Onsite magnet winding

as a proposal of ILD (& SiD) magnet manufacture

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LCWS2024

09.07.2024

Contents

Conceptual Design of the ILD Detector Magnet System

By courtesy of

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Transportation of coil modules from factory to Assembly-Hall

Onsite coil winding and magnet manufacture

Y. Makida

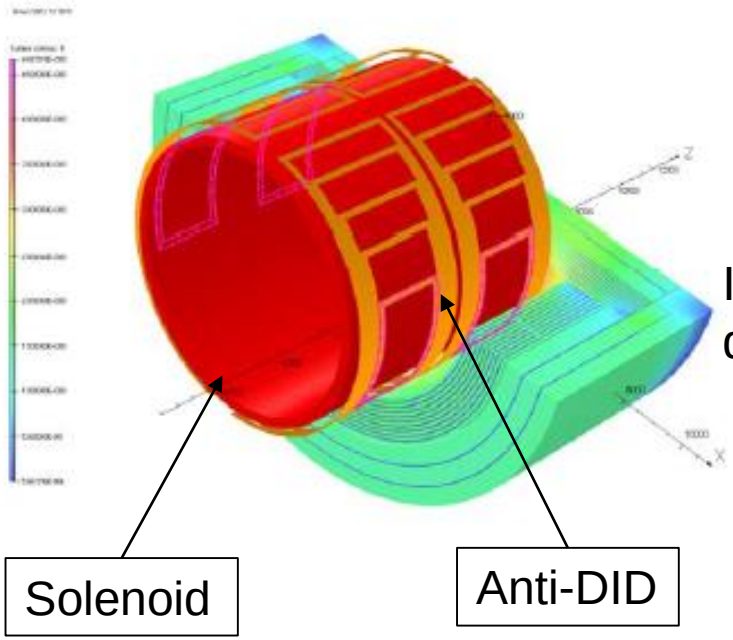
Conceptual Design of the ILD Detector Magnet System

Magnetic Field Requirement for Physics

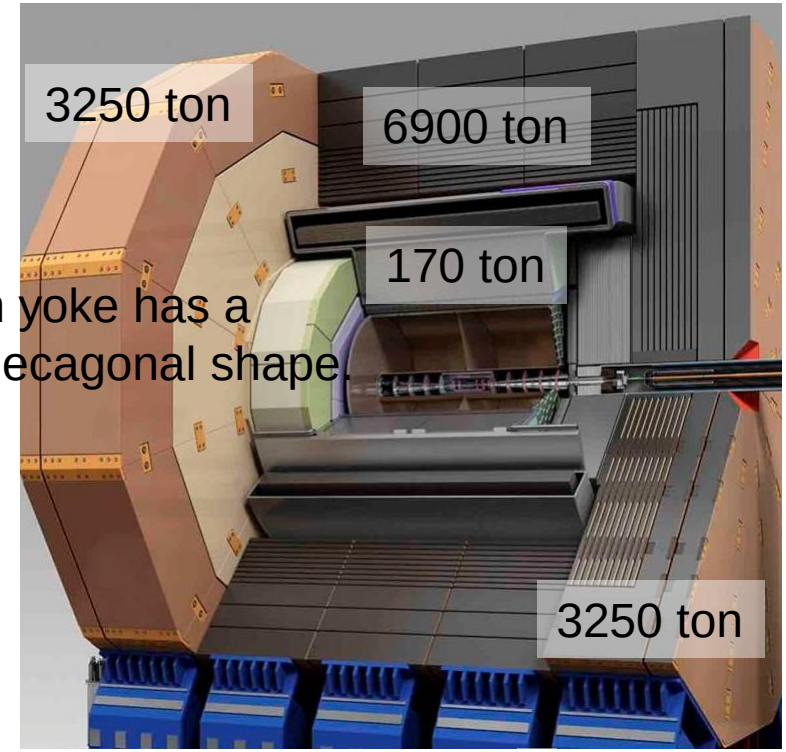
- ILD detector design asks for
  - **solenoidal** magnet field of **3.5 T** (4 T in maximum) in a warm aperture of **6.88 m in diameter and 7.35 m in length.**
  - Anti-DID (Detector Integrated Dipole) horizontal magnetic field of **0.035 T in maximum within Z=3.0 m**.
  - No stringent field homogeneity is required, but an **accurate field mapping will be requested** before installation of the sub-detectors inside the solenoid.
  - For safety reasons, constraints have been put on **the fringe field should be less than 50 Gauss at 15 m from the interaction point (IP) in the radial direction**.
  - **Iron yoke**, besides returning and shielding magnetic field, will be instrumented to be used for **the detection of muons and for measuring showers** .

Features of ILD Magnet General Design

- Many technical solutions successfully used for CMS are proposed for the design of the ILD magnet.
  - Solenoid coil consist of **3 modules** mechanically and electrically connected .
  - A multi-layer coil geometry is required to obtain the 4 T.
- Presence of anti-DID complicates coil design.



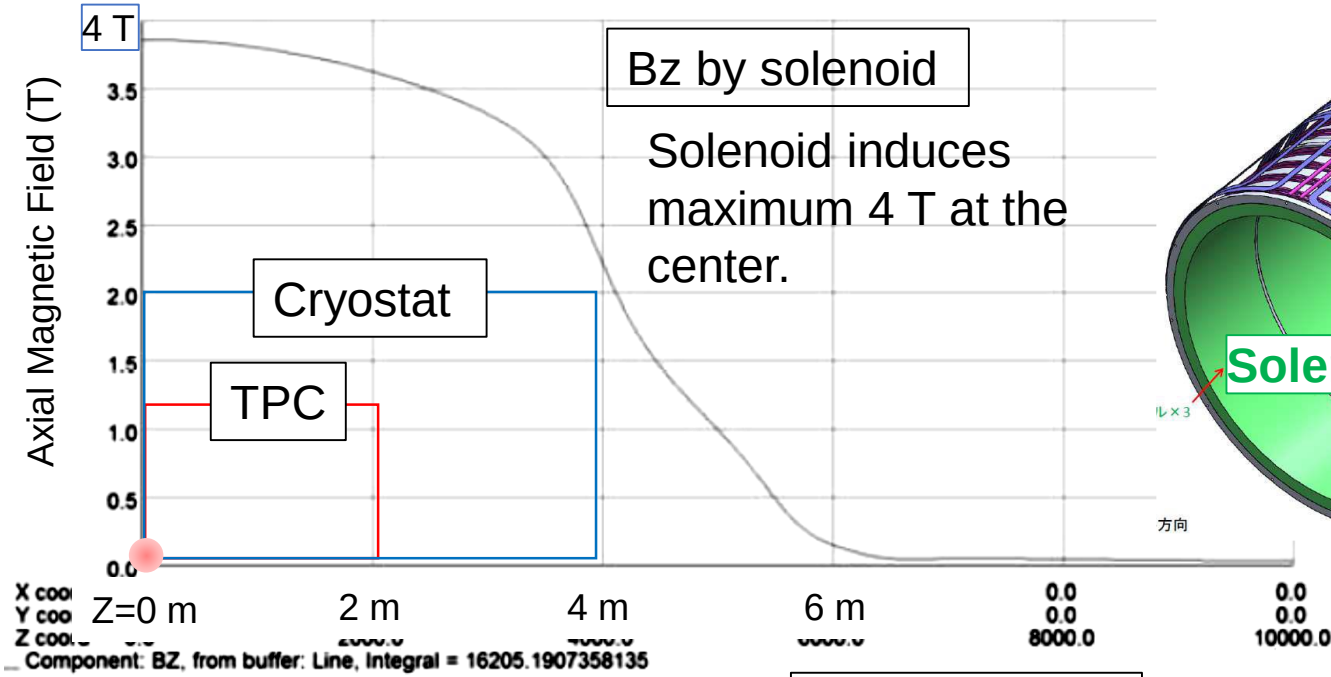
OPERA 3D input for field calculation including anti-DID

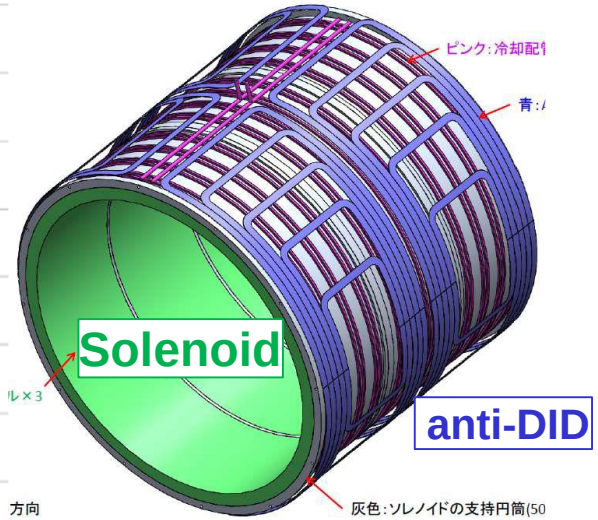


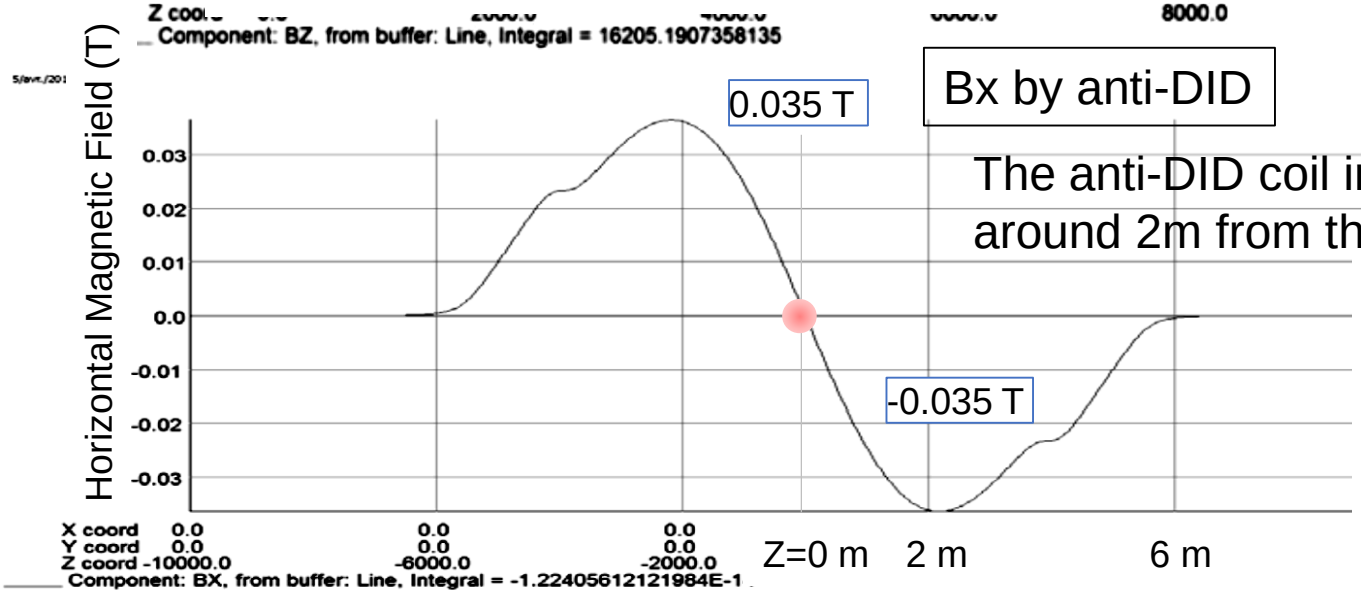
Iron yoke has a dodecagonal shape.

Cut illustration of ILD magnet

ILD Magnetic Field



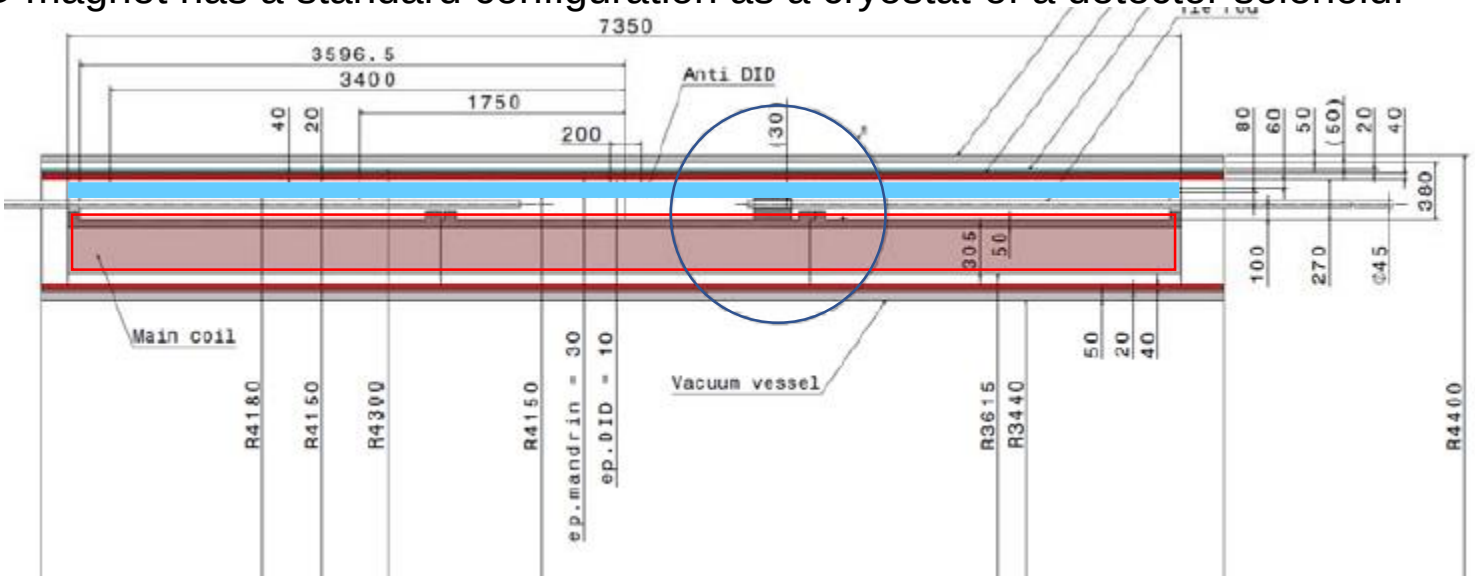


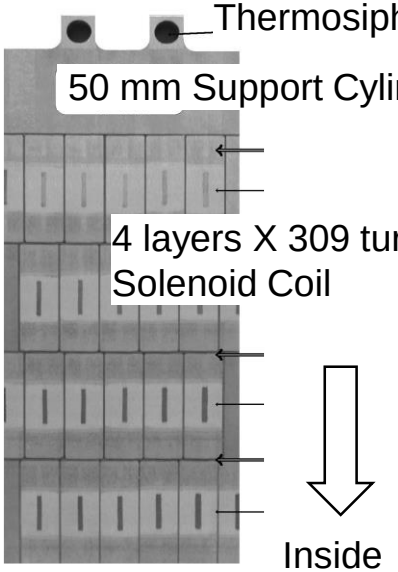


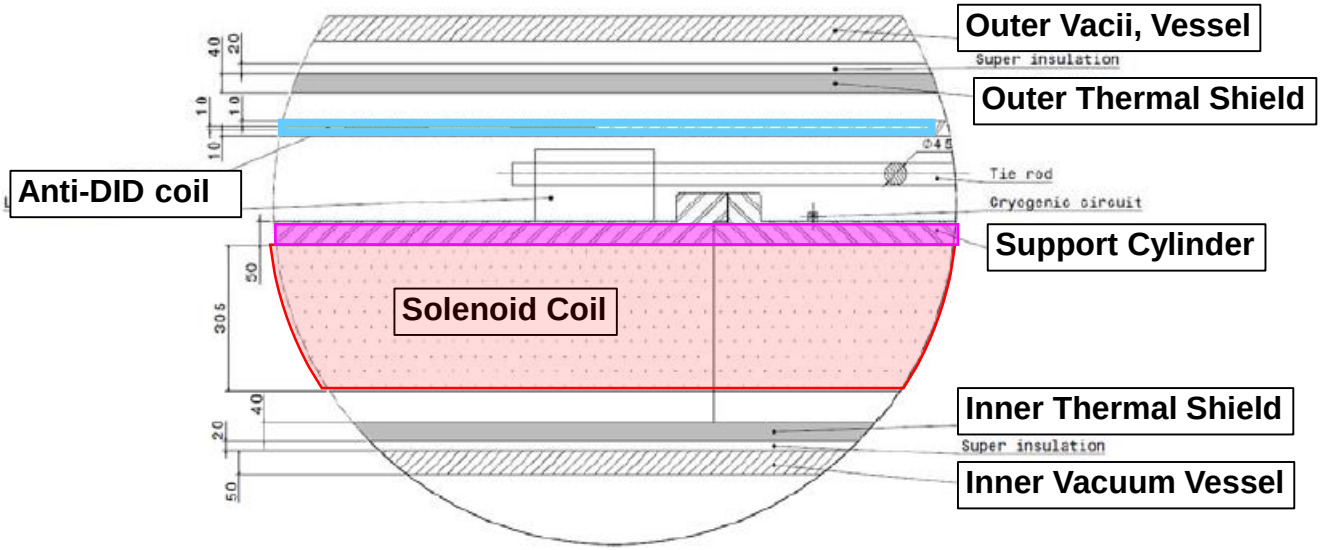
The anti-DID coil is formed with two dipoles centered on the beam axis with magnetic field in opposite direction. The angular distribution of the turns is such as to get an cosθ distribution to obtain a homogeneous dipole field.

ILD Cryostat Configuration

ILD magnet has a standard configuration as a cryostat of a detector solenoid.







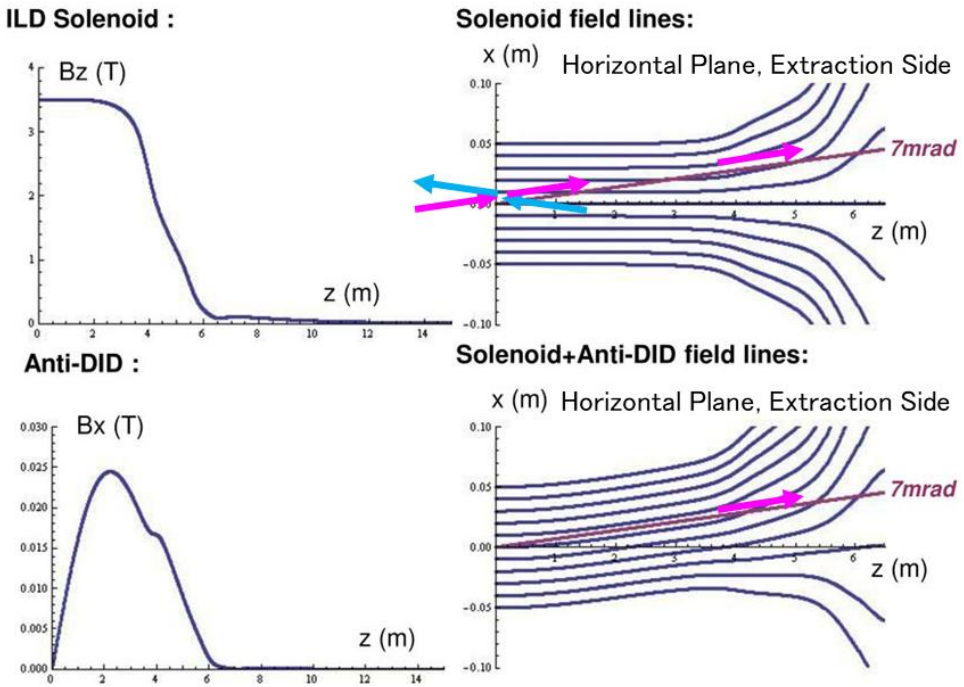
ILD Solenoid Design (Parameter List)

Coil Inner Radius (mm)	3615
Coil Outer Radius (mm)	3970
Coil Length (mm)	7350
Cold Mass Weight (ton)	**170**
Turn × Layer	309 X 4
Nominal Current (kA)	22.4
Current Density (A/mm^2)	10.6
Central Field (T)	4.0
Maximum Field (T)	4.6
Inductance (H)	9.2
Stored Energy (GJ)	2.3
S.Energy / Cold Mass (kJ/kg)	13
Support Shell Thickness (mm)	50
Cryostat I. R. (mm)	3440
Cryostat O. R. (mm)	4400

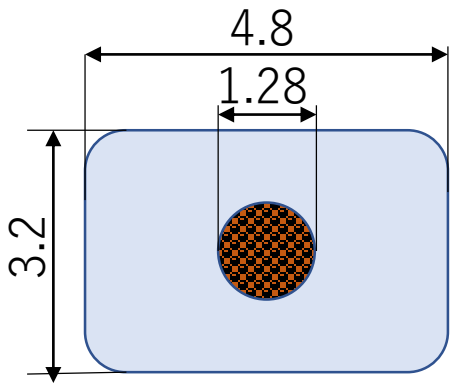
- A multi-layer coil geometry is required to obtain the 4 T.
- Similarly to CMS, a 4-layer coil was retained, with a nominal current in the range of 20 kA.
- The ILD solenoid coil enables to make it in **3 modules**, each 2.45 m long.
  Odd number of module is preferable , because in case of even number, an interface between modules is set at the coil mid-plane where the axal compressive forces are at a maximum and delamination risk in the module-to-module coupling region should be reduced.
- **Each conductor length** of 1 layer in 1 module is **2.6 km**, that is fine for conductor fabrication. Conductors are spliced every inter layers.
- The coil is wound with inner winding technique, where **aluminum alloy support cylinder of 50 mm thickness** is used as an external mandrel.

ILD anti-DID Design (Parameter List)

Design Max. Dipole Central Field on Beam Axis (T)	0.035
Position of max Bx within Z (mm)	3000
Maximum Field on Conductor (T)	2.0
Anti DID I.R. (mm)	4160
Anti DID Length (mm)	6820
Nominal Current (A)	615
Current Density (A/mm^2)	40
Conductor size (mm x mm)	4.8 x 3.2
Inductance (H)	23
Stored Energy (GJ)	4.4



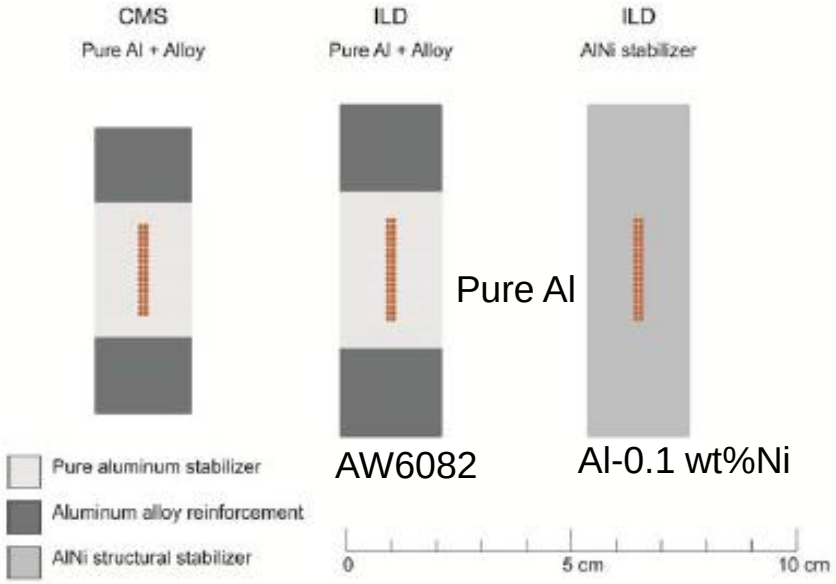
Anti-DID makes improved flux direction along the beam line. Low energy electrons & positrons, background, are kept inside the beam pipe.



Maximum field in the anti-DID coil is 2.T, which value is rather higher than effective field of 0.035 T
Nominal current is 615 A, which flow through this small aluminum stabilized conductor..

ILD Superconducting Conductor

Superconducting Strand in virgin state	
Strand diameter (mm)	1.28
Cu matrix / NbTi	1.1 ± 0.1
Jc (A/mm^2) @ 4.2 K, 5 T	3300
Rutherford Cable	
Number of Strand	36
Cable Transposition Pitch(mm)	185
Final Conductor (AL clad)	
Overall Dimensions (mm x mm)	**74.3 X 22.8**
Total Length (km)	**32**
Spool #, Length (km) per spool	**12, 2.6**
Al/NbTi	≈75
Critical Current (A @ 4.2 K, 5T)	67500



- Conductor consists of a superconducting Rutherford cable, sheathed in Al stabilizer and Al alloy mechanically reinforces.
- Al clad makes SC coil stable and quench safety.
- Two solutions are considered for the reinforcement. ATLAS CS type or CMS type.

Serious Situation (in Karsten's talk)

Currently no manufacturer of Al clad conductor in Europe, Japan or US is available. All superconductor manufacturer have dismounted Al clad machine or doesn't receive its order. Effort to resume of this technique has been in progress.

Transportation of coil modules from factory to Assembly-Hall

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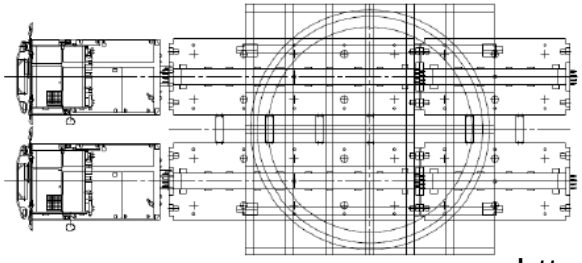
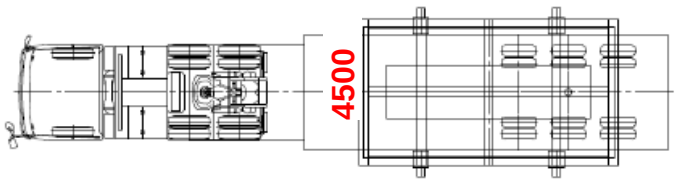
Coil Module Transportation

	Solenoid	Support Cylinder	Anti DID
ID(mm)	7230	7940	8300
OD(mm)	7940	8100	8360
L(mm)	7350	7350	6820
Density (g/cc)	2.7	2.7	2.7
Weight (ton)	168	40	14
1 of 4 coils (ton)			3.7
1of 3 modules (ton)	56	70	14

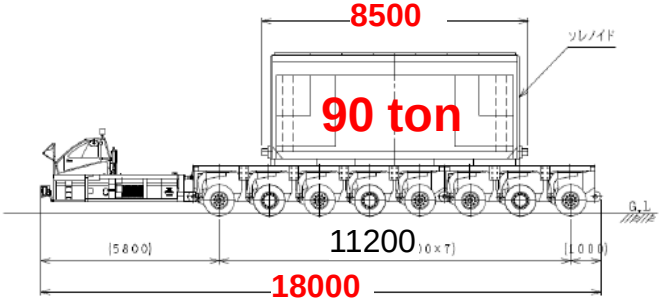
1/3 Solenoid Coil Package	
Dimension	8500 × 8500 × 3608 mm^3
Weight	**90.0** ton (module **70** ton)
Package No.	3

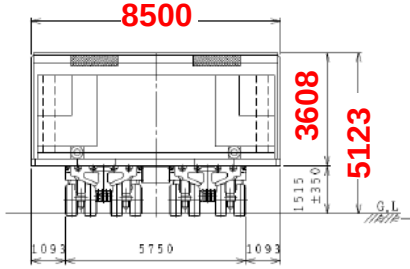
1 Anti-DID coil Package	
Dimension	8500 × 4500 × 3500 mm^3
Weight	16.0 ton (coil **3.7** ton)
Package No.	4

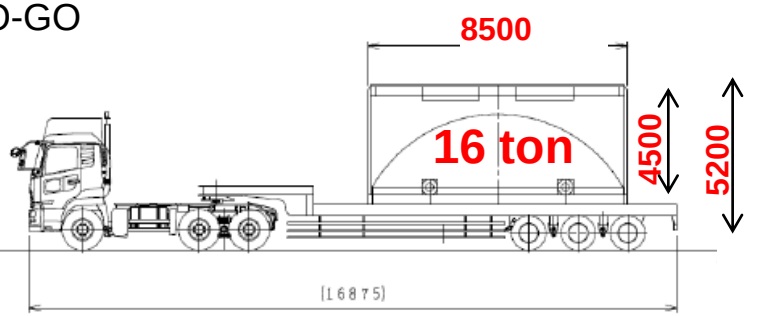




https://www.youtube.com/watch?v=x2HmezHobW8&ab_channel=Kurofumo-sanGO-GO







Road condition from a port to IP

Land Transportation is not impossible, but

- There are many traffic signs, signals, electric poles, street lights, fences and trees to be temporally removed.
  - A few hundreds obstacle points
  - Keeping stacking height less than GL4.9 m and width less than 6.0 m is preferable in JP
  - Preparation and recovery cost may be comparable with transportation fee.
    - \300M ($2.2M, €2M）×2
- Some bridges must be reinforced.
  - Reinforcement cost may be huge.
- Tunnels based on national highways have enough cross sections.
- Permissions and public approvals are necessary to occupy the road and removing road instruments.

Tunnels have enough size.

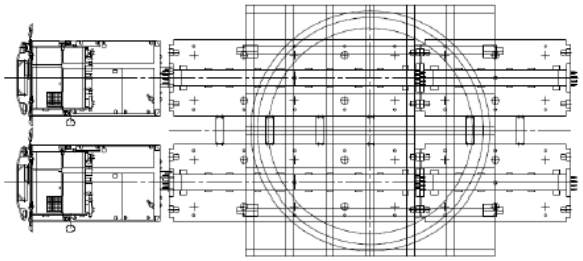
SiD Coil Module Transportation ?

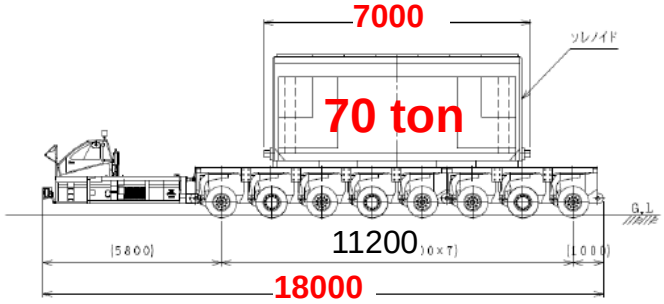
	Solenoid	Support Cylinder	Anti DID
ID(mm)	5462	6224	6324
OD(mm)	6224	6324	6404
L(mm)	5586	5586	5586
½ L (mm)	2793		
Density (g/cc)	2.7		
Weight (ton)	133		
½ Weight(ton)	70		

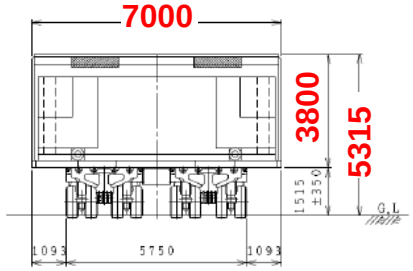
½ Solenoid Coil + 1 anti – DID coil Package	
Dimension	7000 × 7000 × 3800 mm^3
Weight	90.0 ton (module **70** ton)
Package No.	2

Keeping stacking height less than GL4.9 m and width less than 6.0 m is preferable in JP

So, SiD modules transportation is costly and need public agreement, too.







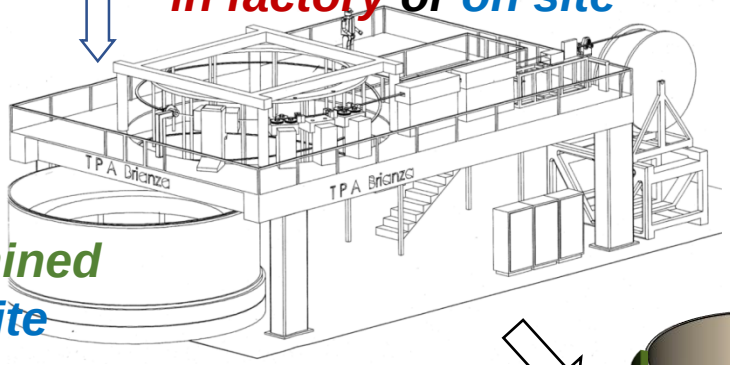
Onsite coil winding and magnet manufacture

It became obvious that transportation of coil modules are a kind of risky work. That cause started to study about onsite manufacture of cold mass.

Outline of ILD Magnet manufacturing process coil manufacture and cryostat assembly

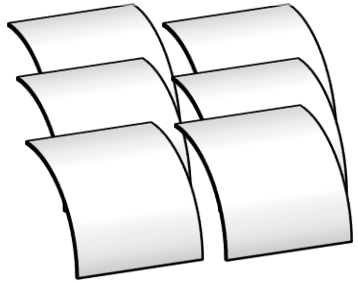
SC conductor
from Factory

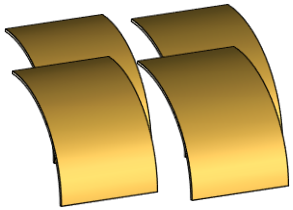
Coil Winding
in factory or on site



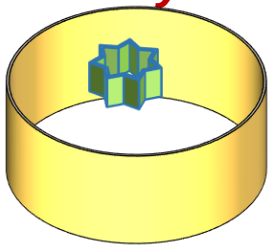
From P. Fabbricatore, IEEE Trans. Appl. Super., Vol. 12, p.358

Thermal shield
From Factory

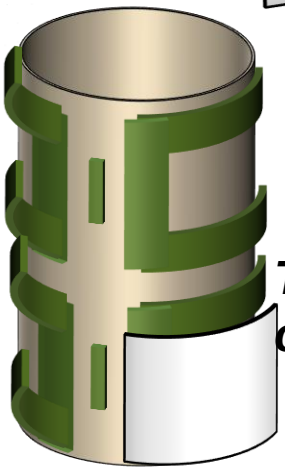




Support cylinder
welded and machined
in factory or on site

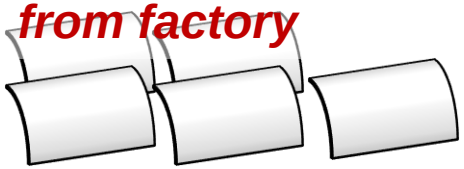


Cold mass
assembly
In AH(on site)

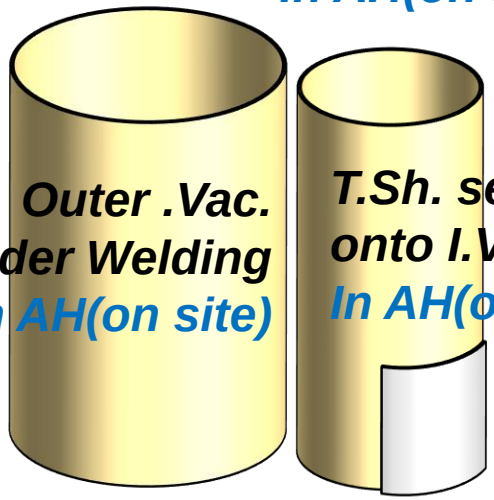


T.Sh. setting
onto C.Mass

Thermal shield
from factory



Vacuum vessel Shells
from factory



Outer .Vac.
Cylinder Welding
In AH(on site)

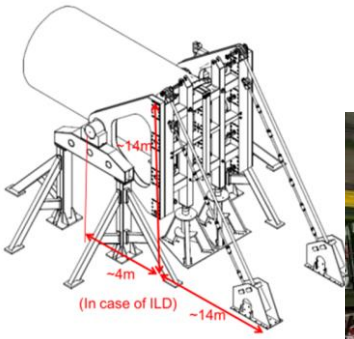
T.Sh. setting
onto I.V.C.
In AH(on site)

Cryostat Assembly
In AH(on site)

Cryostat Assembly (Learning from CMS experience)

3 solenoid modules are stacked on a swiveling platform Setting anti-DID

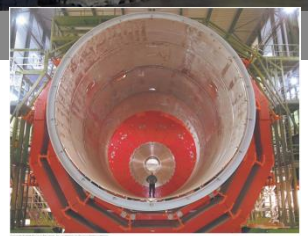
Setting outer thermal shield Horizontal position



Inserting the cold mass + O.Th.S
Inserting Inner V.V + I.Th.S

Cryostat welded

Setting Outer Vacuum C. in Barrel Yoke Center Block

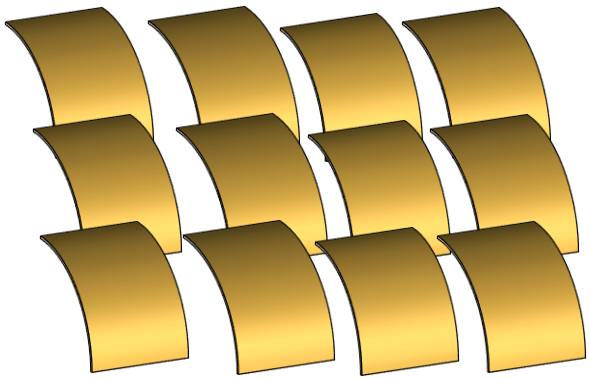


Descent to cavern

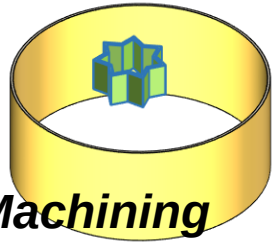
These photos are copied from CMS web sites.

In detail

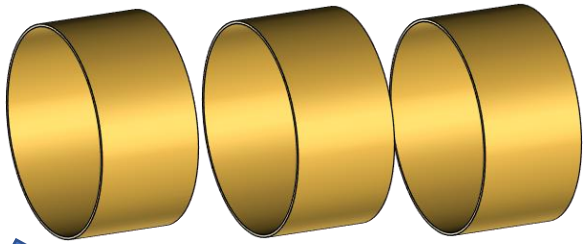
Manufacture of cold mass (solenoid coil)



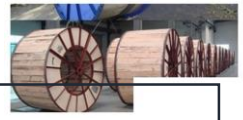
Welding shells *to support cylinder*

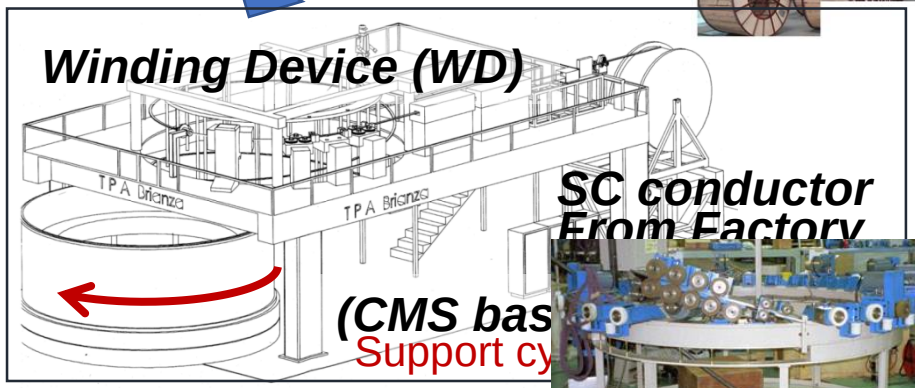


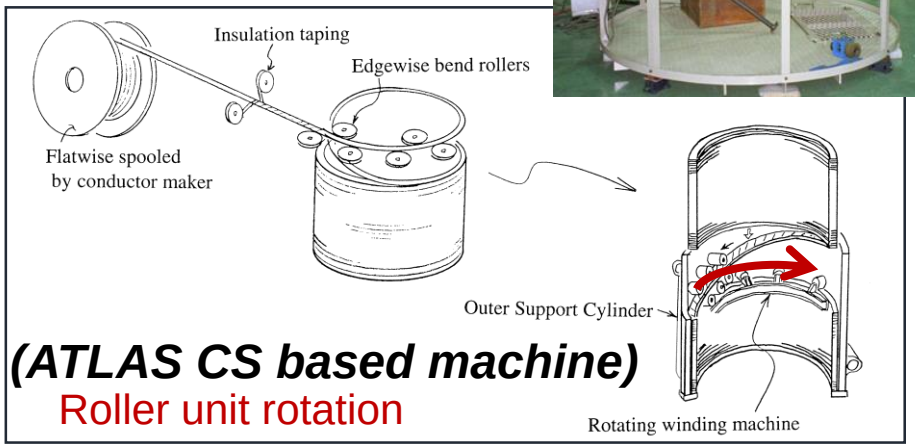
Machining
to make smooth surface for winding
GND Insulation

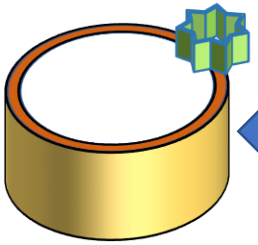


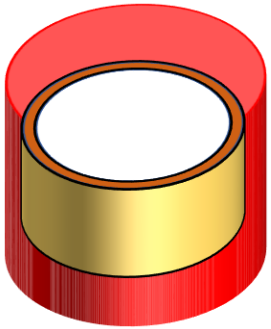
Set support cylinder onto WD





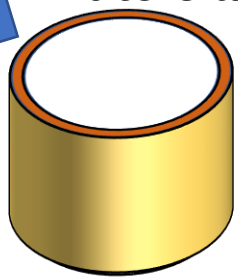






Lathe
to make flat surface for stacking

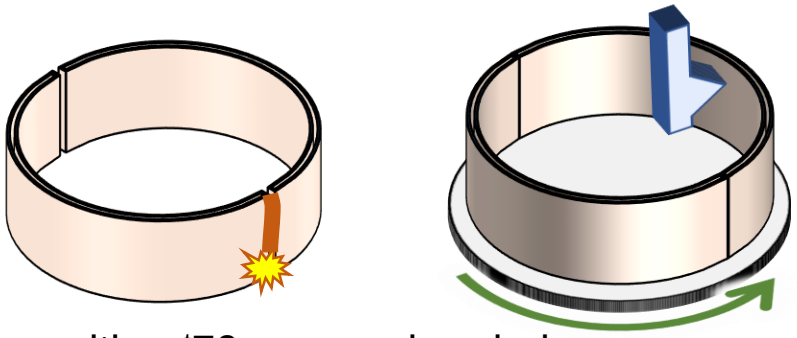
Auto clave



Complete
1/3 solenoid

In detail
Manufacture of support cylinder

Manufacture 1/3 length of support cylinder

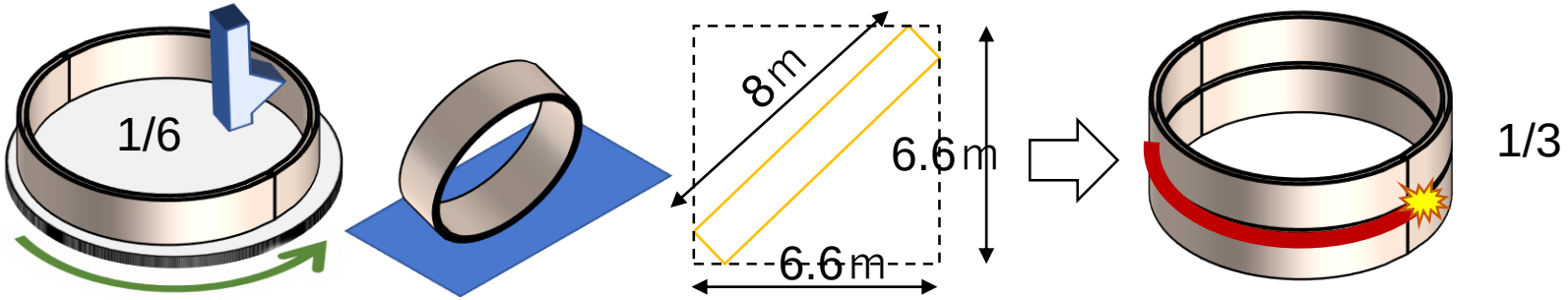


Vertical turning lathe

- Plates with > ^{t}70 mm are bended.
- Plates are welded to 1/3 length cylinders.
- Inner cylindrical surface, outer complicated surface and both end surface are formed by turning and machining process. ~ ^{t}50 mm (design)
- **A large and combined machining lathe is necessary**.
  ~\800M ~$6M ~€5.4M expensive!
  Onsite or In factory need investigation.

Column type milling machine

Transport shorter length cylinder ?

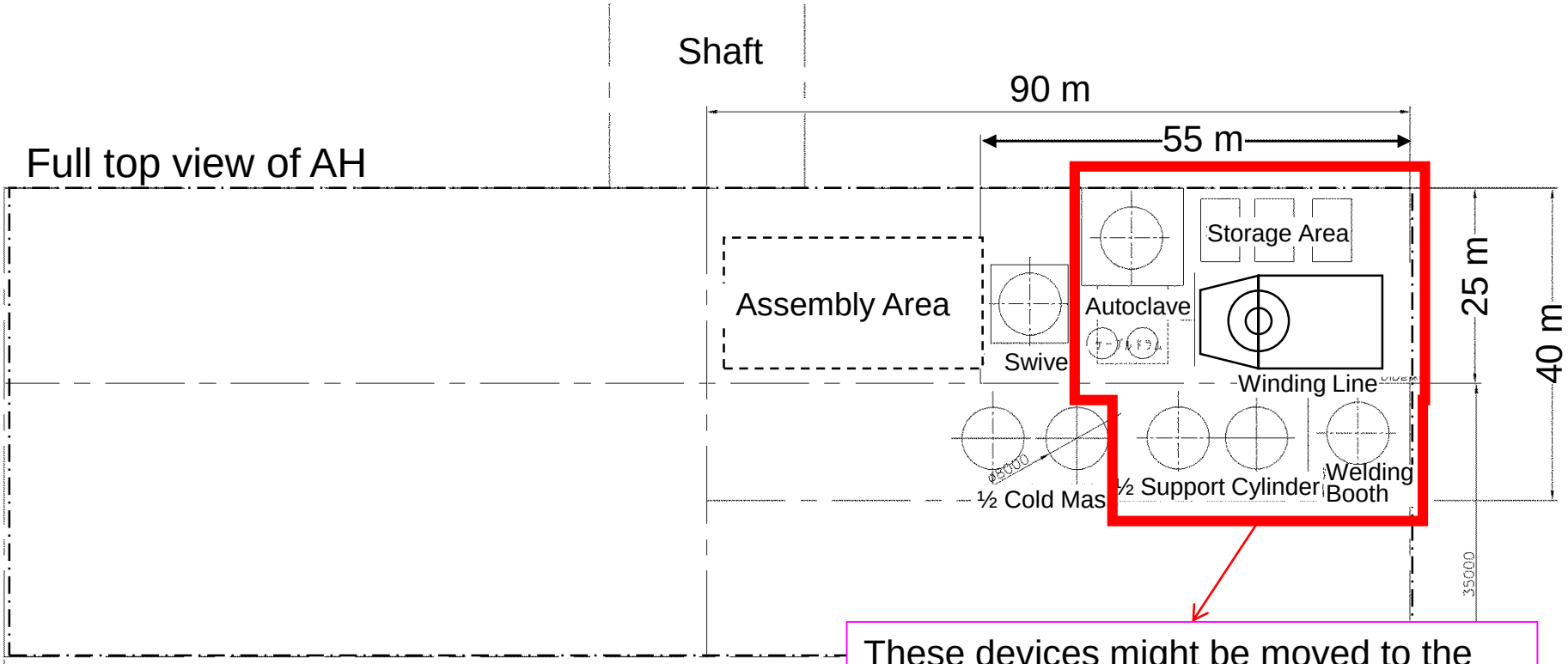


Is it possible to combine Winding device with Machining Device?

Conclusion

- Technical design of ILD magnet is summarized.
  - **solenoidal** magnet field of **3.5 T and 4 T in maximum** central field in a warm aperture **of 6.88 m in diameter and 7.35 m length**.
  - Anti-DID (Detector Integrated **Dipole**) horizontal magnetic field of **0.035 T in maximum in Z=0.3 m**
- Conductor consists of a superconducting Rutherford cable, sheathed in a stabilizer and mechanically reinforces.
  - It has the overall dimensions of **74.3 X 22.8** mm^2. Length demand is 32 km, breakdowns **2.6 km x 12 spools**.
  - Two solutions, CMS type, ATLAS CS type, has been considered.
    Resume of Al clad conductor supply is the most serious subject.
- **Magnet manufacture procedure has been investigated** with the cooperation by magnet makers, forwarding agents and local support organizations.
  - In the CMS experience, the coil modules were manufactured in the factories and were transported to the experimental site.
  - It is not impossible for ILD coil module to be transported on surface. But its cost and getting public agreement to occupy regional traffic has been promoting its onsite manufacture.
  - In case of onsite winding, large massive device machining the support cylinder is to be prepared. It's very costly, so **transportation of support cylinder modules from factories before onsite winding**. **Or more simple machining device combined with a winding machine has been investigated**.
  - **We should consider common usage of winding and machining device with SiD group.**

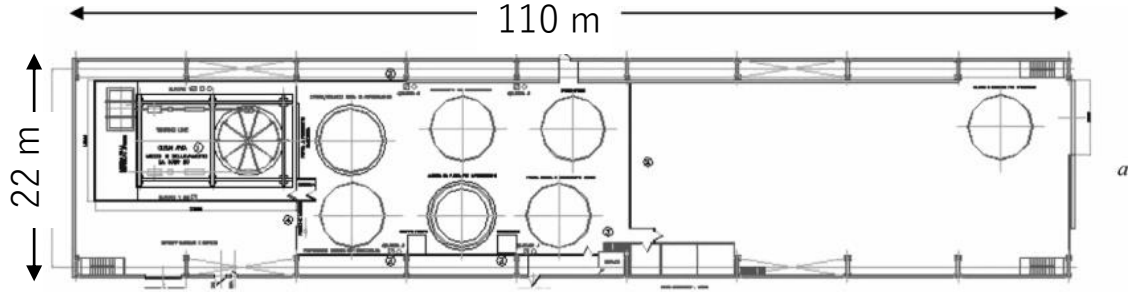
Workplace in AH for SC Magnet



Timeline of area requirement has been considered.

These devices might be moved to the **winding factory** nearby AH, because winding can start before AH completion.

CMS Case



Back up Schedule