Upgrades to the Injector Complex for Diamond-II

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On behalf of the Diamond-II design team

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diamond

Diamond Light Source and Diamond-II Upgrade

Diamond Light Source is the UK's national synchrotron radiation facility located on Harwell Campus, Oxfordshire

Currently engaged in a major facility upgrade, Diamond-II:

- Objective #1: Optimise the science enabled at Diamond
- Objective #2: Maximise the impact it has for researchers both in universities and in industry

Objectives achieved through several means:

- New Modified Hybrid 6-Bend Achromat (M-H6BA) storage ring
  - Lower emittance to increase brightness and coherence
  - Double number of straight sections to increase capacity
- Raise energy from 3 GeV to 3.5 GeV to increase flux and brightness above 10 keV
- Upgrade insertion devices, new flagship beamlines
- Improved data handling/computation, automation, ...

Technical Design Report published in October 2022:

https://www.diamond.ac.uk/Diamond-II.html

	Diamond-I	Diamond-II
Lattice Type	DBA	M-H6BA
Circumference	561.6 m	560.561 m
Straight Sections	24	48
Energy	3 GeV	3.5 GeV
Energy Spread	0.096 %	0.094 %
Natural Emittance	2.7 nm.rad	161 pm.rad
Emittance with IDs	3.1 nm.rad	120 pm.rad

Storage Ring Injection

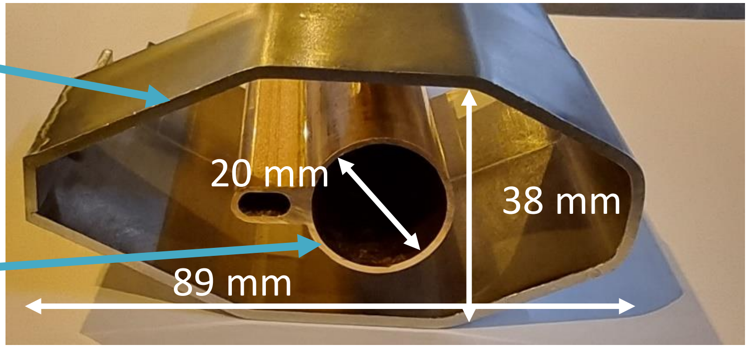
Injection into the Diamond-II storage ring will be more demanding than for the existing ring:

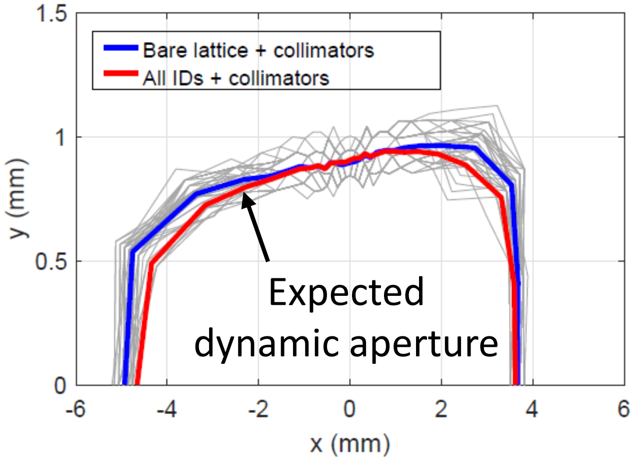
Compact, high gradient lattice ⇒ small bore magnets ⇒ narrow vacuum chambers

Strong quadrupoles + small dispersion ⇒ strong sextupoles ⇒ small dynamic aperture

Diamond

Diamond-II





⇒ Factor 4 reduction in aperture horizontally

⇒ Factor 6 reduction in aperture vertically

Consequences:

1) Need to reduce horizontal separation between stored and injected beams
2) Need to reduce the dimensions of the beam extracted from the booster

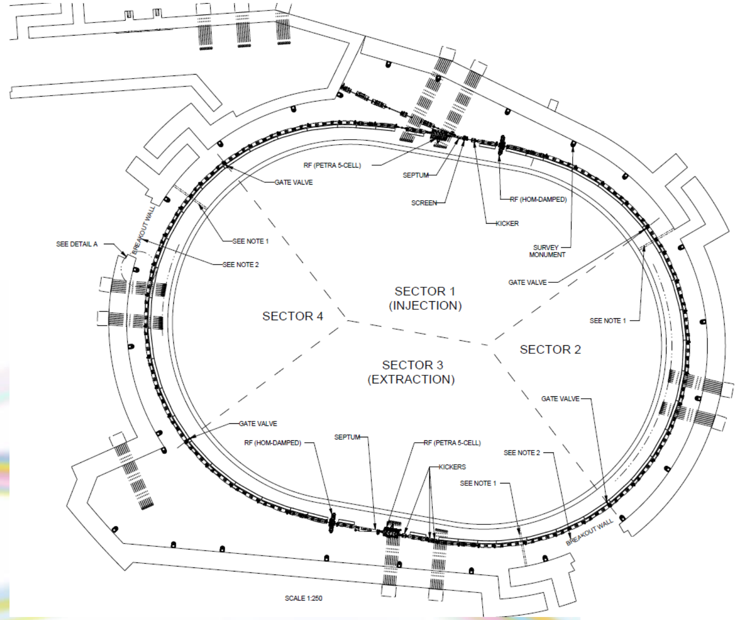
	Existing booster	Target
Energy	0.1 - 3.0 GeV	0.1 - 3.5 GeV
Emittance	134 nm.rad	<30 nm.rad
Bunch length	100 ps	<40 ps
Max. SB charge	~0.2-0.4 nC	~5 nC
Max. MB charge	~1-2 nC	~15 nC

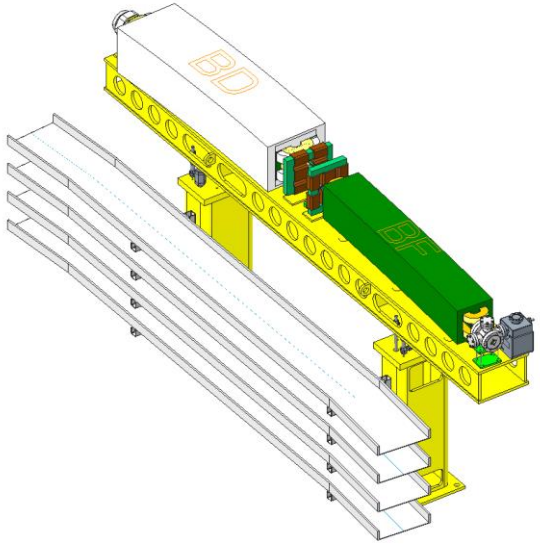
New Booster Synchrotron

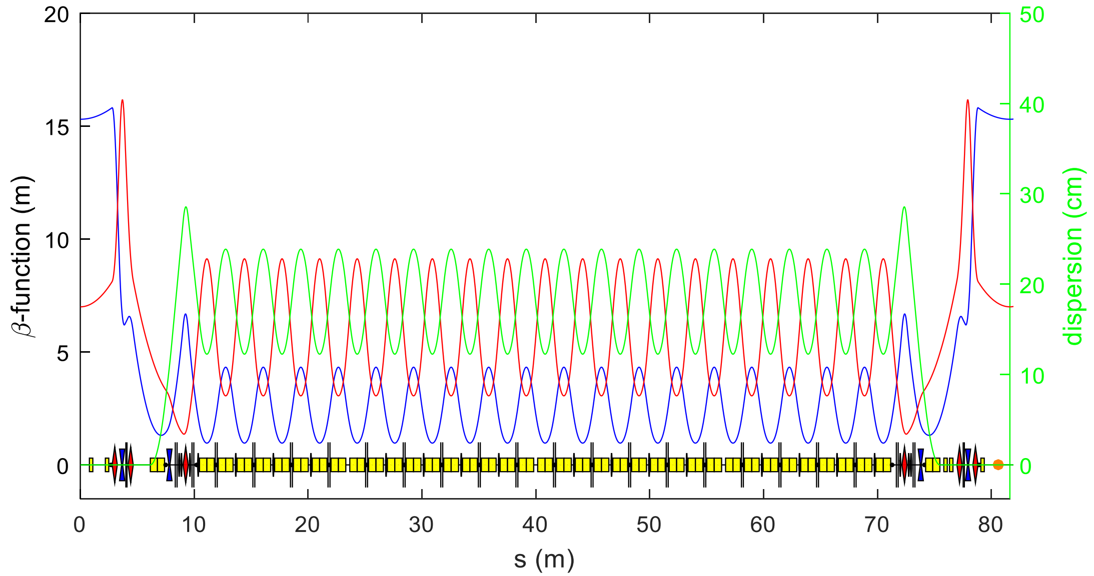
<u>Design for Booster-II:</u>

- Racetrack structure (fit in existing tunnel)
- Unit cells built from combined-function magnets
- Two dispersion-free straight sections
- Quadrupole triplets in straights for tune control
- Distributed trim sextupoles to counter eddy-currents and allow fine-tuning of the chromaticity

Parameter	Booster-I	Booster-II
Energy Range	0.1-3.0	0.1-3.5
Circumference	158.4	163.847
Tunes	[7.18, 4.27]	[12.41, 5.38]
Emittance	**134 nm.rad**	**17.4 nm.rad**
Energy Spread	0.073 %	0.086 %
Bunch Length	**100 ps**	**38 ps**
Energy Loss / Turn	580 keV	947 keV



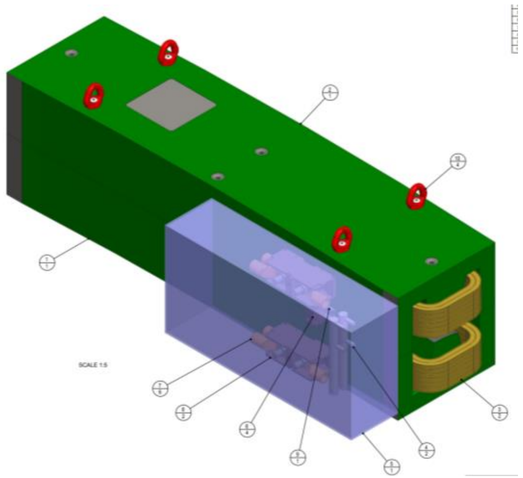




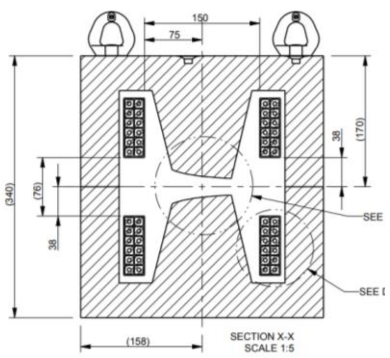
Booster-II Hardware

Magnet Parameters at 3.5 GeV

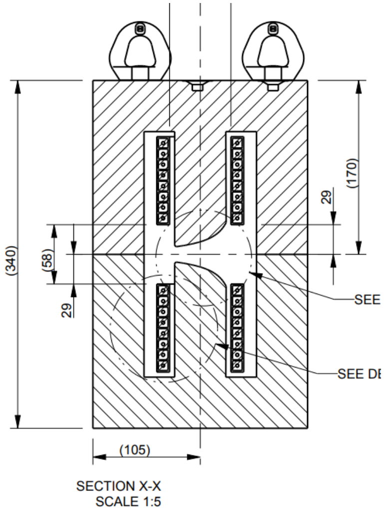
Magnet	Number	L (m)	B (T)	G (T/m)	S (T/m²)
BB	4	1.25	0.95	-	-
BD	38	1.3	0.99	-8.24	-44.0
BF	36	1.3	0.42	11.2	36.0
Quad.	20	0.45	-	30	-
Sext.	44	0.05	-	-	300



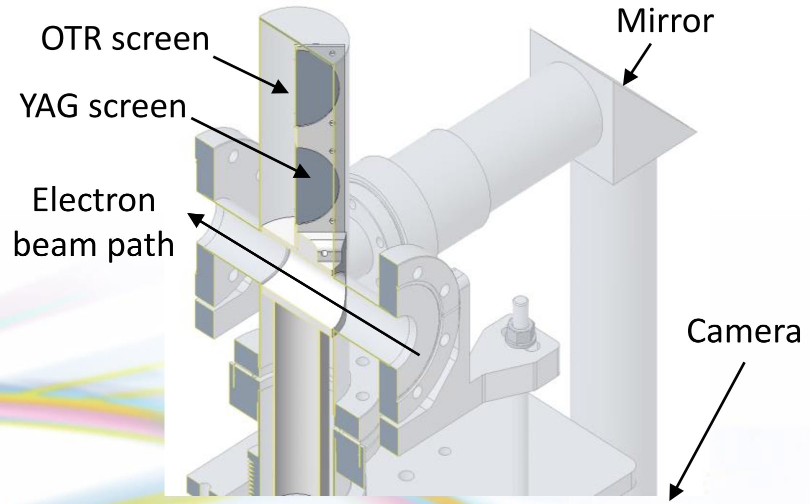
BD Dipole



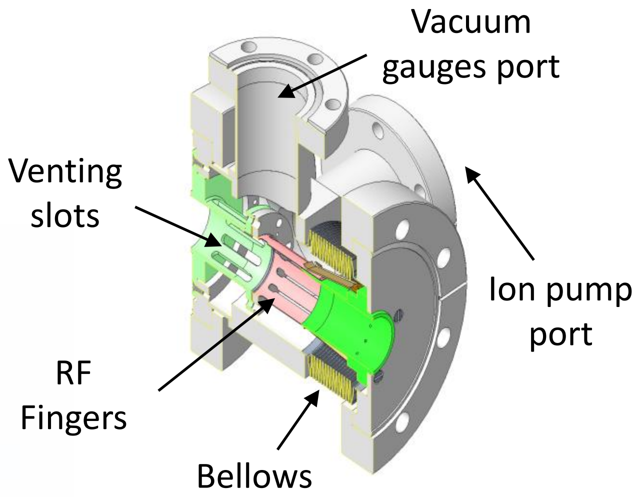
BF Dipole



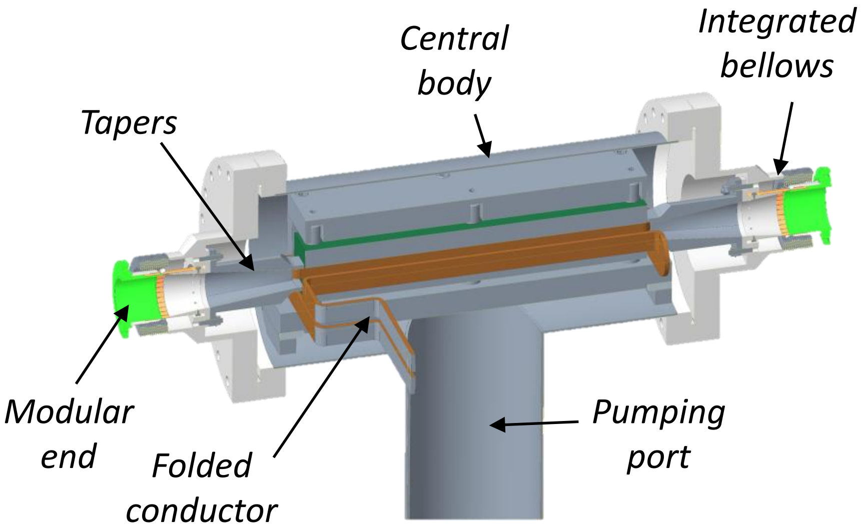
Diagnostic Screens



Pumping / Bellows Assembly



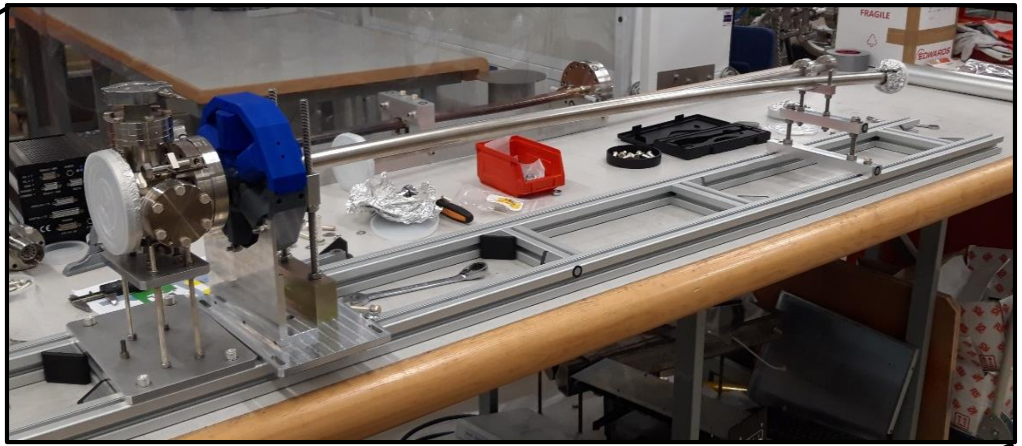
Injection / Extraction Kickers

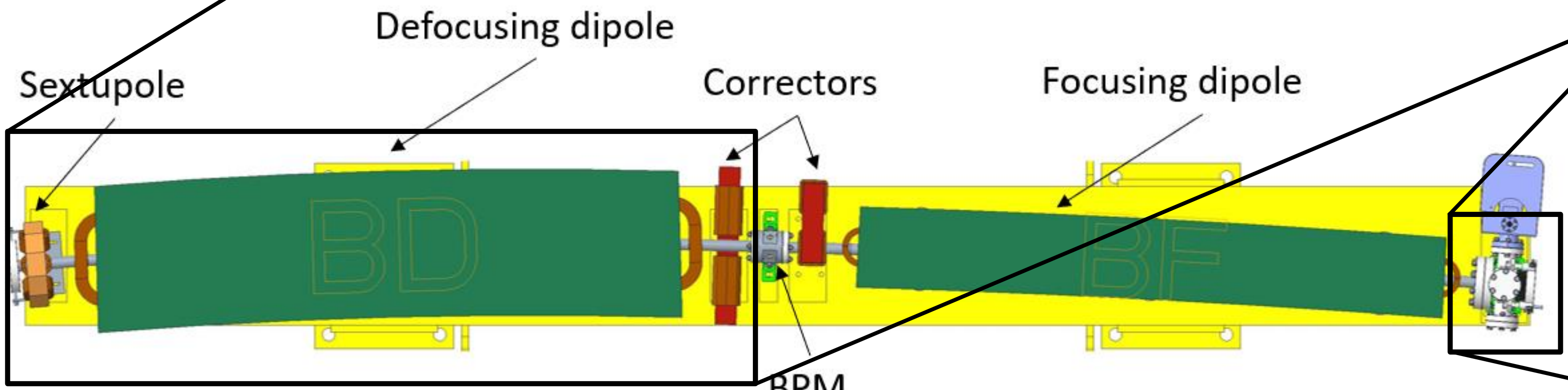


Prototyping for Booster-II

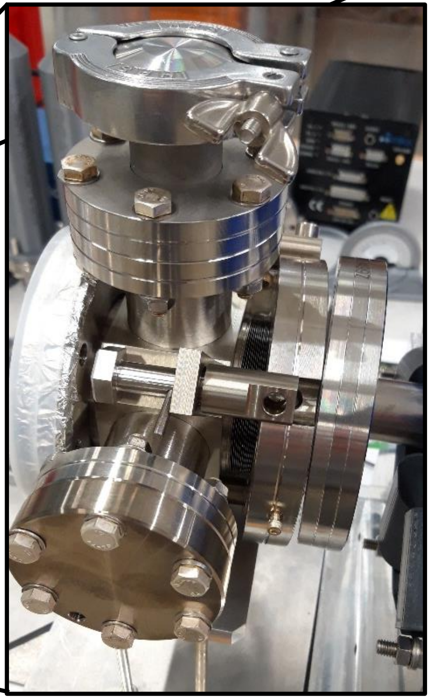
<u>Prototyping of components to check:</u>

- Vessel stiffness / clearance from magnet poles
- Material thickness (1 mm stainless steel)
- Assembly procedure / ease of access to bolts
- Functionality of pumping cross / bellow assembly
- Robustness of RF fingers
- Vessel supports / alignment

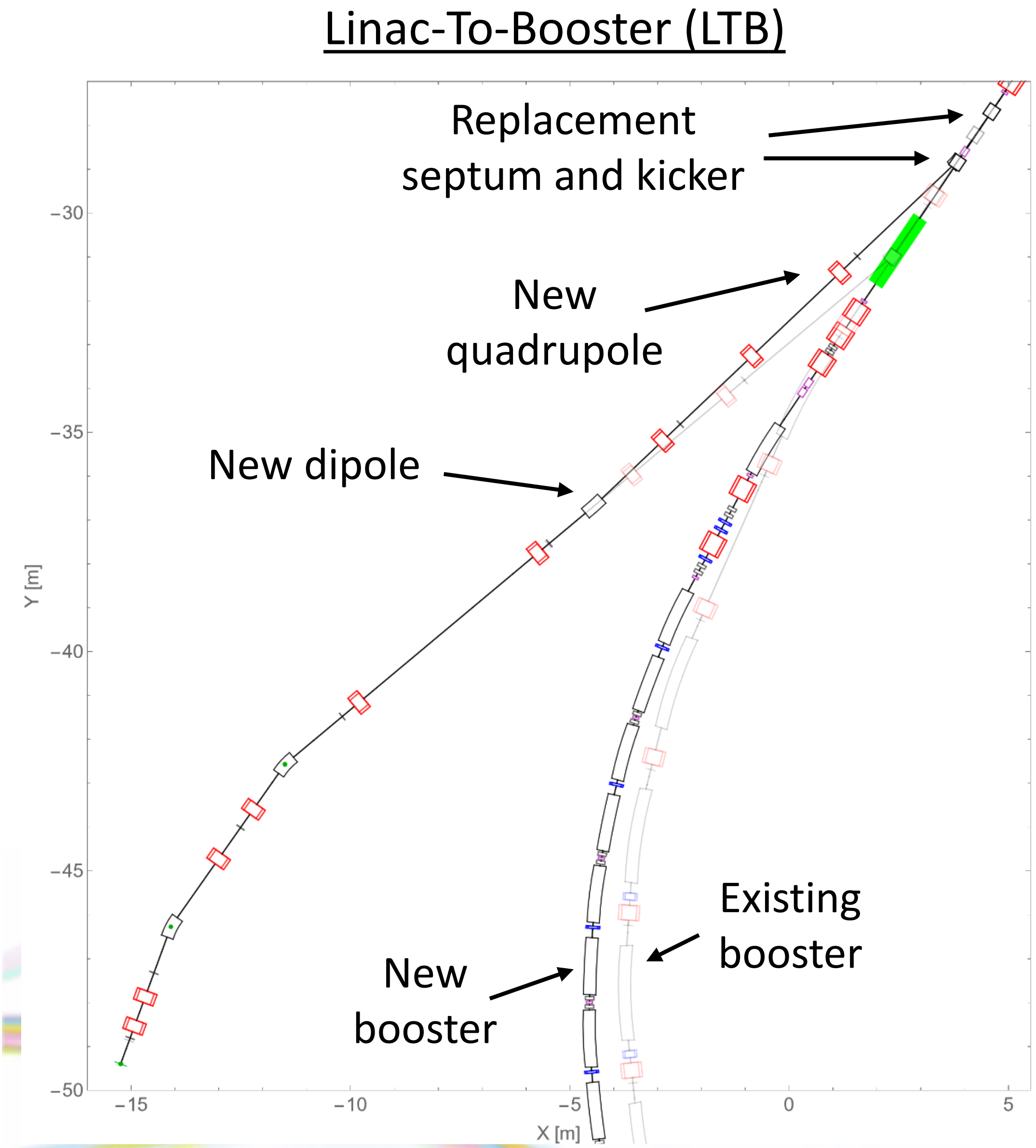


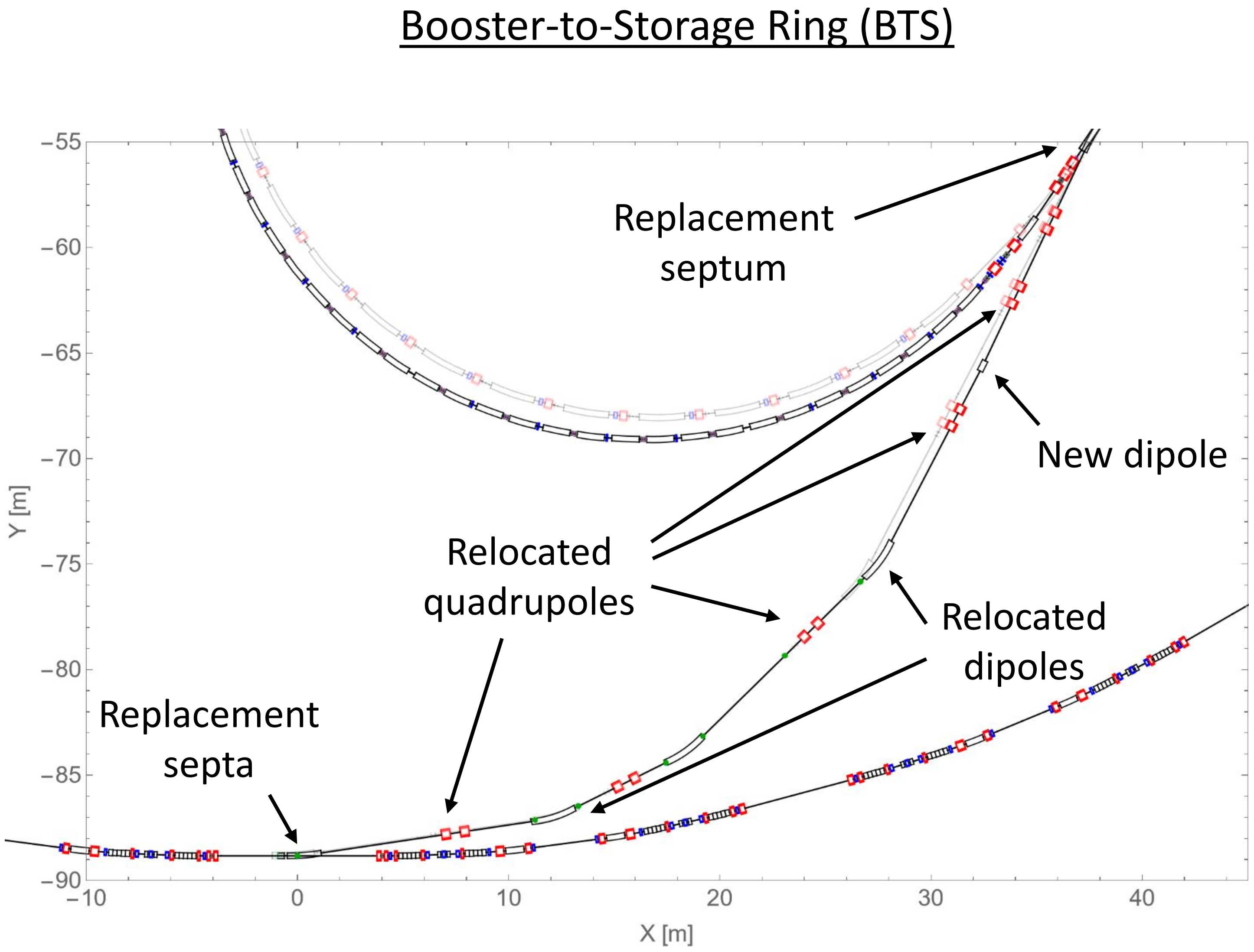


Booster girder assembly (type 1)



Transfer Line Modifications

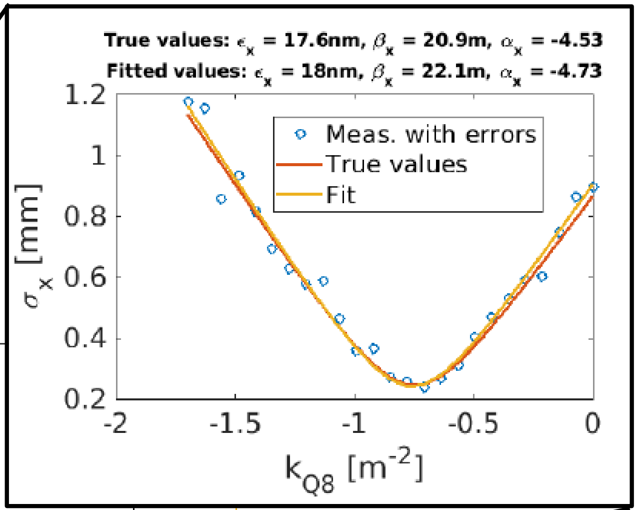


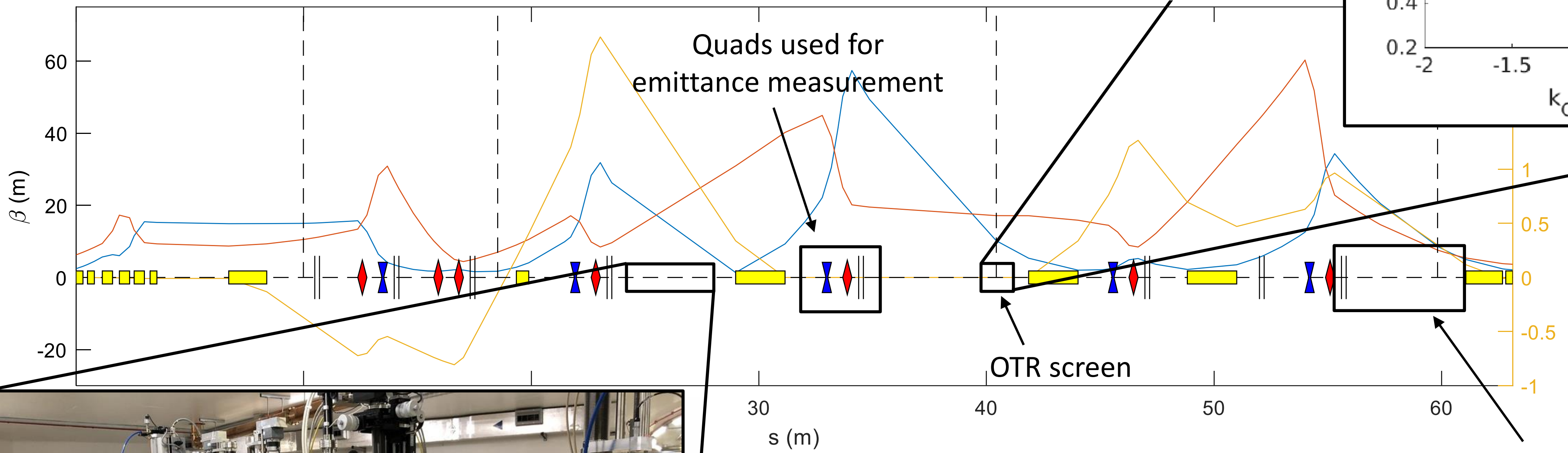


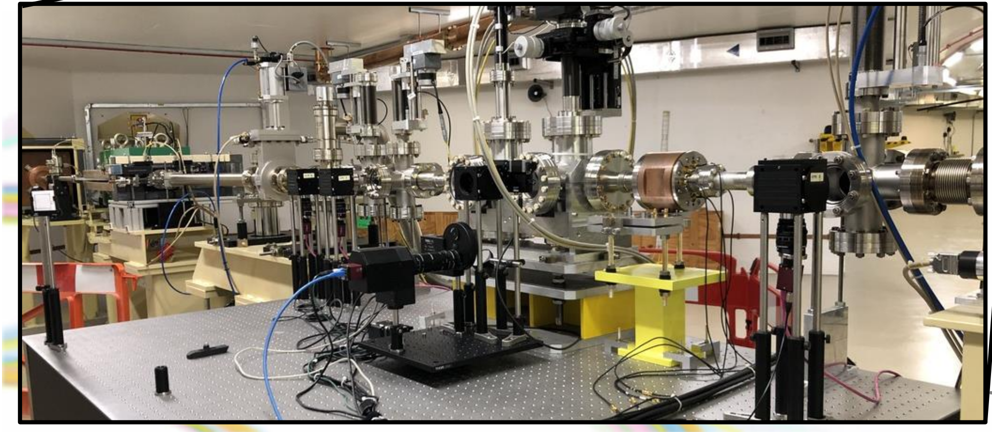
BTS Diagnostics Improvements

The BTS will be upgraded to improve its diagnostics capabilities:

- ➢ Dispersion-free emittance measurement for the beam extracted from booster
- ➢ Increase control of the beam position / angle at storage ring injection septum
- ➢ Space retained for BTS Test Stand







R&D:

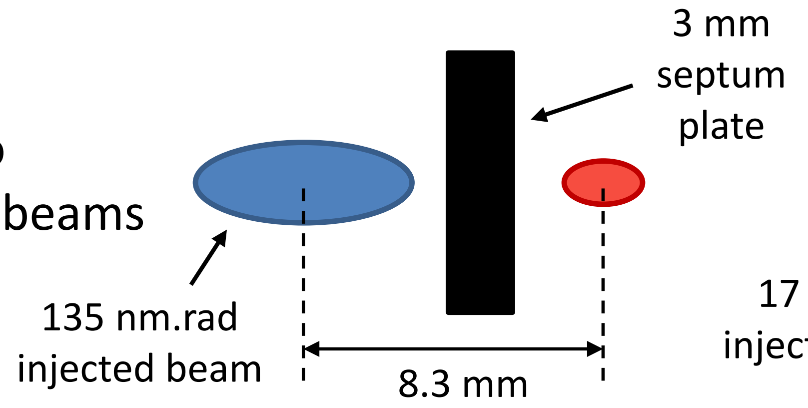
- Pepper pot for single-shot emittance measurement
- Cavity BPMs
- Cherenkov Diffraction Radiation monitors
- …

Storage Ring Septum Magnets

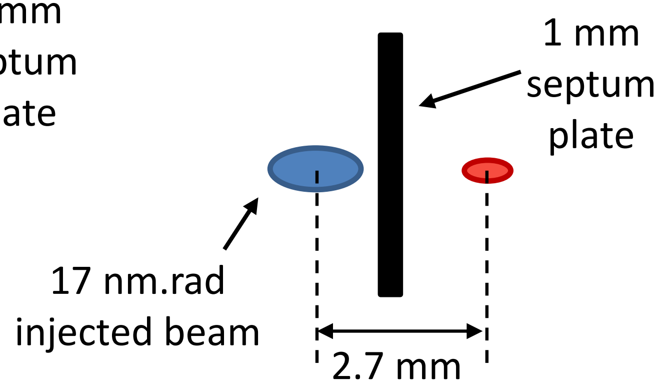
<u>Storage ring septum magnet will have several sections:</u>

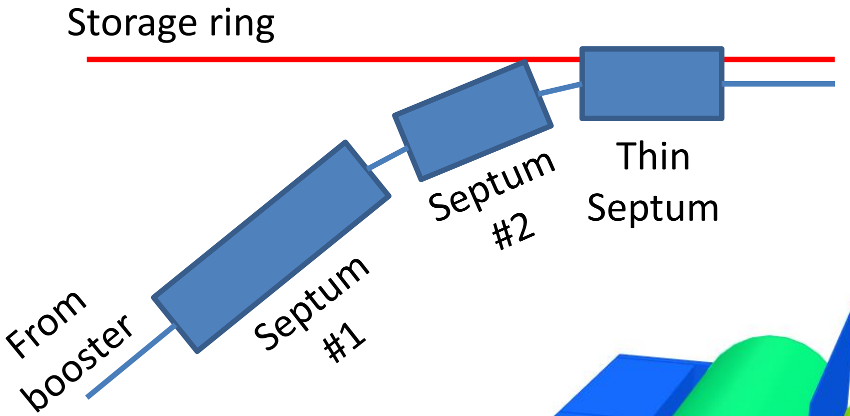
- Investigating PM designs for first two modules
- Final section pulsed magnet, with 1 mm plate to reduce separation between stored and injected beams
- Short pulse duration to minimise leakage field

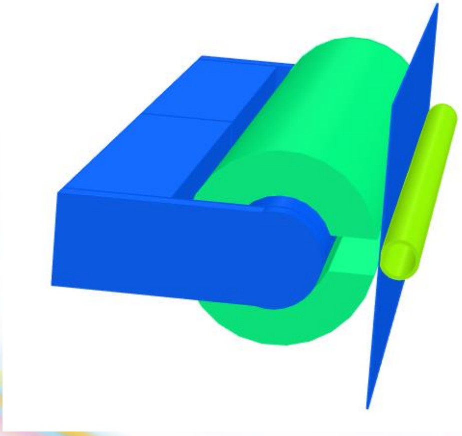
Diamond

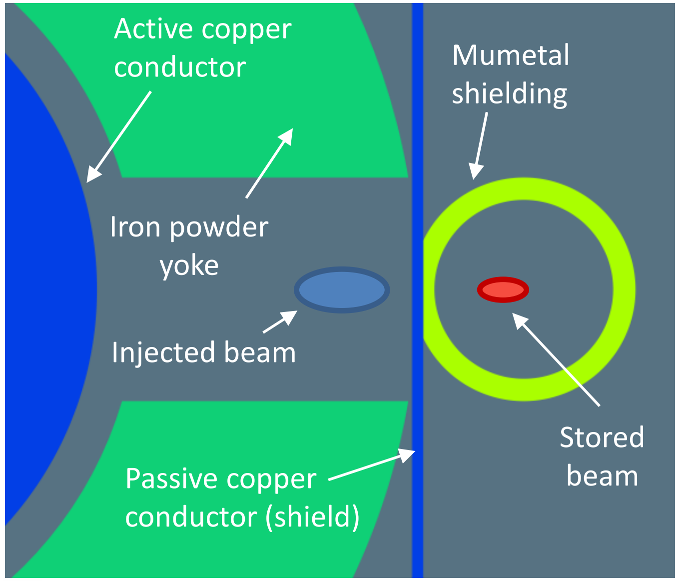


Diamond-II







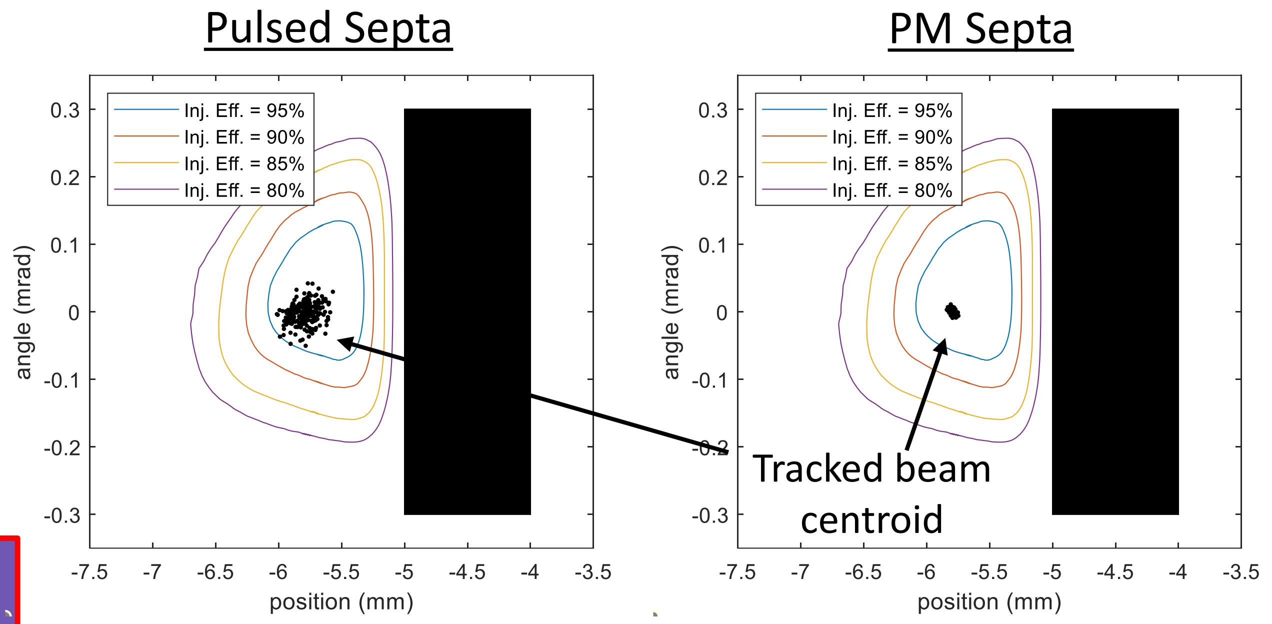


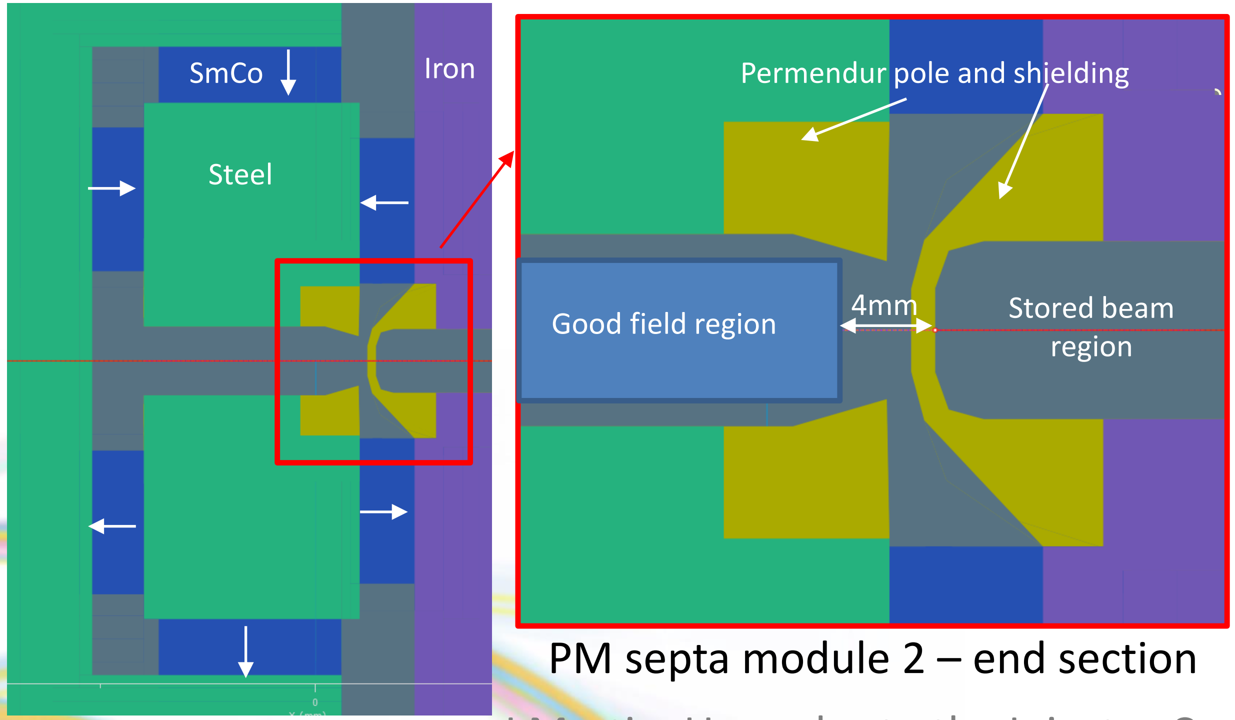
Parameter	Value
Length	330 mm
Peak Field	<0.6 T
Bend angle	~1 degree
Septum blade thickness	1 mm
Pole gap	±5 mm
Pulse shape	Full-sine
Pulse duration	10 µs
Peak magnet current	<6 kA
Leakage field (pulsed)	<3 µT

Storage Ring Septum Magnets

PM designs for main septa under study:

- PM septum reduces shot-to-shot jitter for injected beam position and angle
- Storage ring main septum has two modules, each optimised for leakage field and bend angles
- Booster extraction septum challenging due to larger aperture requirements





PM septa module 2 – end section

Parameter	Module 1	Module 2
Length	1400 mm?	200 mm?
Peak Field	<1.5 T	<0.6 T
Bend angle	~6.9 degree	~0.6 degree
Septum blade thickness	-	1 mm (4 mm gap)
Pole full gap	10 mm	8 mm
Leakage field (static)	-	Below 1 mT

Project Status

Milestone	Planned Date
Treasury approval for the Diamond-II Project and start of funding	July / August 2023?
Start of dark period	1st December 2027
Start of booster commissioning	1st June 2028
Start of storage ring commissioning	1st December 2028
End of dark period / start of regular beamline x-ray commissioning	1st June 2029
First operational beamline	1st September 2029
End of Diamond-II project	1st March 2030

Acknowledgements (partial!)

DLS: *Jonas Kallestrup, Filip Malinowski, Ben Nicholson, Walter Tizzano, Vitalii Zhiltsov*

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JAI/Oxford: *Riyasat Husain*

Extra Slides

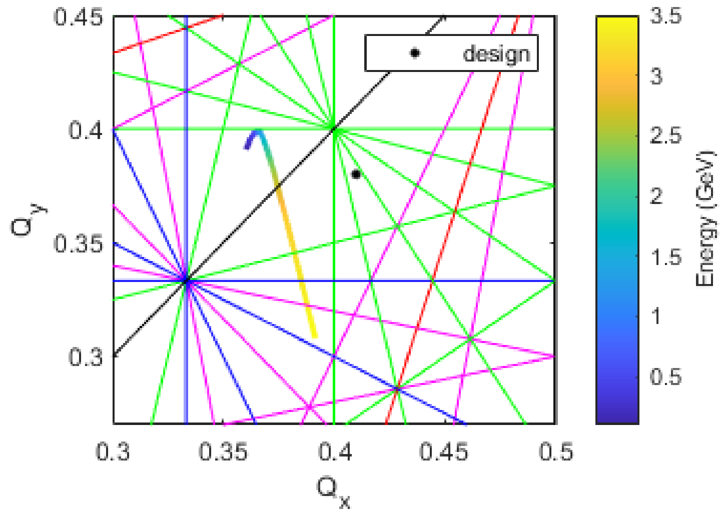
Booster-II Simulated Performance (WIP!)

Beam dynamics studies are ongoing:

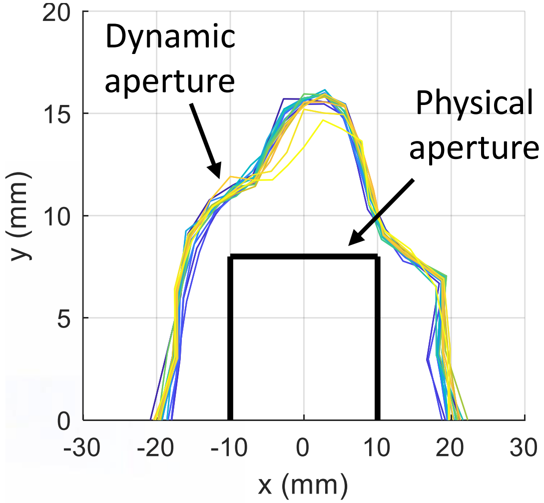
- Dynamic aperture including field and alignment errors, vacuum chamber eddy currents, etc.
- Impact of magnet fringe fields and saturation effects
- Intra-beam scattering
- Short and long range wakefields
- Transfer efficiency and loss locations

So far, so good!

Betatron tunes vs energy



Average dynamic aperture vs energy



Electron beam parameters during the ramp for 100 MeV injection / zero chromaticity