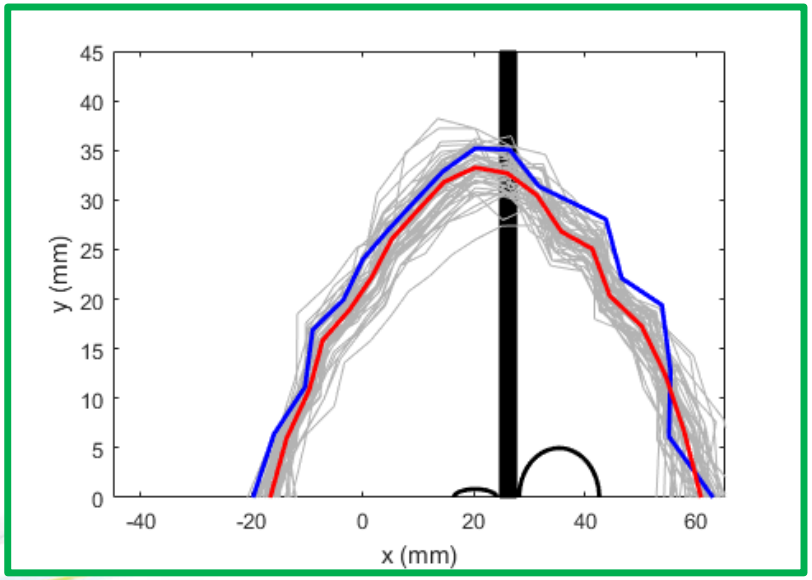
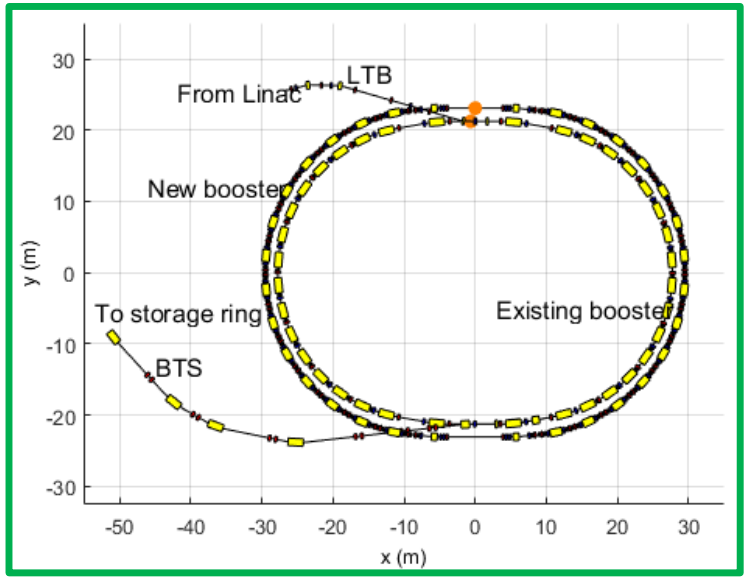
Design of an Accumulator Ring for the Diamond-II Upgrade





Ian Martin,

On behalf of the Diamond-II design team

2nd Topical Workshop on Injection and Injection Systems
Paul Scherrer Institute
2nd April 2019

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Talk Outline

Requirements for Diamond-II injector:

Diamond-II upgrade project
proposed storage ring injection scheme
specification for injector

Combined booster / accumulator ring:

proposed lattice design
injection/extraction schemes for new booster
beam parameters during energy ramp
impact of errors
installation strategy

Summary

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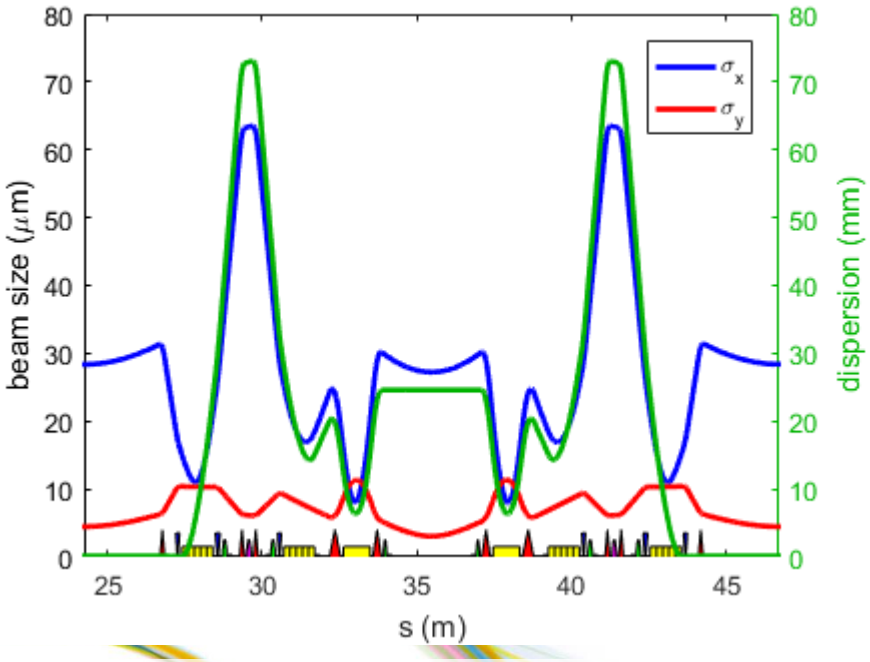
Diamond-II: Lattice

Proposal for Diamond-II is a 'Modified Hybrid 6 Bend Achromat'

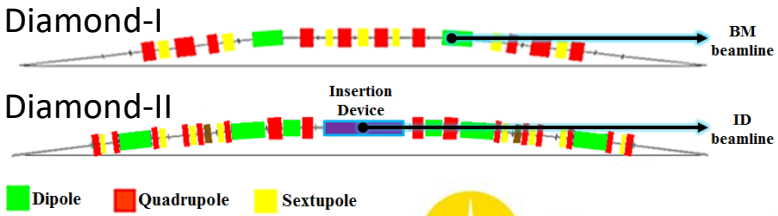
- Increased photon beam quality (brightness, coherence, spot size, spectrum, ...)
- Increased capacity (additional straights, upgraded/relocated/new beamlines)

Combines two concepts:

- The ESRF-EBS upgrade lattice*
- The Double-Double Bend Achromat cell**

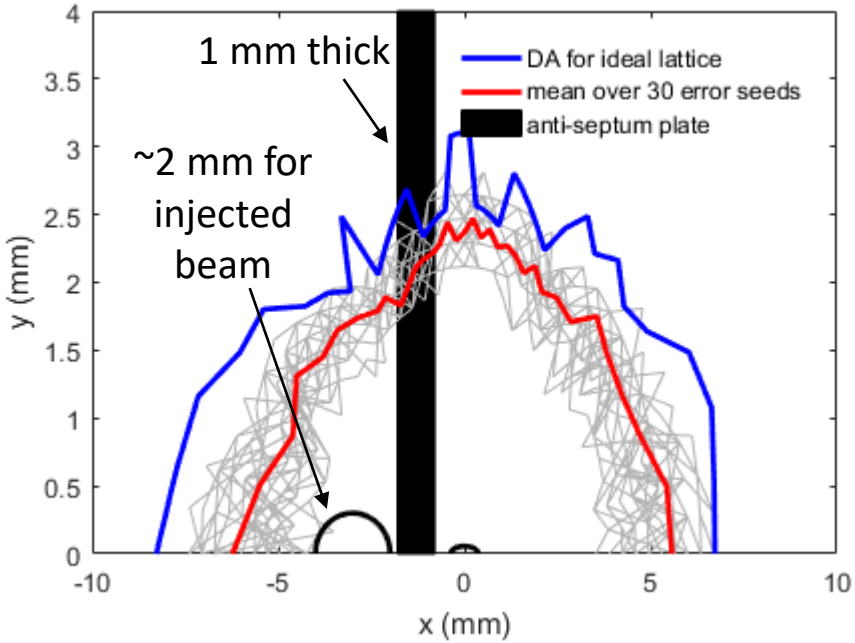


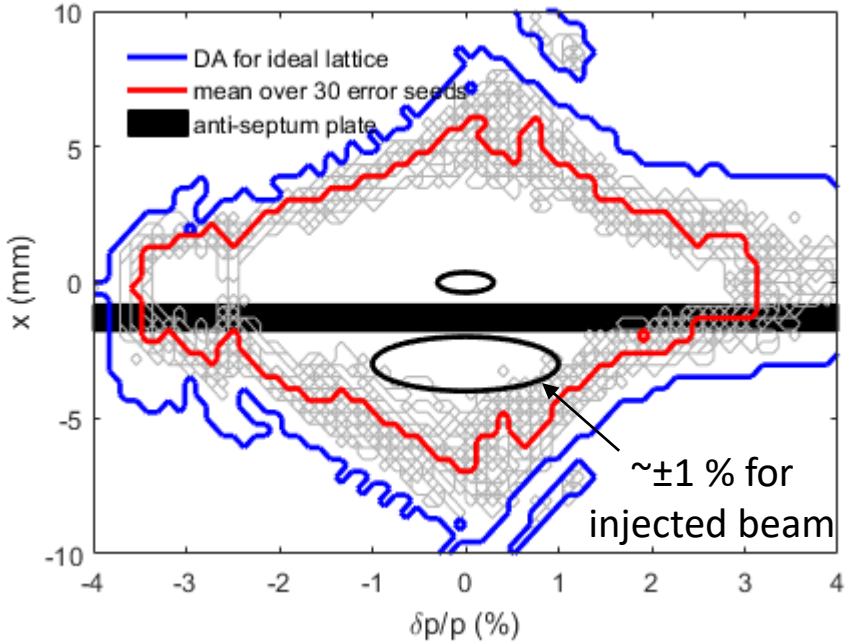
	Diamond-I	Diamond-II
Lattice Type	DBA	M-H6BA
Circumference	561.6 m	560.574 m
Energy	3 GeV	3.5 GeV
Beam Current	300 mA	300 mA
Straight Sections	24	48
Emittance	2.7 nm.rad	~0.16 nm.rad
Energy Spread	0.096 %	0.078 %



*ESRF Technical Design Study, "The Orange Book" (2014)
R. Bartolini et al., PRAB **21, 050701 (2018)

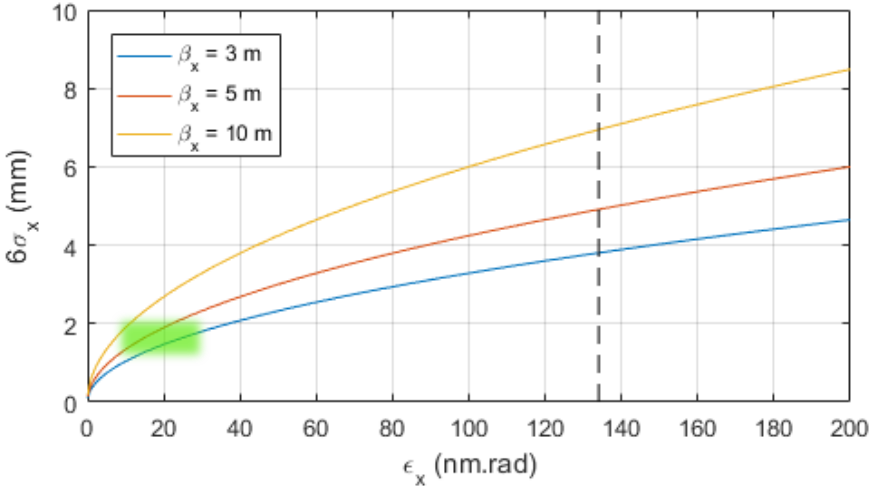
Diamond-II: Injection





Requirements on injected beam:

- 3.5 GeV
- emittance in range 10-30 nm.rad
- bunch length in range 20-40 ps



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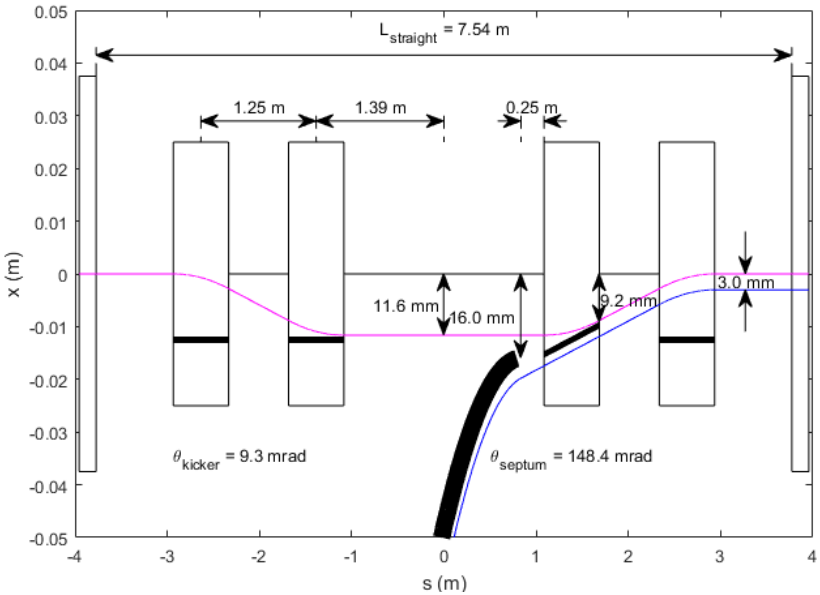
Diamond-II: Injection

Proposal is to use 'anti-septum' storage ring injection scheme*

- Off-axis accumulation
- Standard 4-kicker bumps for stored beam
- Kicker 3 contains thin (1 mm) 'anti-septum' plate
- Appears like a drift space for injected beam
- Separation of stored / injected beams ~ 3mm



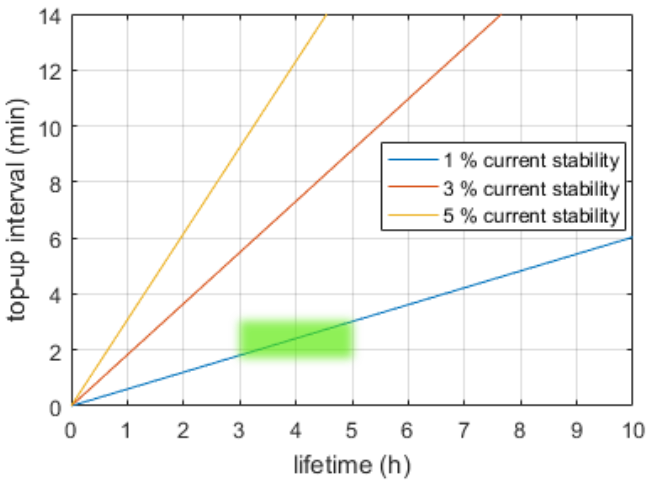
Parameter	Septum	Kicker
Magnetic Length	1.67 m	0.6 m
Bend angle	148.4 mrad	9.3 mrad
Bend radius	11.3 m	64.5 m
Magnetic field	1.04 T	0.18 T
Pulse shape	Full-sine	Half-sine
Pulse duration	160 µs	6 µs
Rep rate	5 Hz	5 Hz

**C. Gough, M. Aiba, IPAC'17, MOPIK104*

Diamond-II: Injection

Top-up cycle assumptions:

- Anticipate storage ring lifetime ~3-5 hours (900 bunches, 0.62 nC/bunch)
- Aim to maintain current stability in the storage ring of ~1%
  ⇒ ~2-3 minutes between top-up cycles
- Single bunch injection ~0.1-0.2 nC/shot
  ⇒ ~50 shots per top-up cycle



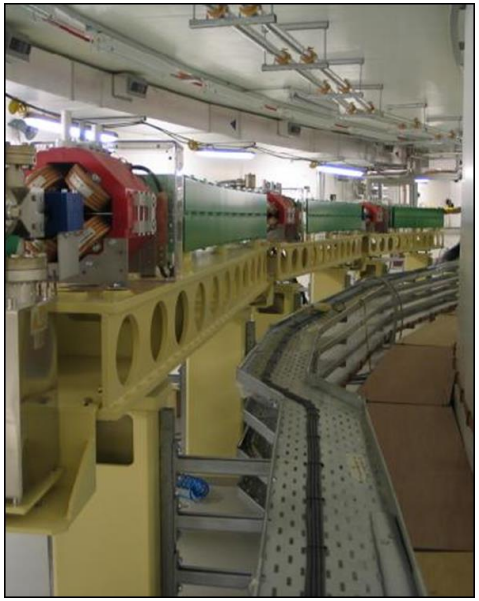
Potential Issue: Non-closure of orbit bump
⇒ well-matched kicker pulsers
⇒ uniform coating in kicker vessels
⇒ with-beam correction of kicker roll
⇒ active suppression of residual kick (TMBF, compensation kicker, …)
⇒ gating signals to beamlines

Could also accumulate in the booster, and only extract beam on the final shot?
(i.e. single-shot top-up into the storage ring, ~5-10 nC/shot, multi-bunch)

New Booster: Specification

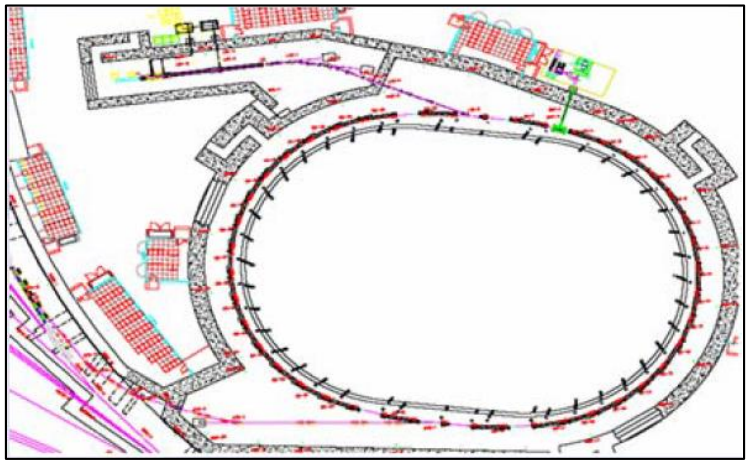
Existing booster:

	Requirement	Existing booster
Energy	0.1 - 3.5 GeV	0.1 - 3.0 GeV
Emittance	<30 nm.rad	134 nm.rad
Bunch length	<40 ps	100 ps
Max. extracted current	>10 nC	~2 nC



Requirements for new booster:

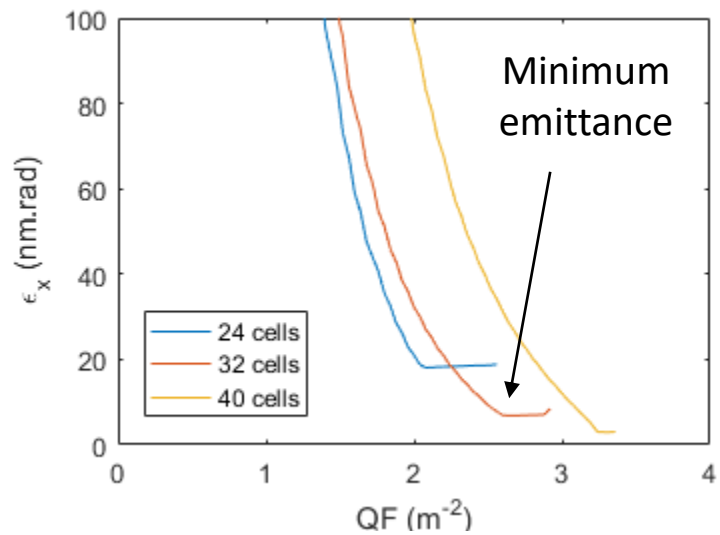
- must fit in existing tunnel
- high injection efficiency
- long lifetime w.r.t. top-up duration
- long-term reliability
- large dynamic aperture for off-axis accumulation
- low impedance for high-current bunches



New Booster: Concept

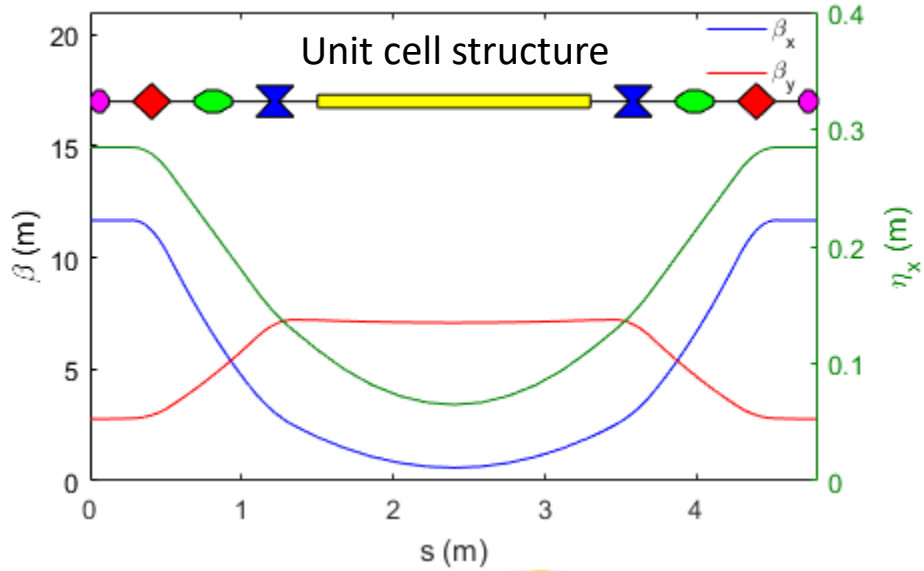
Concept for new booster lattice:

- Construct arcs from 'TME-style' unit cells
- 'Dispersion suppressor' matching cells
- Straights for injection / extraction / RF
- Average bend radius of arcs ~23 m
  (to fit around outside of existing booster)



Conducted systematic scan of:

- Number of unit cells
- Magnet / drift lengths
- Quadrupole gradients



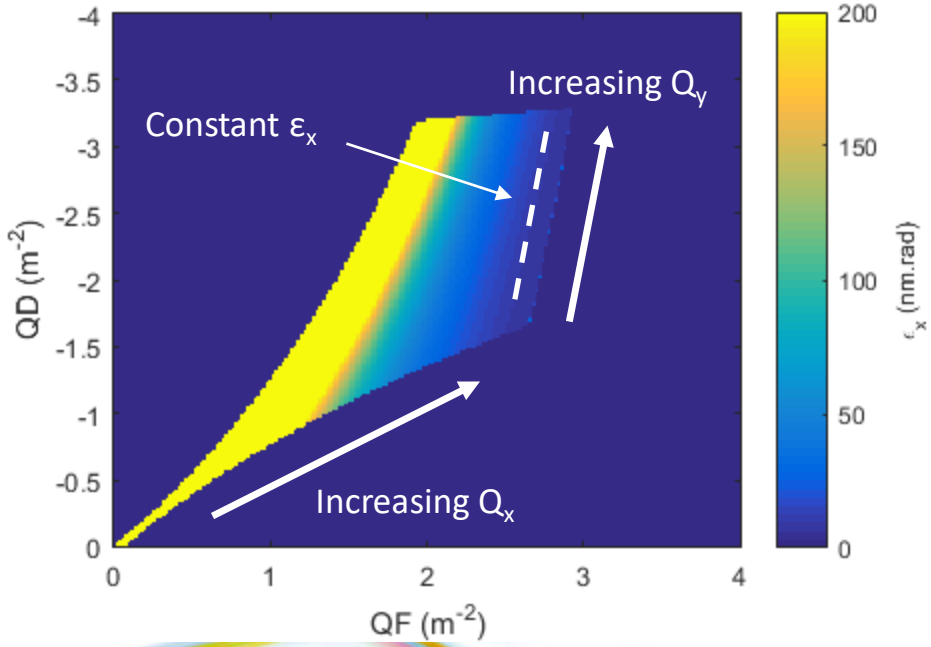
Monitored impact on:

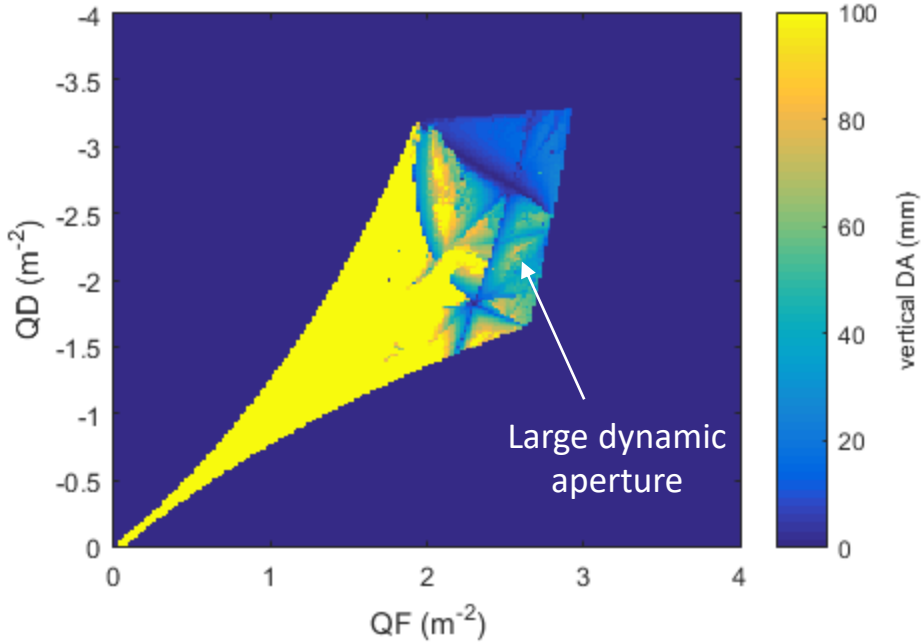
- ε_x / α_c / max $\beta_{x/y}$ / chromaticity
- σ_E / U_0 / τ_x / τ_y / τ_s
- Hor. / vert. dynamic aperture

New Booster: Unit Cell Optimisation

Identification of optimal working point:

- Horizontal tune set for low emittance and moderate phase advance (~145°/cell)
- Several vertical tune points offer good dynamic aperture

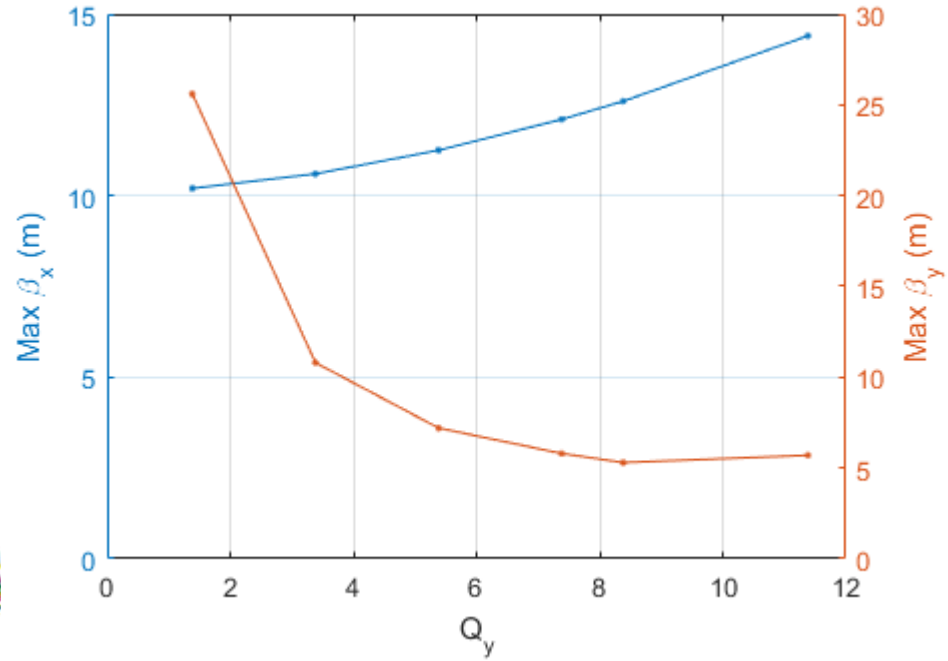


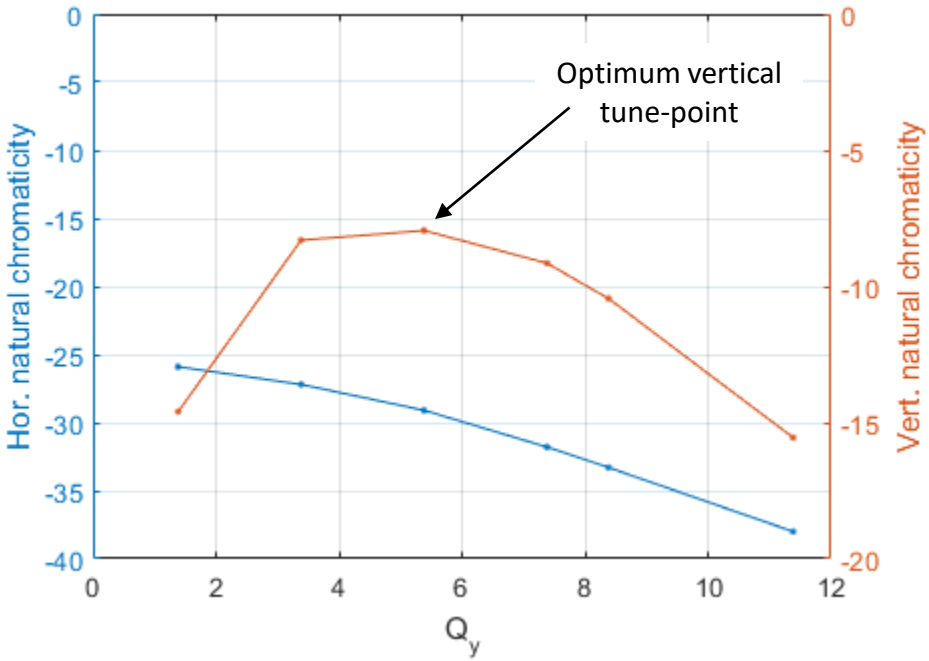


New Booster: Unit Cell Optimisation

Identification of optimal working point:

- Vertical tune set to minimise natural chromaticity
- Compromise between lowering quadrupole gradients and lowering β_y





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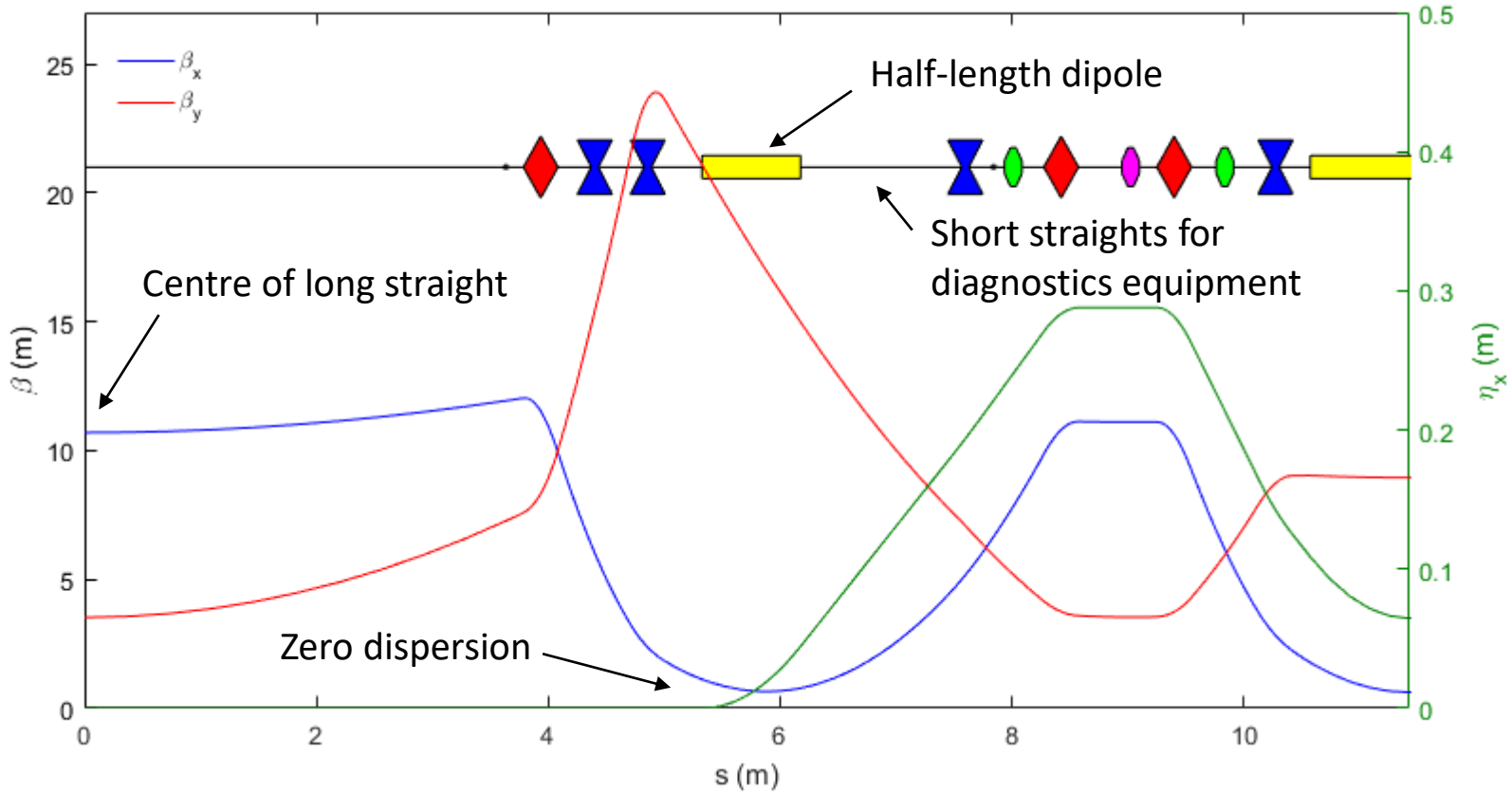
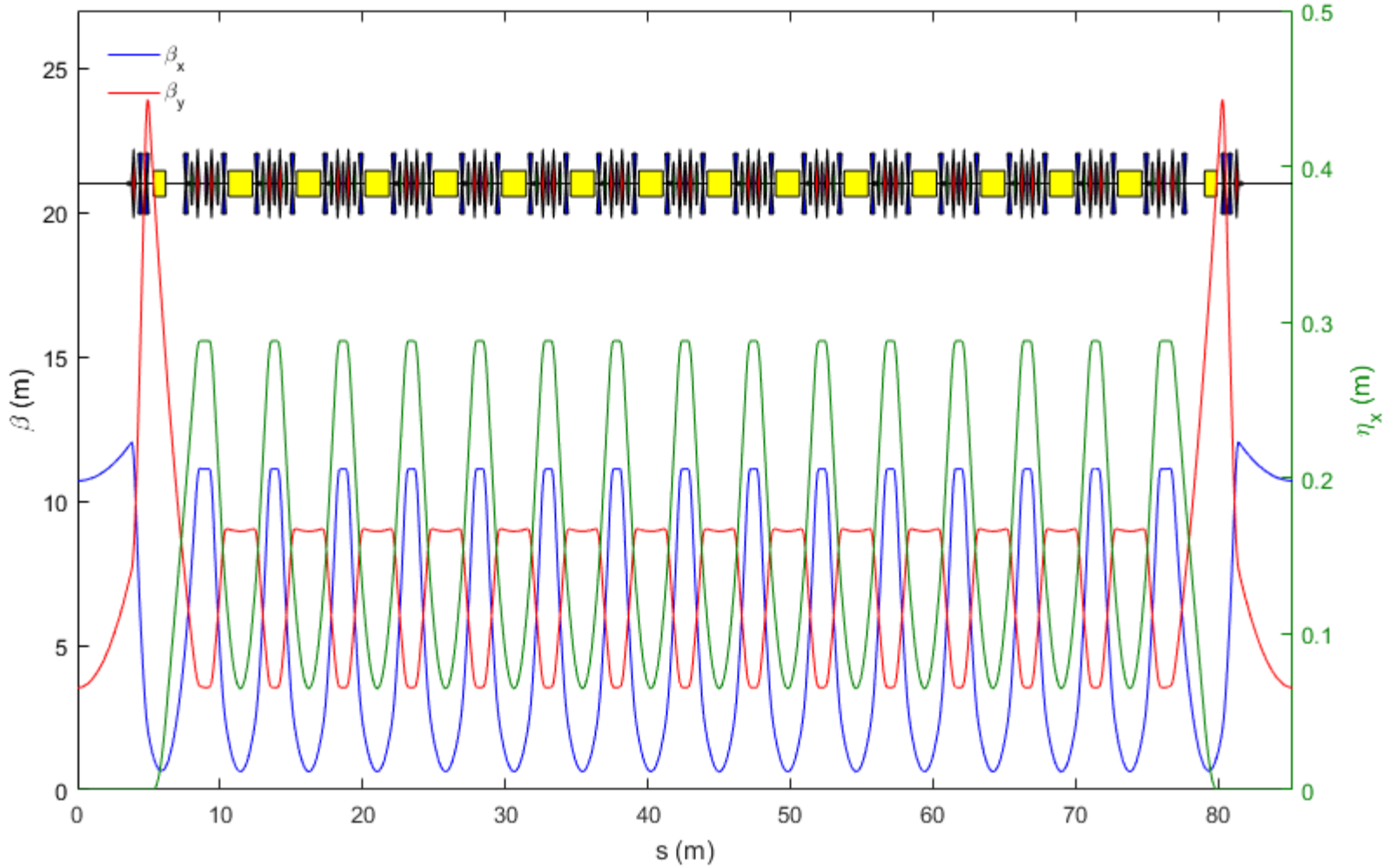
New Booster: Matching Cell

Main features:

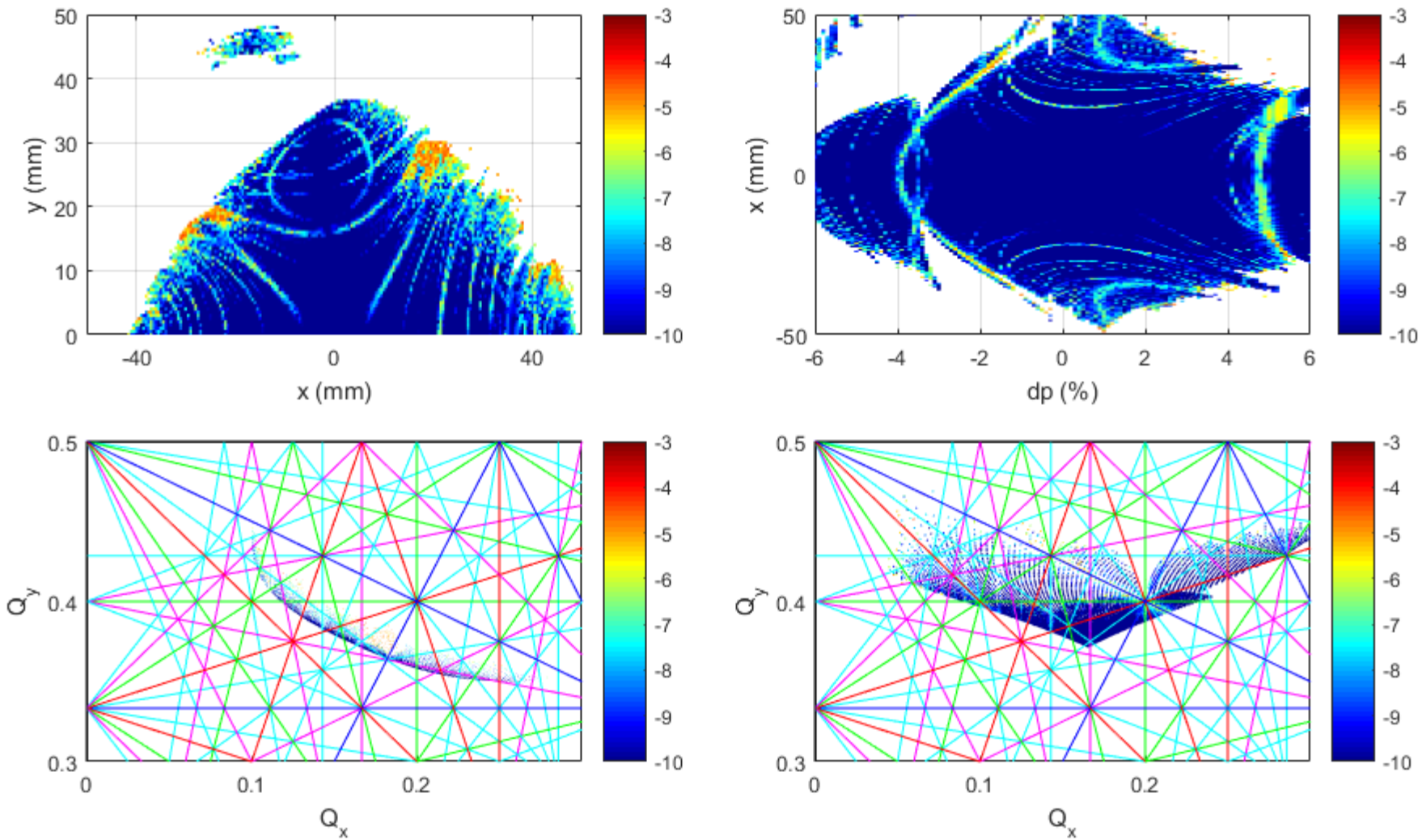
- Zero dispersion long straight section
- Controllable phase advance / beta-functions at injection point



New Booster: Optical Functions



New Booster: Frequency Maps



New Booster: Main Parameters

Parameter	Unit	Existing Booster	Upgraded Booster
Energy Range	GeV	0.1 to 3.0	0.1 to 3.5
Final Emittance	nm.rad	134.4	13.9
Circumference	m	158.4	170.5
Betatron Tunes	-	[7.18, 4.27]	[13.17, 4.37]
Natural Chromaticity	-	[-9.7, -6.3]	[-25.7, -10.1]
Final Energy Spread	-	7.3×10^{-4}	10.5×10^{-4}
Peak Energy Loss per Turn	MeV	0.58	1.64
Mom. Compact. Factor	-	25.2×10^{-3}	2.77×10^{-3}
Natural Bunch Length	ps	99.3	41.1
Peak RF voltage	MV	0.9	2.0
RF acceptance	%	0.24	0.58
Damping Times (τ_x, τ_y, τ_s)	ms	[5.46, 5.47, 2.74]	[2.43, 2.43, 1.22]
Repetition Rate	Hz	5	5

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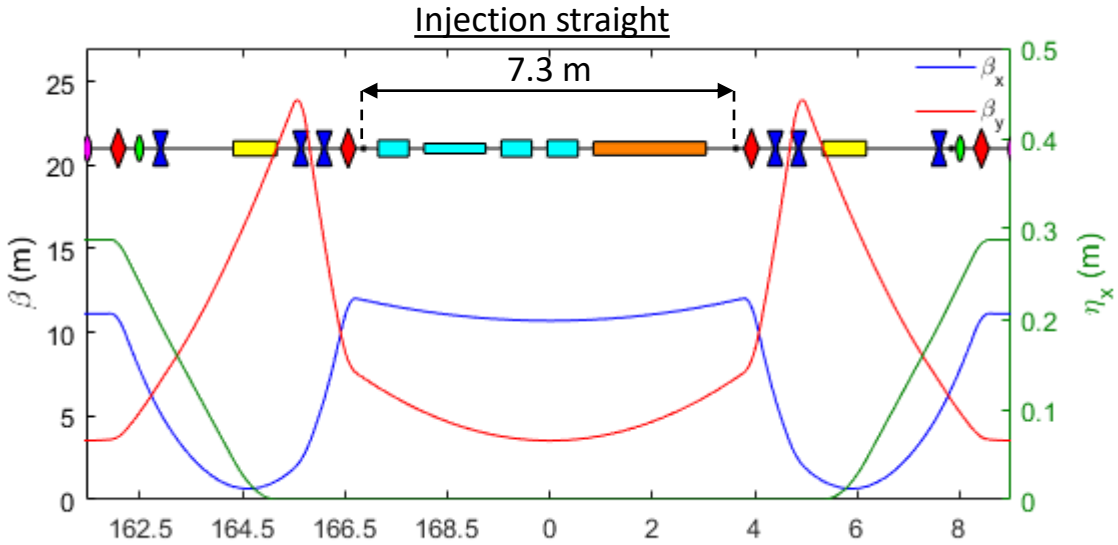
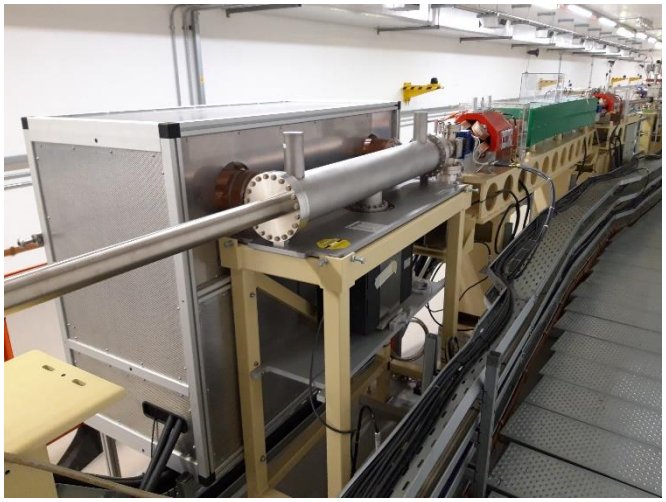
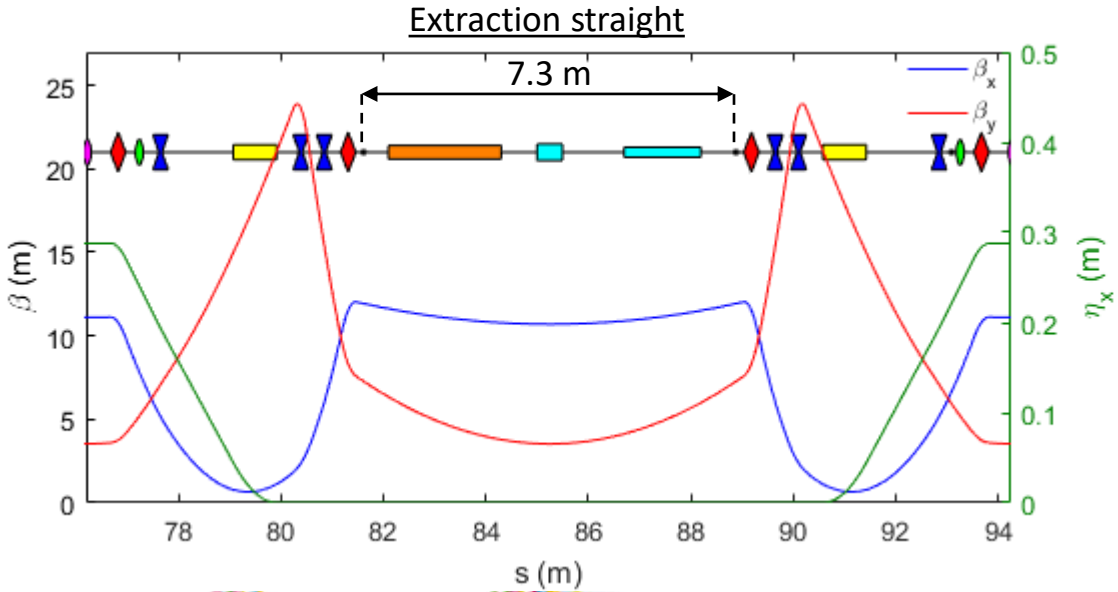
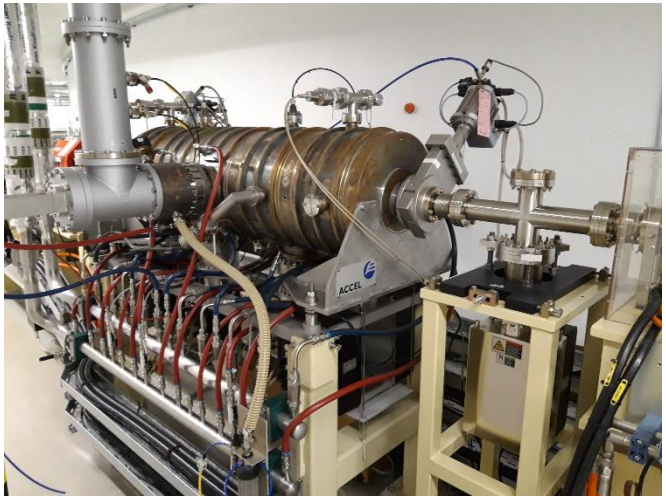
New Booster: Long Straights

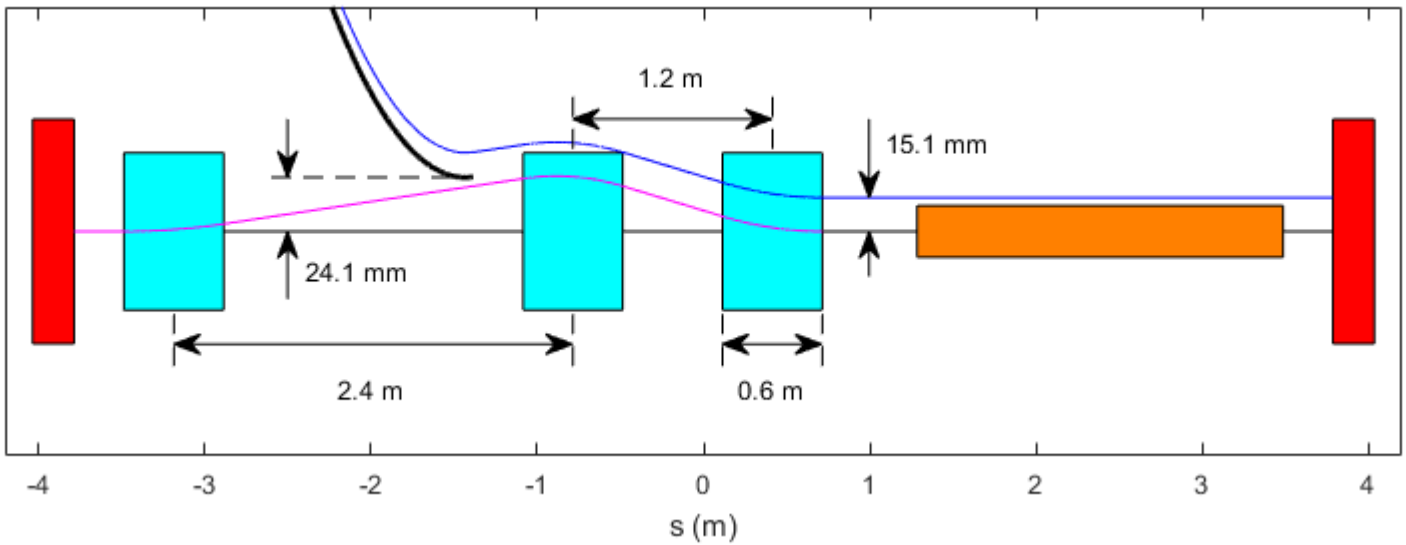


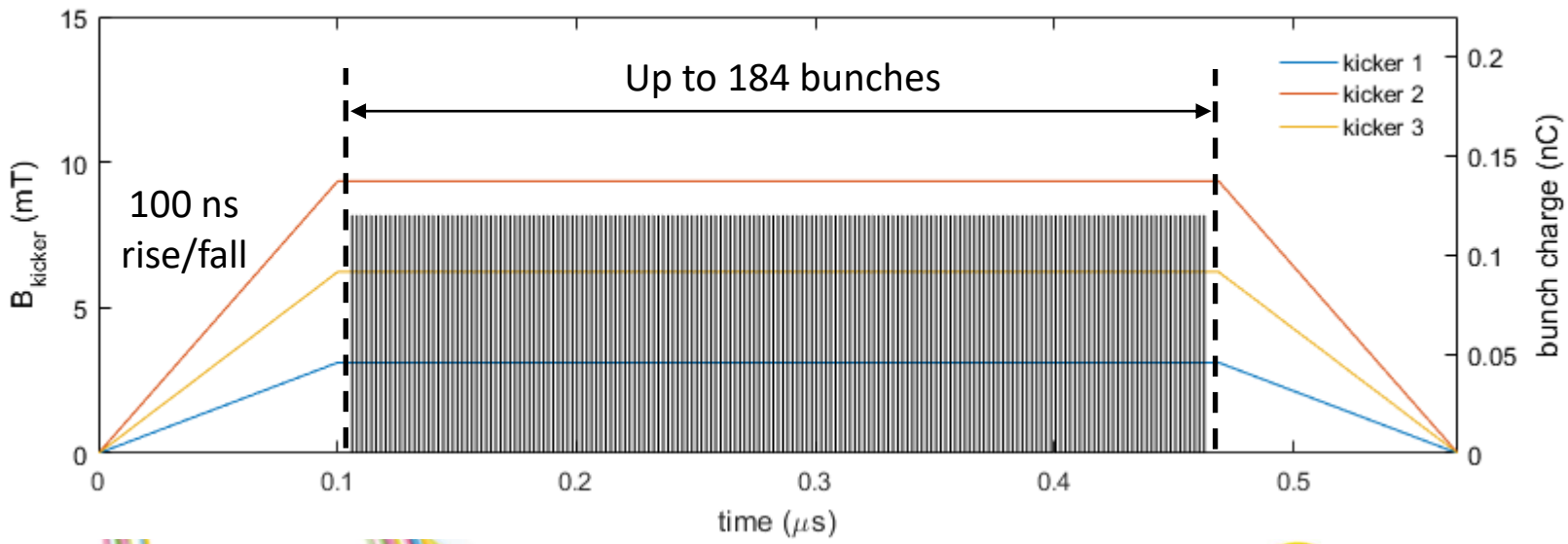






New Booster: Injection





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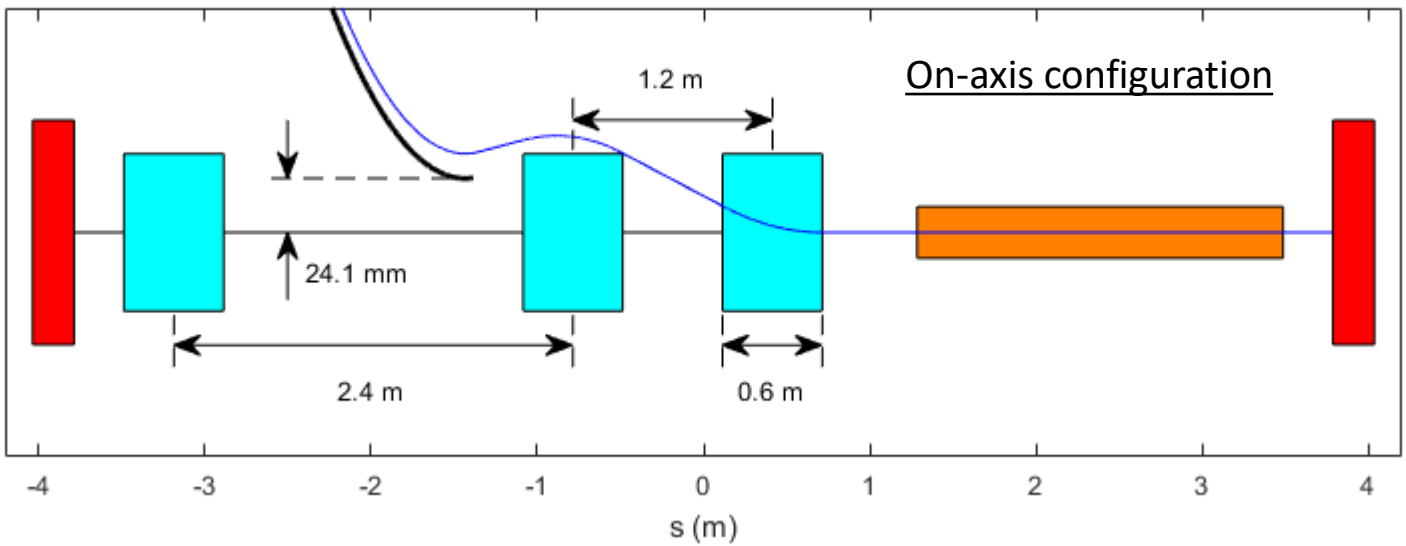
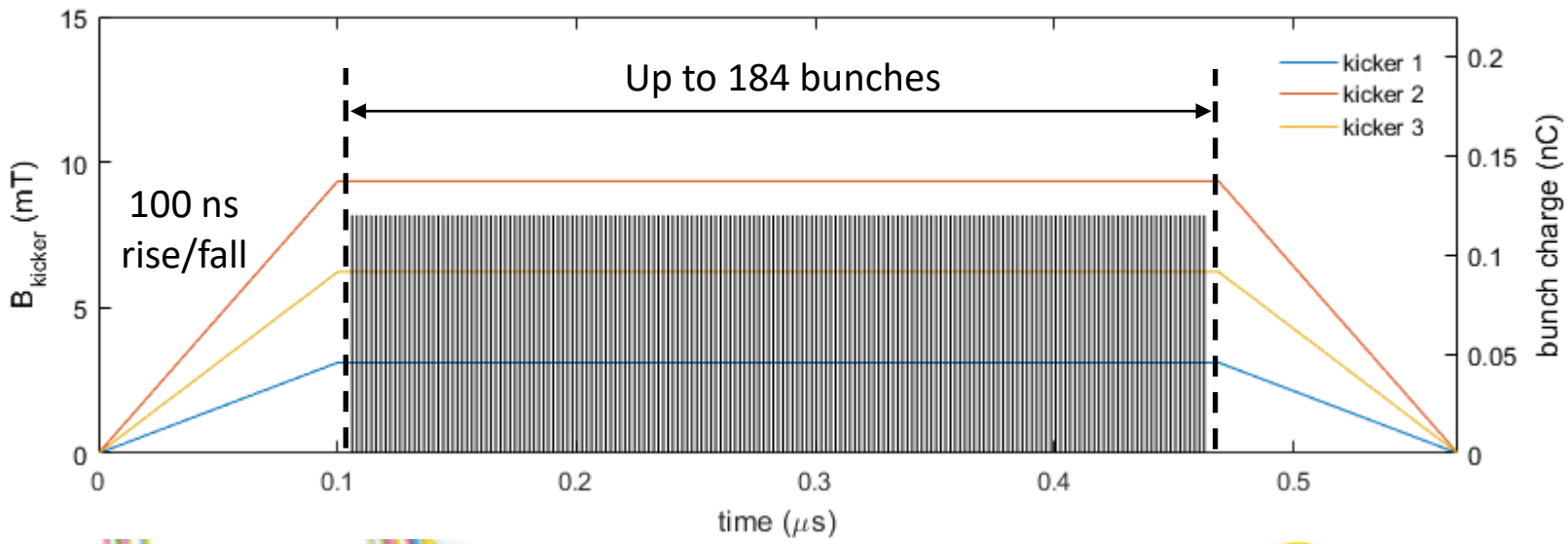
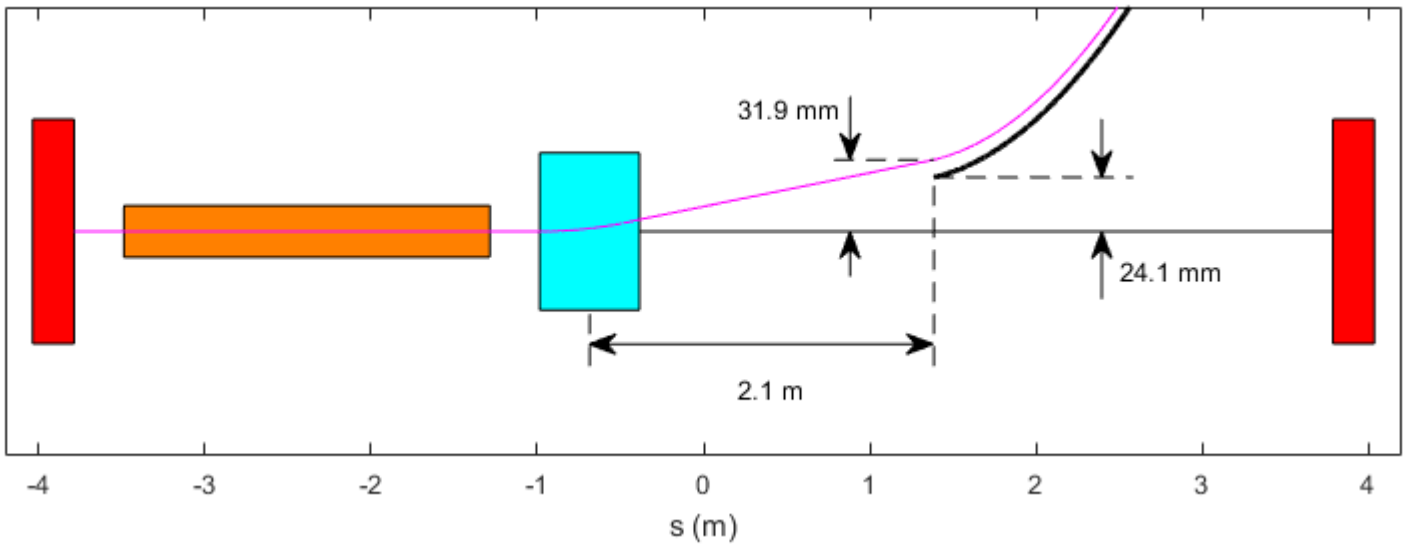
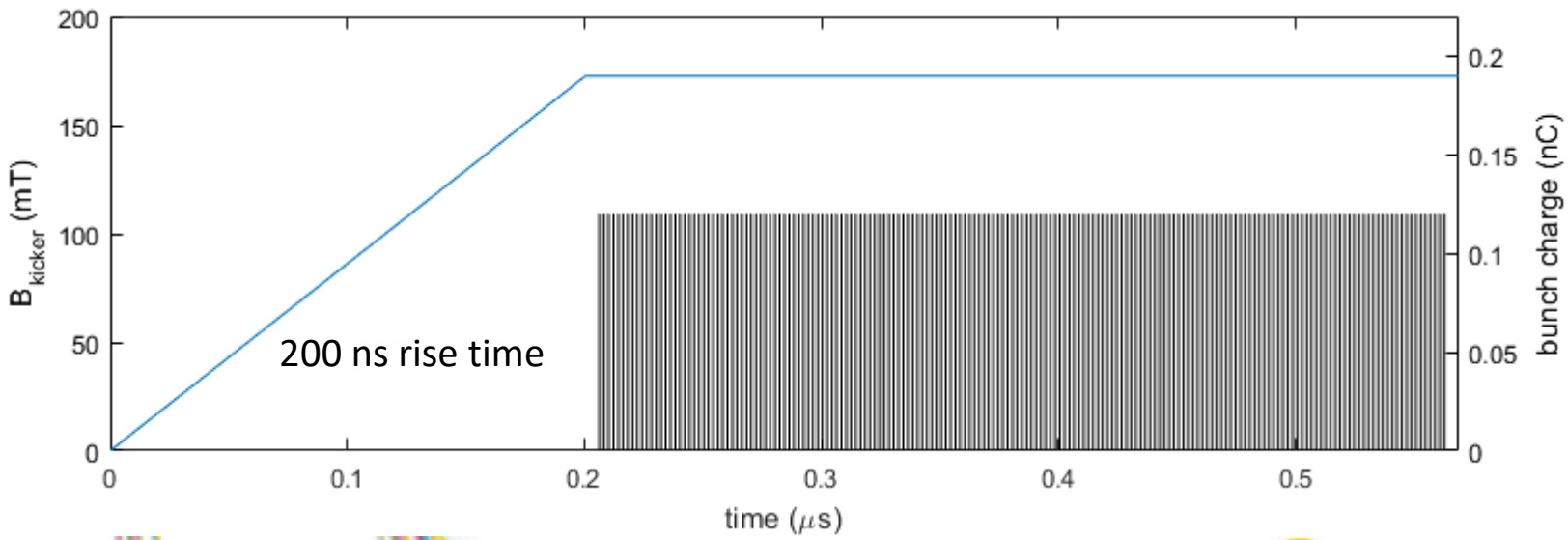
New Booster: Injection



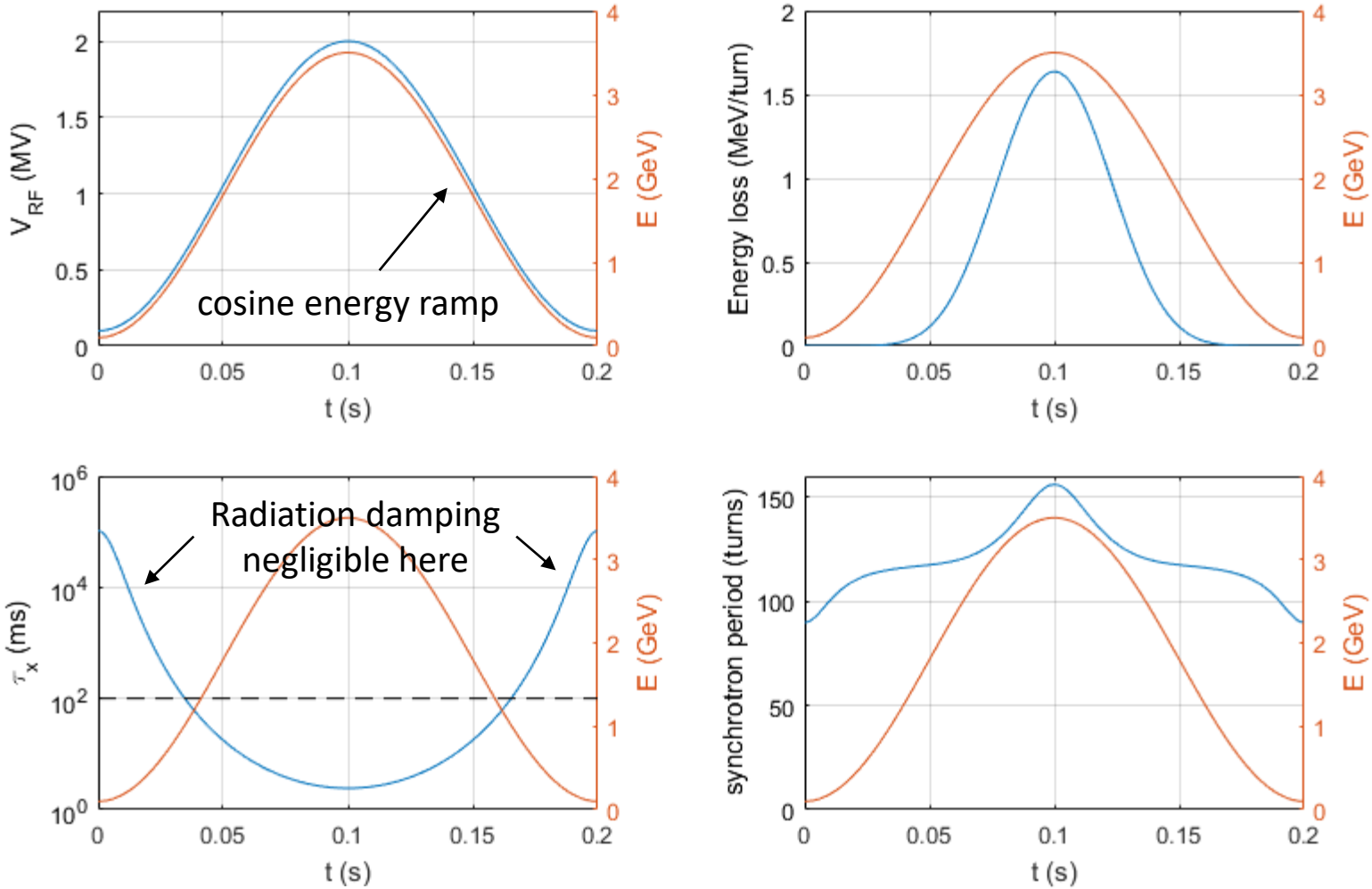


New Booster: Extraction



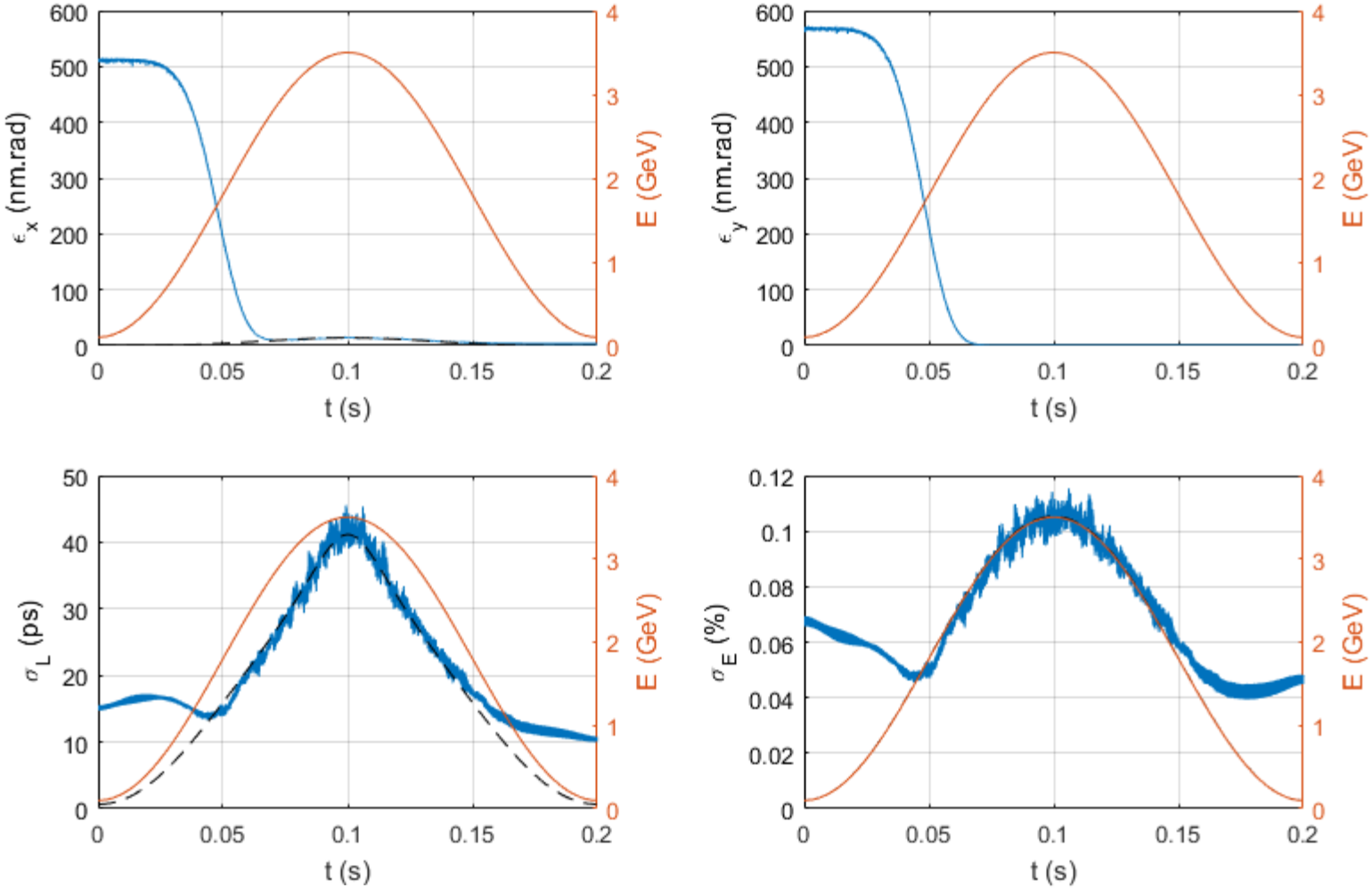


New Booster: Energy Ramp



Note: exaction at 3.5 GeV, 0.1 s into the ramp

New Booster: Energy Ramp



Note: exaction at 3.5 GeV, 0.1 s into the ramp

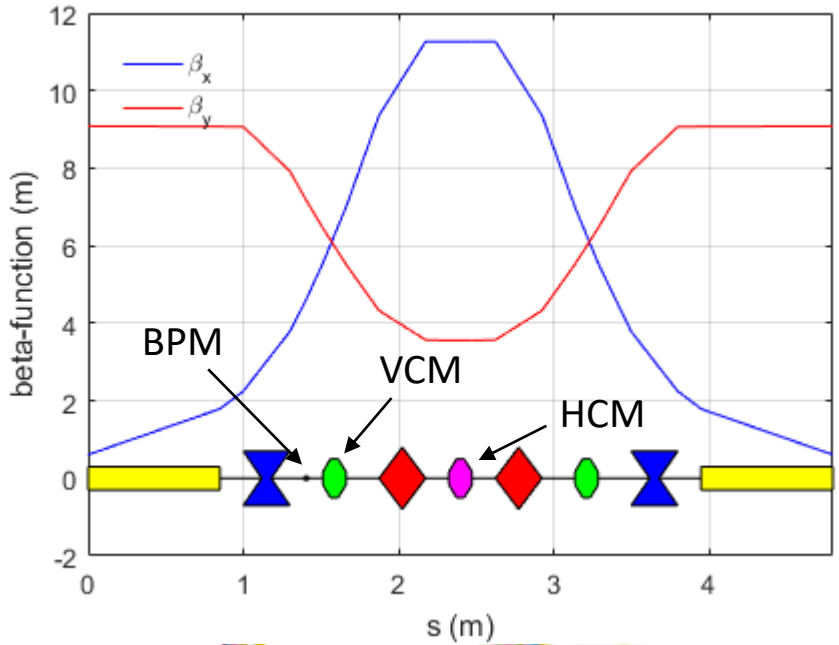
New Booster: Impact of Errors

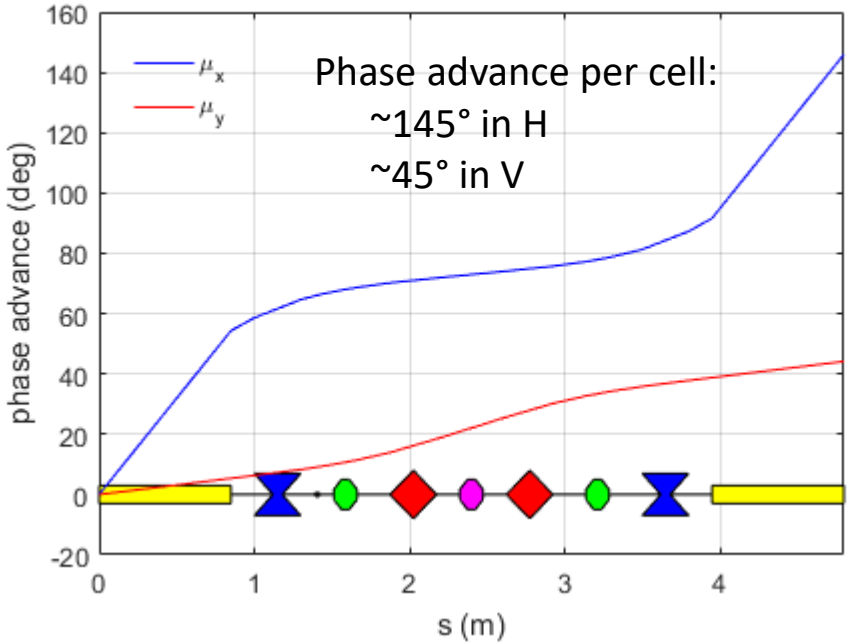
Preliminary assessment made of errors:

- Errors added in Gaussian distribution (3σ)
- One BPM/HCM/VCM per unit cell
- Orbit / tune / chromaticity correction

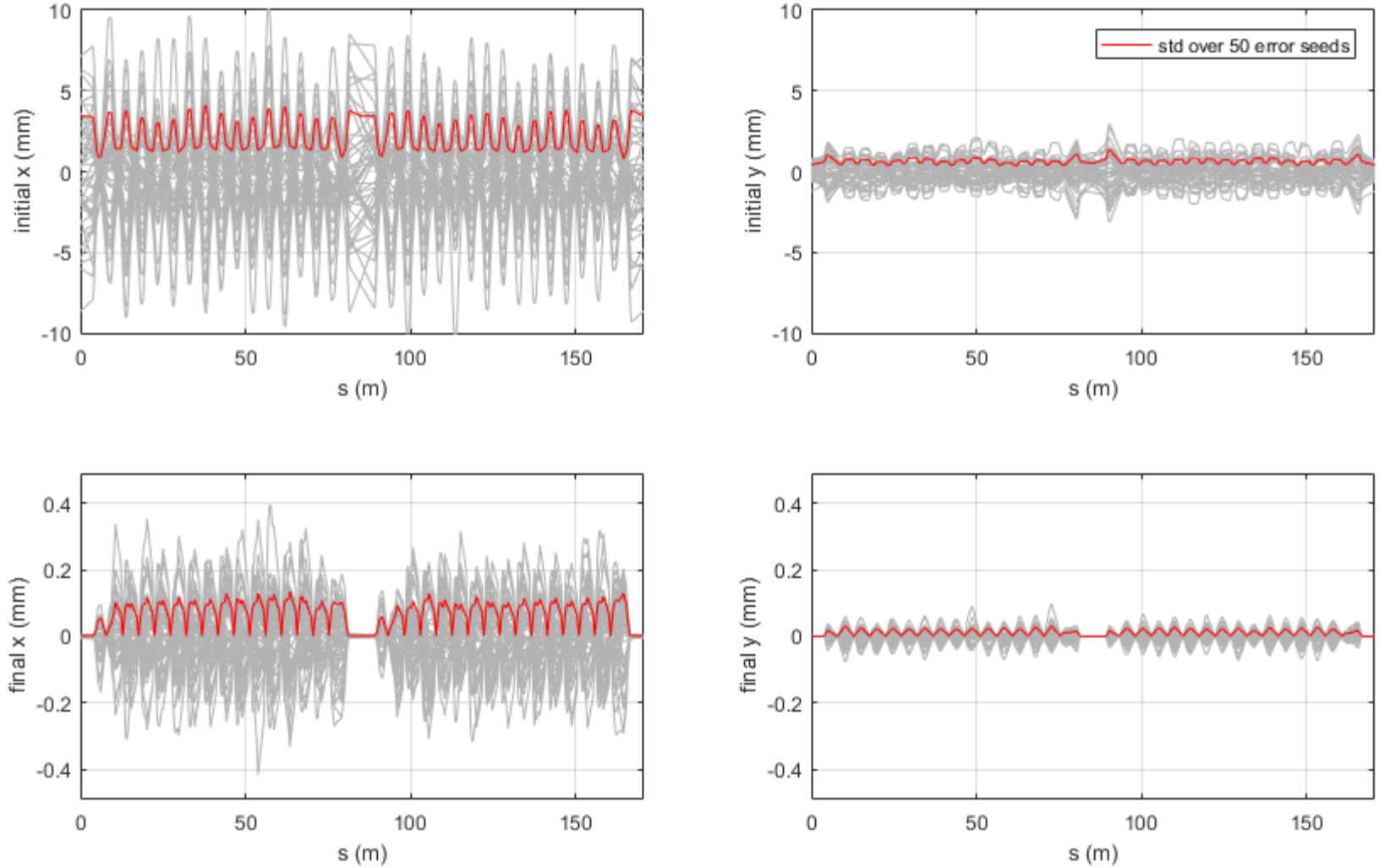
(i.e. no beta-beat or coupling correction)

Element	x/y (μm)	Tilt (μrad)	Strength Error
Dipole	30	200	1×10^{-3}
Quadrupole	30	200	3×10^{-3}
Sextupole	30	200	5×10^{-3}

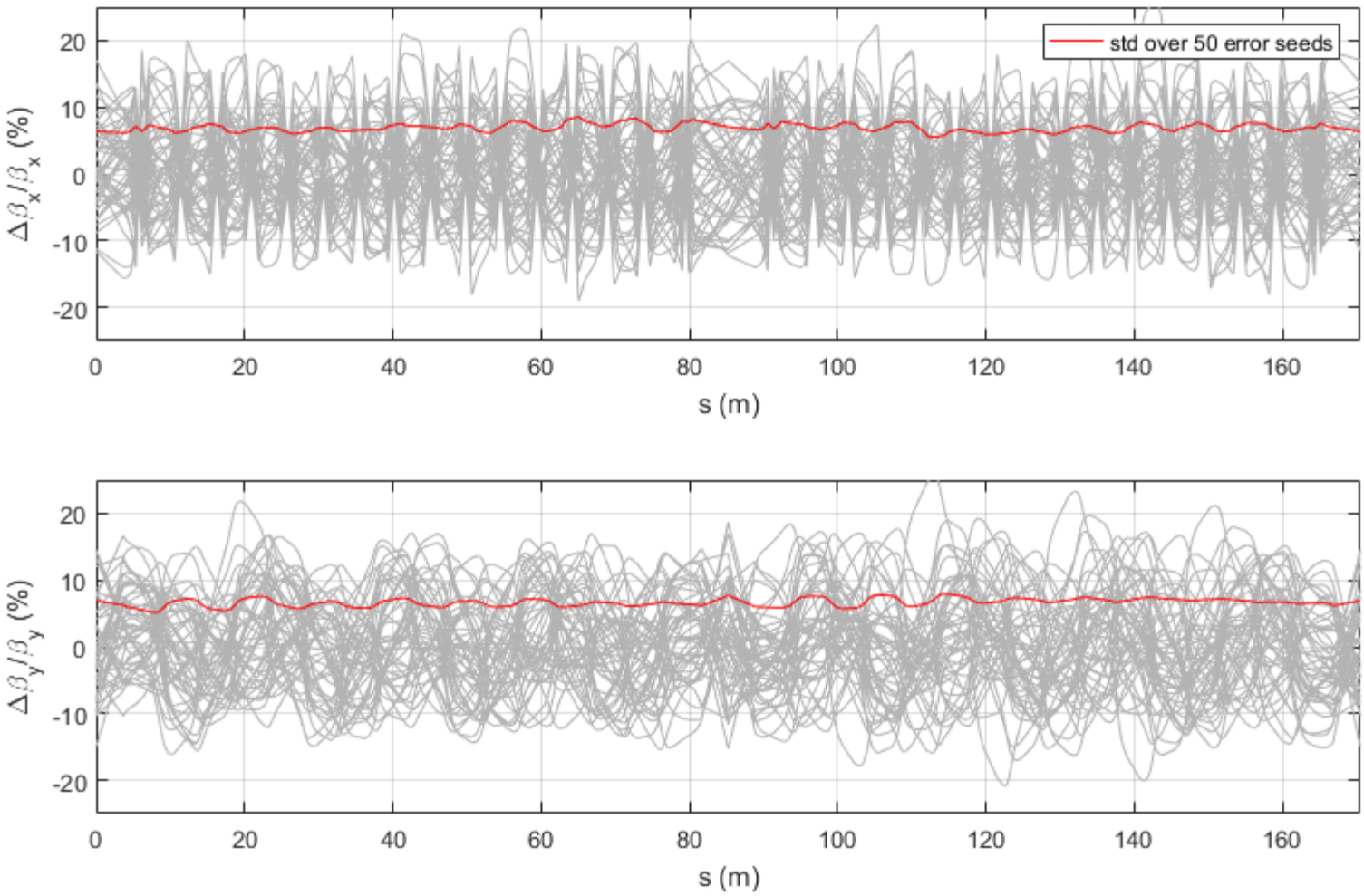




New Booster: Impact of Errors



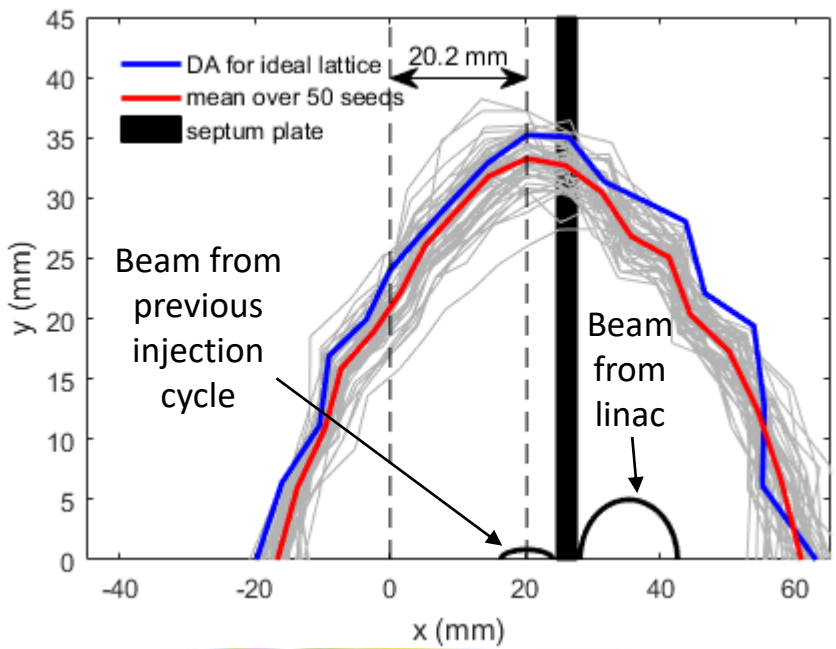
New Booster: Impact of Errors



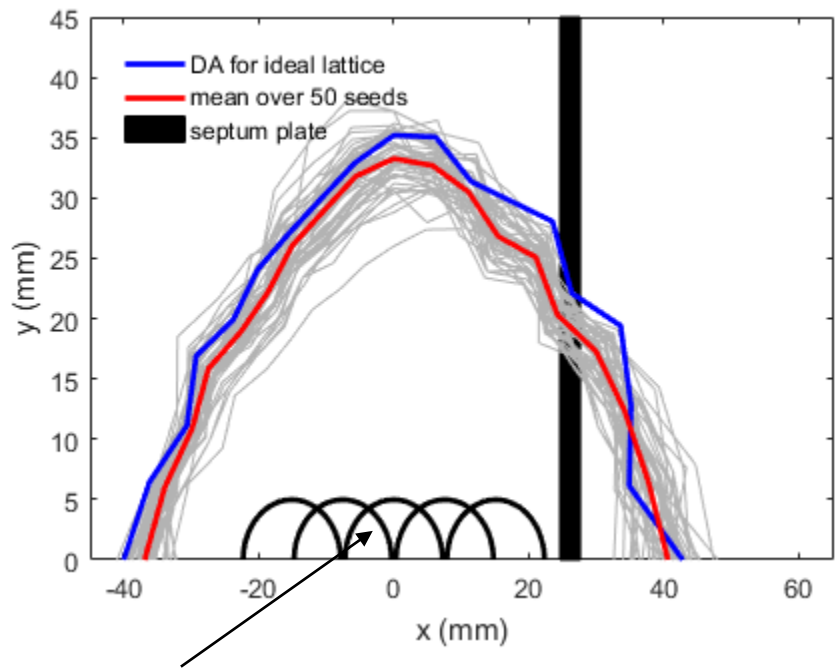
New Booster: Impact of Errors

6D tracking for dynamic apertures:

<u>During injection</u>

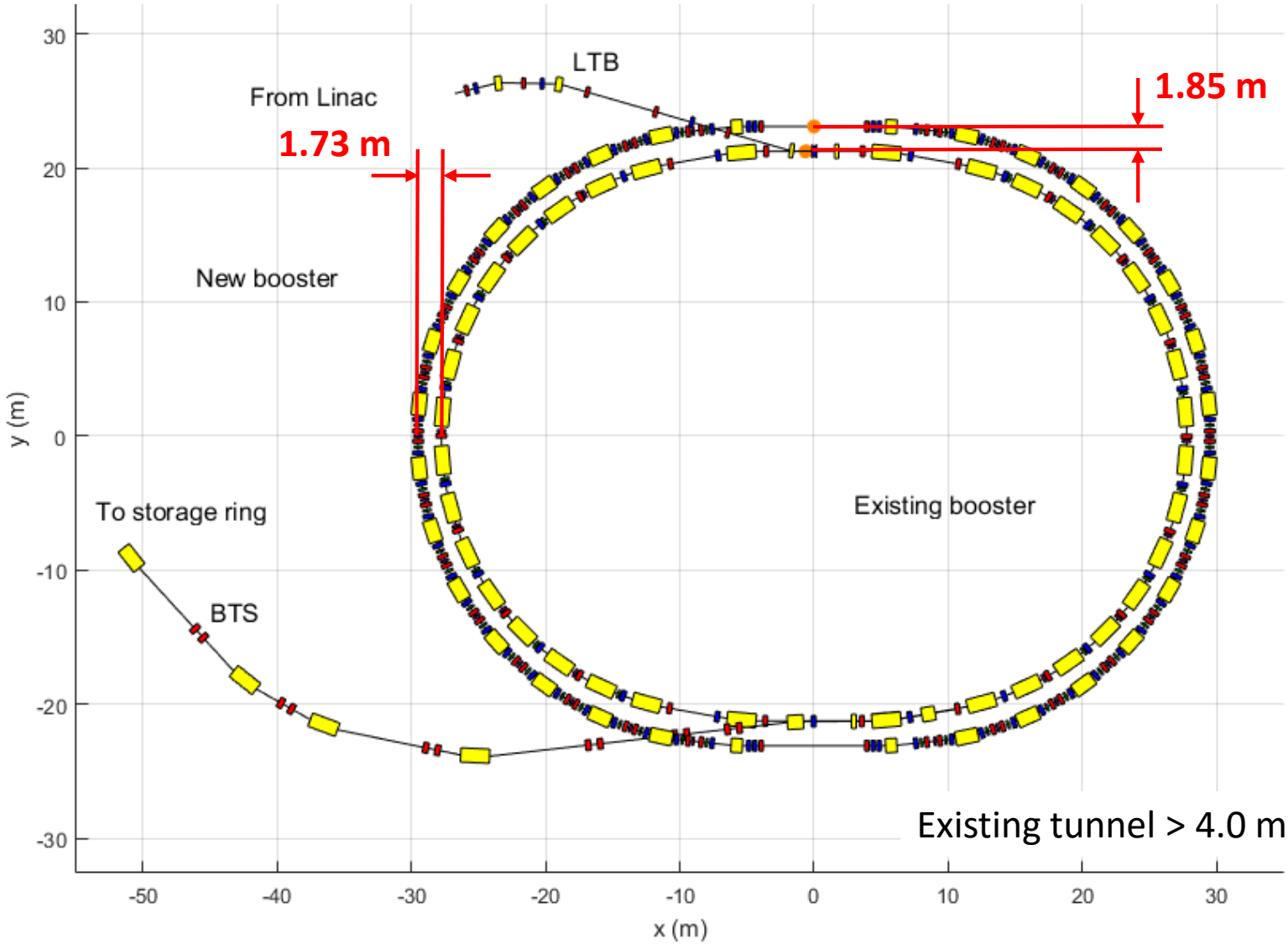


<u>Injection bump off</u>



Off-axis beam from linac oscillates around closed orbit once injection bump is off

New Booster: Installation Strategy



Existing tunnel > 4.0 m wide

New Booster: Installation Strategy

Strategy:

- Existing booster will remain in use until the long shutdown
- New booster to be partially installed (~80 %) during standard shutdowns over a two-year period preceding this
- Completion of the booster installation and re-configuration of the transfer lines as the storage ring is being removed
- Booster commissioning to be carried out in parallel with storage ring installation

Details:

- Engineering design to be developed in parallel with the storage ring
- Circumference to be consistent with storage ring RF frequency
- Anticipate design and construction will be largely out-sourced, with the new booster based on pre-assembled, pre-aligned and functionally tested girders delivered to site ready to install
- Vacuum vessels pre-installed and under vacuum
- Existing two PETRA-type 5-cell RF cavities to be re-used on new booster
- Additional control and instrumentation areas required to be built

Summary

Injection into Diamond-II storage ring places tight tolerances on injected bunch:

- Increase in beam energy (>3.5 GeV)
- Reduction in emittance (<~30 nm.rad)
- Short bunch length (<40 ps)

Desire to keep off-axis accumulation in the SR whilst minimising disturbance to users during top-up suggest replacing old booster with new combined booster-accumulator ring

Conceptual design of new ring complete

Much work still to do to convert AP design into practical solution

<u>Acknowledgements:</u>

C. Abraham, R. Bartolini, A. Day, H. Ghasem, N. Hammond, V. Kempson, J. Kennedy, R. Walker

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