Chapter 1

Introduction to Compton scattering

Compton scattering is the scattering of a photon by an electron. It has first been proposed when describing the process that occur in the atomic shell where the photons have more energy than the electrons. As the typical energy of a visible photon is about 1 eV whereas the typical energy of an electron in an accelerator is several MeV, this process is called *Inverse Compton Scattering*. It is represented by the Feynman diagram on figure 1.1.

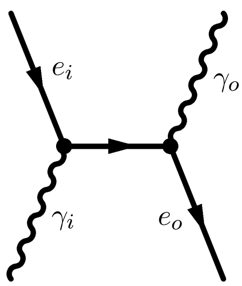

Figure 1.1: Feynman diagram of Compton scattering.

In this process the outgoing photon (γ_o) will gain energy and be scattered at an angle θ_o with respect to the plane defined by the incoming electron (e_i) and photon (γ_i). The angle between the incoming photon and electron is θ_γ. In most experiments described in this document the later will be injected transversely with respect to the electron beam, hence $\theta_\gamma = 90°$. To compute the photon energy gain one needs to look at the frequency of the incoming photon in the lab frame ν_i and the electron frame [1]:

$$\nu'_i = \nu_i[\gamma(1 + \beta \sin\theta_\gamma)] = \nu_i[\gamma(1 + \beta)] \quad (1.1)$$

In the electron frame the photon frequency does not change during the Compton scattering ($\nu'_i = \nu'_o$) however the emitted photon is boosted by the electron with respect to the lab frame:

$$\nu_o = \nu'_o[\gamma(1 + \beta \cos\theta_o)] = \nu_i[\gamma^2(1 + \beta)(1 + \beta \cos\theta_o)] \tag{1.2}$$

and with $\beta \to 1$:

$$\nu_o \simeq \nu_i[2\gamma^2(1 + \cos\theta_o)] \tag{1.3}$$

The maximum energy shift is achieved for $\theta_o = 0°$:

$$\nu_o = 4\gamma^2\nu_i \tag{1.4}$$

For Laser-Wire and MightyLaser the electron beam energy at the ATF was 1.27 GeV (that is $\gamma = 2540$) hence the maximum scattered photon energy was about 26 MeV. For ThomX, the beam energy will be 50 MeV and the maximum photon energy about 40 keV.

If we take $\theta_o = \gamma^{-1}$, from equation 1.3 we see that the energy of the outgoing photons drop by half.

The cross-section for the process is given by the Thompson scattering cross-section:

$$\sigma_T = \frac{8\pi}{3} r_e^2 \simeq 6.65 \times 10^{-29}\,\mathrm{m}^2 \tag{1.5}$$

with r_e the classical radius of the electron.

The luminosity of an electron-photon collider is given by:

$$\mathcal{L} = f \frac{n_e n_\gamma}{4\pi\sigma_x\sigma_y} \tag{1.6}$$

where f is the collision rate, n_e and n_γ the number of electrons and photons respectively in the interaction area and σ_x and σ_y the transverse dimensions of the interaction area.

Assuming a beam squeezed to a size of $\sigma_x = 25\,\mu\mathrm{m}$ and $\sigma_y = 10\,\mu\mathrm{m}$, the luminosity per particle and per crossing becomes $\mathcal{L} = 3.18 \times 10^4 \frac{\mathrm{m}^{-2}}{n_e \times n_\gamma}$.

The scattering probability at each crossing is therefore :

$$\mathcal{P}_{\mathrm{scat}} = \mathcal{L} \times \sigma_T = 2.12 \times 10^{-24} \text{ per electron and per photon} \tag{1.7}$$

Assuming a bunch of 160 pC, that is $N_e = 10^9$, each photon has a probability $\mathcal{P}_{\mathrm{scat}} = 2.12 \times 10^{-15}$ of colliding during the crossing between the laser and the electron bunch.

As we can see this probability is very small and this explains why in the MightyLaser experiment the photons are recycled in a Fabry-Perot cavity.

A laser pulse of $E = 1\,\mathrm{nJ}$ of infra-red photons ($\lambda = 1048\,\mathrm{nm}$; $E_\gamma \simeq 2 \times 10^{-19}$ J) contains $n_\gamma \simeq 5 \times 10^9$ photons and the probability of scattering for an electron when the two bunches cross is therefore 10^{-14}. The use of a ring to circulate the electrons is therefore also justified.

1.1 Undefined references

chap:plasmaAccelerationMecanism chap:pepper-pot chap:SP chap:thomx sec:thomxsynchro sec:ESCULAP

Bibliography

[1] P Rullhusen, X Artru, and P Dhez. *Novel radiation sources using relativistic electrons: from infrared to x-rays*. Synchrotr Radiat. Techniques Appl. World Scientific, Singapore, 1998.