# Distorted Coherent Synchrotron Radiation Kicks

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MAX IV

# Coherent Synchrotron Radiation

Synchrotron radiation is EM radiation emitted by a relativistic charged particle moving in an arc i.e. in a dipole.

A bunch will radiate coherently when the following inequality is satisfied.

$$\lambda \geq 2\pi\sigma_z$$

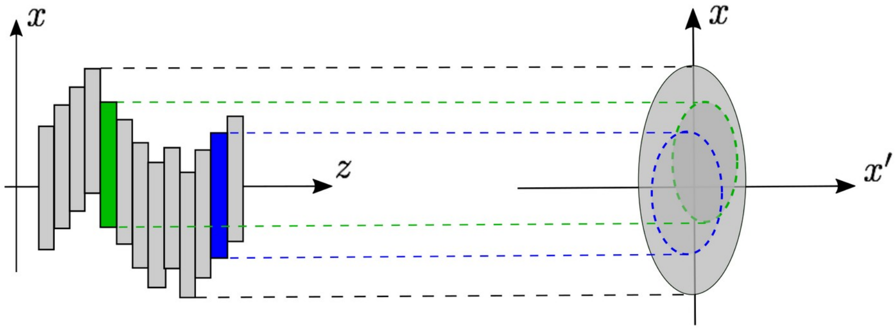


Figure 2: Slice offset due to CSR [1].

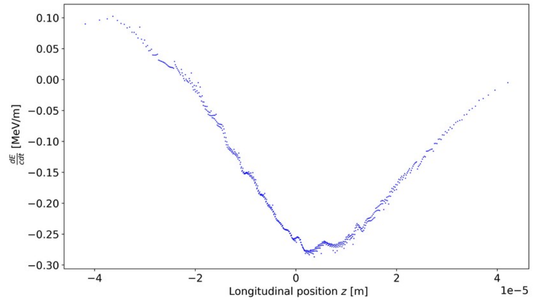


Figure 1: CSR wake at the centre of a dipole.

- CSR is a head-tail effect and leads to time-dependant energy change in the bunch.
- All particles emit CSR while the particles towards the head of the bunch will 'see' the radiation emitted by the tail and absorb the CSR. CSR wake seen in Fig. 1.
- In a dispersive region i.e. a dipole, the CSR-induced slice energy change results in an offset in position and momentum in the bending plane.
- Slice offsets lead to projected emittance growth, as seen in Fig. 2.

# Point-Kick Model

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

Where ρ and θ are the bend radius and bend angle of the dipole, δ is energy deviation at the centre of the dipole and $k = \delta_{CSR}\rho^{2/3}/L$ [2].

After transport between $s_0$ and $s_1$ the kicks become,

$$x_k(z;s_1) = \sqrt{\frac{\beta_x(s_1)}{\beta_x(s_0)}}(\cos(\psi_x(s_1)) + \alpha_x(s_0)\sin(\psi_x(s_1)))x_k(z;s_0) + \sqrt{\beta_x(s_0)\beta_x(s_1)}\sin(\psi_x(s_1))x'_k(z;s_0)$$

$$x'_k(z;s_1) = \frac{(\alpha_x(s_0) - \alpha_x(s_1))\cos(\psi_x(s_1)) - (1 + \alpha_x(s_0)\alpha_x(s_1))\sin(\psi_x(s_1))}{\sqrt{\beta_x(s_0)\beta_x(s_1)}}x_k(z;s_0) + \sqrt{\frac{\beta_x(s_0)}{\beta_x(s_1)}}(\cos(\psi_x(s_1)) - \alpha_x(s_1)\sin(\psi_x(s_1)))x'_k(z;s_0)$$

Final emittance due to CSR [2]:

$$\varepsilon_x = \sqrt{(\varepsilon_{0,x}\beta_x + x^2_{k,rms})(\varepsilon_{0,x}\gamma_x + x'^2_{k,rms}) - (\varepsilon_{0,x}\alpha_x - x_{k,rms}x'_{k,rms})^2}$$

# CSR Cancellation Methods

- Optical balance – Suppression of CSR-induced emittance growth through optimising the phase advance between achromats [3,4].
- CSR kick matching – CSR-induced emittance growth is minimised by matching CSR wake dispersion matches the betatron envelope [5,6].
- Pulse shaping – The current profile is shaped in order to produce a linear CSR wake [7].

# Distorted CSR Kicks

- As the bunch compressors use a bunch with an energy chirp and have multipole magnets in dispersive sections, the optics of the lattice is slice dependent. This results in non-uniform slice beam parameters.
- As the slice parameters are non-uniform along the bunch the slices will not transform in the same way. Using the slice parameters to transform the CSR kicks we would expect them to become distorted. If the CSR kicks become distorted the cancellation methods could be less effective [8].

$$
\begin{aligned}
x_k(z;s_1) = & \sqrt{\frac{\beta_x(z;s_1)}{\beta_x(z;s_0)}}\left(\cos(\psi_x(z;s_1)) + \alpha_x(z;s_0)\sin(\psi_x(z;s_1))\right)x_k(z;s_0) \\
& + \sqrt{\beta_x(z;s_0)\beta_x(z;s_1)}\sin(\psi_x(z;s_1))x'_k(z;s_0)
\end{aligned}
$$

$$
\begin{aligned}
x'_k(z;s_1) = & \frac{(\alpha_x(z;s_0) - \alpha_x(z;s_1))\cos(\psi_x(z;s_1)) - (1 + \alpha_x(z;s_0)\alpha_x(z;s_1))\sin(\psi_x(z;s_1))}{\sqrt{\beta_x(z;s_0)\beta_x(z;s_1)}}x_k(z;s_0) \\
& + \sqrt{\frac{\beta_x(z;s_0)}{\beta_x(z;s_1)}}\left(\cos(\psi_x(z;s_1)) - \alpha_x(z;s_1)\sin(\psi_x(z;s_1))\right)x'_k(z)
\end{aligned}
$$

# MAX-IV Linac

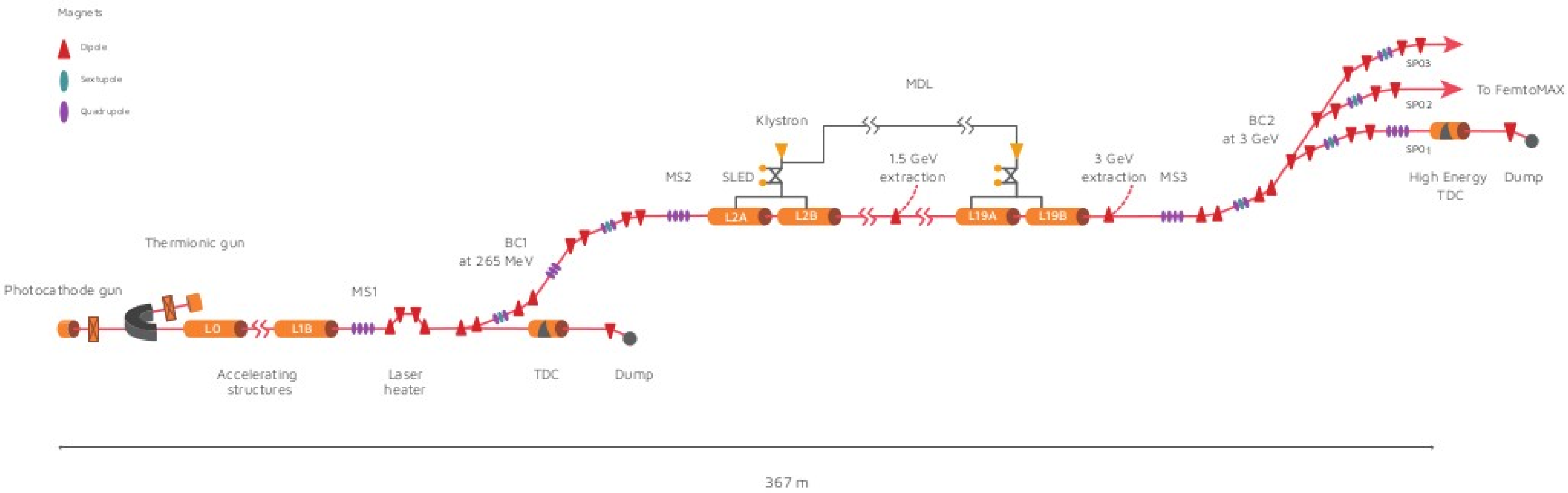


Figure 3: Layout of the MAX-IV linac [9].

| BC2 | $R_{56}$ [cm] | $T_{566}$ [cm] | $U_{5666}$ [cm] |
|---|---|---|---|
| Short Pulse Facility (SPF) | 2.6 | 6.0 | -2.0 |
| Soft X-ray Laser (SXL) | 2.6 | 5.3 | 1.4 |

# MAX-IV Short Pulse Facility

The short pulse facility (SPF) uses a 100pC electron bunch for FemtoMAX. FemtoMAX is used for ultra-fast X-ray diffraction experiments.

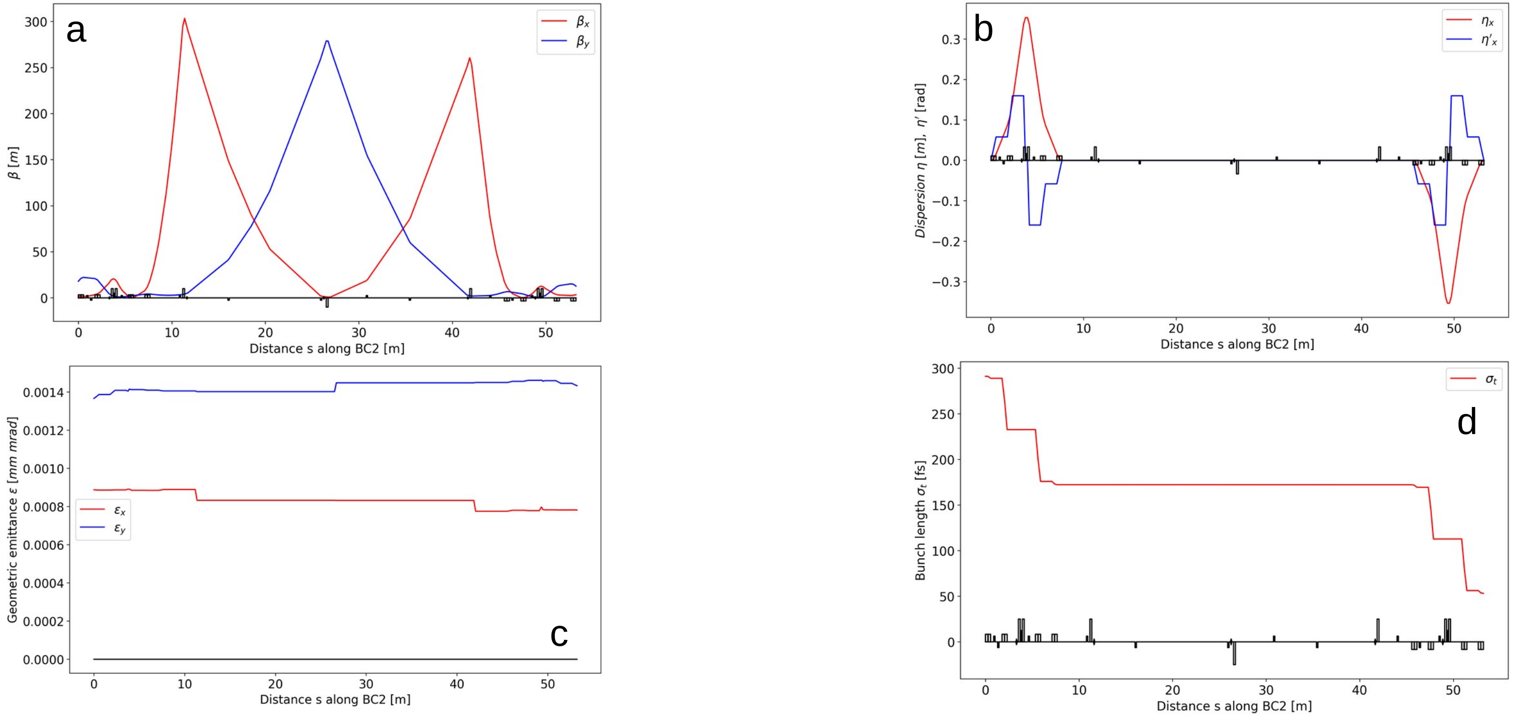


Figure 4: (a) β-function, (b) horizontal dipersion, (c) geometric emittance and (d) bunch length as a function of distance along bunch compressor.

# MAX-IV Short Pulse Facility – CSR Kicks

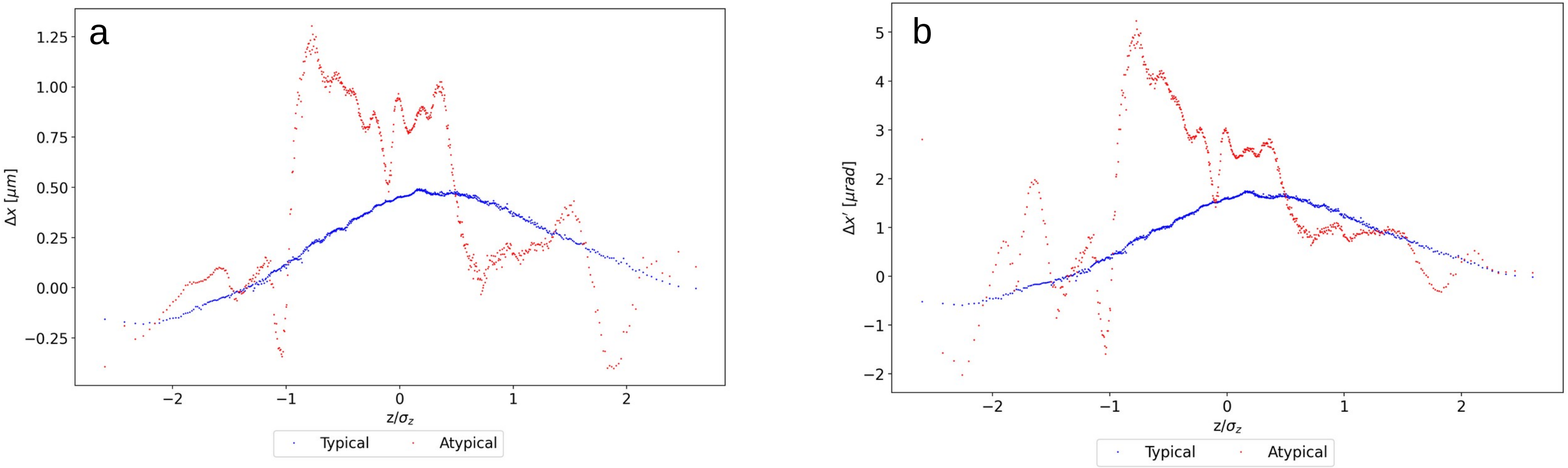


Figure 5: (a) Δx and (b) Δx’ at the end of the second bunch compressor.

Final geometric emittance:

- ELEGANT - 7.82e-10 m rad
- Typical CSR kick - 8.90e-10 m rad
- Atypical CSR kick - 8.95e-10 m rad

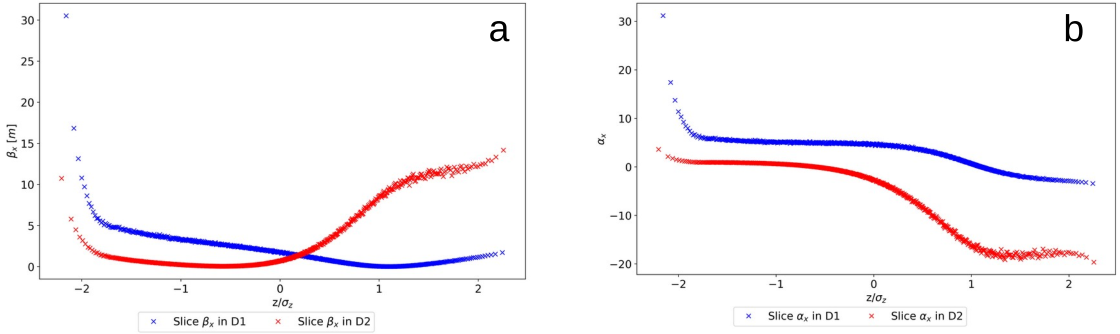


Figure 6: (a) Slice β and (b) slice α at the centre of dipole 1 and 2.

# MAX-IV Soft X-ray Laser

A soft X-ray laser (SXL) is a proposed free-electron laser project at MAX-IV laboratory, details can be found in the conceptual design report [9]. One of the operating modes uses a 10pC electron bunch to drive the FEL.

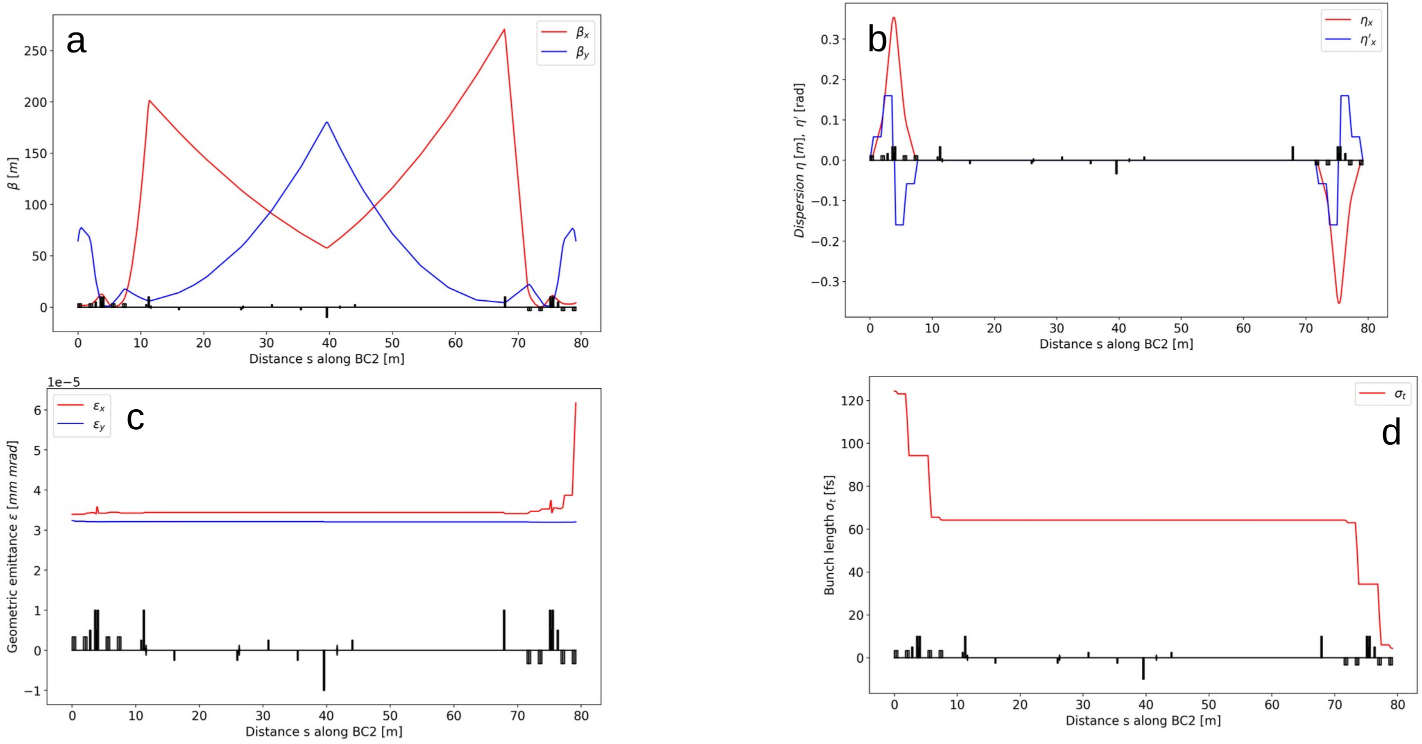


Figure 7: (a) β-function, (b) horizontal dipersion, (c) geometric emittance and (d) bunch length as a function of distance along bunch compressor.

# MAX-IV Soft X-ray Laser – CSR Kicks

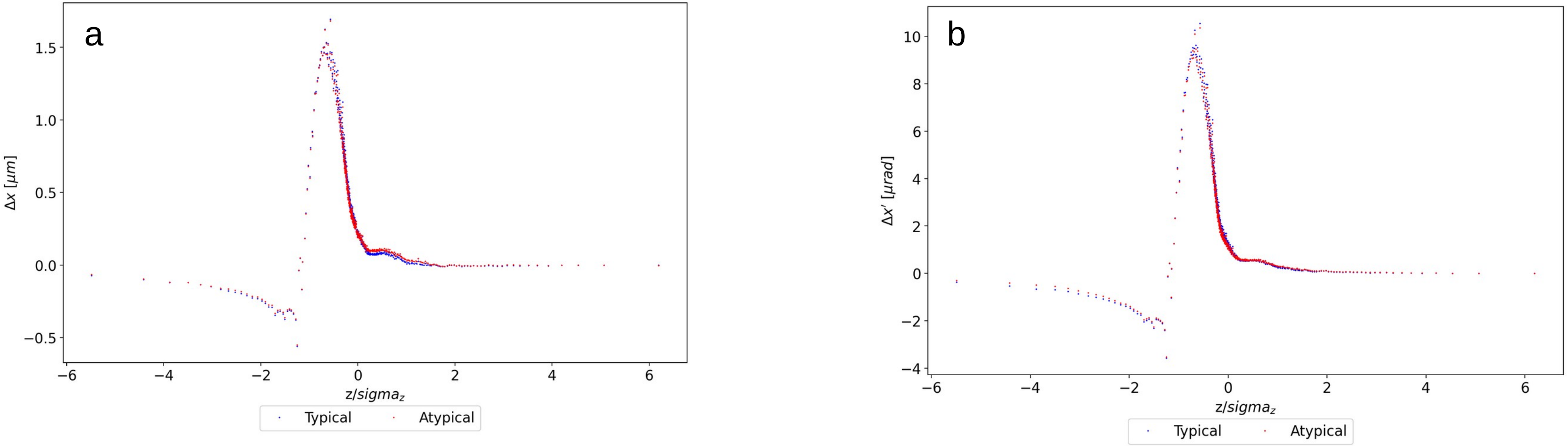


Figure 8: (a) Δx and (b) Δx' at the end of the second bunch compressor.

Final geometric emittance:

- ELEGANT - 6.17e-11 m rad
- Typical CSR kick - 5.03e-11 m rad
- Atypical CSR kick - 4.95e-11 m rad

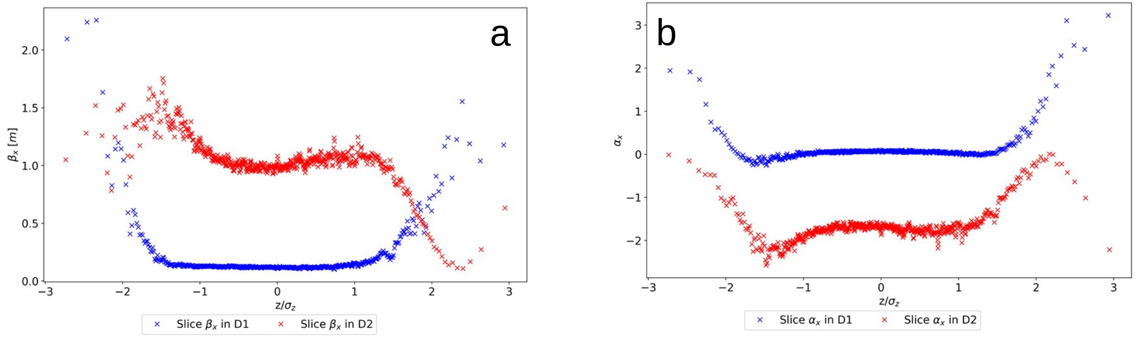


Figure 9: (a) Slice β and (b) slice α at the centre of dipole 1 and 2.

# Summary

Summary:

- CSR leads to projected emittance growth and is detrimental to the performance of FELs.
- CSR kicks calculated with non-uniform slice beam parameters ($\beta$, $\alpha$ and $\psi$) become distorted in shape and size i.e. CSR kicks on the SPF bunch.
- Distorted CSR kicks could make CSR cancellation less effecttive.

Next Steps:

- Cancellation of distorted CSR kicks.
- Experimental verification of distorted CSR kicks at MAX-IV.

# References


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# Questions

Thank you for listening!

Any questions?