LhARA Stage 1 Final Focus

Matt Pereira - 01/10/24

LhARA Stage 1 Uniformity
Overview

- Current Octupole position sees the beam where the transverse profile approximately symmetric
- There is an ongoing design effort to introduce a set of quadrupoles final 2 meters of drift in Stage 1 as a final focus to produce mini beams (2σ ~ mm)
- These quadrupoles could create a more effective position for the octupole or a scheme of higher order multipoles.

LhARA Stage 1 in the BDSIM Visualiser

LhARA Stage 1 Final Focus

Overview

Initial State

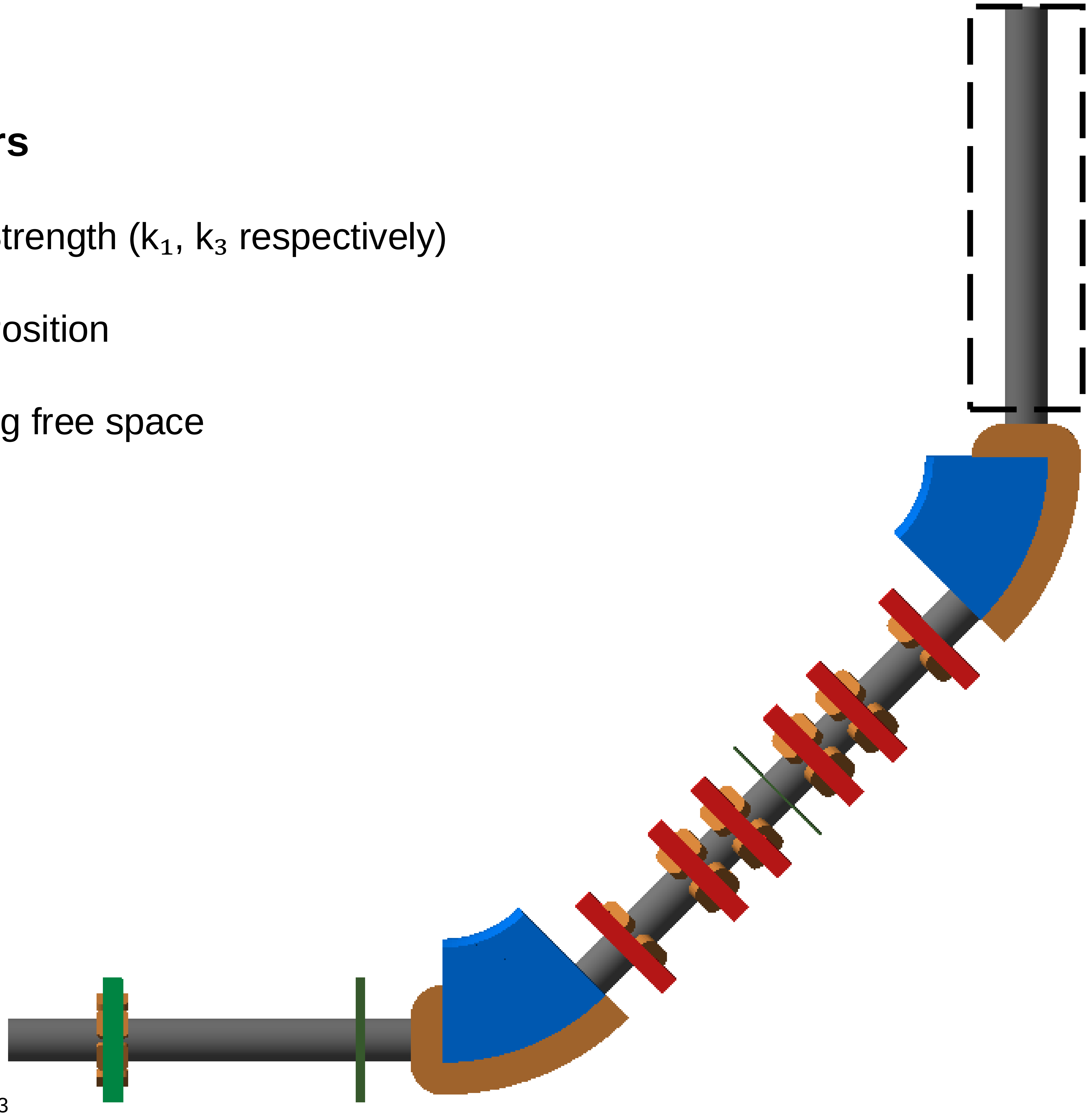
- 2.0m total drift after the arc, before the end station, to work with.
- Presently working with the 3cm beam which arrives parallel at the final focus.

Design Aims

- Spot size must be maintained at the end station
- Provide enough transverse defocusing for an octupole to induce higher uniformity at the end station (target 95%)
- No defined hard minimum on free space but the more the better for engineering purposes
(Shielding, instrumentation etc.)

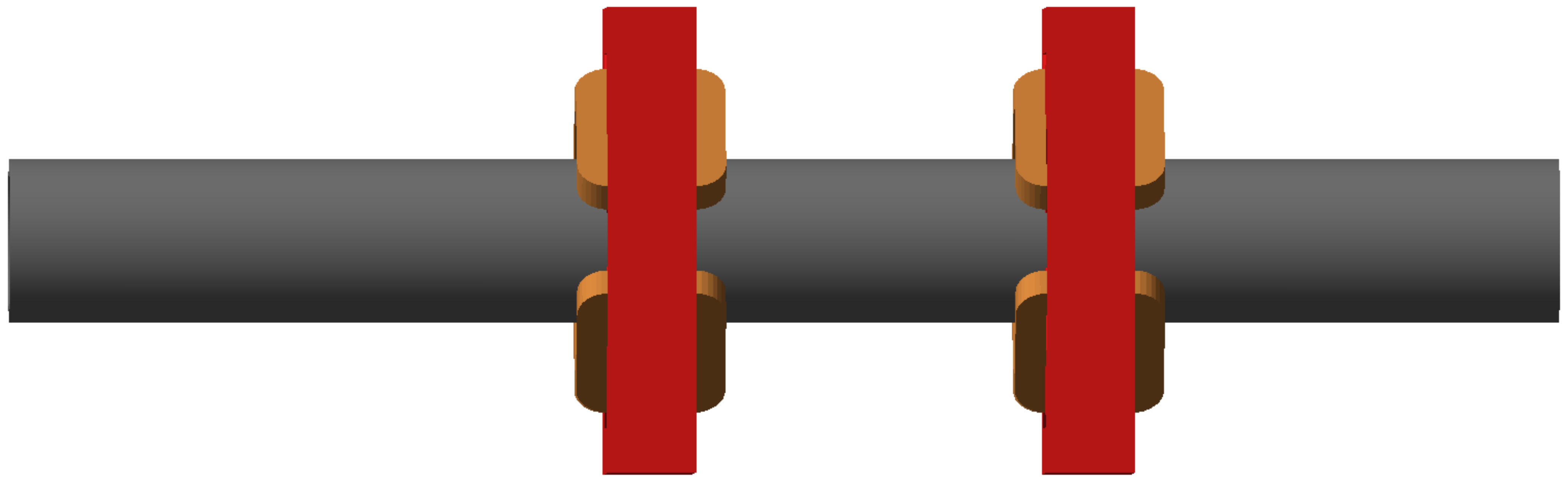
Parameters

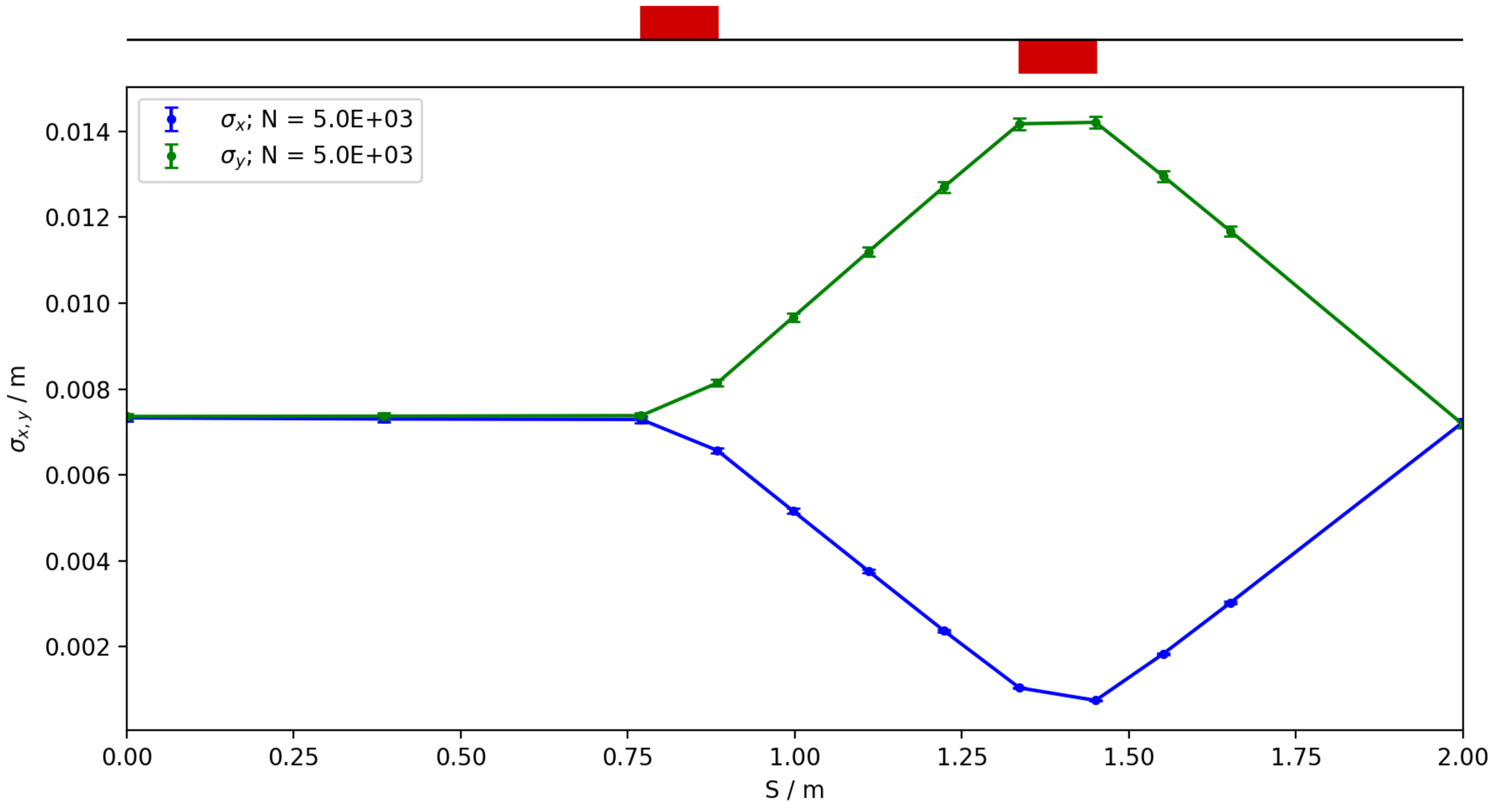
- Magnet Strength (k_1, k_3 respectively)
- Magnet Position
- Remaining free space



LhARA Stage 1 Final Focus
Quadrupoles

- The octupole is best positioned where the transverse ratio is large and so its position is entirely governed by the optics of the quadrupoles
- Quadrupole strength can be varied up to a present maximum/minimum of $k_1 = \pm 24\ m^{-1}$ to stay in the resistive magnet range (for a 0.114m quadrupole)
- Optimisation must constrain $\sigma_{x,y}$ such that it does not exceed the aperture as it is defocused in either dimension
- With two quadrupoles, the beam is parallel entering this region but will not be parallel afterwards
    - For spot scanning with a scanning magnet, a parallel beam is required to ensure consistent spot irradiation
- To get a parallel beam at the ES, a second quad doublet is required, a configuration for which is currently being optimised with LhARA Linear Optics.





Field Maps

FieldMapper

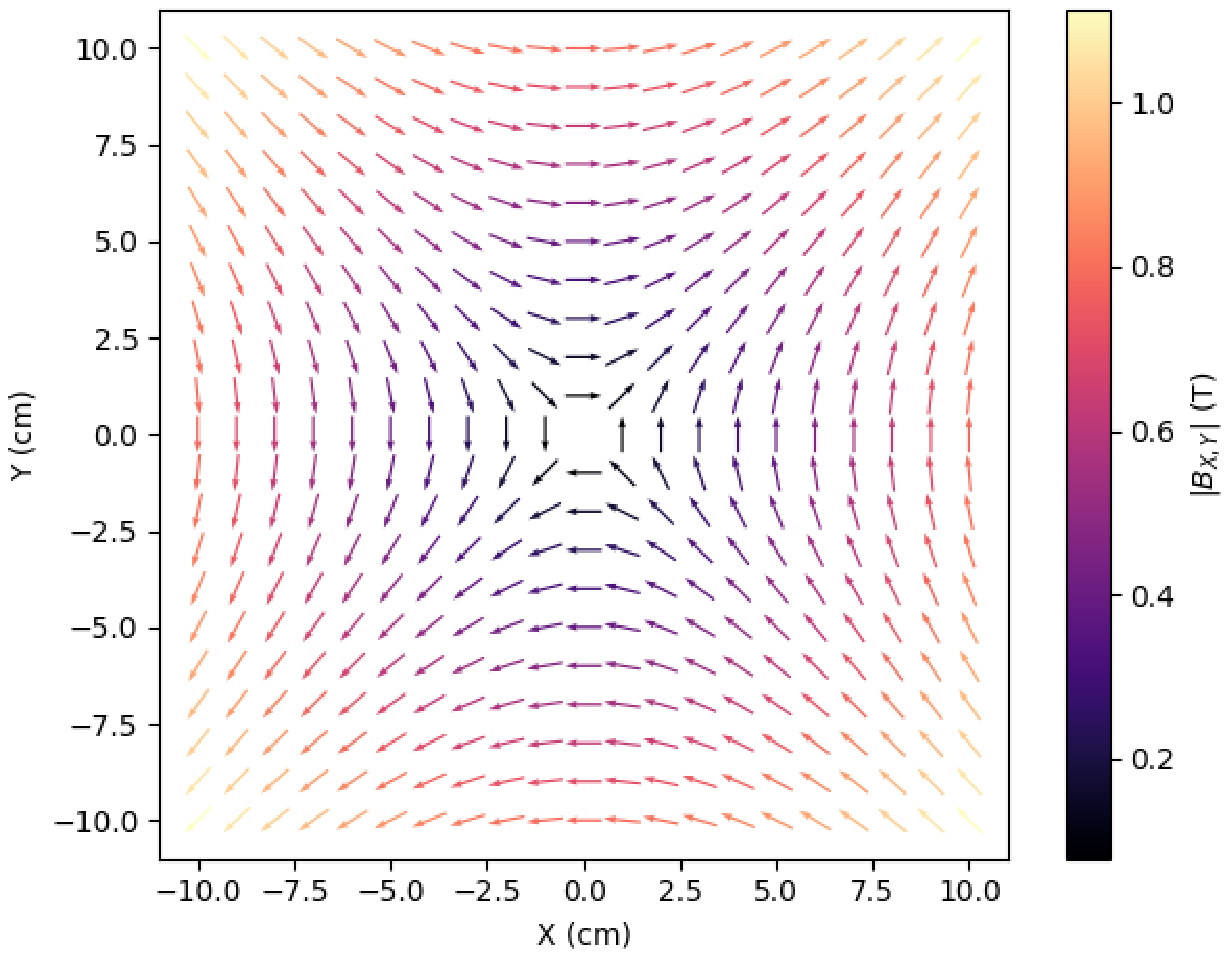
- Python library to generate 2D multipole field maps for a given order, k_n strength, aperture and beam rigidity.
- Writes the field to a .dat file in the bdsim2d file format which can be attached to an element without any further conversion

Why field maps and not just BDSIM Elements?

- Space charge simulations of these configurations, especially those with the aims of generating mini beams, will need to be carried out.
- A single source of field maps that can be used with both BDSIM and GPT ensures consistency in the field across both programs especially since there is no defined octupole element in GPT.

Validating with BDSIM

- Identical drift-multipole-drift environment run with both the BDSIM multipole element and a drift with the field map attached
- Absolute residuals of x, x’, y, y’ calculated (BDSIM – FM) and plotted



Field Map of a k_1=14 Quadrupole generated with FieldMapper (20x20 resolution)

Field Map Validation

Quadrupole Residuals – $k_1 = 14\ m^{-1}$

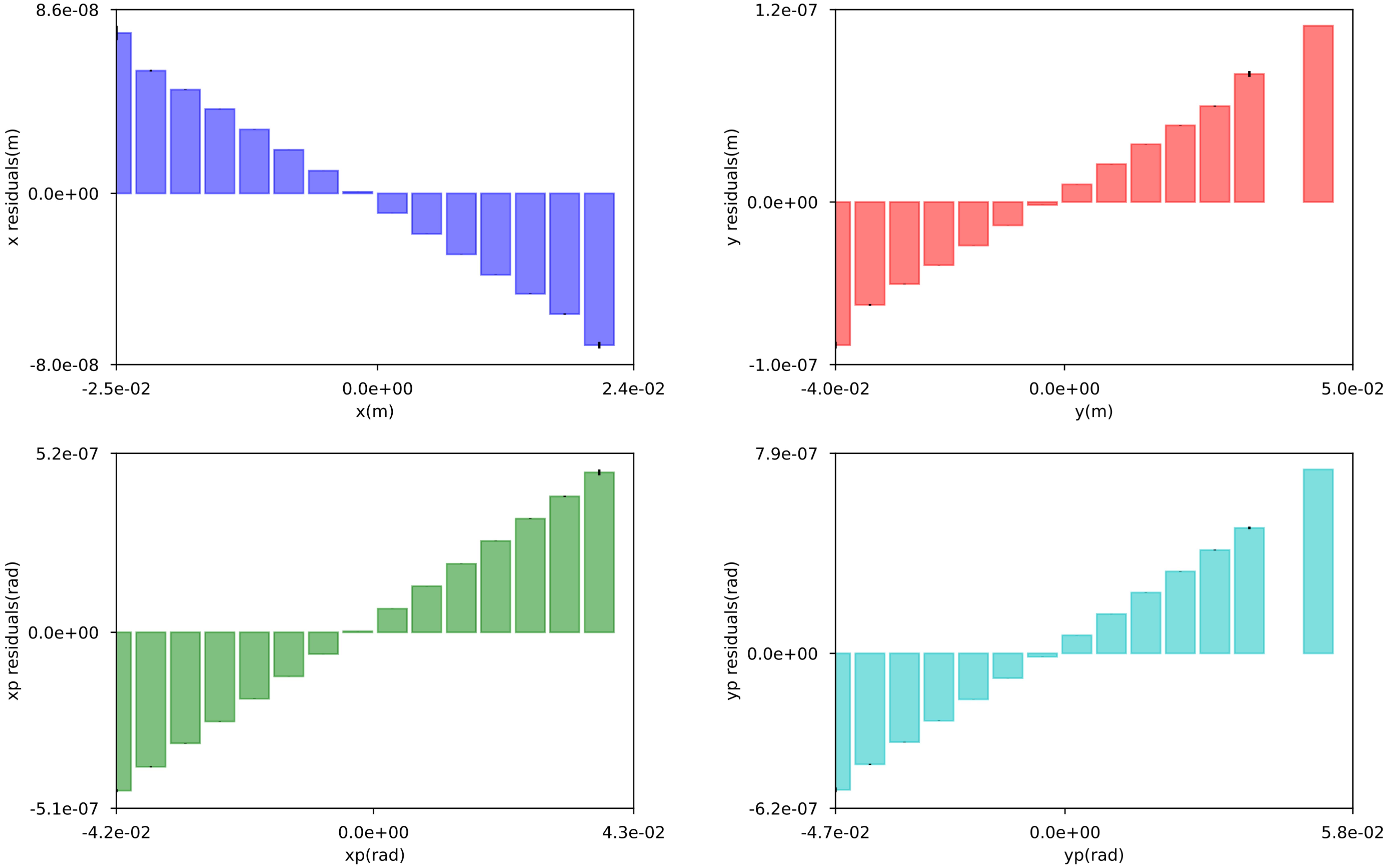
Field Map Generation

- 10 cm Aperture
  100x100 resolution

BDSIM

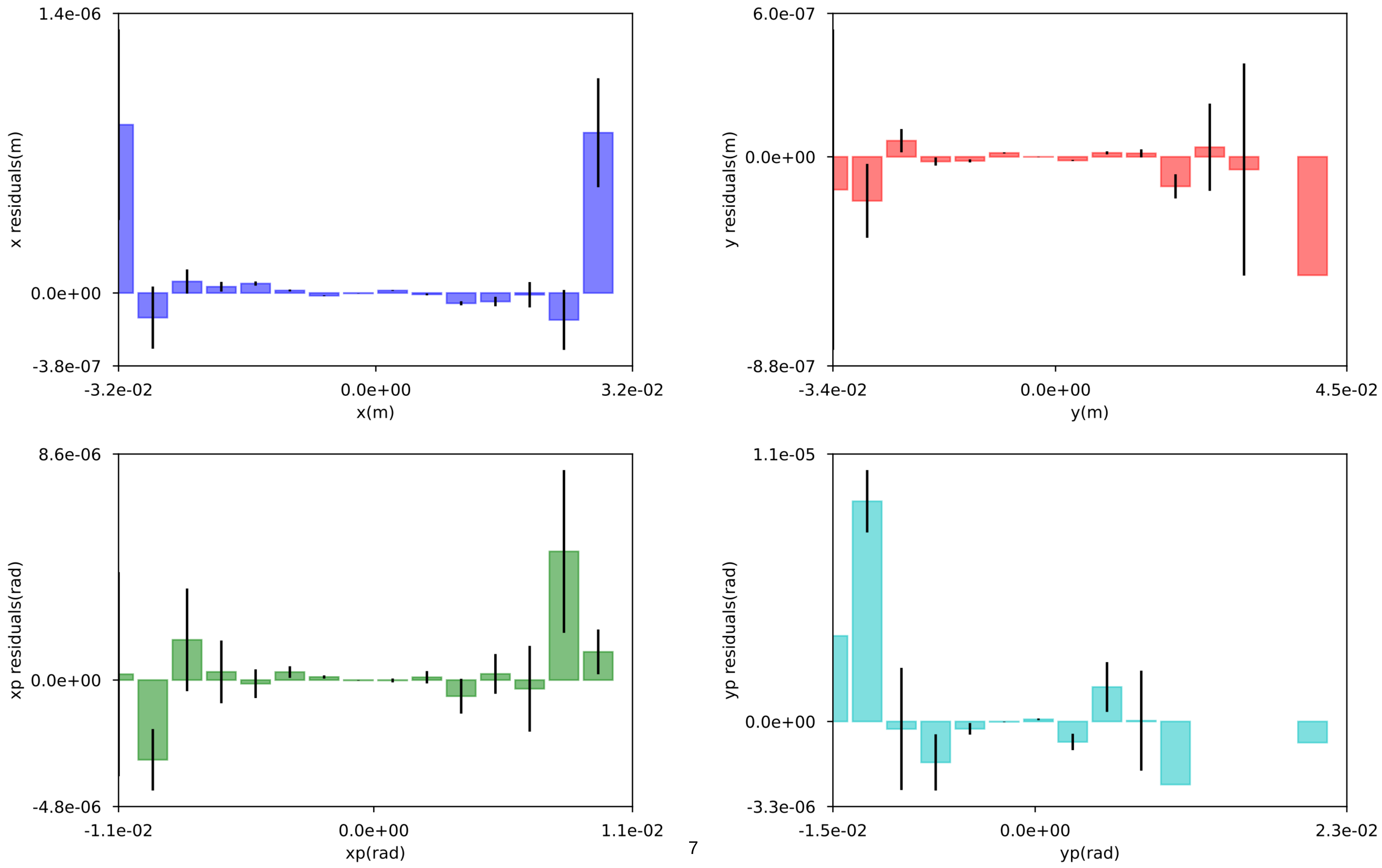
- **Beam**
  100,000 particles
  3.0cm Gaussian
  15 MeV Protons
  $B\rho = 0.561$

- **Options**
  Geant4 integrator
  Linear field interpolator
  1 mm max step length



Field Map Validation

Octupole Residuals – k_3 = 20,000 m^{-3}



Further Work

Design Aims – Configuration with two quadrupole doublets

For mini beams

- Focus to a spot size ~ mm, create a region of larger transverse ratio for octupole placement, and have the beam parallel at the Stage 1 End Station

For 3.0-1.0cm spot sizes

- Maintain spot size whilst create a region of larger transverse ratio for octupole placement, and have the beam parallel at the Stage 1 End Station

Next Steps – Octupole studies and further field map validation

- Simulate octupole and/or quadrupole-octupole combined function magnet in the four-quadrupole configuration with a 3.0 cm beam and make uniformity calculations at the end of Stage 1
- Simulate as above for the smaller spot sizes and the mini-beam configurations
- **FieldMapper –** Prepare for conversion of the optimal fields to GPT accepted formats and extract GPT quadrupole field for three-way validation between BDSIM, GPT and FieldMapper.