High Field Twin-aperture Dipole Magnet R&D for SPPC Pre-study

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Institute of High Energy Physics (IHEP)
Chinese Academy of Sciences (CAS)
2017.8.28
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• Conceptual Design of the SPPC Dipole Magnets
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  \(Design, Fabrication and test plan\)
• Domestic Collaboration Towards HTS SPPC
• International Collaboration
• Summary
CEPC is an 240-250 GeV Circular Electron Positron Collider, proposed to carry out high precision study on Higgs bosons, which can be upgraded to a 70-150 (Upgrading phase) TeV pp collider SPPC, to study the new physics beyond the Standard Model.

50/100 km in circumference

The 1st CEPC International Workshop 2017: http://cepcws17.ihep.ac.cn/
**SPPC Accelerator and Magnets**

**SPPC**
- **50 100 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

**Main dipoles**

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

- Field strength: 20 12~24 (Upgrading) Tesla
- Aperture diameter: 40~50 mm
- Field quality: \(10^{-4}\) at the 2/3 aperture radius
- Outer diameter: **900 mm** in a 1.5 m cryostat
- Tunnel cross section: 6 m wide and 5.4 m high

Conceptual design of the SPPC 12-T magnet with IBS and common coil configuration

6-m Tunnel for CEPC-SPPC

Q. Xu, MIT25, Amsterdam, Aug 27 - Sep 1 2017
SPPC Design Scope (201701 version)

• 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 -24T, 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 required HTS magnet technology before applicable iron-based wire is available
  ➢ ReBCO & Bi-2212 and LTS wires be used for model magnet studies and as an option for SPPC: stress management, quench protection, field quality control and fabrication methods

Top priority: reducing cost! Instead of increasing field
**J_e of IBS: 2016-2025**

**Modified version by Q. Xu**

- **REBCO B∥ Tape Plane**
  - SuperPower "Turbo" Double Layer Tape, measured at NHMFL 2009
- **REBCO B⊥ Tape Plane**
- **Tape Plane 45 μm substrate**
  - SuperPower tape, ~5 μm Cu, measured at NHMFL 2017
- **Expected IBS 2025**
  - Y. Ma (IEECAS)
- **2212**
  - 121×18 filament OST strand with NHMFL 50 bar Over-Pressure HT. J. Jiang et al. ASC’16
- **SuperPower “Turbo” Double Layer Tape, measured at NHMFL 2009**

**IBS 2016**
- **Nb-Ti**
  - 4.22 K High Field MRI strand (Luvata)
- **4.2 K LHC insertion quadrupole strand** (Boutboul et al. 2006)

**High-J_c Nb3Sn**
- **Compiled from ASC’02 and ICMC’03 papers (J. Parrell OI-ST)**

**Iron-Based Superconductor**
- Much lower cost and better mechanical properties expected

- **Q. Xu, MT25, Amsterdam, Aug 27 - Sep 1 2017**
- **Y. Ma (IEECAS)**

**January 2017**

**Whole Wire Critical Current Density (A/mm², 4.2 K)**

**Applied Magnetic Field (T)**

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**Q. Xu, MT25, Amsterdam, Aug 27 - Sep 1 2017**

**Peter J. Lee**

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World’s first 100 m Fe-based superconductor by IEE, CAS, China (Aug. 2016)

115 m long 7-filament wire

Minimum $J_c > 12000 \text{A/cm}^2$ @10T, 4.2K

At 4.2K, 10T, transport $J_c$ distribution along the length of the first 115 m long 7-filament Sr122 tape
The 12-T Fe-based Dipole Magnet

- The required length of the 0.8 mm IBS is 6.1 Km/m
- For 100-km SPPC accelerator, 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

ROXIE simulation results

<table>
<thead>
<tr>
<th>Term</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Main Field (T)</td>
<td>12.020868</td>
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<tr>
<td>Magnet Strength (T/(m^{n-1}))</td>
<td>12.0209</td>
</tr>
</tbody>
</table>

Normal Relative Multipoles \((1,D,-4):\)

- \(b_1: 10000.00000\) b_2: 0.00000 b_3: -0.83157
- \(b_4: 0.00000\) b_5: 0.92916 b_6: -0.00000
- \(b_7: 0.00983\) b_8: -0.00000 b_9: 0.95010
- \(b_{10}: -0.00000\) b_{11}: 3.81956 b_{12}: 0.00000
- \(b_{13}: -0.26538\) b_{14}: 0.00000 b_{15}: -0.35810
- \(b_{16}: -0.23049\) b_{17}: 0.00000 b_{18}: 0.23220

<10^-4 field quality within 2/3 aperture

Stray field around the dipole with R= 500 mm

With 500 mm Yoke OD
Superconducting Rutherford Cable R&D

Collaboration between WST, NIN, Toly Electric and IHEP

Y. Zhu (WST), Y. Zhao (Toly), C. Li (NIN), Q. Xu et al.

Rutherford cabling machine at Toly

Nb$_3$Sn Rutherford cable

Bi-2212 Rutherford cable

Superconducting Rutherford cable

Insulated cable

Cable insulation

Dielectric strength test ~5kV

Q. Xu, MT25, Amsterdam, Aug 27 - Sep 1 2017
## Nb₃Sn cable fabrication with WST strand

Y. Zhu (WST), Y. Zhao (Toly) et al.

<table>
<thead>
<tr>
<th>股数</th>
<th>绞缆角</th>
<th>节距/mm</th>
<th>尺寸/mm</th>
<th>填充系数</th>
<th>1c损降/%</th>
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<tr>
<td>18</td>
<td>17.13°</td>
<td>50</td>
<td>8.22*1.48</td>
<td>81.3%</td>
<td>3.64%</td>
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<td>7.87*1.48</td>
<td>85%</td>
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<td>7.95*1.52</td>
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<td>7.83*1.48</td>
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<td>7.87*1.44</td>
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<td>7.87*1.52</td>
<td>82.7%</td>
<td>1.41%</td>
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<td>36</td>
<td>18.46°</td>
<td>93</td>
<td>15.38*1.50</td>
<td>86.5%</td>
<td>4.63~6.70</td>
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<tr>
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<td></td>
<td>15.29*1.49</td>
<td>87.5%</td>
<td>8.96~10.92</td>
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<td></td>
<td></td>
<td>15.23*1.45</td>
<td>90.3%</td>
<td>5.76~9.36</td>
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<td>15.19*1.44</td>
<td>91.2%</td>
<td>8.71~13.17</td>
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<td></td>
<td>15.16*1.39</td>
<td>94.7%</td>
<td>9.43~11.31</td>
</tr>
</tbody>
</table>

### 微观结构

![Microstructure Image](image1)

![Microstructure Image](image2)

### Q. XU, MT25, Amsterdam, Aug 27 - Sep 1 2017
Superconducting Rutherford Cable R&D

Bi-2212 cable fabrication with NIN strand

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Cable 1</th>
<th>Cable 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter Φ (mm)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Wire processing</td>
<td>300℃退火</td>
<td>200℃退火</td>
</tr>
<tr>
<td>Number of Strands</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Cable size (mm²)</td>
<td>1.90×4.77</td>
<td>1.78×4.21</td>
</tr>
<tr>
<td>Filling factor</td>
<td>70.5%</td>
<td>85.2%</td>
</tr>
<tr>
<td>Length</td>
<td>2.5米</td>
<td>2米</td>
</tr>
</tbody>
</table>

◆ 成功绞制两根8线电缆
◆ 绞制过程中电缆变形均匀
◆ 每根线材外观完整无破损
◆ 线材芯丝无明显破损

Cabling

Bi-2212 Cable

Before cabling

After cabling

Q. Hao, C. Li (NIN), Y. Zhao (Toly) et al.
Superconducting Rutherford Cable R&D

Y. Zhu (WST), Y. Zhao (Toly), C. Li (NIN), Q. Xu et al.

~700 m NbTi and Nb₃Sn cables have been fabricated by Toly Electric (Wuxi, China), Jc degradation <3%; R&D of HTS cable is ongoing.

24股NbTi缆193m  38股NbTi缆142m  20股Nb₃Sn缆138m  18股NbTi缆300m
R&D of 12T twin-aperture dipole magnet

Operation load line at 12 T: ~80% at 4.2K

NbTi+Nb$_3$Sn, 2*φ10 aperture → All Nb$_3$Sn, 2*φ20 aperture → Nb$_3$Sn+HTS, 2*φ30 aperture

The 1$^{st}$ high field accelerator magnet in China!

C. Wang, K. Zhang, Y. Wang, D. Cheng, E. Kong (USTC), Q. Xu et al.
R&D of 12T twin-aperture dipole magnet

Coil winding ➔ Heat reaction ➔ VPI ➔ Magnet assembly ➔ Test

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R&D of 12T twin-aperture dipole magnet

Coil winding ➔ Heat reaction ➔ VPI ➔ Magnet assembly ➔ Test
R&D of 12T twin-aperture dipole magnet

To be assembled and tested next month!

ReBCO and IBS insert coils to be fabricated and tested in 6 months.
Domestic Collaboration

“Applied High Temperature Superconductor Collaboration (AHTSC, 实用化高温超导材料产学研合作组)” was formed in Oct. 2016.

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

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

- **Collaboration meetings:** every 3 months, to report the progress and discuss plan for next months.
For now

- IHEP, IMP, WST and ASIPP will work together on the CCT magnet and HTSCL development for HL-LHC.
- Funding application is ongoing from MOST, NSFC and CAS.

In Future: Leading more activities for the HL-LHC collaboration with expected funding.

Benefit from the HL-LHC collaboration

- Speed up R&D process of the advanced superconducting magnet technology in China.
IHEP & CERN Collaboration

March 2017, Launch of CERN-China IHEP collaboration for HiLumi LHC

Glyn Kirby, Ezio Todesco (CERN)
Summary

• **SPPC latest baseline**: 12 T all-HTS (iron-base superconductor, IBS) magnets with 100 km circumference and > 70TeV center-of-mass energy. **Cost reduction is the top priority**!

• **SPPC Upgrading phase**: 20~24 T all-HTS (IBS) magnets with the same tunnel and 125~150 TeV center-of-mass energy.

• Starting to develop HTS magnet technology before applicable iron-based wire is available: ReBCO & Bi-2212 and LTS wires be used for model magnet studies and as an option for SPPC.

• 12 T NbTi+Nb$_3$Sn and Nb$_3$Sn+HTS model magnets under development for SPPC pre-study.

• **Domestic and international collaborations are being formed to pursue the advanced HTS superconductor and magnet R&D.**

Q. XU, MT25, Amsterdam, Aug 27 - Sep 1 2017
Welcome to the CEPC
International Workshop 2017
Nov. 6-8 2017, IHEP, Beijing, China

http://cepcws17.ihep.ac.cn/

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