An ultimate Compton ring for positron production and cooling

Eugene Bulyak, Frank Zimmermann, Junji Urakawa

Thanks to: P.Galdkikh, A.Dovbnya, T.Omori, L.Rinolfi

PosiPol 2012, Zeuthen, Sept, 2012

Work supported by the Quantum Beam Technology Program and in parts of KAKENHI 17GS0210 project of MEXT.

Outline

- Problem setup: what gamma beams necessary for positron production and applications
- Why storage ring is an efficient source
- Fast radiative cooling in Compton rings
- Ultimate ring: Summary and Outlook

Gamma Beams for Positrons Production

Reference source: max/ave energy 20/10 MeV, equ. current 5 mA (ILC)

- Non–head–on collision between electron bunches and laser pulses – 50 kW of gamma power unsustainable for mirrors
- Moderate yield: even with array of lasers available in near future, yield of gammas scattered per electron–pass through CP will not exceed 0.01...0.1 (actually it is not reasonable to overcome this level because of deterioration of the spectra).
- With 1 Amp of circulating current this yield is equivalent to $\approx 10^{17}$ gammas/s.

- Circumference (orbit length) 150 m – 0.5 μs, 2 MHz orbiting frequency.
- Beam energy 1 GeV.
- Average current 1 A.

Number of electrons in the orbit (3.1208×10^{12}, charge 0.5 μC). To build up this charge in the orbit it is necessary to spend 500.0 Joule of energy in beam's lifetime. (To compare with the linac: 1 GW of continuous power, 1 G Joule/s).

Drawbacks and How to Overcome

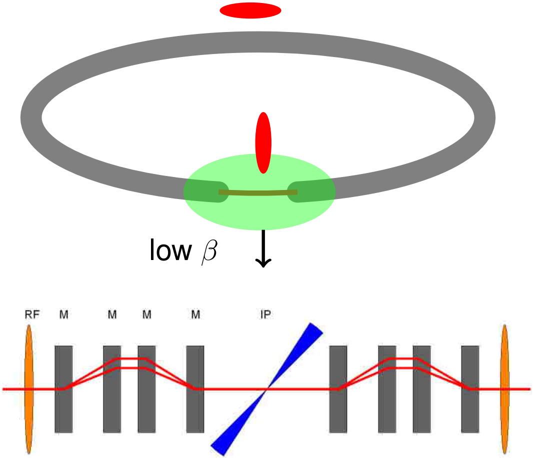
- Large recoil requires large energy acceptance
- Prolonging bunch length reduce the yield
- Fluctuations of the recoil increases quantum losses

Two ideas have been proposed:

- Longitudinal Low–Beta Insertion (in: E. Bulyak, P. Gladkikh, M. Kuriki, T. Omori, J. Urakawa, A. Variola, 2007)
- Asymmetric ‘fast’ cooling (E. Bulyak, J. Urakawa, F. Zimmermann, 2011)

A Method to Lock the Spread

Longitudinal Low-β Insertion (orig. idea: J.Urakawa, 2006)



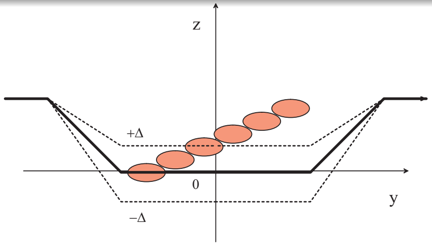
Idea: Strong Focusing

- Emittance (not spread) is conserved.
- Balance ‘heating–cooling’ at IP determines the spread.
- Chicane+RF rotates the emittance shape.
- RF+chicane restores the emittance shape.

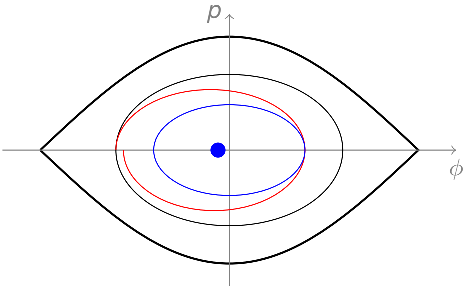
Necessary: RF-voltage > spread

for the model $U_{\mathrm{rf}} > 0.06 \times 1\,\mathrm{GeV} \approx 60\,\mathrm{MV}$

Asymmetric Collision Point



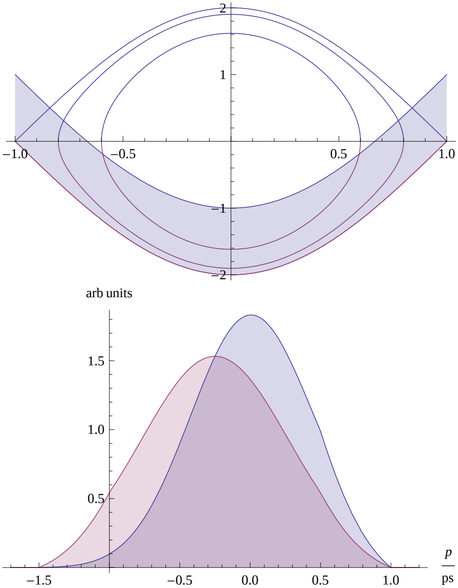
Model setup



Synchrotron phase plane

- Dispersion at CP provides transverse position–energy coupling
- Cooling in the upper half plane, $p > 0$, no heating below $p = 0$

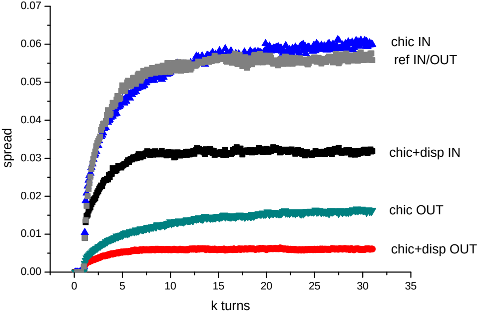
Quantum Lifetime



Density of scattered particles

- Steady–state density distribution over the longitudinal phase space
- Quantum losses caused by dropping down of particles from *band of losses*
- Width of the band equal to maximal recoil due to Compton scattering
- Asymmetry at CP may substantially reduce quantum losses

Ultimate Ring: Simulations
Model: 1.06 GeV + 1.16 eV, 20 CPs$\times$50 mJ



yield: 0+0: 0.013; chic+0: 0.008 (losses); chic+disp: 0.008; 0+disp: 0.005

Gamma ray source

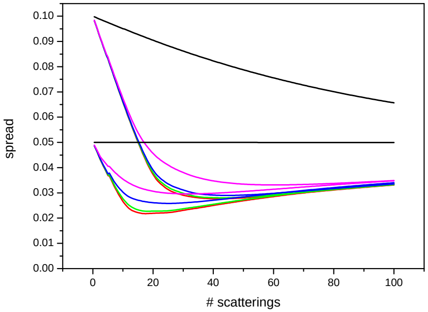
- Average yield eq. 10 mA (6×10^{16} gammas/s)
- Spectral density 10^{14} gammas/0.1% bw at 20 MeV
- Spectral brightness $\approx$ spectral density $\times 10^6 \approx 10^{20}$ /(mm^{2}mr^2 0.1% bw)

Positron source

Yield of polarized positrons 100 μA possible up to 0.5 mA

Fast Cooling

0.8 GeV + 1.16 eV, $g = (0, 1, 2, 3, 6) \times 10^{-3}$



- Faster non–exponential damping
- Smaller steady–state spread
- Low–energy cooling ring

Summary and Outlook

- Ring–based Compton gamma source will provide enough gammas for ILC/CLIC polarized positron source
- Asymmetric “fast” cooling eases realization of the intense gamma source due to the decreased spread:
  - decreased quantum losses
  - shorter the bunches
- Problems to solve
  - laser cavities – up to 0.5…1 J in the array
  - high RF voltage
- Long wavelength lasers are desirable for cooling rings
- Lasers with shorter wavelength may be employed for the lower-energy (less expensive, more compact) rings for applications

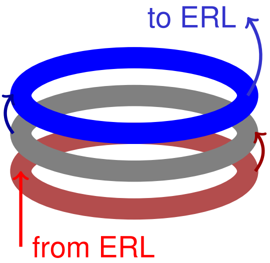
Proof–of–principle experiments to check up the ‘fast cooling’ scheme is highly desirable. Also some improvement to this scheme will be studied both theoretically and by simulations.

Min Current in Compton Ring

param	unit	SLC	CLIC (3TeV)	LHeC p–140	LHeC ERL
I_{e+} at IP	μA	0.96	18	290	7050
min I_{e-}	A	7.2E-3	0.13	2.2	53

Overhead 0.5 accounted.

LHeC ERL requirements exceed reasonable limits



- Basic cycle
  - *N*–turn injection from ERL in accumulating ring
  - *N*–turn cooling in cooling ring (laser fast cooling may employed)
  - *N*–turn slow extraction from extracting ring into ERL
- 1–turn transfer from cooling ring into extracting ring
- 1–turn transfer from accumulating ring into cooling ring

Average current in the cooling ring is $N\times$average ERL current.

Laser cooling may generate positrons to compensate losses.