Optimal Compton Ring Length and Performance

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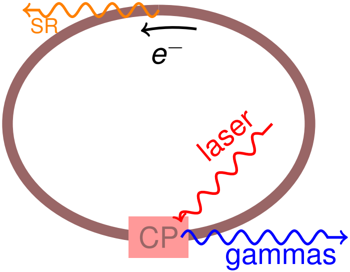
Thanks to: P.Gladkikh, M.Kuriki, T.Omori, L.Rinolfi, J.Urakawa, A.Variola, F.Zimmermann

Compton Gamma Source Functioning

Source = CP + Supplier of electron bunches. Longitudinal (y) direction of prime concern. Main problem is spread of energy in the bunches



- Collision point(s) to generate gammas by scattering off the laser pulses from the electron bunches. Number of gammas:

$$N_\gamma \propto \frac{N_e N_{\rm ph}}{\sqrt{\sigma_z^2 + \sigma_z'^2}\sqrt{\sigma_x^2 + \sigma_x'^2 + (\sigma_y^2 + \sigma_y'^2)\tan^2\frac{\varphi}{2}}} \times \exp\left(-\frac{y^2 \tan^2\frac{\varphi}{2}}{2\left[\sigma_x'^2 + \sigma_x^2 + (\sigma_y^2 + \sigma_y'^2)\tan^2\frac{\varphi}{2}\right]}\right)$$

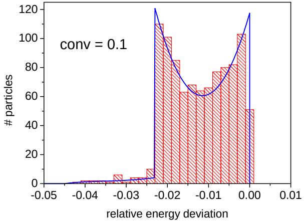
  (laser pulse dimensions primed).

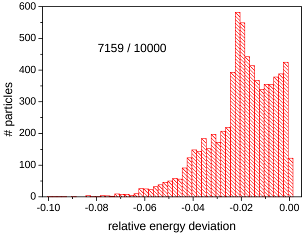
  Equal average current of bunches with equal dimensions produce equal yield of gammas

- Supplier of electron bunches to CP: Storage ring (SR) y self-consistent, linear accelerator (LR) $y = 0$, energy recovery linac (ERL) $y = 0$

Evolution of Bunch in Compton Ring

Spectra of recoils initially monoenergetic bunch 1.3 GeV, 1 μm laser





- **Along the ring:**
  Pendulum at synchrotron frequency (increase in spread induces increase in bunch length in half of period)
- **Passing CP:**
  Each electron loses its energy:
  $E_e \rightarrow E_e - n_\gamma \times E_\gamma$
  Process is of statistical nature:
  $n_\gamma = 0, 1, 2, \ldots,$ average
  $\langle n_\gamma \rangle \approx$ conversion factor (number of scattered photons per electron-passage)
  E_γ ranges from 0 to $E_\gamma^{\max} \approx 4\gamma^2 E_{\mathrm{las}}$
  average $\langle E_\gamma \rangle = E_\gamma^{\max}/2$

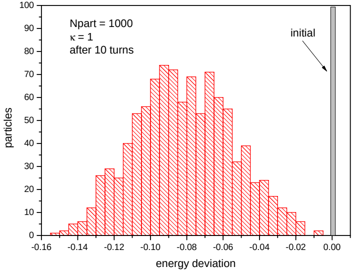
Specific Time Intervals in Compton Ring

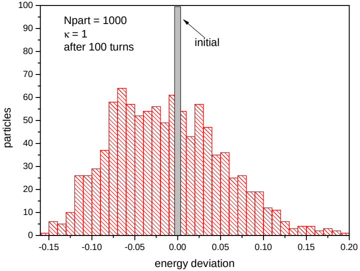
- Turn of bunch along the orbit $t_{\mathrm{turn}} = 1$ (unit of time).
- Synchrotron period T_{synch} (energy recovery) depends on the momentum compaction, RF voltage, ring's length.
  Ranges from 2 (double–chicane scheme) to 100.
- Gamma generation pulse T_{gamma} length of single pulse of generation in turns.
  Ranges from 10 (long ring) to 2500 (CLIC).
- Compton 'damping' time $T_{\mathrm{Comp}} = E_{\mathrm{e}} / \langle E_\gamma \times f_{\mathrm{conv}} \rangle$ (f_{conv} is average number of scattered photons per electron–turn), ranged from 55 turns (ILC 1.8 GeV) to 100 turns (ILC 1 GeV) CLIC 10 . . . 20 times longer
- Synchrotron cooling time $T_{\mathrm{cool}} = E_{\mathrm{e}} / \Delta E_{\mathrm{synch}} \gg T_{\mathrm{Comp}}$

Stationary generation: $T_{\mathrm{gamma}} \gg T_{\mathrm{Comp}} \gg T_{\mathrm{synch}}$ allows analytical description
CLIC: $T_{\mathrm{gamma}} \approx T_{\mathrm{Comp}}$ simulation required
ILC: $T_{\mathrm{gamma}} < T_{\mathrm{Comp}}$ simulation required

Simulations for Long and Short Rings

Long ring (10 turn generation), P. Gladkikh, 2008; Short ring (100 turn generation)

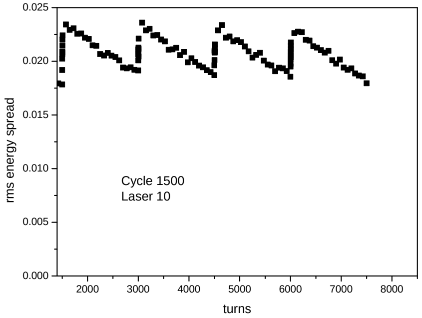




RMS spread smaller in the long ring. Span about the same: the distribution is flipping around zero after generation cycle.

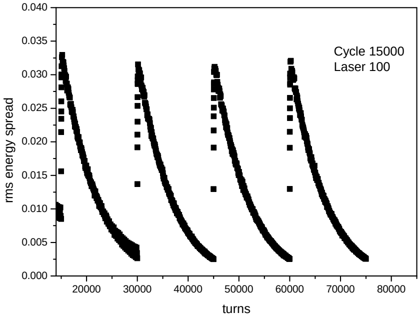
Simulations of Real Sources

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 (0.3 vs. 0.225)

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)
  or reduced spread by $1/\sqrt{2}$ times at the same energy of gammas (1.4 GeV electrons)
- CLIC–like long bursts (semi–steady mode) deserves attention: lower laser power needed,
  but (pre) accumulation of positron bunches as for ERL source

Yield vs. Laser Pulse Length

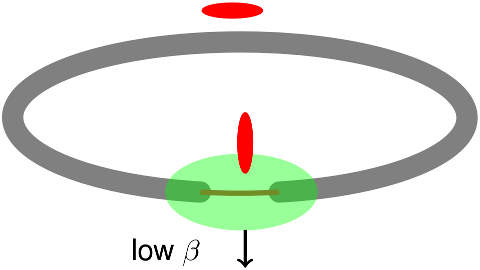
CLIC-like Ring: 1.03 GeV, 2546/14888 Work Cycle, $\phi = 8^{\circ}$

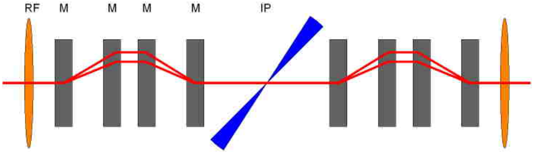
Pulse length, mm	Yield/e/cycle
1.92	100
0.96	126
0.48	145
0.24	150

For the case the yield of gammas shows weak dependence on the laser pulse length.

Ring: A Method to Reduce Spread

Longitudinal Low-β Insertion (Junji Urakawa, 2006)





Idea: Strong Focusing

- Emittance (not spread) is conserved.
- Balance 'heating–cooling' at IP determines the spread.
- Chicane+RF transforms the emittance.
- RF+chicane restores the emittance.