Bunch Compression and CSR Mitigation

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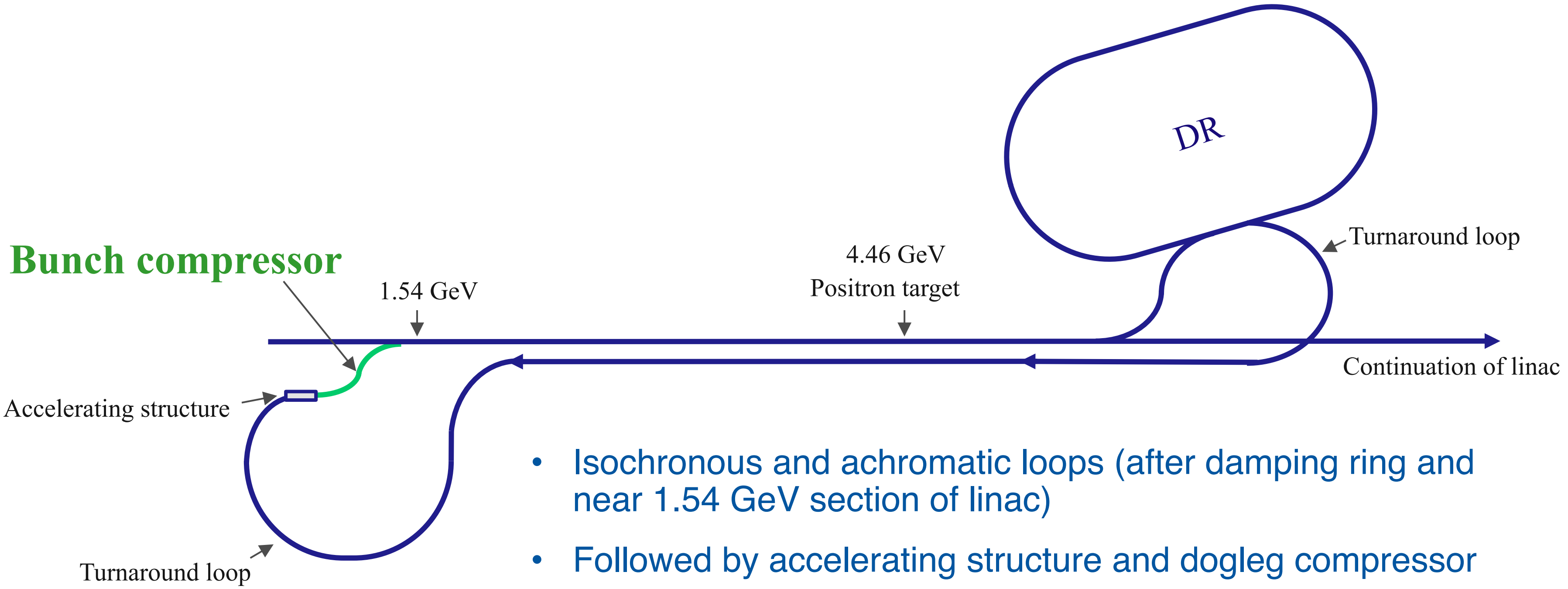
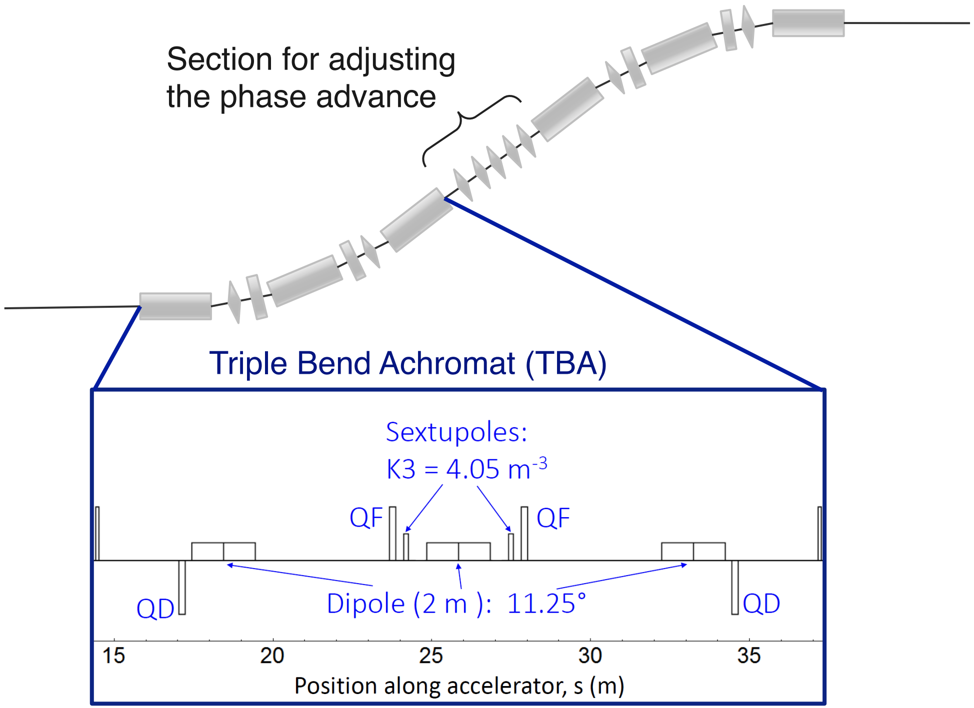
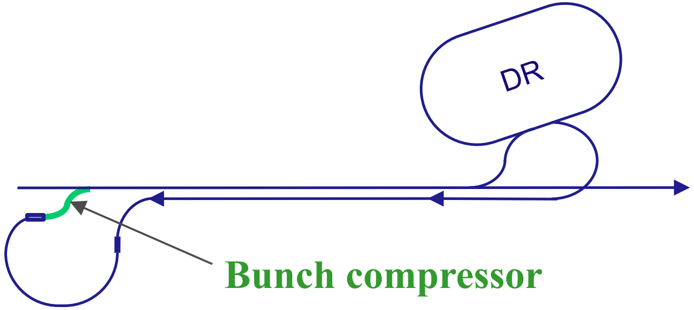
Bunch compressor for the FCCee injector complex



- Isochronous and achromatic loops (after damping ring and near 1.54 GeV section of linac)
- Followed by accelerating structure and dogleg compressor

The proposed bunch compressor is a dogleg comprised of two TBAs.



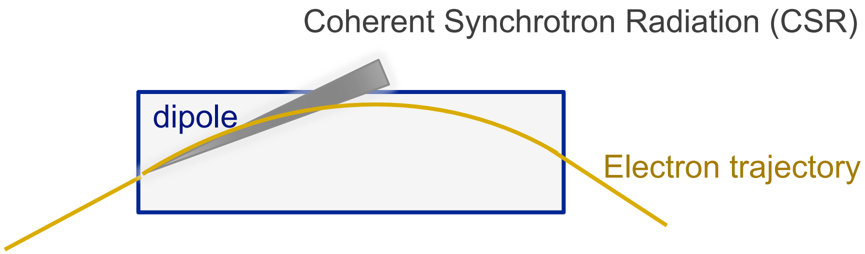


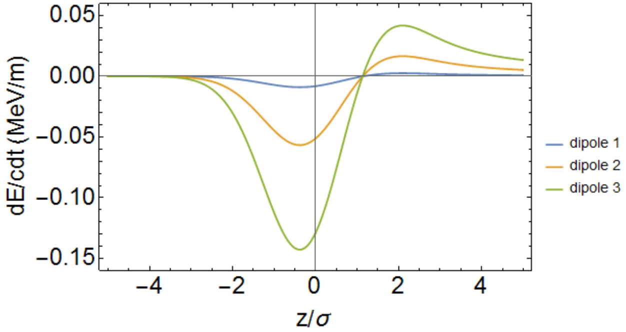
Properties of dogleg:

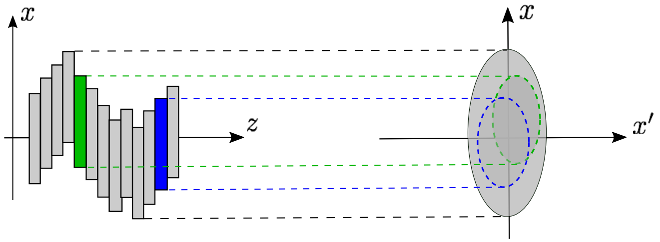
R56 = 0.409 m
T566 = 0.161 m
U5666 = 0.163 m

CSR is a head-tail effect which offsets slices, increasing the projected emittance.

$$\frac{dE}{cdt} = \frac{-2e^2}{4\pi\epsilon_0(3R^2)^{1/3}} \int_{\tilde{z}-z_L}^{\tilde{z}} \frac{d\lambda}{dz} \left(\frac{1}{\tilde{z}-z}\right)^{1/3} dz,$$

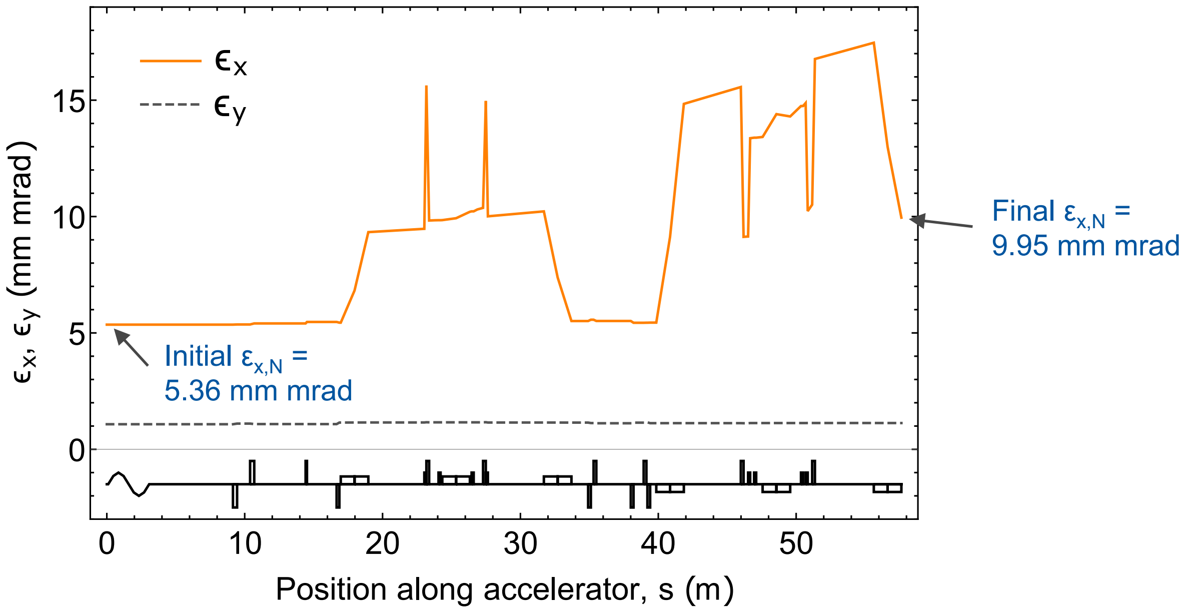






CSR can cause time-dependent transverse kicks, resulting in a centroid off-set of different slices of the bunch, which smears out the transverse phase space and enlargement of the projected emittance.

If left unchecked, CSR will increase the projected horizontal emittance by 85.8 %



CSR kicks can be cancelled through manipulating the optics.

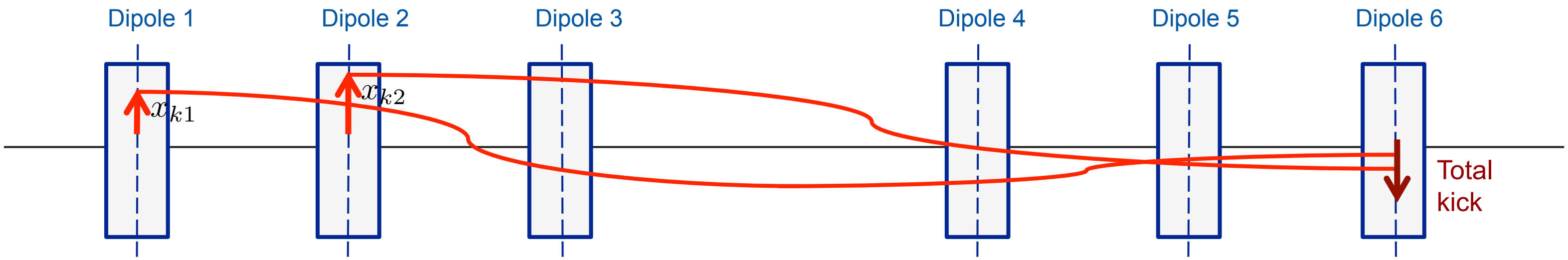
As the bunch passes through dipole, CSR causes a change in energy. The particle starts a betatron oscillation around a new reference trajectory, increasing its Courant-Snyder invariant.

$$X_k = \begin{pmatrix} x_k \\ x'_k \end{pmatrix} = \begin{pmatrix} \rho^{4/3}[\theta cos(\theta/2) - 2sin(\theta/2)] \\ sin(\theta/2)(2\delta + \rho^{1/3}\theta k) \end{pmatrix}$$

$$k = \delta_{CSR}\frac{R^{2/3}}{L_b}$$
$$= 0.2459\frac{r_e Q}{e\gamma\sigma^{4/3}}$$

where δ_{CSR} is from the steady-state solution.

from Y. Jiao et. al (2014) Phys. Rev. ST AB **17** 060701



CSR kicks propagated to end of the dogleg

$$\Delta x_1 = \sqrt{\frac{\beta_6}{\beta_1}}\left[\cos(\phi_{16}) + \alpha_1 \sin(\phi_{16})\right] x_{k1} + \sqrt{\beta_1\beta_6}\,\sin(\phi_{16})\; x'_{k1}$$

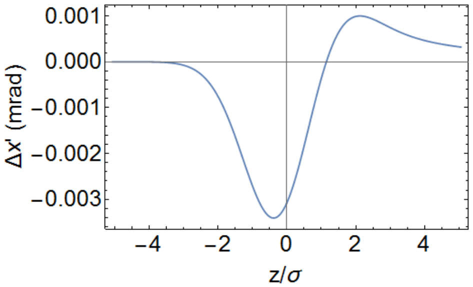
$$\Delta x'_1 = \frac{(\alpha_1-\alpha_6)\cos(\phi_{16})-(1+\alpha_1\alpha_6)\sin(\phi_{16})}{\sqrt{\beta_1\beta_6}}\; x_{k1} - \alpha_6\sqrt{\frac{\beta_1}{\beta_6}}\; x'_{k1}$$

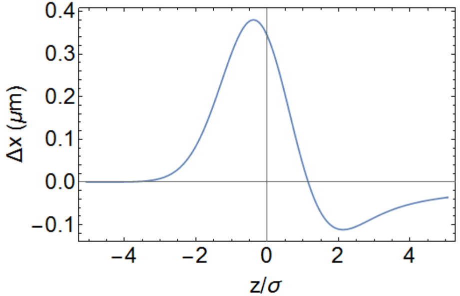
where

$$x_{k1} = \rho_1^{4/3} k_1\left[\theta_1 \cos(\tfrac{\theta_1}{2}) - 2\sin(\tfrac{\theta_1}{2})\right]$$
$$x'_{k1} = \sin(\tfrac{\theta_1}{2})\left[2\delta_1 + \rho_1^{1/3}\theta_1 k_1\right]$$

where $k_1 = \frac{W}{E_0} = \frac{dE}{cdt}\frac{\rho_1^{2/3}}{E_0}$ and $\delta_1 = \frac{L_{dip}}{E_0}$

$$\frac{dE}{cdt} = \frac{-2e^2}{4\pi\epsilon_0(3R^2)^{1/3}}\int_{\tilde{z}-z_L}^{\tilde{z}} \frac{d\lambda(z)}{dz}\frac{1}{(z-\tilde{z})^{1/3}}\,dz$$





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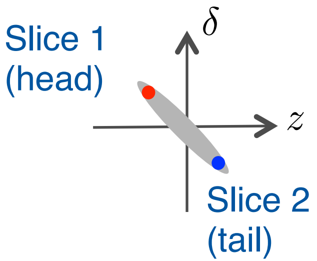
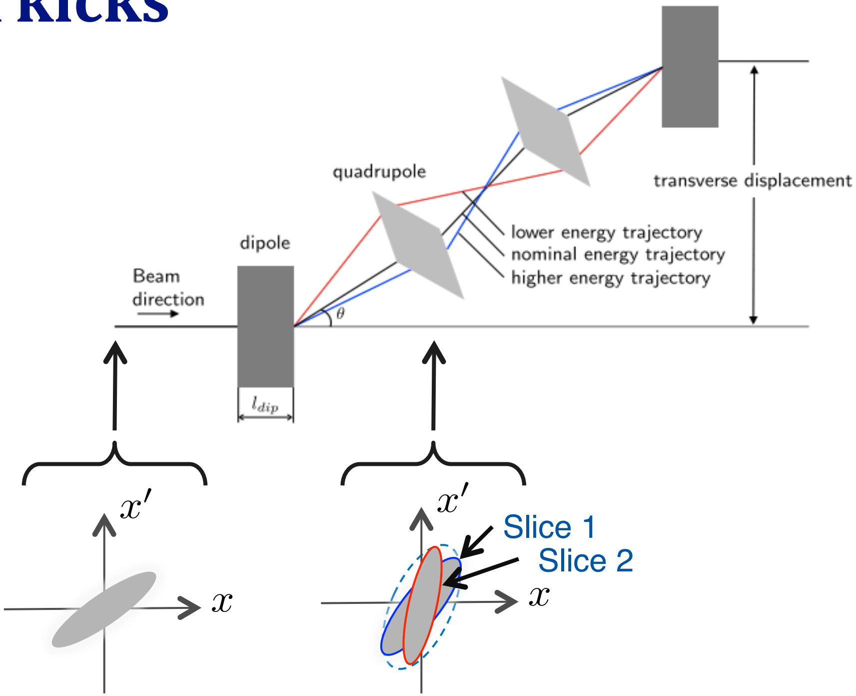
Slice twiss parameters in the middle dipoles change the CSR kicks





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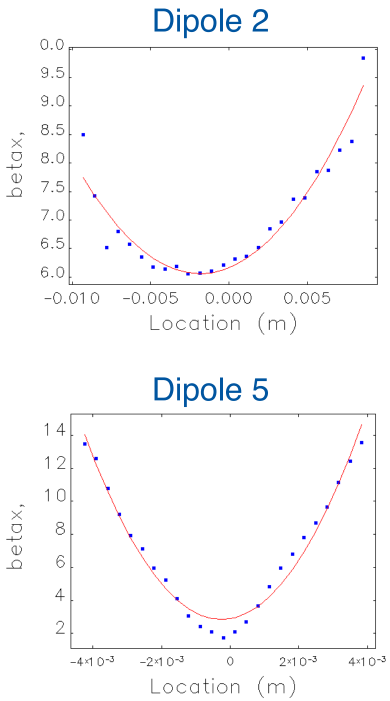
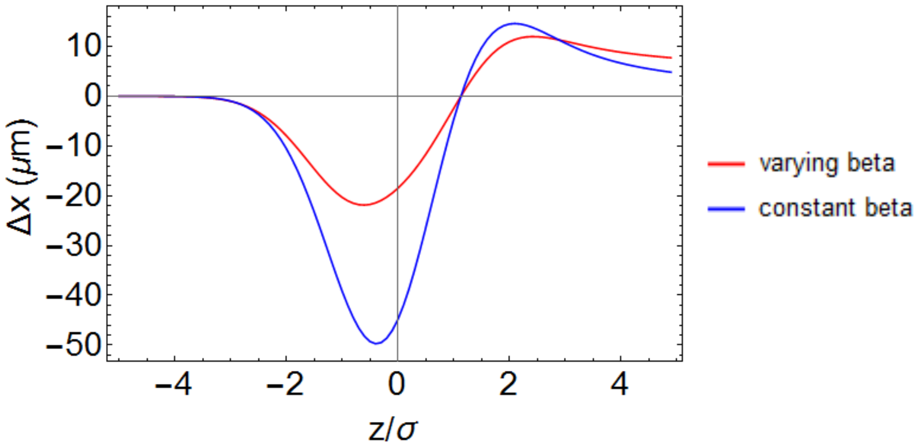
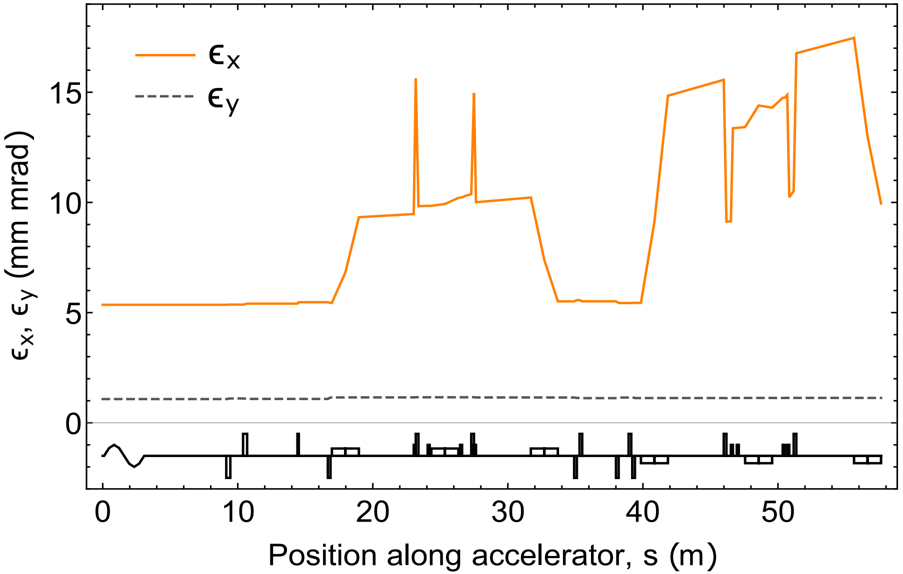


$$\Delta x_5 = \sqrt{\frac{\beta_6}{<\beta_5>}}[\cos(\phi_{56}) + \alpha_6 \sin(\phi_{56})]x_{k5} + \sqrt{<\beta_5>\beta_6}\sin(\phi_{56})\ x'_{k5}$$

$$\Delta x_5 = \sqrt{\frac{\beta_6}{\beta_5(z)}}[\cos(\phi_{56}) + \alpha_6 \sin(\phi_{56})]x_{k5} + \sqrt{\beta_5(z)\beta_6}\sin(\phi_{56})\ x'_{k5}$$

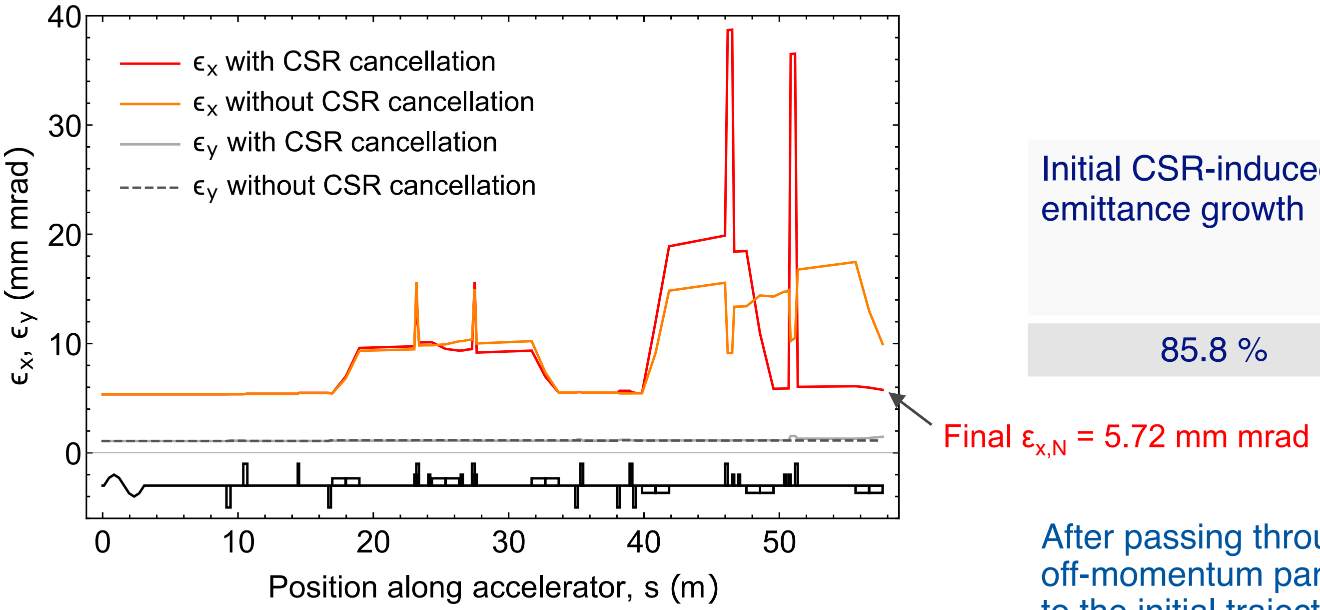


CSR mitigation can greatly reduce emittance growth



Initial CSR-induced emittance growth
85.8 %

CSR mitigation can greatly reduce emittance growth



CSR is included in drifts, and ISR included.

Initial CSR-induced emittance growth	Emittance growth after CSR cancellation technique applied
85.8 %	6.9 %

After passing through all of the dipoles, the off-momentum particles (in each slice) return to the initial trajectory. Therefore, minimizing the emittance growth.

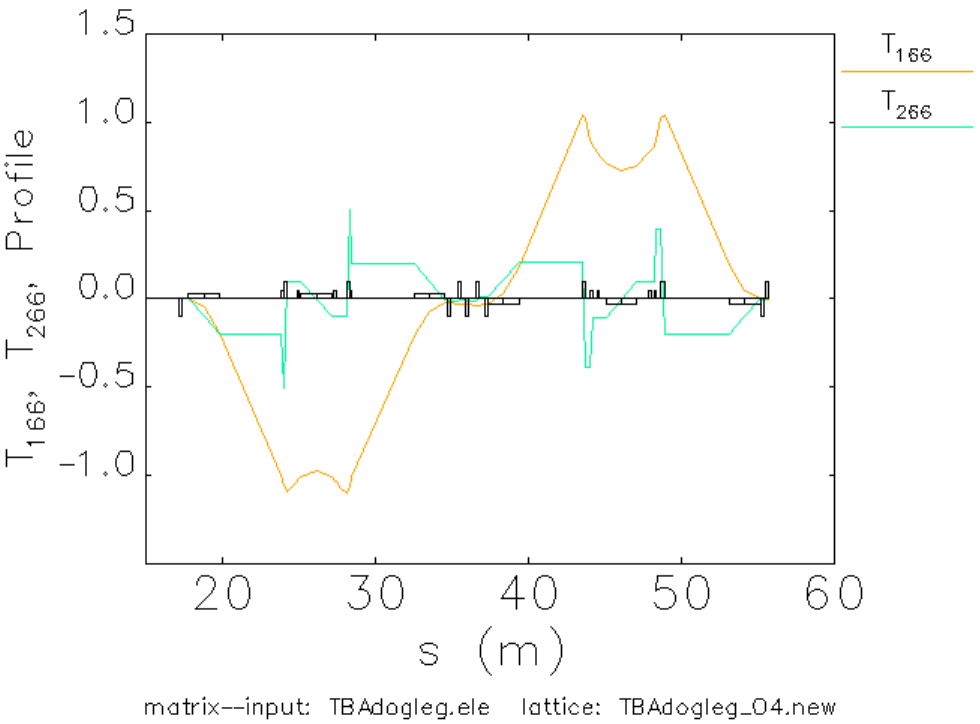
Conclusions

- Bunch compressor proposed for the FCC-ee injector complex is a dogleg compressor comprised of two TBAs for a positive R_{56} and favourable T_{566}.
- CSR kicks can be cancelled to large extent. Reducing emittance growth from 85.8 % to 6.9 %.

Thank you for your attention

Back up slides …

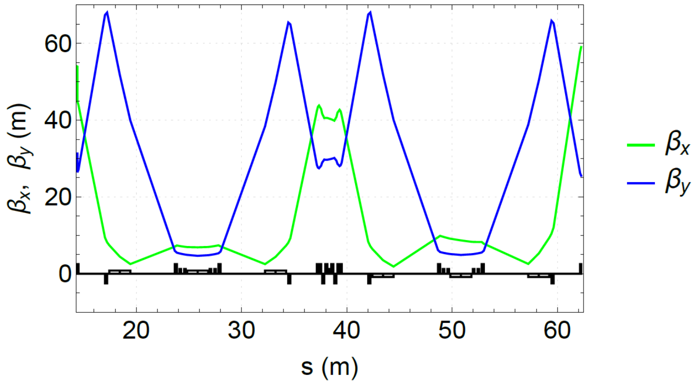
T166, T266 through dogleg

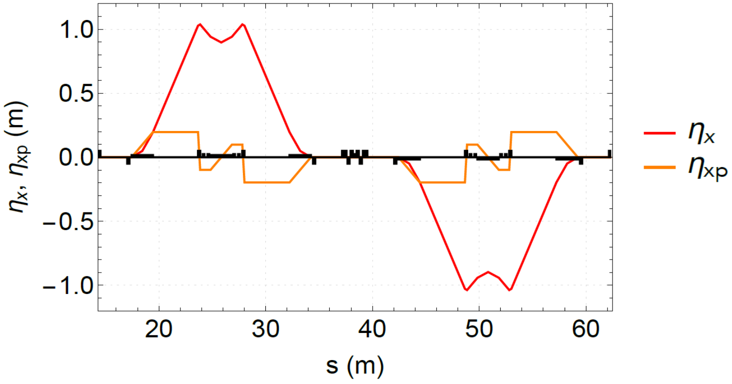


This layout has three benefits:
1. it allows for a reasonably large R56 value

$$\frac{z_f}{z_i} = 1 + R_{56} h_1$$
$$\sigma_{z,f} = (1 + R_{56} h_1)\sigma_{z,i}, \qquad (1)$$

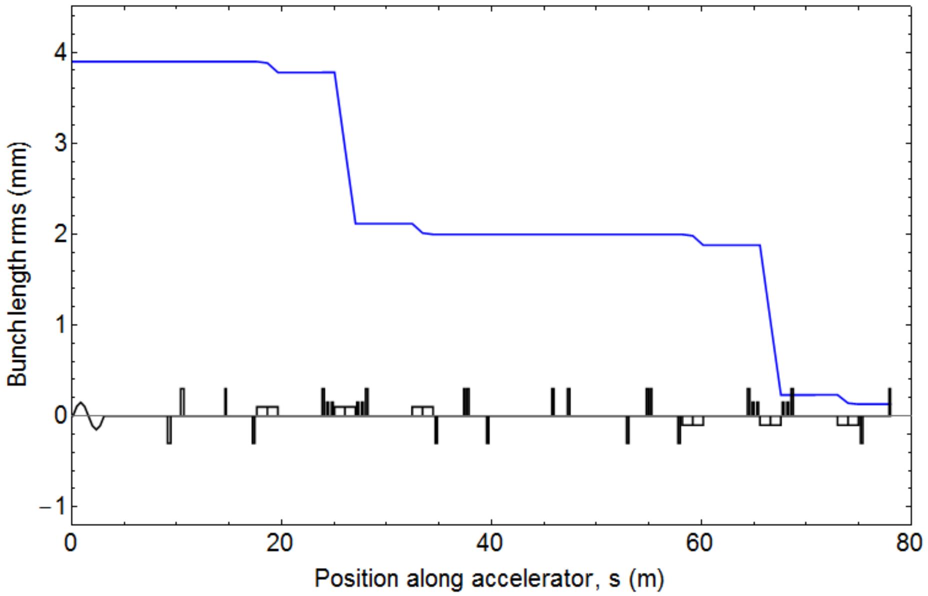
Properties of dogleg:
R56 = 0.409 m
T566 = 0.161 m
U5666 = 0.163 m





This layout has three benefits:
2. there is no parasitic compression

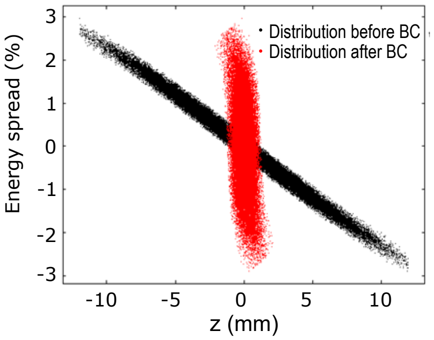
The positive R_{56} BC ensures the bunch length gets progressively shorter, unlike a chicane where the bunch reaches the shortest bunch length before lengthening out again by the end of the compressor.



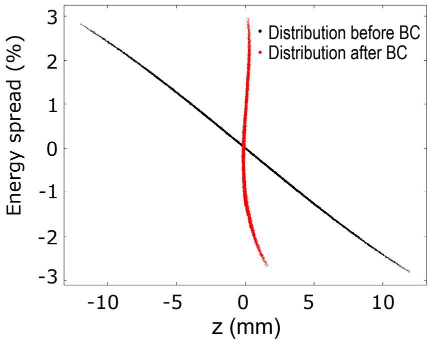
This layout has three benefits:
3. Self- linearizing achromats.

- Sextupoles strengths optimized for chromaticity, rather than for T566. However the resulting T566 is close to optimal anyway.
- No need for a harmonic cavity.

σδ, intial = 0.1 %

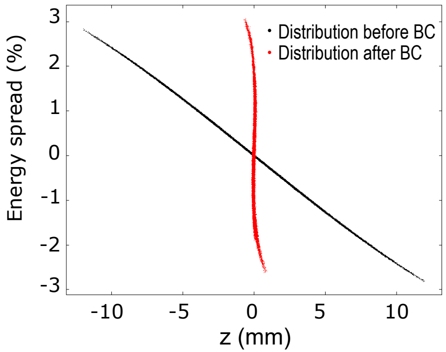


Without sextupoles



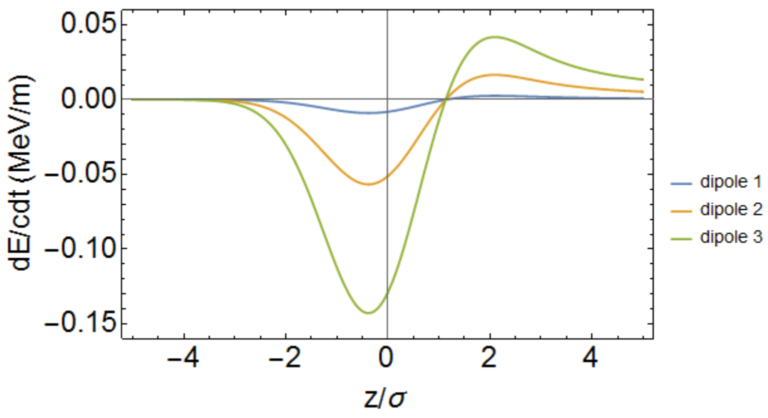
R56 = 0.409 m
T566 = 1.23 m
U5666 = 3.04 m

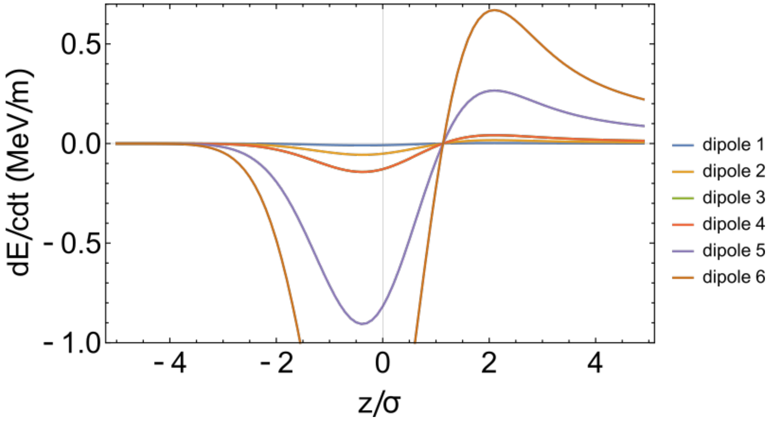
With sextupoles



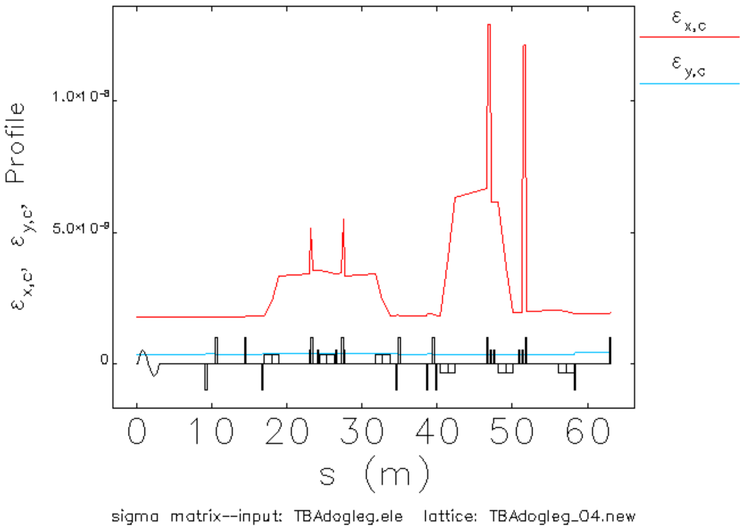
R56 = 0.409 m
T566 = 0.161 m
U5666 = 0.163 m

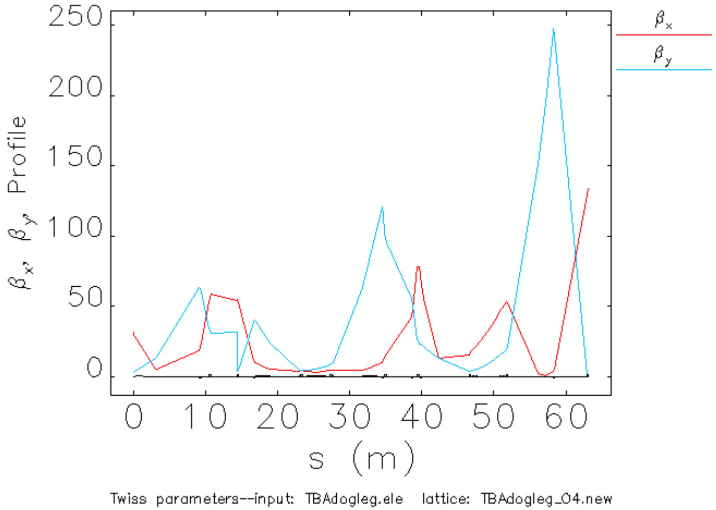
Impact of Coherent Synchrotron Radiation (CSR)





Optics with CSR cancellation





Distributions before and after BC (with CSR cancellation)

- Initial distribution
- Final distribution