Discussion of EPOL

Shanhong Chen

27 September 2022

极化讨论会议

Outline

- 1. Super-B *https://cds.cern.ch/record/1296190/files/arXiv:1009.6178.pdf*
- 2. FCC *https://arxiv.org/pdf/2208.00585.pdf*

https://cds.cern.ch/record/1296190/files/arXiv:1009.6178.pdf

Super-B

Super-B (Longitudinal polarization)		
Physical motivation (ΔP/P)	<1%	
Method	Compton polarimeter	
Location	Upstream of the IR	
Physical IP/Spin projection in Compton IP	1/0.968	
Systematical uncertainties	1 mrad in the orbit	0.25%
	Beam energy uncertainty 20MeV at the 4.18 GeV	0.2%

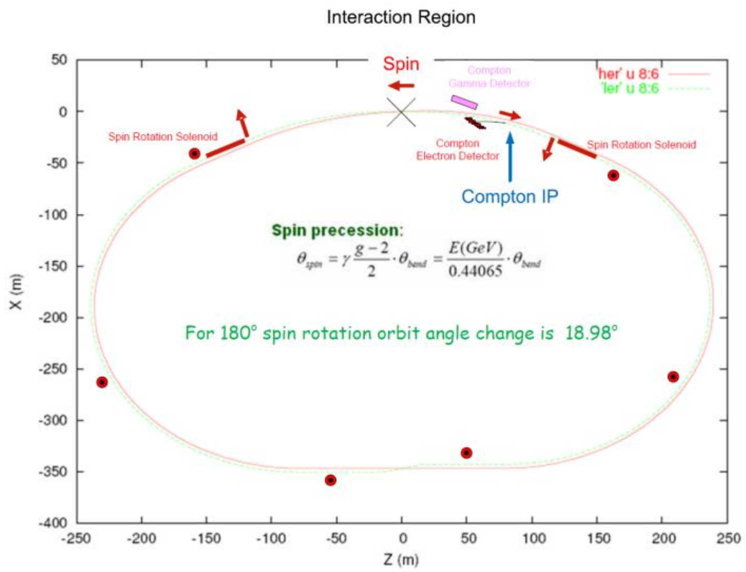
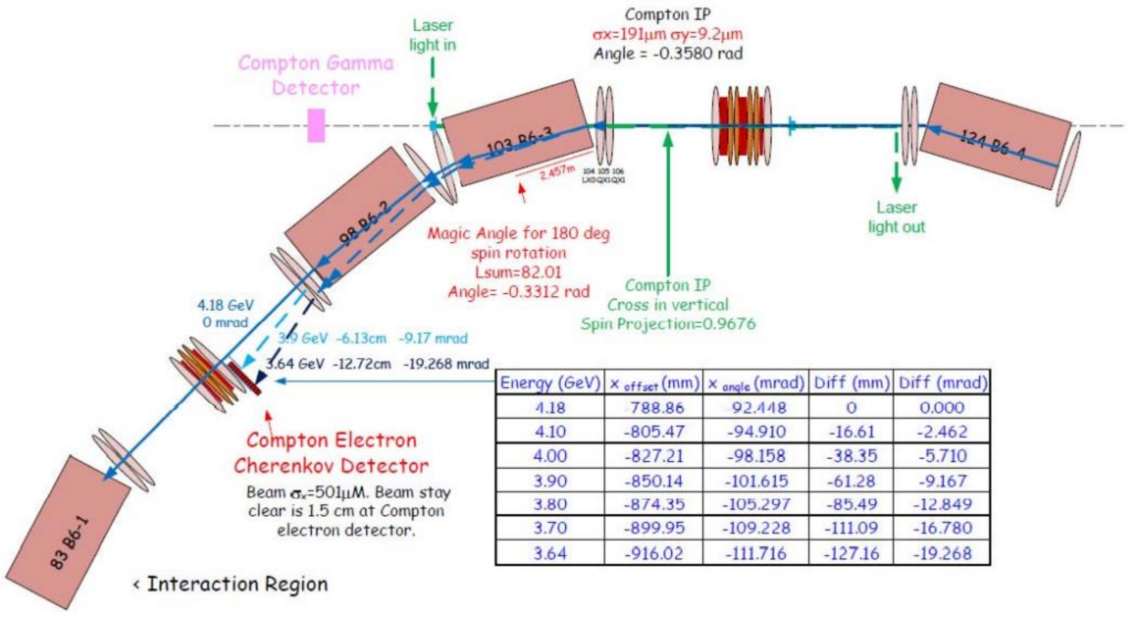


Figure 16.8: SuperB ring showing the location of spin rotation solenoids and the Compton polarimeter at z = 87 m upstream of the Interaction Region.

- 不放在下游的原因:
  - the space at this location is minimal to locate the Compton IP
  - severe backgrounds from the e+ e - collisions would be intolerable in the Compton gamma and electron detectors.
- The orbit angle change for π spin rotation is -0.3312 radians at 4.18 GeV. The selected location of the Compton IP in a magnetic field free region has an orbit angle change of -0.3580 radians between the Compton IP and the Interaction Region resulting in the spin direction ~14 degrees from longitudinal. At the Compton IP the longitudinal spin projection is 0.968. The longitudinal polarization at the IR will be larger by 1/0.968 than that measured in the Compton polarimeter

Super-B



Energy (GeV)	x_{offset} (mm)	x_{angle} (mrad)	Diff (mm)	Diff (mrad)
4.18	788.86	92.448	0	0.000
4.10	-805.47	-94.910	-16.61	-2.462
4.00	-827.21	-98.158	-38.35	-5.710
3.90	-850.14	-101.615	-61.28	-9.167
3.80	-874.35	-105.297	-85.49	-12.849
3.70	-899.95	-109.228	-111.09	-16.780
3.64	-916.02	-111.716	-127.16	-19.268

Figure 16.9: Layout of the Compton polarimeter.

Compton polarimeter	
Laser	Nd:YLF circularly polarized laser
Laser length	10 ps
Laser photons	2.3×1e10
Electron beam	4.06 GeV
Compton edge electrons	3.64 GeV
Compton rates	~196980 /sec

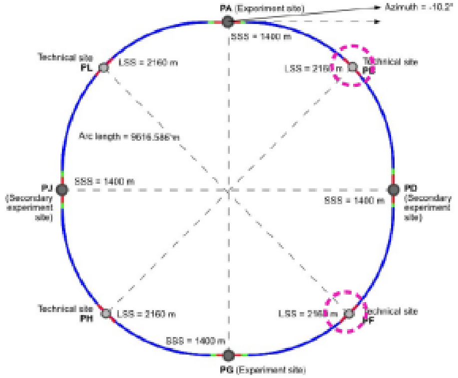
Table 16.4: Systematic errors expected for the polarization measurement.

Item	**δP/P**
Laser Polarization	<0.1%
Background uncertainty	<0.25%
Linearity of phototube response	<0.25%
Uncertainty in dP (Difference between the luminosity weighted polarization and the Compton IP polarization. Includes uncertainties due to beam energy and direction uncertainties.)	<0.4%
Uncertainty in asymmetry analyzing power	~0.5%
Total Systematic Error	**<1.0%**

M. Hofer, A. Martens, N. Muchnoi, K. Oide, J. Wenninger

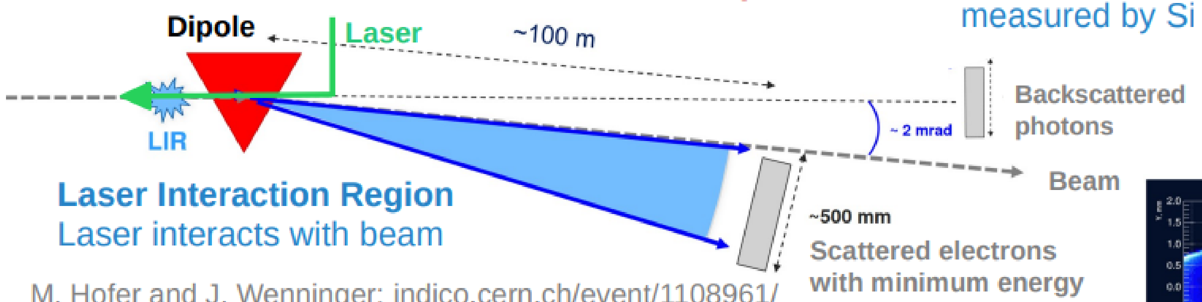
Polarimeter

- One polarimeter per beam
- First definition of specifications
  - 2 mrad angle
  - 100 m drift space
  - 2 m space for LIR (monitoring of location to be designed)

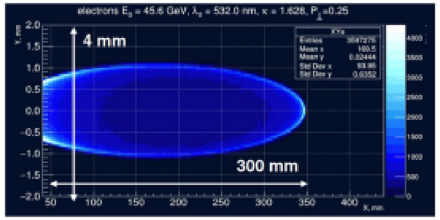


Allows measurement of three coordinates of beam polarization

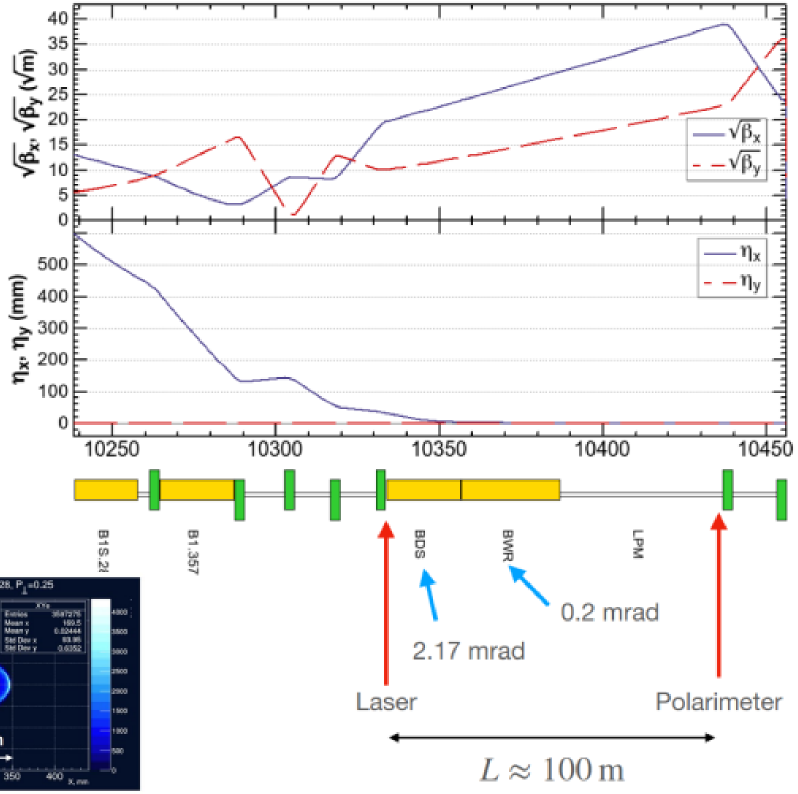
Scattered electrons to be measured by Si pixel detector



Laser Interaction Region
Laser interacts with beam



Polarimeter implemented in straight section without IP or RF



M. Hofer and J. Wenninger: indico.cern.ch/event/1108961/
N. Muchnoi: indico.cern.ch/event/1119730/
K. Oide: indico.cern.ch/event/1162192

FCC-Compton polarimeter

https://arxiv.org/pdf/2208.00585.pdf

A Stokes parameters

The Stokes parameters describe the polarization state of electromagnetic radiation. Their definition is slightly different in different sources, so below are the definition that we use here.

- $\xi_0 = E_x^2 + E_y^2$ is the intensity of light.
  With normalization $E_x^2 + E_y^2 = 1$ for 100% polarized laser radiation $\xi_0 = \sqrt{\xi_1^2 + \xi_2^2 + \xi_3^2} = 1$.
- $\xi_1 = E_x^2 - E_y^2$.

  $E_x = 1, E_y = 0, \xi_1 = +1$: 100% linear polarization along x-axis.

  $E_x = 0, E_y = 1, \xi_1 = -1$: 100% linear polarization along y-axis.
- $\xi_2 = 2E_xE_y\cos(\delta)$.

  $E_x = E_y, \delta = 0, \xi_2 = +1$: 100% linear polarization along $\varphi = +\pi/4$.

  $E_x = E_y, \delta = \pi, \xi_2 = -1$: 100% linear polarization along $\varphi = -\pi/4$.
- $\xi_3 = 2E_xE_y\sin(\delta)$.

  $E_x = E_y, \delta = +\pi/2, \xi_3 = +1$: 100% right circular polarization.

  $E_x = E_y, \delta = -\pi/2, \xi_3 = -1$: 100% left circular polarization.

FCC-Compton polarimeter

1.1 Cross section

ICS cross section depends on polarization states of all initial and final particles. In case of averaging over the polarizations of the final states the cross section depends solely from the initial photon and electron polarizations. Stokes parameters ξ_1, ξ_2, ξ_3 describe the polarization of laser light as it is explained in Appendix A. The electron beam polarization has three components $\zeta_x, \zeta_y, \zeta_z$, the total degree of polarization $\sqrt{\zeta_x^2 + \zeta_y^2 + \zeta_z^2} \in [0 : 1]$. We take differential cross section from ref. [34] and after Lorentz transformations it is represented in u and φ variables by the sum of the six terms:

Unpolarized polarized →

$$\frac{1}{r_e^2}\frac{d\sigma_0}{du\,d\varphi} = \frac{1}{\kappa(1+u)^3}\left[1 + (1+u)^2 - 4\frac{u}{\kappa}\left(1-\frac{u}{\kappa}\right)(1+u)\right],$$

Laser linearly polarized

$$\frac{1}{r_e^2}\frac{d\sigma_{\xi_1}}{du\,d\varphi} = \frac{4\,\xi_1}{\kappa(1+u)^2}\frac{u}{\kappa}\left(1-\frac{u}{\kappa}\right)\cos(2\varphi),$$

$$\frac{1}{r_e^2}\frac{d\sigma_{\xi_2}}{du\,d\varphi} = \frac{4\,\xi_2}{\kappa(1+u)^2}\frac{u}{\kappa}\left(1-\frac{u}{\kappa}\right)\sin(2\varphi),$$

Laser circularly polarized
&
electron three polarization

$$\frac{1}{r_e^2}\frac{d\sigma_x}{du\,d\varphi} = \frac{-2\,\xi_3\,\zeta_x}{(1+u)^3}\frac{u}{\kappa}\sqrt{\frac{u}{\kappa}\left(1-\frac{u}{\kappa}\right)}\cos(\varphi),$$

$$\frac{1}{r_e^2}\frac{d\sigma_y}{du\,d\varphi} = \frac{-2\,\xi_3\,\zeta_y}{(1+u)^3}\frac{u}{\kappa}\sqrt{\frac{u}{\kappa}\left(1-\frac{u}{\kappa}\right)}\sin(\varphi),$$

$$\frac{1}{r_e^2}\frac{d\sigma_z}{du\,d\varphi} = \frac{\xi_3\,\zeta_z}{(1+u)^3}\frac{u}{\kappa}(u+2)\left(1-2\frac{u}{\kappa}\right). \tag{1.7}$$

FCC-Compton polarimeter

check the fitting procedure. The subject of this study is the trivial case when the Stokes vector of laser polarization is $[\xi_1, \xi_2, \xi_3] = [0, 0, 1]$ and the electron beam is unpolarized $\zeta_x, \zeta_y, \zeta_z = [0, 0, 0]$.

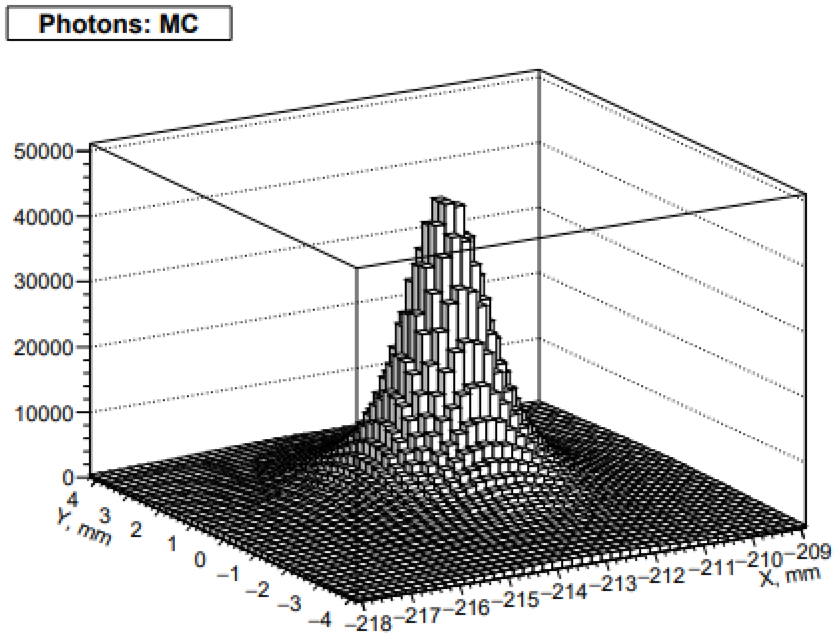


Table 4. Photon spot fit results.

$X_0 = -213.538 \pm 0.001$ mm	$Y_0 = -0.002 \pm 0.001$ mm
$\sigma_x = 255 \pm 3\ \mu m$	$\sigma_y = 30 \pm 18\ \mu m$
$\xi_1 = 0.000 \pm 0.002$	$\xi_2 = -0.001 \pm 0.001$
$\xi_3\zeta_x = 0.004 \pm 0.006$	$\xi_3\zeta_y = -0.008 \pm 0.006$
$\xi_3\zeta_z = 0.000 \pm 0.002$	$\chi^2/NDF = 9796.9/9990$

FCC-Compton polarimeter

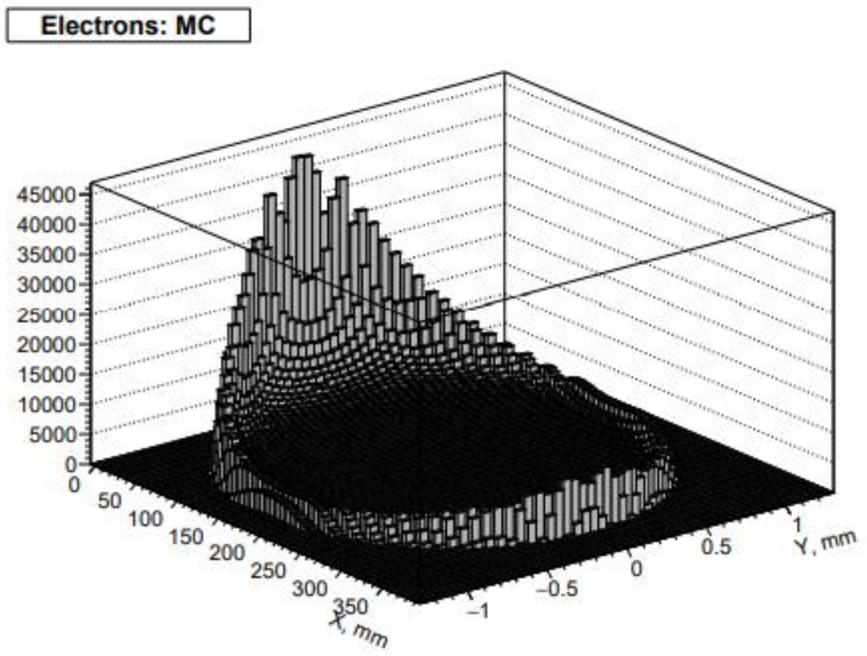


Table 5. Scattered electrons ellipse fit results.

$X_1 = 0.0035 \pm 0.0016$ mm	$X_2 = 347.635 \pm 0.003$ mm
$Y_1 = -1.0682 \pm 0.0001$ mm	$Y_2 = 1.0682 \pm 0.0001$ mm
$\sigma_x = 320.7 \pm 1.5\ \mu$m	$\sigma_y = 27.06 \pm 0.03\ \mu$m
$\xi_1 = 0.001 \pm 0.001$	$\xi_2 = 0.432 \pm 0.198$
$\xi_3\zeta_x = 1.000 \pm 0.195$	$\xi_3\zeta_y = -0.001 \pm 0.002$
$\xi_3\zeta_z = 0.000 \pm 0.001$	$\chi^2/\mathrm{NDF} = 51568.9/52270$
$\varepsilon_0 = 45.5997 \pm 0.0007$ GeV	

$$\varepsilon_0 = \frac{(mc^2)^2}{4\omega_0} \frac{X_2 - X_1}{X_1 - X_0}.$$

FCC-Compton polarimeter

the electron beam. The Stokes vector of laser polarization is chosen as $[\xi_1, \xi_2, \xi_3] = [0.1, 0.1, 0.99]$ with small amount of vestigial linear polarization which may exist due to imperfect polarization control. The set of the electron beam polarization parameters is $[\zeta_x, \zeta_y, \zeta_z] = [0.1, 0.25, 0.1]$. The expected polarization of the pilot electron bunches at FCC-ee (averaged over thousands beam revolutions) has ζ_y component only. The ζ_x and ζ_z components are added to the simulations in order to investigate the possibility of measuring the electron beam polarization in general case.

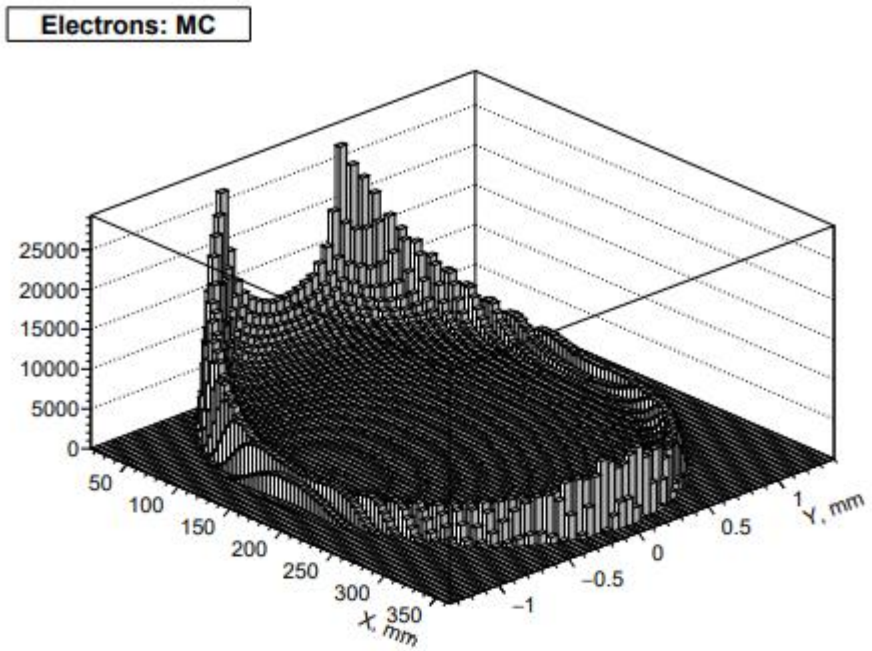


Table 6. Photon spot fit results.

$X_0 = -213.539 \pm 0.002$ mm	$Y_0 = 0.000 \pm 0.001$ mm
$\sigma_x = 246 \pm 4\ \mu m$	$\sigma_y = 13 \pm 70\ \mu m$
$\xi_1 = 0.102 \pm 0.002$	$\xi_2 = 0.100 \pm 0.001$
$\xi_3\zeta_x = 0.095 \pm 0.007$	$\xi_3\zeta_y = 0.247 \pm 0.006$
$\xi_3\zeta_z = 0.105 \pm 0.002$	$\chi^2/NDF = 9935.8/9990$

Table 7. Scattered electrons ellipse fit results.

$X_1 = 0.013 \pm 0.007$ mm	$X_2 = 347.632 \pm 0.004$ mm
$Y_1 = -1.0682 \pm 0.0001$ mm	$Y_2 = 1.0684 \pm 0.0001$ mm
$\sigma_x = 319.6 \pm 4.3\ \mu m$	$\sigma_y = 27.15 \pm 0.03\ \mu m$
$\xi_1 = 0.100 \pm 0.001$	$\xi_2 = 0.100$
$\xi_3\zeta_x = 0.099$	$\xi_3\zeta_y = 0.246 \pm 0.002$
$\xi_3\zeta_z = 0.099 \pm 0.001$	$\chi^2/NDF = 50152.7/51245$
$\varepsilon_0 = 45.5959 \pm 0.0025$ GeV	

Discussion and Summary

1. 从物理角度推导截面公式
2. 探测器角度摆放