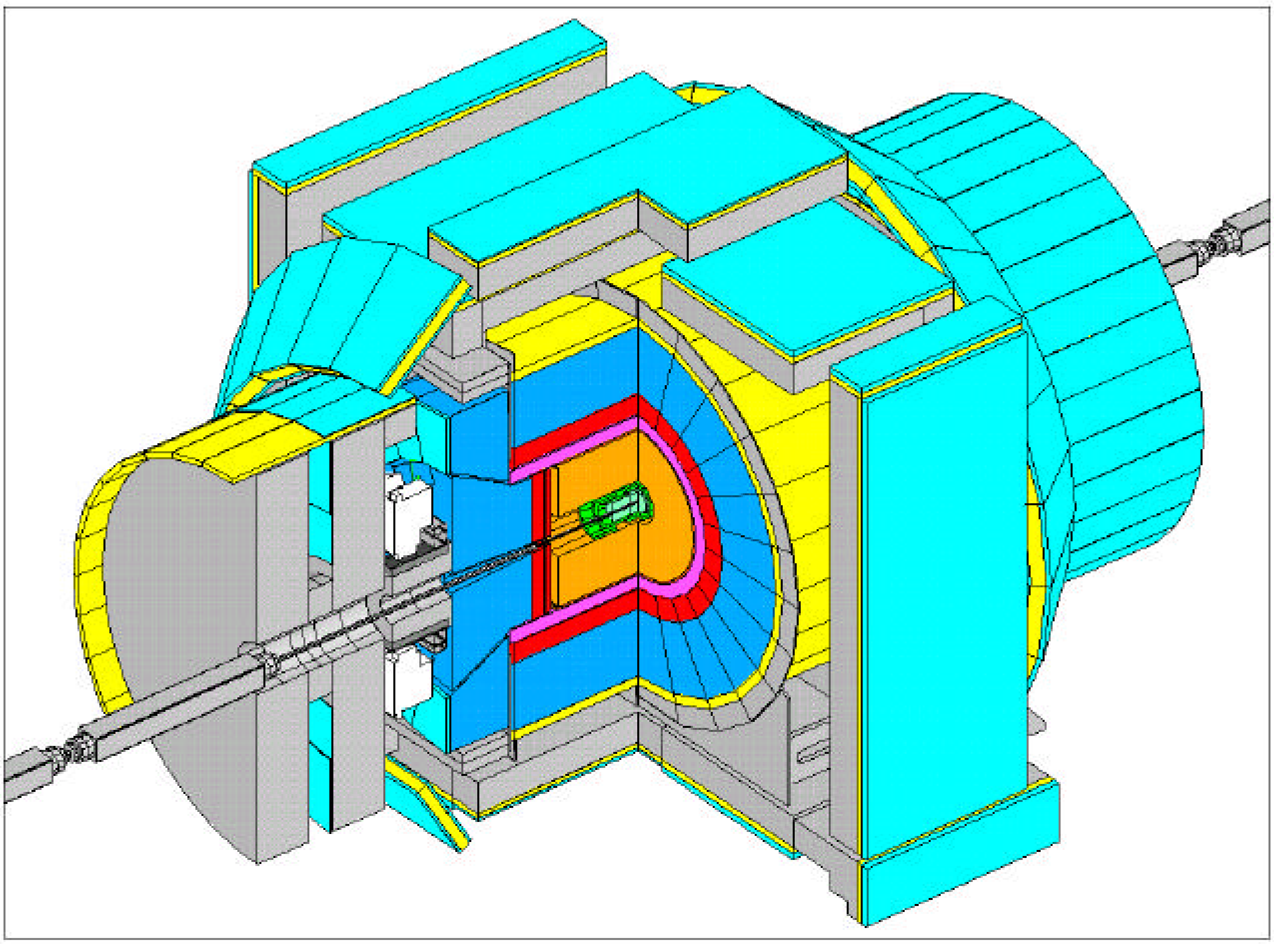
Ready for Operations
CD – 4 Report

The *CDF II* Upgrade



CDF Collaboration

DOE Review

CDF Upgrade Project

Ready for Operations (CD-4) Report

Introduction

The purpose of this report is to obtain Critical Decision no. 4 (CD-4) approval to begin detector operations. The report consists of six sections: 1) Project Cost; 2) Schedule; 3) Technical Objectives; 4) Safety; 5) Photographs; and 6) Ready for Operations Sign-off sheet.

The purpose of the CDF Upgrade Project is to rebuild the CDF detector to exploit the physics opportunities available with an upgraded Tevatron Collider for Run II. The Run II Tevatron Collider will operate at the energy frontier by providing proton-antiproton collisions at 2 TeV in the center-of-mass, peak luminosities of 2 x 10^{32} cm^{-2} sec^{-1}, and bunch spacing as short as 132 ns.

The CDF II detector will carry out a broad physics program that addresses the most fundamental questions in modern high energy physics. This program will include studies of the W and Z bosons (the carriers of the weak force), precision measurements of the top quark mass and its decay properties, QCD studies, and studies of particles containing a *b* quark. Using hadrons containing *b* quarks CDF II will study CP violation in the B sector and B_s mixing. CDF II will also search for the Higgs boson and will explore the origins of electroweak symmetry breaking. In addition CDF II will search for exotic physics beyond the Standard Model such as supersymmetry or extra dimensions.

The CDF II detector will achieve these goals by accurate measurement of the properties of the hadrons and leptons produced by proton-antiproton collisions over the largest possible solid angle. CDF II employs precision tracking in a large solenoidal magnet to measure charged particle trajectories and momenta. Micro-vertex detectors identify secondary vertices from *b* and *c* quark decay. Calorimeters are used to measure the energy and position of hadrons and electrons. Additional iron absorbers and chambers located beyond the calorimeters identify penetrating muons. Particle identification is provided by dE/dx and a time-of-flight system. A data acquisition system and a three-level trigger select events of interest at a few 10's of Hz from the more than 10 million collisions that occur each second of collider operation. The selected events are written to mass storage for additional off-line analysis.

For Run II, the CDF detector retains the Run I superconducting magnet, central calorimeters, and portions of the Run I muon system. All other systems including the micro-vertex and central tracking systems, the endplug calorimeters, front-end readout electronics, data acquisition system, and the experiment infrastructure are new.

Project Cost

The table below contains the cost baseline and the current completion projection. The project will be completed within the cost baseline. The baseline was established on February 13, 1997. The DOE-Equipment portion of the baseline is controlled by DOE via change control procedures. The DOE Operating portion of the baseline is controlled by Fermilab in constant FY 1995 dollars, and for the purposes of this report has been converted to then-year dollars in accordance with Fermilab's actual funding profile.

Cost Table (Then-Year M$)			
	Baseline	Obligations through 12/00	Est. at Complete
DOE Equipment	57.8	57.0	57.5
DOE Operating (FY 97-present)	37.4	35.8	37.4
Non-DOE	18.2	15.2	17.2
Total	113.4	108.0	112.1

A cost closeout report for this project is scheduled for submission to DOE by March 2002.

Schedule

The project has one remaining level 1 milestone, "Ready for Collisions," of March 2001. This milestone was established on December 14, 1999, and has not changed since that time. This milestone will be met.

Technical Objectives

This section presents how the subsystem requirements presented in the Technical Objectives section of the Project Management Plan have been met by the upgrade.

1. *Replace the plug and forward gas calorimeters with new scintillator-based calorimeters.*

The Run I Plug and forward calorimeters were read out with gas proportional chambers as the active medium. These calorimeters suffered from sampling errors, electrical noise and glow discharges. These problems would have been more severe at the high luminosity expected in Run II. In addition they had a pulse formation time that precluded full charge collection in 132 ns. The Run I calorimeters have been replaced with new scintillator-based endplug calorimeters (see page 8). The new calorimeters cover the solid angle of both the Run I endplug and forward calorimeters. This choice eliminates corrections and loss of efficiency at the former 10° boundary between the forward and endplug systems and allows the CDF muon system to be more hermetic for Run II. The new calorimeter uses scintillator as the active medium. The scintillator is read out with wavelength-shifting fibers. The light is then transported over clear fibers to photomultipliers located at the back of the endplugs. The hadronic section reuses the Run I steel plates that form part of the magnet return yoke, but adds additional stainless steel to close the polar angle to 3°. The electromagnetic section uses lead as a radiator and is entirely new. The resolution of the electromagnetic section has been demonstrated with the test beam and cosmic rays to be 16%/$\sqrt{E}$ with a 1% constant term. Similarly the hadronic calorimeter has achieved its design resolution of 80%/$\sqrt{E}$. **Performance of the endplug calorimeter was verified during the November 2000 CDF commissioning run.**

2. *Replace the silicon micro-vertex detector with a device capable of withstanding the expected radiation dose for Run II and with fast r-ϕ r-z readout.*

A new five-layer radiation hard micro-vertex detector (SVX II) has been constructed (see pages 13 and 15). It features five double-sided layers of silicon. All layers are read out in r-ϕ. There are three small-angle stereo and two 90° r-z readout layers. The detector was built as three 12-sided barrels and its overall length is about twice that of the Run I silicon detector. Each barrel is made up of 60 ladders of silicon detectors with readout electronics mounted at the ends. The ladder support structure is fabricated from carbon fiber and supported by beryllium bulkheads to achieve very low mass. An additional very radiation- hard inner layer of silicon (L00) was added to the system to extend the radiation lifetime of the detector. This detector is built directly on the beryllium beam pipe. The entire silicon detector assembly geometry was controlled to micron accuracy. The on-detector electronics is cooled by a water-glycol system. The silicon signals are read out via a custom VLSI dead-time-less SVX3 chip. Signals are transported from the detector on high-speed optical fibers to VME readout electronics. The system includes a novel and unique secondary vertex trigger capable of triggering the CDF detector at Level 2 on displaced vertices due to *b* or *c* quark decays. This should be a powerful feature for B physics studies and the search for a light Higgs. **Performance of the silicon tracking system has been verified with cosmic rays and with a subset of Run II production silicon detectors installed inside the COT for the November 2000 commissioning run. Data from tracks produced by collisions indicate that the desired construction accuracy, detector noise, and spatial accuracy were achieved.** Verification of this performance for the final silicon system awaits testing of the final system with Run II collision data.

3. *Add additional layers of silicon detectors outside the silicon micro-vertex detector to provide track reconstruction and momentum measurement to $|\eta| < 2$.*

The CDF II Intermediate Silicon Layers (ISL) provide a complete sixth and partial seventh layer of double-sided silicon (see pages 14-15). These layers make it possible to do stand-alone silicon tracking to $|\eta| < 2$. This nearly doubles the solid angle over which CDF will be able to track charged particles, allows measurement of momenta and charge ID over this solid angle and will substantially improve efficiency for *b*-tagging in Run II. In addition, the ISL will allow CDF to resolve ambiguities in the dense tracking environment of Run II. **Initial survey data from this detector indicate that the detectors were built to the required precision, and numerous**

electrical checks have verified that the detectors are working correctly. Final verification of system performance requires Run II collision data. The ISL system employs the same readout electronics as SVX II.

4. *Replace the Central Tracking Chamber with a device with shorter drift time to allow tracking in a high-luminosity environment.*

   A new Central Outer Tracker (COT) has been built for Run II (see pages 10-11). It provides high efficiency 3D track reconstruction for tracks with $|\eta| < 1.3$. In addition it provides precision momentum determination for charged particles corresponding to 150 micron *r*-ϕ error. The COT provides track-based trigger information at Level 1 and dE/dx information for particle identification. The COT also provides the mechanical support for the Run II silicon detectors and for a time-of-flight (TOF) system. The chamber itself has a cylindrical geometry with near axial sense wires strung between precision aluminum endplates. The sense wires are grouped into 12 superlayers, six axial and six small-angle stereo. The chamber has many novel features. Field shaping is provided by gold plated mylar field sheets, and wires were pre-wound on PC boards so that chamber assembly was much faster than hand stringing. Each superlayer presents 12 wires to an outgoing track for a total of 96 measurements at $\eta = 0$. The cells in the chamber are tilted at 35° to compensate for the Lorentz angle of drifting ionization in the 1.4 Tesla field of the superconducting solenoid. The cells themselves have a maximum drift distance of 8.8 mm. This permits full charge collection in 132 ns when the chamber is operated with a "fast" gas containing CF_4. There is a total of 30,240 sense wires in the chamber. They are read out via Amplifier Shaper Discriminators that encode charge (ASDQ). The signals pass through micro-coax to repeater cards before being read out by VME pipelined Time to Digital Converters (TDCs). **The chamber was operated in the November 2000 commissioning run with a portion of its final electronics. The chamber worked exceedingly well and is expected to meet all its performance goals. The track-based trigger (XFT) was also exercised and achieved its design goals for momentum resolution and spatial accuracy.** Final tune up of the COT and its reconstruction algorithms will be a focus of the early detector commissioning activities in Run II.

5. *Improve muon detection systems to increase acceptance and allow the electronics to work with shorter bunch spacing.*

   The Run I Central Muon (CMU, CMP, CMX) systems have been upgraded with new electronics that permits operation of these chambers at the lower gas gains required at the higher luminosities expected for Run II. The readout TDCs are fully pipelined to permit dead-time-less operation. Additional steel, chambers and scintillator have been added to the CDF II detector to fill the gaps in the Run I central muon coverage and to reduce accidental trigger rates. Modifications were performed to the CMP scintillator to improve the light output to insure high efficiency. An entirely new Intermediate Muon system (IMU) was constructed. The IMU takes advantage of the more hermetic muon coverage possible now that the function of the Run I forward calorimeters is incorporated into the Run II endplug calorimeter. The IMU consists of chambers and scintillator in a barrel-like configuration that surrounds the former toroid steel which is now located 5.5 m closer to the interaction point. Toroid scintillators extend the IMU coverage to $|\eta|= 2$. The upgraded muon systems for Run II provide more than twice the coverage for central muons compared to that of the Run I CDF detector. Photos of the upgraded Run II muon systems can be seen on pages 9 and 10. All muon systems have been tested with cosmic rays. **Many of the upgraded muon systems were in operation for the November 2000 commissioning run. All performance goals either have been or are expected to be achieved.**

6. *Upgrade the front-end electronics and trigger systems to accommodate data-taking at higher rates and with shorter bunch spacing.*

   The front-end electronics for the entire Run II detector is new. The new electronics is designed to record signals with the precision and dynamic range required for Run II. The electronics systems are designed to work at beam crossing separations as small as 132 ns and to allow association of signals with a single crossing. The main readout modules are housed in 160 water-cooled 9U VME crates distributed on the detector and in the counting rooms. TDCs record information from the central tracking and muon chambers. They also measure arrival times in the hadron calorimeters. Analog signals are recorded in ADMEM modules that measure energy deposition in the calorimeters. Variants of this electronics read out pre-radiators and shower max detectors. Silicon detectors are read out over optical fibers to a Fiber Interface Board. Nearly all of this detector data is then digitized and read out by crate-level CPUs. The data is transmitted to the control room over optical fibers and collected in VME memory boards The electronics is synchronized via a distributed precision clock. Trigger information at Level 1 and 2 is provided from tracking and calorimeters via a parallel digital path. The hardware trigger can select events of interest based on calorimeter energy deposition, tracking information in the chambers or silicon detectors or on more sophisticated event topology information. The front-end electronics is fully pipelined and allows detector signals to be stored for up to 5 microseconds while Level 1 and 2 trigger decisions are made. **Simulations of the electronics architecture and buffering indicate that the detector can operate at luminosities in excess of 2 x 10^{32} cm^{-2} s^{-1} with > 90% livetime. Preliminary results from the November 2000 commissioning run support these conclusions.** Commissioning of the final Run II trigger hardware and software requires collision data.

7. *Upgrade the data acquisition system to increase throughput and reliability.*

   The upgraded CDF II Data Acquisition System (DAQ) delivers data from the front-end VME crates to the Level 3 trigger at 300 Hz. The DAQ system delivers hardware trigger decisions to all front-end crates and initiates readout of events. Event Builder hardware and software transmits event fragments from the front end crates through an ATM optical switch to a target Level 3 processor in which the full event is assembled.

The Level 3 trigger system, which consists of a farm of commercial PC's, determines which events to save. The events are then delivered to local mass storage at rates up to 50 Hz and shipped over fiber optic links to the Feynman Computing Center for long term storage on robotically mounted magnetic tape media. The system also provides for operator control of data taking and for on-line monitoring of the experiment. **The entire DAQ system was exercised in a commissioning run in November 2000, and it met or exceeded all performance specifications**.

8. *Install and commission the detector.*

Most of the infrastructure and subsystems that support operation of the CDF II detector are new. These additions include new HVAC controls for the collision and assembly halls, new AC power distribution in the collision hall, new control systems for Low Conductivity Water, a new electronics cooling water system, a new environment-friendly freon based cooling system for the Central Outer Tracker electronics, a new cable plant for the entire detector, a new water-glycol cooling system for the silicon detectors, new controls and interlocks for the superconducting solenoid and cryogenic system, and significant upgrades to the CDF flammable gas system including provisions for custom mixing the required chamber gases. New equipment was also built to allow the rapid opening of large muon steel structures. **All major components of the Run II CDF detector have been transported and installed in the CDF collision hall. Many of these systems were already extensively tested during the November 2000 commissioning run (see page 17). The experimental infrastructure and installation sub-project has met its objectives.** Final commissioning of the detector requires collision data.

Safety

The design, construction, commissioning, operation, and de-commissioning of all CDF Upgrade systems have been and will continue to be designed to conform to the applicable Fermilab standards as specified by the URA-DOE contract. The Work Smart (formerly Necessary and Sufficient) Standards Set itemizes all the laws, regulations, and standards to which Fermilab must adhere. The standards set is part of Fermilab's contract. The Fermilab ES&H Manual (FESHM) incorporates the applicable external requirements with internal standards and thus represents the full set of ES&H requirements used at Fermilab. When no specific codes or Fermilab standards exist, the designers use best engineering practices and peer review during the design stage. All CDF employees and Collaborators are trained for local area emergencies. They also receive specialized training for areas that present unique hazards if their work exposes them to the hazard.

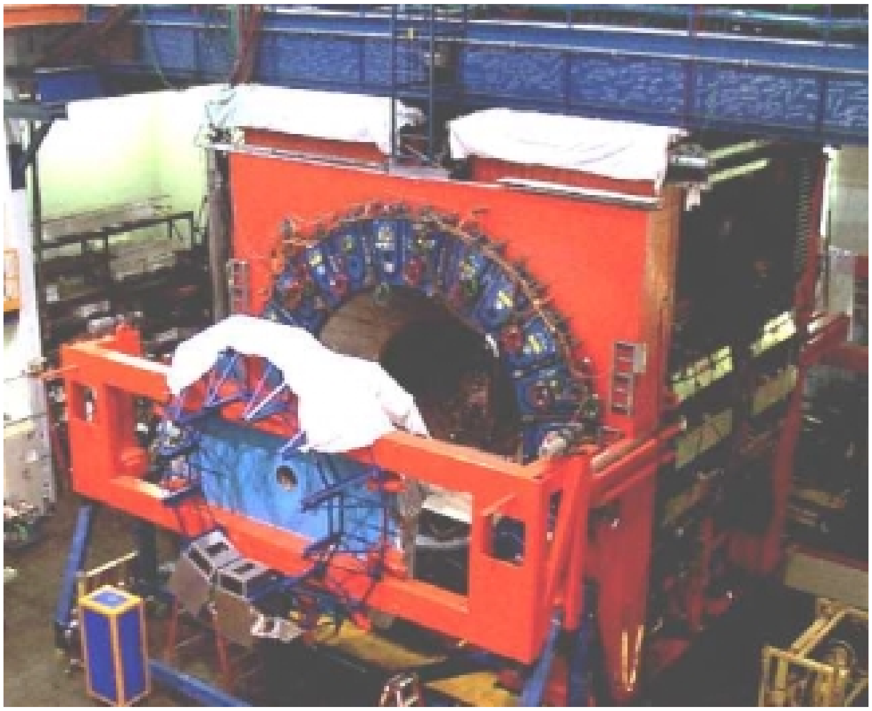
The original CDF Detector was designated a Low Hazard Radiological Facility and the Safety Envelope was approved in " Memo to Dr. J. Peoples from Andrew E. Mravca, Subject: APPROVAL OF THE SAFETY ENVELOPE FOR THE COLLIDER DETECTOR AT FERMILAB" received on Nov. 14, 1995, following submission of a Safety Assessment Document (SAD). The CDF Upgrade Project does not influence that determination.

In compliance with the Fermilab ES&H Manual, the Directorate, through the ES&H Section, determined the need for an update or addendum to the CDF SAD. The Fermi Area Office ES&H Team reviewed and commented on CDF's SAD Addendum. At the time of the commissioning run, the SAD Addendum was approved by Fermilab's Directorate, with concurrence from the Fermi Area Office. The addendum has been modified to incorporate the transition to operations and has been approved.

The Particle Physics Division established a CDF Upgrade ES&H Review Committee. The committee is composed of experts in mechanical engineering, electrical engineering, fire protection, and cryogenics/ODH who are independent of the CDF Upgrade Project. They were free to draw on other experts as the need arose. Their charge was to review certain Upgrade detector components and associated support equipment to ensure that adequate analyses and documentation existed to demonstrate compliance with ES&H requirements. They conducted reviews at appropriate points in the design process and again prior to the initial operation of systems. They prepared reports for the Head of the Particle Physics Division that summarized the compliance status of each reviewed system and made recommendations for correcting any deficiencies or approving initial operations. The Fermi Area Office and Fermilab's ES&H Section conducted an oversight review of CDF's safety assessment and readiness review process and found “Fermilab’s overall authorization process and procedures for verifying detector hardware, personnel and procedural readiness sufficient to support a continued high level of safety during CDF operations.”

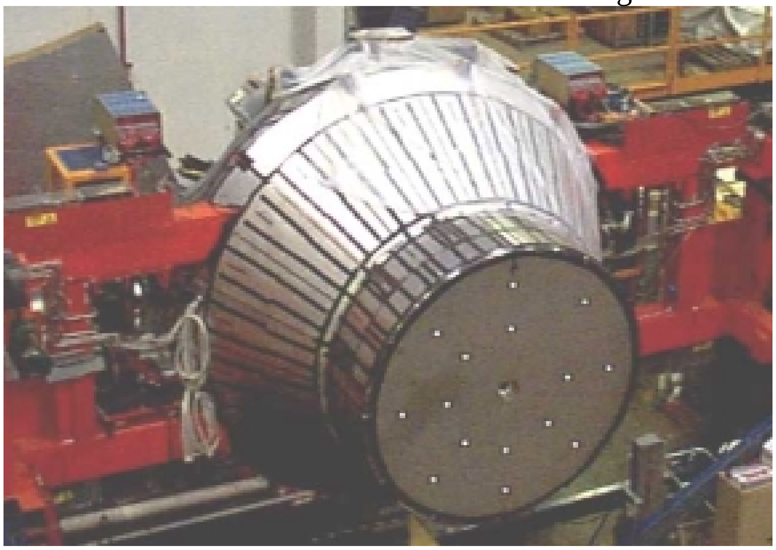
Photographs

Presented below are photographs of the major systems of the project.

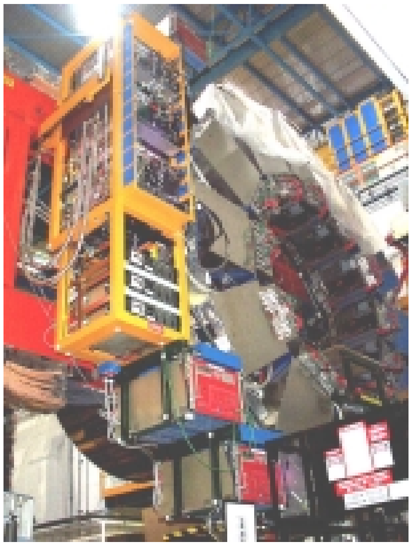


The Run I detector stripped of electronics and Run I equipment prior to the removal of the Run I central tracking chamber. The plug steel has already been modified to the Run II geometry. This shows the starting point for the Run II upgrades.

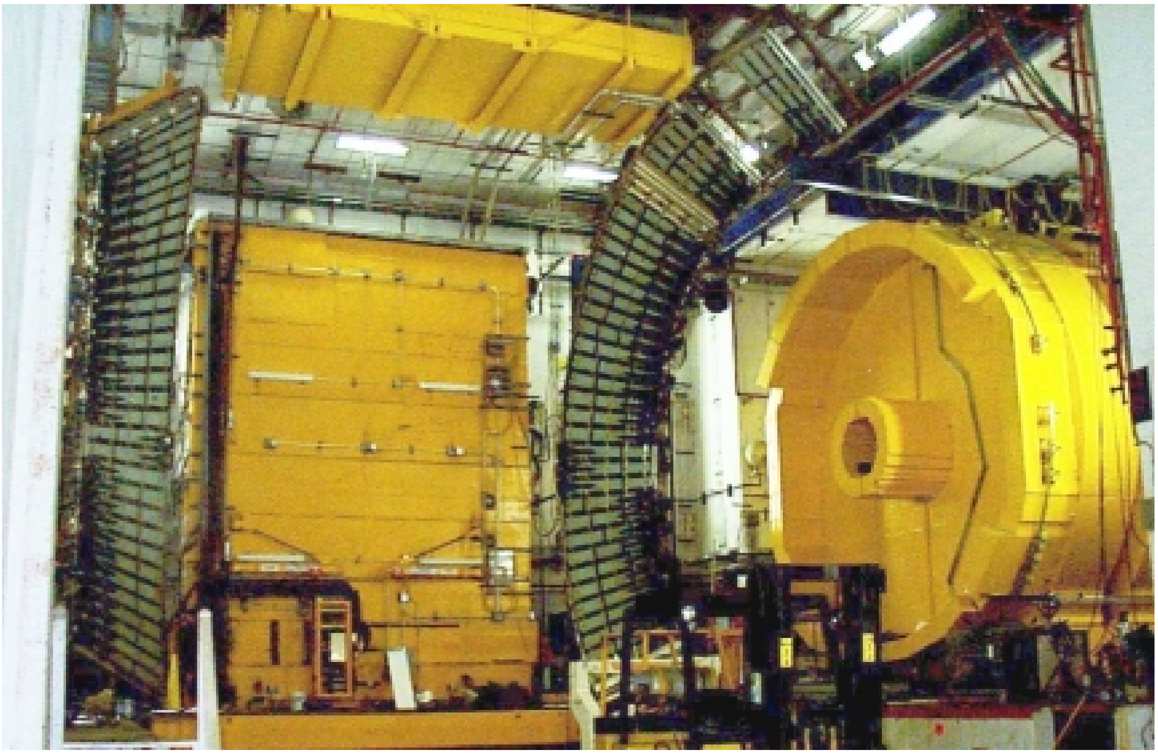
End Plug Calorimeter Upgrade:



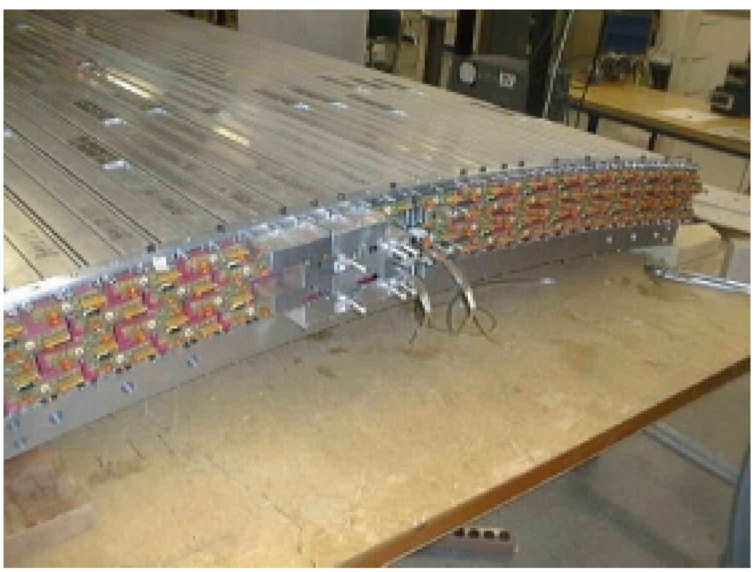
West Endplug Calorimeter with new electromagnetic section in place.



West Plug Calorimeter viewed from back with new electronics and infrastucture in place. Racks contain VME crates with ADC's and Low Voltage Power Supplies. Red boxes are HV supplies. Aluminum boxes provide temperature control and light tightness for Photomultipliers .

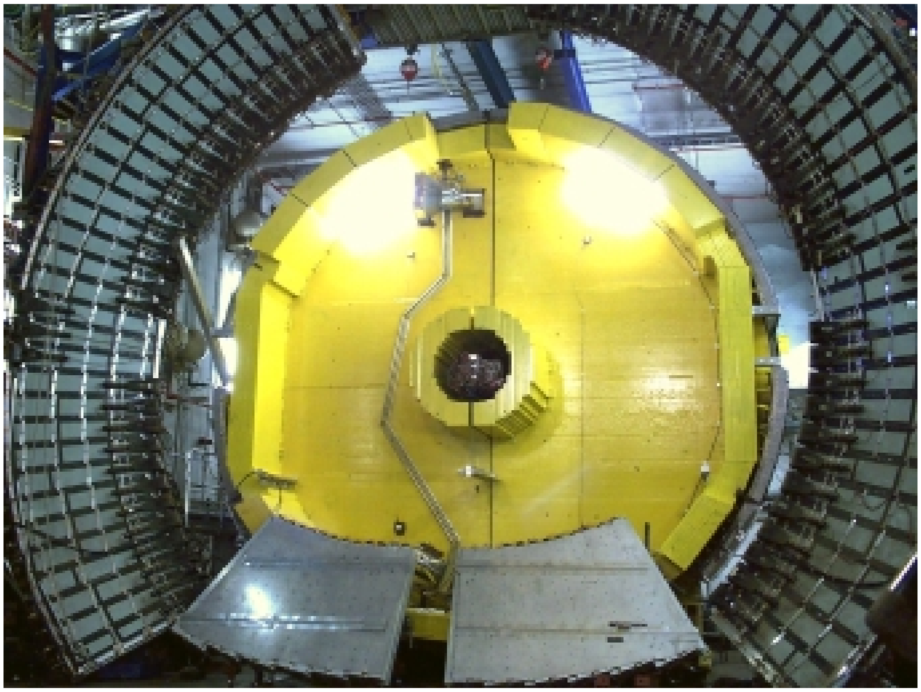


Collision Hall view of steel modifications for Run II muon systems. The yellow structures at the right of this picture are the West Toroids modified for the IMU system. Note internal and external snouts that provide additional shielding for CMX detectors. South arches of CMX chambers are visible, note wedges being supported from collision hall ceiling. The yellow rectangle at top of picture is CMP notch steel suspended from collision hall ceiling. The south Muon CMP wall is visible at back of picture. Modified CMP chambers and CMP scintillator are mounted behind this wall.

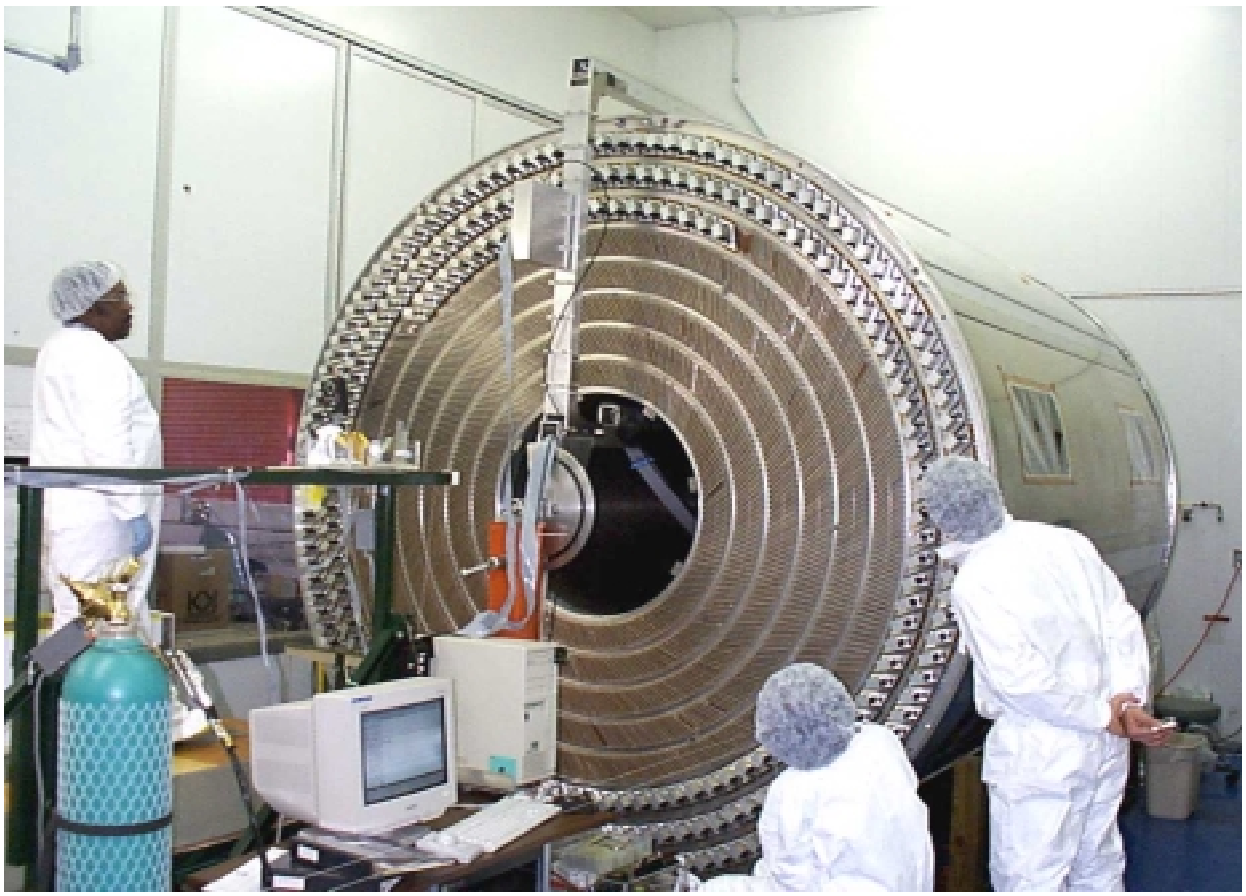


IMU Chambers under construction at University of Wisconsin.

IMU chambers mounted on modified Toroid steel in collision hall.



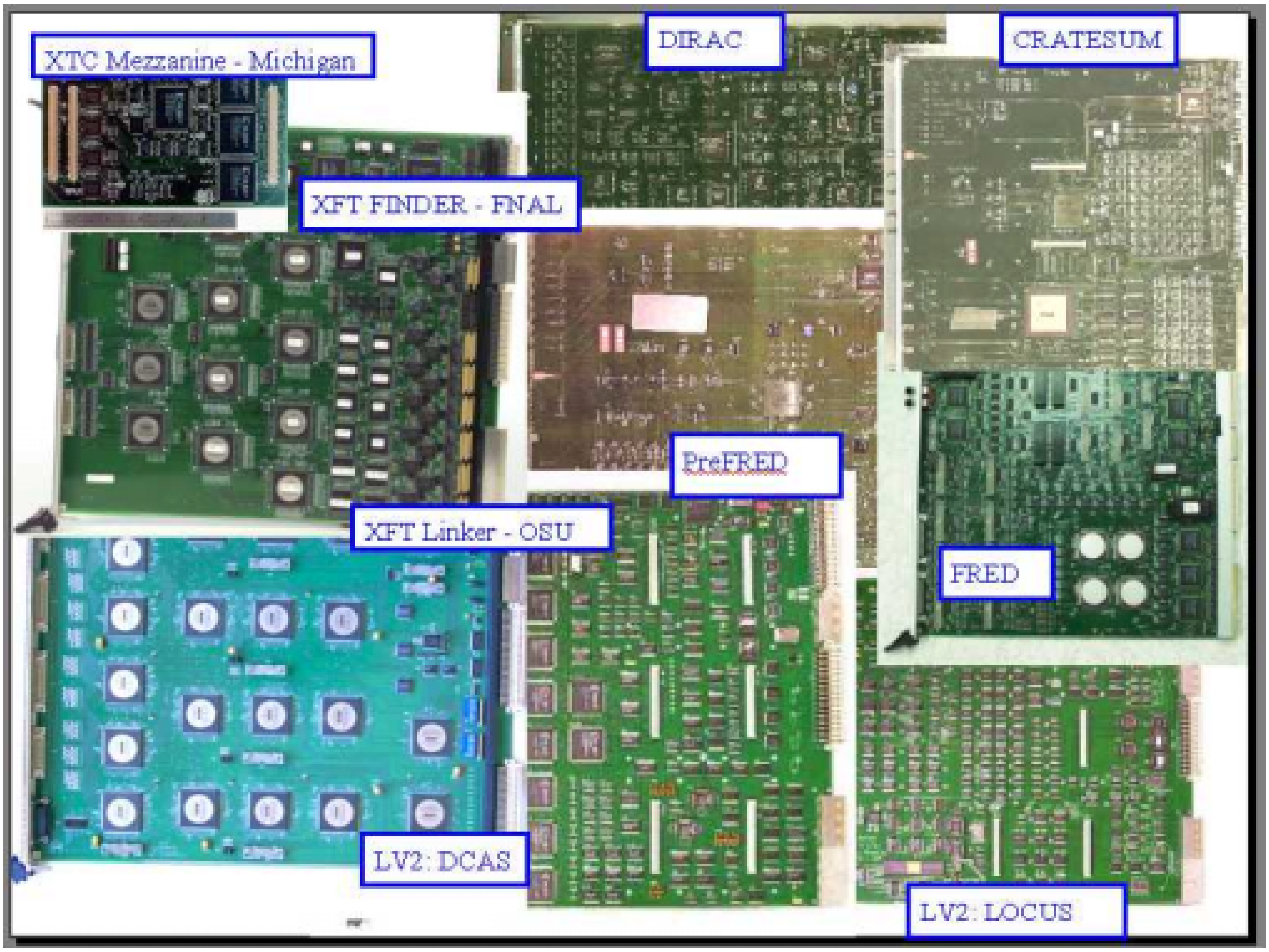
View of CMX system from interaction point Jan 30, 2001 just before installation of central detector. New 30 degree sections of CMX miniskirt are in raised position for central detector insertion.



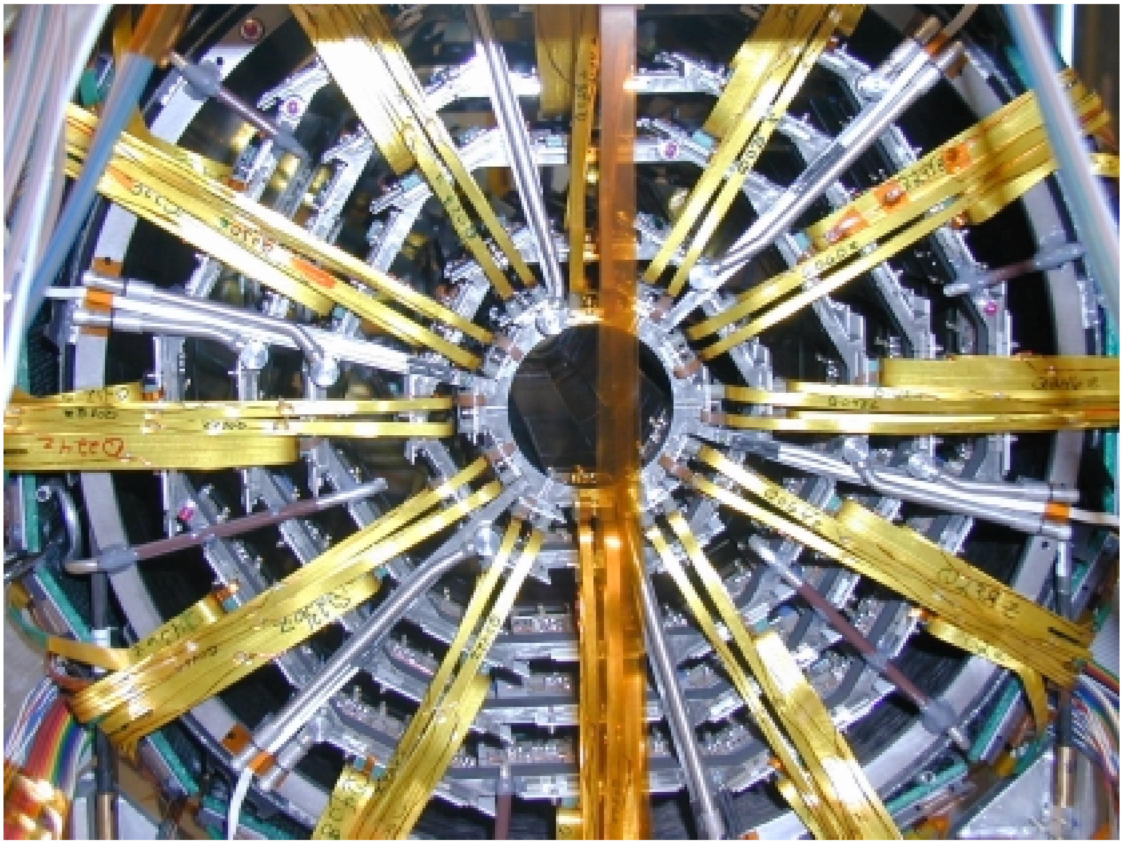
Central Outer Tracker wire plane and field sheet insertion in IB4. Outer superlayers still have preload fixtures in place Frame supports magnets used to measure wire tensions

Installation of gold plated mylar field sheets in the Central Outer Tracker

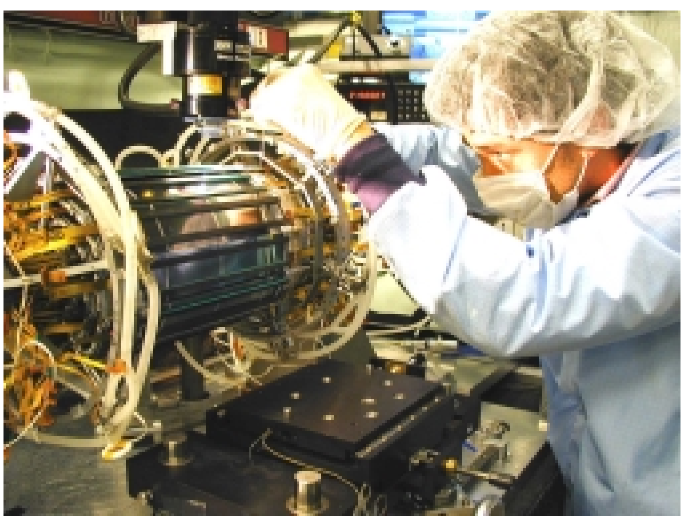
Installation of Central Outer Tracker



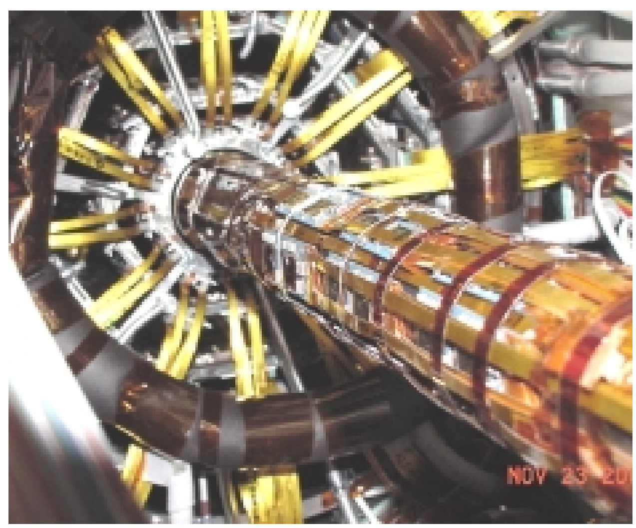
A collection of some of the Run II Front End & trigger electronics boards



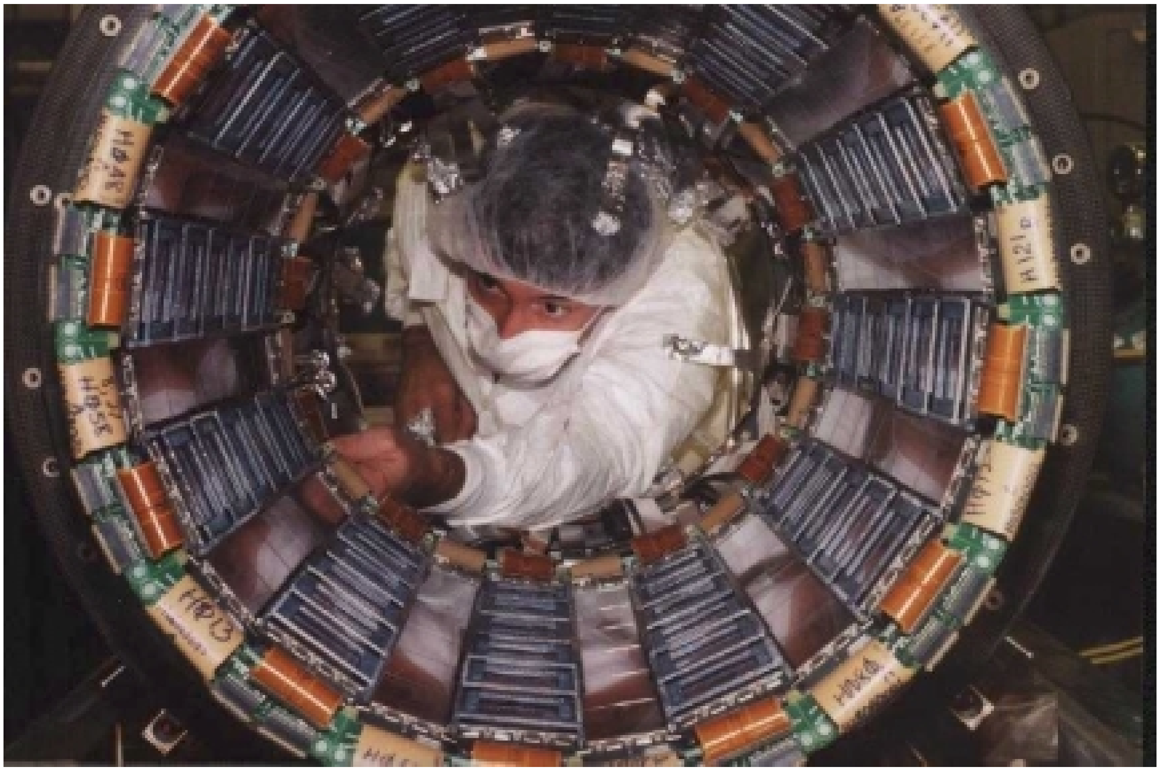
End view of an SVX II barrel. The 5 layers of silicon are supported by a beryllium bulkhead. The 12 sided structure and wedge geometry are evident. Aluminum tubing provides water cooling for the electronics. Copper Kapton ribbons carry signals to port cards where the signals are received and sent out over very low mass optical links.



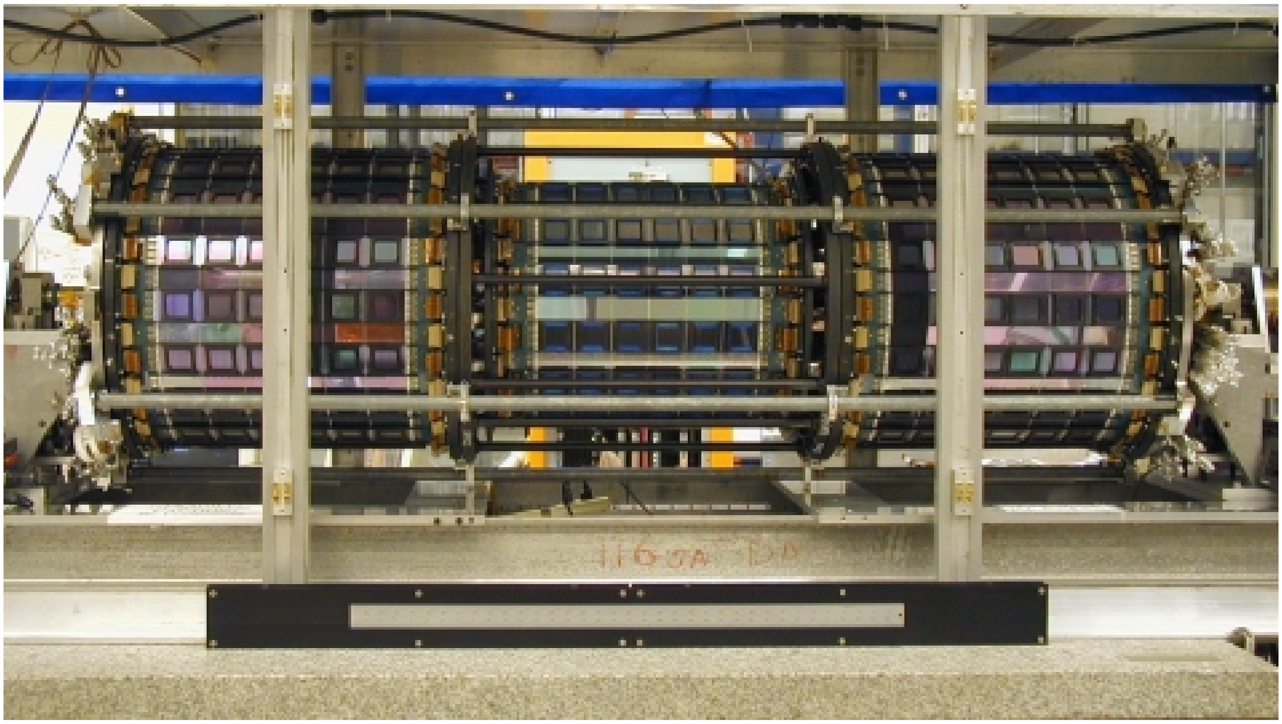
SVX II barrel during assembly at the Silicon Detector Facility.



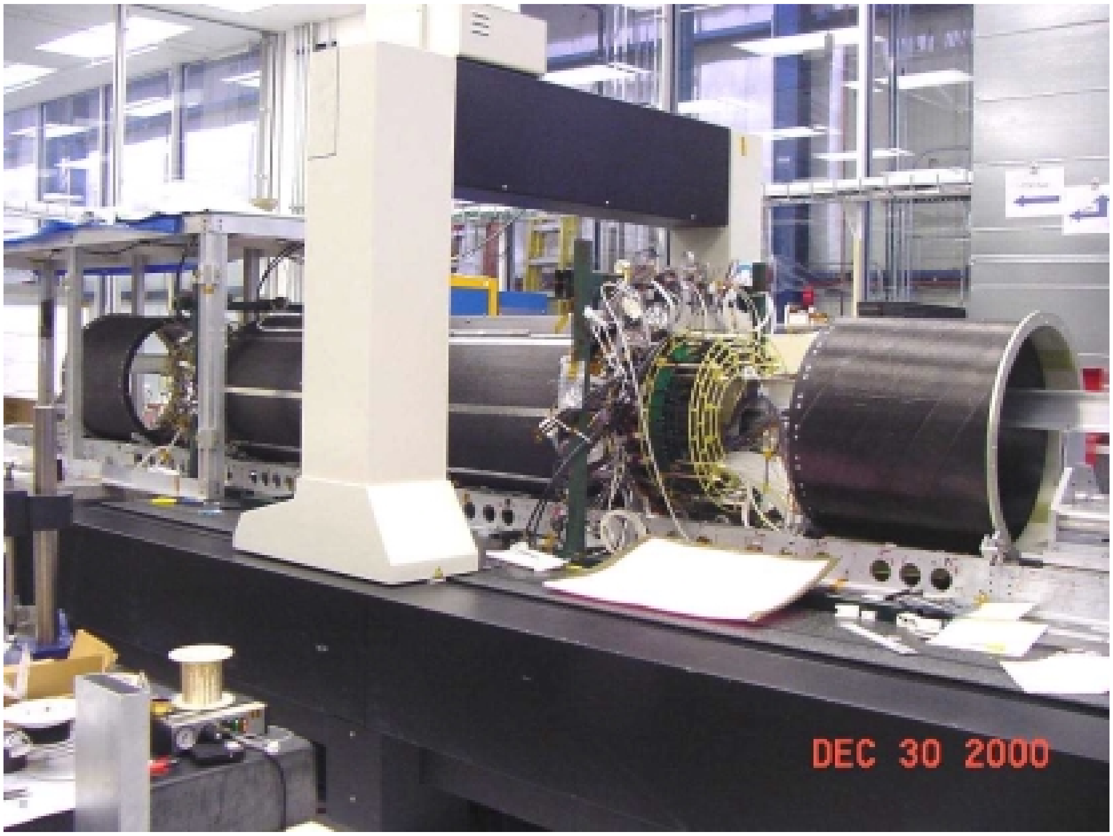
Beryllium beam pipe with L00 mounted outside being inserted into assembly containing all three completed SVX II barrels.



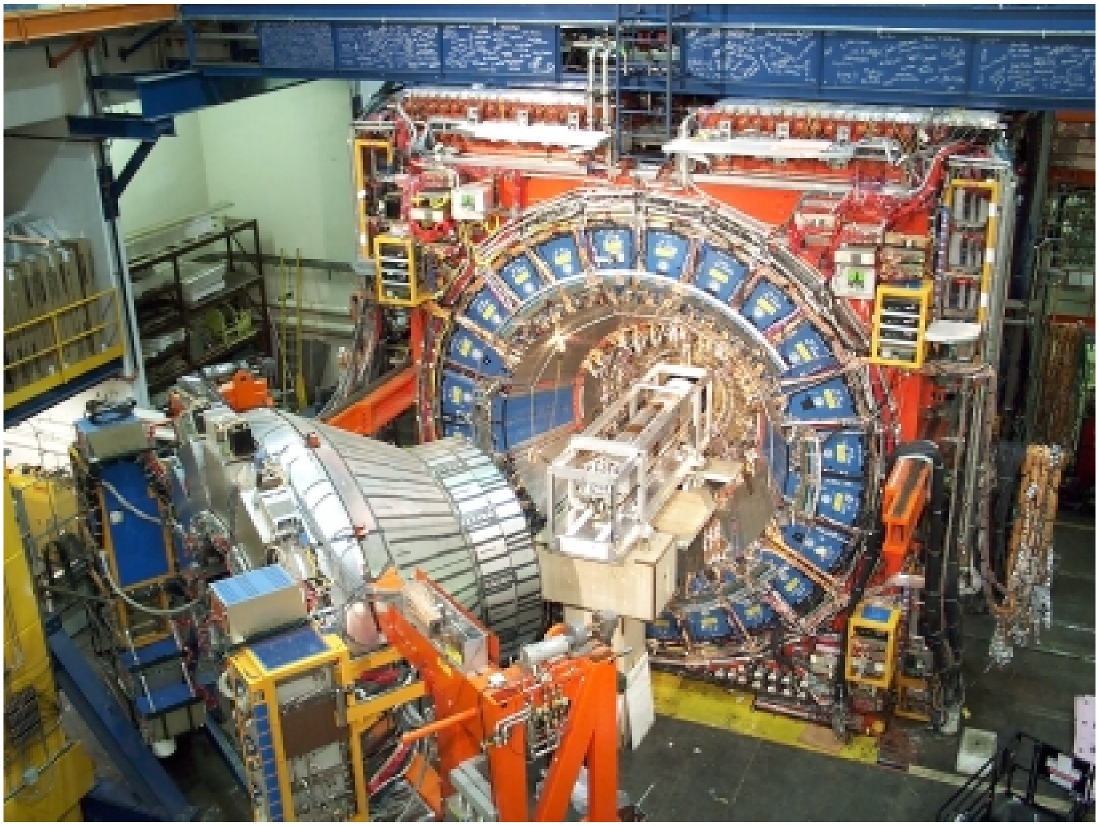
ISL at the Silicon Detector Facility. The silicon detectors of layer 6 are visible.

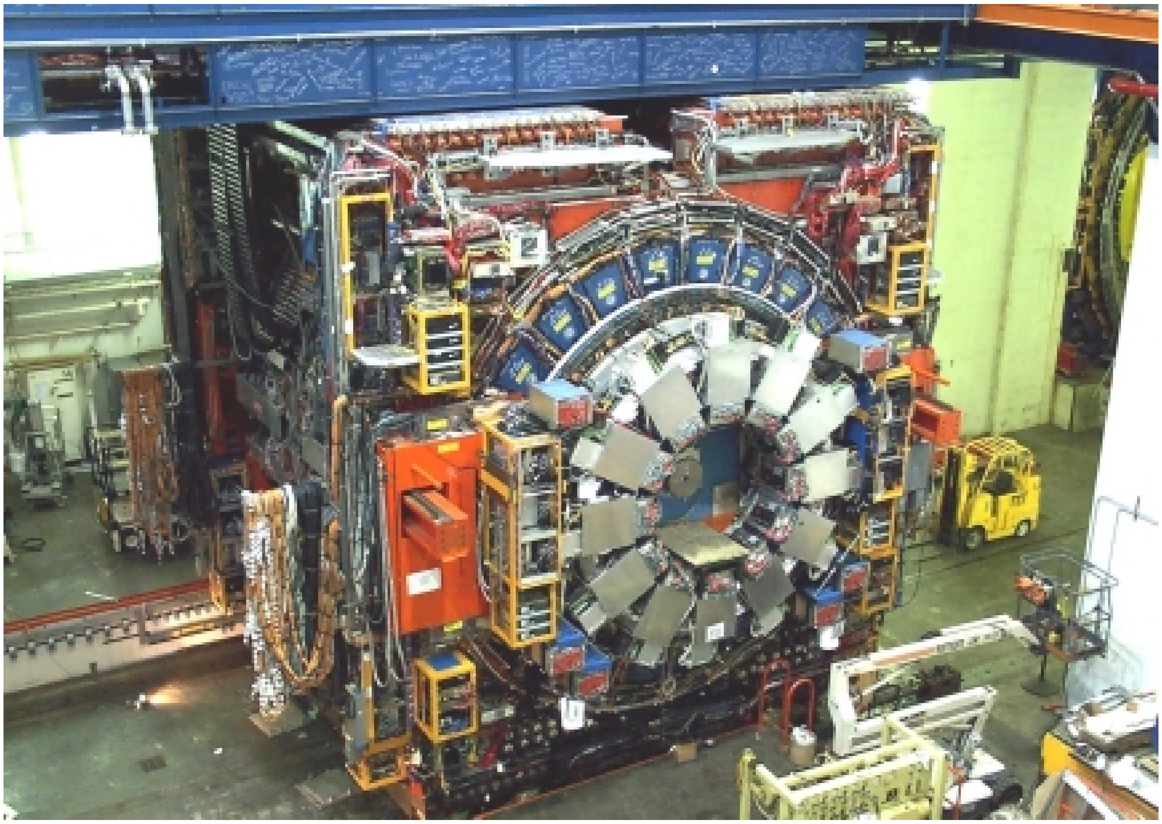


ISL at the Silicon Detector Facility. The silicon detectors of the central barrel of layer 6 and all of layer 7 are visible. Note meter stick at bottom of picture for scale. The ISL was then mounted inside a graphite epoxy cylinder that supports it inside the COT bore. The SVX II/ L00 assembly was then mounted inside ISL.

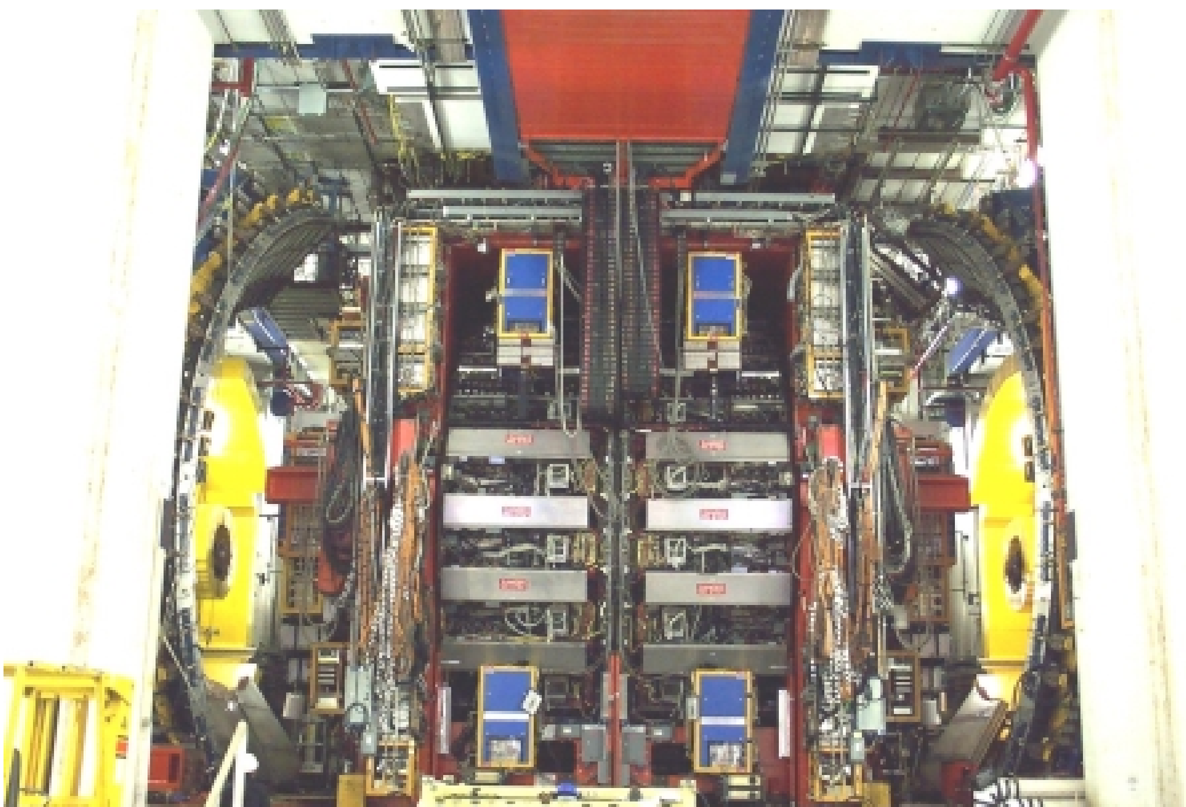


L00/SVX II/ISL Silicon detectors during final assembly at the Silicon Detector Facility

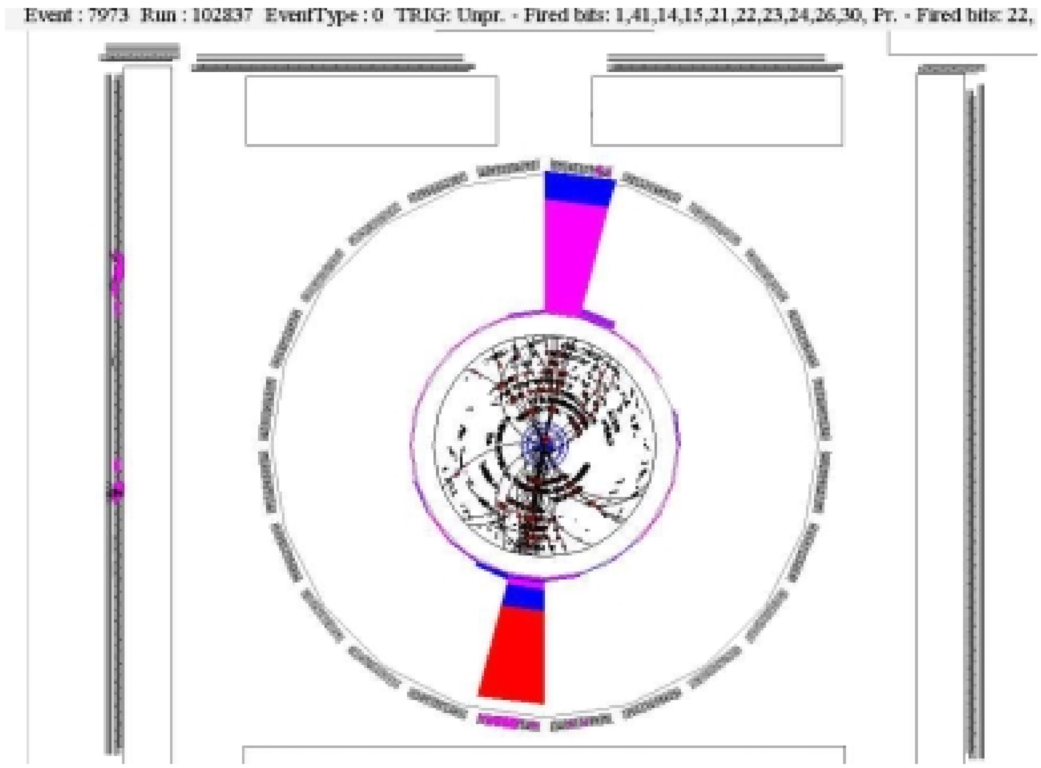

L00/SVX II/ISL Silicon detectors being inserted in the bore of the Central Outer Tracker on Jan 16, 2001. West endplug is in the foreground and has been moved back and rotated to permit the insertion.



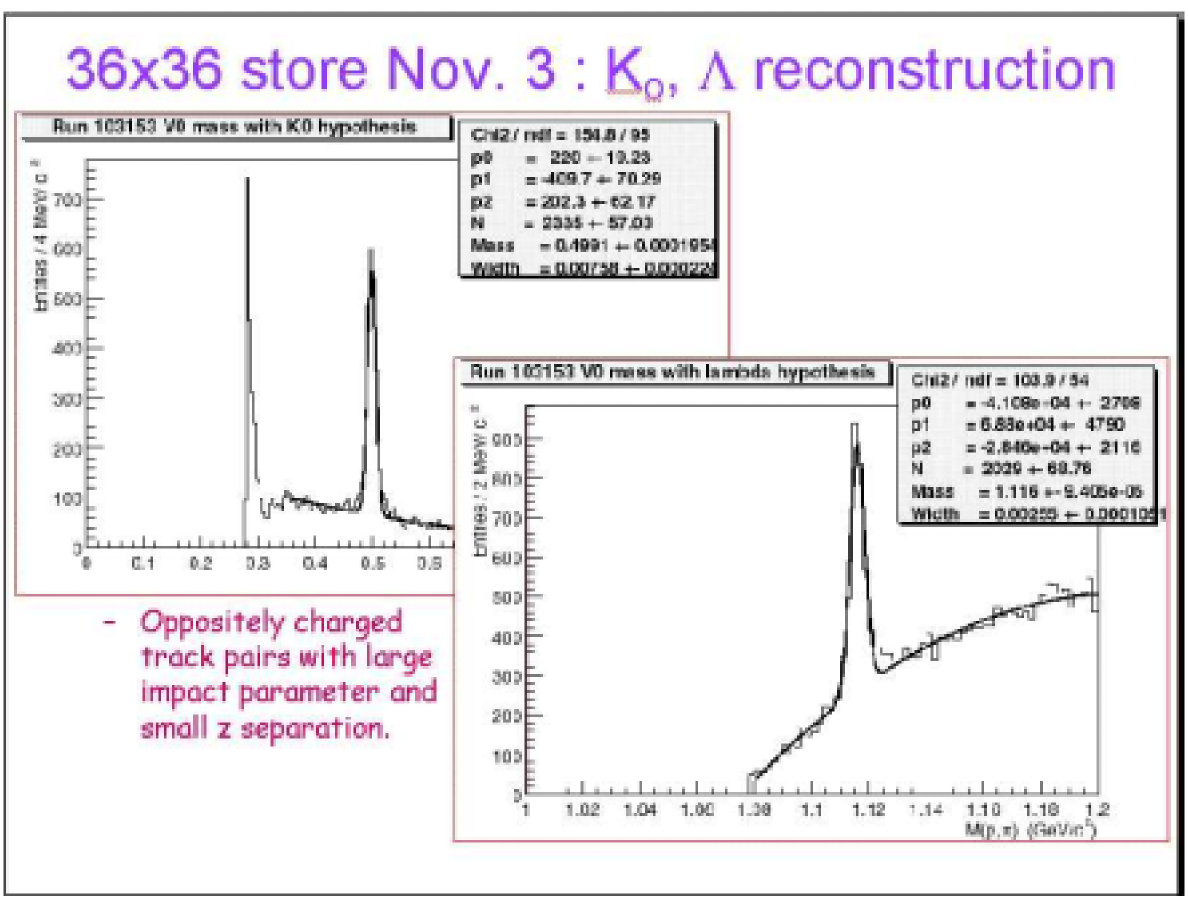
The CDF II detector moving into the Collision Hall Jan 29, 2001 in preparation for Run II.



CDF II detector on Tevatron beam line Jan 30, 2001



Event display of a collision containing two high E_T jets in the CDF II detector during Nov 2000 commissioning run. Tracks in COT, calorimeter energy deposits, and muon chamber hits can be seen.



$K_0 \rightarrow \pi^+ \pi^-$ and $\Lambda_0 \rightarrow p\pi$ peaks reconstructed with COT tracks from Nov 2000 commissioning run

Sign-off Sheet

Recommend approval to begin Run II operations (Critical Decision 4):

Bob Kephart Co-Project Manager	date
Catherine Newman-Holmes Co-Project Manager	date
Al Goshaw Co-Spokesperson	date
Franco Bedeschi Co-Spokesperson	date
Ken Stanfield Fermilab Deputy Director	date
Paul Philp DOE Project Manager	date
Jane Monhart Fermi Area Office Manager	date
John O'Fallon High Energy Physics Div. Director	date

ESAAB Equivalent Board
CD-4, Ready for Operations
Approval Sheet
for the CDF Upgrade Project

The undersigned recommend approval of CD-4.

____ Yes_____ No_____
Representative, ES&H Division (SC-83)/Date

____ Yes_____ No_____
Representative, Financial Mgmt. Div.(SC-63)/Date

____ Yes_____ No_____
Representative, Grants & Contracts Div. (SC-64)/Date

____ Yes_____ No_____
Representative, EM Office of Proj. Mgmt. (EM-6)/Date

<u>Approval</u>

Critical Decision 4, Start of Operations Approval:

____
Peter Rosen, Associate Director (SC-20)/Date
Office of High Energy and Nuclear Physics
Office of Science