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
Beam dynamics

International workshop on CEPC2018
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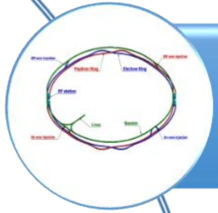
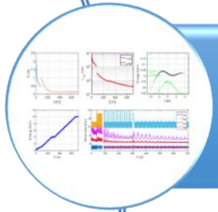
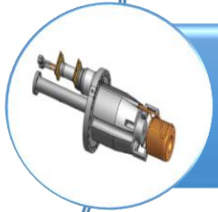
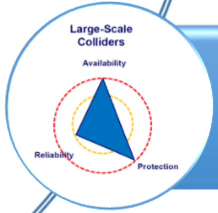
Outline

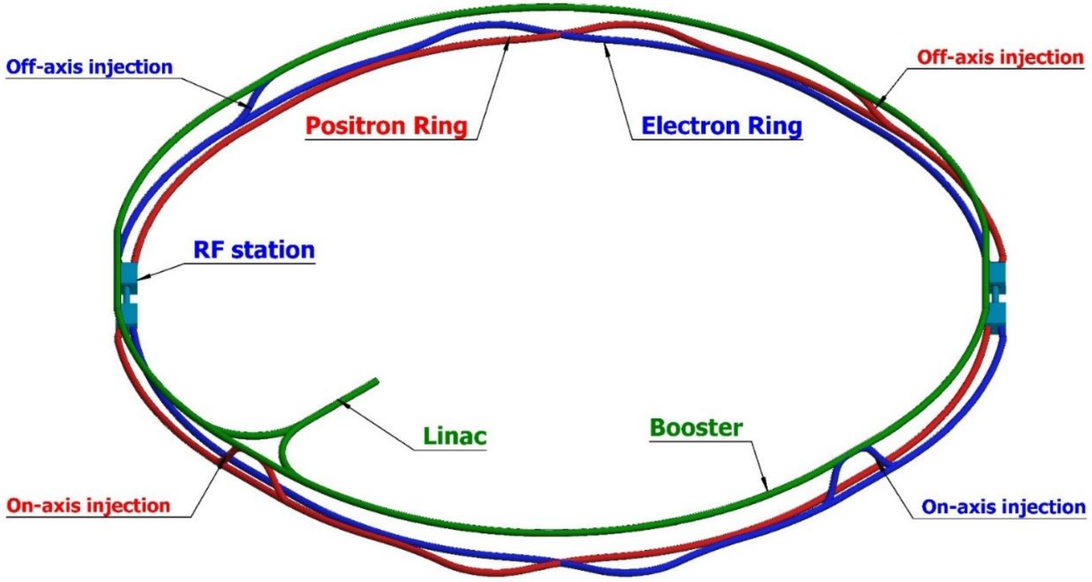

Introduction


CDR Linac design


TDR issues



Summary



Introduction

- **Goal && principles**
- **Main parameters**

Introduction

- 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**

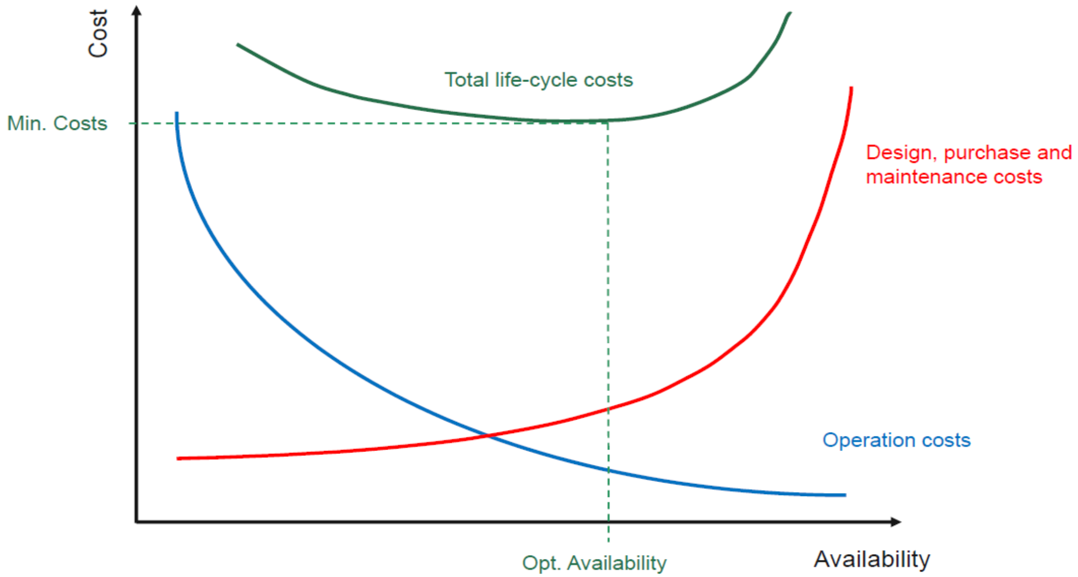
$$L_{\text{int}} = \int_0^T L(t)dt = \langle L \rangle \bullet T_s \bullet \eta$$

- As the first injector part, high availability of the Linac is very important
  - Beam commission, operation

➢Linac design goal and principles

- **High Availability and Reliability**
  - ~ 15% backups for Klystrons and accelerating structure, need to study in the future (TDR)
  - **Simplicity**
    - **Layout** / S-band accelerating structure (2860MHz)/Thermionic electron gun
    - 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+		>9.4×10^9
		nC	>1.5
Energy spread (e^- /e^+)	σ_E		<2×10^{-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

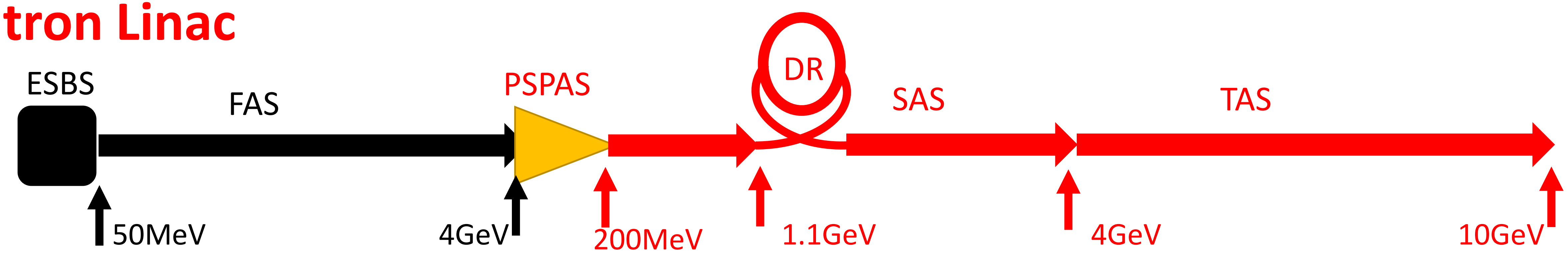
- Emittance:
  - ✓ Linac emittance can meet the requirement without damping ring
  - ✓ **Damping Ring** for positron beam
    - ☐ Higher transmission of linac
    - ☐ Larger errors tolerance
    - ☐ Higher injection efficiency, easier injection design, smaller damping time in some case
- Bunch charge: 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 the linac design

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	-

CDR Linac design

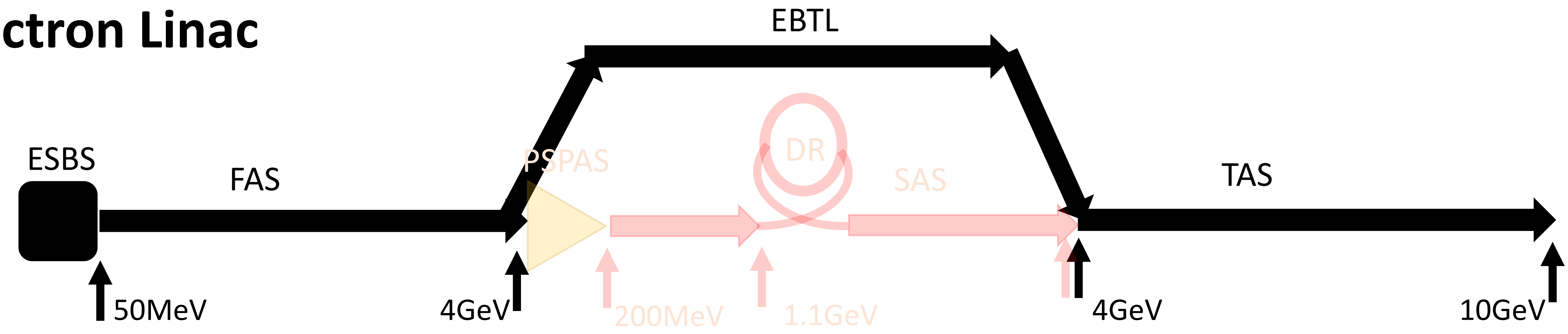
- Layout scheme
- Source design: electron/positron source
- Main linac design
- Error study
- Damping Ring

Positron Linac



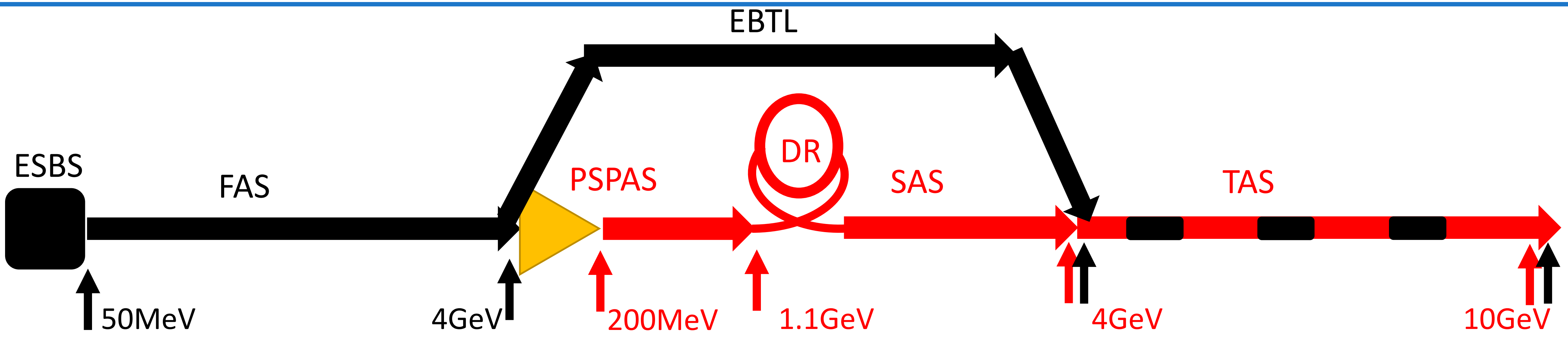
- ESBS (*Electron Source and Bunching System*)
  - 50 MeV && 11nC for positron production
- FAS (*the First Accelerating Section*)
  - Electron beam to 4 GeV && 10nC for positron production
- PSPAS (*Positron Source and Pre-Accelerating Section*)
  - Positron beam larger than 200 MeV && larger than 3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

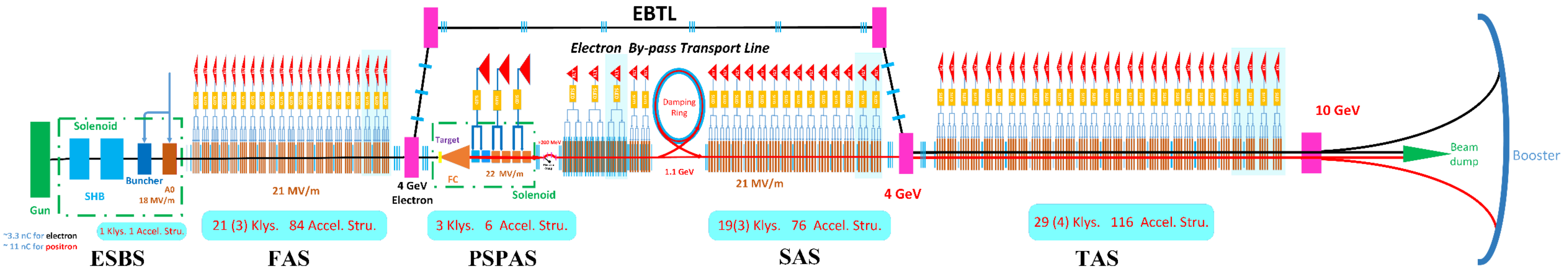
Electron Linac



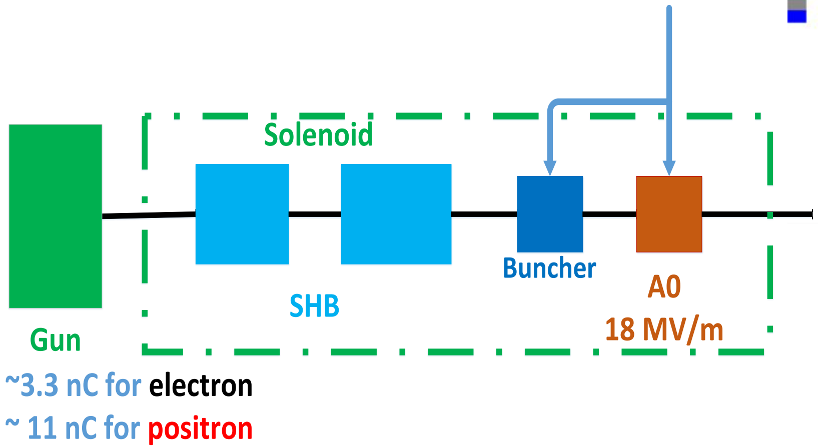
- ESBS (*Electron Source and Bunching System*)
  - 50 MeV && 3 nC
- FAS (*the First Accelerating Section*)
  - Electron beam to 4 GeV && 3 nC
- EBTL (*Electron Bypass Transport Line*)
  - Electron beam @ 4 GeV && 3 nC
- TAS (*the Third Accelerating Section*)
  - Electron beam to 10 GeV && 3 nC

Linac

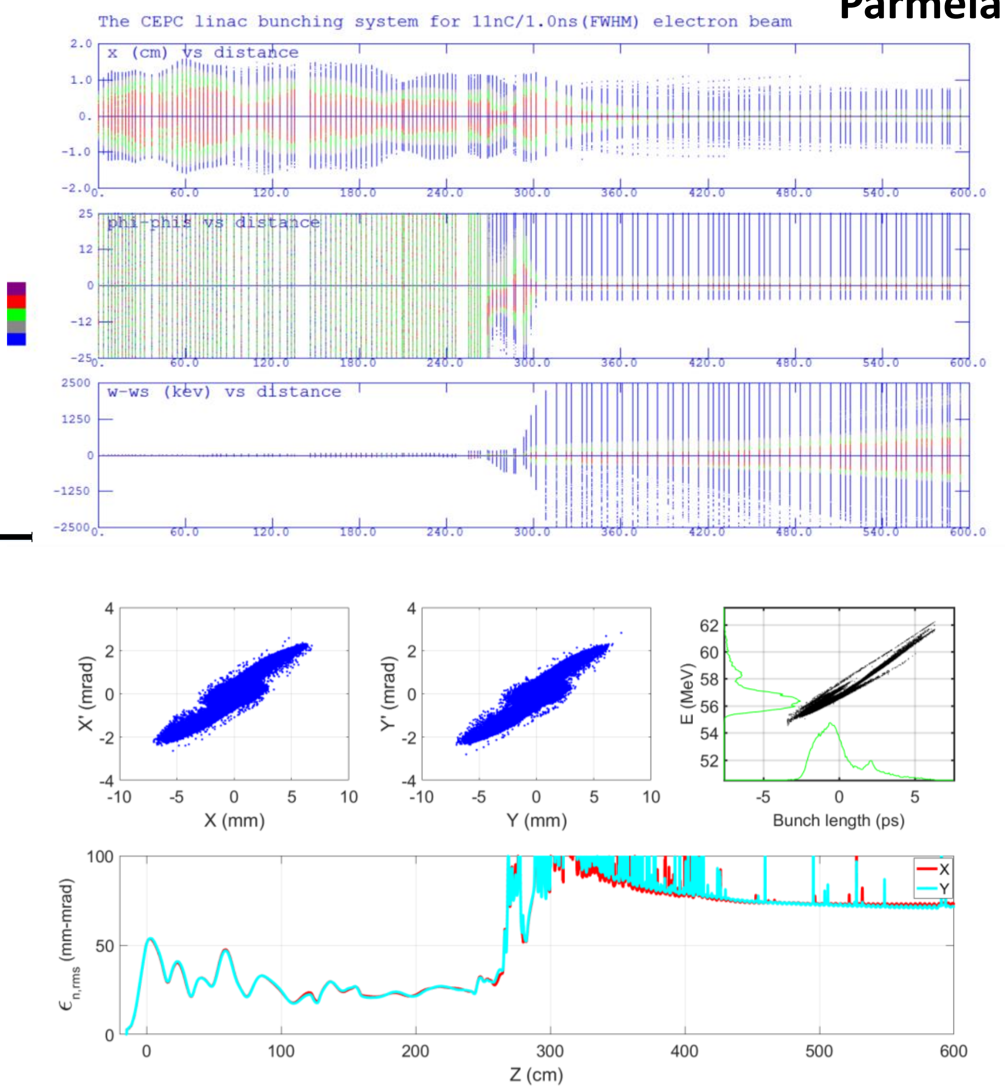

EBTL
ESBS
FAS
PSPAS
DR
SAS
TAS
50MeV
4GeV
200MeV
1.1GeV
4GeV
10GeV


EBTL
Electron By-pass Transport Line
Solenoid
Gun
SHB
Buncher
A0
18 MV/m
~3.3 nC for electron
~ 11 nC for positron
1 Klys. 1 Accel. Stru.
ESBS
21 MV/m
21 (3) Klys. 84 Accel. Stru.
FAS
4 GeV
Electron
Target
FC
22 MV/m
Solenoid
3 Klys. 6 Accel. Stru.
PSPAS
Damping
Ring
1.1 GeV
21 MV/m
19(3) Klys. 76 Accel. Stru.
SAS
4 GeV
29 (4) Klys. 116 Accel. Stru.
TAS
10 GeV
Beam
dump
Booster

- **Thermionic** electron gun
- Sub-harmonic pre-buncher
  - 143 MHz (20th)
  - 572 MHz (5th)
- Buncher & A0
  - 2860 MHz
- Focusing structure
  - Solenoid
- Emittance
  - <100 mm-mrad (Norm.Rms)
- **Transmission**
  - ~90%



Parmela

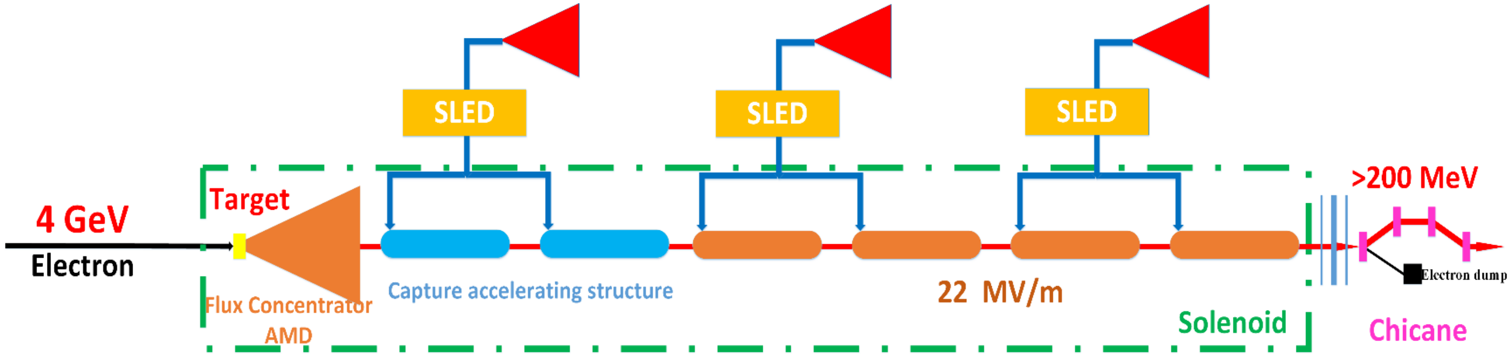


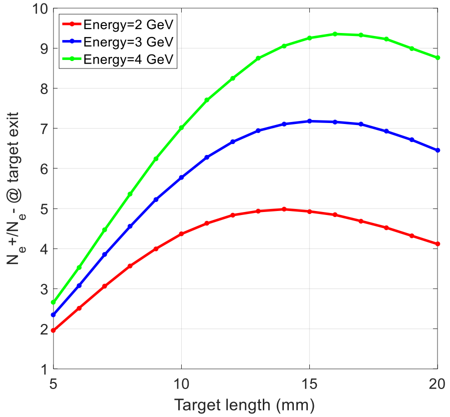
Source design

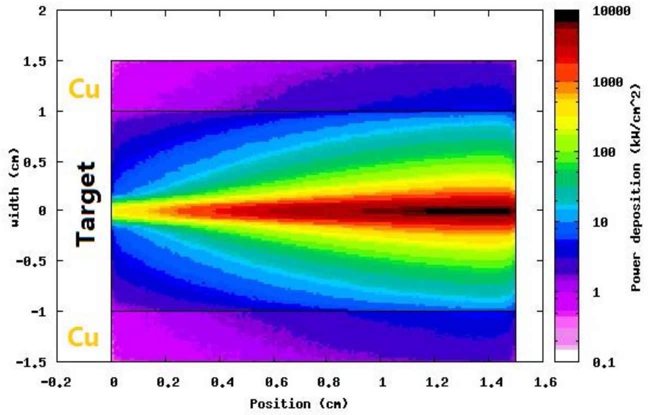
Positron source

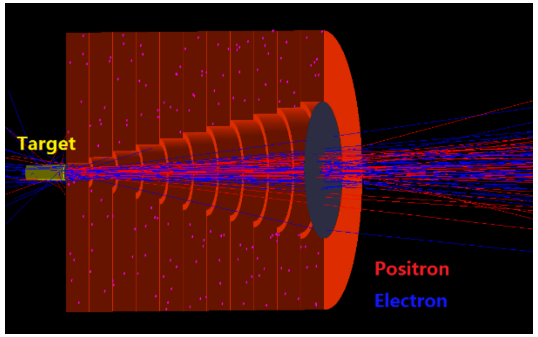
➢Layout of positron source

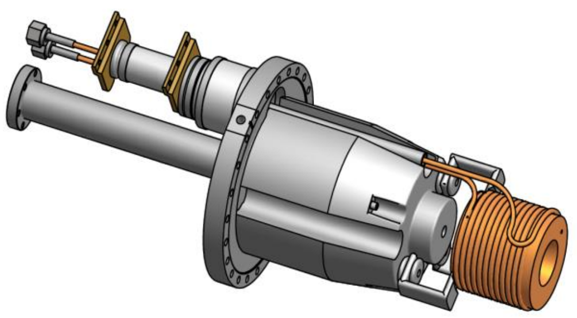
- Target (Conventional)
  - ✓tungsten@15 mm
  - ✓Beam size: 0.5 mm
- Energy deposition
  - ✓0.784 GeV/e- @ FLUKA
  - ✓784 W → water cooling
  - ✓The cylindrical W target is embedded in a cuboid copper block for supporting and cooling
- AMD (Adiabatic Matching Device)
  - ✓Length: 100mm
  - ✓Aperture: 8mm→26mm
  - ✓Magnetic field: (5.5T→0T) + 0.5T









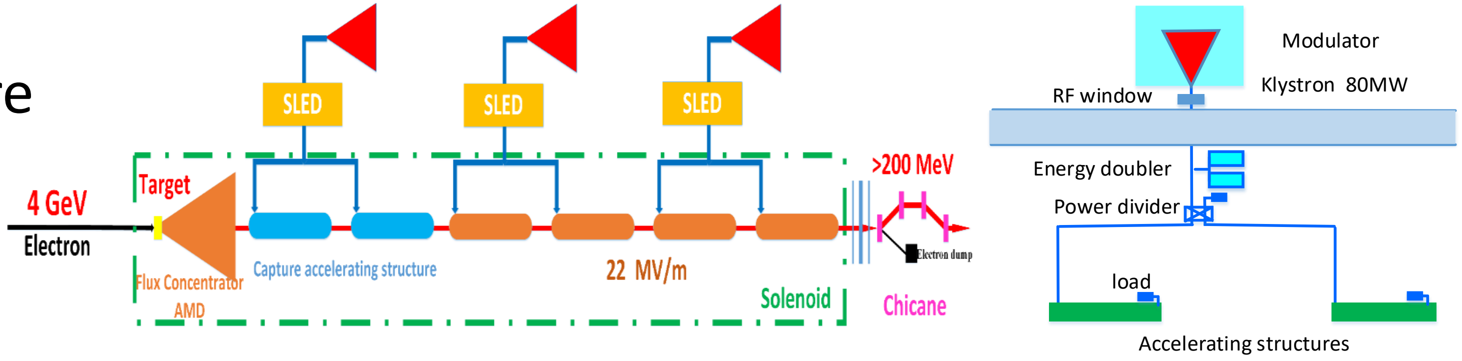


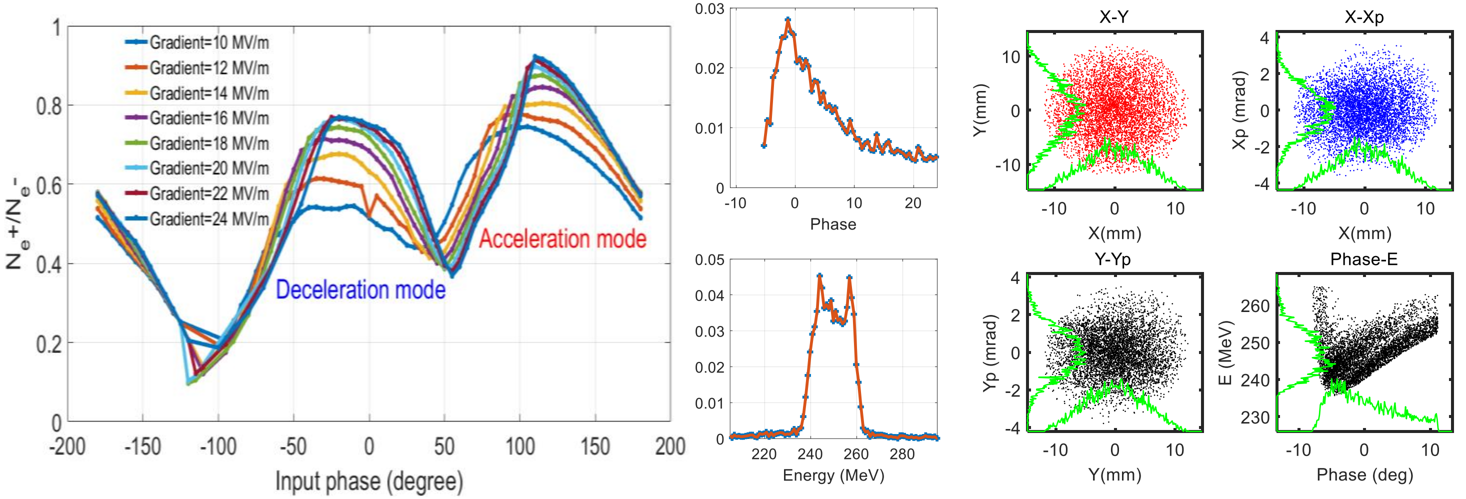
Source design

Positron source

➢ Layout of positron source

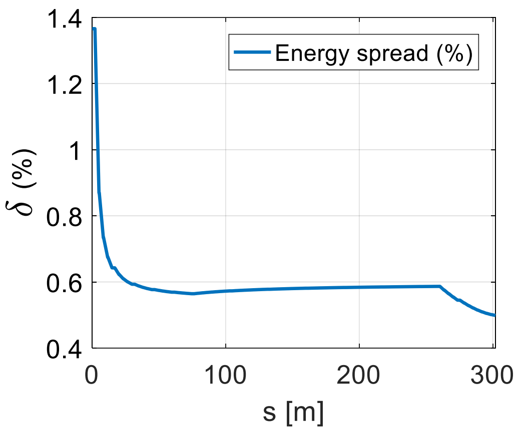
- Capture & Pre-accelerating structure
  - ✓ Length:2 m
  - ✓ **Aperture**: 25 mm
  - ✓ Gradient: 22 MV/m
- Chicane
  - ✓ Wasted electron separation
- Norm. RMS. Emittance
  - ✓ ~2400 mm-mrad→~120nm@10GeV
  - ✓ Capture section & low energy part of positron linac
- Energy: >200 MeV
- Positron yield
  - ✓ Ne+/Ne- > **0.55** @ [-8°，12°，235MeV, 265MeV]

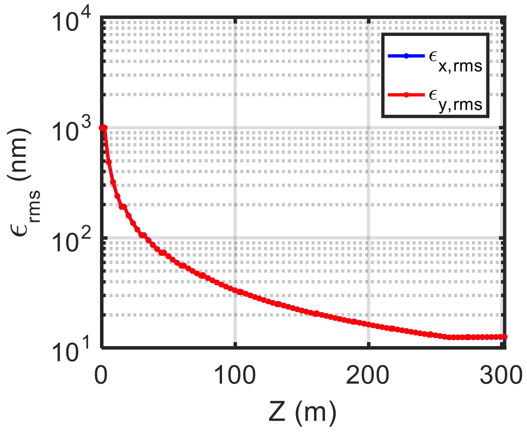


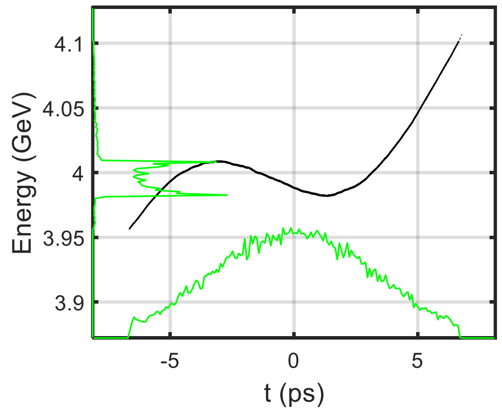


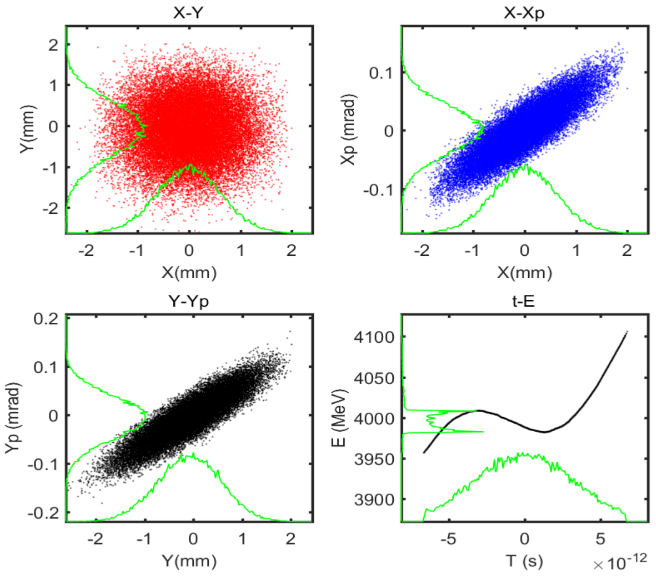
Electron linac→ *Positron production*

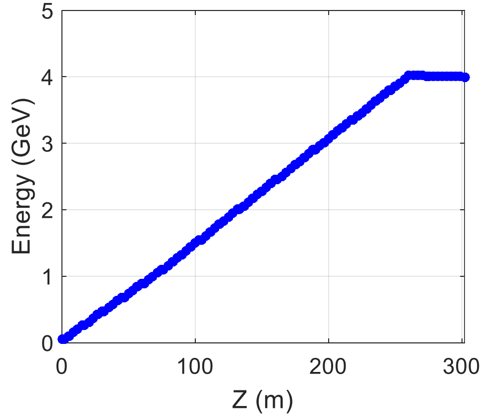
- High charge mode
  - 10 nC @ 4 GeV
  - Energy spread (rms): 0.5%
  - Emittance growth with errors
  - Meet requirements for positron production

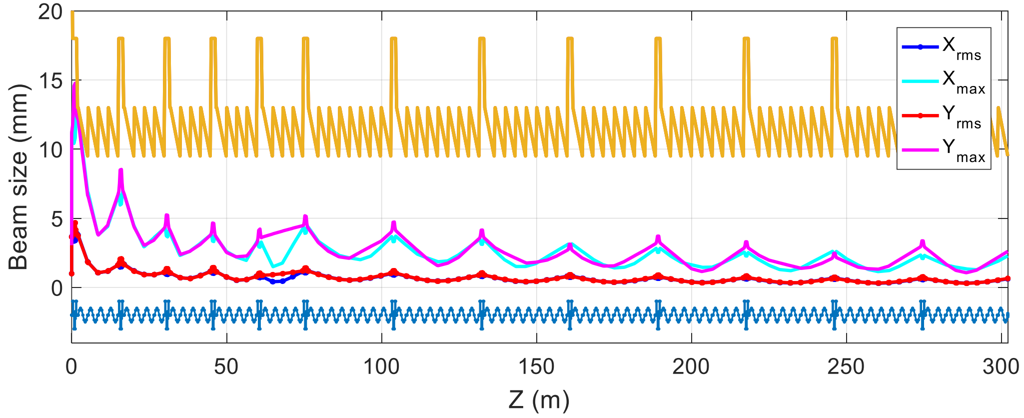






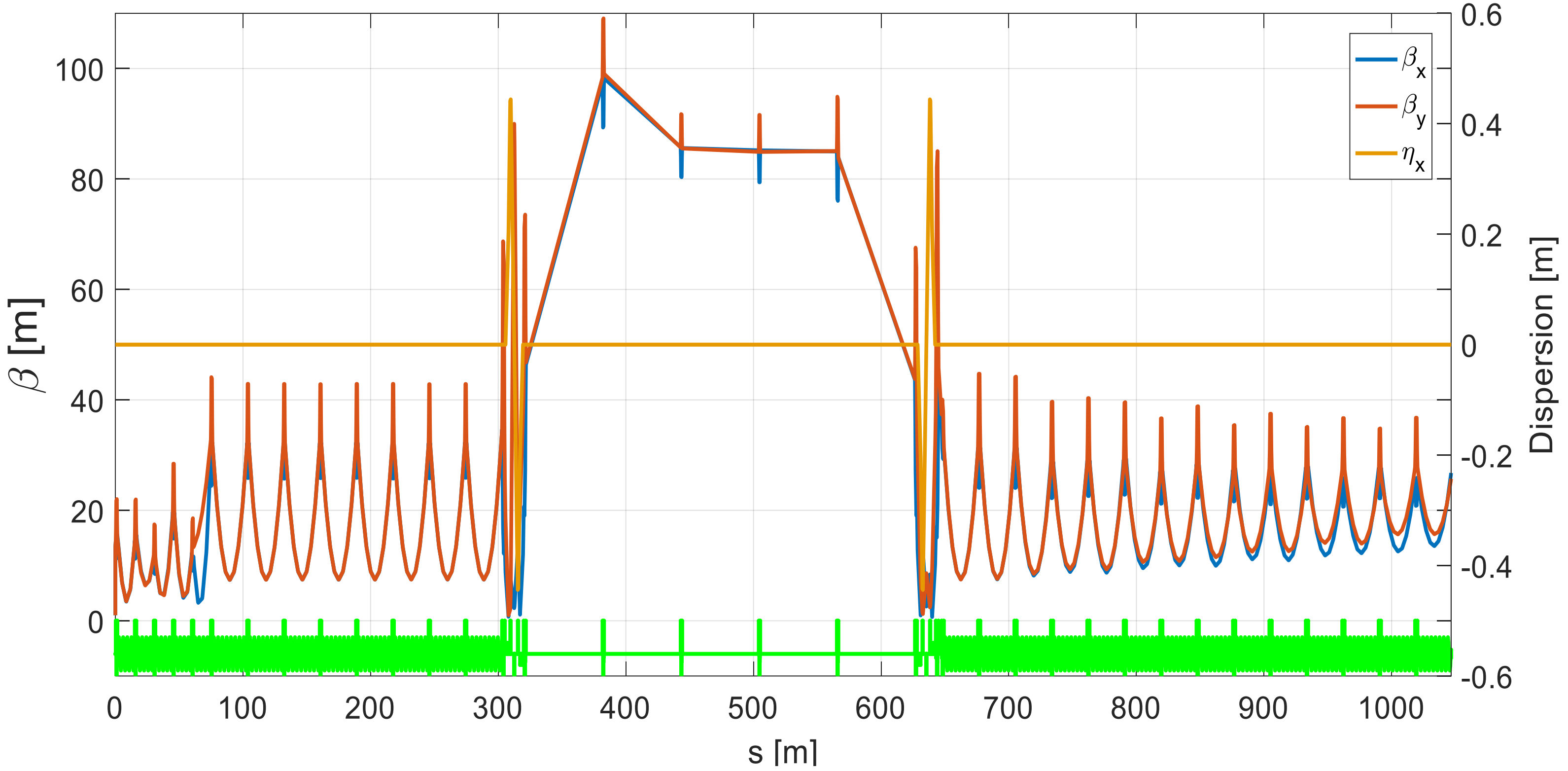






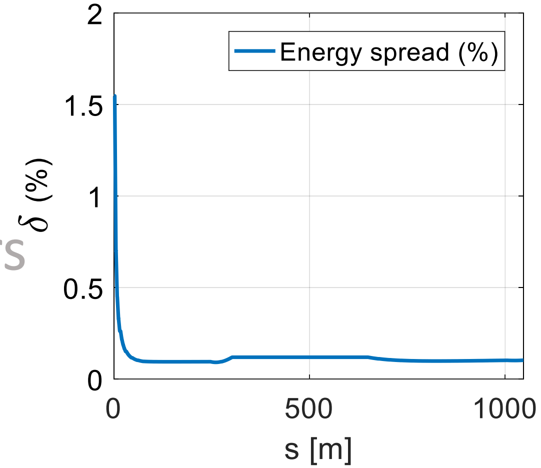
Linac design **Electron linac→ *Electron injection***

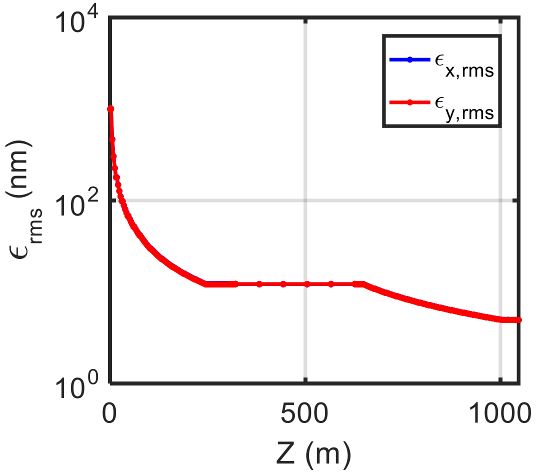
- High charge mode
  - 10 nC @ 4 GeV
  - Energy spread (rms): 0.5%
  - Emittance growth with errors
- Low charge mode
  - EBTL
    - ✓ Local achromatic
    - ✓ Matching
    - ✓ Collimator (momentum tail)
  - Bypass distance is 2 m

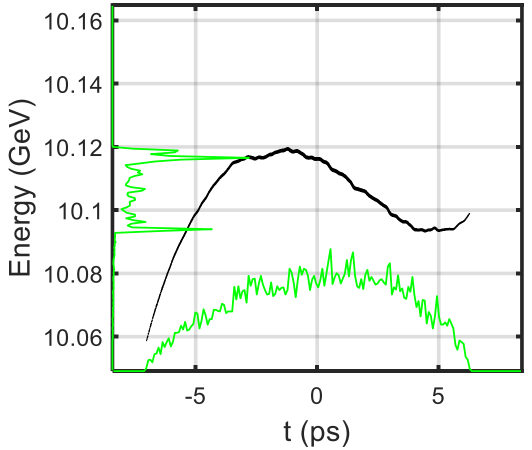


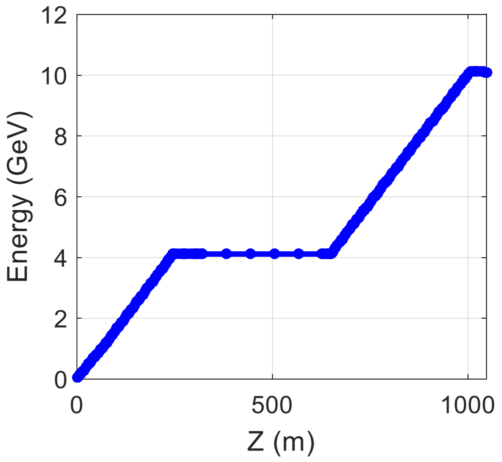
Linac design Electron linac→ *Electron injection*

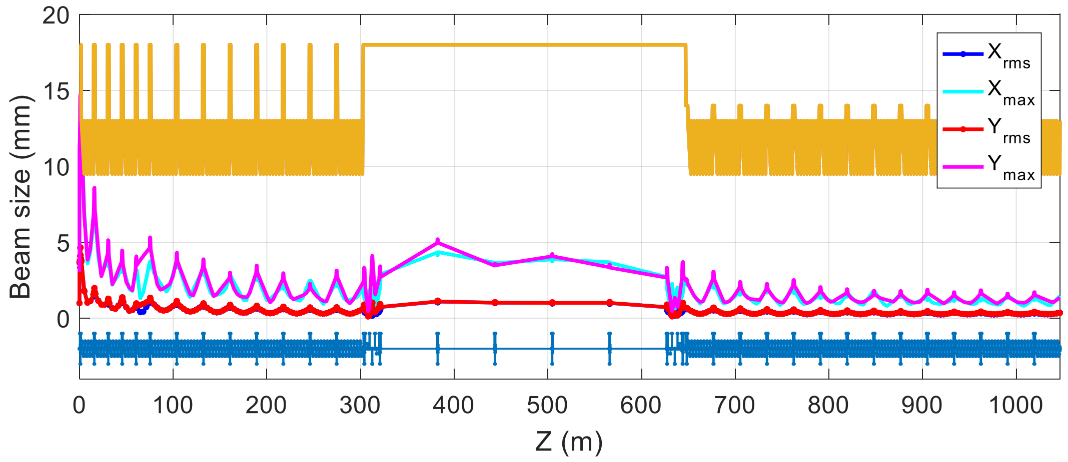
- ➢High charge mode
  - 10 nC @ 4 GeV
  - Energy spread (rms): 0.5%
  - Emittance growth with errors
- ➢Low charge mode
  - 3 nC @ 10 GeV
  - Energy spread (rms): 0.15%
  - Emittance (rms): 5 nm







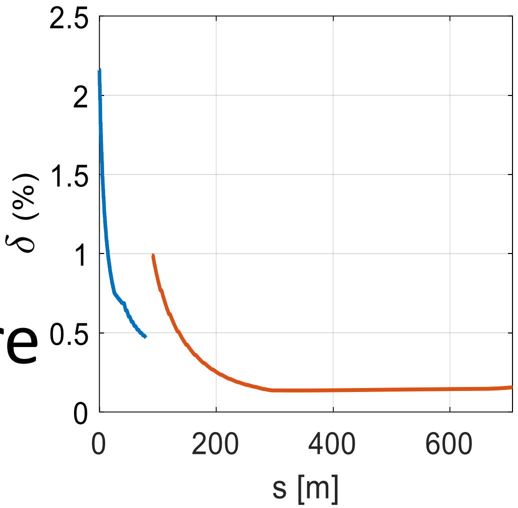


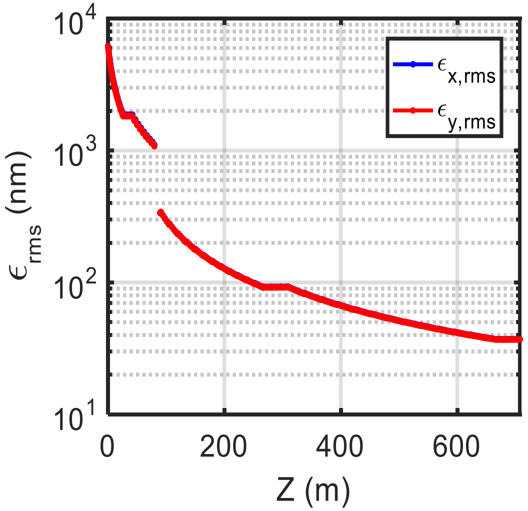


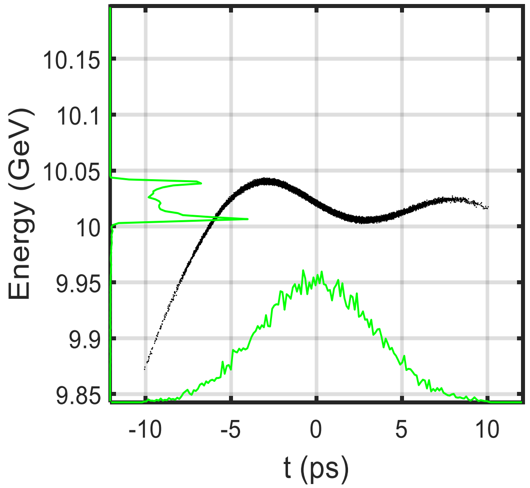
Linac design

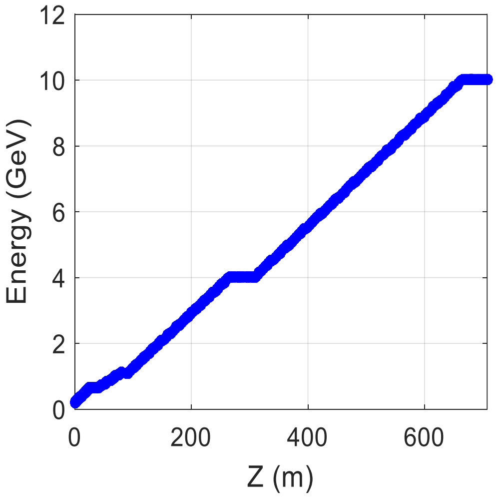
Positron linac

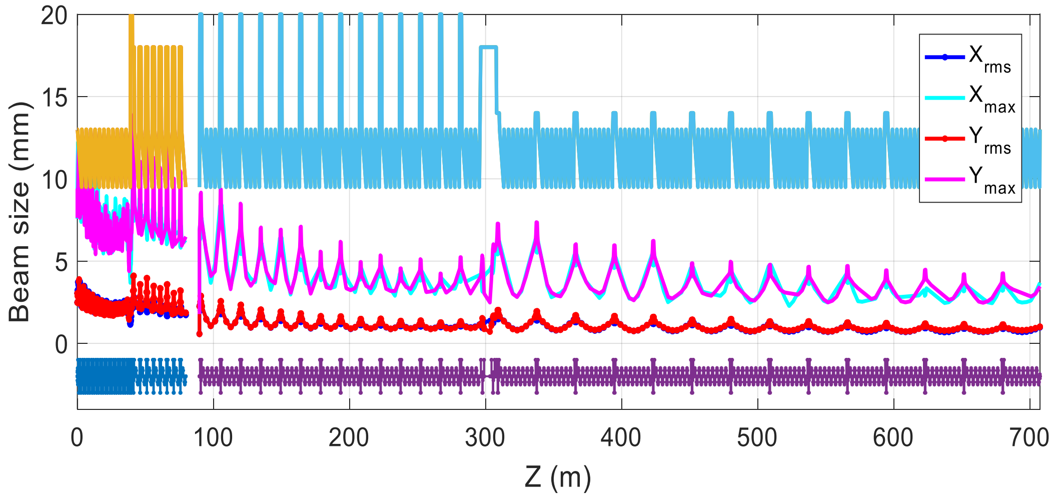
- PSPAS→SAS (DR) +TAS
  - **SAS**: 200 MeV→4 GeV
  - Damping Ring @ 1.1 GeV
  - TAS: 4GeV→10 GeV
- Transverse focusing structure
  - FODO, nesting on Acc. Stru.
  - Triplet
- Positron linac
  - 3 nC && 10 GeV
  - Energy spread (rms): 0.16%
  - Emittance with DR (rms): 30/10nm
  - Emittance without DR (rms): ~120/120nm







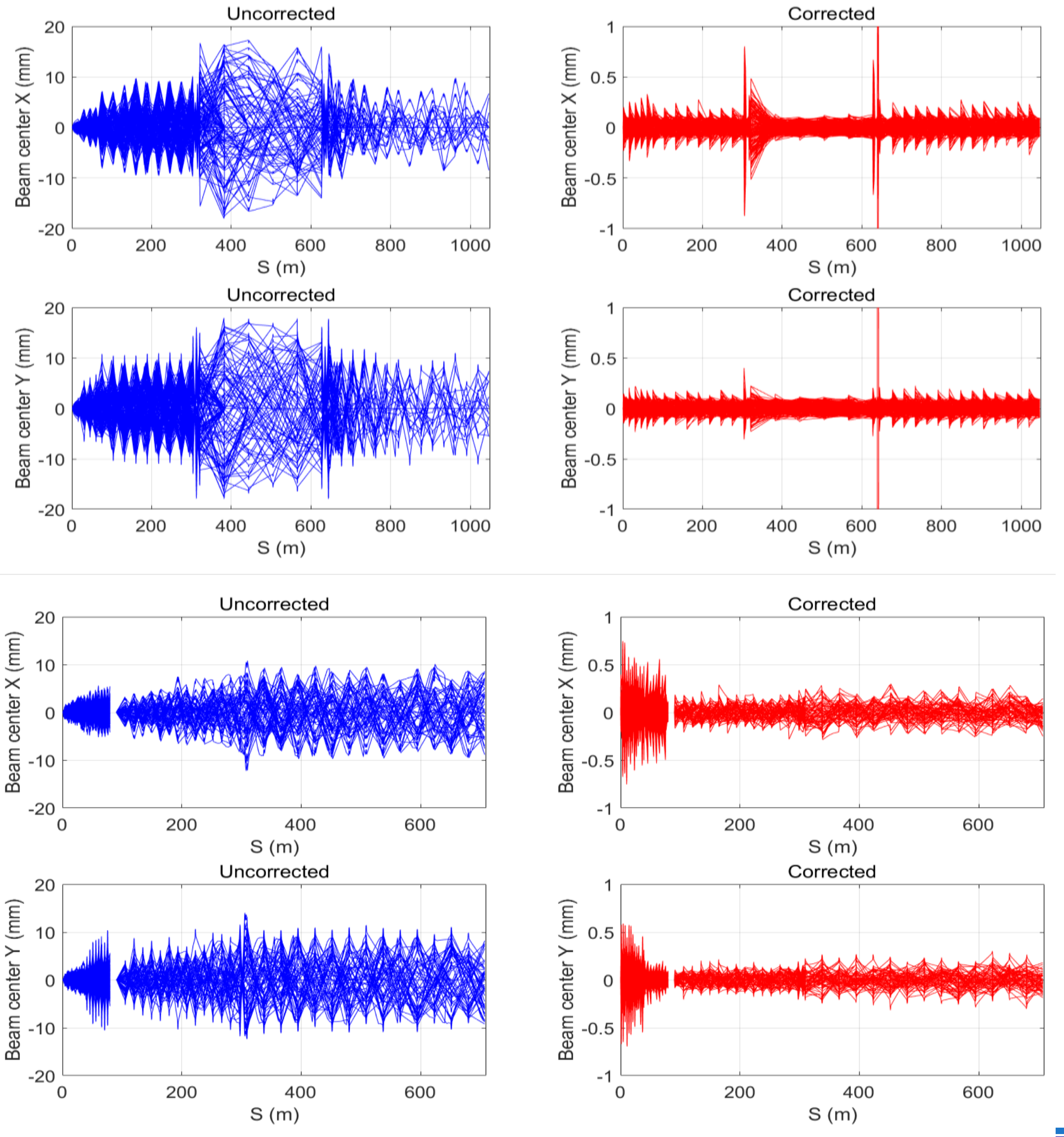




Linac design

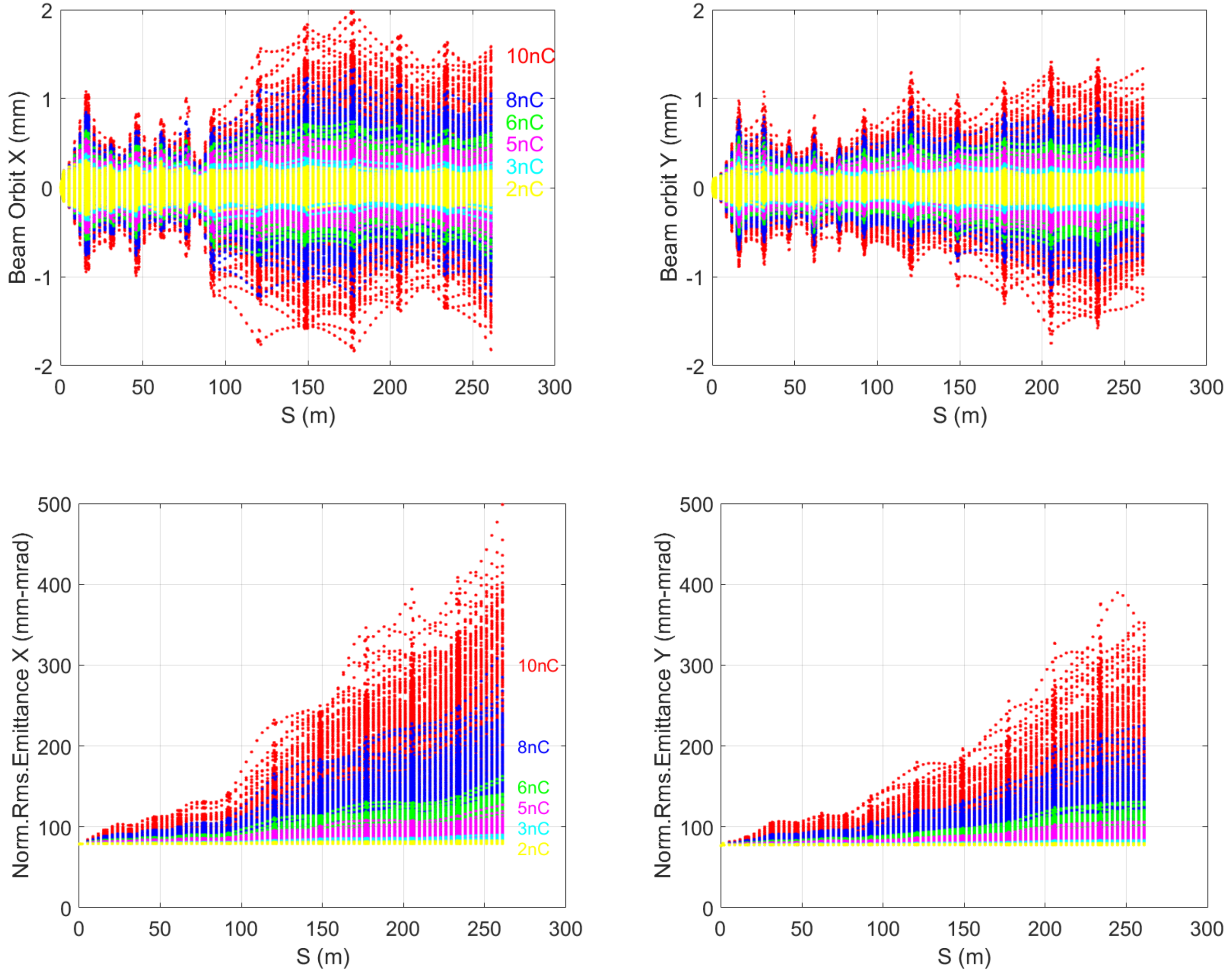
- linac
  - One-to-one correction scheme
  - Errors: Gaussian distribution, 3σ truncated
- Beam orbit
  - <1mm

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



Error study Misalignment errors with correction

- Electron linac
  - First orbit correction + multi-particles simulation
  - Low charge
    - ✓ Beam orbit can be controlled well
  - High charge
    - ✓ Misalignments of Acc. Tubes
    - ✓ BPM noisy
    - ✓ **Wakefield**
  - In operation, the orbit and emittance growth can be controlled better. Correction is based on multi-particles orbit
  - Meet the requirements for positron production

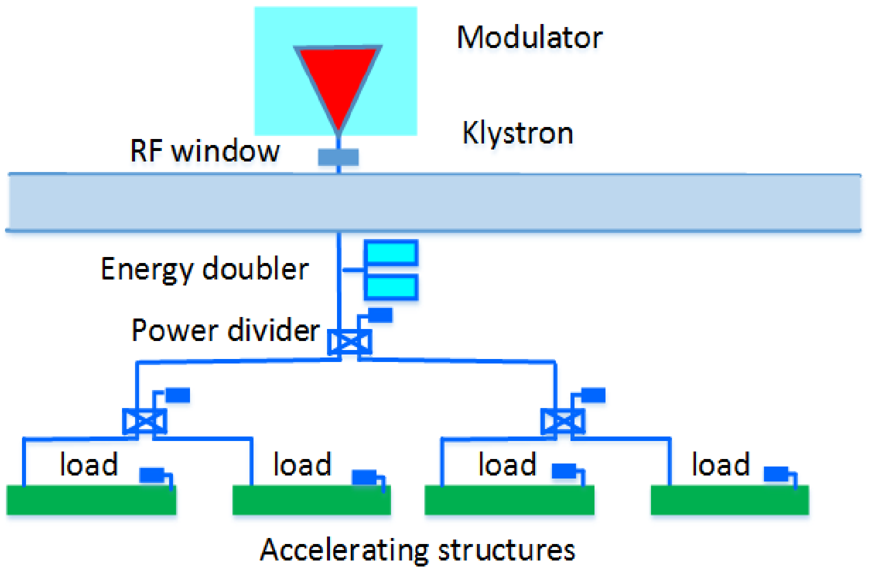


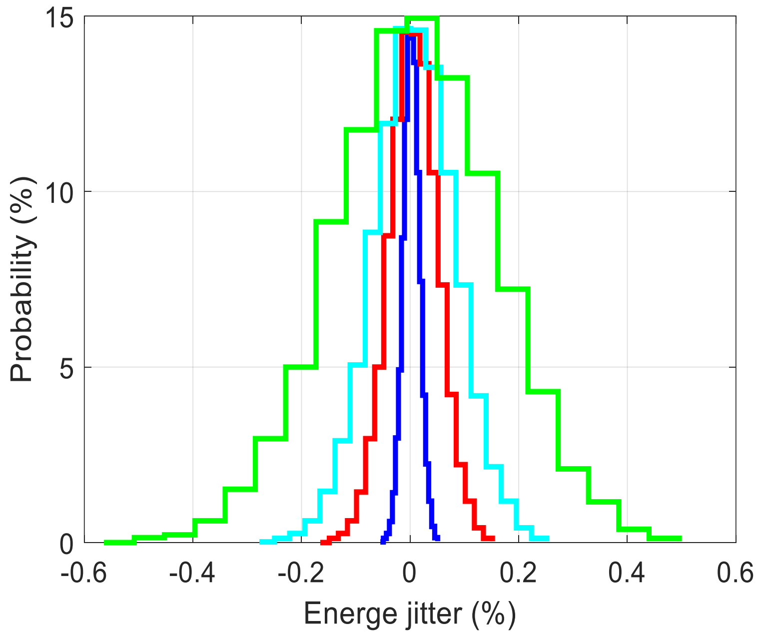
Linac design

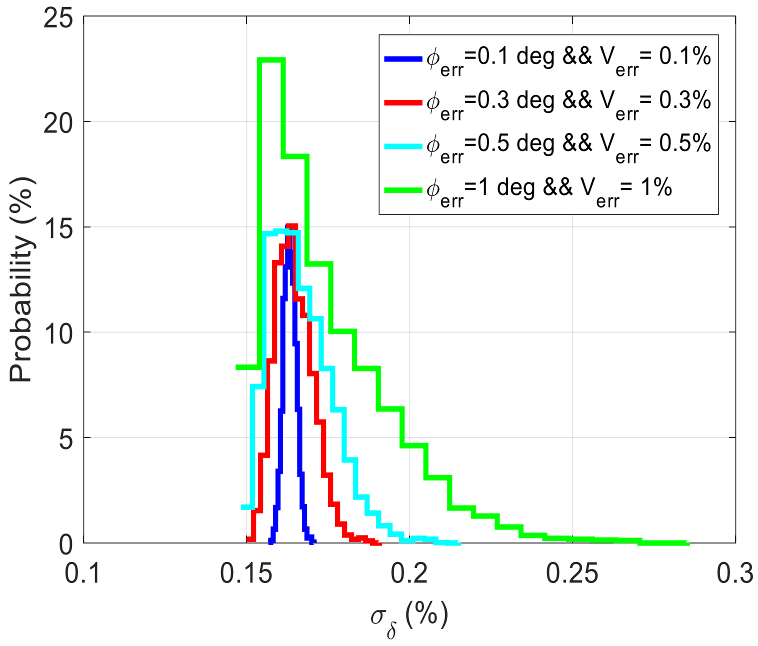
Field errors

- Simulation condition
  - 5000 seeds
  - Accelerating structure
    - 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)



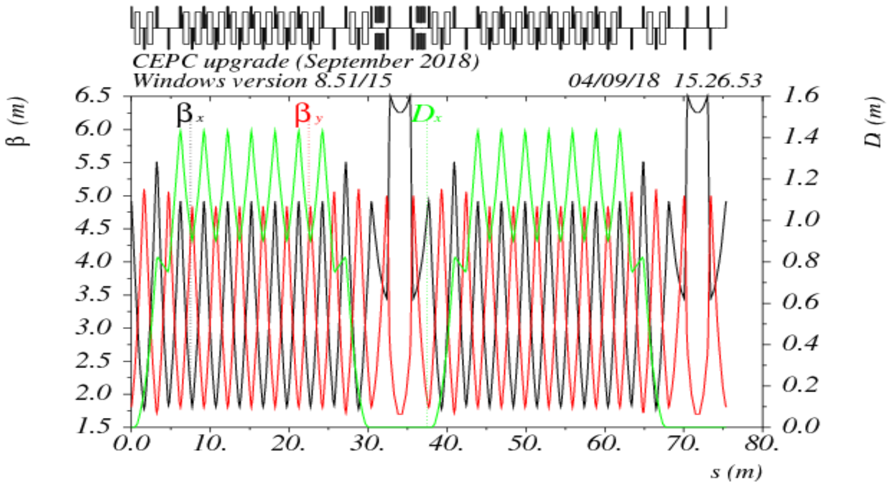


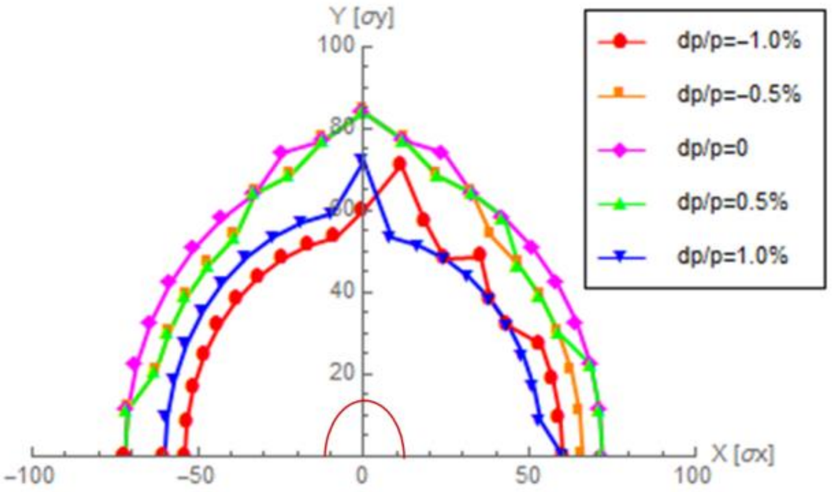


Linac design Damping Ring--Updates

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
$\delta_{inj}/\delta_{ext}$	%	0.2/0.05
Energy acceptance by RF	%	1.0
f_{RF}	MHz	650
V_{RF}	MV	2.0

@ D. Wang





- Emittance not critical
- two bunch in DR (251ns)
  - 20ms
- **IBS**
  - Emittance growth
- **CSR (Coherent synchrotron radiation)**
  - CSR Instability
- Energy-spread compression system (**ECS**) before DR
- bunch compression system (**BCS**) after DT

TDR issues

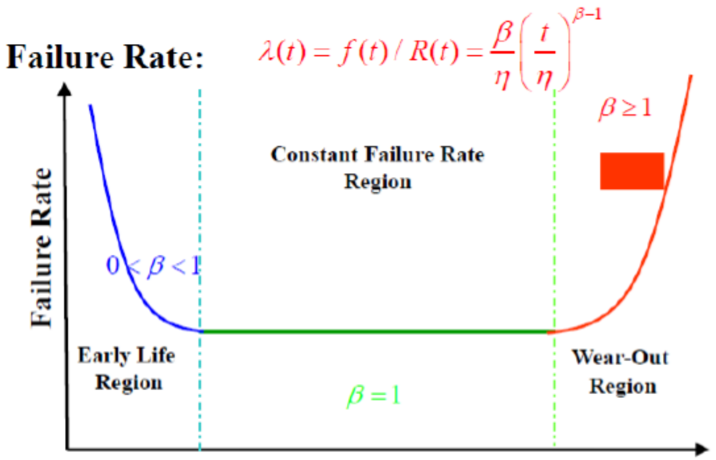
- **Lattice optimization**
  - Actual element dimensions
  - Positron source: target thermal stress and mechanical analysis
  - Error study
  - Damp Ring
- **RAMI analysis**

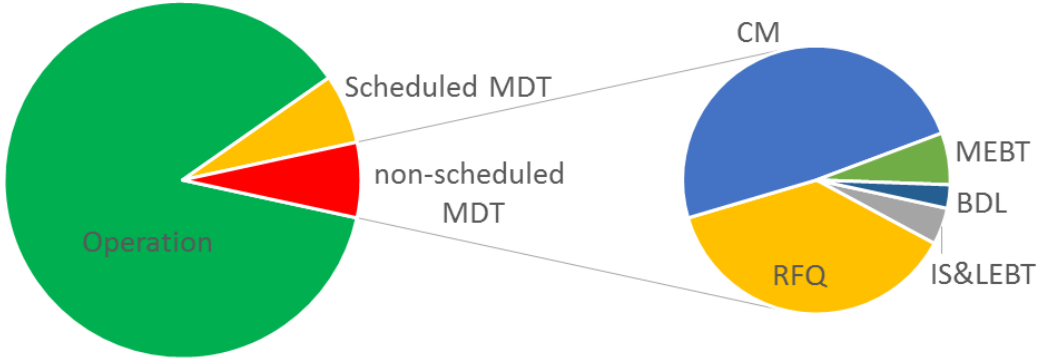
Lattice optimization

- Installation space
  - The lattice of CDR Linac design have included accelerating structures, quadrupoles, dipoles (EBTL+AMs), correctors, BPMs, ICTs, PRs; **have provide the first version survey data.**
  - The install space have been considered, but need to check with the “actual” element;
  - Parameters of magnets maybe have some modification, especially the aperture of quadrupoles at the low energy part of positron linac;
  - Solenoids and waveguide installation space of positron source part
  - Maybe more PRs …
- Positron source
  - Target and supporting thermal stress and mechanical analysis
- Damping Ring
  - IBS && CSR consideration
  - ECS && BCS design
- Error study
  - Start-to-end simulation
  - Including more errors

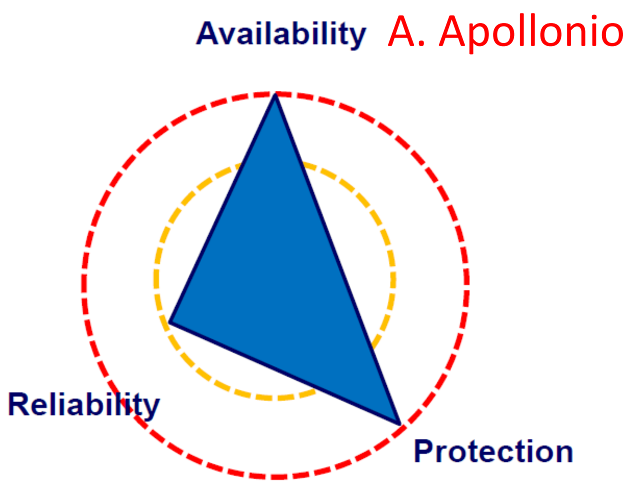
RAMI analysis

- RAMI（Reliability, Availability, Maintainability, Inspectability）
  - Higher availability means higher **Integral Luminosity** **, e.g. LHC-2016 running**
  - At the design beginning, should consider these issues, such as SNS, ILC, ESS, IFMIF, HL_LHC (LHC)…
- CEPC Linac have some consideration on the availability in the CDR
- Detailed simulation and analysis in the **TDR**
  - Based on AvailSim2.0, we are developing the RAAS-1.0





Proton Linac Front-End example



Summary

- The CEPC Linac design of CDR have finished and can meet the requirements of Booster including Linac scheme design, beam dynamics and error study;
- The Linac have the potential to meet higher requirements and updates in the future;
- Some TDR issues and plans are presented including lattice optimization and availability analysis.