



## **CEPC Polarization Study Status**

Zhe Duan

On behalf of the CEPC Polarization Working Group

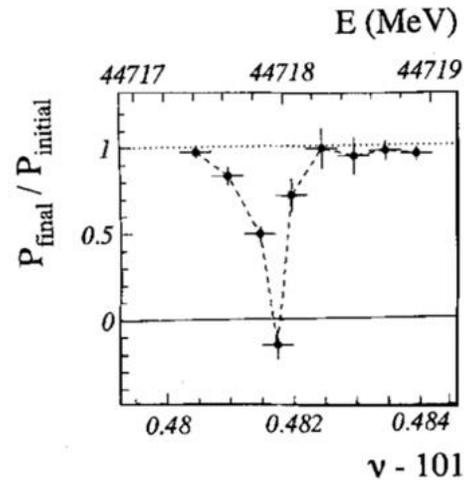
# Outline

- Overview of beam polarization issues for CEPC
- R&D in the Engineering Design Phase
- Concepts of longitudinal polarization at BEPCII
- Summary

# Physics motivation of polarized beams @ CEPC

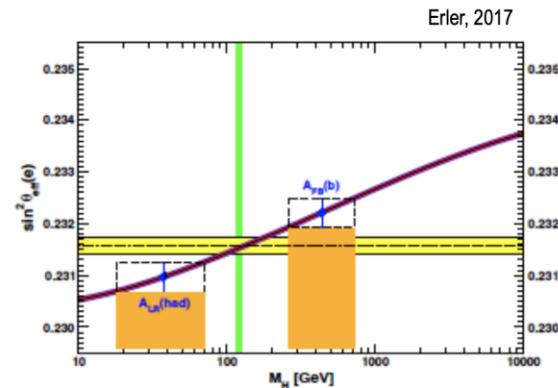
- Precision beam energy calibration @ Z, W (~100keV)
  - resonant depolarization with vertically polarized beams
- Precision measurement of weak mixing angle @ Z
  - Longitudinally polarized colliding beams for measuring  $A_{LR}$
  - could resolve the tension between  $A_{FB}$  &  $A_{LR}$ , by **measuring both in the same experiment**
- CPV with polarized beams in  $e^+e^- \rightarrow HZ$ .  $H \rightarrow \tau\tau$  etc [ECFA meeting on e+e- to ZH angular measurements](#)

Polarized beam applications @ ILC,  
arXiv:2105.09691, 2111.06687, 2202.07385



(a)  $\Delta\nu_{\text{con}}/\Delta t = 1.67 \cdot 10^{-4} \text{s}^{-1}$ .

L. Arnaudon, et al., Z. Phys. C 66, 45-62 (1995).



Erlar, 2017

LEP:

$$\sin^2\theta_{\text{eff}}(A_{FB}^b) = 0.23221 \pm 0.00029$$

SLC:

$$\sin^2\theta_{\text{eff}}(A_{LR}) = 0.23098 \pm 0.00026$$

Current central values:

$$\sin^2\theta_{\text{eff}} = 0.23105 \pm 0.00087 \text{ (LHC)}$$

$$0.23179 \pm 0.00035 \text{ (Tevatron)}$$



Discrepancy between the most precise measurements

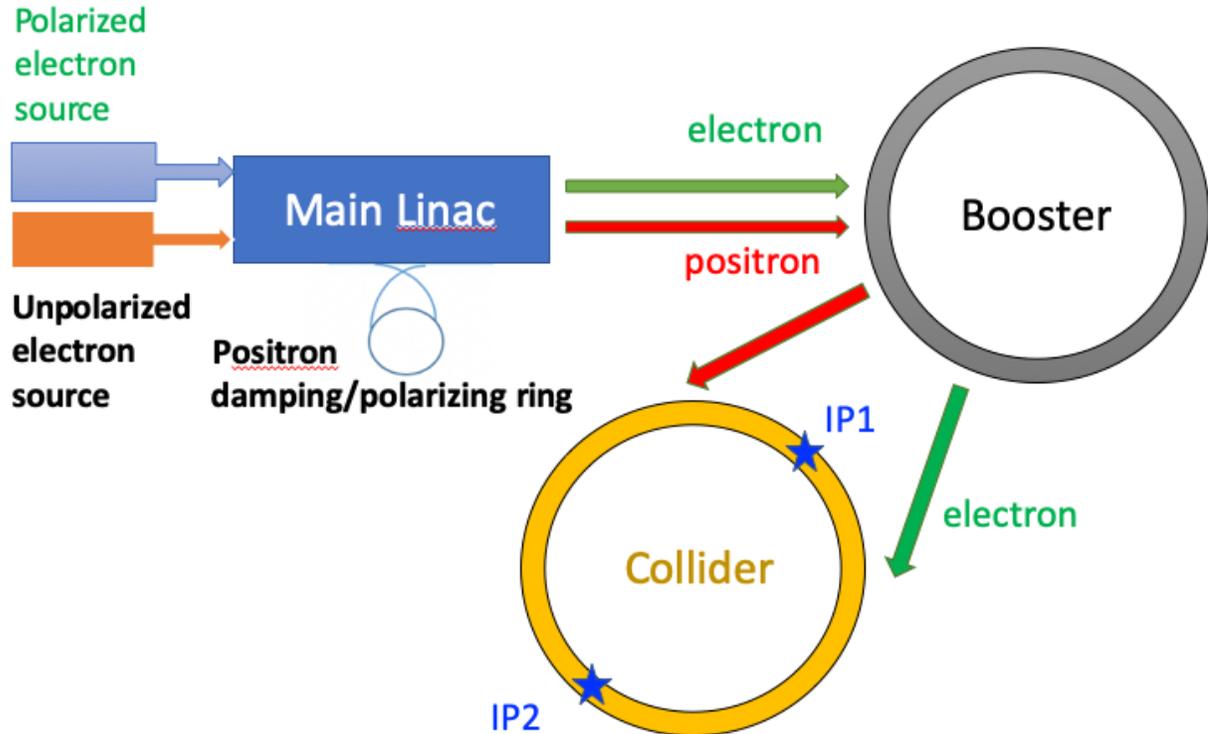
Central value has large impact on physics predictions!

[G. Moortgat-Pick's talk on CEPC Workshop EU @ Marseille, 2024 April](#)

# Injecting polarized beams

## ■ Polarized source

- Polarized electron gun w/ superlattice GaAs cathode (>85% polarization)
- Positron damping/polarizing ring (>20% polarization, sufficient for RD)



## ■ Linac & Transport lines

- no interleaved H & V bendings
- polarization loss is negligible

## ■ Booster

- free from intrinsic spin resonances
- polarization can be well maintained for Z & W

T. Chen, Z. Duan, D. H. Ji, D. Wang, Phys. Rev. Accel. Beams, 26, 051003 (2023).

## ■ Collider

- polarization for Higgs under investigation

W. Xia, Z. Duan, D. P. Barber, Y. Wang, B. Wang and J. Gao, Phys. Rev. Accel. Beams, 26, 091001 (2023).

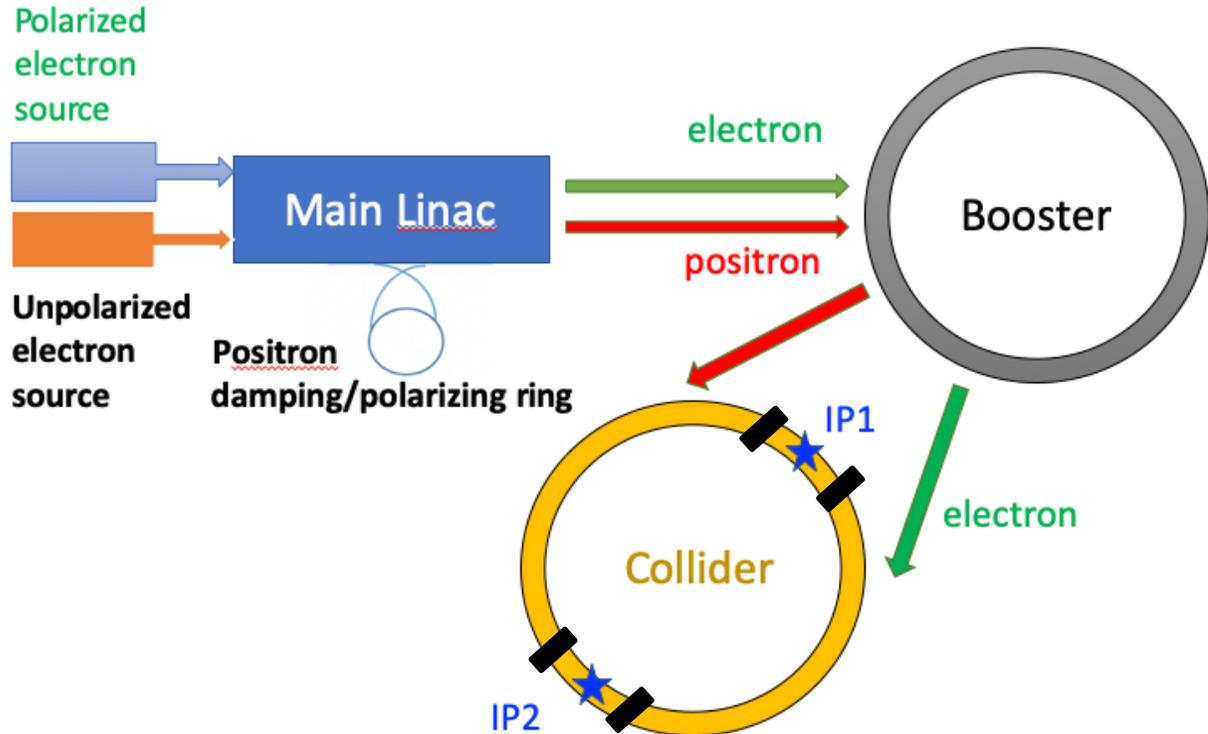
Similar approach is now being studied for FCC-ee

[J. Wenninger, Injecting polarized beams , FCC Week 2025, FCC-FS EPOL group meeting 40](#)

# Injecting polarized beams

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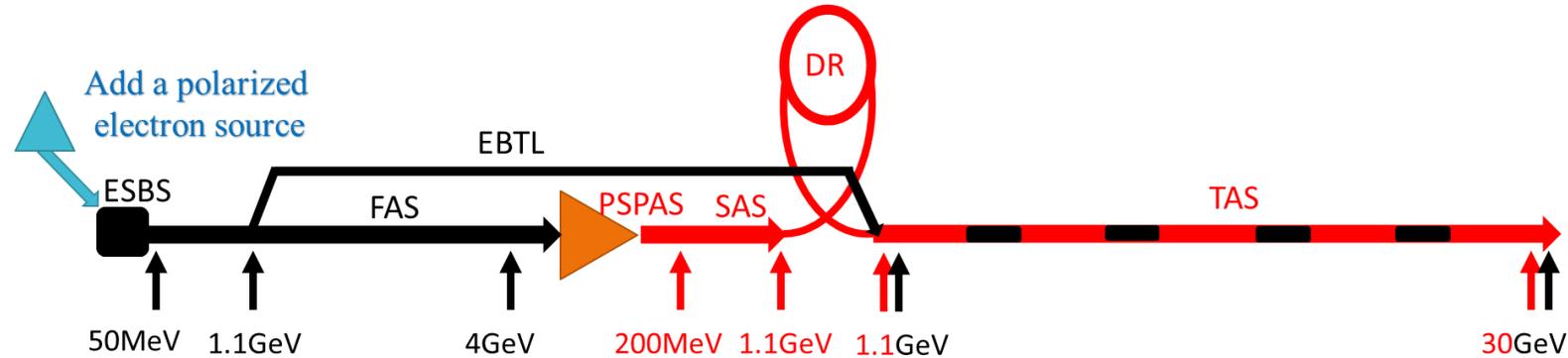
- solenoid spin rotators @ 45.6 GeV
- ~70% longitudinal polarization for e-

W. Xia et al., *Investigation of spin rotators in CEPC at the Z-pole*, *Radiat. Det. Tech. Meth.* 6:490 (2022).

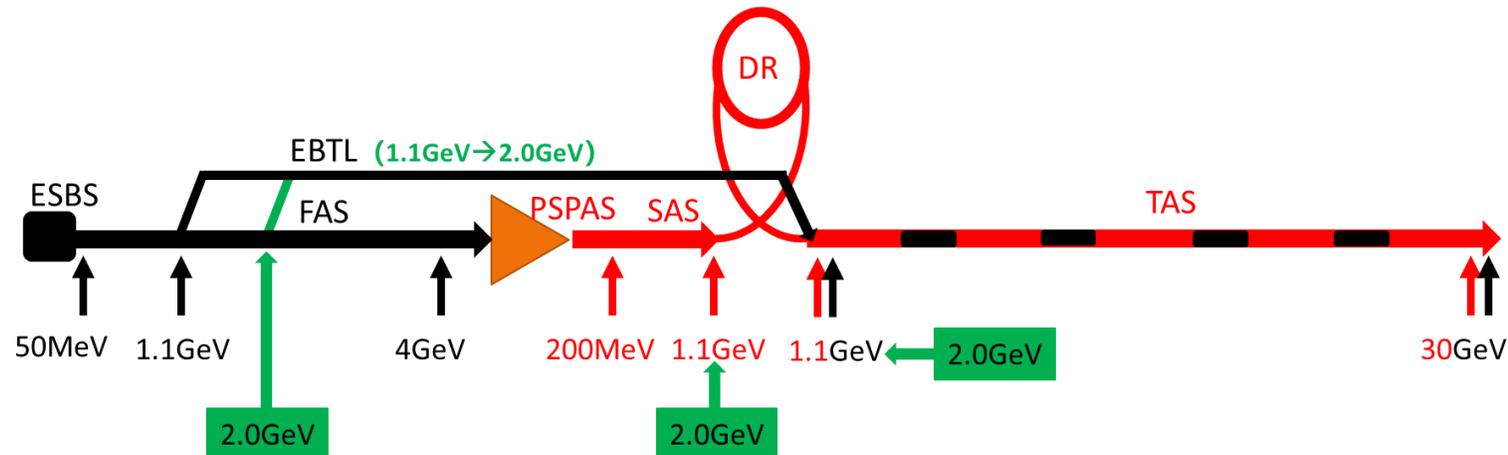
# Modification to the linac

- For e- linac, only local adjustments are made at the electron source

By Cai Meng



- For e+ linac, change in EBTL energy, replaced of C-band power source by S-band, length increase of 30 m



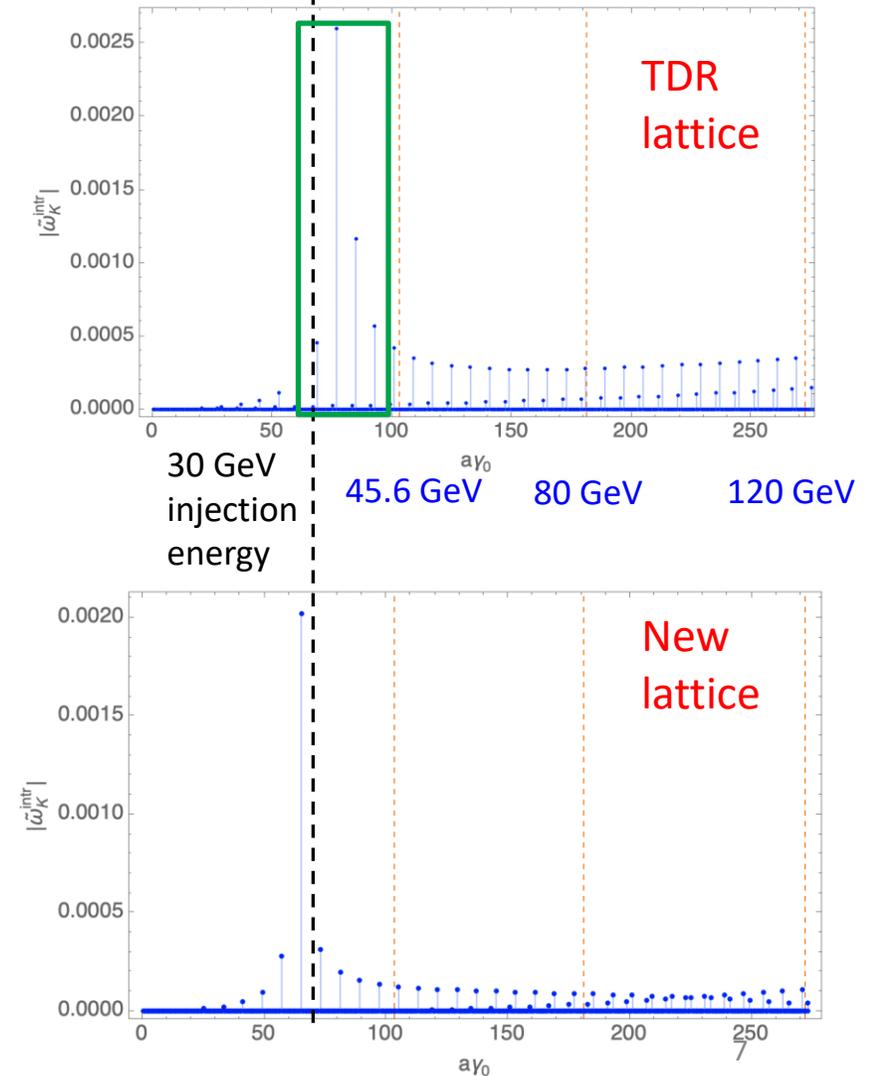
# Updates on booster polarization maintenance

By Dou Wang, Daheng Ji

## ■ Optimization of polarization transmission for TDR lattice

- Vertical betatron tune changed by  $\sim -11$  units
- W/o change of layout & beam emittance
- Promising for Z & W
- Stronger imperfection resonances for Higgs, under study

	TDR lattice	New lattice
$\nu_y$	116.83	105.18
$\nu_B/\eta_{\text{arc}}$	79	50
Polarization transmission to Z	$\sim 50\%$	$\sim 99\%$
Polarization transmission to W	$\sim 50\%$	$\sim 95\%$
Polarization transmission to H	$\sim 20\%$	$\sim 0\%$

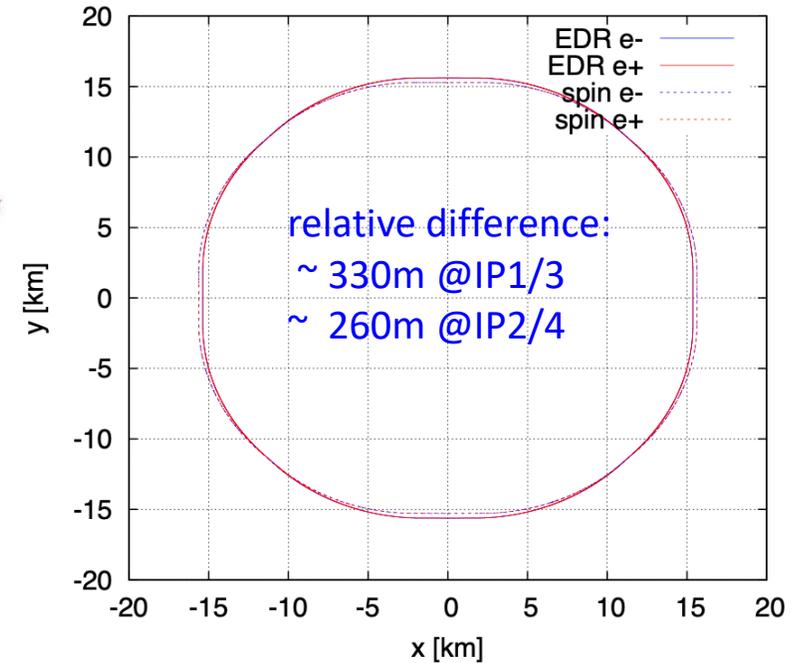
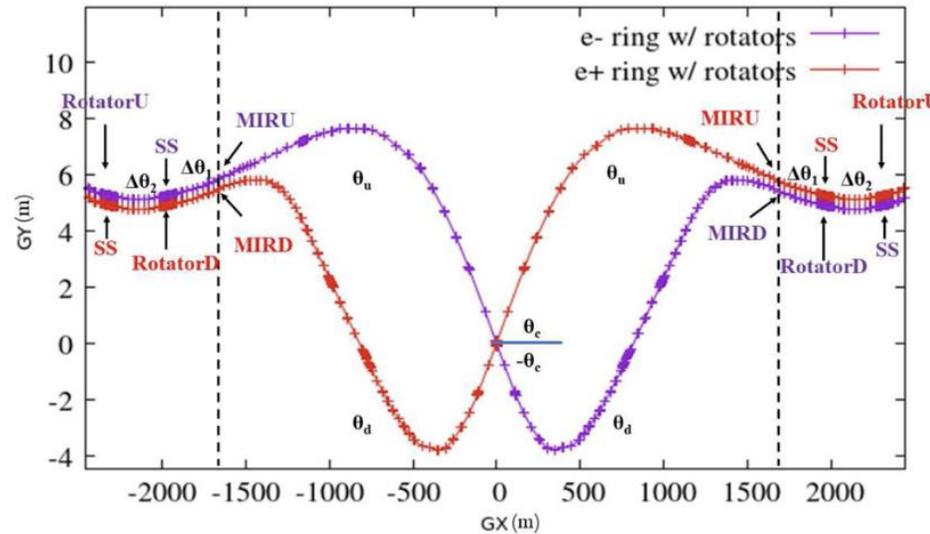
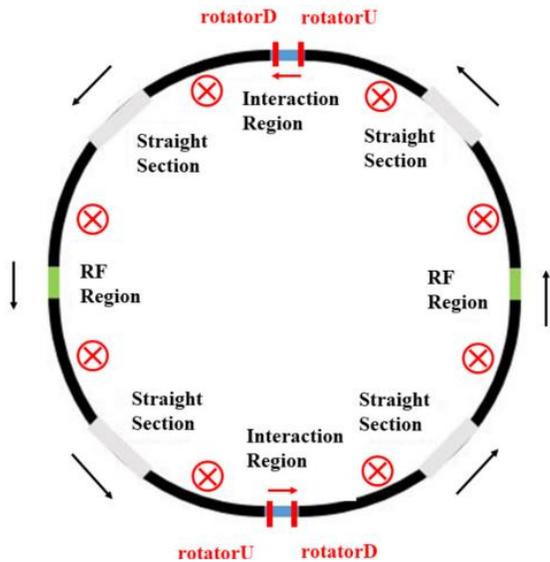


# Spin rotator implementation in Colliders

- Spin rotators have been implemented into the TDR lattice

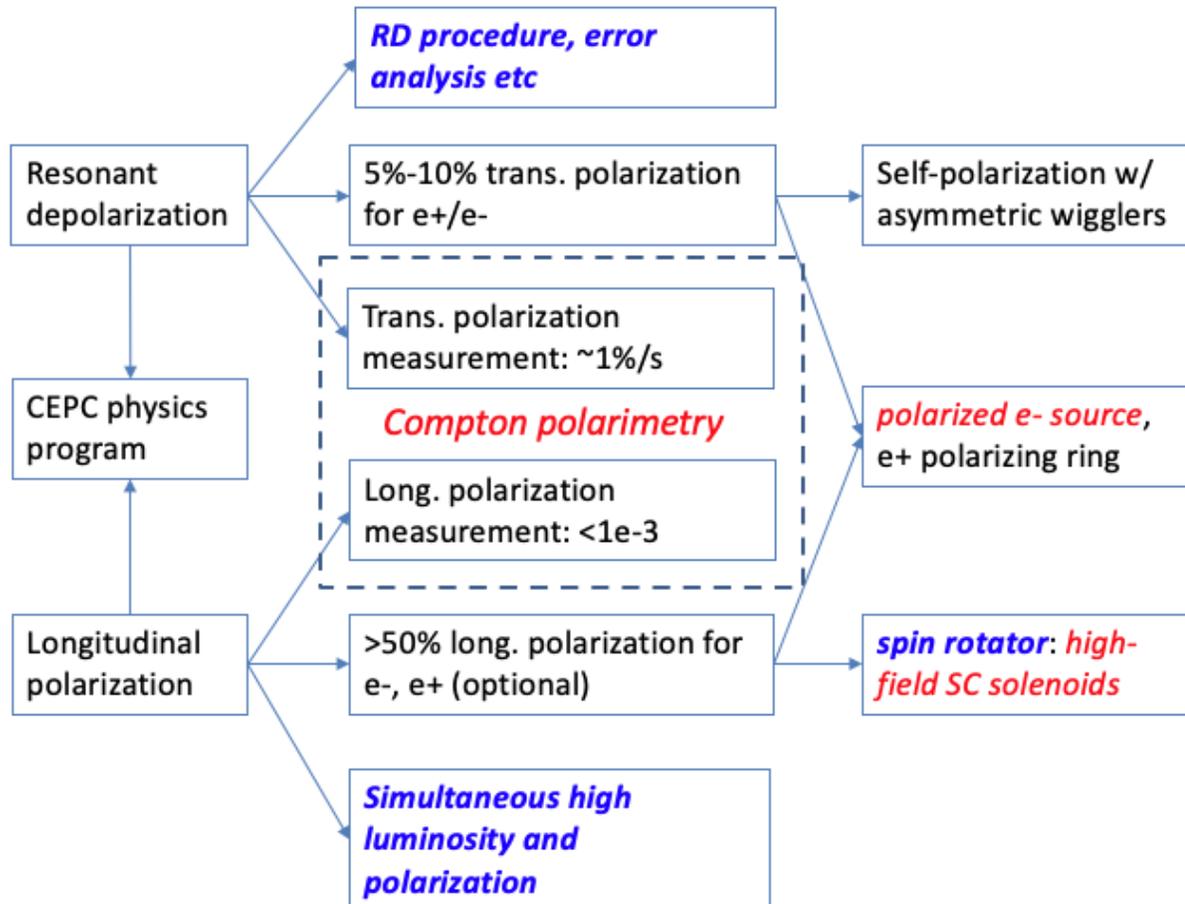
By Yiwei Wang

- Length of each spin rotator ~ 400m, total length of 4 rotators ~ 1.6 km (reduced from 2.8 km)
- The deflection angles and lengths of ARC dipoles are reduced
- The circumference of the whole ring is 99.913km
- More detailed optics optimization and performance evaluation is under way

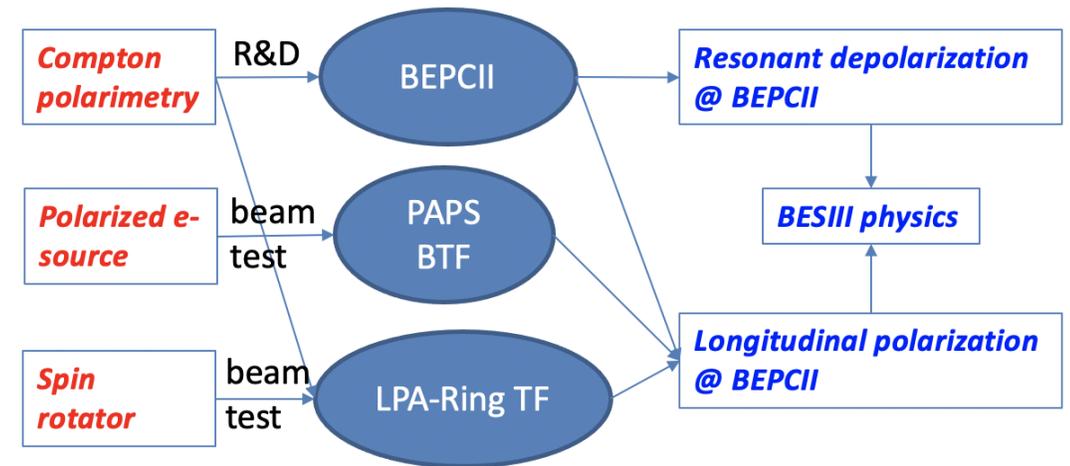


# Beam polarization R&D in the EDR phase

CEPC requirements, *R&D items*,  
and *required experiment demonstration*



R&D, beam tests, and foreseen experimental demonstration at IHEP accelerator facilities

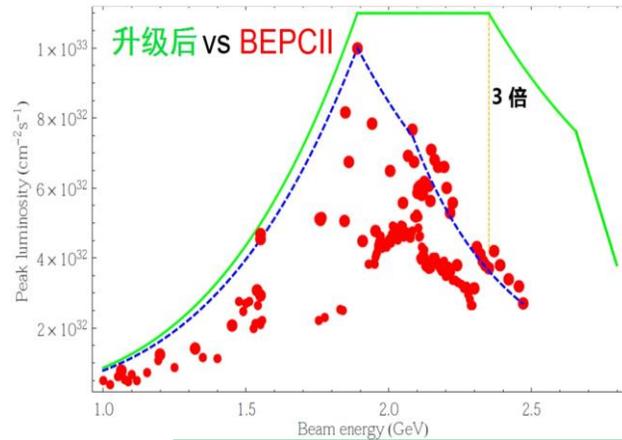
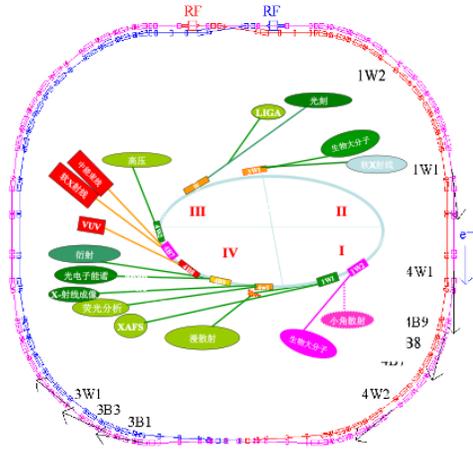


These activities will set the basis for polarized beam applications @ CEPC.

# BEPCII upgrade project and beam polarization

- BEPCII upgrade project (2025-2030): higher luminosity (x3 @ 2.35 GeV) & higher energy (up to 2.8 GeV)
- Home-developed SCQ, SRF; CGEM detector (Italy)

- e- beam is spontaneously vertical polarized due to spin flip in synchrotron radiation
- Simulations show a sizable polarization in routine operation conditions



Start tunnel installation

SR commissioning  
Colliding beams at 1.84 GeV

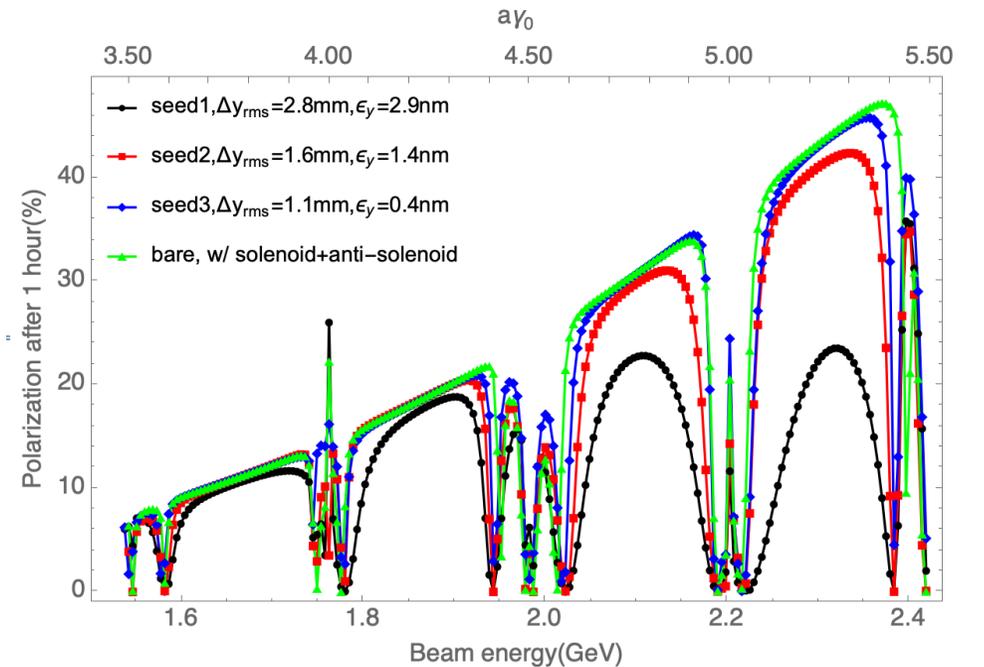
2024.7

2025.1

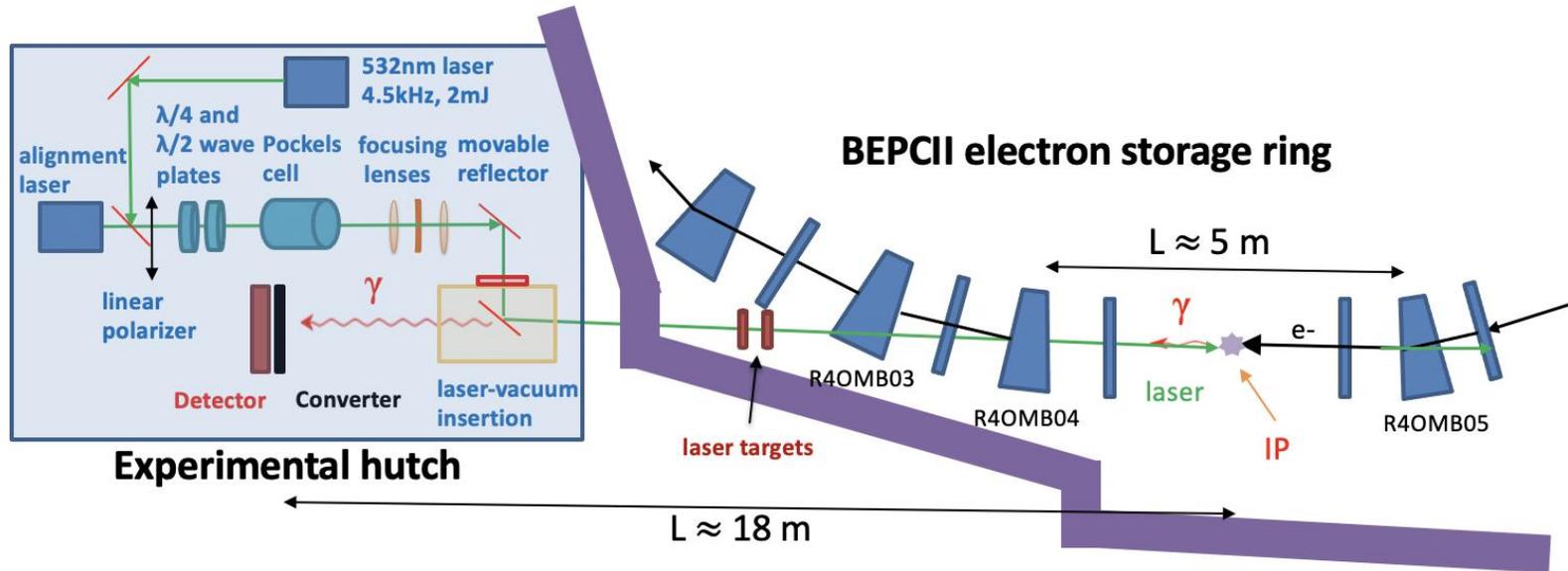
2025.5

Linac resumes operation

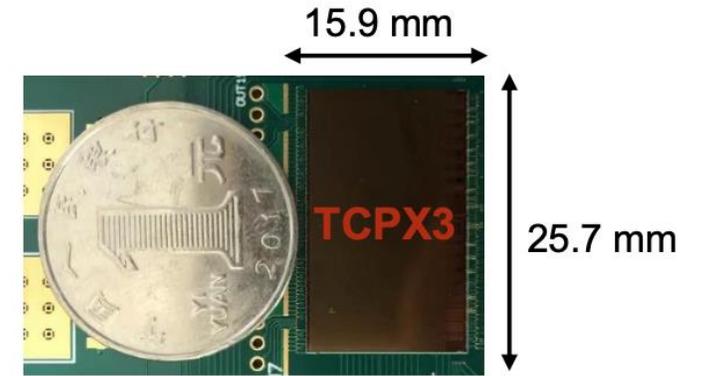
## Vertical polarization 1 hour after injection



# Compton polarimeter @ BEPCII

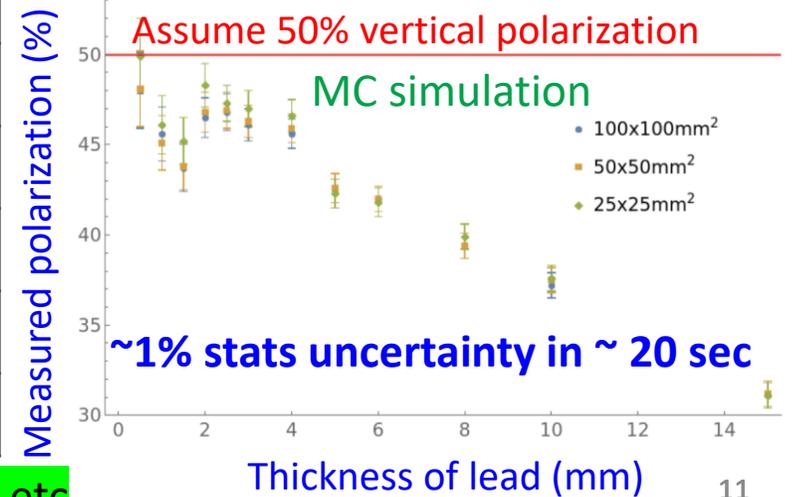


prototype of CEPC vertex detector

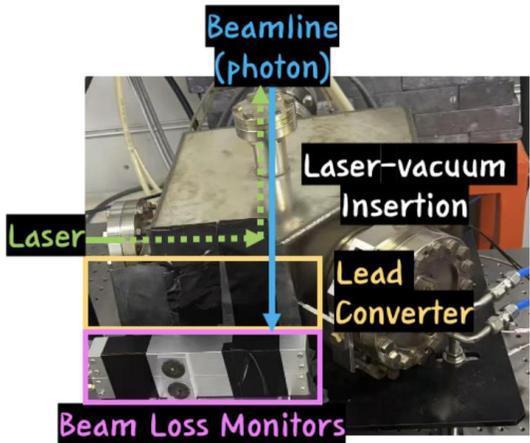
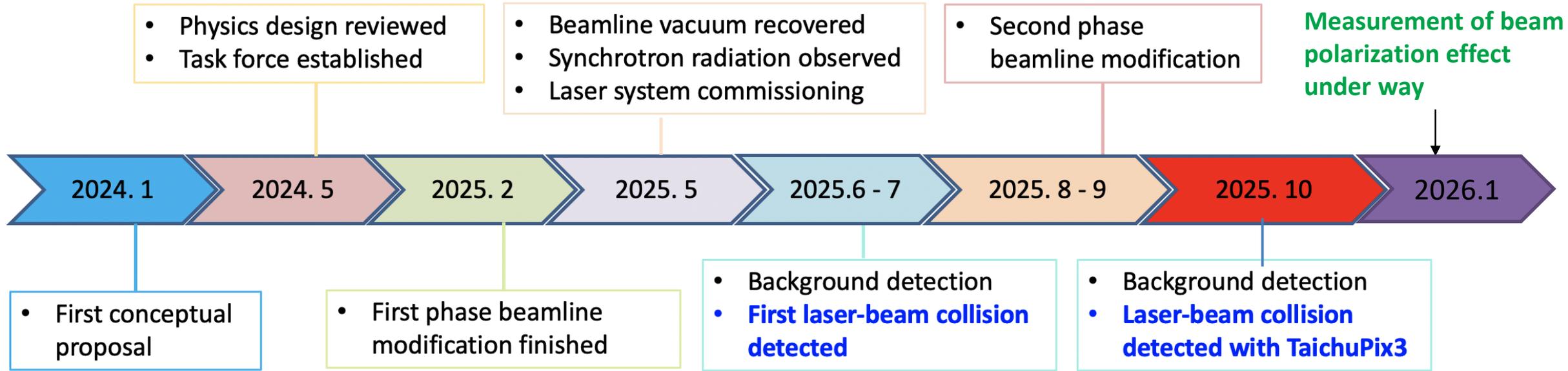


**TaichuPix-3**  
Pixel size:  $25 \mu\text{m} \times 25 \mu\text{m}$

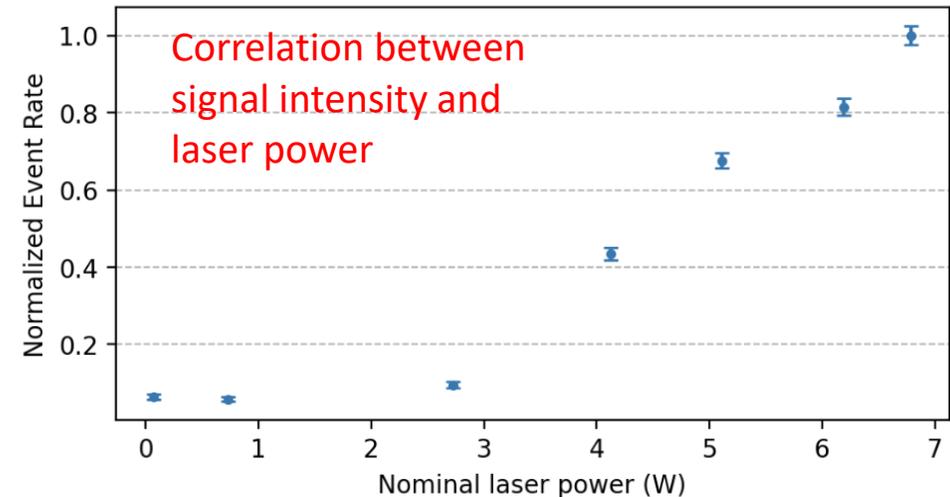
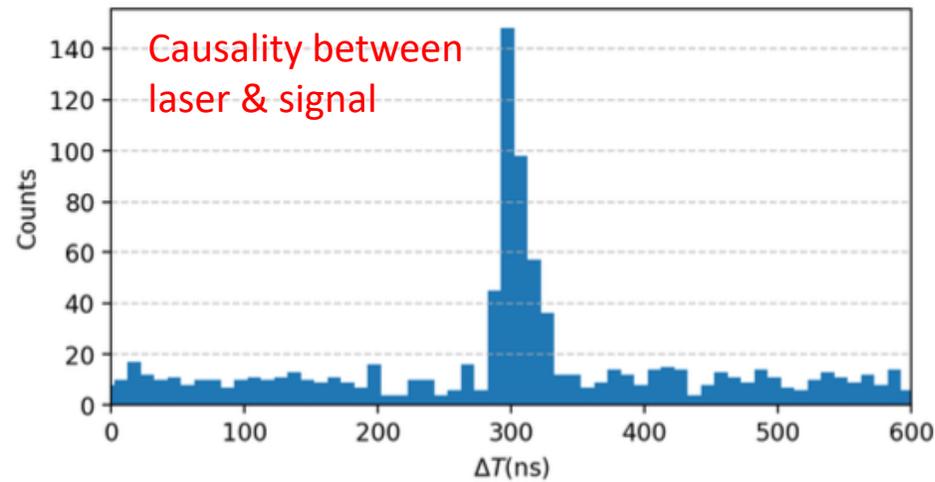
Location	beamline and experimental hall of 4W2 wiggler
Laser	532nm, 4.5 kHz, 2 mJ, 1 ns, flippable circular polarization
Observable	Vertical asymmetry of backscattered $\gamma$ (up to 180 MeV)
Detector	lead preshower + silicon pixel detector
Signal	backscattered $\gamma$ $\sim 20\text{kHz}/\text{mA}/\text{W}$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



# Progress and status

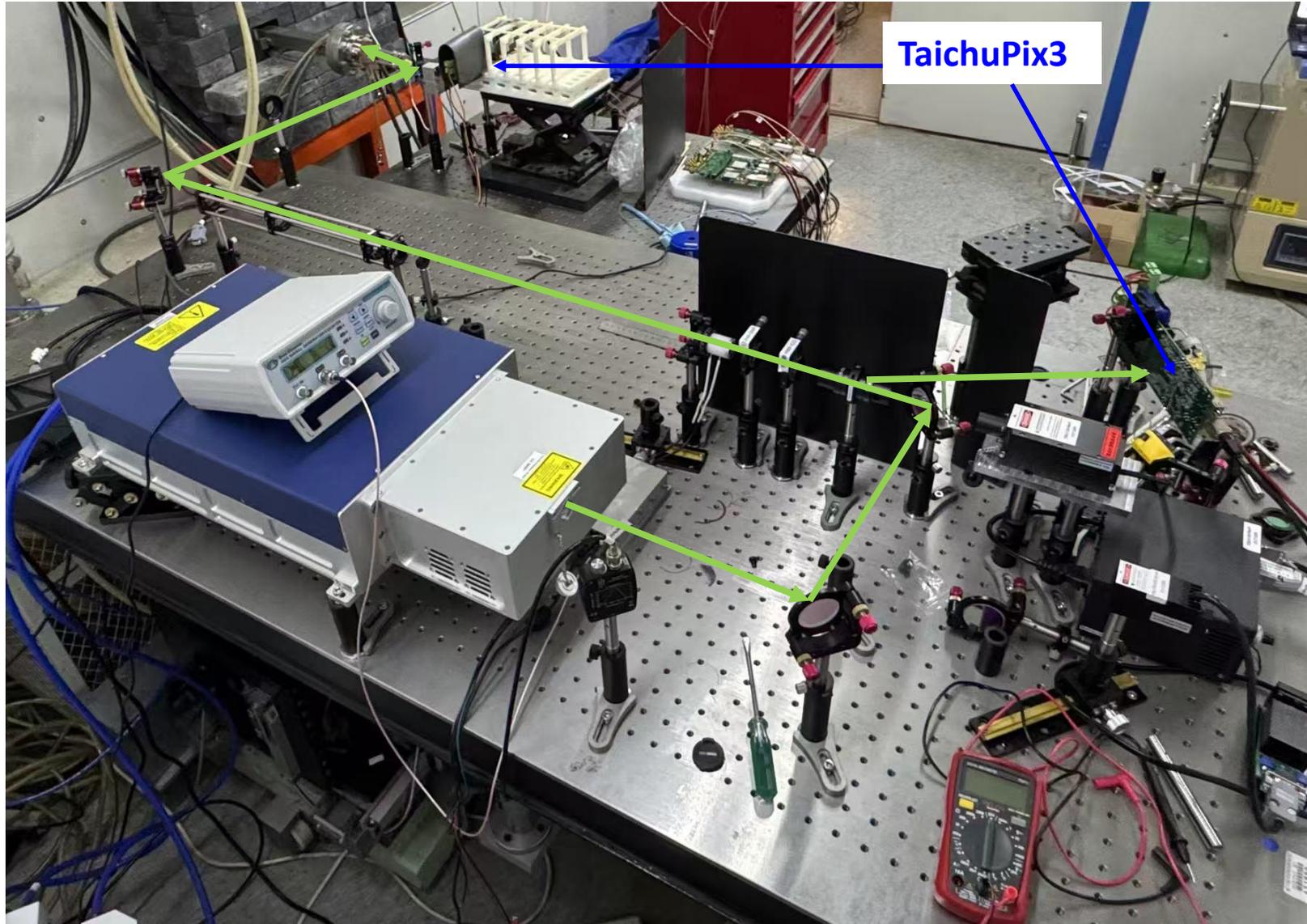


plastic scintiliator + PMT



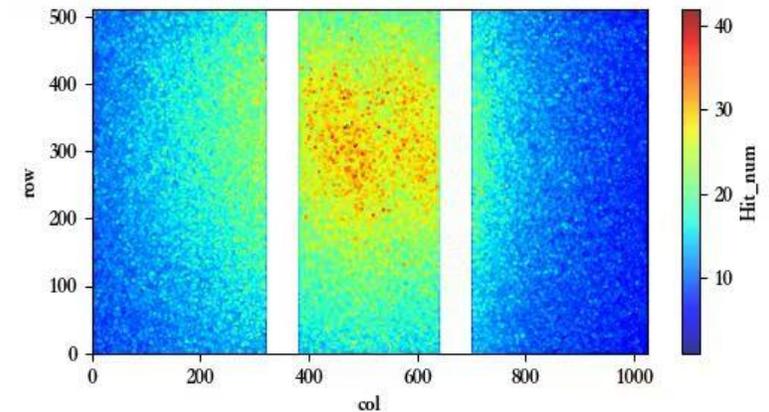
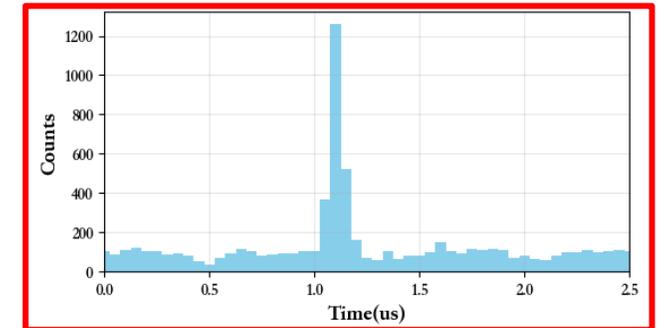
Status report submitted to RDTM

# Recent experiments with TaichuPix3



Commissioning of TaichuPix-3

- Laser-to-Taichu as trigger
- Laser-signal causality observed
- Offline analysis of beam polarization effects is underway



# Prospects of a Compton polarimeter @ BEPCII

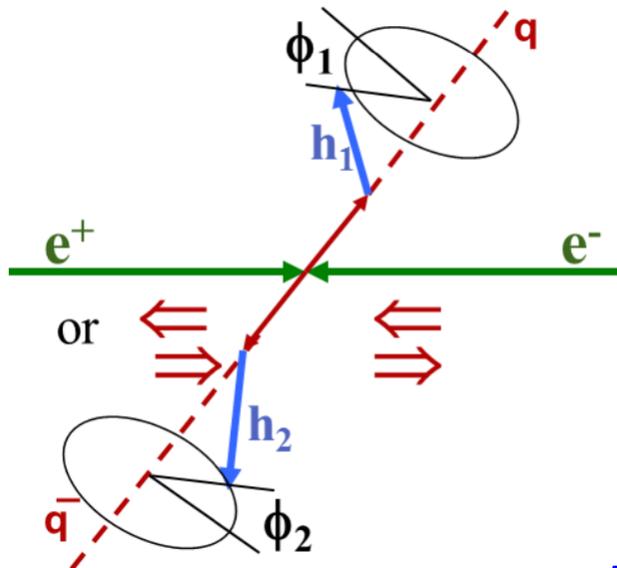
Experimental studies to address

- How to precisely measure beam polarization?
- How to precisely calibrate beam energy?
- How to mitigate depolarization effects in storage ring?

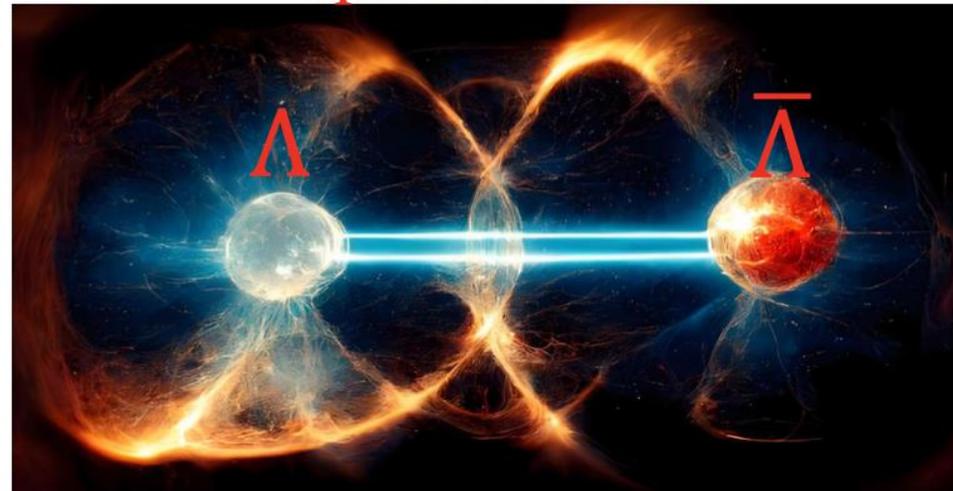
Aspects	R&D item
Compton polarimeter	laser polarization measurement/control, silicon pixel detector
Resonant depolarization	Operation scenarios, error analysis, colliding bunches & pilot bunches
Depolarization mechanism	Rich data of parameter dependence, beam-beam depolarization
Polarization tuning/optimization	spin matching, machine learning techniques

# Motivation for longitudinal polarization at BEPCII

- BESIII spin physics has flourishes, focusing on polarization of final products of  $e^+e^-$  collisions
  - Nature,606,64-69,2022; PRL 116,042001, 2016; PRL 130, 231901, 2023; arXiv:2502.16084
- e- longitudinal polarization will enhance the spin physics potential at BESIII
  - Search for CP violation in production & decay of Hyperon-Antihyperon pairs (arXiv:2502.20274)
  - Spin dependent fragmentation function etc.



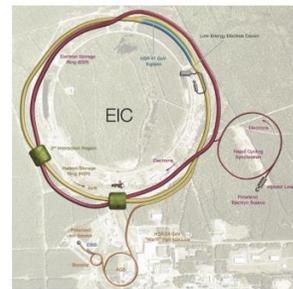
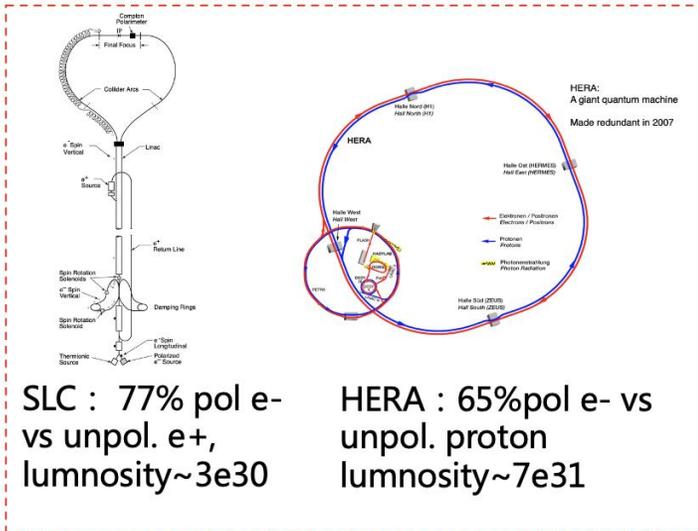
Spin correlation!



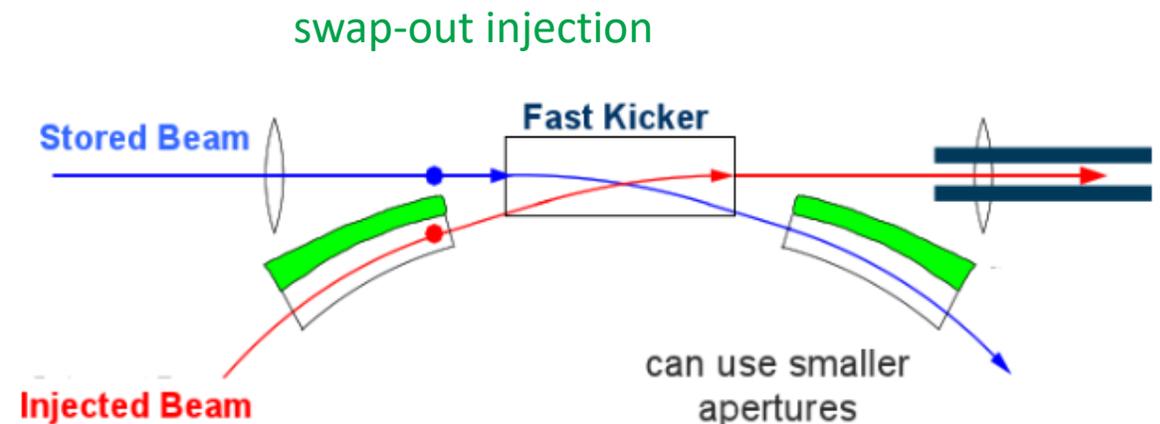
Refer to LI Haibo, "Spin physics at BESIII", SPIN 2025, Qingdao, Sep 2025

# Motivation for longitudinal polarization at BEPCII

- e- longitudinal polarization at BEPCII: a demonstrator for future colliders including CEPC
  - simultaneous achievement of high luminosity and high longitudinal polarization
  - swap-out injection applied to e+e- collider, *already demonstrated at APS-U & HEPS*
  - Long-term operation of polarized electron source
  - Precision Compton polarimetry



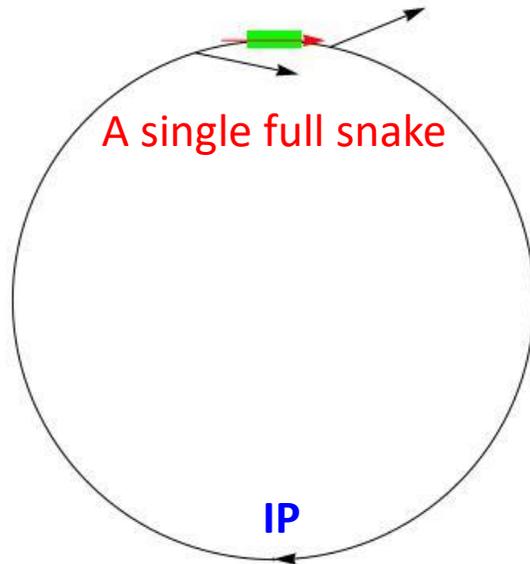
EIC : 70%pol e- vs pol proton, luminosity ~1e34  
 Next generation e+e- colliders 1e34~1e36



Courtesy of C. Steier

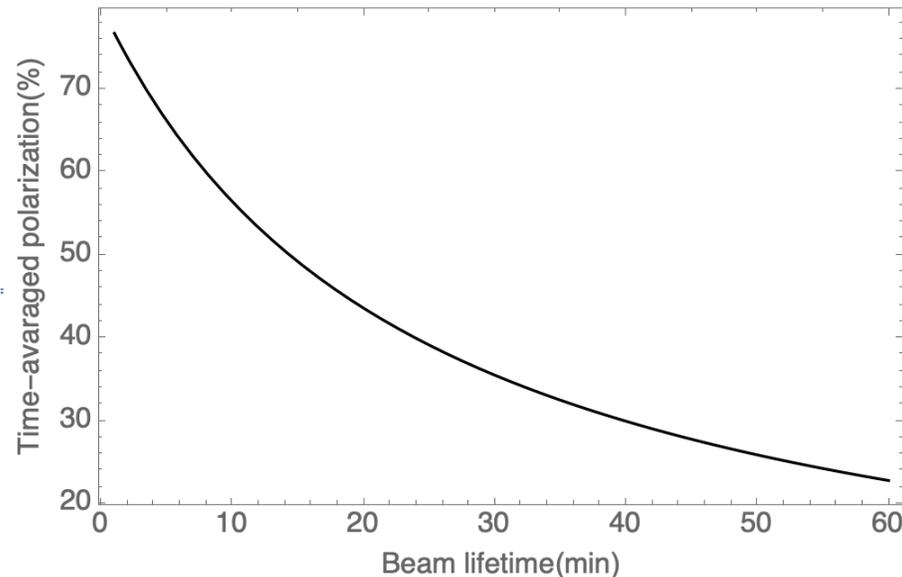
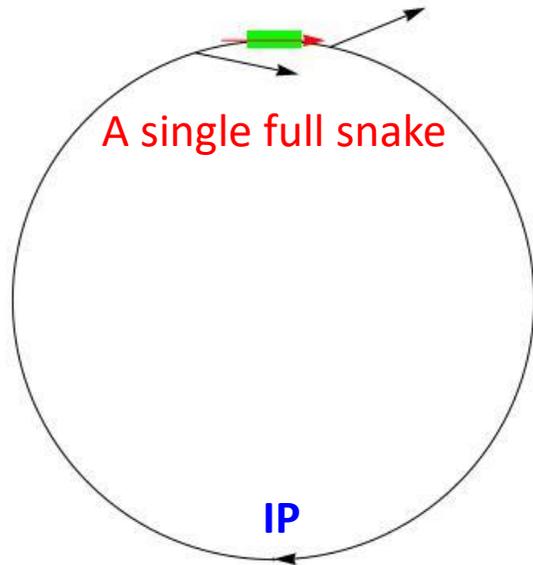
# Longitudinal polarization scheme @ BEPCII

- Longitudinal polarized e- versus unpolarized e+
- Inserting a Siberian snake to attain longitudinal polarization at IP
  - Superconducting solenoid,  $BL[\text{T}\cdot\text{m}]=10.467E[\text{GeV}]$ ,  $\sim 20\text{T}\cdot\text{m}$  @  $1.89\text{GeV}$
  - Depolarization time  $\sim E^{-7}$ , 24 min @  $1.55\text{ GeV}$  (*for spin matched snake*)



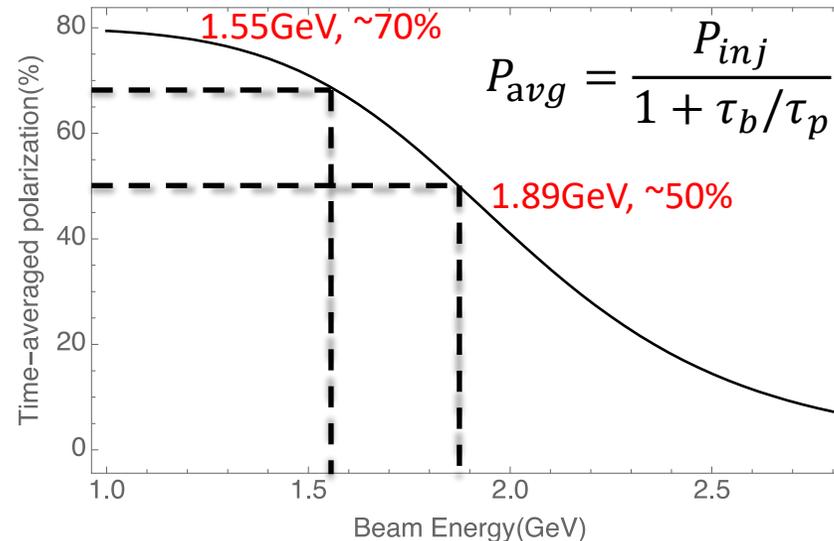
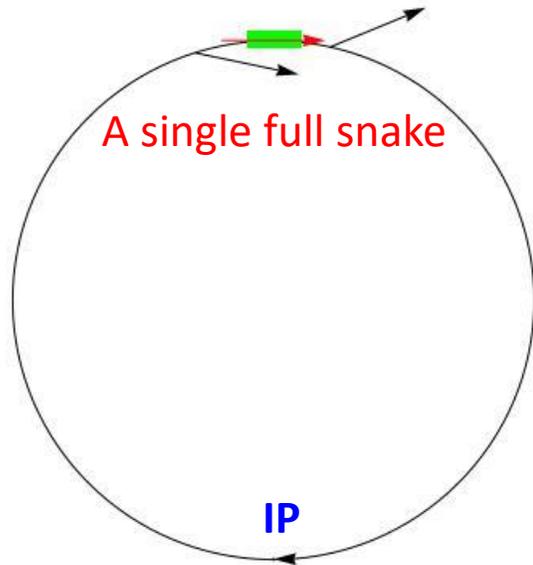
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  - Depolarization time  $\sim E^{-7}$ , 24 min @ 1.55 GeV (*for spin matched snake*)
- **top-up injection**: frequently **refill** depleted depolarized bunches with fresh polarized bunches
  - *Polarized electron source can deliver injected beam polarization > 80%*
  - *A shorter beam lifetime -> higher time-averaged beam polarization*



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  - Depolarization time  $\sim E^{-7}$ , 24 min @ 1.55 GeV (*for spin matched snake*)
- **Swap-out injection**: frequently **dump** depolarized bunches and **replace** with fresh polarized bunches
  - *Polarized electron source can deliver injected beam polarization > 80%*
  - e.g. replace 1/12 of all 120 bunches every 20 seconds, corresponding to a beam lifetime of  $\sim 4\text{min}$



# What does that mean for the injector?

- Top-up injection is prohibited by injection beam loss & dark current in BESIII detector
  - A polarized electron source features a much smaller beam emittance, alleviating the injection beam loss
- Increase in the duty factor of the linac, the burden is much relaxed than SuperKEKB linac
- The required average beam current of the polarized e- source is moderate

## Iida, IPAC'23, Beam injection issues at SuperKEKB

Table 1: Beam Parameters for a Luminosity of  $1 \times 10^{35}/\text{cm}^2\text{s}$ ;  
\* denotes the values at the interaction point.

Parameters	LER	HER	LER	HER
bunches/ring	2345+1		2345+1	
Luminosity [ $1/\text{cm}^2\text{s}$ ]	$1 \times 10^{35}$		$1 \times 10^{35}$	
$I_{\text{total}}$ [A]	2.08	1.48	2.78	1.65
$\beta_y^*$ [mm]	0.8	0.8	1	1
$\sigma_x$ [mm]	6.49	6.35	7.26	6.51
$\tau_{\text{beam}}$ [min.]	3.4	14.8	4.7	16.9
$\epsilon_{\text{inj}}^*$ [%]	68	17	66	16
$Q_e^{\text{inj}} \times n_{\text{bi}}^a$ [nC]	3×2	2×2	3×2	2×2
$r_{\text{inj}}^a$ [nC/pulse]	4.1	0.68	4.0	0.64
$r_{\text{inj}}^b$ [nC/pulse]			2.3	0.34-0.65

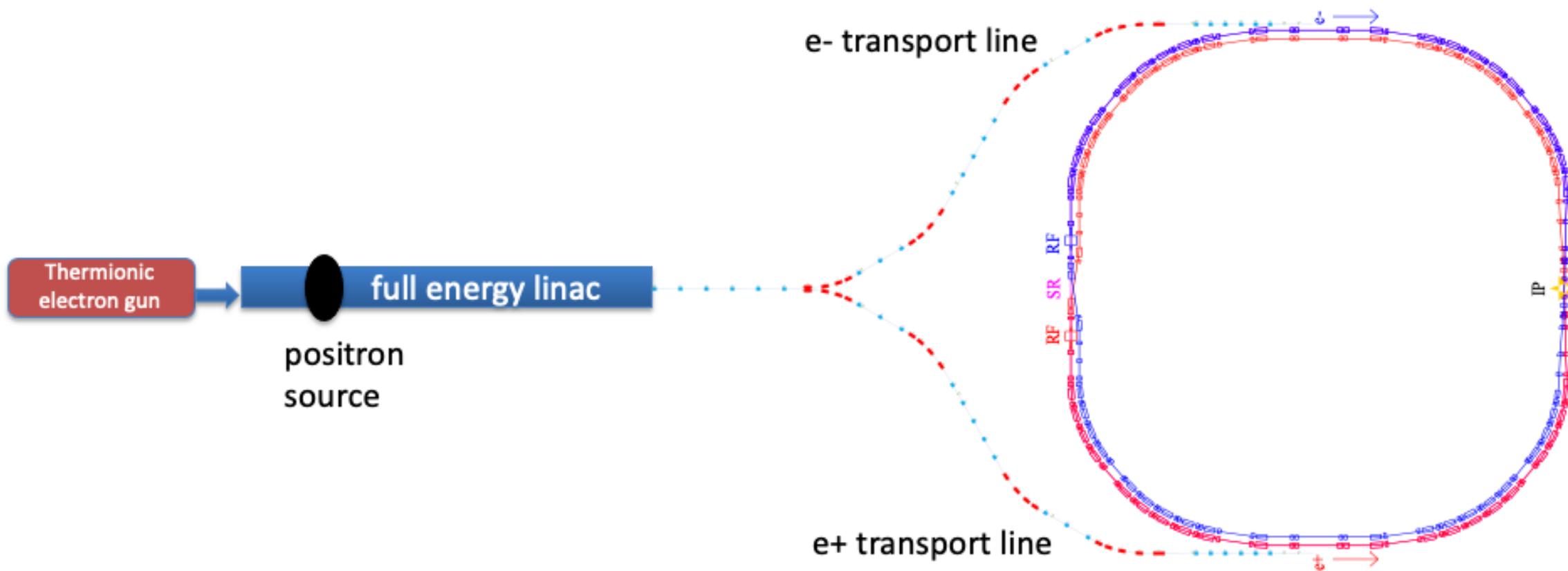
<sup>a</sup> Requirement for injection for 25 Hz,  $r_{\text{inj}} \equiv \epsilon_{\text{inj}} Q_e n_{\text{bi}}$ .

<sup>b</sup> Parameters when maximum luminosity was achieved in 2022.

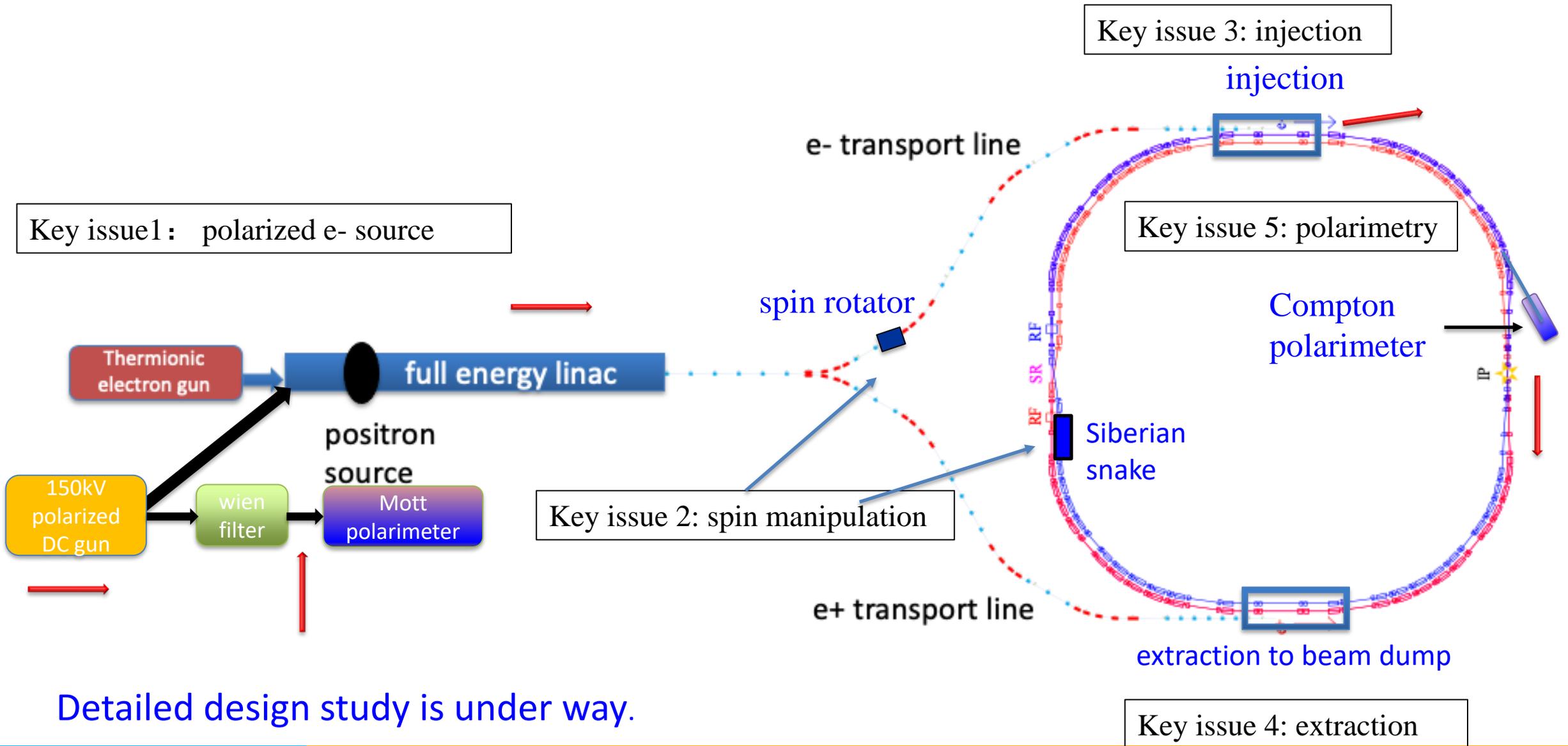
## Comparison between parameters of polarized electron sources

Parameter	BEPCII	SLC	ILC	CLIC	EIC
polarization	>80%	85%	>80%	>80%	85%
Bunch charge	2nC	9-16nC	3.2nC	1nC	7nC
Bunch number	1	1	1312	312	8
Repetition rate	50Hz	120Hz	5Hz	50Hz	100Hz
Average current	0.1uA	1.1-1.9uA	21uA	15.6uA	5.6uA

# Layout of BEPCII



# Modified layout for longitudinal polarization



Key issue 1: polarized e- source

Key issue 3: injection

Key issue 5: polarimetry

Key issue 2: spin manipulation

Key issue 4: extraction

Detailed design study is under way.

# International collaborators

- Spin dynamics studies
  - D. Barber (DESY), E. Forest (KEK), S. Nikitin (BINP)
  - contribute to FCC-ee EPOL collaboration
- Compton polarimeter
  - A. Martens (IJCLab, supported by FCPPN 2024/2025, Caiyuanpei PhD/Project 2026 )
  - Instructive discussions with I. Nikolaev, V. Kaminskiy (BINP)
  - A laser-vacuum insertion was borrowed from BEMS @ BESIII for early commissioning, granted by N. Muchnoi and M. Achasov (BINP)

# Summary

- Potential of polarized beam at CEPC is reviewed
- R&D of key technologies in progress
- Longitudinal polarization option is being studied for BEPCII
- These activities will set the basis for polarization applications at CEPC

**Thank you for your attention!**