Design of CEPC LTS detector magnet

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On behalf of the Superconducting Magnet Group

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Outline

- BASELINE design of detector magnet
- Progress of R&D
- New requirement for the detector magnet
- Challenges from new requirements

History of High Energy Physics Detector Magnets

- 1969 CERN –BEBC, Big European Bubble Chamber (solenoid)
- 1972 CERN –Omegamagnet (large aperture dipole)
- 1977 CERN/ISR –Solenoid
- 1978 DESY –CELLO (solenoid)
- 1983 SLAC/PEP4 –TPC solenoid
- 1985 KEK/TRISTAN –TOPAZ, VENUS (solenoids)
- 1988 CERN/LEP –ALEPH, DELPHI (solenoids)
- 1990 DESY/HERA –ZEUS (solenoid)
- 1997 SLAC –BABAR (solenoid)
- 2004 KEK –BESS-Polar (ultra-thin solenoid)
- 2007 CERN/LHC –CMS (solenoid), ATLAS (Toroids, solenoid)

T. M. Taylor, CERN Summer Student Lecture, 2006

Main parameters of detector magnets

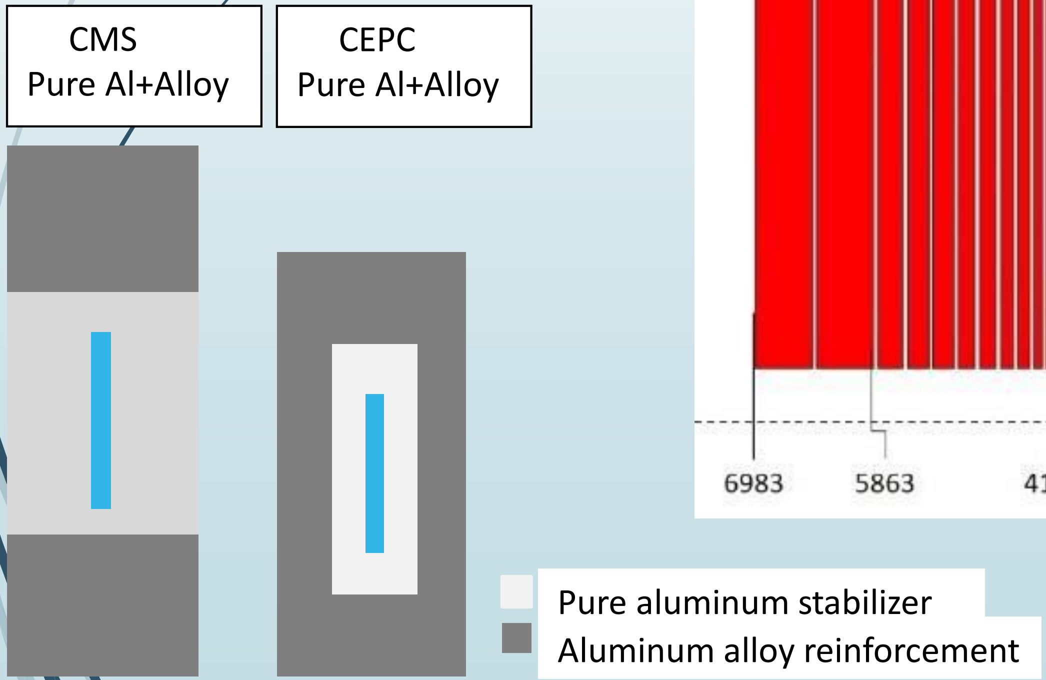
Experiment	Laboratory	B [T]	Radius [m]	Length [m]	Energy [MJ]	X/X_0	E/M [kJ/kg]
TOPAZ*	KEK	1.2	1.45	5.4	20	0.70	4.3
CDF*	Tsukuba/Fermi	1.5	1.5	5.07	30	0.84	5.4
VENUS*	KEK	0.75	1.75	5.64	12	0.52	2.8
AMY*	KEK	3	1.29	3	40	†	
CLEO-II*	Cornell	1.5	1.55	3.8	25	2.5	3.7
ALEPH*	Saclay/CERN	1.5	2.75	7.0	130	2.0	5.5
DELPHI*	RAL/CERN	1.2	2.8	7.4	109	1.7	4.2
ZEUS*	INFN/DESY	1.8	1.5	2.85	11	0.9	5.5
H1*	RAL/DESY	1.2	2.8	5.75	120	1.8	4.8
BaBar*	INFN/SLAC	1.5	1.5	3.46	27	†	3.6
D0*	Fermi	2.0	0.6	2.73	5.6	0.9	3.7
BELLE*	KEK	1.5	1.8	4	42	†	5.3
BES-III	IHEP	1.0	1.475	3.5	9.5	†	2.6
ATLAS-CS	ATLAS/CERN	2.0	1.25	5.3	38	0.66	7.0
ATLAS-BT	ATLAS/CERN	1	4.7–9.75	26	1080	(Toroid)†	
ATLAS-ET	ATLAS/CERN	1	0.825–5.35	5	2×250	(Toroid)†	
CMS	CMS/CERN	4	6	12.5	2600	†	12
SiD**	ILC	5	2.9	5.6	1560	†	12
ILD**	ILC	4	3.8	7.5	2300	†	13
SiD**	CLIC	5	2.8	6.2	2300	†	14
ILD**	CLIC	4	3.8	7.9	2300	†	
FCC**		6	6	23	54000	†	12

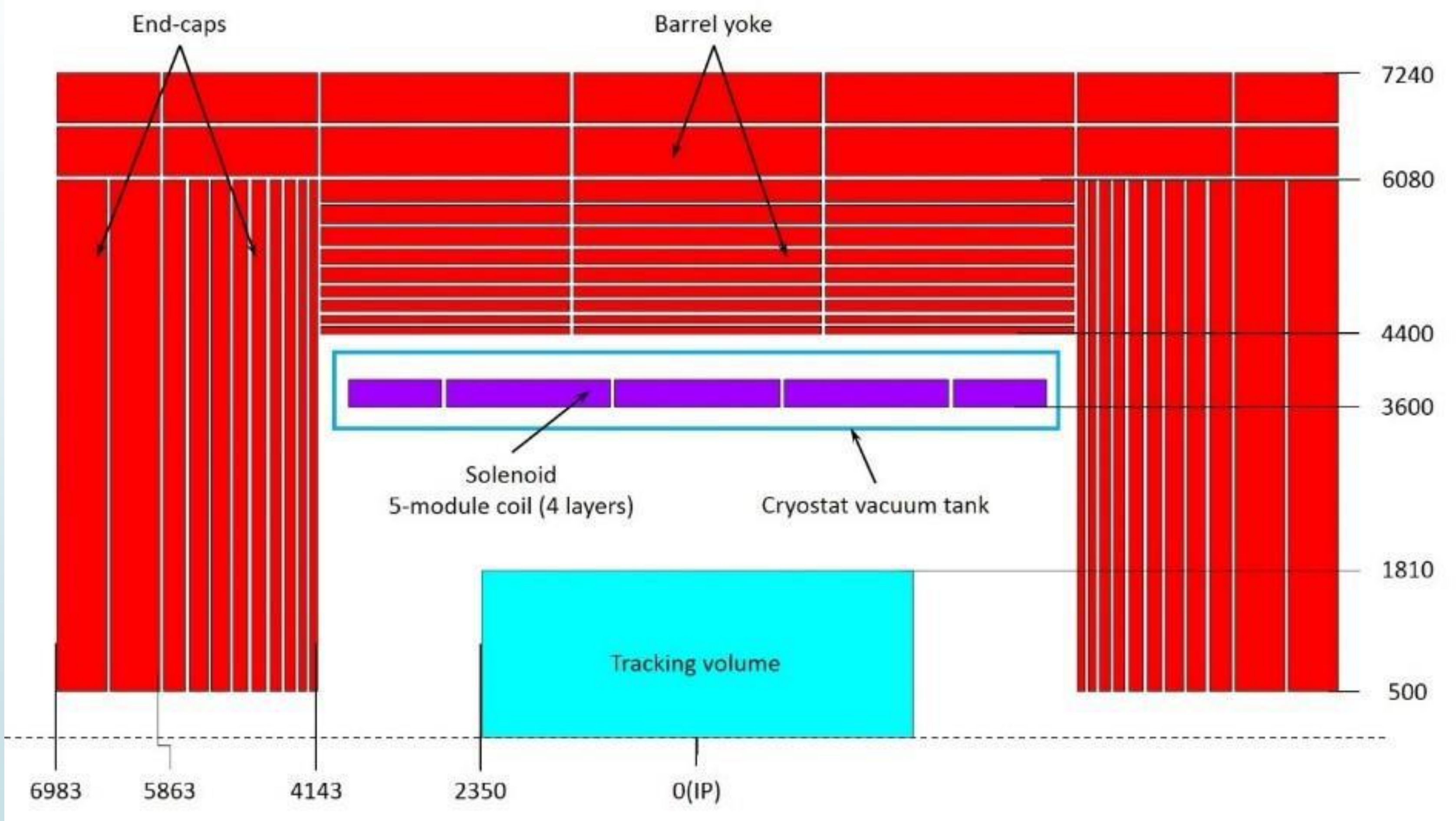
* No longer in service
** Conceptual design in future
† EM calorimeter is inside solenoid, so small X/X_0 is not a goal

Revised August 2017 by Y. Makida (KEK)

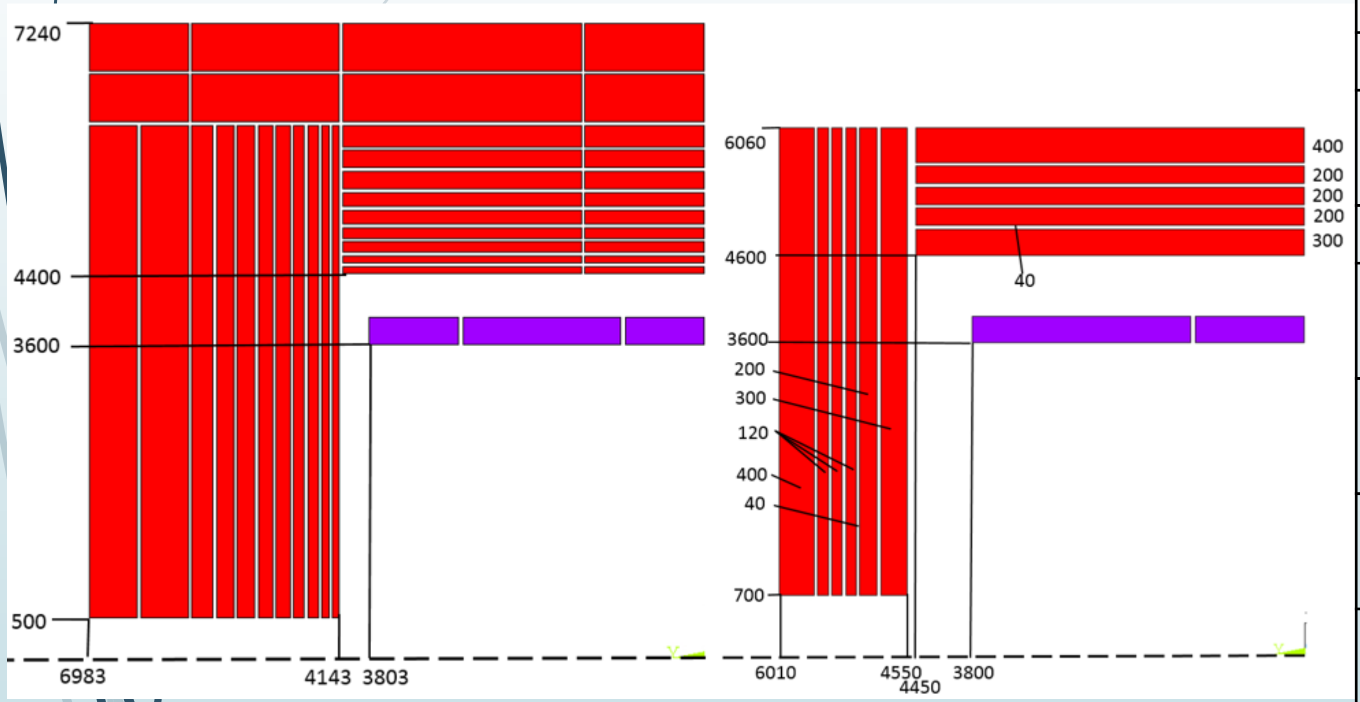
Design of LTS DETECTOR MAGNET in CDR

Solenoid central field ： 3T
Working current： 15779A
Coil inner radius： 3600mm
Cable length： 30.1km





New Yoke Design of LTS DETECTOR MAGNET

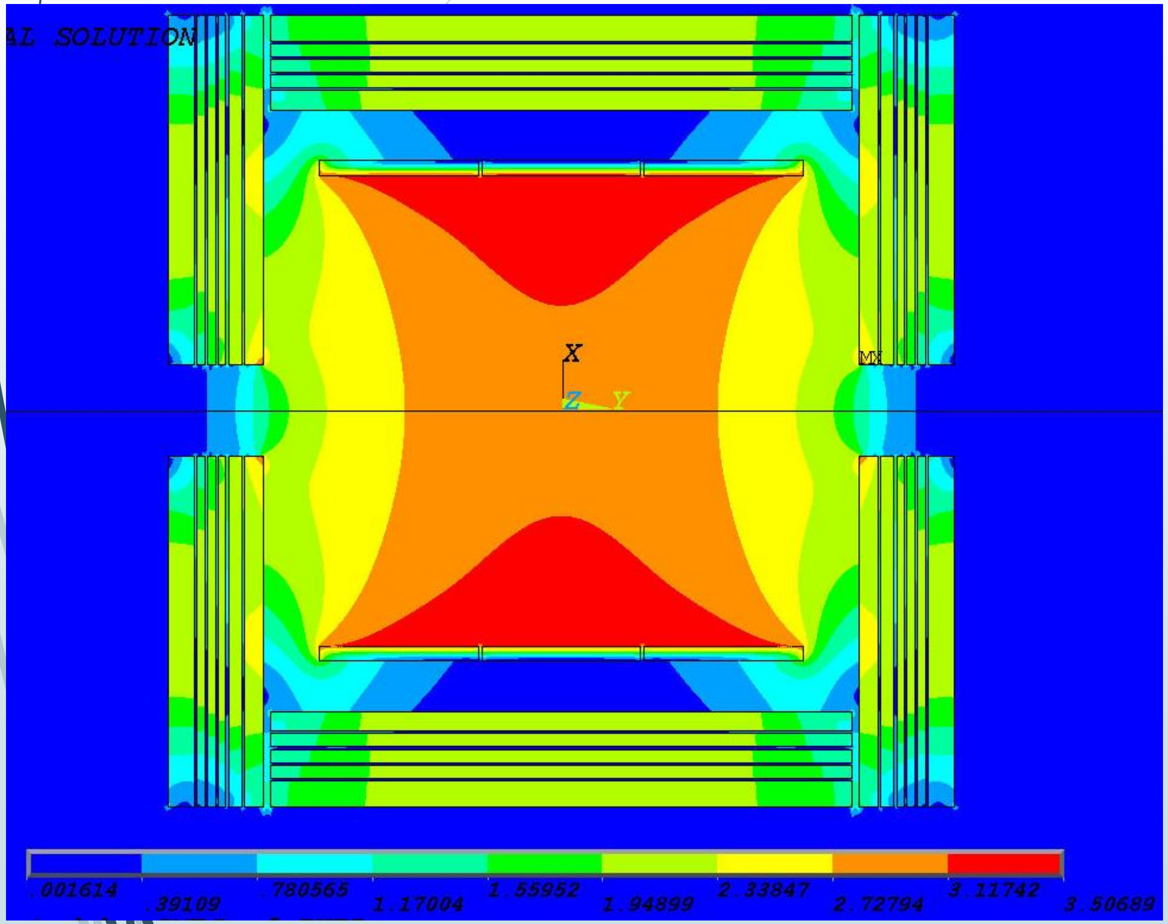


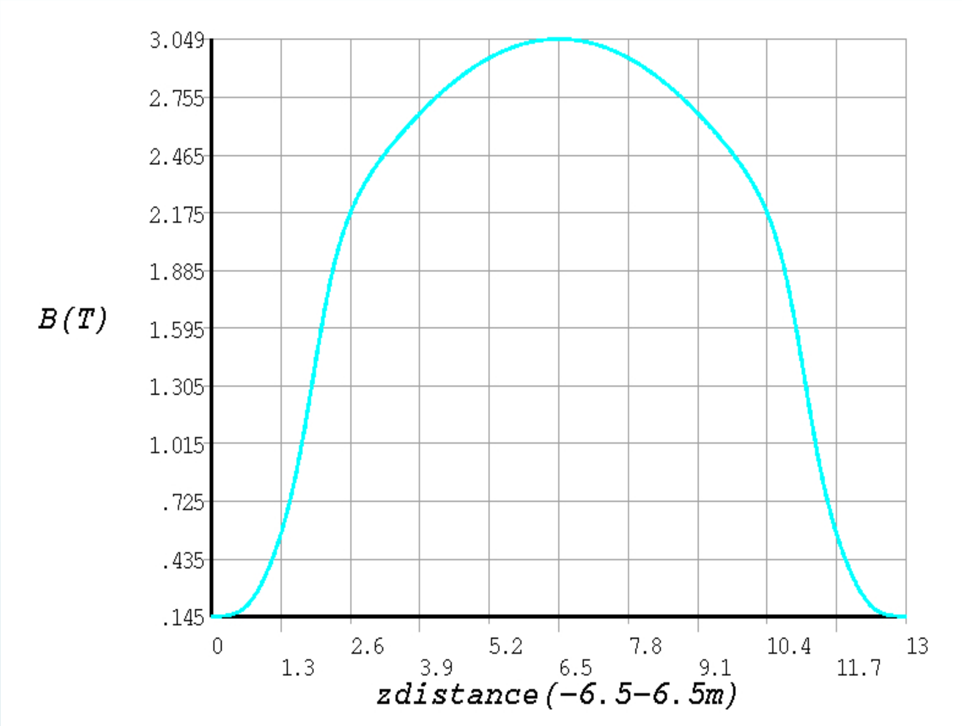
CDR version

New Yoke version

	CEPC CDR version	CEPC New version
Central field (T)	3	3
Operating current (A)	15779	16796
Inner diameter of coil (mm)	7200	7200
Length of coil (mm)	7606	7600
Barrel yoke inner diameter (mm)	8800	9200
Barrel yoke outer diameter (mm)	14480	12120
Total length of yoke (mm)	13966	12020
Weight of barrel yoke (t)	5940	3137
Weight of each end cap (t)	3316.6	1144
Total weight of yoke (t)	**12,573**	**5,425**

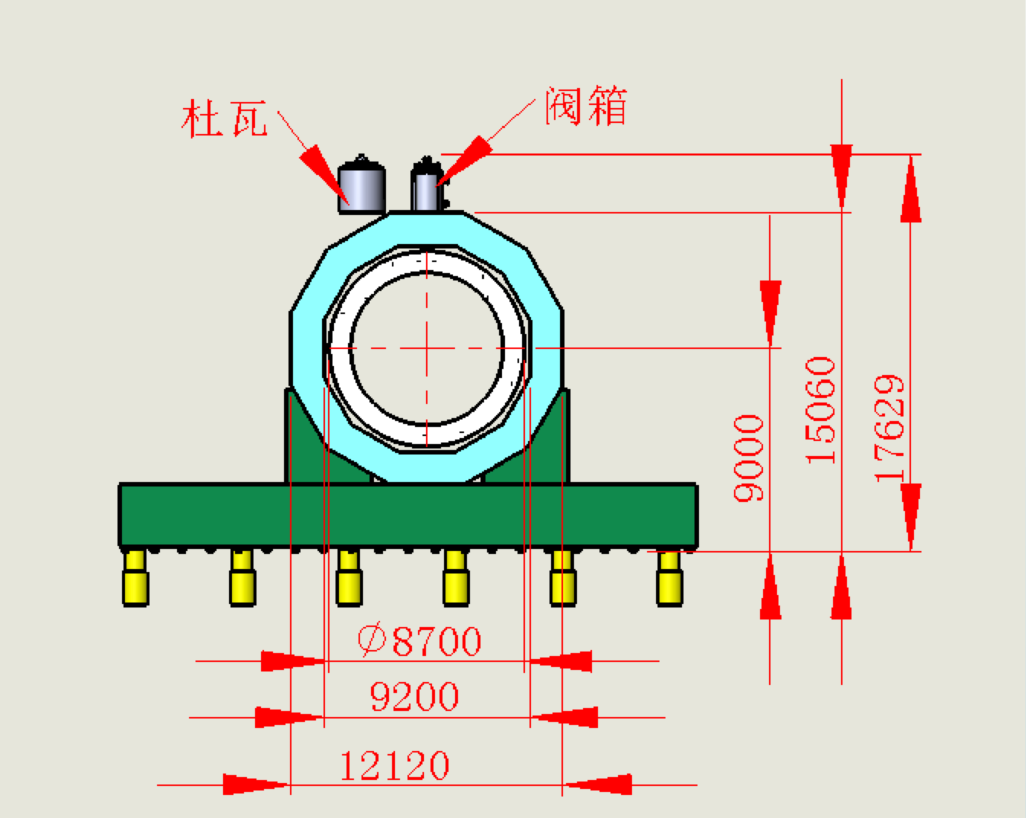
Field Distribution with new yoke design



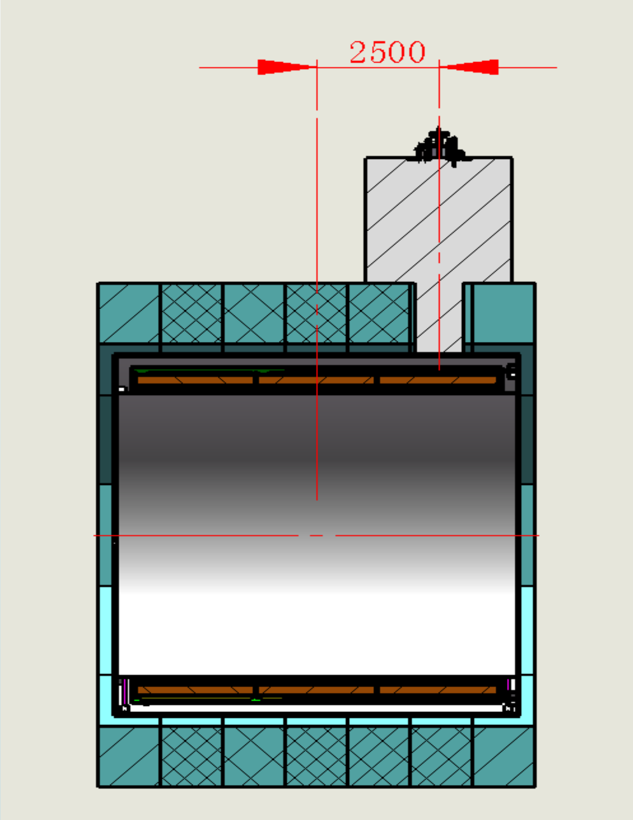


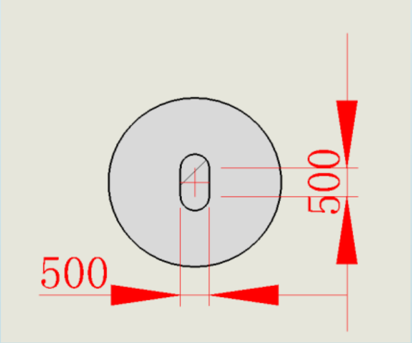
Distribution curve of magnetic field on central axis

Valve box and chimney design in CDR



Two Valve box



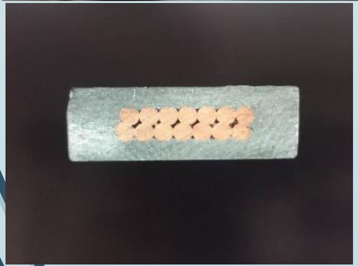


One bigger Valve box

Cable development

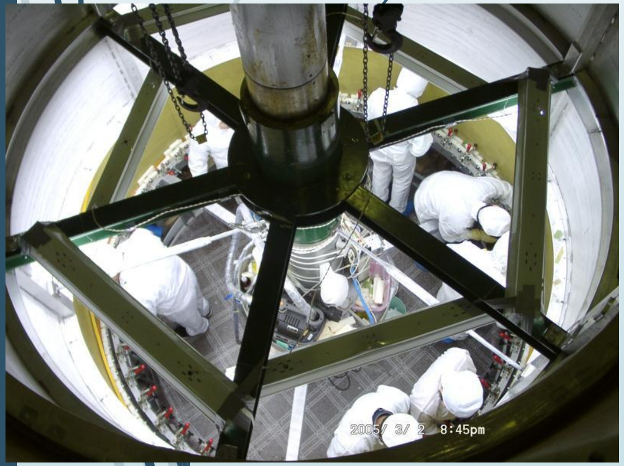
- Al Stabilized Rutherford cable development
  - Short sample (10000 A, 100 m) meets the requirements.
  - The secondary coextrusion process of aluminium alloy is under development by the support of IHEP.
  - The RRR value test device and critical current test device have been completed in IHEP.





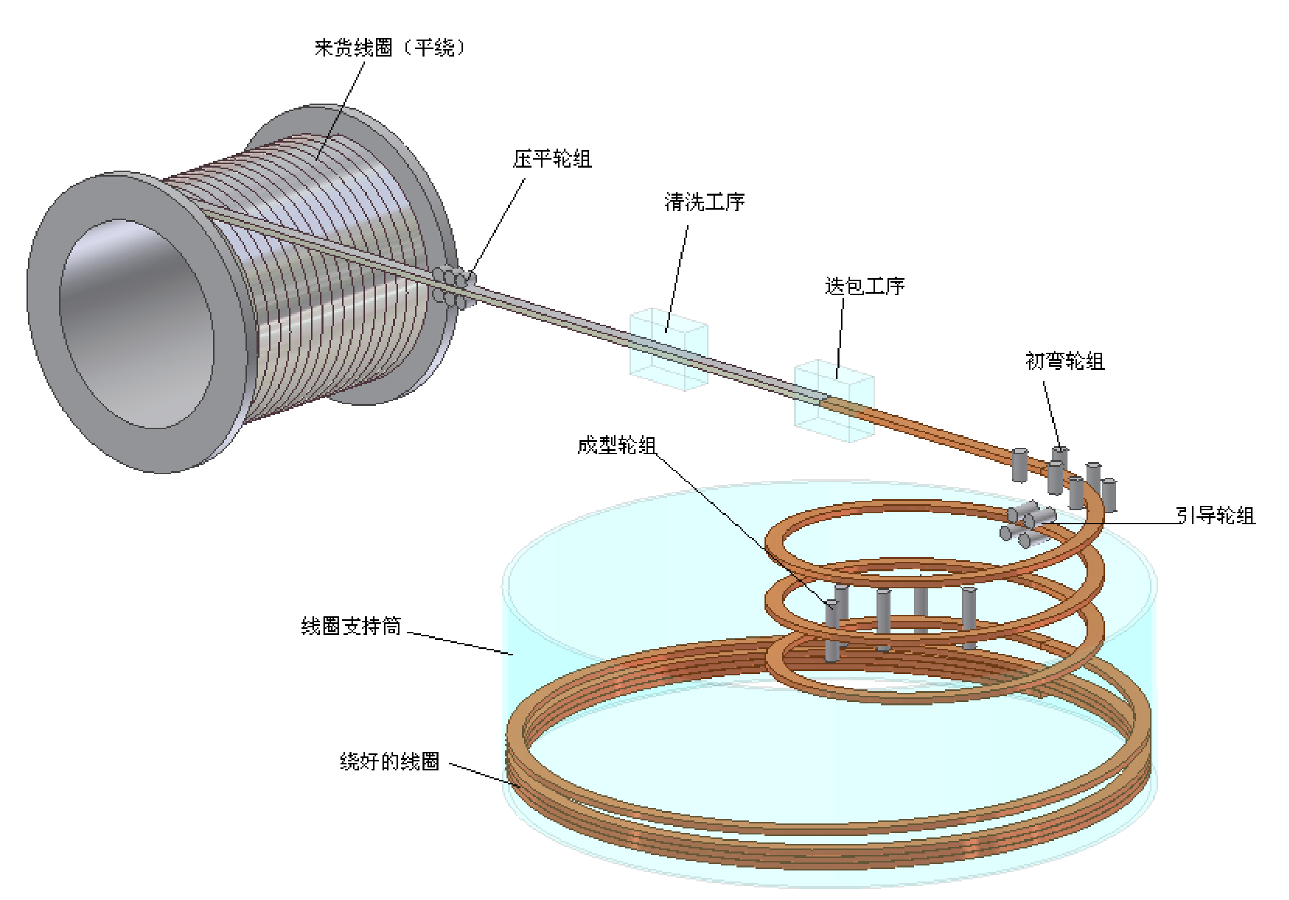
Coil winding process

- Coil winding process
  - Cooperation has been established with KEYE .
  - The design of winding tooling is about to be completed.



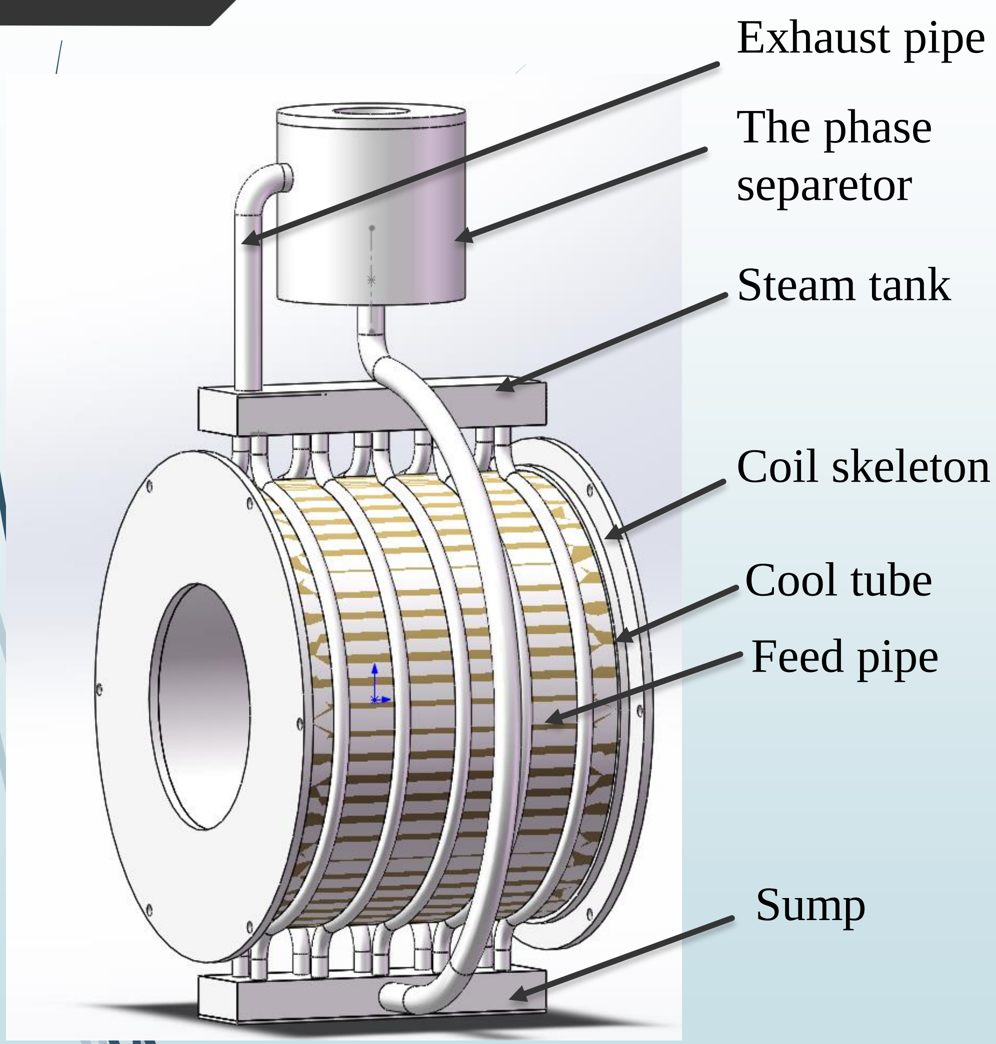
BES III

CMS



Inner winding

coil cooling design



Schematic diagram of thermosiphon pipeline

	Internal section size(mm)	Wall thickness(mm)	Length(mm)
Cooltube	Φ8	1	400
Feed pipe	Φ12	2	600
Exhaust pipe	Φ12	2	140
The phase separator	Φ100	the upper plate 6，the bottom palte 10, cylinder 6	106
Steam tank、Sump	50×20	2	203

The experiment involves filling the tube with the room temperature helium at first.According to preliminary exploration ,the whole thermosiphon circut performs better when the liquid level in the phase separator is around 50%.This is to say ,the requirement of the liquid helium is around 0.35L.

New requirement

- The detector magnet will be located between the Hadron calorimeter and Electromagnetic calorimeter ;
- Reduce mass : Increase coil current density, and superconductor were reduced from four layers to two or three layers.
- Reduce the radial space occupied by magnet.

	CMS	BESIII	IDEA*	BESS-POLAR	CDR(CEPC)	NEW DESIGN
Central field (T)	4	1	2	0.8	3	3
Operating current (A)	19600	3369	20000	380	16796	16956
Inner diameter of coil (mm)	6360	2960	2200	900	7200	4600
Length of coil (mm)	12480	3520	6000	1400	7606	6000
Outer shell external diameter(mm)	7600	3292	4600	1060	8700	5600
Inner shell inside diameter(mm)	5940	2750	4000	800	6800	4200

undetermined

New design of solenoid

Coil with two layers superconductor ： weight of superconductor is 11.4t。

coil	Rin(m)	Rout(m)	Layer	Zin(m)	Zout(m)	Turn	Length(m)	I(A)	J(A/mm2)	Bmax	hoopstress (Mpa)
1	2.3	2.36	2	-2.5	-2.14	36	1054.07	16956	56.52	3.73	484.89
2	2.3	2.36	2	-2.09	-0.73	136	3982.03	16956	56.52	3.73	484.89
3	2.3	2.36	2	-0.68	0.68	136	3982.03	16956	56.52	3.73	484.89
4	2.3	2.36	2	0.73	2.09	136	3982.03	16956	56.52	3.73	484.89
5	2.3	2.36	2	2.14	2.5	36	1054.07	16956	56.52	3.73	484.89

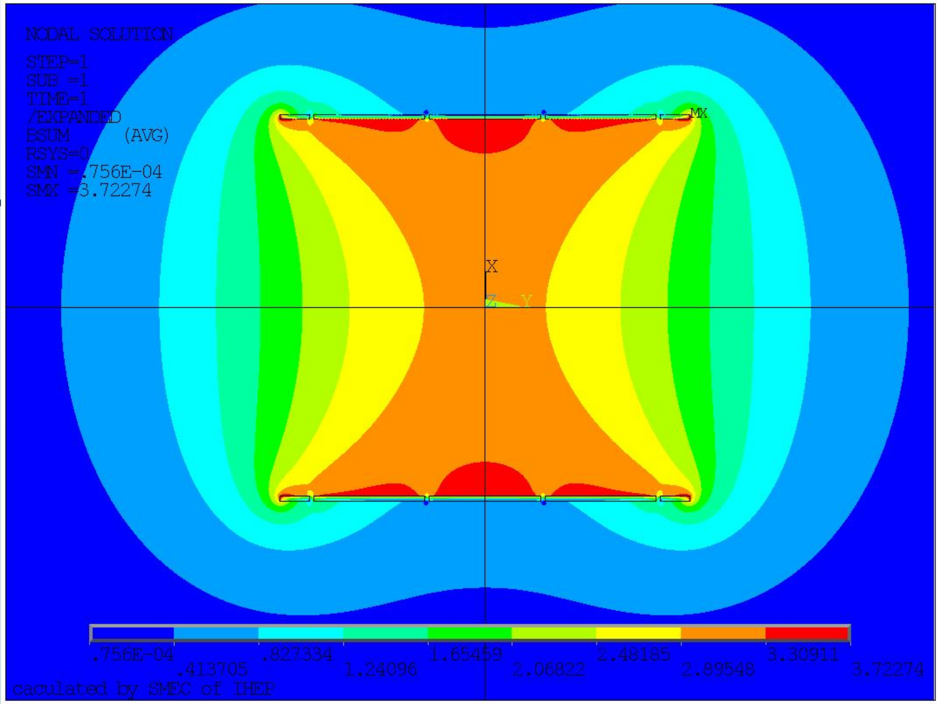
Coil with three layers superconductor： weight of superconductor is 17.2t.

coil	Rin(m)	Rout(m)	Layer	Zin(m)	Zout(m)	Turn	Length(m)	I(A)	J(A/mm2)	Bmax	hoopstress (Mpa)
1	2.3	2.39	3	-2.5	-2.14	36	1591.28	11338	33.7933	3.495	271.65
2	2.3	2.39	3	-2.09	-0.73	136	6011.50	11338	33.7933	3.495	271.65
3	2.3	2.39	3	-0.68	0.68	136	6011.50	11338	33.7933	3.495	271.65
4	2.3	2.39	3	0.73	2.09	136	6011.50	11338	33.7933	3.495	271.65
5	2.3	2.39	3	2.14	2.5	36	1591.28	11338	33.7933	3.495	271.65

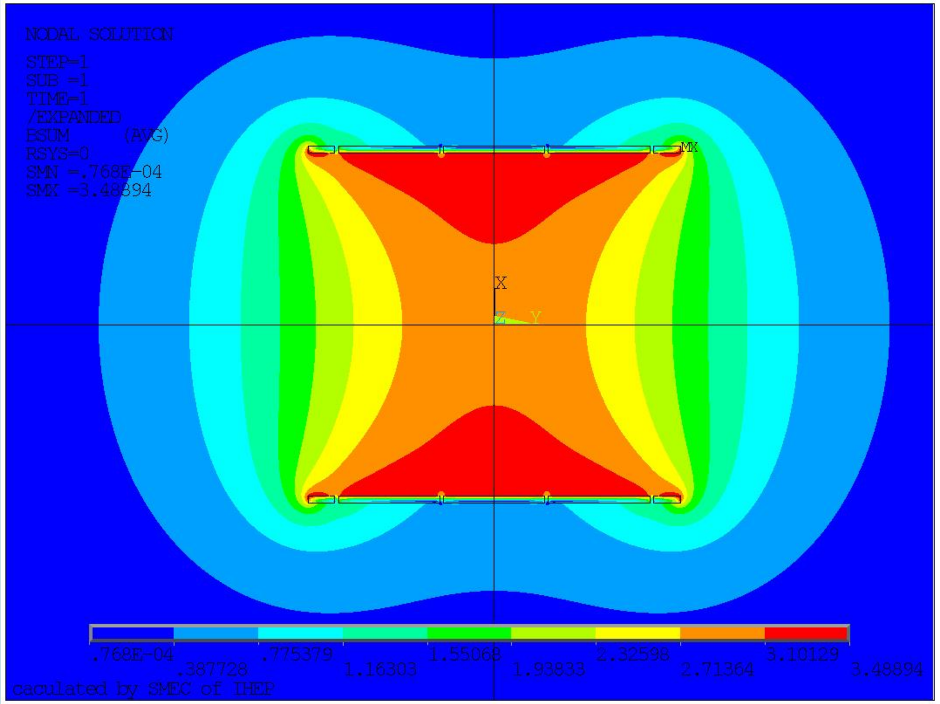
Field design based on the new requirement

- Central field： 3.0T；
- Max field on coil： 3.73T/3.495T；
- Stored energy ： 0.3959GJ/0.40024GJ ；
  Energy-over-mass ratio:34kJ/kg/23kJ/kg;
- Working current： 16956A/11338A；

Two layers coil



three layers coil



Field Distribution

Challenges from new requirements

- High hoopstress on the superconductor because of the higher current density.

  → new structure of the superconductor which can bear the hoopstress.

- Reduce mass of the magnet

  → thin coil, Vacuum vessel with special material or structure.

- Reduce the radial space occupied by magnet.

  → Optimization of supporting structure and cooling line.

- The position of chimney need to be adjusted?

  → one valve box? position? Influence on cooling effect?