

CEPC Compton Polarimeter

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21/03/2023

Beam Polarization Group Meeting, Beijing

Outline

- Motivation and requirement
- Compton scattering
- Measurement of the beam polarization
 - Methods
 - Simulations
 - Errors
- Discussions

Beam polarization

Transverse polarization

- <u>Resonant depolarization technique (RD)</u> using transversely polarized e+ and e- beams are essential for precision measurements of mass & widths of Z and W bosons.
- A beam with transverse polarization of <u>5%~10%</u> is required.
- Plan to inject about 150 <u>non-colliding e+/e- bunches</u>, and conduct RD on one bunch every 12 min, to continuously monitor the evolution of center of mass energies.

<u>Ref:</u> Snowmass2021 White Paper AF3- CEPC, CEPC Accelerator Study Group

Longitudinal polarization

• Longitudinally polarized colliding beam experiments are beneficial for precision electroweak measurements and probe for new physics.

<u>Ref:</u> https://www.slac.stanford.edu/pubs/slacpubs/4500/slac-pub-4656.pdf

Theoretical basis

Compton back-scattering

• Feynman diagrams for Compton scattering



- Compton scattering is a classical QED process.
- e⁻γ → e⁻γ, e⁻γγ, e⁻e⁺e⁻ spin-dependence cross-section high order (order-α³) correction. In HERA Compton polarimeter, +0.08% systematic uncertainties for transverse polarization measurement, -0.2% for longitudinal polarization measurement.

Compton back-scattering cross-section

Case 1: no-polarized formula

$$d\sigma = 8\pi r_e^2 \frac{m_e^2}{(s-m_e^2)^2} \left[(\frac{m_e^2}{s-m_e^2} + \frac{m_e^2}{u-m_e^2})^2 + \left(\frac{m_e^2}{s-m_e^2} + \frac{m_e^2}{u-m_e^2} \right) - \frac{1}{4} \left(\frac{s-m_e^2}{u-m_e^2} + \frac{u-m_e^2}{s-m_e^2} \right) \right]$$

where s, t, u is the Mandelstam variables.

Berestetskii V B, Quantum electrodynamics: Volume 4

• Differential cross-section and the total cross-section



Distribution of scattered photons

Case 1: no-polarized formula

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Spatial distribution of scattered photons

- The distance between IP and detector is 60 m. •
- 532 nm laser collide with 120 GeV electrn beam •

Compton back-scattering cross-section

Case 2: polarization-dependence formula











$$\frac{d\sigma}{d\omega} = \frac{d\sigma}{du}\frac{\partial u}{\partial \omega} = 2\pi \frac{\epsilon_0}{(\epsilon_0 - \omega)^2}(P_0 + P_{\parallel})$$



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Compton polarimeter

➤ setup



Parameters						
Energy	120 GeV		45.5 GeV			
N_b	242(CDR)		12000(CDR)			
N _e	15× 10 ¹⁰ (CDR)		8× 10 ¹⁰ (CDR)			
Total cross section		120 GeV + 532 nm		202 mb		
		45.5 GeV + 1064 nm		402 mb		

- The technique is "non-destructive": Proportion of scattering:
 - $\sim \frac{2.7 \cdot 10^7}{15 \cdot 10^{10}}$ for one electron bunch
- QED corrections error is ~0.2%
- Analyzing power can be calculated by QED
- Laser on-off
- Suit for high electron energy

The method to measure the vertical polarization

• Compton polarimeters

技术	原理	装置	
机齿盘化	散射光子的能量	TRISTAN[122]	
纵回仪化		NIKHEF[123]	
		HERA[124]	
	散射电子的事例率的不对称性	JLab(HallC)[126] SLC[125]	
横向极化	散射光子垂直角分布的不对称	LEP TRISTAN[122]	
		SPEAR[127]	
		ELSA[129] HERA[130]	
		BEPC[131, 132]	
	散射电子的探测器平面的二维分布	ILC[133] FCC[44]	

• CEPC 测横向极化的技术路线



The method to measure the vertical polarization

• Fit the spatial distribution of the scattered electrons by analyzing power

 $A_{exp.} = P_{\perp} \cdot A_{theo.}$ $A_{exp.}: \text{ Experimental value of the asymmetry}$ $A_{theo.}: \text{ Theoretical value of the asymmetry}$ $P_{\perp} = \xi_{\cup} \zeta_{\perp} \ (\zeta_{\perp} \text{ is transverse polarization})$

Experimental asymmetry

• The Monte Carlo simulation to obtain the Experimental value of the asymmetry

$$Y_e|_{X_e} = \frac{\sum_{i=0} Y_e}{n_i}$$

Represents the relationship of the Ye mean value in the i_{th} x-axis bin and the n_i is the counts number of the per x-bin.

$$\overline{Y_e}|_{X_e} = \frac{\overline{Y_e}|_{X_e}(left\ helicity) - \overline{Y_e}|_{X_e}(right\ helicity)}{2}$$



Theoretical asymmetry

Based on Compton scattering differential cross section

$$\Pi \left(X_e \right) = \frac{\int Y_e \frac{d\sigma}{dX_e dY_e} dY_e}{\int \frac{d\sigma}{dX_e dY_e} dY_e}$$





The results

- method 1: Fit by the analyzing power $A(Y_e) = \overline{Y_e}|_{X_e} = P_{\perp} \Pi(X_e)$
- method 2: the polarization is equal to the ratio of the integral of the distribution of the Experimental value and the Theoretical value



Estimation of statistical error



Table 4: Electron beam and laser beam properties used in simulation (based on CDR)

symbol	meaning	Unit
E_b	Electron beam energy	120 eV
ω_0	Laser photon energy	1.24 eV
$\sigma_{\gamma,x}\ /\sigma_{\gamma,y}$	Laser focus radius	160 µm
N _e	Bunch population	8×10 ¹⁰
Nγ	Laser photon population	1.5×10^{16}
α	Cross angle = π -collision angle	2.35 mrad
I	luminosity	$7 \times 10^{33} \text{ m}^2 \text{s}^{-1}$
σ_t	Total Compton cross-section	402 mb

Estimation of systematical uncertainties

Table 5: polarimeter-related systematic uncertainties (polarization is 10%)

Sources of systematic uncertainties	$\Delta P_{\perp}/P_{\perp}$ %
Dipole strength	0.062%
ΔL_1 (IP-to-detector)	0.007%
ΔL_2 (magnet-to-detector)	0.051%
Beam energy	0.0001%
Detector resolution	0.278%
Detector placement	ignored
Laser polarization	0.2 %
Total	< 1%

• Response of the efficiency detector variation was simulated. The fit result for $P_{\perp} = 10\%$ and $P_{\perp} = 2\%$ fitted by the analyzing power. The deviation between the fitting result and the theoretical value shows that variation less than 10% could be considered to be acceptable





(b) $P_{\perp} = 2\%$ as the pixel ceth size is 200 μ m × 25 μ m

Polarimeter layout



• parameters

- Vacuum tube inner diameter radius 28 mm + wall thickness 3 mm = 31 mm
- Energy of scattered electrons: 25.11 GeV ~ 45.5 GeV
- Electrons need to be detected: 25.11 GeV ~ 40 GeV
- The restrictions on the drift distance and the bending magnet is:

 $L_2\theta_0 > 0.2255m$



Summary and discussion

- Polarization can be obtained by measuring the position or energy of scattering particles by Compton scattering.
- CEPC Compton polarimeter aim to deduce the beam polarization through the asymmetry of the scattered electron position distribution.
- Monte Carlo simulation has been conducted based on CDR
- The layout on the collider ring is under discussion

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