CEPC Linac injector design status

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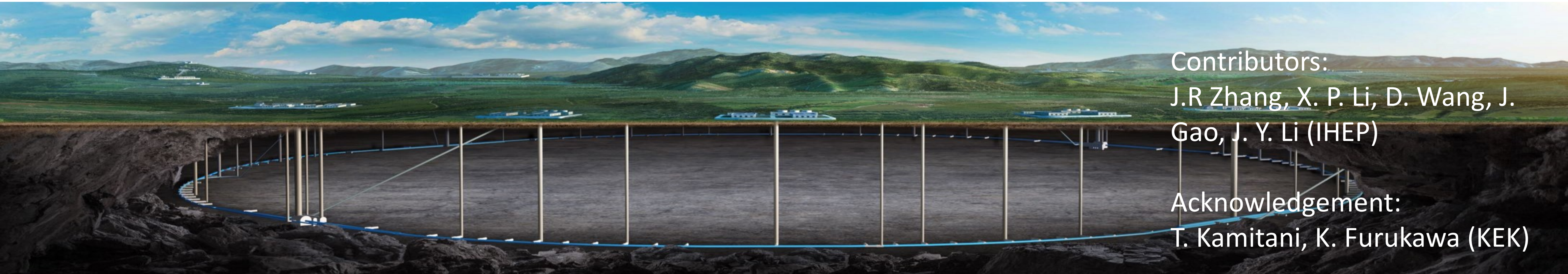

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Content

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
    - 10%~15% accelerating units backup
  - Reserve upgrade potential

$$L_{\text{int}} = \int_0^T L(t)dt = L_{max} \ \ T_s \ \ \eta_{PDT}$$

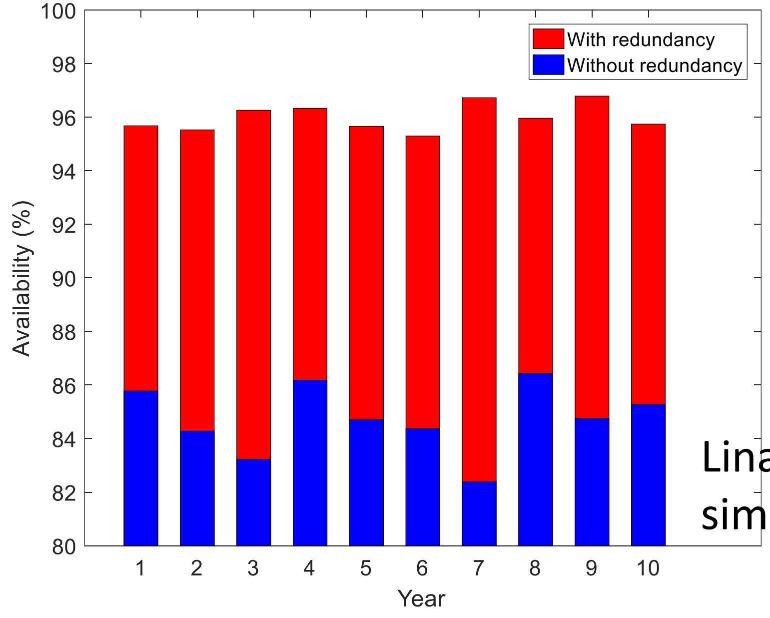
$\eta_{PDT} = \eta_{HA}\, \eta_{BE}\, \eta_{CE}$

η_{PDT}: Physics data taking efficiency

η_{HA}: Hardware availability

η_{BE}: Beam effectiveness

η_{CE}: Collision effectiveness

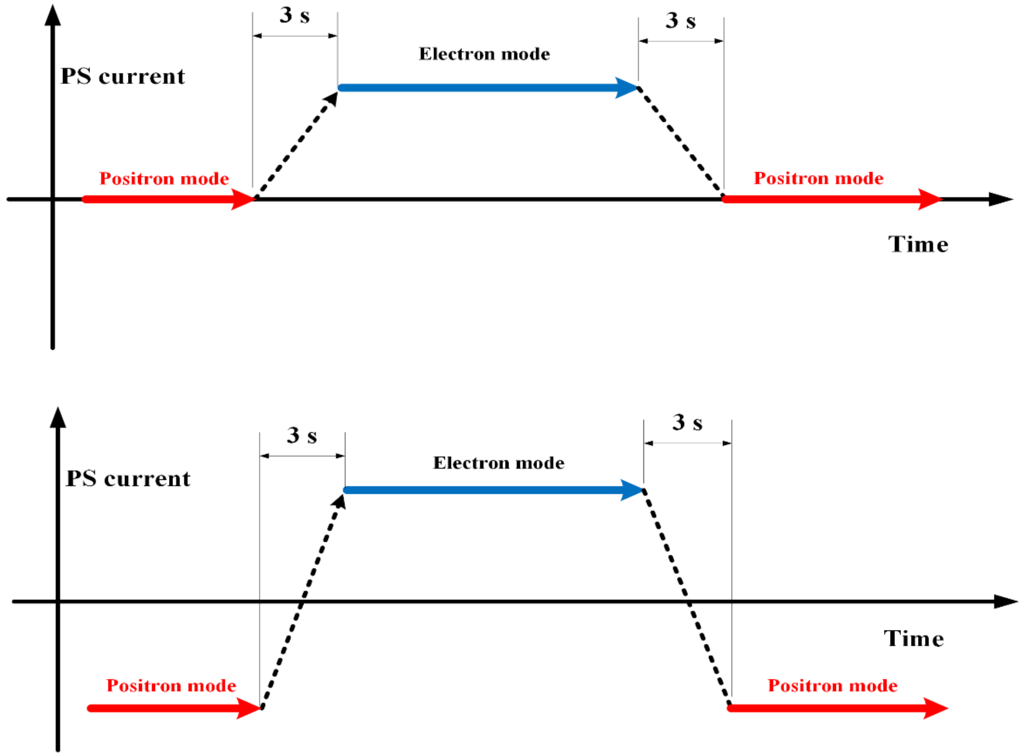


Linac availability simulation @ CDR

Introduction: Linac parameters

- CEPC Linac is a high energy electron and positron linear accelerator

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
Switch time for electron and positron		s	3.0



Introduction: Why is 30-GeV needed?

- 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 and total-cost-saving solution

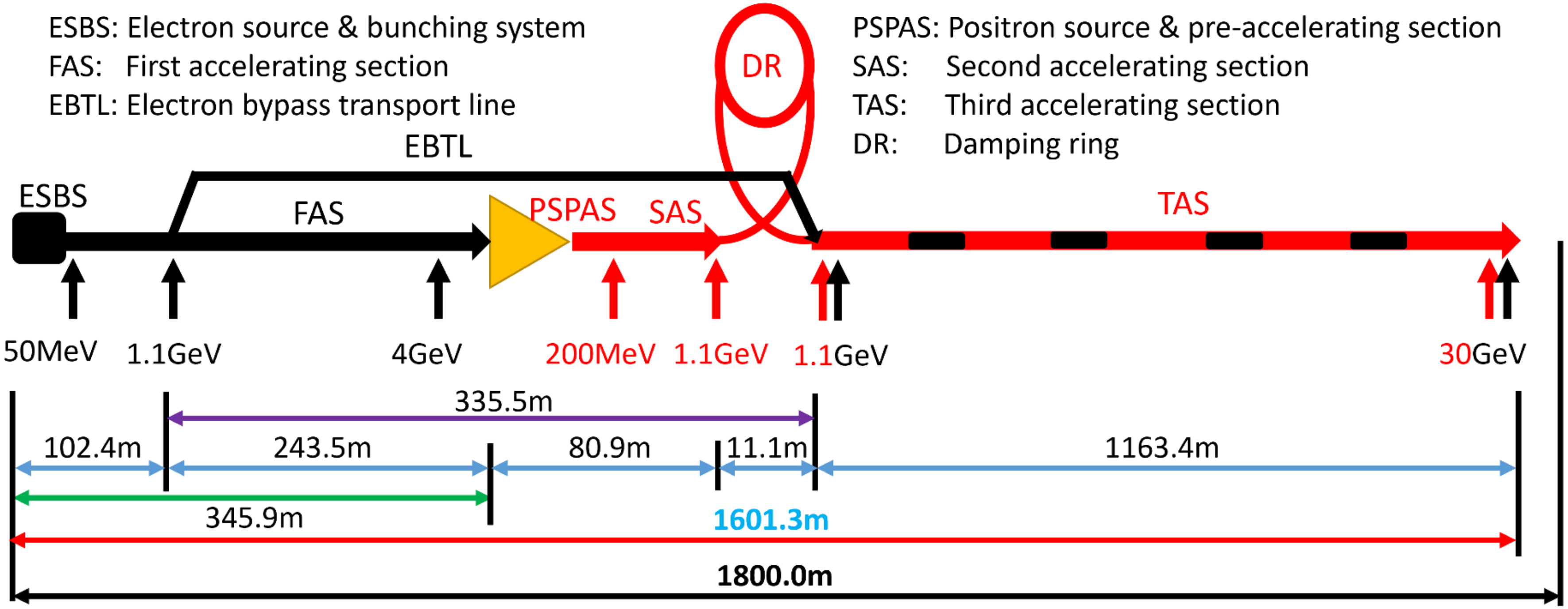
Magnet		Low injection energy			Max. Extraction energy	Cost
		10GeV	20GeV	30GeV	180GeV	
CT Air-core coil		Yes	Yes	Yes	No	Very high
iron-corn magnet	oriented silicon steel sheet	No	Yes	Yes	Yes	high
iron-corn magnet	Non-oriented silicon steel sheet	No	No	Yes	Yes	low

Introduction: How to achieve 30-GeV

- S-band accelerating structure@ low energy part and high bunch charge part
- C-band accelerating structure @TAS (1.1GeV→30GeV)
  - Cost saving (Only consider the RF system and Power Source system)
    - S-band: 44.6 Million CNY/GeV   @ 80 MW klystron
      - 1 klystron drive 4 accelerating structure, 22 MV/m
    - C-band: 42.9 Million CNY/GeV   @ 50 MW klystron [Baseline scheme]
      - 1 klystron drive 2 accelerating structure, 40 MV/m
    - C-band: 27.3 Million CNY/GeV   @ 80 MW klystron
      - 1 klystron drive 4 accelerating structure , 40 MV/m
  - Higher gradient → Shorter linac tunnel length → cost saving
  - Small aperture → Strong wakefield

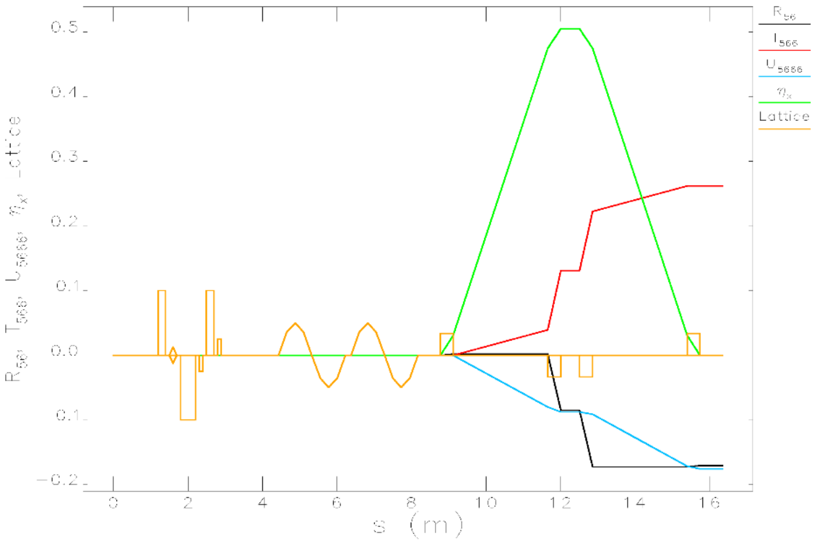
Introduction: Layout

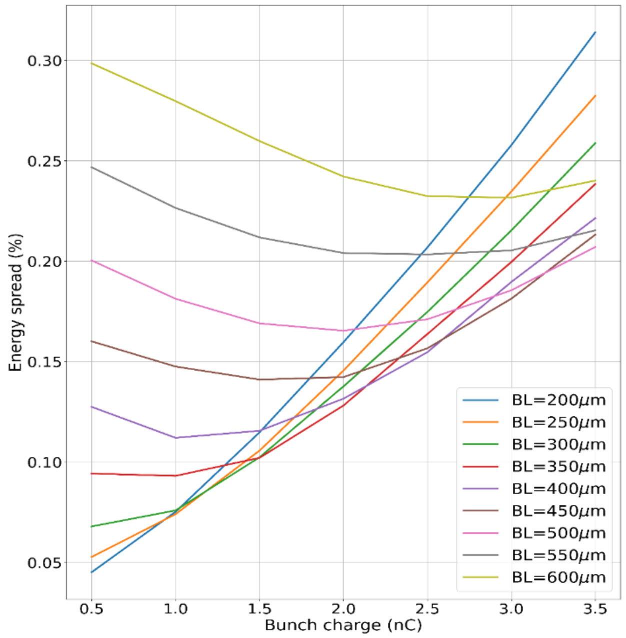
- The tunnel is 1.8km
  - Linac is about 1.6 km
  - 200 m as reserved space

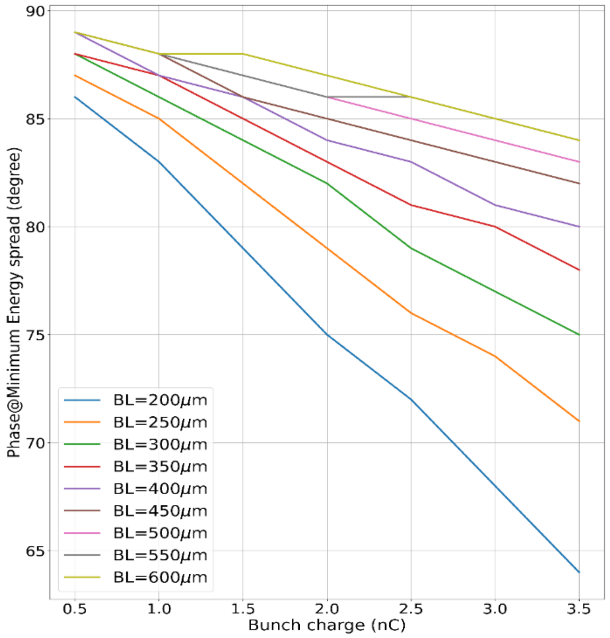


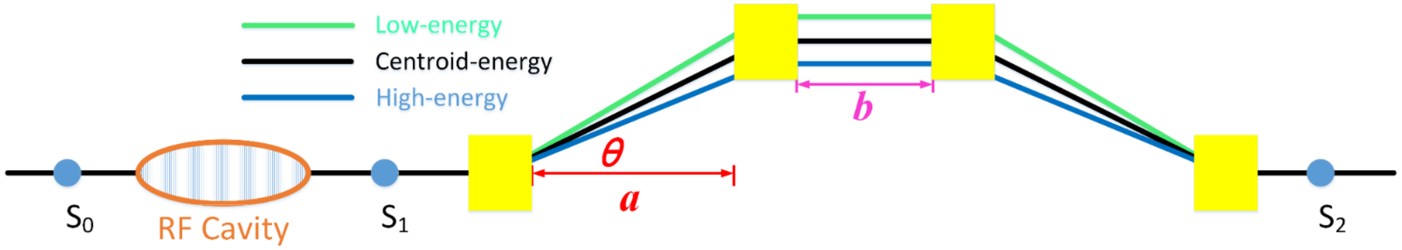
Basic consideration: Bunch length

- Energy spread is determined by Wakefield and bunch length of TAS
  - 400 μm
- Bunch compressor
  - Chicane-type
  - 1.0~1.2 mm → 0.4 mm





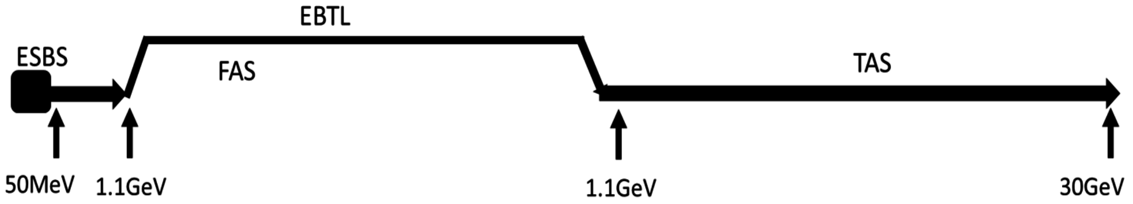


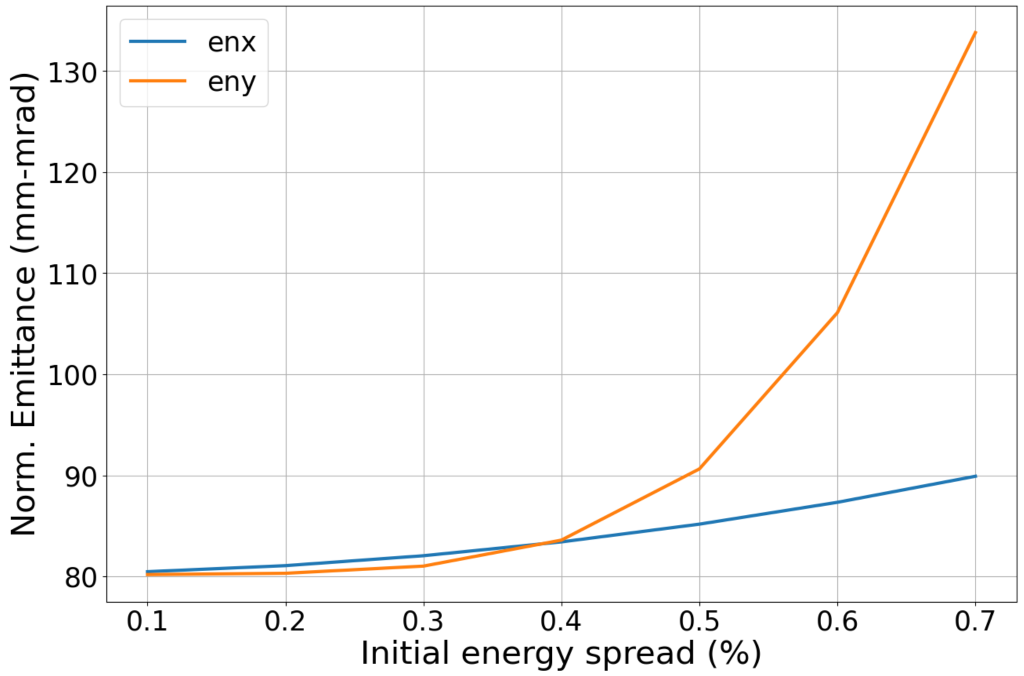


Electron Linac: Acceleration section

- ESBS
  - Thermionic cathode electron gun
  - Two subharmonic buncher
- FAS:50MeV→1.1GeV
  - 5+1(redundancy) S-band klystron
  - 1 klystron →4 accelerating structures @22MV/m
- EBTL
  - Vertical separation
  - Local achromatic design
  - Emittance growth (T366 and U3666)
    - In the design, energy spread is 0.2%
- TAS: 1.1GeV→30GeV
  - 215+21(redundancy) C-band klystron
    - 1 klystron →2 accelerating structures@40MV/m
    - 9% backups

ESBS: Electron source & bunching system
FAS: First accelerating section
EBTL: Electron bypass transport line
TAS: Third accelerating section

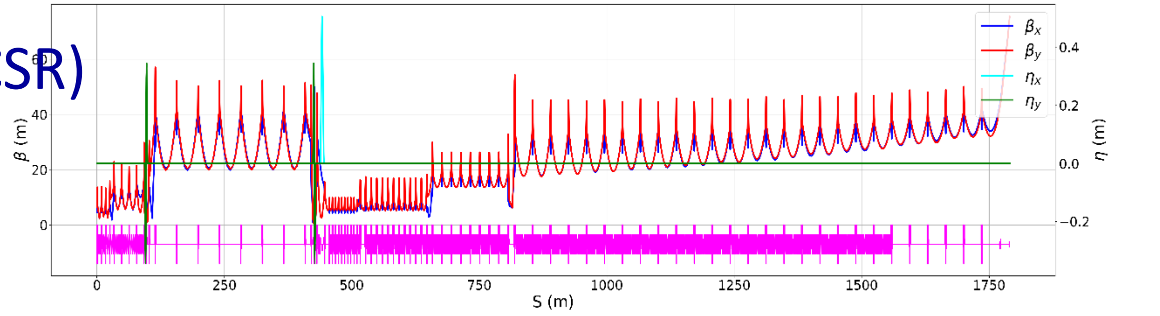


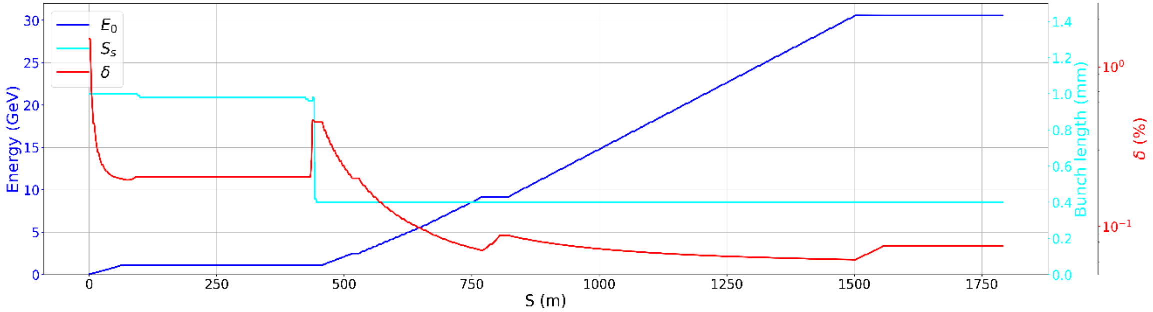


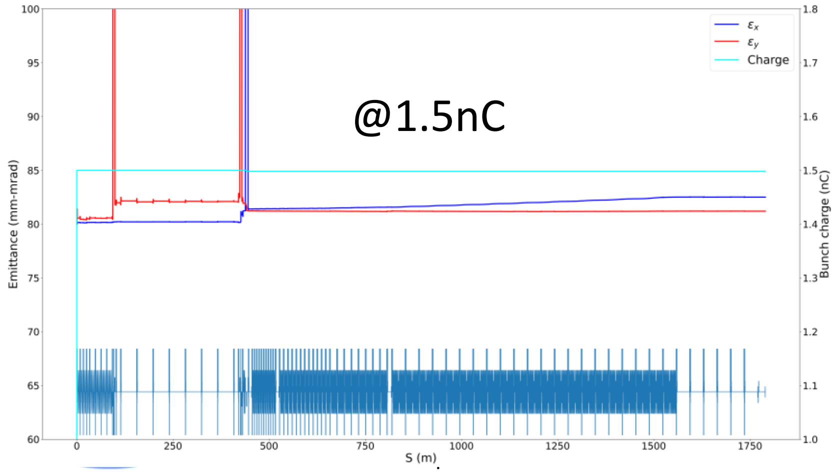
Electron Linac: Beam dynamics results

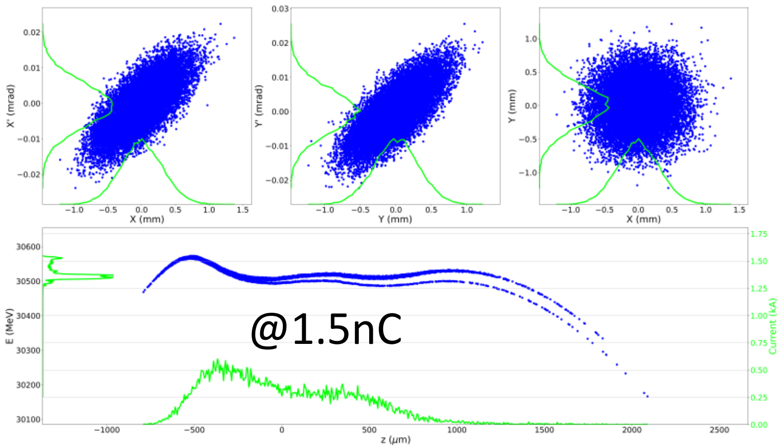
- Simulation results(including Wakefield & CSR)

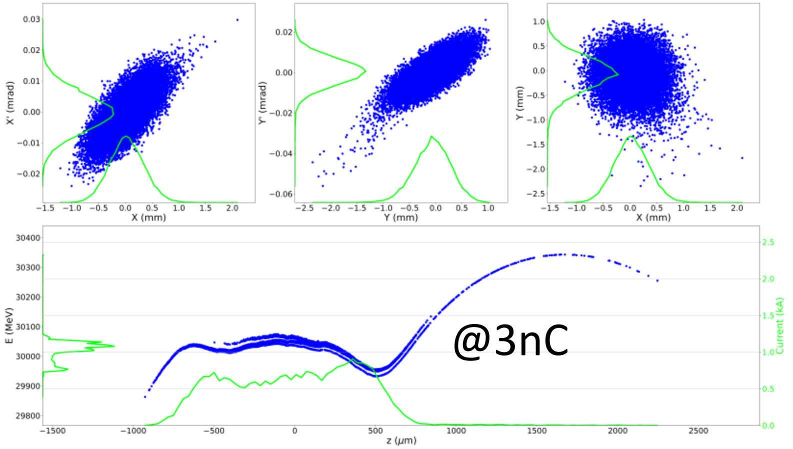
Parameter	Unit	Value	Simulated	
			Electron	
Beam energy	GeV	30	30.56	30.06
Bunch charge	nC	1.5	1.5	3.0
Energy spread	10^{-3}	1.5	0.76	1.34
Emittance(x/y)	nm	6.5	1.38/1.36	1.46/1.75
Bunch length (RMS)	mm	/	0.4	0.4





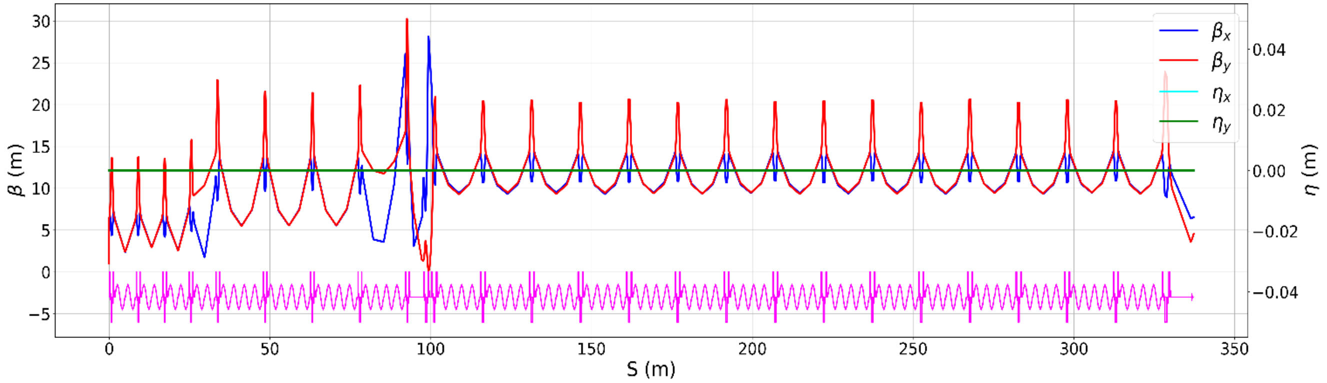


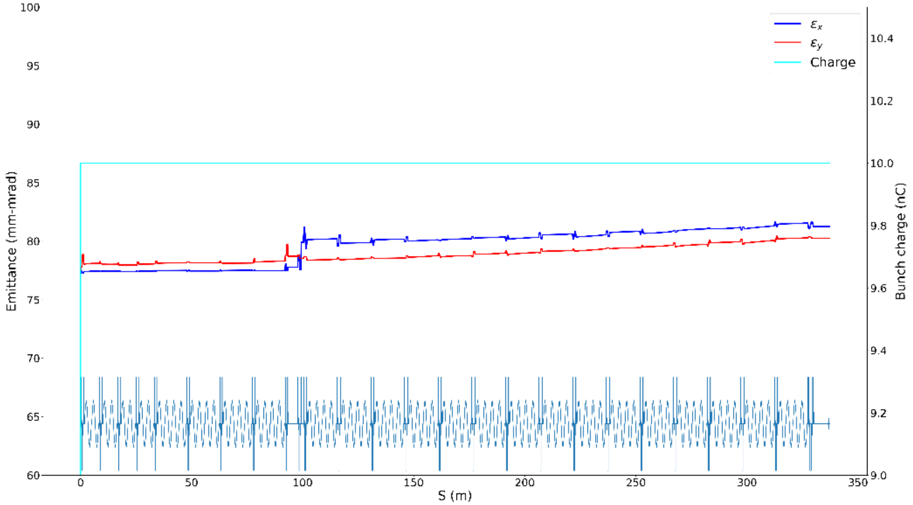


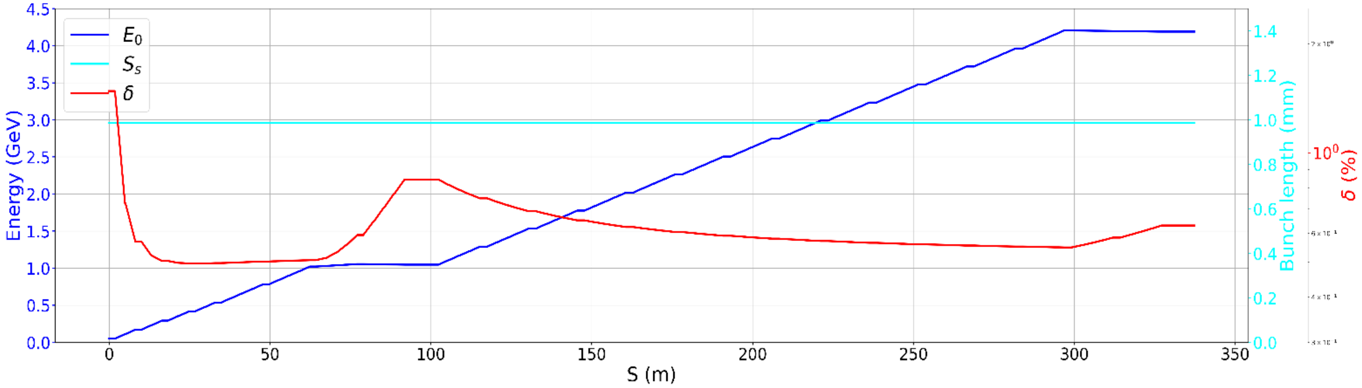


Positron Linac： FAS for positron production

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

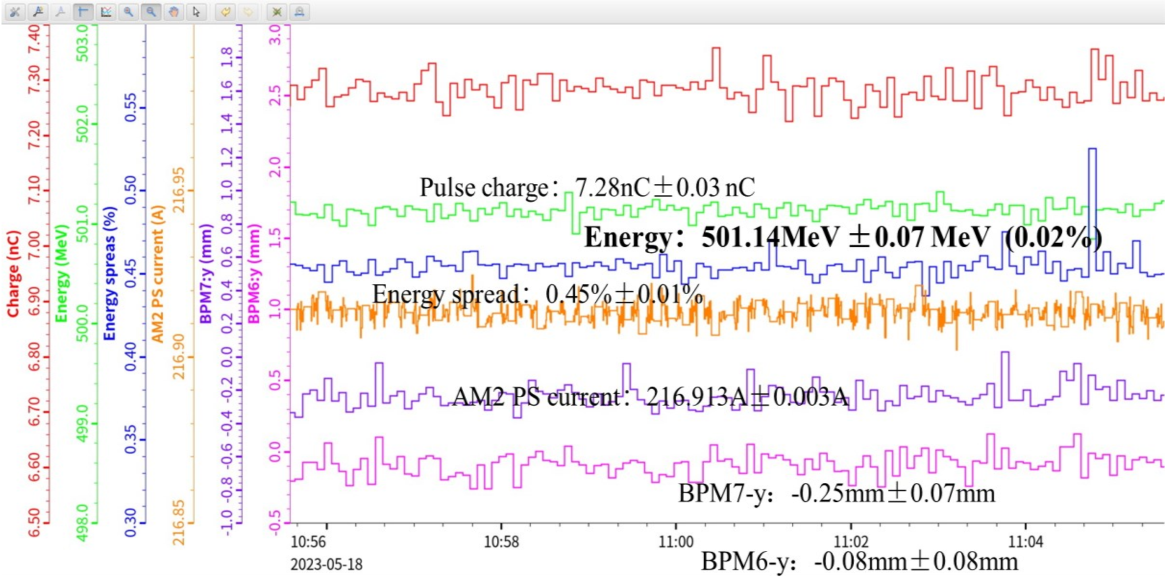


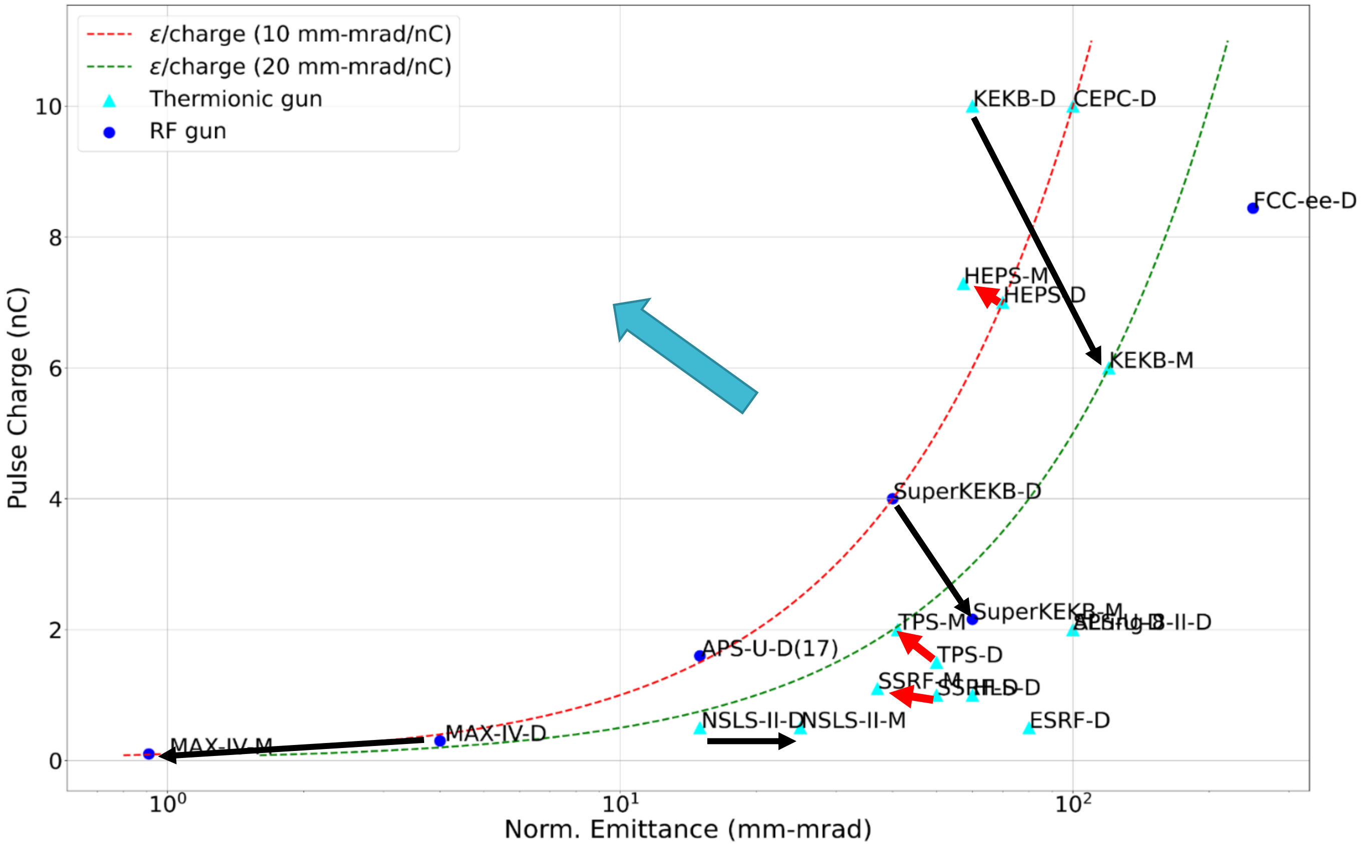




High bunch charge Linac

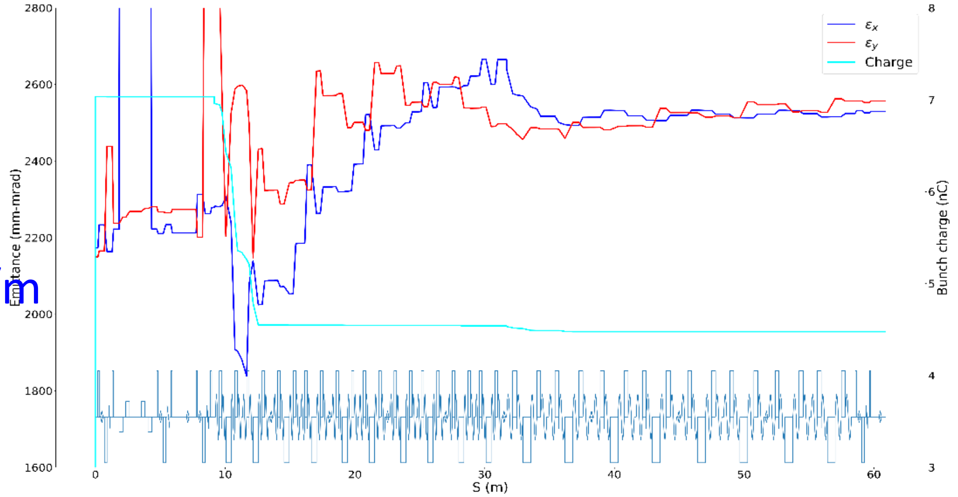
- High Energy Photon Source Linac
  - Bunch charge: 7nC
  - Energy: 500MeV
  - Energy jitter: 0.02%



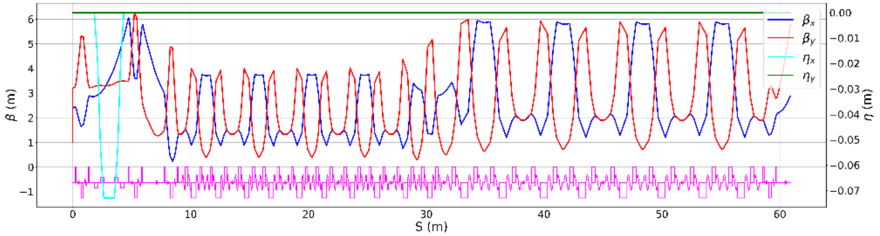


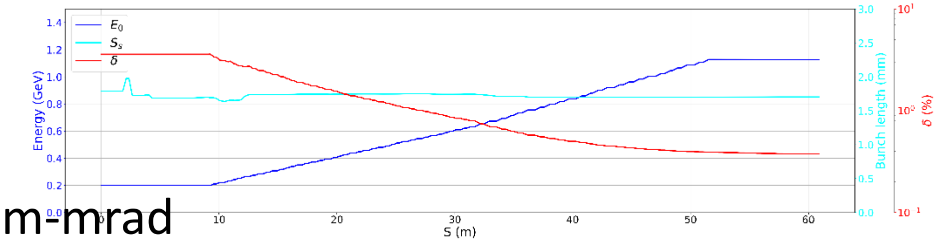
Positron Linac: SAS

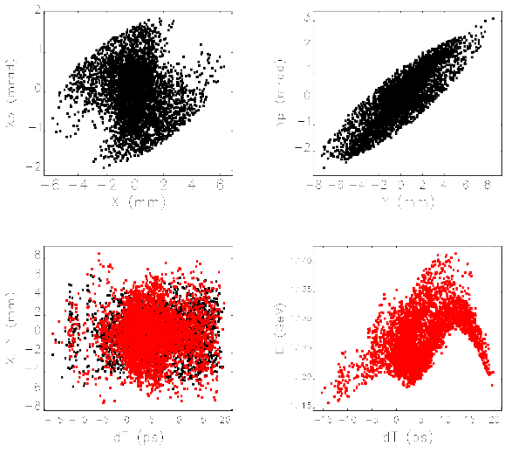
- Acceleration： 200MeV→1.1GeV
  - 8+1(redundancy) S-band klystron
  - 1 klystron →2 accelerating structures
    - 10 Larger aperture S-band accelerating structure@22MV/m
    - 8 normal S-band accelerating structure@27MV/m
    - HEPS: 26MV/m with beam (limit by power source)



- Transverse focusing
  - Triplet quadrupoles are outside each accelerating structure
- Simulation results
  - Energy spread: 0.4%
  - Bunch charge: ~4.5nC
  - Normalized rms Emittance: 2500mm-mrad



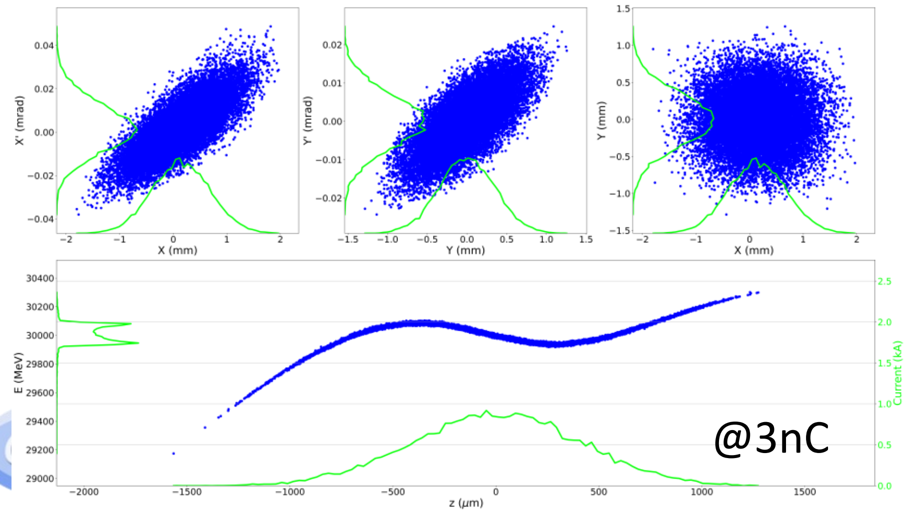


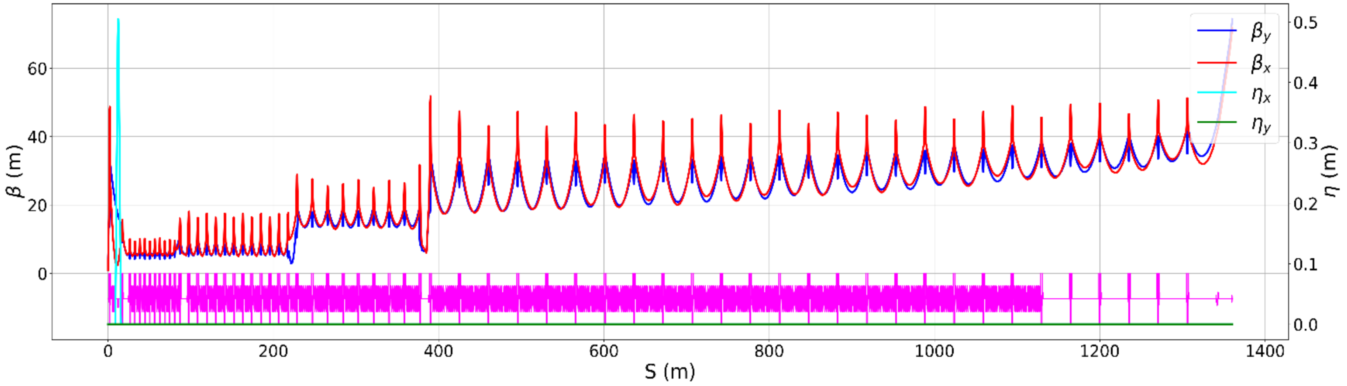


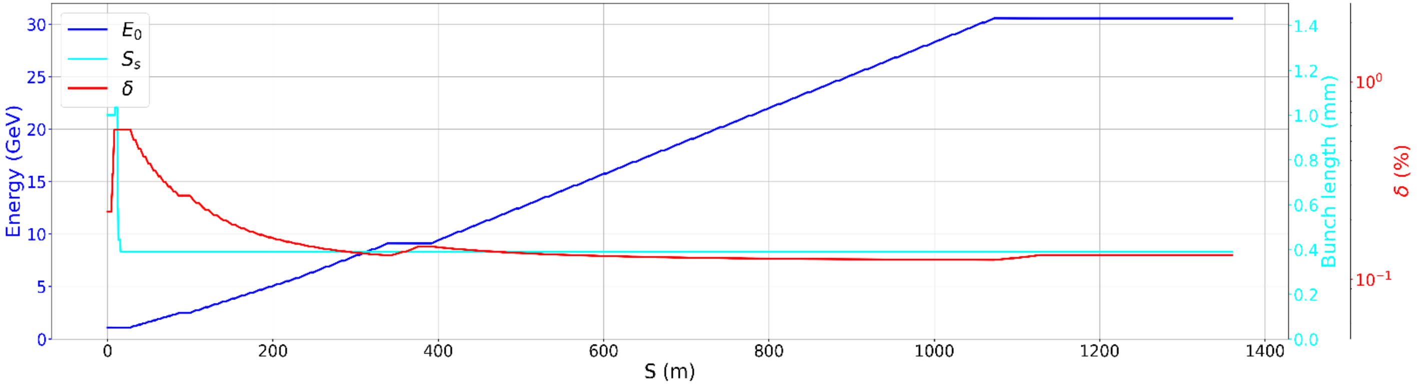
Positron Linac: TAS

- 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	2.2
Emittance(x/y)	nm	6.5	3.37/1.68	4.01/1.71
Bunch length (RMS)	mm	/	0.4	0.4







Error study: simulation results

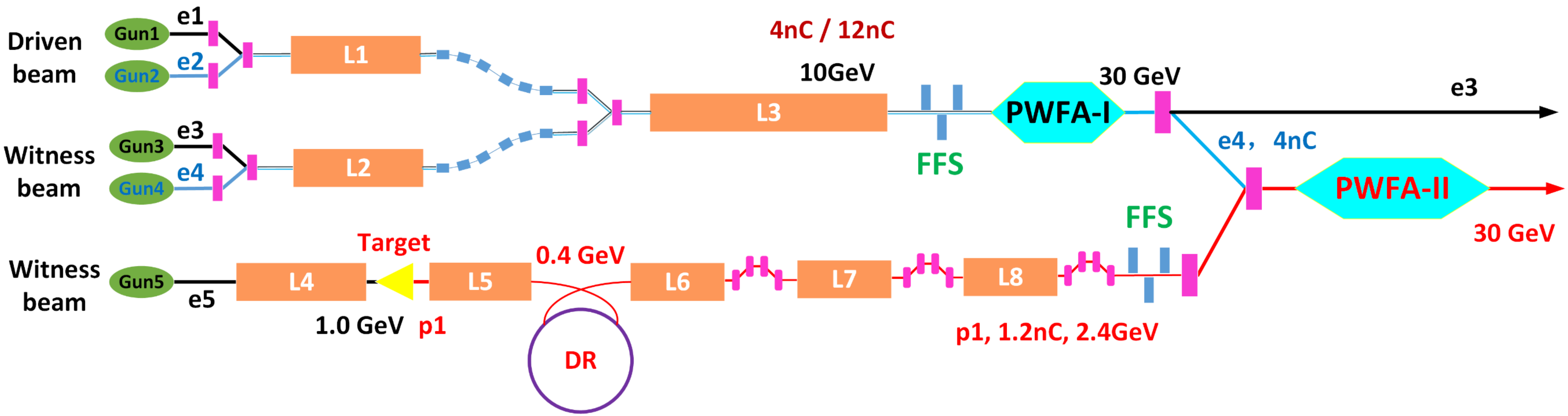
- According to simulation, the Linac with errors can meet the requirements @ 1.5nC
  - Misalignment errors, gradient errors, phase errors

Parameter		Unit	Value	Simulated			
				Electron		Positron	
Beam energy		GeV	30	30.5	30.0	30.5	30.0
Bunch charge		nC	1.5	1.5	3.0	1.5	3.0
Energy spread	W/O error	$\times10^{-3}$	1.5	0.76	1.34	1.33	2.2
	W/ error			0.75±0.14	1.45±0.13	1.33±0.01	2.2±0.01
Energy jitter		$\times10^{-3}$	1.0	0.22	0.24	0.21	0.22
Emittance(H/V)	W/O error	nm	6.5	1.38 1.36	1.46 1.75	3.37 1.68	4.01 1.71
	W/ error			1.41±0.07 1.40±0.06	2.11±0.30 2.41±0.62	3.39±0.08 1.69±0.03	5.33±1.63 2.36±0.56

PWFA injector

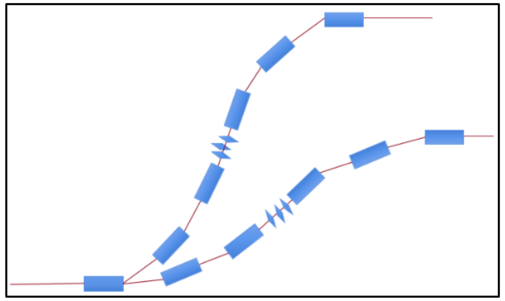
Detailed in talk of Prof. D. Z. Li

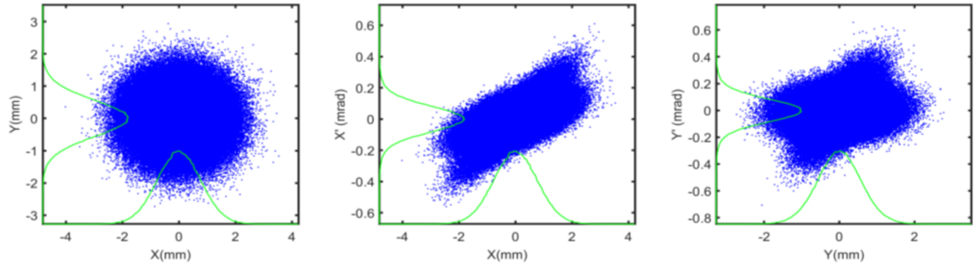
- A 30 GeV injector based on Plasma WakeField Acceleration (PWFA) is currently being designed.

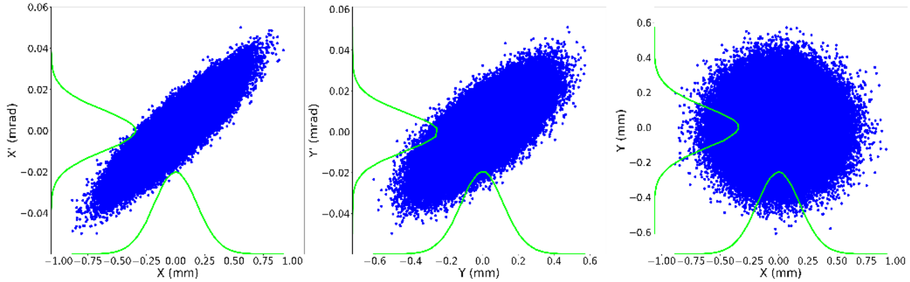


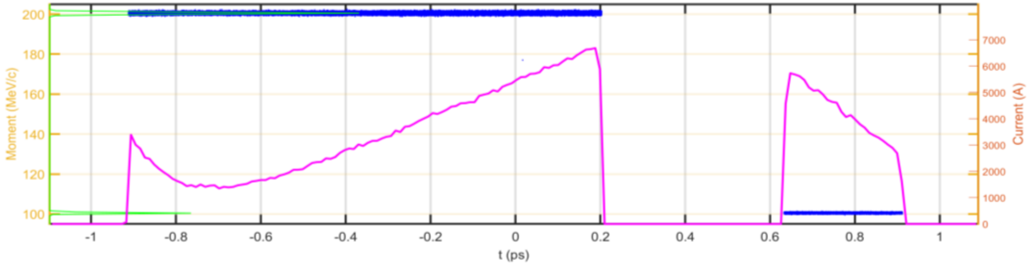
PWFA injector

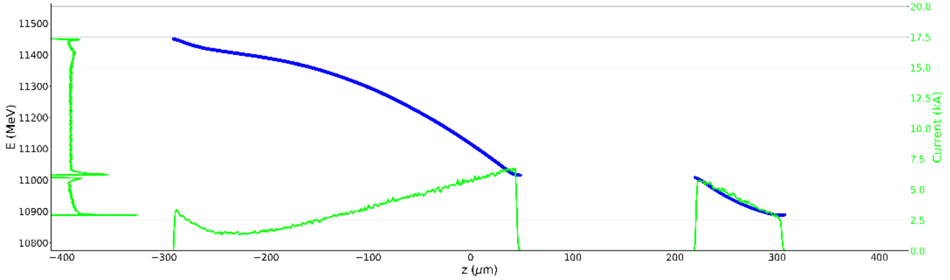
- An external injected drive-witness bunch pair merge system with femtosecond timescale jitter
  - The two-electron beam with different energy can be merge by one common dipole
  - High order isochronous merge system
- Main Linac acceleration



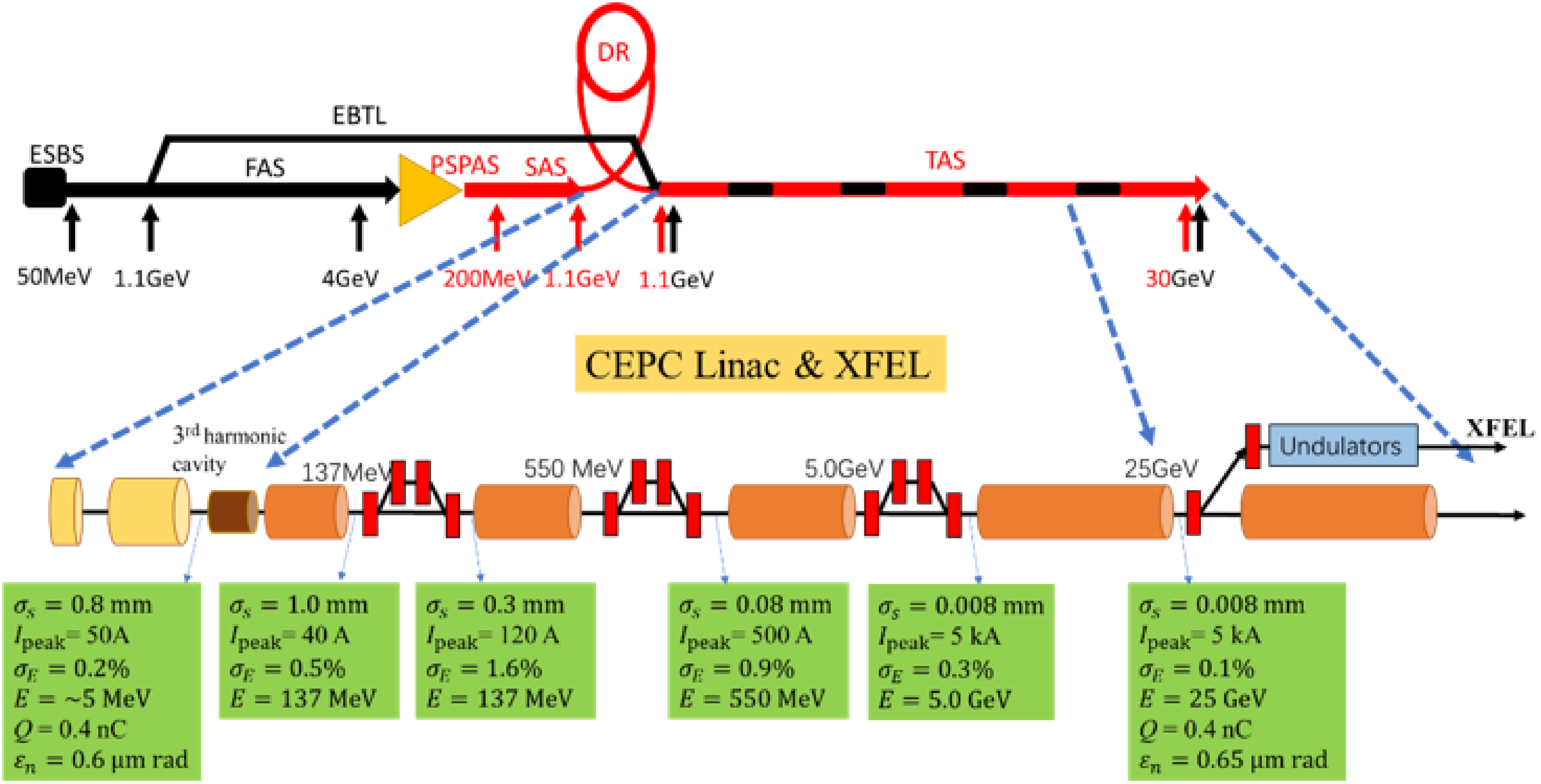








A high energy FEL

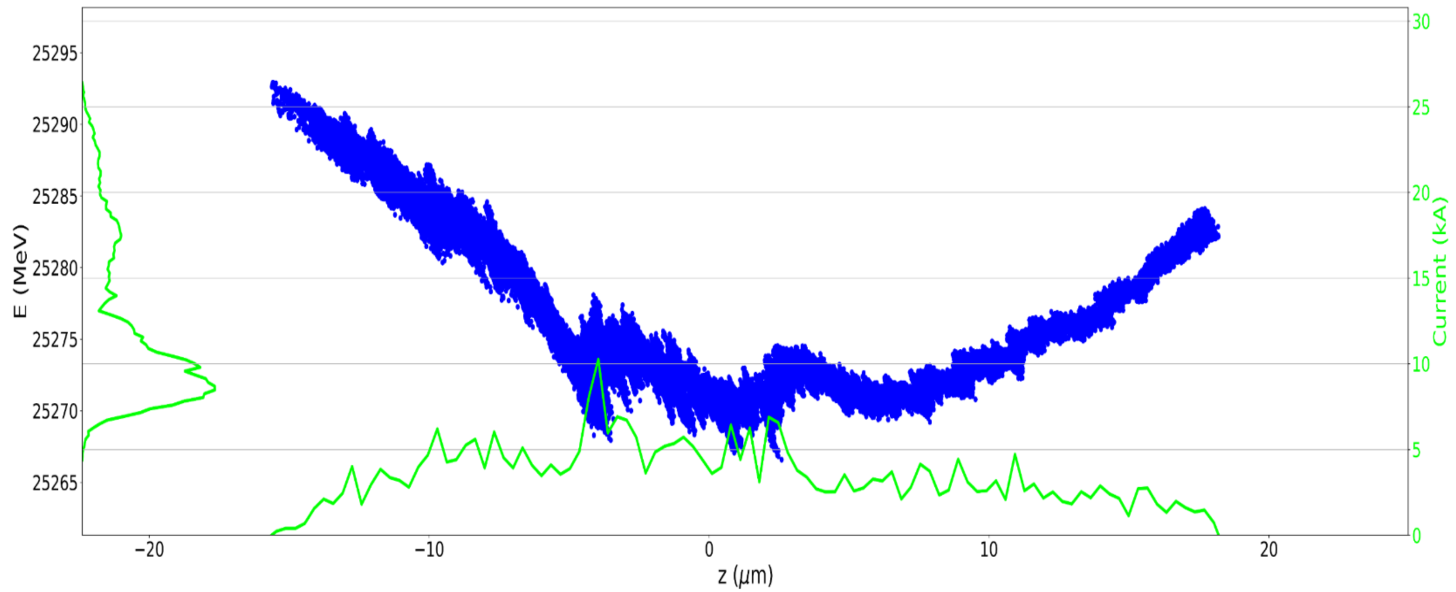


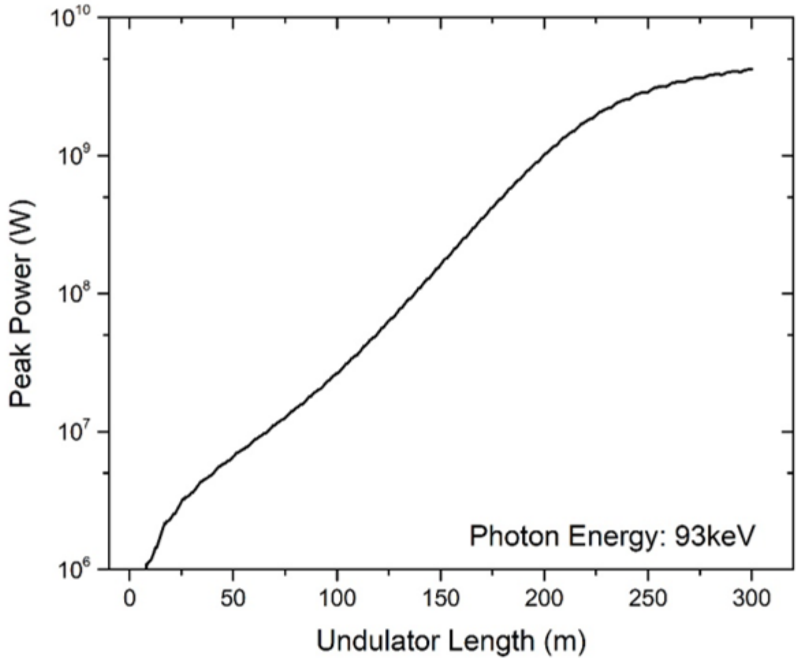
A high energy FEL

- Beam
  - 25GeV
  - Slice energy spread 2 MeV
- SASE-FEL
  - 93keV

	Unit	tt	Higgs	W	Z
Injection interval for collision	s	32	20	36	71
Linac time for FEL	s	28	14	20	3
Duty ratio	%	88	70	56	4

@Dou Wang





Summary

- The Linac energy is designed to 30 GeV to ease the booster magnet design difficulties (low field at injection energy and large magnetic field range) and save the total cost.
- The C-band accelerating structure is used from 1.1 GeV to 30 GeV and is the main acceleration part.
- The lattice design and dynamic simulation have been finished, the design can meet the requirements.
- During the EDR stage, double-bunch acceleration and availability analysis will be further study.
- As the high energy injector, the study of PWFA and high energy FEL is under going.

Thank you for your attention!