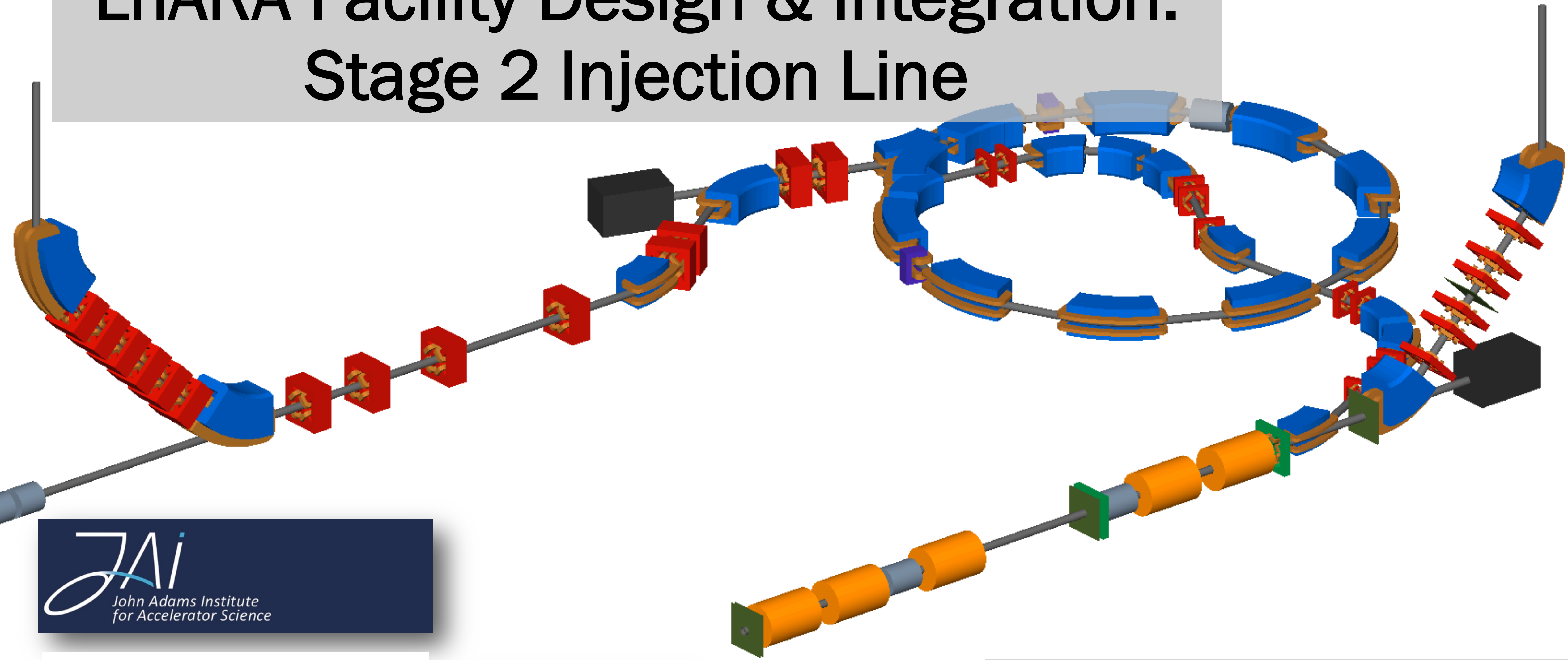
LhARA Facility Design & Integration: Stage 2 Injection Line



John Adams Institute for Accelerator Science

LhARA Laser-hybrid Accelerator for Radiobiological Applications

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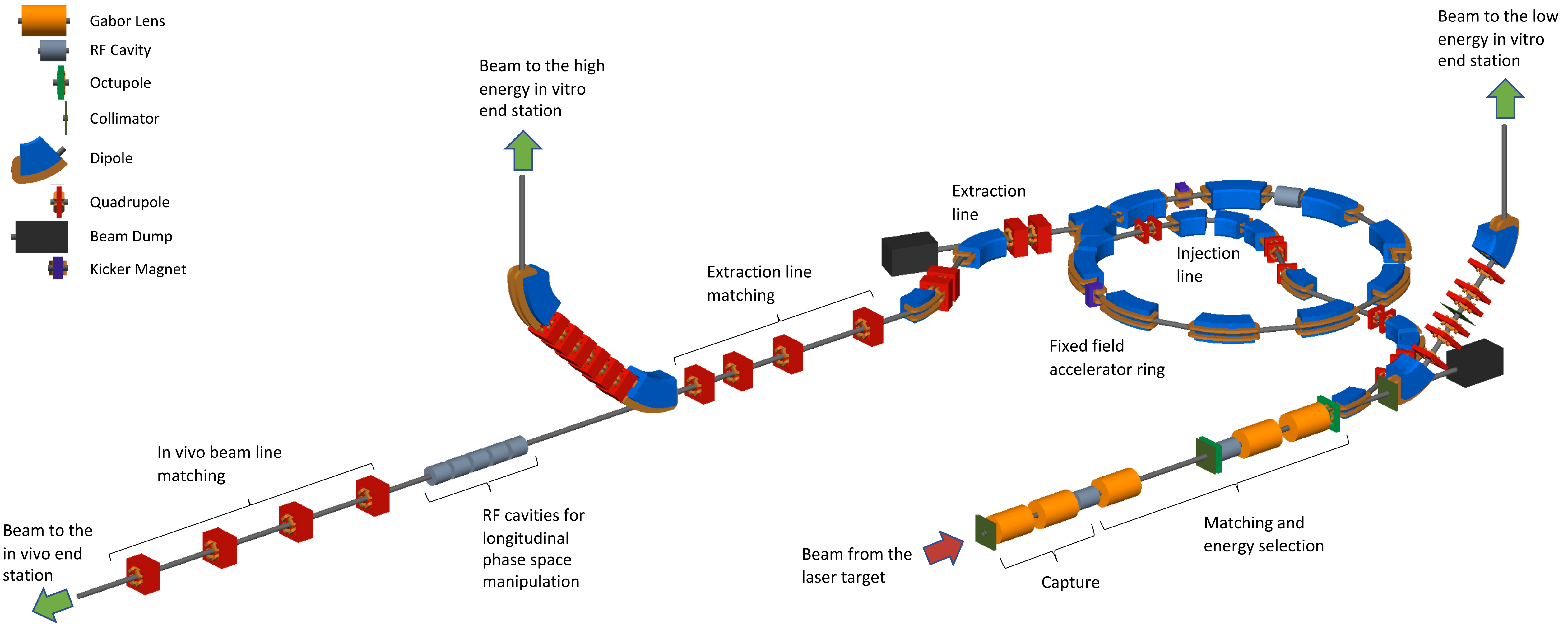
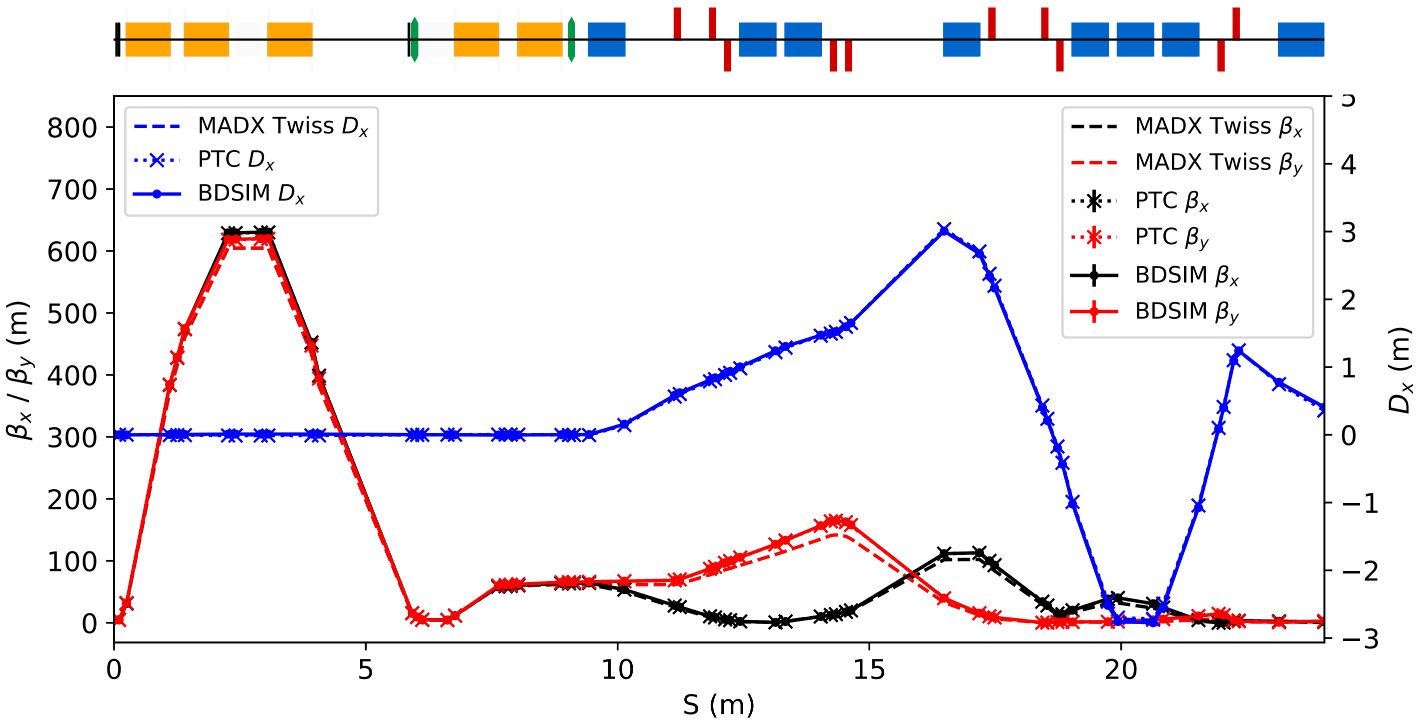
LhARA: Overview

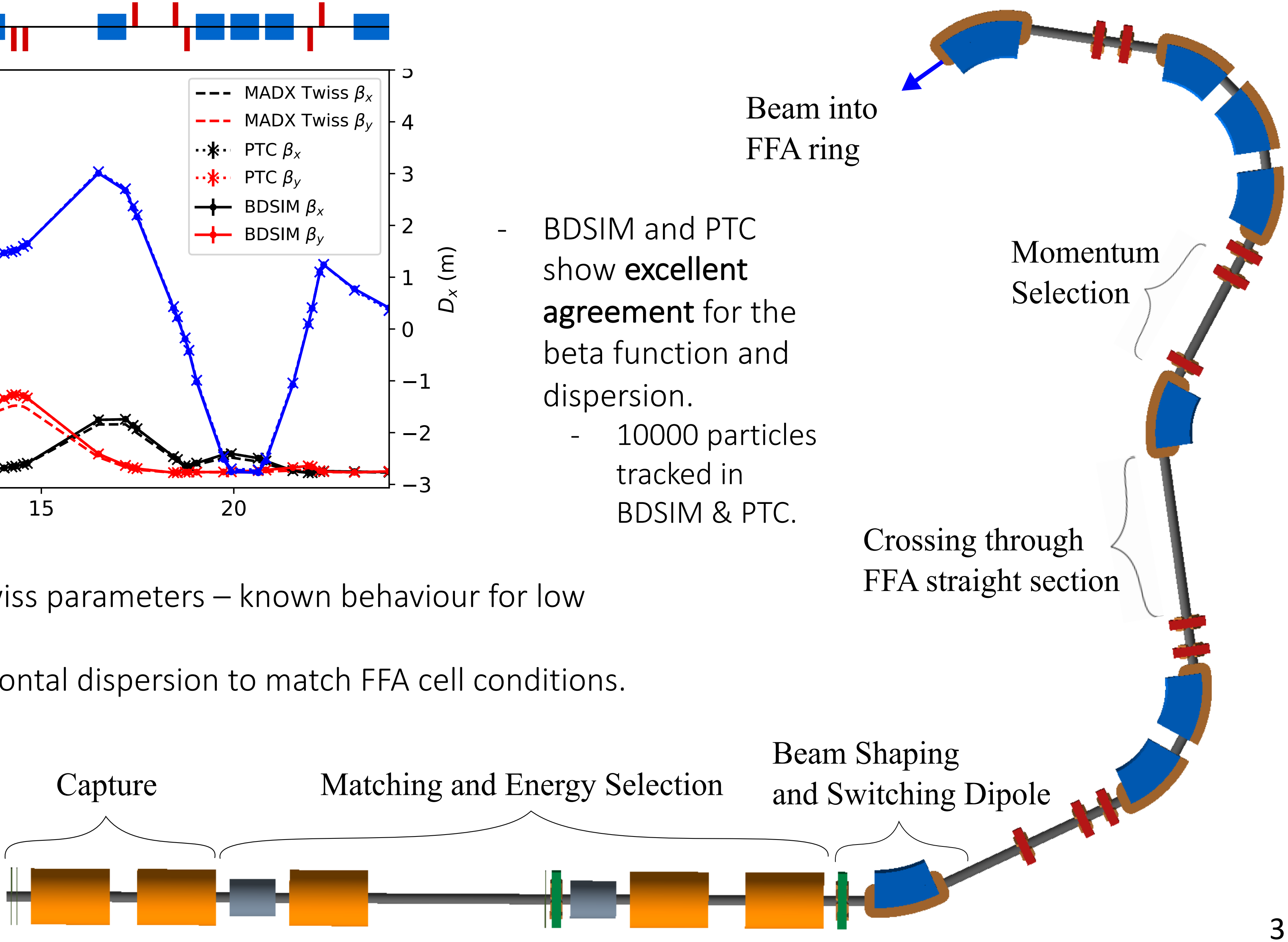


- Up to date full model
  - Collimators including laser-target nozzle

LhARA Injection Line: Optical Verification

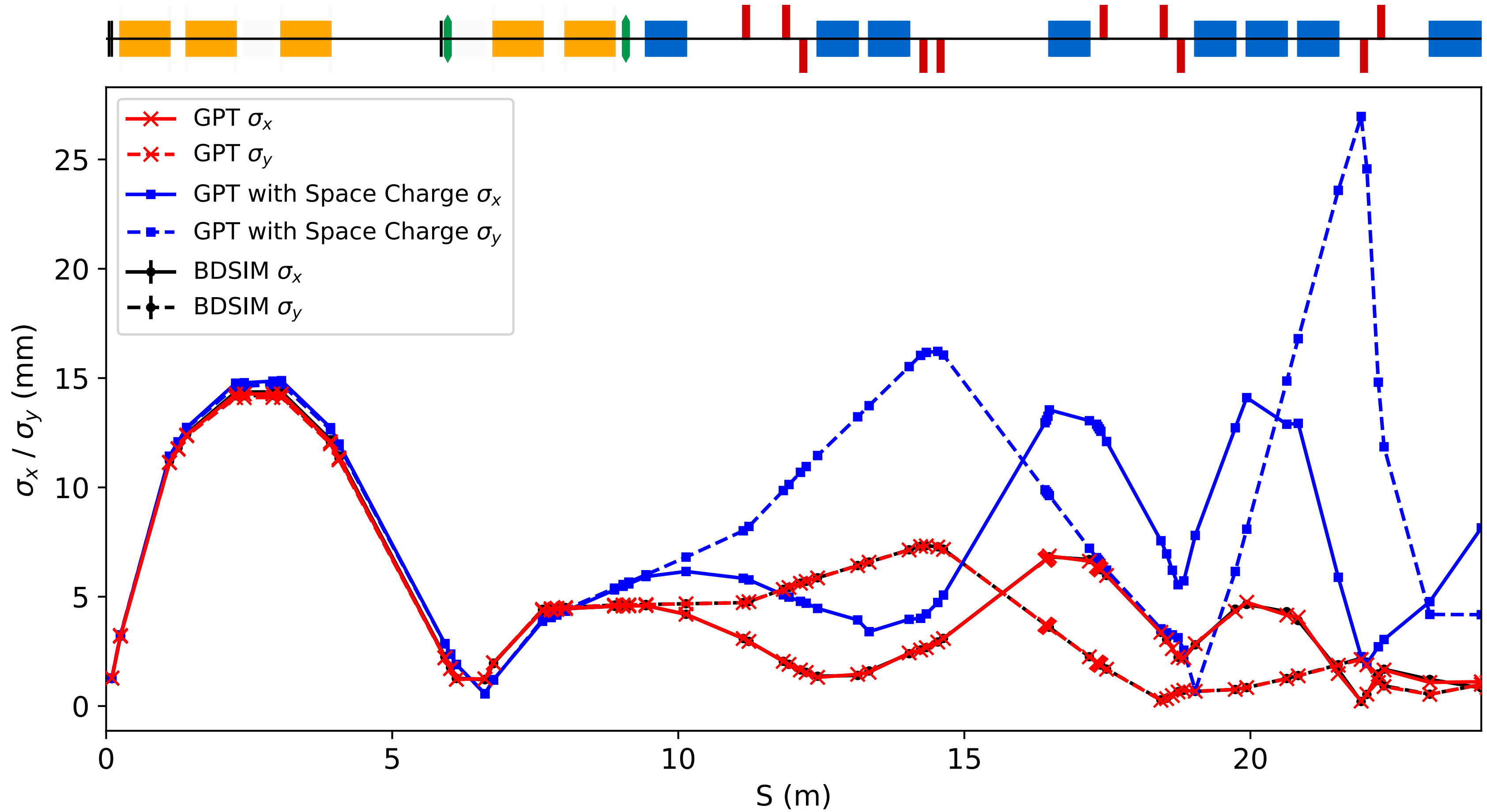


- BDSIM and PTC show **excellent agreement** for the beta function and dispersion.
  - 10000 particles tracked in BDSIM & PTC.



- 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.

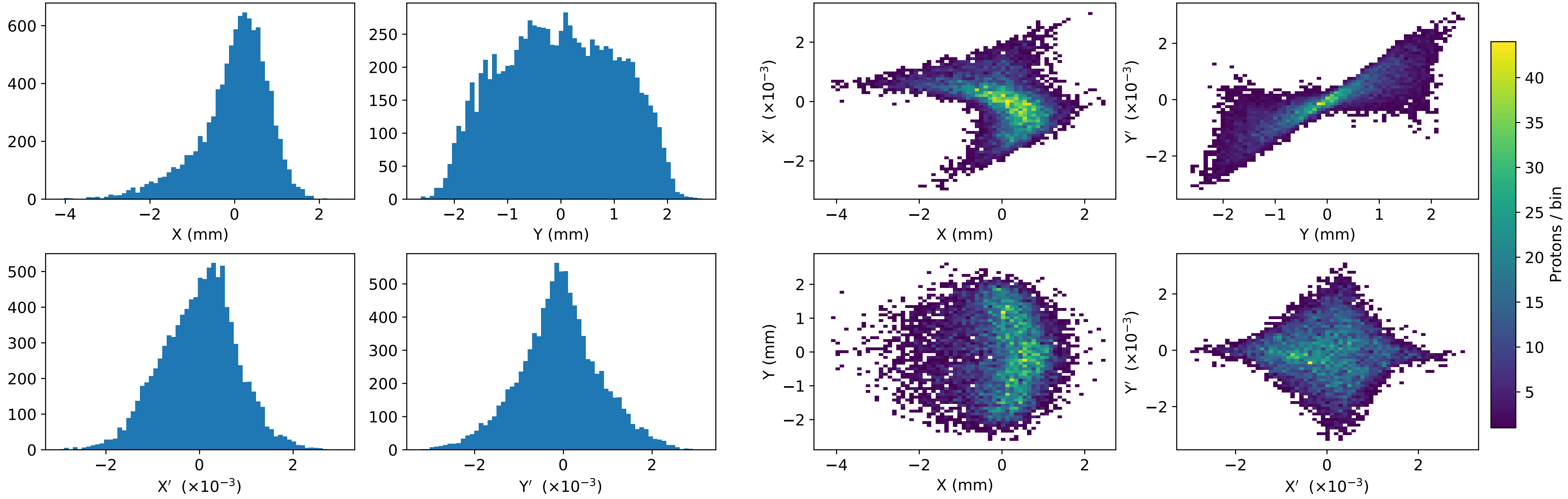
Optical Performance with Space Charge Effects



- Simulation of an ideal beam. No nozzle collimation.
- BDSIM and GPT show excellent agreement when not considering space charge.
- Space charge was simulated with 10000 particles representing a total bunch charge of 10^9 protons. An **initial emittance growth** results in a larger than nominal beam in the capture section.

- A significant impact on the downstream optical performance is observed, deviating from the design optics.
- Injection line beam focusing is limited to one dimension, we anticipate **minimal impact** from space charge effects after the switching dipole.
- Further **optimisation is needed** to improve capture performance.

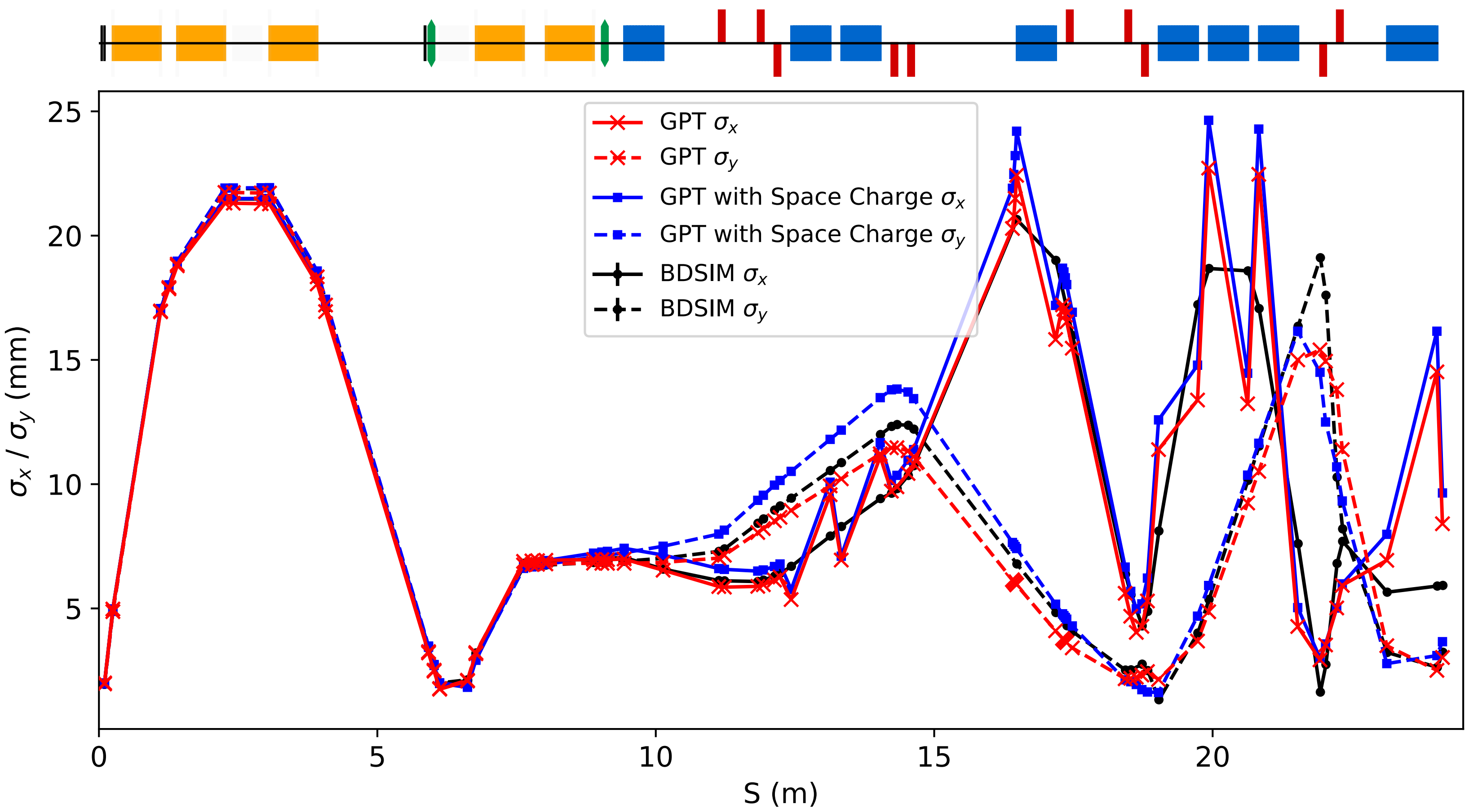
Ideal Beam Phase Space – Stage 2 Injection Line



- Stage 1 aberration also seen in the injection line
    - Arises in the capture section solenoids & persist throughout the injection line

- Further investigation needed – source & potential mitigation if necessary
    - Replacement of the solenoids by full electromagnetic simulations of the Gabor lenses.

Performance with a Laser-Target Sampled Beam



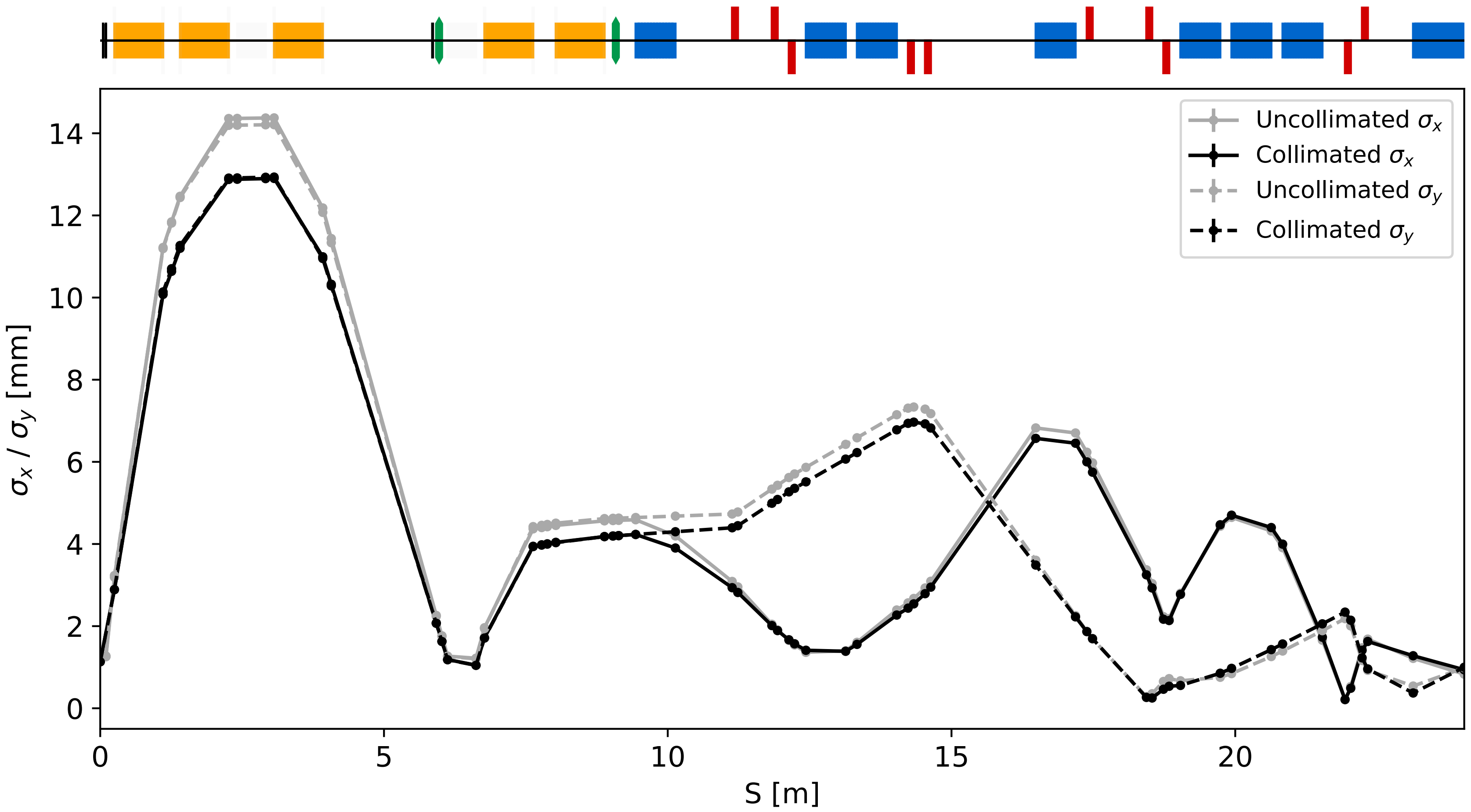
- Semi-realistic beam generated from sampled output of laser-target interaction simulation (not collimated).

- Particles outside of the 3.65cm Gabor lens radius were not fully focussed, resulting in a beam halo and subsequent losses.
  - Radius widened to study downstream optical performance.

- Broadly similar results obtained with BDSIM & GPT. Smaller emittance growth from space charge effects.
  - Final dimensions do not match FFA cell requirements. Further **optimisation is therefore required**.

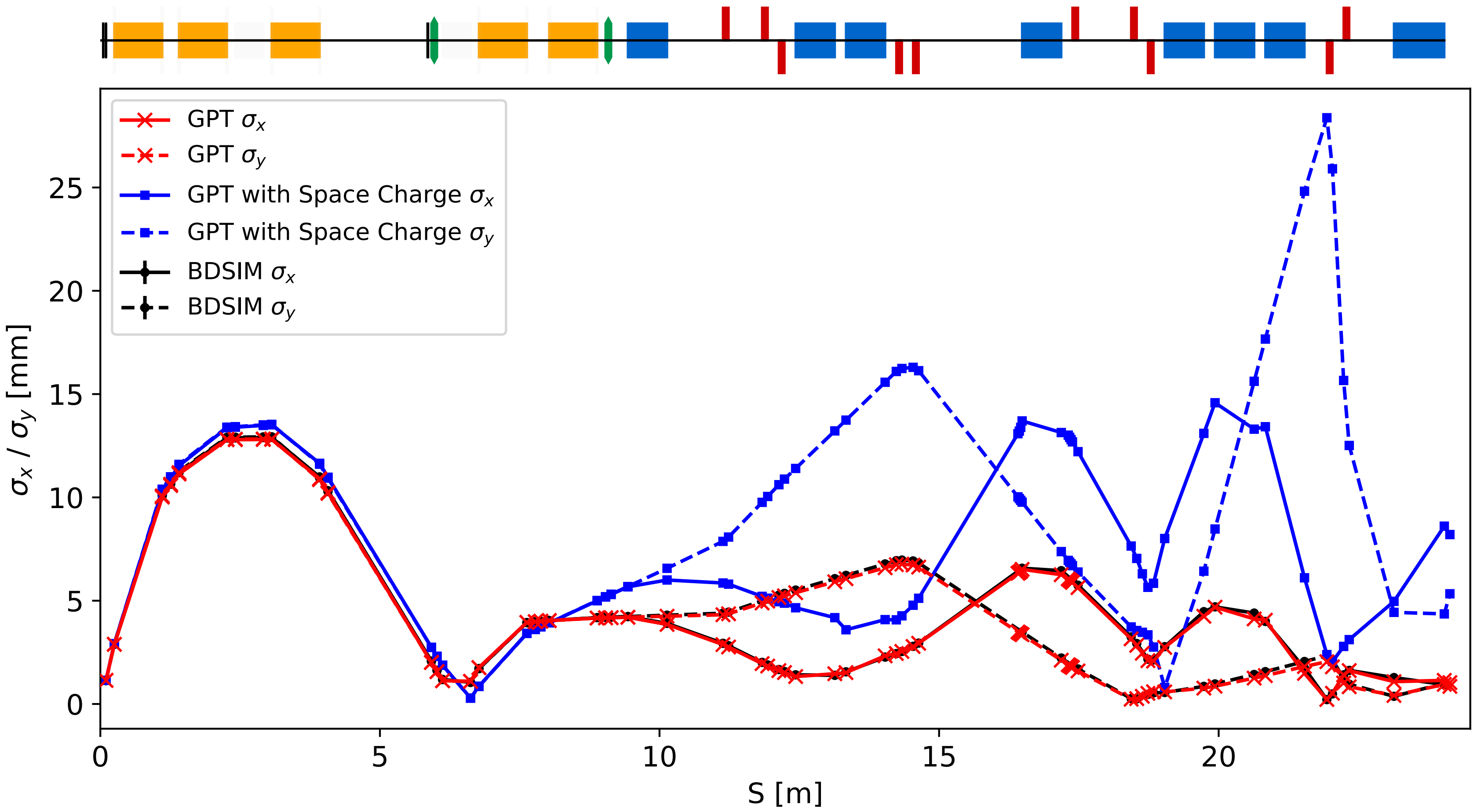
- Horizontal beam size jumps are due to a longer temporal profile in GPT snapshots capturing the bunch partially within sector-bend fields.

Ideal Beam: Vacuum Nozzle Collimation



- Ideal beam collimated using stage 1 operation settings (see HT's slides).
- 10000 particles in BDSIM
- Similar behaviour observed. Only a small deviation in the beam dimensions at the point of FFA injection is observed.

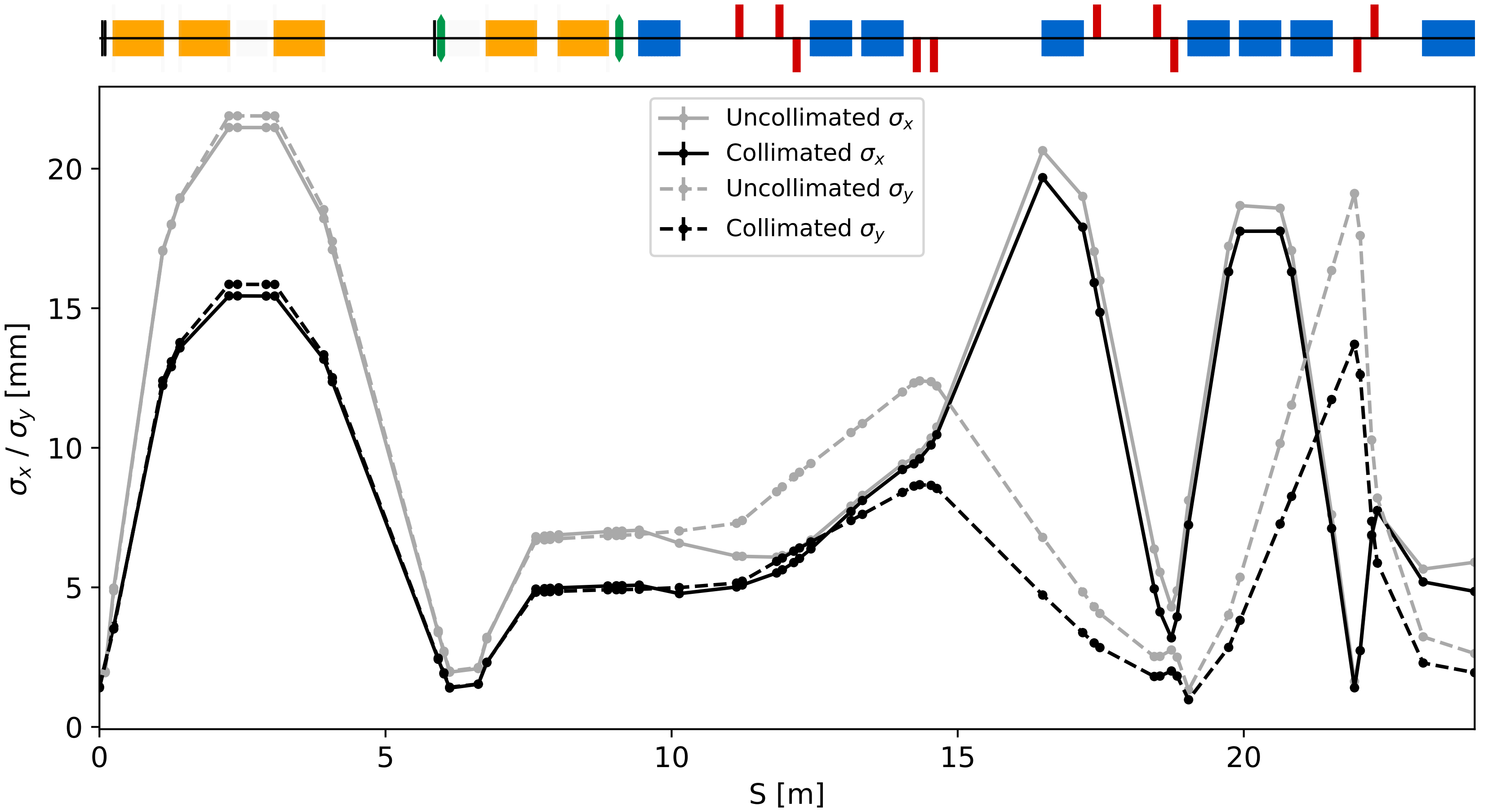
Ideal Collimated Beam: Optical Performance



- Collimated beam simulated in GPT with & without space charge.
- 10000 particles representing a total bunch charge of 10^9 protons.
- Excellent agreement between BDSIM and GPT without space charge.

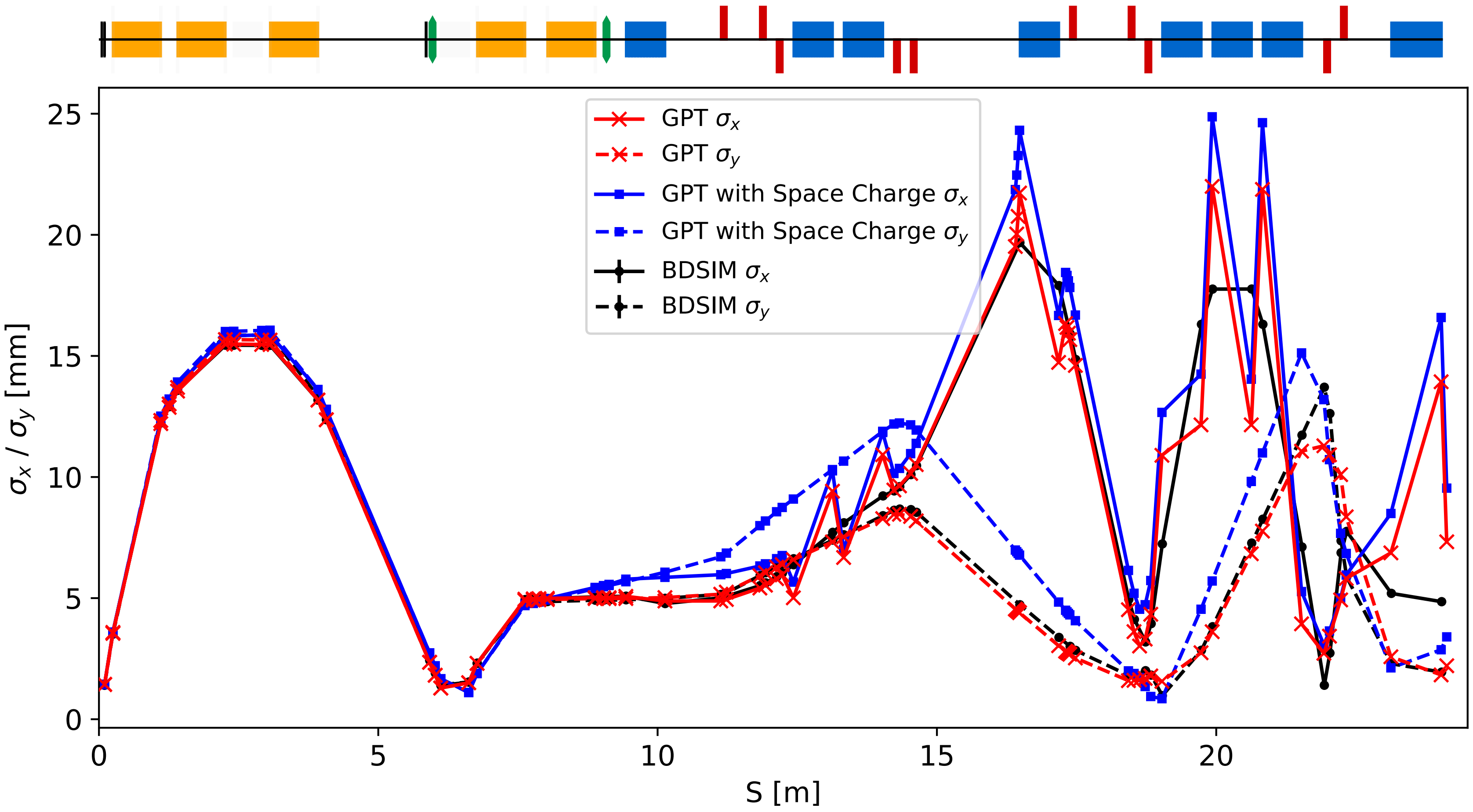
- Early emittance growth due to space charge persists despite vacuum nozzle collimation.
- Optimization of the Gabor Lens strengths is needed.

Sampled Beam: Vacuum Nozzle Collimation



- Sampled beam collimated using stage 1 operation settings.
- 10000 particles in BDSIM
- More of a discrepancy observed, but the final beam parameters are not too dissimilar to the uncollimated beam.

Sampled Collimated Beam: Transport Performance.

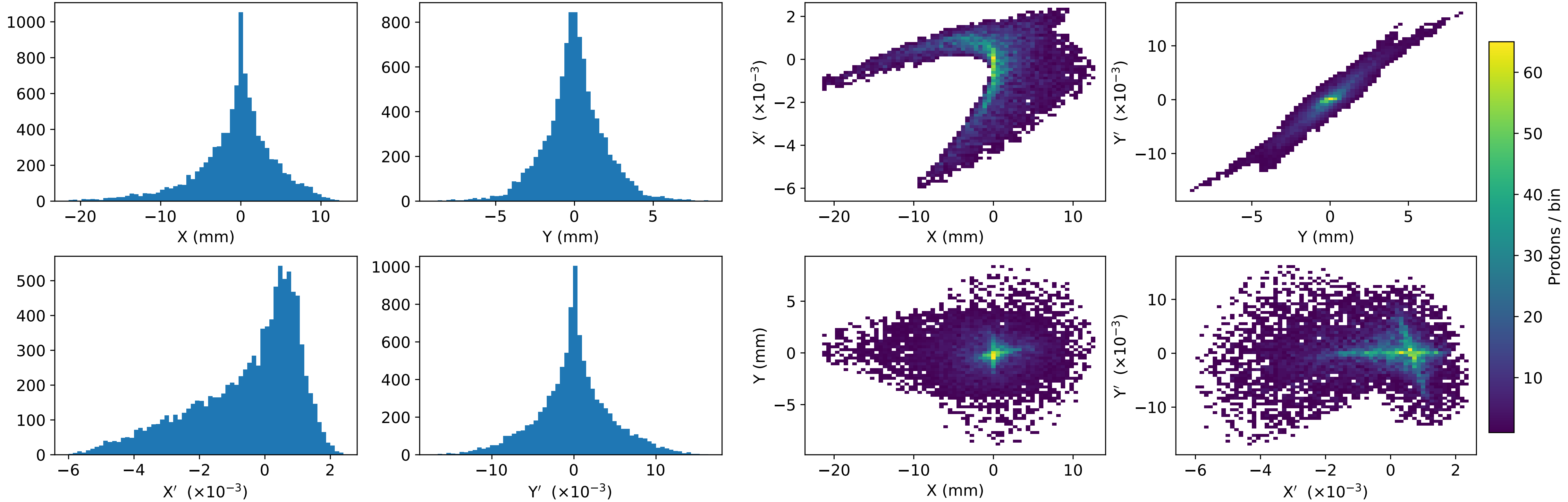


- Collimated beam simulated in GPT with & without space charge.
- 10000 particles representing a total bunch charge of 10^9 protons.
- Good agreement between BDSIM and GPT without space charge.

- Emittance growth still observed
  - Final dimensions do not match FFA cell requirements. Further optimisation is therefore required.

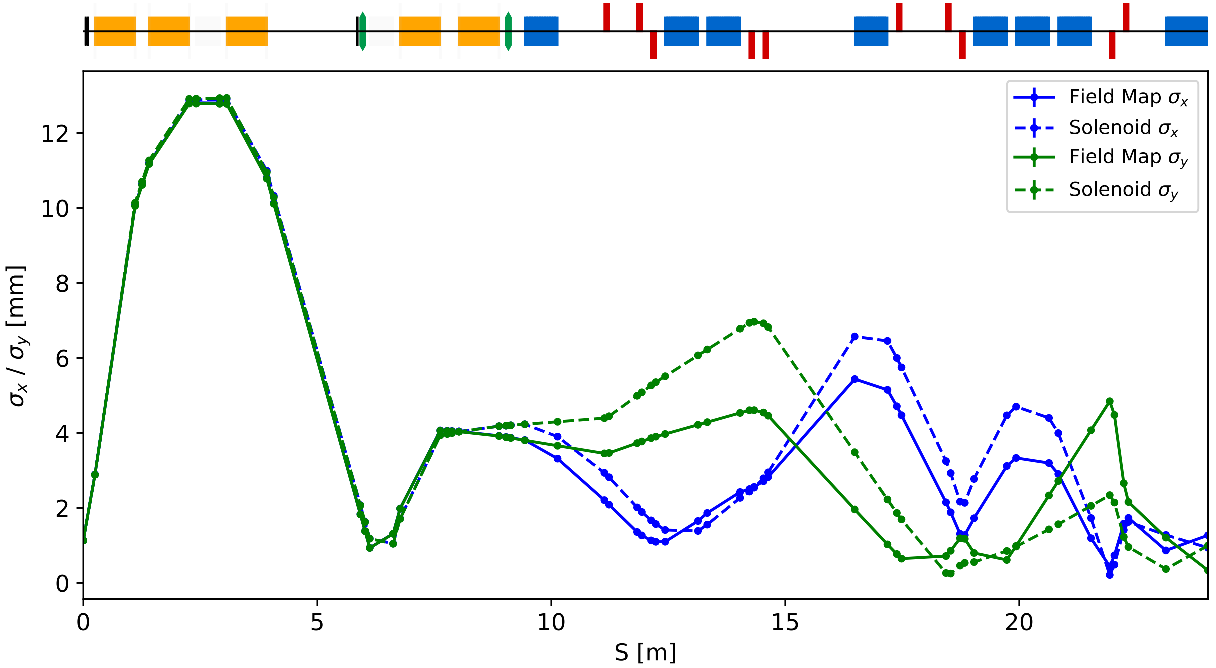
- Artificial GPT beam size jumping inhibiting the comparison at the point of FFA injection.
  - Strategy needed to mitigate GPT simulation **output control**

Sampled Collimated Beam: Phase Space Distributions

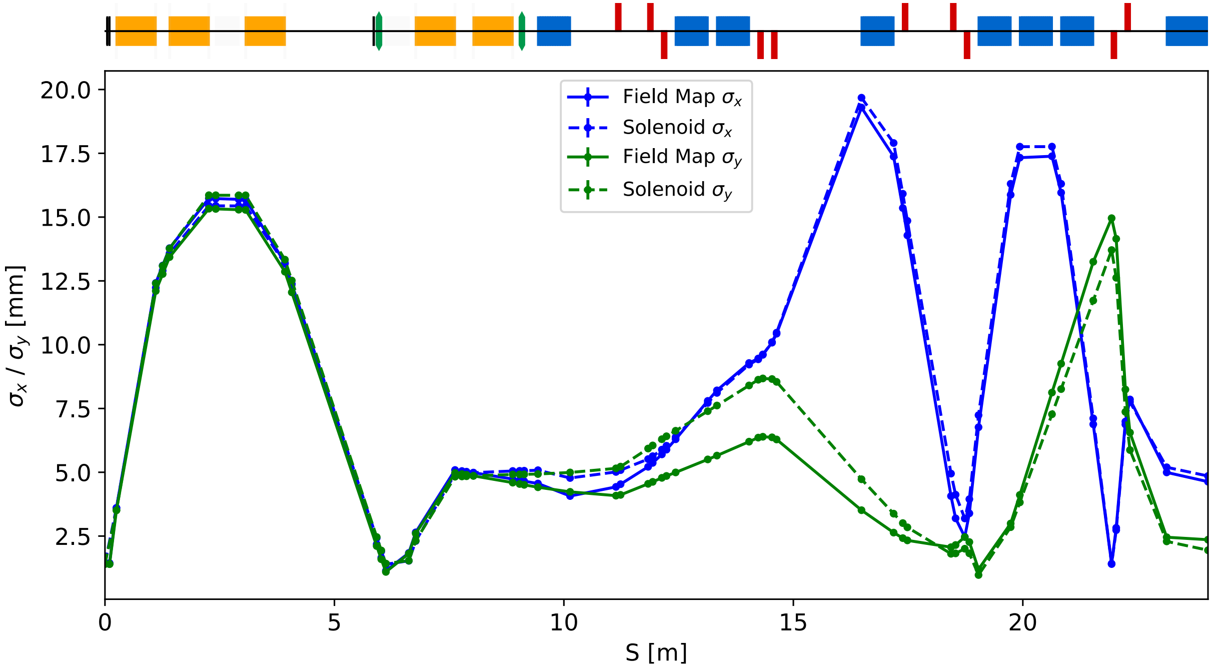


- Aberration still persists, but extends further in all dimensions
- The result of wider energy spread – **momentum selection / cleaning** is needed.

Field Maps Vs Solenoids



Ideal Beam



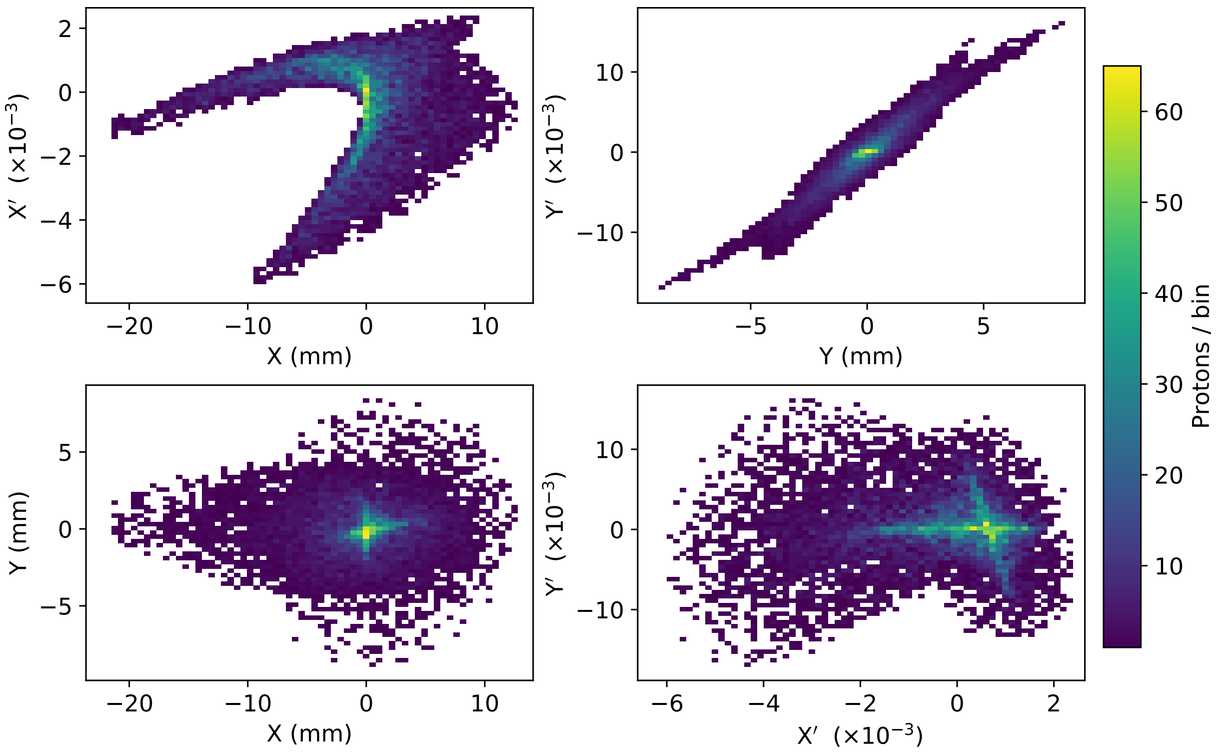
Sampled Beam

- Gabor Lens field maps generated for low beta injection configuration (TSD script updated with HT's collimation fixes).
  - Ideal & sampled collimated beams simulated with 10k particles.

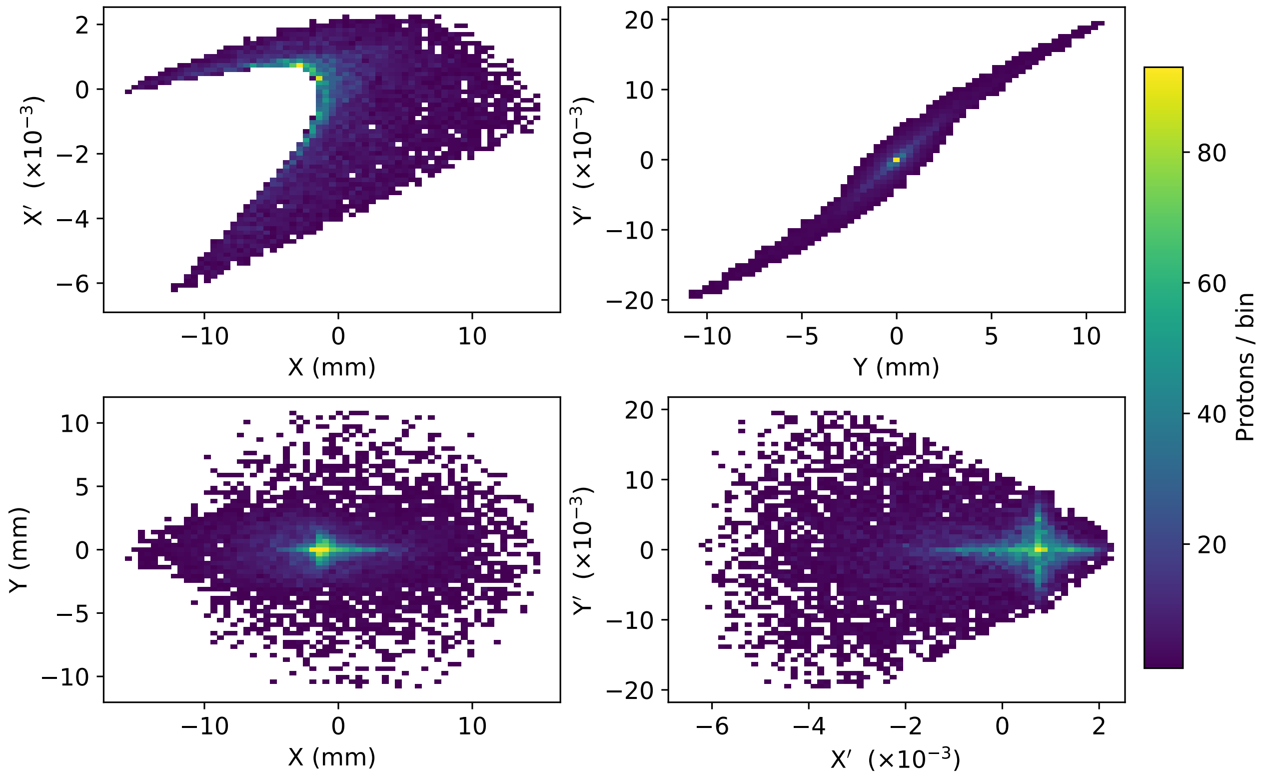
- Small differences accrue resulting in observed discrepancies with the ideal beam.

- Better matching with the sampled beam. Vertical discrepancy arising around S=9m in subsides downstream.
  - Matches solenoid well at the point of injection. FFA beam requirements are not met, however.

Gabor Lens Field Map: Phase Space.



Solenoid

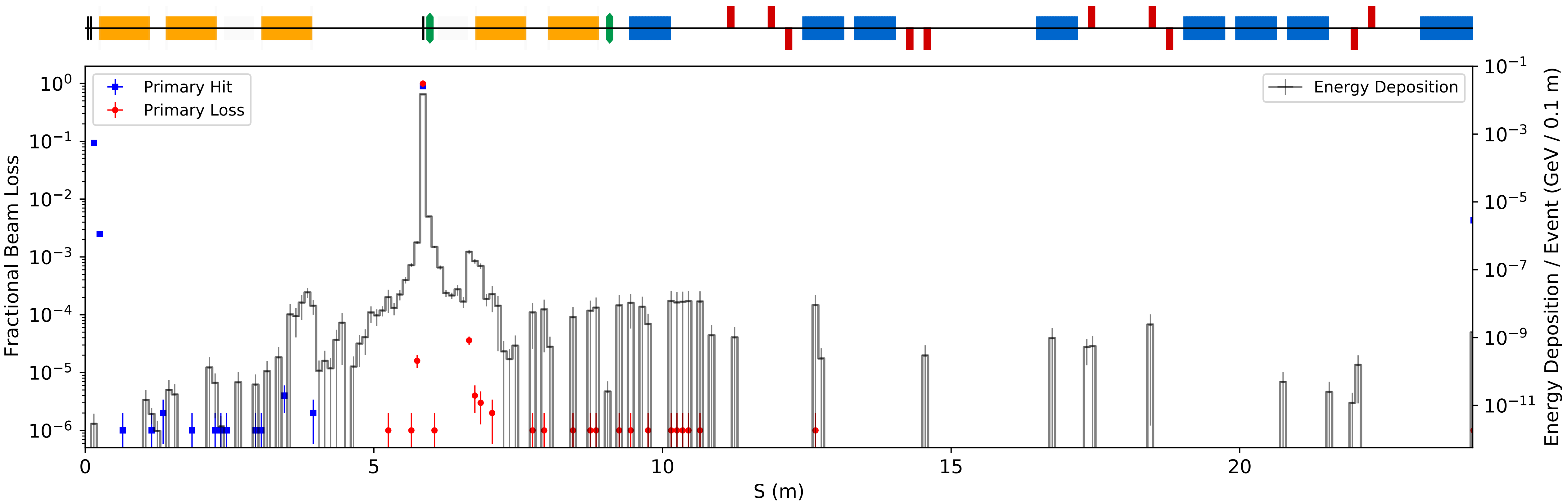


Field map

- Similar phase space observed to that of the solenoid beam line simulations

- The aberration arises in **both** solenoid AND Gabor Lens fields.

Laser-Target Sampled Beam: Losses & Energy Deposition



- The uncollimated ideal beam was simulated in BDSIM with particle-matter interactions and the momentum selection collimator aperture radius set to 0.5mm (the settings for stage 1 *in vitro* energy collimation).
- Heavy losses are observed with < 1% of the beam reaching the FFA septum magnet.
- Energy deposition is mostly restricted to within +/- 2m of the collimator.
- New collimator settings are required for energy selection through the injection line.
  - **Beam line transmissio**n must be considered.

Conclusions

- Space charge causes early emittance growth resulting in neither the ideal or sampled beam matching the FFA cell requirements.
  - The **Gabor lens strengths need optimising** to mitigate this effect.

- The vacuum nozzle collimation impacts the sampled beam performance.
  - Stage 1 settings may be applicable to the injection line, **but Gabor Lens optimisation is needed first**.

- The sampled beam’s phase space extends further due to the beam’s larger energy spread.
  - **Momentum selection / cleaning collimation** studies are needed**. Beam line transmission** must be considered**.**

- GPT simulation artefacts are impeding optics comparisons.
  - Tweaking of the simulation **output control** is required.

- Gabor Lens field maps match solenoid tracking well for the sampled beam.
  - **Phase space aberrations are still observed.**