WP1.6: Design & Integration: Stage 1 Design

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LhARA Collaboration Meeting #4

20th September 2023

ROYAL HOLLOWAY UNIVERSITY OF LONDON

BDSIM

LhARA Laser-hybrid Accelerator for Radiobiological Applications

JAI John Adams Institute for Accelerator Science

Outline

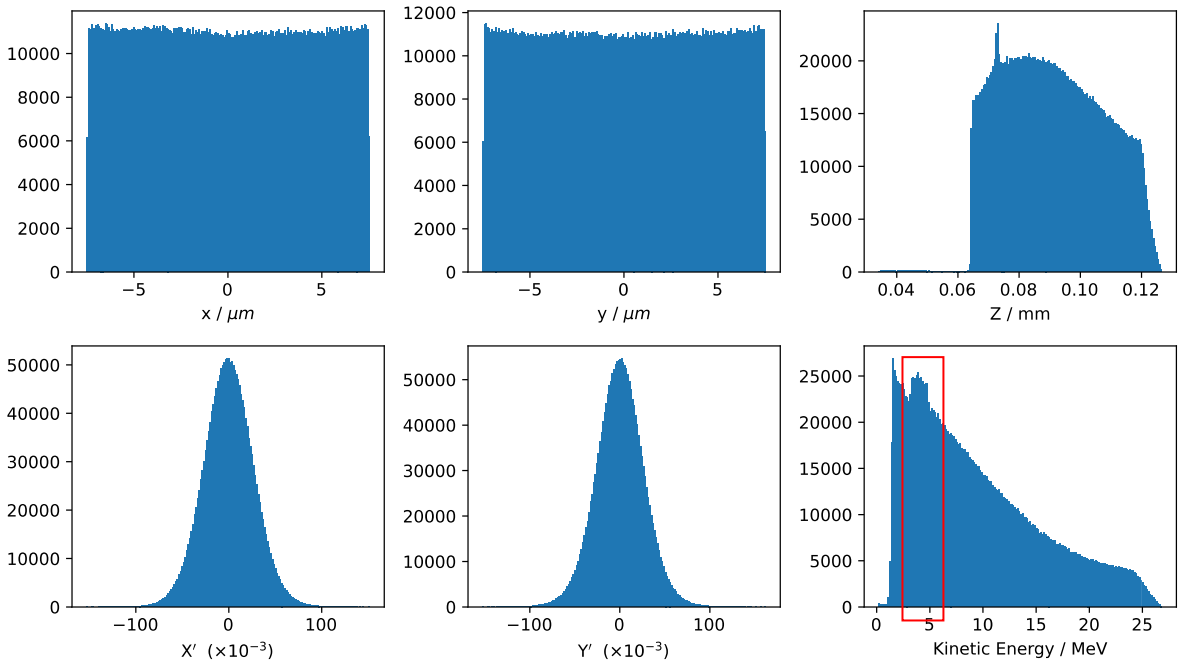
- Beam and baseline design performance review
- 7 Gabor lens configuration
- Optimised optics & spot size flexibility
- Beam uniformity
- Dose delivery validation

Re-simulated Beam Parameters

	Pre-CDR Beam	Smilei Sampled Beam	SCAPA Beam (6 month report)	SCAPA Beam (updated)
Mean RMS emittance [m]	3.26×10^{-7}	1.43×10^{-8}	7.98×10^{-8}	**8.25×10^{-8}**
Mean beta [m]	4.89	141.34	21.62	**20.24**
Mean alpha	-50.22	-1418.43	-222.23	**-204.99**

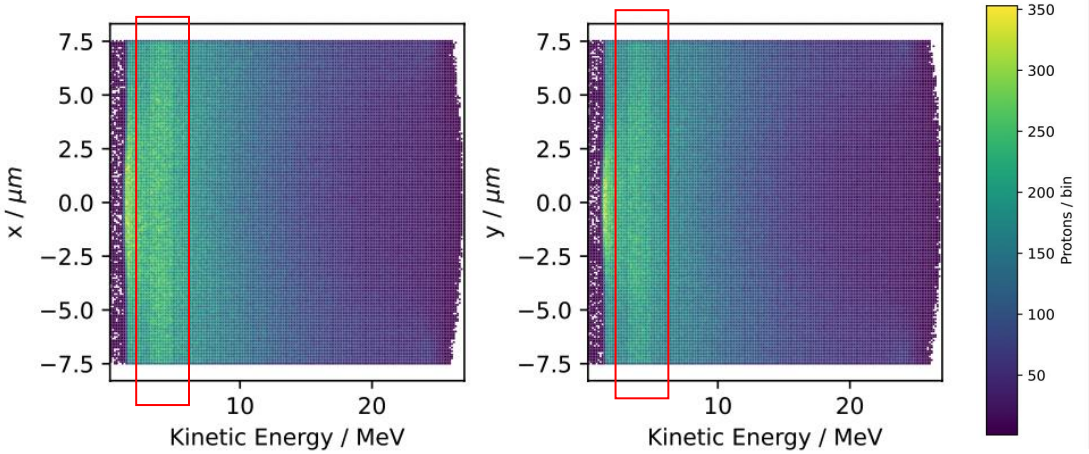
- GPT simulation artefact discovered, artificial emittance growth
- Target housing beam transport remodelled
- Beam transport simulation drafted into technical note.

SCAPA Beam: Full Spectrum



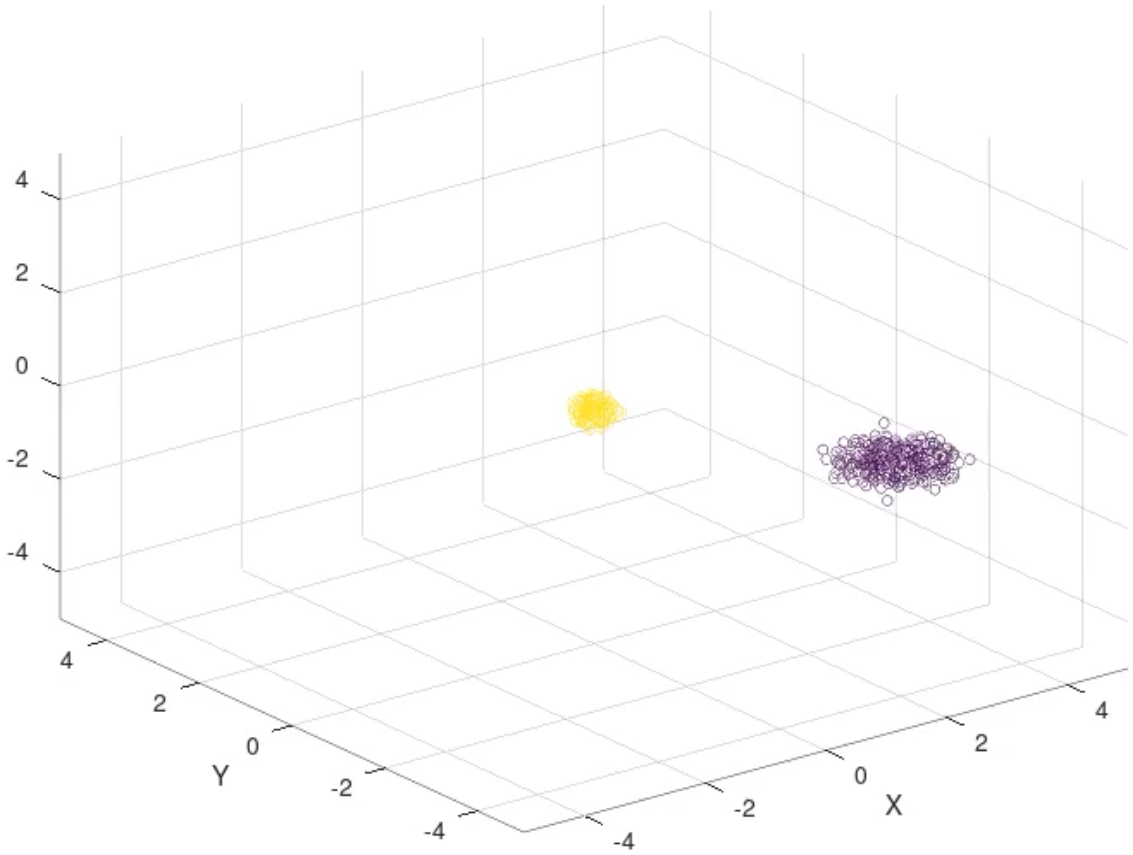
- 15 MeV ± 100 % beam
- Excess at ~ 4 MeV

- Constant bandwidth across transverse spatial distribution
  - Suspected simulation artefact
- Negligible impact on 15 MeV ± 2% region

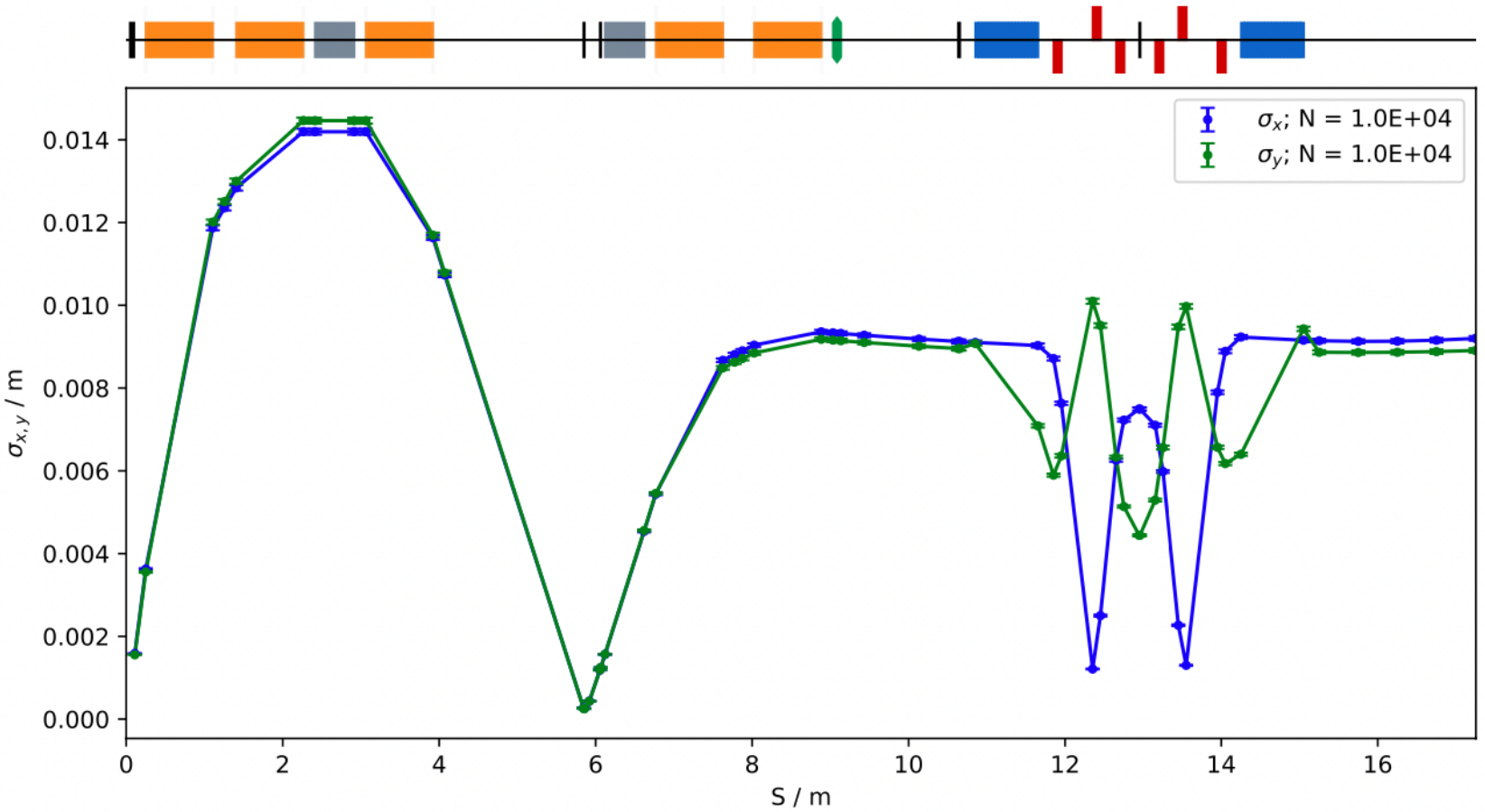


Co-propagating Beam Modelling

- RF-Track: modelling composite beams with space charge forces
- RF track example: 1000 protons & 1000 electrons (all macroparticles)
- Aim: model LhARA proton & electron co-propagation in the target housing
- <u>Simulated electron data needed</u>



Baseline Design Performance



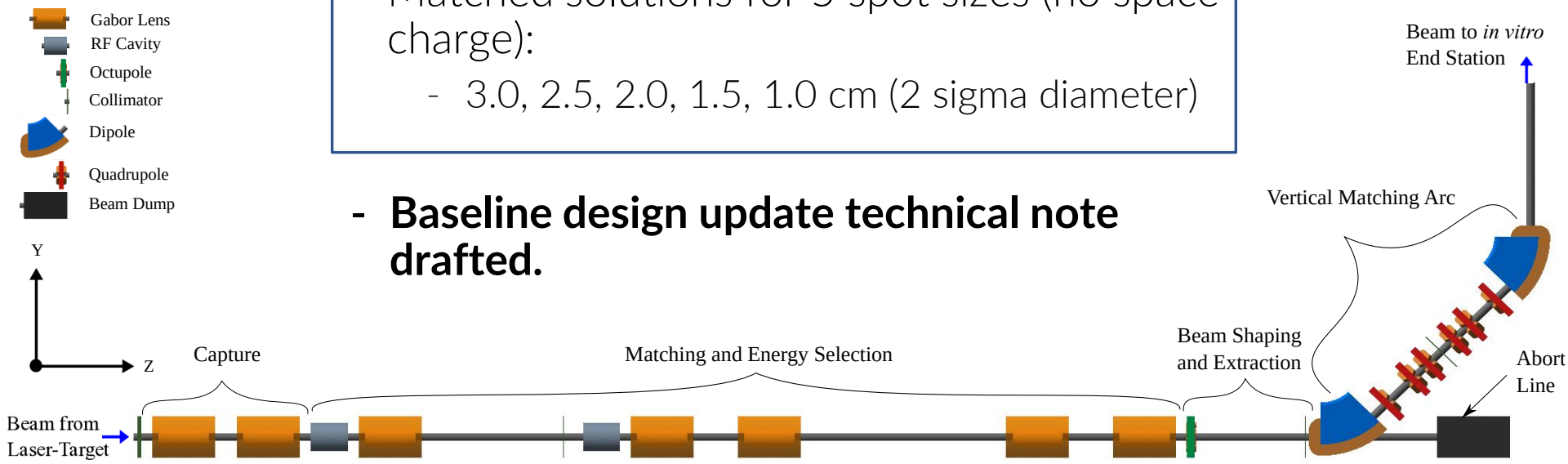
- Optimised solutions for 3.6 cm and 3.2 cm beam. Smaller beams challenging.
- No solutions for FFA injection line conditions.

7 Gabor Lens Configuration

- Investigation of 7 Gabor lens / solenoids configuration
- Single energy collimator
- Geometry modifications:
  - Extra 0.2m between GL4 & GL5
  - 2.5m long drift after GL5
  - GL6 & GL7 added in same configuration as GL4 & GL5

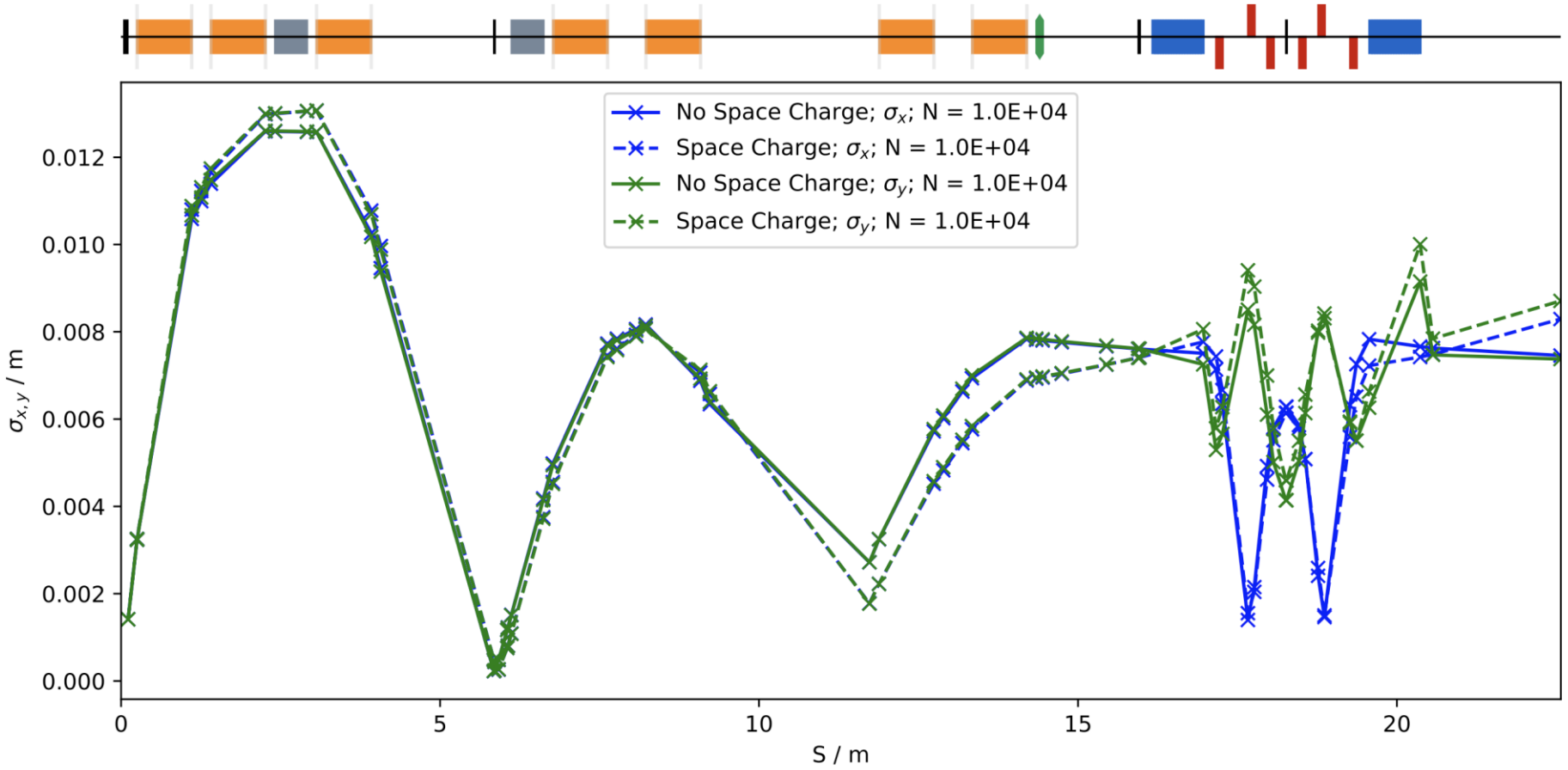
- Matched solutions for 5 spot sizes (no space charge):
  - 3.0, 2.5, 2.0, 1.5, 1.0 cm (2 sigma diameter)

- **Baseline design update technical note drafted.**

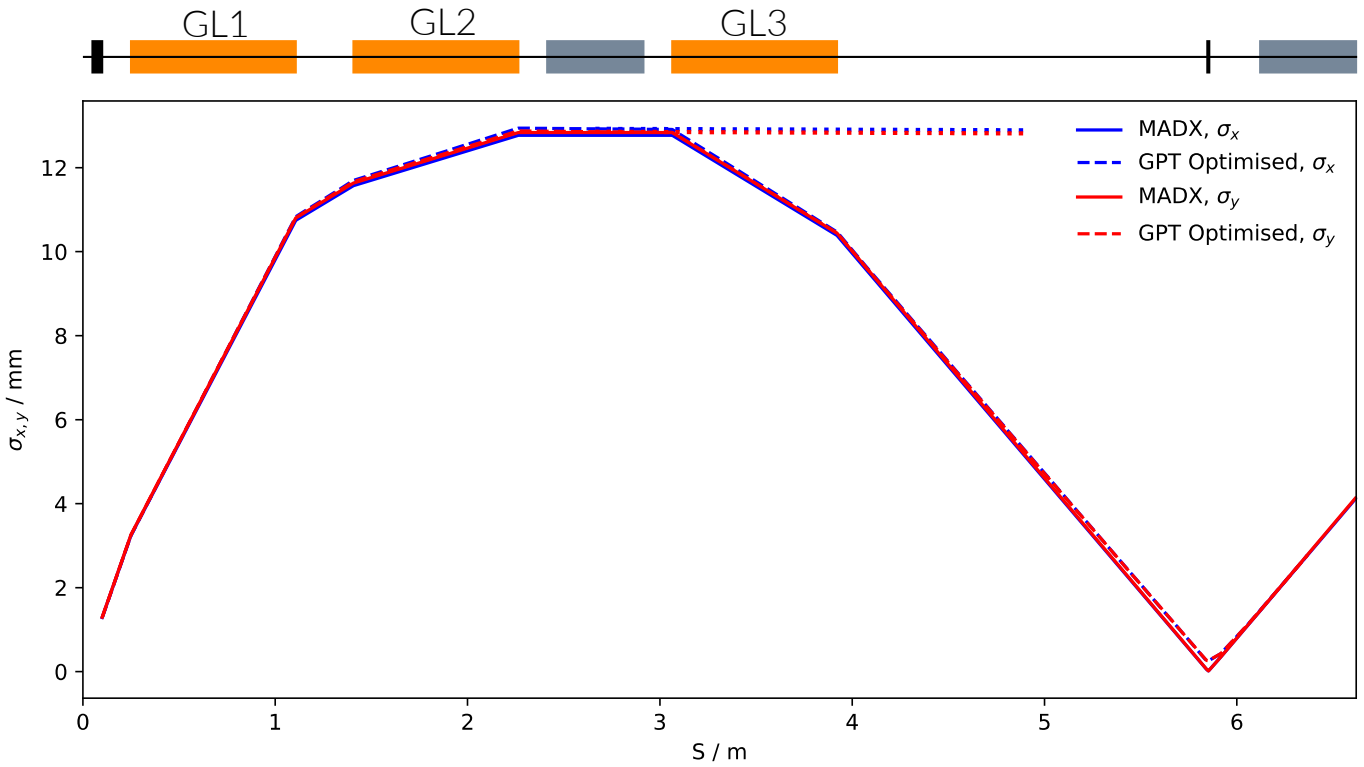


Model Validation & Performance

- Space charge impacting performance



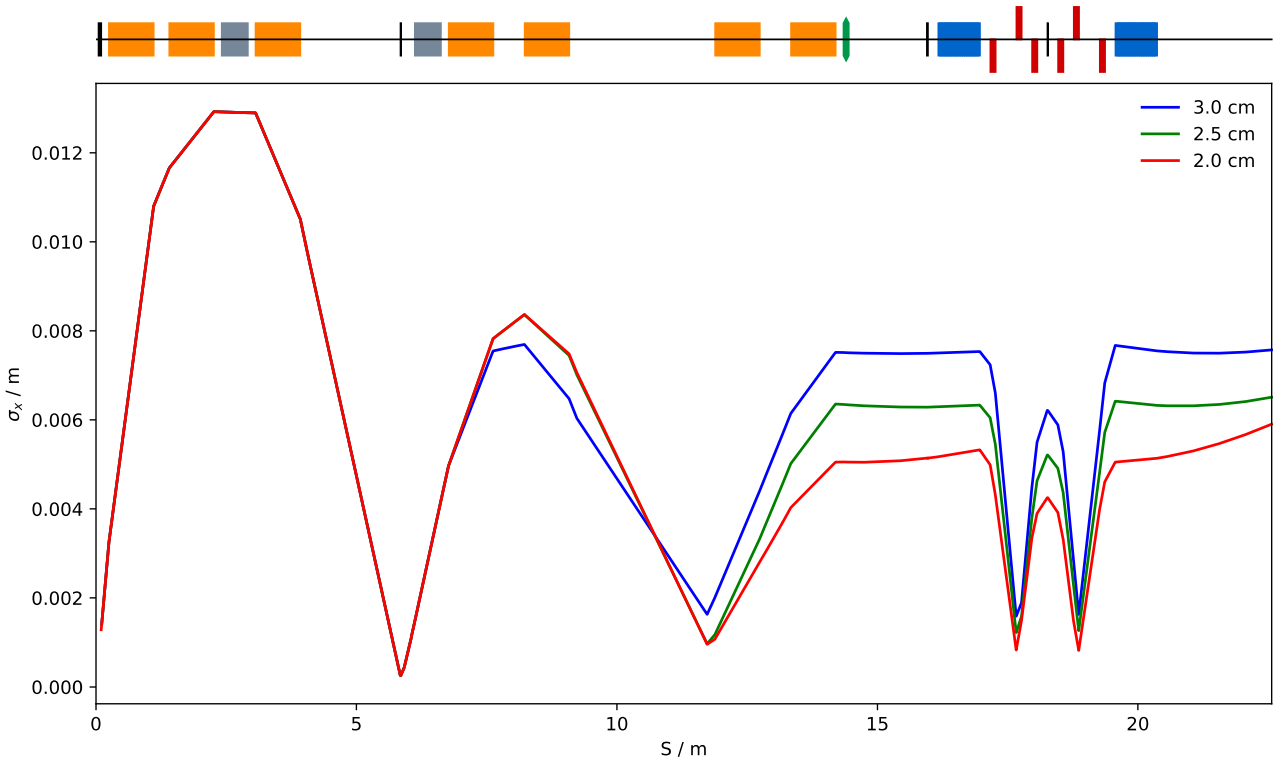
Capture Section Optimisation



- Machine length flexibility between GL2 & GL3 achieved
  - ~ 2.5 m

	Original		Optimized	
	KS	B [T]	KS	B [T]
Gabor Lens 1	2.491764	1.4	2.491764	1.4
Gabor Lens 2	1.018776	0.572400	1.045545	0.587440
Gabor Lens 3	1.448605	0.813900	1.449852	0.814601

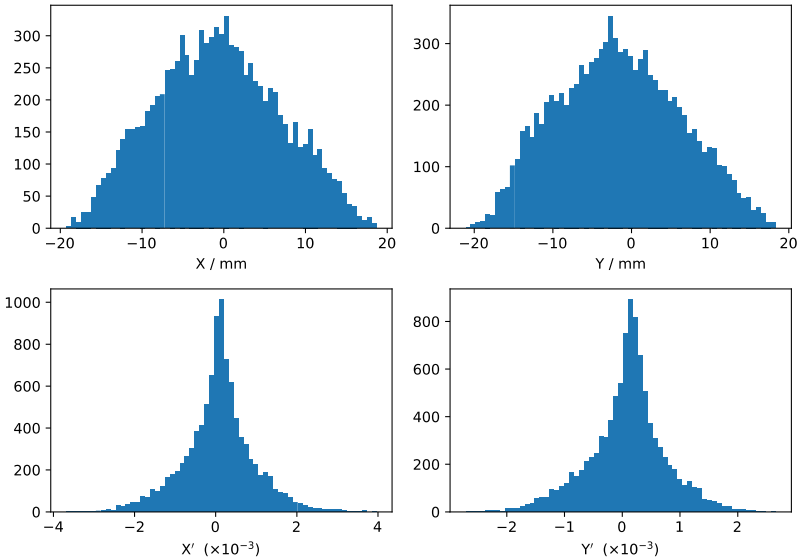
Spot-size Optimisation

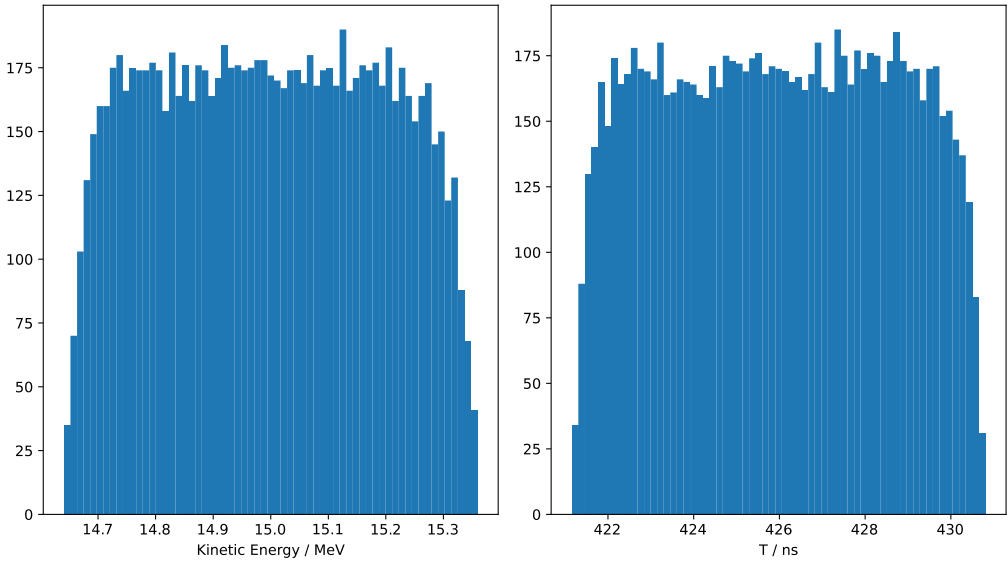


- Optimised solutions found for 3.0, 2.5, and 2.0 cm spot sizes
- Trending to divergent beam, focus after GL7.

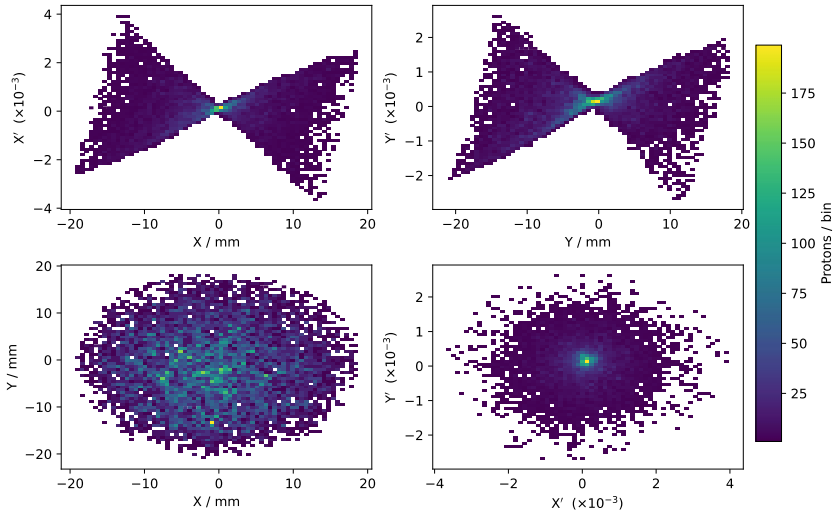
Spot Size [cm]	Solenoid Equivalent Field [T]			
	Gabor Lens 4	Gabor Lens 5	Gabor Lens 6	Gabor Lens 7
3.0	1.072940	0.807211	0.001191	0.787153
2.5	0.996313	0.832585	0.000871	0.858701
2.0	0.995976	0.823955	0.749300	0.836557

Optimised Optics: Beam Profile

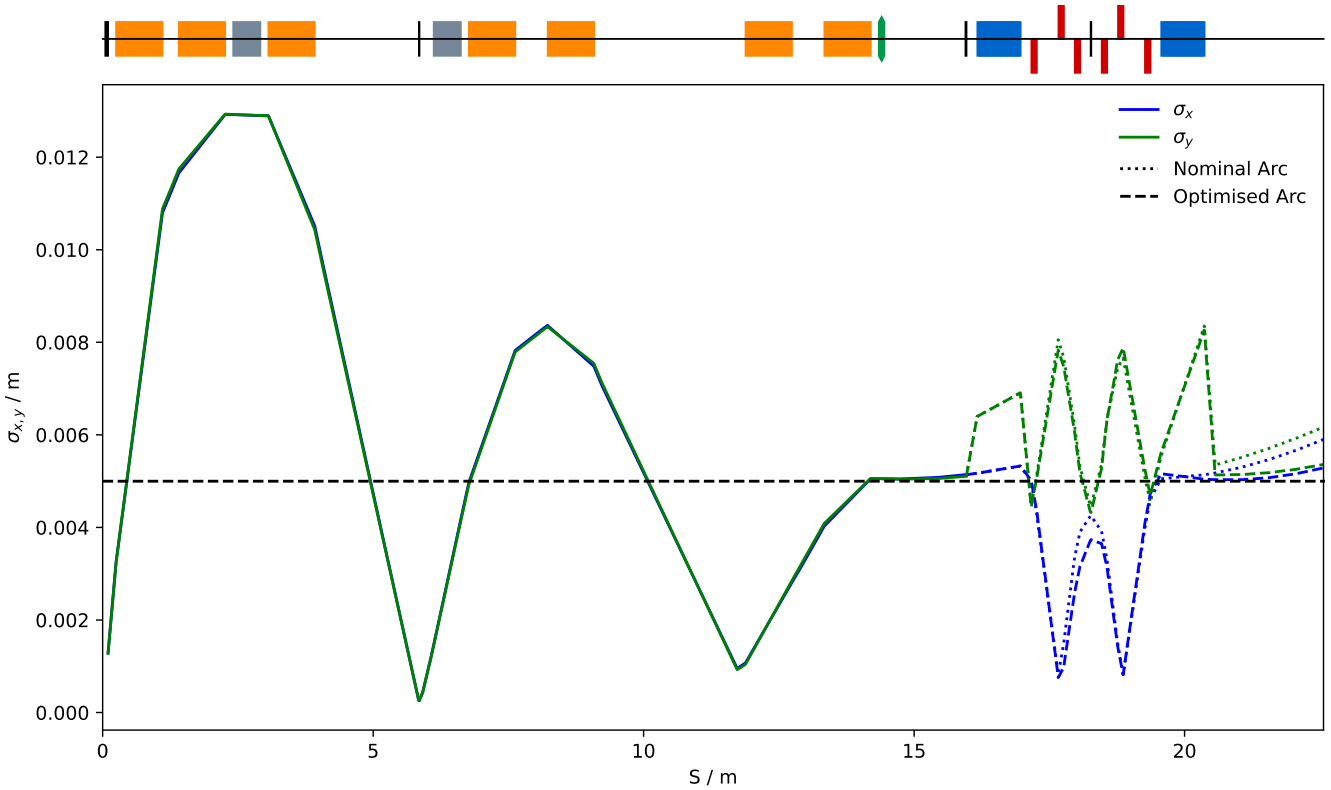




- Similar end station profile and phase space to pre-CDR beam.



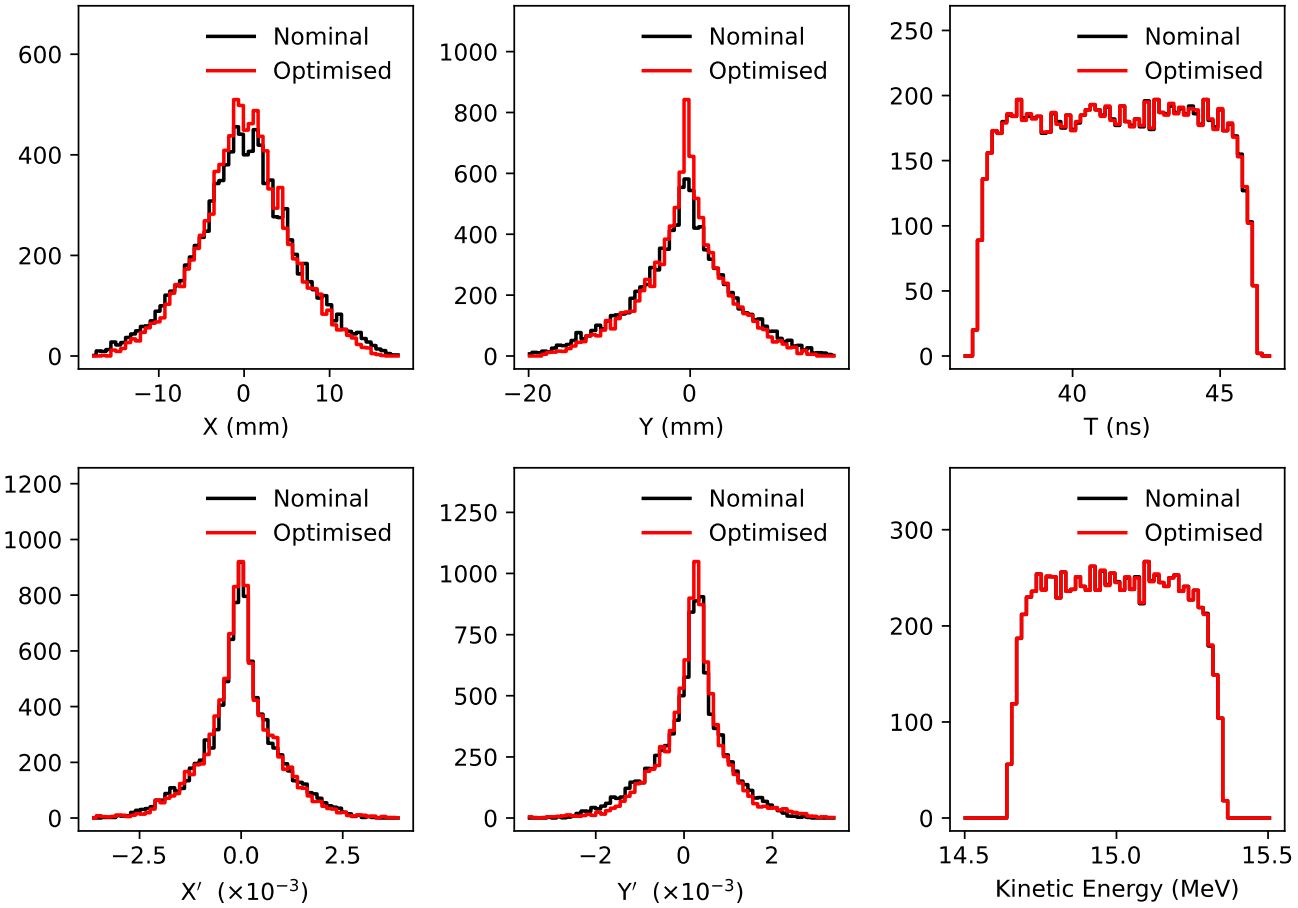
2.0cm Spot Size: Arc Optimisation



- Arc quadrupoles varied, improved solution for 2.0 cm spot size beam.
  - Quad gradient constrained to ± 22.4 T/m (pole tip field = 0.82 T, 3.65cm radius)

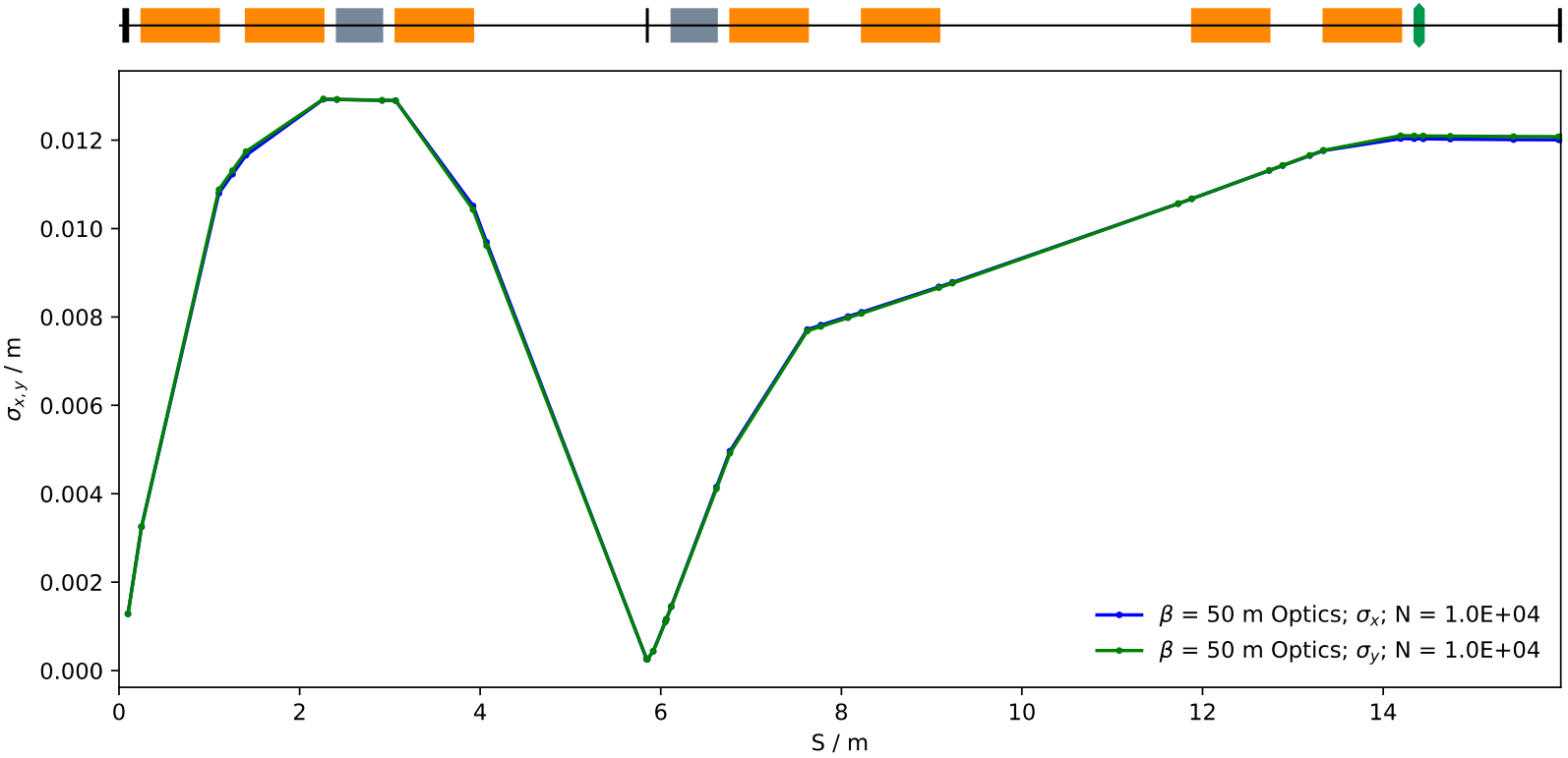
- Solutions for smaller spot sizes remains challenging.

2.0cm Spot Size: Beam Profile



- No major impact on end station beam profile.

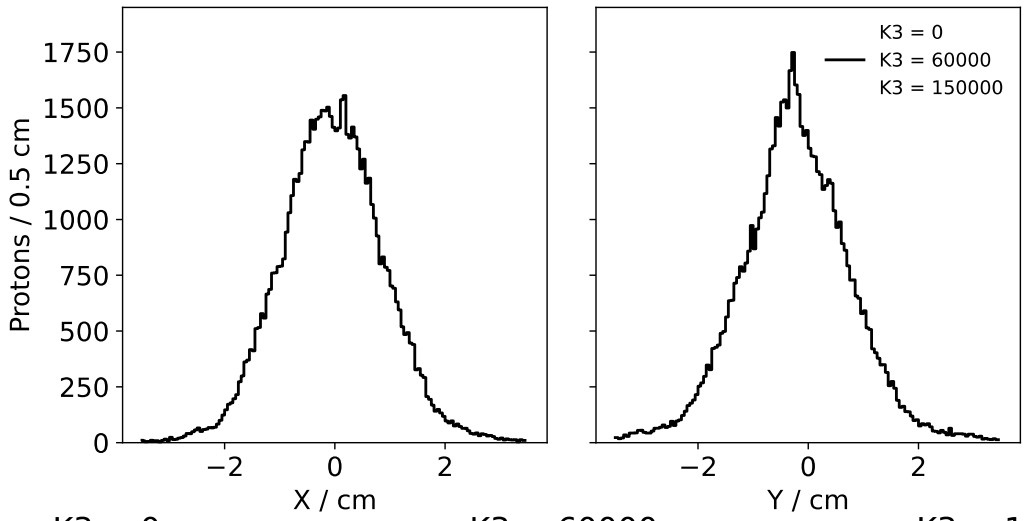
Matched Solution for FFA Injection Line



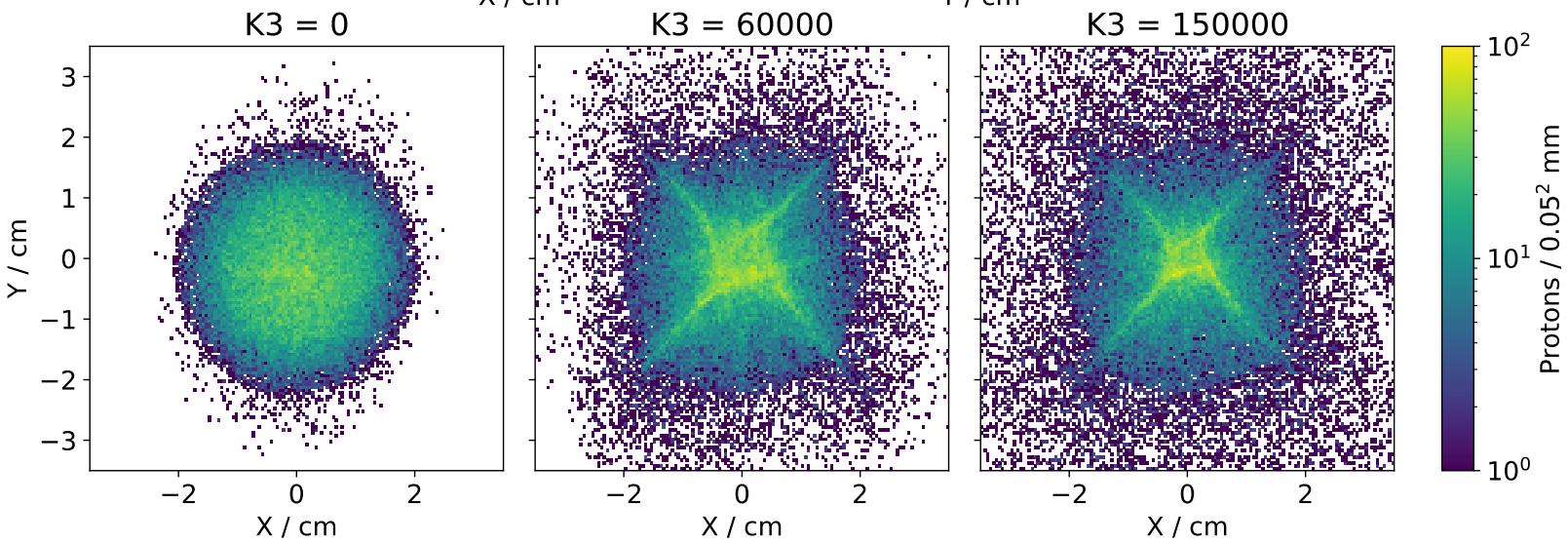
	Optimized Solenoid Strength	
	KS	B [T]
Gabor Lens 4	1.82756	1.02682
Gabor Lens 7	0. 55688	0.31288

Beam Parameter	Value
Mean RMS Emittance [m rad]	2.959 x 10^{-6}
Mean Beta [m]	**49.92**
Mean Alpha	0. 075

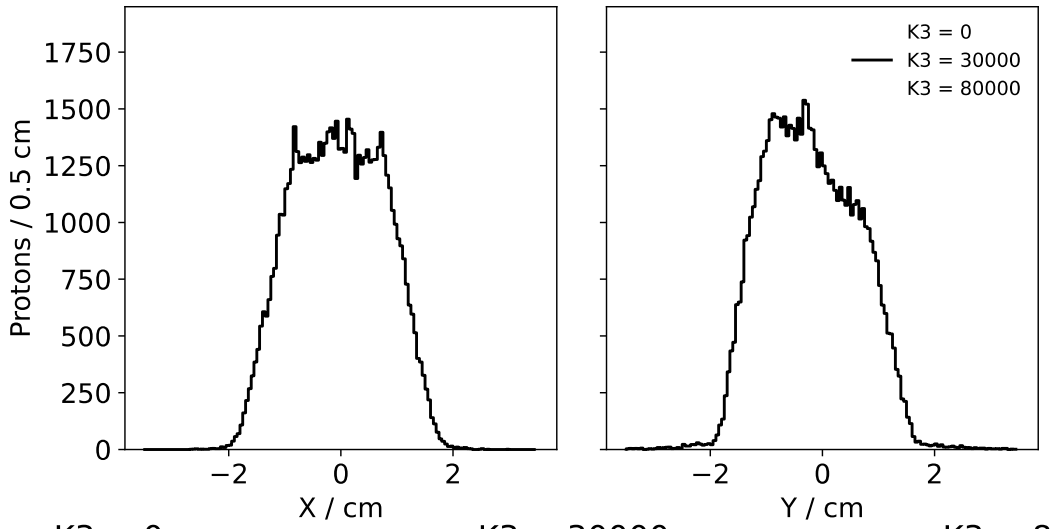
Preliminary Octupole Simulations



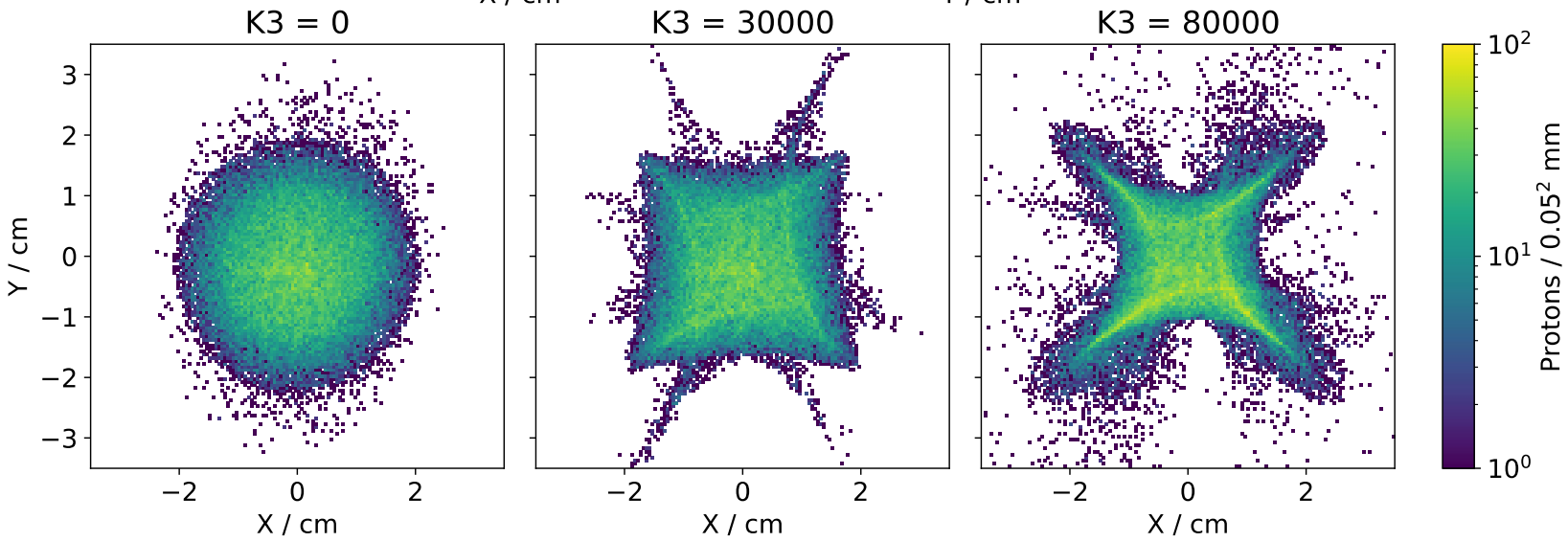
- No octupole strength found producing sufficient uniformity over the spot size area.
- Arbitrary K3 values shown.



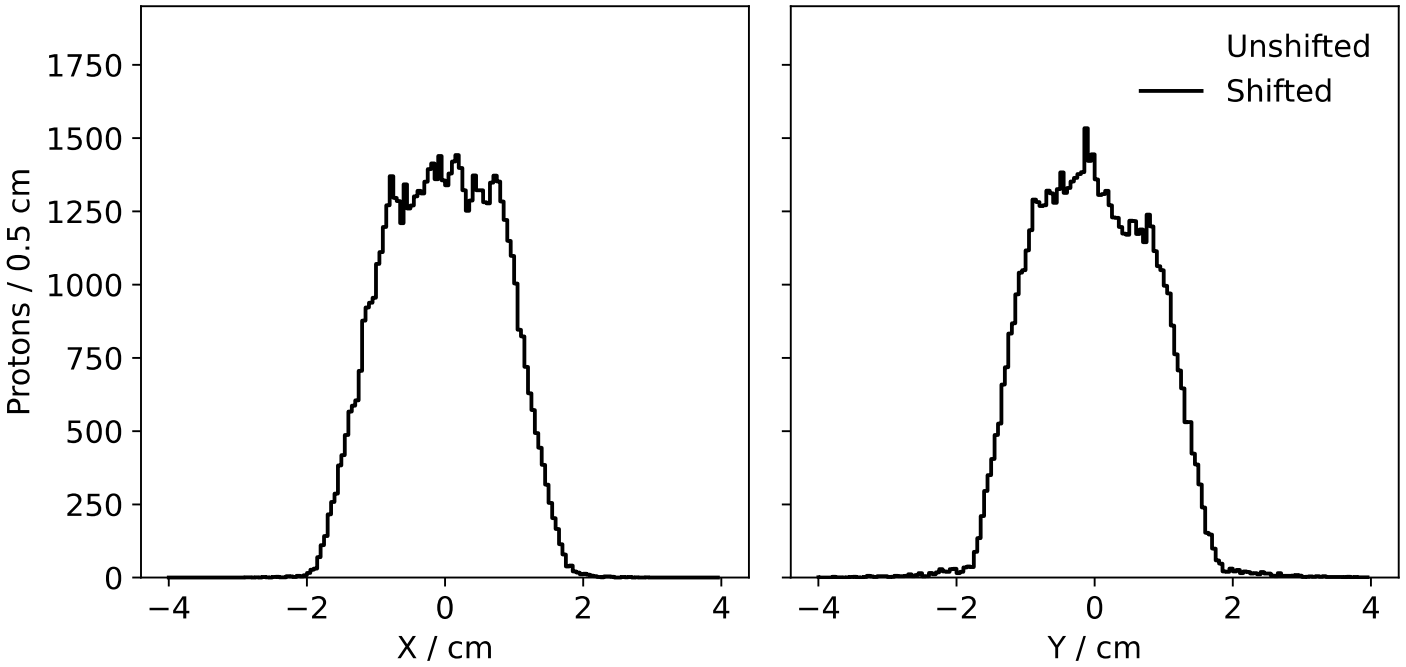
Repositioned Octupole: Arc End



- Moving the octupole to the end of the vertical arc improves uniformity significantly.
- Octupole strength to be optimised.



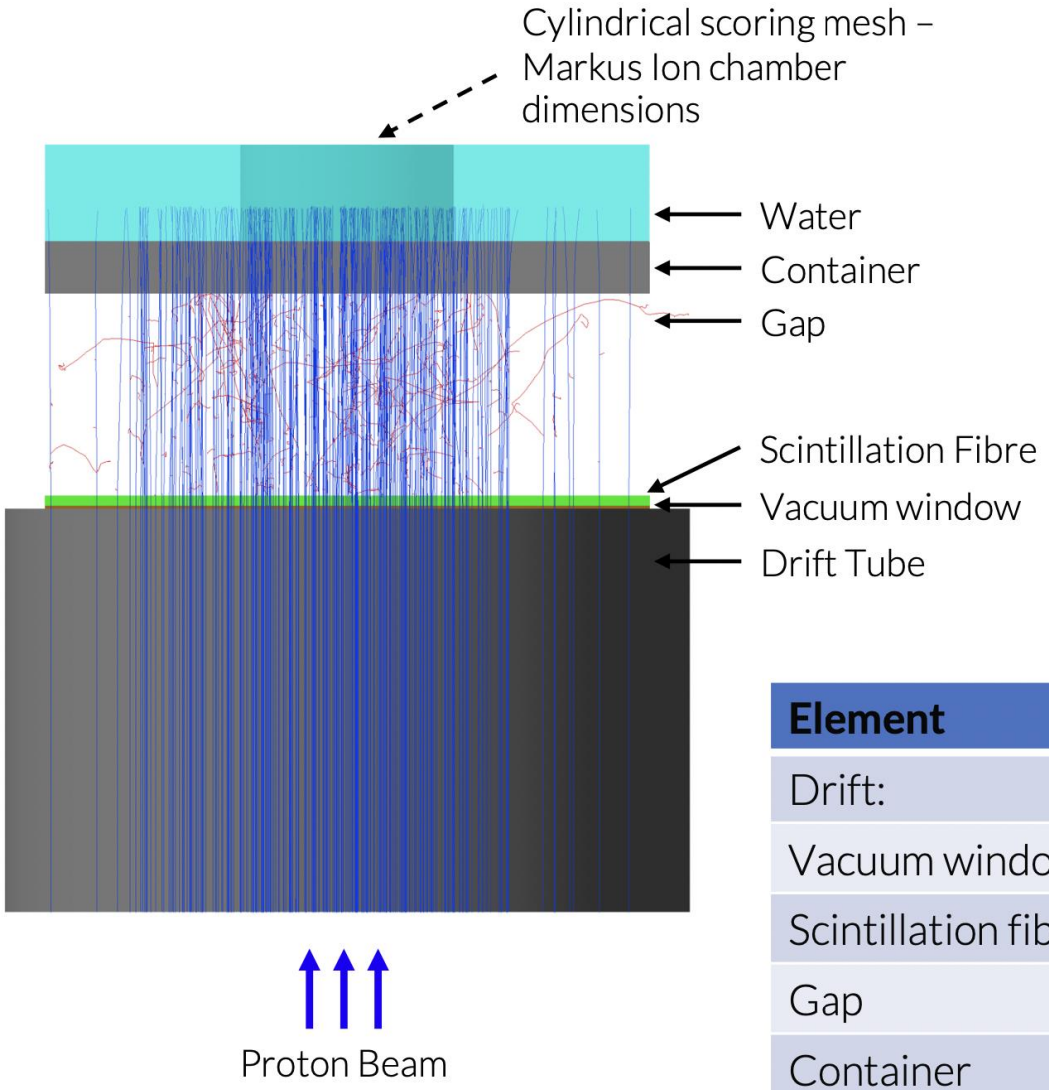
Octupole Position Sensitivity



- Artificial shift of mean vertical position entering the arc improved uniformity asymmetry.

- Uniformity sensitive to beam position – correctors likely needed

Dose Rate Check: End Station Model



- No cell layer
- **1.0 cm spot size beam**
  - Gaussian
  - 2.5mm sigma
- 15 MeV mono-energetic
- PhysicsList : "g4QGSP_BIC_EMZ" [1]
- Markus Ion Chamber (cylinder):
  - 2.65 mm radius
  - 2.00 mm length

Element	Material	Length (m)
Drift:	Vacuum	0.01
Vacuum window	Mylar	75e-6
Scintillation fibre	Polystyrene	250e-6
Gap	Air	5e-3
Container	Polystyrene	1.3e-3
Water Block	Water	2.4e-3

1. Geant4 medical physics list recommendations: https://doi.org/10.1002/mp.14226

End Station Dose Rate

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End Station Dose

Dose per proton (event)
  Scored Dose in GeV    : 3.362E-03 +/- 3.908E-05
  Calculated Dose in GeV: 3.361E-03 +/- 2.090E-05
  Calculated Dose in J  : 5.386E-13 +/- 3.348E-15
  Calculated Dose in Gy : 1.221E-08 +/- 7.588E-11
  Scored Dose in Gy     : 1.221E-08 +/- 1.419E-10


Dose scaled to 10⁹ protons per bunch
  Scored Dose in GeV    : 3.362E+06 +/- 3.908E+04
  Calculated Dose in GeV: 3.361E+06 +/- 2.090E+04
  Calculated Dose in J  : 5.386E-04 +/- 3.348E-06
  Calculated Dose in Gy : 1.221E+01 +/- 7.588E-02
  Scored Dose in Gy     : 1.221E+01 +/- 1.419E-01
```

- Dose re-simulated to be **12.21 ± 0.14 Gy / shot**
- Instantaneous dose rate: 1.7×10^9 Gy/s
  - Based on pre-CDR bunch length of 7.0 ns
- Average dose rate: **122.1 ± 1.4 Gy/s**

Summary

- Demonstrated flexibility of 7 Gabor lens configuration
- Optimised solutions for spot sizes & FFA injection line
- Re-established octupole feasibility
- Validated end station dose calculations

Thank you

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