eXtremely Fast Tracker Performance in CDF Run 2a Data

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CDF Collaboration

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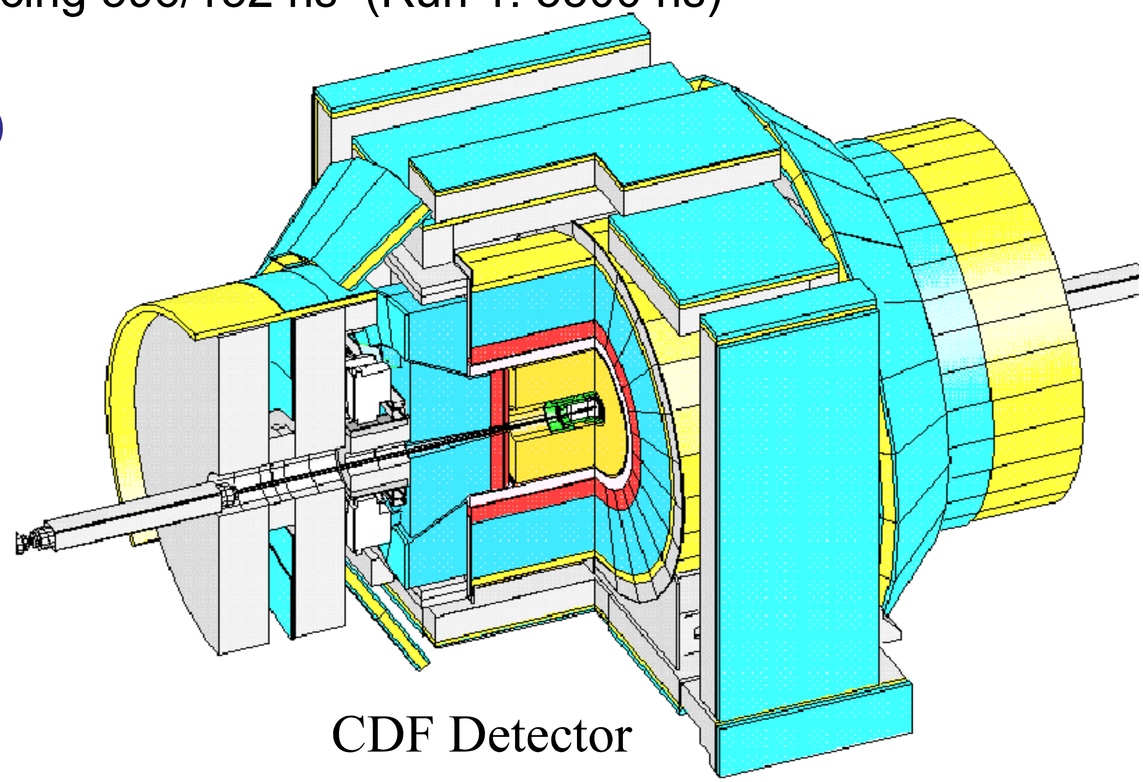
Outline

- Introduction
- Design of XFT
- Performance of XFT
- Conclusions

Tevatron and CDF Upgrades for Run 2

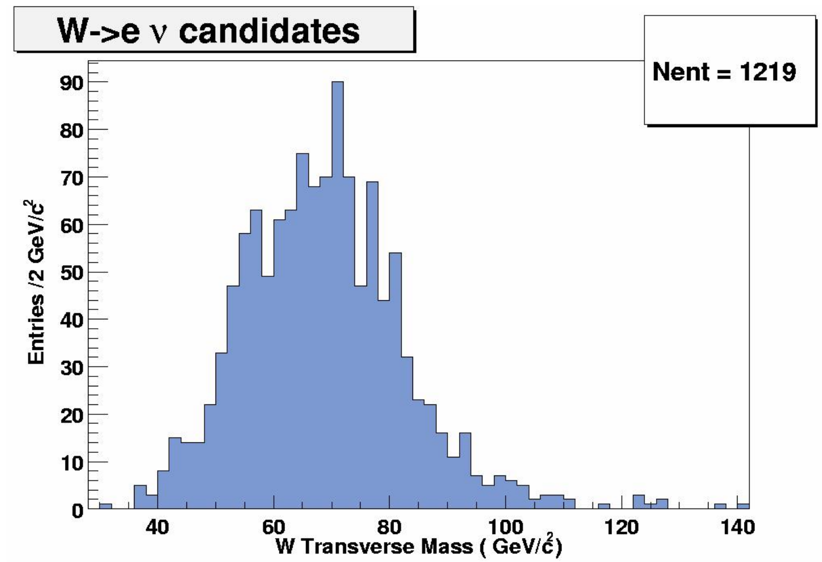
- **Tevatron Accelerator**
  - Luminosity 2 x 10^{32} cm^{-2} s^{-1} (Run 1: 2 x 10^{31} cm^{-2} s^{-1})
  - Proton-antiproton bunch spacing 396/132 ns (Run 1: 3500 ns)
- **Tracking System**
  - Central Outer Tracker (COT)
  - Silicon Tracking
- **Trigger and DAQ System**
  - Tracking at Level 1 (XFT)
  - Pipelined
  - Three Level System
- Front-end Electronics
  - Buffered data
- Endplug Calorimeter
  - Scin. Tile Fiber (fast)
- Muon System extensions

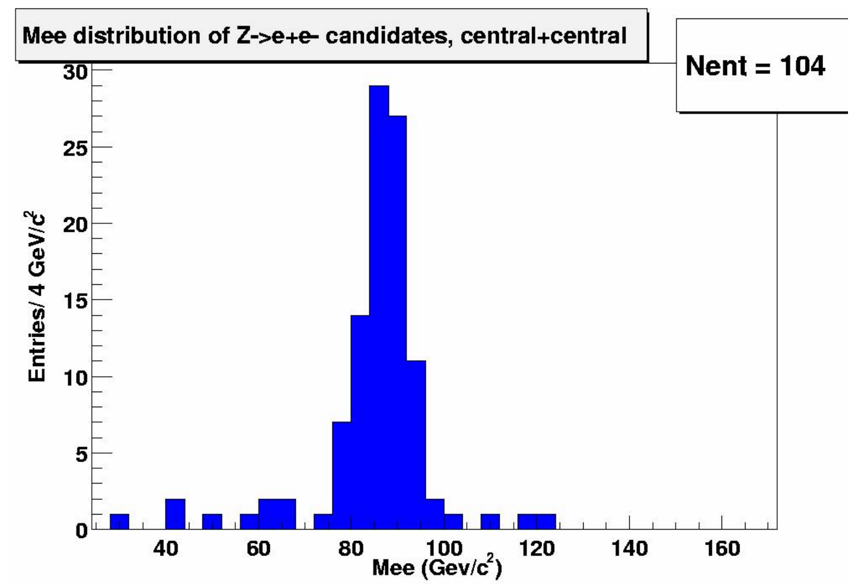


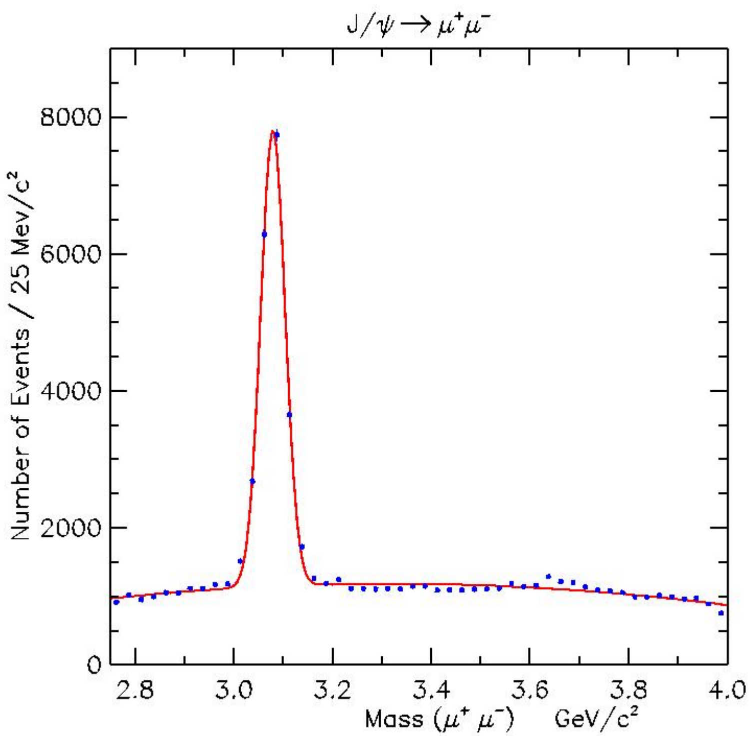
CDF Detector

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







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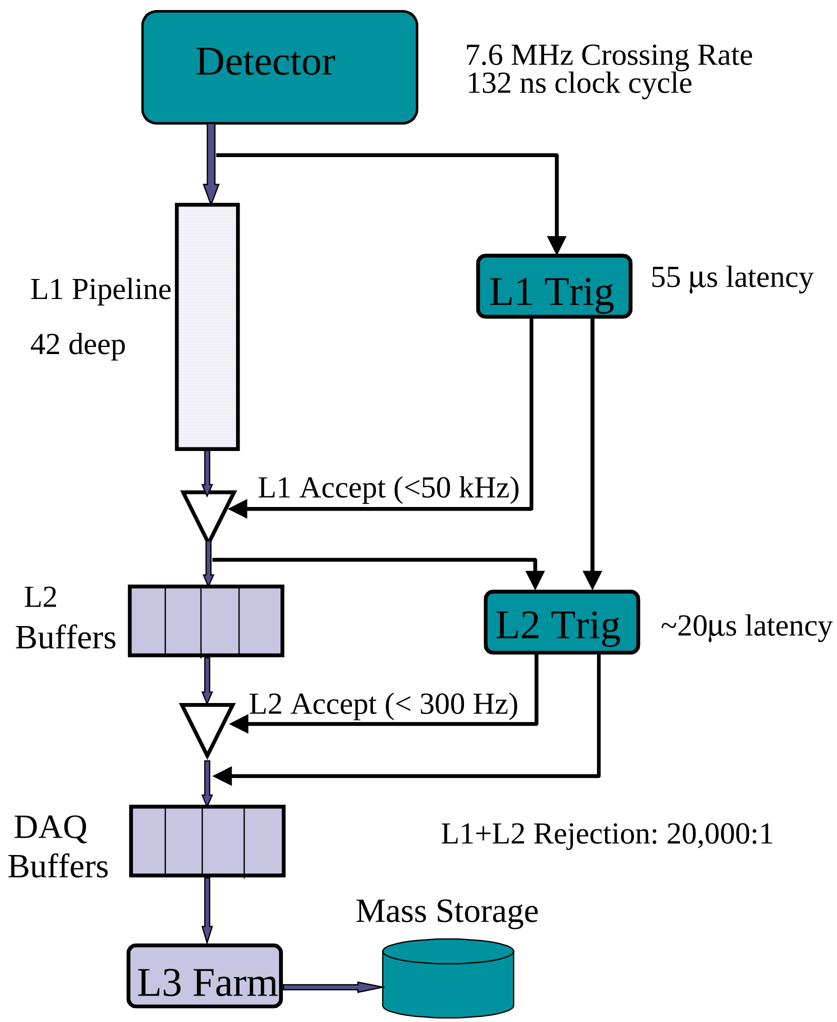
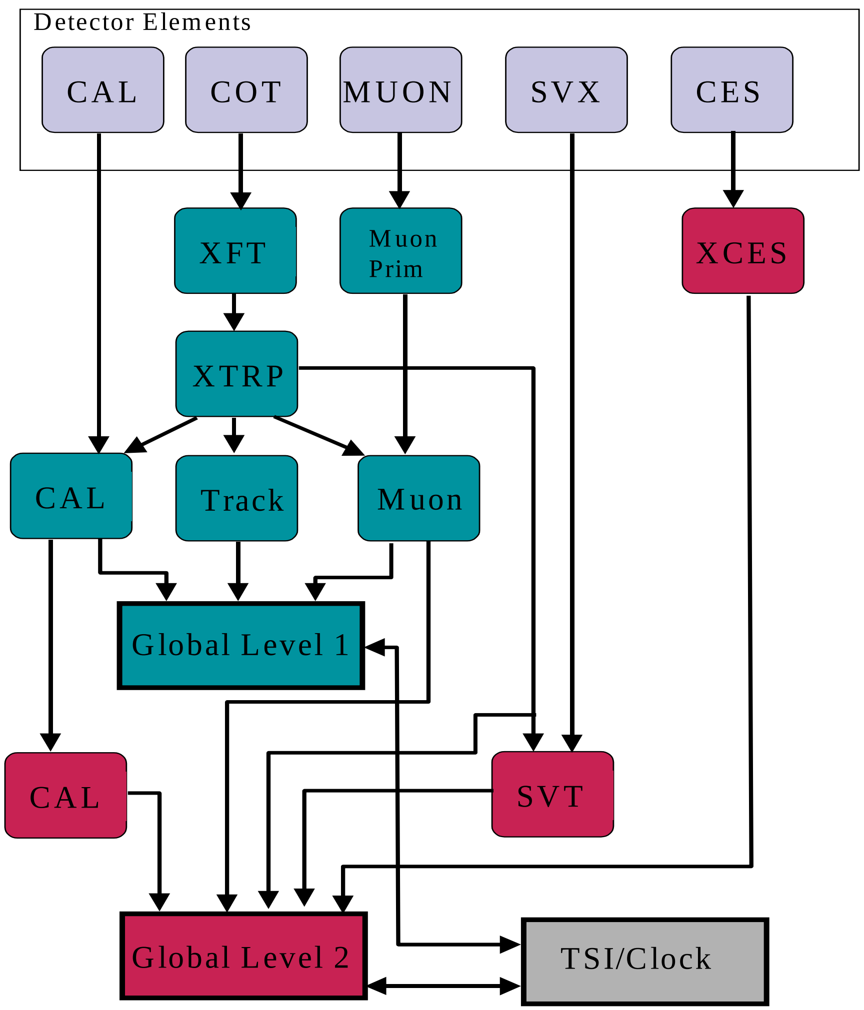
DAQ/Trigger System



- 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 System



- 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
- Trigger Electrons
  - Trigger track + EM cluster
- Trigger Muons
  - Trigger track + muon stub

- 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

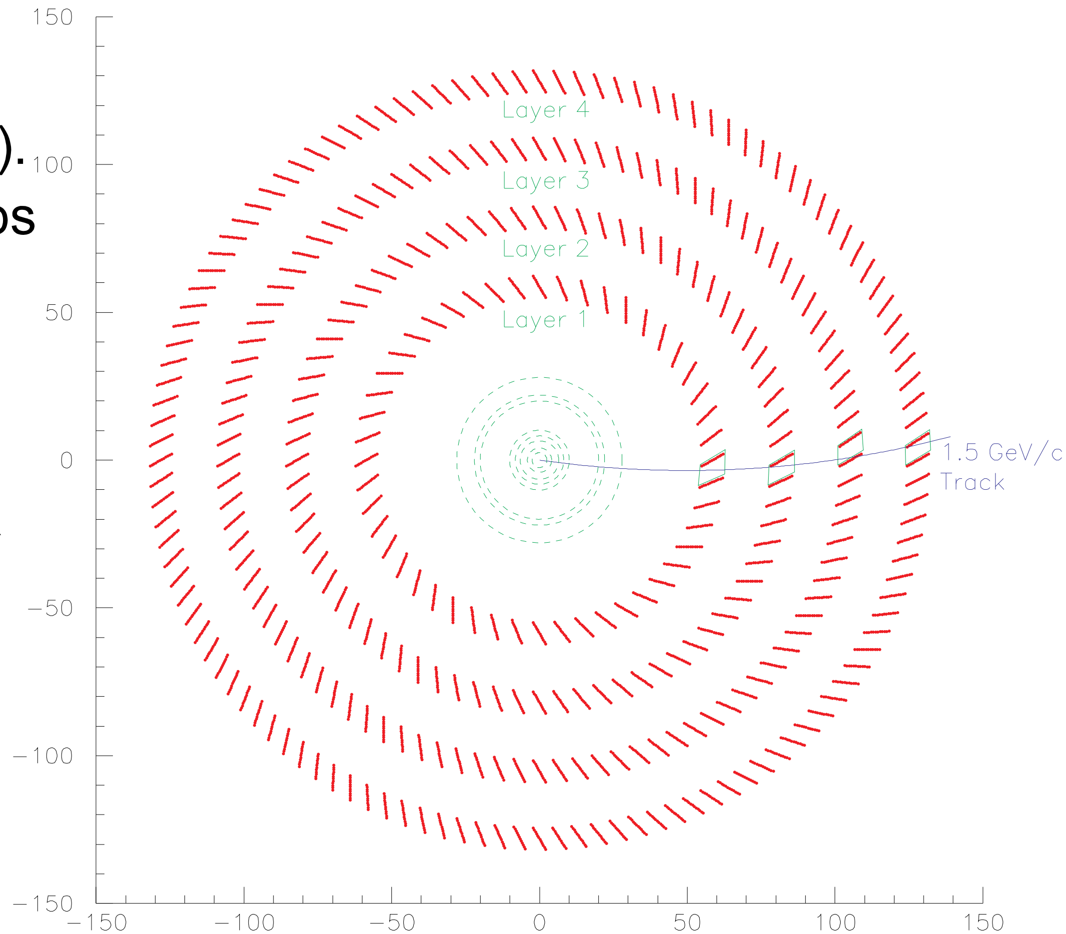
XFT

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!



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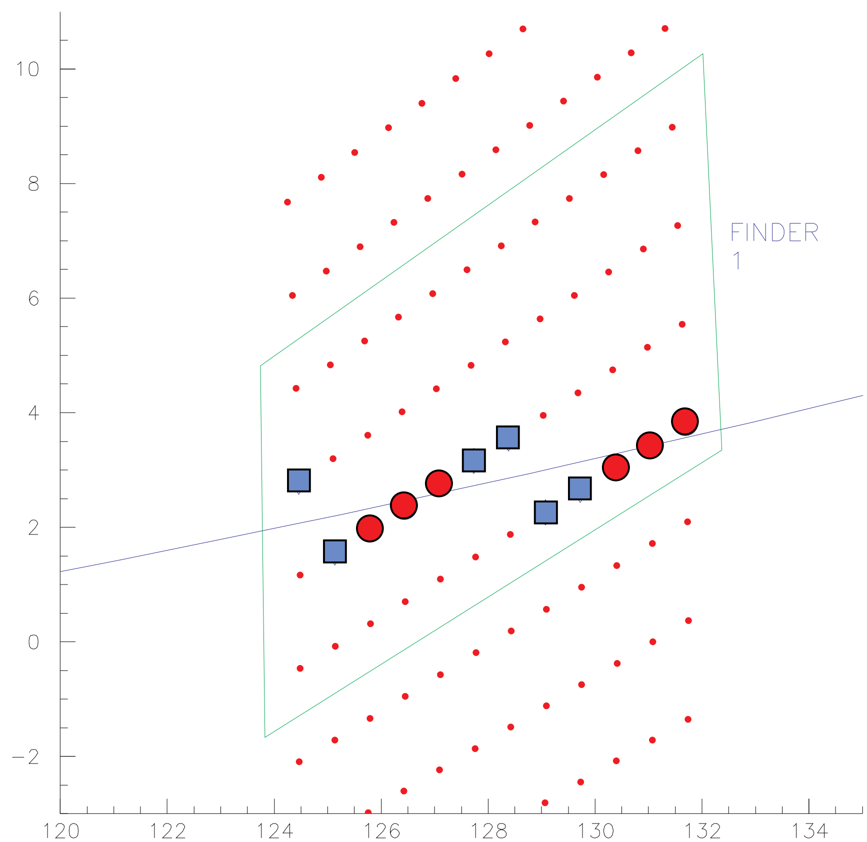
TDC Mezzanine Card

As tracks pass through each layer of the COT, they generate "hits" at each of the 12 wire-layers within a superlayer.



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 45-132ns

396 ns bunch spacing

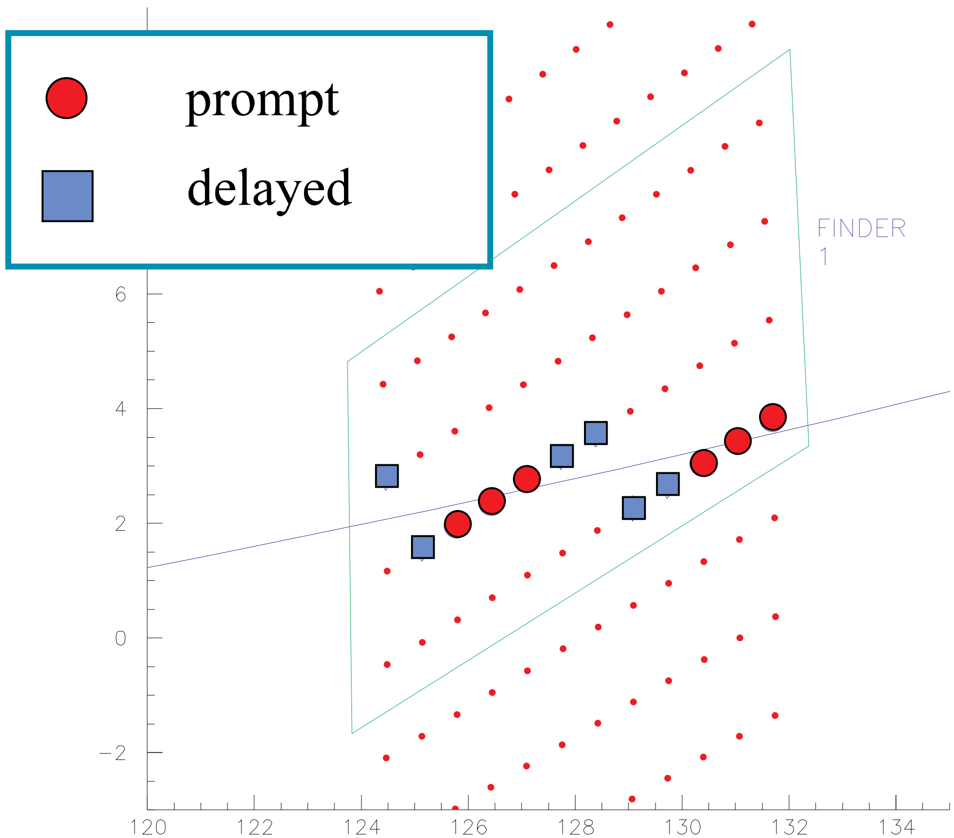
- Prompt: Drift time from 0-66 ns
- Delayed: Drift time 67-220 ns

"Prompt" hit

"Delayed" hit

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:

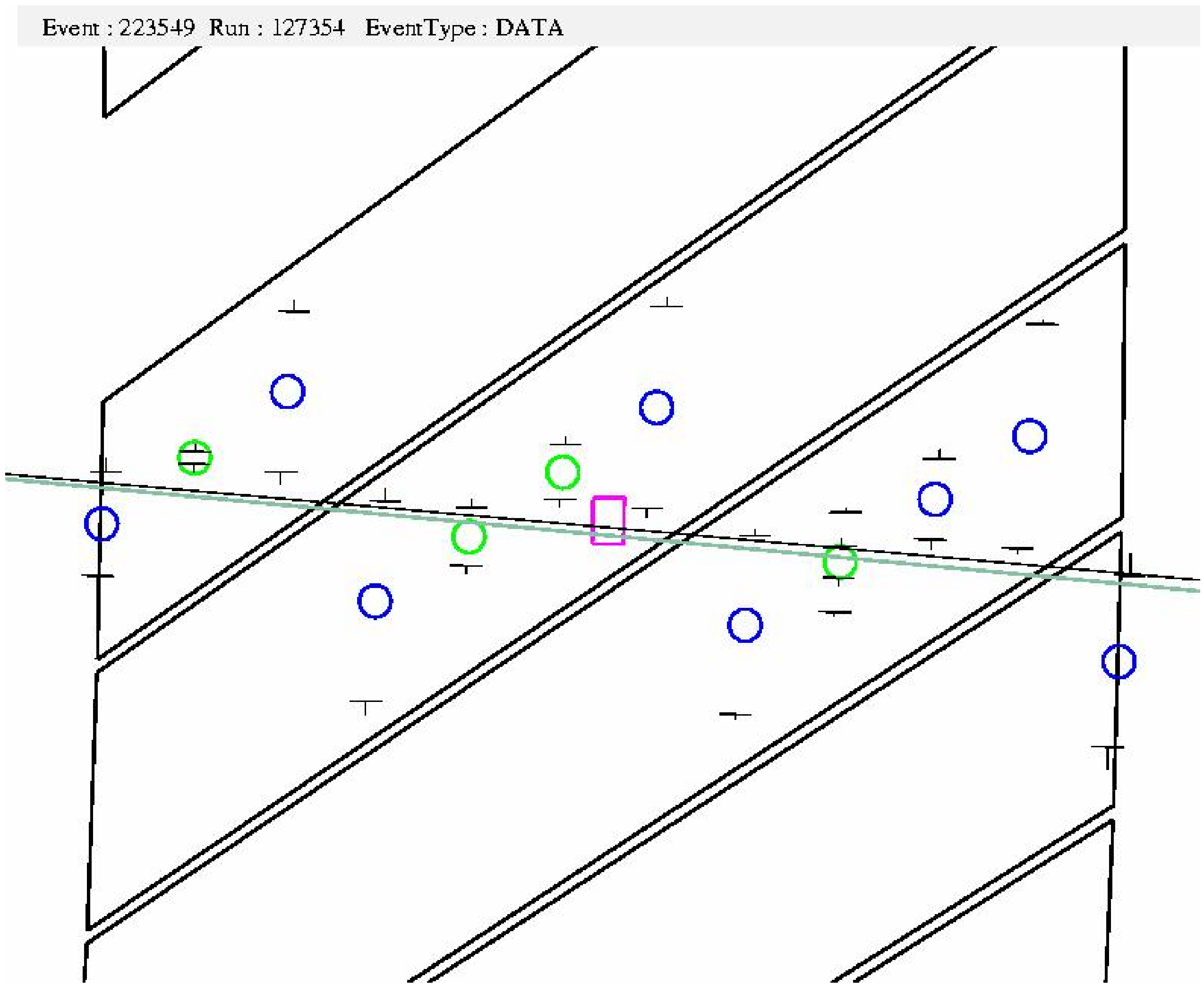
- A specific pattern of prompt and delayed hits on the 12 wires of an axial COT layer.

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)

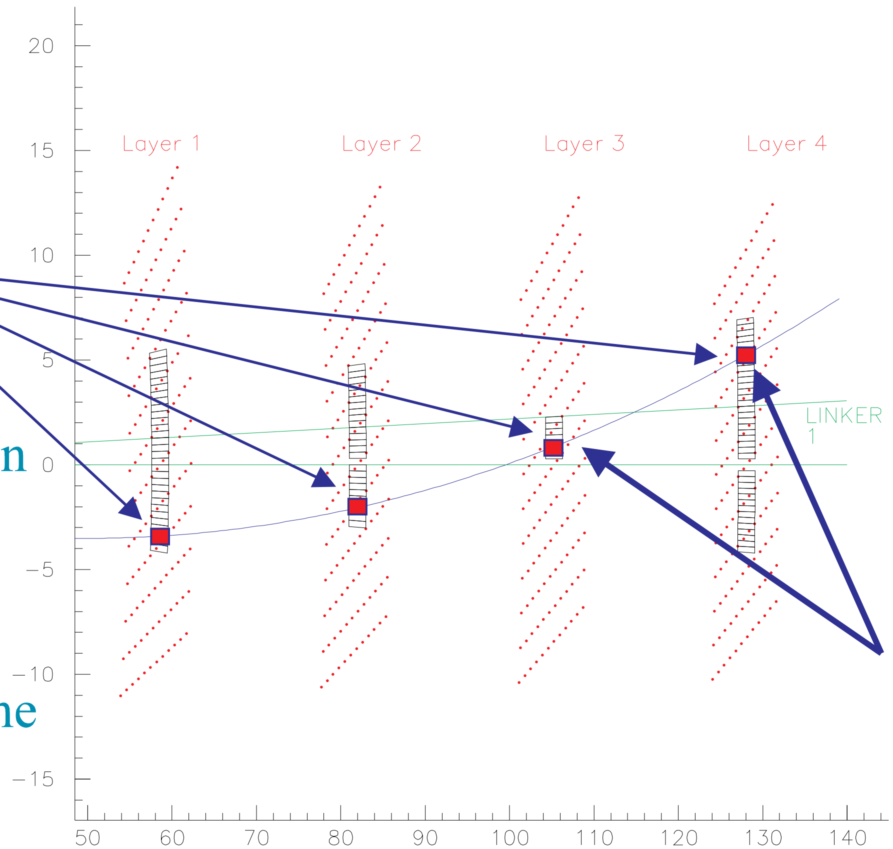
Event Display



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°.

Pixels must match



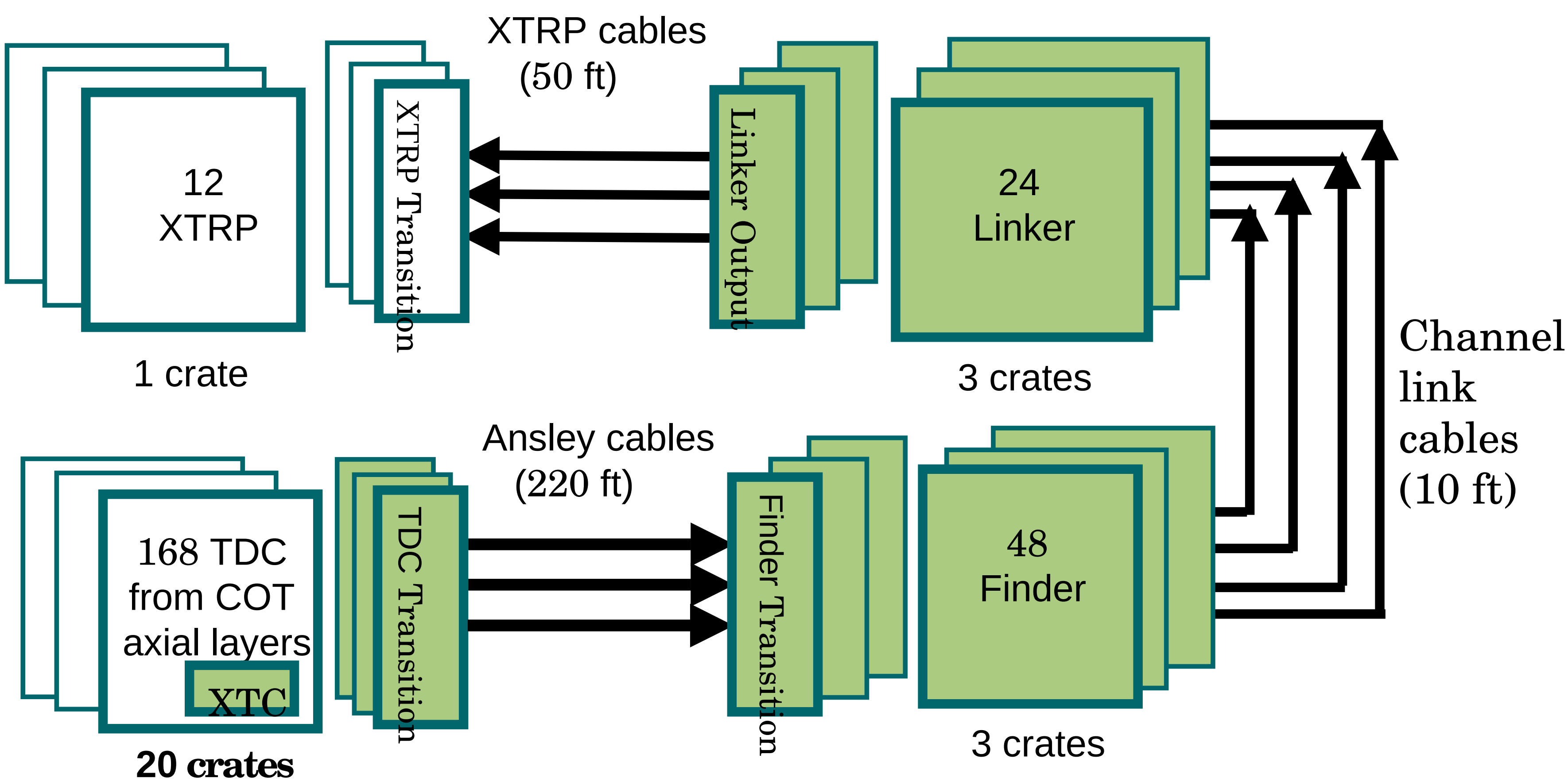
Number of roads proportional to 1/pt minimum

Slopes must match

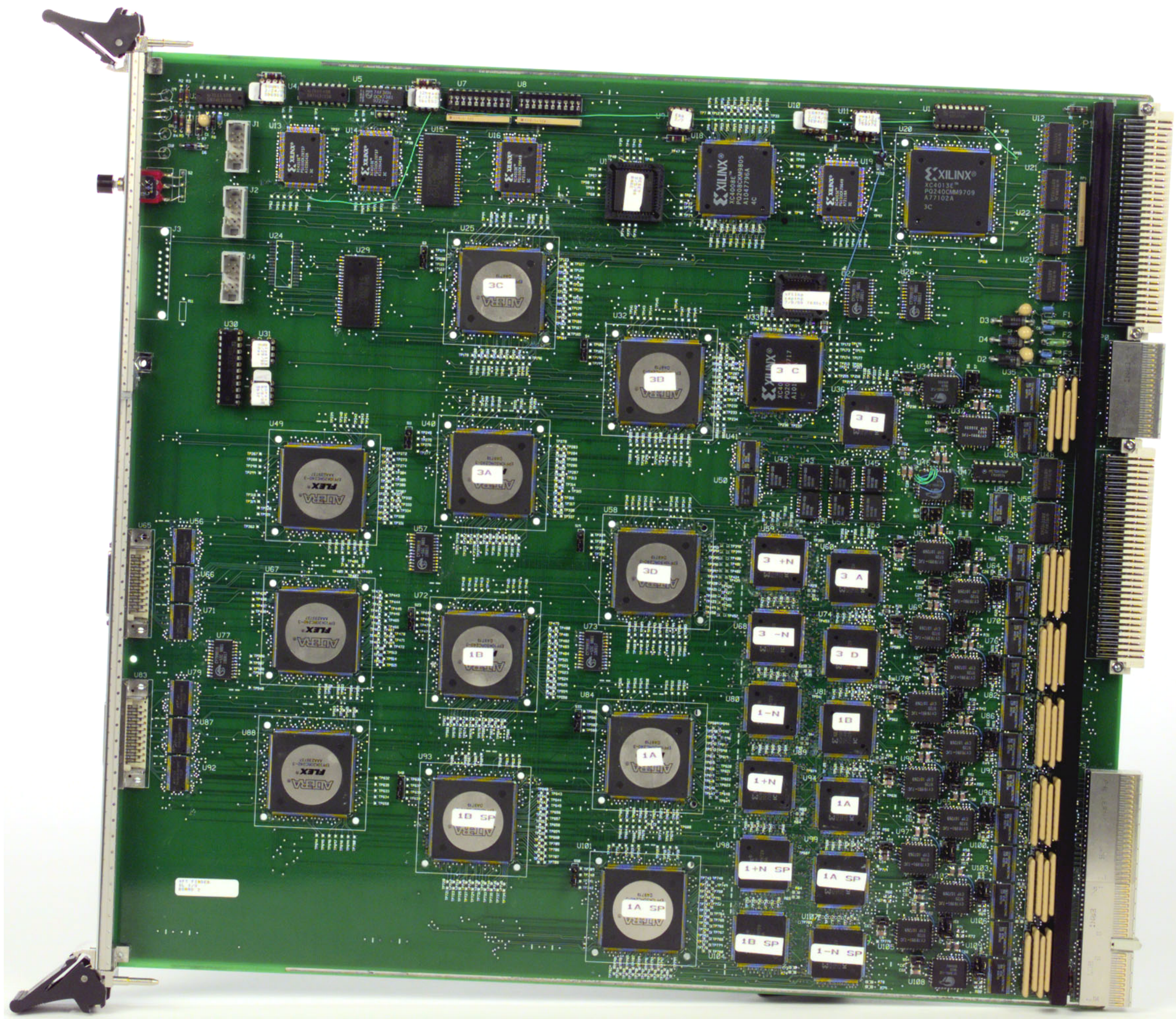
Algorithm implemented in a PLD ("Linker chip"). Each chip covers 1.25° (288 chips total) and reports the best track to the Level 1 trigger.

XFT Hardware

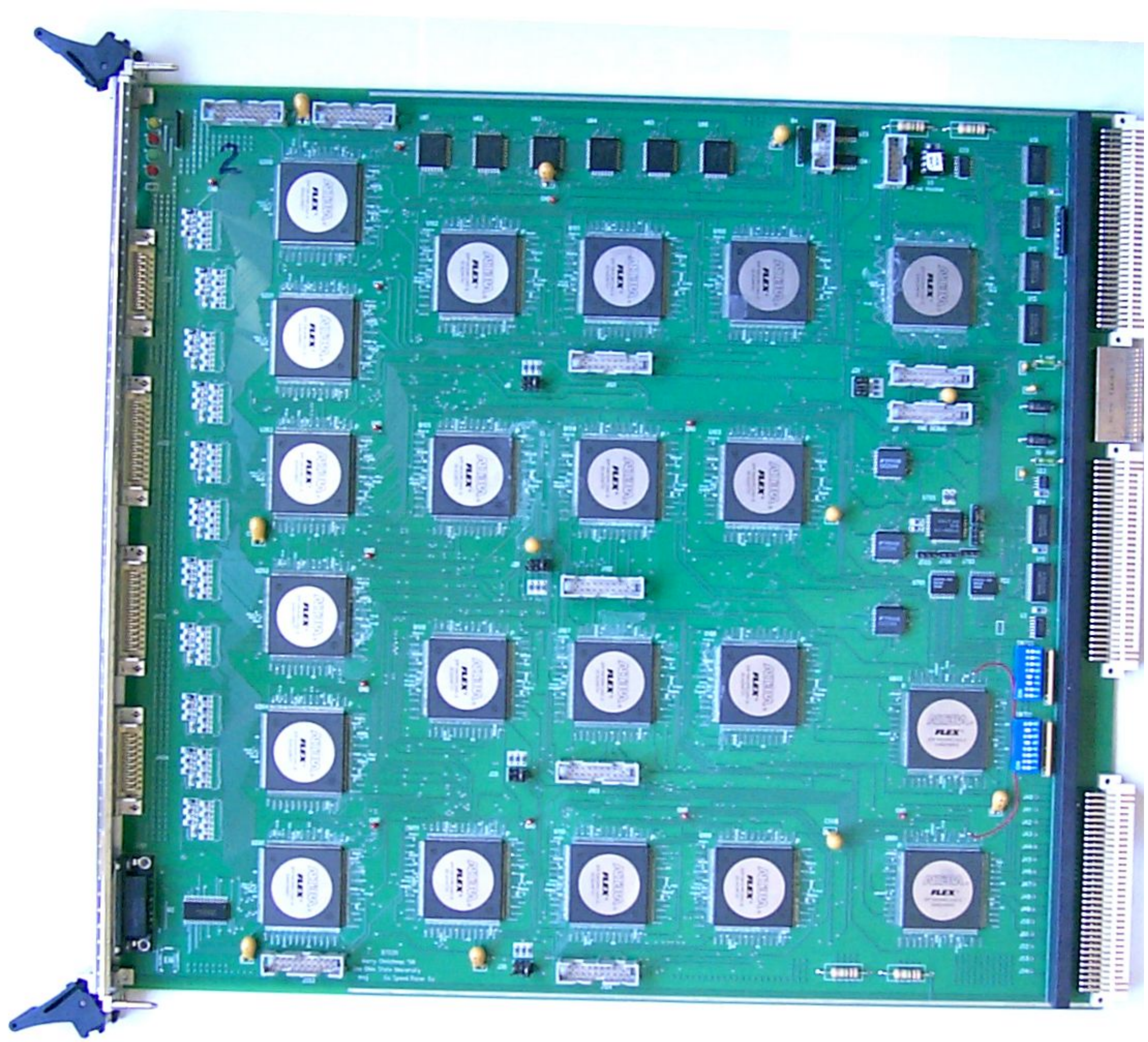
- Complete system ready for Commissioning Run in September 2000 and Run 2a in March 2001
- Able to send simulated data through entire XFT system – useful diagnostic test
- Very stable system – less than 1 hour of downtime since March 2001



The Finder Board



The Linker Board



Event Display

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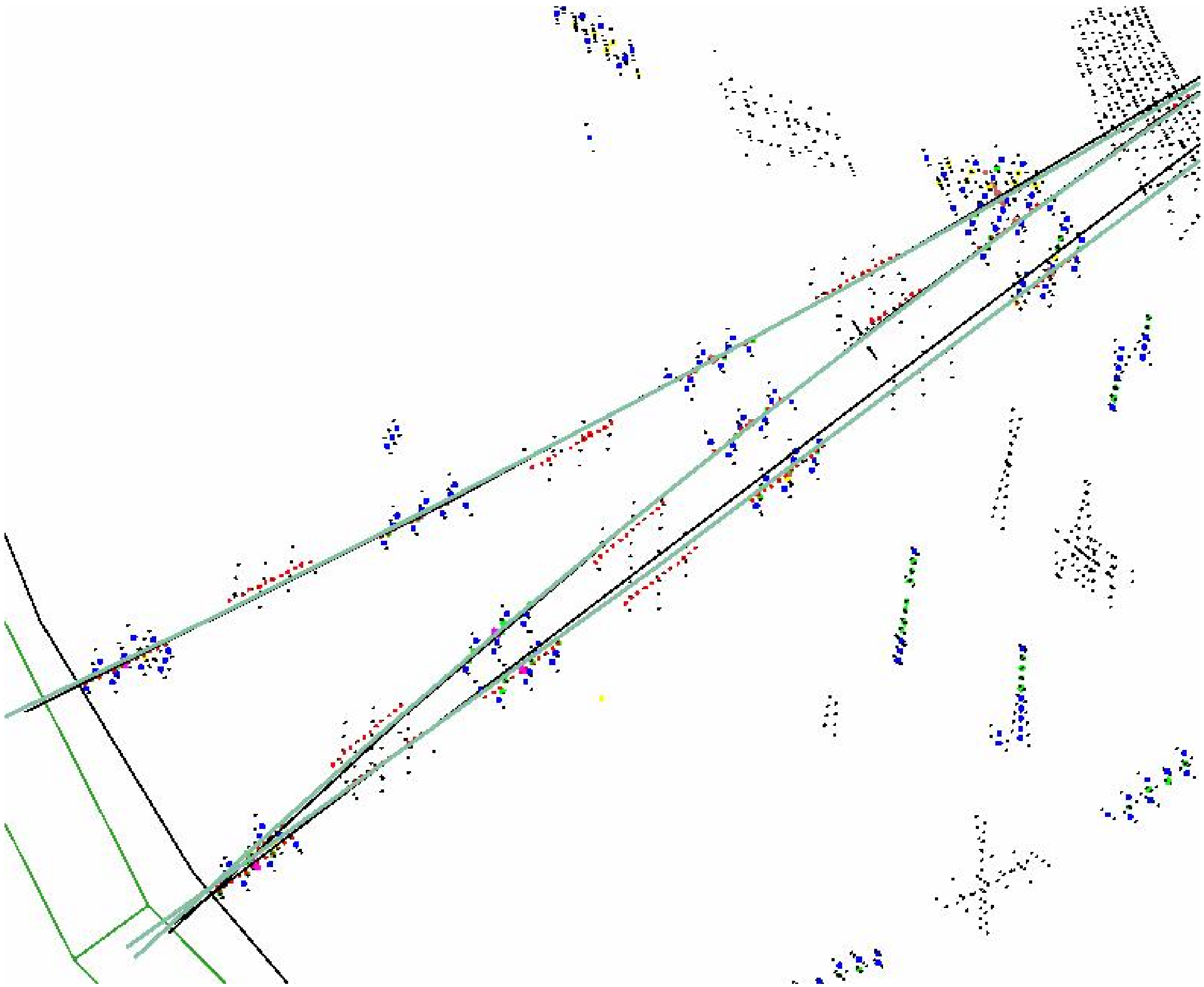

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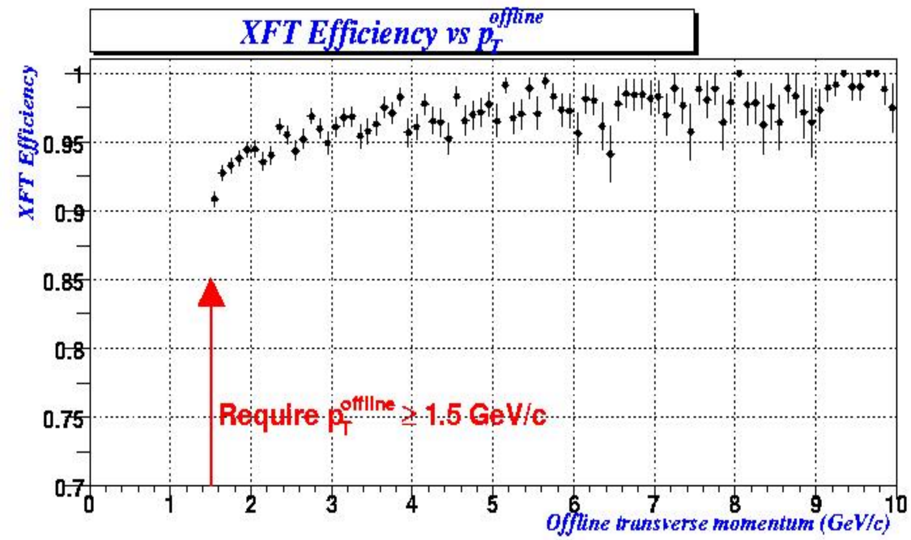
XFT Efficiency

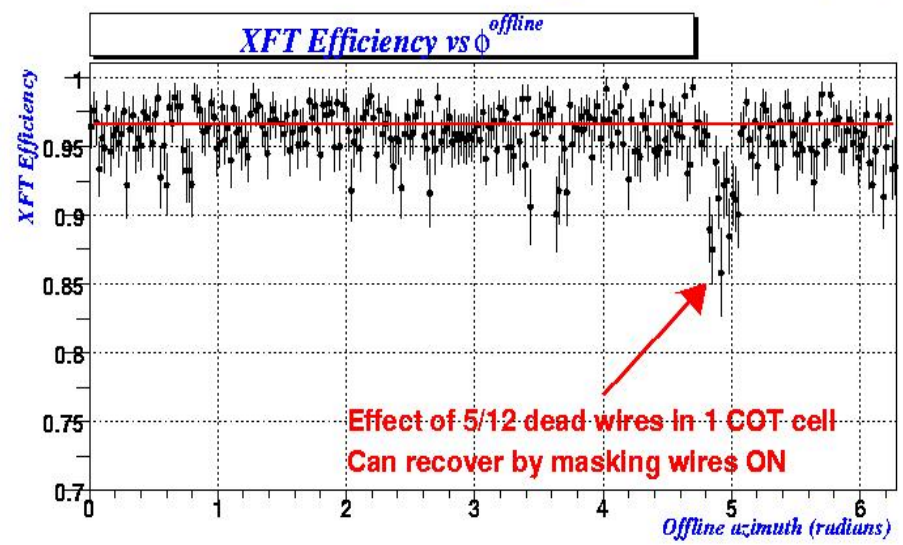
How well does XFT find tracks?

- Events from 10 GeV Jet trigger
- CDF reconstructed tracks:
  - Hits>24 in axial and stereo layers
  - pT>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





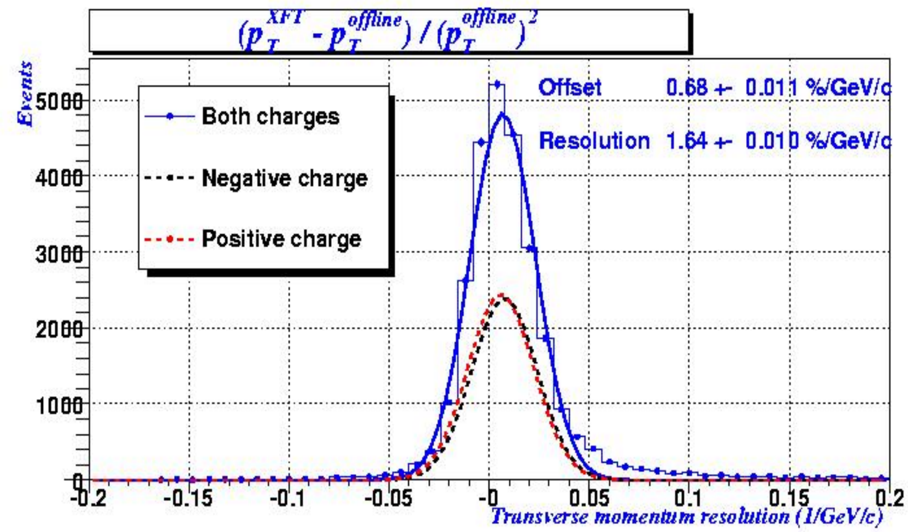
XFT Resolution

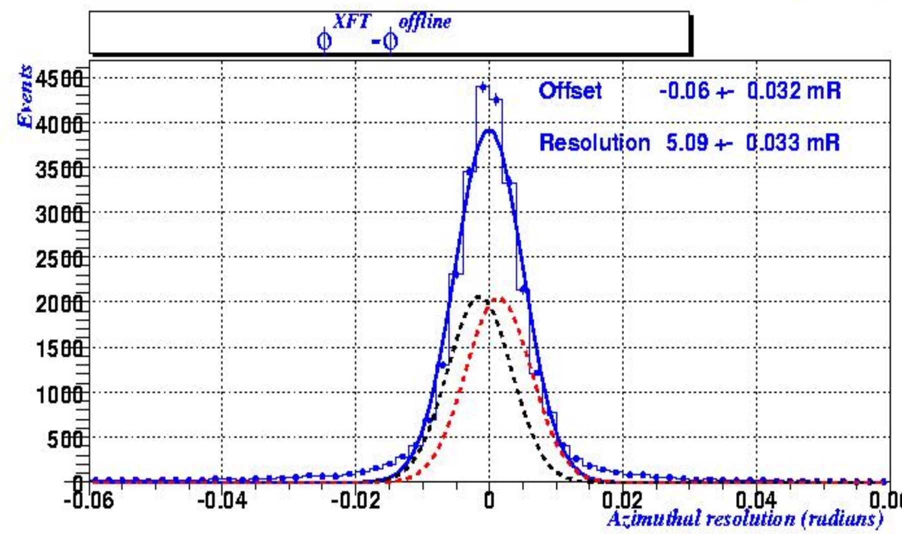
How well does XFT measure tracks?

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

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

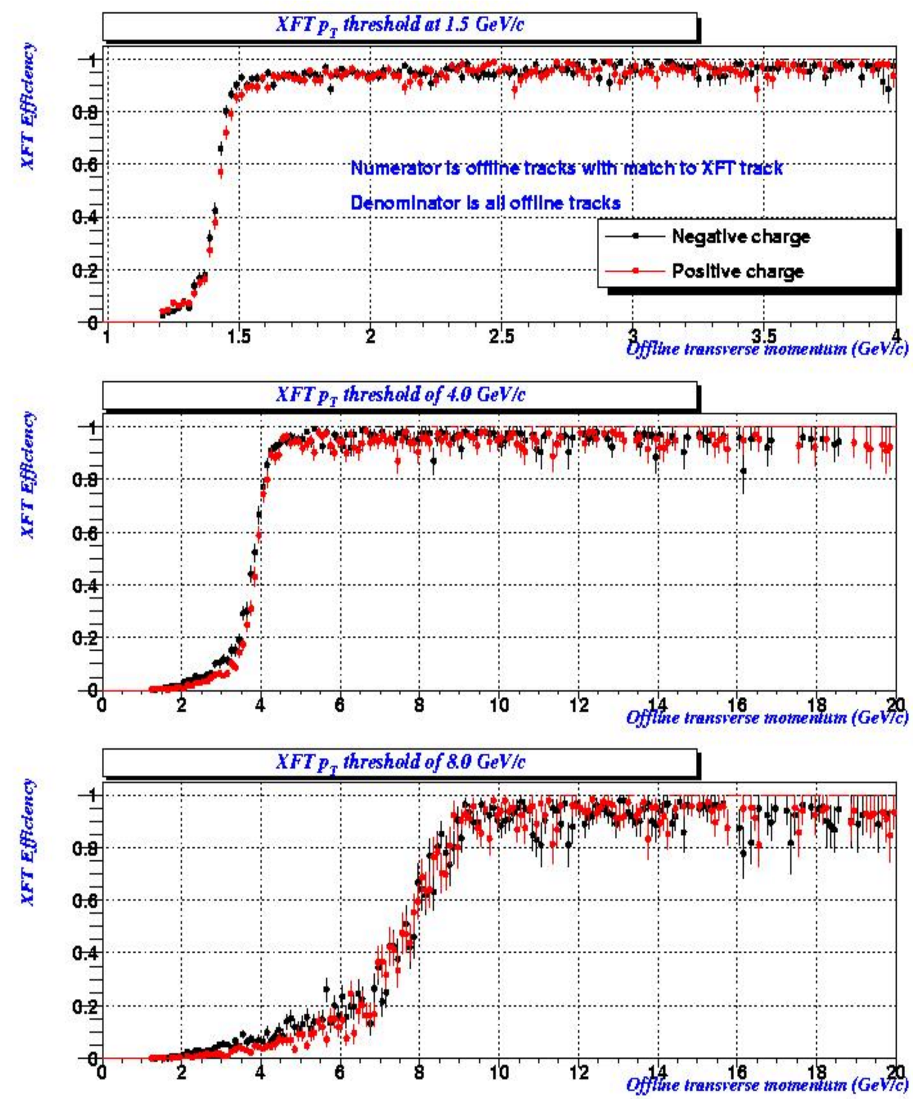
Meet design specifications!





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.



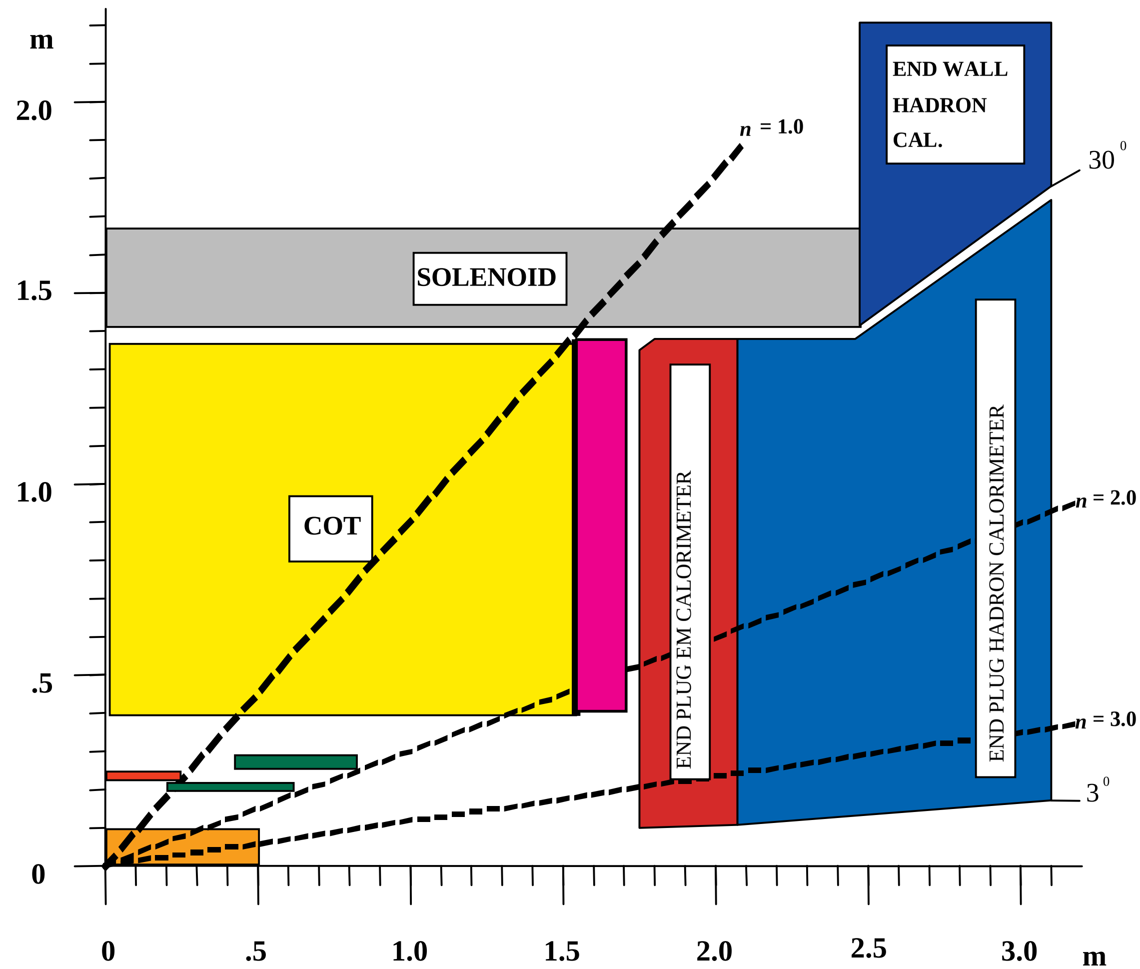
Conclusions

- 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

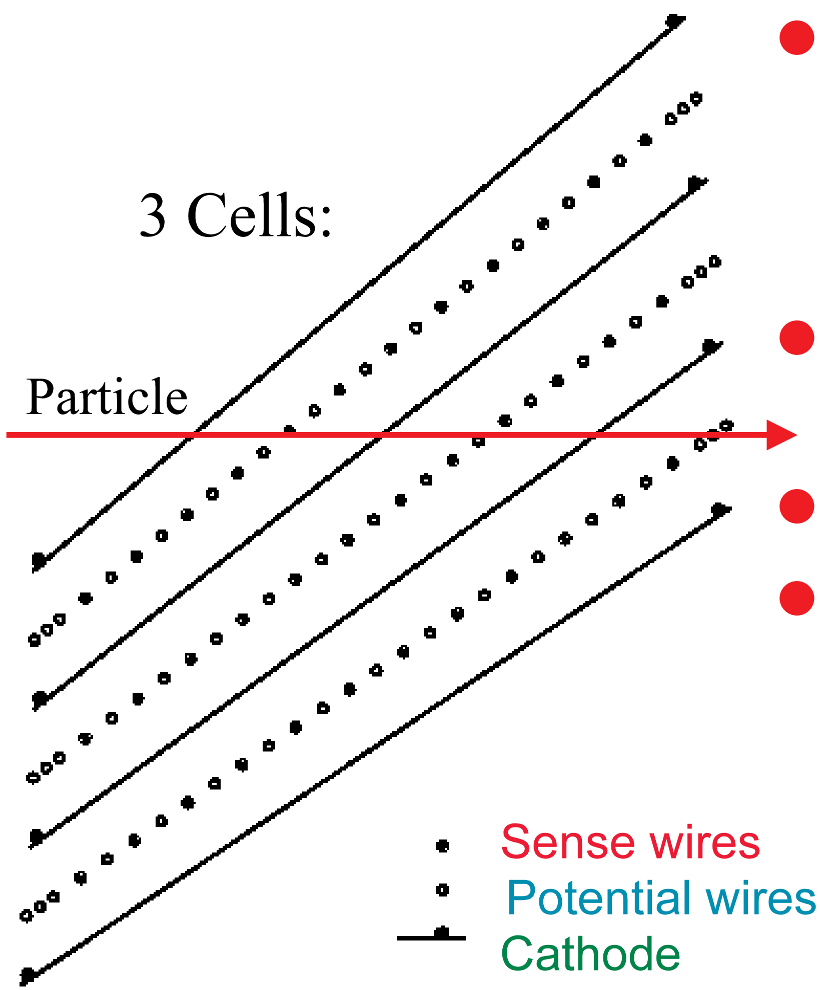
Parameter	Specification	Simulation	Data
Efficiency	> 96 %	99 %	96 %
pT Threshold	1.5 GeV/c	1.5 GeV/c	1.5 GeV/c
pT resolution	< 2.0 %/GeVc	1.0 %/GeV/c	1.6 %/GeV/c
Angular resolution	< 8.0 mR	4.0 mR	5.1 mR

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 - ϕ 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 ^{o} 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