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 linac injector beam dynamics with S band and C band structures to 20 GeV

**CEPC Working Day Meeting**
**27 September, 2019**

**Cai Meng**

**On behalf of CEPC AP/LN group**

# Outline

- Introduction
- Alternative design of CEPC Linac
  - 20 GeV scheme with C-band
  - Lattice design
  - Error study
  - Cost analysis
- Summary

# Introduction

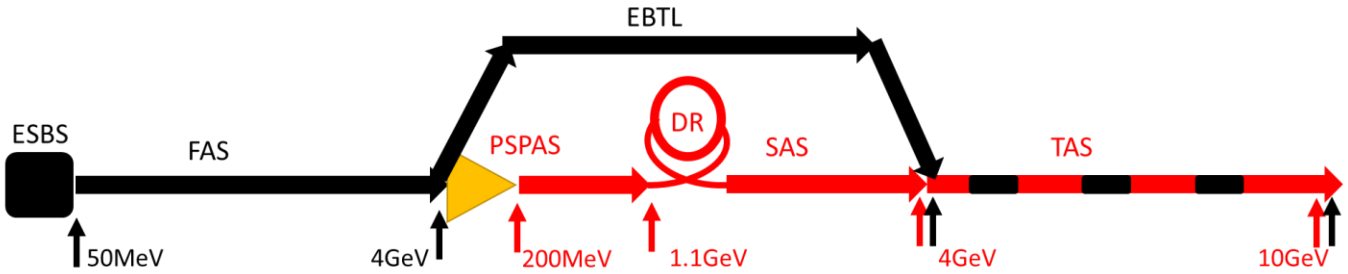
## Basic information

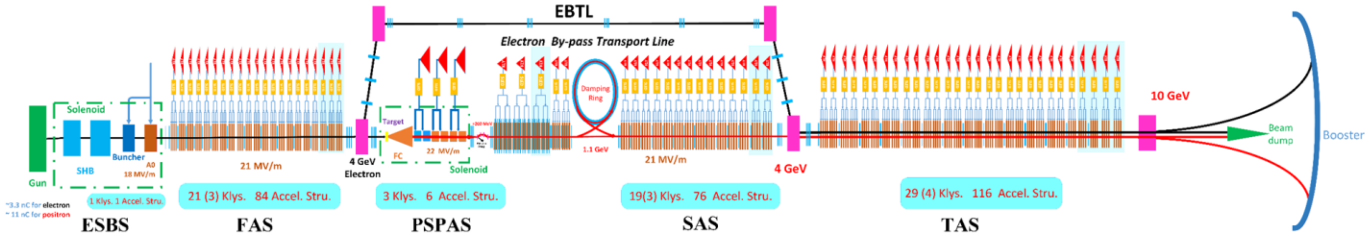
➢CEPC baseline Linac

- 10 GeV S-band (2860MHz) normal conducting Linac
- High availability is the key design principle
- Conventional positron source
  - ✓ Fixed target
- 1.1 GeV damping ring

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

| 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 | $Ne$-/$Ne$+ | | >9.4×10$^9$ | >1.9×10$^{10}$ |
| | | nC | >1.5 | >3 |
| Energy spread (e⁻ /e⁺ ) | $\sigma_E$ | | <2×10$^{-3}$ | - |
| Emittance (e⁻ /e⁺ ) | $\varepsilon_r$ | nm | <120 | <40 |
| e⁻ beam energy on Target | | GeV | 4 | - |
| e⁻ bunch charge on Target | | nC | 10 | - |



# IAC report

- *The IAC notes the plasma wakefield acceleration alternative to the conventional scheme for injection. It also recommends that the team examine a C-band solution, as mentioned in the CDR review recommendations.*
- Advantage (High energy)
  - *Reduce the technical risk of low magnetic field magnets of the Booster*
  - *Reduce the difficulty of the Booster design*
- **CEPC alternative Linac (20GeV)**
  - **S-band + C-band : 10GeV→20GeV**
- PWFA
  - 45GeV injector + Booster

# Requirements

➢ Smaller emittance requirement for LINAC, even baseline design

| Parameter | Symbol | Unit | Baseline | Alternative |
|---|---|---|---|---|
| $e^-$ /$e^+$ beam energy | $E_{e-}/E_{e+}$ | GeV | 10 | **20** |
| Repetition rate | $f_{rep}$ | Hz | 100 | 100 |
| Bunches/pulse | | | 1 | 1 |
| $e^-$ /$e^+$ bunch population | *Ne-/Ne+* | | $>9.4\times10^9$ | $>9.4\times10^9$ |
| | | nC | >1.5 (3) | >1.5 (3) |
| Energy spread ($e^-$ /$e^+$ ) | $\sigma_E$ | | $<2\times10^{-3}$ | $<2\times10^{-3}$ |
| Emittance ($e^-$ /$e^+$ ) Req. | $\varepsilon_r$ | nm | <120→**40** | <60→**20** |

# Alternative Linac consideration

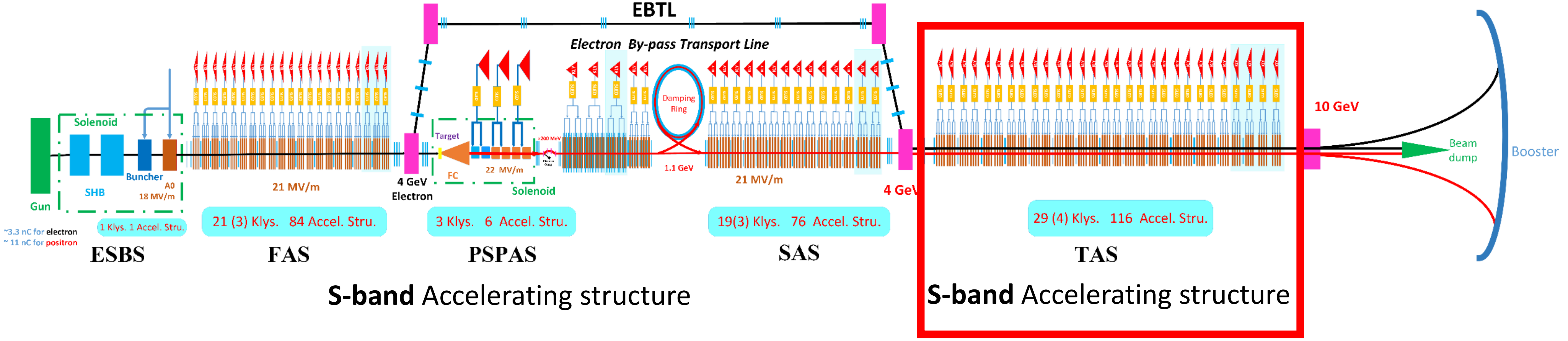
- Energy raise
  - Energy at Linac exit > 20GeV
  - High gradient accelerating structure to control Linac length
  - Keep the bunch potential → Wakefield, accelerating structure aperture
  - **C-band**

| Parameter | Unit | S-band | C-band |
|---|---|---|---|
| Frequency | MHz | 2860 | 5720 |
| Length | m | 3.1 | 1.8 |
| Cavity mode | | 2π/3 | 3π/4 |
| Aperture diameter (mm) | mm | 20~24 | 11.8~16 |
| Gradient | MV/m | 21 | **45** |

# Alternative Linac Layout

➢Alternative Linac design

- Linac exit energy: 10GeV → 20GeV




- **C-band: start energy~ 4GeV**
- Transverse focusing
  - ✓Triplet

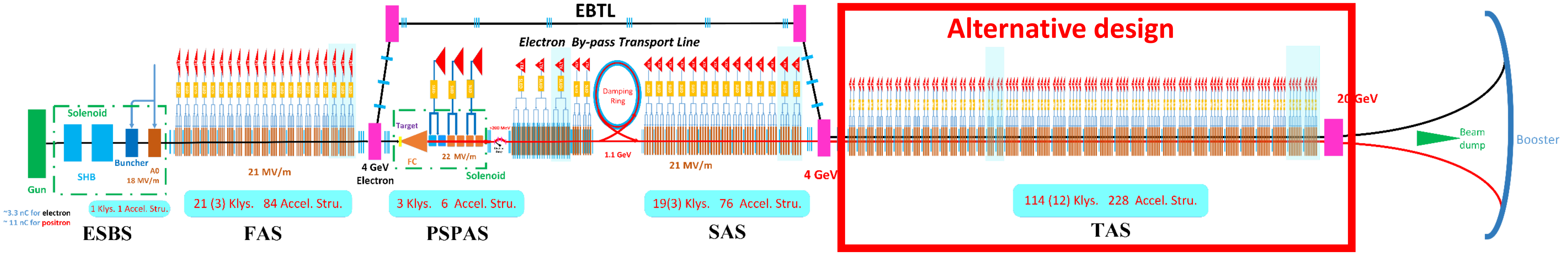
S-band: **4** GeV → 10GeV

**C-band: 4 GeV → 20GeV**

# Alternative Linac Layout

➢Alternative Linac design

- Linac exit energy: 10GeV → 20GeV




**S-band** Accelerating structure

**C-band** Accelerating structure

- **C-band: start energy~ 4GeV**
- Transverse focusing
  - ✓Triplet

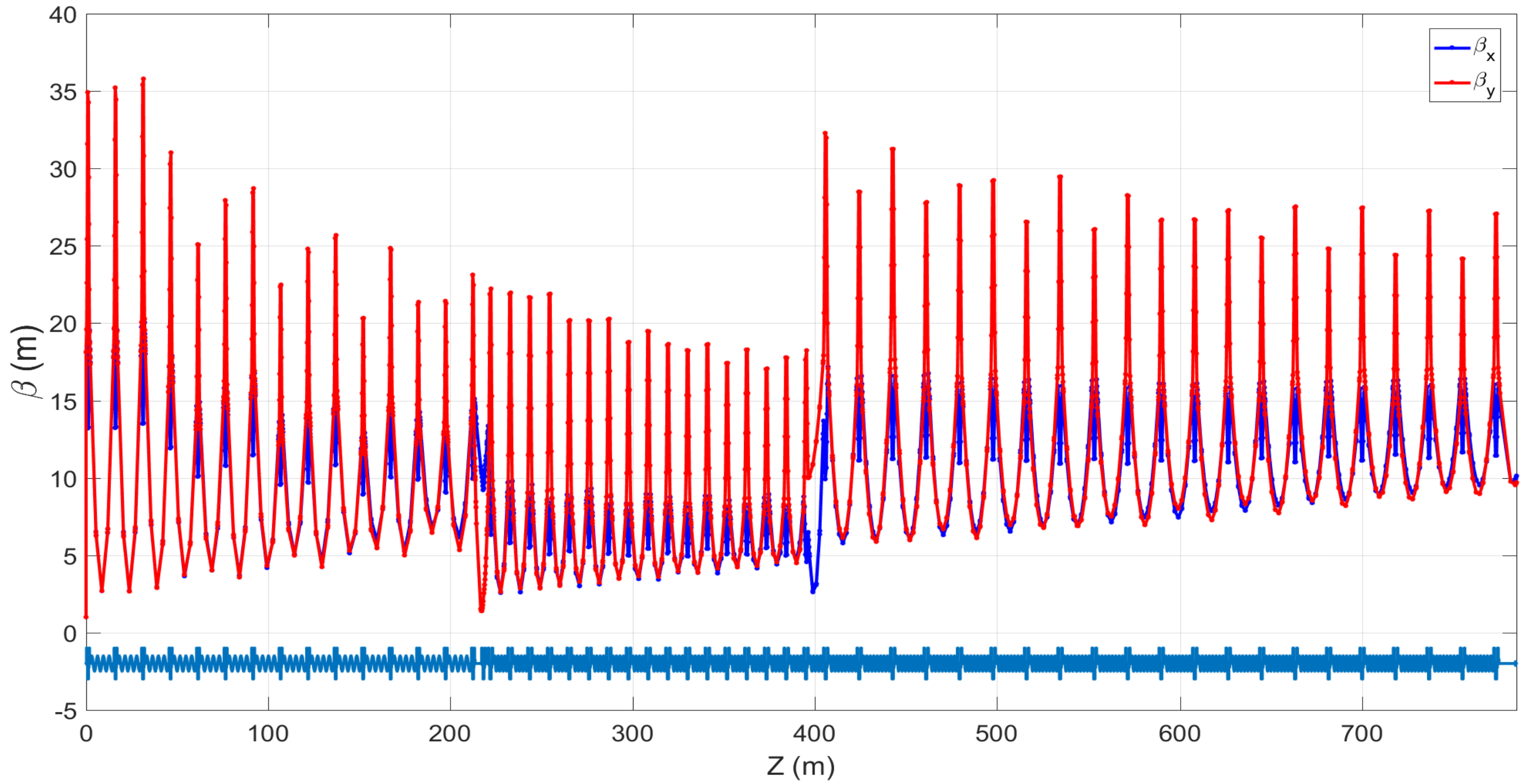
S-band: **4** GeV → 10GeV

**C-band: 4 GeV → 20GeV**

# Alternative Linac Optics function

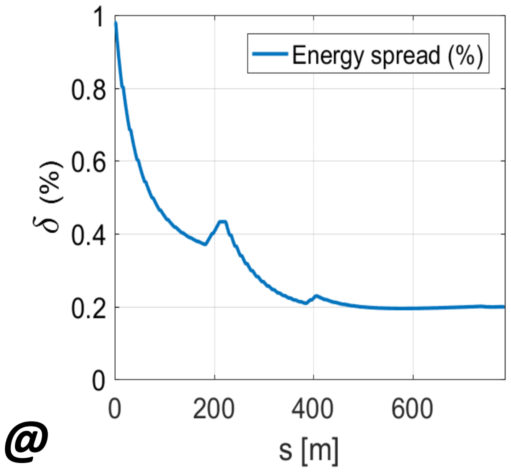
➢Lattice design (optics)

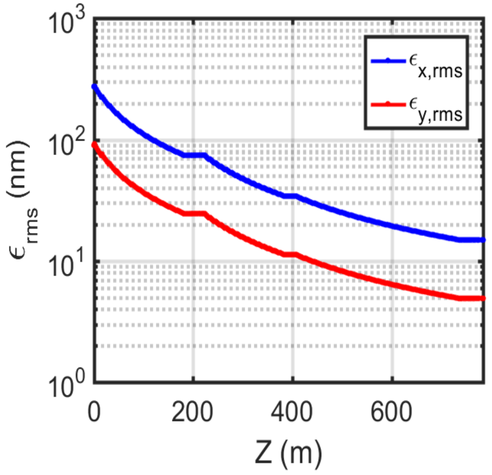
- 1.1GeV (damping ring) →20GeV
- Shorter bunch length (High frequency)

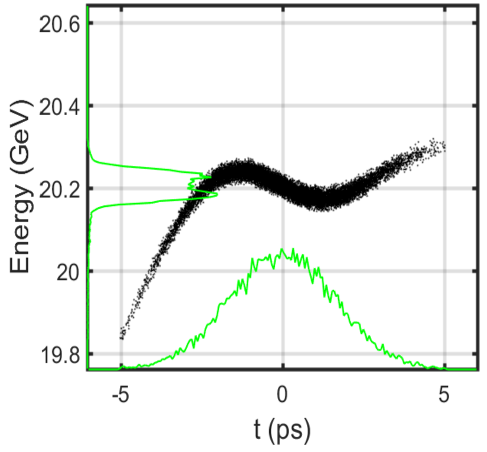


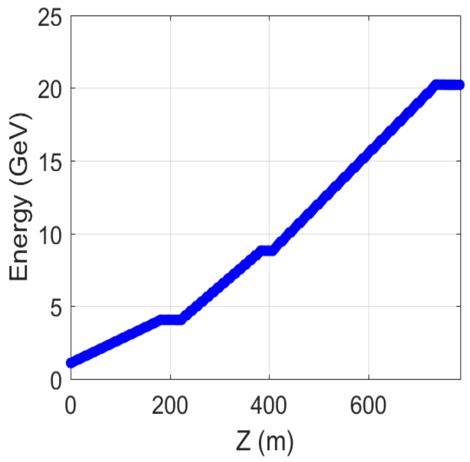
## Beam dynamics

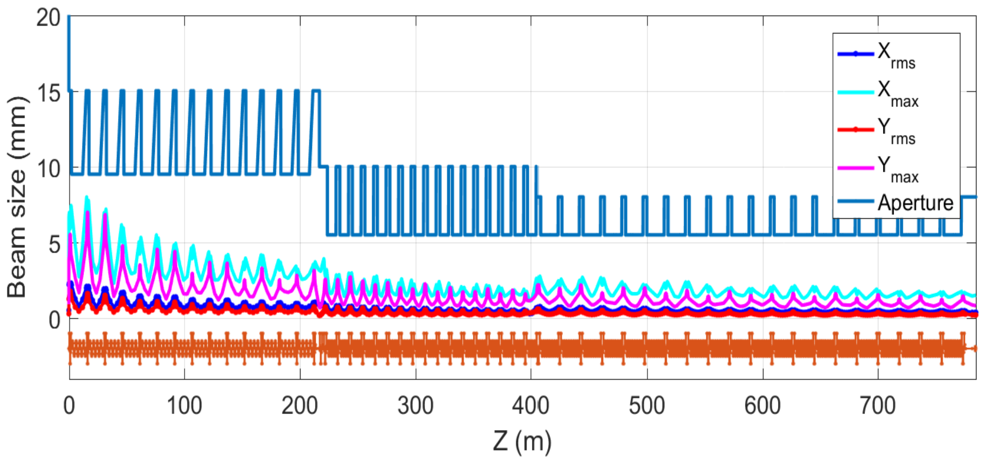
- Energy spread
  - 0.2%
  - ***Rms Bunch length<0.5mm***
    - ✓ ***Difficulty design of BCS after Damping Ring***
    - ✓ ***Difficulty design for booster RF @ injection***
- Emittance
  - 15nm
  - More damping time in DR



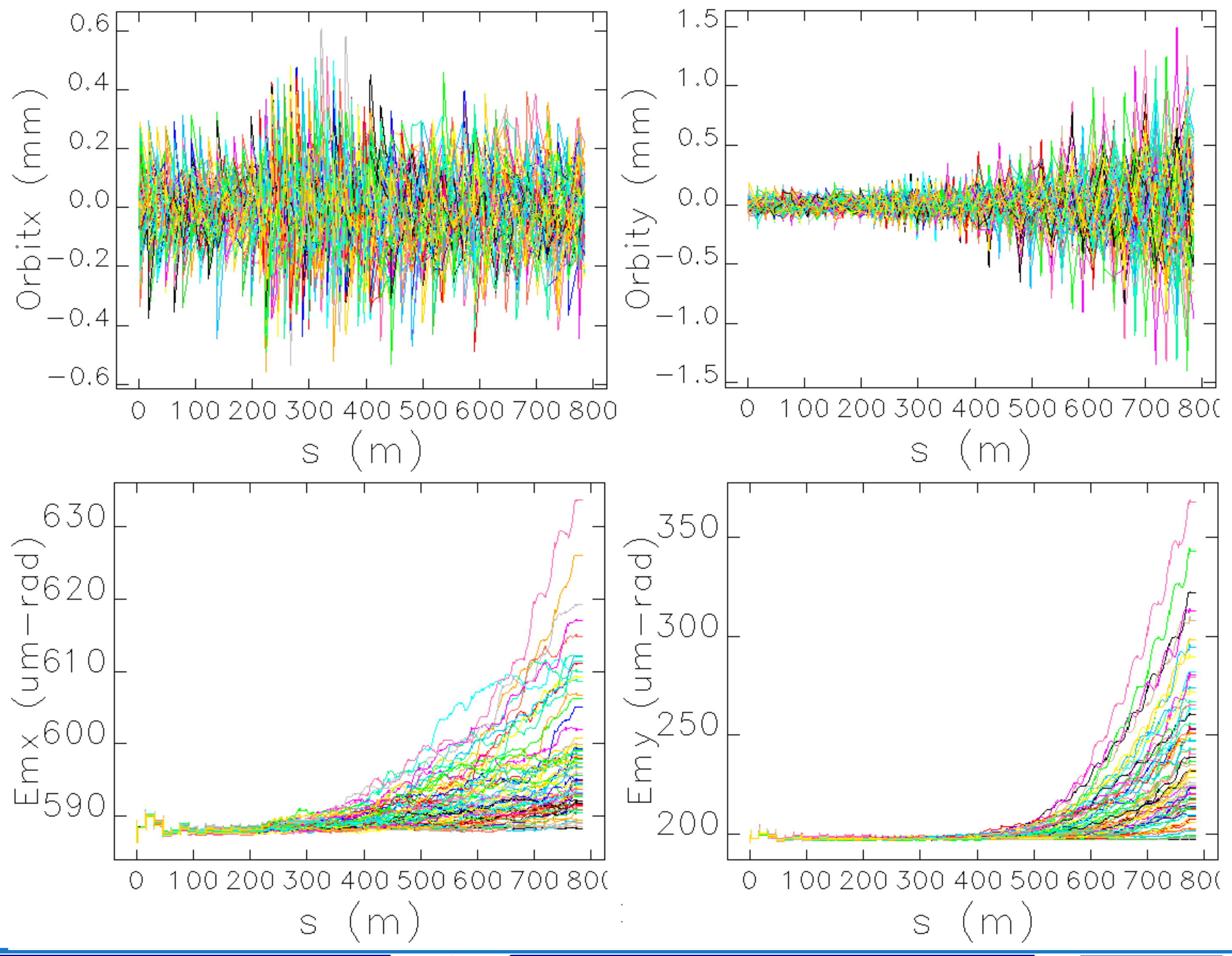



# Alternative design    Error study

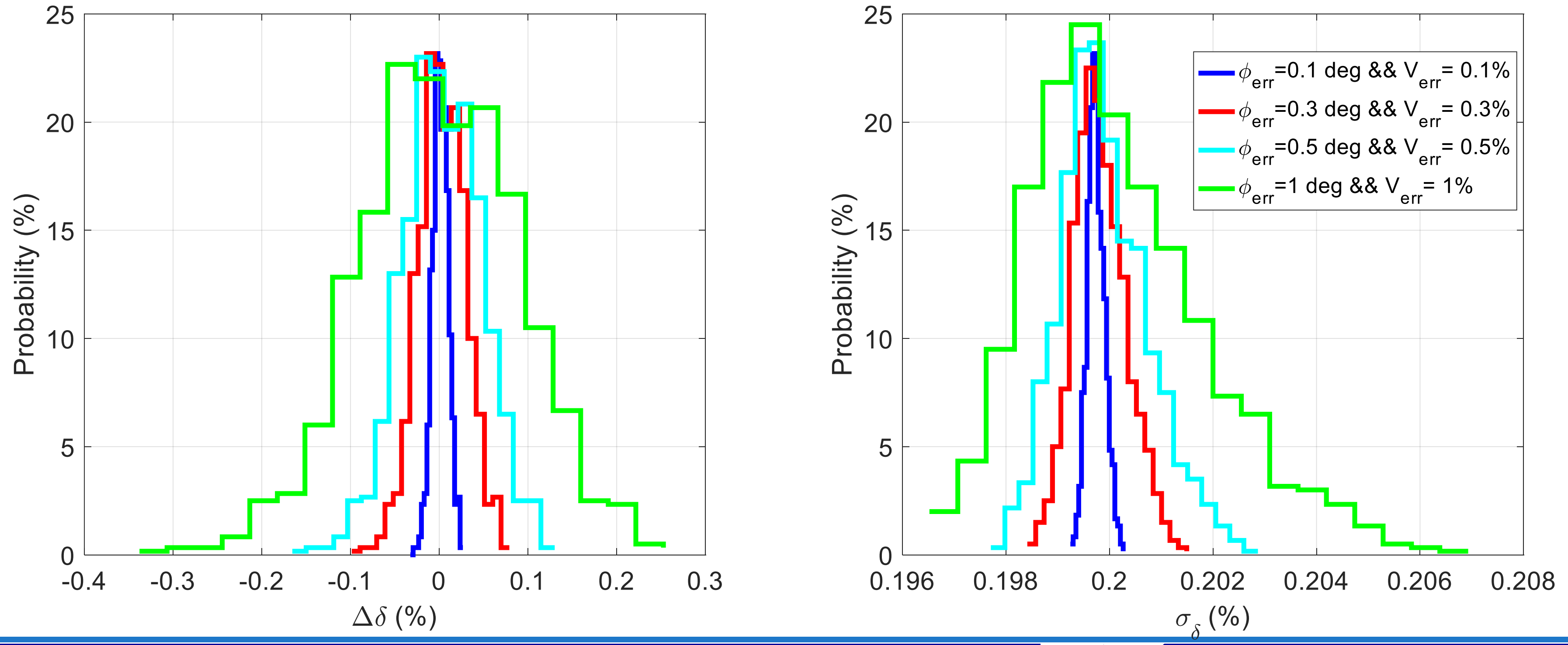
- Orbit distortion (75 seeds)
  - Without correction, beam lost at most case
  - With correction
    - ✓ Cx<0.6mm, emittance growth~2%
    - ✓ Cy is growth greatly, which is need more analysis, emittance growth~20%
    - ✓ Emittance smaller than the required value

| Element | Error | Value (rms) |
|---|---|---|
| Quadrupole | Misalignment(x/y/z) | 0.1/0.1/0.2 |
| | Field error | 0.1% |
| Accelerating structure | Misalignment(x/y) | 0.1/0.1mm |
| BPM | Uncertainty | 0.1mm |



# Alternative design        Dynamic errors

- Accelerating structure
  - Phase errors and amplitude errors
    - ✓ 1 klystron → 4 S-band accelerating structure
    - ✓ 1 klystron → 2 C-band accelerating structure
  - **0.5 degree && 0.5%**        (More accelerating structure)



# Alternative design



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➢ Requirements

- Bunch length compression section (BSC) after DR, RMS bunch length should be **shorter than 0.5 mm**
- Higher magnetic field for LTB (Linac to Booster) magnets

| Parameter | Symbol | Unit | Alternative design | Status |
|---|---|---|---|---|
| $e^-$ /$e^+$ beam energy | $E_{e-}/E_{e+}$ | GeV | 20 | 20 |
| Repetition rate | $f_{rep}$ | Hz | 100 | 100 |
| Bunches/pulse | | | 1 | 1 |
| $e^-$ /$e^+$ bunch population | $Ne-/Ne+$ | nC | >1.5 (3) | 3 |
| Energy spread ($e^-$ /$e^+$ ) | $\sigma_E$ | | $2\times10^{-3}$ | $\sim2\times10^{-3}$ |
| Emittance ($e^-$ /$e^+$ ) Req. | $\varepsilon_r$ | nm | 20 | 15/6 |
| Linac length | | m | | 1400 |

# Alternative design elements

➢Devices

- Magnet system
- Power source system
- Microwave system
- Beam diagnostic system
- Power supply system

| Type | Baseline | Alternative | Value |
|---|---|---|---|
| S-band KLY | 73 | 44 | 80 MW |
| C-band KLY | -- | 114 | 50 MW |
| Solid state power source | 2 | 2 | 10kW |
| S-band Acc. Structure | 277 | 161 | 21 MV/m |
| C-band Acc. Structure | -- | 228 | 45MV/m |
| S-band LAS Acc. Structure | 6 | 6 | 22 MV/m@Ø25mm |
| SHB | 2 | 2 | 143/572MHz |
| Buncher | 1 | 1 | 2860 MHz |
| BPM | 86 | 108 | 0.1 mm |
| 流强测量 | 42 | 50 | |
| 发射度测量 | 4 | 5 | |
| 能量分析站 | 3 | 4 | |
| 束团截面测量（PR） | 60 | 70 | |

| Type | | Baseline | Alternative | 参数要求 | 备注 |
|---|---|---|---|---|---|
| 二极磁铁 | B | 4 | 4 | Dipole, Gap 34mm, Field 1T, Length 2.356m. | |
| | CB1 | 4 | 4 | Dipole, Gap 54mm, Field 0.5T, Length 0.279m. | |
| | AM1 | 2 | 2 | Dipole, Gap 34mm, Field 0.3T, Length 0.262m. | |
| | AM2 | 1 | 1 | Dipole, Gap 34mm, Field 0.8T, Length 5.236m. | |
| | AM3 | 1 | 2 | Dipole, Gap 34mm, Field 1T, Length 5.847m. | |
| 四极磁铁 | **150Q** | 48 | 48 | Quadrupole, R 150mm, Field 10T/m, Length 0.3m. | |
| | 60SQ | 6 | 6 | Quadrupole, R 60mm, Field 15T/m, Length 0.1m. | 两个磁铁一个电源 |
| | 60LQ | 3 | 3 | Quadrupole, R 60mm, Field 15T/m, Length 0.2m. | |
| | 40SQ | 88 | 88 | Quadrupole, R 40mm, Field 28T/m, Length 0.2m. | 两个磁铁一个电源 |
| | 40LQ | 50 | 50 | Quadrupole, R 40mm, Field 28T/m, Length 0.4m. | |
| | 32SQ | 38 | 8 | Quadrupole, R 32mm, Field 36T/m, Length 0.3m. | 两个磁铁一个电源 |
| | 32LQ | 19 | 4 | Quadrupole, R 32mm, Field 36T/m, Length 0.6m. | |
| | 24SQ | -- | 32 | Quadrupole, R 24mm, Field 48T/m, Length 0.3m. | 两个磁铁一个电源 |
| | 24LQ | -- | 16 | Quadrupole, R 24mm, Field 48T/m, Length 0.6m. | |
| | 20SQ | -- | 42 | Quadrupole, R 20mm, Field 60T/m, Length 0.3m. | 两个磁铁一个电源 |
| | 20LQ | -- | 21 | Quadrupole, R 20mm, Field 60T/m, Length 0.6m. | |

| Type | | Baseline | Alternative | 备注 |
|---|---|---|---|---|
| 螺线管 | S1 | 4 | 4 | Solenoid,Aperture 90 mm, Field 0.06T, Max.Length 80mm |
| | S2 | 6 | 6 | Solenoid,Aperture 200 mm, Field 0.1T, Max.Length 120mm |
| | S3 | 20 | 20 | Solenoid,Aperture 200 mm, Field 0.05T, Max.Length 70 mm |
| | S4 | 15 | 15 | Solenoid,Aperture 400 mm, Field 0.5T, Max.Length 1m |
| 校正磁铁 | 150C | 17 | 17 | Corrector x and y, Gap 150mm, Field 0.015T, Length 0.25m. |
| | L60C | 3 | 3 | Corrector x and y, Gap 60mm, Field 0.015T, Length 0.1m. |
| | L40C | 46 | 46 | Corrector x and y, Gap 40mm, Field 0.08T, Length 0.1m. |
| | L32C | 19 | 4 | Corrector x and y, Gap 32mm, Field 0.085T, Length 0.2m. |
| | L24C | -- | 16 | Corrector x and y, Gap 24mm, Field 0.085T, Length 0.2m. |
| | L20C | -- | 21 | Corrector x and y, Gap 20mm, Field 0.12T, Length 0.2m. |

# Alternative design COST!

➢The cost **not** included

- Source & Damping ring & transport lines @ LINAC
- All LTB hardware device

@J. R. Zhang

➢The cost increase 0.34 Billion CNY (38%), the energy grows up from 10 GeV to 20GeV

| No. | System | Price （Ten thousand） | | |
|---|---|---|---|---|
| | | S-band (10 GeV) | S&C-band (20 GeV) | Gap |
| 1 | RF system (Ch 6.5.1) | 33338 | 45622 | 12284 |
| 2 | RF power source (Ch 6.5.2) | 32190 | 46740 | 14550 |
| 3 | Magnets (Ch 6.5.3) | 2183 | 3323 | 1140 |
| 4 | Magnet power supplies (Ch 6.5.4) | 2050 | 2328 | 278 |
| 5 | Vacuum system (Ch.6.5.5) | 6060 | 10221 | 1847 |
| 6 | Instrumentation (Ch 6.5.6) | 6400 | 7335 | 935 |
| 7 | Control system (Ch 6.5.7) | 5793 | 6112 | 319 |
| 8 | Mechanical systems (Ch 6.5.8) | 1070 | 1327 | 257 |
| | Total | 89084 | 123008 | 33924 |

# Summary

- The alternative design with C-band accelerating structure and energy up to 20 GeV have been proposed and designed.
- The preliminary error study have been finished, more optimization is ongoing.
- The dynamic simulation results can meet the requirements.
- The cost without source/Damping ring/ transport lines(LTD,DTL,LTB) will increase 0.34 billion with the beam energy increase from 10 GeV to 20GeV.