THE 2019 INTERNATIONAL WORKSHOP ON THE HIGH ENERGY CIRCULAR ELECTRON POSITRON COLLIDER

November 18-20, 2019

Institute of High Energy Physics, Beijing, China

High Field Magnet R&D for SPPC

Qingjin XU
Institute of High Energy Physics (IHEP)
Chinese Academy of Sciences (CAS)
Nov 19 2019

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

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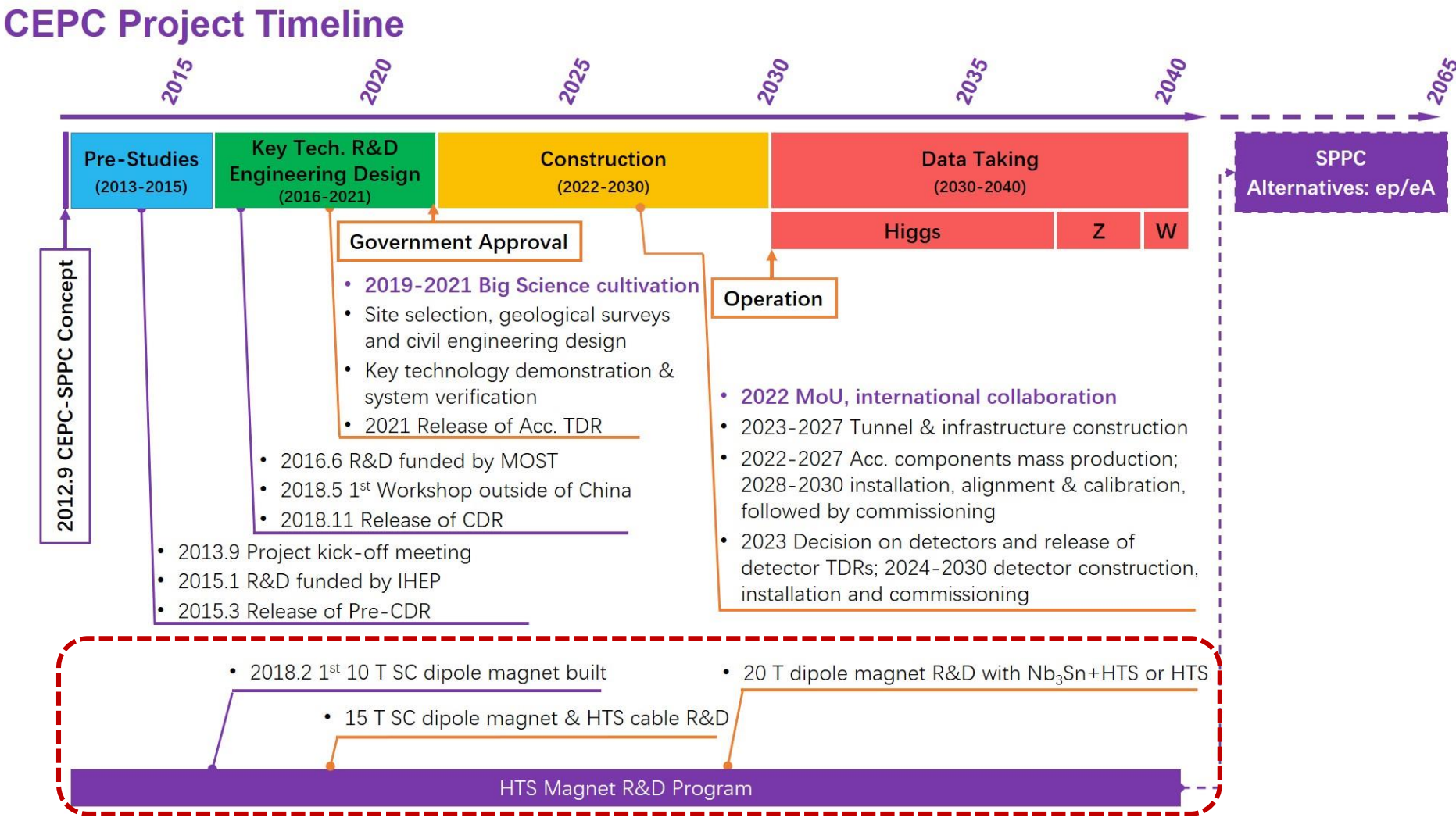
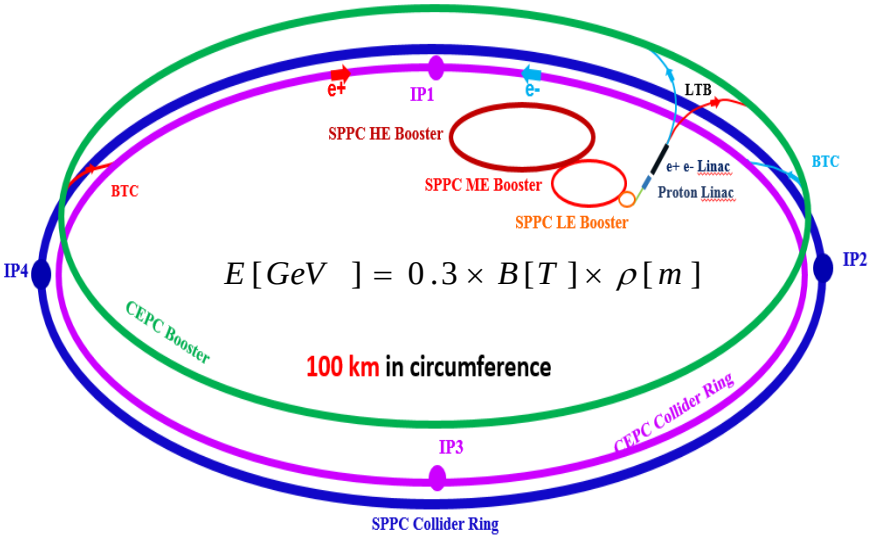
CEPC-SPPC Project Timeline



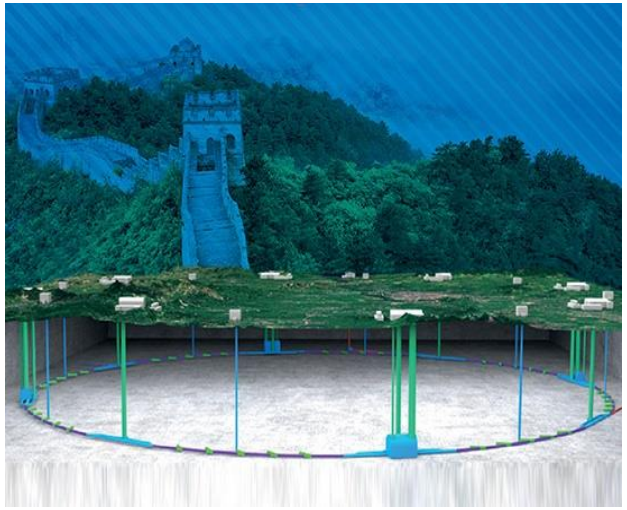
SPPC Magnet Design Scope

Main dipoles

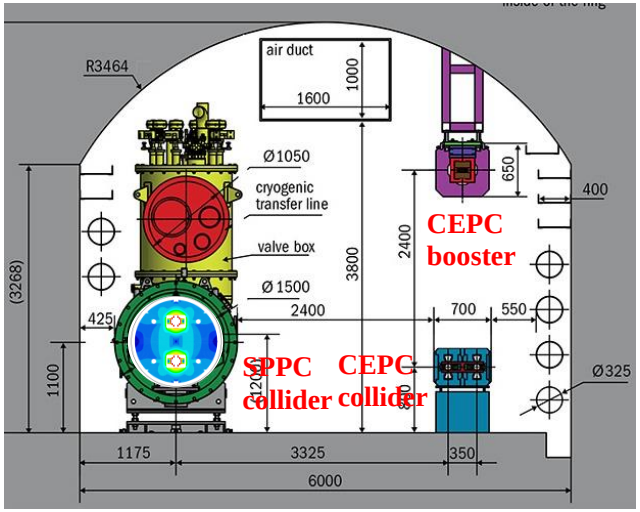
- *Field strength: 12-24 Tesla to get 75-150 TeV in a 100-km tunnel*
- *Baseline Iron-Based Superconductor (IBS), Nb_3Sn/ReBCO as options*
- *Aperture diameter: 40~50 mm*
- *Field quality: 10^{-4} at the 2/3 radius*



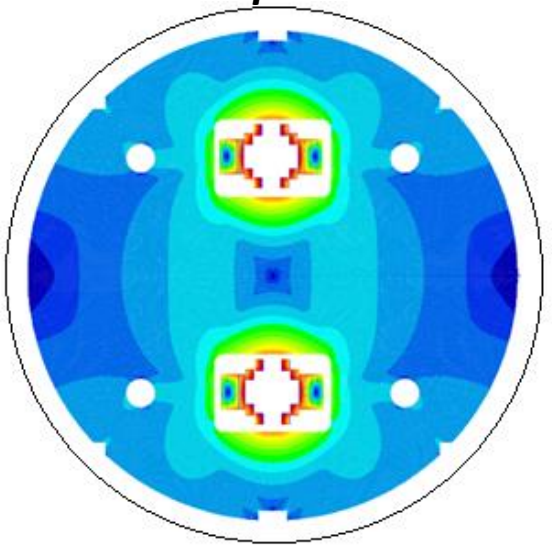
Site study of the CEPC-SPPC



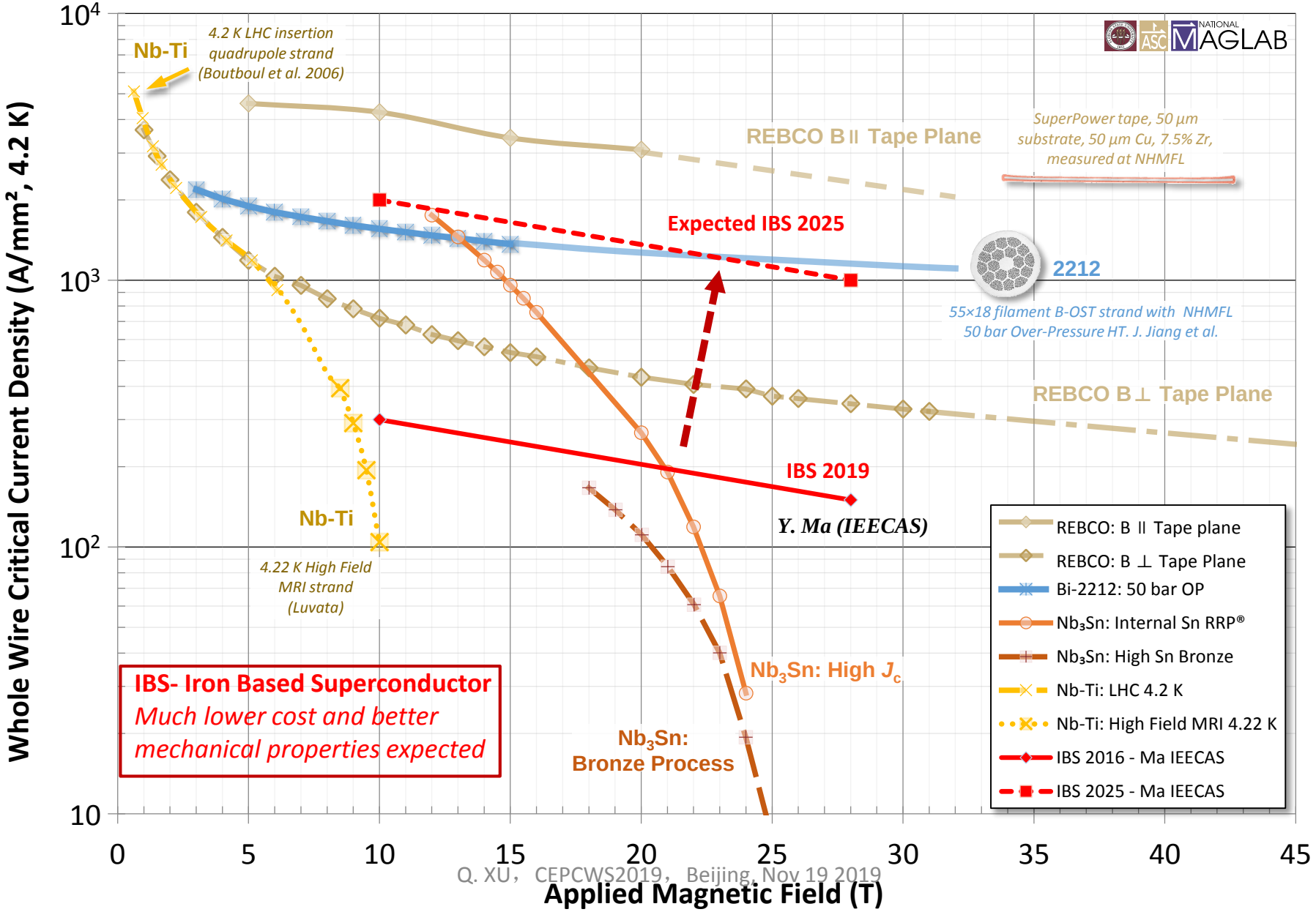
6-m width Tunnel for CEPC-SPPC



SPPC 12-T Dipole with IBS



J_e of IBS: 2016-2025

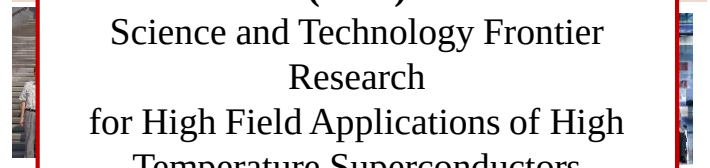


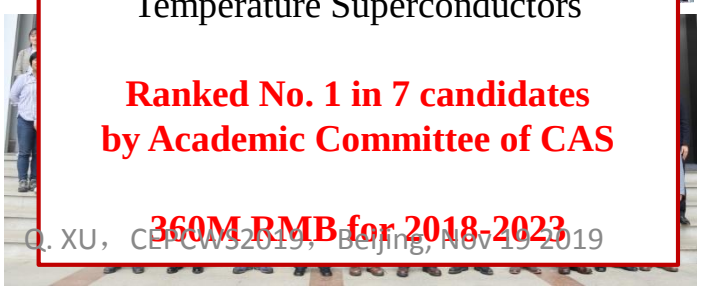
Domestic Collaboration for HTS R&D

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**



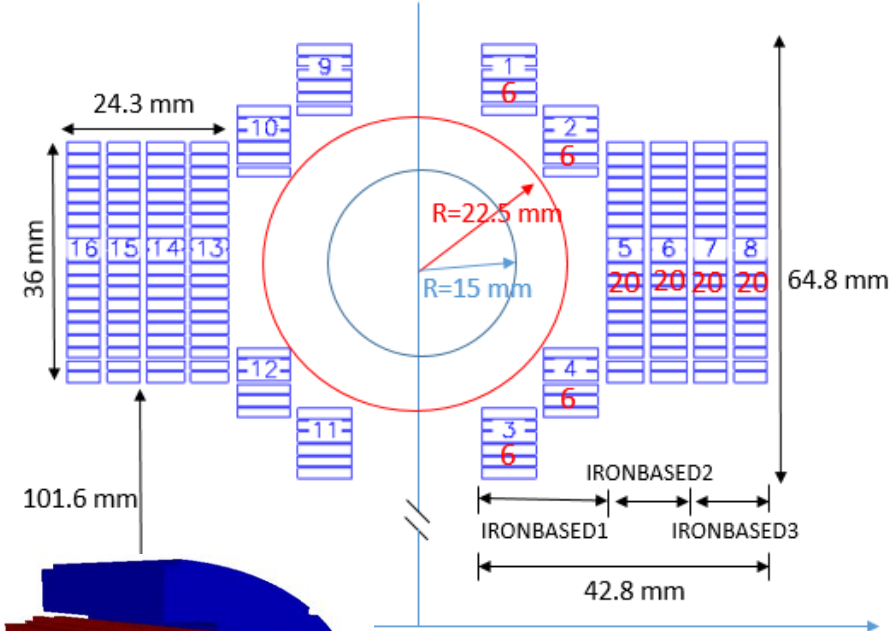


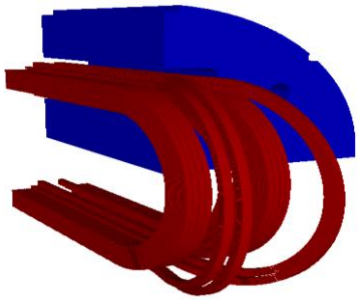
Proposal for
Strategic Priority Research Program of Chinese Academy of Sciences (CAS)
Science and Technology Frontier Research
for High Field Applications of High Temperature Superconductors

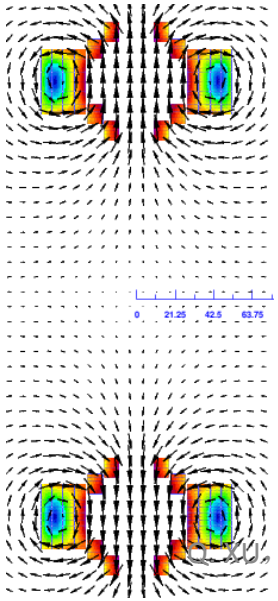
Ranked No. 1 in 7 candidates by Academic Committee of CAS

360M RMB for 2018-2023

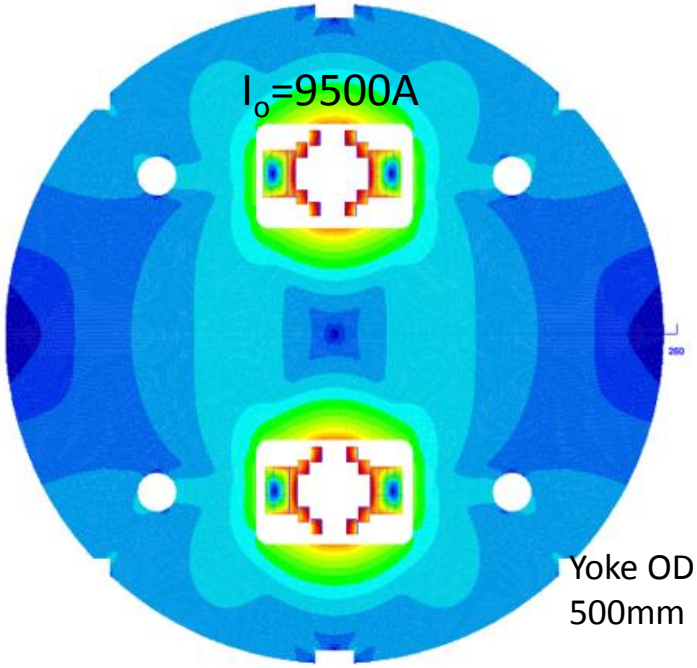
The 12-T Fe-based Dipole Magnet







IJMPA 2019,34(13n14),1940003



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

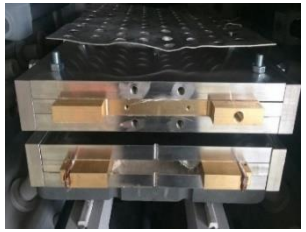
Field quality	2D with R_f=13.3mm	3D with R_f= 8/13.3 mm
b3	0.45	0.79/1.91
b5	1.01	-0.65/-2.24
b7	0.46	0.08/0.67
b9	-0.27	-0.13/-0.22
a2	3.53	-1.00/-2.31
a4	0.49	-0.46/0.69
a6	0.33	0.26/2.49
a8	0.58	-0.12/0.84
a10	2.23	0.06/2.18

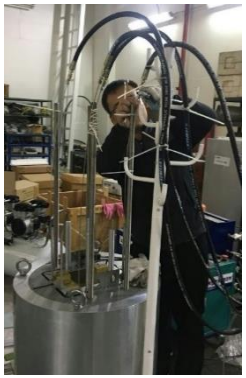
- For 100-km SPPC, needs **3000 tons of IBS**
- Target cost of IBS: **20 RMB /kAm @12 T**

R&D Fabrication Procedures and Challenges

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

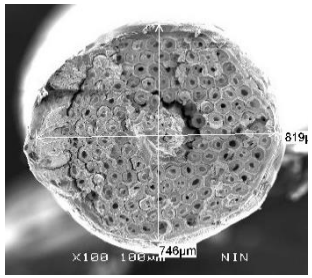
Temperature control, Thermal stress control
J_c and RRR degradation.



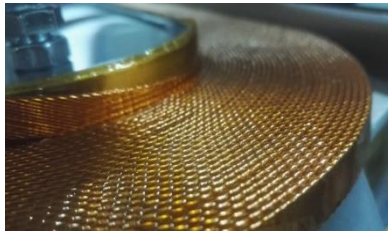


Pre-stress control
Stress of coils, Mechanical Stability…

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…

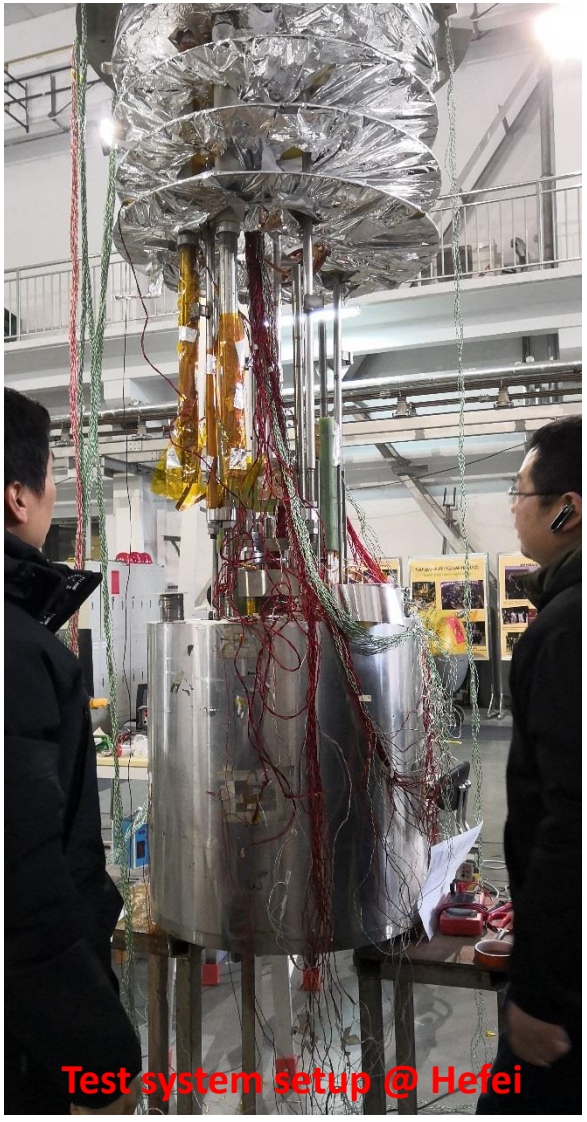
Impregnation quality control:
type of epoxy, procedures; Mechanical strength and stability

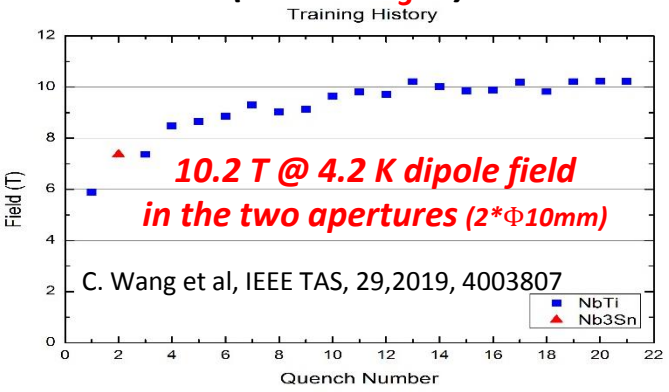
EM force, Quench protection
Training, Strain of coils…

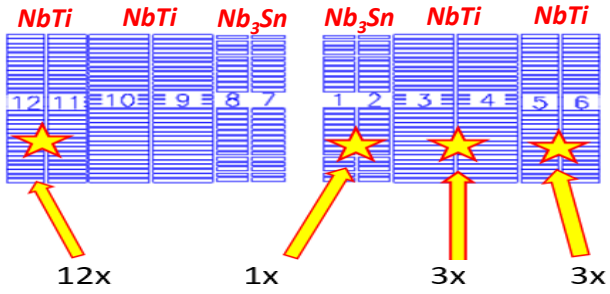
The 1st High-Field Dipole Magnet LPF1

Test results of LPF1

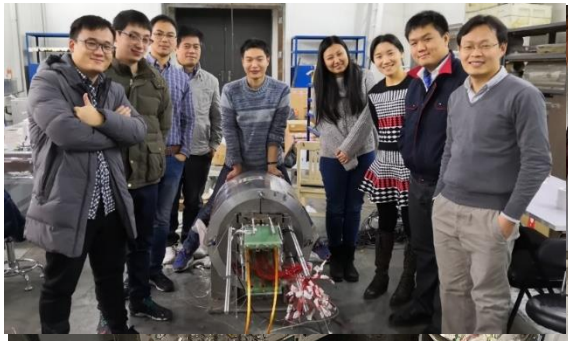
(NbTi+Nb_3Sn)

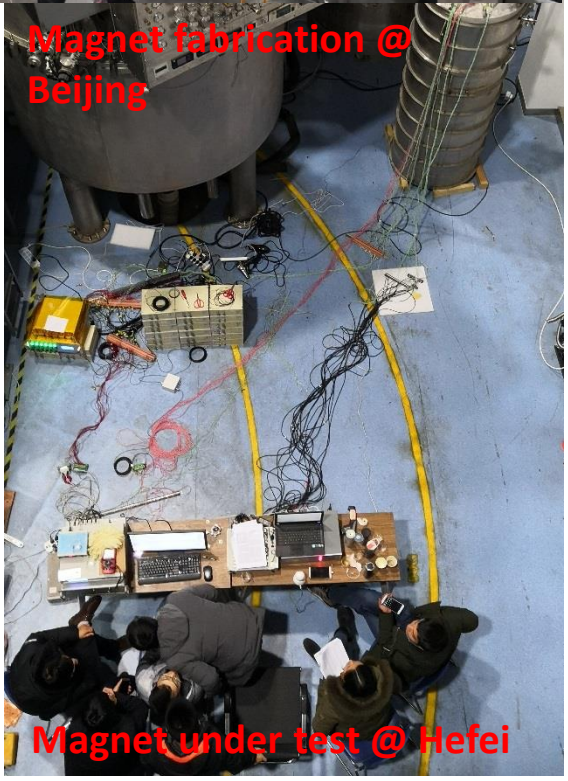






- ***Performance limited by the outermost NbTi coil.***
- ***Very possibly caused by less of pre-stress.***
- ***Being tested again now with higher Pre-stress (from 30 MPa to 80 MPa).***





International Conference on Magnet Technology

September 22 - 27, 2019.

Hosted by TRIUMF

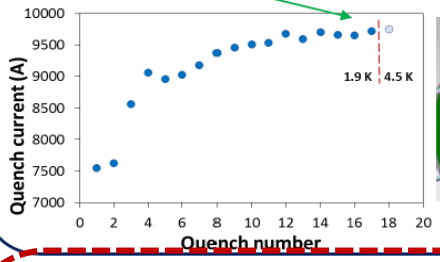
Models development toward 16 T magnets

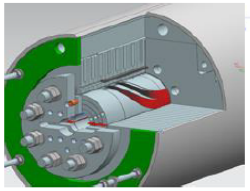
U.S. MAGNET DEVELOPMENT PROGRAM

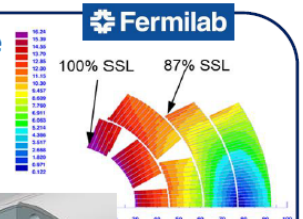
Key milestone: 15 T dipole

Fermilab

- 4 layer graded magnet, 1-m long
- 1st step: **14.1 T performance**







Courtesy of A. Zlobin, FNAL

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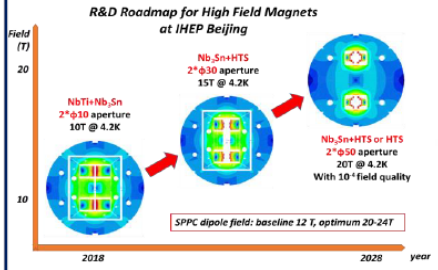
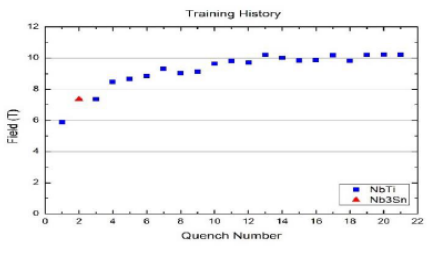
Chinese Academy of Sciences

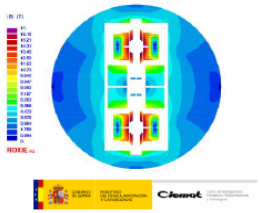


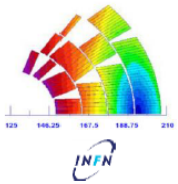


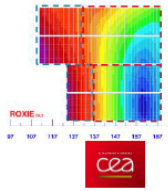
Courtesy of Q. Xu, IHEP

10.2 T at 4.2 K in 2 apertures

FCC 16 T Model Magnet Development





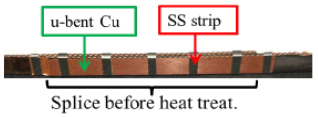


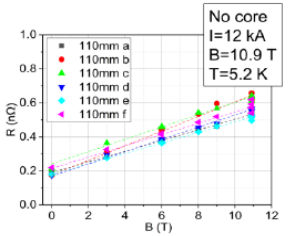
Nb_3Sn GRADING

eRMC
No bore
16 T target

Racetrack Model Magnet = RMM
50 mm bore
16 T target

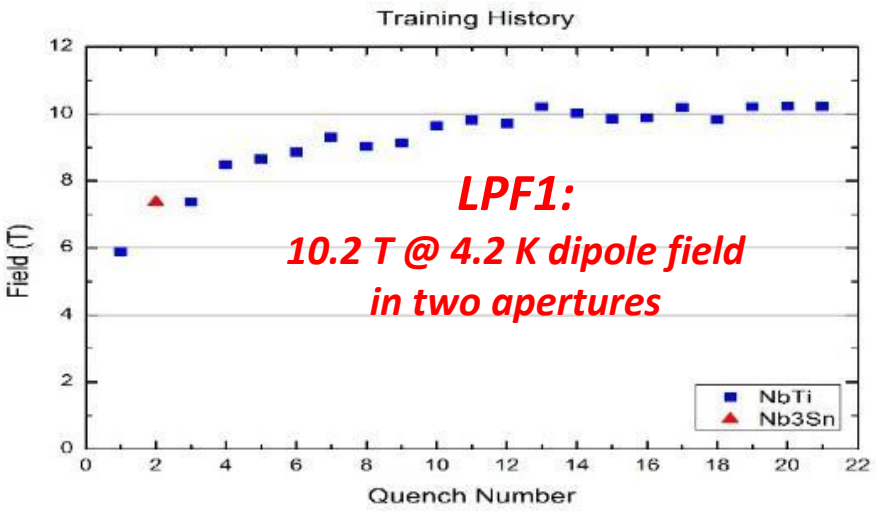
Nb_3Sn joints





Courtesy of V. D'Auria, EPFL

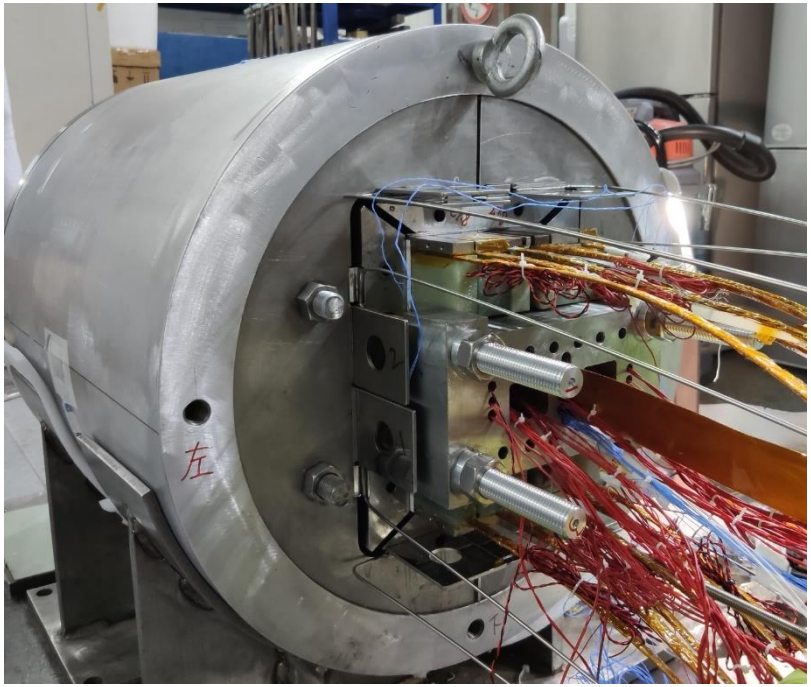
LPF1s:LPF1 with improved pre-stress

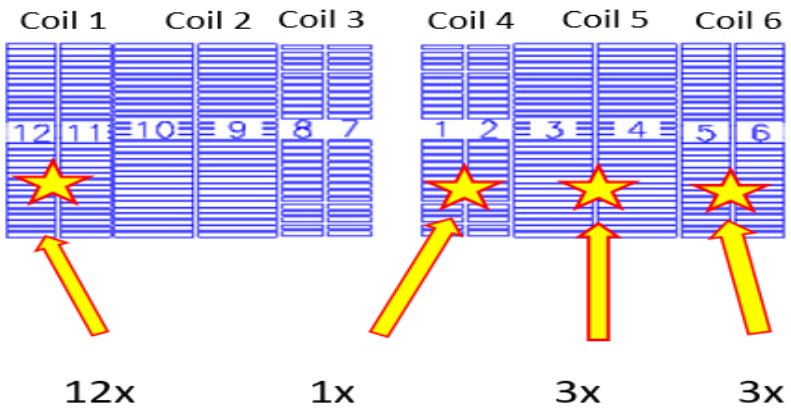


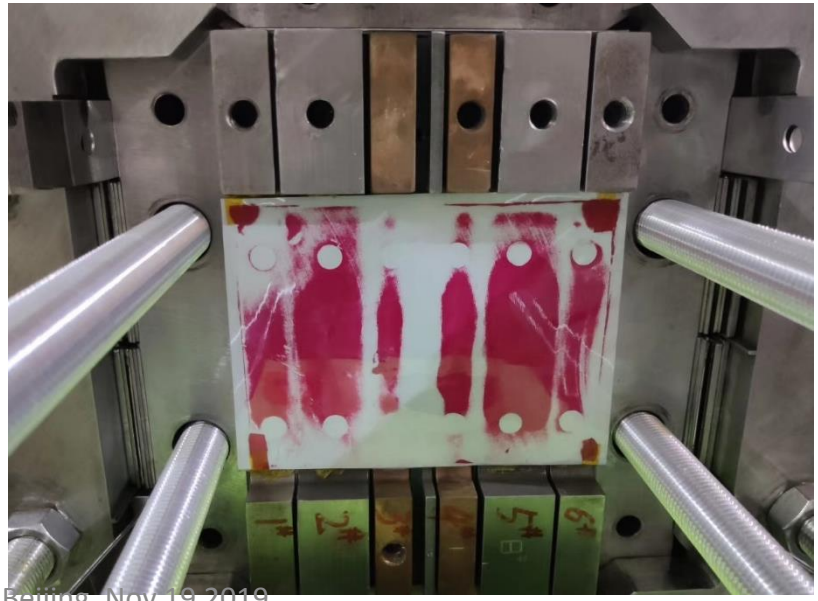
LPF1:

10.2 T @ 4.2 K dipole field

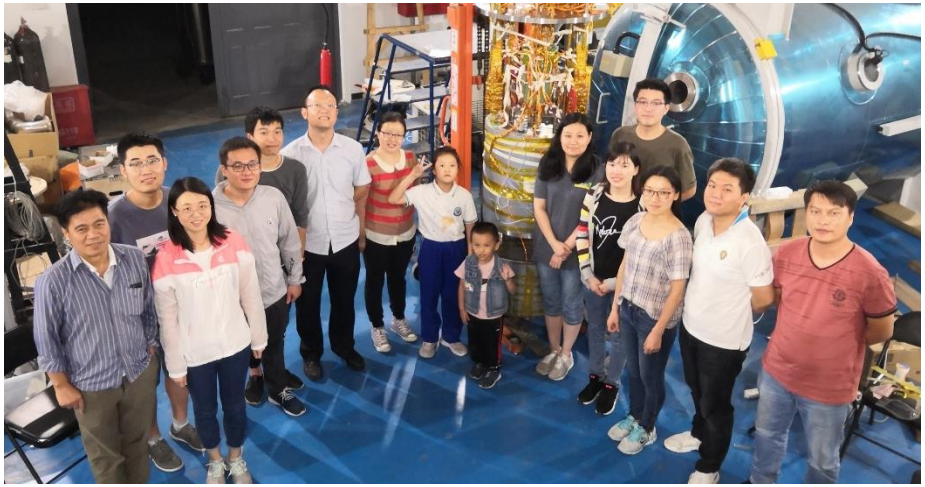
in two apertures

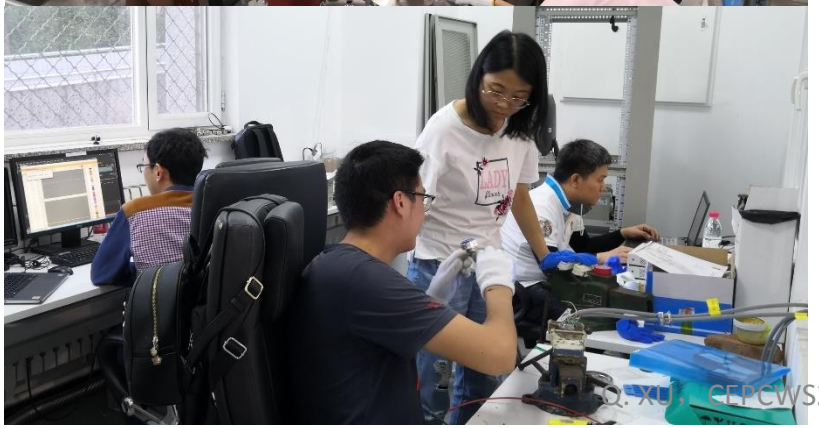






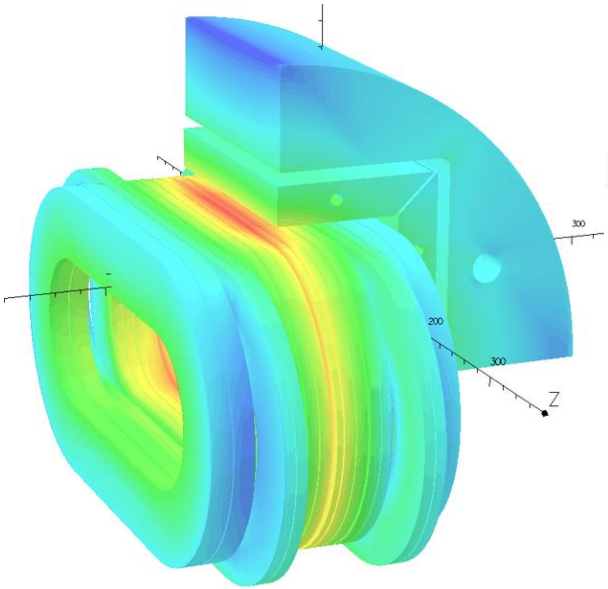
Test preparation of LPF1s

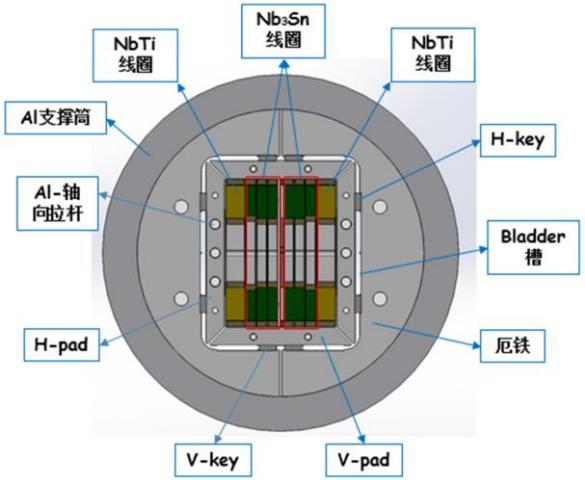


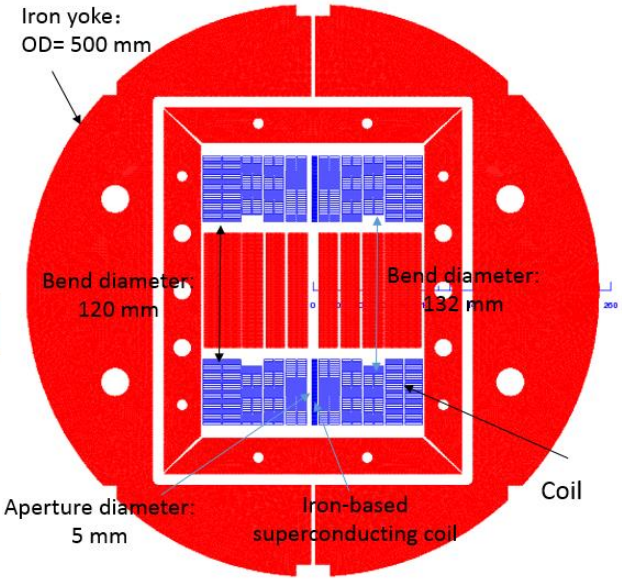


Development of LPF2

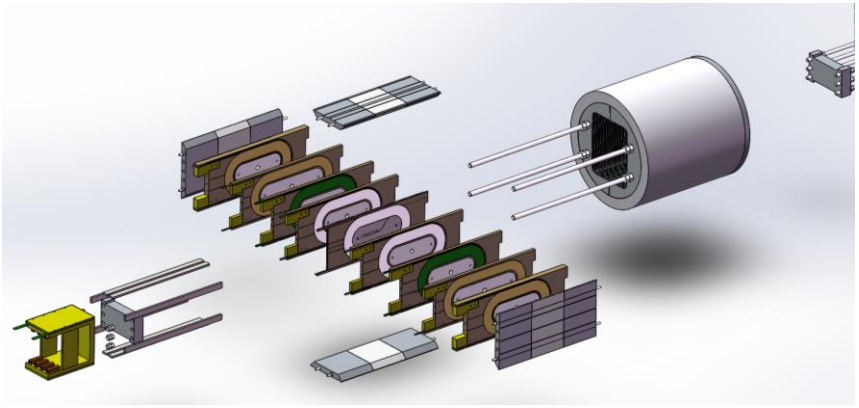
（ NbTi +Nb_3Sn + IBS）



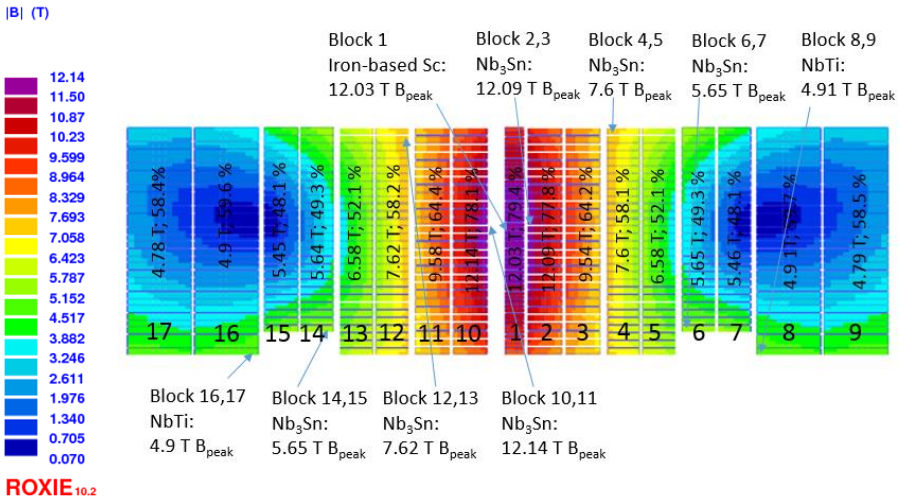




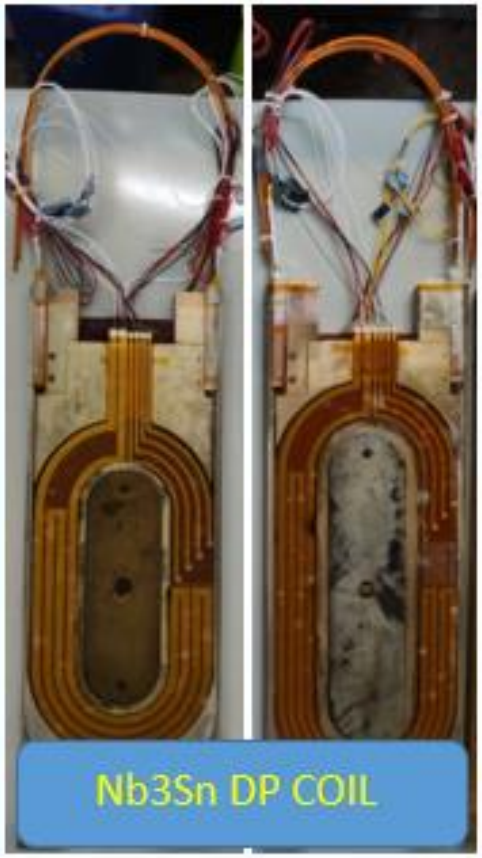
3D Magnetic & Mechanical model

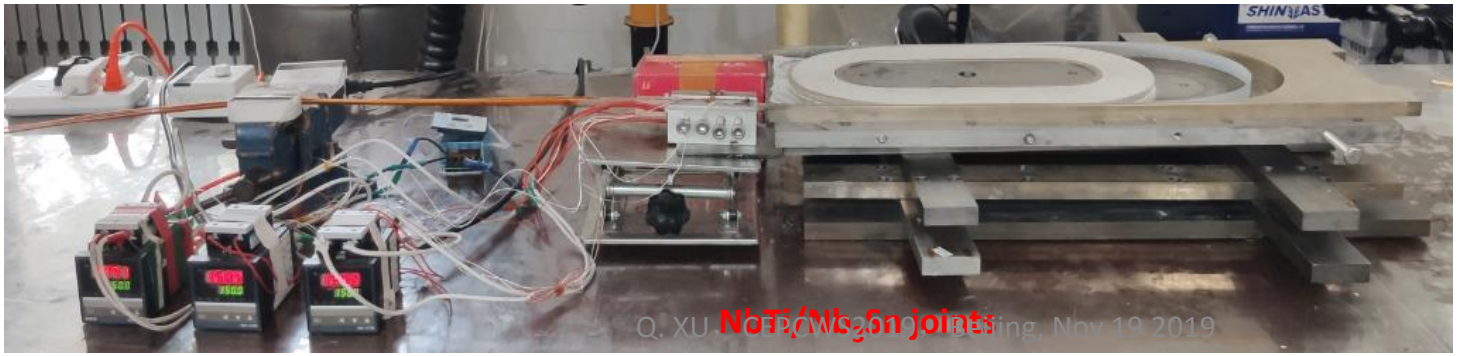


Cross section of the magnet



Development of LPF2





R&D of High Field Dipole Magnets

R&D Roadmap for the next years

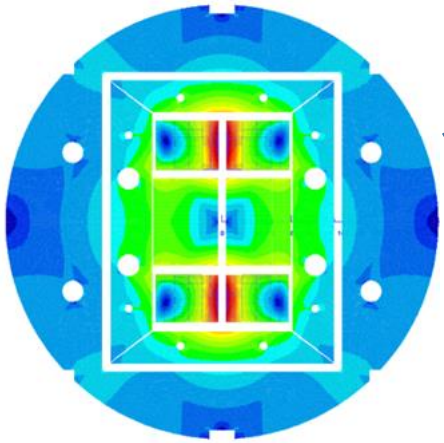
Field (T)

20

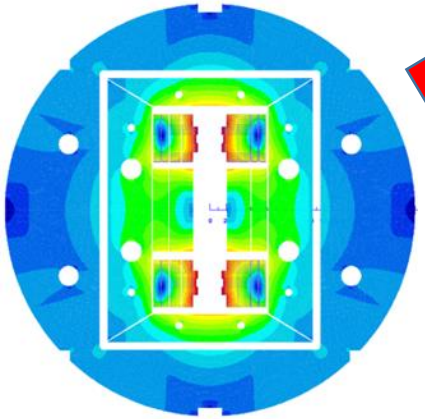
10

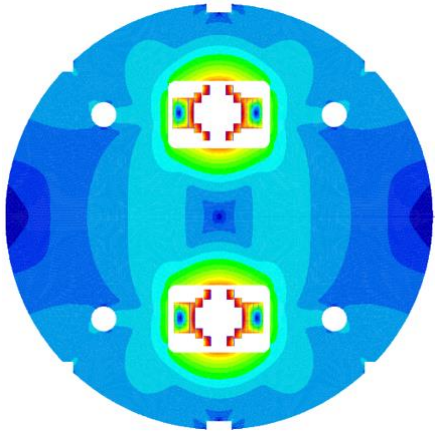
SPPC dipole field: baseline 12 T, optimum 20-24T

$NbTi+Nb_3Sn$
2*ϕ10 aperture
10T @ 4.2K



Nb_3Sn+HTS
2*ϕ45 aperture
15T @ 4.2K





Nb_3Sn+HTS or HTS
2*ϕ45 aperture
20T @ 4.2K
With 10^{-4} field quality

IEEE TAS 2019, 29(7), 4003807
IJMPA 2016, 31(33):1644018
IEEE TAS 2016, 26(4): 4000404

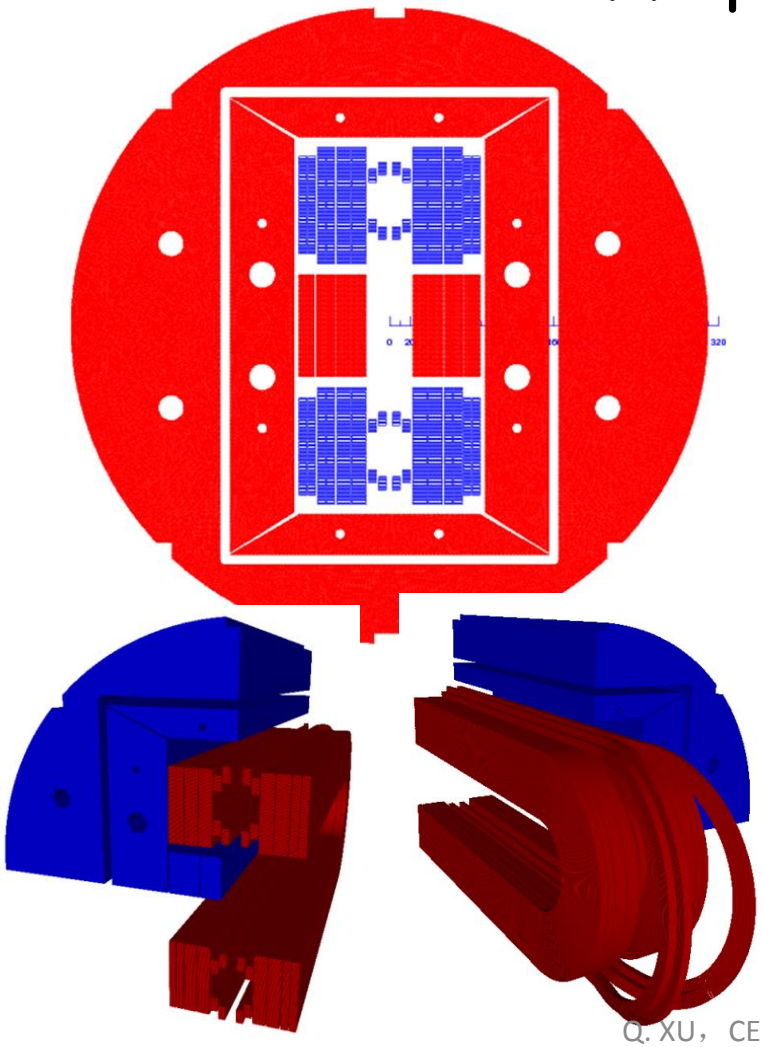
2018

2028

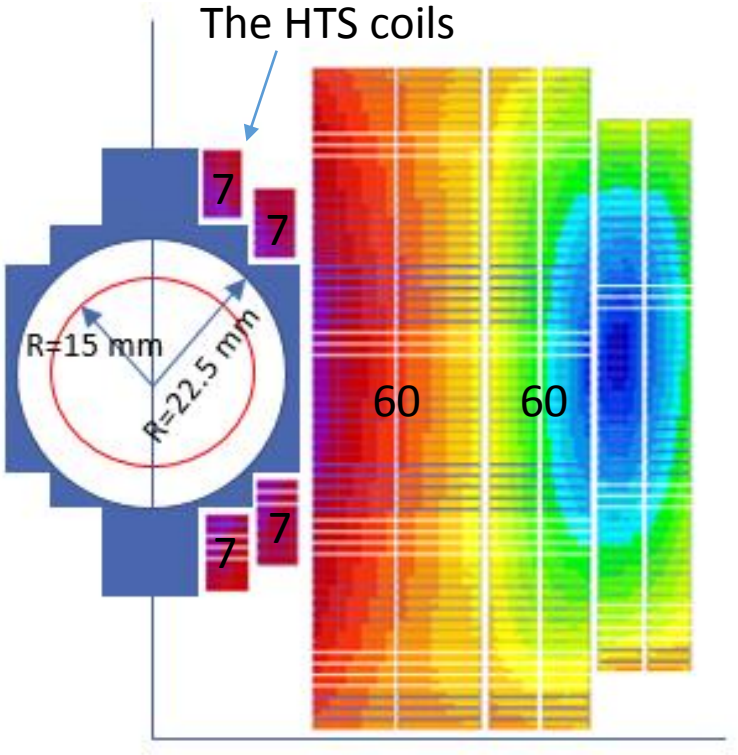
year

LPC:12~16T Prototype Dipole with Field Quality

Nb_3Sn+HTS
45mm aperture and 1m long



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



Field distribution

Performance of the 1st IBS solenoid Coil

Fabrication and test of IBS solenoid coil at 24T

IOP Publishing
Supercond. Sci. Technol. 32 (2019) 04LT01 (5pp)
Superconductor Science and Technology
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Letter

First performance test of a 30mm iron-based superconductor single pancake coil under a 24T background field

Dongliang Wang[1,2,5], Zhan Zhang[3,5], Xianping Zhang[1,2], Donghui Jiang[4], Chiheng Dong[1], He Huang[1,2], Wenge Chen[4], Qingjin Xu[3,6] and Yanwei Ma[1,2,6]

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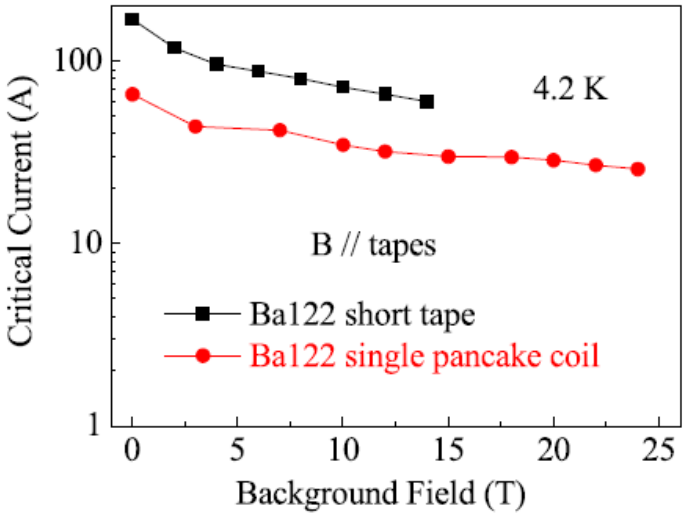

Viewpoint by NHMFL

'From a practical point of view, **IBS are ideal candidates for applications**. Indeed, some of them have quite a **high critical current density, even in strong magnetic fields**, and a low superconducting anisotropy.

Moreover, **the cost of IBS wire can be four to five times lower than that of Nb_3Sn**……

IOP Publishing
Supercond. Sci. Technol. 32 (2019) 070501 (3pp)
Superconductor Science and Technology
https://doi.org/10.1088/1361-6668/ab1fc9

Viewpoint

Constructing high field magnets is a real tour de force

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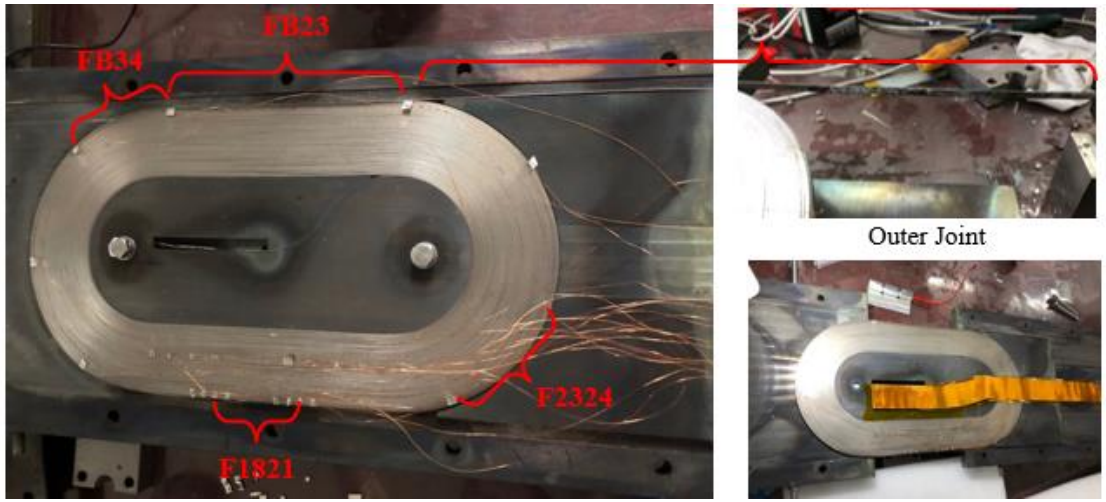
This is a viewpoint on the letter by Dongliang Wang *et al* (2019 *Supercond. Sci. Technol.* **32** 04LT01).

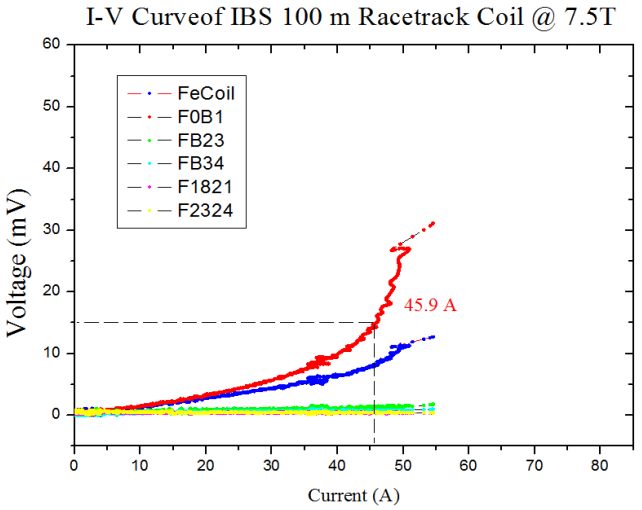
Following the discovery of superconductivity in 1911, Heike Kamerlingh Onnes foresaw the generation of strong magnetic fields as its possible application. He designed a 10 T electromagnet made of lead–tin wire, citing only the difficulty

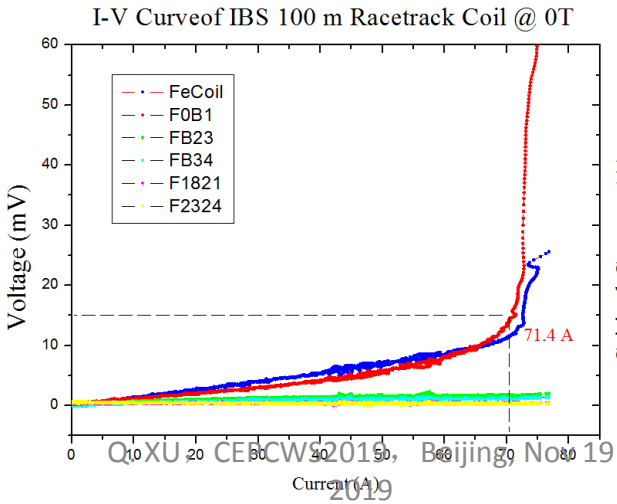
Fabrication and test of the 1st IBS racetrack coil at 8T

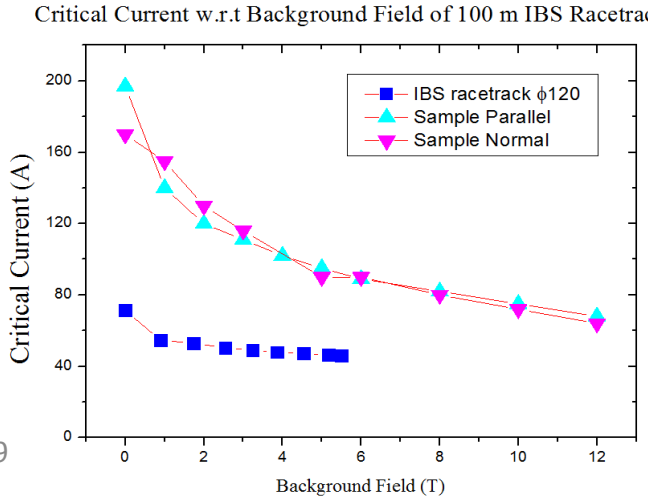
- The 1st racetrack coil with 100m long IBS tape fabricated and tested with up to 8T background field. Performance limited by unsatisfying joints.
- The 2nd IBS racerack coil has been fabricated and to be tested at 10-12T.



Outer Joint





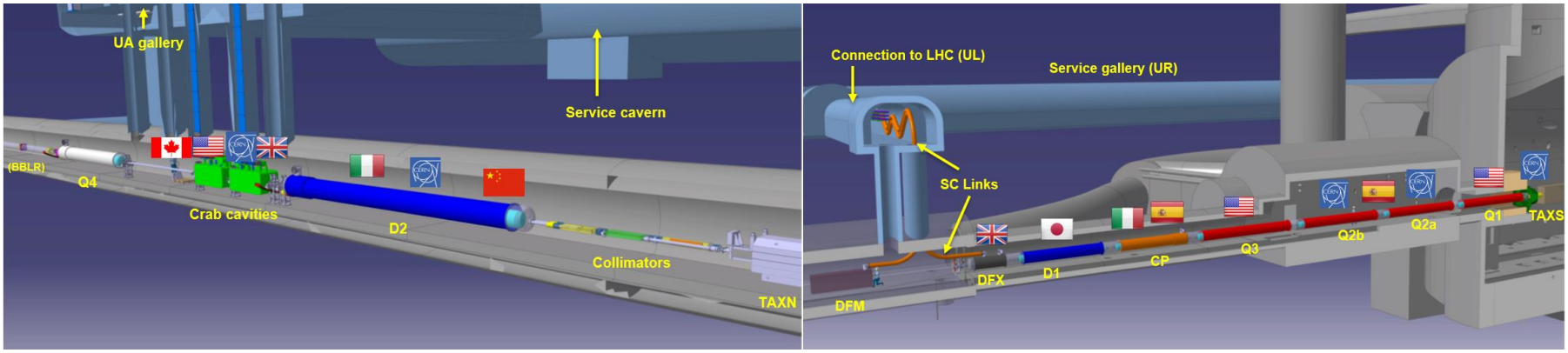


R&D of HL-LHC CCT Magnets

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

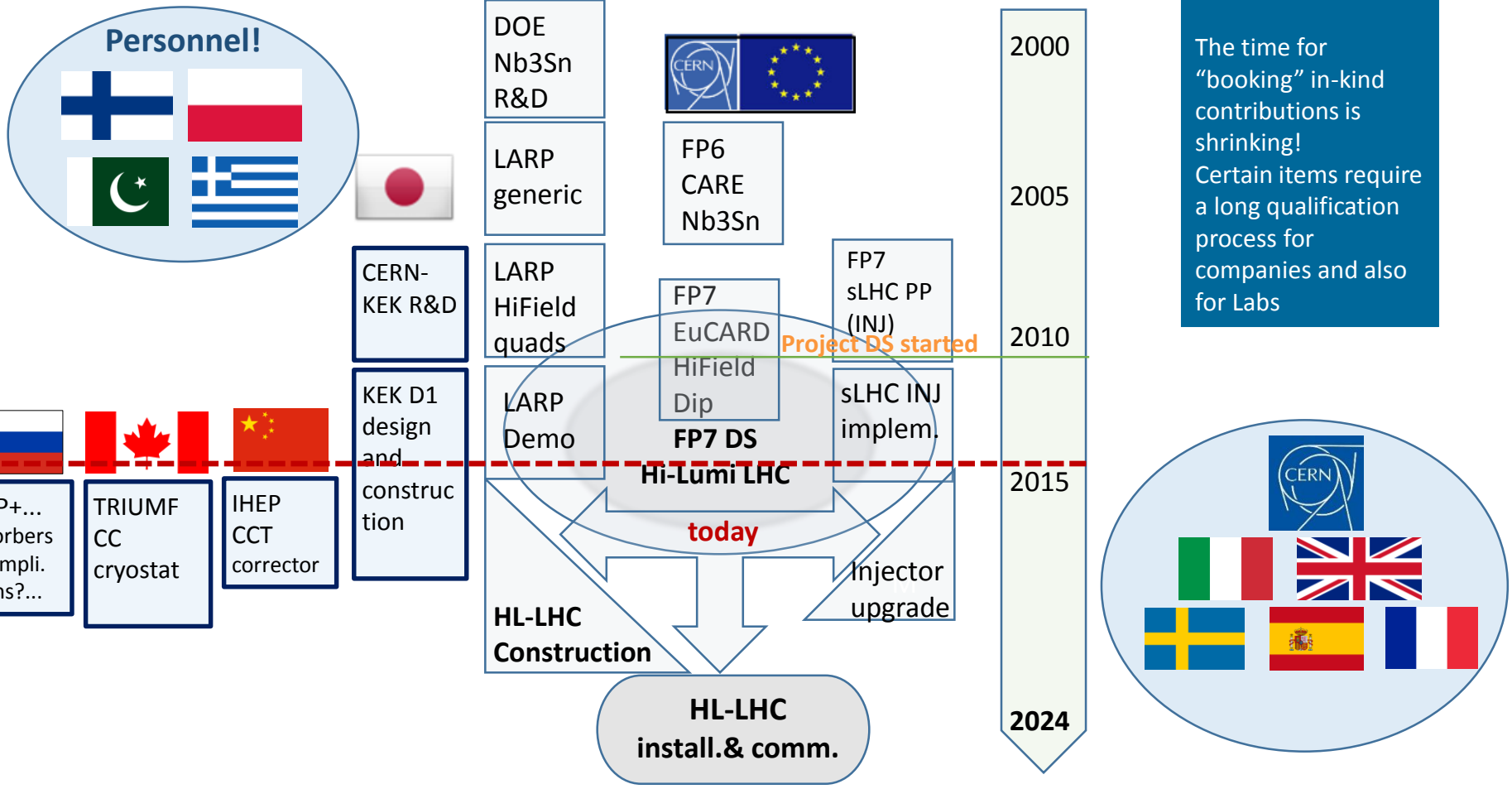
2*2.6T dipole field in the two apertures. 2.2m prototype being fabricated.

Agreement For HL-LHC CCT Magnets Signned in Sep 2018



Layout of the HL-LHC Magnets and Contributors

R&D of HL-LHC CCT Magnets

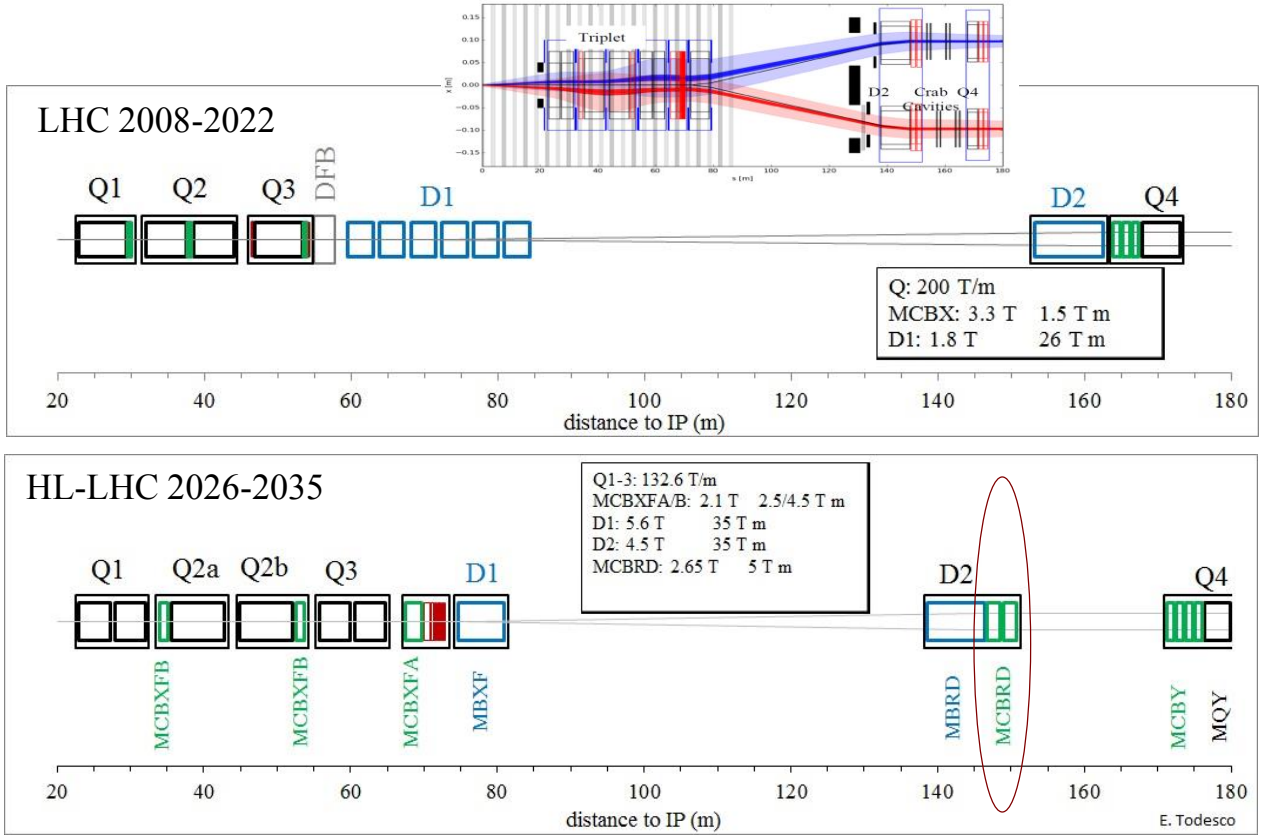


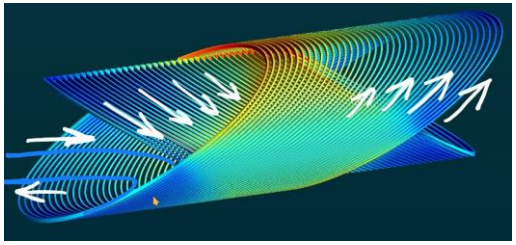
Non binding MoU for HL-LHC

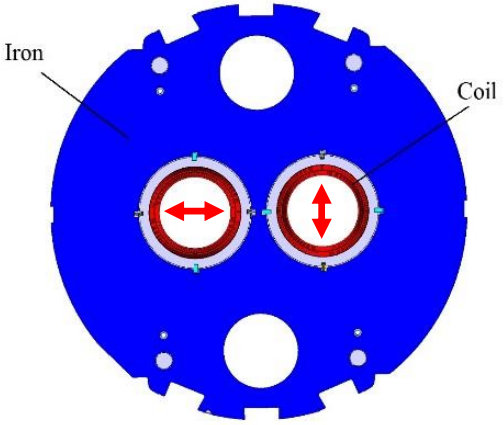
The time for "booking" in-kind contributions is shrinking!
Certain items require a long qualification process for companies and also for Labs

R&D of HL-LHC CCT Magnets

MCBRD: the HL-LHC orbit correctors, providing a maximum 5 Tm integrated field in two apertures, vertical in one and horizontal in the other.



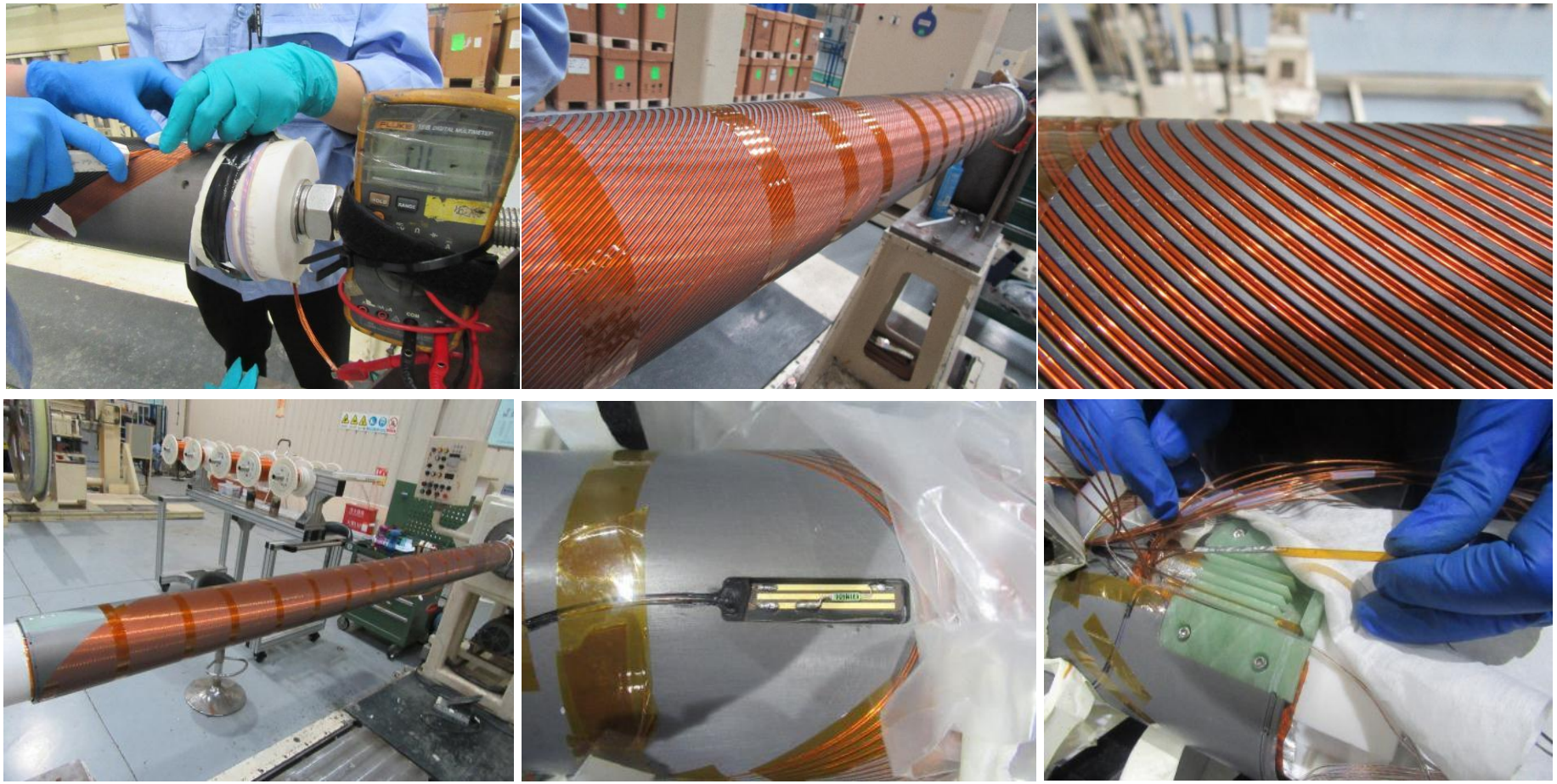




E. Todesco

R&D of HL-LHC CCT Magnets

0.5m prototype completed. 2.2m prototype being fabricated and to be tested and delivered to CERN by Feb. 2020. Prodution to be started in spring 2020.

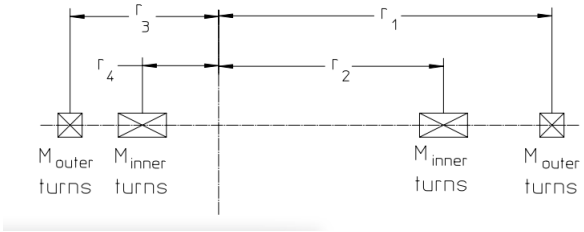


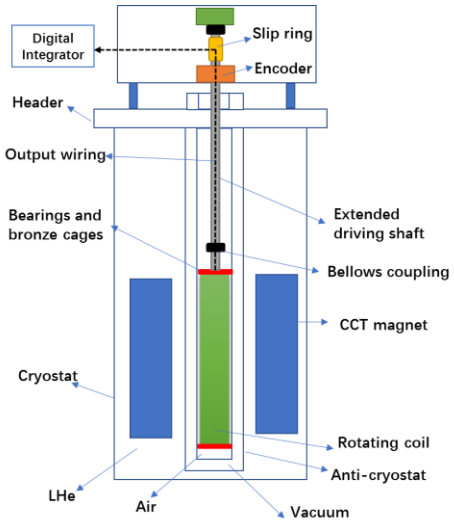
Fabrication of the 2.2m prototype CCT Magnet

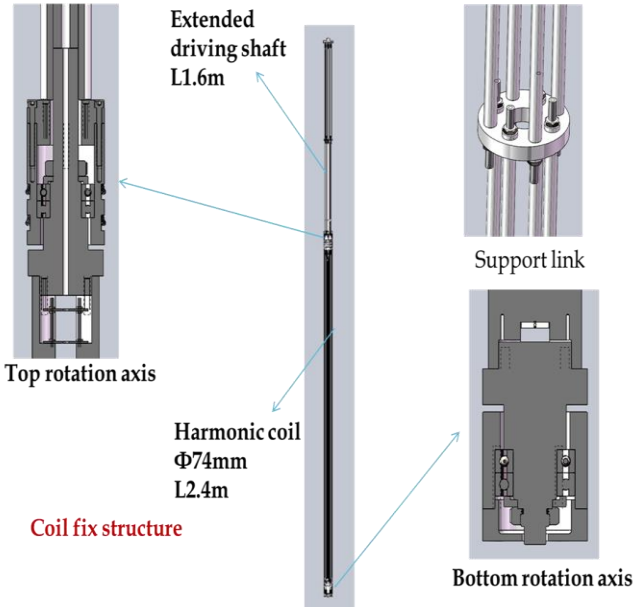
R&D of HL-LHC CCT Magnets

Field Measurement System at 4.2K

Harmonic coil parameters						
r1/mm	r2/mm	r3/mm	r4/mm	Mout/turns	Min/turns	Rref/mm
35	23	-25	-17	80	120	35







- ✓ Mainly by the rotating coil.
- ✓ Subsidiarily by Hall probe and NMR probe.
- ✓ The field measurement system is ready.

- Two radius coils symmetric to the axis;
- Outer Coil :main winding
- Inner Coil :dipole bucking which cancel the dipole component: V_A− V_B
- Typical accuracy of the system :10^{-4}.
- The rotating coil is positioned in two anti-cryostats.

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; 12-16 T model dipole being developed.*
- ***CERN & China Collaboration on accelerator technology:*** *Start with the HL-LHC CCT magnets, and more in future.*
- *More collaborations with worldwide labs in future.*

Thanks for your attention