R&D Progess of CEPC Detector Magnet

Zian Zhu

Institute of High Energy Physics

Workshop on CEPC, Rome, May 2018

outline

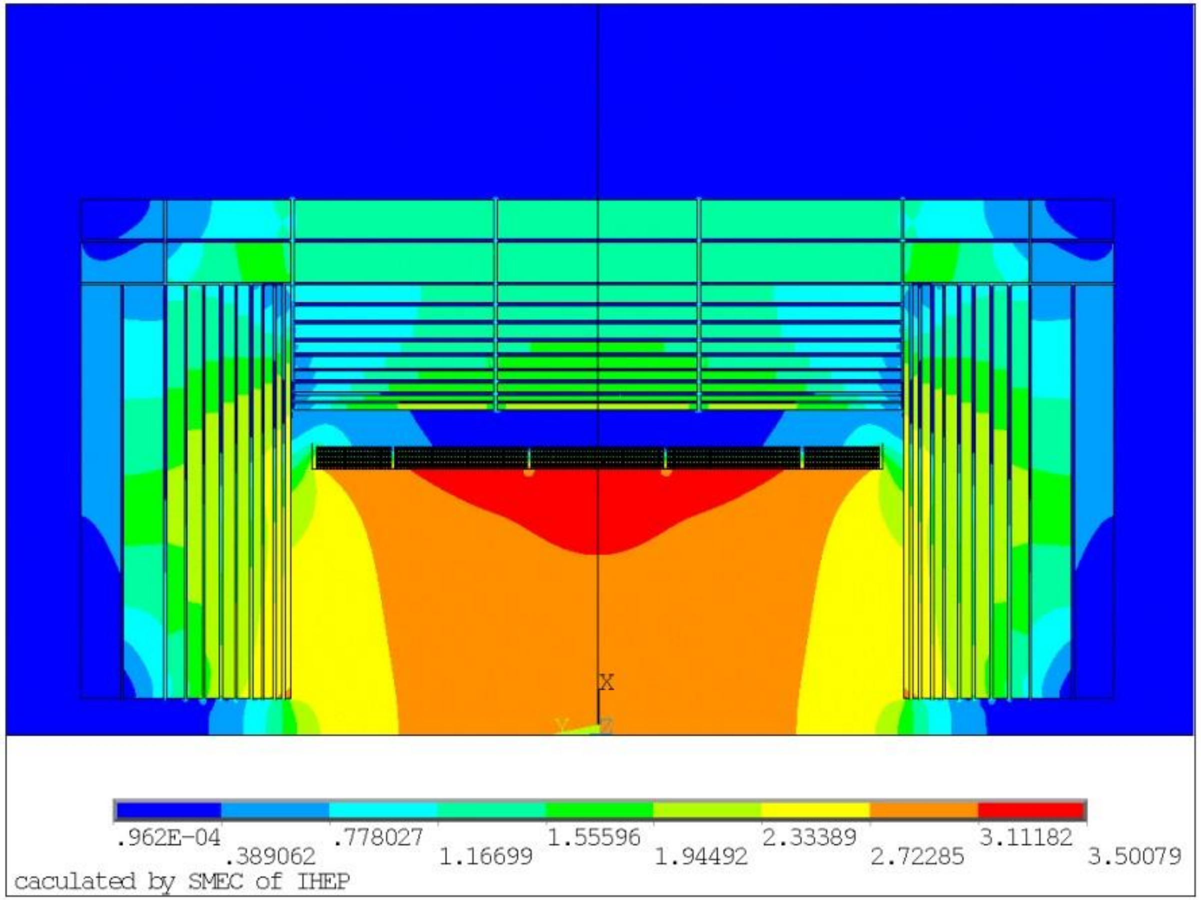
- **Main parameters**
- **R&D progress**
- **Future plan**

The Magnetic Field Requirements and Design

main parameters of the solenoid coil

The central magnetic field: From 3.5T to 3T

The solenoid central field (T)	**3**	**Working current (kA)**	**15.8**
Maximum field on conductor (T)	**3.5**	**Total ampere-turns of the solenoid (MAt)**	**20.3**
Coil inner radius (m)	**3.6**	**Inductance (H)**	**10.5**
Coil outer radius (m)	**3.9**	**Stored energy (GJ)**	**1.3**
Coil length (m)	**7.6**	**Cable length (km)**	**30.4**

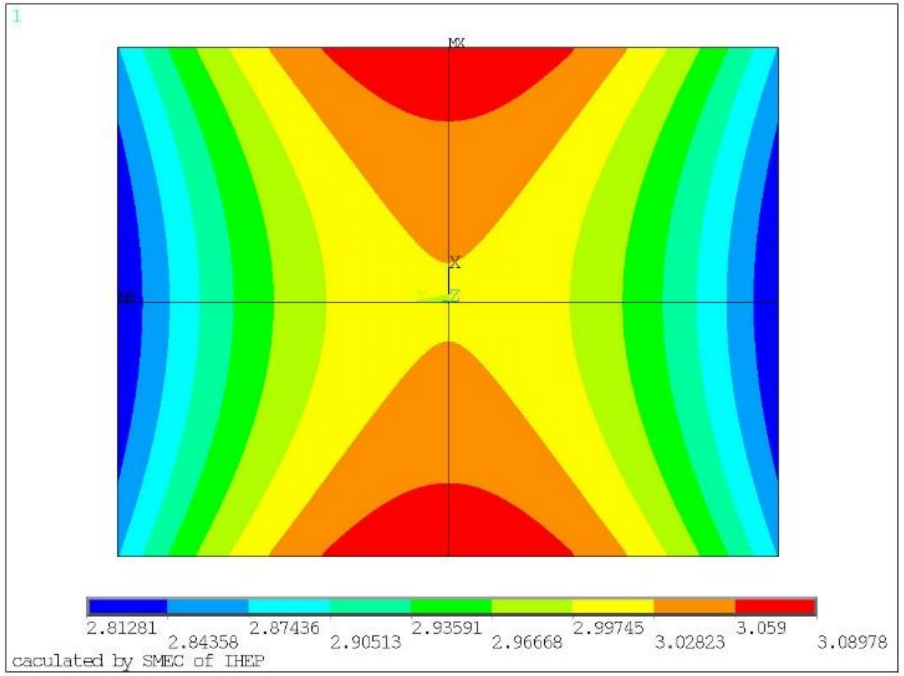


Field map of the magnet (T)

The Magnetic Field Requirements and Design

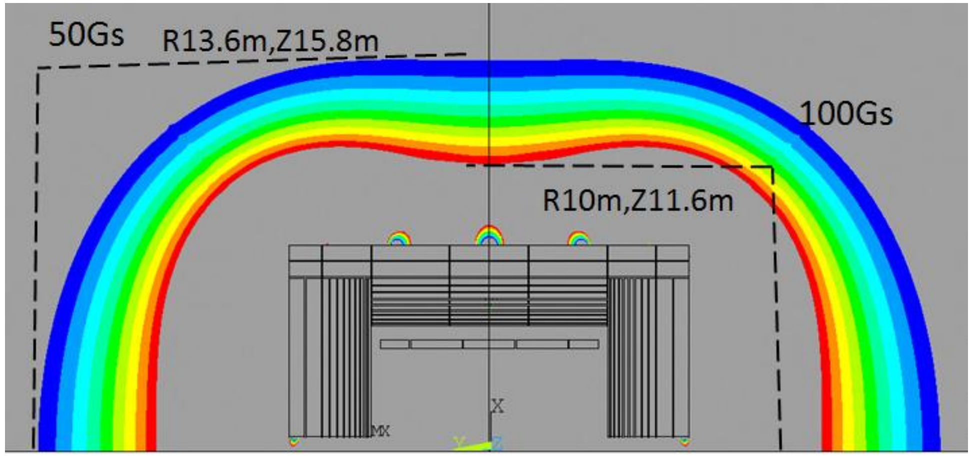
The non-uniformity of Tracking Volume (diameter 3.62m, length 4.7m) is 9.1%.

$$B_p = \frac{B_{max} - B_{min}}{B_{center}} = 9.1\%$$



magnetic field distribution within the Tracking Volume

Stray field		
50 Gs	R direction	13.6 m
	Z direction	15.8 m
100 Gs	R direction	10 m
	Z direction	11.6 m



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

R&D Progress related to detector magnet at IHEP

Requirements of CEPC detector:

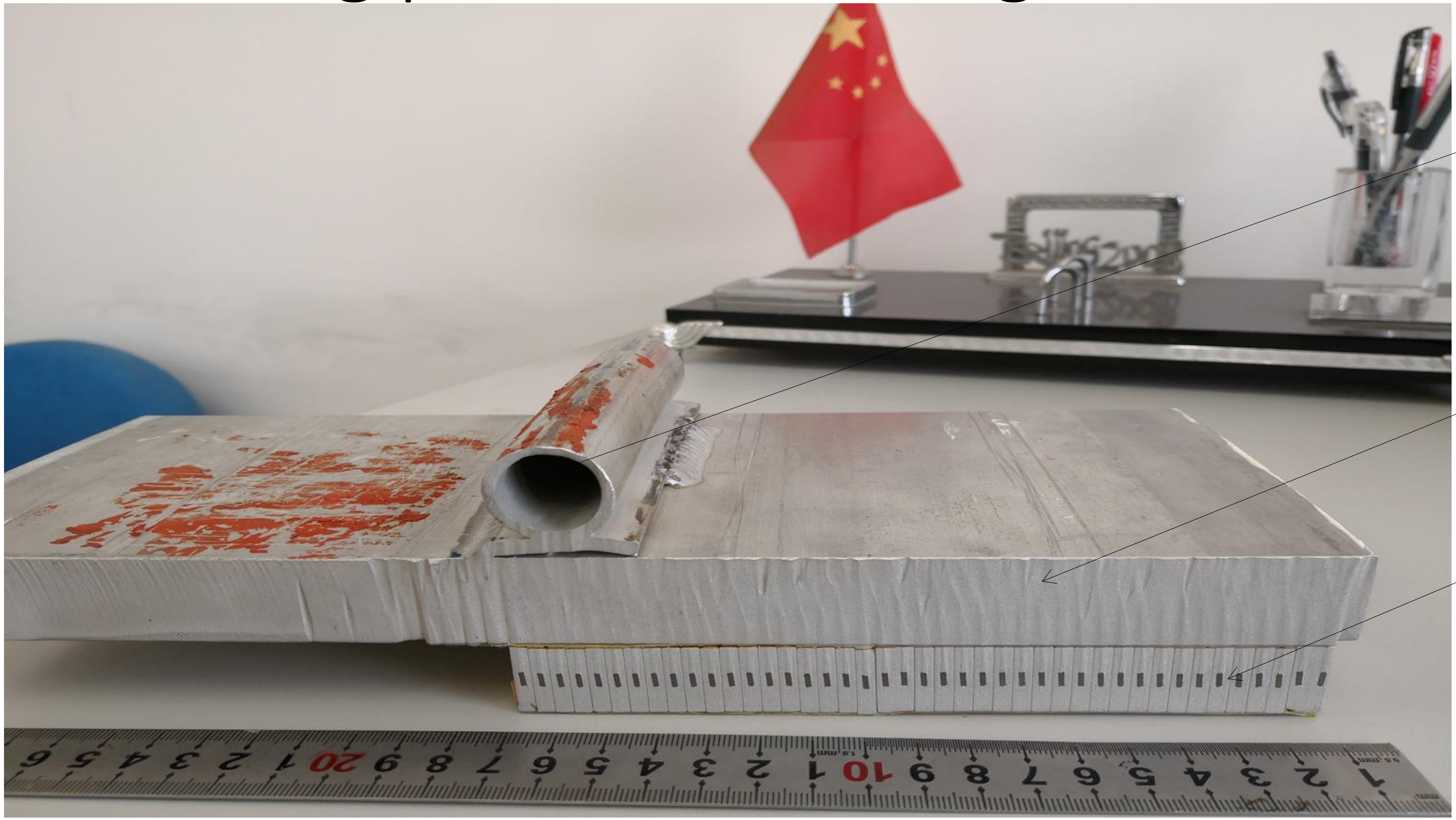
a larger size and higher field magnet

- Strong Solenoid
  - Better Momentum resolution for energetic tracks
  - Better separations
- Baseline Value: 3 Tesla, 7m bore diameter
- Technology well existed by CMS magnet(4T/7m), motivation is to reduce the cost

This R&D work is supported by Innovation Fund of IHEP for CEPC

Prepared by Manqi Ruan

Starting point: BESIII Magnet



Pipe for
Liquid He at 4.2 K

Aluminum
Mechanic support

Nb-Ti Superconductor
(Rutherford Cable)
Embed in pure Aluminum
Structure

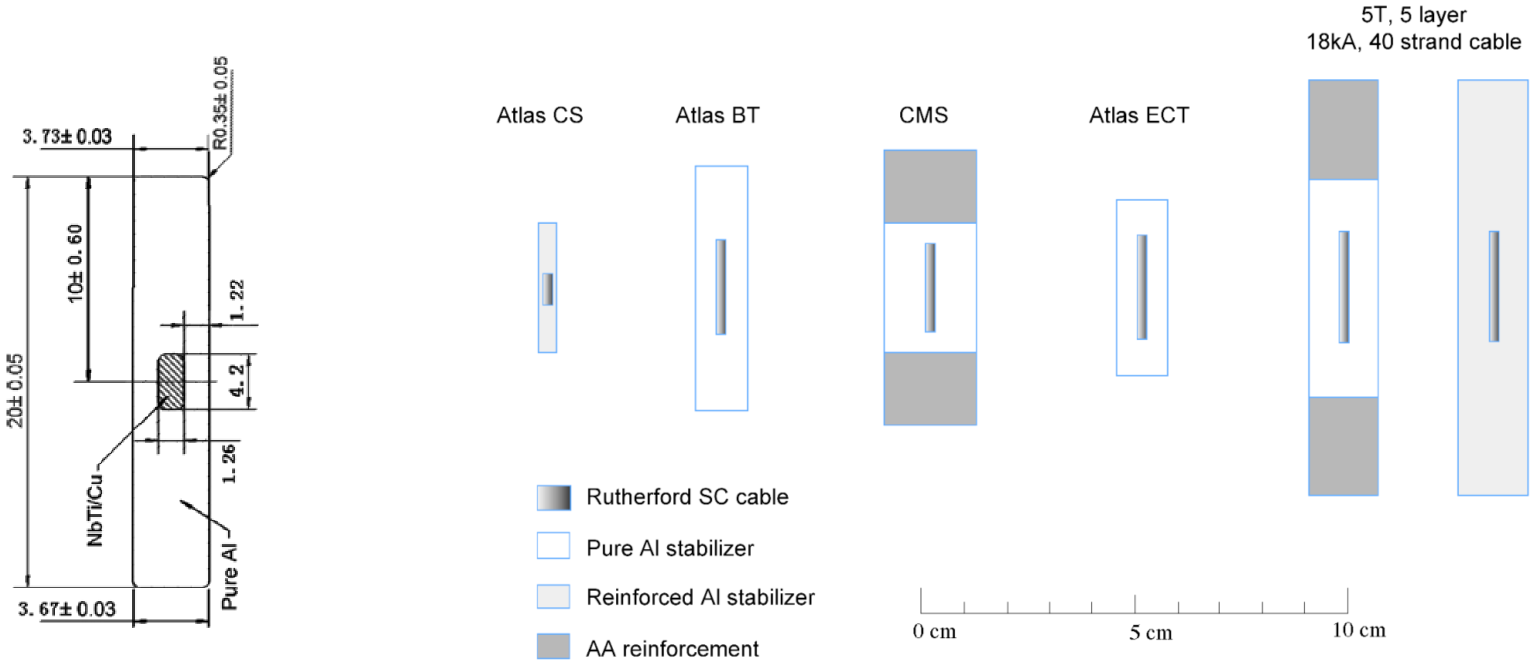
1 T, length 4 m
Bore diameter 2.7 m

Cutting slice from the BESIII magnet prototype

Special Cable

- Development progress of Al-based superconductor

  Al-based Superconducting conductor was mainly used for large detector magnets, such as ATLAS and CMS, …, FCC detector. We had the experience of using in BEPCII-BESIII detector.



Cross sections of Al stabilized and reinforced conductors previously used and will be used

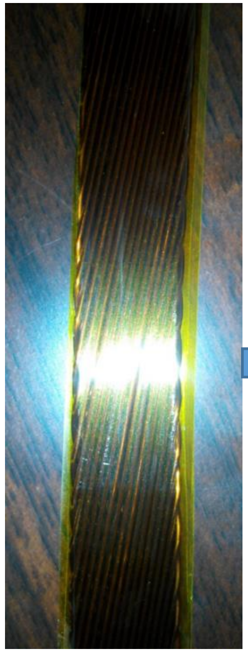
Ling Zhao

Rutherford cable

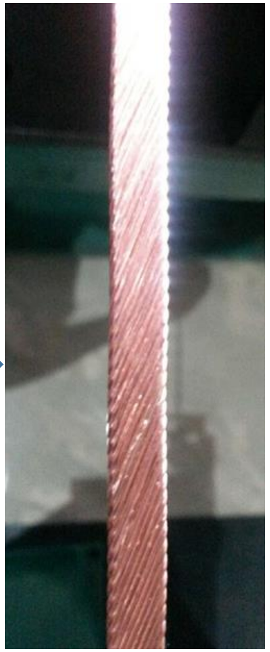
- Cooperation with Toly Electric Ltd. since 2015
- Development of Rutherford cable in the first step by using old machine
- New cabling machine and tension control system of strands were put into use in 2016 to improve quality

Ling Zhao

Rutherford cable



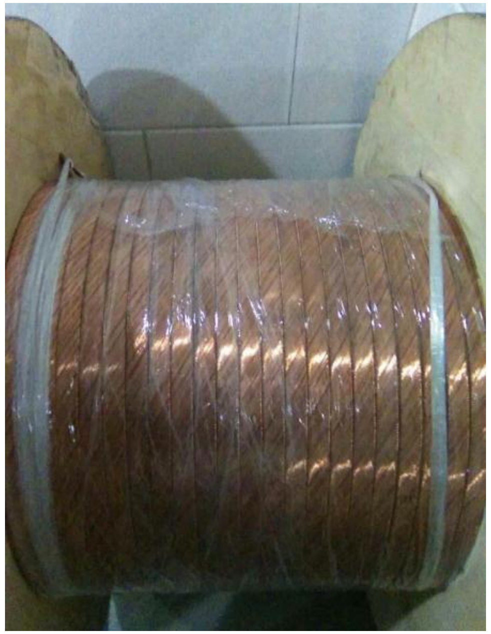
Number of strands： 20
Strand diameter： 1.0mm
Materiel: Copper
Complete time: 2015.5



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

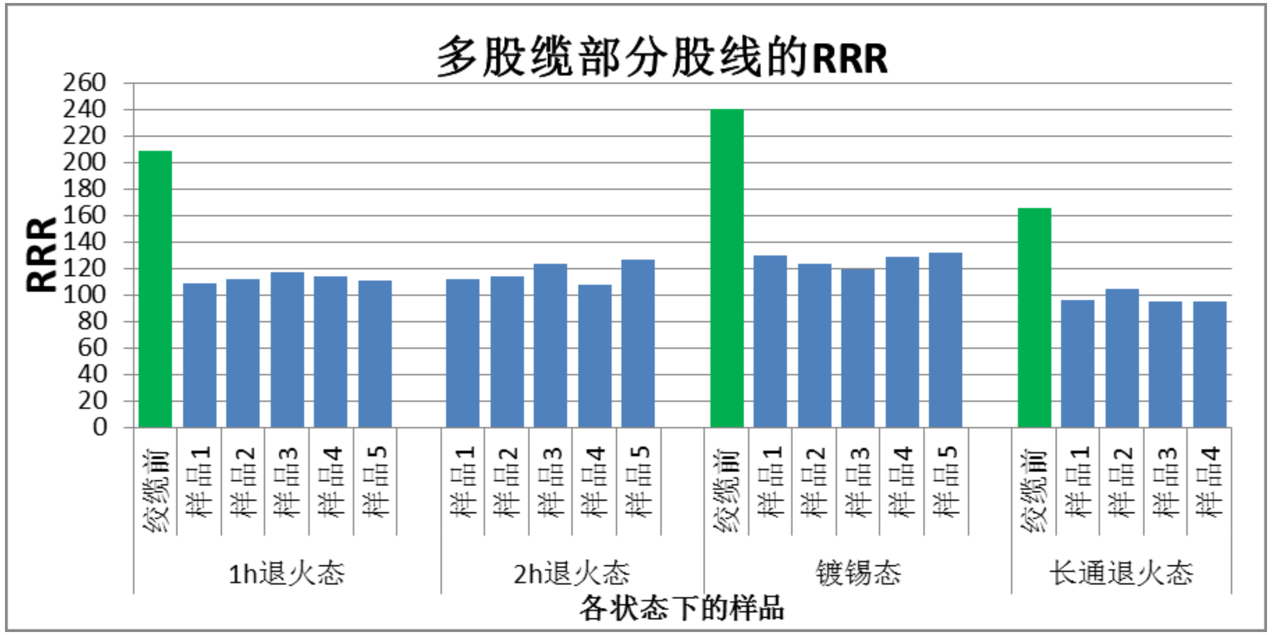
Number of strands ： 24
Strand diameter ： 0.727mm
Materiel: Nb/Ti
Complete time: 2015.8

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

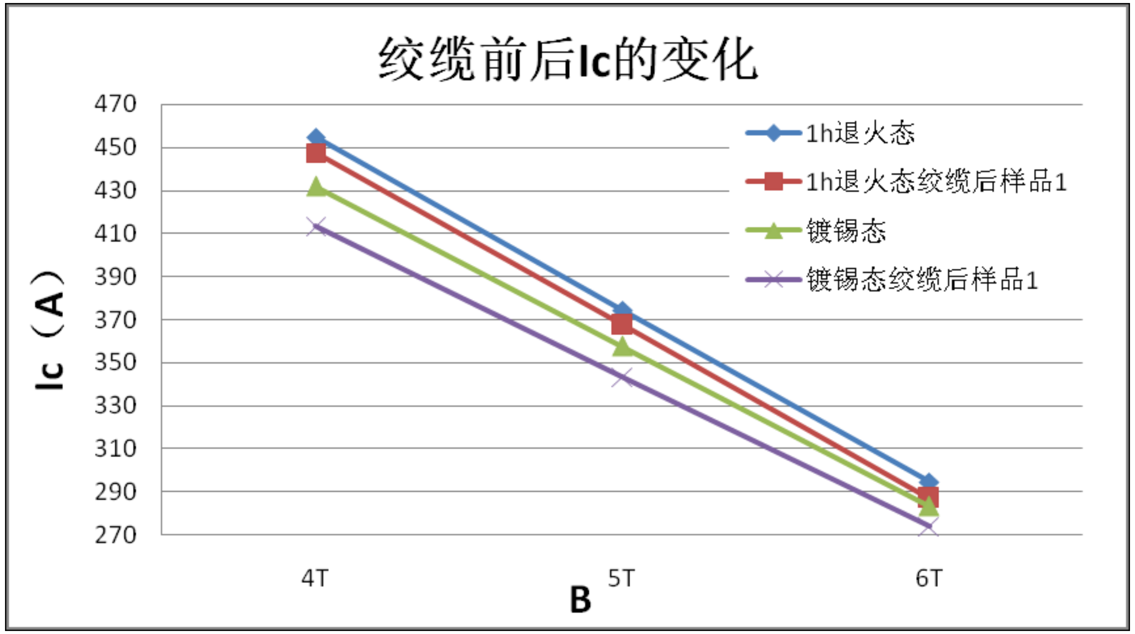


Number of strands ： 32
Strand diameter ： 1.2mm
Materiel: Nb/Ti
Tangle： 17.32
Length： 》100m
RRR： 》100
Complete time: 2016.5

Strand of Rutherford cable test results



Test by WTS

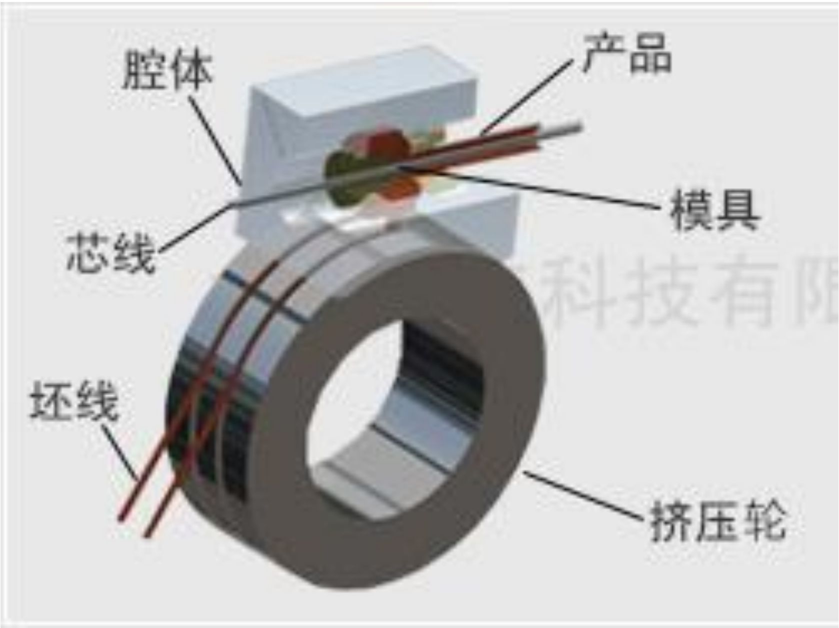


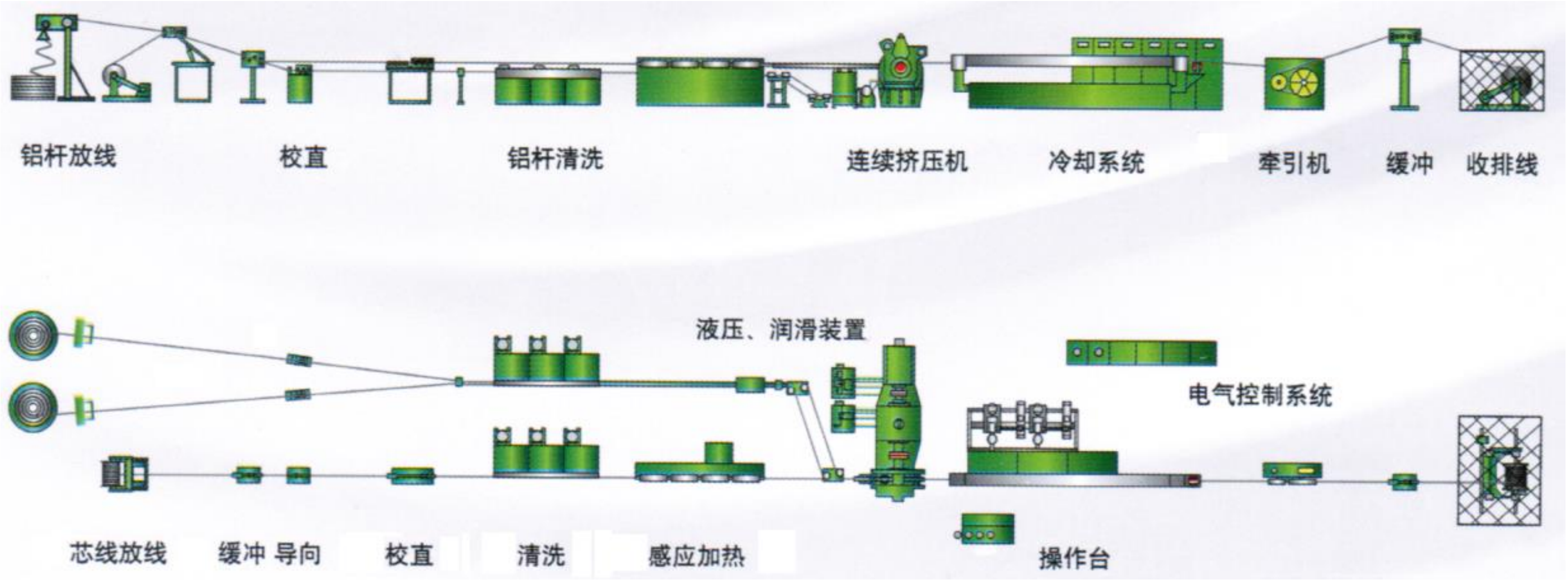
1. RRR value declined by about 1/3 after the stranding process

2.Less affected by larger twist pitch of strands.

The decrease of the critical current is less than 7% after the stranding process.

Extrusion of Aluminum with insert of Rutherford cable



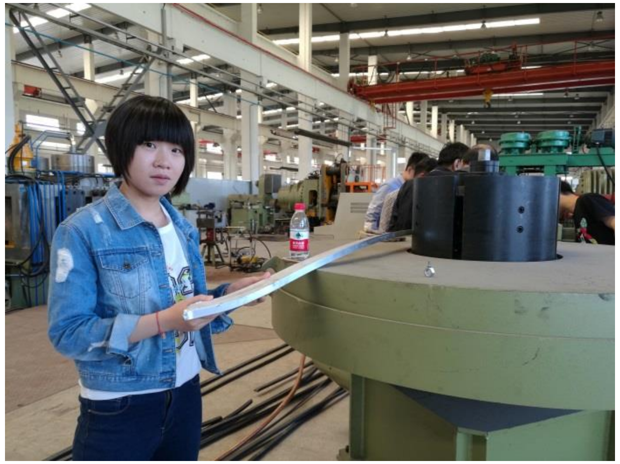


Conform Process

Drawing Process

Aluminum cladding process study and improvement

Zian Zhu, Ye Yuan, Zhilong Hou, Zhihui Mu



Continuous extrusion and continuous cladding technology

Engineering Research Center of the Ministry of education for continuous extrusion

Dalian Conform Ltd.（Dalian Jiaotong University）

Ling Zhao

Insert progress

- **Completed two rounds of insert process:**

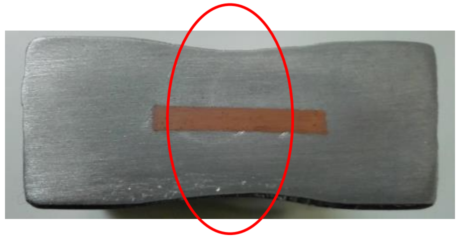
  Hollow aluminum alloy, Aluminum alloy + copper cable

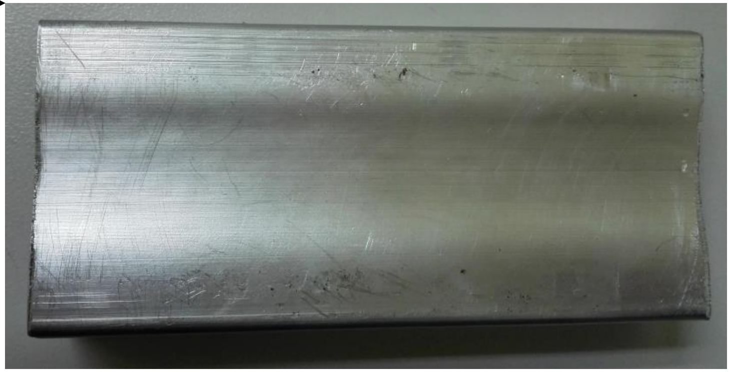
- **Result: Depression in the middle and the tooling needs to be improved(2016.4)**

  The strands of the cable are separate after the tooling improvement.

- **There is a great improvement from the latest result, but the shear strength 8MPa not enough to reach 20MPa.**

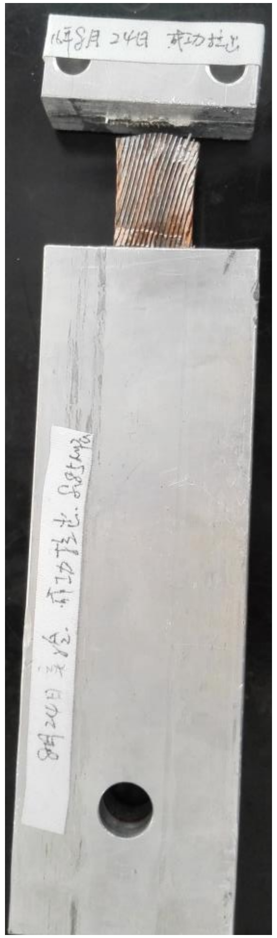
2016.1
Hollow aluminum alloy





2016.2
Aluminum alloy + copper cable

2016.5~6：
Aluminum alloy + copper cable

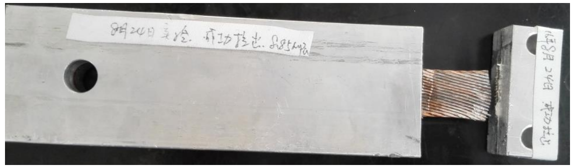


2016.8：
Aluminum alloy + copper cable

Ling Zhao

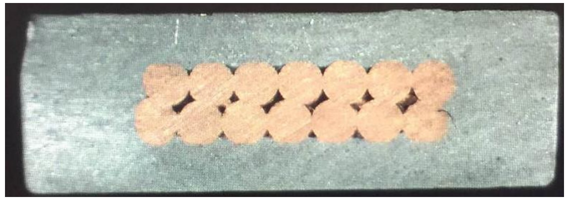
R&D progress

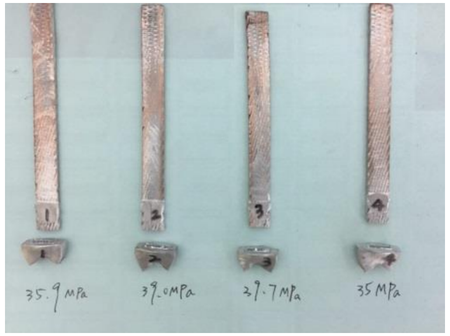
- **Different aluminum alloy and copper cable shear strength test**
  - ✓ The shear strength is larger than the required (20MPa) in the latest test. We used 99.99% aluminum material to improve the shear strength.



Number of strands： 32
Strand diameter： 1.2mm
Materiel :COPPER+Al
Length: 1m
Complete time: 2016.8
Shear strength（copper &Al）：
8.85 MPa

Dimensions: 15*4.7mm^2
Number of strands： 14
Materiel : COPPER+Al(99% purity)
Complete time: 2017.4
Shear strength（COPPER &Al）：
10 MPa



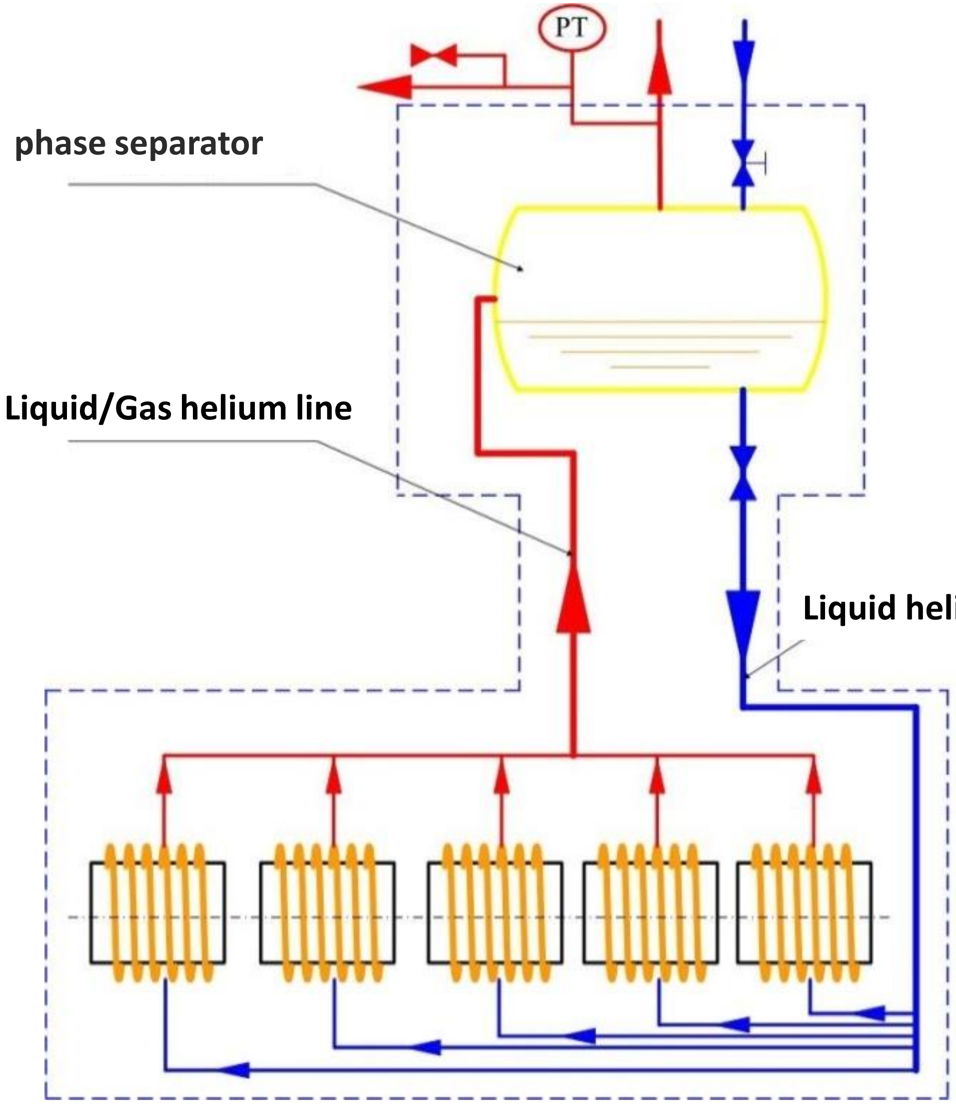


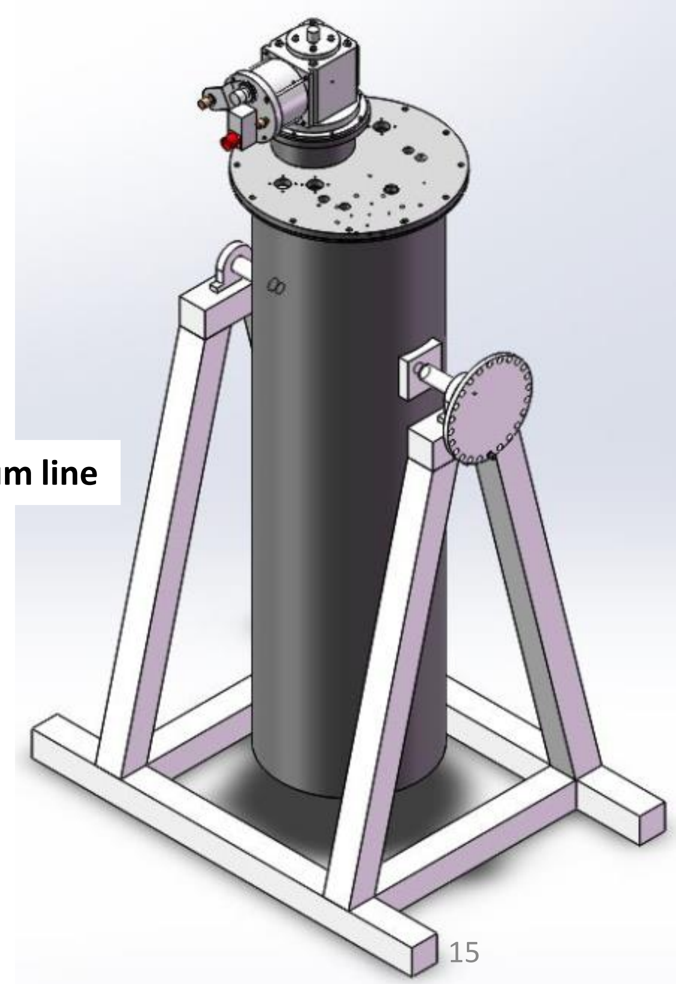
Dimensions: 15*4.7mm^2
Number of strands： 14
Materiel : NbTi+Al(99.99% purity)
Complete time: 2017.8
Shear strength（COPPER &Al）： >**35MPa**

Meifen Wang

Progress of coil cooling research

- The magnet coils will be cooled by liquid helium thermosiphon conductive cooling method.
- Set up a small thermal siphon principle experiment device





Motivation：

- **BESIII magnet Suffered too much quenches caused by cryogenics failure**
- **Need to study thermal syphon cooling for the next large magnet**

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

Quenches of BESIII detector magnet @BEPCII collider in the past 10 years

Two phase helium force flow cooling

Total 35 quenches

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

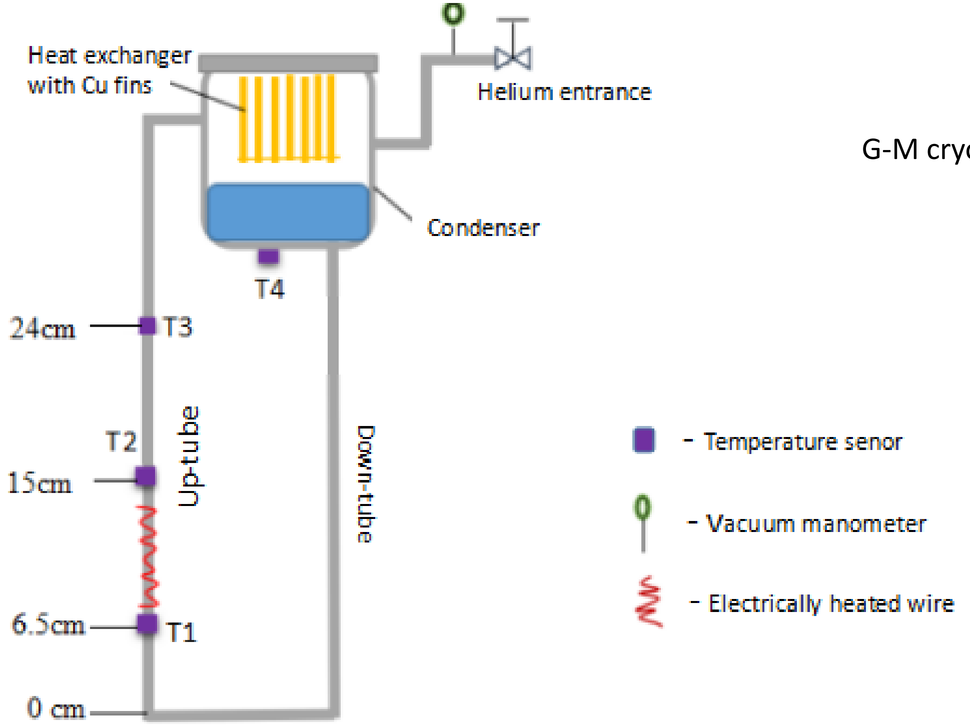
Detector magnet @CEPC: Liquid helium thermal siphon cooling to avoid quench caused by cryogenics failure

Baotang Zhang, Meifen Wang

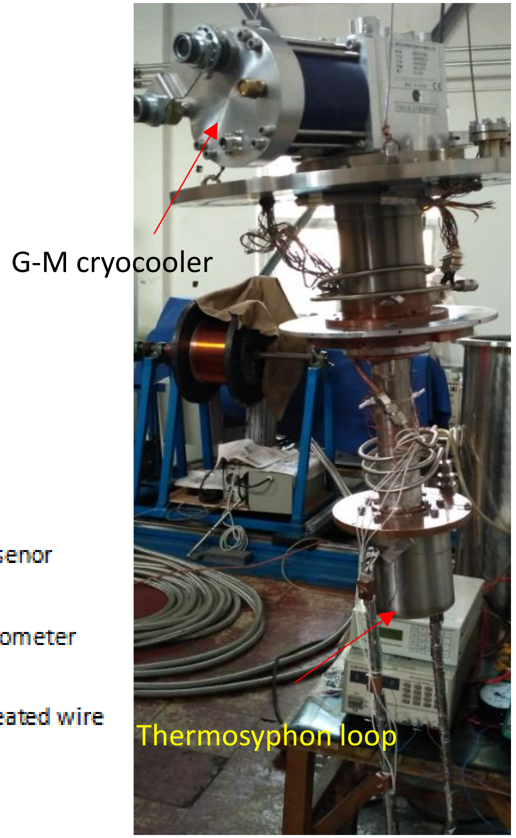
Magnet Cryogenics

- A mini set-up for thermal siphon study based on liquid helium (LTS)

- 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
- Numerical modelling of mass flow rate in a thermal syphon



Schematic of the circuit loop



Experimental apparatus

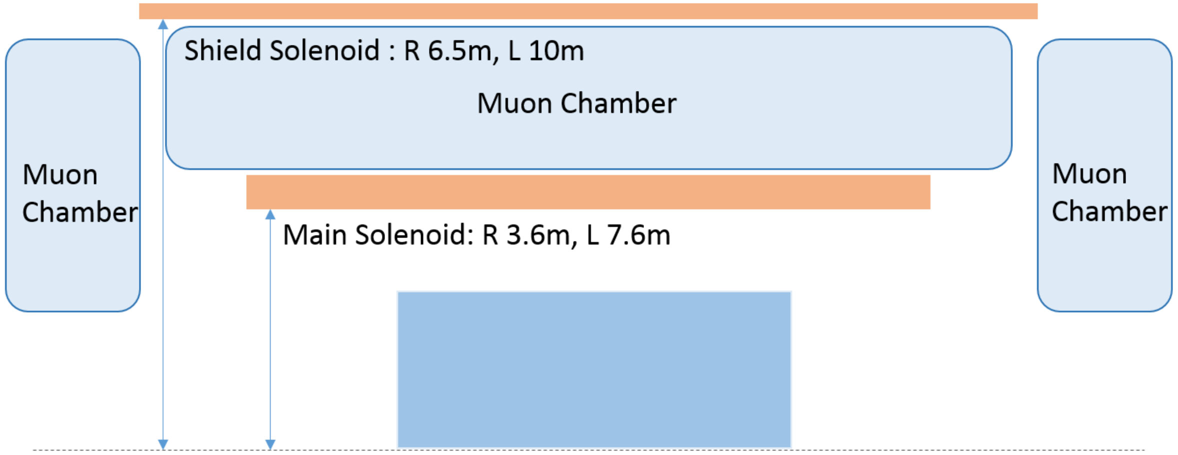
HTS option

- Compared with the use of LTS(low temperature superconductor), the HTS(high temperature superconductor) detector magnet has the following highlights:
    - 1. Three HTS supplier existed in China
    - 2. It is possible HTS cost 10 times cheaper in 5 years
    - 3. Working at a relatively high temperature (20 K), cooling get easier
    - 4. More stability, HTS magnet not easy to quench
    - 5. Cost maybe comparable with the LTS magnet especially in the case of active shielding design(without iron yoke)
    - 6. Push the development of full HTS high field solenoid magnet

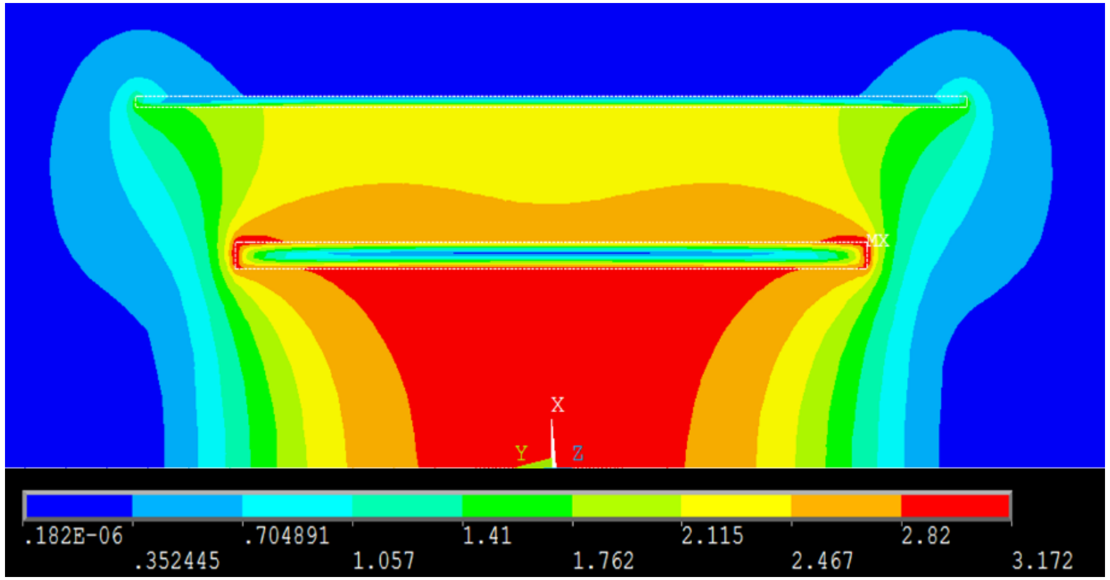
Wei Zhao

Active shielding Scenario

- **The active shielding design has been applied widely for commercial MRI magnets. Comparing to the one solenoid and yoke design, this design achieves a similar performance while being much lighter and more compact, which has been improved by FCC previous studies .**
- **The main solenoid provides 5 T central field over an room temperature bore of 7.2 m and a length of 7.6 m. The outer solenoid provides -2 T central field, with a radius of 6.5 m and a length of 10 m.**



Sketch figure of the active shielding magnet, with the available areas for muon chambers



Field map of the active shielding magnet

Summary

- Some progress in the development of specific LTS superconductor, thermal siphon cooling
  - **Constructed 10 meter short length aluminum stabilized NiTi Rutherford superconductor of 10kA@4T**
  - **Key performances: Shear Strength meet the requirement, RRR, Ic under evaluation**
- Will add 2T detector magnet design proposed by Italia team into CDR
- Keep iron yoke structure as the default option, and the Active Shielding scenario as an candidate option
- Need further discussion: 2 IP@CEPC, one 3T, another 2T

Next Steps

- **1. Further development of longer and higher Ic Al-based NbTi conductor (>100m,>10kA@4T)**
- **2. Study of thermal siphon cooling system for LTS coil**
- **3. Study of candidate option(HTS, no iron yoke, HTS coil cooling method @20K)**

Thank you for your attention!

Zian Zhu

Email: zhuza@ihep.ac.cn