CEPC high energy plasma injector and PWFA driven coherent light source based on SXFEL facility

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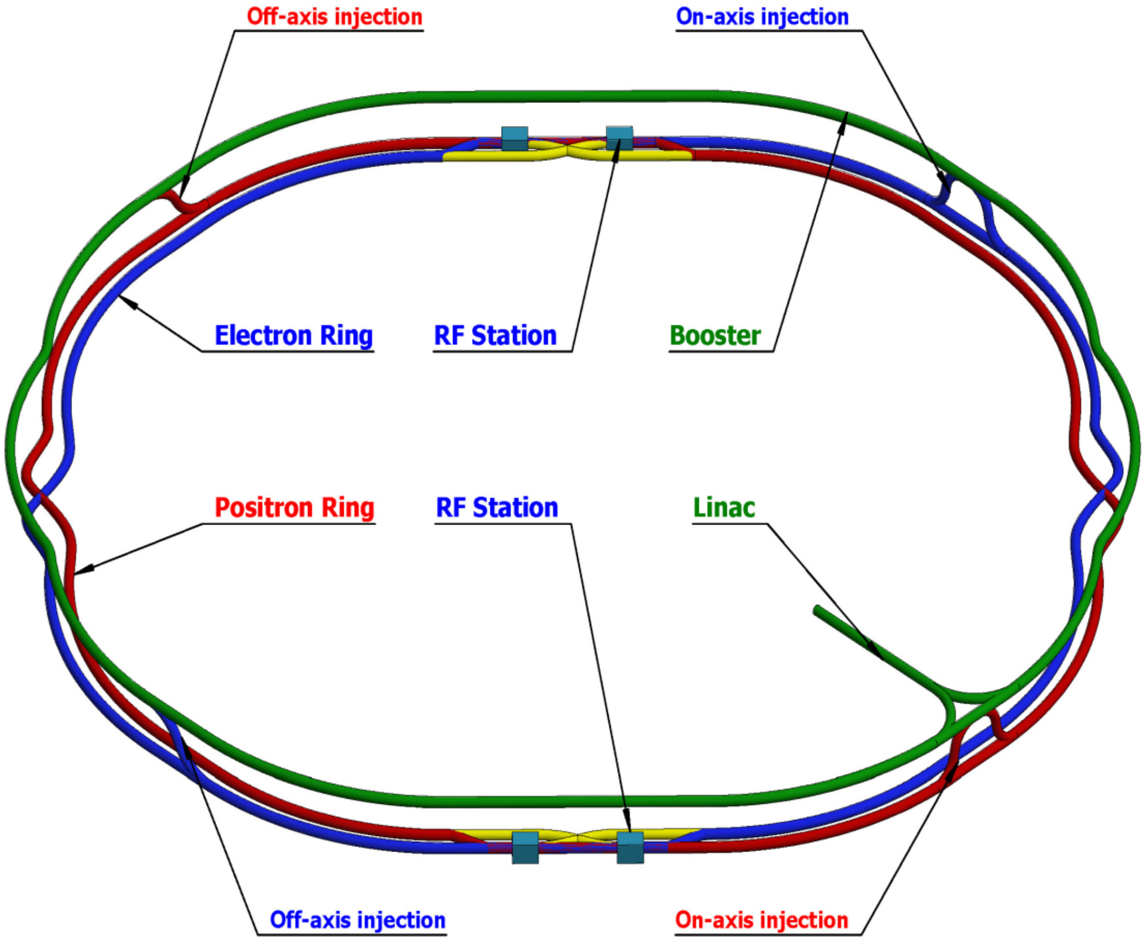
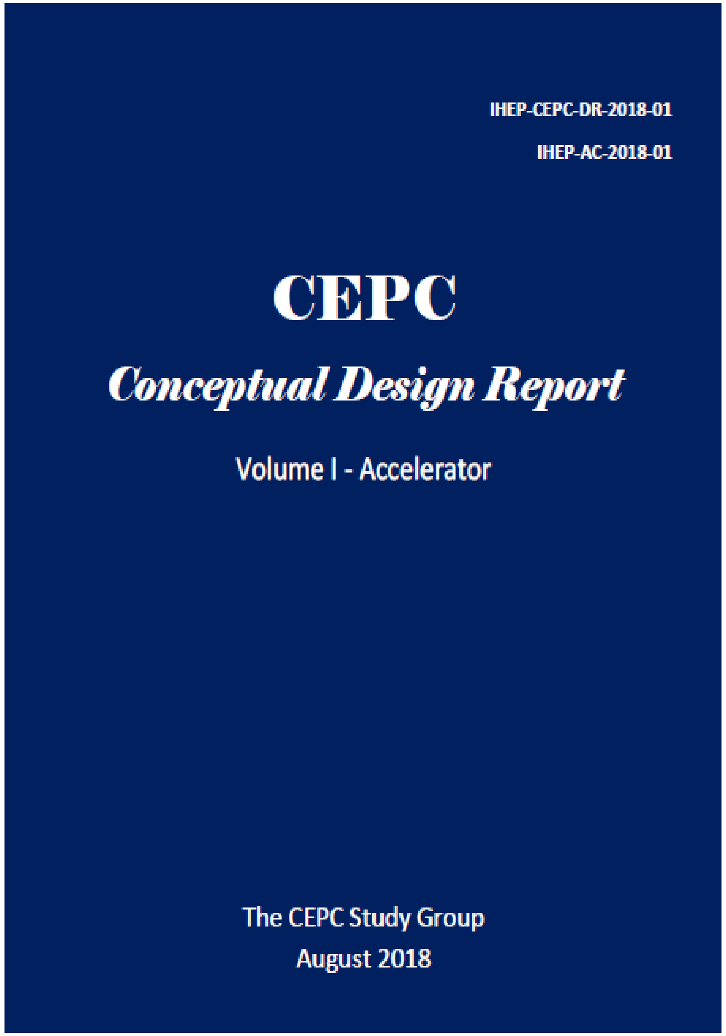
Outline

- High energy plasma injector for CEPC (circular electron positron collider)
- PWFA driven FEL test facility based on SXFEL in Shanghai

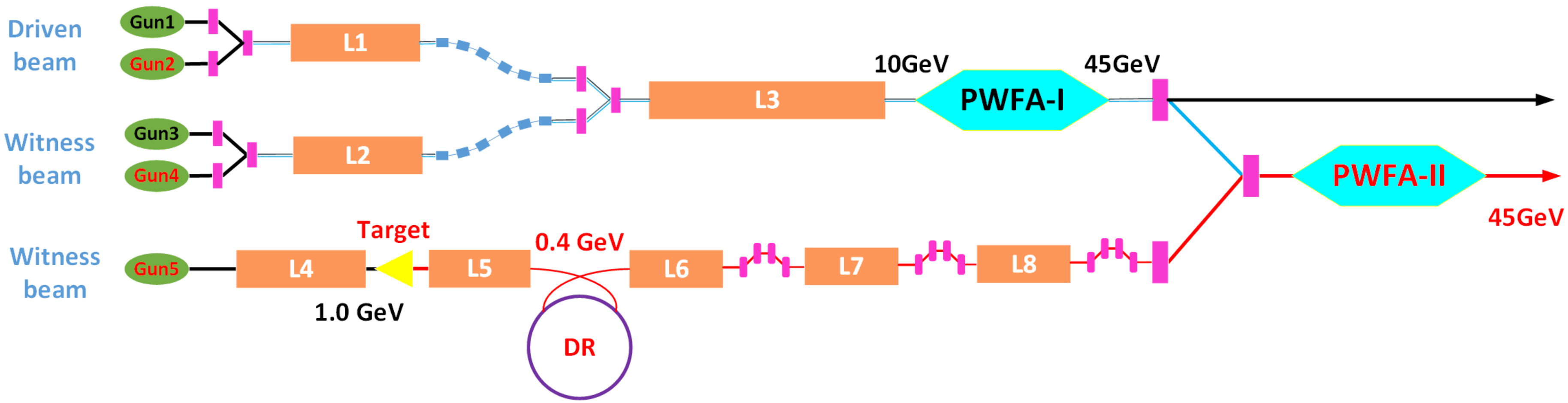
Background: CEPC





CDR (Acc.) International Review @ 2018.6.28-6.30 & Final Released @ 2018.9.2

CEPC plasma injector concept design（V2.0）



Parameter	Symbol	Unit	Requirement	Achieved(in sim.)
Energy	E_e	GeV	45.5	45.3(e-) / 45.2(+)
Energy Spread	σ_e		< 0.2%	0.2%(e-) / 0.14%(e+)
Frequency	f_{rep}	Hz	100	100
Bunch Charge	N_e	nC	> 1.0	1
Emittance	ε_r	nm·rad	< 30	1.89(e-) / 1.0(e+)
Bunch Length	σ_l	mm	< 3	0.3(e-) / 0.3(e+)
Energy Stability			< 0.2%	
Longitudinal Stability		mm	< 2	
Orbit Stability		mm	< 5(H) / 3(V)	

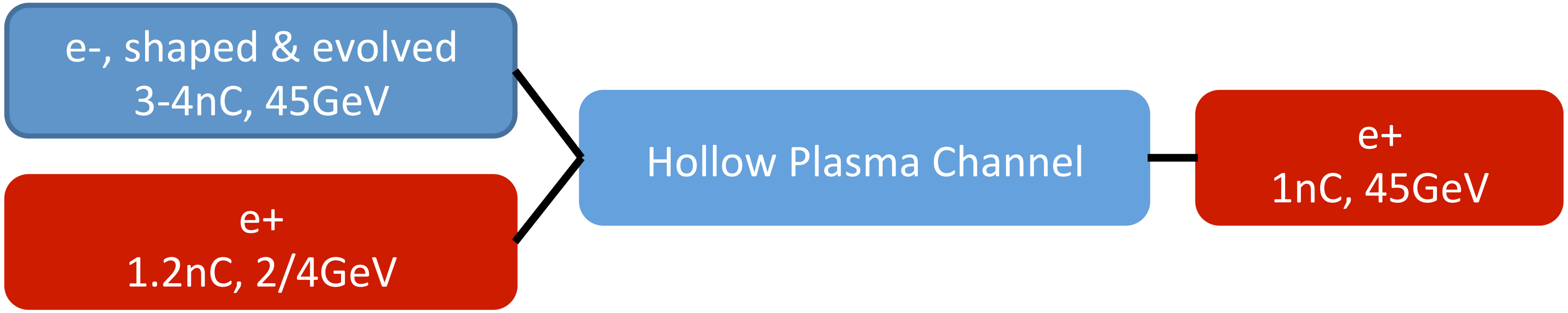
CEPC Plasma Injector/Overall Goal

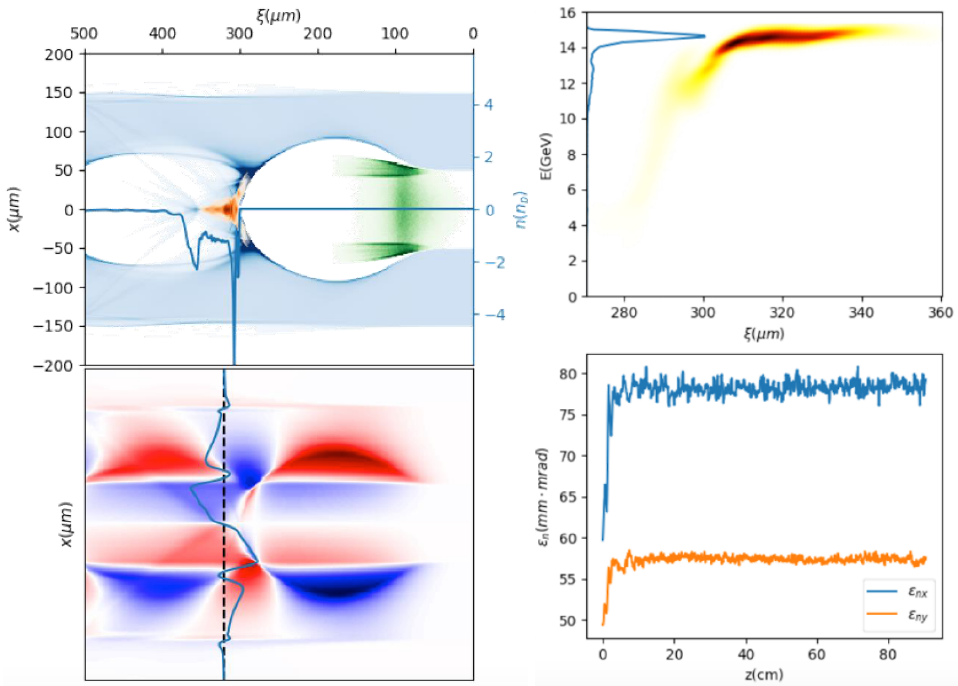
- Working out a conclusion on the feasibility of plasma injector for 45GeV energy.
- If feasible, presenting a technology design with as much as possible details.
- Meantime, also working on the feasibility study of a full energy plasma injector at 120-180GeV

Key Issue to address:

- ✓ Driver/ Trailer design：large charge（10+ nC) shaped bunch generation
- ✓ Plasma source：meter-10meter scale uniform/hollow plasma source
- ✓ High transformer ratio high efficiency electron acceleration
- ✓ Stable high efficiency positron acceleration in electron beam driven PWFA
- ✓ Staging between different accelerators

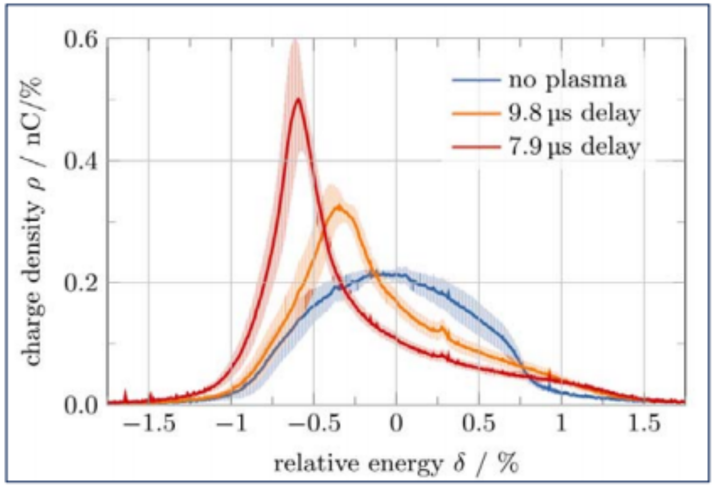
Positron Acceleration Scheme 2 (Stable mode)

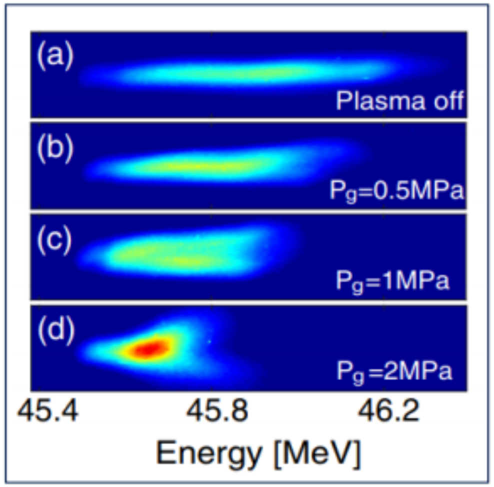


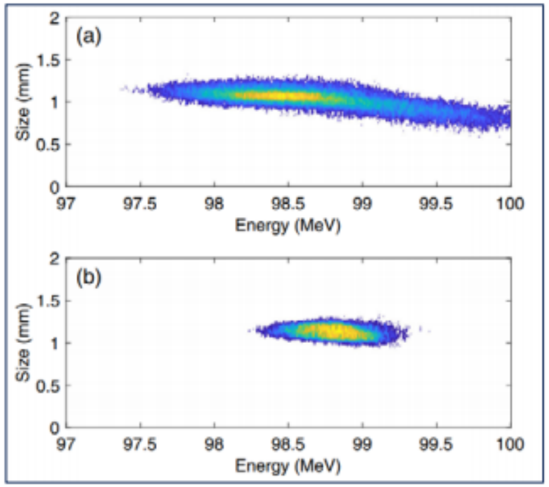


- Energy efficiency ~ 40%
- Slice energy spread ~1% (to be optimized)
- Tolerable emittance growth
- High tolerance on beam tilt and offset
- debuncher + dechirper to reduce energy spread down to 0.2%

Plasma dechirper for reducing energy spread down to ~0.1%







PHYSICAL REVIEW LETTERS **122,** 204804 (2019)

Phase Space Dynamics of a Plasma Wakefield Dechirper for Energy Spread Reduction

Y. P. Wu,[1] J. F. Hua,[1,*] Z. Zhou,[1] J. Zhang,[1] S. Liu,[1] B. Peng,[1] Y. Fang,[1] Z. Nie,[1] X. N. Ning,[1] C.-H. Pai,[1] Y. C. Du,[1] W. Lu,[1,†] C. J. Zhang,[2] W. B. Mori,[2] and C. Joshi[2]
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Plasma-based accelerators have made impressive progress in recent years. However, the beam energy spread obtained in these accelerators is still at the ~1% level, nearly one order of magnitude larger than what is needed for challenging applications like coherent light sources or colliders. In plasma accelerators, the beam energy spread is mainly dominated by its energy chirp (longitudinally correlated energy spread). Here we demonstrate that when an initially chirped electron beam from a linac with a proper current profile is sent through a low-density plasma structure, the self-wake of the beam can significantly reduce its energy chirp and the overall energy spread. The resolution-limited energy spectrum measurements show at least a threefold reduction of the beam energy spread from 1.28% to 0.41% FWHM with a dechirping strength of ~1 (MV/m)/(mm pC). Refined time-resolved phase space measurements, combined with high-fidelity three-dimensional particle-in-cell simulations, further indicate the real energy spread after the dechirper is only about 0.13% (FWHM), a factor of 10 reduction of the initial energy spread.

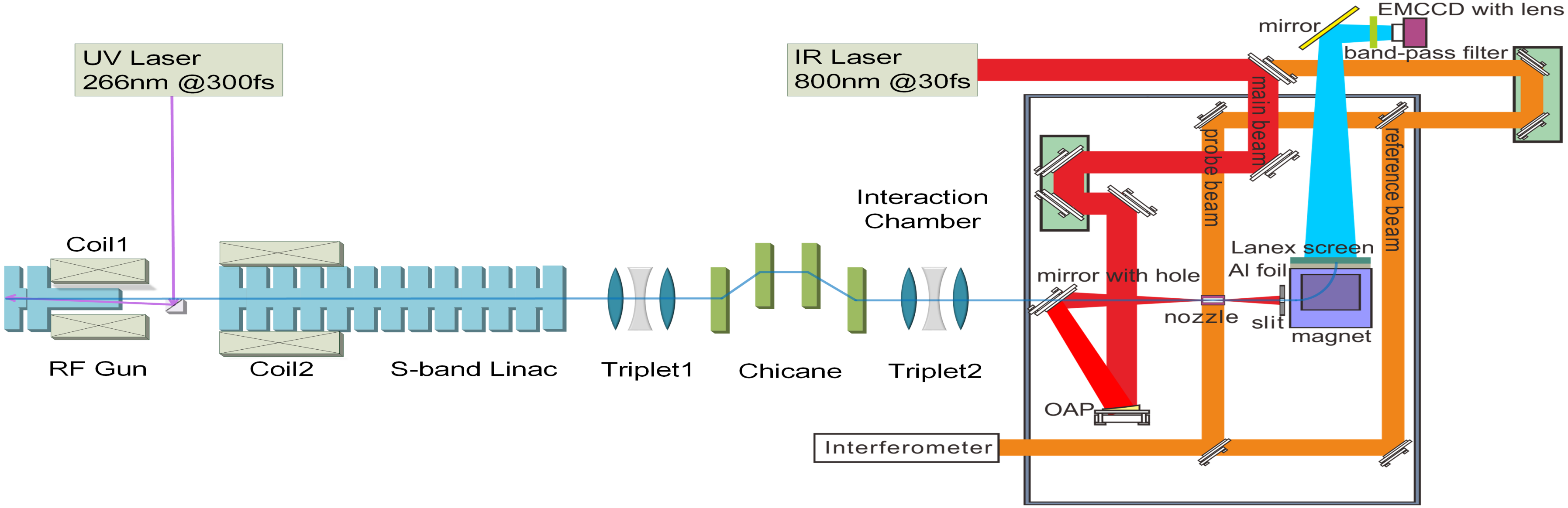
DOI: 10.1103/PhysRevLett.122.204804

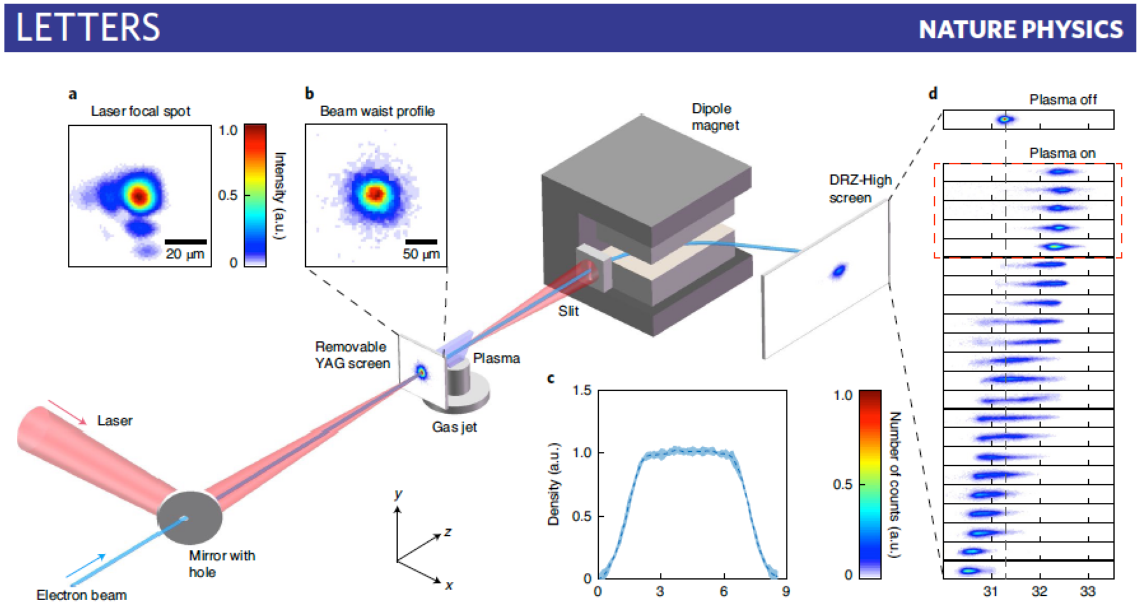
Energy spread reduction down to 0.2% level

AAC 2018, Plenary

- Hollow channel dechriper has reached 0.1% without emittance growth

~100% coupling efficiency from Linac to LWFA

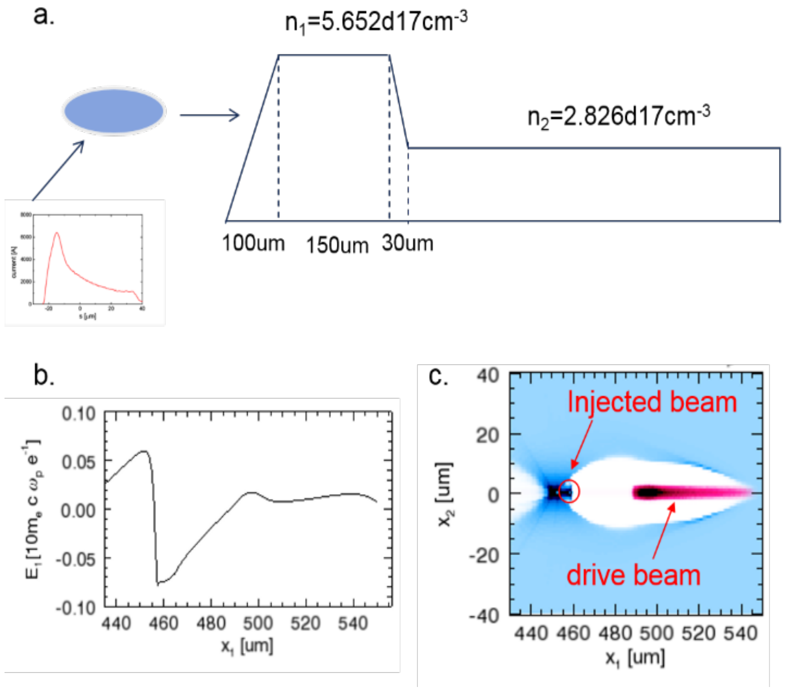




external injection with ~100% capture efficiency

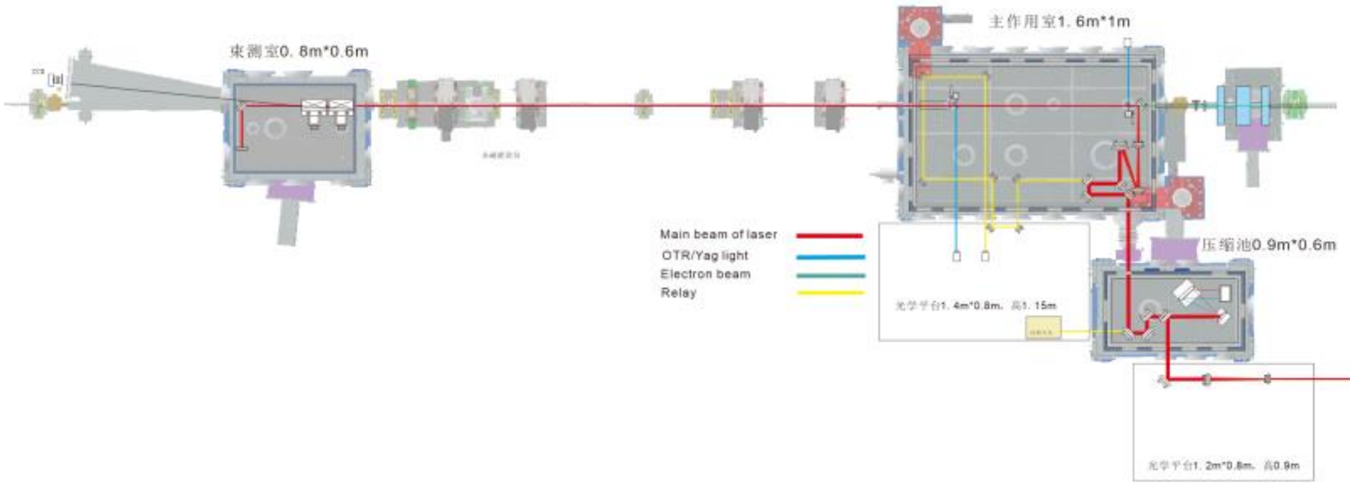
PWFA based FEL study in China

SXFEL Facility in Shanghai



S. Huang et al., IPAC proceeding 2017

A test facility based on SXFEL



PART 1

Where do you see HEP applications of advanced accelerators in 30 years?

An electron/positron circular collider with a high energy plasma based injector (~120-180GeV). A study is underway in China to explore this possibility.

What intermediate physics applications/steps do you see until a HEP linear collider?

For collider application, a high energy plasma based injector for a circular collider like CEPC.
For other applications, at the large facility scales, coherent FEL light sources based on compact LWFA/PWFA electron accelerators can become one important candidate for the fifth generation light sources. At smaller scales on a table top, compact laser driven sources (Betatron、Compton、electron、ions、THz etc) can find various applications.

What is the synergy with related fields?

The key technologies developed for HEP applications, such as high average power drivers and plasma sources can first be applied for a compact light source with reduced challenges.

What is the role of your work here?

We are exploring the possibility of a high energy plasma based injector for circular electron/positron collider (CEPC). This is a joint effort between IHEP, Tsinghua University and several other institutes in China, with a goal to reach a viable physical design in about 5 years, and also develop relevant key technologies required in a longer time scale.

PART 2

What are the important milestones for the next 10 years to get there from today?

Three key milestones:
Stable high transformer ratio (3-10) PWFA with high efficiency and low energy spread.
Stable positron acceleration with high efficiency and low energy spread in an electron beam driven PWFA.

Large charge electron/positron external injection into a LWFA/PWFA at high energy with near 100% coupling efficiency .

What additional support is needed to achieve these?

A test facility with capabilities beyond FACETII.

What should be proposed as deliverables until 2026? Please list in order of priority.

Stable high transformer ratio (3-5) PWFA with high efficiency and low energy spread.

Is the R&D work for each of those deliverables already funded and, if not, what additional resources / support would be needed?

It is partially supported in the test facility based on SXFEL at Shanghai.

Thank you for your attention!