Stage 1 Design

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LhARA Collaboration Meeting

25th April 2024

Royal Holloway University of London

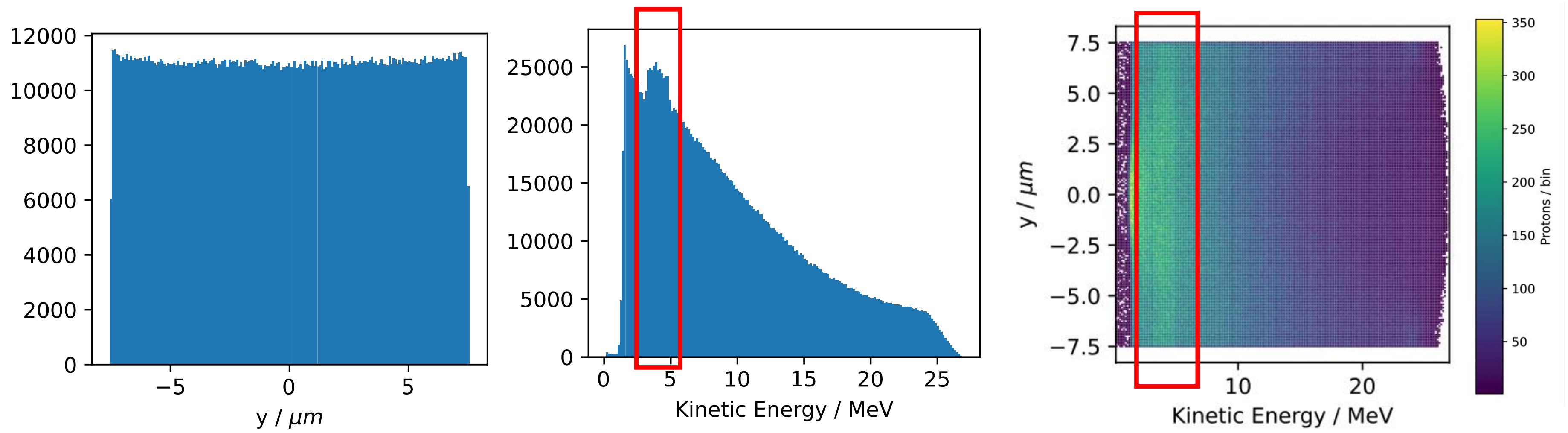
LhARA Laser-hybrid Accelerator for Radiobiological Applications

JAI John Adams Institute for Accelerator Science

Outline

- Standard parameterised source
- Stage 1 status
- Stage 1 proposed accelerator updates
- Gabor lens tracking performance
- Alternative injection line design

Simulated Beam Reliability



- SCAPA simulations – OSIRIS PIC code
    - 15 MeV ± 100 % beam

- Distribution uncertainties
    - Excess at ~ 4 MeV – unphysical
    - Absence of protons at low energies
    - Questionable reliability

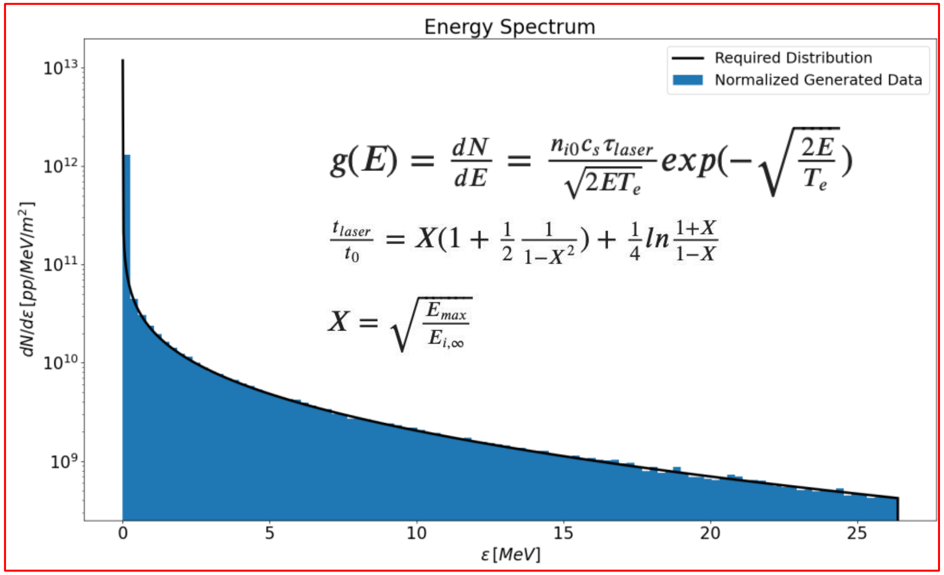
Parameterised Source Distribution

- LhARALinearOptics
  - K. Long, M. Maxouti & N. Dover
  - Code for modelling LhARA beam lines
    - Also LION beamline
  - Optics, losses, particle source

- Variety of source options
  - Default: "exponential" energy spectrum with h/e cut off
  - Gaussian angular distribution, pointing $\boldsymbol{\theta}$, flat $\boldsymbol{\phi}$

- Under-sampling uncertainty as E -> 0
  - Impact on LhARA performance unlikely

- Update accordingly to match experimental data



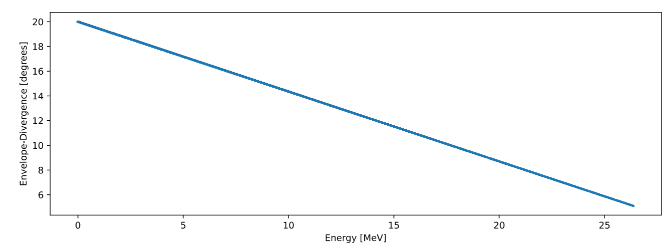
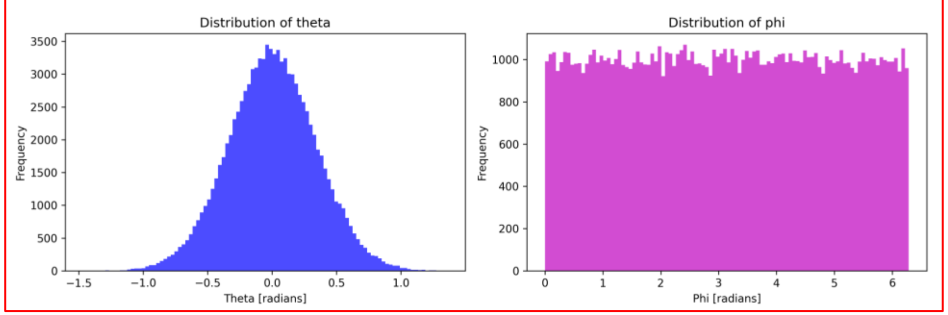


Figure 2: Energy dependent envelope divergence.

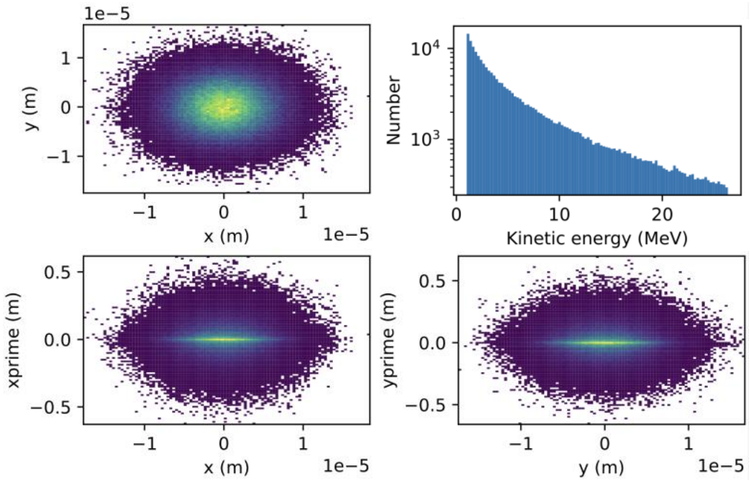


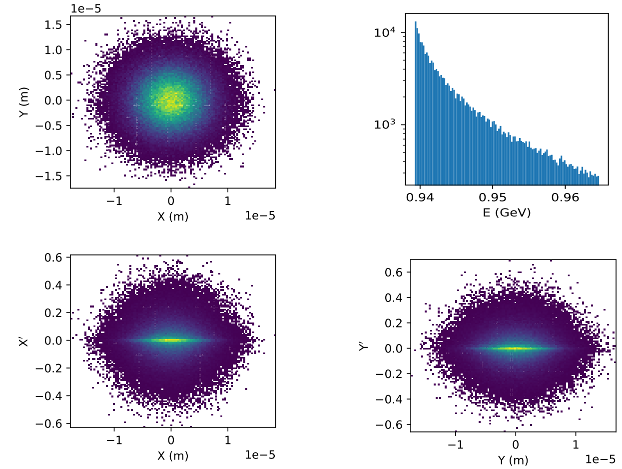
LhARA Linear Optics

LhARALinearOptics

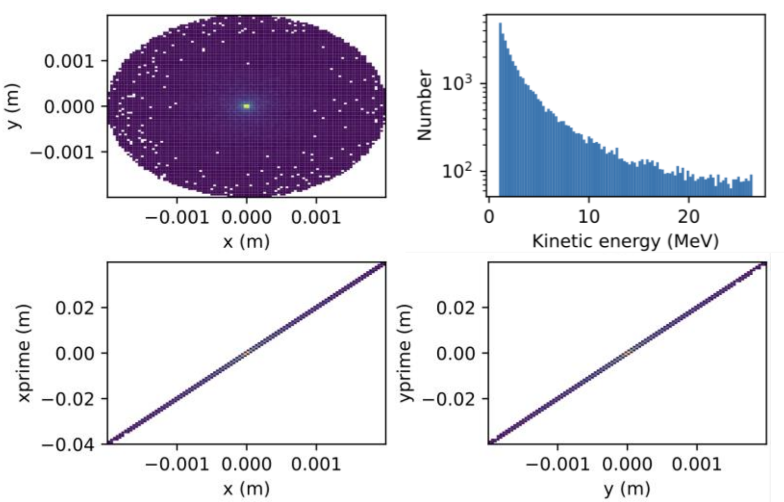
Conversion & BDSIM tracking:

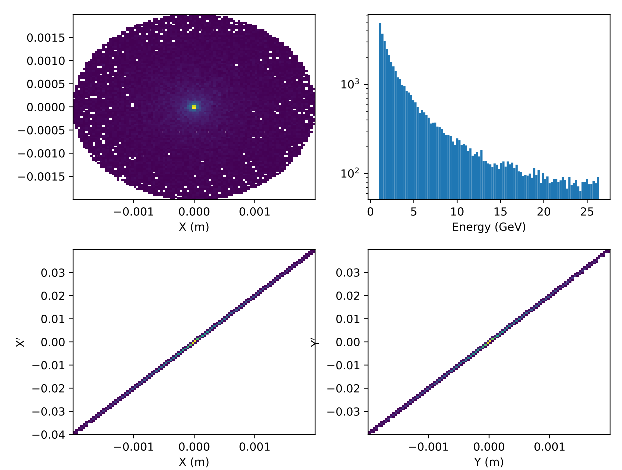
Source





Nozzle entrance aperture



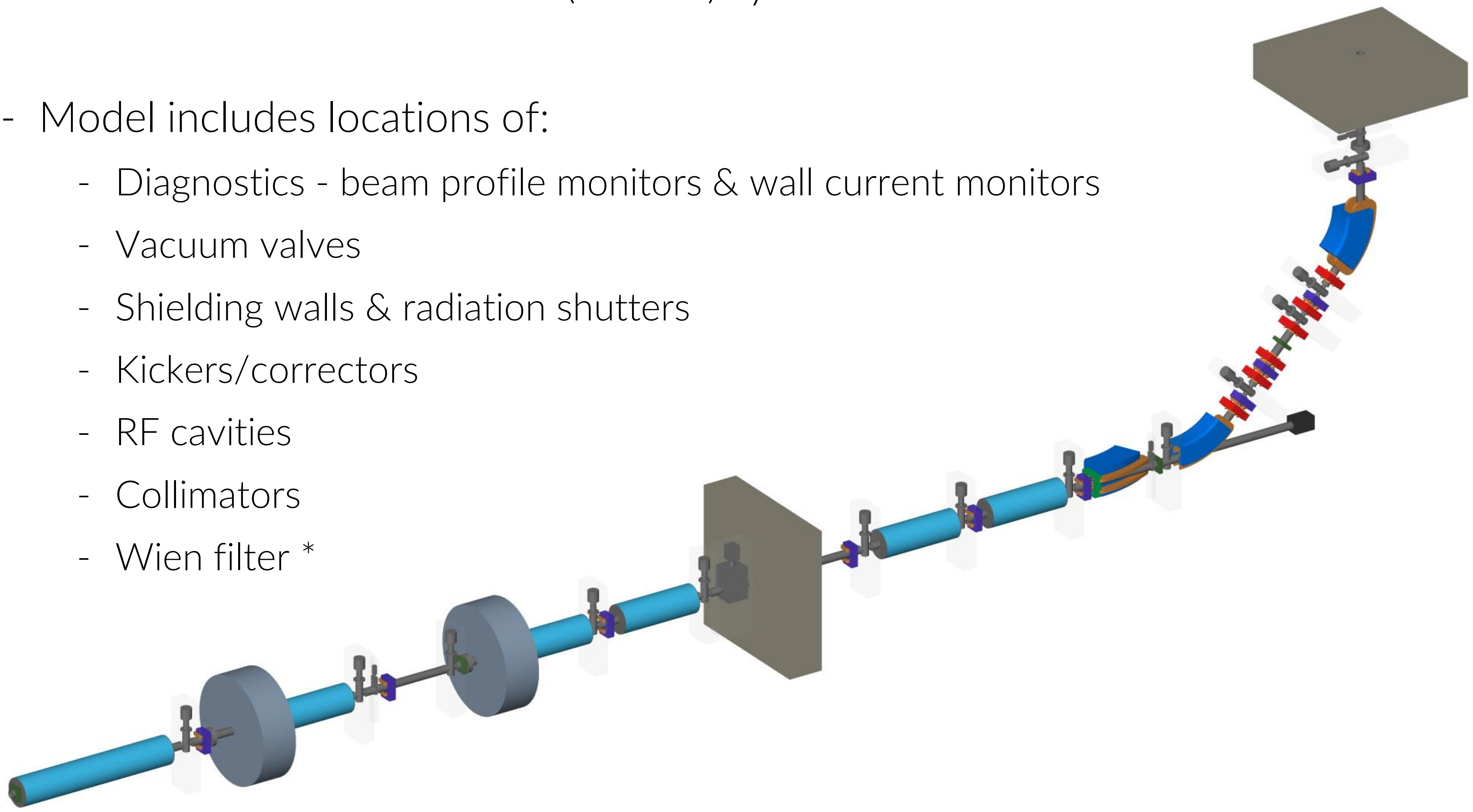


Next step: full beam line optics calculations

Stage 1 Overview

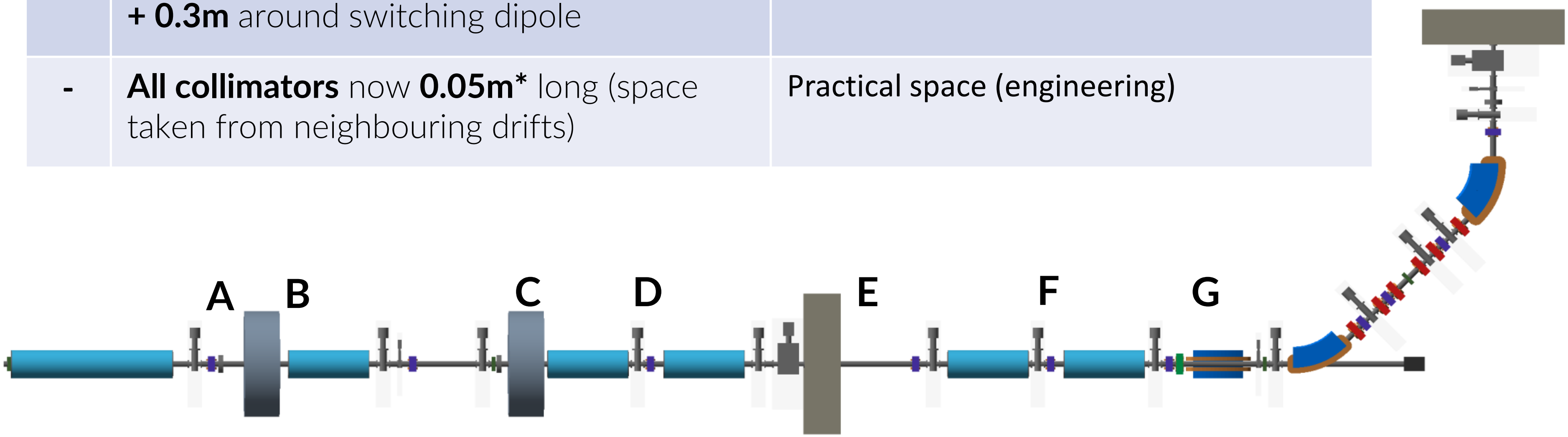
- CAD & Monte Carlo models (BDSIM) synchronised

- Model includes locations of:
    - Diagnostics - beam profile monitors & wall current monitors
    - Vacuum valves
    - Shielding walls & radiation shutters
    - Kickers/correctors
    - RF cavities
    - Collimators
    - Wien filter *



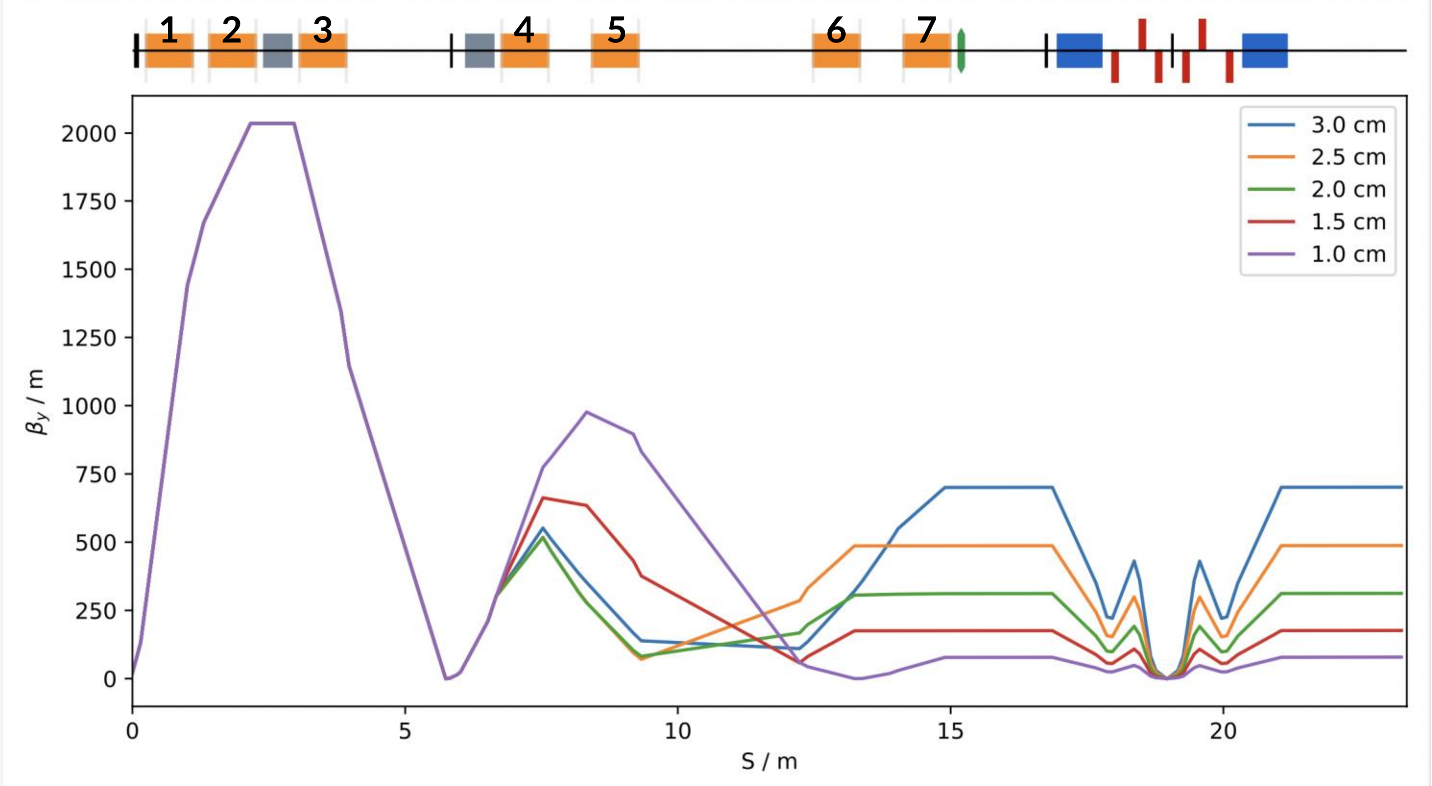
Changes from Baseline design

	Update	Reason
A	**+1.0185m*** between **GL2 & RF CAV 1**	Diagnostics, corrector magnet
B	**+ 0.127m*** between **RF CAV 1 & GL3**	Practical space (engineering)
C	**RF CAV 02** moved upstream by **0.0546m***	Practical space (engineering)
D	**+ 0.2m** between GL4 and GL5	Diagnostics, corrector magnet
E	**+ 0.4m** between GL4 and GL5	Diagnostics, Radiation shutter, Wien filter
F	**+ 0.2m** between GL6 and GL7	Diagnostics, corrector magnet
G	**Octupole** moved downstream by **0.15m***, **+ 0.3m** around switching dipole	Practical space (engineering)
-	**All collimators** now **0.05m*** long (space taken from neighbouring drifts)	Practical space (engineering)



Stage 1 Optics Flexibility

	Update	Reason
D	**+ 0.2m** between GL4 and GL5	Diagnostics, corrector magnet
E	**+ 0.4m** between GL4 and GL5	Diagnostics, Radiation shutter, Wien filter
F	**+ 0.2m** between GL6 and GL7	Diagnostics, corrector magnet

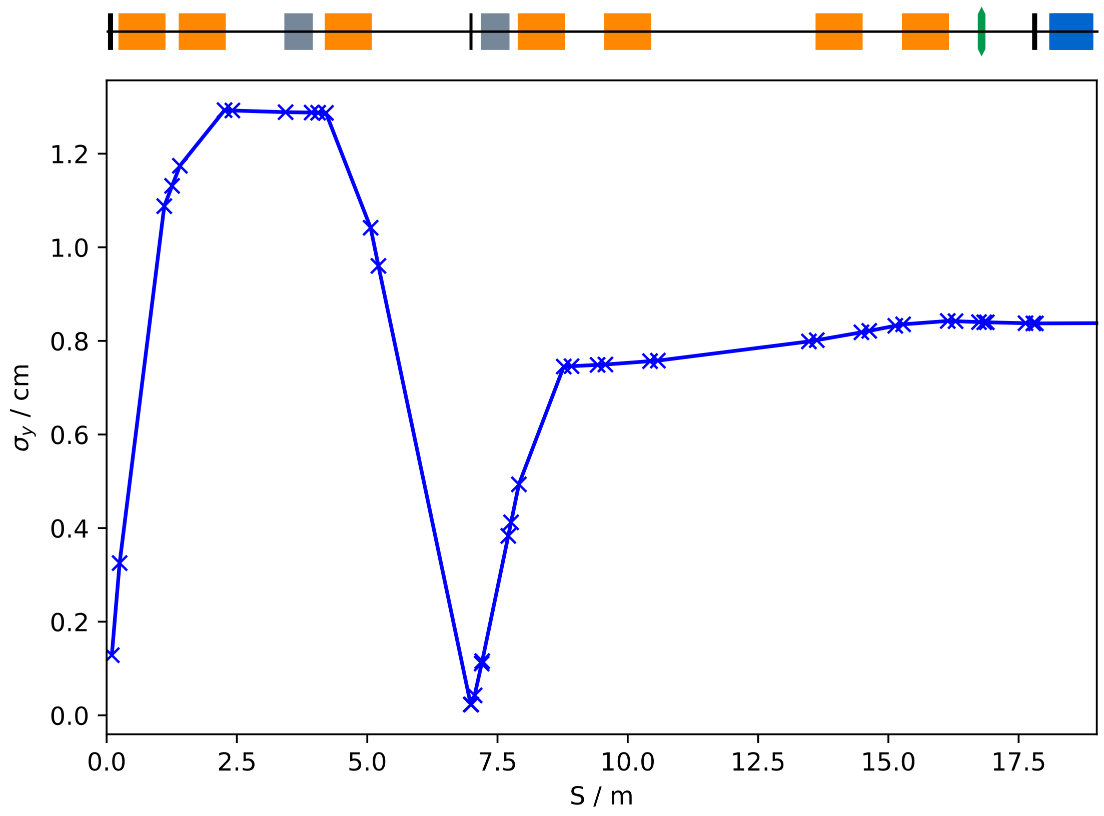


- **Flexibility preserved for delivering 1-3 cm spot sizes.**

Stage 1 Optics for FFA Injection

- Emittance growth introducing difficulties optimising for injection line conditions
  - Emittance ~2.7e-6, beta of 50m = 1 sigma beam radius of 1.16 cm.
  - Prioritise alpha = 0
- Solution: beam at start of switching dipole:

Alpha x: 0.094
Alpha y: 0.104
Beta x: 25.092
Beta y: 26.463
Emit x: 2.822e-06
Emit y: 2.707e-06



- Solenoids 5 & 6 off
- Solenoid 4 KS = 1.95
  - Field = **1.096 T**
- Solenoid 7 KS = 0.4
  - Field = **0.225 T**

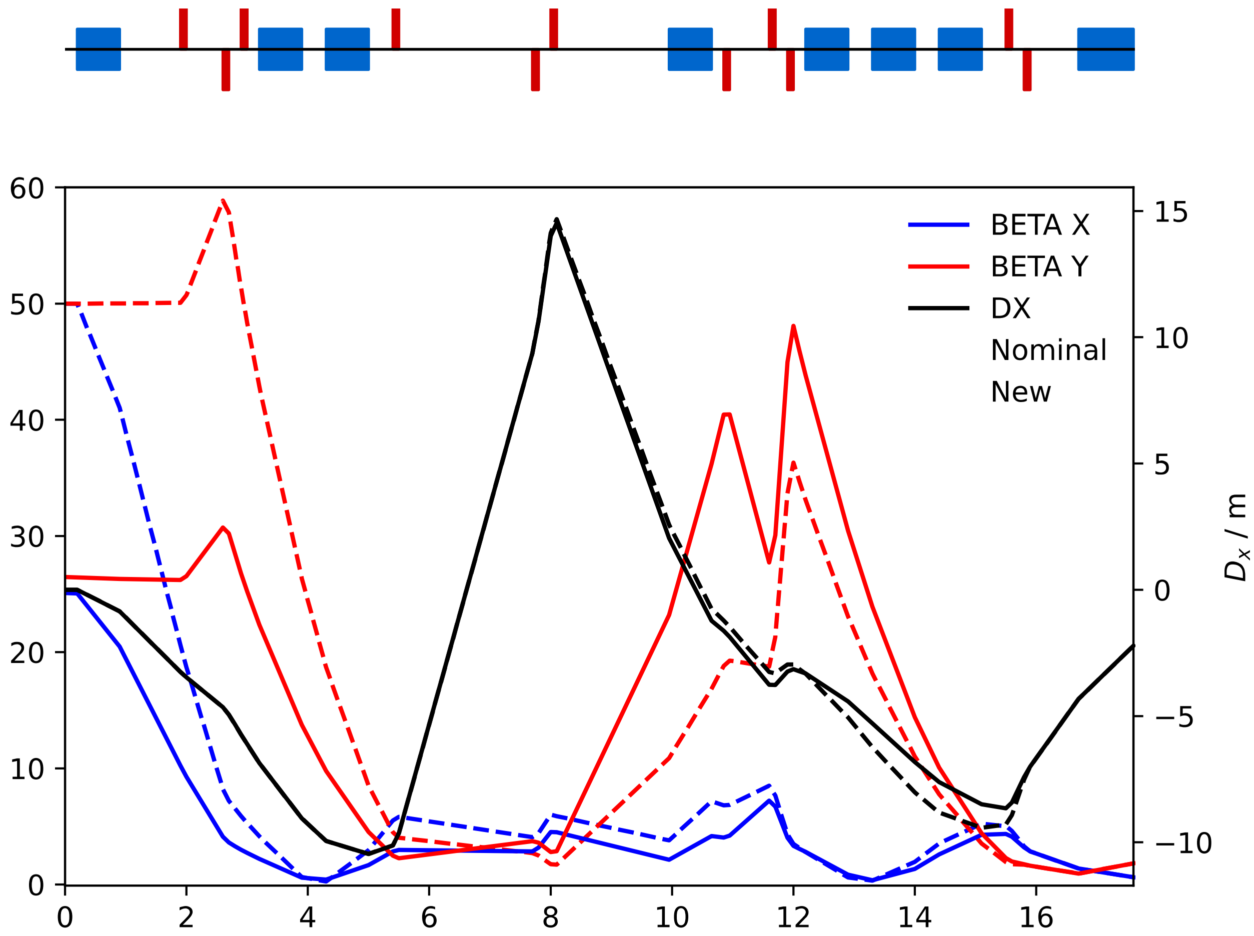
Injection Line: Optics Optimisation

- **Able to meet conditions at injection septum**

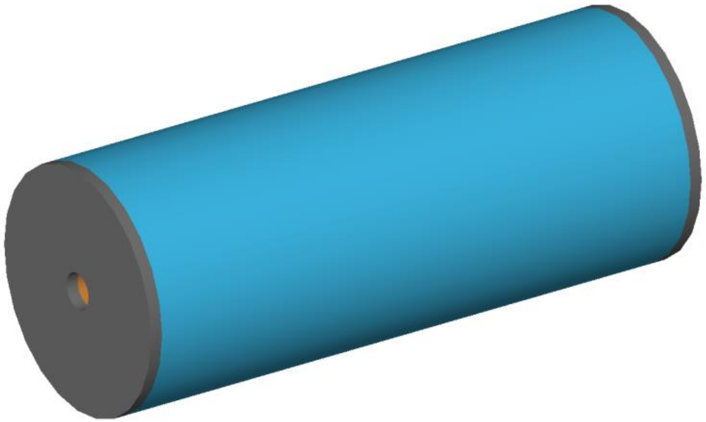
- Vary last 7 quads only
  - Constraint of 9.55 T/m.

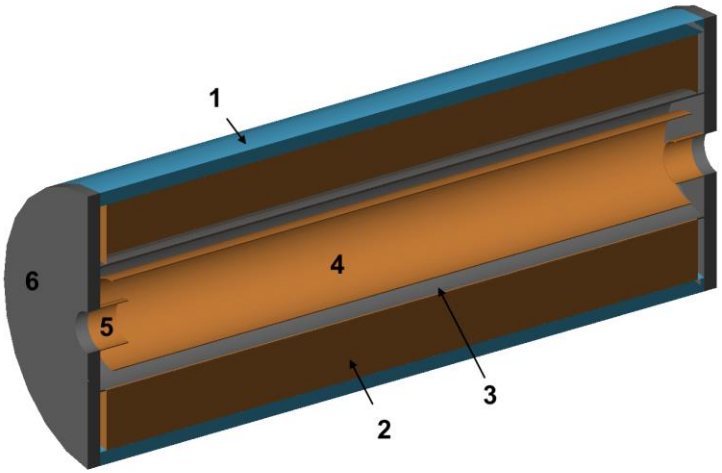
- Solution found:
  - Small changes to field gradients

- Further updates will be required - engineering
  - Proximity between magnets / coils
  - Collimator location
  - See Clive Hill's talk later



Gabor Lens in BDSIM

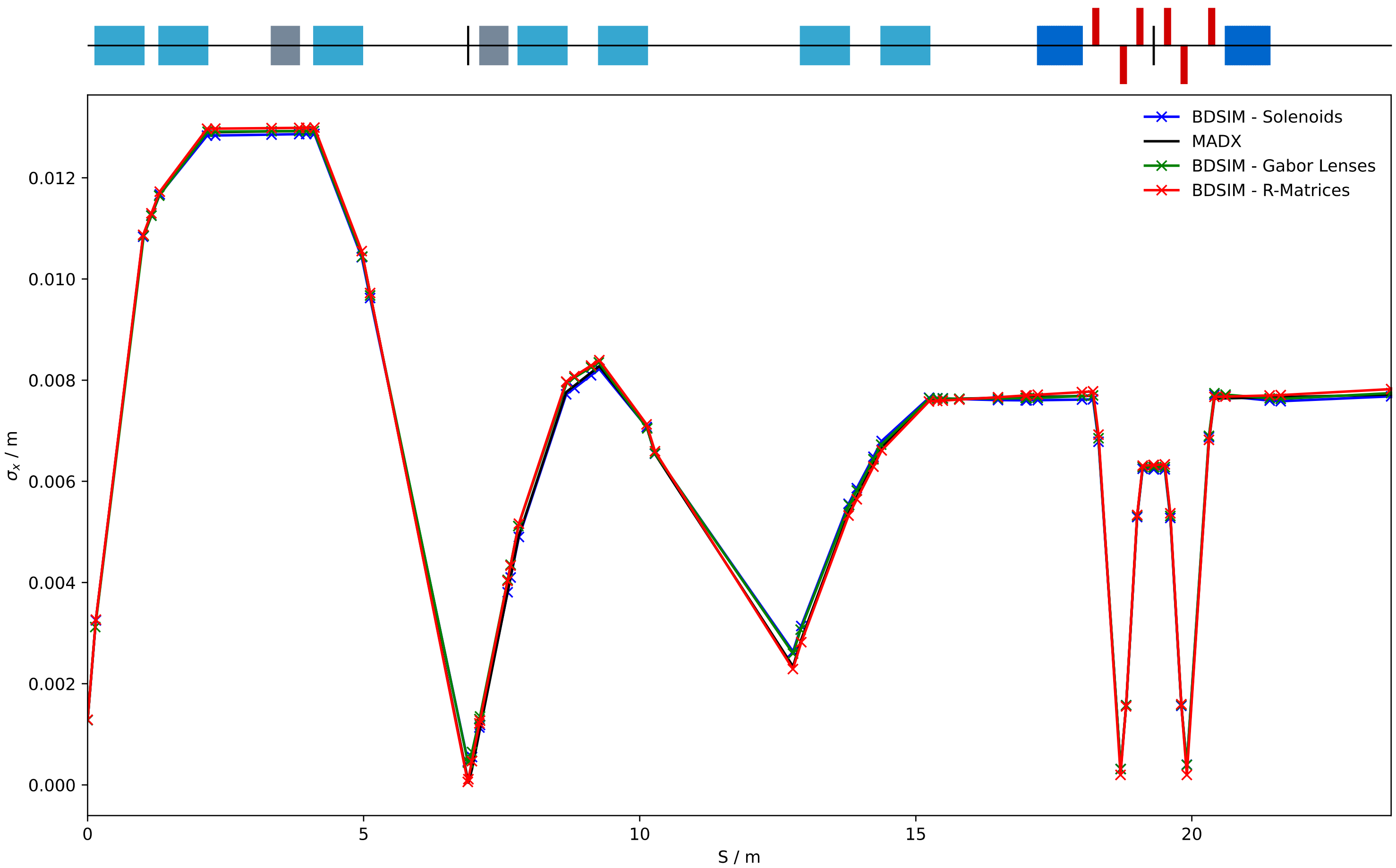




- Geometry:
  1) Outer tube (variable, default iron)
  2) Solenoid coils (copper)
  3) Vacuum tube
  4) Anode (copper)
  5) Electrode (copper)
  6) End caps (stainless steel)

- Example anode & electrode
  - Will be updated to match WP3 / LhARA apparatus
- EM field
  - **Radial plasma (electric) field only**
  - Future-proofed to later allow addition of confinement fields

LhARA Tracking Performance



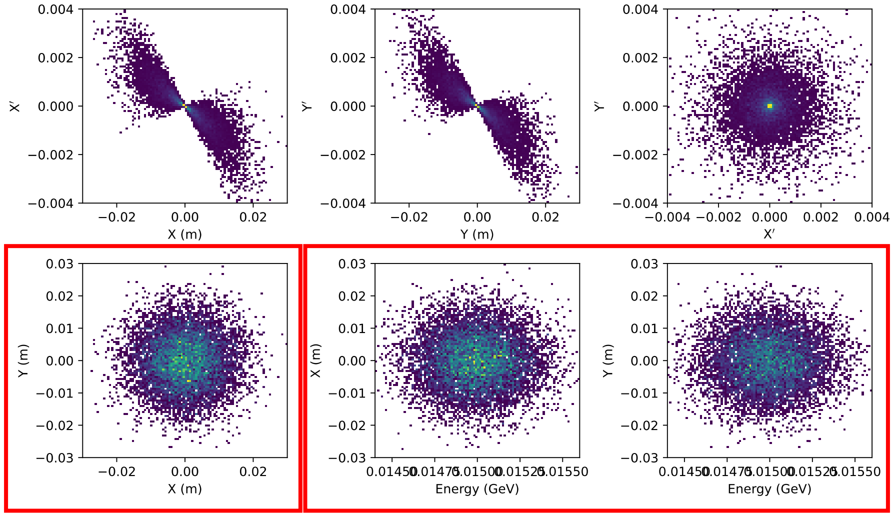
- **Tracking performance of Gabor lenses demonstrated**
    - SCAPA beam, 15 MeV ± 2%

Gabor Lens Strength Updates

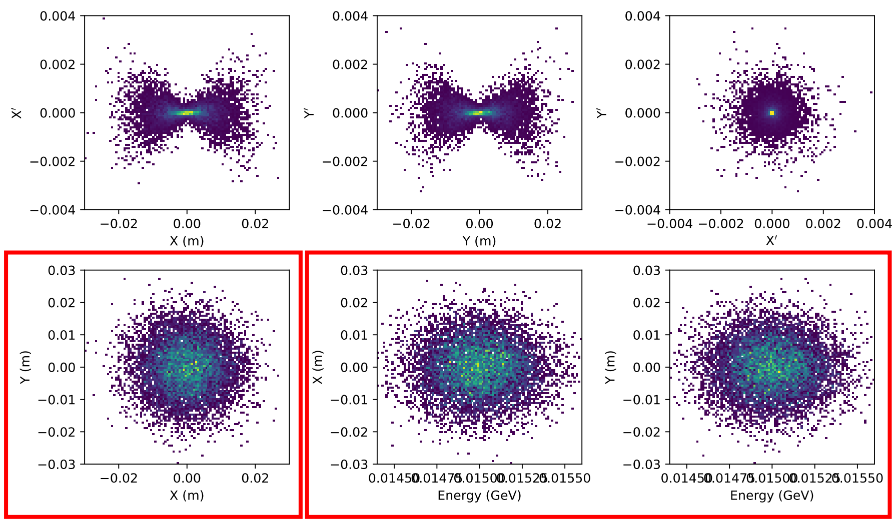
Solenoid / Gabor Lens	Solenoid (Design parameters)		Gabor Lens (simulation optimized)		
	KS	B [T]	B [equivalent]	ΔB/B (%)	Kg
1	2.4917	1.4000	1.3850	**1.07**	1.5433
2	1.0187	0.5724	0.5724	**0**	0.2636
3	1.4486	0.8139	0.8120	**0.23**	0.5304
4	1.7889	1.0051	1.0051	**0**	0.8126
5	1.6043	0.9014	0.8750	**2.929**	0.6160
6	1.2448	0.6994	0.6994	**0**	0.3936
7	1.1660	0.6551	0.6450	**1.54**	0.3347

End Station 1 Phase Space

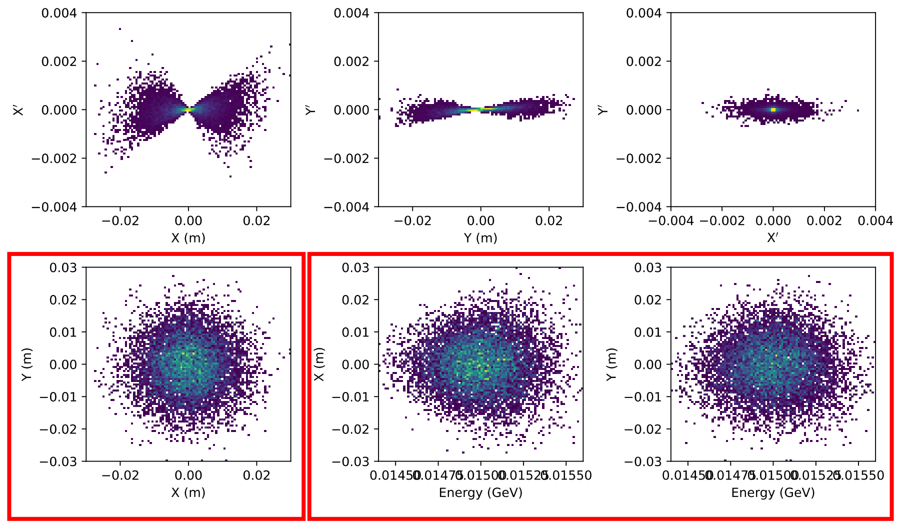
Gabor Lens



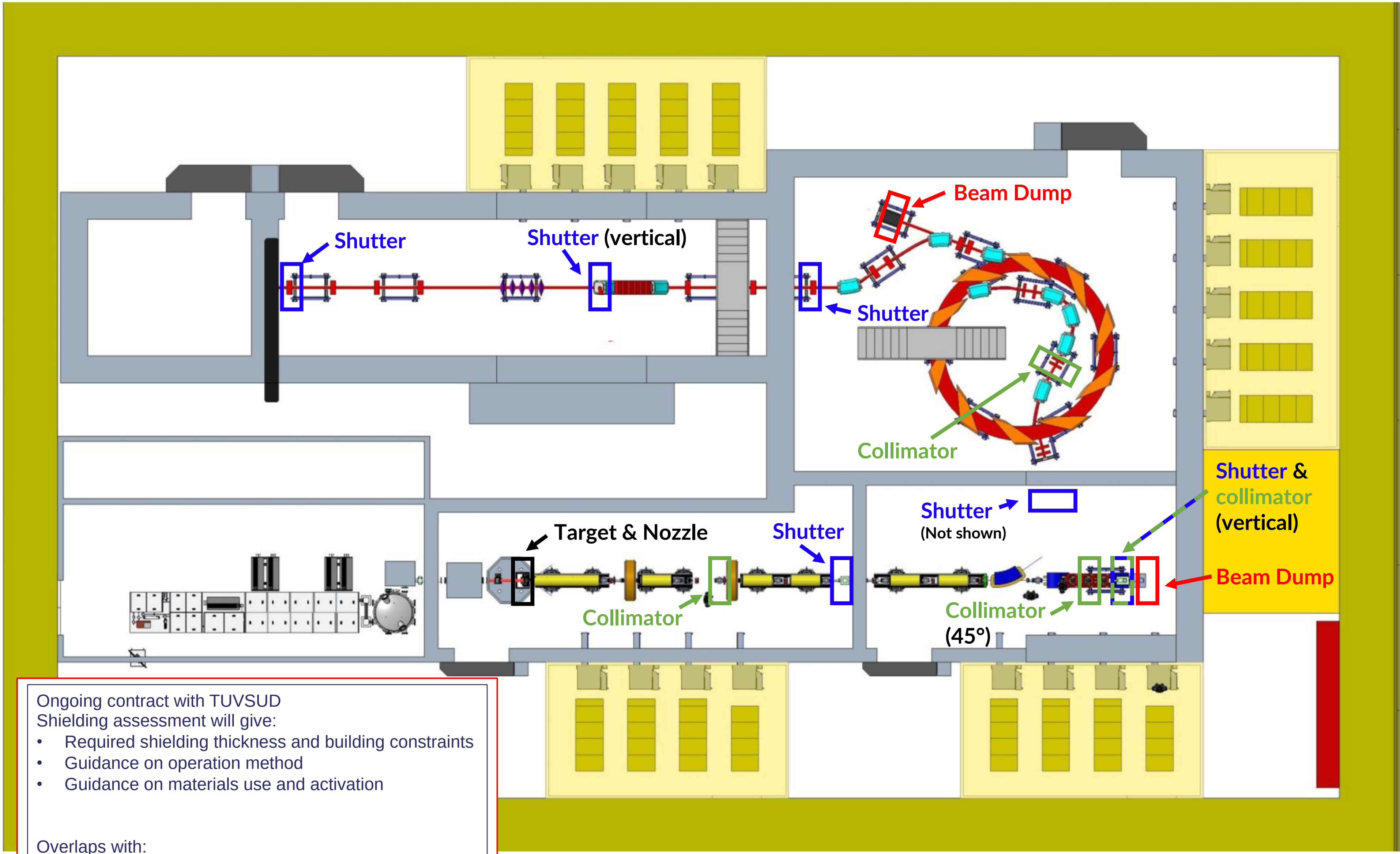
Solenoid



R-Matrix



Radiation Modelling: Loss Map



Ongoing contract with TUVSUD
Shielding assessment will give:

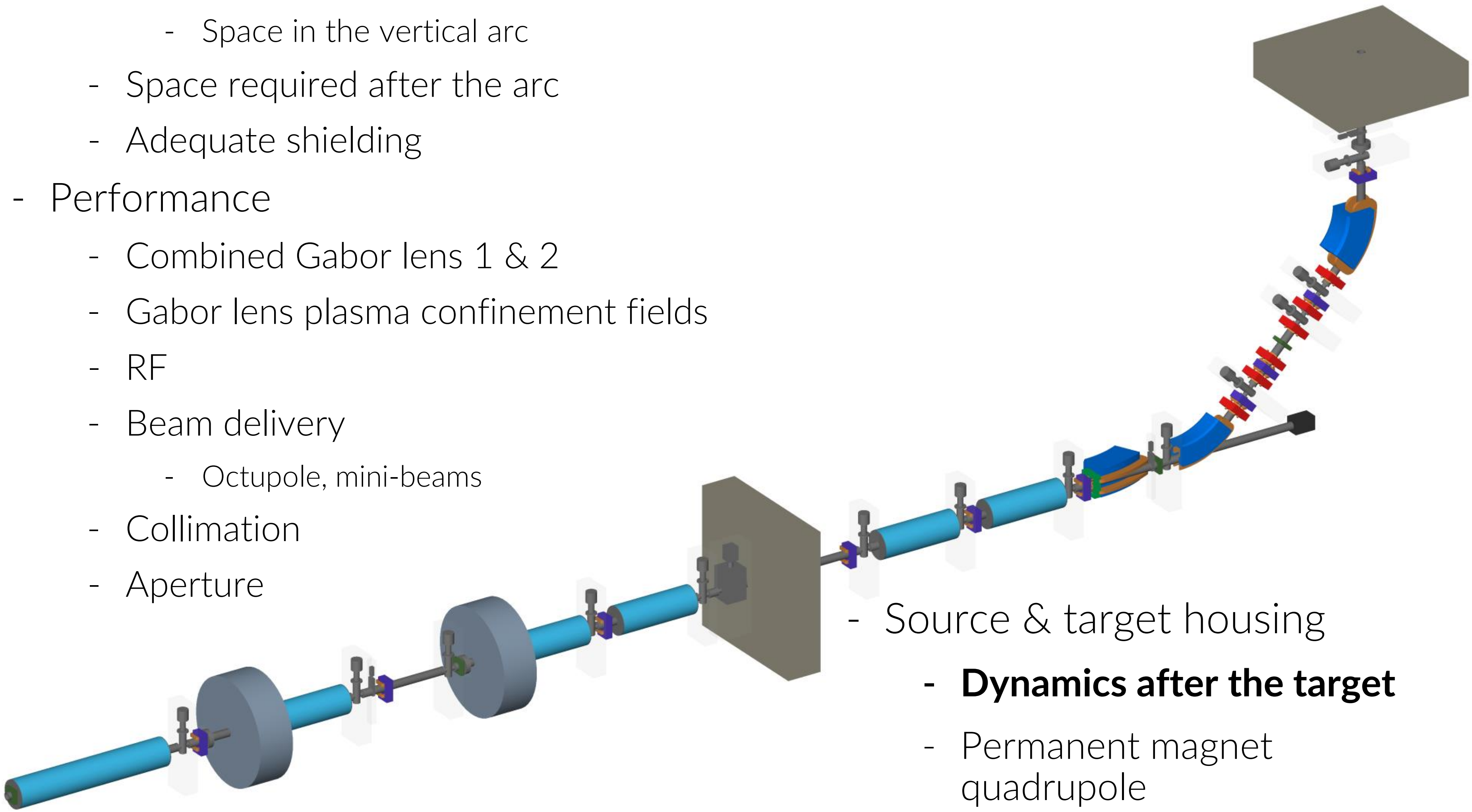
- Required shielding thickness and building constraints
- Guidance on operation method
- Guidance on materials use and activation

Overlaps with:

- Source modelling, definition and experiments
- Development of Stage 1 Gabor lens design
- Stage 2 FFA design

Stage 1: Outstanding Questions

- Infrastructure
  - Sufficient diagnostics & infrastructure systems
    - Space in the vertical arc
  - Space required after the arc
  - Adequate shielding
- Performance
  - Combined Gabor lens 1 & 2
  - Gabor lens plasma confinement fields
  - RF
  - Beam delivery
    - Octupole, mini-beams
  - Collimation
  - Aperture



- Source & target housing
  - **Dynamics after the target**
  - Permanent magnet quadrupole

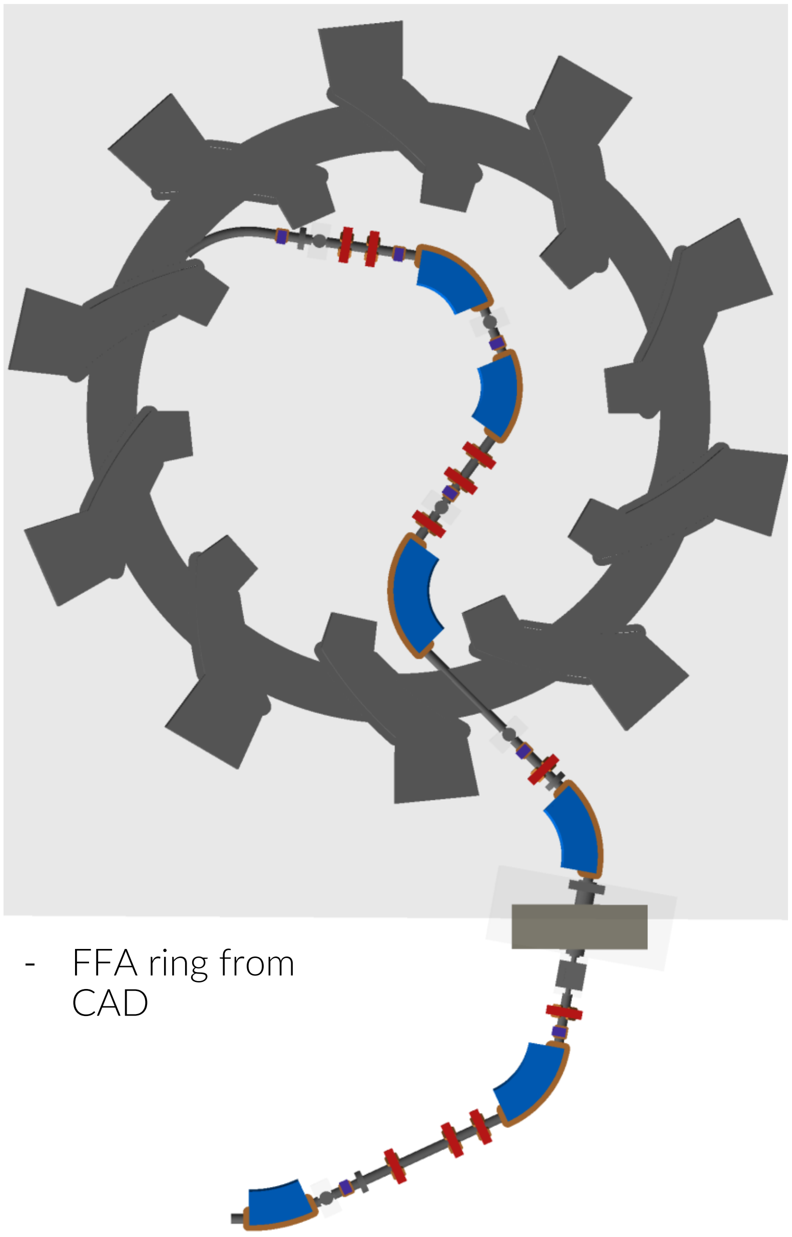
Alternative Injection Line Design

- Aim: mitigate injection line engineering challenges
  - FFA crossing too close to magnets
  - Insufficient space for people to work

- New solution found
  - Three unique dipoles (fields kept < 1T)
  - Integrated bending angle preserved
  - Quad strength constrained to ± 9.55 T/m

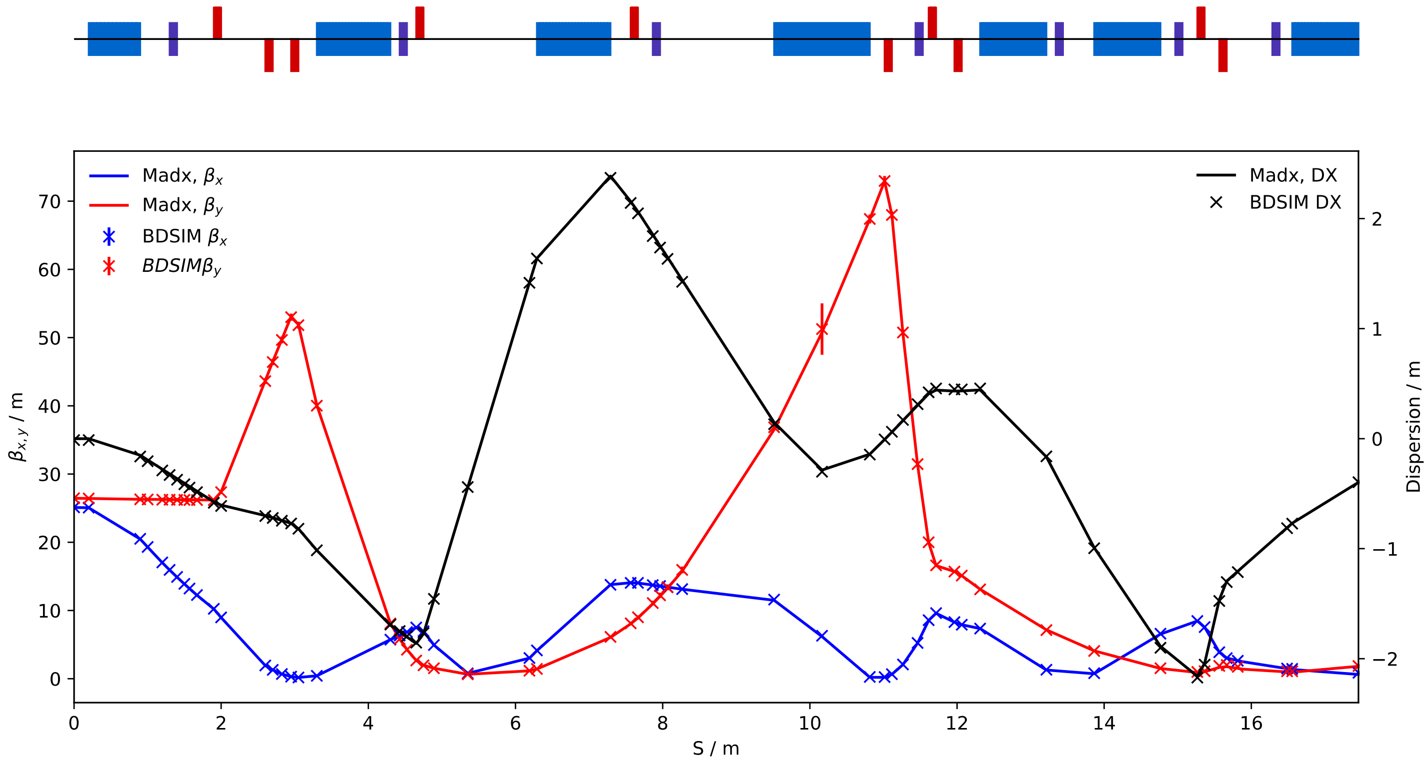
- Space reserved for:
  - Magnet coils - minimum 200mm separation
  - Shielding wall + shutter
  - Collimator
  - Diagnostics + corrector magnets

- Limited degree of FFA translation
  - Exact injection point definition needed



- FFA ring from CAD

Alternative Injection Line: Optics



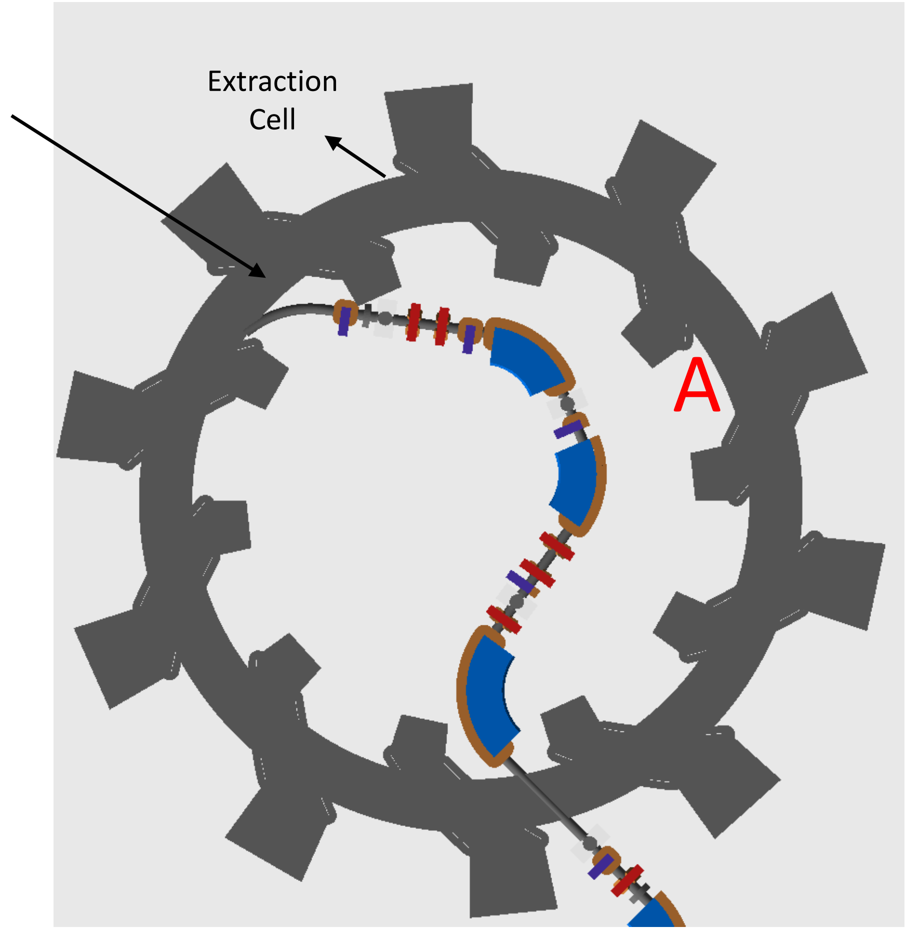
- Injection conditions are preserved at the end of the injection septum magnet
  - Beta, Alpha, Dispersion, and Dispersion'
- BDSIM & MADX models in good agreement
  - Small BDSIM losses (~0.2%)
- Caveat: a beam pipe aperture of ~10cm diameter will be needed

LhARA Injection Line: Direction

- Does injection have to be in the chosen cell?
  - Potential alternative at A ?
  - Other cells would be challenging
    - Too strong angle for optics
    - Cell occupied (extraction)
    - Next cell occupied – prohibits corrector magnets

- **Address FFA challenges first**
  - Dictates direction of injection line design

- **Injection line solutions exist for current FFA configuration.**



Summary

- Standard parameterised source developed
- Stage 1 accelerator updates proposed
- Gabor lens tracking performance demonstrated
- Alternative FFA injection line designed
- **Stage 1 design is in a good position**

Thank you

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