Overall Design of the CEPC Injector Linac

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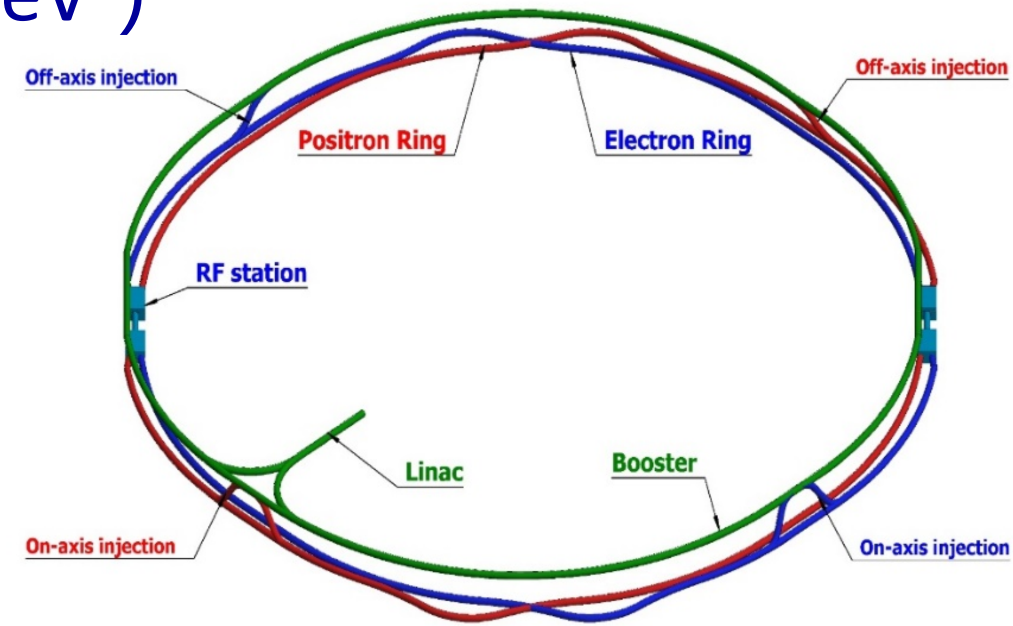
Outline

CEPC layout

- CEPC (Circular Electron-Positron Collider) was proposed by Chinese Scientists in Sep. 2012
- It is a Higgs Factory
- There will be two detectors in the main ring
- The CDR has been official released in Nov 14, 2018
- From 2018-2022, finish TDR

CEPC layout

- The circumference of the collider is 100 km (120Gev)
- The booster circumference is 100 km.
- The total length of the linac is about 1.2 km （10GeV）



Outline

1. CEPC layout
2. CEPC linac design
3. CEPC linac key technologies development
4. Summary

CEPC linac design

- The requirements of the booster to the linac

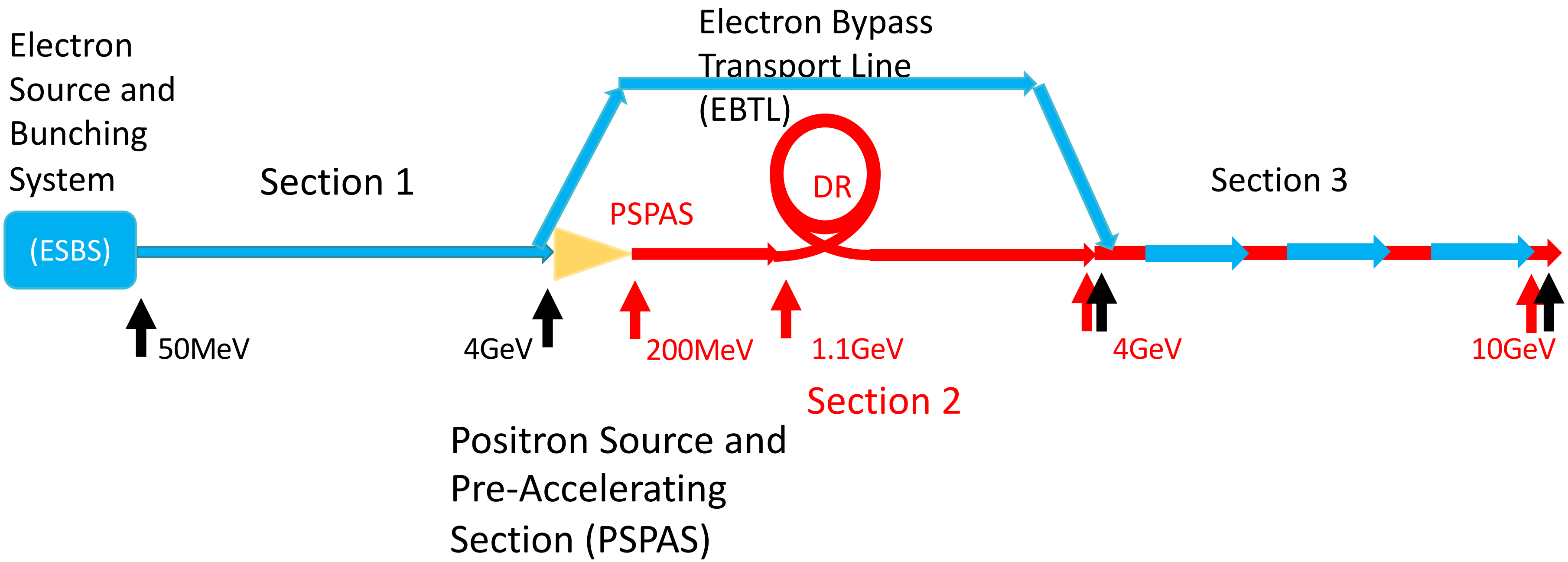
Parameter	Symbol	Unit	Value
e^-/e^+ beam energy	E_{e-}/E_{e+}	GeV	10
Repetition rate	f_{rep}	Hz	100
Bunch numbers per pulse			1
e^-/e^+ bunch population	$Ne-/Ne+$		$>9.4\times10^9$
		nC	>1.5
Energy spread (e^-/e^+)	σ_E		$<2\times10^{-3}$
Emittance (e^-/e^+)	ε_r	nm	<120

CEPC linac design

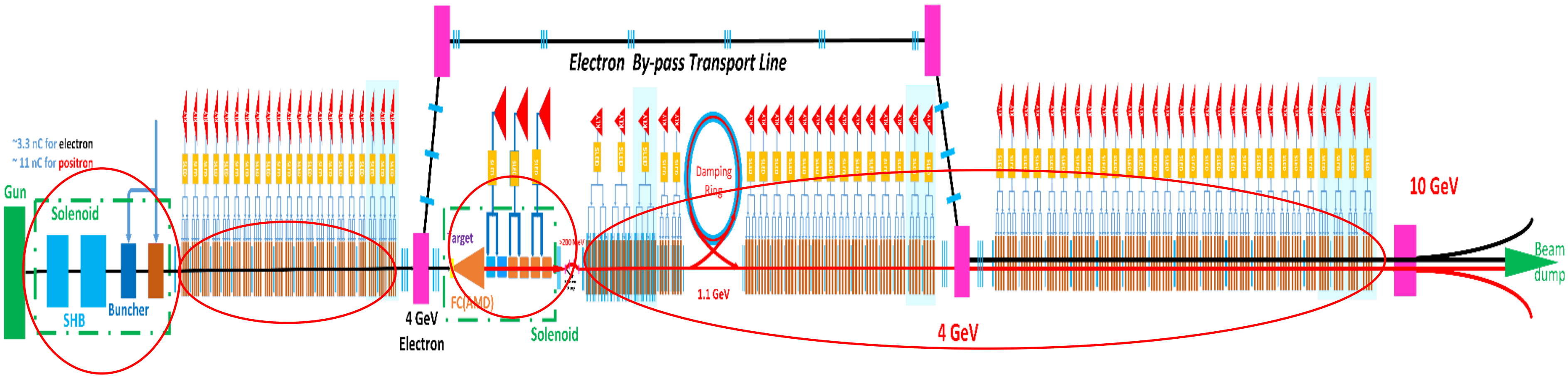
- Linac design goals
  - Should provide beams that can meet requirements of Booster
  - Top-up injection can be implemented
  - Should have the high availability and reliability
    - Thermionic electron gun (High charge)
    - Normal conducting structures and mature technologies
    - ~ 15% backups for linac RF units
  - Should have the potential to meet the higher requirements and updates in the future, such as
    - Two bunches accelerating mode
    - Increasing of charge quantity
    - ……

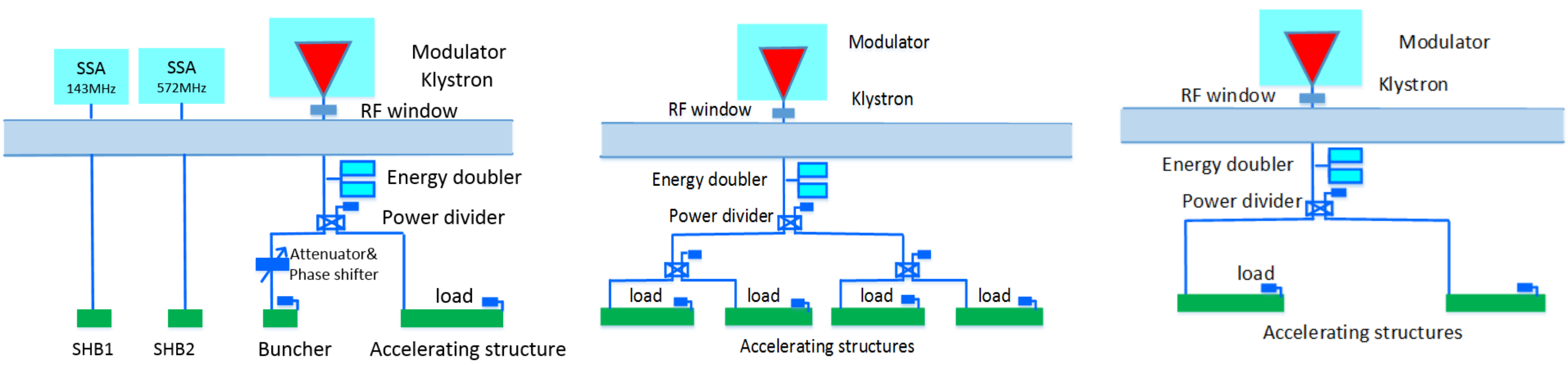
CEPC linac design

- Layout of the linac
  - Electron linac
  - Positron linac



CEPC linac design

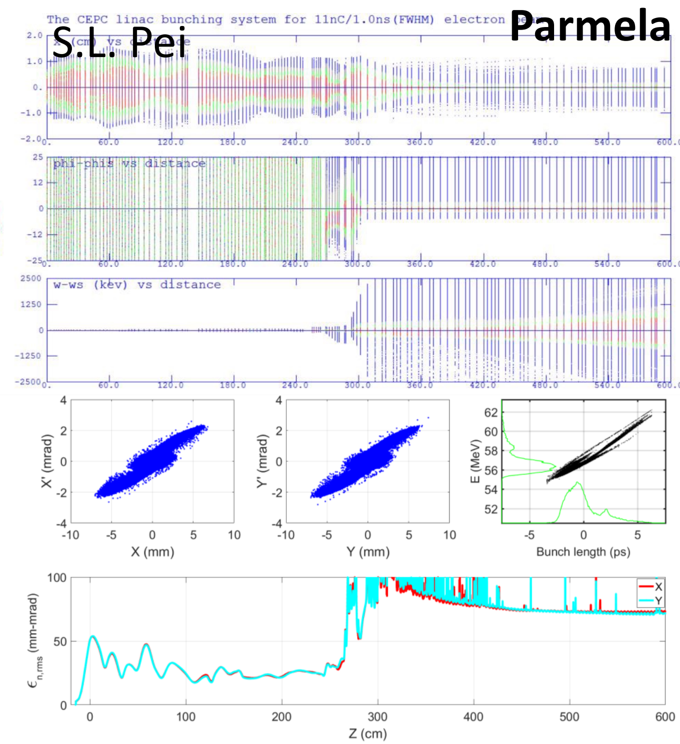


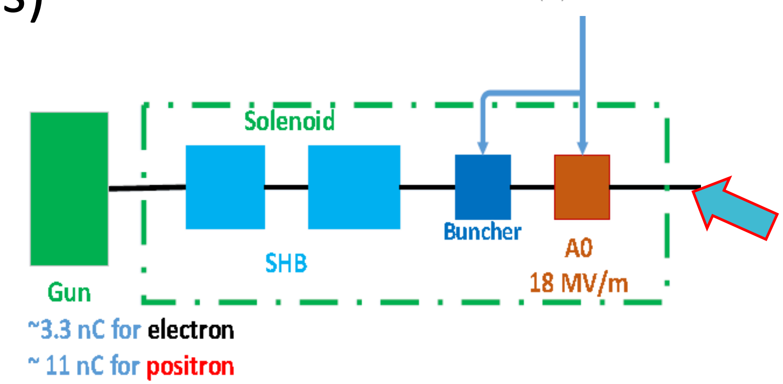


80MW klystron

CEPC linac design

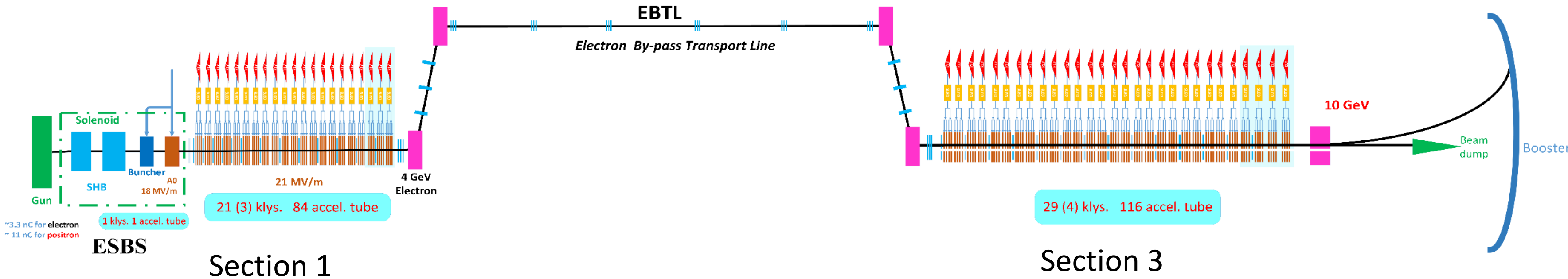
- Electron linac (source)
  - Thermionic triode electron gun
  - Sub-harmonic pre-buncher
    - 143 MHz
    - 572 MHz
  - Buncher & A0
    - 2860 MHz
  - Emittance
    - <100 mm-mrad (Norm.Rms)
  - Transmission efficiency
    - ~90%



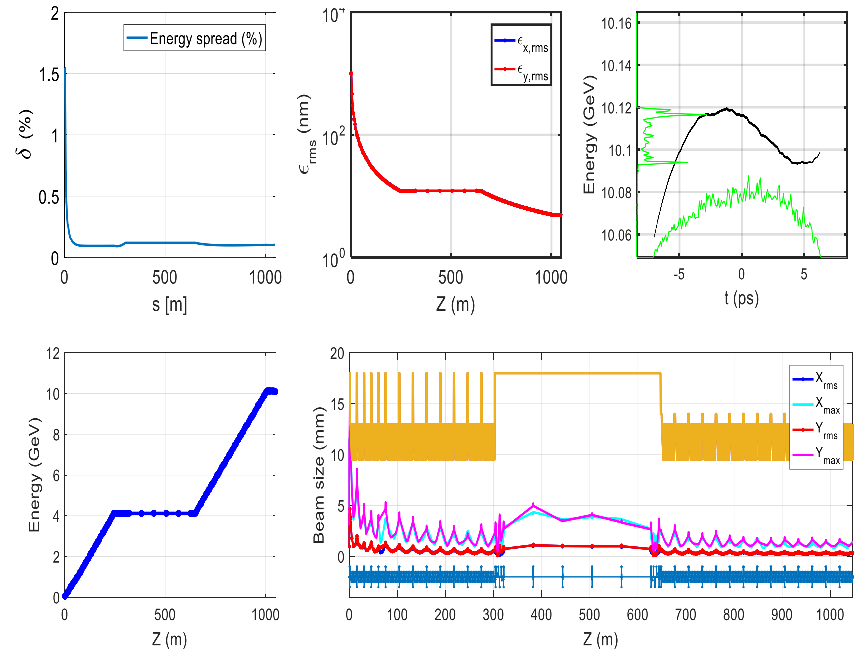


CEPC linac design

•Electron linac



- 10 GeV with 3nC charge
- Energy spread (rms): 0.15%
- Emittance (rms): 5nm



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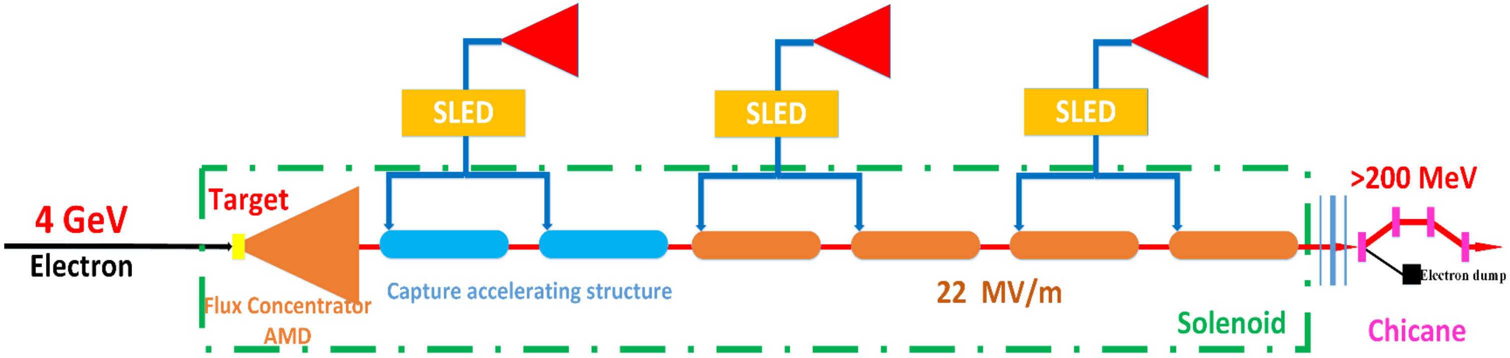
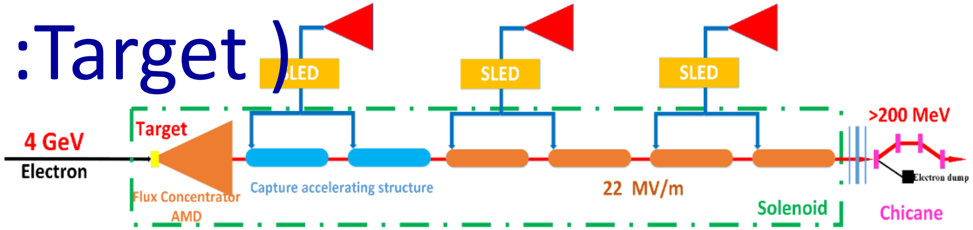
CEPC linac design

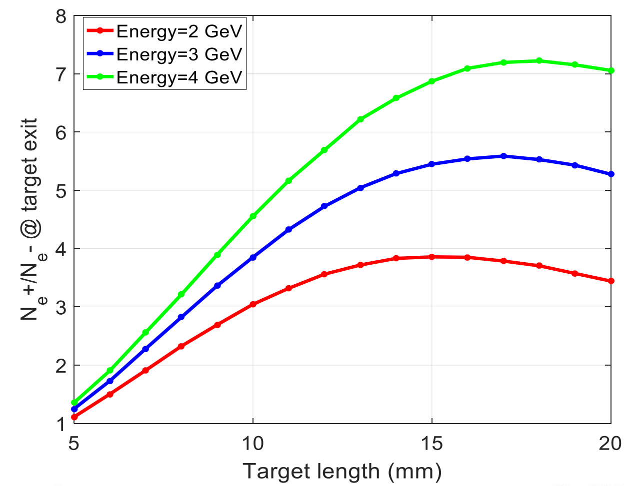
- Positron linac (Source)
  - Target (conventional)
  - Adiabatic Matching Device (AMD)
  - Capture section
  - Pre-accelerating section
  - Chicane (Deflecting the useless electrons and photons)

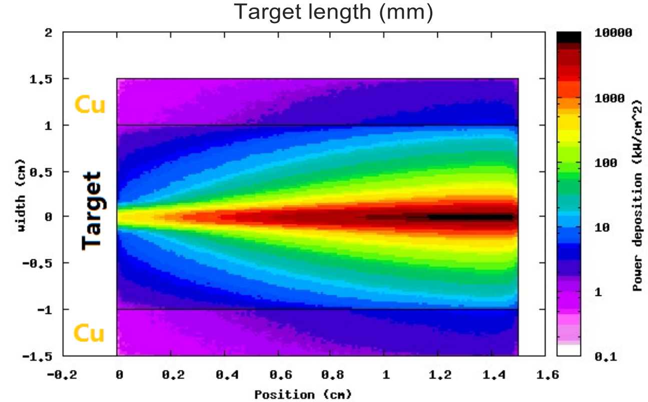


CEPC linac design

- Positron linac (Source :Target)
  - Electron beam
    - 4 GeV/10 nC/100 Hz
    - Beam size (Rms): 0.5 mm
    - Beam power: 4 kW
  - Target
    - Tungsten
    - Thickness 15 mm
  - Energy deposition
    - 0.784 GeV/e- @ FLUKA
    - 784 W → water cooling
  - Support && cooling
    - Copper

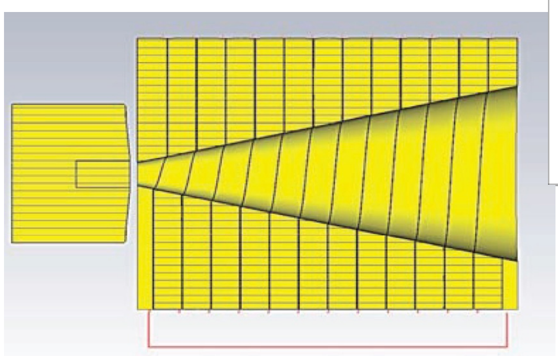


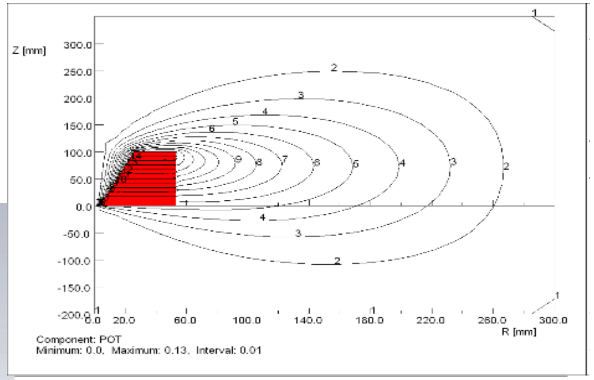


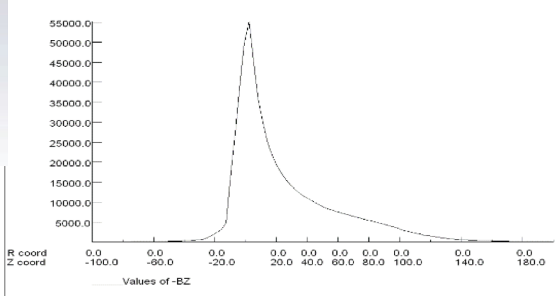


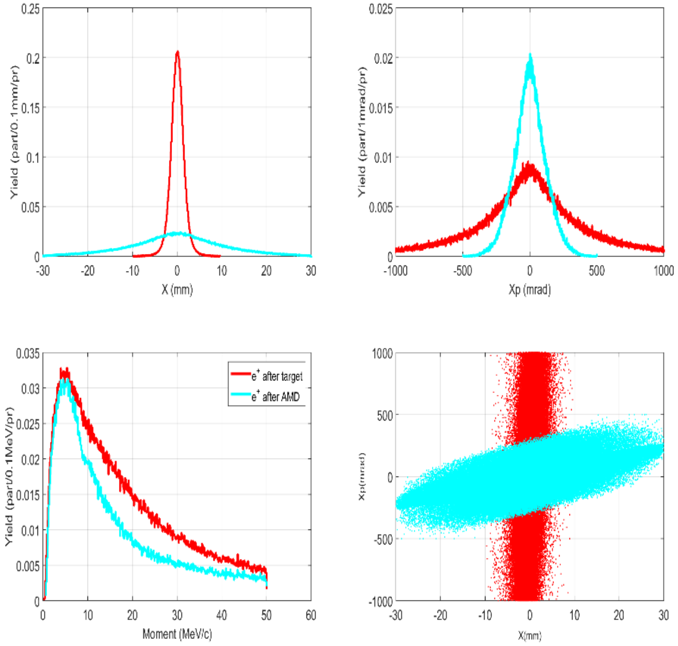
CEPC linac design

- Positron linac (Source :AMD)
  - Length: 100 mm
  - Aperture: 7 mm→52 mm (accelerating structure aperture is 25mm)
  - Magnetic field: (5.5 T→0 T) + 0.5 T



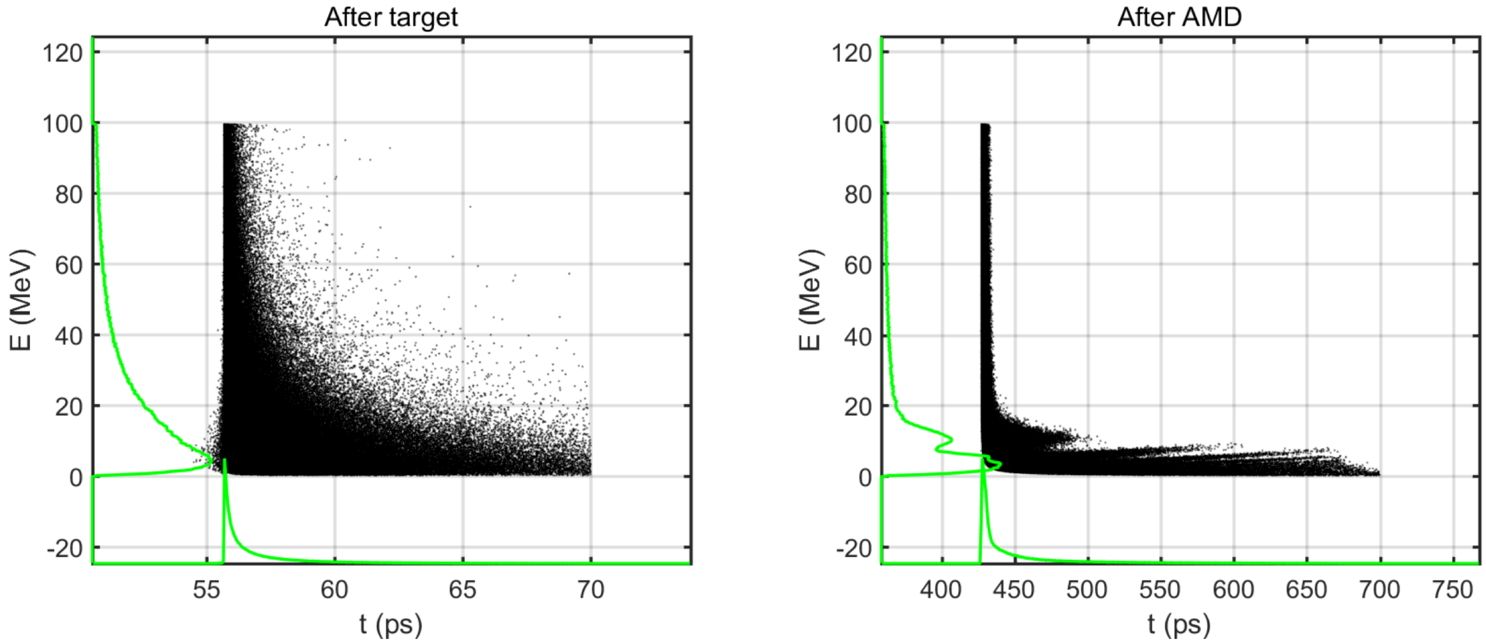






CEPC linac design

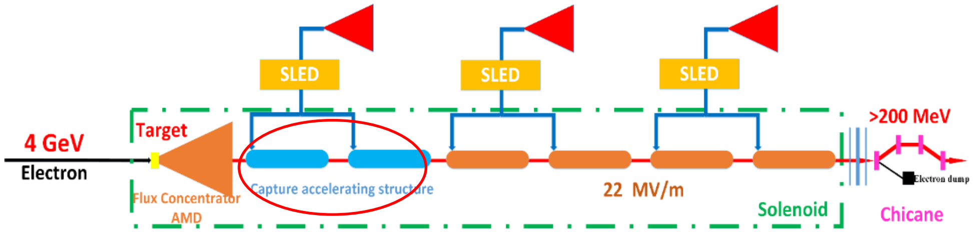
- Positron linac (Source: AMD)
  - Longer bunch length
    - Different energy
    - Different horizontal momentum

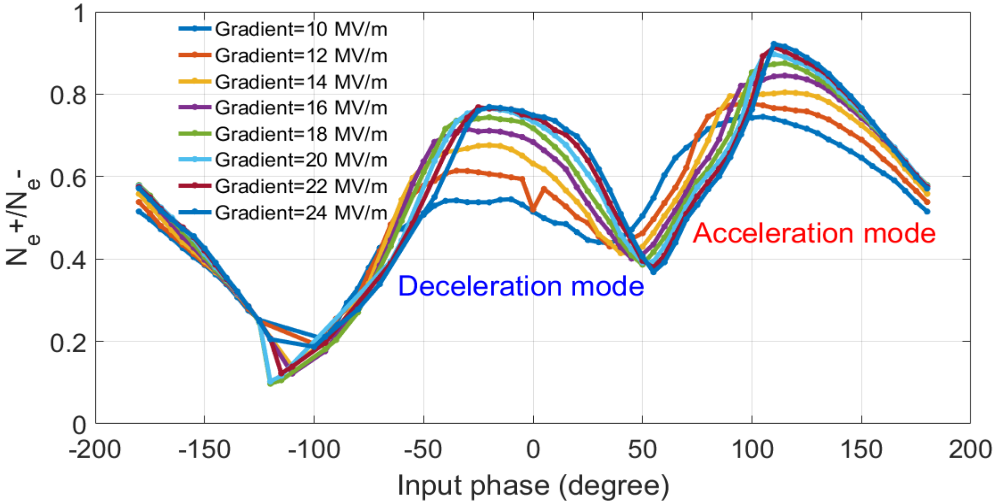


Distribution before and after AMD

CEPC linac design

- Positron linac (Source: Capture section)
  - Capture structure
    - Length:2 m
    - Aperture: 25 mm
    - Gradient: 22 MV/m
  - The capture RF phase



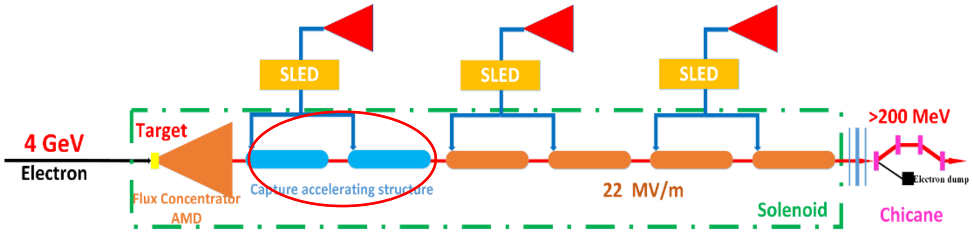


Capture efficiency VS. input RF phase

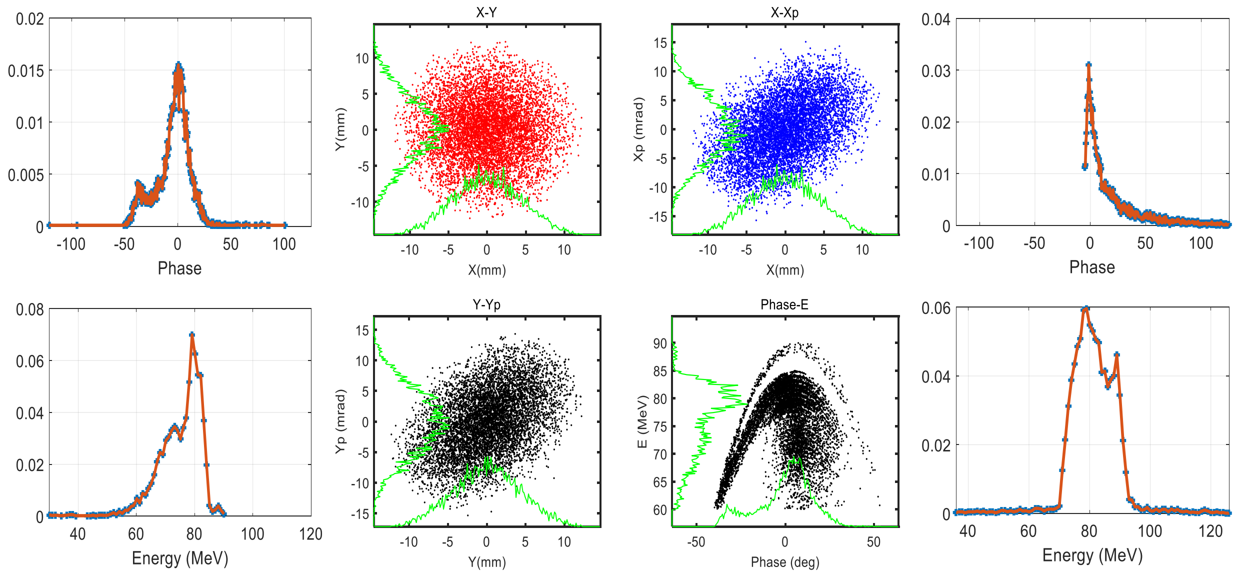
CEPC linac design

•Positron linac (Source: Capture section)

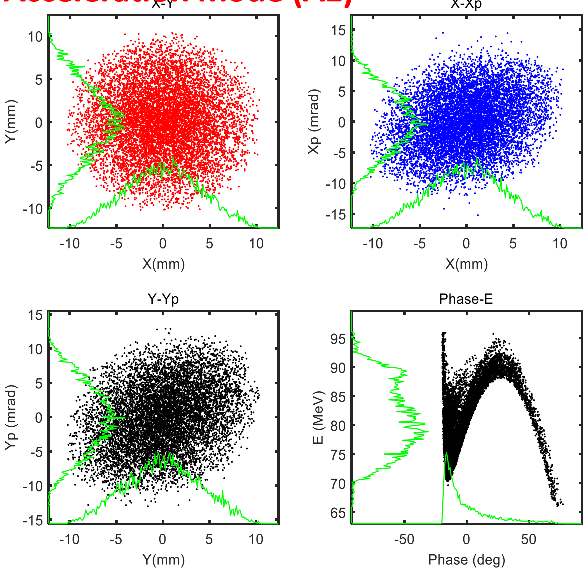
- ▪The capture phase
  - ◆Accelerating mode
  - ◆ better moment chip
  - ◆small phase spread



Deceleration mode (D1)



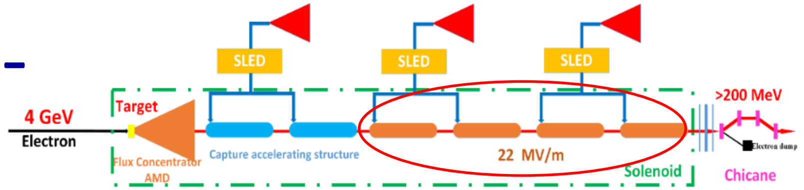
Acceleration mode (A1)

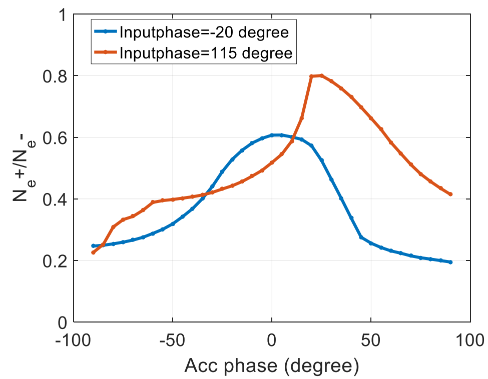


Distribution of different mode

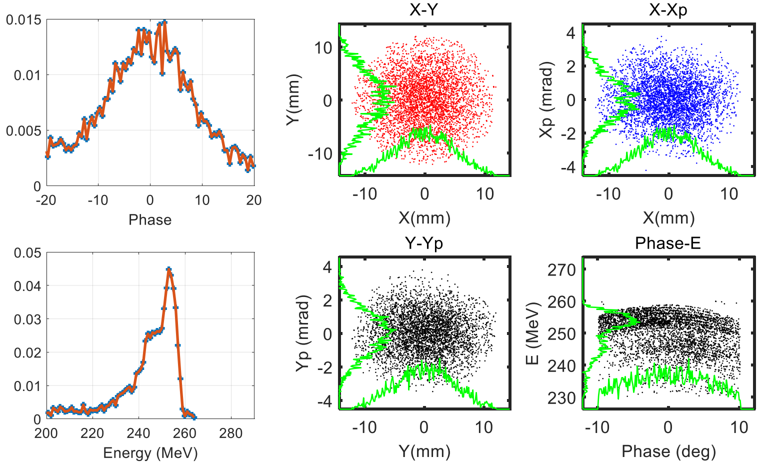
CEPC linac design

- Positron linac (Source: The pre-accelerating structure)
  - Different modes have different optimal accelerating phases
  - Acceleration mode have higher positron yield
    - Stray bunches should be considered



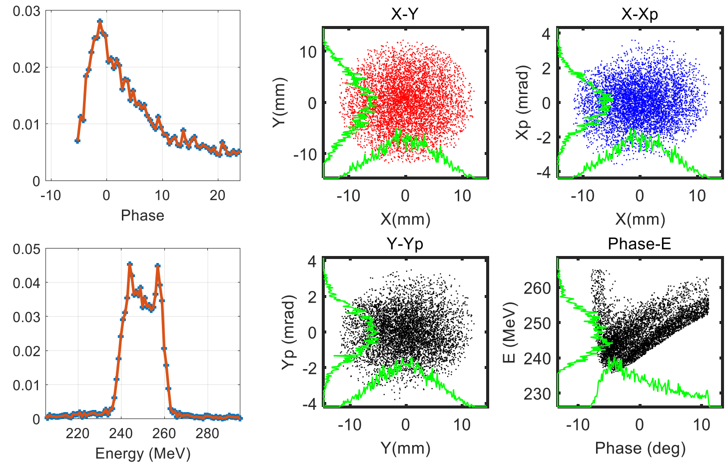


Deceleration mode (D1)



Ne+/Ne-[-10°,10°,230 MeV,260 MeV]=**0.4**

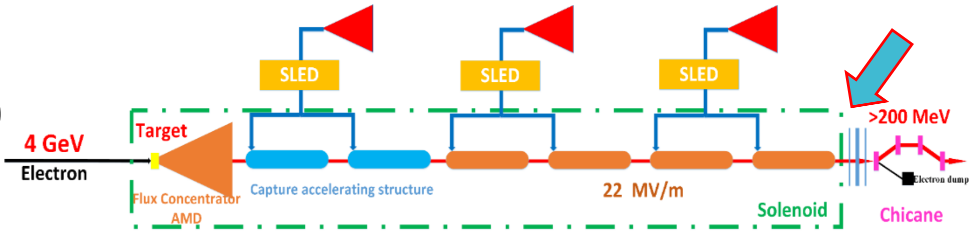
Acceleration mode (A1)

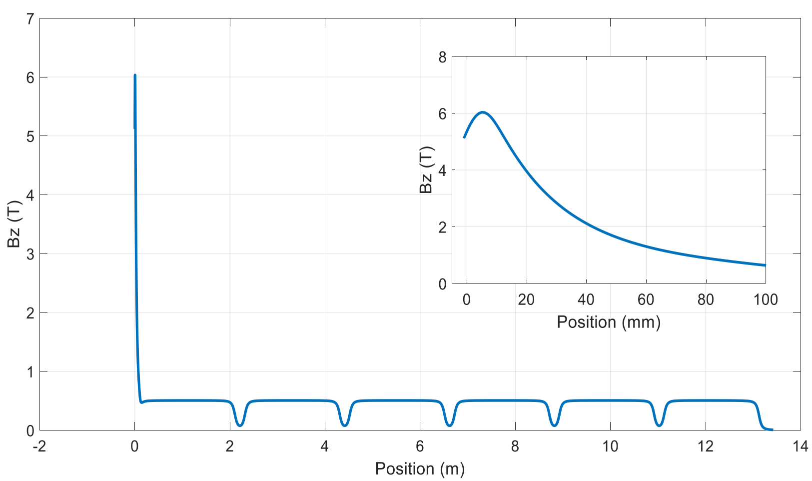


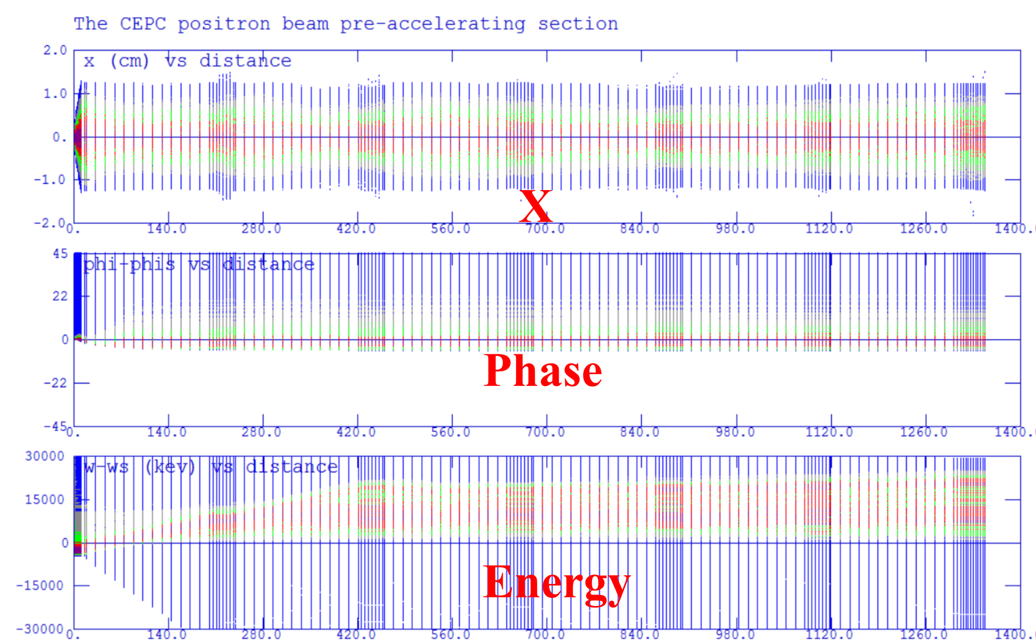
Ne+/Ne-[-8°,12°,235 MeV,265 MeV]=**0.55**

CEPC linac design

- Positron linac (Source)
  - Norm. RMS. Emittance is about 2500 mm-mrad
  - Energy: >200 MeV
  - Positron yield
    - Ne+/Ne- ~=0.55
    - [-8°,12°,235 MeV,265 MeV]







CEPC linac design

•Positron linac (Damping ring)

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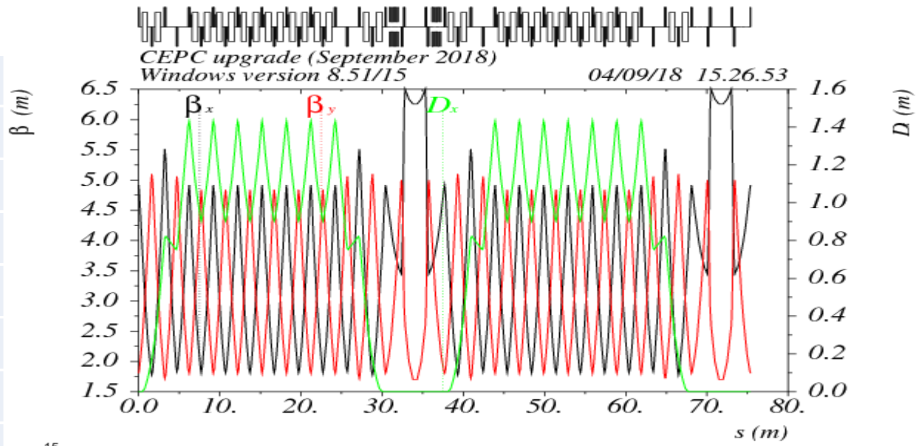
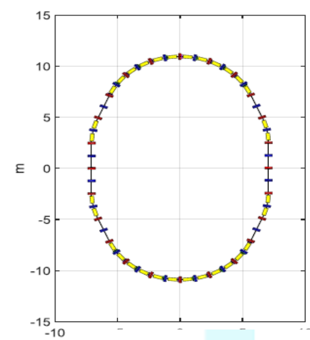
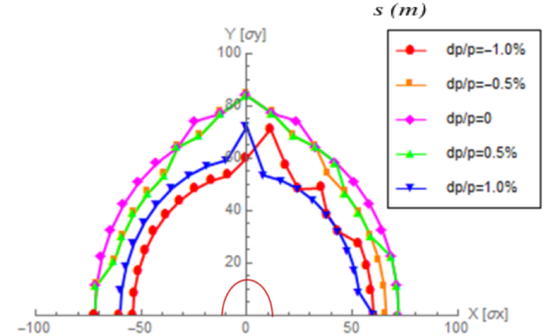
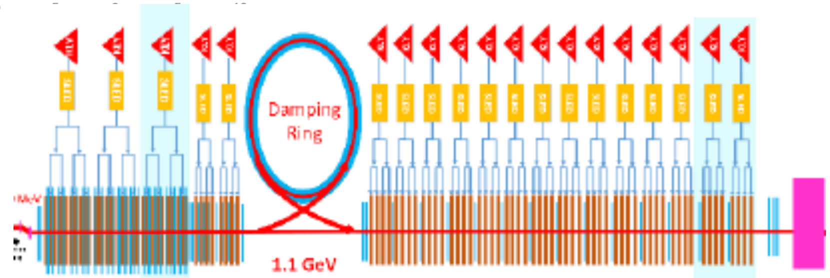
DR V2.0	Unit	Value
Energy	GeV	1.1
Circumference	m	75.4
Storage time	ms	20
Bending radius	M	3.565
Dipole strength B_0	T	1.03
U_0	keV	36.3
Damping time x/y/z	ms	15.2/15.2/7.6
δ_0	%	0.05
ε_0	mm.mrad	376.7
$\sigma_{z\ ,\ inj}$	mm	5.0
Nature σ_z	mm	7.5
ε_{inj}	mm.mrad	2500
$\varepsilon_{ext\ x/y}$	mm.mrad	530/180
δ_{inj} /δ_{ext}	%	0.2/0.05
Energy acceptance by RF	%	1.0
f_{RF}	MHz	650
V_{RF}	MV	2.0



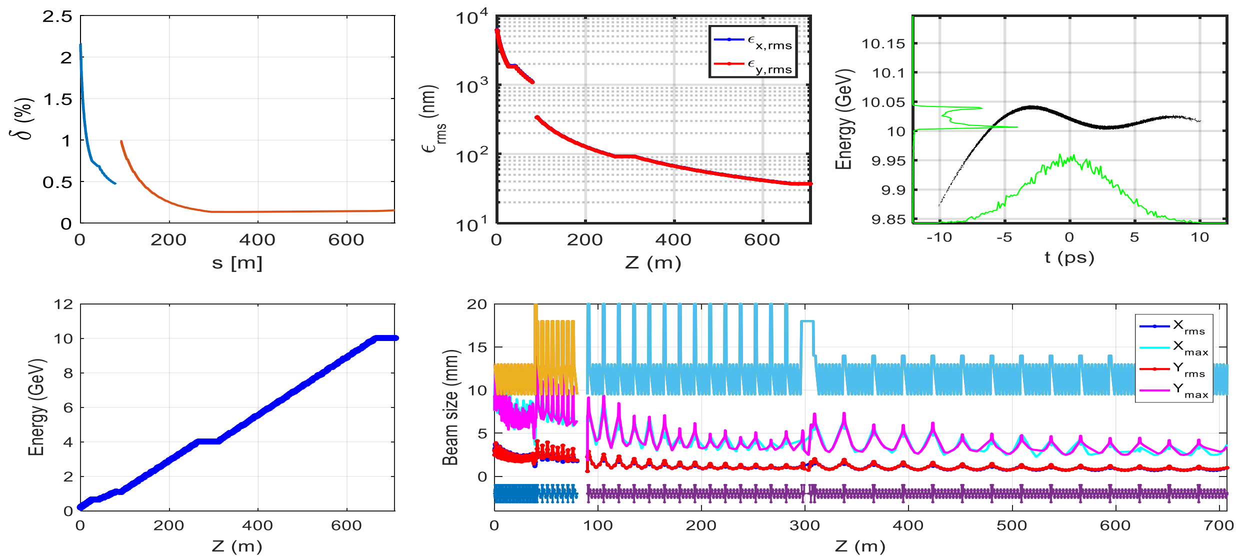


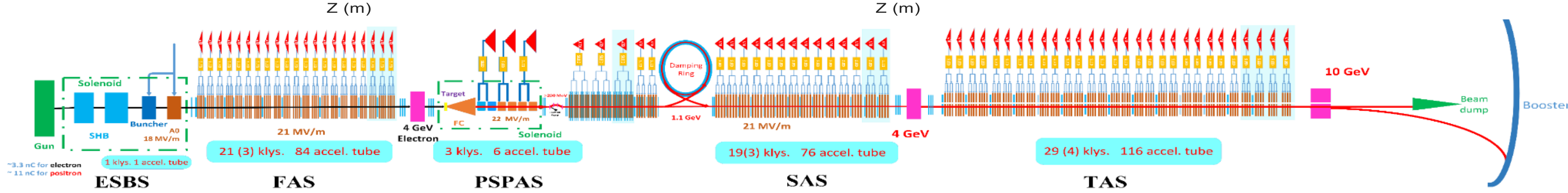




CEPC linac design

- Positron linac
  - 10 Gev with 3 nC charge
  - Energy spread (rms): 0.16%
  - Emittance with DR (rms): 30(H)/10nm(V)





Outline

1. CEPC layout
2. CEPC linac design
3. CEPC linac key technologies development
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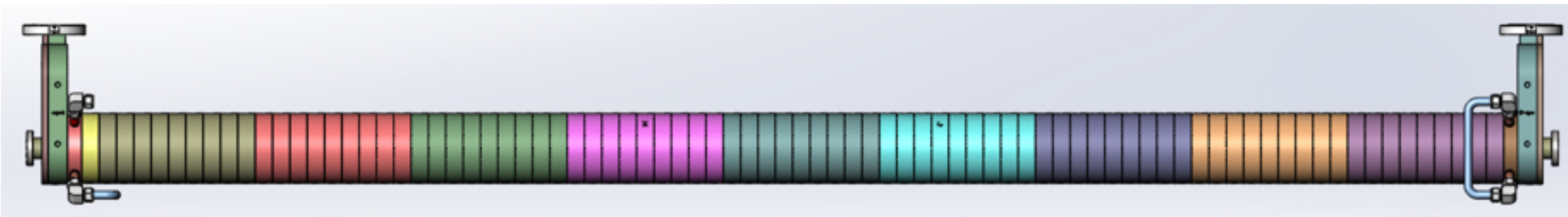
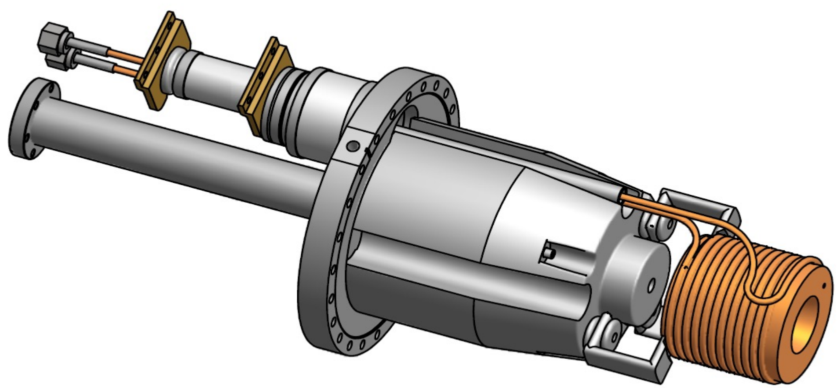
CEPC linac key technologies development

- S-band accelerating structure



- Flux concentrator



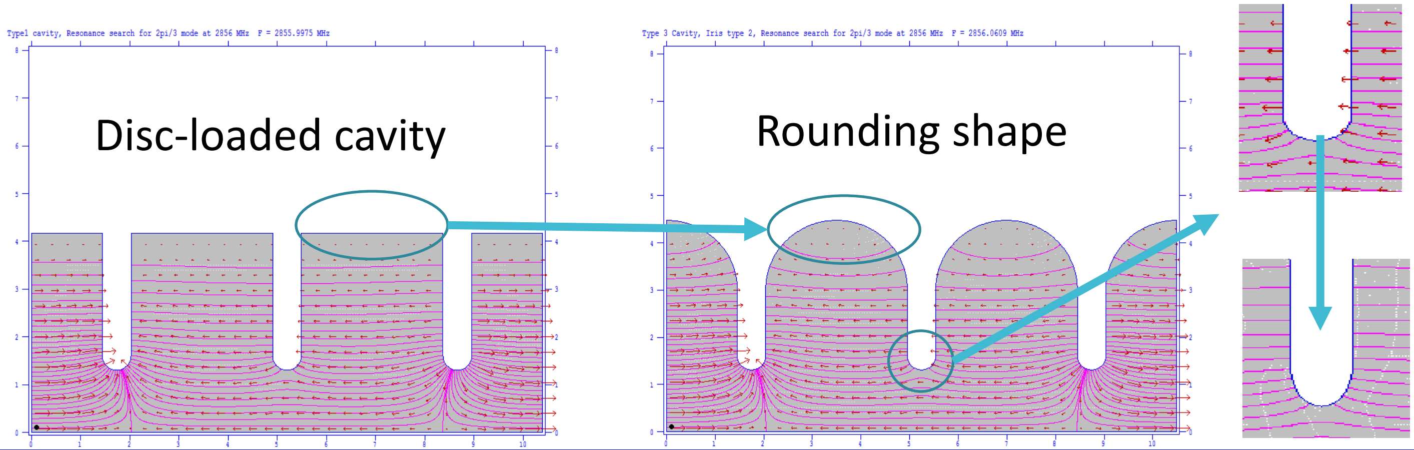
CEPC linac key technologies development

•S-band accelerating structure design

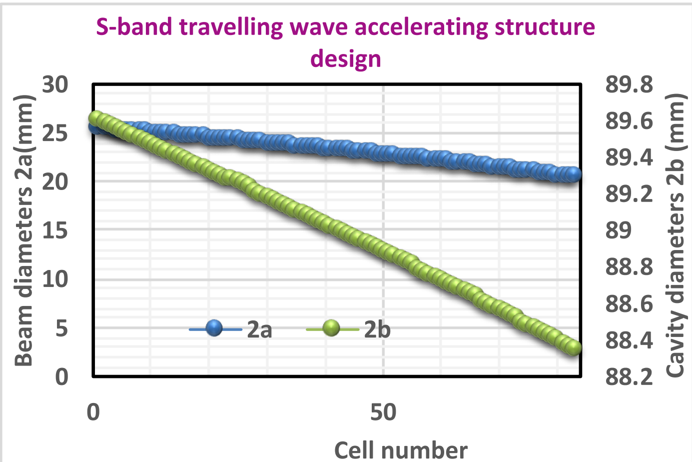
- Motivation: The total energy of the main Linac is 14 GeV.
- Goal: For the 3 meters long accelerating structure, about 30 MV/m@1μS (without beam) is expected.

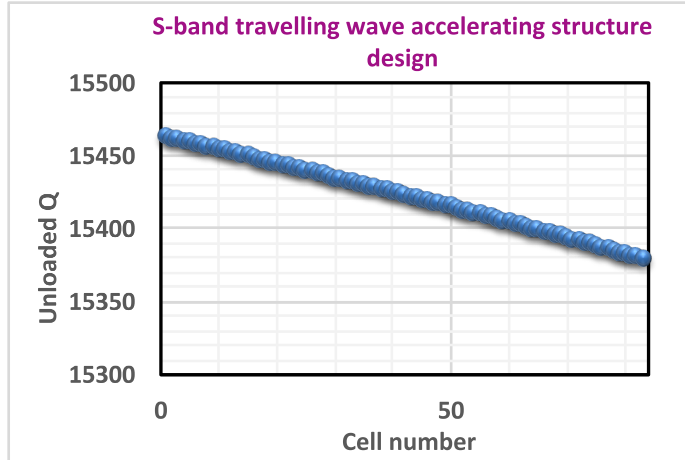
CEPC linac key technologies development

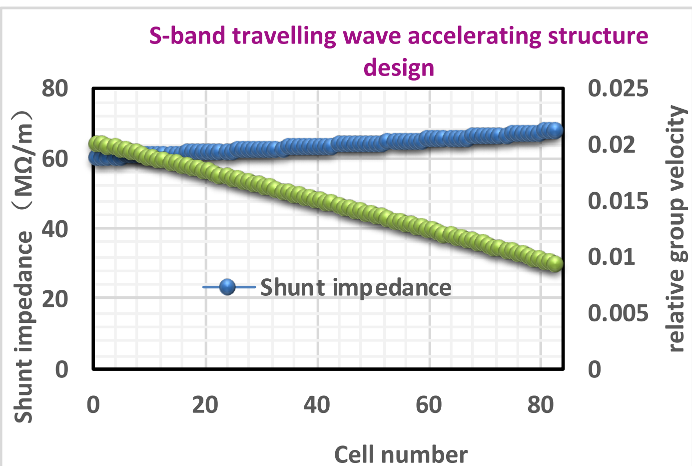
- S-band accelerating structure design
  - Cavity shape optimization
    - Superfish is used to optimize the single cell.
    - Rounding the cell improves the quality factor by >12% and reduces the wall power consumption. At the same time, the shunt impedance increases by ~10.9%.
    - Irises with elliptical shape (r2/r1=1.8) can reduce the peak surface field by 13%.

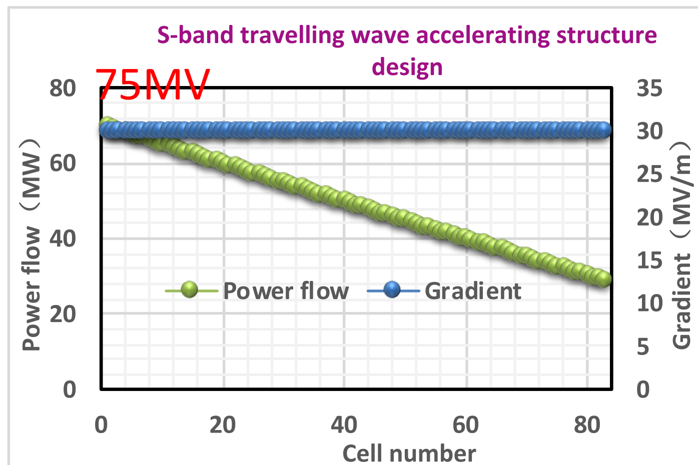


•S-band accelerating structure design









CEPC linac key technologies development

•S-band accelerating structure design

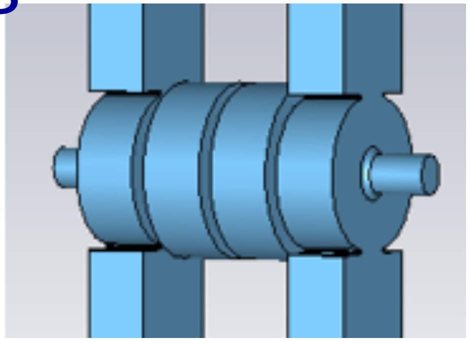
Parameters	Values	Unit
No. of Cells	84+2*0.5	-
Phase advance	2π/3	rad
Total length	3.1	m
Length of cell (d)	34.988	mm
Disk thickness (t)	5.5	mm
Shunt impedance (Rs)	60.3~67.8	MΩ/m
Quality factor	15465~15373	-
Group velocity: Vg/c (%)	2% ~ 0.94%	-
Filling time (t_f)	784	ns
Attenuation factor (τ)	0.46	Np

•S-band accelerating structure design

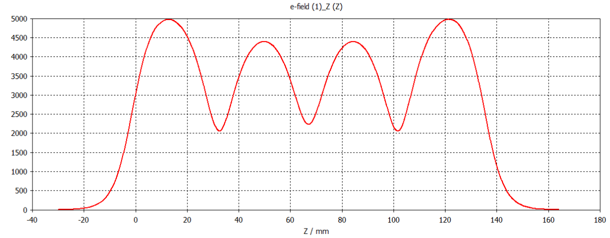
- Coupler design
  - The asymmetry of the coupling cavity will cause emittance growth.
  - The shape of the coupling cavity is racetrack dual-feed type.
  - Kyhl method is used to match the coupler.

$$\varepsilon_{n-final} = \sqrt{\varepsilon_{n-initial}^2 + \sigma_x^2 \left(\frac{\sigma_{\Delta p_x}}{mc}\right)^2}$$

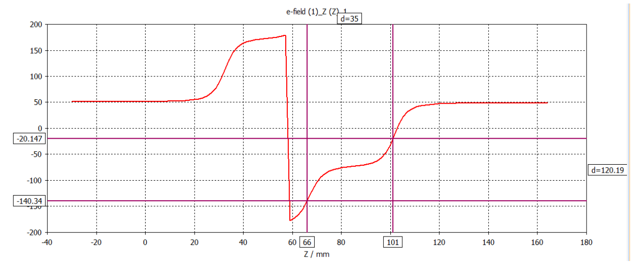
$$\Delta p_x = -\frac{e\Delta z E_0}{2\omega a}\left[\Delta\theta * sin\varphi - \frac{\Delta E}{E_0}\cos\varphi\right]$$



The calculation model



The *distribution of* the electric field on axis



Phase advance per cell

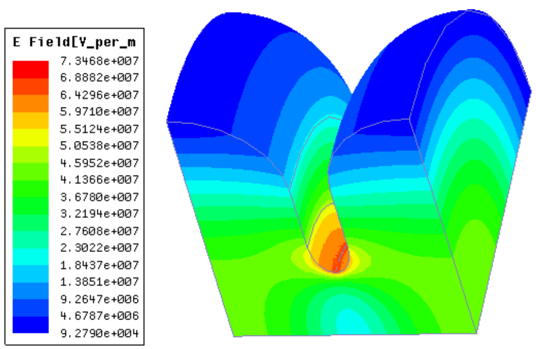
CEPC linac key technologies development

- Factors to limit the gradient:
  - Peak surface electric field (E_peak)
    - E_peak < 160MV/m at S-band.
  - Peak surface magnetic field (H_peak)
    - Pulsed heating effect will cause the temperature rise at the coupler window. $\Delta T = \frac{|H_{||}|^2 \sqrt{t_p}}{\sigma\delta\sqrt{\pi\rho c k}}$, for S-band ΔT < 50℃ is safe.
  - Modified Poynting vector (Sc),
    - $S_c = Re\{\bar{s}\} + \frac{Im\{\bar{s}\}}{6}$, $\frac{{S_c}^{15}{t_p}^{5}}{BDR}$=const. If the beam break down rate is $1*10^{-6}$bpp/m, the safe value for 1μs pulse length is 2.3 MW/mm^2.
  - Pulse length（1μS）

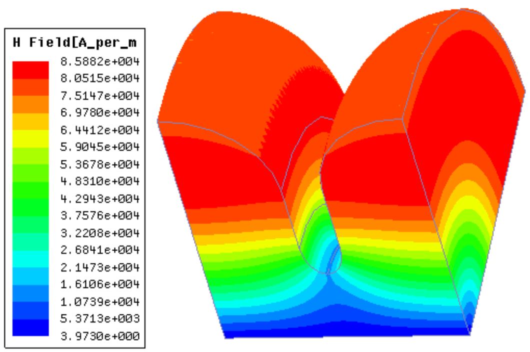
CEPC linac key technologies development

- Factors to limit the gradient:
  - 3D program HFSS is used to confirm the design.
  - The 1st cell adjacent the input coupler is simulated for Pin=75 MW.
  - The values are safe. Both E_peak and Sc locates at the iris area.

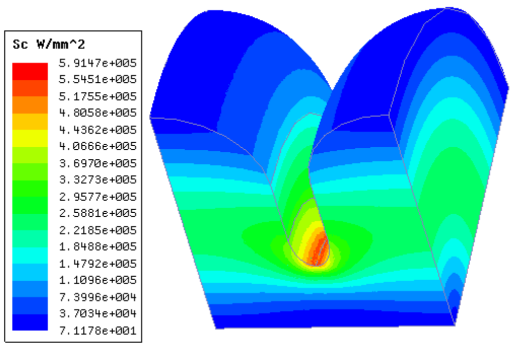
E_peak=73 MV/m. H_peak=86 kA/m. Sc_max=0.59 MW/mm^2.



Surface electric field



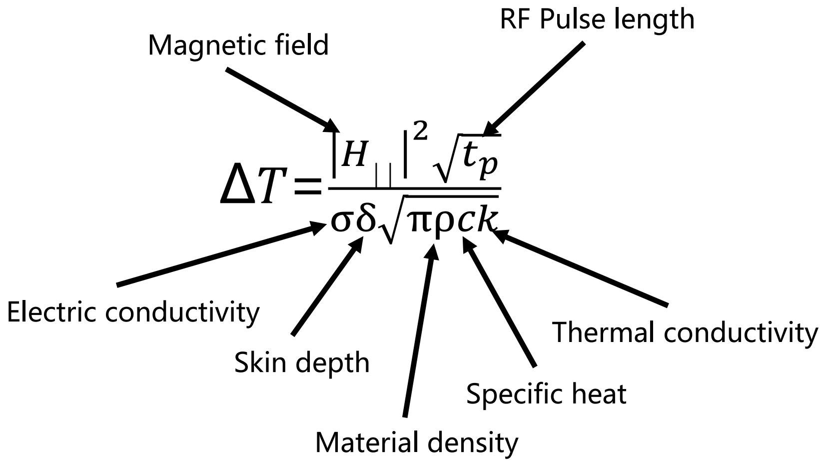
Surface magnetic field



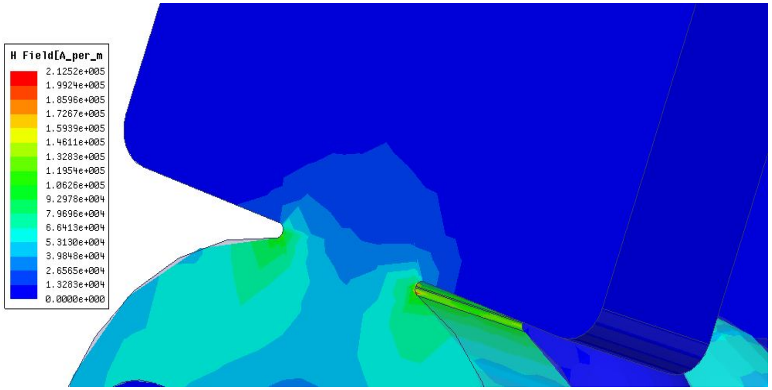
Modified Poynting vector

CEPC linac key technologies development

- Factors to limit the gradient:
  - To reduce the pulsed heating, the coupler window edge is rounded.
  - For S-band copper: $\Delta T[^{0}c]=127\left|H_{||}[MA/m]\right|^{2}\sqrt{f.[GHz].t_{p}[uS]}$
  - For 75 MW input power, the maximum value of the peak surface magnetic field is 2.1*105 A/m. for 1μS pulse length, $\Delta T=9.4^{0}C$.



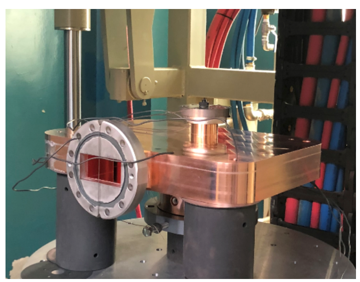
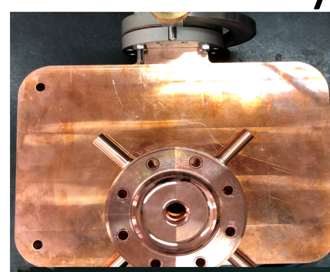
$$\Delta T=\frac{\left|H_{||}\right|^{2}\sqrt{t_{p}}}{\sigma\delta\sqrt{\pi\rho ck}}$$

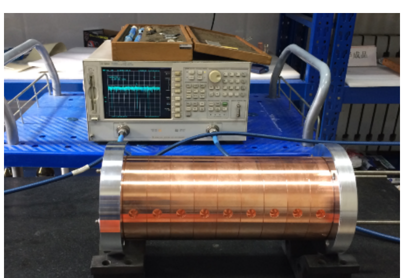


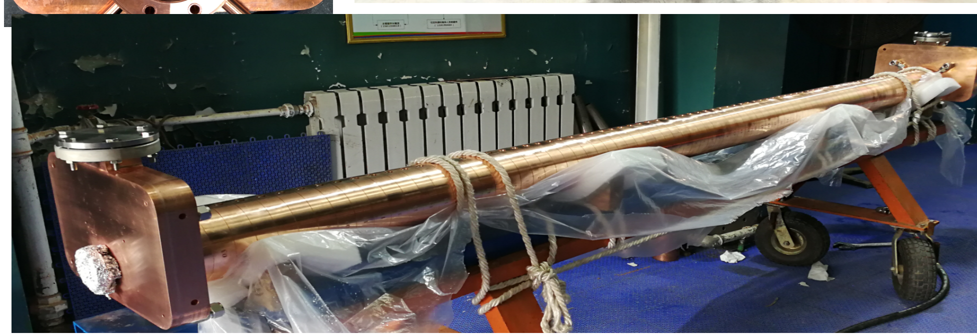
CEPC linac key technologies development

•S-band accelerating structure design

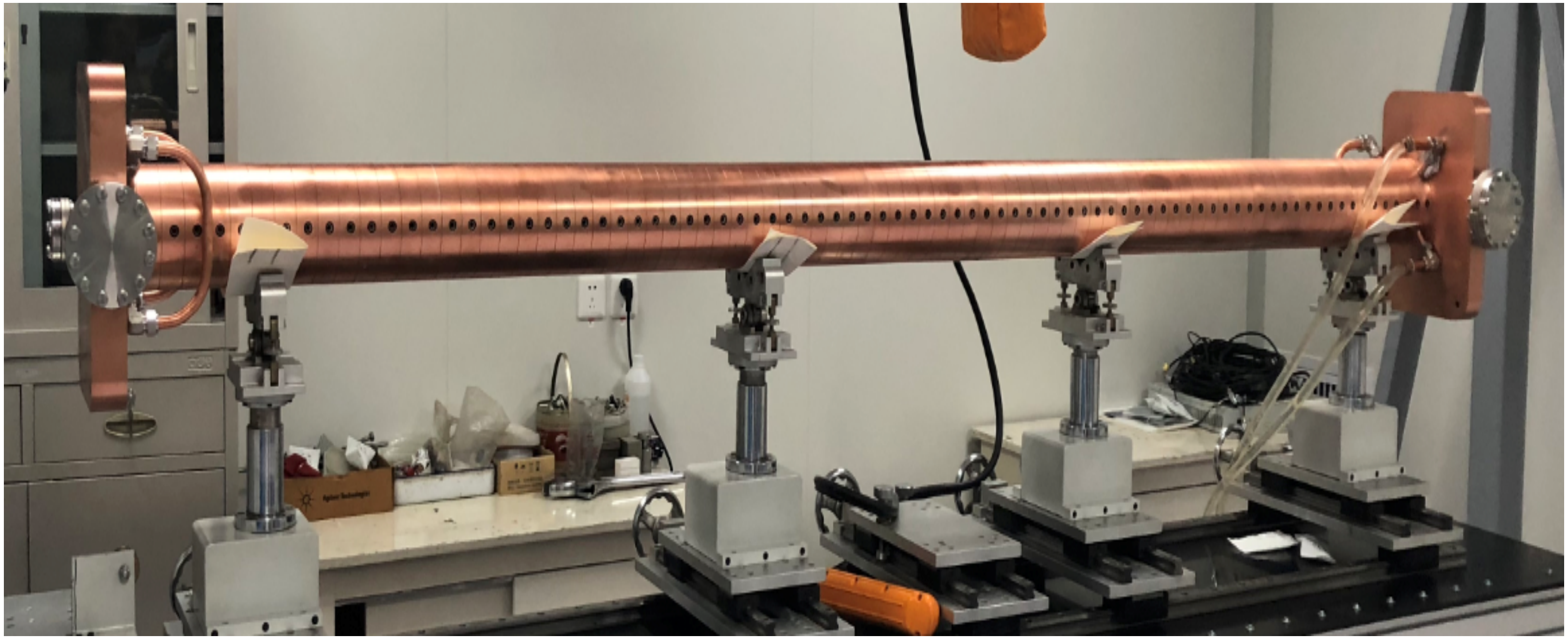
- Mechanical design
  - Inner water-cooling has been adopted. 8 pipes are around the cavity.
  - Compact coupler arrangements. The splitter is milling together with the coupling cavity.
  - Two tuners are outside the cavity.





•Mechanical design



Accelerating structure under cold test

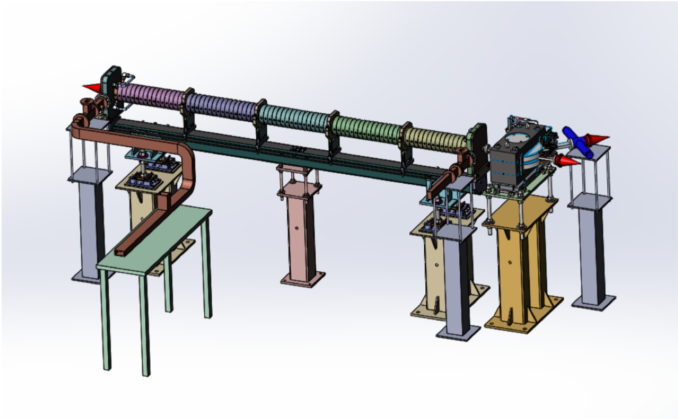
CEPC linac key technologies development

•S-band accelerating structure design

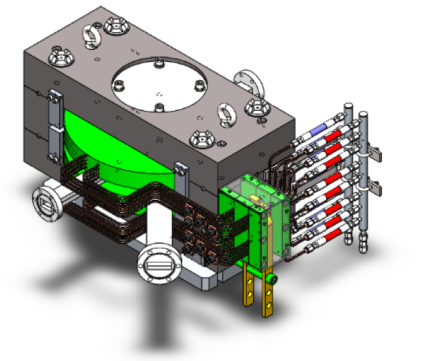
■High power test bench

- ◆The power source is available at IHEP.
- ◆The faraday cup and magnet has been designed in order to diagnostic the dark current.
- ◆The high power test will begin recently.

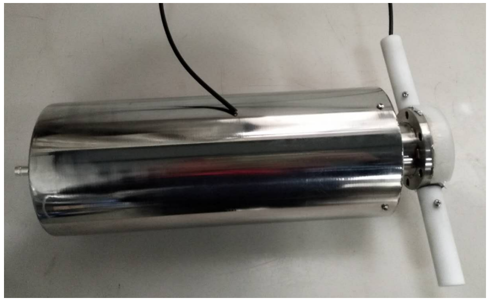
Modulator and klystron



Test bench upgrade



Analyzing Magnet

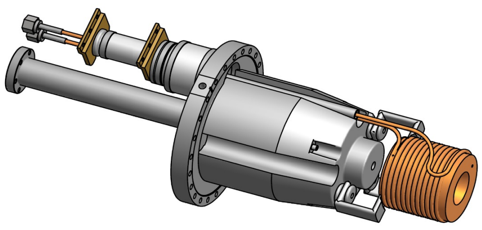


Faraday Cup

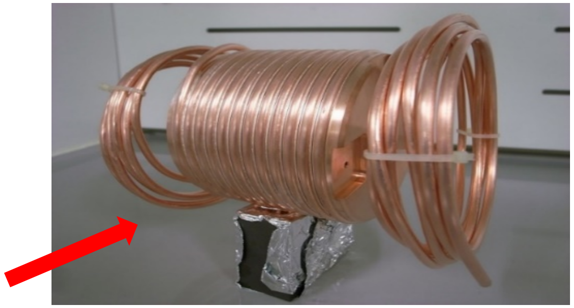
CEPC linac key technologies development

Flux concentrator design

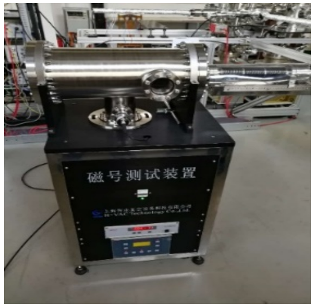
- The FLUX concentrator produces a pulsed magnetic field of 6 T to 0.5 T and It is difficult to machining.
- An MOU was signed with KEK to assist us in the spiral wire cutting process.



The mechanical design of FLUX concentrator



The finished FLUX concentrator



The test bench of the FLUX concentrator

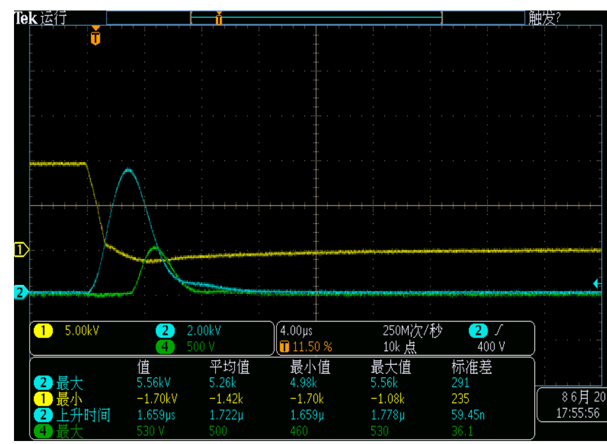
•Flux concentrator design

▪solid-state pulsed power generator

- The maximum output value is 15 kA / 15 kV / 5 μs;
- Solid state IGCT discharge switch module is used;
- The 10 kA output power has tested successfully;
- Full output power 15 kA will be tested in the near future.

Parameters	Value	Unit
Peak pulse current	≥15	kA
Pulse width (bottom width)	5±0.5	us
Pulse waveform	Half sine wave	-
Repetition frequency	50	Hz
Long term stability	±0.5%	-
Peak voltage of charging	15	kV
The type of discharge switch	IGCT	-

solid-state pulsed power generator



The output of 10kA measurement

Summary

- The linac provides 10 GeV electron and positron beam with single bunch mode to the Booster.
- A bypass section has been designed for the e- to make the e+ target simple.
- A fixed tungsten target is used in the positron source system. The e- beam on the target is 4 GeV & 10 nC.
- A damping ring is in the position of 1.1 GeV to reduce the positron emittance.
- An S-band accelerating structure and A FLUX concentrator are designed and fabricated. The prototypes are under test.

Thank you for your attention!