eXtremely Fast Tracker
Performance
in CDF Run 2a Data

Outline
• Introduction
• Design of XFT
• Performance of XFT
• Conclusions

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CDF Collaboration
IEEE NSS/MIC Conference
8 November 2001 San Diego
Session 24: HEP Instrumentation 3
Tevatron and CDF Upgrades for Run 2

- **Tevatron Accelerator**
  - Luminosity $2 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ (Run 1: $2 \times 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$)
  - Proton-antiproton bunch spacing 396/132 ns (Run 1: 3500 ns)

- **Tracking System**
  - Central Outer Tracker (COT)
  - Silicon Tracking

- **Trigger and DAQ System**
  - Tracking at Level 1 (XFT)
  - Pipelined
  - Three Level System

- **Front-end Electronics**
  - Buffered data

- **Endplug Calorimeter**
  - Scin. Tile Fiber (fast)

- **Muon System extensions**
CDF Run 2 Data

- CDF has collected 4 pb\(^{-1}\)
- XFT is important for high pT W/Z and low pT J/ψ triggers at Level 1
DAQ/Trigger System

- Pipeline Readout
- Data sampled every 132 ns (TDC’s Calorimetry, Silicon).
- New Level 1 trigger decision every 132ns. Latency 5.5 µs. (*Pipelined*)
- Data --> Level 2 Buffer.
- Level 2 Dec: Asynchronous, 20 µs
- Readout --> Level 3 Farm.
- Accept rates 10x more than Run I
  - Level 1: < 50 kHz
  - Level 2: 300 Hz
  - Level 3: 50 Hz --> tape
- Design: 90% Live at 90% max. bandwidth.
- Trigger combines primitives from tracking, muons, EM and HAD calorimeters, SVX II, etc.
- Similar in concept to the Run I trigger, multilevel, flexible, programmable, etc. but now all information must be pipelined.
- **New**: Central tracking info available at Level 1.
- Impact parameter information at Level 2 from SVT.
Tracking in the Level 1 Trigger

- Role of tracking
  - Top, W/Z, Exotic Physics: triggers require high momentum electron and muon Level 1 trigger candidates
  - Bottom Physics: require low momentum tracking at the Level 1 trigger
    - electrons
    - muons
    - hadronic tracks

- The tracking trigger needs to provide a track list in time for the Level 1 trigger decision
- The tracks are used as seeds for the Silicon Vertex Trigger (SVT) in Level 2. Trigger on displaced vertices...first at hadron collider!
- The tracking trigger needs to find tracks every crossing, hence the name:

  eXtremely Fast Tracker

  XFT
Identifying Tracks with the XFT

To find tracks in time for the Level 1 trigger, we use parallel processing and pipelining:

- The first stage classifies hits on the COT wires (**Mezzanine Card**).
- The second stage (**Finder**) groups the hits in a layer and looks for segments.
- The third stage (**Linker**) looks at segments across layers, finds valid tracks, and calculates track momentum.
  - Low fake rate
  - High Efficiency for $|\eta| < 1.0$
  - Excellent momentum resolution

Must report the results for an event every 132 ns! It has to be fast!
The mezzanine card is responsible for classifying each hit on a wire as either prompt or delayed.

132 ns bunch spacing
- **Prompt**: Drift time from 0-44 ns
- **Delayed**: Drift time from 45-132 ns

396 ns bunch spacing
- **Prompt**: Drift time from 0-66 ns
- **Delayed**: Drift time 67-220 ns
The Finder

Track segments are found by comparing hit patterns in a given layer to a list of valid patterns or “masks”. Can allow up to 3 misses. Presently using a 2 miss design to obtain high efficiency.

A Mask is:
- A specific pattern of prompt and delayed hits on the 12 wires of an axial COT layer.

Each Mask corresponds to:
- Inner Layers: 1 of 12 pixel positions
- Outer Layers: 1 of 6 pixel positions and 1 of 3 slopes (low pt+, low pt -, high pt)

Algorithm implemented in a programmable logic device (“Finder chip”). Chips within a layer are identical. Each chip is responsible for four adjacent cells. (336 Altera 10K50 chips)
The Linker

Tracks are found by comparing pixels in all 4 layers to a list of valid pixel patterns or “roads”. Each chip contains all the roads needed (2400) to find tracks with transverse momentum $> 1.5$ GeV/c. Can generate roads for any beam spot position, sensitive to $> 1$ mm changes. Presently using a design with a 4 mm offset at $105^\circ$.

Algorithm implemented in a PLD (“Linker chip”). Each chip covers $1.25^\circ$ (288 chips total) and reports the best track to the Level 1 trigger.

Pixels must match

Number of roads proportional to $1/\text{pt}$ minimum

Slopes must match
XFT Hardware

- **Complete system** ready for Commissioning Run in September 2000 and Run 2a in March 2001
- Able to send simulated data through entire XFT system – useful diagnostic test
- Very stable system – less than 1 hour of downtime since March 2001

Diagram:
- 168 TDC from COT axial layers
- 12 XTRP (1 crate)
- XTRP cables (50 ft)
- Linker Output
- 24 Linker (3 crates)
- Ansley cables (220 ft)
- 12 TDC Transition
- 20 crates
- 48 Finder (3 crates)
- 12 Finder Transition
- Channel link cables (10 ft)
The Finder Board
The Linker Board
XFT Efficiency

How well does XFT find tracks?

- Events from 10 GeV Jet trigger
- CDF reconstructed tracks:
  - Hits > 24 in axial and stereo layers
  - $p_T$ > 1.5 GeV/c
  - Fiducial
- Match if XFT track within 10 pixels (about 1.5°) in at least 3 layers

Find XFT track for 96.1±0.1% of these reconstructed tracks

- Azimuthal coverage flat
  - only 20 / 16,128 COT wires off
XFT Resolution

How well does XFT measure tracks?

- Transverse momentum resolution
  1.64+-0.01 %/GeV/c (< 2 %/GeV/c)

- Angular resolution at COT SL3:
  5.09+-0.03 mR (< 8 mR)

Meet design specifications!
XFT pT Threshold

- Sharp threshold at pT=1.5 GeV/c
  - Important for B physics Level 1 trigger rate
    - Run 1 threshold was 2.2 GeV/c at Level 2
  - Thresholds look same in 1/pT

- XFT track is fake ~ 3% at low pT
- XFT track is fake ~ 6% in 8 GeV electron triggers

- Single track trigger cross-section with pt>1.5 GeV/c is ~11mb, close to extrapolations from Run I data.
Conclusions

- XFT fully installed in early 2000
  - In time for Commissioning Run in September 2000
  - In time for Run 2a in March 2001
  - Very stable system – downtime < 1 hour

- XFT performance in Run 2a meets/exceeds specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
<th>Simulation</th>
<th>Data</th>
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<tr>
<td>Efficiency</td>
<td>&gt; 96 %</td>
<td>99 %</td>
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<td>pT Threshold</td>
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<td>5.1 mR</td>
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Central Outer Tracker (COT)

- Previous chamber (CTC) needed to be replaced:
  - Drift time too long
  - Chamber had aged
- 8 “superlayers”
  - 4 with axial wires
    - \( r - \phi \) measurement
  - 4 with stereo wires
    - \( z \) measurement
- Small Cells
  - 0.88 cm drift (avg.)
  - Fast Gas
    - Drift time < 132 ns
COT Design

- Basic Cell:
  - 12 sense, 17 potential wires
  - 40 μ diameter gold plated W
  - Cathode: 350 A gold on 0.25 mil mylar

- Drift trajectories very uniform over most of the cell

- Cell tilted 35° for Lorentz angle

- Construction:
  - Use winding machine
  - 29 wires/pc board, precision length
  - Snap in assembly fast vs wire stringing
  - 30,240 sense wires vs 6156 in CTC
  - Total wires 73,000 vs 36,504 in CTC