中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

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

CEPC Injector Linac Design

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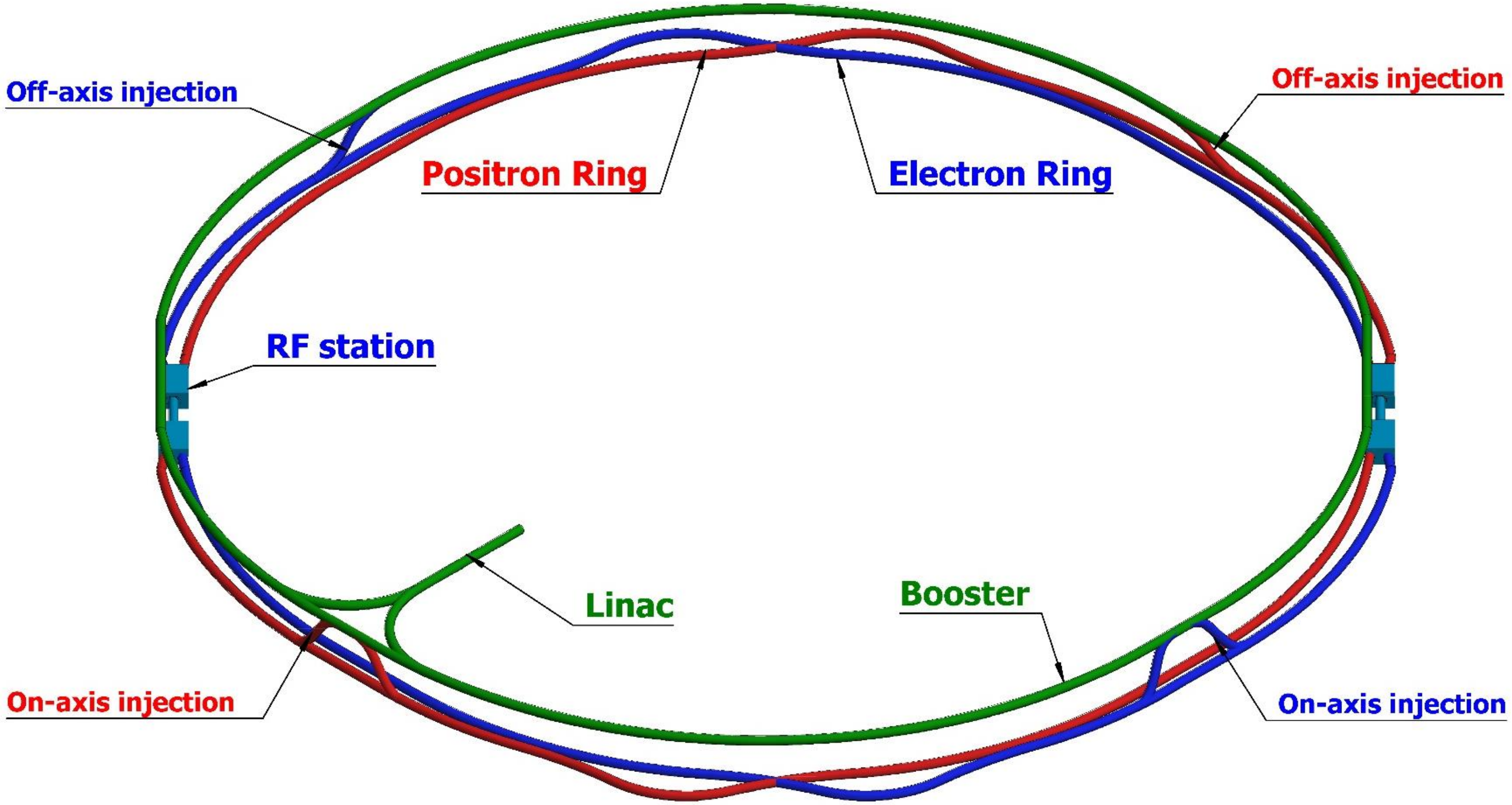
Outline

- Introduction
  - Main parameters
  - Layout of Linac
- Source design
  - Electron source
  - Positron source
- Linac design
  - Electron/Positron mode
  - Error study
- Summary



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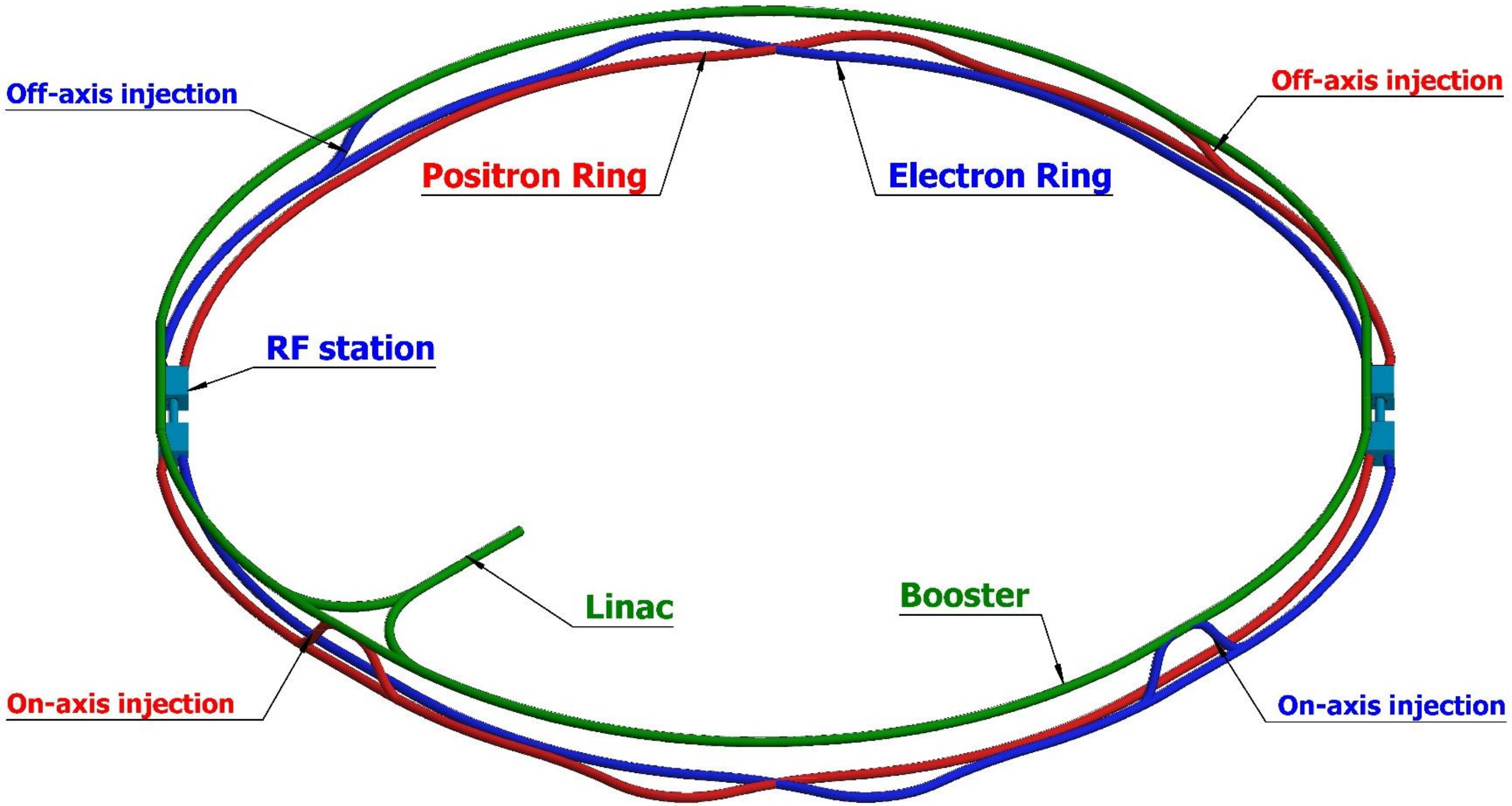


Introduction

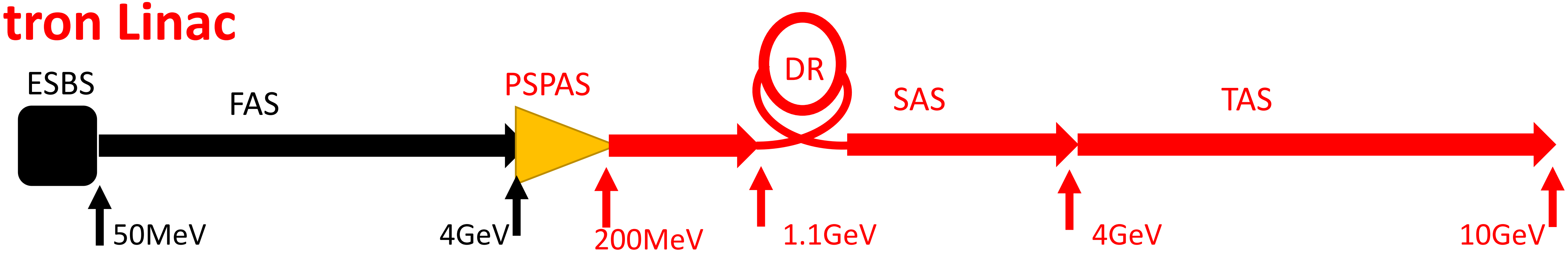
Main parameters

- Linac design goal
  - **High Availability and Reliability**
    - **Simple structure and mature technology:** S-band accelerating structure as baseline(2856.75MHz)
  - Always should provide beams that can **meet requirements** of Booster
    - Should be have **potential** to meet the higher requirements and updates in the future

Parameter	Symbol	Unit	Value	Potential
e^- /e^+ beam energy	E_{e-}/E_{e+}	GeV	10	>10
Repetition rate	f_{rep}	Hz	100	
e^- /e^+ bunch population	Ne-/Ne+		$>9.4\times10^{9}$	$>1.9\times10^{10}$
		nC	>1.5	>3
Energy spread (e^- /e^+)	σ_E		$<2\times10^{-3}$	
Emittance (e^- /e^+)	ε_r	nm	<120	<40
e^- beam energy on Target		GeV	4	
e^- bunch charge on Target		nC	10	

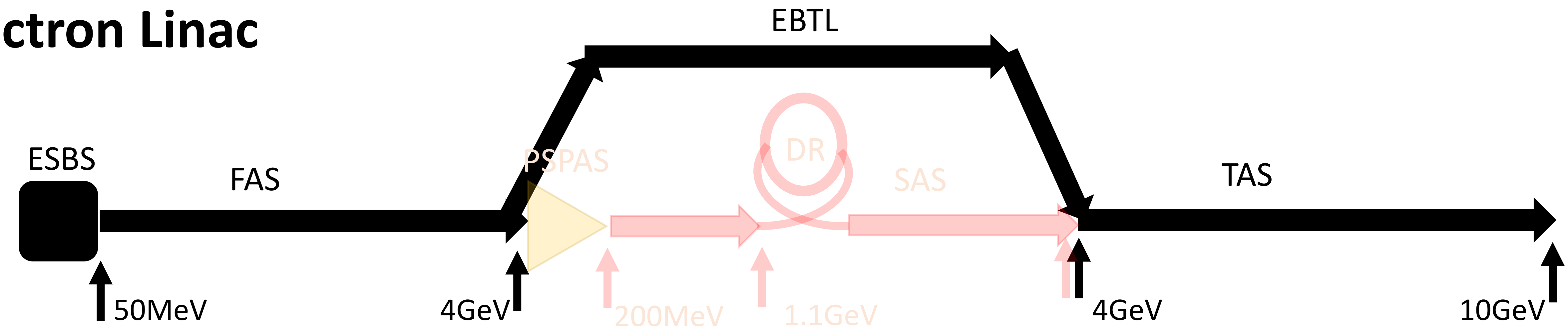
Layout of Linac

Positron Linac



- ESBS (*Electron Source and Bunching System*)
  - 50 MeV && 11nC for positron production
- FAS (*the First Accelerating Section*)
  - Electron beam to 4 GeV && 10nC for positron production
- PSPAS (*Positron Source and Pre-Accelerating Section*)
  - Positron beam larger than 200 MeV && larger than 3 nC
- SAS (*the Second Accelerating Section*)
  - Positron beam to 4 GeV && 3 nC
- DR (Damping Ring)
  - Positron beam 1.1GeV, 60m
- TAS (*the Third Accelerating Section*)
  - Positron beam to 10 GeV && 3 nC

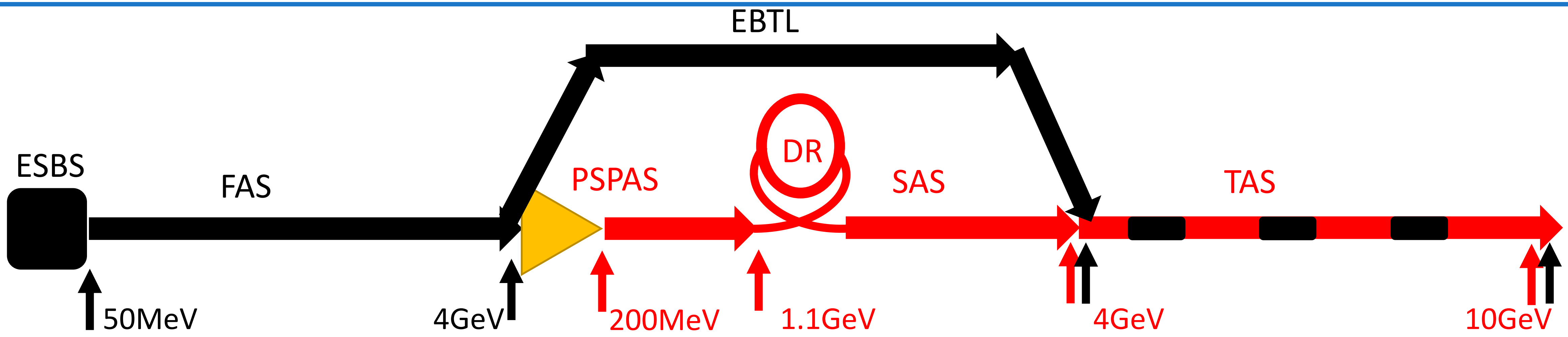
Electron Linac

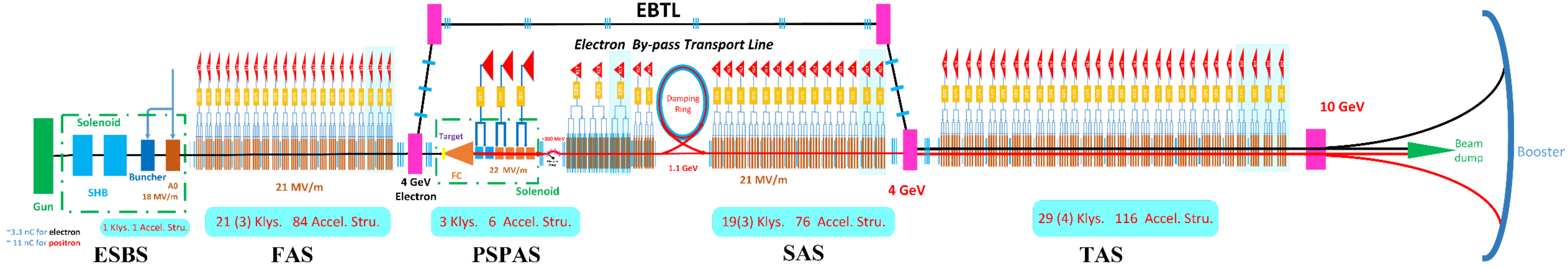


- ESBS (*Electron Source and Bunching System*)
  - 50 MeV && 3 nC
- FAS (*the First Accelerating Section*)
  - Electron beam to 4 GeV && 3 nC
- EBTL (*Electron Bypass Transport Line*)
  - Electron beam @ 4 GeV && 3 nC
- TAS (*the Third Accelerating Section*)
  - Electron beam to 10 GeV && 3 nC

Introduction

Layout of Linac





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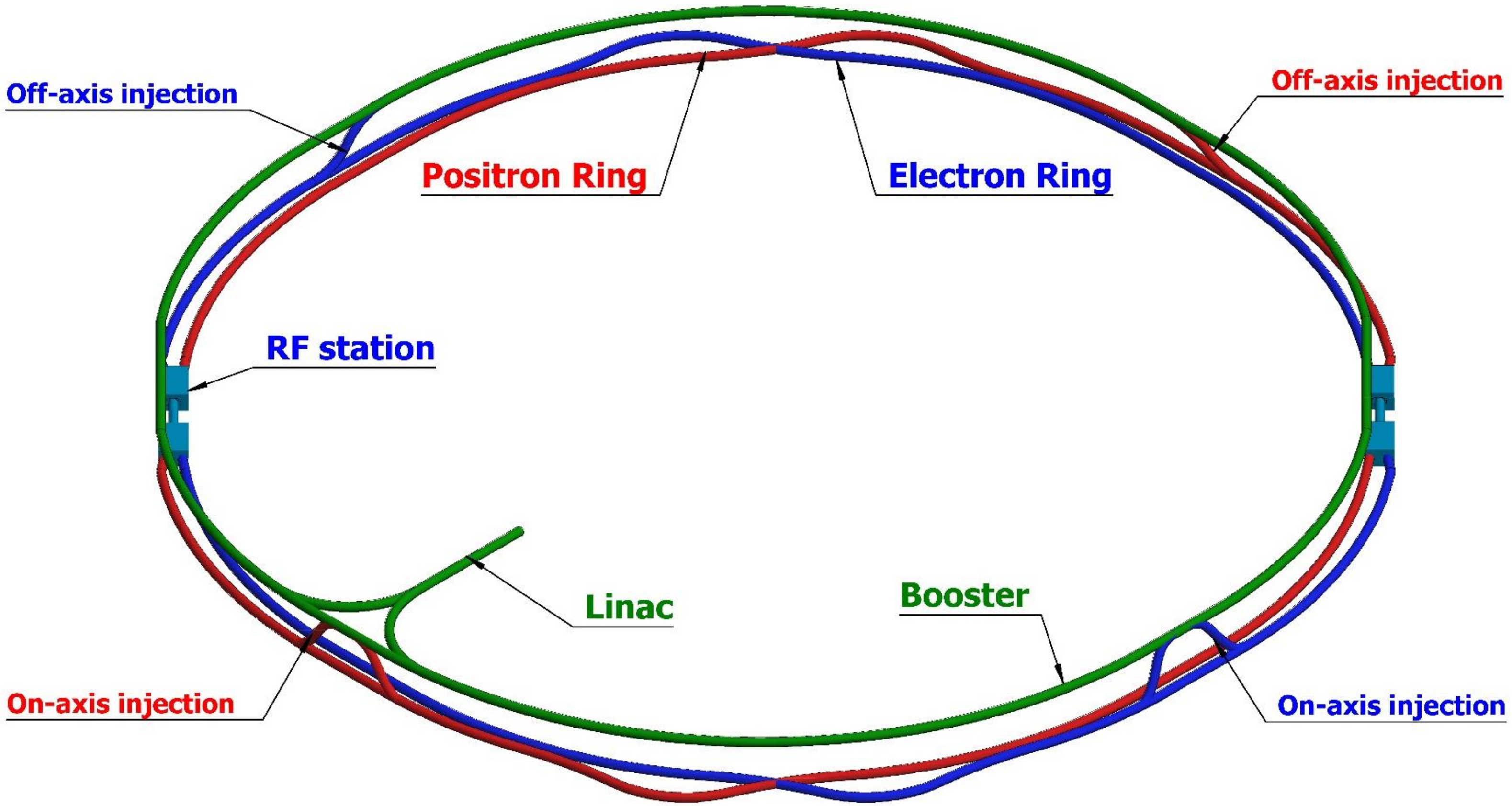
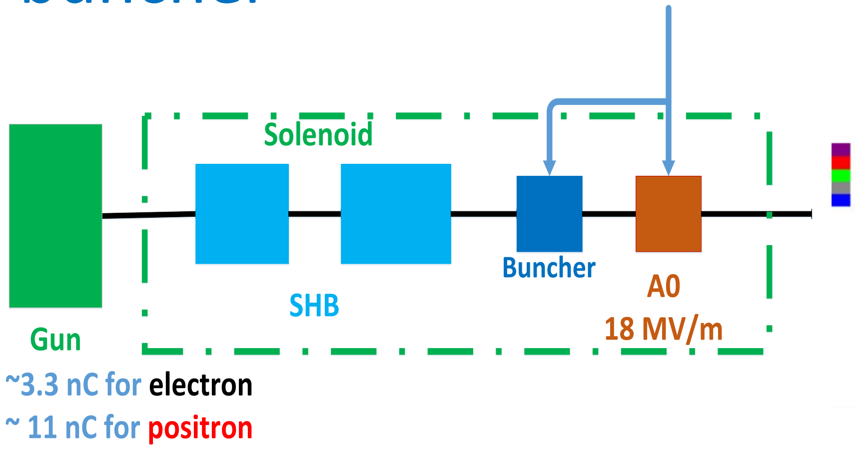


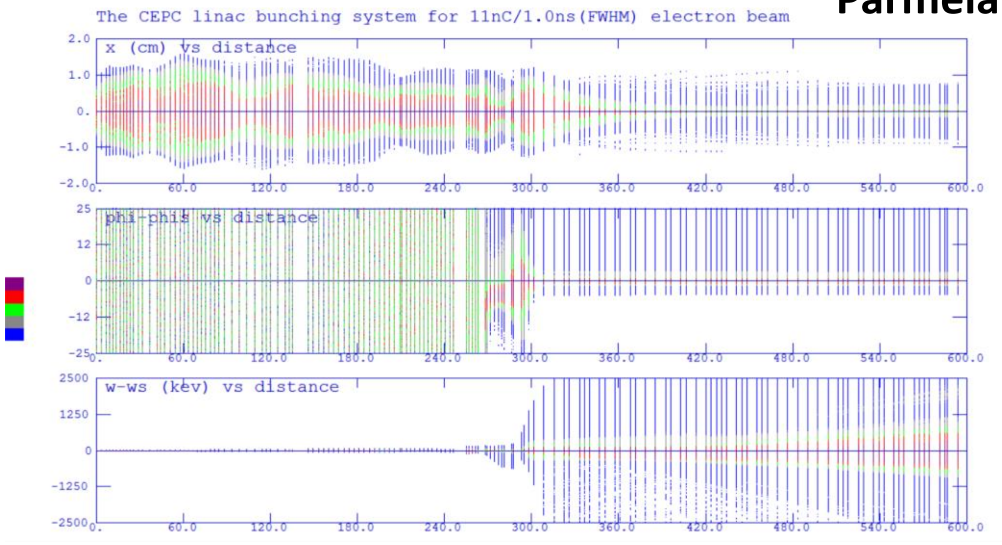
Source design

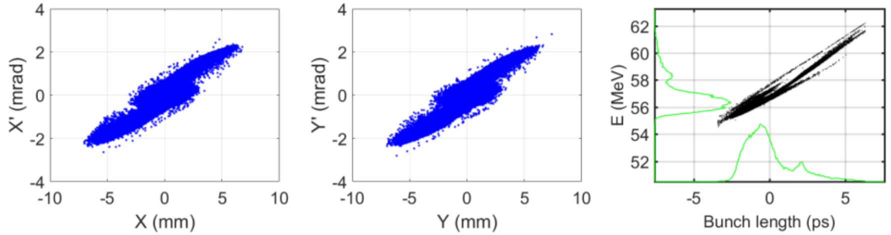
Electron source

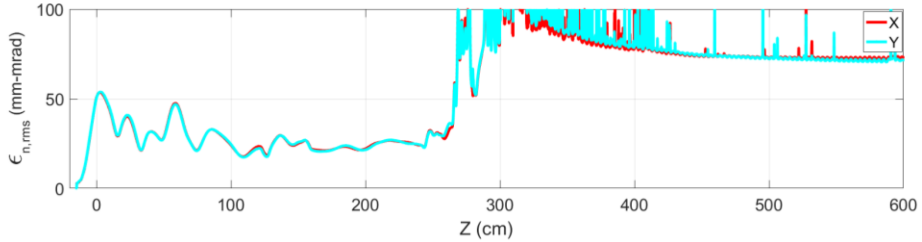
- **Thermionic Triode** electron gun
- Sub-harmonic pre-buncher
  - 142.8375 MHz
  - 571.35 MHz
- Buncher & A0
  - 2856.75 MHz
- Emittance
  - <100 mm-mrad (Norm.Rms) @11nC
- **Transmission**
  - ~90%



Parmela

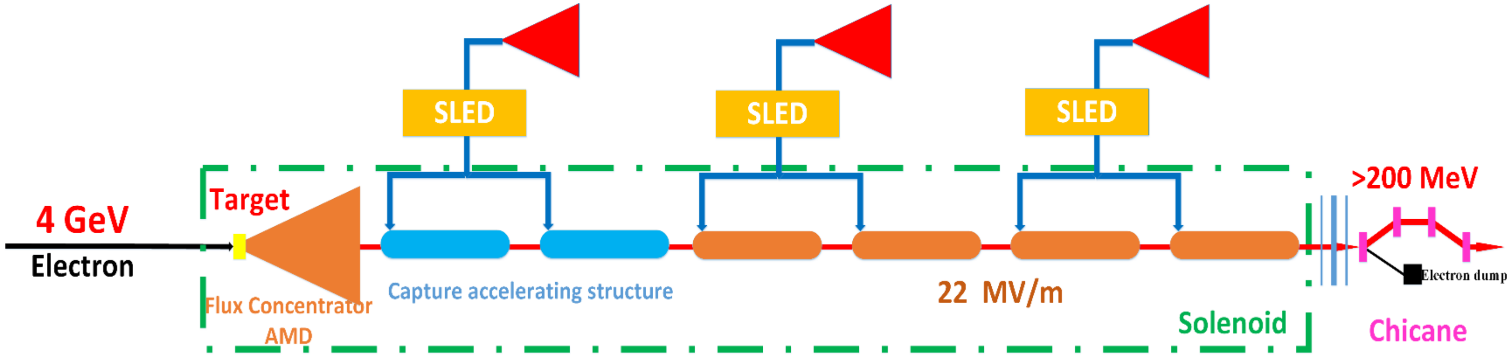


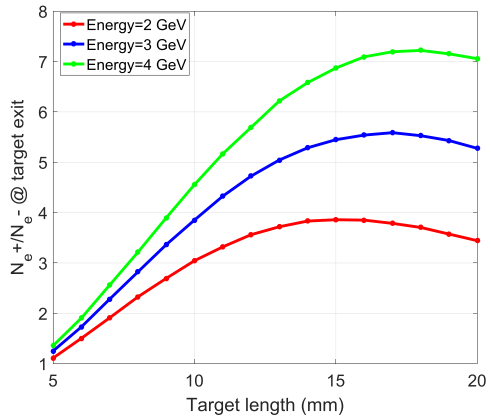


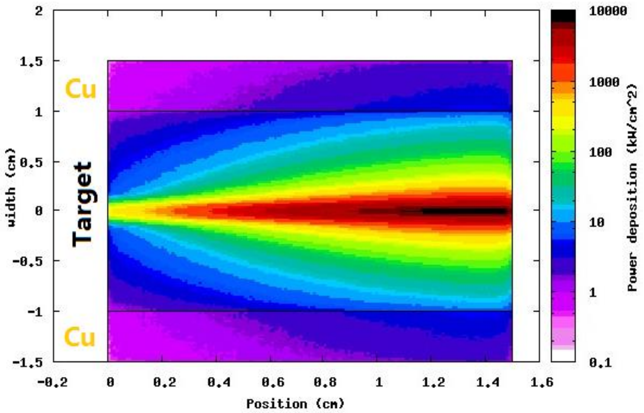


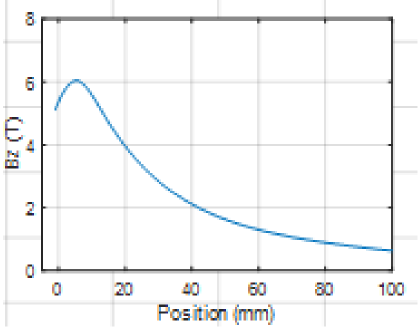
Positron source

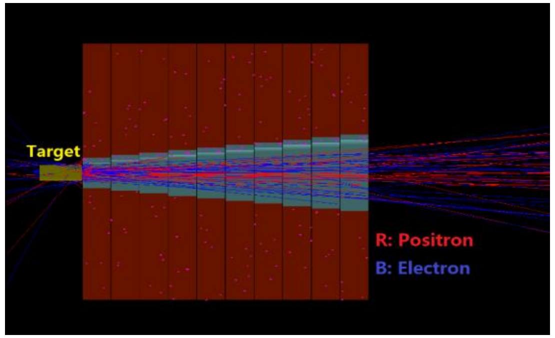
- Layout of positron source
  - Target (Conventional)
    - ✓ tungsten@15 mm
    - ✓ Beam size: 0.5 mm
  - Electron Beam
    - ✓ 4GeV/10nC/100Hz
    - ✓ Beam power 4kW
  - Energy deposition
    - ✓ 0.784 GeV/e- @ FLUKA
    - ✓ 784 W → water cooling
  - AMD (Adiabatic Matching Device)
    - ✓ Flux Concentrator
    - ✓ Length: 100mm
    - ✓ Aperture: 8mm→26mm
    - ✓ Magnetic field: (5.5T→0T) + 0.5T









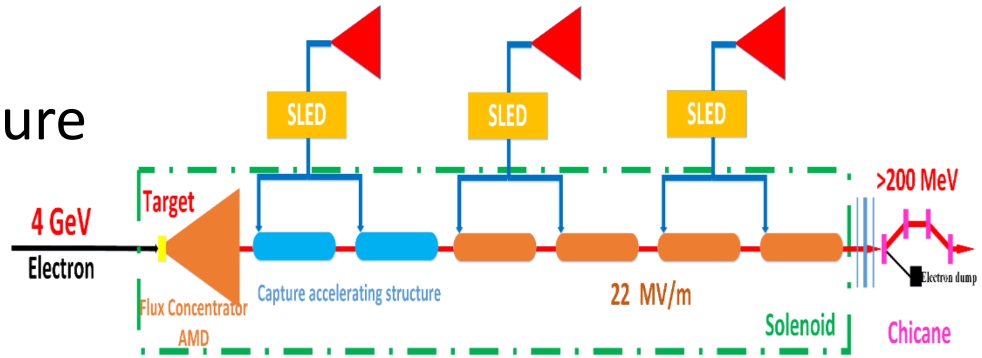


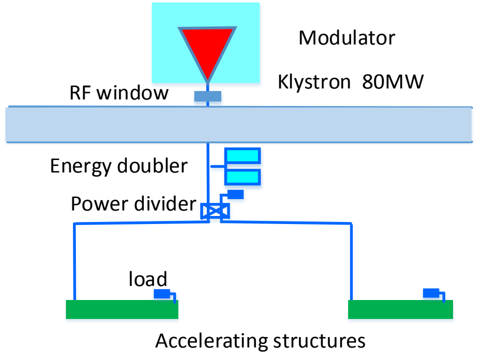
Source design

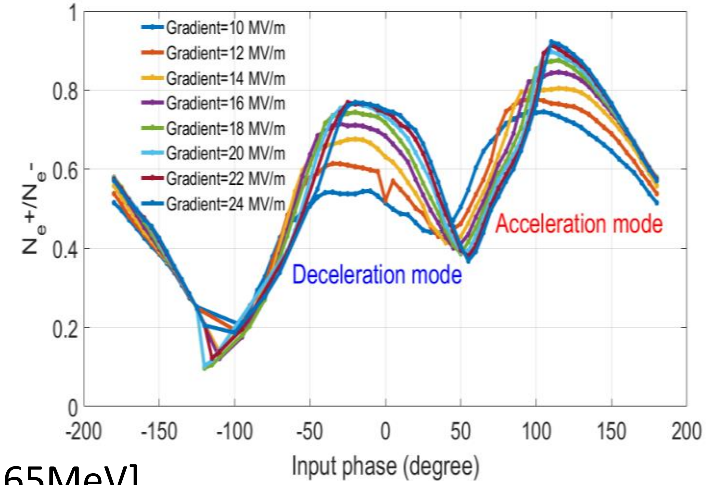
Positron source

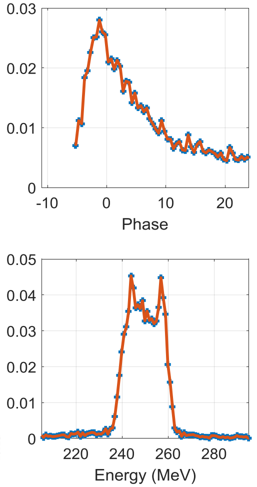
➢ Layout of positron source

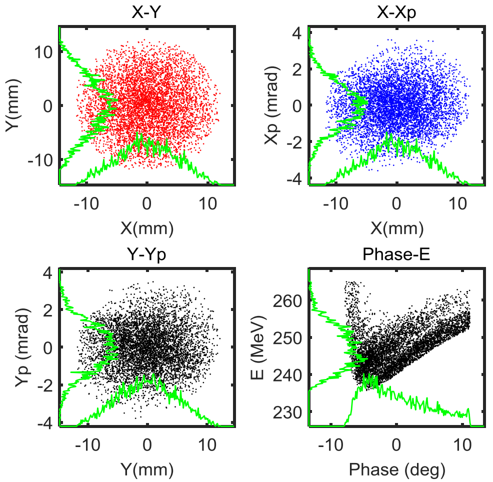
- Capture & Pre-accelerating structure
  - ✓ Length:2 m
  - ✓ **Aperture**: 25 mm
  - ✓ Gradient: 22 MV/m
- Chicane
  - ✓ Wasted electron separation
- Norm. RMS. Emittance
  - ✓ ~2400 mm-mrad→~120nm@10GeV
- Energy: >200 MeV
- Positron yield
  - ✓ Ne+/Ne- > **0.5** @ [-8°,12°,235MeV, 265MeV]











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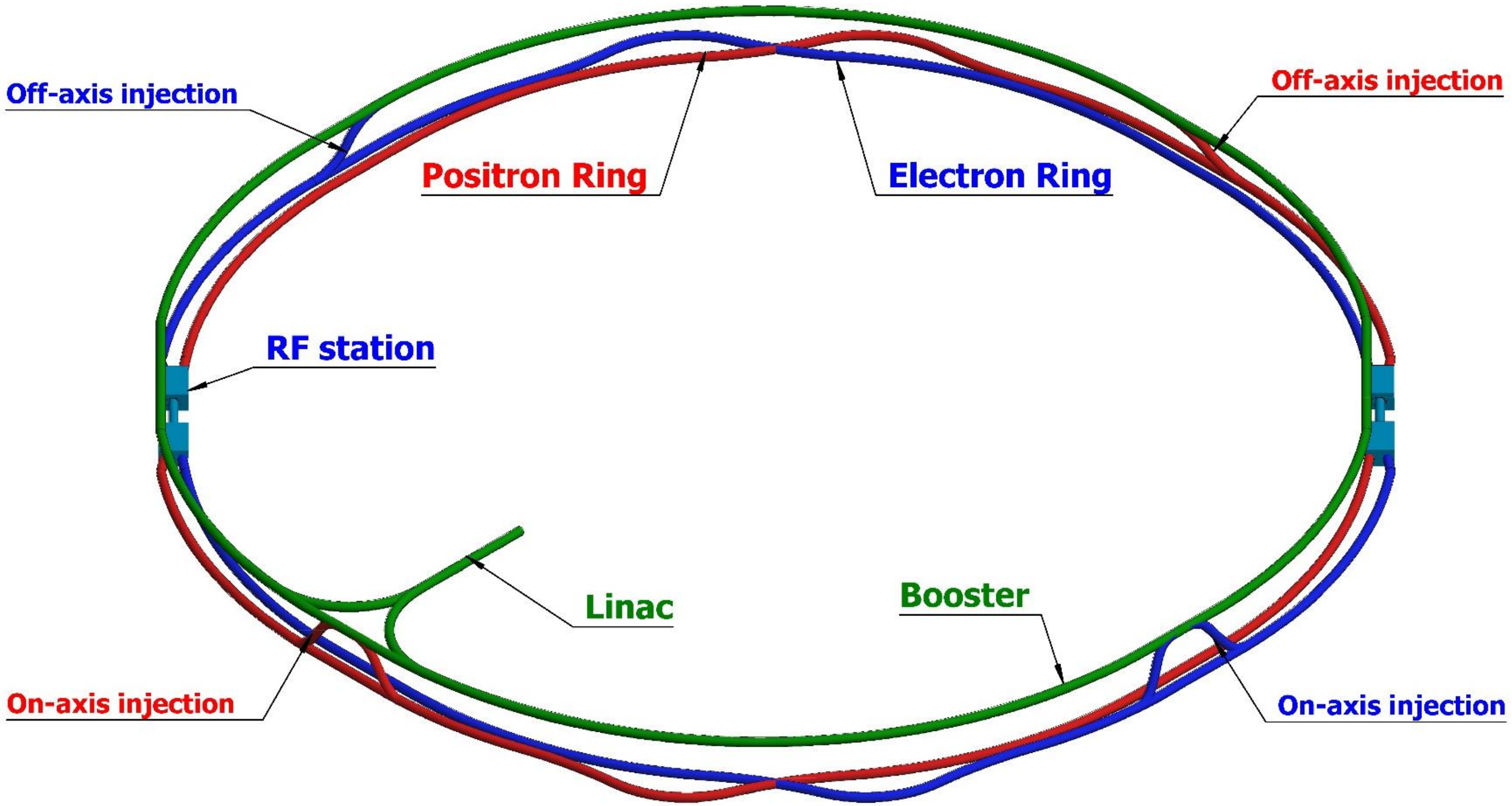
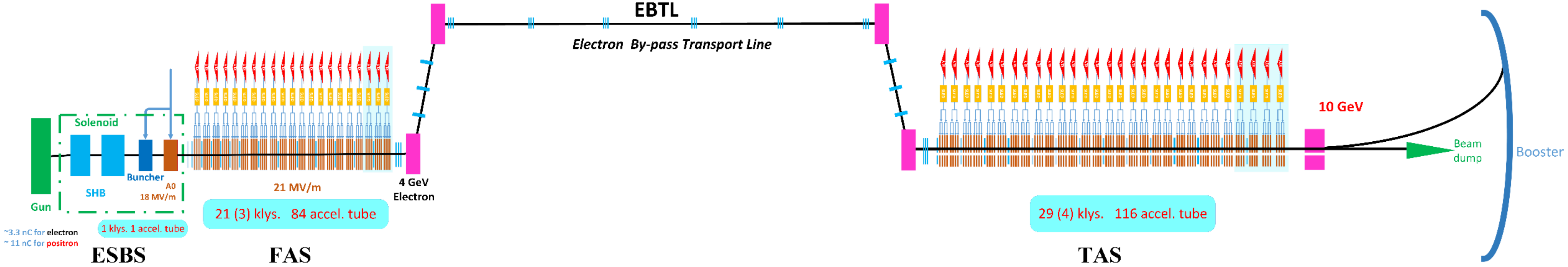
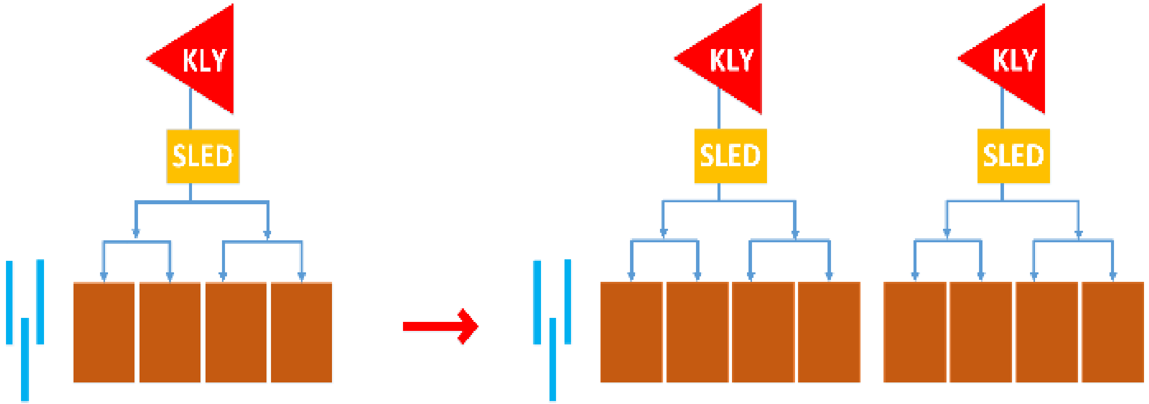


Electron linac

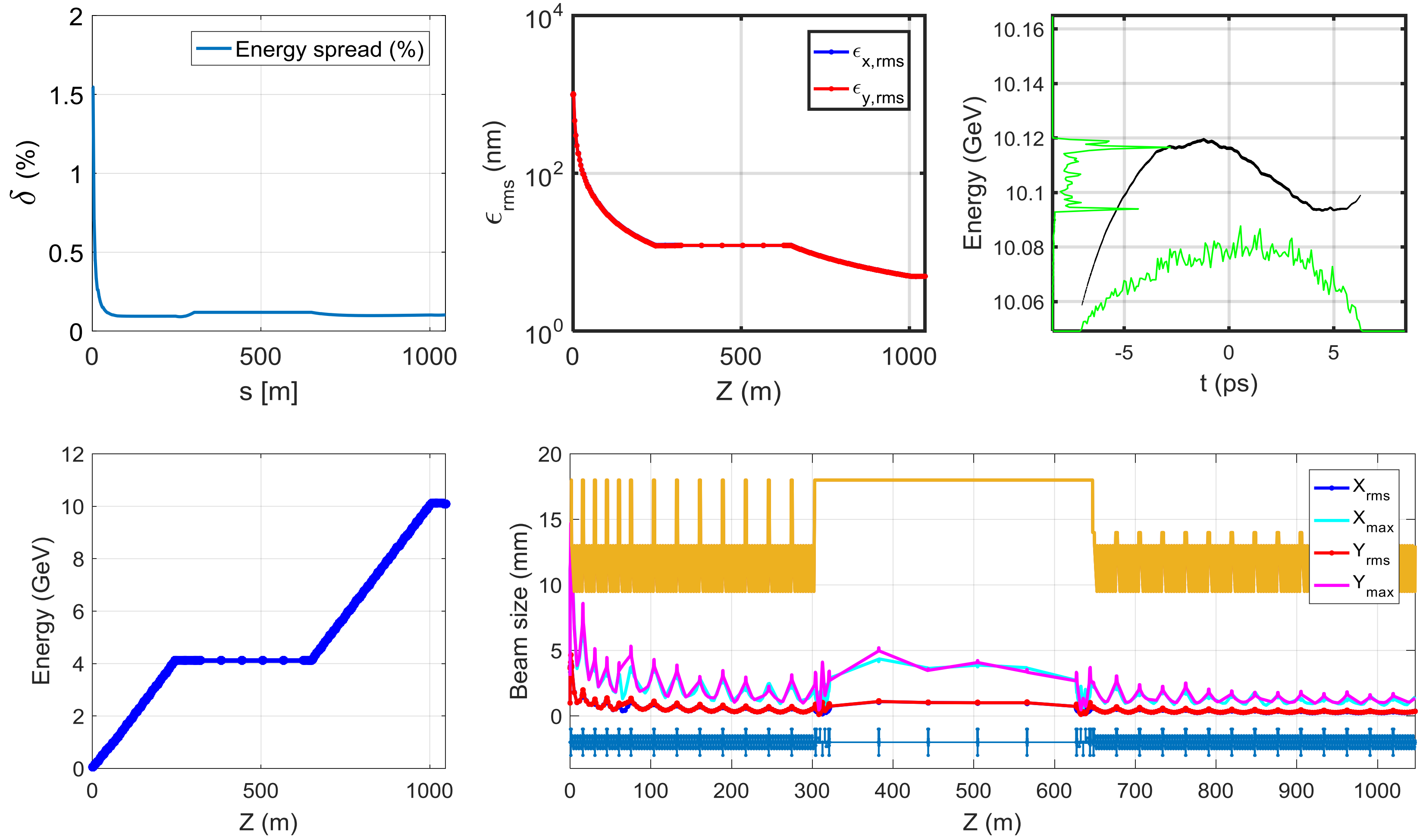


- Focusing device: ***Triplet***
  - *1 triplet+4 Acc. Stru.→1 triplet+8 Acc. Stru.*
- Operation mode :
  - High charge mode (positron production)
    - 4GeV & 10 nC
    - **ESBS+FAS**
  - Low charge mode (electron injection)
    - 10 GeV & 3 nC
    - **ESBS+FAS+EBTL+TAS**



CEPC

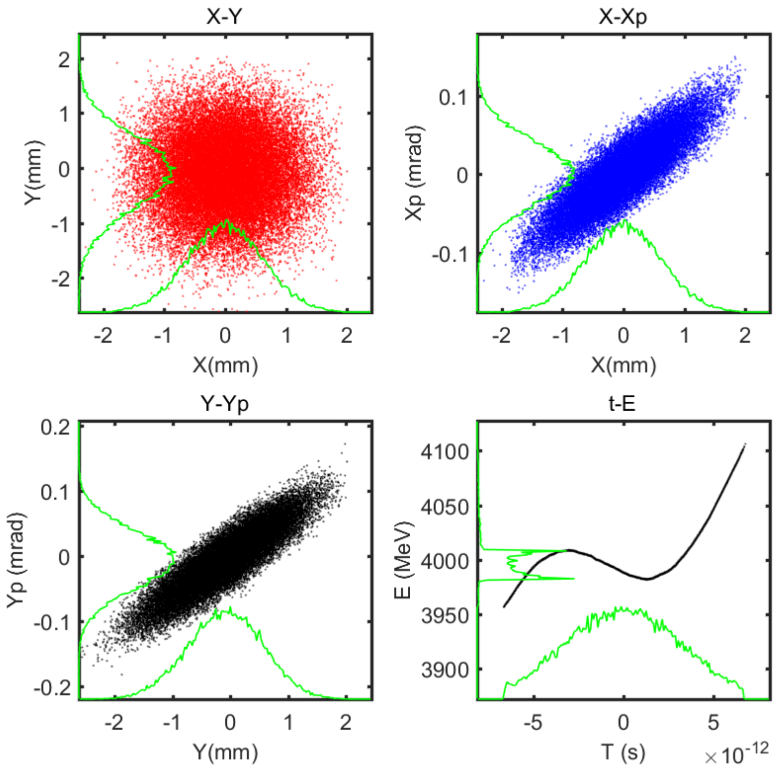
- Low charge mode
  - 10 GeV with 3 nC charge
  - Energy spread (rms): 0.15%
  - Emittance (rms): 5 nm

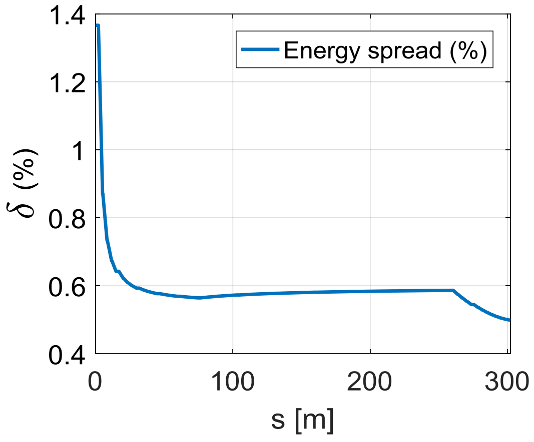


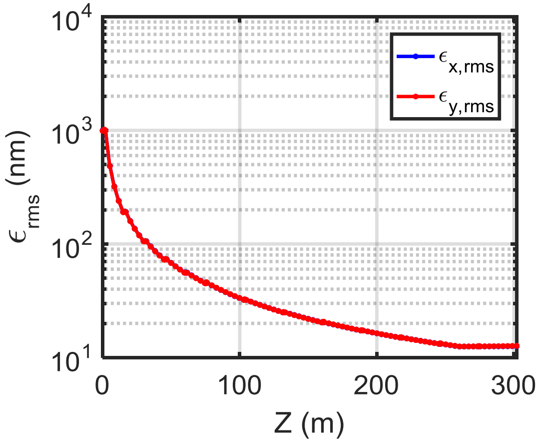
Linac design Electron linac→ *Positron production*

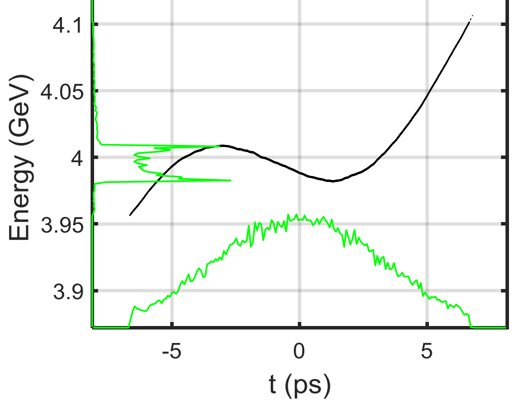
CEPC

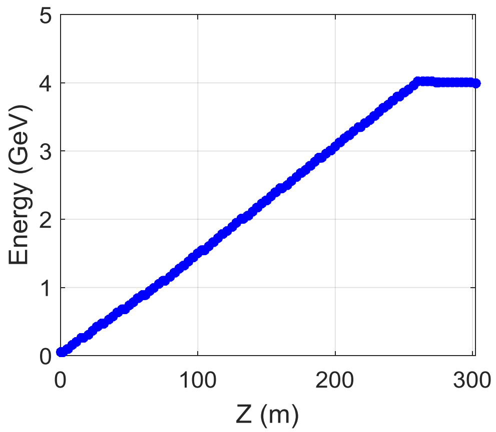
- High charge mode
  - 4 GeV with 10 nC charge
  - Energy spread (rms): 0.6%

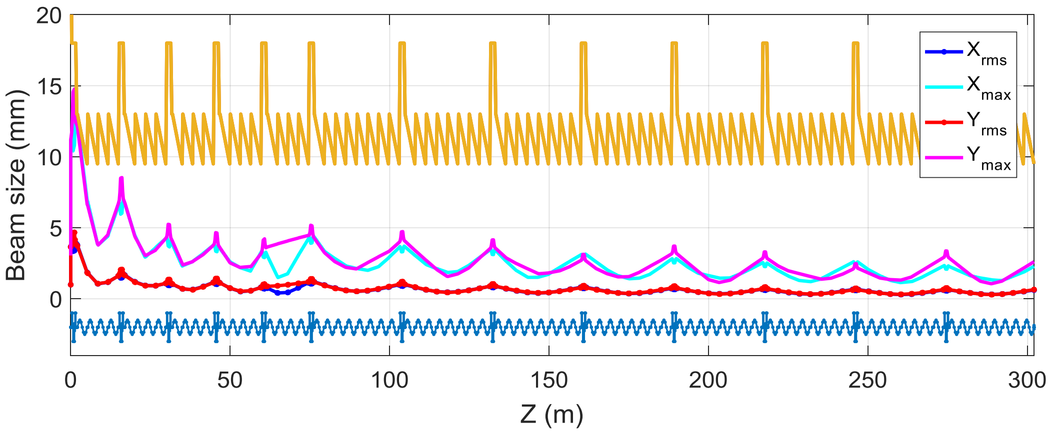






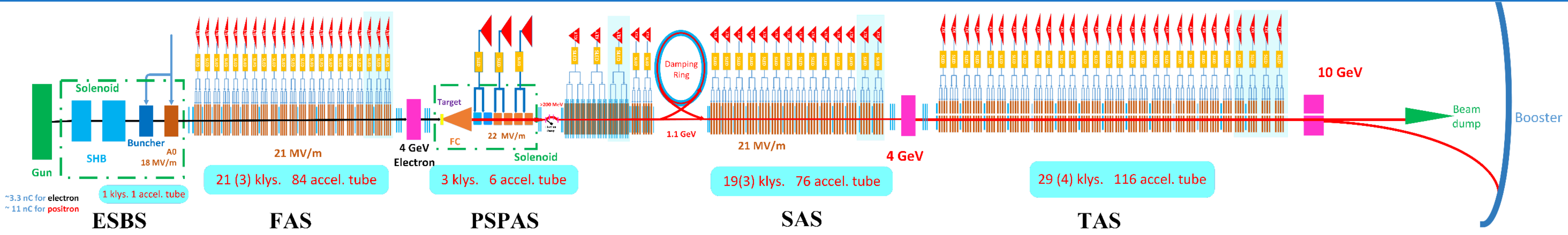




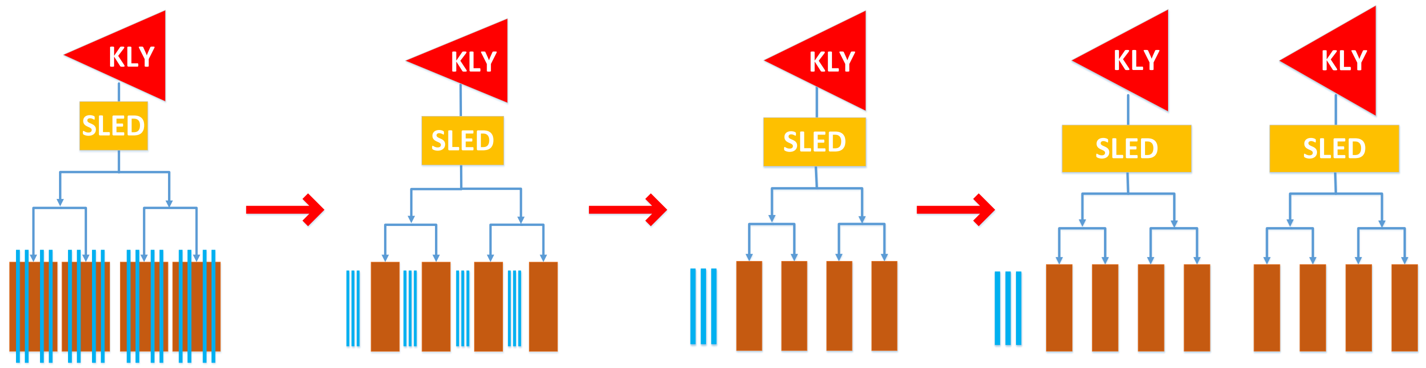


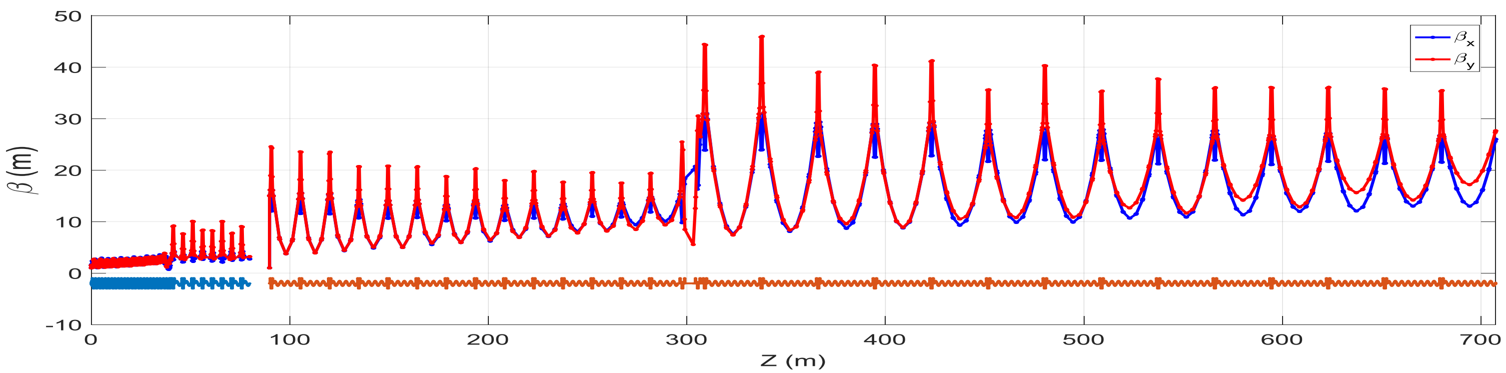
Linac design

Positron linac

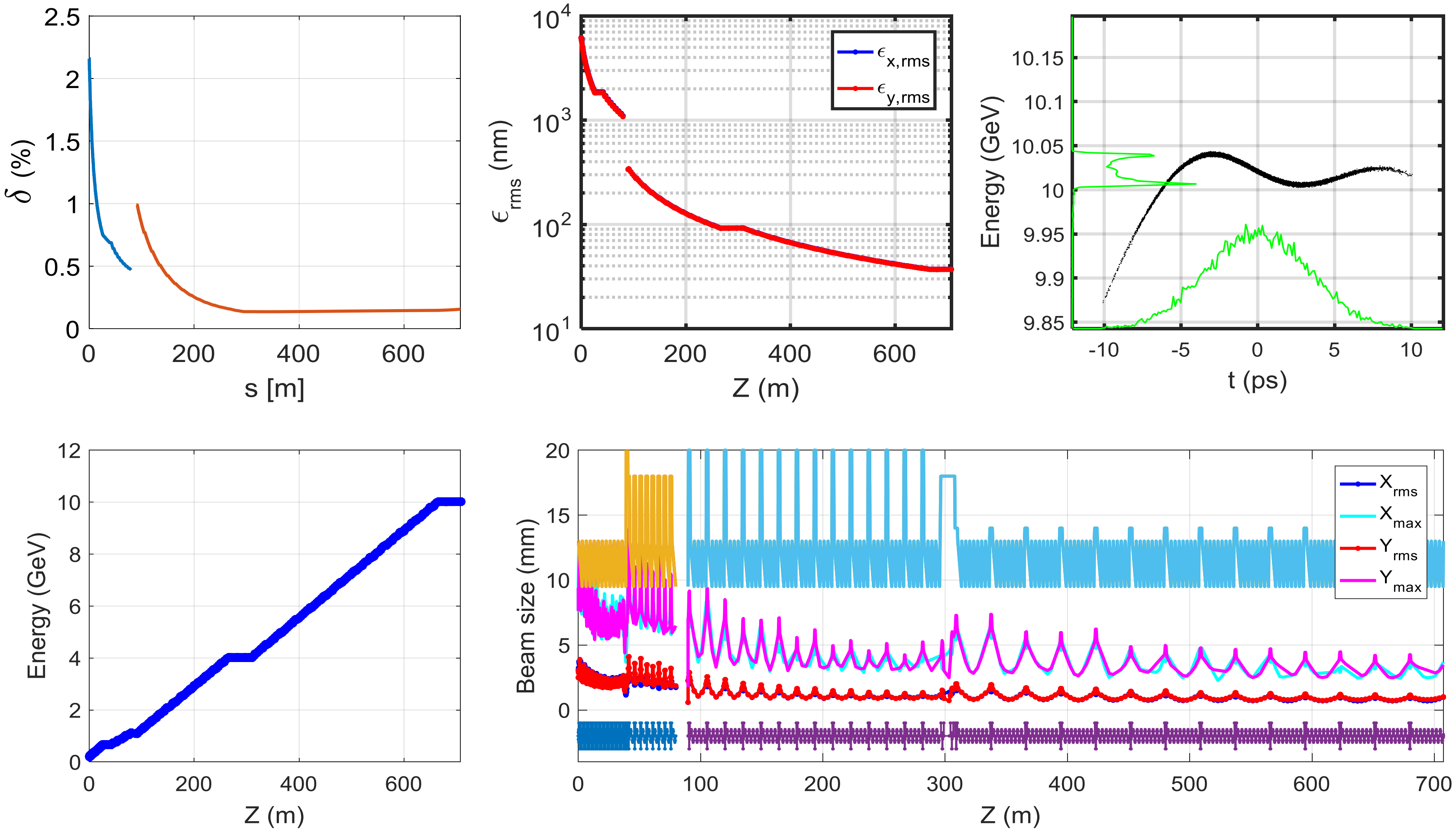


- ➢PSPAS→SAS (DR) +TAS
  - **SAS**: 200 MeV→4 GeV
  - Damping Ring @ 1.1 GeV
  - TAS: 4GeV→10 GeV
- ➢Transverse focusing devices
  - FODO structure at low energy
  - Triplet at high energy





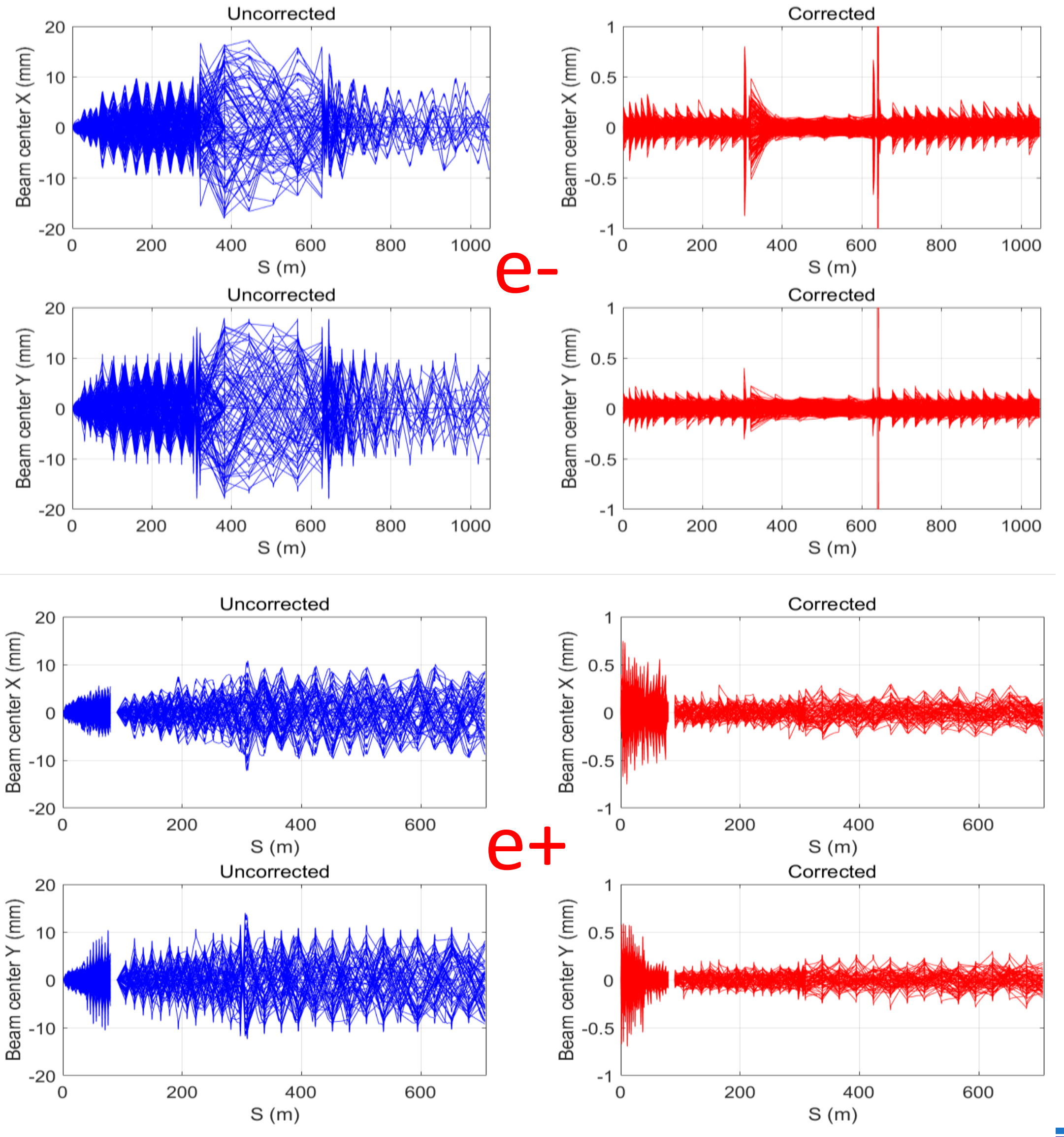
- Positron linac
  - 10 GeV with 3 nC charge
  - Energy spread (rms): 0.16%
  - Emittance with DR (rms): 40(H)/24nm(V)



Linac design Misalignment errors with correction

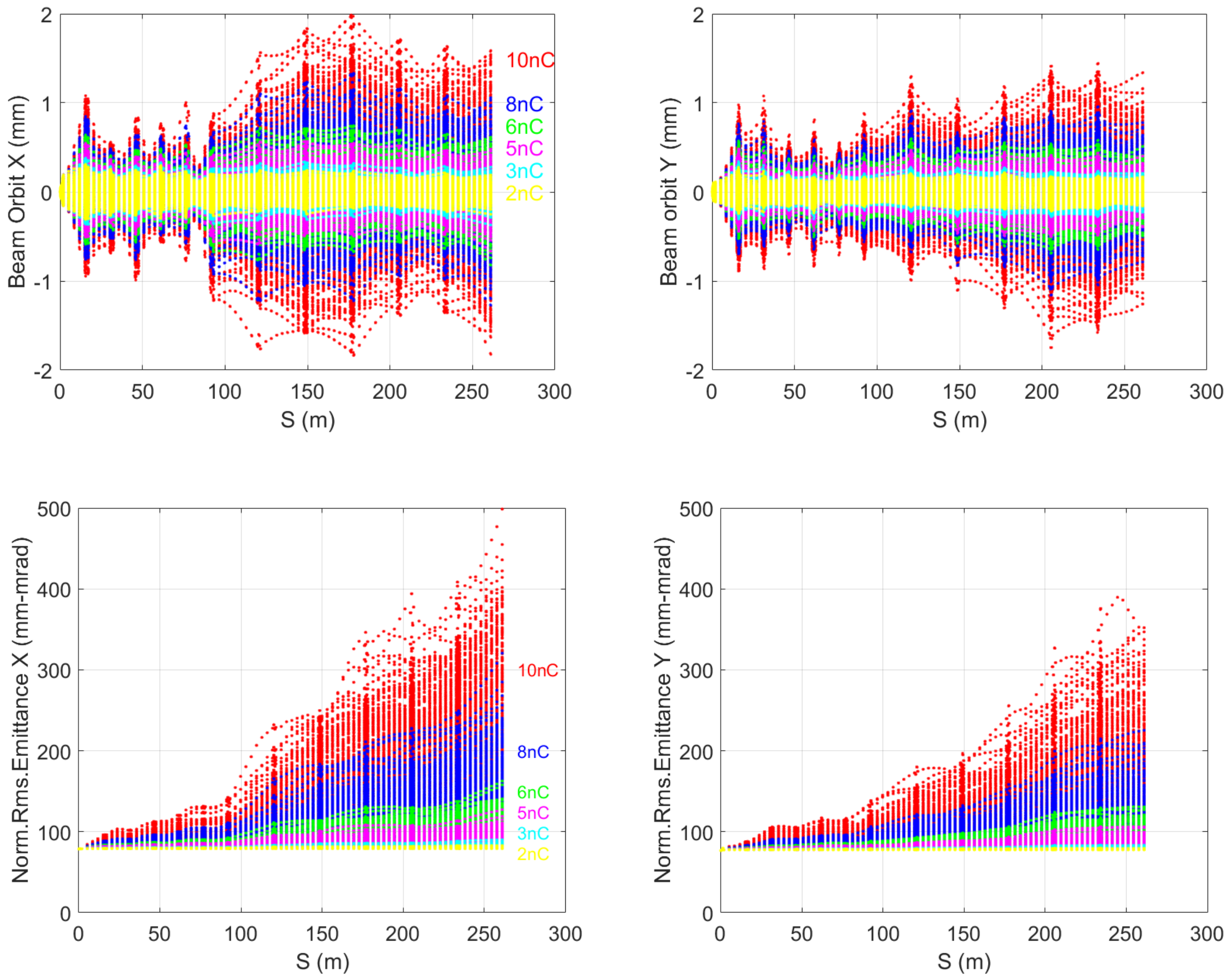
- Whole Linac
  - One-to-one correction method for both e- and e+
  - Errors: Gaussian distribution, 3σ truncated
- Beam orbit
  - <1mm
  - <0.5mm at high energy region

Error description	Unit	Value
Translational error	mm	0.1
Rotation error	mrad	0.2
Magnetic element field error	%	0.1
BPM uncertainty	mm	0.1



Linac design Misalignment errors with correction

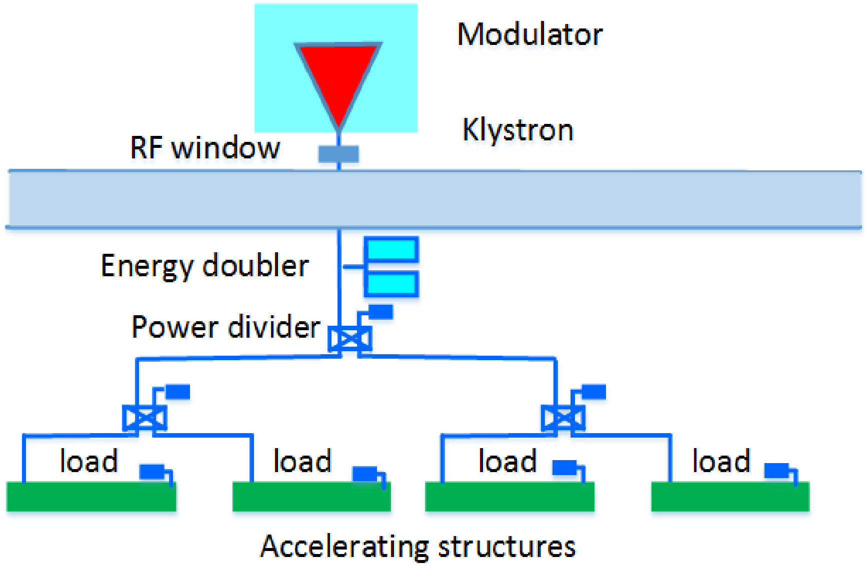
- 4GeV Electron Linac with high charge
  - Method: First orbit correction + multi-particles simulation
  - Low charge
    - ✓ Beam orbit can be controlled well
  - High charge
    - ✓ Misalignments of Acc. Tubes
    - ✓ **Wakefield**
  - In a real operation, correction is based on multi-particles orbit, so the orbit and emittance growth can be controlled better.



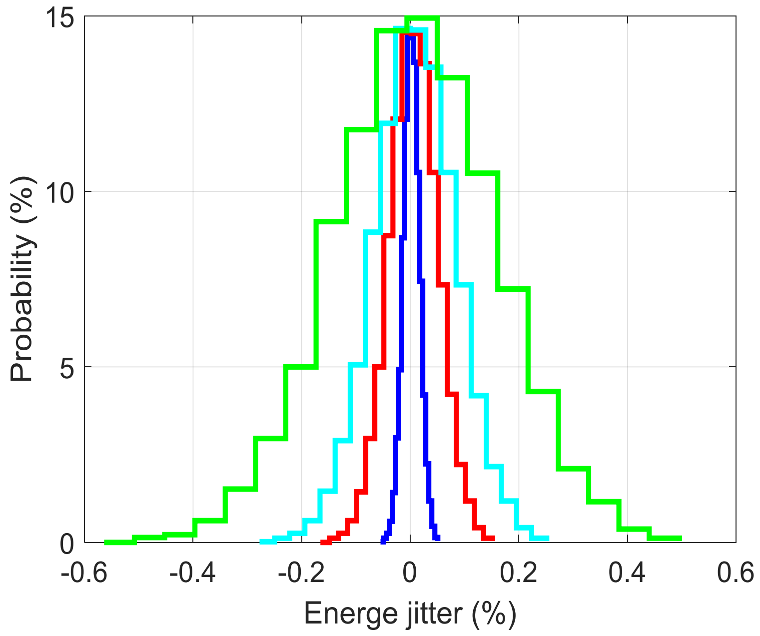
Linac design

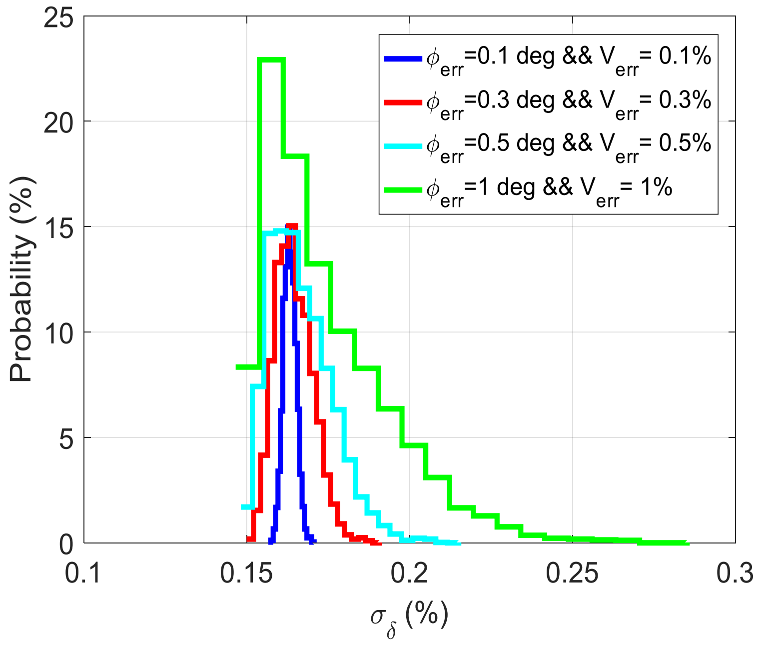
Field errors

- Simulation condition
  - 5000 seeds
  - Accelerating structure
    - phase errors and amp errors
    - 4 accelerating structures in one KLY
    - 3σ--Gaussian



- Energy jitter: 0.2%
- Energy spread < 0.2%
  - Phase errors: 0.5 degree (rms)
  - Grad. errors: 0.5% (rms)

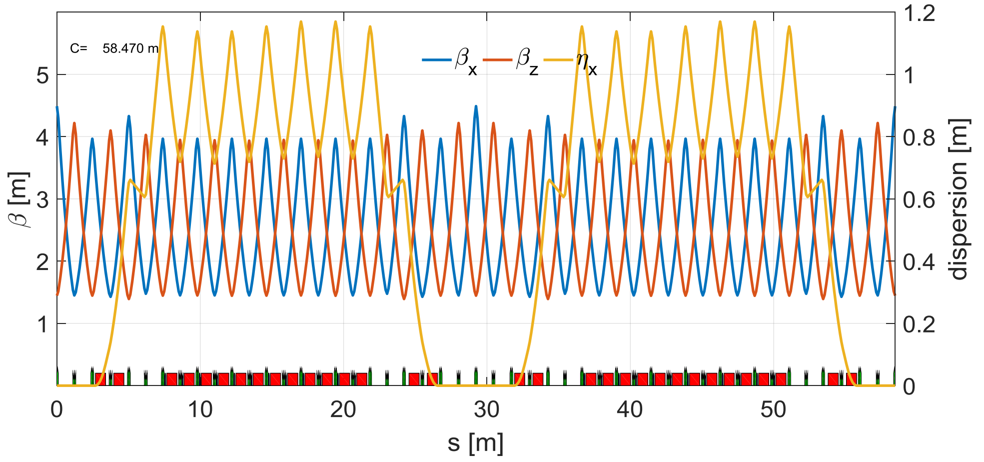


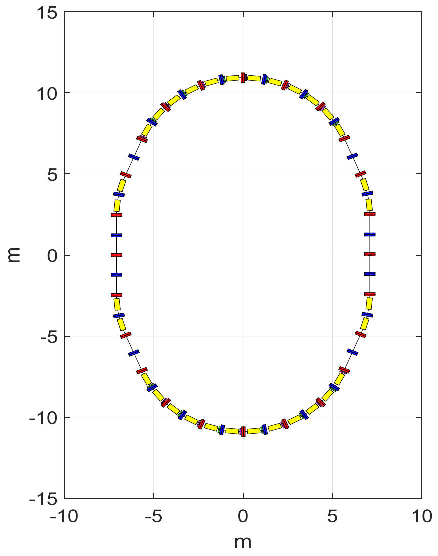


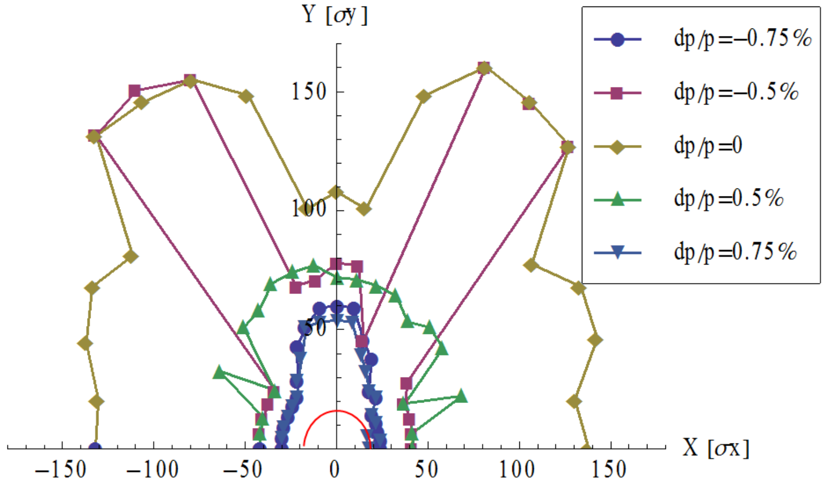
Damping Ring

@ D. Wang

DR V1.0	Unit	Value
Energy	GeV	1.1
Circumference	M	58.5
Repetition frequency	Hz	100
Bending radius	M	3.62
Dipole strength B_0	T	1.01
U_0	keV	35.8
Damping time x/y/z	ms	12/12/6
δ_0	%	0.05
ε_0	mm.mrad	287.4
Nature σ_z	mm	7 (23ps)
ε_{inj}	mm.mrad	2500
$\varepsilon_{ext\ x/y}$	mm.mrad	704/471
$\delta_{inj}/\delta_{ext}$	%	0.3/0.06
Energy acceptance by RF	%	1.0
f_{RF}	MHz	650
V_{RF}	MV	1.8







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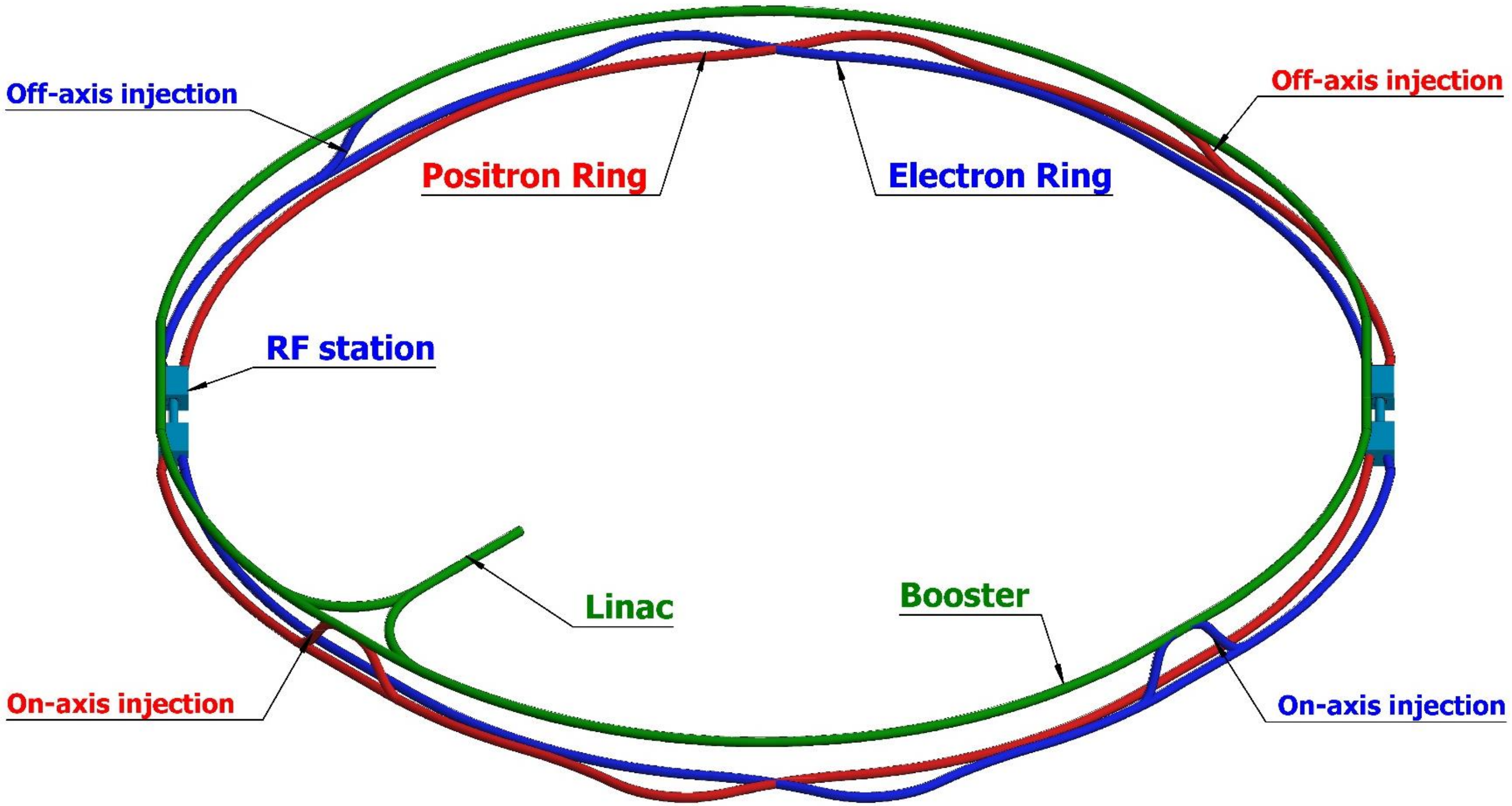


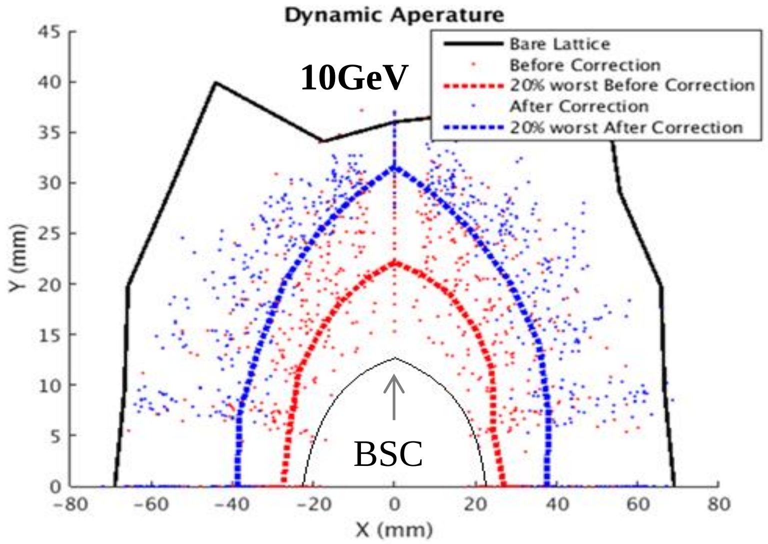
Summary

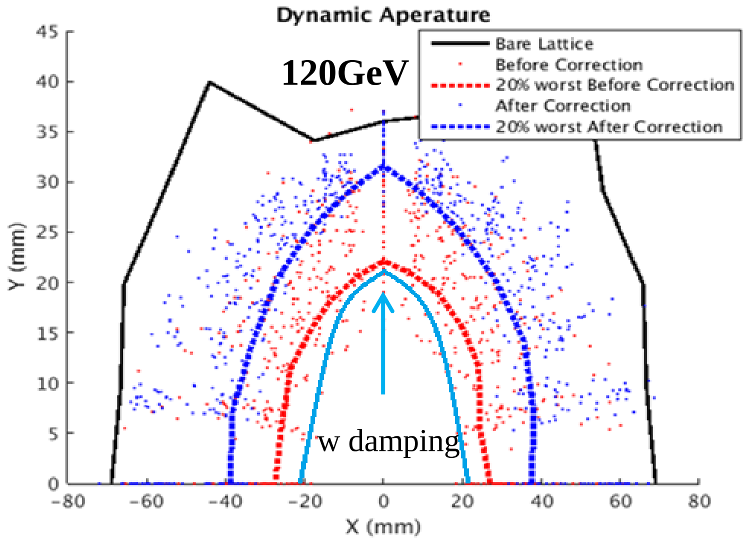
- The CEPC linac works with 100 Hz repetition, 10 GeV and one-bunch-per-pulse, which can meet the requirements of Booster;
- The linac have the potential to provide positron beam and electron beam with bunch charge larger than 3nC;
- One preliminary damping ring is proposed, the emittance with DR is smaller than 40 nm;
- Up to now, there's no bottleneck in linac design and further works continues.

Thank you!

Dynamic aperture with errors

- With only COD corrections, DA is nearly two thirds of bare lattice
- At 120GeV, radiative damping was considered.
- DA requirement @ 10GeV determined by the beam stay clear region
- DA requirement @ 120GeV: 1) H- quantum lifetime, 2) V- re-injection process from the collider in the on-axis injection scheme





	DA requirement		DA results	
	H	V	H	V
10GeV ($\varepsilon_x = \varepsilon_y = 120$nm)	$4\sigma_x$ +5mm	$4\sigma_y$ +5mm	$7.7\sigma_x$ +5mm	$14.3\sigma_y$ +5mm
120GeV (ε_x=3.57nm, $\varepsilon_y = \varepsilon_x$*0.005)	$6\sigma_x$ +3mm	$49\sigma_y$ +3mm	$21.8\sigma_x$ +3mm	$779\sigma_y$ +3mm

- Requirement for linac emittance: **< 150nm**, otherwise BSC > beam pipe