Solenoid Magnet and Return Yoke for GLD

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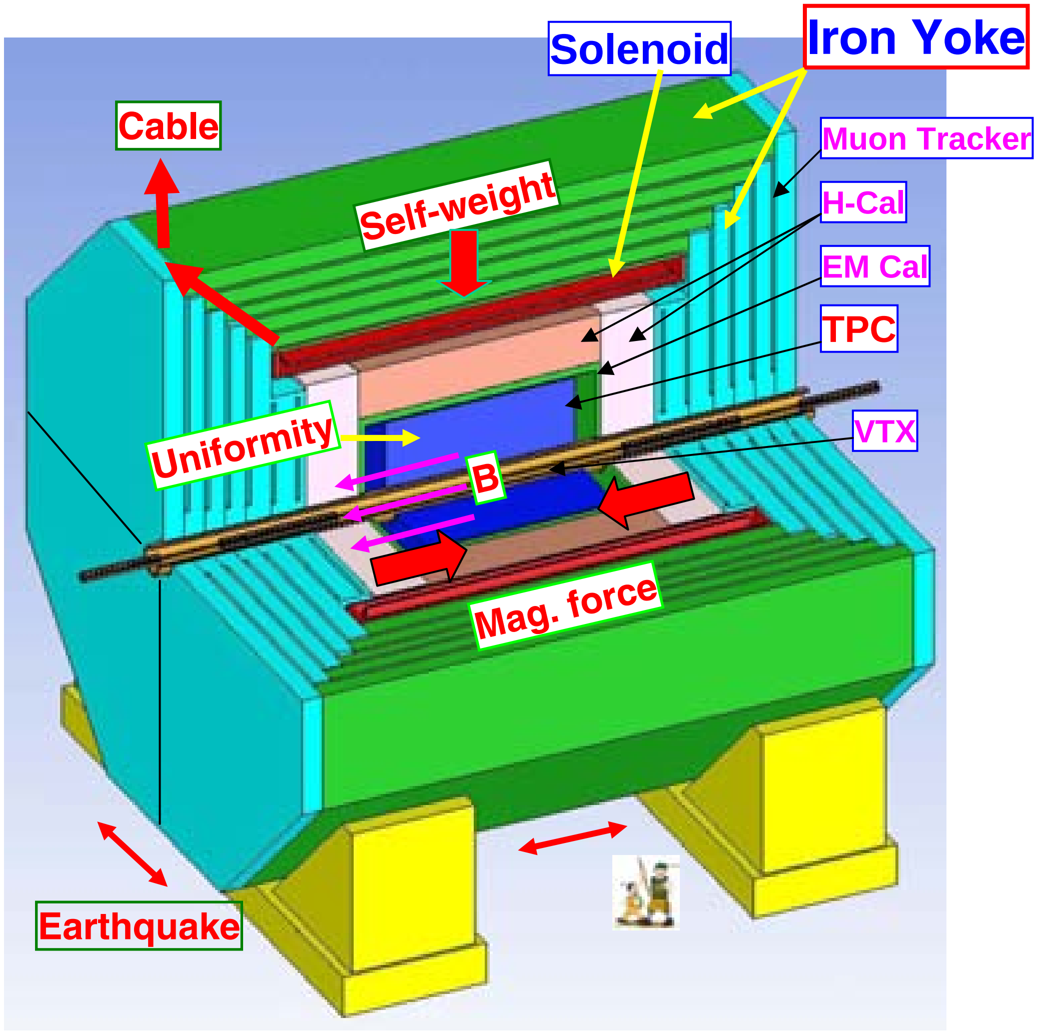
Ken-ichi Tanaka

Introduction



Solenoid/Iron yoke

Magnetic field: 3T

Mean radius: 4m

Uniformity(TPC): <2mm

Yoke Design

- Design against magnetic field
- Design against forces
- Assembly procedure
- Cable path
- Support for sub-detectors
- Access plan to the sub-detector

Solenoid Design

- Coil/superconductor design
- Cryostat design
- Coil support
- Assembly/Installation
- Thermal design
- Cryogenics system

Boundary condition

<u>Magnetic Field</u>

Bc= 3 Tesla

<u>Material: S10C(JIS)</u>

Carbon= 0.1wt%

σ_t=310MPa

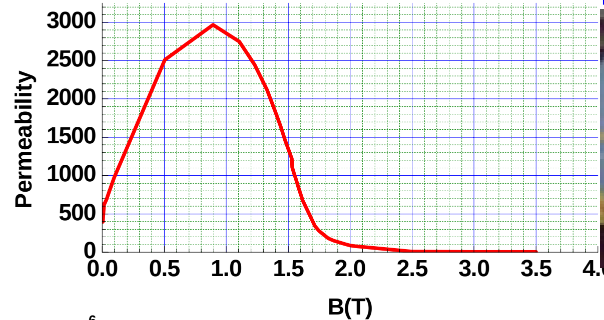
σ_e=205MPa

σ_{allow}=120MPa

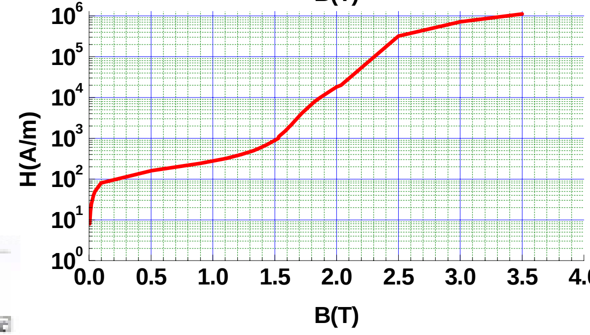
<u>Field Uniformity</u>

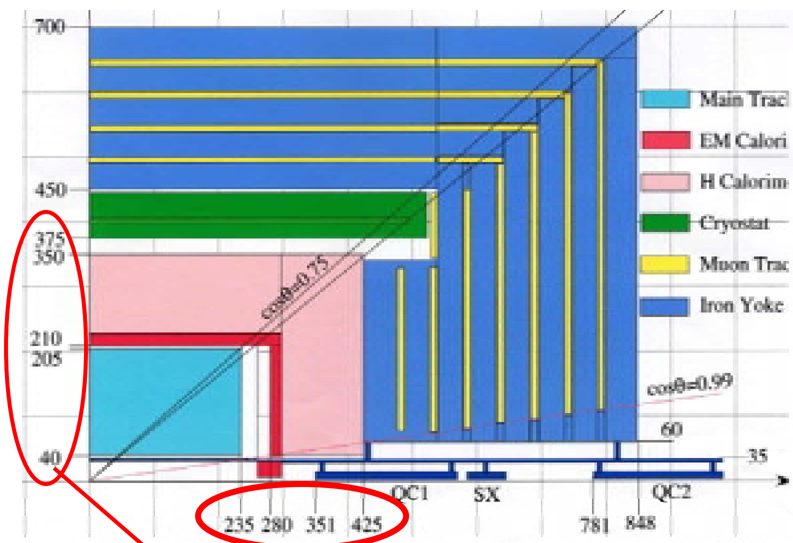
<2mm

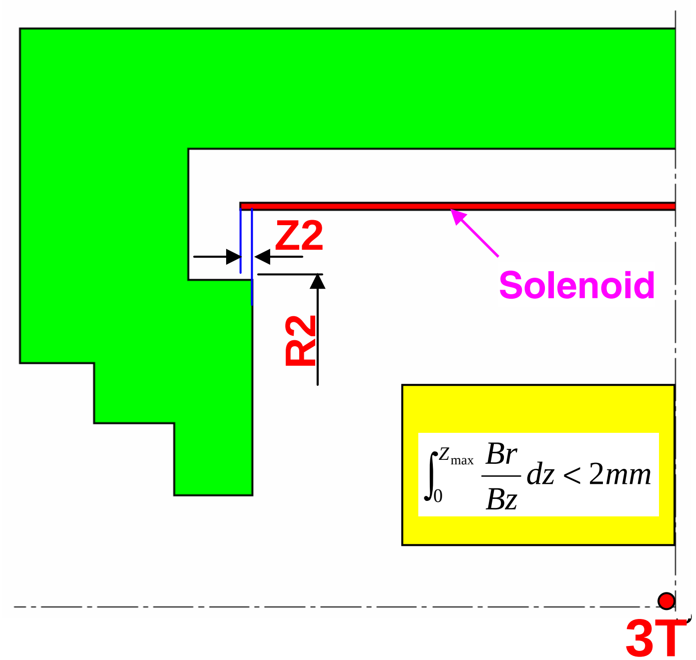
Permeability



Belle

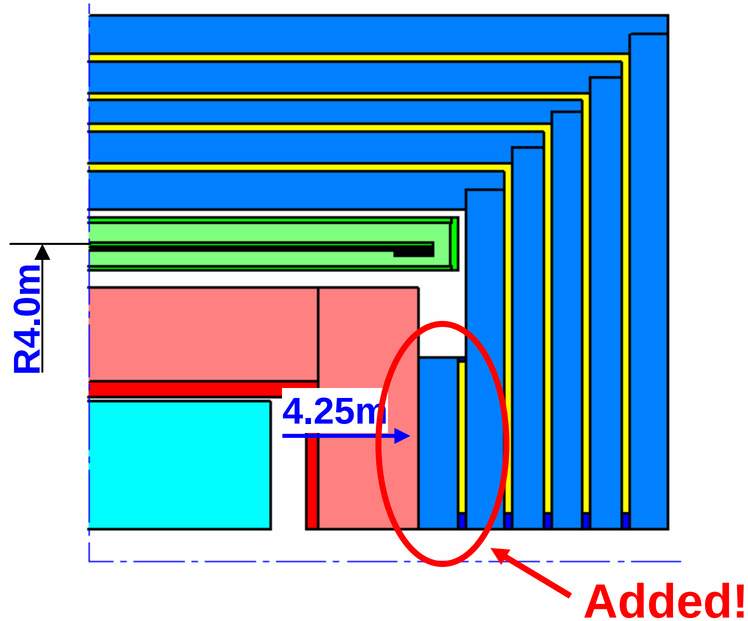


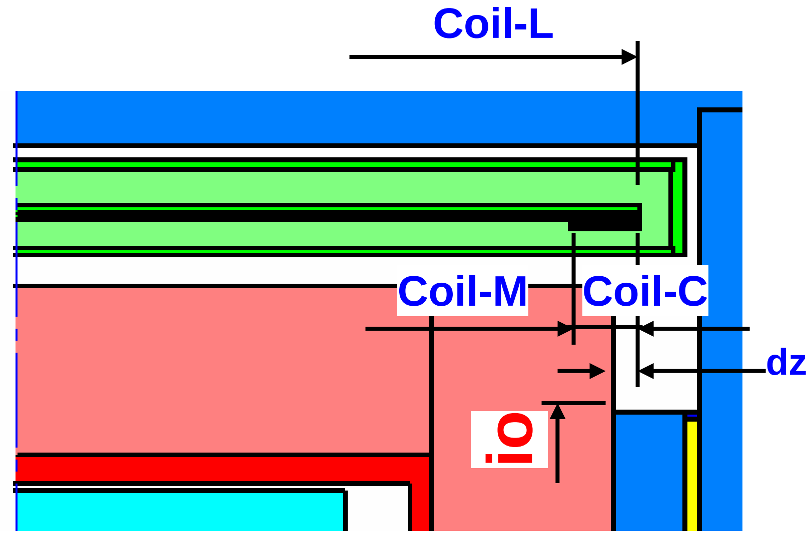




<u>These dimensions are fixed</u>,

Coil length, yoke dimensions are changed.

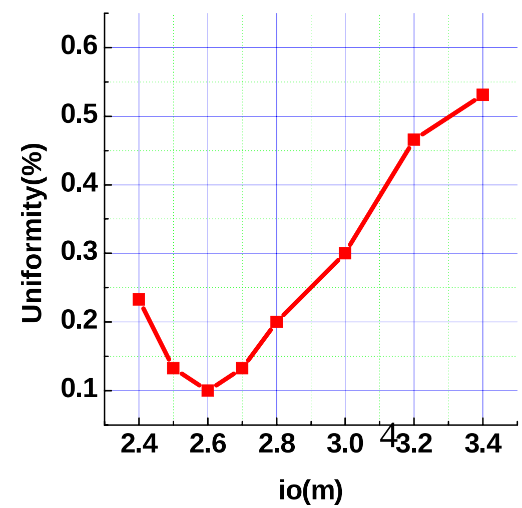




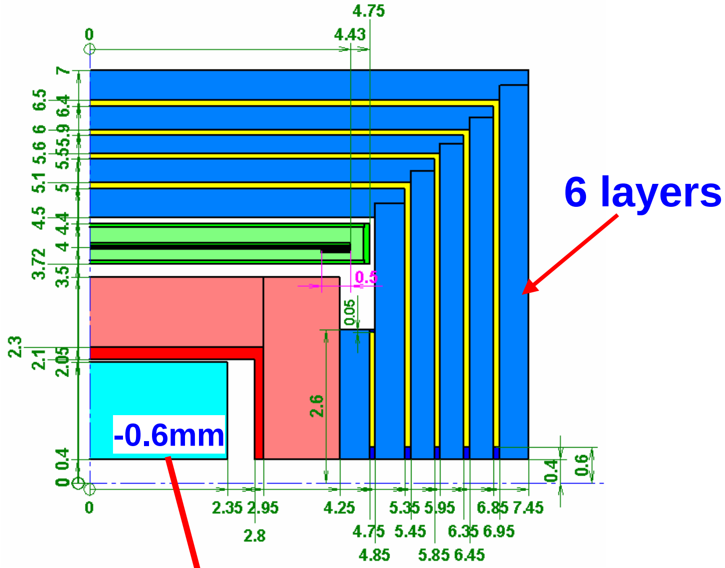
J_{corr}/J_{main}

dr	io	ithck	dz	eyinra	eyinr	Coil-L	CoilL -Main	CoilL-Corr	Ratio	Bmin	Bmax	Bc	Unif
0.4	3.6	0.5	0.18	0.47	0.75	4.43	3.43	1	1.5	2.970	2.998	2.976	0.934
0.4	3.6	0.5	0.18	0.47	0.75	4.43	3.43	1	1.3	2.993	3.040	3.031	1.546
0.4	3.6	0.5	0.18	0.47	0.75	4.43	3.43	1	1.4	3.035	3.067	3.031	1.043
0.4	3.6	0.5	0.18	0.47	0.75	4.43	3.93	0.5	2.0	2.955	2.977	2.960	0.739
0.4	3.6	0.5	0.18	0.4	0.6	4.43	3.93	0.5	2.0	2.957	2.977	2.961	0.672
0.4	3.6	0.5	0.18	0.4	0.6	4.43	3.83	0.6	2.0	2.980	3.018	2.989	1.259
0.4	3.6	0.5	0.18	0.4	0.6	4.43	4.03	0.4	2.0	2.981	3.004	3.000	0.766
0.4	3.6	0.5	0.18	0.4	0.6	4.43	3.98	0.45	2.0	3.001	3.022	3.015	0.695
0.6	3.4	0.5	0.18	0.4	0.6	4.43	3.93	0.5	2.0	2.997	3.013	3.001	0.531
0.8	3.2	0.5	0.18	0.4	0.6	4.43	3.93	0.5	2.0	2.993	3.007	2.996	0.466
1	3	0.5	0.18	0.4	0.6	4.43	3.93	0.5	2.0	2.989	2.998	2.991	0.300
1.2	2.8	0.5	0.18	0.4	0.6	4.43	3.93	0.5	2.0	2.998	3.004	3.000	0.200
1.4	2.6	0.5	0.18	0.4	0.6	4.43	3.93	0.5	2.0	2.995	2.998	2.997	0.100
1.6	2.4	0.5	0.18	0.4	0.6	4.43	3.93	0.5	2.0	2.992	2.999	2.998	0.233
1.5	2.5	0.5	0.18	0.4	0.6	4.43	3.93	0.5	2.0	2.997	3.001	3.000	0.133
1.3	2.7	0.5	0.18	0.4	0.6	4.43	3.93	0.5	2.0	2.998	3.002	2.999	0.133

$$Unif\,(\%) = \left(1 - \frac{B_{min}}{B_{max}}\right) \times 100$$

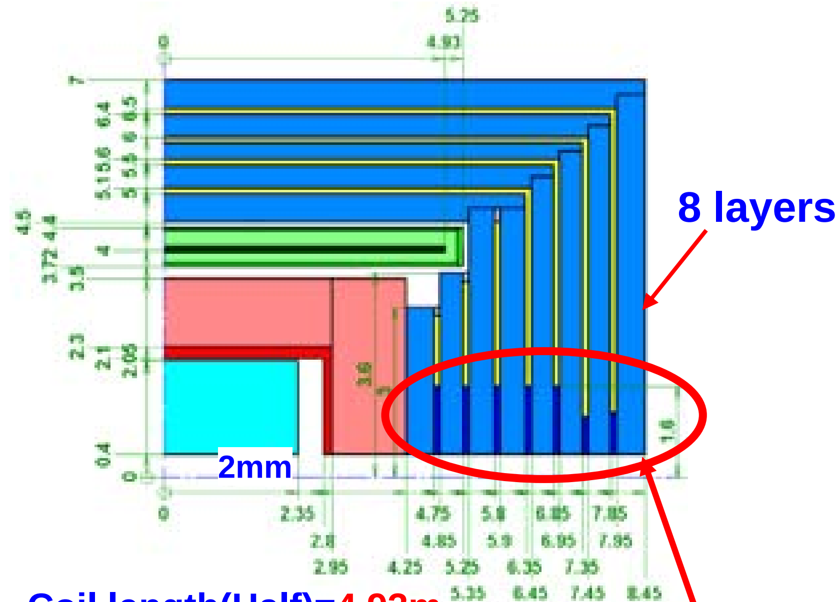


A. Unif.<2mm, With correction Coil

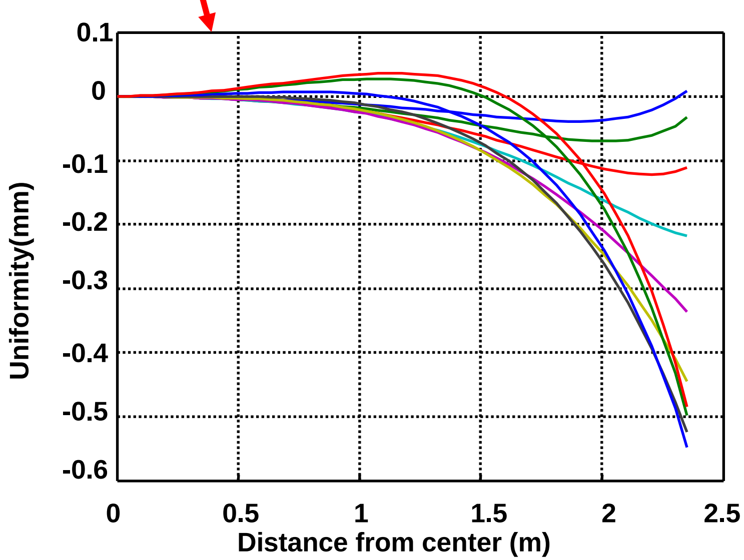


Coil length(Half)=4.43m

A'. Unif.<2mm, No correction Coil

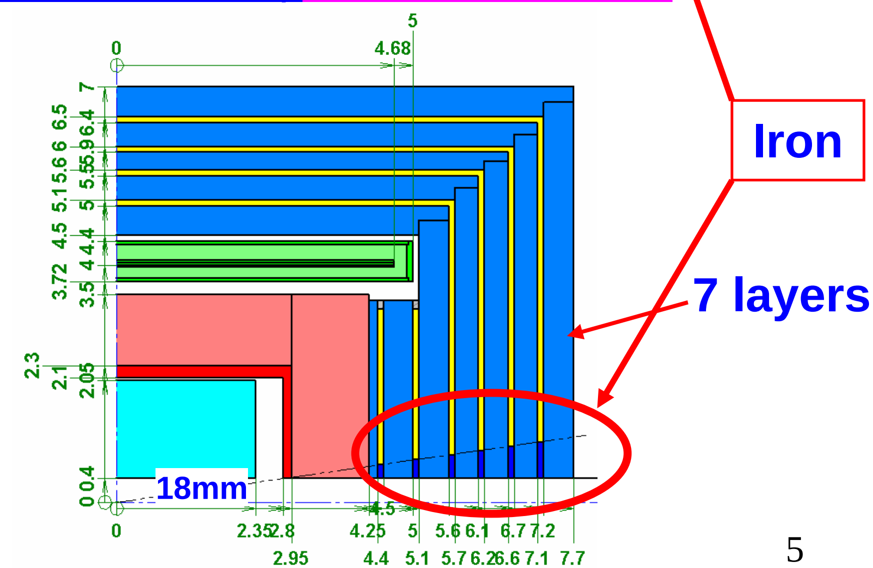


Coil length(Half)=4.93m



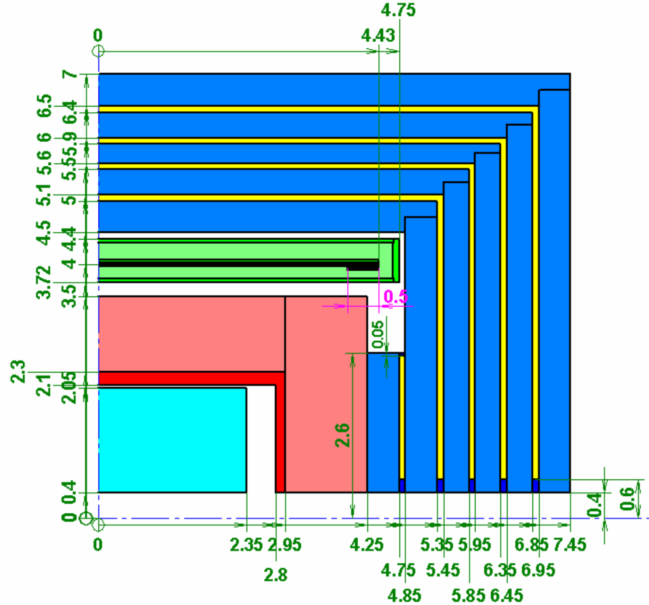
*Air gap=10cm

B. Unif.<20mm, No correction Coil

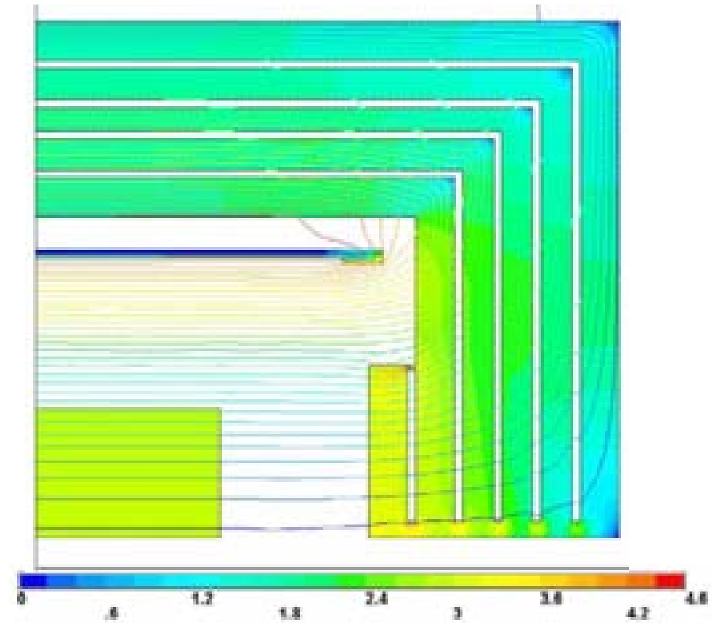


Coil length(Half)=4.68m

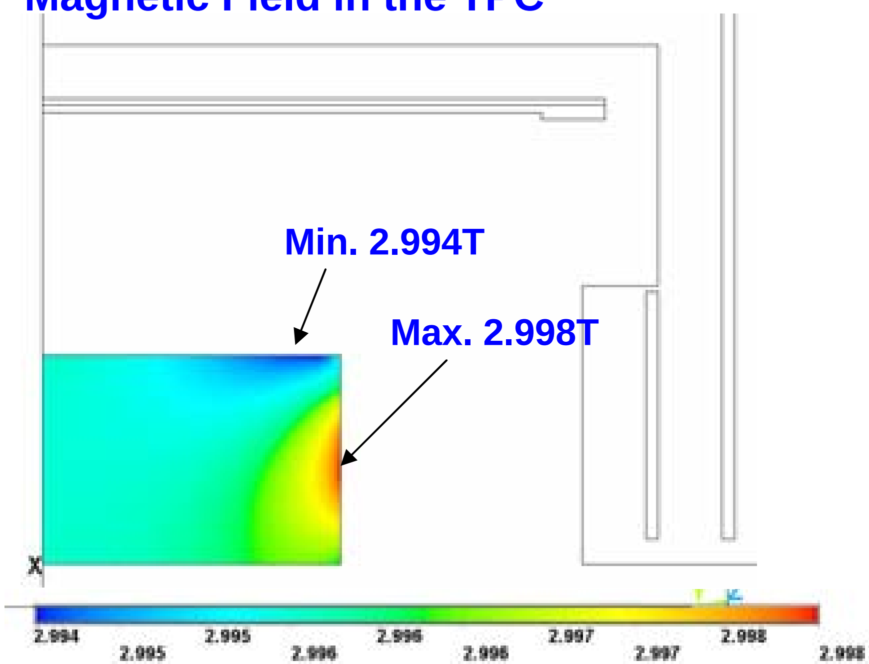
A. Unif.<2mm, With correction Coil, Air gap=10cm



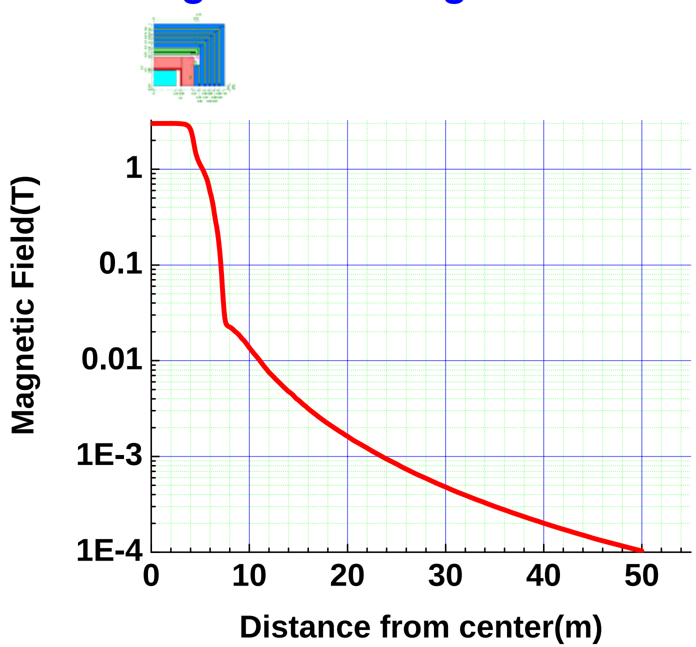
Magnetic Field/Flux lines



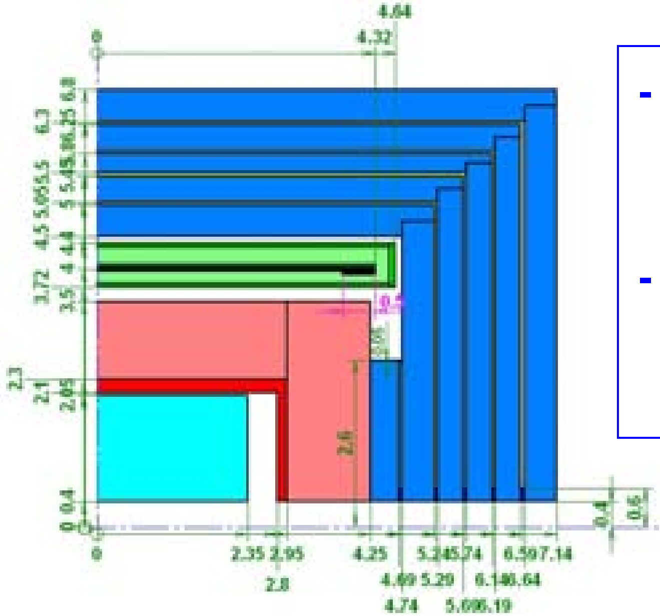
Magnetic Field in the TPC



Leakage Field along the beam line

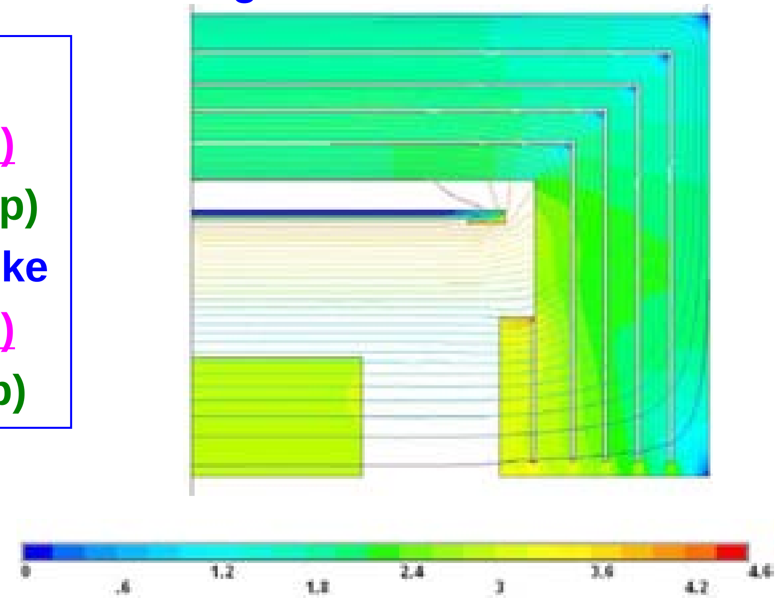


In case of Air gap=5cm + Corr. coil

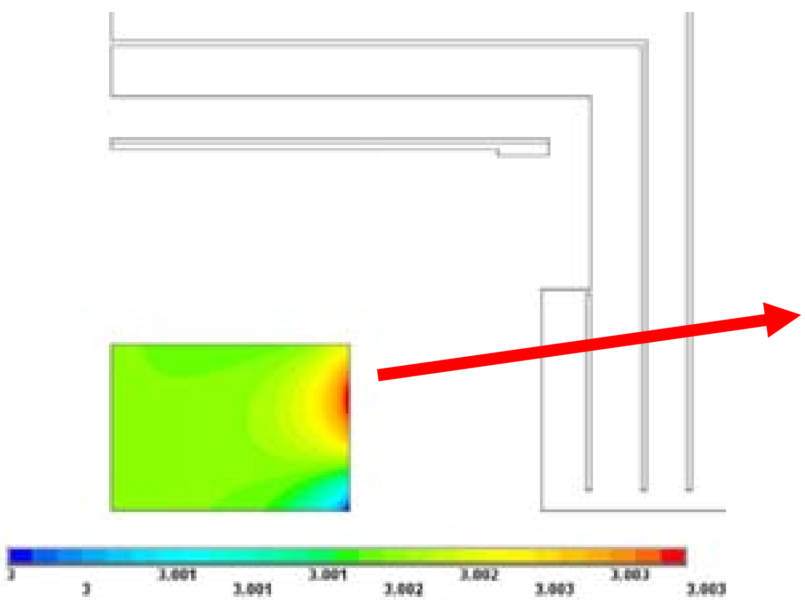


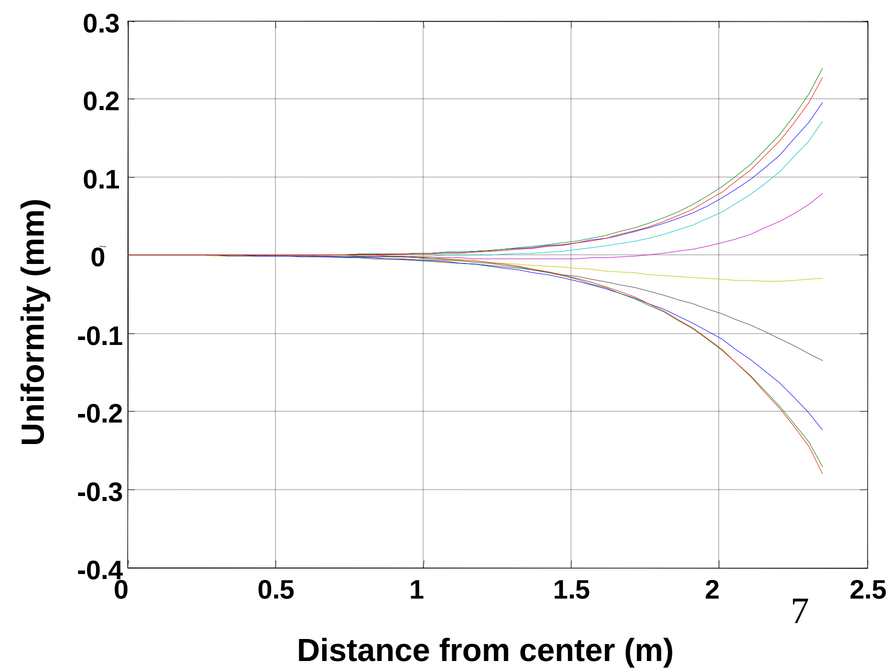
- **Half Coil length:**
  - 4.32m (5cm gap)
  - 4.43m (10cm gap)
- **Width of Iron Yoke**
  - 7.14m (5cm gap)
  - 7.45m (10cm gap)

Magnetic Field/Flux lines

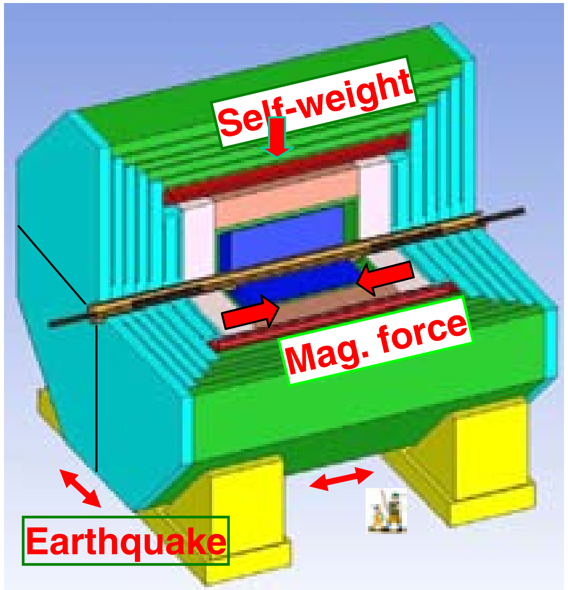


Magnetic Field in the TPC

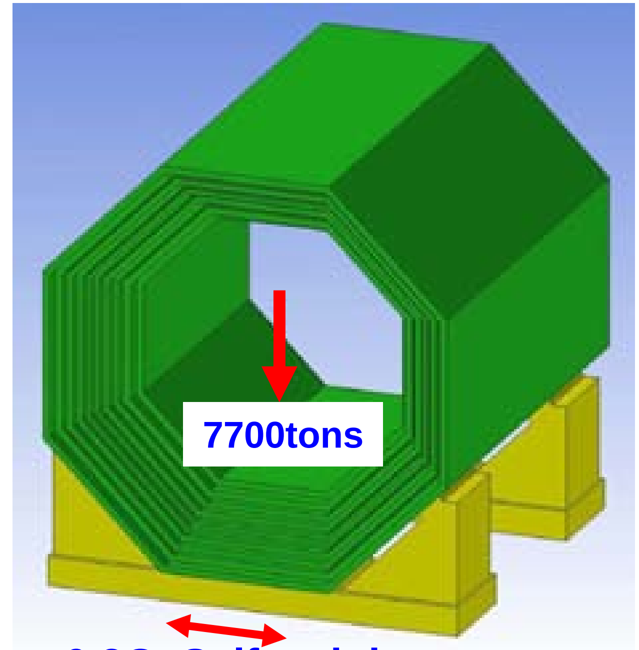




Stress/deformation of Iron Yoke

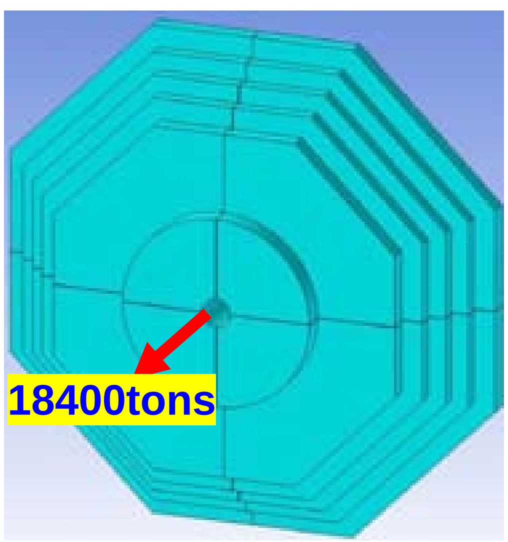


Self-weight
Seismic force



0.3GxSelf-weight

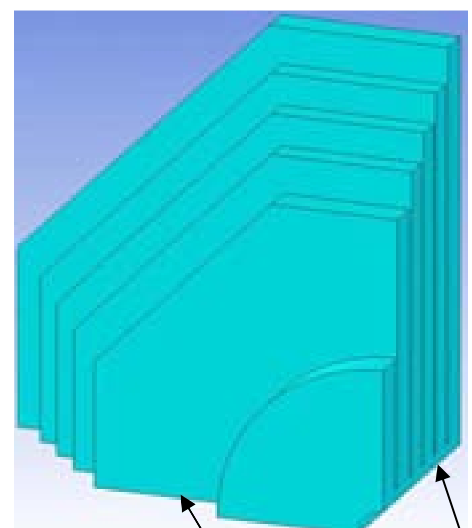
Magnetic force



$$F_z = \frac{B^2}{2\mu_0} \cdot S$$
$$= \frac{3^2}{2 \times 4\pi \times 10^{-7}} \cdot \frac{\pi}{4} \cdot 8^2$$

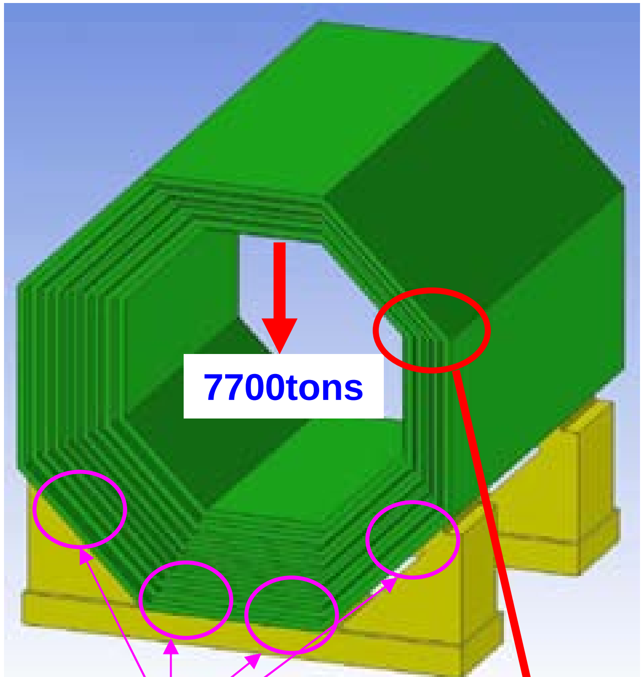
= <u>18400tons</u>

ANSYS: <u>18342tons</u>

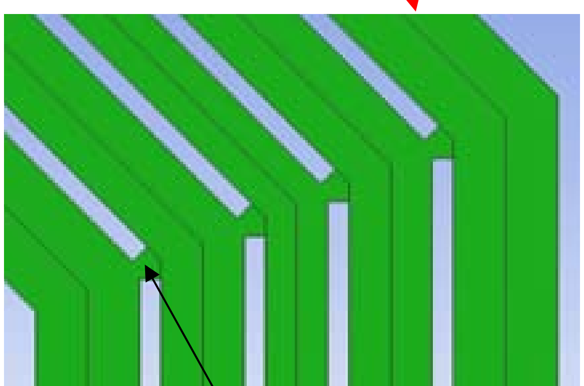


<u>Symmetry is NOT defined!</u>

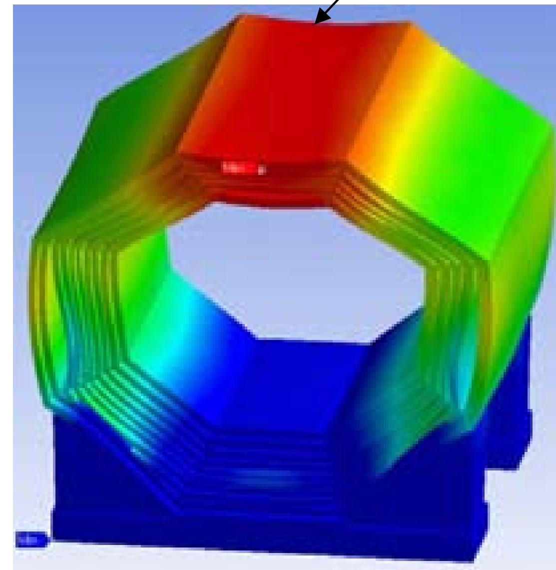
Results



Support positions

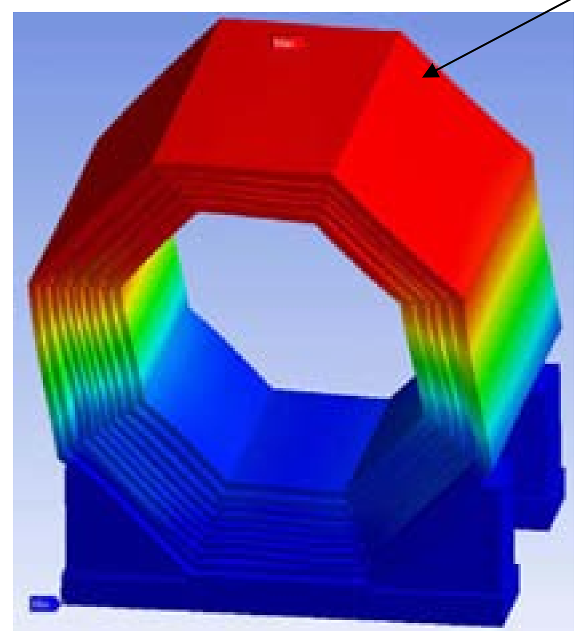


Thickness= 5cm



0.8mm

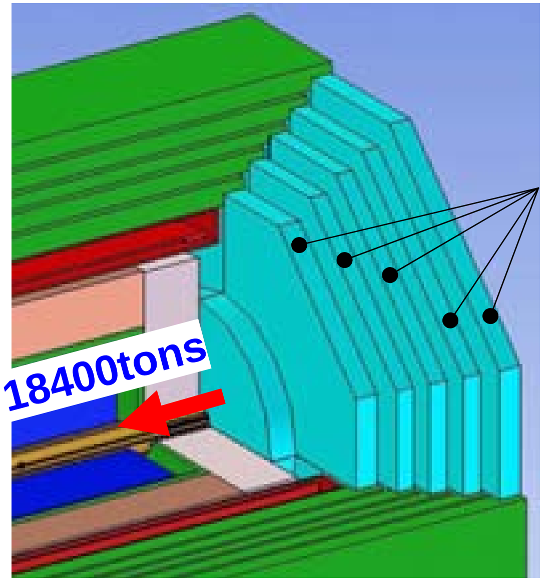
1.5mm



0.3G

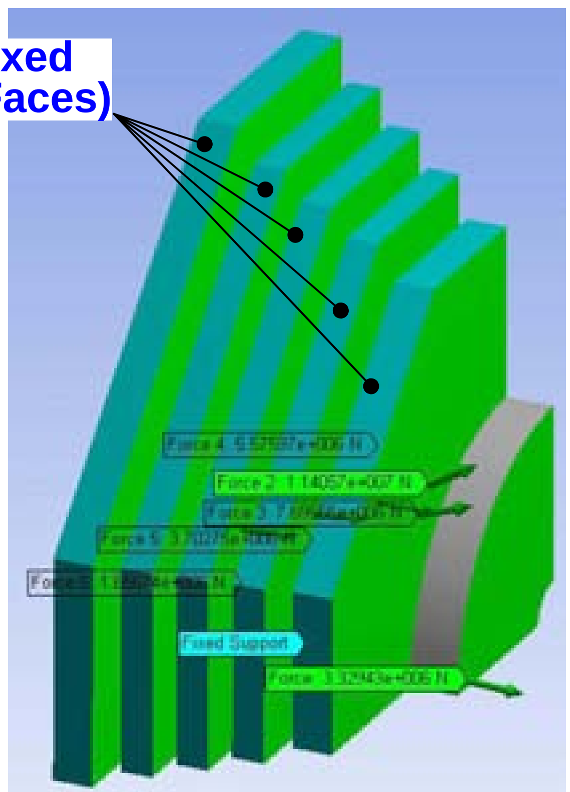
Stress level is small enough.

End Yoke

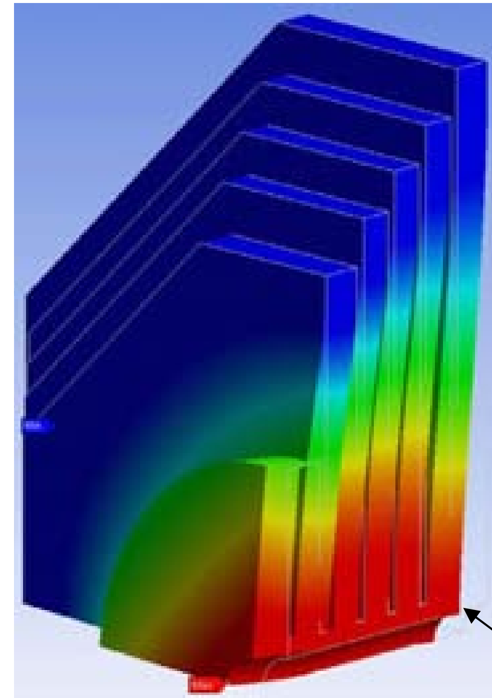


Fixed
(Faces)

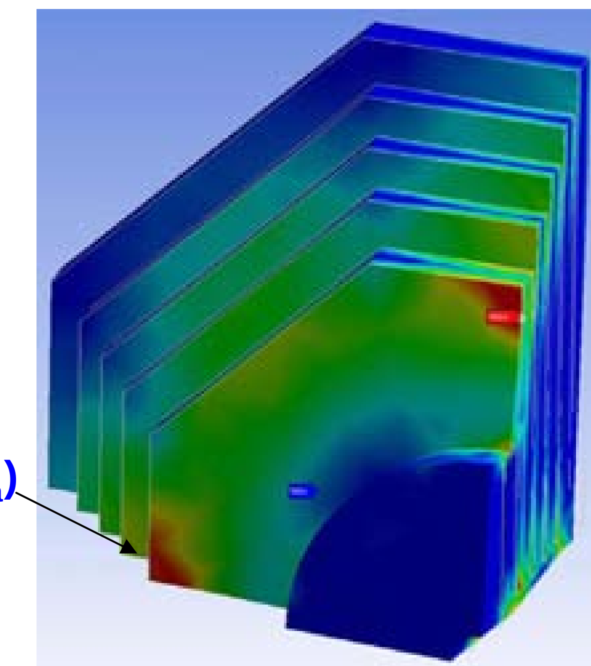
Fixed
(Faces)



Results



4mm



55MPa

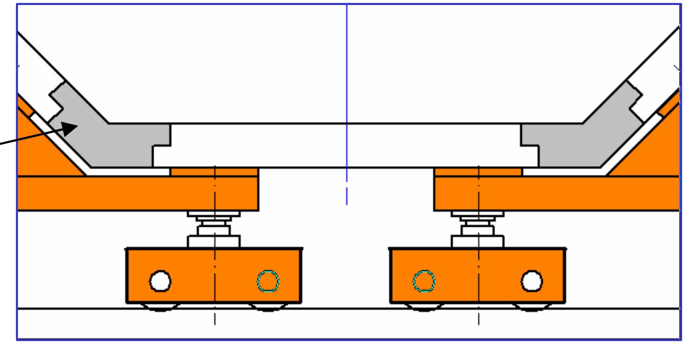
<120MPa(σ_a)

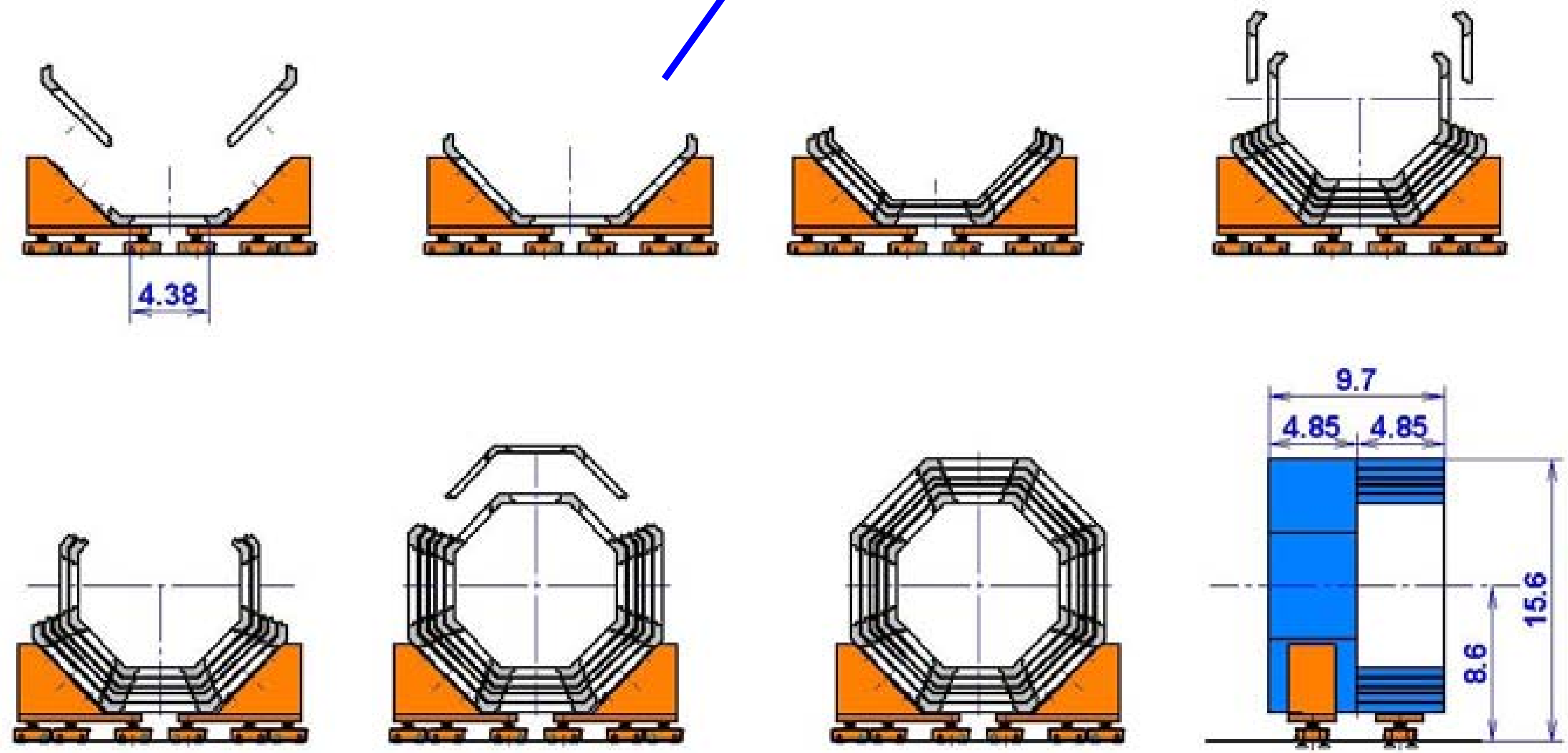
Assembling procedure

Barrel Yoke

Iron plates to be bolted on the support frame

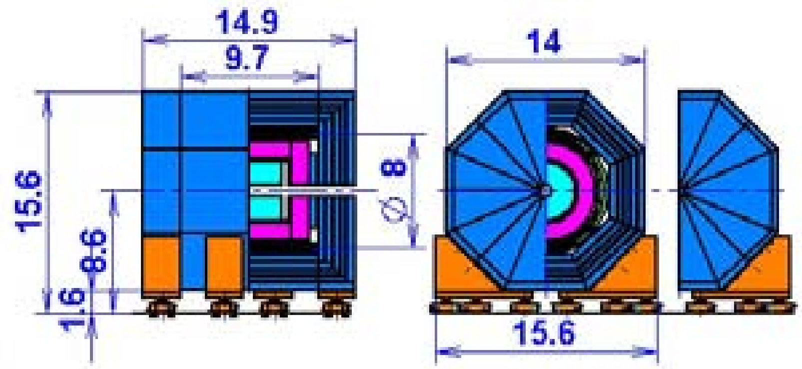
Support jig at each corners



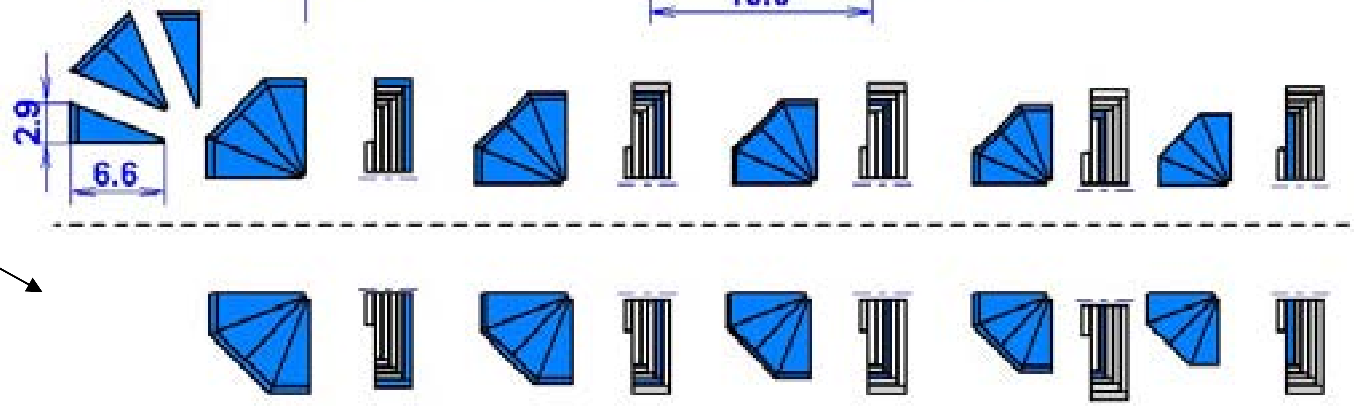


End Yoke

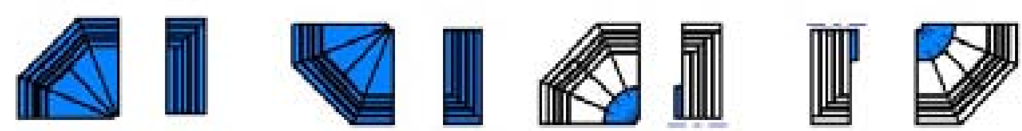
Transportation limit
3.2W x 12m Length



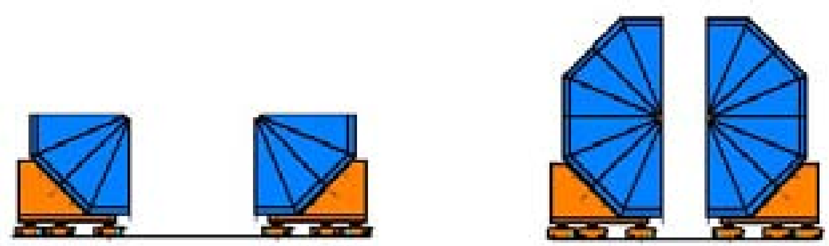
Iron plates (Blue parts) are assembled by welding.



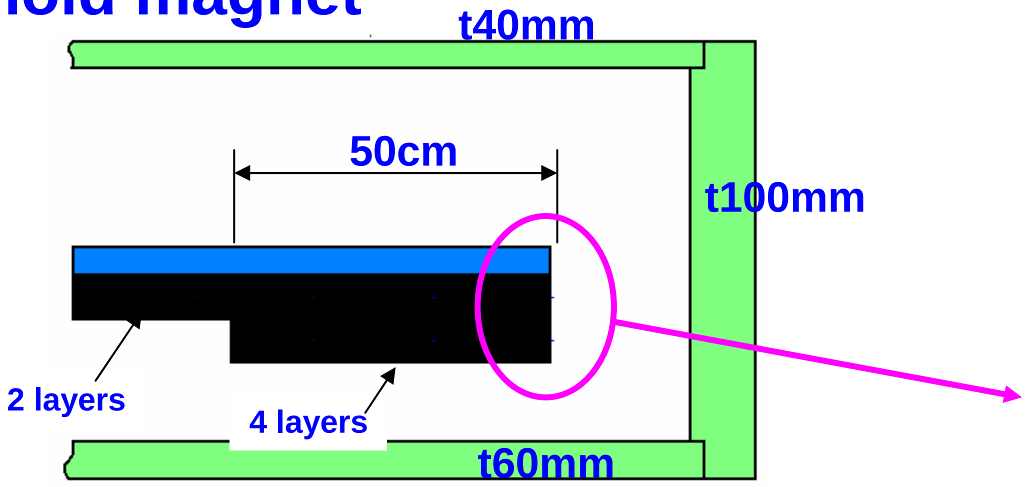
Upper/Lower end yoke is ssembled by welding.

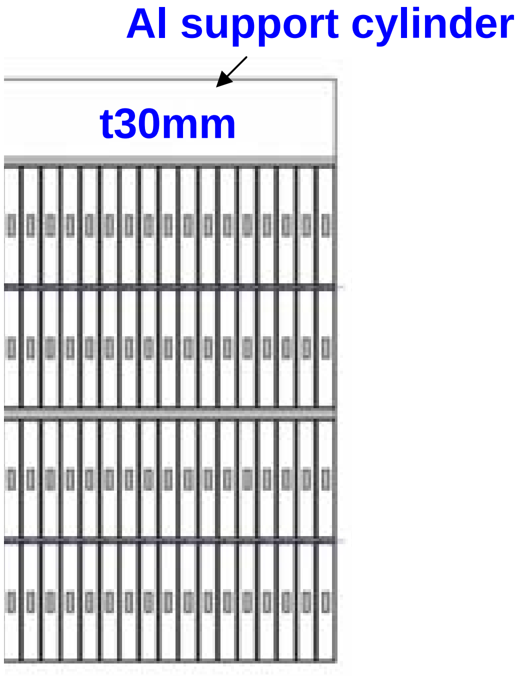


Put them on the support stand



Solenoid magnet

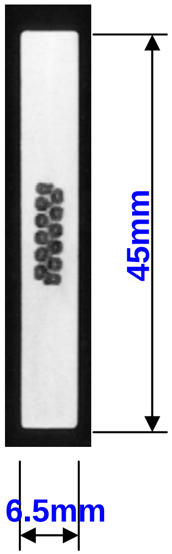




2 layers coil + Correction Coil(4 layers)

Config.		2 layer+Correction Coil	
Air Gap		10cm	5cm
Uniformity(mm)		(-0.55) - 0	(-0.3) - (+0.25)
Cryostat	Inner radius	3.72m	3.72m
	Outer radius	4.4m	4.4m
	Half length	4.75m	4.64m
	Weight(tons)	191	186
Coil	Mean radius	4.0m	4.0m
	Half length	4.43m	4.32m
	Weight(tons)	78	76
Central magnetic field		3T	3T
# of turns(2 layers)		2880	2812
Current density		741A/mm^2	741A/mm^2
Nominal current		7956A	8159A
Stored Energy		1.60GJ	1.56GJ

Superconductor



(Based on ATLAS coil)

NbTi:Cu:Al= 1:0.9:15.6

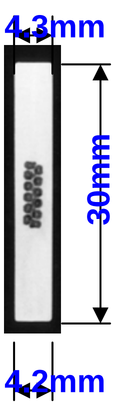
Strand diameter: 1.23mm

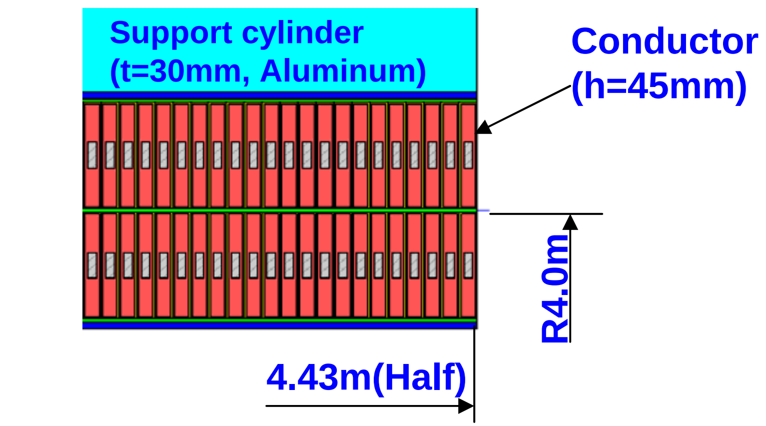
Filament diameter: 20μm

Jc in NbTi at 5T, 4.2K:

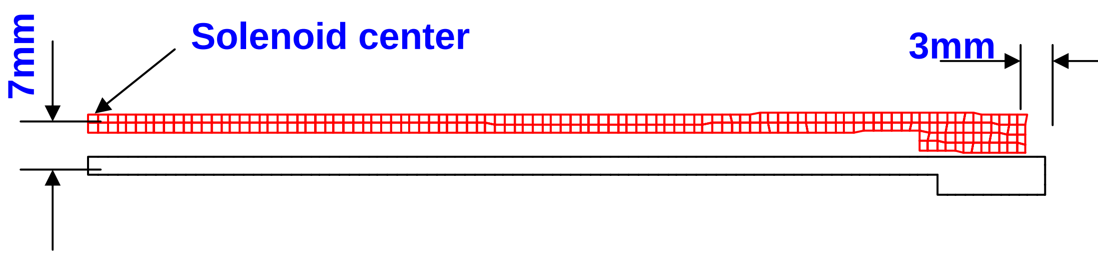
> 2750A/mm^2

Ic at 5T, 4.2K: > 20300A

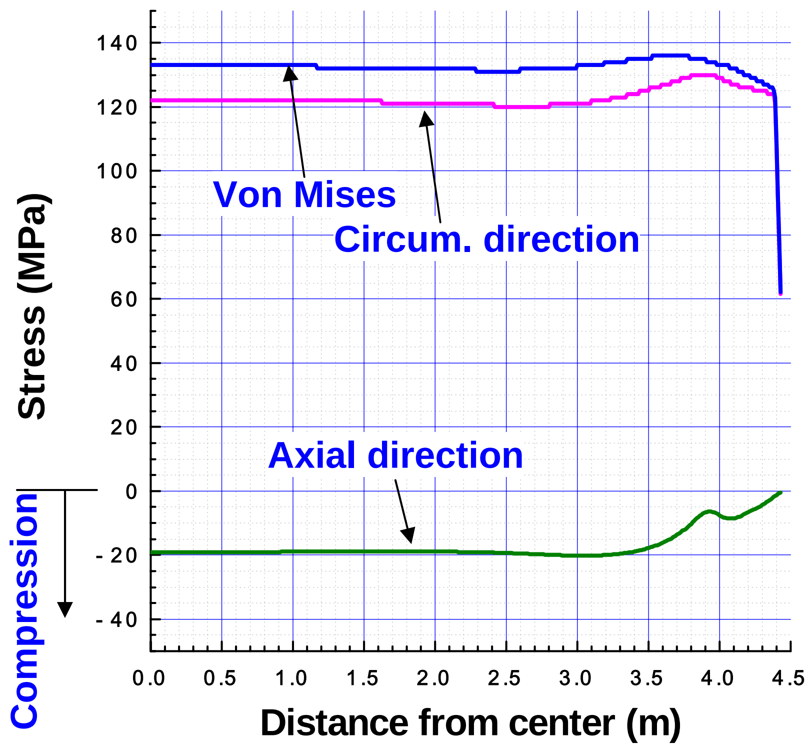




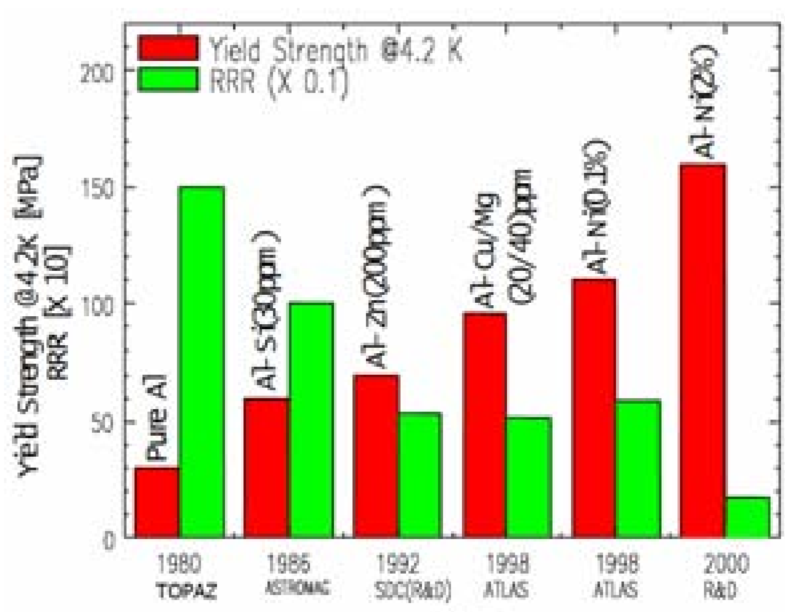
Deformation of the coil (By K.Tanaka)



Stress level in the coil (By K. Tanaka)



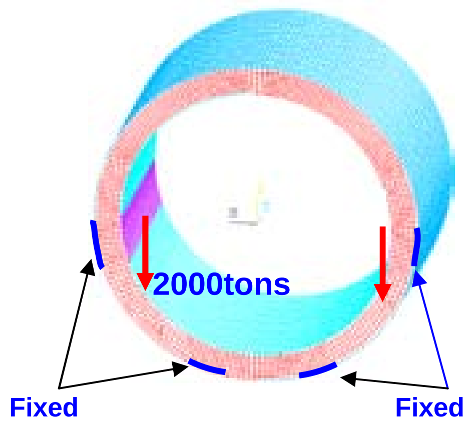
Development of High-strength Al

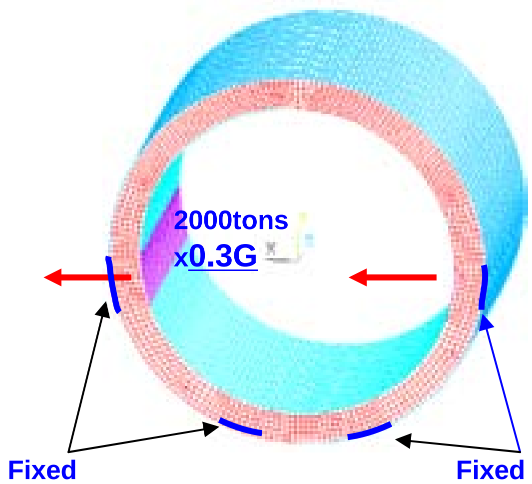


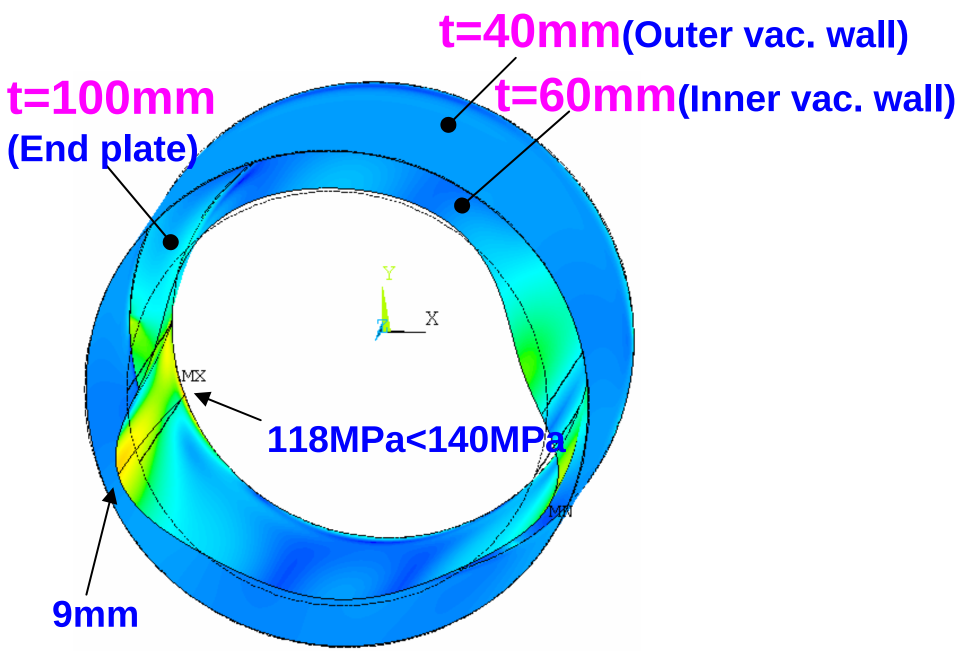
By Makida

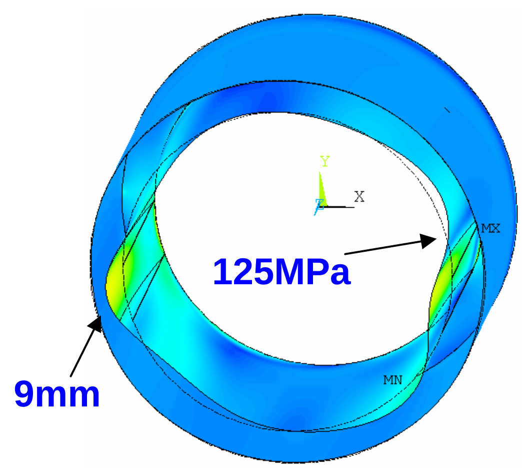
Cryostat

Material: SUS304







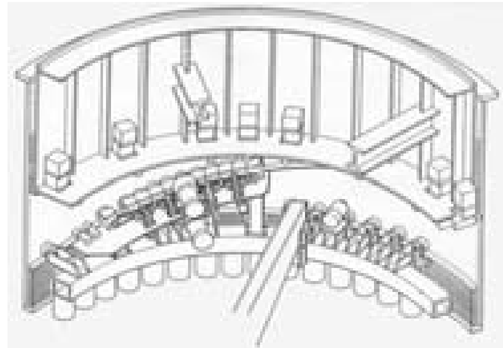


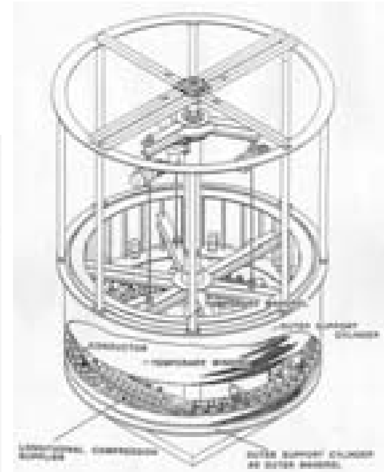
Assembly procedure

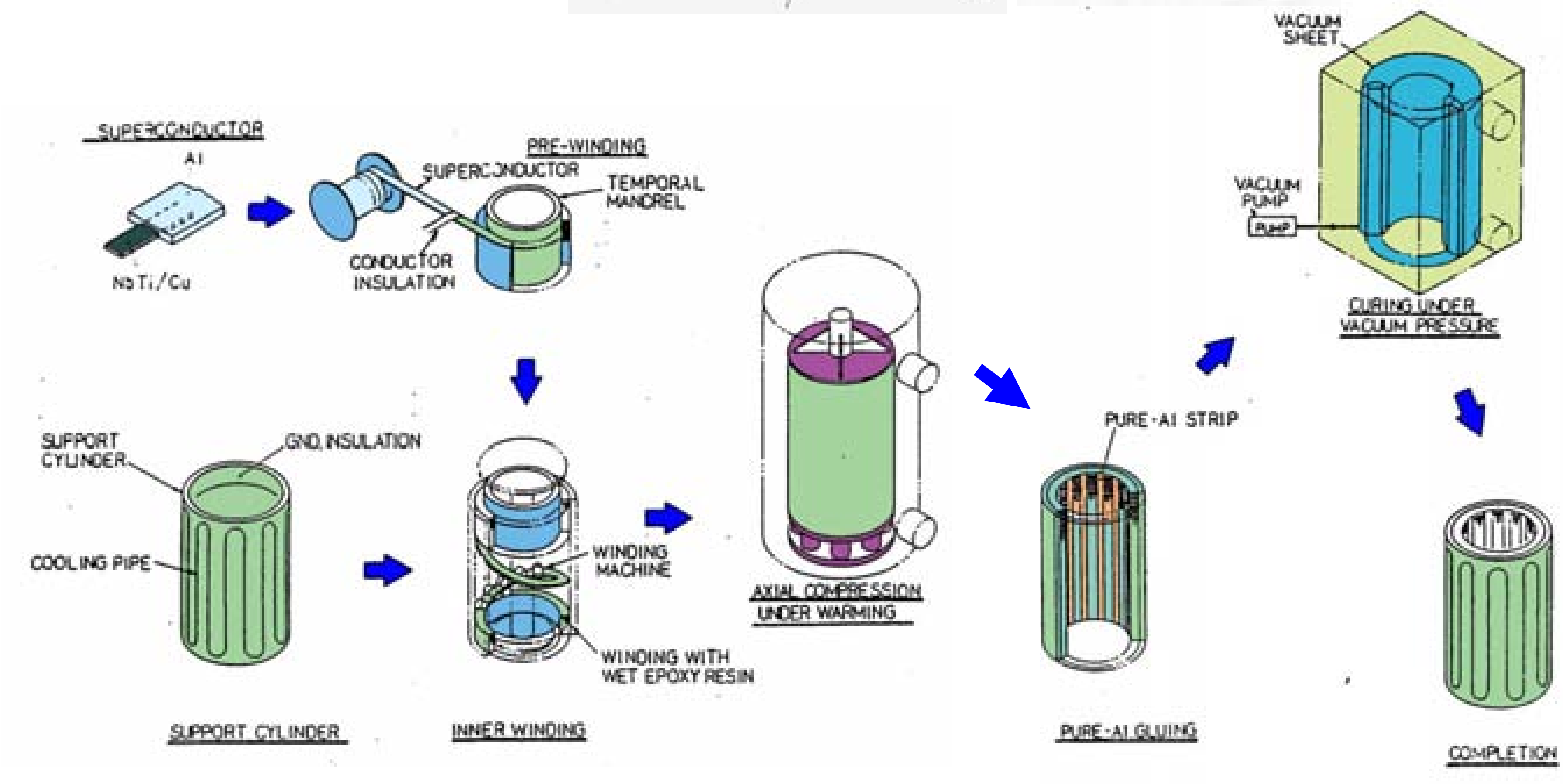
Coil assembly process

Winding Machine

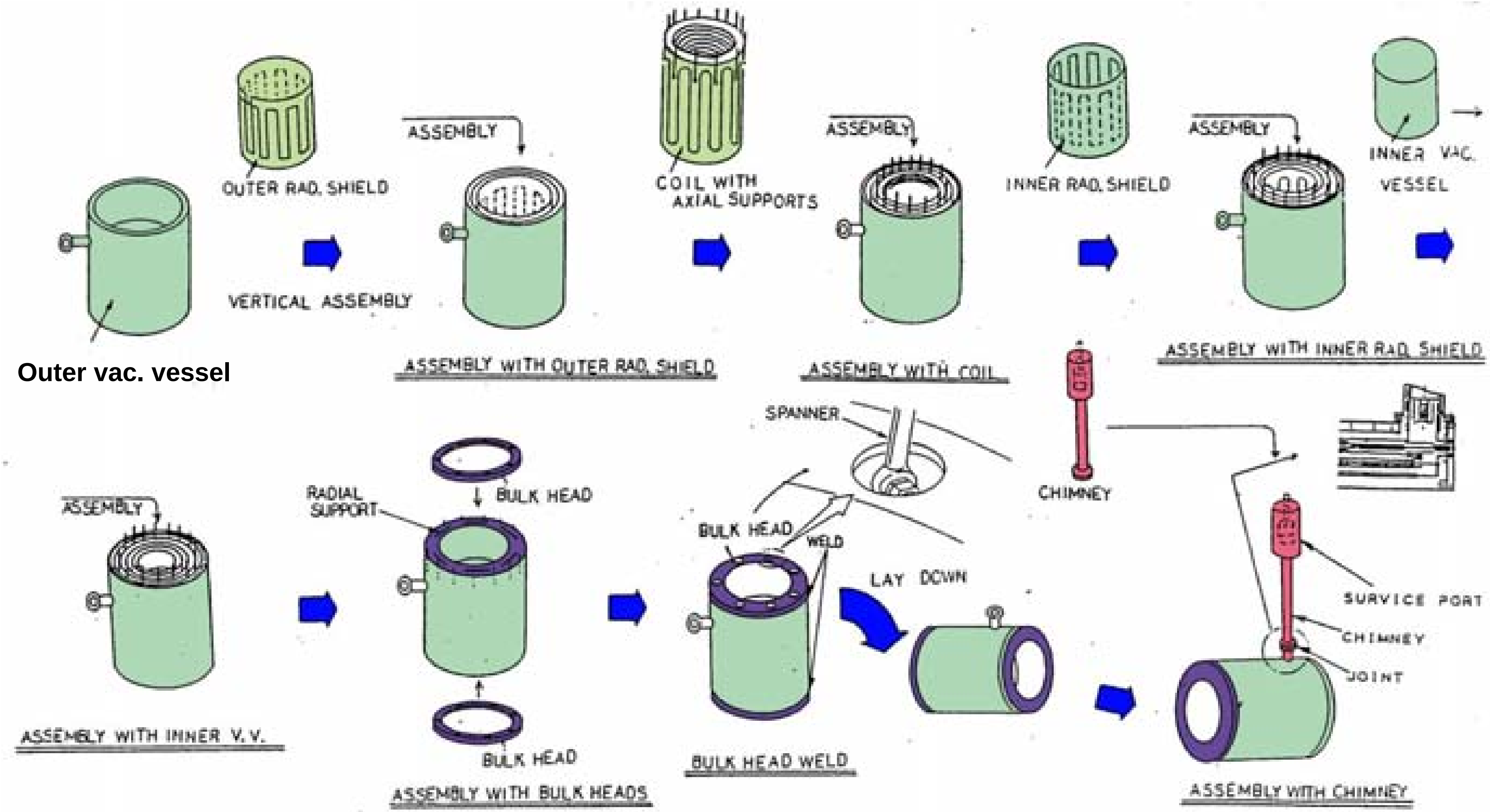
Reference:
SDC
Thin superconducting solenoid view graphs for the DOE review presentation
Oct. 26-27, '92







Magnet assembly process



Outer vac. vessel

Reference:
SDC
Thin superconducting solenoid view graphs for the DOE review presentation
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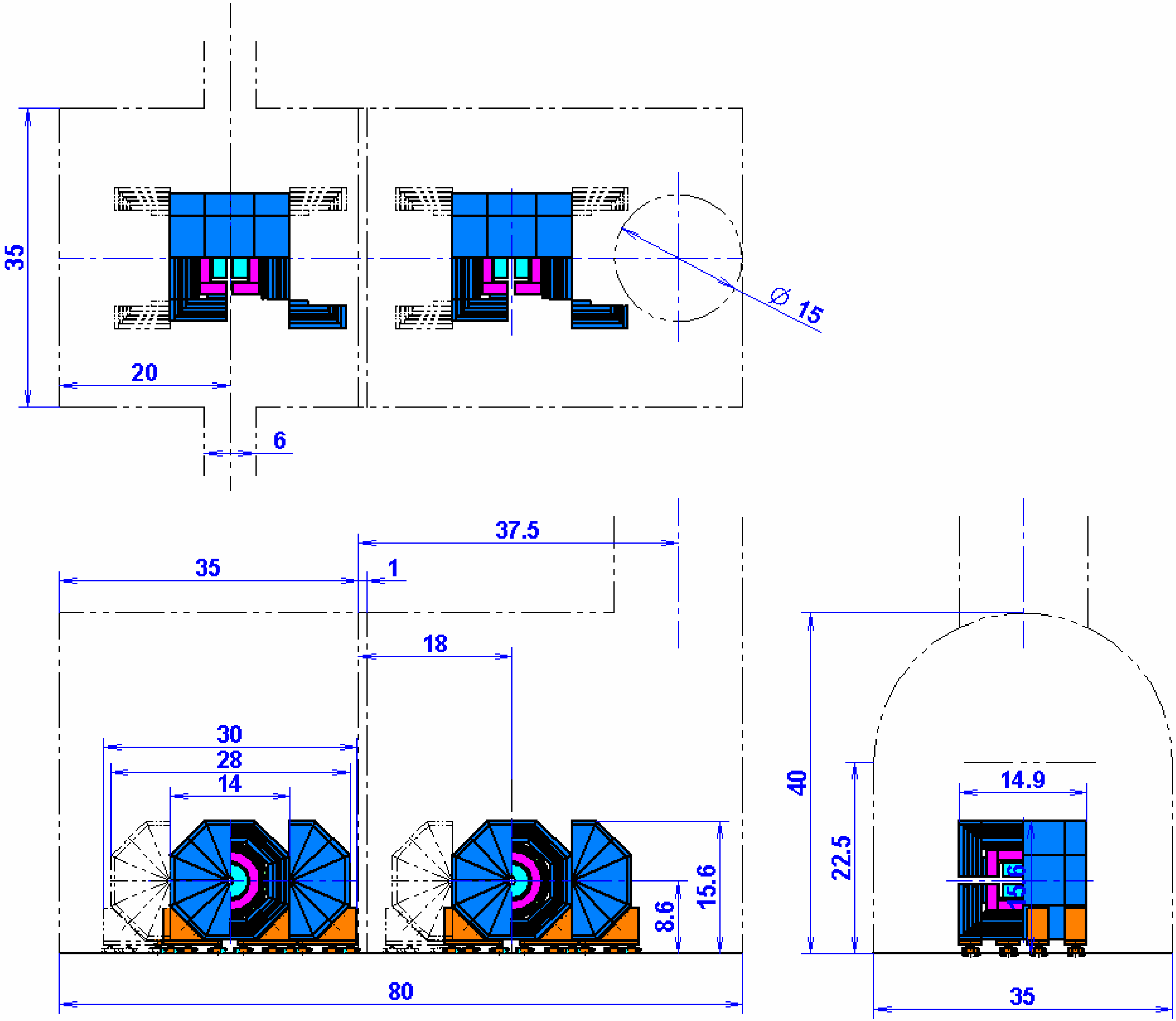

35
20
6
Ø 15
37.5
35
1
18
30
28
14
8.6
15.6
80
40
22.5
14.9
15.6
35

Cost Estimates

Reference: M.A.Green, S.J.St.Lorant, “**Estimating the Cost of Large Superconducting Thin Solenoid Magnets**”, Advances in Cryogenic Engineering, 39A,pp. 271-pp.276, Plenum Press, New York(1991)

Solenoid magnet

$C1(m\$)=0.458\times[E(MJ)]^{0.700}$

$= 0.458\times 1600^{0.7000}$

$= 80$ M$

= 9 billion Yen

E(MJ): Stored energy

Chosen!!

$C2(m\$)=0.376\times[G(T\cdot m^3)]^{0.655}$

$= 0.376\times(3\times\pi/4\times 8^2\times 8.83)^{0.655}$

$= 42$ M$

=5 BYen

G(T· m3): TeslaxVolume

$C3(m\$)=0.559\times[M(tons)]^{0.719}$

$= 0.599\times(78+191)^{0.719}$

$= 34$ M$

= 4 BYen

M(tons): Weight(Coil+Cryostat)

$CR(m\$)^{2)} = 1.51\times[R(kW)]^{0.7}$

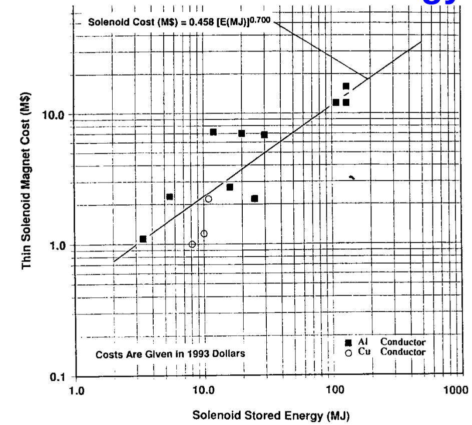
Total Cost

9 BYen + 1BYen(Refrigerators + alpha)

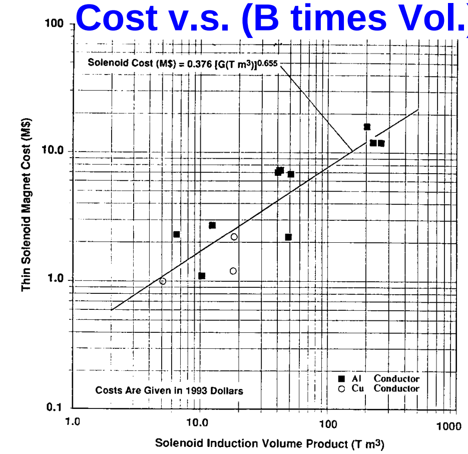
= 10BYen (85M$)

2): M.A.Green, R.A.Byrns, S.J.St.Lorant, “**Estimating the Cost of Superconducting Magnets and the Refrigerators needed to keep them cold**”, Advances in Cryogenic Engineering, 37A,pp. 637-pp.643, Plenum Press, New York(1991)

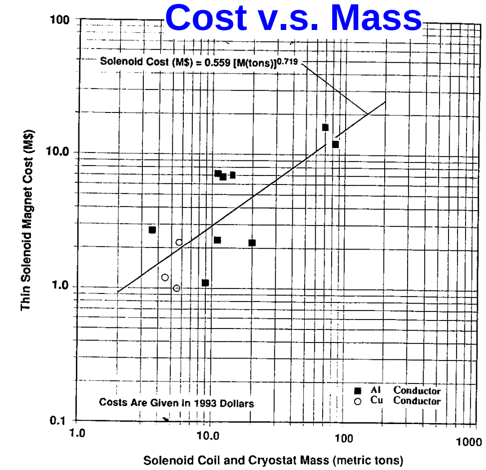
Cost v.s. Stored energy



Cost v.s. (B times Vol.)



Cost v.s. Mass



Return Yoke

○ Law material

\180/kg x 14900e3kg = 2.7BYen

2.7 x 1.2(+alpha) = 3BYen

○ Machining

Total area for machining of Barrel yoke

400m^2

End Yoke:

661m^2

Machining cost per 1m^2

\200,000/m^2

Total:

(400+601)m^{2}x \200,000/m^2 = 0.2BYen

0.2 x 1.2(+alpha) = 0.24BYen

○ Design cost

0.1BYen

○ Cost for Quality Control

50 MYen

○ Profit

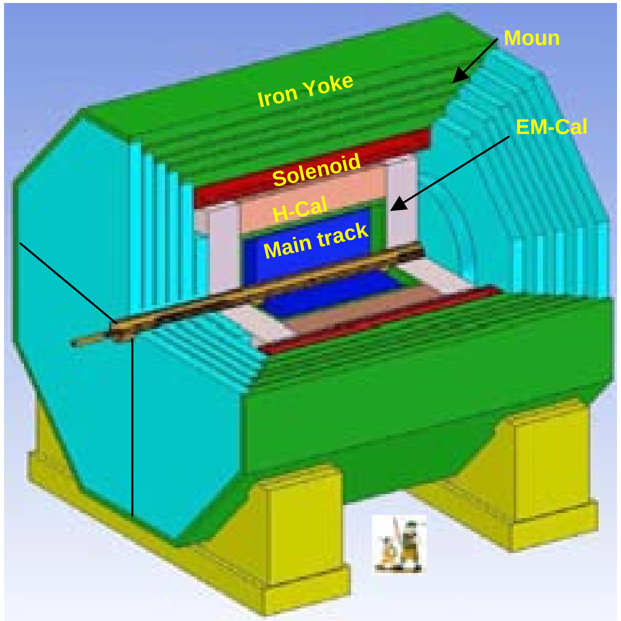
20%

3.24BYenx0.2= 1BYen

Total

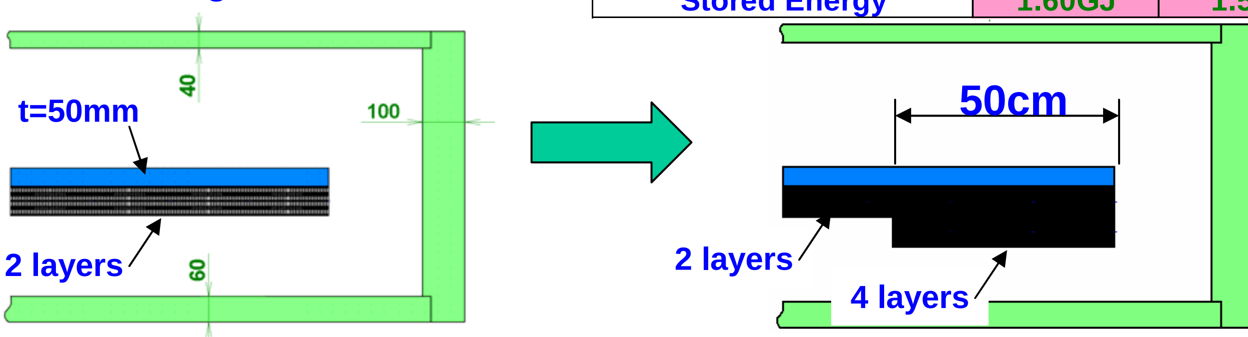
4BYen(35M$)

Conclusion



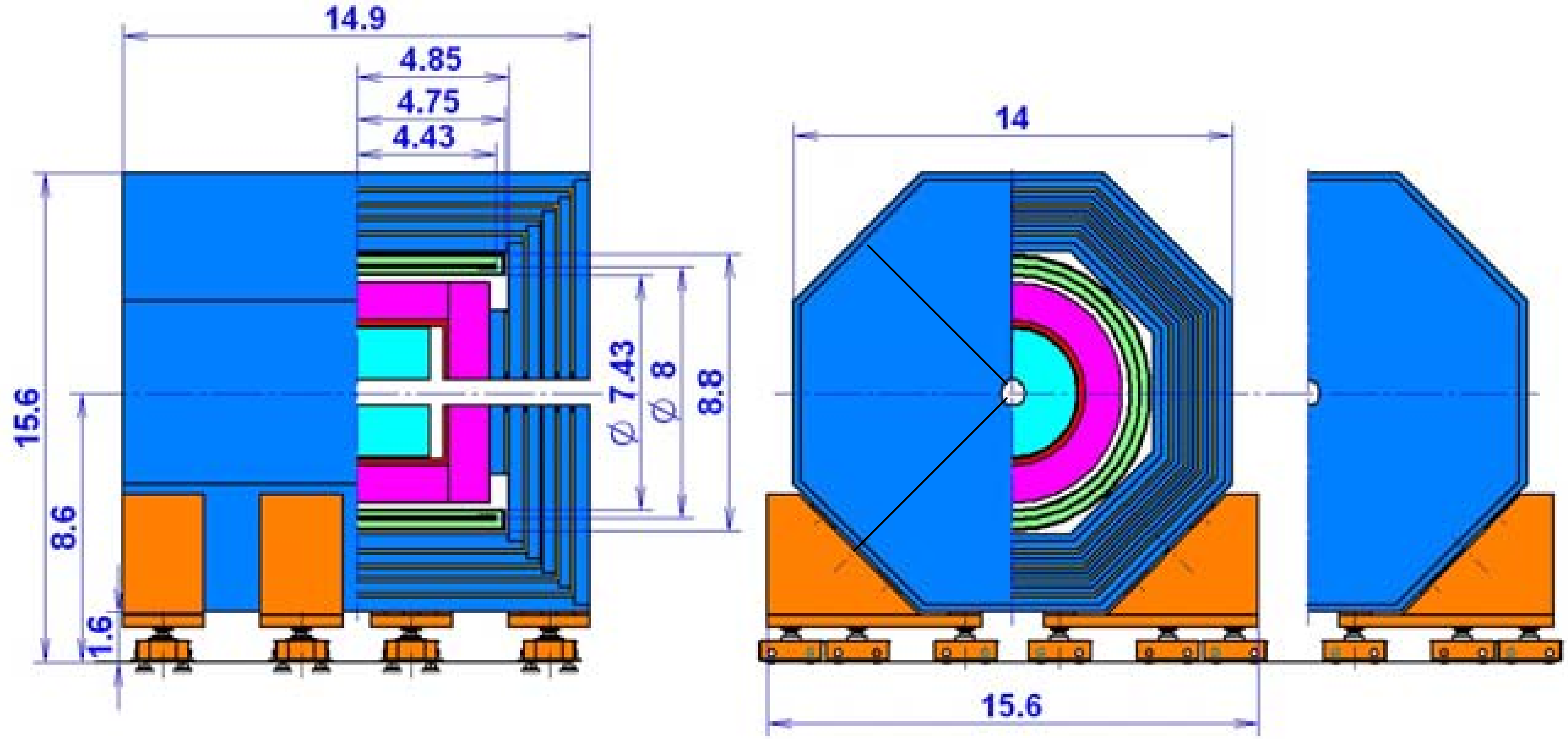
Config.		2mm+Corr. Coil		2mm+No Corr	20mm+No corr
Air Gap		10cm	5cm	10cm	
Uniformity(mm)		(-0.55) - 0	(-0.3) - (+0.25)	(+0.2) - (+2)	(+4) - (+18)
Yoke	Barrel	5 layers	5 layers	5 layers	5 layers
	End	6 layers	6 layers	8 layers	7 layers
	Width(Half)	7.45m	7.14m	8.45m	7.7m
	B.Yoke(tons)	7900	7600	9100	7950
	E.Yoke(tons)	2000x2	2000x2	2450x2	2250x2
	Detector(tons)	3000	3000	3000	3000
	Total(tons)	14900	14600	17000	15450
Cryostat	Inner radius	3.72m	3.72m	3.72m	3.72m
	Outer radius	4.4m	4.4m	4.4m	4.4m
	Half length	4.75m	4.64m	5.25m	5.0m
	Weight(tons)	191	186	211	201
Coil	Mean radius	4.0m	4.0m	4.0m	4.0m
	Half length	4.43m	4.32m	4.93m	4.63m
	Weight(tons)	78	76	82	77
Central magnetic field		3T	3T	3T	3T
# of turns(2 layers)		2880	2812	4586 turns	4306turns
Current density		741A/mm^2	741A/mm^2	741A/mm^2	741A/mm^2
Nominal current		7956A	8159A	5338A	5338A
Stored Energy		1.60GJ	1.56GJ	1.77GJ	1.67GJ

Solenoid Magnet



- 2 layers coil + 4 layers coil(L=500mm at both ends).
- Same current density.
-Power supply for the correction coil is not necessary.

Next step



Solenoid

Coil support
Solenoid support
Installation, etc.

Iron Yoke

Support structure for barrel/end yoke
Easy/quick access device
Design support structure for inner detector