Silicon Detector (SiD) at the International Linear Collider

T. Markiewicz/SLAC

Superconducting Magnet Workshop, CERN

2022-09-12

U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

People

Marty Breidenbach*: overall design concept

Wes Craddock: Coil and Cryo design

Marco Oriunno: Return Flux optimization

Tom Markiewicz: Interface with final quad package (MDI) & A.O.B.

*See unpublished note by M.I.B, attached to INDICO:
“SiD SUPERCONDUCTING MAGNET DESIGN AND SUPERCONDUCTING CABLE DEVELOPMENT FOR SiD and BEYOND”; 11 Jan 2008

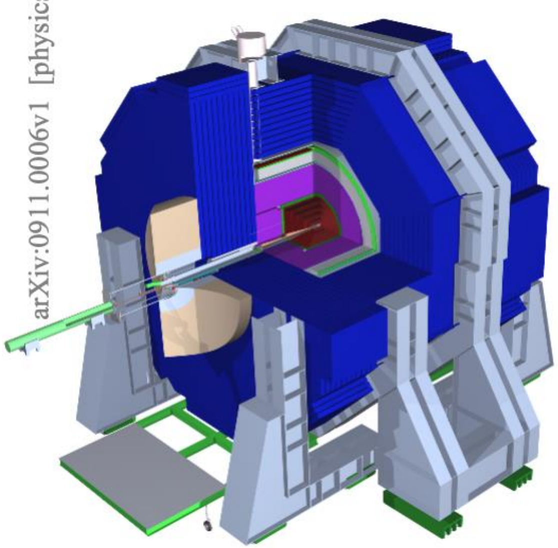
Documentation

arXiv:0911.0006v1 [physics.ins-det] 30 Oct 2009

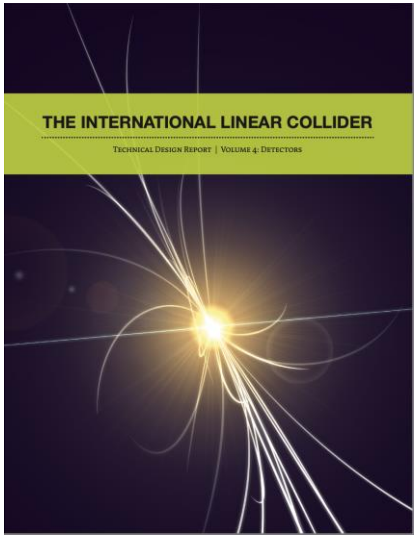
SiD Letter of Intent

2009

31 March 2009



2013



Technical Design Report

https://arxiv.org/abs/1306.6329

https://arxiv.org/pdf/0911.0006.pdf

Wes Craddock Talks

- SiD Magnet Overview, ECFA 2013, 2013-05-28
  https://agenda.linearcollider.org/event/5840/contributions/26238/attachments/21682/33998/ECFA_LC2013_SiD_Magnet_Talk_5-28-2013.pdf
- Magnet DBD STATUS, SiD Workshop, 2013-01-17
  https://agenda.linearcollider.org/event/5950/contributions/27184/attachments/22543/35173/SiD_Magnet_DBD_Talk_1-17-2013.pptx
- Magnet DBD STATUS, SiD Workshop, 2012-08-22
  https://agenda.linearcollider.org/event/5759/contributions/25909/attachments/21328/33488/SiD_Magnet_DBD_Talk_8-21-2012.pdf
- SiD Cryogenics, SLD/ILD Interface Meeting, 2011-12-12
  https://agenda.linearcollider.org/event/5399/contributions/23298/attachments/19107/30465/2011-12-12-Craddock-ILC_IR_Cryo_Design.pptx
- SiD Solenoid Update, LCD Magnet Meeting, CERN, 2010-05-18
  https://indico.cern.ch/event/94798/contributions/1282809/attachments/1106746/1578957/CERN_LCD_Magnet_Meeting__May__2010.pdf
- SiD SC Magnet & Cable, SiD Workshop, 2008-09-18
  https://agenda.linearcollider.org/event/2784/contributions/9370/attachments/7264/12152/SiD_SC_Magnet_and_Cable.pdf

Design Philosophy

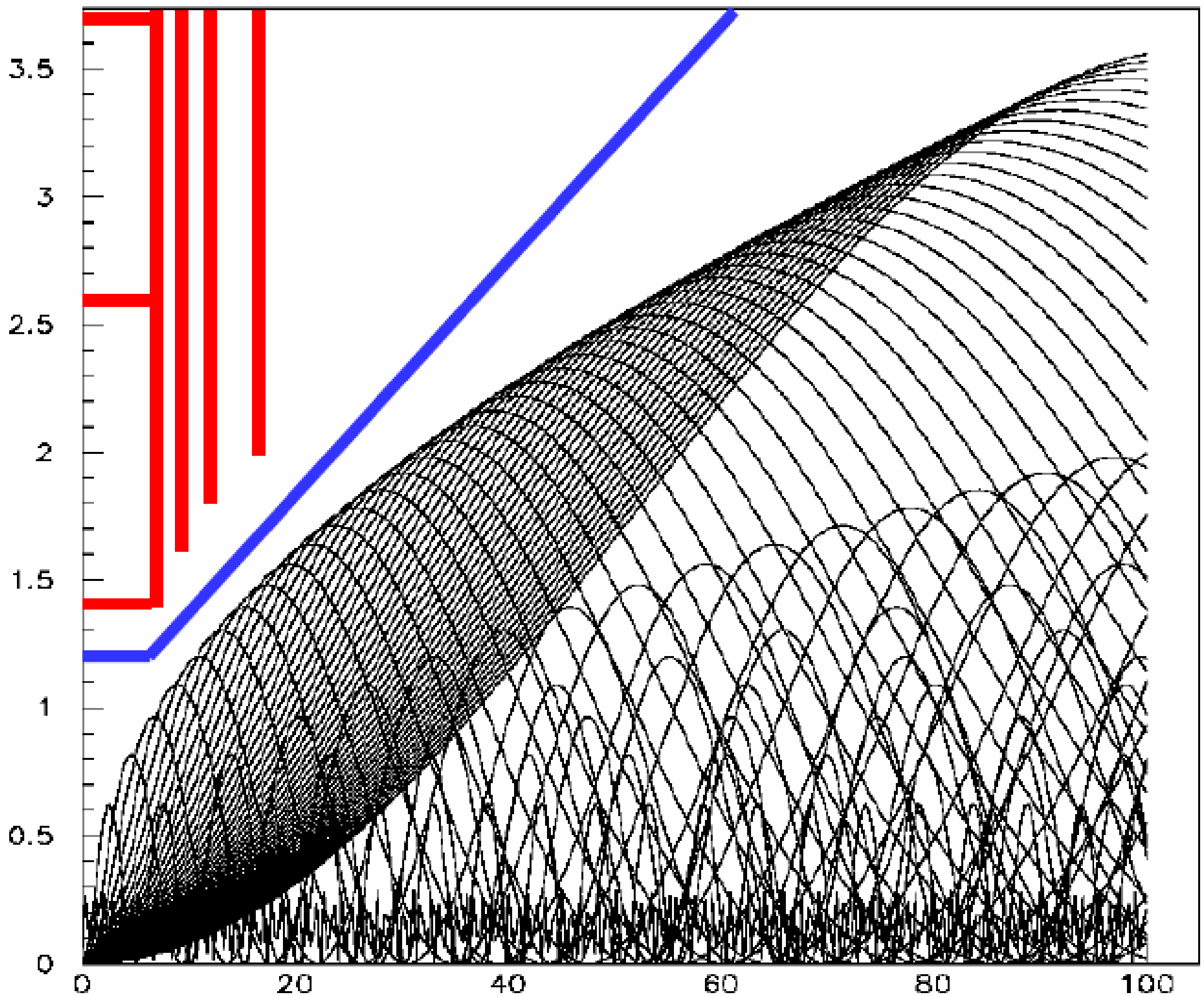
Highest Field Possible

- Best tracking while
  - Limiting volume
  - Limiting cost of entire detector
- Best suppression of e+e- pair background
  - Lowest radius beampipe and vertex detector closest to IP as possible
- Integrate FF quad package at lowest possible L*

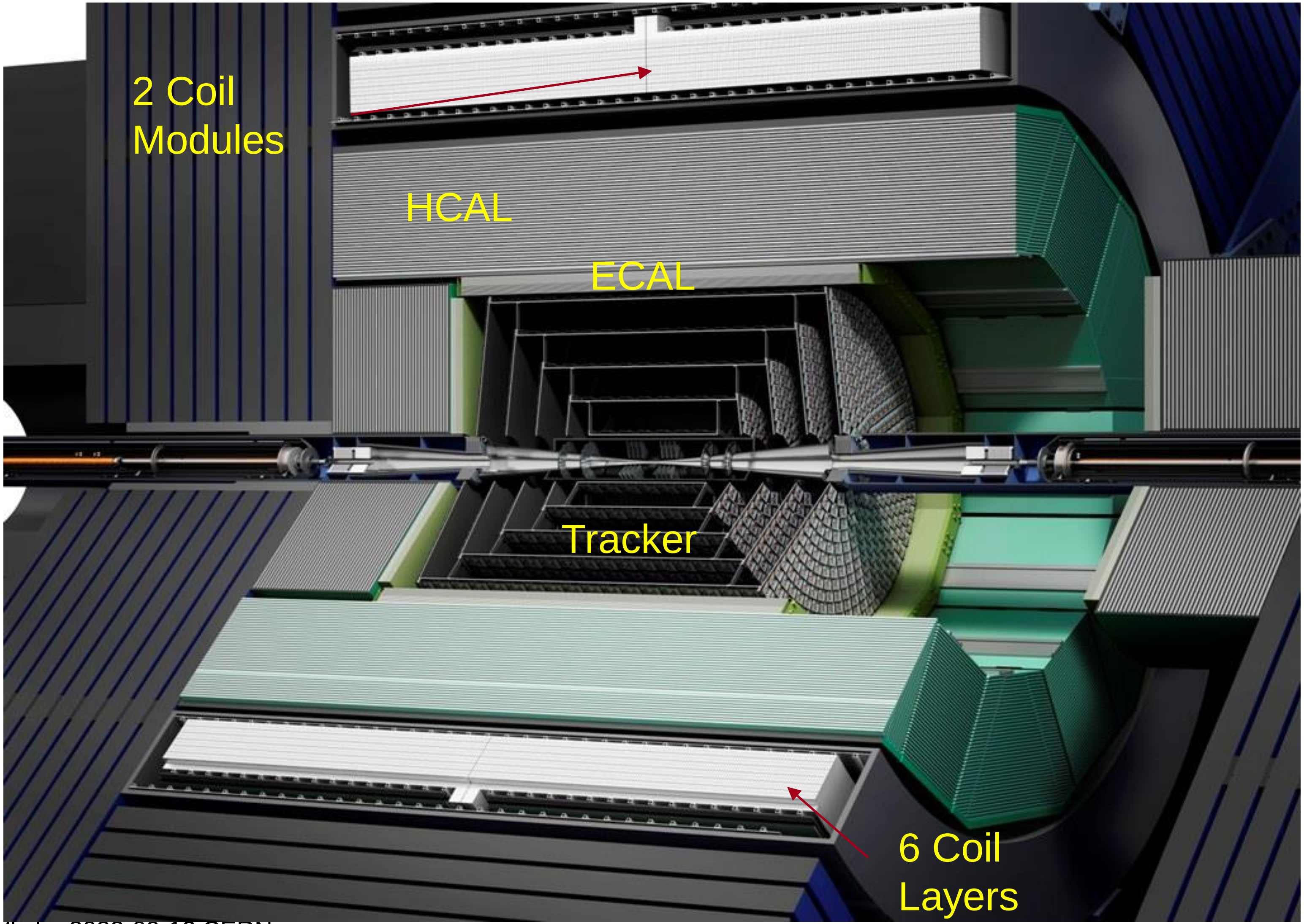
Use of robust Silicon Detectors integral to magnet design

- To be contrasted with a wire TPC in a larger but lower field as selected by ILD
- SLD at SLC experience

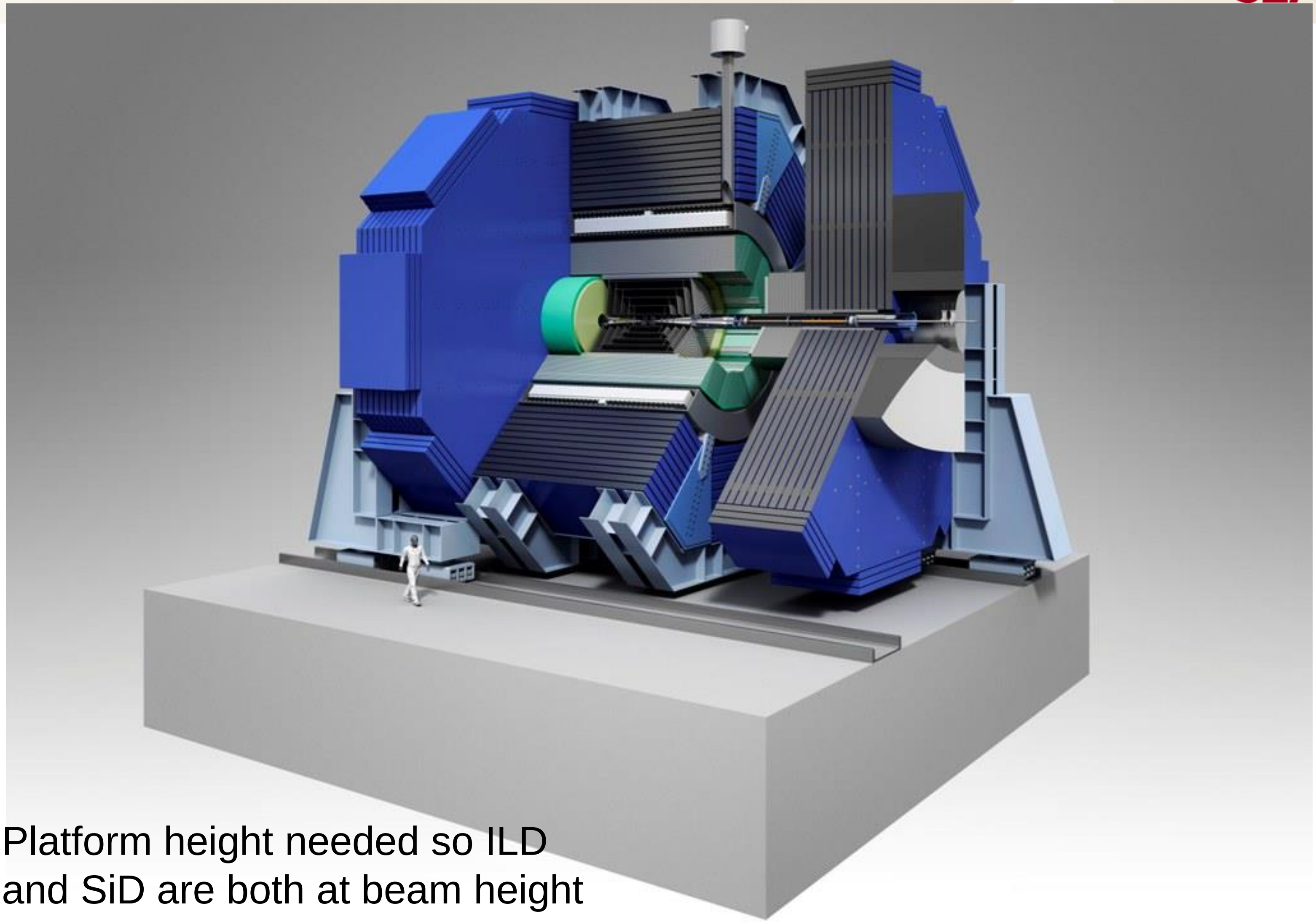
12mm Beam Pipe and VXD Detail
e+e- pair background spiral in 5T field



SiD ~2013

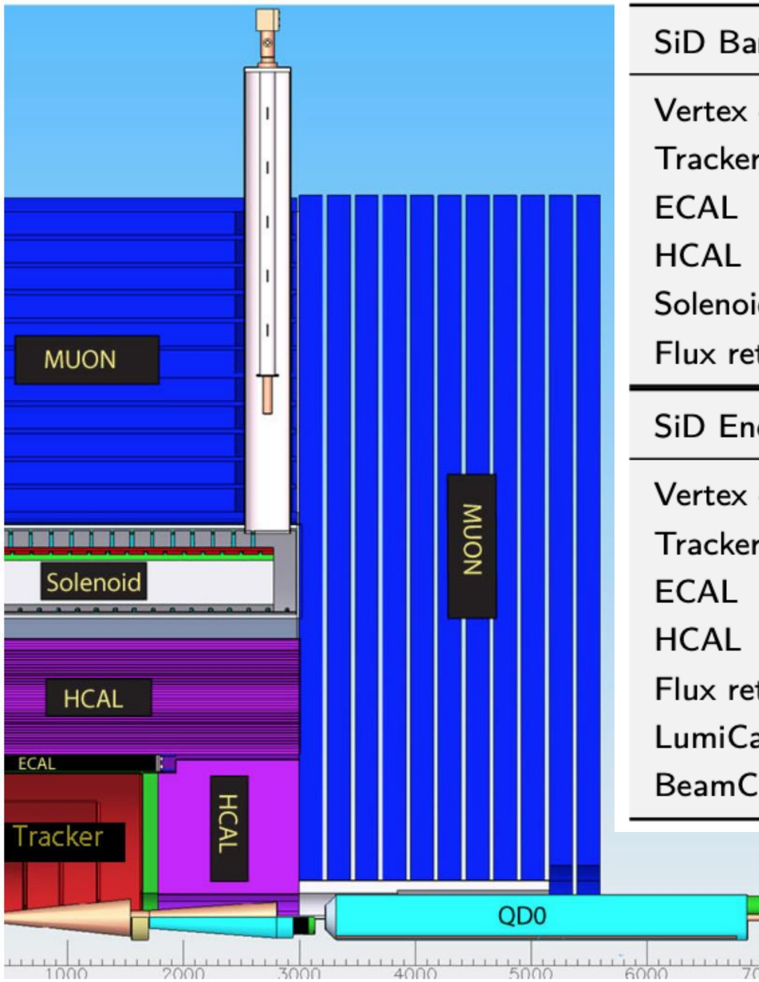


SiD on Concrete Platform w/ 2013 Iron Design



Platform height needed so ILD and SiD are both at beam height

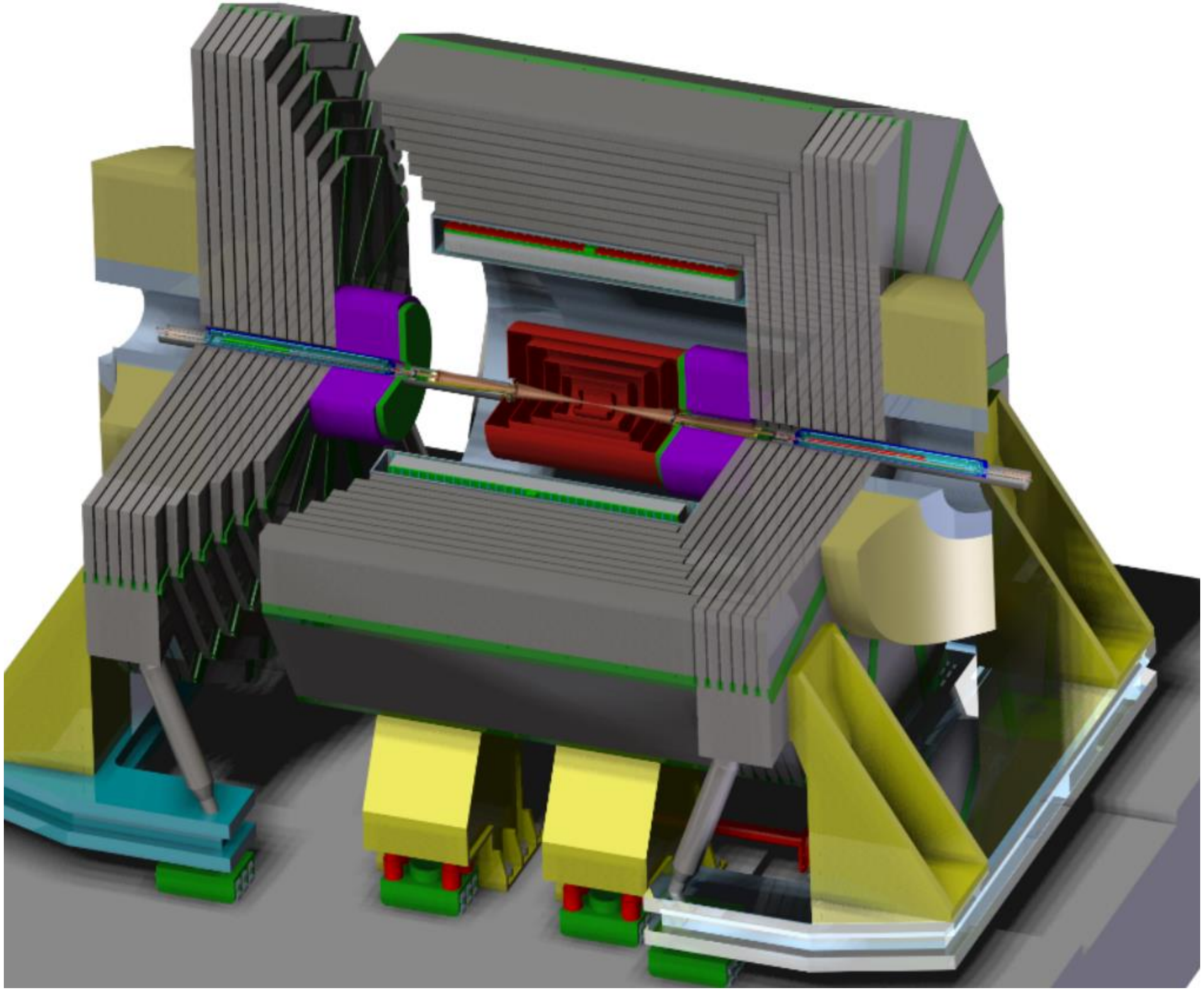
SiD ~2013 with Key Dimensions



SiD Barrel	Technology	Inner radius	Outer radius	z extent
Vertex detector	Silicon pixels	1.4	6.0	± 6.25
Tracker	Silicon strips	21.7	122.1	± 152.2
ECAL	Silicon pixels-W	126.5	140.9	± 176.5
HCAL	RPC-steel	141.7	249.3	± 301.8
Solenoid	5 Tesla SC	259.1	339.2	± 298.3
Flux return	Scintillator-steel	340.2	604.2	± 303.3

SiD Endcap	Technology	Inner z	Outer z	Outer radius
Vertex detector	Silicon pixels	7.3	83.4	16.6
Tracker	Silicon strips	77.0	164.3	125.5
ECAL	Silicon pixel-W	165.7	180.0	125.0
HCAL	RPC-steel	180.5	302.8	140.2
Flux return	Scintillator/steel	303.3	567.3	604.2
LumiCal	Silicon-W	155.7	170.0	20.0
BeamCal	Semiconductor-W	277.5	300.7	13.5

SiD ~2015 with Modified Yoke: 30° Door-Barrel Joint Reduced Fringe Field with Less Steel



Engineering Design Philosophy

Guided by CMS and BaBar Experience

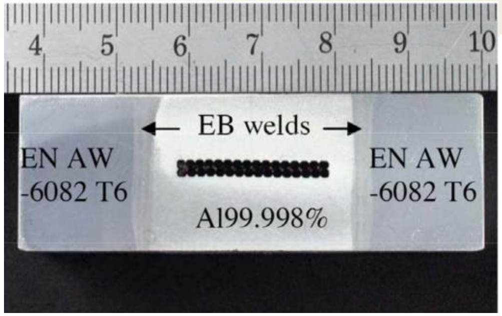
- Limited funding prevents additional R&D as suggested by MIB

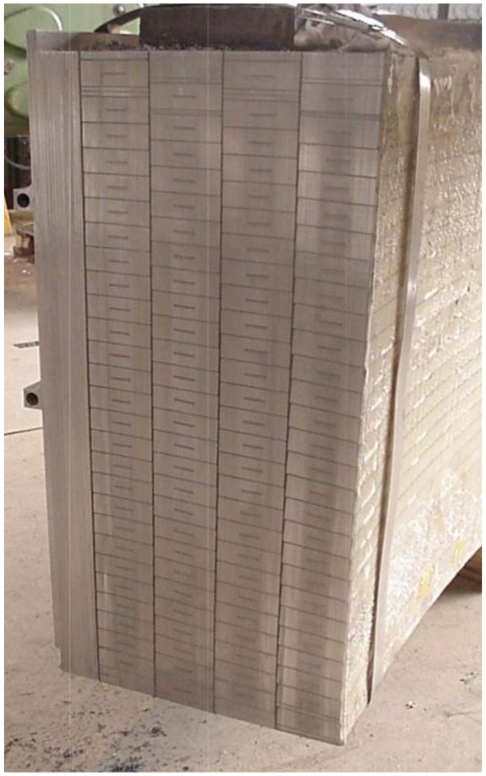
- Same winding pattern against outer mandrel
  - vacuum impregnation
  - mandrel joining techniques
  - conductor splicing methods.

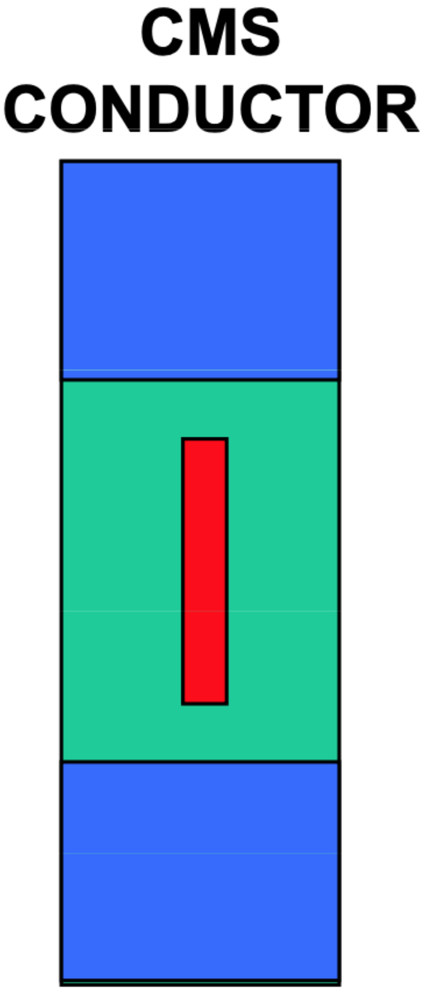
- Same ~coil length of each coil layer
- Conduction cooling of coil
  - SiD and CMS safety rely on the winding mandrel serving as a quench back cylinder spreading the quench over the outer layer and absorbing some of the stored energy.

- SiD uses a compact pressurized water-cooled dump resistor

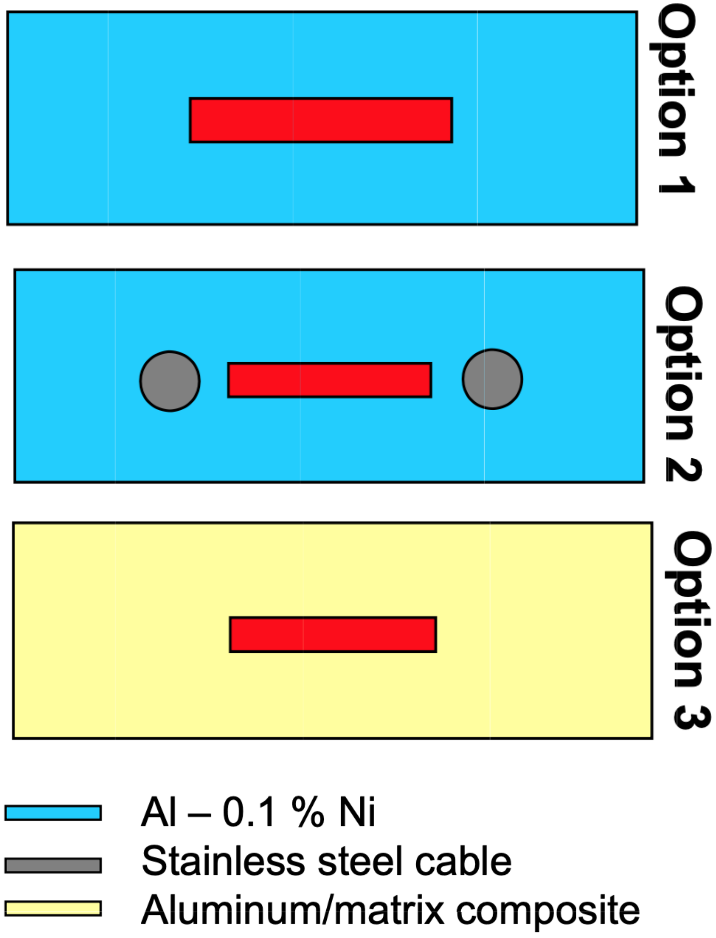
SiD Conductor = Slightly Modified CMS Conductor







Many Options Considered but not pursued

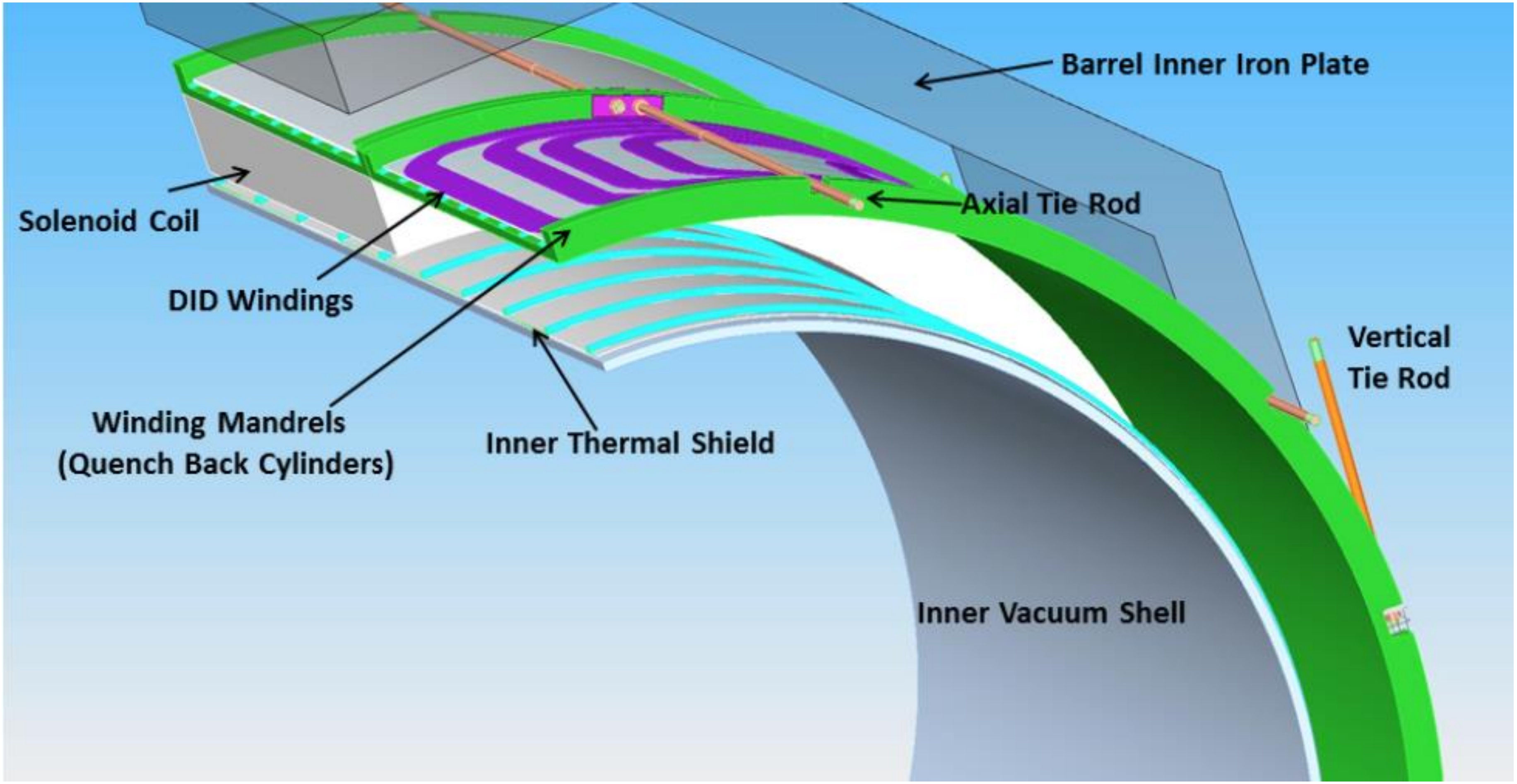


Comparison of SiD and CMS Coils

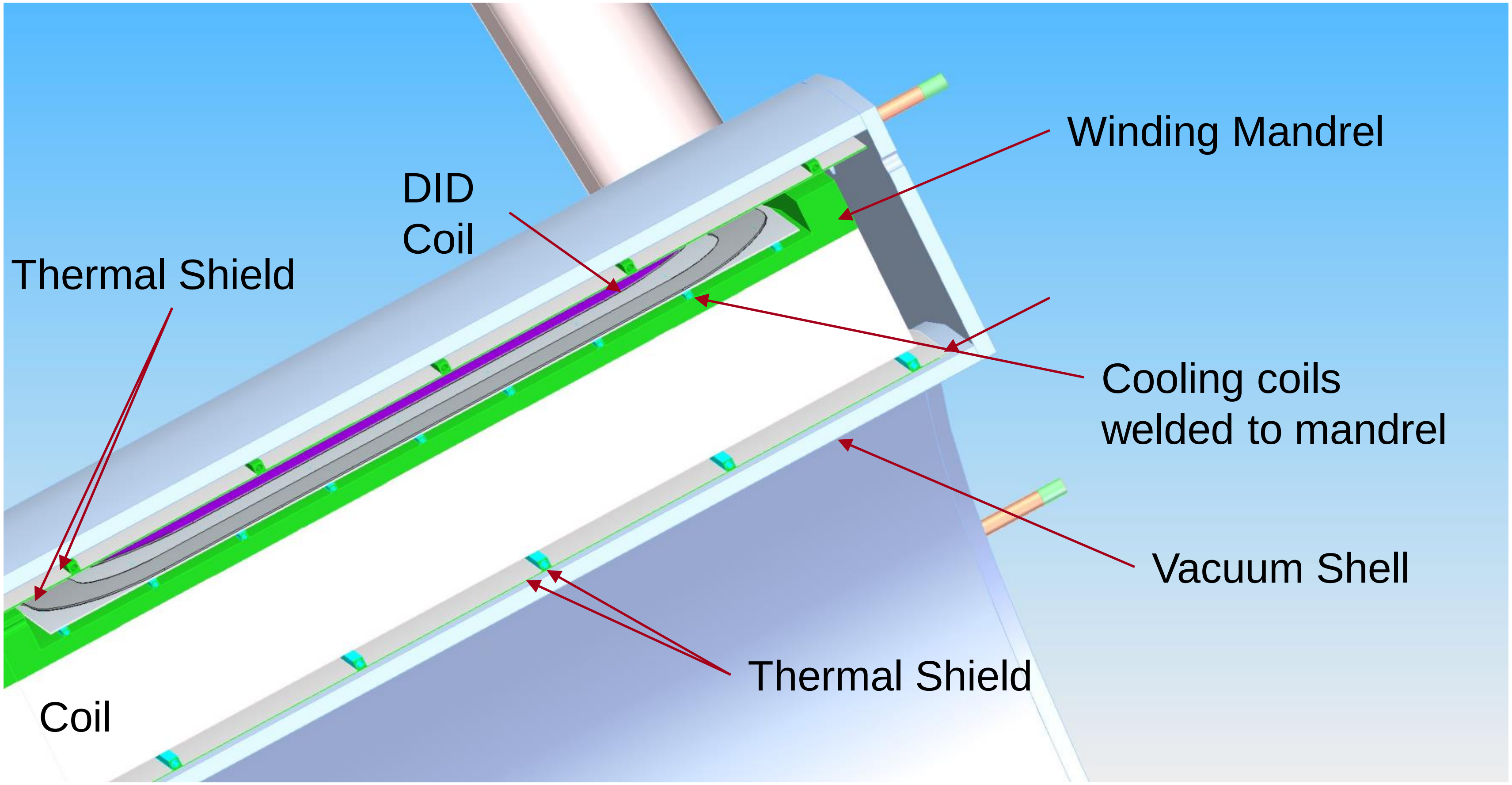
Quantity	SiD	CMS	Units
Central Field	5.0	4.0	T
Stored Energy	1.59	2.69	GJ
Stored Energy Per Unit Cold Mass	12	11.6	kJ/kg
Operating Current	17.724	19.2	kA
Inductance	9.9	14.2	H
Fast Discharge Voltage to Ground	300	300	V
Number of Layers	6	4	
Total Number of Turns	1459	2168	
Peak Field on Superconductor	5.75	4.6	T
Number of CMS superconductor strands	40	32	
% of Short Sample	32	33	
Temperature Stability Margin	1.6	1.8	K
Total Cold Mass of Solenoid	130	220	tonne
Number of Winding Modules	2	5	
R_{min} Cryostat	2.591	2.97	m
R_{min} Coil	2.731	3.18	m
R_{max} Coil	3.112	3.49	m
R_{max} Cryostat	3.392	3.78	m
Z_{max} Cryostat	$\pm$ 3.033	$\pm$ 6.5	m
Z_{max} Coil	$\pm$ 2.793	$\pm$ 6.2	m
Operating Temperature	4.5	4.5	K
Cooling Method	Forced flow	Thermosiphon	

6.8m OD x 6m Length

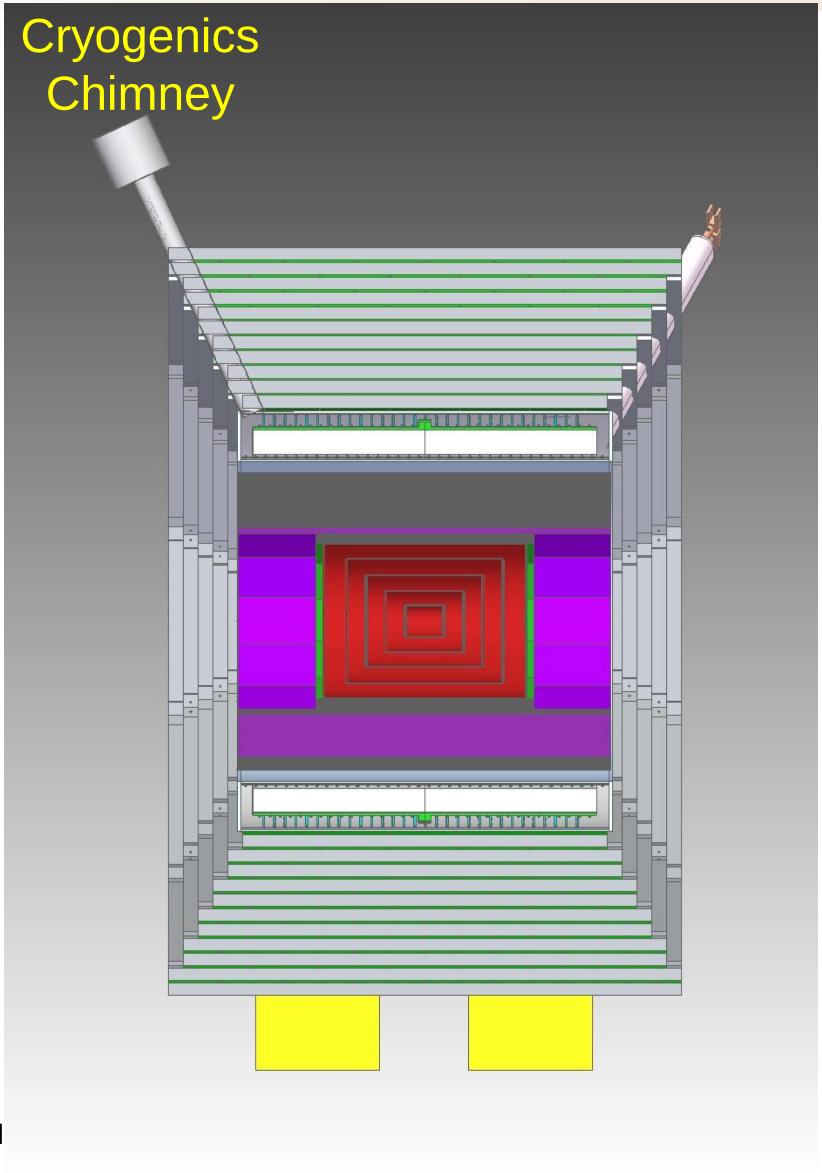
Elements of Coil Package

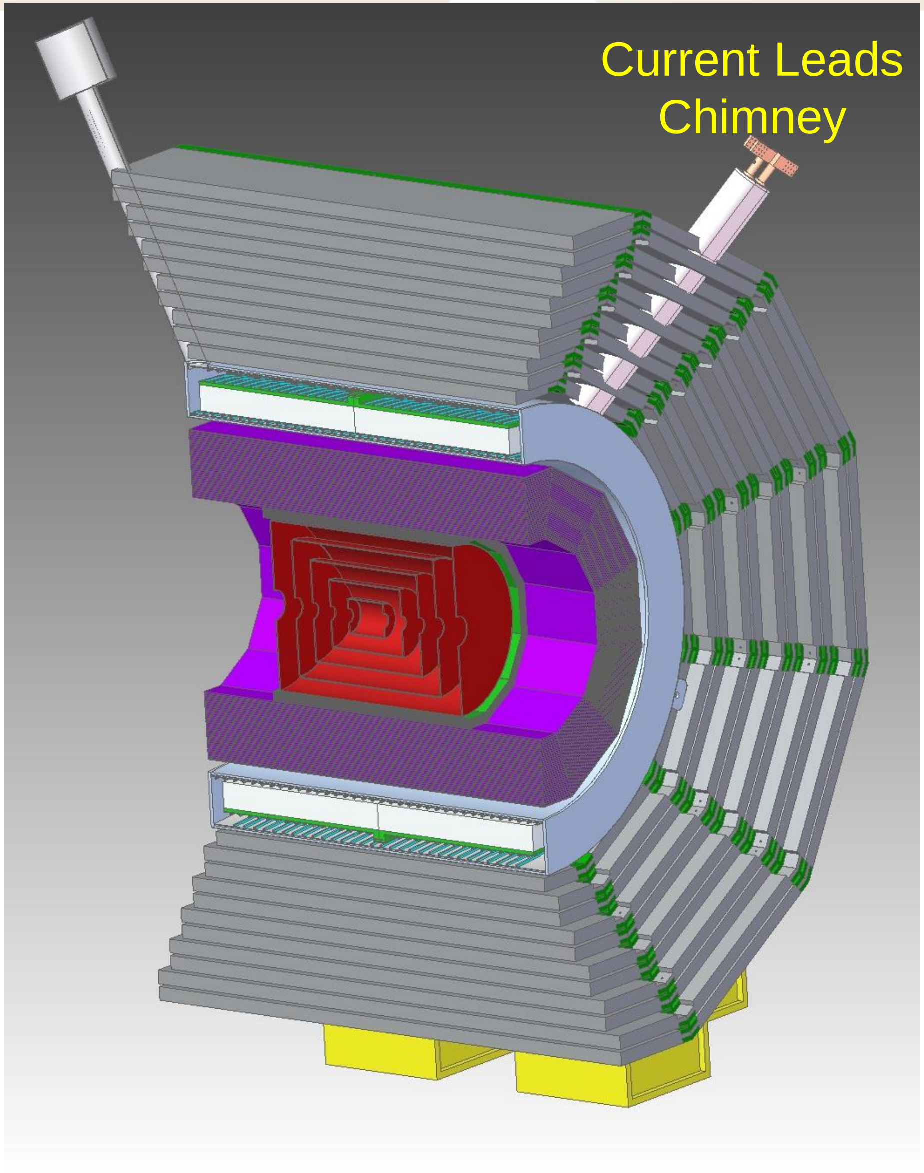


Another View of the coil package

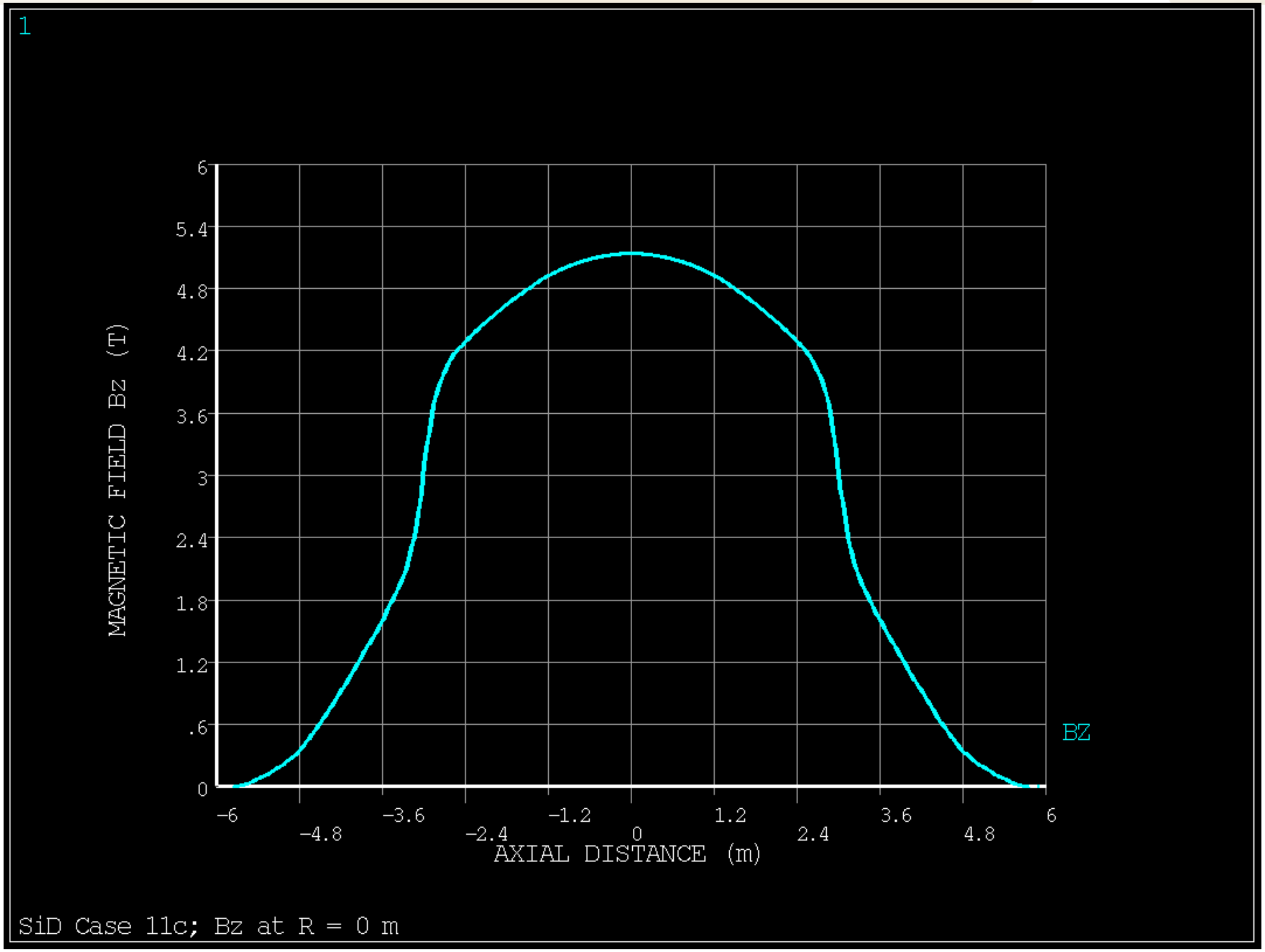


Total Barrel with Coil, HCAL and Feet: Mass=4540 Tons

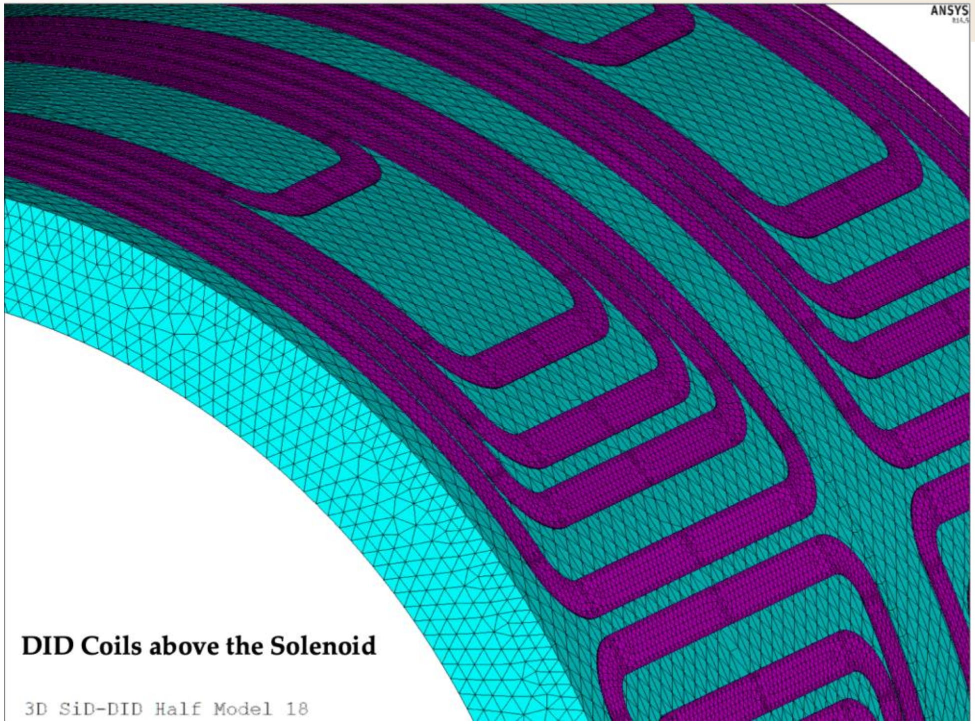




Bz at R=0


1
6
5.4
4.8
4.2
3.6
3
2.4
1.8
1.2
.6
0
MAGNETIC FIELD Bz (T)
-6
-4.8
-3.6
-2.4
-1.2
0
1.2
2.4
3.6
4.8
6
AXIAL DISTANCE (m)
BZ
SiD Case 11c; Bz at R = 0 m

600-Gauss Sinusoidal "Detector Integrated Dipole" compensates for transverse field from the 14 mrad Crossing Angle and Directs Background e+e- pairs through exit aperture

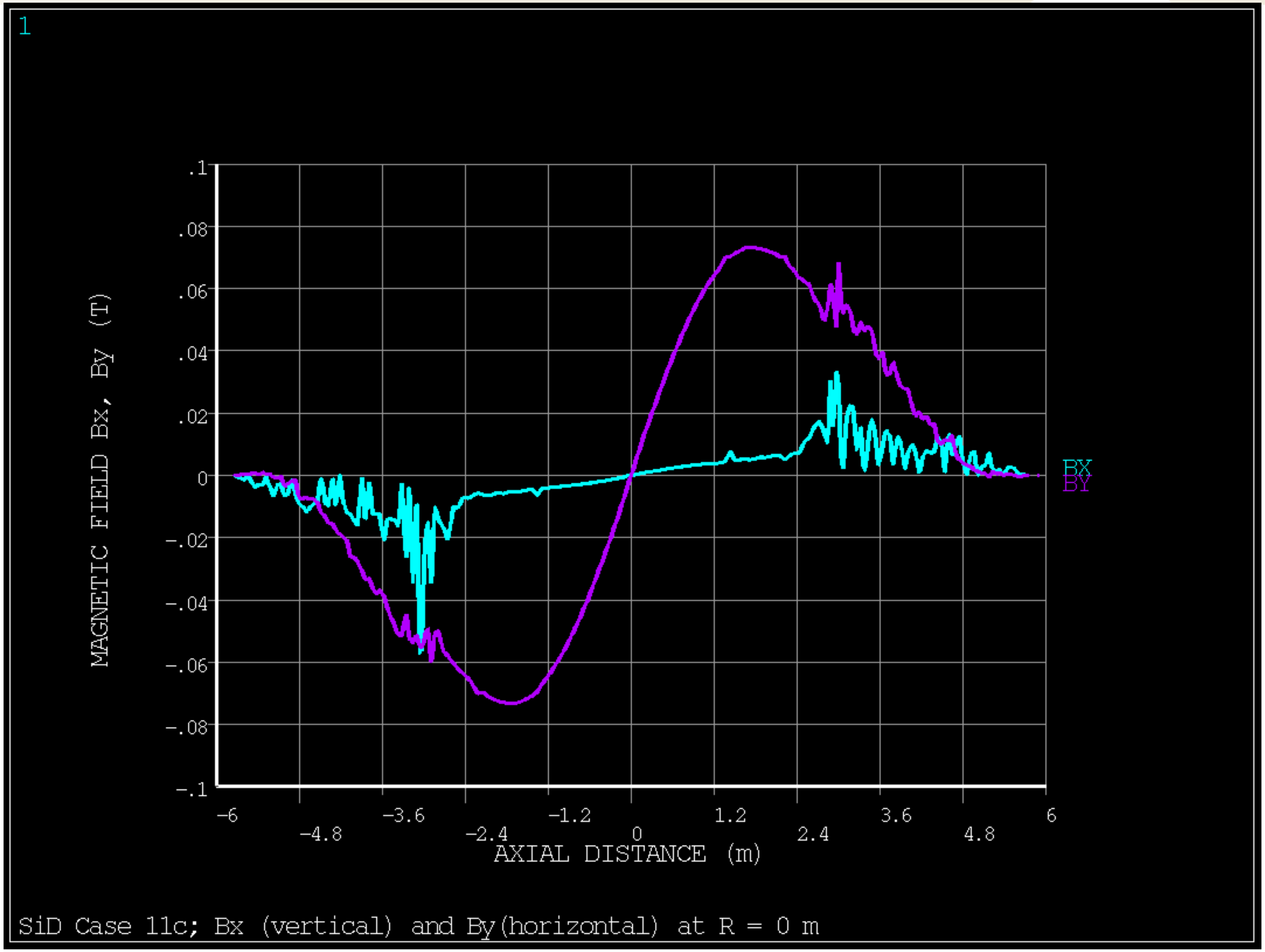


Four separate 600 kA turn winding packages are sandwiched between a lower 3 mm Al sheet and an upper 5 mm Al sheet.

DID coils wound from a high purity aluminum and a CMS single superconducting strand co-extrusion. Two layers of 75 turns of 2.5 mm x 1.8 mm superconductor per winding are proposed.

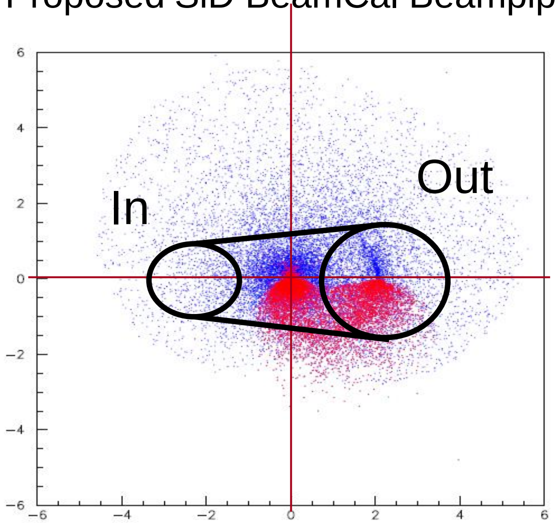
The practical implementation of carefully and successfully winding and installing this coil system is far from trivial. It will add significant cost, increase the difficulty of solenoid splicing and cryogenic plumbing and perhaps add significant time to the schedule. The coils are very large and flimsy while being handled. Stability criteria must be conservative so that a DID fast dump does not cause a solenoid discharge.

Bx and By(crossing angle) at R=0



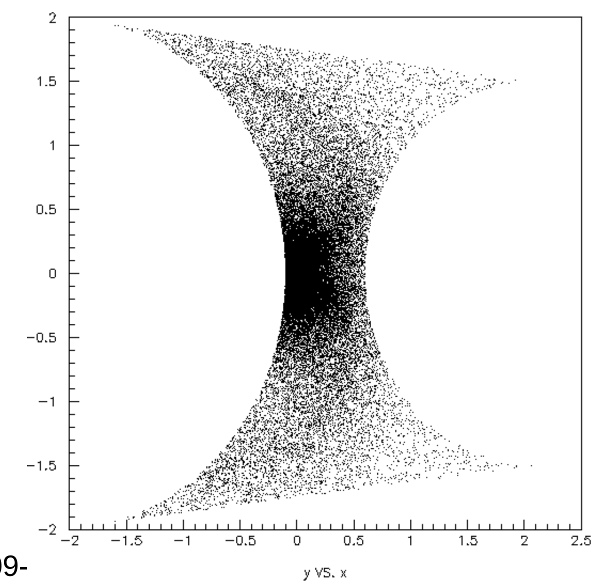
Do We Really Need an Anti-DID Coil
Hits in the Plug Region between the 2 beampipes

Proposed SiD BeamCal Beampipe

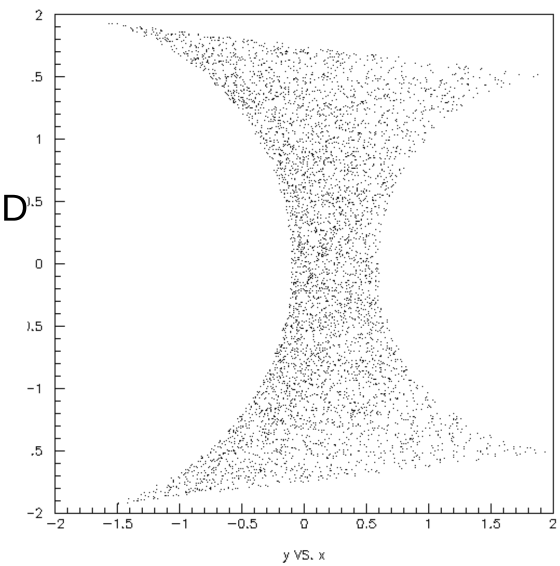


- How important is the backsplash to the VXD and Tracker?
- How important is it to try to extract physics signals from an instrumented detector between the beampipes?

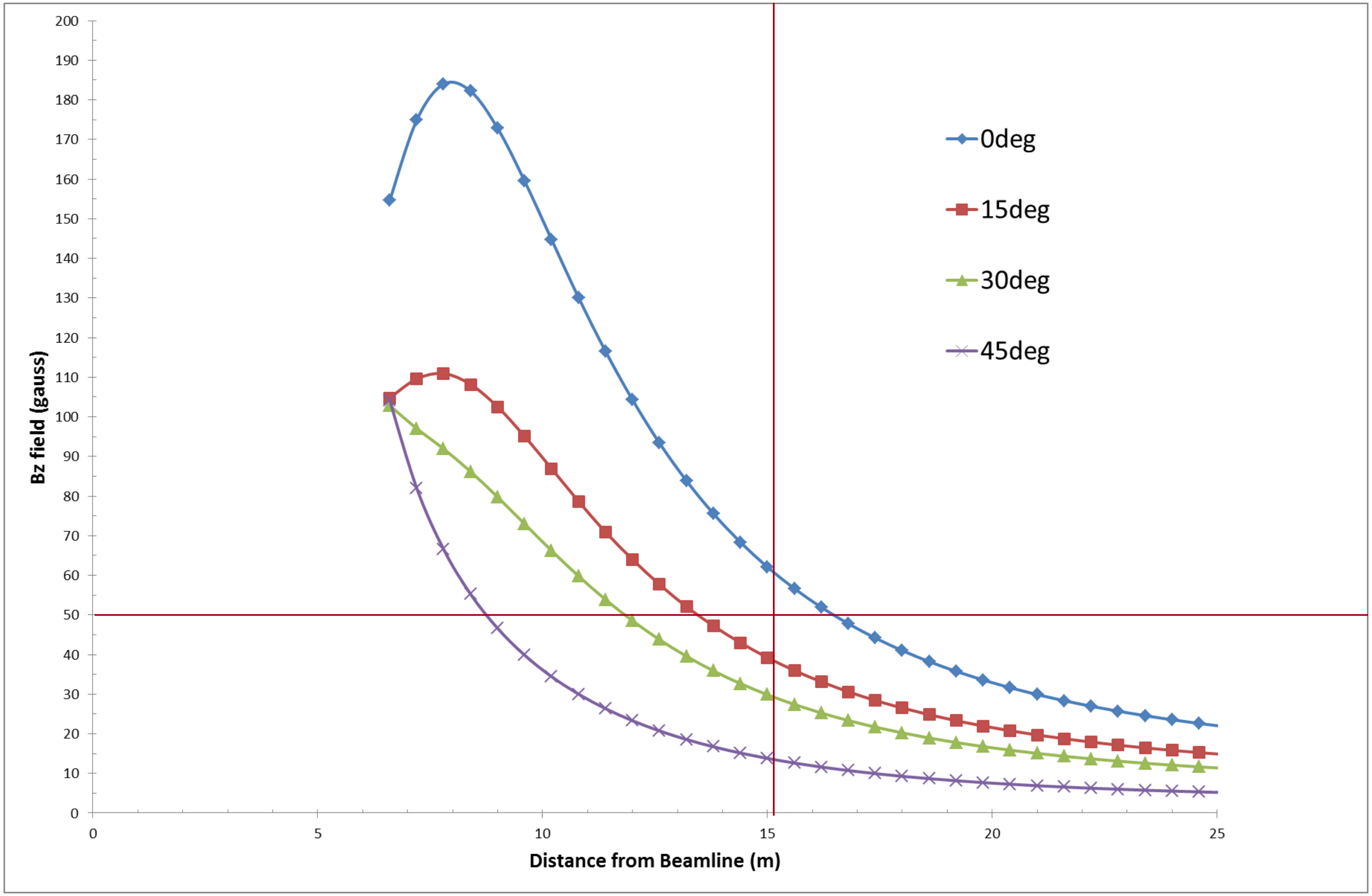
AntiDID OFF



AntiDID ON



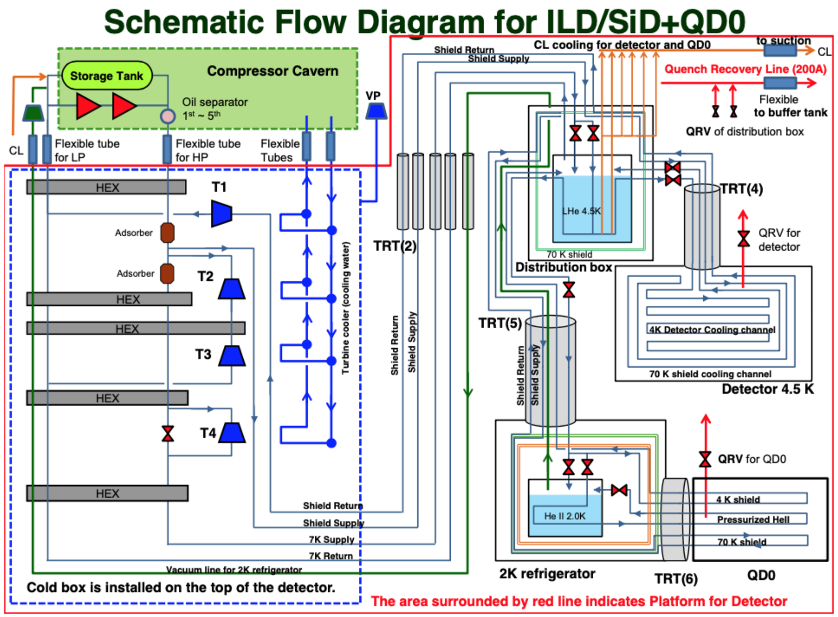
Bz- Outside Detector at z=0 (2015 design 11 plate yoke)
Goal: <50 Gauss at 15m



Assembly Sequence Described in Tech Design Report For reference only

1. The coil mandrels are precision machined with welding of seamless end rings and cooling loops. The cooling loops are extensively leak tested.
2. The solenoid modules are wound with each layer in alternating direction.
3. The four DID coil modules are wound on a 3 mm thick Al sheet that is mounted onto a machined cylinder. The internal coil to coil splices for each of the four modules are completed. A 5 mm sheet is attached to the outer diameter of the DID coils.
4. The DID coils are vacuum impregnated. This is a higher temperature resin than the solenoid resin.
5. The DID coils are mechanically attached on top of the solenoid cooling loops with screws to the solenoid mandrel.
6. The Solenoid modules with attached DID coils are vacuum impregnated.
7. The two mating ends of the solenoid modules are precision machined.
8. The solenoid modules are stacked vertically and joined above ground at the detector site.
9. All 24 solenoid splices are completed above the DID. All DID module to module splices are completed
10. The axial tie rods are attached to the solenoid.
11. The inner and outer thermal shields are mounted to inner and outer vacuum shells.
12. The inner and outer vacuum shells are placed on the solenoid.
13. The vertical and radial tie rods are attached to the outer vacuum shell.
14. All internal plumbing and electrical connections are completed along with the mounting of the thermal shield end plates. Piping extends a short distance past the chimney opening. The solenoid lead ends and DID lead ends extend through the vacuum shell current lead opening and are wrapped in a loop.
15. Top and bottom vacuum end plates are welded.
16. All tie rods are tightened.
17. The completed magnet assembly is rotated horizontal on a shaft parallel to the ground using the overhead crane and two pulling cables.
18. The magnet is moved to the detector cavern and lowered vertically into the bottom half of the magnet iron.
19. The current leads and cryogenic chimney pipe assemblies are completed and welded.

See TDR for Stress Analysis, Cryogenics, Powering, Safety
For reference only



Quantity	SiD	CMS
Von Mises Stress in High Purity Aluminium (MPa)	22.4	22
Von Mises Stress in Structural Aluminium (MPa)	165	145
Von Mises Stress in Rutherford Cable (MPa)	132	128
Maximum Radial Displacement (mm)	5.9	5
Maximum Axial Displacement	2.9	3.5
Maximum Shear Stress on Insulation (MPa)	22.6	21
Radial Decentering Force (kN/cm)	280	80
Axial Decentering Force (kN/cm)	1870	850

Table II-6.3
Cryostat vacuum shell maximal stress and deflection

Load	Stress (MPa)	Deflection (mm)	Location of Max Stress
Axial Magnetic	125	1.5	Axial Support Pad
Detector Mass	45	2.3	Inner Vacuum Shell
Cold Mass + Radial Magnetic	23	0.44	Vertical Tie Rod Support Pad
Vacuum	7.5	0.17	Outer Shell
Gravity on Shell	Small	0.11	Both Shells
All Loads Combined	**190**	**3.5**	**Vacuum Shell End Plate**

Summary

SiD 5T Magnet with 6m (length) x 6.8m OD coil package has been designed ~2006-2013

Coil based on the successful CMS magnet

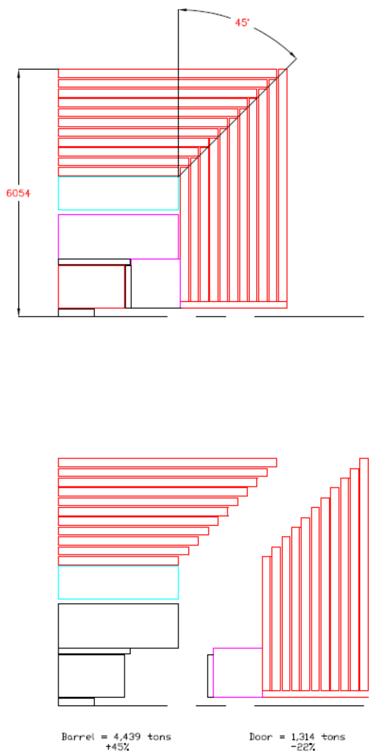
Return Flux optimized ~2015 to reduce mass and reduce fringe field

Many engineering details and calculations are available

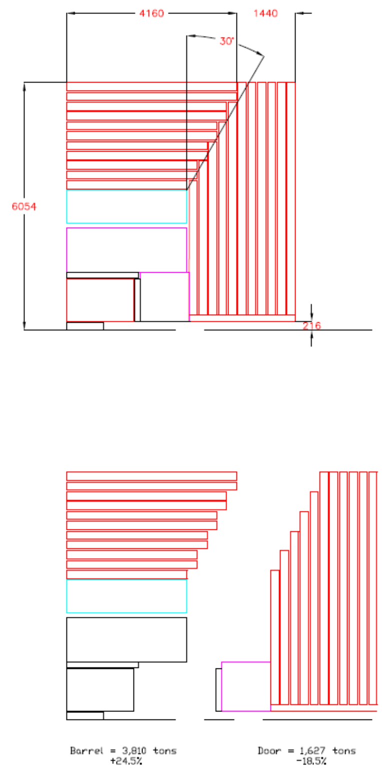
Performance and cost optimization would be required before a project could be realized.

Thank you for your attention
Extra Material Follows

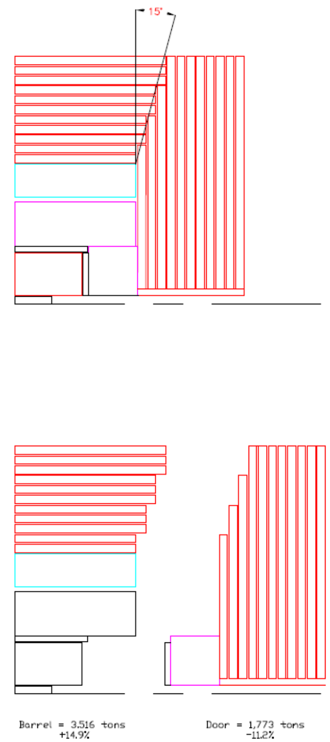
Barrel-Door Partitions: 30° selected



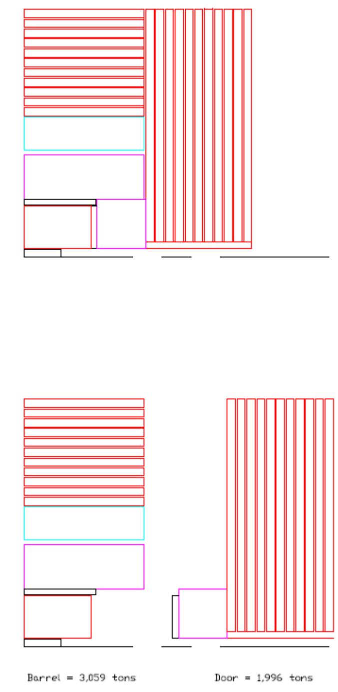
45 deg
Heaviest Barrel
Lightest Doors



30 deg
Barrel < 4000 t
but will need 5kT gantry



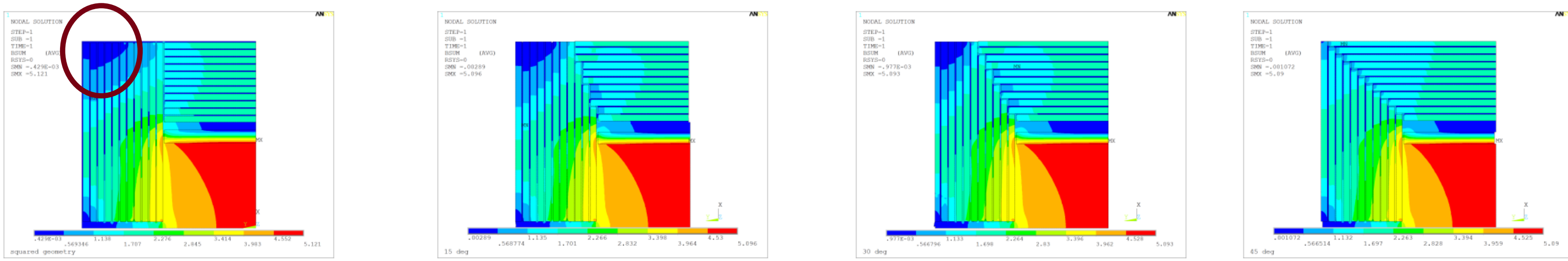
15 deg



0 deg
Baseline

B Field – 11 plates, each 200mm thick

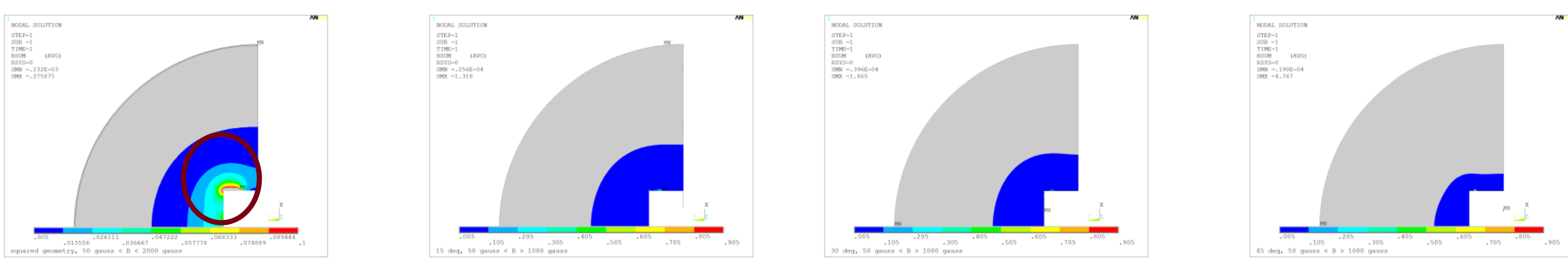
0° Baseline | 15° | 30° | 45°



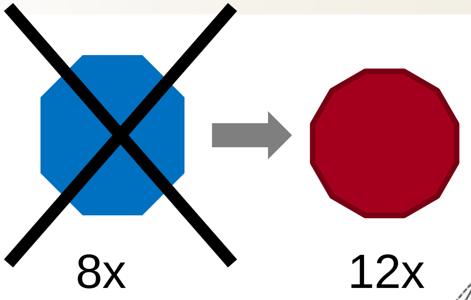
Red=5.1 Tesla; Blue=4.3Gauss: More efficient use of iron at 45°

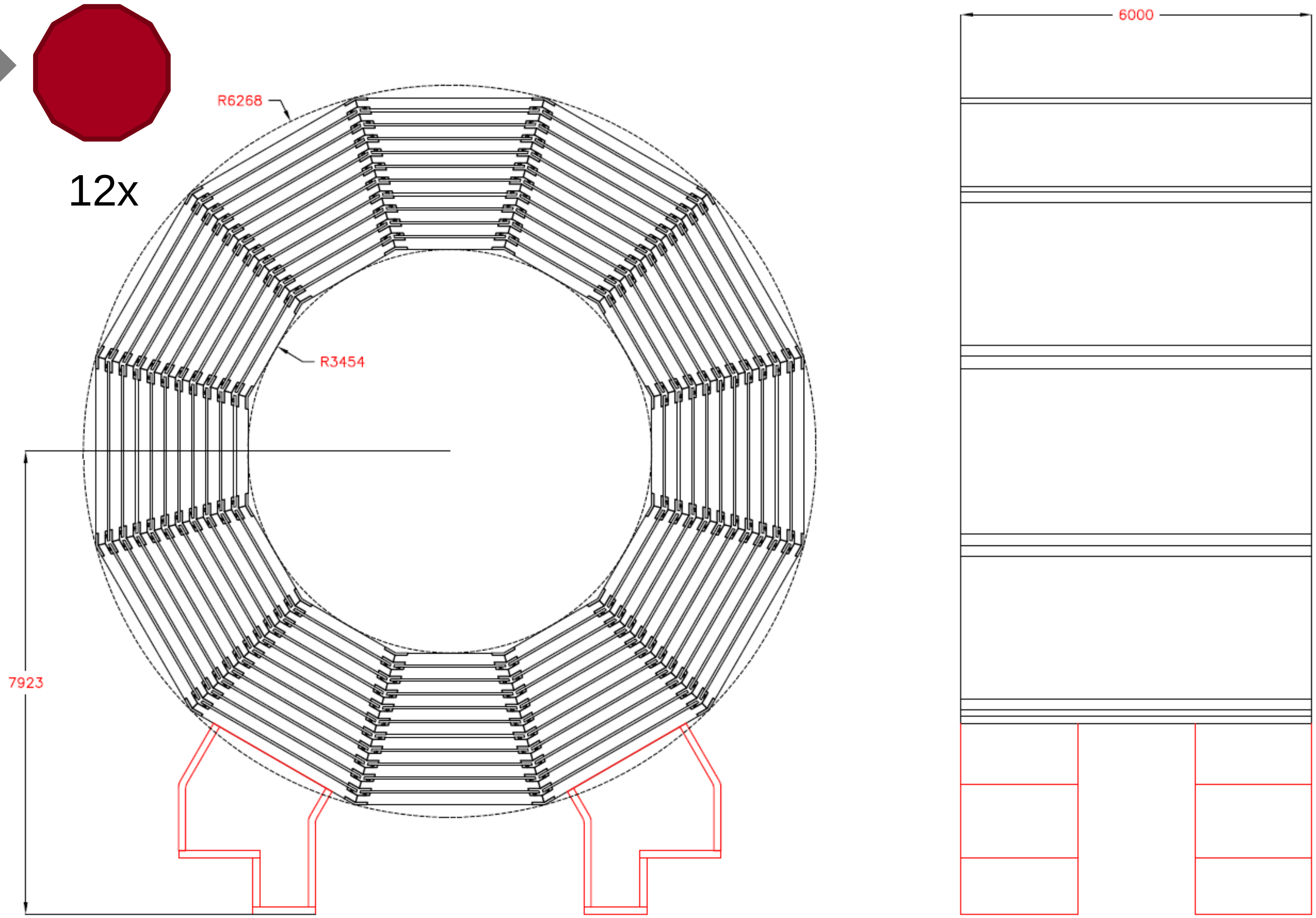
Red=1kG; Blue=50 Gauss; Gray ends at 30m:

- 50G fringe field extends less
- Lower field on surface of yoke where electronics will reside as interface goes from 0 to 45°



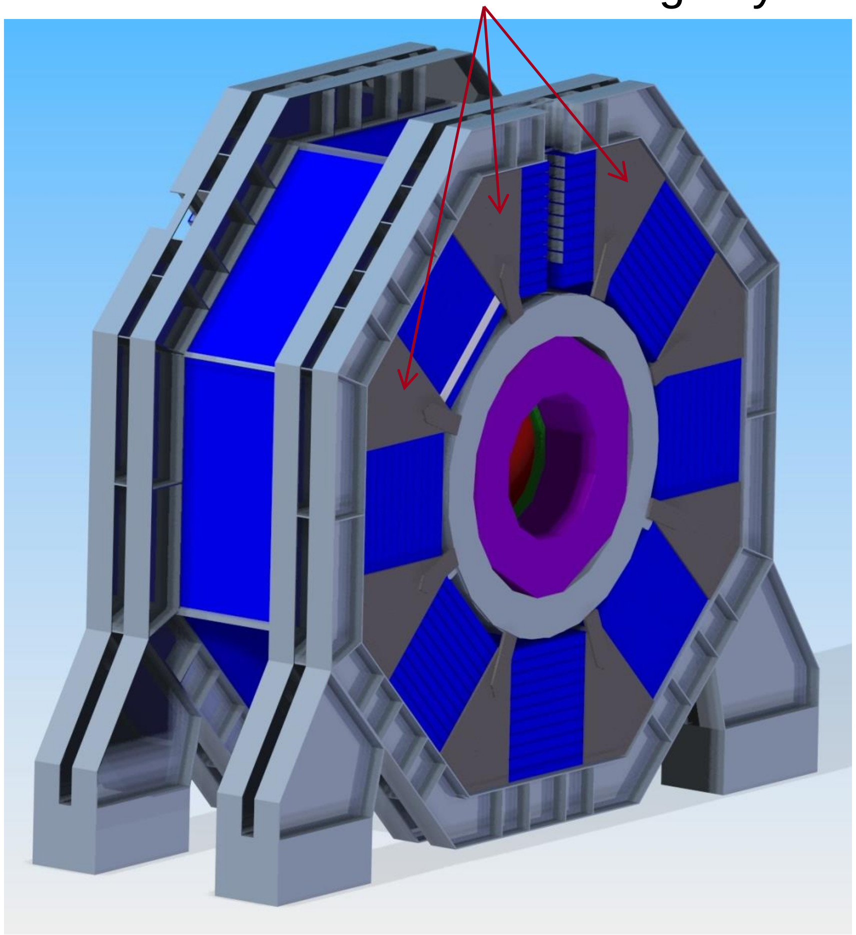
New Iron Design – Higher Phi segmentation



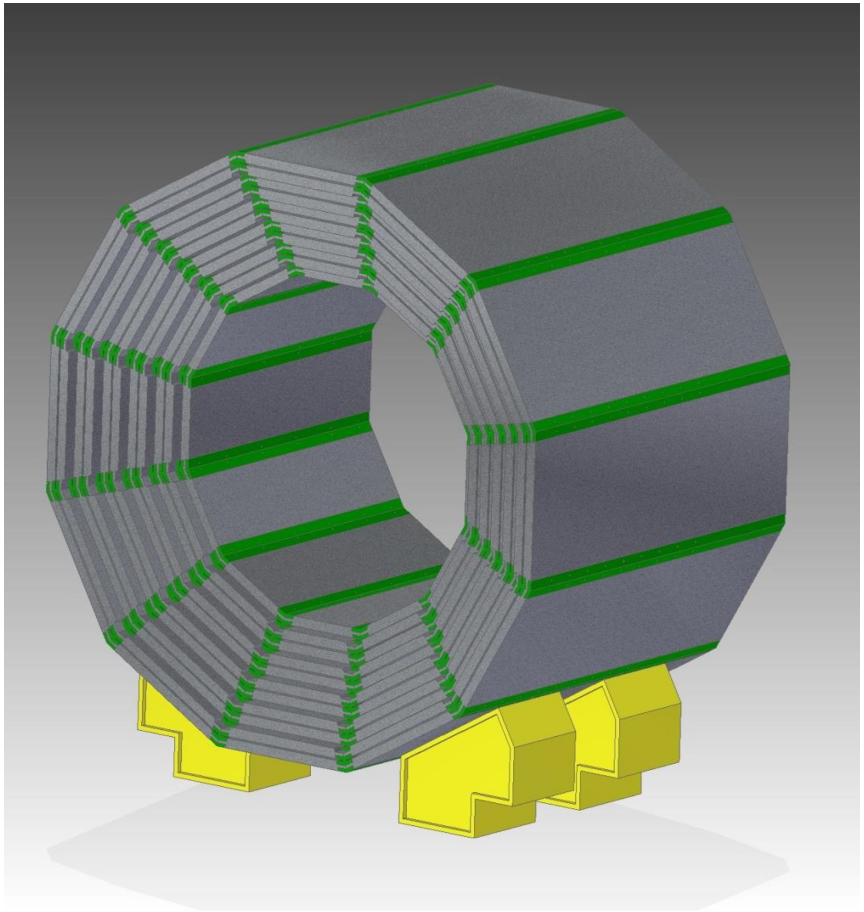


Feet Instead of Arches
Edge-Edge Connectors in Phi to Handle Changing Plate Lengths

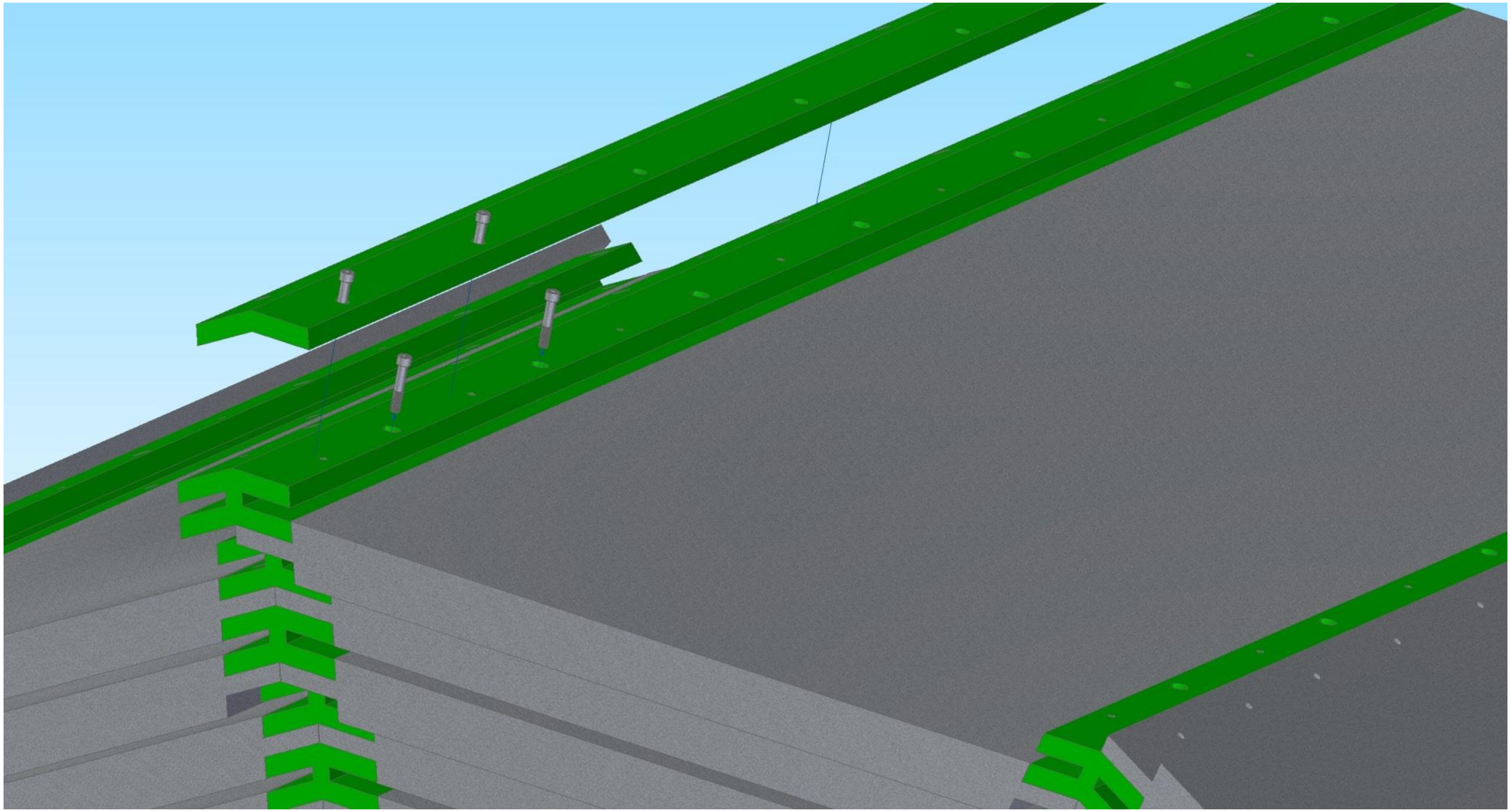
DBD Arches with Plates Joining Layers



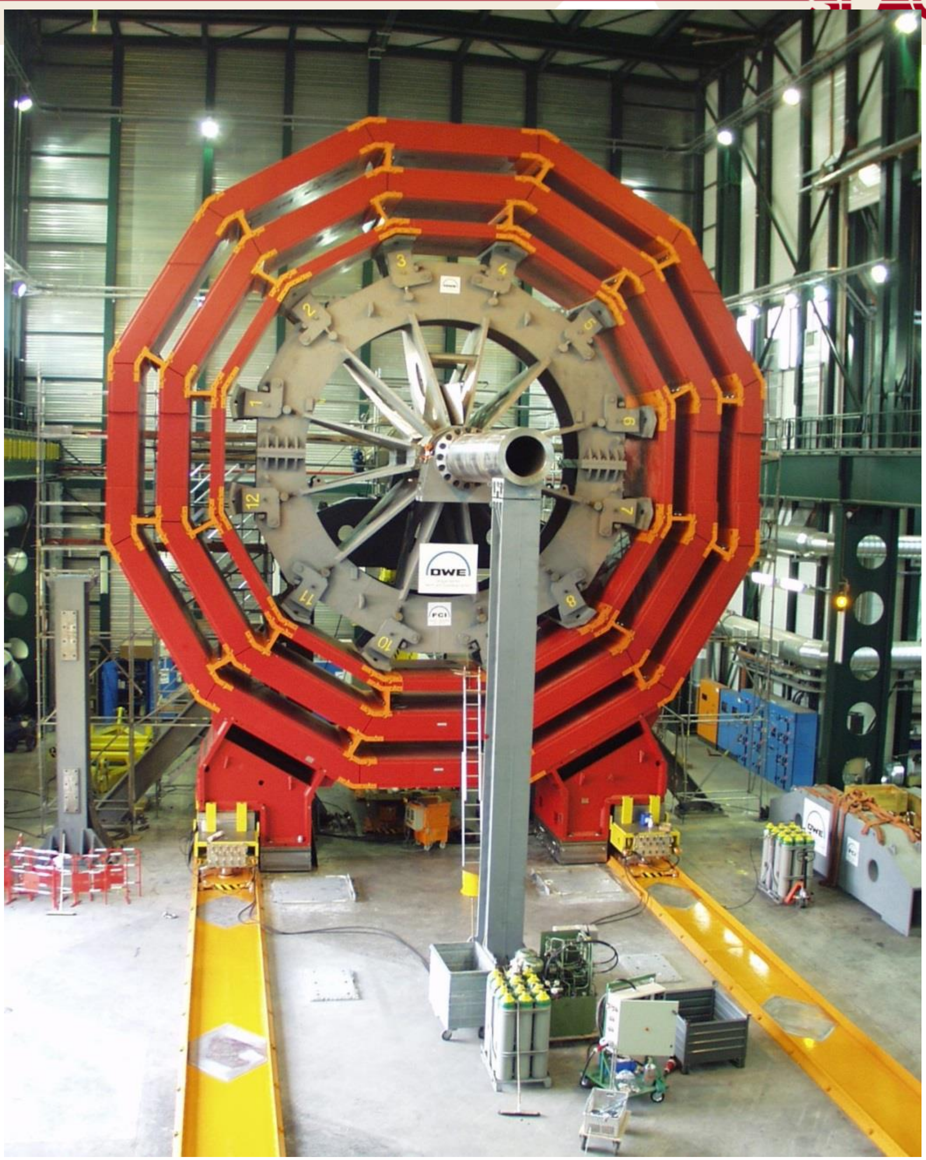
Support Feet & Plates with Connectors



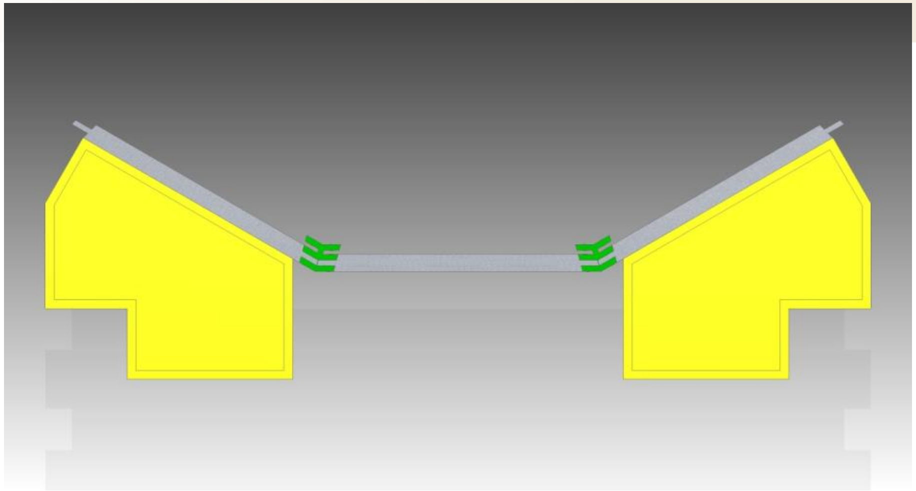
Connector Detail

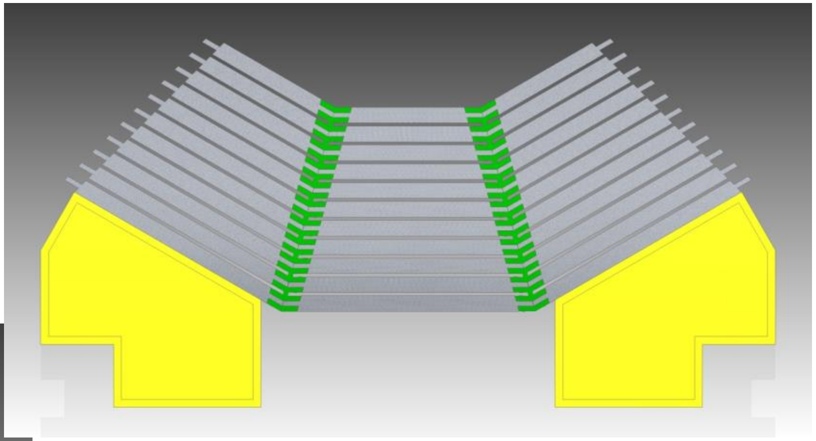


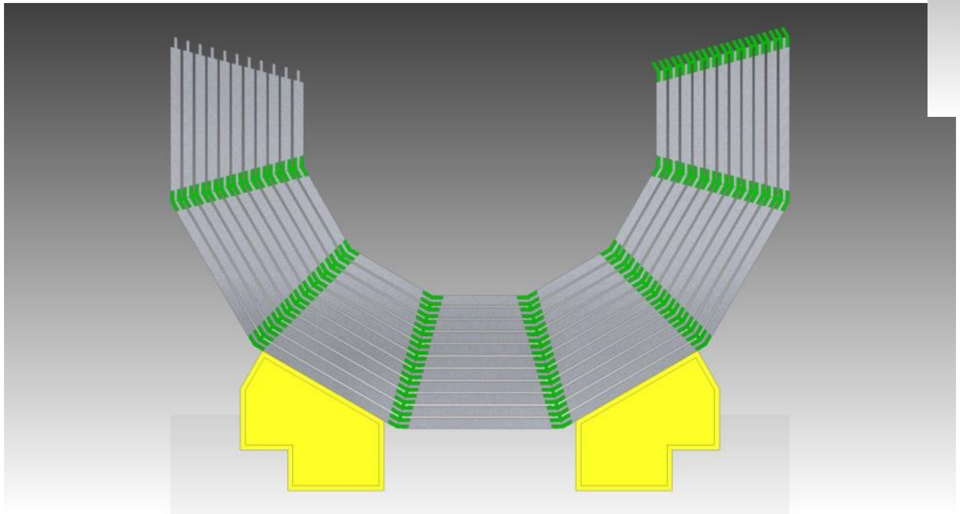
CMS Used Similar Connectors
CMS Used Ferris Wheel to Assemble Layer-by-Layer



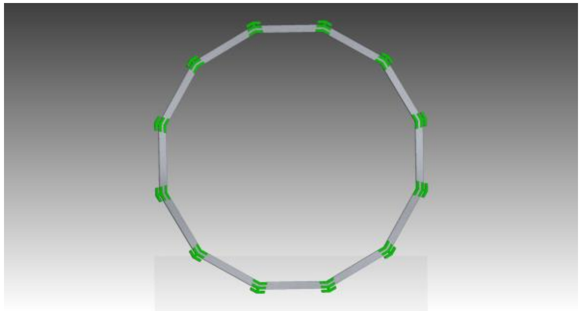
Barrel Assembly



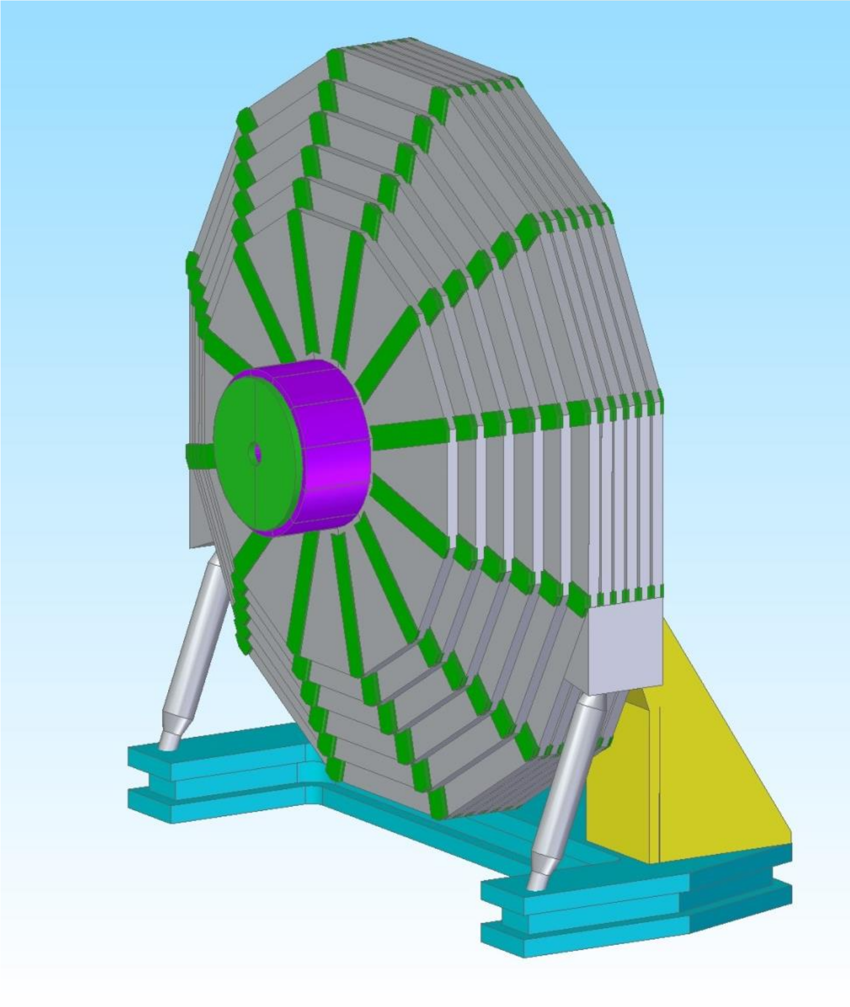


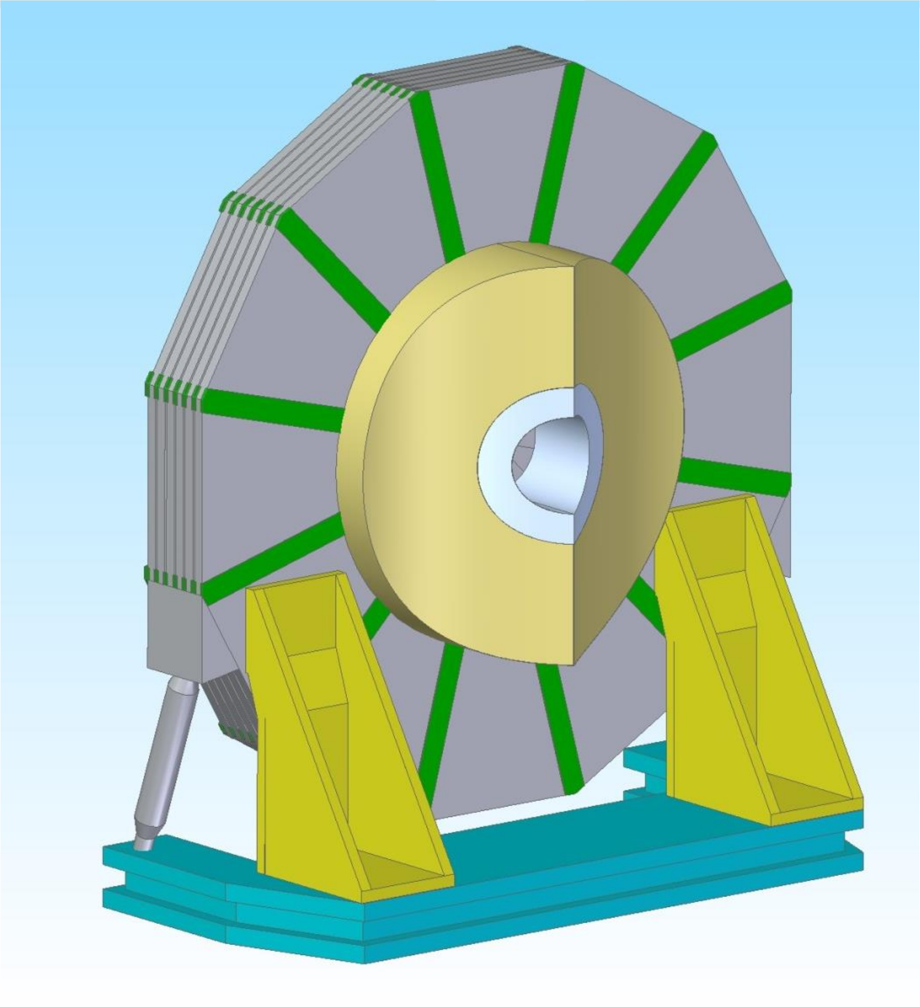


Alternate Assembly Using CMS Ferris Wheel Tooling

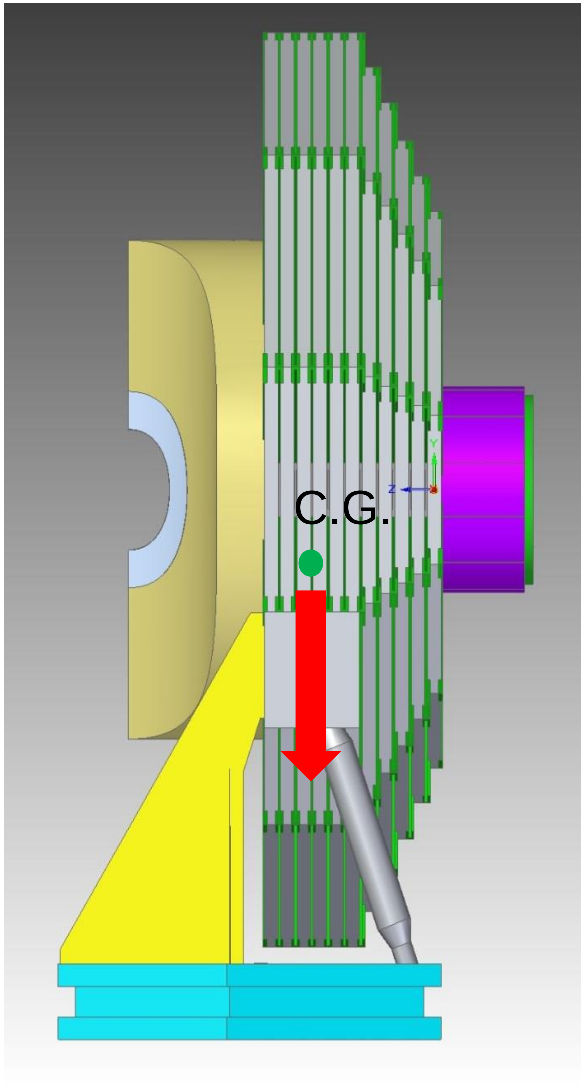


Doors with New Supports and Interplate Connectors





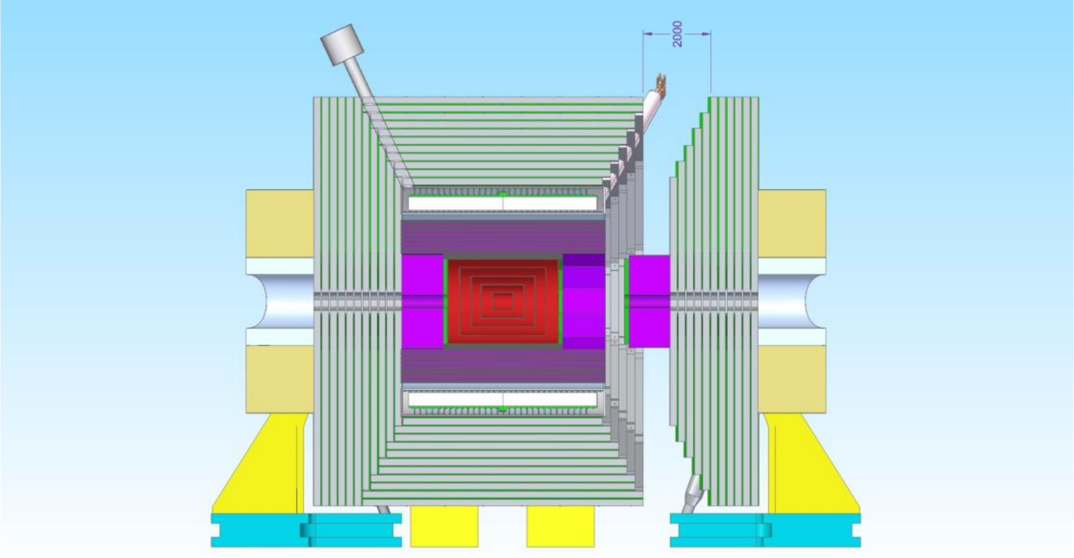
Total Door with HCAL, Feet & PACMAN

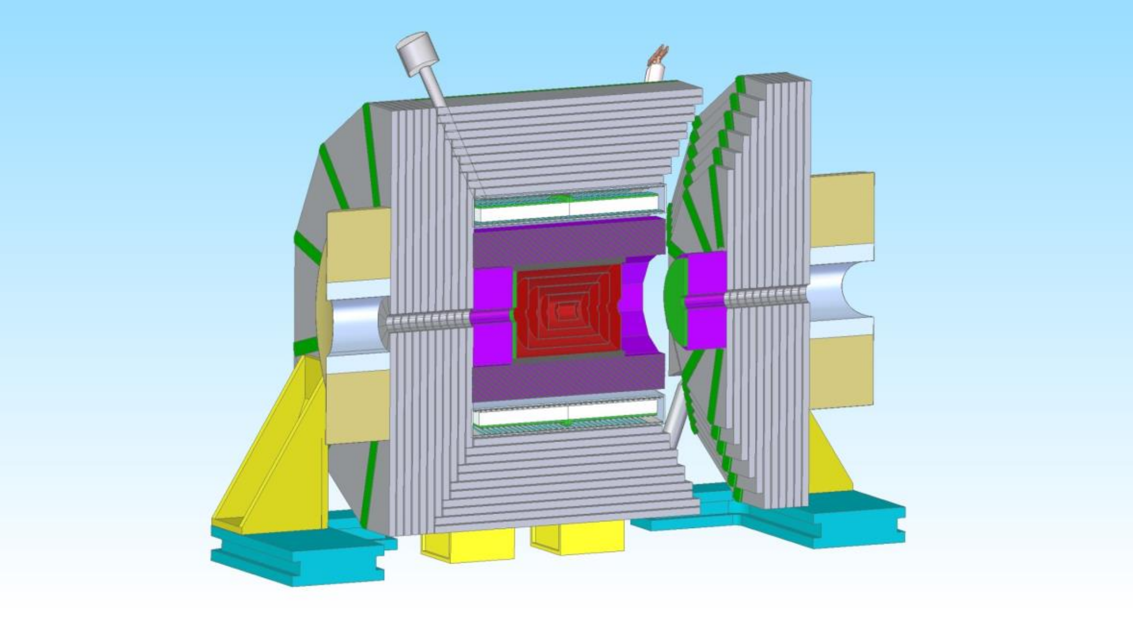


Total Mass 2,312 tons

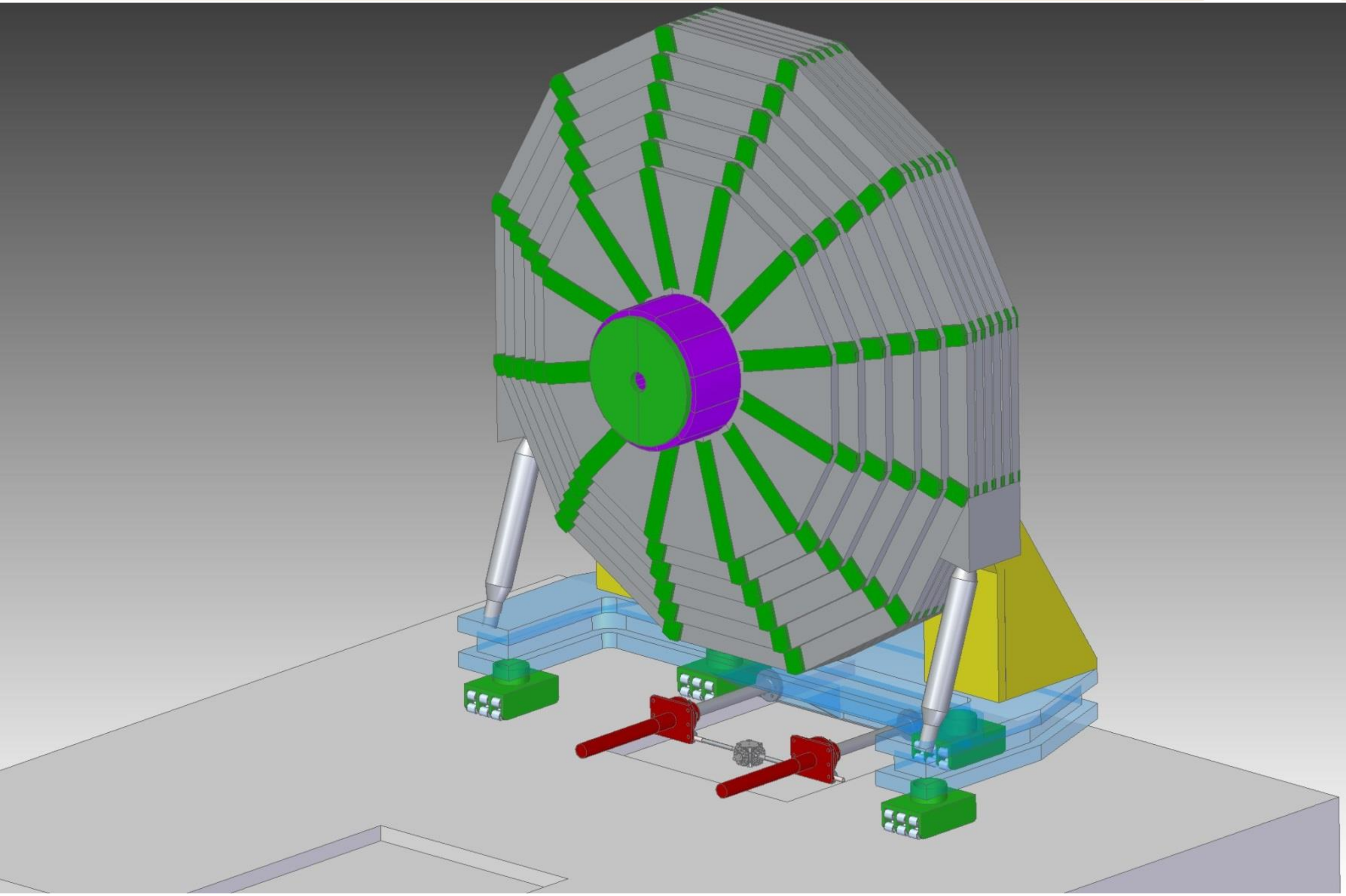
Center of Gravity
X = 0 mm
Y = -996 mm
Z = 1826 mm

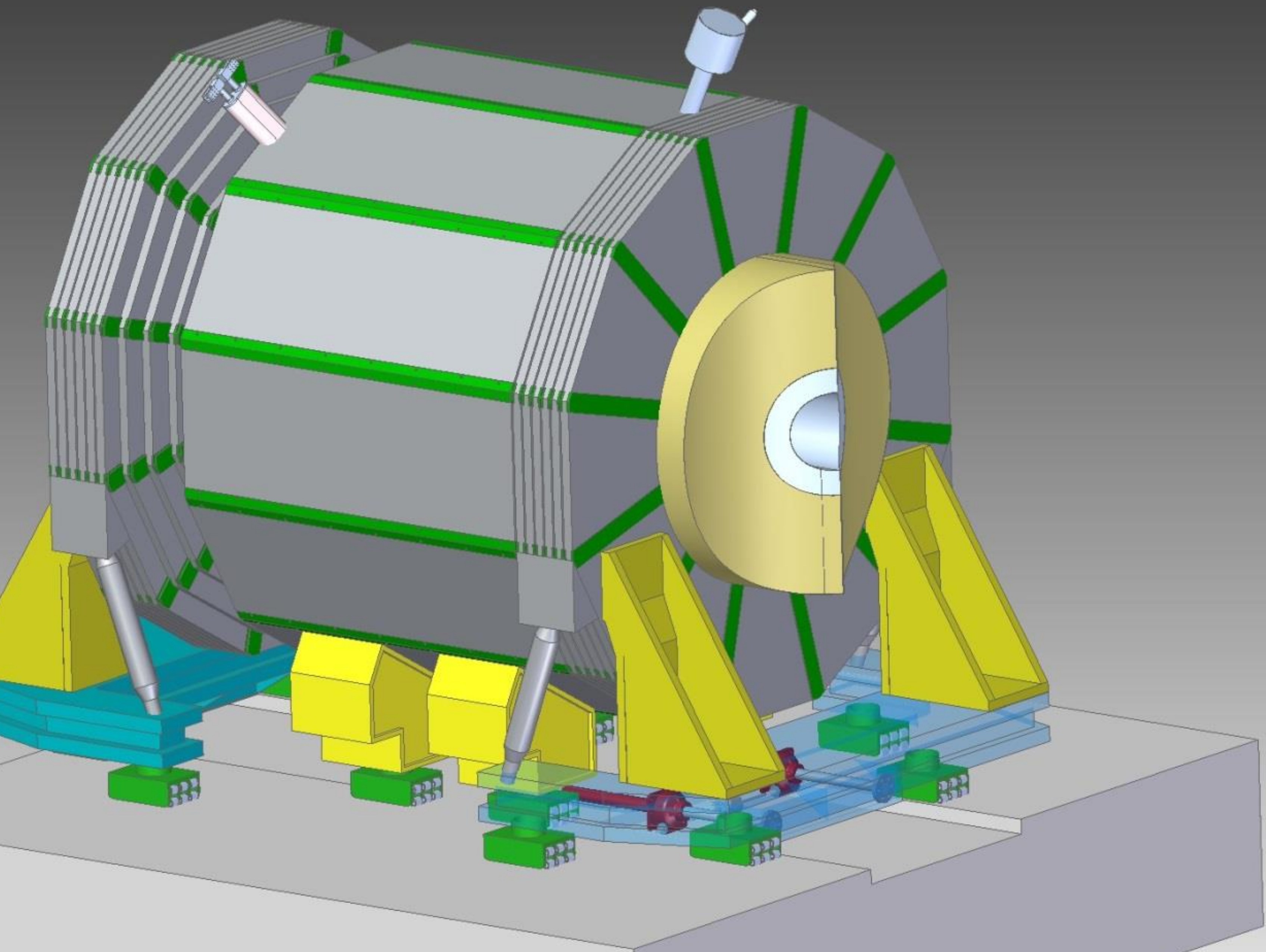
2D and Isometric Views of SiD



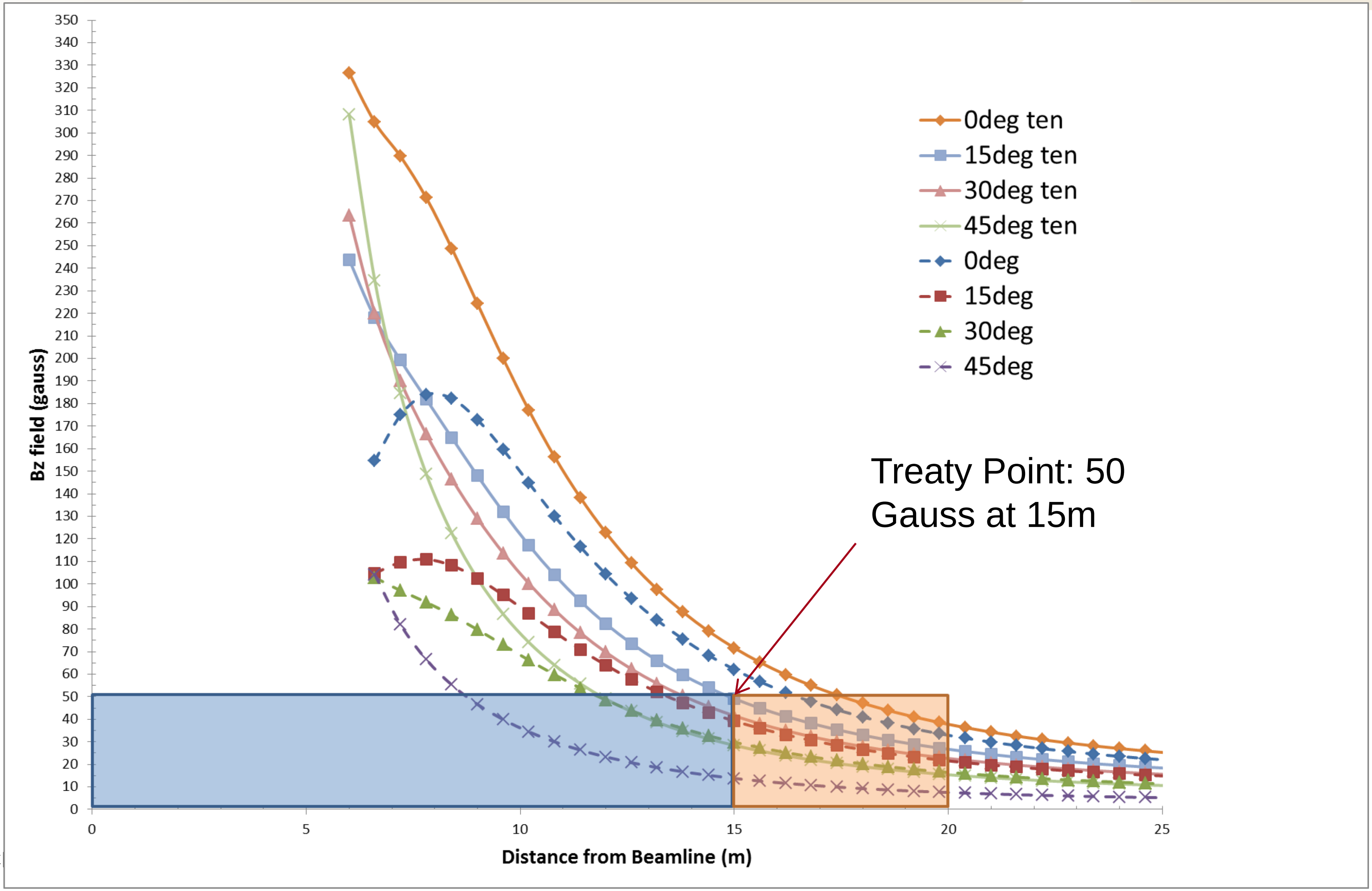


Door with Motion System



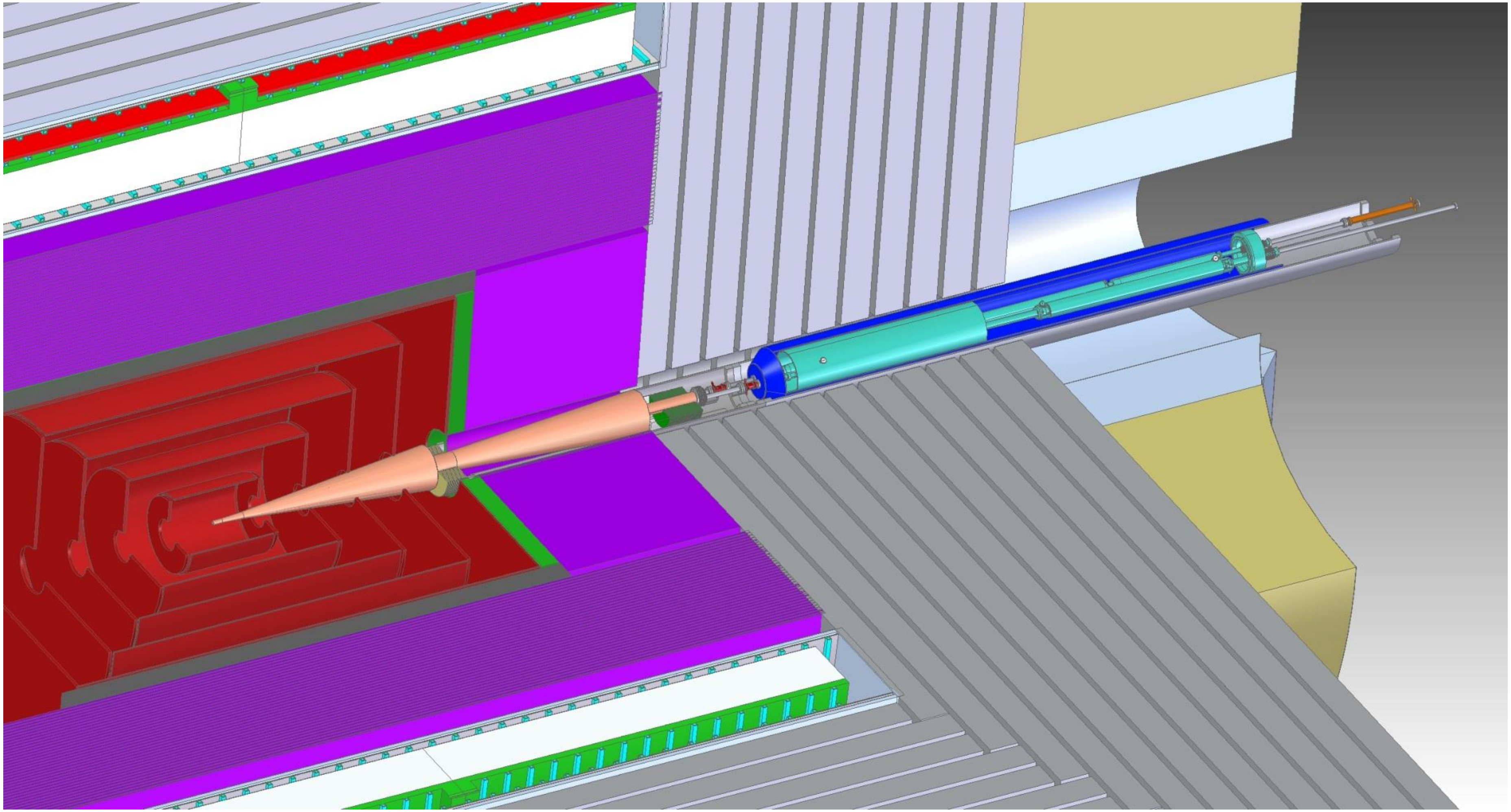


Under Discussion: 10 Plate Yoke – Seems Feasible
Bz- Outside Detector at z=0



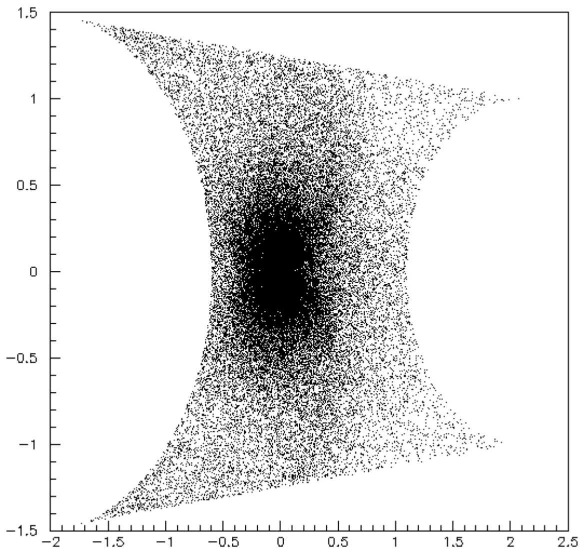
SC

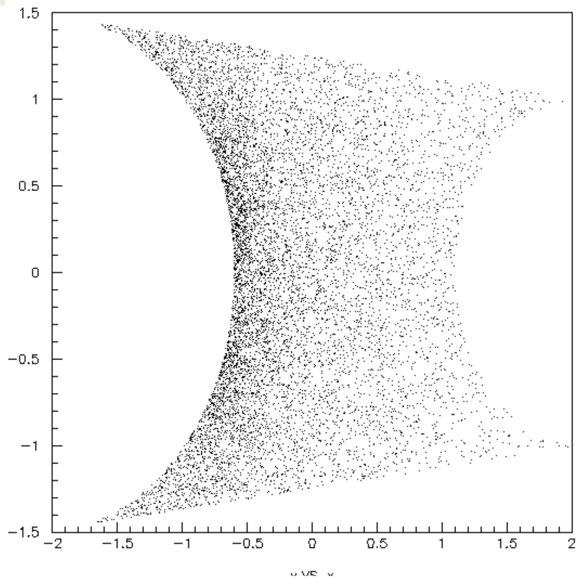
Isometric View



Do We Really Need an Anti-DID Coil
Hits in the Plug Region

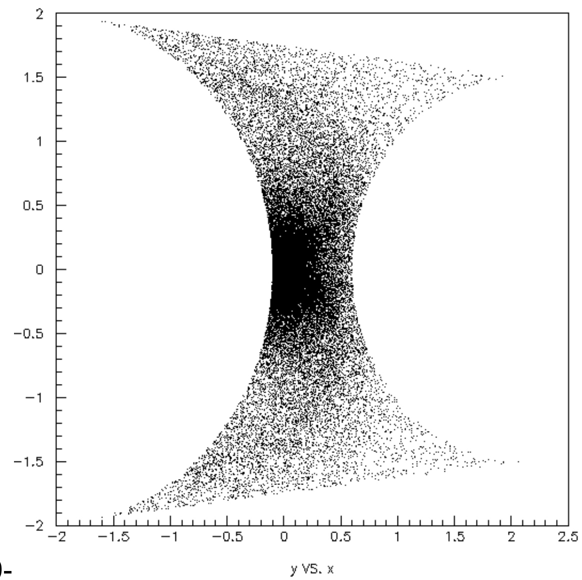
AntiDID
OFF
15,10mm

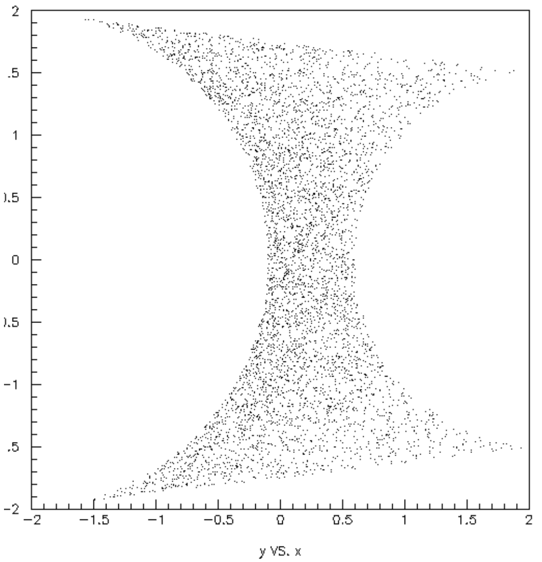




AntiDID
ON
15,10mm

AntiDID
OFF
20,15mm





AntiDID
ON
20,15mm

SBWO2_pairs0001.dat (2009 IP w/o TF) 174k particles, 409.2TeV

Where to the e+e- pairs go

15,20mm	No DID		AntiDID	
	# Hits	Energy	#Hits	Energy
Go out 4cm exit hole	32.1%	85.2%	87.9%	90.3%
Go out 3cm entrance	4.5%	0.8%	1.5%	0.7%
Hit the plug	54.6%	5.3%	3.0%	1.4%
Outside the plug in “physics” region	8.8%	8.7%	7.6%	7.7%

- The Anti-DID really only helps the plug region between the beam pipes
- The Anti-DID buys you 1% less energy in the region outside the plug and the 40mm/30mm exit/entrance apertures in the BeamCal silicon