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 1st Conference on Strong-Interaction Spin Physics

Design and Preliminary Implementation of a Laser Compton Polarimeter for BEPCII

Reporter：Mengyu Su

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Date：20260729

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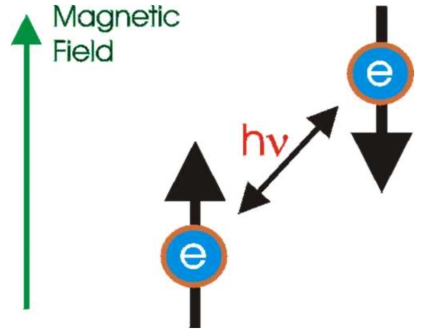
Background

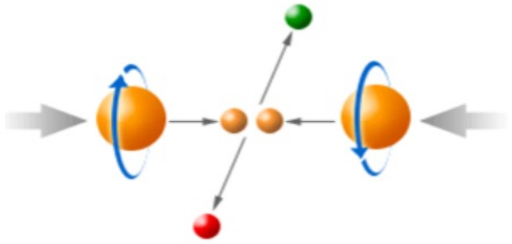
1.1 Polarized lepton beams

- 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: ~10^{-6}) (Blinov: 10.1016/j.nuclphysbps.2015.09.028)
  - Longitudinal polarization:
    - Longitudinally polarized colliding beams help enhance the physics reach (J. Clendenin: 10.1016/0168-9002(94)91275-0; G. Moortgat-Pick: 10.1016/j.physrep.2007.12.003; T. M. C. Abbott: 10.1103/PhysRevD.99.123505)



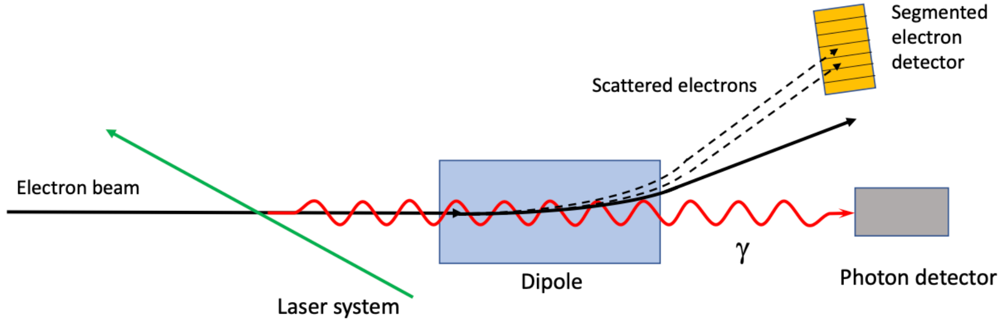
Longitudinal polarized lepton beam collision
Achieved： SLC, HERA
Planning： CEPC, SuperTC, EIC, SuperKEKB

Require high precision polarimeter !

(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 (I. F. Ginzburg: 10.1016/0167-5087(84)90128-5, SLAC-PUB-4656)

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

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

➔ $S_3 = \pm 1$

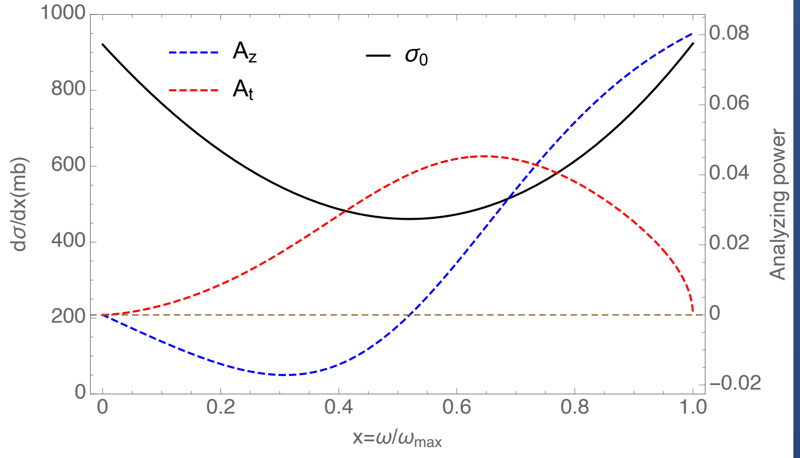
➔ Asymmetry along Y

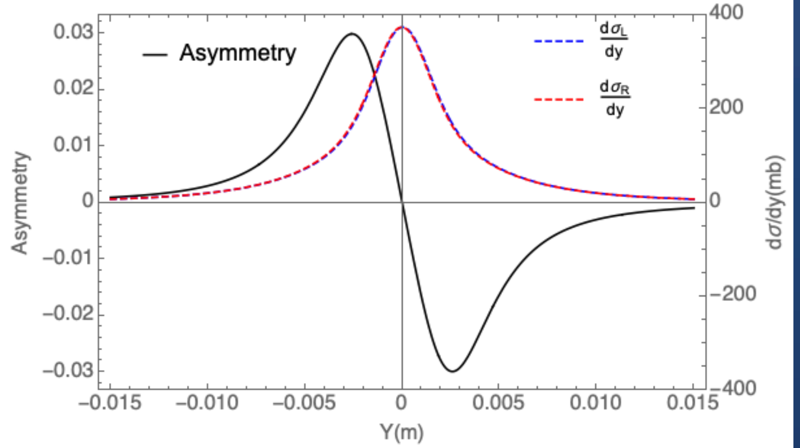
$$\boxed{\text{Asymmetry} = \frac{N_L - N_R}{N_L + N_R}(Y)} = |S_3| P_y A_y(Y)$$

Analyzing power
Can be calculated

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

E_b=2.35 GeV, λ_{laser}=532 nm





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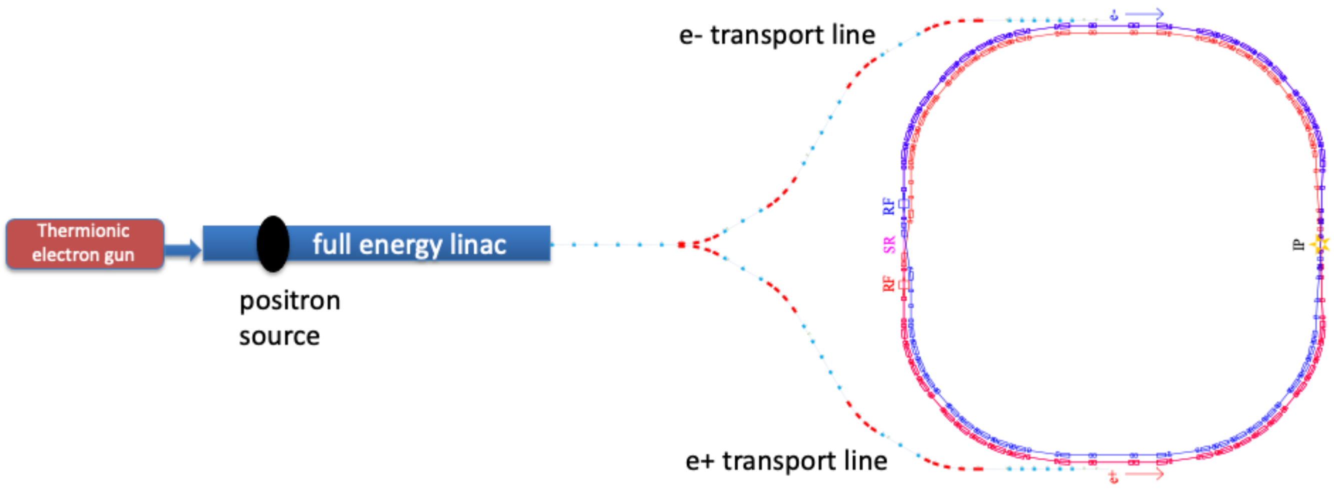
Design considerations

2.1 Introduction to BEPCII

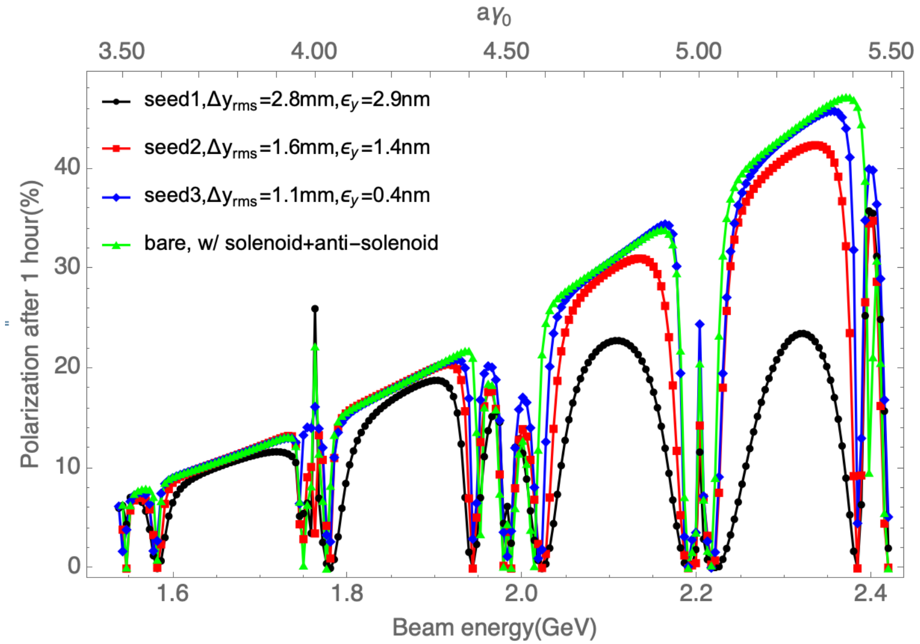
- Beijing Electron Positron Collider II (BEPCII), a double-ring electron positron collider operating in the tau-charm energy range.
- Driven by increasing particle physics research interests at higher beam energies, BEPCII-U, to achieve a threefold increase in the luminosity at 2.35GeV and a higher beam energy up to 2.8 GeV.

(Jie Gao: 10.48550/arXiv.2505.02401)

- 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.

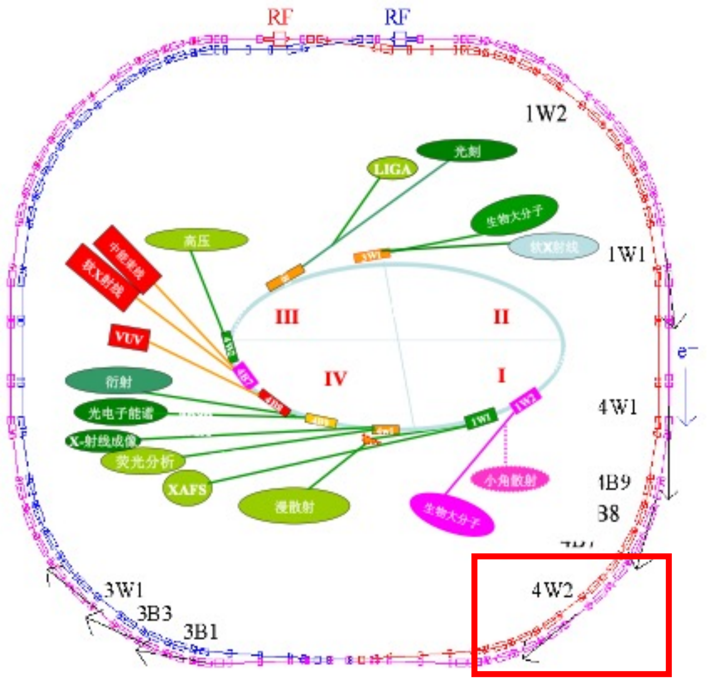


Vertical polarization 1 hour after injection

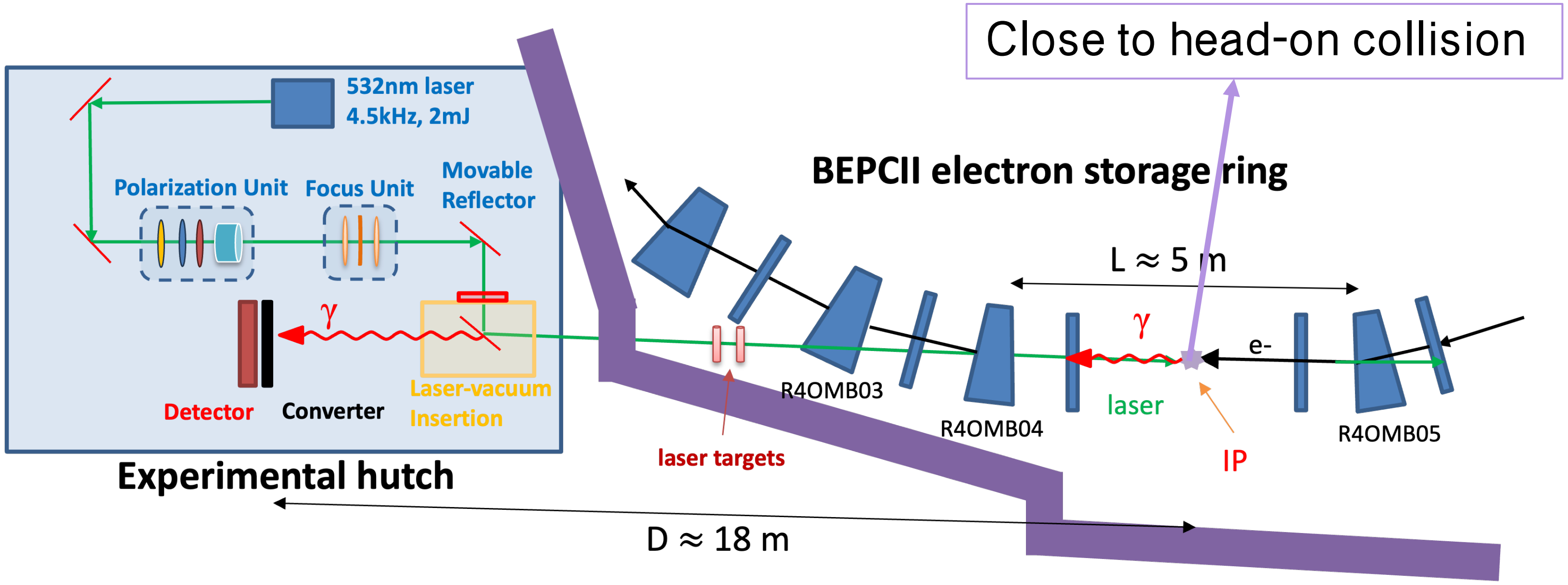


2.2 A Compton polarimeter at BEPCII

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



LOOK HERE!



2.3 The luminosity of laser Compton polarimeter

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

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

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

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

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

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

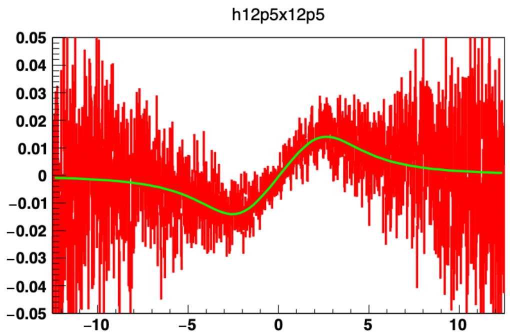
Reduce beam size, increase luminosity

2.4 Design parameters and MC simulation

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

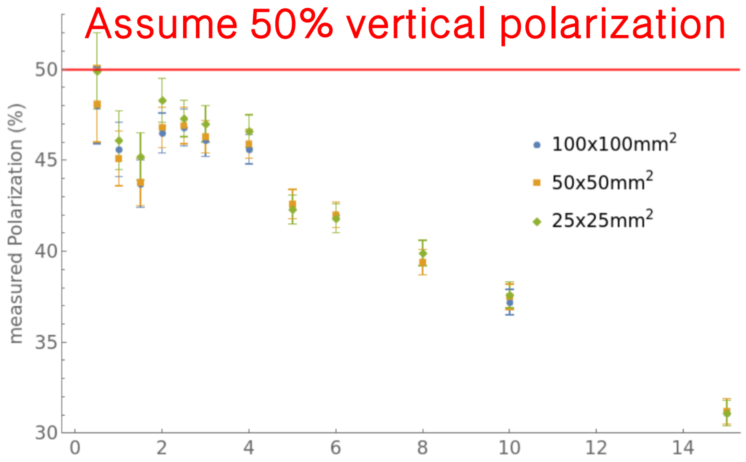
Parameters	Electron	Laser
Energy(eV)	2.35×10^9	2.33
e- bunch population	3.7×10^{10}	-
Pulse energy(mJ)	-	2
Repetition rate(kHz)	1.26×10^3 $\xrightarrow{\times \frac{1}{280}}$	4.508
Pulse length(ps)	50	1277
Rms emittances(nm)	157/0.53	-
Beta function(m)	5.66/5.31	-
Rms energy spread	6.35×10^{-4}	-
Dispersion function(m)	1.32/0	-
Rms beam size(mm)	1.3/0.05	0.5/0.5
Horizontal crossing angle(mrad)	0.5	
Luminosity (barn^{-1}s^{-1})	2.1×10^7	
γ-yield per crossing	2842	
γ-yield rate(MHz)	12.8	
Statistical uncertainty	0.9% @ 16 s	

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



Asymmetry of a simulation of 10^8 gamma

[Guangyi Tang]

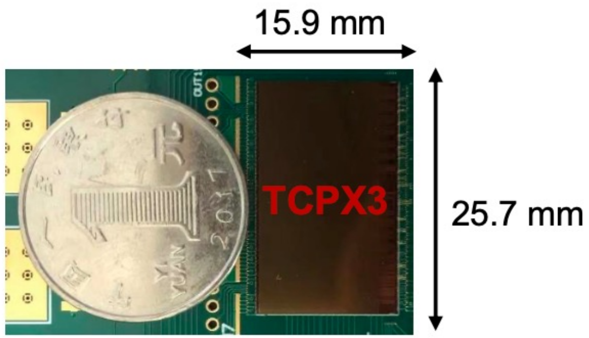


Thickness of lead (mm)

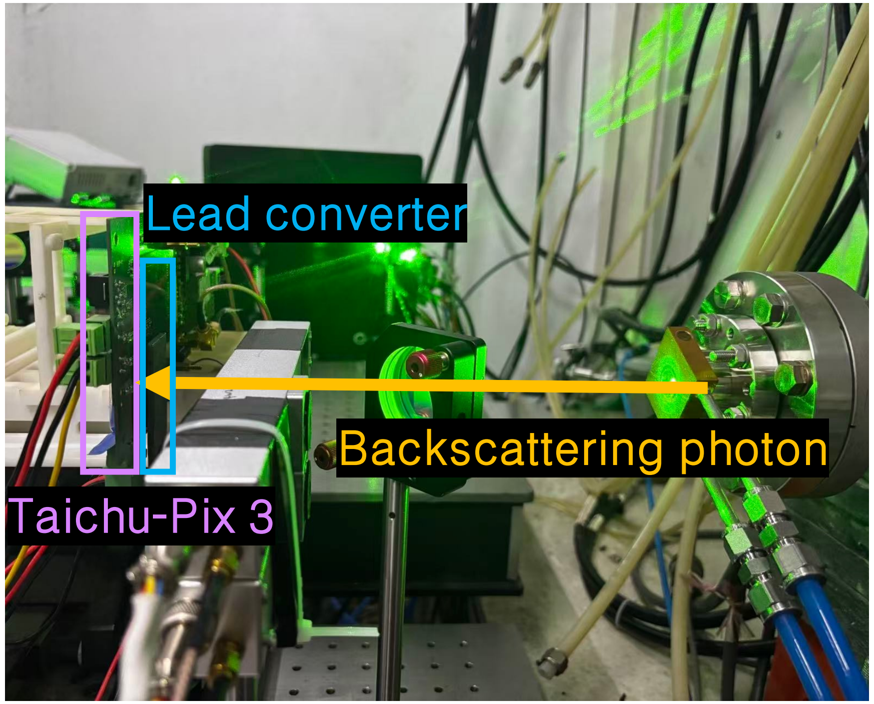
[Guangyi Tang]

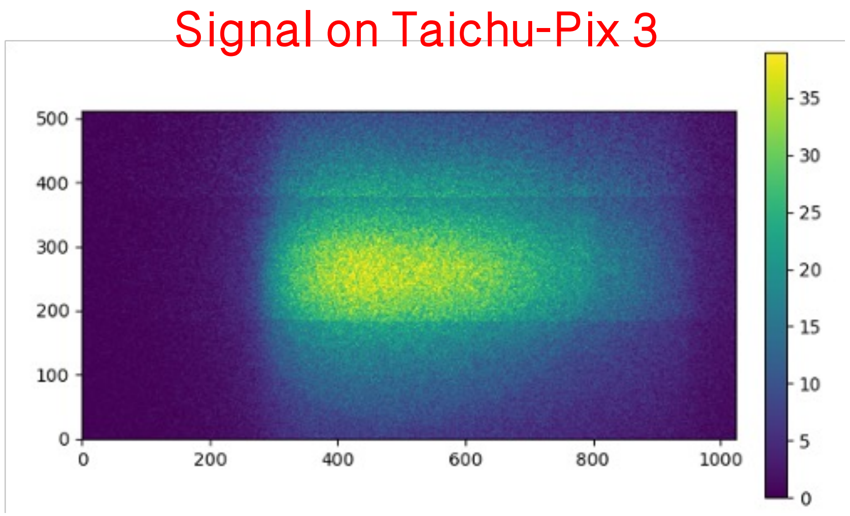
2.5 Detection system

- The TaichuPix-3 silicon detector, a CMOS pixel sensor prototype for the CEPC vertex detector with a sensitive area of $15.9 \times 25.7\ \mathrm{mm}^2$, a pixel size of $25 \times 25\ \mu\mathrm{m}^2$ and a time resolution of 50 ns.
- 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.



TaichuPix-3
Pixel size: 25 μm × 25 μm





2.6 The principle of laser Compton polarimeter for BEPCII

Laser-Electron Interaction

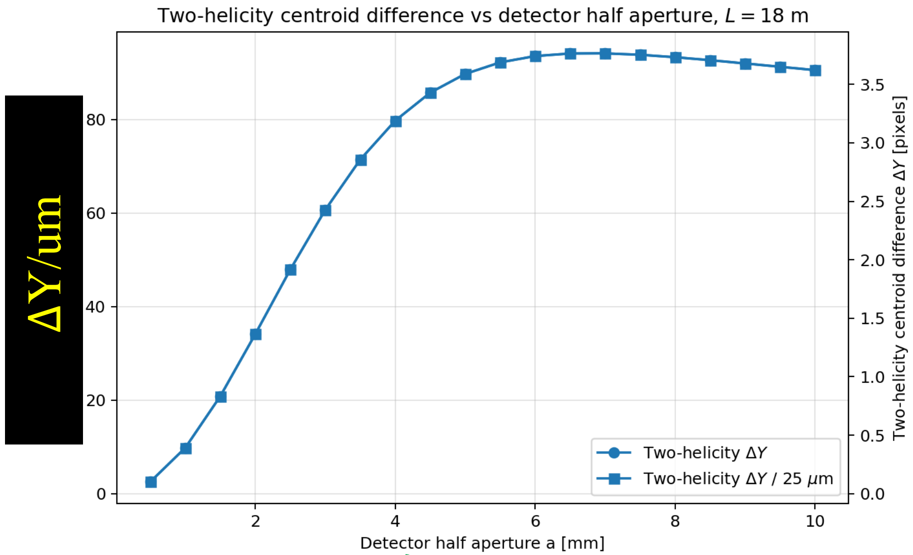
- Head-on collision
- circularly polarized laser beam
- vertically polarized electron beam

Helicity Modulation

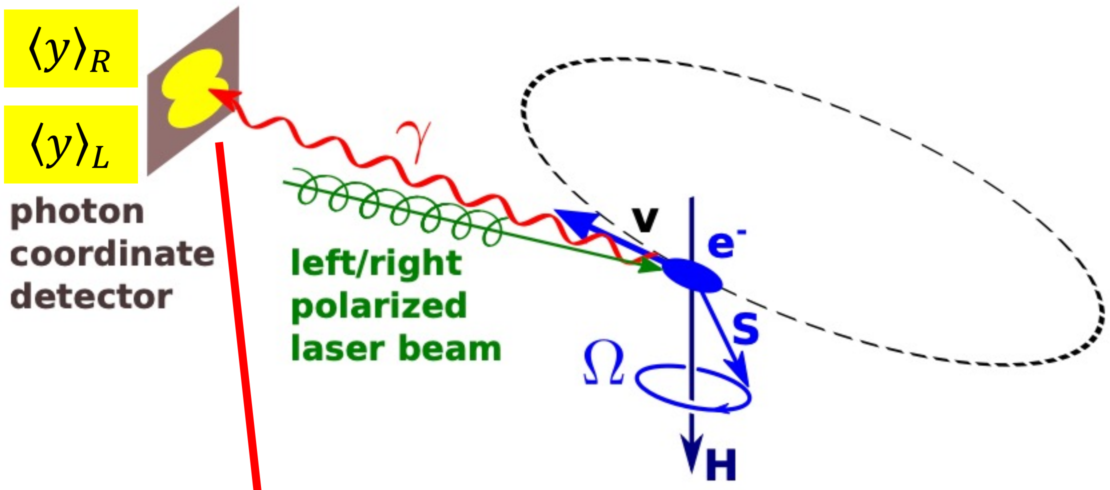
- Switching of the laser’s circular polarization between Left-Handed (LHC) and Right-Handed (RHC) states

Data Acquisition

- Spatial distribution of backscattered gamma (γ)



E_b=2.35 GeV, λ_{laser}=532 nm， L=20m



The principle of laser Compton polarimeter

$$\Delta\langle y\rangle = \langle y\rangle_R - \langle y\rangle_L = \left|P_C^L\right| P_y^e \Delta Y$$

where ΔY is the analyzing power, which depends on the energies of the electron and photon, the position of the detector and the angular range accepted by the detector

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Implementation status

3.0 Project milestones and future outlook

2024.1 → 2025.07 → 2025.10 → 2026.06 → Future → …

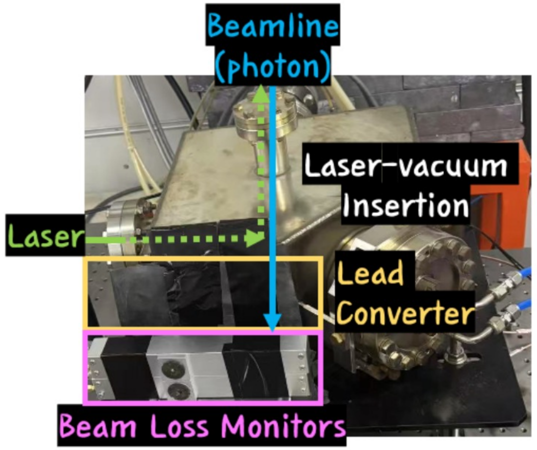
2024.1
- ✓ First conceptual proposal

2025.07
- ✓ Physics design reviewed
- ✓ First beamline modification
- ✓ First laser-beam collision

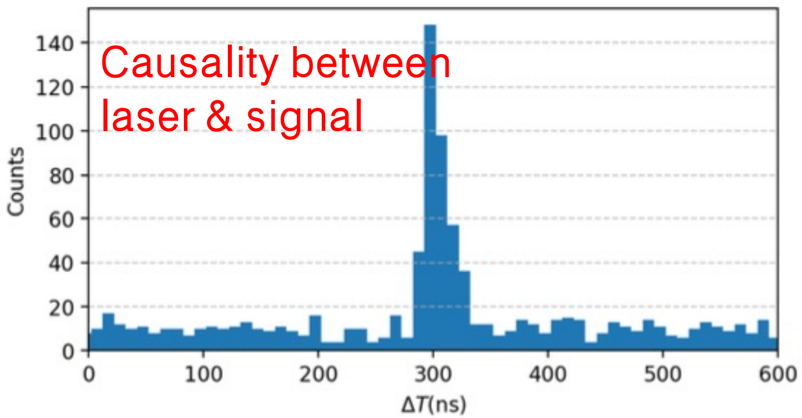
2025.10
- ✓ Diamond window installation
- ✓ First laser-beam collision detected by Taichu-Pix 3

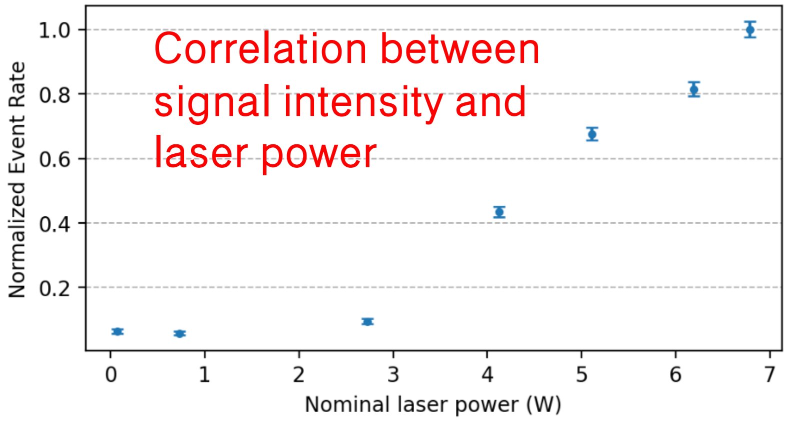
2026.06
- ✓ First observation of self-polarization buildup

Future
- ☐ Polarization calculation and experimental error analysis
- ☐ Realtime measurement system
- ☐ Experimental precision optimization



plastic scintillator + PMT



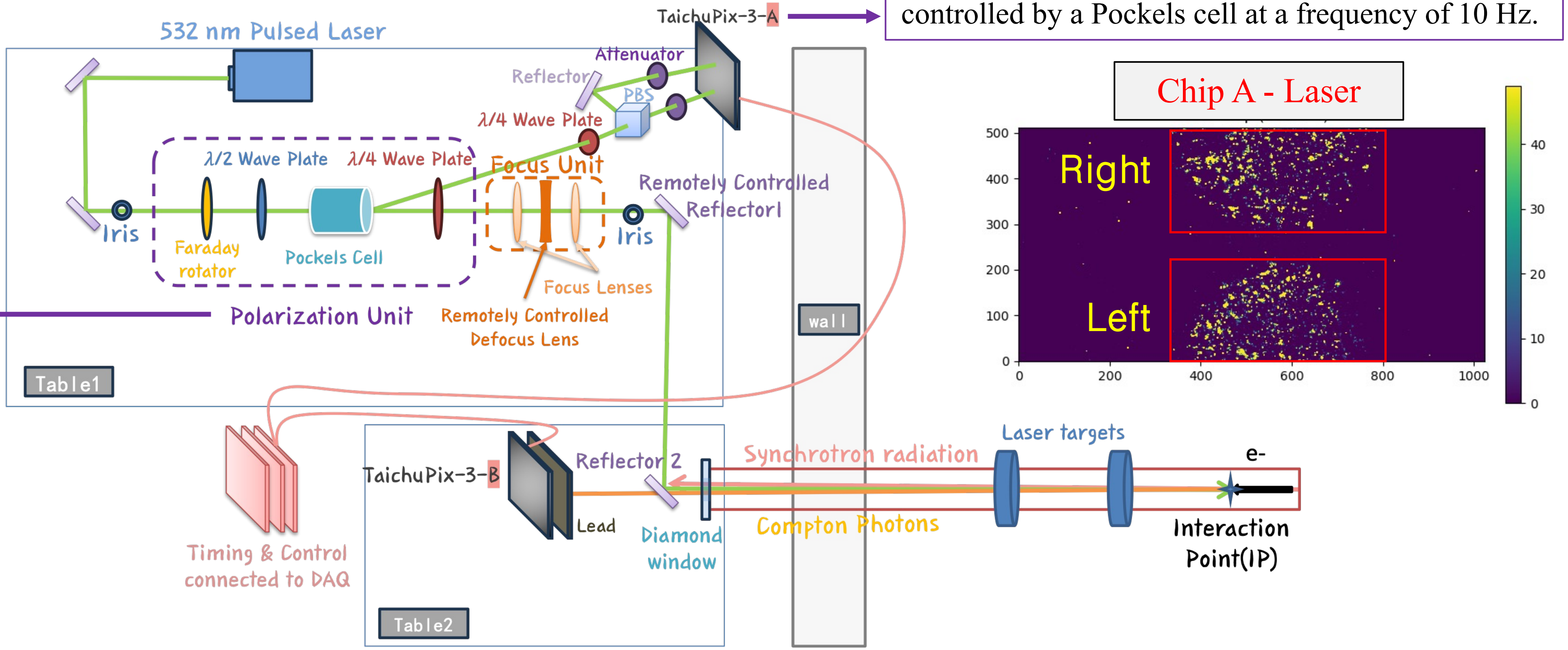


M. Su et al., Status report toward implementation of a Compton polarimeter at BEPCII 10.1007/s41605-026-00675-4

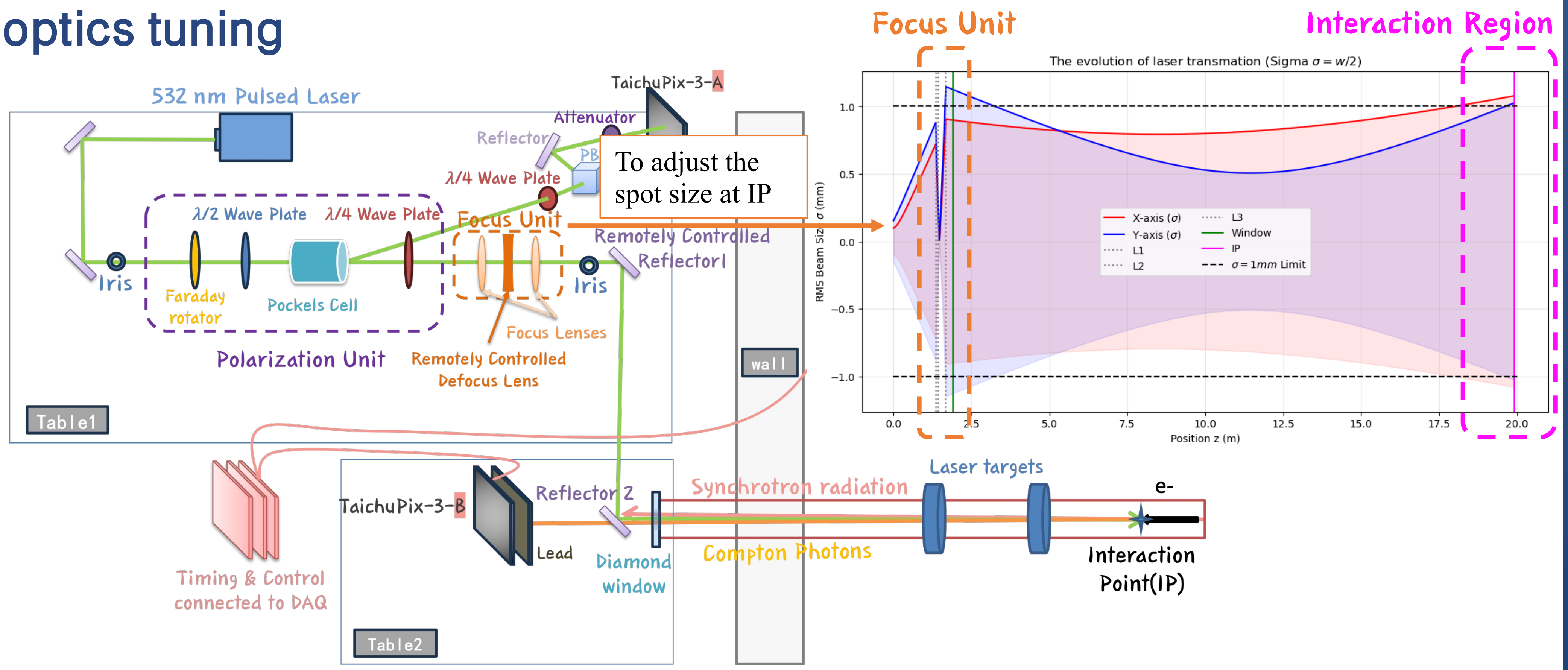
3.1 Laser optics tuning

The upper/lower light spot corresponds to the right/left circular polarization state of the laser, controlled by a Pockels cell at a frequency of 10 Hz.

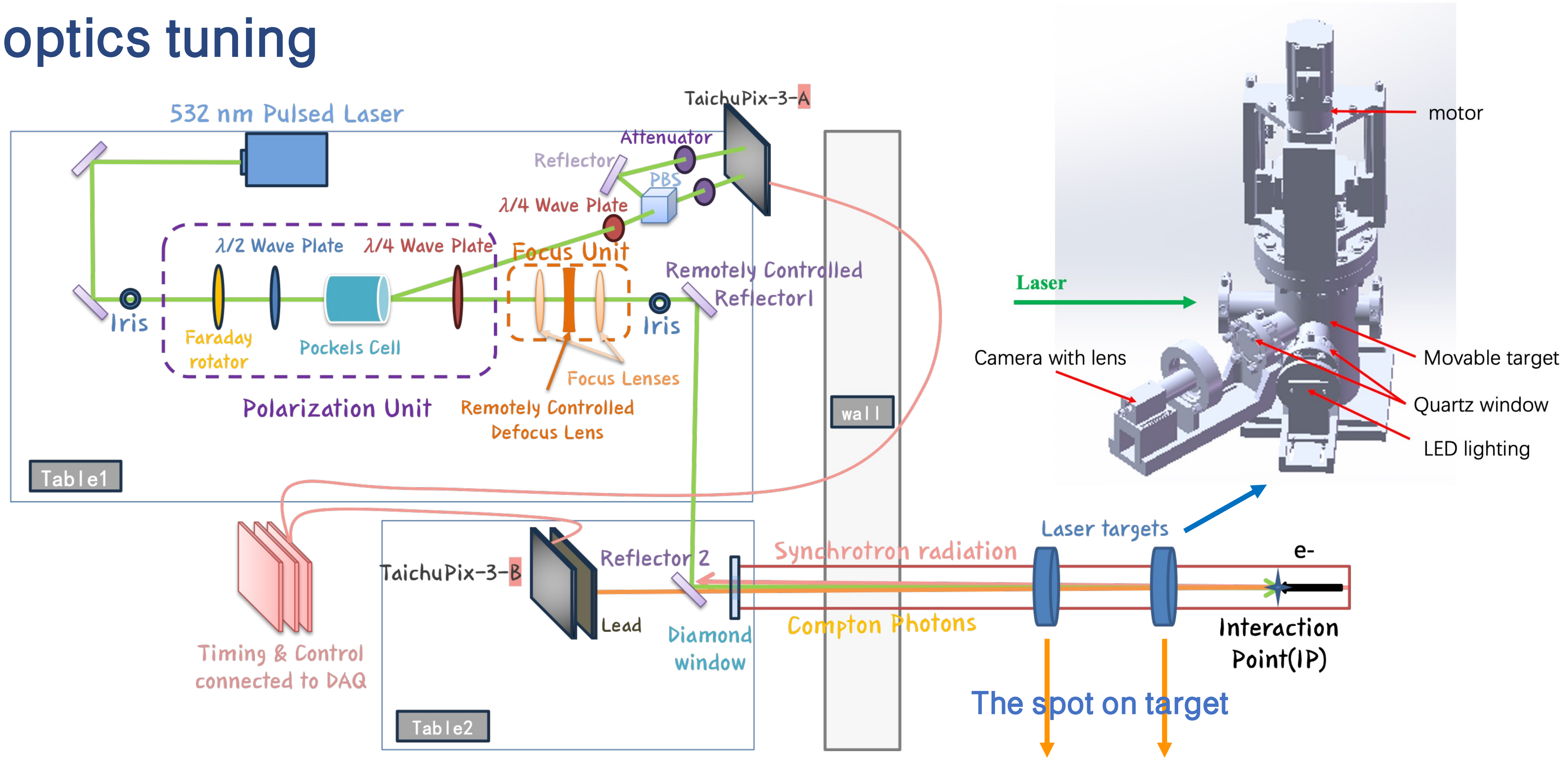
To ensure a specific circular polarization state at the IP.

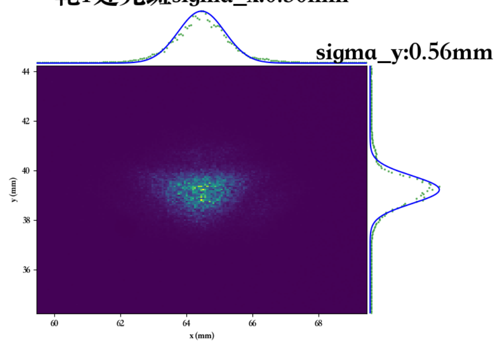


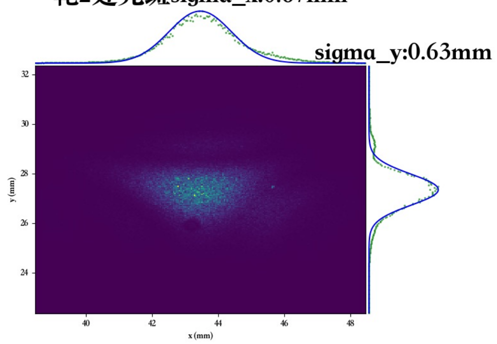
3.1 Laser optics tuning



3.1 Laser optics tuning





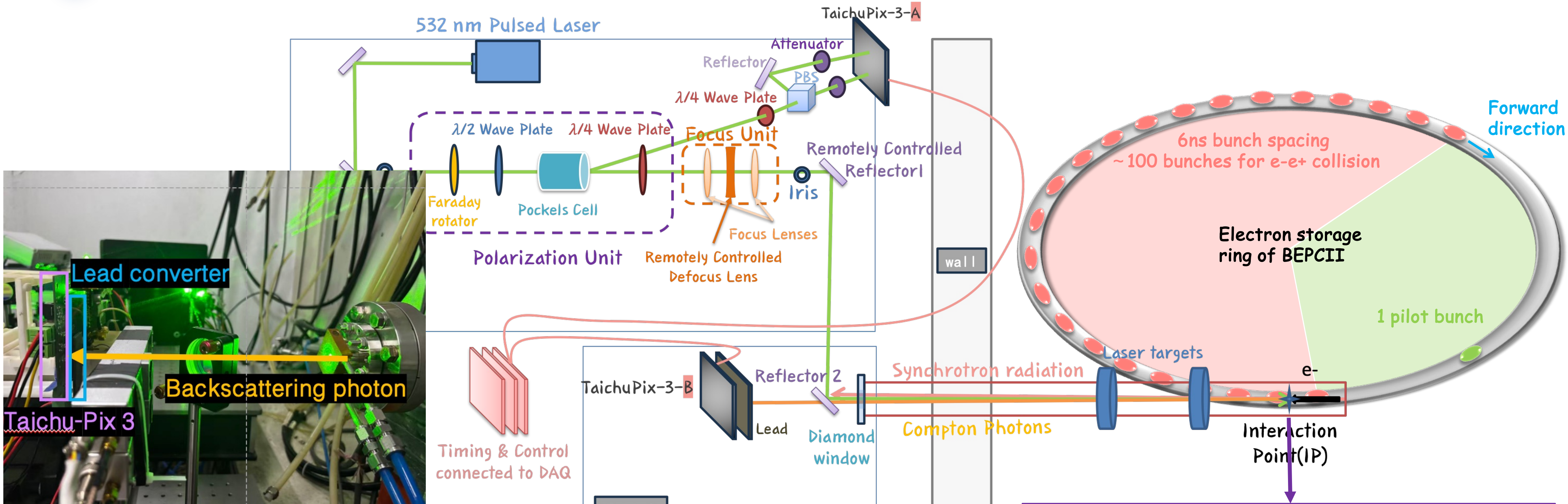


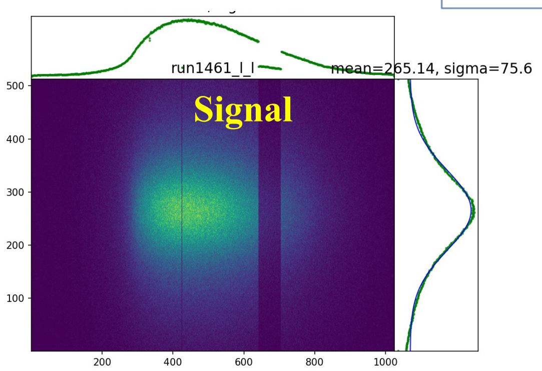
Diamond Window Induced Effects

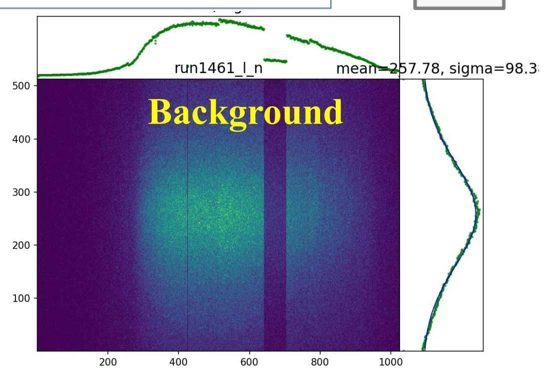
Stress induced wavefront distortion: aberrated laser beam

Observed polarization-dependent spot sizes: might be explained by stress of window too. To be further investigated.

3.2 Beam commissioning







Interaction Timing Configuration

Laser Source:

532 nm, Pulsed, 4.508 kHz, **RF-synchronized**

Electron:

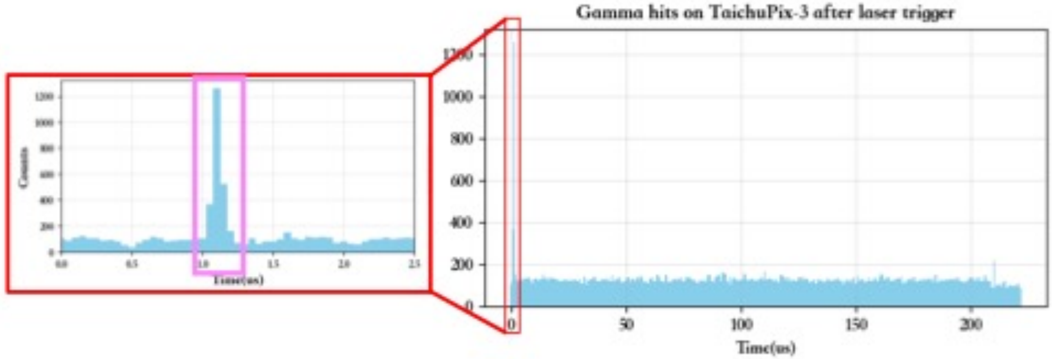
Mode A: Pilot bunches

(Measuring self-polarization buildup)

Mode B: BESIII Colliding bunches

(Measuring polarization under collision)

3.3 Data analysis



Denoising, triggering and grouping

Analysis chain

Detector A: laser triggering

↓

Detector B: photon-induced hit distribution

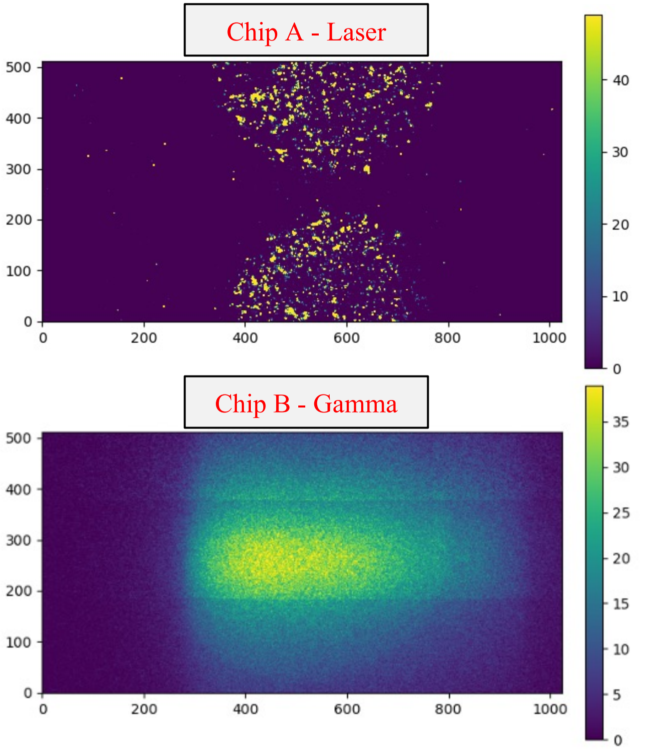
↓

Offline sorting: laser-on/off, helicity +/-, background subtraction

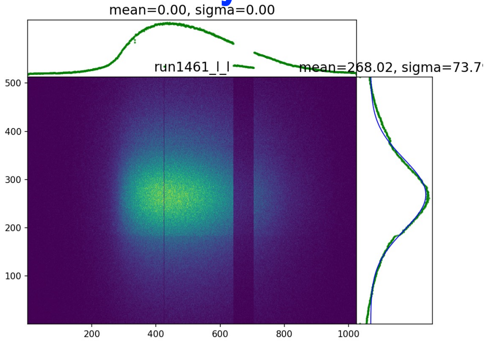
↓

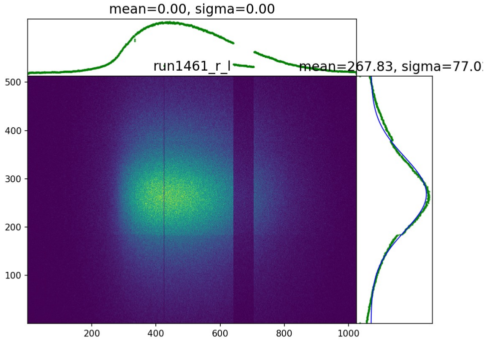
Observable: Δ<y>

Raw hit map



Left helicity





Right helicity

3.4 Preliminary result

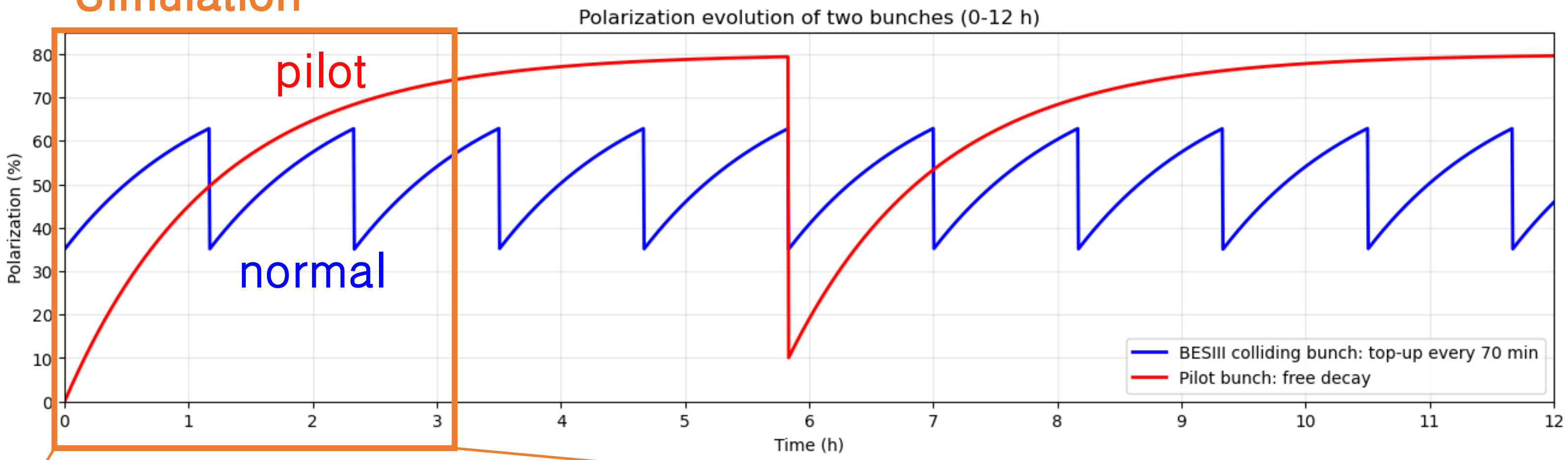
First observation of self-polarization buildup

Preliminary data shows the evolution of electron beam polarization ($\Delta\langle y\rangle$) and significant discrepancies in polarization levels between BESIII colliding bunches and pilot bunches.

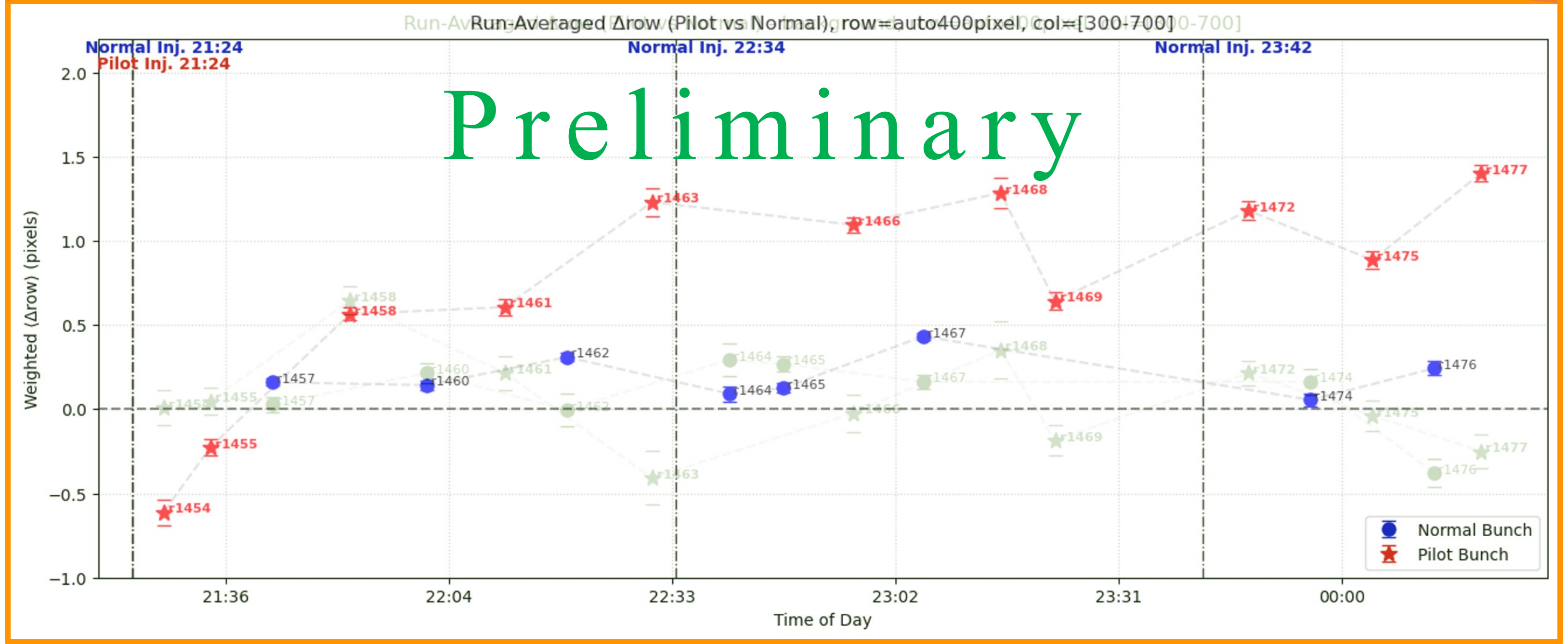
Next Steps:

- ☐ Polarization calculation and experimental error analysis
- ☐ Realtime measurement system
- ☐ Experimental precision optimization

Simulation



Experiment



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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.
- Signature of electron beam polarization build-up is revealed in the measured asymmetry data.

- Next steps
  - Polarization calculation and experimental error analysis
  - Realtime measurement system
  - Experimental precision optimization

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THANKS

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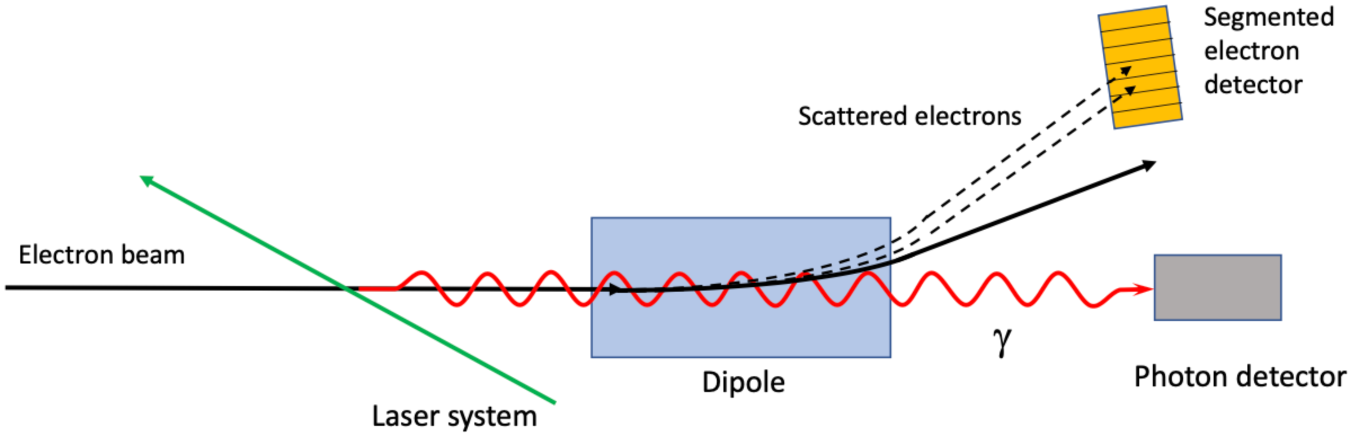
Date：20260729

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

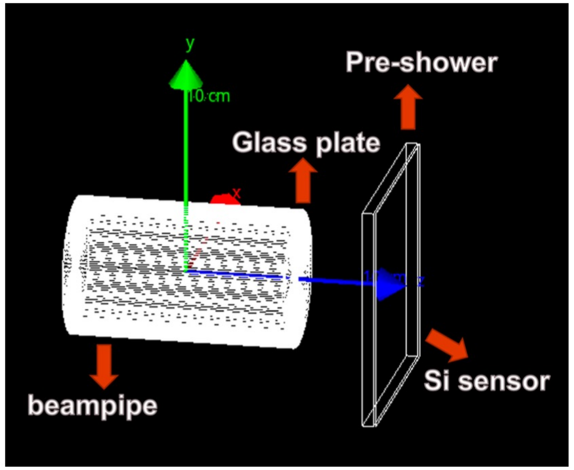


Figure 3: The sketch of the Geant4 model. The vacuum pipe with a one-mm-glass end cap is located on the left. The lead pre-shower and silicon sensor are located on the right.

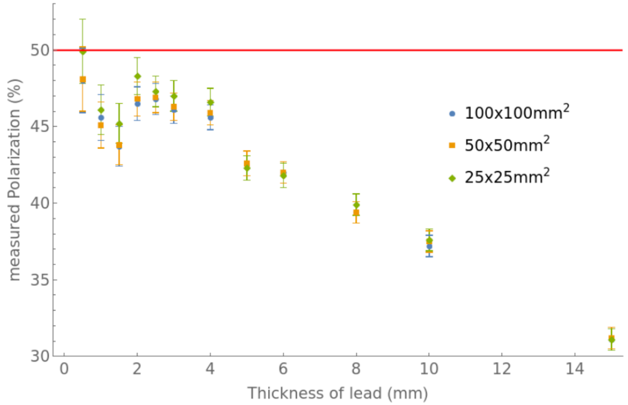
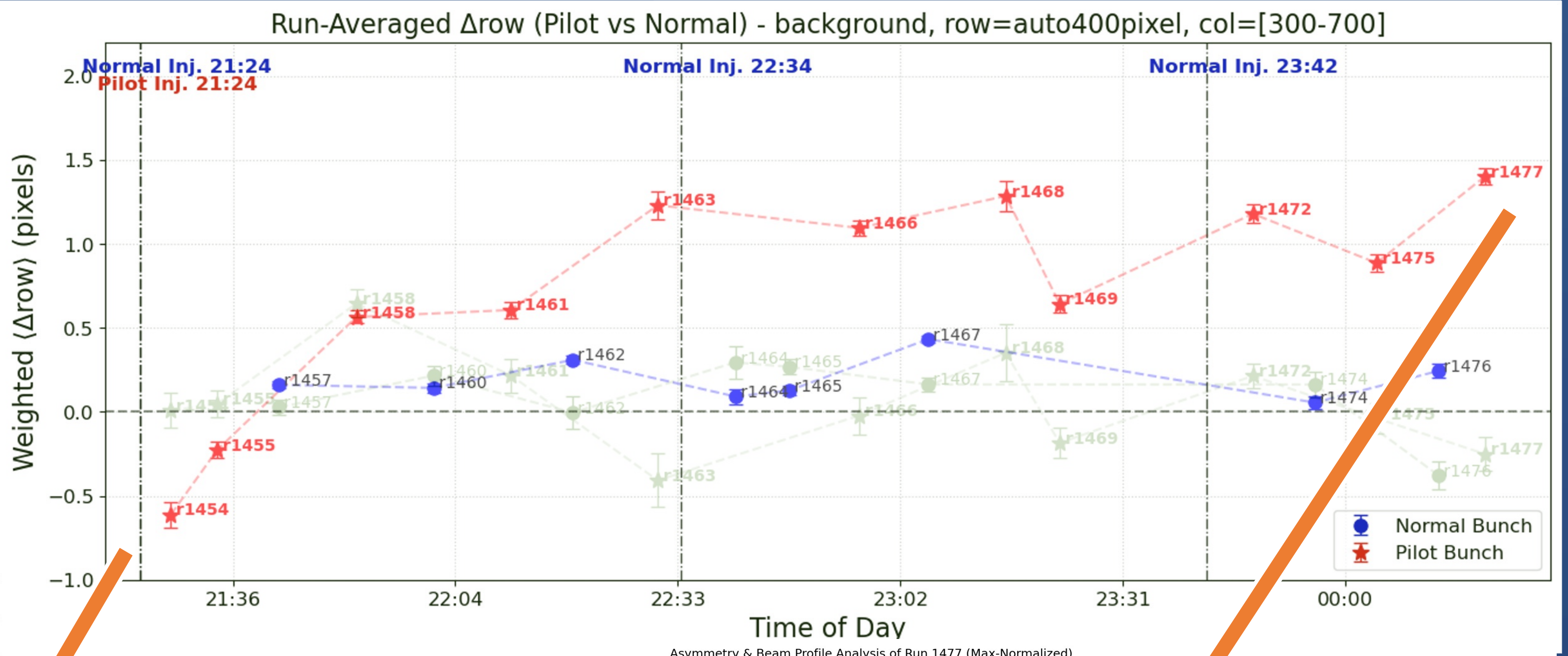
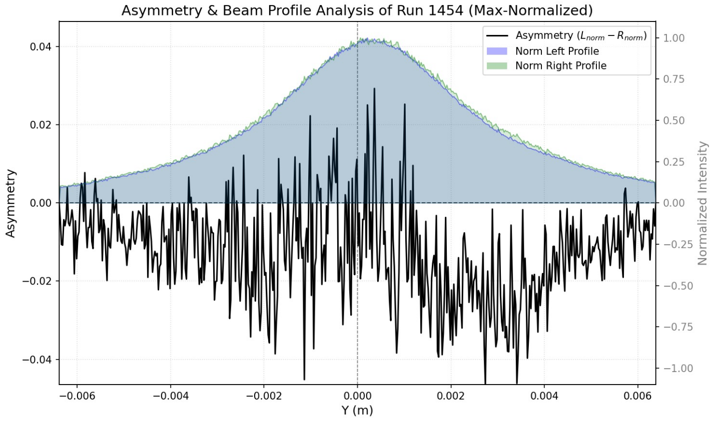


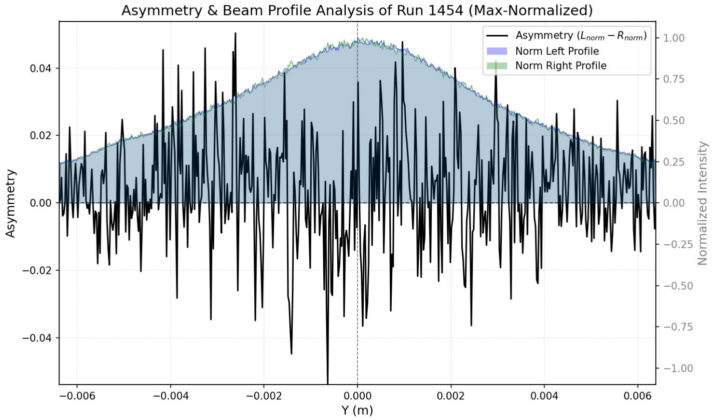
Figure 4: The measured polarization as a function of the thickness of the lead pre-shower and the area of the sensor. The areas of the sensor are 100×100 mm^2, 50×50 mm^2 and 25×25 mm^2. The red line indicates the true value of beam polarization.

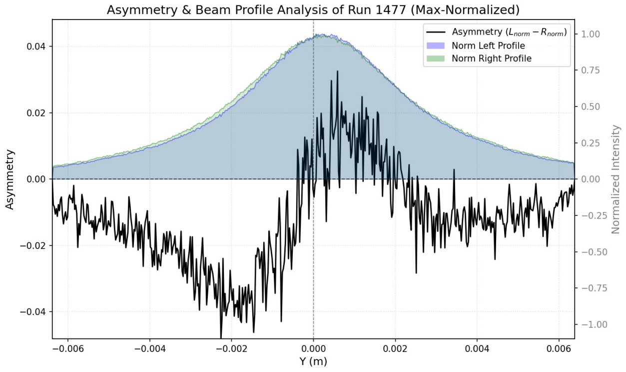
Backup

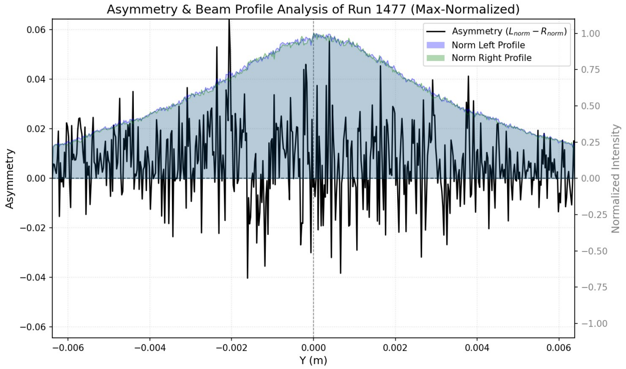
0616experiment ΔY Asymmetry





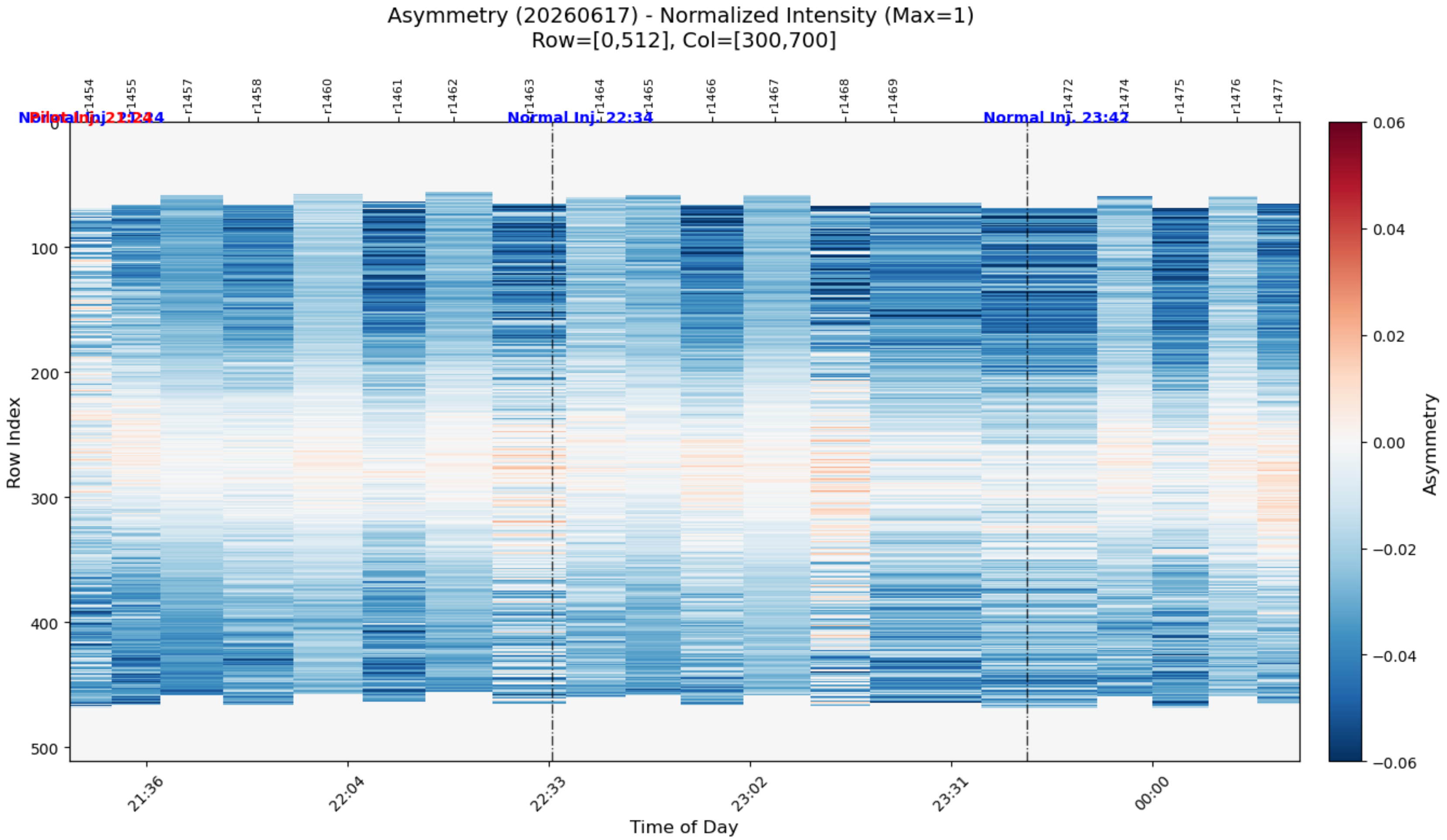


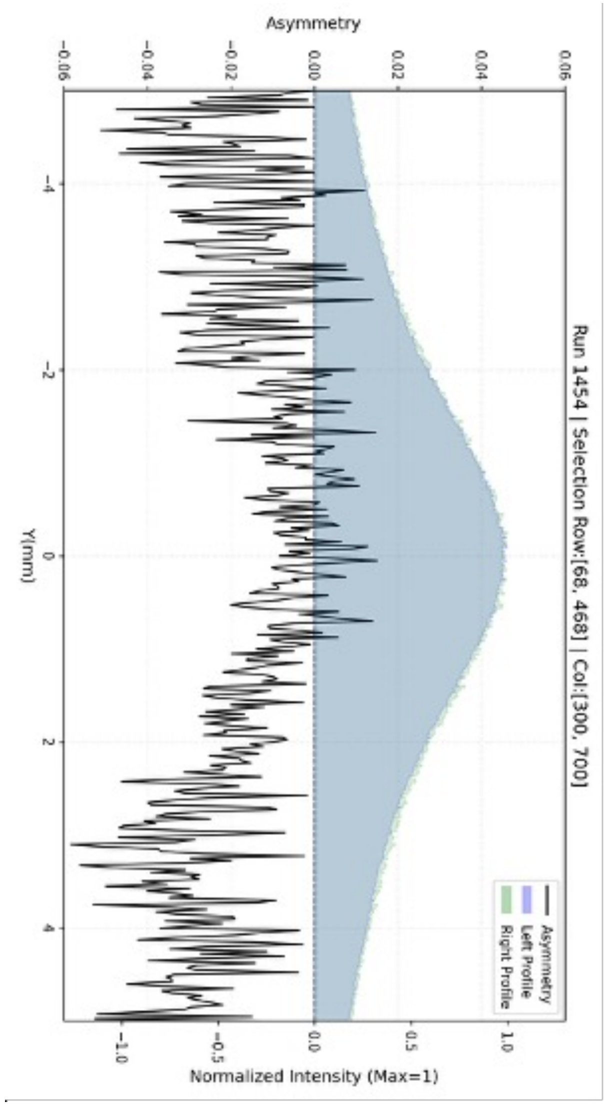




Backup

signal+background-max

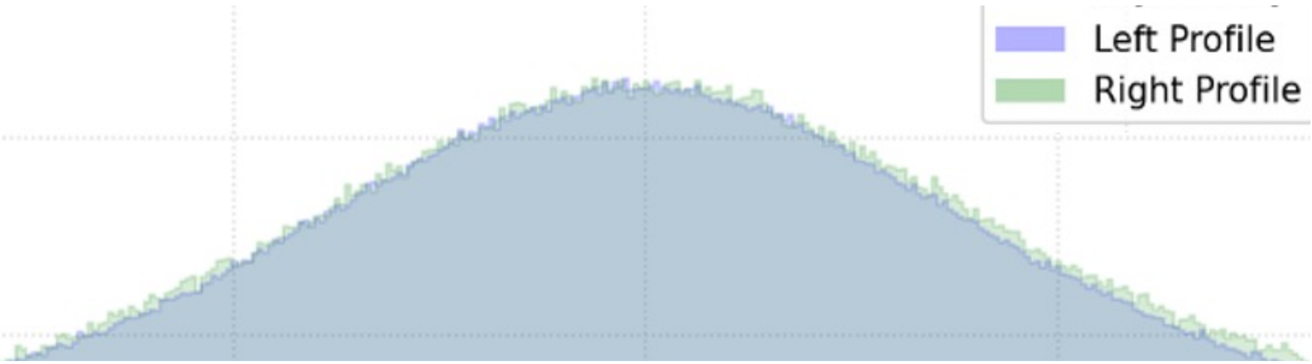


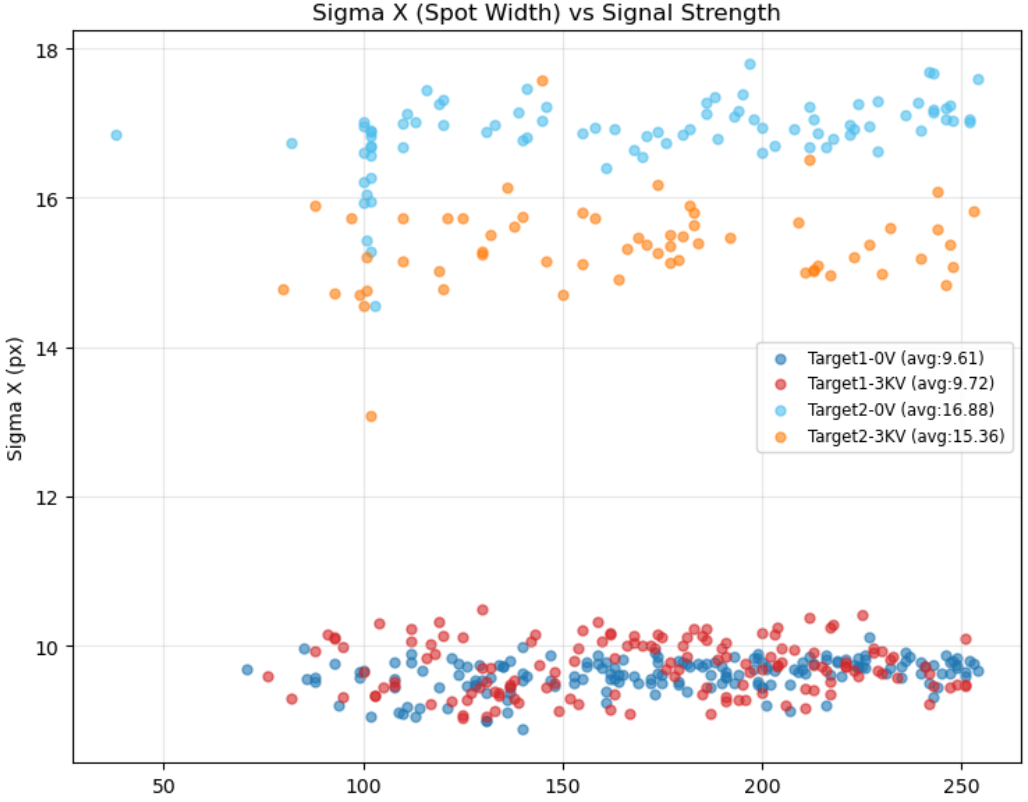


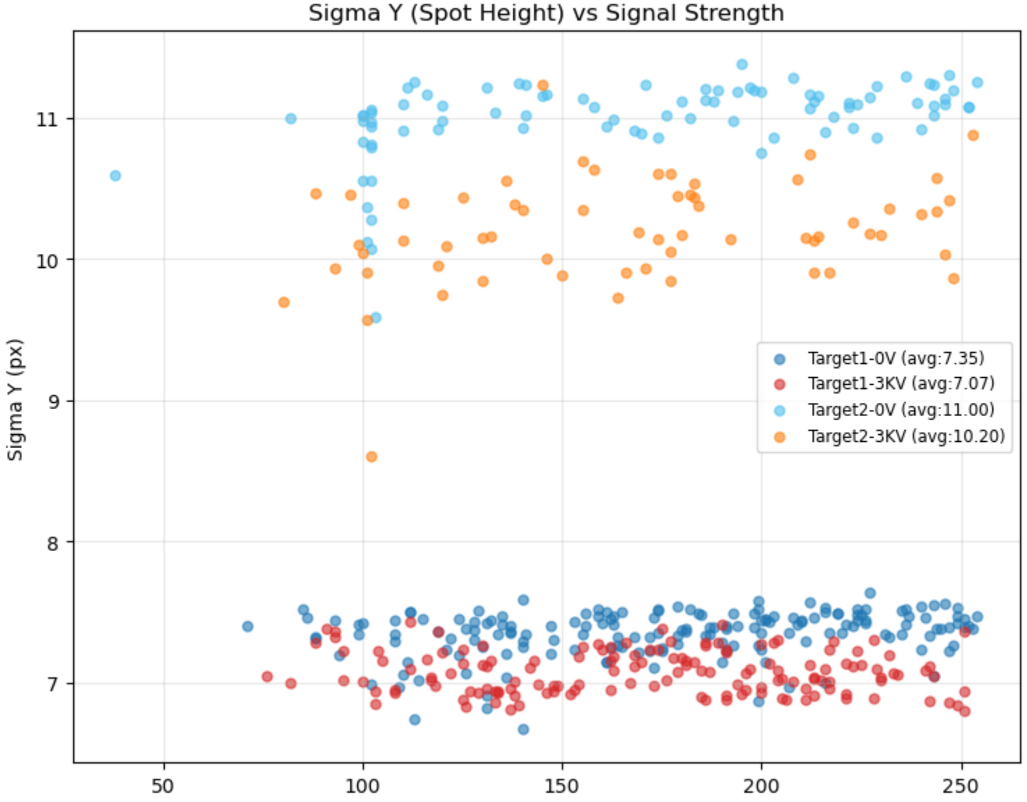
Backup

RCP is wider

- Beam size at target1&2

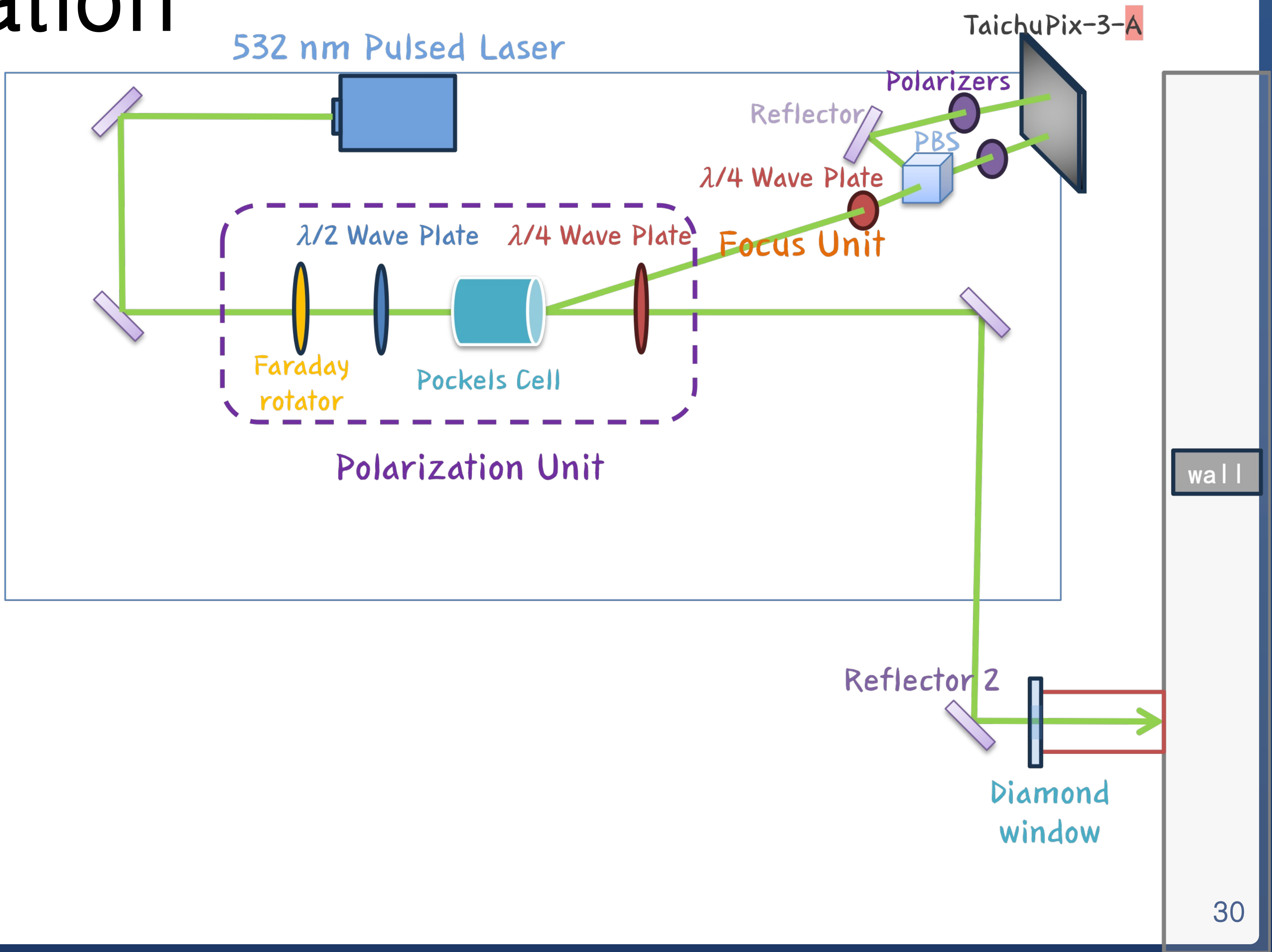






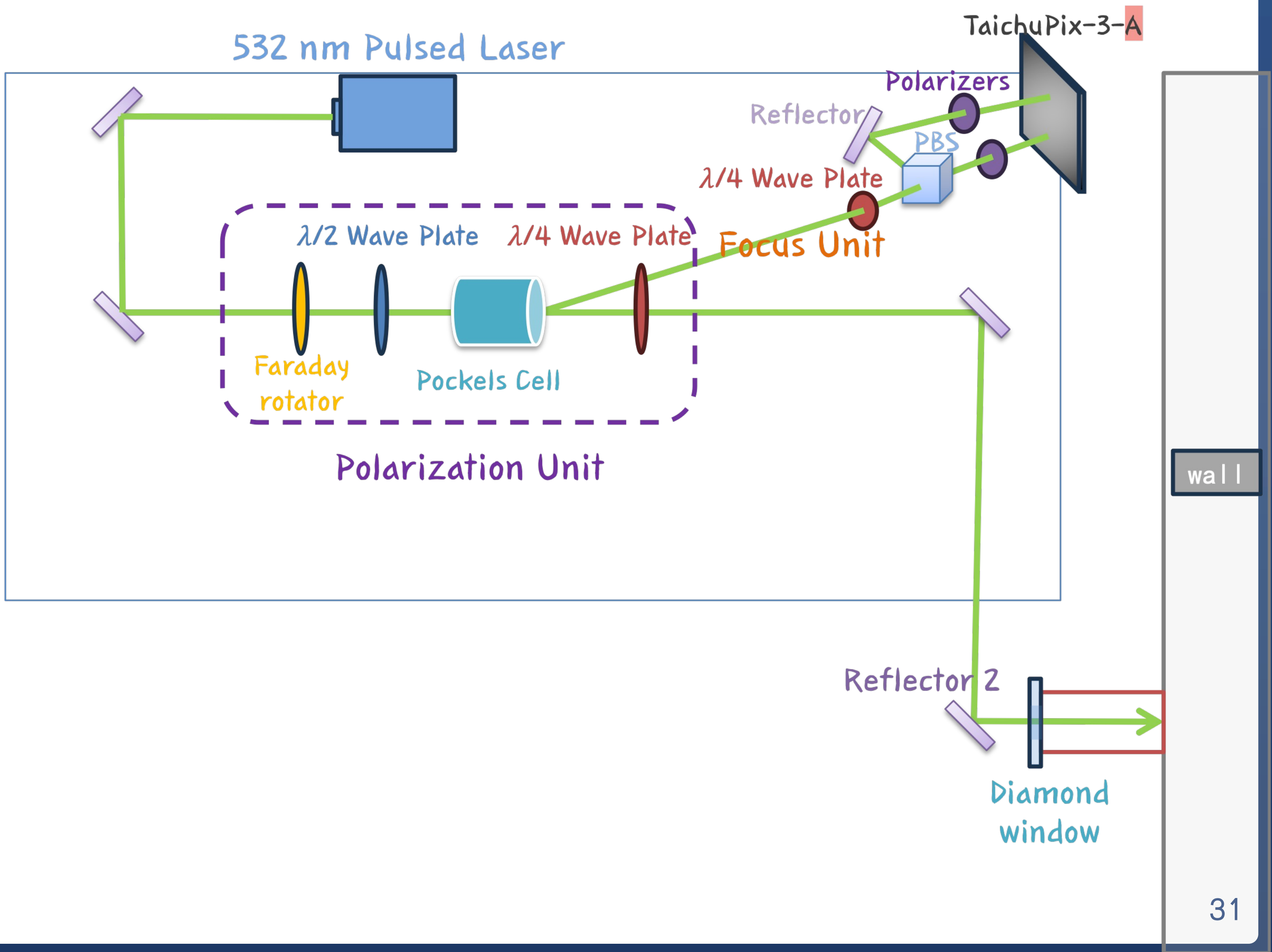
Laser polarization

- the order of the elements of polarization unit:
  - A Faraday rotator is positioned after two mirrors to **generate linear polarization.** It provides a **45° rotation** and **isolates the system from back-reflections.**
  - HWP for rotating the linear polarization and **creating two orthogonal linear polarizations.**
  - The following Pockels cell is responsible for **switching** between the two linear polarization states **alternately.**
  - QWP for **producing circular polarization.**

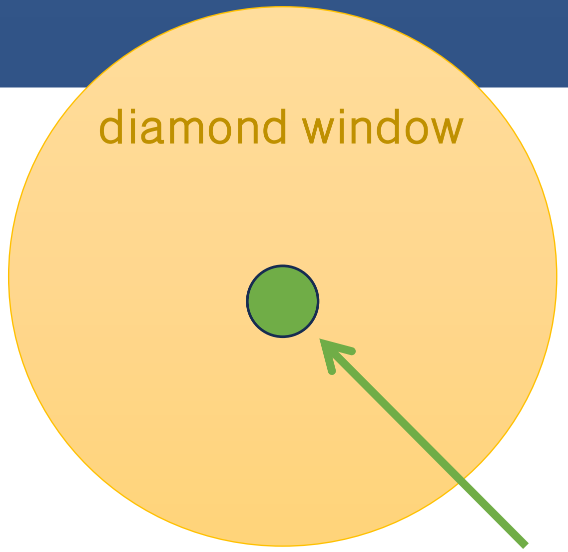


Laser polarization on chip

- Stray light after the Pockels cell is mainly **circularly polarized**
- a QWP converts R/L CP laser into **s-/ p- polarization states**, which are then split by a PBS to hit distinct locations on the chip
- Given that these are now linear polarizations, linear polarizers were added as **attenuators** to control the power of the two beams individually.



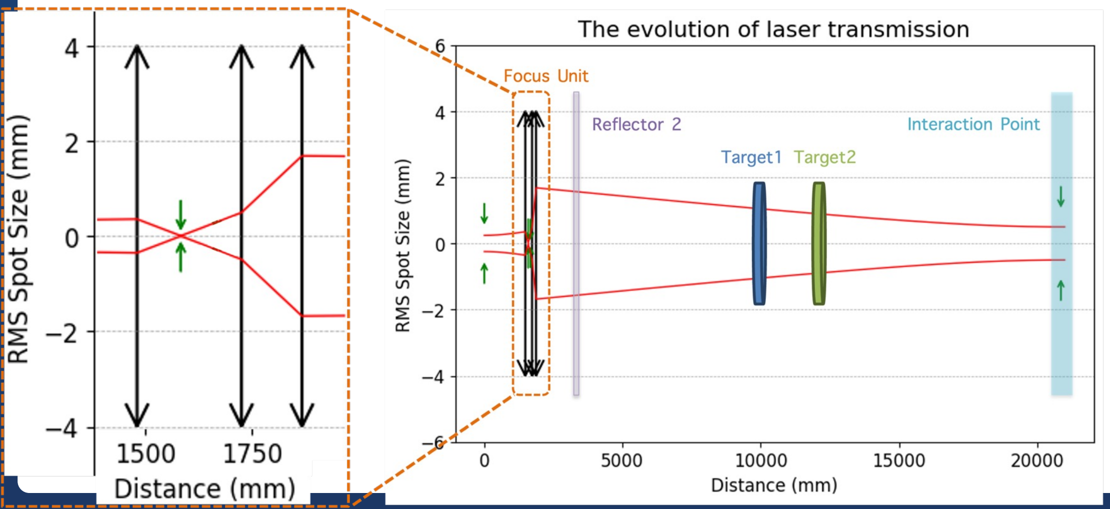
Focus and triangle effect



Parameters of Elliptical Non-ideal Gaussian Beam:
Reference point
Spot sizes (x, y) at 0.5m
Spot sizes (x, y) at 1m
M^2 factors for x and y axes
Objective: Simulate beam propagation along the minor axis (x') and major axis (y')

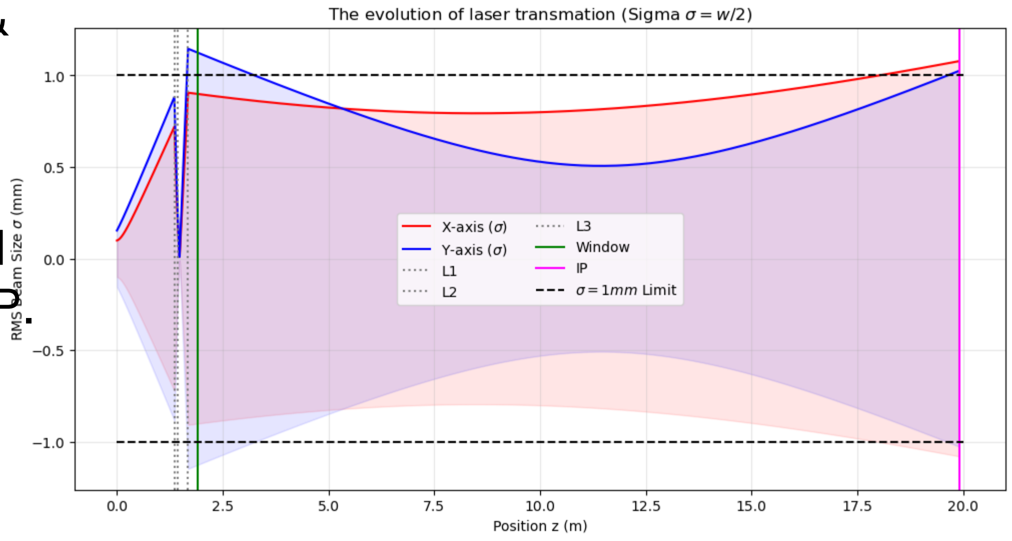
We find that **small, well-centered** laser beams at the diamond window help prevent the **triangle effect**， which also results in **high energy throughput.**

Before: focus on IP



After:

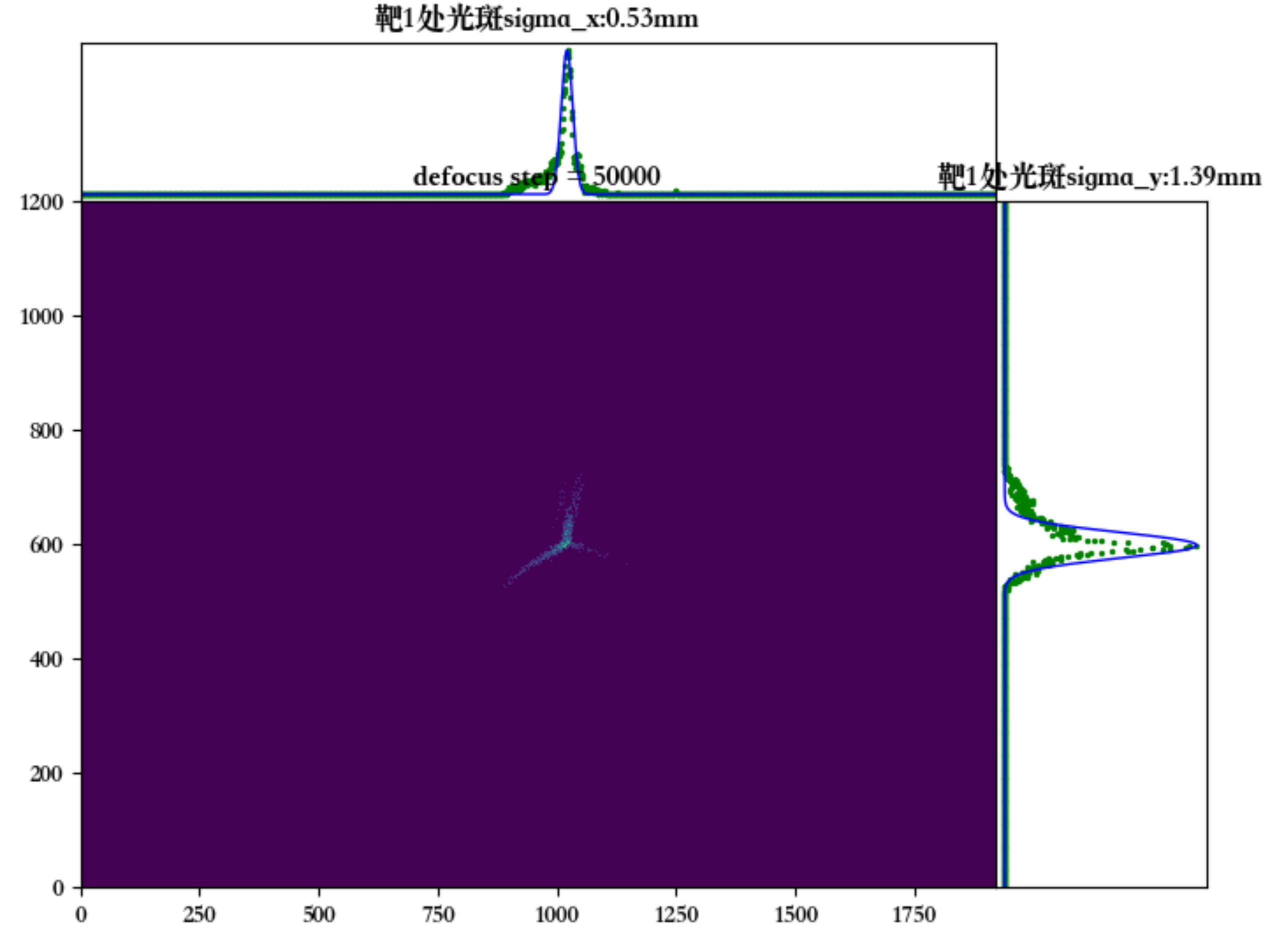
- Simulation for x & y.
- Account for spot size reduction at both the diamond window and the IP.



Focus and triangle effect

laser beam spot on target 1

- Before



- After