Conceptual Design and Budgetary Estimate for Supporting the ORKA detector in CDF

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Introduction

The ORKA detector is a proposed detector that would be mounted in the bore of the solenoid of the CDF detector. See figure 1. The largest object of the detector is the outer calorimeter which would be constructed of wedges forming an approximate cylindrical barrel. The baseline design would contain a large amount of lead and the weight would be approximately 100 tons. The ORKA detector must be installed in the CDF collision hall because the CDF detector will no longer be able to roll into the assembly hall by the time the ORKA detector is complete. However, preparation work to accept the ORCA detector can be done in the assembly hall in advance.

The scope of this report is a conceptual design and for the support and installation of the ORCA detector into the bore of CDF. A cost estimate for the design, materials and services is also included as a separate excel file.

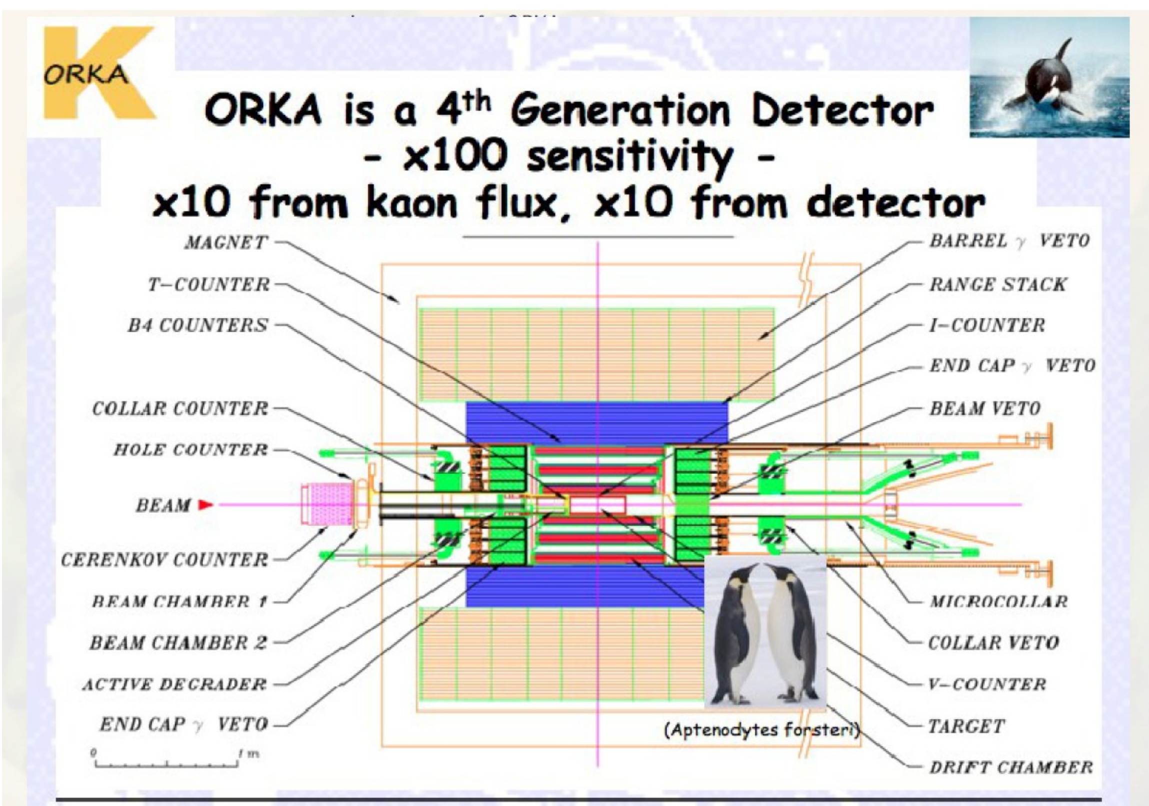

Figure 1Schematic figure of ORKA detector

Requirements and Assumptions

After initial discussions regarding the task, several requirements and working assumptions were established. These are listed below:

- Weight ~ 100 tons
- Calorimeter dimensions radius < 1.35m, length ~ 2.5 m (half the length of the solenoid)
- ORCA must be installed in the collision hall
- Preparation work with the CDF detector can be done in the assembly hall if done in advance
- Large portions of the CDF detector at the 710 level (CMEX, end Toroids, the quads and the quad shielding) will be removed.
- For the installation of ORKA, the CDF end plugs can be placed on their stands in the collision hall.
- The shell of the solenoid cannot support a significant portion of the weight of ORKA
- Austenitic stainless steel (300 series) would be acceptable for beams used to support ORKA inside the solenoid.
- ORKA would include a structure that can transfer loads to supports near the 3 and 9 o'clock positions.
- The preference would be to locate ORKA a few inches from the West End plug.

Description of the relevant features of the CDF detector

Some of the features of the CDF detector create constraints on a support design. The relevant features will be described along with the impact on the design choices.

The shell of the solenoid is made of aluminum and the shell cannot support large loads. The solenoid is connected to the inner radius plates of the Yoke end wall. The solenoid is constrained axially to one wall and has keyed connections that allow that other end to float axially. The Yoke end wall consists of an inner carbon Steel plate connected to an outer stainless steel plate. See figure 2 for a sketch of the central detector Yoke. The plates are 2" thick.

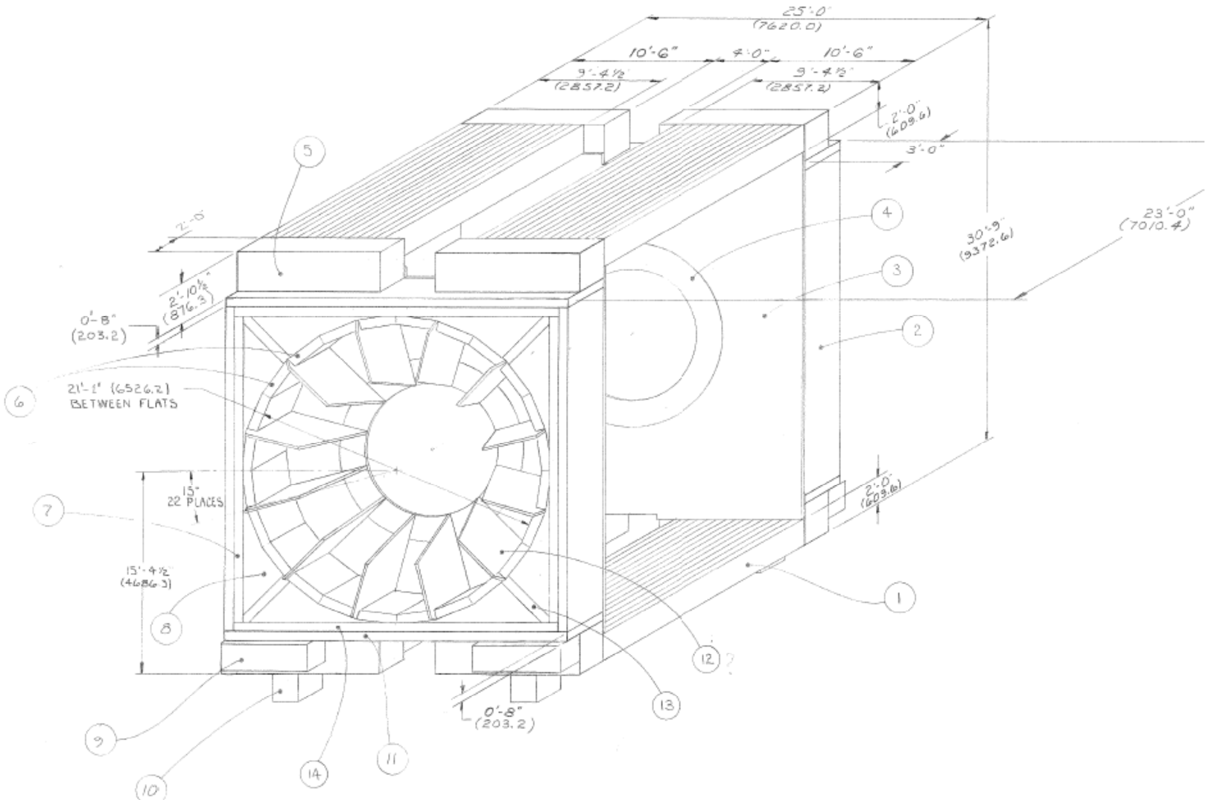

Figure 2 Central Detector Yoke, drawing MD-134695

The Yoke end walls are the first structure beyond the solenoid that could support a beam like structure that could span the length of the solenoid. 12 Ribs made from 2” thick steel are welded to each of the end walls. 2 End Wall Modules are mounted between each set of ribs. See figure 3 for a photo of one end of the central detector Yoke with most of the End Wall Modules installed. The End Wall modules are connected to the Yoke structure with bolts through the Yoke end wall stainless steel plate and the through a bracket to the outer ring of the Yoke. The bolts through the Yoke end wall can be accessed when the Central Arches are moved out of the central detector.

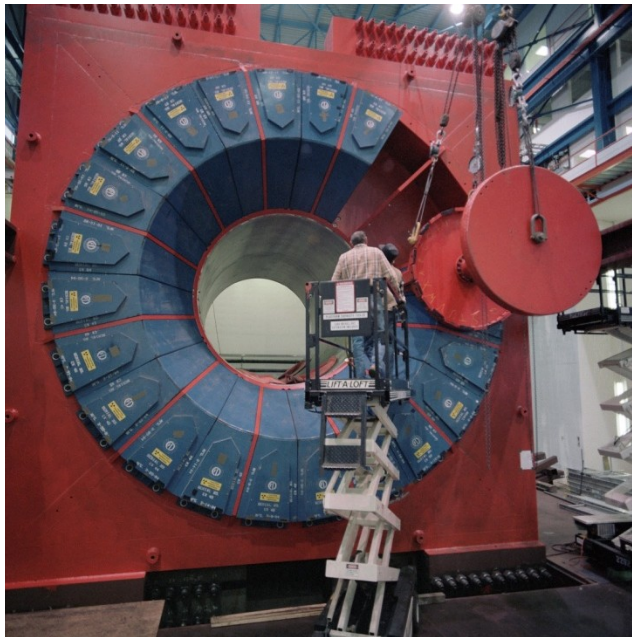

Figure 3 End Wall Module installation to Yoke

The fit of the end plug into the detector creates a radial constraint on the thickness of the ends of the support beam. See figure 4 for a cross section showing the gap at the end plug. The gap varies from ~ 1.1” to ~ 2.3”. The ends of a support beam must fit in this radial gap.

Figure 4 CDF cross section showing radial gap at end plug

Support Rail Design

The design concept for ORKA consists of two stainless steel beams located at 3 and 9 o'clock. The support beams are shown figure 5 in a CAD model of the central detector. The beams are colored red and one beam is shifted from its final position to make it more visible. The detector will slide along these beams during installation and the beams will generally be referred to as rails.

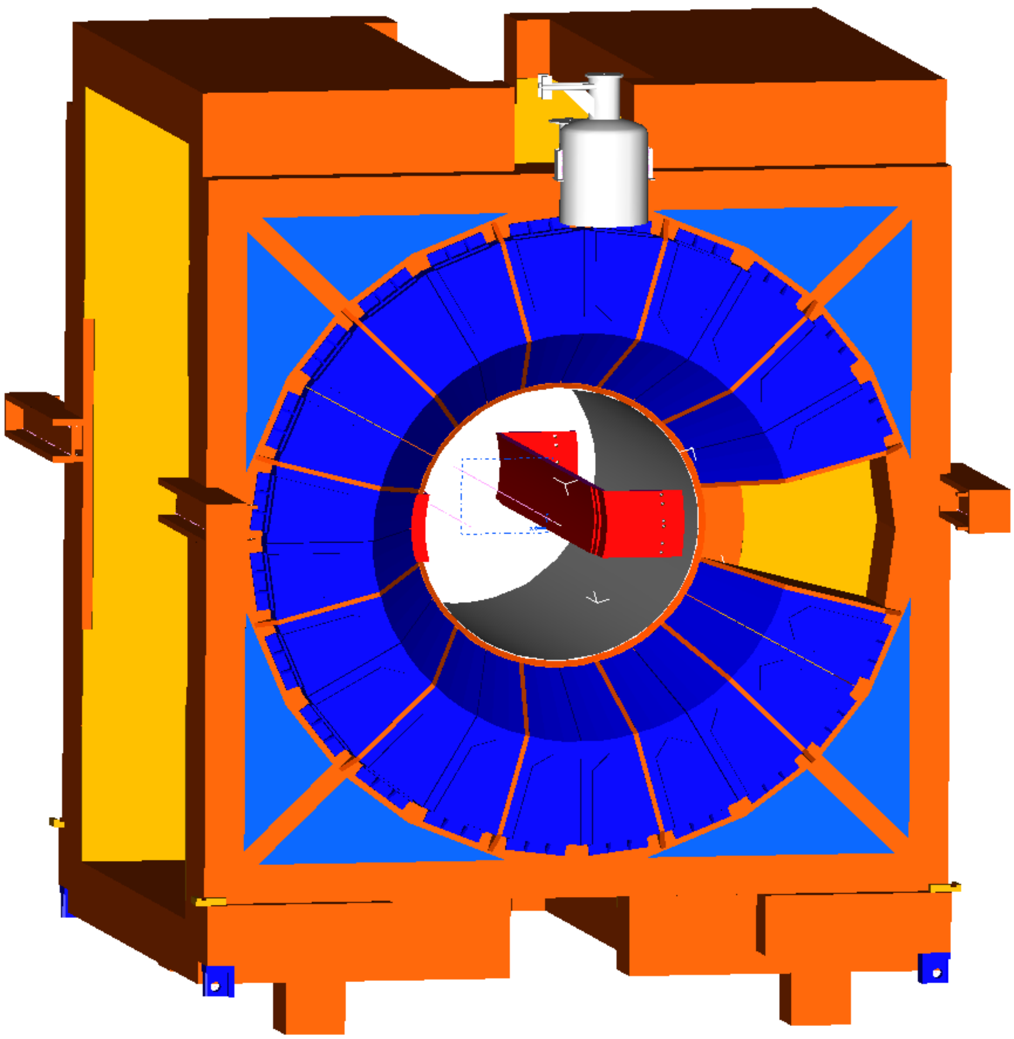

Figure 5 Support rails (red) in bore of CDF detector

The ends of the rails will have 90 degree angle portions by which the rails will be attached to the Yoke end walls. In figure 5 two end wall modules are removed to show the area where the rails will be connected. A model of a one rail is shown in figure 6.

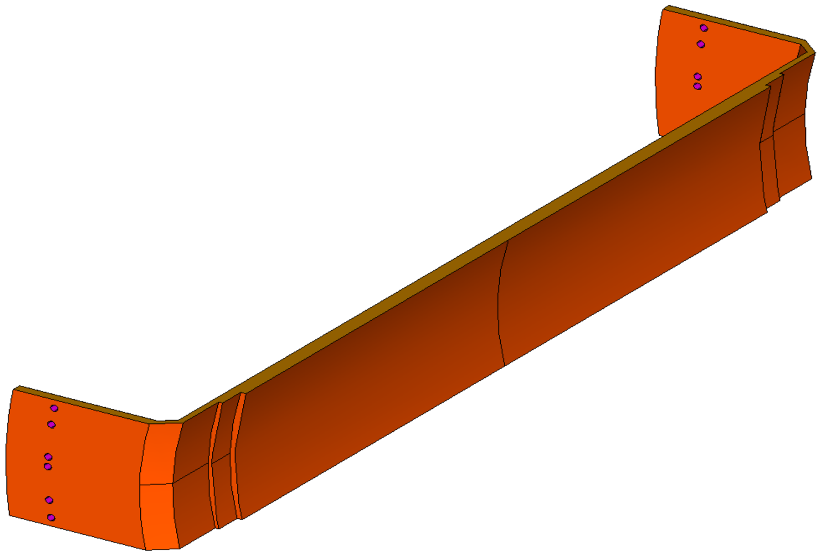

Figure 6 Model of support rail

The rail is 27” deep and 3” thick in the middle section. The initial concept is shown here and includes a curved middle section that optimizes the space for the ORKA detector. The additional machining and initial stock material thickness will make fabrication of a rail with a curved middle section quite expensive. For cost estimating the middle section was considered to be a rectangular cross section of 3” x 27”. The curved steps at the ends of the rail are required for the rail to fit within the gap when the end plugs are closed. Figure 7 shows the cross section of the CDF detector with the support rail (orange color) in the radial gap.

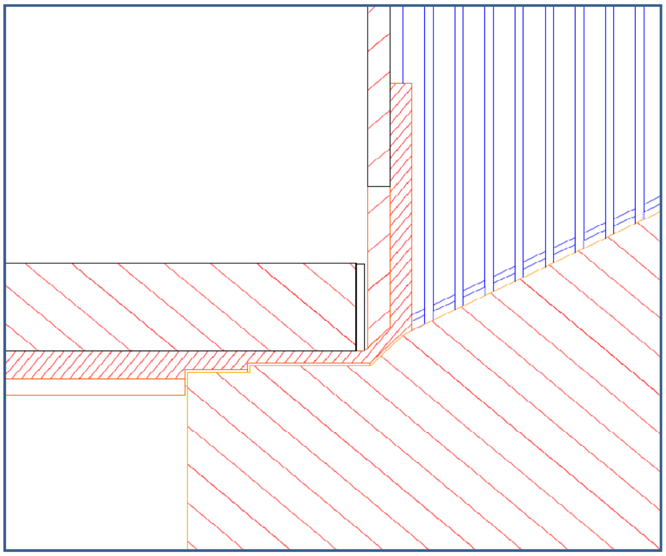

Figure 7 Cross section shown contour of support rail in end plug gap

The support rail will need to be made from multiple pieces to create the shape required for the portions at the two ends. It is assumed that the rail will be constructed from welded sections although bolted sections might be possible. A finite element analysis was performed for the loading conditions shown in figure 8. The assumption for the loading on the beam was that the ORKA detector support structure contacted each rail at two points near the ends of the calorimeter. The maximum stress which occurs at the midspan of the support rail is 15.5 ksi with and allowable stress of 19.8 ksi. The maximum vertical deflection is 0.1 (2.5 mm) and occurs at the midspan. The contact points to the rail could be shimmed to compensate for the rail deflection.

Figure 8 Load and constraint conditions for rail analysis

The stress and vertical deflection results are shown in figure 9 and figure 10. The analysis included a buckling analysis that showed that the deflected shape was stable. This means that the support structure for the ORKA detector does not need to provide any lateral constraint to stabilize the rails.

Figure 9 Stress Contours for support rail

Figure 10 Vertical Deflection Contours for support rail

The rail has a small twist under load and will move about .04” (1 mm) in the radial gap with the end plug. For this conceptual design the end plug did not contact the end of the rail.

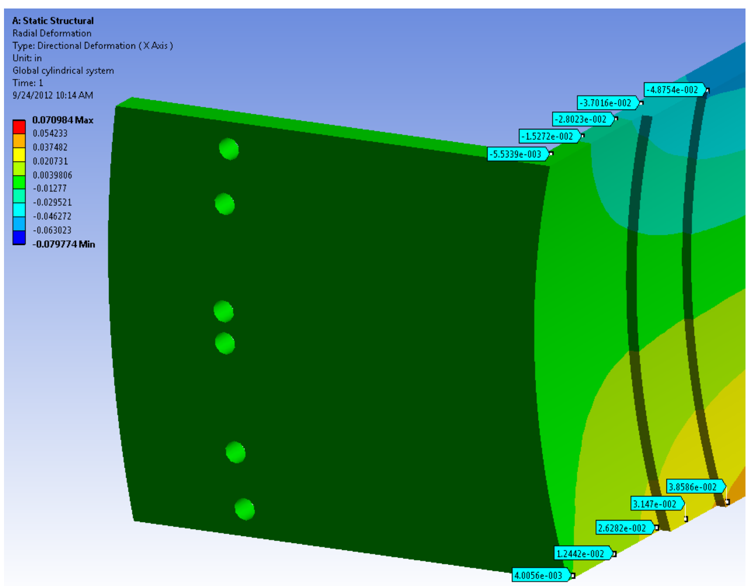

Figure 10b Lateral displacement of the rail end in the gap of the end plug

Support Rail Connections

The ends of the rails will be supported by bolted connections to the stainless steel plate of the Yoke end wall. The angle portion of the rail end is 2” thick in the conceptual design. The connection area is covered by two End Wall Modules at the end of each rail. To provide space for the angled portion of the ends of the rails the End Wall Modules will either need to be spaced away from the Yoke end wall or the End Wall Modules in this area will need to be modified to provide space for the ends of the rails. Additional investigation of the gap between the End Wall Module would be required to confirm that the End Wall Modules can simply be shimmed to provide space for the rail end connections. For this conceptual design it was assumed that the End Wall Modules would need to be modified. Figure 11 shows the side view of an End Wall Module and the red box indicates the area where the modules will need to be modified to provide space for the end of the support rail. The End Wall module could be modified by machining a step in the first 2" thick plate or the entire thickness of the plate could be torch cut to provide clearance.

Details of the bolt connections were not developed for this conceptual design but the following are some of the considerations that will guide that design.

- Each End Wall Modules is connected to the Yoke end wall with two 1" bolts. Only two holes of the 4 holes lie within the projection of the rail support end.
- The allowable shear load for 1" bolts is 6 tons per bolt (ASTM 193 B8 class) therefore some additional bolts will need to be added.
- The connection on the side from which ORKA is inserted will need to be designed to accommodate the loads during installation which will likely be larger than the loads from the detector in the final position.
- Additional holes can be drilled in the Yoke end plate in the field with a drill template and drill mounted to the Yoke end plate using the existing module mounting holes to hold the template and drill.
- The torque that the bolts of the rail connection must react could be reduced significantly if the vertical load at the end of the beam could be reacted by a bearing contact at the inner radius of the Yoke end wall bracing ring. The solenoid is connected to this ring and we did not consider any modification of the ring for this conceptual design.
- There may be some axial motion of the Yoke end walls with respect to each other when the solenoid is energized. To prevent large axial loads from being applied to the support rails the connections at one end of the rail should be allowed to slide in the beam axis direction. The end of the rail closest to the ORKA detector should be the fixed side.

Figure 11 Side view of End Wall Module

Magnetic Field Analysis of the affect of End Wall Module Modification

The steel of the End Wall Modules is part of the magnetic flux path of the CDF detector. An analysis was made with an axisymmetric model to gage the impact of a change to the end wall modules. A full 3D model would require significant additional effort. To quickly approximate the effects of the End Wall Module modifications the inner most iron plate was removed in the model. Figure 12 shows a comparison of the field in the model with and without the modification. The central field is 1.4015 T with for an operating current of 4683 A.

Figure 12 Comparison of End Wall Module modification from axisymmetric model

The high-quality field region for the ORKA detector would be the tracker volume which would extend in z from 90cm to 190cm from the west pole face (i.e. the last steel plate of the plug) with a radius of 50cm. Figure 13 shows the tracker region for the model and figure 14 shows the difference in the magnetic field when the 1st plate of the end wall module is removed. The difference in the field is less than 36 gauss.

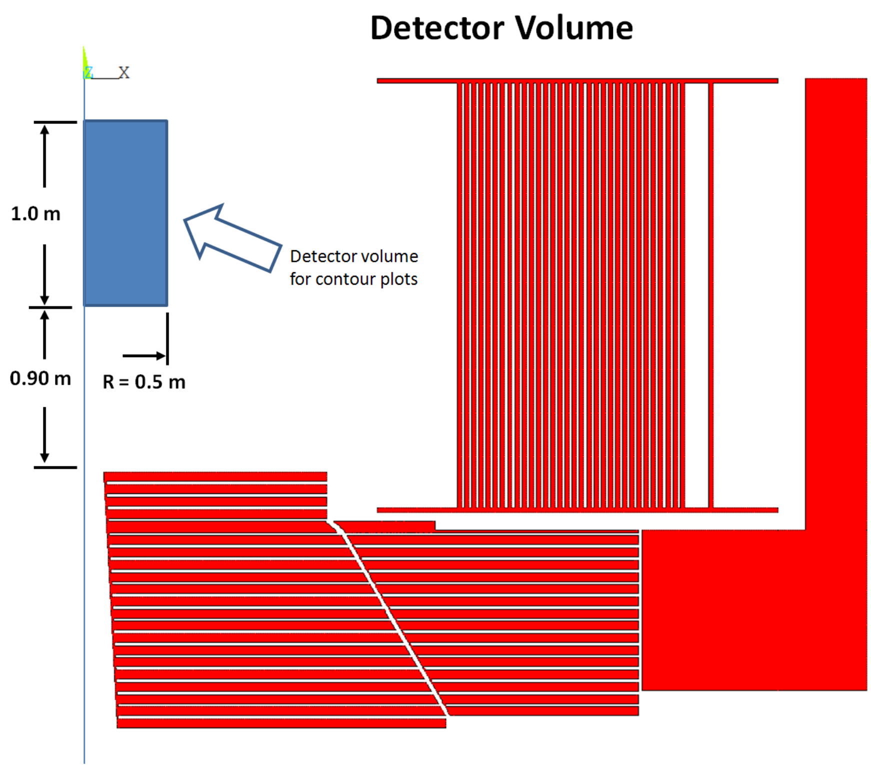

Figure 13 Region of model covering ORKA track volume

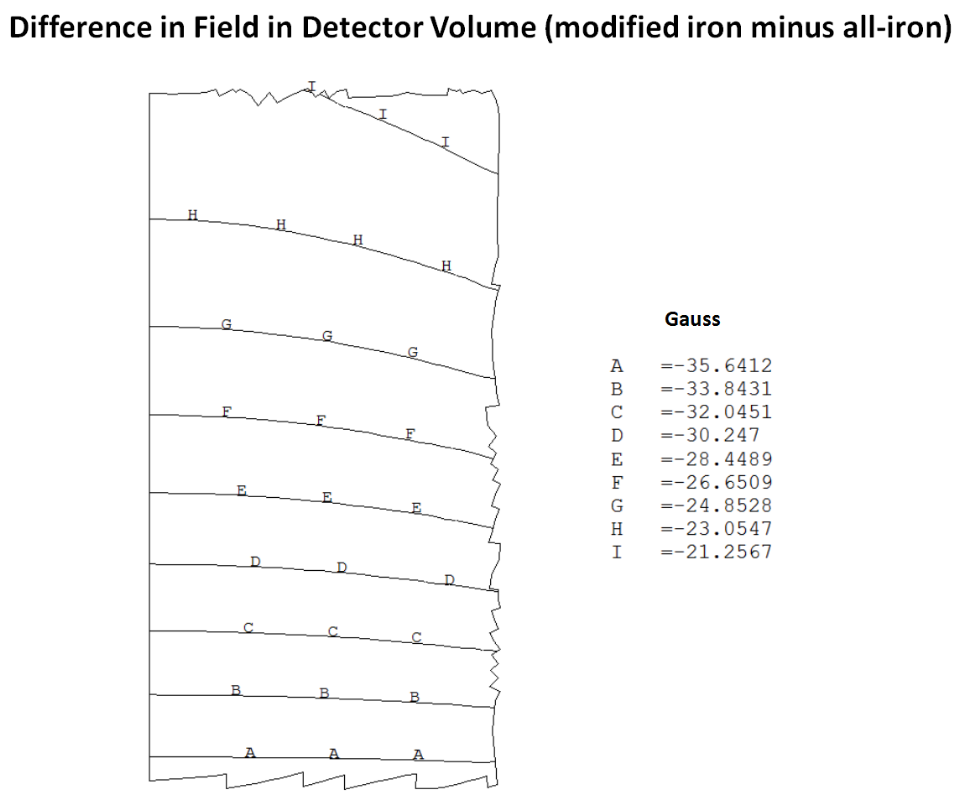

Figure 14 Difference in field in ORKA tracker volume with 1st End Wall Module plates removed

Installation Cart Design

The conceptual design was developed for a cart to move the ORKA detector from the CDF assembly hall into the collision hall and slide the detector on to the support rails that would already be mounted inside the bore the CDF detector. The cart has two rails that mimic the support rails which will be mounted in the CDF detector bore. The ORKA detector would be supported on the cart rails in exactly the same way as the support rails. The cart has rail extensions and telescoping legs that will be used to slide ORKA on to the support rails after it is in the collision hall.

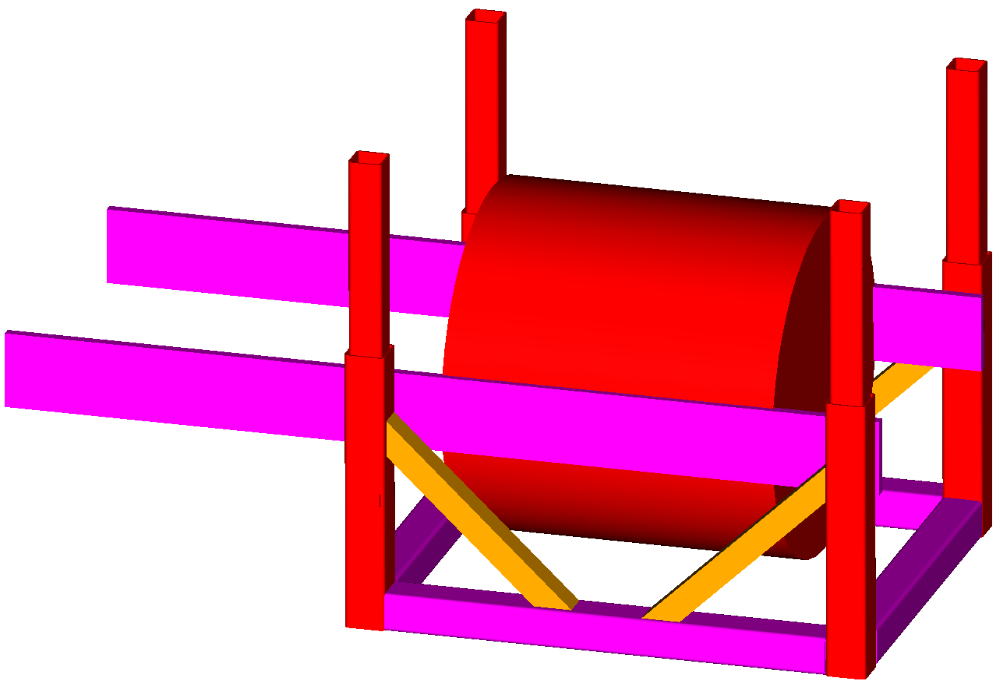

Figure 15 Installation Cart configured for transportation

It is expected that portions of the ORKA detector that are within the capacity of the 50 ton CDF building crane would be assembled on to the cart rails while the cart is in the assembly hall. The cart would be moved in to the assembly hall in the configuration shown in figure 15. After the cart is moved close to the CDF detector, the cart will be raised 94" and will be adjusted to bring the cart rail extensions into alignment with the support rails in the CDF bore as shown in figure 16. The cart can be raised with a set of 4 hydraulic cylinders mounted to the leg posts and push against adjusted brackets on the extendable legs. The cylinders would be connected to a unified lift system to raise the detector evenly. The legs will have a series of holes to engage pins to allow the brackets to be moved in increments within the stroke of the hydraulic cylinders. A safety latch will prevent the detector from dropping if any cylinder fails. The end of the rail extensions will be connected to the ends of the support. The ORKA detector will be pushed or pulled along the extension rails on to the support rails and into the final position.

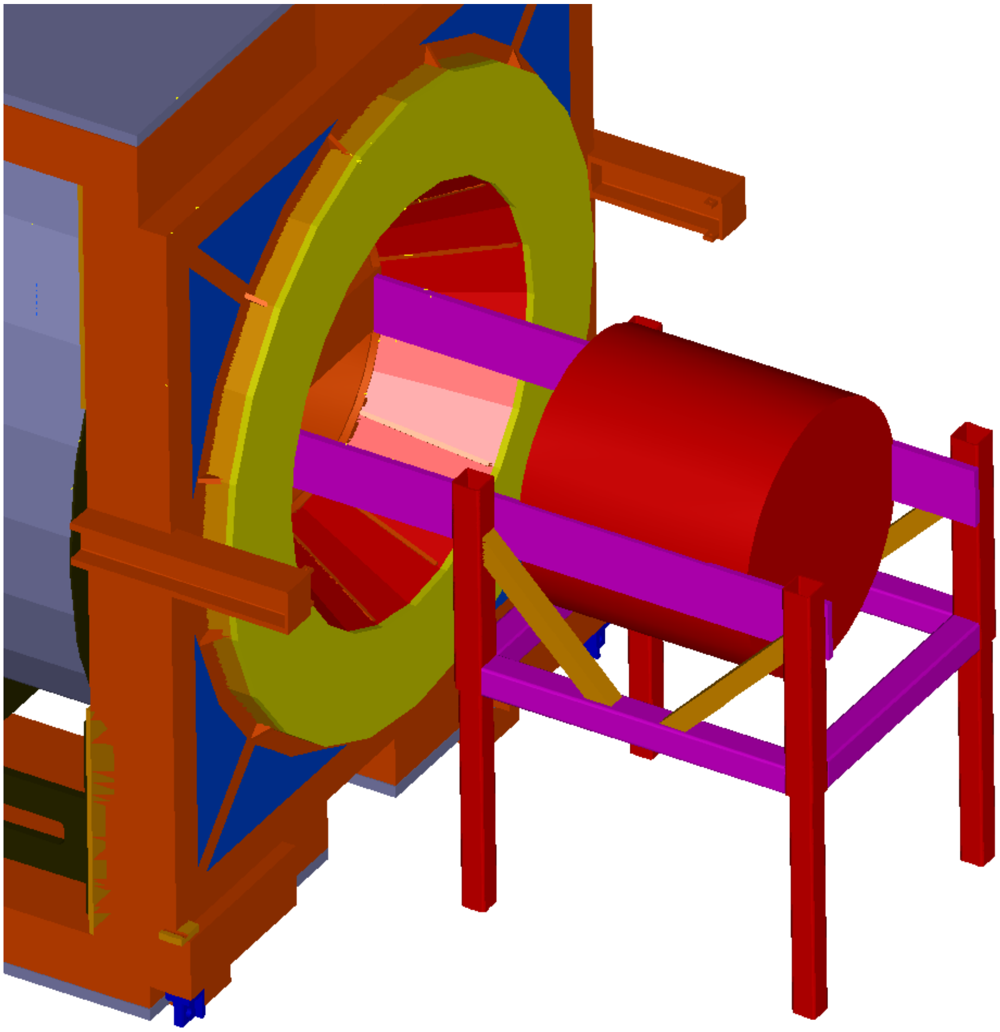

Figure 16 Installation cart configured to slide ORKA into CDF bore

A variety of ways could be used to slide the detector along the rail extensions. One option would use the same techniques as the cart leg extensions and use a pair of hydraulic cylinders to push against adjustable brackets that are attached to the cart rails. The minimum pushing force would be achieved by using roller bearings between the ORKA detector support and the rails. However most roller bearings are made of magnetic material and would need to be removed after the detector was installed. Another option would be to use a self lubricating bearing plate like the Garlock DU product shown in figure 17. The friction coefficient of DU bearing plate can be well under 0.1 and it has been used in multiple applications around Fermilab. The pushing force would be less than 10 tons.

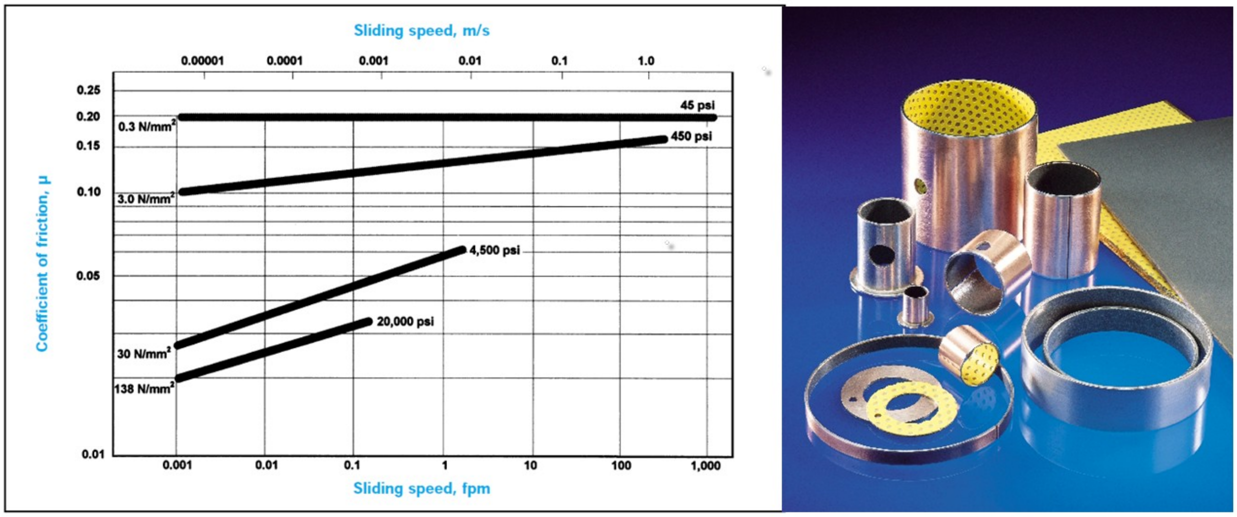

Figure 17 Garlock DU bearing plate

The stepped portions of the rails near the end may not provide sufficient bearing surface for a carriage contact to slide along. If this area is a problem then the carriage that runs along the rail may need three contact points to allow the stepped sections of the rails to be skipped over.

Rail Installation

The support rails will be installed in the assembly hall before the ORKA detector is complete. The sequence of steps is shown in Figure 18.

As described earlier, 8 End Wall Modules near at the 3 and 9 o'clock positions will need to be removed and modified. Several items such as gas lines, electronics and racks mounted to the face may need to be removed in order remove the End Wall Modules. The fixture for handling the End Wall Modules was shown in Figure 3.

The ISL and COT detectors will need to be removed to clear the bore of CDF for the ORKA detector. The fixture used for removing the COT is shown in Figure 18 and could be used for installing the support rails. Each support rail will weigh close to 2.5 tons and will require a fixture to position and hold it while it is connected. If an additional fixture with transverse and vertical motion is attached to the long boom of the COT fixture, the boom could be used to move the support rails into the bore. The lateral adjustments of an additional fixture can be used to move the rail to the final position where the bolts at the end connections can be installed. The modified End Wall Modules would be reinstalled after the rails are installed.

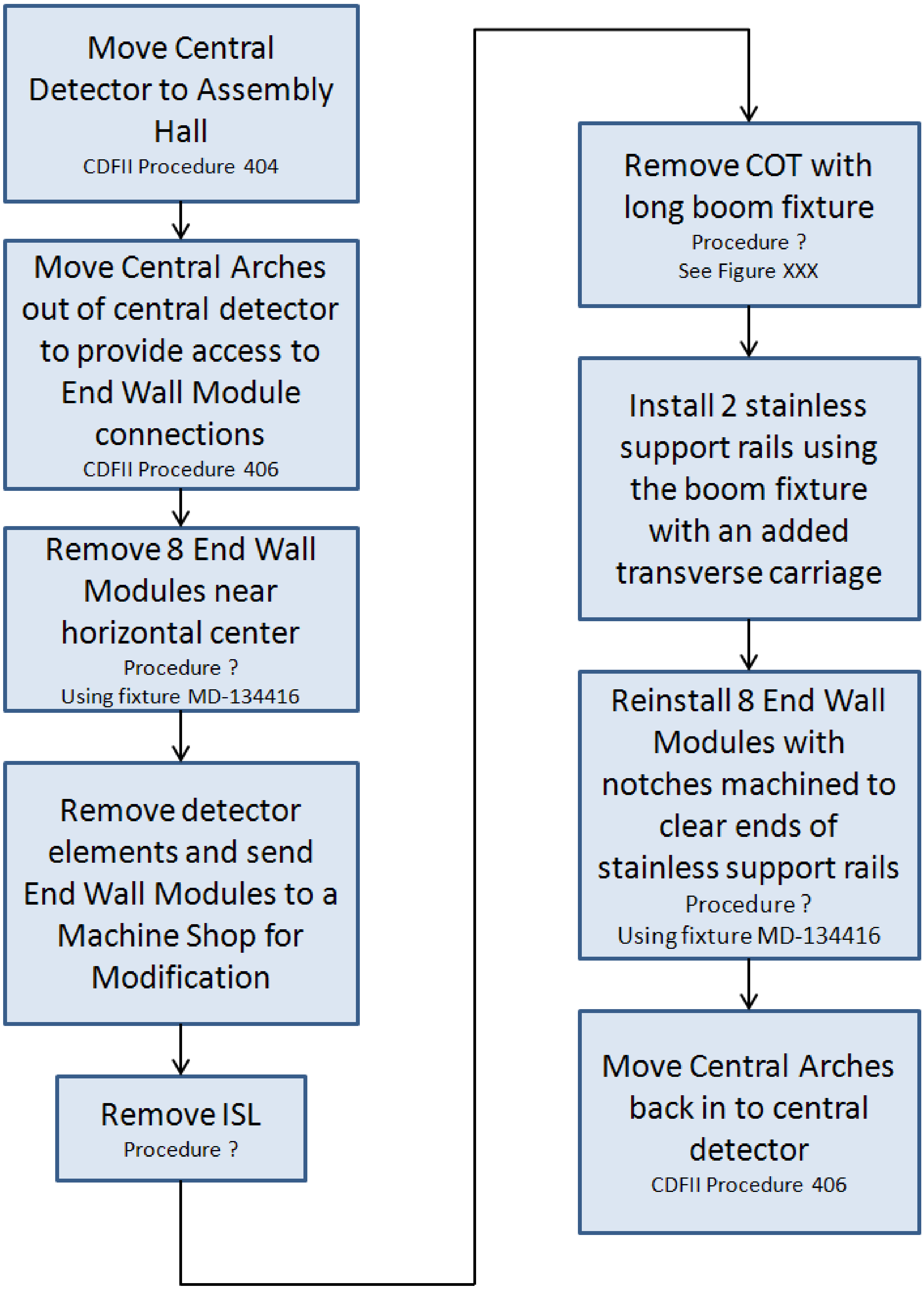

Figure 18 Steps for installation support rails in CDF bore

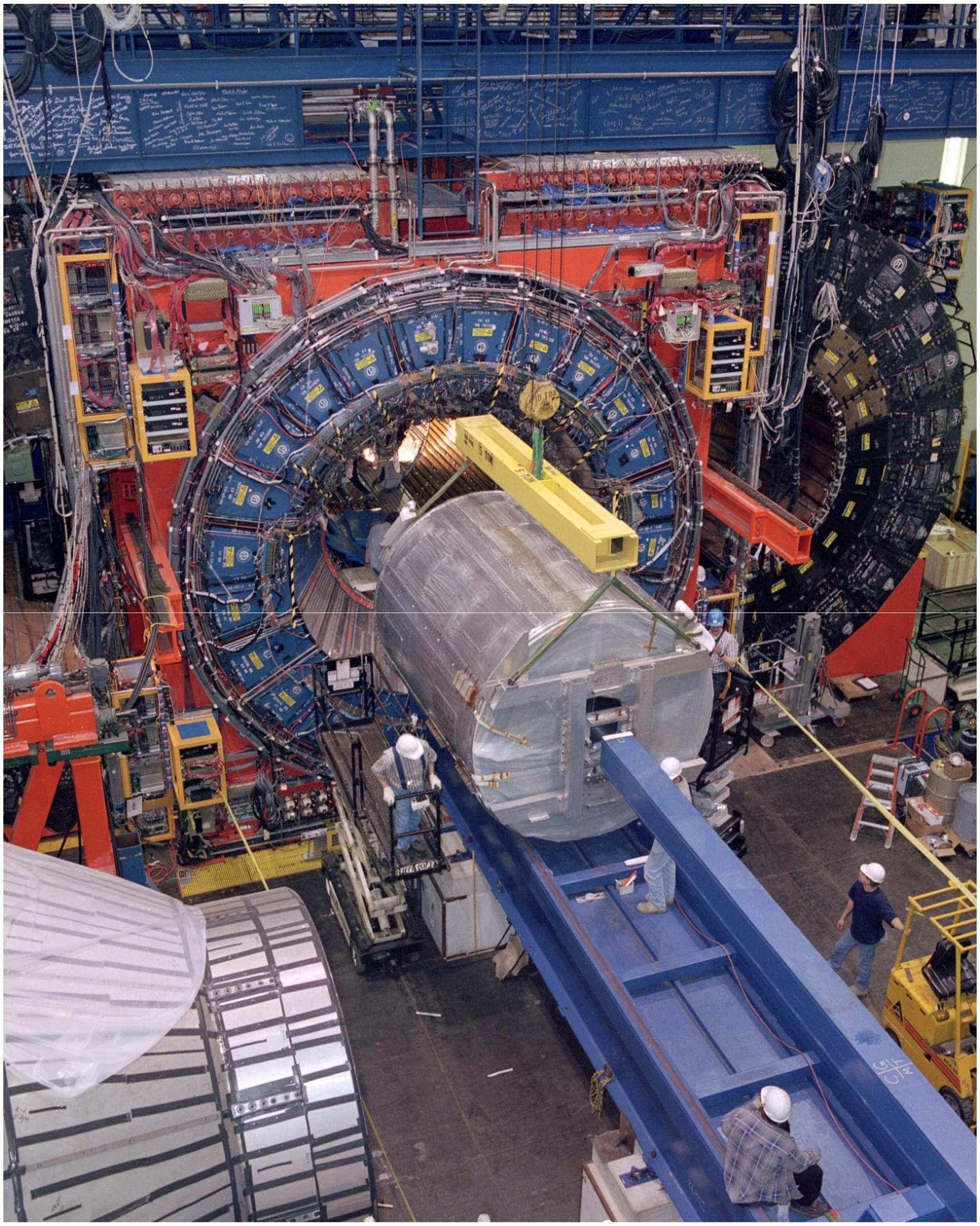
Figure 19 Fixture used to install COT

ORKA transport to Collision Hall and Installation into CDF bore

The sequence of steps to move the ORKA detector from the collision hall and install it into the CDF detector is shown in figure 20. The ORKA detector on the installation cart would be moved from the assembly hall to the collision hall using one of the two existing CDF “transporters” used to move large objects like the central arches. The transportation cart could be moved around the 710 elevation in the collision hall with Hillman rollers and cylinders and chains connected to tie points located in the collision hall. See the installation cart description for the use of the cart to slide the ORKA detector into the bore of CDF.

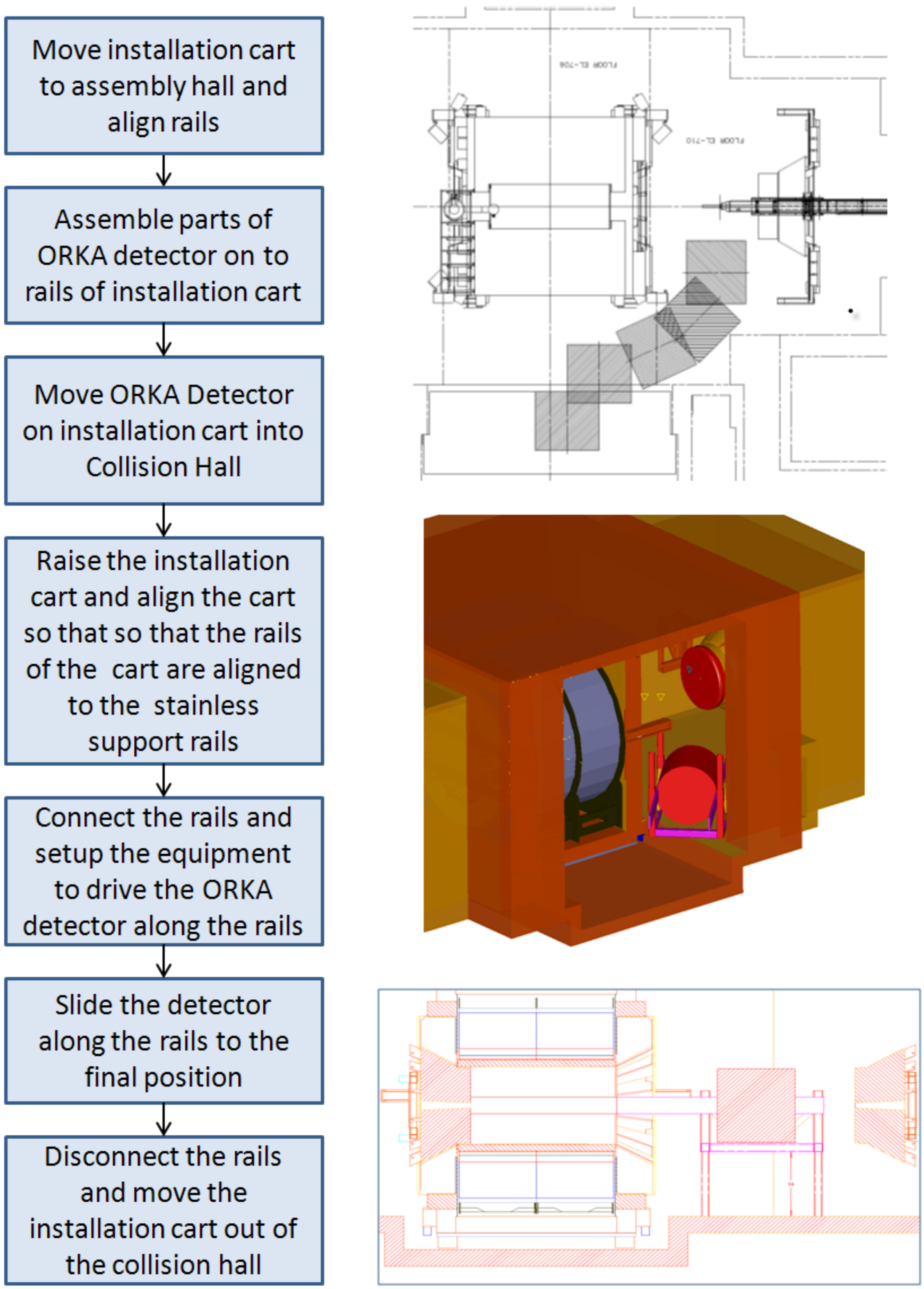

Figure 20 Sequence of steps to install ORKA detector

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Cost Estimate for Rail Support and Installation Cart

A cost estimate table was created that lists the design, procurement and installation costs for the support and installation of the ORKA detector. The table includes a description of the task and labor and M&S cost associated with that task. The design labor estimates were made by John Rauch and the engineering estimates were made by Joe Howell. A budgetary estimate was obtained for the support beam and the installation cart was estimated based on the weight and fabrication unit cost for similar large steel weldments with some machining. The Village Machine Shop was contacted about machining notches in the End Wall Modules but the modules at 11,000 lb are beyond the capacity of the 5 ton building crane and there has not been time to find an alternate source. An estimate of 24 shop hours per module was used for the machining option and the flame cut option would be considerably lower cost. Estimates for the installation labor were not prepared because it became apparent that many of the steps are standard operations used on the past and people involved with those operations in the past would be able to provide much more reliable labor estimates.

Summary and discussion

The proposed 100 ton ORKA detector can be supported by a pair of stainless steel rails inside the bore of the CDF detector. The rails can be connected to the Yoke End Wall and bridge the length of the solenoid with a maximum stress of 15 ksi (allowable of 19.8 ksi) and a vertical deflection at the center of 0.1 in (2.5 mm). 8 of the End Wall modules will need to be removed temporarily and modified or spaced out to provide access and clearance for the connections of the ends of the rails. The ORKA detector can be installed in the collision hall using a cart with extensions rail that connect to the support rails and allow the detector to be slid into final position.

The support and installation concept for a lighter detector of 35 tons would generally be the same as the design presented here. The size of the support rail and end connections could be reduced.

For this report we have assumed that the ORKA detector would include a support structure that would be capable of spanning between the two rails. That support structure should be an early integral part of the detector design.

Reference Information

The following list of procedure some of which

http://www-cdf.fnal.gov/htbin/cdfproc/listProc

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CDF Mechanical Group Operational Procedures: *(Numbered CDF II PROC-401 through CDF II PROC-499)*		
CDF II PROC-401	"CDF 1200 Ton Shielding Door Move Procedure"	Submitted to approval
CDF II PROC-404	CDF Central Detector Move Procedure	Submitted to approval
CDF II PROC-405	"Moving CMP Walls in the CDF Collision Hall"	Submitted to approval
CDF II PROC-406	Moving a Central Arch in or out of the Central Detector	Approved
CDF II PROC-407	"How to move a CMEX in the Collision Hall"	Submitted to approval
CDF II PROC-414	Moving IMU Steel	Approved; 1 HPC made.
CDF II PROC-414	Moving IMU Steel	Approved
CDF II PROC-415	□Procedure for Maintenance and Repair of the CDF Electronics	Approved; 1 HPC made.
CDF II PROC-416	□Operation of the CDF Electronics Cooling Water System□	Approved; 1 HPC made.
CDF II PROC-417	Operation of the COT Endplate Cooling System	Approved
CDF II PROC-420	Operation of the CDF CEM Source Calibration System	Approved
CDF II PROC-423	Procedure for Operating the End Plug Source Drive System	Approved
CDF II PROC-424	Plug Move	Submitted to approval

CDF procedures that will be needed to install the ORKA detector are marked with arrows

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MD-134231_end_wall_module_plate0-15_flamecut.pdf
MD-134231_end_wall_module_plate0.pdf
MD-134234_end_wall_module.pdf
MD-134254_end_wall_lift_fixture_assy_82.pdf
MD-134416_end_wall_lift_fixture_assy_83.pdf
MD-134693_endplug_ss_weldment.pdf
MD-134693_hole_coordinates.pdf
MD-134694_end_wall_tower_degrees.pdf
MD-134695_yoke_oblique_projection.pdf
MD-134767_end_wall_module_steel_frame_assy.pdf
MD-134959_end_wall_bracing_ring.pdf
ME-134693_stainless_plate_weldment.pdf
ME-134930_stainless_rib_weldment.pdf

List of drawings from TD Archive showing features of the Yoke End Wall and End Wall Modules