

LhARA Stage 1 as a Proton Source

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On behalf of the LhARA Collaboration

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ISIS2/LhARA Common Themes Meeting

1st June 2023

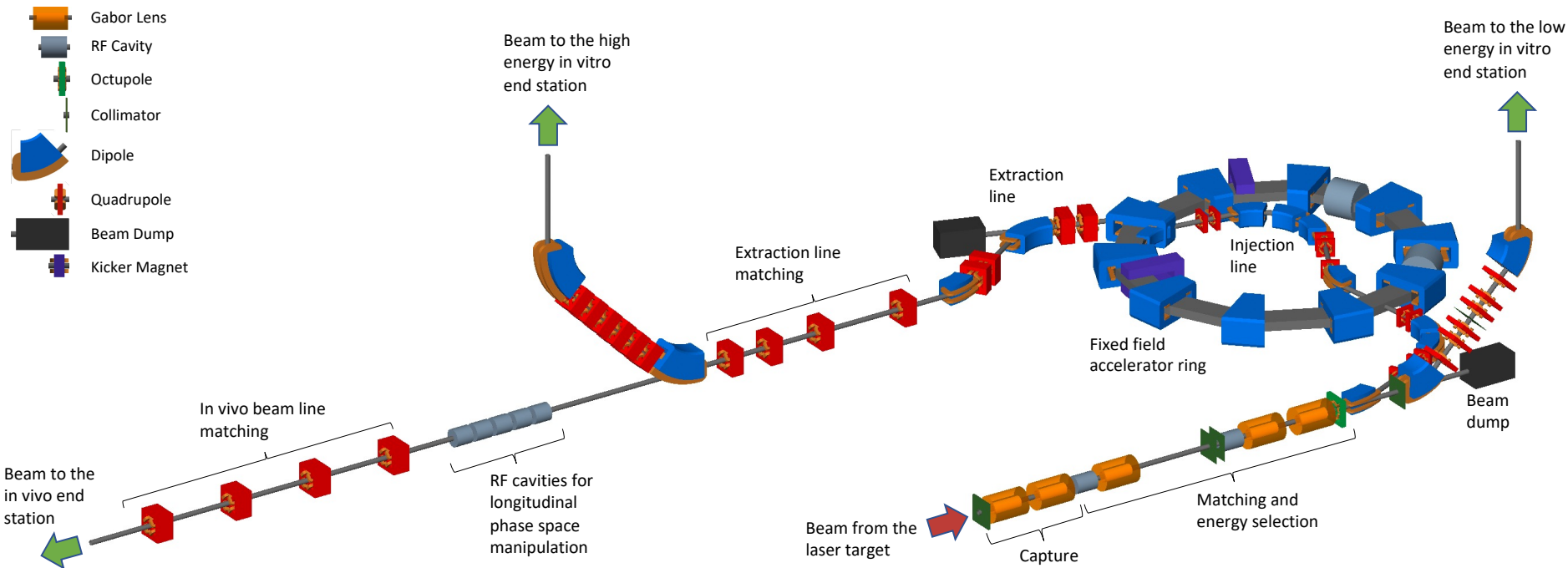


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- LhARA Overview
- Baseline design
- Beam generation
- FFA injection
- Recent progress
- Future work

LhARA Overview



Pre-conceptual design report (pre-CDR) publication:

[Aymar, G. et al, Frontiers in Physics, \(8\), September 2020, 567738](https://doi.org/10.3389/fphy.2020.567738)

LhARA baseline design technical note:

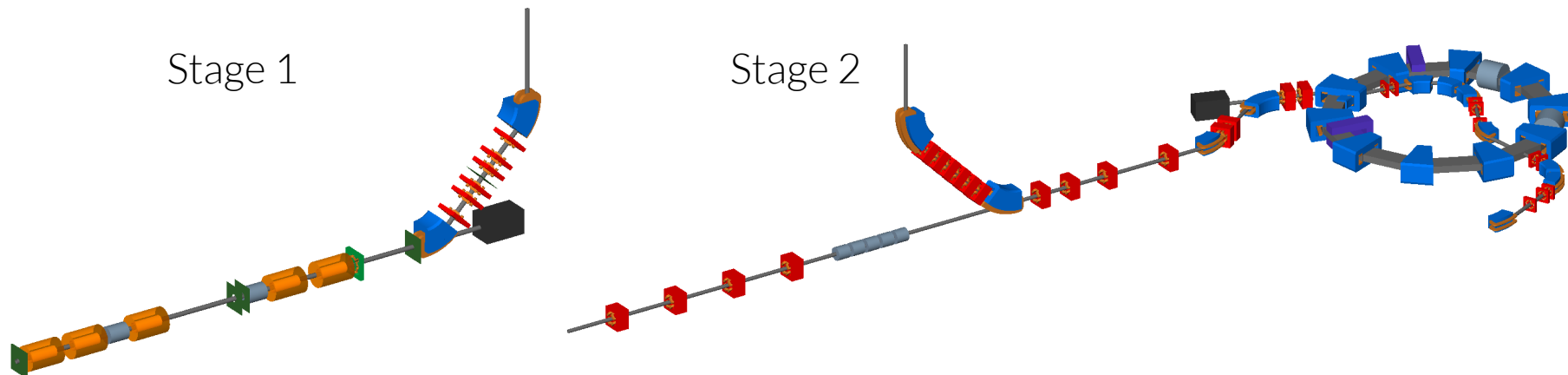
<https://ccap.hep.ph.ic.ac.uk/trac/raw-attachment/wiki/Communication/Notes/CCAP-TN-11-LhARA-Design-Baseline.pdf>

LhARA performance summary

arXiv:2006.00493

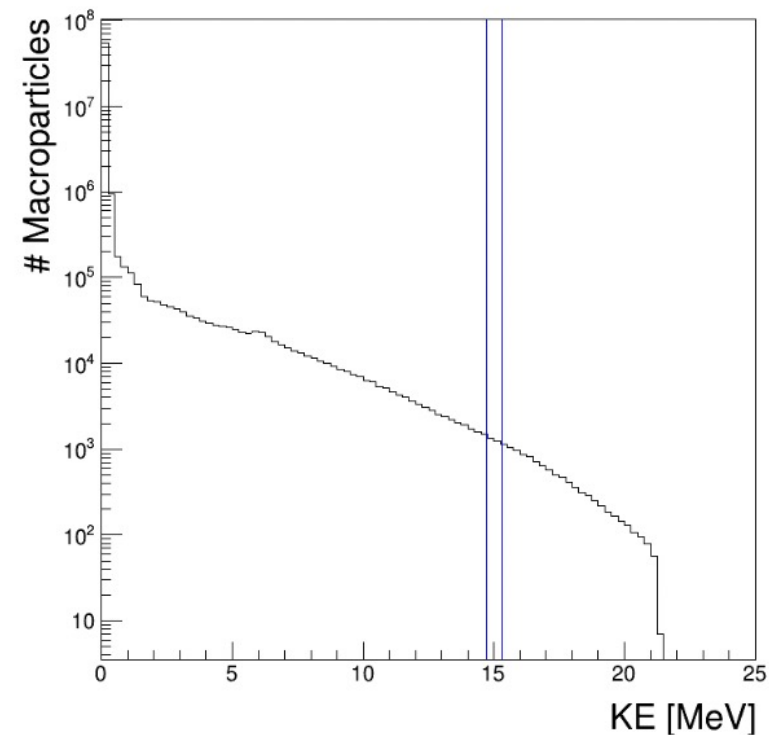
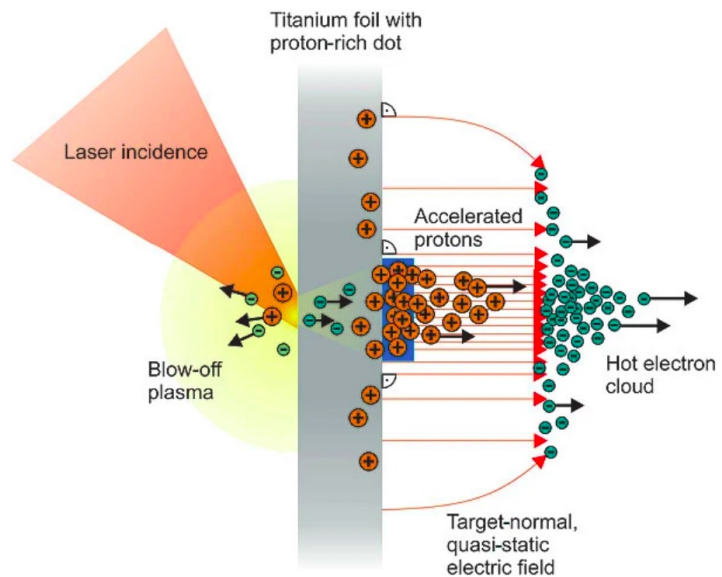
	12 MeV Protons	15 MeV Protons	127 MeV Protons	33.4 MeV/u Carbon
Dose per pulse	7.1 Gy	12.8 Gy	15.6 Gy	73.0 Gy
Instantaneous dose rate	1.0×10^9 Gy/s	1.8×10^9 Gy/s	3.8×10^8 Gy/s	9.7×10^8 Gy/s
Average dose rate	71 Gy/s	128 Gy/s	156 Gy/s	730 Gy/s

- Multi stage:



- Design & validate the LhARA accelerator
 - Performance evaluation
- Monte Carlo particle tracking
 - Hybrid strategy:
 - Madx
 - BDSIM
 - GPT
- Status:
 - Full stage 1 model
 - Injection line
 - Stage 2 high energy lines
- FFA ring design ongoing
 - Jaroslaw's talk

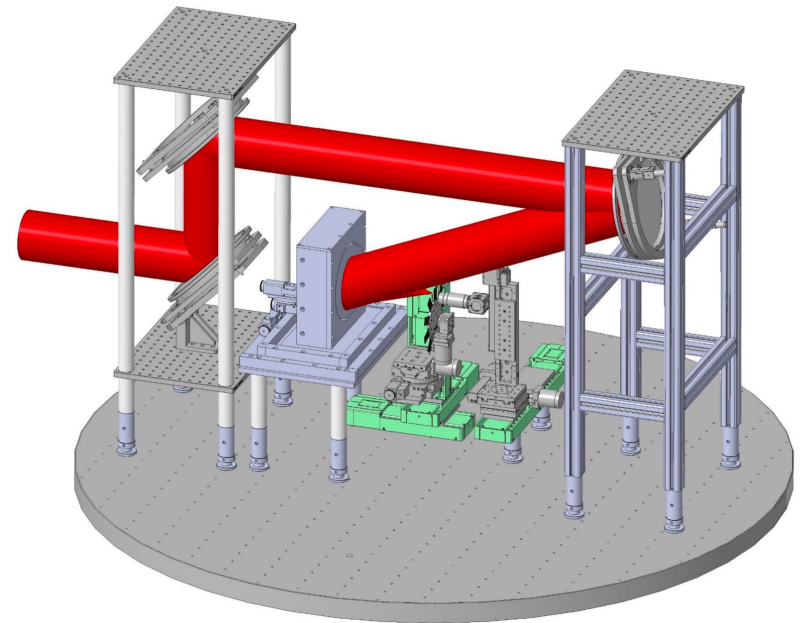
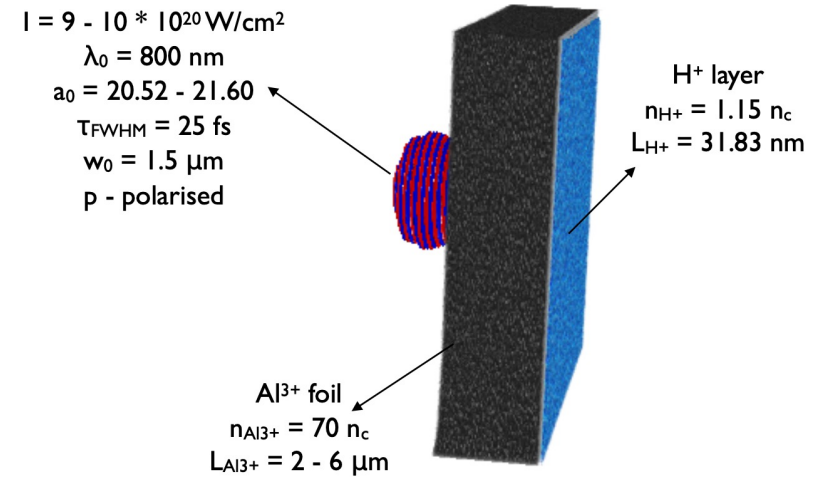
- Laser-driven target normal sheath acceleration (TNSA)
 - 10 GV/m - up to 40 MeV/u.
 - 100 TW laser provides suitable proton flux at LhARA energies
 - Broad quasi-thermal particle spectrum



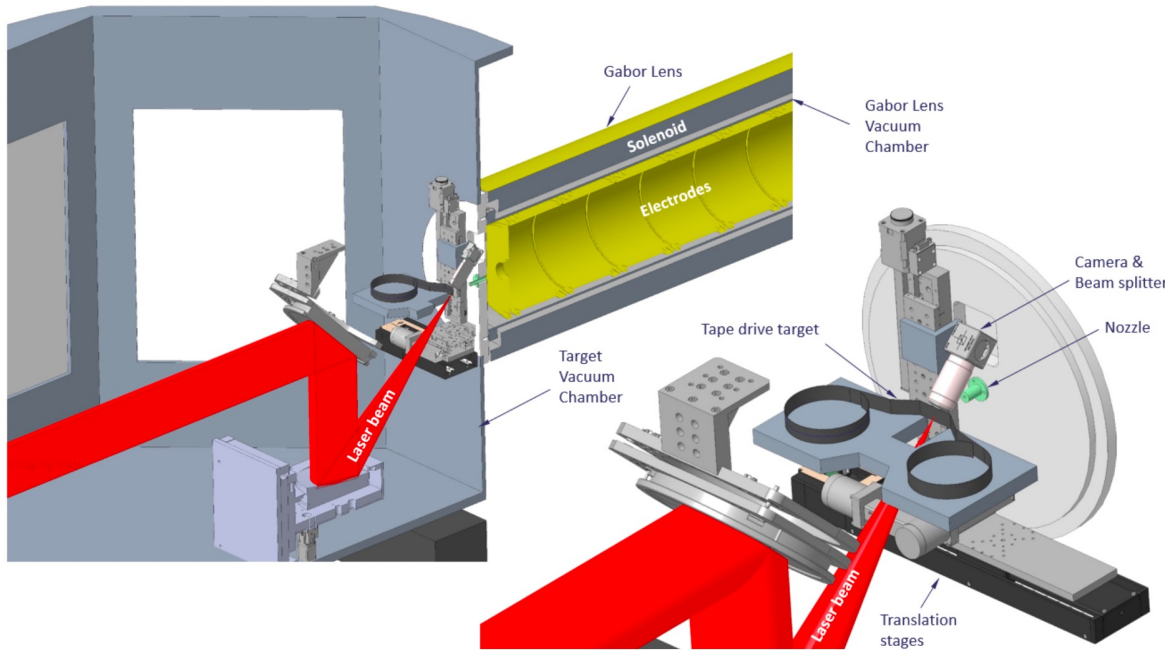
- High bunch charge – 10^9 protons at 15 MeV
- Low transverse emittance ($< 10^{-2}$ mm-mrad)
- Reduced space-charge effects
 - ~ Neutral charge from low energy contaminants

Figure: Schematic diagram of the TNSA process from Schworer [1].

- High intensity laser driven ion sources:
 - High instantaneous dose rate - 10-40 ns bunches
 - 10 Hz repetition rate
 - Triggerable; arbitrary pulse structure
- Proton & ion source prediction
 - 3D TNSA simulations
 - PIC code Osiris
 - SCAPA facility & experimental beam time
- WP1.2: Identify LhARA facility laser requirements
 - Generation of proton (15 MeV) and carbon (4 MeV/u) beams using existing “tape” targets
 - Understanding of debris & stabilisation schemes

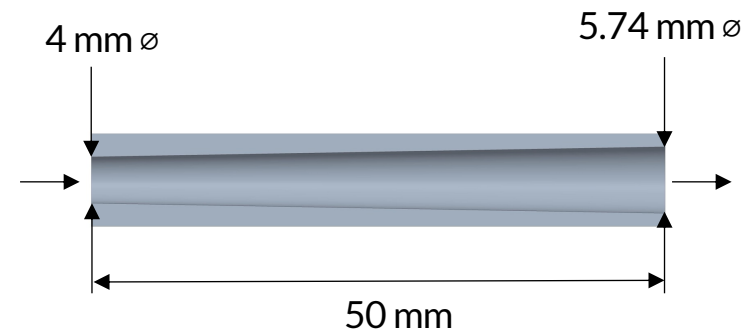


Nozzle & Target Housing

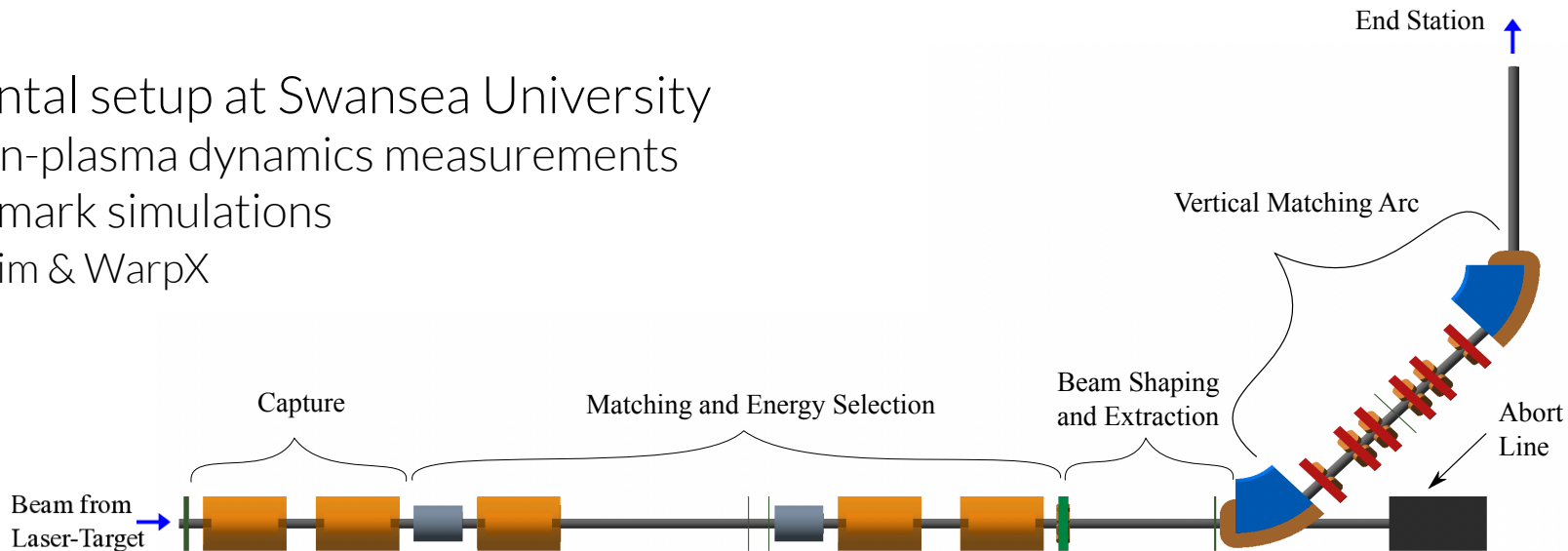
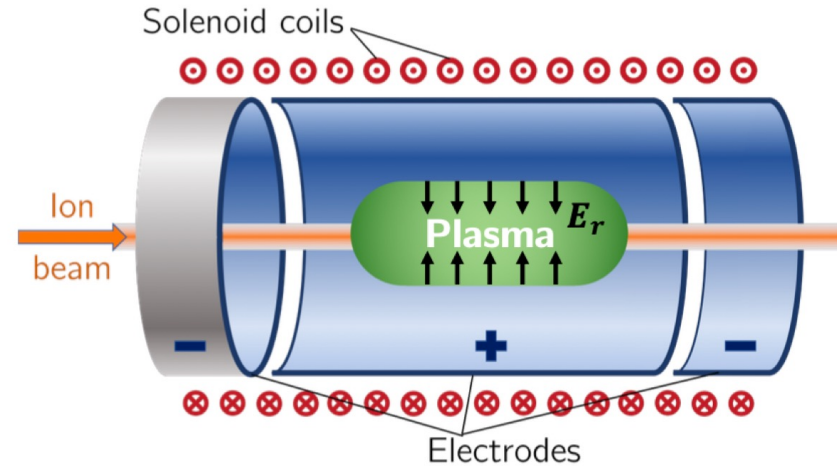


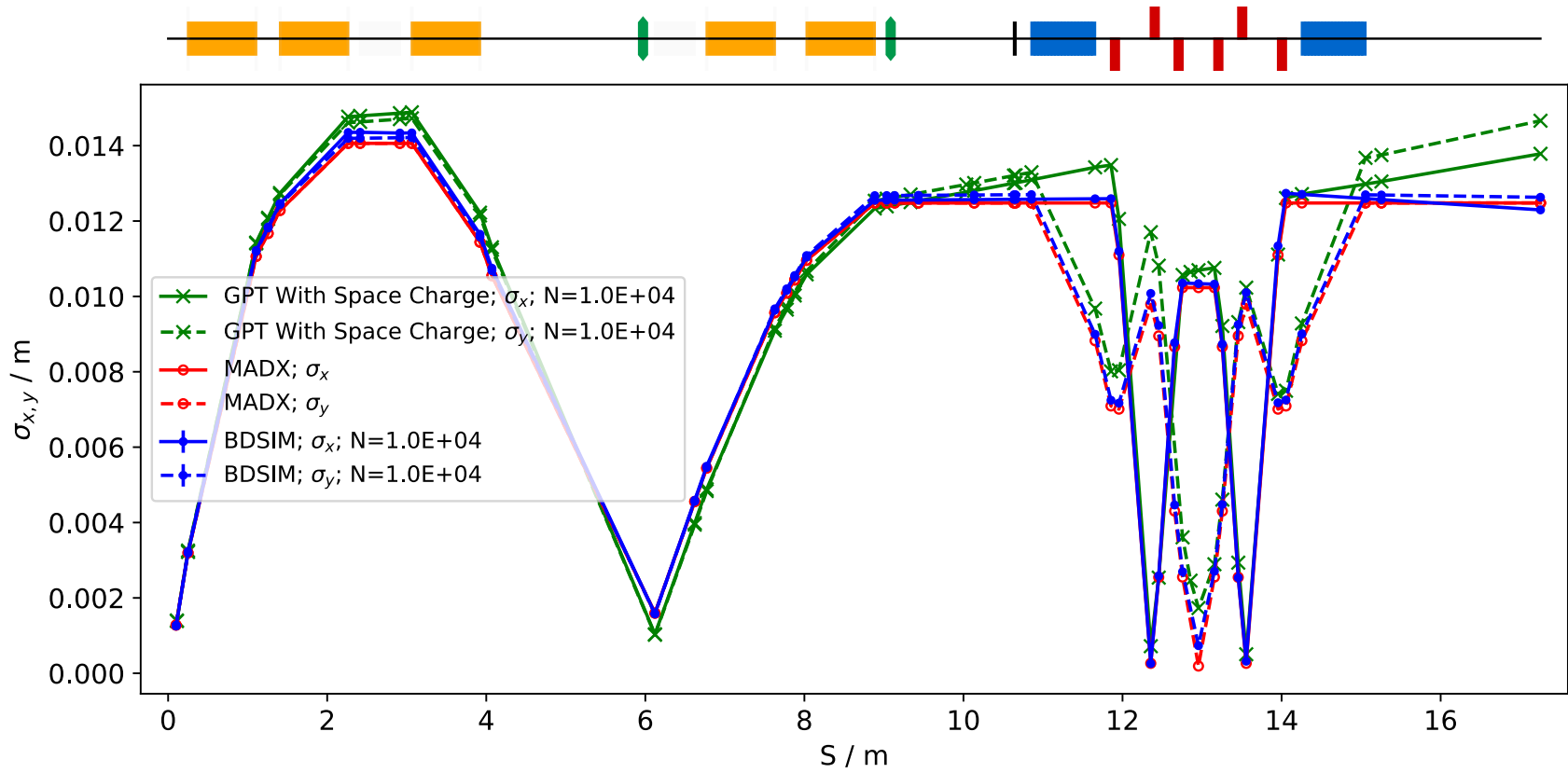
- Ongoing engineering & CAD designs
 - Tight spatial constraints – laser transport, target holder, diagnostics, particle beam profilers, vacuum, ...
- Gabor lens target proximity for capture efficiency

- Vacuum nozzle collimation
 - Aperture dictates downstream beam dimensions
- Beam tracking including space-charge forces
- Studies of co-propagating beam to be performed
 - Uncertainty in beam profile & spectrum.



- Novel Gabor electron-plasma-lens
 - Capture & focusing
 - Strong focusing without high power, high-field solenoid
 - Focus in both planes simultaneously
 - Energy-dependent focusing strength
- Develop a detailed design of the next generation Gabor-lens prototype
- Experimental setup at Swansea University
 - Electron-plasma dynamics measurements
 - Bench-mark simulations
 - VSim & WarpX





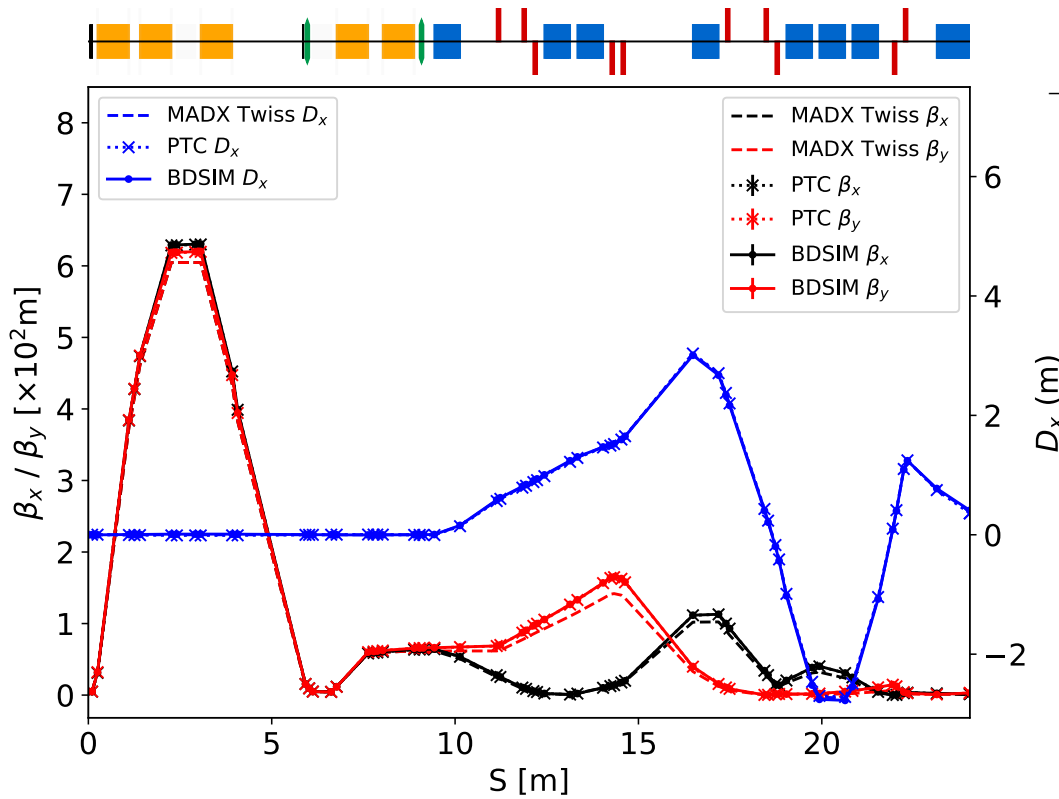
- Requirements:

- Parallel beam between GL2 & GL3
 - Flexibility: RF, shielding wall, ...
- GL3 focal plane at the stage 1 energy collimator location
- Parallel beam after GL5

- Solutions found

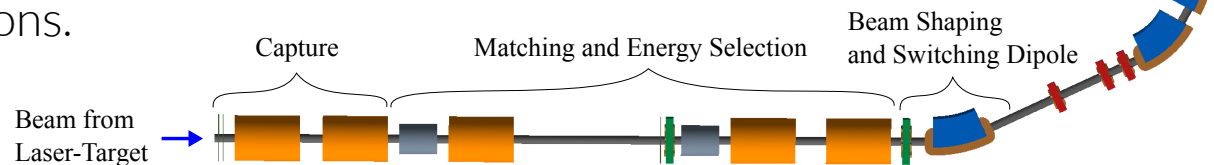
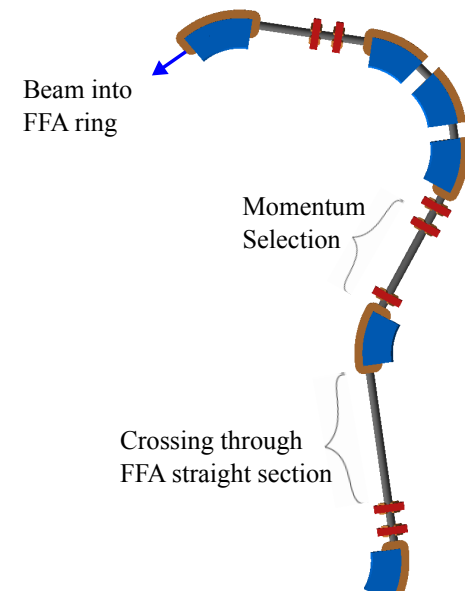
- 1.4 T solenoid field limit
- Optimise collimation, octupoles, etc....

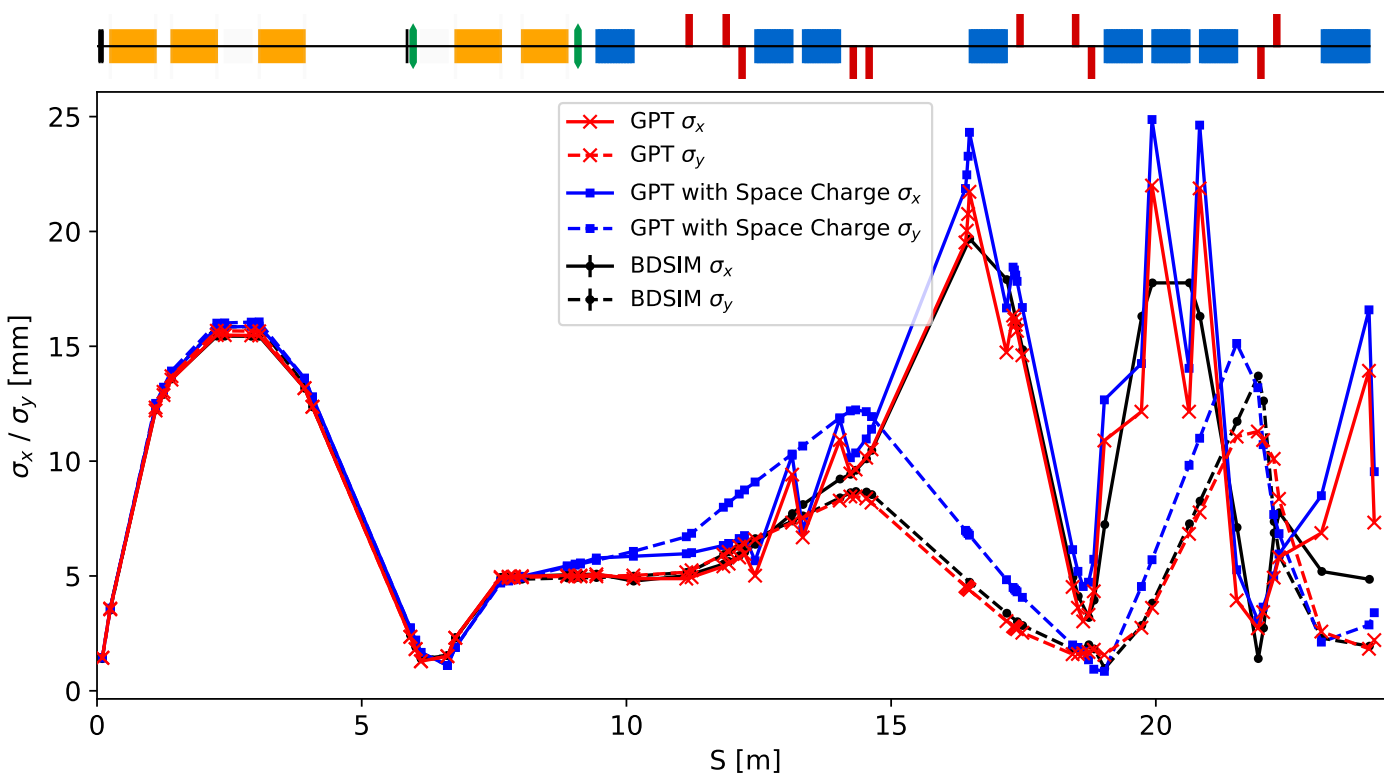
FFA Injection Line



- BDSIM and PTC show excellent agreement for the beta function and dispersion.
 - 10000 particles tracked in BDSIM & PTC – idealised beam.

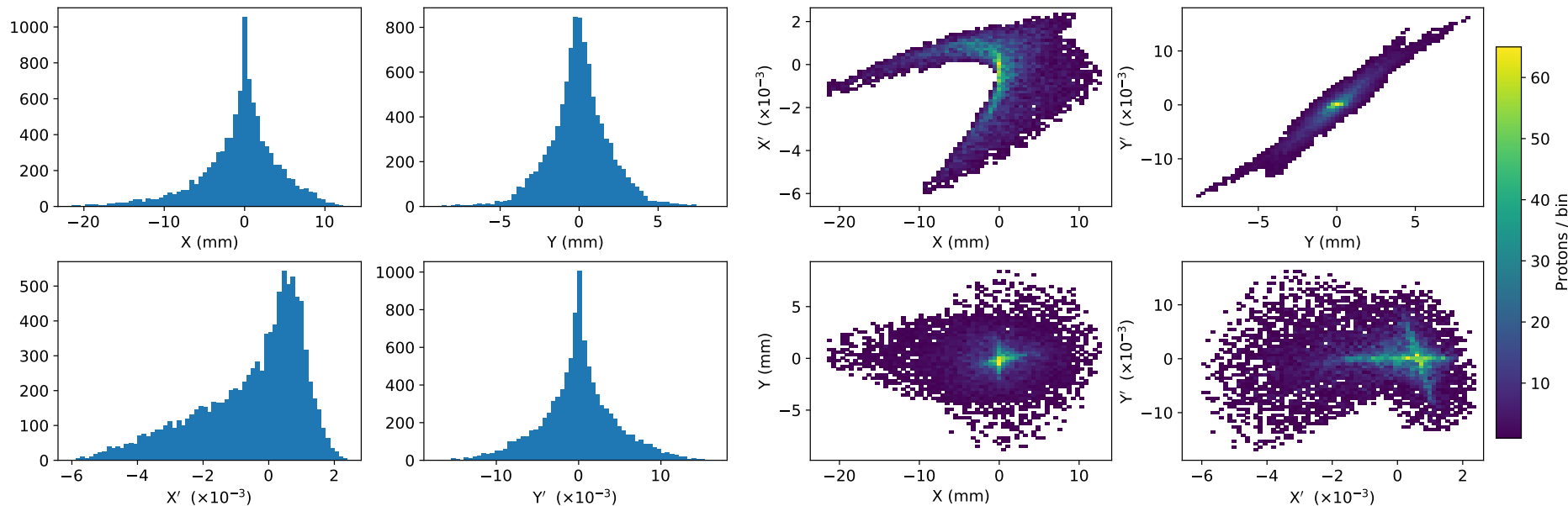
- Slight discrepancy w.r.t. original MADX Twiss parameters – known behaviour for low energy, non-paraxial beams.
- Minor tweaks required for beta and horizontal dispersion to match FFA cell conditions.





- 10000 particles representing a total bunch charge of 10^9 protons.
- Good agreement between BDSIM and GPT without space charge.
- Beam size jumping is a GPT simulation artefact

- Emittance growth impacts performance
 - Final dimensions do not match FFA cell requirements - optimisation is required
- Remodelling with SCAPA beam required
 - Dependant on stage 1 optics solutions

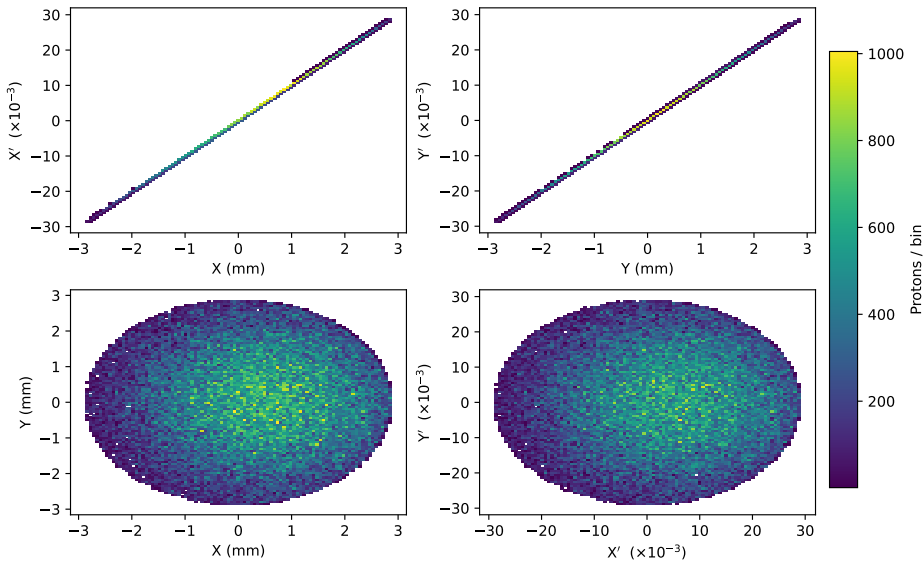
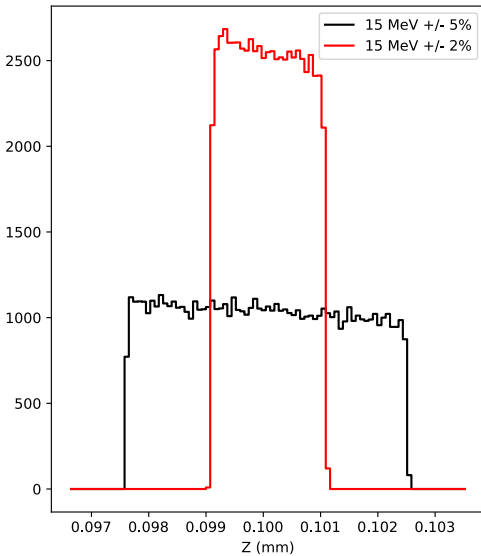
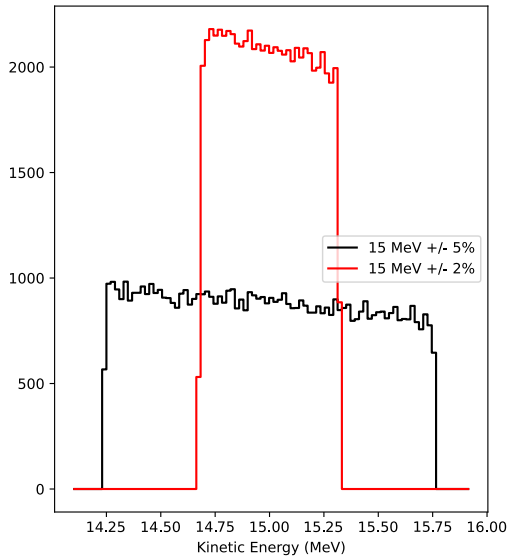
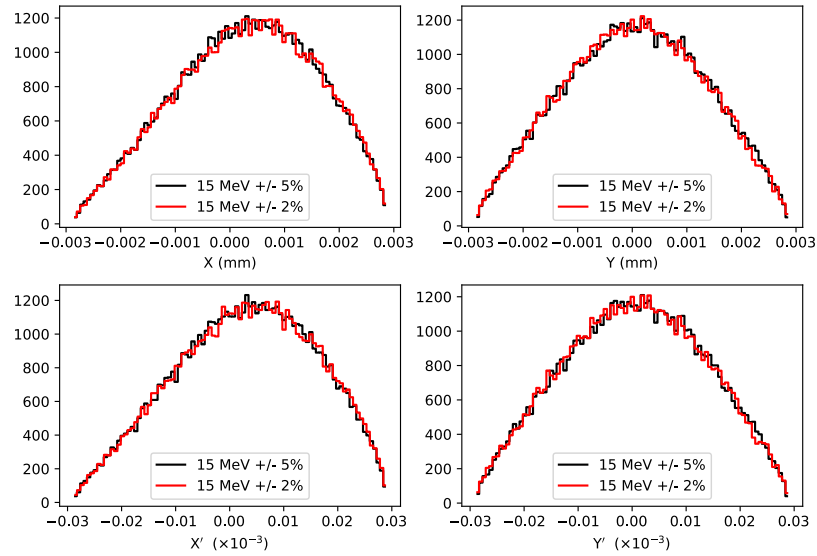


- Aberration originates in the solenoids / Gabor lenses
 - Challenging to mitigate
 - Anticipate little impact on tracking performance & FFA acceptance
- Further momentum selection / cleaning studies are required.

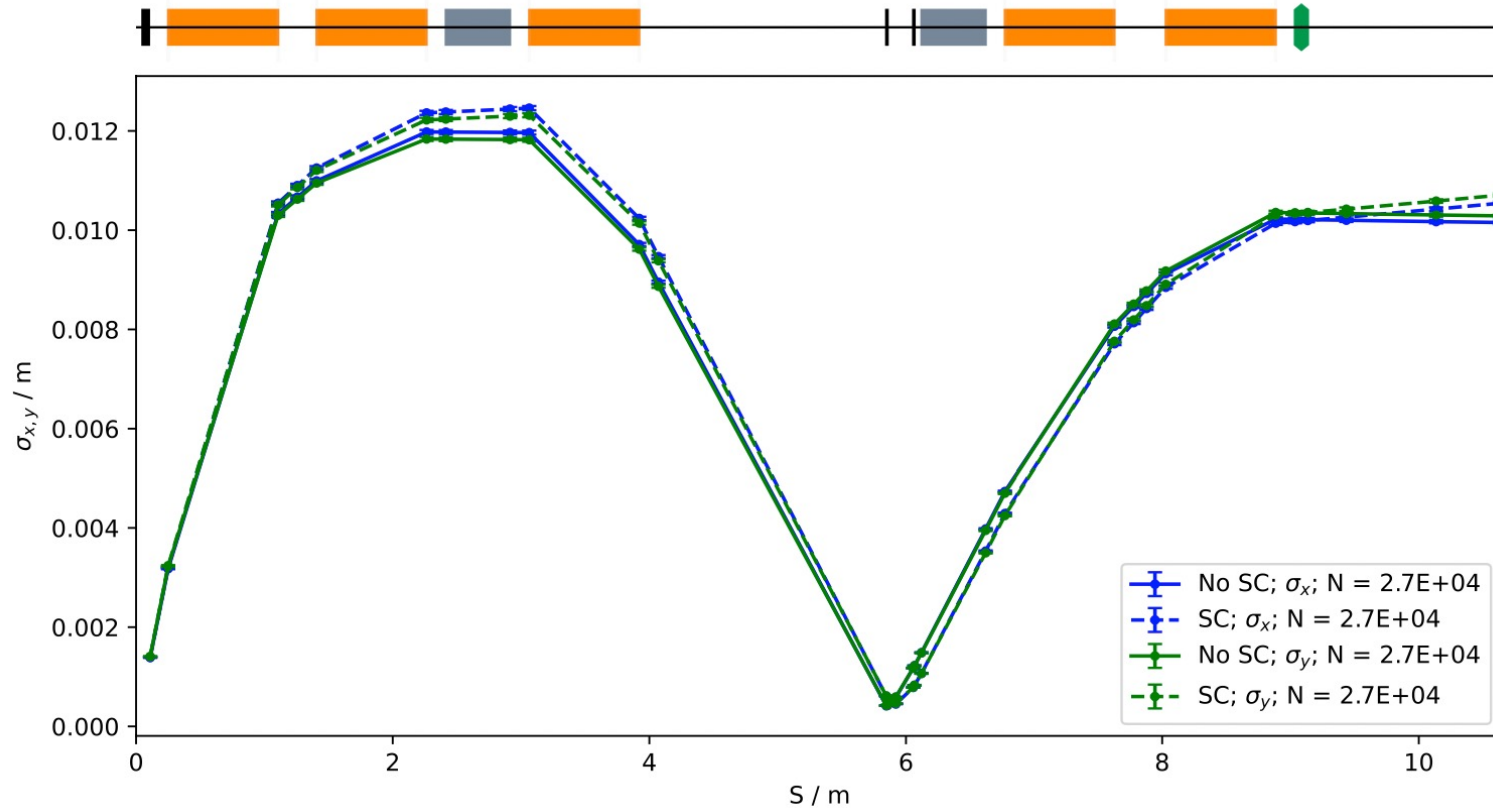
	Smilei Sampled Beam	SCAPA Beam	Pre-CDR Beam
Mean RMS emittance [m]	1.43×10^{-8}	7.98×10^{-8}	3.26×10^{-7}
Mean beta [m]	141.34	21.62	4.89
Mean alpha	-1418.43	-222.23	-50.22

- Large discrepancy between SMILEI sampled beam and assumed pre-CDR emittance
 - Not fully understood. 2D simulations known to suffer from several issues.
 - SMILEI beam not considered reliable
- 3D SCAPA simulation shows improved agreement
 - Down-sample to 15 MeV \pm 2%
 - 15 MeV \pm 5% for collimation studies

Stage 1 SCAPA Beam



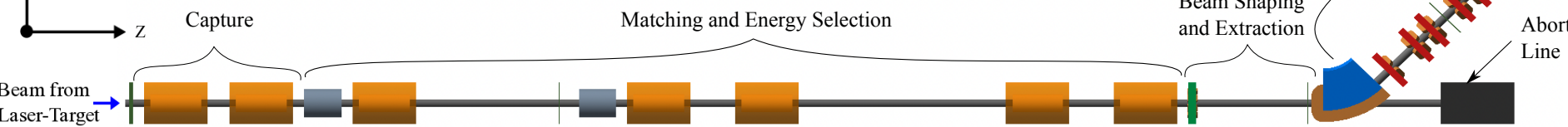
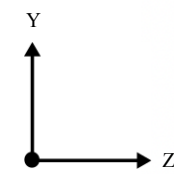
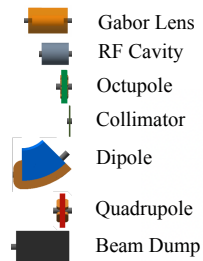
- Vacuum nozzle transmission ~ 77%
- Minimal spectral impact
 - Greater emphasis on downstream collimators performance
- Horizontal offset does not impact tracking performance

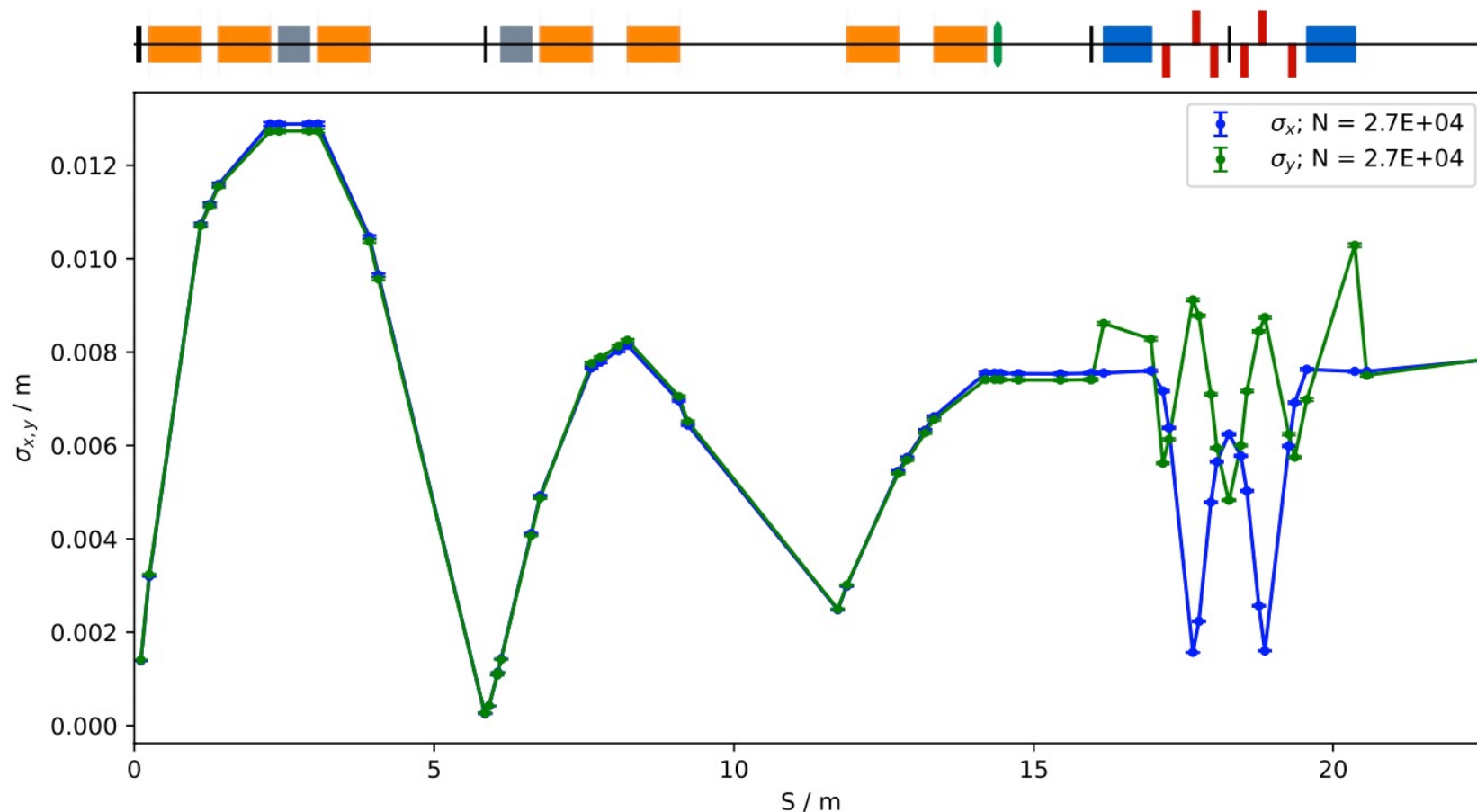


- Nominal stage 1 Gabor lens settings optimised
- Additional solutions for smaller spot sizes
- Difficulties in achieving beam parameters for FFA injection requirements ($\beta = 50\text{m}$).
 - Challenging without space-charge considerations

7 Gabor Lens Configuration

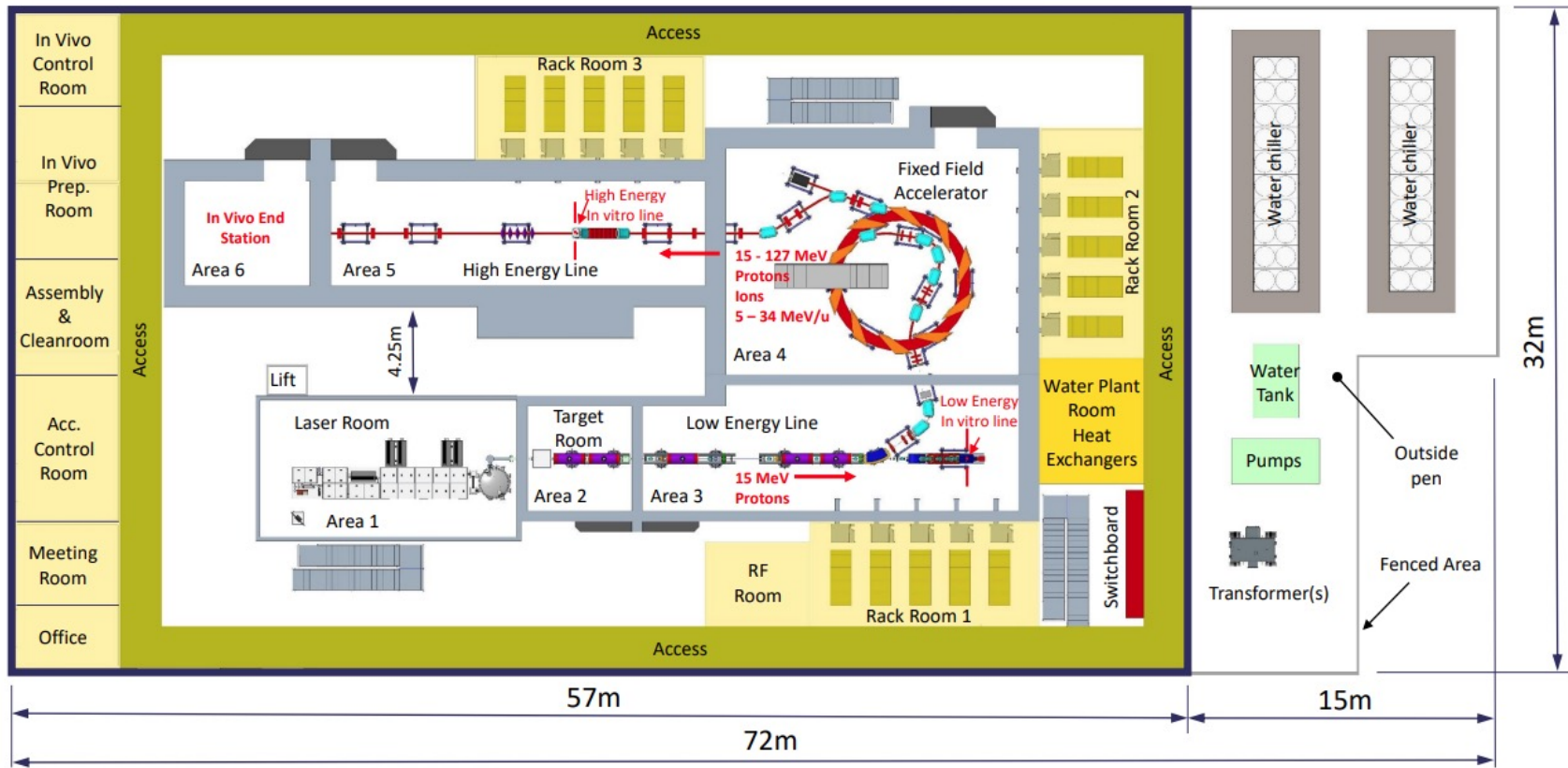
- Investigation of 7 Gabor lens / solenoids configuration
- Improved spot-size flexibility & FFA injection performance
- Geometry modifications:
 - Single energy collimator
 - Extra 0.2m between GL4 & GL5
 - 2.5m long drift after GL5
 - GL6 & GL7 added in same configuration as GL4 & GL5
 - 5.314m total length increase





- Space charge impacting performance
 - Same requirements as 5 lens configuration
 - Optimised solutions for 7.5, 6.25, & 5.0 mm spot size with space charge
 - Smaller beams remains focus of ongoing work.

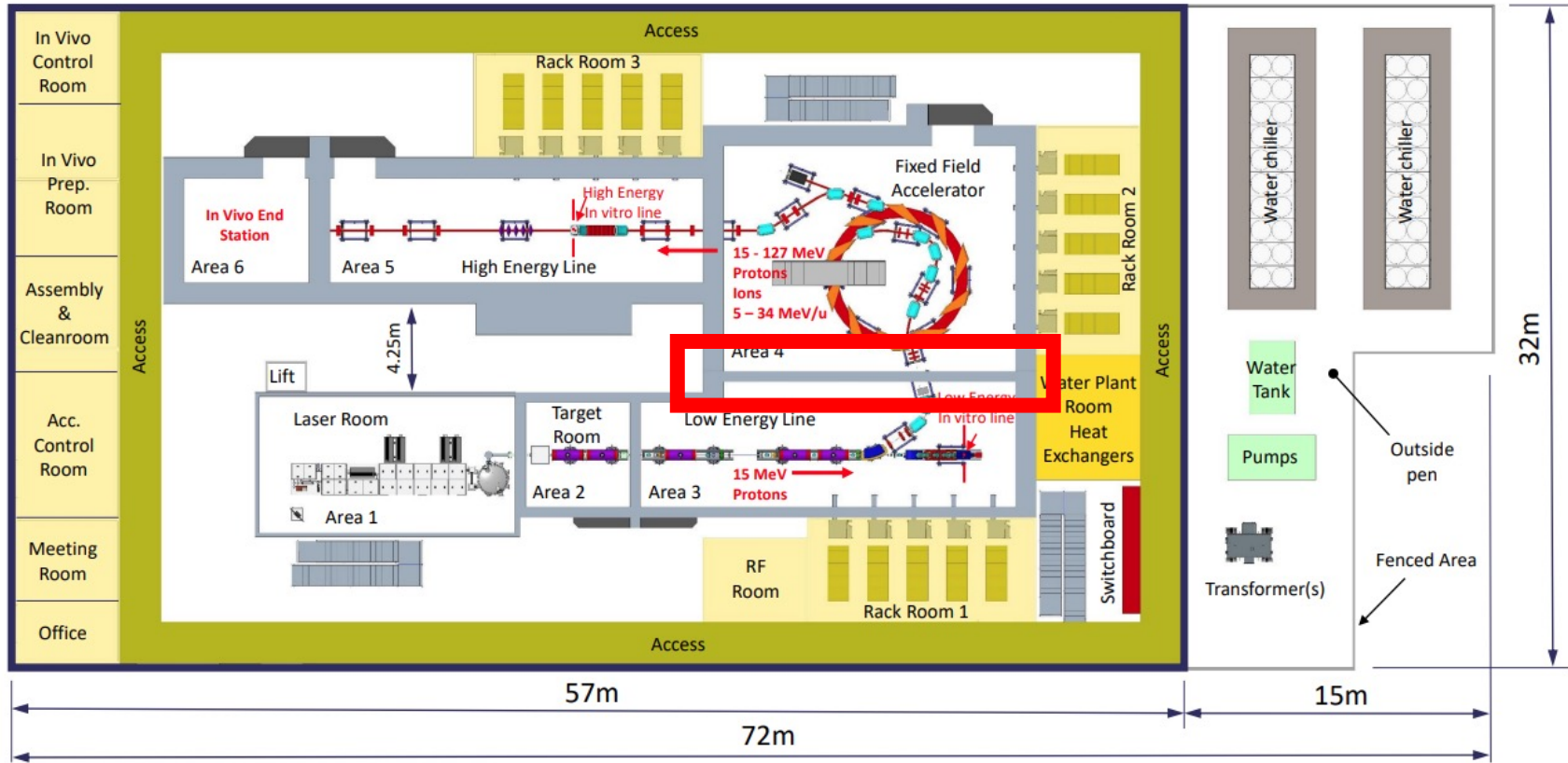
Facility Integration



- Engineering design underway
 - Iterate as systems develop

Magnets, RF, Diagnostics, End stations, Shielding, Electrical power, Cooling, Vacuum, Controls, ...

Injection Line Redesign



- Shielding wall for concurrent development/operation of stage 1 & stage 2.
- Injection line redesign needed.
 - Optics dependant on FFA injection requirements

- Continued evaluation of 7 Gabor lens configuration
 - Comparison to baseline design performance
- FFA Modelling
 - Optical performance, space-charge evaluation, injection & extraction, RF,
- Redesign efforts
 - FFA – today's raison d'être.
 - Injection line
- Stage 2 post-FFA evaluation
 - Extracted beam parameters

- Established stage 1 performance of the baseline design
- Encouraging stage 1 experimental configuration in development
 - Impact studies on injection line performance planned
- Ongoing work program for FFA & injection line redesign



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Thank you

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Parameter Summary

