Collimation and Polarization in Positron Sources

Summary of PosiPol WebEx/Fuze discussion

E.Bulyak, I.Bailey, W.Gai, J.Gronberg, M.Jenkins, W.Liu, T.Omori, S.Riemann, N.Shulga, F.Staufenbiel, A.Ushakov, J.Urakawa, *et al*

PosiPol'13, ANL, September 4, 2013

Outline

- Introduction. Subject of Discussion
- Polarization of gammas and positrons
- Difference between undulator and Compton spectra
- Collimation
- Effect of interference

Discussion on Collimation

Compton vs. Undulator Sources of Polarized Gammas

Starting points of discussion, October 2012

- No effect of collimation on polarization in Compton sources (Eugene Bulyak)
- Significant effect of collimation in undulator sources (Wei Gai, Friedrich Staufenbiel, Andriy Ushakov)

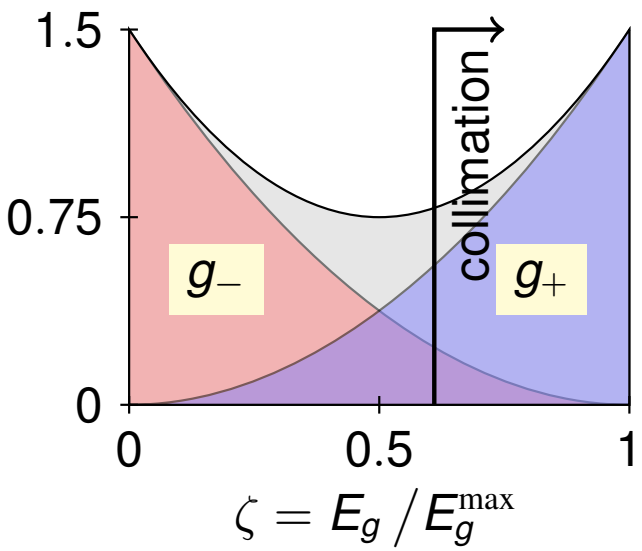
Compton radiation $\approx$ undulator radiation

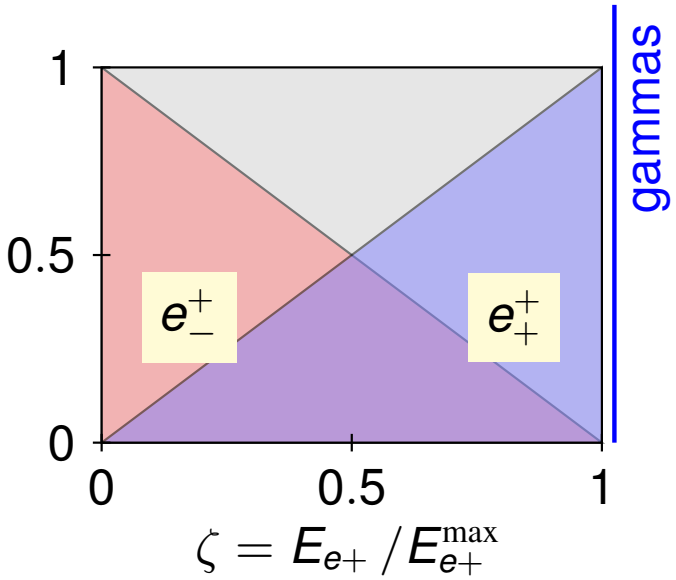
difference

- deflection parameter $\alpha \ll 1$
- # gammas per pass $\lesssim 0.1$
- $\lambda_\gamma = \frac{\lambda_{\rm las}(1+\alpha^2)}{4\gamma^2}$
- Quantum description

- deflection parameter $\alpha \lesssim 1$
- # gammas per pass $\lesssim 300$
- $\lambda_\gamma = \frac{\lambda_{\rm und}(1+\alpha^2)}{2\gamma^2}$
- Classical description

Transformation of Polarized Gammas into Positrons

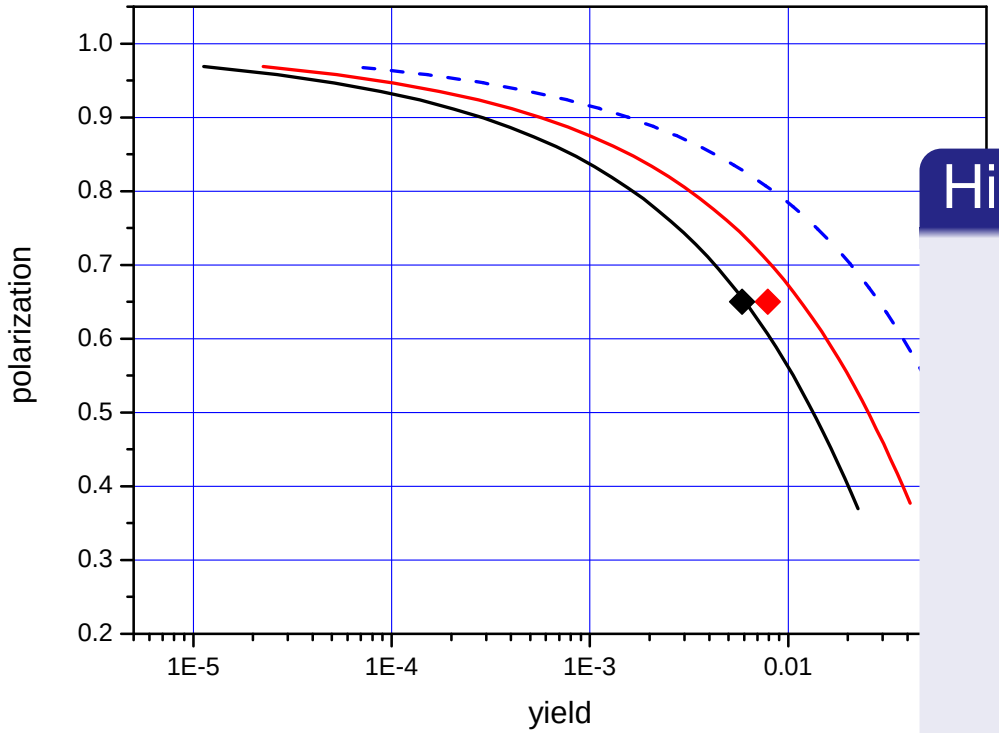




- Positively polarized gammas at high energy cutoff of the spectrum
- Positively polarized positrons at high energy cutoff of the spectrum
- Valid for any harmonics of gamma spectrum

Compton source – the only fundamental harmonics $\Rightarrow$ no effect of collimation (preselection) upon polarization

Maximal yield and polarization (Compton)



Envelopes for Ti and W targets (optimal thickness)
Diamonds: simulation
done by A. Schalicke, A. Ushakov, S. Riemann

Higher the polarization:

- lower the yield
- higher the quality of positron beam (smaller energy spread, emittance)
- thinner the conversion target, lower the power load

Argumentation. Undulator Source

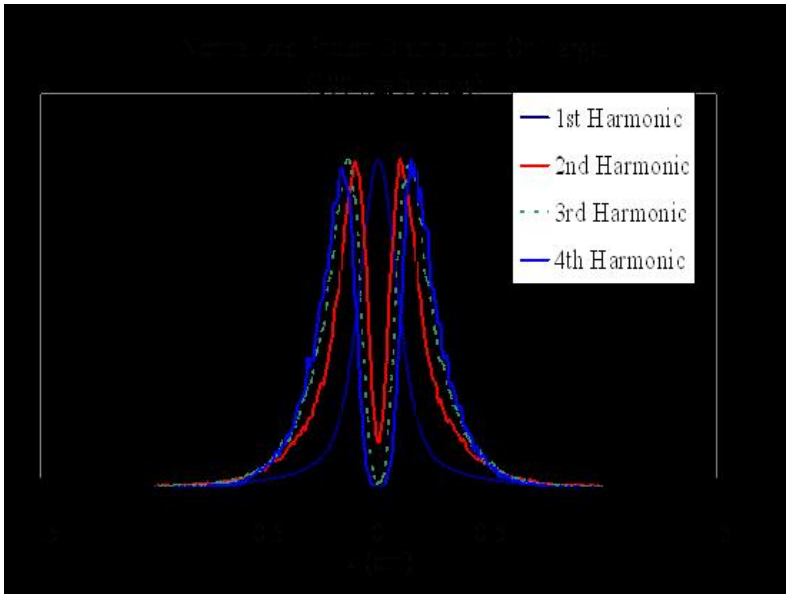
Collimation is important

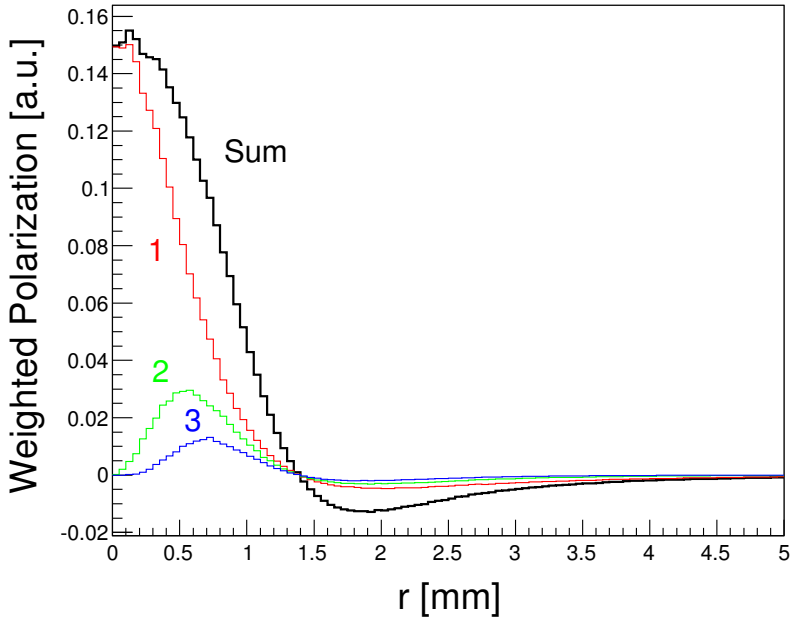
- Reduction of power load in conversion target (Friedrich)
- Mitigation of higher harmonics (Wanming, Andriy)

Undulator's Higher Harmonics

Wanming

Andriy

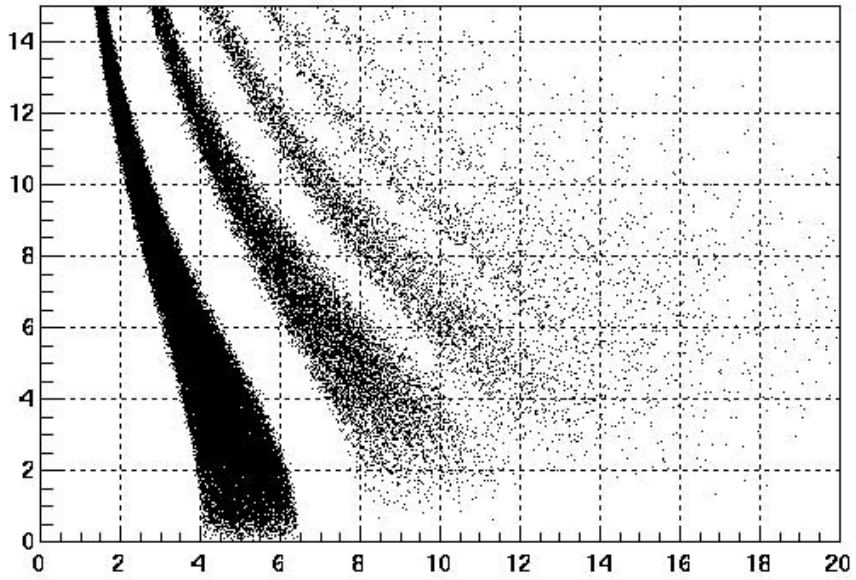




Spectral–Angular Density

From: Y.Kamiya et.al. *Experimental Study of Laser Compton Scattering . . .*

$\theta\gamma$, $\times 0.1$



X–ray energy, keV. $\alpha = 0.77$

- Energy of gammas at $1/\gamma$ angle = half of maximum, zero polarization. (γ the Lorentz factor of electrons.)
- Collimator opening angle of $(0.1 \ldots 0.2)/\gamma$ sufficiently mitigates higher harmonics

Polarization vs. Collimation

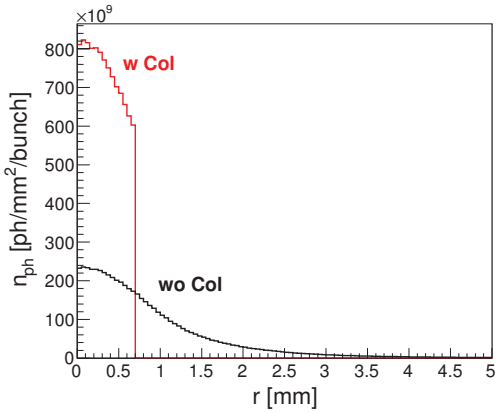
Andriy's slide

Intensity and Energy of Photons on Target

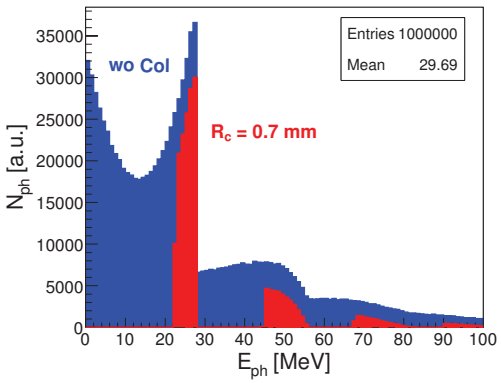
250 GeV e^-, $K = 0.92$

- L_u = 41.1 m wo collimator,
- L_u = 143.5 m with collimator $R_c = 0.7$ mm

Photon Density on Target after Bunch



Energy Distribution of Photons



Polarization destructed by higher harmonics

$$\mathrm{Plz} = \frac{\sum_i \mathrm{pos}_i - \sum_i \mathrm{neg}_i}{\sum_i \mathrm{pos}_i + \sum_i \mathrm{neg}_i}$$

- Second harmonics contribute to the denominator, third and higher diminish the numerator as well
- Positron production increase (logarithmical) with energy, i.e. harmonic number

Maximal Collimation Angle

Rough estimations, 150 GeV

- Angle $1/\gamma$ zero polarization
- Angular spread in electron bunch, $\left\langle (x')^2 \right\rangle = [\epsilon\gamma]/(\beta\gamma) < 1/\gamma^2$ (β the envelope of transversal oscillations)

$\beta > \gamma[\epsilon\gamma]$

For ILC $[\epsilon\gamma]_{x,y} = 10\,\mu\text{m}/35\,\text{nm}$

minimal beta functions average over the undulator

$\beta_{x,y} > 3\,\text{m}\,, 1\,\text{cm}$

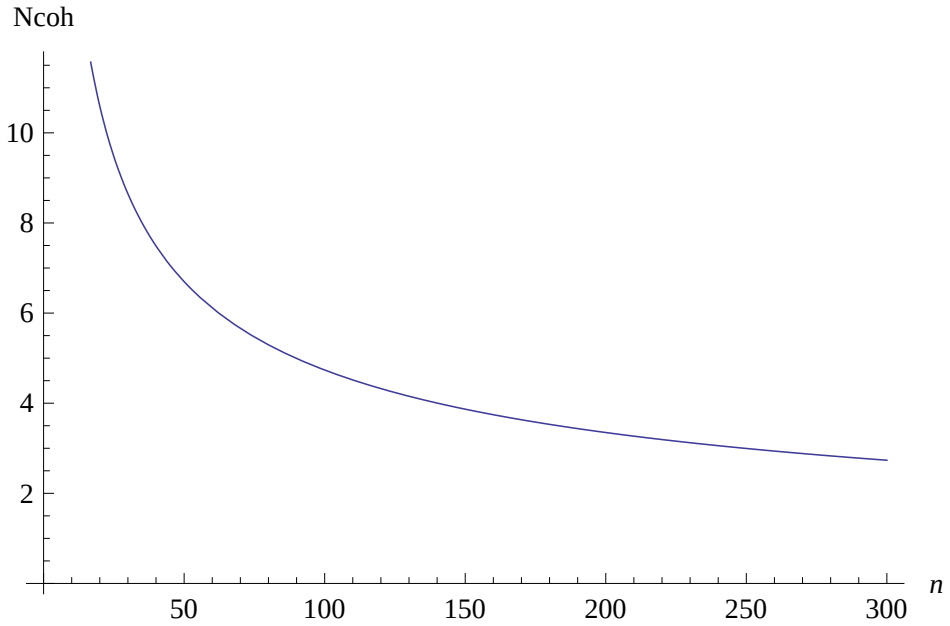
Central Petal Opening Angle
Interference of waves

- Central cone (classical) $\sim (\gamma\sqrt{N})^{-1}$ too small (N - # undulator periods)
- Quantum approach should at least $N_{\mathrm{undul}} \to N_{\mathrm{photon}}$ - # of quanta emitted by an electron over the undulator length

For energy spread was shown by: G. Geloni, V. Kocharyan, and E. Saldin *On quantum effects in spontaneous emission by a relativistic electron beam in an undulator.* arXiv://physics/1202.0691v1 (2012)

Number of Coherent Gammas

E.Bulyak, N.Shulga, 2013



Coherent gammas vs. # of emitted

$$\eta = 0.13 \frac{1}{\mathcal{N}\sqrt{n}} \left(\frac{E_\mathrm{b}}{\mathcal{E}_\mathrm{max}} \right) .$$

For ILC undulator $\mathcal{N} \approx 43$ periods/photon (number of periods to emit a photon); $n \leq 300$, $E_\mathrm{b} = 150\,\mathrm{GeV}$, $\mathcal{E}_\mathrm{max} \approx 10\,\mathrm{MeV}$, the undulator length $\approx 1.2 \times 10^4$ (127 meters at 11.5 mm period).

no coherence (interference) downstream beyond the undulator

Undulator = nonlinear Compton in gamma–ray range

Summary and Outlook

- Collimation is highly desirable to reduce the conversion target power load
- Polarization of positrons
  - No effect in Compton sources
  - Increase in undulator sources due to mitigation of higher harmonics
- Strength of transverse focusing of the electron beam over the undulator should fit the collimation opening angle
- Experimental study on polarized positron production may be carried out via Compton scheme on existing electron storage rings, e.g. ATF DR of KEK.