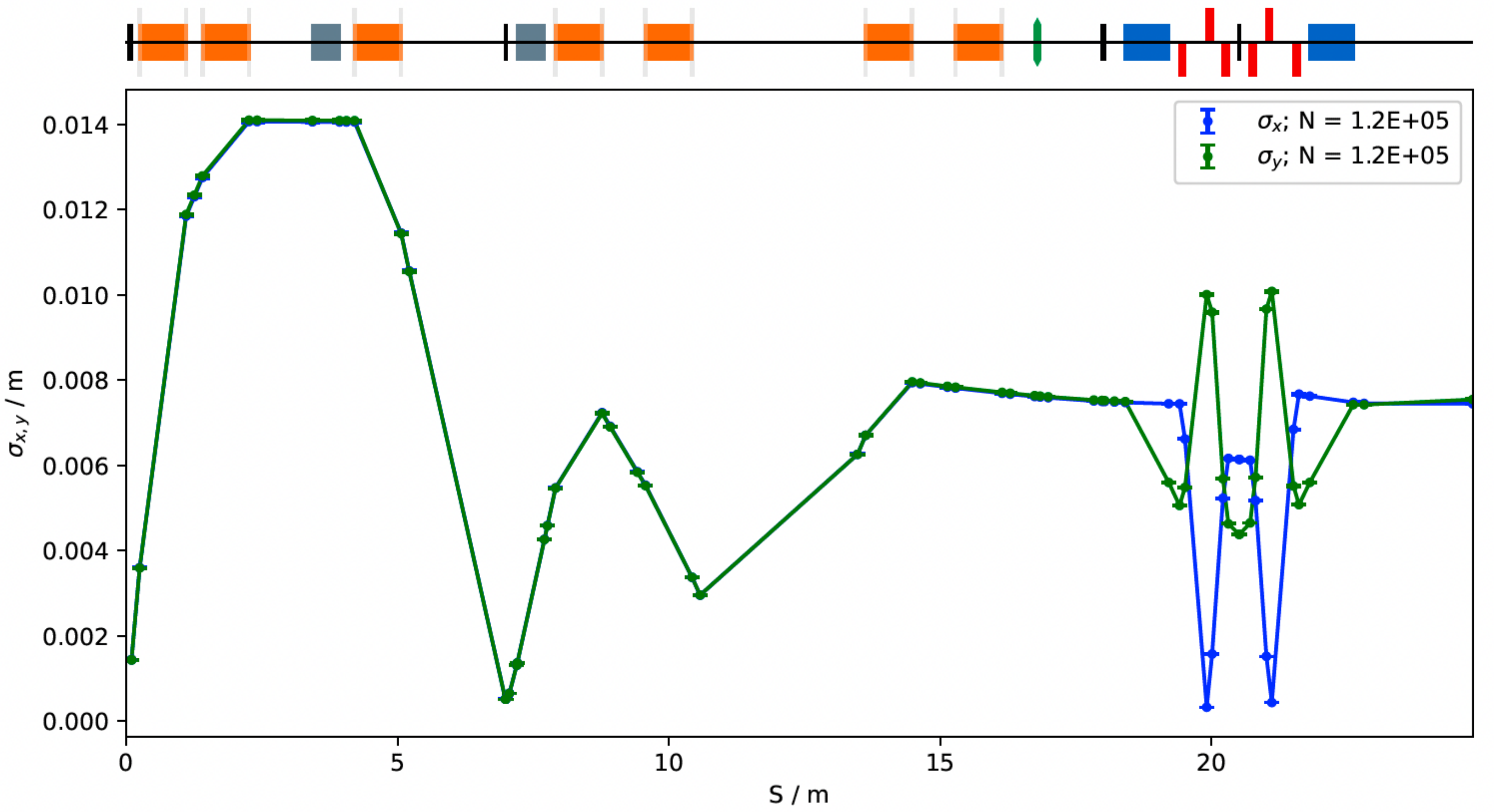
John Adams Institute for Accelerator Science

Non-Linear Focusing Effects

Stage 1 Optics

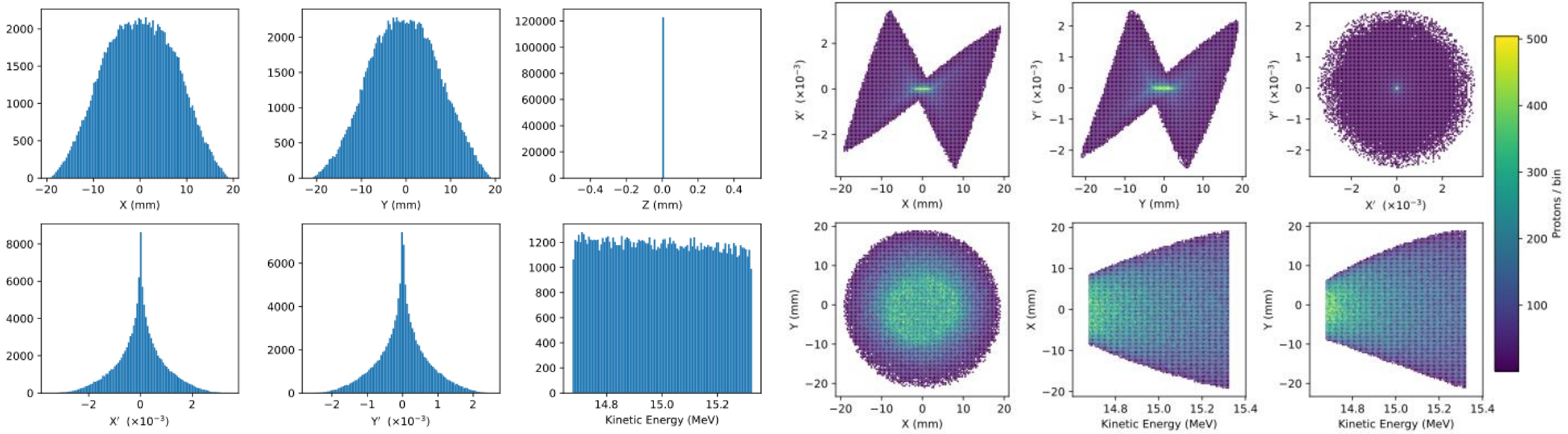
Start-to-end tracking of Stage 1

- Primary beam taken at the nozzle from a combination of LharaLinearOptics source output and GPT simulation of the first 10 cm.
- Beam of 123,000 protons from LLO (Higher NParts than previous 10k)
- Solenoid Strengths for spot size optimised in MADX
- This configuration appears to satisfy the intended scheme and provide the desired beam size at the S1 end station.



Non-Linear Focusing Effects

3.0 cm Beam at the End Station

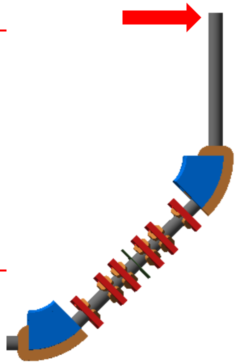


Full width of the beam ~ 4.0cm

- MADX matching works with linear optics for an ideal beam envelope so will not account for non-linear effects.

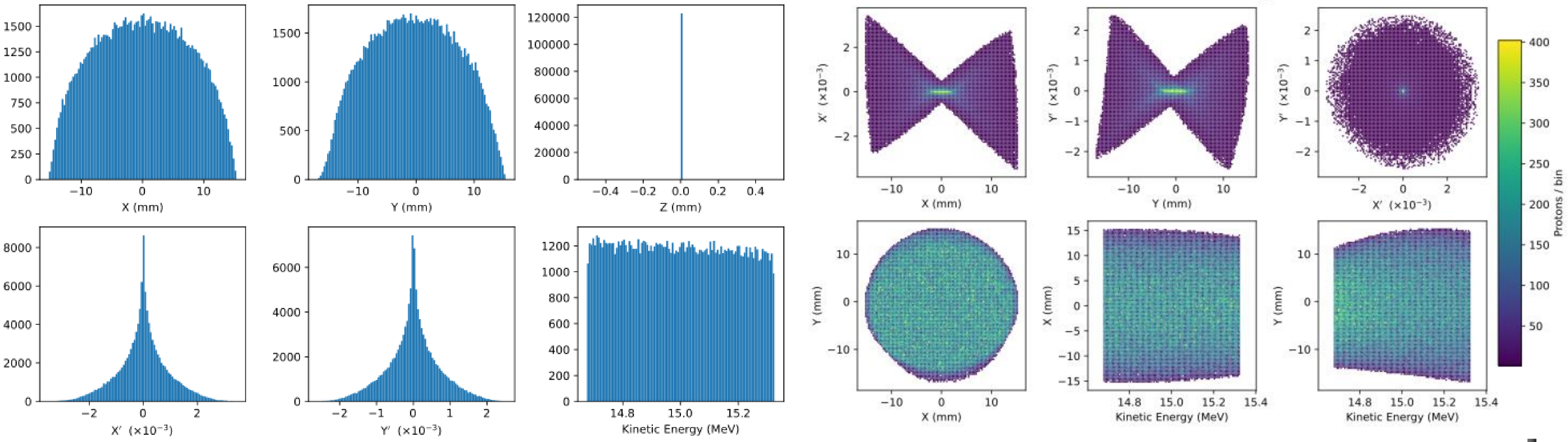
Energy-Position Relationship

- Low energy particles more central
- High energy particles in the outer extent



Non-Linear Focusing Effects

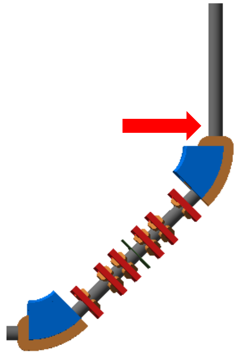
Beam Out of the Vertical Arc



At the exit of the arc, the effects observed at the end station are only vaguely present.

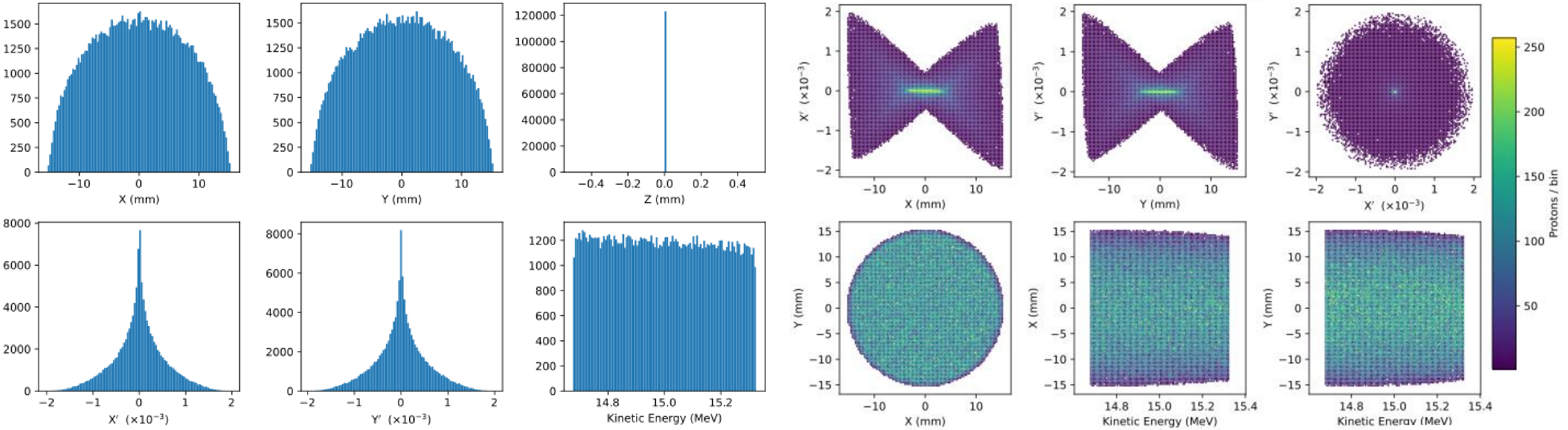
These effects are propagating over 2.0 m of empty drift.

Raises questions about the transparent optics of the vertical arc.



Non-Linear Focusing Effects

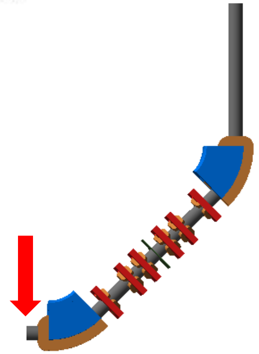
Beam Entering the Vertical Arc



Beam entering the arc looks very similar to the beam coming out.

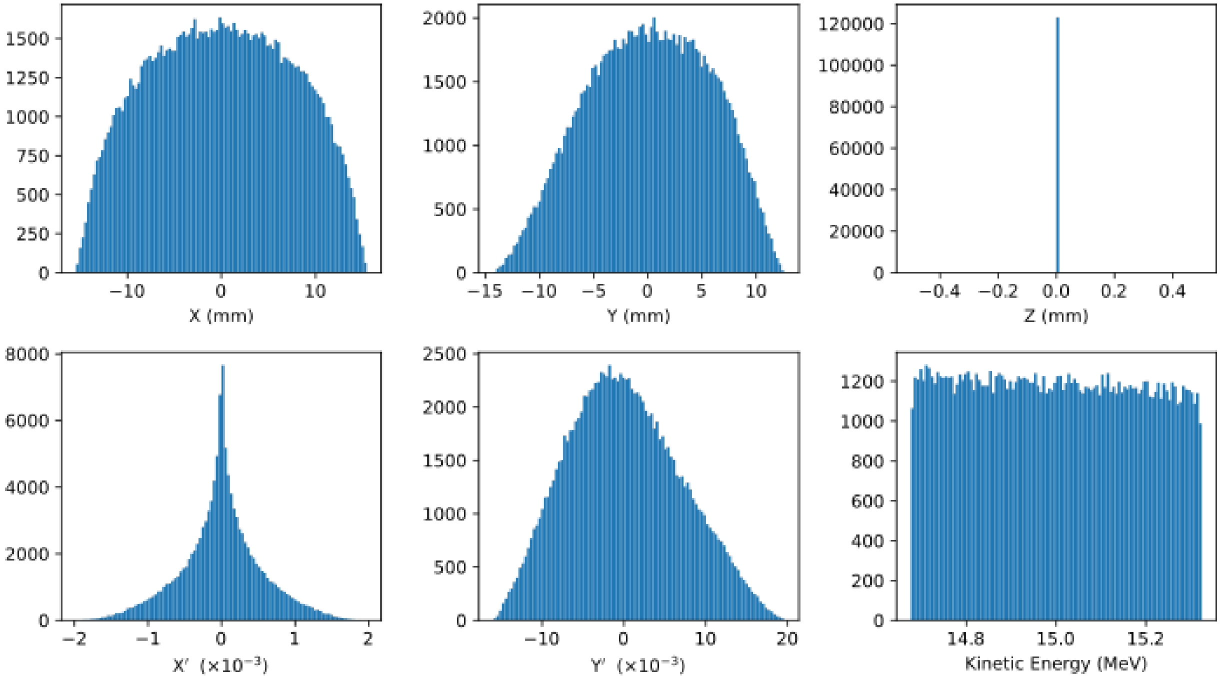
The arc itself must therefore only be 'transparent' when looking at the immediate beginning and end.

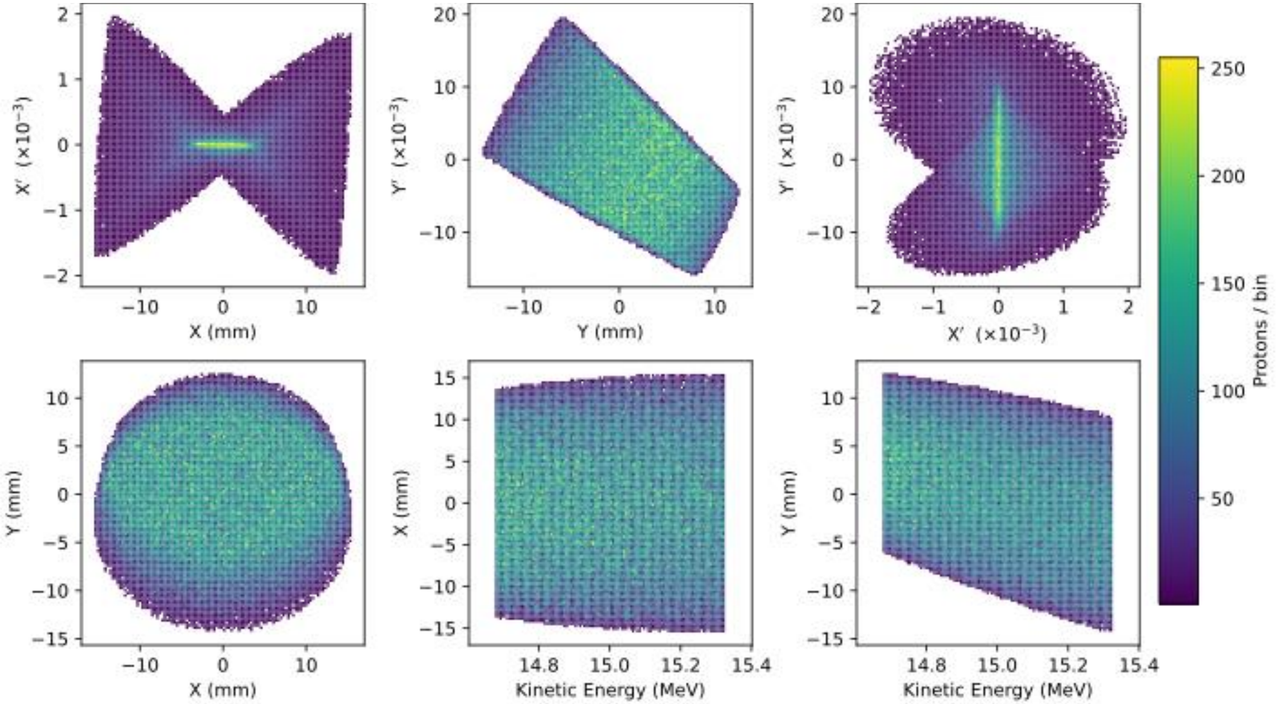
Magnetic manipulation of the beam in the arc must introduce non-linearities that propagate forward.



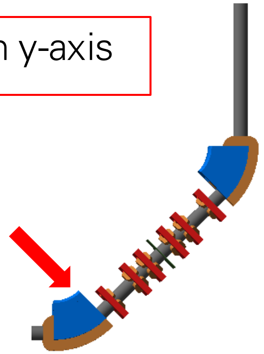
Non-Linear Focusing Effects

After First Arc Dipole



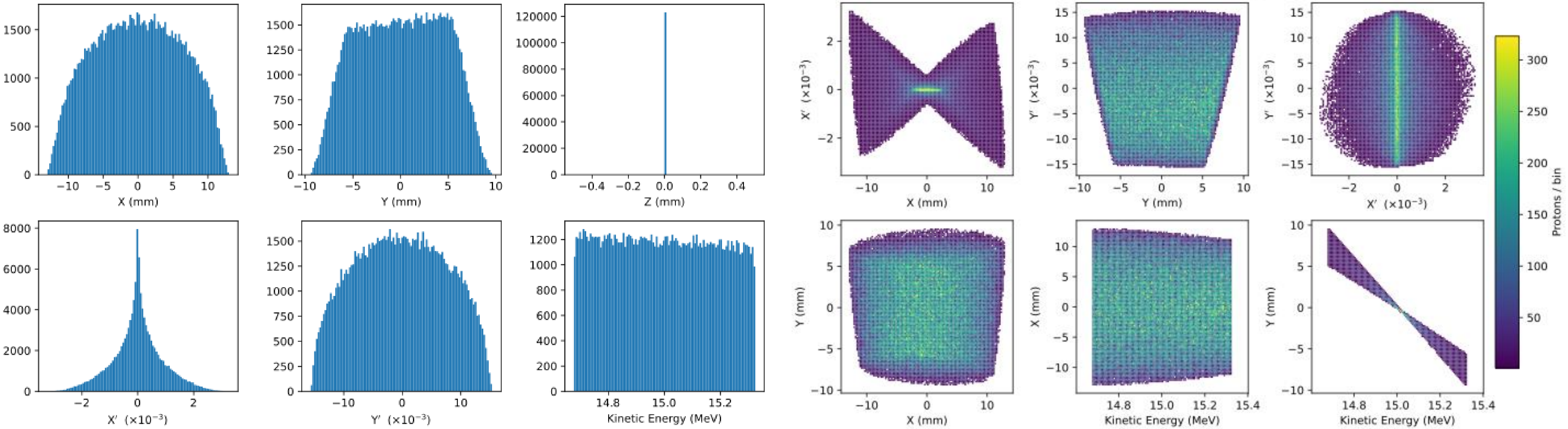


Expected dispersive effects of the dipole on y-axis

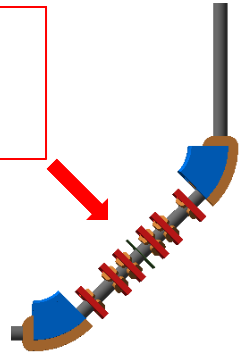


Non-Linear Focusing Effects

Middle of the Arc – No Collimation Simulated

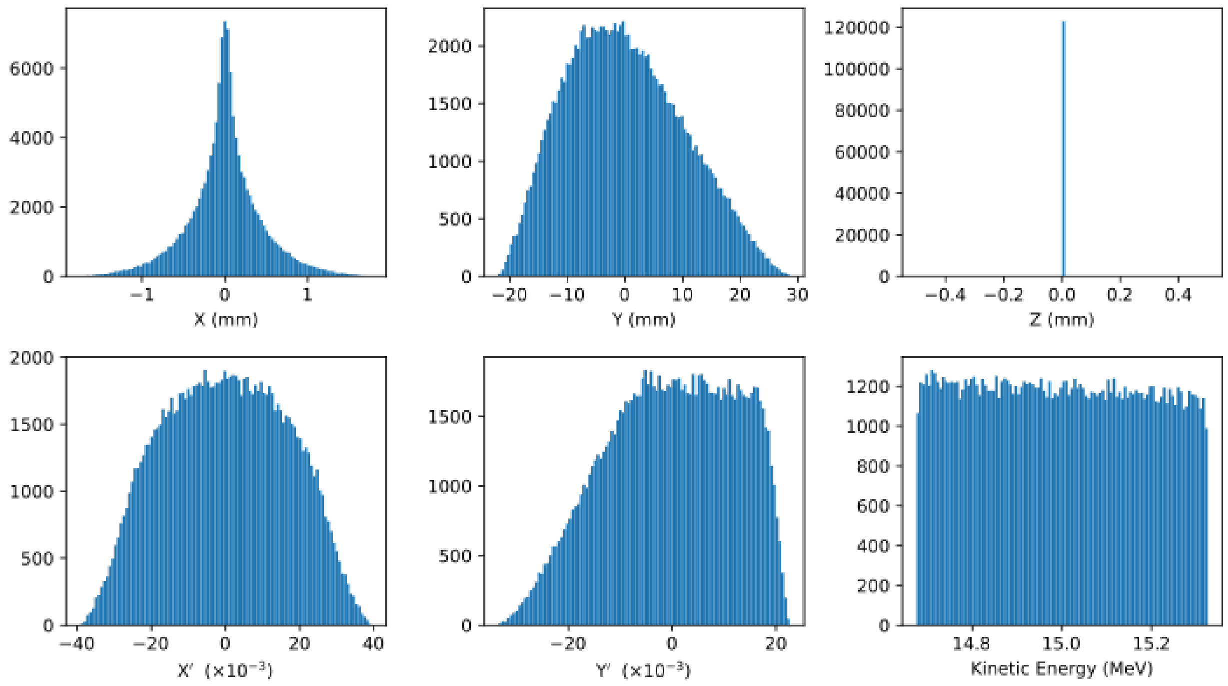


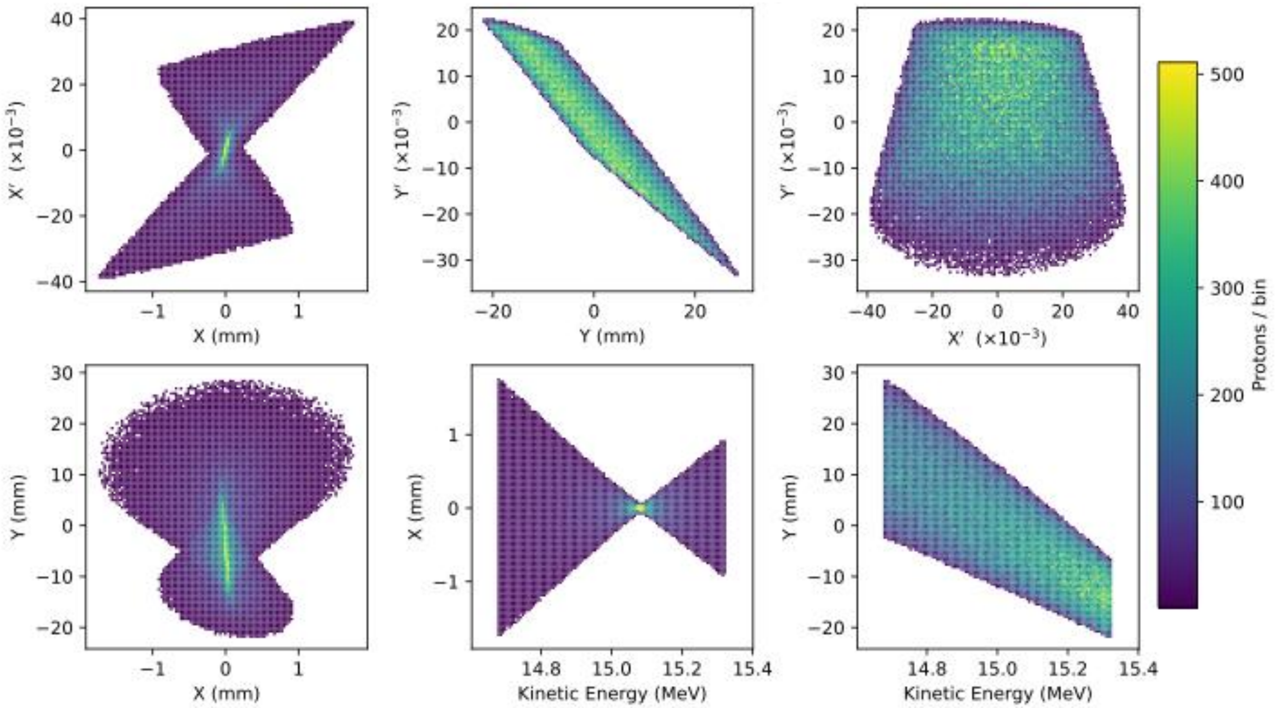
Where collimation would take place, the off-momentum particles are at the spatial extents of the y-axis, as designed.



Non-Linear Focusing Effects

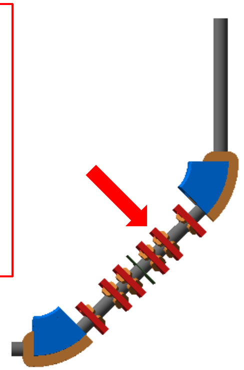
Penultimate Arc Quadrupole – Point of Maximum Dispersion





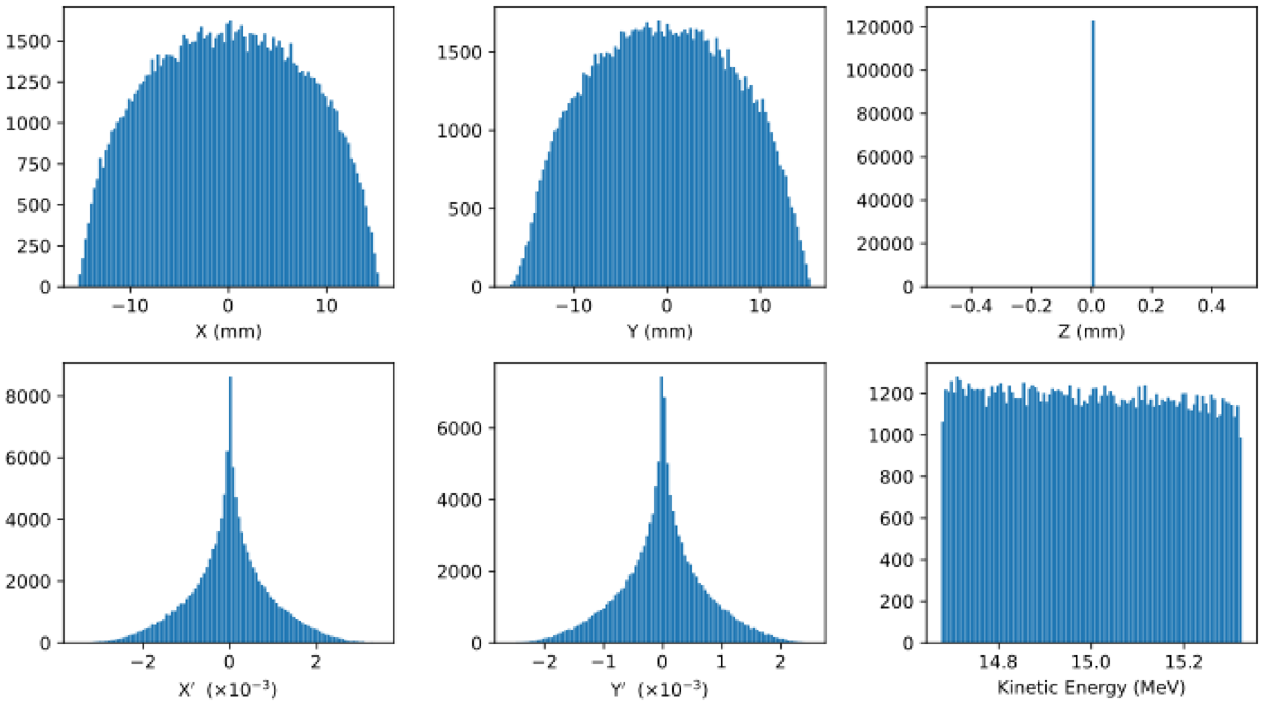
Dispersive effects in y-axis are at maximum, as designed.

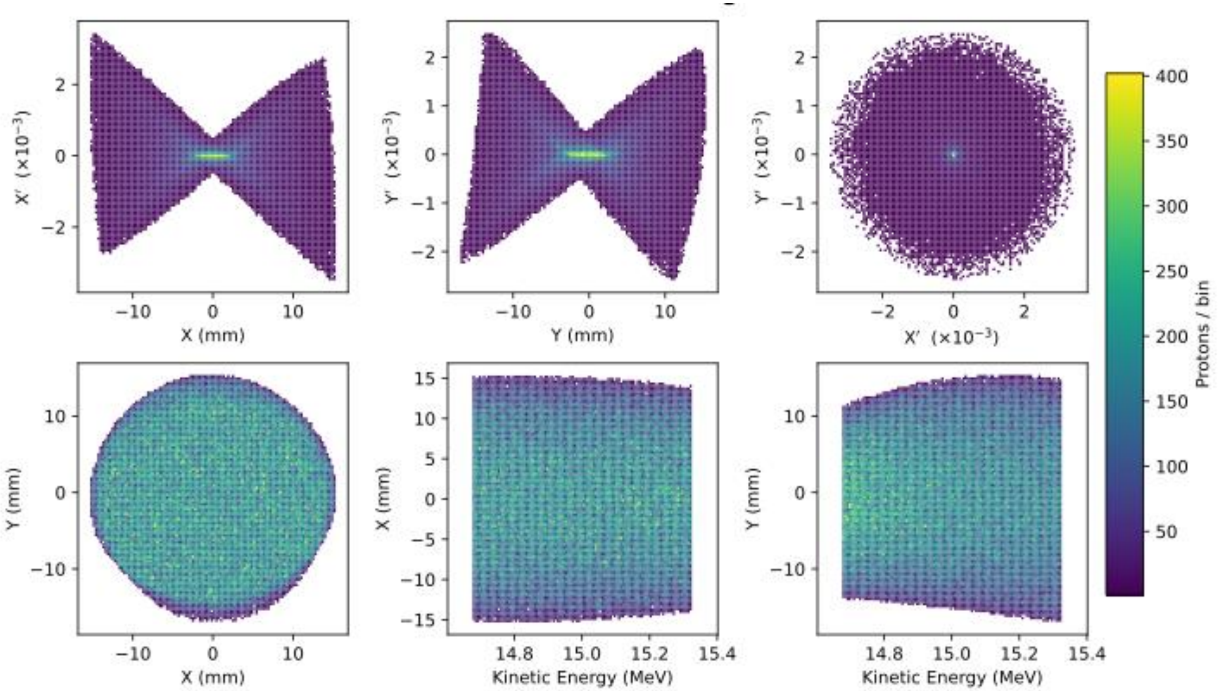
There is a new energy-dependent focus in the x-axis which can only mean that some non-linear effect is being propagated through the quadrupoles



Non-Linear Focusing Effects

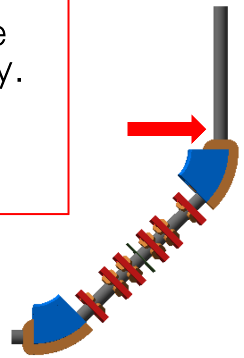
Beam Out of the Vertical Arc





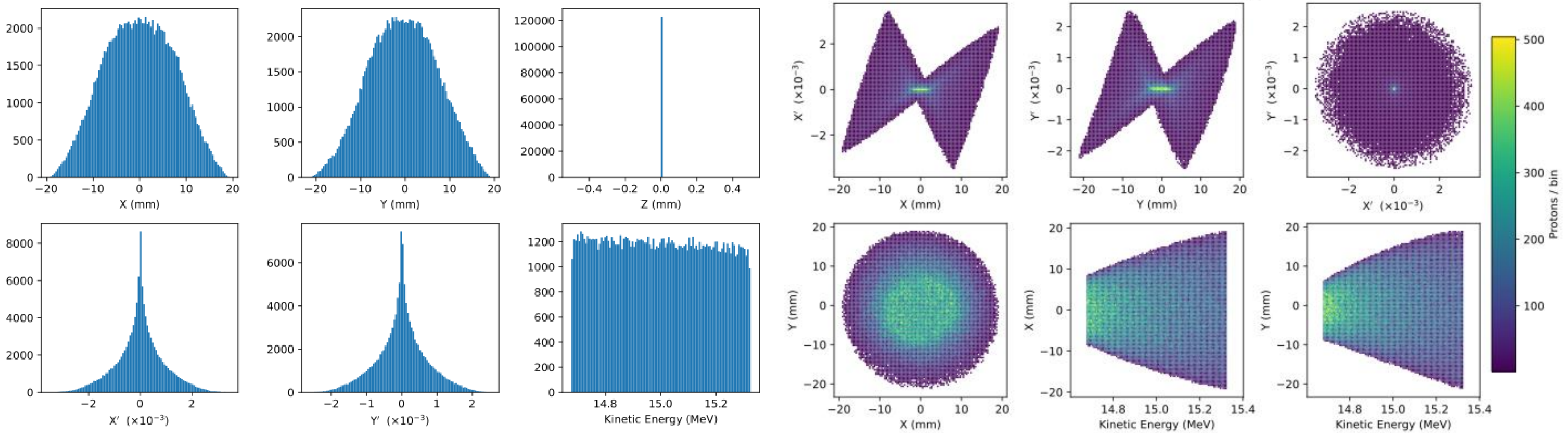
All distributions appear to have been returned to their states at the start of the arc, with some small differences spatially.

There is a small distortion of the relationship between y-position and KE.

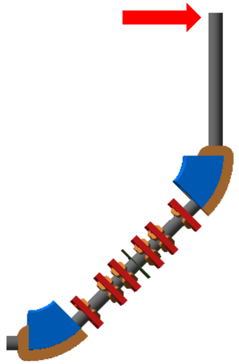


Non-Linear Focusing Effects

3.0 cm Beam at the End Station

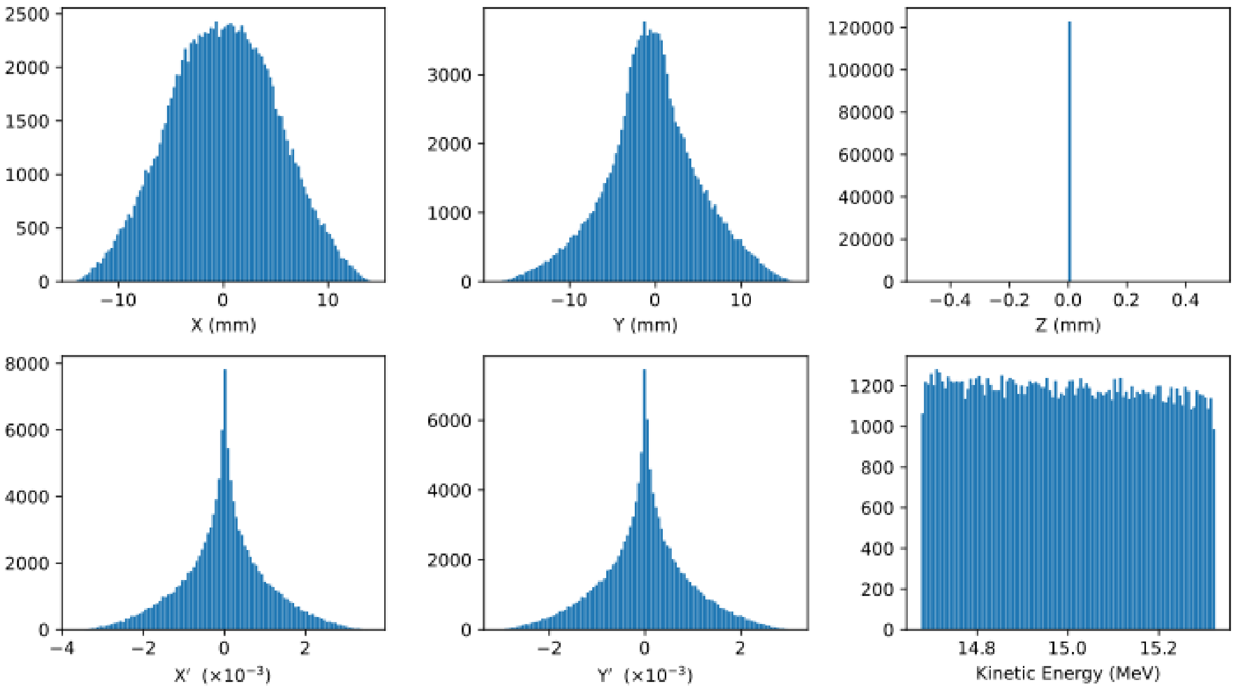


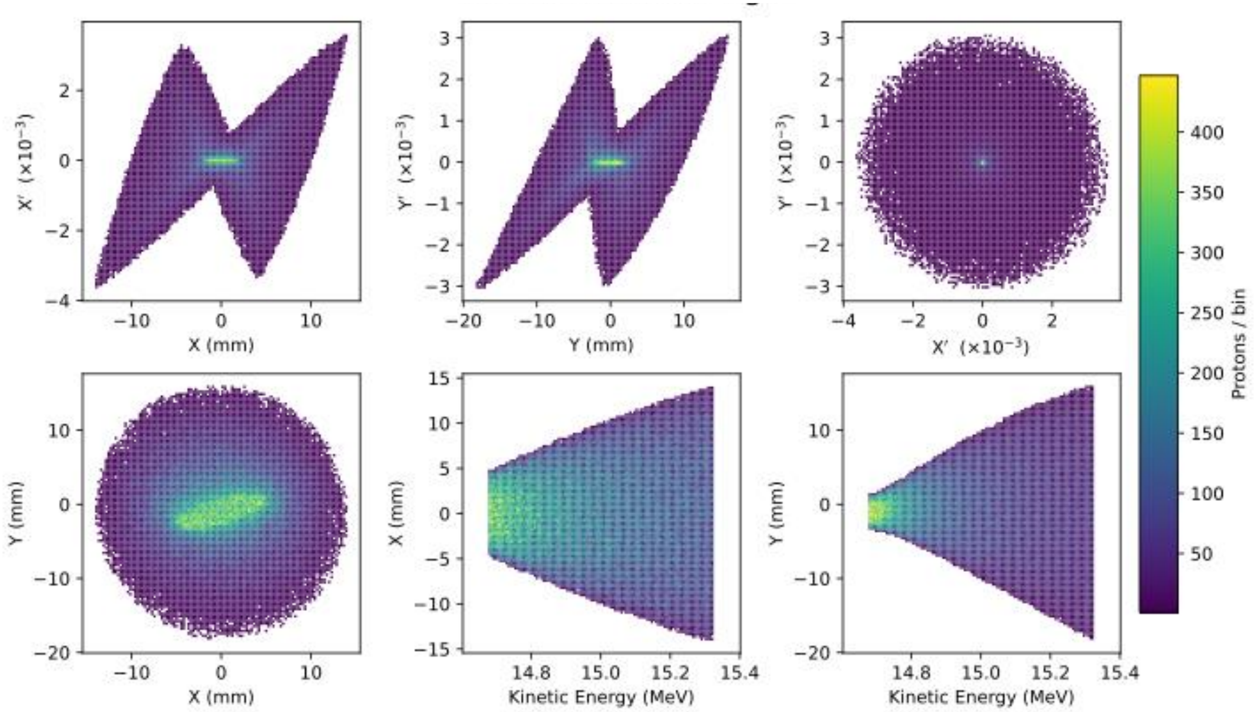
The energy dependence is present in both axis and the transverse spatial profile has lost its uniformity as a result.



Non-Linear Focusing Effects

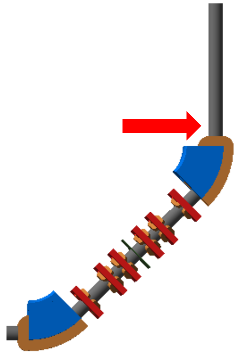
2.0 cm Out of the Vertical Arc





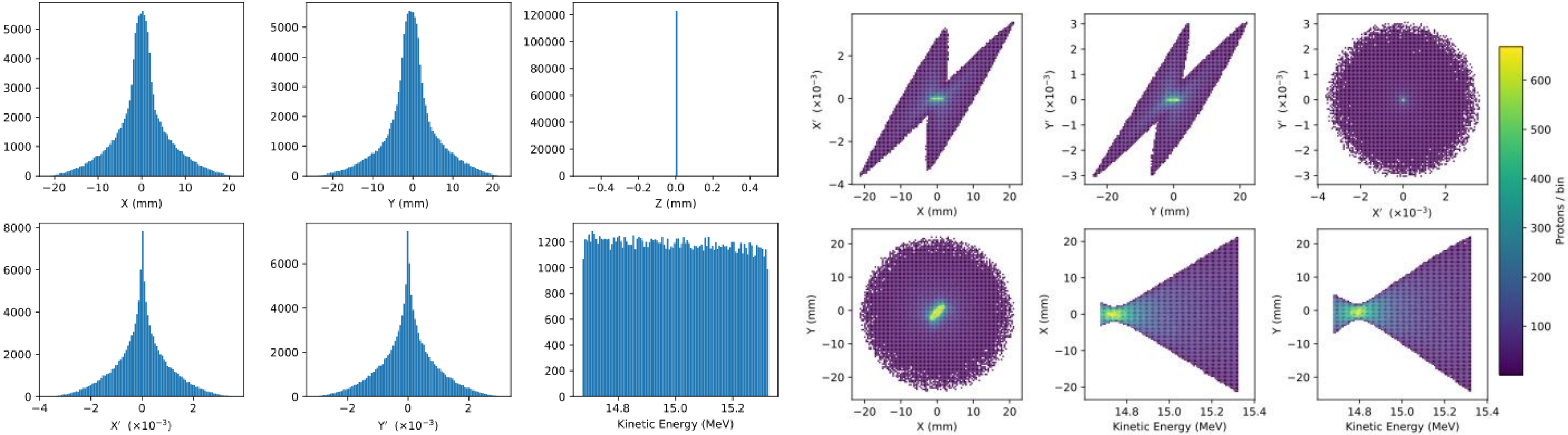
For the 2.0 cm beam, these effects are already pronounced at the exit of the arc where they were not visible with the larger beam.

The focusing is stronger in y than x, which is likely an effect of the dipole.



Non-Linear Focusing Effects

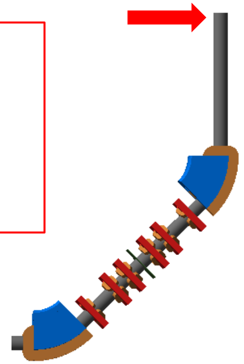
2.0 cm Beam at the End Station



When allowed to drift for 2.0 m to the end station, the focus becomes very strong.

The energy dependent effects are stronger as beam size decreases.

These effects are not present for monoenergetic beams, as expected, so these effects are the result of energy spread



Dose Modelling with Energy Spread

Model and Method

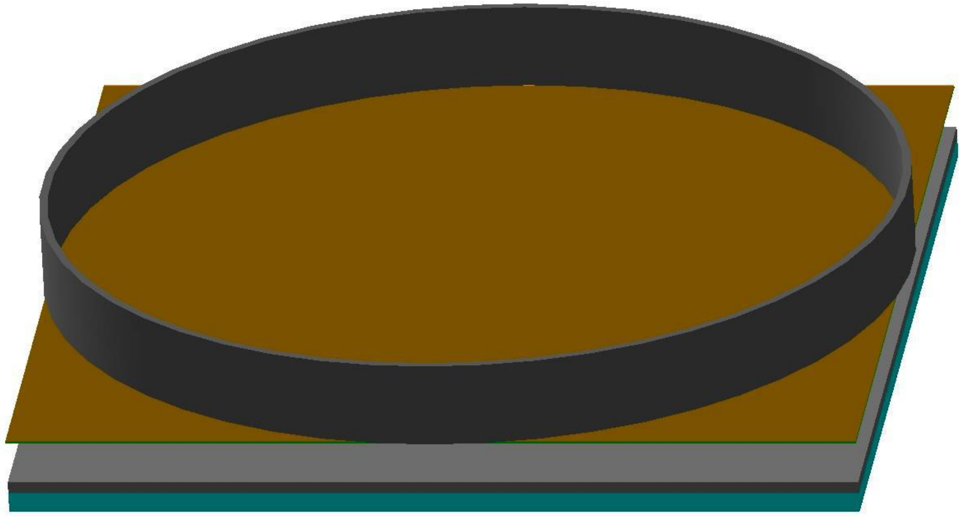
An idealised dose model gives theoretical maximum dose values that function as a 'gold standard' to compare to in start-to-end tracking.

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

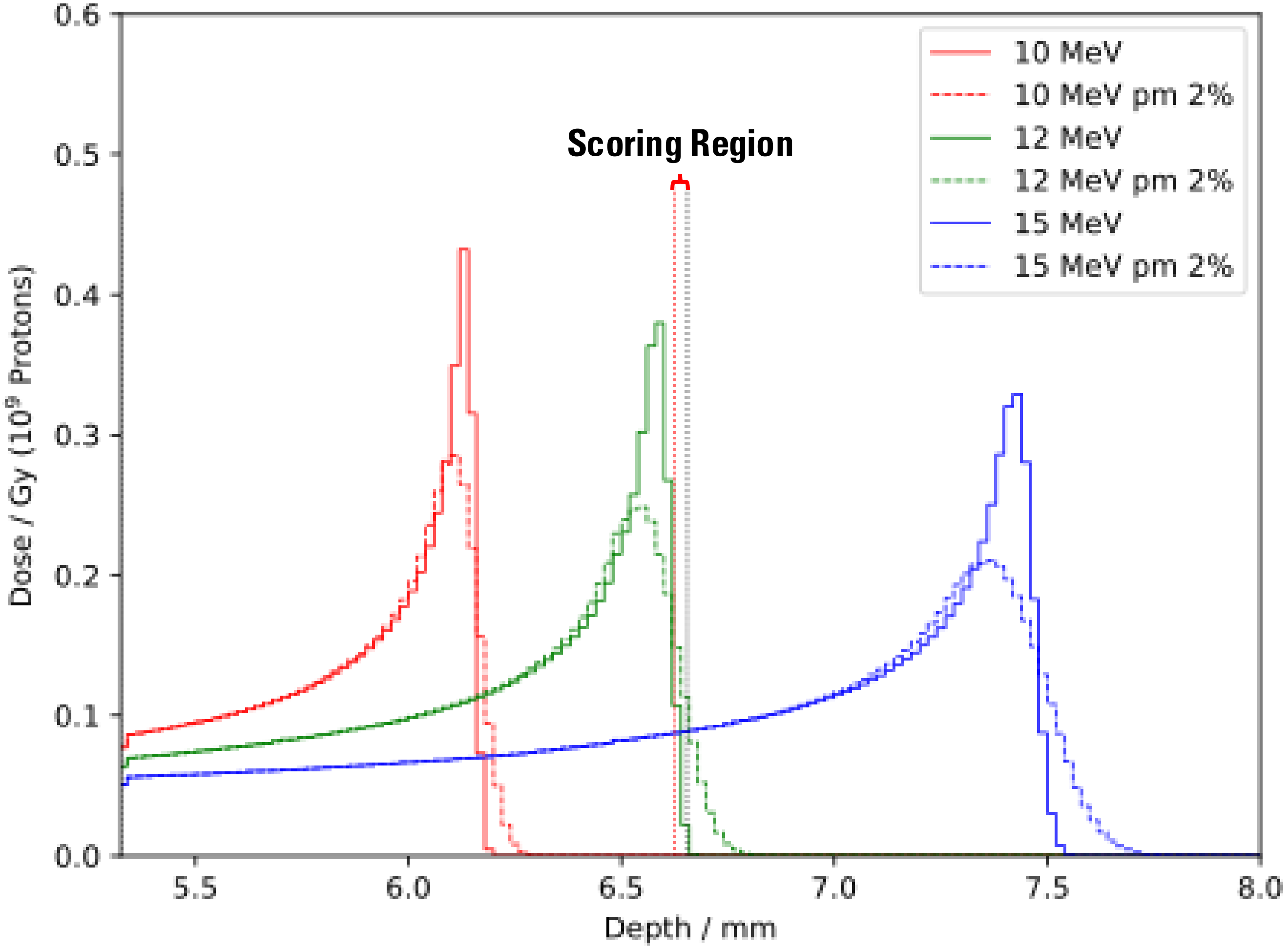
- Scoring mesh within the water volume, flush to the surface with a 2 mm length in z.
- Radius of 2.65 mm to imitate a Markus Ion Chamber.
- Dose per proton scaled by 10^{10} to represent dose of 10^{9} protons at a 10 Hz repetition rate.



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

Dose Modelling with Energy Spread

Bragg Peak Comparison and Dose Rate calculation



Bragg peaks still fall where expected:

- 10 MeV well before the cell layer
- 12 Mev just before the cell layer
- 15 MeV well beyond the cell layer

Energy Spread

- Broadens all Bragg peaks
- For 15 MeV, introducing energy spread has little effect as the region of the curve seen by the scoring mesh has little difference.
- Larger impact on 12 MeV dose as the high energy particles deposit more within the scoring region

Beam Energy [MeV]	Dose Rate [Gy / s]
12	0.96 ± 0.05
12 ± 2%	7.09 ± 0.20
15	121.93 ± 1.42
15 ± 2%	123.69 ± 1.43

Summary

Beam Profile

- Energy spread introduces energy dependent focusing that is stronger as beam size decreases.
- The factors changing the transverse profile must be better understood before further octupole studies.
- Additionally, primary beam profile expected to change further with the introduction of PMQs before the nozzle.

End Station Dose Modelling

- Introducing energy spread has a small effect on the 15 MeV beam but has now been included in calculation of the reference theoretical maximum dose rate.

Beam Energy [MeV]	Dose Rate [Gy / s]
15	121.93 ± 1.42
15 ± 2%	123.69 ± 1.43

Thank You

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