Progress of the High Field Magnet R&D for CEPC-SPPC

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• Summary
**Main dipoles**

\[ E[GeV] = 0.3 \times B[T] \times \rho[m] \]

- **Field strength**: 12~24 (Upgrading) Tesla
- **Aperture diameter**: 40~50 mm
- **Field quality**: \(10^{-4}\) at the 2/3 aperture radius
- **Outer diameter**: 650-900 mm in a 1.5 m cryostat
- **Tunnel cross section**: 6 m wide and 5.4 m high

**SPPC**

100 km in circumference

- C.M. energy 70-150 (Upgrading) TeV
- Timeline
  - *Pre-study*: 2013-2020
  - *R&D*: 2020-2030
  - *Eng. Design*: 2030-2035
  - *Construction*: 2035-2042

**Conceptual design of the SPPC 12-T magnet with IBS and common coil configuration**
SPPC Magnet Design Scope

• Baseline design
  ➢ Tunnel circumference: 100 km
  ➢ Dipole magnet field: 12 T, iron-based HTS technology (IBS)
  ➢ Center of Mass energy: >70 TeV
  ➢ Injector chain: 2.1 TeV

• Upgrading phase
  ➢ Dipole magnet field: 20-24 T, IBS technology
  ➢ Center of Mass energy: >125 TeV
  ➢ Injector chain: 4.2 TeV (adding a high-energy booster ring in the main tunnel in the place of the electron ring and booster)

• Development of high-field superconducting magnet technology
  ➢ Starting to develop HTS magnet technology before applicable IBS wire is available
  ➢ ReBCO & Bi-2212 and LTS wires be used for model magnet studies and as options for SPPC: stress management, quench protection, field quality control and fabrication methods

Top priority: reducing cost!
Instead of increasing field

Make IBS the high-field “NbTi” Conductor in 10 years!
Domestic Collaboration for HTS R&D


- **Goal:**
  a) 1) To increase the $J_c$ of iron-based superconductor (IBS) by 10 times, reduce the cost to 20 Rmb/kAm @ 12T & 4.2K; and realize the industrialization of the conductor;
  b) 2) To reduce the cost of ReBCO and Bi-2212 conductors to 20 Rmb/kAm @ 12T & 4.2K;
  c) 3) Realization and Industrialization of IBS magnets and SRF cavities.

- **Working groups:**
  1) Fundamental science study;
  2) IBS conductor R&D;
  3) ReBCO conductor R&D;
  4) Bi-2212 conductor R&D;
  5) Performance evaluation;
  6) Magnet and SRF technology.

“实用化高温超导材料产学研合作组成立大会”2016年10月10日

“高温超导材料及磁体技术应用研究”院先导专项培育项目启动会
2017年10月28日 中科院高能物理研究所

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Q. XU, FCC Week 2018, April 9-13 2018
Progress on IBS wires


Y. Ma (IEECAS) et al.

Latest transport property of IBS tape (2017):

Short tape (~4 mm wide, 0.3 mm thick):

$I_c \sim 423 \text{ A} (J_c > 1450 \text{ A/mm}^2) @ 4.2 \text{ K, 12 T}$

100 meter long tape:

$J_c > 200 \text{ A/mm}^2 @ 4.2 \text{ K, 12 T}$

115 meter long 7-core tape

Key steps to the application

IEEE TAS 27 (2017) 7300705
The 12-T Fe-based Dipole Magnet

Design with expected $J_e$ of IBS in 2025

<table>
<thead>
<tr>
<th>Strand</th>
<th>diam.</th>
<th>cu/sc</th>
<th>RRR</th>
<th>Tref</th>
<th>Bref</th>
<th>$J_c$ @ BrTr</th>
<th>d$J_c$/dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>IBS</td>
<td>0.802</td>
<td>1</td>
<td>200</td>
<td>4.2</td>
<td>10</td>
<td>4000</td>
<td>111</td>
</tr>
</tbody>
</table>

- The required length of the 0.8 mm IBS is 6.1 Km/m
- For 100-km SPPC, 3000 tons of IBS is needed
- Target cost of IBS: 20 RMB (~2.6 Eur) /kAm @12 T
The 12-T Fe-based Dipole Magnet

Field quality in the aperture <3\times10^{-4} within 2/3 bore
(ROXIE simulation results)

<table>
<thead>
<tr>
<th>Field quality</th>
<th>2D with $R_f=13.3\text{mm}$</th>
<th>3D with $R_f=8/13.3\text{ mm}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>b3</td>
<td>0.45</td>
<td>0.79/1.91</td>
</tr>
<tr>
<td>b5</td>
<td>1.01</td>
<td>-0.65/-2.24</td>
</tr>
<tr>
<td>b7</td>
<td>0.46</td>
<td>0.08/0.67</td>
</tr>
<tr>
<td>b9</td>
<td>-0.27</td>
<td>-0.13/-0.22</td>
</tr>
<tr>
<td>a2</td>
<td>3.53</td>
<td>-1.00/-2.31</td>
</tr>
<tr>
<td>a4</td>
<td>0.49</td>
<td>-0.46/0.69</td>
</tr>
<tr>
<td>a6</td>
<td>0.33</td>
<td>0.26/2.49</td>
</tr>
<tr>
<td>a8</td>
<td>0.58</td>
<td>-0.12/0.84</td>
</tr>
<tr>
<td>a10</td>
<td>2.23</td>
<td>0.06/2.18</td>
</tr>
</tbody>
</table>
R&D of 12T Twin-aperture Dipole Magnet

R&D Roadmap for the next 10~15 years

NbTi+Nb₃Sn, 2*φ10 aperture → Nb₃Sn+HTS, 2*φ20 aperture → All HTS, 2*φ40 aperture

Magnetic flux distribution

3d coil layout

3D magnetic field distribution

Components and assembly

Q. XU, FCC Week 2018, April 9 - 13 2018
R&D of 12T Twin-aperture Dipole Magnet

Fabrication of the 1st model magnet (NbTi+Nb₃Sn)

Cabling ➔ Coil winding ➔ HT ➔ VPI ➔ Magnet assembly ➔ Test
R&D of 12T Twin-aperture Dipole Magnet

1\textsuperscript{st} test of the 1\textsuperscript{st} model magnet (NbTi+Nb\textsubscript{3}Sn)

Magnet under test @ Hefei

Magnet fabrication @ Beijing

Test system setup @ Hefei

10.2 T @ 4.2 K dipole field in two apertures (Performance limited by NbTi coils)

Q. XU, FCC WeeK 2018, April 9 - 13 2018
Next step: Replace NbTi coils with new Nb$_3$Sn coils to further increase the field, and insert the IBS coil to test its high field performance.
CERN & China Collaboration

Making 12 units CCT corrector magnets for HL-LHC before mid 2021

A 0.5m model magnet to be fabricated and tested by May or June 2018

Glyn Kirby, Ezie Todesco (CERN)

0.5m model magnet
China Version

0.5m model magnet
CERN Version

0.5m model magnet
China Version
Summary

• **SPPC design scope:** 12 T IBS magnets to reach 70TeV with 100 km circumference. Upgrading phase: 20~24 T IBS magnets to reach 125~150 TeV.

• **Strong domestic collaboration for the advanced HTS conductor R&D:** Make IBS the high-field “NbTi” conductor in 10 years!

• **R&D of high field magnet technology:** 1st model dipole (NbTi+Nb$_3$Sn) reached 10.2 T @ 4.2 K in two apertures; 2nd model dipole (Nb$_3$Sn+IBS) to be fabricated and tested in Mid 2018.

• **CERN & China Collaboration:** Making 12 units CCT corrector magnets for HL-LHC before mid 2021.

Thanks for your attention!