Discussion of Compton scattering rates

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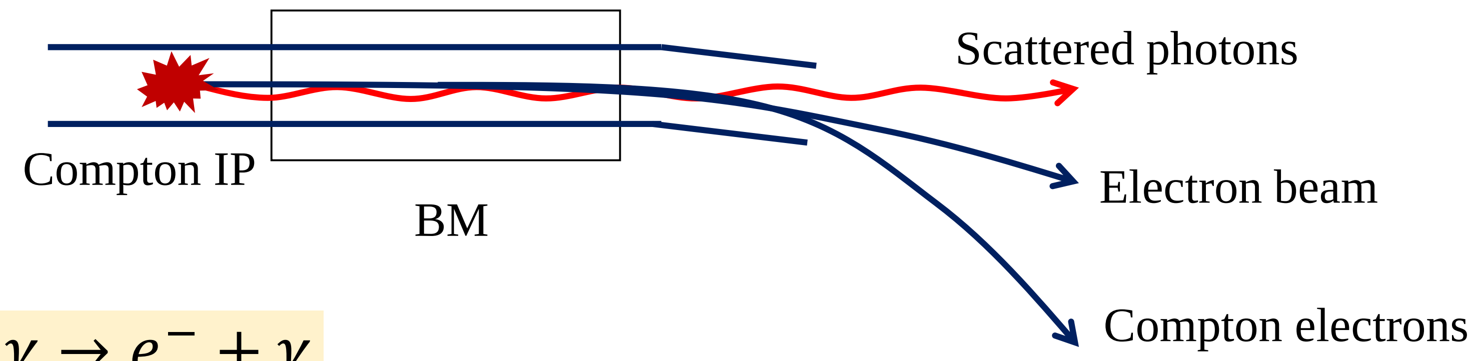
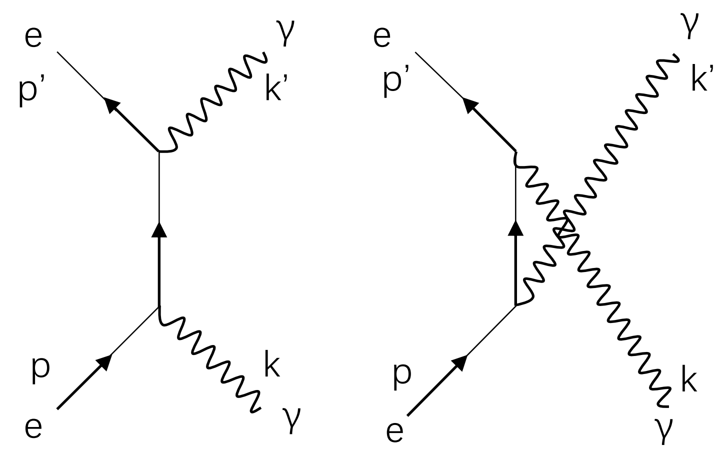
Inverse Compton scattering



$$e^- + \gamma \rightarrow e^- + \gamma$$

- Feynman diagrams for Compton scattering



- The aim of the Compton polarimeter is to measure the spatial distribution of the scattered particles to calibrate the beam energy and the beam transverse polarization.
- The Compton scattering is a classic QED process.
  - Kinetics
  - Cross-section

Berestetskii V B,Quantum electrodynamics: Volume 4

Polarimeter scattering rates

$$N = \sigma_t \cdot L$$

symbol	meaning	Unit
N	散射事例率	Number/s
L	亮度	$m^2 s^{-1}$
σ_t	截面	m^2

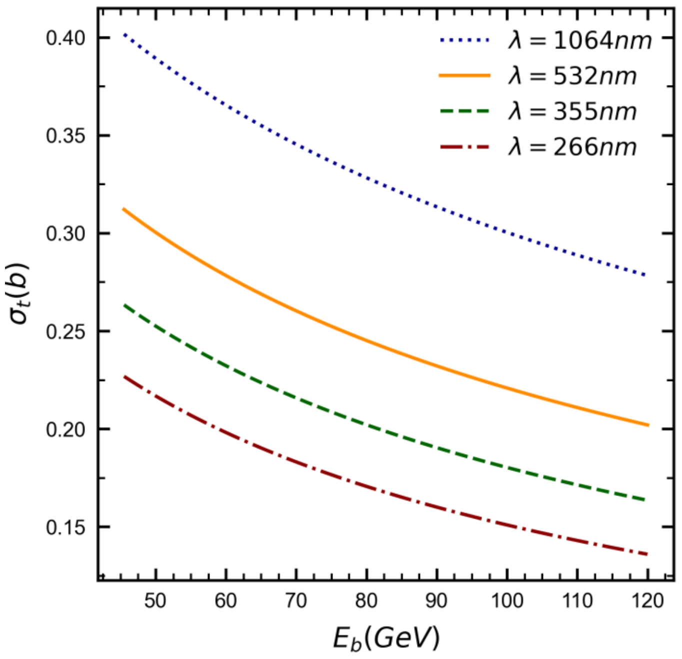
Compton scattering cross-section, σ_t

- 截面与电子束流能量E_b和激光光子能量ω_0有关。

$$\sigma_t = \pi r_e^2 \Gamma \left[\frac{2\Gamma^2 + 12\Gamma + 2}{(1-\Gamma)^2} \right] + \Gamma - 1 + \frac{6\Gamma^2 + 12\Gamma - 2}{(1-\Gamma)^3} ln\Gamma$$

其中，

$$\Gamma = \frac{1}{1 + \frac{4E_b\omega_0}{m_e^2}}$$



symbol	meaning	FCC	CEPC
$\boldsymbol{r}_e$	电子经典半径	2.8179403267*1e-15 [m]	2.8179403267*1e-15 [m]
E_b	电子束流能量	45.6 [GeV]	45.5 [GeV]
ω_0	激光单光子的能量	532 [nm] → 2.3305 [eV]	1064 [nm] → 1.1653 [eV]
Γ	与电子束流能量E_b和激光光子能量ω_0有关的参量	0.38053	0.55182
σ_t	康普顿散射总截面	3.11759e-29 [m^2]	4.0162e-29 [m^2]

Compton scattering luminosity, $\mathcal{L}$

- 亮度与电子束团中的电子束和激光光子能量&激光能量（即激光脉冲中的光子数）有关。
  且与电子束团尺寸和激光束斑尺寸有关, 且与对撞角度有关

symbol		meaning
N_e		束团中的电子数目
$\boldsymbol{\omega}$		激光光子能量
N_γ		束团中的光子数目
α		交叉角 = 180°-对撞角度
电子束的尺寸	$\sigma_{e,x}$	电子束尺寸 x
	$\sigma_{e,y}$	电子束尺寸 y
	$\sigma_{e,z}$	束长
激光束斑的尺寸	$\sigma_{\gamma,x}$	光斑尺寸 x
	$\sigma_{\gamma,y}$	光斑尺寸 y
	$\sigma_{\gamma,z}$	脉冲长度
$\mathcal{L}$		亮度

$$\mathcal{L} = N_e N_\gamma \frac{\cos(\alpha/2)}{2\pi} \frac{1}{\sqrt{\sigma_{e,y}^2 + \sigma_{\gamma,y}^2}} \frac{1}{\sqrt{(\sigma_{e,x}^2+\sigma_{\gamma,x}^2)cos^2(\alpha/2) + (\sigma_{e,z}^2+\sigma_{\gamma,z}^2)sin^2(\alpha/2)}}$$

- My prestation: *https://indico.ihep.ac.cn/event/15918/*
- *Article: T. Suzuki, General formulae of luminosity for various of collider beam machines, Report No. KEK-76-83, 1976.*
- *Similar work: Alessandro Variola (LAL,Orsay) Compton backscattering, LA³NET Topical Workshop: Beam Diagnostics, Mallorca, Spain , 23-24 March 2015*
- FCC prestation: https://indico.belle2.org/event/7500/sessions/2601/#20230208

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Scattered photon rate

Compton cross-section

Laser-beam single pulse energy

Electron bunch charge (25nC or 6nC) pilots

Geometrical factor

Photon rate $n = \sigma_C \frac{\mathcal{E}}{E_\lambda} \frac{Q}{q} \frac{\mathcal{F}}{4\pi\sigma_y\sigma_x}$

- $\mathcal{F}^{-1} = \sqrt{1 + \left(\frac{\sigma_z}{\sigma_x}\tan\frac{\theta_0}{2}\right)^2}$
- $\theta_0 \sim 2mrad$

Laser photon energy
(2.4eV for 0.5µm wavelengths)

Transverse beam sizes:

- $\sigma_{x,y,z} = \sqrt{\sigma^2_{x,y,z,laser} + \sigma^2_{x,y,z,e-}}$
- $\sigma_{x,laser} = \sigma_{y,laser}$=300µm
- $\sigma_{x,e-}$ = 200µm, $\sigma_{y,e-}$=25µm, $\sigma_{z,e-}$~10mm

FCC prestation: https://indico.belle2.org/event/7500/sessions/2601/#20230208

Some possible laser systems

baseline ↓ (1 pilot)

Laser param.	1 pilot	1 pilot v2	All colliding bunches (at Z)
Repetition rate	3 kHz	3 kHz	50 MHz
Pulse energy	1 mJ	1 mJ	100 nJ
Pulse duration	5 ns	5 ps (**)	5 ps (**)
Average power	3 W	3 W (***)	5 W (***)
Scattering rate	4×10^5/s (*)	2×10^6/s (****)	2×10^6/s (****)
Scattering rate per bunch	4×10^5/s (*)	2×10^6/s	1.7×10^2/s

Same oscillator may be used but two different amplification schemes (1 pilot v2 and All colliding bunches)

(*) Large piwinski contribution, nearly scales as crossing angle, very dependent on laser beam size (was 2×10^6/s in ref. paper)
(**) Short pulse duration → broader laser spectrum, energy measurement from threshold more difficult
(***) Can be increased to typically ~100W (nowadays) but requires operational validation, management of thermal effects…
(****) not limited by Piwinski contribution → significantly increases when decreasing laser beam size

Version-1

symbol		meaning	FCC		CEPC
N_{e}		束团中的电子数目	$25nC$ (pilot bunch)→1.5625× 10^{11}	$6nC$ (pilot bunch) → 3.75× 10^{10}	8×10^{10}
$\boldsymbol{\omega}$		激光光子能量	2.4 eV (wavelength = 0.5 μm)		1.165 eV (1064 nm)
N_{γ}		束团中的光子数目	2.6× 10^{15} (pulse energy = 1 mJ)		2.8 mJ/1.165 eV = 1.5× 10^{16}
α		交叉角 = 180°-对撞角度	2 [mrad]		2.35 [mrad]
电子束的尺寸	$\sigma_{\mathrm{e},x}$	电子束尺寸 x	200 [μm]		54.3 [μm]
	$\sigma_{\mathrm{e},y}$	电子束尺寸 y	25 [μm]		7.9 [μm]
	$\sigma_{\mathrm{e},z}$	束长	10 mm		8.5 [mm]
激光束斑的尺寸	$\sigma_{\gamma,x}$	光斑尺寸 x	300 [μm]		160 [μm]
	$\sigma_{\gamma,y}$	光斑尺寸 y	300 [μm]		160 [μm]
	$\sigma_{\gamma,z}$	脉冲长度	1.5 m (Pulse duration = 5 ns)		8.5 [mm]
L		亮度	$1.392 \times 10^{32}\ [m^{-2}s^{-1}]$	$3.341 \times 10^{31}\ [m^{-2}s^{-1}]$	$7.04 \times 10^{33} [m^{-2}s^{-1}]$
σ_t		Total cross section	304.0869 [mb]	304.0869 [mb]	402 mb
N		Scattering rates	1.27×10^{7}	3.05× 10^{6}	2.827× 10^{5}

Version-2

symbol		meaning	FCC		CEPC
N_e		束团中的电子数目	$25nC$ (pilot bunch)→1.5625×10^{11}	$6nC$ (pilot bunch) → 3.75×10^{10}	8×10^{10}
$\boldsymbol{\omega}$		激光光子能量	2.4 eV (wavelength = 0.5 μm)		1.165 eV (1064 nm)
N_γ		束团中的光子数目	2.6×10^{15} (pulse energy = 1 mJ)		2.8 mJ/1.165 eV = 1.5×10^{16}
α		交叉角 = 180°-对撞角度	2 [mrad]		2.35 [mrad]
电子束的尺寸	$\sigma_{e,x}$	电子束尺寸 x	200 [μm]		54.3 [μm]
	$\sigma_{e,y}$	电子束尺寸 y	25 [μm]		7.9 [μm]
	$\sigma_{e,z}$	束长	10 mm		8.5 [mm]
激光束斑的尺寸	$\sigma_{\gamma,x}$	光斑尺寸 x	300 [μm]		160 [μm]
	$\sigma_{\gamma,y}$	光斑尺寸 y	300 [μm]		160 [μm]
	$\sigma_{\gamma,z}$	脉冲长度	1.5 mm (Pulse duration = 5 ps)		8.5 [mm]
L		亮度	$5.9545\times 10^{32}\ [m^{-2}s^{-1}]$	$1.429\times 10^{32}\ [m^{-2}s^{-1}]$	$7.04\times 10^{33}[m^{-2}s^{-1}]$
σ_t		Total cross section	304.0869 [mb]	304.0869 [mb]	402 mb
N		Scattering rates	5.43×10^{7}	1.30×10^{7}	2.827×10^{5}

- Problems and discussions:
    - Pulse frequency
    - Laser pulse length
    - Update the beam bunch parameters

Update the beam bunch parameters

- CDR vs TDR

Electron beam				
Energy	120 GeV		45.5 GeV	
N_b	242(CDR)	268(TDR)	12000(CDR)	11934(TDR)
N_e	15×10^{10}(CDR)	13×10^{10}(TDR)	8×10^{10}(CDR)	14×10^{10} (TDR)
Total cross section		120 GeV + 532 nm		202 mb
		45.5 GeV + 1064 nm		402 mb

- *Ref:* Cheng, Huajie, et al. "The physics potential of the CEPC. prepared for the US Snowmass community planning exercise (snowmass 2021)." arXiv preprint arXiv:2205.08553 (2022).

1.4.9 Polarization options

Operation of polarized beams at Z-pole and W threshold are under study. Firstly, resonant depolarization technique (RD) using transversely polarized e+ and e- beams are essential for precision measurements of mass & widths of Z and W bosons. To this end, we plan to inject about 150 non-colliding e+/e- bunches, and conduct RD on one bunch every 12 min, to continuously monitor the evolution of center of mass energies. Since the polarization build-up time is 250 hours in the collider ring at 45 GeV, asymmetric wigglers are added to the lattice to boost the initial polarization build-up, about 10% beam polarization can be achieved in 2.6 hours with these wigglers, then these wigglers are turned off to avoid influence on colliding beam experiments. Conceptual designs of transverse Compton polarimeter and depolarizer are also under way. At W threshold, the polarization build-up time is about 15 hours, asymmetric wigglers are not needed. We plan to inject 12 non-colliding e+/e- bunches, and conduct RD on one bunch every 10 min, to continuously monitor of evolution of center of mass energies. The RD technique is itself nontrivial at W energy, with the increasing influence of synchrotron sideband spin resonances, how to properly conduct the RD measurement is also to be studied.