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Evaluation and Optimization of Bunch Compressor for APS LEUTL

- Addition of CSR to **elegant**.
- Comparison with results from P. Emma and V. Bharadwaj.
- Use of **elegant** to optimize FEL performance including CSR and wakefields.

Addition of CSR to elegant

- Based on the work of E. L. Saldin, *et. al.,* in NIM A 398 (1997). They give,

$$\frac{dE(s,\phi)}{cdt} = \frac{-2e^2}{3^{1/3}R^{2/3}}\left\{\left(\frac{24}{R\phi^3}\right)^{1/3}[\lambda(s-s_L)-\lambda(s-4s_L)] + \int_{(s-s_L)}^{s}\frac{1}{(s-z)^{1/3}}\lambda(z)'dz\right\}$$

  where R is bend radius, ϕ is the angle into the bend, $s = ct$, s_L is the slippage length, and $\lambda(s)$ is the linear density of the bunch.

- Algorithm:
  - The dipole is divided into a user-specified number of pieces. 60 is adequate but 100 is better.
  - For each piece, a fourth-order canonical integration is done for the dipole fields.
  - Following this, the CSR energy kicks are applied.

Computation of CSR "Wake"

- Particle arrival times at the end of the dipole piece are binned. About 3000-4000 bins are recommended for 10000 particles in a gaussian distribution.
- The density histogram is smoothed using FFT convolution with a Savitzky-Golay filter. I usually use a 420 point filter (user controlled).
- The same filter is used to take the derivative of the smoothed density.
- The $\frac{dE}{cdt}$ function is computed for each bin using simple sums for the integration.
- Each particle's energy is changed according the value of $\frac{dE}{cdt}$ for the bin it occupies.

Checks of the CSR Implementation

- I compared the tracking results to those in Saldin, *et. al.,* and to my own numerical computation of $\frac{dE}{cdt}$ for a gaussian. The agreement was very good. The parameters were 1nC, 50um bunch length, and 1.5m bending radius.
- The results converge as the number of dipole pieces is increased.
- For a compressor and linac simulation, results with 2500 particles are quite similar to those with 10000 particles. Similarly, varying between 3000 and 4000 bins doesn't change the result much.

Compressor Simulations

- Started with designs from **Bunch Compressor Options for the LEUTL Facility at the APS**, by P. Emma and V. Bharadwaj.
- Longitudinal wakefields are included, using the “knsl45.liwake” file provided by V. Bharadwaj.
- I added FEL computations using M. Xie’s formulae, so FEL performance can be optimized directly.

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- For the runs shown here, 10000 particles where used with 3072 CSR bins and 100 sections for each dipole. The 3m linac sectors are split into 10 pieces each, with wakefields applied at the end of each piece.
- A limit of 0.5% on the momentum deviation was imposed at the end of the accelerator, to eliminate a low-energy tail.

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Comparison of elegant with LITRACK

Results for Four-Magnet Chicane

Quantity	LITRACK steady-state CSR	elegant steady-state CSR	elegant transient CSR
σ_z (um)	160	143	143
σ_δ (%)	0.13	0.128	0.128
$\Delta\frac{\varepsilon}{\varepsilon_o}$ (%)	8	12	9.1

Results for Four-Magnet Wiggler

Quantity	LITRACK steady-state CSR	elegant steady-state CSR	elegant transient CSR
σ_z (um)	160	148	149
σ_δ (%)	0.13	0.127	0.127
$\Delta\frac{\varepsilon}{\varepsilon_o}$ (%)	3	7.8	3.1

Results for Six-Magnet Wiggler

Quantity	LITRACK steady-state CSR	elegant steady-state CSR	elegant transient CSR
σ_z (um)	160	145	145
σ_δ (%)	0.13	0.126	0.126
$\Delta\frac{\varepsilon}{\varepsilon_o}$ (%)	7	18	10

Results for Asymmetric Four-Magnet Chicane

Quantity	LITRACK steady-state CSR	elegant steady-state CSR	elegant transient CSR
σ_z (um)	160	152	152
σ_δ (%)	0.13	0.127	0.127
$\Delta\frac{\varepsilon}{\varepsilon_o}$ (%)	4	1.0	0.15

SASE FEL Optimization

- Performed runs for 4-magnet chicane.
- Fixed parameters:
  - K = 3.1
  - $\lambda_u = 3.3cm$
  - $\beta = 1m$
- **elegant** varies:
  - Pre-compressor linac phase.
  - Post-compressor linac phase.
  - Position of scrapers at high-dispersion point.
- Attempt to minimize L_{sat} and λ while keeping tranmission high.