Overall Design of the CEPC Injector Linac

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On behalf of CEPC team

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Outline

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

- CEPC (Circular Electron-Positron Collider) was proposed by Chinese Scientists in Sep. 2012
- CEPC consists of Linac, Booster and Collider
  - The energy of the Collider is 120 GeV.
  - The injector linac provides 10 GeV electron and positron beam to the Booster.

- The booster and collider circumference is about 100 km.
- The total length of the linac is about 1.2 km.
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### CEPC linac design

- The requirements of the booster to the linac

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>e^− /e^+ beam energy</td>
<td>$E_{e^-}/E_{e^+}$</td>
<td>GeV</td>
<td>10</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>$f_{rep}$</td>
<td>Hz</td>
<td>100</td>
</tr>
<tr>
<td>Bunch numbers per pulse</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>e^− /e^+ bunch population</td>
<td>$N_{e^-}/N_{e^+}$</td>
<td></td>
<td>$&gt;9.4 \times 10^9$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>nC</td>
<td>$&gt;1.5$</td>
</tr>
<tr>
<td>Energy spread (e^− /e^+ )</td>
<td>$\sigma_E$</td>
<td></td>
<td>$&lt;2 \times 10^{-3}$</td>
</tr>
<tr>
<td>Emittance (e^− /e^+ )</td>
<td>$\varepsilon_r$</td>
<td>nm</td>
<td>$&lt;120$</td>
</tr>
</tbody>
</table>
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**

  ![Diagram of CEPC linac design](image)
CEPC linac design
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

C. Meng
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 $\rightarrow$ 52 mm (accelerating structure aperture is 25 mm)
  - Magnetic field: (5.5 T $\rightarrow$ 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
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
**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)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DR V2.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy</td>
<td>GeV</td>
<td>1.1</td>
</tr>
<tr>
<td>Circumference</td>
<td>m</td>
<td>75.4</td>
</tr>
<tr>
<td>Storage time</td>
<td>ms</td>
<td>20</td>
</tr>
<tr>
<td>Bending radius</td>
<td>M</td>
<td>3.565</td>
</tr>
<tr>
<td>Dipole strength $B_0$</td>
<td>T</td>
<td>1.03</td>
</tr>
<tr>
<td>$U_0$</td>
<td>keV</td>
<td>36.3</td>
</tr>
<tr>
<td>Damping time $x/y/z$</td>
<td>ms</td>
<td>15.2/15.2/7.6</td>
</tr>
<tr>
<td>$\delta_0$</td>
<td>%</td>
<td>0.05</td>
</tr>
<tr>
<td>$\varepsilon_0$</td>
<td>mm.mrad</td>
<td>376.7</td>
</tr>
<tr>
<td>$\sigma_z$, inj</td>
<td>mm</td>
<td>5.0</td>
</tr>
<tr>
<td>Nature $\sigma_z$</td>
<td>mm</td>
<td>7.5</td>
</tr>
<tr>
<td>$\varepsilon_{inj}$</td>
<td>mm.mrad</td>
<td>2500</td>
</tr>
<tr>
<td>$\varepsilon_{ext x/y}$</td>
<td>mm.mrad</td>
<td>530/180</td>
</tr>
<tr>
<td>$\delta_{inj}/\delta_{ext}$</td>
<td>%</td>
<td>0.2/0.05</td>
</tr>
<tr>
<td>Energy acceptance by RF</td>
<td>%</td>
<td>1.0</td>
</tr>
<tr>
<td>$f_{RF}$</td>
<td>MHz</td>
<td>650</td>
</tr>
<tr>
<td>$V_{RF}$</td>
<td>MV</td>
<td>2.0</td>
</tr>
</tbody>
</table>

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*Figure showing the damping ring with various parameters and graphs.*

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**D, Wang**
• Positron linac
  ■ 10 Gev with 3 nC charge
  ■ Energy spread (rms): 0.16%
  ■ Emittance with DR (rms): 30(H)/10nm(V)
## Hardware quantity statistics

<table>
<thead>
<tr>
<th>Type</th>
<th>No.</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>KLY</td>
<td>75</td>
<td>80 MW</td>
</tr>
<tr>
<td>S-band Acc. Tube</td>
<td>279</td>
<td>21 MV/m</td>
</tr>
<tr>
<td>S-band LAS Acc. Tube</td>
<td>6</td>
<td>21 MV/m@φ25mm</td>
</tr>
<tr>
<td>SHB</td>
<td>2</td>
<td>143/572 MHz</td>
</tr>
<tr>
<td>Buncher</td>
<td>1</td>
<td>2860 MHz</td>
</tr>
<tr>
<td>RF cavity</td>
<td>2</td>
<td>650 MHz</td>
</tr>
<tr>
<td>Solenoid1</td>
<td>22</td>
<td>0.1T</td>
</tr>
<tr>
<td>Solenoid 2</td>
<td>15</td>
<td>0.5 T@1m</td>
</tr>
<tr>
<td>Quadrupole Larger Aperture</td>
<td>48</td>
<td>φ150 mm</td>
</tr>
<tr>
<td>Quadrupole</td>
<td>296</td>
<td>φ26 mm-φ40 mm</td>
</tr>
<tr>
<td>Dipole</td>
<td>80</td>
<td></td>
</tr>
</tbody>
</table>
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CEPC linac key technologies development

- S-band accelerating structure

- Flux concentrator
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.
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

![Graphs showing S-band travelling wave accelerating structure design](image)

S-band travelling wave accelerating structure design

- Beam diameters 2a (mm)
- Cavity diameters 2b (mm)
- Cell number
- Shunt impedance (MΩ/m)
- Relative group velocity
- Unloaded Q
- Gradient (MV/m)
- Power flow (MW)

75MV
### S-band accelerating structure design

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

CEPC linac key technologies development
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.

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

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

Test bench upgrade

Analyzing Magnet

Faraday Cup

Modulator and klystron
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
CEPC linac key technologies development

- 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.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak pulse current</td>
<td>≥15</td>
<td>kA</td>
</tr>
<tr>
<td>Pulse width (bottom width)</td>
<td>5 ± 0.5</td>
<td>μs</td>
</tr>
<tr>
<td>Pulse waveform</td>
<td>Half sine wave</td>
<td>-</td>
</tr>
<tr>
<td>Repetition frequency</td>
<td>50</td>
<td>Hz</td>
</tr>
<tr>
<td>Long term stability</td>
<td>±0.5%</td>
<td>-</td>
</tr>
<tr>
<td>Peak voltage of charging</td>
<td>15</td>
<td>kV</td>
</tr>
<tr>
<td>The type of discharge switch</td>
<td>IGCT</td>
<td>-</td>
</tr>
</tbody>
</table>
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!

ACKNOWLEDGEMENTS:
T. kamitani, K. Furukawa, S. Fukuda