Analytic Study on Compton Rings

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Work supported by “Grant-In-Aid for Creative Scientific Research of JSPS (KAKENHI 17GS0210)”
PosiPol’09 Lyon, 23 June 2009

Underline

- Advantages and limitations of ring-based Compton gamma sources
- Large recoils from scattered off gammas: how to overcome
- Steady–state spread and continual generation
- Laser cooling of electron bunches in gamma sources

Advantages
c.f. baseline undulator-based

- Independence on the electron leg of a collider
  - Enables the positron leg to be maintained and operated independently from the electron's
  - Possibility to transform positron bunches before input
- High polarization degree
- Wide beam of gamma, easy to collimate

Limitations and Drawbacks

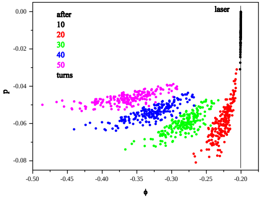
- Technological limitations (will be overcome in future)
  - High power in laser pulses necessary
  - High electron currents and dense bunches required
- Essential limitations
  - Large recoil underwent electrons while scattering off laser photons
    each scattered gamma carries away the energy up to

    $$\Delta\gamma \leq 4\gamma^2\gamma_{\rm las}$$

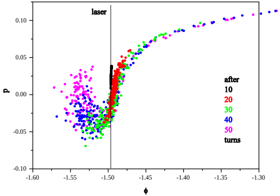
    (YAG laser: 20 MeV for $E_{\rm b} = 1$ GeV, 30 MeV for 1.3 GeV, and so on)
  - For the next turns the electron may avoid scattering

Pulsed Operation of Gamma Sources

RF Phase Manipulation, [Phys. Rev. ST-AB, 2006]



ILC CO2 ring, no RFPM

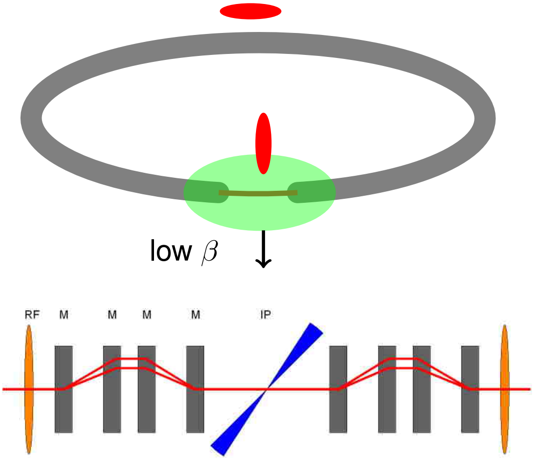


ILC CO2 ring, RFPM

- Storage ring with RFPM makes possible to get necessary yield (60 gammas per 100 turns per electron)
- Scheme requires nonlinear orbit compaction with rather low linear term
- Very large deviation of momenta (causes problems with the transverse motion)
- Stability problems for intense bunches would arise because of the weak longitudinal focusing and the short bunches along the orbit
- Train length should not exceed half of the synchrotron period: the scheme requires high laser power and wigglers for intercooling

Strong Longitudinal Focusing

Longitudinal Low–β Insert (Idea: Junji Urakawa, 2006)



- Emittance (not spread) preserved along ring's orbit.
- Spread locked within the chicanes.
- Balance 'heating–cooling' at CP determines the spread.
- Short bunches within chicanes, low spread beyond.
- LLBI scheme is capable to produce long trains of gammas.

Goals

- Is it possible to get continual generation of gammas?
- Can we rid off the cooling wigglers?
- What is ‘minimal’ Compton ring?

Compton X–ray Rings
Model: low intensity wide laser pulse

Partial energy spread, $\Delta y = \Delta\gamma/\gamma$, induced by interactions of circulating electrons with the laser pulse,

$$\sigma_y^2 = \frac{\left\langle(\Delta y)^2\right\rangle}{4\left\langle\Delta y\right\rangle} = \frac{7}{10}\gamma\gamma_{\rm las}$$

for Compton scattering $\langle\Delta y\rangle = 2\gamma\gamma_{\rm las}$, $\left\langle(\Delta y)^2\right\rangle = 28/5(\gamma\gamma_{\rm las})^2$
as was obtained earlier and verified by simulations,
independent on the laser pulse power
and machine parameters.

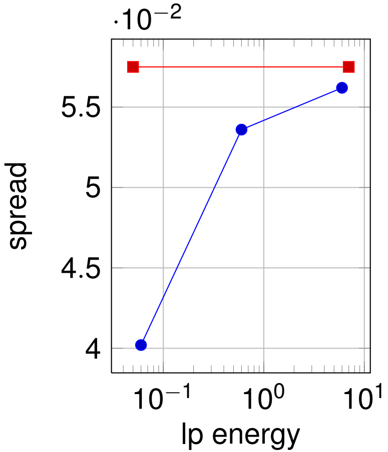
Compton Gamma–ray Rings

Dependence of spread on laser power

- In gamma rings the electron may scatter off several photons per pass of CP. The ratio of mean squared losses to average losses becomes dependent on the power in the laser pulse. The steady–state spread increases with the laser pulse power.
- Symmetry between number of electrons per bunch and number of laser photons per pulse is broken:
  - Yield proportional to $N_{\mathrm{electrons}} \times N_{\mathrm{photons}}$
  - Spread (and bunch length) increases with N_{photons}
- To increase yield it is preferable to store more electrons

Compton Gamma–ray Rings

Dependence of spread on laser pulse dimensions

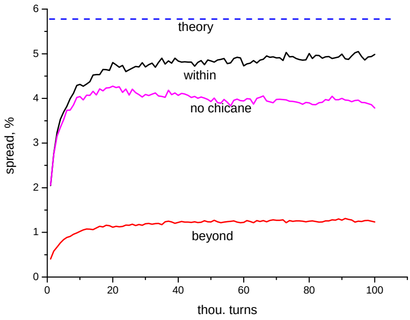


- If only the central volume of the bunch interacts with the laser pulse (small dimensions of the laser pulse) then:
  - Heating of the bunch remains the same
  - Cooling increases up to twofold (maximum cooling from point–size laser pulse)
- Spread decreased, by factor $1/\sqrt{2}$ maximum

Effect of intensity of the pulse is reverse to the effect of its dimensions

Compton Gamma–ray Rings

Spread in double–chicane ring



- Strong longitudinal focusing:
  - High synchrotron frequency, period of oscillations is about two turns
  - Small amplitude of oscillations at CP
- Energy spread reads

$$\sigma_y^2 = \beta_{cp} \left\langle \frac{1}{\beta} \right\rangle \boxed{\frac{7}{10}\gamma\gamma_{las}}$$

Simulations: spread in LLBI was not decreased

Transverse Laser Cooling

Analytics and simulations

Partial transverse Compton emittance

$$\epsilon_{x,z} \approx \frac{3}{10}\beta_{x,z}^{(CP)}\frac{\gamma_{\rm las}}{\gamma}$$

and dimensions

$$\sigma_{x,z}^2 = \frac{\beta_{x,z}^2\gamma_{\rm las}}{3\gamma}$$

will help to get dense bunches to collide with the laser pulses.

- Simulations for $E = 1$ GeV Chicanes
  - $\epsilon_{x,z} = (21, 1.05) \times 10^{-9}$ m rad
  - $P_{\rm las} = 0.6$ J, $5\,\mu$m $\times$ 0.9 mm
  - $8^{\rm o}$ crossing in (x, y) (horizontal) plane
- Results of simulation
  - $\beta_{x,z} = 0.5$ m — $\epsilon_{x,z} = (45.6, 7.47) \times 10^{-11}$ m rad (theo $\epsilon_{x,z} = 1.65 \times 10^{-10}$ m rad)
  - $\beta_{x,z} = 0.05$ m — $\epsilon_{x,z} = (26.8, 1.9) \times 10^{-11}$ m rad (theo $\epsilon_{x,z} = 1.65 \times 10^{-11}$ m rad)

Summary

- Spread of energy in Comptom ring is controllable
- Better way to enhance yield is to increase beam current than to store more laser photons
- 'Thin' laser waist is preferable
- Compton ring can operate in continual mode with laser cooling (no wiggler required)
- Very high rf-voltage necessary (about 100…200 MV)
- Collision insertion – chicanes + transverse low betas – has to be designed

Outlook. Minimal machine

- ILC baseline
  - Average electron current 50 μA
  - Positron current $=$ electron's$\times$1.5 (50 % overhead)
  - Gammas–to–positrons conversion 0.005, equiv current of gammas $0.05 \times 1.5/0.005 = 15$ mA
  - Ring's electrons–to–gammas conversion at 0.6 J of pulse $= 0.04$
- Minimal stored current 350 mA (ILC), 100 mA (CLIC) is attainable.
- Enhancement in gammas–to–positrons conversion is of prime importance

Simulation of Continual Mode

1.03 GeV, YAG laser 0.6 J, Max $E_{\mathrm{gamma}} = 20$ MeV

- Input
  - 100000 turns
  - betaX = 0.6, betaZ = 0.2,
  - alpha1 = 2.0E-4
  - emit0X = 2.1E-8,
  - emit0Z = 1.05E-9,
  - Urf = 2E8,
  - Frf = 2E9,
  - harmNUM = 312,
  - synLOSS = 20000.0,
  - lambdaChic = 0.9688
- Output
  - dispFI 8.9871876E-02
  - dispP 5.8855113E-02
  - Xdim 1.4911203E-05
  - emitX 3.6549094E-10
  - Zdim 2.7703127E-06
  - emitZ 3.8011181E-11
  - total quanta scattered 3941.89975775439