On Coherency of Gamma Photons

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Abstract

Intense beams of electromagnetic radiation in gamma region are in demand in a number of applications. These applications include nuclear nonproliferation, nuclear waste management requiring beams of gammas in MeV range and production of polarized positrons for future lepton colliders requiring energy of gammas above ten MeV. Coherency of radiation greatly increases its intensity at the target. We report estimates on production of coherent photons in gamma region by relativistic electrons in periodic structures. Two aspects of coherency were considered: nonlocal – coherency of photons emitted by a single electron over the system, and local – coherency of the photons emitted by a bunch of electrons at a given position. The first aspect provides density of radiation in proportion to squared number of photons per electron; the second aspect provides density proportional to squared number of electrons in a coherent bunch. As shown, the degree of coherency in both processes decreases with the increase of the energy of gammas, due to stochastic process of energy losses by the electron connected to quantum nature of the radiation emission. The degree of coherency for both processes is estimated analytically, as well as the overall coherency.

I. Coherent electrons

Width of the electron's spectrum increases due to radiation

Coherent field $F(X) = \int_0^X f(\gamma_*, x)dx$, spectral density $Sd(X) = \left[\int_0^X f(\gamma_*, x)dx\right]^2$.

A factor of 'overall' coherency:

$$Fc(X) = \frac{2\log F(X)}{\log X},$$

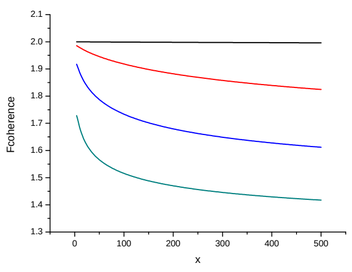
maximum = 2 (full coherent); minimum = 1 (incoherent).

Normal diffusion (gaussian):

$$f(\gamma, x) = \frac{1}{\sqrt{2\pi(x\sigma^2 + \sigma_0^2)}} \exp\left[-\frac{(\gamma - \gamma_*)^2}{2(x\sigma^2 + \sigma_0^2)}\right],$$

for $\beta \equiv \sigma/\sigma_0$: $F(X,\beta) = \frac{2\left(\sqrt{\beta^2 X+1}-1\right)}{\beta^2}$, $\lim_{\beta\to 0} F(X,\beta) = X \quad \to \quad Fc(X) = 2$;

$\lim_{X\to\infty} F(X,\beta) \sim \sqrt{X} \ \to \ Fc(X) \geq 1$

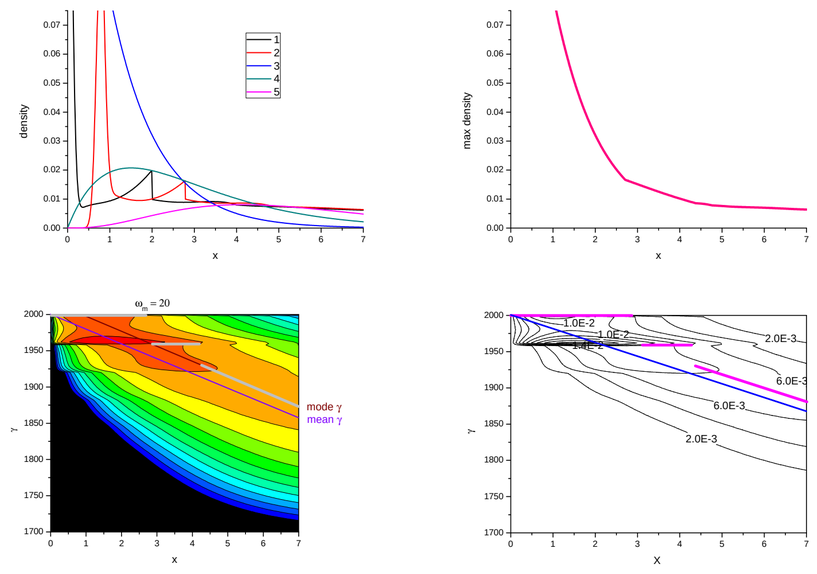


Coherence factor

$\sigma/\sigma_0 = 0.01, 0.1, 0.25, 0.5$ from top to bottom

$SB_{coh}/SB(\sigma/\sigma_0) = 1.02, 3, 11, 37$ at $X = 500$

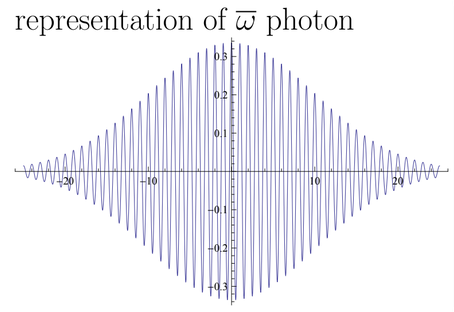
Undulator tuning



I. Coherent photons

- The 'average' electron (given spectrum) emits a photon pulse
- Sampling of the photons' stream
- Derivation of the photons coherence parameter

representation of $\overline{\omega}$ photon



Different names for the same

- electromagnetic pulse 'carrier–envelope'
- Gabor wavelet – signal processing
- a wave function (package) of the massless particle

Coherence Factor

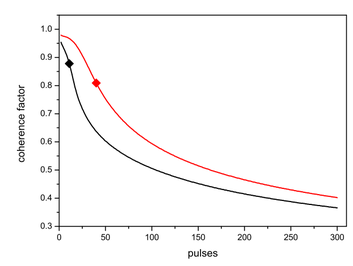
$$\mathcal{C}_k = \frac{\log\left[\int_t \left(\sum_{i=1}^k P_1\right)^2 \mathrm{d}t\right]}{\log k}$$

$\mathcal{C}_k = 2$ full coherence, $\mathcal{C}_k = 1$ incoherent photons.

$k(k-1)/2$ cross terms responsible for coherence

Cross term for Gaussian pulses

$$T_{i,j} \approx \sqrt{\frac{2\sigma_i\sigma_j}{(\sigma_i^2+\sigma_j^2)}}\, \mathrm{e}^{\left[-\frac{\sigma_i^2\sigma_j^2(k_i-k_j)^2+\tau^2}{2(\sigma_i^2+\sigma_j^2)}\right]} \cos\left[\tau\frac{k_i\sigma_i^2 + k_j\sigma_j^2}{\sigma_i^2+\sigma_j^2}\right].$$



Undulator

non-tapered and tapered helical undulators, $K = 1$

Summary

The degree of coherency in both processes decreases with the increase of the energy of gammas, due to stochastic process of energy losses by the electron connected to quantum nature of the radiation emission. The degree of coherency for both processes is estimated analytically, as well as the overall coherency.