THE COLLIDER DETECTOR FACILITY AT FERMILAB

Alvin Tollestrup,
CDF Collaboration†

Introduction

The $\bar{p}p$ colliding-beam facility at Fermilab is rapidly nearing completion and will be commissioned in 1986. A visit to B0, or to the area where the new Debuncher and Accumulator Rings are being installed, gives striking visual proof of the exciting times that are approaching. With the completion of D0 and the B0 overpass, the long period of constructing new facilities at Fermilab will come to an end, and then exploitation for physics will begin. In addition, we have high expectations that the increased energy of 2 TeV in the center-of-mass will bring into view the area beyond that of the Standard Model which has been so brilliantly explored at CERN. The commissioning is coming at a time of anticipation over the possibility of discovering the effects of supersymmetry, finding the Higgs, or testing for an additional generation of substructures within the quark. We are incredibly fortunate to have a machine that is so well suited to explore this frontier between now and when the SSC will take over.

It is hard to realize now, when viewing the activity in B0, that the first beam was stored almost nine years ago--June 10, 1976--in the Main Ring. It has taken a long time to bring reality to the original dream of colliding beams, but the activity in B0 quickly dispells any doubt about the reality of the program to achieve 2 TeV colliding beams. The first step was construction of the B0 Collision Hall, a part of the TeV I project, which began July 1, 1982, and was completed in March 1983.

The detector design was the result of a combined Italy/Japan/US effort. During this collaboration the design has been greatly strengthened by the various unique contributions that each of the participants has been able to make. There are many examples of individual institutions having access to specialized technology that has improved the performance of the detector. The vitality of a collaboration extending over 16 time zones has been well demonstrated.

At present, one can view the completed magnet in the assembly pit. The magnet consists of the yoke, the end wall calorimeters, the end plugs, and the 3 m × 5 m superconducting solenoid. This magnet has just been tested to its full operating field of 1.5 T and is the first such magnet to be excited without either major or minor disaster! The coil was designed by a collaboration of physicists and engineers from CDF and the Research Division Cryogenic Department at Fermilab, together with physicists and engineers from the University of Tsukuba, Japan, and Hitachi Heavy Industries, Japan. The power supply, refrigerator,

and controls were constructed at Fermilab. The coil itself was assembled at Hitachi Heavy Industries.

One arch of the central calorimeter, comprised of modules that have all been calibrated in the test beam, is fully assembled at the side of the magnet. The rest of the modules are now being tested and will be assembled into three more arches. The end plug electromagnetic and hadron calorimeters are under construction and will complete the central calorimetry. One may also observe in the pit two sets of iron plates for the forward hadron calorimeters which are waiting to be moved into the Collision Hall during the April shutdown.

A visit to the counting rooms will give evidence to the progress that is being made with the FASTBUS-based data-acquisition system. Major components of this system which have been tested, and are now working, include the SLAC Scanner Processor as well as the Fermilab-constructed RABBIT System with its MX processor.

The excitement, of course, is being heightened by prospects of the Antiproton Source and Detector tests that are being planned for August 1985. Although many uncertainties exist, there is an excellent possibility that the Source will be working well enough in August, and that the machine-related backgrounds will be low enough, that the central calorimeter, a vertex time-projection chamber (VTPC), and the beam-beam trigger counters can all be installed and made operational. Admittedly with some optimism, we will be able to study QCD jets using the VTPC and the central calorimeter whose granularity is well suited for just such measurements.

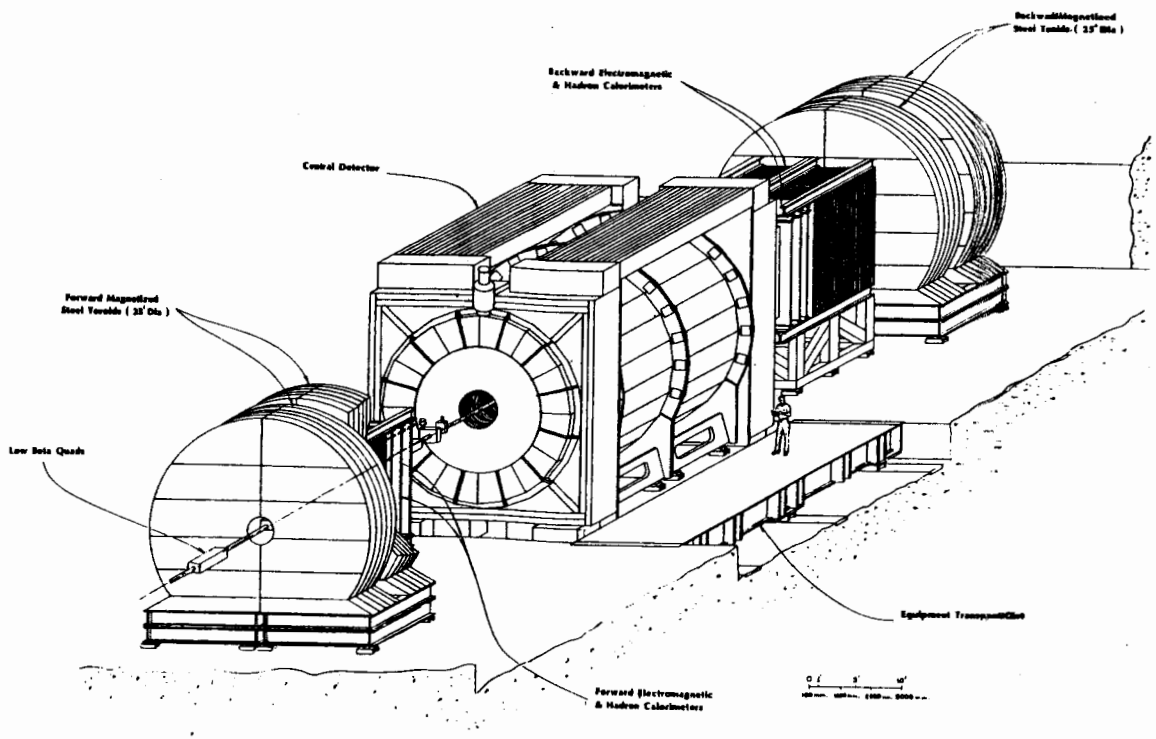
The completion of the detector will take place by the end of FY86 when the first major physics run will occur. We now give a brief description of the detector elements.

Brief Detector Description

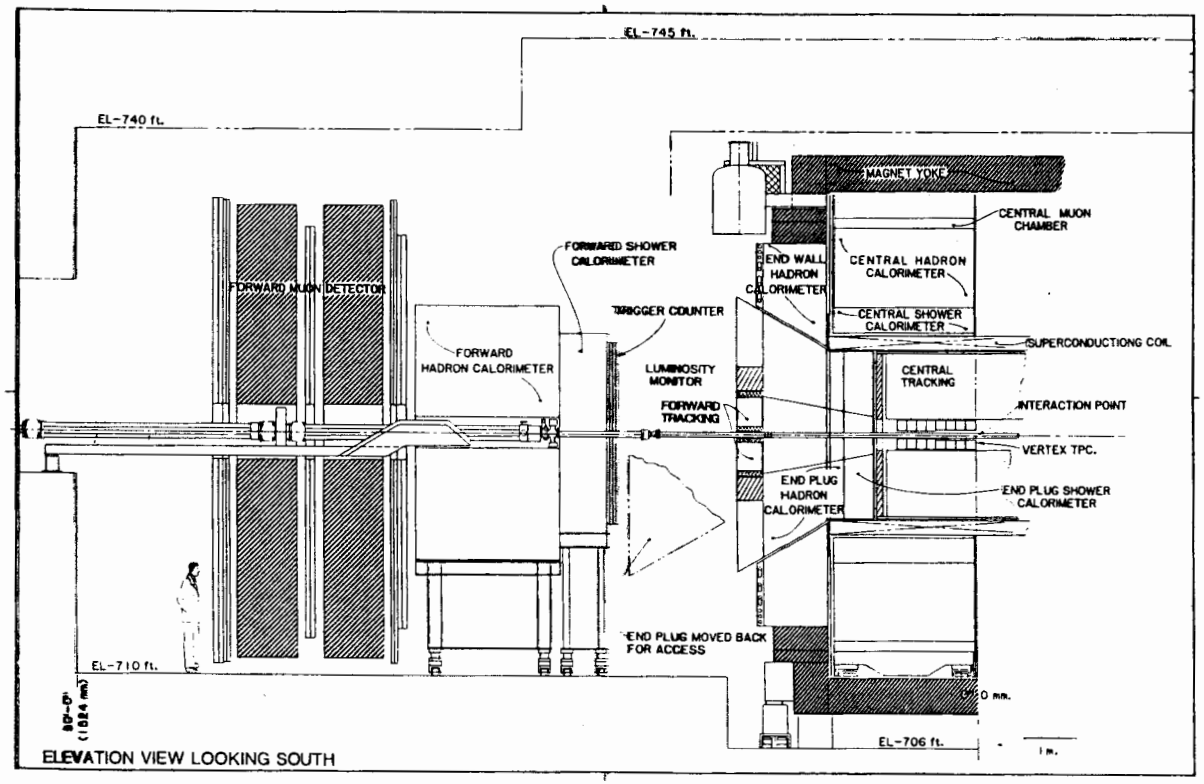
The diagram on page 10 shows a perspective drawing of the detector, and a cross section is shown on page 11. The detector components can be described best by considering what instrumentation is being constructed for each angular interval.

Inside the beam pipe

The region inside the beam pipe is being fitted with Si detectors to make measurements of the elastic scattering cross sections and to implement a trigger for diffractive processes. There are four stations--two on either side of the IR. The nearest stations are in front of the low-β quadrupoles, and the two farthest are actually in the machine lattice where they are used in conjunction with a lattice dipole to form a very high-resolution spectrometer for very high-momentum forward particles.



Perspective drawing of the Collider Detector.



Cross section of the Collider Detector.

Beam pipe to 2°

This region will be instrumented in the future.

2° to 10°

This region is covered by a VTPC and a forward drift chamber using a "Bicycle Wheel" type construction with planes of radial sense wires. Behind these chambers are the forward electromagnetic (EM) and hadron calorimeters. The forward muon system, consisting of drift chambers and magnetized iron toroids, covers this region and extends out to 20°.

10° to 30°

The end plugs of the magnet carry the EM and hadron calorimeters that service this region. Tracking is accomplished jointly by means of the VTPC and the central tracking chamber (CTC).

30° to 90°

Starting on axis, we first come to the VTPC which gives good track information in the RZ plane. Next, the CTC, in conjunction with the 1.5 T magnetic field, allows for precision measurement of individual tracks. There are five superlayers of cells with axial wires, and four superlayers whose wires are skew with respect to the axis and are used to give stereo information. At the outside of the CTC and just inside the coil, an axial set of tubes in the avalanche mode gives z determination on tracks by means of current division to a precision of ±3 mm. This helps in track reconstruction. After passing through the coil ~ 1 X_0 and .5 λ_0, one finds the central EM and hadron calorimetry. A strip chamber is located at approximately EM shower maximum to aid in identifying EM showers and measuring their positions to ~ 3 mm. Finally, on the outside of the hadron calorimeter is located a set of tubes in the avalanche mode which are instrumented with a time-digital converter (TDC) and current division to provide z and ϕ information on muons which succeed in penetrating the calorimeter.

Table Ia and Ib show the characteristics of the various calorimeter elements of the detector. In general, the size of the projective calorimeter towers is such that a QCD jet will span several, allowing an accurate determination of the energy flow vector. In addition, the EM strip chambers have elements that are comparable in size to an EM shower in order to help with the identification of electrons and photons.

The characteristics of the tracking elements of the detector are given in Table IIa, IIb, IIc, and IId. The system is comprised of two drift chamber systems: the CTC and the forward tracking chamber (FTC). These provide track information from 2° to 178°. The vertex time-digital converter (VTDC) provides complementary information to these chambers near the origin. It will also allow multiple interactions to be rapidly identified.

The Si detectors in the beam pipe will cover very small angles, providing a means to identify diffractive events.

The characteristics of the Tevatron are such that with a β^* = 1 m the beam σ is about 60 μ. With such a small interaction transverse cross section, it is anticipated that a very high-resolution vertex detector will be extremely useful for identifying long-lived particles. For this reason a silicon-strip detector that fits inside the VTPC is being developed by the Pisa group. The technology is challenging: the detector must fit in a very confined space and operate at high rates in a location where there is always the possibility of severe radiation damage by accidental beam loss.

The solenoid field of 1.5 T is produced by a NbTi superconductor stabilized by a sheath of extruded, very pure aluminum. The conductor is cooled and supported by means of an external cylinder of aluminum with tubing, which carries liquid He, welded to its surface. This configuration was achieved by first winding the coil on an internal mandrel. This structure was then insulated with glass epoxy, cured, and then ground to a precision round cylinder. The outer support cylinder was heated in order to achieve radial expansion of 3 mm, and then slipped over the coil assembly, after which the inner mandrel was removed.

At present, the detector is being rapidly assembled. The central detector calorimetry is nearly complete and is being calibrated in test beams. The magnet yoke is complete, and the field is being mapped. The tracking chambers are being manufactured, and the VTPC will be ready for preliminary beam tests in the summer of 1985. The spring of 1986 will see all components ready for test with the beam in preparation for the first physics run in the fall of that year.

Table Ia
EM CALORIMETERS

	Forward	End Plug	Central
Angular range	2° to 10°	10° to 37°	37° to 90°
Size of towers in η	(18) $\Delta\eta \sim 0.1$	(15) $.05 < \Delta\eta < 0.1$	(10) $.087 < \Delta\eta < .133$
Angular size in ϕ	$\Delta\eta = 5°$	$\Delta\phi = 5°$	$\Delta\phi = 15°$
Material	Pb-gas tubes	Pb-gas tubes	Pb-scintillator
Number of layers	6 24	5 20 13	20
R.l. each layer	.85 X_0 .85 X_0	.56 X_0 .56 X_0 .56 X_0	.95 X_0
Layers in section	5 X_0 20 5 X_0	2.8 X_0 11.26 X_0 7.32 X_0	19 X_0
Total X_0	25.5 X_0	22.4 X_0	19 X_0
$\delta E/E$	$\sim 30\%/\sqrt{E}$	$\sim 24\%/\sqrt{E}$	$14\%/\sqrt{E}$
Position resolution	1-5 mm	1-2 mm	1.5-3 mm

Table Ib
HADRON CALORIMETERS

	Forward	End Plug	End Wall	Central
Angular range	2° to 10°	10° to 30°	30° to 45°	~ 45° to 90°
Construction	2 in. Fe + gas tubes	2 in. Fe + gas tubes	2 in. Fe + scint	1 in. Fe + scint
Tower size in η	$\Delta\eta = 0.1$	$\Delta\eta = .09$	$.079 < \Delta\eta < .117$	$.1 < \Delta\eta < .15$
Tower size in ϕ	$\Delta\phi = 5°$	$\Delta\phi = 5°$	$\Delta\phi = 15°$	15°
$\delta E/E$		~ 14% at 50 GeV	~ 14% at 50 GeV	$70\%/\sqrt{E}$

Tracking Chamber Characteristics

The following tables list some of the properties of these chambers.

IIa. VTPC

Drift distance (axial): 150 mm
Sense wires/octant: 16 (22) for R = 3-1/2 (2)
Pads/octant: 84 in three rows of 5; 8; 11 pads
Sense wire spacing: 5.5 mm
Sense wire/pad separation: 10 mm
Pad size: 12 × 45 mm
Gas: Argon/methane - 80%:20%
Drift field: 200 V/cm
Total number of sense wires: 2176
Total number of pads: 2448
Average radiation length: 1.5%
Resolution in Z: 200-350 μ
Resolution in Rϕ: 250 μ (isolated tracks)

IIb. CTC

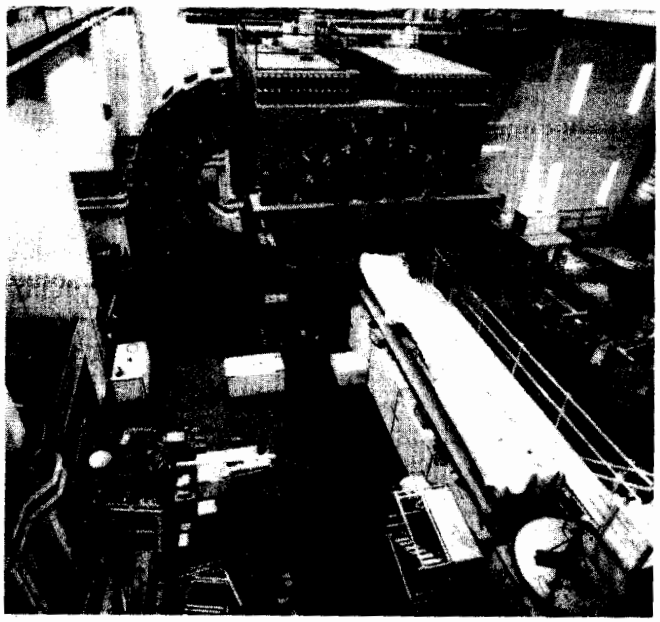
Number of superlayers: 9
Stereo angle: 0°; 3°; 0°; -3°; 0°; +3°; 0°; -3°; 0°
Sense wires/layer: 12; 6; 12; 6; 12; 6; 12; 6; 12
Number supercells/superlayers: 30; 42; 48; 60; 72; 84; 96; 108; 120
Maximum drift distance: 35 mm
Sense wire spacing: 10 mm in plane of wires
Electric field at center of drift space: 1000 V/cm
Radius innermost sense wires: 309 mm
Radius outermost sense wires: 1320 mm
Length of wires: 3214 mm
Total number of sense wires: 6156
Total number of wires: ~ 36000
Axial load on endplates: 17 tons
Gas - Argon:Ethane:Alcohol: 49.65%:49.65%:0.7%
Resolution: < 200 μ/wire
Double track resolution: ≤ 5 mm or 100 nsec
Z resolution: ~ 4 mm
Momentum resolution: $\Delta p_t/p_t < .002\ p_t$ in GeV at 90°

IIc. FTC

Angular coverage: 2°-10°
Inner radius: 12.5 cm
Outer radius: 72.5 cm
Cell: 5° in ϕ or 7272 sectors
Sense wires/sector: 20
ϕ accuracy: $\sigma_{rms} = 130\ \mu$
Total TDC: 3020
Total ADC: 1728

IId. Si Strip Vertex Detector

Length: 67 cm, 4 sections
Layers: 4
Thickness: 1 200 μ
2 250 μ
3 250 μ
4 250 μ
Electrode spacing: 1 200 μm
2 250 μm
3 250 μm
4 250 μm
Spatial resolution in Rϕ ~ 20 μm on all layers
Number of ϕ electrodes: 1 936
2 1248
3 1740
4 2232
Total ϕ electrodes: 6156



Detector view showing the magnet with the end-wall hadron calorimeter in place, and one arch of the central calorimeter withdrawn to the side. Parts of the apparatus for measuring the magnetic field are visible in the foreground. *(Fermilab photograph 85-202-9)*

CDF COLLABORATION†

R. Diebold, E. May, L. Nodulman, J. Proudfoot, J. Schlereth,
P. Schoessow, N. Solomey, D. Underwood, R. Wagner,
and A. Wicklund
Argonne National Laboratory

J. Bensinger, L. DeMortier, L. Kirsch, W. Lewis, R. Poster,
L. Spencer, and S. Tarem
Brandeis University

D. Amidei, M. Campbell, H. Frisch, C. Grosso-Pilcher, T. Liss,
G. Redlinger, M. Shochet, R. Snider, S. Somalwar, and Y. Tsay
University of Chicago

M. Atac, E. Barsotti, P. Berge, M. Binkley, A. Brenner,
T. Carroll, C. Day, T. Droege, J. Elias, B. Foster, J. Freeman,
I. Gaines, D. Hanssen, H. Jensen, D. Johnson, R. Kadel,
H. Kautzky, R. Kephart, C. Newman-Holmes, J. Patrick,
R. Perchonok, D. Quarrie, D. Theriot, A. Tollestrup, K. Turner,
C. van Ingen, R. Vidal, R. Wagner, G.P. Yeh, and J. Yoh
Fermi National Accelerator Laboratory

S. Bartalucci, S. Bertolucci, M. Cordelli, M. Curatolo,
P. Esposito, P. Giromini, M. Pallotta, and A. Sansoni
INFN--Frascati, Italy

M. Kawaguchi
Fukui University, Japan

C. Blocker, G. Brandenburg, D. Brown, R. Carey, M. Eaton,
E. Kearns, R. Schwitters, and R. St. Denis
Harvard University

G. Ascoli, S. Cihangir, R. Downing, S. Errede, L. Holloway,
I. Karlinger, H. Keutelian, U. Kruse, R. Sard, D. Smith,
and T. Westhusing
University of Illinois

Y. Fukui, S. Mikamo, and M. Mishina
KEK, Japan

W. Carithers, W. Chinowsky, R. Ely, M. Franklin, J. Siegrist,
and E. Wood
Lawrence Berkeley Laboratory

D. Bauer, D. Connor, J. Cooper, S. Hahn, N. Lockyer, M. Miller,
M. Newcomer, T. Rohlay, R. VanBerg, and H. Williams
University of Pennsylvania

F. Bedeschi, G. Bellettini, L. Bosisio, F. Cervlli,
R. Del Fabbro, M. Dell'Orso, A. Di Virgilio, E. Focardi,
S. Galeotti, P. Giannetti, M. Giorgi, A. Menzione,
D. Passuello, L. Ristori, A. Scribano, A. Stefanini,
and G. Toneli
INFN--University of Pisa, Italy

V. Barnes, K. Chadwick, R. Christian, A. Garfinkel, S. Kuhlmann,
A. Laasanen, and J. Simmons
Purdue University

S. Belforte, T. Chapin, K. Goulianos, S. White, and C. Young
Rockefeller University

A. Beretvas, A. Caracappa, T. Devlin, K. Krueger, L. Scott,
T. Watts, and T. Yang
Rutgers University

A. Murakami
Saga University of Japan

A. Giordana, P. McIntyre, T. Meyer, M. Shepko, and R. Webb
Texas A&M University

Y. Muraki
ICRR, Tokyo University, Japan

Y. Asano, Y. Hayashide, M. Ito, T. Kamon, Y. Kikuchi, S. Kim,
K. Kondo, S. Miyashita, H. Miyata, S. Mori, Y. Morita,
H. Sekiguchi, M. Shibata, Y. Takaiwa, K. Takikawa, A. Yamashita,
and K. Yasuoka
Tsukuba University, Japan

D. Cline, R. Handler, R. Loveless, L. Pondrom, D. Reeder,
J. Rhoades, and M. Sheaff
University of Wisconsin

The E-605 collaboration trying on their spectrometer analyzing magnet.
(Fermilab photograph 82-42-27)