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

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

CEPC Linac Injector

Workshop on Circular Electron Positron Collider
24-26 May, 2018

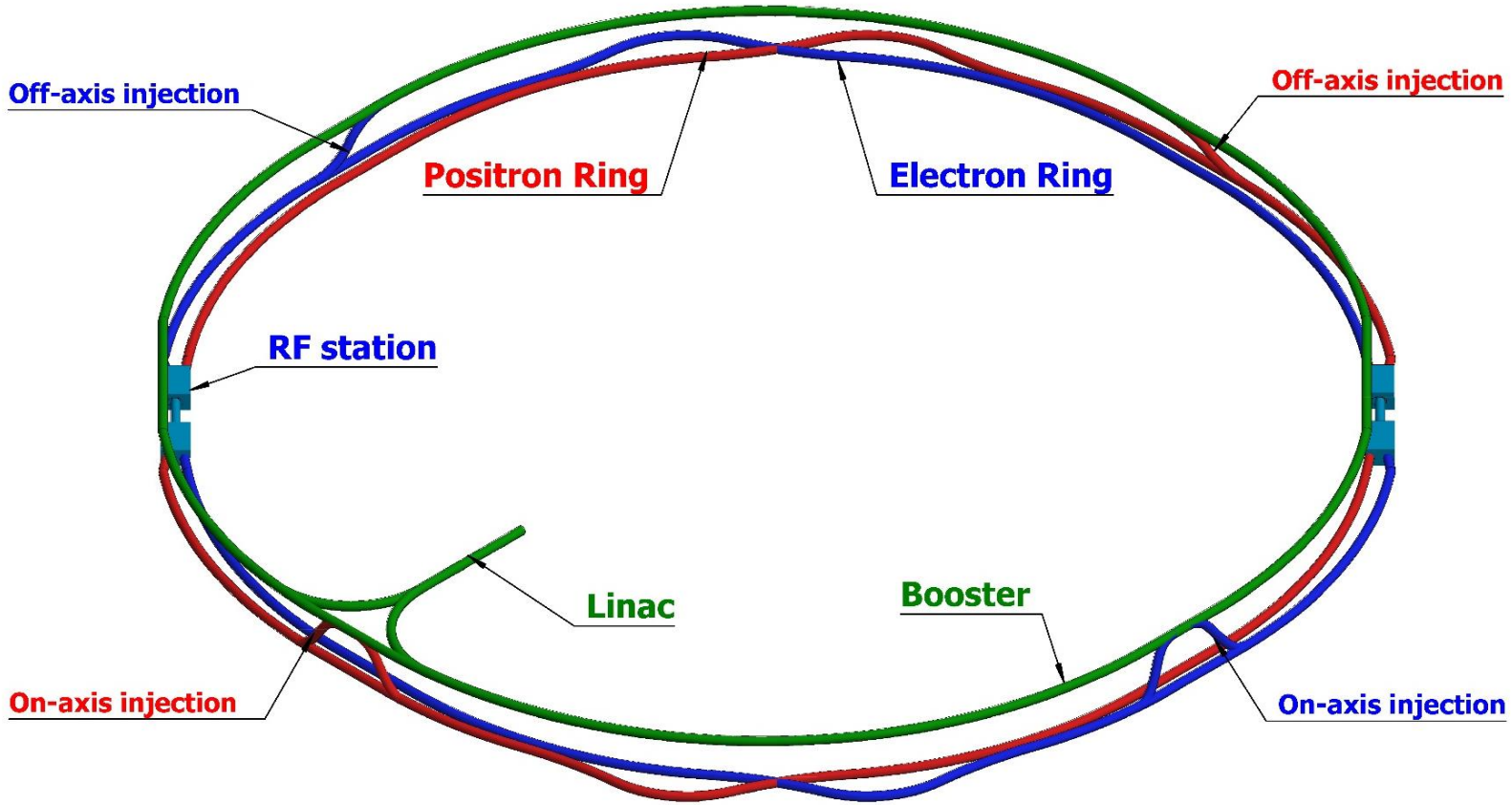
Cai Meng, Guoxi Pei, Jingru Zhang, Xiaoping Li,

Dou Wang, Jie Gao, Shilun Pei, Yunlong Chi

Institute of High Energy Physics, CAS, Beijing

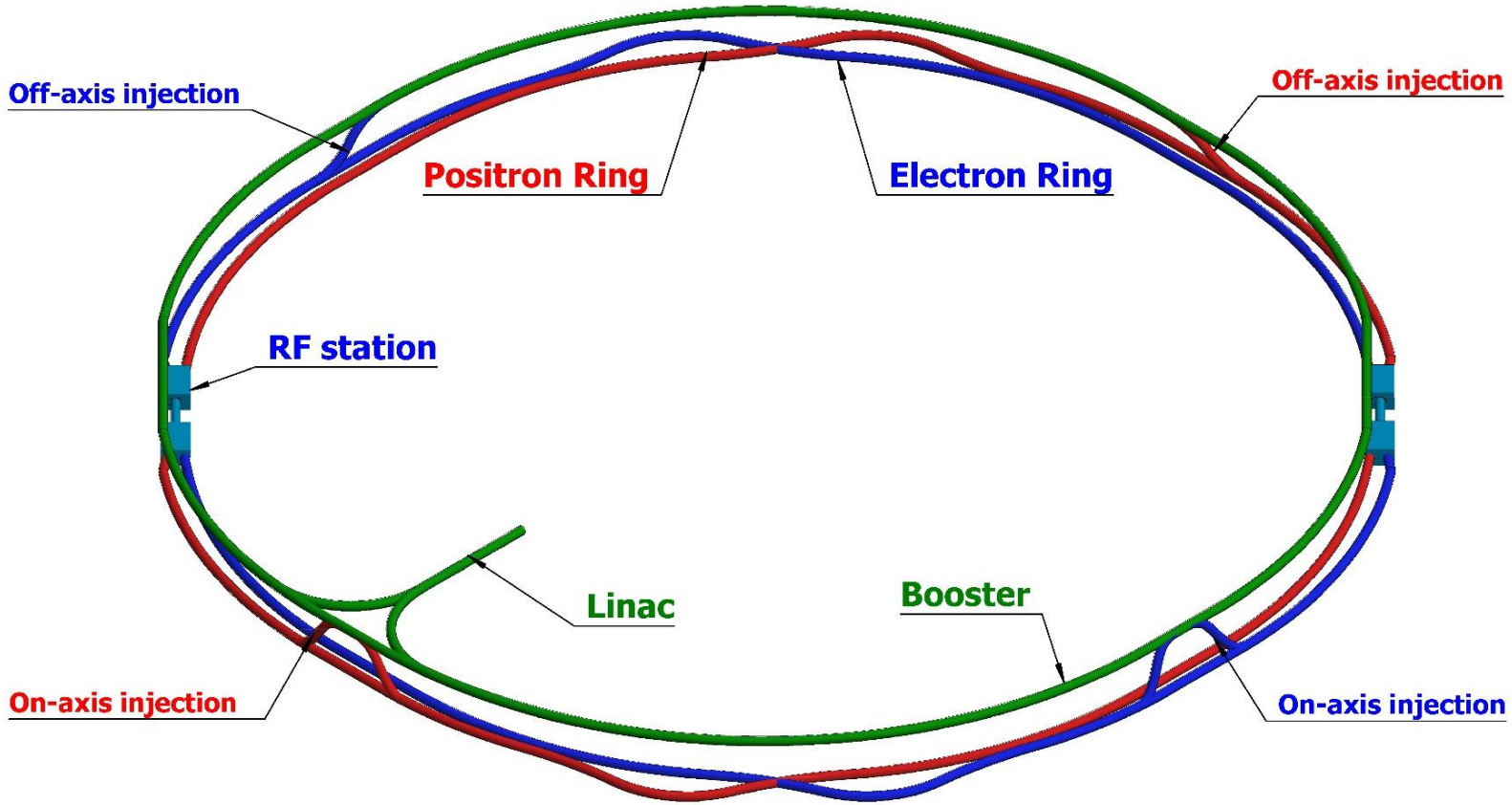
Outline

- Introduction
  - Main parameters
  - Linac layout
- Source design
  - Electron source
  - Positron source
- Linac design
  - Electron mode
  - Positron mode
- Summary



Outline

- Introduction
  - Main parameters
  - Linac layout
- Source design
  - Electron source
  - Positron source
- Linac design
  - Electron mode
  - Positron mode
- Summary



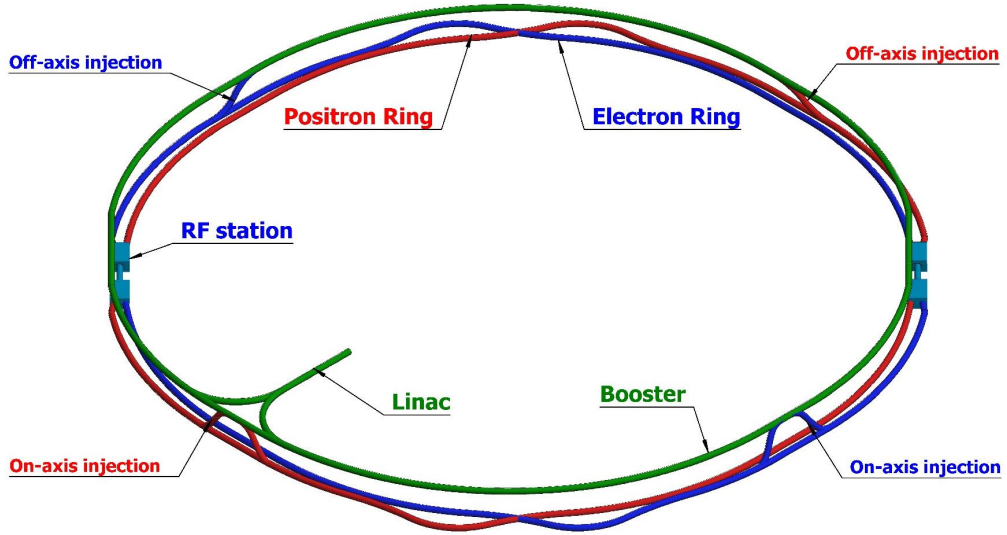
Introduction

Basic information

- Luminosity is the core and key parameter of the collider
- **Integral Luminosity** is the fundamental value of the collider
  - T_s is the scheduled operation time
  - η is the **availability**

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

- As the first injector part, high availability of the Linac is very important
  - Beam commission, operation
  - The root of Big tree!

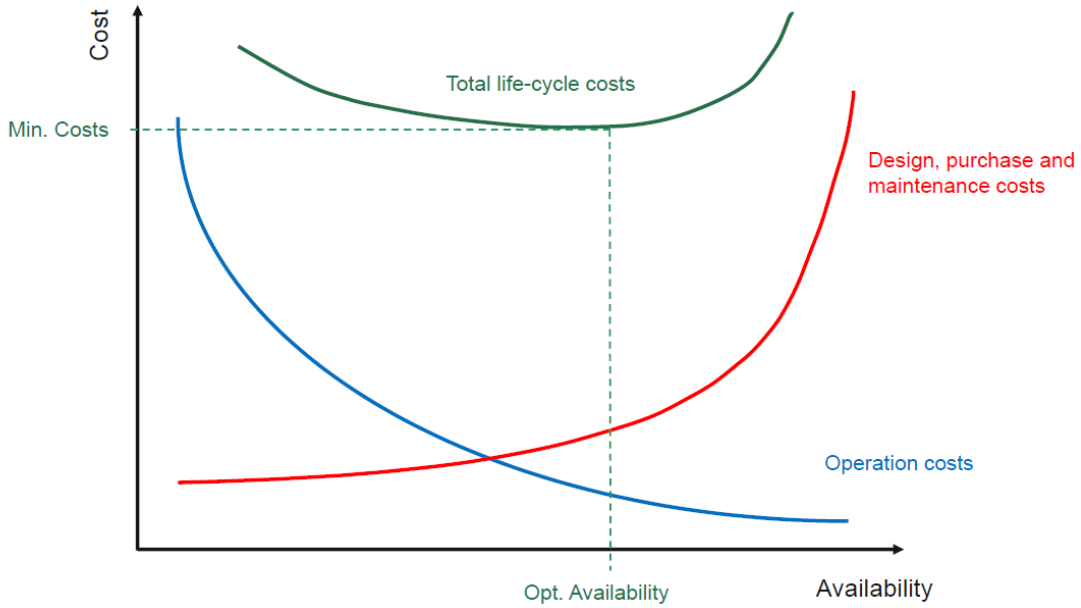


Introduction

Linac design goal

- Linac design goal and principles
  - **High Availability and Reliability**
    - ~ 15% backups for Klystrons and accelerating structure, need to study in the future
    - **Simplicity**
      - **Layout** / S-band accelerating structure (2856.75MHz)
  - Always providing beams that can **meet requirements** of Booster

Parameter	Symbol	Unit	Value
e^- /e^+ beam energy	E_{e-}/E_{e+}	GeV	10
Repetition rate	f_{rep}	Hz	100
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
e^- beam energy on Target		GeV	4
e^- bunch charge on Target		nC	10



A. Apollonio's figure

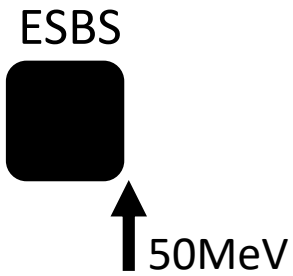
Introduction

Potential

- The linac should be have potential to meet the higher requirements and updates in the future, which is very likely for mostly accelerators
  - Emittance: smaller than 120 nm
    - **Damping Ring** for positron beam and *layout*
      - Higher transmission
      - Larger errors tolerance
      - Higher injection efficiency, easier injection design
  - Bunch charge: larger than 3 nC
    - Positron production and *layout*
      - 4 GeV electron beam
  - Bunch structure
    - One-bunch-per-pulse
      - ***short-range Wakefield***
    - Two-bunch-per-pulse is possible for linac, but should be carefully considered in DR

Layout of Linac

Positron Linac



- ESBS (*Electron Source and Bunching System*)
  - 50 MeV && 10nC for positron production

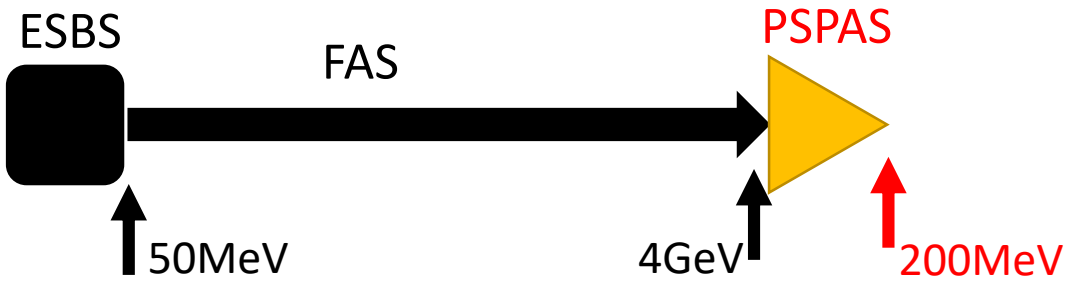
Layout of Linac

Positron Linac

- ESBS (*Electron Source and Bunching System*)
  - 50 MeV && 10nC for positron production
- FAS (*the First Accelerating Section*)
  - Electron beam to 4 GeV && 10nC for positron production

Layout of Linac

Positron Linac

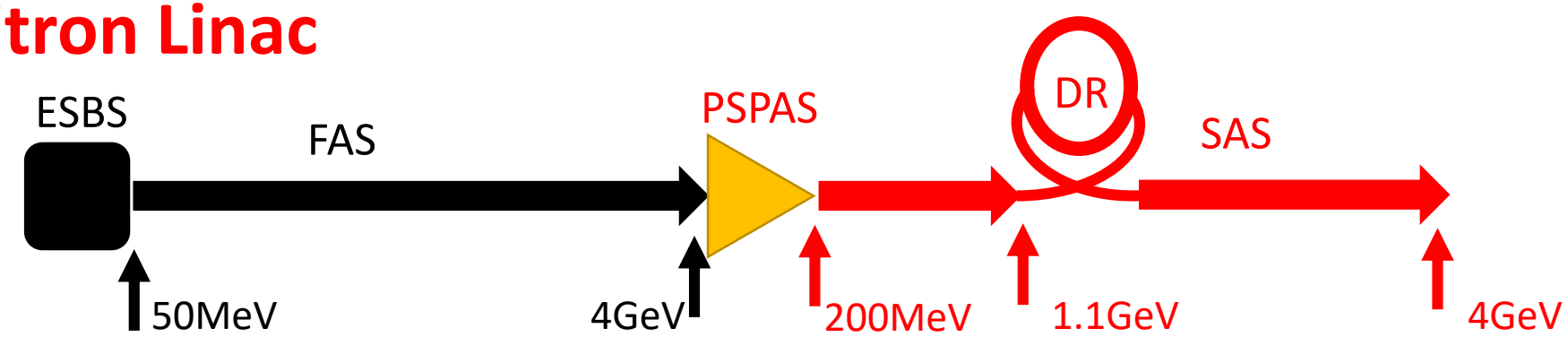


- ESBS (*Electron Source and Bunching System*)
  - 50 MeV && 11nC for positron production
- FAS (*the First Accelerating Section*)
  - Electron beam to 4 GeV && 10nC for positron production
- PSPAS (*Positron Source and Pre-Accelerating Section*)
  - Positron beam larger than 200 MeV && larger than 3 nC

Introduction

Layout of Linac

Positron Linac

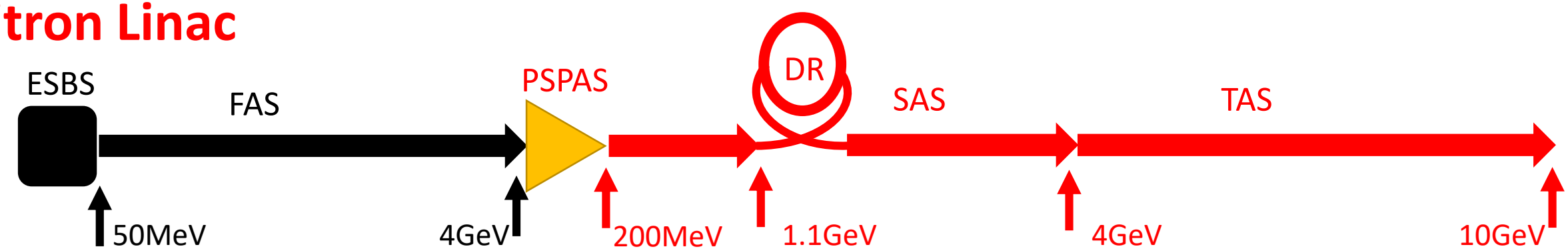


- ESBS (*Electron Source and Bunching System*)
  - 50 MeV && 11nC for positron production
- FAS (*the First Accelerating Section*)
  - Electron beam to 4 GeV && 10nC for positron production
- PSPAS (*Positron Source and Pre-Accelerating Section*)
  - Positron beam larger than 200 MeV && larger than 3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

Introduction

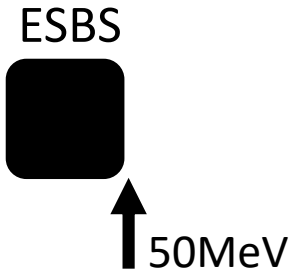
Layout of Linac

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



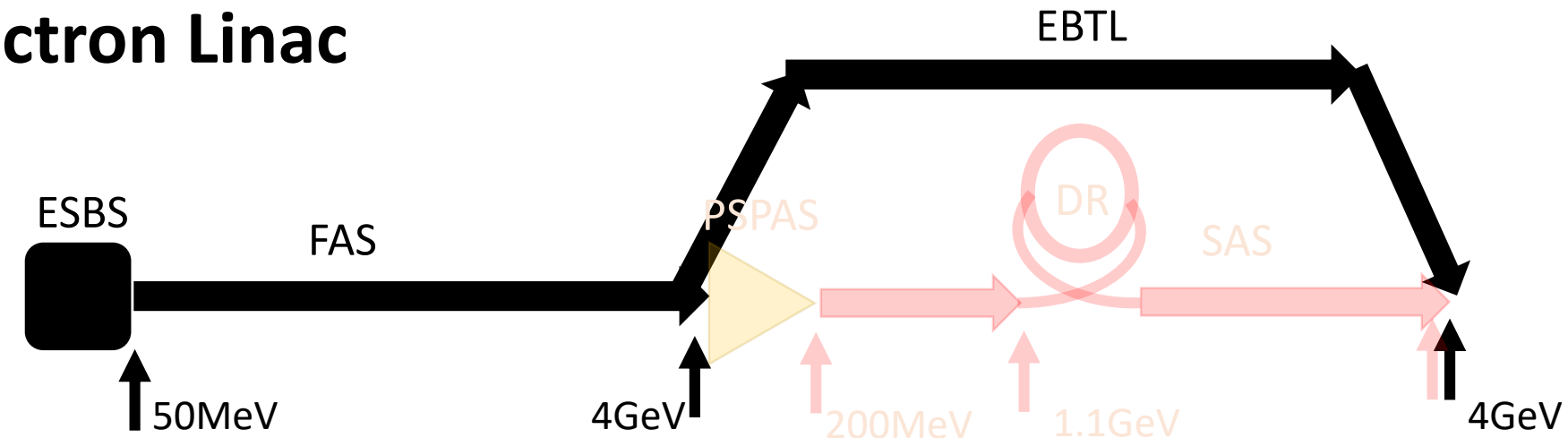
- ESBS (*Electron Source and Bunching System*)
  - 50 MeV && 3 nC

Electron Linac

- ESBS (*Electron Source and Bunching System*)
  - 50 MeV && 3 nC
- FAS (*the First Accelerating Section*)
  - Electron beam to 4 GeV && 3 nC

Layout of Linac

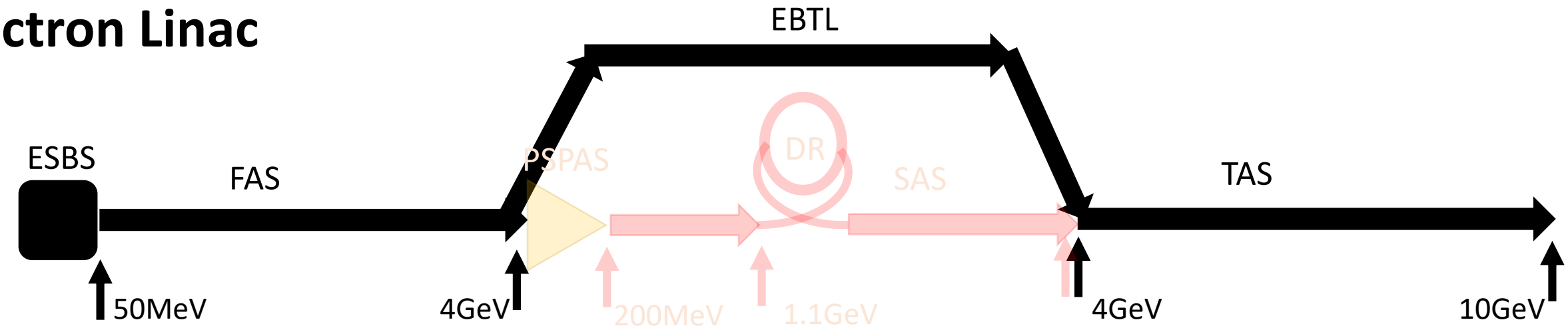
Electron Linac



- 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

Layout of Linac

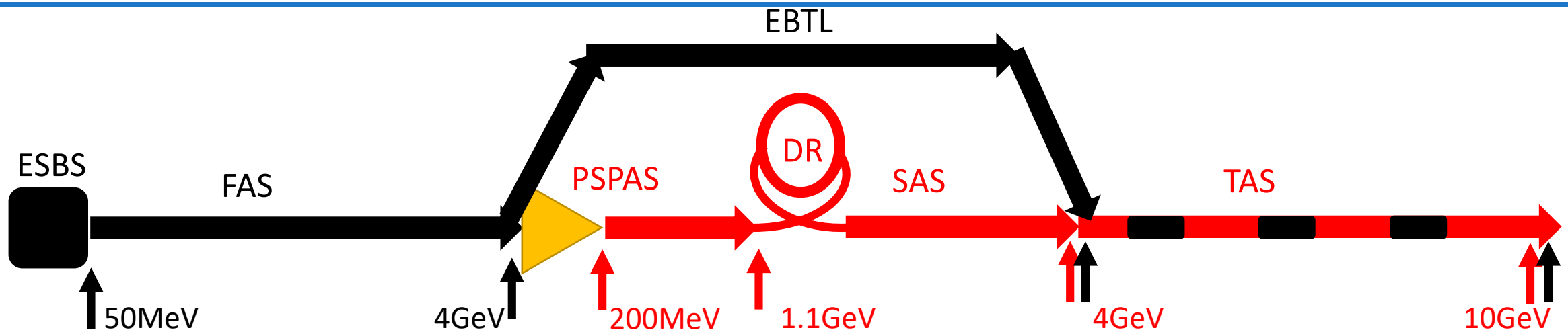
Electron Linac



- 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

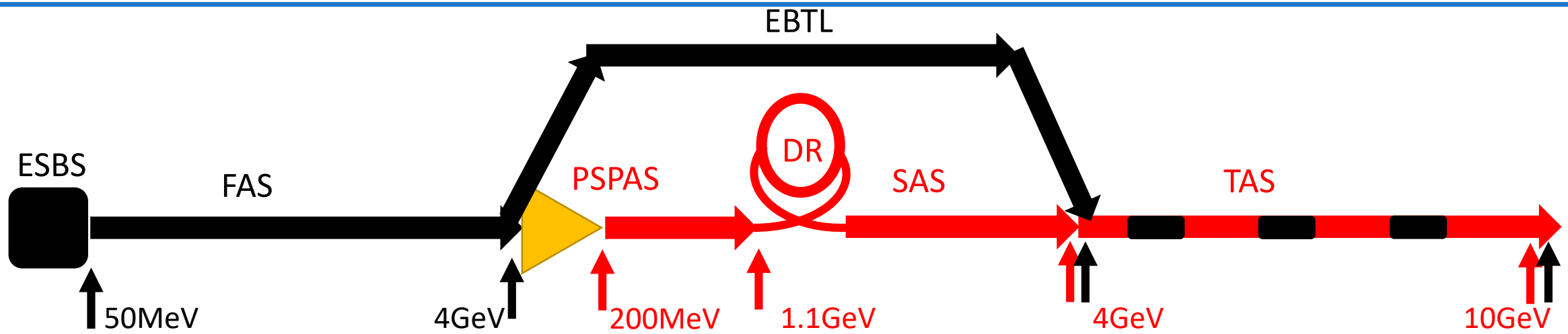
Introduction

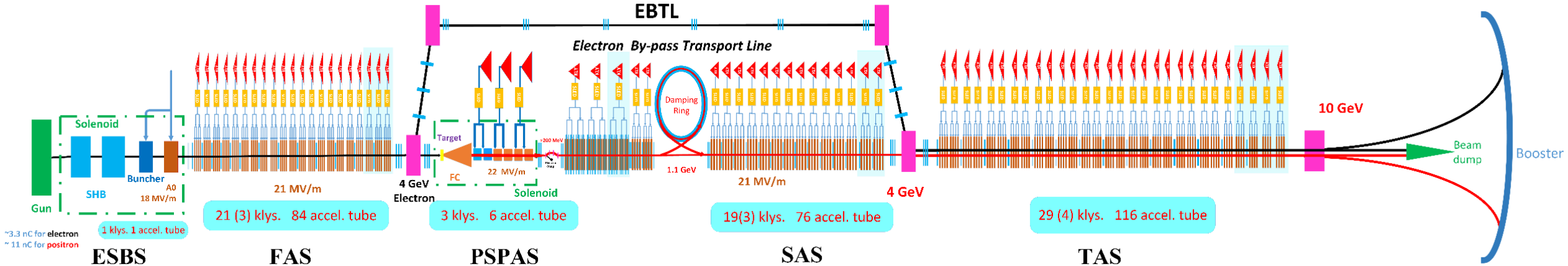
Layout of Linac



Introduction

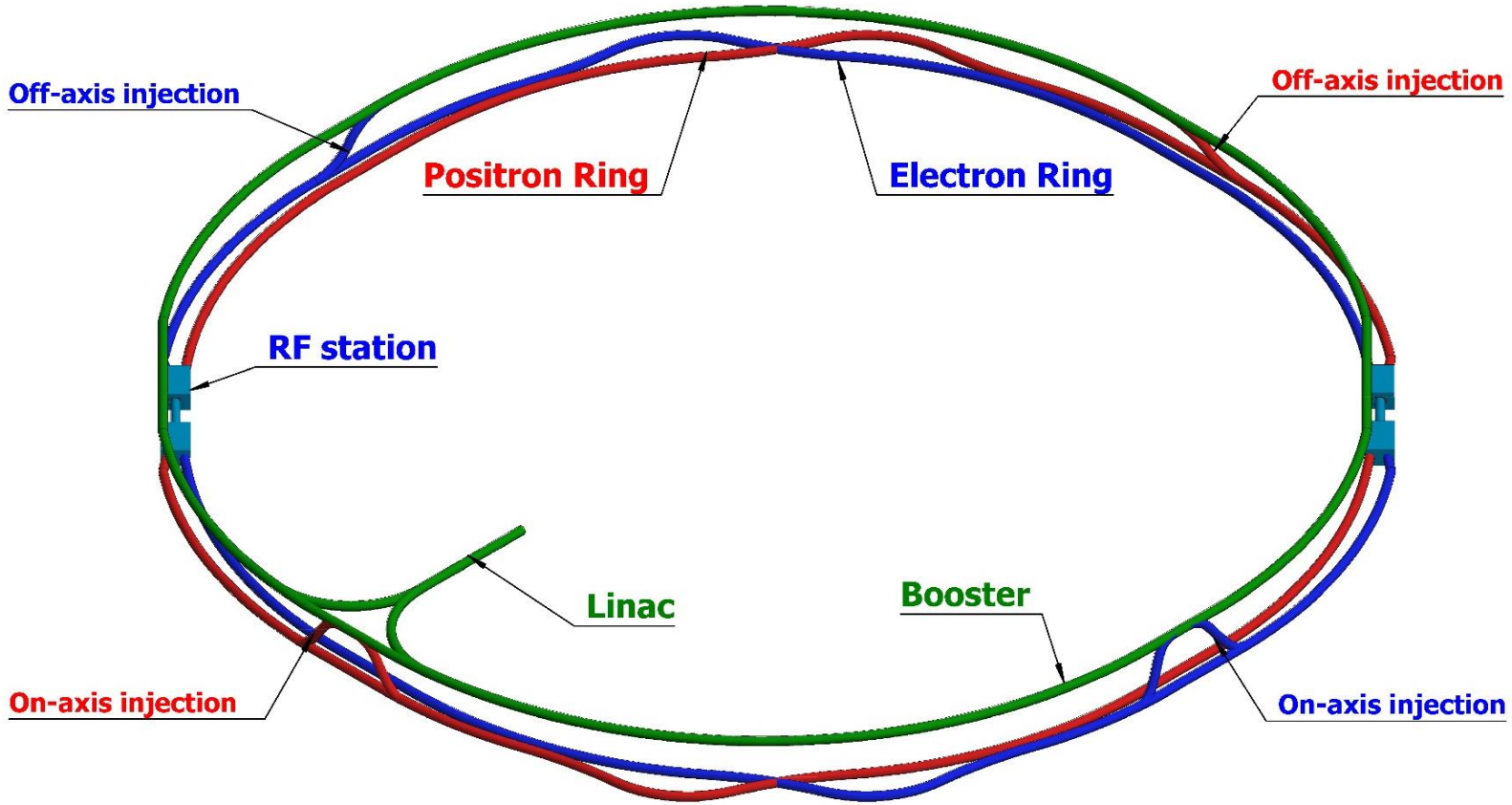
Layout of Linac





Outline

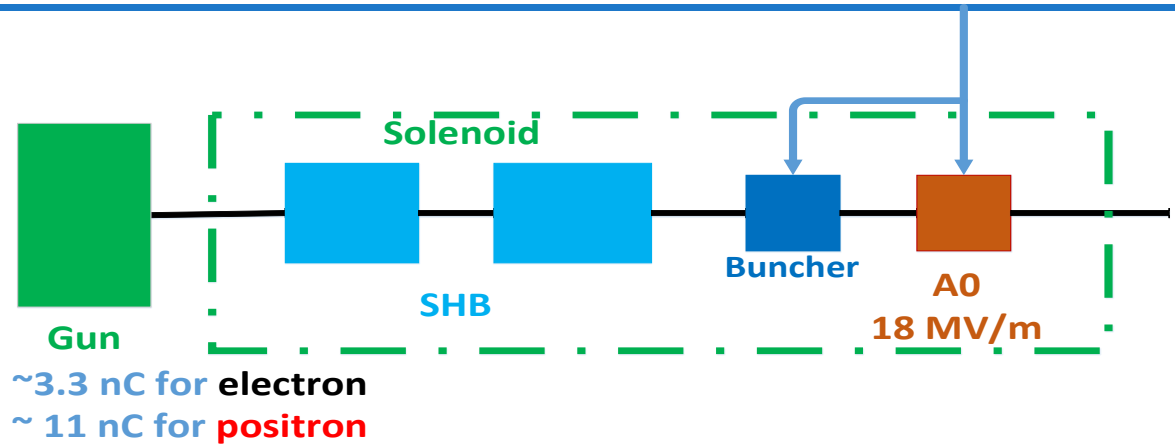
- Introduction
  - Main parameters
  - Linac layout
- Source design
  - Electron source
  - Positron source
- Linac design
  - Electron mode
  - Positron mode
- Summary

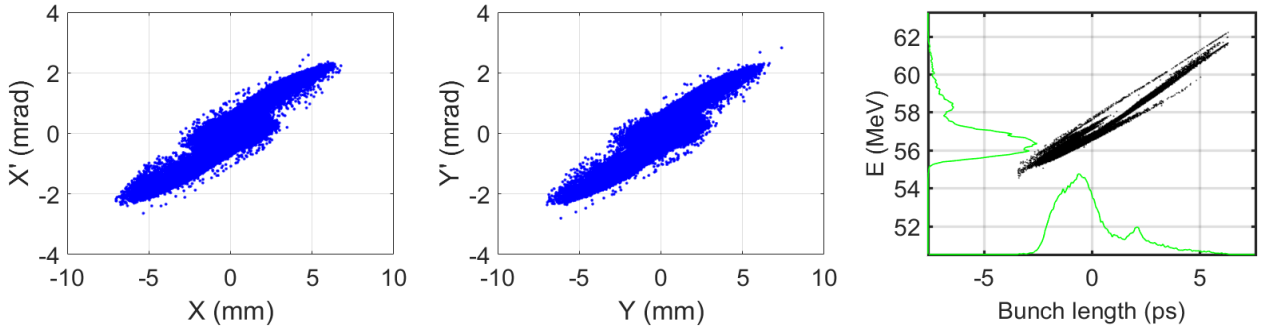


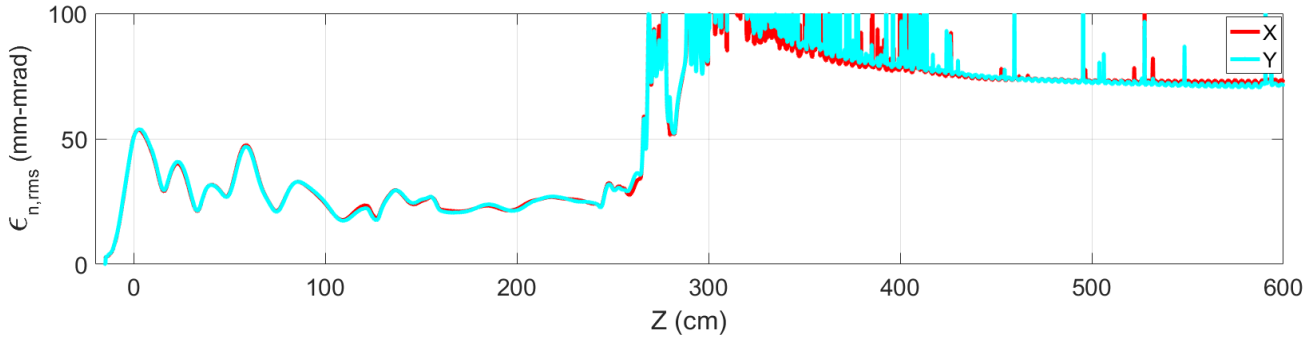
Source design

Electron source

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



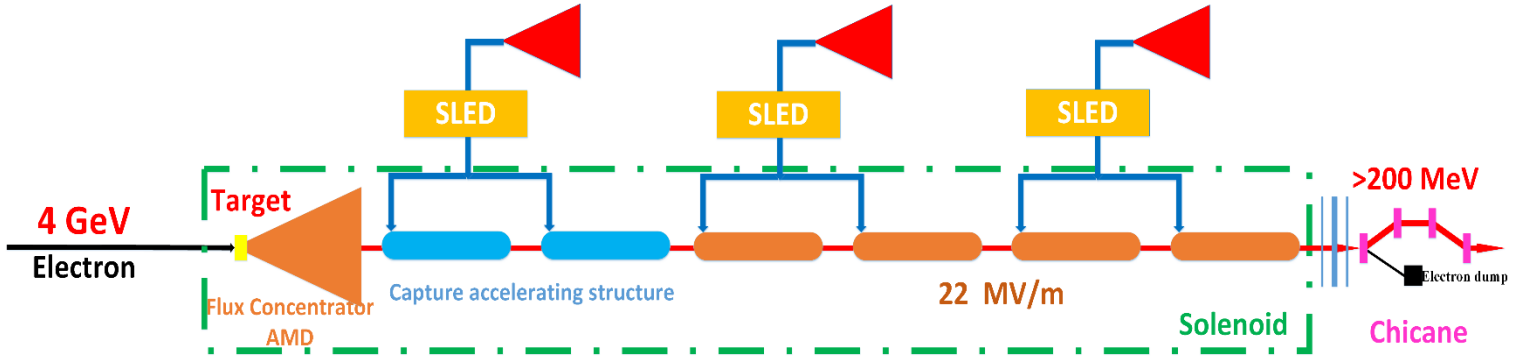


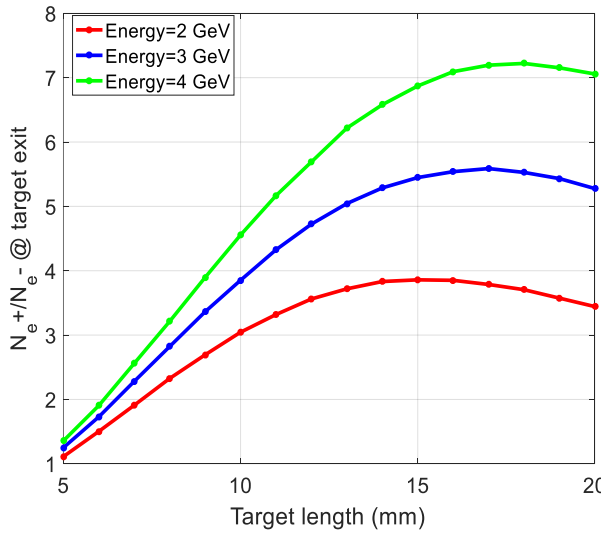


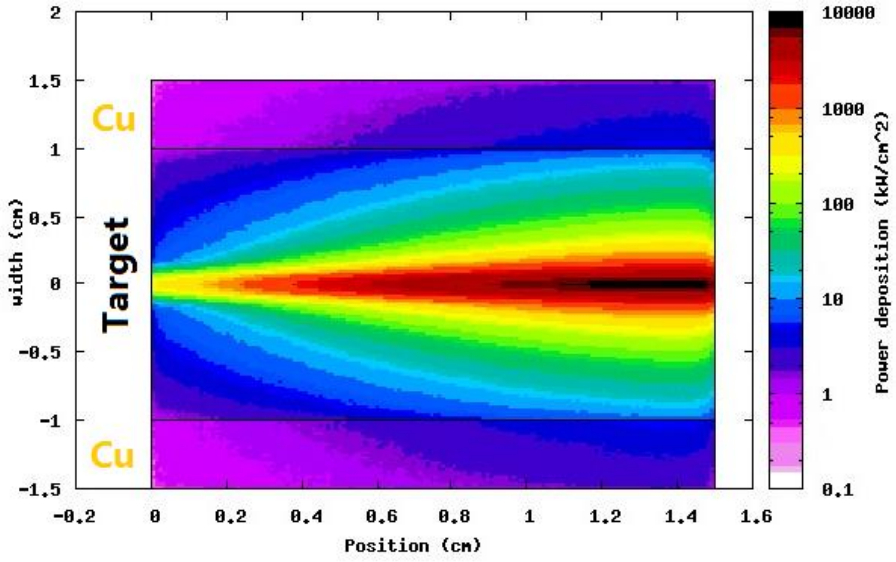
Source design

Positron source

- Layout of positron source
  - Target (Conventional)
    - tungsten@15 mm
    - Beam size: 0.5 mm
  - Energy deposition
    - 0.784 GeV/e- @ FLUKA
    - 784 W → water cooling
  - Electron beam
    - 4GeV
    - 10nC/bunch (maybe lower)
    - Beam power: 4 kW



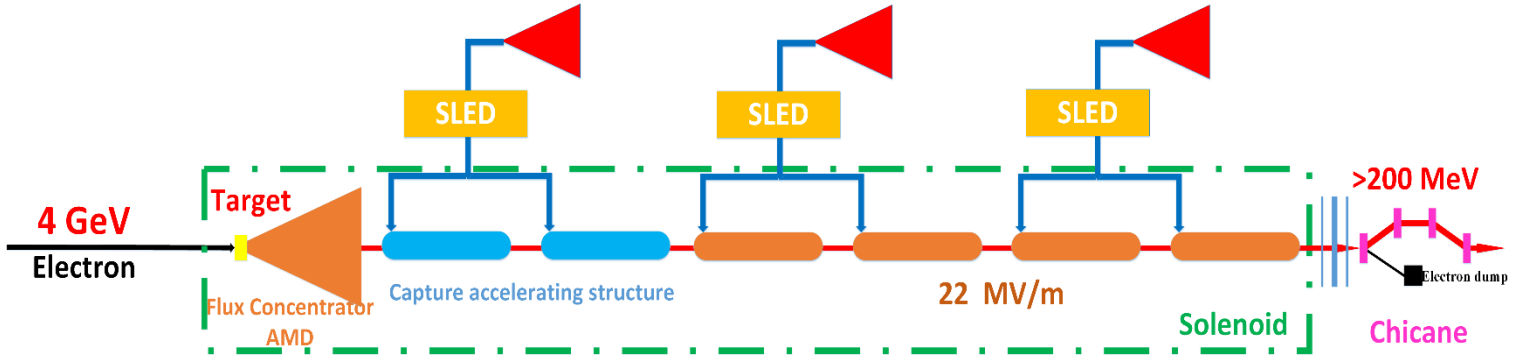


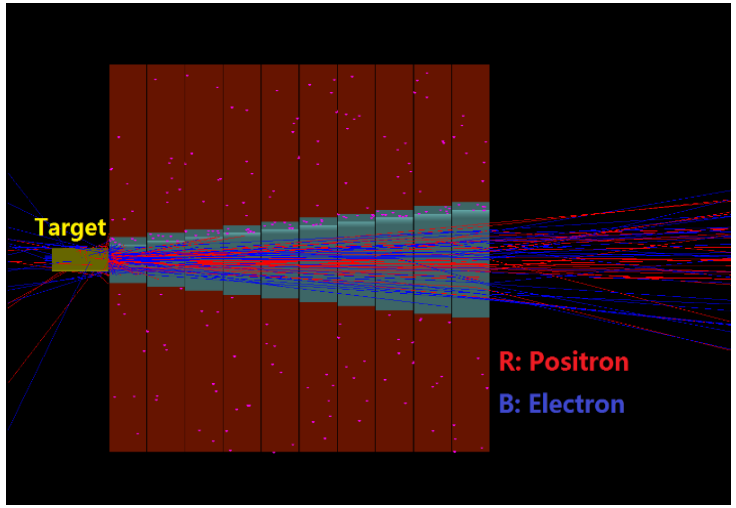


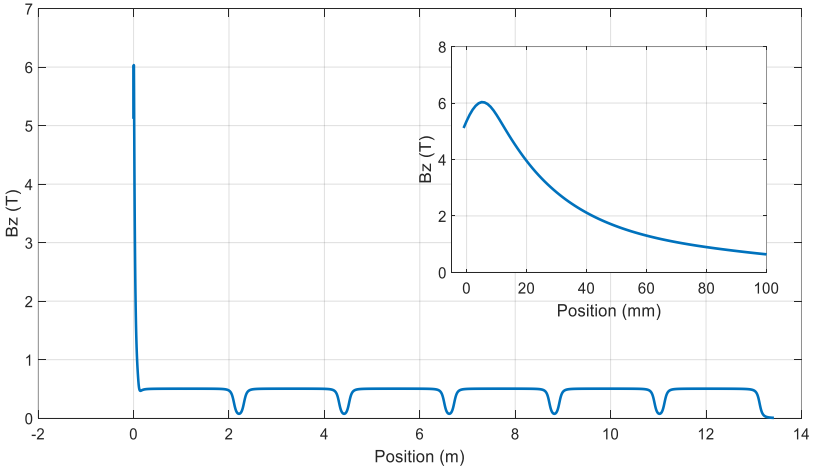
Source design

Positron source

- Layout of positron source
  - AMD (Adiabatic Matching Device)
    - Length: 100mm
    - Aperture: 8mm→26mm
    - Magnetic field: (5.5T→0T) + 0.5T
  - Capture & Pre-accelerating structure
    - Length:2 m
    - **Aperture**: 25 mm
    - Gradient: 22 MV/m
  - Chicane
    - Wasted electron separation
  - Focusing structure
    - Solenoid



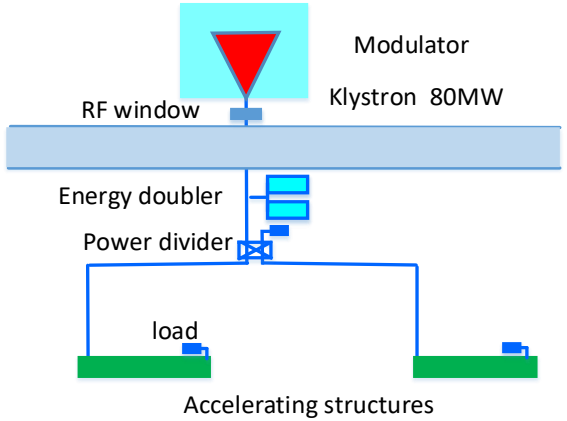


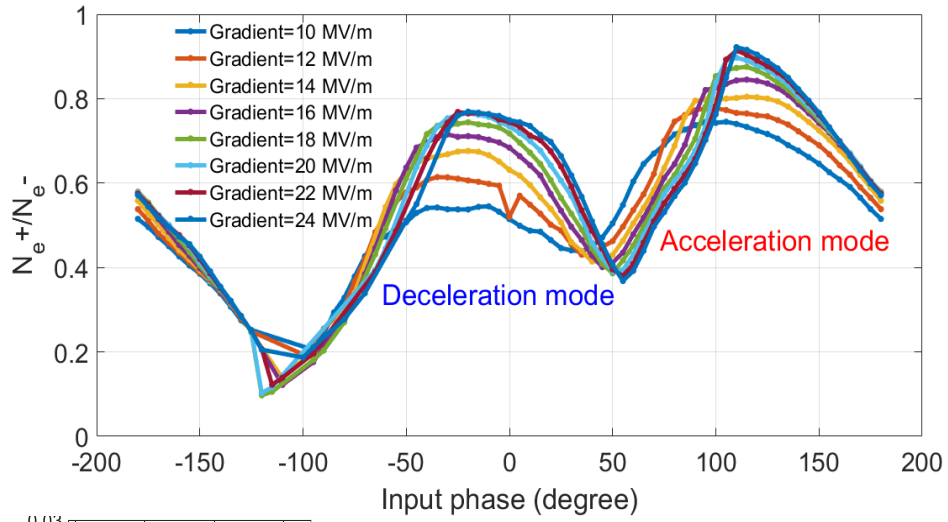


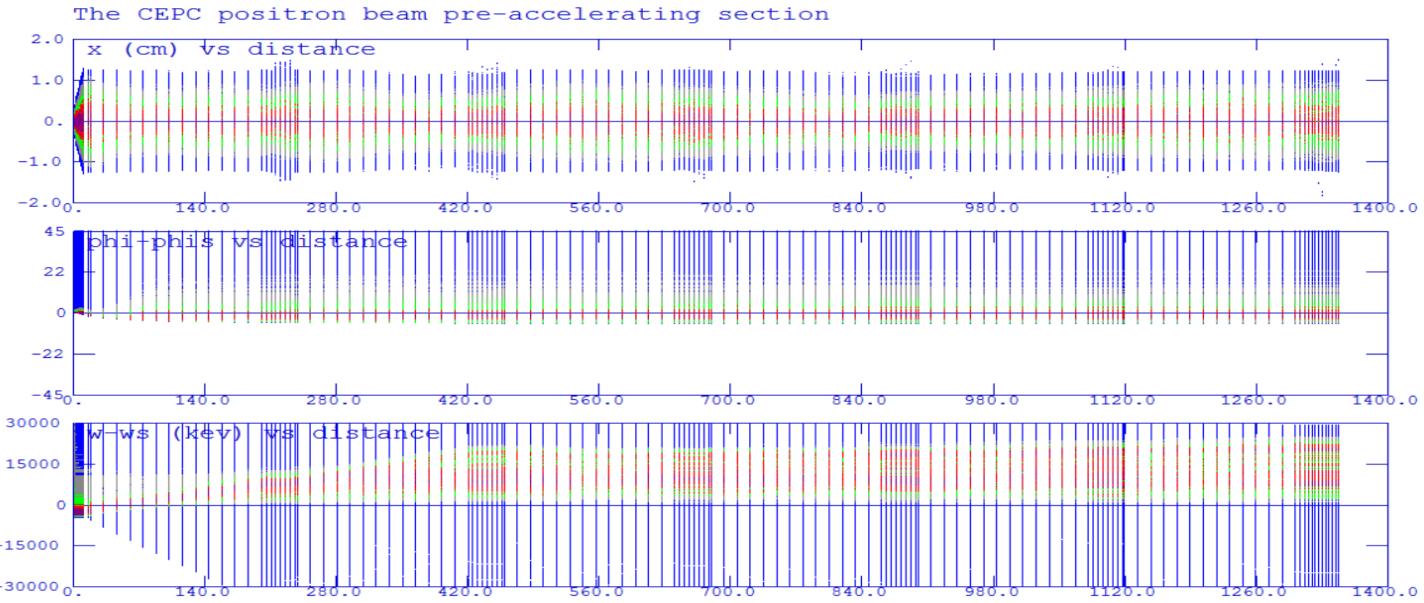
Source design

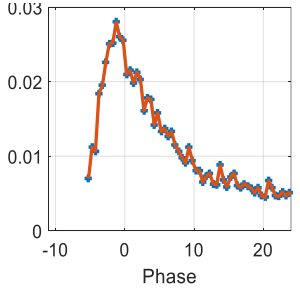
Positron source

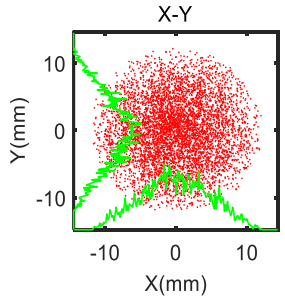
- Norm. RMS. Emittance
  - 2500 mm-mrad
- Energy: >200 MeV
- Positron yield
  - Ne+/Ne- > **0.55** @ [-8°,12°,235MeV, 265MeV]

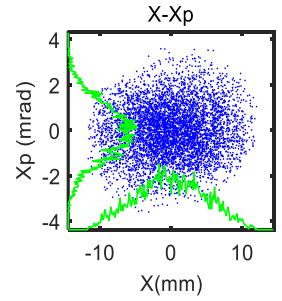


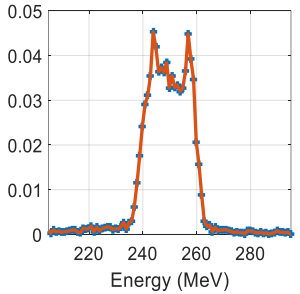


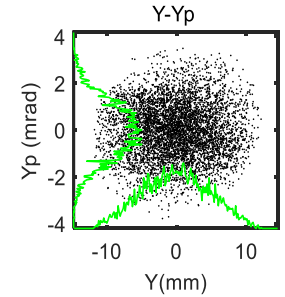


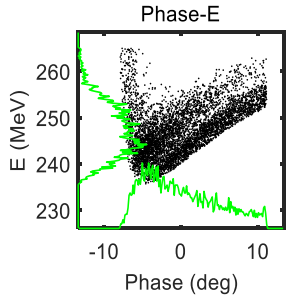






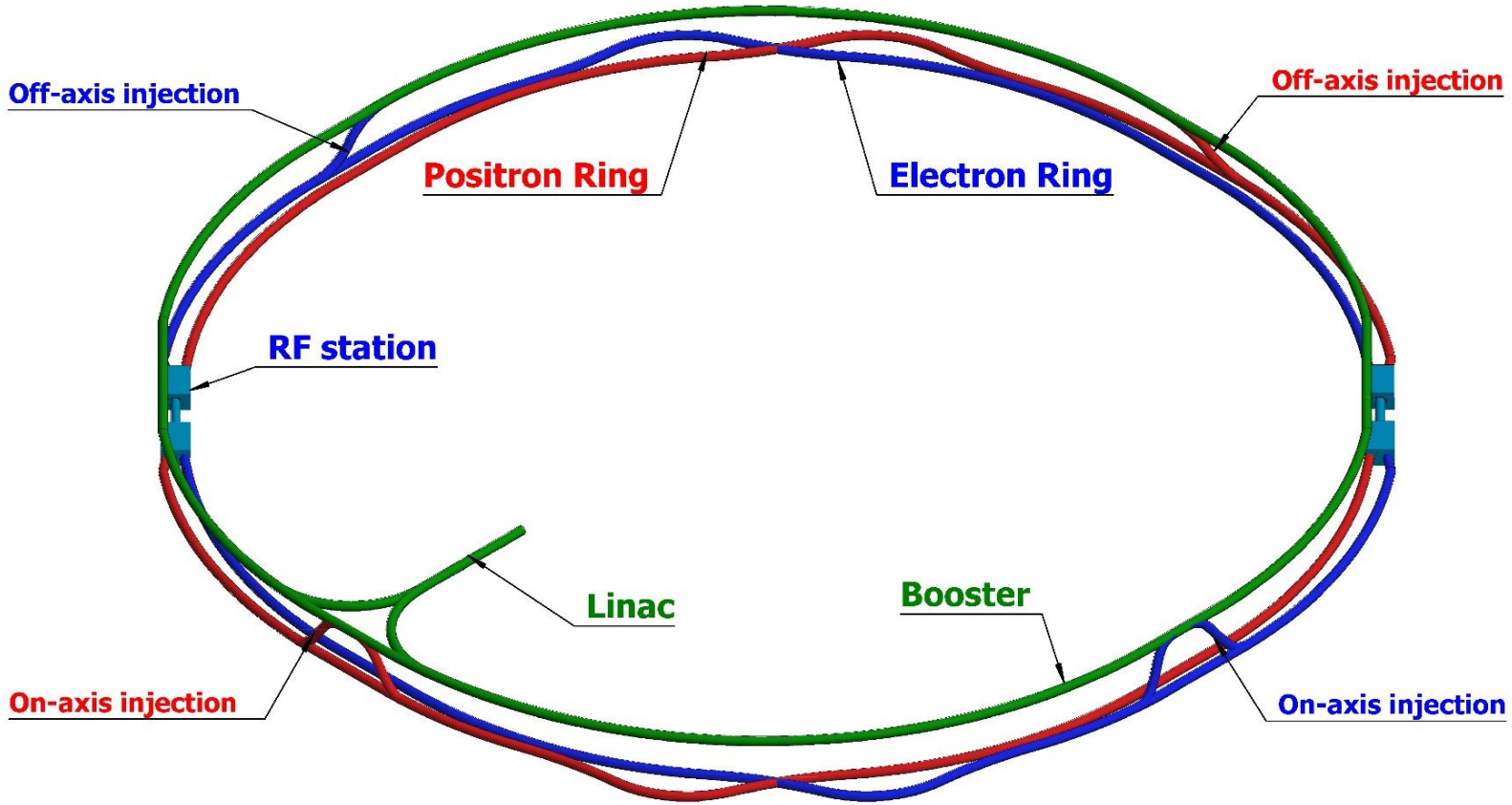






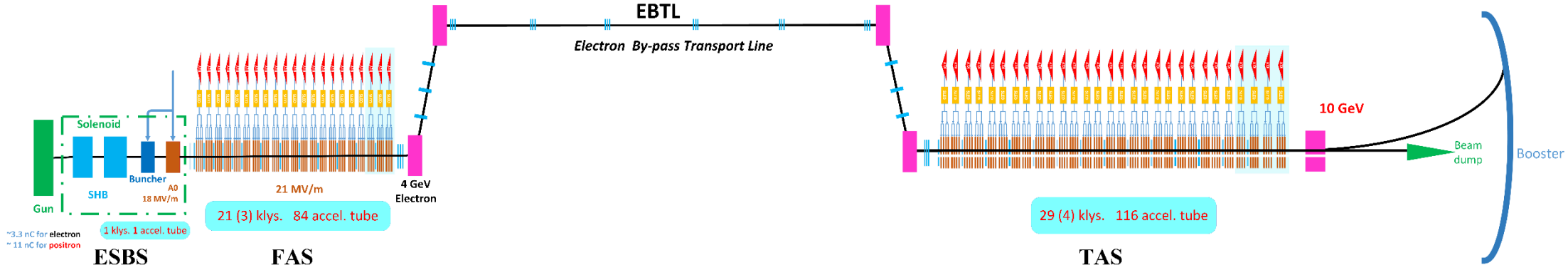
Outline

- Introduction
  - Main parameters
  - Linac layout
- Source design
  - Electron source
  - Positron source
- Linac design
  - Electron mode
  - Positron mode
- Summary

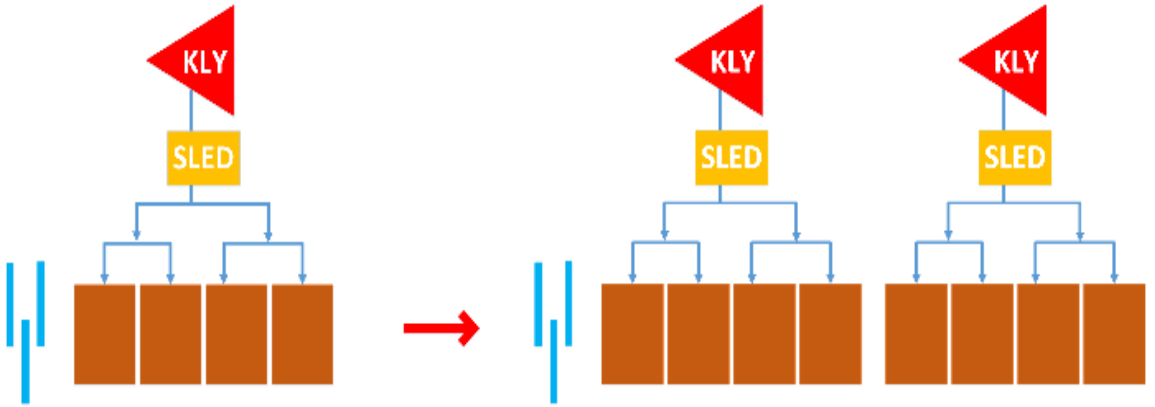


Linac design

Electron linac



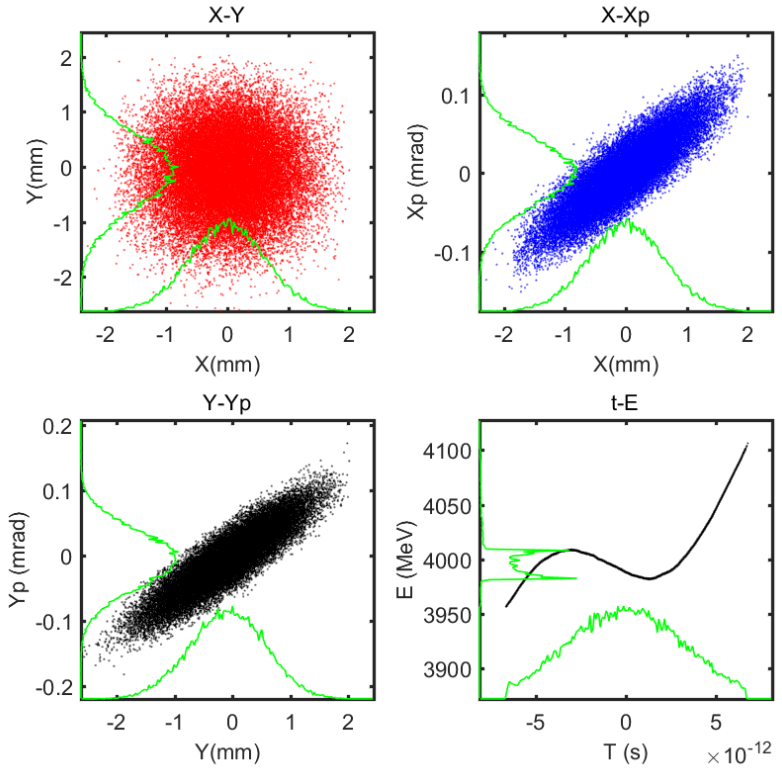
- Focusing structure: ***Triplet***
  - Same beam envelopes at X/Y planes
  - *1 triplet+4 Acc. Stru.→1 triplet+8 Acc. Stru.*
- Operation mode :
  - High charge mode (positron production)
    - 4GeV & 10 nC
    - ESBS+FAS
  - Low charge mode (electron injection)
    - 10 GeV & 3 nC
    - ESBS+FAS+EBTL+TAS

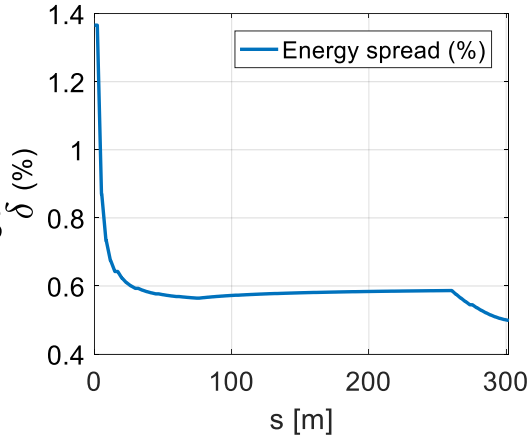


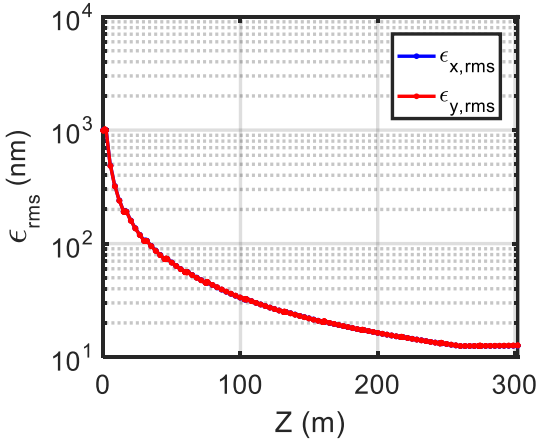
Linac design

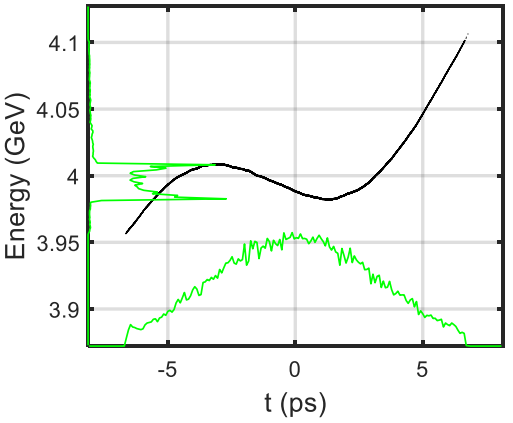
Electron linac→ *Positron production*

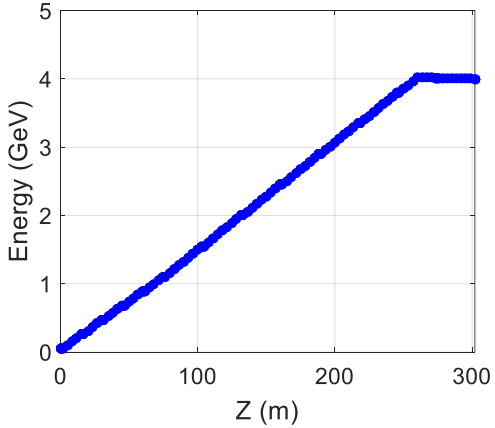
- High charge mode
  - 10 nC @ 4 GeV
  - Energy spread (rms): 0.5%
  - Emittance growth with errors

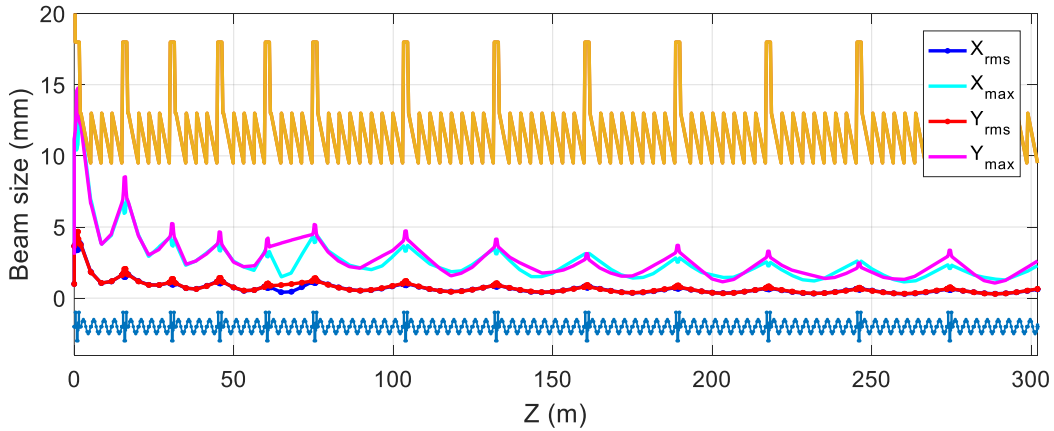








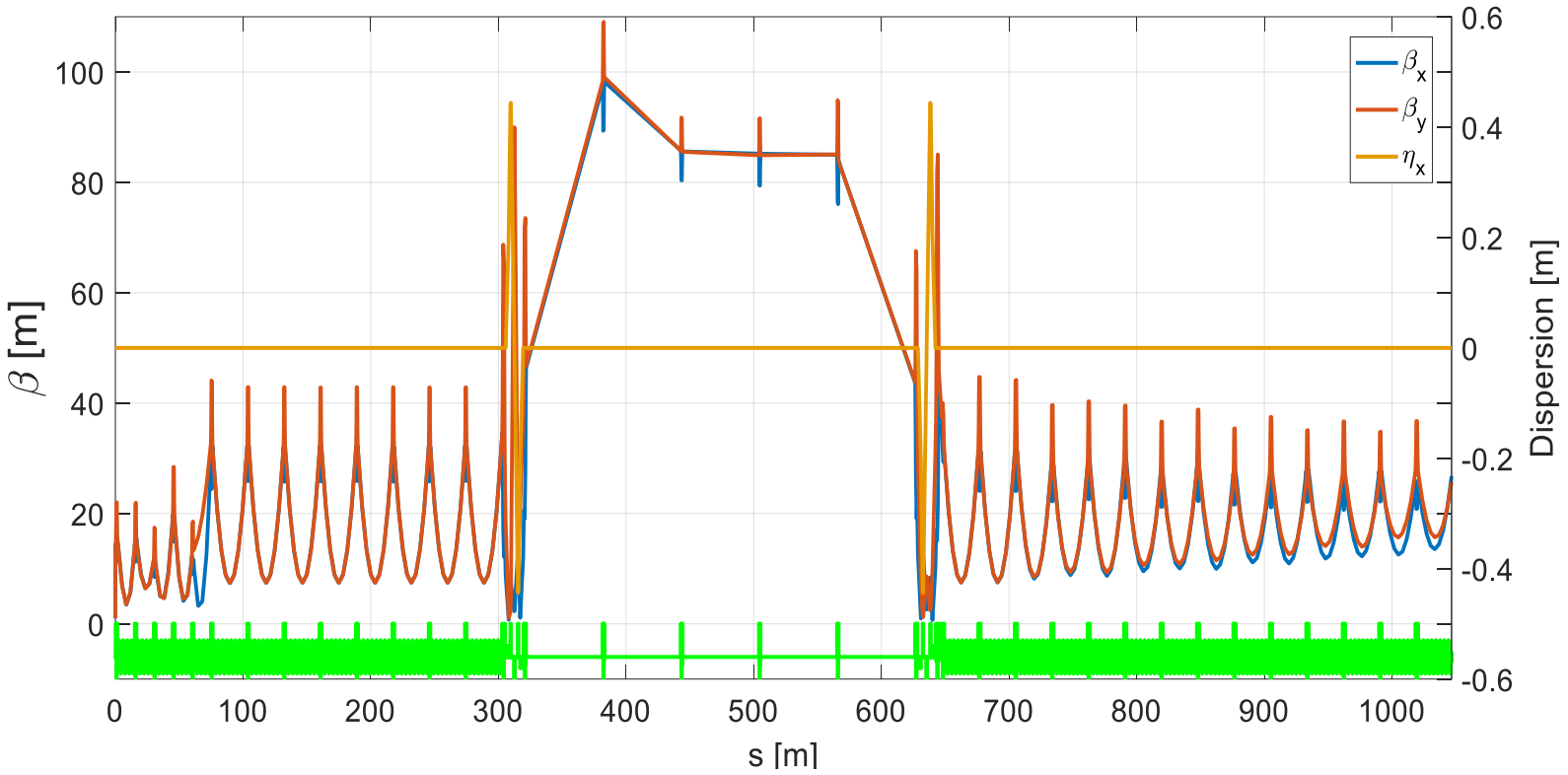




Linac design

Electron linac→ *Electron injection*

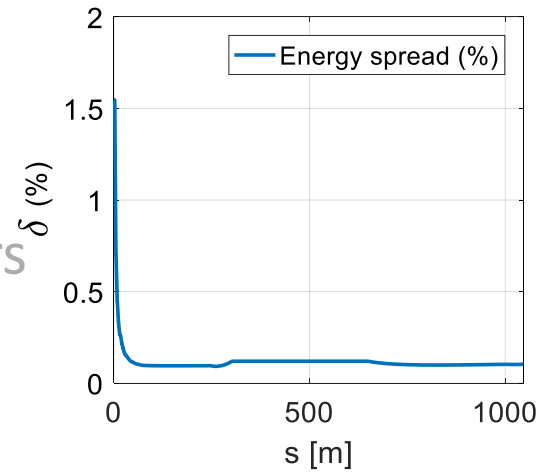
- High charge mode
  - 10 nC @ 4 GeV
  - Energy spread (rms): 0.5%
  - Emittance growth with errors
- Low charge mode
  - EBTL
    - Local achromatic
    - Matching
    - Collimator (momentum tail)
  -

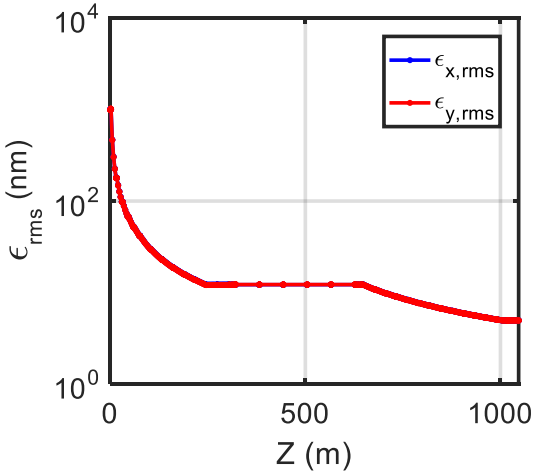


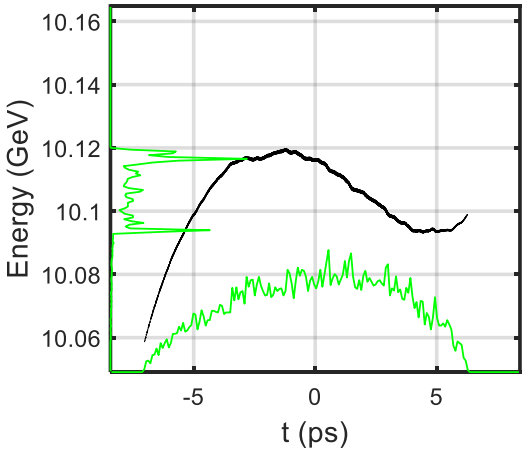
Linac design

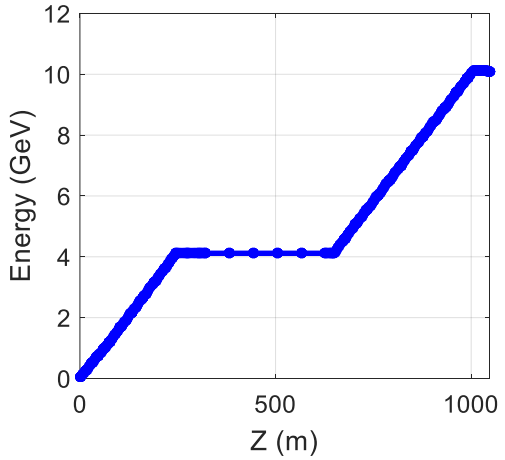
Electron linac→ *Electron injection*

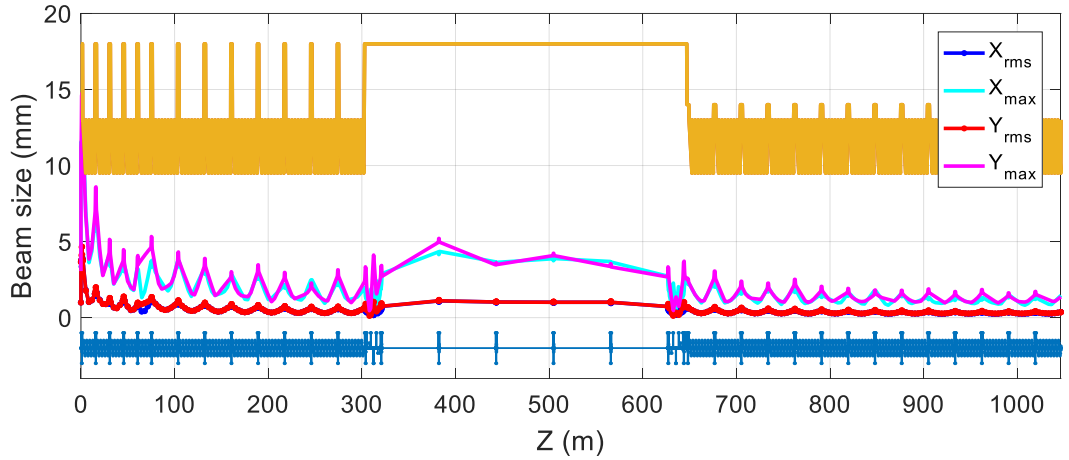
- High charge mode
  - 10 nC @ 4 GeV
  - Energy spread (rms): 0.5%
  - Emittance growth with errors
- Low charge mode
  - 3 nC @ 10 GeV
  - Energy spread (rms): 0.15%
  - Emittance (rms): 5 nm





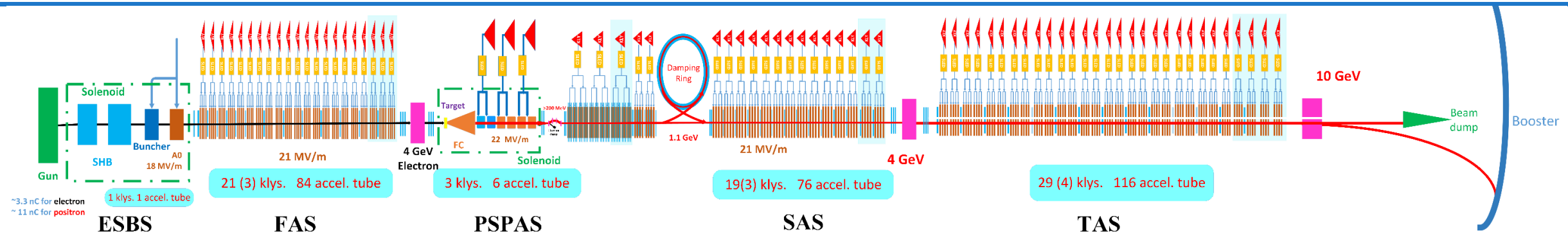




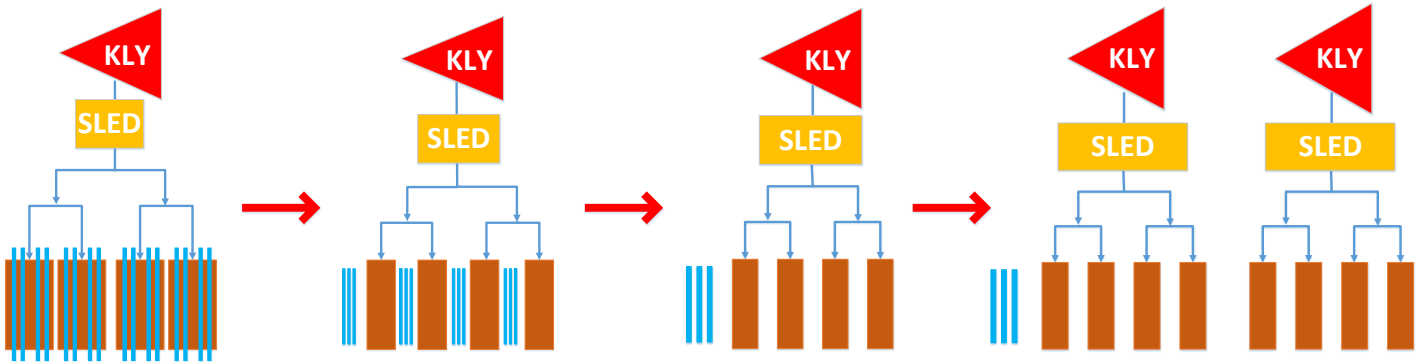


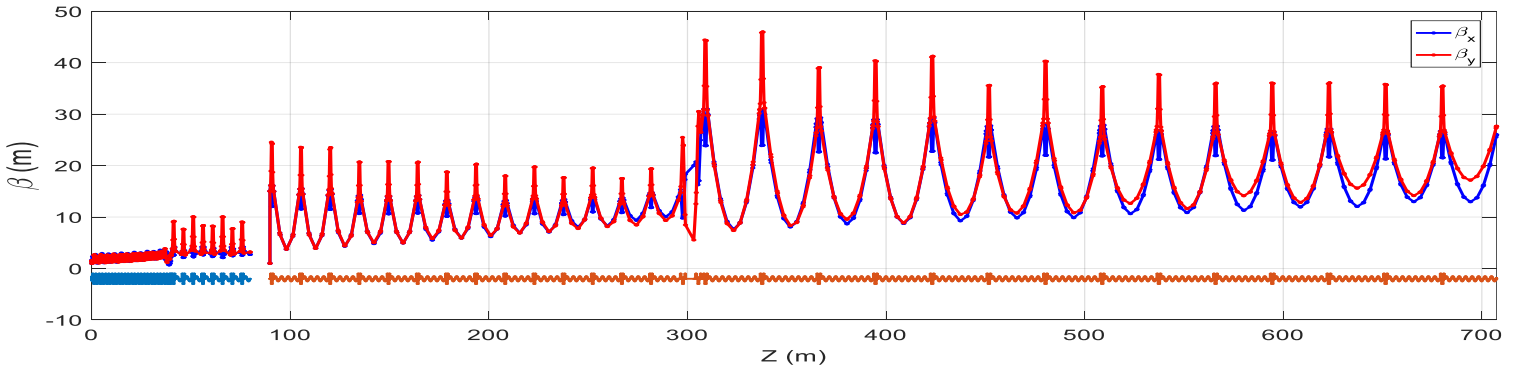
Linac design

Positron linac



- PSPAS→SAS (DR) +TAS
  - SAS: 200 MeV→4 GeV
  - Damping Ring @ 1.1 GeV
  - TAS: 4GeV→10 GeV
- Transverse focusing structure
  - FODO, nesting on Acc. Stru.
  - Triplet

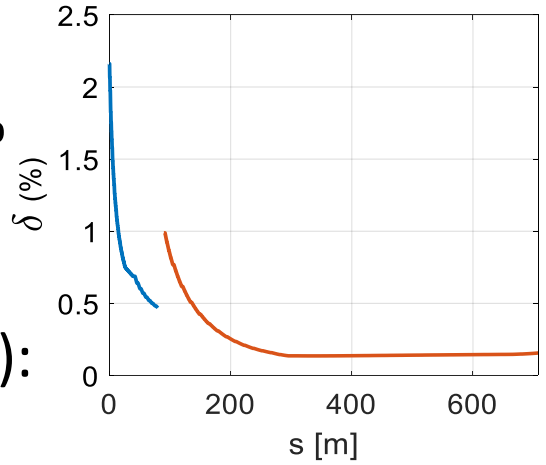


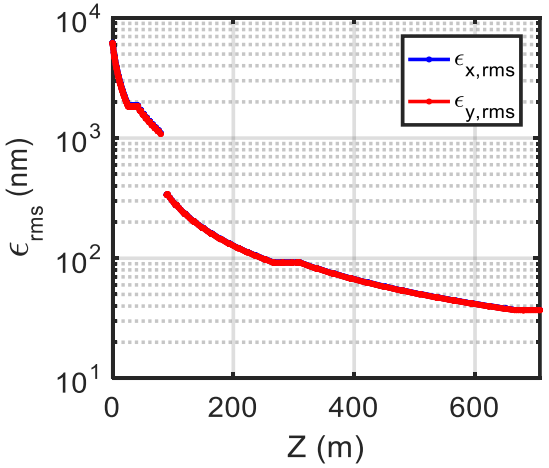


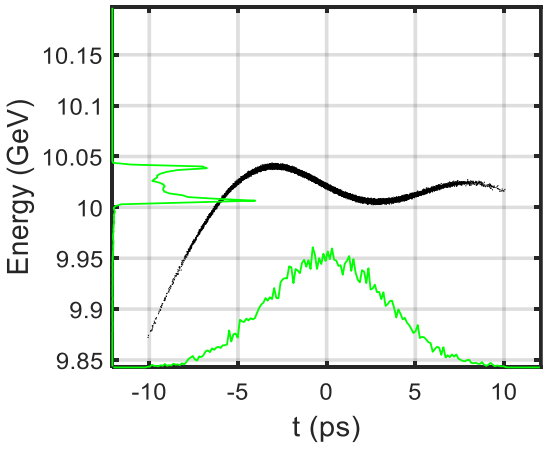
Linac design

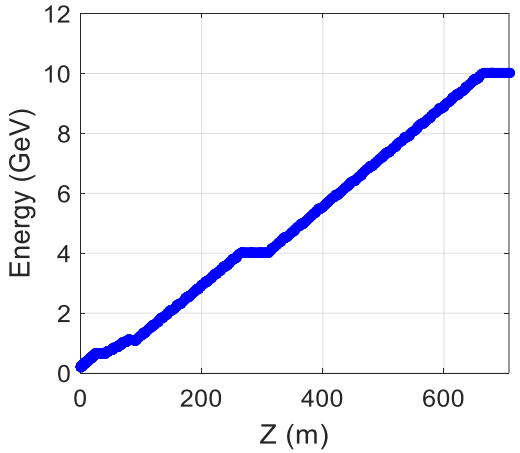
Positron linac

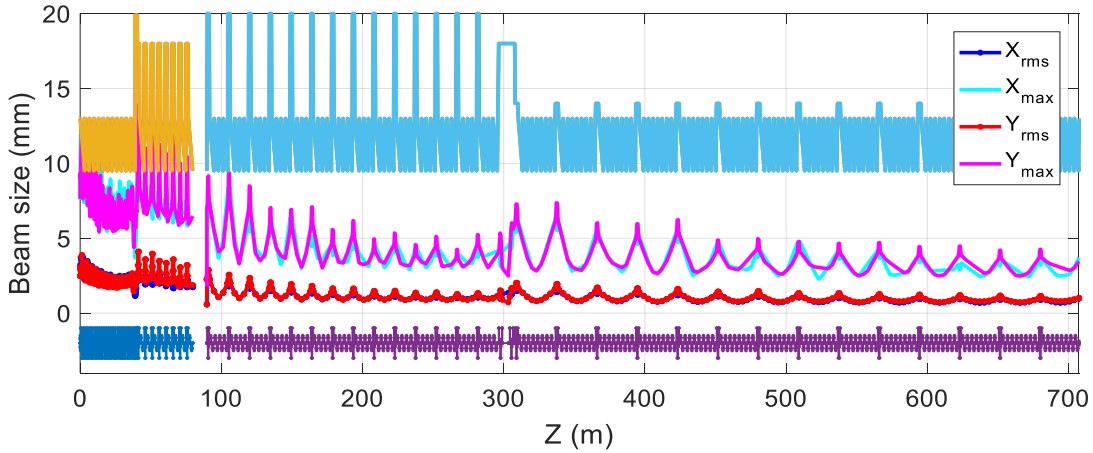
- Positron linac
  - 3 nC && 10 GeV
  - Energy spread (rms): 0.16%
  - Emittance with DR (rms): 40/24nm
  - Emittance without DR (rms): 120/120nm









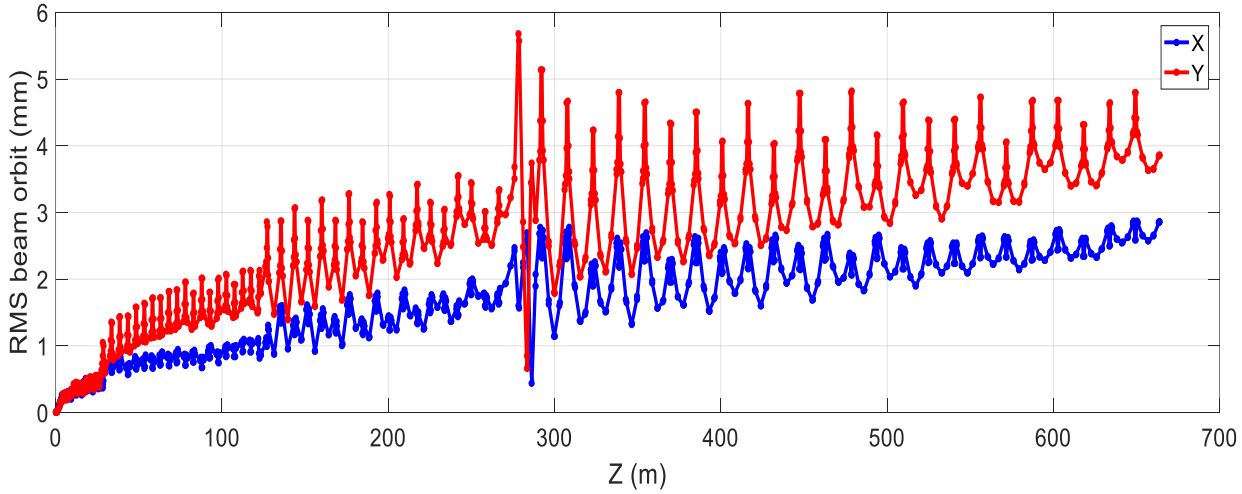


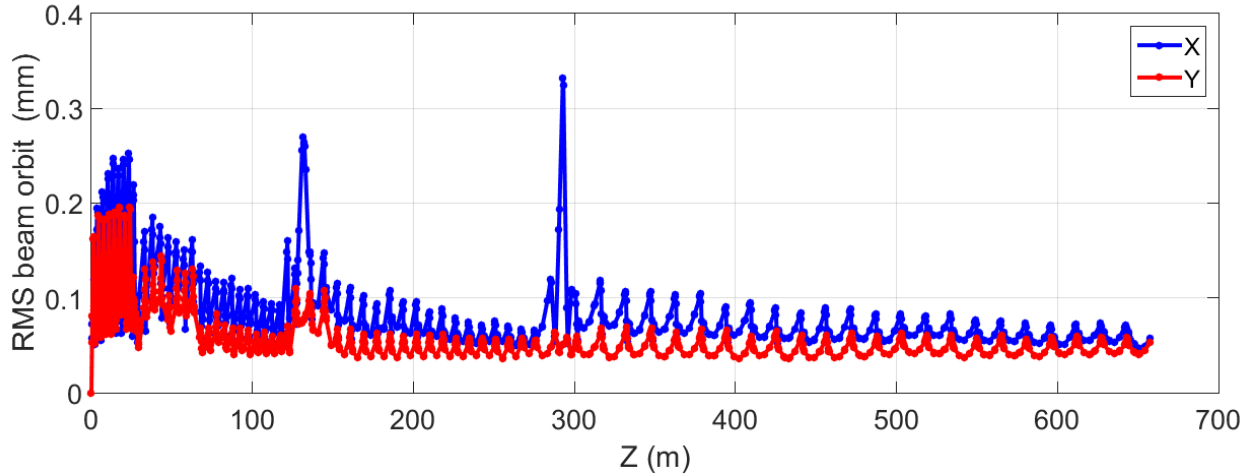
Linac design

Misalignment errors with correction

- Positron linac
  - One-to-one correction scheme
  - Errors: Gaussian distribution, 3σ truncated
- Beam orbit
  - RMS value< 0.3 mm
  - Rms value< 0.1 mm (high energy part)

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

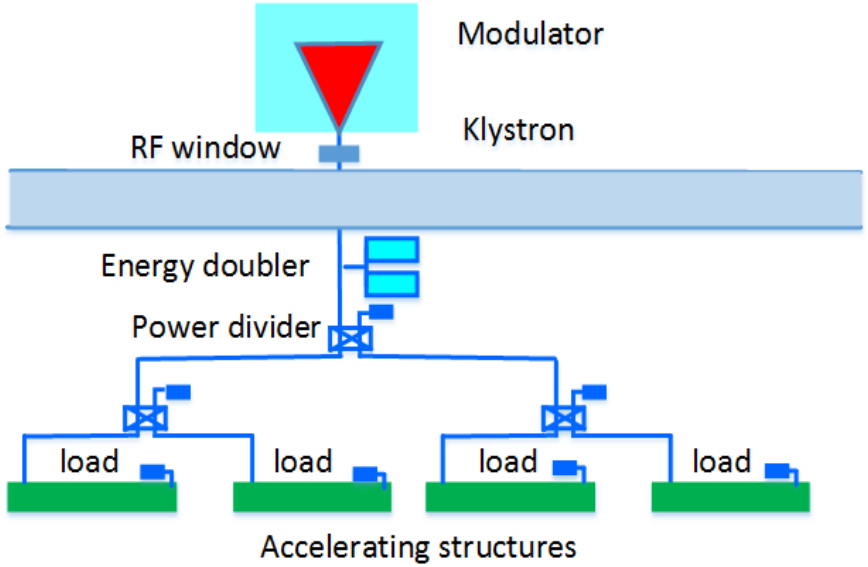




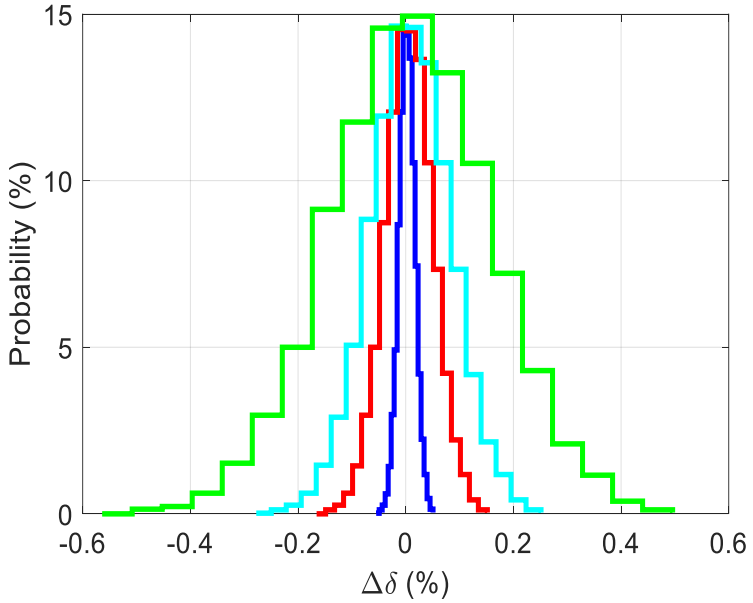
Linac design

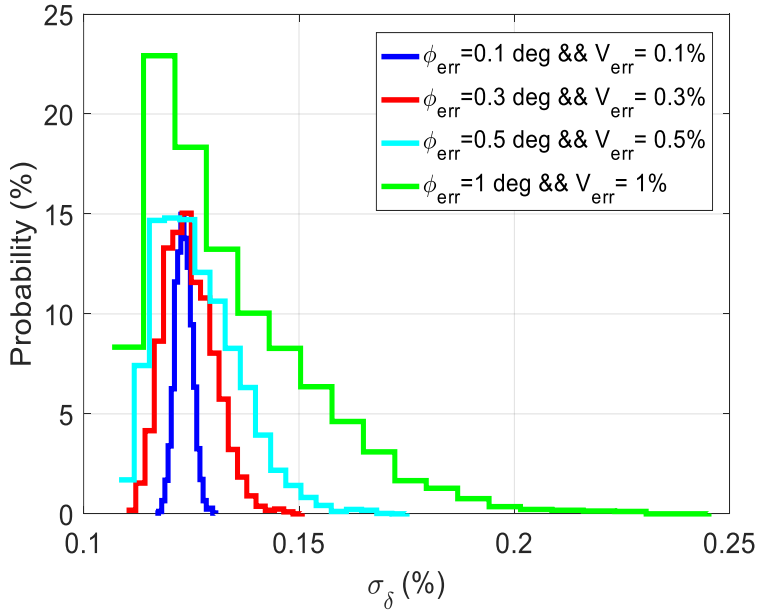
Field errors

- Simulation condition
  - 5000 seeds
  - Accelerating tubes
    - phase errors and amp errors
    - 4 in 1 KLY, 4 accelerating tubes in one group
    - 3σ--Gaussian



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



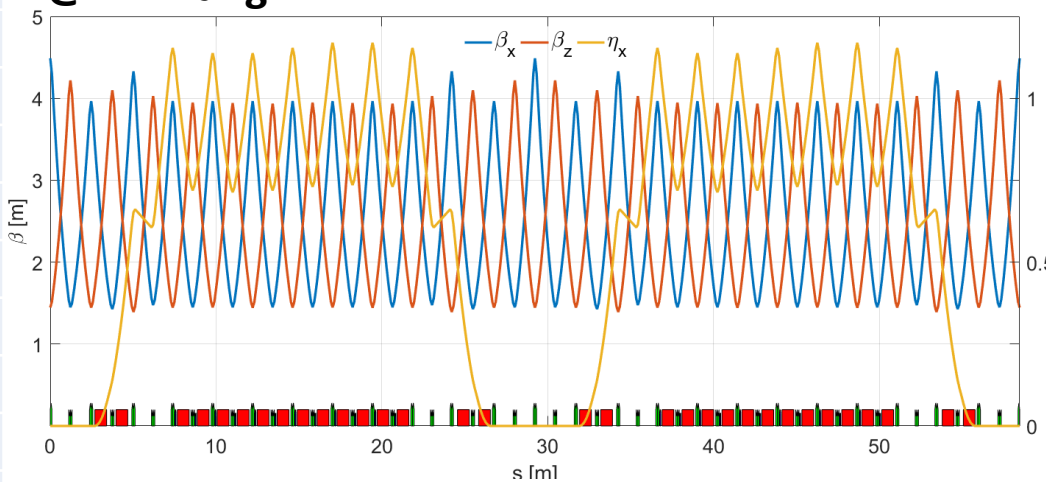


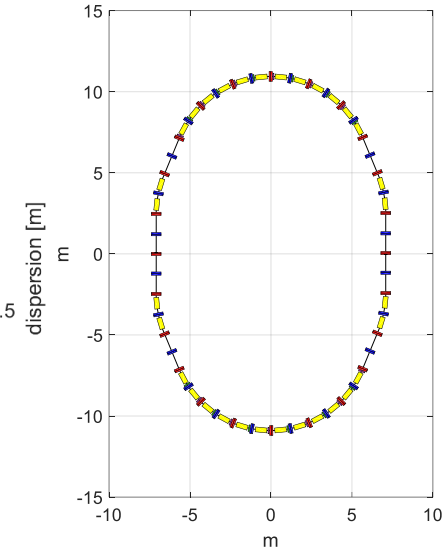
Linac design

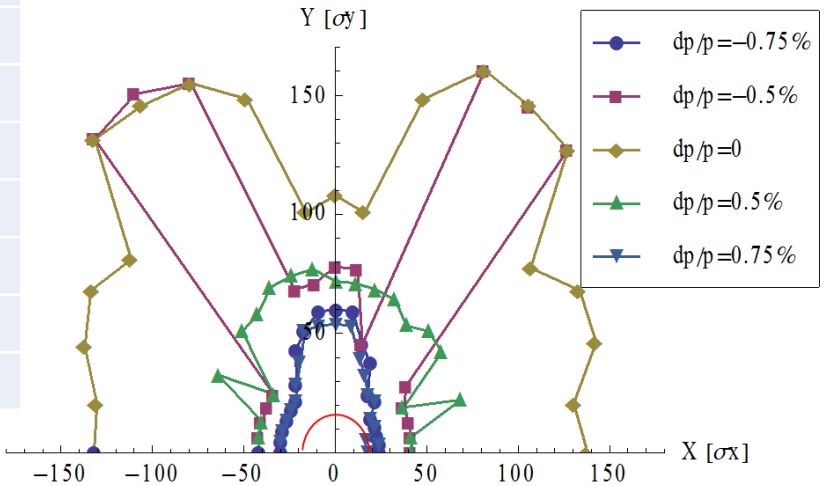
Damping Ring

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

@ D. Wang







- Emittance not critical
- One bunch in DR(200ns)
  - 10 ms→20ms
  - Two bunch: yes
- **IBS**
  - Emittance growth
- **CSR (Coherent synchrotron radiation)**
  - CSR Instability

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 can provide positron beam and electron beam larger than 3nC bunch charge, which is larger than the requirements;
- One preliminary damping ring is proposed, the emittance with DR is smaller than the required value;
- By now seems it's no problem in linac design and further works are on the way.