JLAB-TN-00-017
29 August 2000

Preliminary Estimate of CSR Effects in the IR Upgrade FEL Driver

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Abstract
Results of a rudimentary simulation of CSR effects in the IR Upgrade FEL driver are presented. They suggest that little performance impact will be observed at IR Upgrade parameters (energies of 100-200 MeV, 135 pC/bunch, beam normalized emittances of 10-30 mm-mrad) but that interesting effects may arise as performance is extended to more aggressive values (such as 100 MeV, 540 pC/bunch, and normalized emittances of order 5 mm-mrad).

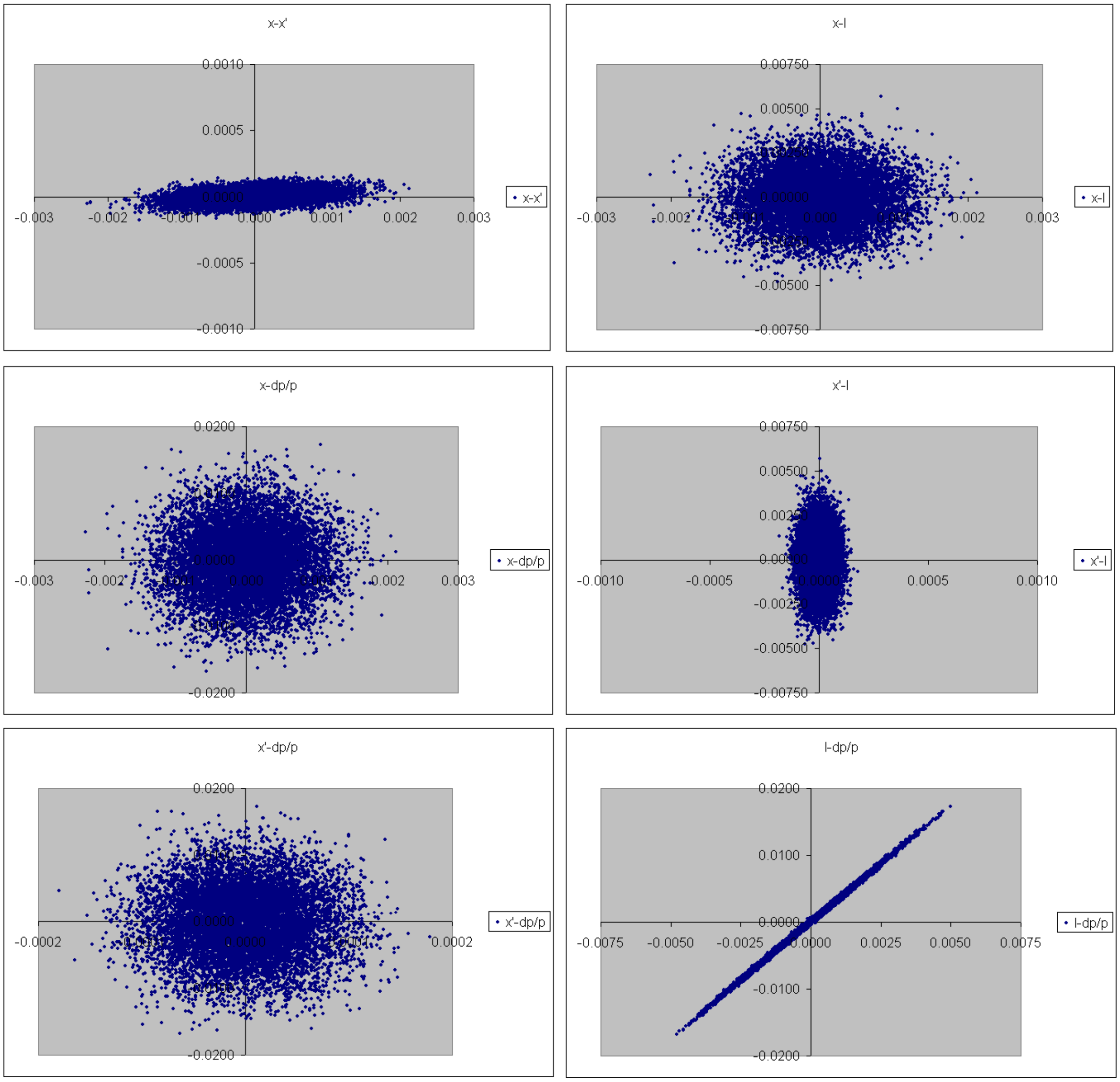
CSR Model
The simulations under consideration were preformed using a previously documented (very rudimentary) CSR model that is implemented in DIMAD [1]. The model was applied to lattice revision 1.0 [2] to simulate the effect of CSR in the linac-to-wiggler transport. A matched (at nominal transverse and longitudinal parameters) six-dimensional truncated (6σ) Gaussian bunch populated with 10000 particles was transported through the system at energies from 100 to 200 MeV (at 20 MeV increments). This was examined at each of 0, 60, 135, 270, and 540 pC per bunch for each of 5, 10, 15, 20, 25, and 30 mm-mrad normalized transverse emittances. In all cases, the initial longitudinal emittance was the same; it was selected to provide 200 fsec rms bunch length at ½% rms momentum spread at the wiggler.

Figure 1 provides various "cuts" of the initial and unperturbed (CSR off) final phase spaces at 100 MeV, 5 mm-mrad transverse emittance, and longitudinal parameters as discussed above.

Simulation Results
The results of 144 DIMAD runs at the various energies, charge states, and emittances are summarized in Figure 2, which shows the dependence of normalized horizontal emittance as a function of energy for different emittances and bunch charges.

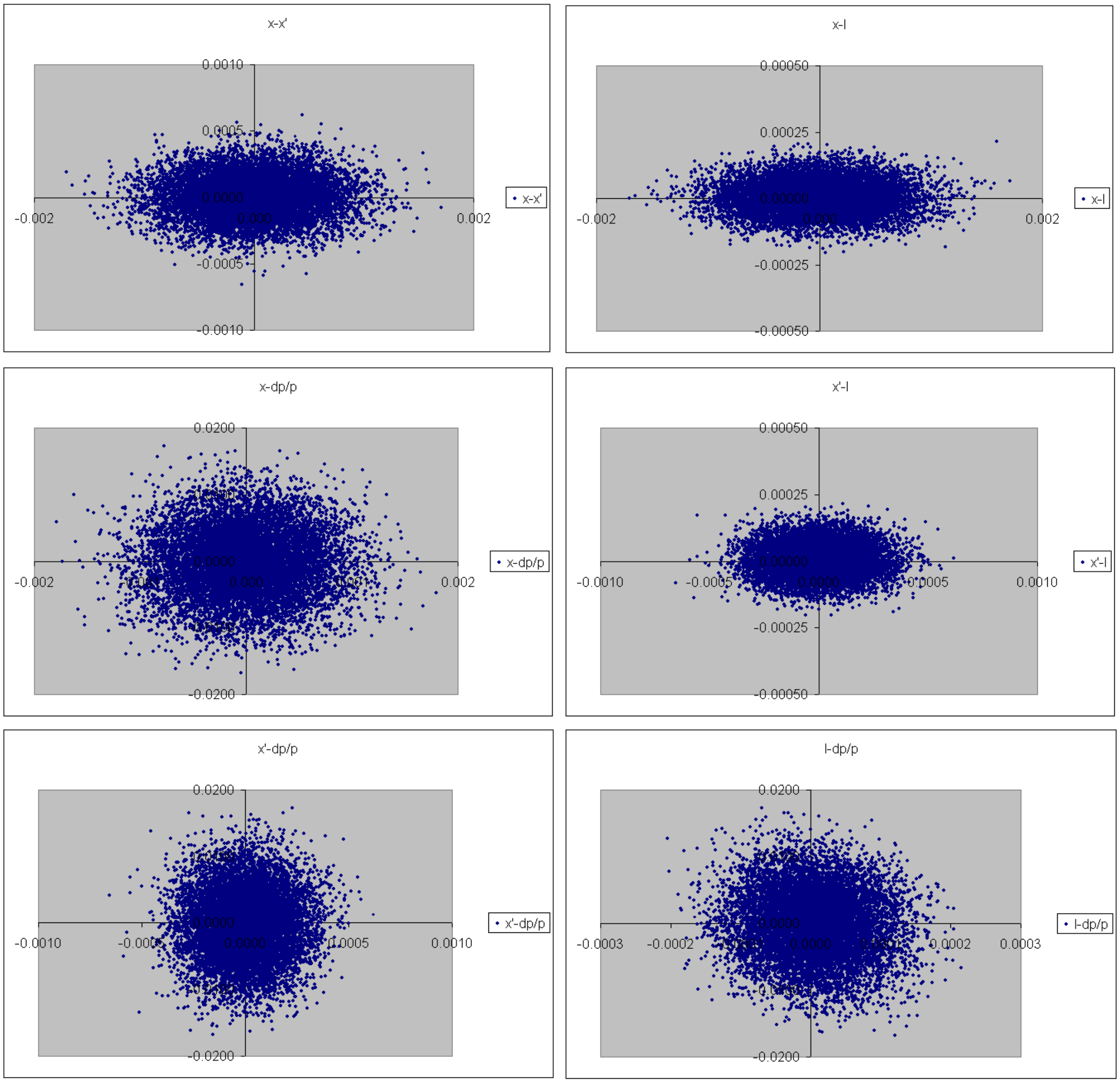
Emittance Growth – The most obvious feature of Figure 2 is the dependence of normalized emittance growth on charge/bunch. The secondary dependence of emittance on initial emittance is also apparent. This latter effect is presumably due to path length correlations with transverse position in the Bates recirculator structure; larger emittances correspond to longitudinally dispersed bunches, leading to lower CSR wake fields with commensurately smaller emittance growth. An alternate view of the dependences is given in Figure 3, showing surface plots of normalized emittance growth as a function of both energy and initial emittance at each of 60, 135, 270 and 540 pC charge/bunch.

Figure 1a: Initial phase space – 6σ Gaussian of 10000 particles – matched to linac-to-wiggler transport.



Phase Space Distortion – CSR driven emittance degradation is in fact due to phase space distortion resulting from the intra-bunch interaction mediated by CSR. This distortion is illustrated by Figure 4, which presents final phase space sections at the wiggler at 100 MeV for 5 mm-mrad injected emittances at both the nominal 135 pC Upgrade operating point and for a more aggressive 540 pC working point.

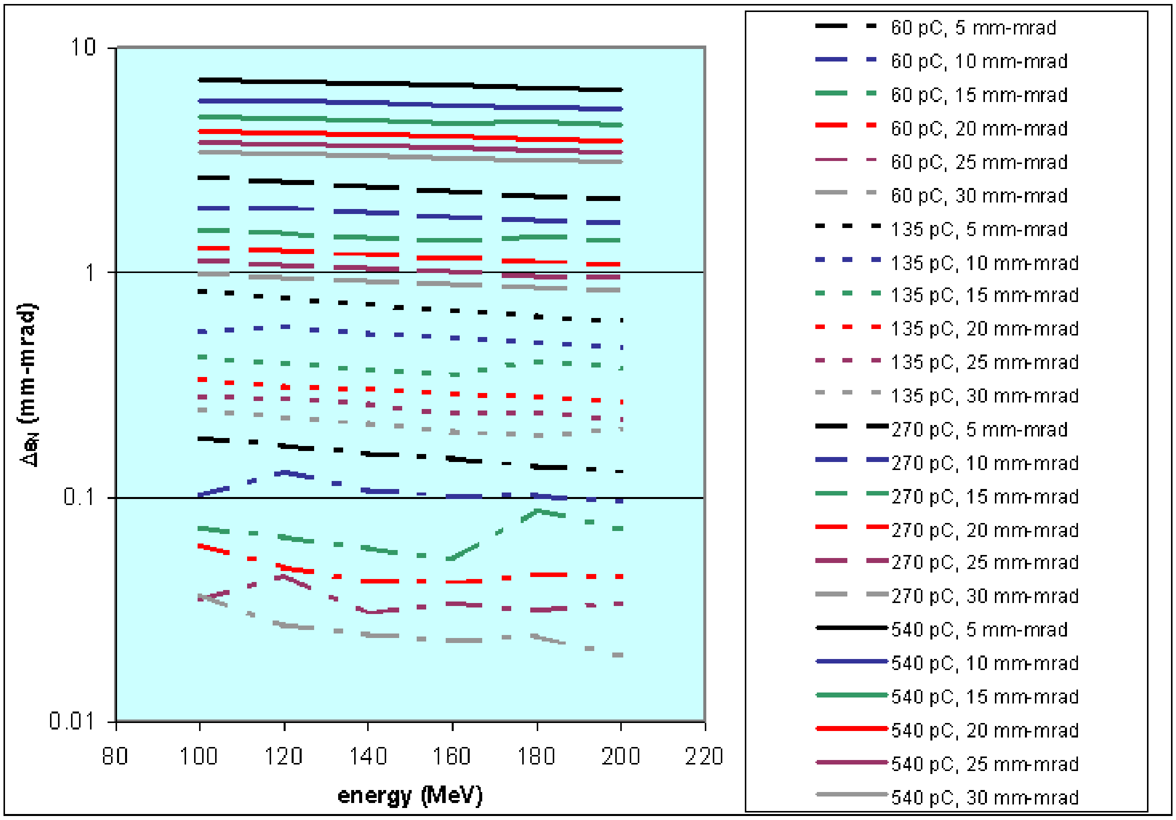
Figure 1b: Image of Figure 1a initial phase space after transport to wiggler with CSR “off”.



Observations and Conclusions

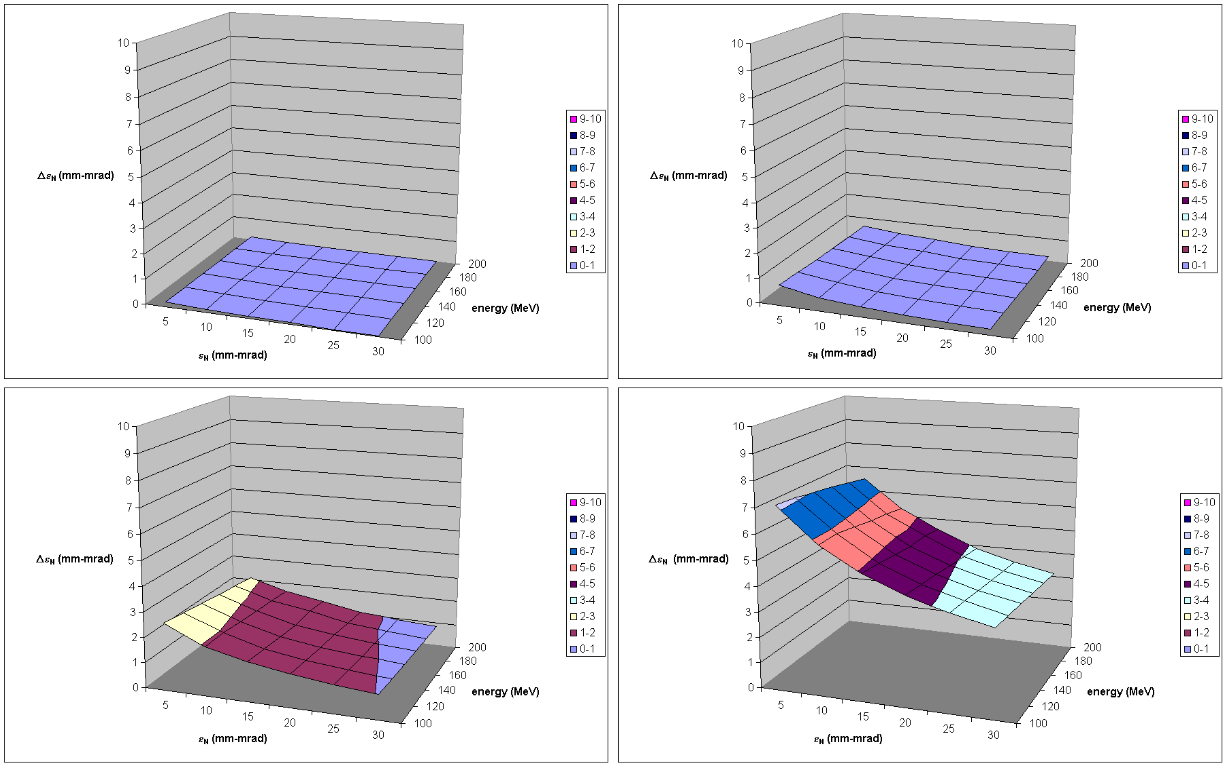
Figures 2 and 3 suggest that CSR effects will not be an issue at nominal Upgrade performance parameters (135 pC, emittances up to 30 mm-mrad). This is supported by a comparison of Figures 1b and 4a; this illustrates the minimal phase space distortion generated by CSR even at a low (5 mm-mrad) injected emittance and low (100 MeV) energy. In contrast, Figures 2, 3, and 4b indicate that CSR can well become an issue for more aggressive performance parameters, such as 270 or 540 pC/bunch at 5 mm-mrad injected emittance. The UV upgrade may well become “interesting”.

Figure 2: CSR driven degradation of normalized horizontal emittance as function of energy for various bunch charge states and emittances.



We note that the observed growth is manifested as a phase space distortion rather than a statistical redistribution of particles across a phase space volume. We should therefore apply tomographic methods to the analysis of the phase space – rather than the moment definitions used here – to more carefully define phase space parameters (such as mismatched beam envelopes) and quantify degraded emittances. We note as well that unlike the IR Demo, there is no end-to-end symmetry in the IR Upgrade. Cancellation of CSR effects [3] is thus precluded in the present design. Appropriate design of the UV bypass may however allow some cancellation. Use, for example, of a “staircase” bypass may allow some suppression of CSR effects through interference between successive steps, which nominally would be separated by a half-betatron wavelength.

Figure 3: Emittance dilution as a function of energy and injected emittance at 60, 135, 270, and 540 pC/bunch.



References

[1] D. Douglas, "Suppression and Enhancement of CSR-Driven Emittance Degradation in the IR-FEL Driver", JLAB-TN-98-012, 24 March 1998.

[2] D. Douglas, "IR FEL Upgrade Driver Accelerator Design, Revision 1.0", JLAB-TN-00-013, 8 June 2000.

[3] D. Douglas, "Suppression and Enhancement of CSR-Driven Emittance Degradation in the IR-FEL Driver", *op. cit.*

Figure 4a: Phase space at wiggler with CSR on: 100 MeV, 135 pC/bunch, 5 mm-mrad injected emittance.

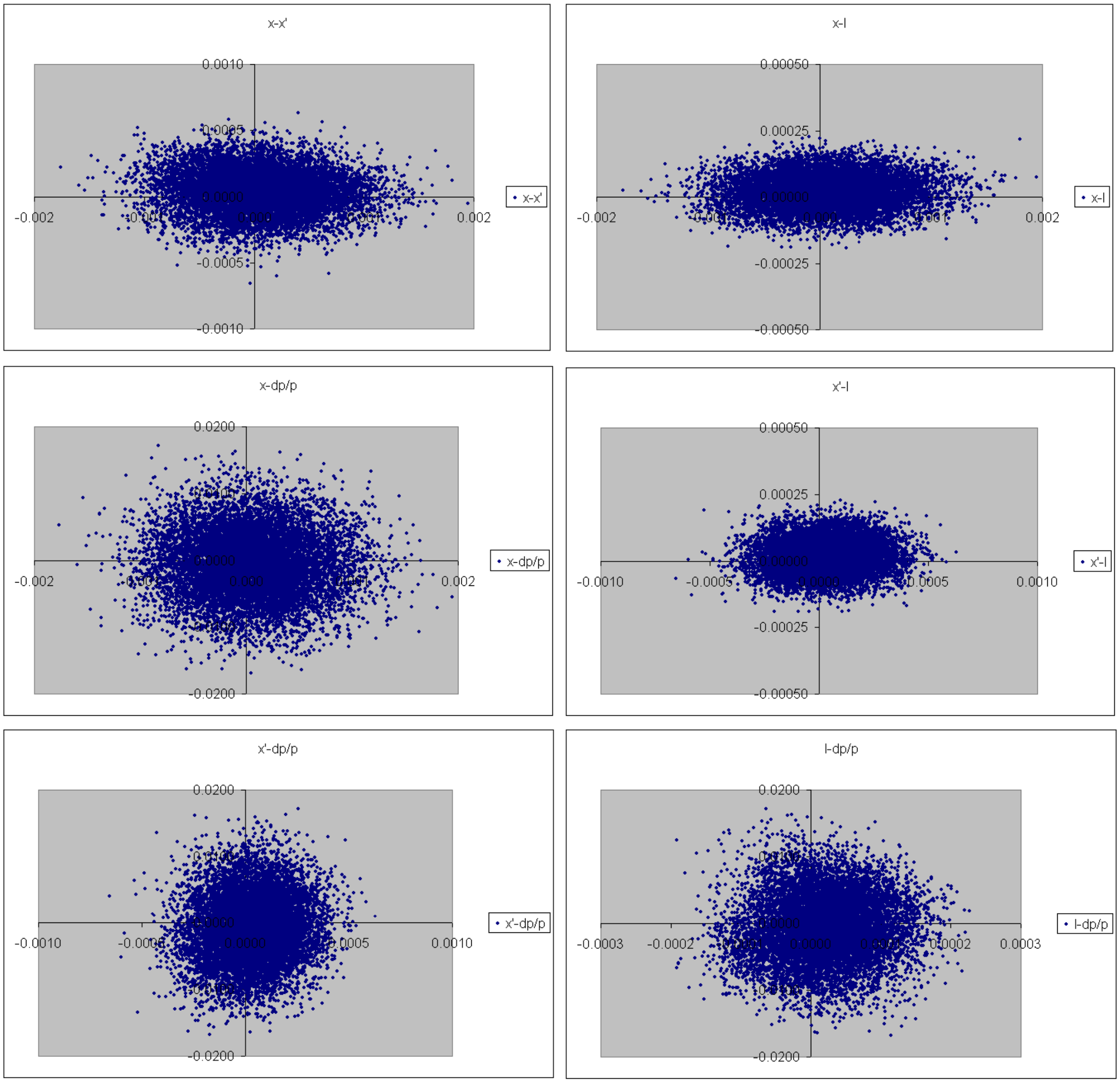


Figure 4b: Phase space at wiggler with CSR on: 100 MeV, 540 pC/bunch, 5 mm-mrad injected emittance.