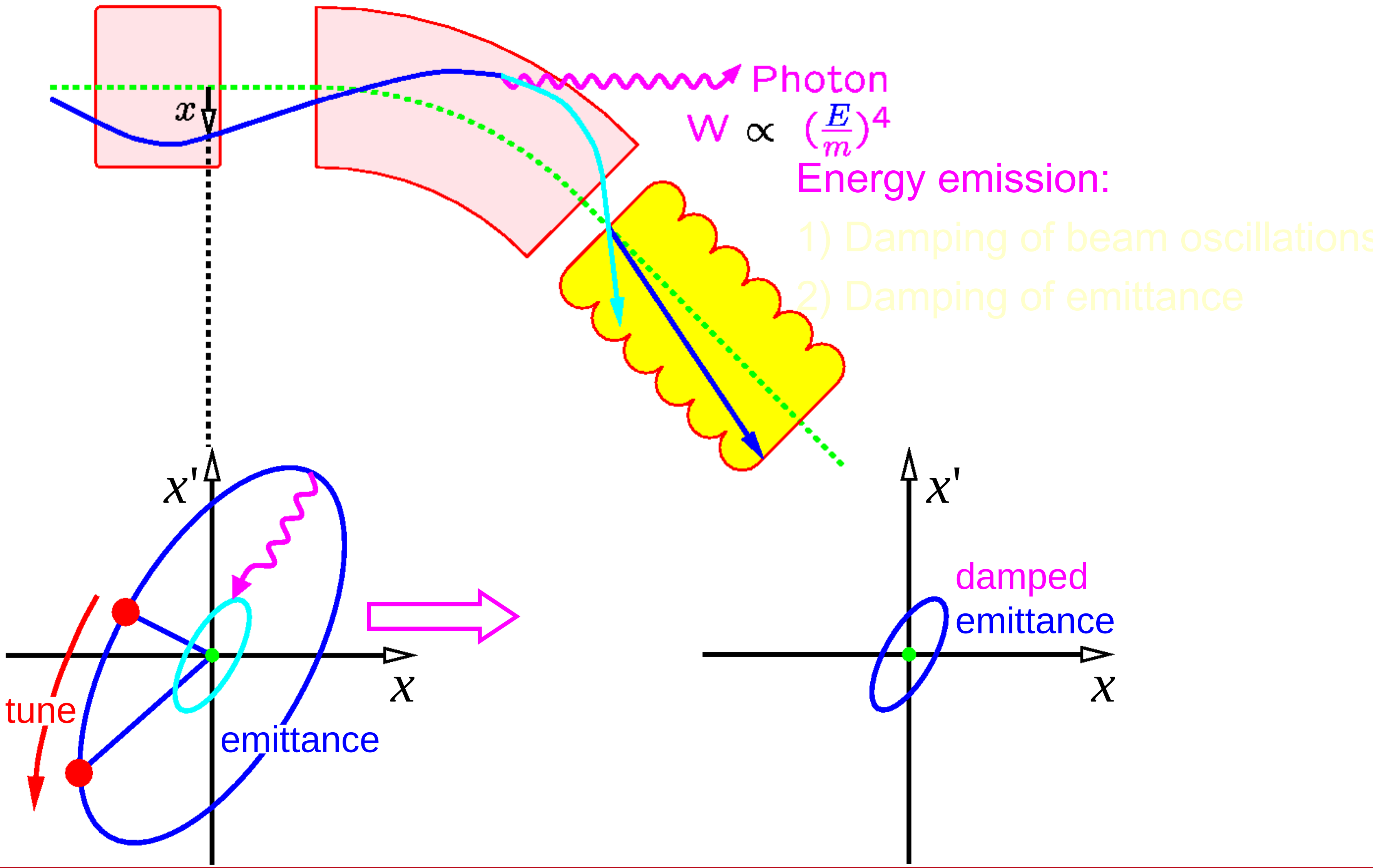
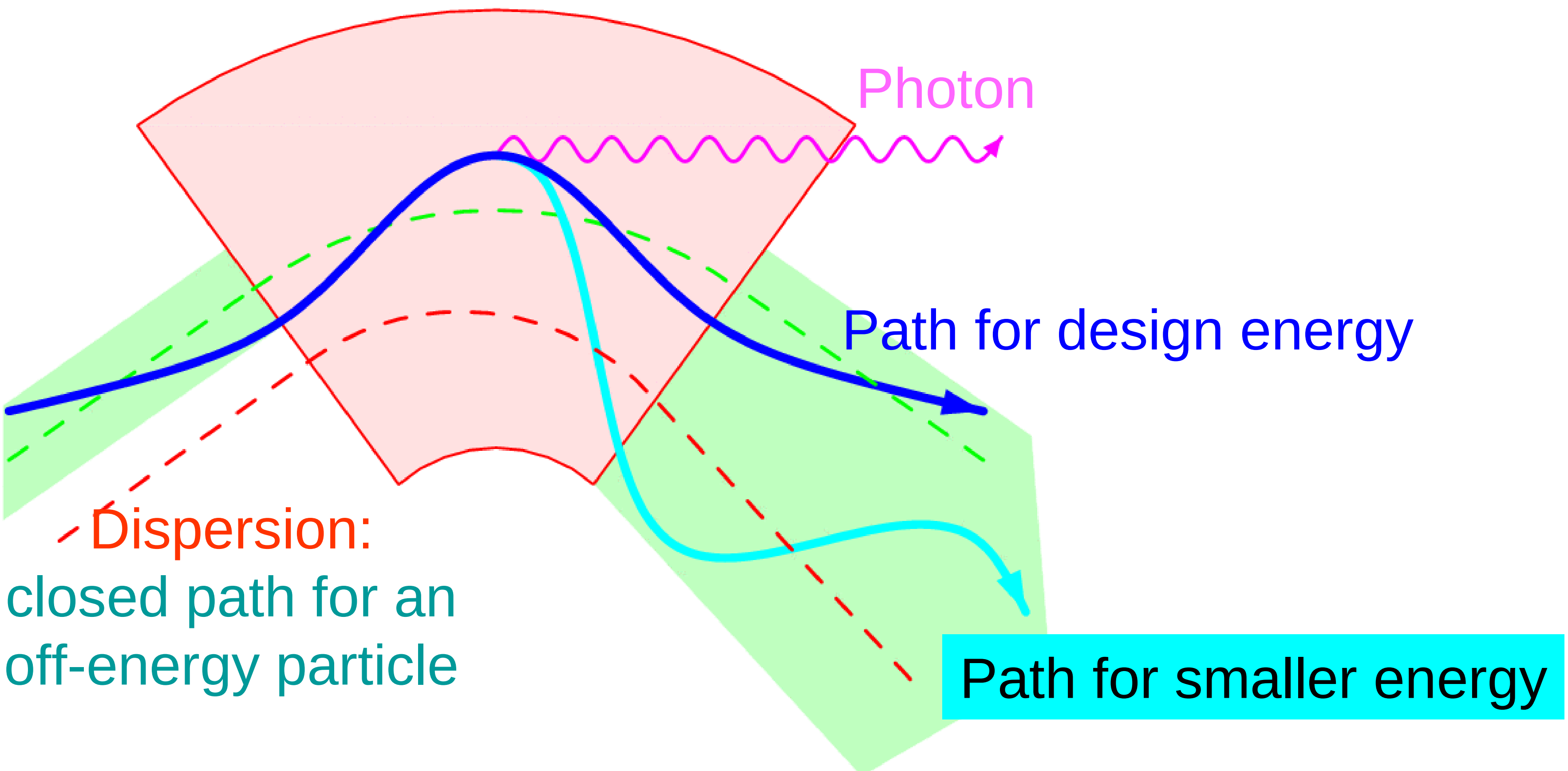
Damping of Oscillations in Storage Rings



Emittance Generation by Radiation

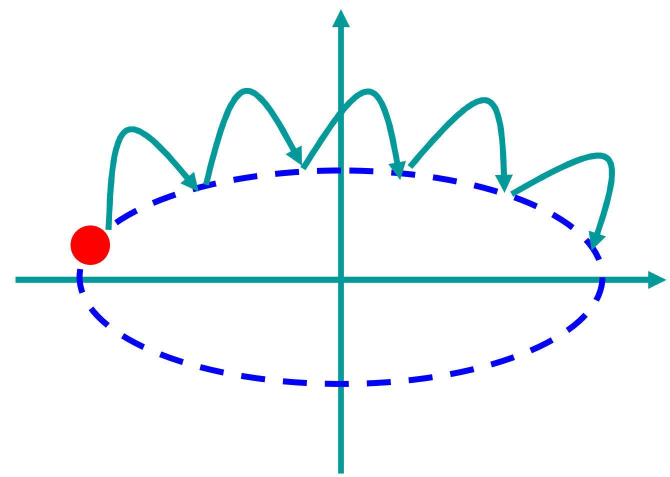
CHESS & LEPP

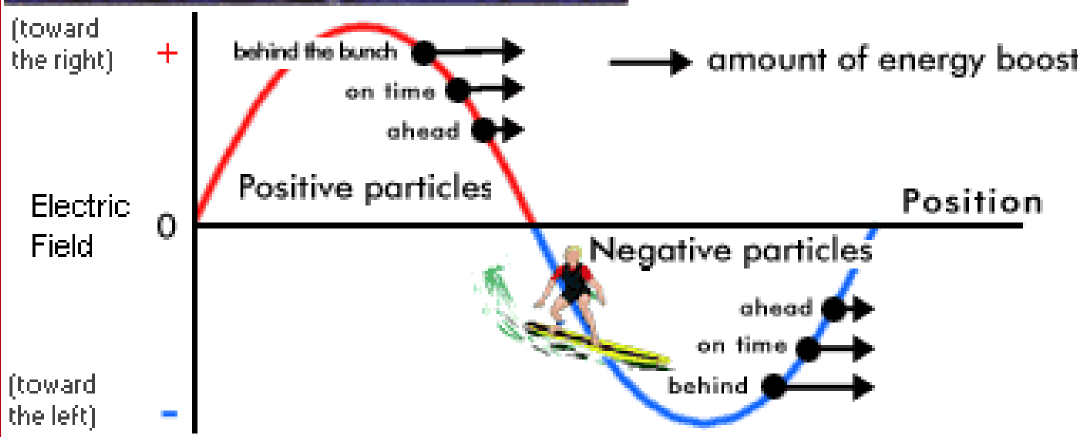
Smaller dispersion → Smaller emittance



Phase Focusing

Acceleration
in an RF system:

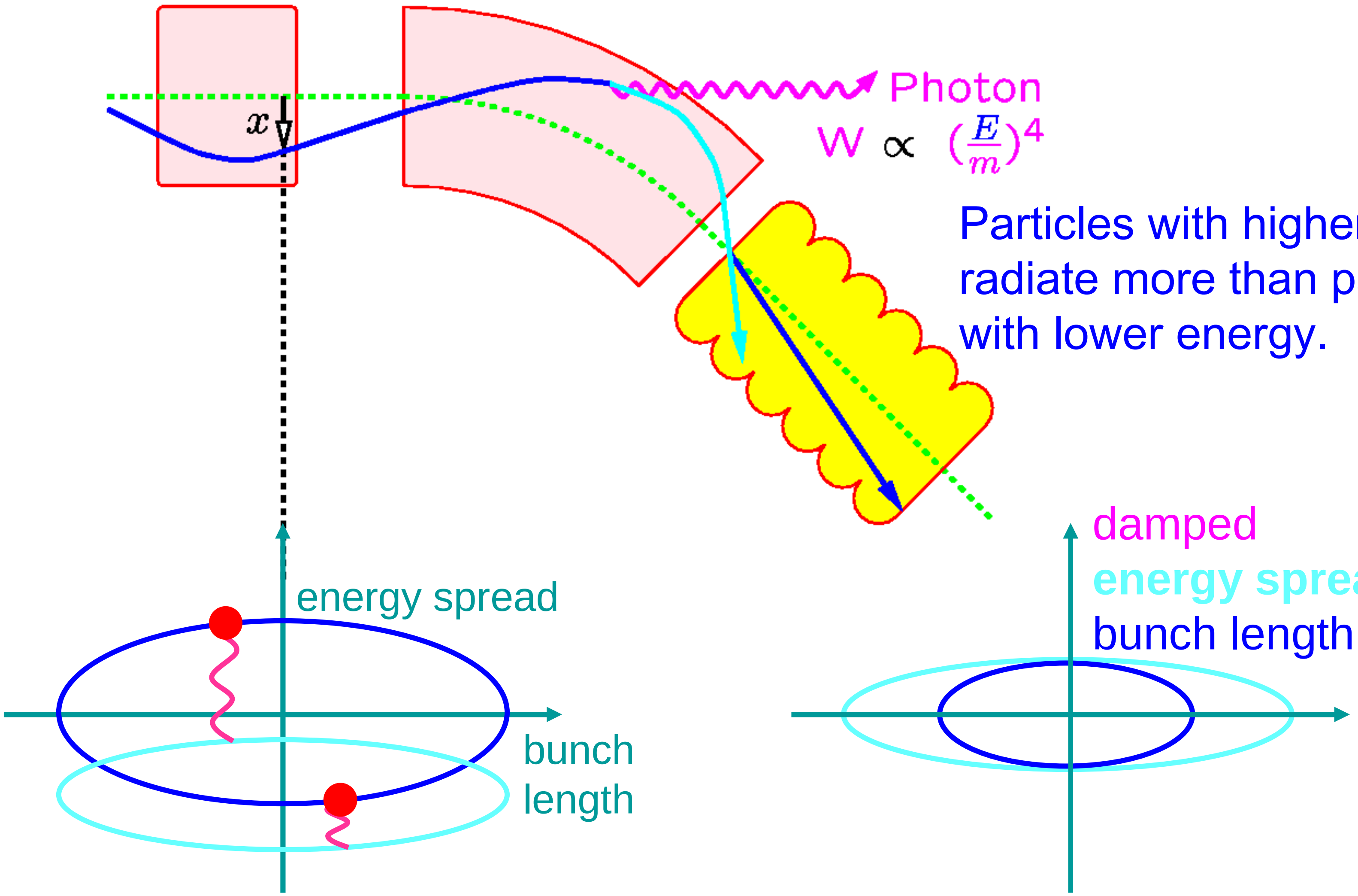




After some revolutions, energy difference turns into phase difference and vice versa.

$$\Delta K = qU(t) = qU_{\max}\sin(\omega(t - t_0) + \psi_0)$$

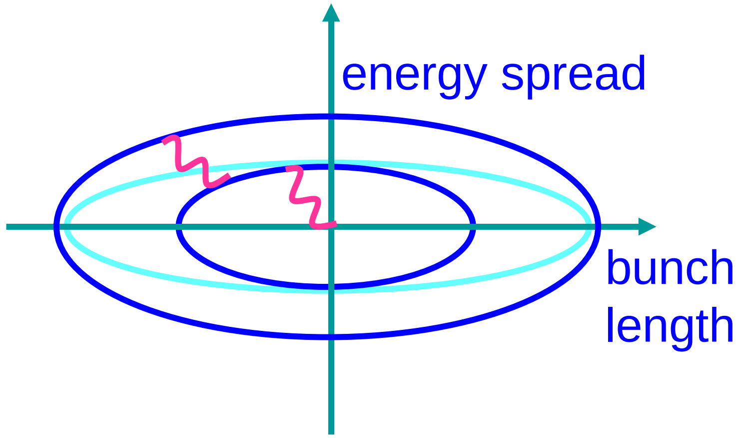
Damping of Energy Spread in Rings



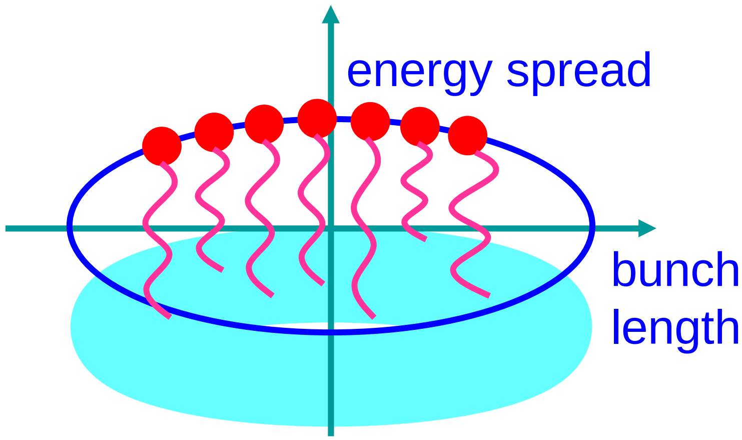
Particles with higher energy radiate more than particles with lower energy.

Excitation of Energy Spread

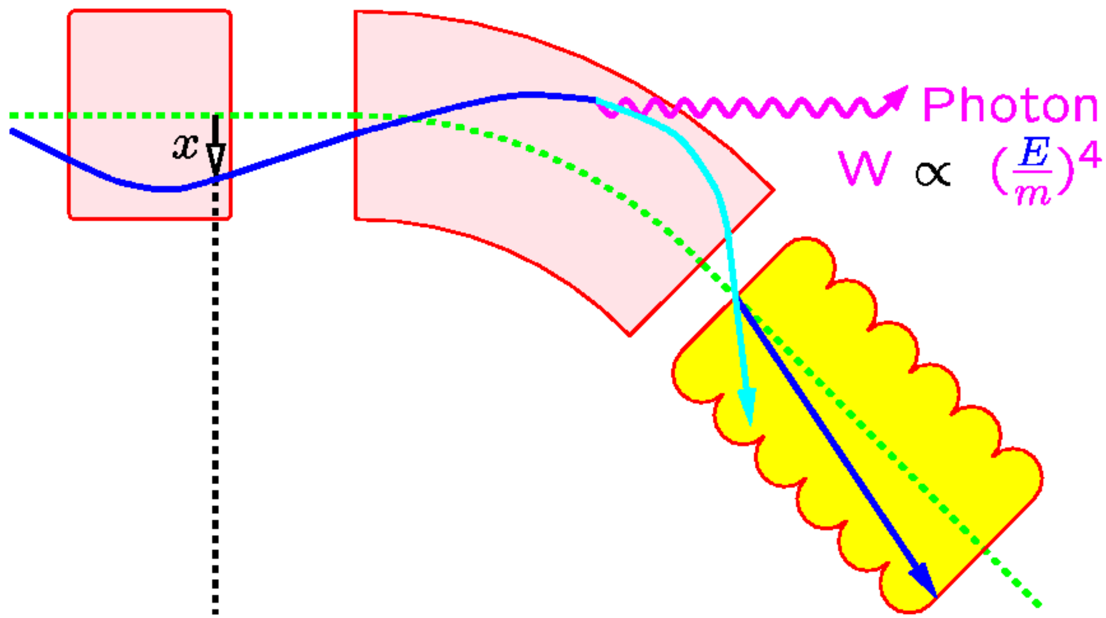
Why does this radiative reduction of energy spread not reduce the energy spread and bunch length to zero ?



The stochastic nature of synchrotron radiation lets every electron loose a different amount of energy, leading to an energy spread.



Damping by Synchrotron Radiation



Damping rate:

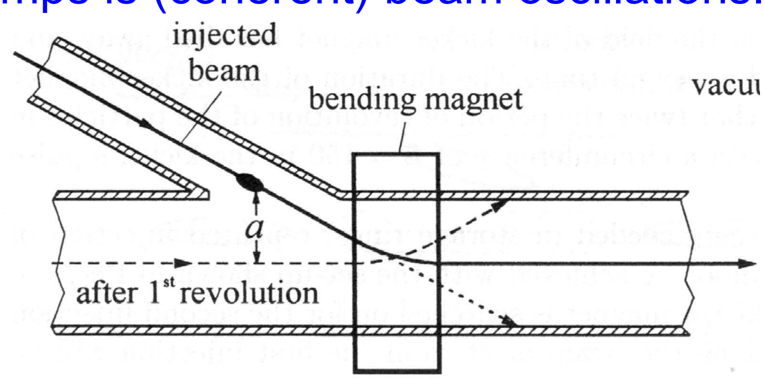
$$\frac{1}{\tau} \approx \frac{P_\gamma}{E_0} \propto \frac{1}{\rho^2}$$

Energy emission: A wiggler damps (and excites) just like a dipole (only more)

1) The only thing that a wiggler only damps is (coherent) beam oscillations.

This is essential for:

- Damping of injection oscillations
- Damping of coherent instabilities, e.g. due to HOMs in cavities.



X-Ray and Damping Wigglers

X-ray rings with wigglers (examples):

- SSRL: BL11 decreases lifetime
  decrease dynamic aperture

- SPRING8 10T wiggler: increases emittance from 6.4nm to 13nm
  increases energy spread from 0.1% to 0.15%

Wigglers in non-X-ray rings:

- VEPP-2M 700MeV with 8T wiggler in about 1980
- DAPHNE 0.51GeV with wigglers
- CESR-c 1.9 GeV with twelve 2T wigglers

} $\varepsilon_x \Uparrow$

- ILC, pre-damper (30%), NLC (20%), CLIC (40%) wigglers
- ATF test damping ring with wigglers
- PETRA III with damping wigglers (i.e. no beamline)

} $\varepsilon_y \Downarrow$

Beam Control by Radiation

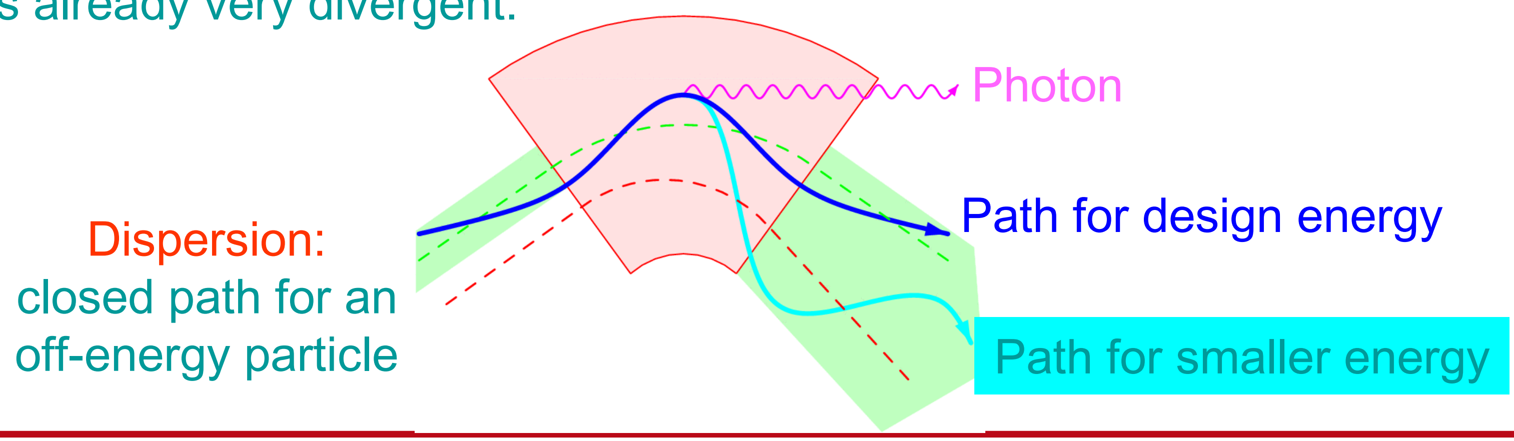
Other quantities that are related to damping and thus can be controlled by (damping) wigglers:

The bunch length and energy spread (by strength of wigglers)

The horizontal emittance

a) by changing the dispersion in the wiggler, so that a radiative energy loss causes a different oscillation.

b) By changing the beam shape in the wiggler, since
   - the creation of an oscillation amplitude by radiative energy loss is less important where the beam is already very wide.
   - the creation of a oscillation angle causes large emittance increase where the beam is wide, but matters little at a place where the beam is already very divergent.



Independent Controls in a Wiggler

Damping rate

$$\frac{1}{\tau} \approx \frac{P_\gamma}{E_0} \propto \frac{1}{\rho^2}$$

The bunch length and energy spread

$$\sigma_\delta \propto \frac{\left\langle {}^{1}\!/\!_{\rho^3} \right\rangle}{\left\langle {}^{1}\!/\!_{\rho^2} \right\rangle}$$

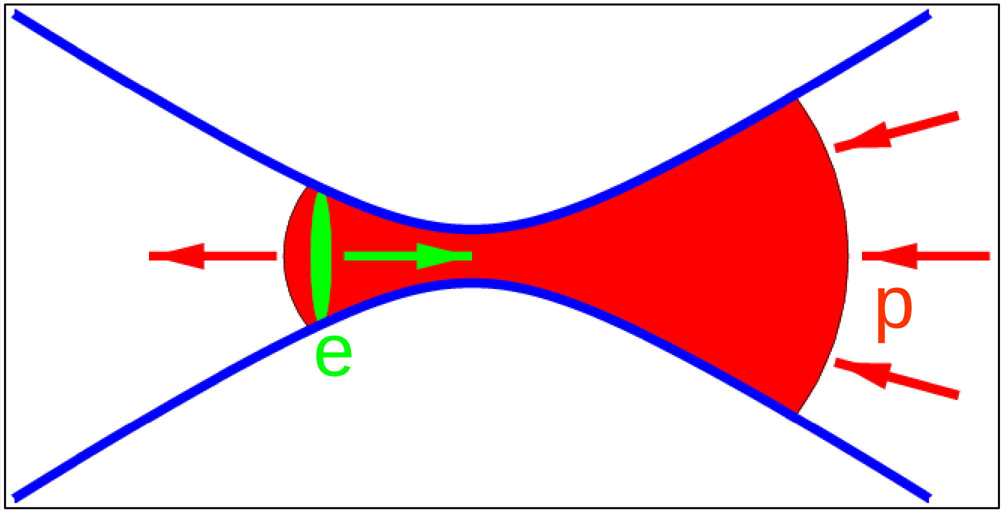
The horizontal emittance

$$\varepsilon_x \propto \frac{\left\langle H(optics) / \rho^3 \right\rangle}{\left\langle {}^{1}\!/\!_{\rho^2} \right\rangle}$$

The vertical emittance

$$\varepsilon_y \propto f(optics) \cdot \varepsilon_x$$

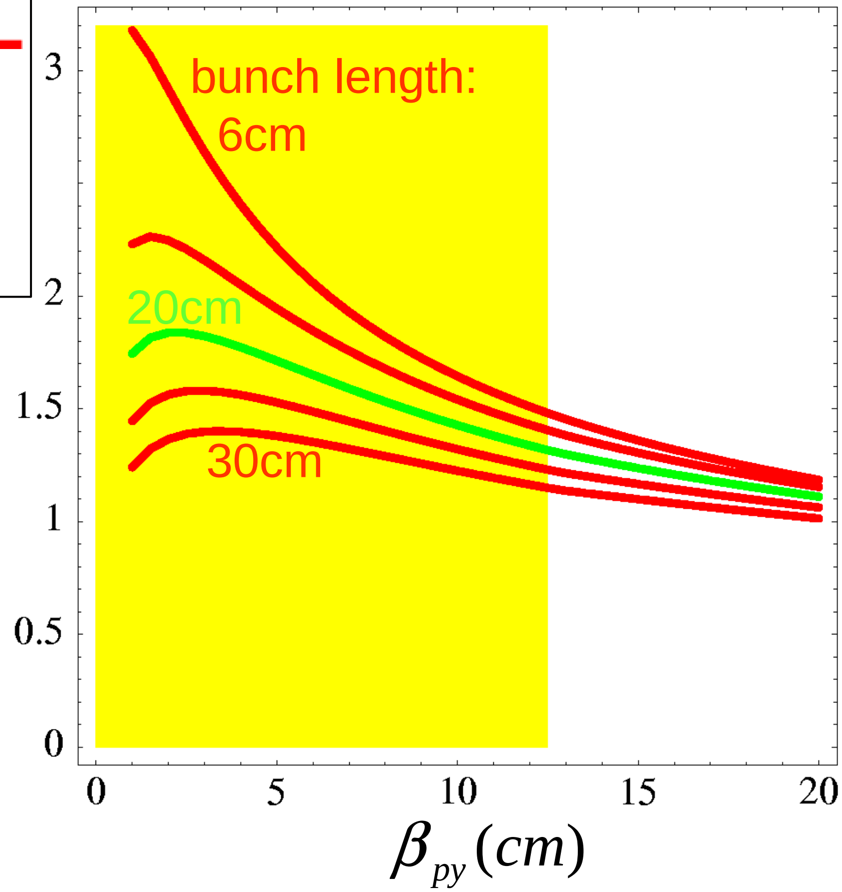
Why Control of Bunchlength



- **Reducing** the bunch length leads to a relevant increase in average cross section during collision if
bunch length X divergence > beam size

- **Increasing** the bunch length reduces the beam density and therefore intra-beam scattering. (better lifetime)

Example luminosity



Why Control the Emittance

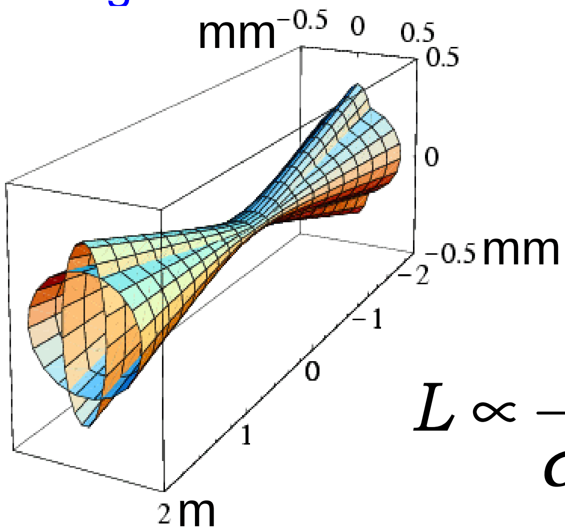
CHESS & LEPP

- **Smaller** emittance for more coherence in a light source (e.g. PETRA III)
  Limit: The trajectories in the wiggler are different for different energy,
  i.e. there is some minimum dispersion.

- **Larger** emittance results in smaller beam density and less intra beam scattering

- **Smaller** emittance allows smaller colliding beam area and larger luminosity.

- **Larger** emittance means that for the same beam area the beam is more divergent so that an additional beam-beam kick is less important.



$$L \propto \frac{1}{\sigma_x \sigma_y}$$