# SPPC Status and HFM R&D Progress

Jingyu Tang, Qingjin Xu
for the SPPC study group

International Workshop on CEPC, Nov. 12-14, 2018, IHEP

# Outline

- SPPC chapter in the CDR
- Ongoing efforts in accelerator physics
- High-field magnet R&D progress
- Funding for the study
- Summary

# SPPC Chapter in the CEPC CDR

- The SPPC design is included in the CDR as a single chapter of Vol.1 (Accelerator), and the HFM R&D as a section in the CEPC R&D efforts chapter.

# SPPC main parameters (since 2017.5)

| Parameter | Unit | Value | | |
|---|---|---|---|---|
| | | PreCDR | CDR | Ultimate |
| Circumference | km | 54.4 | 100 | 100 |
| C.M. energy | TeV | 70.6 | 75 | 125-150 |
| Dipole field | T | 20 | 12 | 20-24 |
| Injection energy | TeV | 2.1 | 2.1 | 4.2 |
| Number of IPs | | 2 | 2 | 2 |
| Nominal luminosity per IP | $cm^{-2}s^{-1}$ | 1.2e35 | 1.0e35 | - |
| Beta function at collision | m | 0.75 | 0.75 | - |
| Circulating beam current | A | 1.0 | 0.7 | - |
| Bunch separation | ns | 25 | 25 | - |
| Bunch population | | 2.0e11 | 1.5e11 | - |
| SR power per beam | MW | 2.1 | 1.1 | - |
| SR heat load per aperture @arc | W/m | 45 | 13 | - |

# Ongoing SPPC Study

- As SPPC is a long-term project and due to very limited resources, no need to carry out engineering-related studies and only those with typical challenges in design and long-term R&D are picked up for study.
  - Describing what a future proton-proton collider looks like, physics performance
  - Following the CEPC project, try to avoid what will hinder the future upgrading to SPPC, e.g. tunnel circumference and layout
  - Studying key accelerator physics issues of that scale accelerators, which is also a contribution to the accelerator community, e.g. collimation, beam-beam effects
  - Identifying key technical challenges, for some of them needing long-term R&D efforts, we should start them as early as possible, e.g. high-field superconducting magnets, beam screen

# Accelerator Physics

- Since beginning 2018, man power on accelerator physics has reduced significantly. Due to short of funding, collaborative institutions almost stopped activities on SPPC, and now the main force relies on several IHEP PhD students. Monthly meeting paused.
- Still active:
  - Lattice design and dynamic aperture
  - Beam collimation
  - Beam-beam effects and luminosity
  - Long beam dynamics
  - Some selective topics on the injector chain

Details in the SPPC parallel session (Tue. Morning)

# R&D progress on high-field SC magnets

- High-field superconducting magnets are key technical challenges for future p-p colliders, but there is a hope to solve the technical and too-costly problem in the next 15 years.
- SPPC design scope
  - Phase I: 12 T, all-HTS (iron-based conductors)
  - Phase II: 20-24 T, all-HTS
- Thanks to good financial support, these R&D efforts have gone quite well, and are supported by a good collaboration

# 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

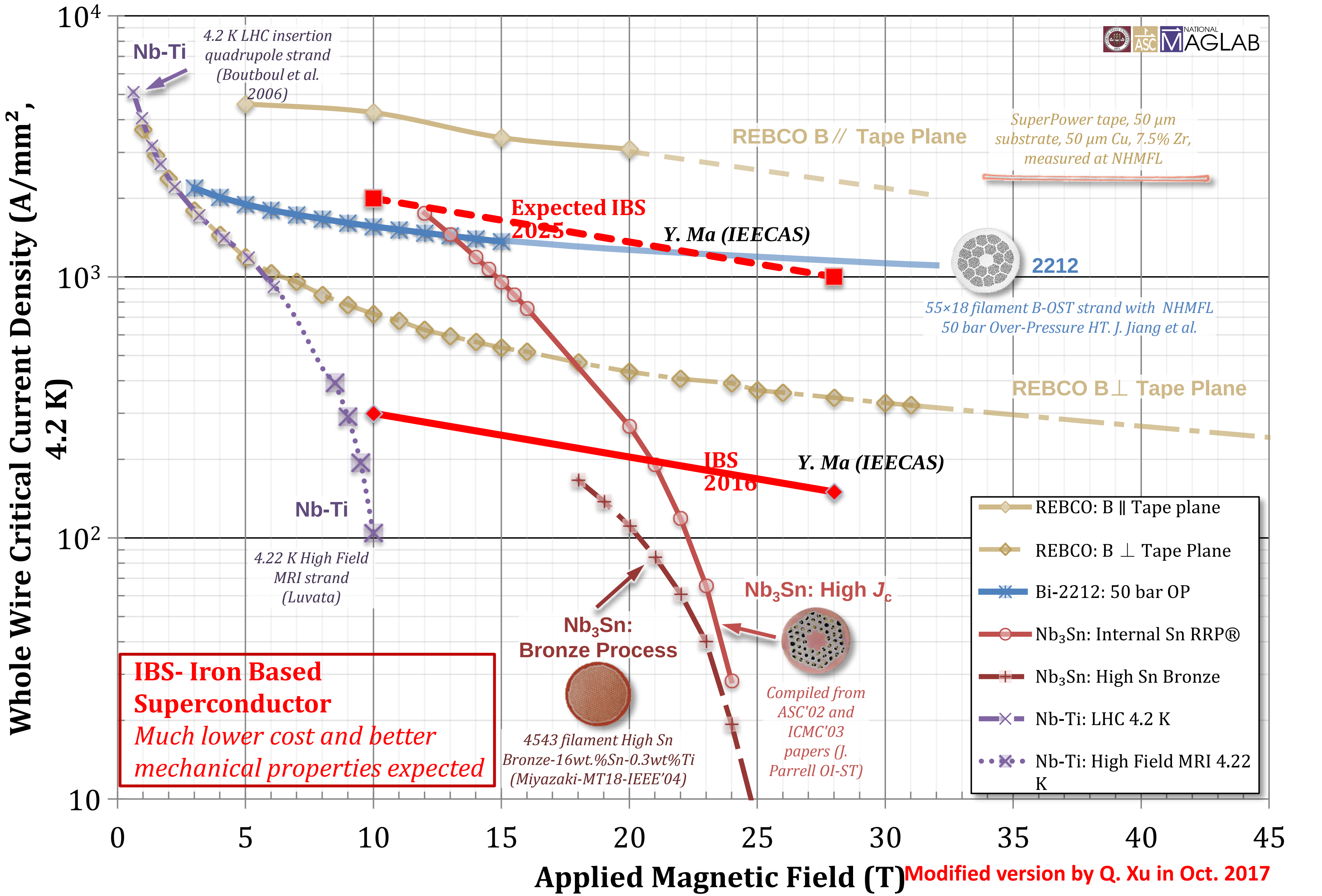
***Top priority: reducing cost!***
***Instead of increasing field***

- **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)

***Make IBS the High-$T_c$ and High-Field "NbTi" superconductor in 10 years!***

- **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

# $J_e$ of IBS: 2016-2025



# Domestic Collaboration for HTS R&D

***"Applied High Temperature Superconductor Collaboration (AHTSC)" formed in Oct. 2016.***

***Including 18 institutions and companies in China. Regular meeting every 3 months.***

- ***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;*

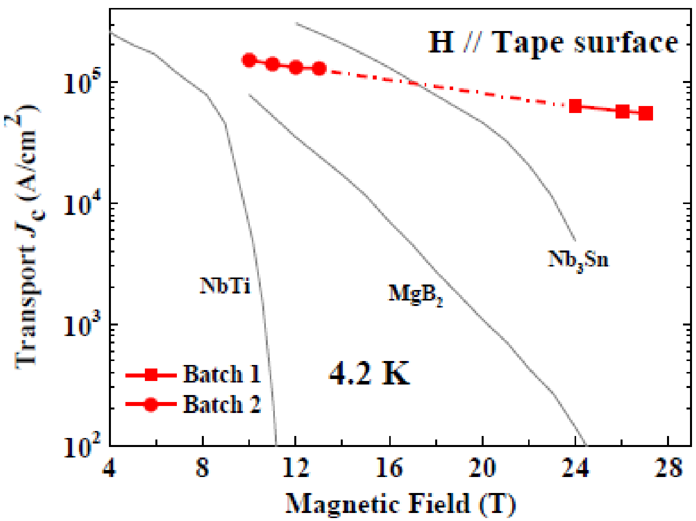
c) 3) *Realization and Industrialization of IBS magnets and SRF cavities.*

- ***Working groups :*** *1) **Fundamental sciences** 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.*

# Progress on IBS wires

*Supercond. Sci. Technol. 31 (2018) 015017*

*Y. Ma (IEECAS) et al.*




**Latest transport property of IBS tape (2017):**

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

**$I_c$~423 A ($J_c$>1450 A/mm$^2$) @ 4.2 K, 12 T**

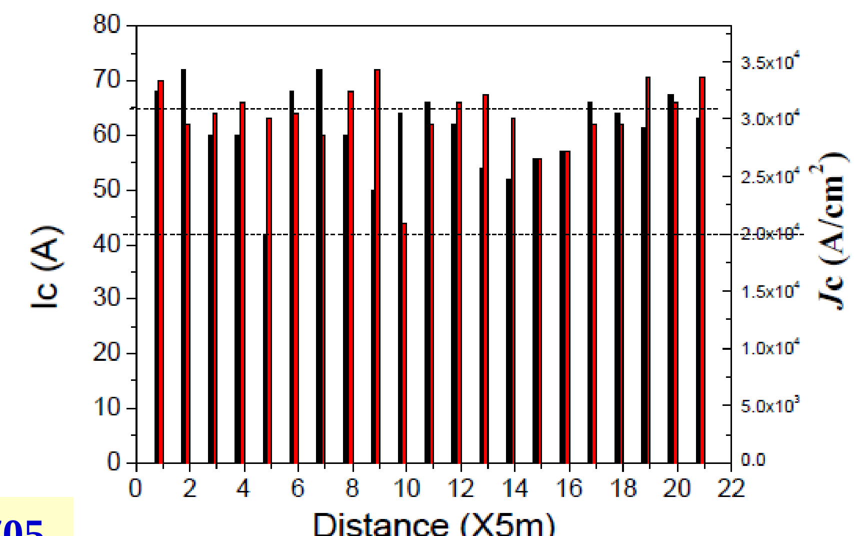
**100 meter long tape:**

**$J_c$>200 A/mm$^2$ @ 4.2 K, 12 T**

**Key steps to the application**

115 meter long 7-core tape

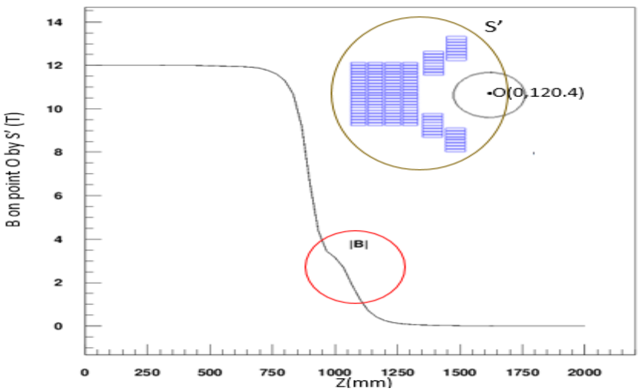
*IEEE TAS 27 (2017) 7300705*



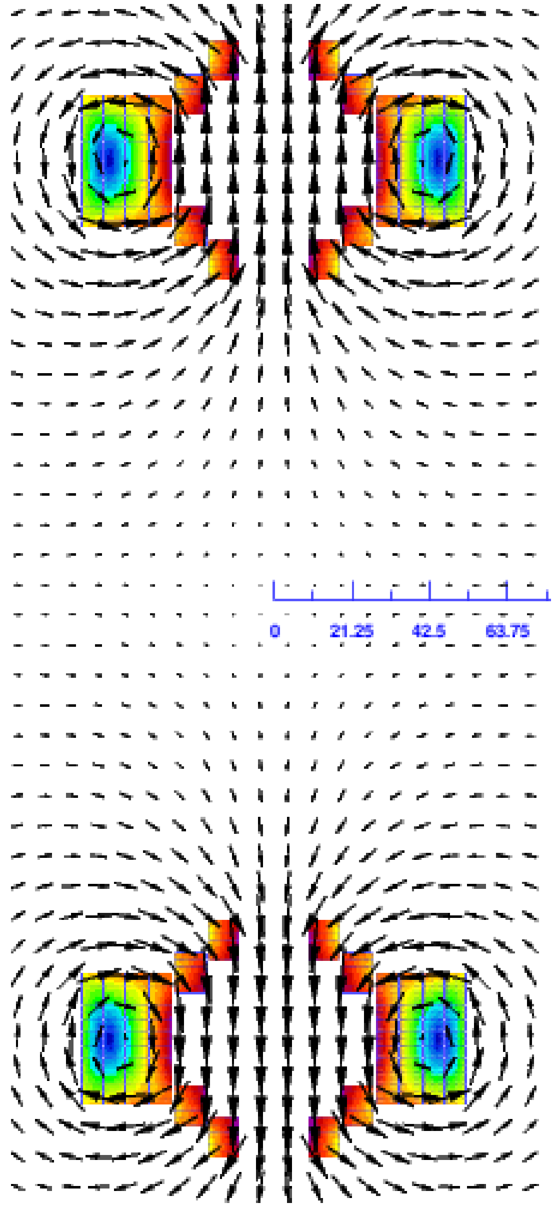
# The 12-T Fe-based Dipole Magnet

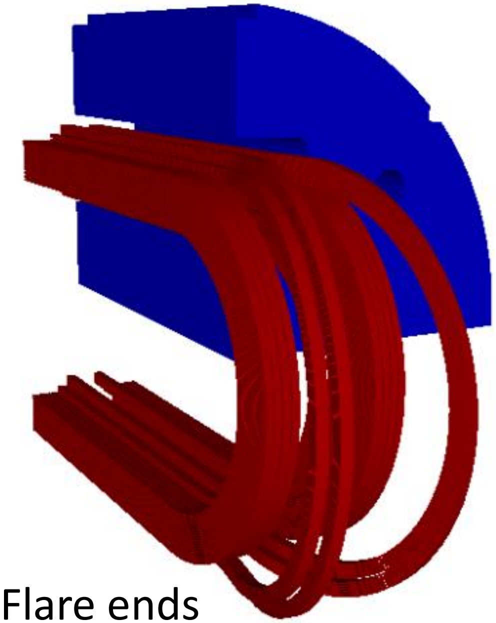
**Field quality in the aperture $<3*10^{-4}$ within 2/3 bore**

**(ROXIE simulation results)**

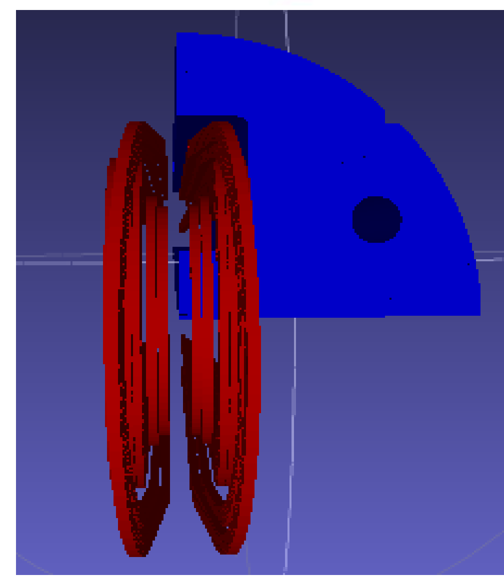



| Field quality | 2D with $R_f$= 13.3mm | 3D with $R_f$= 8/13.3 mm |
|---|---|---|
| b3 | 0.45 | 0.79/1.91 |
| b5 | 1.01 | -0.65/-2.24 |
| b7 | 0.46 | 0.08/0.67 |
| b9 | -0.27 | -0.13/-0.22 |
| a2 | 3.53 | -1.00/-2.31 |
| a4 | 0.49 | -0.46/0.69 |
| a6 | 0.33 | 0.26/2.49 |
| a8 | 0.58 | -0.12/0.84 |
| a10 | 2.23 | 0.06/2.18 |



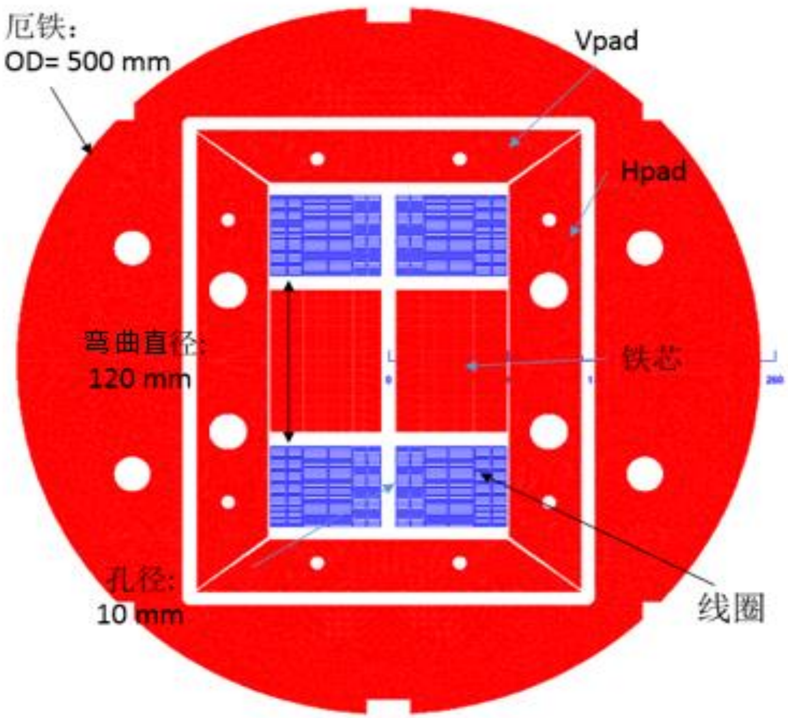
Flare ends



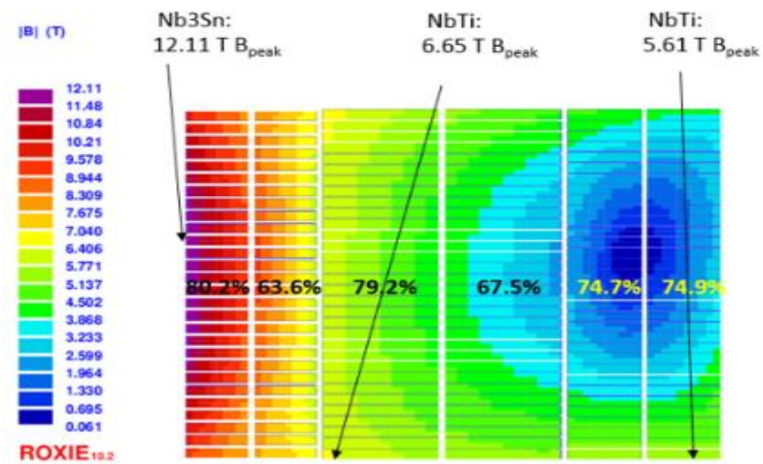
# R&D of High Field Dipole Magnets

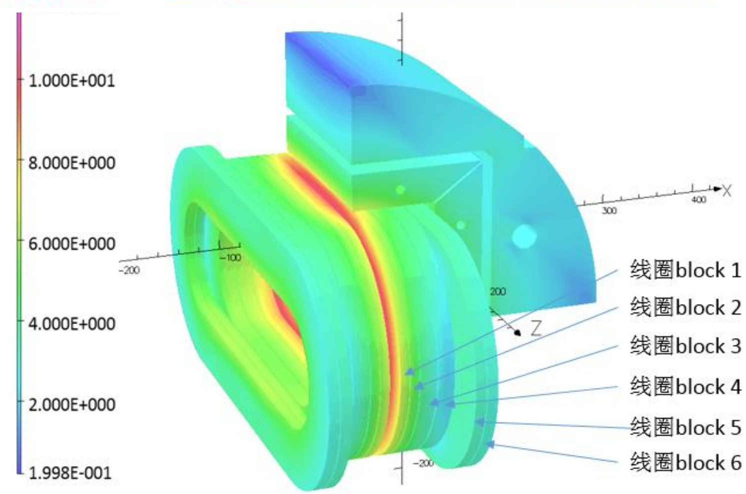
## *The 1st High Field Dipole LPF1: NbTi+$Nb_3Sn$*

### Cross section of LPF1




### Magnetic field distribution



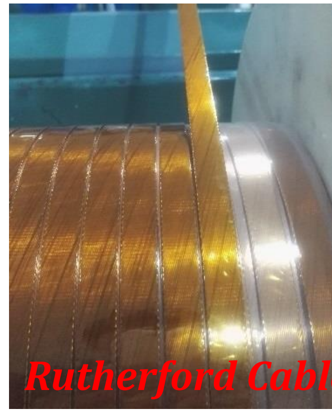

Main parameters of the strands

| Strand | diam. (mm) | cu/sc | RRR | Tref (K) | Bref (T) | Jc@ BrTr (A/mm2) | Ic@ BrTr (A) |
|---|---|---|---|---|---|---|---|
| $Nb_3Sn$ | 0.802 | 1 | 200 | 4.2 | 12 | 2700 | 682 |
| NbTi | 0.82 | 1 | 130 | 4.2 | 5 | 2613 | 690 |

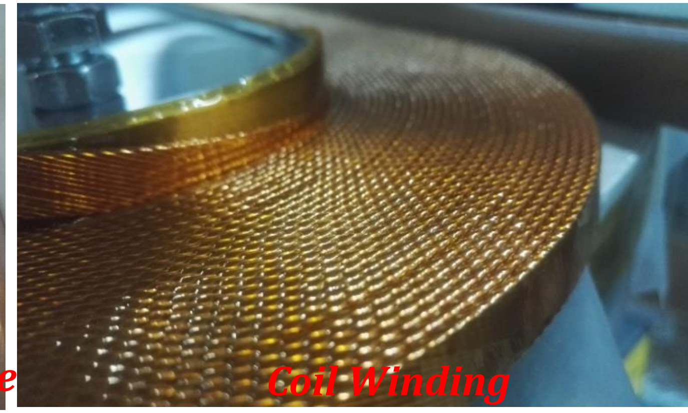
# R&D of High Field Dipole Magnets

## *Fabrication of the 1st model dipole magnet (NbTi+$Nb_3Sn$)*

Cabling Machine



Rutherford Cable

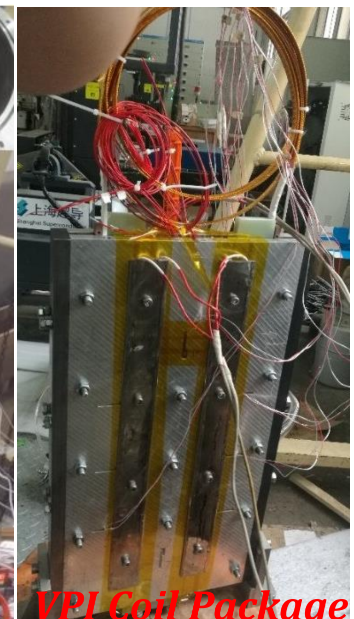


Coil Winding

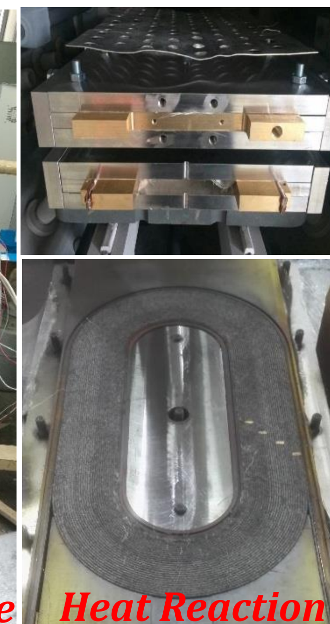
Magnet Assembly

Impregnated Coil

VPI



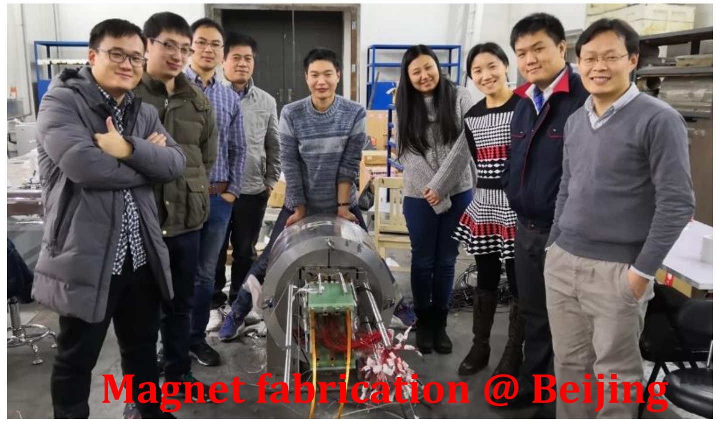
VPI Coil Package

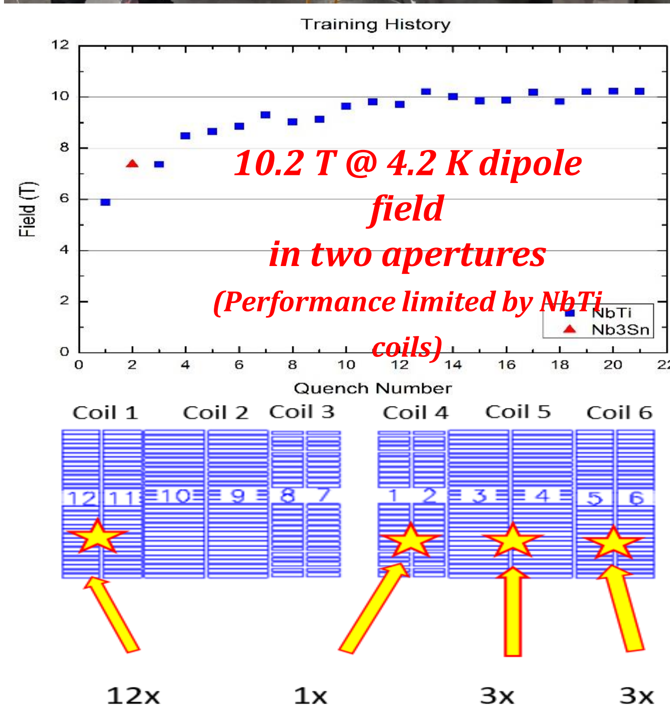


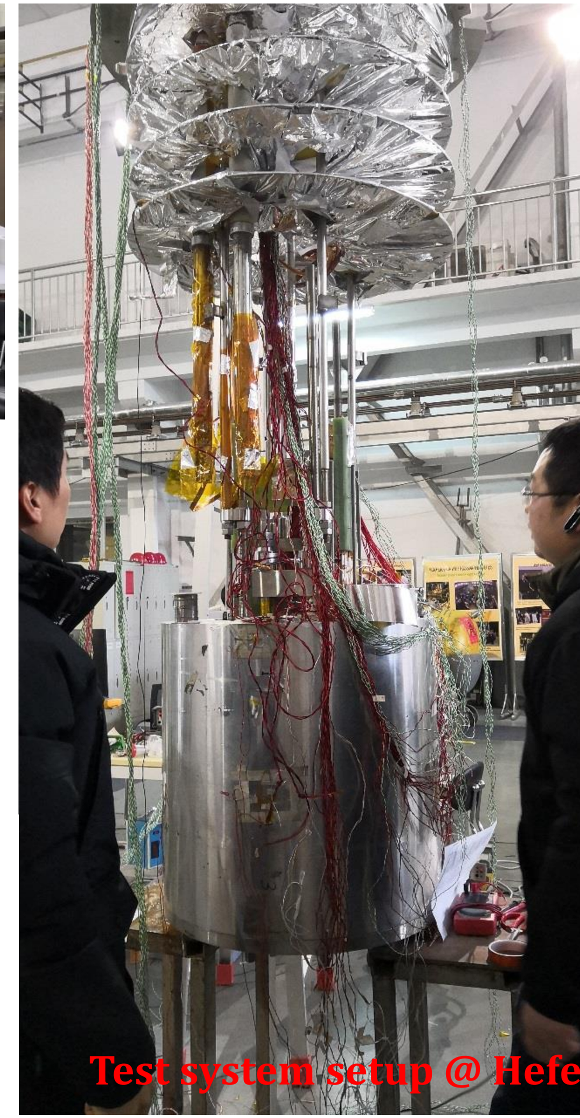
Heat Reaction

# R&D of High Field Dipole Magnets

***Test results of the 1st high-field dipole magnet in China* Feb. 2018**

# R&D of High Field Dipole Magnets

## *The 2nd High Field Dipole LPF2: $Nb_3Sn$ with IBS*

### Cross section of LPF2

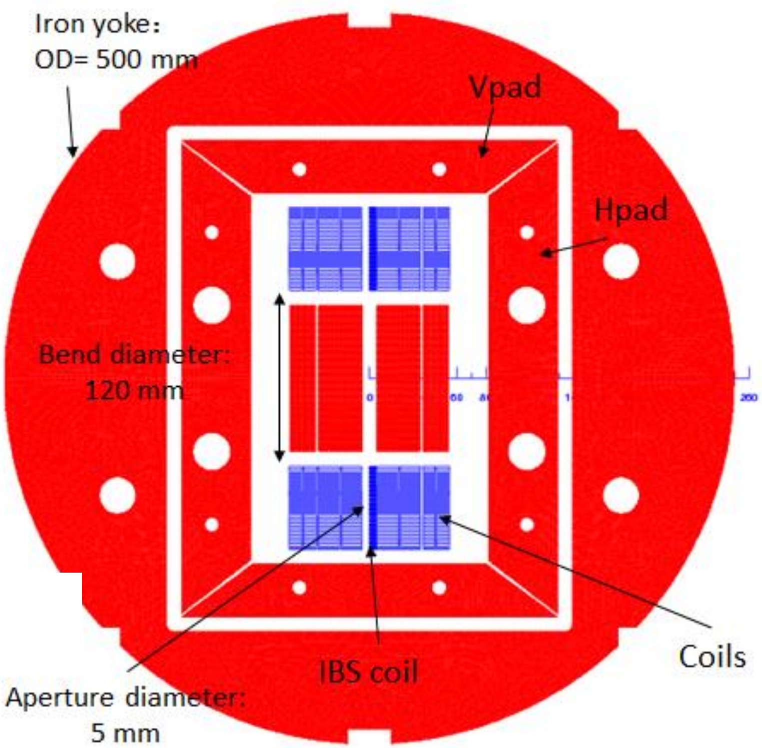
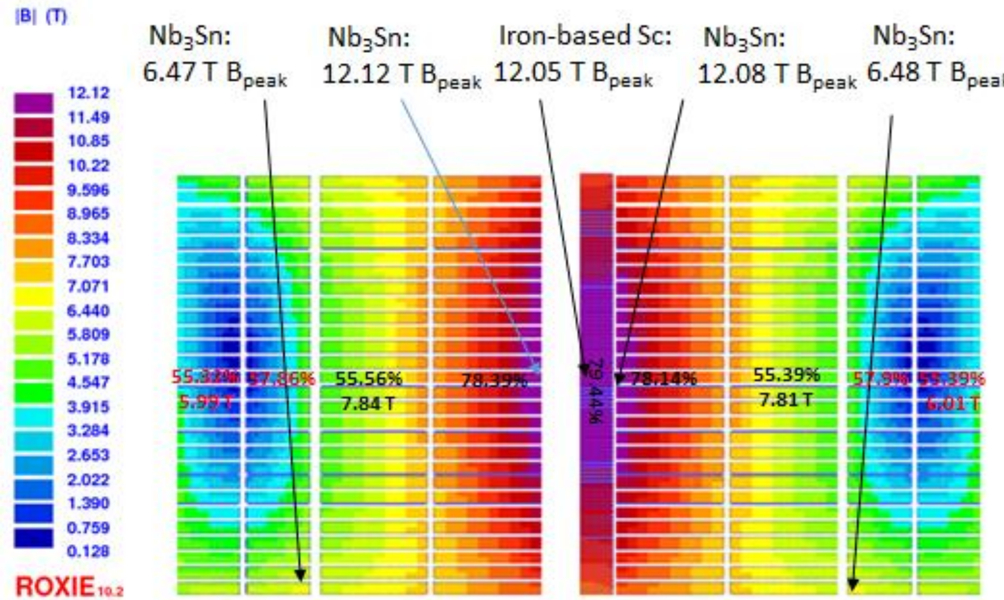



Fig. 1: The cross section of the 12-T common-coil dipole (with inserted iron-based coil)

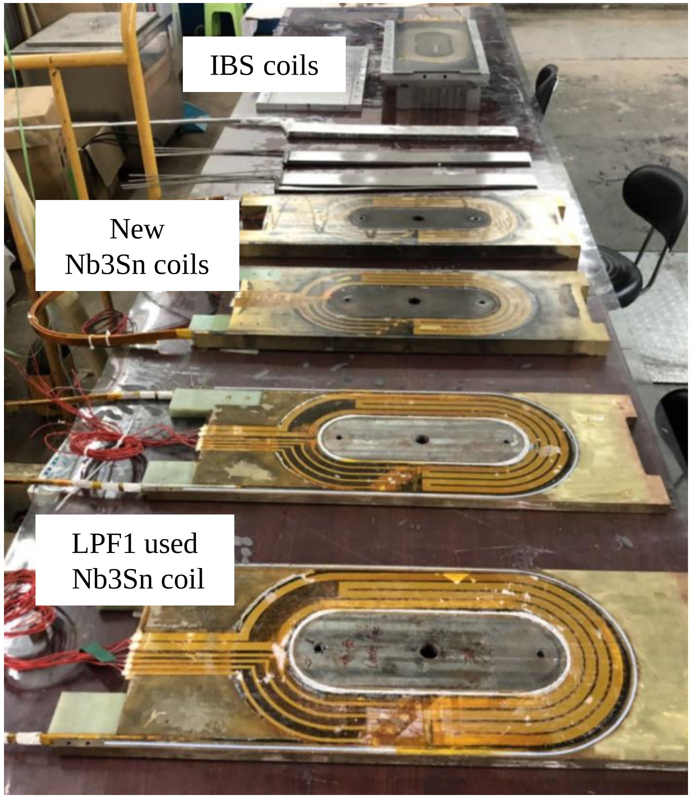
### Magnetic field distribution

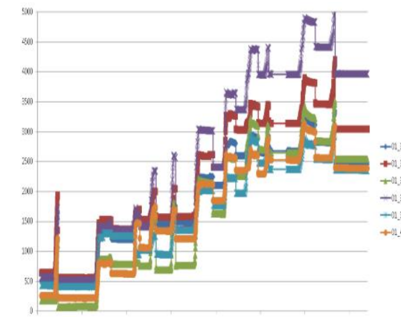



| Strand | diam. | cu/sc | RRR | Tref(K) | Bref(T) | Jc@ BrTr | Ic@ BrTr(A) |
|---|---|---|---|---|---|---|---|
| IHEP WCJC | 0.802 | 1 | 200 | 4.2 | 12 | 2700 | 682 |
| Iron-based | - | 6.7 | 100 | 4.2 | 12 | 216.5 | 38 |

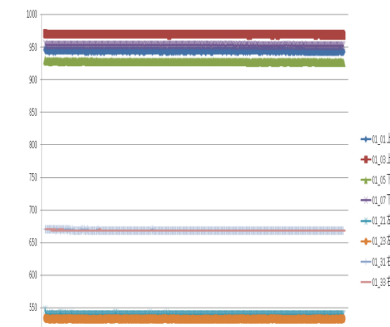
# R&D of High Field Dipole Magnets

## 2 new $Nb_3Sn$ coils + 1 IBS coils

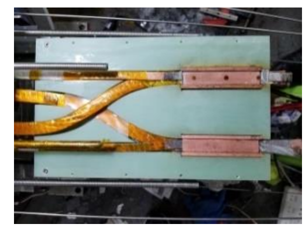


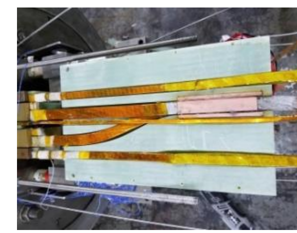



轴向预紧>40ton

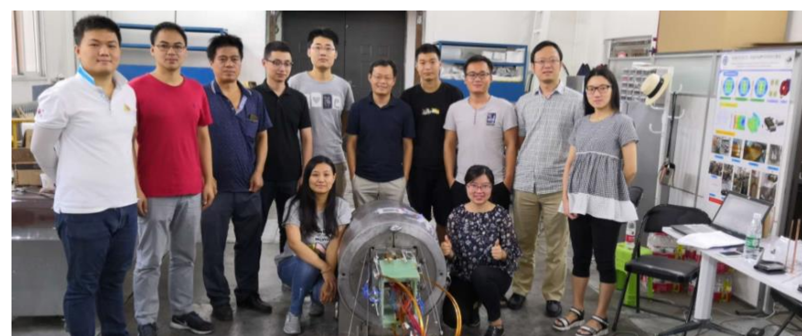


环向预紧78.8Mpa





磁体制作完成@中科院高能所

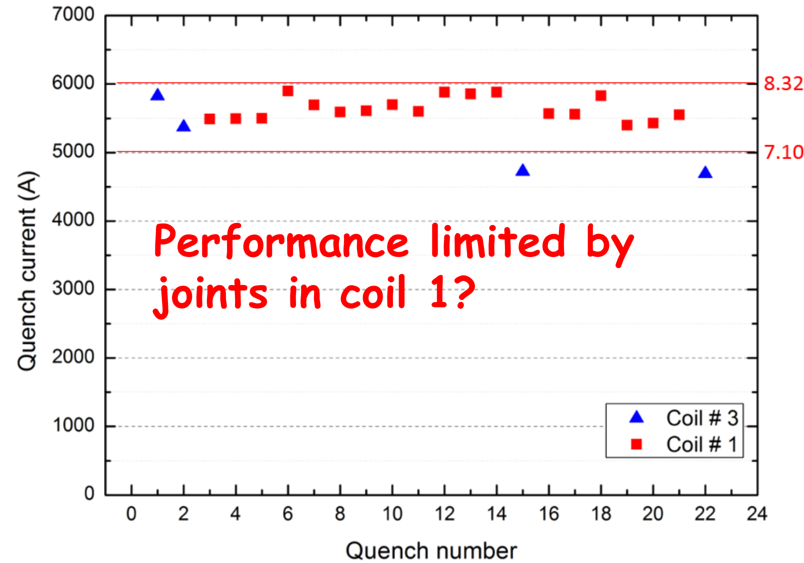


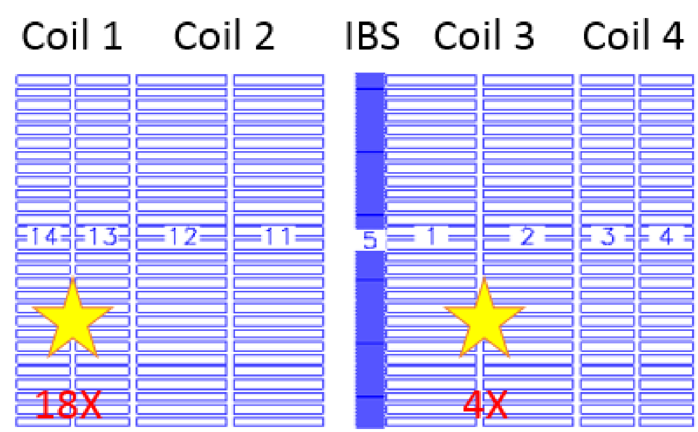
# R&D of High Field Dipole Magnets

**Test stopped due to problems of joints? (to be verified)**

磁体测试系统组装
@中科院等离子体所

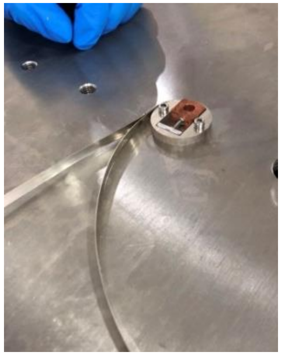
磁体低温性能测试
@中科院强场中心

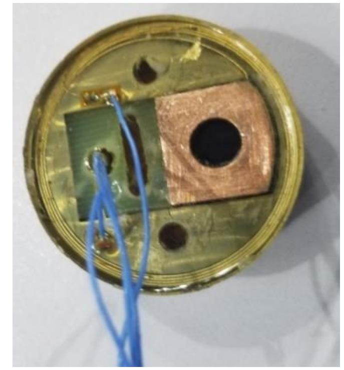


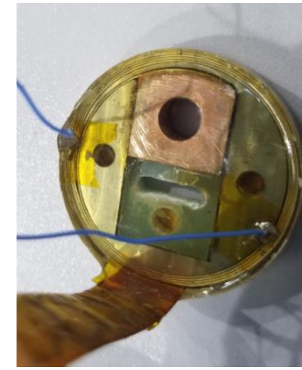



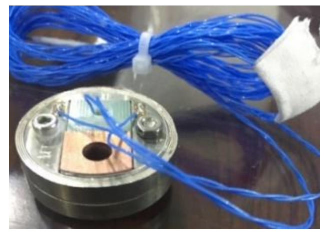
# R&D of High Field Dipole Magnets

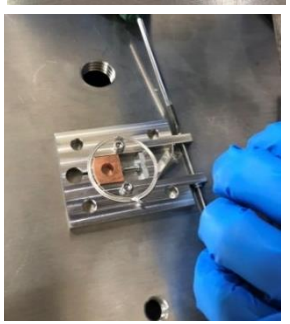
## Fabrication of IBS coils.







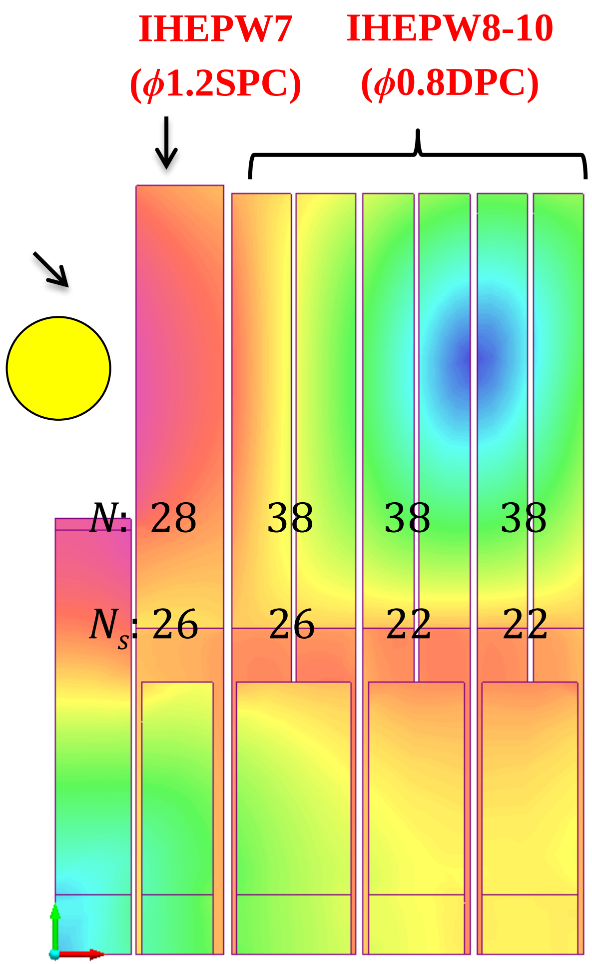




共4个SPC，6个DPC

# R&D of High Field Dipole Magnets

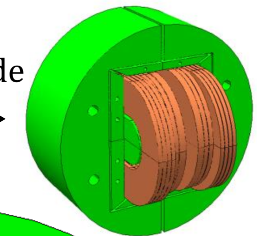
## Next step 1: 15T twin-aperture dipole @ 4.2K

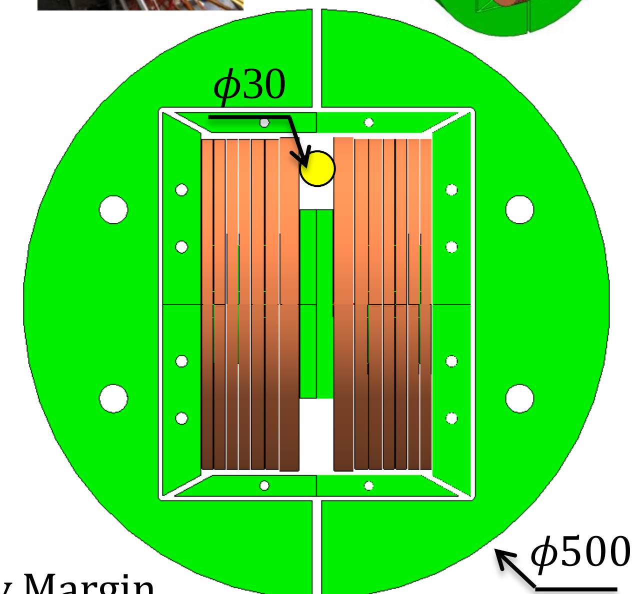



Coil configuration in the 1st quadrant

| Windings | $B_{max}$(T) | Loadline(%) |
|---|---|---|
| IHEPW7 | 15.281 | 89.427 |
| IHEPW8 A | 13.001 | 88.384 |
| IHEPW8 B | 12.844 | 87.535 |
| IHEPW9 A | 12.444 | 88.666 |
| IHEPW9 B | 12.612 | 89.574 |
| IHEPW10 A | 12.470 | 88.806 |
| IHEPW10 B | 12.028 | 86.417 |

Upgrade



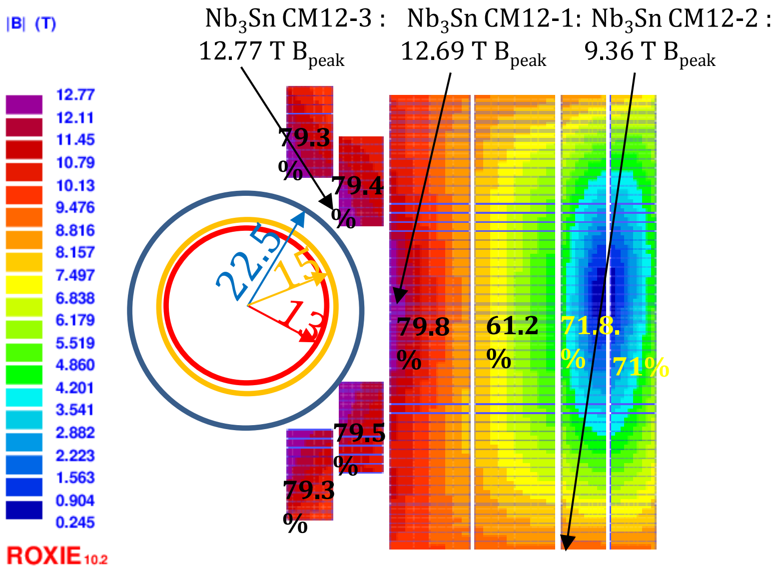



$I_{op}$= 8800A with 10% Safety Margin

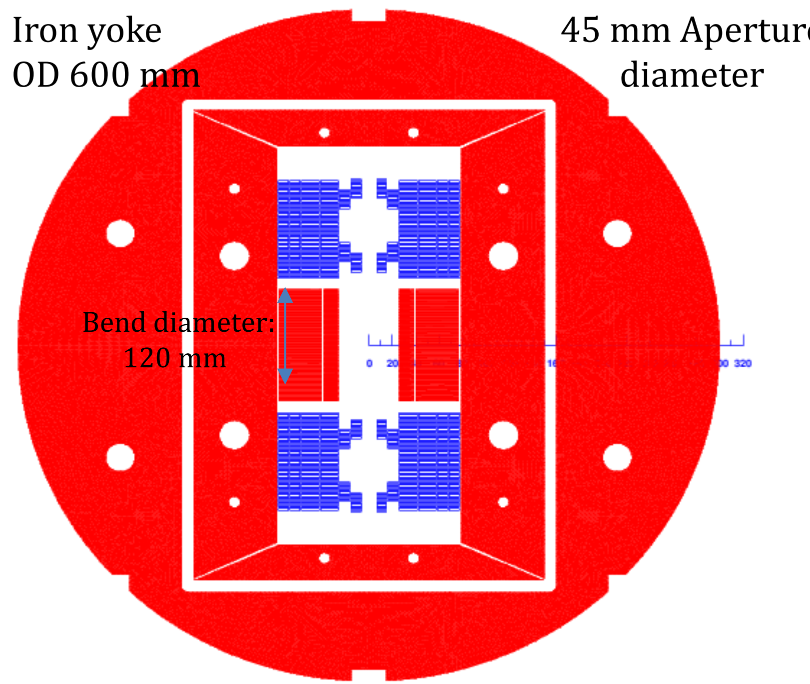
| Strand | diam. | cu/sc | RRR | Tref(K) | Bref(T) | Jc@ BrTr | dJc/dB | Ic@ BrTr(A) |
|---|---|---|---|---|---|---|---|---|
| IHEP WCJC | 0.802 | 1 | 200 | 4.2 | 14 | 1800 | 400 | 454.65 |
| | | | | 4.2 | 15 | 1400 | 350 | 353.61 |
| | 1.2 | 1 | 200 | 4.2 | 14 | 1800 | 400 | 1017 |
| | | | | 4.2 | 15 | 1400 | 350 | 791 |

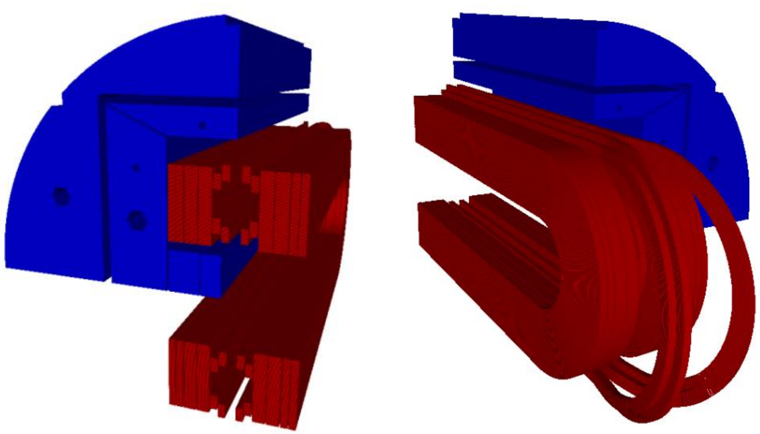
# R&D of High Field Dipole Magnets

## Next step 2: 12T twin-aperture dipole @ 4.2K with $10^{-4}$ field quality




**Field distribution at 12.47T**



**3D model (half length of the straight section: 500 mm)**

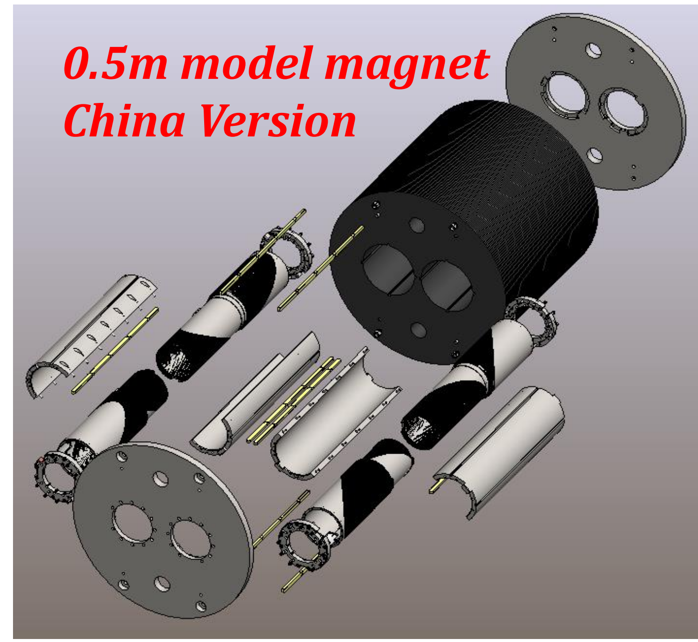
### Field quality analysis

| Rref | b3 | b5 | b7 | b9 | a2 | a4 | a6 | a8 |
|---|---|---|---|---|---|---|---|---|
| 15 mm | -0.06 | 0.06 | 2.31 | 2.84 | -0.004 | 0.43 | 1.88 | 2.53 |
| 13 mm | -0.05 | 0.03 | 0.98 | 0.9 | -0.004 | 0.28 | 0.92 | 0.93 |

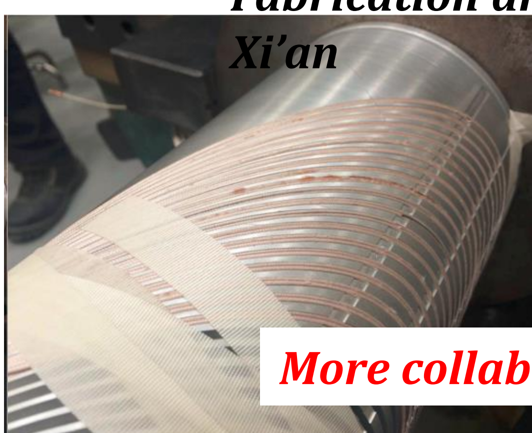
# CERN & China Collaboration

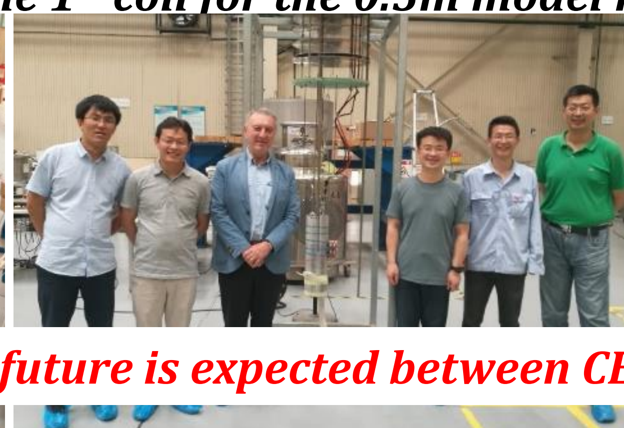
**China will provide 12 units CCT corrector magnets for HL-LHC before 2022**

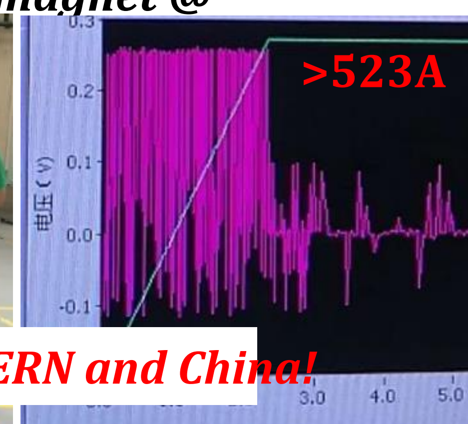
**A 0.5m model and 2.2m prototype to be fabricated and tested by June 2019**


**Fabrication and test of the 1st coil for the 0.5m model magnet @ Xi'an**








**More collaboration in future is expected between CERN and China!**

# Funding for the SPPC study

- On accelerator physics
  - NSFC general (since 2015): general design
  - A new NSFC youth: lattice and beam dynamics
- On HF Magnets
  - CAS Strategic Priority Research Program
  - CAS Key Research Program
  - CAS Hundred Talents Program
  - NSFC general

# International collaboration

- Modest international collaboration continues:
  - With LAL and CERN, beam collimation
  - With KEK and Fermilab, beam-beam effects
  - With CERN, high-field superconducting magnets

# Summary

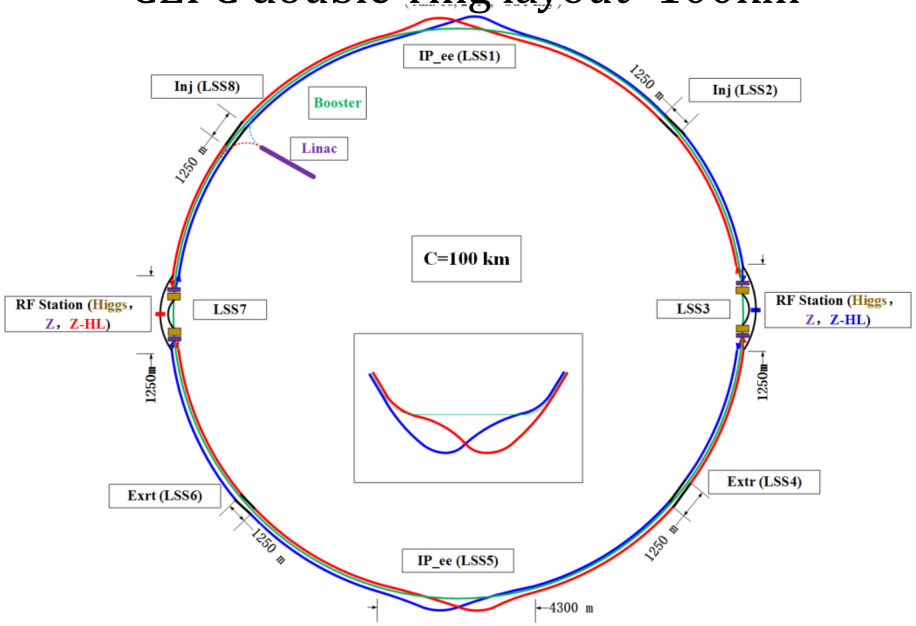
- One SPPC chapter and one HFM R&D section in the CEPC CDR report
- Low-level efforts on the SPPC accelerator physics continue
- R&D efforts on high-field magnets are well supported and result in good progress

# THANK YOU FOR ATTENTION!

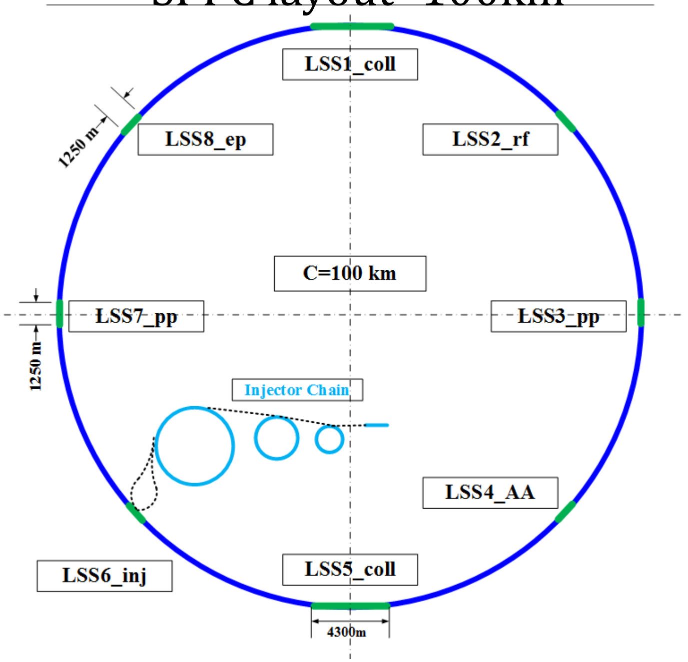
# Compatibility between CEPC and SPPC

- CEPC first to be built, with potential to add SPPC later
- Three machines in one tunnel: e booster, ee double-ring collider, pp double-ring collider
- Allow ep collision in the future, to solve the problem in circumference difference (CEPC outside of SPPC)
- Layout: 8 long straights and arcs, LHC-like DS lattice, lengths for LSSs
- Several rounds of interactions between CEPC and SPPC design teams, tbc

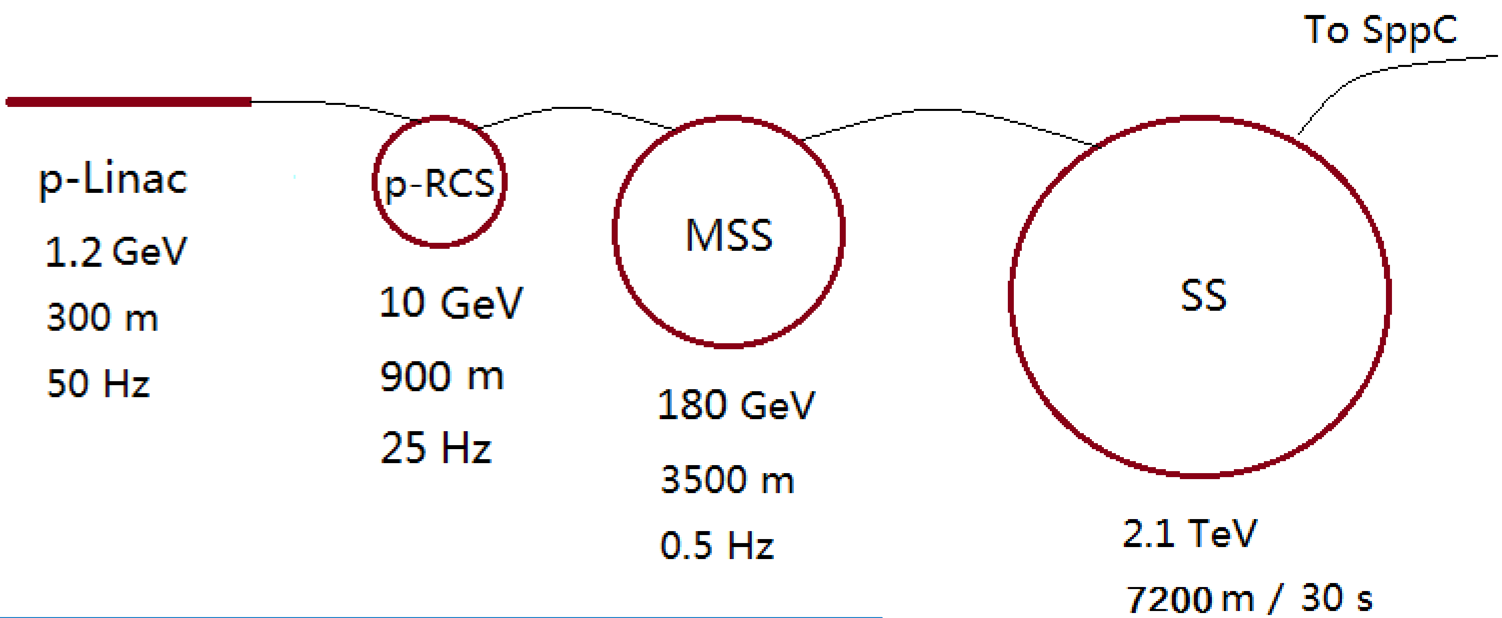
CEPC double-ring layout- 100km




SPPC layout- 100km



# Injector chain
## (for proton beam)




p-Linac: proton superconducting linac

p-RCS: proton rapid cycling synchrotron

MSS: Medium-Stage Synchrotron

SS: Super Synchrotron

Ion beams have dedicated linac (I-Linac) and RCS (I-RCS)

# Major parameters for the injector chain

| | Value | Unit | | Value | Unit |
|---|---|---|---|---|---|
| p-Linac | | | MSS | | |
| Energy | 1.2 | GeV | Energy | 180 | GeV |
| Average current | 1.4 | mA | Average current | 20 | uA |
| Length | ~300 | m | Circumference | 3500 | m |
| RF frequency | 325/650 | MHz | RF frequency | 40 | MHz |
| Repetition rate | 50 | Hz | Repetition rate | 0.5 | Hz |
| Beam power | 1.6 | MW | Beam power | 3.7 | MW |
| p-RCS | | | SS | | |
| Energy | 10 | GeV | Energy | 2.1 | TeV |
| Average current | 0.34 | mA | Accum. protons | 1.0E14 | |
| Circumference | 970 | m | Circumference | 7200 | m |
| RF frequency | 36-40 | MHz | RF frequency | 200 | MHz |
| Repetition rate | 25 | Hz | Repetition period | 30 | s |
| Beam power | 3.4 | MW | Protons per bunch | 1.5E11 | |
| | | | Dipole field | 8.3 | T |