# Can we use laser to stop electrons? (Can we use a laser beam dump?)

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# Introduction

- Green ILC (see Saeki san's talk)
- Major Problem of plasma decelerator or plasma beam dump
- The front part of an electron bunch is not decelerated.
- => New proposal
  - How about using laser for beam dump??
  - The interaction of very high energy electrons with intense lasers is one of active research fields in high-field science!

# Radiation Damping Equation

- Cannot integrate forward in time
- Can only integrate backwards in time

**Minkowski equation** → 

$$mc\frac{du^i}{ds} = \frac{e}{c}F^{ik}u_k + g^i$$

← **Damping force**

$$F^{ik} = \begin{pmatrix} 0 & -E_x & -E_y & -E_z \\ E_x & 0 & -H_z & H_y \\ E_y & H_z & 0 & -H_x \\ E_z & -H_y & H_x & 0 \end{pmatrix}$$

$$g^i = \frac{2e^2}{3c}\left(\frac{d^2u^i}{ds^2} - u^i u^k \frac{d^2u_k}{ds^2}\right)$$

$$u^i = \left(\gamma, \gamma\vec{\beta}\right) \qquad ds = c\,dt\sqrt{1 - \frac{v^2}{c^2}}$$

Problems

# First Order Perturbation Expansion (Landau-Lifshitz) Equation

$$\frac{d\vec{p}}{dt} = -e\left\{\vec{E} + \vec{\beta} \times \vec{B}\right\} + \vec{f}_{RD}$$

$$\vec{f}_{RD} = -e\frac{2r_e}{3}\gamma\left(\frac{\partial}{c\partial t} + \vec{\beta}\cdot\vec{\nabla}\right)\left(\vec{E} + \vec{\beta}\times\vec{B}\right) + \frac{2r_e^2}{3}\left\{\vec{E}(\vec{\beta}\cdot\vec{E}) + \left(\vec{E} + \vec{\beta}\times\vec{B}\right)\times\vec{B}\right\} - \frac{2r_e^2}{3}\gamma^2\vec{\beta}\left\{\left(\vec{E} + \vec{\beta}\times\vec{B}\right)^2 - (\vec{\beta}\cdot\vec{E})^2\right\}$$

$$r_e = \frac{e^2}{mc^2}$$

1) Exact for a point particle

Rohrlich, Phys. Lett. A **283**, 276 (2001)

2) Particle with structure

O'Connell, Phys. Lett A **313**, 491 (2003)

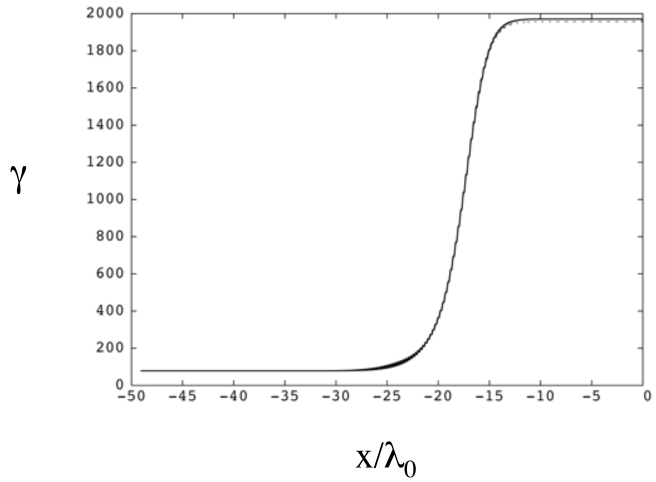
3) Accurate for all electron motion in the classical regime

Koga, Phys. Rev. E **70**, 046502 (2004)

# Radiation damping

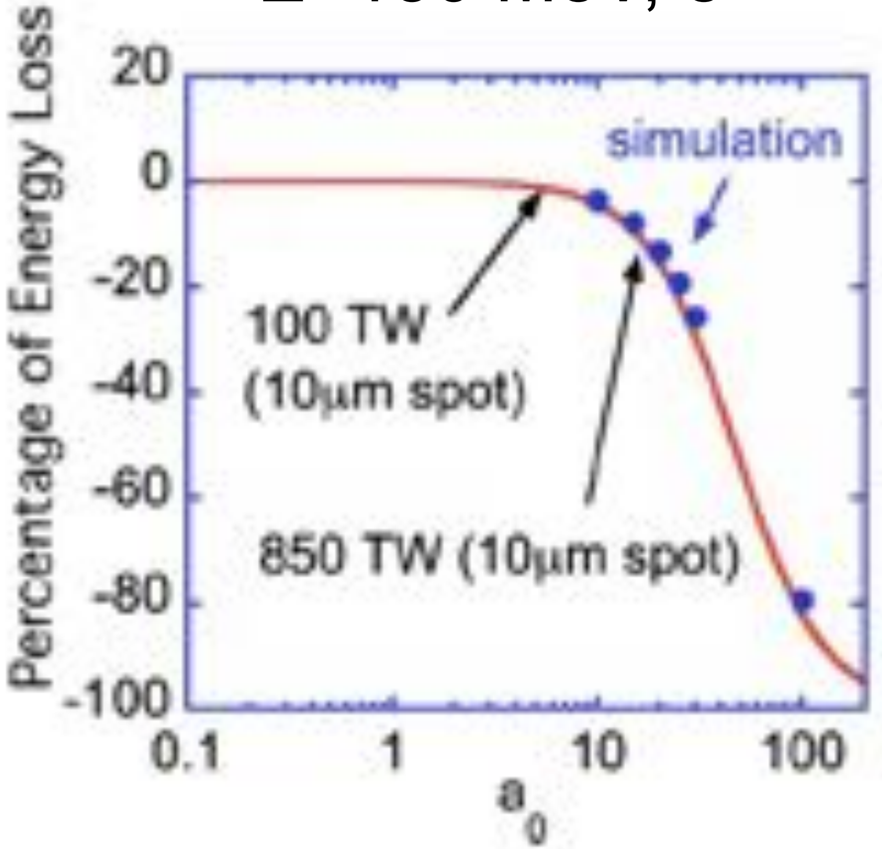
J. Koga, T. Zh. Esirkepov, and S. V. Bulanov, Phys. Plasmas 12, 093106 (2005)

❖ Classical case




•1 GeV electron stops ~3 cm in lead
•Converts > 95% to Bremsstrahlung.
•Nearly 4000 times longer

E=150 MeV, e-




$$a = \frac{E}{mc\omega} = \left(\frac{\lambda[\mu\mathrm{m}]}{1}\right)\sqrt{\frac{I[\mathrm{W/cm^2}]}{1.37\times 10^{18}}}$$

# Problems

- Koga’s paper treats classical radiation damping regime.
- In linear colliders electron energies are very high (125 GeV/250 GeV), thus we enter quantum regime and nonlinear QED regimes.
- This regime itself is an active subject of high-field science.
- highly dissipative

# Parameters

- Strong damping and pair creation

- Both >1 when [1]: $\chi_e, \chi_\gamma > 1$

$$a > \frac{2}{3} \frac{\alpha}{\gamma_{e,\gamma} \epsilon_{rad}} \qquad \epsilon_{rad} \equiv 4\pi r_e / 3\lambda_0$$

$$125 \text{ and } 250 \text{ GeV} (\gamma_e = 2.4 \sim 4.9 \times 10^5)$$

$$a \approx 1.35 (3.9 \times 10^{18} \text{W/cm}^2) \text{ or } a \approx 0.67 (9.7 \times 10^{17} \text{W/cm}^2)$$

- **Moderate Intensity laser!**
- **However, Quantum effects large →significant reduction [2]**

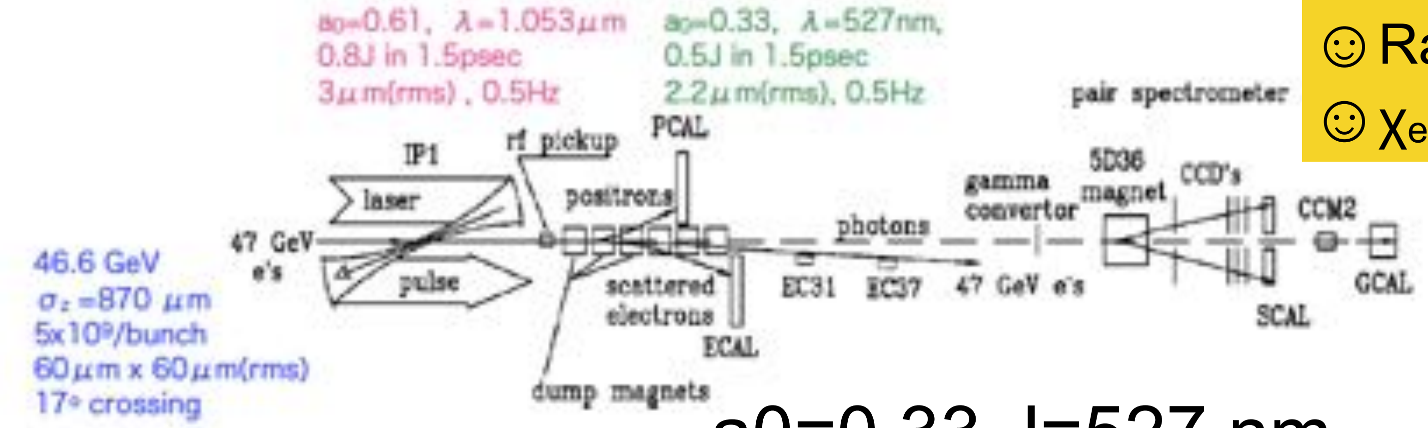

[1] S. V. Bulanov, et al., Nucl. Instr. Meth. A 660, 31 (2011)
[2] C. P. Ridgers, et al., J. Plasma Phys. 83, 715830502 (2017)

# Tauch's calculation (Hayama 2011)

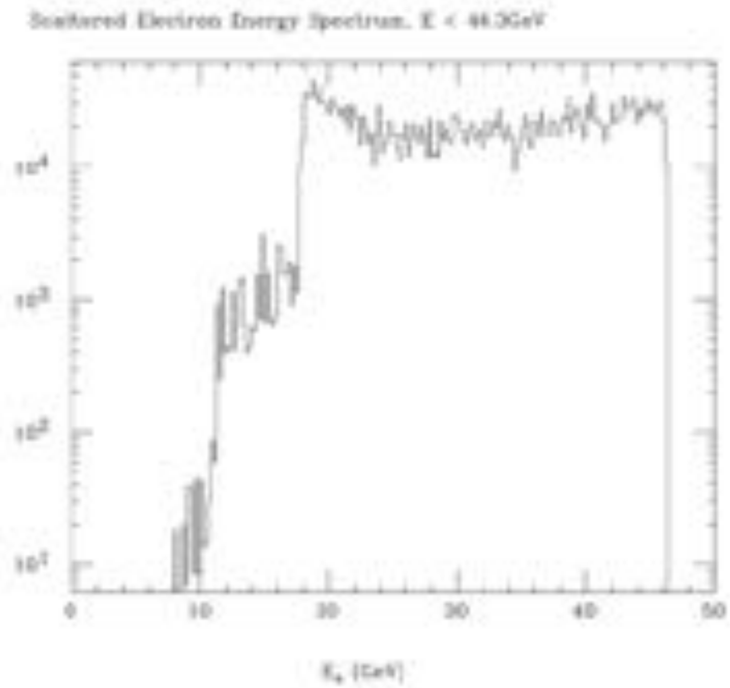
SLAC experiment, PR D60, 092004(1999), PRL 76, 3116 (1996)

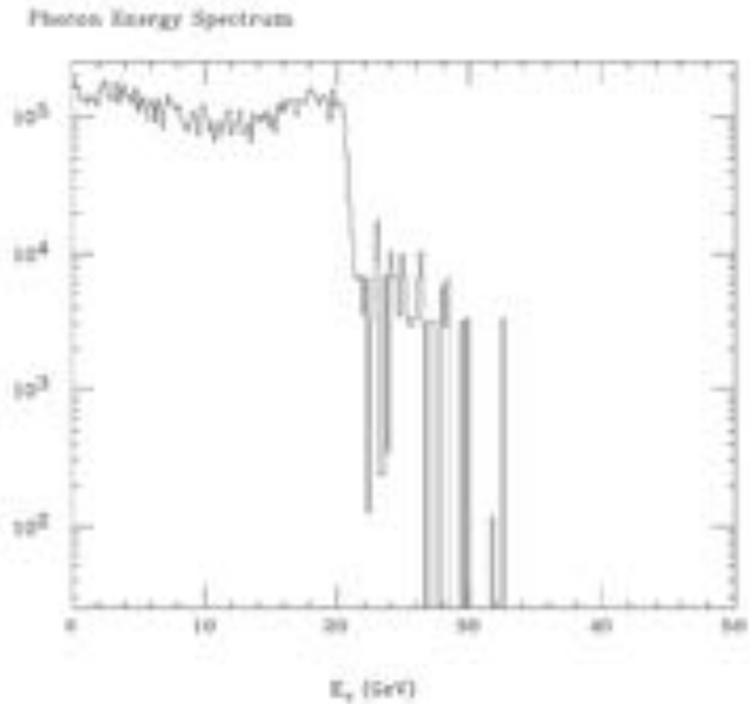
☺ Radiation damping regime

☺ $\chi_e$~0.1<<1



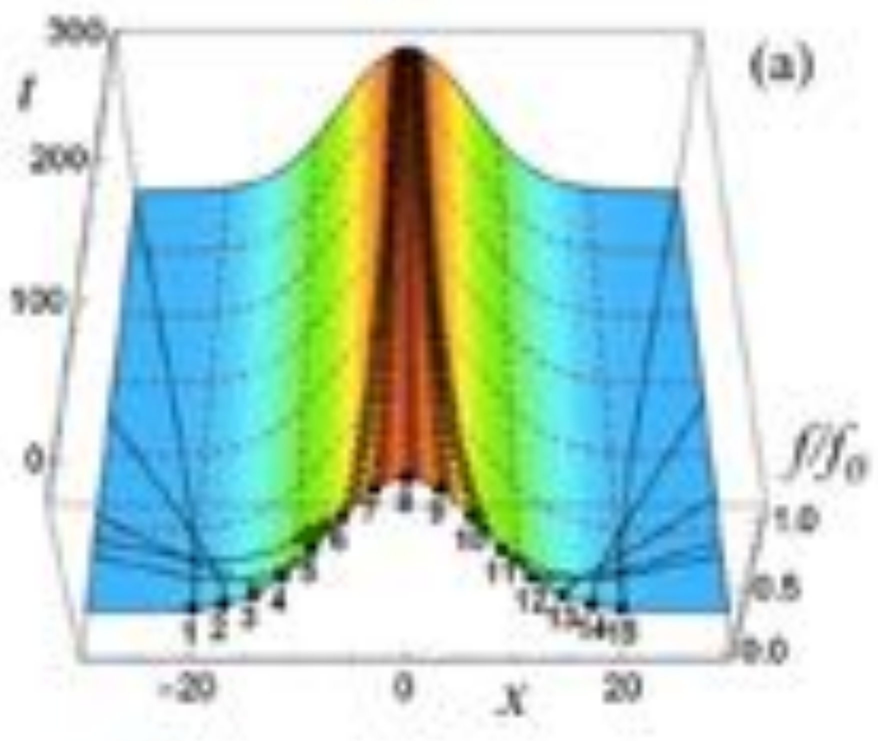

a0=0.33, l=527 nm



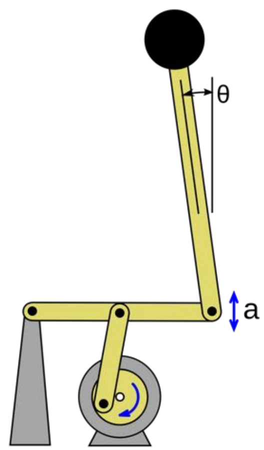


# Conclusions

- ❖ Laser can stop high energy electrons in appropriate regimes.
- ❖ Needs more study.
- ❖ The intensity regime itself is a new field for research.




cf. Stephenson-Kapitza Pendulum




T. Zh. Esirkepov and S. V. Bulanov, Phys. Lett. A 381 (2017)

Stephenson-Kapitza Pendulum

Youtube