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

# Positron sources and collaboration

Xiaoping Li (IHEP，Beijing)

# Content

- **Positron Source introduction**
- **CEPC Linac, electron source and positron source**
- **Investigations on generation of polarized positron**
- **France-China Cooperation in R&D for PPS**
  - A FCPPN Project for 2025
  - Progress from IHEP
- **Summary**

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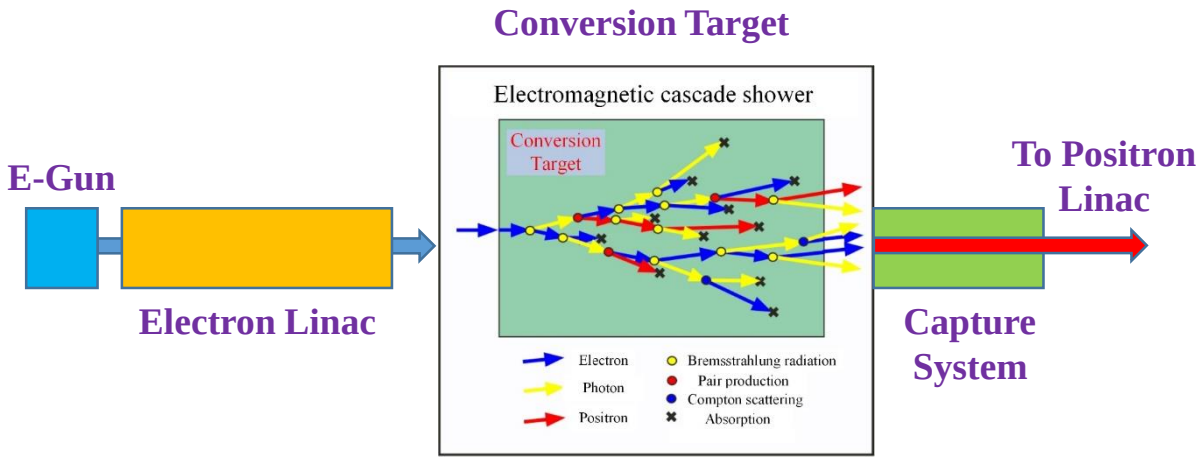
# Positron Source introduction

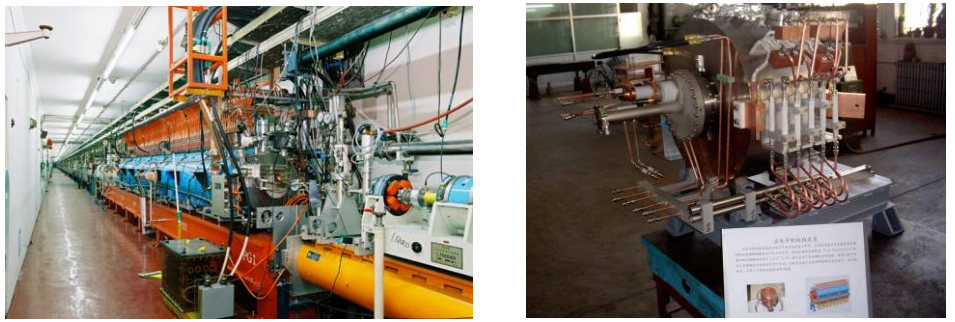
## Introduction to Positron Source

- Positron source is an essential part of an electron-positron collider (Linear & Circular)
- In high energy accelerators, positrons are typically generated through the electromagnetic cascade shower process when a high-energy electron beams incident on a conversion target
- Positron source of BEPCII: conventional positron source schemes with mature technology




A typical conventional positron source scheme

| Parameters | BEPCII |
|---|---|
| Electron energy（GeV） | 0.240 |
| Electron bunch charge（nC） | 6 |
| Repetition rate（Hz） | 50Hz |
| Electron beam size（mm） | 2.5 |
| Conversion Target | Tungsten |
| Target thickness（mm） | 8 |



Positron source of BEPCII

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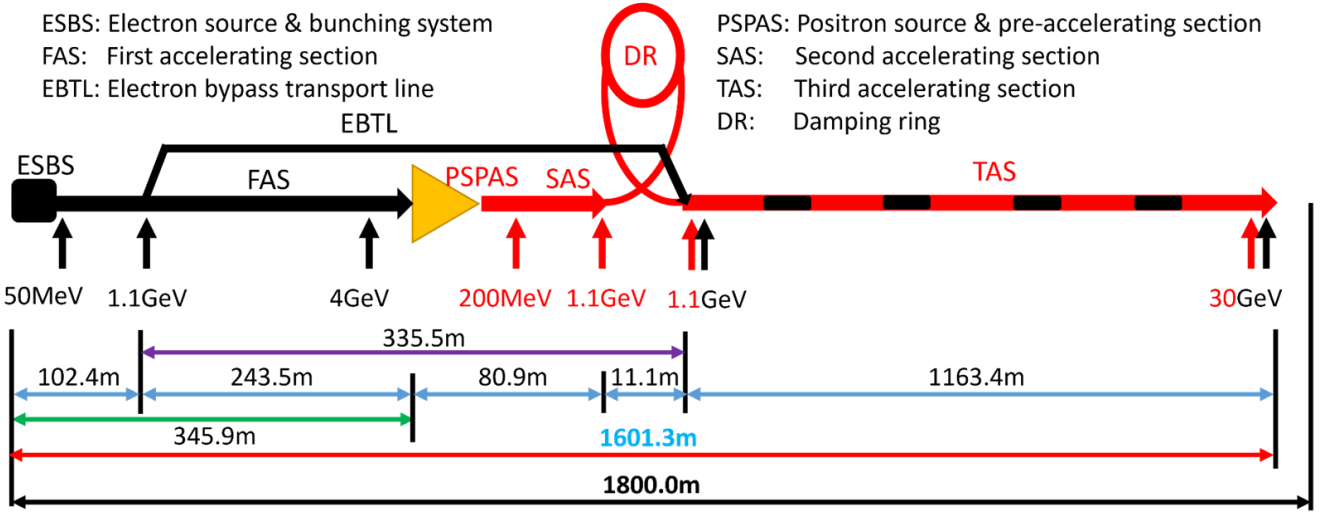
# CEPC Linac

- **Baseline design of the CEPC Linac**
  - A **30GeV** room temperature Linac
  - A combination of **S-Band (2860MHz)** and **C-Band (5720MHz)**
  - FAS+PSPAS+SAS： S-Band
  - TAS： C-Band （Higher gradient → Shorter linac tunnel length）
  - The Linac tunnel length is **1.8km**



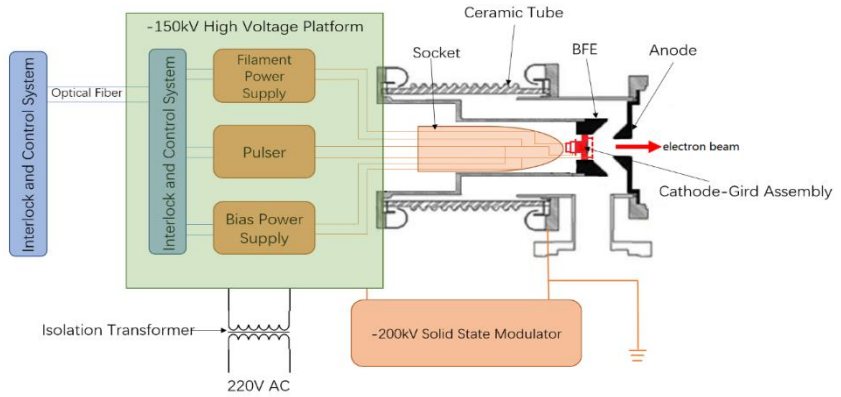

| Parameter | Symbol | Unit | Baseline |
|---|---|---|---|
| Energy | $E_{e-}/E_{e+}$ | GeV | 30 |
| Repetition rate | $f_{rep}$ | Hz | 100 |
| Bunch number per pulse | | | 1 or 2 |
| Bunch charge | | nC | **1.5** |
| Energy spread | $\sigma_E$ | | $1.5\times10^{-3}$ |
| Emittance | $\varepsilon_r$ | nm | 6.5 |

# CEPC Electron Source

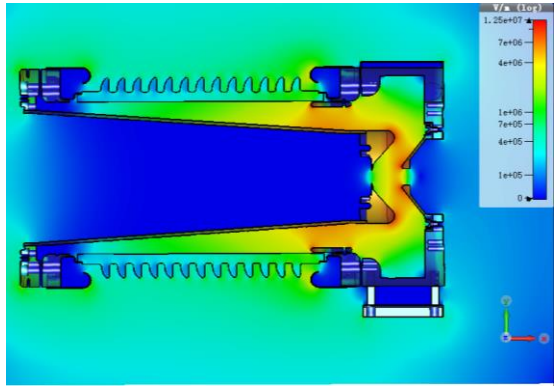
## CEPC Electron Source

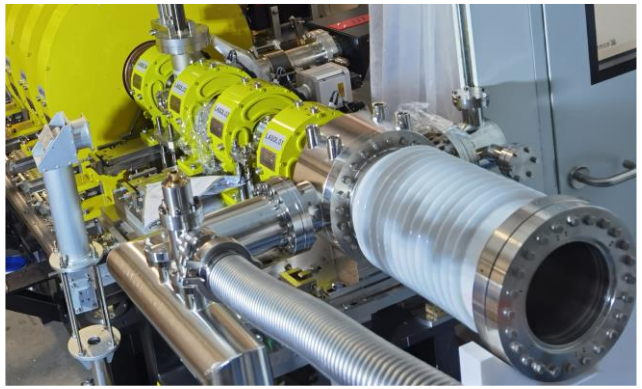
The electron source is used for generating an electron beam with a specific longitudinal distribution that can be accelerated for injection and positron production.

- **Electron Gun (Baseline design)**
  - A traditional thermionic triode gun with two operation modes
  - **1.5nC** for electron injection
  - **10nC** for positron generation
- **Has been verified at BEPCII and HEPS Linac**




| Parameter | Unit | Value |
|---|---|---|
| Type | - | Thermionic Triode Gun |
| Cathode | - | Dispenser cathode |
| Beam current | A | > 10 |
| High voltage of anode | kV | 150 |
| Bunch charge 1 | nC | 1.5 ($e^-$ injection) |
| Bunch charge 2 | nC | 10 ($e^+$ production) |
| Repetition | Hz | 100 |



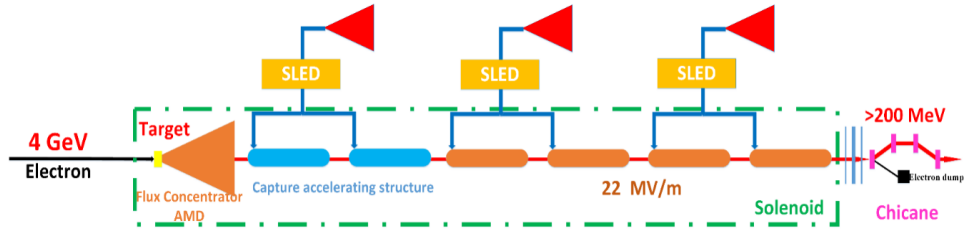


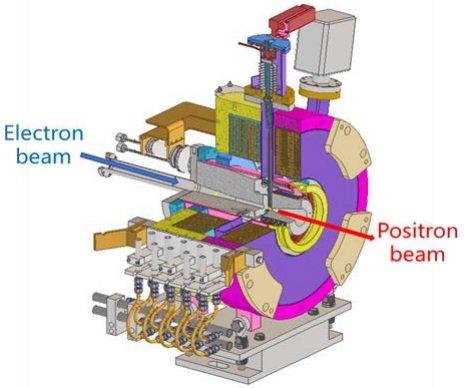
CEPC electron source parameters and its design

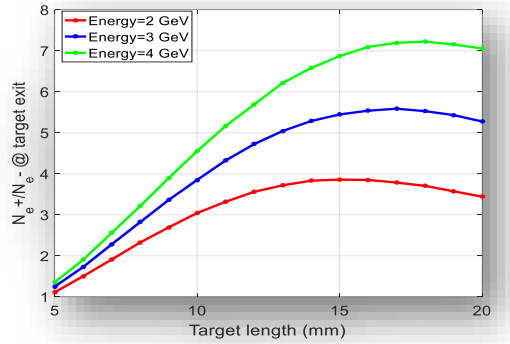
# CEPC Positron Source

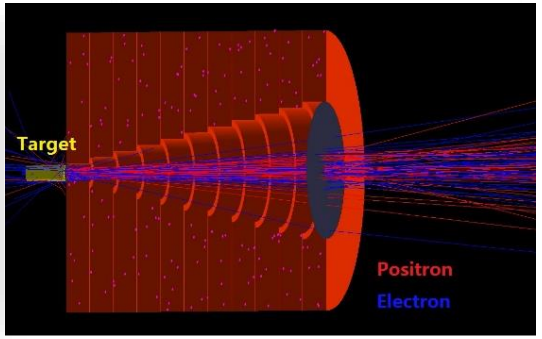
## CEPC Positron Source

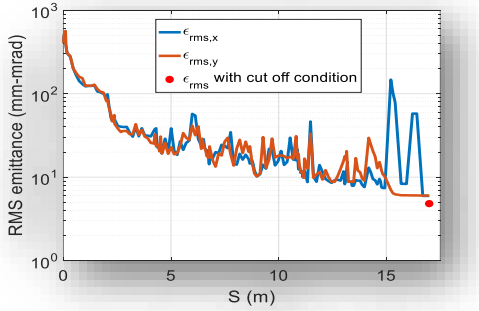
- **Positron source**
  - Target (Conventional)
    - Electron beam: 10nC@4GeV
    - Tungsten@**15 mm**
    - Beam size: **0.5 mm**
- **AMD (Adiabatic Matching Device)**
  - A flux concentrator
  - Magnetic field: (5.5T→0T) + 0.5T Solenoid
- **Capture & Pre-accelerating structure**
  - 1 klystron → 2 accelerating structures
    - Larger aperture S-band accelerating structure with aperture is 25 mm
- **Chicane @ 200MeV**
  - Wasted electron separation
  - Exit: ~5.5nC, Nor. Emittance: 2370mm-mrad

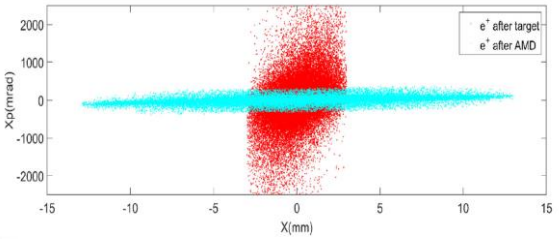


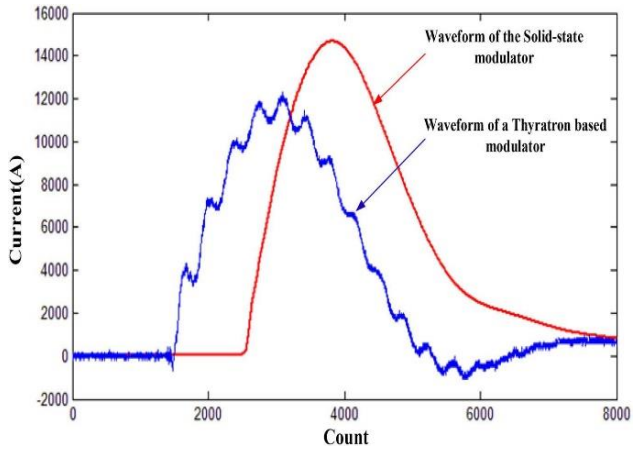



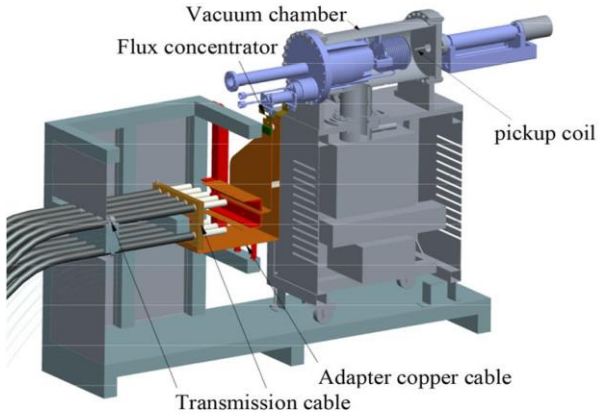
# CEPC Positron Source

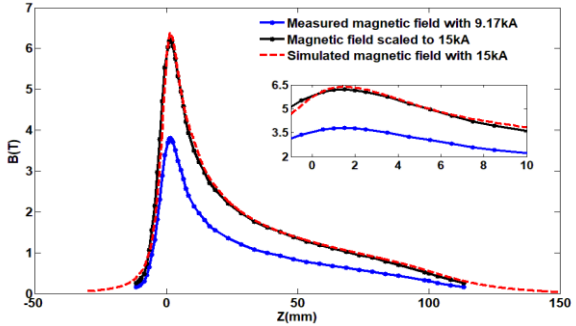
## CEPC Positron Source related R&D

- **Developed of a flux concentrator prototype and its pulse modulator**
  - A SLAC-type flux concentrator
  - A 15kA/15kV all-solid-state pulse modulator (now used for BEPCII positron source operation )
  - A peak magnetic field of **6.2 T** had been obtained inside the FC at a 15kA driving current




A solid-state pulse modulator and its waveform




A Flux-Concentrator prototype and magnetic field

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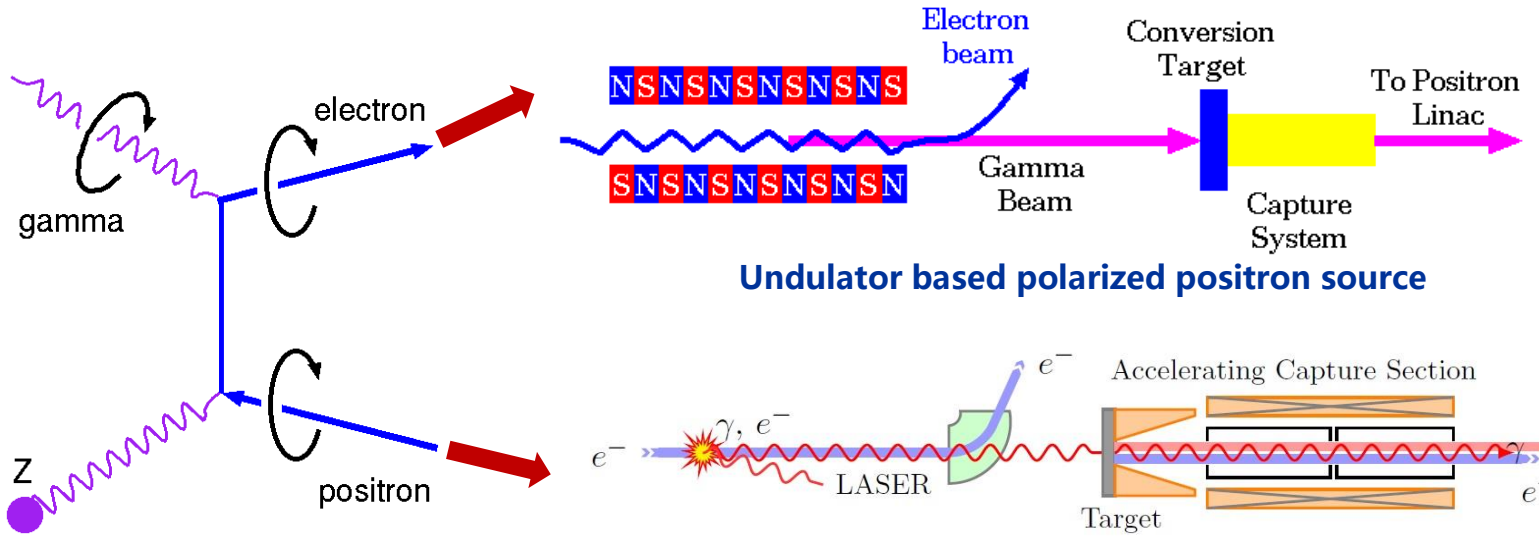
# Investigations on generation of polarized positron

## Polarized positron production from circularly polarized gamma photons

- One effective method for generating polarized positrons is to directly use high-energy polarized gamma photons to incident on the conversion target (low Z and thin target)
- Positrons are generated through the pair production process
- When the incident high-energy gamma photon beam has **circular polarization**, it can generate **longitudinally polarized positrons**







Undulator based polarized positron source




Inverse Compton scattering based polarized positron source

**ILC baseline design**
**150GeV electron beam**
**147m helical undulator**
**Polarization:~30%**

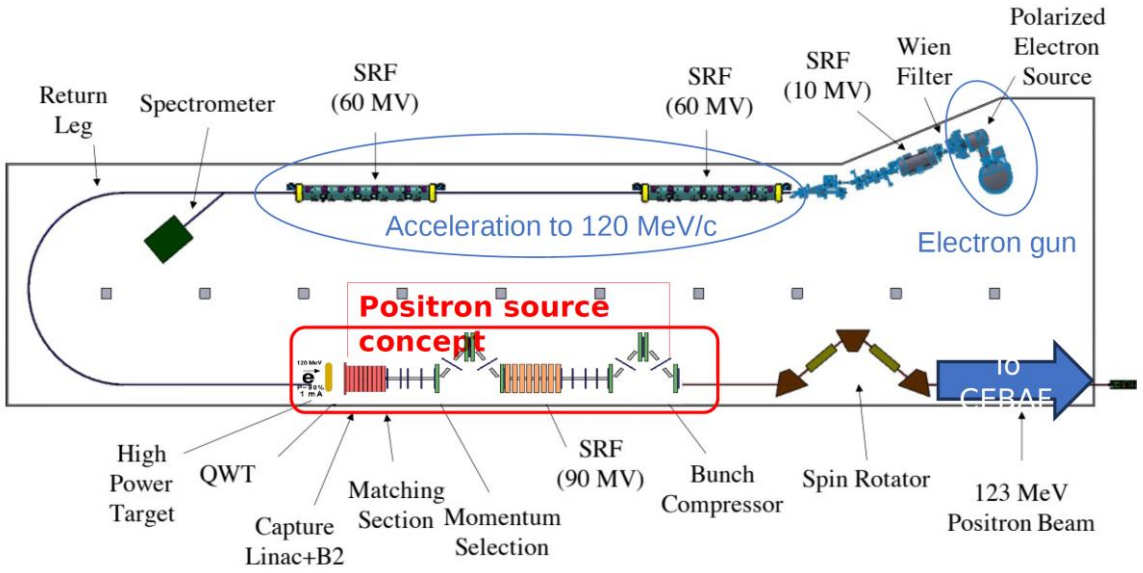
**Alternative scheme for ILC and CLIC**
**Bunch charge VS polarization**
**Compton ring and laser stacking cavity**
**Positron accumulator ring**

"Polarized positron sources for the future linear colliders"
Iryna Chaikovska

# Investigations on generation of polarized positron

## Polarized positron production from polarized electrons

- Another way to obtain polarized positrons is to use a highly polarized electron beam directly incident on the conversion target
- Only selecting the high energy tail of the produced positrons
- This part of positrons can preserve the initial primary beam polarization
- Low positron yield means low bunch charge



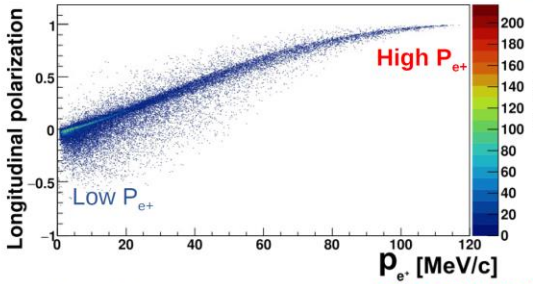

CeBAF facility at JLab

**"Polarized positron source design study at JLab"**
**Sami Habet**

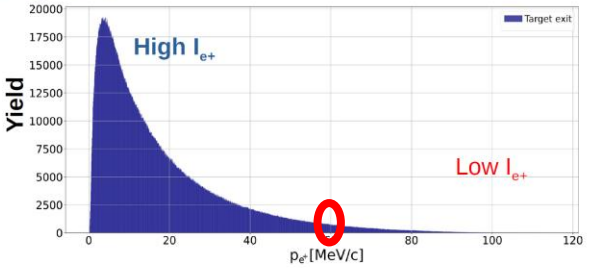
**Parameters:**

- Simulation software: **Geant4**
- Electron beam energy: **120 MeV**
- Electron beam polarization: **90%**
- Target: **Tungsten (Z=74)**

**At the target exit**




**Highly polarization** is associated with **higher momenta**




**High positron yield** is associated with **low momenta**

**Electron beam: 120MeV**
**Electron beam polarization: 90%**
**Positron beam polarization: ~60%**
**Yield: 0.01% $e^+/e^-$**

**Polarized positron yield is also a big challenge nC bunch charge**

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# France-China Cooperation in R&D for PPS

## A FCPPN Project for 2025

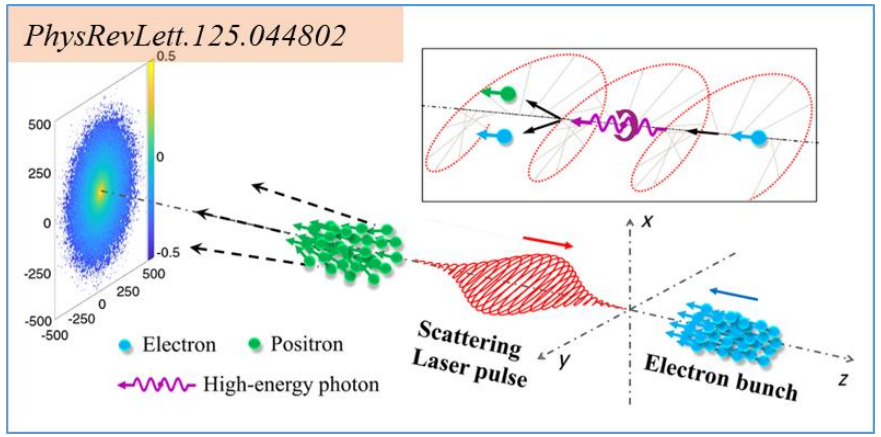
Actually, the cooperation between France and China focusing on positron sources can be traced back to 15 years ago, joint training of graduate students on advanced positron generation technologies.

- **Project Title**
  - Polarized Positrons for Next Generation Circular Colliders (POLAR-P)
- **Team member**
  - IJCLab: **Iryna Chaikovska** (Leader), Viktor. Mytrochenko, Yuting Wang, Fahad Alharthi
  - IHEP: **Xiaoping Li** (Leader), Zhe Duan, Cai Meng, Dou Wang, Huan Wang, Yuxin Liu
- **Research goal**
  - **Focuses on designing advanced polarized positron injectors to meet the technical requirements for next-generation lepton colliders, including FCC and CEPC.**
  - Test of suitable simulation tools with spin-tracking capabilities
- **More to come**
  - Personnel exchange & joint training of graduate students

# Progress from IHEP

## A novel consideration of generating polarized positrons (Prof. Yanfei LI)

– Method: Laser field replaces the high-Z target, effectively avoiding the influence of Coulomb scattering (resulting in large angular spread and low yield)



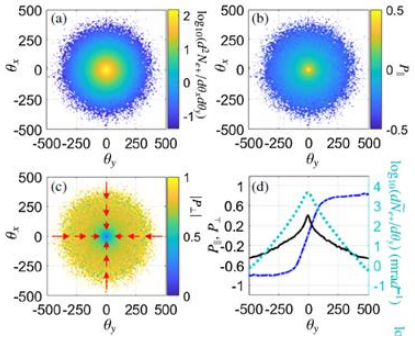

**Generation of polarized positrons from an ultra-intense laser pulse head-on colliding with a counter-propagating polarized electron beam.**

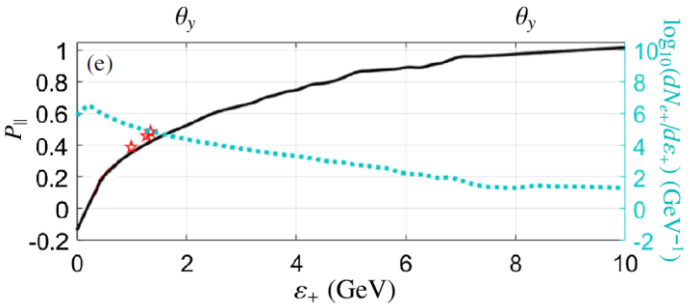
1. **Longitudinal polarization is transferred from electron to photon during NCS (nonlinear Compton scattering)**
2. **Polarization is transferred from high-energy photon to positron through NBW (nonlinear Breit-Wheeler) process**

◆ Simulation parameters

Laser pulse: $\mathrm{CP}, I_0 = 2.75 \times 10^{22}, \tau = 5T_0, w_0 = 5\lambda_0, \lambda_0 = 1\mu\mathrm{m}.$

Electron bunch: LSP, $\varepsilon_e = 10\mathrm{GeV}, L_e = 6\lambda_0, \Delta\theta = 0.2\mathrm{mrad}, \frac{\Delta\varepsilon}{\varepsilon} = 6\%$, tens~100 nC






| | Angular divergence | density | polarization |
|---|---|---|---|
| Laser | ~10 mrad | $\sim 10^9 e^+$ /bunch | 30%-80% |

**Although simulating parameters is challenging, it is a potential approach**

# Progress from IHEP

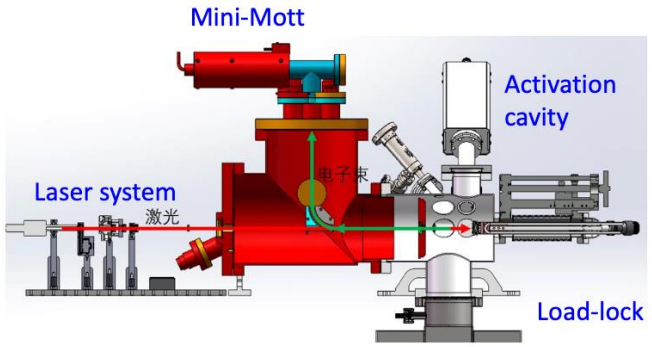
## High polarization electron source R&D at IHEP

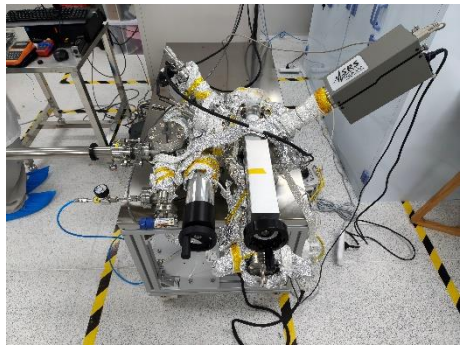
**Domestic R&D on Superlattice GaAs photocathode** (**Goal: polarization ≥ 85%, QE ≥ 0.8%** )

- In collaboration with a domestic company Acken Optoelectronics Ltd. @ Suzhou
- First test sampled produced through a MBE system in June 2025
- A platform for SL photocathode performance test now under construction (activation, QE, polarization)
- A SL GaAs wafer has been cut, and a quarter had been delivered to JGU Mainz (Valery. Tyukin)

| GaAs | 5 nm | $p=5\times10^{19}$ cm$^{-3}$ |
|---|---|---|
| GaAs/GaAsP SL | (4/3 nm) ×14 | $p=5\times10^{17}$ cm$^{-3}$ |
| $GaAsP_{0.35}$ | 2750 nm | $p=5\times10^{18}$ cm$^{-3}$ |
| Graded $GaAsP_x$ (x = 0~0.35) | 5000 nm | $p=5\times10^{18}$ cm$^{-3}$ |
| GaAs buffer | 200 nm | $p=2\times10^{18}$ cm$^{-3}$ |
| p-GaAs substrate ($p>10^{18}$ cm$^{-3}$) | | |

SL GaAs layer structure and produced wafers



A platform for SL photocathode performance test

V. Tyukin (JGU Mainz) sliced the SL wafer @ Acken

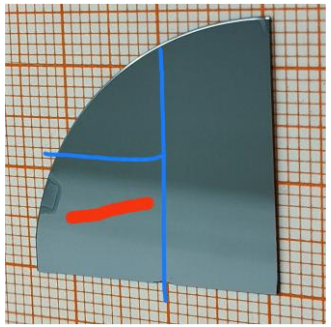
# Progress from IHEP

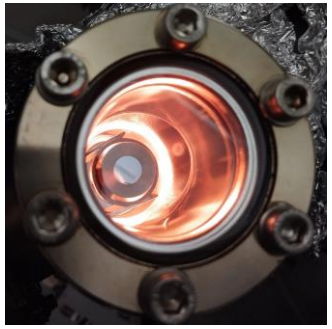
## High polarization electron source R&D at IHEP

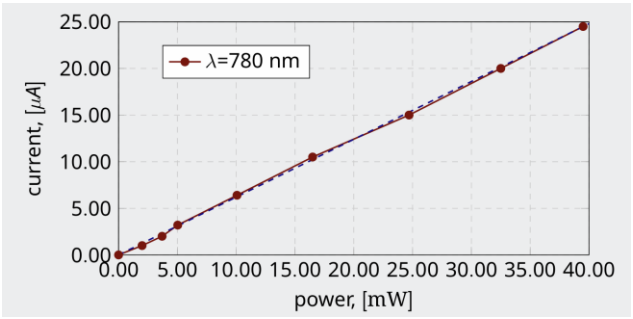
### Performance test of Superlattice GaAs photocathode

- Activation experiment and performance test of the SL GaAs had been carried out
- Preliminary performance tests show promising results in polarization and QE
- Beam polarization measurement results will be used for our Mott polarimeter calibration in future

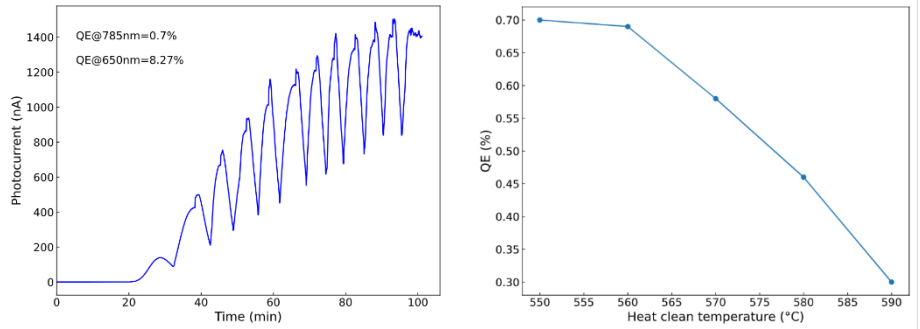
| Parameter | Valery Tyukin @ JGU Mainz | Wei Liu @ Chongqing University |
|---|---|---|
| Beam polarization | **80%~82%**, slightly higher or comparable to SVT SL wafer | — |
| Activation method | Yo-Yo method, Cs + $NF_3$ | Yo-Yo method, Cs + $O_2$ |
| Quantum efficiency | 0.1% @ 780 nm | **0.7% @ 785 nm** |








SL GaAs photocathode test at JGU Mainz

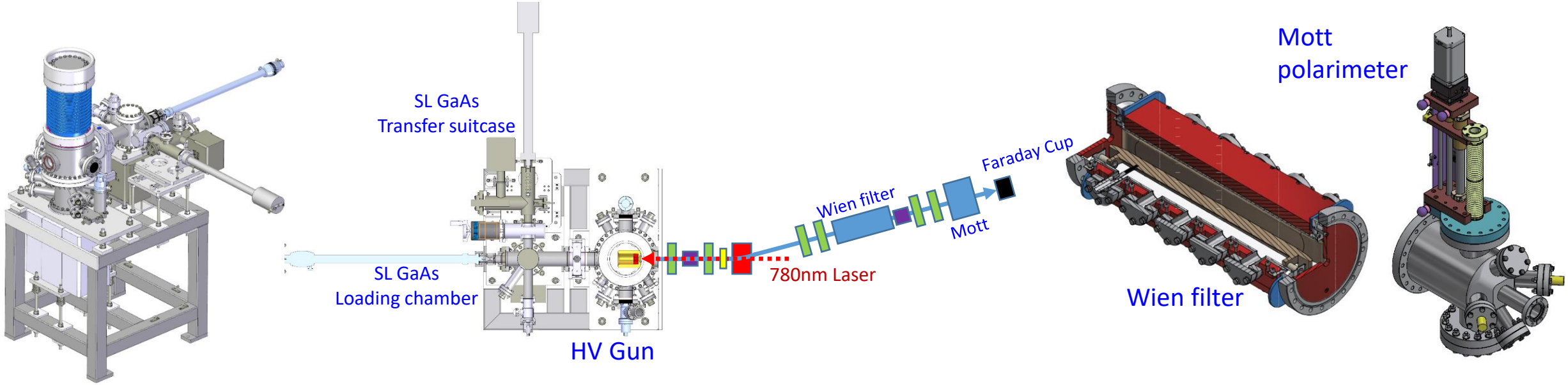



SL GaAs photocathode test at Chongqing University

# Progress from IHEP

## Next step for polarized electron source R&D

- Improved the MBE process, and started the growth of the second batch of SL wafers (Completed this July)
- Start a polarized electron source prototype development (150kV Gun, Laser, Wien filter, Mott and test beam line,  nC bunch charge and 85% polarization)
- As an alternative solution for CEPC electron source and also can be used on BEPCII




**A polarized electron source prototype development**

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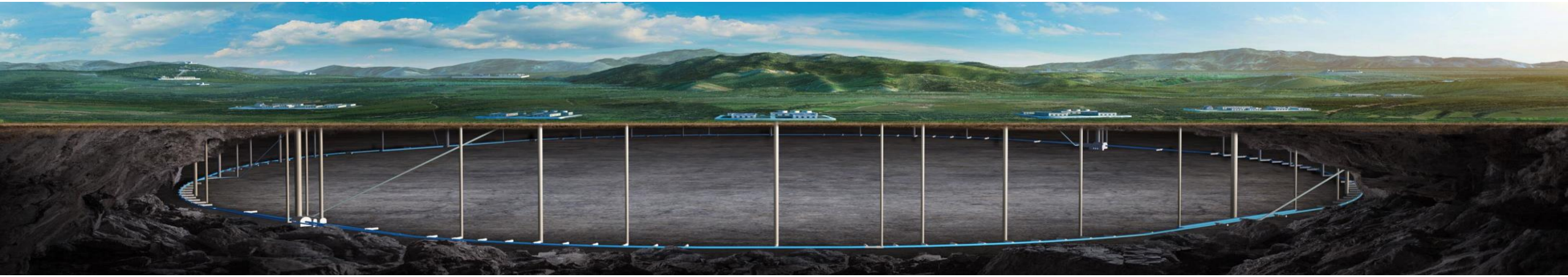
# Summary

- Introduction of Positron source
- CEPC Linac, electron source and positron source
- The method of generating polarized positrons and its challenge for future colliders
- A FCPPN Project already started in 2025, the main research goal is Polarized Positrons for Next Generation Circular Colliders (POLAR-P)
- Introduced progress from IHEP, including a novel consideration on generating polarized positrons and polarized electron source R&D progress

# Thank you for your attention!



# France-China Cooperation in R&D for PPS

## Progress from IHEP

### 1. Polarized positrons generation for CEPC

- Preliminary design study based on a Compton Ring and a Stacking Ring for the generation of polarized positrons
  - It can be a potential solution to generate polarized positrons in CEPC
  - Up to now, just a conceptual consideration (requires a lot of further simulation works in future)
- Using the self-polarization to generate polarized e+ beams in DR (**Zhe DUAN**)
  - Need a higher energy in DR around 2GeV and a strong dipole strength
  - Current research shows that extracted beam polarization @ **10min ~ 44%**