Compensation of insertion device induced emittance variations in ultralow emittance storage rings

Fernando Sannibale

IPAC 18

Vancouver, BC Canada, May 2, 2018

BERKELEY LAB

U.S. DEPARTMENT OF ENERGY | Office of Science

ALS ADVANCED LIGHT SOURCE

Content

- Problem definition.
- Possible compensation schemes:
  - Use a variable gap wiggler to generate emittance.
  - Use of a “dispersion bump” inside a wiggler with gap at a fixed position.
  - Compensation by small variation of the beam momentum.
  - Using intra-beam scattering (IBS).
- Final Considerations.

The MBA Lattice Revolution

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Tens of pm emittances, orders of magnitude brightness increase, approaching fully photon coherence in the transverse plane!

Ultra-Low Emittance MBA Lattices

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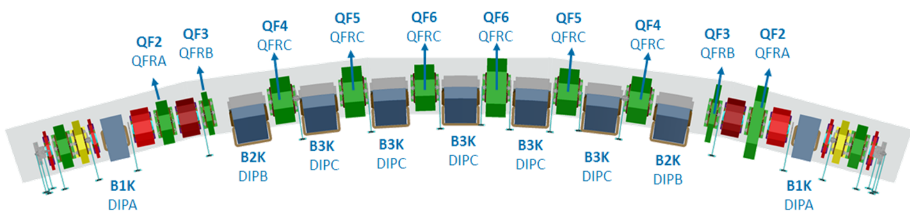
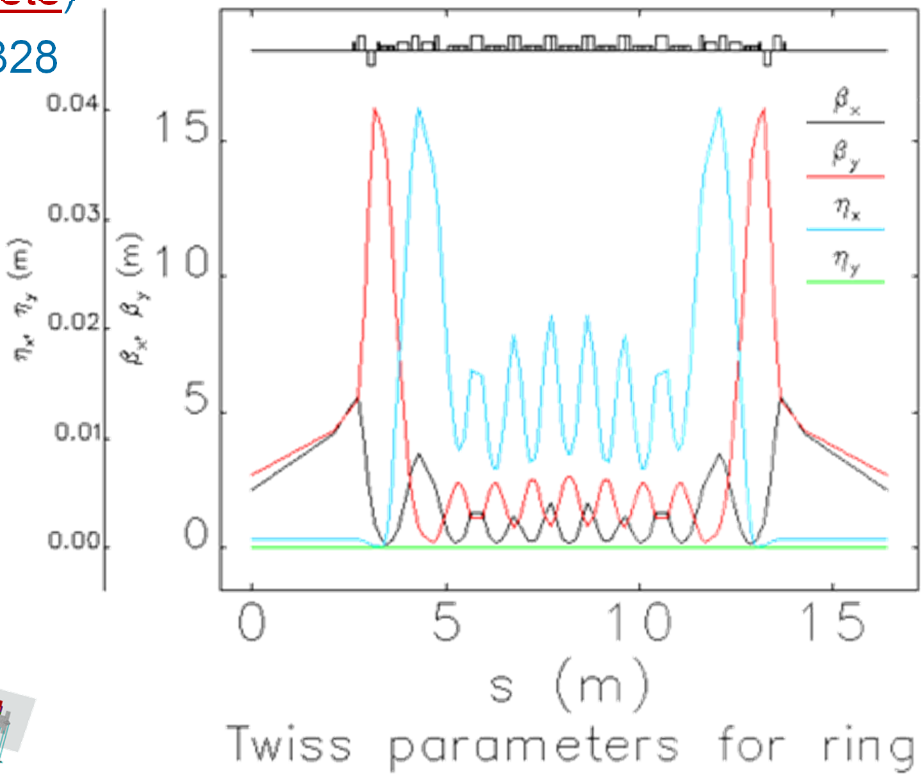
Example: ALS-U 9BA Lattice v18_127 (obsolete)

- 1.15 nC/bunch - 2 GeV - L = 196.5 m - h = 328
- Dipole: ρ = 8.6 m ; k_1= -7 m^{-2}; θ = 3.33 deg
- ε_0 = 109 pm (no IBS) – 12 super-periods
- Full coupling:
- $\varepsilon_x = \varepsilon_y$ = 81.32 pm (with IBS and harm. cav.)
- σ_z = 14.56 mm (with IBS and harm. cavities)
- δ_0 = 0.0828% - U_0 = 181.9 keV (no IDs)
- α_c= 2.68 10^{-4} - j_x=1.865





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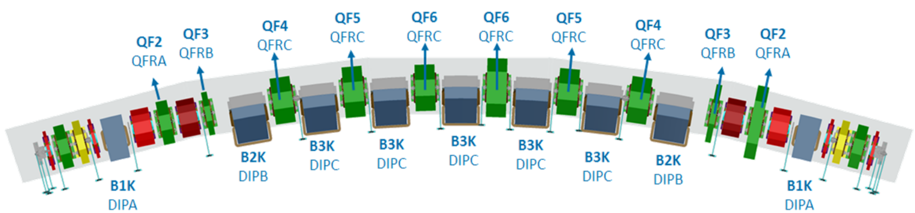

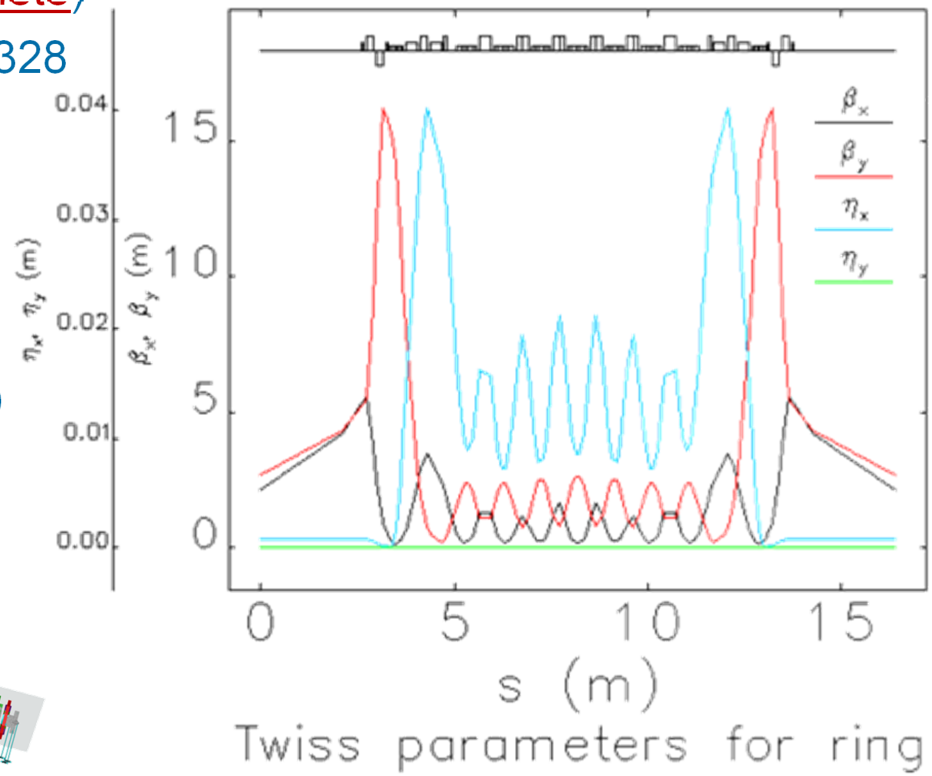

In such lattices, the typically large bending radius decreases the energy radiated in the bends making it comparable to that radiated in insertion devices (IDs).

In this situation, the IDs' contribution significantly contributes to radiation damping and hence in defining the ring natural emittance.

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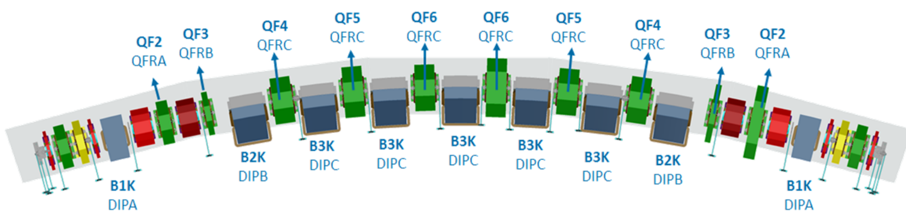

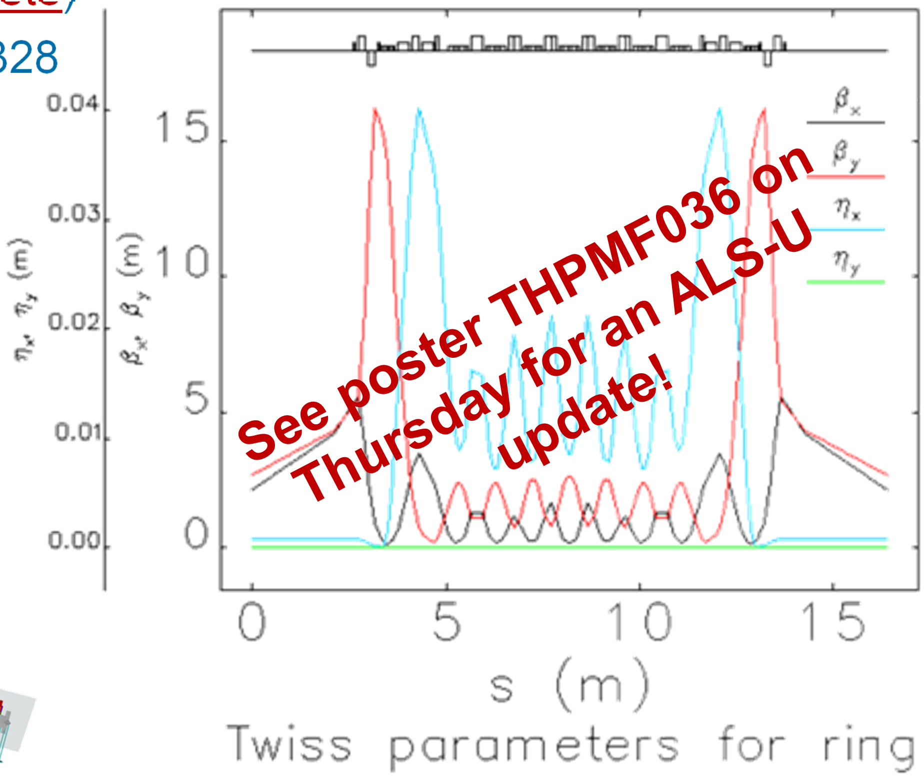

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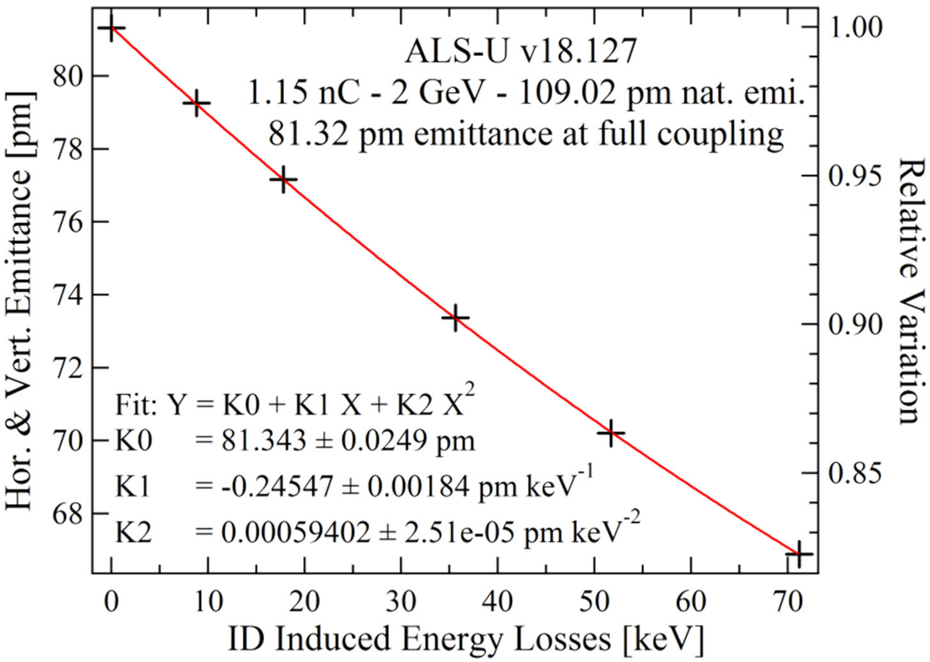

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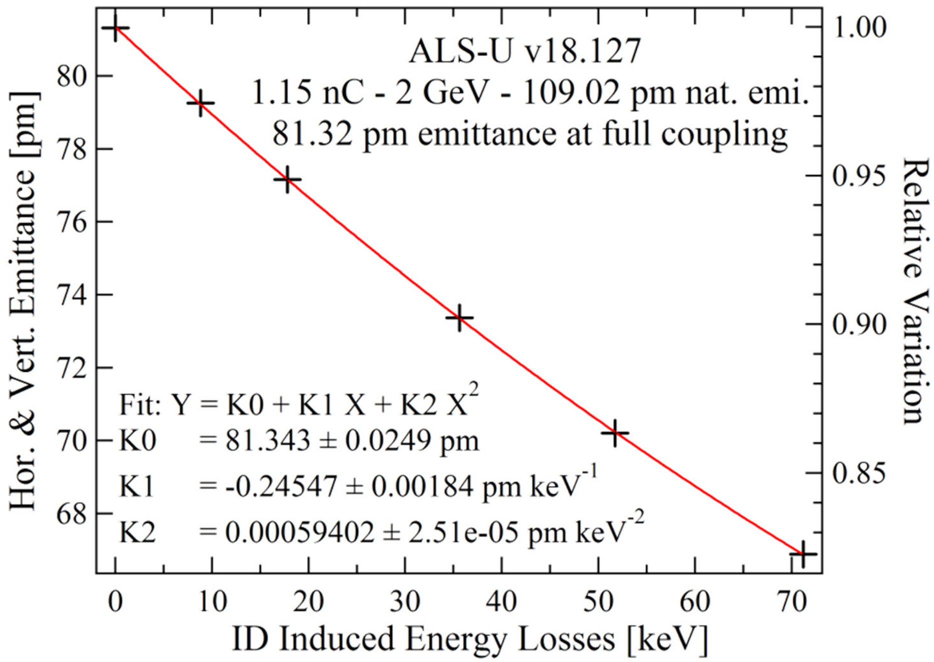

In this particular example using the ALS-U lattice v18.127, a 20 keV energy loss induced by IDs decreases the emittance by about 5 pm equivalent to ~6% of emittance reduction.

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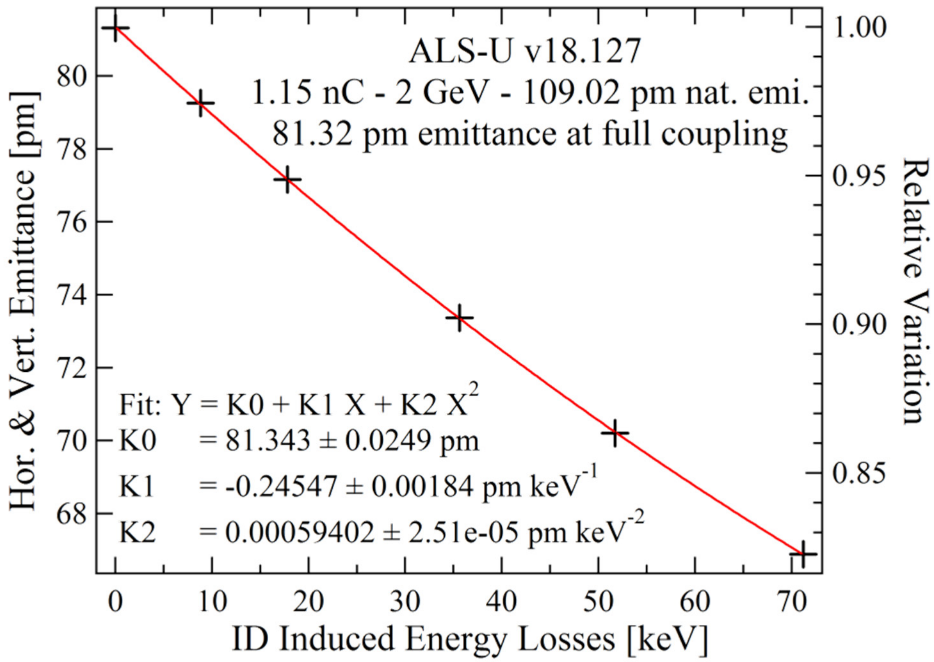

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How large are ID induced energy losses in a real ring?

Example of ID Induced Energy Losses in a Ring

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ALS Insertion Devices

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EPU50		4.0.2	No	50	0.58	0.1	0.8	0.1	37
QEPU90	MERLIN	4.0.3	No	90	0.78	0.06	1.18	0.06	20.5
U114		5.0.1	No	114	1.94	0.03	0	0	29
EPU38	COSMIC	7.0.1	No	38	0.89	0.11	0.67	0.11	44.5
EPU70	MAESTRO	7.0.2	No	70	1.18	0.07	0	0	26.5
U50		8.0.1	No	50	0.85	0.1	0	0	80
U100		9.0.1	No	100	0.98	0.05	0	0	43
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EPU50		11.0.1	No	50	0.85	0.1	0.57	0.1	36.5
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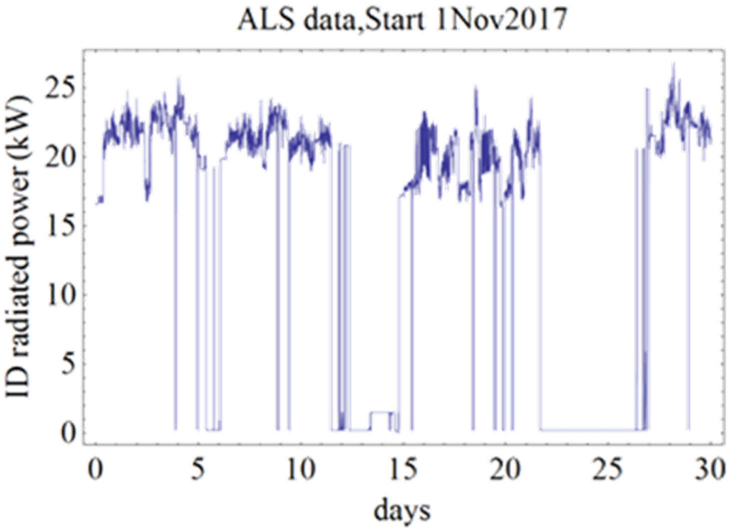

Random ID gaps variation generates random beam radiated power variations.

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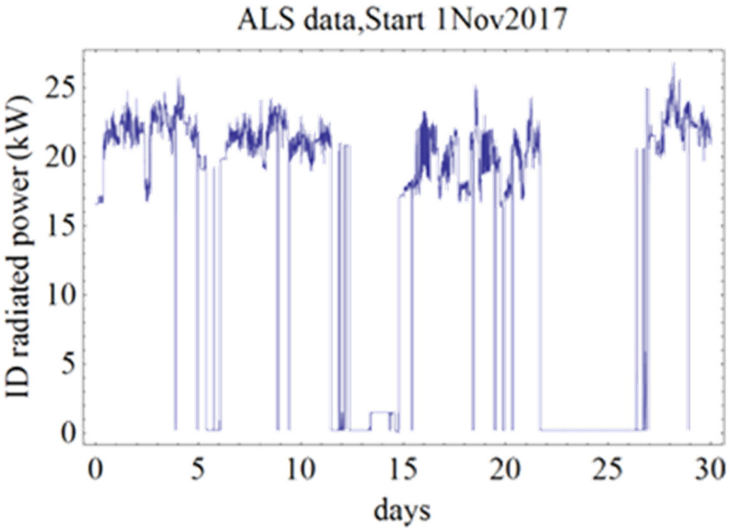

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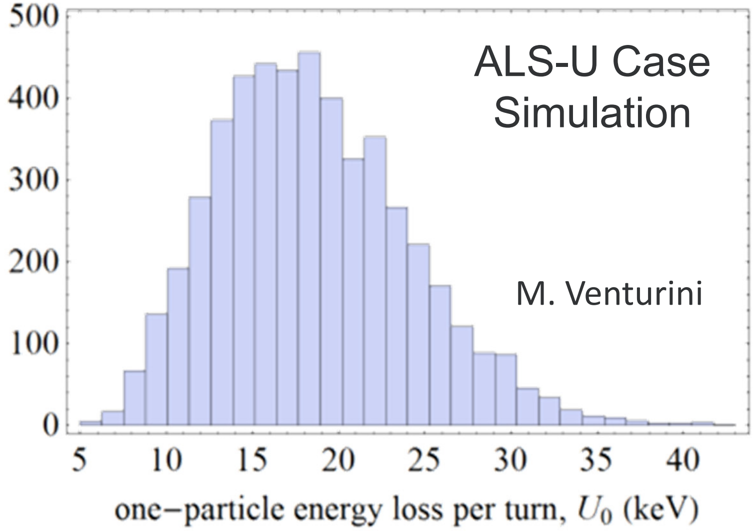

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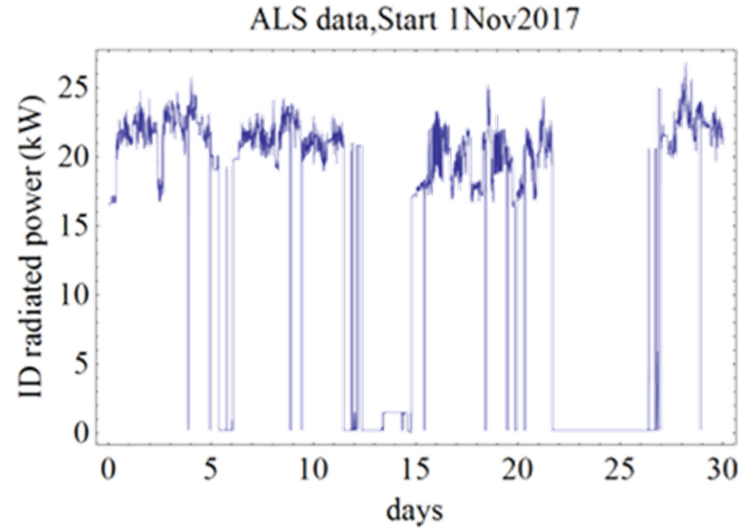

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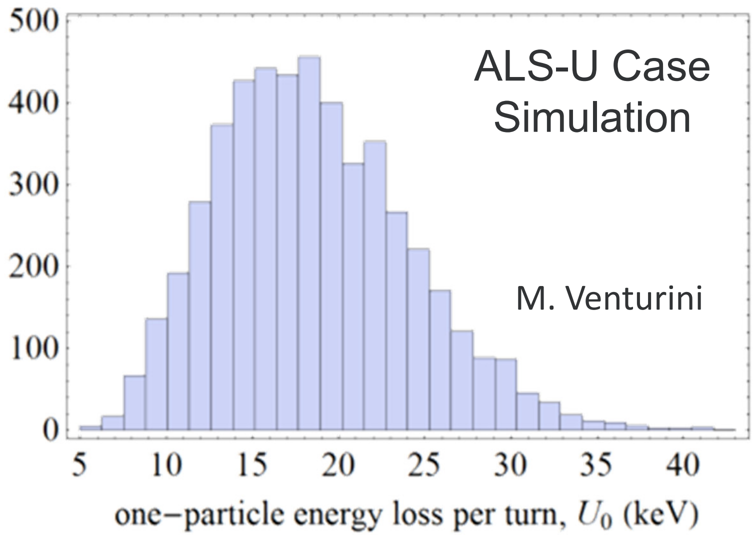

$$\langle U_0 \rangle = 18.5 \text{ keV}, \ \sigma_{U0} = 5.6 \text{ keV}$$

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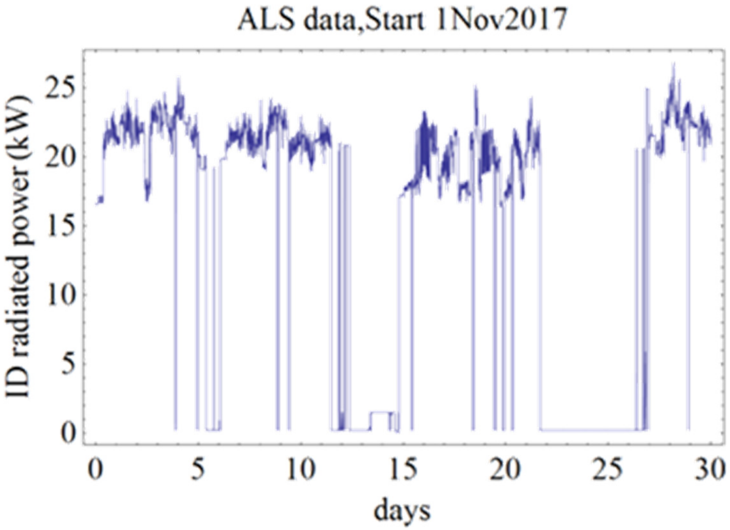

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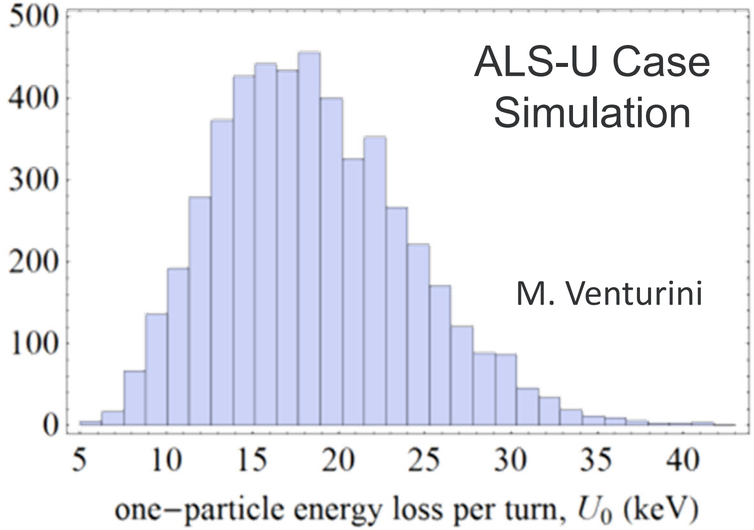

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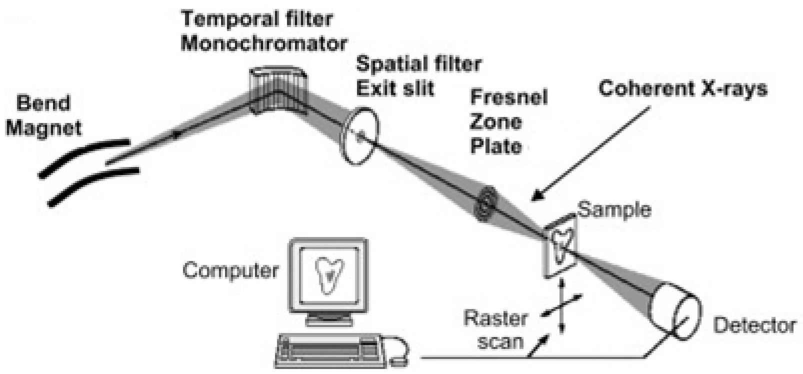
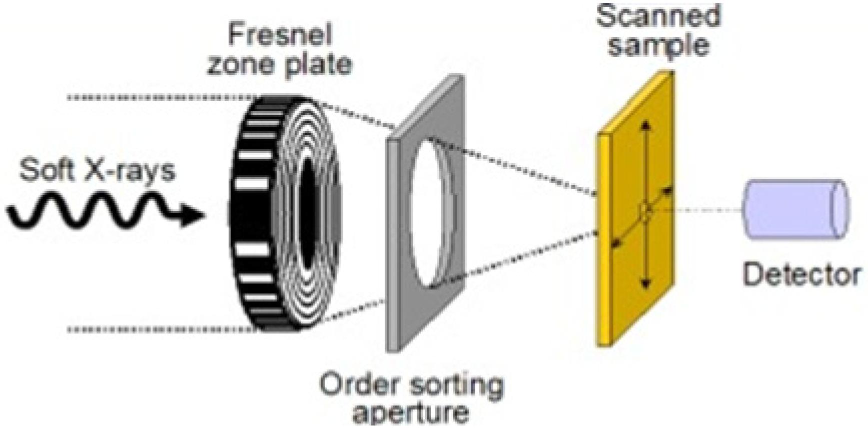
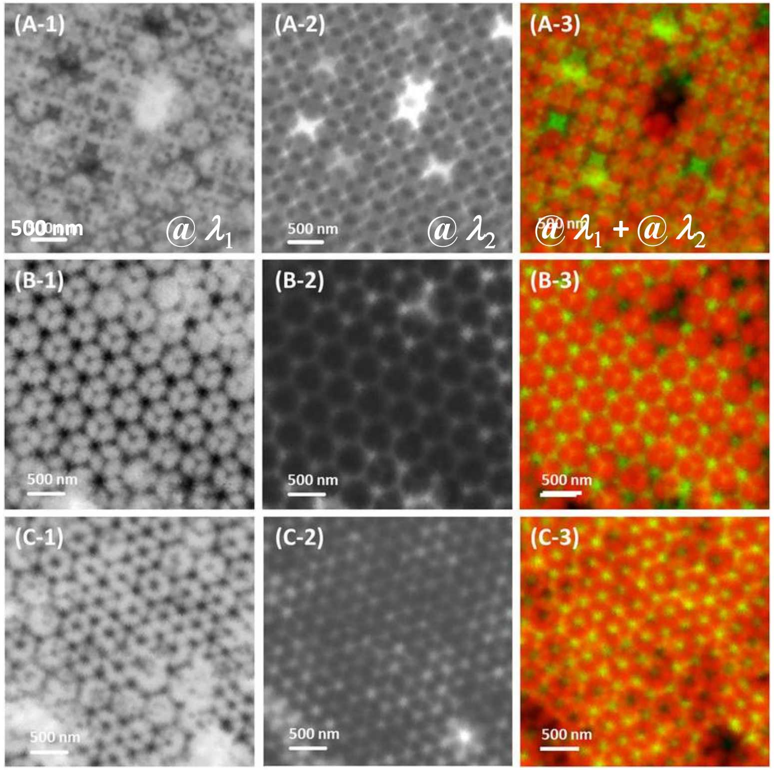
How important such an emittance variation to experiments?

STXM- Scanning Transmission X-Ray Microscopy







Colloid Crystal STXM Image. H. W. Nho, T. H. Yoon, (2017). Scientific Rep. 7. 10.1038/s41598-017-12831-4.

X-ray microscopy/spectroscopy technique very sensitive to beam size and hence to emittance variations.

Compensation by Variable Gap Wiggler

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$$U_0 = \frac{C_\gamma}{2\pi} E^4 I_2 \qquad C_\gamma = 8.846\ 10^{-5}\ m/GeV^3$$

$$I_2 = \oint \frac{ds}{\rho^2} = \frac{B^2 L_w}{2\,(B\rho)^2} \quad (wiggler)$$

$$B = 2\pi \frac{mc}{e} \frac{K_w}{\lambda_w} \quad (wiggler)$$

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ALS Wiggler example: λ_W = 0.114 m; $N_{Periods}$ = 29; L_W = 3.3 m; K_W = 20.6; B_W = 1.94 T;

U_0 = 28.3 keV @ 1.9 GeV or 31.4 keV @ 2 GeV

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$$\rightarrow \Delta I_{5W} \sim \frac{4}{3\,\pi} \frac{B_W{}^3}{(B\rho)^3} L_w \langle \gamma_x \rangle\, \eta_x{}^2, \qquad \Delta I_{2W} = 0, \qquad \Delta I_{4W} \sim 0$$

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Cons.:

- Requires extra knobs to perform the local dispersion bump.
- Bump size significant. Possible effects on beam dynamics should be evaluated.

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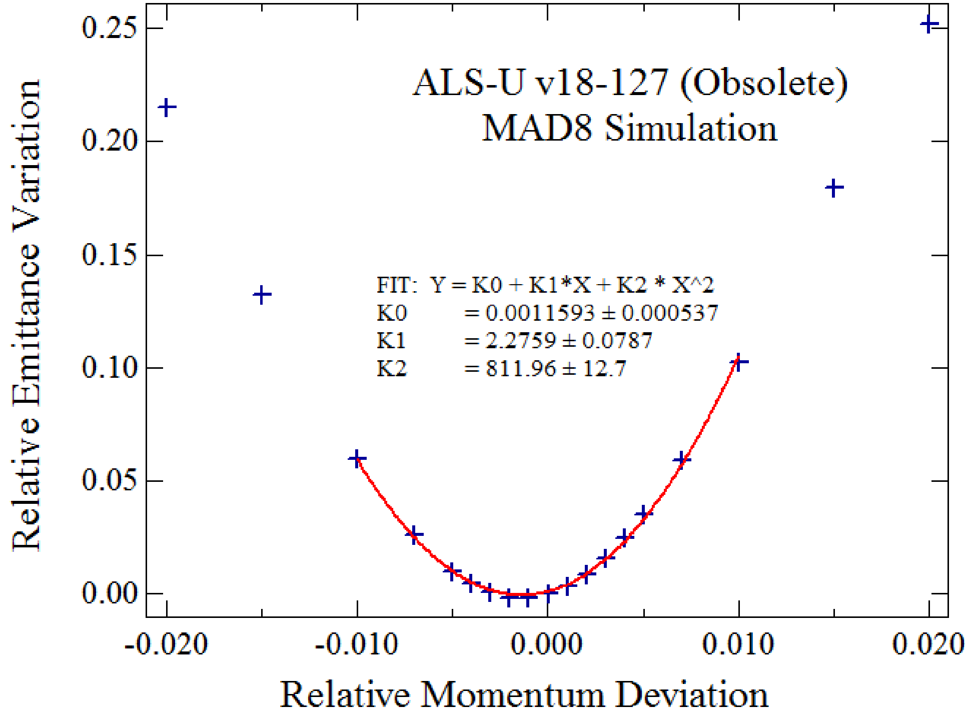

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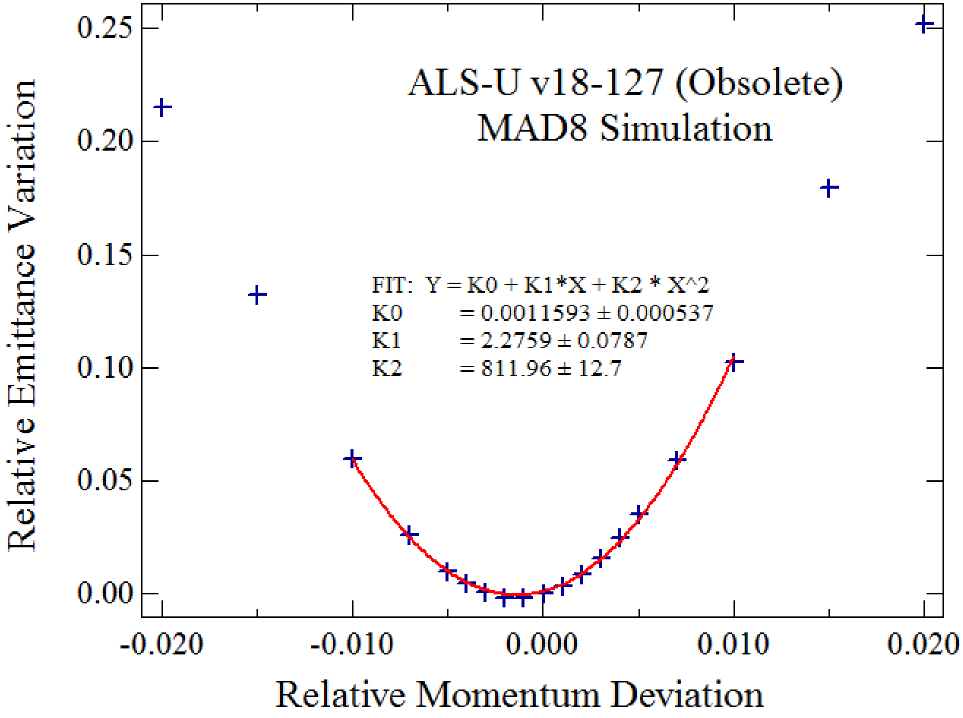

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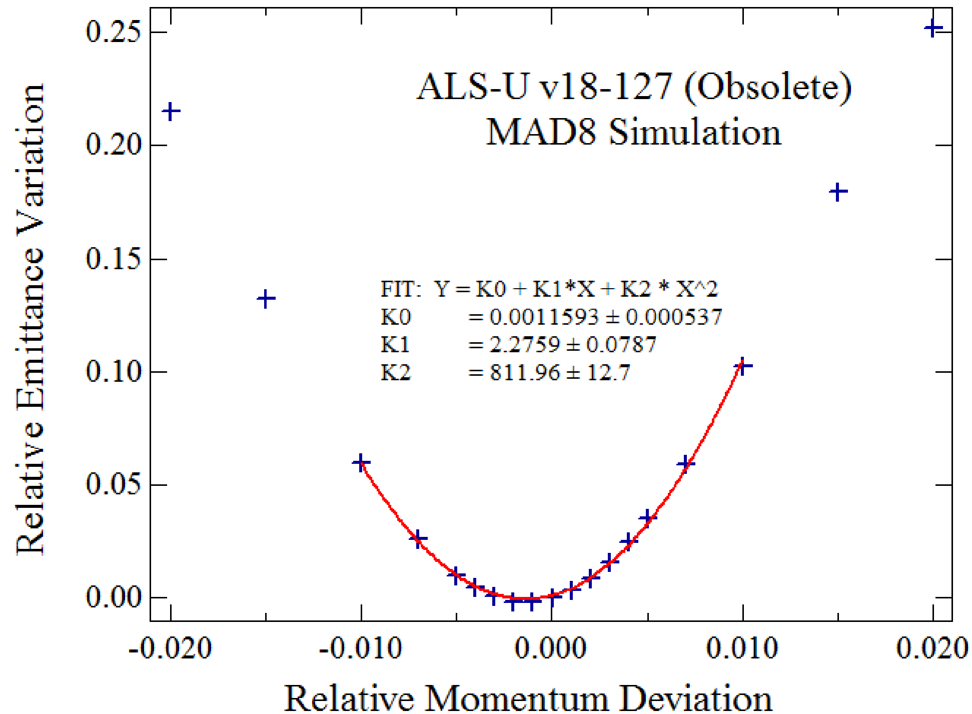

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The scheme it is not practical because it moves source points in dipoles, change the energy of the radiated photons, and can challenge the ring dynamic aperture.

Using Intra-beam Scattering (IBS) to Compensate Emittance

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$$\varepsilon'_{x0} = \frac{1}{1 - \frac{\tau_x}{T_x}} \varepsilon_{x0}$$

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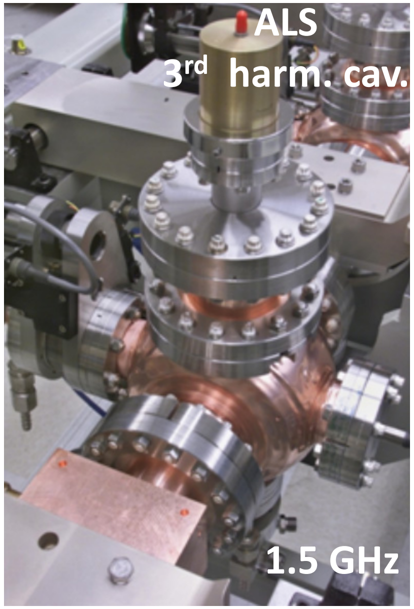
Harmonic cavities, when present, can be used for that purpose



Using Intra-beam Scattering (IBS) to Compensate Emittance

IDs losses simulated with ELEGANT by adding 12 wigglers to the ALS-U v18.127 lattice :
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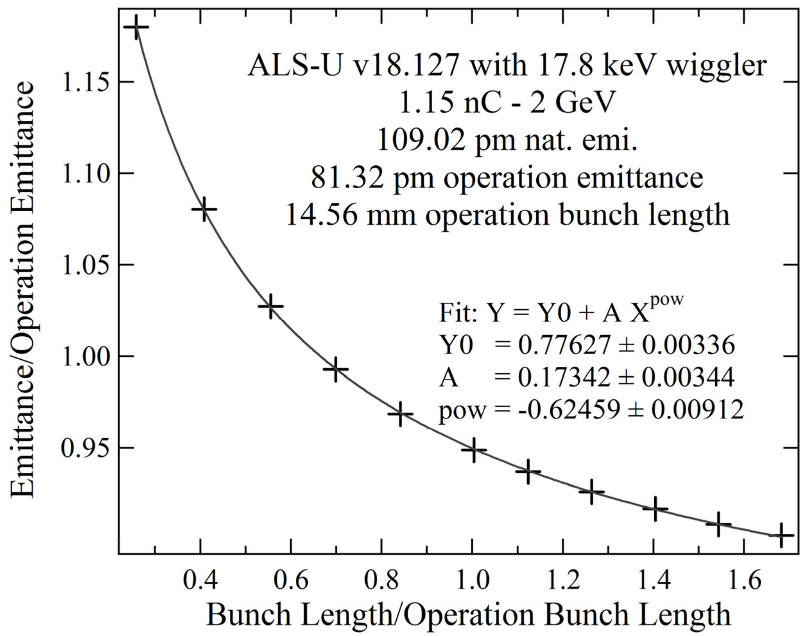

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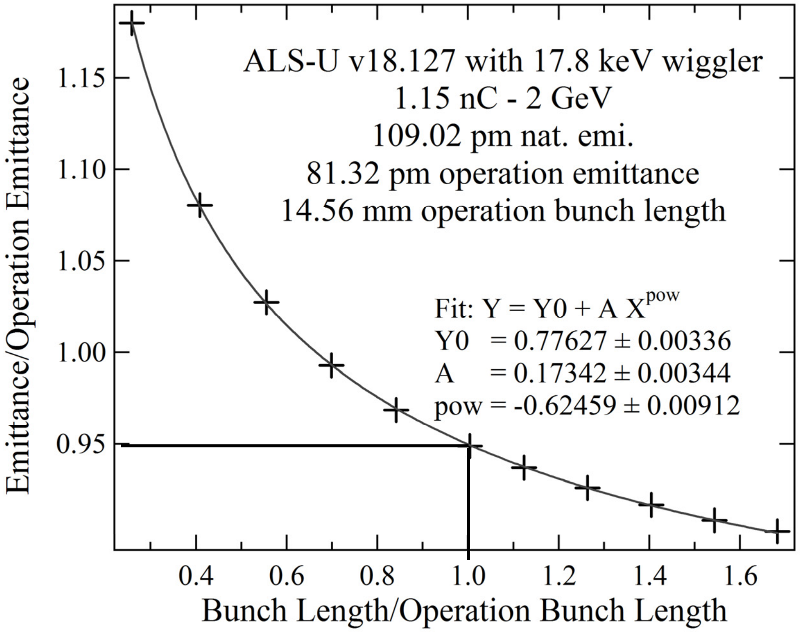

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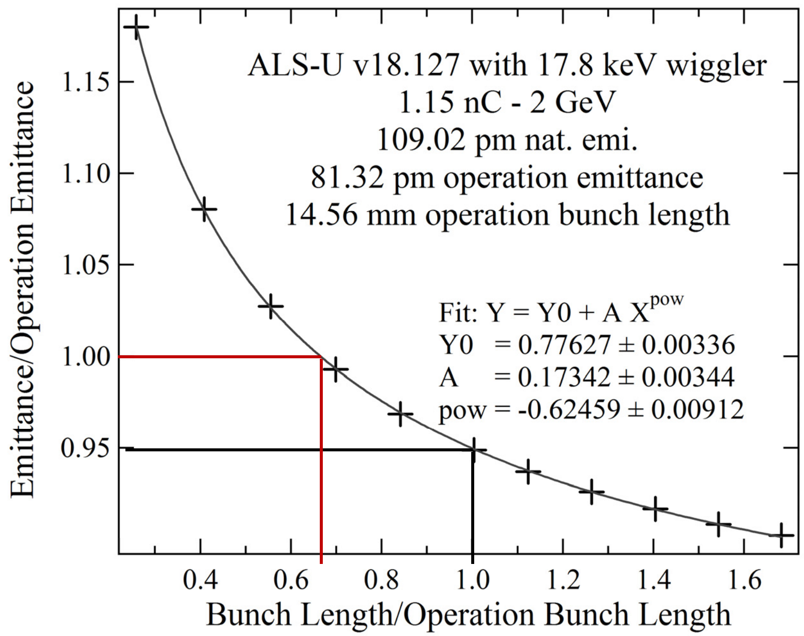

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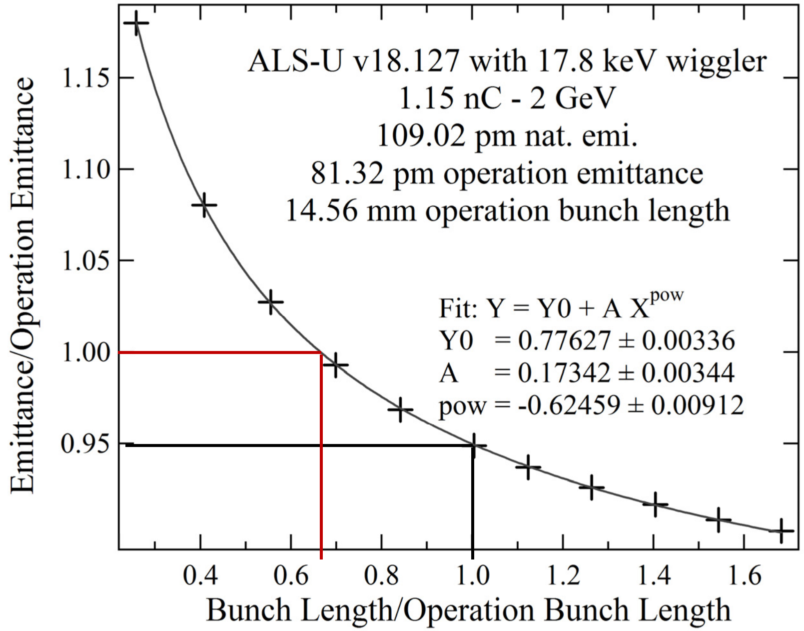

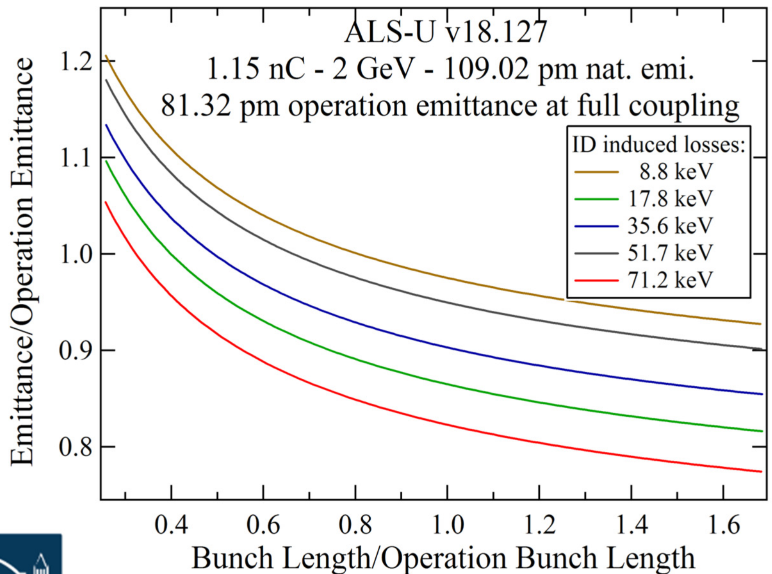

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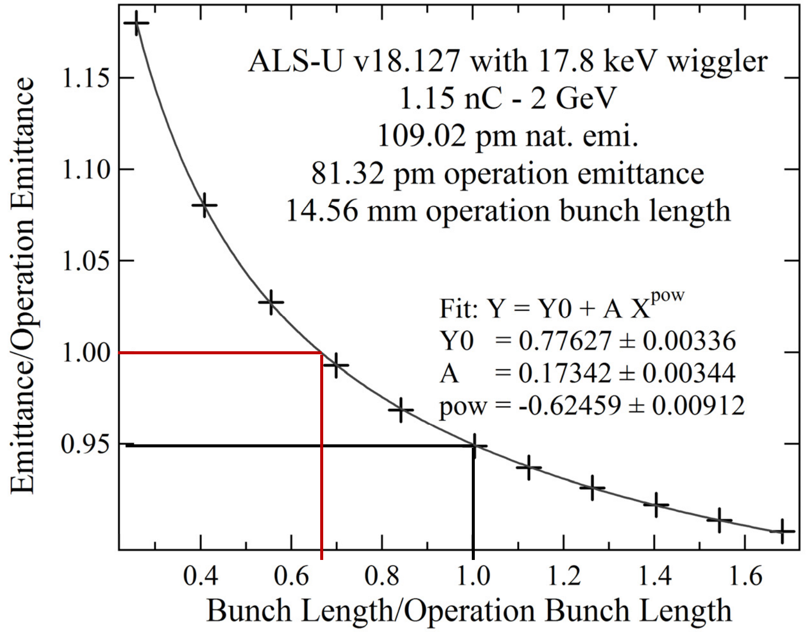

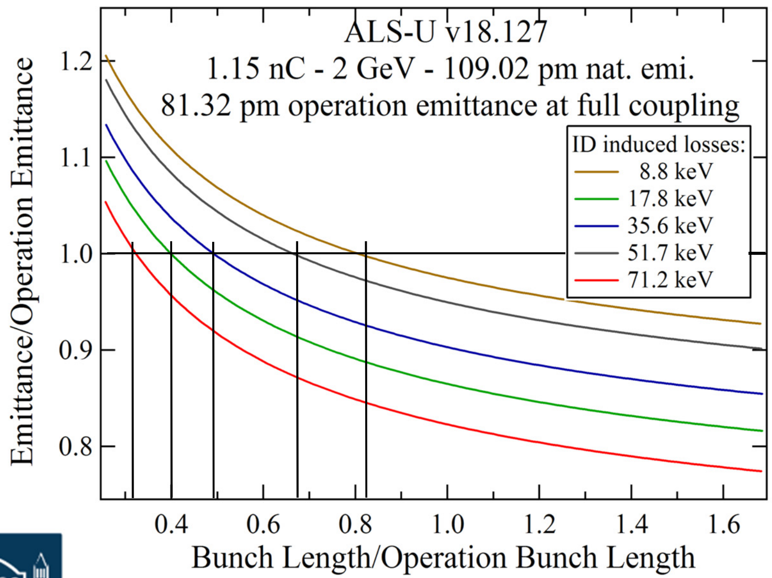

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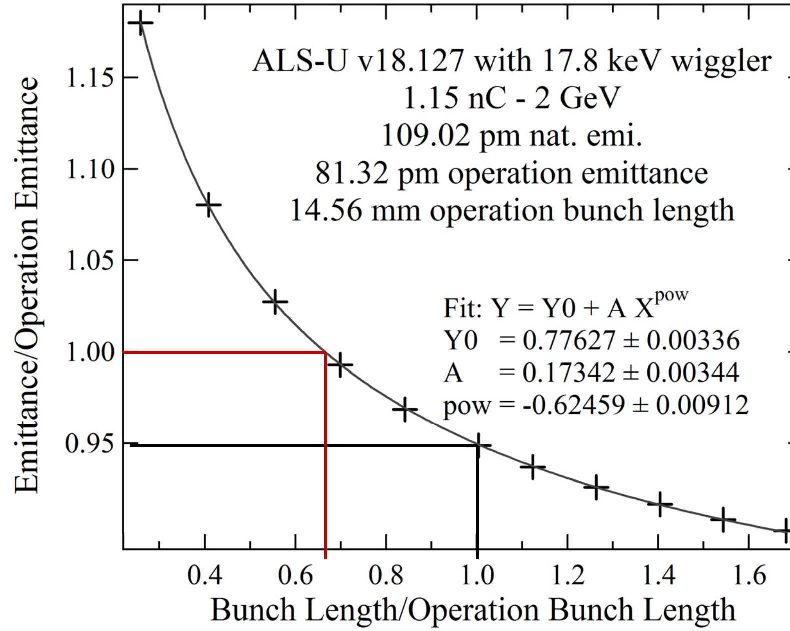

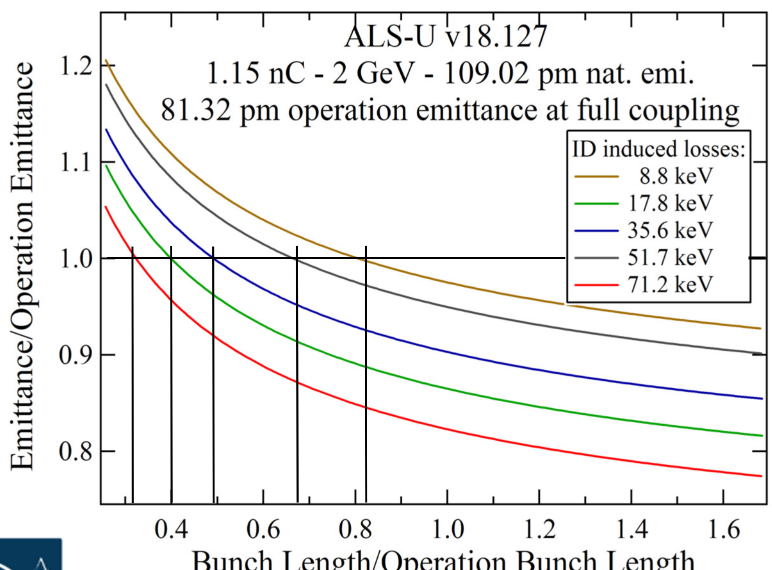

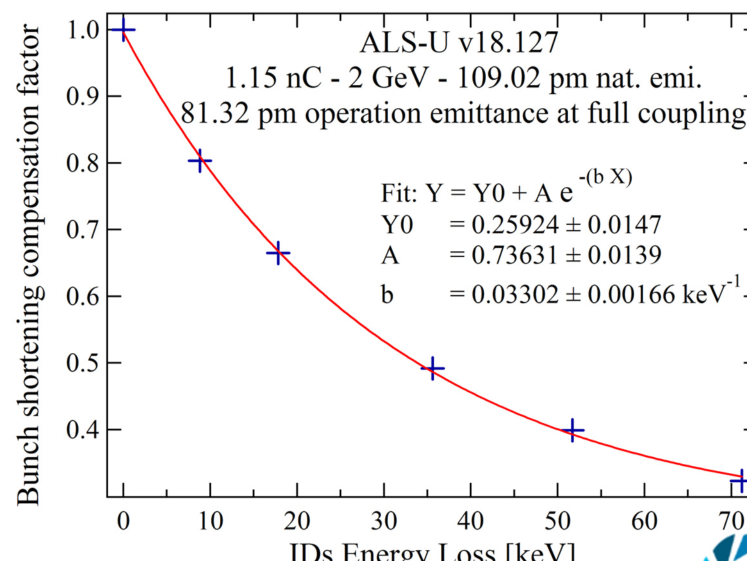

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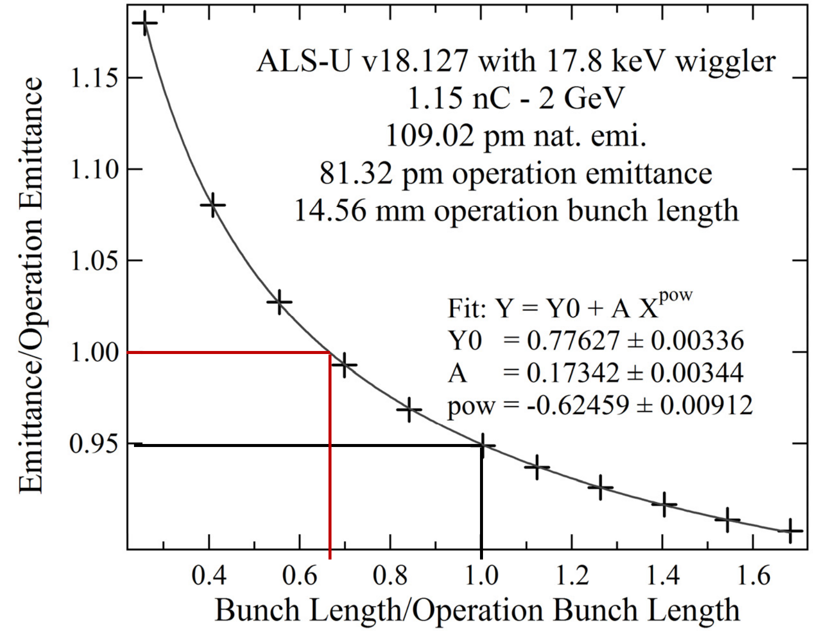
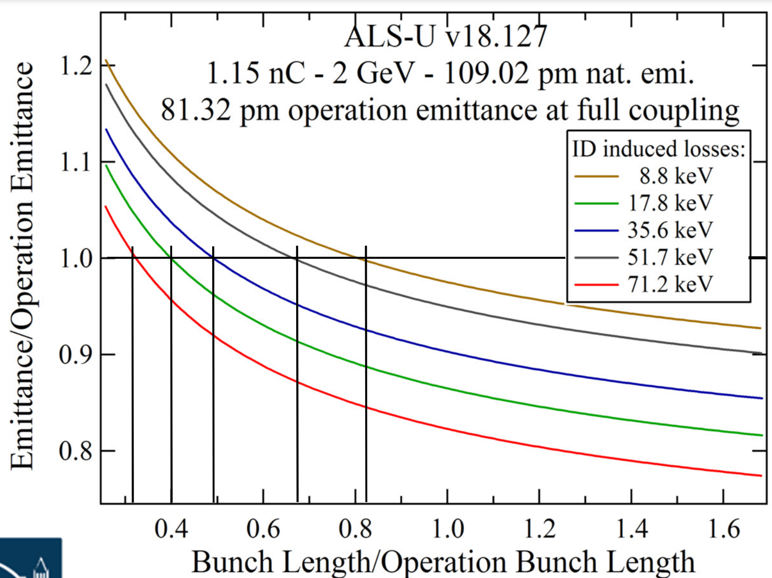
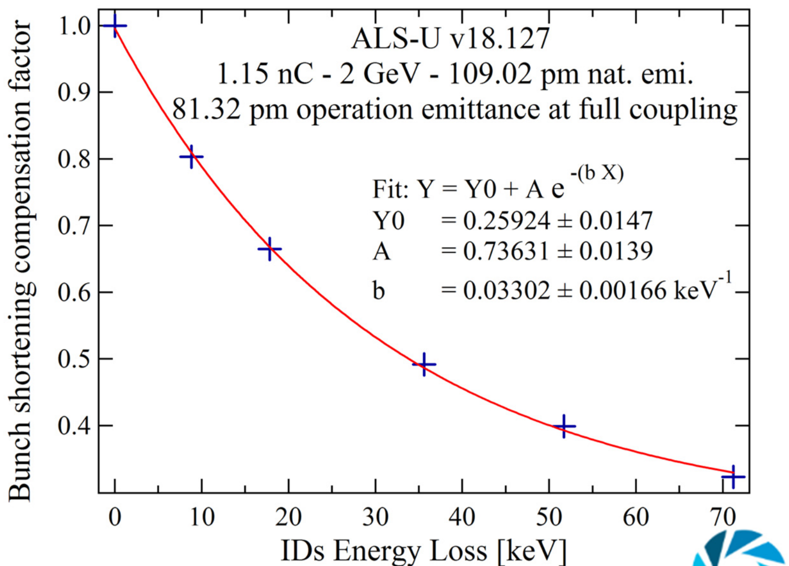
Example: Wigglers tuned for ~ 18 keV losses. Emittance decreases to ~95% of the no ID value if the bunch length is not changed.

To reestablish the emittance to the original value the bunch must be shortened to ~ 66% of the no ID value (using the harmonic cavities).

Lifetime will be also reduced by the same factor!







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