Energy emission:
1) Damping of beam oscillations
2) Damping of emittance
Emittance Generation by Radiation

- Smaller dispersion
- Smaller emittance
- Photon
- Path for design energy
- Dispersion: closed path for an off-energy particle
- Path for smaller energy
After some revolutions, energy difference turns into phase difference and vice versa.

\[ \Delta K = qU(t) = qU_{\text{max}} \sin(\omega(t - t_0) + \psi_0) \]
Particles with higher energy radiate more than particles with lower energy.

\[ W \propto \left( \frac{E}{m} \right)^4 \]

Damping of Energy Spread in Rings
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

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 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

\[ \begin{align*}
\mathcal{E}_x & \uparrow \\
\mathcal{E}_y & \downarrow
\end{align*} \]
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

\[ \frac{1}{\tau} \approx \frac{P_y}{E_0} \propto \frac{1}{\rho^2} \]

The bunch length and energy spread

\[ \sigma_\delta \propto \frac{1}{\rho^3} \left( \frac{1}{\rho^2} \right) \]

The horizontal emittance

\[ \varepsilon_x \propto \frac{H(\text{optics})}{\rho^3} \left( \frac{1}{\rho^2} \right) \]

The vertical emittance

\[ \varepsilon_y \propto f(\text{optics}) \cdot \varepsilon_x \]
• **Reducing** the bunch length leads to a relevant increase in average cross section during collision if \( \text{bunch length} \times \text{divergence} > \text{beam size} \)

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

- **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.

\[ L \propto \frac{1}{\sigma_x \sigma_y} \]