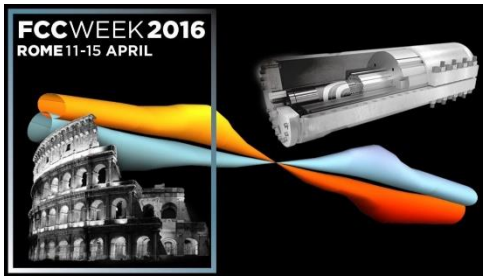


SPPC High Field Magnets - Preliminary Design Study and R&D Steps

Qingjin XU
On behalf of the SPPC magnet working group

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

2016.4.13

Contents

Requirements of the SPPC Magnets

SPPC

- *50/100 km in circumference*
- *C.M. energy 70 TeV or higher*
- *Timeline*

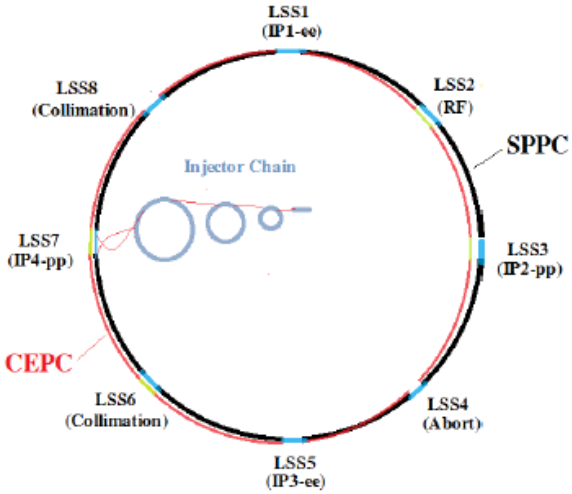
Pre-study:	*2013-2020*
R&D:	*2020-2030*
Eng. Design:	*2030-2035*
Construction:	***2035-2042***

Main dipoles

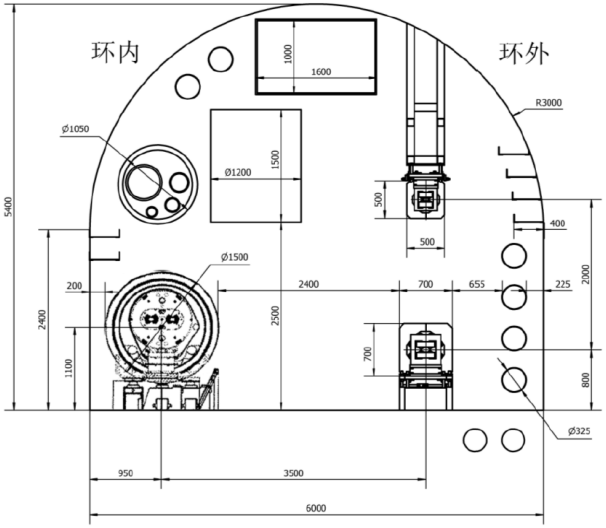
$$E[GeV] = 0.3 \times B[T] \times \rho[m]$$

- *Field strength: 20 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*

The CEPC-SPPC ring sited in Qinhuangdao, 50 km and 100 km options .



SPPC accelerator complex



6-m Tunnel for CEPC-SPPC. Left: SPPC collider. Right: CEPC collider (bottom) and Booster (top)

Refer to CEPC-SPPC Pre-CDR, Mar. 2015: http://cepc.ihep.ac.cn/preCDR/volume.html

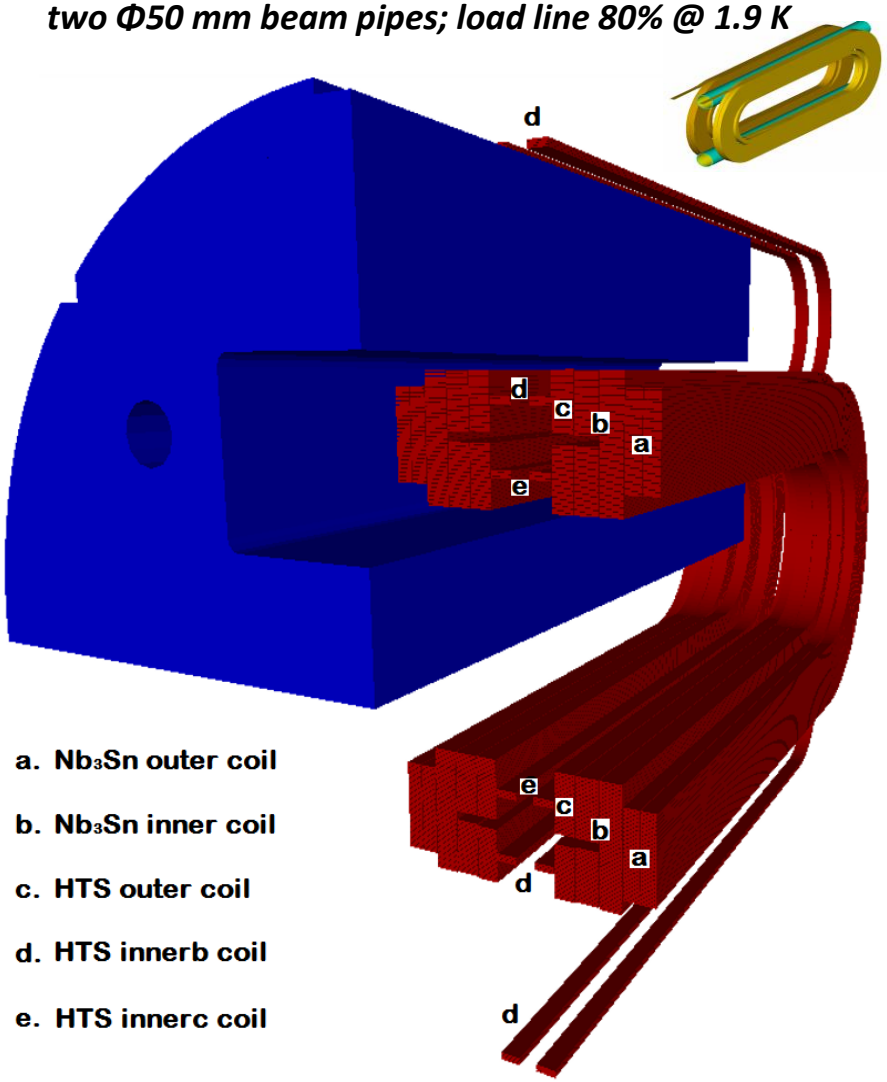
Design Study of the SPPC Dipole Magnet

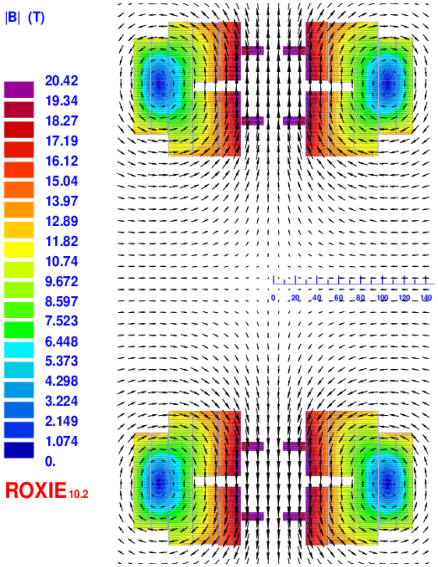
Q. Xu, K. Zhang, C. Wang et al.

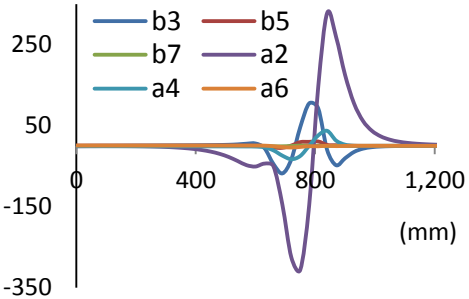
With common coil configuration

20-T dipole magnet with common coil configuration

two Φ50 mm beam pipes; load line 80% @ 1.9 K







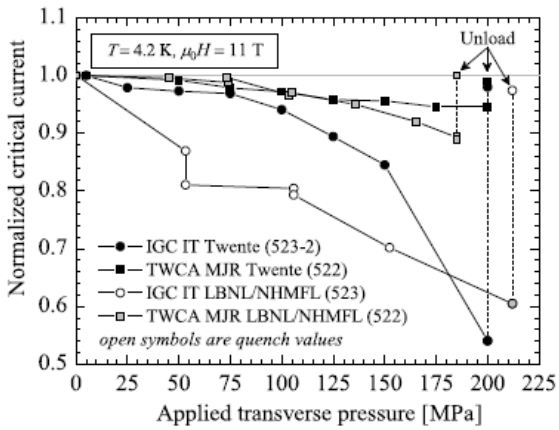
Integrated b_n/a_n	Value (10^{-4})
b3	0.14
b5	1.42
b7	-0.40
a2	-0.29
a4	-1.81
a6	0.03

Magnet		Number of apertures	2
		Aperture diameter (mm)	50
		Inter-aperture spacing (mm)	333
		Operating current (A)	14700
		Operating temperature (K)	4.2
		Operating field (T)	20
		Peak field (T)	20.4
		Margin along the load line (%)	11
		Stored magnetic energy (MJ/m)	7.8
		Inductance (mH/m)	72.1
		Yoke ID (mm)	260
		Yoke OD (mm)	800
		Weight per unit length (kg/m)	3200
		Energy density (coil volume) (MJ/m^3)	738
		Force per aperture – X / Y (MN/m)	23.5/4.4
		Peak stress in coil (MPa)	240
		Fringe Field (@ r = 750 mm (T)	0.02
Coil	Nb_3Sn outer	Number of layers	2
		Number of turns per layer	46
(2 Nb_3Sn outer + 2 Nb_3Sn inner + 2 HTS outer + 4 HTS inner-b + 2 HTS inner-c)		Bending radius (mm)	127.8
	Nb_3Sn inner	Number of layers	2
		Number of turns per layer	59/64
		Bending radius (mm)	109.1
	HTS outer	Number of layers	1
		Number of turns per layer	59
		Bending radius (mm)	109.0
	HTS inner-b	Number of layers	1
		Number of turns per layer	4
		Bending radius (mm)	135.7
	HTS inner-c	Number of layers	1
		Number of turns per layer	4
		Bending radius (mm)	100.9
Cable	Nb_3Sn outer	Number of strands	38
		Cable dimension (mm^2)	15*1.5
(Nb_3Sn outer + Nb_3Sn inner + HTS cable)		Insulation thickness (mm)	0.15
	Nb_3Sn inner	Number of strands	56
		Cable dimension (mm^2)	22*1.5
		Insulation thickness (mm)	0.15
	HTS	Number of strands	50
		Cable dimension (mm^2)	20*1.5
		Insulation thickness (mm)	0.15
Strand	Nb_3Sn	Diameter (mm)	0.82
		Copper/Superconductor ratio	1
(Nb_3Sn + HTS)		Non-Cu J_c (A/mm^2 @15 T, 4.2 K)	1500
		dJ_c/dB (A/T)	350
	HTS	Diameter (mm)	0.82
		Copper/Superconductor ratio	1
		Non-Cu J_c (A/mm^2 @20 T, 4.2 K)	1300
		dJ_c/dB (A/T)	13

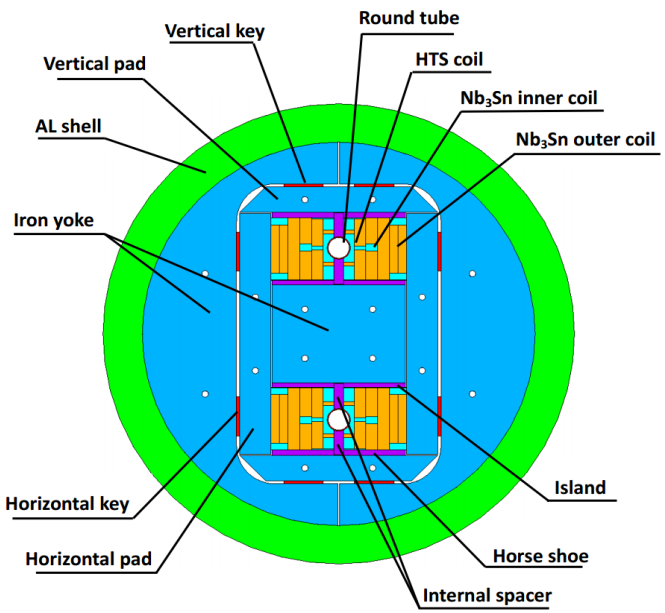
Q. Xu, K. Zhang, C. Wang et. al., 20-T Dipole Magnet with Common Coil Configuration: Main Characteristics and Challenges, IEEE Trans. Appl. Supercond., VOL. 26, NO. 4, 2016，4000404

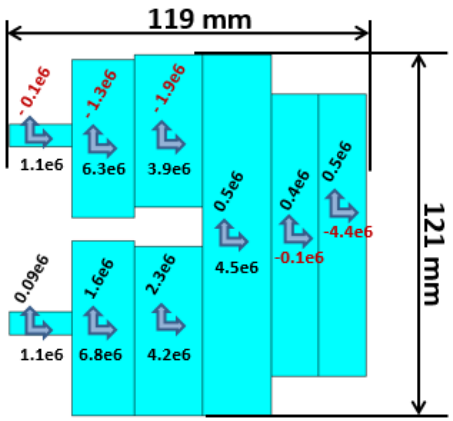
Design Study of the SPPC Dipole Magnet

K. Zhang, Q. Xu, C. Wang et al.

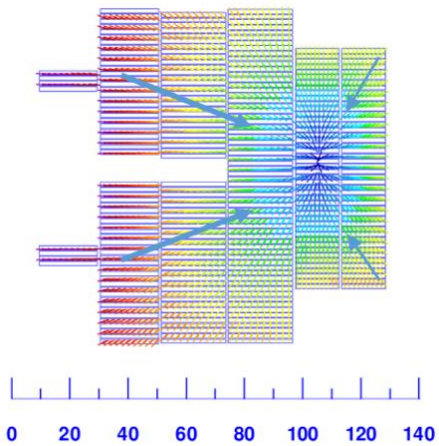


D.R. Dietderich, A. Godeke / Cryogenics 48 (2008) 331–340



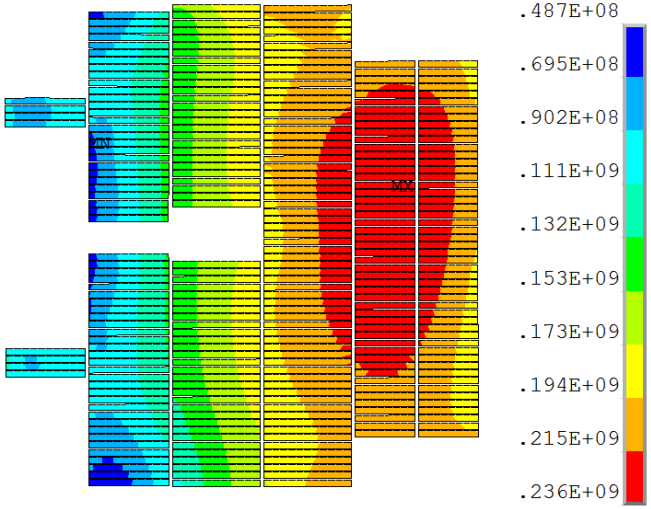


Lorentz force per aperture:
Fmag_x=23.4 MN/m
Fmag_y=2.38 MN/m

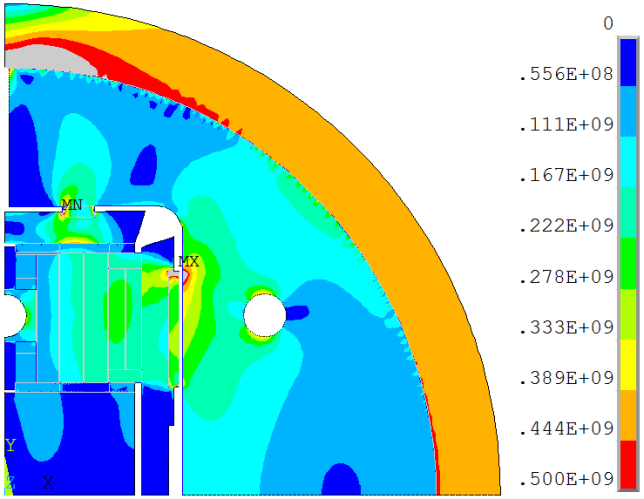


Direction of Magnetic force

With common coil configuration



Stress in coil after excitation



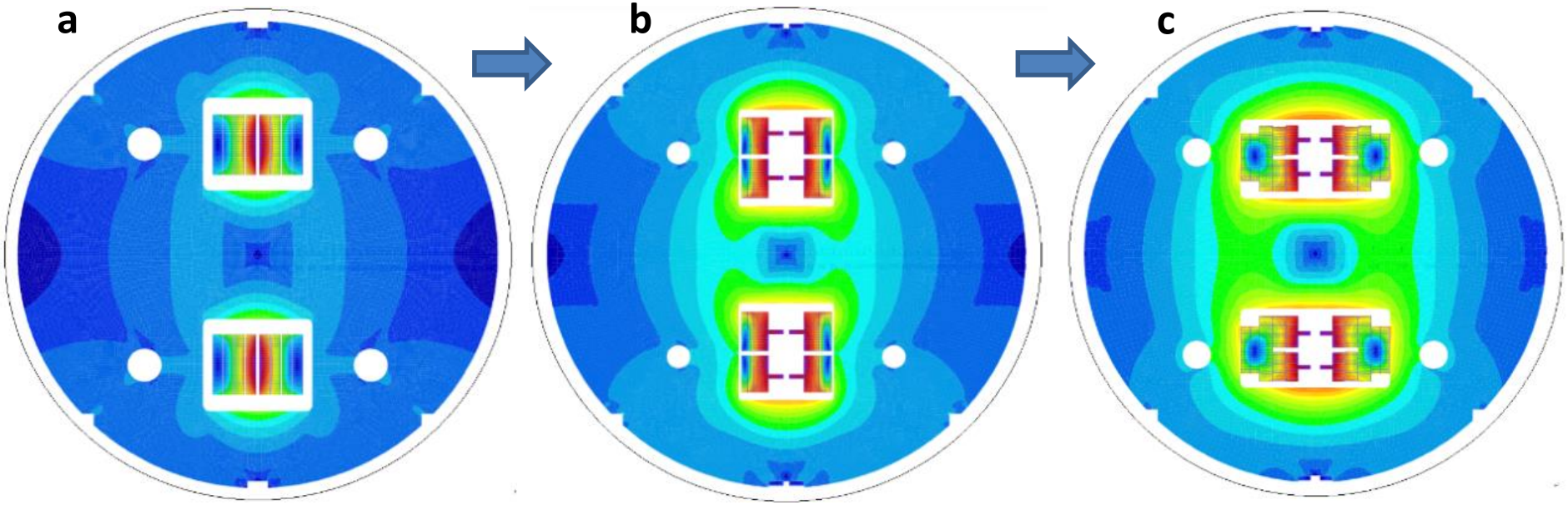
Stress in shell after excitation

K. Zhang et. al., 2-D Mechanical Design Study of a 20-T Two-in-One Common-Coil Dipole Magnet for High-Energy Accelerators, IEEE Trans. Appl. Supercond., VOL. 26, NO. 4, 2016, 4003705

R&D Steps for the SPPC Dipole Magnet

Q. Xu, K. Zhang, C. Wang et al.

With common coil configuration



1st step ***ongoing***

Fabrication of a 15-T Nb_3Sn or Nb_3Sn+HTS subscale magnet, to test the stress management method for Nb_3Sn & HTS coils and the quench protection method for HTS coils;

By the end of 2018.

2nd step

Fabrication of a 15-T Nb_3Sn or Nb_3Sn+HTS operational field dipole magnet with two Φ50 mm beam pipes and 10^{-4} field quality, to test the field optimization method for HTS coils;

To be funded.

3rd step

Fabrication of the 20-T magnet with Nb_3Sn+HTS or only one of them, if we can get significant progress on the performance of Nb_3Sn or HTS superconductors, i.e., their Jc level is 3~6 times increased or even more, and the cost is significantly reduced.

To be funded.

Q. Xu, K. Zhang, C. Wang et. al., 20-T Dipole Magnet with Common Coil Configuration: Main Characteristics and Challenges, IEEE Trans. Appl. Supercond., VOL. 26, NO. 4, 2016，4000404

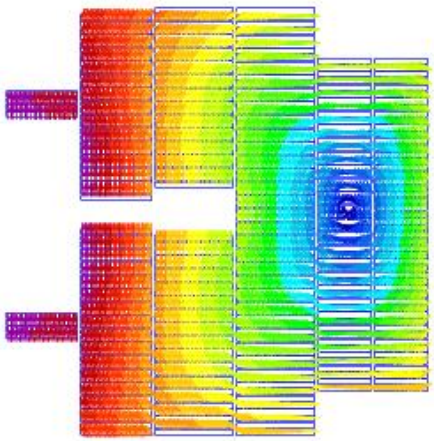
R&D Steps for the SPPC Dipole Magnet

C. Wang et al.

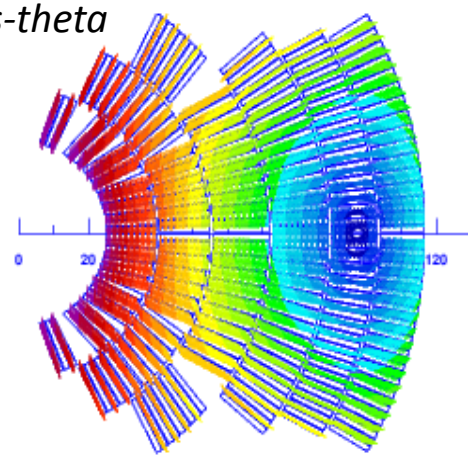
Comparison of different coil configurations

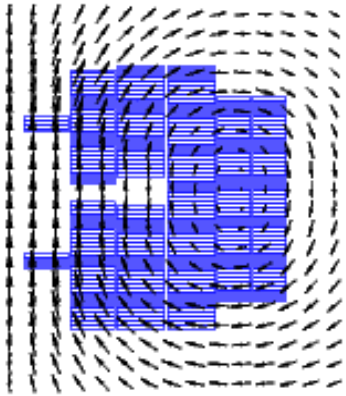
Common coil vs Cos-theta

Common coil



Cos-theta



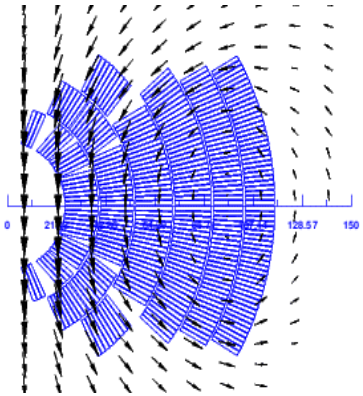


Common coil

Different coil configurations for 20-T dipole magnet

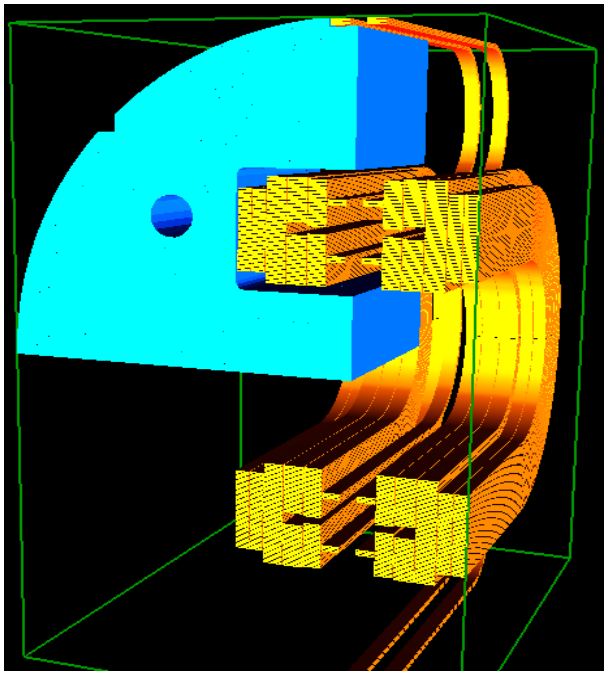
Left: Common coil

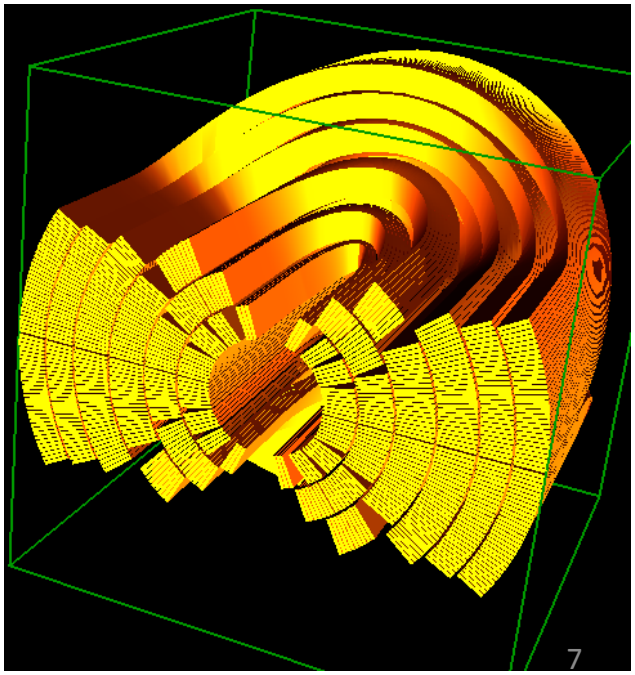
Right: Cos-theta



Cos-theta

Coil ends

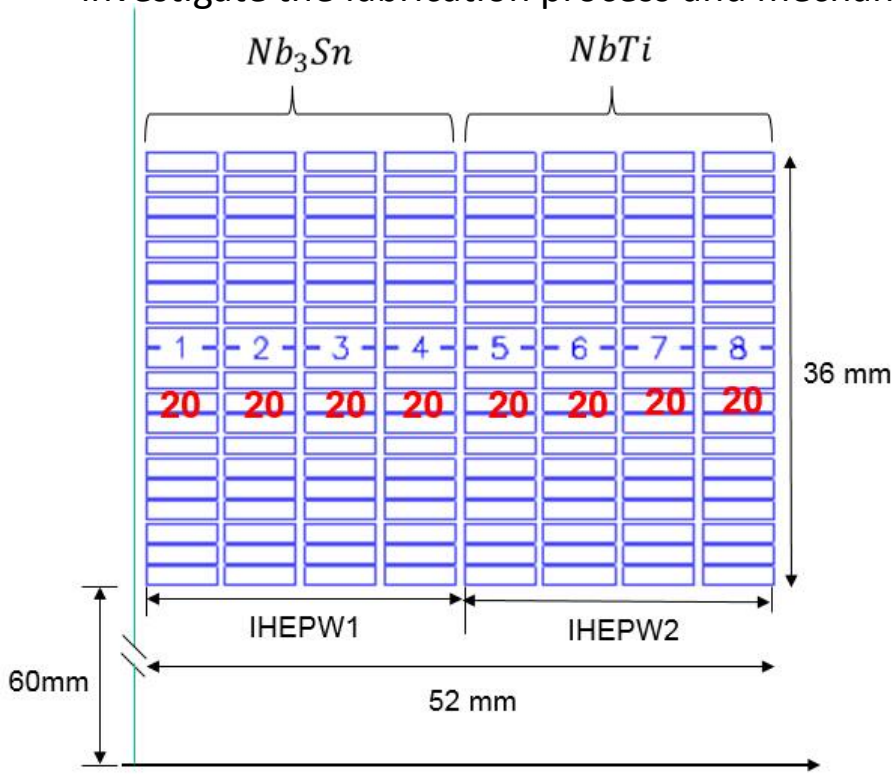




R&D Schedule for 2016-2018

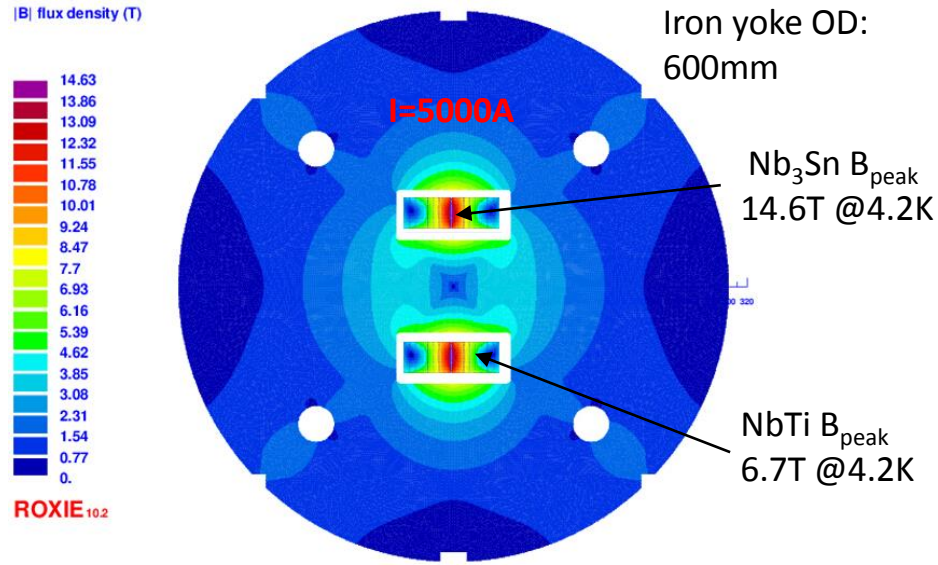
C. Wang, K. Zhang, Q. Xu et al.

1. A 14-T subscale magnet to be fabricated with Nb_3Sn and NbTi superconductors in 2016, to investigate the fabrication process and mechanical characteristics of Nb_3Sn coils.



Coil configuration in the 1st quadrant

For per meter of such magnet, the required length of the strand: Nb_3Sn: 4.48 Km; NbTi: 4.48Km.



Field distribution in the cross section of the magnet

Main parameters of the cables

Cable	Hight	Width-i	Width-o	Ns	Strand	Insulation
IHEPW1	5.8	1.5	1.5	14	IHEPWCJC (Nb_3Sn)	0.15
IHEPW2	5.8	1.5	1.5	14	IHEPWNJC (NbTi)	0.15

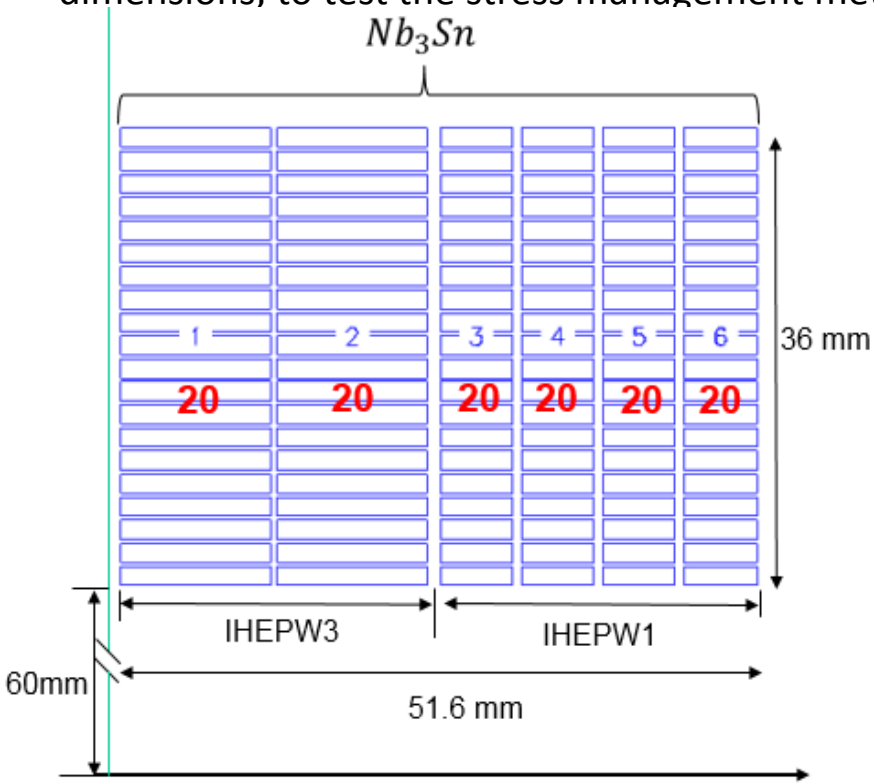
Main parameters of the strands

Strand	diam.	cu/sc	RRR	Tref	Bref	Jc@ BrTr	dJc/dB
IHEPWCJC	0.82	1	100	4.2	12	2400	400
IHEPWNJC	0.82	1	100	4.2	7.2	1500	550

R&D Schedule for 2016-2018

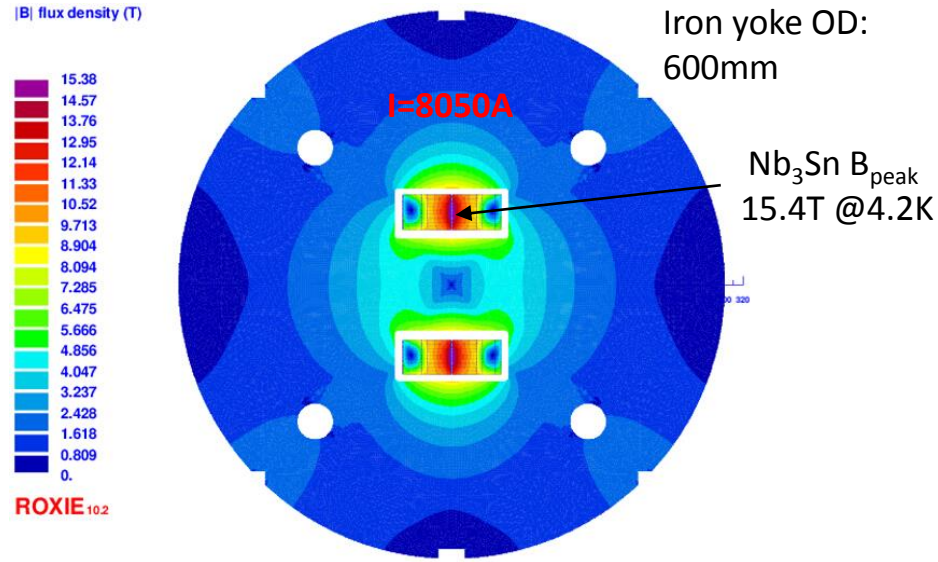
C. Wang, K. Zhang, Q. Xu et al.

2-1. A 15-T subscale magnet to be fabricated with only Nb_3Sn superconductors but different cable dimensions, to test the stress management method of Nb_3Sn coils.



Coil configuration in the 1st quadrant

For per meter of such magnet, the required length of the strand: Nb_3Sn in total: 9.12 Km.



Field distribution in the cross section of the magnet

Main parameters of the cables

Cable	Hight	Width-i	Width-o	Ns	Strand	Insulation
IHEPW1	5.8	1.5	1.5	14	IHEPWCJC (Nb_3Sn)	0.15
IHEPW3	12	1.5	1.5	29	IHEPWCJC (Nb_3Sn)	0.15

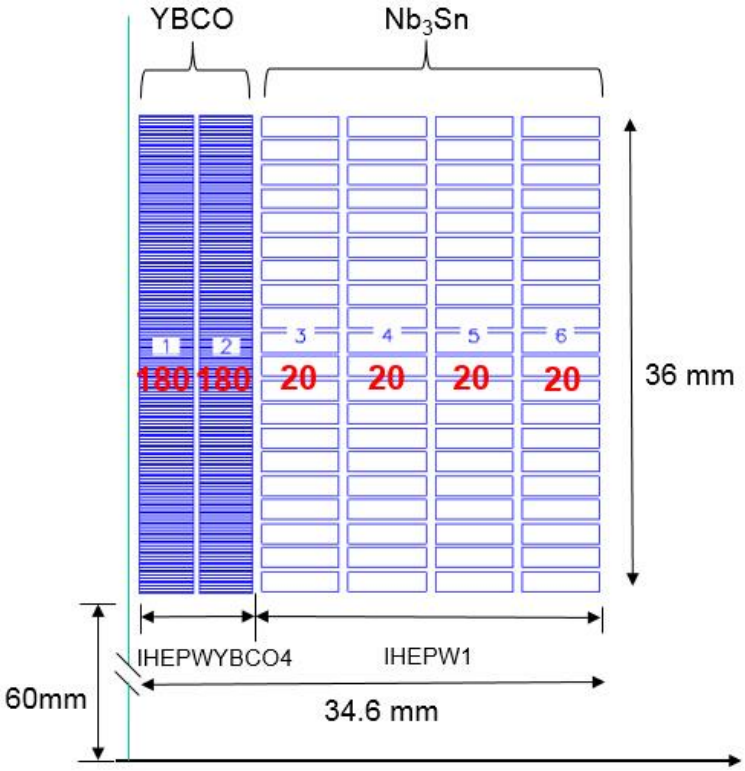
Main parameters of the strands

Strand	diam.	cu/sc	RRR	Tref	Bref	Jc@ BrTr	dJc/dB
IHEPWCJC	0.82	1	100	4.2	12	2400	400

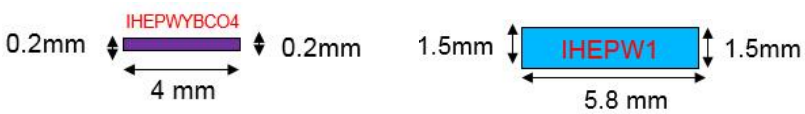
R&D Schedule for 2016-2018

C. Wang, K. Zhang, Q. Xu et al.

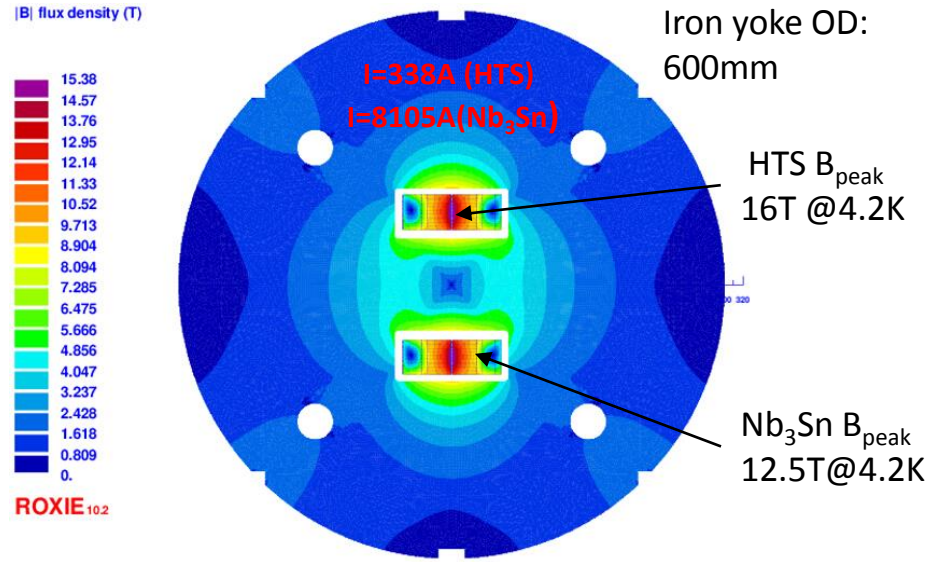
2-2. A 16-T subscale magnet will be fabricated with HTS and Nb_3Sn superconductors, to test the stress management method and quench protection method of HTS coils.



Coil configuration in the 1st quadrant



For per meter of such magnet, the required length of the strand: YBCO: 1.44Km; Nb_3Sn: 4.48 Km



Field distribution in the cross section of the magnet

Main parameters of the cables

Cable	Hight	Width-i	Width-o	Ns	Strand	Filament	Insulation
IHEPW1	5.8	1.5	1.5	14	IHEPWCJC	Nb3Sn	0.15
IHEPWYBCO4	4	0.2	0.2	1	IHEPWYBCO	YBCO	0

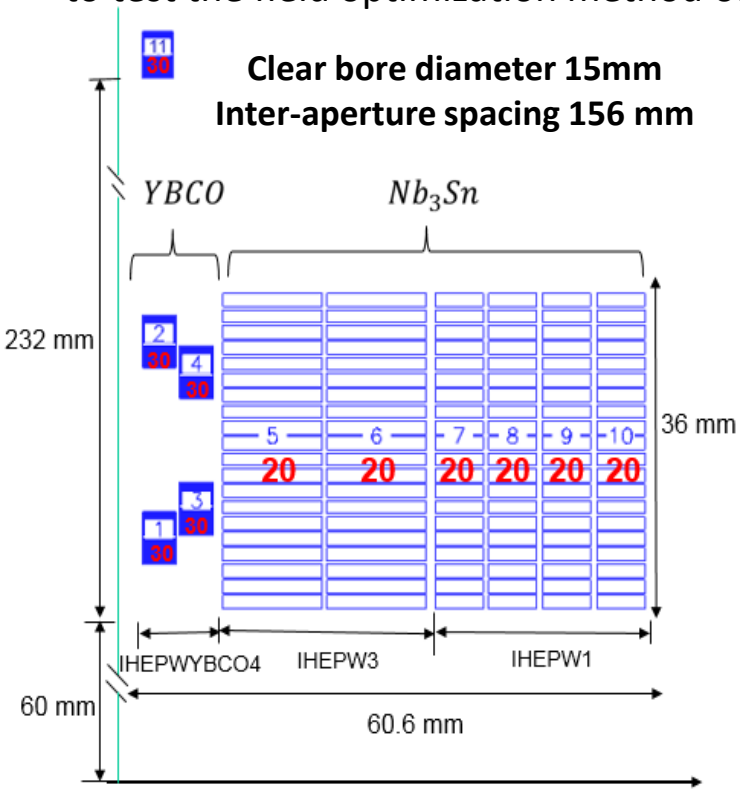
Main parameters of the strands

Strand	diam.	cu/sc	RRR	Tref	Bref	Jc@ BrTr	dJc/dB
IHEPWCJC	0.82	1	100	4.2	12	2400	400
IHEPWYBCO	-	-	-	4.2	12	1020	40

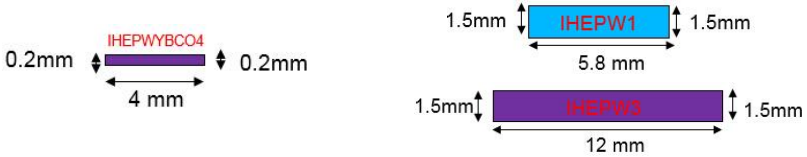
R&D Schedule for 2016-2018

C. Wang, K. Zhang, Q. Xu et al.

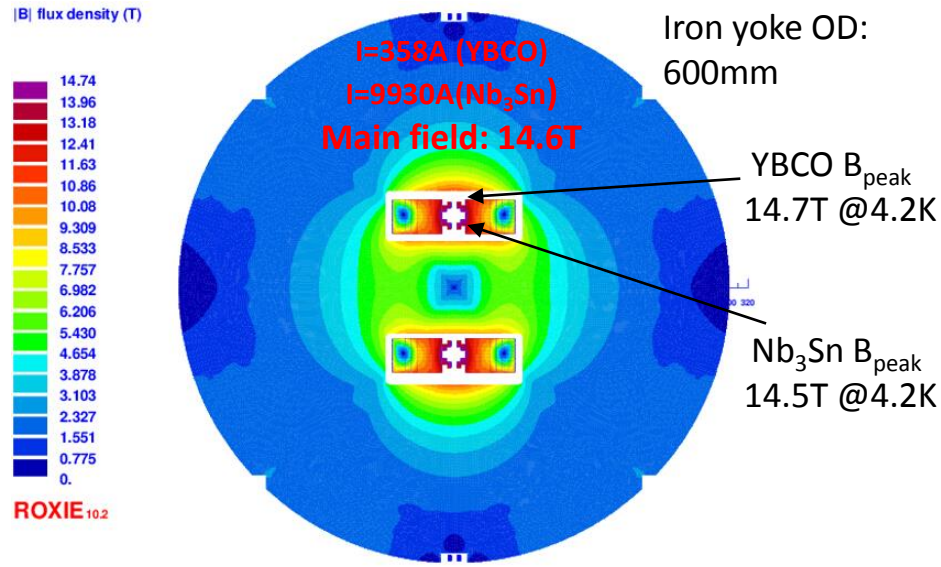
3. To fabricate a 14-T dipole magnet (with two apertures) with HTS and Nb_3Sn superconductors, to test the field optimization method of HTS & Nb_3Sn coils.



Coil configuration in the 1st quadrant



For per meter of such magnet, the required length of the strand: YBCO: 0.6 Km; Nb_3Sn in total: 9.12 Km



Field distribution in the cross section of the magnet

Main parameters of the cables

Cable	High t	Width-i	Width-o	Ns	Strand	Filament	Insulation
IHEPW1	5.8	1.5	1.5	14	IHEPWCJC	Nb3Sn	0.15
IHEPW3	12	1.5	1.5	29	IHEPWCJC	Nb3Sn	0.15
IHEPWYBCO4	4	0.2	0.2	1	IHEPWYBCO	YBCO	0

Main parameters of the strands

Strand	diam.	cu/sc	RRR	Tref	Bref	Jc@ BrTr	dJc/dB
IHEPWCJC	0.82	1	100	4.2	12	2400	400
IHEPWYBCO	-	-	-	4.2	12	1020	40

20-T Magnet Working Group in China

Northwest Institute for Non-ferrous Metal Research (NIN, Xi'an) & Western Superconducting Tech. Co, Ltd (WST, Xi'an)

Qualified Nb_3Sn supplier for ITER; R&D and production of High J_c Nb_3Sn and Bi-2212 superconductors.

Shanghai JiaoTong U.& Shanghai Superconductor Tech. Co., Ltd (SSTC, Shanghai)

R&D and production of ReBCO superconductor.

Tsinghua U. & Innova Superconductor Tech. Co., Ltd (INNOST, Beijing)

R&D and production of Bi-2223 superconductor.

Institute of Plasma Physics, Chinese Academy of Sciences (IPP, Hefei)

Test stand with 12-T background field, Nb_3Sn CICC cable fabrication;…

High Magnetic Field Laboratory, Chinese Academy of Sciences (CHMFL, Hefei)

Development of High field solenoids;…

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

30+ years R&D and production of conventional accelerator magnets, plus 10+ years R&D and production of superconducting magnets for particle detectors and industries.

and USTC, IMP, CIAE…

Welcome new members to join us!

20-T Magnet Working Group in China

20-T Magnet Working Group in China

高温与高场超导材料及其应用技术研讨会

2016 年 4 月 28 日-29 日

Workshop on HTS & HFS Materials and Applications

http://indico.ihep.ac.cn/event/5946/

会议组织委员会(按姓氏拼音排序)：

陈仙辉	中国科学技术大学
匡光力	中科院合肥物质科学研究院
李贻杰	上海交通大学
林良真	中科院电工研究所
王秋良	中科院电工研究所
王贻芳	中科院高能物理研究所
吴茂昆	台湾中研院
张平祥	西北有色金属研究院
周兴江	中科院物理研究所

主办：中科院高能物理研究所

协办：上海交通大学

中科院合肥物质科学研究院

承办：上海超导科技股份有限公司

中国科学院高能物理研究所 Institute of High Energy Physics Chinese Academy of Sciences

中国科学院合肥物质科学研究院 Hefei Institutes of Physical Science Chinese Academy of Sciences

上海交通大学 SHANGHAI JIAO TONG UNIVERSITY

上海超导科技股份有限公司 Shanghai Superconductor Technology Co., Ltd.

4 月 28 日（星期四）

09:00-09:10	欢迎致辞：张杰，主持人：王贻芳
09:10-10:50	未来大科学工程中的超导技术需求，主持人：王贻芳
09:10	CFETR 项目总体介绍 30' 万元照
09:40	CEPC-SPPC 总体介绍及概念设计 30'
10:10	SPPC 高场磁体初步概念设计及预研 20'
10:30	讨论 20'
10:50-11:20	集体合影 & 茶歇
11:20-12:40	超导机理研究进展，主持人：甘子钊
11:20	高温超导体的超导机理研究进展 20'
11:40	H-S 系统 200 K 超导电性的预测及实验确认 15'
11:55	铁基高温超导研究综述 25'
12:20	讨论 20'
12:40-14:00	午餐
14:00-15:25	超导材料研究进展（一），主持人：张裕恒
14:00	高场 REBCO 超导带材研制进展 20'
14:20	应用于低温磁场的高密度强钉扎 REBCO 超导带材 20'
14:40	低成本第二代高温超导带材产业化发展与应用挑战 20'
15:00	第二代高温超导带材成品率及产能提升技术探索 20'
15:20-15:40	茶歇
15:40-17:30	超导材料研究进展（二），主持人：张平祥
15:40	新型铁基超导材料的研究进展 20'
16:00	Bi-2212 高温超导线材的制备及性能进展 15'
16:15	面向 65K、3T 应用的 REBCO 超导带材的探索 15'
16:30	高场 Nb_3Sn 超导线材研制进展 15'
16:45	基于第二代高温涂层导体的准各向同性超导股线研究进展
17:00-17:45	讨论（主题：未来发展思路）45'
18:00-20:00	晚宴

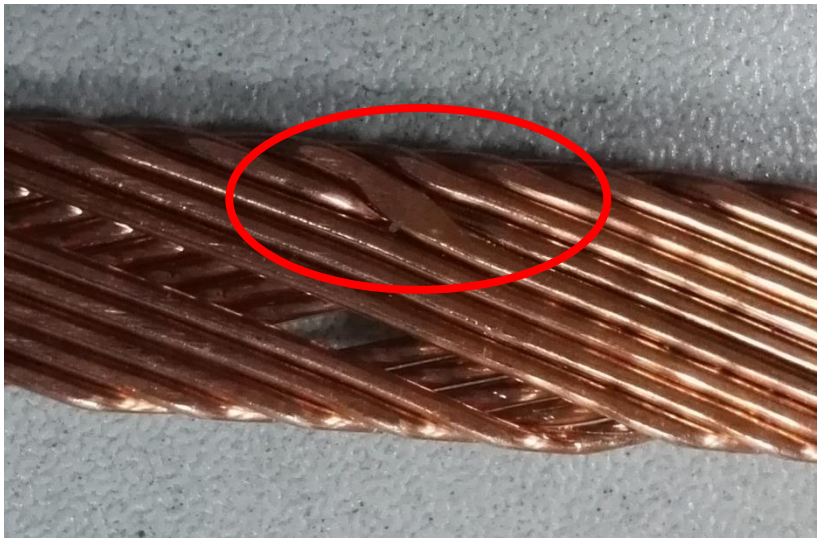
4 月 29 日（星期五）

08:45-10:25	超导应用一（磁体技术），主持人：匡光力
08:45	近物所未来五年的超导需求 20'
09:05	ITER 超导磁体系统及 CICC 导体研制 15'
09:20	强场混合磁体系统 15'
09:35	超导电机研制进展 15'
09:50	超导磁体技术综述 25'
10:15-10:35	茶歇
10:35-12:20	超导应用二（能源电力），主持人：林良真
10:35	超导限流器在可再生能源电网应用探讨 20'
10:55	超导储能研制进展 15'
11:10	第二代高温超导带材接头及封装技术研究进展 15'
11:25	超导风力发电技术研制进展 15'
11:40	高温超导磁悬浮交通研究进展 15'
11:55	讨论 25'
12:20-14:00	午餐
14:00-16:00	集体讨论与总结（主题：未来发展思路）主持人：

Development of Nb_3Sn Rutherford Cable

Y. Zhu (WST) et al.

Collaboration between WST, Toly Electric, Changtong Electric and IHEP



Superconducting Rutherford Cable fabricated by Toly Electric with WST ITER type Nb_3Sn strand

Superconducting Rutherford Cable fabricated by Changtong Electric with WST ITER type Nb_3Sn strand

Development of Nb_3Sn Rutherford Cable

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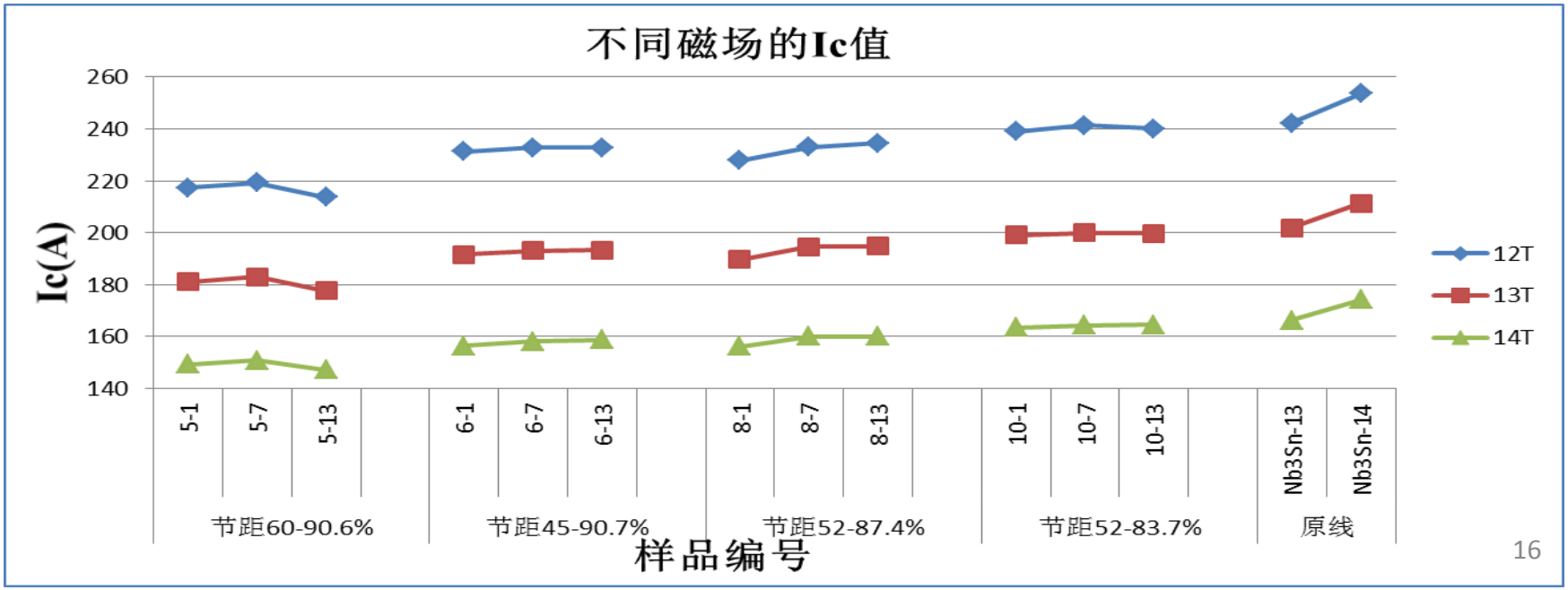
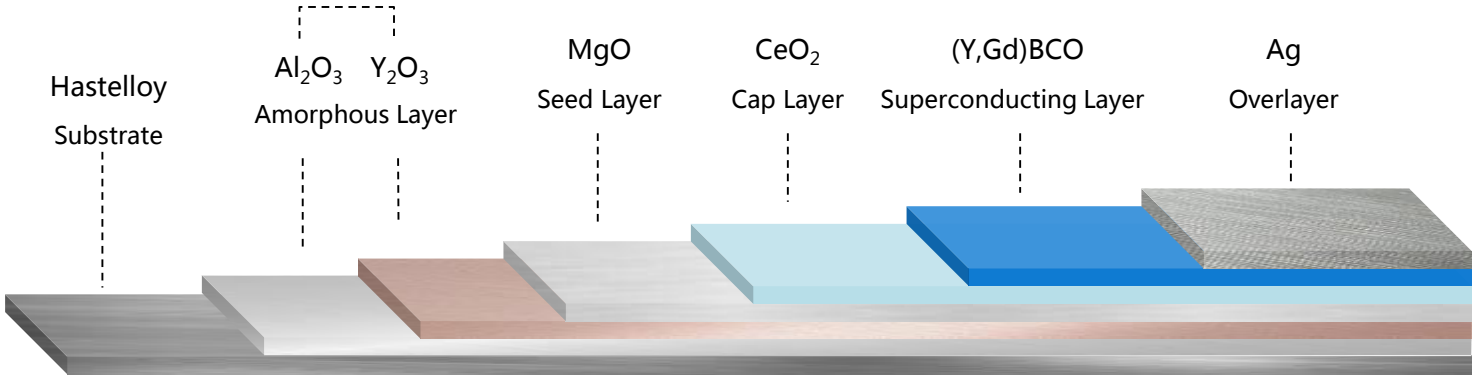
Pitch length	Filling factor (%)	Ic degradation(%)	Average Ic degradation(%)	备注
60	90.6	9.39~16.04	12.48~12.67	损降最大
45	90.7	3.84~10.33	6.31~7.42	损降性能相当
52	87.4	3.18~10.39	6.51~6.76	
52	83.7	0.33~6.2	3.13~3.60	损降最小

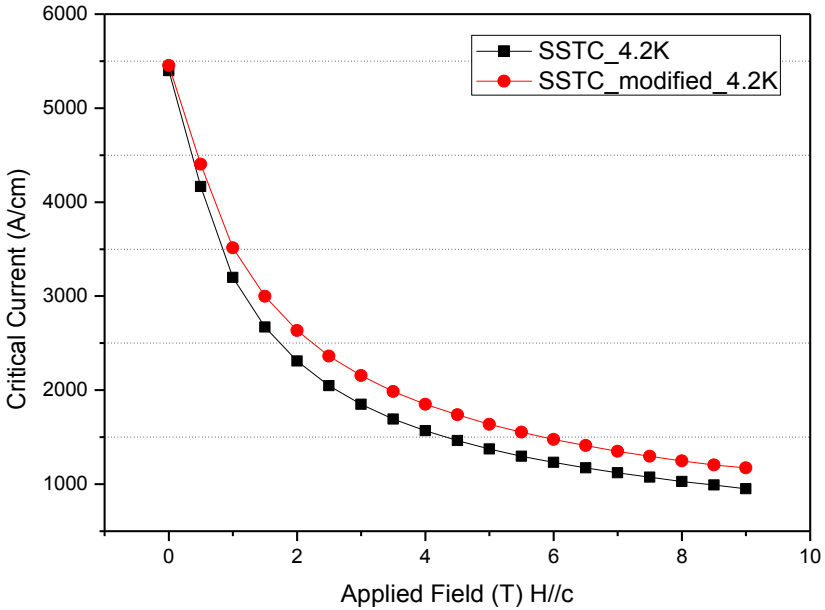


R&D of High Field ReBCO Tape by SSTC

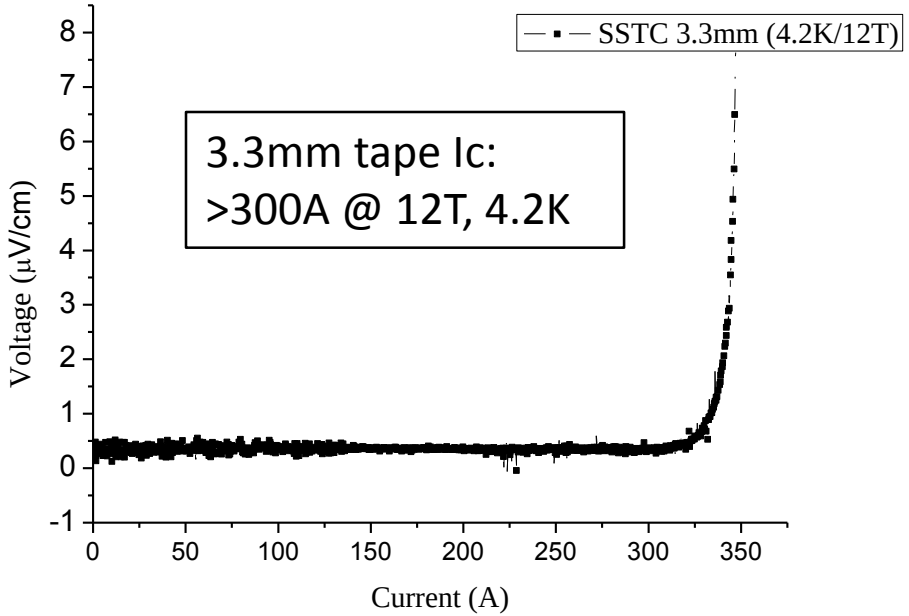
SSTC



Architecture of type II superconductor from SSTC



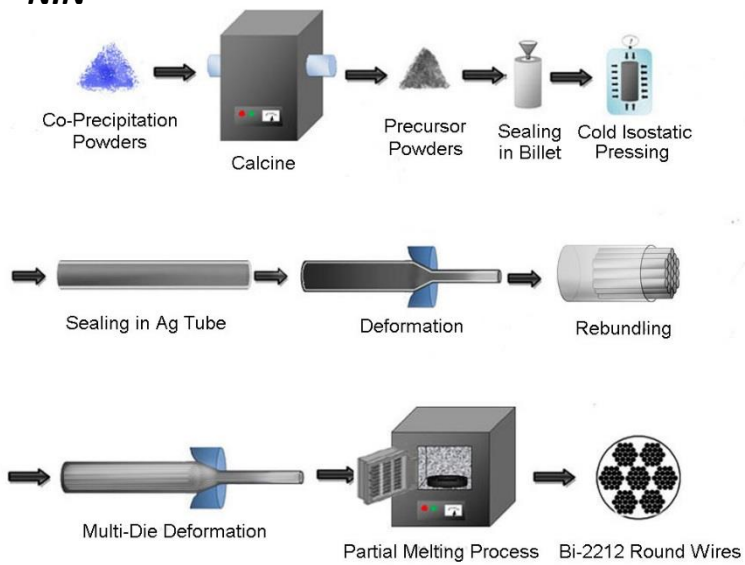
Improved performance of SSTC tape at 4.2K



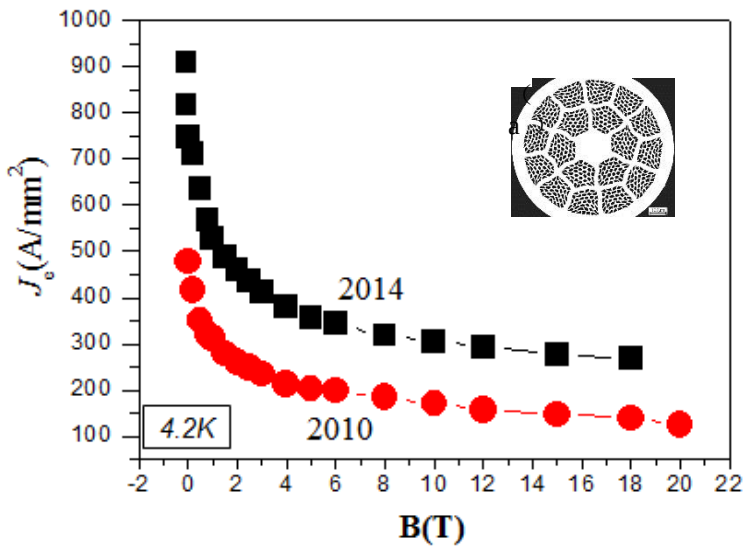
Performance of SSTC tape at 4.2K and 12T

R&D of Bi-2212 Superconductor by NIN

NIN



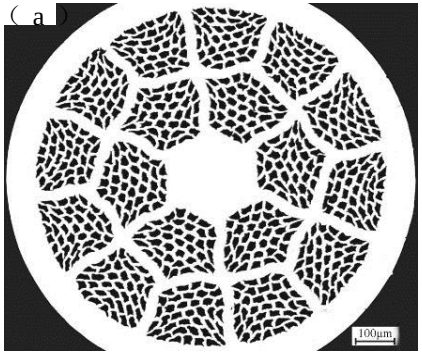
PIT制备Bi-2212线材



Fabrication of hundred meter level Φ1.0mm strands

4.2K、0T：Jce 920A/mm^2，Jc 4400A/mm^2。
4.2K、20T:Jce 270A/mm^2，Jc 1200A/mm^2。

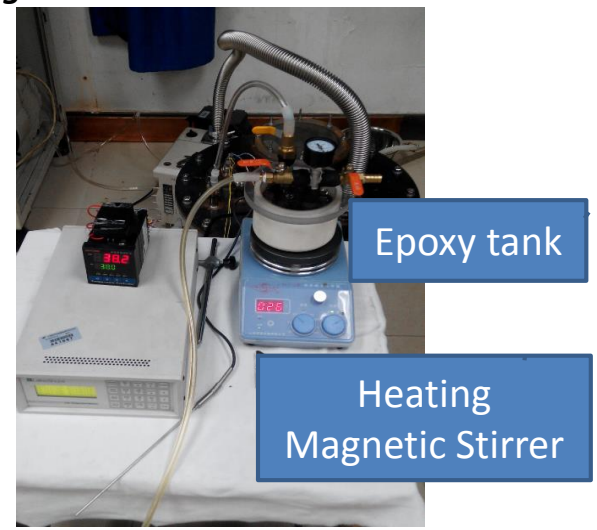
An Over-pressure furnace is ready for heat treatment of strands

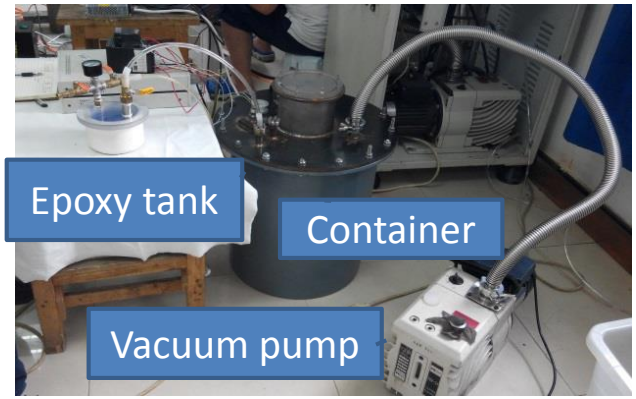


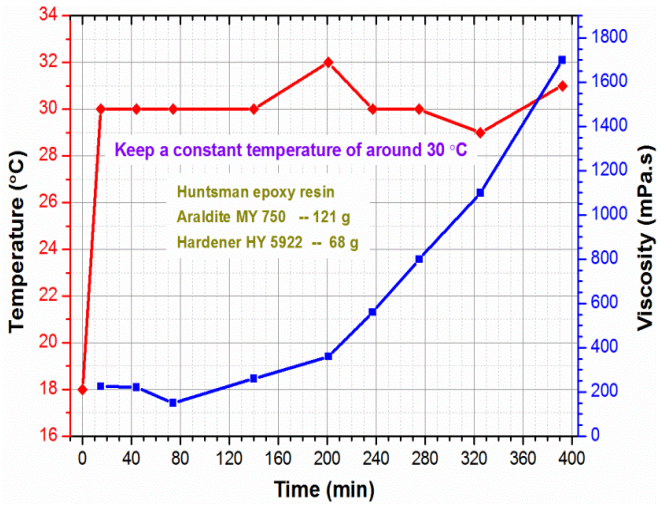
Bi-2212 stands and CICC conductor under development

Dummy Coil Fabrication

Kai Zhang, Chengtao Wang et al.





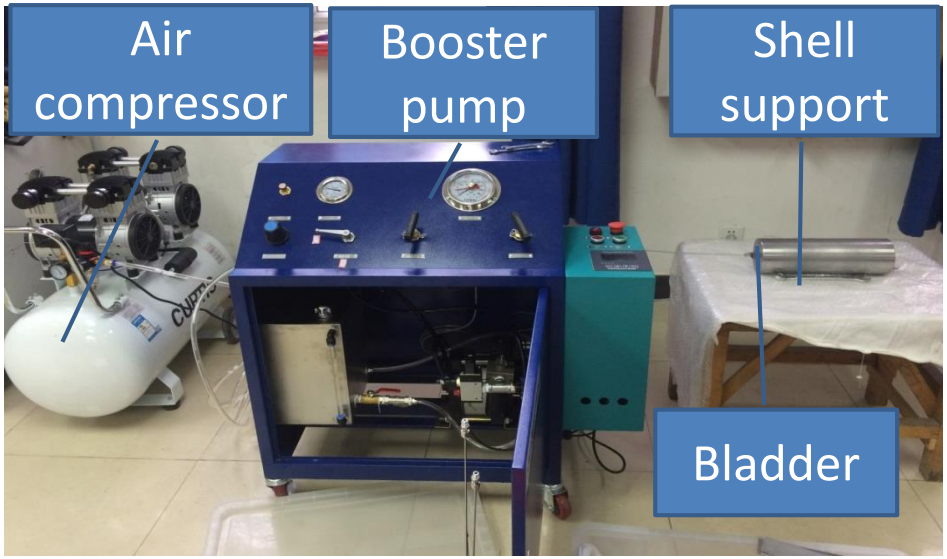


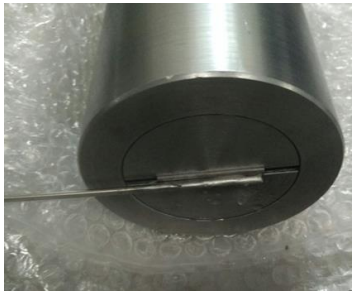
Viscosity increase by time at 30°C (Huntsman epoxy)

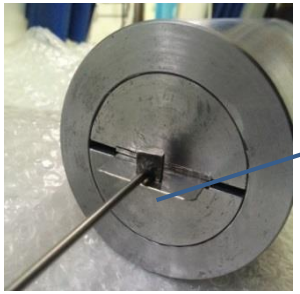
- **Epoxy: Huntsman epoxy & CTD-101K.**
- **0.1 Mpa pressure be applied to the tank after epoxy filling.**
- **Preheat temperature: about 30°C**
- **Practice with copper Rutherford cables.**

Practice of Shell-based Structure

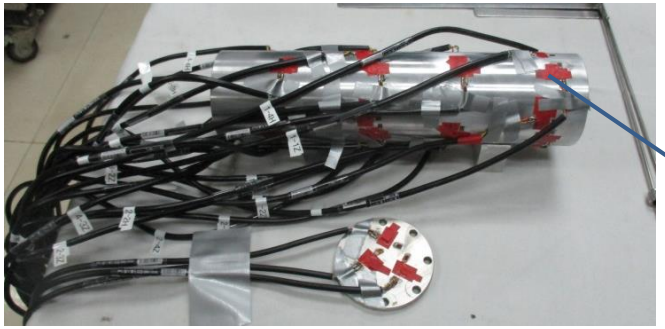
Kai Zhang, Chengtao Wang et al.







Bladder004



Strain sensor

Bladder001-003

Test results

Bladder No.	Water pressure（MPa）
# 001	35
# 002	45
# 003	26
# 004	35

The present thickness of the shim and round tube of the bladder is 0.3 mm.

It's obvious that the welding area between the shim and round tube is week where water leak always appear under high water pressure.

We have increased the thickness of the shim and round tube to 0.5 mm, the new bladder will be tested soon.

Summary

- *Design study of the SPPC high field magnets is ongoing.*
- *A series of 15T level model magnets will be fabricated in the next three years at IHEP, to investigate some fundamental problems for high field magnet R&D.*
- *Based on the collaboration between WST, Toly Electric, Changtong Electric and IHEP, development of high field Nb_3Sn Rutherford cable has got significant progress, almost ready for real cable fabrication.*
- *R&D of HTS superconductors for high field application is ongoing by SSTC and NIN.*
- *Preparation for the model magnet fabrication is ongoing at IHEP*
- *A national workshop on HTS materials and applications will be held at the end of this month in Shanghai.*
- *Next steps: model magnet development, funding application, international collaboration with LBNL, BNL and other interested labs).*

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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