Stage 1 Lattice: Baseline Change Request

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LhARA Fortnightly Meeting

07th November 2023

ROYAL HOLLOWAY UNIVERSITY OF LONDON

BDSIM

LhARA Laser-hybrid Accelerator for Radiobiological Applications

JAI John Adams Institute for Accelerator Science

Outline

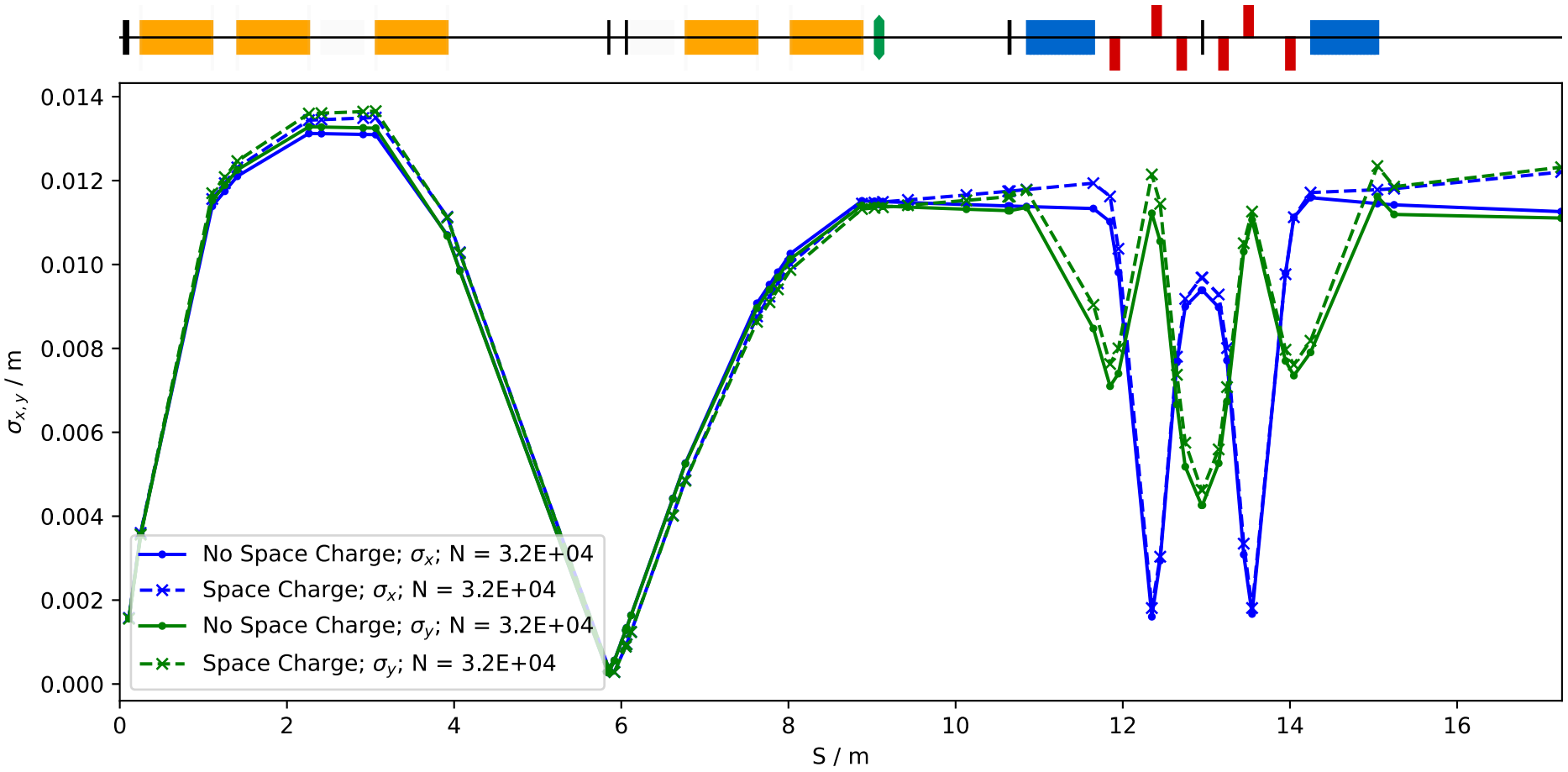
- Baseline design review

- Proposed 7 Gabor lens configuration

- Performance review

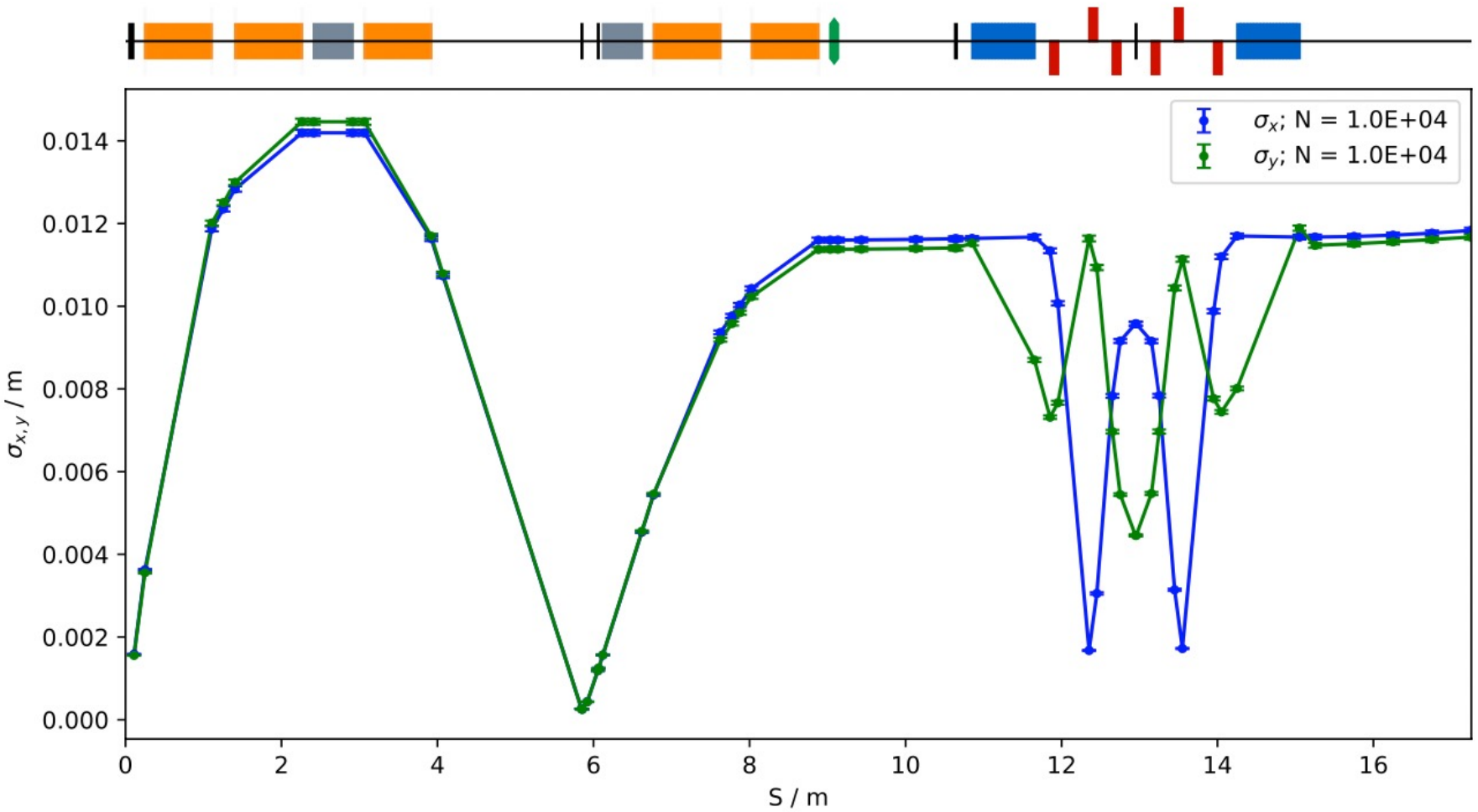
- Optimised optics & spot size flexibility

Baseline design: Nominal Optics



- Sampled beam generated from Smilei
- Optimisation would be required
  - Non-parallel beam between GL2 & GL3, flexibility needed to accommodate RF, shielding wall, etc.

Baseline design: Optimised Performance



- Optimised solutions found for some beam sizes (1σ radius)
- Smaller beam sizes remain a challenge

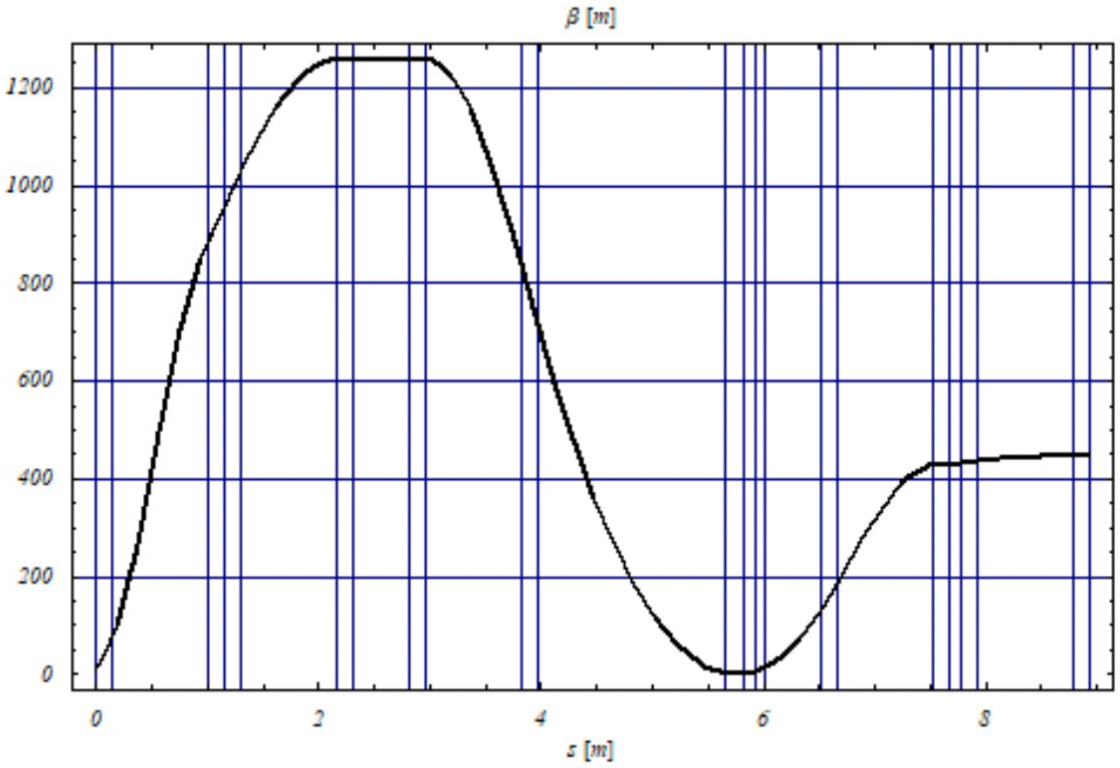
Updated Beam Parameters

- Beam at nozzle exit:

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

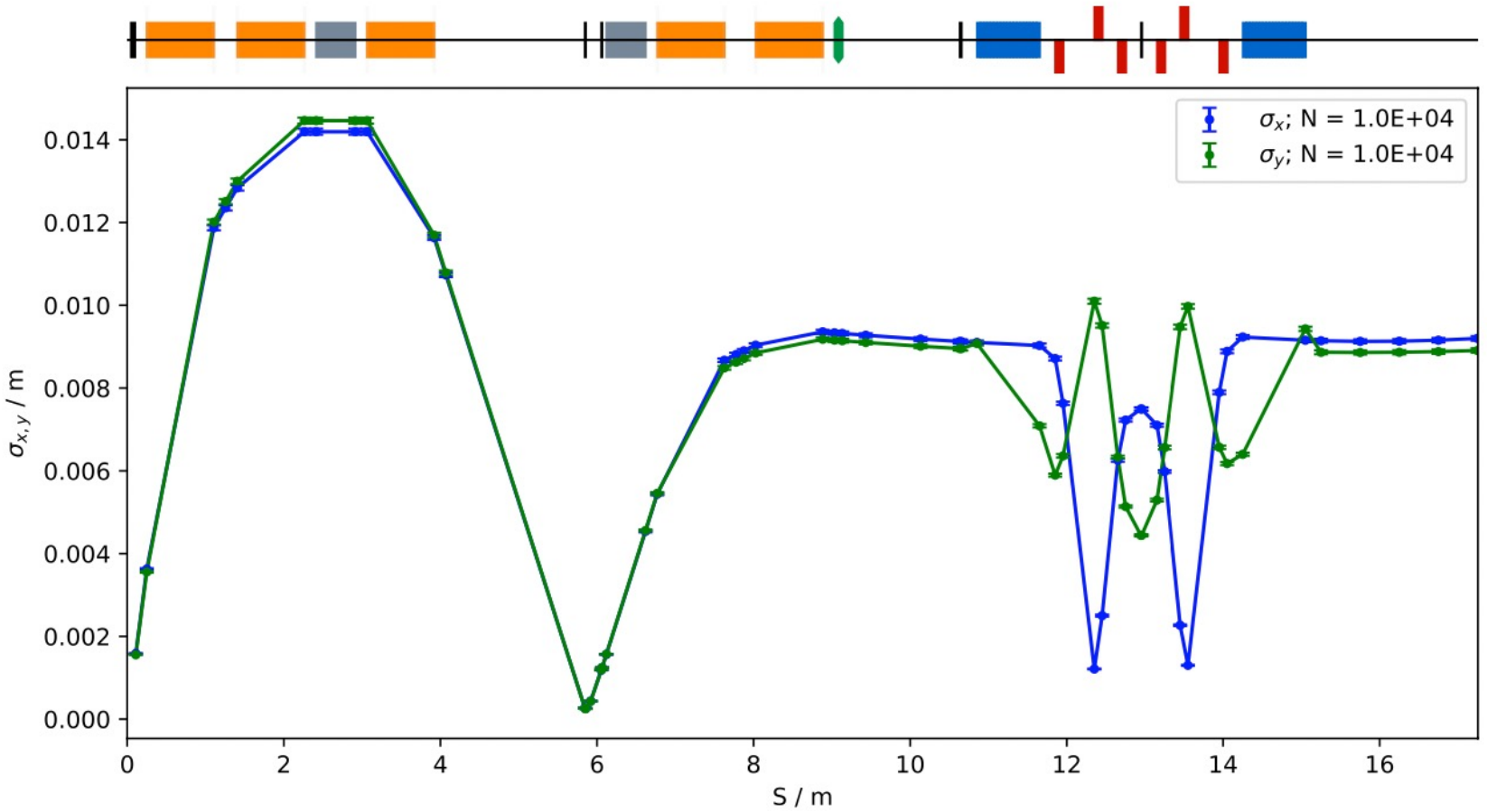
- Smilei simulations unreliable
  - Not full 3D
- 3D PIC simulations in OSIRIS of SCAPA setup
  - Closer to pre-CDR beam

Nominal Performance



- 1σ radius of 0.61 cm can be produced
  - 2σ diameter = 2.4 cm
- Issues with obtaining smaller final beam size
- Issues with matching to the Stage 2

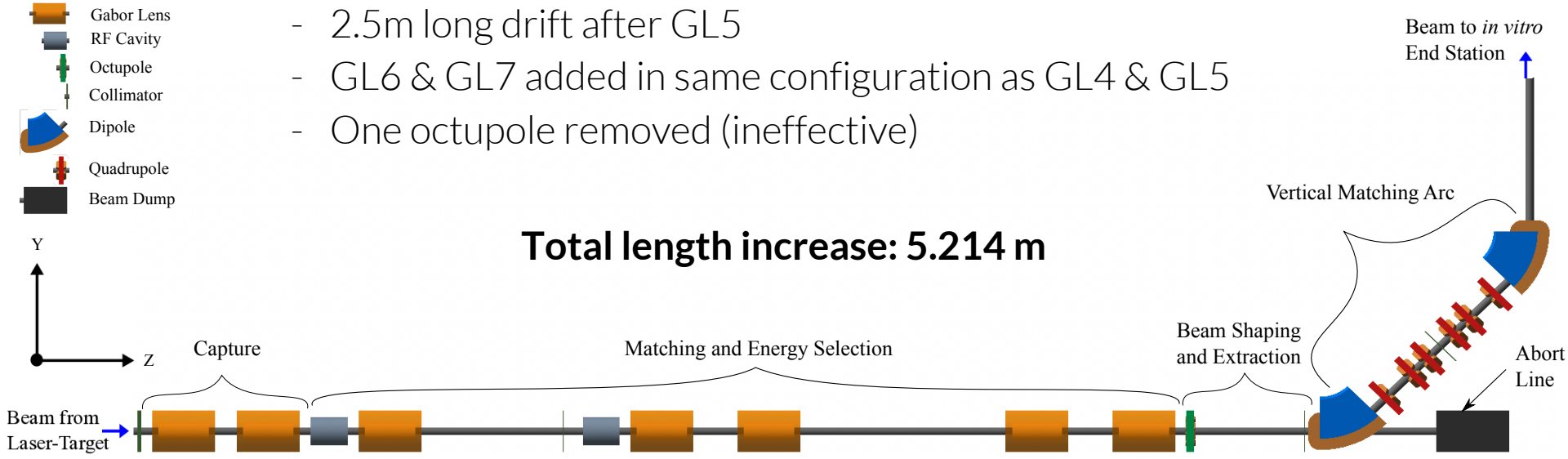
Baseline Design Performance



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

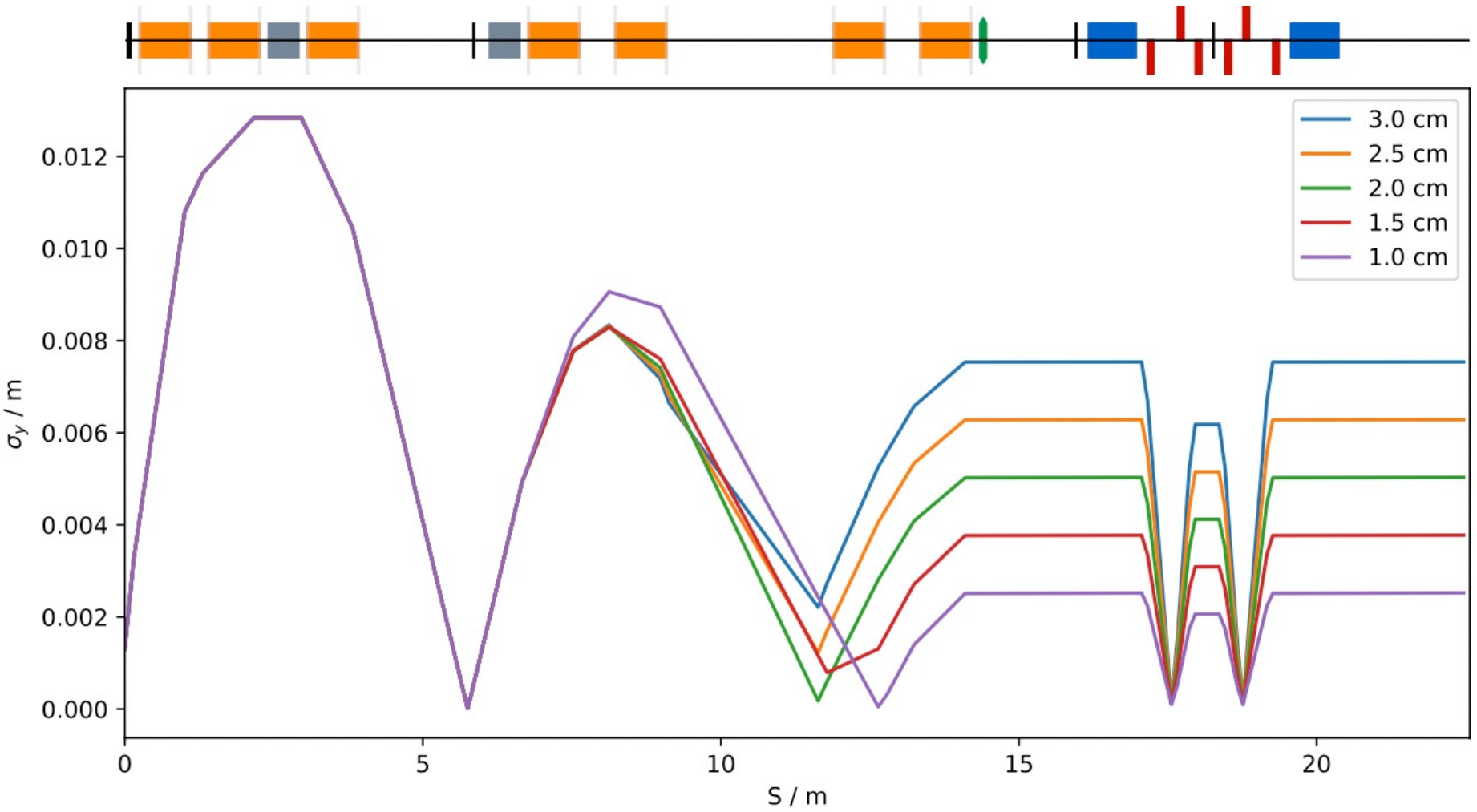
7 Gabor Lens Configuration

- Proposed new configuration using 7 Gabor lens / solenoids
- Matched solutions for 5 spot sizes & FFA injection (no space charge):
  - 3.0, 2.5, 2.0, 1.5, 1.0 cm (2 σ diameter)
- Single energy collimator
  - Second in 5 lens baseline design for stage 2 operation
    - Geometry modifications:
      - Extra 0.2m between GL4 & GL5
      - 2.5m long drift after GL5
      - GL6 & GL7 added in same configuration as GL4 & GL5
      - One octupole removed (ineffective)

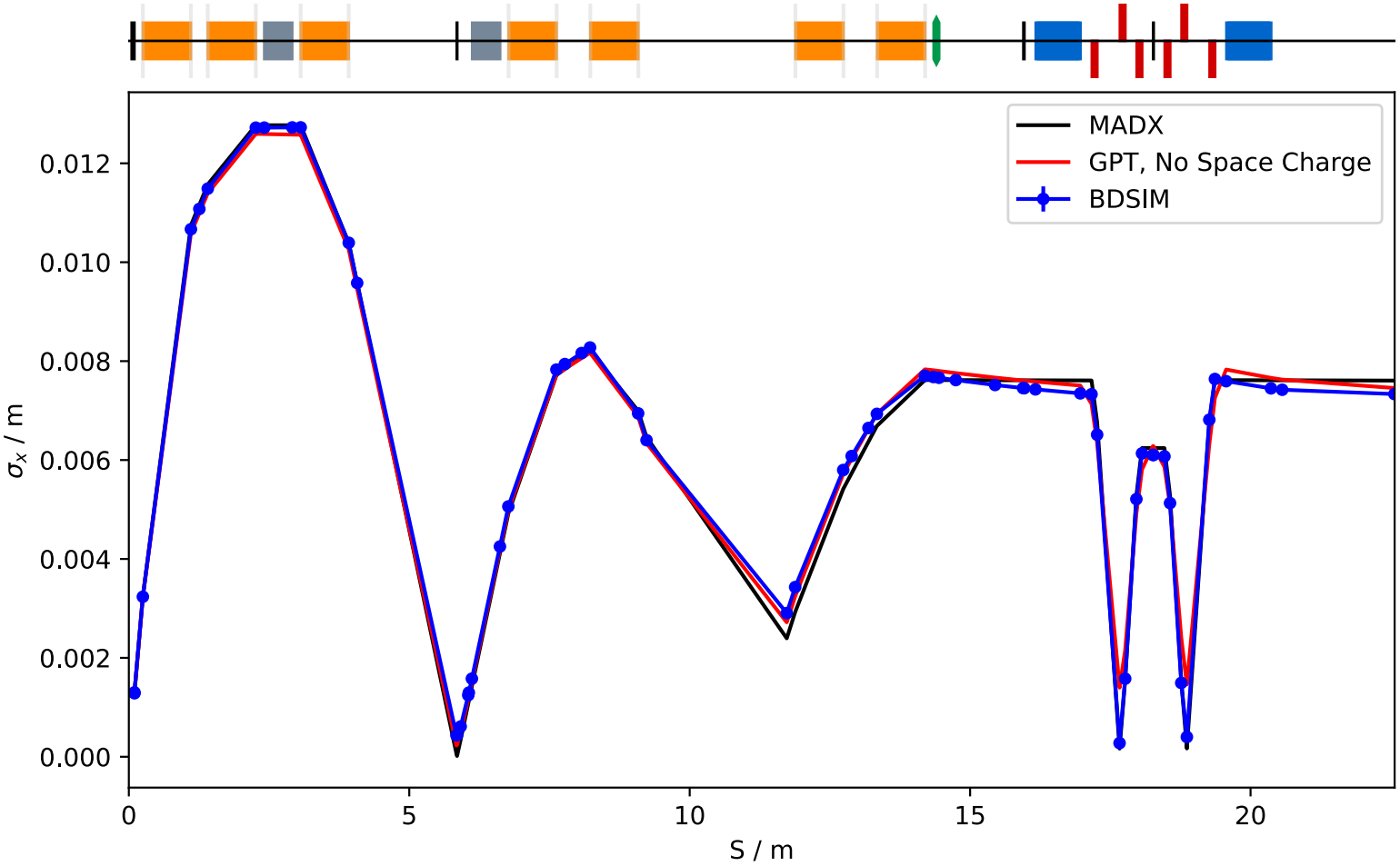


Total length increase: 5.214 m

Nominal Optics



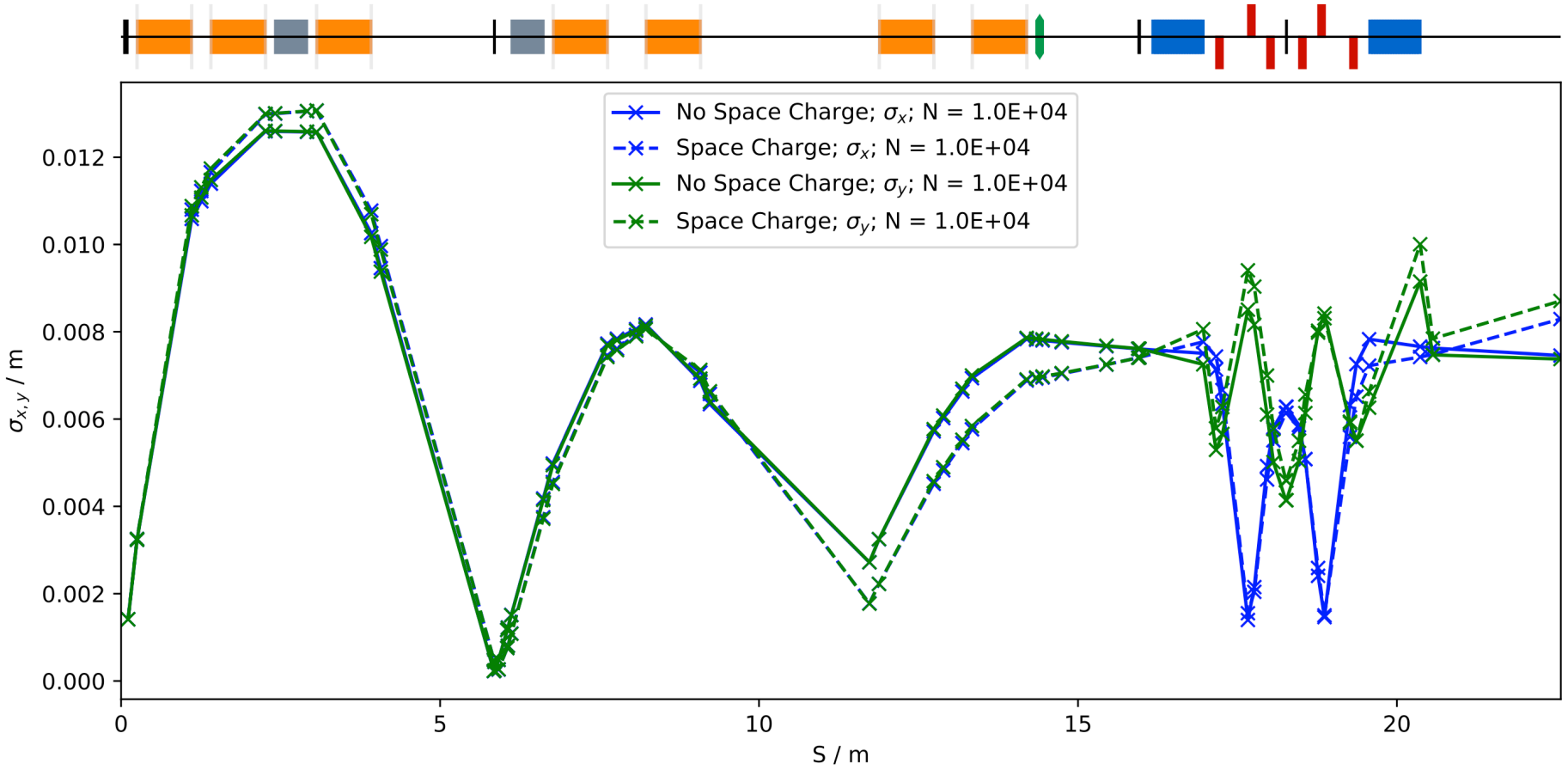
Model Validation



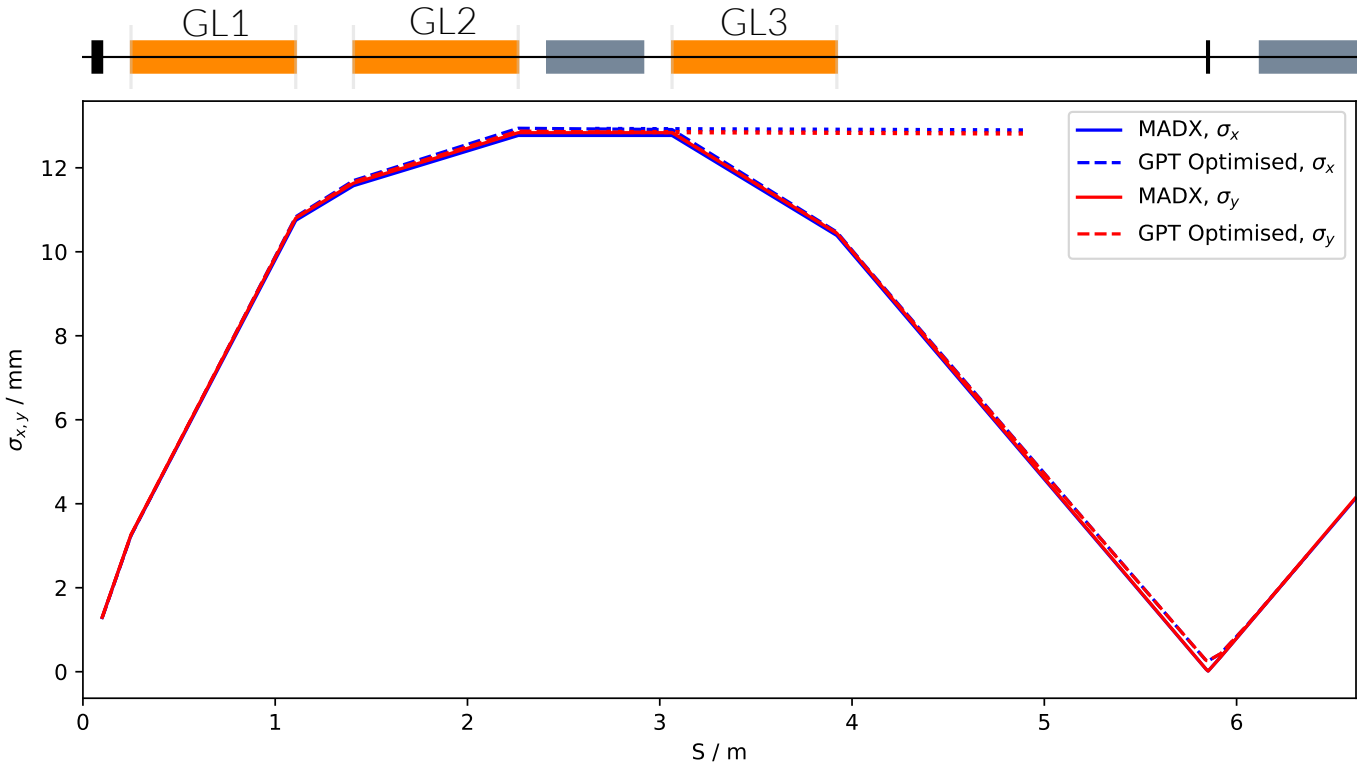
- Good agreement between MADX, BDSIM, and GPT models (no space charge)

Model Performance: Space Charge

- Space charge impacts performance



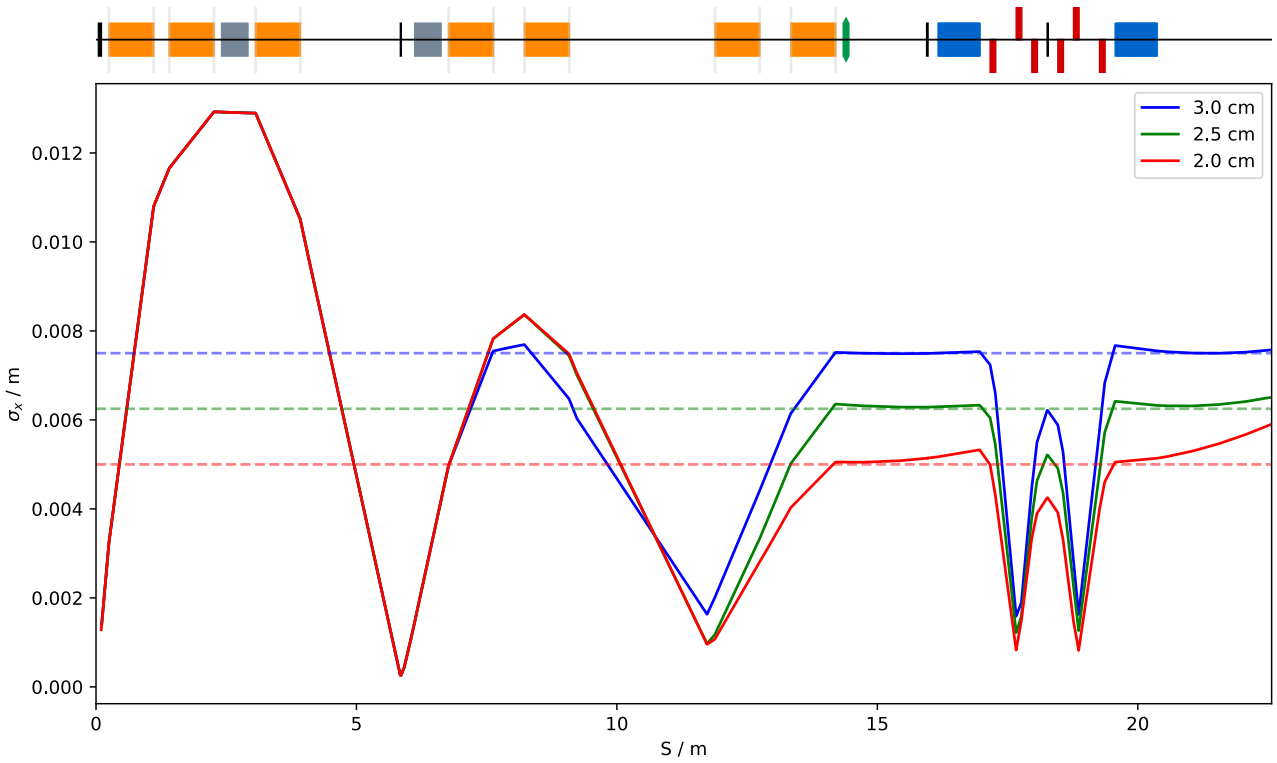
Capture Section Optimisation



- 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

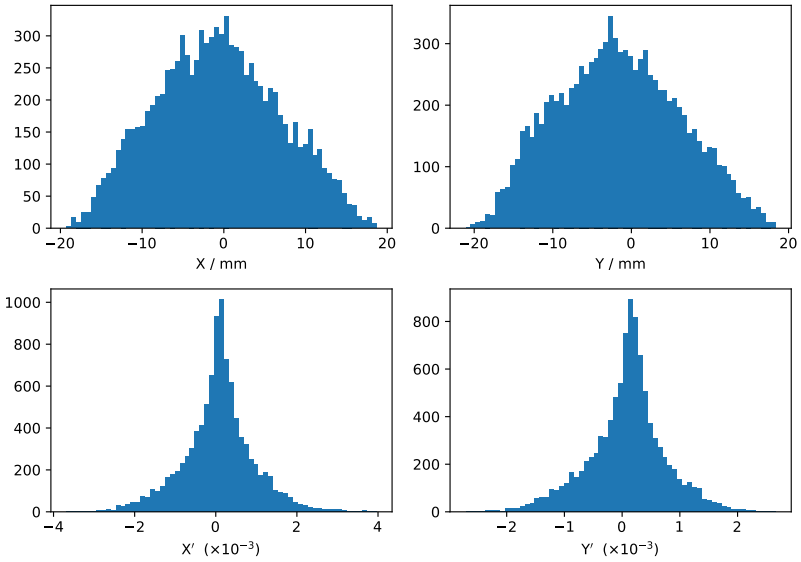
Spot-size Optimisation

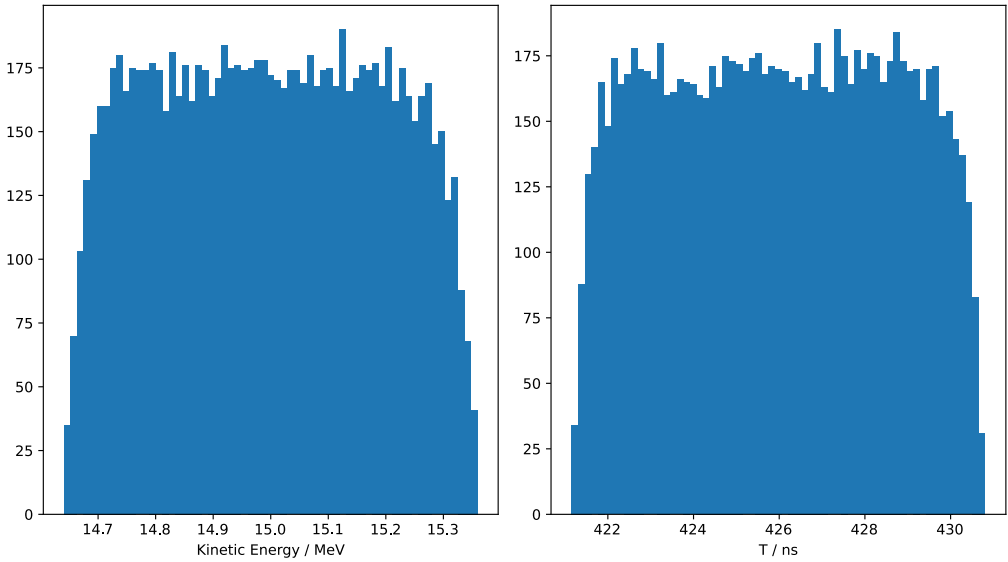


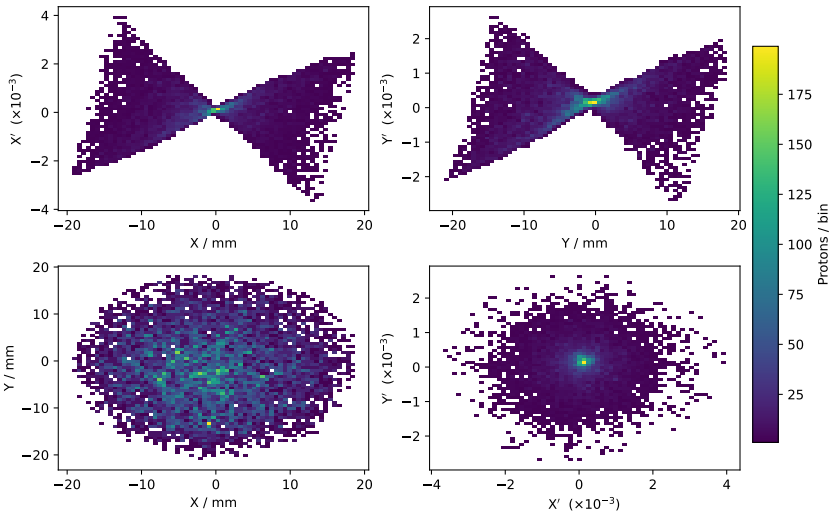
- Optimised solutions found for 3.0, 2.5, and 2.0 cm spot sizes
- Trending to divergent beam, focus after GL7.

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

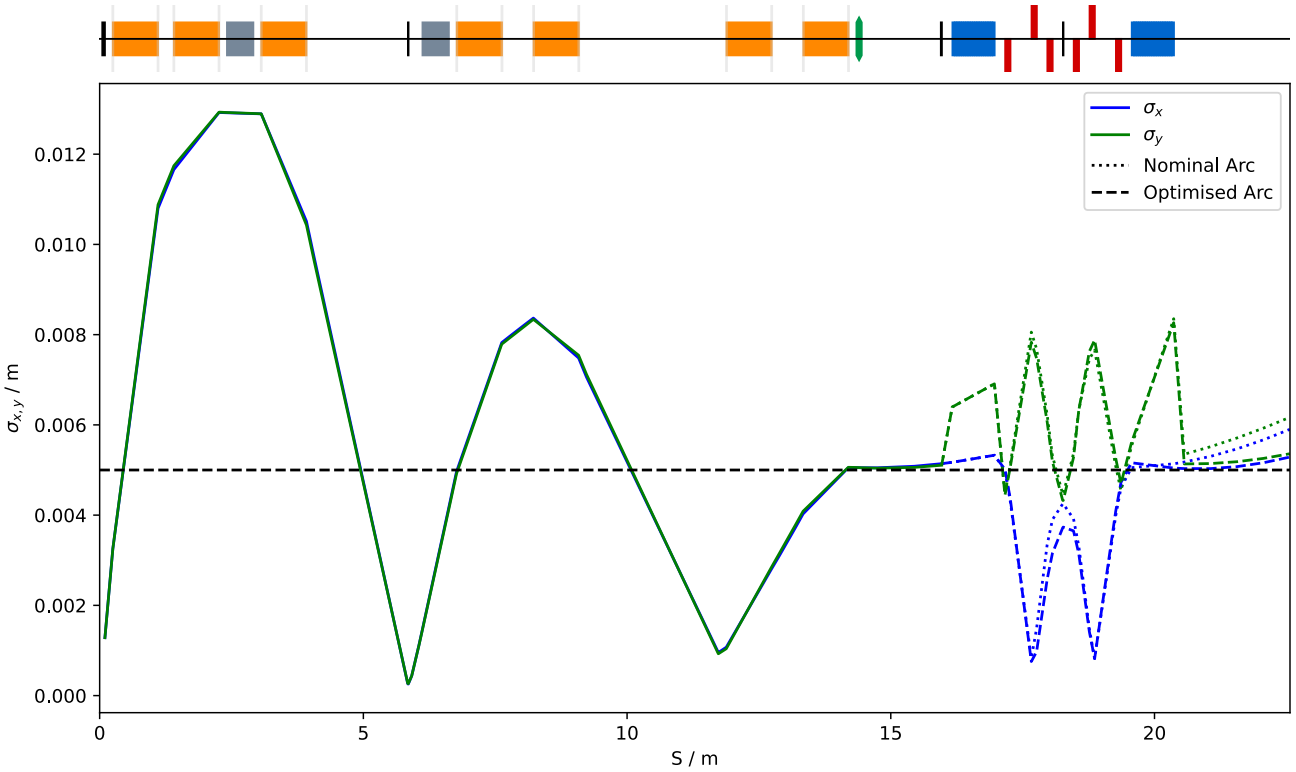






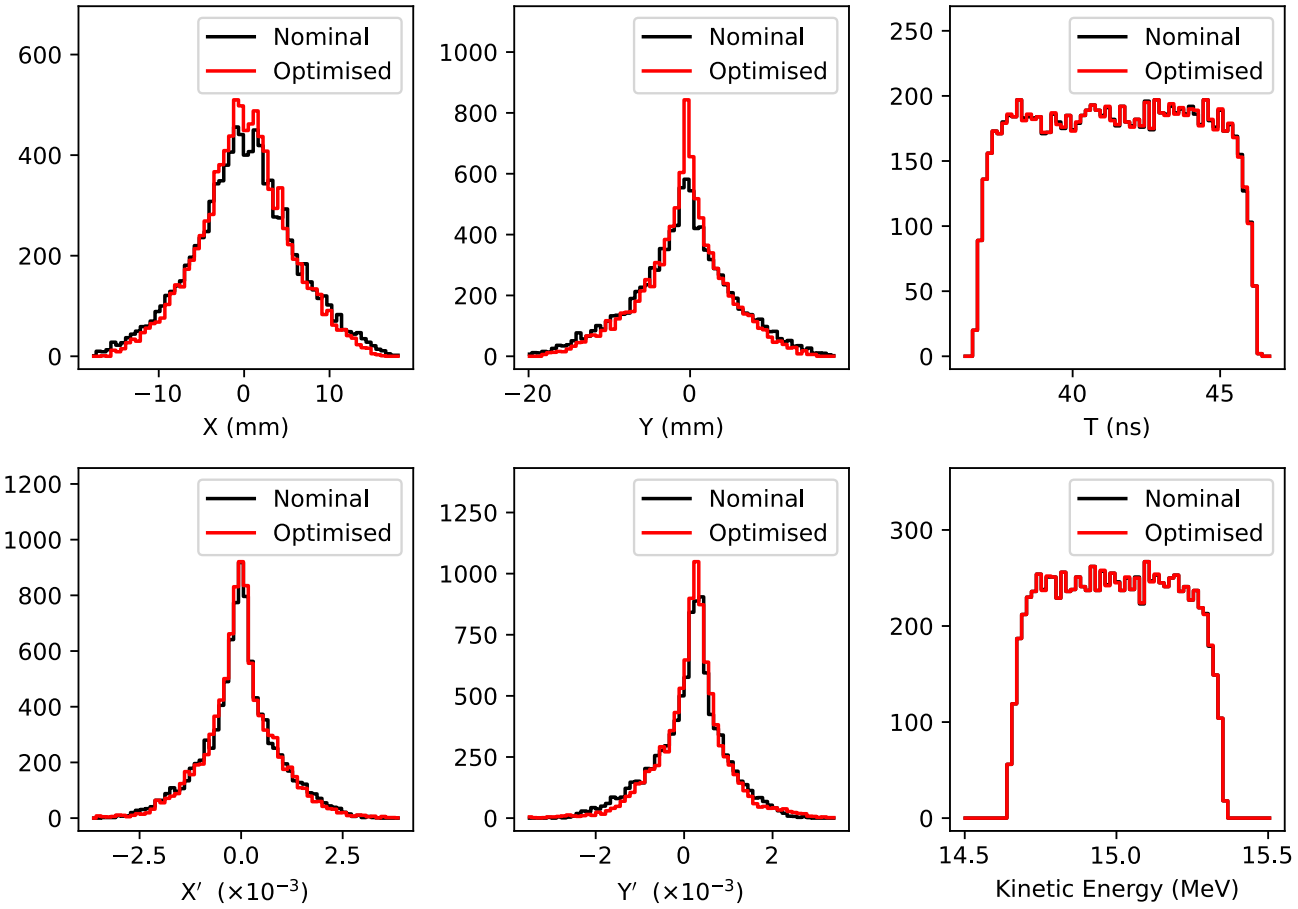
- End station beam parameters (3 cm spot size configuration):
  - Spot size: 3.077 cm (2σ diameter)
  - Bunch length: 10.49 ns
  - Energy: 15 MeV ± 2.0%
  - Divergence ($P_\perp / P_0$): 0.77 x 10^{-3}

2.0cm Spot Size: Arc Optimisation



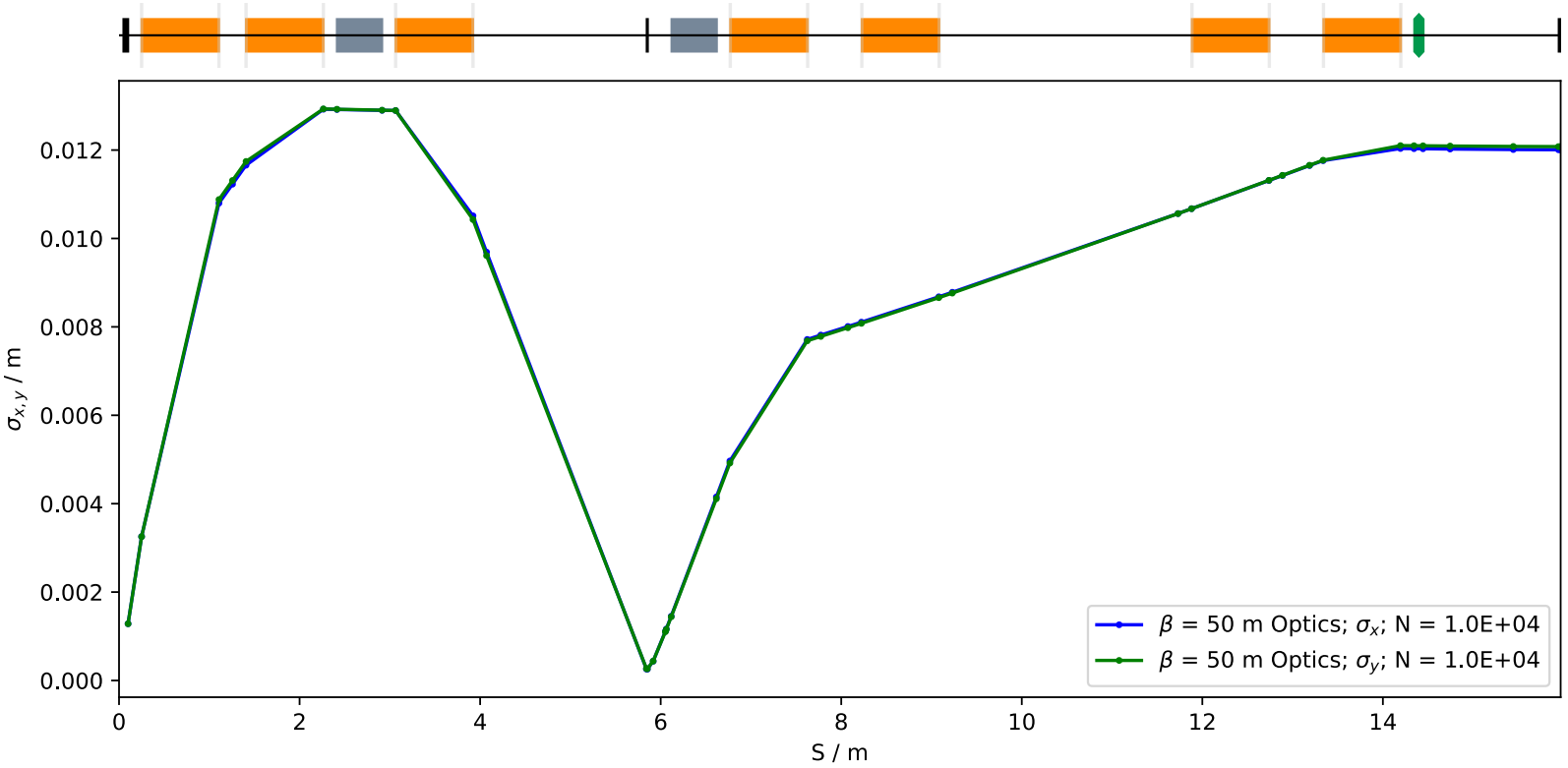
- Arc quadrupoles varied, improved solution for 2.0 cm spot size beam.
  - Quad gradient constrained to ± 22.4 T/m (pole tip field = 0.82 T, 3.65cm radius)
- Arc quadrupole strength variability likely required.
- Solutions for smaller spot sizes remains challenging.

2.0cm Spot Size: Beam Profile



- No major impact on end station beam profile.
- Octupoles not simulated, beam uniformity not expected here.

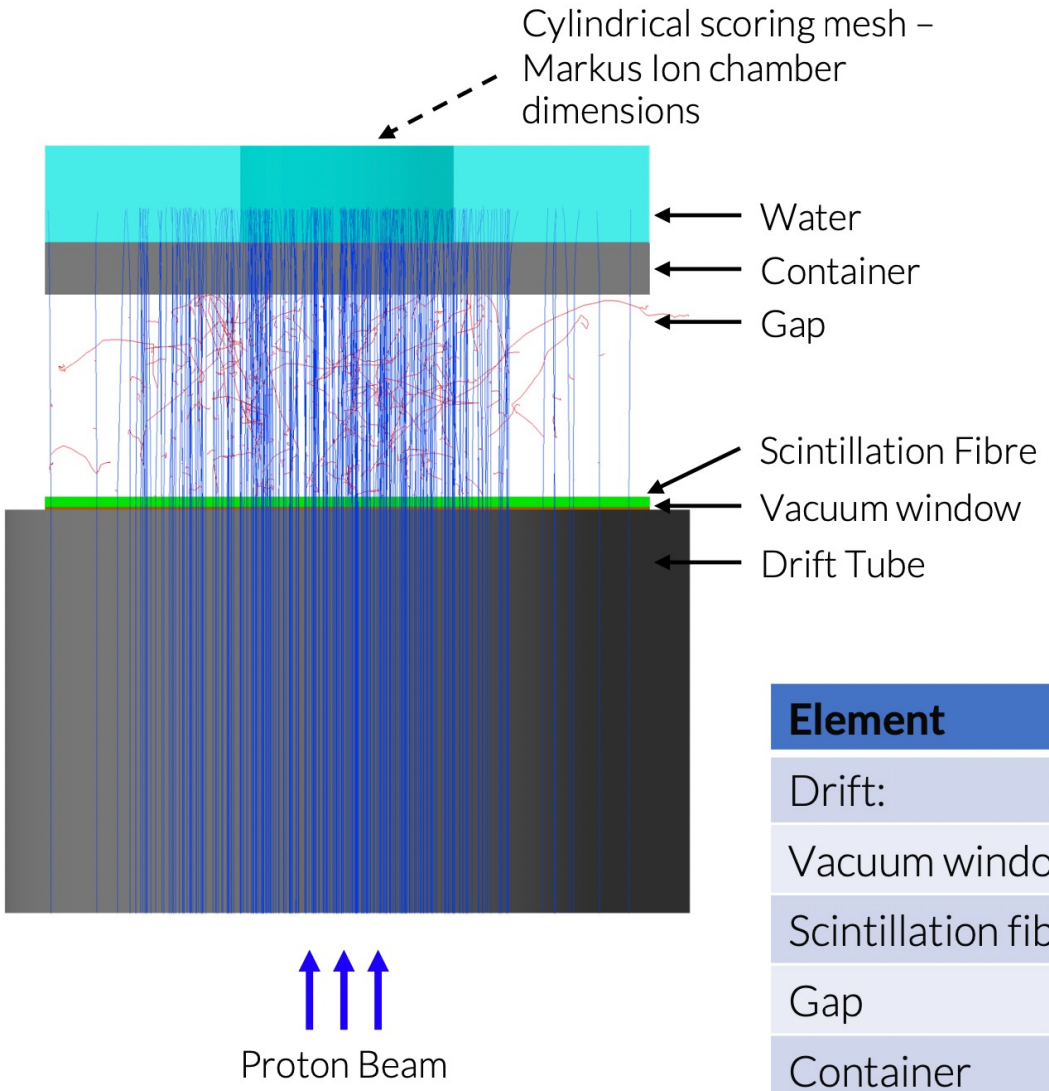
Optimised Solution for FFA Injection Line



	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

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**

Baseline Document Update Schedule

Document section	Description	Status	Estimated draft completion date	Notes / Comments / Questions
01 - Introduction	Introduce document expand with outline changes	Ongoing	17/11/23	Only minor changes
02 – Design Performance	Deliverable dose rates & end station beam profiles	Ongoing	17/11/23	Include dose rate calculation change?
03 – Ion Source	Hardware specification (no simulation contributions)	?	?	Any changes?
04 – Stage 1 Beam Transport	7 Gabor lens model	Ongoing	17/11/23	See section 08
05 – Post Acceleration (Stage 2)	FFA	?	?	Any changes?
06 – End stations	End station specifications	?	?	Dose rates in section 02. Any changes?
07 – Change Log	Dated list of baseline updated	To do	01/12/23	
08 – Baseline evolution	Detailed changes to baseline design	Near complete	01/12/23	Already written separately – split across document accordingly.

- End station dose calculation – separate note?
- Include proposed FFA changes here?
- Other changes to ion source and end station specifications?

Summary

- Improved beam description yielded reduced performance of baseline design model
- 7 Gabor lens configuration developed offering improved flexibility
- Optimised solutions found for multiple spot sizes
- Optimised solution for injection line
- Baseline design update document writing underway.

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