
The research of weak magnetic field measurement

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For

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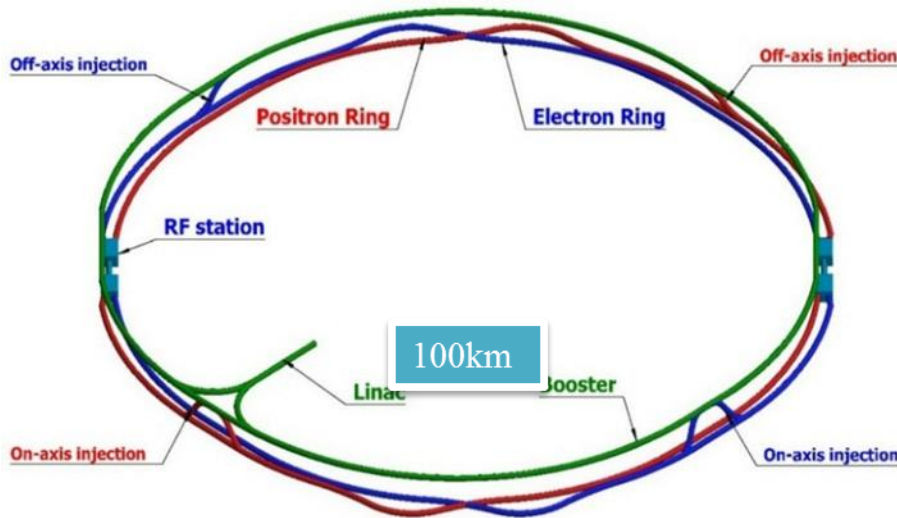
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Outline

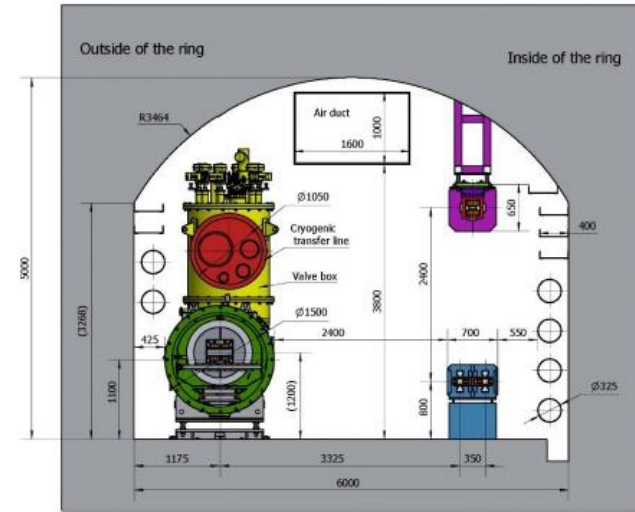
- 1、 Introduction of CEPC booster magnet system
- 2、 Prototypes of the weak field magnet
 - ✓ iron core
 - ✓ CT
 - ✓ CCT
- 3、 Field measurement of the prototypes
- 4、 Further work
- 5、 Summary



1、 Introduction of CEPC booster magnet system



CEPC layout



Tunnel cross section in the arc region

- CEPC is a double ring collider with two interaction points (IPs).
- The layout of CEPC including the Linac, the transfer lines, the Booster and Collider
- The Linac is at ground level and is 1.2 km. in length
- The CEPC collider ring, the CEPC booster ring and the future SPPC collider ring are all housed in the same 100 km circumference tunnel.
- Booster bypasses the collider ring from the outer side at two IPs.
- 10 GeV linac provides electron and positron beams for booster.
- In order to realize full energy injection to the collider, the Booster will accelerate the e-e+ beam from 10GeV to 120GeV or 175GeV.



1、 Introduction of CEPC booster magnet system

Specifications of CEPCB dipole magnets

	BST-63B
Quantity	16320
Minimum field (Gs)	29
Maximum field (Gs)	492
Gap (mm)	63
Magnetic Length (mm)	4700
Good field region (mm)	55
Field uniformity	0.1%
Field reproducibility	0.05%

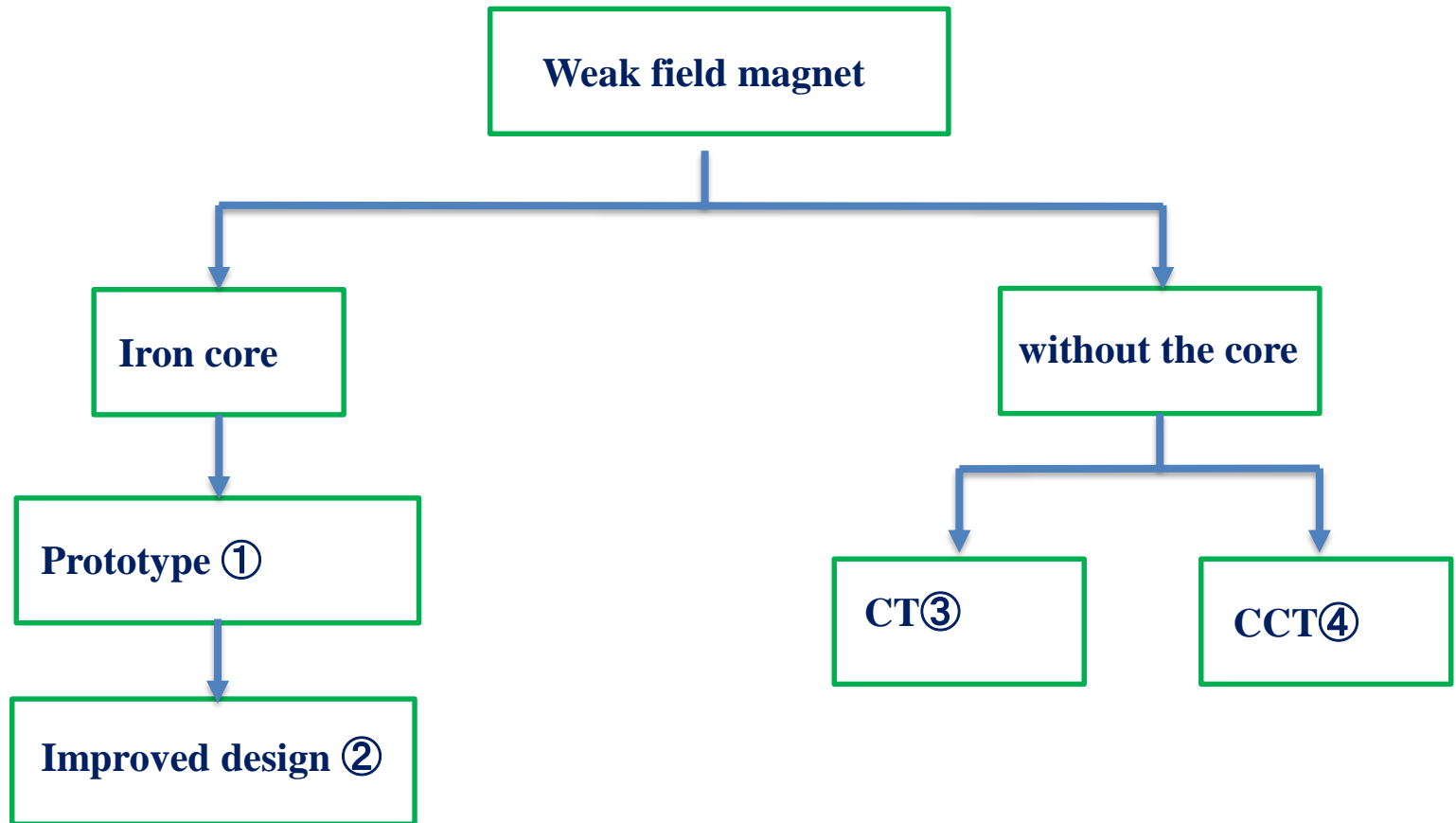
- There are nearly 16320 dipole magnets with length of 4700mm in the Booster, so the total length of all dipole magnets will be 75km.
- The field of the dipole magnets will change with the beam energy, of which the min. working field is 29Gs whereas max. field is 338Gs or 492Gs.

Challenges

- Field error $<29\text{Gs} \times 0.1\% = 0.029\text{Gs}$ how to design
- Field reproducibility $<29\text{Gs} \times 0.05\% = 0.015\text{Gs}$ how to measure



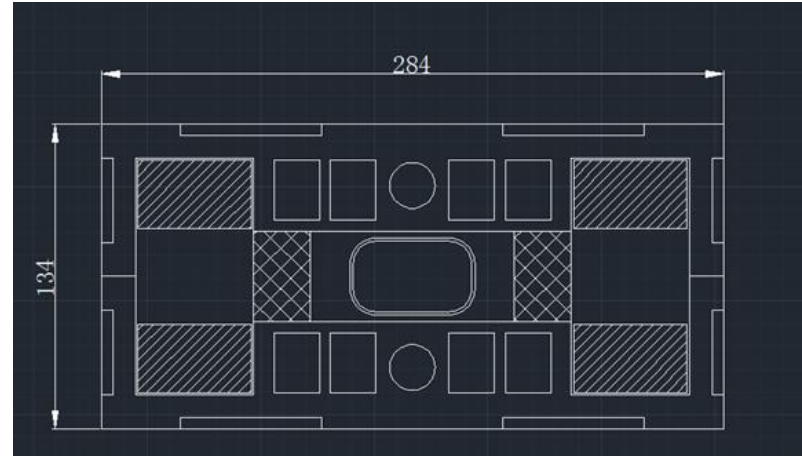
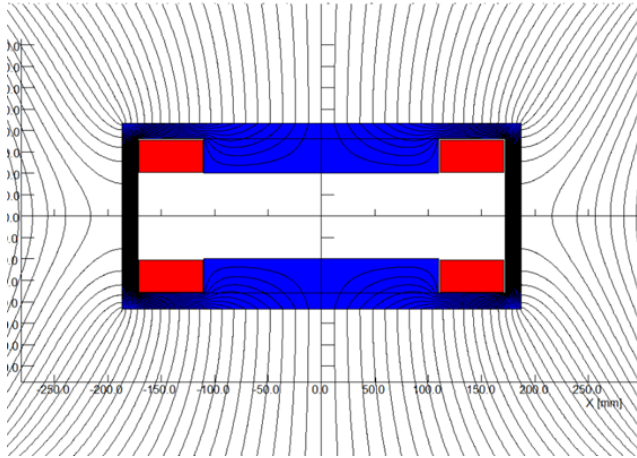
2、 Prototypes of the weak field magnet



Four prototypes will be used to verify weak field magnet technology.



2.1、 Design of the dipole magnet with iron core



- In order to get a better shielding of earth field, a H-type core is selected
- By taking the same technology of core dilution as the low field dipole magnets of the LEP and LHeC, the cores is stacked by silicon steel laminations and aluminum laminations with the ratio of 1:2.
- In order to reduce the weight of the cores and increase the field in the cores further, the core dilution in transversal direction were proposed.
 - ✓ The return yokes were designed as thin as possible.
 - ✓ In the pole areas of the laminations, some holes were stamped.
- The technologies of the core dilution will not only reduce the weight of the magnets, but also increase the field in the cores and decrease the influence of the remnant field.
- Each coil of the magnets is only one turn, which is simply made by aluminum bars.



2.1、 Design of the dipole magnet with iron core

- In order to verify the design of the dipole magnet with iron core, a 1m long subscale prototype magnet was produced and tested in CEPC Pre-CDR stage.

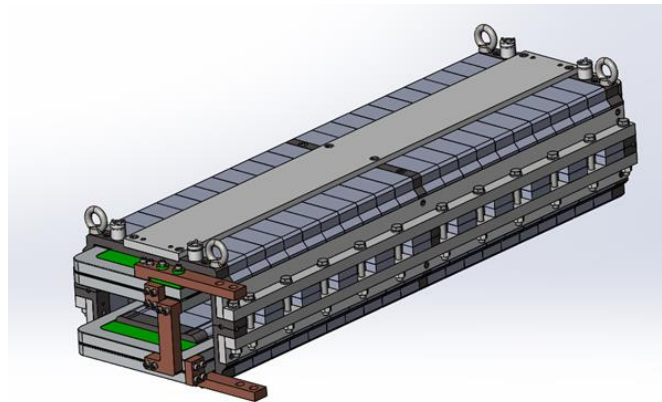
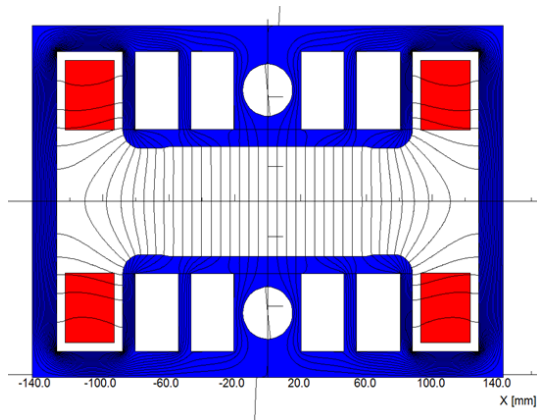


- ✓ One half of the magnet is stacked by the pure steel laminations, another half is stacked by the steel laminations and the aluminum laminations with the thickness ratio of 1:2.



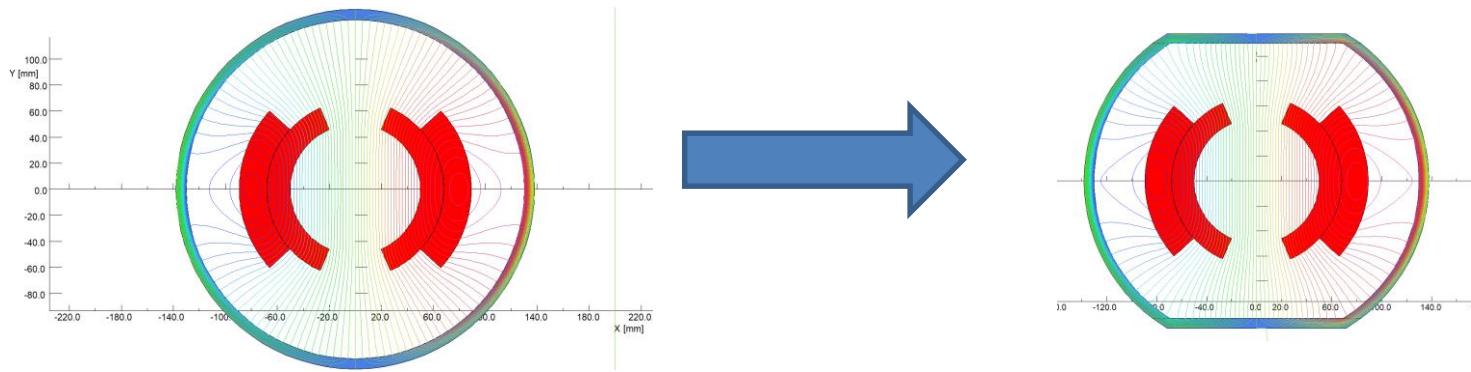
2.2、 Improved design of the magnet with iron core

- ✓ The dipole magnet with iron core is re-designed according to the new requirements of the CDR.
 - 1) The cores will be stacked by silicon steel and aluminium laminations with ratio of 1:1.
 - 2) The return yoke of the cores will be made as thin as possible.
 - 3) In the pole areas of the laminations, some holes will be stamped.
 - 4) Because the oriented silicon steel laminations have 10 time lower coercive force than non-oriented laminations, they will be used to stack the cores of the magnet to reduce the influence of the remnant field at low field level.



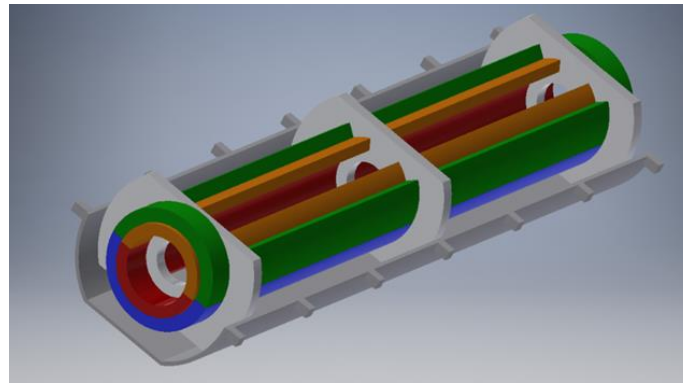
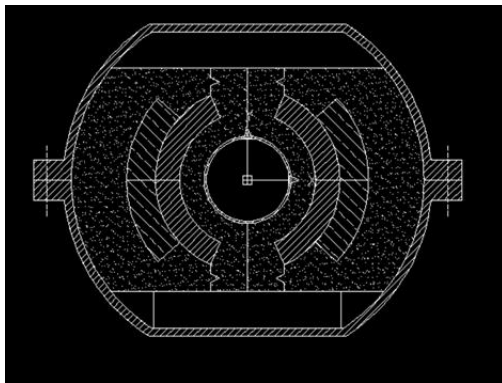
2.3、 Design of the magnet with the CT coil

- ✓ Because the remnant field of the iron cores is the key element that destroys the field quality at low field level, the dipole magnet designs without iron core are considered.
- ✓ Firstly, the dipole magnet with $\cos\theta$ type coils is designed and optimized to reach the field quality at both high and low field levels.
- ✓ To improve the excitation efficiency of the magnet, the top and bottom of the shielding cylinder can be flattened, the simulation results show that it can increase the efficiency by 5%.



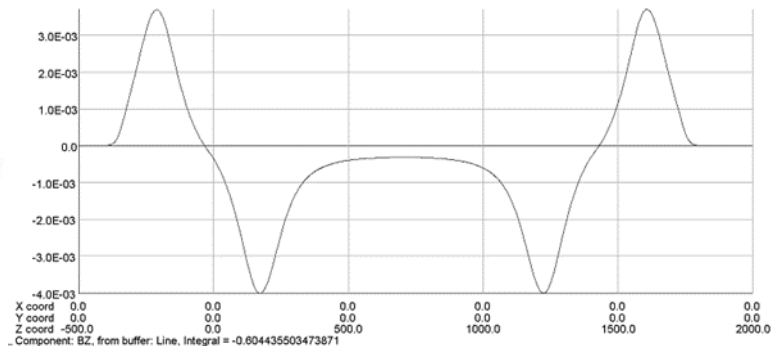
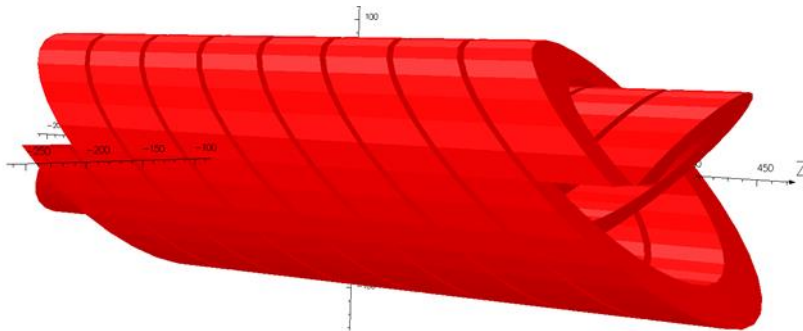
2.3、 Design of the magnet with the CT coil

- ✓ In addition, the flat top and bottom of the cylinder have a function to adjust the field distribution and then to improve field quality.
- ✓ The upper and lower coils of the magnet are formed by two aluminum bars with the same cross section areas, and each coil has two layers and two turns.
- ✓ Because of low field and small force, for 1m long subscale prototype magnet, the supporters at three positions in the longitudinal direction are strong enough to fix the bars of coils.

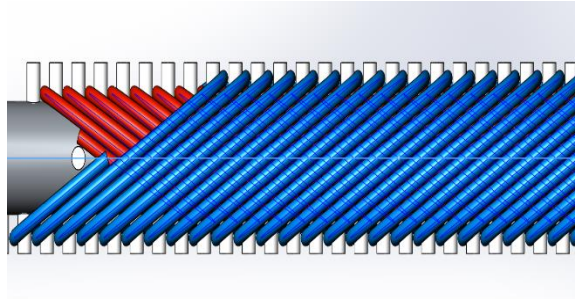
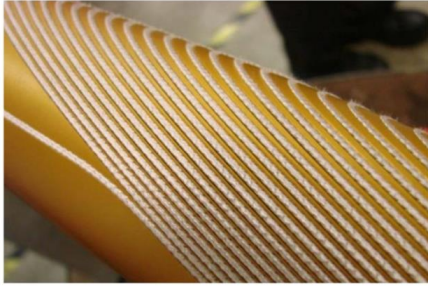


2.4、 Design of the magnet with the CCT coil

- ✓ the dipole magnet with canted $\cos\theta$ coils (CCT) is also designed.
- ✓ The dipole magnet with CCT coils is composed of two or four canted solenoids, of which the excited currents have different direction. The B_y field in the magnet center is $B_y = \mu_0 I / (w * \tan(\alpha))$, in which w is the distance between two turns, α is canted angle. The B_z field is compensated to nearly zero.



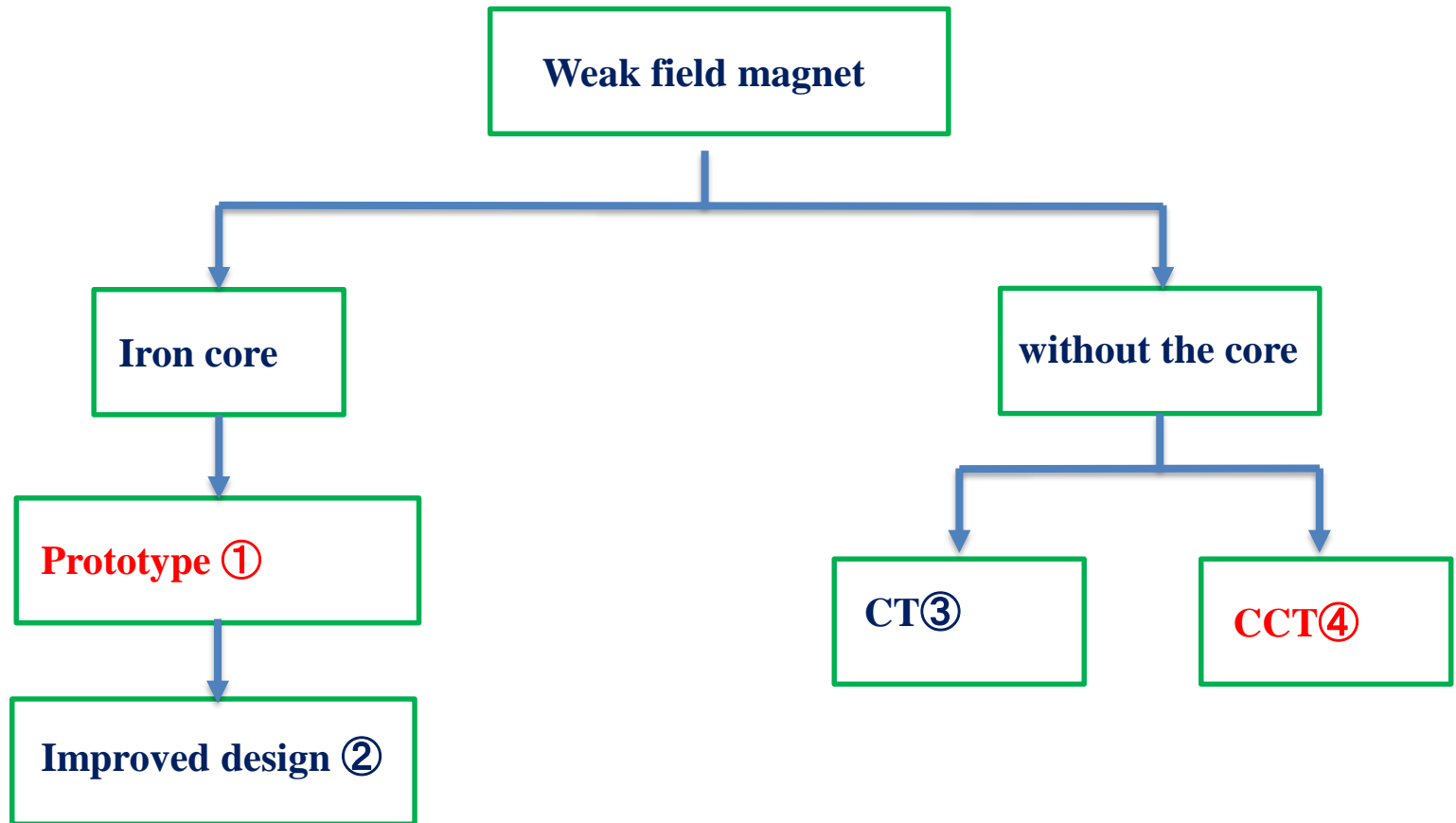
2.4、 Design of the magnet with the CCT coil



- ✓ the position errors directly winding the conductor on the supporting cylinders are probably not small enough to meet the field precision requirement.
- ✓ To ensure the field precision, the alternative way to make CCT coils is to directly fabricate them from the aluminum cylinders.
- ✓ The CCT coils of the dipole magnet have four layers, so four aluminum cylinders with the different diameters are used to fabricate the CCT coils.



3、 Field measurement of the prototypes



Currently, prototypes of No.1 and No.4 have been tested.



3.1、 Field measurement of the Iron core



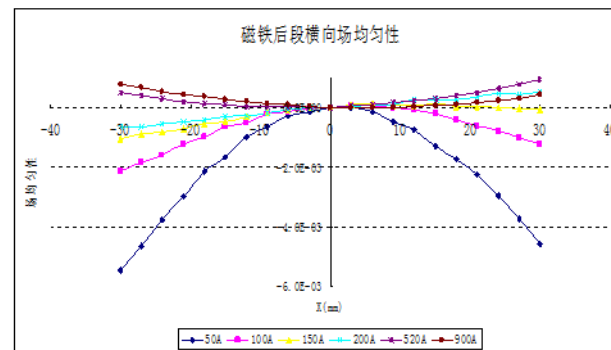
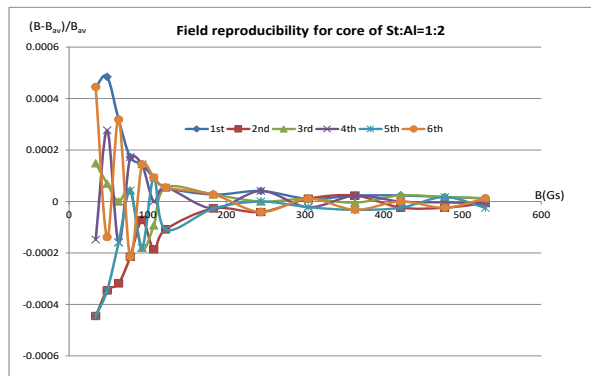
- The field of the No.1 prototype was measured by Hall probe measurement system.
- Group3: DTM-151 Digital Teslameter +MPT-141 probe
- The excitation curve and field distribution at the center of the magnet is measured
- The uniformity of integral field is measured



3.1、 Field measurement of the Iron core

Measurement results:

- ✓ The remnant field in the magnet gap is about 4-6Gs, which is 13%-20% of the low field of 29Gs.
- ✓ Due to the remnant field in the core, the field uniformity at low field becomes 10 time worse than that at high field
- ✓ The field reproducibility at low field becomes 40 time worse than that at high field.



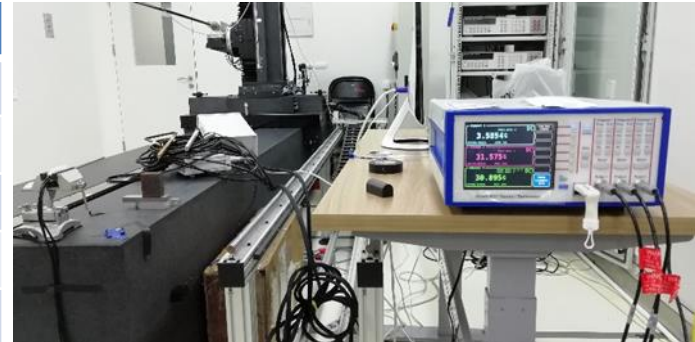
3.2、 Test of new Hall probe

- 1、 A new Gauss meter and probe are selected to measure the characteristics of weak field
- 2、 An experiment was carried out to test the performance of the probe.

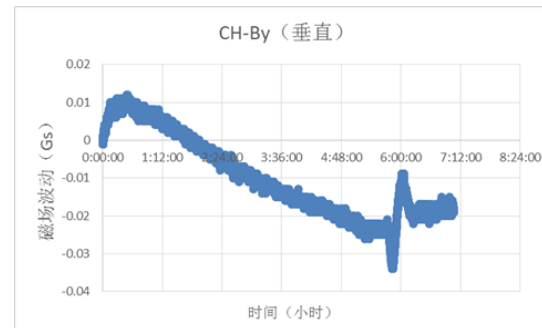
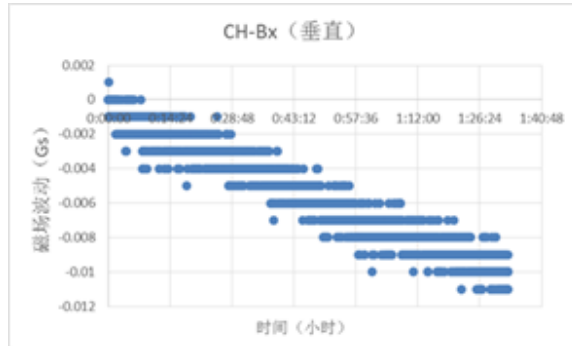
Adjust the distance between the permanent magnet and the probe so that the display of the Gauss meter is about 31Gs.

Record the display changes of the Gauss meter

Specifications	Value
Brand	F.W. Bell
Model of Gauss meter	8030
Model of Probe	ZOA83-3208-10-T
Range	30Gs, 300Gs, 3KGs, 3T
Resolution	0.0001Gs~0.1Gs(depend on range)
Accuracy (Displayed reading)	$\pm 0.05\%$ of reading(DC) $\pm 2\%$ of reading(AC)
Frequency range	dc to 250Hz(DC mode) 10Hz to 50kHz(AC mode)
Analog output	$\pm 3V$ FS. or $\pm 10V$ F.S. or adjustable from 0.1 – 9.9V
Temperature coefficient	$\pm (0.02\%$ of reading ± 1 count)/ $^{\circ}$ C



3.2、 Test of new Hall probe



Test results:

- 1、 There is a drift exist;**
- 2、 Although the probe has the function of temperature compensation, the temperature change still has a large influence on the measurement result.**
- 3、 The jitter of the probe can also cause changes in readings.**
- 4、 After two days'test, the result shows that the change of the reading can be controlled within 0.01Gs in an hour.**



3.3、Field measurement of Single-layer CCT coil



- ✓ Single-layer CCT coil has been measured by the hall probe.
- ✓ When the magnet is excited by 60A current, the central magnetic field can achieve 33Gs.
- ✓ The temperature of the magnet rises from 26 degrees to 43 degrees.
- ✓ Although the probe has a temperature compensation function, the temperature rise affects the measurement accuracy.

26.6°C



32.3°C

33.133Gs

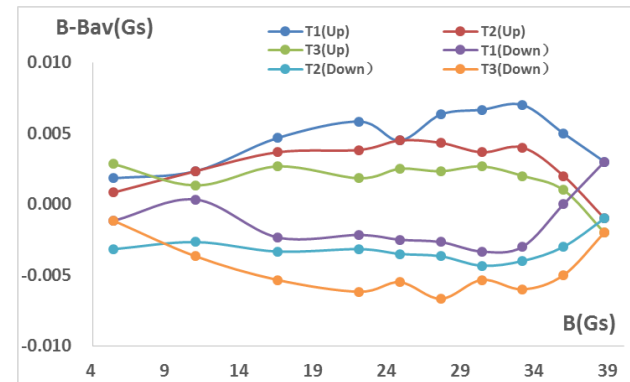
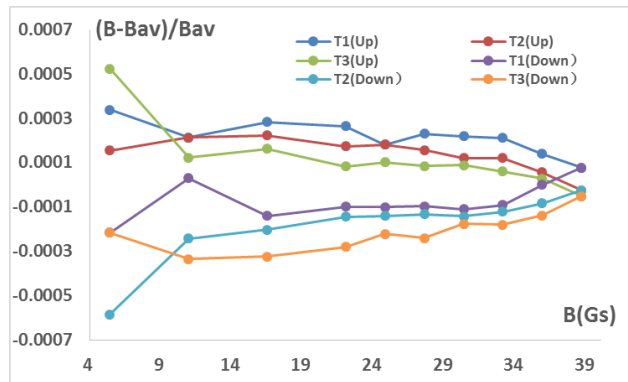


33.074Gs



3.3、Field measurement of Single-layer CCT coil

- ✓ The excitation curve of the central magnetic field is rapidly measured to avoid the influence of temperature rise.

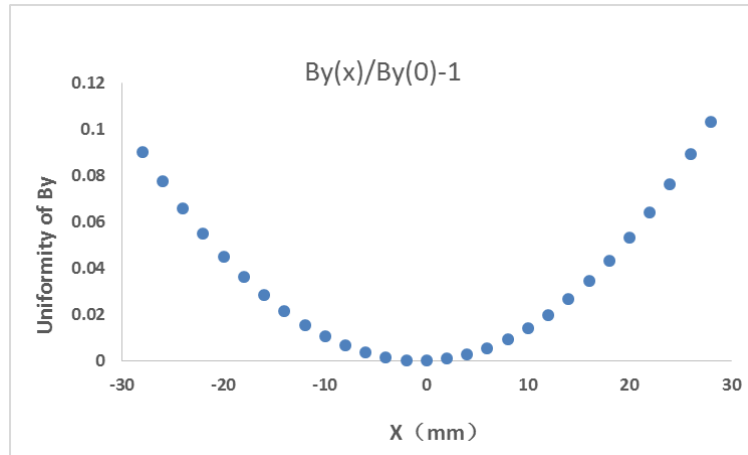


- ✓ The ratio is very large at low field, but the difference of actual magnetic field is very small (<0.005 Gs).
- ✓ The influence of temperature change on probe still exists.
- ✓ The influence of residual magnetism can be ignored.



3.3、Field measurement of Single-layer CCT coil

- ✓ The uniformity of B_y in the center position



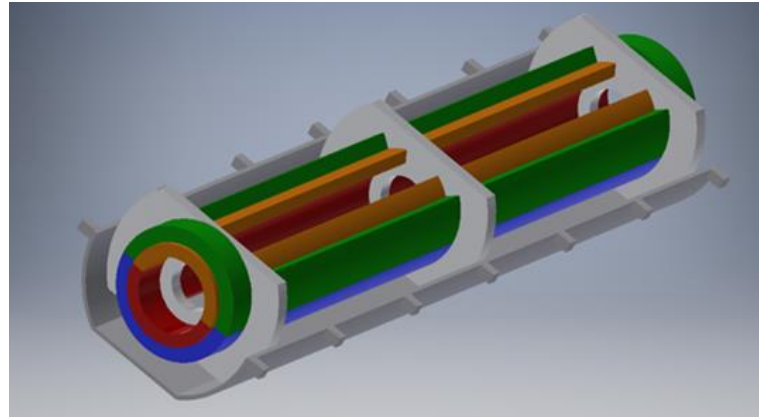
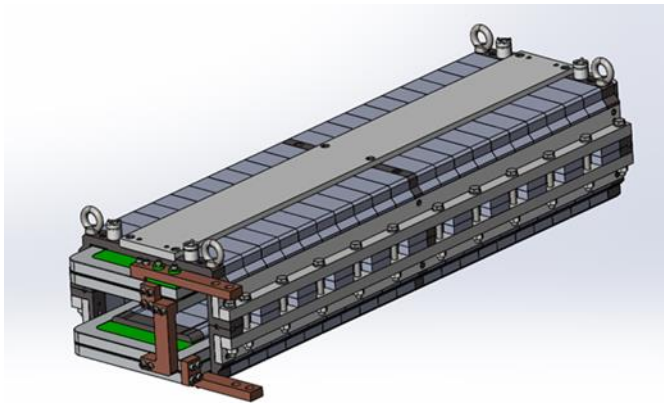
- ✓ The uniformity of B_y is nearly up to 10.33%
- ✓ The scheme was cancelled



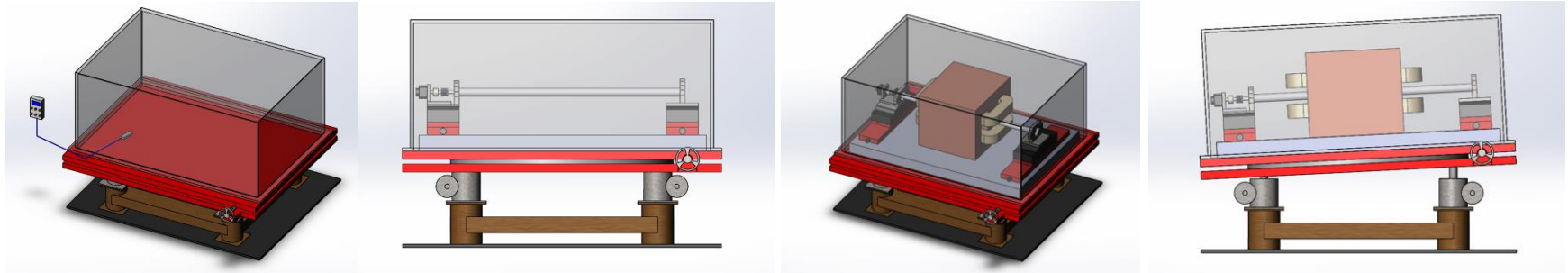
4、 Further work (prototype measurement)

4.1、 Complete the magnetic field measurements of the iron core prototype and the improve one with new probes

4.2、 Complete the magnetic field measurements of the CT coil magnet



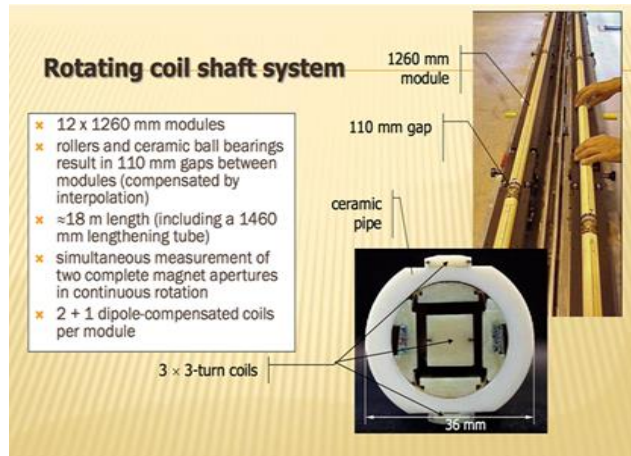
4、Further work (Earth field research)



- ✓ The geomagnetic field is a vector field with an amplitude of about 0.5Gs.
- ✓ A shield is used to shield the earth's magnetic field.
- ✓ Rotating coil is used to measure the background before and after the shield is installed
- ✓ Measure after installing magnet
- ✓ Adjusting the Spatial Position of Magnet
- ✓



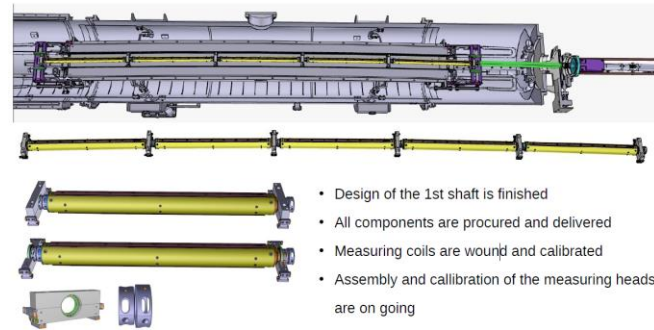
4、 Further work



LHC

Magnetic field measurements: new development

[Shaft of rotating coil for the cold measurements](#), Today status



GSI Helmholtzzentrum für Schwerionenforschung GmbH | A.Mierau, IMMW19, 25th - 30th Oct. 2015, Hsinchu, Taiwan | 19

GSI

- ✓ The actual length of the dipole magnet is 4.7 meters, so the rotating coil is essential.
- ✓ The scheme of multi-segment structure is adopted. They are similar to LHC and GSI rotating coil probe.



5、 Summary

- ✓ It is very difficult to produce a low field magnet with a better field uniformity .
- ✓ For weak field magnets, geomagnetism is one of the factors to be considered.
- ✓ Higher precision probes are needed for low field measurements.



Thanks !

