The CDF Run II Upgrade

DPF2000
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Richard E. Hughes
Department of Physics
The Ohio State University
The CDF Collaboration for Run II

>500 Physicists from 52 Institutions Representing 11 Countries
The Physics Program at CDF

Tevatron Collider accesses an enormous breadth of physics

Many explorations limited by available luminosity ==> Improve this for Run II!

- Mass Production
- Decay modes
- Rare decays
- Structure at small distances
- CP Violation
- $B_s$ Mixing
- Heavy quark states
- Spectroscopy
- Lifetimes
- Direct production
- High $E_T$ jets
- Anomalous couplings
- Secondary Vertex trigger
- Mass Width
- Associated Prod
- Signals for new physics
- SUSY, higgs, $tq$, $tc$, ...
Many explorations limited by available luminosity ==> Improve this for Run II!

- 1985: first collisions
- 1987: 30 nb\(^{-1}\)
- 1988-89: 4.7 pb\(^{-1}\)
- 1992-96: Run I 110 pb\(^{-1}\)
- 2001-02: Run II  2 fb\(^{-1}\)
- 2002-07: Run II >15 fb\(^{-1}\)

Possible luminosity evolution:
CDF II - Goals

● Upgrade CDF to exploit the physics opportunities available in Tevatron Collider Run II.
  ➢ Improvements to the Tevatron, including the Main Injector, ==> much higher luminosity. (factor of 200 above original design)
  ➢ Many parts of the existing detector must be improved or replaced due to decreased bunch spacing:
    - Tracking (drift and SVX), gas calorimetry, trigger, DAQ

● Initial Goals:
  ➢ 2 fb$^{-1}$ of integrated luminosity on tape.
  ➢ Detector should be capable of handling peak luminosity up to $2 \times 10^{32}$ cm$^{-2}$ sec$^{-1}$.
  ➢ Bunch spacing will begin at 396 ns then go to 132 ns.
CDF Detector Components
Reused for Run II

- Central + Endwall Calorimeters
  - scintillator-based
- Central muon (CMU + CMP) system
- Muon Extension (CMX) system
- Magnet
  - Superconducting Solenoid
  - Refrigerator/Power Supply (new controls)
  - Endplug Steel structure

new frontend and trigger electronics
New Detector Systems

CDF II Detector cross section

- **Tracking**
  - Silicon Vertex Detector
  - Intermediate Silicon Layers
  - Layer 00
  - Central Outer Tracker

- **Time Of Flight**

- **Muon systems**

- Endplug Calorimeter

- **Trigger (pipelined)**

- Front End Electronics

- DAQ system

- Offline software
Silicon Detectors SVX II

- 5 layers (60 μ pitch) from 2.4cm - 10.6cm
- Double sided Si ($r_\phi + rz$)
- Longer $\implies$ Better geometric acceptance:

See talk by Juan Fernandez tomorrow
# SVX II vs. Run I Silicon

<table>
<thead>
<tr>
<th></th>
<th>SVX'</th>
<th>SVX II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Readout Coor.</td>
<td>r-φ</td>
<td>r-φ, z</td>
</tr>
<tr>
<td># of Barrels</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td># of layers / barrel</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td># of wedges / barrel</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Ladder length</td>
<td>26.5 cm</td>
<td>29.0 cm</td>
</tr>
<tr>
<td>Barrel length</td>
<td>51 cm</td>
<td>87 cm</td>
</tr>
<tr>
<td>Layer geometry</td>
<td>3° tilt</td>
<td>staggered radii</td>
</tr>
<tr>
<td>Radius inner layer</td>
<td>3.0 cm</td>
<td>2.44 cm</td>
</tr>
<tr>
<td>Radius outer layer</td>
<td>7.8 cm</td>
<td>10.6 cm</td>
</tr>
<tr>
<td>r-φ readout pitch</td>
<td>60, 60, 60, 55 μm</td>
<td>60, 62, 60, 60, 65 μm</td>
</tr>
<tr>
<td>r-z readout pitch</td>
<td>absent</td>
<td>141, 125, 5, 60, 141, 65 μm</td>
</tr>
<tr>
<td>Length readout channel (r-φ)</td>
<td>25.5 cm</td>
<td>14.5 cm</td>
</tr>
<tr>
<td>r-φ chips / ladder</td>
<td>2; 3; 4; 6</td>
<td>4; 6; 10; 12; 14</td>
</tr>
<tr>
<td>r-z chips / ladder</td>
<td>absent</td>
<td>4; 6; 10; 9; 14</td>
</tr>
<tr>
<td>r-φ channels</td>
<td>46, 080</td>
<td>211, 988</td>
</tr>
<tr>
<td>r-z channels</td>
<td>absent</td>
<td>193, 536</td>
</tr>
<tr>
<td>Total channels</td>
<td>46, 080</td>
<td>405, 504</td>
</tr>
<tr>
<td>Total chips</td>
<td>360</td>
<td>3168</td>
</tr>
<tr>
<td>Total detectors</td>
<td>288</td>
<td>720</td>
</tr>
<tr>
<td>Total Ladders</td>
<td>98</td>
<td>186</td>
</tr>
</tbody>
</table>

- 5 double sided layers versus 4 single sided
- Much longer - covers the full interaction region
- Added rz readout
- 400k channels vs 46k
Intermediate Silicon Layers (ISL)

- Intermediate/FWD angle tracking
- Additional layers of silicon outside SVX II:
  - 6th full layer at $r = 20$ cm.
  - 7th partial layer at $r = 28$ cm, $1 < |\eta| < 2$
- Combined with SVX II => New powerful stand-alone tracking capability for $|\eta| < 2$.
- Extends lepton ID and b-tagging to cover entire end plug region $1 < |\eta| < 2$.
- Allows in situ calibration of new Plug Calorimeter.

See talk by Tim Nelson later today
Silicon System: Layer 00

- Beam pipe layer of 1-Sided Silicon
  - Improve IP resolution:
  - Extend useful lifetime
  - Long-term operational experience with LHC rad-hard silicon

- Layer Geometry
  - 6 readout groups in $z$
  - 6 narrow + 6 wide groups in $\phi$
    - 72 narrow, 72 wide sensors
    - 13,824 channels = 1.7% of SVXII/ISL
  - Silicon Radii: 1.4 and 1.6 cm.
  - Hybrids:
    - Will use long flex from silicon
    - Chips at radii of 3 to 7 cm

See talk by Joel Goldstein later today
Silicon System Final Assembly

- **Hybrids:**
  - SVXII hybrids done June
  - ISL hybrids now complete

- **Ladders**
  - Production complete and all ladders have been tested and burned in

- **Barrels:**
  - Two full barrels have all ladders installed. Started on last barrel.

- **Integration**
  - L00/BP in SVXII Oct, 2000
  - SVXII/L00 in ISL Nov, 2000

Silicon System ready to install in the COT by November, 2000
Central Outer Tracker (COT)

- New open cell drift chamber
  - 3m sense wires strung along z direction
- 8 “superlayers”
  - 4 with axial wires for r - \( \phi \)
  - 4 with stereo wires for z
- Layer made of Cells of 12 sense wires
  - 2540 cells
  - 96 radial measurements
  - 30240 channels
- Basic Cell:
  - 12 sense wires, 17 potential
  - Drift time < 132 ns (Fast Gas)
  - cell tilted 35° for Lorentz angle

See talk by Mike Kirby Thursday
Central Outer Tracker Status

- Central Outer Tracker (COT) assembly was completed in April.
- COT was installed in CDF in May, 2000.
- Most of the electronics and cabling checked out.
- High voltage tests now.
- The COT will be ready for an Engineering run in Aug-Nov, 2000.
Time Of Flight System

See talk by Ivan Vila Friday
Time Of Flight System

- **Scintillator**
  - 216 bars Bicron BC408
  - 2.8 m long
  - \( \sim 4 \times 4 \text{cm trapezoidal xsec} \)
  - \( \Lambda_{\text{att}} \sim 2.1 \text{m, rise time } 0.9 \text{nsec} \)

- **Photomultiplier**
  - Hamamatsu R5946M, 19 stage, 1.5in diameter, fine mesh
  - Testing in progress

- **Expect to achieve 100 ps resolution**
  - Based on 20 bar in-situ test
  - UV Laser test
  - Assumes combined left and right PMTs
Result using 20 Bar prototype

With 100 ps resolution: 2σ separation of
- $K$ and $\pi$ for $p < 1.6 \text{ GeV/c}$
- $p$ and $K$ for $p < 2.7 \text{ GeV/c}$
- $p$ and $\pi$ for $p < 3.2 \text{ GeV/c}$

TOF and $dE/dx$ are complementary
Replace the old Plug and Forward calorimeters ($1.1 < |\eta| < 3.6$) with a single new fast, hermetic, scintillator based calorimeter

- $21 \lambda_0$ Electromagnetic cal. (4 mm lead radiator)
- $6.6 \lambda_{\text{int}}$ Hadronic (2” Fe)
- Shower maximum detector at 6 $\lambda_0$ in the EM
- Reuse existing plug steel
- Use SS to avoid changing the flux return geometry $\Rightarrow$ Avoid remapping the field

See talk by Diego Cauz Friday
Muon System Upgrades

- Fill gaps in $\phi$ in CMP muon system
  - Increase coverage 17%
- Fill gaps in $\phi$ in CMX muon system
  - Increase coverage 45%
- Add IMU system to extend $\eta$ coverage
  - Total muon coverage almost doubles

See talks by Julian Budagov, Carl Bromberg Friday
Improved Central Muon Coverage

Run I

CMP coverage increases by 17 %
CMX coverage increases by 45 %

With the IMU: CDF’s muon coverage ~doubles

Run II

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Front End/ Trigger Electronics

- Pipeline Readout - 42 stages in Level 1 (5.5 µs)
- Data sampled every 132 ns (TDC’s Calorimetry, Silicon)
- Level 1 trigger Decision every crossing (synchronous)
- Data → Level 2 Buffer
- Level 2 Dec: Asynchronous, 20 µs
- Readout → Level 3 Farm
- Accept rates x 10 more than Run I
  - Level 1: < 50 Khz
  - Level 2: 300 hz
  - Level 3: 30 hz → tape
- deadtime < 10 %

See talk by Brian Winer Saturday
Level 1 Tracking Trigger: eXtremely Fast Tracker (XFT)

- Process divided into several steps:
  - Hit Classification (TDC Mezzanine Card -- XTC)
  - Segment Finding (Finder)
    - Track stubs within an axial superlayer
    - Works on the COT cell-by-cell
  - Segment Linking (Linker)
    - Links track stubs to form full track
    - Determines azimuthal location
    - Determines $P_T$ from curvature
- Highly Parallel: Tracks found every 132 nsec
  - 336 Finder Chips
  - 288 Linker Chips

See talk by Ken Bloom Saturday

Richard E. Hughes, The Ohio State University
The SVT uses XFT tracks (PT, phi) plus hits in the silicon to determine 3 track parameters in the transverse plane.

Combined XFT+SVT resolution:

\[
\frac{\Delta p_T}{p_T^2} = \frac{0.3\%}{\text{GeV} / c}
\]

\[
\Delta \phi = 1\text{mrad}
\]

\[
\Delta d = 35\mu m
\]

SVT allows all-hadronic B triggers!
CDF Schedule Highlights

- CDF Detector Roll-in: Sep 2000
- First p-pbar Collisions at CDF: Oct 2000
- CDF Detector Roll-out: Nov 2000
- Silicon System Finished: Oct 2000
- Silicon System Installed in COT: Jan 2001
- CDF Detector Roll-in: Feb 2001

CDF Ready for Collisions March 2001
Cosmic Ray Run
(Full-Chain test)

DAQ, calib., database, trigger, online monitor, offline, detector

Data Flow

Front End Crates

MiniBanks

Detector

Run II Raw Data Format

Data to FCC
Process/Analyze
Online Event Display
(Full-Chain Test with Cosmics)

Cosmic ray data taken on 5/26/00

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CDF Run II Upgrade
Data Analysis
(Full-Chain Test with Cosmics)

- Data files move to FCC automatically.
- Processed & analyzed (debugging offline codes).

Cosmic ray data
taken on 5/26/00
Triggers:
  SumEt 1, 10GeV
  single tower 6 GeV
Commissioning with Cosmics

**Goals of CR running**
- Help focusing on integration.
- Establish regular, reliable running of the detector and DAQ.
- Preliminary synchronization of readout pipelines (detectors & triggers).
- Provide real data to L2, L3, consumers, loggers, etc.
- Online monitoring of peds, ped widths, occupancy.
- Set calorimeter readout thresholds.
- Measure calorimeter noise rates (e.g. 1 PMT in plug)

**Milestones**
- Late June : 1 CMU arch, South CMP & L1 Muon trigger
- Beg. July : the full central calor. & South, Top, Bottom CMP
- Mid. July : the full plug calor. & 3 CMU arches
- Late July : COT upper half
- Beg. Aug.: the full CMU system

**Cosmic ray running with the COT.**
- There is time on the schedule for 10 days.
- The goal here is not to acquire tracking data (B=0), but only to establish stable operation and determine that the COT is ready to roll in. The 10 days can be used as contingency if necessary.

**Systems currently included**
- 2 central arches, endwall, & ½ of plug calorimeters.
- CLC
The Commissioning Run (2)

Detectors ready at the beginning of the comm. run

<table>
<thead>
<tr>
<th>System</th>
<th>Coverage</th>
<th>Limitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Track</td>
<td>COT</td>
<td>(0^\circ &lt; \phi &lt; 180^\circ) (\phi \sim 270^\circ)</td>
</tr>
<tr>
<td></td>
<td>SI-4</td>
<td>(45^\circ &lt; \phi &lt; 105^\circ)</td>
</tr>
<tr>
<td>Muon</td>
<td>CMU</td>
<td>full</td>
</tr>
<tr>
<td></td>
<td>CMP</td>
<td>Top, Bottom, South Wall</td>
</tr>
<tr>
<td></td>
<td>CMX</td>
<td>SE, SW (1 \text{ wedge of miniskirt})</td>
</tr>
<tr>
<td></td>
<td>IMU</td>
<td>1/2 of IMU</td>
</tr>
<tr>
<td>Calor.</td>
<td>CEM</td>
<td>full</td>
</tr>
<tr>
<td></td>
<td>CHA</td>
<td>full</td>
</tr>
<tr>
<td></td>
<td>WHA</td>
<td>full</td>
</tr>
<tr>
<td></td>
<td>PEM</td>
<td>full</td>
</tr>
<tr>
<td></td>
<td>PHA</td>
<td>full</td>
</tr>
<tr>
<td></td>
<td>CES</td>
<td>(45^\circ &lt; \phi &lt; 75^\circ \text{ (West)})</td>
</tr>
<tr>
<td></td>
<td>PES</td>
<td>50-100% of East plug</td>
</tr>
<tr>
<td>Lum.</td>
<td>CLC</td>
<td>full</td>
</tr>
<tr>
<td>Par.ID</td>
<td>TOF</td>
<td>Pulse height only?</td>
</tr>
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</table>

Triggers ready at the beginning of the comm. run

<table>
<thead>
<tr>
<th>System</th>
<th>Coverage</th>
<th>Trigger</th>
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</thead>
<tbody>
<tr>
<td>L1</td>
<td>XFT</td>
<td>full</td>
</tr>
<tr>
<td></td>
<td>XTRP</td>
<td>(30^\circ &lt; \phi &lt; 90^\circ)</td>
</tr>
<tr>
<td></td>
<td>Cal</td>
<td>full</td>
</tr>
<tr>
<td></td>
<td>CMU</td>
<td>full</td>
</tr>
<tr>
<td></td>
<td>2-Track</td>
<td>none</td>
</tr>
<tr>
<td></td>
<td>Global</td>
<td>Complete system</td>
</tr>
<tr>
<td>L2</td>
<td>Cal</td>
<td>full</td>
</tr>
<tr>
<td></td>
<td>SVT</td>
<td>(45^\circ &lt; \phi &lt; 105^\circ)</td>
</tr>
<tr>
<td></td>
<td>XCES</td>
<td>(45^\circ &lt; \phi &lt; 75^\circ)</td>
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<tr>
<td></td>
<td>Global</td>
<td>2/4 processors</td>
</tr>
<tr>
<td>L3</td>
<td></td>
<td>full</td>
</tr>
</tbody>
</table>

Richard E. Hughes, The Ohio State University

CDF Run II Upgrade

DPF2000, 8/9-12/00  p. 29
<table>
<thead>
<tr>
<th>Year</th>
<th>Month</th>
<th>Events</th>
</tr>
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<tbody>
<tr>
<td>2000</td>
<td>M</td>
<td>Cosmic Ray Running</td>
</tr>
<tr>
<td></td>
<td>J</td>
<td>Roll in</td>
</tr>
<tr>
<td></td>
<td>J</td>
<td>Partial SM installation</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>L1 trig commissioning</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>L2, L3 trig commissioning</td>
</tr>
<tr>
<td></td>
<td>O</td>
<td>Cooling, FE, DAQ commissioning</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>ADMEM &amp; Calor. Commissioning</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>µ chamber commissioning</td>
</tr>
<tr>
<td></td>
<td>J</td>
<td>µ TDCs</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>COT TDCs</td>
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<tr>
<td></td>
<td>M</td>
<td>Install/survey Si</td>
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<tr>
<td>2001</td>
<td>J</td>
<td>Connect/check-out Si</td>
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<tr>
<td></td>
<td>F</td>
<td>Si cabling</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>Roll out</td>
</tr>
</tbody>
</table>

**CDF Timeline**

- **Detector in collision hall**
- **Complete SM**
- **Ready for collisions**

**Key Events:**
- **W/COT**
- **Commissioning Run**
- **Roll in**
- **Roll out**
Fermilab Schedule

October 1999 to March 2001 Schedule

<table>
<thead>
<tr>
<th>CY</th>
<th>1999</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Oct</td>
<td>Nov</td>
</tr>
<tr>
<td>Proton Source</td>
<td>M&amp;D</td>
<td>Operation</td>
</tr>
<tr>
<td>Main Injector</td>
<td>M&amp;D</td>
<td>Operation</td>
</tr>
<tr>
<td>Recycler</td>
<td>Bake out</td>
<td>Installation &amp; Commissioning</td>
</tr>
<tr>
<td>Pbar Source</td>
<td>M&amp;D</td>
<td>Commissioning</td>
</tr>
<tr>
<td>Tevatron</td>
<td>1 TeV test</td>
<td>Operation</td>
</tr>
<tr>
<td>Switchyard</td>
<td>M&amp;D</td>
<td>Operation</td>
</tr>
</tbody>
</table>

1/17

CDF Engineering Run

Start of Run II Data Taking!

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a) Band 1 & 2 Installation and E835 installation
b) Possible KAMI Test
c) Operation for Pbar Source Commissioning, Recycler Engineering Run, and parasitic Run of E835