High energy plasma injector for future electron-positron collider

CEPC Plasma Injector Study Group

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Outlines

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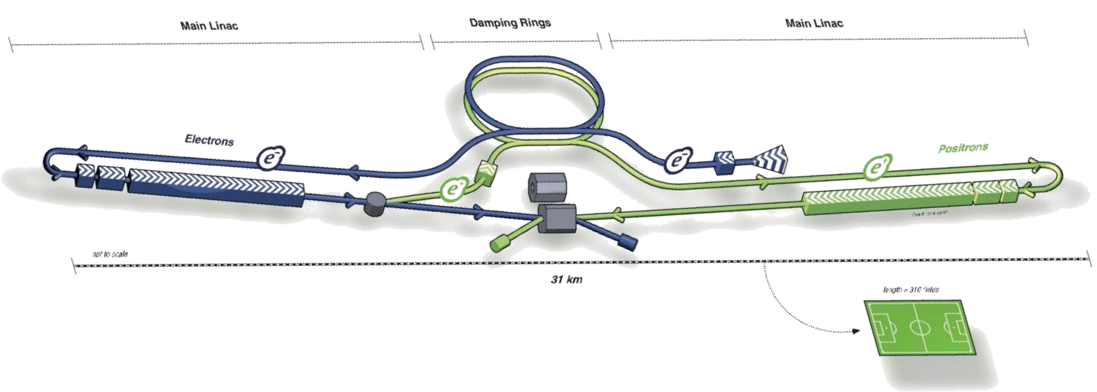
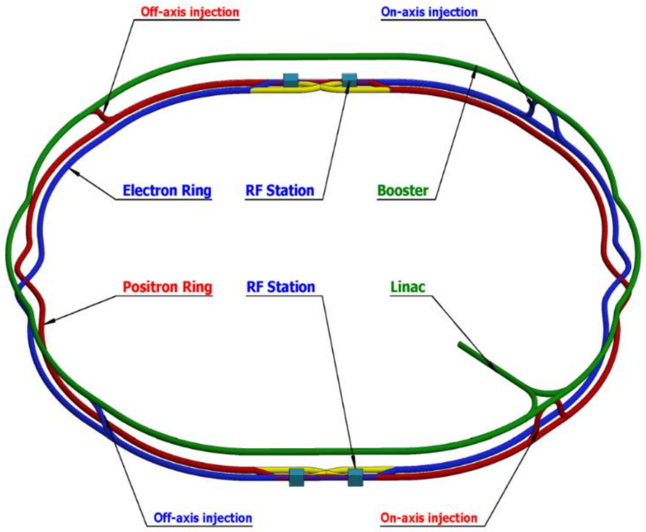
- Introduction to plasma injector
- Current status of CEPC plasma injector
- Test facility plan

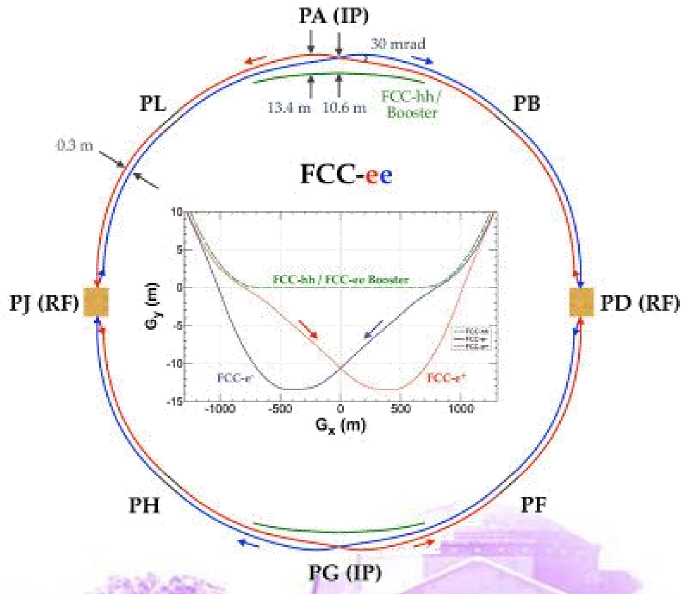
Frontiers of high energy physics

- **Precision measurement of the Higgs Boson and other particles with high energy electron-positron collider is of the most important issues for particle physics.**

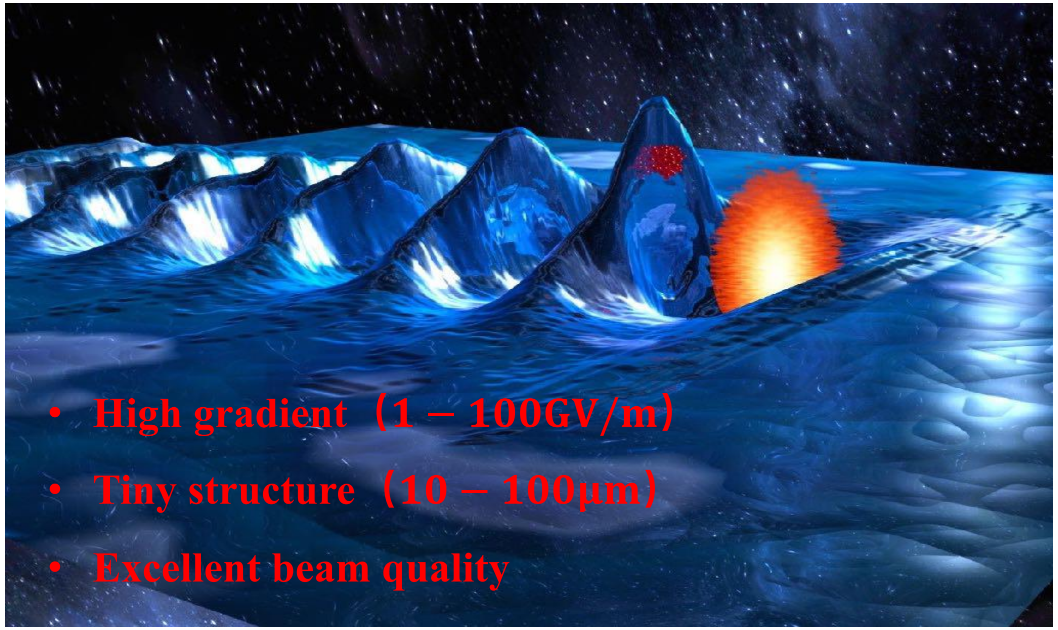


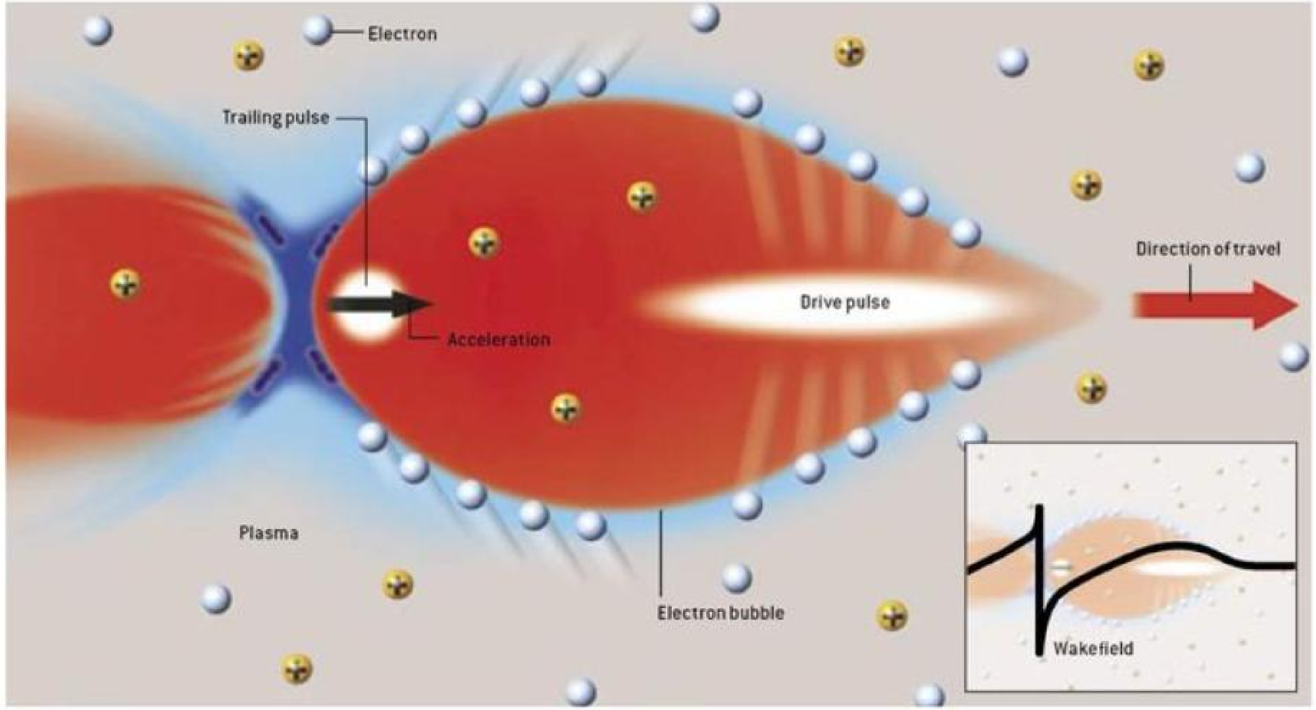
- **The candidates for the future electron-positron collider**
  - The International Linear Collider (ILC)
  - Circular Electron Positron Collider (CEPC) (with plasma injector)
  - Future Circular Collider (FCC-ee)





Plasma Based Accelerator





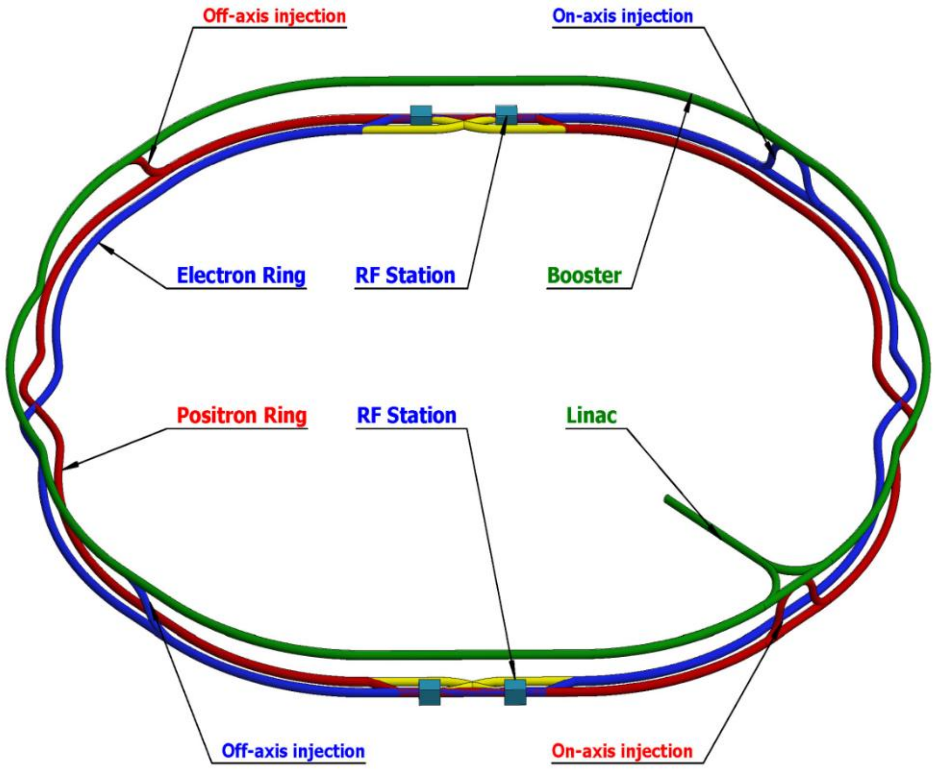
The drive beam can be a laser (LWFA) or a charged beam (PWFA). Considering the beam power required by a collider, PWFA has an advantage.

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

CEPC plasma injector (CPI)

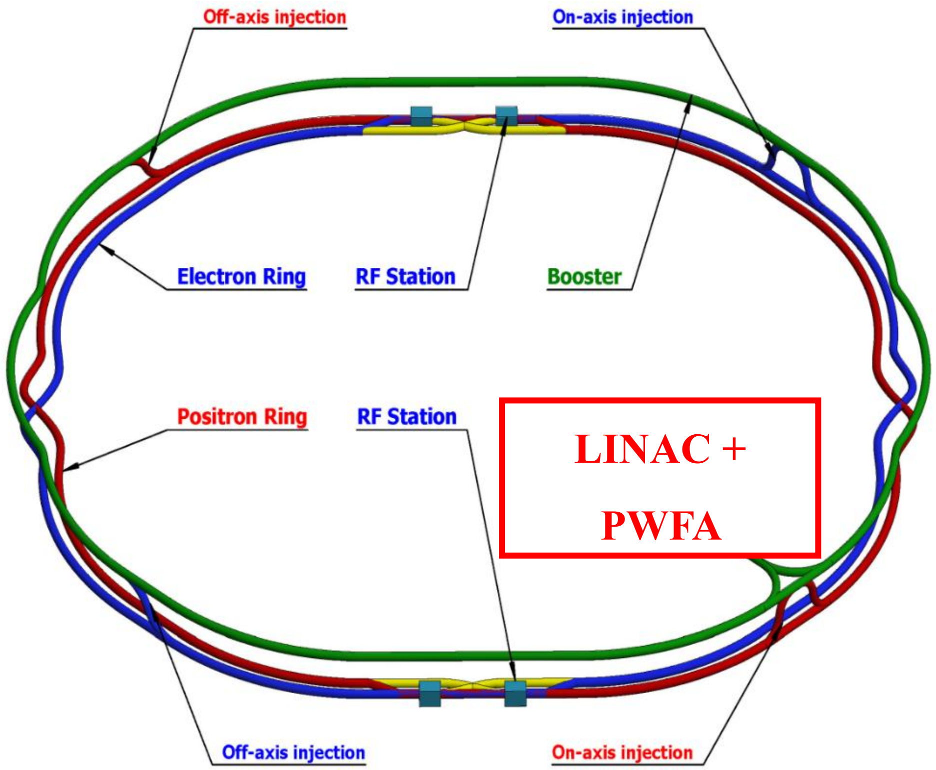
CEPC baseline

10GeV Linac + 120GeV Booster + Collider Rings



CEPC + CPI

10GeV Linac + 30/45GeV Plasma Injector+ 120GeV Booster + Collider Rings



CEPC, CDR(2018)

The development of CPI

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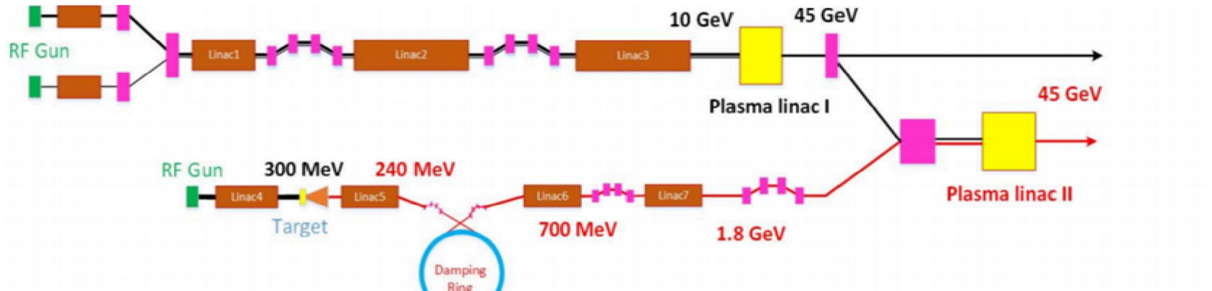
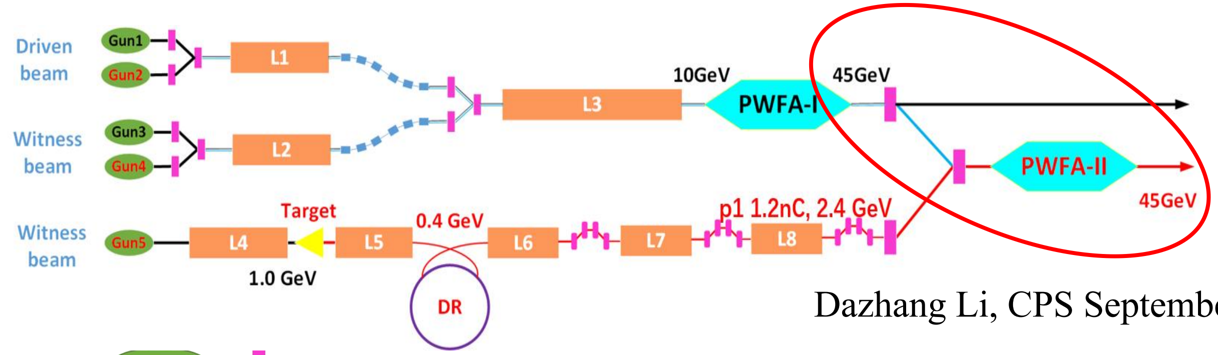
- 2017 CPI study group established
- 2018 "CEPC Conceptual Design Report" released，with CPI as a part of the appendix v1.0



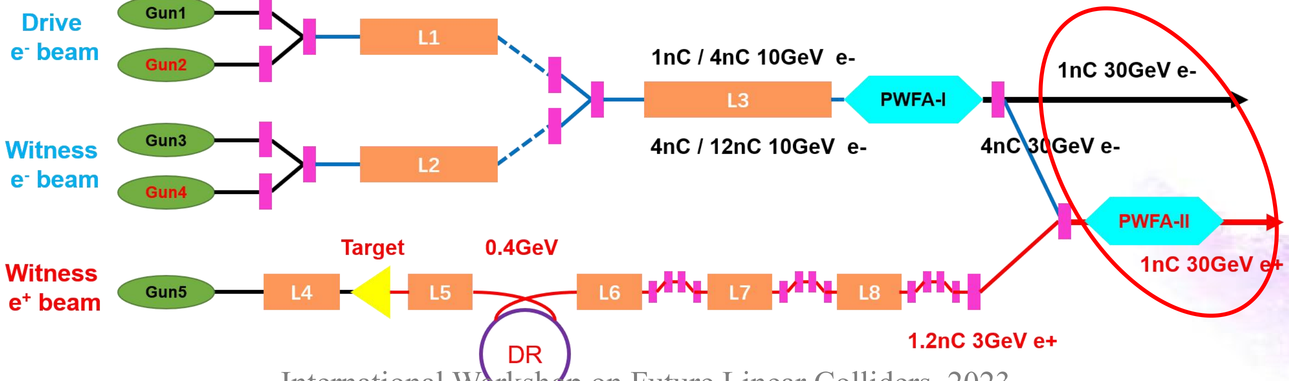
Jianfei Hua, ACC, August 2018

- 2019 CPI v2.0



Dazhang Li, CPS September 2019

- 2022 CPI v3.0



Booster Requirements for CPI @ 30GeV

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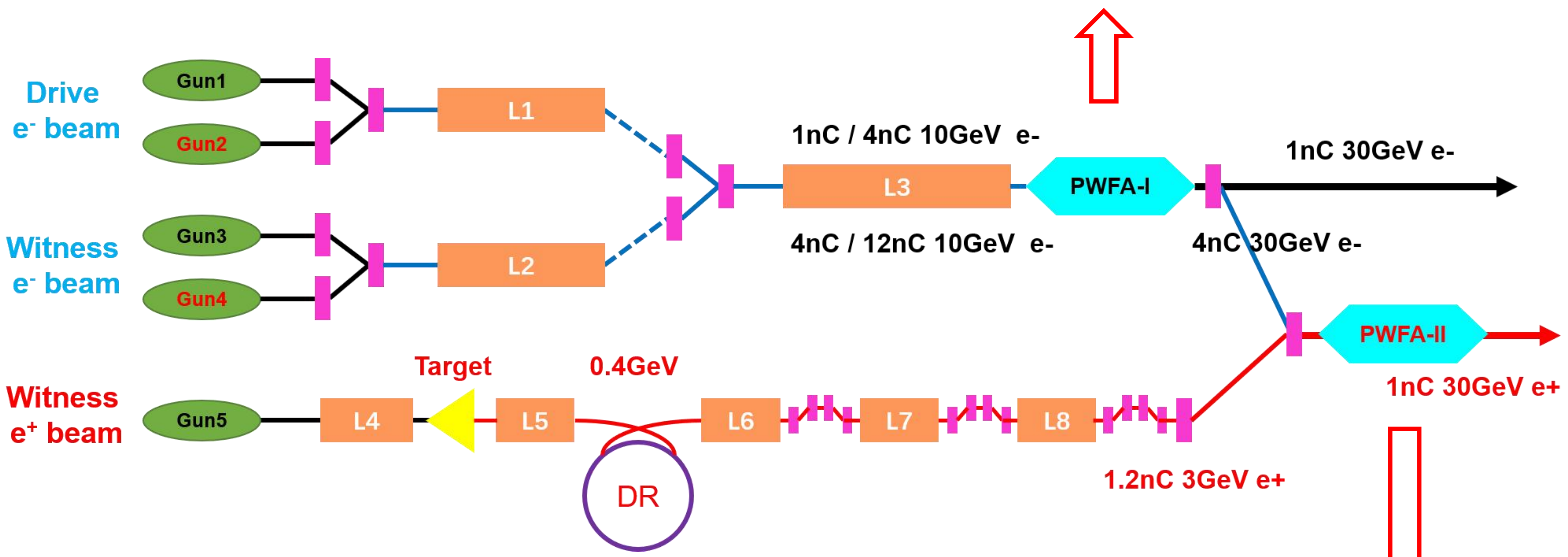
Parameter	Symbol	Unit	Requirement	ILC
e^-/e^+ beam energy	E_{e-}/E_{e+}	GeV	30	125
frequency	f_{rep}	Hz	100	10
e^-/e^+ bunch population	N_{e-}/N_{e+}	nC	> 1.0	3.2
Energy spread (e^-/e^+)	σ_e	%	< 0.2	0.19 (e+) / 0.15 (e-)
Emittance (e^-/e^+)	$\gamma\varepsilon_r$	mm· mrad	< 800	10 (H) / 0.035 (V)
Bunch length (e^-/e^+)	σ_l	mm	0.2~ 2	
Switch time e^-/e^+		s	< 2	
Energy stability		%	< 0.2	
Longitudinal stability		mm	< 2	
Orbit stability		mm	<3 (H) / 3 (V)	
Failure rate		%	< 1	

By Dou Wang

Plasma injector is an important step to the plasma based linear collider!

Current status of CEPC Plasma Injector

Via single stage high transformer ratio (HTR) PWFA

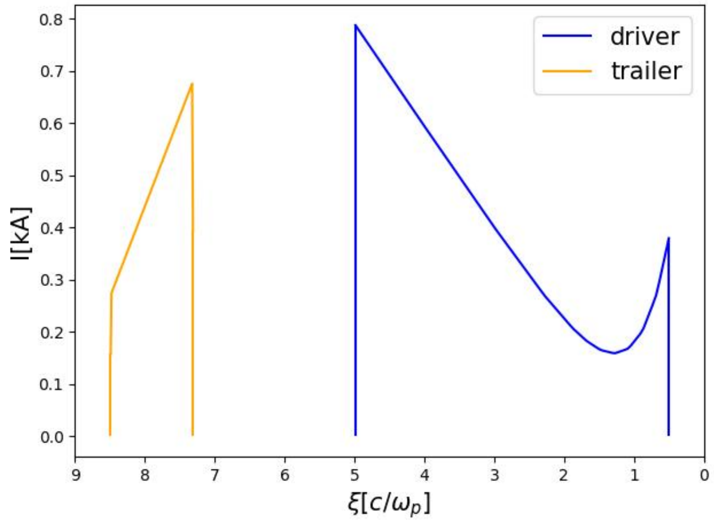


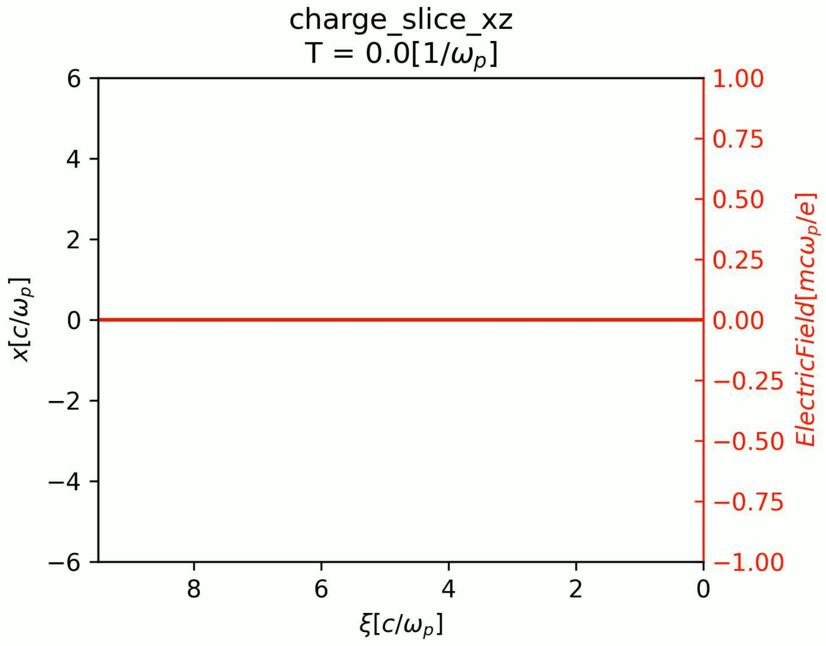
Develop novel high efficiency plasma wakefield positron acceleration regime

CPI electron acceleration

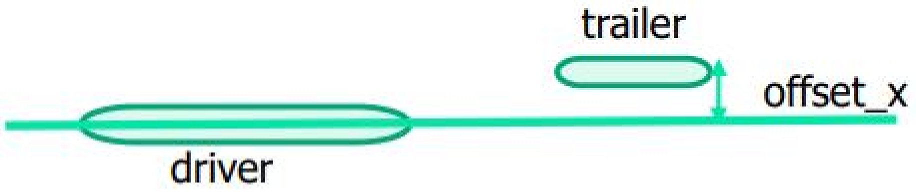
Plasma parameters		
Plasma density $n_p(\times 10^{16} cm^{-3})$	0.50334	
Ramp Length (m)	0.1	
Beam Parameters	**Driver**	**Trailer**
Driver energy E(GeV)	10	10
Normalized emittance $\epsilon_n(mm\ mrad)$	20	10
Length(um)	340	89.2
Spot size(um)	3.89	2.75
Charge(nC)	3.87	1.19

Accelerating distance (m)	7.70
Trailer energy E(GeV)	30.41
Energy spread (%)	0.21
Normalized emittance $\epsilon_x(mm\ mrad)$	74.6
Normalized emittance $\epsilon_y(mm\ mrad)$	123.0
Charge(nC)	1.19

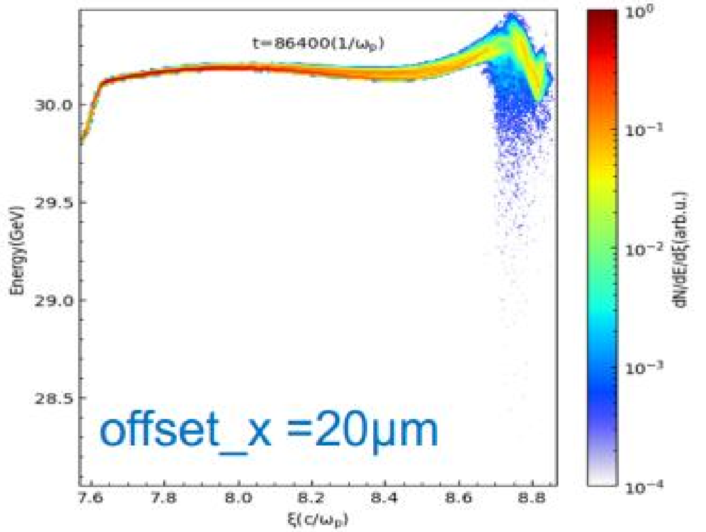


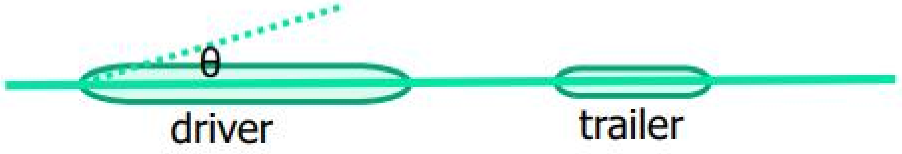


CPI electron acceleration – tolerance analysis

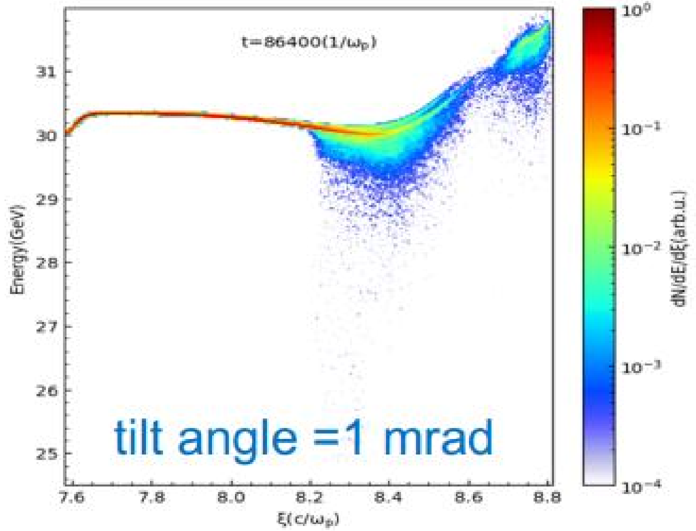


Offset (x direction)	4 μm	12 μm	20 μm	30 μm
Bunch charge [nC]	1.197	1.197	1.174	1.079
Energy [GeV]	30.01	30.04	30.16	30.37
RMS energy spread	0.43	0.41	0.22	0.72





Tilt angle	10 μrad	100 μrad	1 mrad
Bunch charge [nC]	1.197	1.197	0.903
Energy [GeV]	30.01	30.01	30.24
RMS energy spread	0.41	0.41	0.65



CPI positron acceleration

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PHYSICAL REVIEW LETTERS **127**, 174801 (2021)

Editors' Suggestion

High Efficiency Uniform Wakefield Acceleration of a Positron Beam Using Stable Asymmetric Mode in a Hollow Channel Plasma

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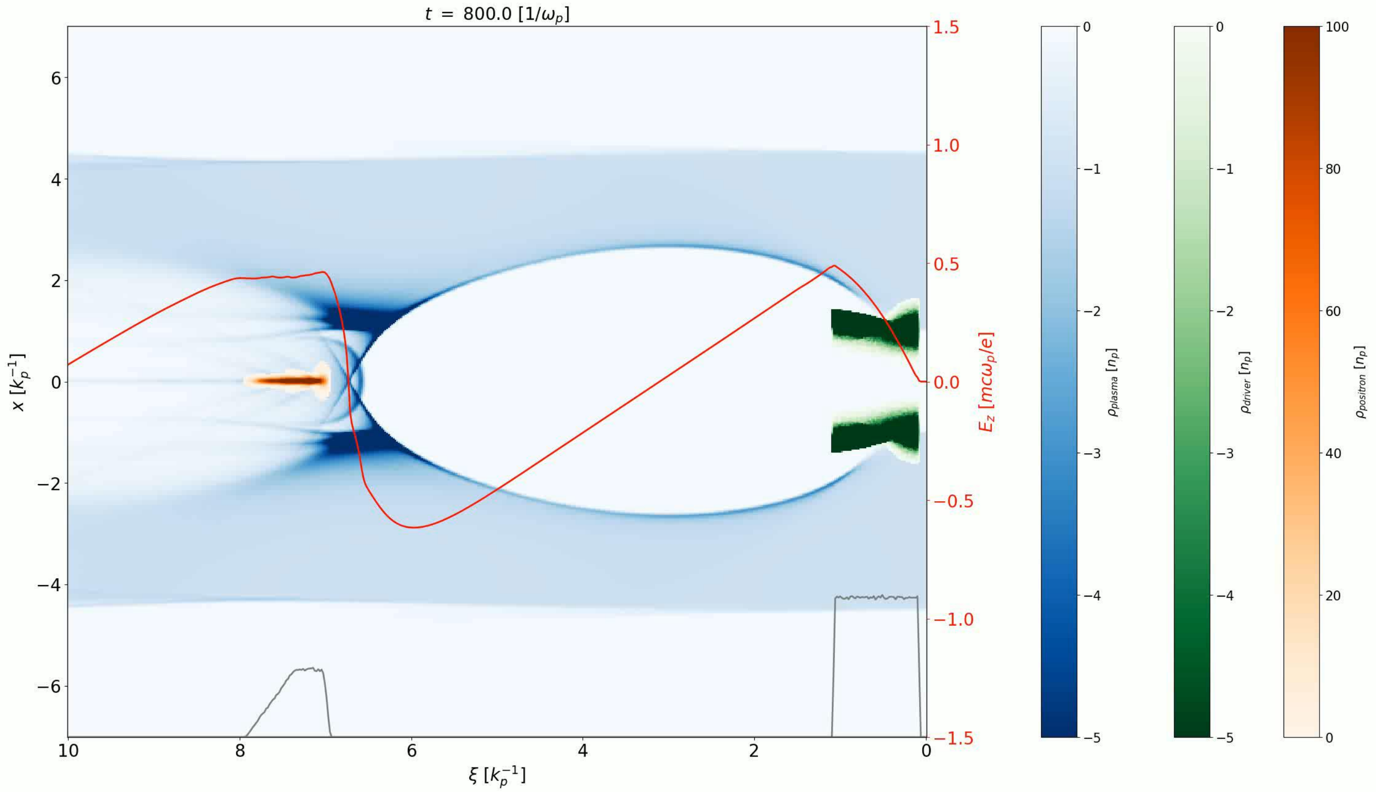
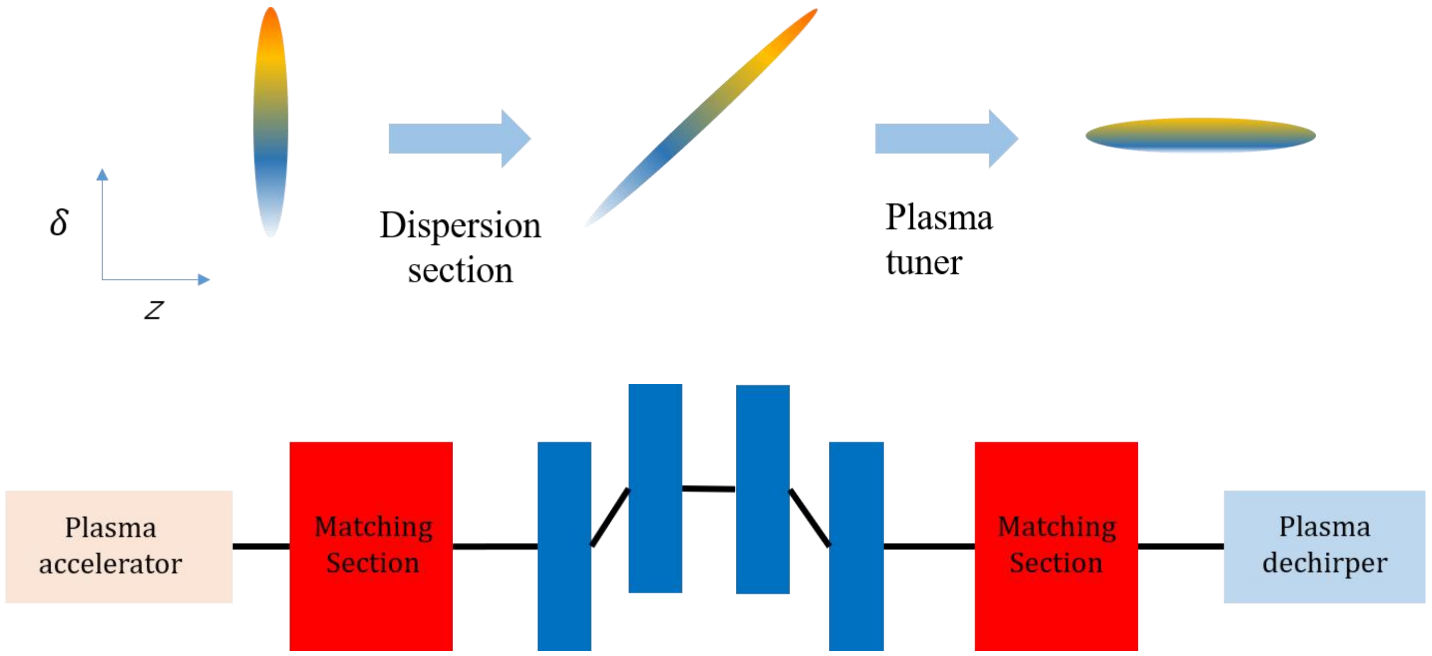
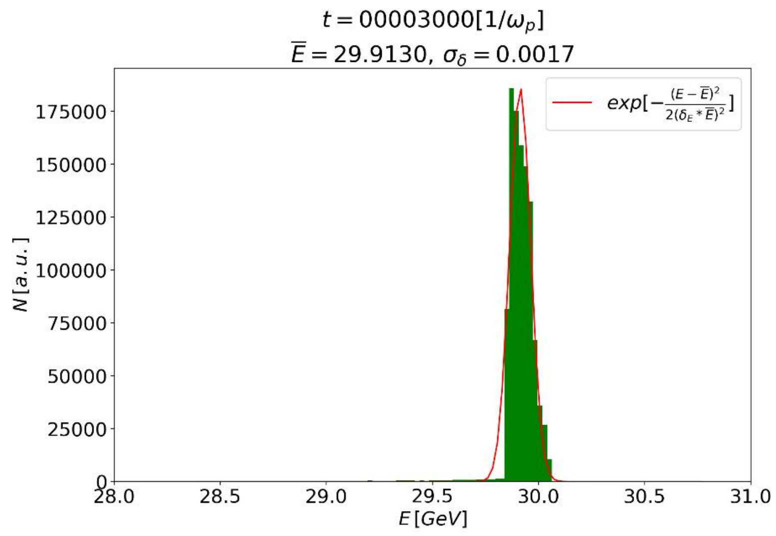


Plasma	density	1e15cm^{-3}
	Inner radius	1.0 k_p^{-1} (168μm)
	Outer radius	4.5 k_p^{-1} (756μm)
e- bunch	Charge (single bunch)	3.4 nC
	energy	30 GeV
e+ bunch	charge	1.1 nC
	energy	3 GeV
	Transverse size	6.55 um
	Normalized emittance	17.472 mm·mrad
Results	Acceleration length	**23.5 m**
	gradient	**1.166 GV/m**
	Beam loading efficiency	19.00%
	e+ charge	**1.1 nC**
	e+ energy	**30.42 GeV**
	e+ rms energy spread	0.85%
	e+ ϵ_x/ϵ_y	45mm·mrad (x) 183mm·mrad (y)

Energy compression for positron beam



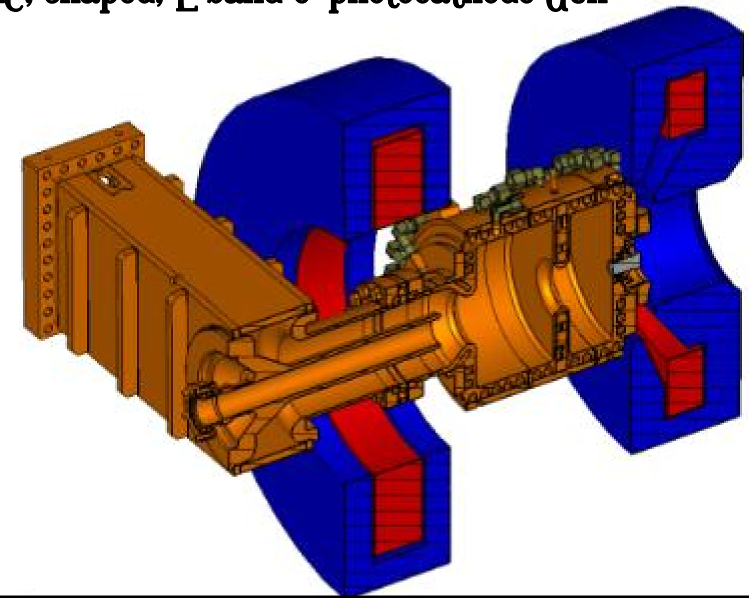


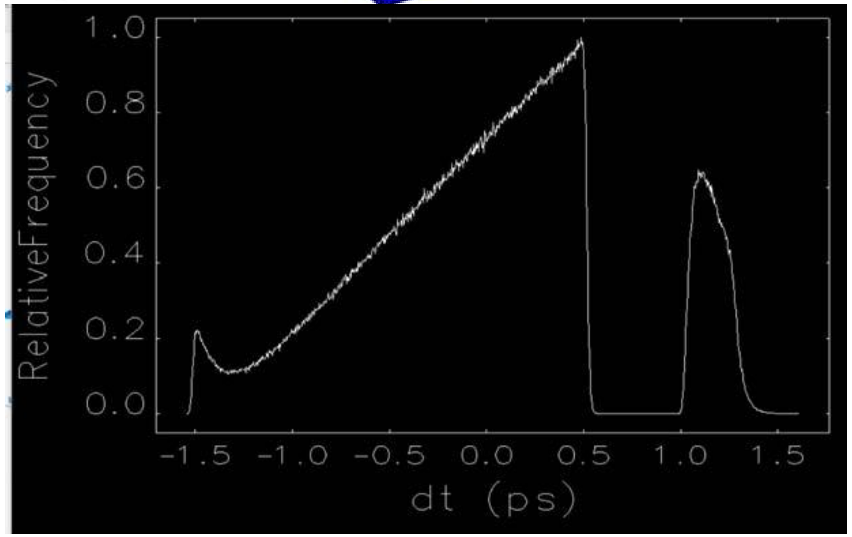
Output	
charge	1.053 nC
energy	29.9 GeV
Rms energy spread	0.156%
ϵ_x/ϵ_y	~200mm·mrad

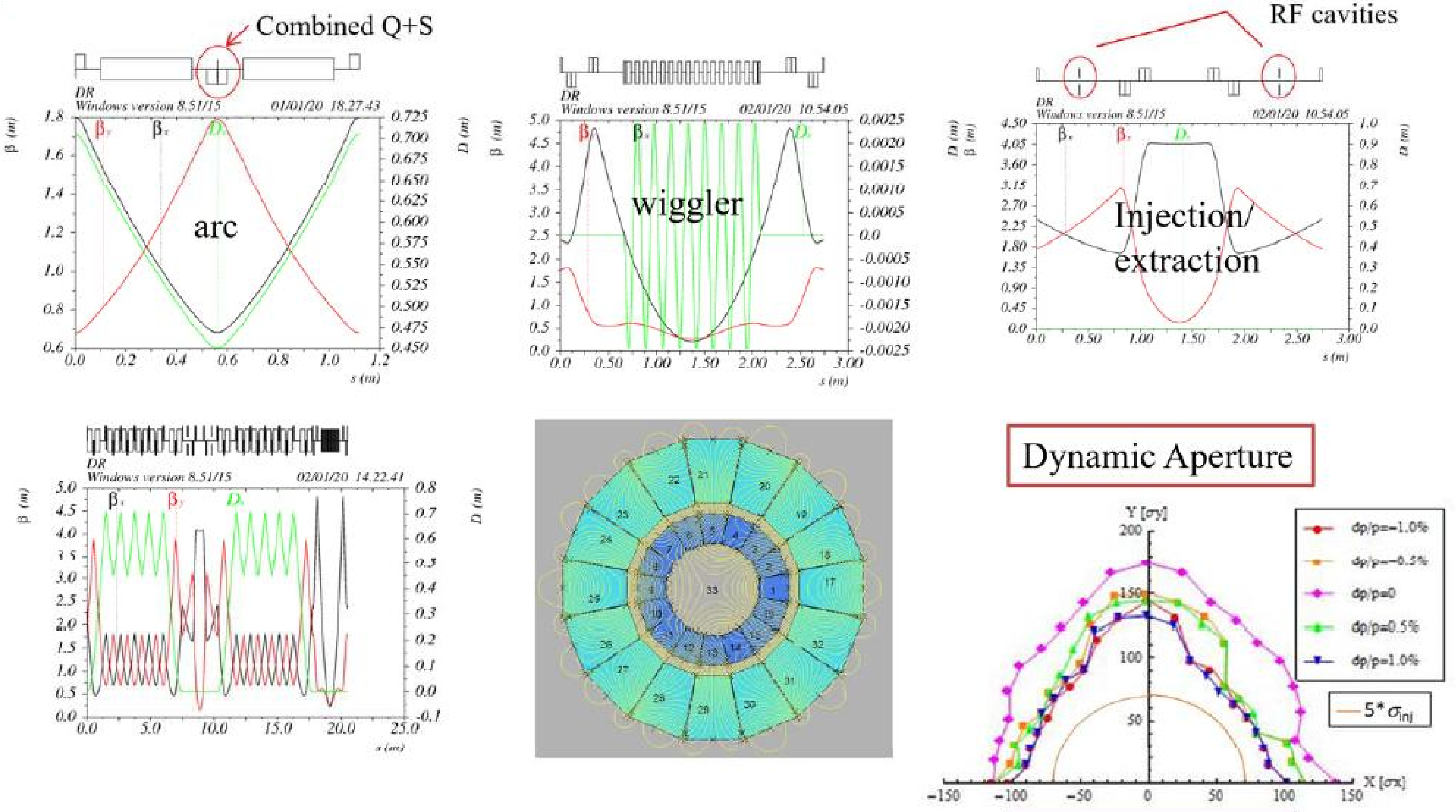
A. Ferran Pousa, et al. PRL 129, 094801 (2022)

Linac and damping ring design

10nC, shaped, L-band e- photocathode Gun







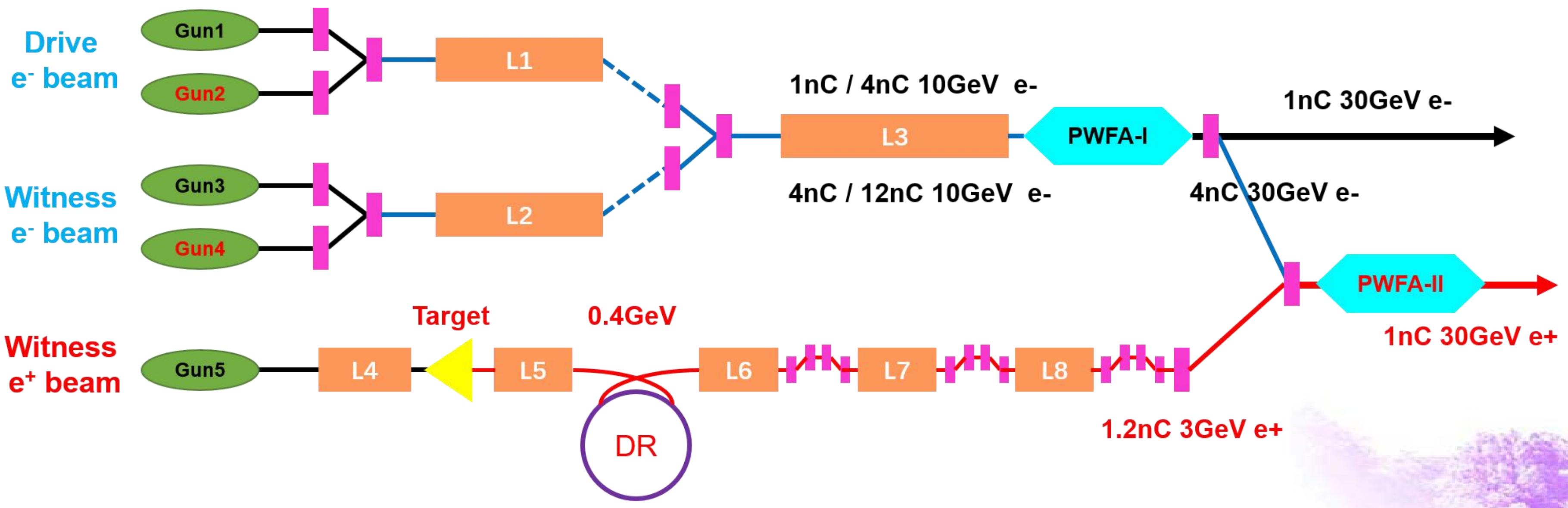
- Combined quadrupole + sextupole (permanent magnet)
- Superconducting wiggler → shorter damping time & smaller equilibrium emittance

$\nu_x / \nu_y = 3.16/3.21$

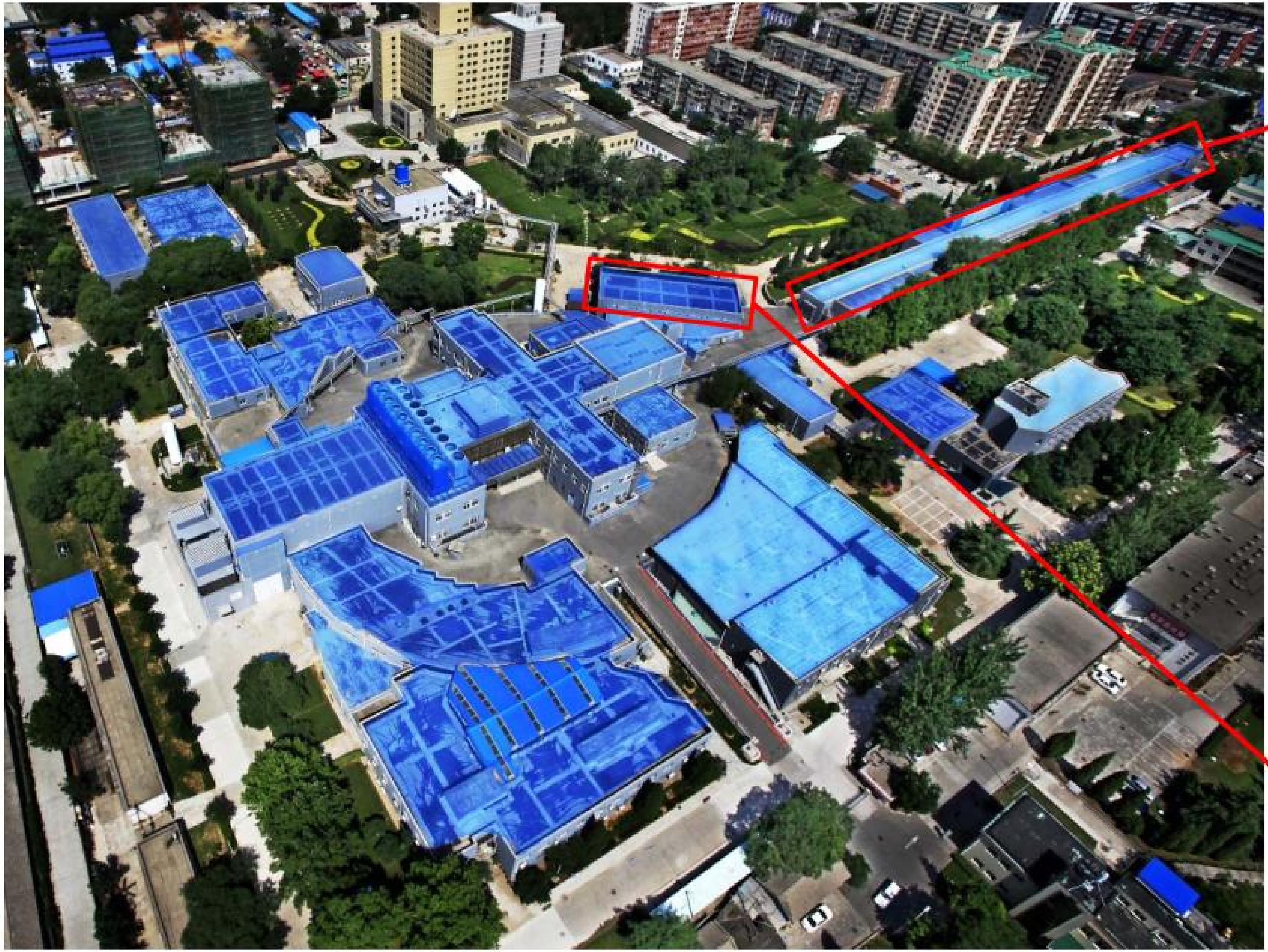
By Dr. Dou Wang and Cai Meng from IHEP (2020)

Summary of CEPC plasma injector

- Overall conceptual design already has several versions.
- Parameter design and tolerance analysis for electron acceleration show high feasibility.
- Baseline design for positron acceleration arm is almost done.
- Results from PIC simulations basically fulfill the requirement of booster.
- It needs quite a lot of synergy between the rf accelerator and plasma accelerator group.

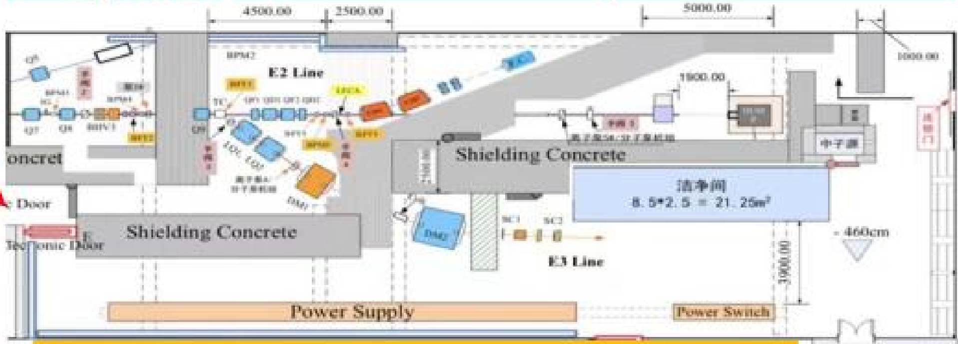


Test Facility @ IHEP



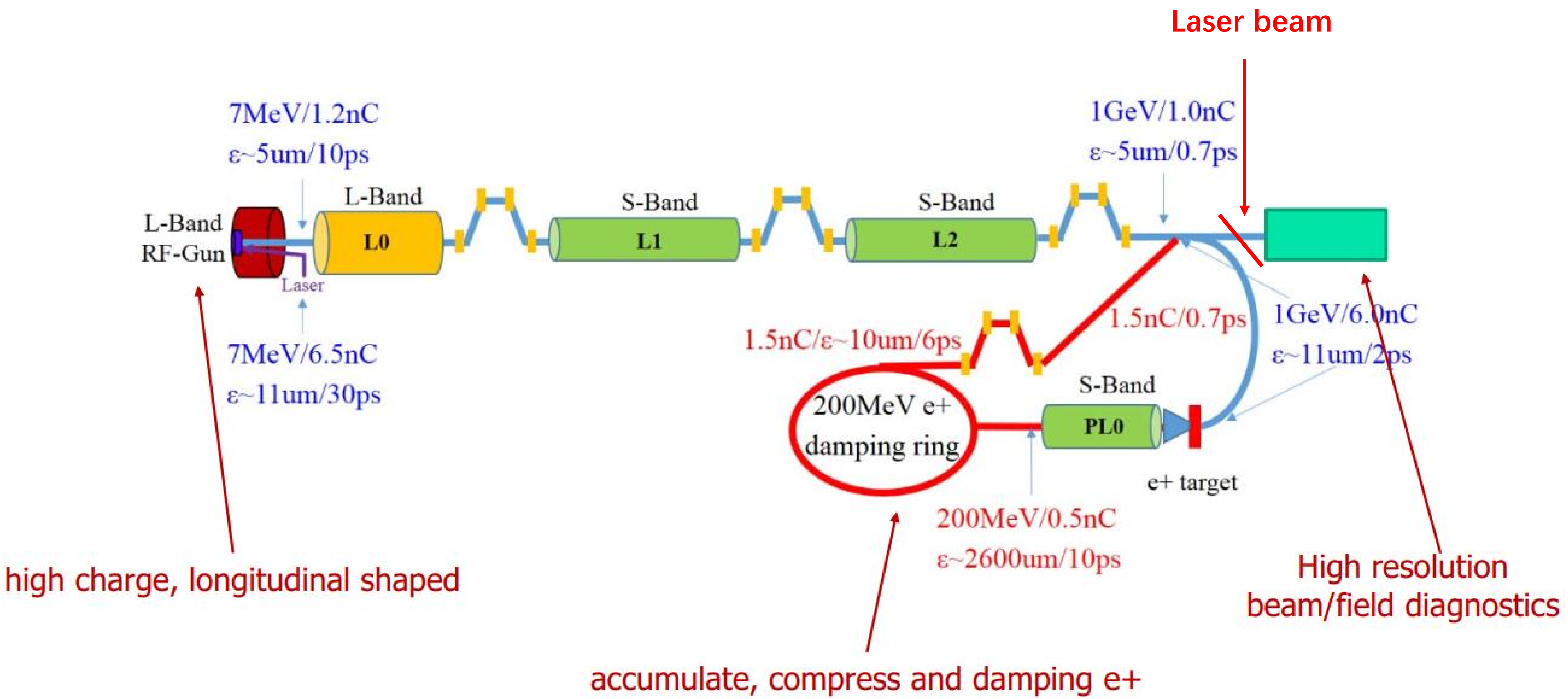
BEPC-II linac (200m)

	e-	e+
Energy	≤ 2.5 GeV	≤ 2.5 GeV
Geometry Emittance	0.1 mm·mrad	0.4 mm·mrad
Peak current	0.5 kA	~ 0.01 kA
Bunch charge	2 nC	< 0.1nC
Beam size	1.1mm×1.1mm	2mm×2mm
Energy spread	0.5%	0.5%



Experimental Hall: 35m × 14m

Test Facility @ IHEP



Test Facility @ IHEP

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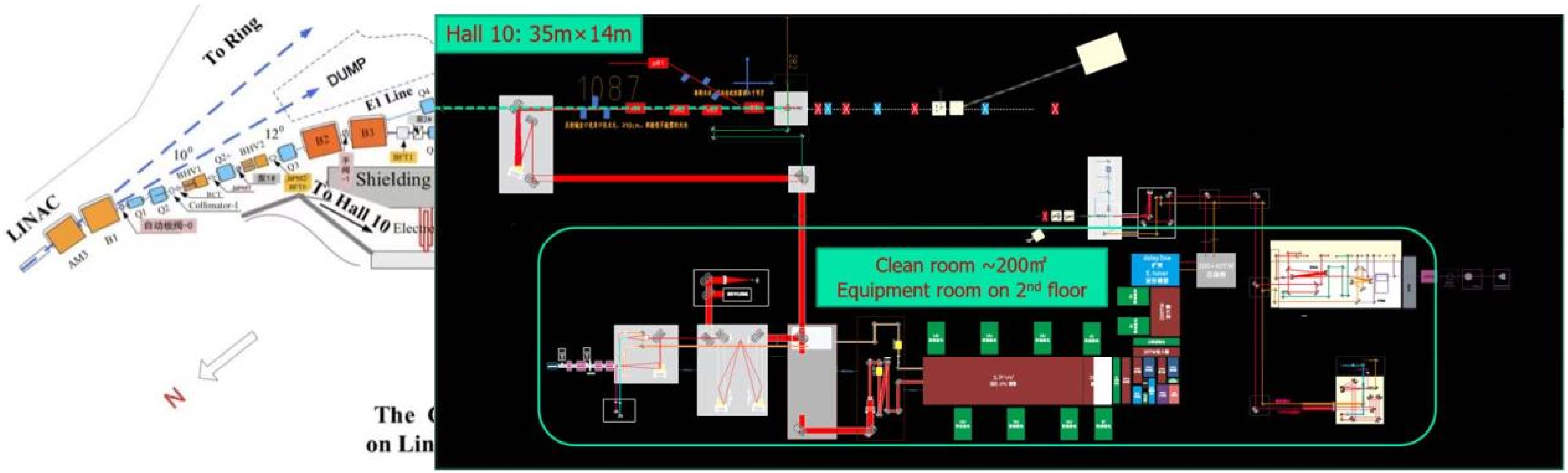
➢ Short Term Goal:

- New transport beamline installation & commissioning
- New Final Focus system in Exp. Hall
- Clean room + laser system installation + laser-beam synchroniza
- 10+ nC L-band RF gun design



Thanks for your attention!