Energy Spread of Electrons in Compton Sources (Long vs. Short Ring)

Eugene Bulyak

Thanks to: P.Gladkikh, T.Omori, L.Rinolfi, J.Urakawa,
A.Variola, F.Zimmermann

Nomenclature

- Short ring 100–turn generation of gammas
- Long ring 10–turn generation of gammas (proposed by P.Gladkikh)
- CLIC ring 2500–turn generation of gammas, low laser power

Spread: Why Important ?

Recoil limits performance

- Undulator increases (nonreduceable) energy spread in electron linac
- ERL Problems in recover energy from bunches with wide energy spread
- Compton ring: wide energy spread need to be accepted
    - longitudinal motion: *small momentum compaction, high RF voltage*
    - transverse motion: *achromaticity of ring to avoid resonances*

Two aspects for rings

- r.m.s. coordinate (phase) spread reduces yield (non head–on collision)
- span (tails) of energy distribution causes particle losses

Analytics: Laser "Cooling." Longitudinal Dynamics.

Dependence of spread $p \equiv (E - E_\mathrm{s})/E_\mathrm{s}$ on time t (in turns)

$$\left\langle p^2 \right\rangle = p_\mathrm{st}^2 \left(1 - \mathrm{e}^{-2t/T}\right) \quad ; \quad p_\mathrm{st}^2 = \frac{7}{10}\frac{\gamma E_\mathrm{las}}{E_0} \, , \qquad T^{-1} \approx 2\kappa \frac{\gamma E_\mathrm{las}}{E_0} \, .$$

with κ the number of gammas/(electron turn)

Natural conditions

stab $\kappa \langle E_\mathrm{C} \rangle \, T_\mathrm{syn} < eV_\mathrm{rf}$,
$T_\mathrm{syn} = Q_\mathrm{syn}^{-1}$ period of synchrotron oscillations (turns)

adia $T \gg T_\mathrm{syn}$ condition of adiabatic damping

Asymptotes

- Dynamic (a few turn cycle)

$$\left\langle p^2 \right\rangle \approx \frac{14}{5} t\kappa \left(\frac{\gamma E_{\rm las}}{E_0} \right)^2 \qquad \text{at} \qquad 2t\kappa\gamma E_{\rm las} / E_0 \ll 1 \ .$$

- Steady (many turn cycle)

$$\left\langle p^2 \right\rangle_{\rm st} \approx \frac{7}{10} \left(\frac{E_{\rm las}\gamma}{E_0} \right) \qquad \text{at} \qquad t\kappa\gamma E_{\rm las} / E_0 \gg 1 \ .$$

$\left(\frac{E_{\rm las}\gamma}{E_0}\right) \approx (4\ldots6) \times 10^{-3}$ attractive for dynamic mode

Do Compton Sources Meet the Conditions ?

Model: $E_s = 1$ GeV, $E_{las} = 1.164$ eV

Analytical estimations valid if

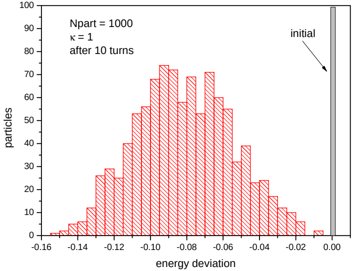
$$t > 1/Q_s \, ; \qquad 1/Q_s < T \, .$$

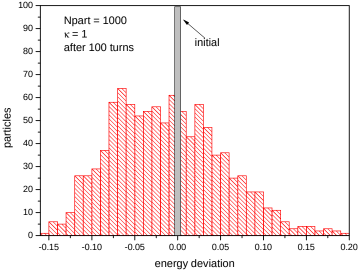
machine	κ	burst	$1/Q_s$	damping	mode	cond
ILC long	1	10	270	100	dynamic	no
ILC short	1	100	270	100	dynamic	no
CLIC	0.1	2500	270	1000	steady	yes

Analytics (r.m.s. spread) for ILC rings not valid, but not wrong

Simulations for Long and Short Rings

Wide laser pulse, head–on

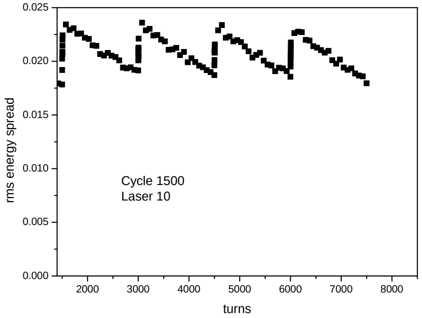




Span about the same: in half of synchrotron period the distribution flips around the initial

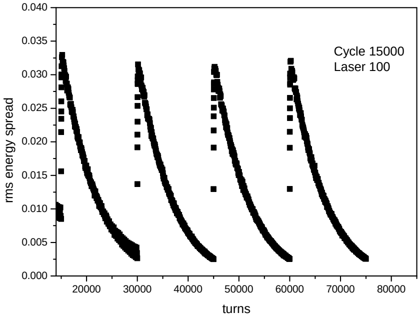
Simulations of Real Sources

Long: 10 turns of 1500



Yield 3 gammas/(electron cycle)

Short: 100 turns of 15000



Yield 22.5 gammas/(electron cycle)

Summary: Short Ring vs. Long Ring

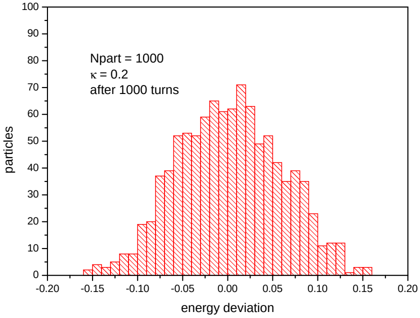
- Spans of distribution over energy in short– and long rings almost equal, thus transverse motion issues and life time
- Long ring will perform higher yield since the burst much shorter than the synchrotron period

Outlook: Ultimate Ring

- LLBI (double chicane) scheme reduces spread in the ring except for the interaction insert (LLBI requires special design)
- Since spread $\sim \gamma E_{\text{las}}$ and gammas energy $\sim \gamma^2 E_{\text{las}}$ then 2 μm laser and 2 GeV electrons produce the same spread as 1 μm laser and 1 GeV but double the gammas energy (40 MeV)
- CLIC–like long bursts (semi–steady mode) deserves attention: lower laser power needed,
  but (pre) accumulation of positron bunches

Example of Ring

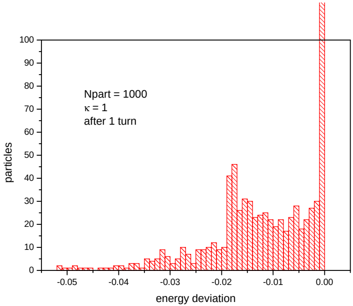
2 GeV, 2 μm, 1000 turns

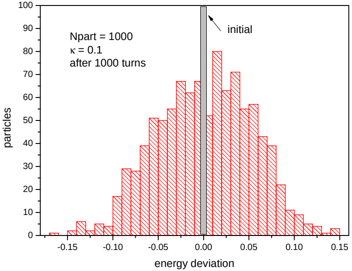


- Same laser power
- Same spread
- Double yield
- Double energy of gammas

Back–up Slide

Simulations: ERL $\kappa = 1$ and CLIC $\kappa = 0.1$





Span in CLIC ring about 3 times higher than after single pass.
CLIC generates 100 gammas, ERL – one gamma.