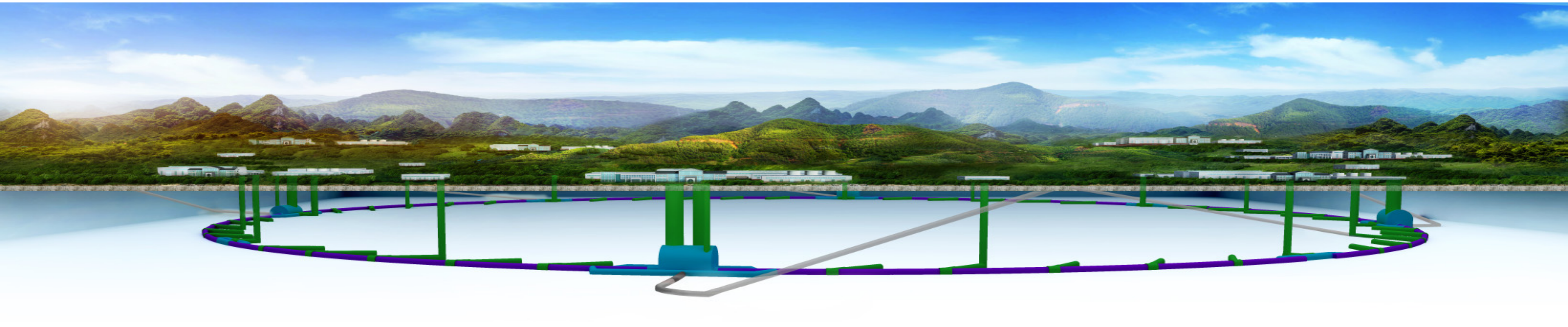
High Field Superconducting Magnet Program for Accelerators in China

Qingjin XU
Institute of High Energy Physics (IHEP)
Chinese Academy of Sciences (CAS)
2019.5



Team Members & Collaborators

IHEP-CAS: *Chengtao Wang, Zhan Zhang, Shaoqing Wei, Lingling Gong, Da Cheng, Yingzhe Wang, Ershuai Kong, Zhen Zhang, Xiangchen Yang, Quanling Peng, Qing Qin, Yifang Wang,*

IEE-CAS: *Xianping Zhang, Dongliang Wang, Yanwei Ma*

HIPS-CAS: *Huajun Liu, Tao Zhao, Yanlan Hu,…*

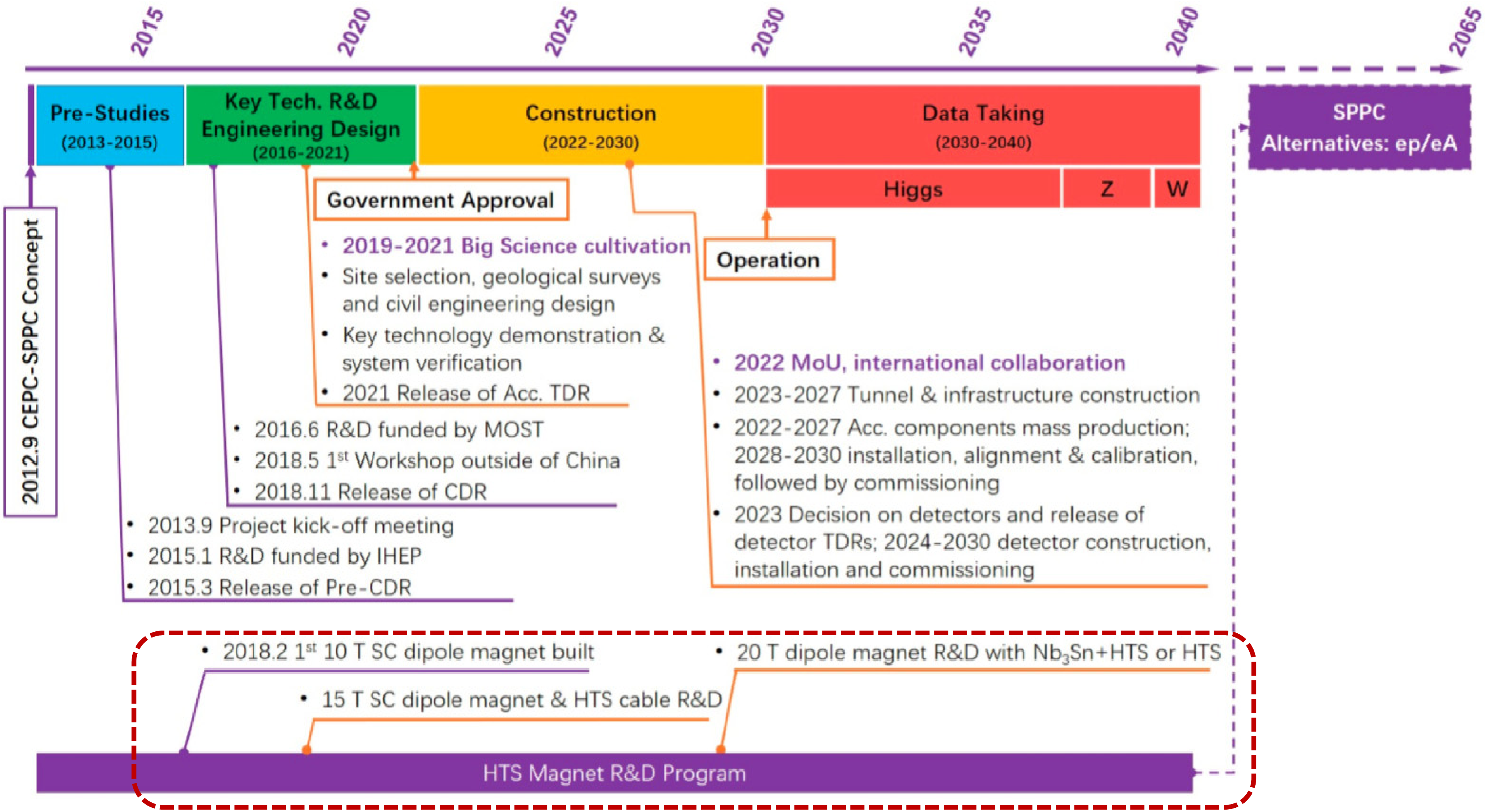
IMP-CAS: *Wei Wu, Yu Liang, Wenjie Liang, Lizhen Ma,…*

WST: *Meng Li, Chao Li, Bo Wu, Yanmin Zhu, Jianwei Liu, Jianfeng Li,…*

Toly Electric: *Yu Zhao, Hean Liao, Bingxing Lu,…*

**Work supported by the Strategic Priority Research Program of the Chinese Academy of Sciences (CAS) Grant No. XDB25000000, the Hundred Talents Program of CAS and National natural Science Foundation of China Grant No. 11675193, 11575214, 11604335.*

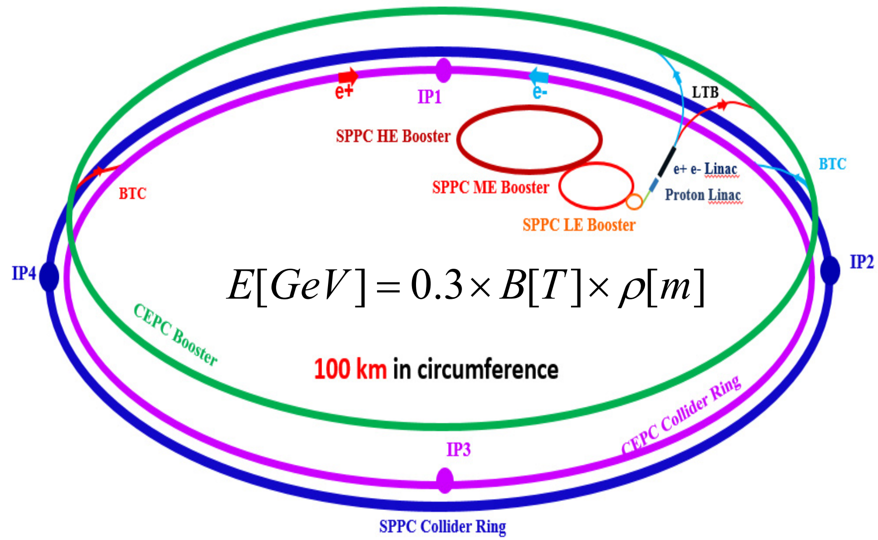
CEPC-SPPC Project Timeline



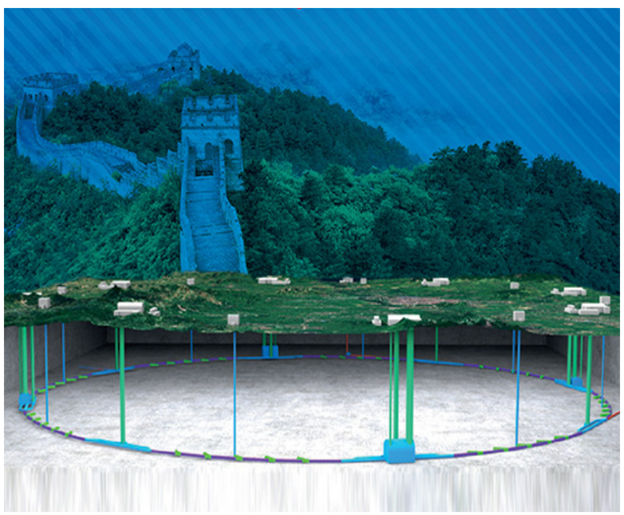
SPPC Magnet Design Scope (V201701)

Main dipoles

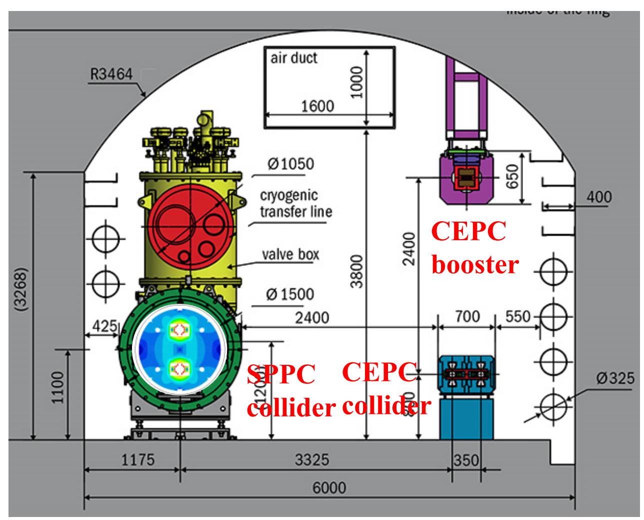
- *Field strength: 12-24 Tesla to get 75-150 TeV in a 100-km tunnel*
- *Baseline Iron-Based Superconductor (IBS), Nb_3Sn/ReBCO as options*
- *Aperture diameter: 40~50 mm*
- *Field quality: 10^{-4} at the 2/3 radius*



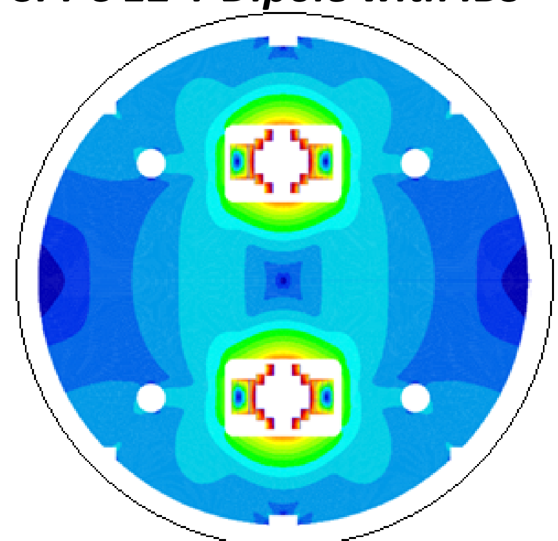
Site study of the CEPC-SPPC



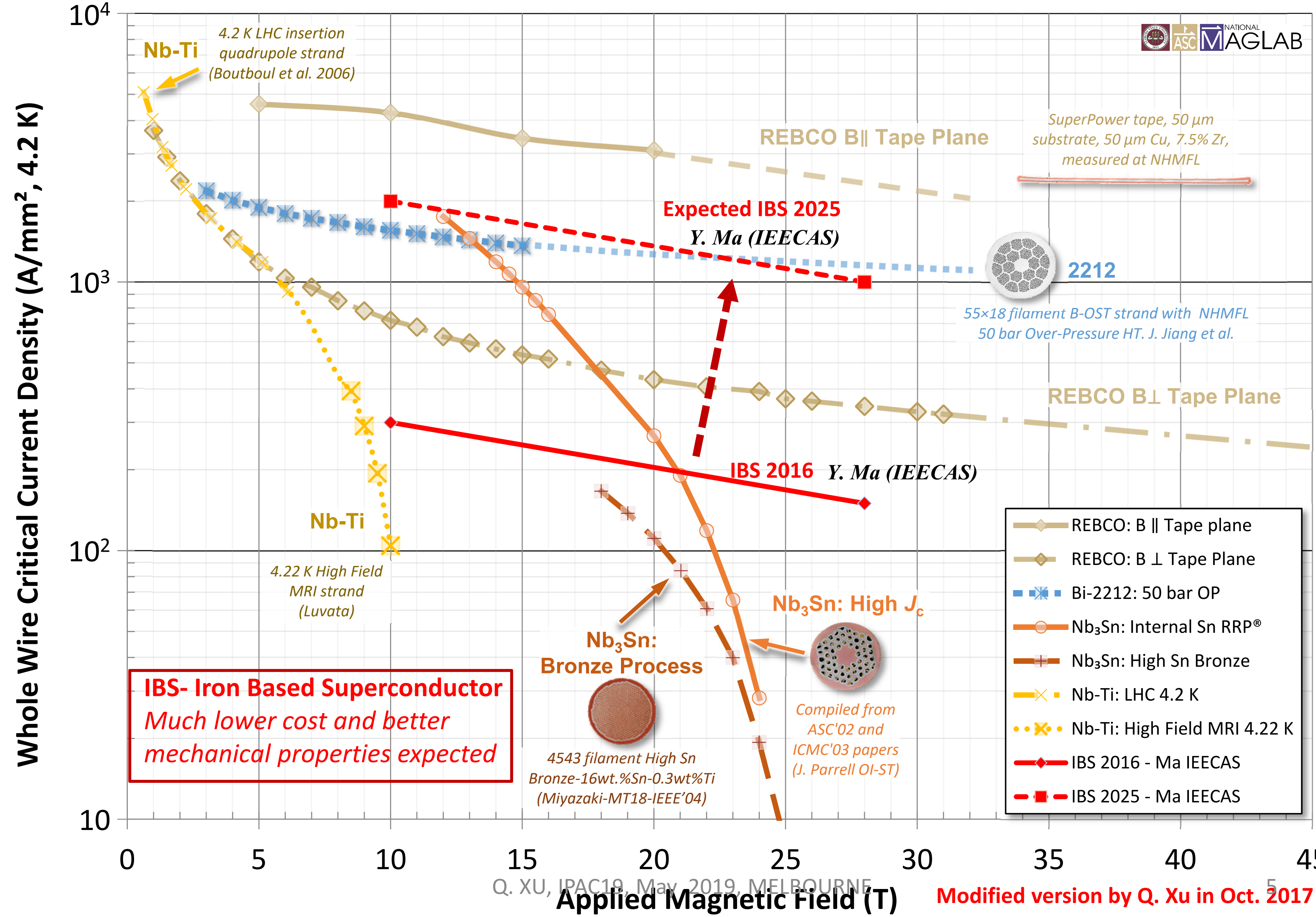
6-m width Tunnel for CEPC-SPPC



SPPC 12-T Dipole with IBS



J_e of IBS: 2016-2025



Domestic Collaboration for HTS R&D

Applied High Temperature Superconductor Collaboration (AHTSC)

- ➢ R&D from **Fundamental sciences** of superconductivity, **advanced HTS superconductors** to **Magnet & SRF technology**.
- ➢ **Regular meetings every 3 months** from Oct. 2016
- ➢ **Goal** :
- • **Increasing J_c** of iron-based superconductor **by 10 times**.
- • **Reducing the cost** of HTS conductors to be **similar with "NbTi conductor"**
- • Industrialization of the **advanced superconductors**, **magnets and cavities**

Domestic Collaboration for HTS R&D

Applied High Temperature Superconductor Collaboration (AHTSC)

- R&D from **Fundamental sciences** of superconductivity, **advanced HTS superconductors** to **Magnet & SRF technology**.
- **Regular meetings every 3 months** from Oct. 2016
- **Goal** :

- **Increasing J_c** of iron-based superconductor **by 10 times**.
- **Reducing the cost** of HTS conductors to be **similar with "NbTi conductor"**
- Industrialization of the **advanced superconductors, magnets and cavities**

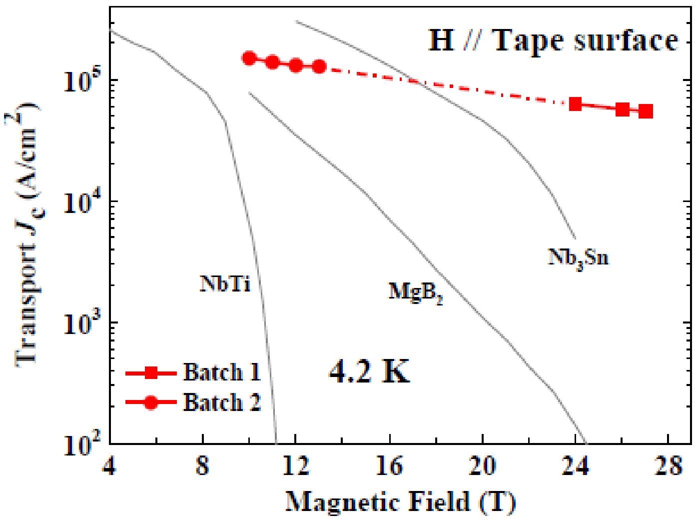
Proposal for
Strategic Priority Research Program of Chinese Academy of Sciences (CAS)
Science and Technology Frontier Research
for High Field Applications of High Temperature Superconductors

Ranked No. 1 in 7 candidates by Academic Committee of CAS

360M RMB for 2018-2023

Latest Progress on IBS wires

Y. Ma (IEECAS) et al.



Transport property of IBS tape (2017):

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

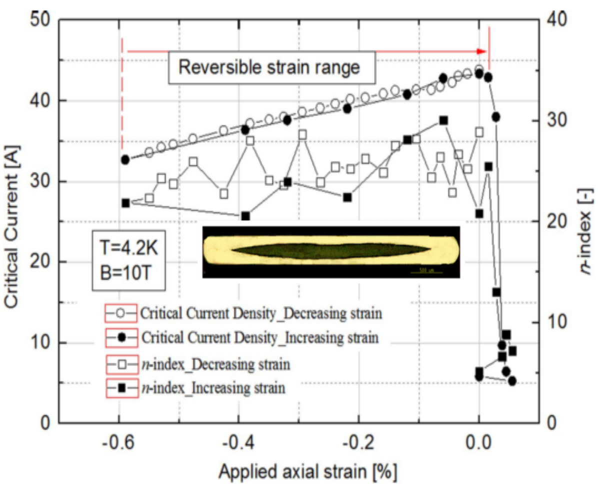
I_c~423 A (J_c>1450 A/mm^2) @ 4.2 K, 12 T

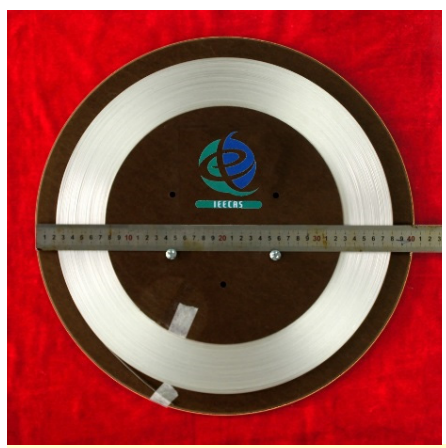
100 meter long tape:

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

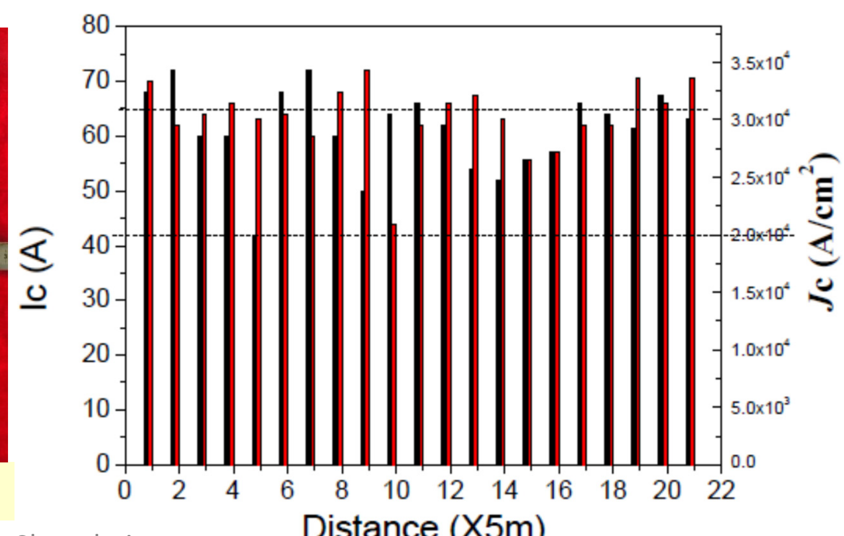
115 meter 7-core tape

Supercond. Sci. Technol. 31 (2018) 015017

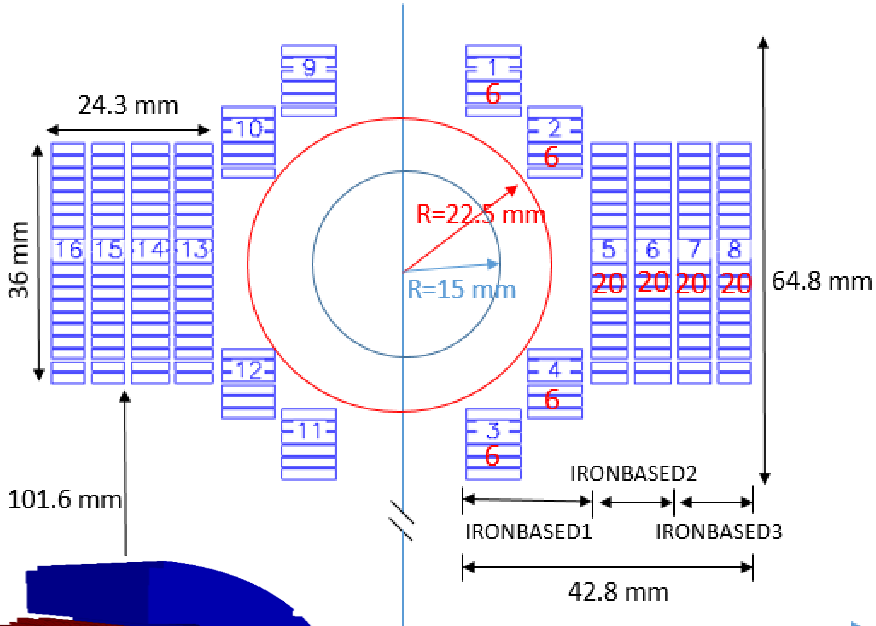


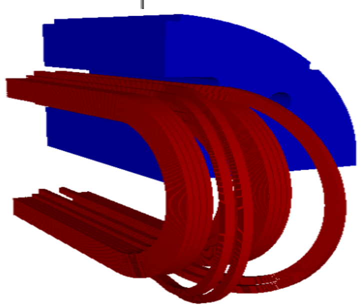


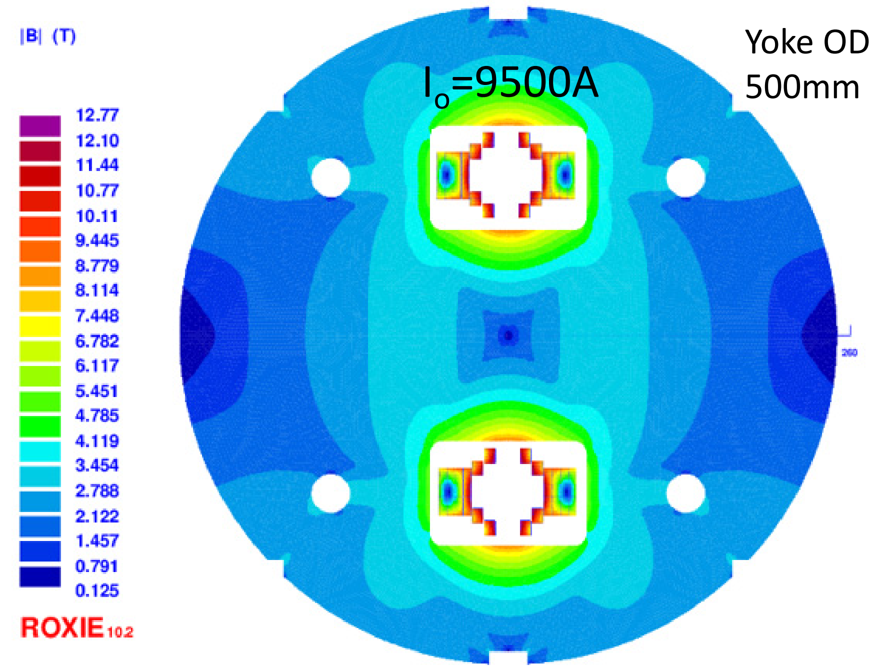
IEEE TAS 27 (2017) 7300705

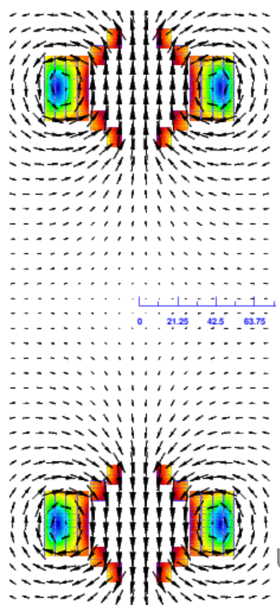


The 12-T Fe-based Dipole Magnet









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

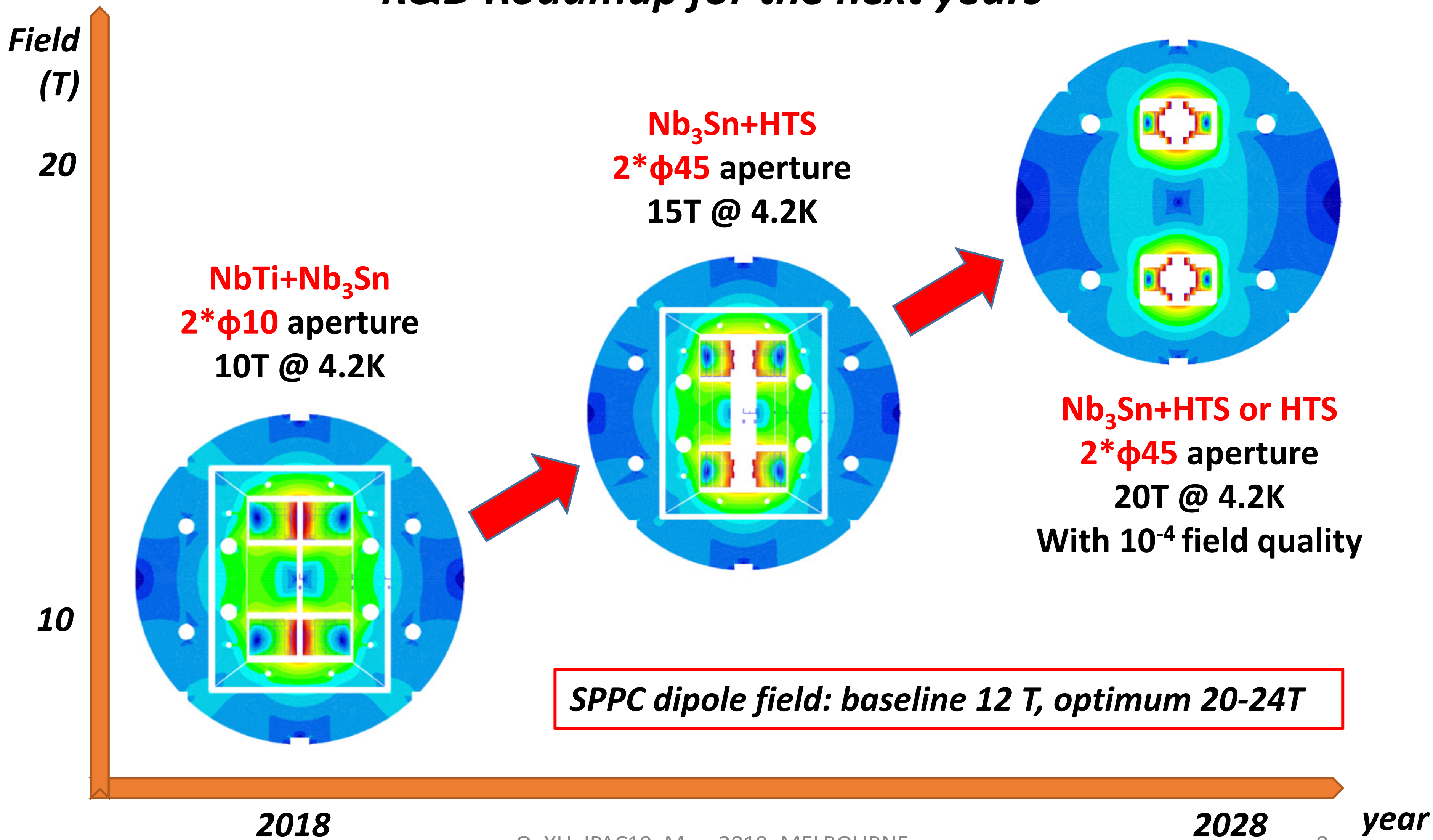
Conceptual design with expected J_e of IBS in 2025

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

- For 100-km SPPC, **3000 tons of IBS** is needed
- Target cost of IBS: **20 RMB /kAm @12 T**
- Total cost for IBS conductors: **~10B RMB**

R&D of High Field Dipole Magnets

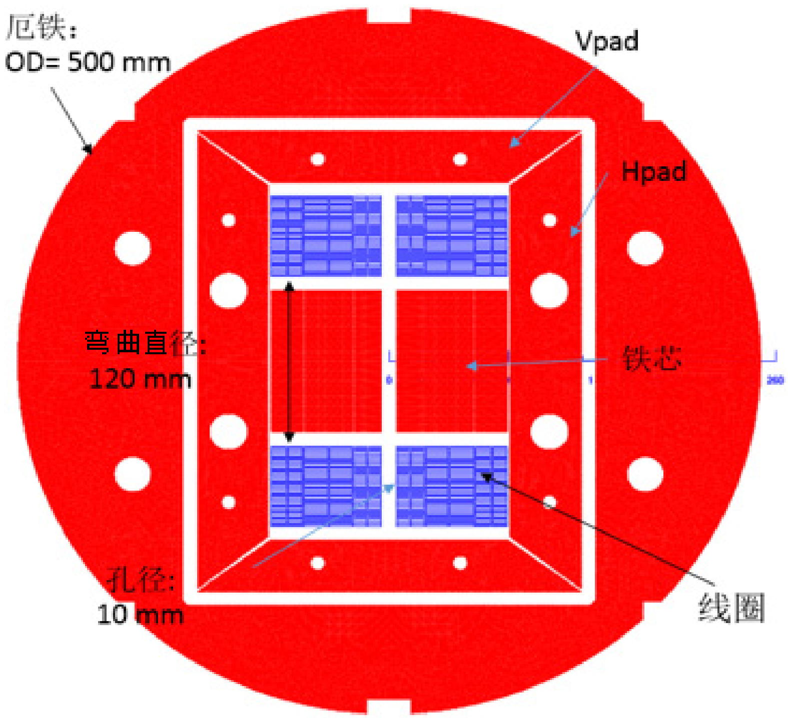
R&D Roadmap for the next years



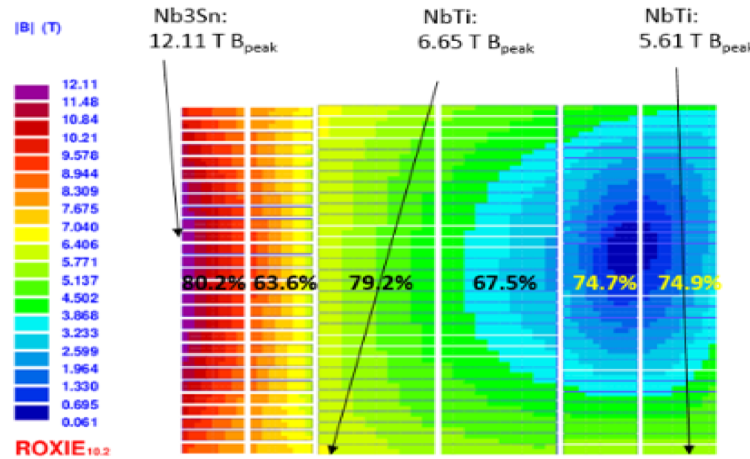
R&D of High Field Dipole Magnets

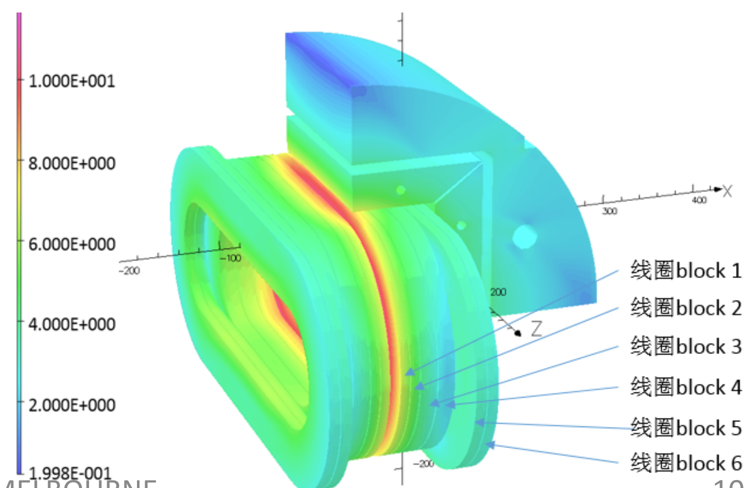
The 1st High Field Dipole LPF1: NbTi+Nb_3Sn

Cross section of LPF1



Magnetic field distribution

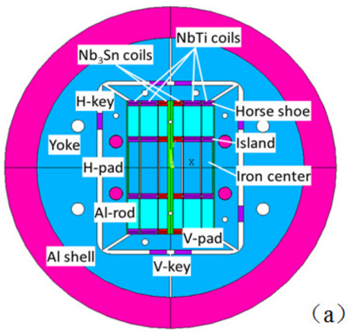


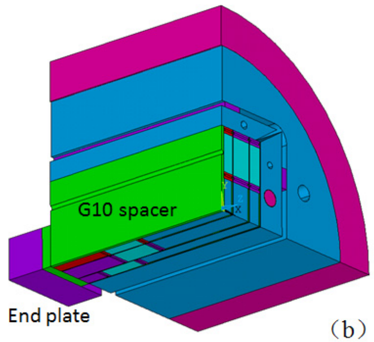


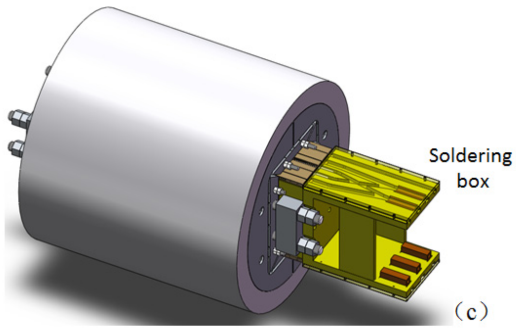
Main parameters of the strands

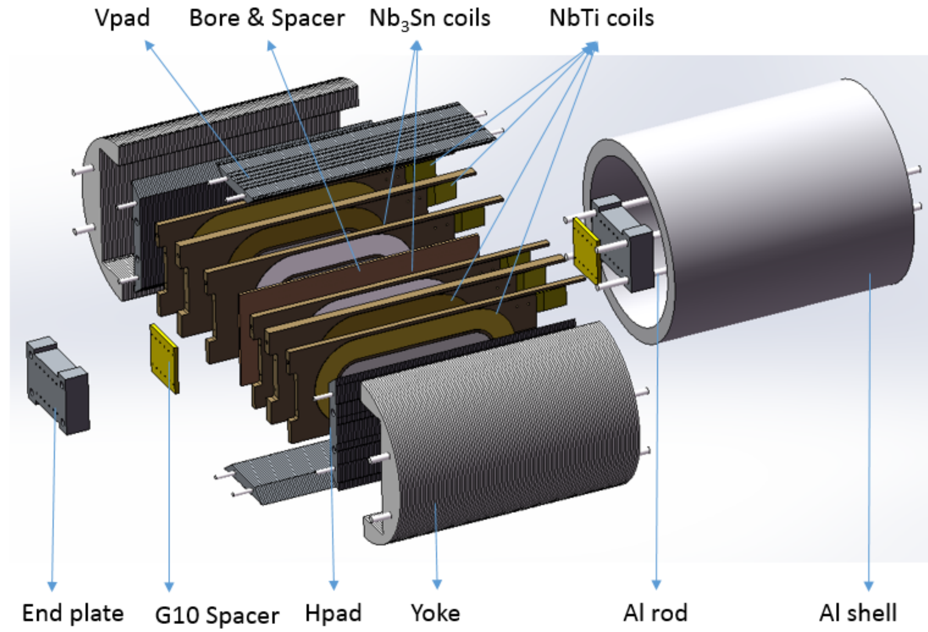
Strand	diam. (mm)	cu/sc	RRR	Tref (K)	Bref (T)	Jc@ BrTr (A/mm2)	Ic@ BrTr (A)
Nb3Sn	0.802	1	200	4.2	12	2700	682
NbTi	0.82	1	130	4.2	5	2613	690

R&D of High Field Dipole Magnets



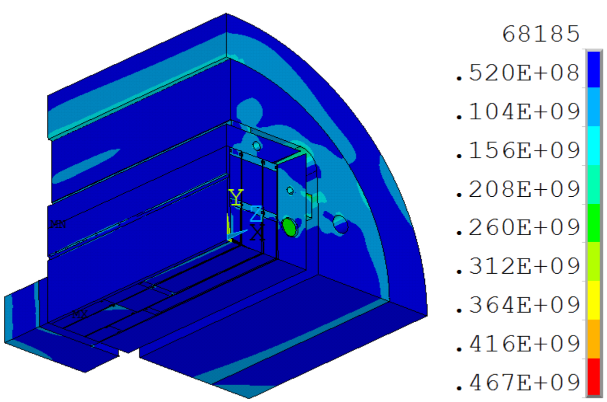




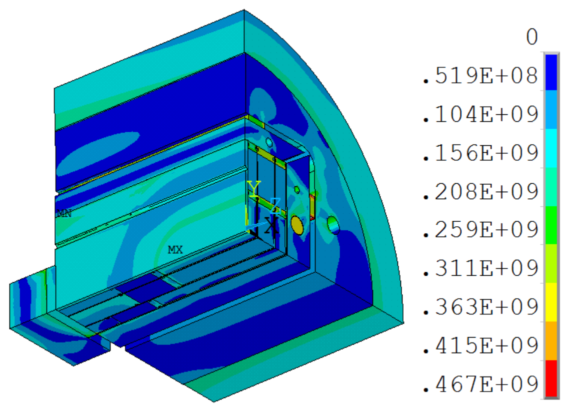


Mechanical FEA magnet model

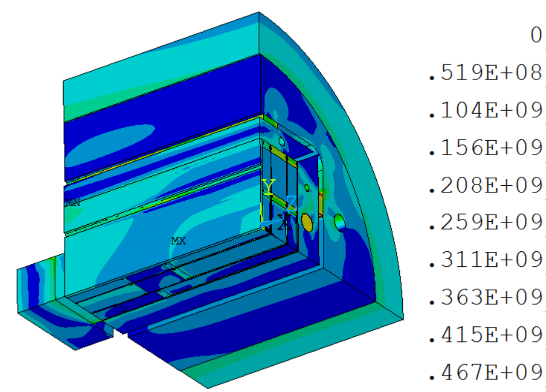
3D CAD configuration of LPF1



Assembly

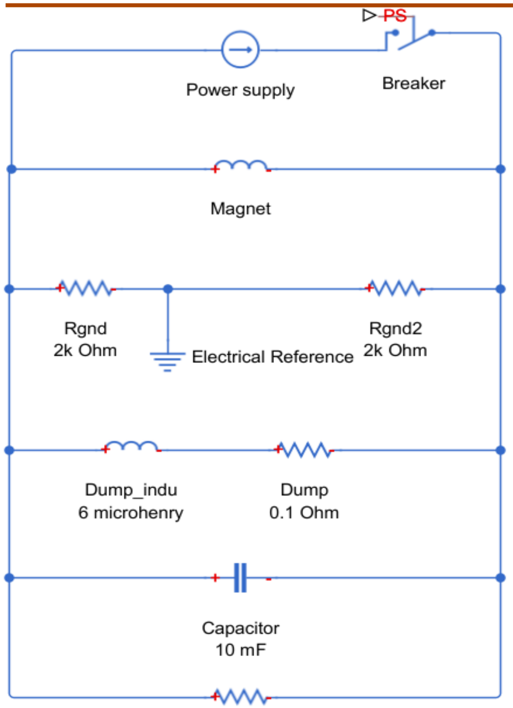


4.2 K

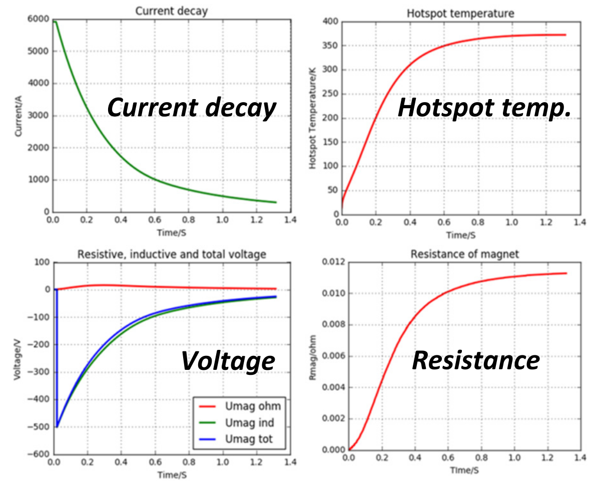


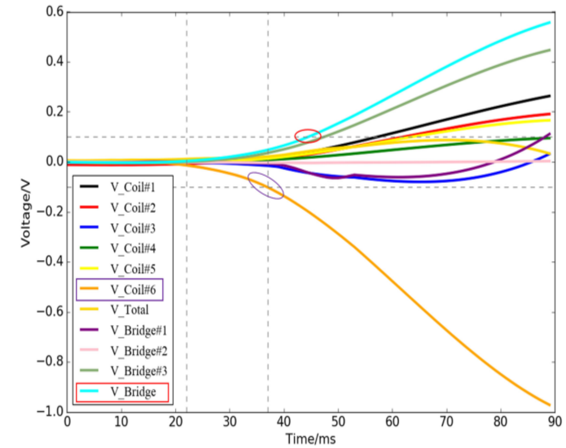
Excitation

R&D of High Field Dipole Magnets



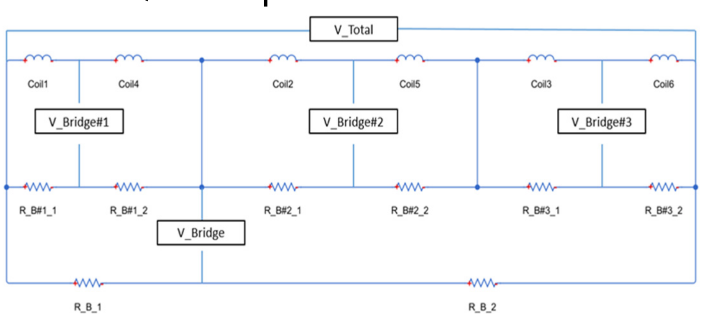
Quench protection circuit

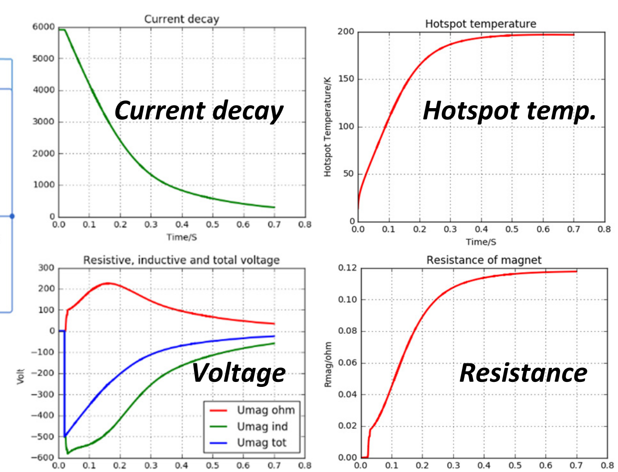


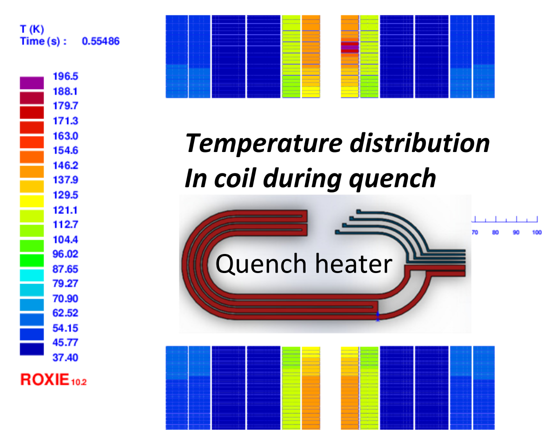


Quench simulation with dump resistor only

Quench simulation with dump resistor and heaters







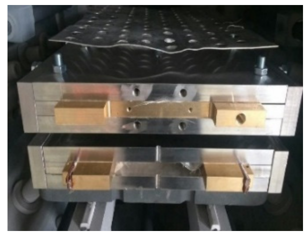
$$\int_0^{\infty}[I_{mag}\ (t)]^2 dt = \int_{T_{cs}}^{T_{max}} f_{cu}[A_{cable}]^2 \frac{(\gamma C_p(T))}{\rho_{cu}(B,T)} dT$$

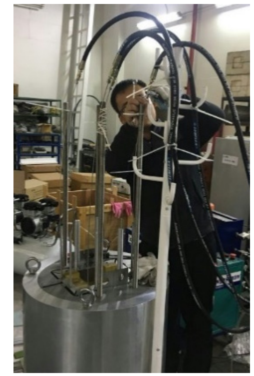
R&D of High Field Dipole Magnets

Fabrication Procedures of the High Field Magnets and Challenges

Tension control, deformation
J_c and RRR degradation, Flux jump…

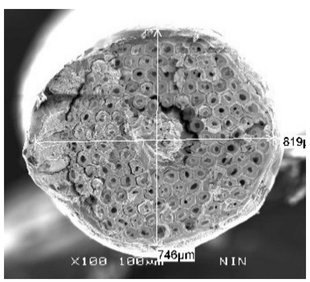
Temperature control, Thermal stress control
J_c and RRR degradation.



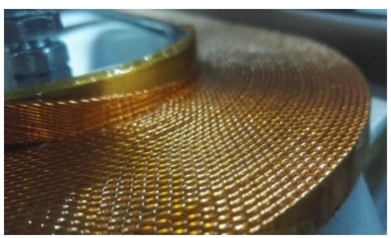


Pre-stress control
Stress of coils, Mechanical Stability…

Cabling ➡ Coil winding ➡ HT ➡ VPI ➡ Magnet assembly ➡ Test

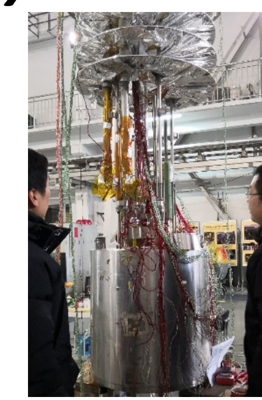


Material, Structure, Processing,…
$J_{c,}$ RRR, Cu ratio, Filament size…



Stress control, Size control, Electrical insulation
J_c and Field quality degradation, Electrical short…

Impregnation quality control:
type of epoxy, procedures; Mechanical strength and stability

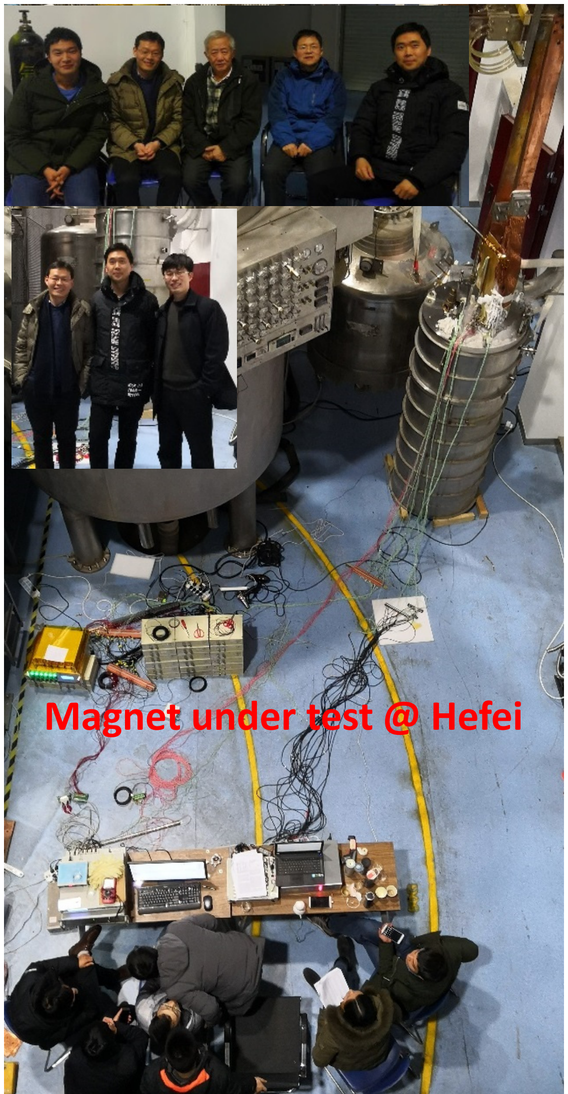


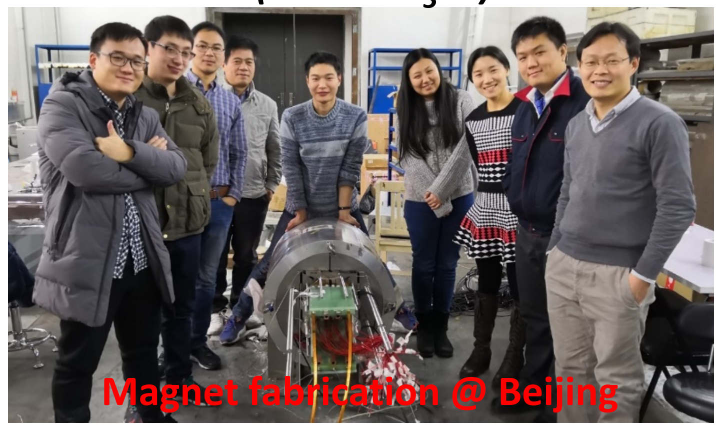
EM force, Quench protection
Training, Strain of coils…

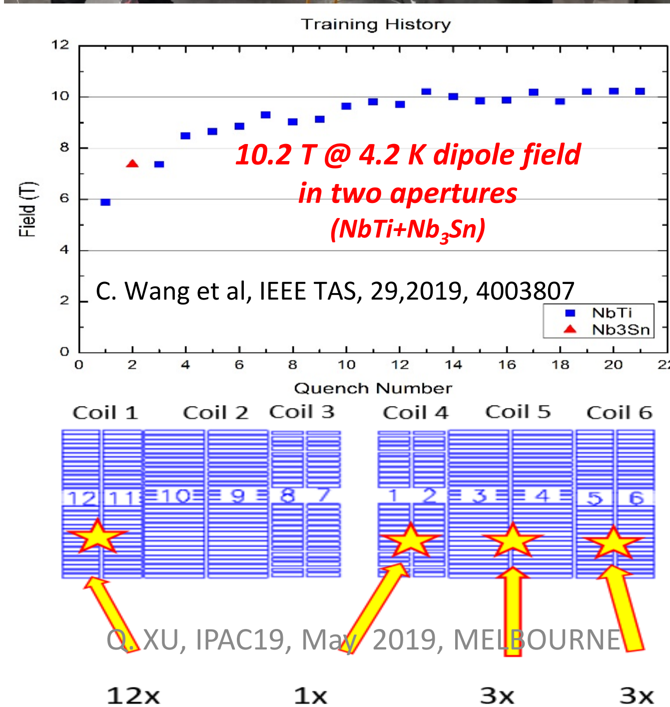
R&D of High Field Dipole Magnets

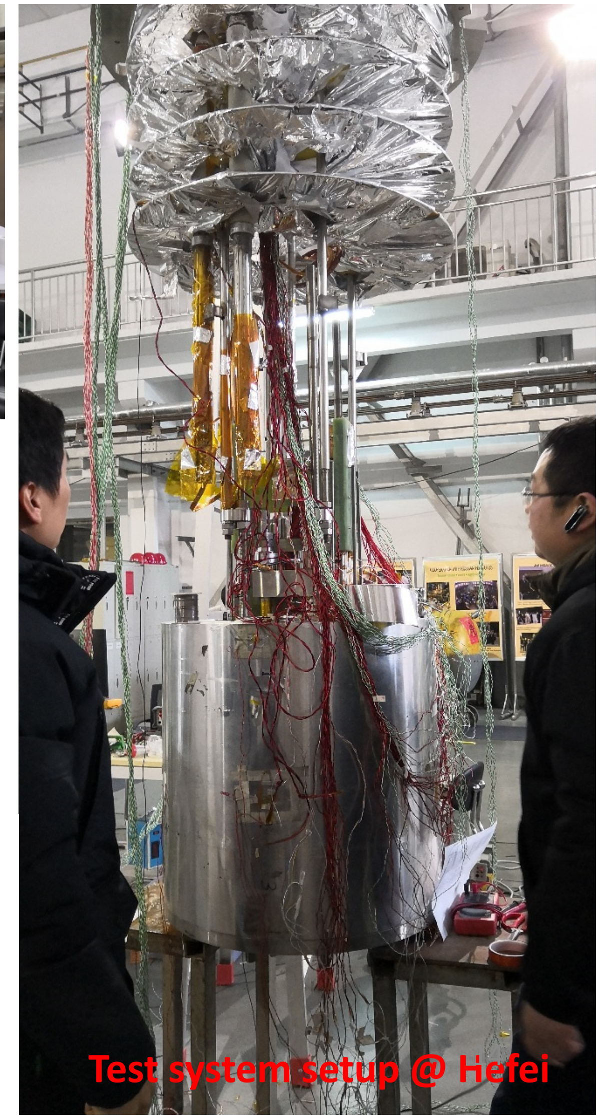
Test results of the 1st high-field dipole magnet in China Feb. 2018

(NbTi+Nb_3Sn)





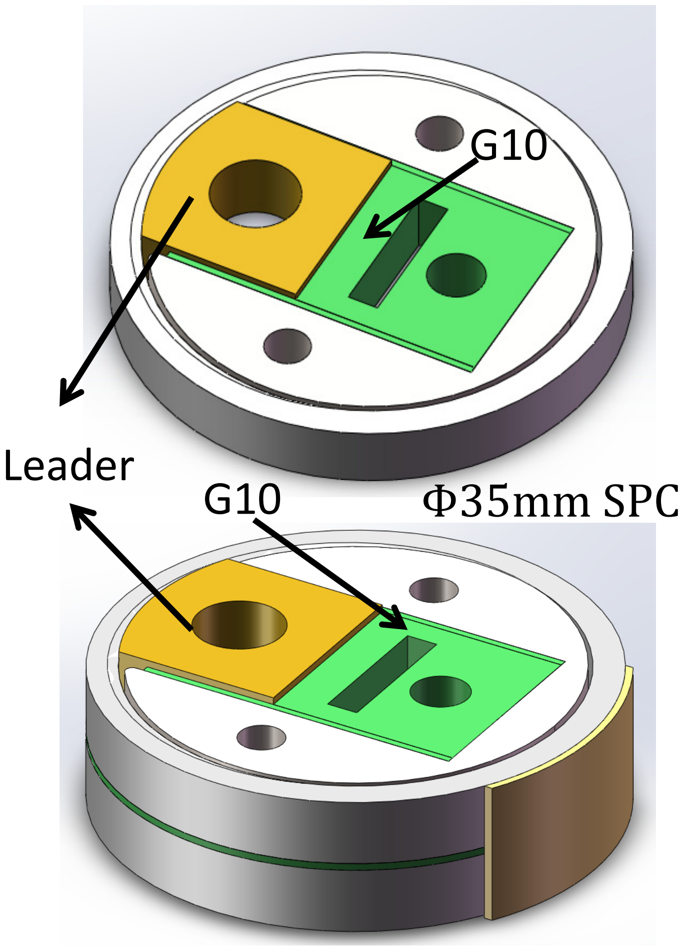




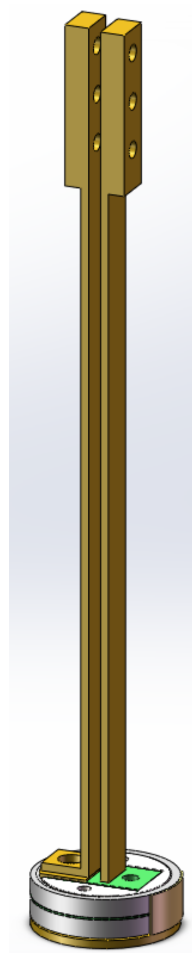
R&D of High Field Dipole Magnets

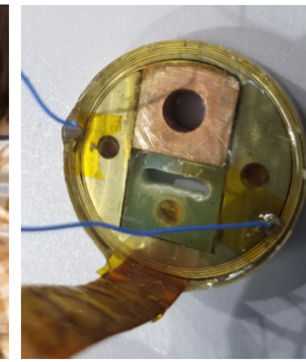
Fabrication of IBS solenoid coil and test at 24T

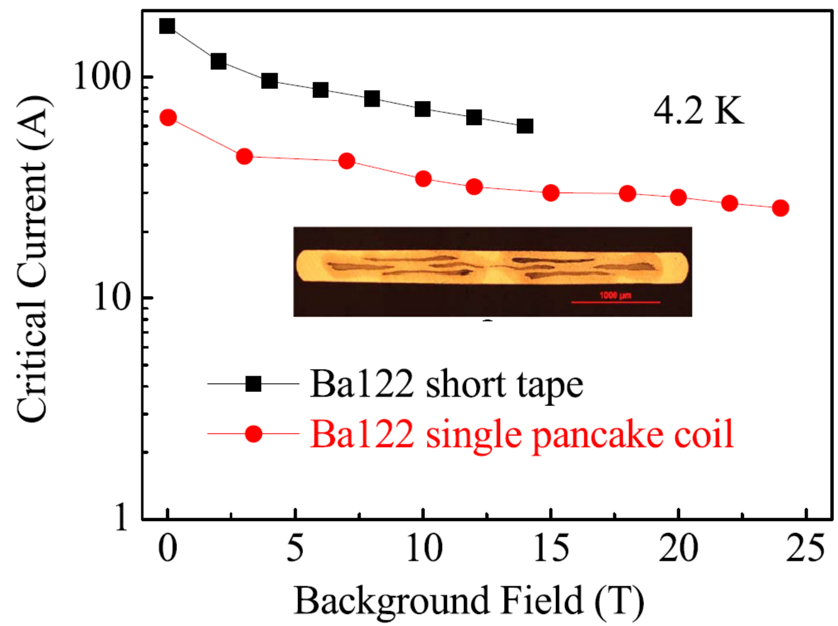
Single and double pancake IBS coils



Φ35mm DPC





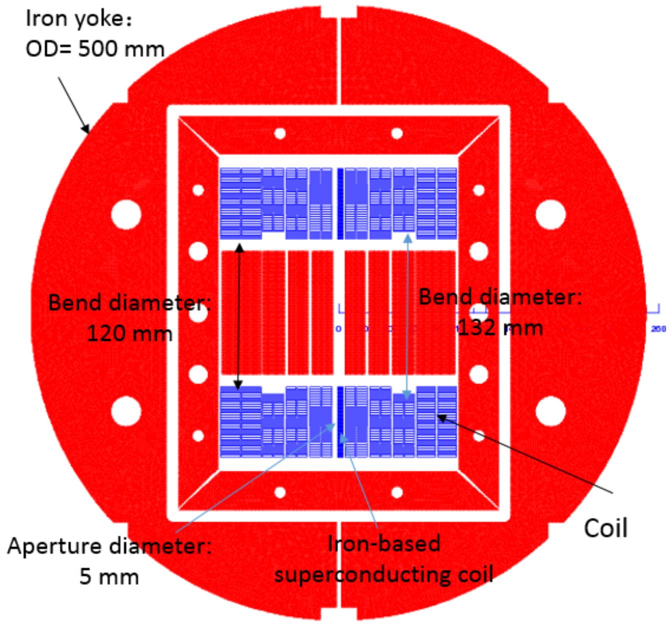


D. Wang et al 2019 Supercond. Sci. Technol. 32 04LT01

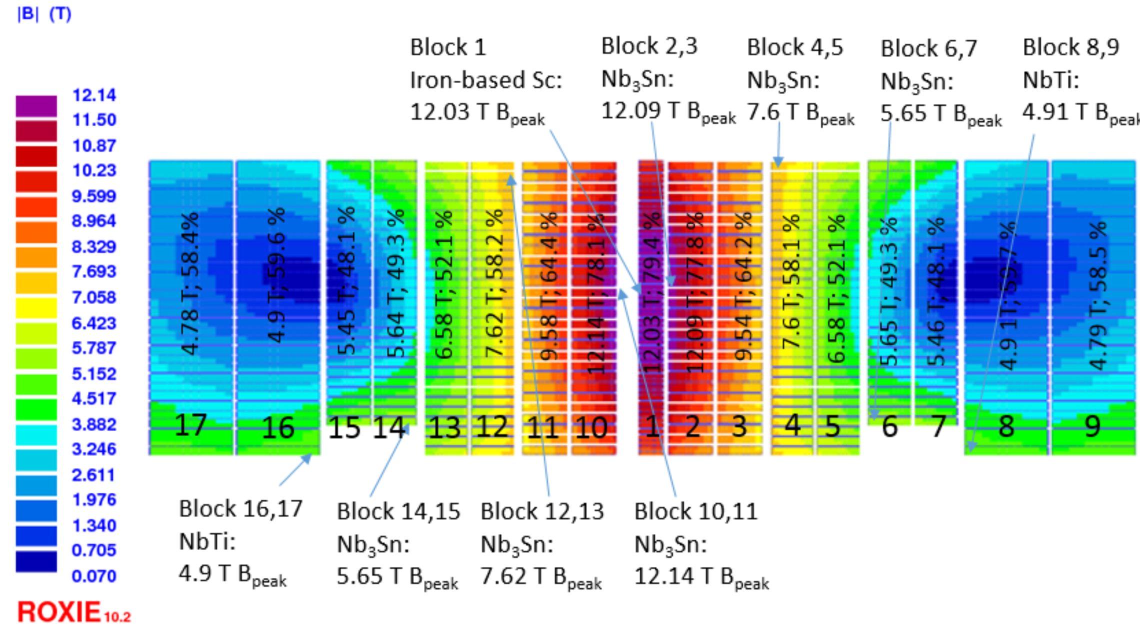
R&D of High Field Dipole Magnets

Ongoing: LPF2-12T model dipole with graded coils

NbTi+Nb_3Sn+IBS



Cross section of LPF2-1

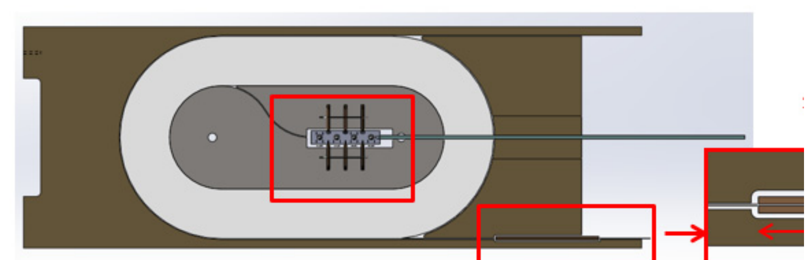


Magnetic field distribution （2D）

145m NbTi cable

145m Nb_3Sn cable
Jc~2000A/mm2@4.2K, 12T

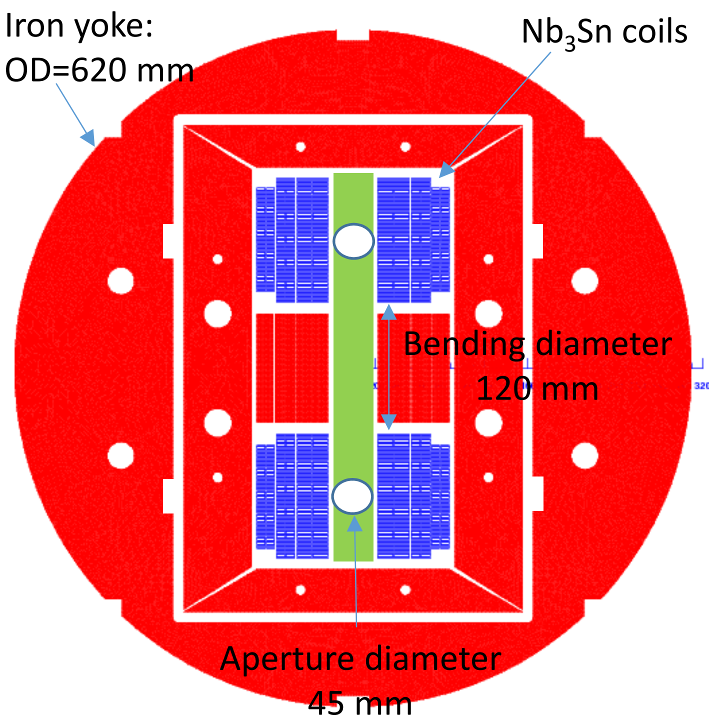
140m Nb_3Sn cable
Jc~2500A/mm^2@4.2K, 12T



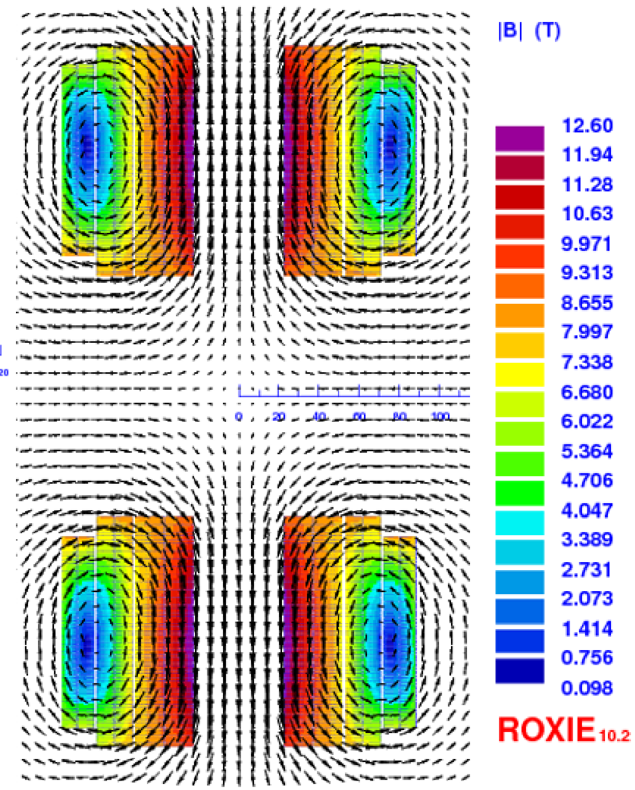
Revised IBS coil design

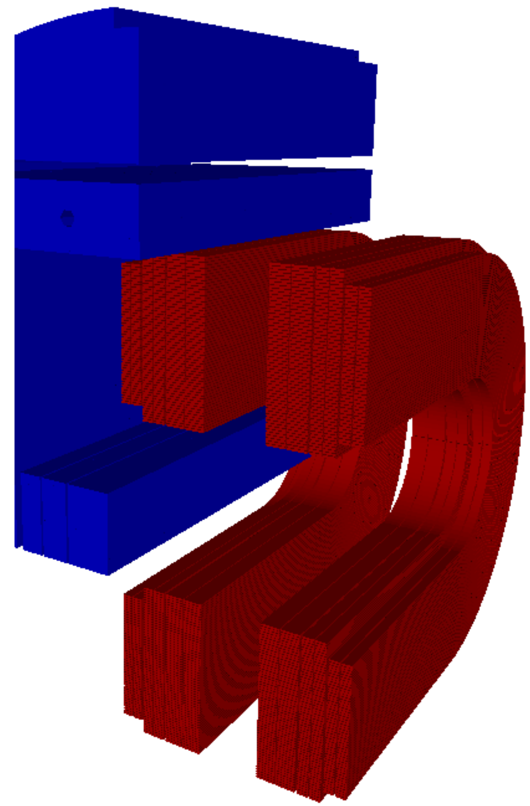
R&D of High Field Dipole Magnets

Next steps: LPF3, a high field dipole magnet with 45-mm aperture



Cross section of LPF3

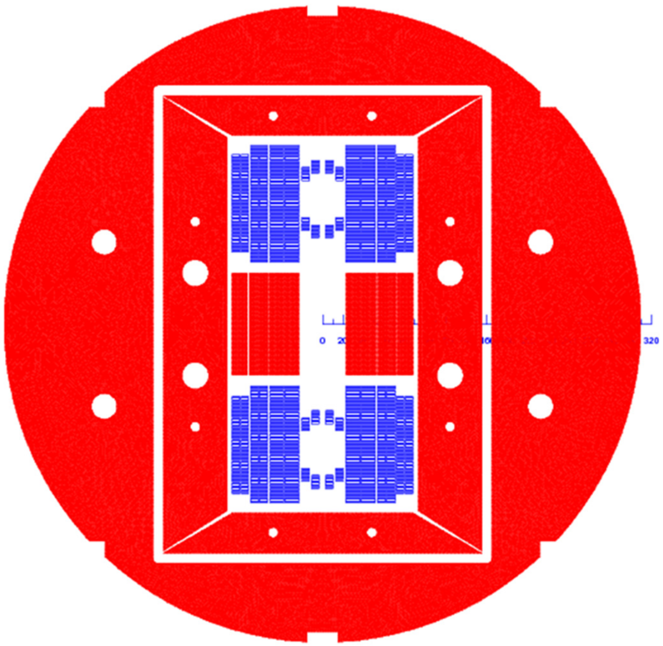


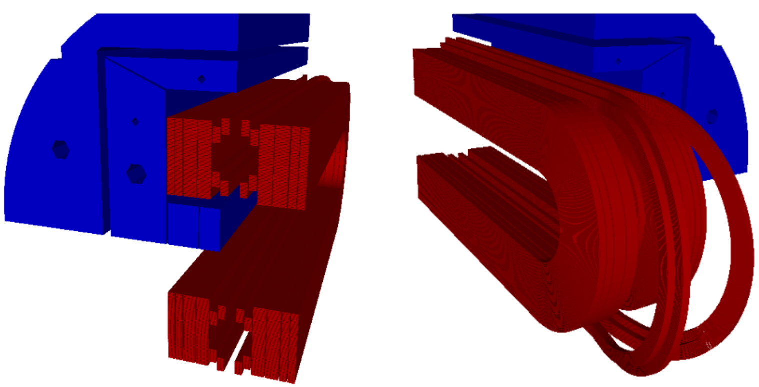


Nb_3Sn magnet, 45-mm diameter twin aperture, main field 12 T with operating current of 5850 A. Load line ~80% at 4.2K. As high field test station for HTS coils.

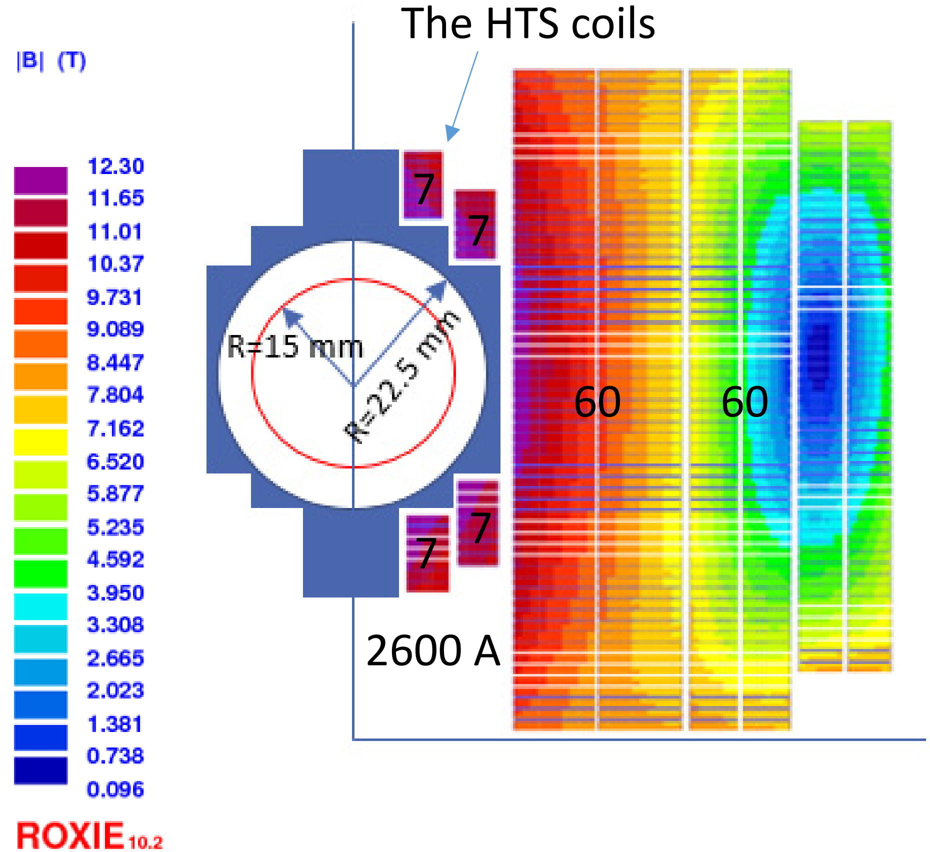
R&D of High Field Dipole Magnets

LPF3+HTS: >12 T dipole magnet with 10^{-4} field quality





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

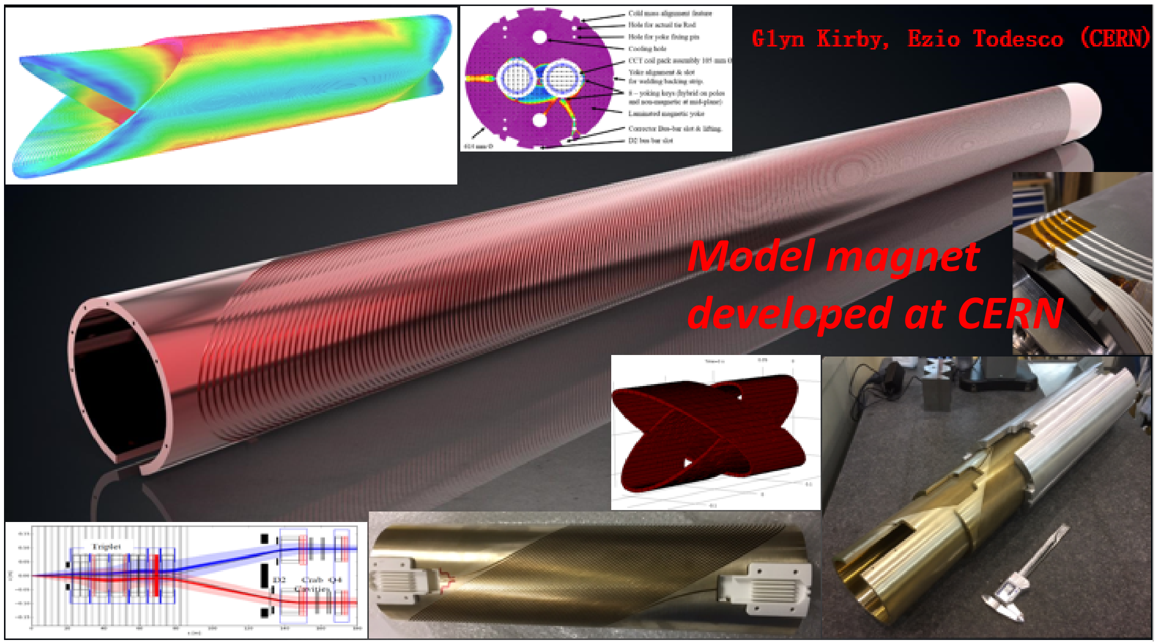


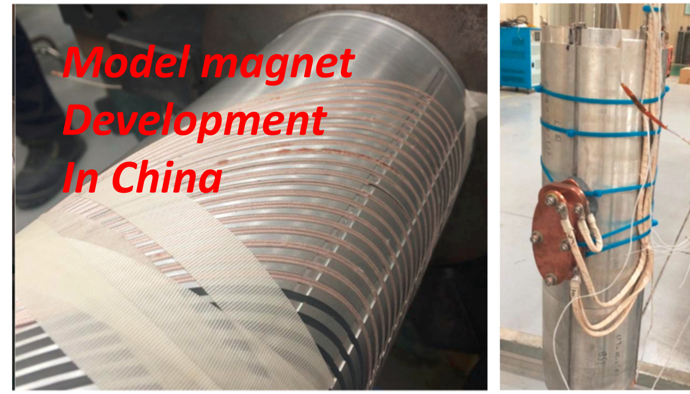
Field distribution

CERN & China Collaboration

China provides 12+1 units CCT corrector magnets for HL-LHC before 2022

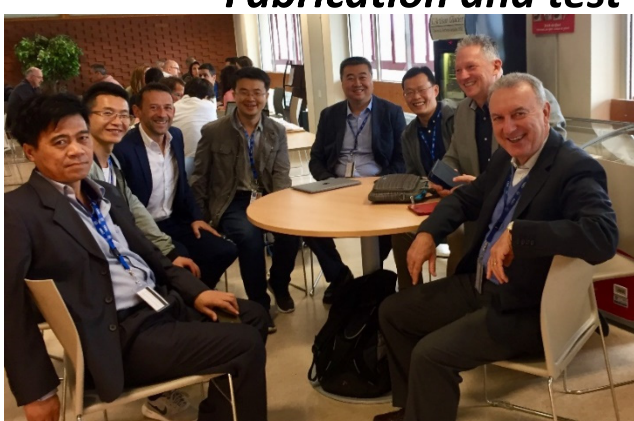
2*2.6T dipole field in the two apertures. 2.2m prototype being fabricated.

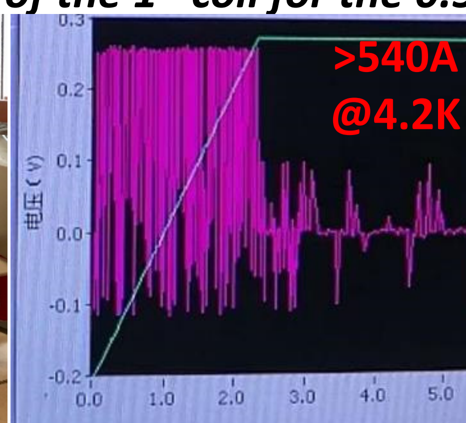


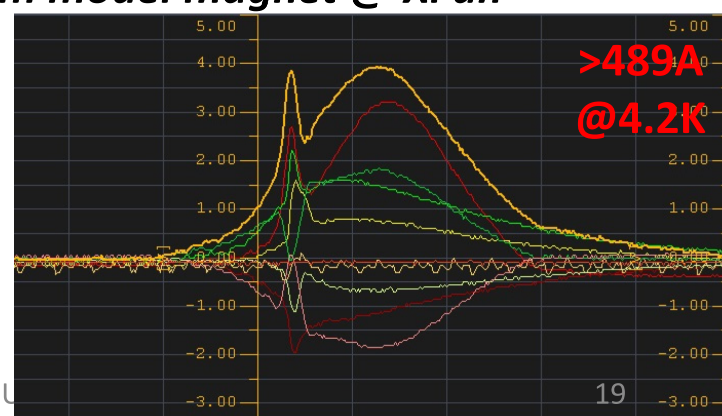


- ✓ *The 1st coil reached 543A @ 4.2K with 5 quench, 83.4% loadline.*
- ✓ *The 2nd coil reached 489A with 5 quench.*
- ✓ *Design current 422A @1.9K.*

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

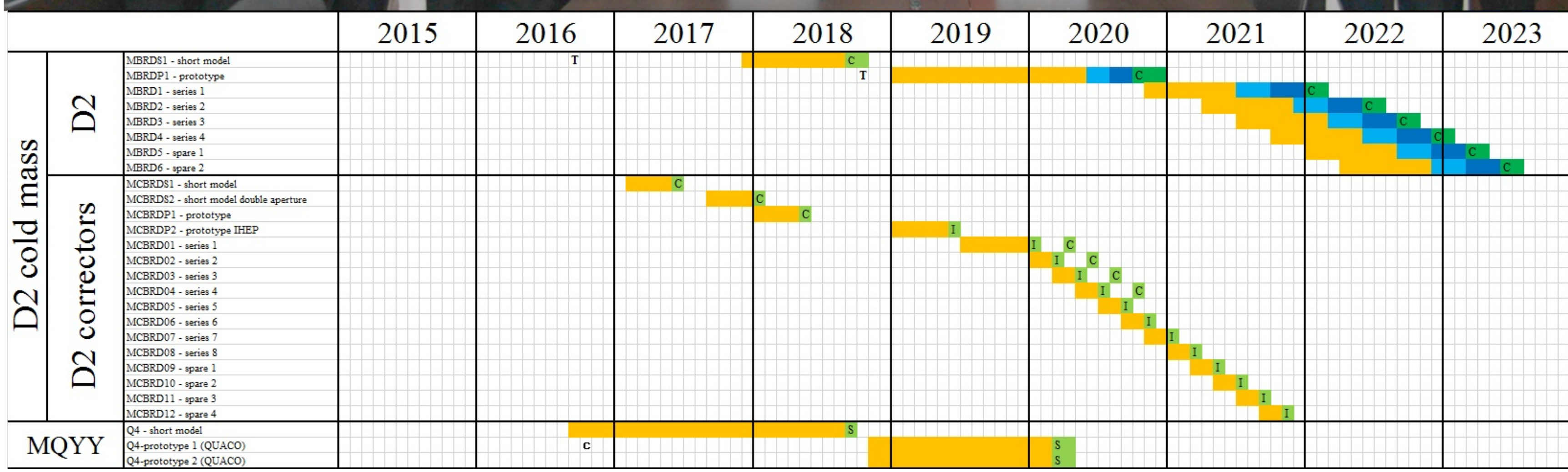






CERN & China Collaboration

MoU formally signed for CCT magnets in September 2018



Summary

- ***High field magnet technology*** *is the key to the success of the high energy accelerators in future.*
- ***SPPC design scope:*** *12-24 T IBS magnets to reach 75-150 TeV with 100 km circumference.*
- *Strong domestic collaboration for the advanced HTS conductor R&D: Make IBS the High-T_c and High-Field "NbTi" conductor in 10 years!*
- ***R&D of high field magnet technology:*** *the 1st twin-aperture model dipole (NbTi+Nb_3Sn) reached 10.2 T @ 4.2 K; 12-15 T model magnet being developed.*
- ***CERN & China Collaboration on accelerator technology:*** *Start with the HL-LHC collaboration, and expecting more in future.*

Thanks for your attention!

Melbourne, May 22 2019