IHEP plasma test facility physics design

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On behalf of the IHEP-THU-BNU Collaboration

2025 International Workshop on the High Energy Circular Electron Positron Collider (CEPC2025)
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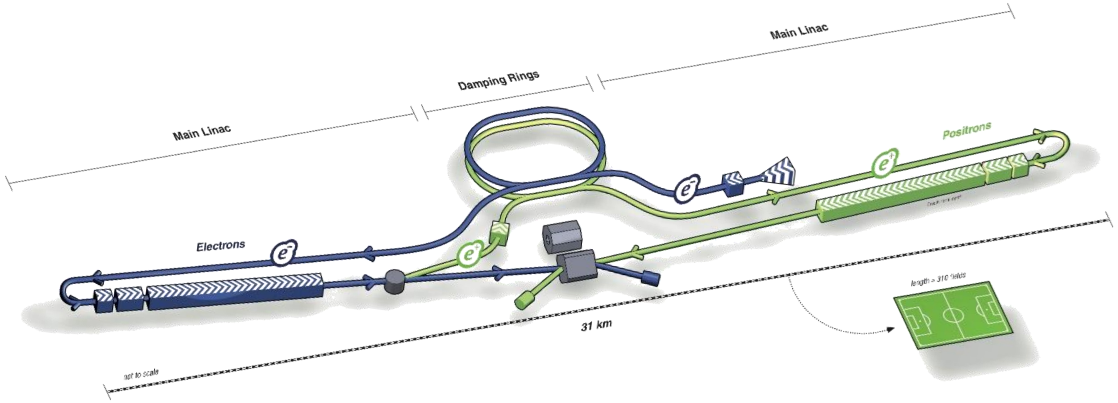
清华大学 Tsinghua University

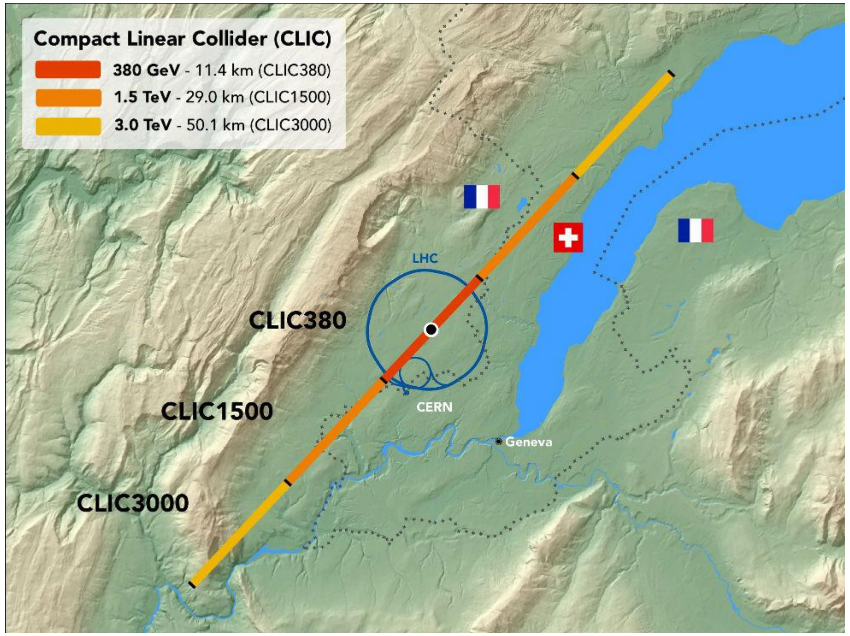
Outlines

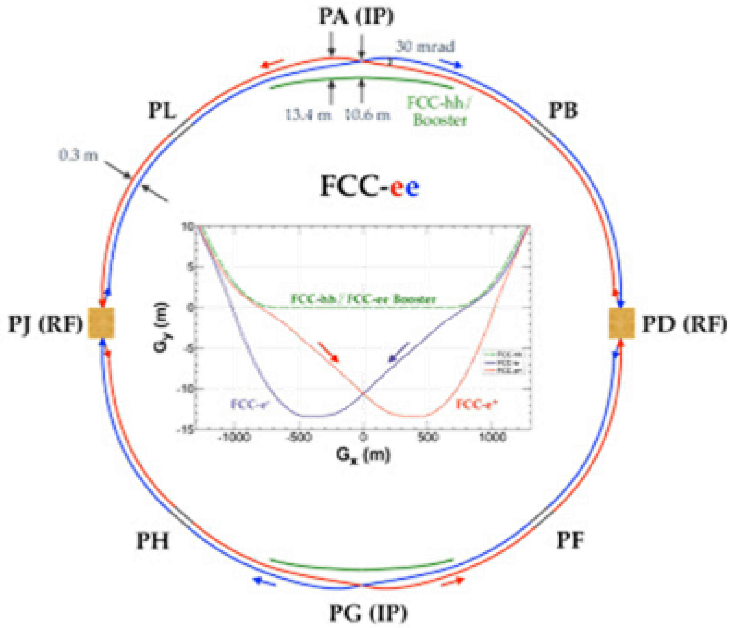
- Introduction and Motivation
- Physics Goal at IHEP Plasma Test Facility
- Physics Design of the Facility
- Summary and Outlook

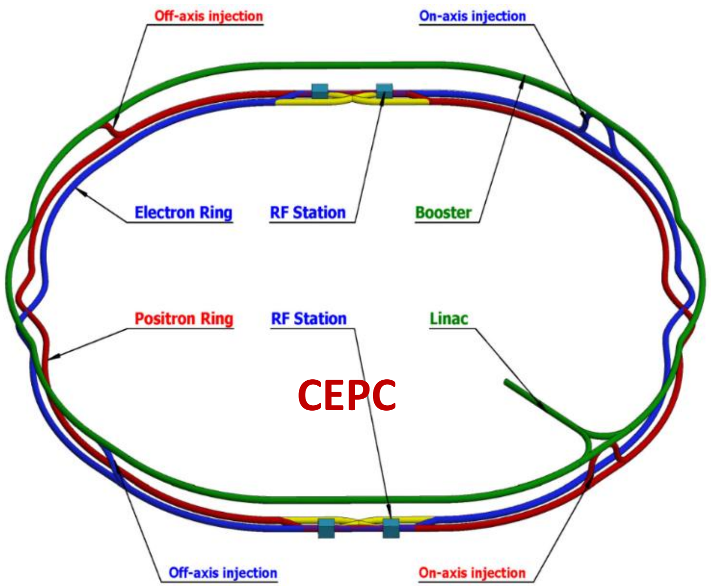
Frontiers of high energy physics

Precision measurement of the Higgs Boson and physics beyond Standard Model with high energy electron-positron collider is of the most important issues for particle physics.

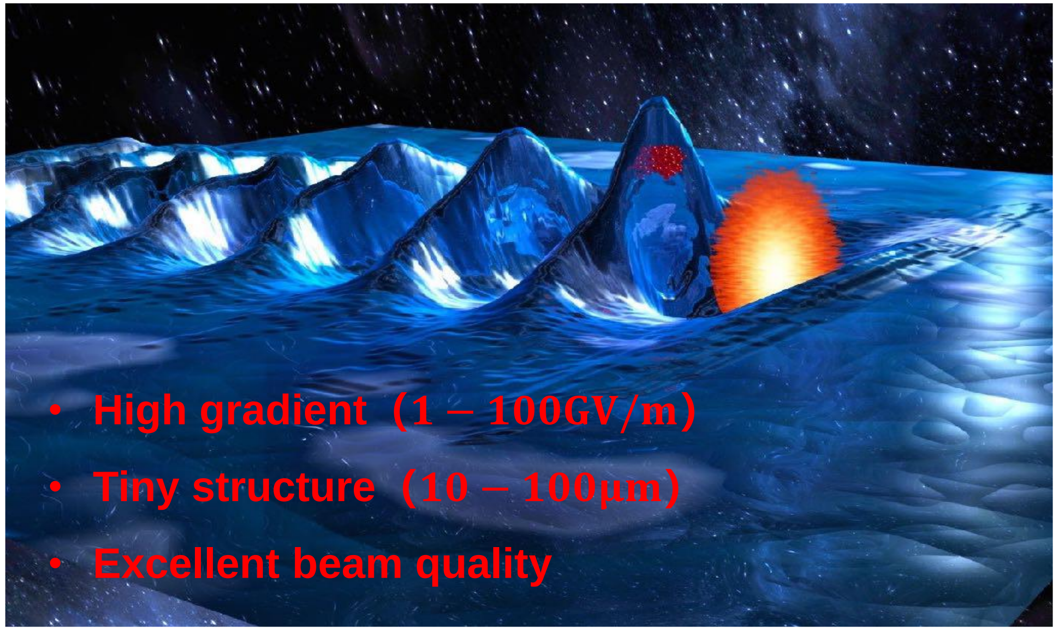








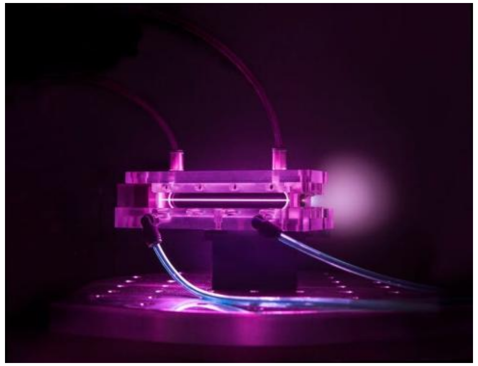
Plasma Accelerator

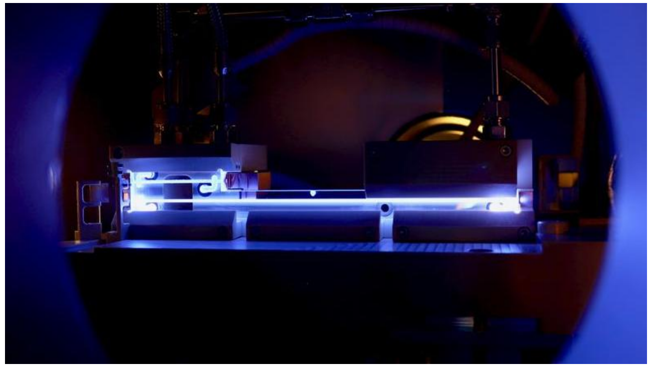


- **High gradient（1 – 100GV/m)**
- **Tiny structure（10 – 100μm)**
- **Excellent beam quality**

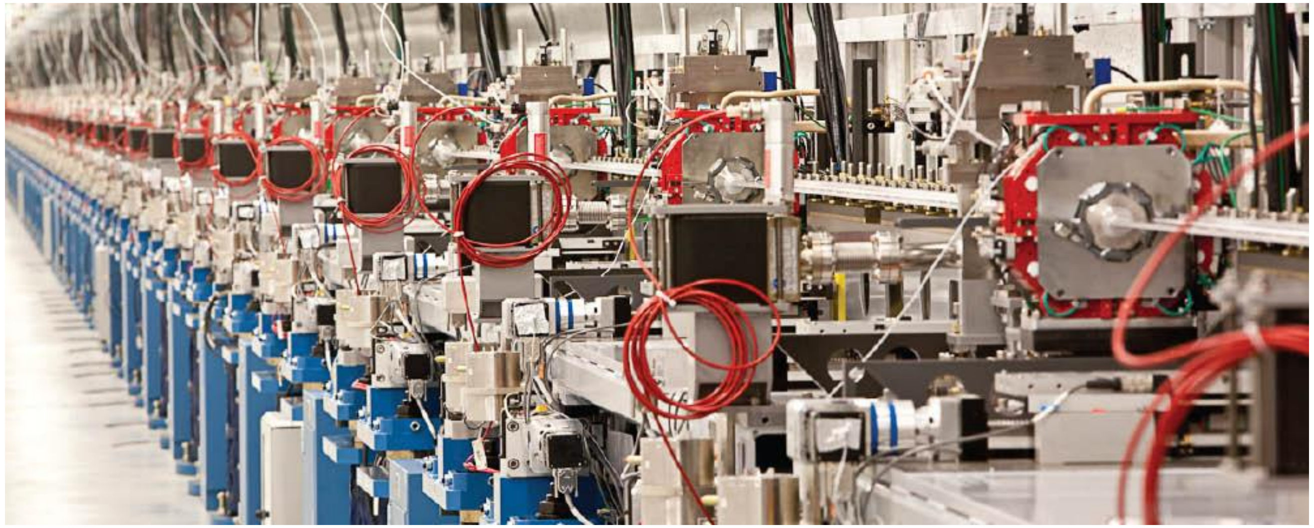
T. Tajima and J.M. Dawson PRL (1979) **LWFA** P. Chen, J.M. Dawson et.al. PRL (1983) **PWFA**

Plasma Cells

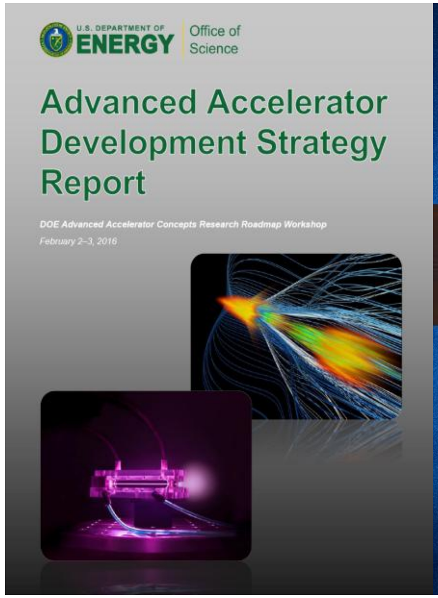


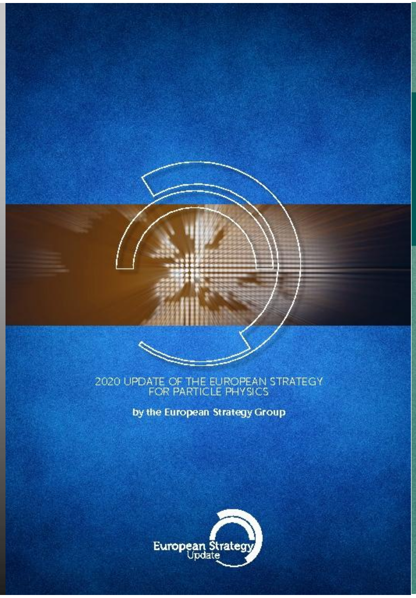


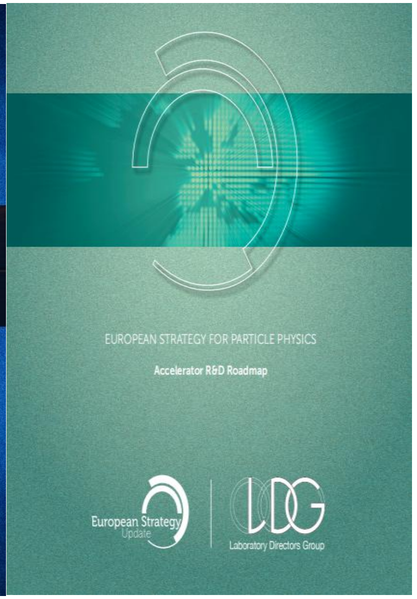
Linac @LCLS

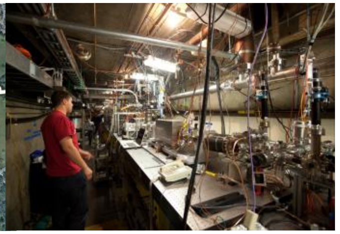


Strategy for Plasma Accelerator Development





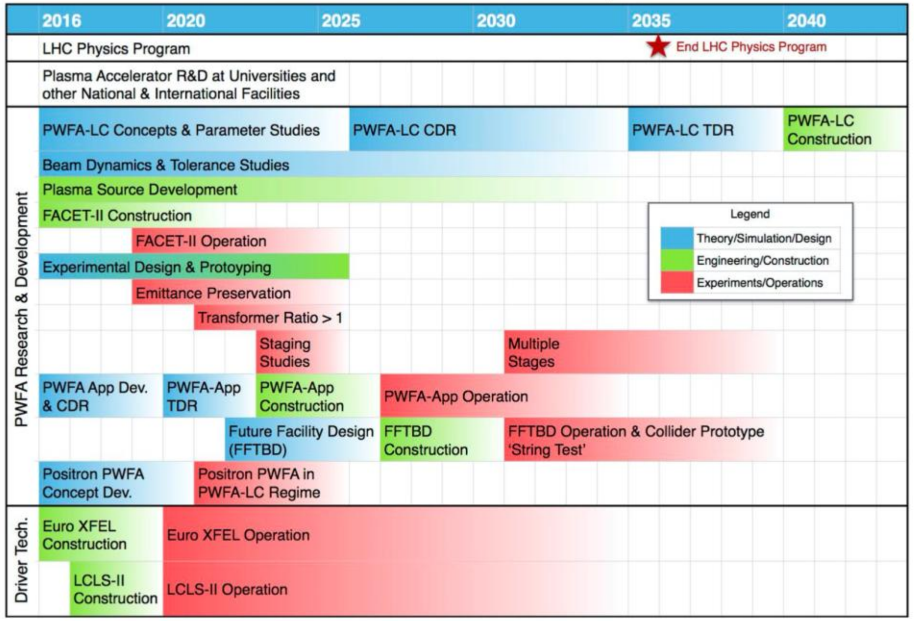




High-priority future initiatives

B. Innovative accelerator technology underpins the physics reach of high-energy and high-intensity colliders. It is also a powerful driver for many accelerator-based fields of science and industry. The technologies under consideration include high-field magnets, high-temperature superconductors, plasma wakefield acceleration and other high-gradient accelerating structures, bright muon beams, energy recovery linacs. ***The European particle physics community must intensify accelerator R&D and sustain it with adequate resources. A roadmap should prioritise the technology, taking into account synergies with international partners and other communities such as photon and neutron sources, fusion energy and industry. Deliverables for this decade should be defined in a timely fashion and coordinated among CERN and national laboratories and institutes.***

Beam Driven Plasma Accelerator Roadmap for HEP

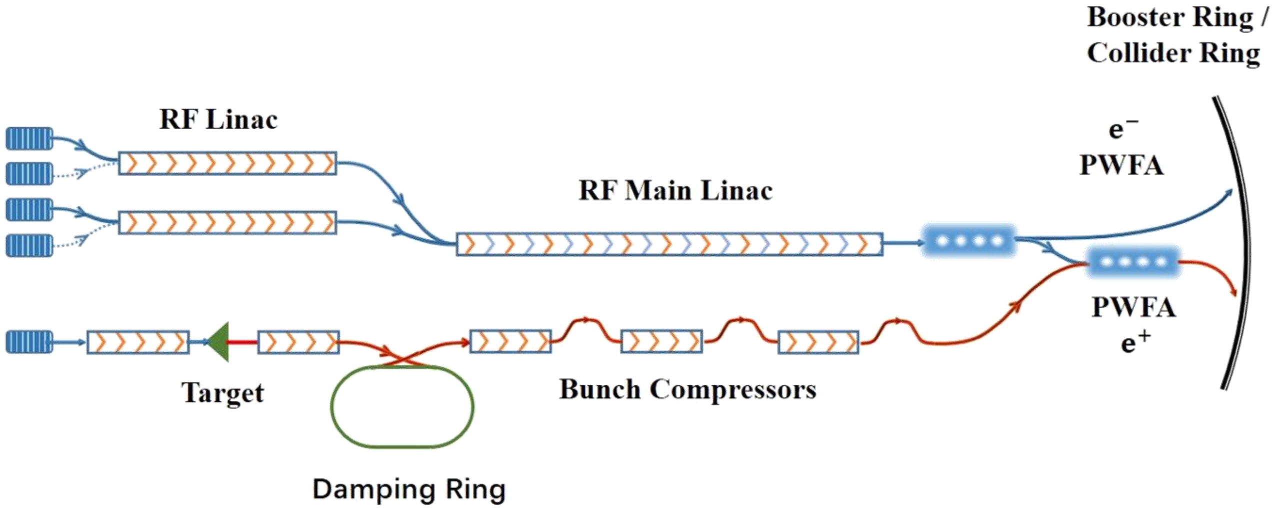


Plasma Accelerator for Higgs Factory

CEPC

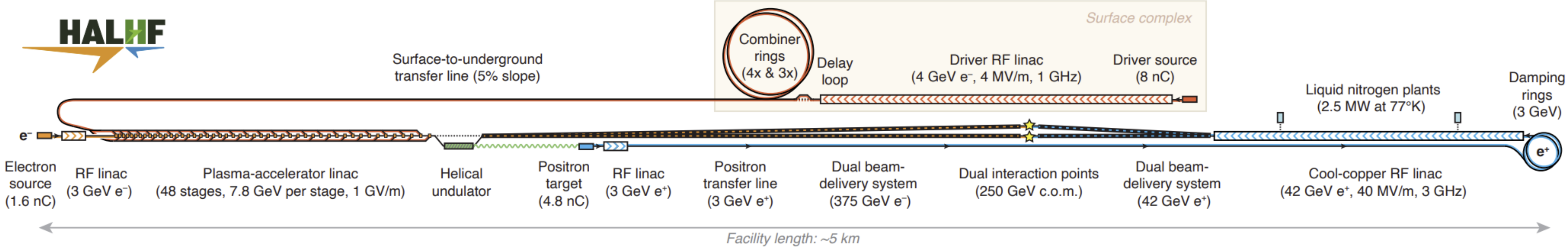
Plasma Injector

CEPC, CDR (2018)
CEPC, TDR (2023)



Goal:

120-180GeV e-/e+



Multi-TeV Electron-Positron Colliders

Advanced accelerator concepts are necessary for colliders with multi-TeV center-of-mass energies.

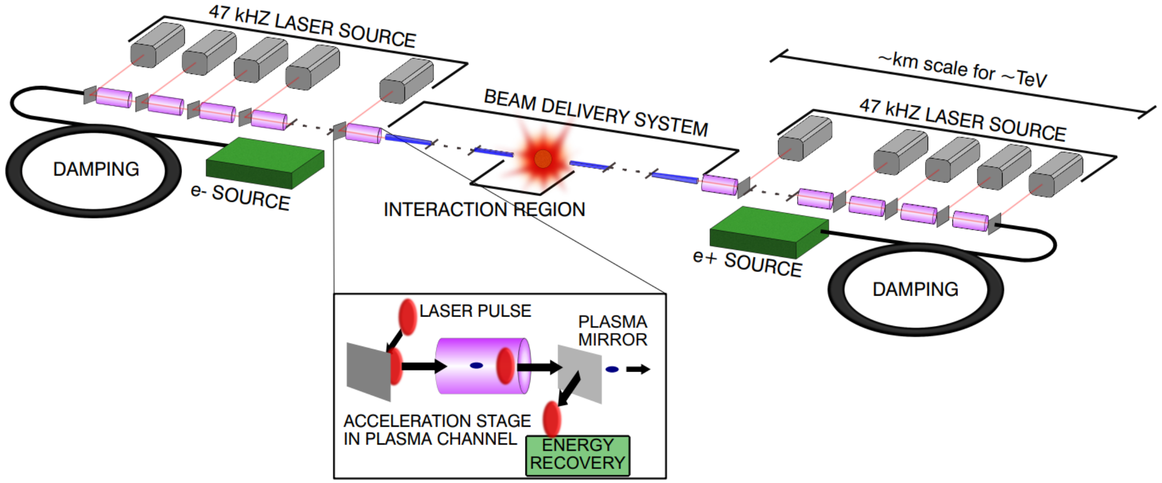
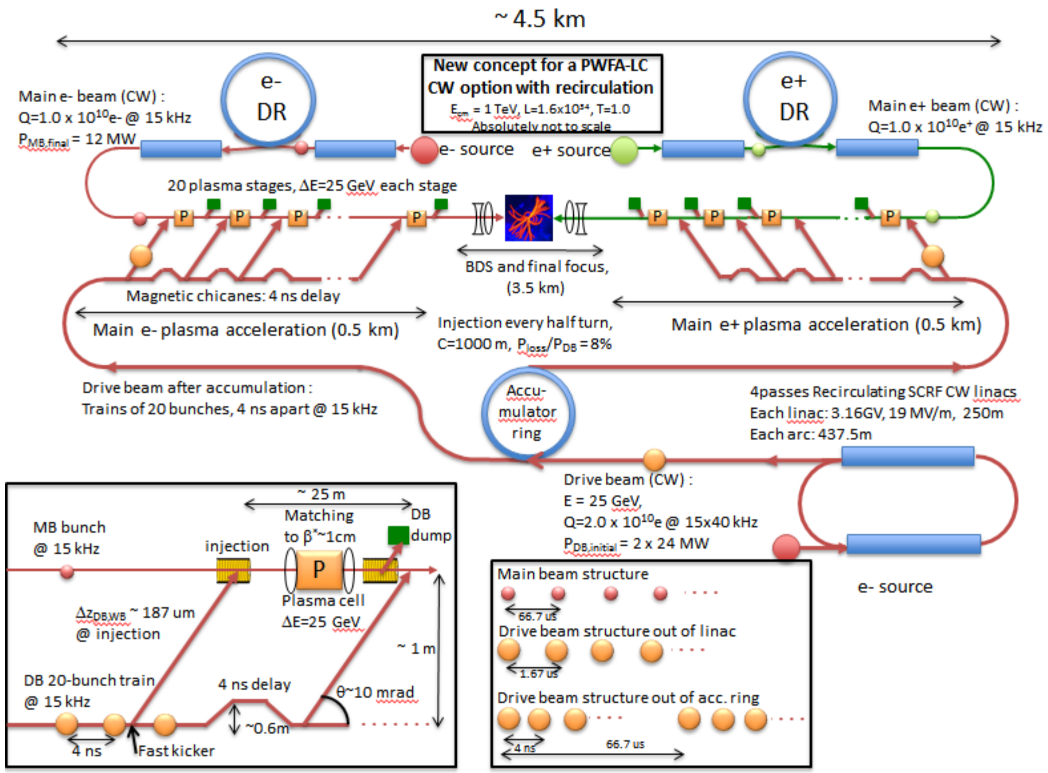


Figure 1. Schematic of an LPA-based linear collider.

Laser Wakefield Collider / 15 TeV / 6.6 km*

C.B. Schroeder *et al.*, **JINST** 18 T06001 (2023)

*for the linac, not including the BDS



Plasma Wakefield Collider / 1 TeV / 4.5 km

E. Adli *et al.*, **Snowmass** (2013)

PATH(Plasma Accelerator towards TeV Horizon)
A roadmap with 4 phases

Phase I: 2024-2028

- **PWFA/LWFA platforms based on BEPCII and SXFEL**
- tabletop LPA applications

Phase II: 2029-2033

- A full energy plasma injector for BEPCII
- PWFA/LWFA driven FELs for applications

Phase III: 2034-2038

- A full energy plasma injector for CEPC or FCC-ee

Phase IV: 2039-…

- 1-10TeV Linear collider technology becoming mature……

*Proposed by Prof. Wei Lu**
**weilu@ihep.ac.cn*

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- **Physics Goal at IHEP Plasma Test Facility**
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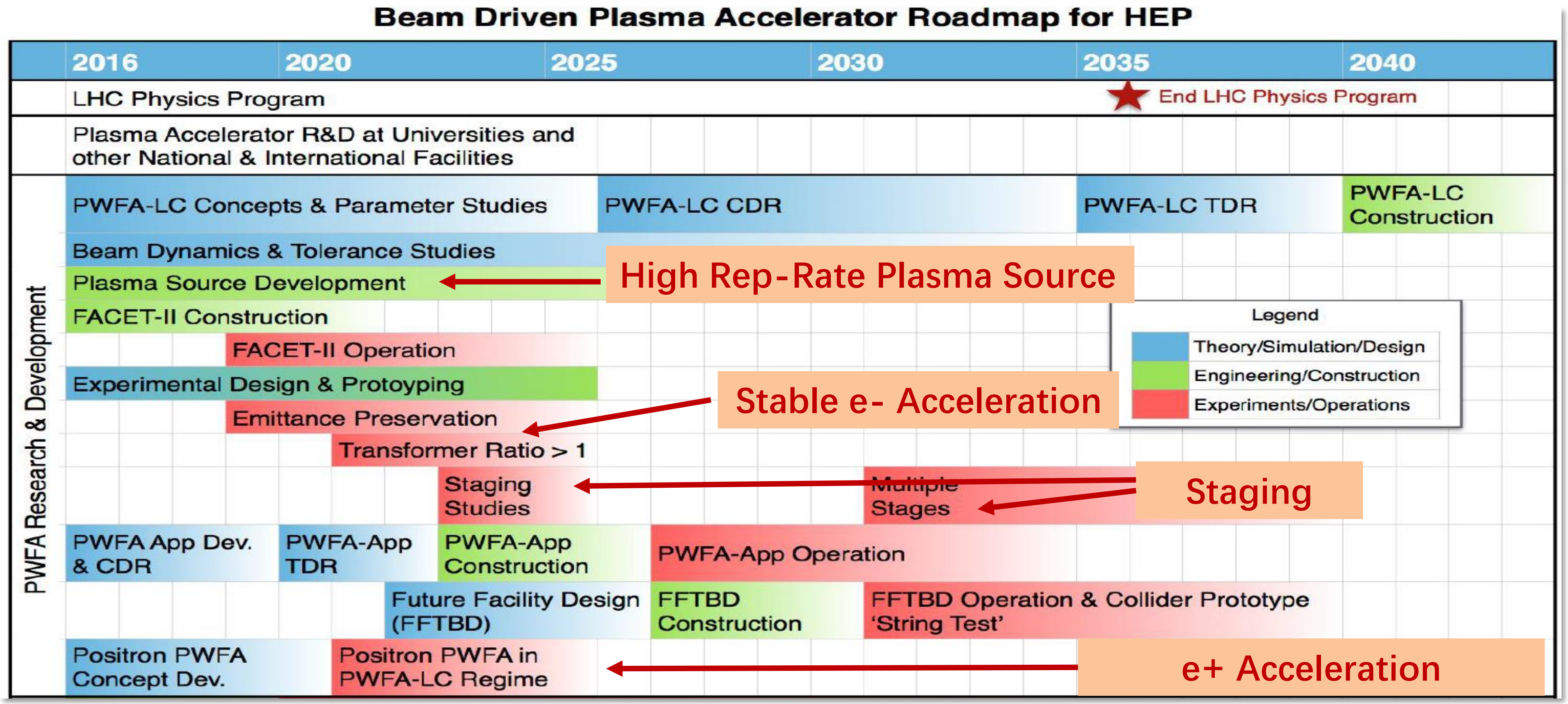
IHEP-THU-BNU··· Collaborated team

Key challenges for plasma accelerators



DOE Workshop Report (2016)

Main physics goals at IHEP test facility

A World-Leading Platform of Plasma Based Acceleration

- **High-Quality Stable Electron Acceleration**
- **Electron/Laser-Driven Positron Acceleration**
- **Staged Plasma Wakefield Acceleration**
- **High Rep-Rate Plasma Source**

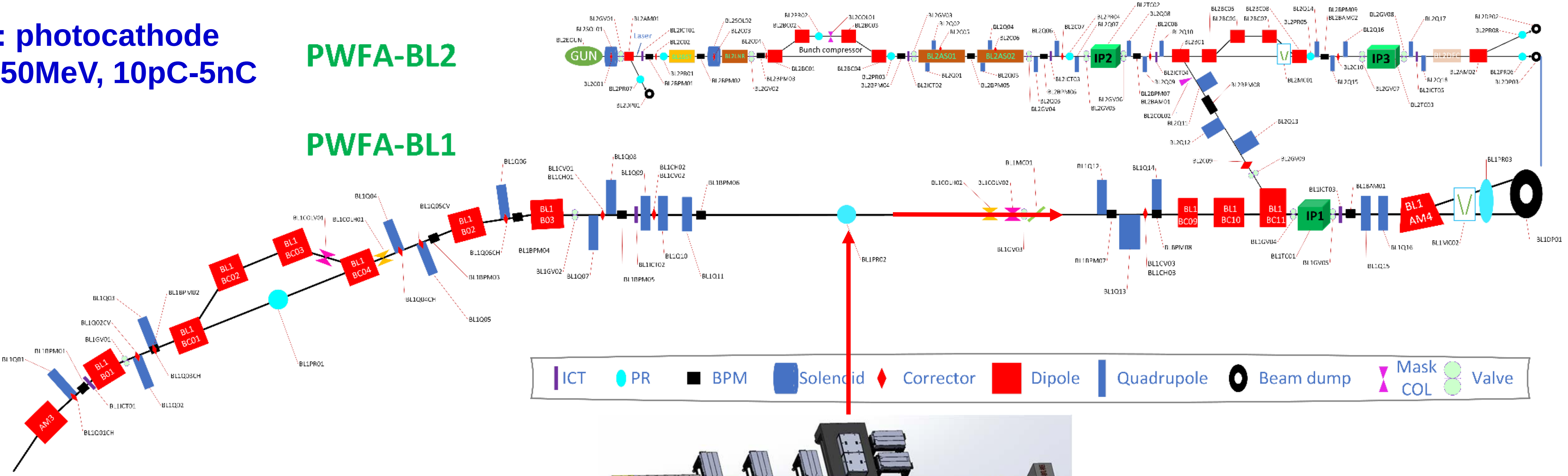
Overview of the platform

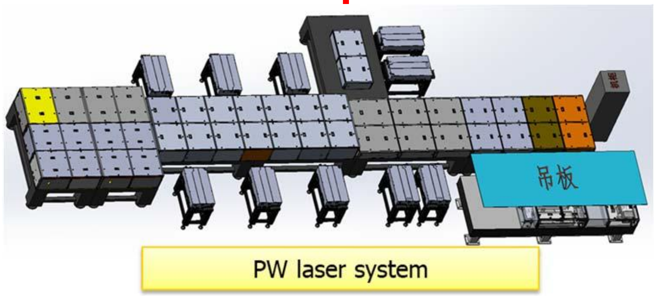
PWFA-Beam Line

BL2: photocathode
e-, 150MeV, 10pC-5nC

PWFA-BL2

PWFA-BL1



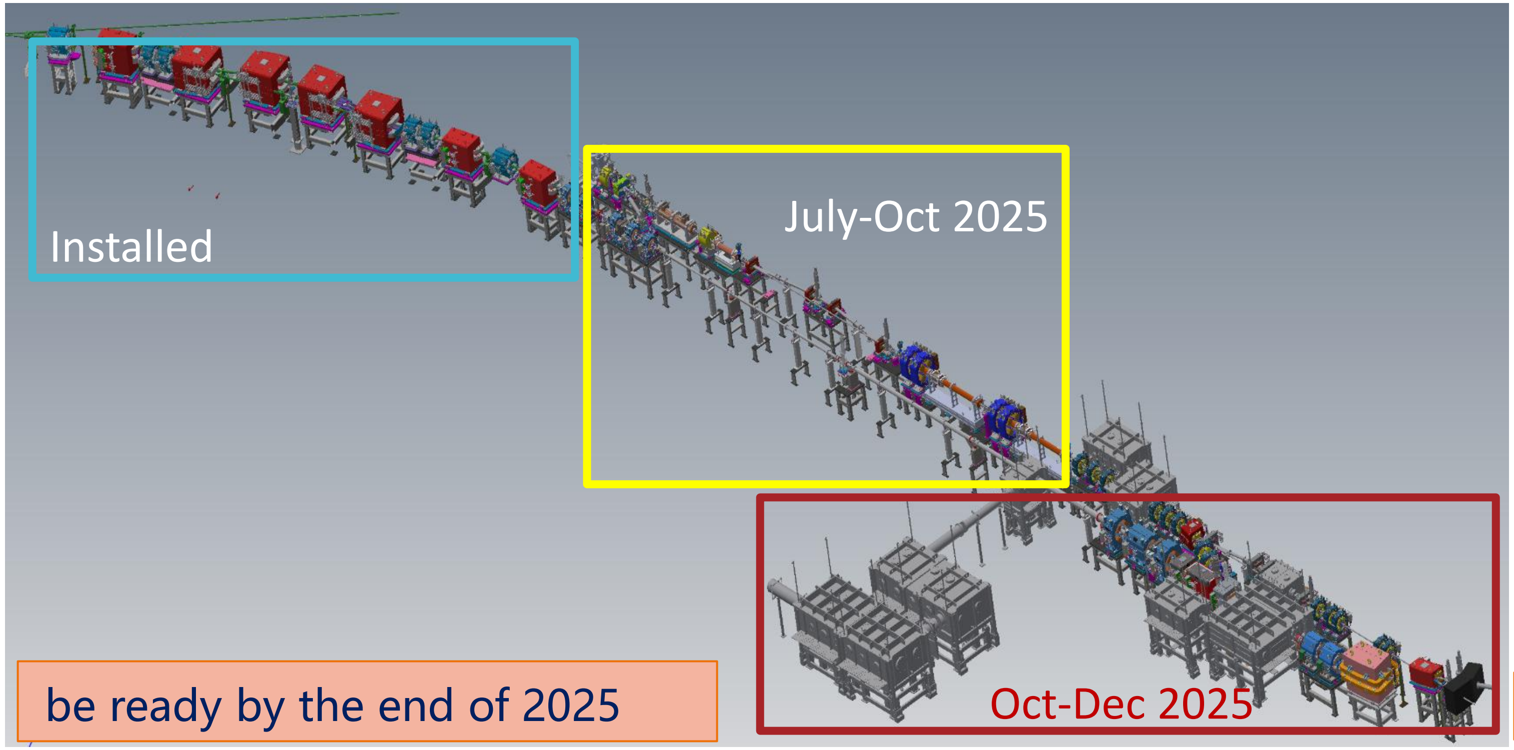


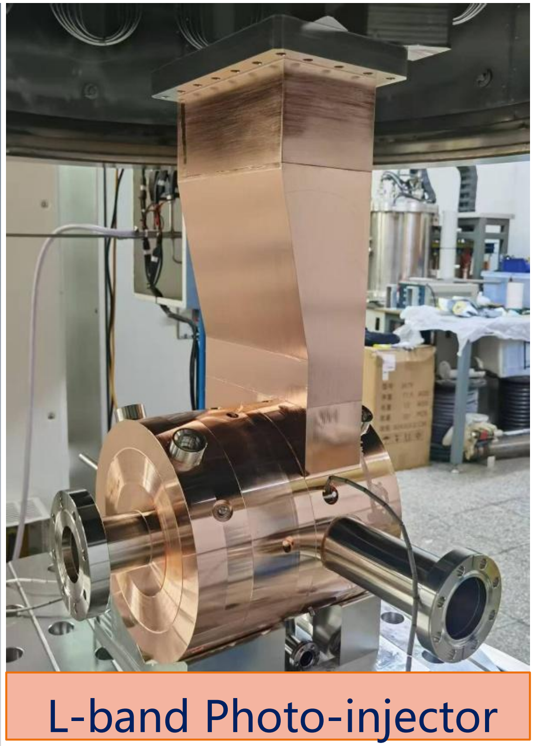
PW
Laser System

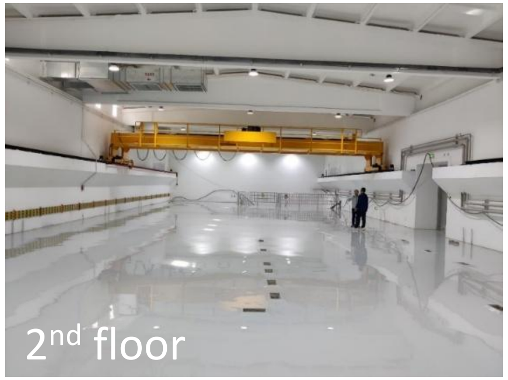
2GeV e-/e+

BL1: Thermal Cathode
e-, 2GeV, 2nC, 400mm·mrad
e+,2GeV, 50pC, 2500mm·mrad

Overview of the platform







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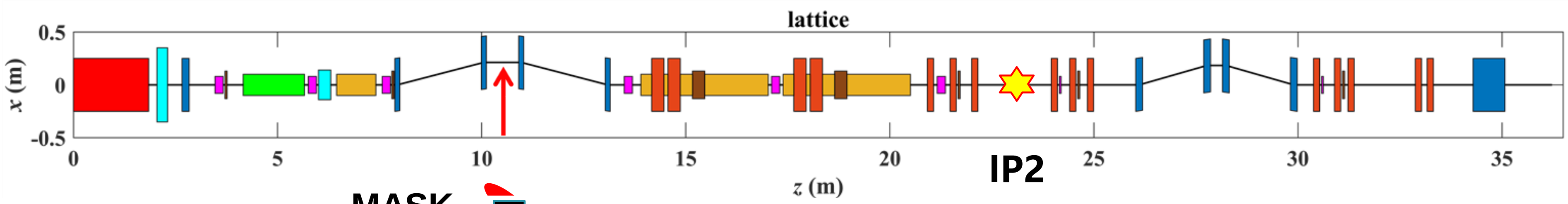
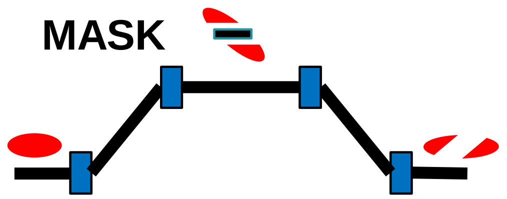
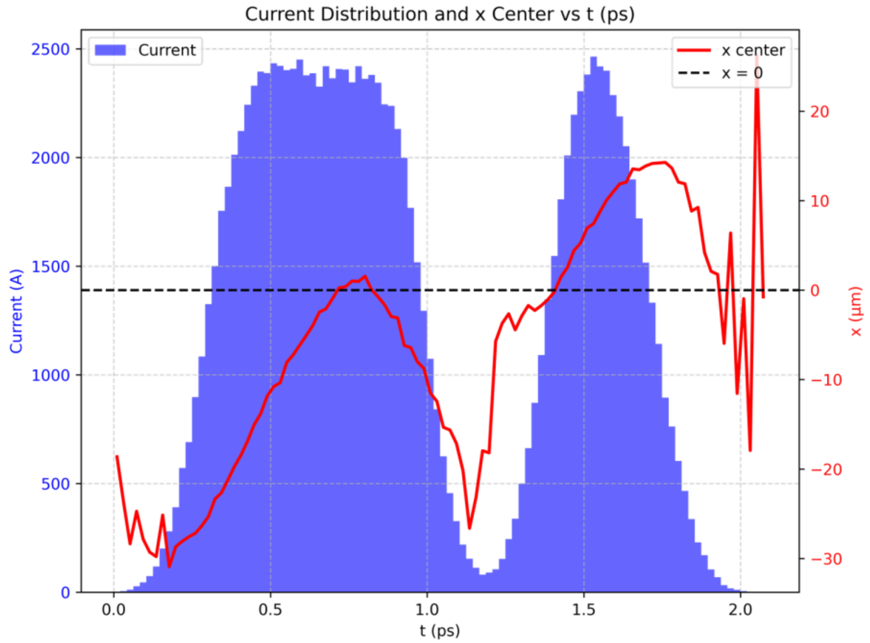
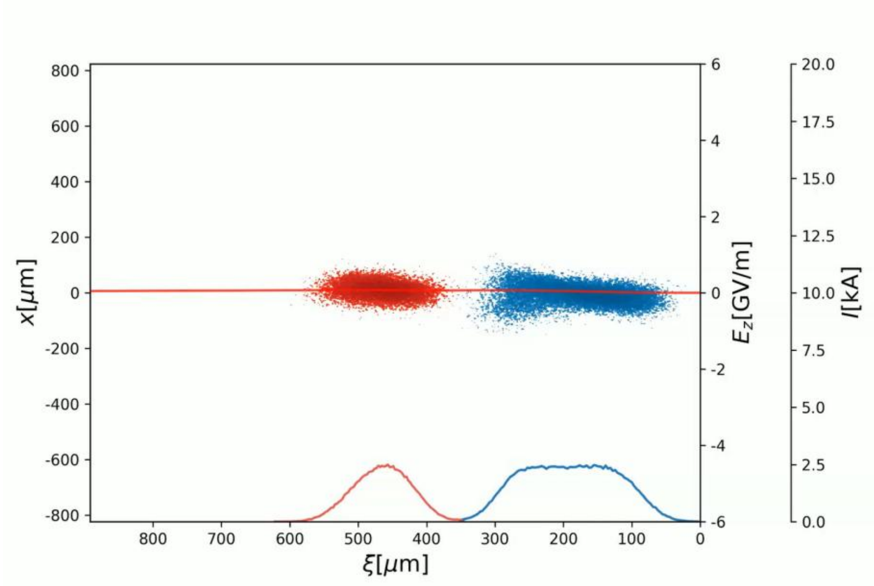
Stable Electron Acceleration





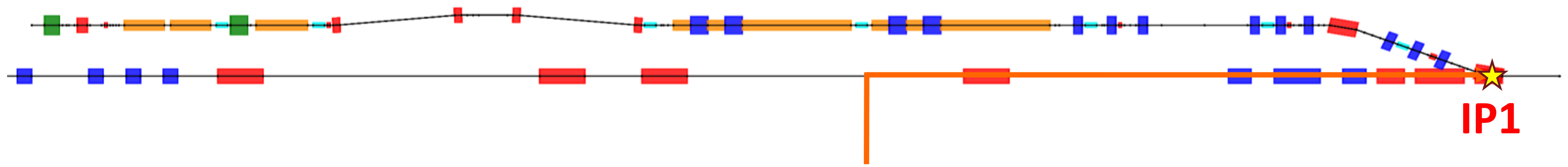
- Lattice design for smaller intra-beam misalignment
- Mitigation of the hosing instability





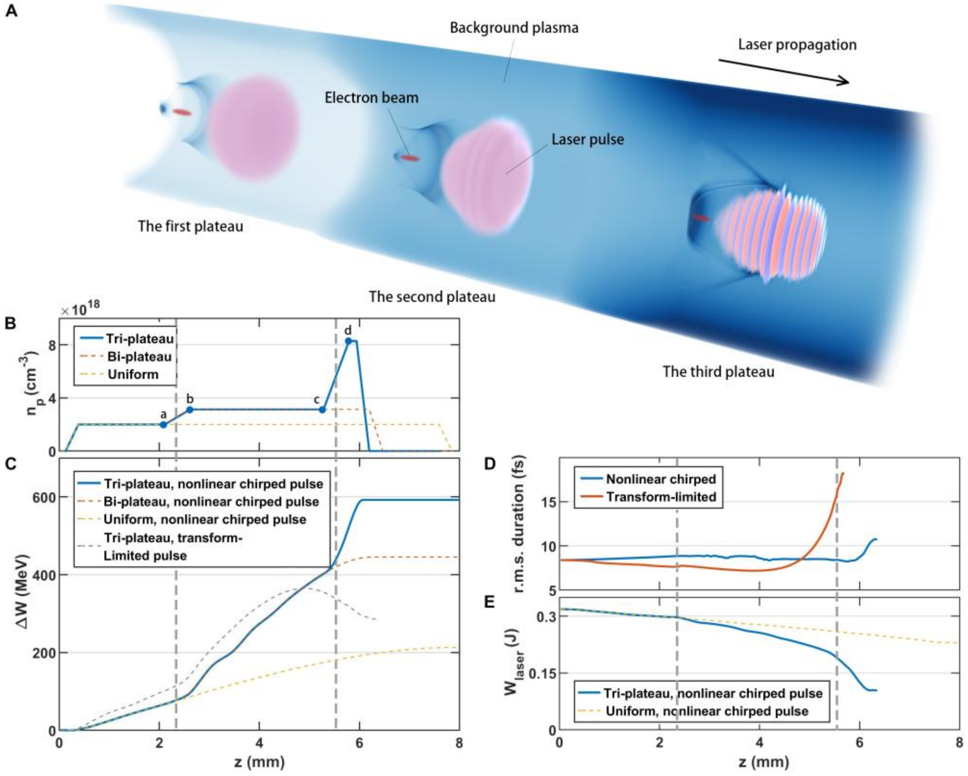
High energy LWFA external e- acceleration

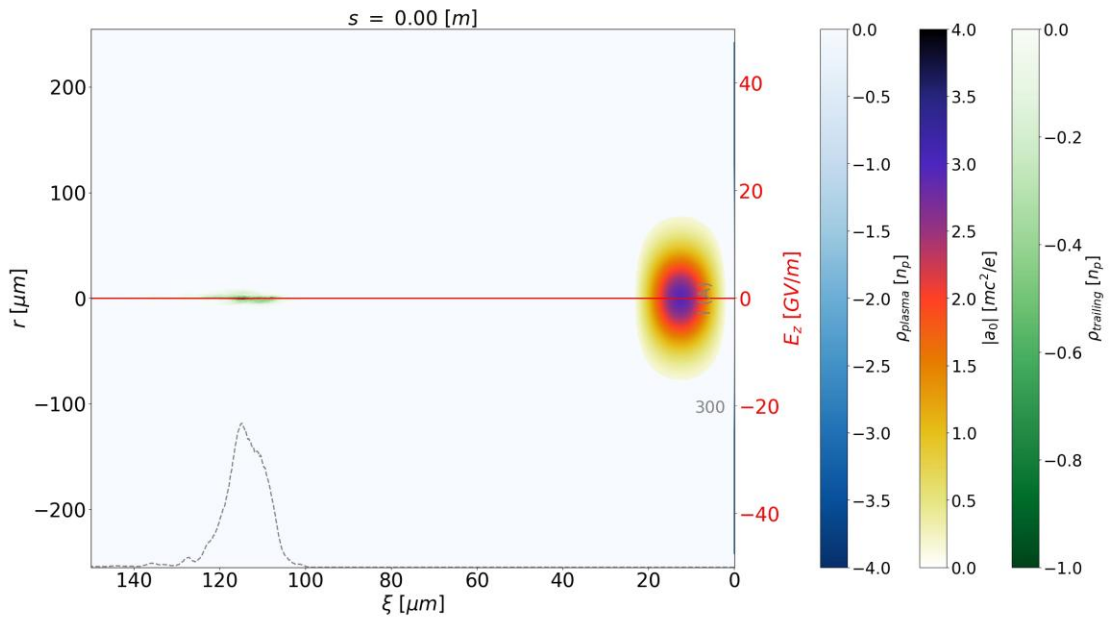
BL2 e-
BL1 e-



IP1

PW laser a_0=2.9， w_0=45μm， E=18J， FWHM=30fs





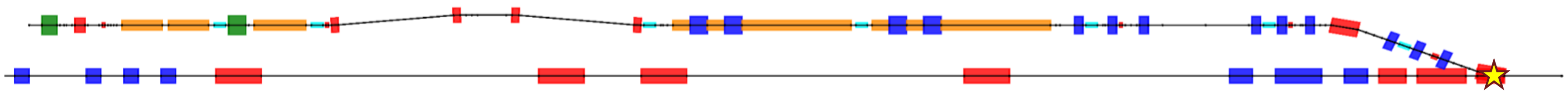
Liu S, et al. *Research* 2024;7:Article 0396.

- **Charge:** ~10 pC
- **Mean Energy:** 16.6 GeV (rms 7.7%)
- **Energy Spectrum Range:** 9.9 - 23.3 GeV (>20 GeV 0.13 pC)

Electron-driven positron acceleration

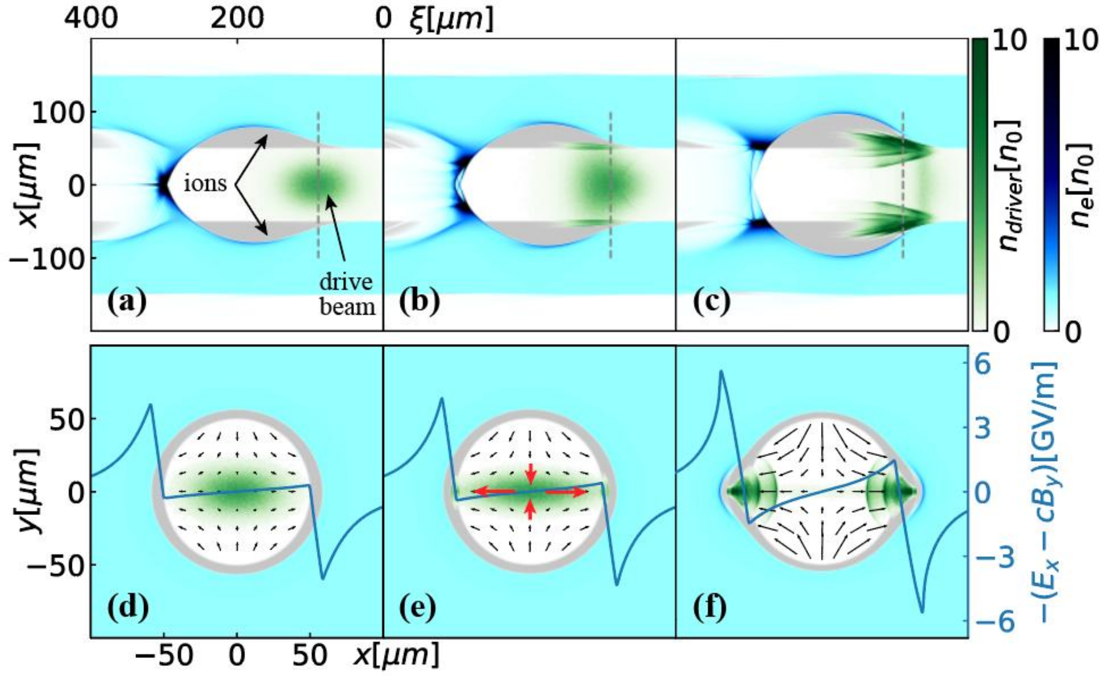
BL2 e-

BL1 e+

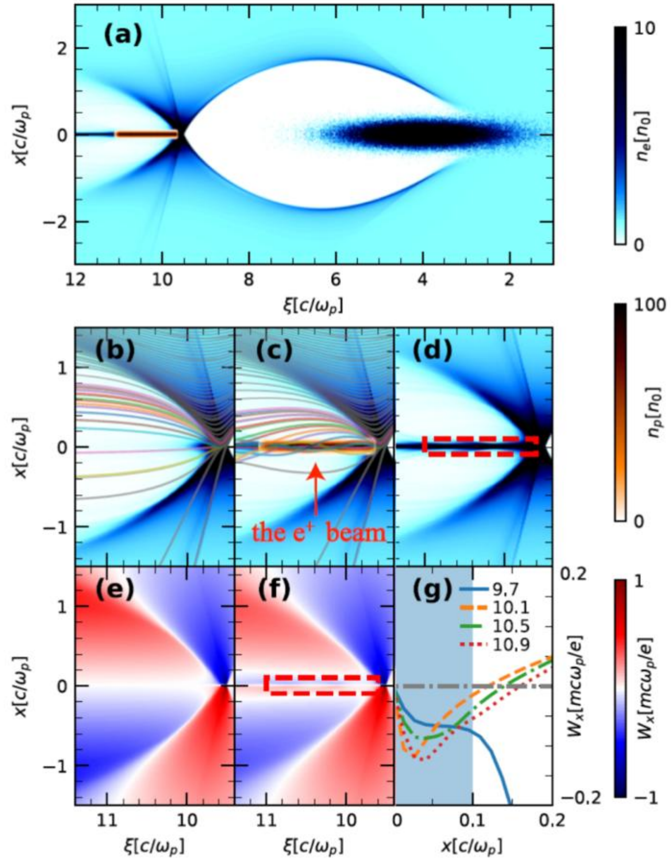


IP1

Hollow plasma channel



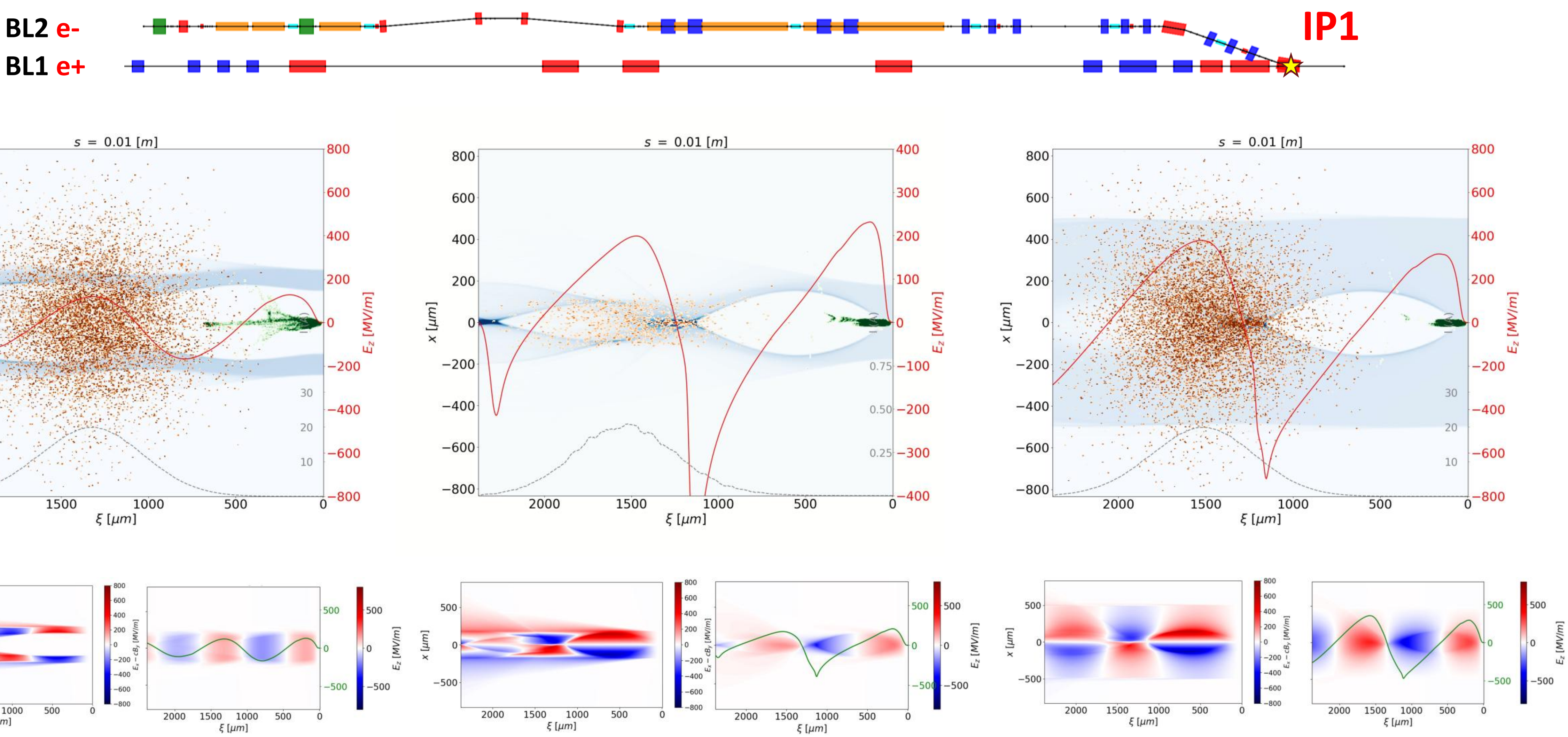
Uniform plasma



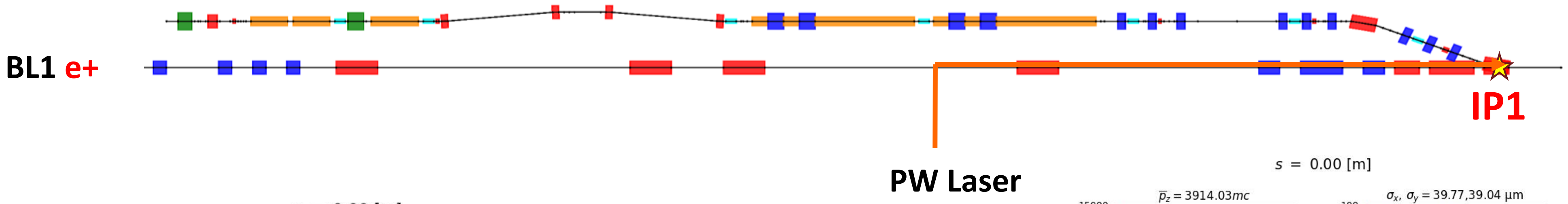
Shiyu Zhou, *et al.*, PRL 127, 174801 (2021)

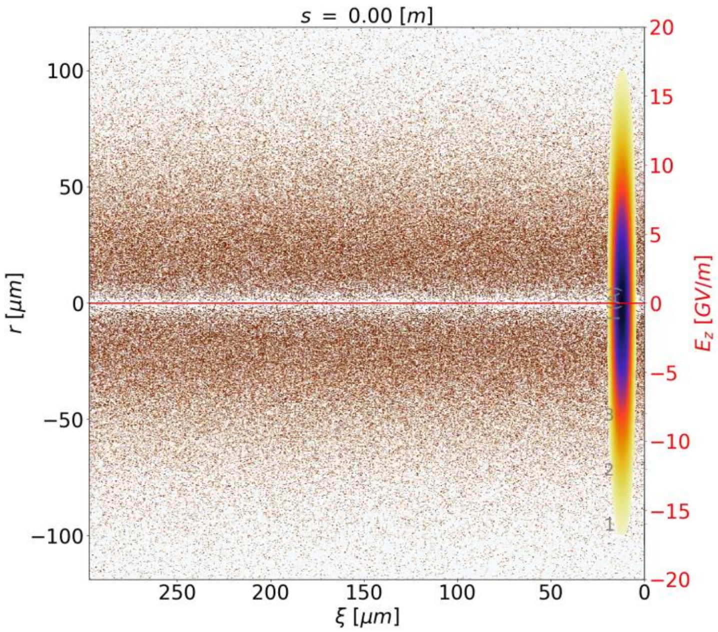
Shiyu Zhou, *et al.*, *Research* 2025;8:Article 0878.

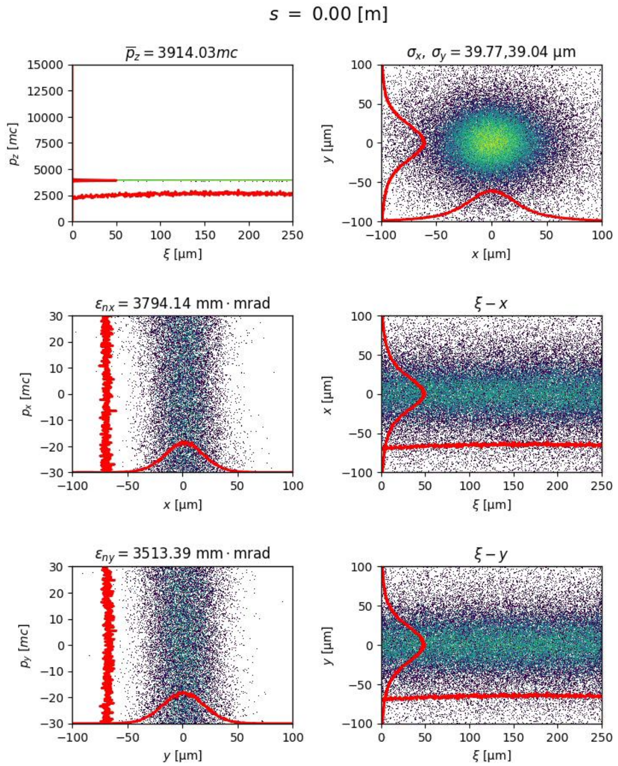
Electron-driven positron acceleration



Laser-driven positron acceleration



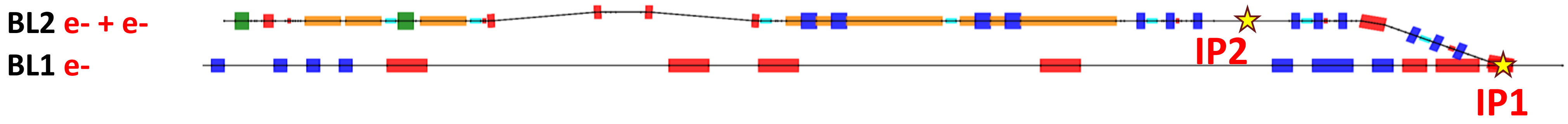


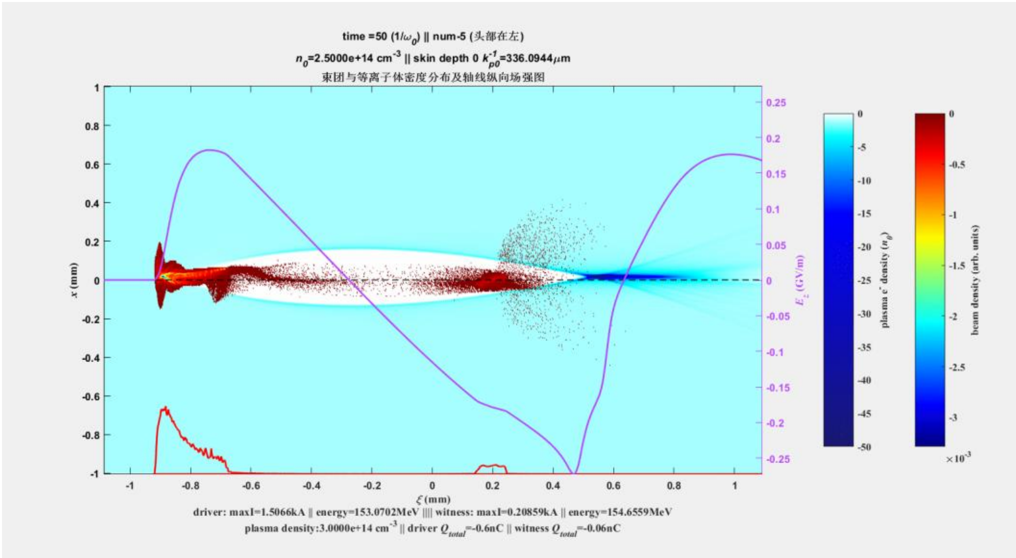


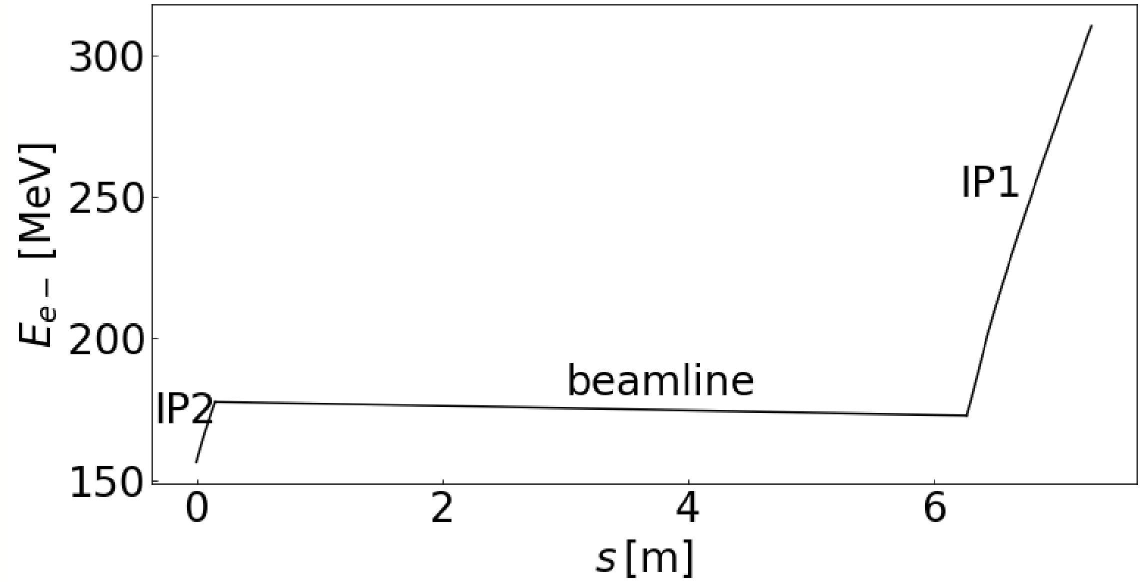
Laser：18J，a0=2.4，w0=60um，τ=25fs
e+：50pC，2GeV，$\sigma_r = 40um$，1ps
Plasma: ~1e17cm-3

Energy Gain > 1GeV

Staged Plasma Wakefield Acceleration







Stage 1: PWFA @ IP2

L-band e- gun generate 2 bunches

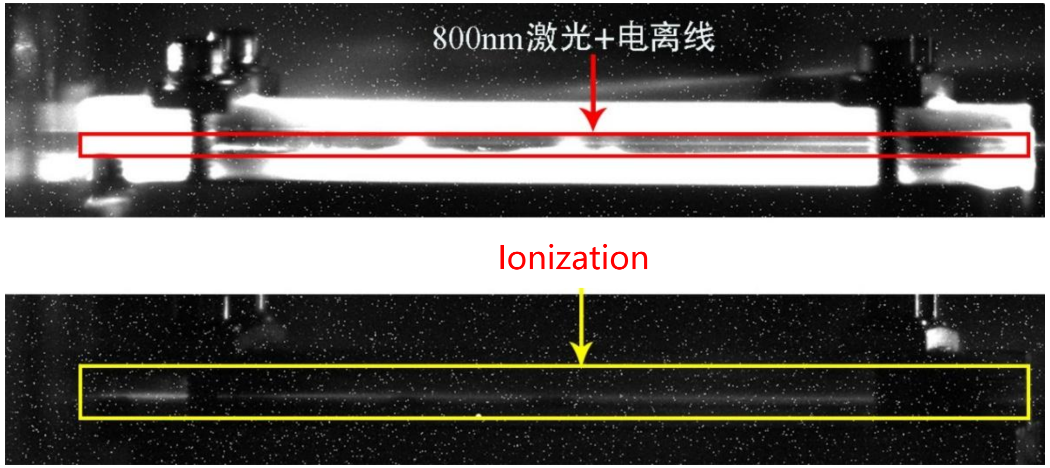
Trailer is accelerated from 150 MeV to 170MeV

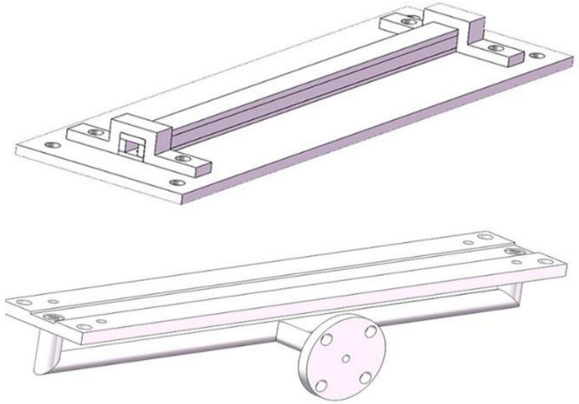
Stage 2: PWFA @ IP1

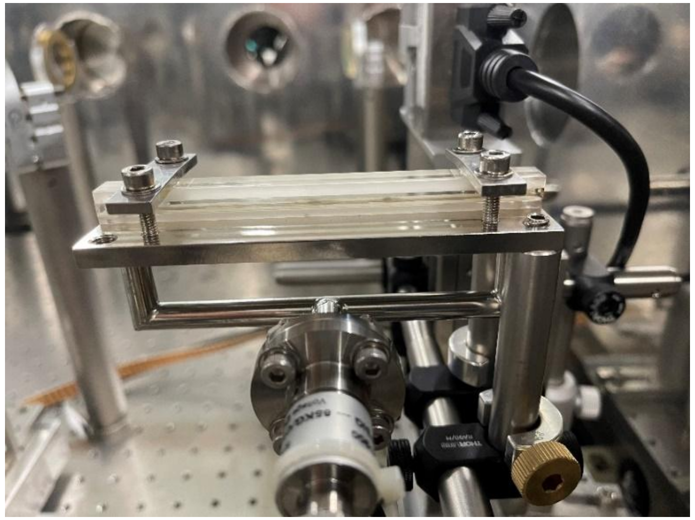
Use 2 GeV e- bunch from BEPCII linac as driver

Trailer is accelerated from 170 MeV to 310 MeV

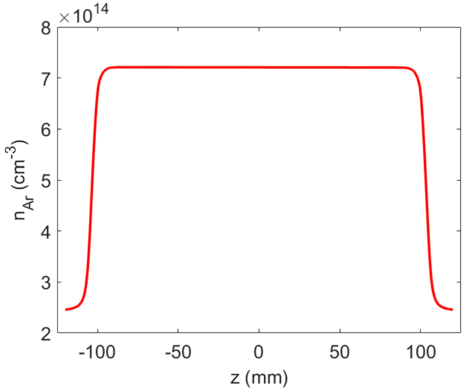
Plasma Source Development

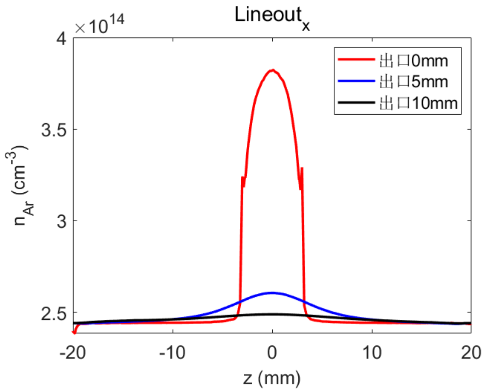


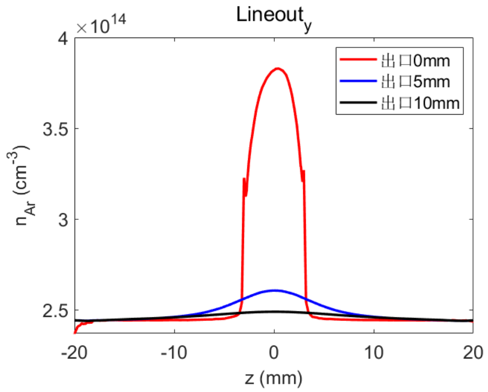




- 10~20cm length
- reliable and uniform plasma density profile
- operated at 2Hz@0.1MPa
- backing pressure 0~5MPa

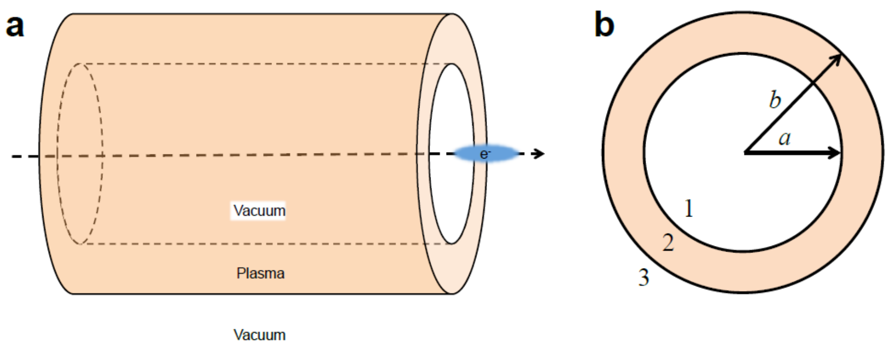


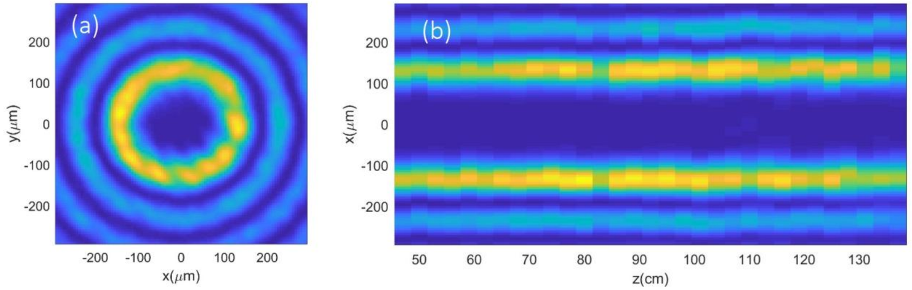




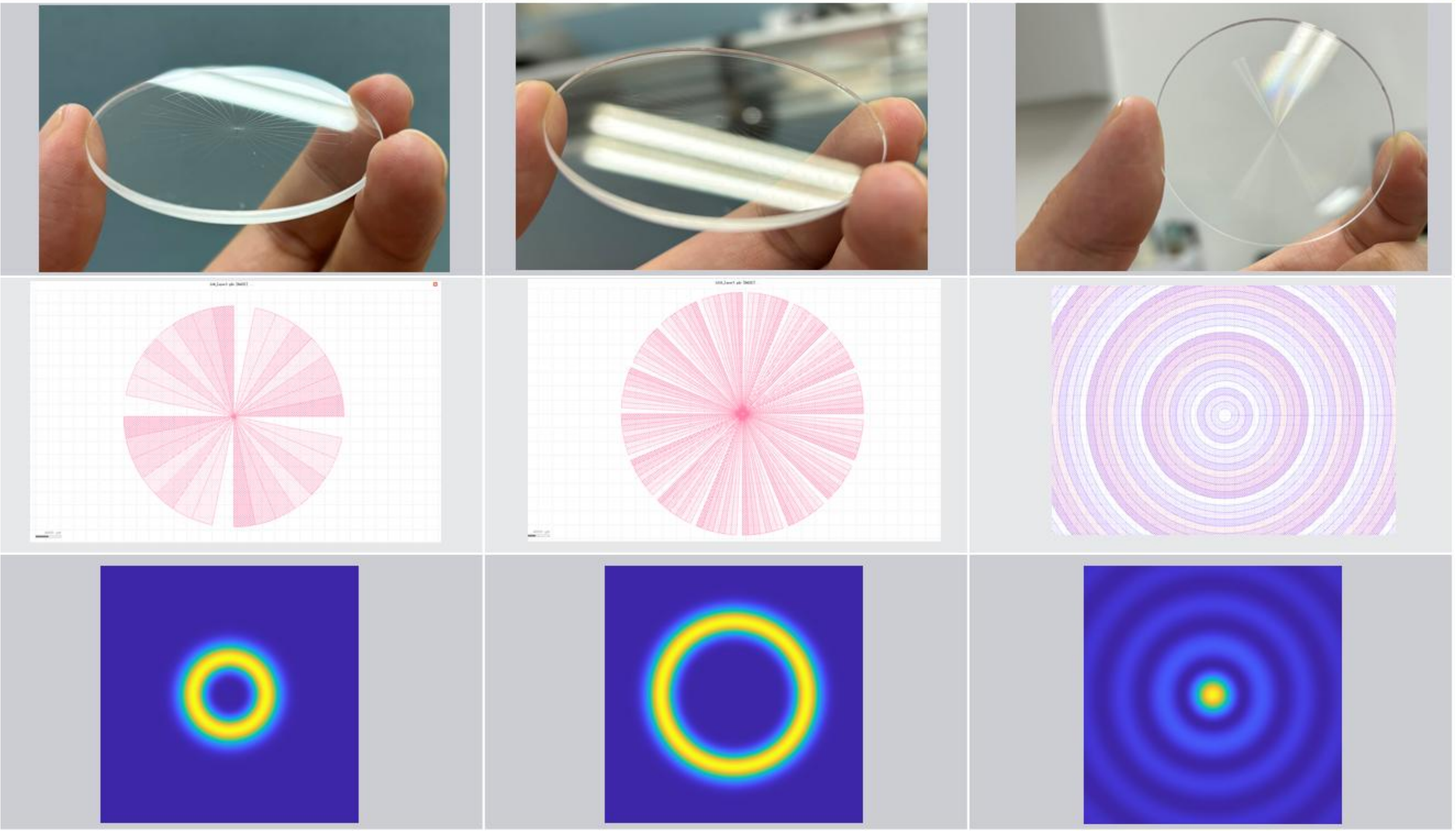
Plasma Source Development

Generate hollow plasma channel





4th order LG laser	16th order LG laser	0th order Bessel laser



Y. P. Wu et al, PR APPLIED 12, 064011 (2019)
Spencer J. Gessner, PHD thesis, Standford University (2016)
S. Liu et al, Phys. Rev. Lett. 133, 175001 (2024)

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Summary

We are building a unique plasma test platform at BEPCII that pioneers multiple firsts:

- A **comprehensive** facility for studying high-quality electron acceleration
- **The first** dedicated platform for electron and laser driven **positron acceleration**
- **The first** to demonstrate **staging** in beam-driven wakefield acceleration
- **The first** dedicated platform for controlled **external injection**
- Development of a **high-repetition-rate, highly controllable plasma source**

Outlook

PATH(Plasma Accelerator towards TeV Horizon)

Phase I: 2024-2028

- PWFA/LWFA platforms based on BEPCII and SXFEL
- tabletop LPA applications

Phase II: 2029-2033

- **A full energy plasma injector for BEPCII**
- **PWFA/LWFA driven FELs for applications**

Phase III: 2034-2038

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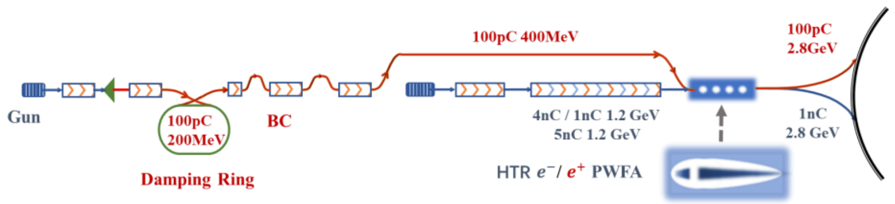
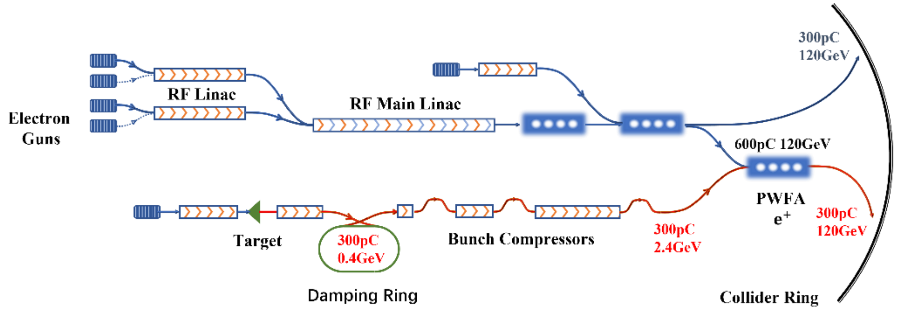
Phase IV: 2039-...

- **1-10TeV Linear collider technology becoming mature……**

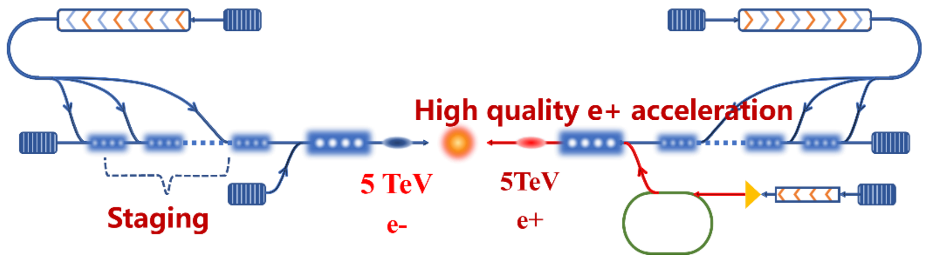
BEPCII injector



CEPC injector



10TeV Collider



Thanks for your attention!

Collaboration is welcome!