Compton Polarimeter: IP

Nickolai Muchnoi

www.muchnoi.net

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Gaussian beam of laser radiation

$\sigma(z)$ is the radius where intensity $I(z,r)$ falls to 1/e of its axial value:

$$\sigma(z) = \sigma_0\sqrt{1+(z/z_R)^2} = \theta_0\sqrt{z^2+z_R^2}$$

- σ_0 is the beam radius at waist,
- $z_R = \frac{4\pi\sigma_0^2}{\lambda_0}$ is the Rayleigh length,
- $\theta_0 = \frac{\sigma_0}{z_R}$ is the far field divergence.

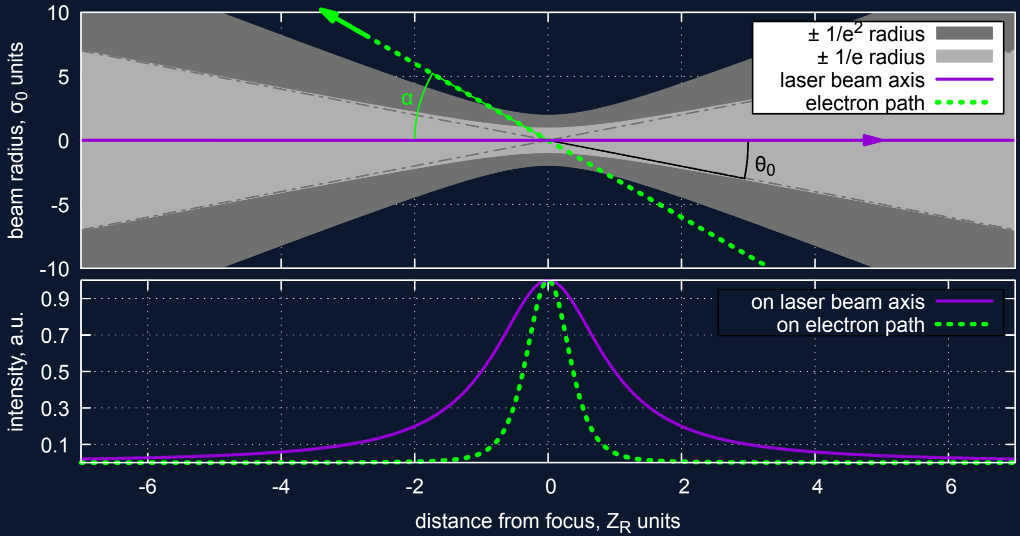
$$\sigma(z) = \sqrt{\epsilon\beta(z)}$$

- $\epsilon = \frac{\lambda_0}{4\pi}$ is the beam emittance,
- $\beta(z) = \beta_0 + \frac{z^2}{\beta_0}$ is the β-function,
- $\beta_0 \equiv z_R,\ \sigma_0 = \sqrt{\epsilon\beta_0},\ \theta_0 = \sqrt{\frac{\epsilon}{\beta_0}}.$

$$I(z,r) = \frac{P}{2\pi\sigma^2(z)}\exp\left(-\frac{r^2}{2\sigma^2(z)}\right)\ [\mathrm{W}\cdot\mathrm{cm}^{-2}]$$

For $\lambda_0 = 532$ nm $\epsilon = 42$ nm. For FCCee $\epsilon_x \simeq 0.5$ nm, $\epsilon_y \simeq 1$ pm.

IP with CW laser: $\alpha/\theta_0 = 3$



Backscattering of CW laser radiation

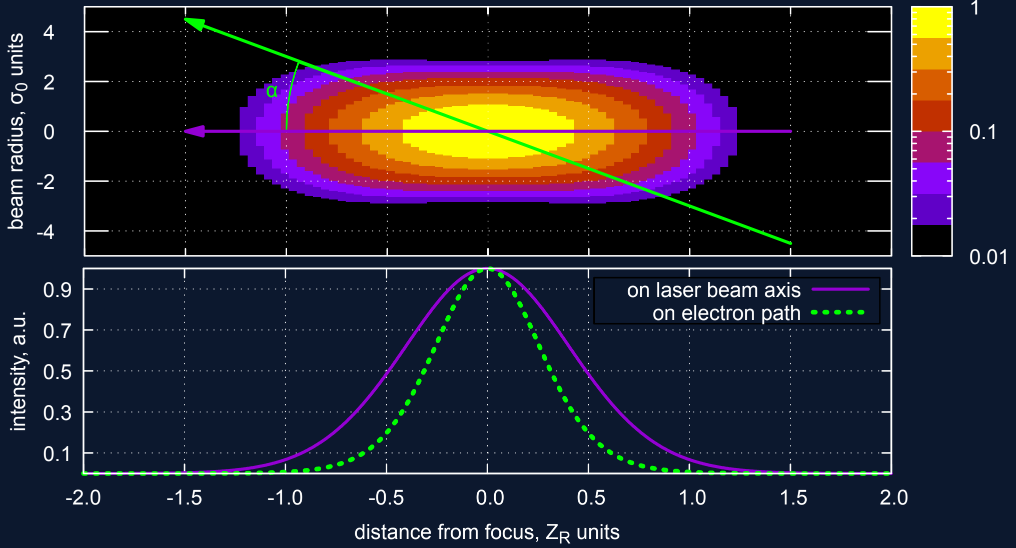
For $\alpha = 0$ the probability of electron scattering depends on laser power P and the $\pm L$ segment, centered at $z = 0$, on which the electron trajectory coincides with the z - axis:

$$W = \frac{P}{P_c} \cdot \frac{\arctan(L/z_R)}{\pi/2}\,, \text{ where } P_c = \frac{hc^2}{4\pi\,\sigma_\text{T}} \simeq 0.7 \cdot 10^{11}\ \ [\text{W}]\,.$$

Interaction angle α affects the following scattering parameters:

- In the lab frame the frequency of laser photon, seen by relativistic electron, will be smaller: $\omega_0^* = \omega_0 \cos^2(\alpha/2)$.
- Decrease in reference frequency accuracy: $\dfrac{\Delta\omega_0^*}{\omega_0^*} = \dfrac{\Delta\omega_0}{\omega_0} \oplus \Delta\alpha \tan\dfrac{\alpha}{2}$.
- Overlap with laser target (could be improved by short laser pulses).
- Photon target density in the lab frame: $\rho^* = 2\rho\cos^2(\alpha/2)$.

IP with pulsed laser: $\alpha/\theta_0 = 3, c\tau/z_R = 1$

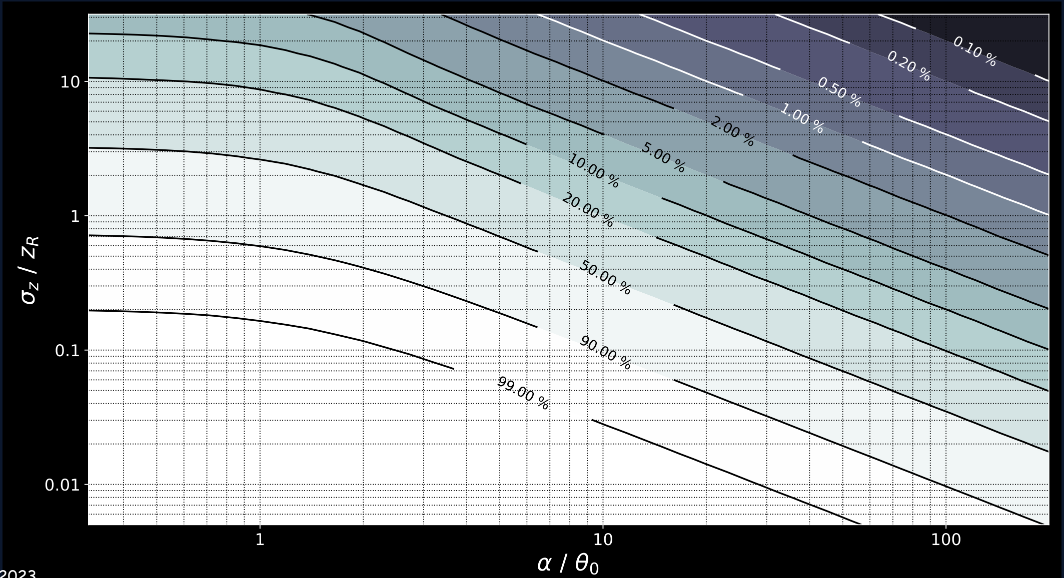


Backscattering of pulsed laser radiation

For $\alpha = 0$ and laser pulse length $\sigma_z = c\tau \ll z_R$ the probability of electron scattering is determined by the pulse energy E and the Rayleigh length z_R :

$$W_0 = \frac{E/z_R}{U_c}\text{ , where } U_c = \frac{hc}{2\,\sigma_\mathsf{T}} \simeq 1.5\,\left[\mathsf{J}\cdot\mathsf{mm}^{-1}\right].$$

Scattering efficiency W/W_0 :



Use of above considerations

1. Approximate transverse $e^{\pm}$ bunch sizes are $\sigma_x \simeq 0.5$ mm, $\sigma_y \simeq 0.02$ mm.
2. Assume a bunch of 10^{10} e^-/e^+ circulating with frequency 3 kHz.
3. Assume we want $\simeq 100$ scattering events per turn ($3 \cdot 10^5$ per second).
4. The scattering probability $W \simeq 10^{-8}$ per turn ($\simeq 3 \cdot 10^{-5}$ per second).
5. The beam lifetime due to scattering is about $3.3 \cdot 10^4$ seconds ($\simeq 10$ hours).
6. Assume we have a laser with $E = 1$ mJ pulse energy.
7. With "zero" pulse length we need $z_R = 10^{-3}/1.5 \cdot 10^{-8}$ mm $\simeq 67$ m.
8. Green laser light with $\lambda_0 = 532$ nm has emittance $\epsilon = 42$ nm.
9. Corresponding waist size $\sigma_0 = \sqrt{\epsilon z_R} \simeq 1.7$ mm ($\simeq 3 \times \sigma_x$).
10. Far field divergence $\theta_0 = \sqrt{\epsilon / z_R} \simeq 0.025$ mrad (misprint in TUPBB03'18).
11. Pulse length $\tau = 1$ ns ($\sigma_z = c\tau = 30$ cm) gives $\sigma_z / z_R \simeq 0.005$.
12. With $\alpha = 100 \cdot \theta_0 \simeq 2.5$ mrad $W/W_0 > 90\%$.

Use of above considerations: continue

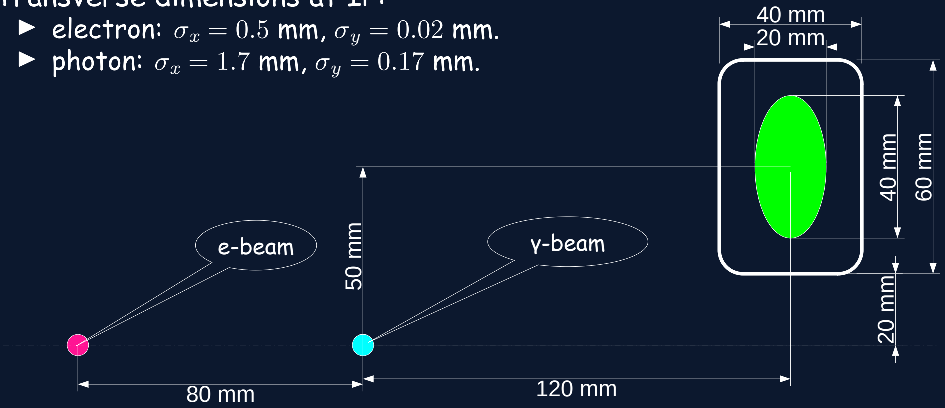
13. "Zero beam size" approximation is satisfied to a sufficient extent.
14. Compton cross section at $E = 45$ GeV is $\simeq 50\%$ from σ_T:
    We obtain 50 scattered photons per pulse out of the planned 100.
15. Perhaps we want to have not 100 but 500 (2 hours beam lifetime)?
16. Can we increase efficiency by 10 times?
17. Possible solutions:
    - Increase pulse energy.
    - Improve focusing i.e. decrease z_R.
    - Use elliptical optics: keep horizontal z_R and make vertical $z_R/100$ ($\sigma_0/10$).

$$W_0 = \frac{E/U_c}{\sqrt{R_x R_y}}\,,\ \text{where } U_c \simeq 1.5\left[\mathsf{J}\cdot\mathsf{mm}^{-1}\right].$$

18. $R_x \simeq 70$ m, $R_y \simeq 0.7$ m gives factor $\times$10 and $\theta_0^y = 10 \cdot \theta_0^x = 0.25$ mrad.

Use of above considerations: continue

19. Assume the vacuum mirror installed 50 m downstream IP:
    - laser spot sizes: $\sigma_x = 2.1$ mm, $\sigma_y = 4.0$ mm.
    - mirror center-to-beam separation required $\Delta_x = 2.5 \cdot 50 = 125$ mm.
20. Transverse dimensions at IP:
    - electron: $\sigma_x = 0.5$ mm, $\sigma_y = 0.02$ mm.
    - photon: $\sigma_x = 1.7$ mm, $\sigma_y = 0.17$ mm.



Summary

- Few mrads interaction angle was considered by a simple method for the scattering efficiency estimation.
- The required scattering rate could be achieved with $\simeq 1$ mJ pulse energy.
- Pulse shorter than 1 ns do not increase the efficiency with $\alpha \simeq 2.5$ mrad.
- Aurélien's suggestion: pulse RMS width $\tau = 10$ ps.

  Spectrum width for head-on electron: $\dfrac{\sigma_{\omega_0}}{\omega_0} = \dfrac{\lambda_0}{\pi c \tau} \simeq 56$ ppm ($\lambda_0 = 532$ nm).

  Absolute scale $\dfrac{\Delta\lambda_0}{\langle\lambda_0\rangle} \simeq 1$ ppm. These parameters are quite acceptable.
- With $\alpha = 1^\circ$ and $\Delta\alpha = 0.1^\circ$ one has $\dfrac{\Delta\lambda_0}{\langle\lambda_0\rangle} \simeq 8$ ppm, so $\Delta\alpha = 0.01^\circ$ is OK.
- Q-switched laser is a simple solution for 1 bunch (3kHz) operation, but it is definitely not suitable for colliding bunch polarization control.