Upgrade of the CDF Track Trigger for High Luminosity Running

Personnel on XFTIIb

- Baylor University: Dittman, Krumnack
- FNAL: Holm, Shaw
- University of Illinois: Budd, Junk, Kasten, Levine, Mokos, Pitts, Rogers, Veramendi
- Ohio State University: Hughes, Johnson, Kilminster ,Lannon, Parks, Winer
- Purdue University: Jones

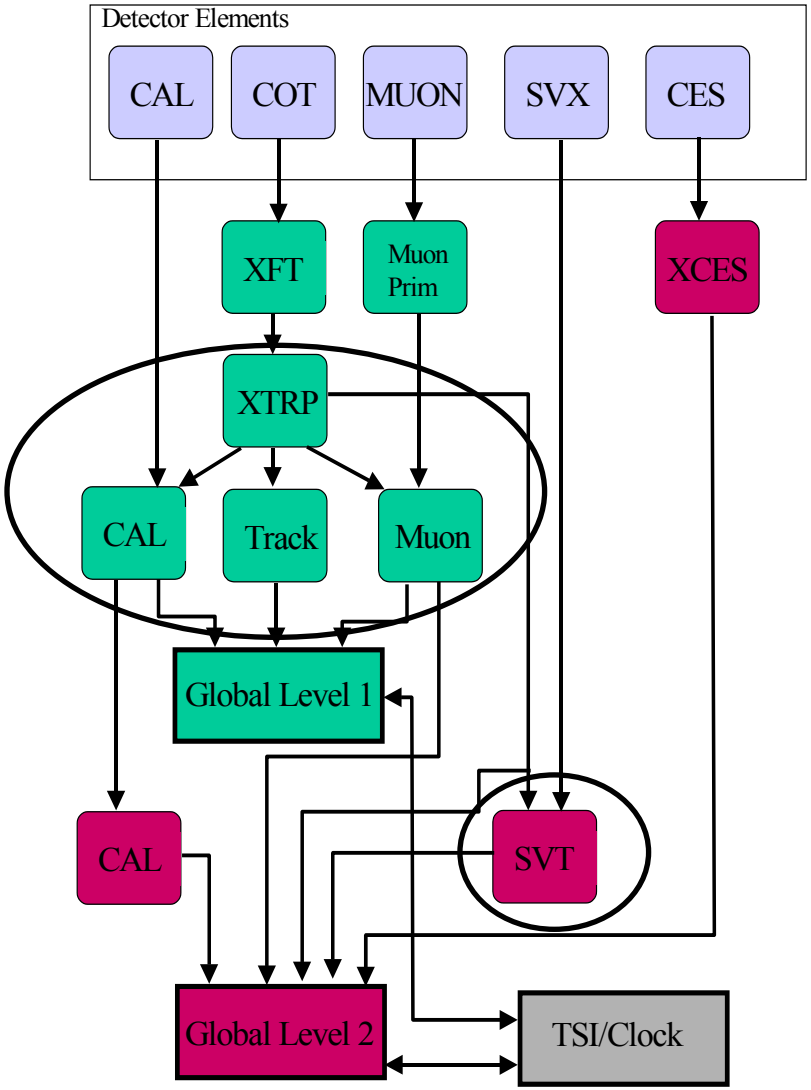
Students
Engineers
Post-Docs
Faculty

eXtremely Fast Tracker = Level 1 Track 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
- L1 Trigger Primitives
  - Electrons: XFT track + EM cluster
  - Muons: XFT track + muon stub
- L2 Trigger Tracks
  - XFT Track + Silicon Hits

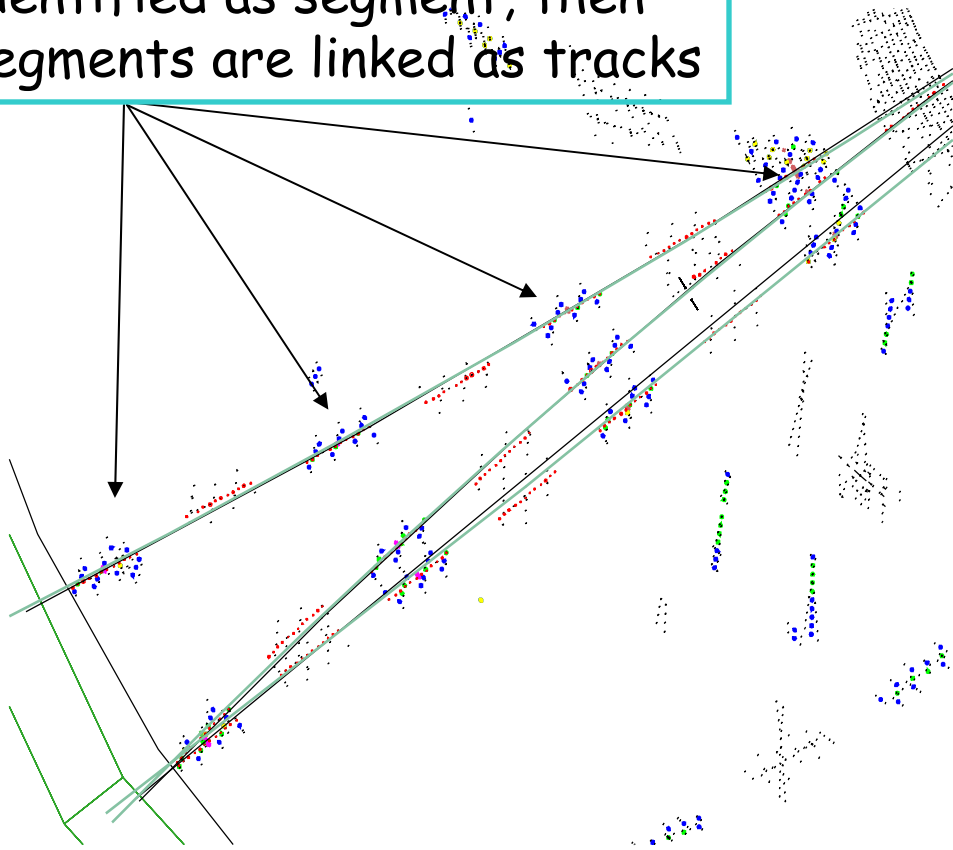
CDF Trigger System



Outline of Current XFT Operation

- Hit Finding: Mezzanine Card
  - Hits are classified as prompt or delayed (i.e. "2-bin")
- Segment Finding
  - In the axial layers, search for patterns of prompt/delayed hits consistent with High Pt tracks
  - Each segment found is assigned a pixel (phi, all layers) and possibly a slope (outer 2 axial layers only)
- Track Finding
  - Looking across 3 or 4 axial layers, search for patterns of segments consistent with Pt>1.5 GeV/c
  - Resultant Pt and Phi of all 1.5 GeV/c tracks sent on to XTRP
  - Maximum of 288 tracks reported

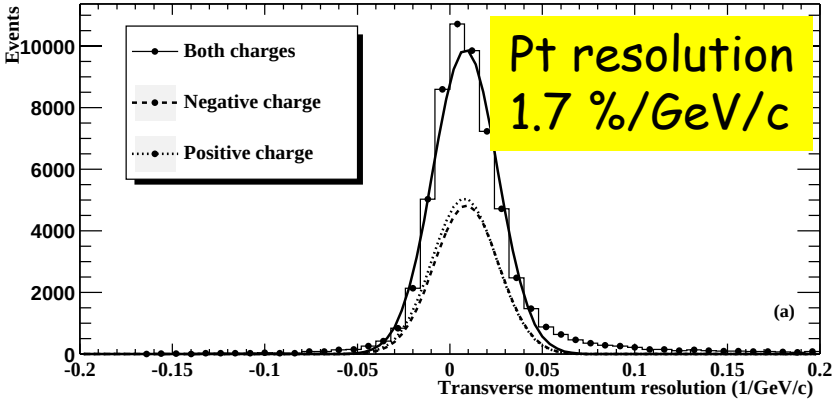
Good hit patterns are identified as segment, then segments are linked as tracks



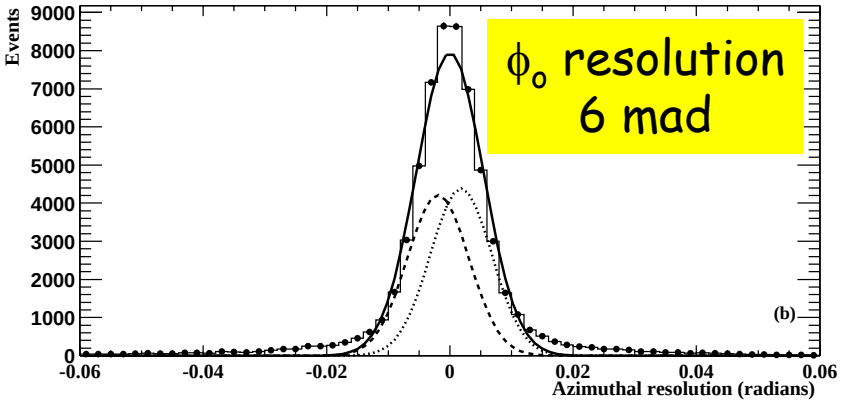
XFT Performance in CDF RunII

Performance of the XFT in CDF's RunII has been excellent

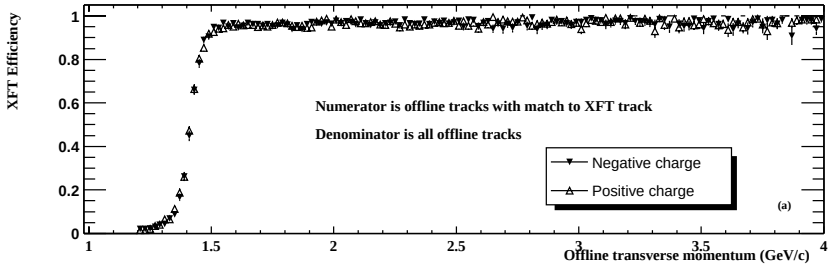
1. Momentum resolution 1.74%/GeV/c
2. Phi Resolution < 6mRad
3. Efficiency ~ 95%

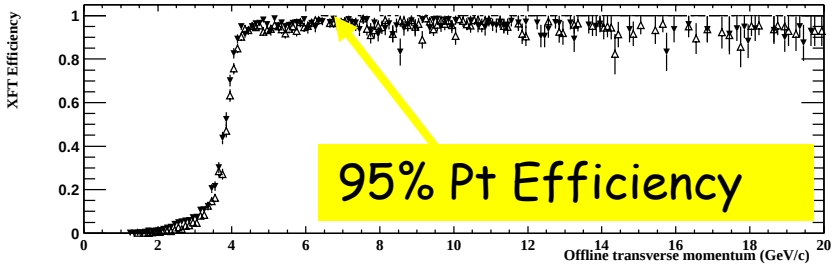


Pt resolution
1.7 %/GeV/c

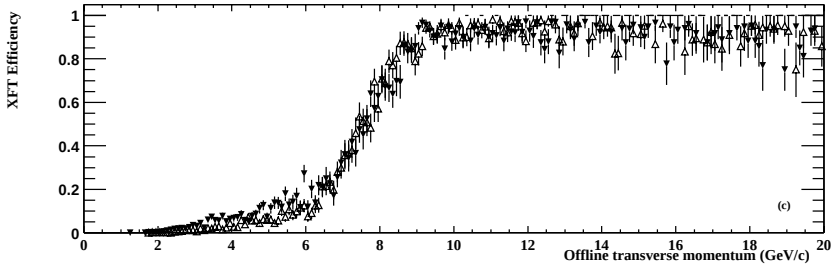


ϕ_0 resolution
6 mad

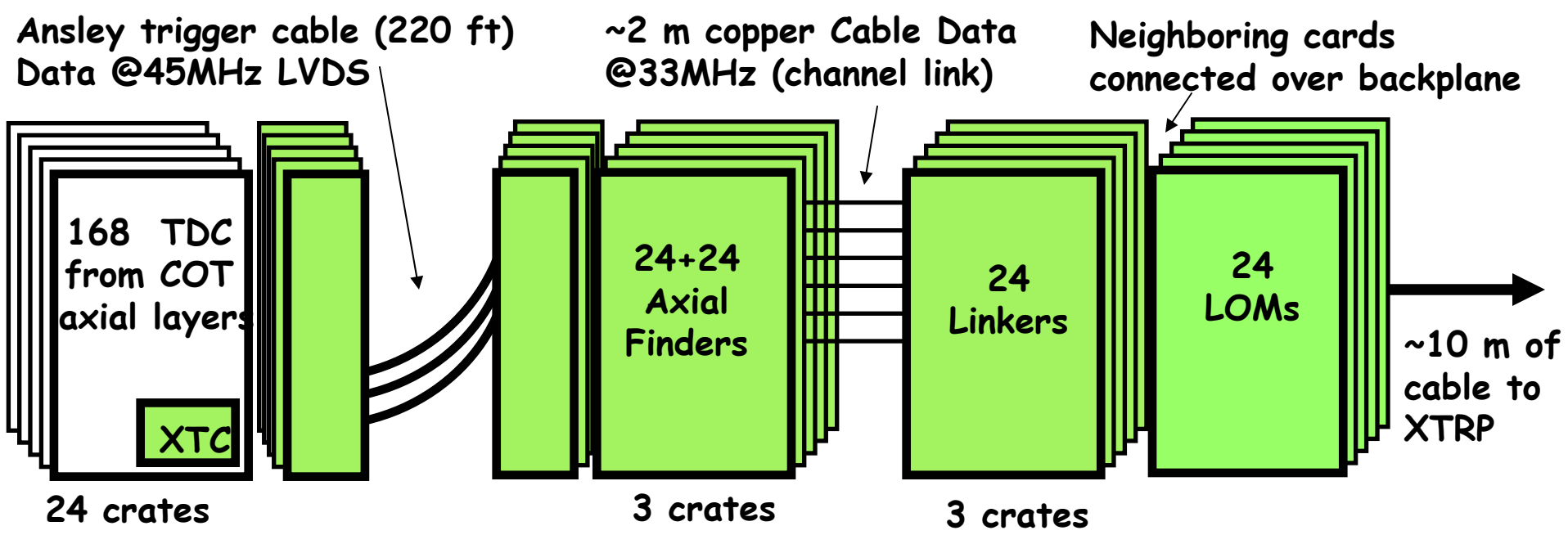


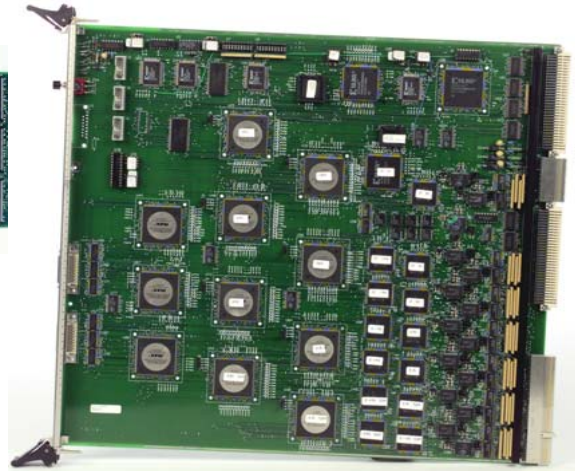


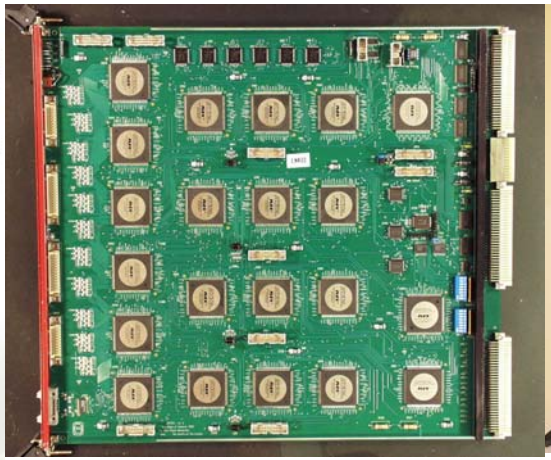
95% Pt Efficiency

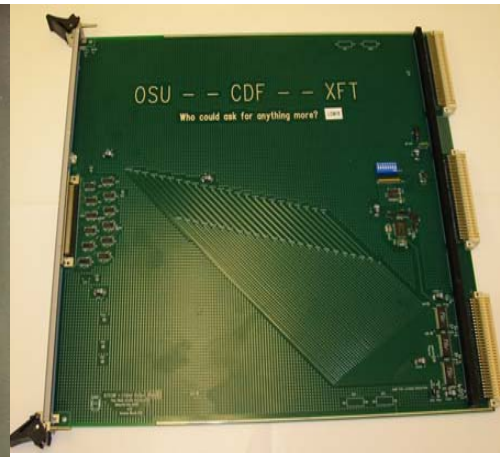


Current XFT Configuration



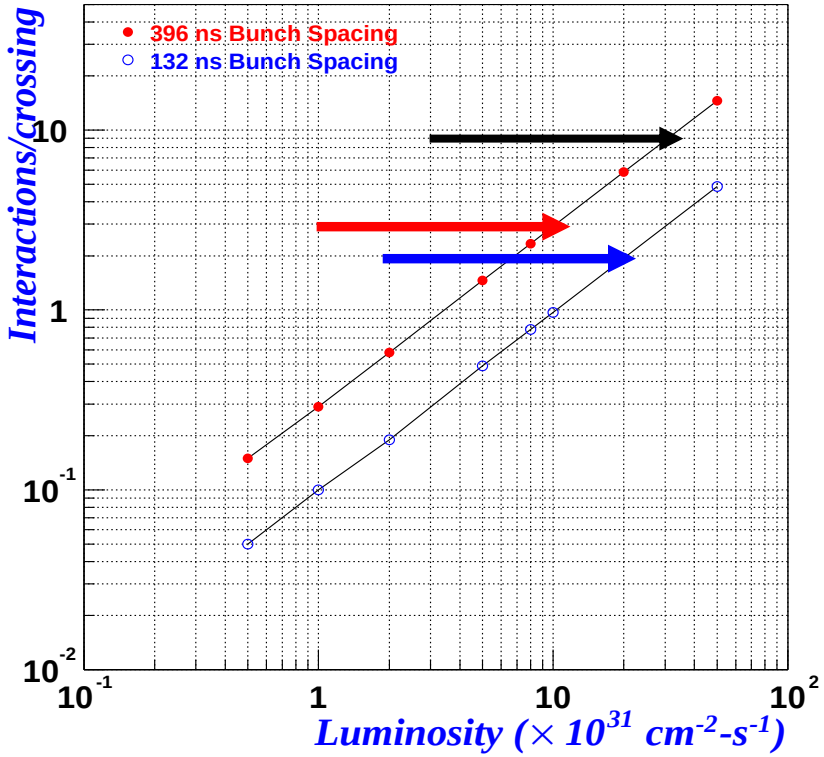


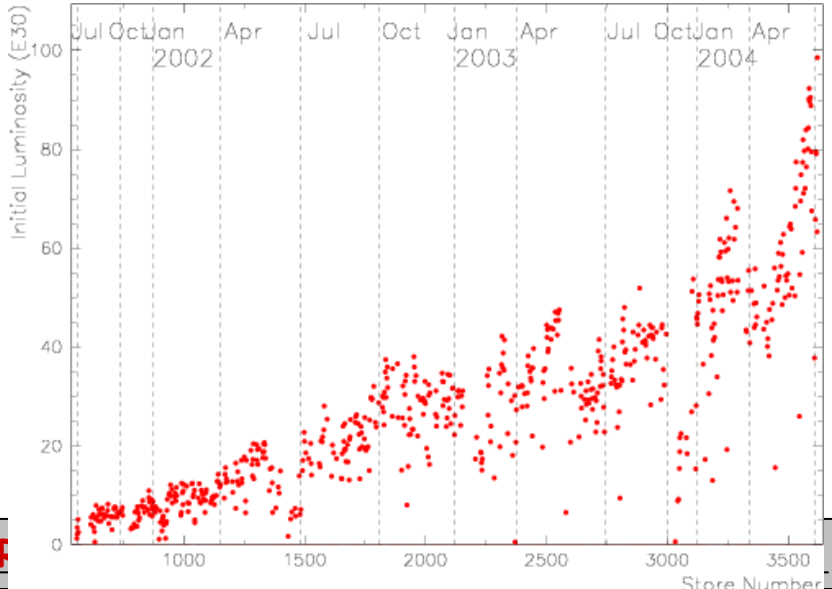


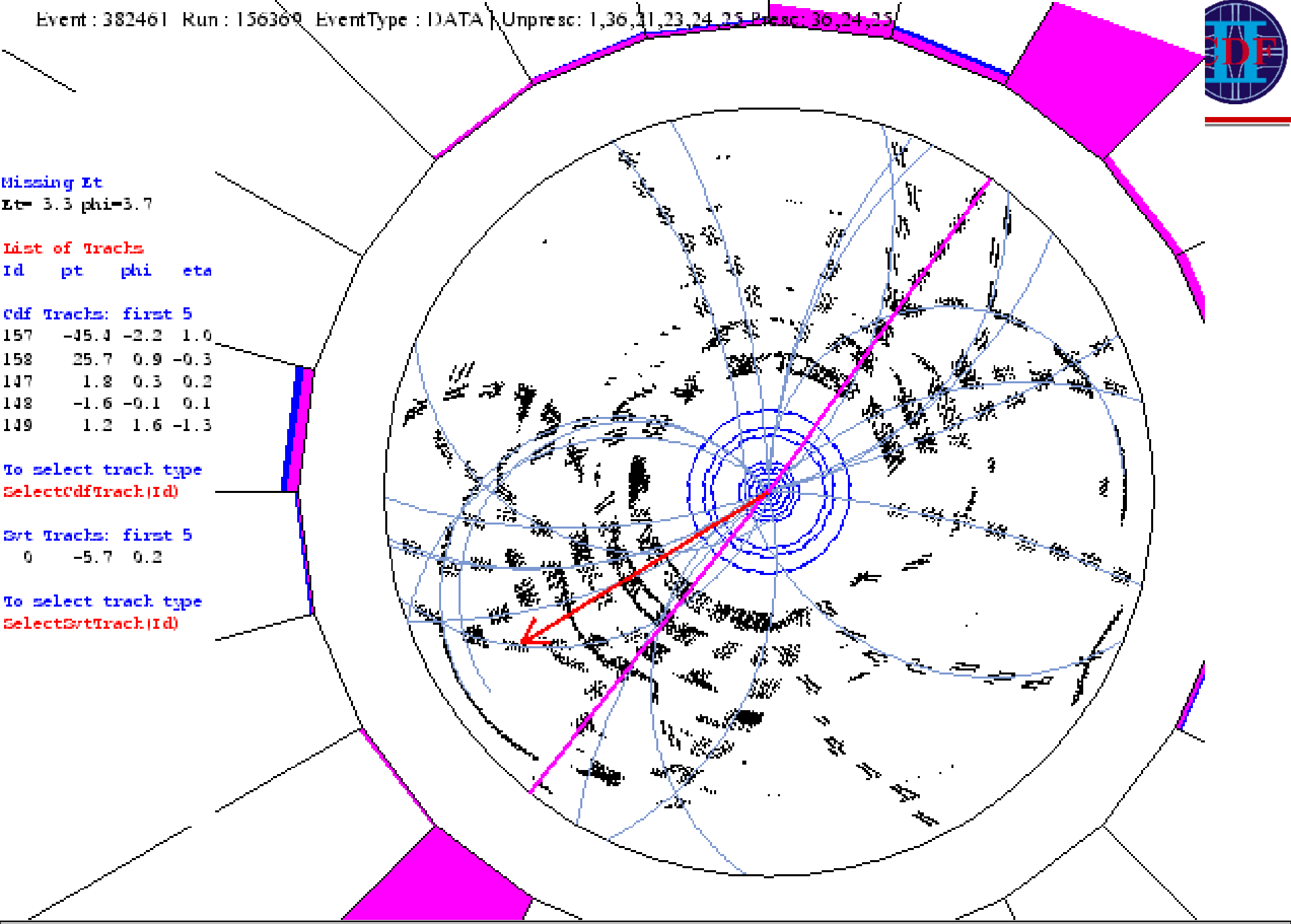


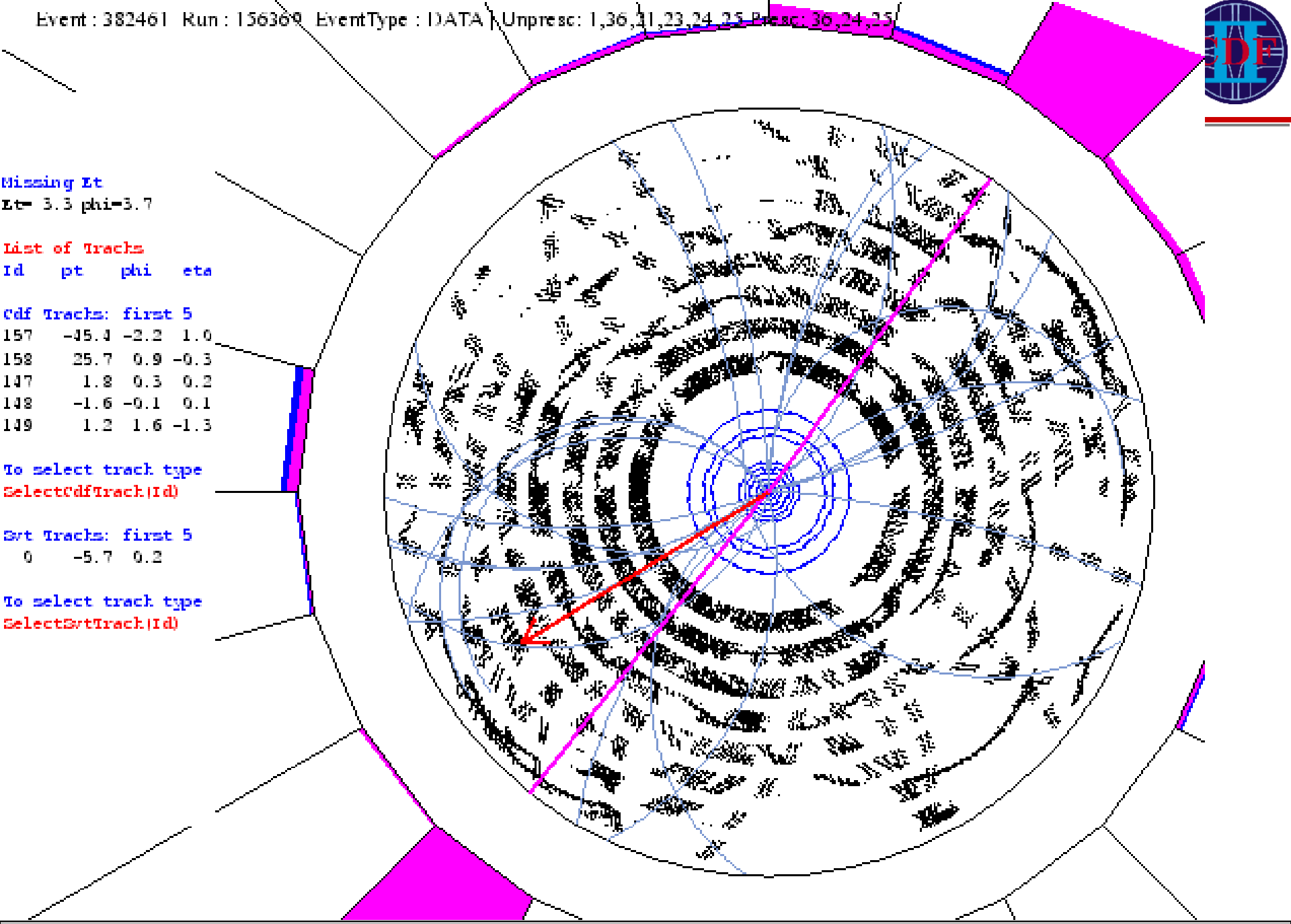
Why an Upgrade?

- The XFT was designed for a luminosity of:
  - $L=1x10^{32}cm^{-2}s^{-1}$ 396nsec bunch
    - ❑<int/crossing> ~ 3
  - $L=2x10^{32}cm^{-2}s^{-1}$ 132nsec bunch
    - ❑<int/crossing> ~ 2
- Accelerator Performance
  - Max luminosity attained: $1x10^{32}cm^{-2}s^{-1}$
  - Expect maximum of $L=3x10^{32}cm^{-2}s^{-1}$ at 396nsec bunch crossing
    - ❑<int/crossing> ~ 9
    - ❑Factor of 3-4 above design






Event : 382461 Run : 156369 EventType : DATA Unpresc: 1,36,31,23,24,25 Presc: 30,24,25
Missing Et
Et= 3.3 phi=3.7
List of Tracks
Id pt phi eta
Cdf Tracks: first 5
157 -45.4 -2.2 1.0
158 25.7 0.9 -0.3
147 1.8 0.3 0.2
148 -1.6 -0.1 0.1
149 1.2 1.6 -1.3
To select track type
SelectCdfTrack(Id)
Svt Tracks: first 5
0 -5.7 0.2
To select track type
SelectSvtTrack(Id)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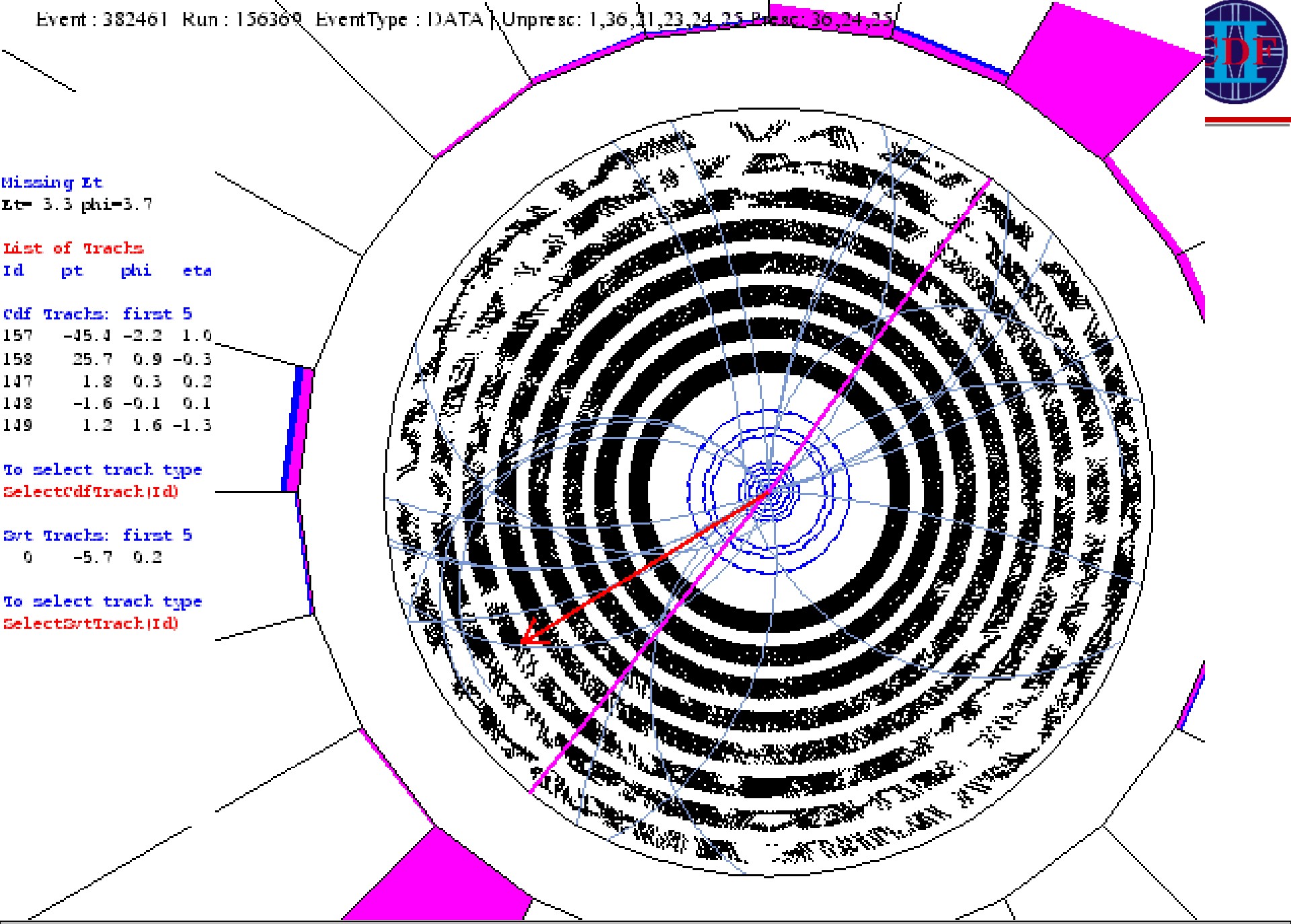
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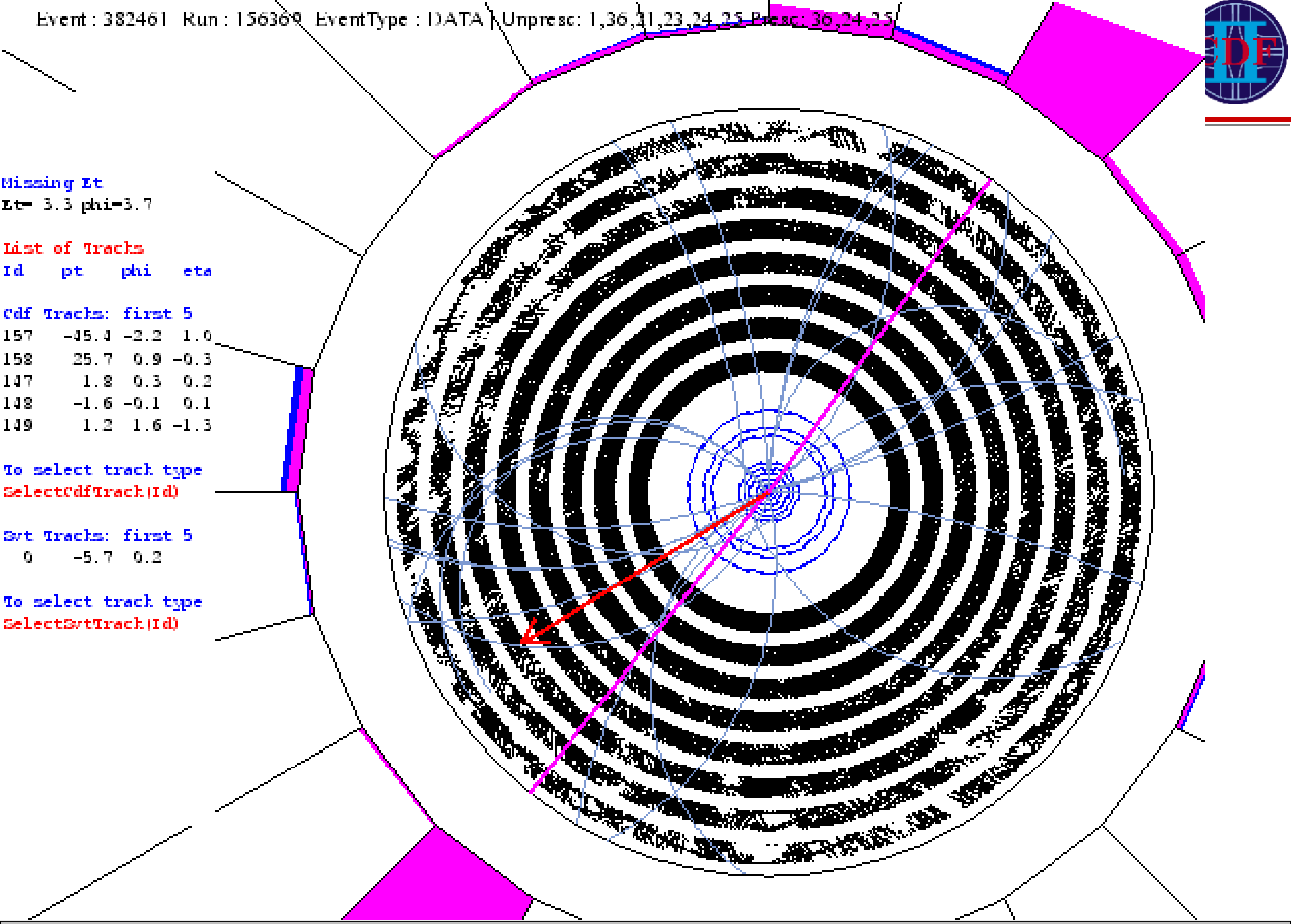
Event : 382461 Run : 156369 EventType : DATA Unpresc: 1,36,31,23,24,25 Presc: 30,24,25
Missing Et
Et= 3.3 phi=3.7
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To select track type
SelectCdfTrack(Id)
Svt Tracks: first 5
0 -5.7 0.2
To select track type
SelectSvtTrack(Id)

Luminosity Profile

- Approximate "design" projections for $\mathcal{L}_{peak}$
  - Spring 2005 Phase 2 8.5E31 (slip stacking)
    - *ACHIEVED SUMMER 2004!*
    - 1.1E32 as of July 16, 2004!
  - Fall 2005 Phase 3 1.25E32 (recycler/e^-cool)
  - Spring 2006 Phase 4 2.25E32 (stacktail)
  - Spring 2007 Phase 5 2.75E32 (run)
  - These are the numbers that get 8.5 fb^{-1}

- "base" projection for maximum $\mathcal{L}_{peak}$ is 1.57E32
  - This is the number that gets 4.4 fb^{-1}

Extrapolating to Higher $\mathcal{L}$

- Assume we can ultimately achieve accept rates of:

  L1A / L2A / L3A = 30kHz / 1kHz / 100Hz

- Trigger cross sections to fit within this budget:

$\mathcal{L}$(E32 cm^{-2}s^{-1})	σ_{L1} (μb)	σ_{L2}(μb)	σ_{L3}(nb)
1	300	10	1000
2	150	5	500
3	100	3.3	330
4	75	2.5	250

  - We currently run at 300μb / 6μb / 1250nb @6E31

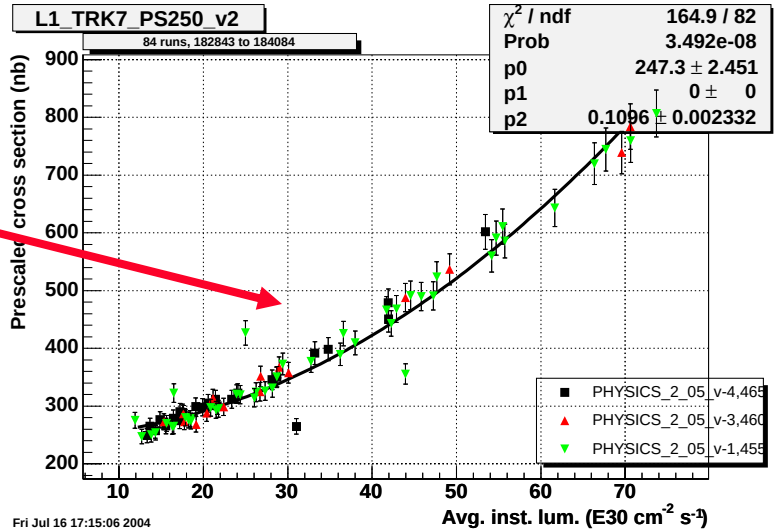
- Even with constant cross sections, we can't continue as we run now…let alone growth terms.
  - We need a factor of 3 reduction in trigger cross section
  - True "physics" cross sections are small: need to reduce Fakes!

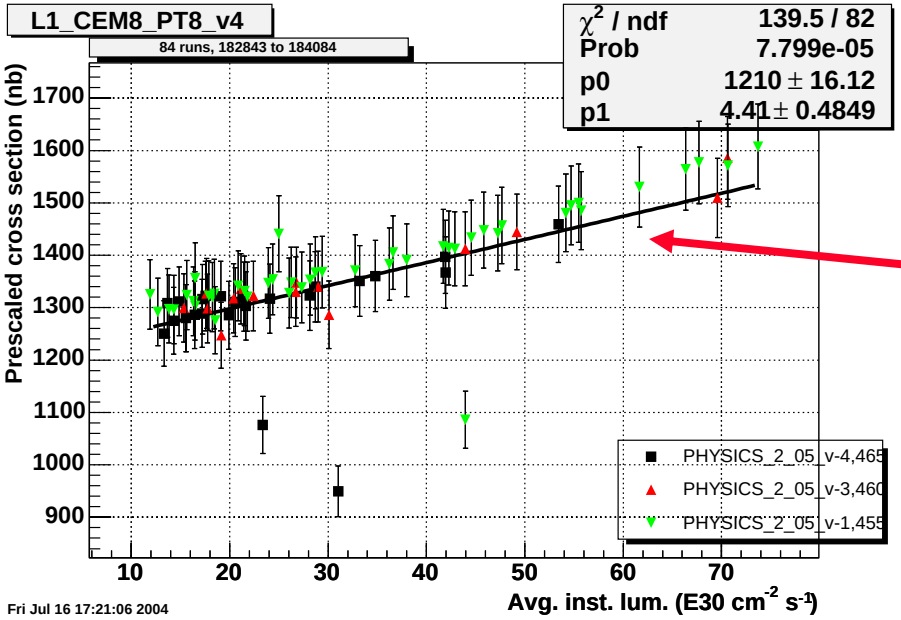
Sample XFT Triggers: Single Tracks and Leptons

7 GeV single track

- Quadratic growth?
- $\sigma(\mathcal{L}=5E31)/\sigma(\mathcal{L}=0)=2.6$

Rate is given by $R=\mathcal{L}\sigma$
Physics processes: σ is independent of $\mathcal{L}$.



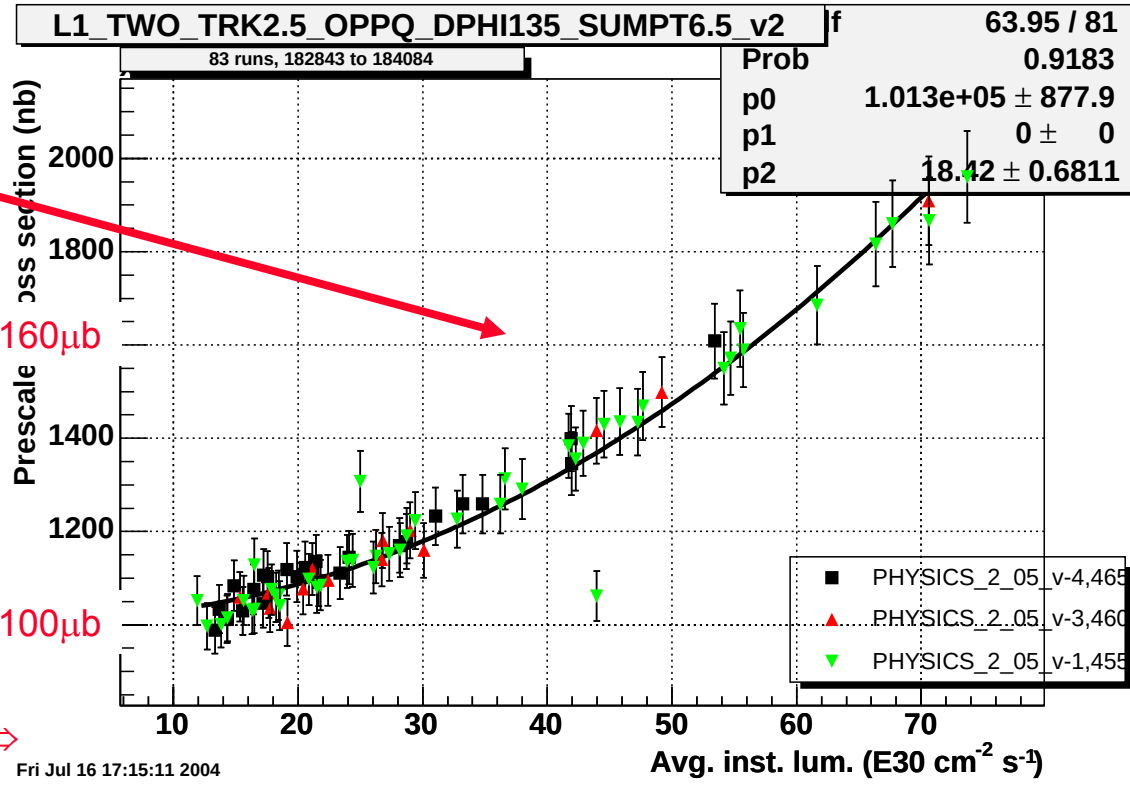


CEM8_PT8

- $\sigma(\mathcal{L}=5E31)/\sigma(\mathcal{L}=0)=1.1$
- Track cross section growing, but controlled by matching to EM cluster

Two-Track Triggers

- "Scenario C"
  - 2 tracks p_T>2.5 GeV
  - Opposite charge
  - $p_T(1)+ p_T(2)$>6.5 GeV
  - $\delta\phi$ < 135°



- Quadratic growth (overlaps + fakes)
  - $\sigma(\mathcal{L}=5E31)/\sigma(\mathcal{L}=0)=1.5$
- Extrapolate:
  - linear $\sigma(\mathcal{L}=1.5E32) = 225\mu b \Rightarrow$ 34kHz
  - Real (from overlapped MB) $\sigma(\mathcal{L}=1.5E32) = 500\mu b \Rightarrow$ 75kHz
- This is a higher purity B trigger…prefer to run scenario A (higher rate, higher yield) but cross section 3x larger.

Comments on Original Run 2b Trigger Table

- Track based triggers are a significant fraction at L1/L2/L3:
  - L1: ~40%
  - L2/L3: ~55%
- Trigger cross sections optimistic and/or unknown.
  - Linear extrapolations!
  - L2 high E_T electron projects to ~220nb (listed at 170nb)
  - 2 high p_T b-jet unknown(1 hi p_T b-jet extrapolates$\rightarrow$700nb)
- No track-only triggers included!
  - B_s mixing is physics unique to CDF. We now know it takes several fb^{-1} of data to observe mixing.
  - $B \rightarrow h^+h^-$ is physics unique to CDF.
  - $B_s \rightarrow \phi\phi$ is physics unique to CDF.
  - All of these analyses are statistics limited forever.
  - Are we really going to give up when $\mathcal{L}_{inst}$ reaches $1E32cm^{-2}s^{-1}$?
- We saturate the available bandwidth *now*. We will continue to do so for the duration of the CDF experiment. Since we will always accumulate data at the maximum possible rates, we have two handles:
  - Improve the system to allow higher rates.
  - Improve the purity (S/N) of the triggers.

XFT Requirements

- Physics goals
  - Maintain core high p_T program up to $\mathcal{L}$=3E32cm^{-2}s^{-1}
  - Maintain scenario C two-track trigger to $\mathcal{L}$=1.5E32cm^{-2}s^{-1}
    - This goal is a challenge for both L1 and L2.
    - This balances physics goals with realistic operating conditions.
    - It is unreasonable to attempt to keep the current physics table beyond 1E32 cm^{-2}s^{-1}
      - parts of the program will be modified or removed.
- XFT requirements
  - Maintain good efficiency (>90%) for high pT tracks.
  - Improve purity to reduce growth terms
  - Maintain (or improve) p_T and ϕ_0 resolution
  - Need a factor of ~3 reduction in extrapolated cross section

How Should We Upgrade the XFT?

- In Run IIb TDR, we advocated:
  - Full replacement of entire track trigger: Hit Finder, Segment Finder, Track Finder
    - More precise timing to obtain better segments ("6 bin")
    - More segment info used to obtain better tracks
  - Addition of Finders for a Single Stereo Layer
    - Used as a veto at Level 1
  - Very aggressive schedule
  - Requires downtime while we bring the new system up

"Baseline"

- An alternate strategy
  - Keep current axial system as is
  - Add Finders on 3 outer Stereo Layers
    - More precise timing to obtain better segments ("6 bin")
    - Used as a Veto at Level 1
    - Used in extrapolation and matching for leptons at Level 2
  - No downtime required: axial system is not modified
    - System will be commissioned in parallel

"Rescope"

"Rescoping" The XFT Upgrade

- Luminosity extrapolations uncertain for RunIIb TDR
  - Only had data up to $L=0.3\times10^{32}cm^{-2}s^{-1}$
- Software Model of COT Uncertain
  - Used Monte Carlo "mixing" of events
- Observed performance degradation of the COT
  - Concern that baseline was not good enough with compromised COT
  - Needed to develop tools to study this
- Manpower limited
  - Same personnel maintaining current XFT, XTRP, Track Triggers (Hughes, Pitts, Winer)
- Present situation
  - Now have luminosity up to ~$1.0\times10^{32}cm^{-2}s^{-1}$
  - Can now mix COT data events to simulate higher luminosity much more accurately
  - Performance of COT has recovered (and is expected to stay that way!)
- Added personnel
  - 4 post-docs (hired in the past year)
  - 3 engineers (freed from LHC responsibilities)
  - 3 new institutions
  - Went from 3 people to 19 in < 1 year

XFT Simulation and High Luminosity

- All events are passed through a hit-level simulation
  - Start with COT hits
  - Gives ***exactly*** the same answer as hardware when run with same masks, roads and XFT hits
  - Outputs XFT hits, pixels, and tracks for axial and XFT pixels for stereo
  - Association of stereo pixels to axial tracks done after simulation

- Simulate High luminosity by Merging events
  - Mix "main" event with zero bias
  - Merge COT hits (combine overlapping hits)
  - Add track collections from individual events together
  - Don't re-run tracking → avoids problems with offline tracking at high luminosities
    - Offline tracks serve as "truth" for the event
  - This method allows us to probe up to 4E32

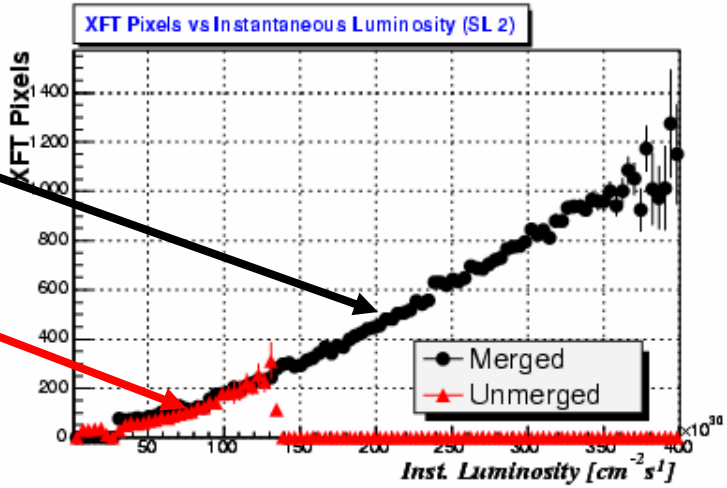
- Test Merging by comparing merged events with real data events

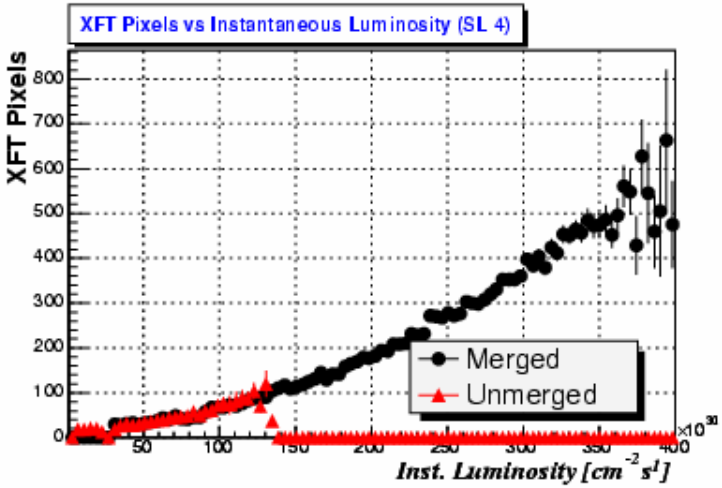
Validation Using Recent Data (XFT Pixels)

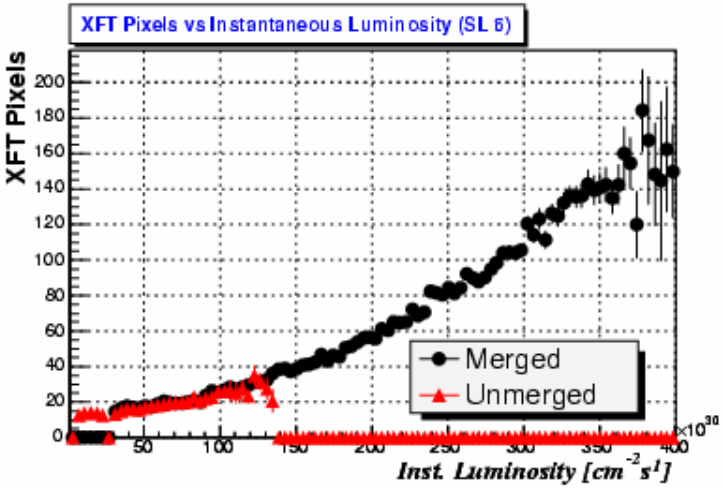
- Average number of XFT pixels (segments) versus luminosity
  - Less sensitive to issues of dead wires masked on, etc.

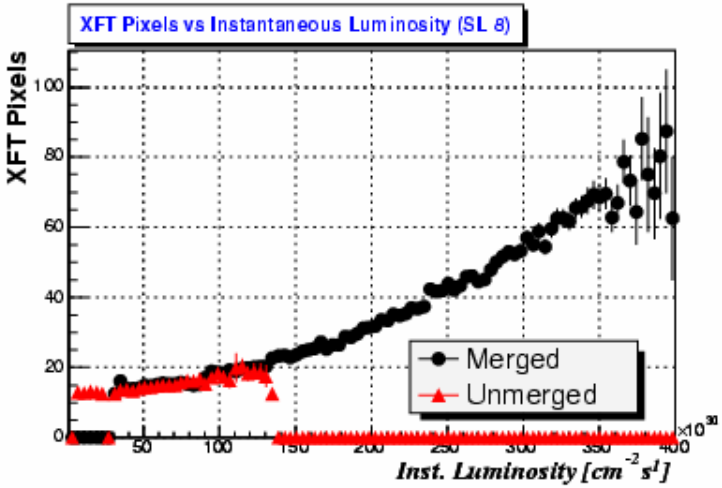
Simulation

Data



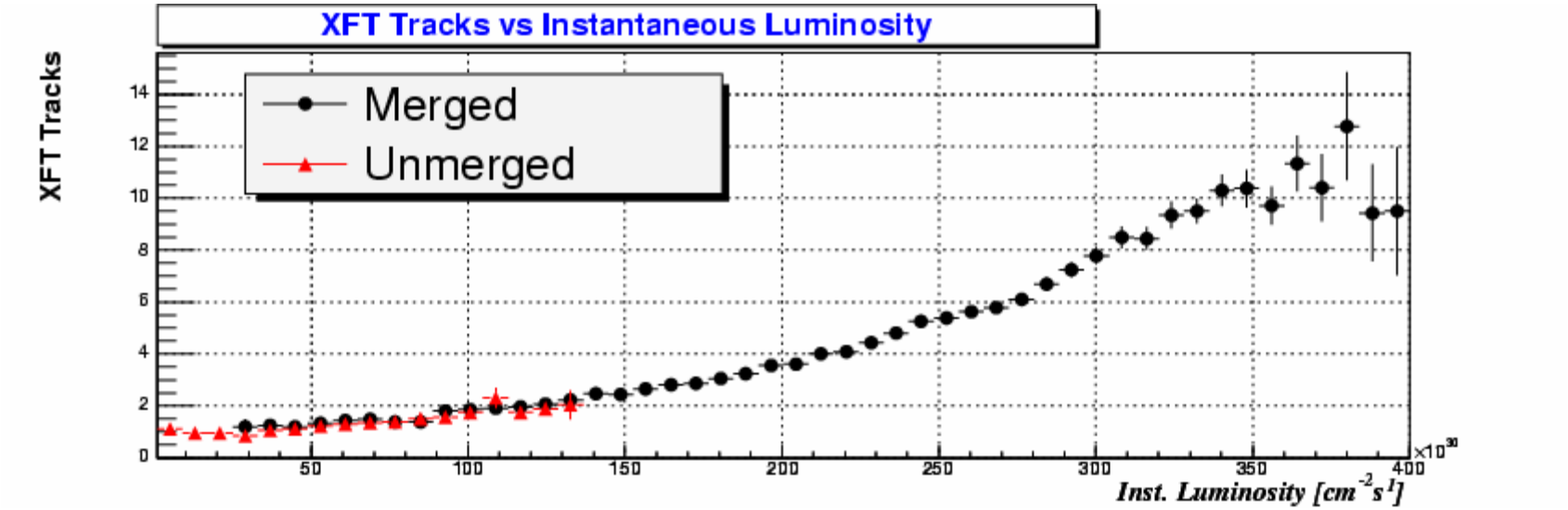






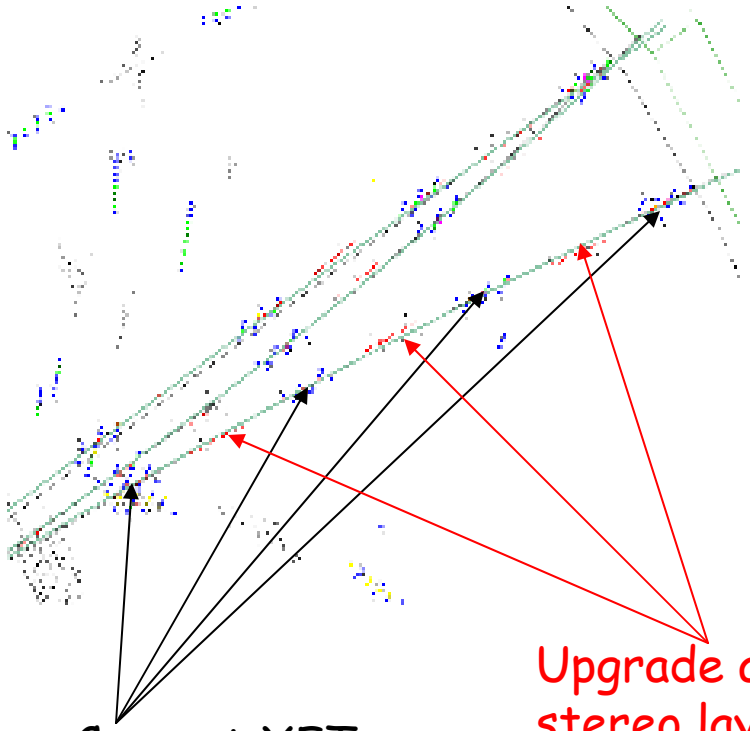
Validation Using Recent Data (Tracks)

- Average number of XFT versus luminosity



- Event merging is an excellent tool for predicting high luminosity performance
  - Outstanding agreement between merged data and actual data
  - This tool was not available at the time of the Run IIb TDR

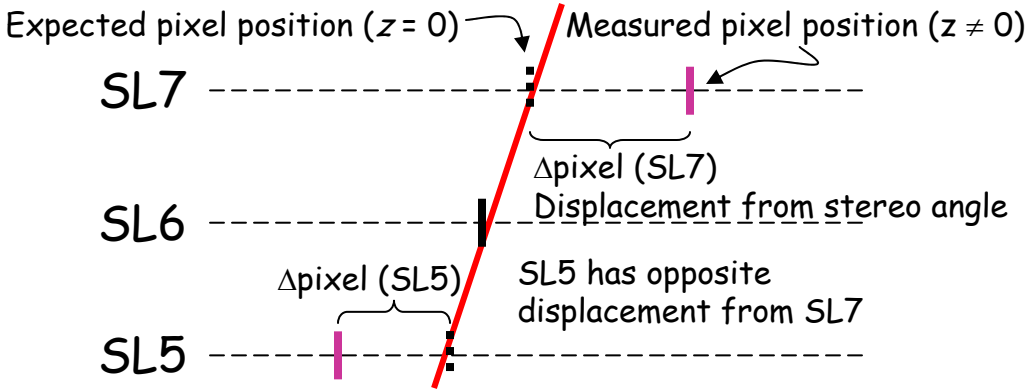
Stereo Simulation Implementation

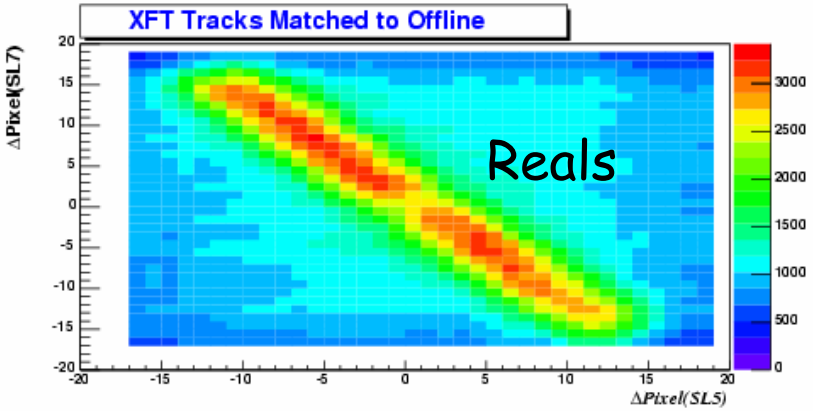


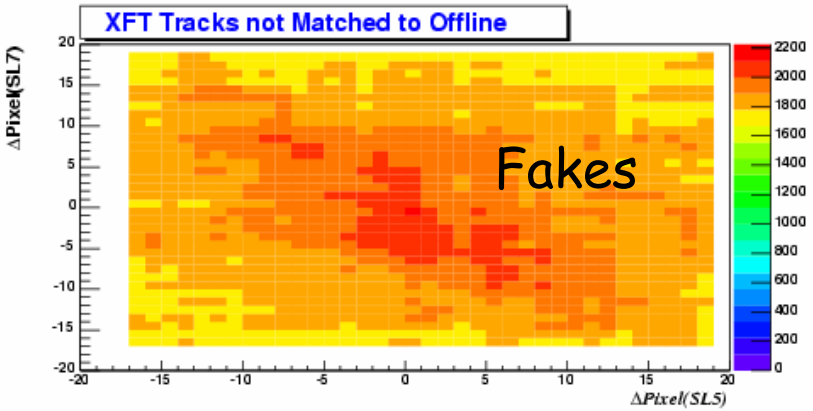
Current XFT uses 4 axial layers only

Upgrade adds 3 stereo layers (~doubling info)

Stereo algorithm exploits correlation expected for real tracks



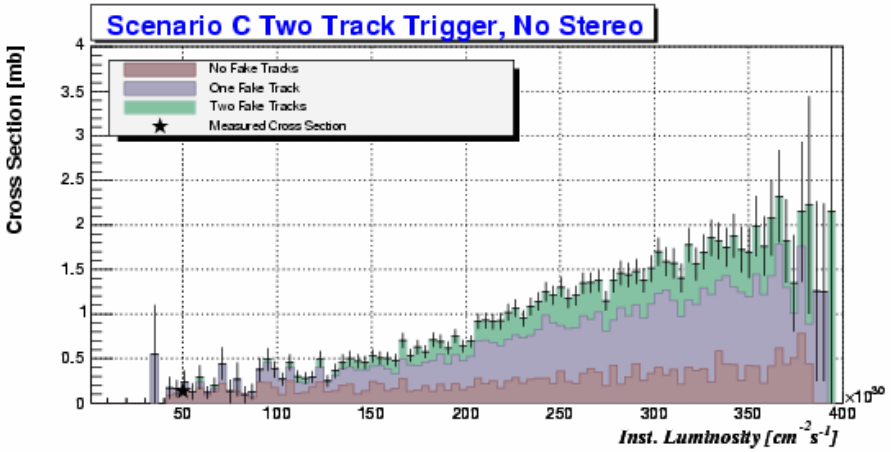


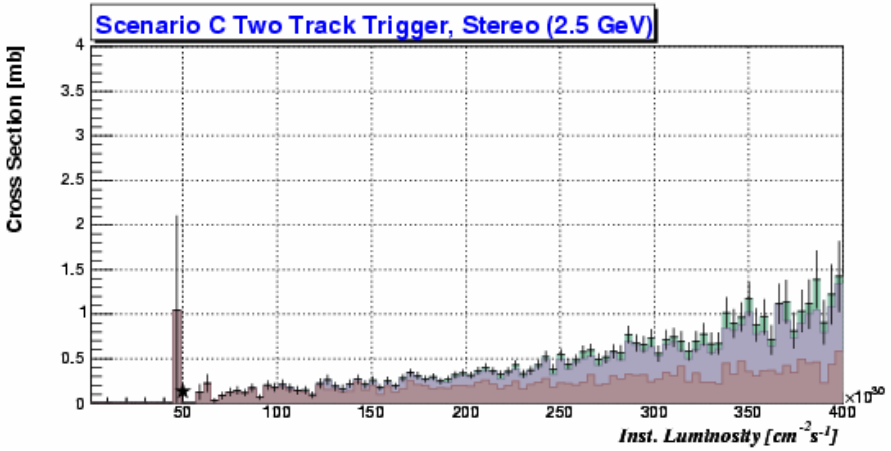


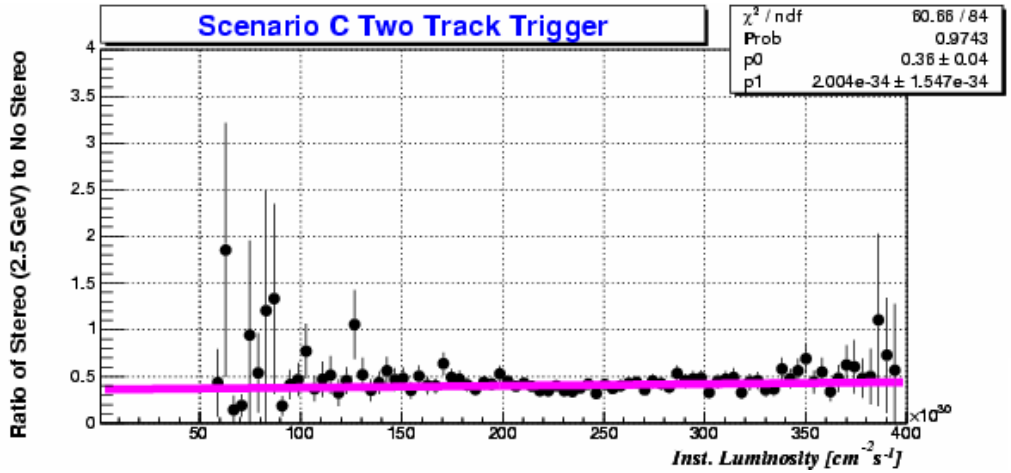
Impact of the Upgrade on a Specific Trigger

- Scenario C Two-Track Trigger

Inst.Luminosity [1E32 $cm^{-2}s^{-1}$]	0.5	1.0	2.0	3.0
2-Bin σ [mb]	0.12	0.28	0.78	1.5
Stereo σ [mb]	0.08	0.13	0.33	0.65
Ratio	0.37	0.38	0.40	0.42



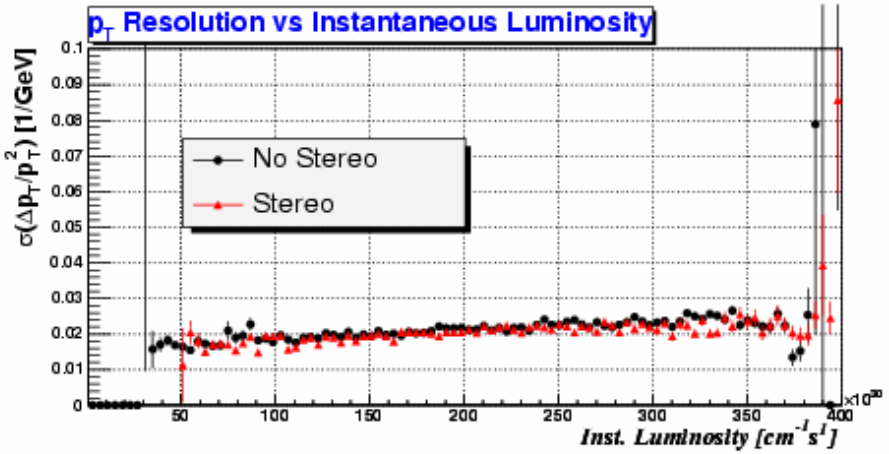




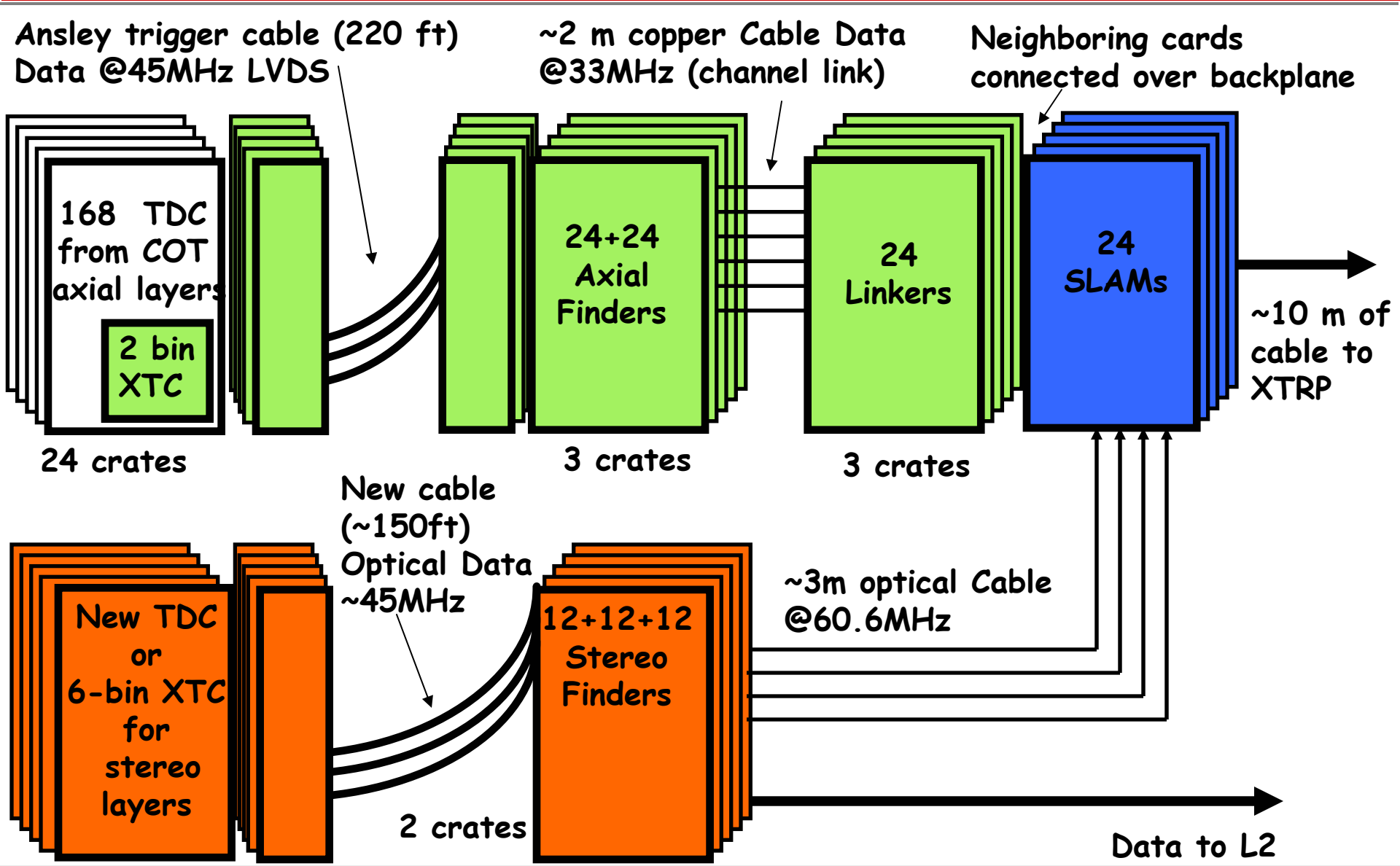
Evaluating The Rescoped Upgrade

Upgrade Option (3E32 $cm^{-2}s^{-1}$)	Single Track (7 GeV)	Scenario C Two-Track
2-Bin (1.5 GeV) (Current System)	1.8 mb	1.5 mb
6-Bin (2.0 GeV) (Baseline Upgrade)	0.40 mb (80% decrease)	0.49 mb (70% decrease)
2-Bin + Stereo (2.5 GeV) (Rescoped Upgrade)	**0.63 mb (65% decrease)**	**0.65 mb (60% decrease)**

Resolutions versus Instantaneous Luminosity



XFT Upgrade Configuration

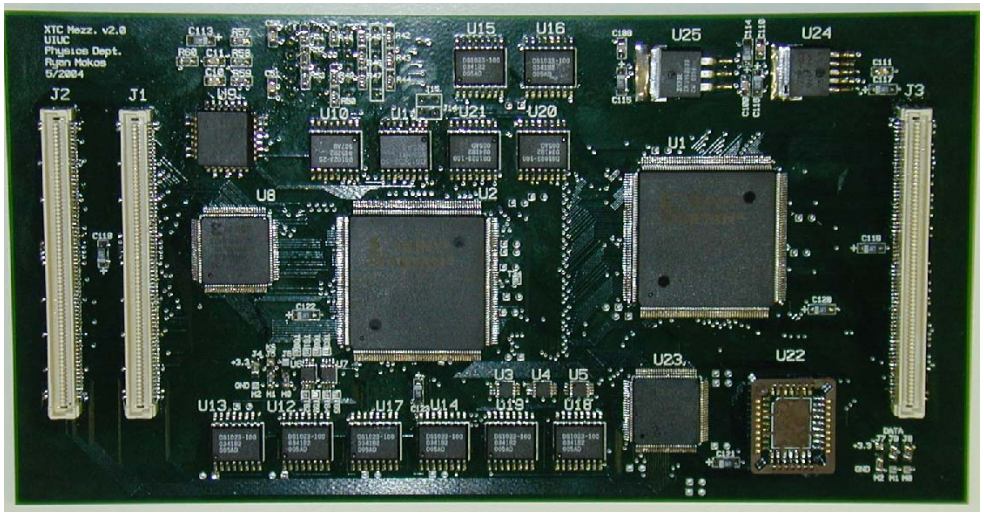


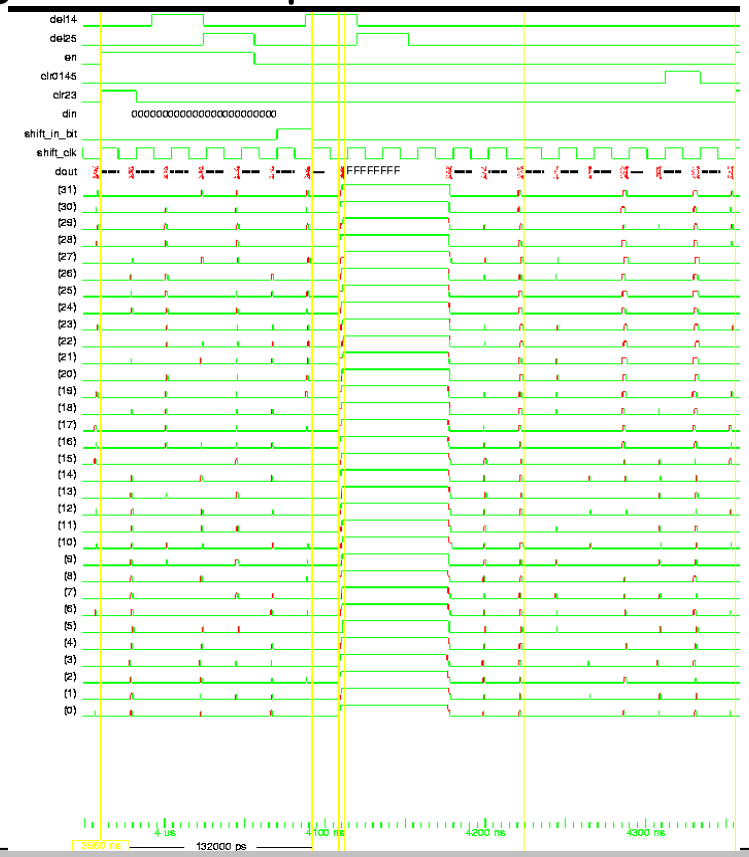
Main Components of the Upgrade

- New Hit Finders for Stereo Layers
  - Functionality provided by new (Chicago) TDC *or*
  - New XTC card to be used on current (Michigan) TDCs
  - Important change: go from 2 bins (prompt/delayed) to 6 bins
- New Stereo Finder Boards
  - Require new transmission method of data from TDC to St. Finders
  - Require new Finder chips
- Method to Use Stereo Information at Level 1
  - New Boards: Stereo Linker Association Module (SLAM)
  - SLAMs replace the current Linker Output Modules (LOMs)
    - Only place where there is an impact on the current device
    - Boards will be installed ONLY after pass-through design (LOM-mode) works
- Method to Use Stereo Information at Level 2
  - Use Existing Pulsar System: no new electronics needed
  - Firmware development required to implement algorithm used in simulation studies

Stereo TDC Mezzanine Board

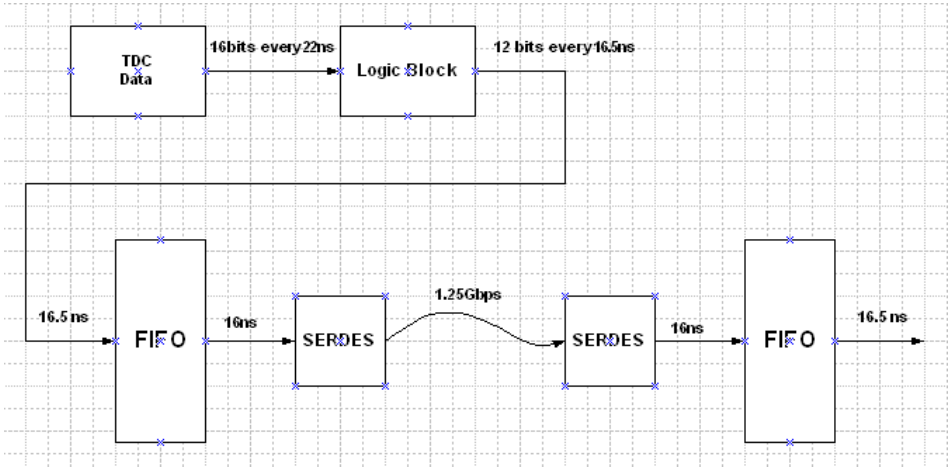
- Illinois developing 6 time-bin TDC mezzanine board.
  - Prototypes assembled.
  - Have configured FPGAs and CPLDs via JTAG
  - Urbana test stand operational, working on data capture tests

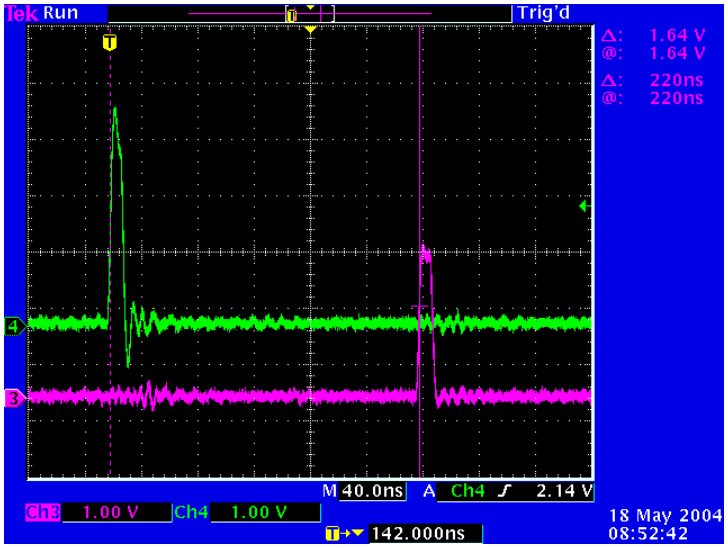


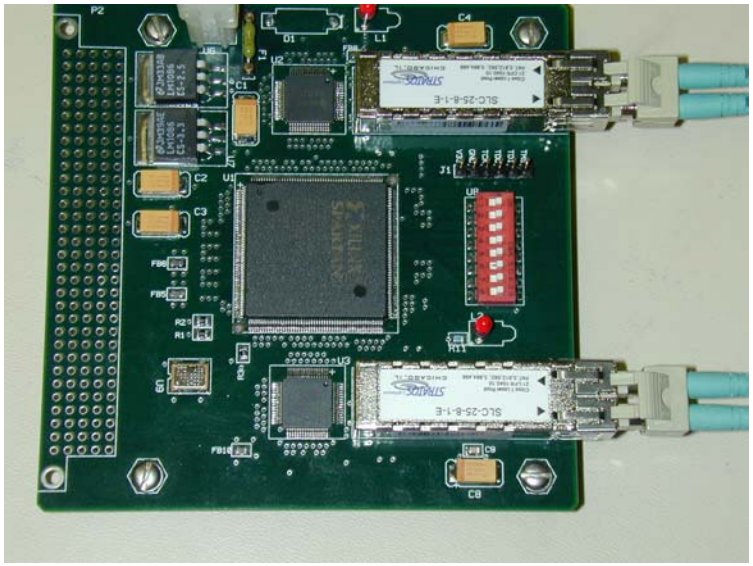


Data Flow: TDC to Finder Boards

- Built a fiber test board to evaluate fiber optics for the XFT upgrade.
- Have performed successful send/receive loop tests
- taking significant advantage of fiber optic R&D done for CMS by the Fermilab group



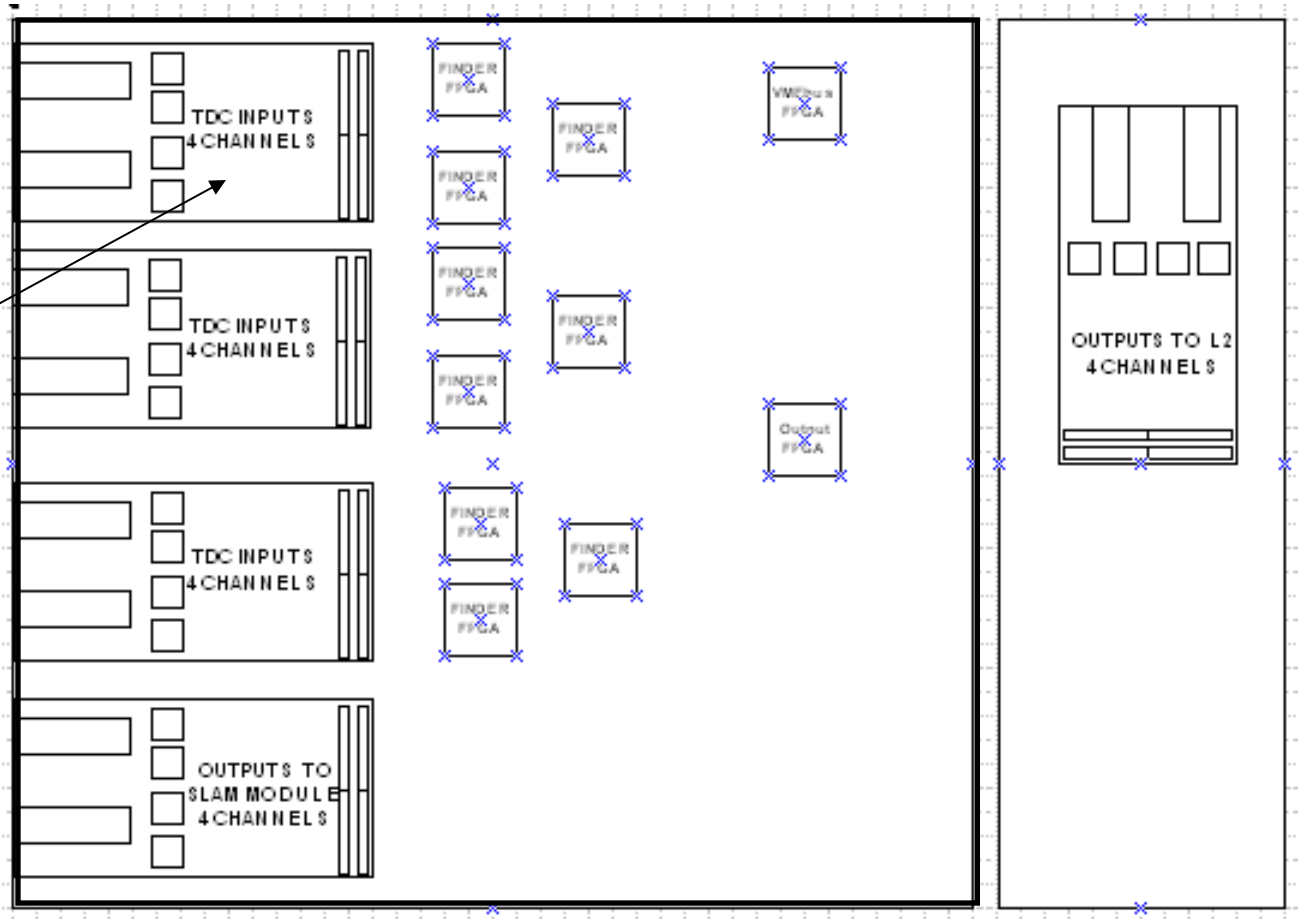




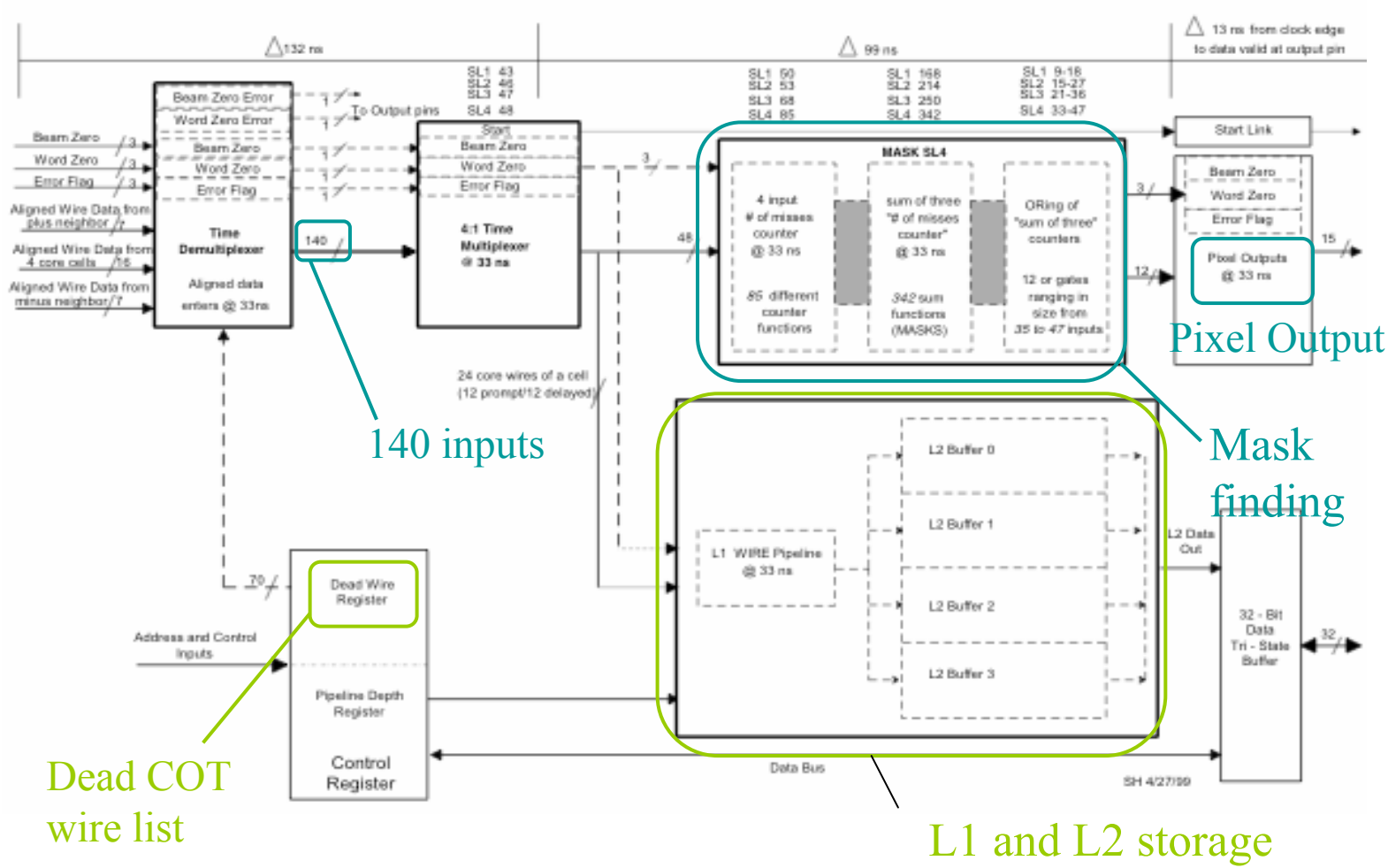
Stereo Finder Board Layout

Stereo Finder board schematic started

Schematic of mezzanine card done; layout started



The Axial Finder Chip



Axial Finder: implemented using Altera FLEX 10K70 chip.
Stereo Finder: targeting Altera Stratix EP1S25 chip

6 Bin Finder Chip Firmware Progress

Currrently have written and compiled onto simulated Stratix chips the mask finding firmware for all 9 of the 6-bin Finder chip designs (3 misses * 3 Stereo SLs)

- Can compare compilation analysis of this design and 2-bin design on various chips

2-Bin, Flex 10K, complete design

- 130 / 189 pins (68%)
- 6,912 / 36,864 memory bits (18%)
- 3,347 / 3,744 Logic Elements (89%)
- Actual time : 23 MHz (43.00 ns)

2-Bin, Flex 10K, Just mask finding

- 72 / 189 pins (38%)
- 0 / 36,864 memory bits (0%)
- 2,041 / 3,744 Logic Elements (55%)
- Actual time: 45 MHz (22.4 ns)

6-Bin, Stratix 1S25, just mask finding

- 151 / 707 pins (21%)
- 0 / 1,944,576 memory bits (0%)
- 13,002 / 25,660 Logic Elements (50%)
- Actual time : 150 MHz (6.6 ns)

Expect remaining infrastructure in chip to increase total LE's to ~19,000, well under the 25,660 LE's available

How does design scale to 6 Bins?

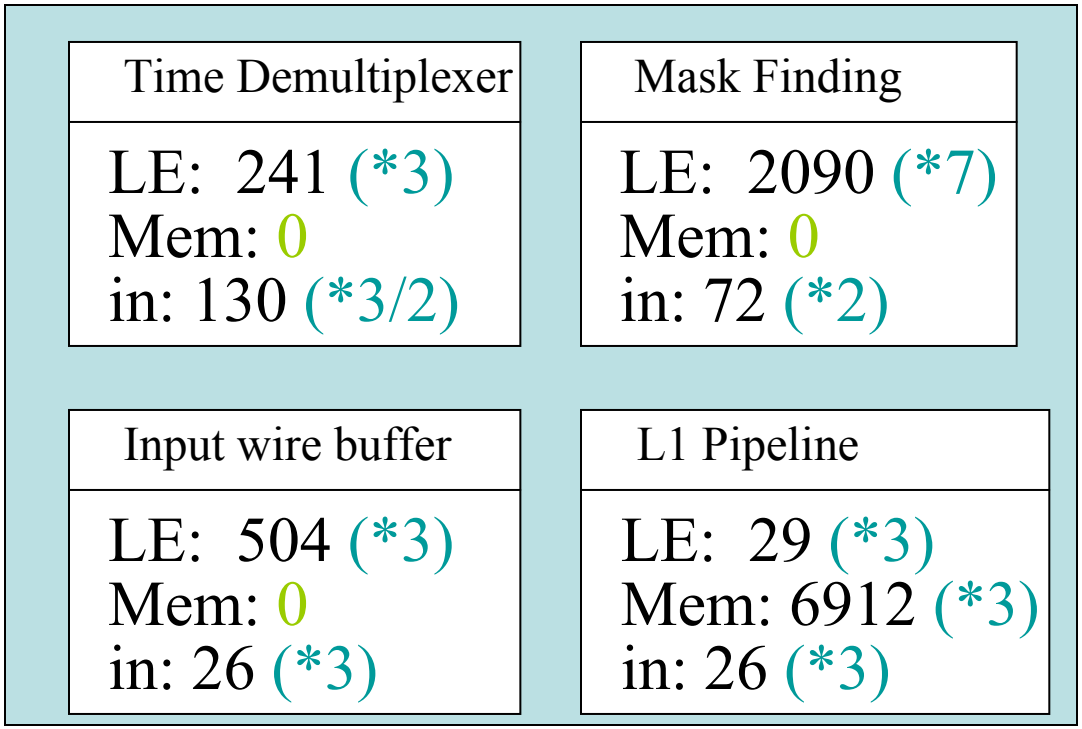
Simplification of finder chip schematic showing resource use of major components

- Expected increases shown when going to 6 Time bins

LE : logic elements
Mem: memory
In: inputs to block

Scales up

Stays same

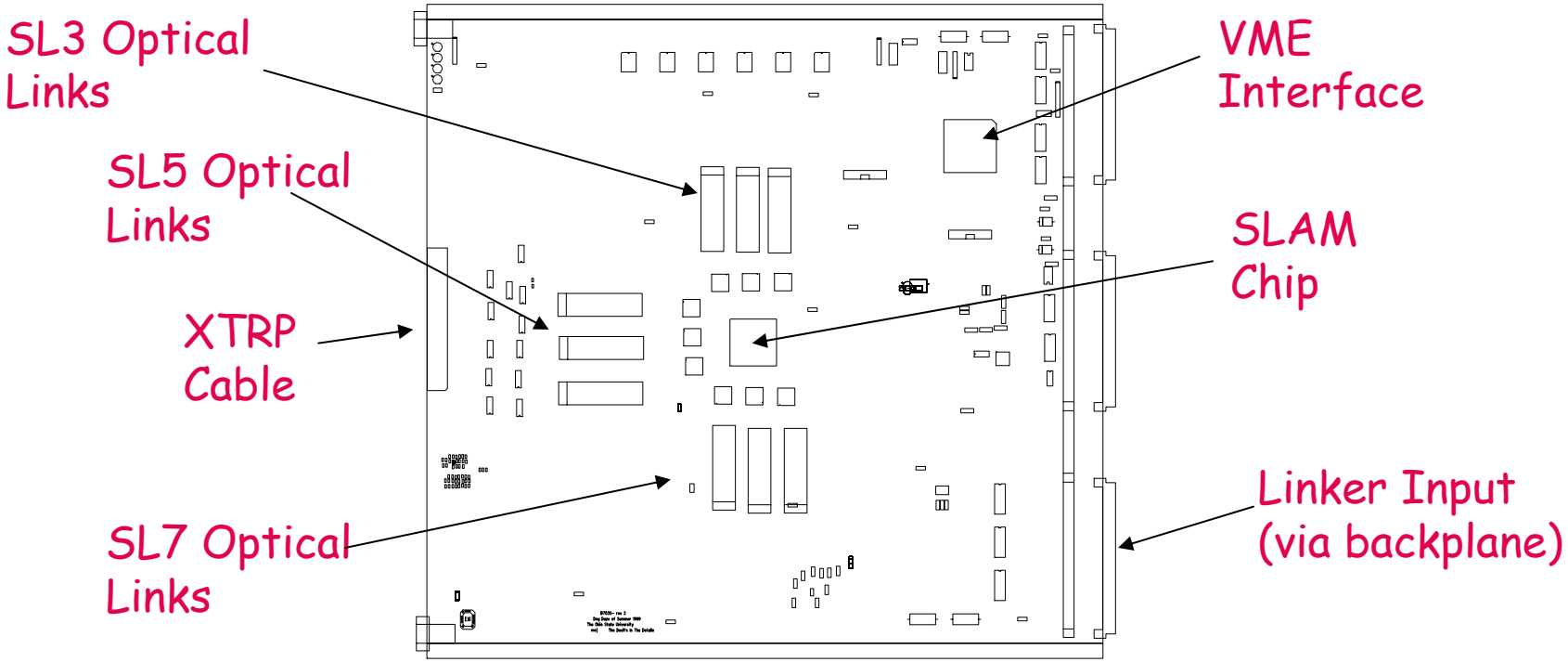


Total LEs : 2-bin : 3,000
6-bin : 19,000

Conservatively on high side, …

Stereo at Level 1: SLAM Board

- SLAM Board replace Linker Output Module
  - Transmits Track list in each 15° ϕ-slice to extrapolation electronics
  - Receives stereo Finder segments and associates with axial tracks
    - Schematic done; layout begun



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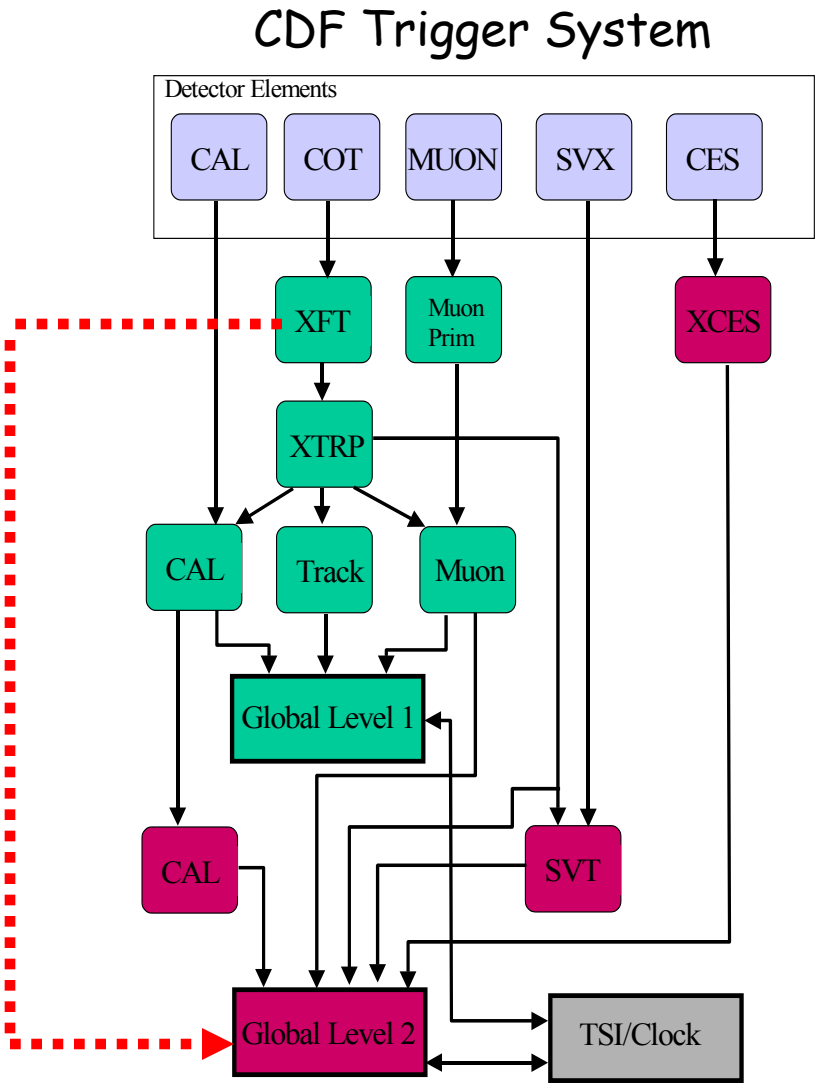
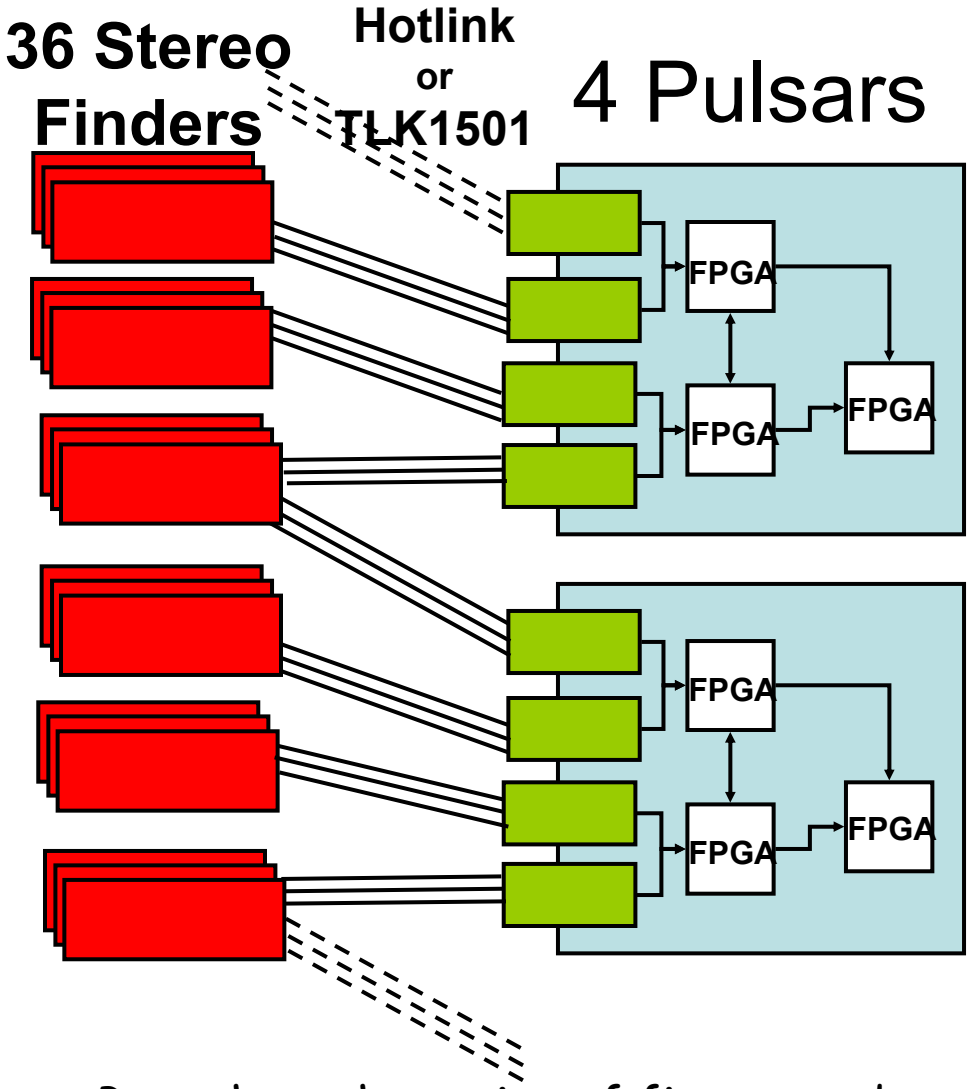
Using Stereo at Level 2

- 6-bin improvement over 2-bin mask resolutions
  - σ(curv): ~3-3.5x better
  - $\sigma(\phi)$: 2.5x better
  - Rejection→only improve
  - L2 has time to send more info
- 3-D track variables:
  - z_0, M_{tt}, η
- SVT: Barrel-track match
- Extrapolation for lepton triggers
- Implementation
  - Use existing hardware (PULSAR)
  - Requires development of firmware for stereo algorithm

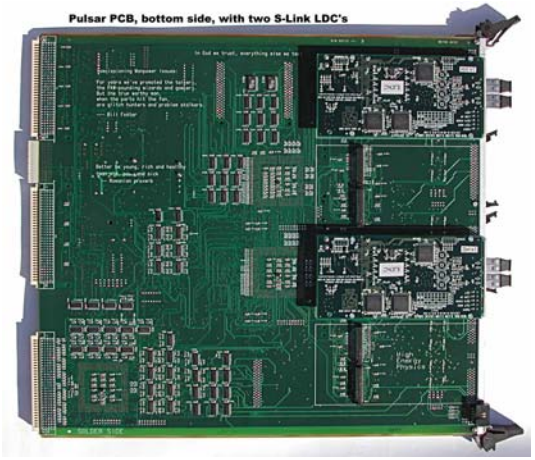


½ of L2 system



Pass through version of firmware done.

- 4 pulsars
  - 3 Finders + 1 for neighbor pixels
  - 90°+30° /pulsar
  - 45°+15° / FPGA



- Pulsars already have complete XFT axial tracklist and L1 trigger bits built in
- 1 additional Pulsar
  - Concatenation
  - Send to L2 processor

Schedule (Broad View-I)

- **Stereo Finder Card**: (FNAL) Boards: 36 + spares
  - Preproduction Design—Assembly : **6/04 – 12/04**
  - Preproduction Testing: **12/04 – 3/05**
  - Production (Checkout) : **1/05 – 7/05** (10 Wks)
- **TDC Trans Card**: (Ill) Boards: 126 + spares
  - Preproduction Design – Assembly: **6/04 – 11/04**
  - Preproduction Testing: **11/04 – 2/05**
  - Production (Checkout): **2/5 – 6/05** (10 wks)
- **SLAM Board** (OSU) Boards: 24 + spares
  - Preproduction Design – Assembly: **7/04 – 11/04**
  - Preproduction Testing: **11/04 – 2/05**
  - Production (Checkout): **2/05 – 7/05** (8 Wks)

Joint Tests: 12/05 – 1/05

Joint Tests: 12/05 – 1/05

Schedule (Broad View-II)

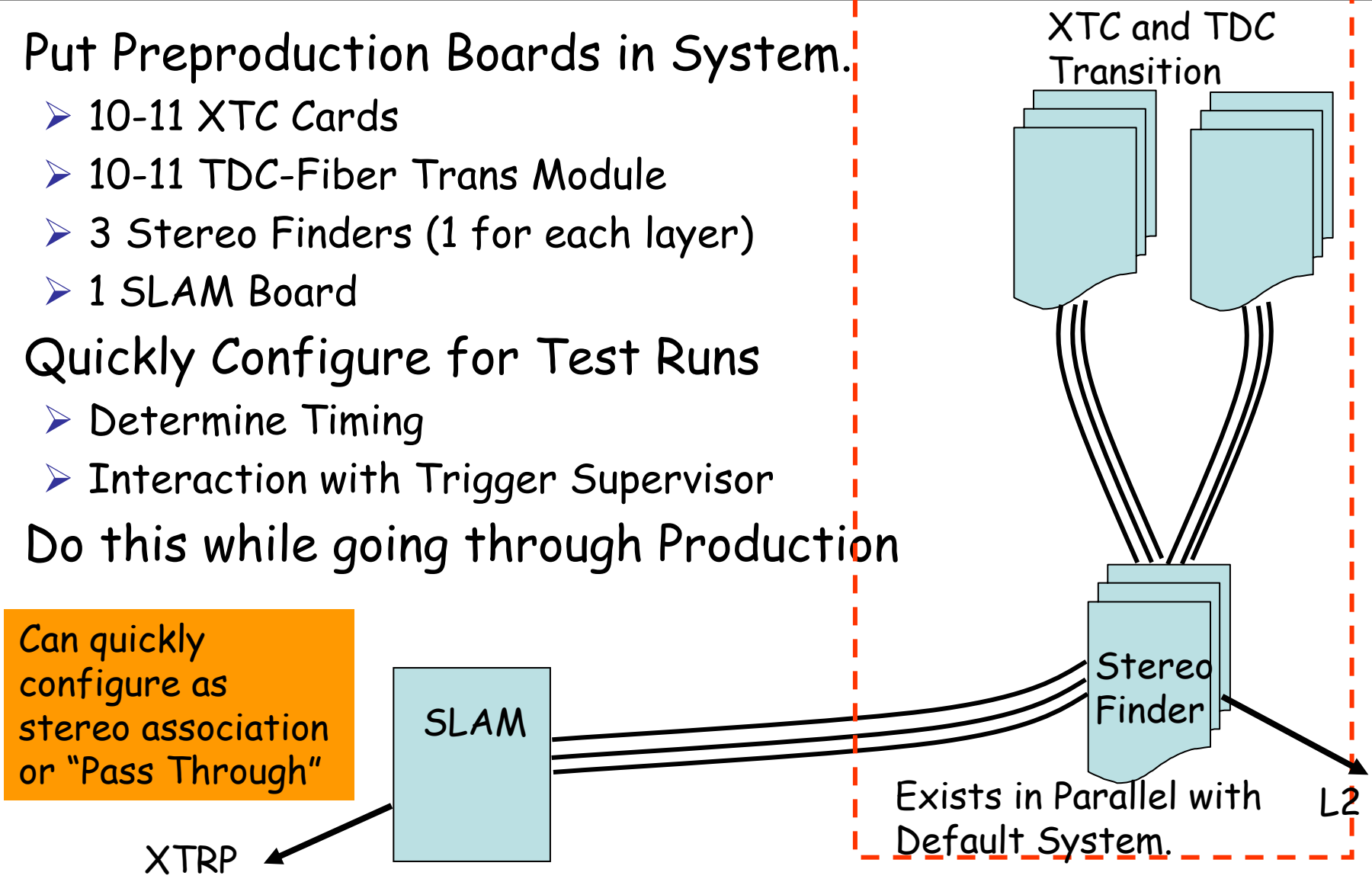
- **Stereo XTC Card**: (Ill) Boards: 126 + spares
  - Preproduction Design—Assembly : **Done**
  - Preproduction Testing: **6/04 – 8/04**
  - Production (Checkout) : **9/04 – 3/05** (10 Wks)
- **L2 Stereo Interface**: (Ill/FNAL)
  - Fabrication/Assembly: **7/04 – 11/04**
  - Testing: **12/05 – 2/05**
- **TDC to Finder Fibers** (FNAL/CDF) Fibers: 324
  - Purchase: **7/04 – 9/04**
  - Installation: **9/04 – 10/04**
- **Other Fibers:**
  - Finder to SLAM (216 Fibers) and Finder to Level 2 (36 Fibers)
  - Spec & Purchase: **9/04 – 11/04**

Joint Tests with Stereo Finder Boards:

1/05 – 2/05

Early Commissioning: 1/05

- Put Preproduction Boards in System.
  - 10-11 XTC Cards
  - 10-11 TDC-Fiber Trans Module
  - 3 Stereo Finders (1 for each layer)
  - 1 SLAM Board
- Quickly Configure for Test Runs
  - Determine Timing
  - Interaction with Trigger Supervisor
- Do this while going through Production



XFTIIb Tasks

- Baylor University: Dittman, Krumnack
  - Fiber specification
  - New XTC, testing, commissoining
- FNAL: Holm, Shaw
  - Stereo Finder board, Finder chip
- University of Illinois: Budd, Junk, Kasten, Levine, Mokos, Pitts, Rogers, Veramendi
  - New XTC, COT transition card, L2 Stereo
  - Simulation, testing software
- Ohio State University: Hughes, Johnson, Kilminster ,Lannon, Parks, Winer
  - SLAM board, Finder Chip
  - Simulation, commissioning
- Purdue University: Jones
  - Finder testing, checkout, commissioning

XFT Upgrade Cost Breakdown

System	Cost (FY04)
XTC	$97K
TDC Trans	$162K
Stereo Finder	$624K
SLAM	$175K
Cables	$45K
Test Equipment	$24K
Total	$1194K

NOTE: Costs do not include overhead or contributed university engineering

Conclusions

- Accelerator performance has been excellent
  - Records seemingly weekly….great!
  - But…high luminosity at 396nsec bunch spacing leads to many interactions/crossing
  - We need to upgrade the XFT to take advantage of the great oppurtunity
- The RunIIb XFT Upgrade **will meet the needs** of high luminosity running
  - This upgrade gives us the required factor of 3 rejection of fakes
  - System can be installed and commissioned with no impact on the current XFT
  - Not all capabilities have been explored
    - Current studies only used 2 of 3 stereo layers (SL5,7 explored, SL3 in progress)
    - Expect another factor of ~2 by using stereo extrapolation in Level 2
    - Mass triggers are also possible at Level 1/2