Status of High Field Magnet R&D for CEPC-SPPC

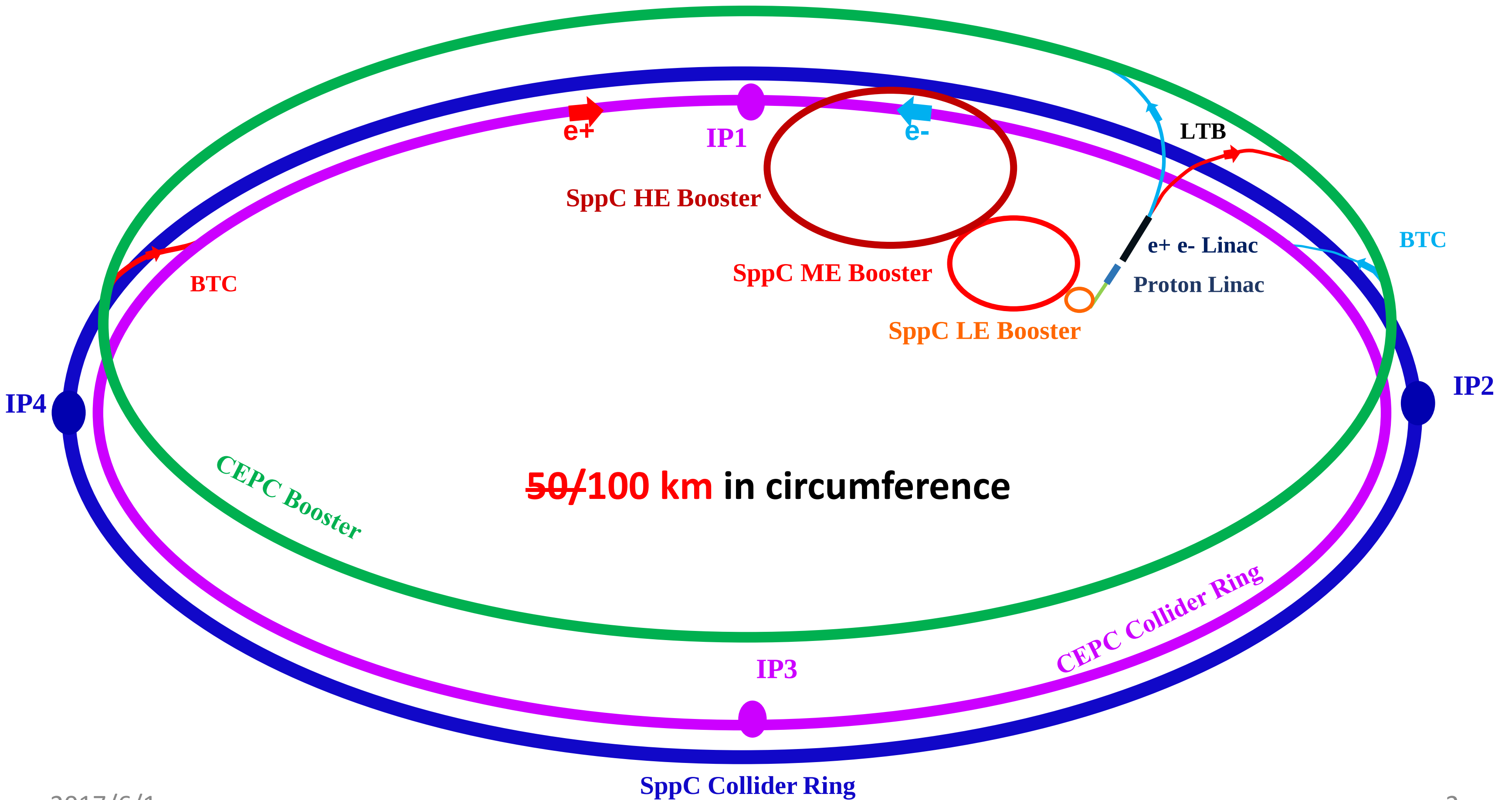
Qingjin XU

On behalf of the SPPC magnet working group

Institute of High Energy Physics (IHEP), Chinese Academy of Sciences (CAS)

CEPC-SPPC

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.



SPPC Accelerator and Magnets

SPPC

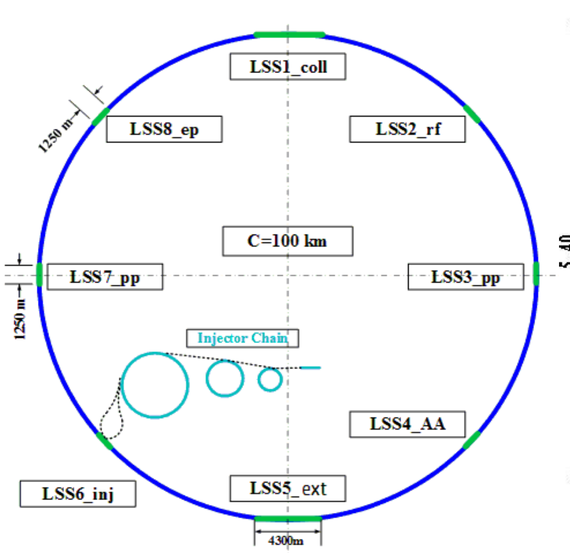
- ~~50~~ **100** km in circumference
- C.M. energy 70-150 (Upgrading) TeV
- Timeline

Pre-study:	*2013-2020*
R&D:	*2020-2030*
Eng. Design:	*2030-2035*
Construction:	***2035-2042***

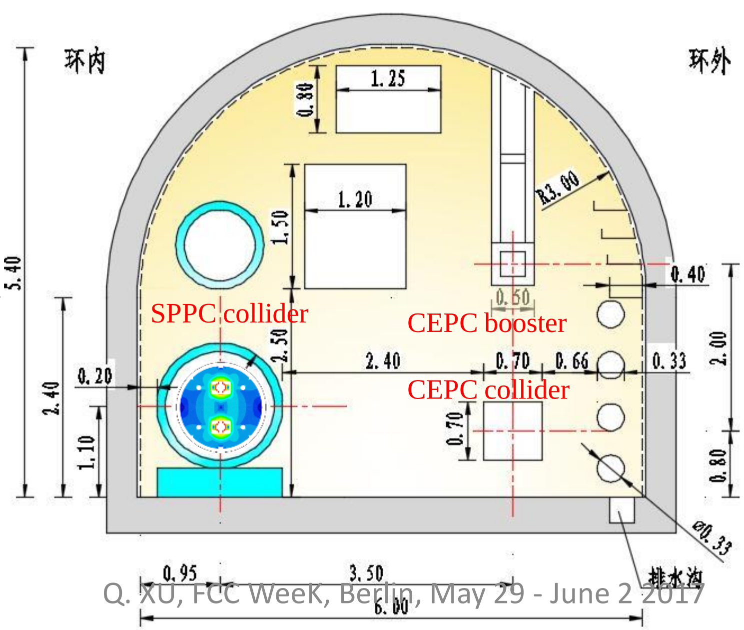
Main dipoles $E[GeV] = 0.3 \times B[T] \times \rho[m]$

- *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*

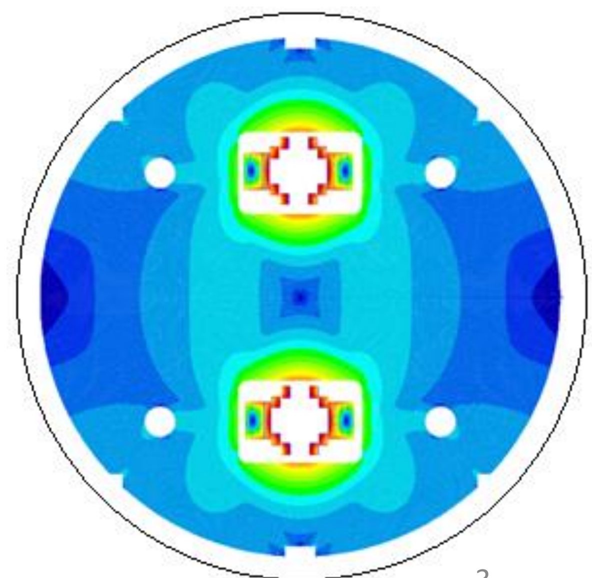
SPPC Layout



6-m Tunnel for CEPC-SPPC



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

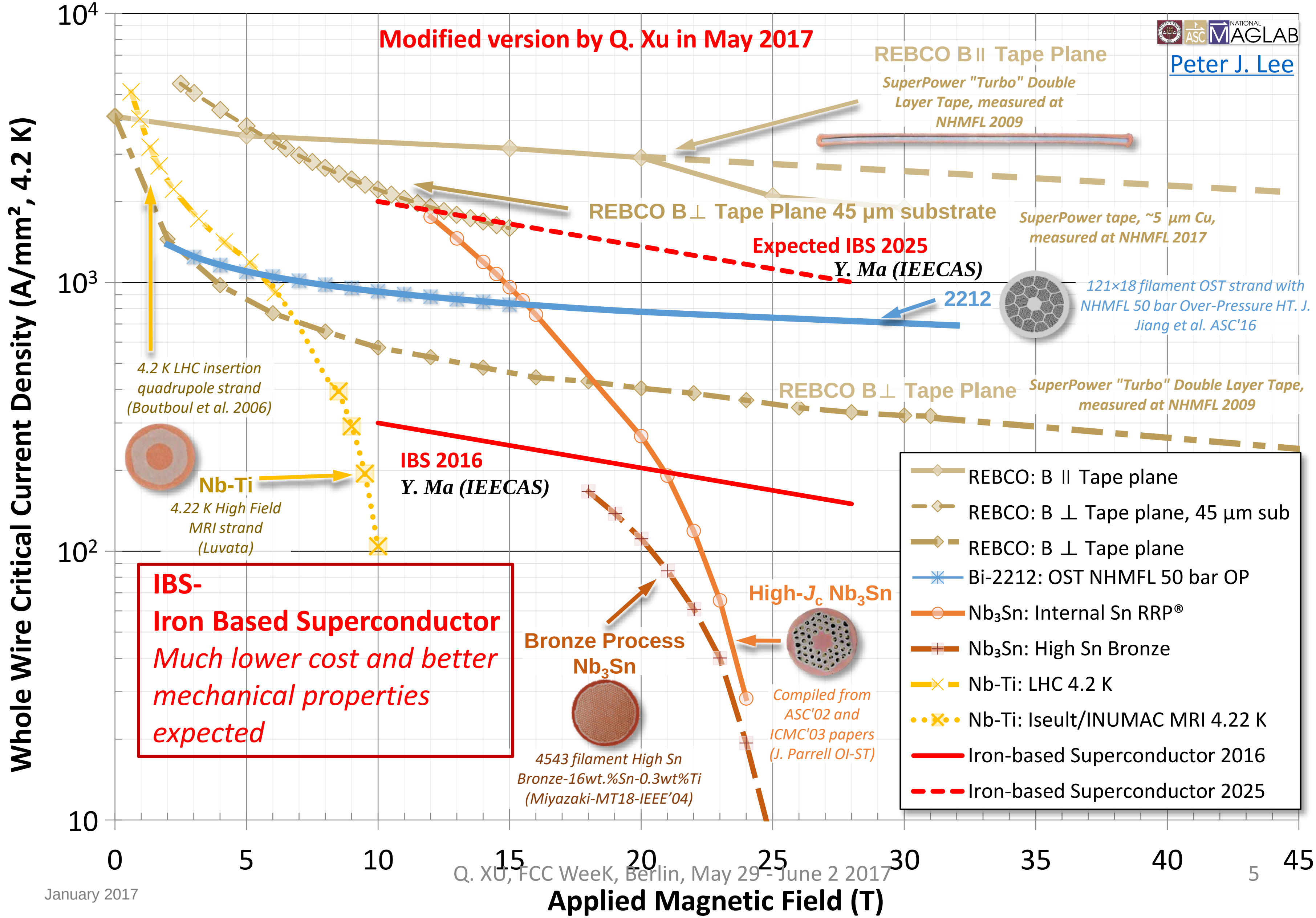


SPPC Design Scope (201701 version)

Top priority: reducing cost!
Instead of increasing field

- **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

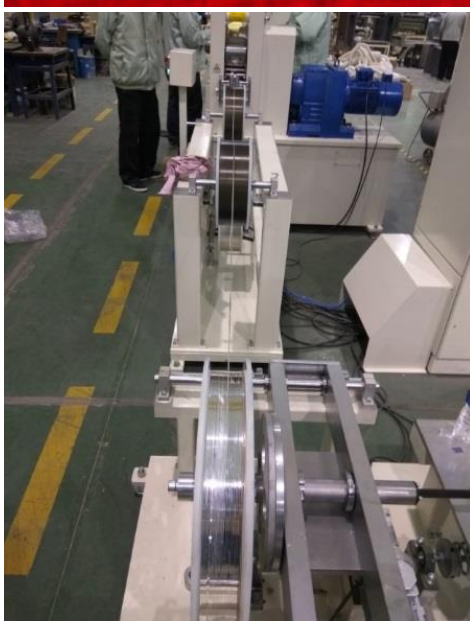
J_e of IBS: 2016-2025

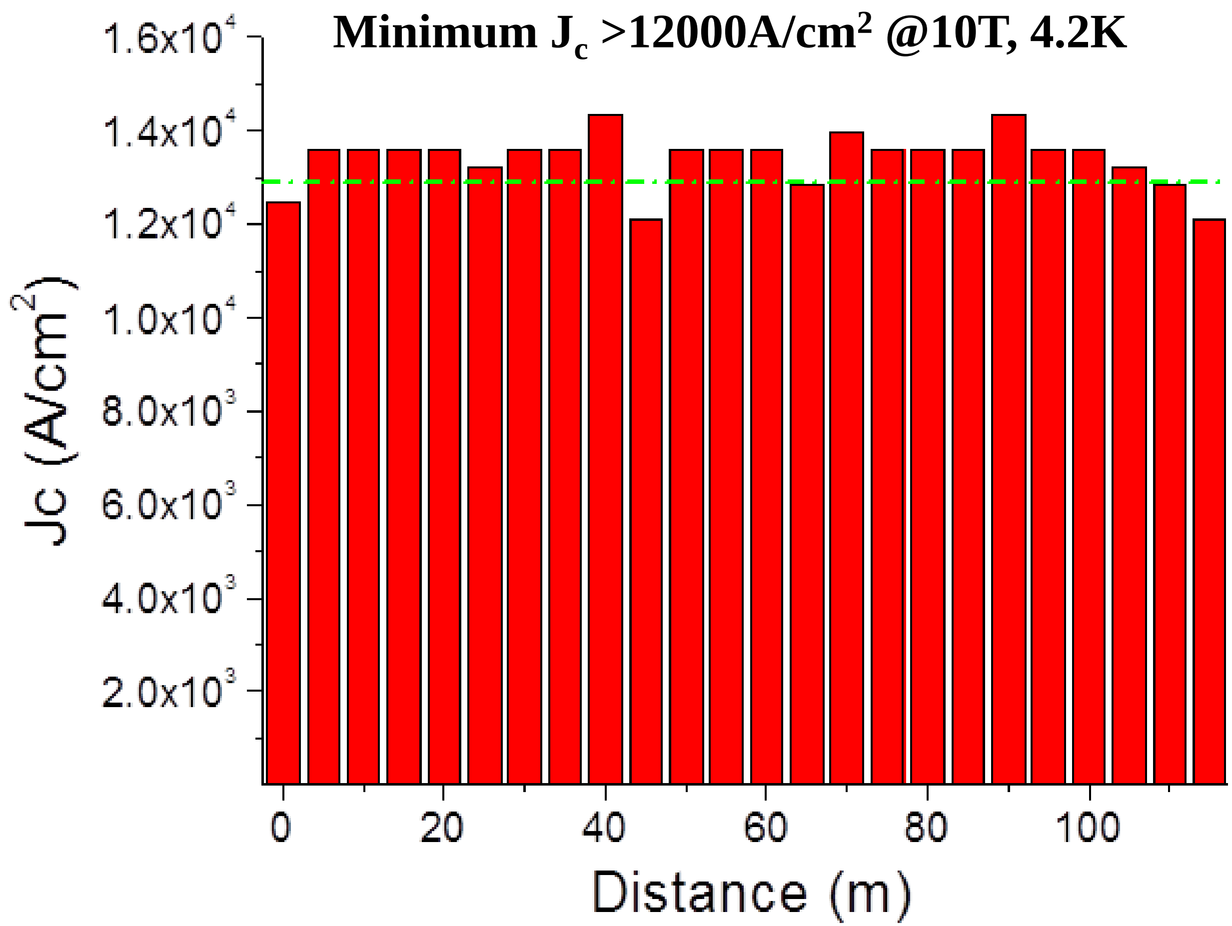


World's first 100 m Fe-based superconductor by IEE, CAS, China (Aug. 2016)

Yanwei Ma (IEECAS)

115 m long **7-filament** wire

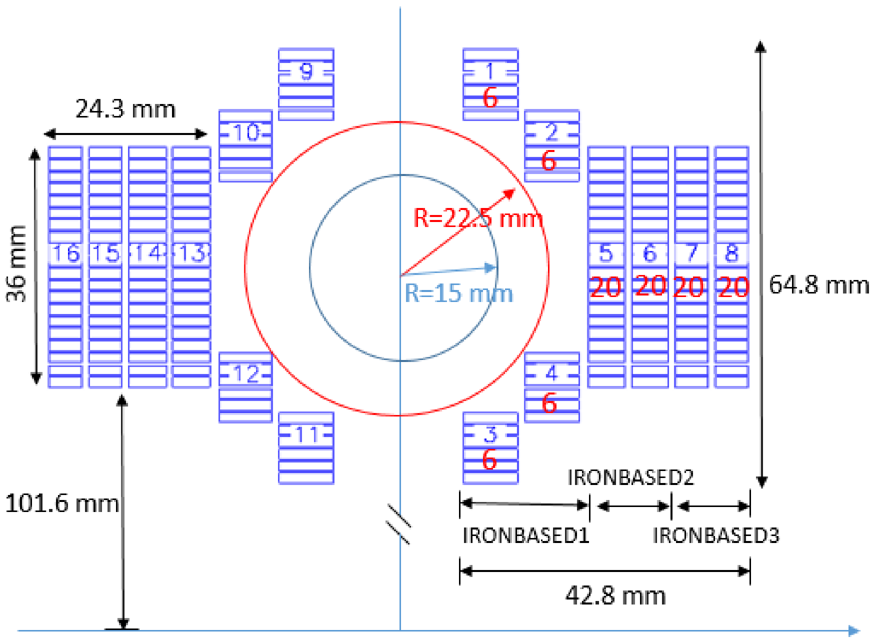


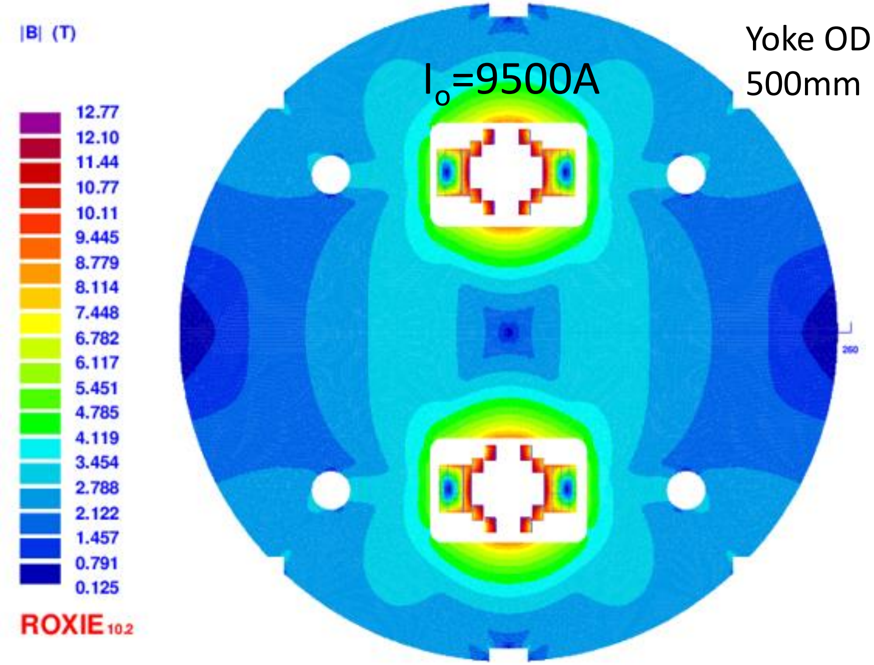


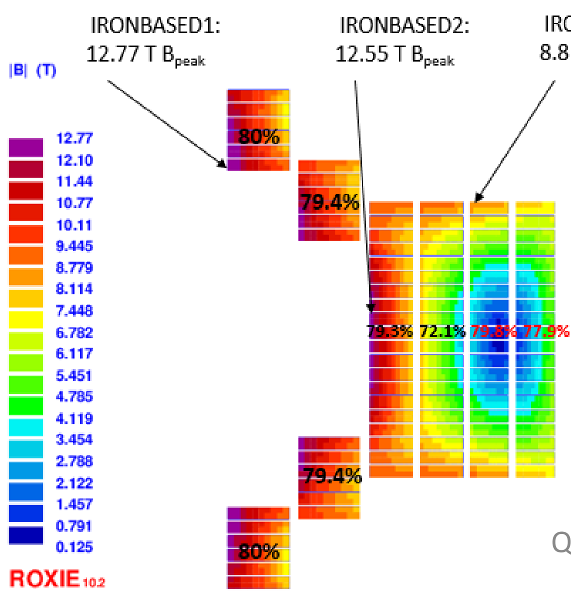
At 4.2K, 10T, transport Jc distribution along the length of the first 115 m long 7-filament Sr122 tape

The 12-T Fe-based Dipole Magnet

C. Wang, E. Kong (USTC), Q. Xu et al.







Design with expected J_e of IBS in 2025

Strand	diam.	cu/sc	RRR	Tref	Bref	Jc@ BrTr	dJc/dB
IBS	0. 802	1	200	4. 2	10	4000	111

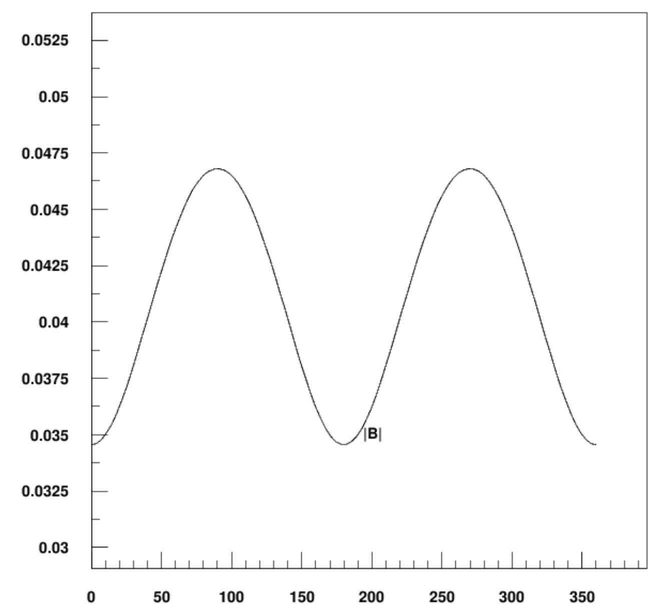
- **The required length of the 0.8 mm IBS is 6.1 Km/m**
- **For 100-km SPPC accelerator, 3000 tons of IBS is needed**
- **Target cost of IBS: 20 RMB (~2.6 Eur) /kAm @12 T**

The 12-T Fe-based Dipole Magnet

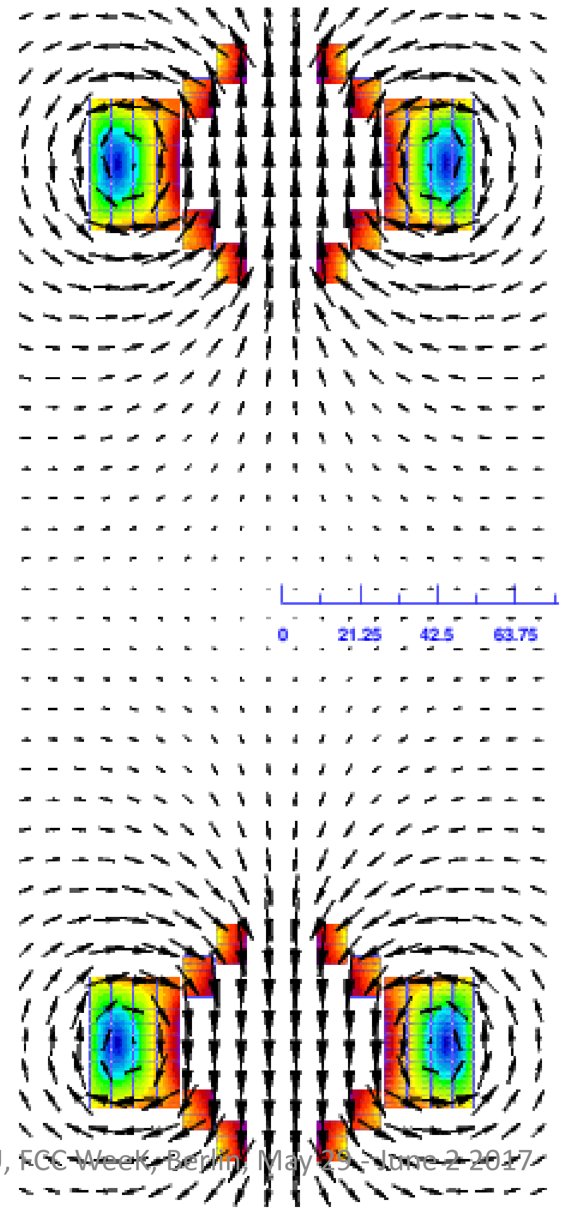
C. Wang, E. Kong (USTC), Q. Xu et al.

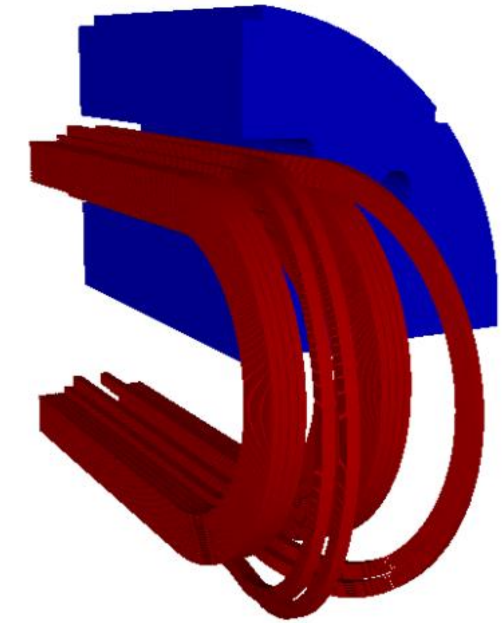
ROXIE simulation results

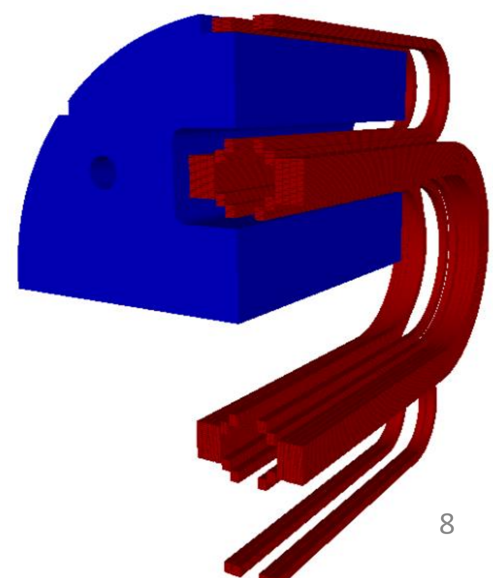
```
MAIN FIELD (T) .....................................    12.020868
MAGNET STRENGTH (T/(m^(n-1)) .......................      12.0209

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
b10:     -0.00000  b11:      3.81956  b12:      0.00000
b13:     -0.26538  b14:      0.00000  b15:     -0.35810
b16:      0.00000  b17:     -0.00089  b18:      0.00000
b19:      0.00834  b20:     -0.00000  b

SKEW RELATIVE MULTIPOLES (1.D-4):
a 1:      0.00000  a 2:     -0.16185  a 3:      0.00000
a 4:      0.01740  a 5:      0.00000  a 6:     -0.00710
a 7:     -0.00000  a 8:     -0.00616  a 9:      0.00000
a10:     -0.42248  a11:      0.00000  a12:      0.03415
a13:     -0.00000  a14:      0.05399  a15:     -0.00000
a16:     -0.00096  a17:     -0.00000  a18:     -0.00134
a19:     -0.00000  a20:     -0.00189  a
```



Stray field around the dipole with R= 500 mm



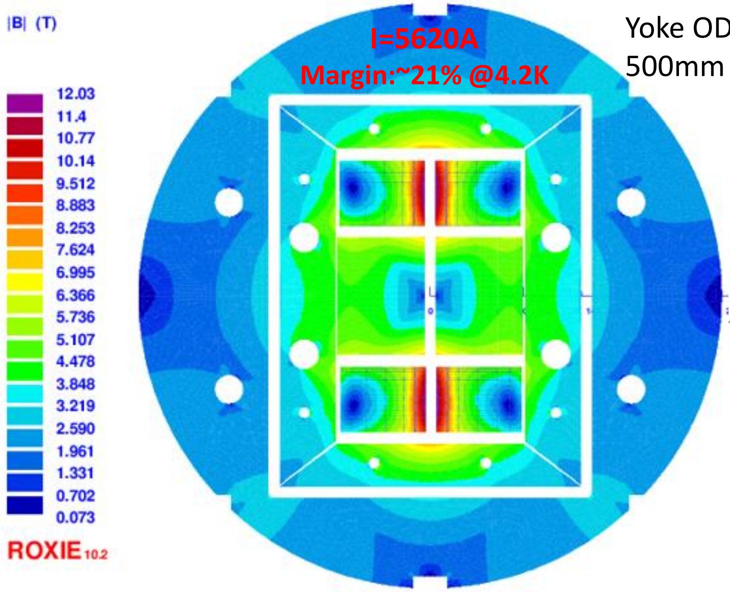




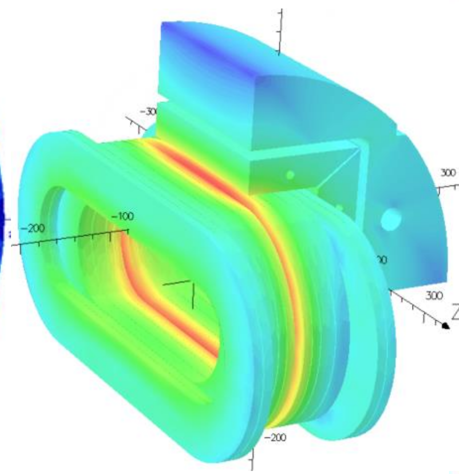
High Field Magnet R&D 2016-2018

Development of a 12T NbTi+Nb_3Sn twin-aperture (Φ10*2) magnet

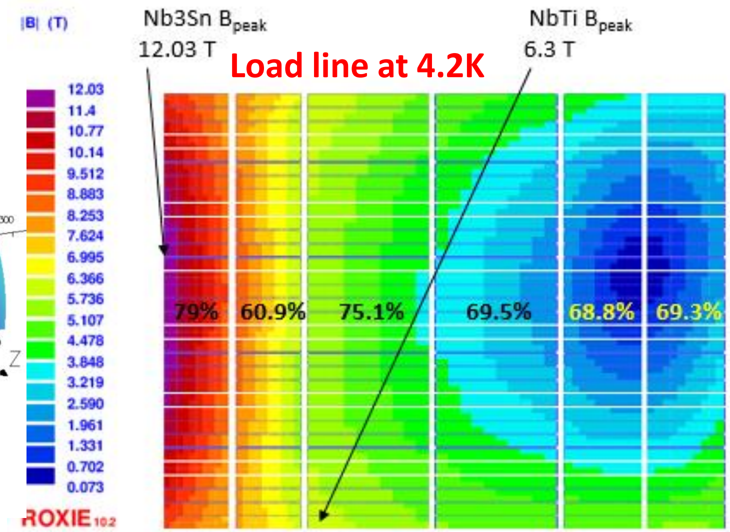
C. Wang, K. Zhang, Y. Wang, D. Cheng, E. Kong (USTC), Q. Xu et al.



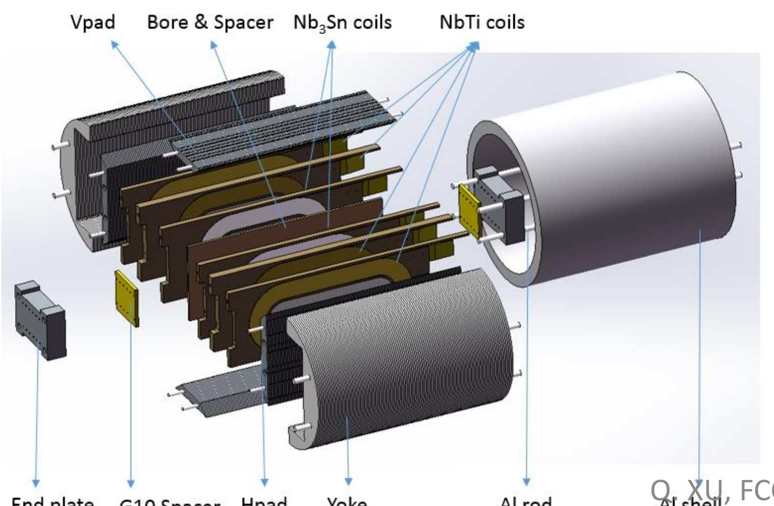
Field distribution in the straight section



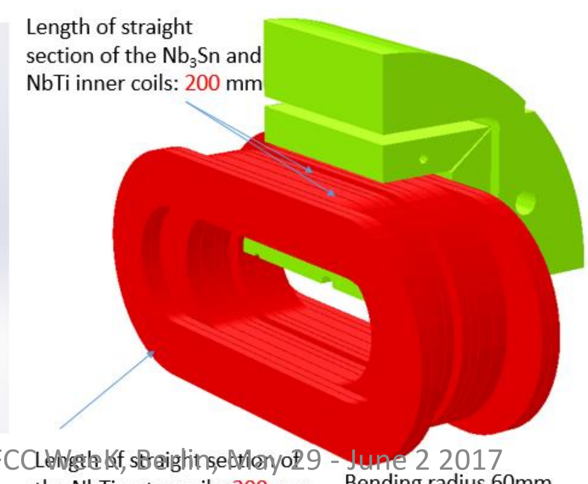
3d coil layout

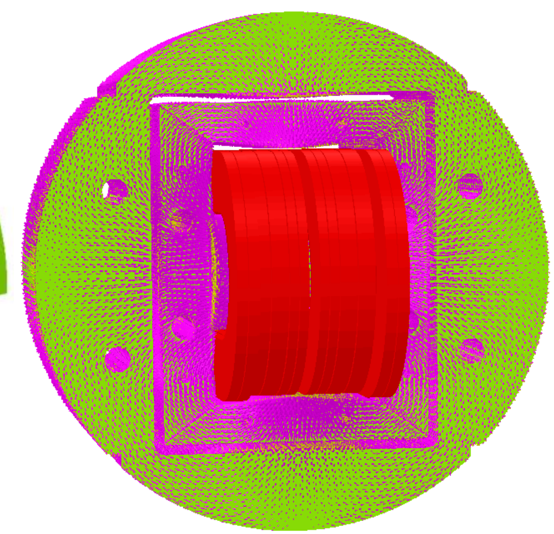


Field distribution in the straight section



Components and assembly



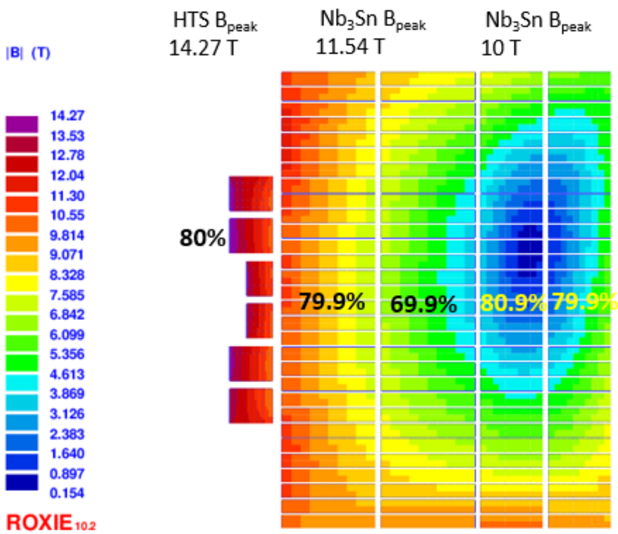


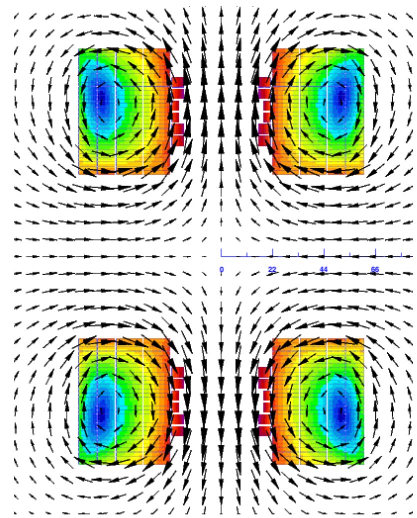
High Field Magnet R&D 2016-2018

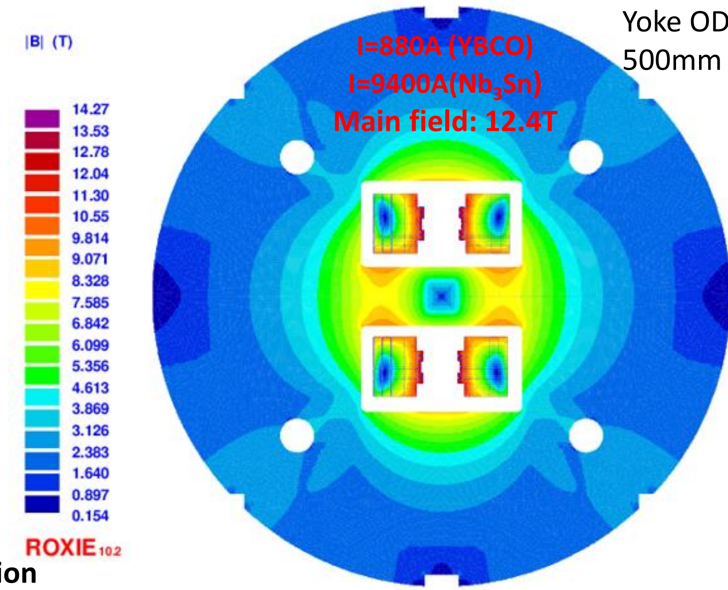
Development of the Nb_3Sn+HTS twin-aperture (Φ30*2) magnet

C. Wang, K. Zhang, Y. Wang, D. Cheng, E. Kong (USTC), Q. Xu et al.

Load line at 4.2K



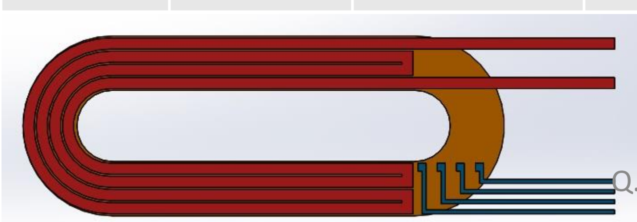




Field distribution in the straight section

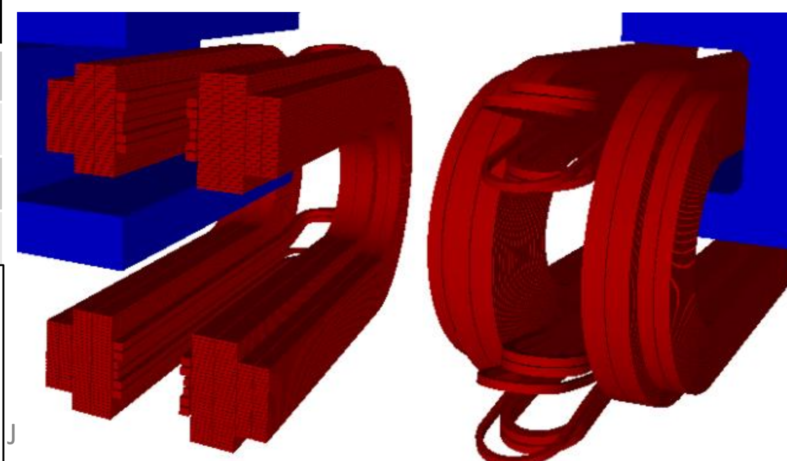
Quench protection for NbTi and Nb_3Sn coils (Great help from Tiina)

Thickness (μm)	Resistance （Ω）	Peak Power （w/cm^2)	Voltage (V)	Current (A)	Capacitance (mF)
50	2.85	50	221.82	77.83	10.53
50	2.85	100	313.7	110.07	10.53
100	1.425	50	156.85	110.07	21.05
100	1.425	100	221.82	155.66	21.05



A 4-fold heater: width 11mm, Heater interval 2mm, Straight section length 300mm, Material 316stainless steel.
4 voltage detection: Width 4mm, Length 200mm, Material copper.

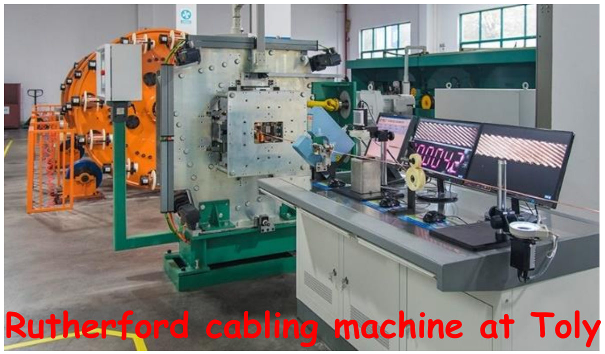
Coil ends layout



Superconducting Rutherford Cable R&D

Collaboration between WST, NIN, Toly Electric and IHEP

~300 m superconducting Rutherford Cable has been fabricated by Toly Electric with WST NbTi strand (Jc degradation <2%) ; Fabrication of Nb_3Sn cable and Bi-2212 cable is ongoing.

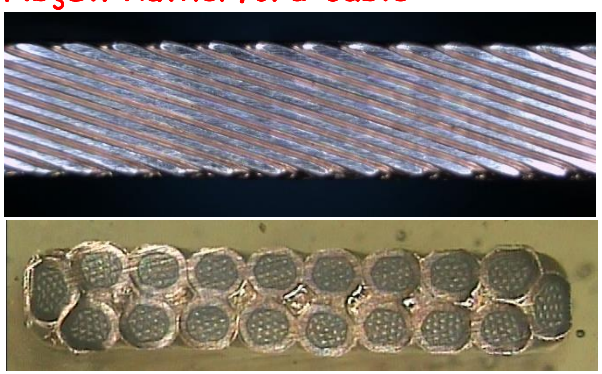


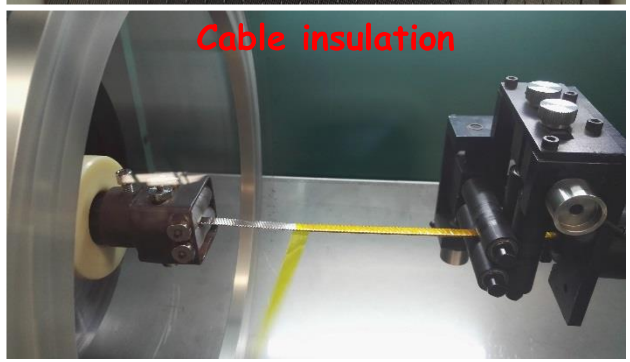
Rutherford cabling machine at Toly

NbTi Rutherford cable

Insulated cable

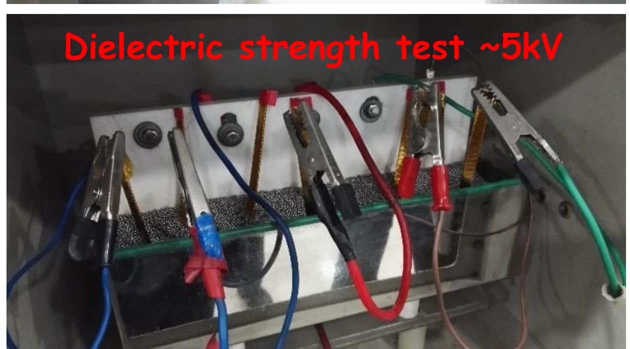
Nb_3Sn Rutherford cable





Cable insulation

Bi-2212 Rutherford cable



Dielectric strength test ~5kV

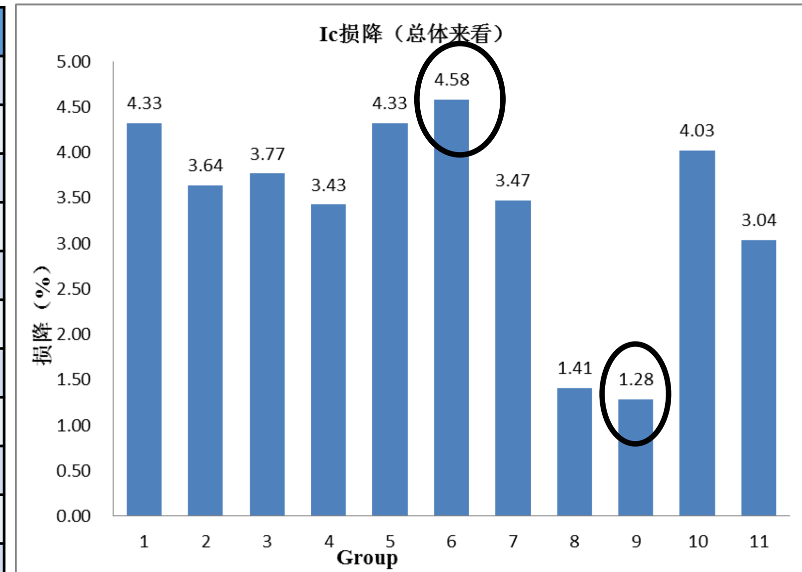
Superconducting Rutherford Cable R&D

Nb_3Sn cable fabrication with WST strand

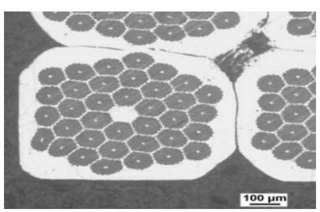
Y. Zhu (WST), Y. Zhao (Toly) et al.

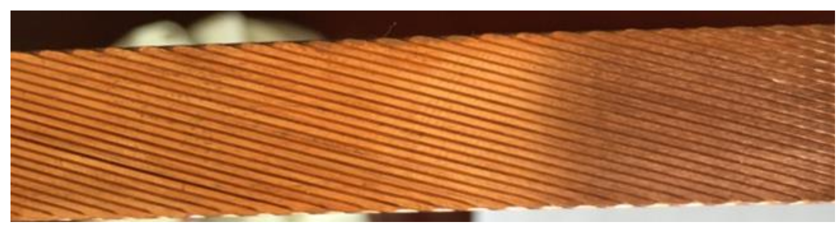
参数及性能

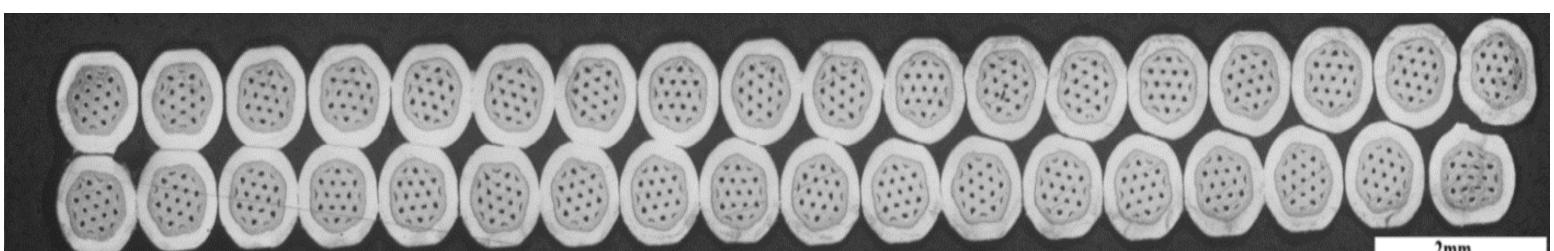
股数	绞缆角	节距/mm	尺寸/mm	填充系数	Ic损降/%
18	17.13°	50	8.22*1.48	81.3%	**3.64%**
			7.87*1.48	85%	**3.43%**
			7.95*1.52	81.9%	**1.28%**
			7.83*1.48	85.4%	**4.33%**
			7.87*1.44	87.3%	**4.58%**
			7.87*1.52	82.7%	**1.41%**
36	18.46°	93	15.38*1.50	86.5%	**4.63~6.70**
			15.29*1.49	87.5%	8.96~10.92
			15.23*1.45	90.3%	**5.76~9.36**
			15.19*1.44	91.2%	8.71~13.17
			15.16*1.39	94.7%	9.43~11.31



微观结构







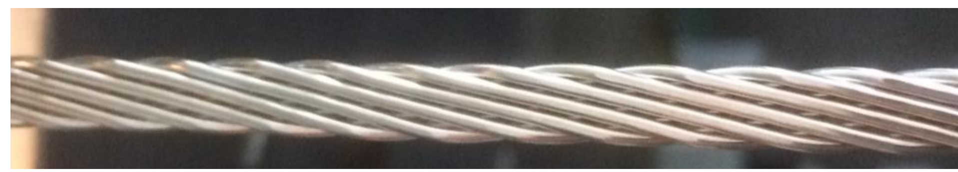
Superconducting Rutherford Cable R&D

Bi-2212 cable fabrication with NIN strand

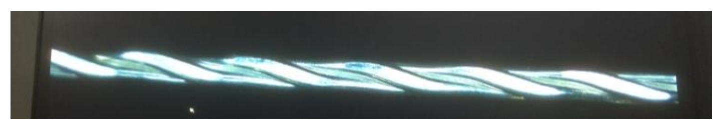
Q. Hao (NIN), Y. Zhao (Toly) et al.

Parameter	Cable 1	Cable 2
Diameter Φ（mm）	1	1
Wire processing	300℃退火	200℃退火
Number of Strands	8	8
Cable size（mm²）	1.90×4.77	1.78×4.21
Filling factor	70.5%	85.2%
Length	2.5米	2米

- ◆*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*



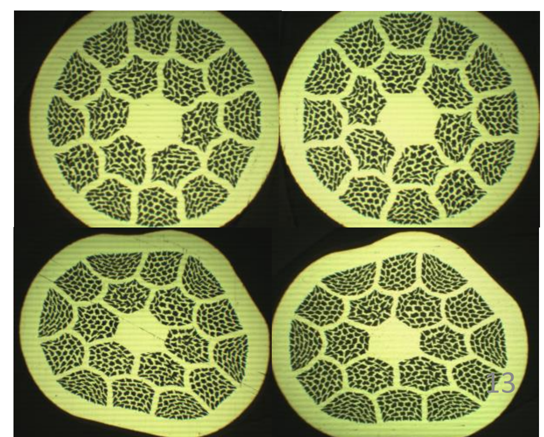
Front view



Side view

Before cabling

After cabling

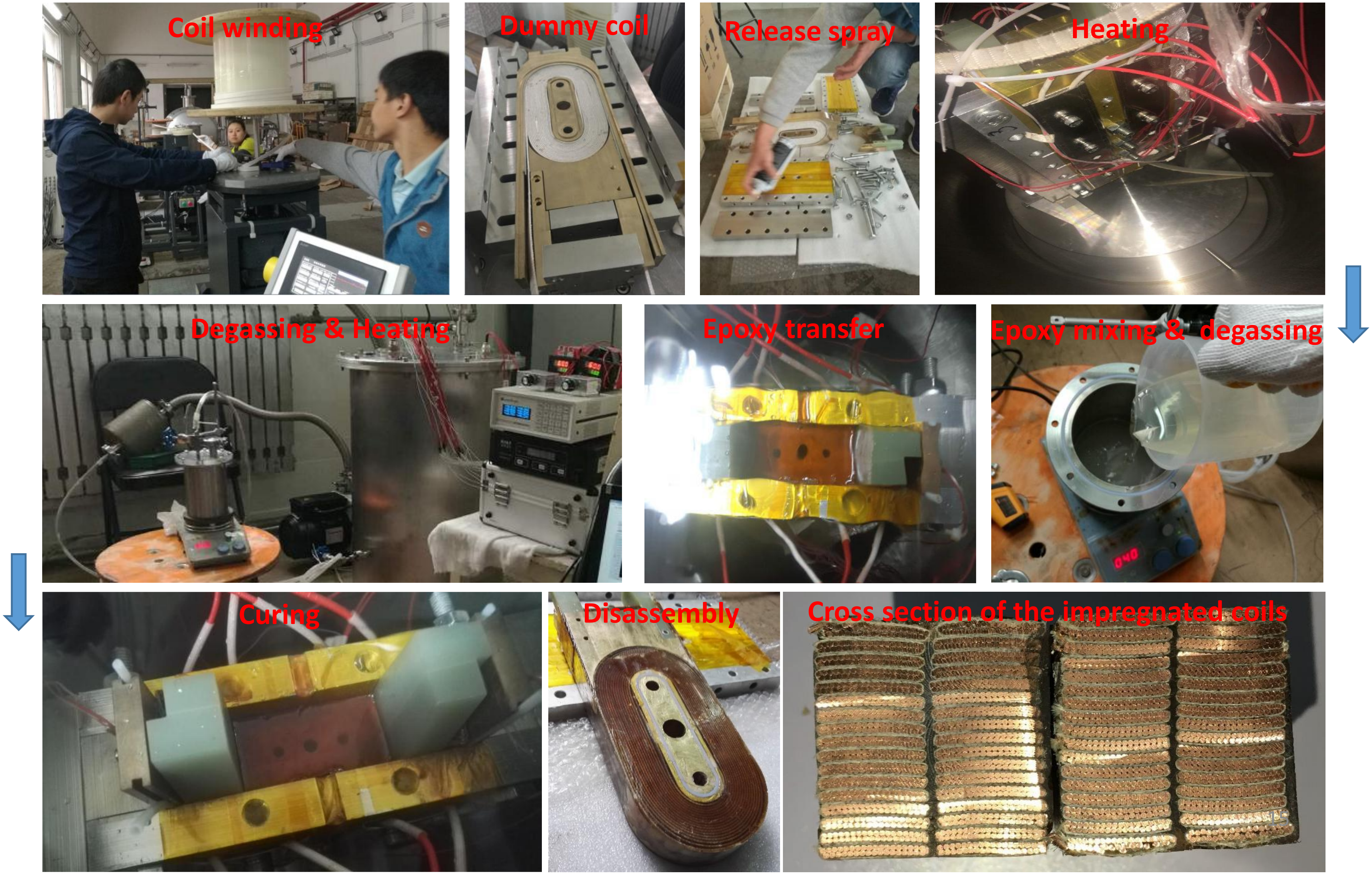


Infrastructure for Model Magnet Fabrication

A new winding machine, VPI system, furnace, bladder & pump, ……

Infrastructure for Model Magnet Fabrication

A dummy Coil Fabrication



Domestic Collaboration

"Applied High Temperature Superconductor Collaboration (AHTSC)" was formed in Oct. 2016. >13 related institutes & companies and 50 scientists & engineers in China joined AHTSC, working together for the advanced HTS R&D and Industrialization.

- **Goal：** 1) To increase the J_c of IBS by 10 times, reduce the cost to 20 Rmb/kAm @ 12T & 4.2K in 10 years, 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 in 10 years; 3) Realization and Industrialization of iron-based SRF technology.
- **Working groups：** 1) Fundamental science investigation; 2) IBS conductor R&D; 3) ReBCO conductor R&D; 4) Bi2212 conductor R&D; 5) performance evaluation; 6) Magnet and SRF technology.
- **Collaboration meetings**: every 2~3 months, to report the progress and discuss plan for next months.

执行委员会 (姓氏拼音排序)	
陈仙辉	中国科技大学
蔡传兵	上海大学/上创超导
李贻杰	上海交通大学/上海超导
马衍伟	中科院电工研究所
王贻芳	中科院高能物理所
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周廉	西北有色院

IHEP & CERN Collaboration

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

For now

- IHEP, IMP, WST and ASIPP will work together on the CCT magnet (D2) 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 we are expecting from the HL-LHC collaboration

Speed up R&D process of the high field magnet technology in China.

EDMS 17655515 V1.0

MEMORANDUM OF UNDERSTANDING
FOR COLLABORATION IN THE HIGH LUMINOSITY LHC PROJECT
AT CERN

BETWEEN: THE EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH ("CERN"), an Intergovernmental Organization having its seat at Geneva, Switzerland, as the Host Organization of the High Luminosity LHC project ("HL-LHC Project");

AND: THE INSTITUTES, LABORATORIES, UNIVERSITIES AND THEIR FUNDING AGENCIES AND OTHER SIGNATORIES OF THIS MEMORANDUM OF UNDERSTANDING,

Hereafter "Participant" and collectively "Participants"

CONSIDERING:

That CERN, an Intergovernmental Organization, is a leading global laboratory in particle physics, providing for collaboration of a pure scientific and fundamental character, with participation by scientific institutes from all over the world;

That *<INSTITUTE name>* wishes to contribute to the HL-LHC Project, which aims at maximizing the performance of the LHC accelerator by increasing its luminosity, and that *<INSTITUTE name>* has internationally recognized experience in fields that are relevant to the HL-LHC Project;

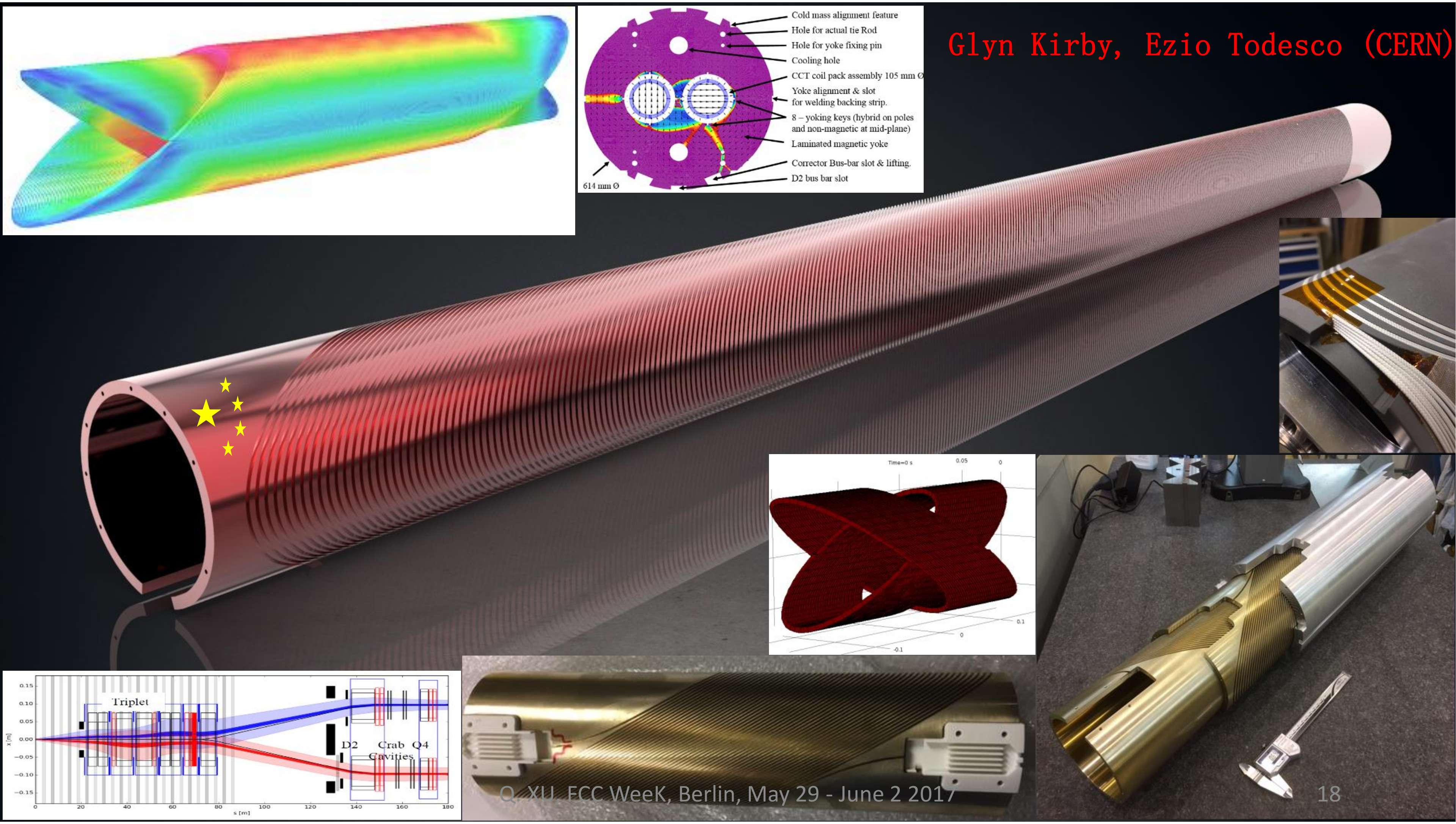
That the Participants will derive mutual benefits from their collaboration in the HL-LHC Project,

AGREE AS FOLLOWS:

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

International Press of Boston

www.intlpress.com

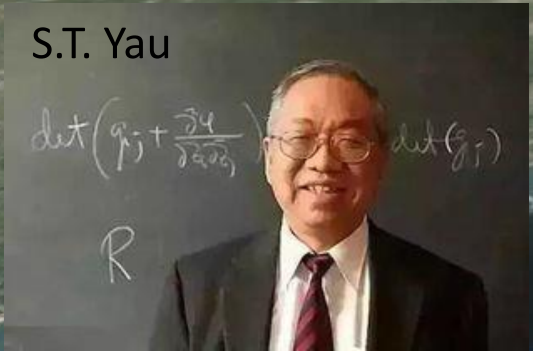
From the Great Wall to the Great Collider

China and the Quest to Uncover the Inner Workings of the Universe

by Steve Nadis & Shing-Tung Yau

The story of the enchanting new physics that lies beyond the Higgs boson discovery — and the gargantuan particle accelerator that might get us there.

Thanks



S.T. Yau

C.N. Yang

Y.F. Wang