中国科学院高能物理研究所
Institute of High Energy Physics，CAS

环形正负电子对撞机
Circular Electron-Positron Collider

CEPC Detector Superconducting Magnet Conceptual Design

Speaker: Zongtai Xie, IHEP
Represent for the Superconducting Magnet team

HKUST, 23th Jan. 2019

Contents

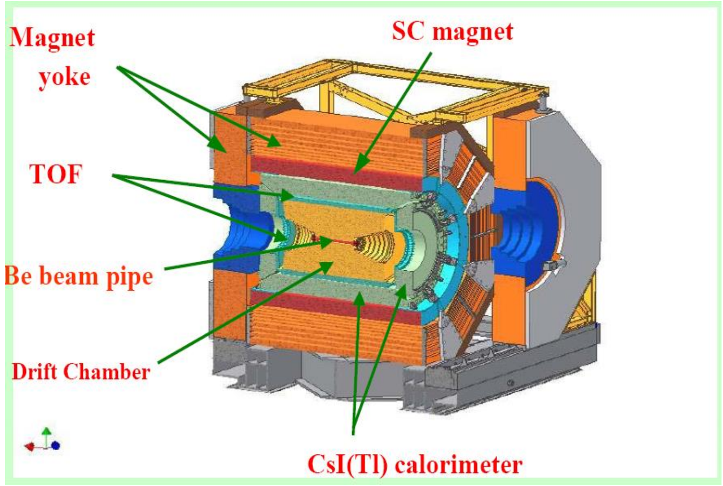
Introduction

Design Philosophy:

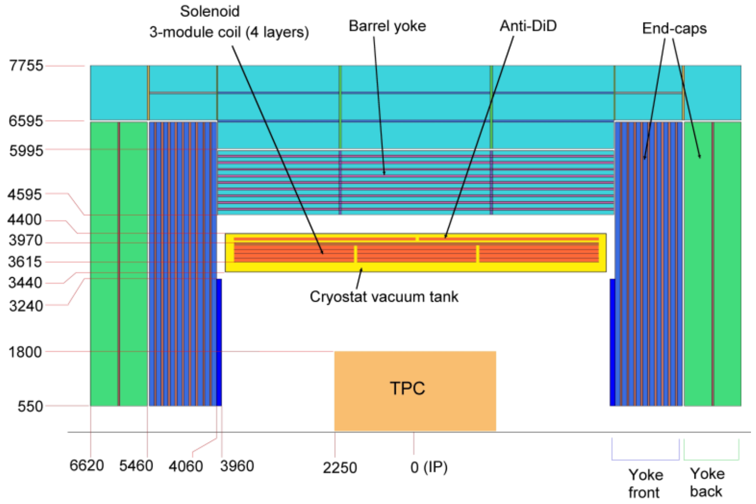
The CEPC detector magnet follows the same design concepts of the BESIII magnet, as well as CMS and ILD.

Baseline Design:

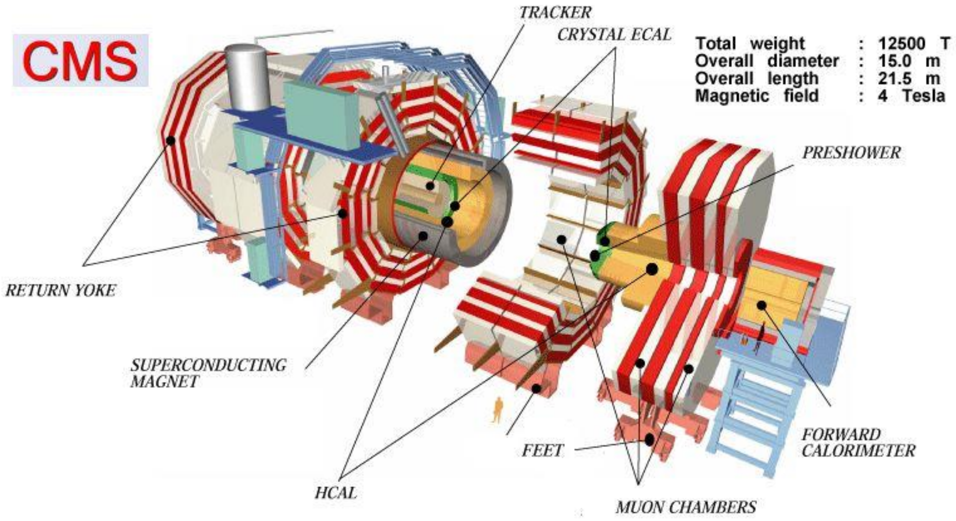
LTS superconducting solenoid and iron yokes outside, based on self-supporting conductor.



Beijing Spectrometer (BESIII) magnet



ILD magnet cross section



CMS Detector Magnet

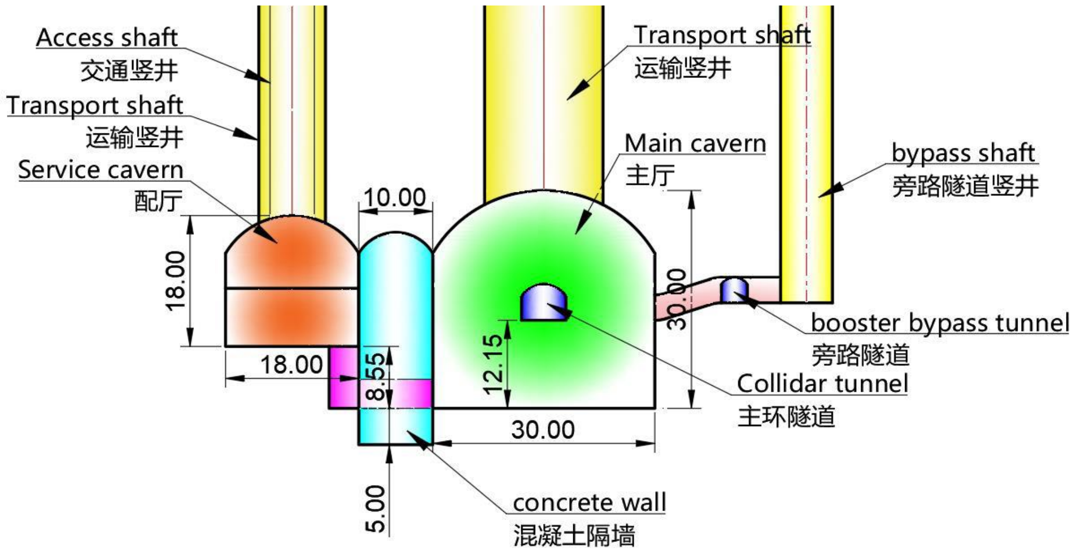
Introduction: Parameters

Magnetic field:
3 Tesla at the interaction point

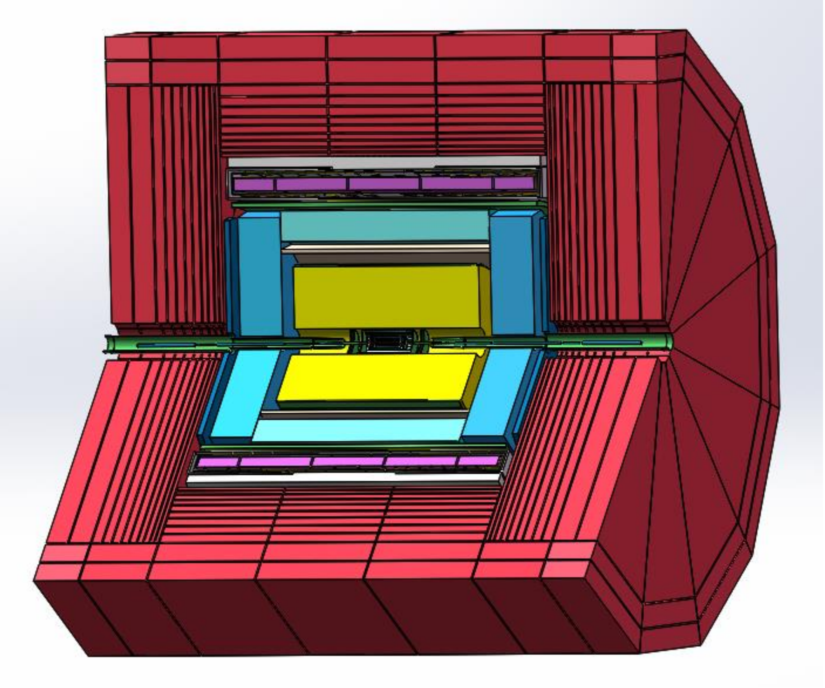
Room Temperature Bore size:
6.8 m in diameter, 8.3 m in length

Larger size, Higher field
(compared to BESIII)

	CMS	CLIC-ILD	ILD	CEPC
Central field(T)	4	4.0	4.0	3
Max. field(T)	4.6		4.77	3.5
Coil inner diameter (mm)	6360	7202	7220	7200
Coil outer diameter (mm)	6980	7888	7940	7656
Coil length (mm)	12400	7890	7350	7445
Superconductor length(Km)	45.4			30.1
Dimension of Superconductor(mm)	22×64			22×56
Layers	4		4	4
Total turns	2168		1260	1288
Stored energy(GJ)	2.69		2.27	1.3
Inductance(H)	14.2		9.26	10.5
Nominal current(A)	19200		22500	15779
Cold mass weight(t)	220	210	168	120
Yoke weight	12000	8900	13400	10000
Cooling Method	Thermosiphon		Thermosiphon	Thermosiphon



Tunnel cross section



Baseline design of CEPC detector magnet

Magnetic Field Design

Magnetic field design of 3 T.

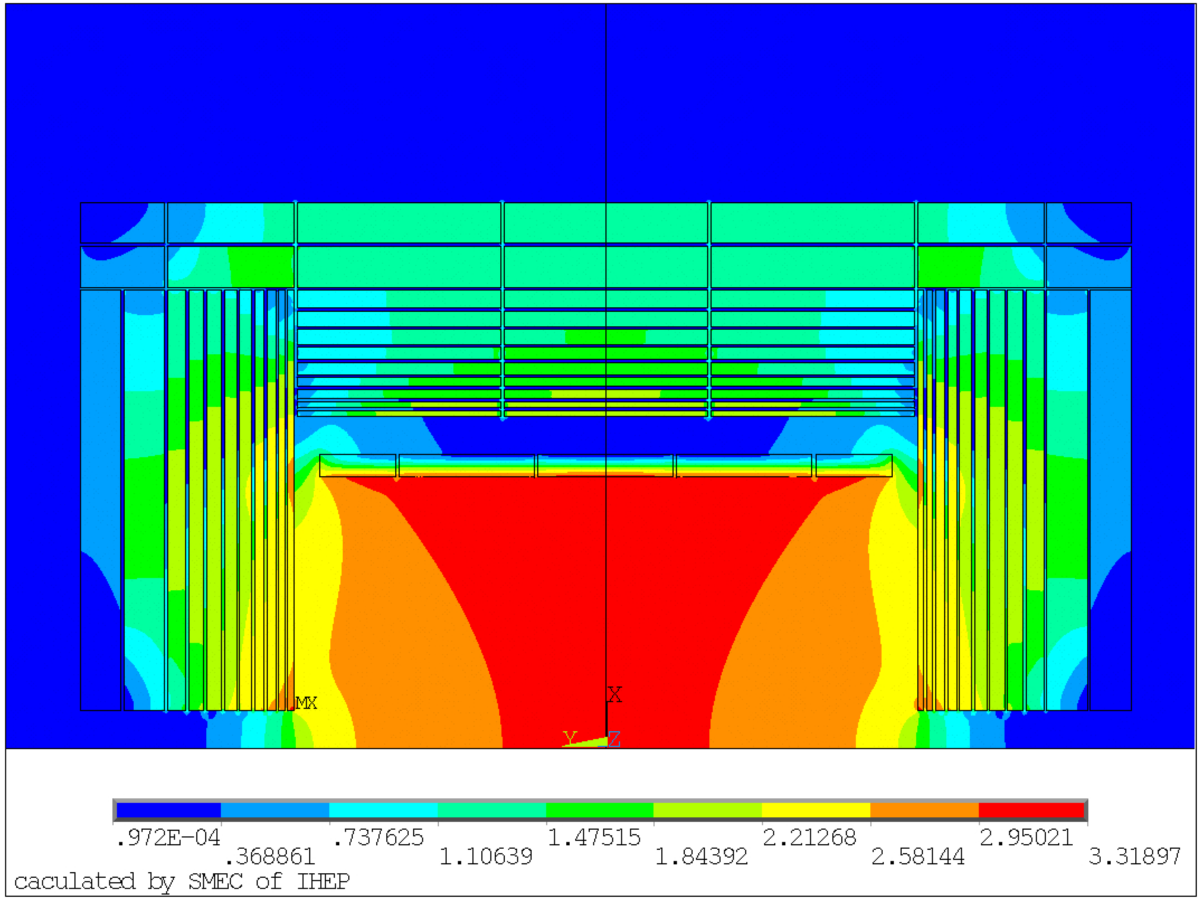
Compared with the design of 3.5T, the dimension is the same;

The current decreases from 18,575 A (3.5T) to 15,921 A

5 Modules each 4 Layers

Operating in the same current

Central magnetic field	3 T
Operating current	15921 A
Stored energy	0.66 GJ
Inductance	10.46 H



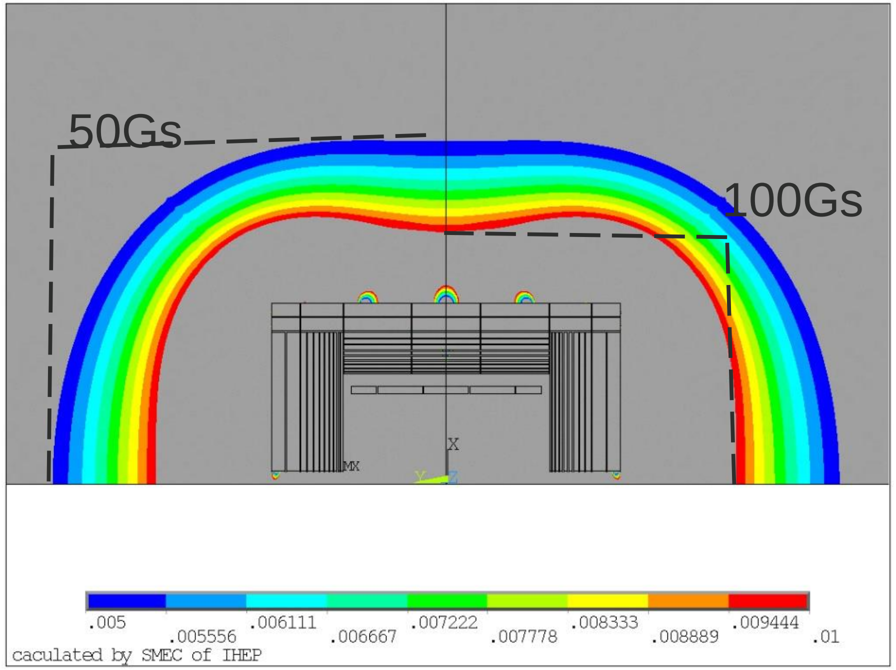
2D Magnetic field distribution(unit： T)

Magnetic Field Design

Stray field distribution:

Compared to 3.5 T, base on the same yoke.

Stray field		3.5 T	3 T
50 Gs	R direction	14.8 m	13.6 m
	Z direction	17.2 m	15.8 m
100 Gs	R direction	11 m	10 m
	Z direction	13 m	11.6 m



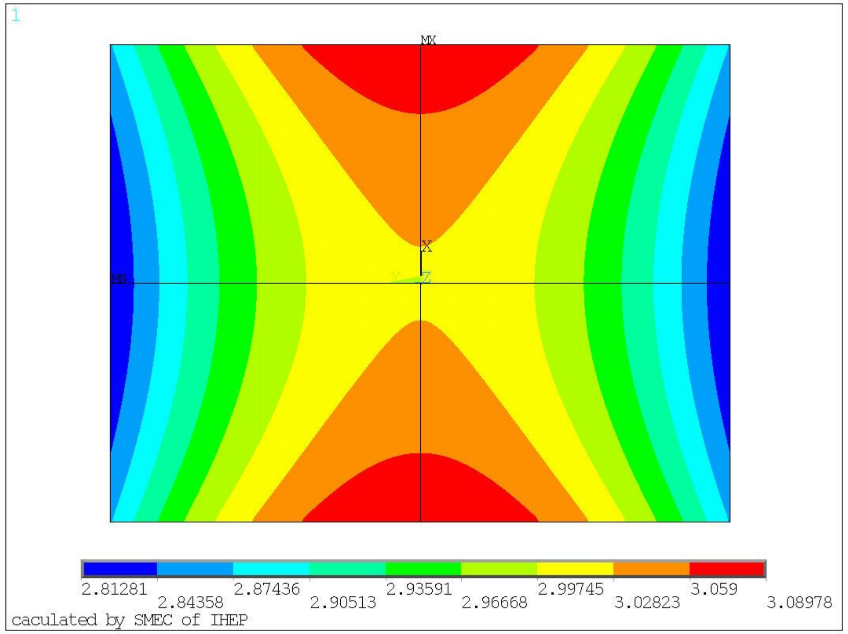
Stray field distribution outside the magnet (the field is given in T)

The non uniformity of Tracking Volume

(diameter 3.62m,length 4.7m) **is 9.2%**

$$B_p = \frac{B_{max}-B_{min}}{B_{center}} = 9.2\%$$

Central field	non uniformity
3.5 T	10.1%
3 T	9.2%



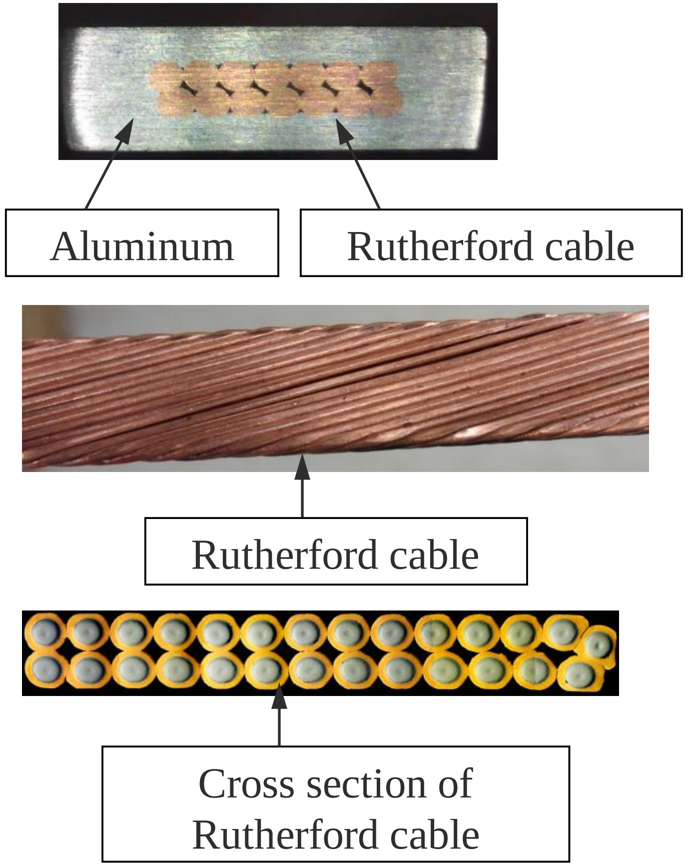
The magnetic field distribution of TV

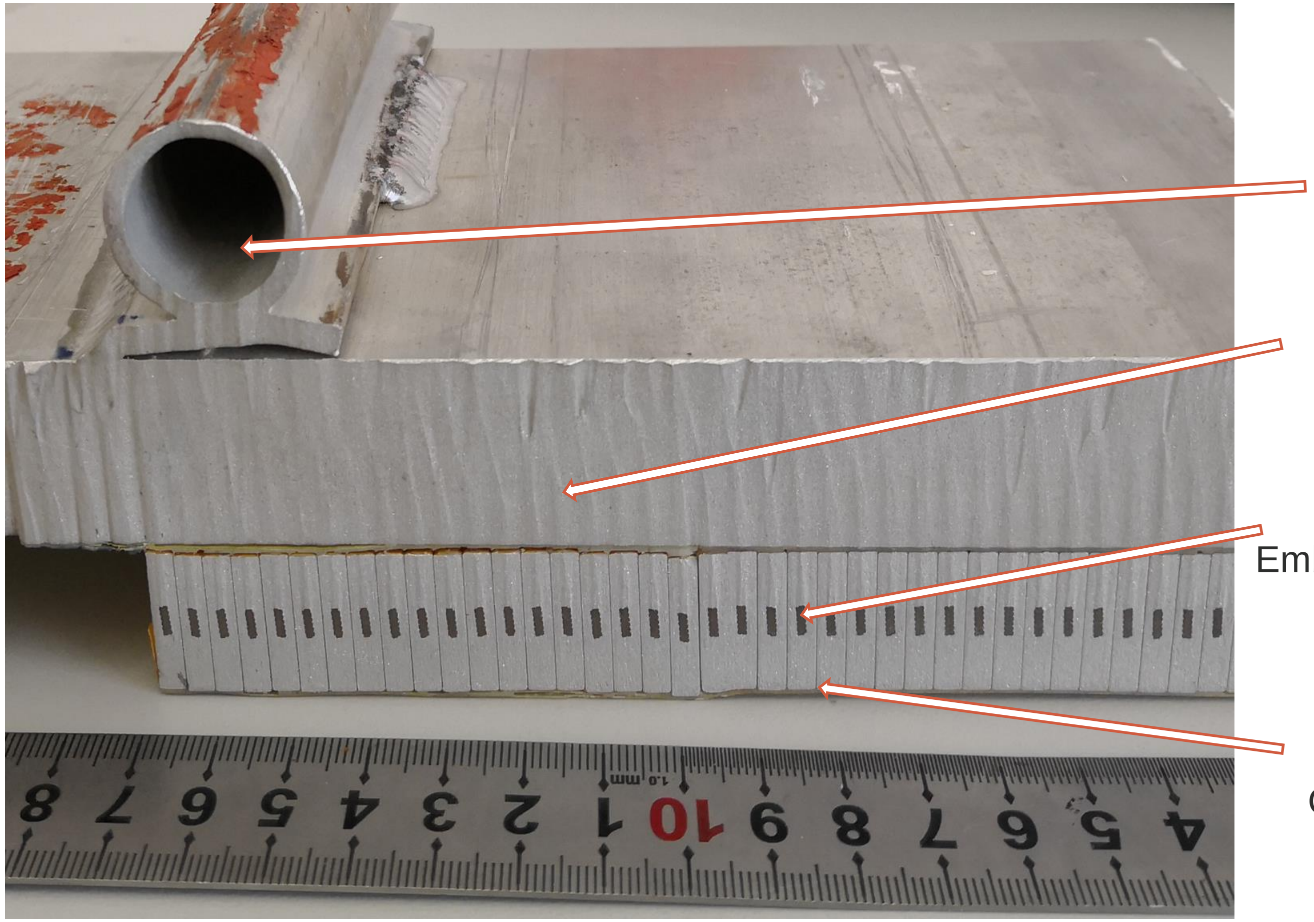
Zian Zhu, Ling Zhao, Xinyu Tong

Superconducting Coil Design

Structure:

Self-supporting winding turn with Aluminum alloy reinforcement

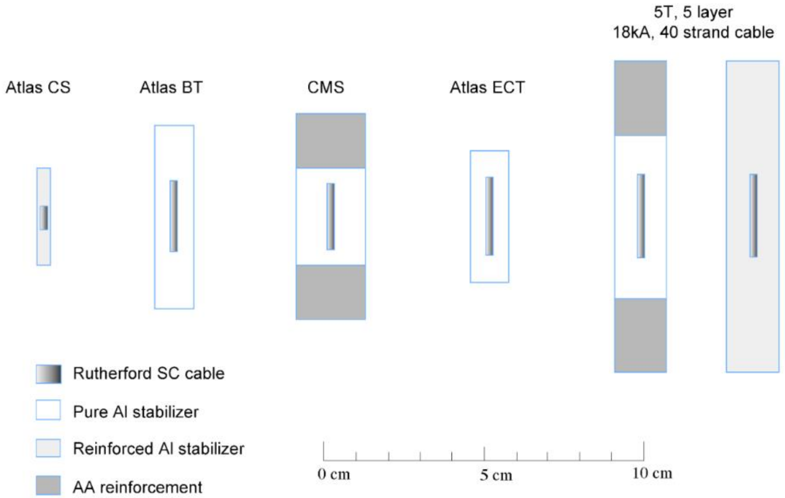




Structure of BESIII(1 T, length 4 m Bore diameter 2.7 m) SC Solenoid

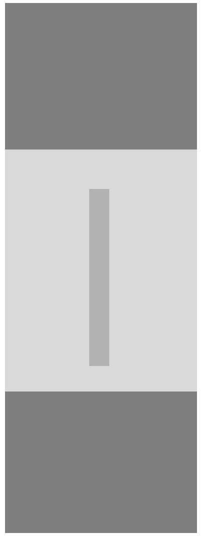
Progress of Rutherford Cable

Fabrication:
The CMS conductor is fabricated by ebeam welding aluminum alloy to the coextruded high purity Al/superconducting cable insert, whereas the CEPC conductor is fabricated by coextrusion of all components.



Rutherford Cable used for Detectors

CMS Pure Al & Alloy	CEPC Pure Al & Alloy



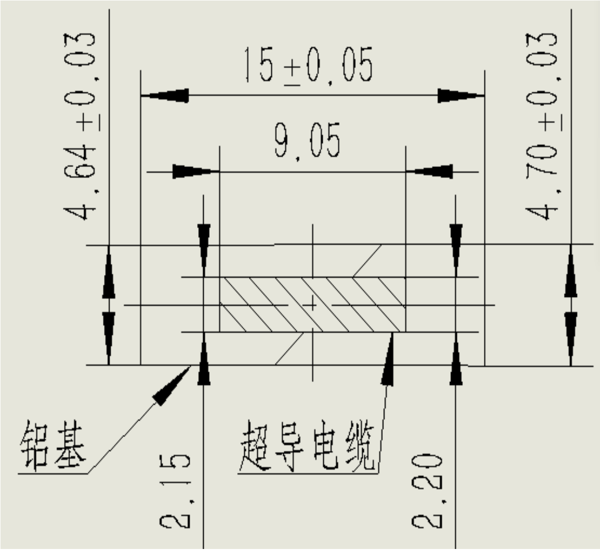
22 mm ×72 mm

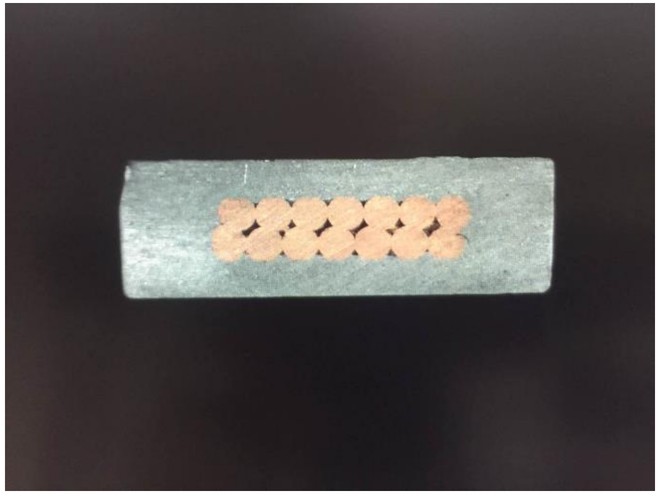
32 NbTi strands

22 mm × 56 mm

Pure aluminum stabilizer

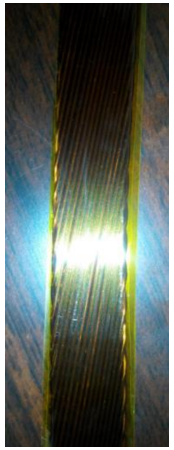
Aluminum alloy reinforcement





Sample Size for Processing Exploration

Progress of Rutherford Cable



Number of strands： 20
Strand diameter： 1.0mm
Materiel: Copper
Complete time:2015.5

Number of strands ： 17
Strand diameter ： 0.727mm
Materiel :Nb/Ti
Complete time:2015.7

Number of strands ： 24
Strand diameter ： 0.727mm
Materiel :Nb/Ti
Complete time:2015.8

Number of strands ： 18
Strand diameter ： 1.2mm
Materiel :Nb/Ti
Complete time:2016.2

Number of strands ： 32
Strand diameter ： 1.2mm
Materiel :Nb/Ti
Tangle： 17.32
Length： >100m
RRR： >100
Complete time:2016.5

2016.1
Hollow aluminum alloy

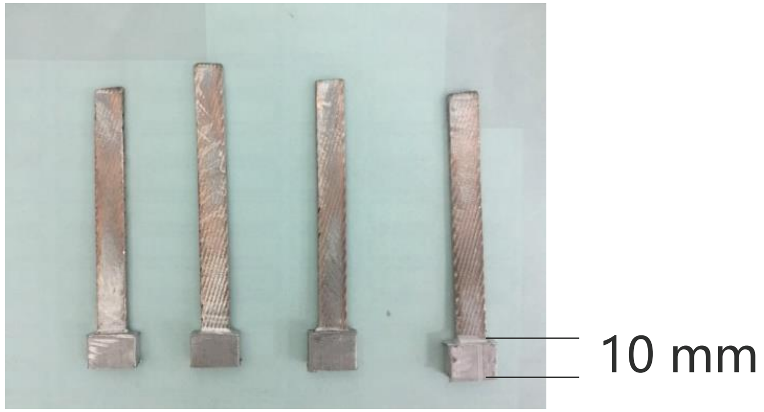
2016.2
Aluminum alloy + copper cable

2016.5~6:
Aluminum alloy + copper cable

2016.8:
Aluminum alloy + copper cable

Progress of Rutherford Cable

Sample of 10 m cable



Sample for testing shear strength

Test of shear strength

No	Length of Tested sample (mm)	load(kN)	Shear strength(MPa)	Length of cable
1	10	5.60	25.07	10 m
2	10	2.50	11.19	10 m
3	10	4.26	19.07	10 m
4	10	5.18	23.19	10 m
5	10	6.31	28.25	10 m
6	10	3.28	14.68	10 m

No.	Length of Tested sample (mm)	Load (kN)	Shear strength (MPa)	Length of cable
1	10	8.03	35.94	1.5 m
2	10	8.72	39.00	1.5 m
3	10	8.87	39.70	1.5 m
4	10	7.88	35.27	1.5 m
5	10	10.15	45.43	1.5 m
6	10	10.03	44.90	1.5 m

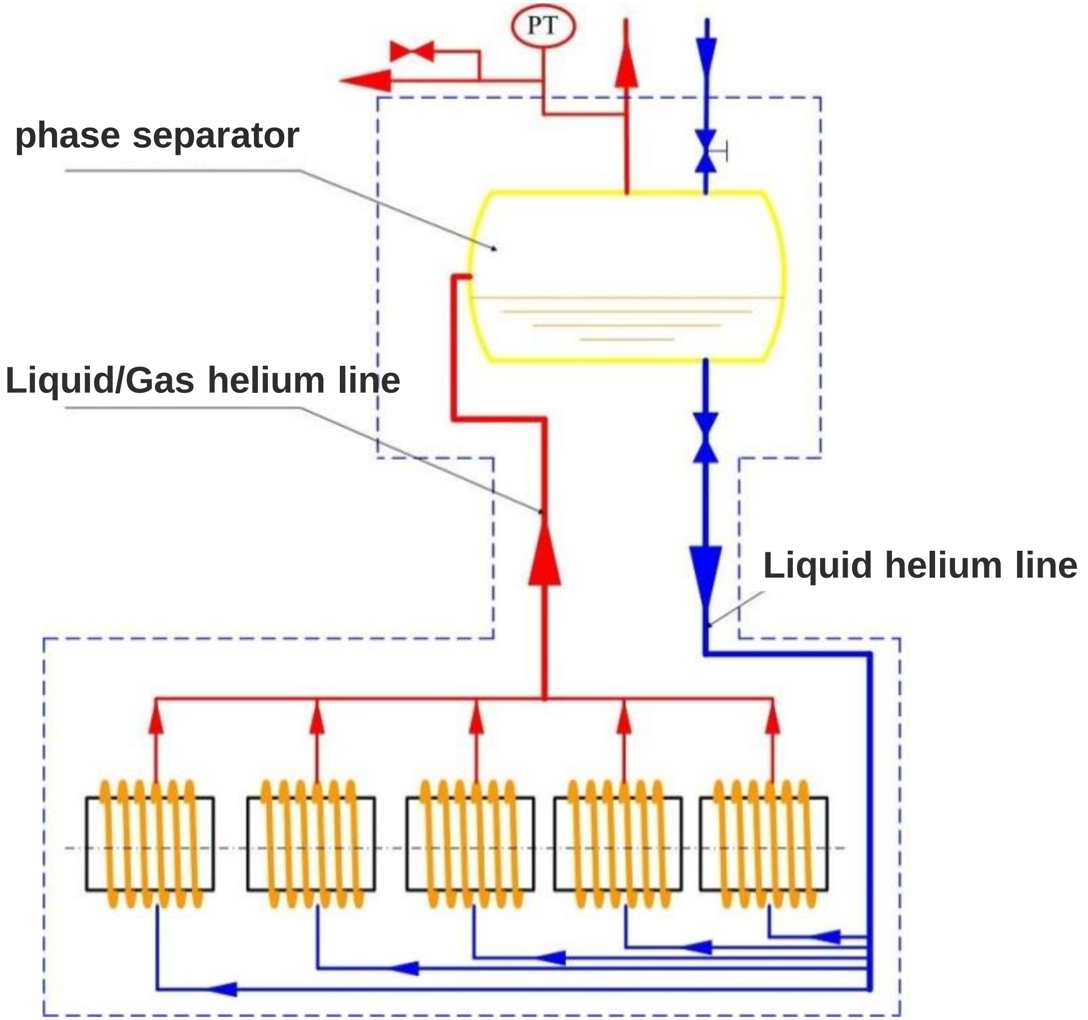
Progress of Cryogenic System

Thermosiphon Loop:
The coils are cooled by conductive method.

A thermosiphon principle experiment platform was built based on G-M cryocooler.

Principle:
Density difference of Liquid Helium & Two-phase Helium

Benefits:
Phase separator operates as an additional buffer.
Provide safety protection up to several hours when external cryogenic system failure occurs.



Progress of Cryogenic System

NO.	Time	cause of quench	Quench current
1	2008.7.29	SCQ's quench	3034A(0.9T)
2	2008.8.18	SCQ's quench	3369A(1.0T)
3	2008.9.23	Current ramping down too fast	3190A
4	2008.12.18	SCQ's quench	3369A
5	2009.2.26	Unknown	3369A
6	2009.3.7	Unknown	3369A
7	2009.3.27	Power grid fault	3369A
8	2009.4.25	Unknown	3369A
9	2009.5.7	Cryogenic system failure	3369A
10	2009.5.31	Cryogenic system failure	3369A
11	2009.12.25	Cryogenic system failure	3369A
12	2010.1.13	Vacuum system failure	3369A
13	2010.11.16	SCQ's quench	3369A
14	2011.1.13	Cryogenic system failure	3369A
15	2011.1.17	Cryogenic system failure	3369A
16	2011.5.10	Cryogenic system failure	3369A
17	2011.5.26	Cryogenic system failure	3369A
18	2011.6.1	Cryogenic system failure	3369A
19	2012.1.29	Cryogenic system failure	3369A
20	2012.2.3	Cryogenic system failure	3369A
21	2012.2.14	SCQ's quench	3369A
22	2012.3.23	Power grid fault	3369A
23	2012.11.15	Power grid fault	3369A
24	2013.2.10	Cryogenic system failure	3369A
25	2014.03.12	Cryogenic system failure	3369A
26	2014.05.26	Quench detector misoperation	3369A
27	2015.02.20	Cryogenic system failure	3369A
28	2015.05.18	Power network problem	3369A
29	2015.12.30	Quench detector misoperation	3200A
30	2016.01.17	Cryogenic system failure	3369A
31	2016.02.9	Cryogenic system failure	3369A
32	2017.04.13	Power Fluctuation	3369A
33	2017.05.07	Cryogenic system failure	3369A
34	2017.11.28	Cryogenic system failure	3369A
35	2018.03.05	Cryogenic system failure	3369A
36	2018.05.26	SCQ's quench	3369A
37	2018.05.28	Cryogenic system failure	3369A

Benefits

**Quenches of BESIII detector magnet @BEPCII collider (Two-phase Helium Forced-flow Cryogenics) :
in the past 10 years**

Total 37 quenches

- 19 cryogenic system failure
- 5 electricity power failure
- 6 caused by SCQ magnet quench
- 2 quench detector failure
- 1 vacuum failure
- 1 operation error
- 3 unknown(during ramping up/down)

Progress of Cryogenic System

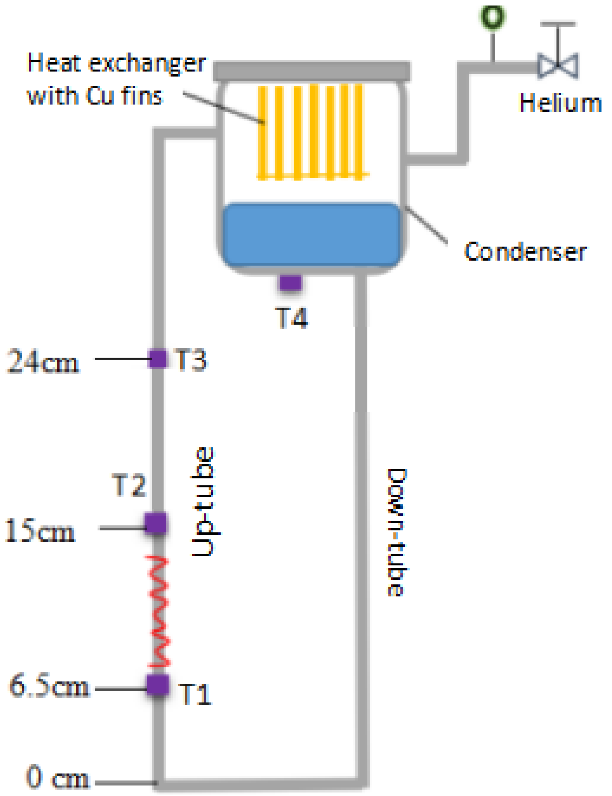
A thermosiphon principle experiment platform based on G-M cryocooler:

Building a two-phase natural circuit loop, helium was used as the working fluid

Investigate the heat and mass transfer characteristics experimentally

Obtain temperature profile with heat flux and critical heat flux(CHF)

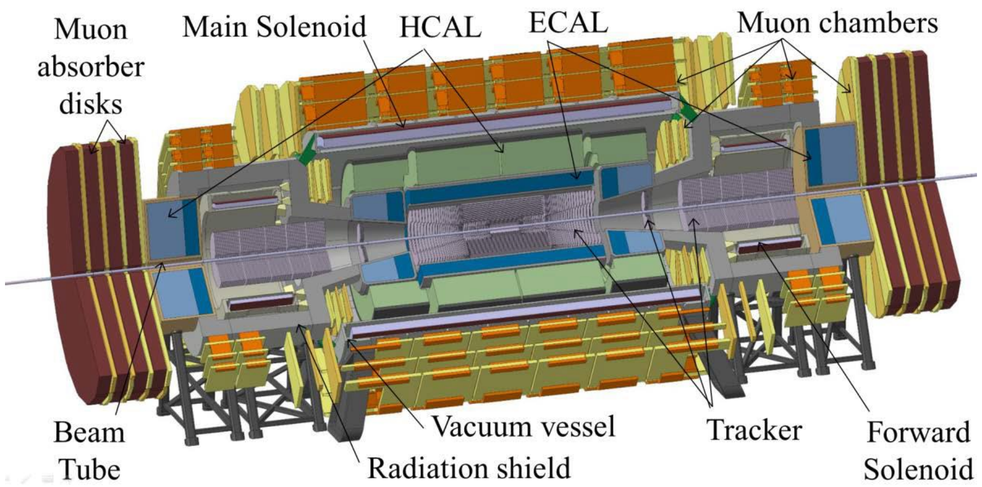
P(W/m²)	51.3	76.5	125.1	247.0
T1(K)	3.62	3.87	4.21	5.19
T2(K)	3.68	3.94	4.33	5.42
T3(K)	3.66	3.98	4.37	5.38



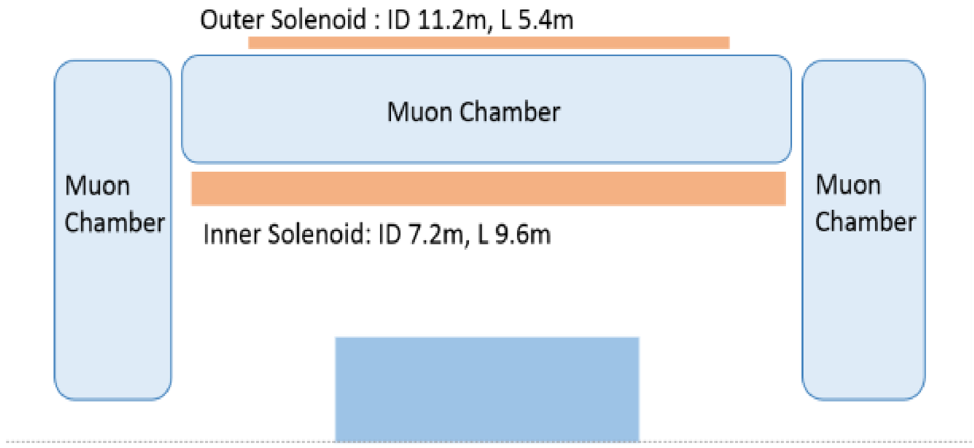
Alternative Designs: Dual Solenoids

Based on FCC Dual Solenoid:
Two series connected superconducting solenoids carrying the opposite direction current

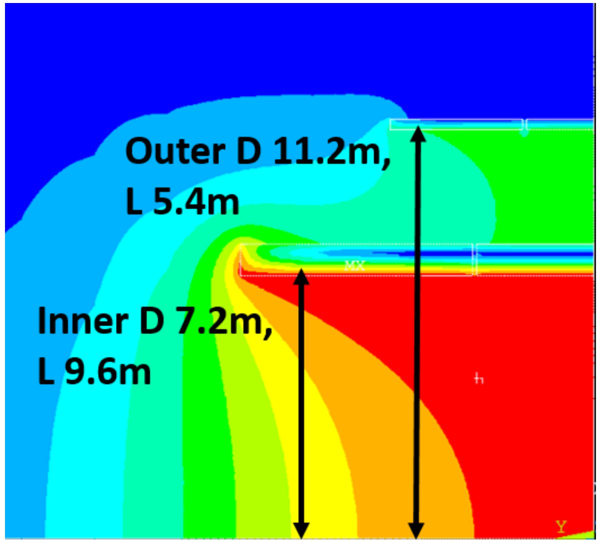
Benefits:
Light-weight and cost saving without iron yoke

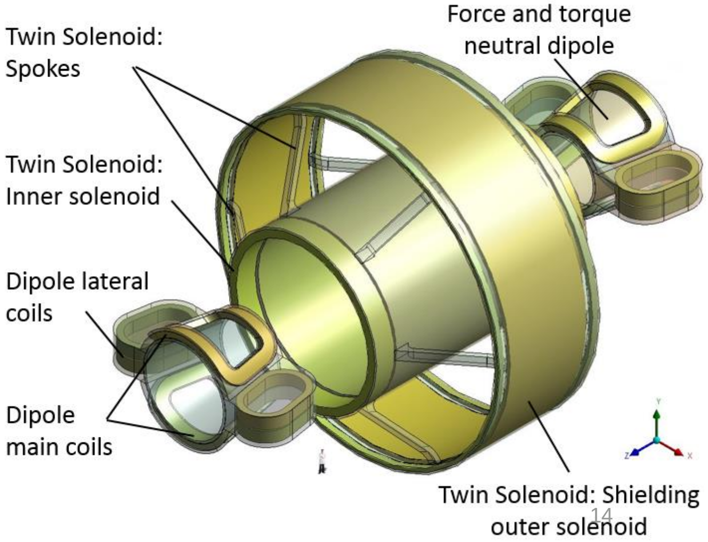


FCC Dual Solenoid



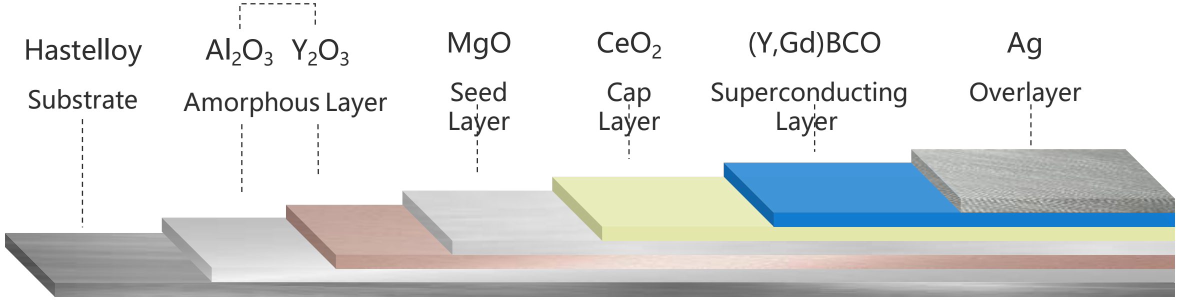
CEPC dual solenoid



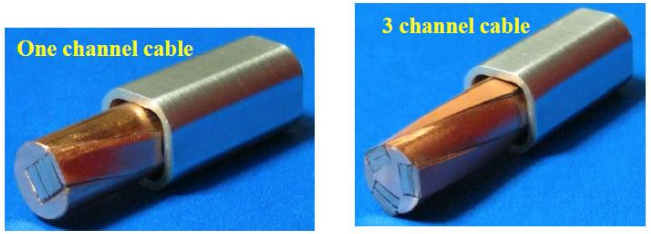


Zongtai Xie, Feipeng Ning, Xuyang Liu

Alternative Designs: HTS



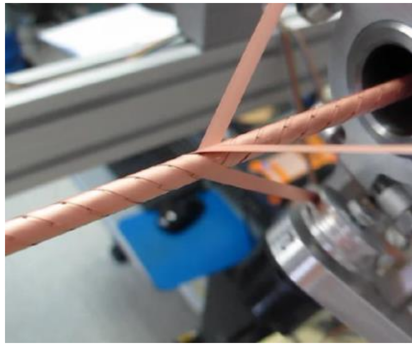
Possibility Research including conductor of High Temperature Superconductor (HTS) solenoid @20K for IDEA (International Detector for Electron- Positron Accelerator) detector.



40 YBCO tapes

20 YBCO tapes in each helical groove (Total 60 tapes)

TSTC HTS Cable (MIT)



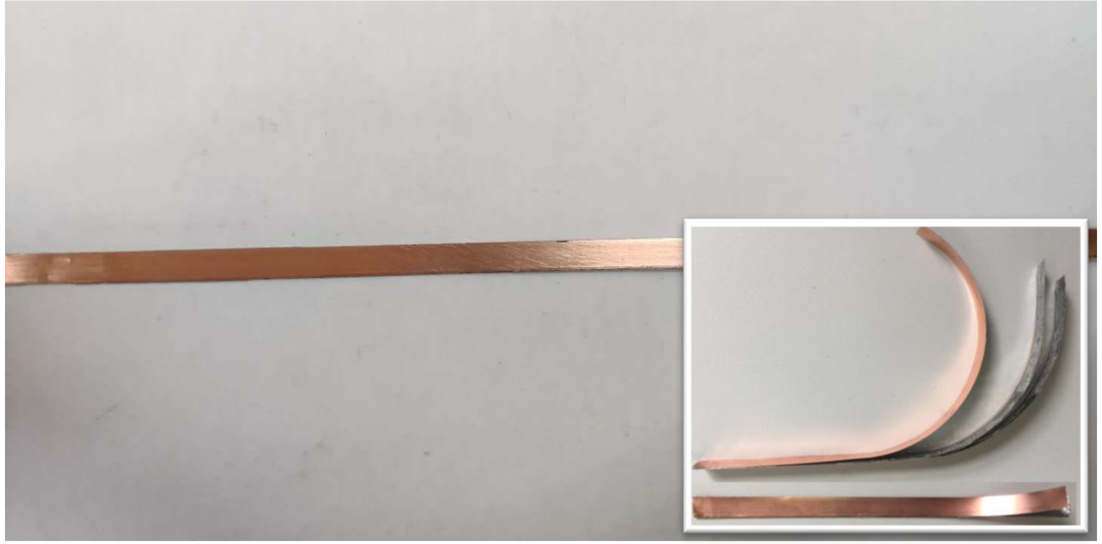
CORC HTS Cable (CERN)

YBCO:

Yttrium Barium Copper Oxide, $YBa_2Cu_3O_7$, Tc=92 K, Multi-layers
Strong angle dependence (non-Isotropic) versus magnetic field
High Ic compared with LTS (Nb-Ti & Nb_3Sn)

YBCO 3S (Square-Soldered-Stack) Conductor:

Basic Component of complex superconducting cable
Directly used on current lead & solenoid



5 Layers YBCO 3S Conductor
Vacuum Soldering by Sn63Pb37

Producing Processing:

Vacuum Soldering to reduce the non-metal oxide between layers

Alternative Designs: HTS

Experiment of 3S Conductor:

Ic strongly associated with self-field environment

Vertical S.F. 523Gs @ 400A

Lower n-value increased stability of conductor

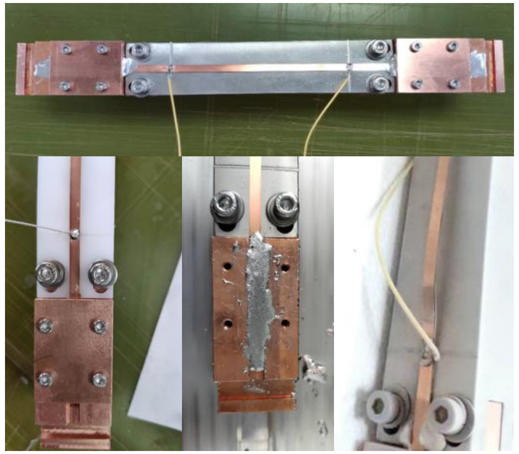
Thermal Conductivity of 3S Conductor:

Associated with thickness of Cu protection layer

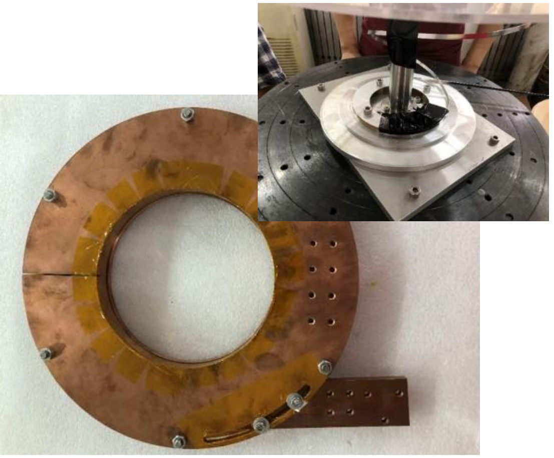
DPC Solenoid Fabrication Method:

Different electrical & stability characteristics between

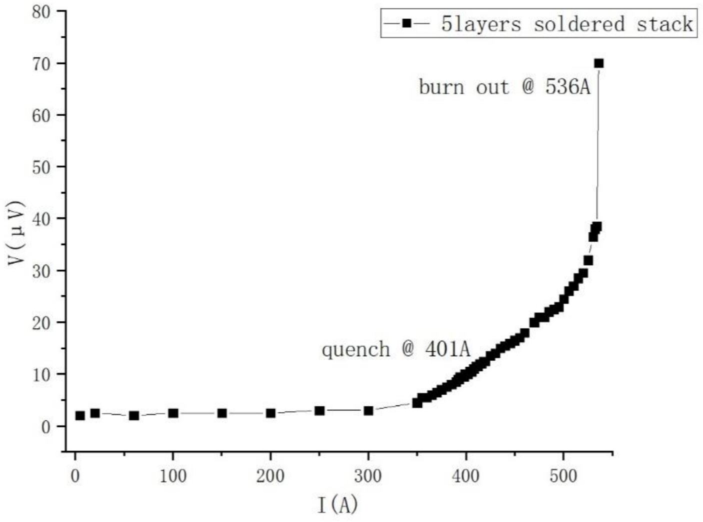
- Non -Insulation Methods
- Kapton /Resin –Insulation Methods
- Stainless Steel –Insulation Methods



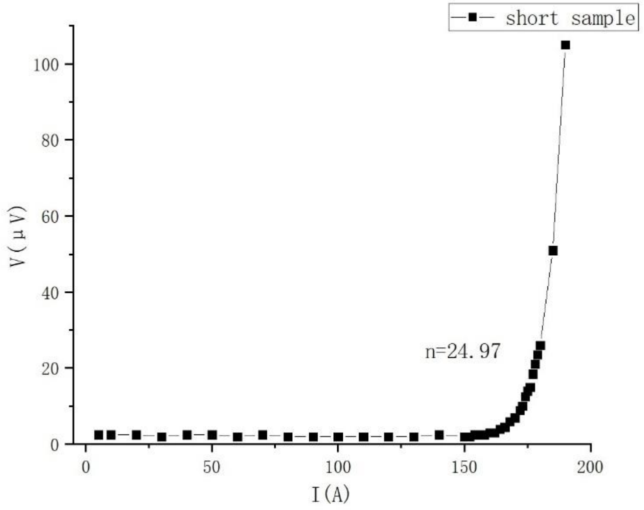
Test of HTS Conductor



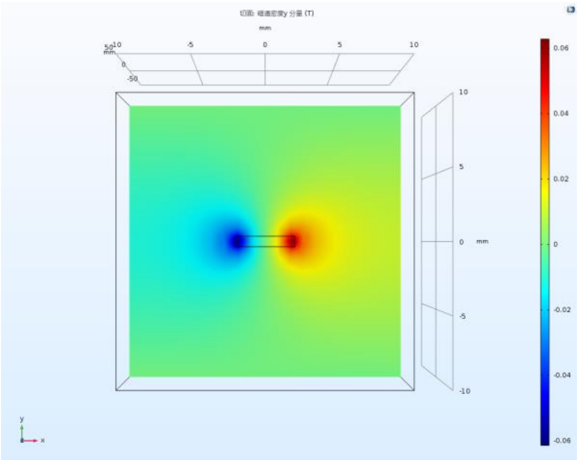
Test of HTS NI Coil



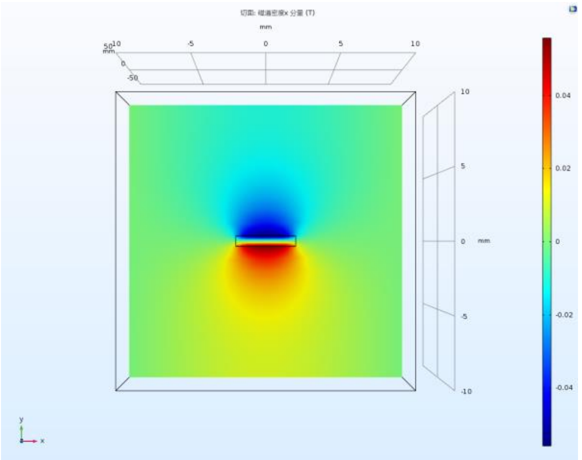
Ic of 5 Layers Stack



Ic of 1 Layer Short Sample



Vertical S.F. of Conductor



Parallel S.F. of Conductor

Zhilong Hou, Zongtai Xie

Research towards TDR

Multi-layers LTS Solenoid:

1 m in diameter & 1 m in length sized superconducting magnet under engineering design and construction.

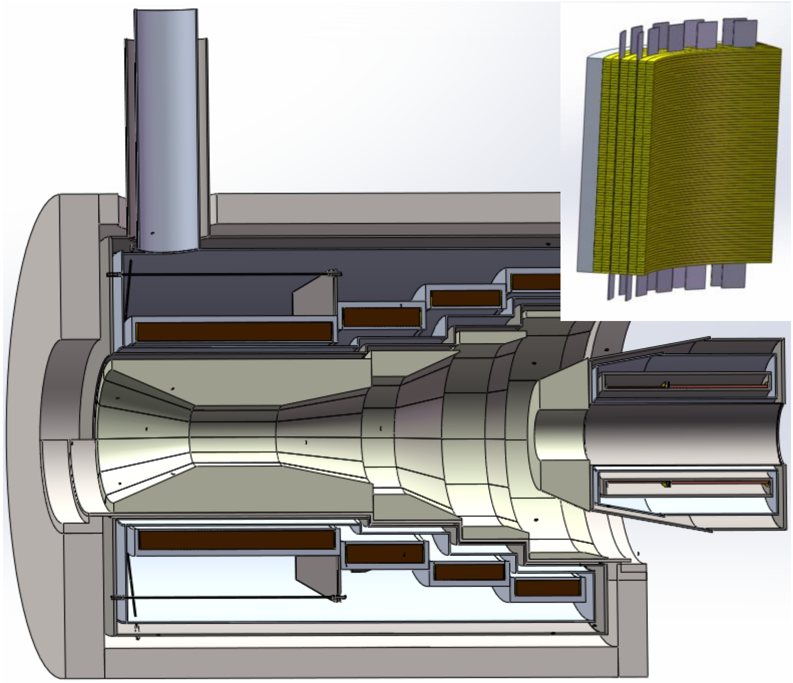
Will be applied on **EMuS** (Experimental Muon Source) of **CSNS** (China Spallation Neutron Source)

Adopting:

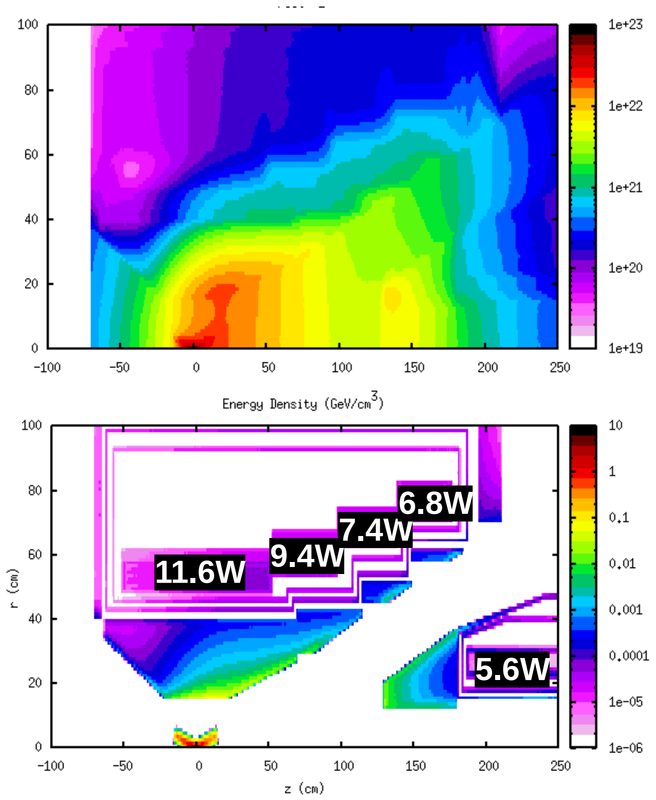
- Multi-layers LTS coil design
- Rutherford cable coextruded with Aluminum stabilizer
- Thermosiphon cryogenics system

Developing:

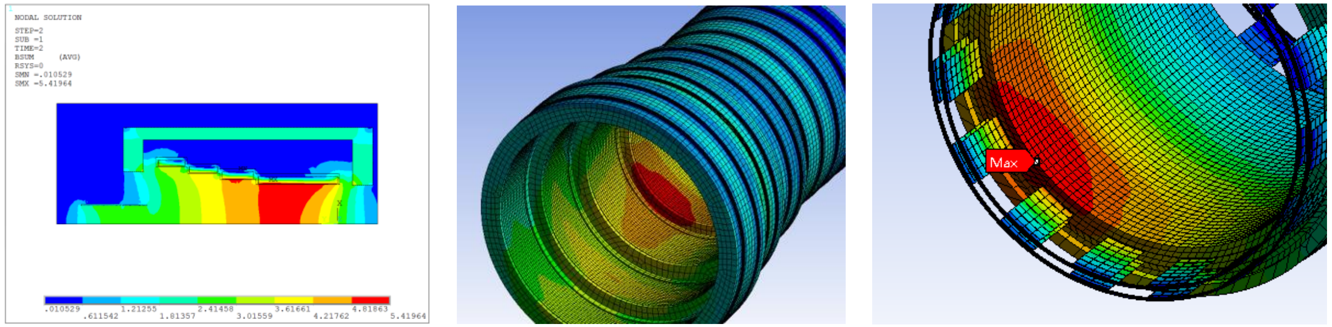
- Multi-layers coil winding processing
- LTS Rutherford cable producing processing
- Thermal design of magnets operating in high radiation environment



Structure of Multi-layers Solenoid applied on EMuS of CSNS



Radiation Environment



Magnetic Field & Thermal Design

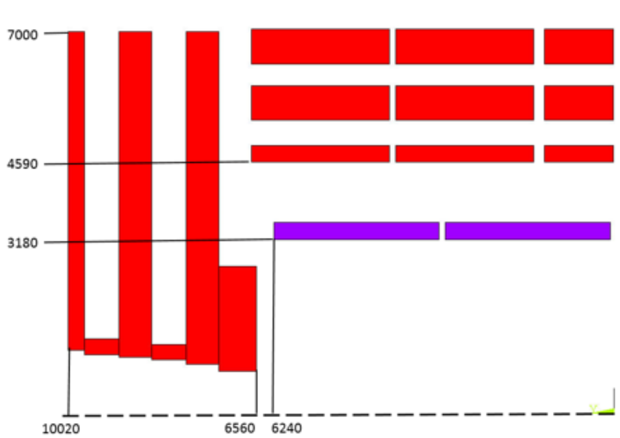
Feipeng Ning

A Reference Design of Iron Yoke

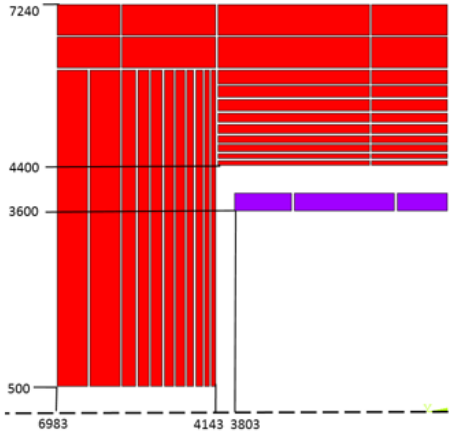
Reduce the Weight of Iron Yoke:

Taking reference of the CMS stray field distribution. We designed a reference Yoke design. This reference Yoke design reduces the thickness and total weight by 70% and 85% w.r.t the original design.

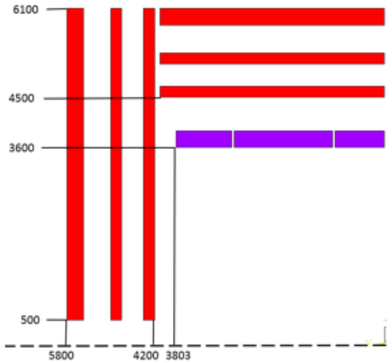
	CMS	CEPC original	CEPC 3 layers yoke	Smaller coil & 3 layer yoke	Smaller coil & 1 layer yoke
Central field (T)	4	3	3	3	3
Inner diameter of coil (mm)	6360	7200	7200	6800	6800
Length of coil (mm)	12480	7606	7606	7238	7238
Barrel yoke inner diameter (mm)	9180	8800	9000	9000	8400
Barrel yoke outer diameter (mm)	14000	14480	12200	12200	9600
Total length of yoke (mm)	20040	13966	11600	11600	9200
Weight of barrel yoke (t)	6000	5940	1608	1560	1125
Weight of each end cap (t)	2000	3316.6	678	657	401
Total weight of yoke (t)	10000	12573	2874.5	2874.5	1927



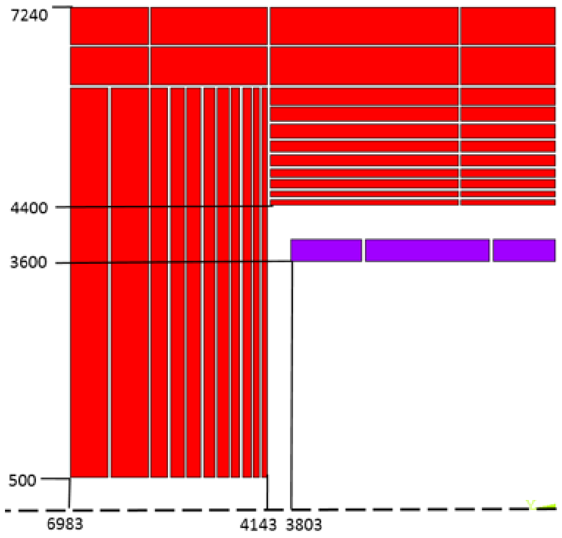
CMS



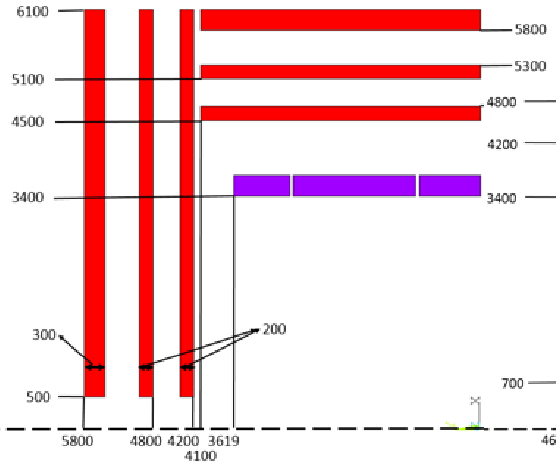
CEPC original



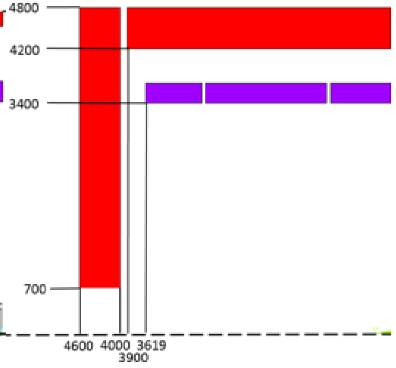
CEPC 3 layers yoke



CEPC original



smaller coil & 3 layers yoke



smaller coil & 1 layer yoke

A Reference Design of Iron Yoke

Stray Field:

The original design of detector magnet has a very thick yoke. New optimized design will take a lot of benefits, not only the magnet itself, but also the entire engineering project.

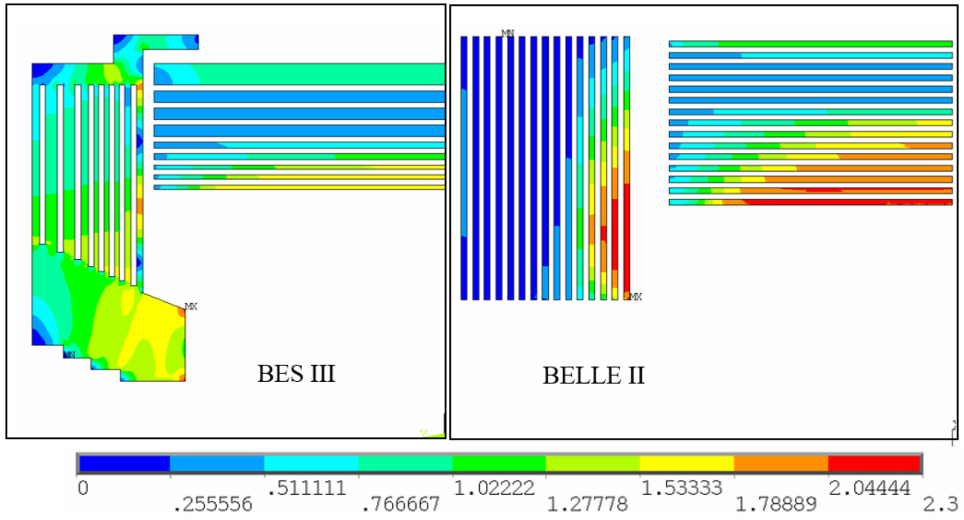
The stray field is still in line with requirements.

Stray field		CMS	CEPC original	CEPC coil smaller& 3 layers yoke	CEPC coil smaller& 1 layers yoke
50 Gs	R direction	25.2 m	13.6 m	23.4 m	24.4m
	Z direction	32 m	15.8 m	28.6 m	30.4 m
100 Gs	R direction	19.2 m	10 m	18.4 m	19.2 m
	Z direction	25.2 m	11.6 m	22.7 m	24.2 m

Other Equipments:

The booster tunnel located 25m from the central line.

Cryogenic pumps.



Other references

Stray field		BES III	BELLE II
50 Gs	R direction	4.2 m	6.65 m
	Z direction	4.4 m	8.35 m
100 Gs	R direction		5.3 m
	Z direction		6.35 m
Coil Inner Diameter		1.49m	4.4m
Coil Length		3.5m	3.6m

中国科学院高能物理研究所
Institute of High Energy Physics，CAS

环形正负电子对撞机
Circular Electron-Positron Collider

Brief Summary：

Baseline Design (CDR) ：
Meet the physics requirements

Preliminary Research on：
Thermosiphon Cryogenic System; HTS Squared-Soldered-Stacked Cable; HTS Non-Insulation Solenoid

Reasearch Towards TDR ：
Developing Key Tech: LTS Rutherford Cable (stabilizer); Multi-layer Coil Fabrication & Insulation Processing

Optimizing the Yoke Structure ：
Meet the requirements of Cryogenics, Booster Ring, etc.

CEPC Detector Superconducting Magnet

——Conceptual Design

Speaker: Zongtai Xie, IHEP
Represent for the Superconducting Magnet team
HKUST, 23th Jan. 2019

Thanks for your attentions

中国科学院高能物理研究所
Institute of High Energy Physics， CAS

环形正负电子对撞机
Circular Electron-Positron Collider

Q&A

CEPC Detector Superconducting Magnet

——Conceptual Design

Speaker: Zongtai Xie, IHEP
Represent for the Superconducting Magnet team
HKUST, 23th Jan. 2019