High Field Magnet Program for Accelerators: Status and Plan for Future

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Nov. 1st 2019

Team Members & Collaborators

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

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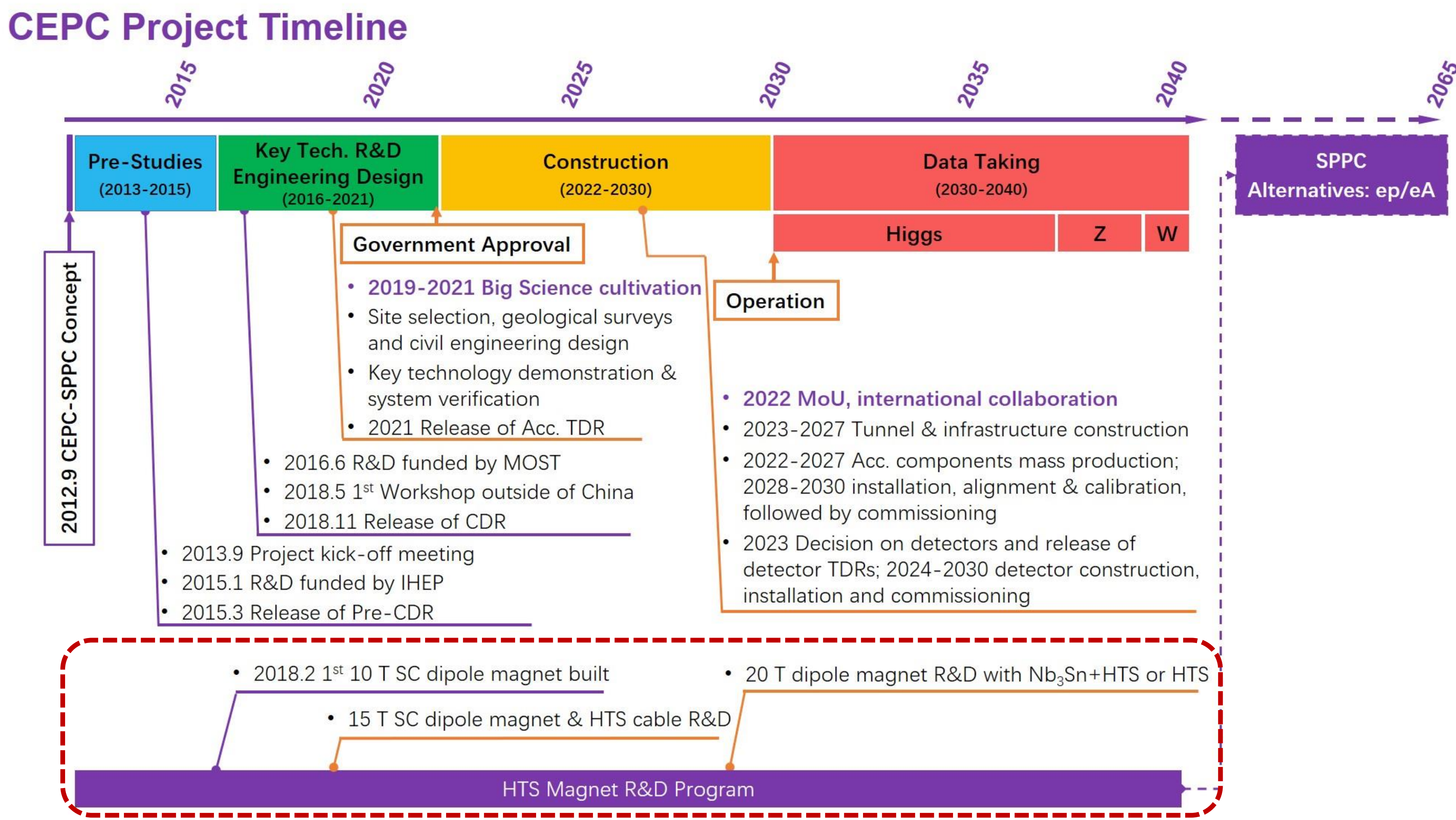
**Work supported by the Strategic Priority Research Program of the Chinese Academy of Sciences (CAS) Grant No. XDB25000000, the Hundred Talents Program of CAS and National natural Science Foundation of China Grant No. 11675193, 11575214, 11604335.*

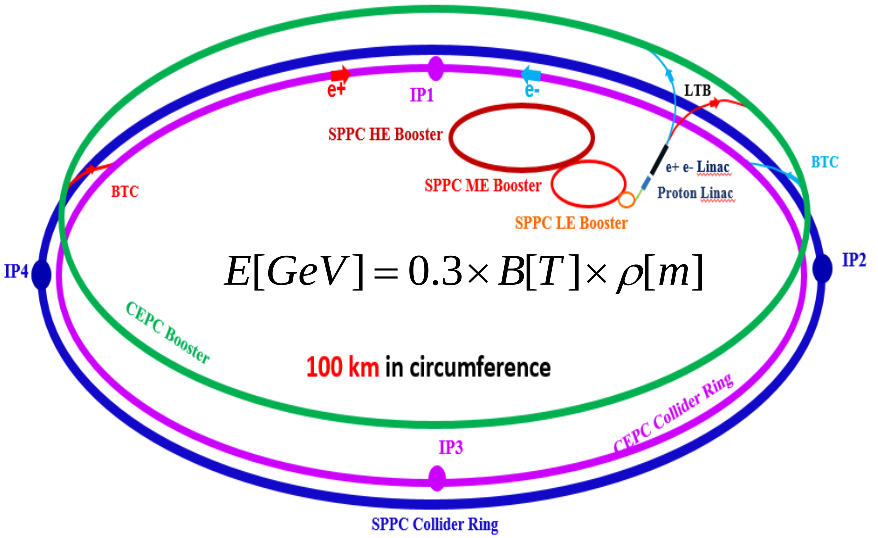
CEPC-SPPC Project Timeline



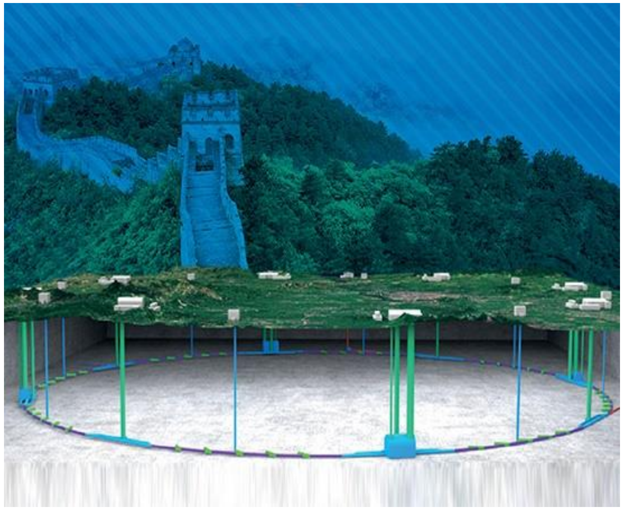
SPPC Magnet Design Scope

Main dipoles

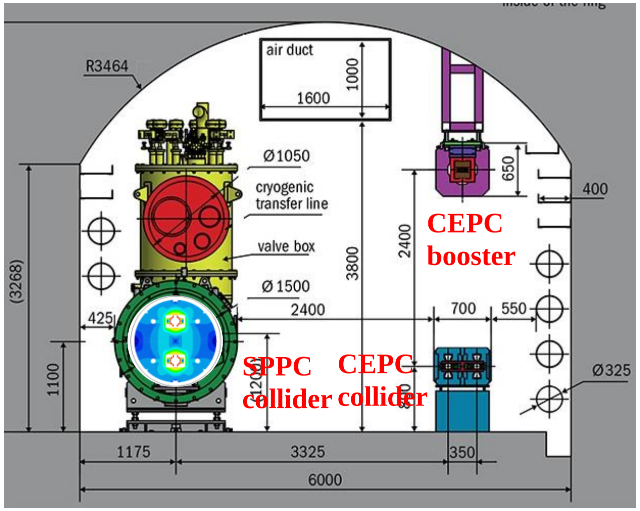
- *Field strength: 12-24 Tesla to get 75-150 TeV in a 100-km tunnel*
- *Baseline Iron-Based Superconductor (IBS), Nb_3Sn/ReBCO as options*
- *Aperture diameter: 40~50 mm*
- *Field quality: 10^{-4} at the 2/3 radius*



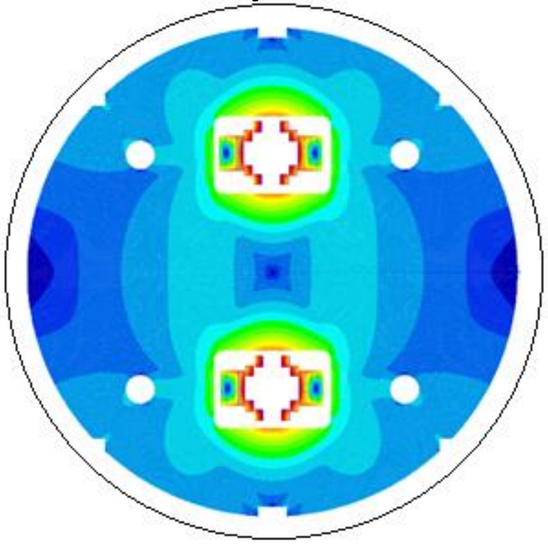
Site study of the CEPC-SPPC



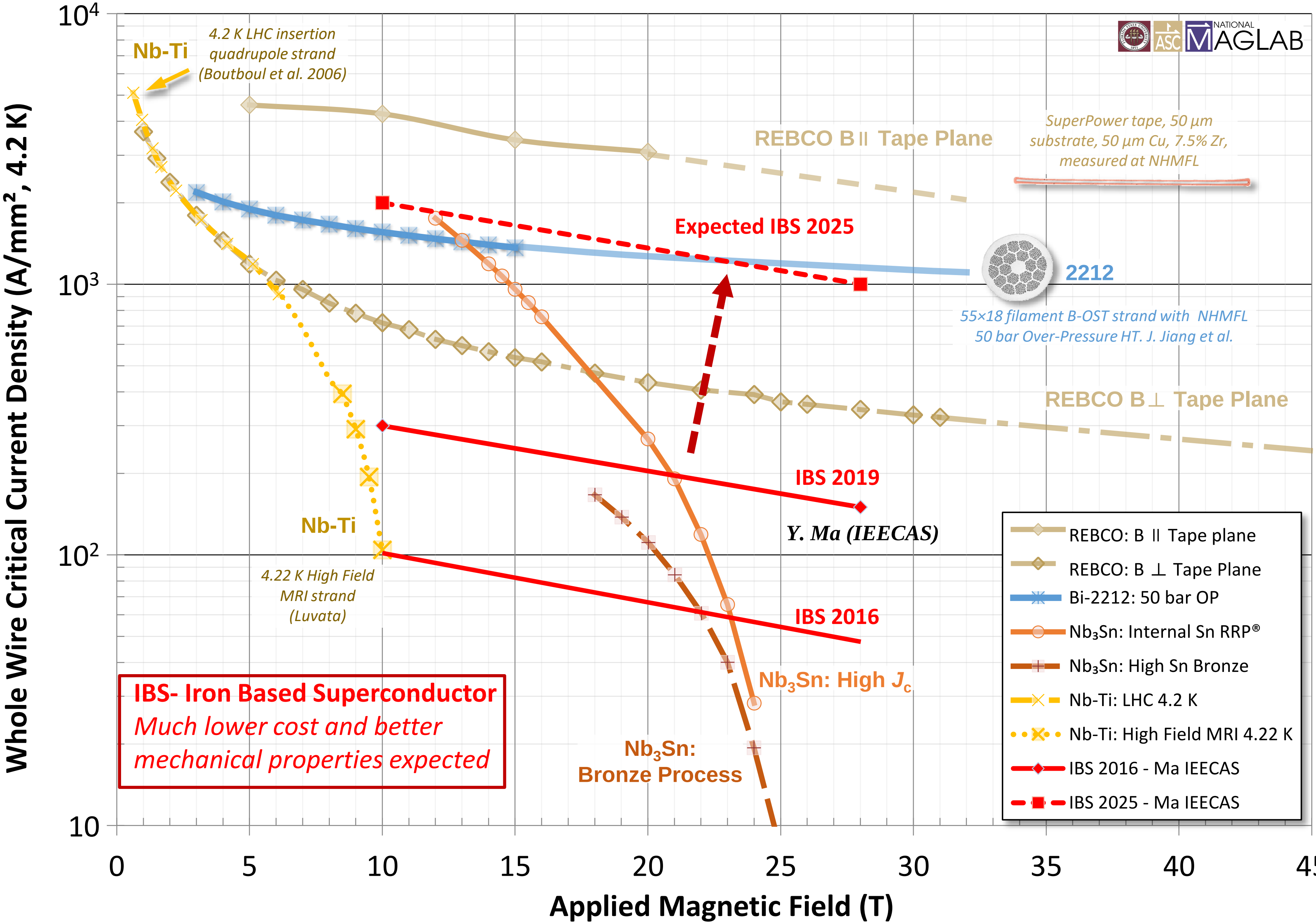
6-m width Tunnel for CEPC-SPPC



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**

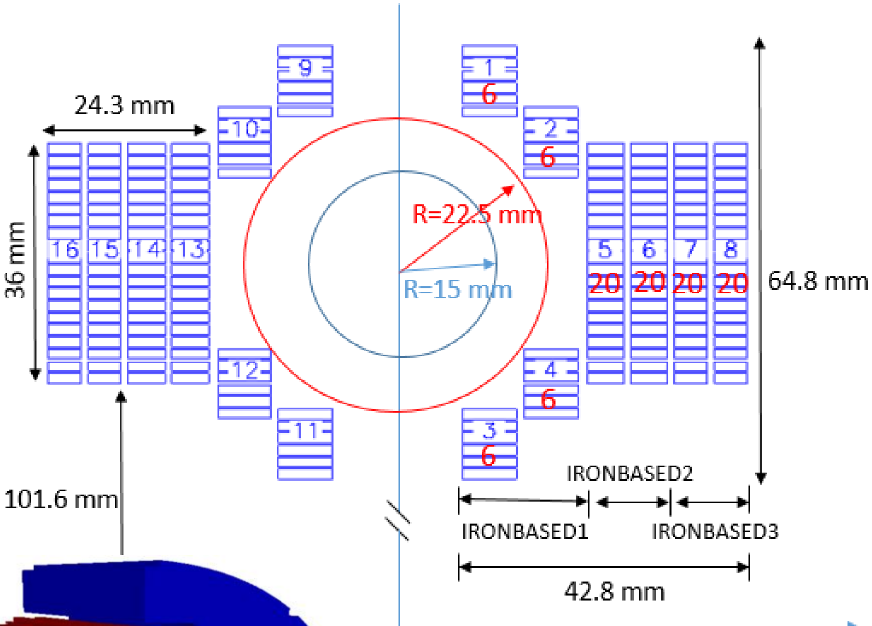
Proposal for
Strategic Priority Research Program of Chinese Academy of Sciences (CAS)
Science and Technology Frontier Research for High Field Applications of High Temperature Superconductors

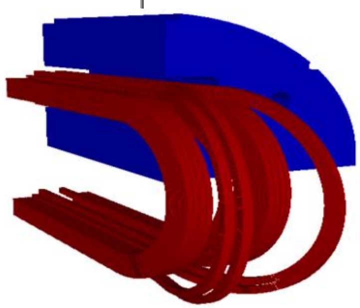
Ranked No. 1 in 7 candidates by Academic Committee of CAS

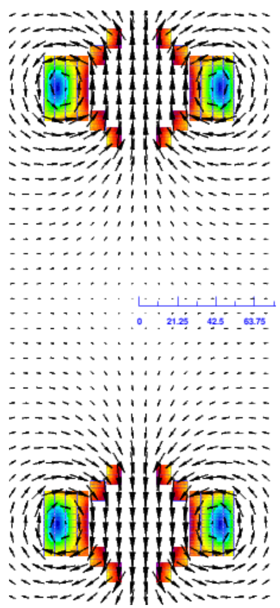
360M RMB for 2018-2023

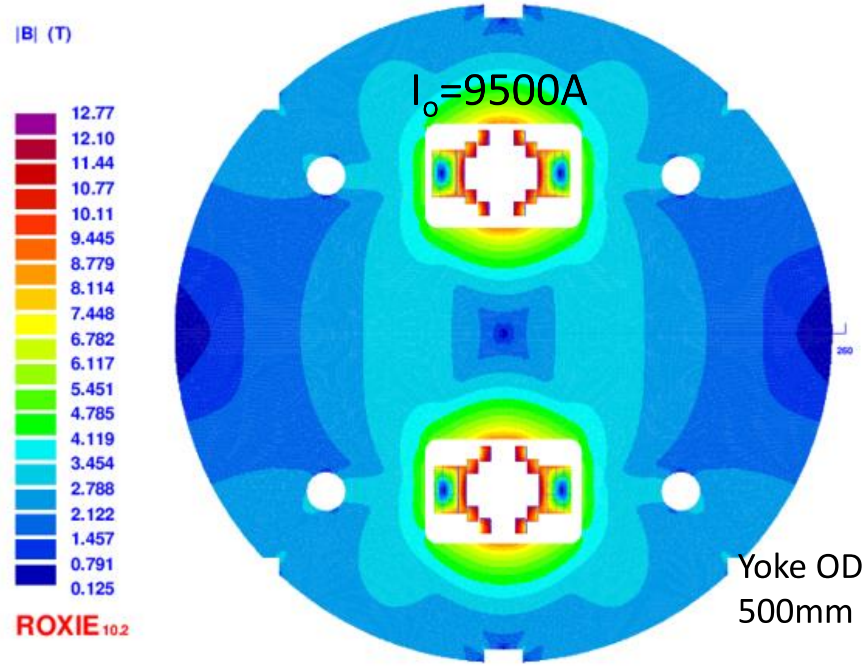
The 12-T Fe-based Dipole Magnet

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

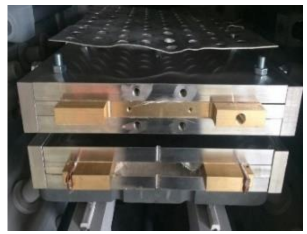
Field quality	2D with R_f=13.3mm	3D with R_f= 8/13.3 mm
b3	0.45	0.79/1.91
b5	1.01	-0.65/-2.24
b7	0.46	0.08/0.67
b9	-0.27	-0.13/-0.22
a2	3.53	-1.00/-2.31
a4	0.49	-0.46/0.69
a6	0.33	0.26/2.49
a8	0.58	-0.12/0.84
a10	2.23	0.06/2.18

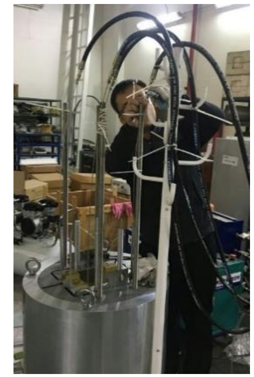
- For 100-km SPPC, needs **3000 tons of IBS**
- Target cost of IBS: **20 RMB /kAm @12 T**

R&D Fabrication Procedures and Challenges

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

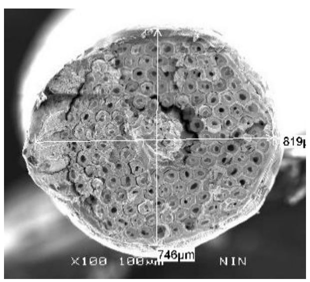
Temperature control, Thermal stress control
J_c and RRR degradation.



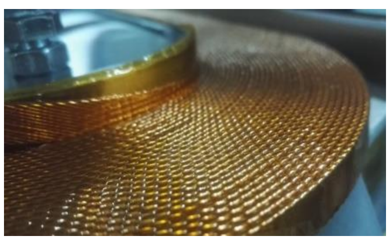


Pre-stress control
Stress of coils, Mechanical Stability…

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

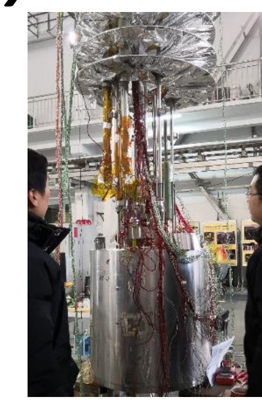


Material, Structure, Processing,…
$J_{c,}$ RRR, Cu ratio, Filament size…



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

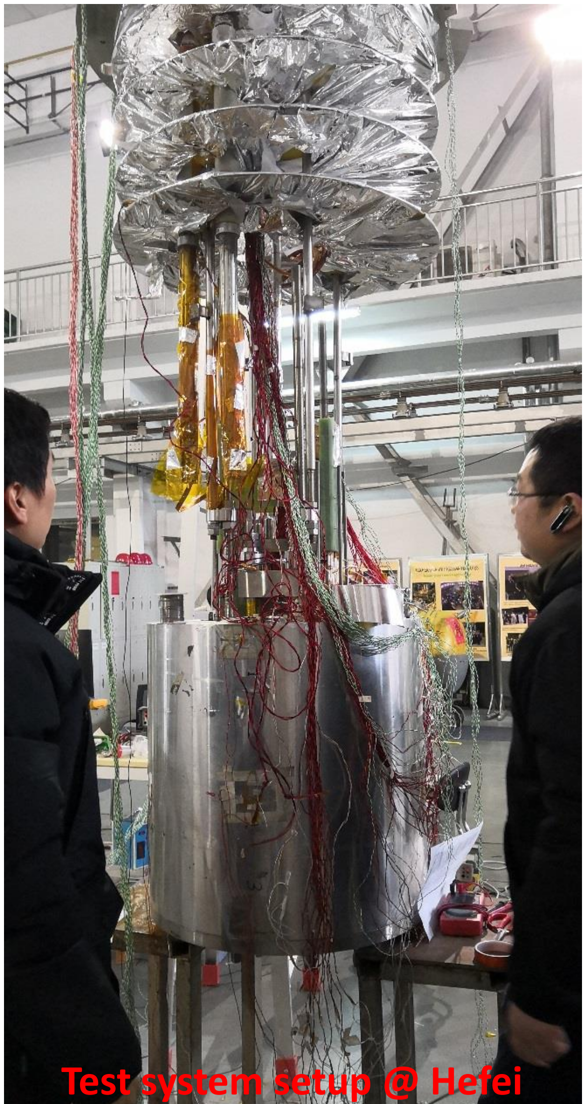


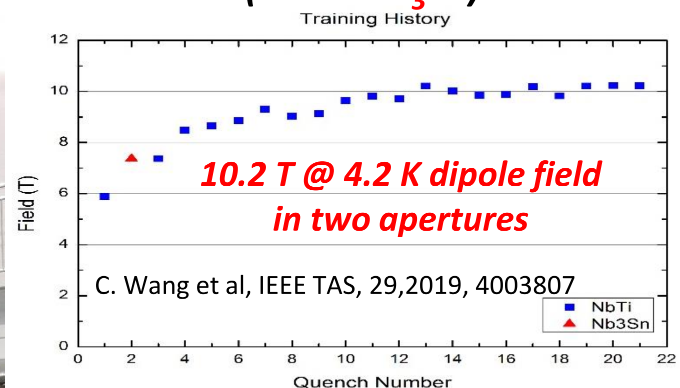
EM force, Quench protection
Training, Strain of coils…

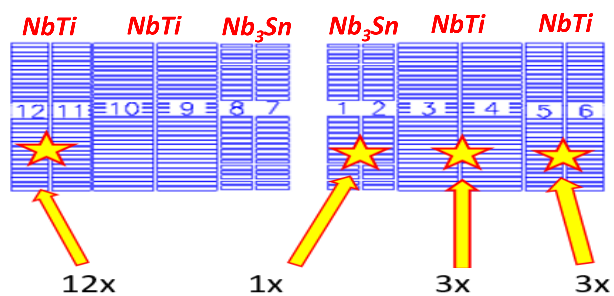
The 1st High-Field Dipole Magnet LPF1

Test results of LPF1

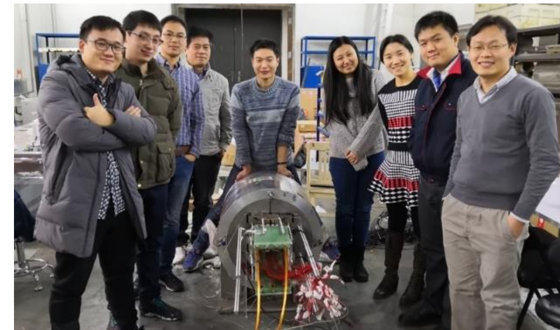
($NbTi+Nb_3Sn$)

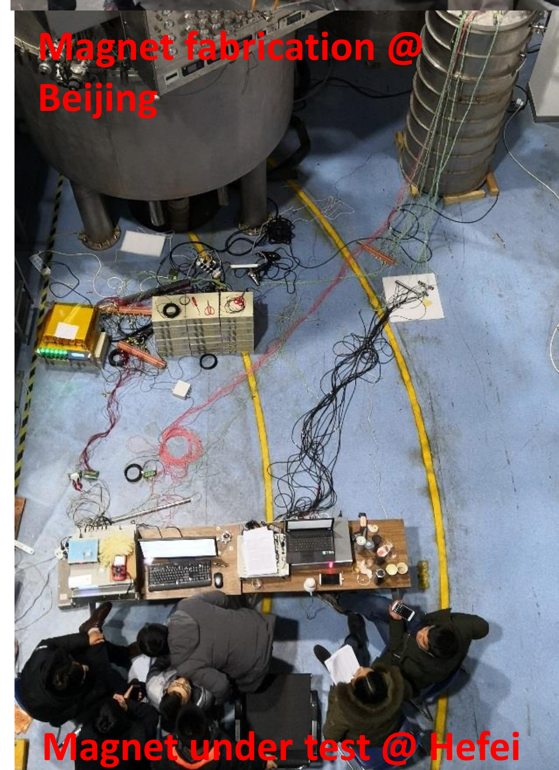






- *Performance limited by the outermost NbTi coil.*
- *Very possibly caused by less of pre-stress.*
- *Being tested again now with higher Pre-stress (from 30 MPa to 80 MPa).*





International Conference on Magnet Technology

September 22 - 27, 2019.

Hosted by

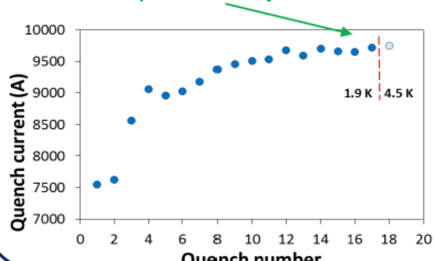
TRIUMF

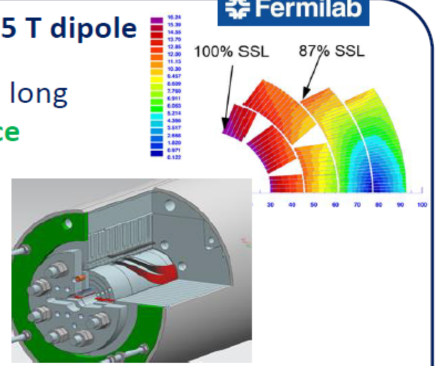
Models development toward 16 T magnets

U.S. MAGNET DEVELOPMENT PROGRAM

Key milestone: 15 T dipole

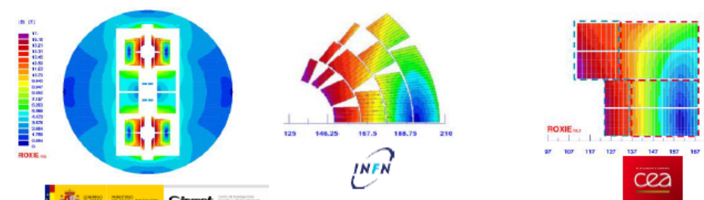
- 4 layer graded magnet, 1-m long
- 1st step: **14.1 T performance**





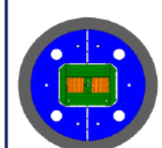
Courtesy of A. Zlobin, FNAL

FCC 16 T Model Magnet Development

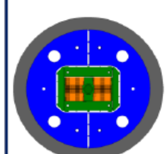


Nb_3Sn GRADING

CERN



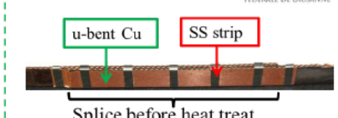
eRMC
No bore
16 T target

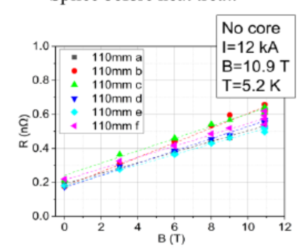


Racetrack Model Magnet = RMM
50 mm bore
16 T target

Nb_3Sn joints

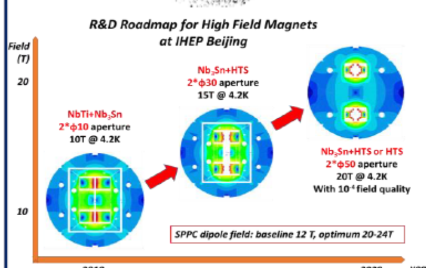
EPFL

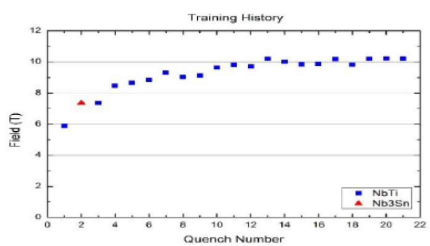




Courtesy of V. D'Auria, EPFL

Institute of High Energy Physics
Chinese Academy of Sciences

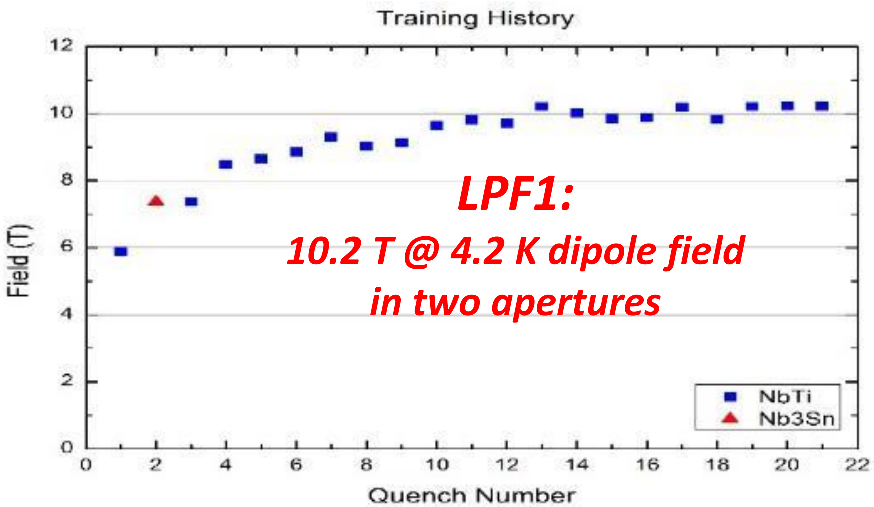


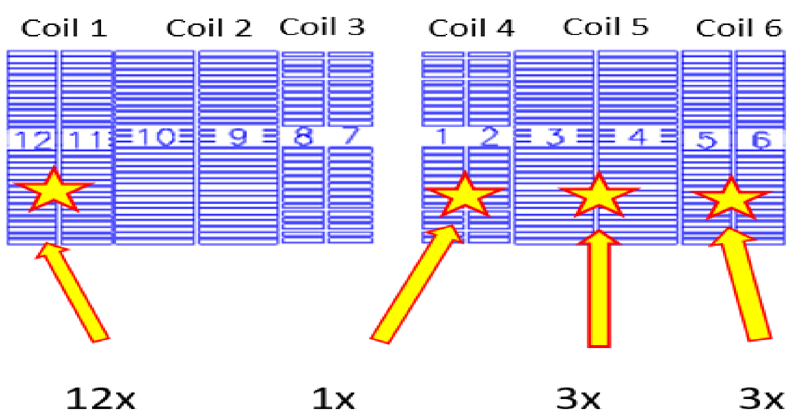


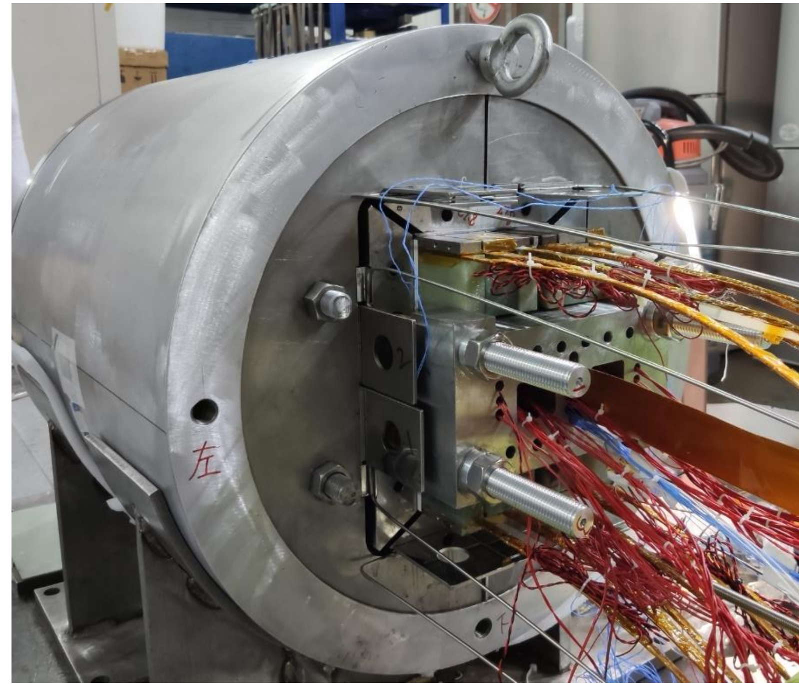
Courtesy of Q. Xu, IHEP

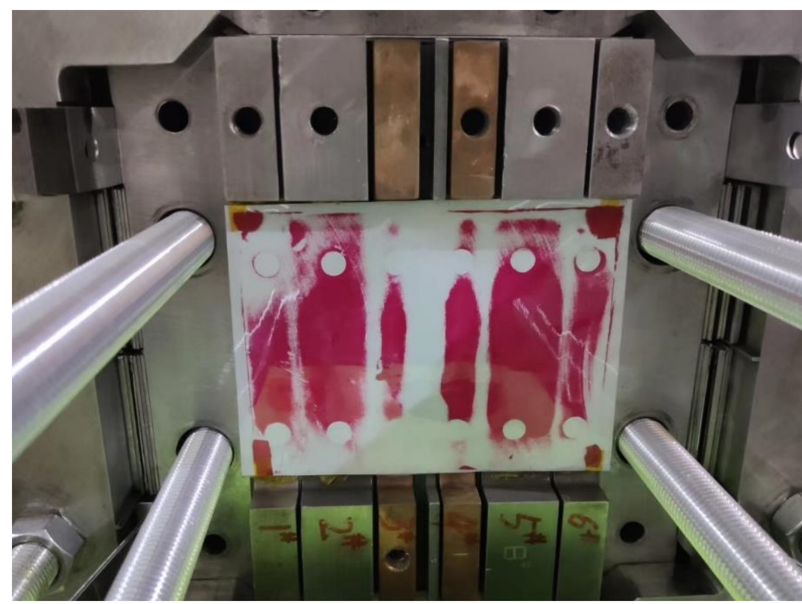
10.2 T at 4.2 K in 2 apertures

LPF1s:LPF1 with improved pre-stress

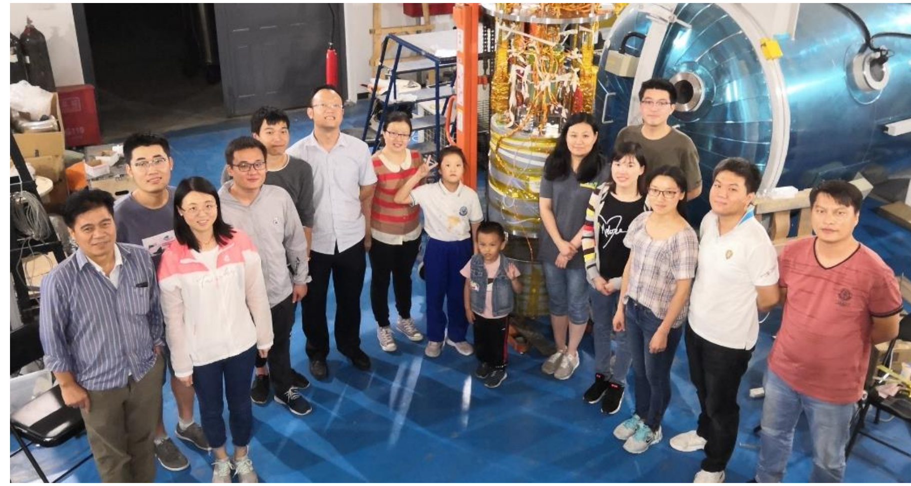


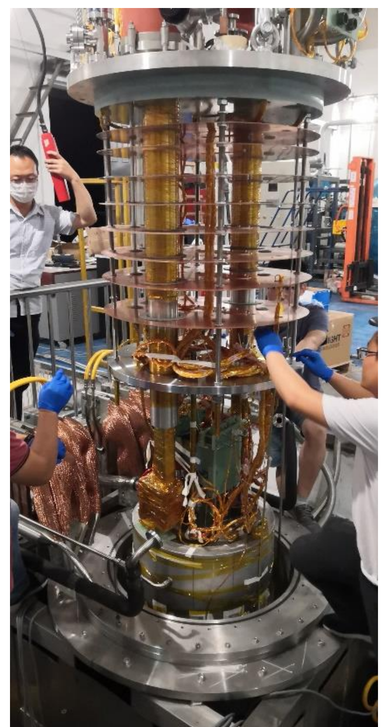






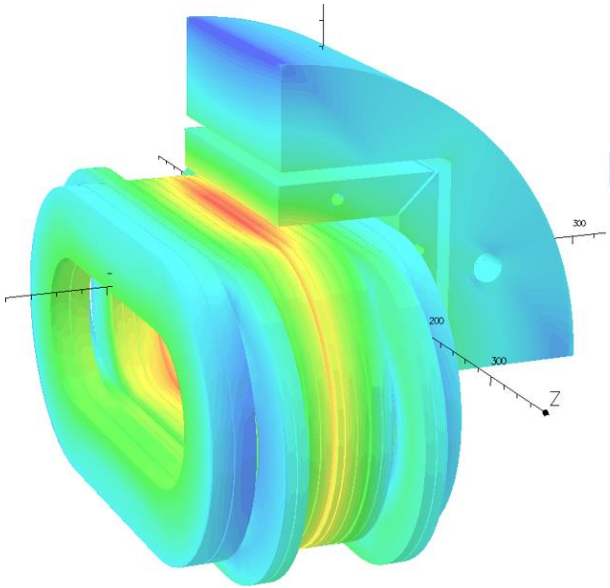
Test preparation of LPF1s

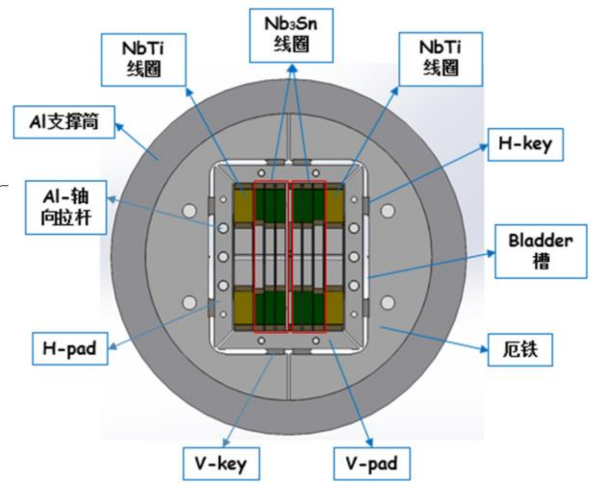


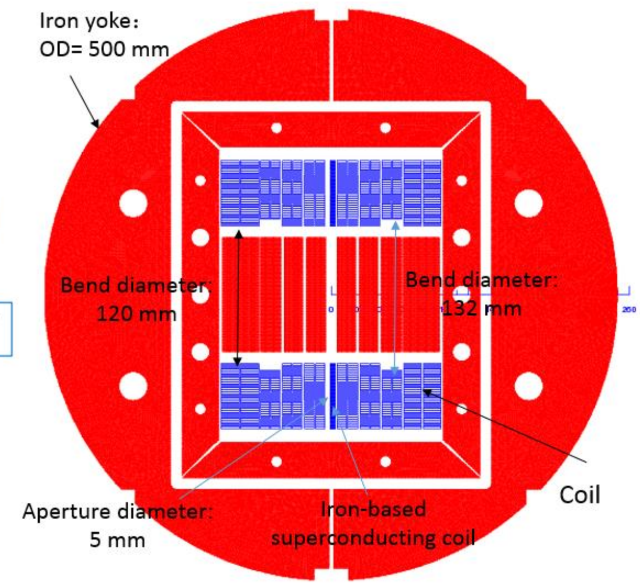


Development of LPF2

（ $NbTi + Nb_3Sn$ + IBS）

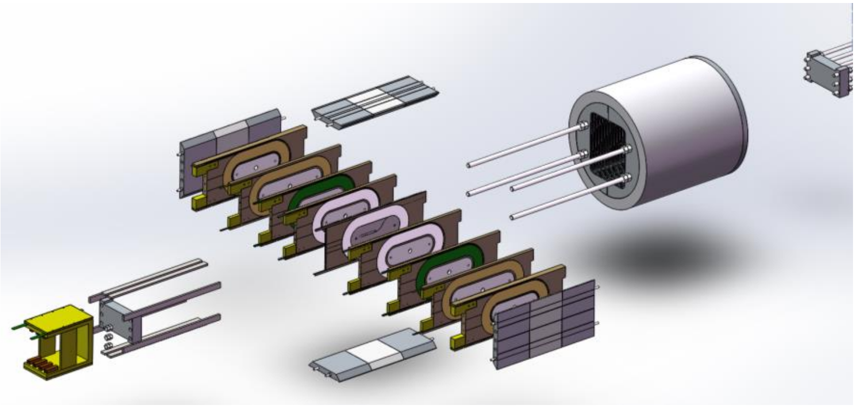


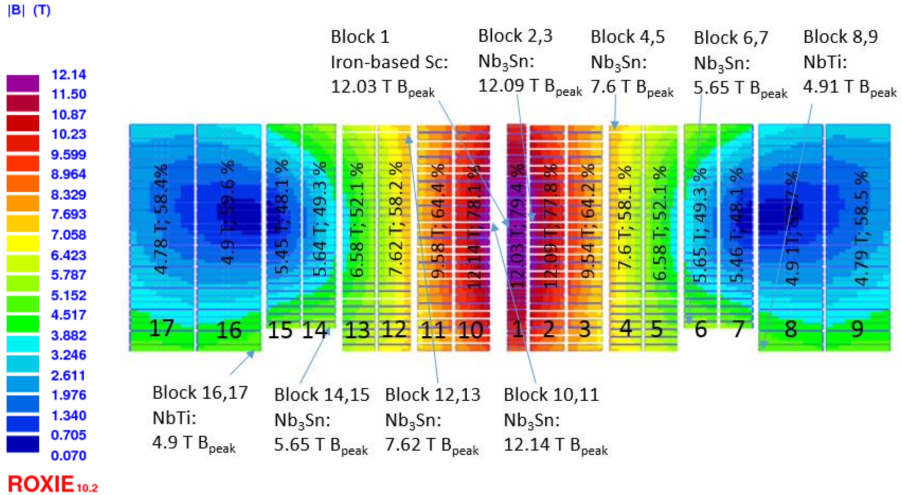




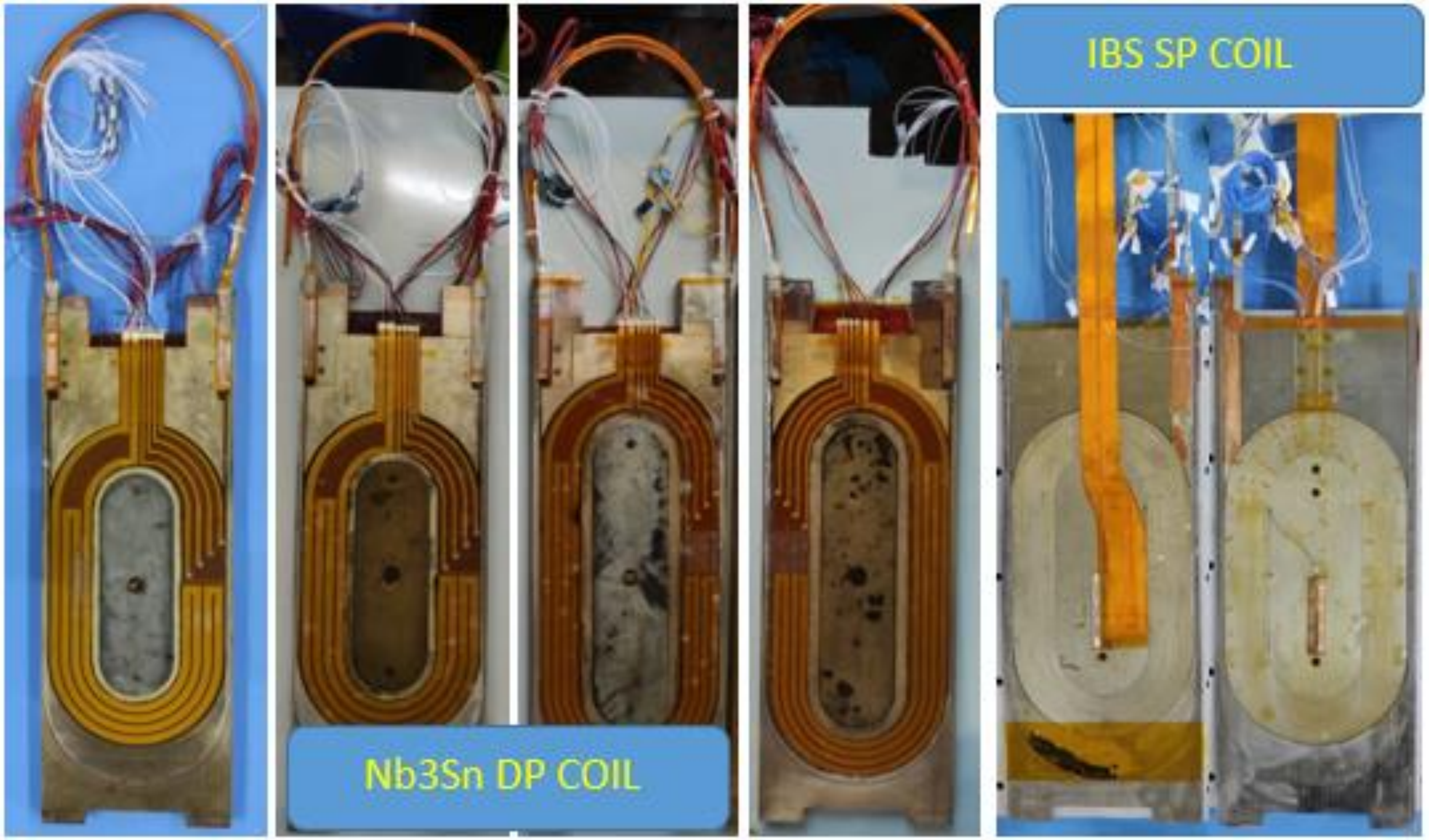
3D Magnetic & Mechanical model

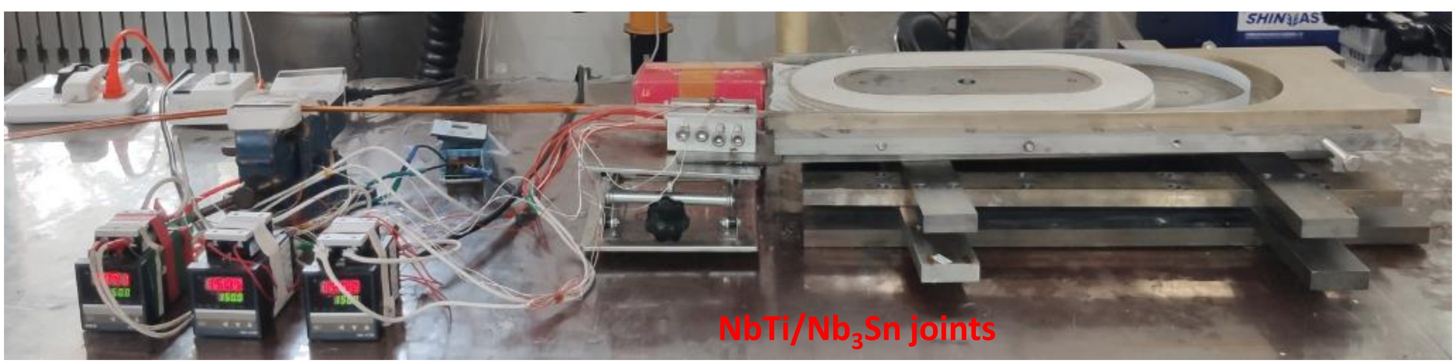
Cross section of the magnet





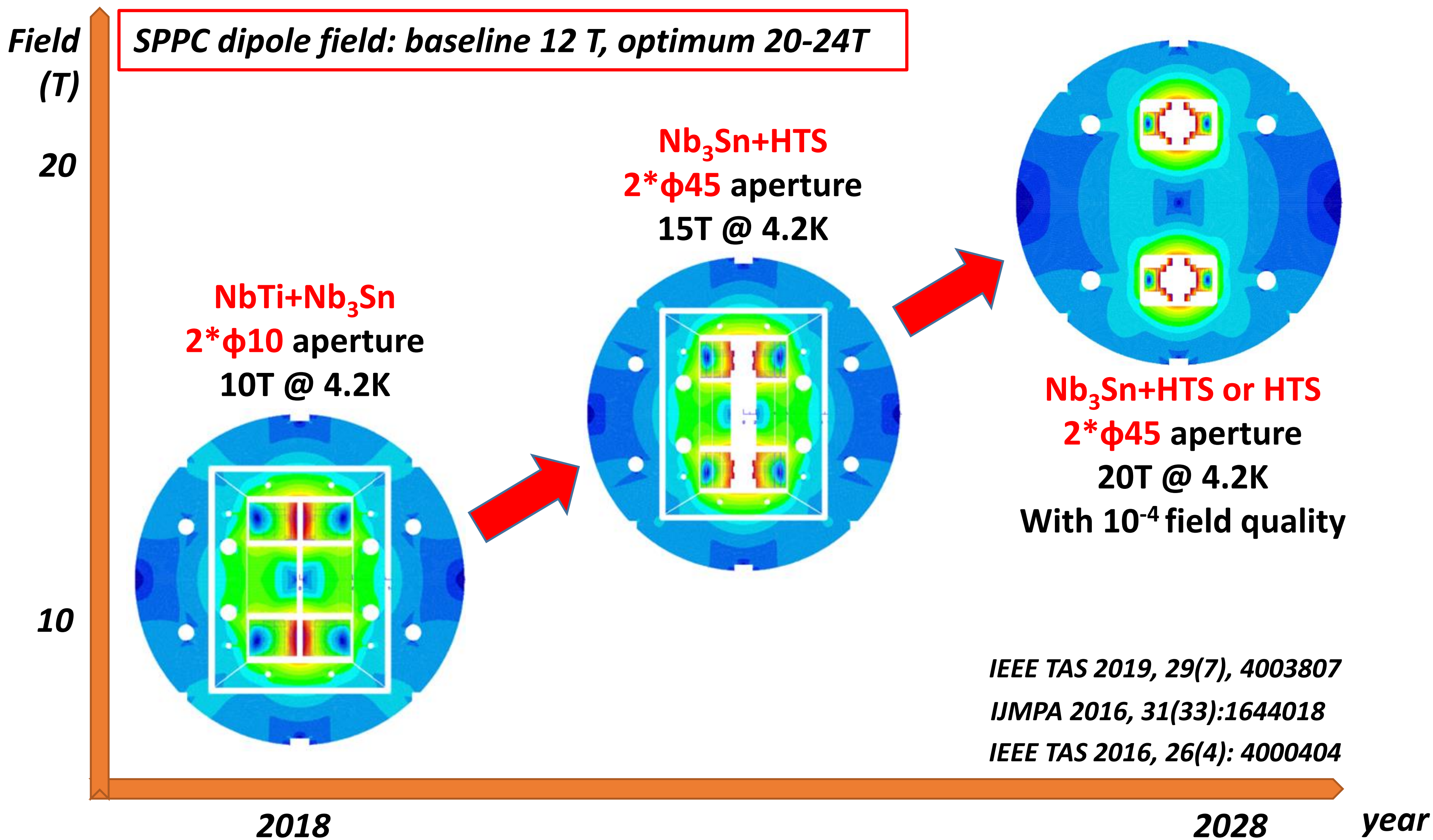
Development of LPF2





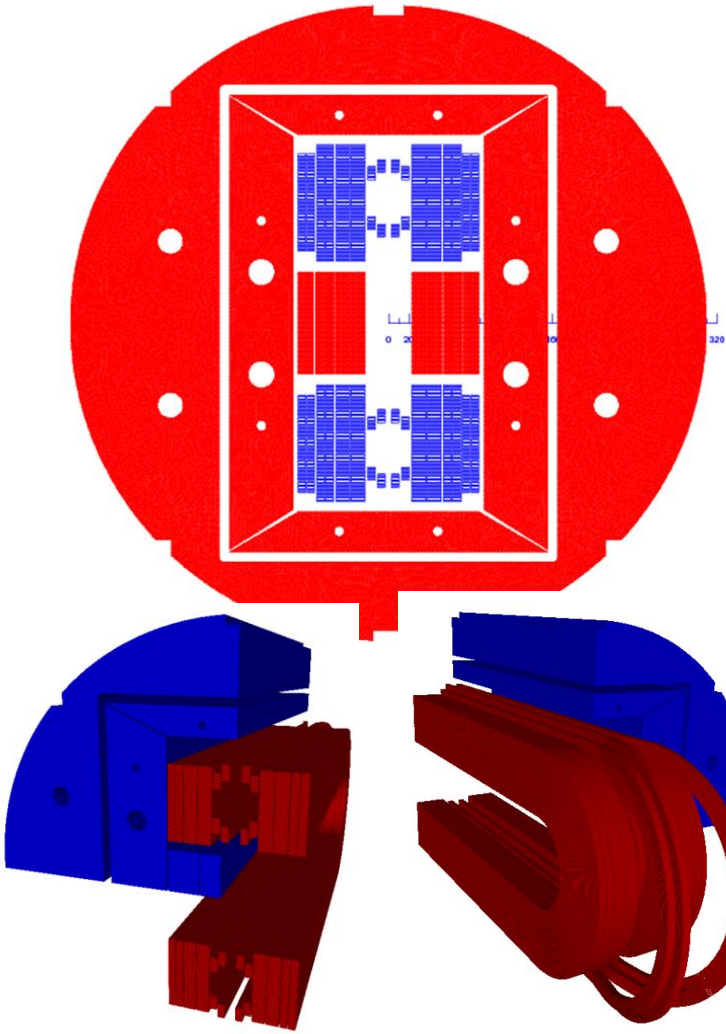
R&D of High Field Dipole Magnets

R&D Roadmap for the next years

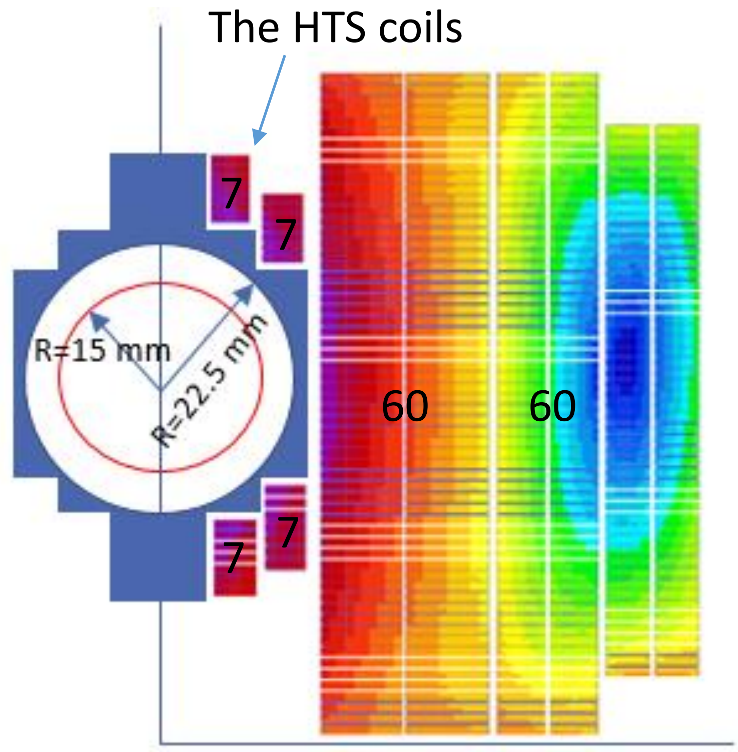


LPC:12~16T Prototype Dipole with Field Quality

NbTi+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 Superconductor Science and Technology
Supercond. Sci. Technol. **32** (2019) 04LT01 (5pp) https://doi.org/10.1088/1361-6668/ab09a4

Letter

First performance test of a 30 mm iron-based superconductor single pancake coil under a 24 T 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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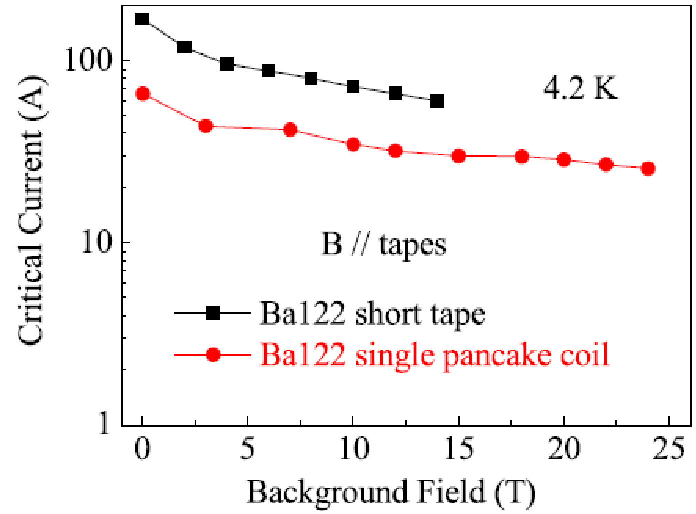
[2] University of Chinese Academy of Sciences, Beijing 100049, People's Republic of China
[3] Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, People's Republic of China
[4] High Magnetic Field Laboratory, Chinese Academy of Sciences, Hefei 230031, People's Republic of China



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

Viewpoint

CrossMark

Constructing high field magnets is a real tour de force

Jan Jaroszynski
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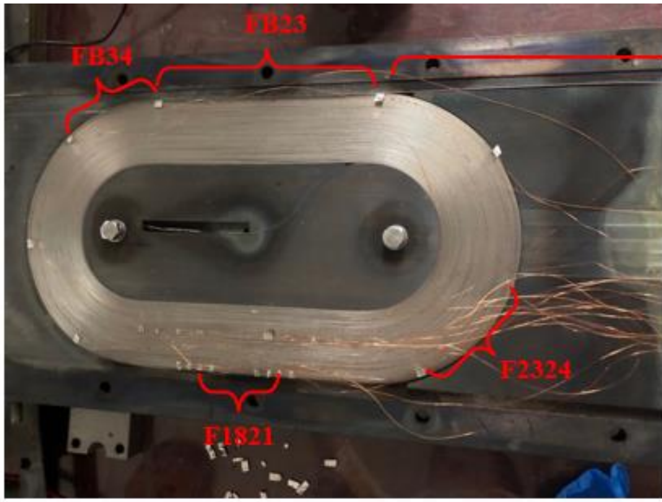
E-mail: jaroszy@magnet.fsu.edu

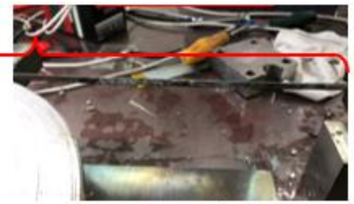
This is a viewpoint on the letter by Dongliang Wang *et al* (2019 *Supercond. Sci. Technol.* **32** 04LT01).

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

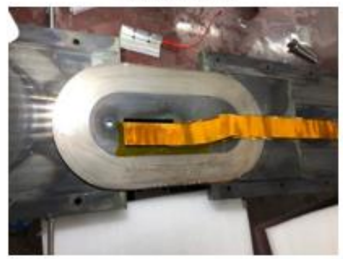
Performance of the 1st IBS Racetrack Coil

Fabrication and test of IBS racetrack coil at 8T

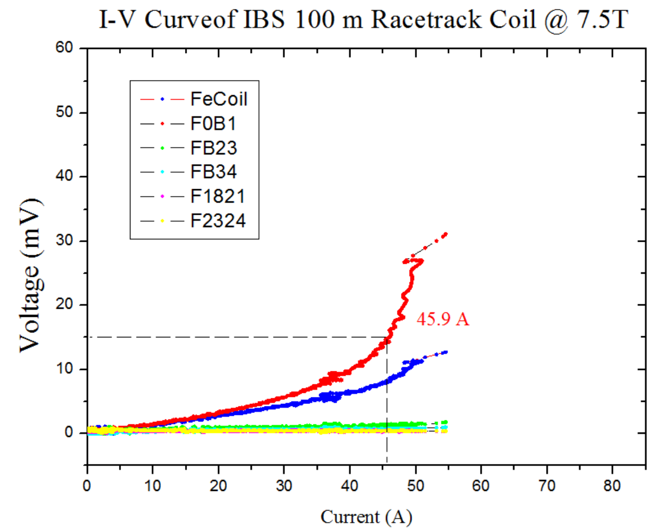


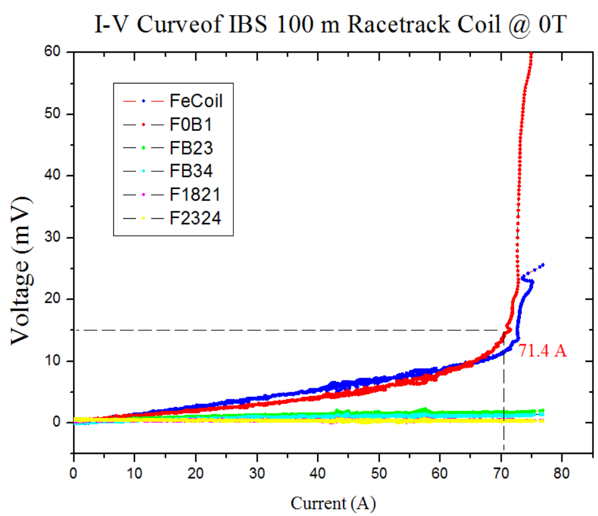


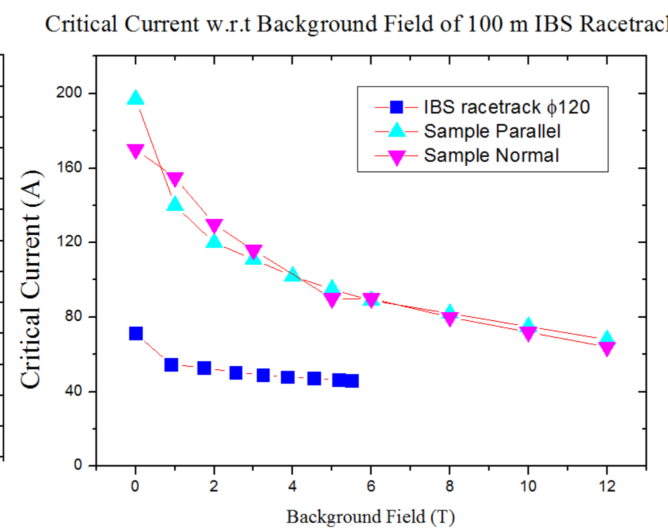
Outer Joint



Inner Joint





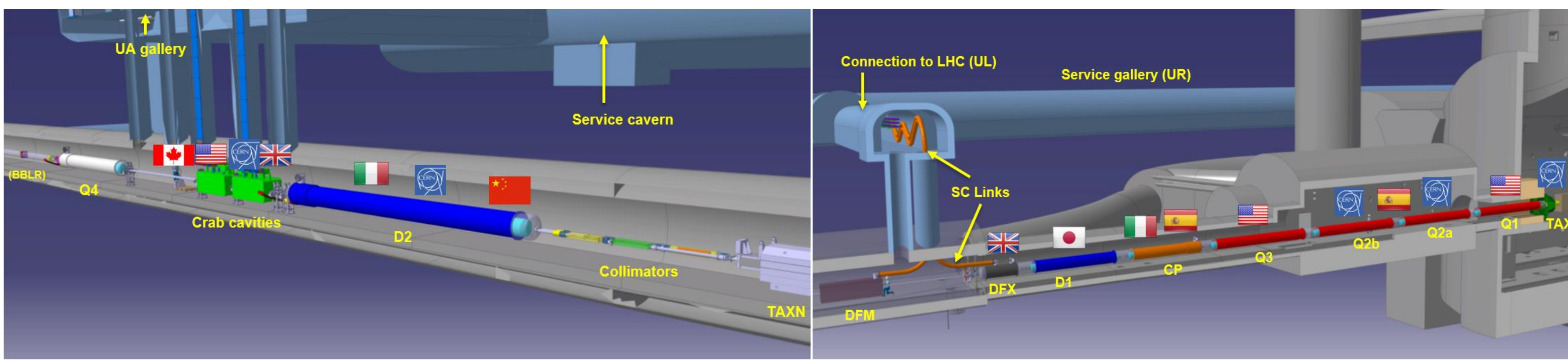


R&D of HL-LHC CCT Magnets

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.

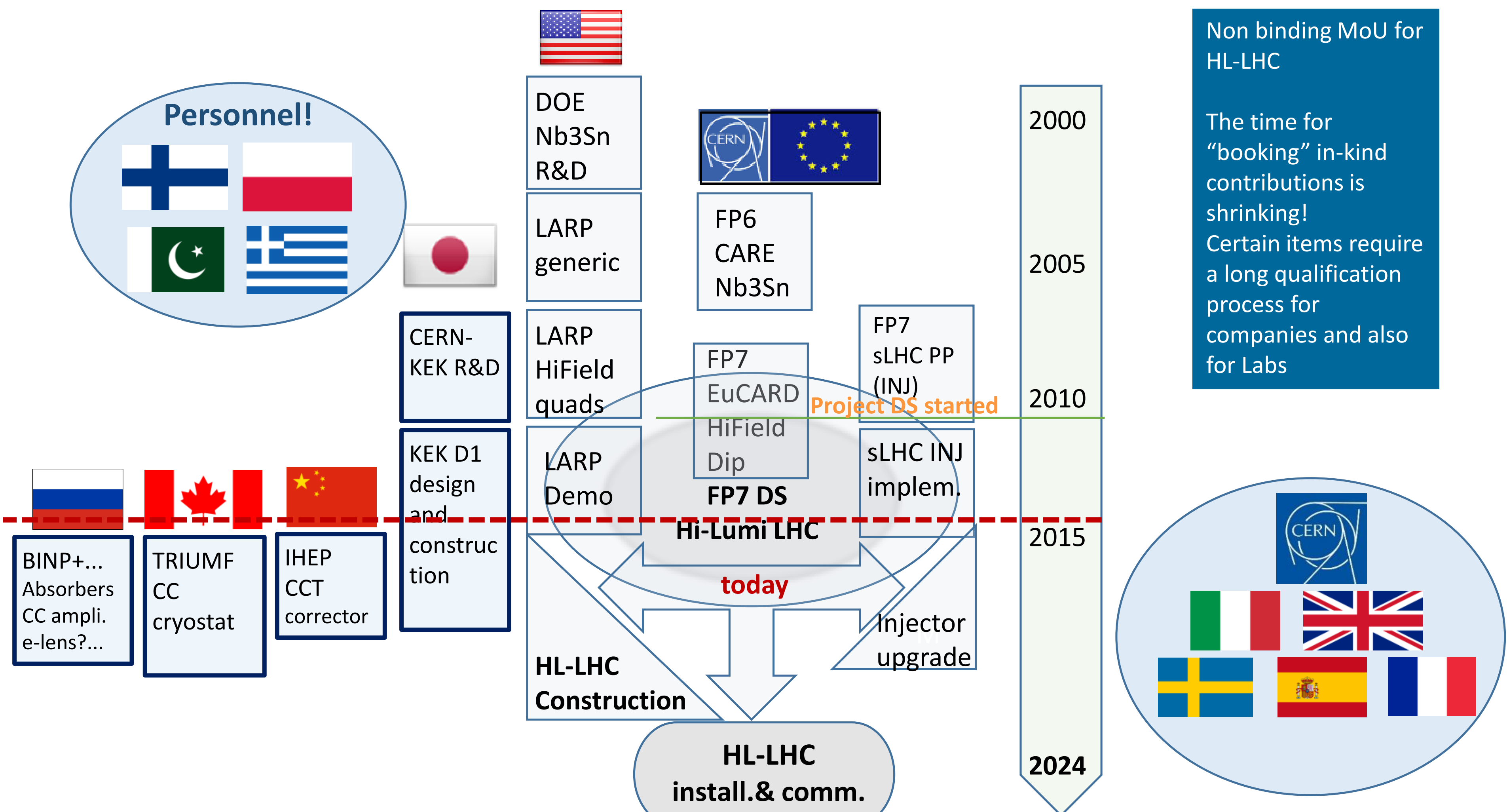
Agreement For HL-LHC CCT Magnets Signed in Sep 2018



R&D of HL-LHC CCT Magnets

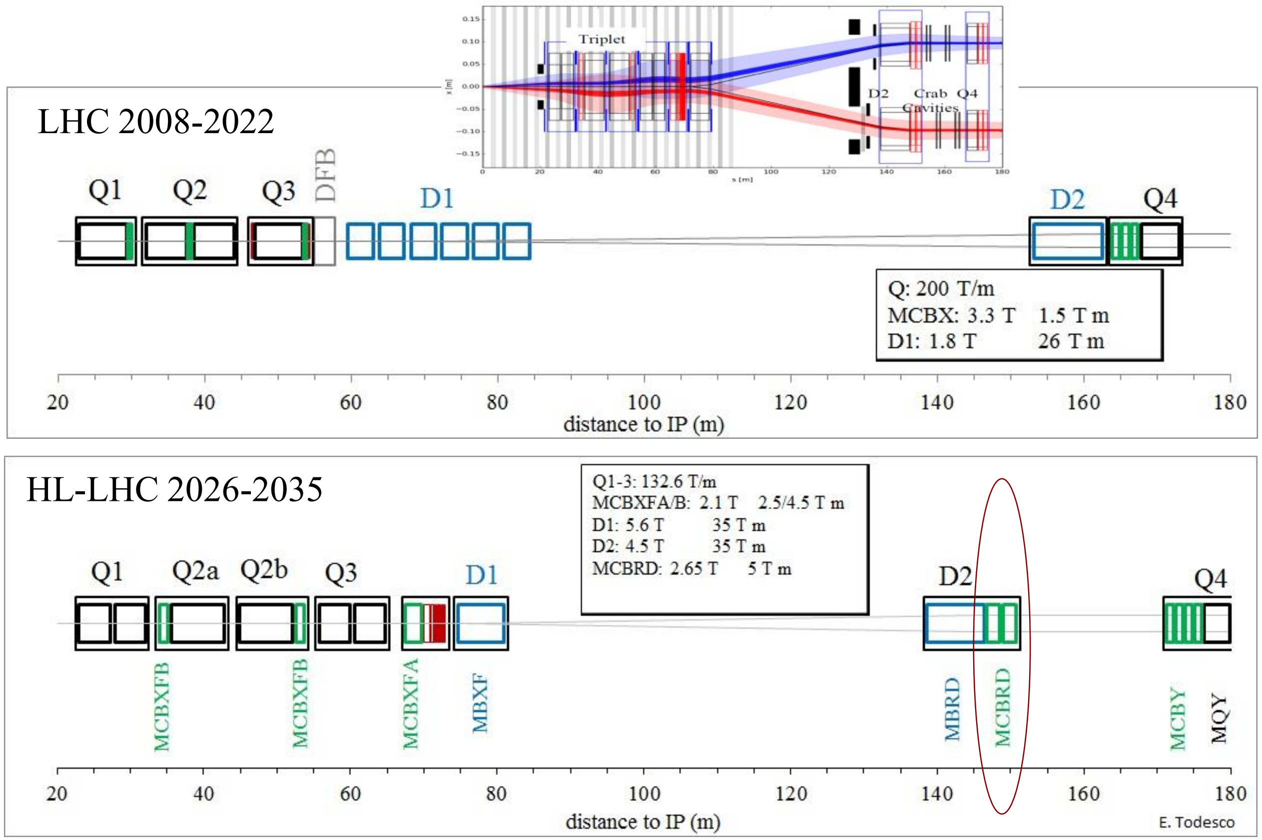
Non binding MoU for HL-LHC

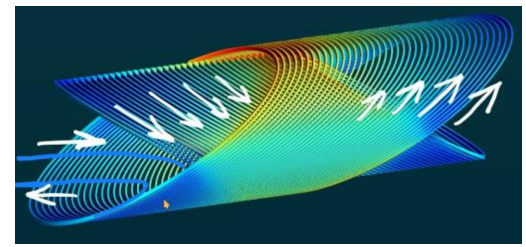
The time for "booking" in-kind contributions is shrinking!
Certain items require a long qualification process for companies and also for Labs

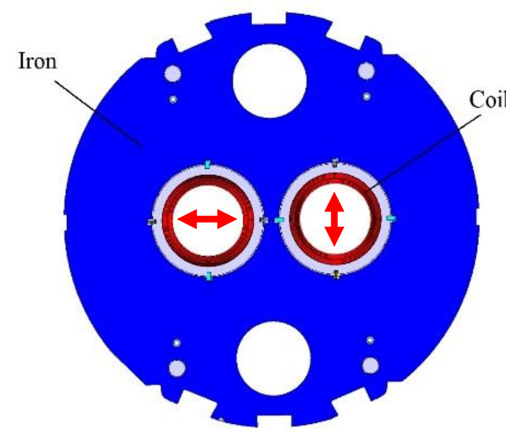


R&D of HL-LHC CCT Magnets

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



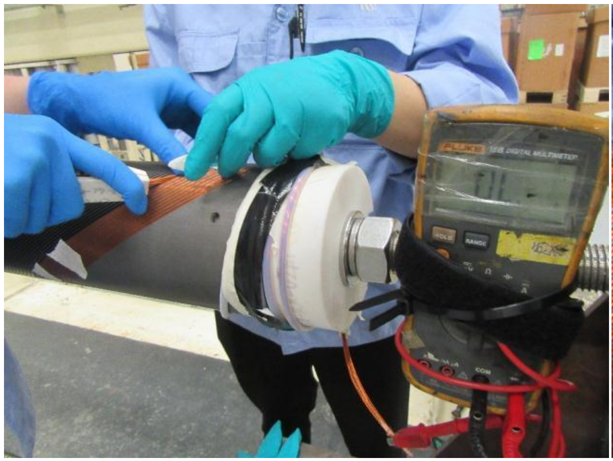


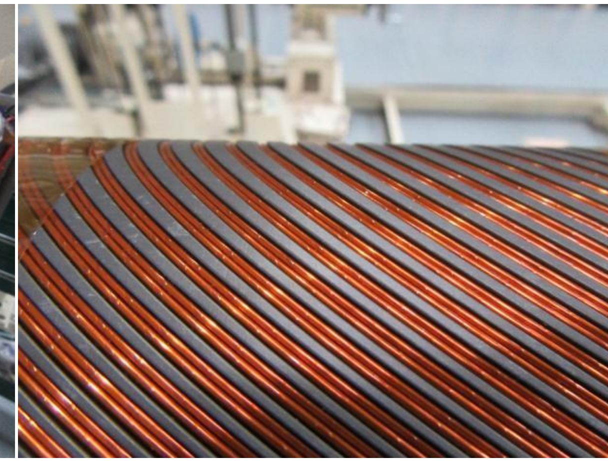


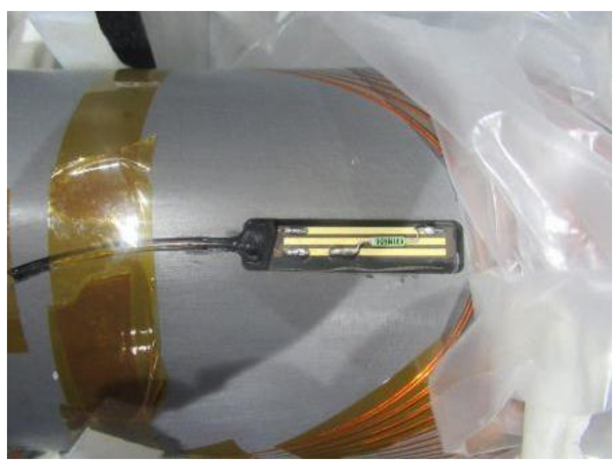
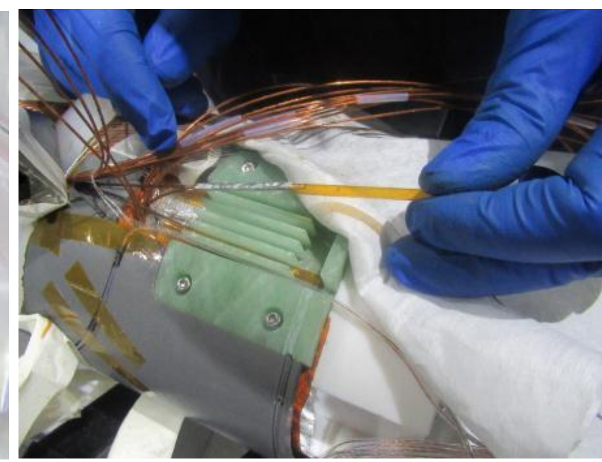
E. Todesco

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.



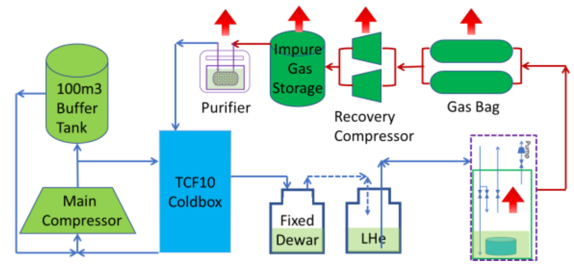


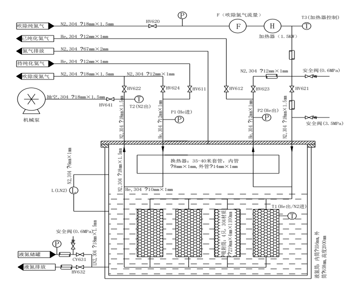



R&D of HL-LHC CCT Magnets

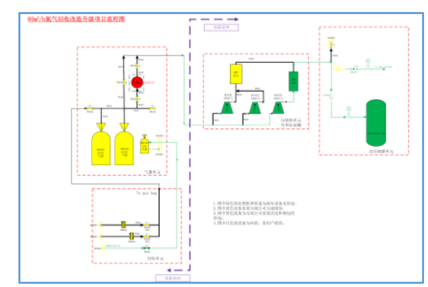
Upgrade Project of the cryogenic system

- First phase (Done)
  - Gas bag → 200 m^3
  - Recovery compressor → 80 m^3/h
  - Impure Gas Storage → ＞10 m^3 @ 15MPa
  - External Purifier → 75 m^3/h
  - Vertical Dewar → Φ 800 x 3800 mm
- Second phase
  - + Valve box for Vertical Test Dewar
  - + Pre-cooler system down & warm up

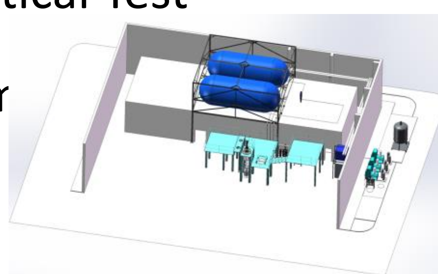


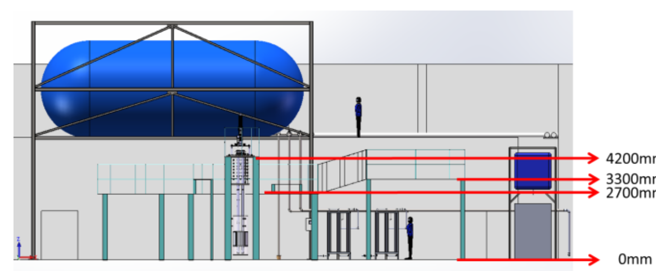


Scheme of the purifier



Scheme of the Recovery System



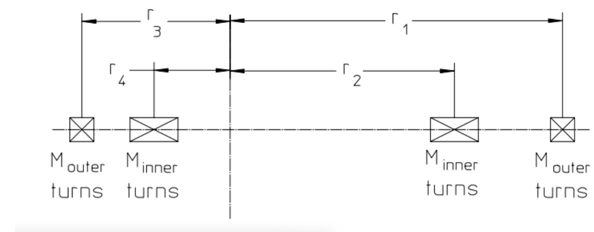


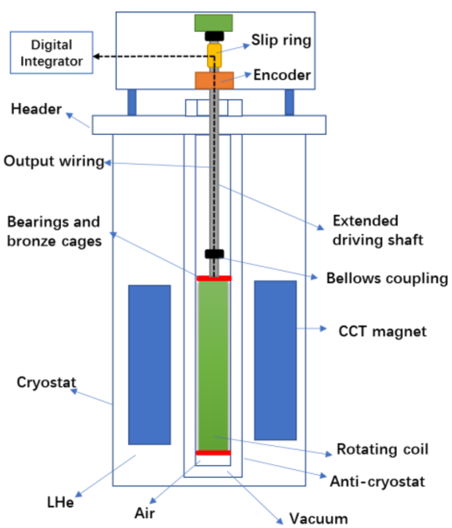
Lay out of the test stand

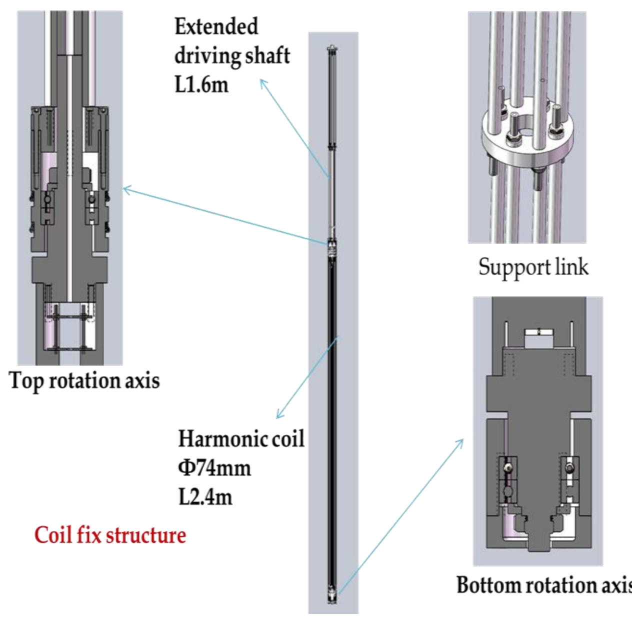
R&D of HL-LHC CCT Magnets

Field Measurement System

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







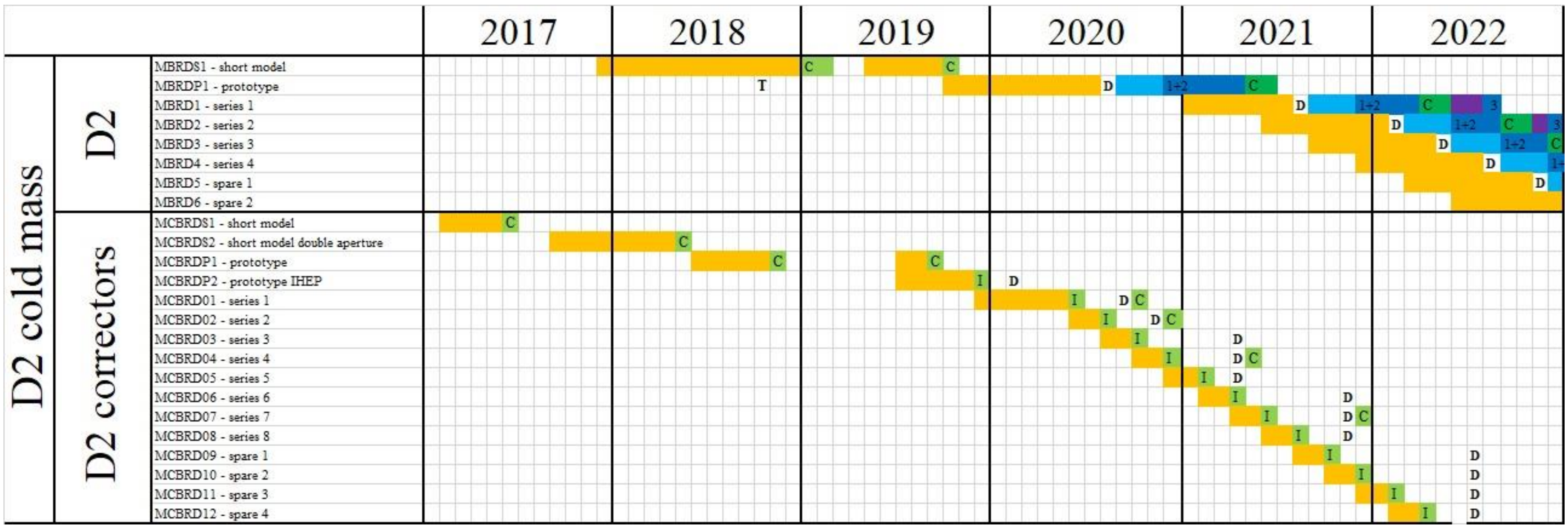
Coil fix structure

- ✓ 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.

R&D of HL-LHC CCT Magnets

Schedule of the 12 Series CCT Magnets



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