Comparison study on first bunch compressor schemes by conventional and double C-chicane for MaRIE XFEL

Haoran Xu,* Bruce E. Carlsten, Leanne D. Duffy, Quinn R. Marksteiner, Petr M. Anisimov, Los Alamos National Laboratory, Los Alamos, NM 87545

We report our comparison study on the first stage electron bunch compression schemes at 750 MeV using a conventional and a double C-chicane for the X-ray free electron laser (XFEL) under development for the Matter-Radiation Interactions in Extremes (MaRIE) project at Los Alamos National Laboratory. Compared to the performance of the conventional C-chicane bunch compressor, the double C-chicane scheme exhibits the capability of utilizing the transverse momentum shift induced by the coherent synchrotron radiation (CSR) in the second C-chicane to compensate that generated in the first C-chicane, resulting in a compressed electron bunch with minimized transverse momentum along the beam. It is also found that the double C-chicane scheme can be designed to significantly better preserve the beam emittance in the course of the bunch compression. This is particularly beneficial for the MaRIE XFEL whose lasing performance critically depends on the preservation of the ultralow beam emittance.

MaRIE XFEL

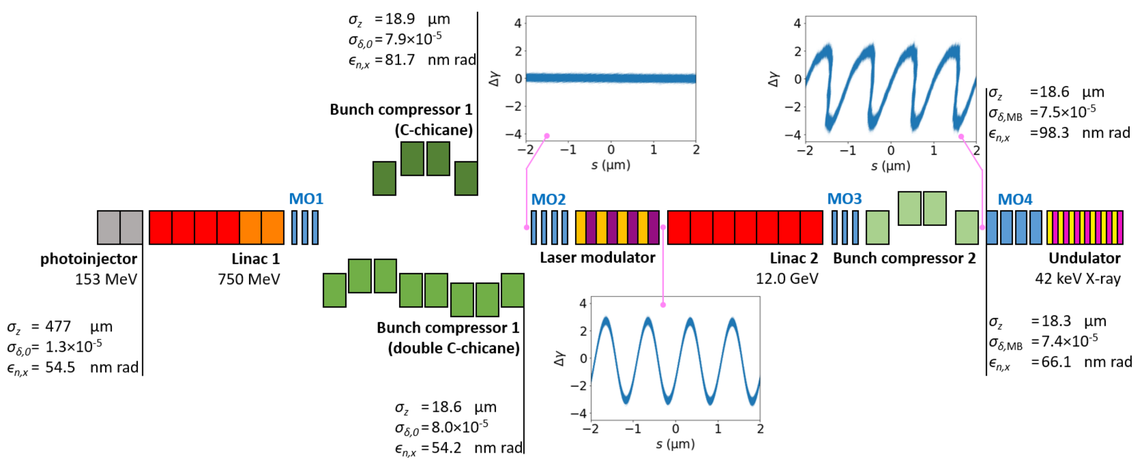
MATTER-RADIATION INTERACTION IN EXTREMES (MaRIE)

Achieving the Dynamic Mesoscale Material Science Capability (DMMSC) at Los Alamos National Laboratory.

LASER ASSISTED BUNCH COMPRESSION (LABC)

Delivering microbunched electron beam with ultra-low emittance and uncorrelated energy spread.

ACCELERATOR FOOTPRINT DESIGN WITH TWO TYPES OF THE FIRST BUNCH COMPRESSOR (BC1)



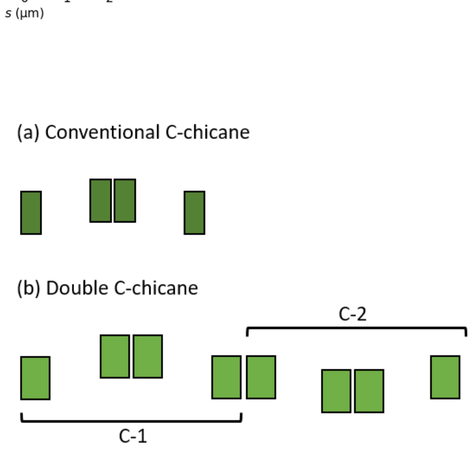
BC1 Schemes

CONVENTIONAL FOUR-DIPOLE C-CHICANE

Shorter length.
Smaller horizontal centroid shift.
Greater horizontal momentum shift.
Greater horizontal projected emittance growth.

DOUBLE C-CHICANE

Greater length.
Greater horizontal centroid shift.
Minimized horizontal momentum shift.
Compensation of horizontal projected emittance.



Optimization of BC1 Double C-chicane

OBJECTIVE OF DOUBLE C-CHICANE OPTIMIZATION STUDY

Minimizing the horizontal momentum shift along the beam caused by coherent synchrotron radiation (CSR),

- facilitating the beam acceleration downstream.
- maintaining the desired horizontal phase space.

Achieving compensation of projected horizontal emittance.

PHYSICAL PICTURE

The optimized double C-chicane has the CSR horizontal momentum shift in C-2 best cancel the CSR horizontal momentum shift in C-1, leading to minimized horizontal momentum shift profile along the beam at the exit of the double C-chicane.

DOUBLE C-CHICANE CONSTANTS

C-1 dipole strength 0.24 T
C-1 dipole length 0.60 m

DOUBLE C-CHICANE VARIABLES – FOR 3D PARAMETER SCAN

C-1 compression ratio
C-2 dipole strength
C-2 dipole length

Analytical Optimization of Double C-chicane

USING SALDIN'S ASSUMPTIONS AND CONCLUSIONS

Eq. (87) in E. L. Saldin, *et al*., "On the coherent radiation of an electron bunch moving in an arc of a circle," *Nucl. Instrum. Methods Phys. Res. A*, vol. 398, no. 2-3, 1997:

$$\frac{\mathrm{d}E_{\mathrm{CSR}}(s,\phi)}{c\mathrm{d}t} = -\frac{2e^2}{3^{1/3}R^{2/3}}\left\{\left(\frac{24}{R\phi^3}\right)^{1/3}\left[\lambda\left(s-\frac{R\phi^3}{24}\right)-\lambda\left(s-\frac{R\phi^3}{6}\right)\right]+\int_{s-R\phi^3/24}^{s}\frac{\mathrm{d}s'}{(s-s')^{1/3}}\frac{\mathrm{d}\lambda(s')}{\mathrm{d}s'}\right\}$$

Conversion of CSR energy profile to the horizontal momentum shift profile:

$$\Delta x'_{\mathrm{CSR}} = \sin\phi_m \cdot \delta_{\mathrm{CSR}}$$

The calculations survey every dipole.

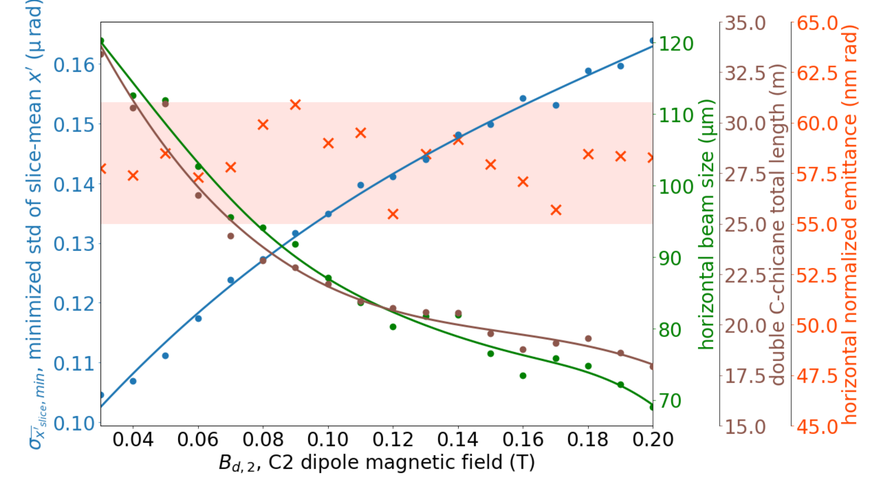
Numerical Optimization of Double C-chicane

DIRECT 3D SCAN USING ELEGANT OPTIMIZER

ELEGANT optimizer variables are the matching optics triplet quadrupole strengths and the inner drift space lengths.
ELEGANT optimizer goal set as minimizing the horizontal and vertical projected emittances.
After each ELEGANT optimizer run, the current weighted standard deviation of the slice average horizontal momentum shift is calculated, symbolized as $\sigma_{\overline{x'},slice}$.
Smaller $\sigma_{\overline{x'},slice}$ indicates suppressed horizontal momentum shift.

3D OPTIMIZATION PARAMETER SCAN SUMMARY

At each value of C-2 dipole strength, a contour plot of the $\sigma_{\overline{x'},slice}$ value as a function of the C-1 compression ratio and of the C-2 dipole length is generated.
The minimal value of $\sigma_{\overline{x'},slice}$ of the contour plot for each C-2 dipole strength is recorded.



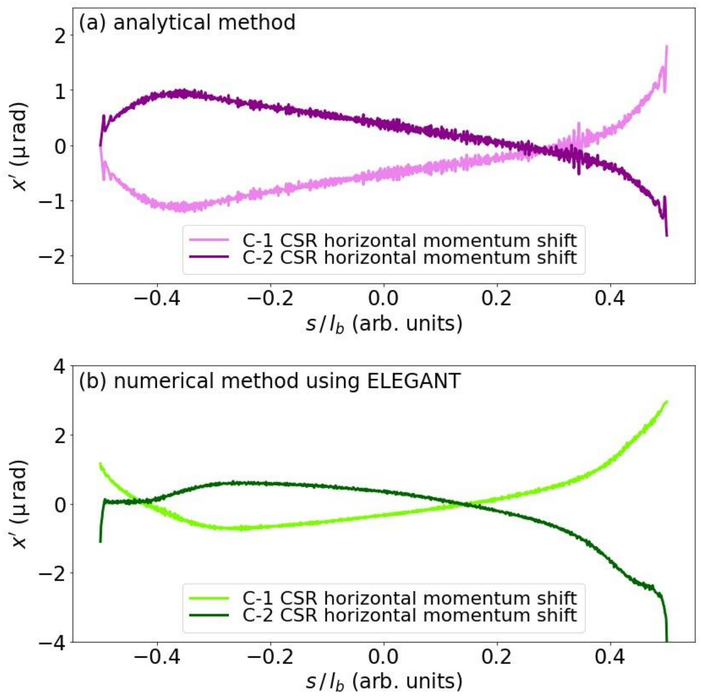
No global minimum of $\sigma_{\overline{x'},slice}$ is obtained. Other factors should be taken into consideration.

FINALIZED PARAMETERS

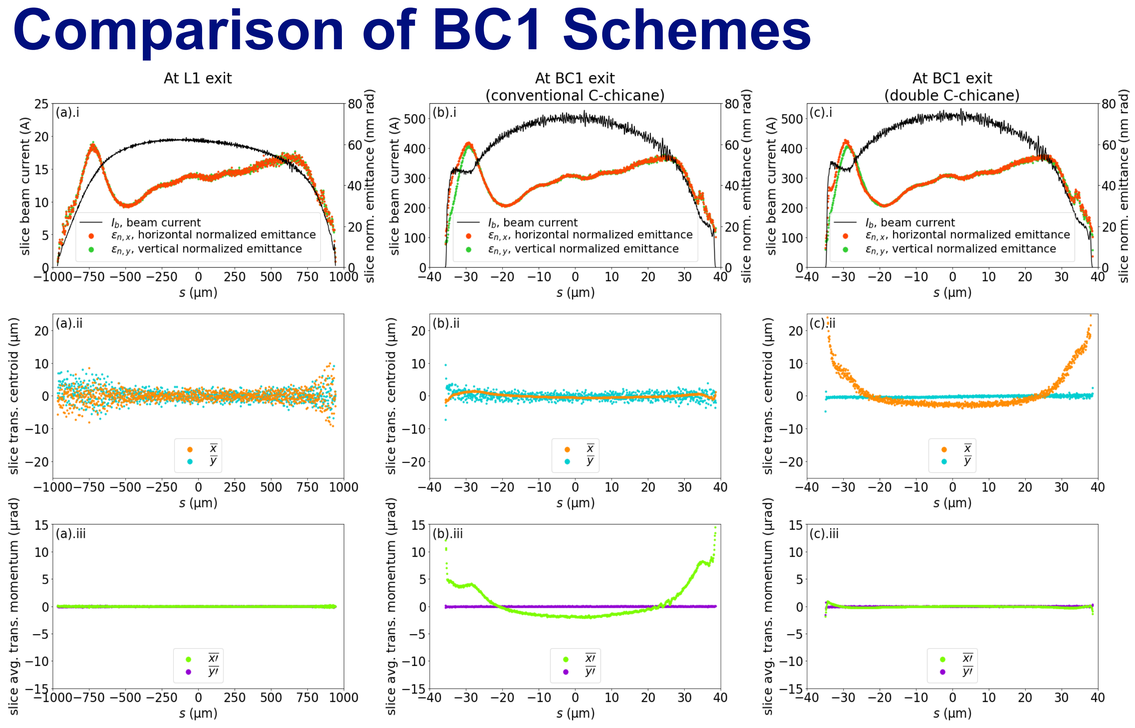
C-1 compression ratio 7.5
C-2 dipole strength 0.10 T
C-2 dipole length 0.60 m

Comparison of optimization methods

Good agreement between the results from the analytical and from the numerical methods.
Analytical method can be used as the coarse localization of the parameter space.
Numerical method using ELEGANT can be used to refine the optimization.



Comparison of BC1 Schemes



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haoranxu@lanl.gov

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