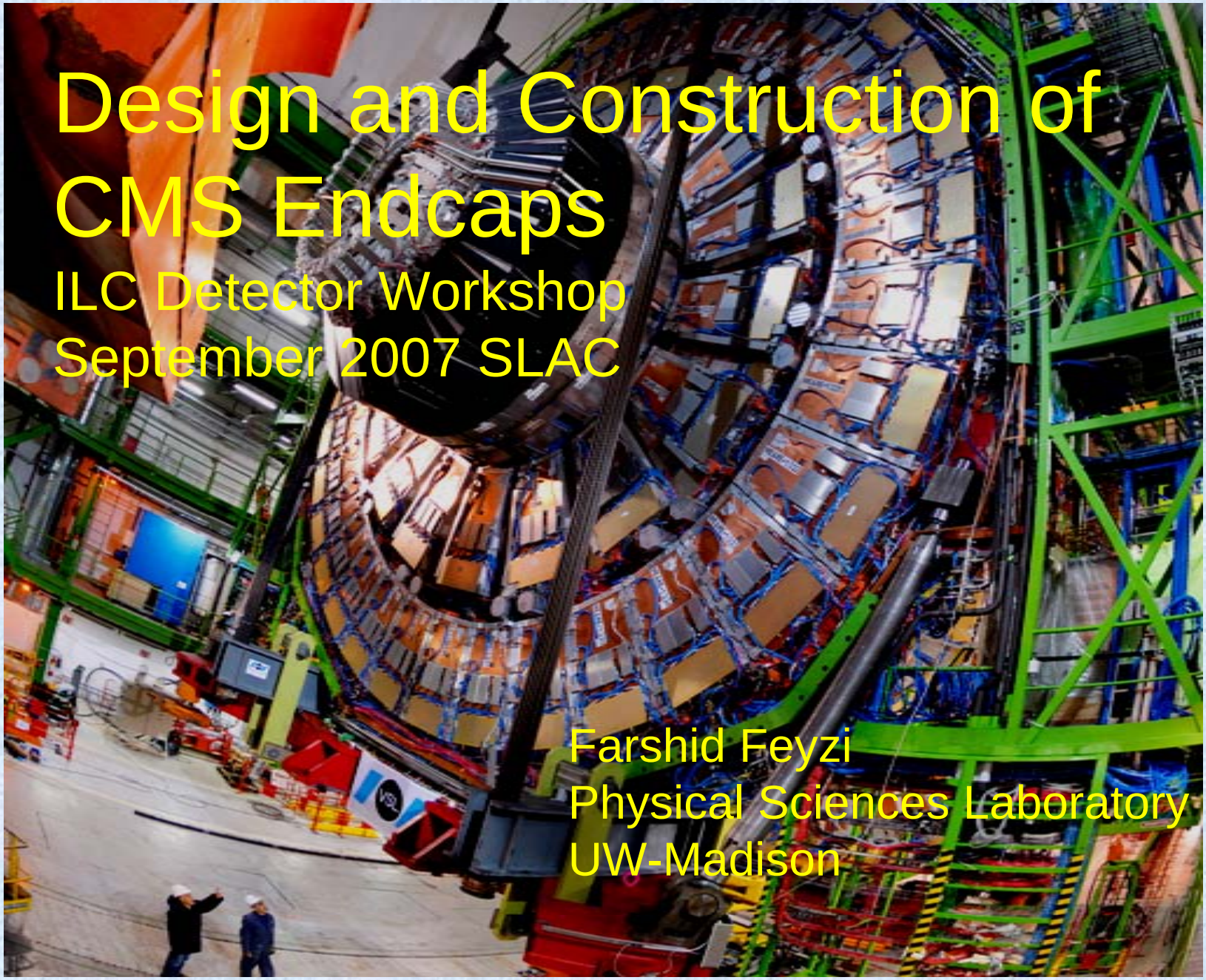
Design and Construction of CMS Endcaps

ILC Detector Workshop
September 2007 SLAC



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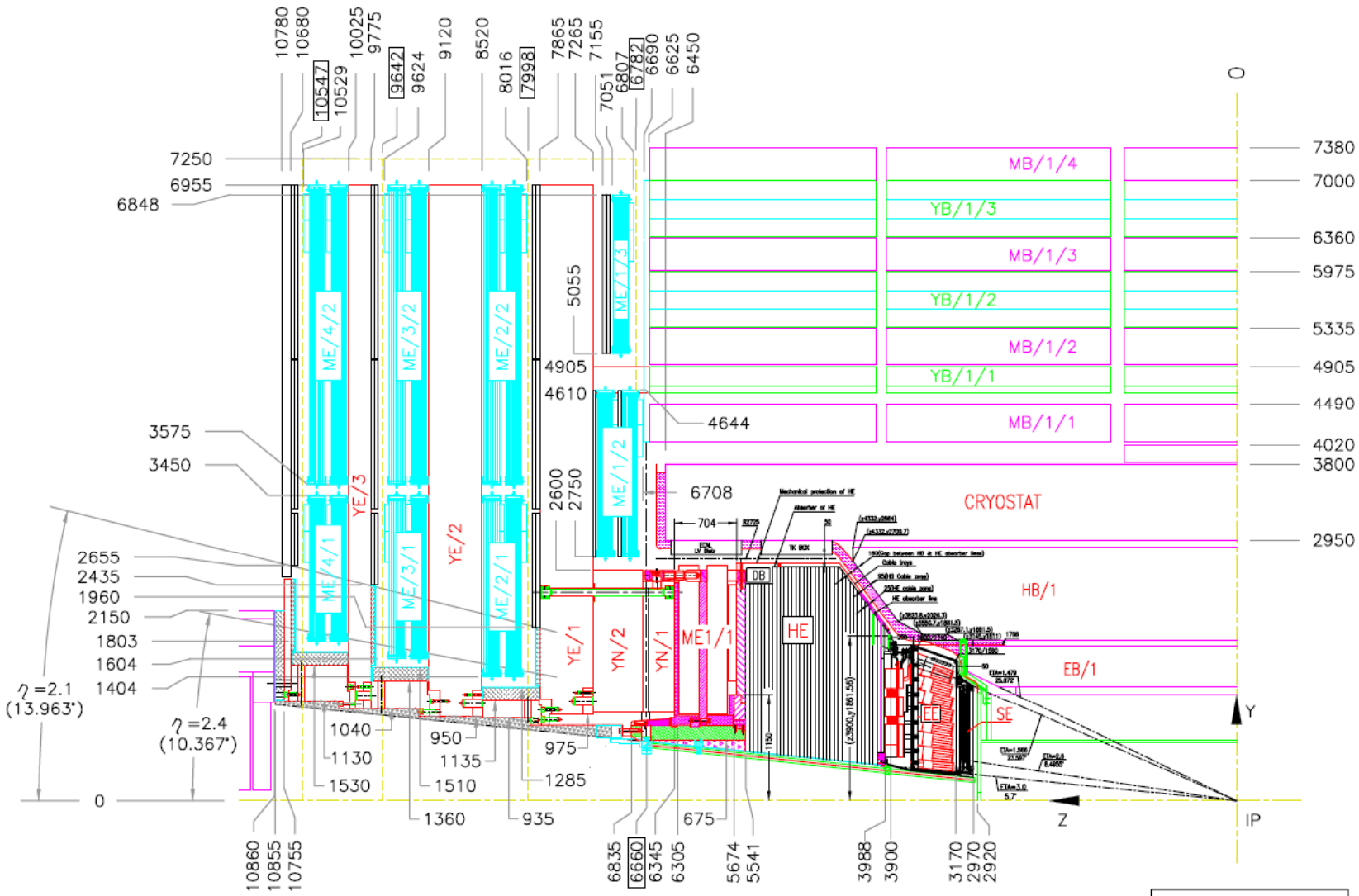
Outline of talk

- Design challenges
- Design and analysis methods
- Material
- Construction methods
- Verification
- Assembly and installation methods
- Integration
- Alignment



Parameter drawing

P-S-L
JDP 1-8-2002
CMS 5185_125

Design Challenges

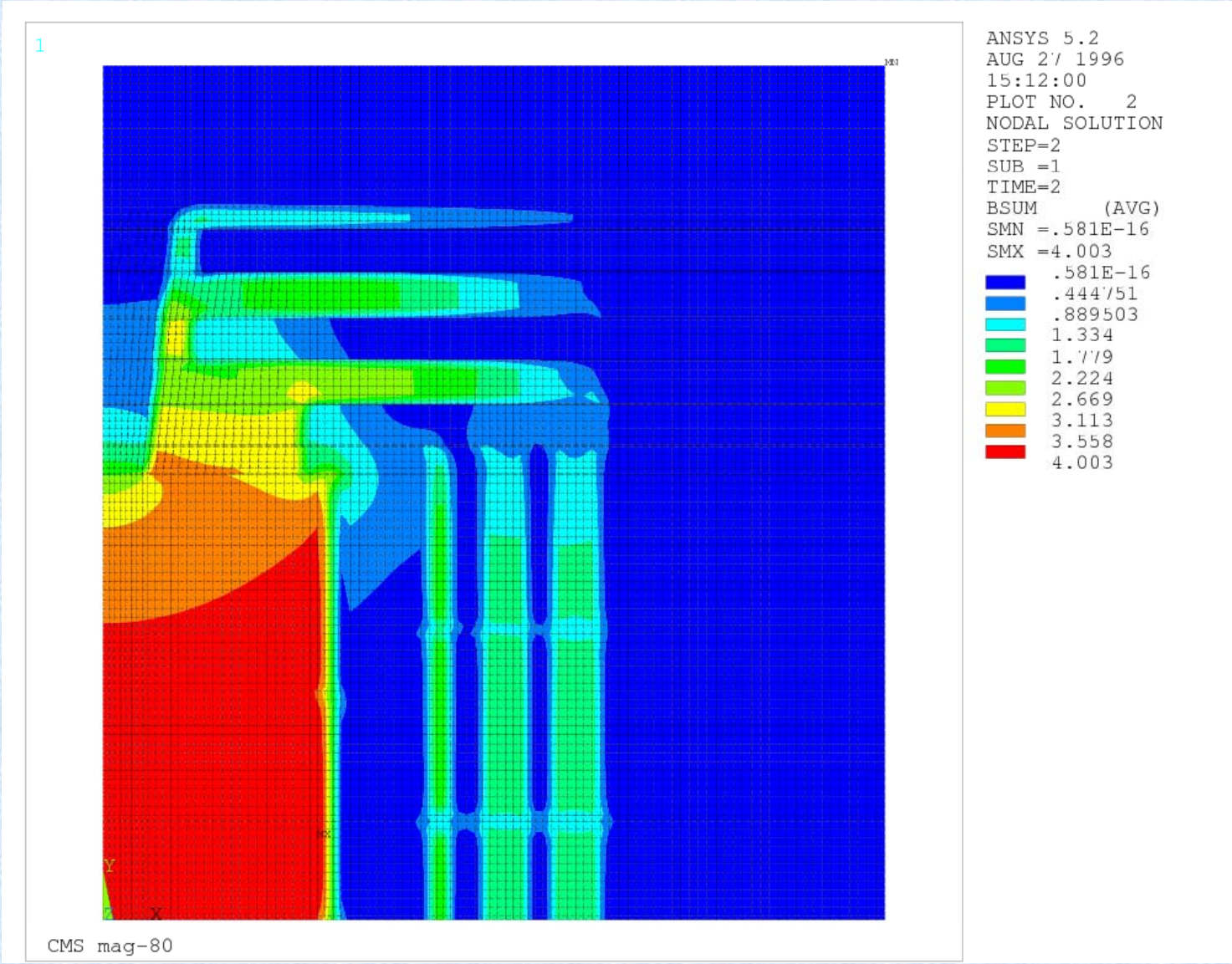
- Return magnetic flux
- Resist large magnetic force
- Economical construction and fast assembly
- Support and moving of tall and thin objects
- Full 3-4 layers of CSC muon detectors
- Support of cantilevered endcap calorimeter
- Integration of muon chambers and services
- Installation and service of muon chambers in tight space
- Lowering into cavern

Design and analysis methods

- Axisymmetric magnetic FEA models
- 3-d structural FEA models with magnetic and gravity loads
- Kinematically determinant support system—know where the loads are
- Full 3-d CAD models to small details
- Load testing and component verification

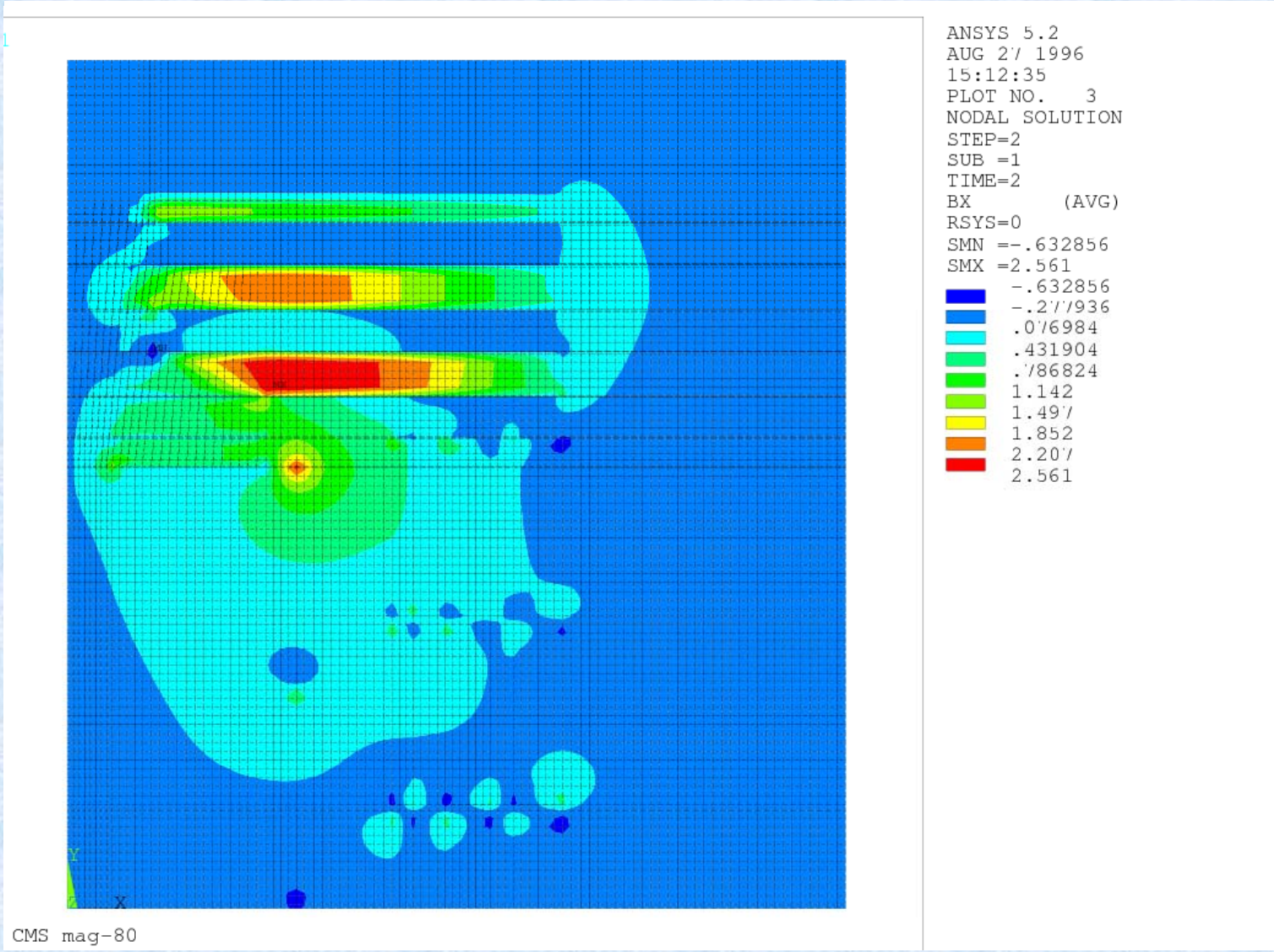
Total field

Beam

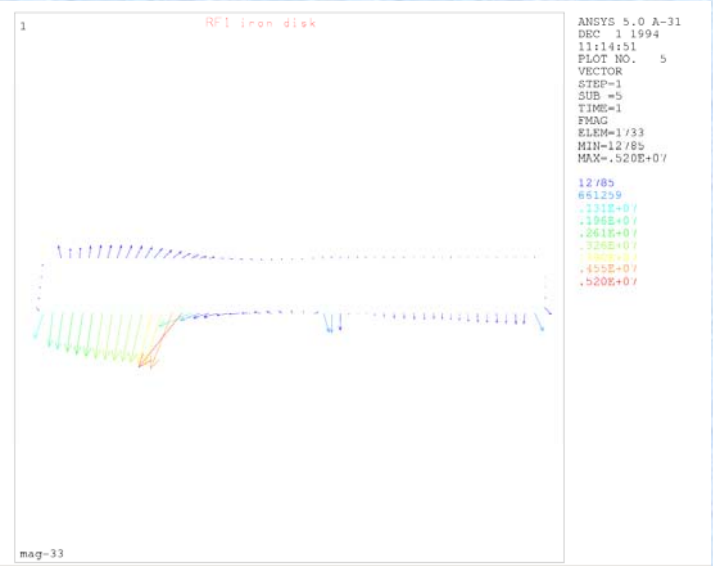


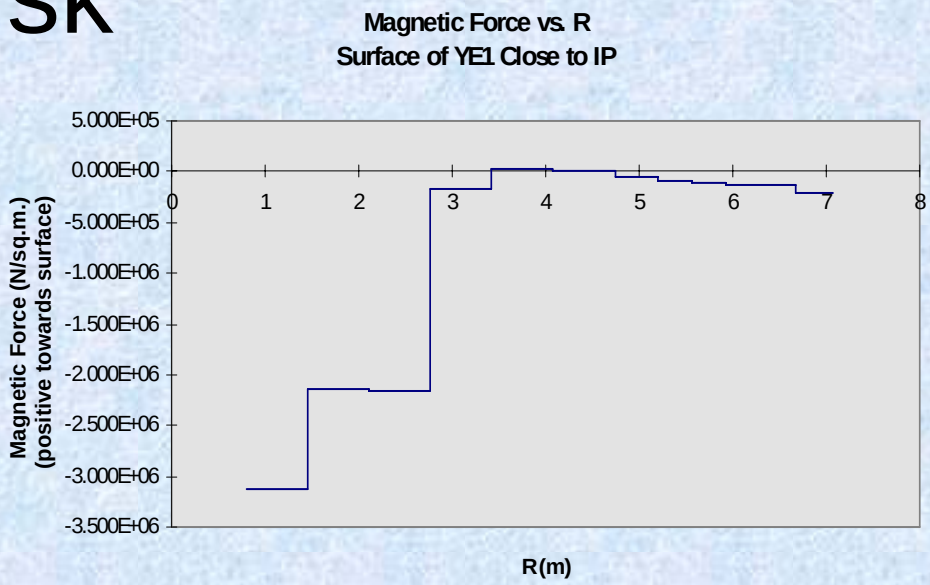
Radial Field

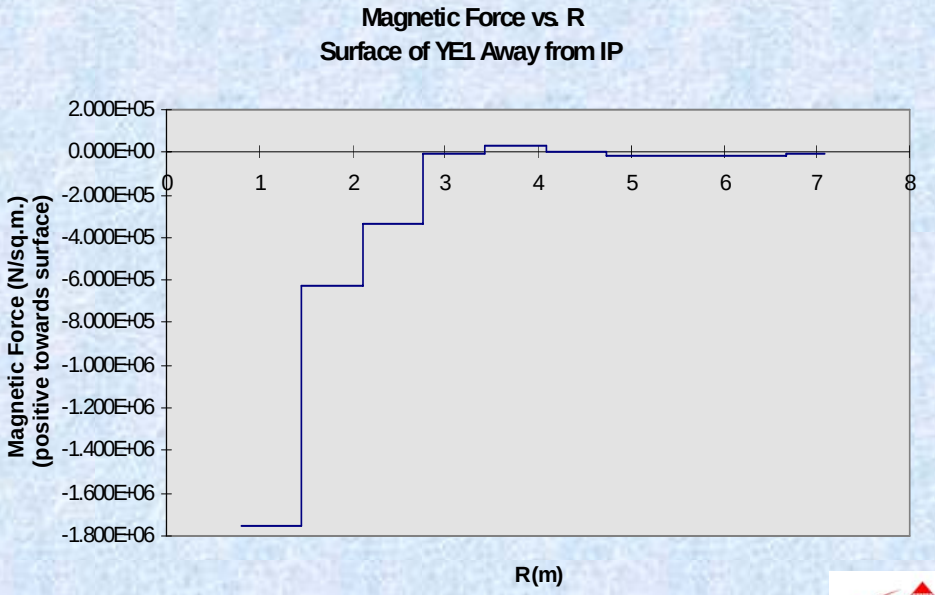
Beam



Forces on first disk







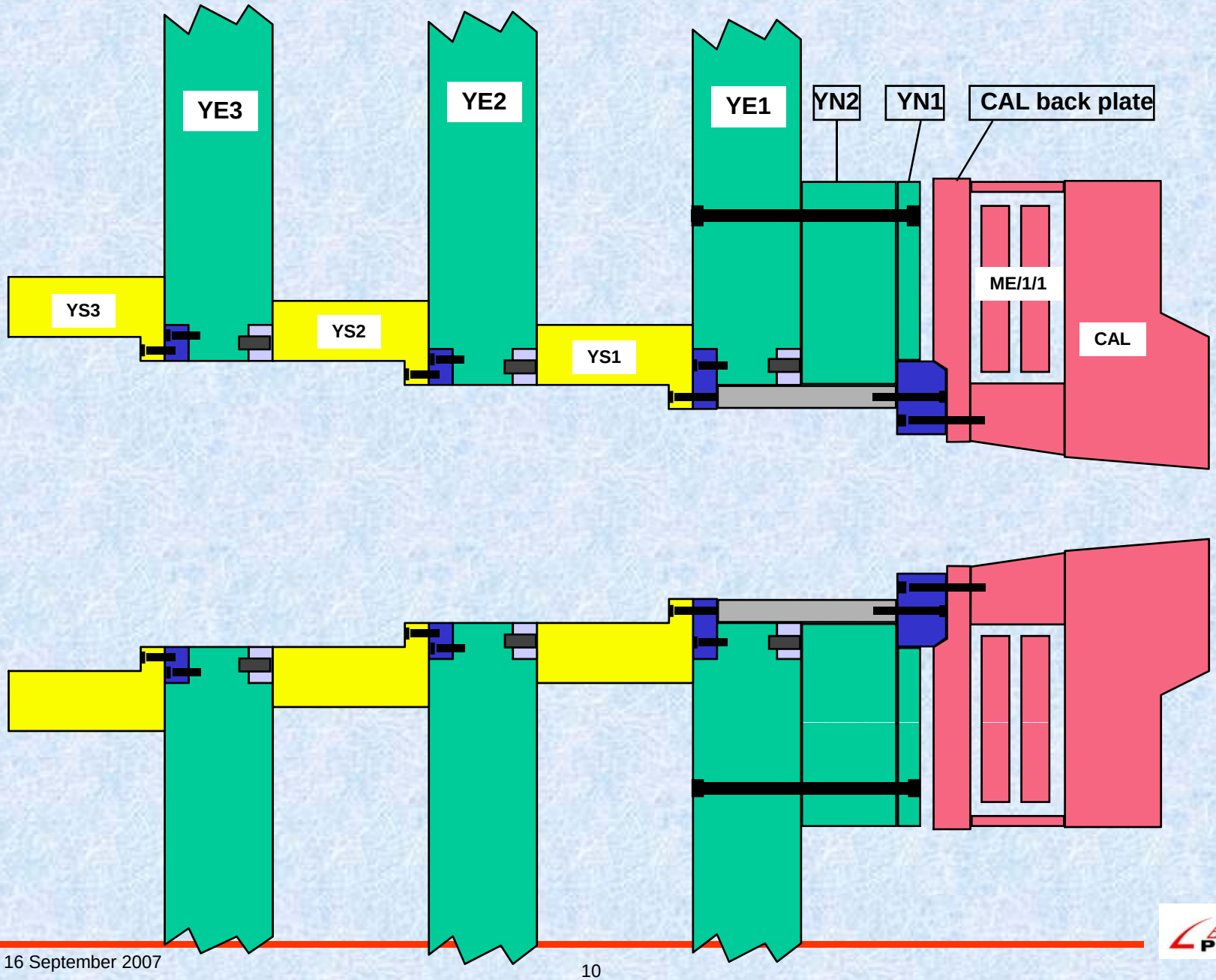
Magnetic forces on Endcap Steel Disks

iron element	YE1	nose	YE2	YE3	total
magnetic force (MN)	48.2	19.8	16.7	1.5	86.2
magnetic force (tons)	4913	2018	1702	153	8786
mass (tons)	710	135	716	285	1846

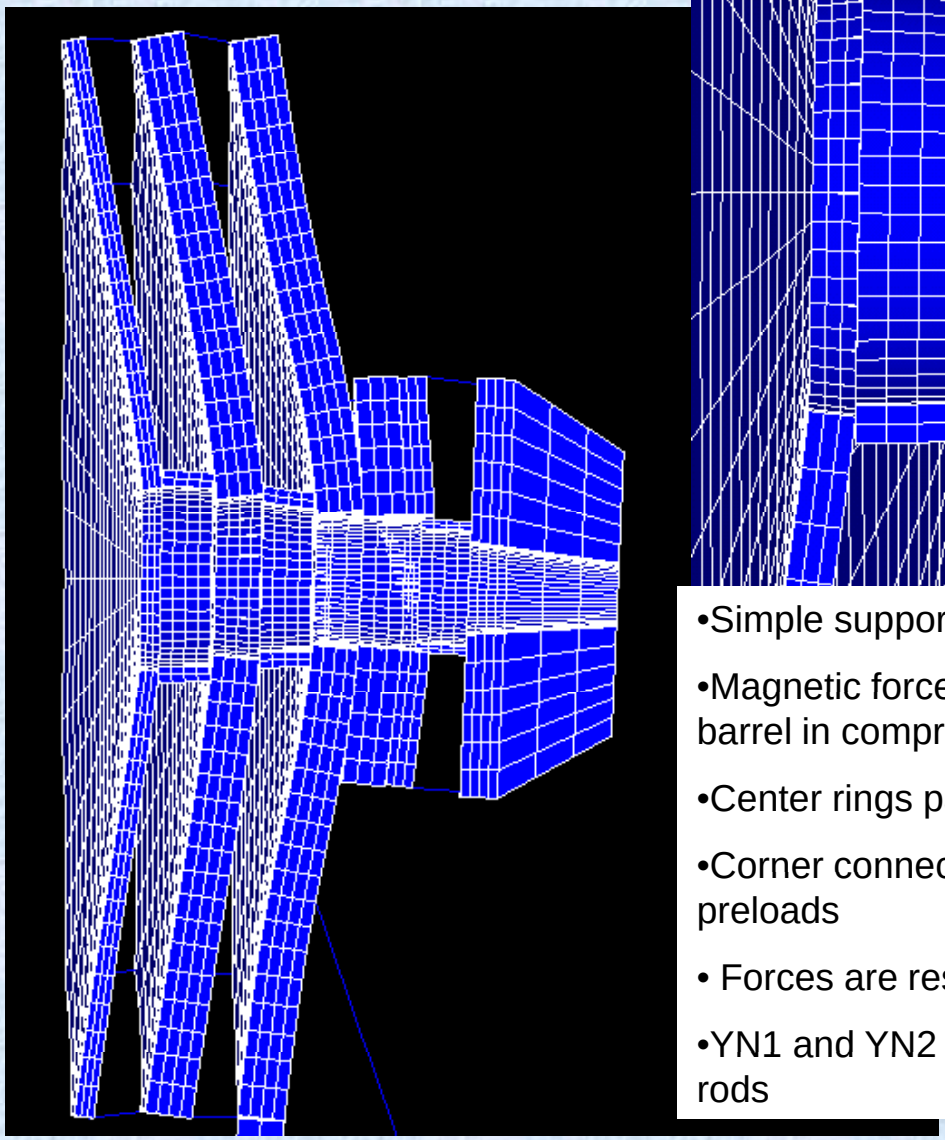
Mechanical Model Summary

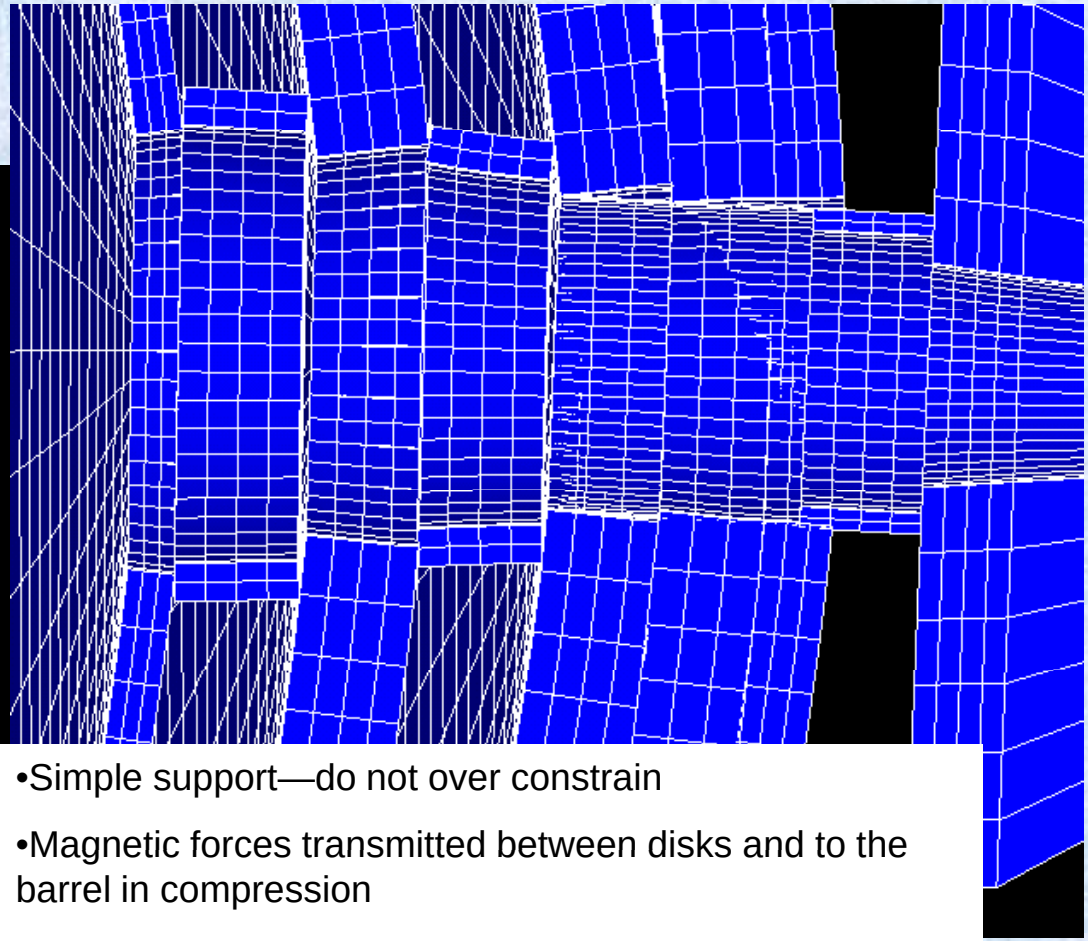
Model (all done with ANSYS)	**Model 20 (L. Greenler, F. Feyzi, PSL)**	**Weld1 (L. Greenler, PSL)**	**Wands1 (R. Wands, FNAL)**	**Weld2 (L. Greenler, PSL)**	**Weld3 (L. Greenler, PSL)**
Purpose	Overall distortions	Weld stresses	Overall distortions, bolt loads, weld stresses	Weld stress refinement	Weld stress distribution
Type of model	½ of endcap, joined nodes for bolts, solid sectors	¼ of YE1, joined nodes for welds and bolts	1/10 of YE1, Actual bolts with preload, weld strip	¼ YE1, Joined node for bolts, weld strip	¼ YE1, Joined node for bolts, weld strip
Loading	Magnetic and gravity	Magnetic	Magnetic	Magnetic	Magnetic
Maximum distortion	11 mm	14 mm	10 mm	14 mm	14 mm
Maximum weld stress		118 MPa Equivalent stress	76 MPa Stress intensity	85 MPa Equivalent stress	85 MPa Equivalent stress,
Method of calculation		Extract nodal forces, divide by area, combine	Extract nodal forces, divide by area, combine	Derived by program	Derived by program

Schematic of main components of endcap yoke



Overall distortion





- Simple support—do not over constrain
- Magnetic forces transmitted between disks and to the barrel in compression
- Center rings part of flux path and load path
- Corner connections resist the force on periphery and preloads
- Forces are resisted in the disks by bending
- YN1 and YN2 add to stiffness of YE1 due to large tie rods

Material Specifications—strike a balance

4.3.1. Chemical Composition

The chemical composition of the material is not a strict requirement. However, the Contractor must determine a target range for carbon and all other elements. This range must be compatible with all other material requirements. The target range must be specified in the material specifications. Cobalt must be kept to less than 0.1%. Radioactivity must be at the safe level for routine shipping and handling.

4.3.2. Mechanical Properties

For YE1 and YE2 the mechanical properties of the plate used in the first layer (towards the I.P.) must meet those listed in Table 1.

Table 1: YE1, YE2 first plate properties

Yield Strength	250 MPa min
Ultimate Strength	350 MPa min
Elongation	25% min
Resilience	40 J min at 20 C

4.3.3. Magnetic Properties

The absolute value of relative permeability must be more than 130 at an induced field of 1.8 Tesla.

The uniformity of the relative permeability within any one disk must be less than 5 at an induced field of 1.8 Tesla.

4.3.4. Weldability

As ancillary elements (like gangways) will be attached to the Disks by welds to be done 'in situ', good weldability of the chosen steel for the sectors is important. The preheating necessary to suppress cold cracking must not exceed 100 C, thus the equivalent carbon C_{eq}, according to BS 5135, must not exceed 0.40%:

$$C_{eq} = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15} < 0.40\%$$

To minimize risks of hot cracking, the ratio of manganese over sulfur must be sufficient:

$$\frac{Mn}{S} > 30$$

If welding is required for the manufacture of the sectors, the use of low hydrogen welding processes and welding materials is recommended to reduce the risk of cold cracking and to minimize the preheat temperature.

CMS SY FS
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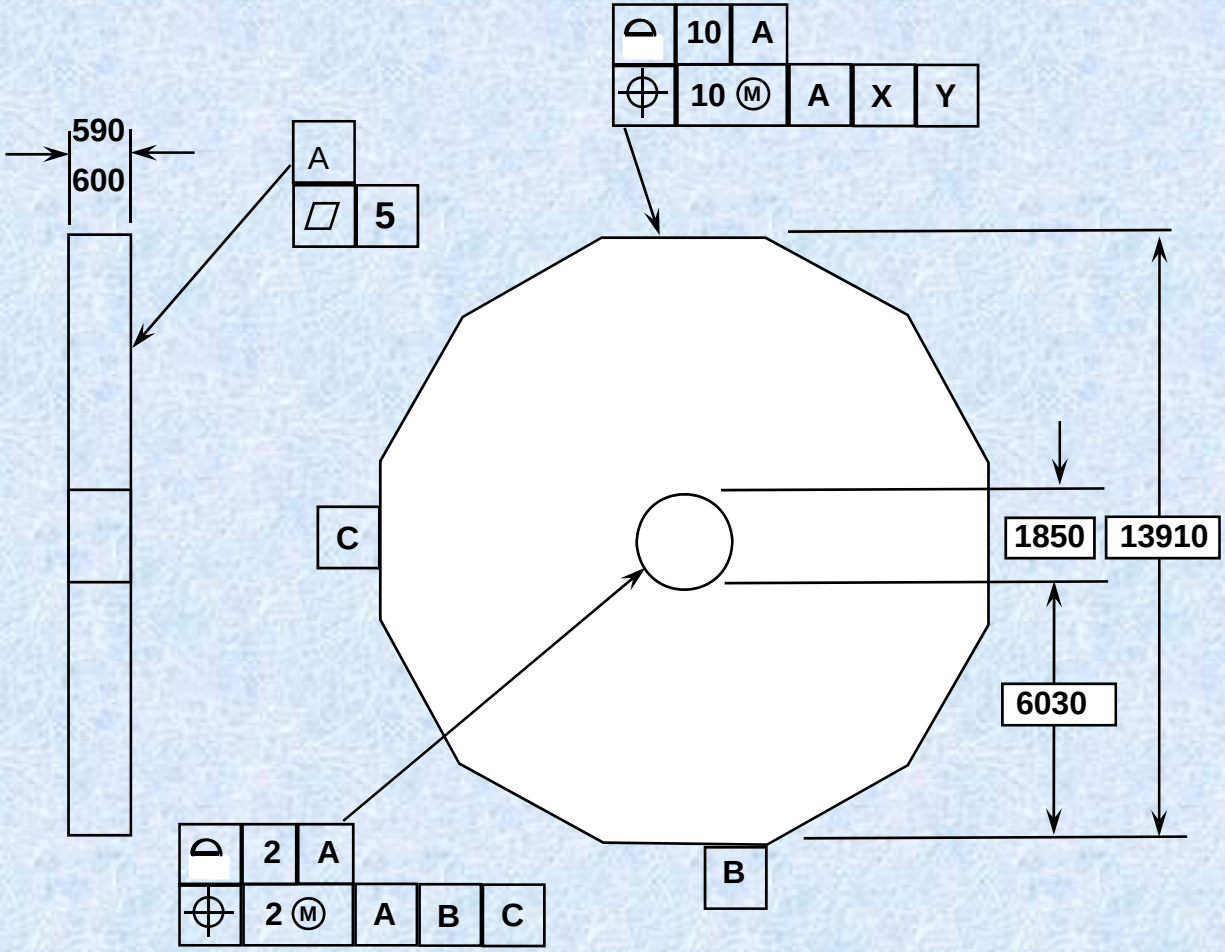
Abstract

This specification concerns the fabrication, machining, trial assembly, packaging, and transport to CERN of six endcap disk and six spacer rings of the magnet for the CMS experiment.

The six Endcap Disks, weighing 4000 tonnes in total, are mainly made from heavy plates of plain carbon steel

These items shall be delivered to CERN site P5 at Cessy (after custom formalities at Prévessin, France), exonerated from all duties and taxes.

Overall tolerances— Establish early but be realistic



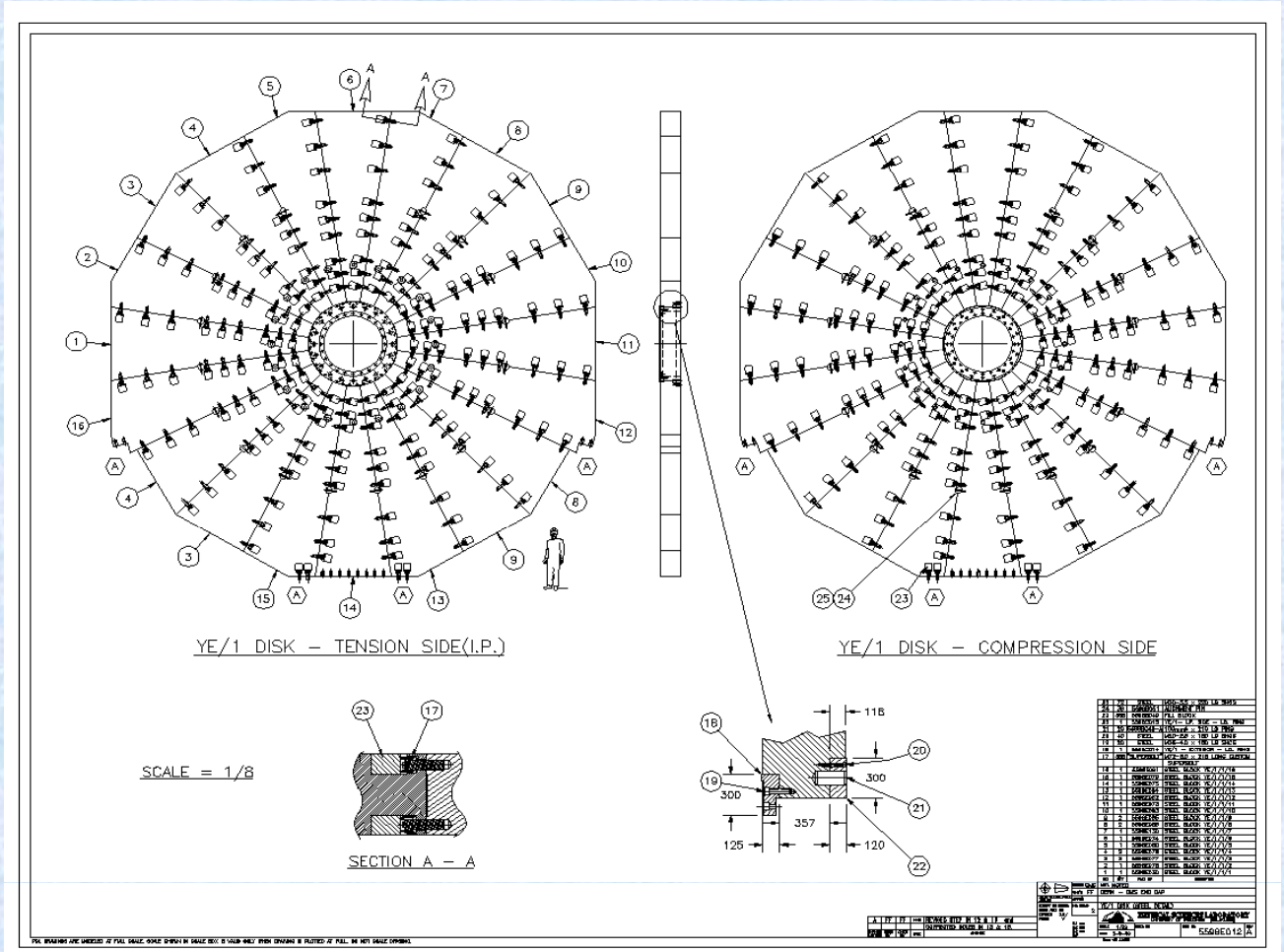
ALL TOLERANCES IN MM

What does it mean?

- The disk thickness varies between 590 mm and 600 mm.
- The boundary of the center hole is within 1 mm of its true form.
- The 12-sided boundary of the disk is within 5 mm of its true form.
- The entire disk is contained in a volume bounded by:
  - A 12-sided shape that is 13925 mm across,
  - by a cylinder that is 1797 in diameter and is centered on this shape,
  - and by two planes that are 600 mm apart.

Disk construction

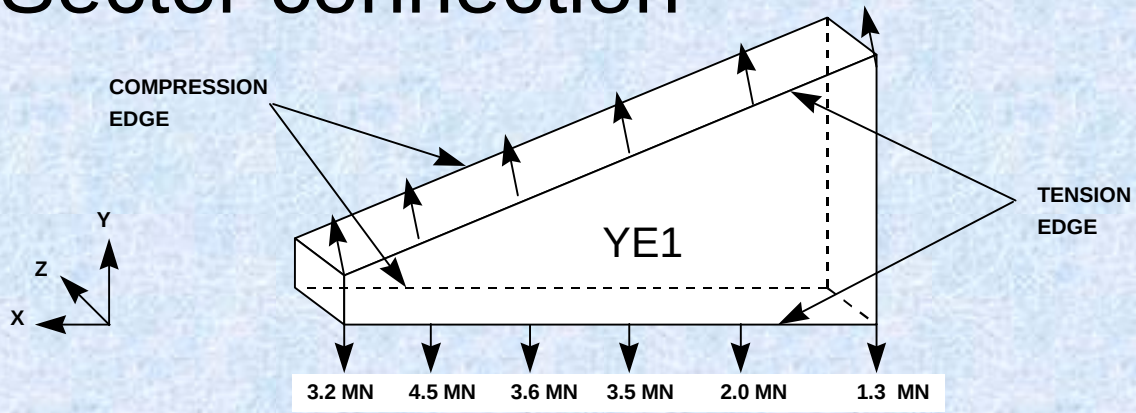
- Divided disks in sectors
- 20 sectors allowed good utilization of steel plates
- Joined by bolts resisting the tangential forces



Sector construction

- 600-mm thick sectors were made by sandwiching three 200-mm plates
- Plates were machined on mating surfaces and with weld prep
- Plates were welded on the edges only using robots
- Sectors were fully machined

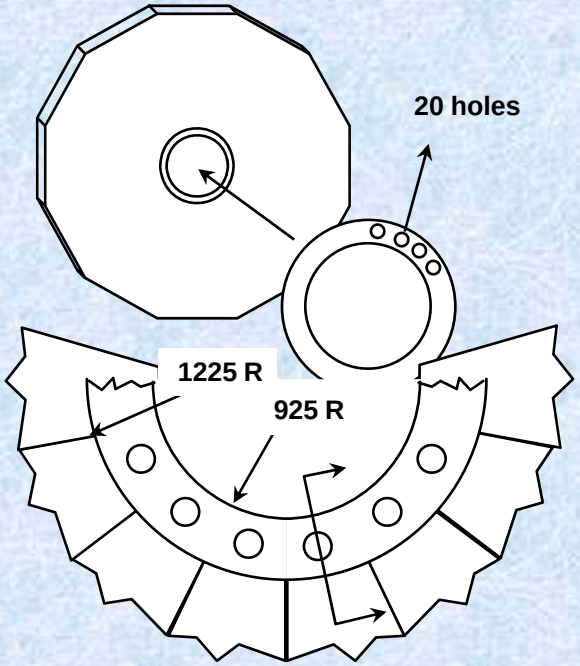
Sector connection

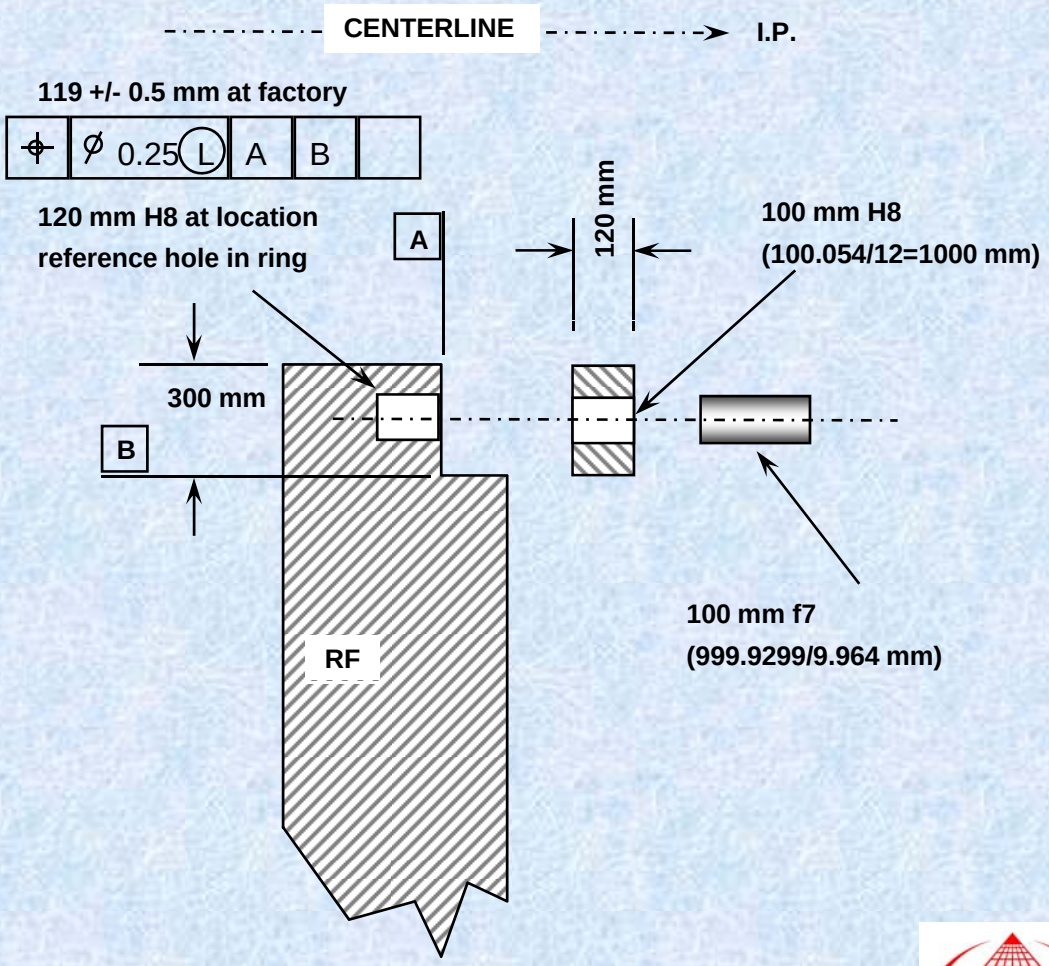


Shared among 10 bolts

- Use Superbolts® for connecting sectors
- All bolts (1600) tested to 2.7 MN
- Each bolt preloaded to 2.5 MN

Holding the center together





TENSION SIDE CENTER RING CONNECTION

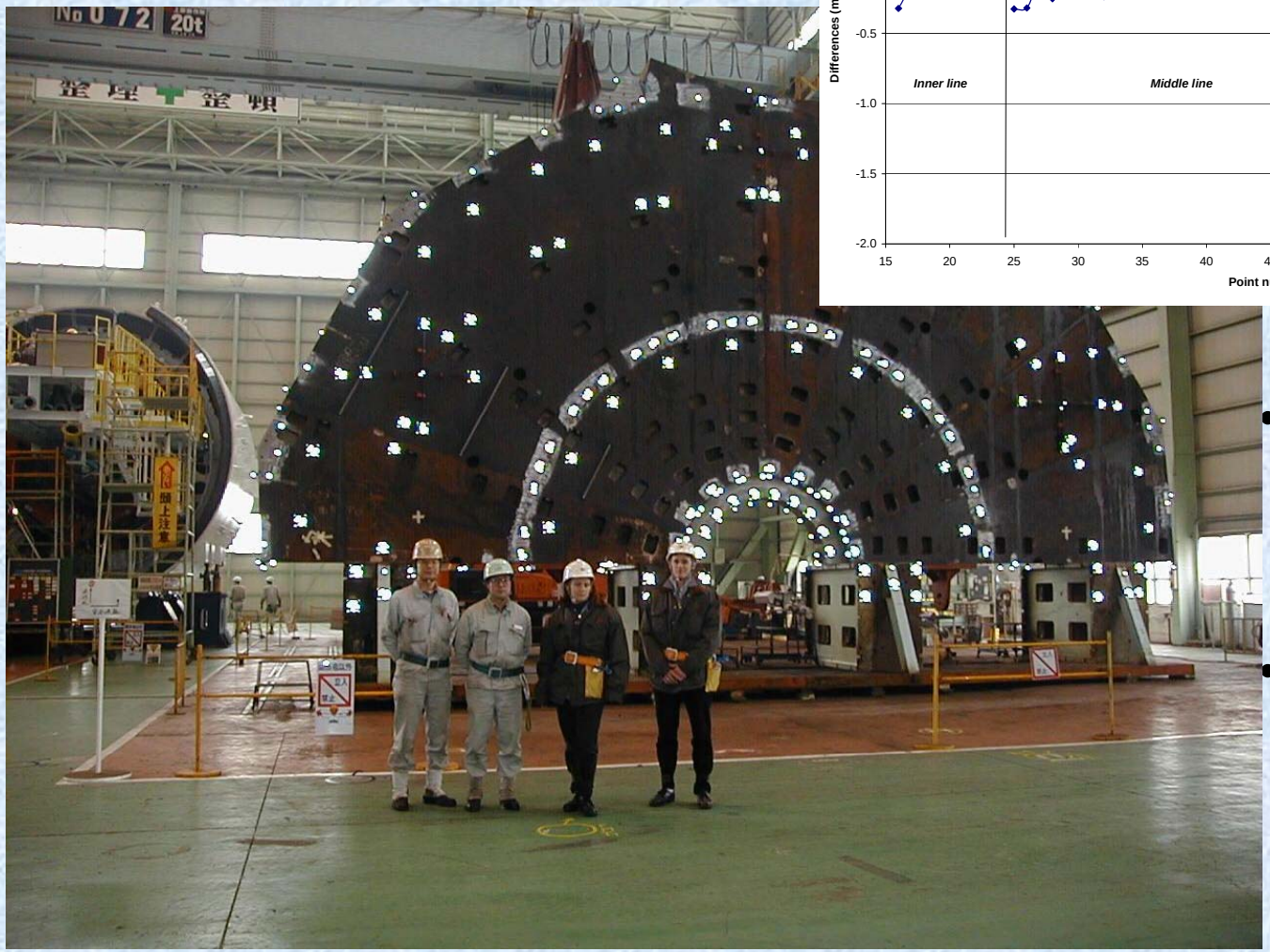
Trial assembly

- 10 sectors were assembled into ½-disk
- Mating surface to other half was machined

Machining

- Machine features for muon chamber installation and others in ½-disk
- Very accurate method—but don't use featured that require very small tools!

Verification

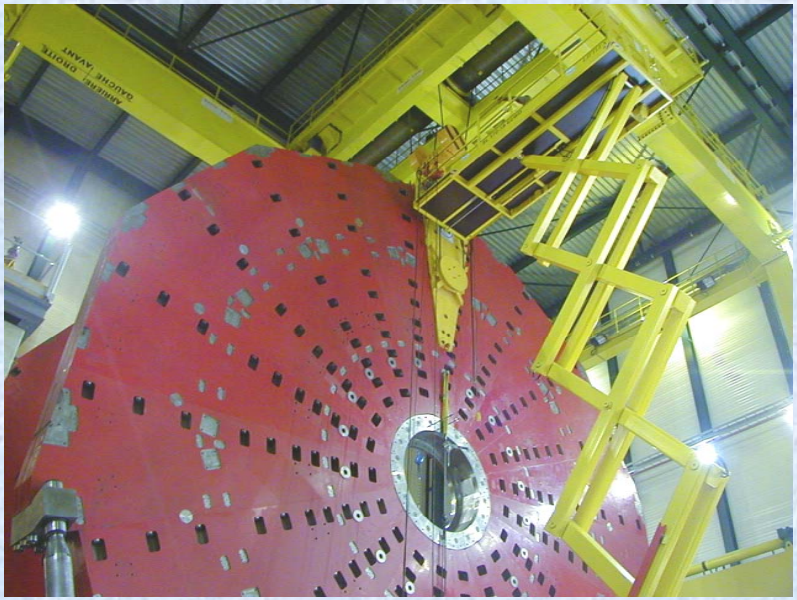


- Used photogrammetry to measure all features
- Trained factory staff to do all ½-disks

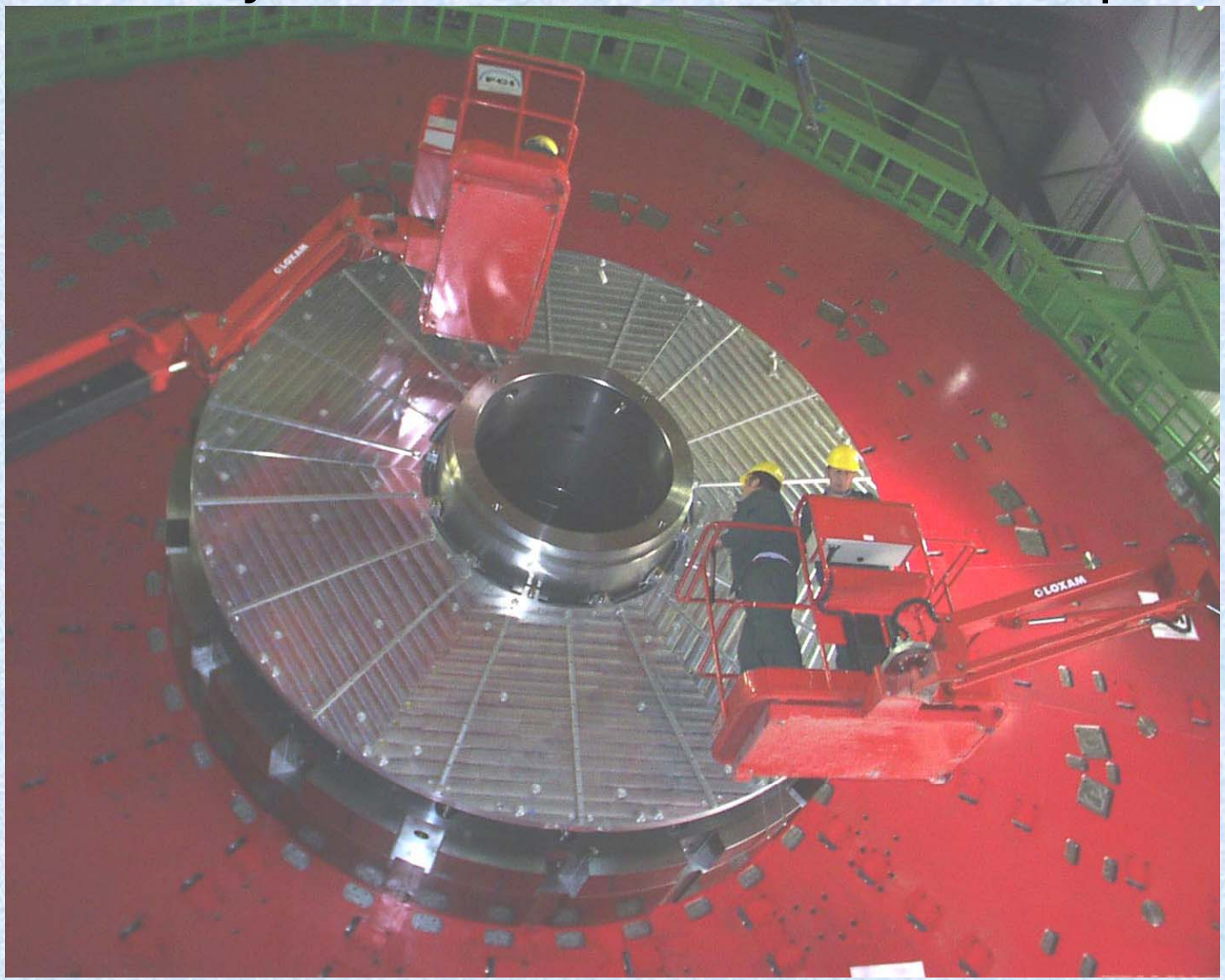
Full assembly

- Disks were fully assembled to fit with center rings and other parts
- All trial assembly was done horizontally

Final assembly on surface



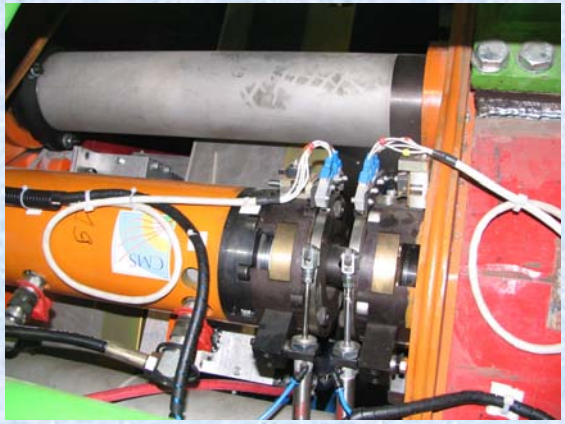
Assembly of nose and calorimeter back plate

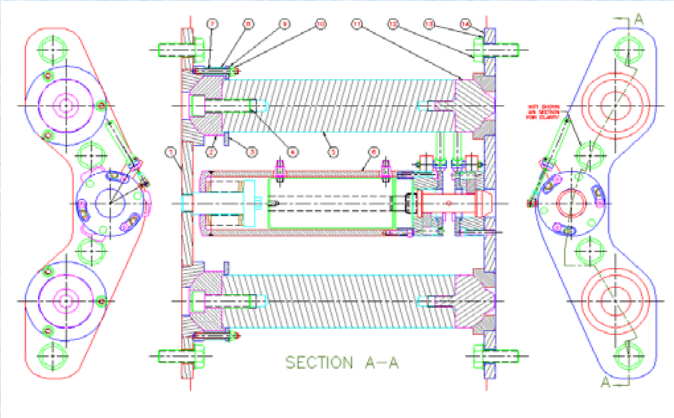


Comment: Access in narrow high places

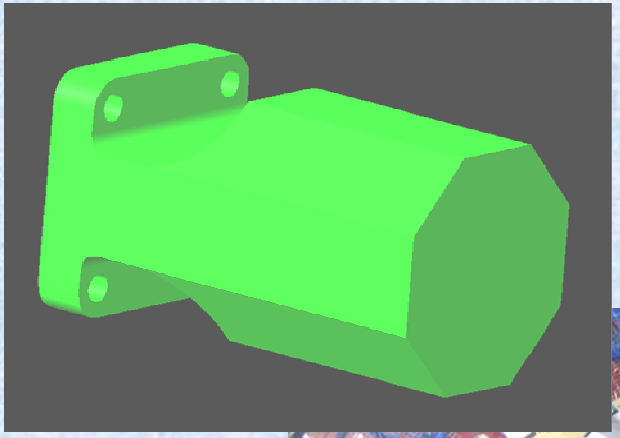
Corner connections

- All 12 corners have two posts resisting the compressive force
- 6 corners have hydraulic jacks to pull disks together and preload
- Jacks are locked and preload is transferred to spring washers
- Hydraulic pressure is resleased
- Jacks and posts are in spherical sockets

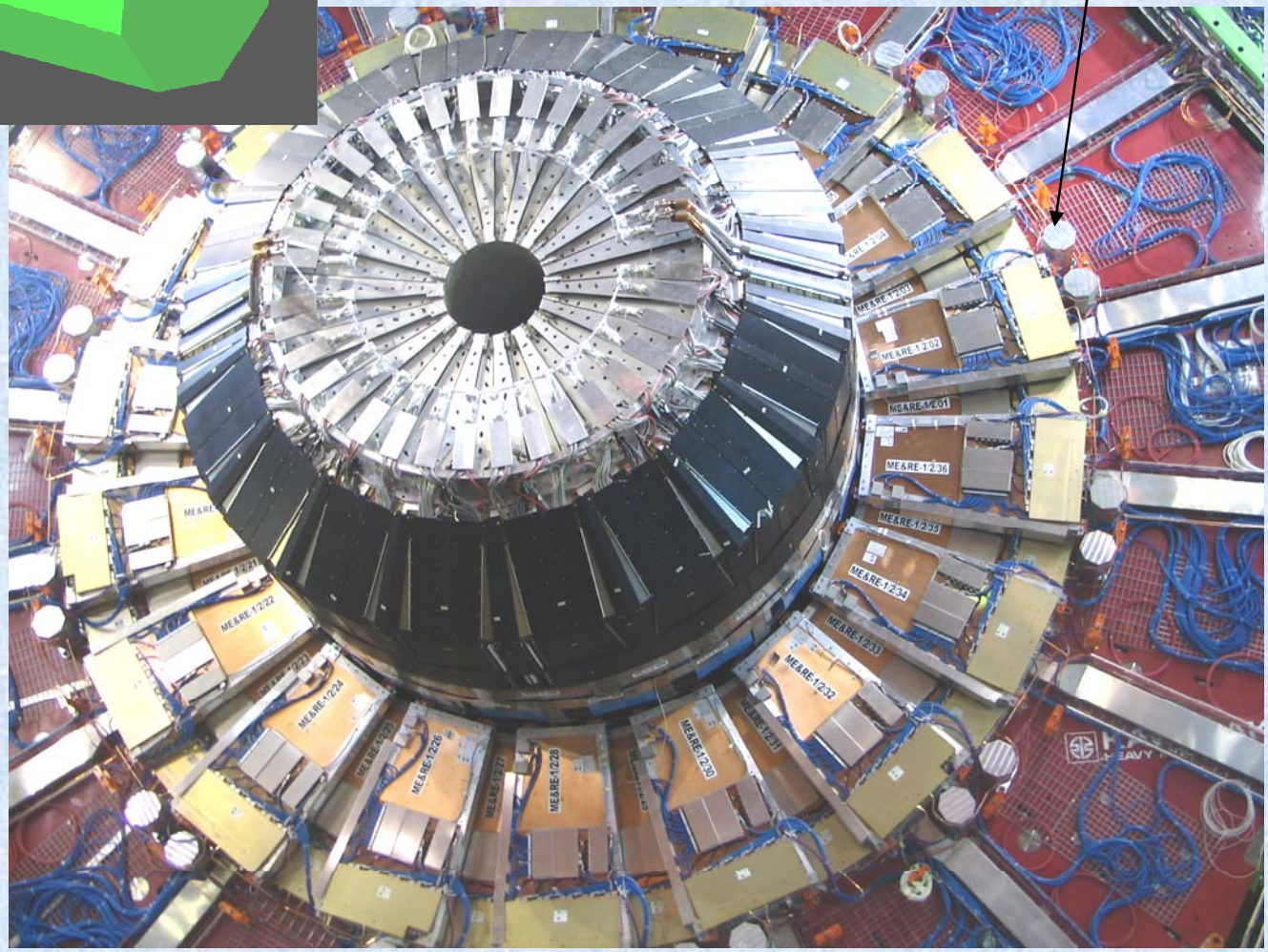




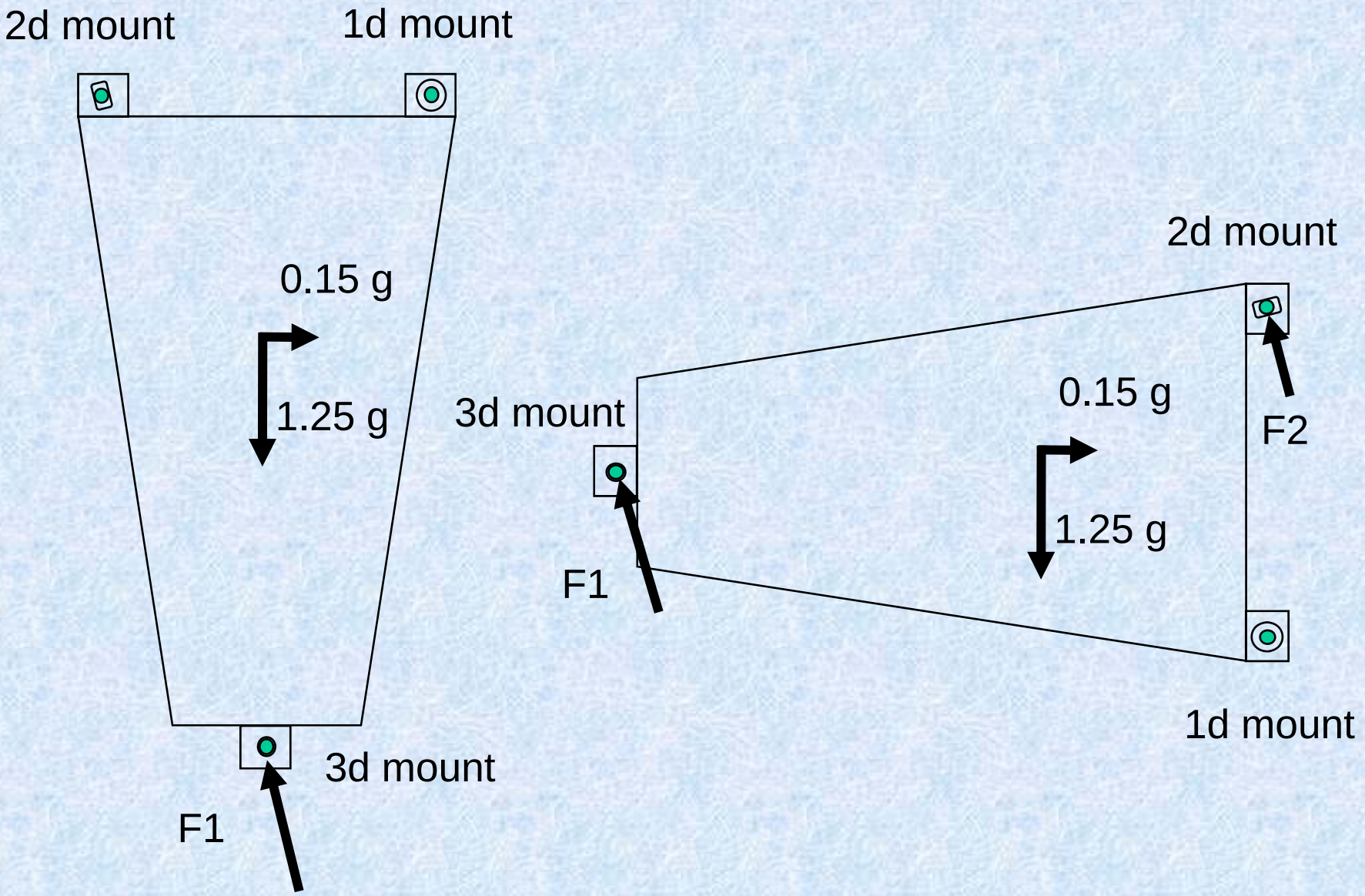
Z-Stops



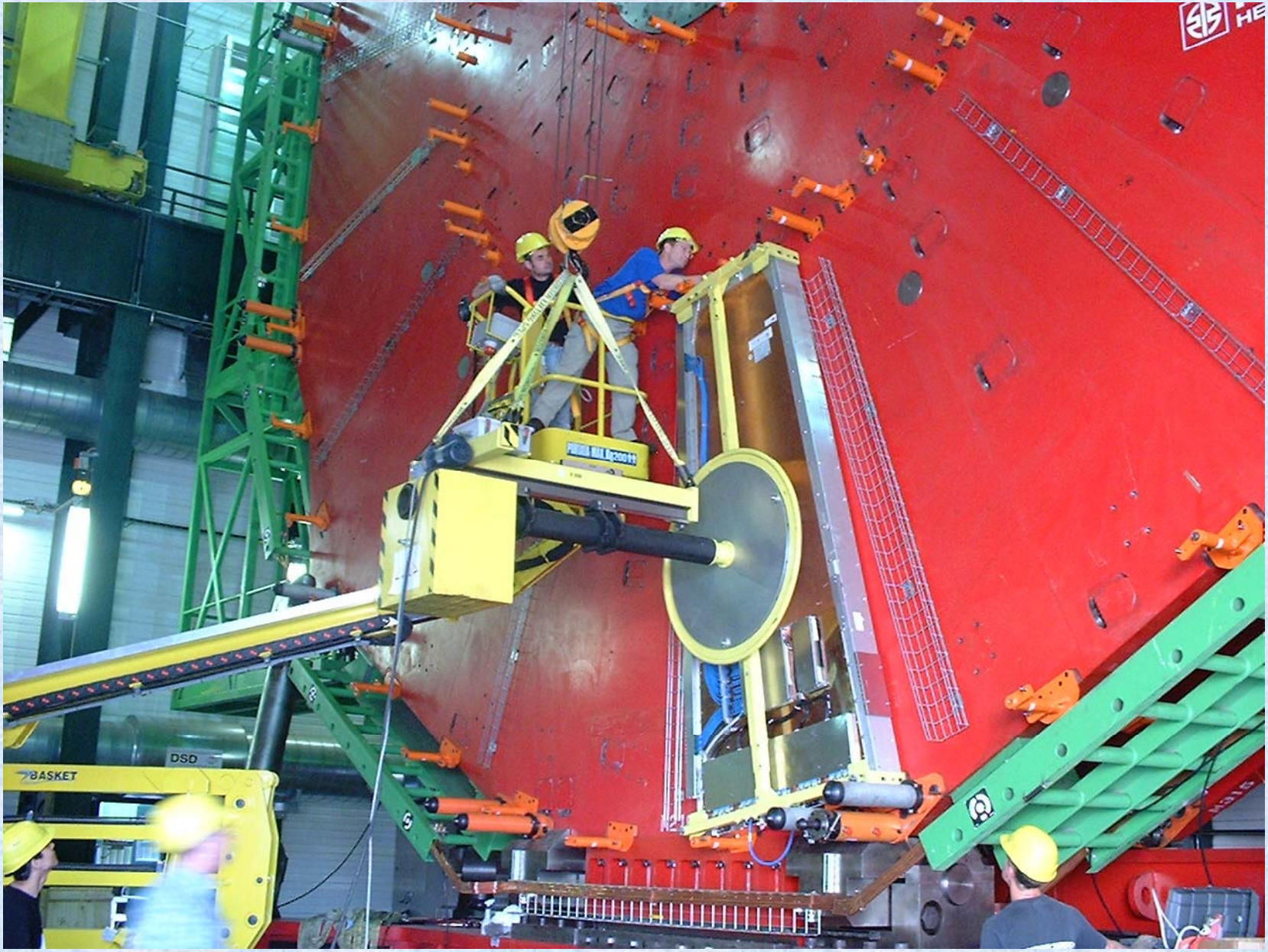
- Made from aluminum
- Accommodate angle difference by bending



Muon chamber mounting

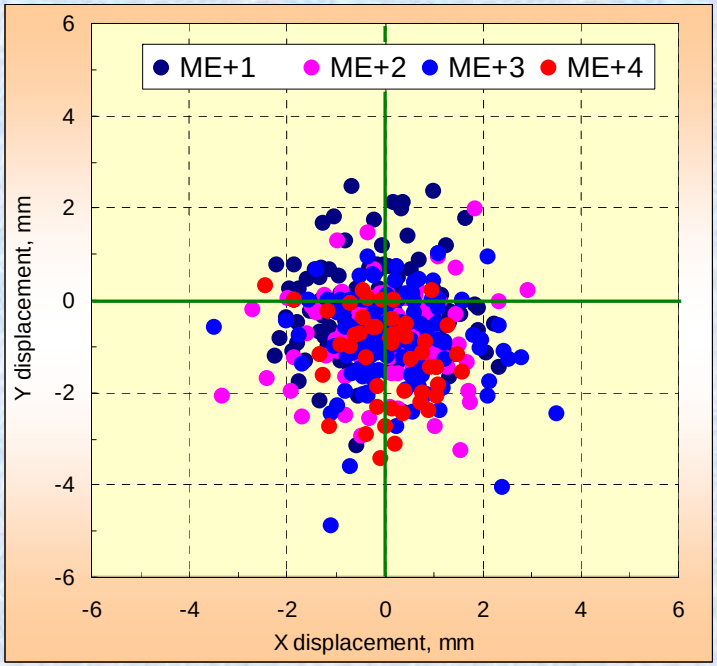


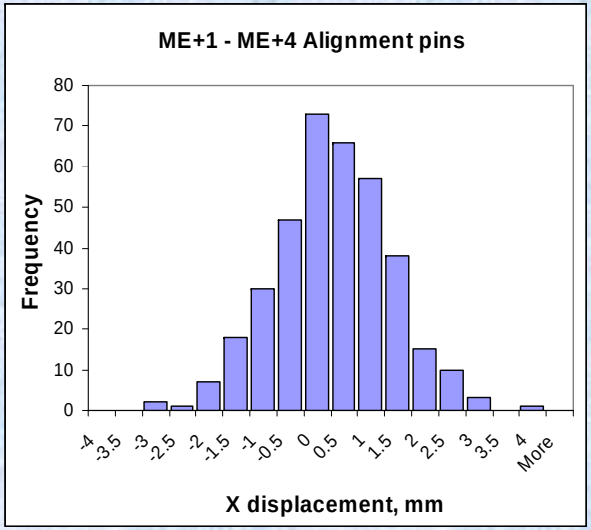
Mounting first CSC muon chamber with special tool

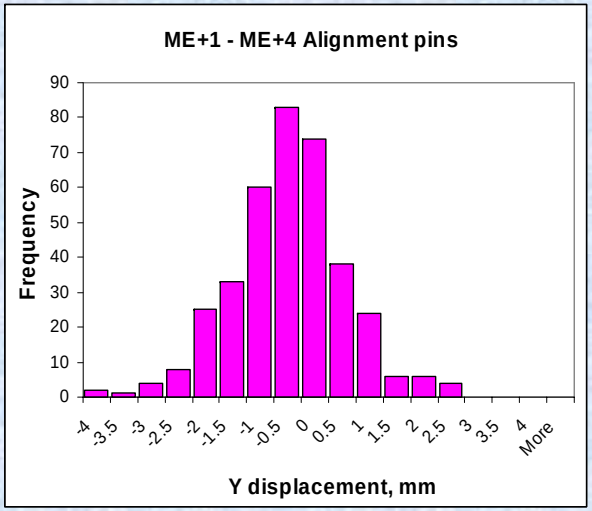


One full muon station with all services

Muon chamber positions on +Endcap



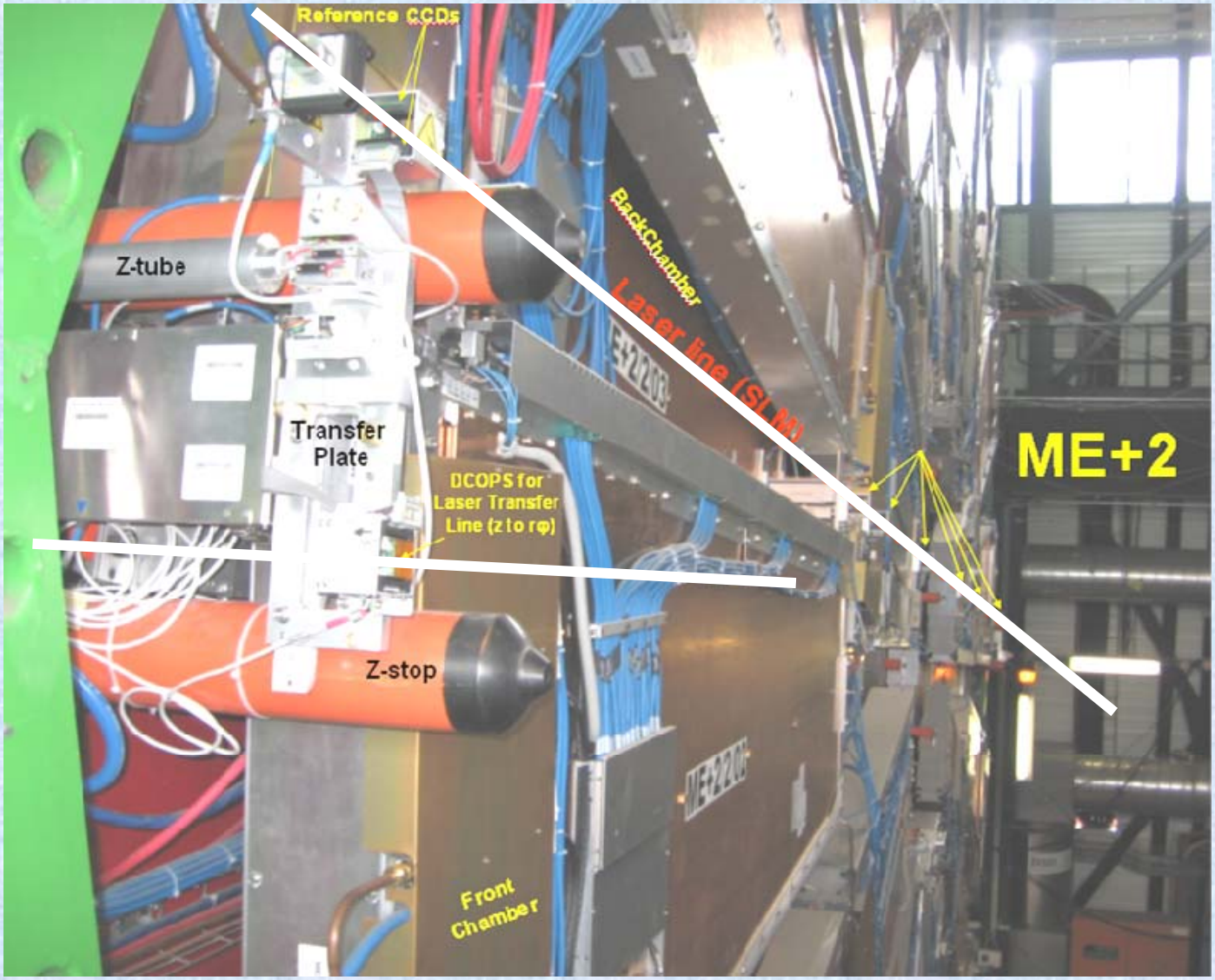




	Mean	RMS
ΔX, mm	0.04	1.07
ΔY, mm	-0.71	1.05

Accuracy chamber installation on the disk (X, Y) is ~ 1.0 mm (RMS)

Part of the CSC alignment system

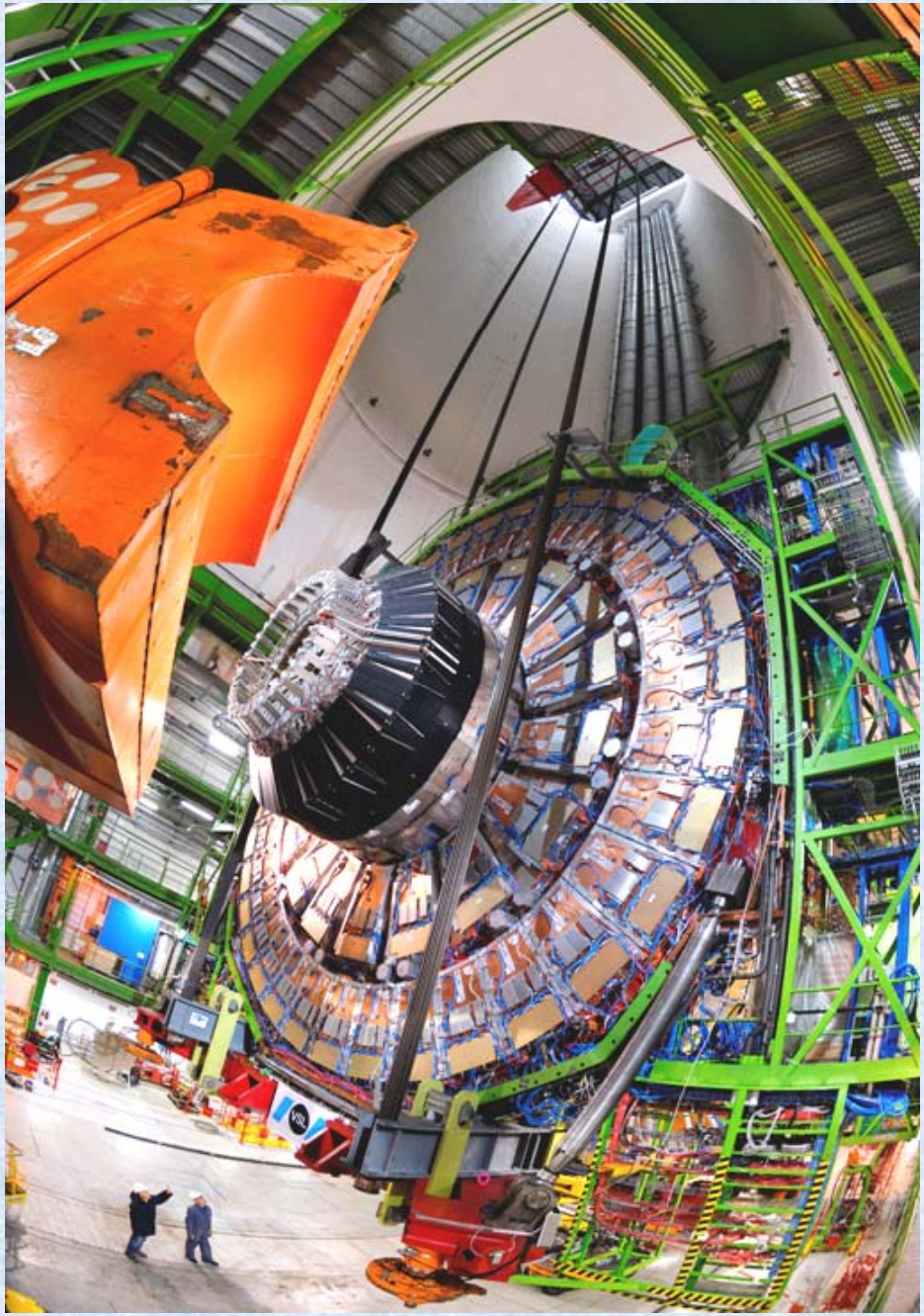


Support carts

- Each disk is independently supported on a cart
- Carts move on airpads for large motion and grease pads for small motion
- Disks sit on hinged blocks on carts—this is due to bending and moving of disk edges

- Large braces and keels keep disks from tipping
- Cart stance allows for 0.15g lateral load before tipping

Lowering YE1 into cavern



Lessons and summary

- Use precision in design and construction—it is NOT more expensive than the alternative
- You only have time to do it right the first time
- Use industrial partners and count on their ideas
- But have a full design just in case
- Strive for high rigidity but know where deflections are
- Make it safe!!!