IBIC 2024-THP72, Bejing, China

A Preliminary Design of a Compton Polarimeter at BEPC

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IBIC2024 Sept. 9-13, 2024 · Beijing, China

Abstract

BEPCII is a double ring e+ e- collider running in the tau-charm energy region. We propose reusing the beamline of a dismantled wiggler magnet to implement a Compton polarimeter detecting scattered γ photons, to measure the self-polarization of the electron beam at BEPCII. This would enable resonant depolarization, and thus provide precision beam energy calibration for BEPCII, and serves as a testbed for future colliders like the CEPC. In this paper, the preliminary design of this Compton polarimeter is presented, and the tentative plan for the implementation and commissioning in the coming years are shown.

Background

- Polarized lepton beams are essential for the physics program of the future colliders like CEPC.
- As a test bed for polarized beams measurement, a Compton polarimeter[1] has been designed for the BEPCII.
- 4W2, a wiggler-based X-ray beamline of BEPCII for high pressure studies, has retired from operation. We propose to modify the front end and the hutch of this beamline to implement a Compton polarimeter.

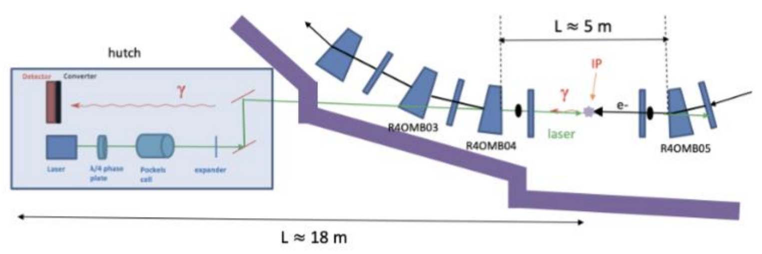

Figure 1: The layout of the Compton polarimeter at the 4W2 beamline of BEPCII.

Design Parameters

- Electron beams tend to become vertically polarized in a storage ring due to the Sokolov-Ternov effect.
- The polarization build-up time is about 75 min at 2.35 GeV for BEPCII.
- The differential cross section of the Compton scatterings between a circularly polarized laser and a vertically polarized electron beam is (1)
- The luminosity L can be approximately calculated by (2)

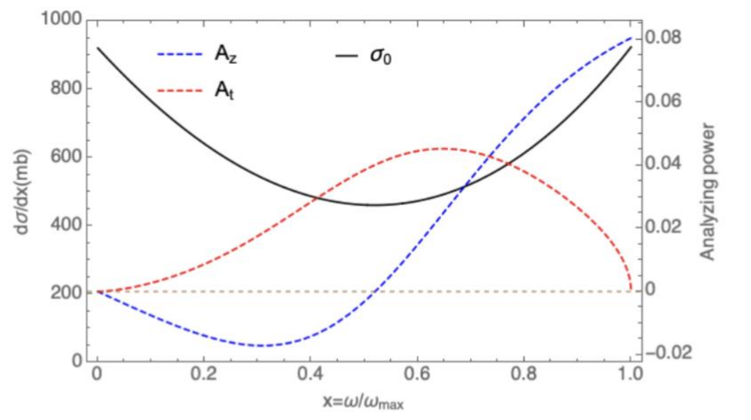

Figure 2: The differential cross section and analyzing powers as a function of the normalized scattered photon energy.

$$\frac{d^2\sigma}{dx d\phi} = \sigma_0(1 + f(S_1^L, S_2^L, \phi) - S_3^L\left[P_z^e A_z + P_t^e A_t \cos\phi\right]) \quad (1)$$

where σ_0 is the differential cross section for unpolarized electron beam, x is the ratio between the scattered γ energy and the Compton edge, and ϕ is the azimuthal angle of direction of the outgoing photon with respect to the electron transverse polarization P_t^e, S_3 is the circular polarization of the laser, the analyzing power A_t reflects the sensitivity of the Compton polarimeter. Note that such measurements can be disturbed by the linear polarization of the laser S_1^L, S_2^L and the electron beam longitudinal polarization P_z^e.

$$L \approx \frac{N_e N_{\text{ph}} f_{\text{laser}}}{2\pi\sqrt{\sigma_{x,e}^2 + \sigma_{x,\text{laser}}^2}\,\sigma_{y,\text{laser}}} \quad (2)$$

where N_e and N_{ph} are the number of electrons and photons per beam, f_{laser} the repetition rate of the laser, σ the rms beam size at the interaction points for electron and laser beams.

Table 1: Electron and laser beam parameters

Parameters	Electron	Laser
Energy(eV)	2.35×10^9	2.33
Pulse energy(mJ)	-	0.25
repetition rate(kHz)	1.26×10^3	1
Pulse length(ps)	50	500
Rms emittances(nm)	157/0.53	-
Rms beam size(mm)	1.3/0.05	0.6/0.6
Vertical crossing angle (mrad)	0.8	
Luminosity ($\text{barn}^{-1}\text{s}^{-1}$)	4.6×10^5	
γ-yield per crossing	283	
γ-yield rate(kHz)	283	

Detection System and Performance Simulation

- γ photon→leptons (better efficiency)
- "TaichuPix" silicon detectors[2]
- 1×10^8 Compton scattering events
- Assumed vertical polarization=50%

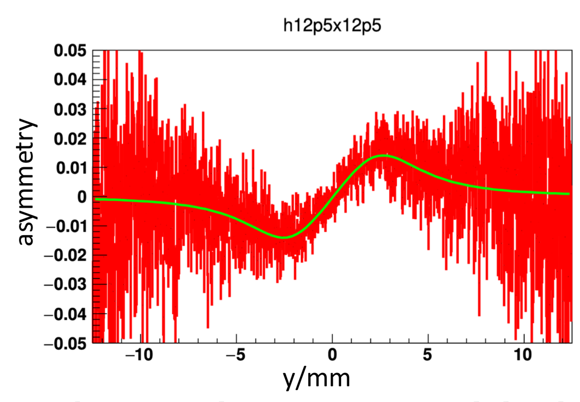

Figure 9: The scattered γ events are recorded and integrated over the horizontal direction, by laser helicity flipping we can obtain an asymmetry as a function of the vertical coordinate, when fitted with the theoretical formula of the asymmetry, the beam polarization is obtained.

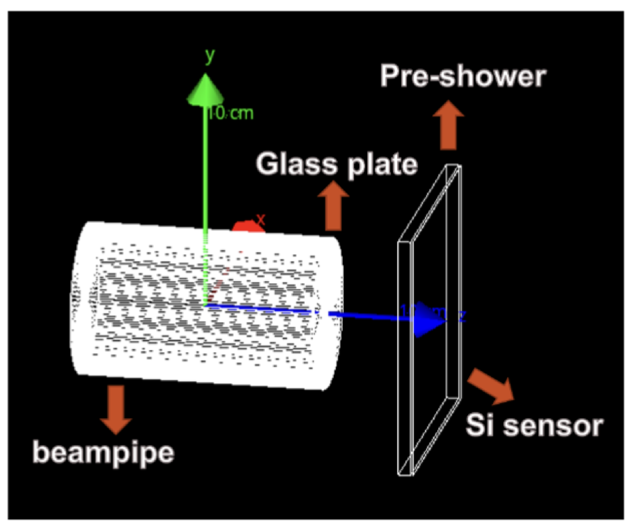

Figure 3: The sketch of the Geant4 model. The vacuum pipe with a one-mm-glass end cap is located on the left. The lead pre-shower and silicon sensor are located on the right.

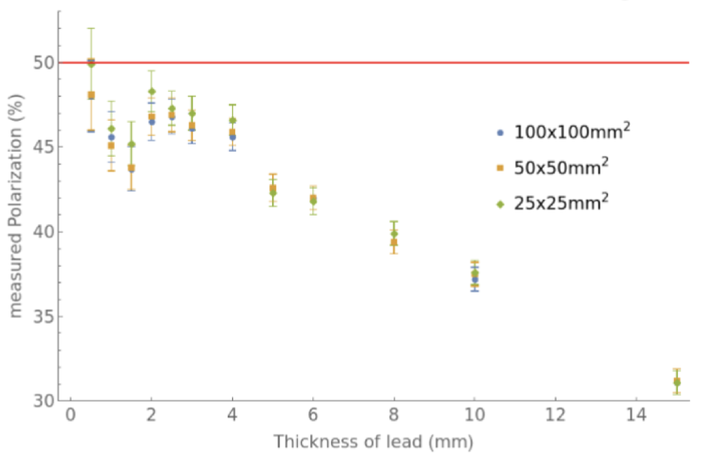

Figure 4: The measured polarization as a function of the thickness of the lead pre-shower and the area of the sensor. The area of the sensor are 100×100 mm^2, 50×50 mm^2 and 25×25 mm^2. The red line indicates the true value of beam polarization.

Laser Alignment Targets

- The laser alignment target(see Fig. 6) have a movable ceramic target inside the chamber, when the target is moved in the way of the laser, when the target is moved in the way of the laser, the diffusely reflected light at about45 degree is captured by an imaging system followed by a CCD camera.
- The design is also compatible with a mirror reflection approach.

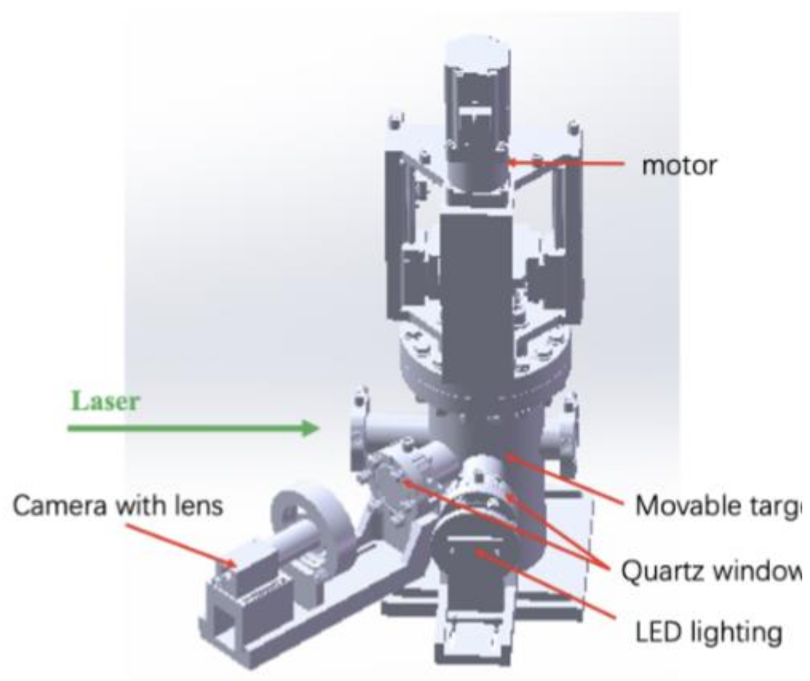

Figure 6: The laser alignment target.

A Proof-of-Principle Experiment

- Aim：to address the concern that the diffuse reflection would deteriorate the position resolution of the optics system
- Result：The position RMS uncertainties are25 μm horizontally and 42 μm vertically, including the fitting error, the measurement reading error and the laser drift error.

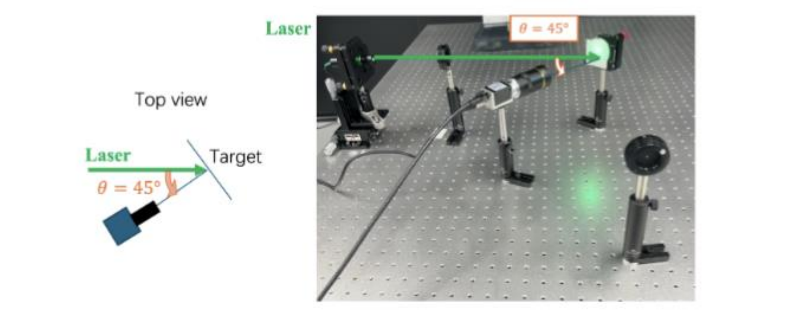

Figure 7: The proof-of-principle experiment for the laser alignment targets.

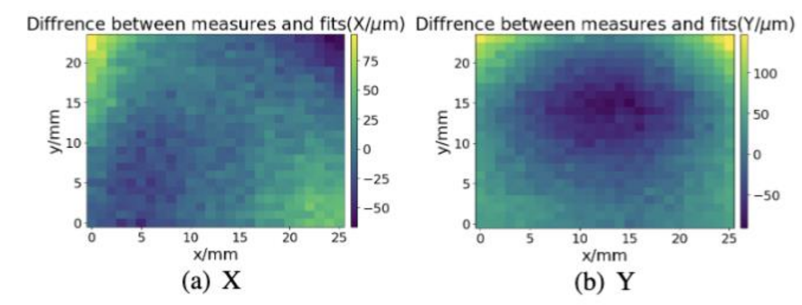

Figure 8: Difference between measurement and linear fitting in the X and Y directions.

Planned Hardware Modifications

- 2024 long shutdown
  - shoot a laser from the hutch and transport till IP
- 2025 summer shutdown
  - modify the timing and synchronization system, the vacuum system
  - install and commission the new laser system and the detector system

Conclusion

- A transverse Compton polarimeter has been designed for BEPCII, reusing the beamline of a dismantled wiggler magnet.
- Preliminary Monte-Carlo simulations show promising performance.
- Beamline modifications are planned for the two shutdown periods of BEPCII in 2024 and 2025.

References

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This work was supported by the France China Particle Physics Network/Laboratory and Youth Innovation Promotion Association CAS (No. 2021012).