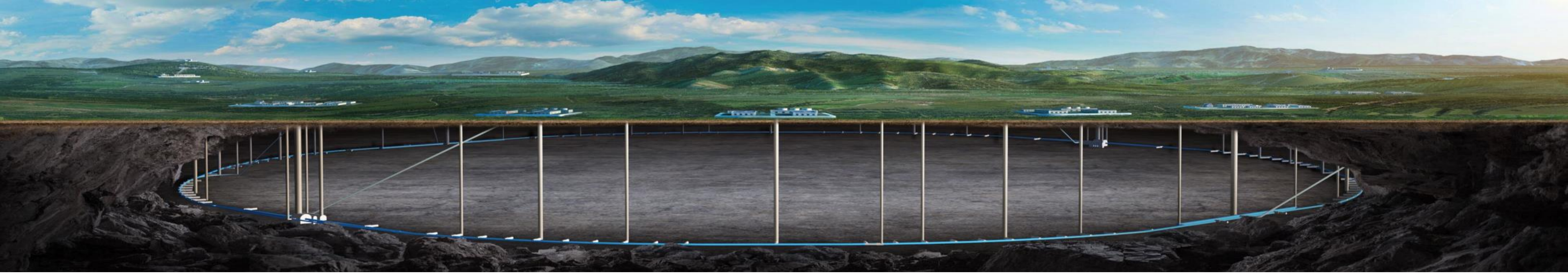

CEPC positron source design and related research activities in IHEP

Xiaoping Li, Cai Meng, Dazhang Li, Jindong Liu, Jie Gao, Wei Lu

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CEPC 环形正负电子对撞机
Circular Electron Positron Collider

Content

- **Parameters and layout of the CEPC Linac**
- **Positron source for CEPC**
  - Electron beam for positron production
  - Positron generation and Pre-acceleration
  - R&D of key components for positron source
- **Other related research activities**
  - CEPC plasma injector introduction
  - A PWFA-TF Based on BEPCII
  - Polarized positron beam generation
- **Summary**

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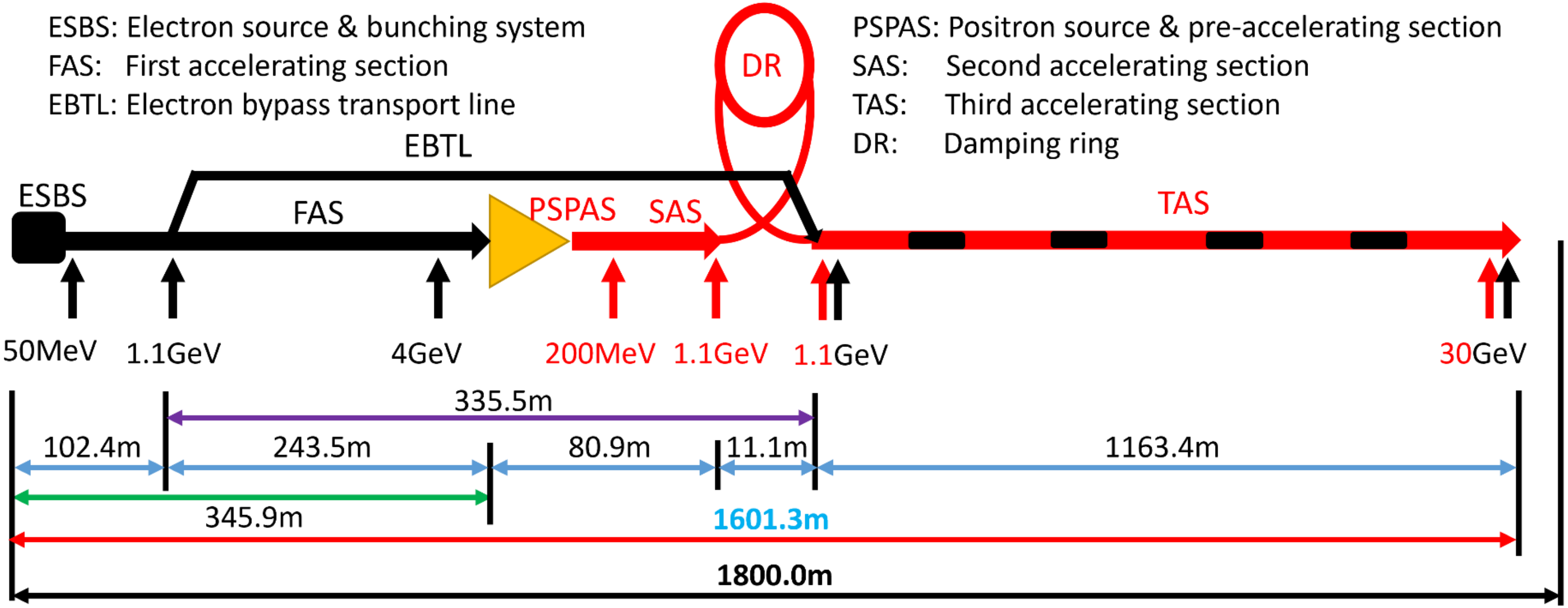
Parameters and layout of the CEPC Linac

- **Baseline design of the CEPC Linac**
  - A **30GeV** room temperature Linac
  - A combination of **S-Band (2860MHz)** and **C-Band (5720MHz)**
  - 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 (3)
Energy spread	σ_E		1.5×10^{-3}
Emittance	ε_r	nm	6.5

Parameters and layout of the CEPC Linac

- **Layout of the CEPC Linac**
  - **FAS+PSPAS+SAS:** S-Band
  - **TAS:** C-Band (Higher gradient → Shorter linac tunnel length)



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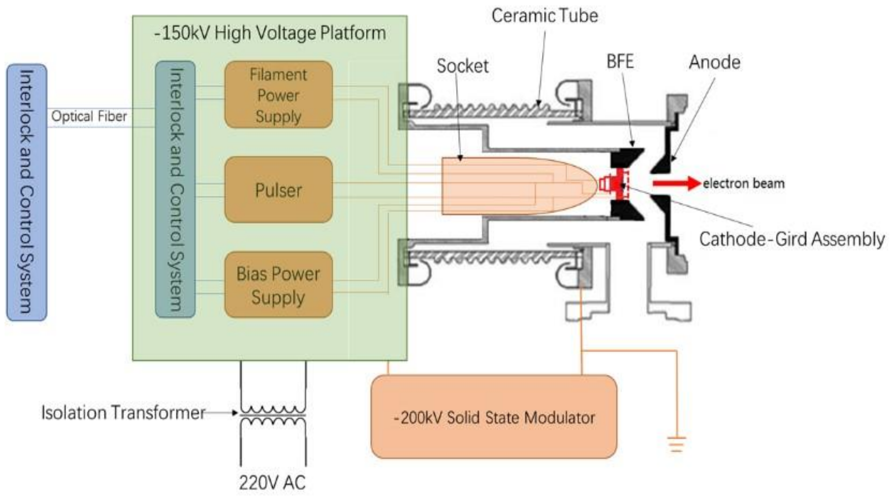
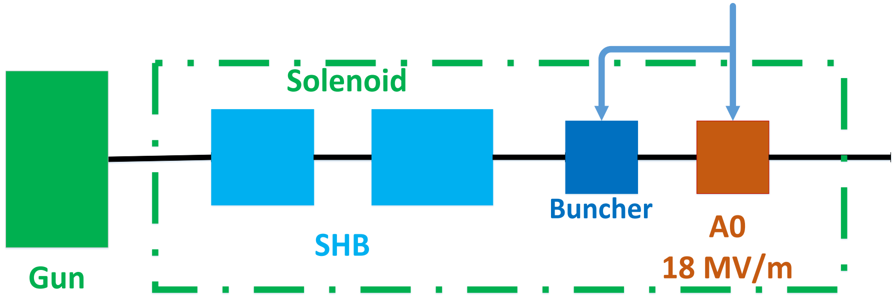
Electron source and bunching system (Baseline)

- **Electron Gun**
  - A traditional thermionic triode gun
  - **3nC** for electron injection
  - **11nC** for positron generation
- **Bunching**
  - Two SHBs (158.89MHz/476.67MHz)
  - Buncher(2860MHz)
  - Accelerating structure (2860MHz)
- **Energy:** 50MeV
- **Normalized Rms Emittance:** 80mm-mrad
- **Transmission**
  - 90%
- **Verified at BEPCII and HEPS Linac**



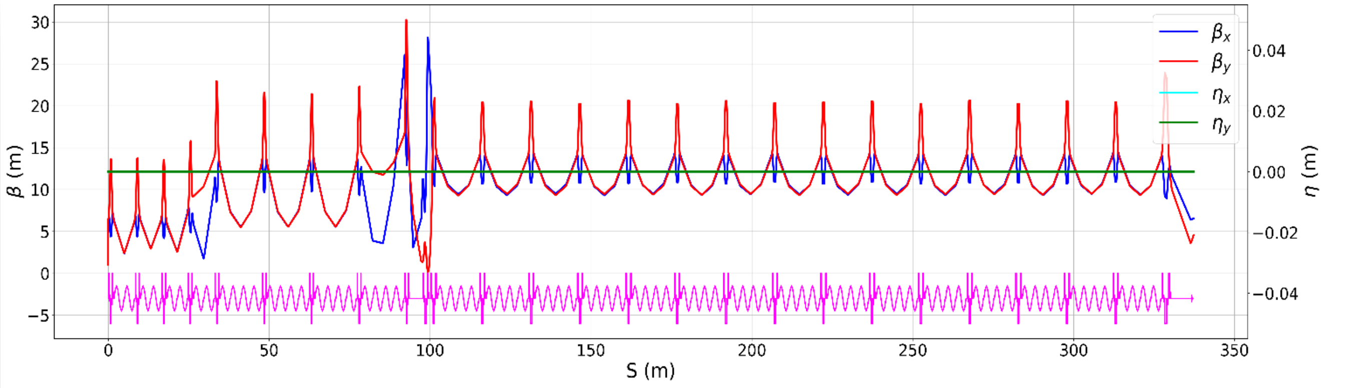


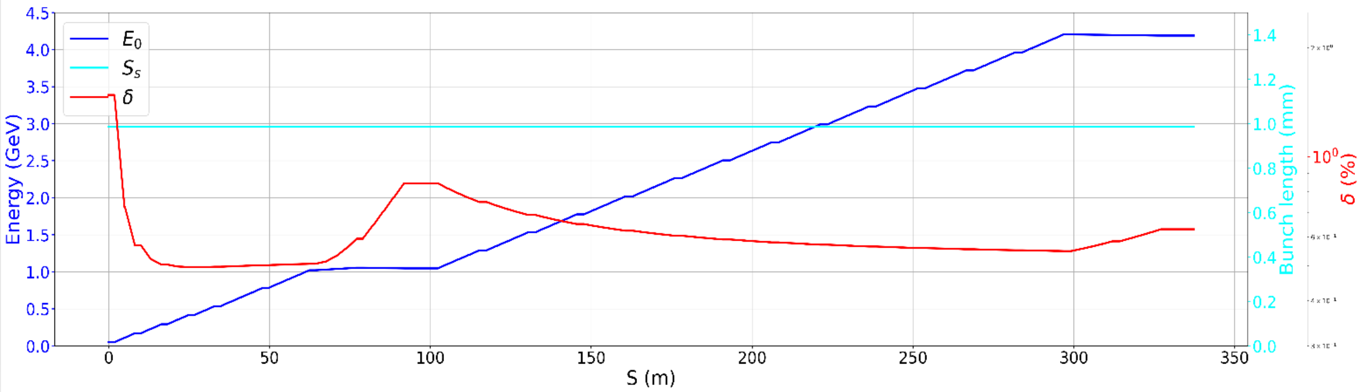
Positron source for CEPC

Electron beam for positron production

- **Acceleration: 50MeV→4GeV**
  - 18+3(redundancy) S-band klystron
  - 1 klystron →4 accelerating structures
  - Gradient: 22MV/m
- **Simulation results**
  - Energy: 4GeV
  - Bunch charge: 10nC
  - Energy spread: 0.63%

10nC@4GeV electron beam for positron production





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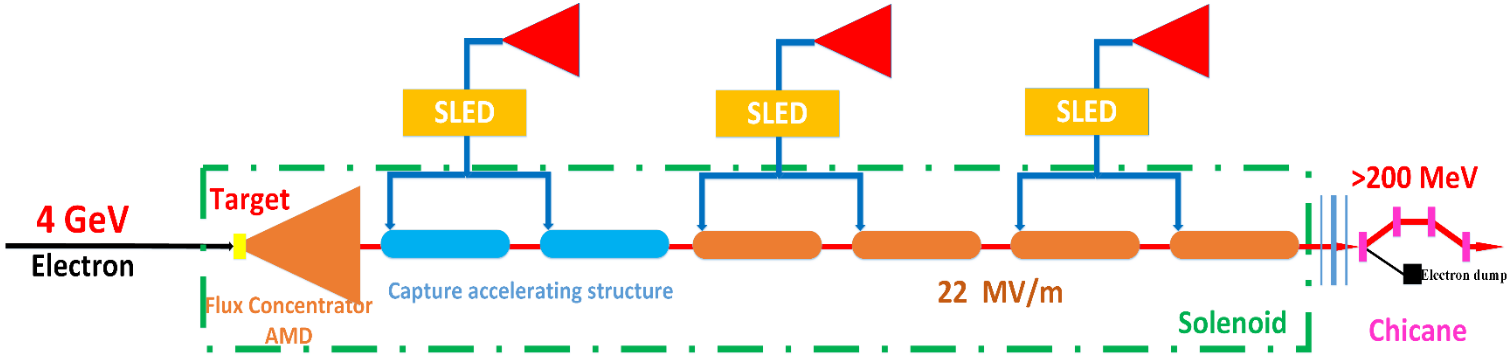
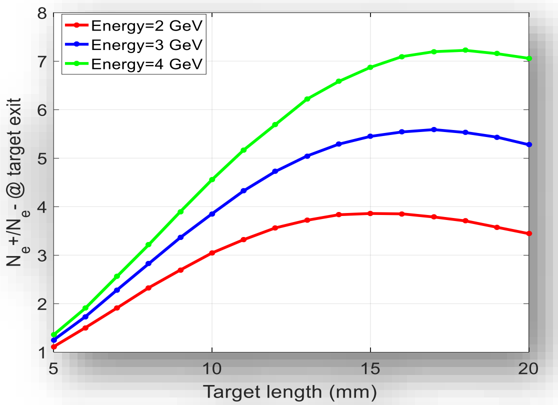
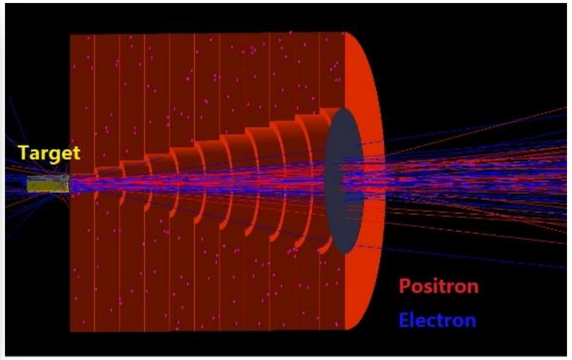
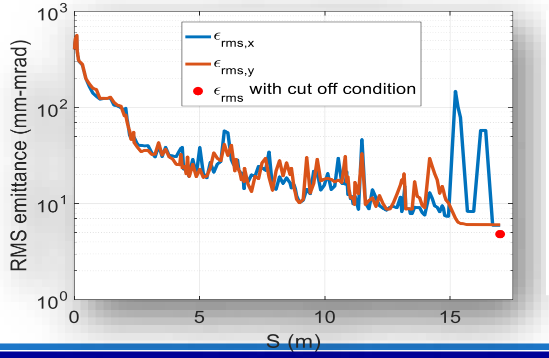
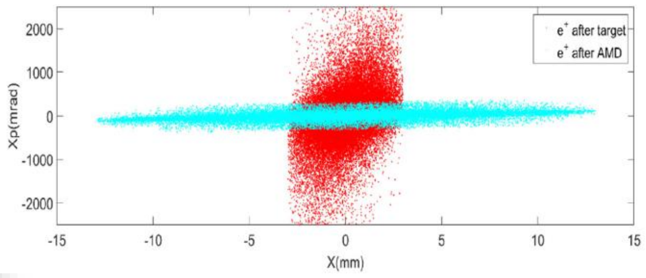
- **Positron source**
  - Target (Conventional)
    - Electron beam: 10nC@4GeV
    - Tungsten@**15 mm**
    - Beam size: **0.5 mm**
- **AMD (Adiabatic Matching Device)**
  - A flux concentrator
  - Magnetic field: (5.5T→0T) + 0.5T Solenoid
- **Capture & Pre-accelerating structure**
  - 1 klystron → 2 accelerating structures
    - Larger aperture S-band accelerating structure with aperture is 25 mm, gradient is 22 MV/m and length is 2 m
- **Chicane @ 200MeV**
  - Wasted electron separation
  - Exit: **~5.5nC**, Nor. Emittance: **2370mm-mrad**







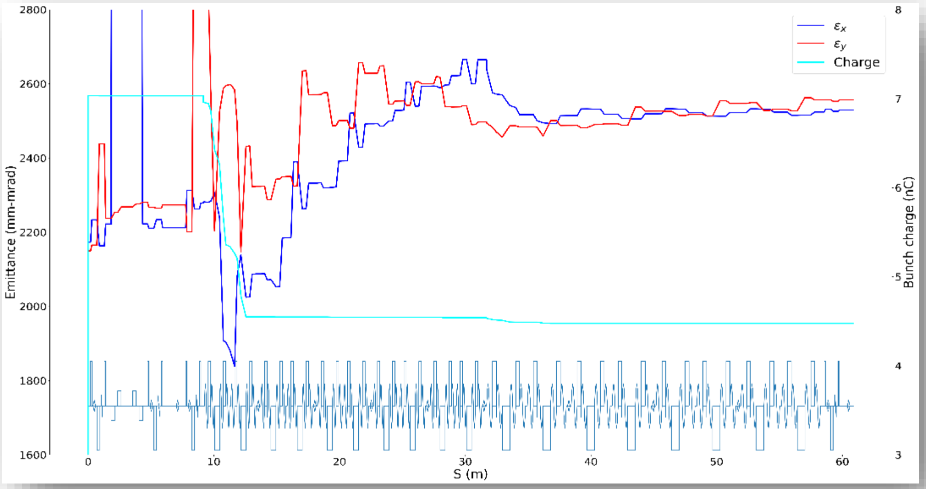


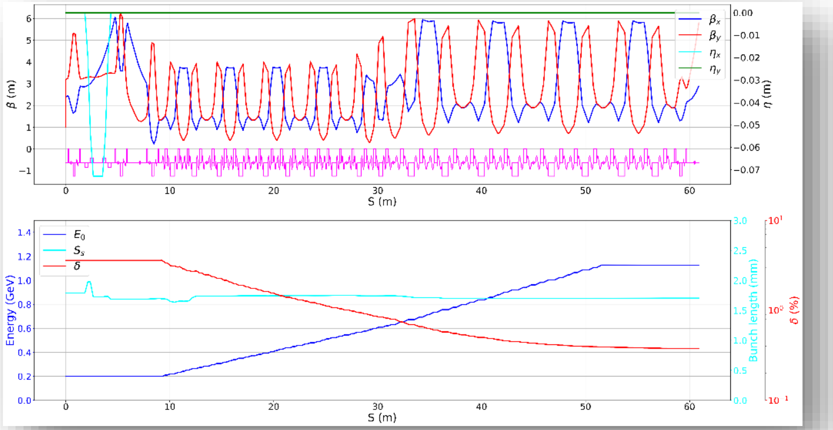


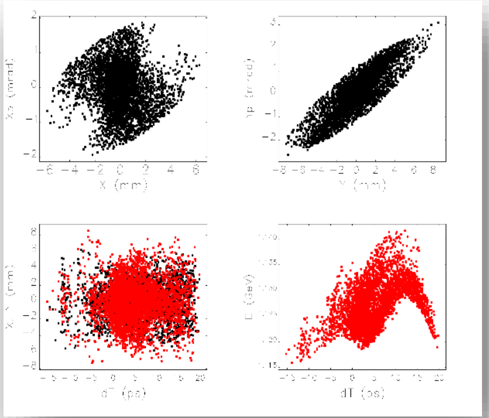
Positron source for CEPC

Positron source and Pre-accelerationg

- **Acceleration: 200MeV→1.1GeV**
  - 8+1(redundancy) S-band klystron
  - 1 klystron →2 accelerating structures
    - 10 Larger aperture S-band accelerating structure@22MV/m
    - 8 normal S-band accelerating structure@27MV/m
- **Transverse focusing**
  - Triplet quadrupoles are outside of each accelerating structure
- **Simulation results**
  - Energy: **1.1GeV**
  - Energy spread: **0.4%**
  - Bunch charge: **~4.5nC**
  - Normalized rms Emittance: **2500mm-mrad**







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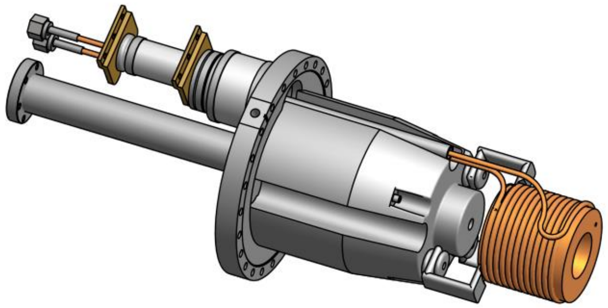
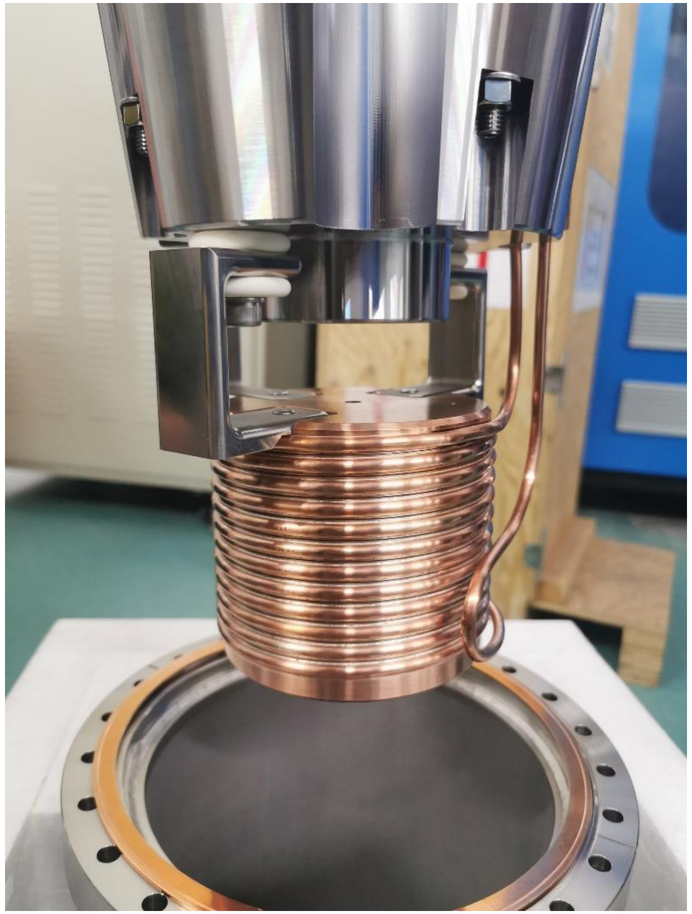
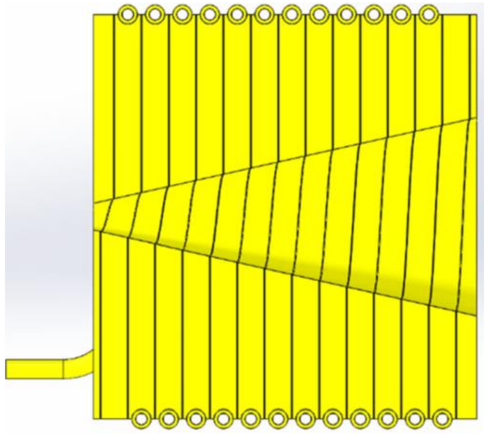
Positron source for CEPC

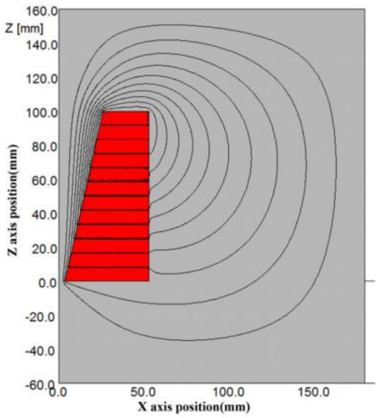
R&D of key components for positron source

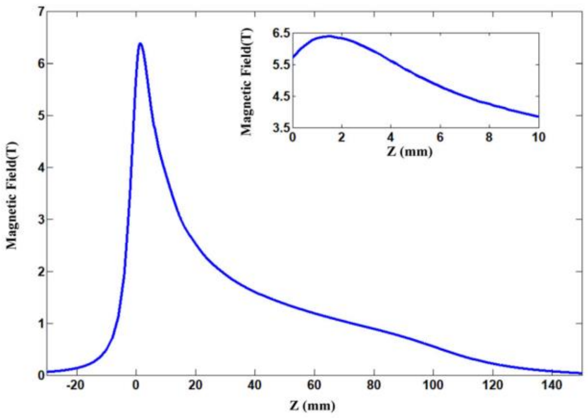
- **A flux concentrator prototype has been successfully developed**
  - Manufactured under a **cooperation MOU with KEK**
  - A trumpet-shaped copper coils： **12 turns**
  - The inner diameters： **7 to 52 mm**
  - Coils distance: **0.2 mm**
  - Total length: **100 mm**
  - Peak current: **15A**
  - Max pulse magnetic field: **>6T@15kA**







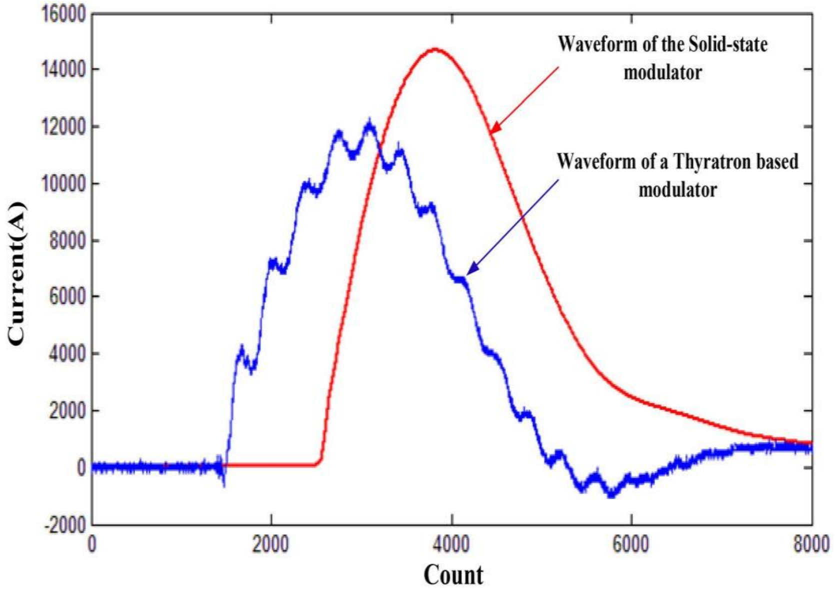




A new pulse modulator has been developed for FC

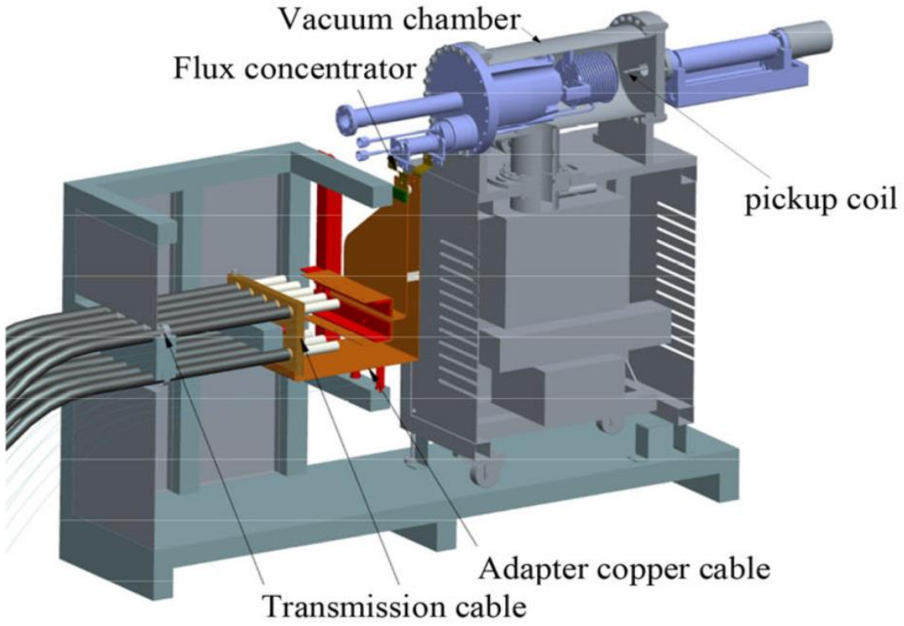
- All-solid-state switching components IGCT instead of hydrogen thyratron (BEPC II)
- Obtained a higher peak current without high-frequency ripples
- Will be used for BEPCII operation this September

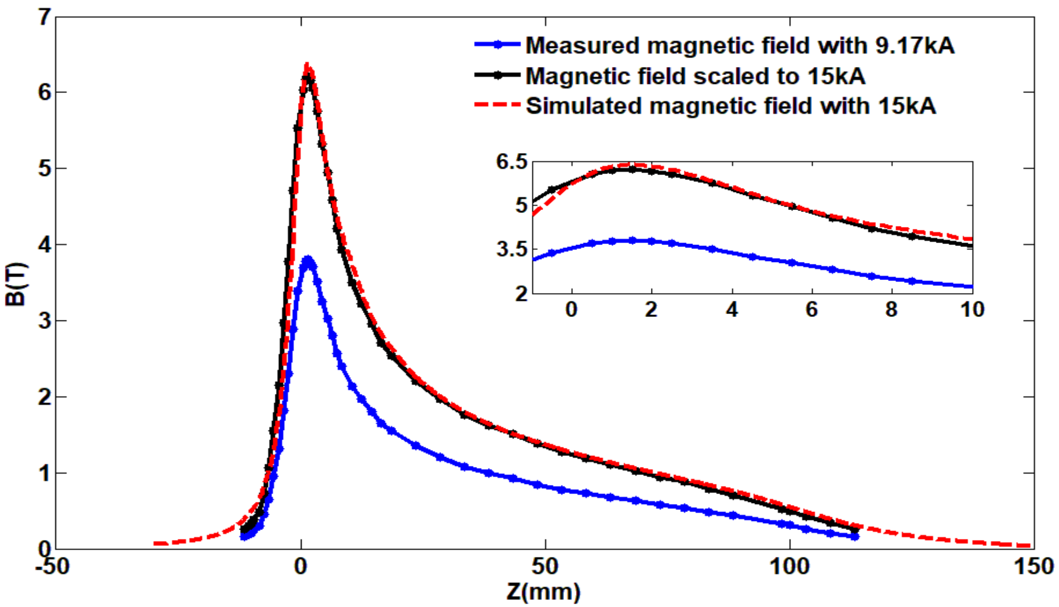
Parameters	Value
Input voltage	380 V ±10%
Output pulse current	15 kA
Pulse width	5 μs
Output waveform	Half sine
Capacity peak voltage	15 kV
Current stability	< 0.1%



Test results of the FC

- A test bench has been built up for performance verification of the FC
- The test results of FC agreed well with the designed parameters
- A peak magnetic field of **6.2 T** had been obtained inside the FC at a **15kA** driving current
- Can meet the requirements of CEPC positron source baseline design





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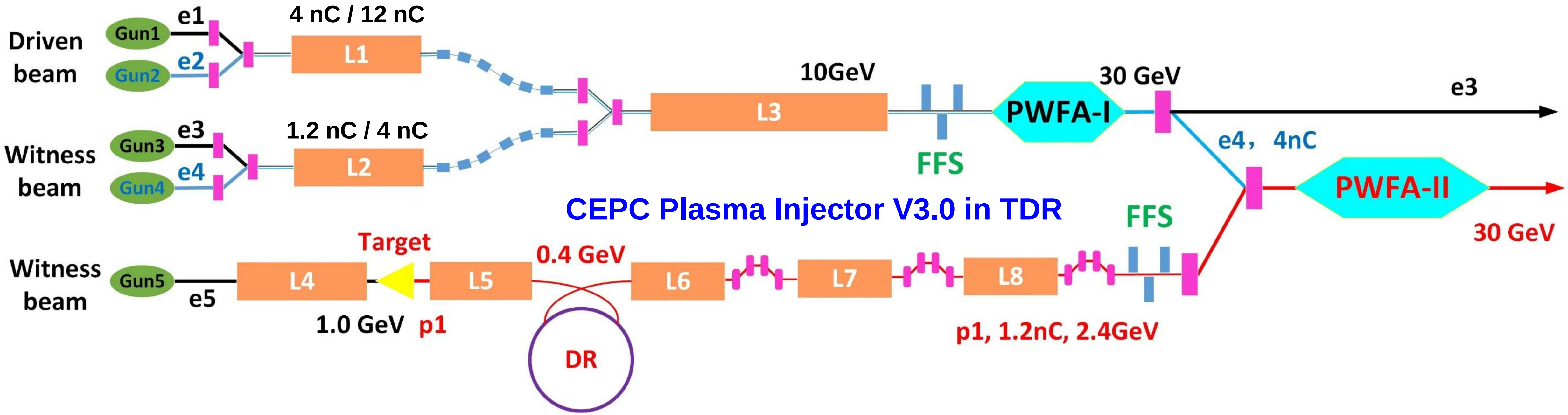
CEPC plasma injector introduction

CEPC plasma injector

- IHEP proposed a CEPC plasma injector scheme as an alternative solution for Linac from 2017
  - New idea: plasma accelerator in combination with traditional accelerators
  - Cost saving to double/triple the energy in one 10-meter-scale plasma
  - Conceptual design based on simulation shows that the scheme is feasible
- Experimental proof and prototyping is required, **especially for positron acceleration**



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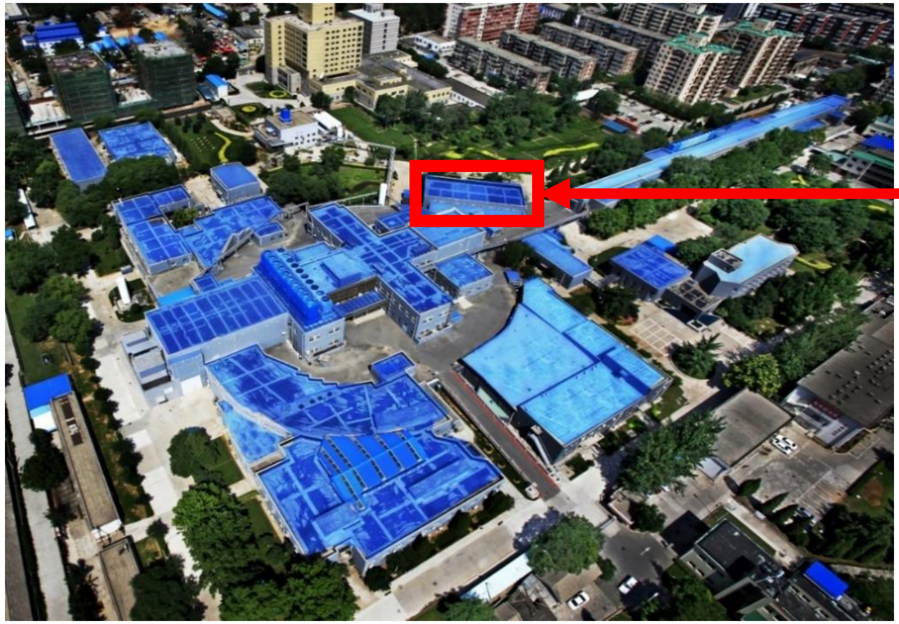
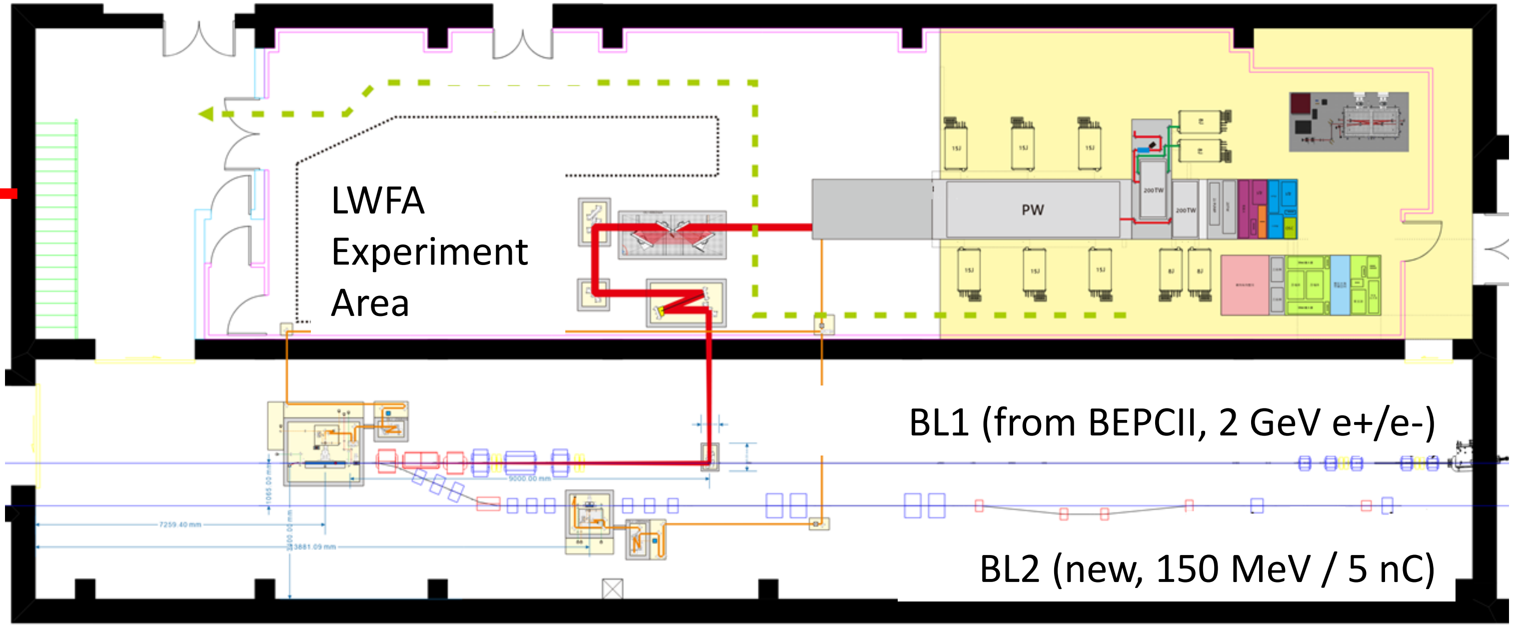
A PWFA-TF Based on BEPCII

A PWFA-TF Based on BEPCII

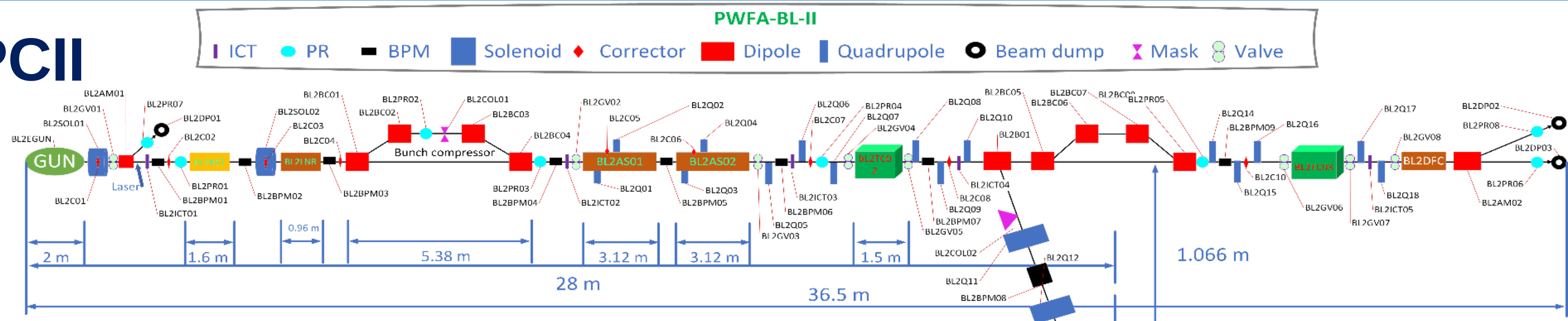
- A new project had been supported by CAS from 2023 October
  - Based on BEPCII: The only in-operation facility can provide high-energy positron beam in China currently
  - For positron acceleration and cascaded acceleration based on PWFA
  - Development of technologies: high charge electron gun and double bunches generation, high power lasers, high rep. plasmas
- CHIEF SCIENTIST: Prof. **Wei Lu**, and first-stage budget ~15M $



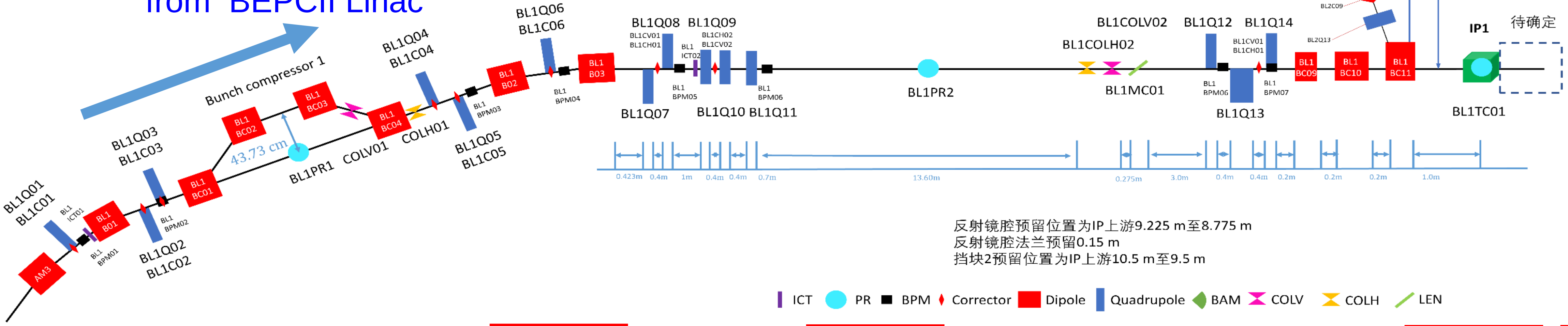


A PWFA-TF Based on BEPCII

A PWFA-TF Based on BEPCII



An extraction beam line from BEPCII Linac

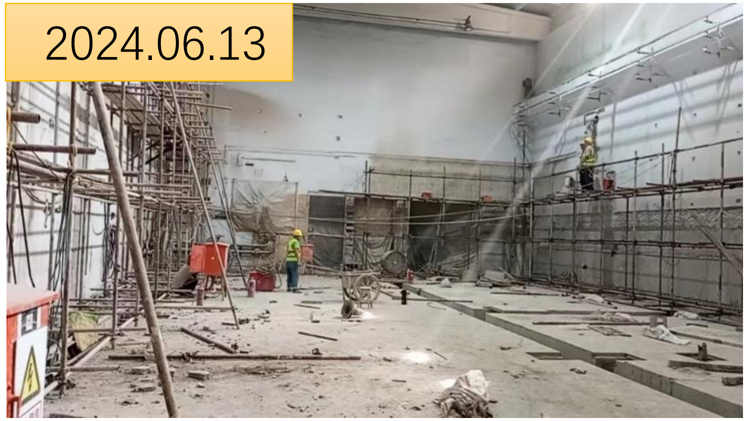


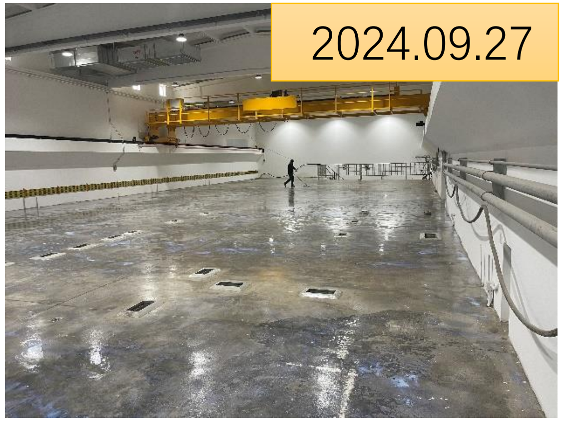
反射镜腔预留位置为IP上游9.225 m至8.775 m
反射镜腔法兰预留0.15 m
挡块2预留位置为IP上游10.5 m至9.5 m

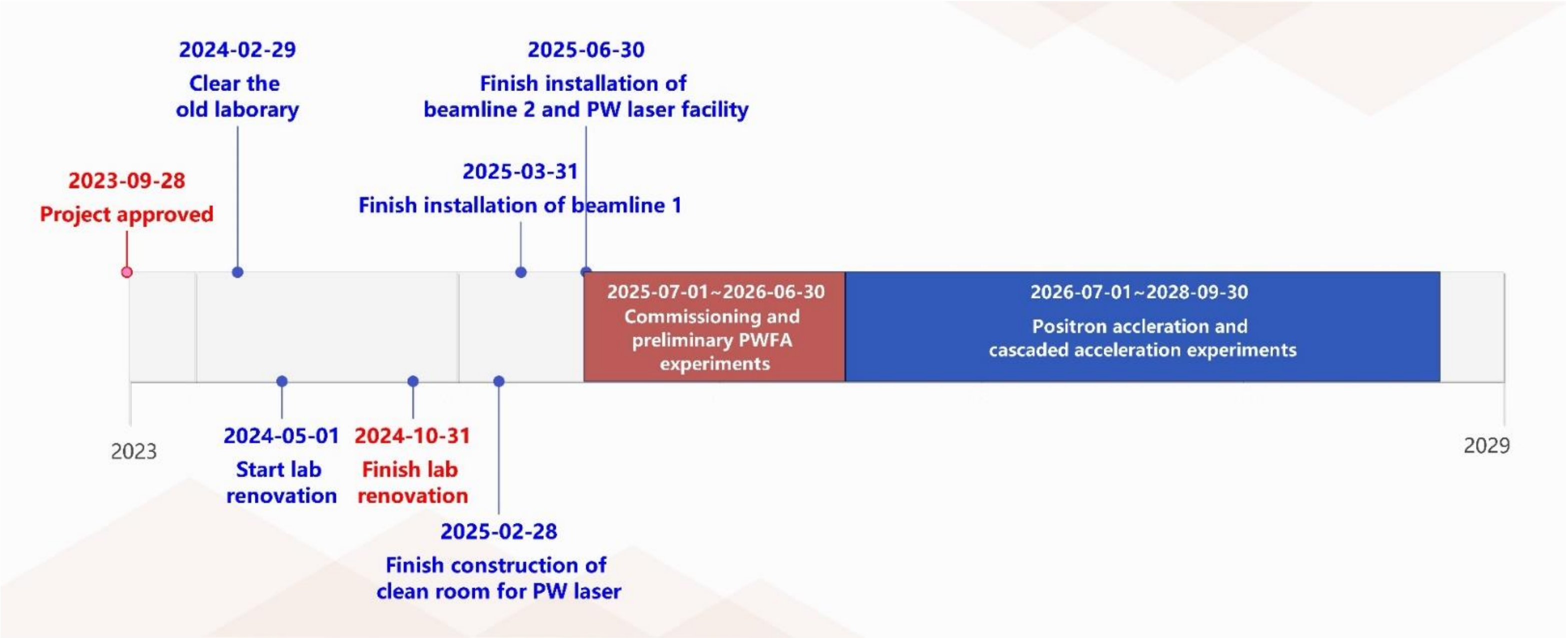
ICT PR BPM Corrector Dipole Quadrupole BAM COLV COLH LEN

Parameters	Unit	BL-I e- (AM3)	BL-I e- (IP1)	BL-I e+ (AM3)	BL-I e+ (IP1)	BL-I e- (IP1, block)	BL-I e+ (IP1, block)	BL-II e- (IP2)	BL-II e- (IP1)
Energy	GeV	2	2	2	2	2	2	0.15	0.15
Charge	pC	2000	2000	100	100	9.4	0.2	5000	1000
bunch length	ps	10	1	10	1	~1	~1	0.7	1
Geo. emittance	mm·mrad	0.1/0.1	0.1/0.1	0.4/0.4	0.4/0.4	0.011/0.005	0.04/0.02		
RMS beam size	µm	-	150/150	-	300/300	30/40	54/76	35/22	100/50

A PWFA-TF Based on BEPCII







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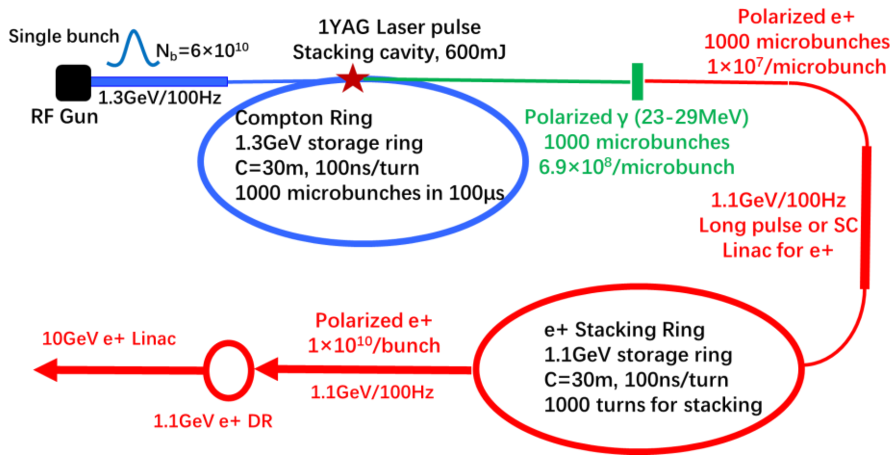
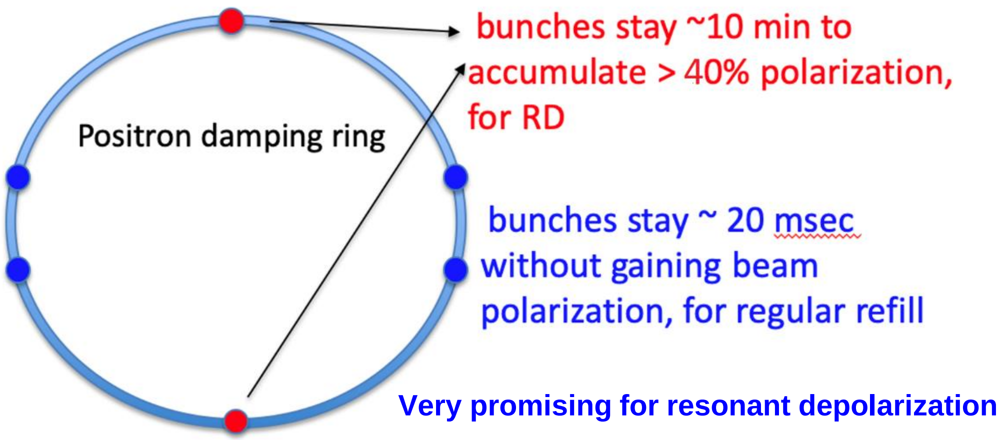
Other related research activities

Polarized positron beam generation

- Preliminary consideration on a Compton Ring and a Stacking Ring for the generation of polarized e+ beams~**1×10^{12}e+/second**
  - 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
  - Need a higher energy in DR around 2GeV and a strong dipole strength
  - Current research shows that extracted beam polarization @ **10min ~ 44%**





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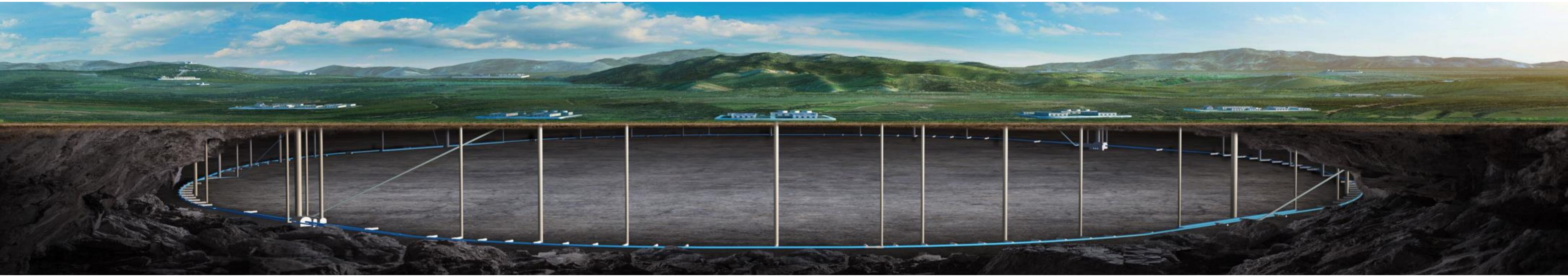
Summary

- The CEPC Linac is a 30 GeV room temperature S-band and C-Band combined linear accelerator working at 100Hz.
- Positron source for CEPC adopting a conventional scheme.
- A flux concentrator prototype and its pulse modulator has been developed and tested.
- A PWFA-TF Based on BEPCII had been supported from 2023 Oct.
- All accelerator devices will be installed by 2025 Jun.

Thank you for your attention!



Parameters		Case-1		
		Req.	Design	W. error
Energy	MeV	150	>150	>150
Bunch charge	nC	5	5	5
Bunch length	ps	≤1 (driver)	0.93	≤1
Beam size	μm	≤70@IP2	39(H)	43±1.8(σ)
			31(V)	32±1.6(σ)
Peak current	kA	≥1.8 (driver)	2.6	

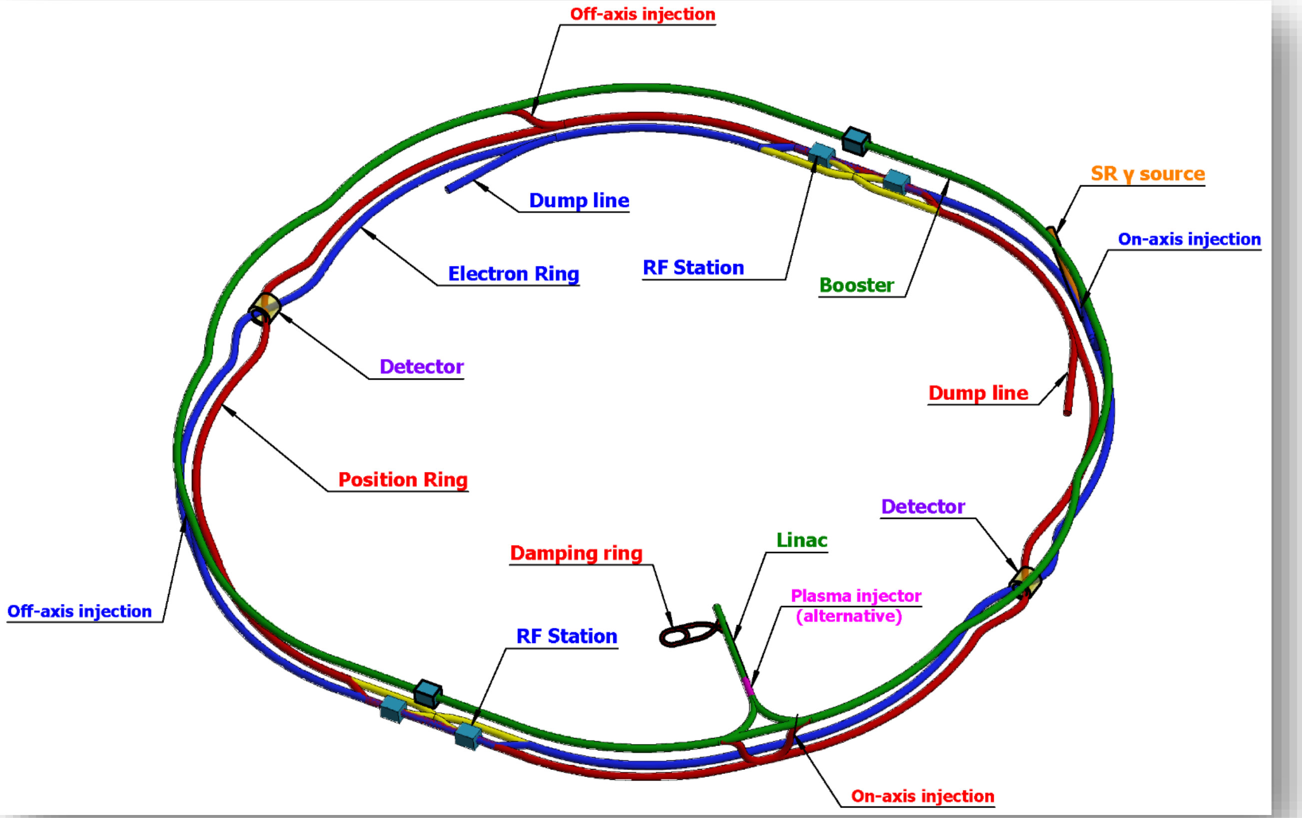
Parameters		Case-2		
		Req.	Design	W. error
Energy	MeV	150	>150	>150
Bunch charge	nC	1	1	1
Bunch length	ps	≤1	0.5	0.51±0.1
Beam size	μm	≤100@IP1	27(H)	38.5±8.3(σ)
			33(V)	36.8±5.4(σ)
Peak current	kA	≥1.5	2.0	
Length	m	28	27.7	

Parameters		Case-3	
		Req.	Design
Energy	MeV	≥170	172.7
Bunch charge	nC	≥0.03	0.042
Bunch length	ps	≤1	0.36
Beam size	μm	≤100@IP1	75/73
Peak current	kA	/	0.05

Introduction: CEPC Layout

- CEPC as a Higgs (ttbar,H, W, Z) Factory
  - **Linac, 30GeV, 1.8km**
  - Full energy Booster, 100km
  - Collider, 100 km
  - Transport lines
- Linac design
  - Meet requirements
  - High availability
  - Reserve upgrade potential

$$L_{\text{int}} = \int_0^T L(t)dt = \langle L \rangle \cdot T_s \cdot \eta$$



Introduction: Linac energy

- The maximum energy of booster is 180GeV and circumference is 100 km
  - Large circumference & Low injection energy → Low magnetic field
    - design difficulty in magnet (*field*) and power supply (*stability*)
  - Large extraction energy → Large field range
    - design difficulty in magnet (*excitation efficiency*) and power supply (*power*)
- Increasing the energy of the Linac is the easiest way: 30 GeV

Wen Kang
Session M2-2: #1

Magnet		Low injection energy			Max. Extraction energy	Cost
		10GeV	20GeV	30GeV	180GeV	
CT Air-core coil		Yes	Yes	Yes	No	Very high
iron-corn magnet	oriented silicon steel sheet	No	Yes	Yes	Yes	high
	Non-oriented silicon steel sheet	No	No	Yes	Yes	low

effect of residual magnetism

Positron Linac: TAS

- Simulation results(including Wakefield & CSR)

Parameter	Unit	Value	Simulated	
			Positron	
Beam energy	GeV	30	30.50	30.01
Repetition rate	Hz	100	/	
Bunch charge	nC	1.5	1.5	3.0
Energy spread	10^{-3}	1.5	1.33	2.19
Emittance(x/y)	nm	6.5	3.37/1.68	3.90/1.71
Bunch length (RMS)	mm	/	0.4	0.4