WP6: Design & Integration

William Shields
(william.shields@rhul.ac.uk)

LhARA Collaboration Meeting #3

08th February 2023

ROYAL HOLLOWAY UNIVERSITY OF LONDON

BDSIM

LhARA Laser-hybrid Accelerator for Radiobiological Applications

JAI John Adams Institute for Accelerator Science

Outline

- CAD model workflow
- Baseline changes
- Matching with space charge
- Review of the initial distribution
- Rematching with SCAPA simulated distribution
- Next steps

CAD Model Workflow

- Automatic generation of spreadsheet containing component surveys
- Generated from BDSIM model
- Matches component naming scheme

LhARAGeometrySurvey-v0.1

0

0 STAGE1INVITRO Component List

1 Document Name: lhara-v1.0 component coordinates

2 8/12/2022

3 Notes: Units = mm.

	Section	X	Y	Z	Component Position	Component Name	Component Type	Aperture Type	Hor. Half Aperture	Ver. Half Aperture	Comments
0	TR	0	0	-100.000	Start	LHA_TR_VAC_DRI_00	drift	circular	50.000	50.000	
1	TR	0	0	-75.000	Middle	LHA_TR_VAC_DRI_00	drift	circular	50.000	50.000	
2	TR	0	0	-50.000	End	LHA_TR_VAC_DRI_00	drift	circular	50.000	50.000	
3	TR	0	0	-50.000	Start	LHA_TR_DIA_COL_01	ecol	circular	2.870	2.870	
4	TR	0	0	-25.000	Middle	LHA_TR_DIA_COL_01	ecol	circular	3.305	3.305	
5	TR	0	0	0	End	LHA_TR_DIA_COL_01	ecol	circular	2.000	2.000	
6	TR	0	0	0	Start	LHA_TR_VAC_DRI_01	drift	circular	50.000	50.000	Reserved for Gabor Lens physical length
7	TR	0	0	75.000	Middle	LHA_TR_VAC_DRI_01	drift	circular	50.000	50.000	Reserved for Gabor Lens physical length
8	TR	0	0	150.000	End	LHA_TR_VAC_DRI_01	drift	circular	50.000	50.000	Reserved for Gabor Lens physical length
9	TR	0	0	150.000	Start	LHA_TR_MAG_SOL_01	solenoid	circular	50.000	50.000	
10	TR	0	0	578.500	Middle	LHA_TR_MAG_SOL_01	solenoid	circular	50.000	50.000	
11	TR	0	0	1007.000	End	LHA_TR_MAG_SOL_01	solenoid	circular	50.000	50.000	
12	TR	0	0	1007.000	Start	LHA_TR_VAC_DRI_02	drift	circular	50.000	50.000	Reserved for Gabor Lens physical length
13	TR	0	0	1082.000	Middle	LHA_TR_VAC_DRI_02	drift	circular	50.000	50.000	Reserved for Gabor Lens physical length
14	TR	0	0	1157.000	End	LHA_TR_VAC_DRI_02	drift	circular	50.000	50.000	Reserved for Gabor Lens physical length
15	TR	0	0	1157.000	Start	LHA_TR_VAC_DRI_03	drift	circular	50.000	50.000	Reserved for Gabor Lens physical length
16	TR	0	0	1232.000	Middle	LHA_TR_VAC_DRI_03	drift	circular	50.000	50.000	Reserved for Gabor Lens physical length
17	TR	0	0	1307.000	End	LHA_TR_VAC_DRI_03	drift	circular	50.000	50.000	Reserved for Gabor Lens physical length
18	TR	0	0	1307.000	Start	LHA_TR_MAG_SOL_02	solenoid	circular	50.000	50.000	
19	TR	0	0	1735.500	Middle	LHA_TR_MAG_SOL_02	solenoid	circular	50.000	50.000	
20	TR	0	0	2164.000	End	LHA_TR_MAG_SOL_02	solenoid	circular	50.000	50.000	
21	TR	0	0	2164.000	Start	LHA_TR_VAC_DRI_04	drift	circular	50.000	50.000	Reserved for Gabor Lens physical length
22	TR	0	0	2239.000	Middle	LHA_TR_VAC_DRI_04	drift	circular	50.000	50.000	Reserved for Gabor Lens physical length
23	TR	0	0	2314.000	End	LHA_TR_VAC_DRI_04	drift	circular	50.000	50.000	Reserved for Gabor Lens physical length
24	LEL	0	0	2314.000	Start	LHA_LEL_HRF_CAV_01	cavity_pillbox	circular	50.000	50.000	
25	LEL	0	0	2564.000	Middle	LHA_LEL_HRF_CAV_01	cavity_pillbox	circular	50.000	50.000	
26	LEL	0	0	2814.000	End	LHA_LEL_HRF_CAV_01	cavity_pillbox	circular	50.000	50.000	
27	LEL	0	0	2814.000	Start	LHA_LEL_VAC_DRI_01	drift	circular	50.000	50.000	Reserved for Gabor Lens physical length
28	LEL	0	0	2889.000	Middle	LHA_LEL_VAC_DRI_01	drift	circular	50.000	50.000	Reserved for Gabor Lens physical length

STAGE1INVITRO | STAGE1ABORT | STAGE1INJECTION | STAGE2ABORT | STAGE2RING | STAGE2INVITRO | STAGE2INVIVO

- Model zero position:
  - Centre of exit plane of target housing flange

Component Strengths

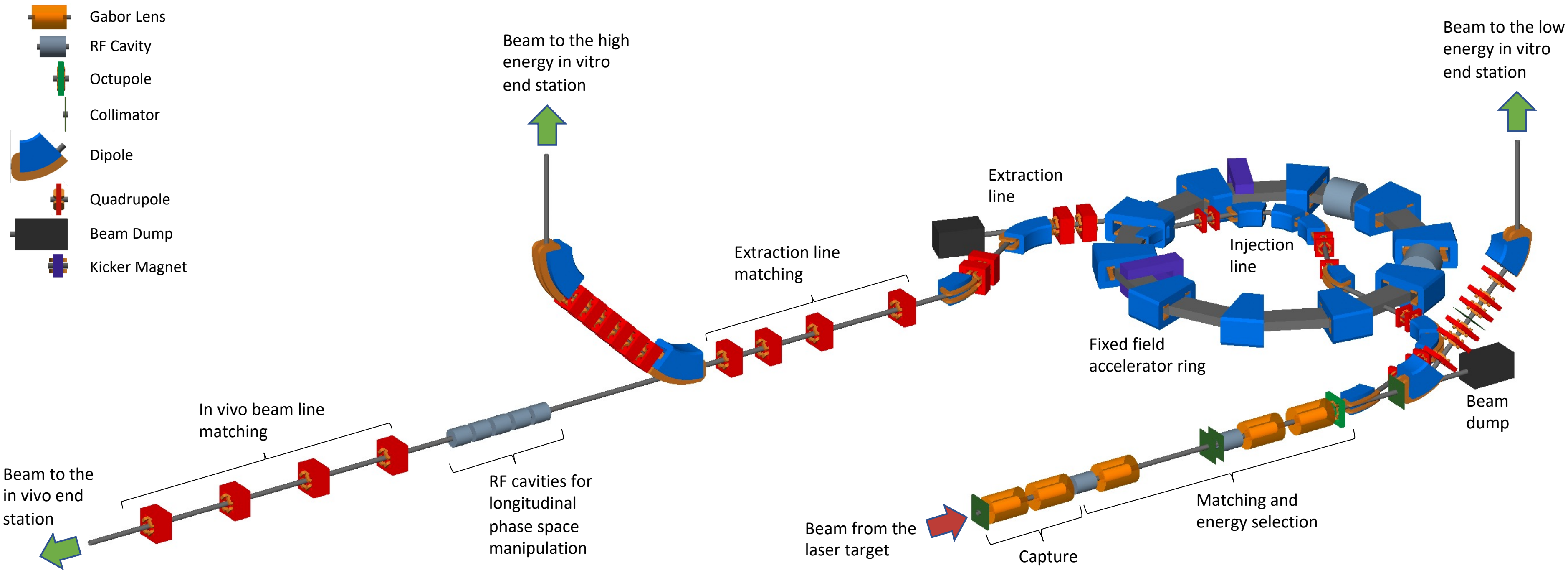
- Automatic generation of component strengths spreadsheet
- Generated from BDSIM model
- Matches component naming scheme

LhARAMagnetSurvey-v0.1 — Saved to my Mac

A	B	C	D	E	F	G	H	I	J	K
	0									
0	STAGE1INVITRO Component List									
1	Document Name: lhara-v1.0 EM Component Strengths									
2	8/12/2022									
3	Notes: Length units = mm									
4	Drifts temporarily named LHA_DDD_VAC_DRI_XX until replaced by other devices									
	Section	Cumulative Length	Component Name	Component Type	Length	Strength Parameter(s)	Strength Value(s)	Unit(s)	Tilt	Comments
0	TR	-0.050	LHA_TR_VAC_DRI_00	drift	0.050					
1	TR	0.000	LHA_TR_DIA_COL_01	ecol	0.050					
2	TR	0.150	LHA_TR_VAC_DRI_01	drift	0.150					Reserved for Gabor Lens physical length
3	TR	1.007	LHA_TR_MAG_SOL_01	solenoid	0.857	ks	2.290287	m^-1		
4	TR	1.157	LHA_TR_VAC_DRI_02	drift	0.150					Reserved for Gabor Lens physical length
5	TR	1.307	LHA_TR_VAC_DRI_03	drift	0.150					Reserved for Gabor Lens physical length
6	TR	2.164	LHA_TR_MAG_SOL_02	solenoid	0.857	ks	1.187325	m^-1		
7	TR	2.314	LHA_TR_VAC_DRI_04	drift	0.150					Reserved for Gabor Lens physical length
8	LEL	2.814	LHA_LEL_HRF_CAV_01	cavity_pillbox	0.500	efield	0.000000	v		
9	LEL	2.964	LHA_LEL_VAC_DRI_01	drift	0.150					Reserved for Gabor Lens physical length
10	LEL	3.821	LHA_LEL_MAG_SOL_01	solenoid	0.857	ks	1.305670	m^-1		
11	LEL	3.971	LHA_LEL_VAC_DRI_02	drift	0.150					Reserved for Gabor Lens physical length
12	LEL	5.746	LHA_LEL_VAC_DRI_03	drift	1.775					
13	LEL	5.756	LHA_LEL_DIA_COL_01	ecol	0.010					Collimator for stage 1 operation
14	LEL	5.821	LHA_LEL_VAC_DRI_04	drift	0.065					
15	LEL	5.956	LHA_LEL_VAC_DRI_05	drift	0.135					
16	LEL	5.966	LHA_LEL_DIA_COL_02	ecol	0.010					Collimator for stage 2 operation
17	LEL	6.021	LHA_LEL_VAC_DRI_06	drift	0.055					
18	LEL	6.521	LHA_LEL_HRF_CAV_02	cavity_pillbox	0.500	efield	0.000000	v		
19	LEL	6.671	LHA_LEL_VAC_DRI_07	drift	0.150					Reserved for Gabor Lens physical length
20	LEL	7.528	LHA_LEL_MAG_SOL_02	solenoid	0.857	ks	2.504240	m^-1		
21	LEL	7.678	LHA_LEL_VAC_DRI_08	drift	0.150					Reserved for Gabor Lens physical length
22	LEL	7.778	LHA_LEL_VAC_DRI_09	drift	0.100					
23	LEL	7.928	LHA_LEL_VAC_DRI_10	drift	0.150					Reserved for Gabor Lens physical length

STAGE1INVITRO | STAGE1ABORT | STAGE1INJECTION | STAGE2ABORT | STAGE2RING | STAGE2INVITRO | STAGE2INVIVO

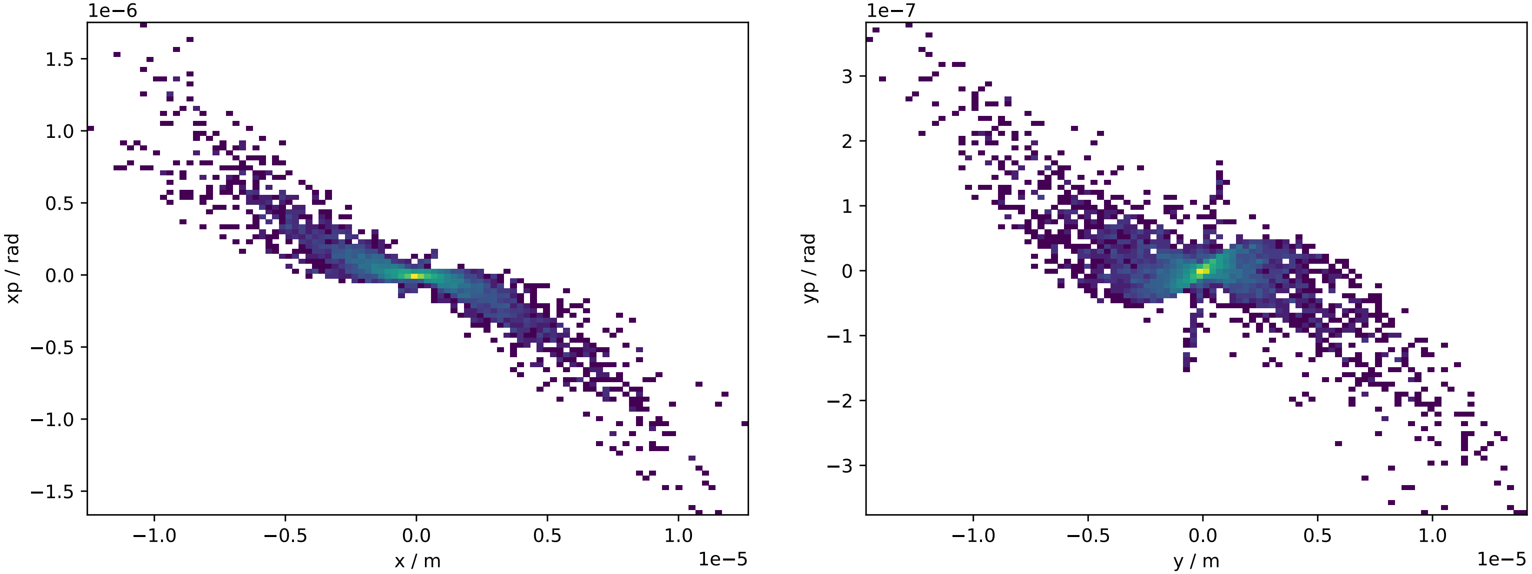
Updated Model Configurations

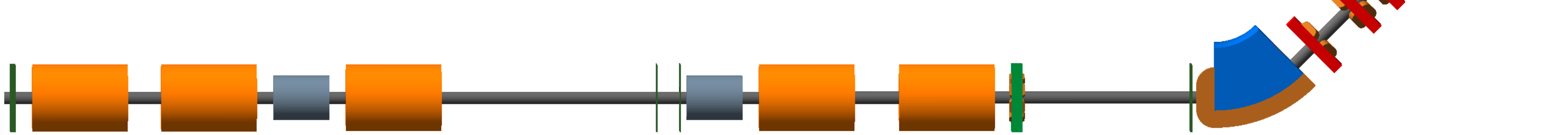


- Updated BDSIM model & schematic diagrams
- New model configurations:
  - V4.4: main baseline design
  - V5.4: alternative baseline design

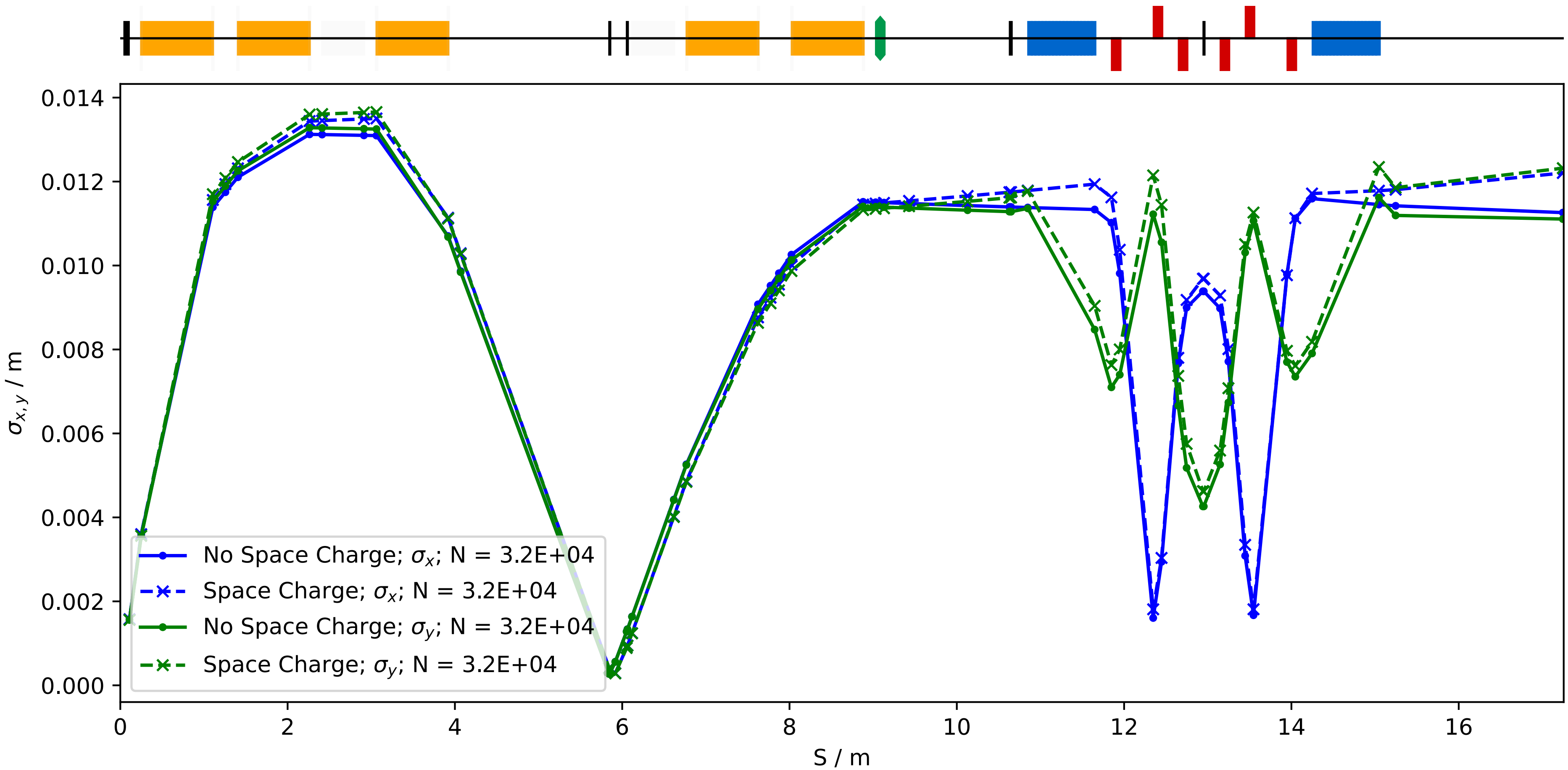
Geometry Configuration Updates

- Stage 2 energy selection collimation added
  - 0.2m downstream of stage 1 collimator (GL3 focal length)
  - Settings to be optimised
- 1st Octupole removed:
  - No discernible impact on bunch uniformity
  - Phase space difference at the stage 1 end station (on – off):



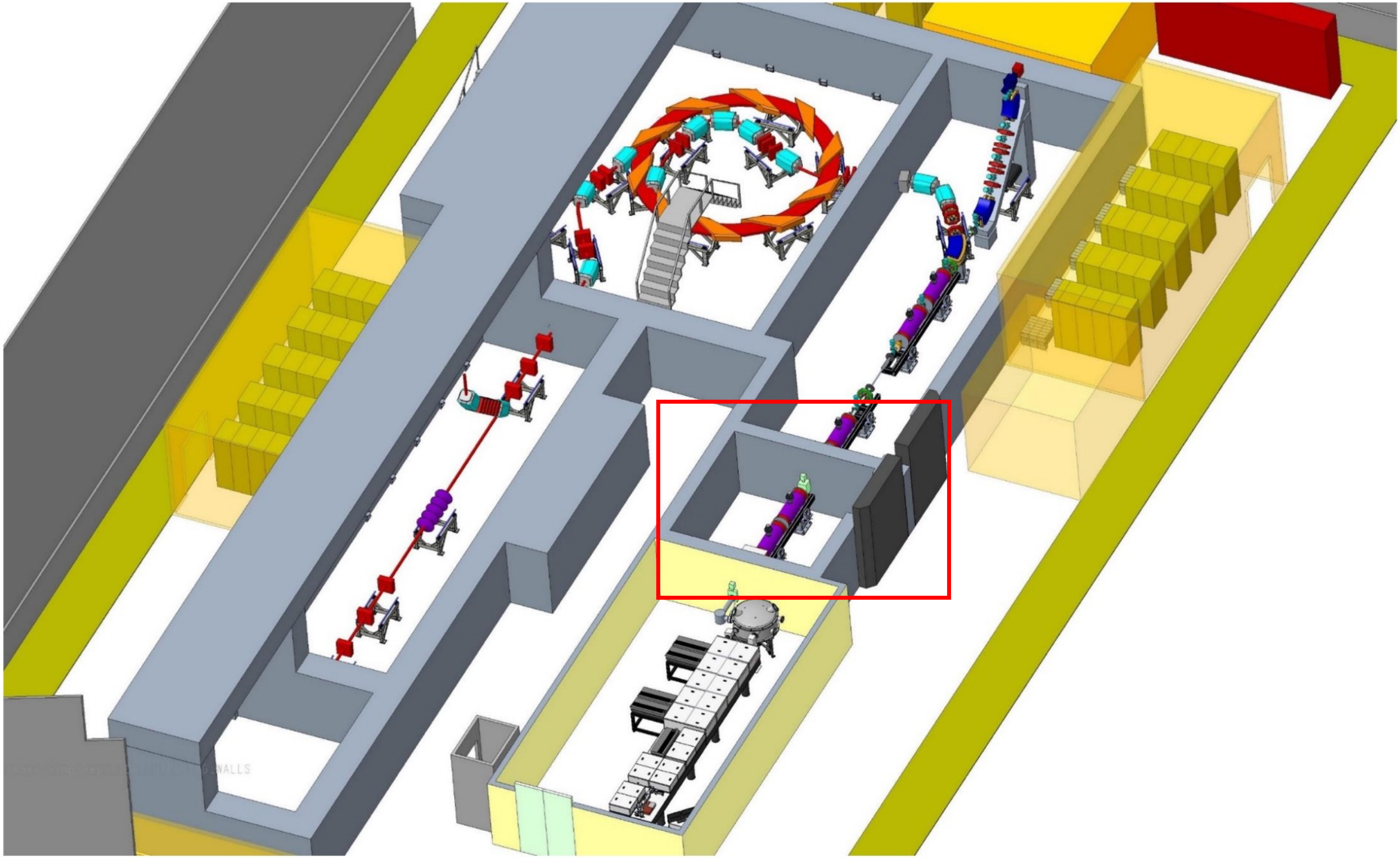


Stage 1: Space Charge Mitigation

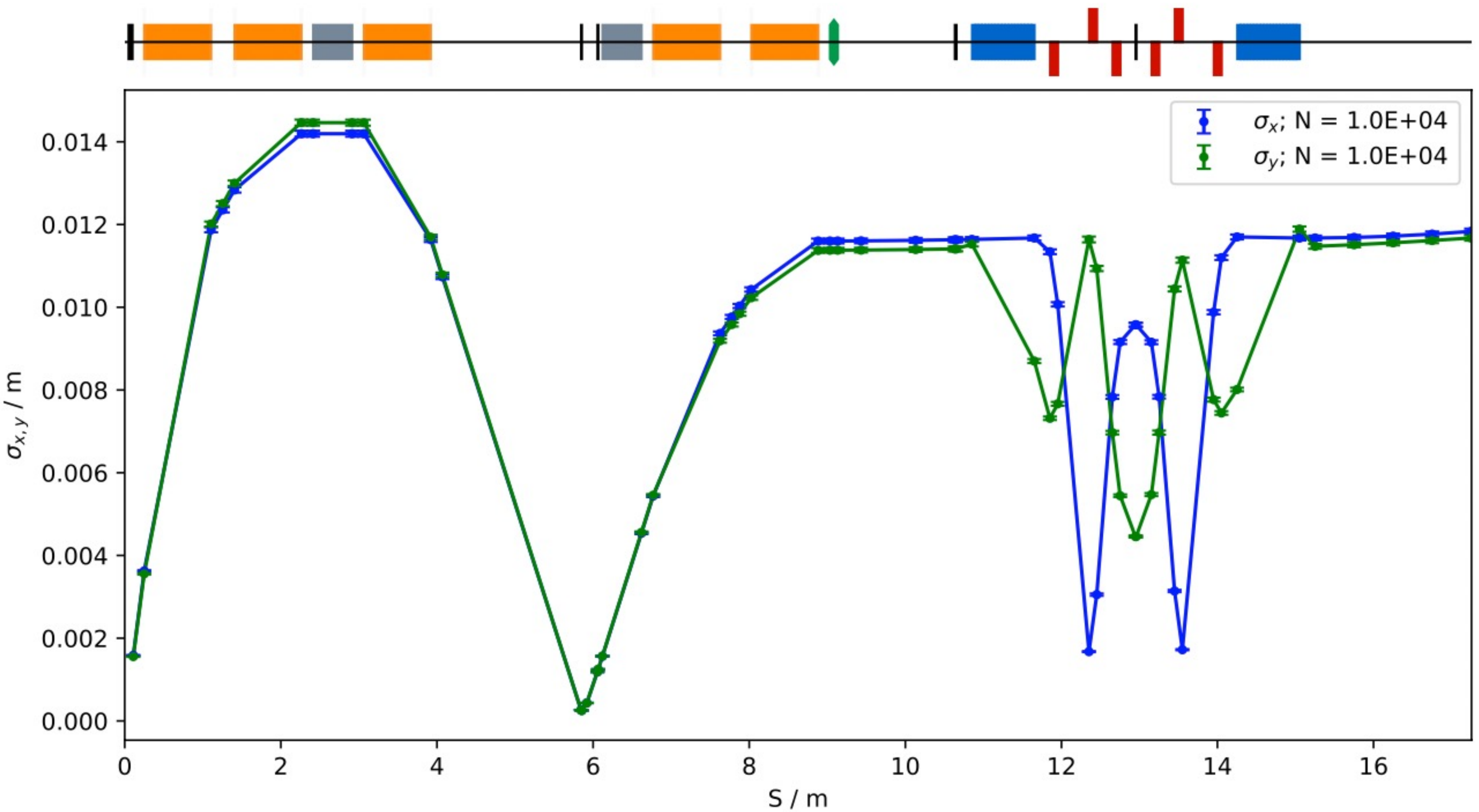


- Sampled beam generated from Smilei
- Non-parallel beam between GL2 & GL3
  - Requirement – flexibility needed to accommodate RF, shielding wall, etc.

Capture Section Shielding

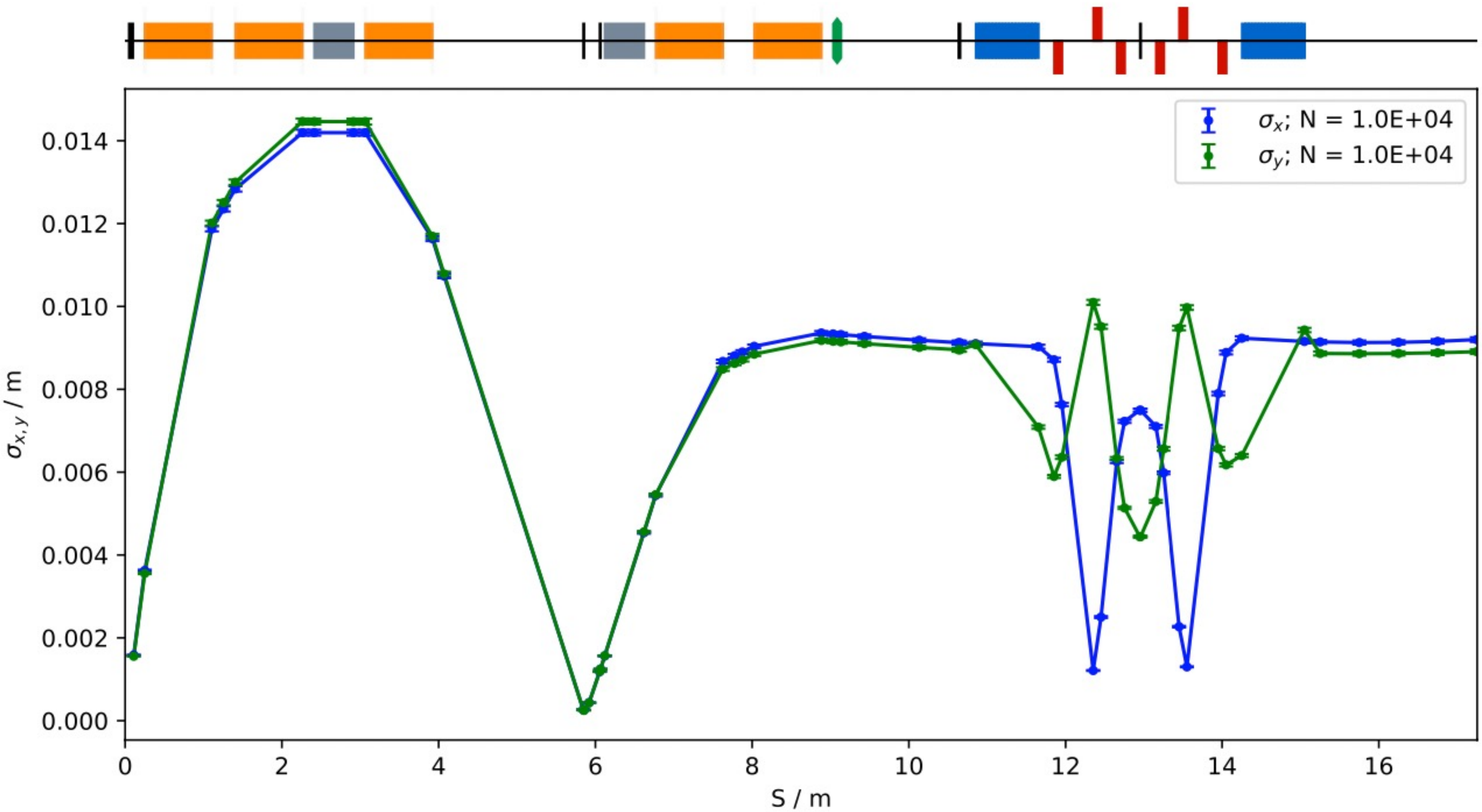


Solenoid Strength Optimisation



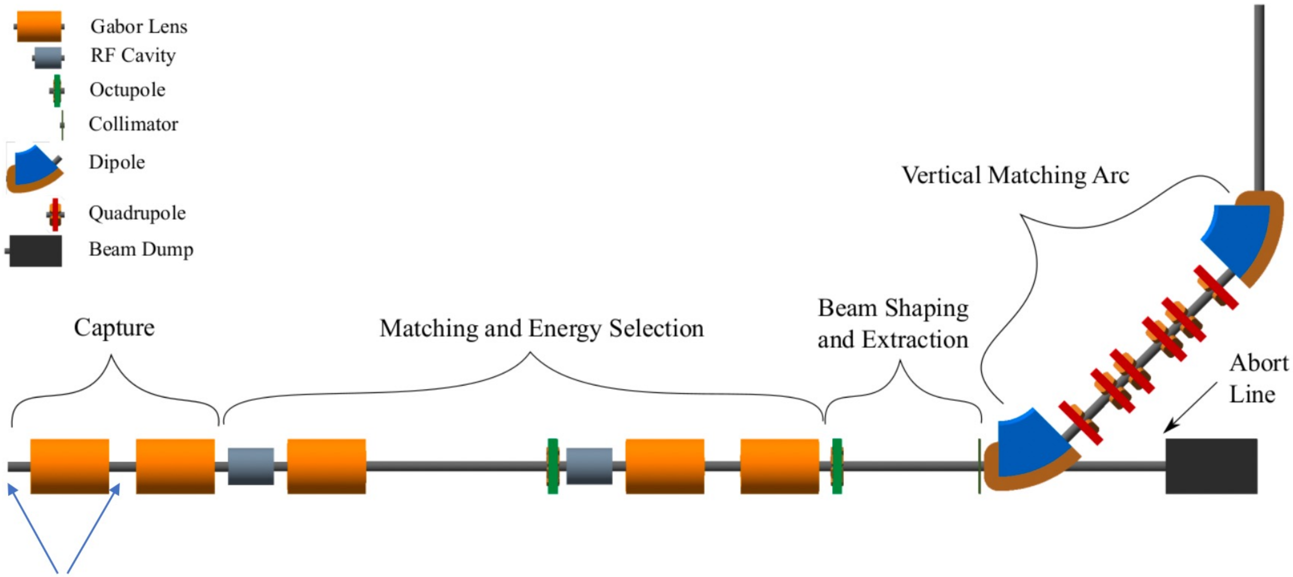
- Sampled beam generated from Smilei

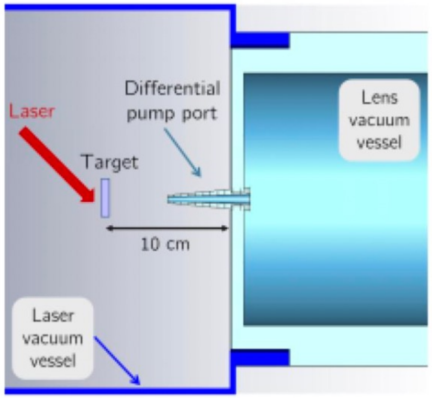
Solenoid Strength Optimisation



Smaller beam sizes remain a challenge

- Requirement for stage 2 FFA injection line





No space! Flange to flange.

- Potential requirement for additional space for vacuum pumps coupling for GL1
  - Additionally, if GL1 needs external filling from off-axis e- source.
- Increasing the distance between GL1 and GL2 decreases the performance
- With the most up to date distribution from the nozzle (from HT), we can add 15cm between the nozzle and the GL1
  - Not much more than that!
  - This is only possible if we trust the target simulation

Outcome

- It was proposed to keep the baseline of the capture system (the first two GLs coupled to the target system) unchanged.

- The filling of both GL1 and GL2 is planned to be performed using the movable electron source on-axis, from the downstream direction from the drift between GL2 and GL3. It is hoped that the plasma will be stable for sufficiently long time so the electron source could be removed for the proton operations.

- The space for vacuum pumps coupling for GL1 on the side of the target vessel seems sufficient, but pumping can be also located downstream including the source chamber, so no changes proposed.

- Question over validity of the Smilei sampled beam
    - Extrapolation from 2D to 3D

SCAPA Simulated Beam - Nozzle

- 71.8% of particles within the energy range (15MeV +/- 2%) survives the entrance nozzle cut (r=2mm)

- 35.6% of particles within the energy range (15MeV +/- 2%) survives the exit nozzle cut (r=2.87mm)
  - 40.1% of particles within the energy range (15MeV +/- 2%) survives the exit nozzle cut (r=2.87mm) if space charge is ignored

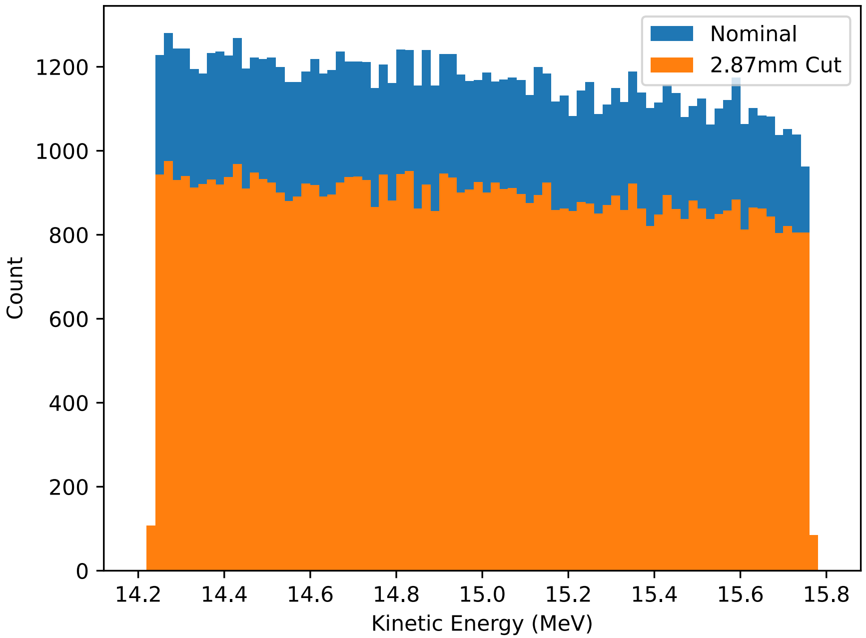
- Previous strategy: 5cm without space charge followed by 5cm with.

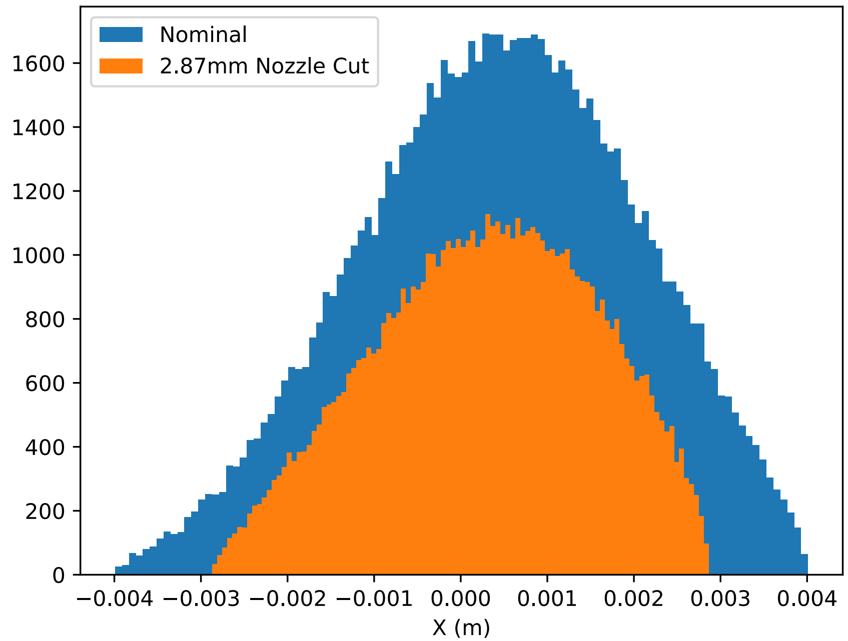
- Now have electron distribution data
  - Co-propagate with proton beam. Non-trivial!

Nozzle Effect: Beam Parameters

	Smilei Sampled Beam	SCAPA Beam	Scapa Beam (No space charge	Pre-CDR Beam
Mean RMS emittance [m]	1.43×10^{-8}	1.26×10^{-7}	5.5×10^{-8}	3.26×10^{-7}
Mean beta [m]	141.34	12.82	28.8	4.89
Mean alpha	-1418.43	-129.79	-288.03	-50.22

Scapa Beam: Larger Energy Spread

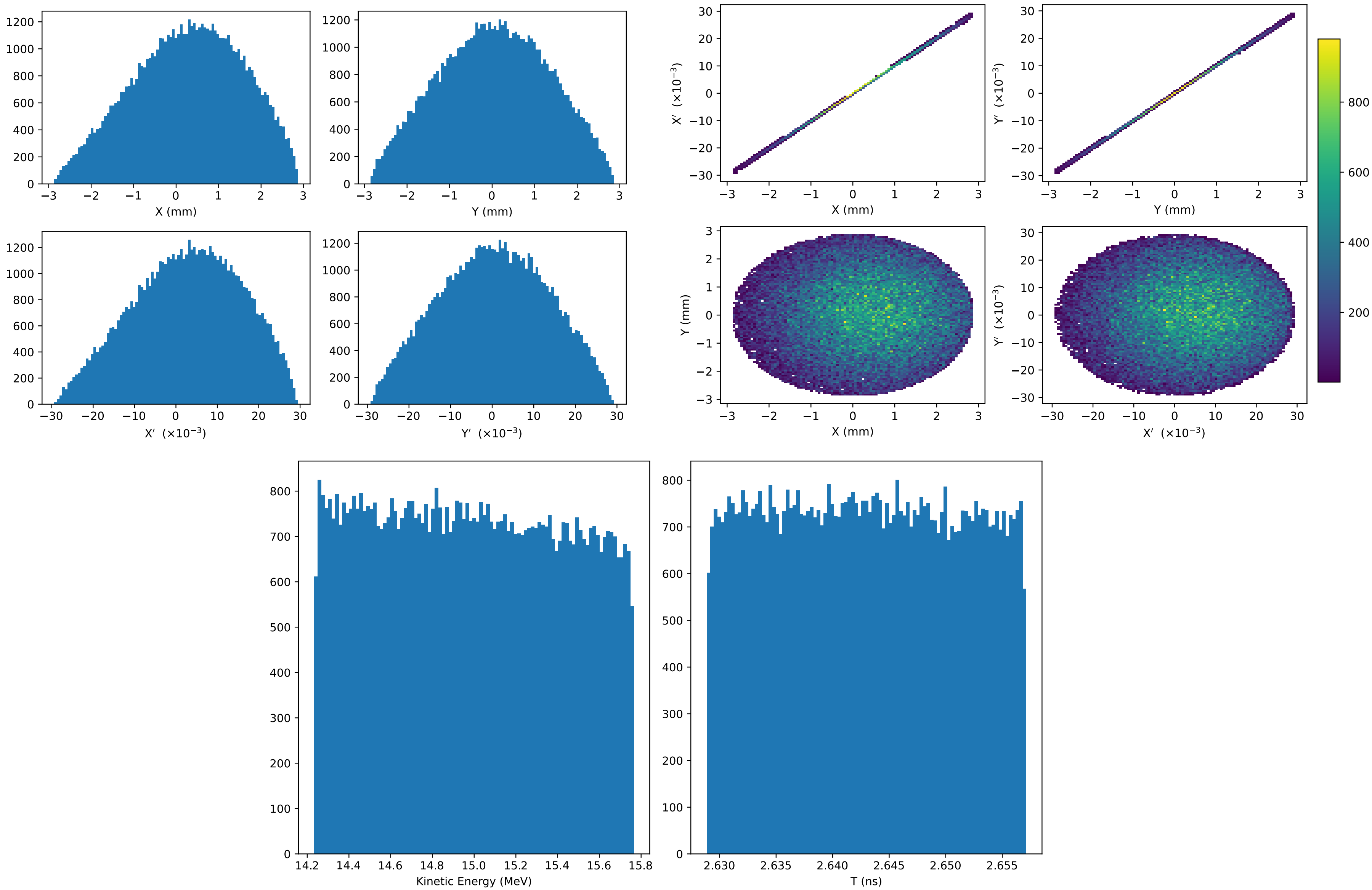




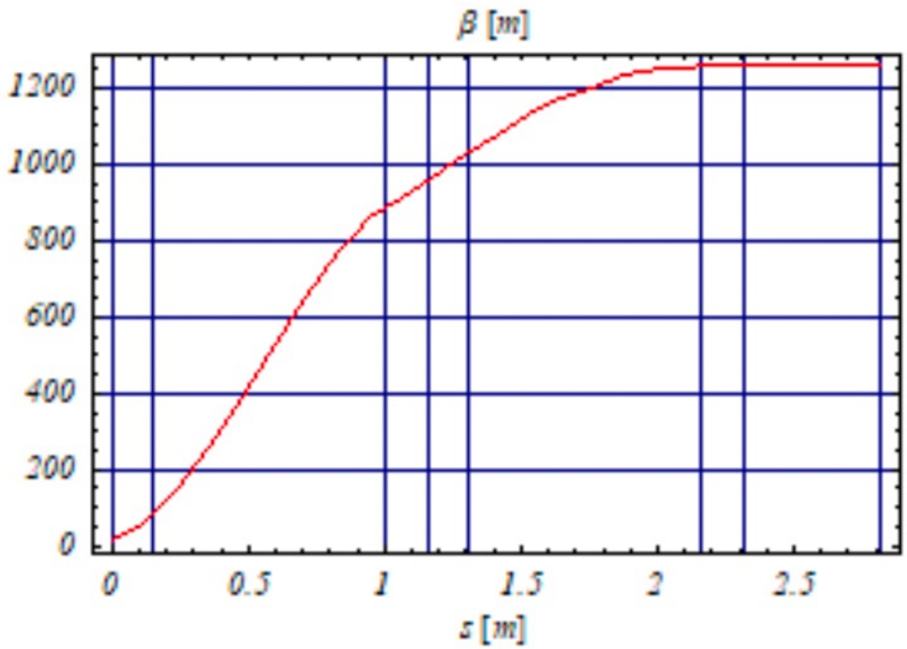
- 77% of particles within the energy range (15MeV +/- 5%) survives the entrance nozzle cut (r=2.87mm)

- Assess energy collimator performance & optimise.

SCAPA Beam Phase Space



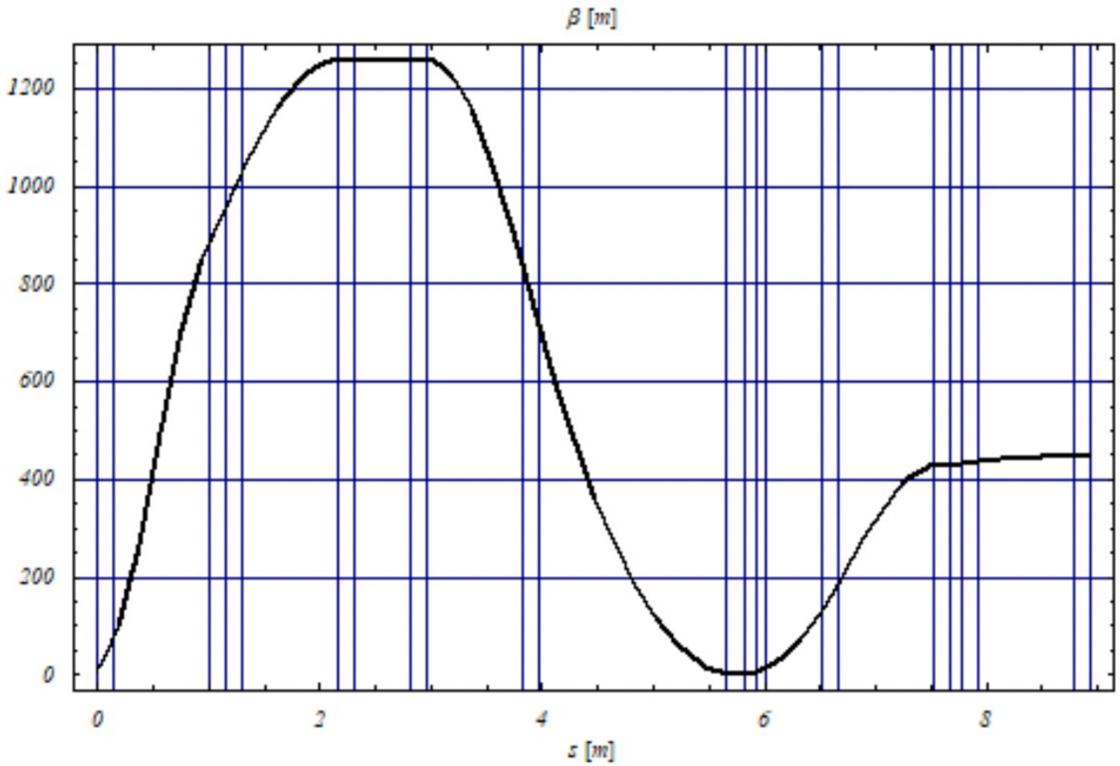
Beam Size & Plasma Radius



- Beam size at the nozzle exit (2.87mm) -2.26σ
- Beam size at the exit of the second GL with 2.26σ is 28.4mm (77.8% of the cathode radius)
  - What is the max radius of the electron cloud we can use?
  - With the solenoid with an aperture of 36.5mm we could accept the beam up to 2.9σ?

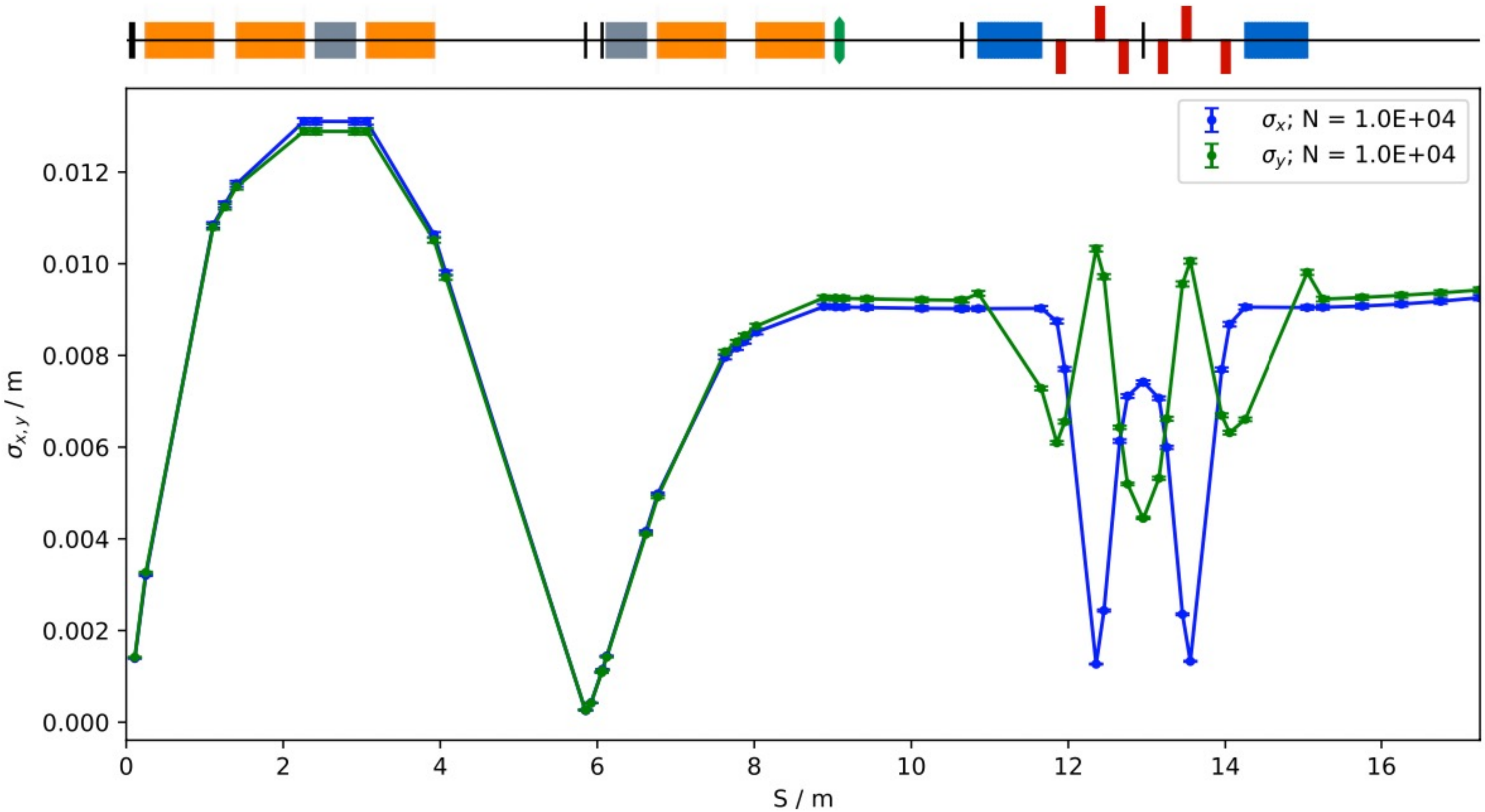
- Maximum radius of the beam in the capture section defines if we need to modify the nozzle or not

Configuration with SCAPA Beam



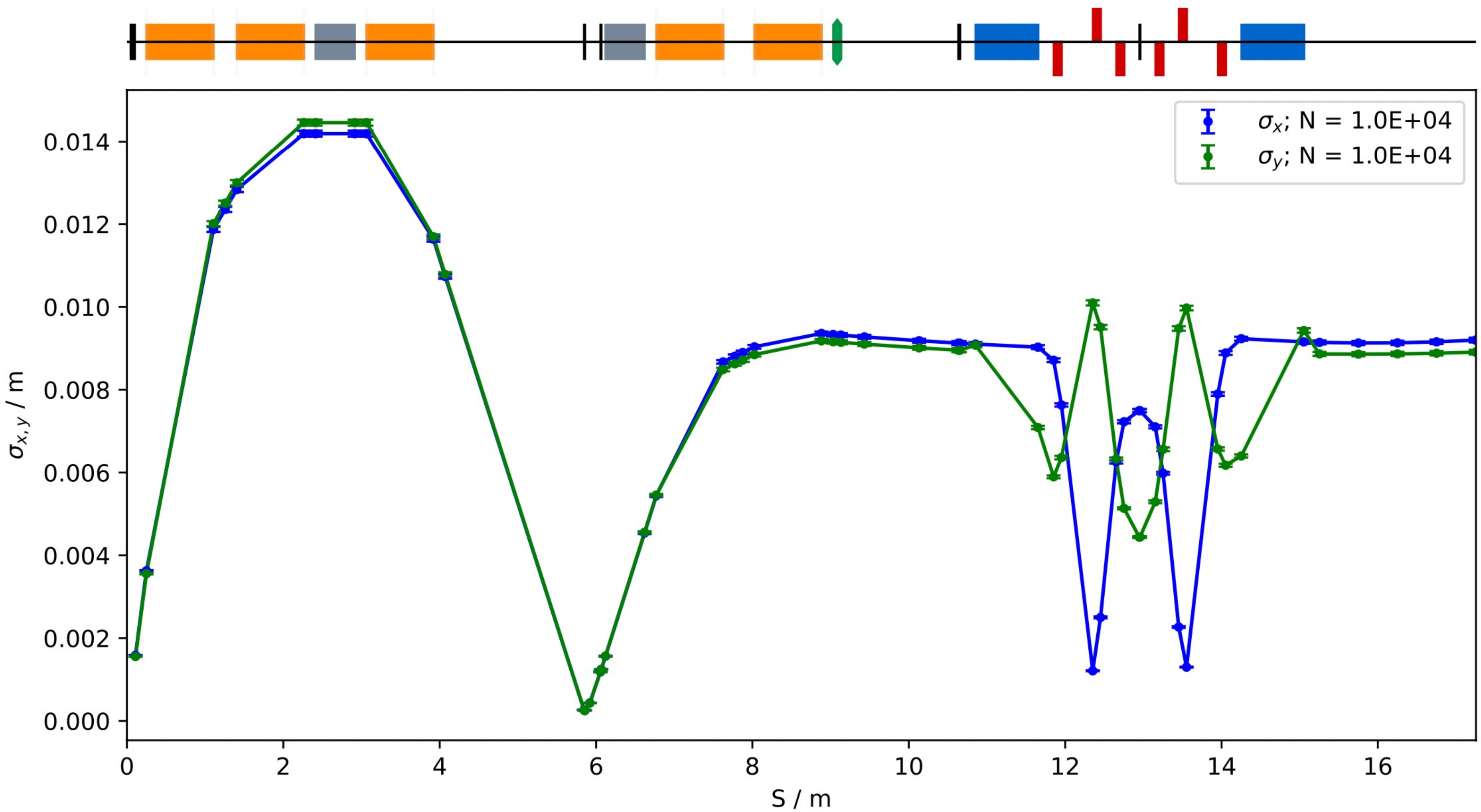
- Beam diameter of 3cm can be produced
- Issues with obtaining smaller final beam size
- Issues with matching to the Stage 2

Solenoid Strength Optimisation



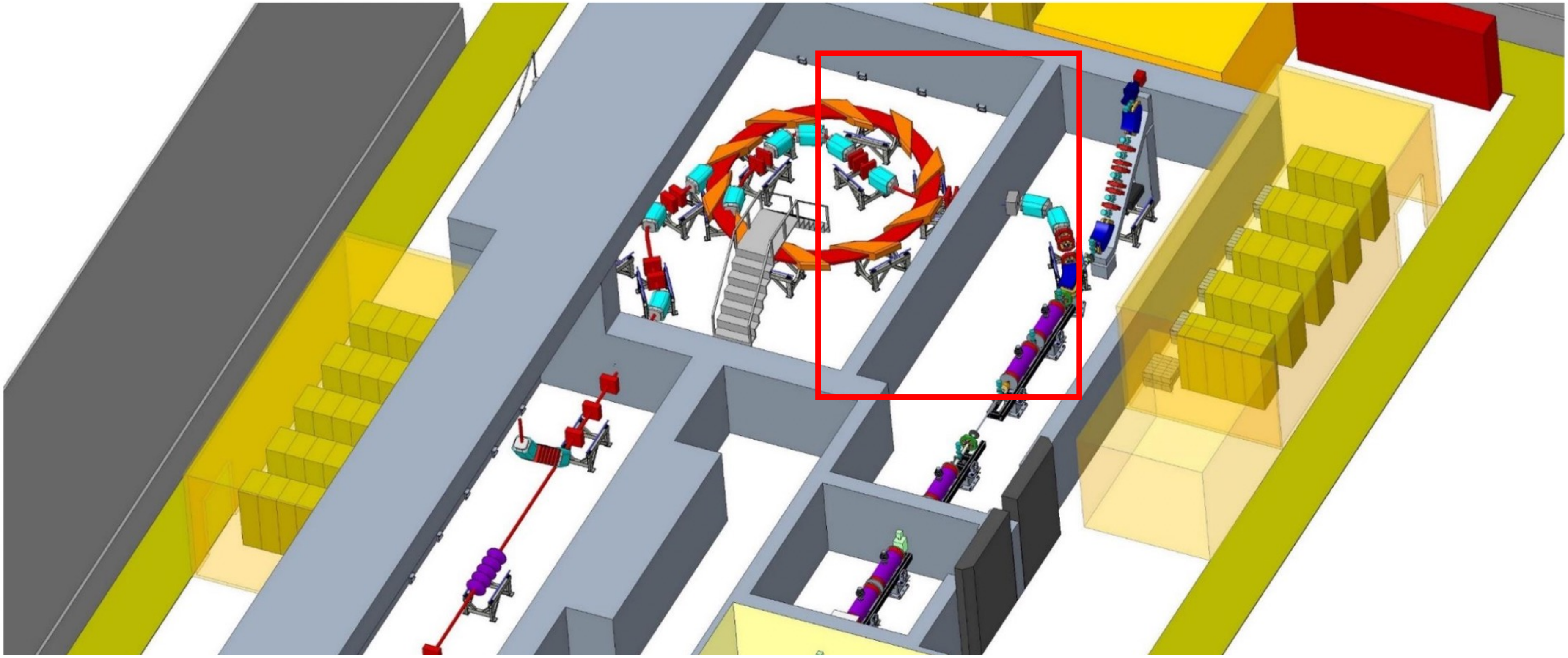
- Solutions found for producing a parallel beam

Solenoid Strength Optimisation



- Smaller beam sizes remain challenging

LhARA: Stage 2

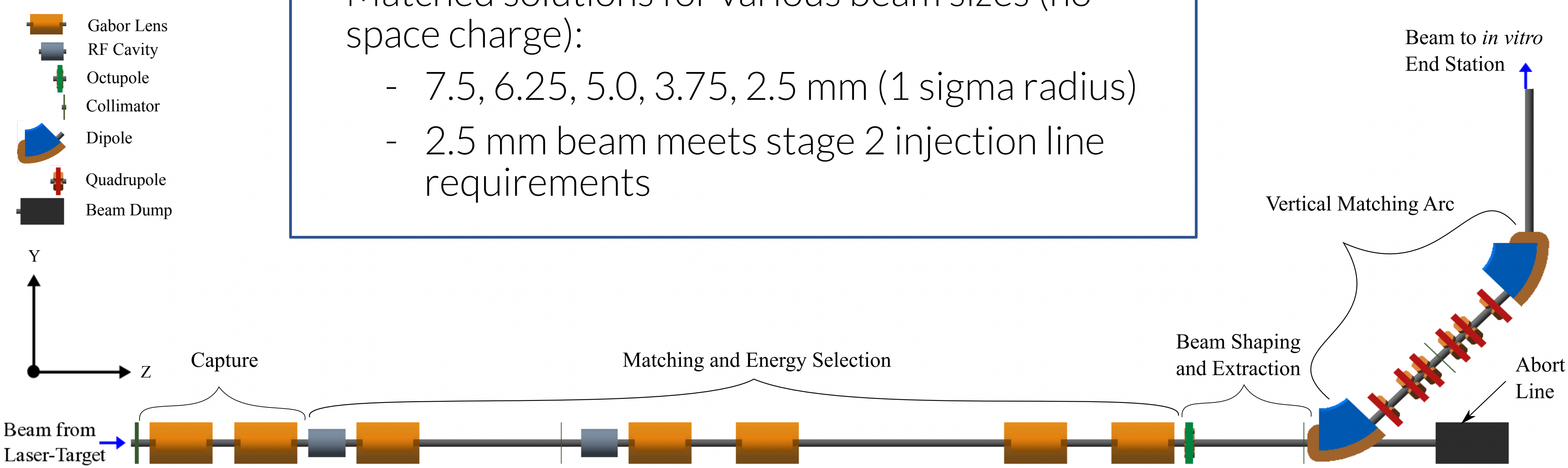


- Stage 2 - no updates.

- Injection line to be updated pending beam update.
  - Necessity to accommodate shielding wall

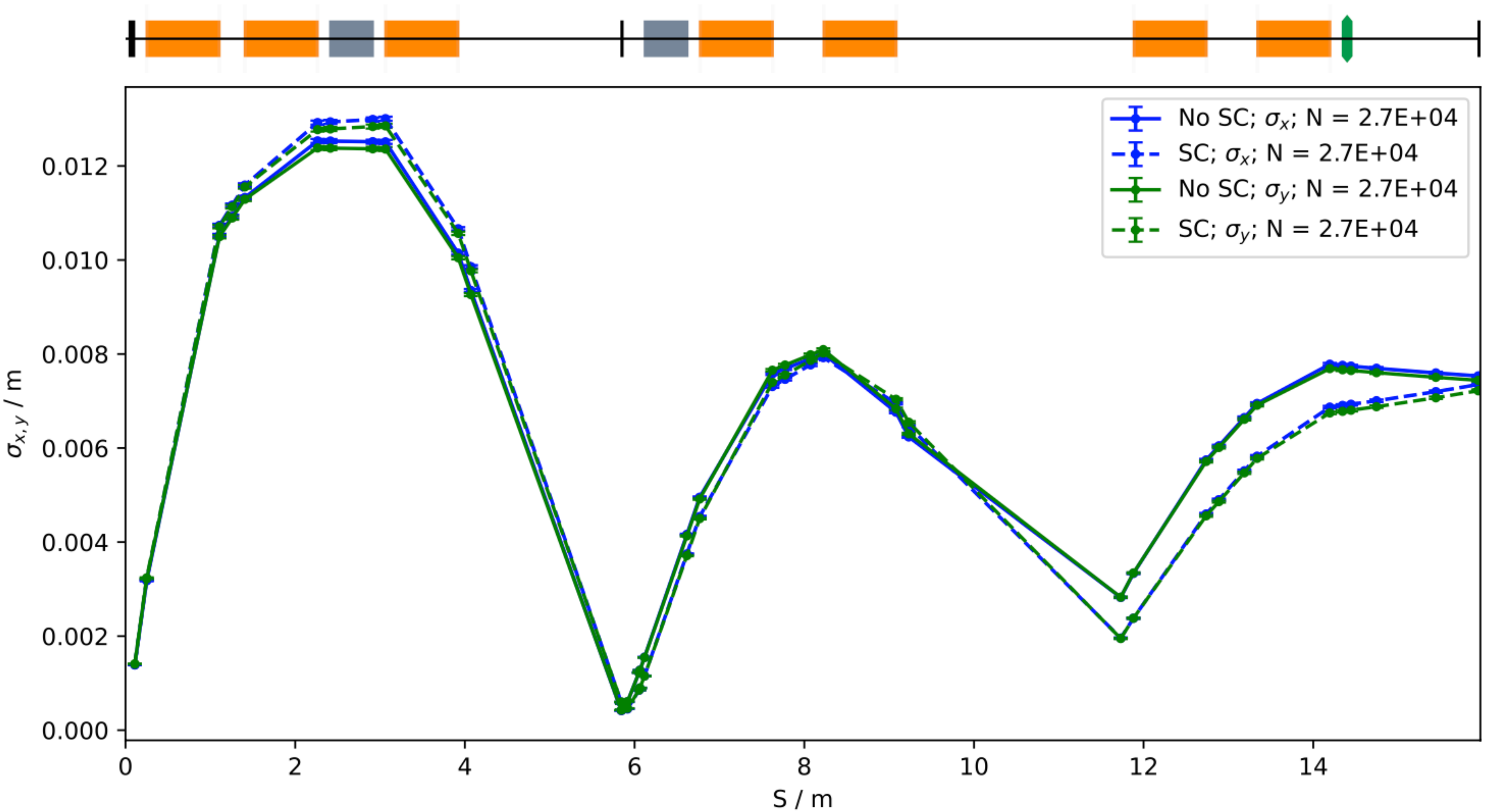
- Investigation of 7 Gabor lens / solenoids configuration
- Single energy collimator
- Geometry modifications:
  - Extra 0.2m between GL4 & GL5
  - 2.5m long drift after GL5
  - GL6 & GL7 added in same configuration as GL4 & GL5

- Matched solutions for various beam sizes (no space charge):
  - 7.5, 6.25, 5.0, 3.75, 2.5 mm (1 sigma radius)
  - 2.5 mm beam meets stage 2 injection line requirements

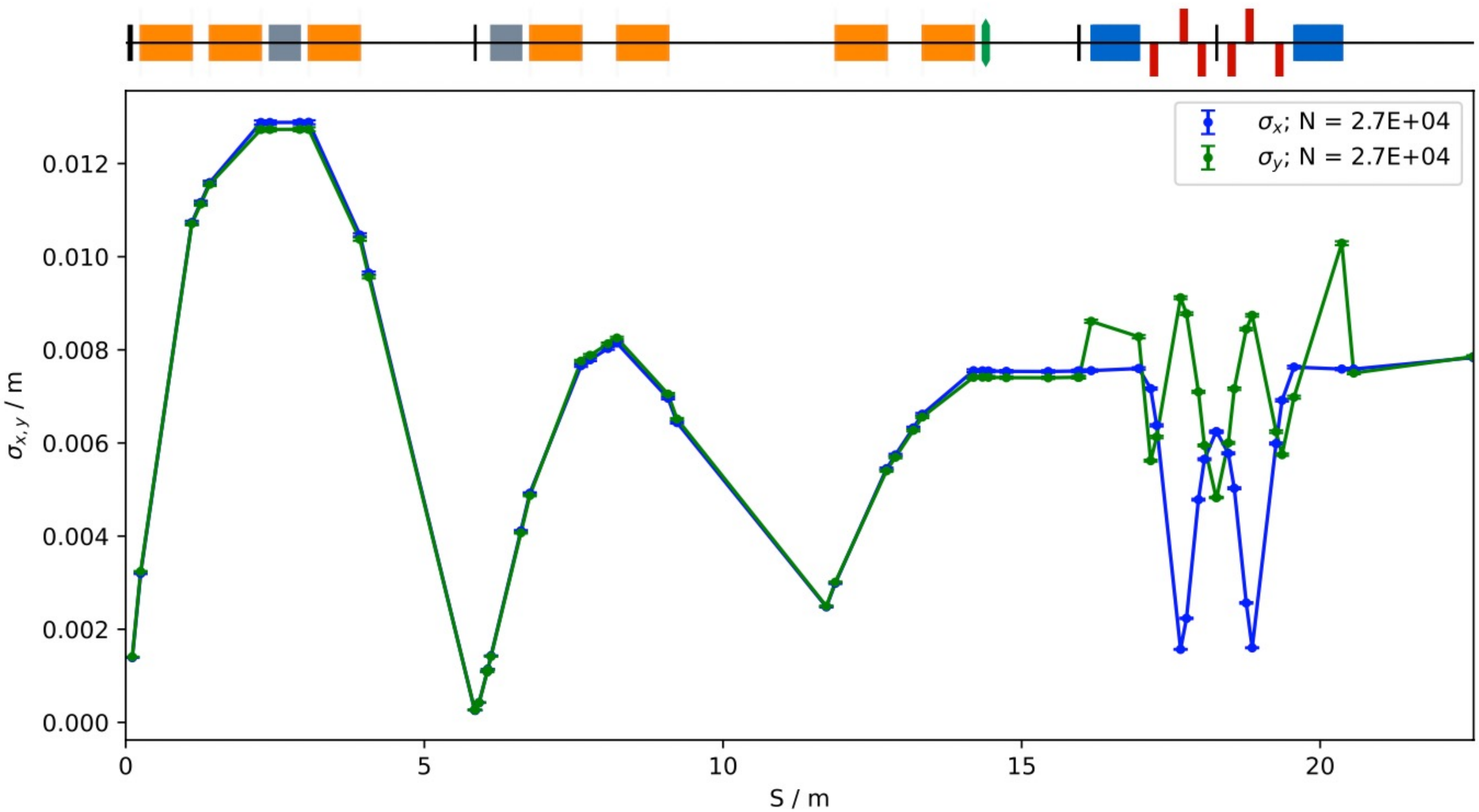


Space Charge Modelling

- Space charge impacting performance

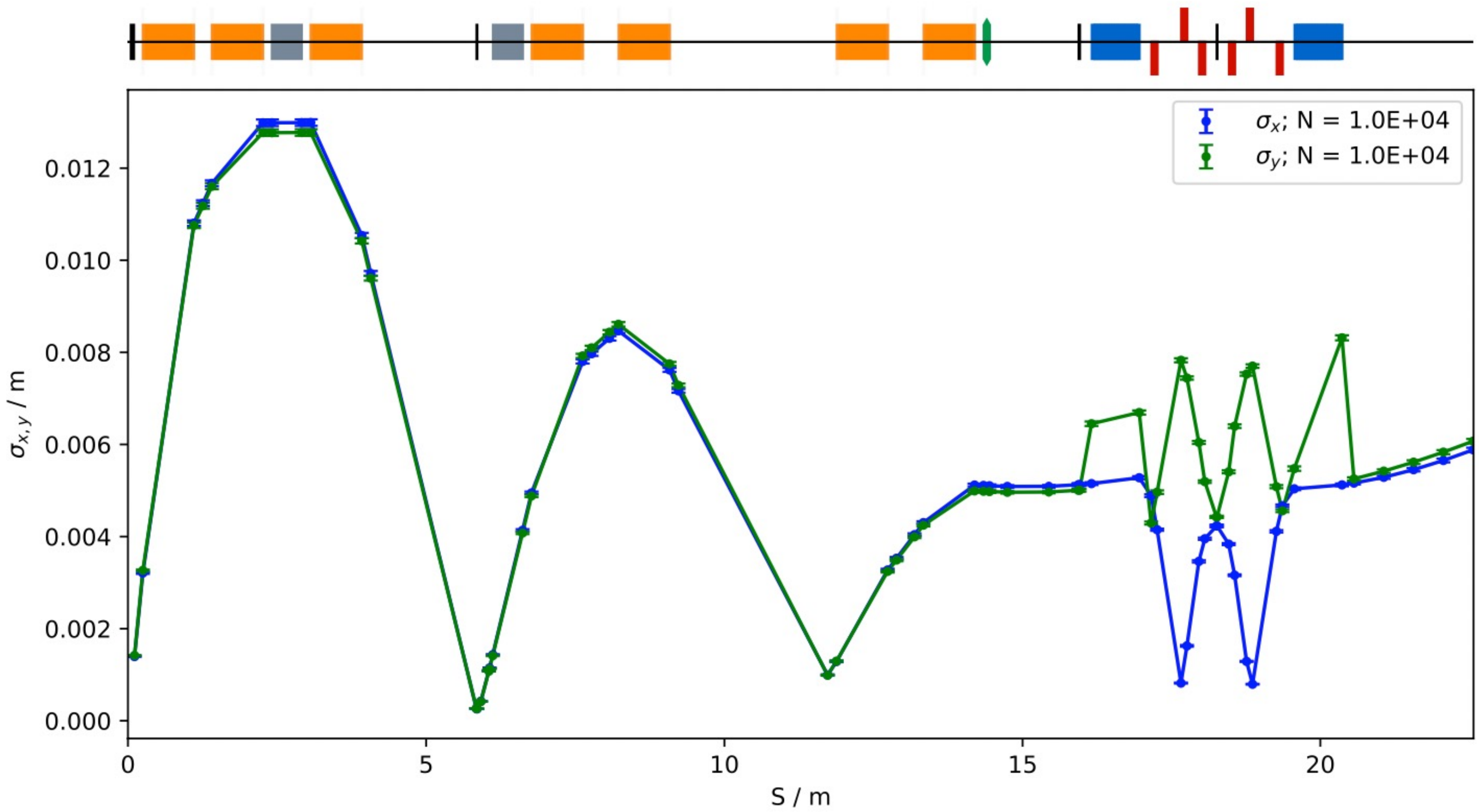


Matching Optimisation



- Same strength GL1 to GL3 for all solutions
- Solutions for GL4 to GL7 for larger beam sizes
- 1.4T solenoid limit

Matching Optimisation



- Smaller beam sizes than 5 lens solution achievable
- Smaller still is an ongoing challenge
  - Minimal space charge impact

Ongoing & Next Steps

- Continue improving flexibility in stage 1 matching
- Continue incorporating space charge in matching
- Find the new injection line
- Work on the FFA update
- Aim: pass lattice to engineers by end of February.

Summary

- Investigation of initial distribution
  - Baseline flexibility issues
- Optimised solutions for delivering beams to the end station
- Smaller beam sizes remains a challenge
  - Injection line requirement
- Promising configuration
  - Optimisation efforts ongoing

ROYAL HOLLOWAY UNIVERSITY OF LONDON

LhARA Laser-hybrid Accelerator for Radiobiological Applications

JAI John Adams Institute for Accelerator Science

Thank you

William Shields
william.shields@rhul.ac.uk