Compton Ring Study Update

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Outline

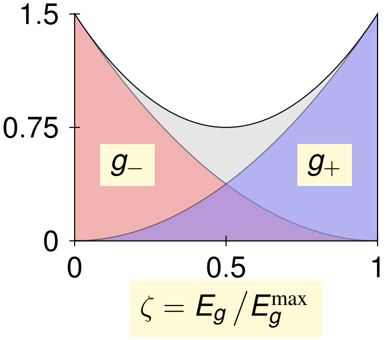
- Reminds
    - Advantages and limitations of Compton gamma sources
    - Advantages and limitations of ring-based Compton sources
    - Large recoils: how to coexist
    - Steady–state spread
- Compton ring update
    - Laser cooling of beams in gamma sources
    - Choice of electrons energy
    - Self–sustained generation of positrons
- Summary and outlook

Advantages of Compton gamma sources

- Autonomous operation
  - Independent construction
  - Enables positron wing operates independently from electron's one
  - Possibility to transform positron bunches to meet the requirements
- High energy of gammas attainable with moderate energy of electrons

Advantages of Compton gamma sources

Gammas Spectrum and Polarization



- High polarization degree (only fundamental harmonic generating)
  - High energy gammas, g_+, mostly polarized positively
  - low energy ones, g_-, negatively
- Wide gamma–ray beam, easier to collimate, lesser power density on the conversion target

Compton Rings: Advantages and Limitations

Yield (number of gammas per second)

$$Y = \sigma_C \mathcal{P} \mathcal{G} \ ,$$

$$\mathcal{P} = N_e N_{las} f_{col} = J_{beam} N_{las} / e \ ;$$

$$\mathcal{G}^{-2} = (2\pi)^2 \left(\sigma'^2_z + \sigma^2_z \right) \left[\sigma^2_x + \sigma'^2_x + \left(\sigma^2_y + \sigma'^2_y \right) \tan^2 \phi/2 \right]$$

σ_C Compton cross section, $\mathcal{P}$ power factor, $\mathcal{G}$ geometrical factor, N_e bunch population, N_{las} laser pulse population, f_{col} frequency of bunch-to-pulse crossings, J_{beam} average beam current.

For storage rings

- $\mathcal{P}$ – maximal ($J_{beam} \gtrsim 1$ Amp)
- $\mathcal{G} = \mathcal{G}(\mathcal{P})$, $\partial\mathcal{G}/\partial\mathcal{P} < 0$ – geometrical factor decreases with power

Limitations and Drawbacks

Principal limitations

- Large recoil 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

For storage rings $\left\langle \left(\frac{\Delta\gamma}{\gamma}\right)^2 \right\rangle = \frac{7}{10}\gamma\gamma_{\rm las}$

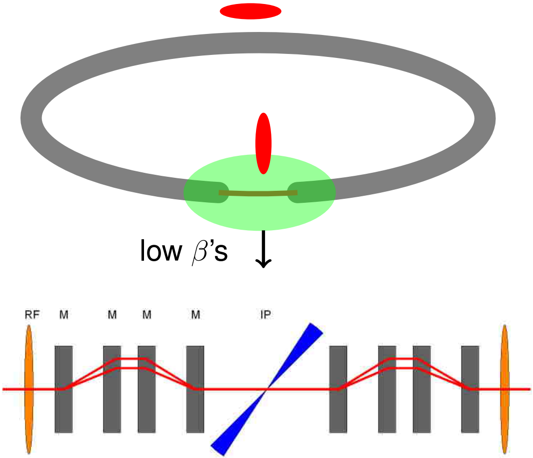
Laser Cooling in Compton Storage Rings

- Basic principles of laser cooling
  - Longitudinal: energy losses $\propto \gamma$, excitation independent.
  - Transversal: momentum losses mostly along the trajectory, excitation independent.
  - Multiturn recovery of losses caused by RF voltage results in stationary emittances and energy spread
- Items facilitate the cooling
  - Laser dominated losses
  - Small amplitudes of betatron and synchrotron oscillations at CP $\rightarrow$ low transversal and longitudinal β–functions
  - Smallest attainable laser pulse dimensions at CP (nonlinear cooling)

Flat laser pulse also enhances the yield

Ring: A Method to Reduce Phase Volume

Low-βs insertion



Steady state = balance 'heating–cooling'

- Heating (per collision) independent
- Cooling inversely prop to βs at CP
- Cooling inversely prop to laser dimensions at CP the height is most important

Simulated Array of Simulated Compton Rings

Lattice with laser cooling conditions: $\beta^{cp}_{hor} = \beta^{cp}_{vert} = 5\,\mathrm{cm}$

Laser pulse: length 0.9 mm, width 25 μm, height 2 μm

param	units	spectrum ≈ undul	base ring	beam dynamics
E_{beam}	GeV	0.75	1.06	1.5
E^{max}_{gamma}	MeV	10	20	20
E_{las}	eV	1.16	1.16	1.16/2
U_{rf}	MV	141	200	200
ϵ_{hor}	10^{-10}m	0.66	2.2	14.5
ϵ_{vert}	10^{-11}m	1.8	2.0	5.2
σ^{cp}_{E}	%	4.7	5.8	4.7
yield	1/(e turn)	0.14	0.12	0.08/0.16

Half of particles lost in 200k turns

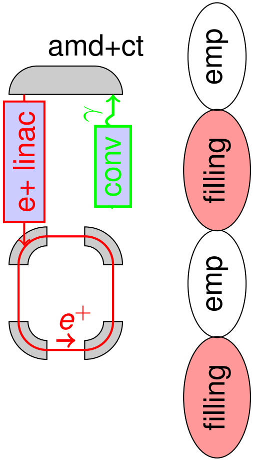
Verdict: *No sufficient enhancement from 2 μm laser*

Feasibility of Compton Rings

- 1 GeV storage ring with 1 μm laser optimal for polarized e^{+} generation
- Effective generation of gammas requires laser pulses up to 0.5 J of energy.
- More gammas require more electrons and better geometry of bunches and pulses at CP
- 1 GeV Compton ring capable to produce about 1 mA of average current of polarized positrons, in a good excess of ILC/CLIC requirements

Self–Sustained Generation of Polarized Positrons

Accumulating (pre-damping) ring acts as Compton ring



Steps of operation (interleave filling)

1. Ignition with conventional source (hybrid target ?)
2. Cooling of stored bunches -> filling of empty rf-buckets, the laser on
3. Extraction of cooled bunches, switching the laser to 'full' buckets

... Steps 2–3 repeat in cycle (polarized positrons)

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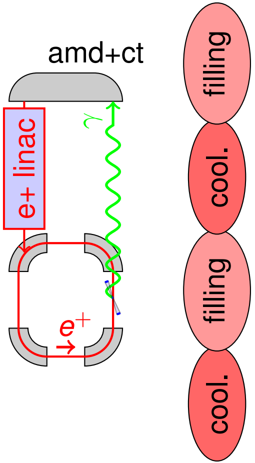

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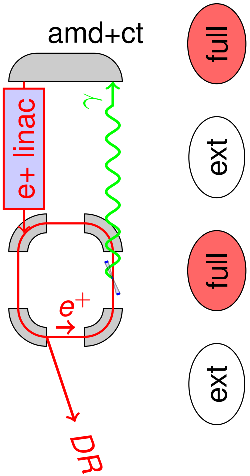

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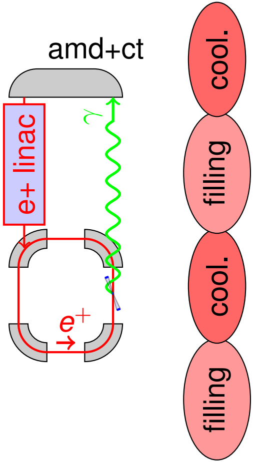

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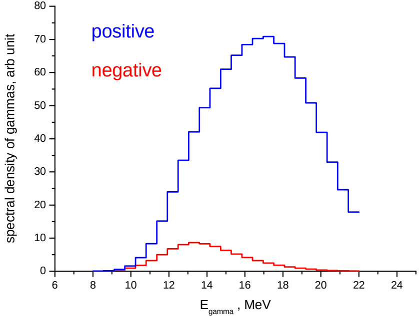
Compton Ring ≡ Pre-damping/Accumulating Ring

Simulated performance: 1 GeV + 1 μm



Base + positrons, 2000 turns/cycle

- Extracted positron bunch
  - emittances
    $\epsilon_{\mathrm{hor/vert}} = (22/2) \times 10^{-11}\mathrm{m}$
  - r.m.s. energy spread beyond chicanes 1 %
  - r.m.s. length 7.4 mm
- Gammas in cooling cycle
  - total # 240 per positron
  - impinged conv. target 96 (40 %)
  - polarization 85 %

Summary

- The laser–cooling Compton rings capable to generate necessary flux of gammas in continual mode – Positron bunches resemble themselves in 1000 – 2000 turns.
- Laser cooling of bunches in the pre–damping ring is a logical upgrade from conventional to polarized positron source.

Outlook

Problems to overcome

- Timing of the operation of positron source:
  Would T.Omori and L.Rinolfi consider?
- The flat and dense laser pulses with up to 0.5 J/pulse(s).
- Conventional source of gammas/positrons for ignition.
- High–voltage rf (up to 200 MV), fast kickers.
- Injection, extraction of positrons.

Determinations and assignments

- Lorentz–factor of electrons (positrons) $\gamma = E_{\mathrm{e}}/m_0 c^2$
- Equivalent Lorentz–factor of laser and gamma-ray photons $\gamma_{\mathrm{las,g}} = E_{\mathrm{las,g}}/m_0 c^2 = \hbar\omega_{\mathrm{las,g}}/m_0 c^2$
- Collision angle φ the angle between trajectories of electron bunch and laser pulse ($\varphi = 0$ for head–on)
- Scattering angle ψ the angle between bunch trajectory and gamma–ray

Transverse Laser Cooling

Analytics and simulations

Partial transverse Compton emittance

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

and dimensions

$$\sigma^2_{x,z} = \frac{\beta^2_{x,z}\gamma_{\rm las}}{3\gamma}$$

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

- Simulations for $E = 1$ GeV Chicanes
  - $\epsilon_{x,z} = (21, 1.05)$ nm rad
  - $P_{\rm las} = 0.6$ J, 5 μm $\times$ 0.9 mm
  - 8° 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)