Transfer lines for the FCC-ee injector complex

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Outline

FCC-ee injector complex transfer lines

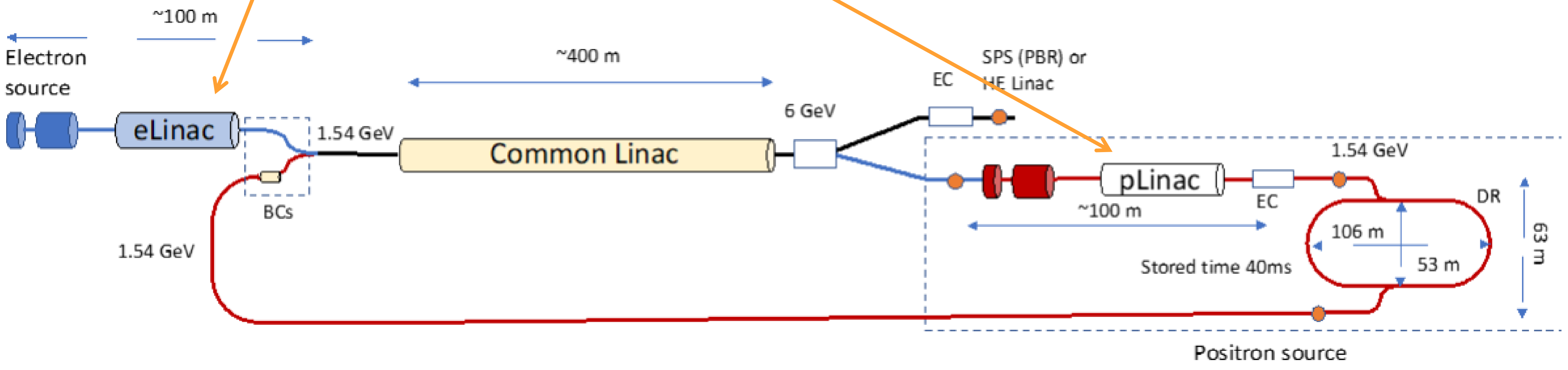
- Positron transfer line from Damping Ring (DR) to Common Linac
  - Transfer line lattice and key parameters
  - Tracking studies and estimates of Coherent Synchrotron Radiation (CSR)
- Electron transfer line - direction of future studies
- Status of transfer line studies and contributions to this work

DR injection system

- Design of the DR injection straight and possible injection schemes
- Preliminary suggestions for hardware parameters

Injector layout overview

- Separate 1.54 GeV e^- and e^+ linacs avoid the long e^- transfer lines of the previous design.
- This is followed by a Common Linac to 6 GeV.
- The e+ transfer line should include a dog-leg at the Damping Ring extraction and a section for bunch compression before the injection into the Common Linac.



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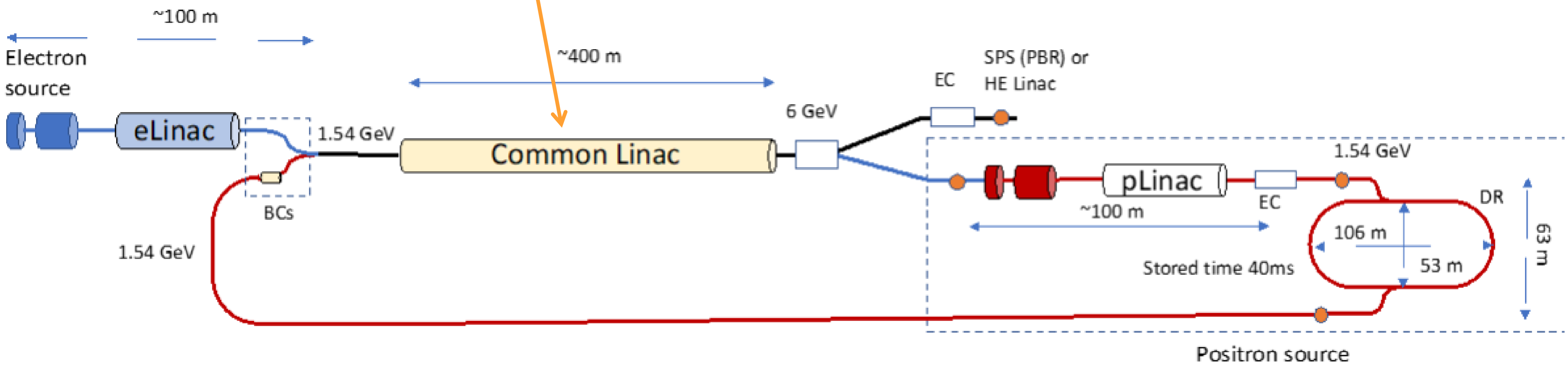

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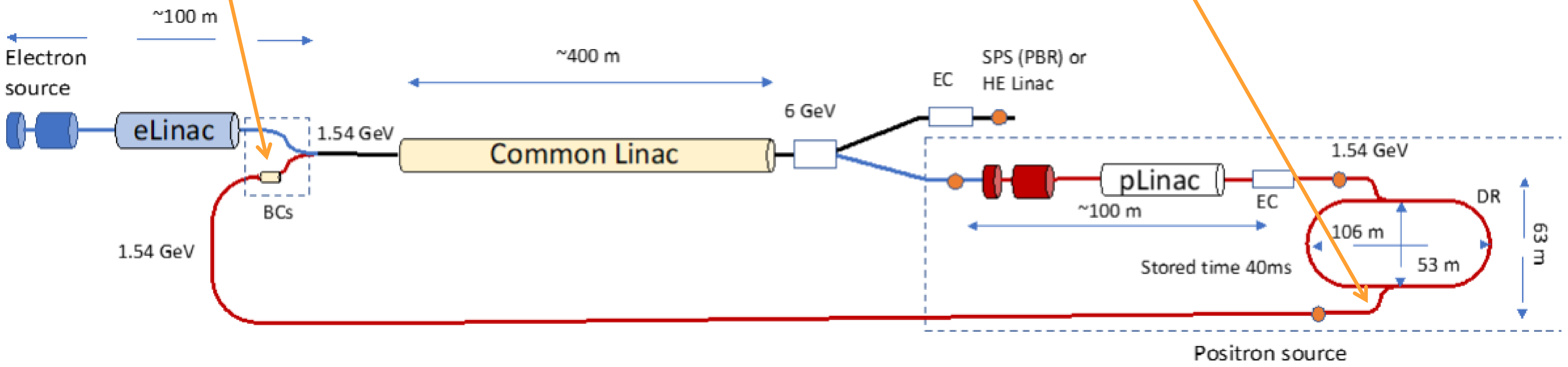

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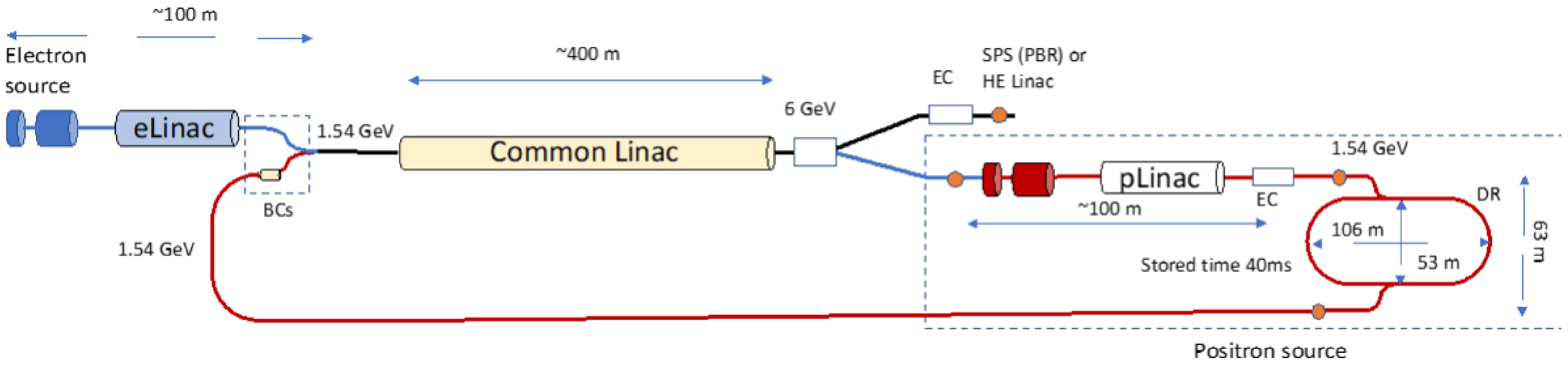

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Status of studies

Injector design WP4: **Transfer lines to/from Damping ring**

- **INFN:** A. De Santis (sub-WP coordinator), C. Milardi (WP coordinator), O. Etisken (from Sept 2022)
- **CERN:** Y. Dutheil, R. Ramjiawan, W. Bartmann

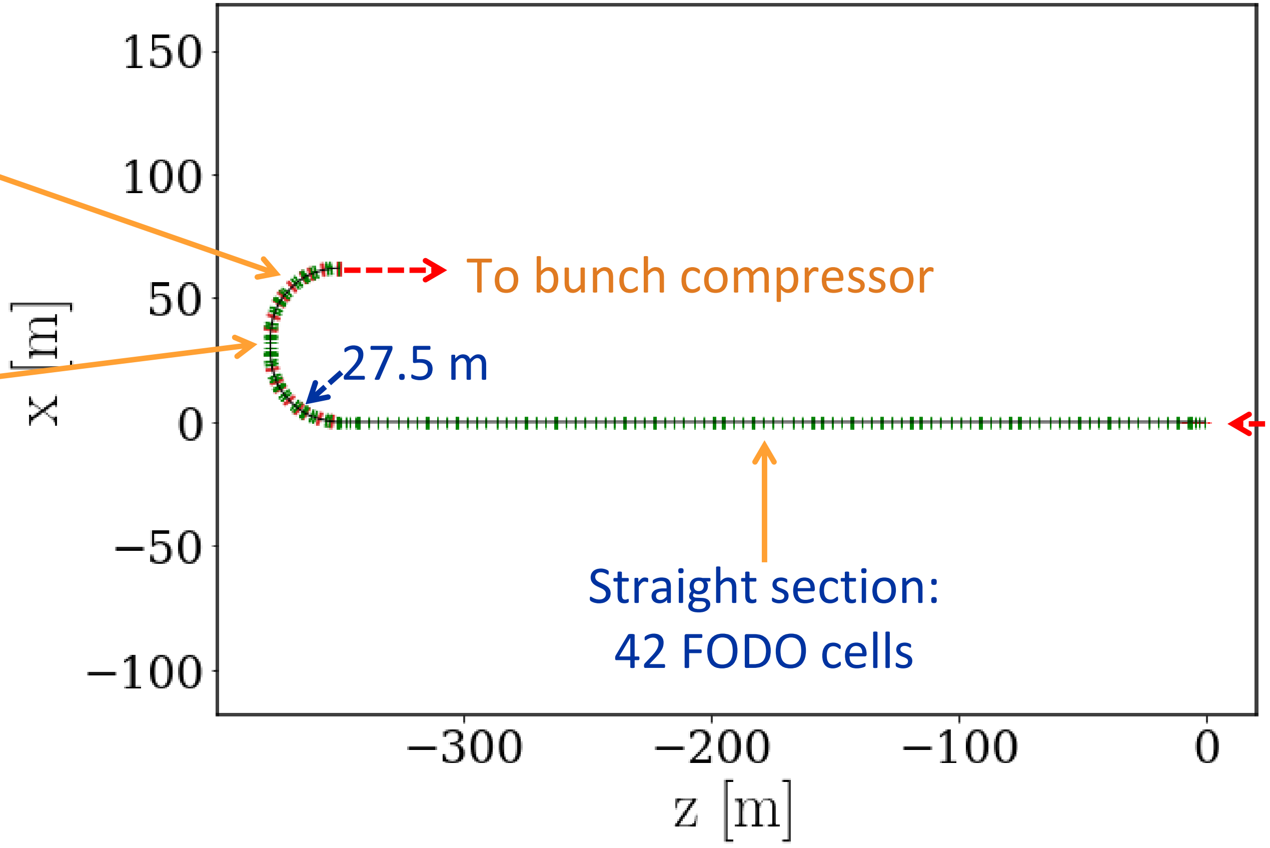
- **Positron transfer line**
  - Baseline design with lattice in MAD-X (C. Milardi, A. De Santis) and tracking in Elegant (R. Ramjiawan)
- **Bunch compression** (e^+) - initial studies T. Charles (presented FCC week 2018)
- **Dog-legs** for injection and extraction into DR (will be studied by INFN)
- **Injection and extraction** from the DR
  - Damping ring design (S. Oğur, K. Oide - 2019)
  - Preliminary injection scenario proposed, currently iterating on optimising layout/optics/hardware decisions
  - The CERN ABT group offers its expertise for the kickers and septa

Positron transfer line layout

The modules for the positron transfer line are from the previous electron transfer line.

90 degree arc:
3 TBA cells

Straight
matching
section



Beam from DR

$E = 1.54$ GeV
$\sigma_s = 1 - 11$ mm
$\epsilon_x = 0.96$ nm
Energy spread 1%

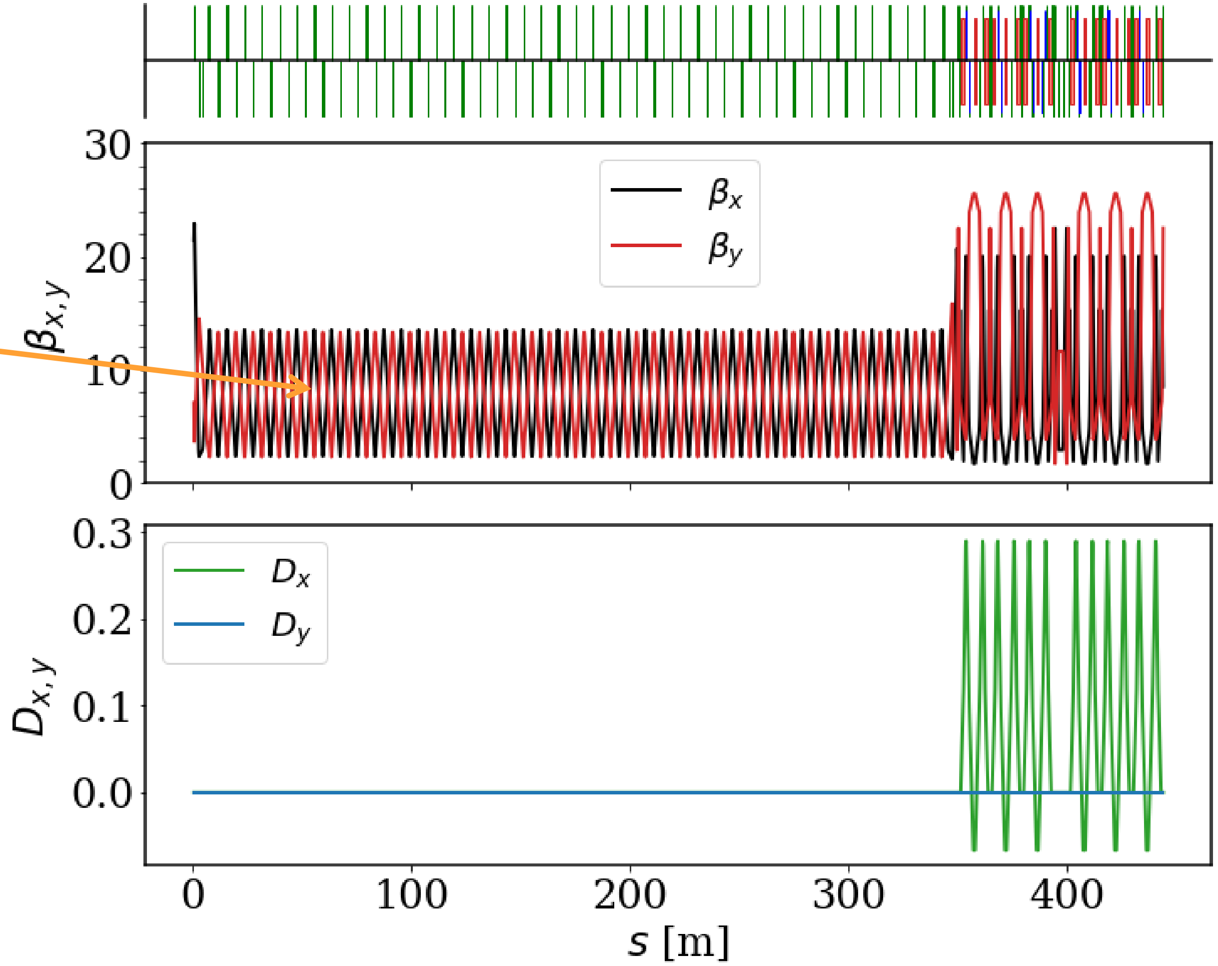
Transfer line design by C. Milardi, et al. (INFN)

Positron transfer line optics

- Lattice in MAD-X and Elegant
- Modular design

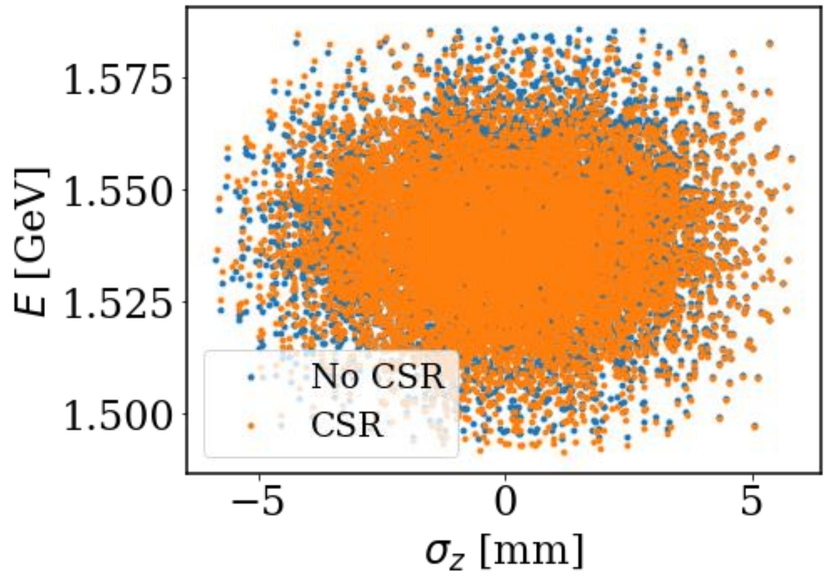
- **FODO cell**:
  - FODO length: 7.98 m
  - Quad length: 0.2 m
  - KF: 1.803923284 m^{-2}
  - KD: -1.809617958 m^{-2}
  - 90 degree phase advance
- **Arcs:**
  - Built around TBA cells
  - Low dispersion, achromatic, isochronous
  - $\alpha_{x,y} = 0$ at ends

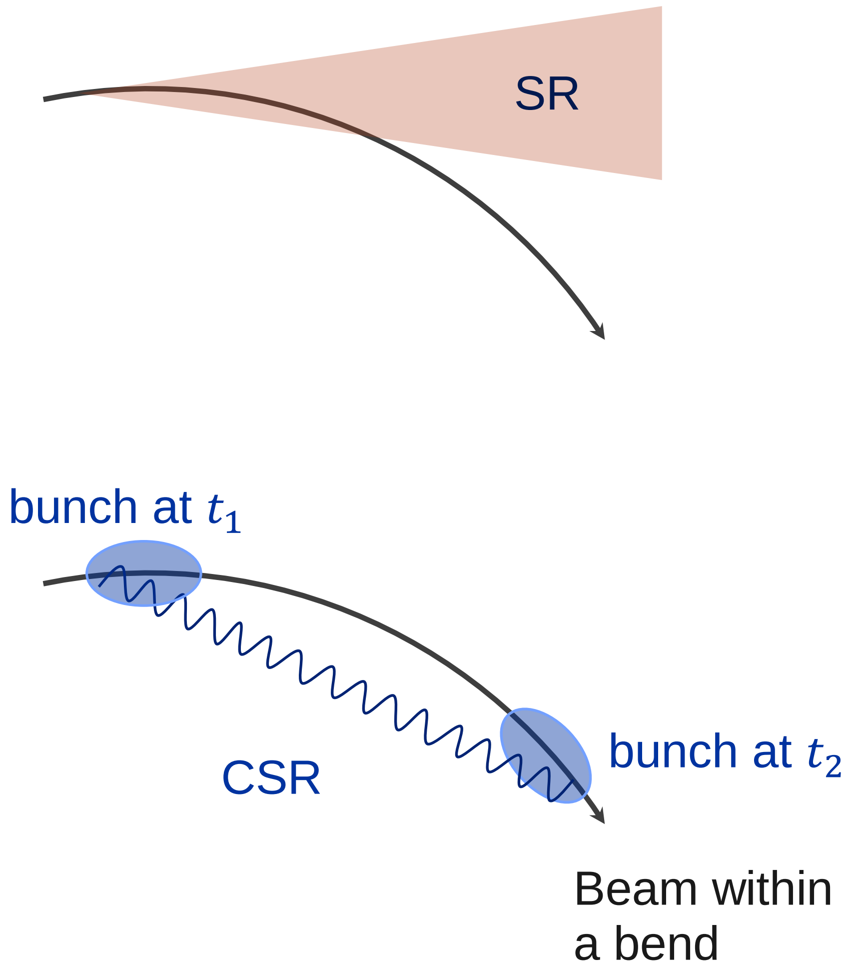
×42



Coherent Synchrotron Radiation (CSR)

- Synchrotron radiation emitted by the tail of the bunch catches up with the head of the bunch in a bend.
- Bunch length 2 mm, energy spread 1%.
- CSR causes **56 keV** increase in energy spread and **1%** increase in horizontal emittance. This is a negligible effect.





DR injection/extraction

Damping ring injection/extraction

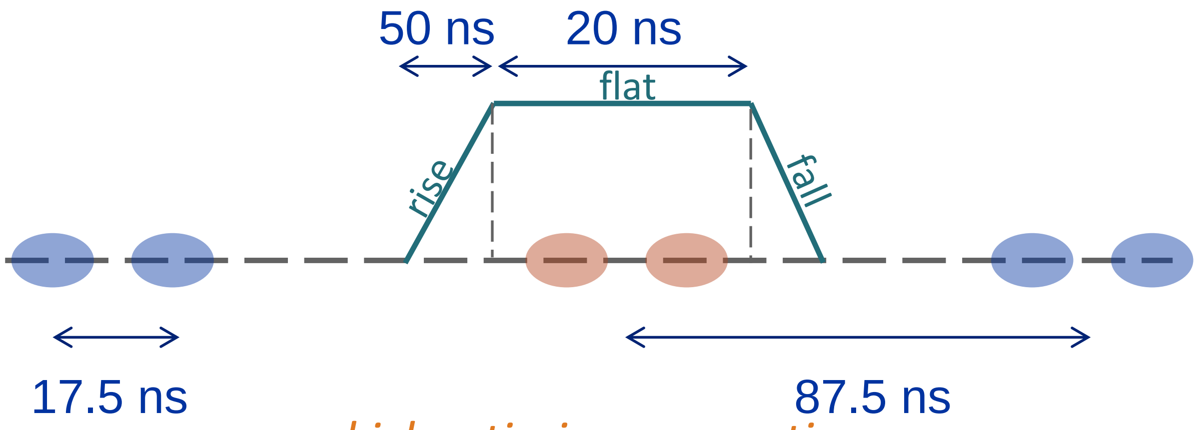
Injection and extraction at 200 Hz

Injection

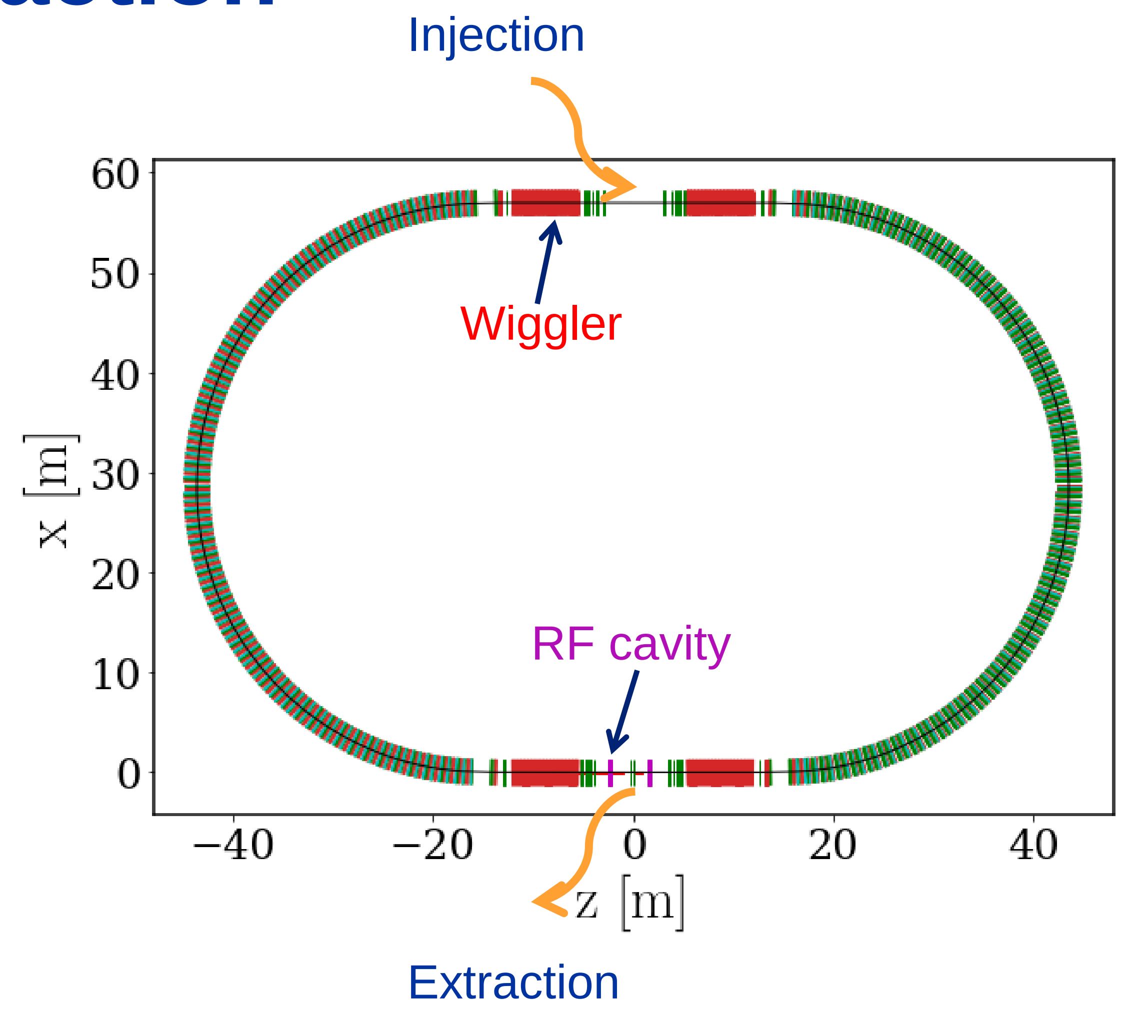
- Separation between bunches: >17.5 ns
- Separation between pulses: 5 ms

Extraction

- Separation between stored pulses: 87.5 ns

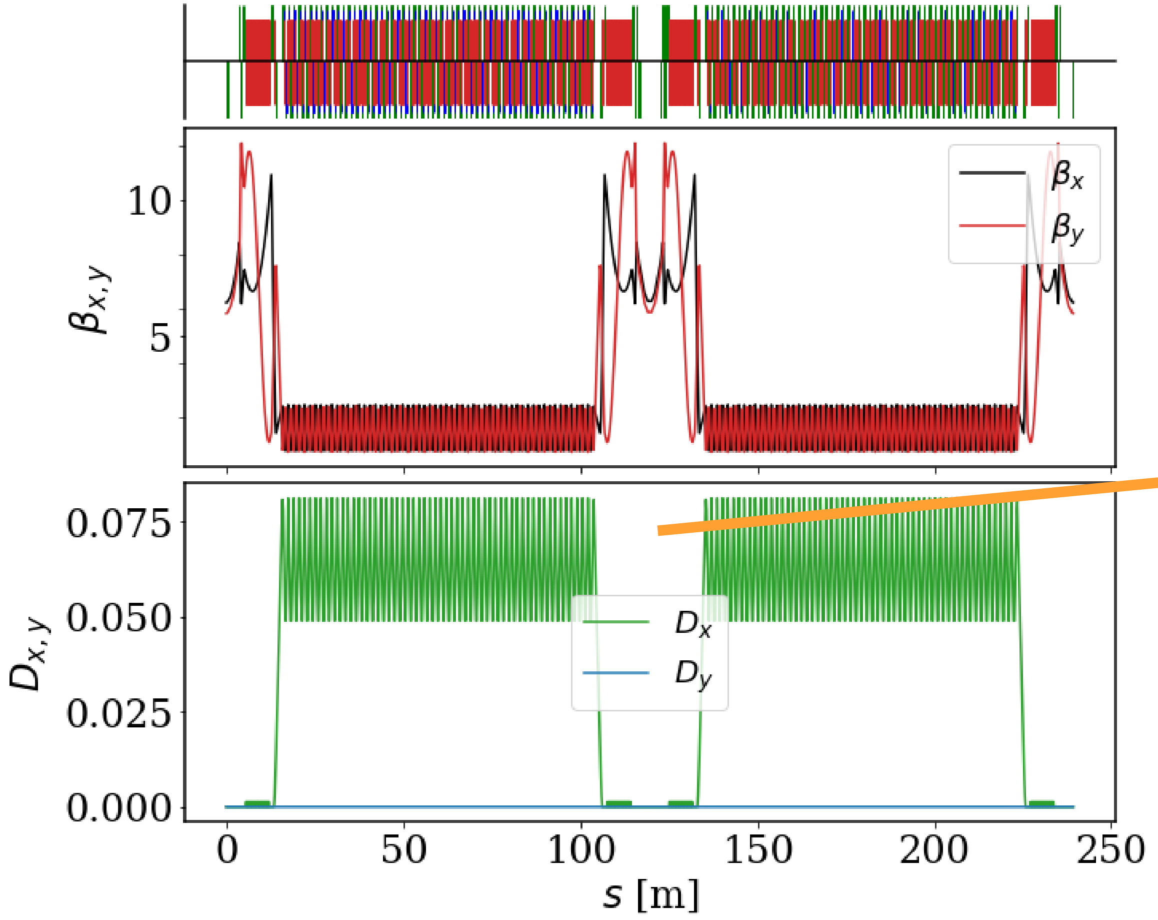


kicker timing suggestion

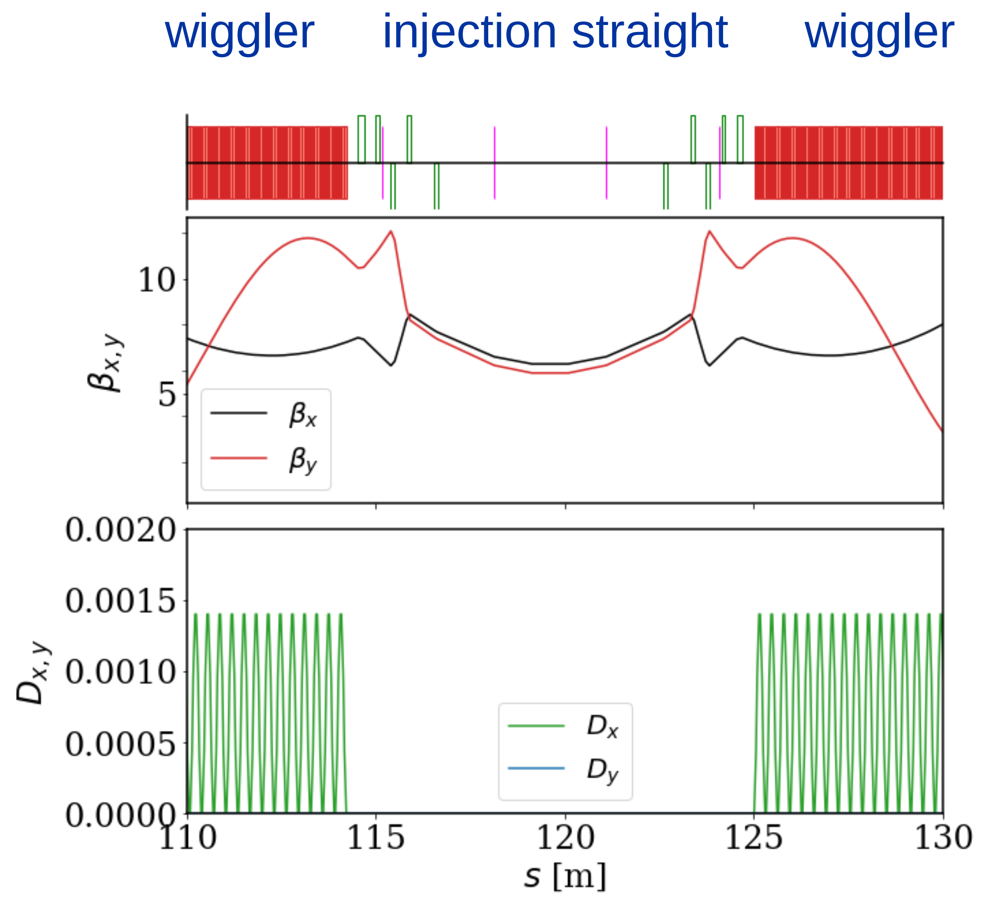


See A. De Santis, FCC-ee Injector Design Coordination meeting 09, 19th May 2022

Damping ring injection region



Damping ring

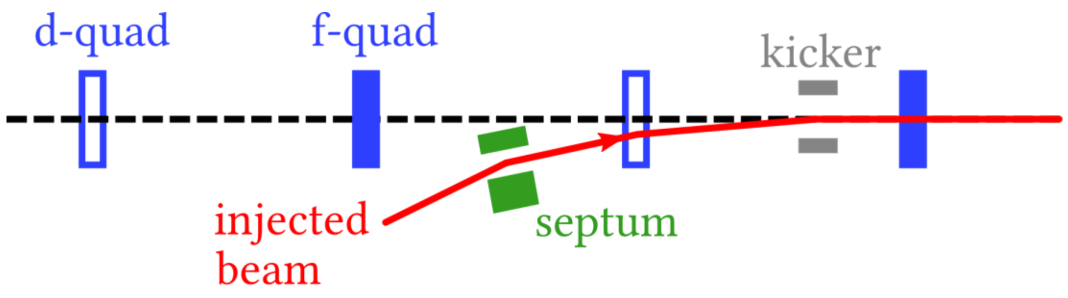


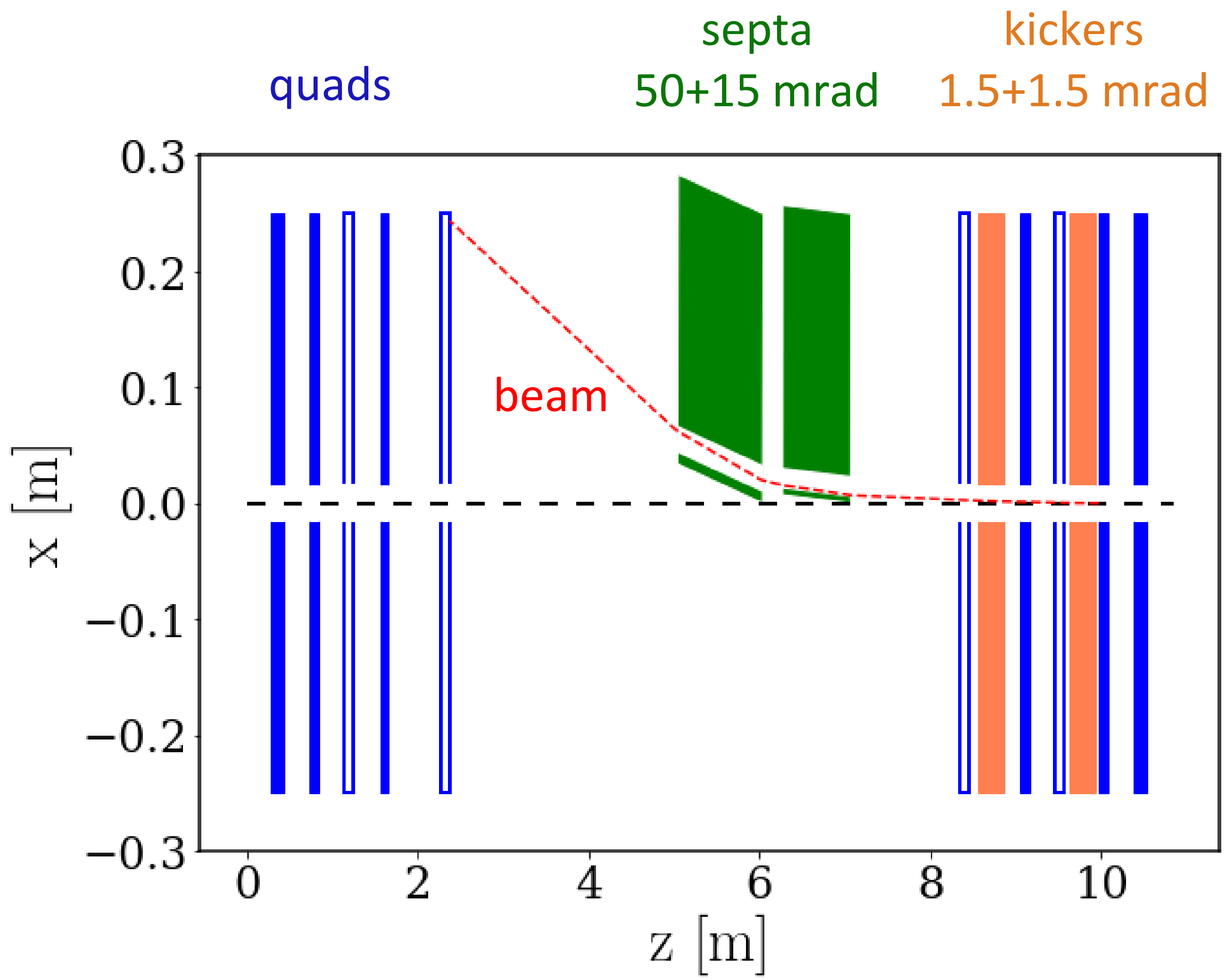
Damping ring injection region

Kicker and septum configuration

Injection straight of about 10 m, so space is limited.

Injection using thin septum with 5 mm width followed by stronger 20 mm septum.





First iteration for septum parameters

Both are DC magnetic septa with the thin septum in-vacuum and the thicker septum outside.

Thin septum

System specifications

Deflection angle: 15 mrad
Int. magnetic field: 0.08 Tm
Available space: >1 m

Design parameters

Gap width w: 75 mm
Gap height d: 15 mm
Magnetic length l: 0.8 m
Septum width t: 5 mm
Magnetic field: 0.10 T
Number of turns: 1
Max. current: 1.1 kA

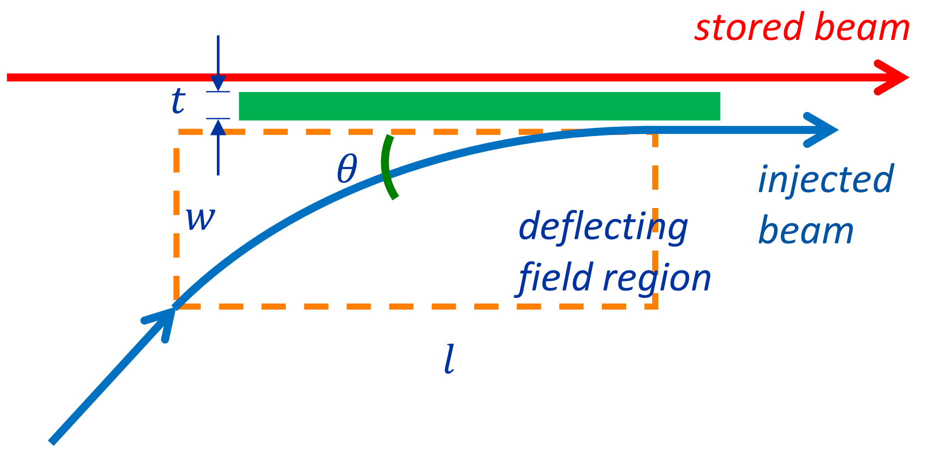
Thick septum

System specifications

Deflection angle: 50 mrad
Int. magnetic field: 0.25 Tm
Available space: >1 m

Design parameters

Gap width w: 52 mm
Gap height d: 20 mm
Magnetic length l: 1 m
Septum width t: 20 mm
Magnetic field: 0.25 T
Number of turns: 4
Max. current: 1.0 kA



- θ = deflecting angle
- w = gap width
- t = septum thickness
- l = septum length

First iteration for kicker parameters

System specifications

Deflection angle: 1.5 mrad

Int. magnetic field $\int \boldsymbol{Bdl}$**:** 3.85 mTm

Int. electric field: 1.15 MV

Available space: 0.3 m (needs extending)

Rise time: 50 ns

Pulse flat-top: 20 ns

Repetition rate: 200 Hz

Design parameters

Kicker type: terminated stripline

Magnetic length l**:** 0.3 m

Plate separation: 0.025 m

Magnetic field: 0.013 T

Voltage: $\pm$**47.5 kV** ⇢ would need to halve this

Assume equal contributions from the electric and magnetic fields [1].

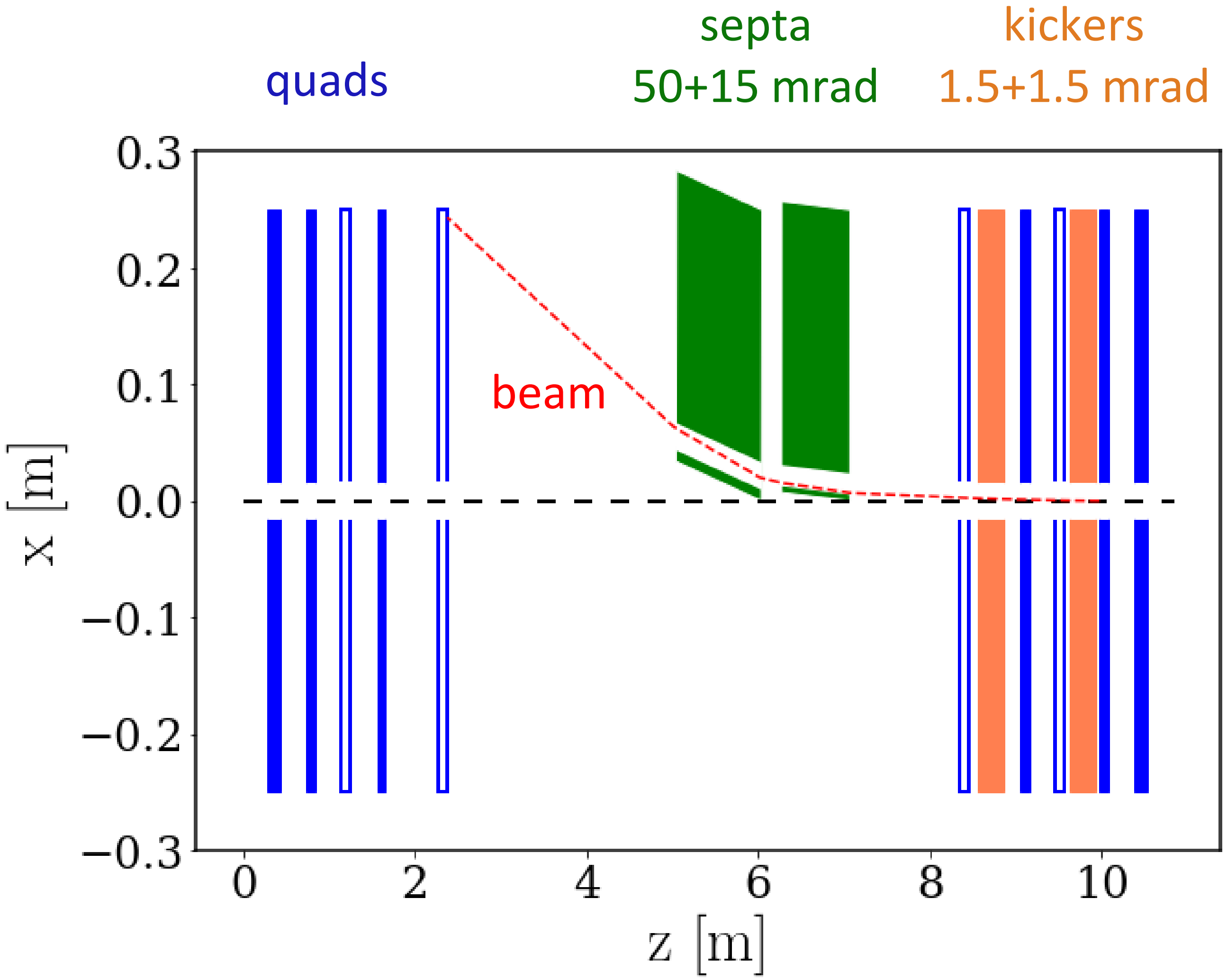
$$\theta[\text{rad}] = \tan^{-1}\left[\frac{E[\text{V/m}]\,l[\text{m}]}{p\left[\frac{\text{GeV}}{\text{c}}\right]\beta\times 10^{9}}\right] + \frac{0.2998\times l_{eff}[\text{m}]}{p\left[\frac{\text{GeV}}{\text{c}}\right]} B[T]$$

Proposed solutions

The injection straight is short so the kicker and septum deflections are challenging.

To make this more feasible:

- Larger magnet separation (longer kicker)
- Longer injection straight
- Optimise injection optics
- Channelling through a quadrupole
- Thinner electrostatic septum - voltage likely to be prohibitive for this



Conclusions

Injector complex transfer lines

- Baseline design for the positron transfer line from Damping Ring to common linac. Tracking suggests CSR should not be an issue.

Injection/extraction systems

- Preliminary design for DR injection straight with initial suggestions for hardware parameters. Iteration needed to get the kickers and septa within hardware limitations.

- Identifying required R&D topics for the DR and/or collider injection/extraction systems.

Further work

- Design for the electron transfer line, this will depend on the specifications for the e-source/e-linac.

- Optimisation of the DR injection and design of the DR extraction.

- Inclusion of the DR extraction dog-leg into the positron transfer line tracking. Study of the bunch compression for the positron transfer line.

Thank you for listening