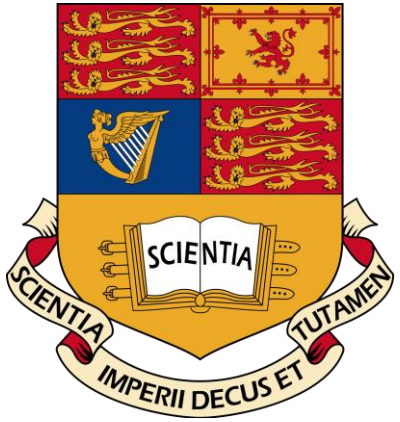
Simulations of CCAP beamline in BDSIM

Capture and Transport



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Aims:

- Using BDSIM in simulations of the radiobiology facility.
- Capturing and transporting a laser driven proton beam, appropriate for in-vitro proton therapy.
- Implementing simulations of a Gabor lens, a compact focusing lens.
- Contributing to the CCAP Conceptual Design Report.

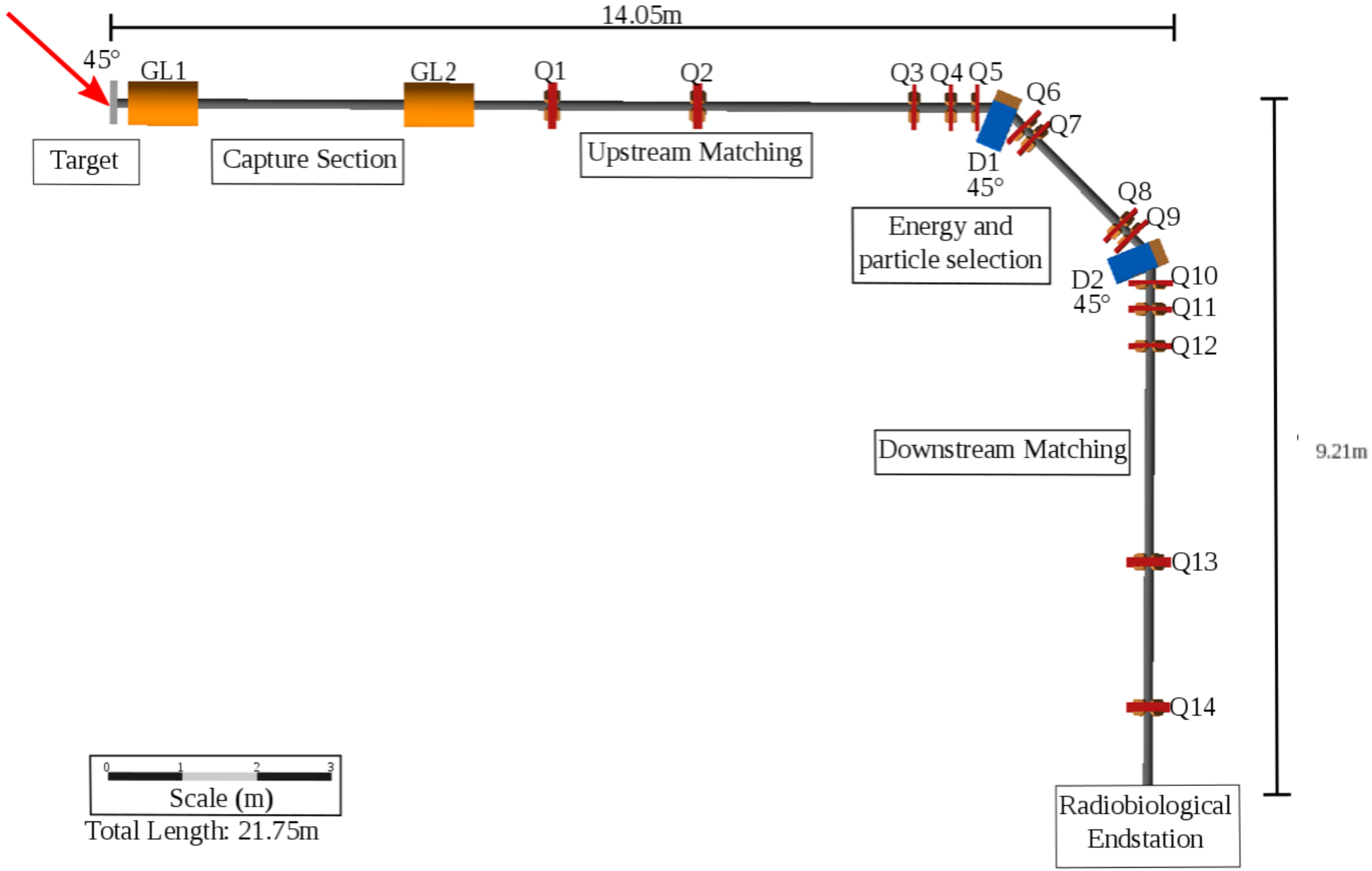
BDSIM (Beam Delivery SIMulation)

› C++ based Geant4 toolkit.

› Simulates particle transport and particle-material interactions.

- Text-based interface
- Accurate with single particle and beam loss simulations
- Compatible with MADX format
- Can form beams via optical parameters
- Customisable with external geometry and fields
- Clear 3D visualisation with displayed tracking

- External formats are inflexible
- Not intended for optical design or optimisation
- Inaccurate with collective effects
- Limited documentation
- Unexplored bugs
- Geant4 DNA not an included physics package

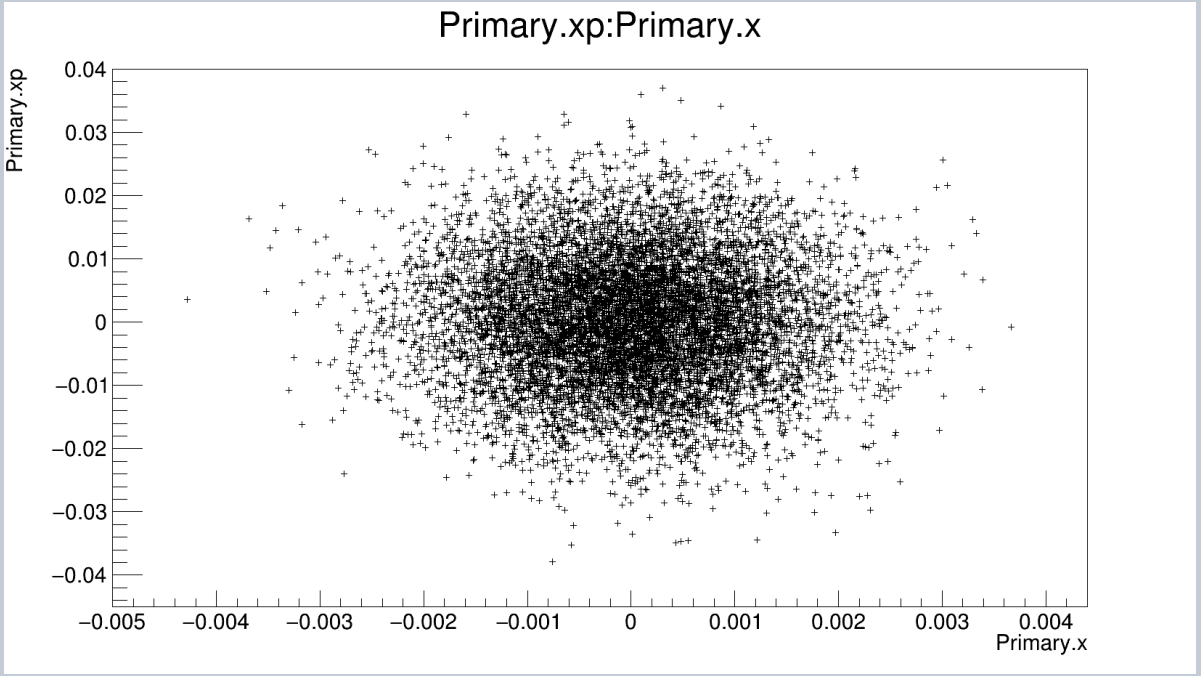


[Figure 1*: Final Annotated BDSIM visualisation of CCAP v2 Beamline]

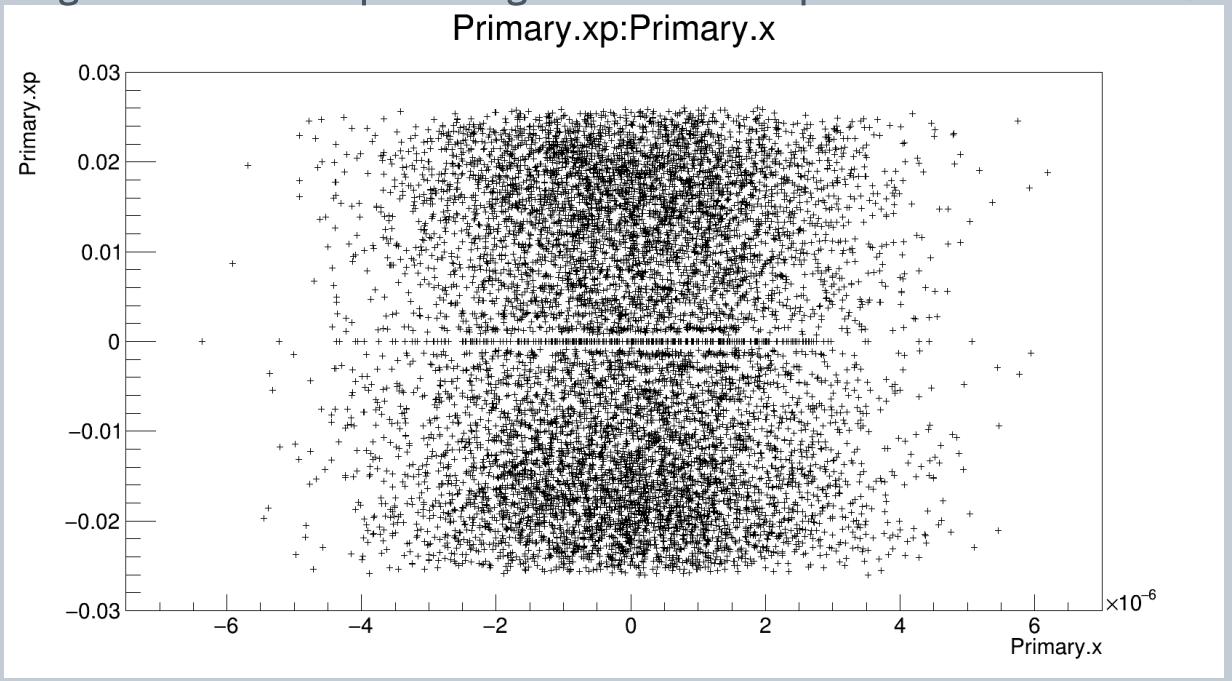
(Figures with * will be shown in conference)

Primary Input Beams

- Reference
- Gaussian
- Twiss-defined Gaussian
- User-defined beam



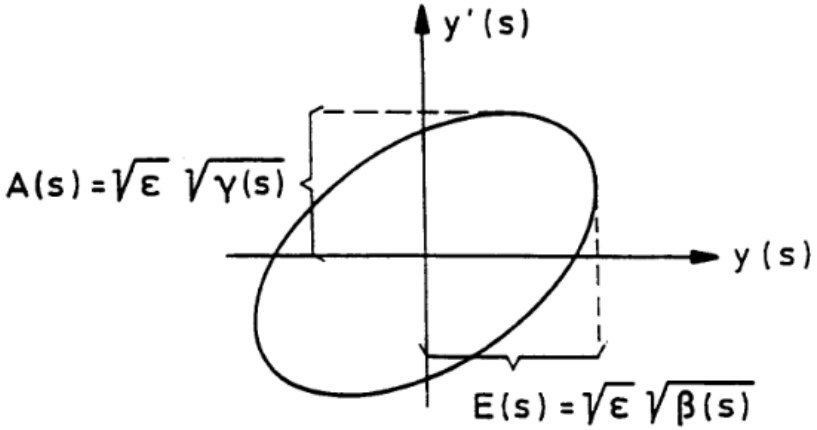
[Figure 2a: Phase-space diagram of a 10000 proton Gaussian beam]



[Figure 2b: Phase-space diagram a 10000 proton user-input beam]

Quadrupole Lattice Simulations

- Producing a stable beam through a FODO cell.
- Using MADX to gain quadrupole strengths.
- Producing and understanding phase-space plots.



[Figure 3a: Beam Emittance and Divergence Diagram] [1]

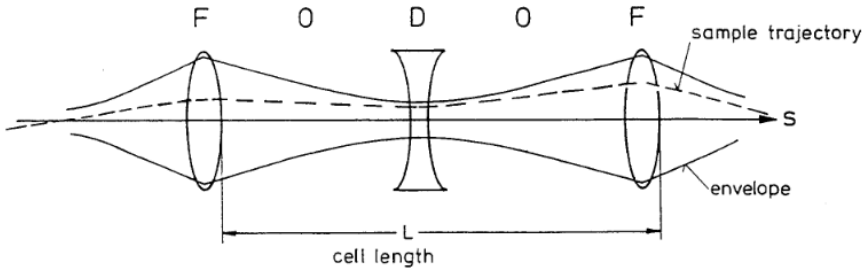
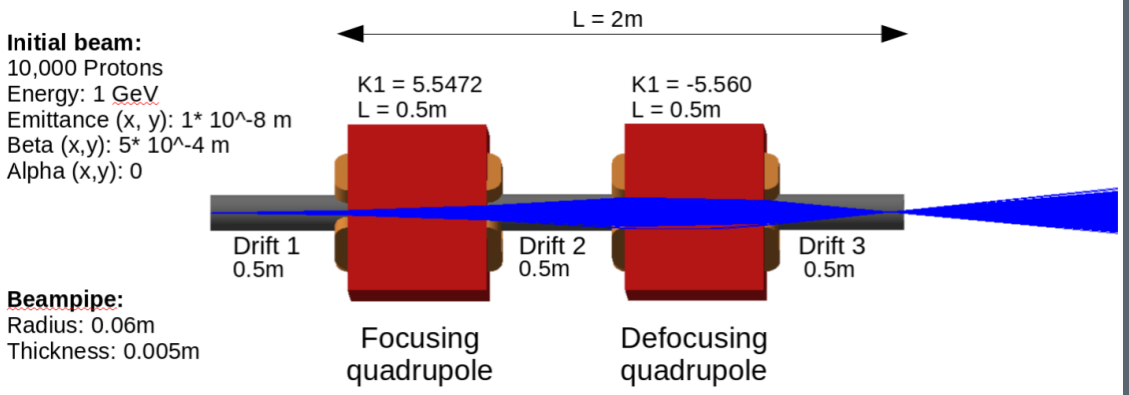


Figure 29: FODO cell

[Figure 3b: FODO Cell Diagram] [1]



[Figure 3c: Annotated visualisation of a quadrupole cell in BDSIM]

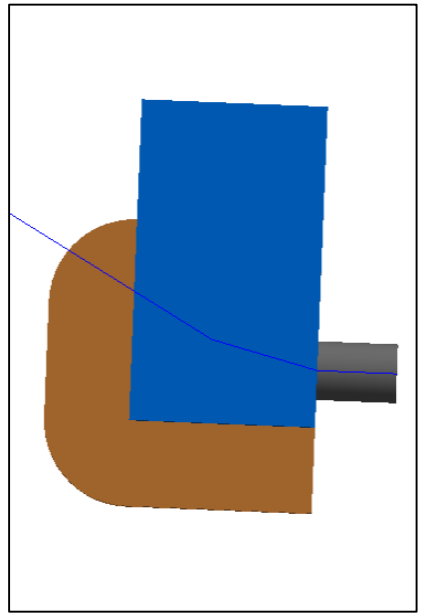
Dipole Fringe modelling

Bending plane

$$dp_x = \frac{q_{x,in}}{\rho} \tan(\theta) \quad (1)$$

Non-bending plane

$$dp_y = \frac{q_{y,in}}{\rho} \tan(\theta - corr.) \quad (2)$$



[Figure 4: BDSIM rbend]

$$corr. = f_{int} \frac{2\, h_{gap}}{\rho} \frac{(1+\sin^2\theta)}{\cos\theta} corr_2. \quad (3)$$

θ= e1, pole face angle

h_{gap} is dipole gap

rho is length / dipole bending angle

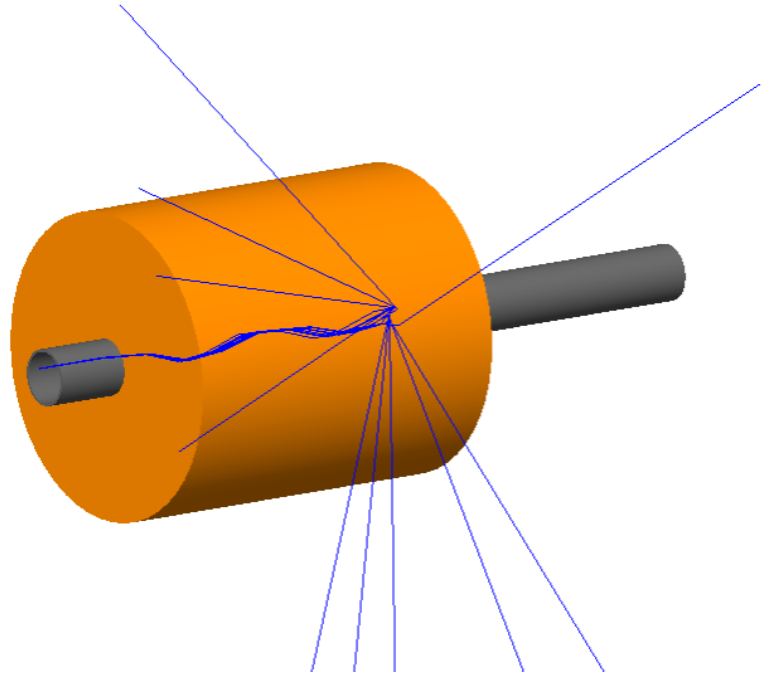
Additional definitions:

$$corr_{2.} = 1 - f_{int}\, f_{intk2}\, \frac{2\, h_{gap}}{\rho}\, \tan\theta \qquad (4)$$

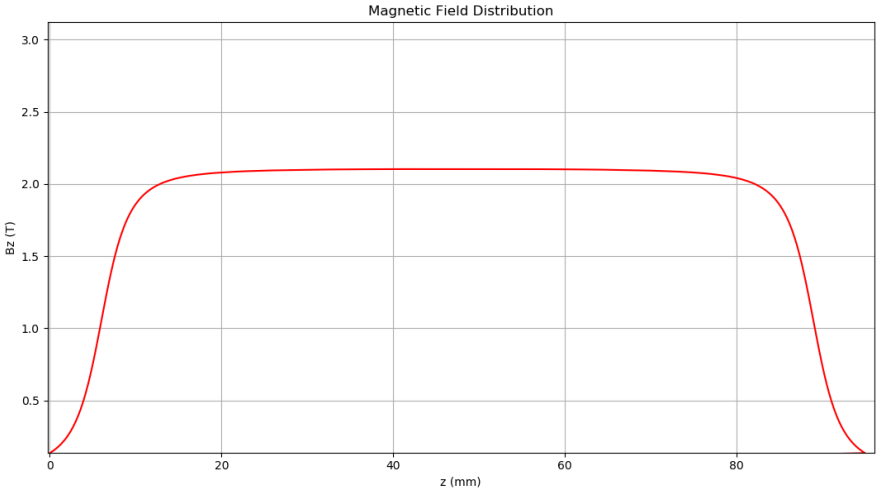
$$f_{int} = \int_{-\infty}^{\infty} \frac{B_y(s)\,\left(B_0 - B_y(s)\right)}{2\, h_{gap}\, B_0^2} \mathrm{d}s \qquad (5)$$

Capture Section Modelling

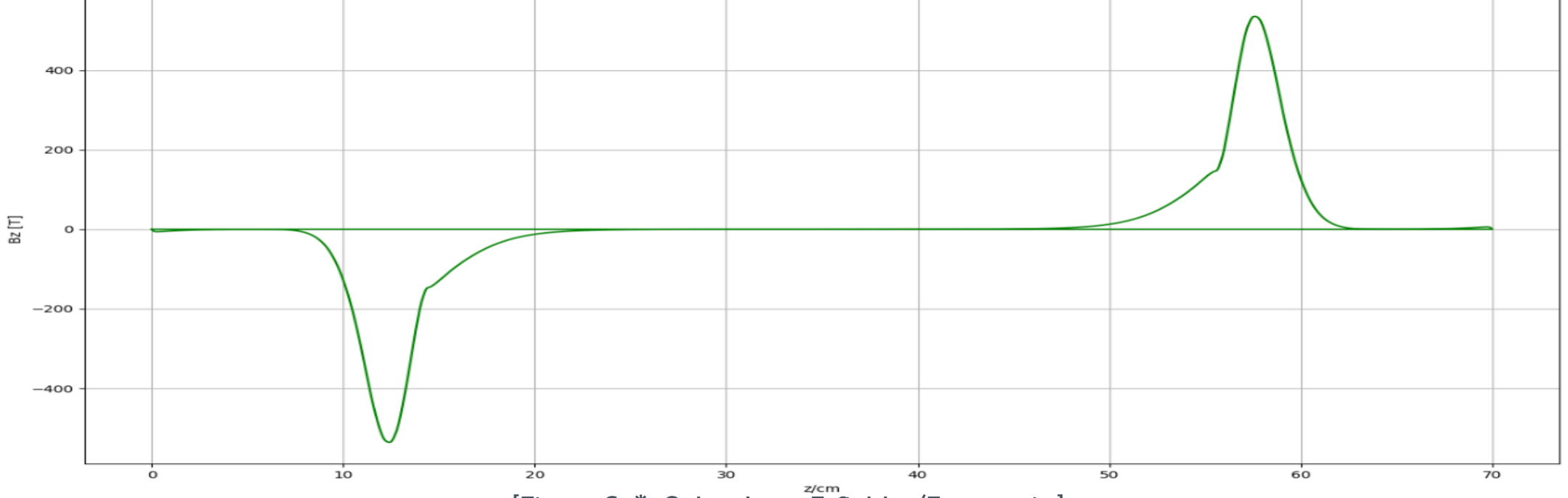
- Built-in Solenoids
- Quadrupoles (1D only)
- Gabor Lens field map
- Solenoid field map



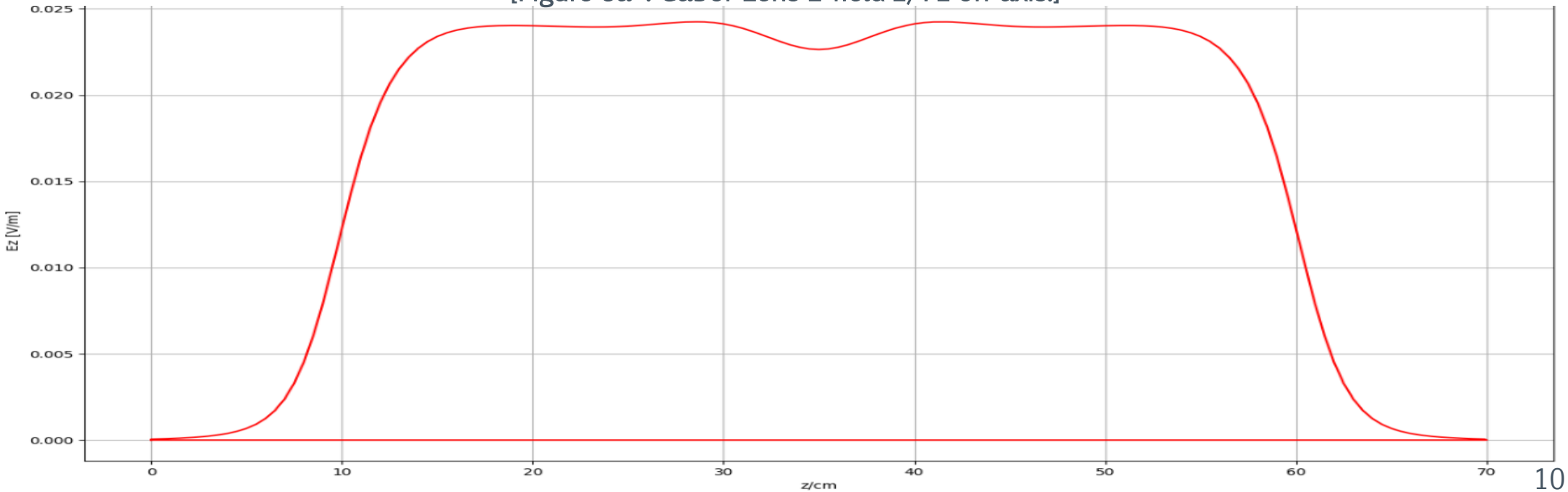
[Figure 5a: Ineffective BDSIM Solenoid using BDSIMone integrator]



[Figure 5b Magnetic field distribution of a solenoidal field map]



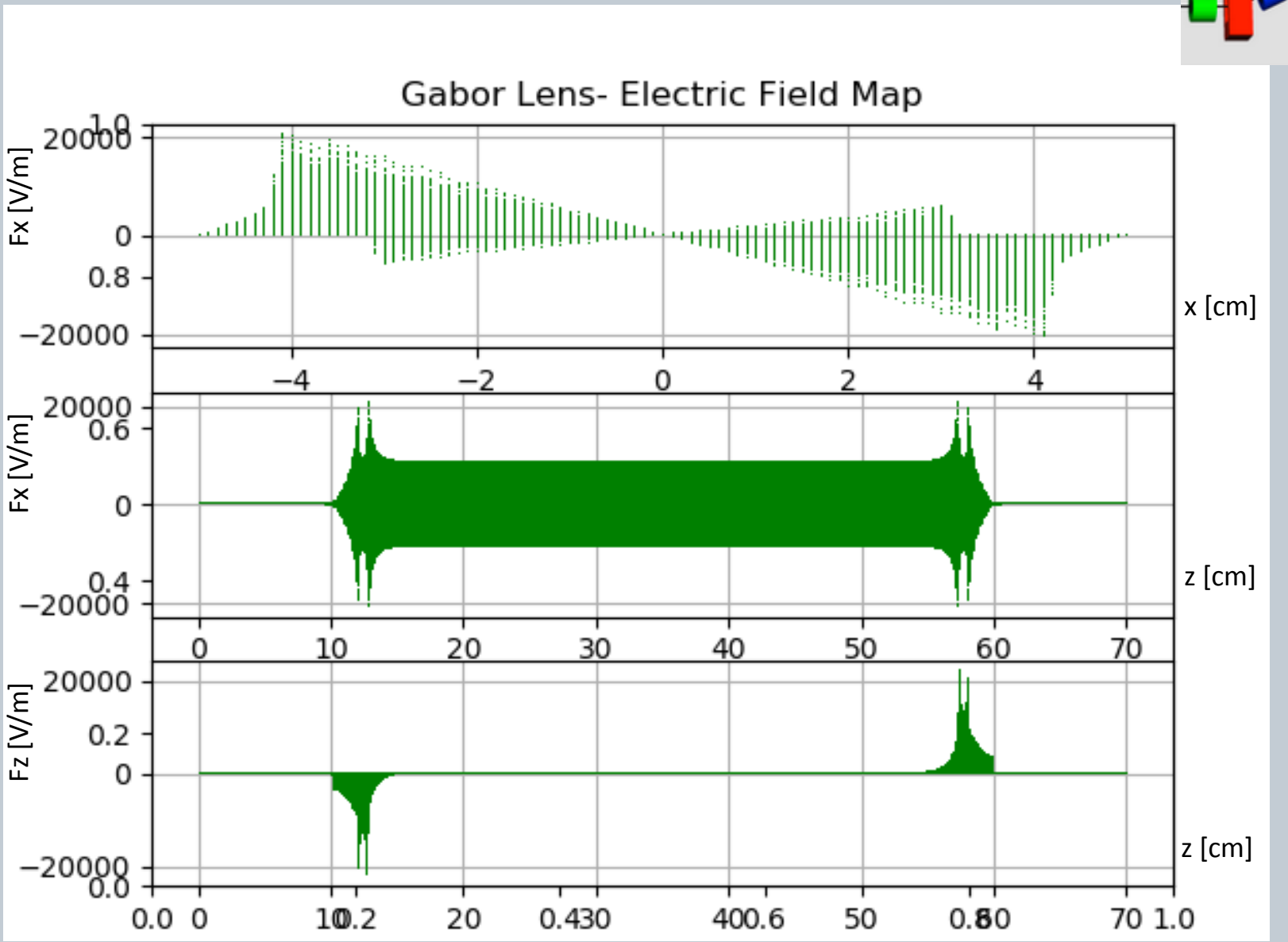
[Figure 6a*: Gabor Lens E-field z/Fz on-axis.]



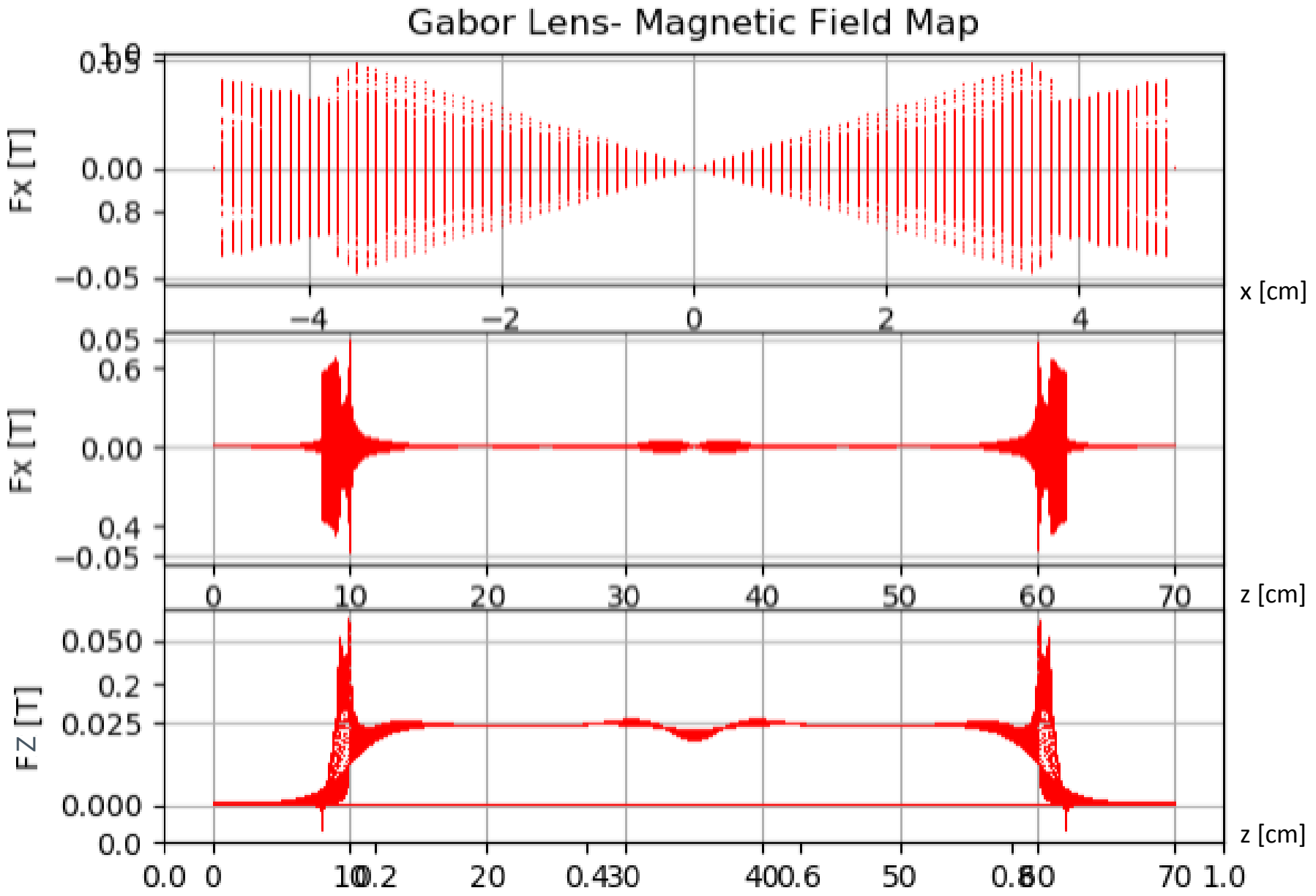
[Figure 6b*: Gabor Lens B-field z/Fz on-axis.]

Gabor lens field map issues

- 2D raw data vs 3D
- Regular grid required
- Length of raw file
- BDSIM electric field effects



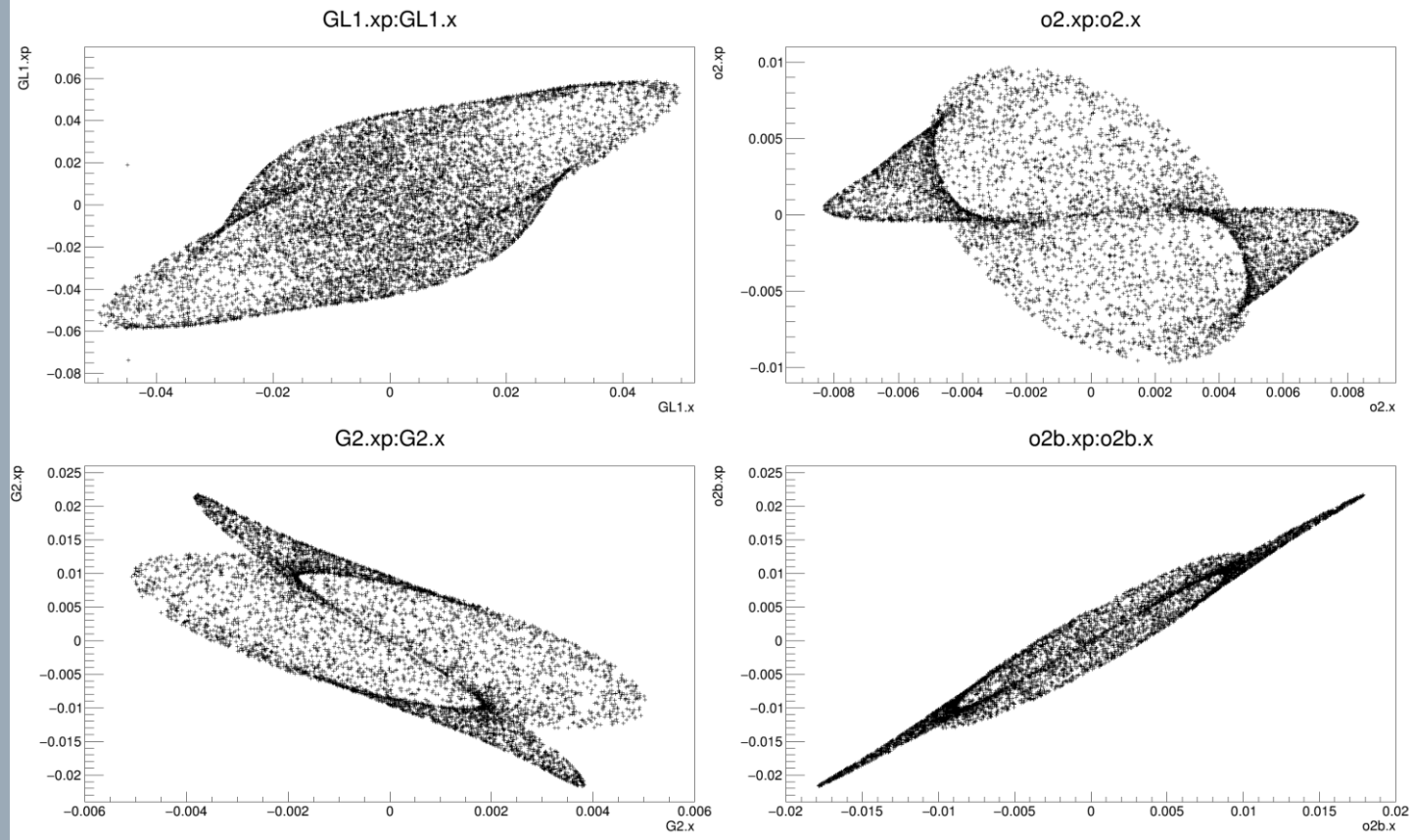
[Figure 7: Gabor Lens E-field in x/Fx, z/Fx and z/Fz .]



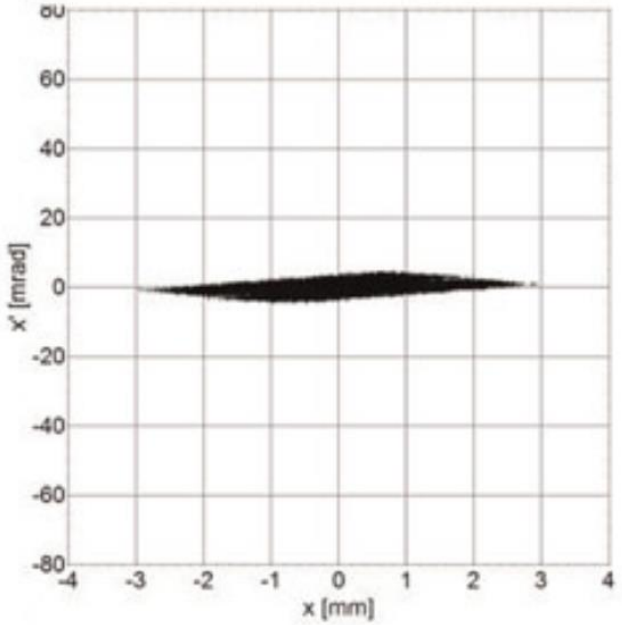
[Figure 8: Gabor Lens B-field in x/Fx, z/Fx and z/Fz .]

Gabor lens focusing

[Figure 9a: Tracking of the beam through the two Gabor lenses (orange)]



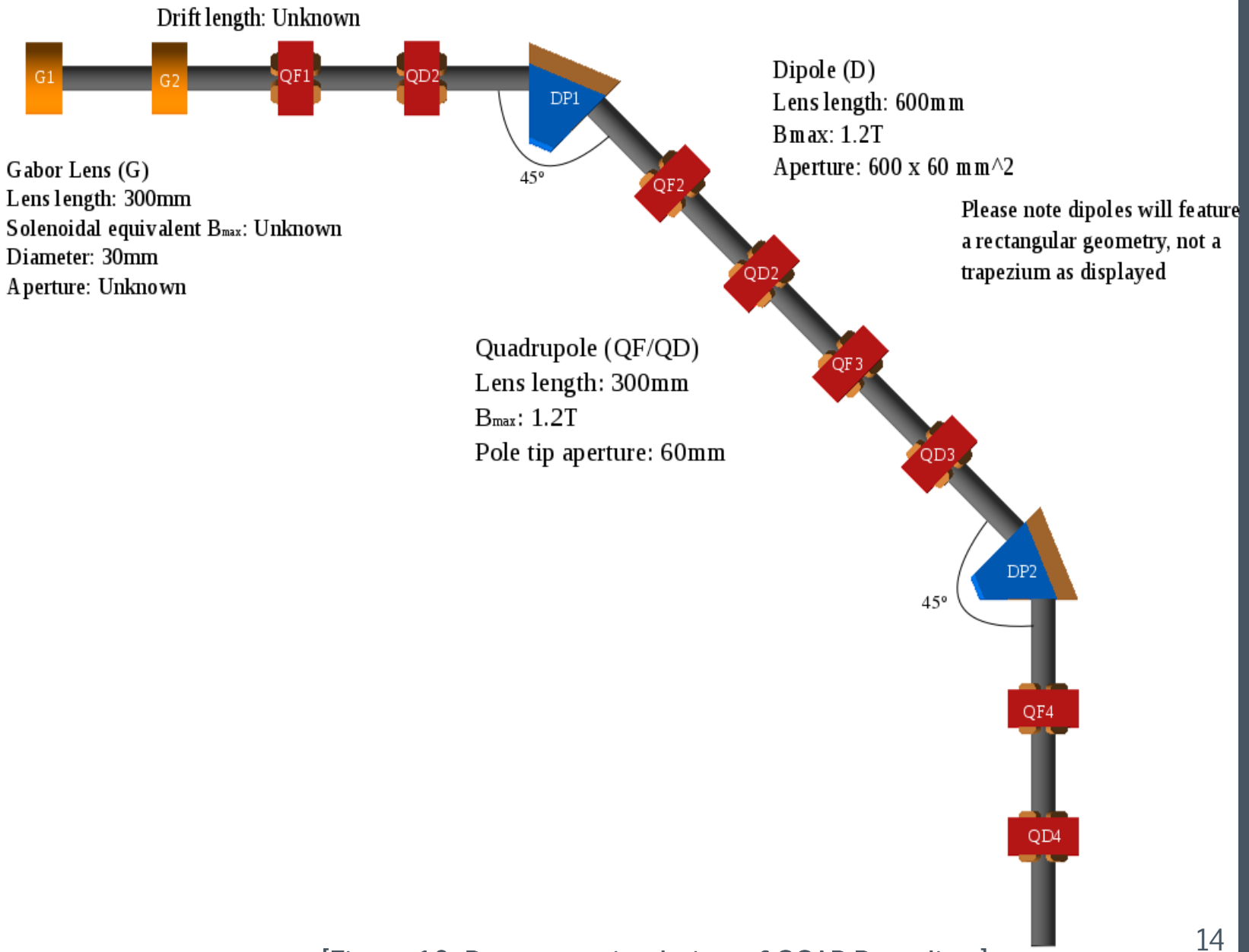
[Figure 9b: Phase-space plots after Gabor lenses and drift lengths]



[Figure 9c: Traversal phase-space at exit of Gabor lattice] [1]

CCAP prototype

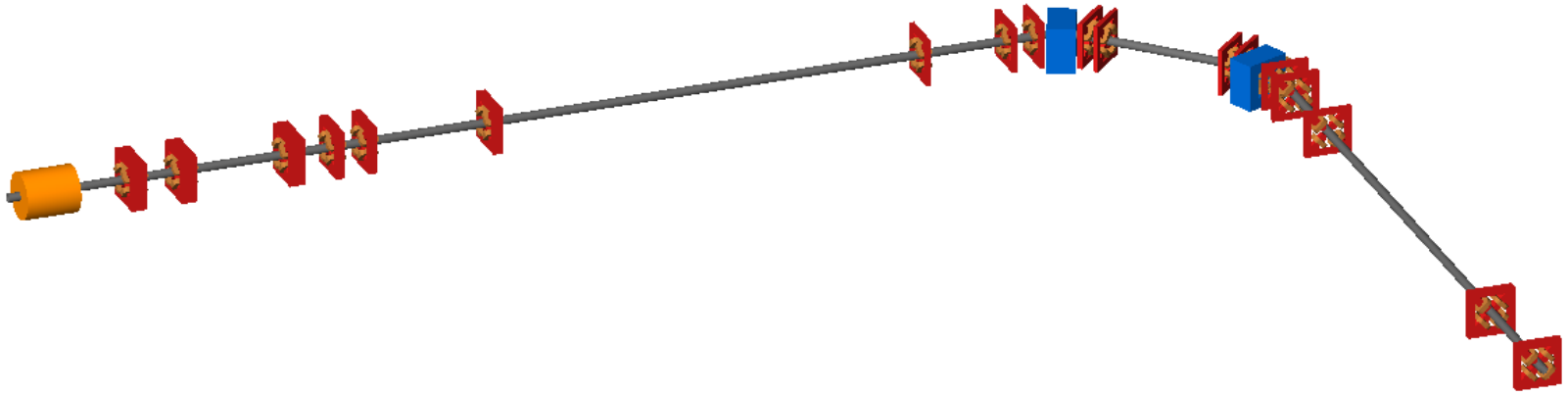
- 10/07/18
- Arbitrary drift lengths
- Two Gabor Lenses of 30cm
- 8 Quadrupoles



[Figure 10: Prototype simulation of CCAP Beamline.]

CCAP Version 1

- 30/07/18
- Long beampipe
- Inefficient optics due to extreme beta and long drifts
- One Gabor Lens of 70cm
- 18 Quadrupoles

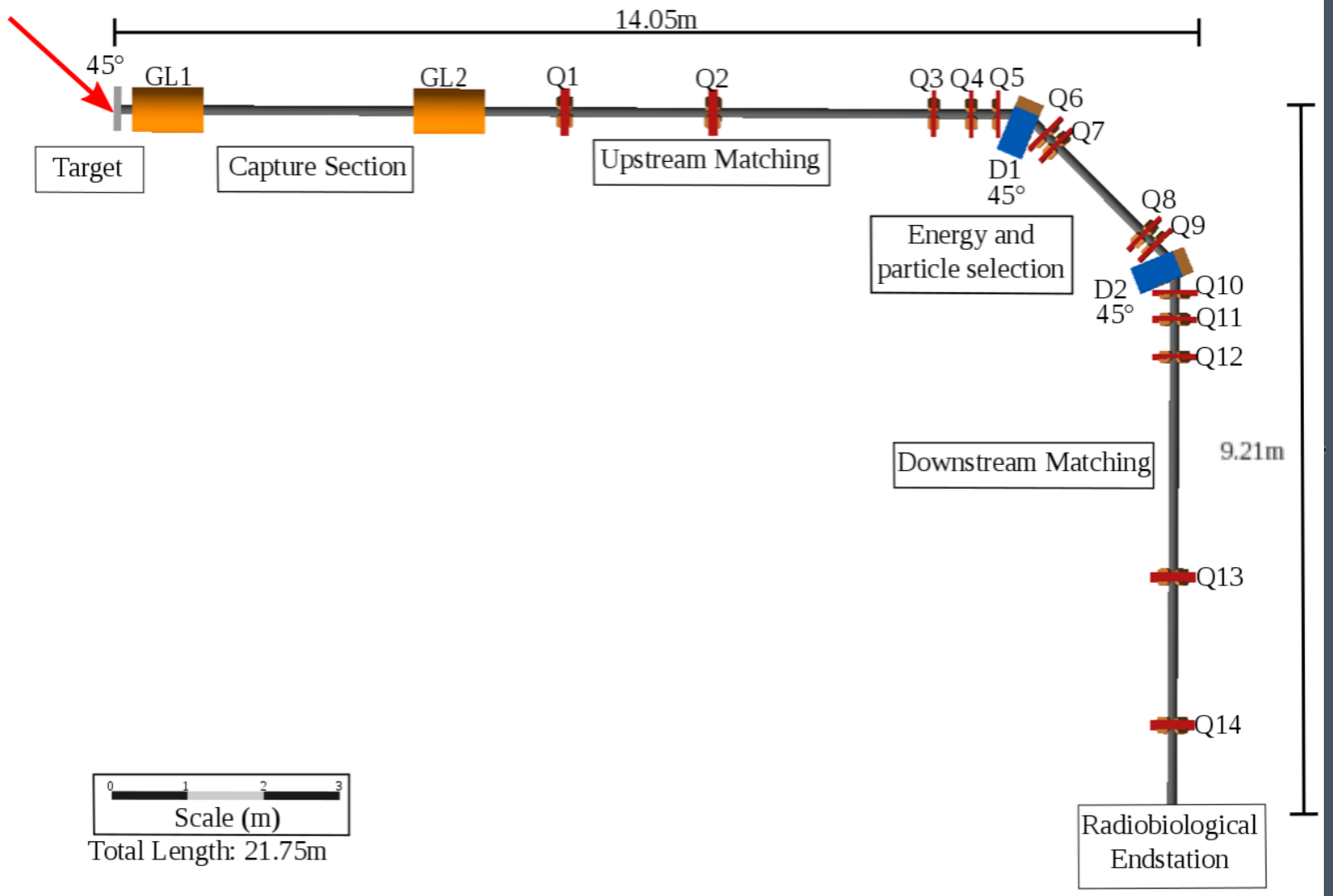


[Figure 11: CCAPv1 Visualisation- unannotated.]

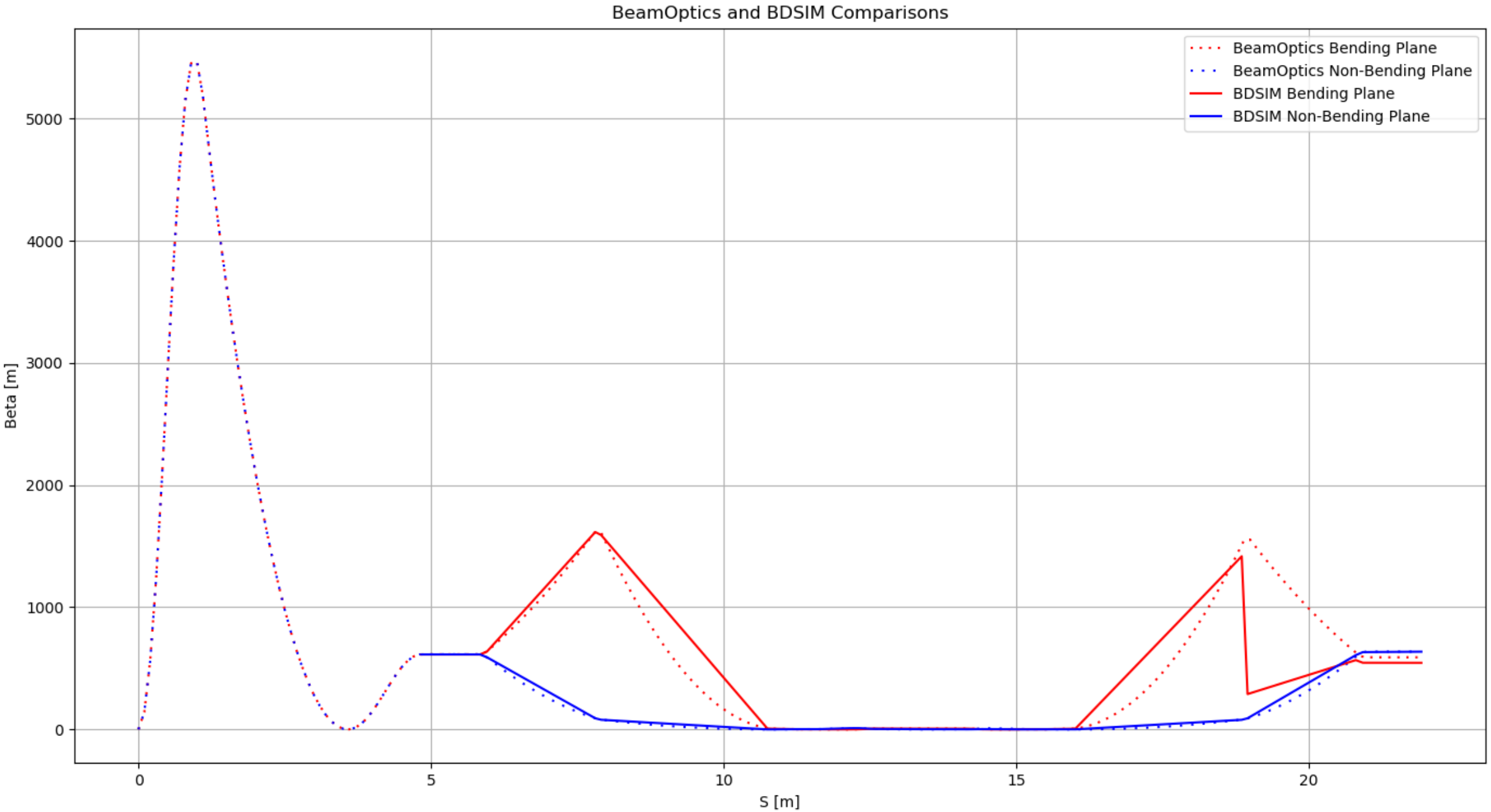
CCAP Version 2

- 09/08/18
- Optics modelled after solenoids
- Two Gabor Lenses of 95cm
- 14 Quadrupoles

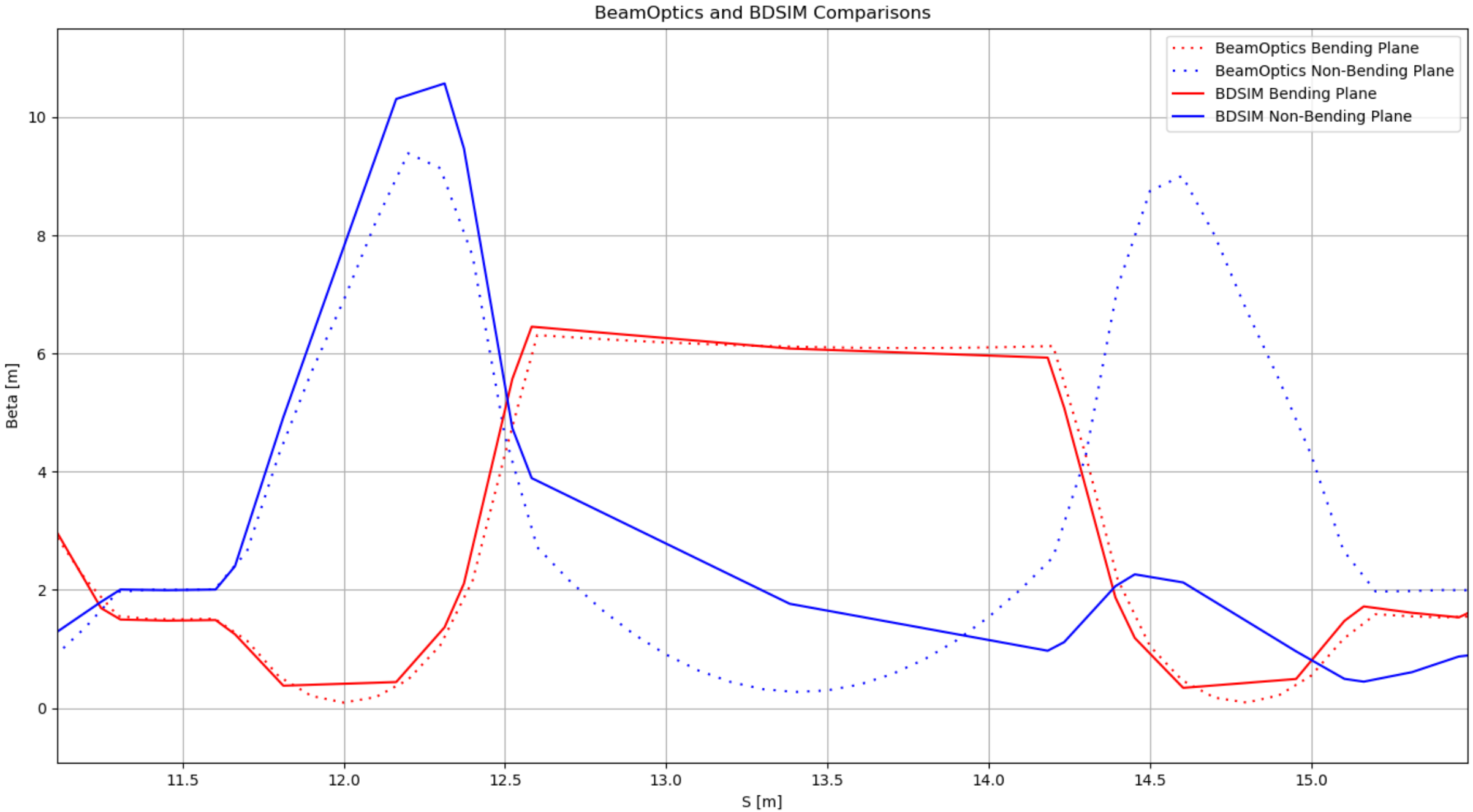
- Possibly over expensive
- Prefer to be more compact
- Likely replace quadrupoles with additional Gabor lenses



[Figure 1*: Final Annotated BDSIM visualisation of CCAP v2 Beamline]

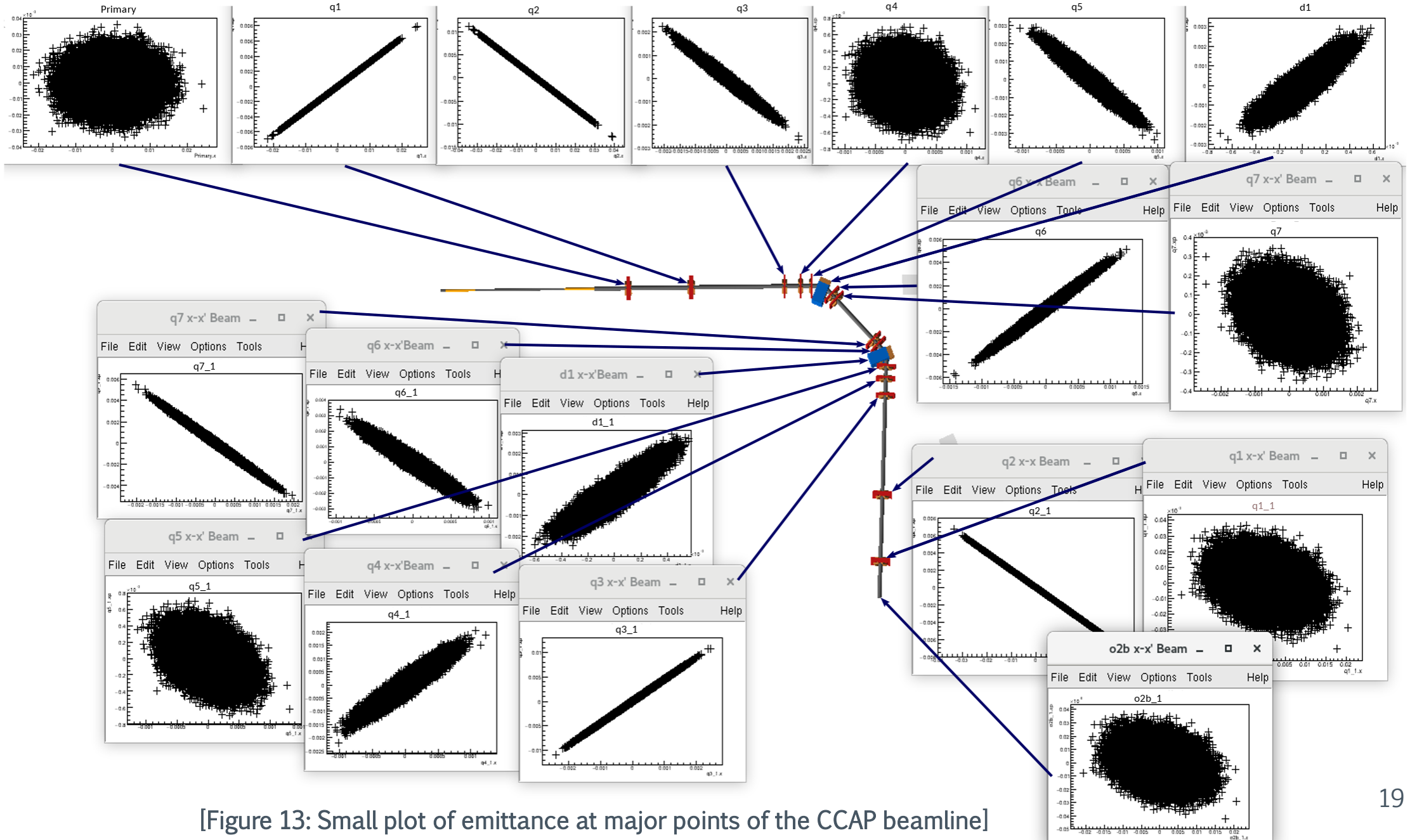


[Figure 12a*: Comparison of CCAPv2 Optics]

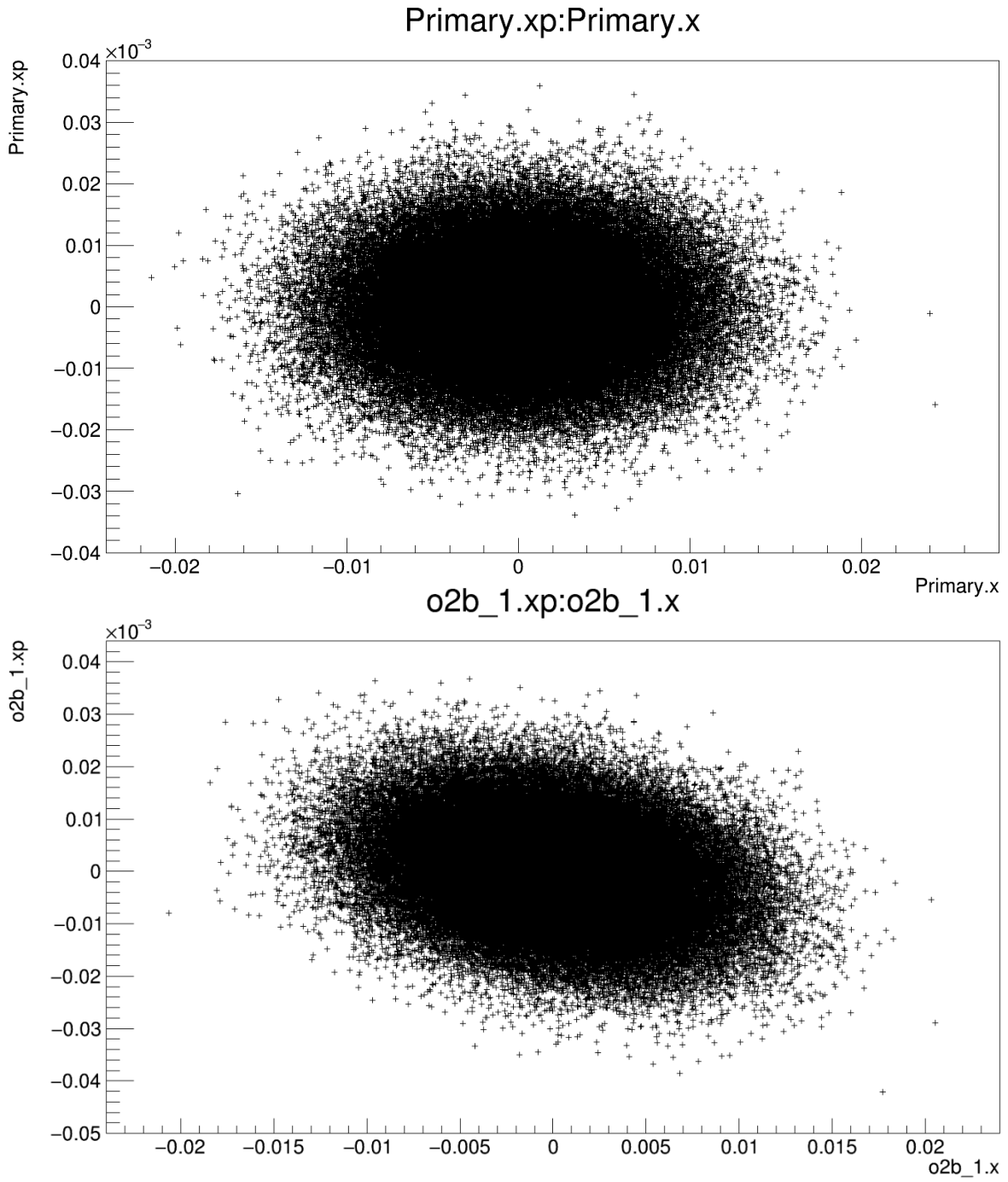


[Figure 12b*: Comparison of CCAPv2 Optics- zoom]

Emittance Plots of CCAPv2 Transport Line



[Figure 13: Small plot of emittance at major points of the CCAP beamline]



[**Figure 14ab:*** First and final emittance of the transport line]

To do next:

- Extending Gabor Lens field map
- Matching optics of capture section
- Combined simulation of capture and transport section
- Implementing working beam dump, collimators and Wein filter
- Implement working model of end station, modelling phantoms
- Flexibility for multiple ions to be transported through the components
- Functioning transport model for input beam

Conclusion

- Provided the foundations in BDSIM usage to simulate a complete CCAP beamline.
- Included files for producing field maps and measuring properties of the simulation.
- Proven that BDSIM can give the desired results.

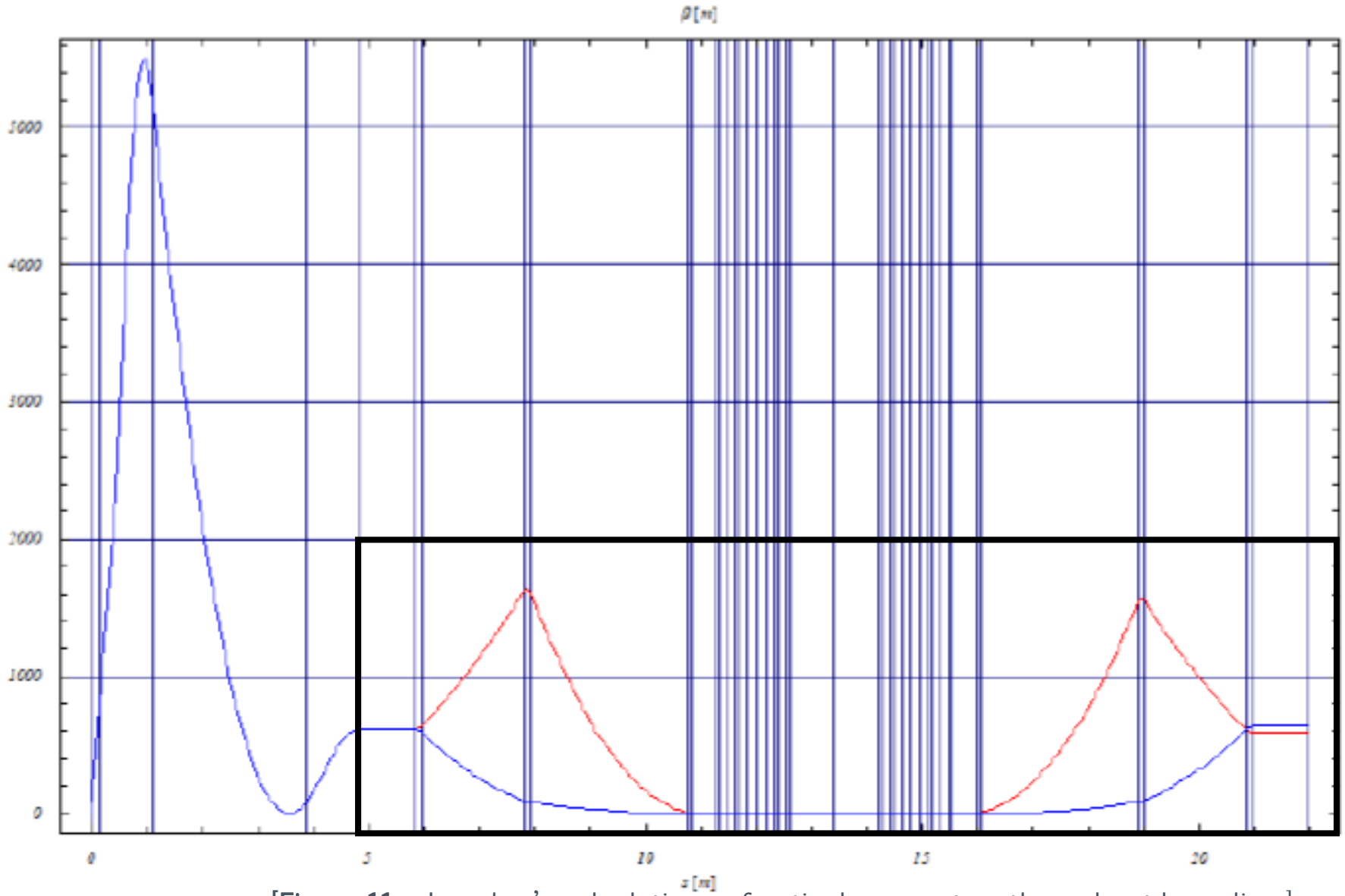
Thank you and I will welcome any questions.

References

[1] S. Turner, *5th General CERN Accelerator School Vol. 1,* CERN 94-01, (1994)

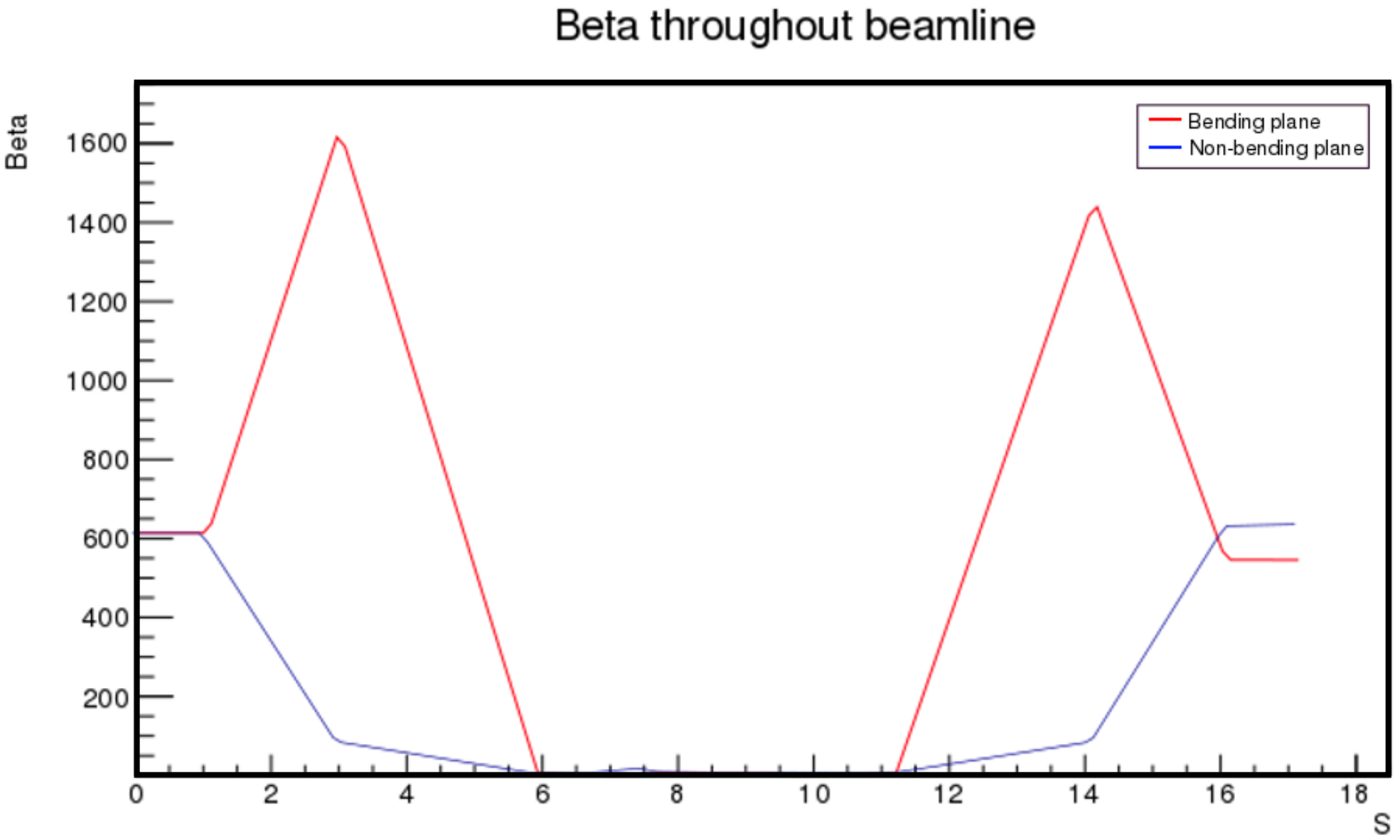
[2] J. Pozimski, *Gabor lenses for capture and energy selection of laser driven ion beams in cancer treatment*, Laser and Particle Beams (2013), 31, 723-733

CCAP v2 Optics- Jaroslaw's Calculations



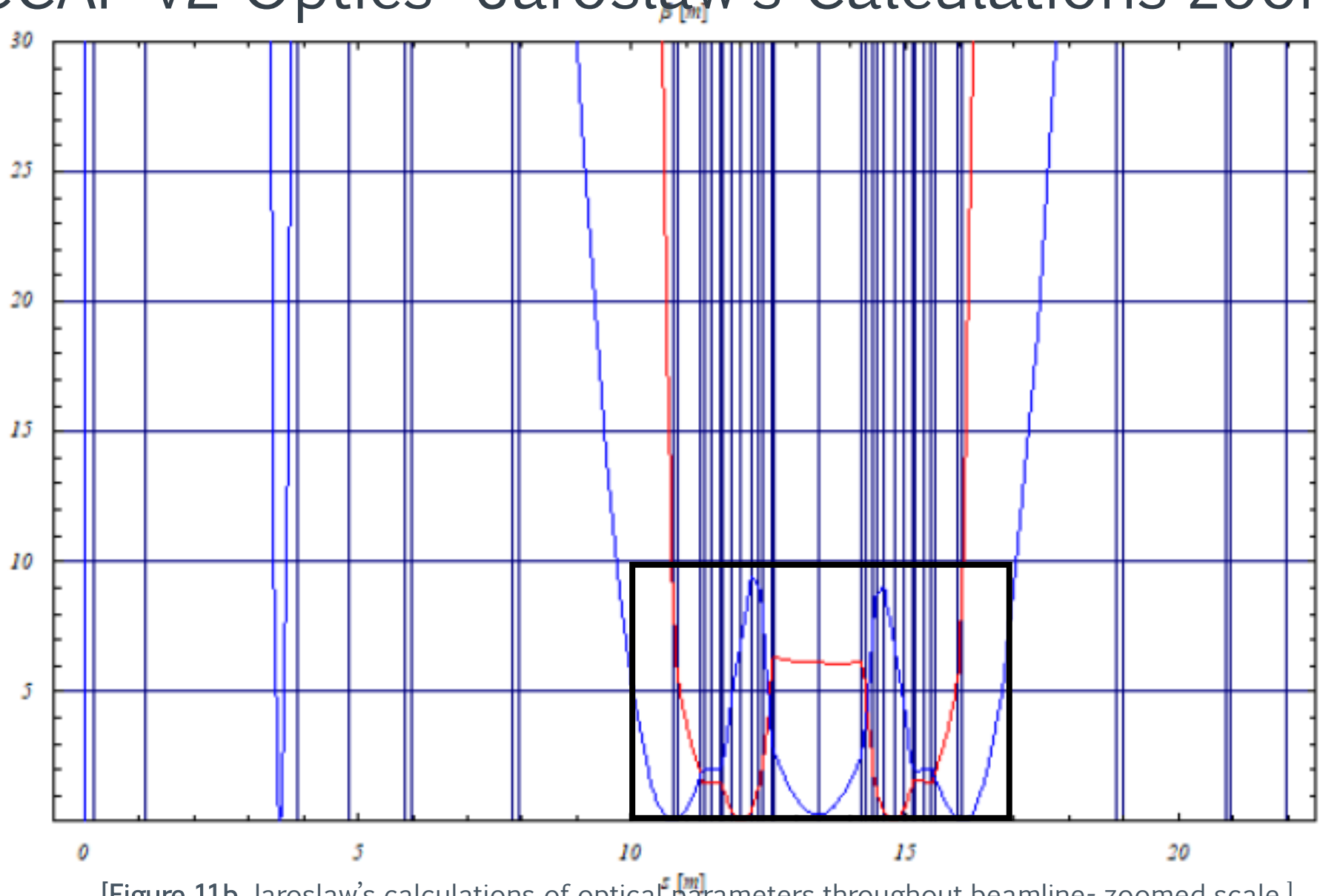
[**Figure 11a** Jaroslaw's calculations of optical parameters throughout beamline.]

CCAP V2 Optics- BDSIM



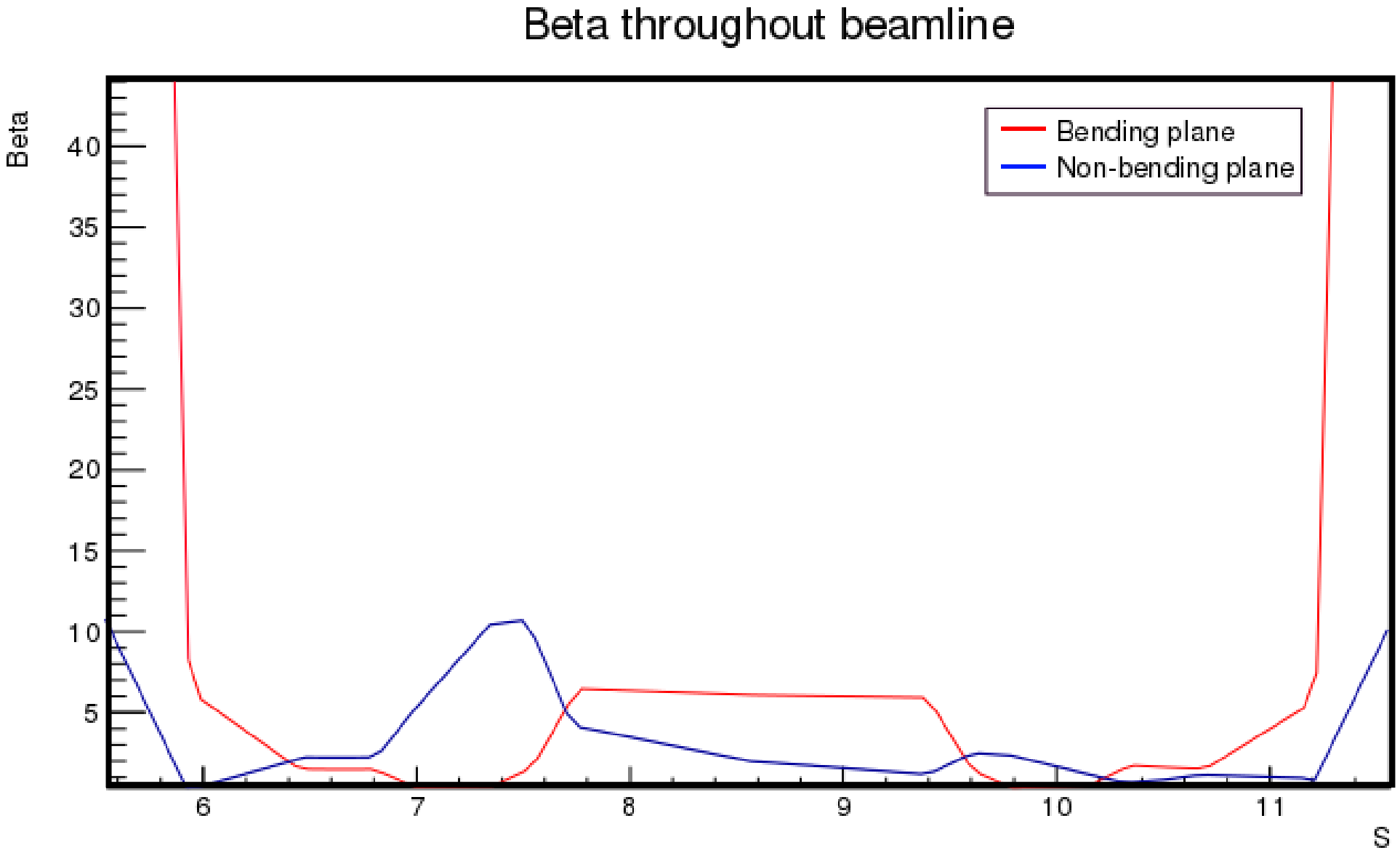
[Figure 12a*: BDSIM calculations of optical parameters throughout beamline.]

CCAP v2 Optics- Jaroslaw's Calculations zoom



[**Figure 11b** Jaroslaw's calculations of optical parameters throughout beamline- zoomed scale.]

CCAP v2 Optics- zoom



[**Figure 12b***: BDSIM calculations of optical parameters throughout beamline- zoomed scale.]