# USPAS – *Simulation of Beam and Plasma Systems*

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## Lecture: Coherent Synchrotron Radiation

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http://uspas.fnal.gov/programs/2018/odu/courses/beam-plasma-systems.shtml

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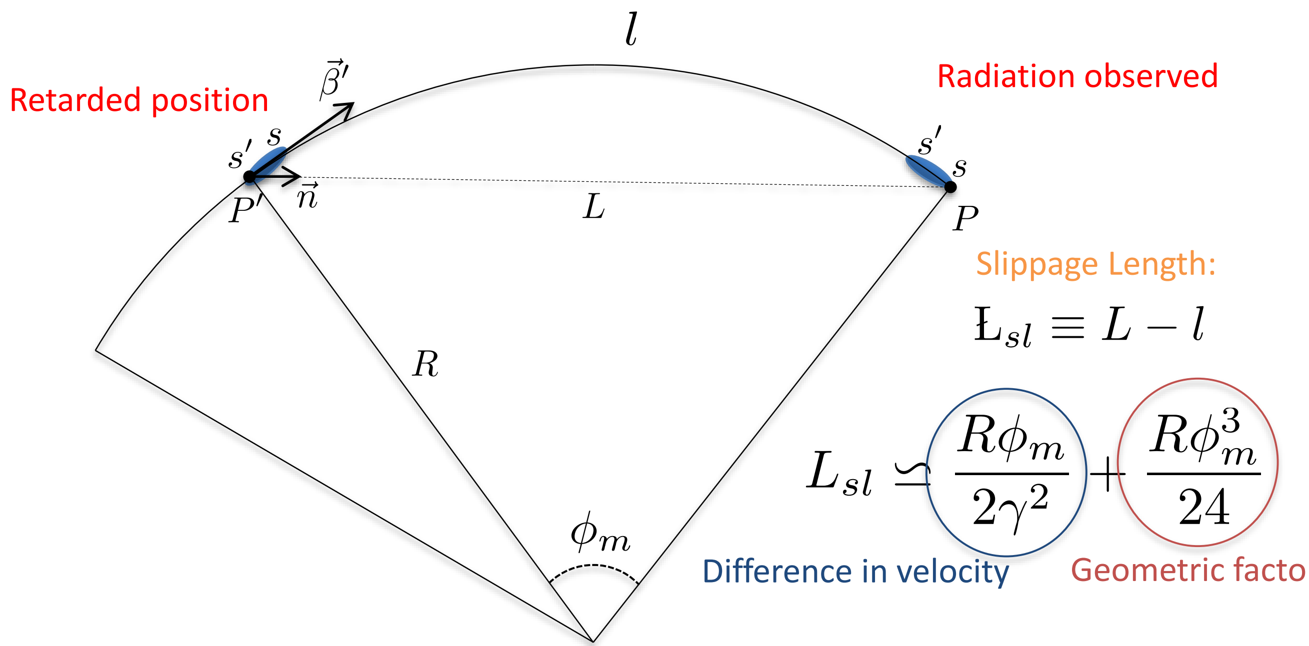
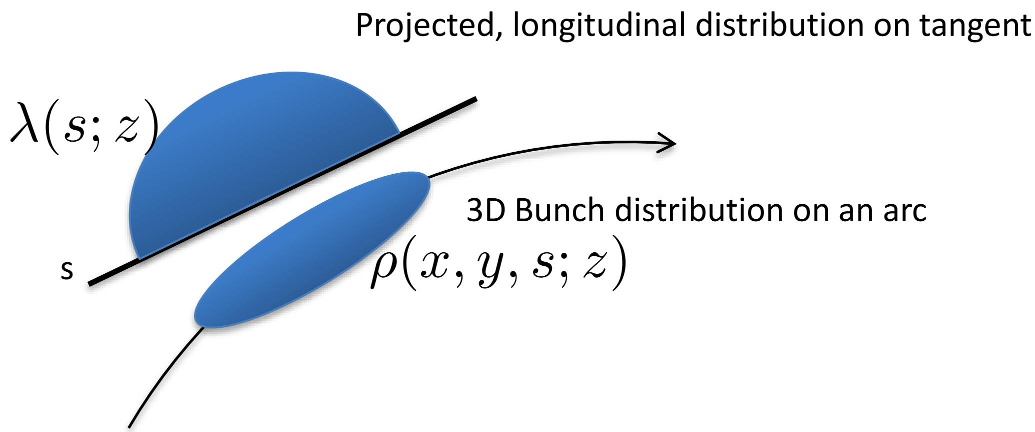
# CSR-Electron Bunch Interaction




- Radiation emitted by bunch tail may overtake the head of the bunch
- Radiation can take a shorter path than electrons in a dipole.

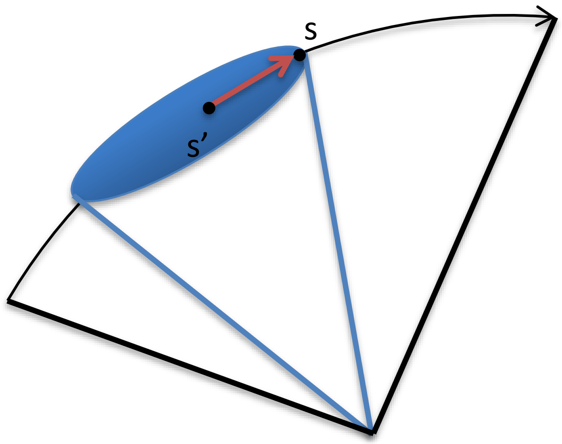
# *1D CSR Model*




- Neglects transverse distribution and forces
- Assumes φ<<1 and γ>>1
- Assumes bunch is rigid over distances of φ

E. Saldin, E. Schneidmiller and M. Yurkov, *NIM A* **398**, 373 (1997).

# CSR Energy Loss On an Arc




While: $L_{sl} = \frac{R\phi^3}{24} < \sigma_z$

Transient fields dominate.
Will eventually slip entirely past bunch if dipole is long enough.

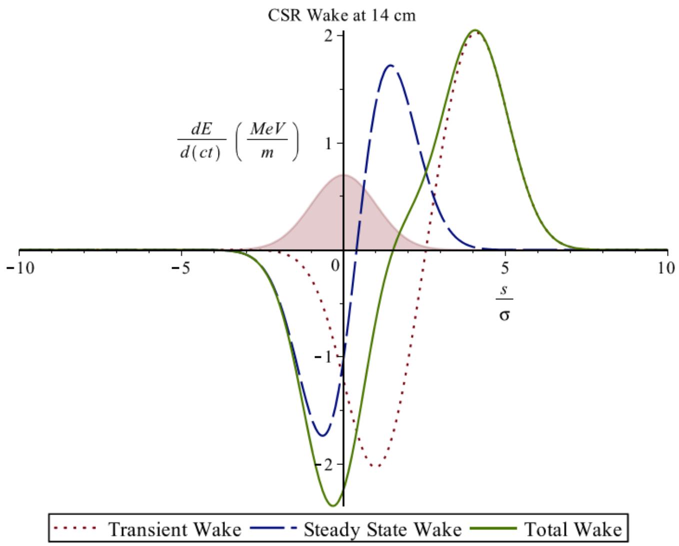
$$\left(\frac{d\mathcal{E}(s,\phi)}{d(ct)}\right)_{Transient} = -\frac{2e^2}{3^{\frac{1}{3}} R^{\frac{2}{3}}} \left(\frac{R\phi^3}{24}\right)^{-\frac{1}{3}} \left[\lambda\left(s - \frac{R\phi^3}{24}\right) - \lambda\left(s - \frac{R\phi^3}{6}\right)\right]$$

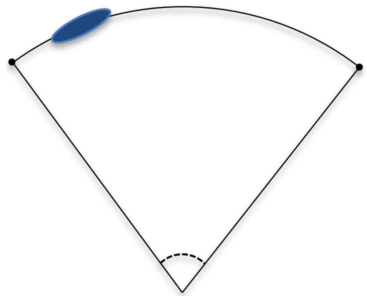
Slippage length

$$\left(\frac{d\mathcal{E}(s,\phi)}{d(ct)}\right)_{Steady} = -\frac{2e^2}{3^{\frac{1}{3}} R^{\frac{2}{3}}} \int_{s-R\phi^3/24}^{s} \frac{ds'}{(s-s')^{\frac{1}{3}}} \frac{d\lambda(s')}{ds'}$$

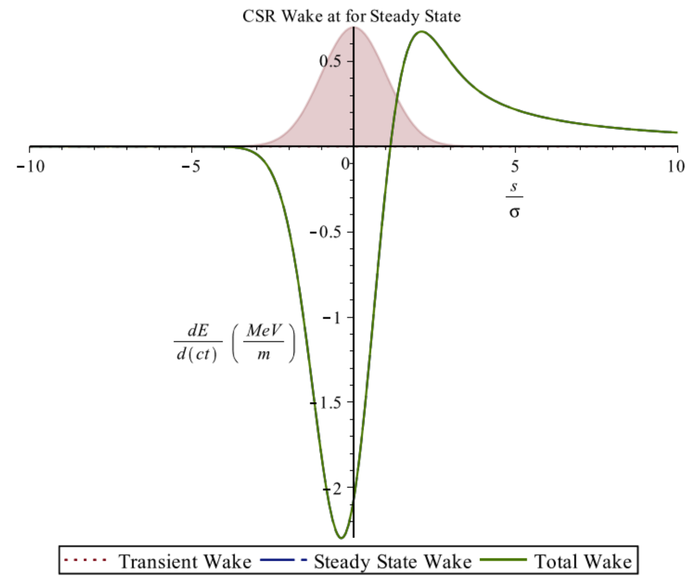
E. Saldin *et. al*, NIM A 398, 373 (1997).

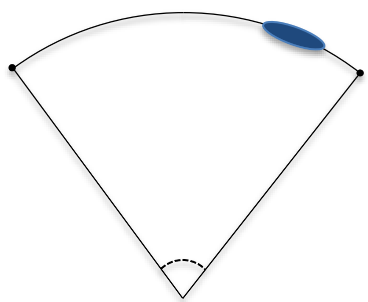
# *Example for a Gaussian Bunch*



Dipole entrance:
Transients strong, steady-state wake forming

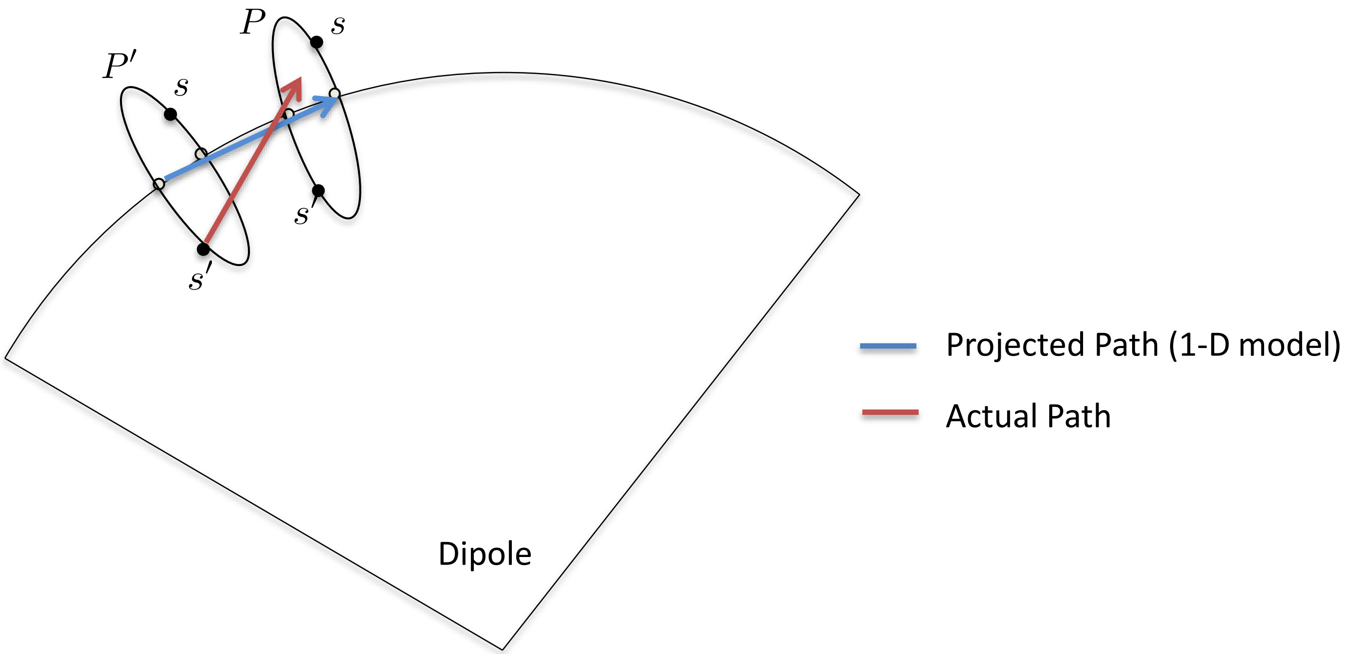


If $L_D >> L_s$

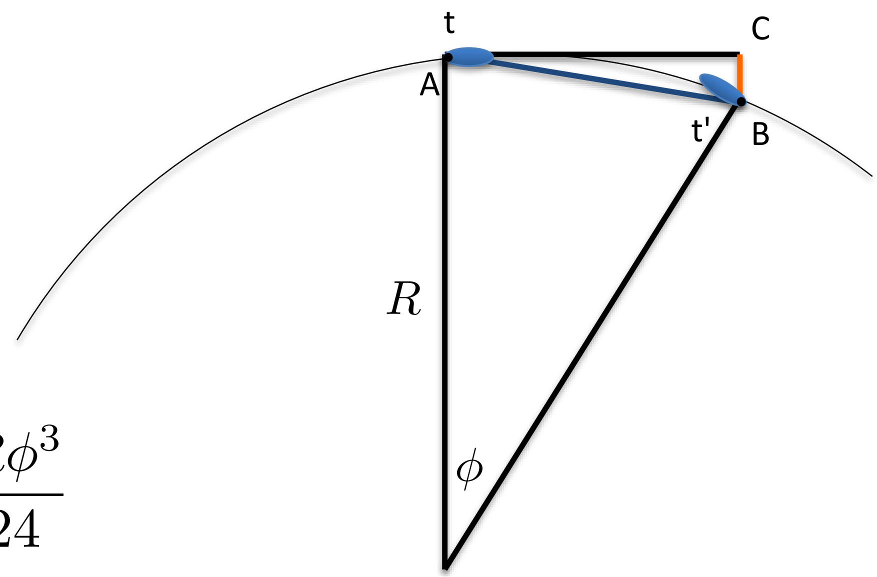
Steady-state wake will dominate for most of dipole

# *Errors in the 1-D CSR Model*




Dispersion in the dipole spreads out the beam in the bending plain → Removing transverse displacement leads to causality violation in 1-D CSR model.

# The Derbenev Criterion




$$L_{sl} = \frac{R\phi^3}{24}$$

Overtaking Length $(24\sigma_z R^2)^{\frac{1}{3}}$

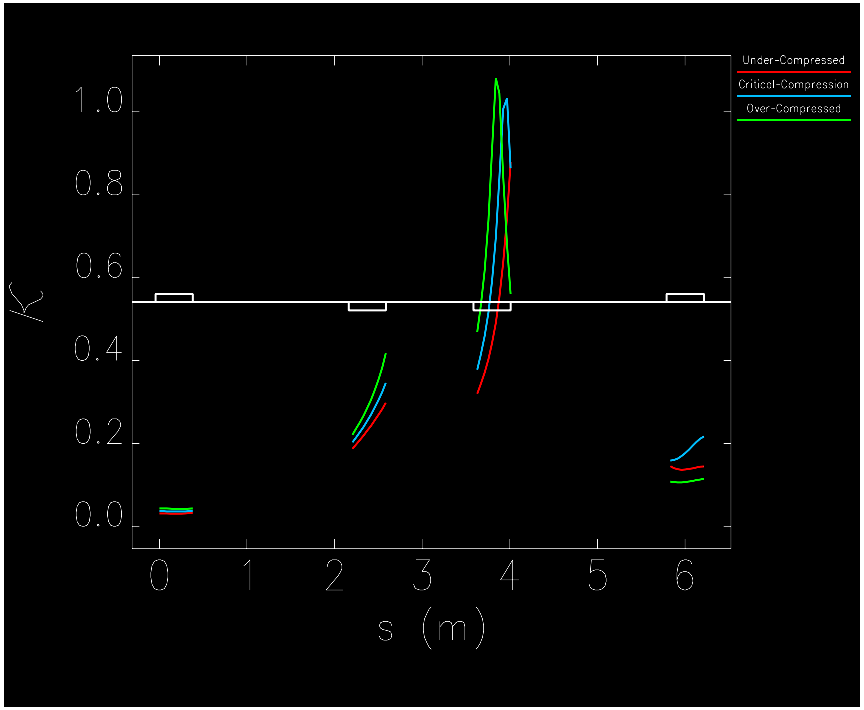
Projection distance $2(9\sigma_z^2 R)^{\frac{1}{3}}$

1D Assumption:

$$\frac{\sigma_x}{BC} \approx \sigma_x \left(\frac{1}{R\sigma_z^2}\right)^{\frac{1}{3}} \ll 1$$

Y. S. Derbenev, J. Rossbach, E. L. Saldin, and V. D. Shiltsev, TESLA-FEL 95-05, TESLA, 1995.

# *The Derbenev Criterion*




For the 1D approximation to be valid:

$$\kappa \equiv \sigma_x \left( \frac{1}{R\sigma_z^2} \right)^{\frac{1}{3}} \ll 1$$

The Derbenev criterion is shown as a function of position through a 4 dipole chicane (the JLab FEL chicane). It should remain small for the 1D algorithm to be valid. In most of the dipoles, this is approximately satisfied, but the 3rd dipole does peak close to 1.

# *Coming up next… CSR Computer Lab*

- Goals
  - consider 1D steady-state CSR in a bunch compressor
  - consider 1D transient CSR in a bunch compressor
  - consider effects of 1D CSR that co-propagates with a beam

# *Add more to your bunch compression simulation*

- This part requires you to follow along with the instructor

# *Simulate Steady-State CSR*

- Begin with your linac and bunch compression beamline
  - the one you built yesterday and today

- Let's turn on steady-state CSR in the dipoles
  - Go to 'Control' and find the 'alter_elements' command with 'item = CSR, name = BEND?'.
  - Change 'Value' from 0 to 1 and save changes.
  - Go back and rerun the simulation.
    - **How does the longitudinal phase space in run_setup.output look different from the picture you saved with CSR off?**

    - **Look at the histograms of deltaFrequency vs delta at the start and end of the chicane.**
    - **Why have they changed?**

    - **Plot *enx vs s* in run_setup.sigma**
    - **Save this plot to record *enx* at the end of beam line**

# *Steady-State CSR – what should you have seen?*

- Steady-state CSR is turned on
  - Should observe a dip at the head where current is high
    - **CSR wake has lowered energy of particles**
  - Should also notice the average energy of the bunch has dropped ~1 MeV
  - After the chicane, the momentum histogram shows two peaks due to CSR shifting the energy of particles in the head bunch down.
  - enx ~ 14 um