26th International Symposium on Spin Physics
A Century of Spin

中国科学院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

中国科学院大学
University of Chinese Academy of Sciences

The 26th international symposium on spin physics (SPIN2025)

Design and Preliminary Implementation of a Laser Compton Polarimeter for BEPCII

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CONTENTS

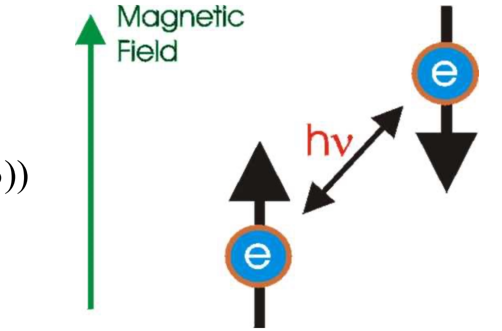
1

PART

Background

1.1 Polarized lepton beams

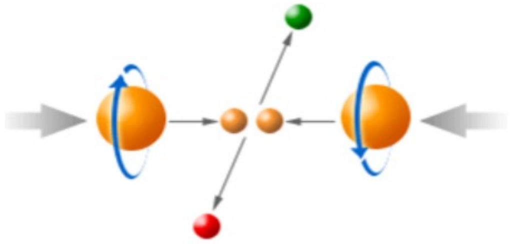
- Sokolov-Ternov effect drives the spontaneous buildup of vertical polarization in electron storage rings (Dokl. Akad. Nauk SSSR 153(5), 1052–1054 (1963))
- Polarization degree: $P = \frac{n_\uparrow - n_\downarrow}{n_\uparrow + n_\downarrow}$



Synchrotron radiation photons can induce electron spin flips, with unequal probabilities for up→down versus down→up transitions.

- Applications of polarized lepton beams
  - Vertical polarization:
    - Precision energy calibration via resonant depolarization technique (VEPP-4M: $\sim 10^{-6}$) (Blinov:Nuclear and Particle Physics Proceedings 273-275, 210–218 (2016)
  - Longitudinal polarization:
    - Longitudinally polarized colliding beams help enhance the physics reach (CLENDENIN19941,Moortgat-Pick:2008,PhysRevD.110.014035)

Require high precision polarimeter !

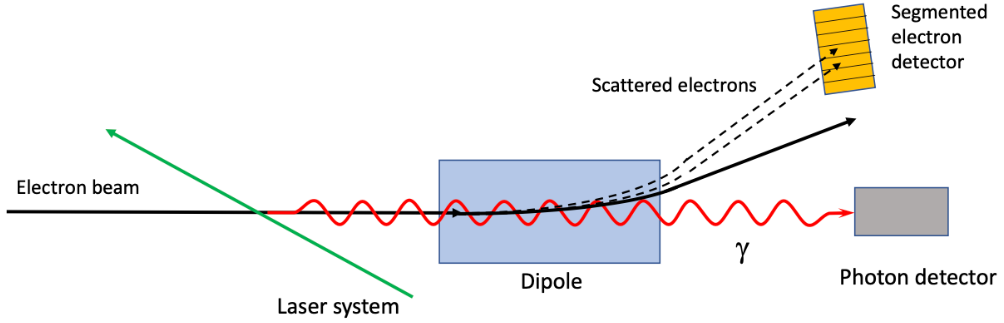


Longitudinal polarized lepton beam collision
Achieved：SLC, HERA
Planning：CEPC, CCF, SuperTC, EIC, SuperKEKB

(CCF study report,CEPC TDR, EIC design report)

1.2 Compton polarimeter

- Compton polarimeter are commonly used in electron storage rings with GeV beam energies because of their advantages of accurate and nondestructive measurement.
- Real-time polarization measurement is required by polarized beam applications



Polarimeter	Direction	Type	Energy (GeV)	Systematic Uncertainty
CERN LEP (R. Assmann:CERN SL/93-02 (BI))	Vertical	γ	46	5%
HERA LPOL (hep/ex 1201.2894)	Longitudinal	γ	27	2.0%
HERA TPOL (hep/ex 1201.2894)	Vertical	γ	27	1.9%
SLD @ SLAC (PhysRevLett.84.5945)	Longitudinal	e	45.6	0.5%
CREX@ JLAB Hall A (PhysRevC.109.024323)	Longitudinal	γ, e	2	0.36%
JLAB Hall C	Longitudinal	γ, e	1.1	0.6%

the above list of polarimeters is not exhaustive

1.3 The principle of laser Compton polarimeter

The differential cross section (ginzburg_colliding_1984, SLAC-PUB-4656)

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

For a circularly polarized laser and transversely polarized electron beam,

$$\frac{d\sigma}{dY}(Y) = \left(\frac{d\sigma}{dY}\right)_{unp}(Y)\left[1 - S_3 P_y A_y(Y)\right]$$

Degree of vertical polarization of electron

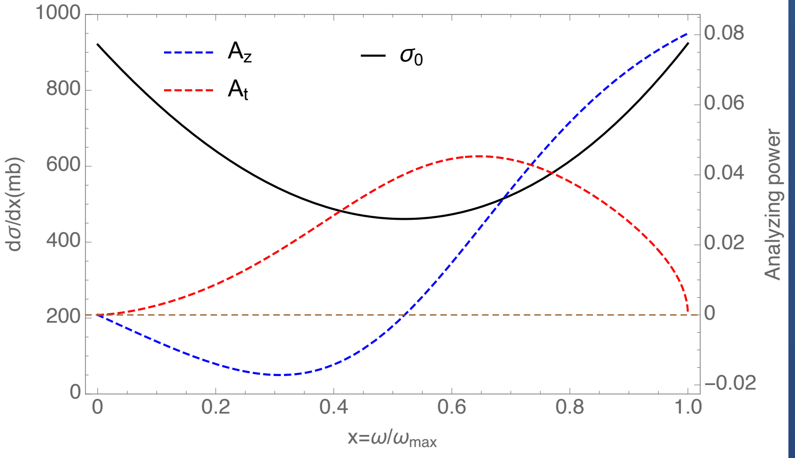
Helicity flips
➔ $S_3 = \pm 1$
➔ Asymmetry along Y

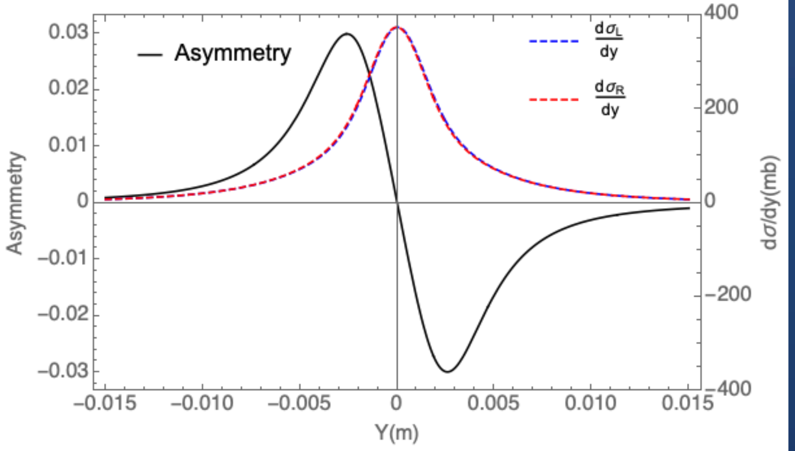
$$\text{Asymmetry} = \frac{N_L - N_R}{N_L + N_R}(Y) = |S_3| P_y A_y(Y)$$

Analyzing power
Can be calculated

Degree of circular
Polarization of laser
~100%
Can be measured

E_b=2.35 GeV, λ_{laser}=532 nm





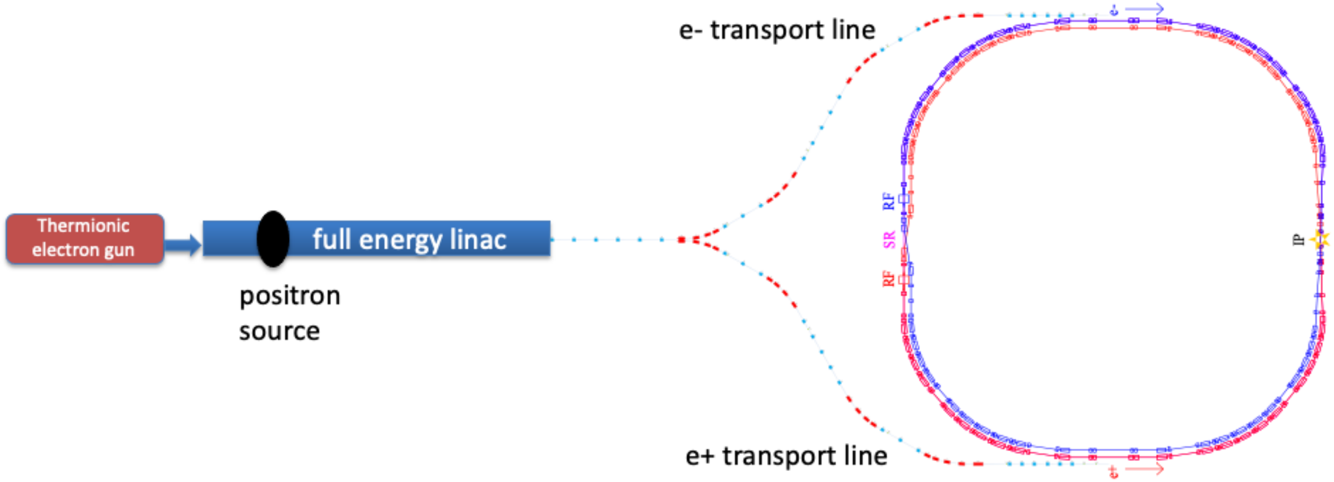
2

PART

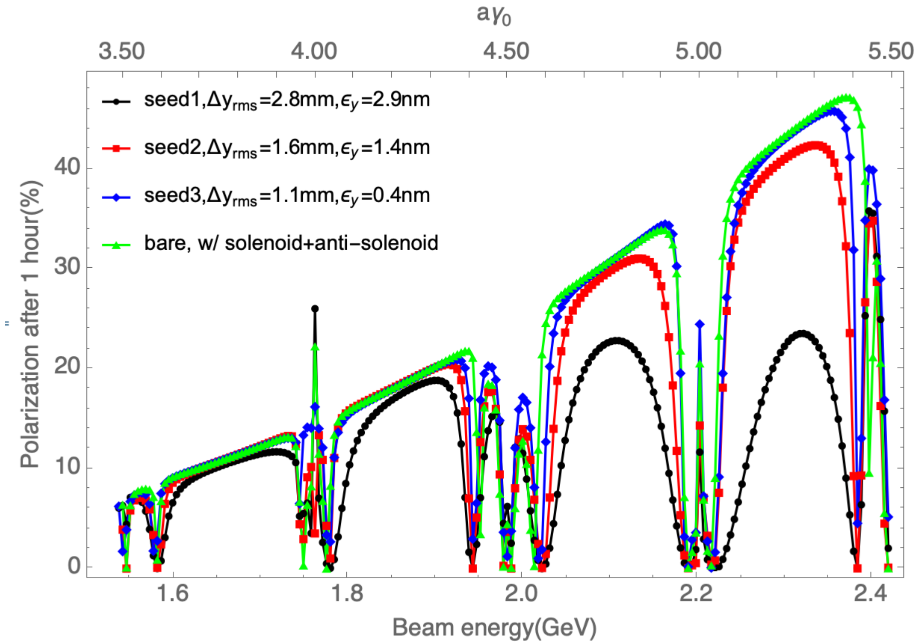
Design considerations

2.1 Introduction to BEPCII

- Beijing Electron Positron Collider II (BEPCII), a double-ring electron positron collider operating in the tau-charm energy range.
- Driven by increasing particle physics research interests at higher beam energies, it is undergoing an upgrade, BEPCII-U, to achieve a threefold increase in the luminosity at 2.35GeV and a higher beam energy up to 2.8 GeV. (Yu: 7th International Particle Accelerator Conference, p.01 (2016))
- The polarization build-up time is about 72.5 min at 2.35 GeV for BEPCII storage rings, and the electron beams are injected normally every 1.5 hour.

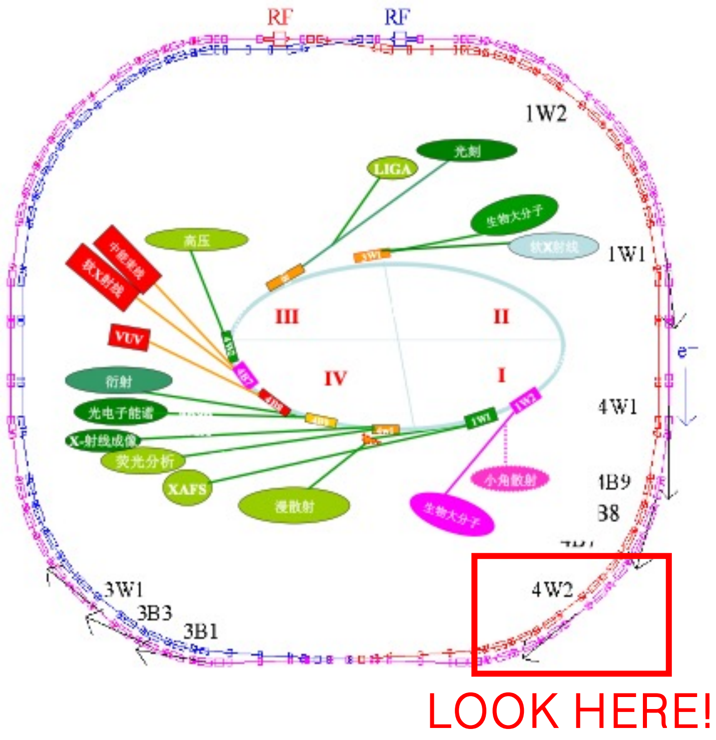


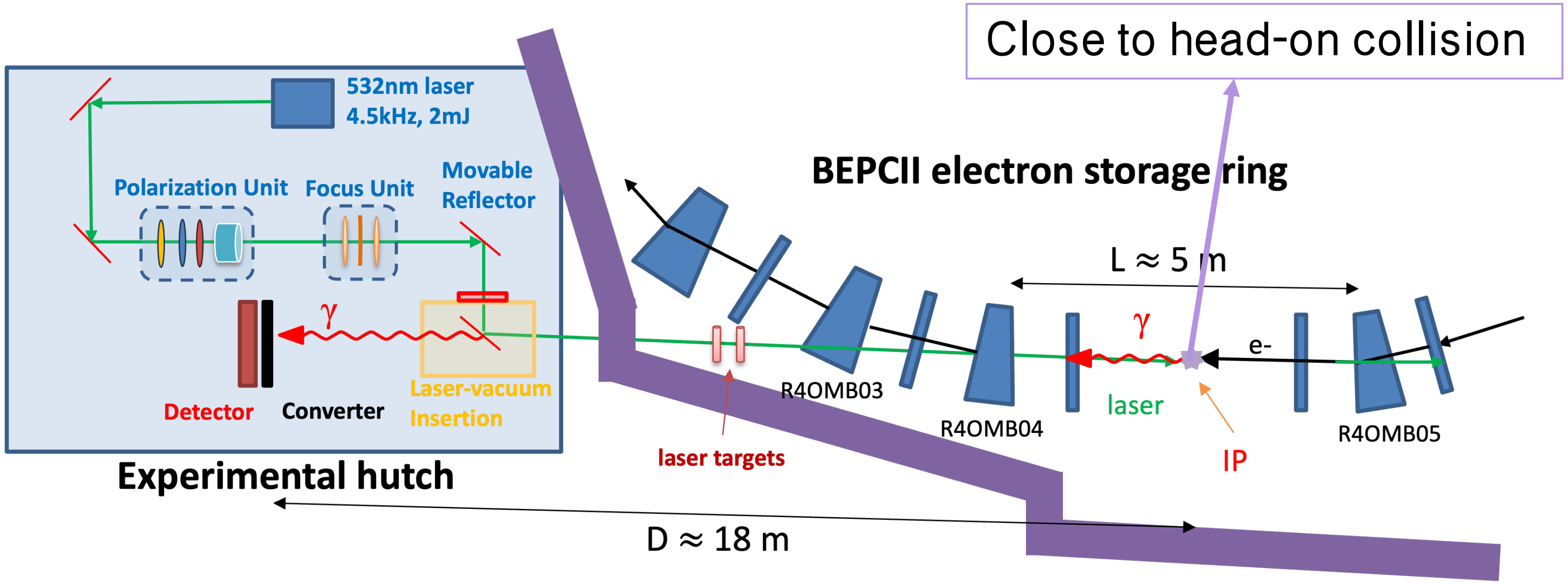
Vertical polarization 1 hour after injection



2.2 A Compton polarimeter at BEPCII

- 4W2, a wiggler-based X-ray beamline of BEPCII has retired from operation under the upgrade
- We propose to modify the front end and the hutch to set up a Compton polarimeter.





2.3 The luminosity of laser Compton polarimeter

For electron beam bunches and pulsed lasers, the collision luminosity is

$$\mathcal{L}_{pulse} = N_e N_\gamma \frac{\cos(\alpha/2)}{2\pi} \Sigma$$

$$\Sigma = \frac{F}{\sqrt{(\sigma_{e,y}^2 + \sigma_{\gamma,y}^2)}\sqrt{(\sigma_{\gamma,x}^2 + \sigma_{e,x}^2)\cos^2\left(\frac{\alpha}{2}\right) + (\sigma_{\gamma,z}^2 + \sigma_{e,z}^2)\sin^2\left(\frac{\alpha}{2}\right)}}$$

The laser frequency and single pulse energy,
need to adjust the time synchronization between the laser and the electron beam.

collision frequency $F = f_{laser}$
cross angle: $\alpha \to 0$
$\sigma_{y,laser} \gg \sigma_{y,e}$

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

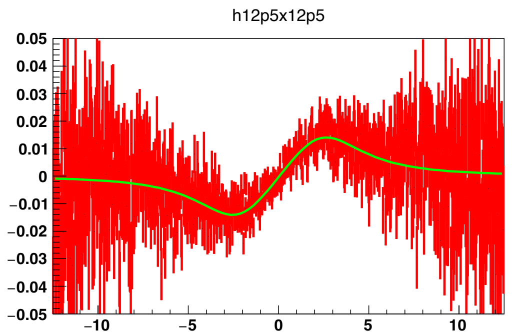
Reduce beam size, increase luminosity

2.4 Design parameters and MC simulation

Tab.1 Electron and laser beam parameters and the calculated luminosity and γ-yield rate.

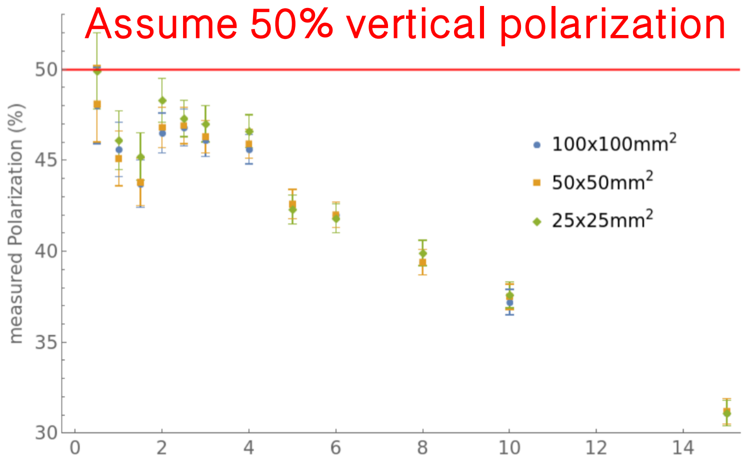
Parameters	Electron	Laser
Energy(eV)	1.84×10^9	2.33 (532nm)
Pulse energy(mJ)	-	2
Repetition rate(kHz)	1.26×10^3 $\times\frac{1}{280}$ →	4.5 (Internal trigger mode) 4.508 (External trigger mode)
Pulse length(ps)	50	1277
Rms emittances(nm·rad)	80/2	-
Rms beam size(mm)	0.7/0.1	2/2
Vertical crossing angle (mrad)	0.5	
Luminosity ($barn^{-1}s^{-1}$)	2.2×10^6	
γ-yield per crossing	310	
γ-yield rate(kHz)	1400	
Statistical uncertainty	~0.9%, 2.5min	

Laser can be synchronized with an arbitrary bunch by the timing system



Asymmetry of a simulation of 10^8 gamma

[Guangyi Tang]

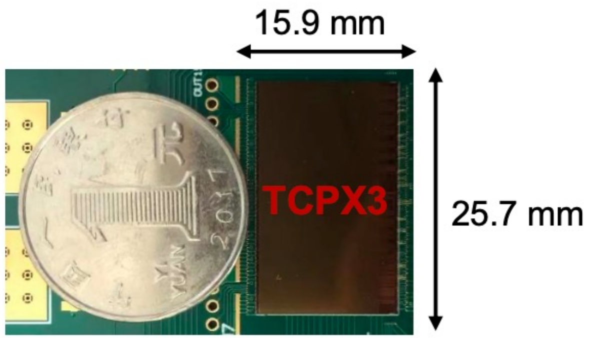


Thickness of lead (mm)

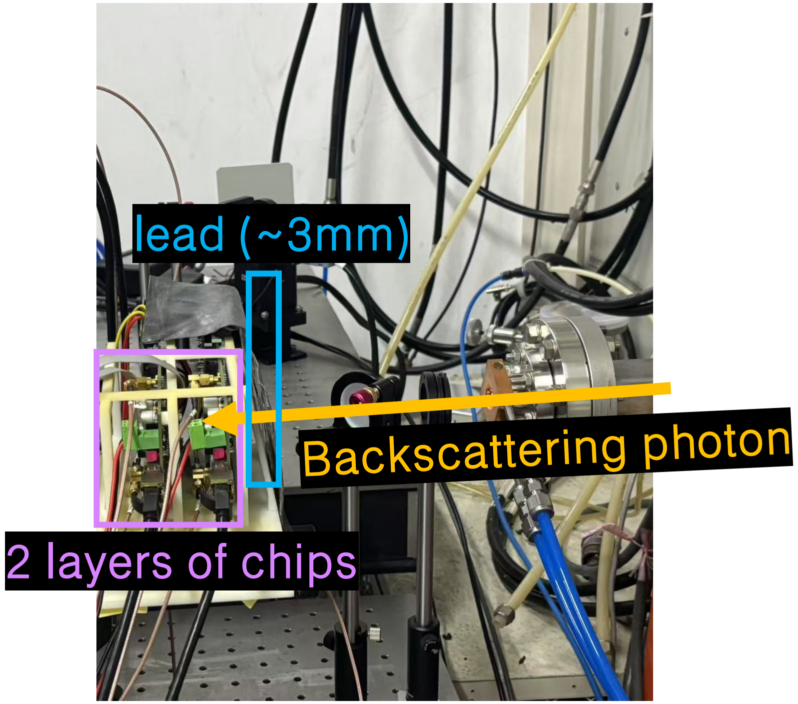
[Guangyi Tang]

2.5 Detection system

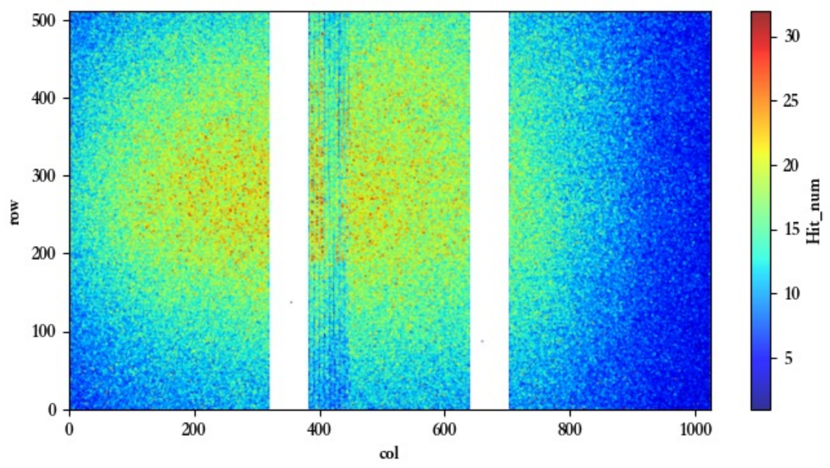
- The TaichuPix-3 silicon detector, a CMOS pixel sensor prototype for the CEPC vertex detector with a sensitive area of $15.9 \times 25.7 mm^2$ and a pixel size of $25 \times 25 \mu m^2$.
- Since the lepton detection efficiency is higher than that of γ photons for such a detector, a lead converter with a thickness of a few millimeters, subject to optimization, is placed just in front of the detector to convert γ photons into leptons.
- Detector readout active pixels with a time resolution of 50ns



TaichuPix-3
Pixel size： 25 μm ✕ 25 μm



Signal on Taichu-Pix 3



3

P A R T

Implementation status

3.1 Overall progress

2024. 1
- First conceptual proposal

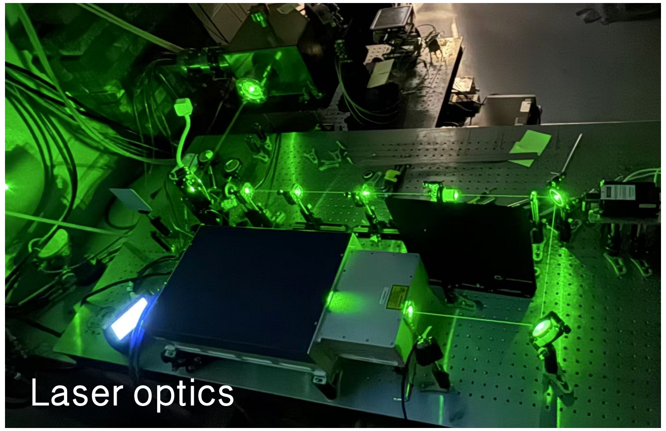
2024. 5
- Physics design reviewed
- Task force established

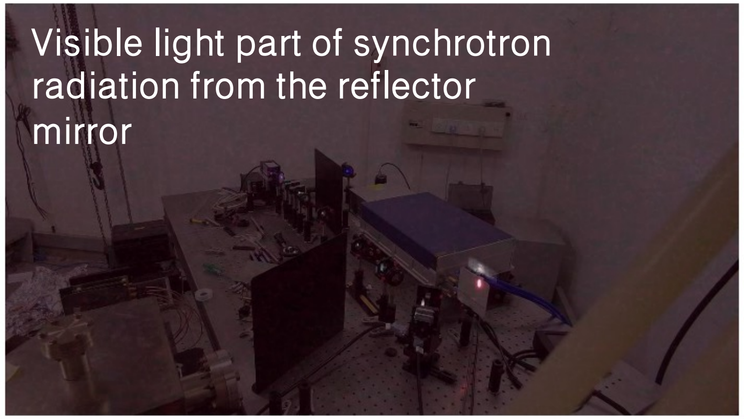
2025. 2
- First phase beamline modification finished

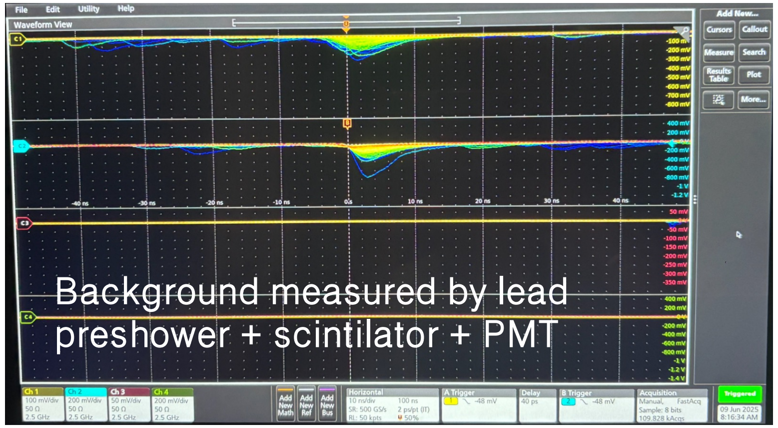
2025. 5-6
- Beamline vacuum recovered
- Synchrotron radiation observed
- Laser system commissioning

2025.7
- **First laser-beam collision**
- Replacement of diamond window

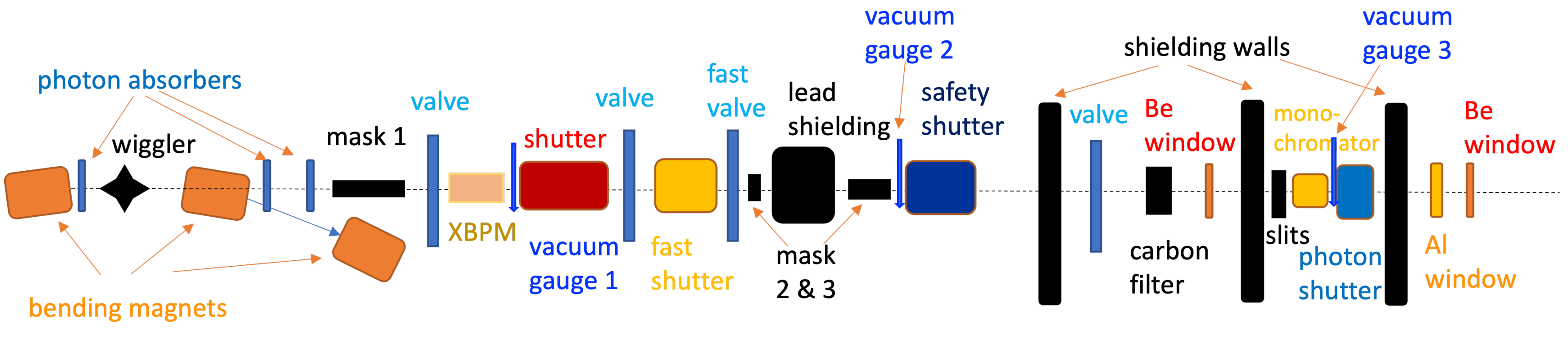
2025. 8 - 9
- Second phase beamline modification


Laser optics

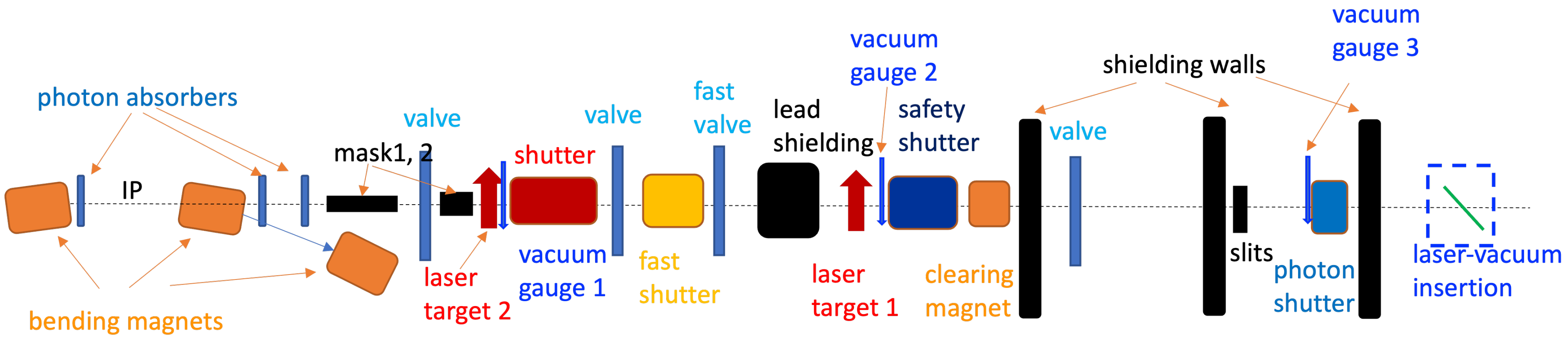

Visible light part of synchrotron radiation from the reflector mirror


Background measured by lead preshower + scintilator + PMT

3.2 Modification of the photon beamline

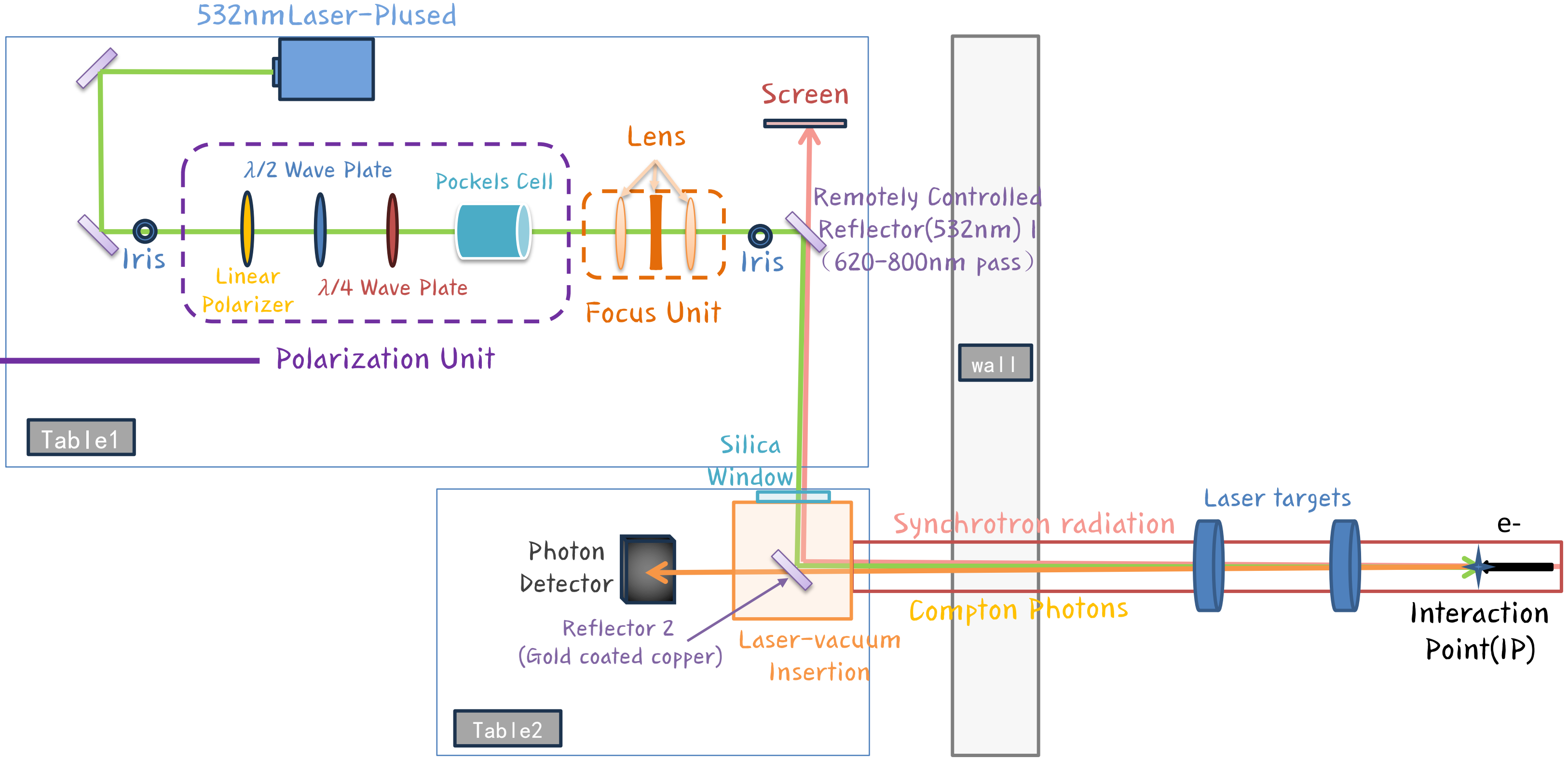


(a) Layout of the original X-ray beamline.



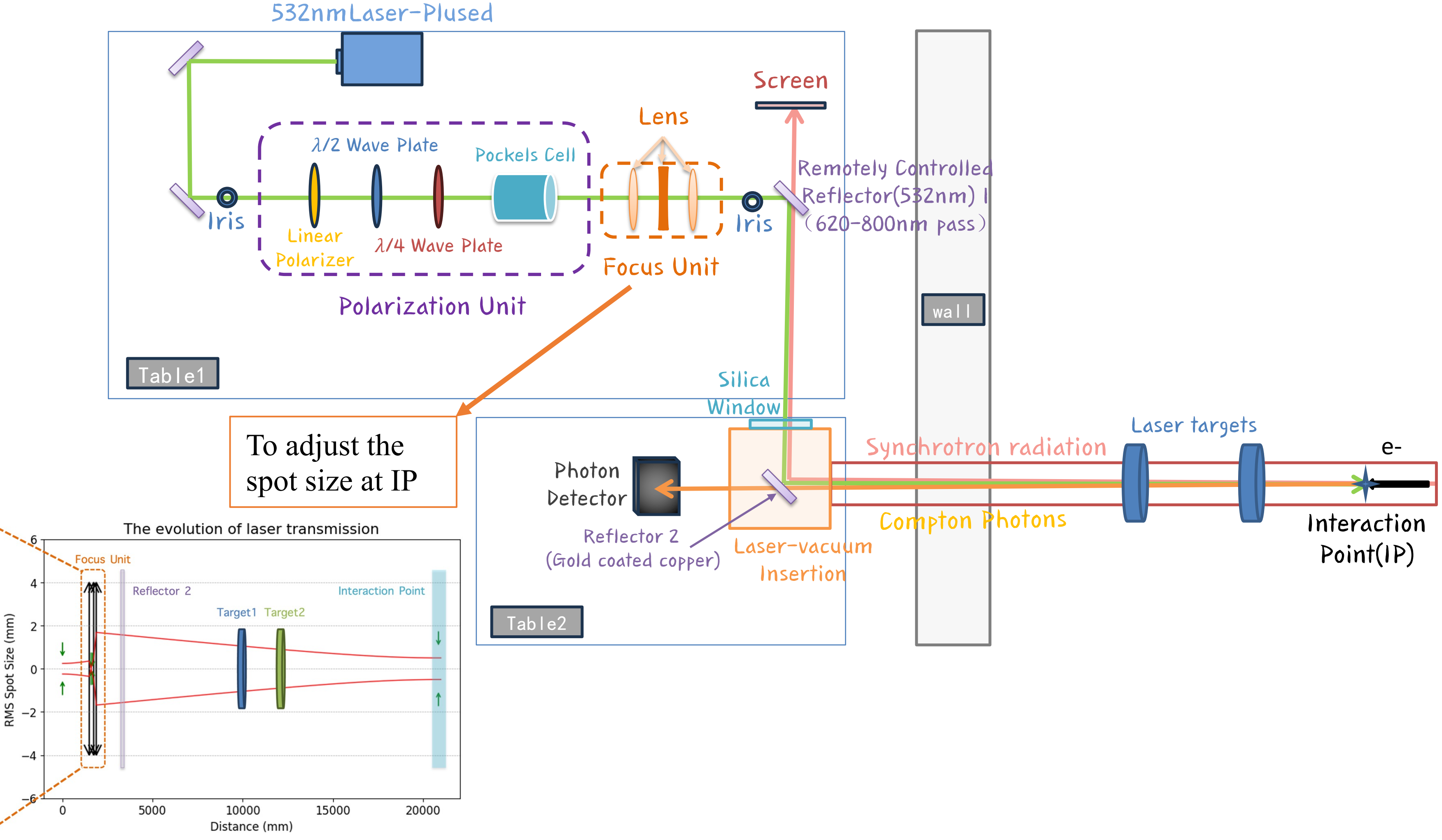
(b) Layout of the modified beamline for transmission of laser & γ beams.

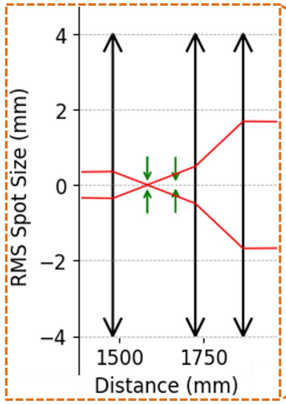
3.3 Laser optics tuning



To ensure a specific circular polarization state at the IP.

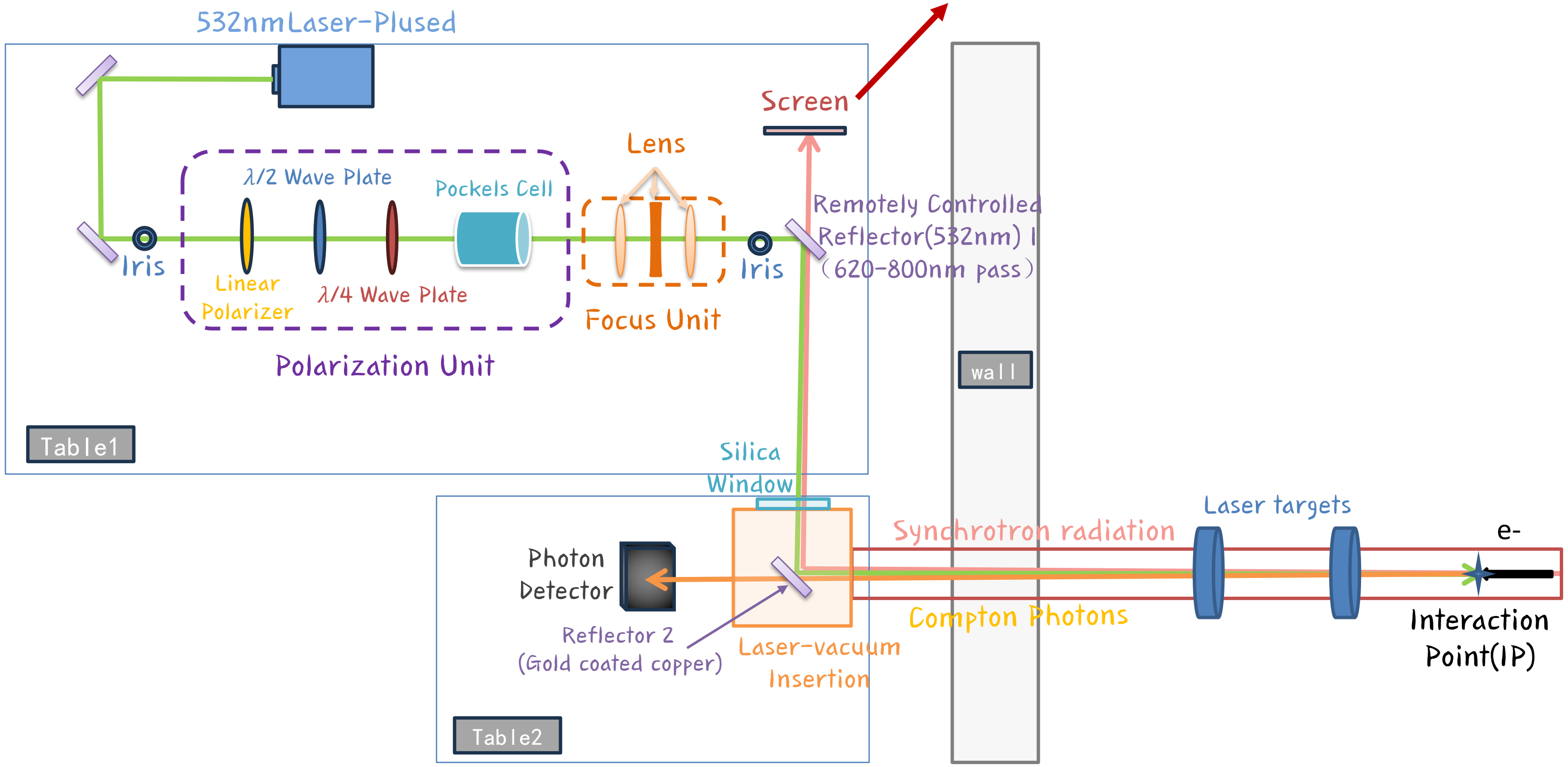
3.3 Laser optics tuning



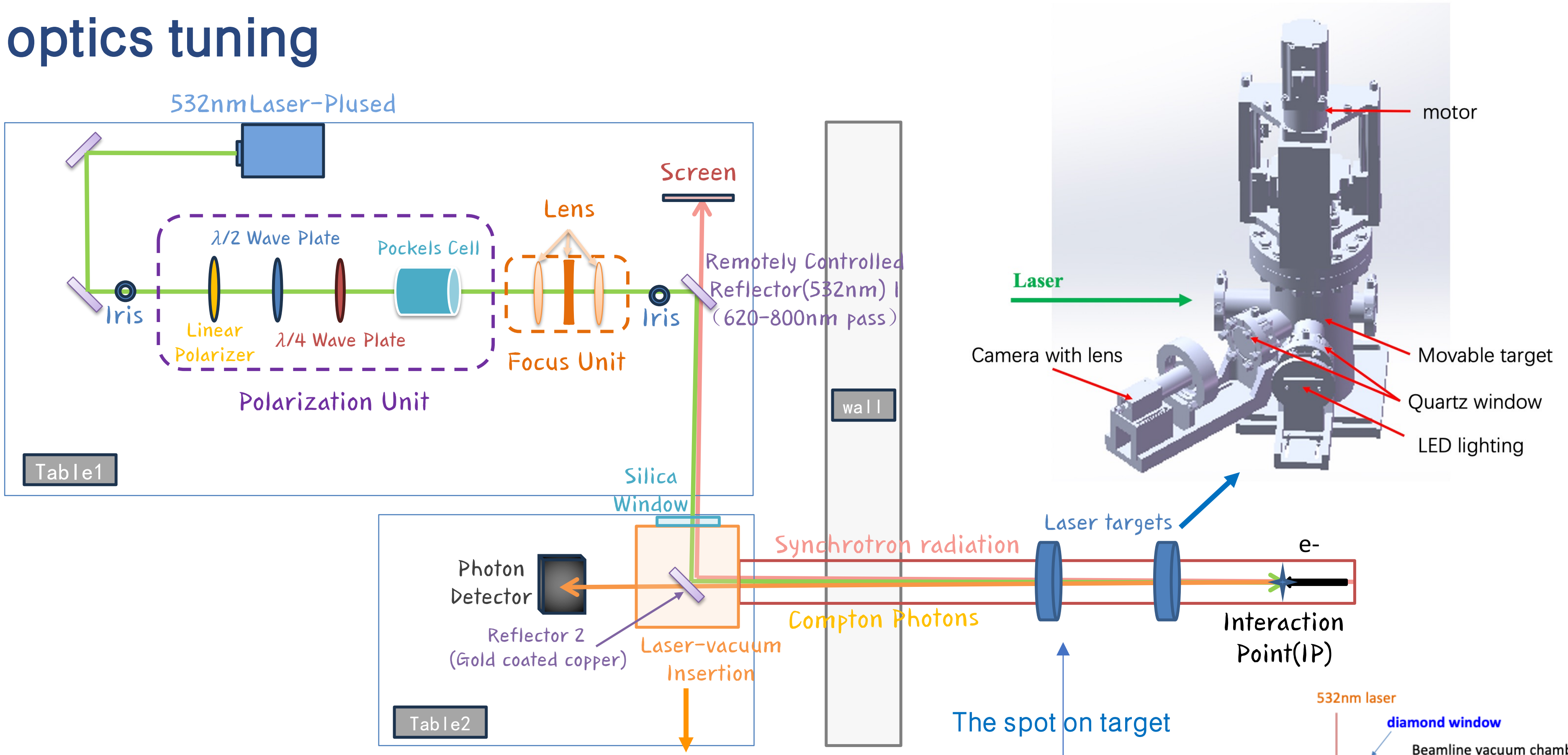


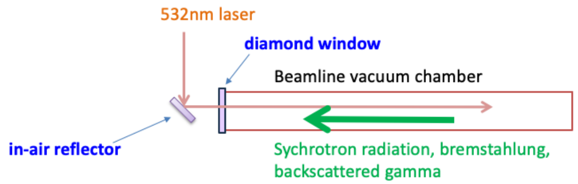
3.3 Laser optics tuning

Here we can see the visual part of synchrotron radiation light

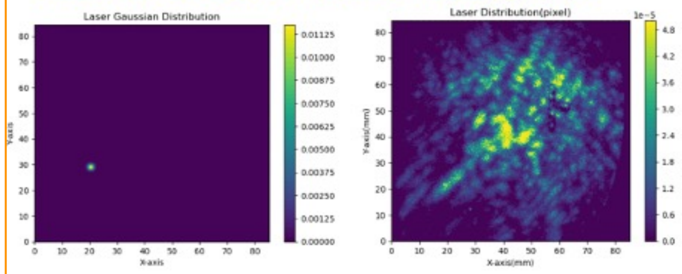


3.3 Laser optics tuning

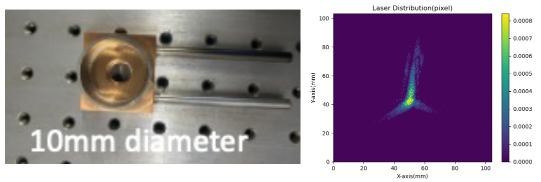




Surface damage of the reflector deteriorate the laser spot size, event rate significantly lower

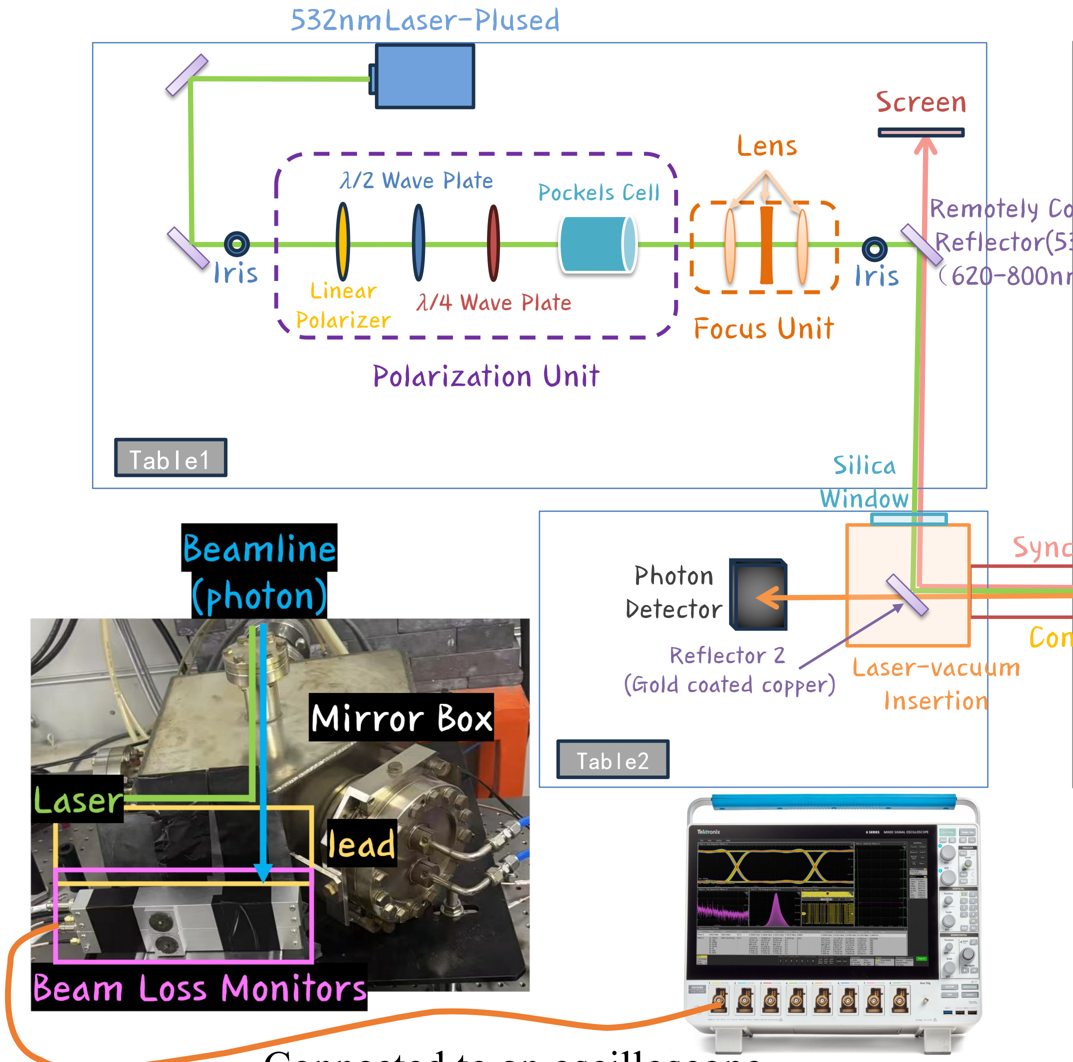


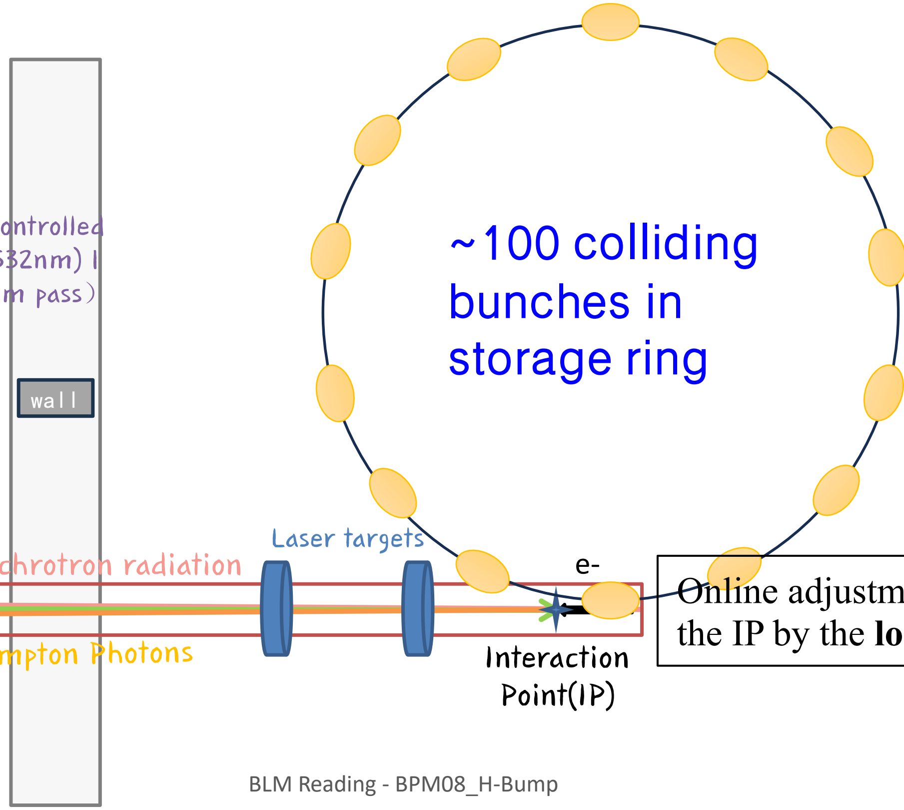
Employ a single crystal diamond window with water cooling to seal the vacuum



3.4 Beam commissioning

- Alignment of detector & electron beam based on background

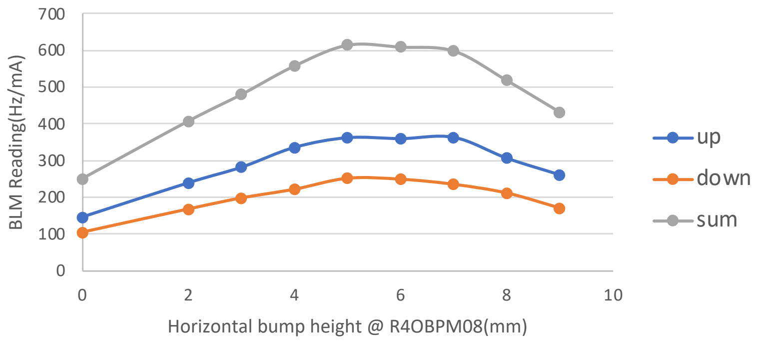


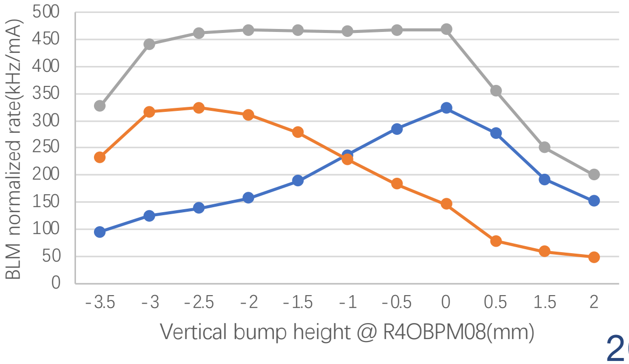


Online adjustment of the electron position at the IP by the **local bump** of the storage orbit.

Connected to an oscilloscope

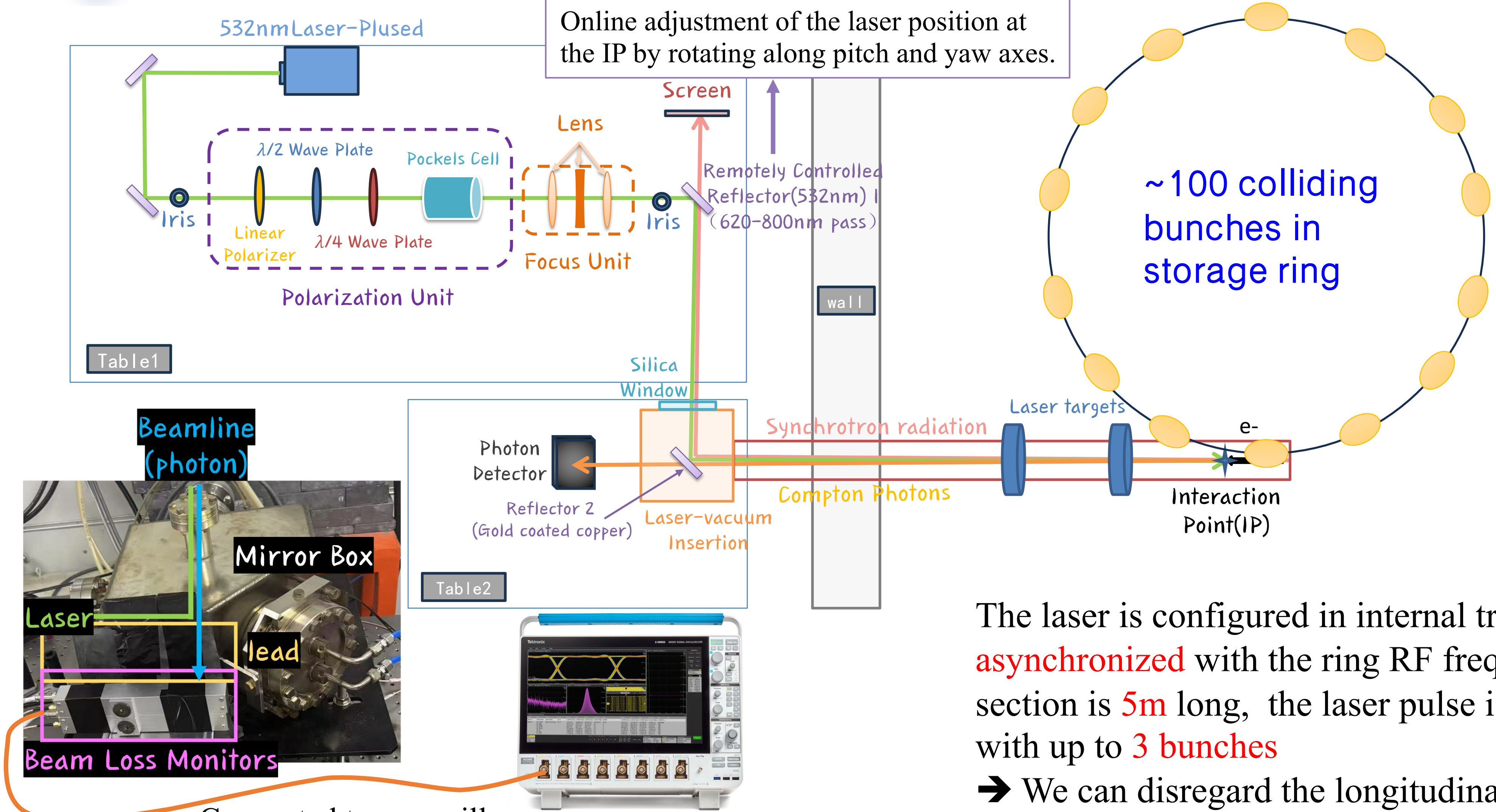
~5mm lead + glass scintillator (~5×5cm^2)+ PMT





3.4 Beam commissioning

- Scan the position of laser to find the collision signal



Connected to an oscilloscope

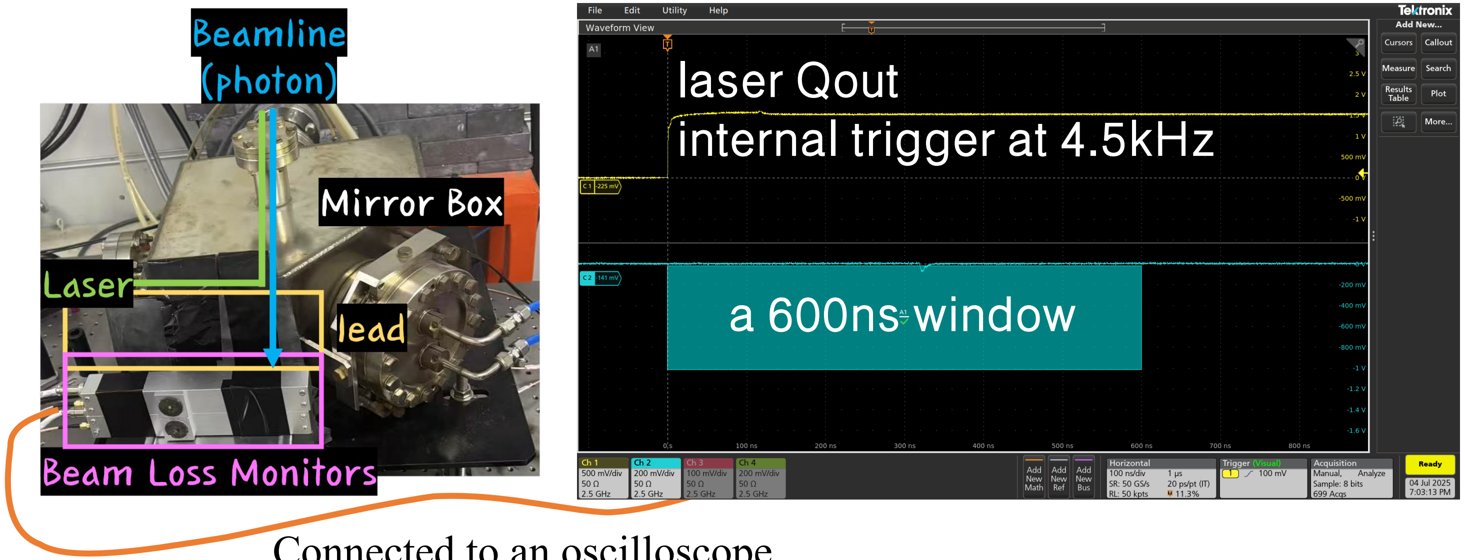
~5mm lead + glass scintillator (~5×5cm^2)+ PMT

The laser is configured in internal trigger mode (4.5 kHz) , asynchronized with the ring RF frequency, the straight section is 5m long, the laser pulse is likely to coincide with up to 3 bunches

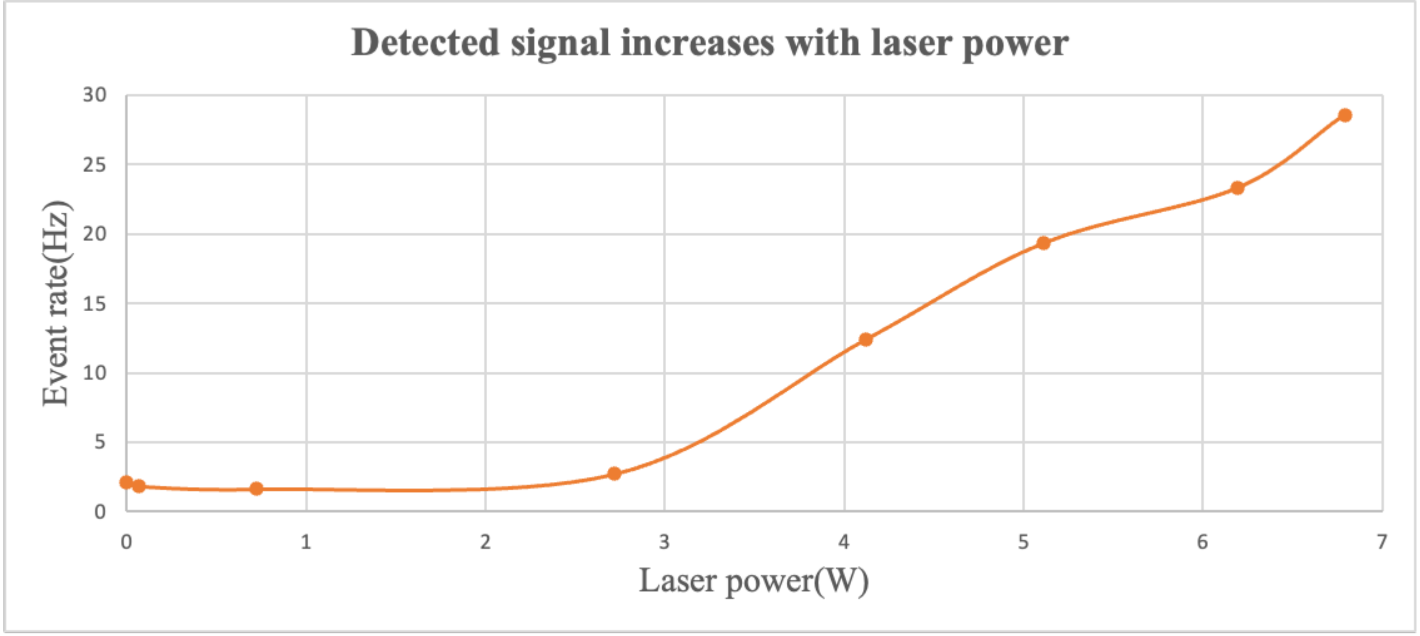
➔ We can disregard the longitudinal matching here

3.4 Beam commissioning

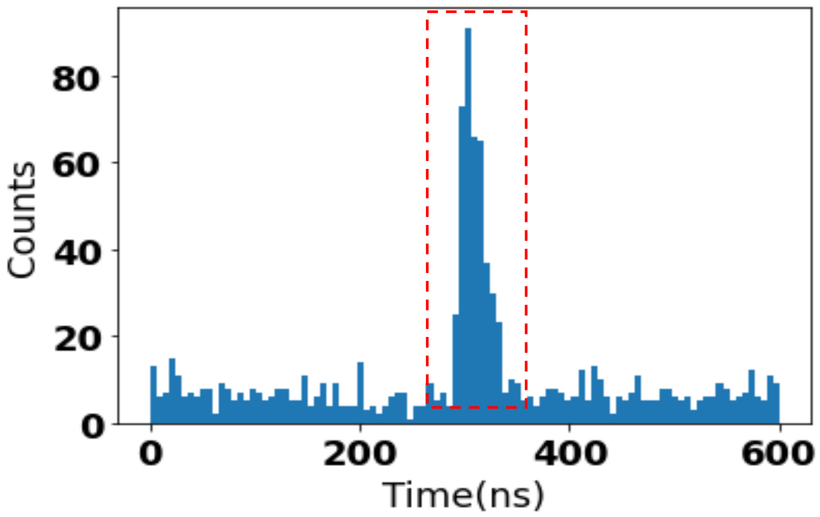
- Causality between laser and backscattered γ signal
- Event rate increases with laser power in a narrow temporal window



Connected to an oscilloscope

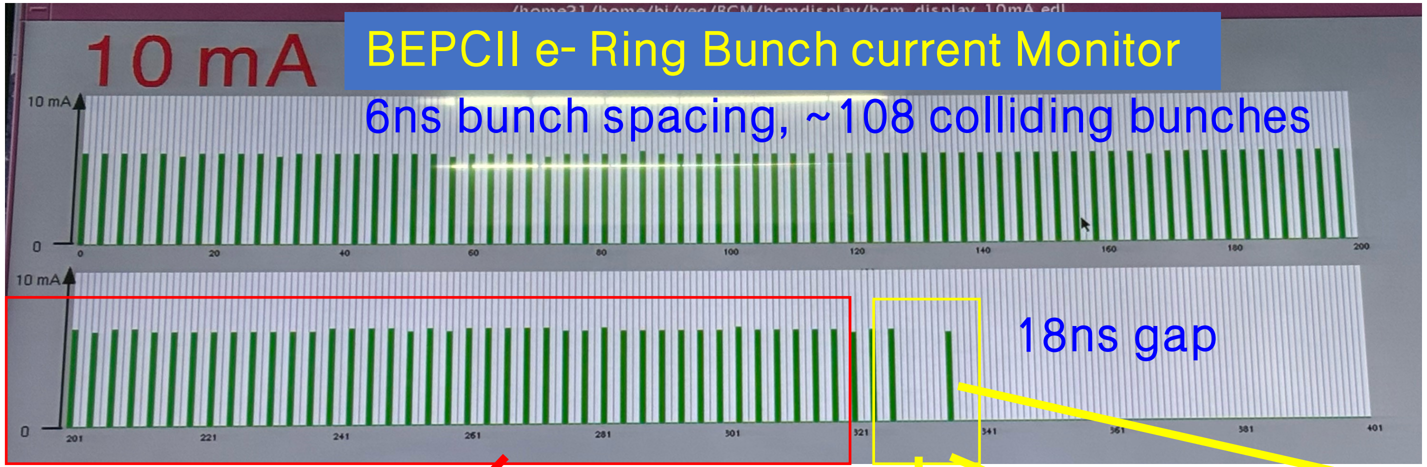


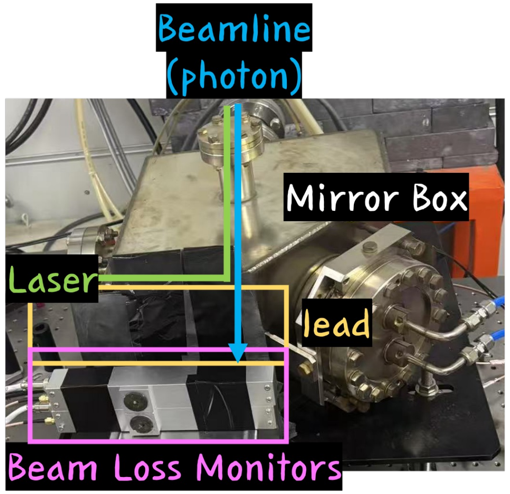
Temporal distribution of detected peaks of 1000 triggered waveforms

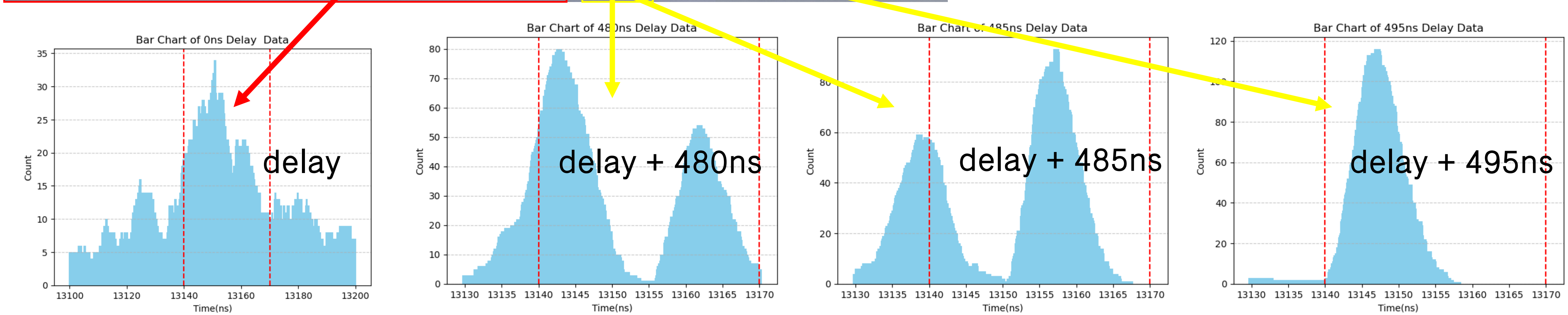


3.4 Beam commissioning

- Timing system sends 4.508kHz trigger to laser, in synchronization with ring RF frequency
- Laser is now synchronized with one pilot bunch



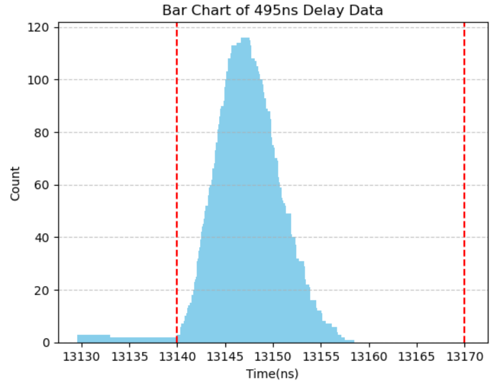




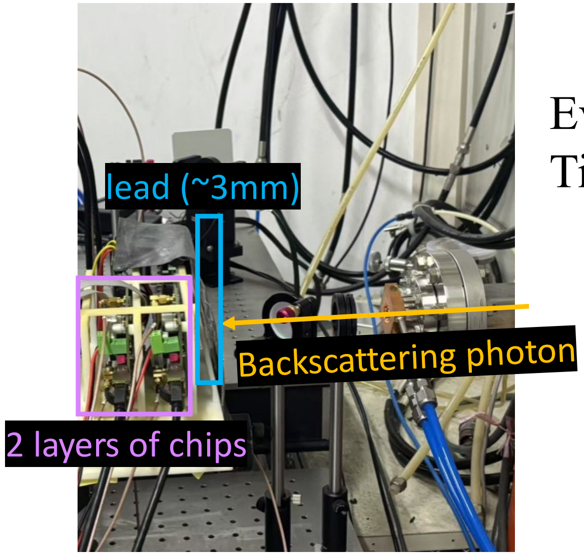
3.5 Detector commissioning

- We have observed the gamma signals via Taichu-Pix 3.
- The next step is to distinguish the collision signals from the background

Single bunch collision via BLM

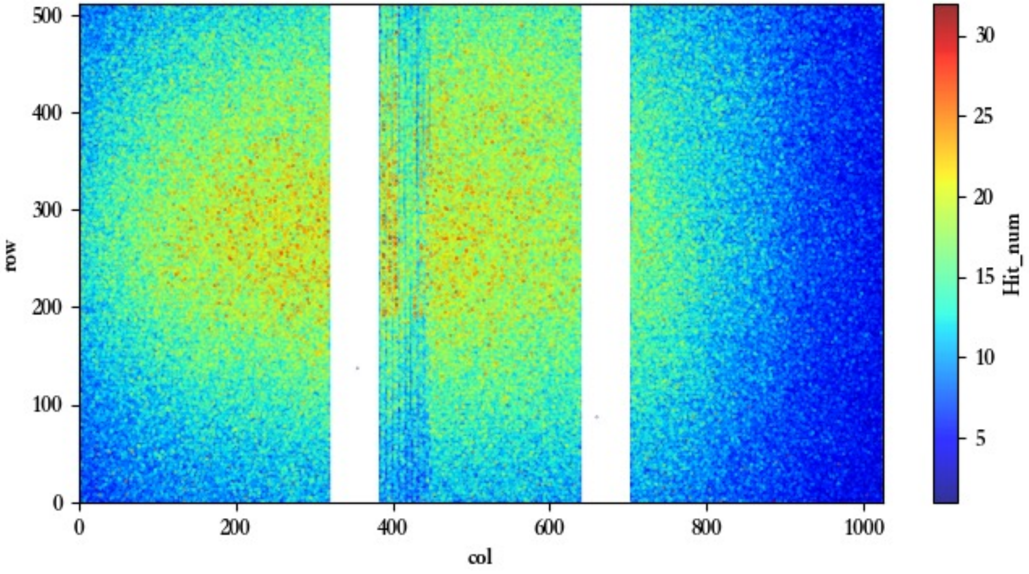


Taichu-Pix 3 detection system



Event timestamp
Time resolution = 50ns

Signal on Taichu-Pix 3



4

P A R T

Summary

4 Summary

- A laser Compton polarimeter has been designed and implemented in the electron storage ring of BEPCII, for vertical polarization measurement via detection of the vertical asymmetry of the back-scattered γ.
- First laser-beam collision has been observed (BLM), commissioning is underway to detect electron beam polarization (TaichuPix-3).
- Such a polarimeter can enable tests of resonant depolarization and study radiative depolarization mechanism, and contribute to spin physics research at BESIII experiments.

The 26th international symposium on spin physics (SPIN2025)

THANKS

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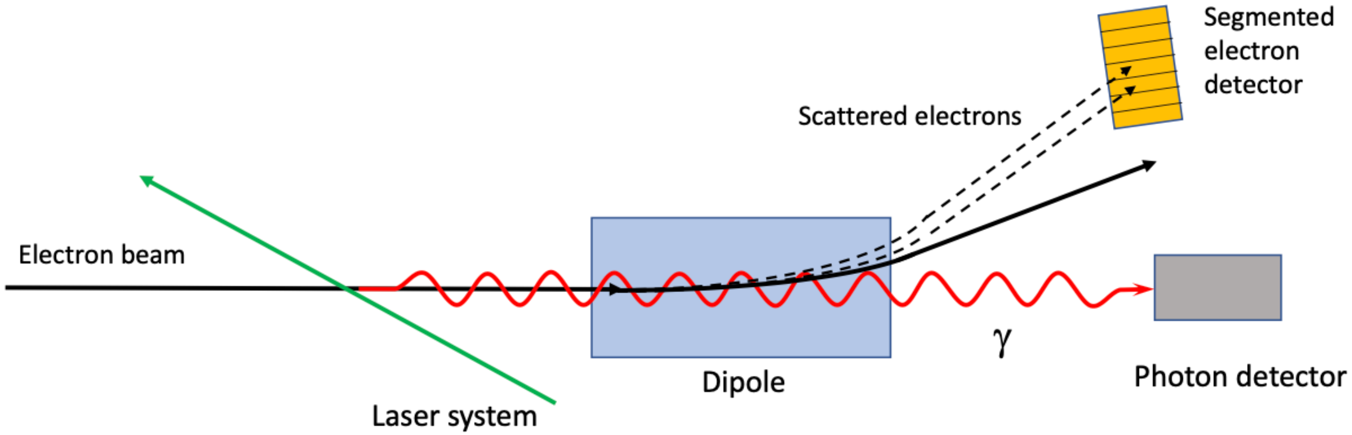
Date： 20250923

Backup



Type	Scattered γ	Scattered e-
Transverse	Calorimeter or pixelized detector	Pixelized detector
Longitudinal		
Accelerator implementation	😀	~100m drift for spectrometer
Background	SR & bremstrahlung	😀
Intrinsic issues	Limited resolution for calorimeter Sys. error due to converter for PD	only measure 2 components

Backup

- 系统误差和统计误差受铅转换体的厚度影响
  - 取铅厚度3mm，则取数20s 统计误差~1%
  - 铅同时用来屏蔽同步辐射
- 背散射gamma事例率12.8MHz，康普顿边缘~180MeV

Location	beamline and experimental hall of 4W2 wiggler
Laser	532nm, 4.5 kHz, 2 mJ, 1 ns, flippable circular polarization
Observable	Vertical asymmetry of backscattered γ (up to 180 MeV)
Detector	lead preshower + silicon pixel detector
Signal	backscattered γ ~ 20kHz/mA/W
Background	bremsstruhlung γ ~ 1kHz/mA

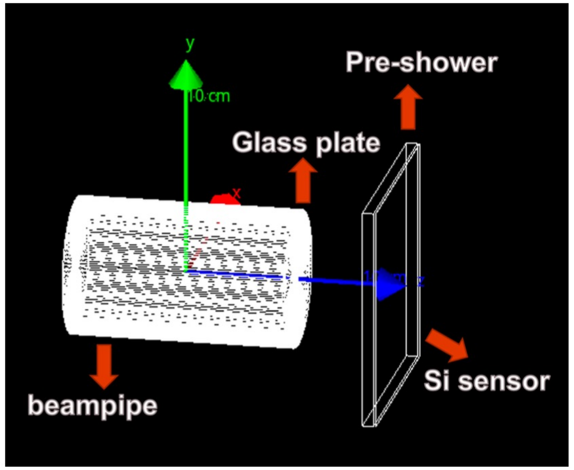


Figure 3: The sketch of the Geant4 model. The vacuum pipe with a one-mm-glass end cap is located on the left. The lead pre-shower and silicon sensor are located on the right.

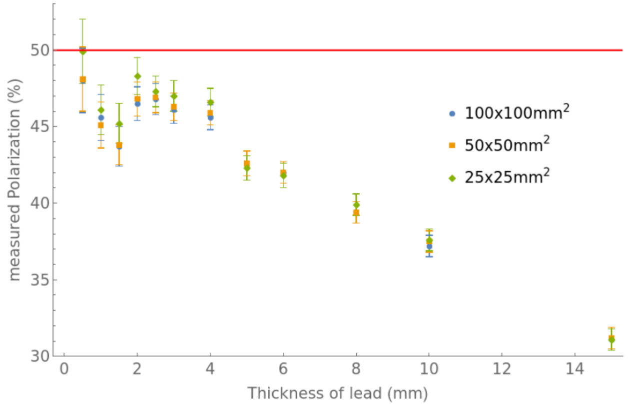


Figure 4: The measured polarization as a function of the thickness of the lead pre-shower and the area of the sensor. The areas of the sensor are 100×100 mm^2, 50×50 mm^2 and 25×25 mm^2. The red line indicates the true value of beam polarization.