DØ RunIIb Trigger Upgrade

WBS 1.2

Darien Wood, Northeastern Univ.
for the DØ Trigger Upgrade Group

Outline

- Trigger Strategies for Run IIb
- Upgrade Design
  - Level 1
    - 1.2.1 Calorimeter trigger
    - 1.2.2: Cal-track matching
    - 1.2.3: Track trigger
  - Level 2
    - 1.2.5: Silicon Track Trigger upgrade
    - 1.2.4: L2 Beta processors
- Simulation & rates
- Project Organization
- Cost and Schedule

WBS 1.2: Trigger Upgrade
H. Evans (Columbia), D. Wood (Northeastern)

WBS 1.2.1: Level 1 Calorimeter
M.Abolins(MSU), H.Evans(Columbia), P.LeDu (Saclay)

WBS 1.2.2: Level 1 Cal-track match
K. Johns (Arizona)

WBS 1.2.3: Level 1 Tracking
M. Narain (Boston)

WBS 1.2.4: Level 2 Beta upgrade
R. Hirosky (Virginia)

WBS 1.2.5: Level 2 STT upgrade
U. Heintz (Boston)

WBS 1.2.6: Trigger Simulation
M. Hildreth (ND), E. Perez (Saclay)

Run IIb Trigger Priorities

- Main physics driver for Run IIb: Higgs search
  - Need efficient triggers for Higgs production/decay in all major modes
  - Trigger objects:
    - Leptons
    - b-jets
    - taus
    - Missing E_T
- SUSY
  - Trigger objects
    - Leptons
    - Missing E_T
    - taus
- Top, W, Z
  - Trigger objects:
    - Leptons
    - Jets
    - Missing E_T
  - precision mass measurement to understand EWSB
  - Also important for background & calibration for Higgs search
- Background/calibration channels
  - $Z \rightarrow b\bar{b}$, reduce top syst error x2
- Some trigger load can be relieved by elimination of low-pt physics menu (lower energy QCD, b-physics, …), but this is not sufficient.

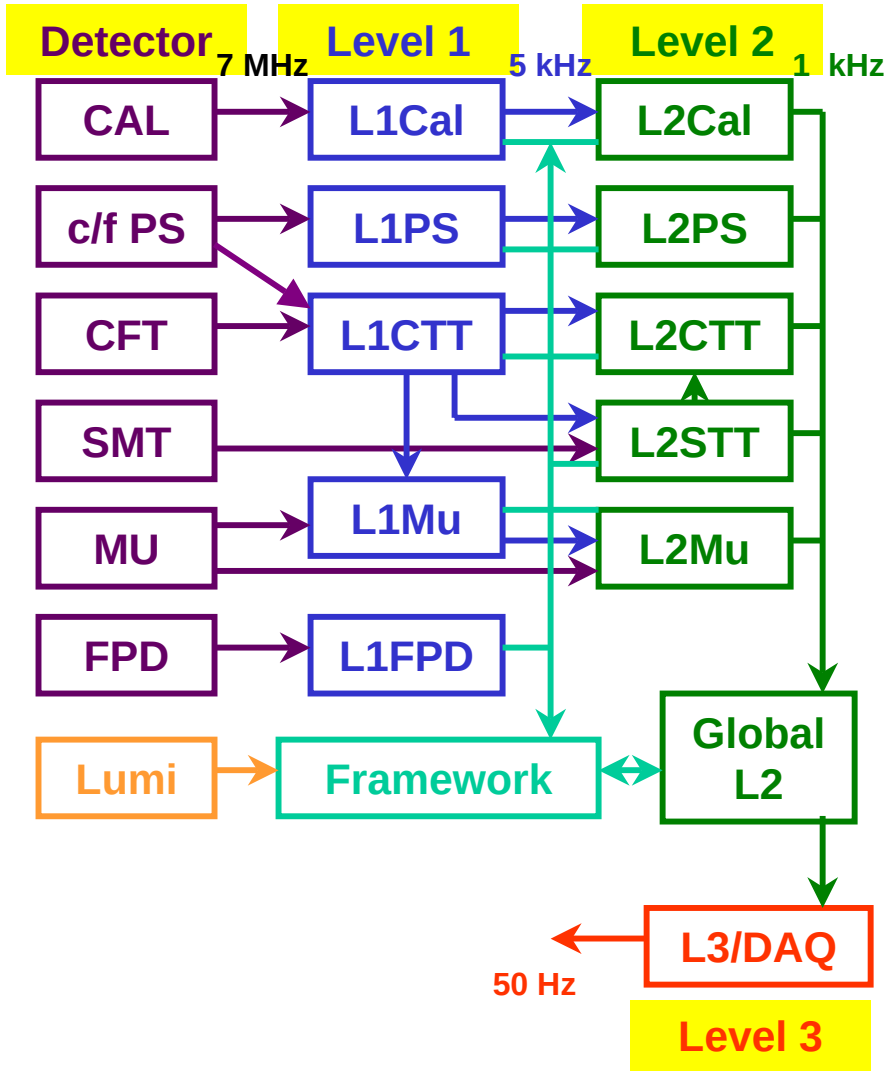
The Run IIa Trigger System

Level-1

- Mainly single-detector-based
- Correlations
  - Cal-Trk: quadrant level
  - Mu-Trk: L1trk info → L1Mu
- Out rate ~5 kHz (r'dout time)

Level-2

- Calibrated data
- Extensive correlations
- Physics objects out (e,μ,τ,j…)
- Out rate < 1 kHz (cal r'dout)



Trigger Rates, w/o upgrade

- **Core trigger menu, simulated at L=2e32, Δt=396 ns**

Trigger	Example Physics Channels	L1 Rate (kHz) (no upgrade)
EM (1 EM TT > 10 GeV)	$W \rightarrow e\nu$ $WH \rightarrow e\nu jj$	1.3
Di-EM (1 EM TT > 7 GeV, 2 EM TT > 5 GeV)	$Z \rightarrow ee$ $ZH \rightarrow eejj$	0.5
Muon (muon p_T > 11 GeV + CFT Track)	$W \rightarrow \mu\nu$ $WH \rightarrow \mu\nu jj$	6
Di-Muons (2 muons p_T > 3 GeV + CFT Tracks)	$Z \rightarrow \mu\mu$, $J/\Psi \rightarrow \mu\mu$ $ZH \rightarrow \mu\mu jj$	0.4
Electron + Jets (1 EM TT > 7 GeV, 2 Had TT > 5 GeV)	$WH \rightarrow e\nu$+jets $tt \rightarrow e\nu$+jets	0.8
Muon + Jet (muon p_T > 3 GeV, 1 Had TT > 5 GeV)	$WH \rightarrow \mu\nu$+jets $tt \rightarrow \mu\nu$+jets	< 0.1
Jet+MET (2 TT > 5 GeV, Missing E_T> 10 GeV)	$ZH \rightarrow \nu\bar{\nu}b\bar{b}$	2.1
Muon + EM (muons p_T > 3 GeV+ CFT track + 1 EM TT > 5 GeV)	$H \rightarrow WW, ZZ$	< 0.1
Single Isolated Track (1 Isolated CFT track, p_T > 10 GeV)	$H \rightarrow \tau\tau$, $W \rightarrow \mu\nu$	17
Di-Track (1 isolated tracks p_T > 10 GeV, 2 tracks p_T > 5 GeV, 1 matched with EM energy)	$H \rightarrow \tau\tau$	0.6

Total rate **~30 kHz**

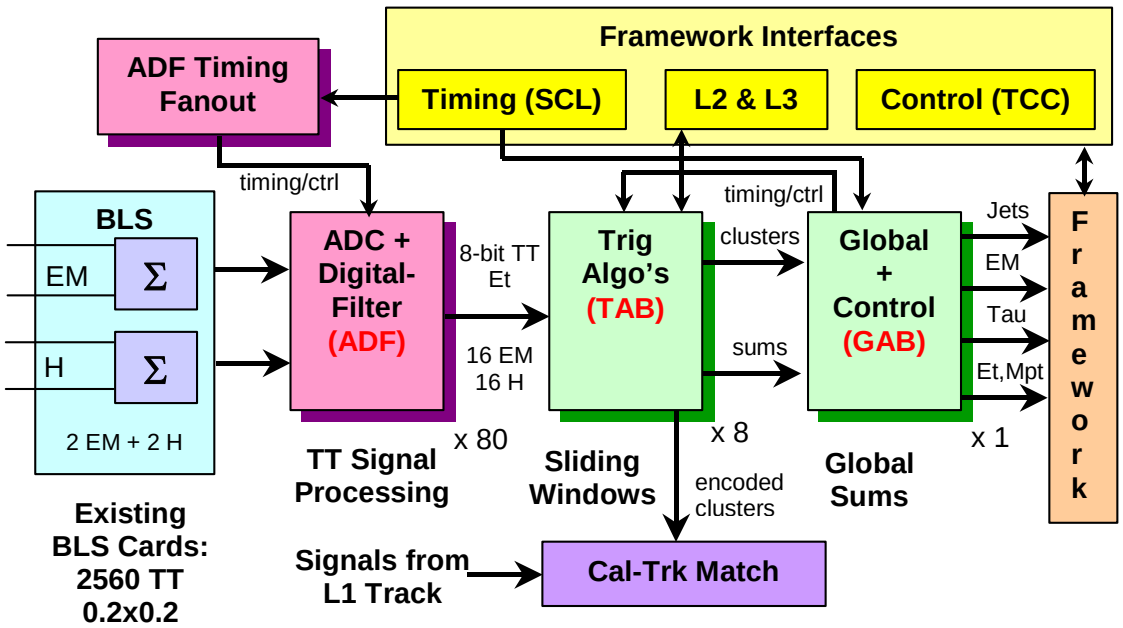
Total L1 bandwidth = 5 kHz

Strategies for Trigger Upgrades

- Run efficient high-p_T trigger menu at L=2e32 @ 396 ns
  - allow headroom for running at L>2e32
  - allow capability of 132 ns operation
- Increase trigger rejection at Level 1
  - **1.2.1:** L1 Calorimeter trigger upgrade to sharpen thresholds
  - **1.2.2:** L1 Tracking trigger upgrade to maintain rejection
  - **1.2.3:** Additional rejection from cal-track matching
- Combat backgrounds at Level 2
  - **1.2.4:** L2 Processor upgrades $\Rightarrow$ more complex algorithms possible
  - **1.2.5:** Expand Silicon Track Trigger (STT) for new silicon detector geometry
- Upgrade/maintain DAQ/Online systems (see talk from S. Fuess)

WBS 1.2.1: Calorimeter Trigger Upgrade

- **Digital Filtering of input signals**
  - **necessary for 132 ns operation**
  - **improves E_T estimate at all beam crossing rates**
- **Jet/EM/tau clustering using ATLAS sliding-window algorithm**
  - **jets broader than 0.2x0.2 Trigger Towers (TT)**
  - **cluster topology cuts possible**



WBS 1.2.1:

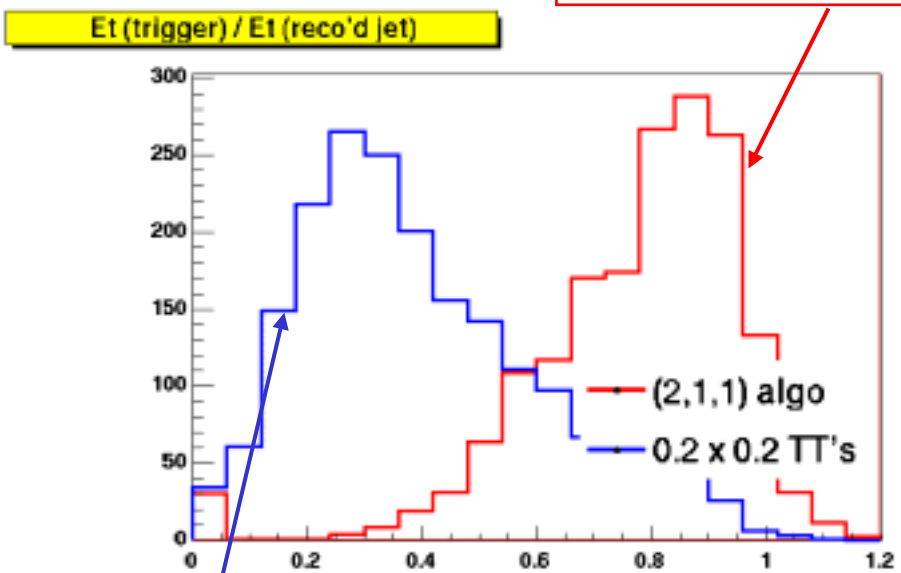
L3 managers:
M. Abolins (MSU),
H. Evans (Columbia),
P. LeDu (Saclay)

Calorimeter Trigger Upgrade

- **Sharpen thresholds by introducing EM, Jet clustering**

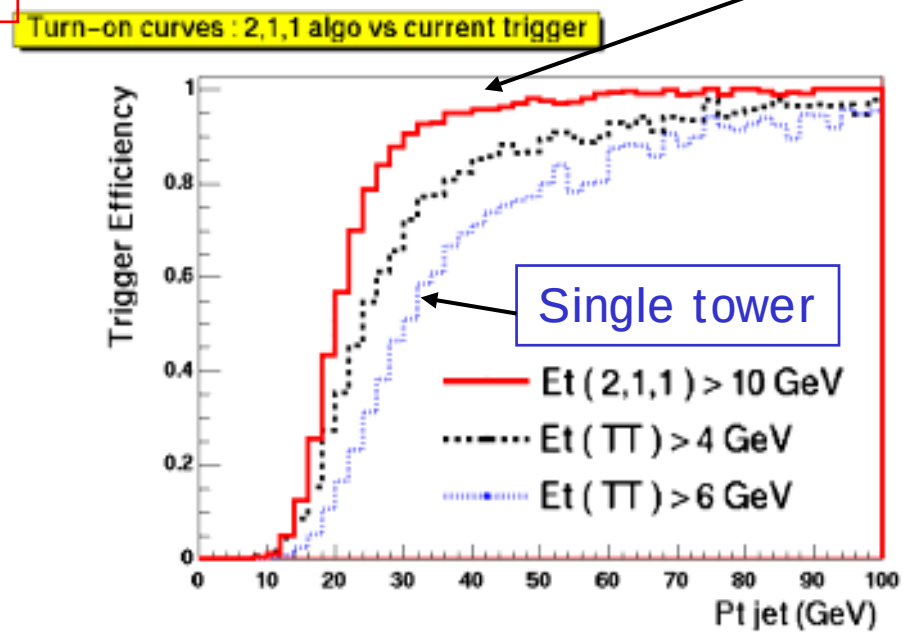
Run IIa data

Sliding window
mean/rms = 0.2



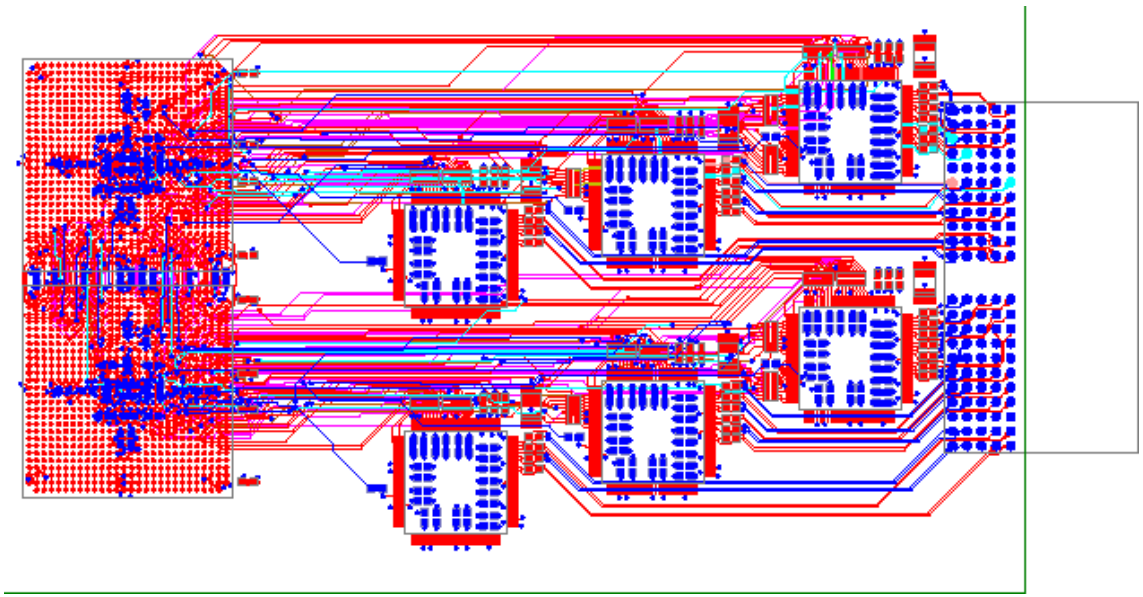
Single tower
mean/rms = 0.5

Sliding window



L1 Cal Design Progress

- **L1 Cal:**
  - ADF prototype design nearing completion
  - analog splitter board being fabricated to test Digital Filter and full system with real data
  - TAB prototype layout started
  - test boards for ADF-to-TAB cables being fabricated



Layout of input section of TAB

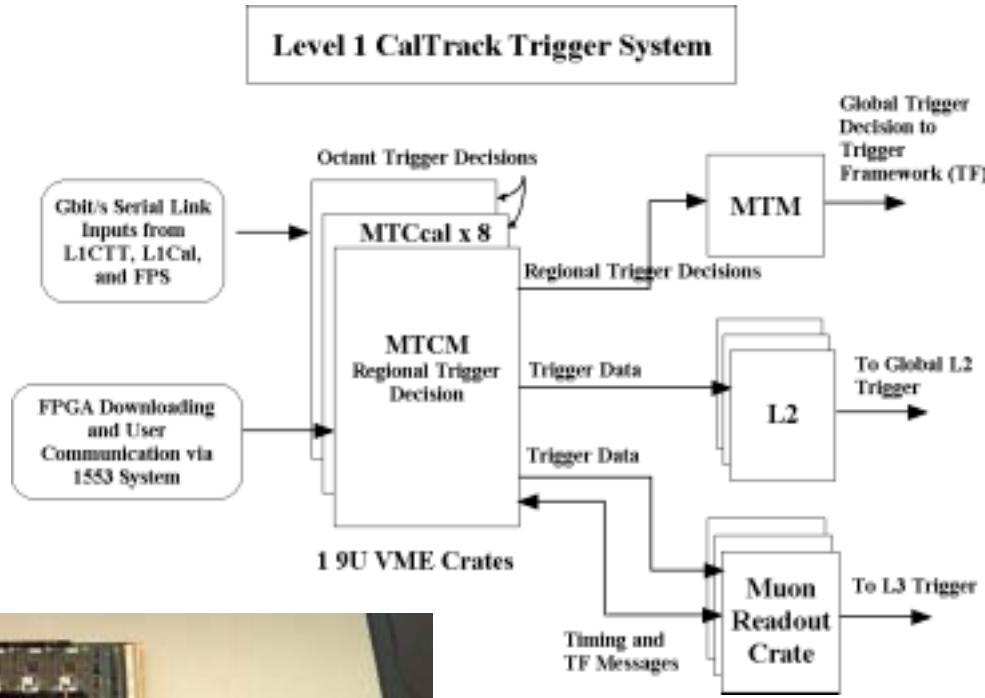
WBS 1.2.2: L1Cal-Track Trigger

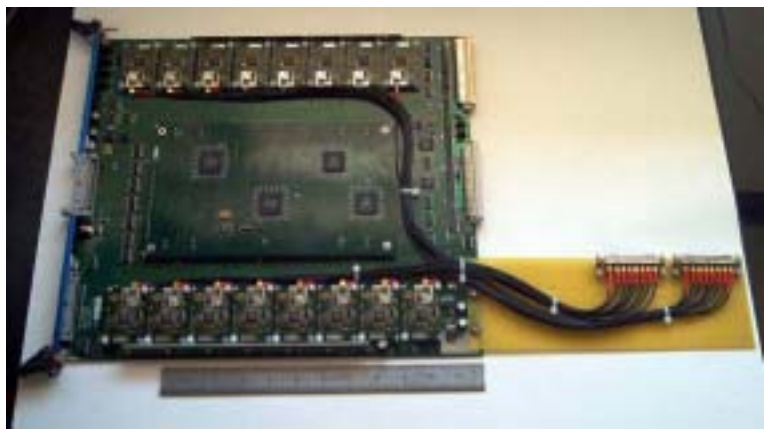
- Exploit new L1Cal trigger
- Improve Run IIa ϕ matching granularity x8
- Needed in triggers for Higgs searches
  - electrons in WH and H $\rightarrow$ W*W modes
  - taus in H $\rightarrow \tau\tau$ and $H^+ \rightarrow \tau\nu$
- Fake EM rejection is improved by ~x2
- Fake τ rejection is improved by ~x10

WBS 1.2.2: L3 manager: K. Johns (Arizona)

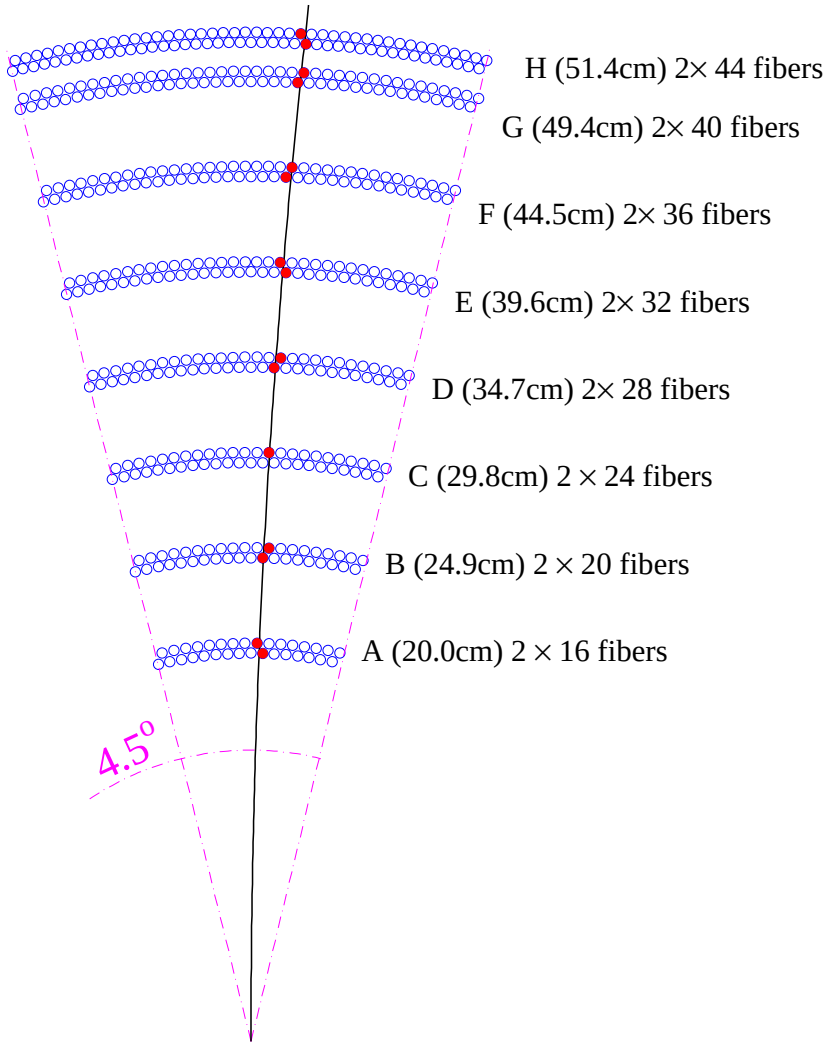
L1 Cal-track matching

- Uses same hardware as existing L1muon
  - modest cost and effort required
- Design Progress:
  - detailed latency calculation for all system ⇒ OK
  - DØ pipeline depth to be increased for extra headroom





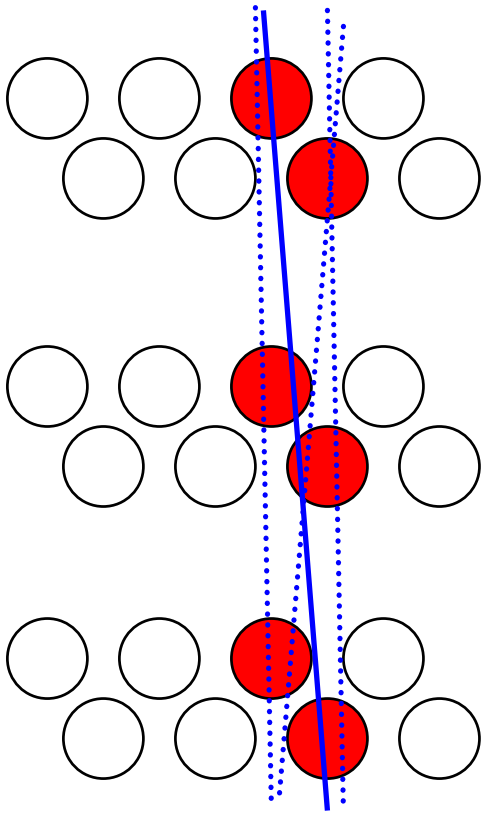
WBS 1.2.3: Level 1 Central Tracking Trigger (CTT)



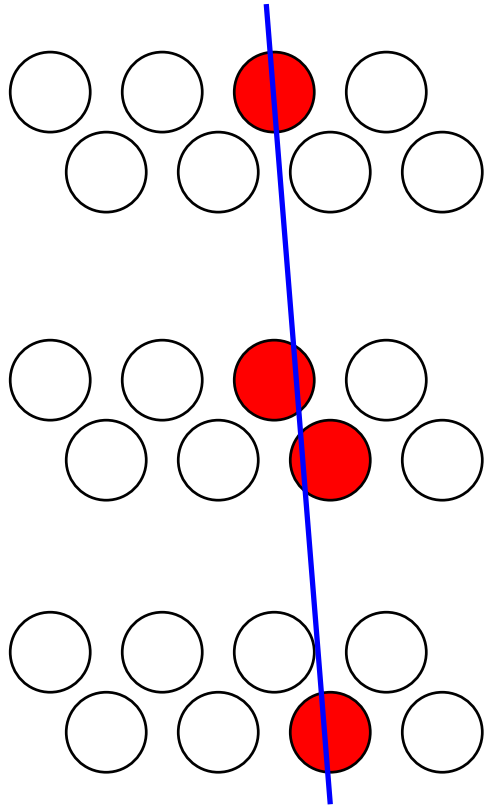
- **Level 1 Central Track Trigger (CTT) essential for electrons, muons, taus (WH→lνjj)**
- **Tracking trigger rates sensitive to occupancy**
- **Upgrade stategy:**
  - **Narrow tracker roads by using individual fiber hits (singlets) rather than pairing adjacent fibers (doublets)**
  - **Cal-track matching**

WBS 1.2.3: L3 manager: M. Narain (Boston U.)

Run IIb L1CTT: Granularity



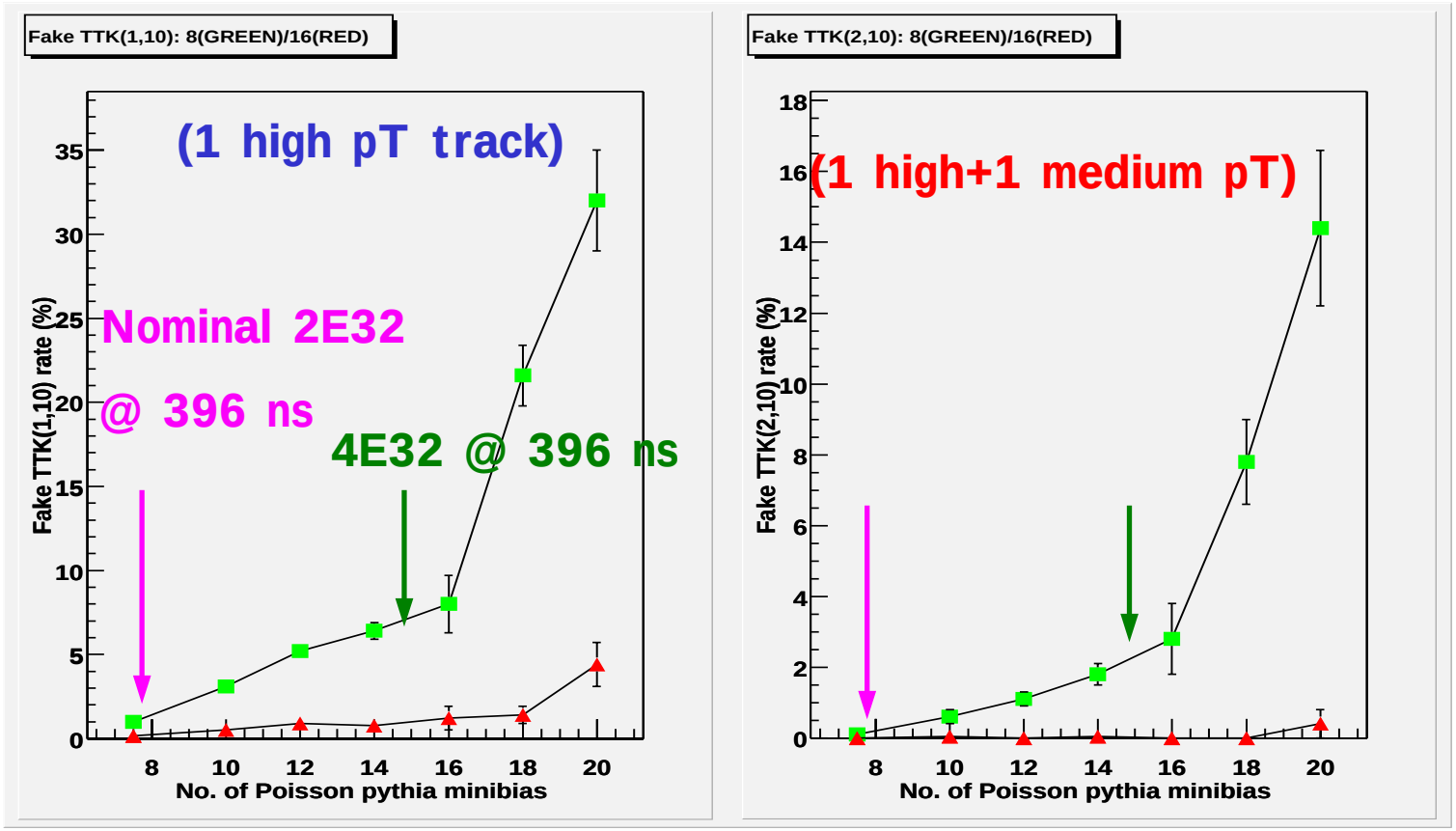
Run IIa



Run IIb

- **Use full fiber resolution to restrict roads**

Fake rate vs.luminosity



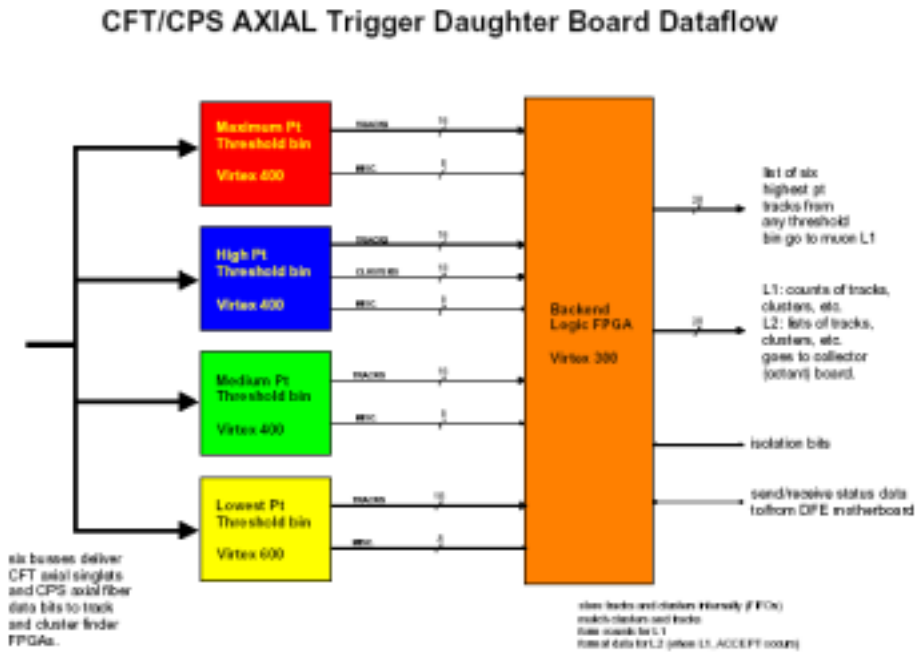
Green points = Run IIa CTT

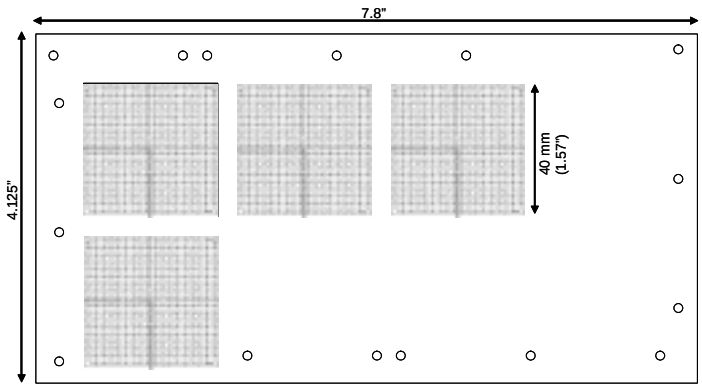
Red points = Run IIb CTT

- Even at modest occupancies, the high-p_T single track trigger would fire at >15 kHZ

L1 CTT Implementation

- Digital Front End Axial (DFEA) daughter cards get replaced with new layout with larger FPGA's (Xilinx Virtex-II XC2V6000)
  - Only 80 daughter cards get replaced;
  - rest of Run IIa system remains intact
- Baseline algorithms compiled; occupy ~40% of the resources of the XC2V6000's.





DFEA layout with new FPGA footprints

L1CTT Algorithm Results

- a(A) = inner superlayer,…, h(H) = outer superlayer
- capital letter = doublet algorithm in that superlayer
- FPGA resources = (# of equations) X (terms/equation)

p_T range	Scheme	Tracking Efficiency (%)	Rate of Fake Tracks (% events)	Resources
p_T>10 GeV (RunIIa)	ABCDEFGH	96.9	1.02 ± 0.10	11k X 8
p_T>10 GeV	abcdefgh	98.03 ± 0.22	0.056 ± 0.009	9.4k X 16
5 GeV<p_T<10 GeV	abcdEFGH	99.20 ± 0.14	0.89 ± 0.11	8.9k X 12
3 GeV<p_T<5 GeV	abcdEFGH	98.40 ± 0.20	4.5 ± 0.2	11.3k X 12
1.5 GeV<p_T<3 GeV	abcdEFGH	95.15 ± 0.32	25.4 ± 0.2	15.5k X 12

- Design progress: baseline algorithm chosen
  - extensive simulation ⇒ achieves performance goals
  - coded and compiled with FPGA tools (Synplify synthesizer)

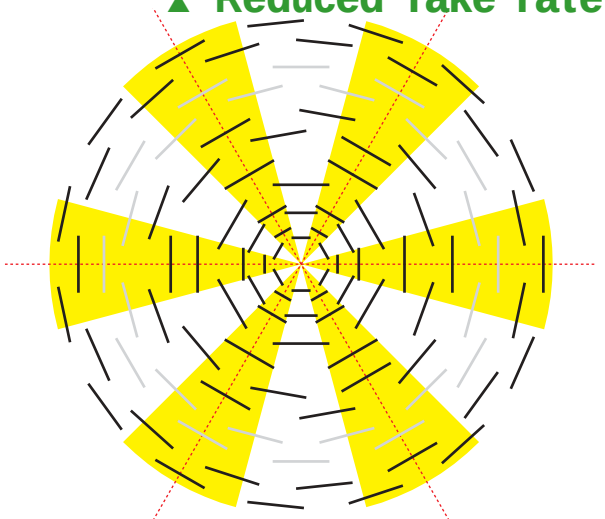
L1: Additional features

- Muon triggers – No change needed to L1muon
  - but requires functioning CTT trigger with <few% fakes
  - CTT upgrade allows higher muon p_T thresholds
- Global calorimeter sums – better missing E_T with incorporation of intercryostat detector and massless gaps
- EM shape and isolation – these cuts can be implemented in Level 1 after cluster finding, giving an additional factor of 2 rejection for electron & photon triggers
- Topology – flexibility to require acoplanar jets, etc.
- Flexibility: New clustering and tracking algorithms can be implemented with FPGA downloads

WBS 1.2.5: Silicon Track Trigger for Run IIb

WBS 1.2.5: L3 manager: U. Heintz (Boston U.)

- Silicon Track Trigger (STT)
  - Run IIa STT available Fall 2002 (beyond the Run IIa baseline)
  - Vital for triggering on b-quarks
    - $ZH \rightarrow \nu\nu bb$
    - $Z \rightarrow bb$
      - b-jet energy scale, di-b-jet mass resolution
  - Improves track trigger
    - Sharper p_T turn-on
    - Reduced fake rate

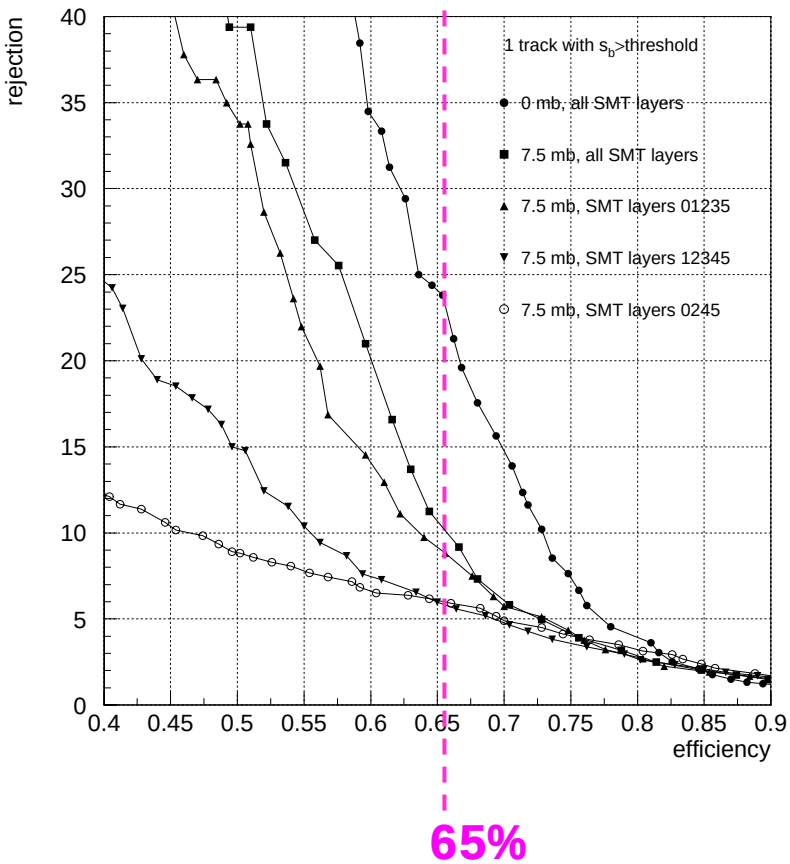


Readout layers 0,1,2,3,5

- STT upgrade needed to accommodate new SMT geometry
- SMT detector replacement: 6 axial barrel layers
  - Modest STT upgrade (5-layer readout) requires small quantity of same boards that are used in Run IIa.

Level2 STT Simulation

$WH \rightarrow \mu\nu\bar{b}b$

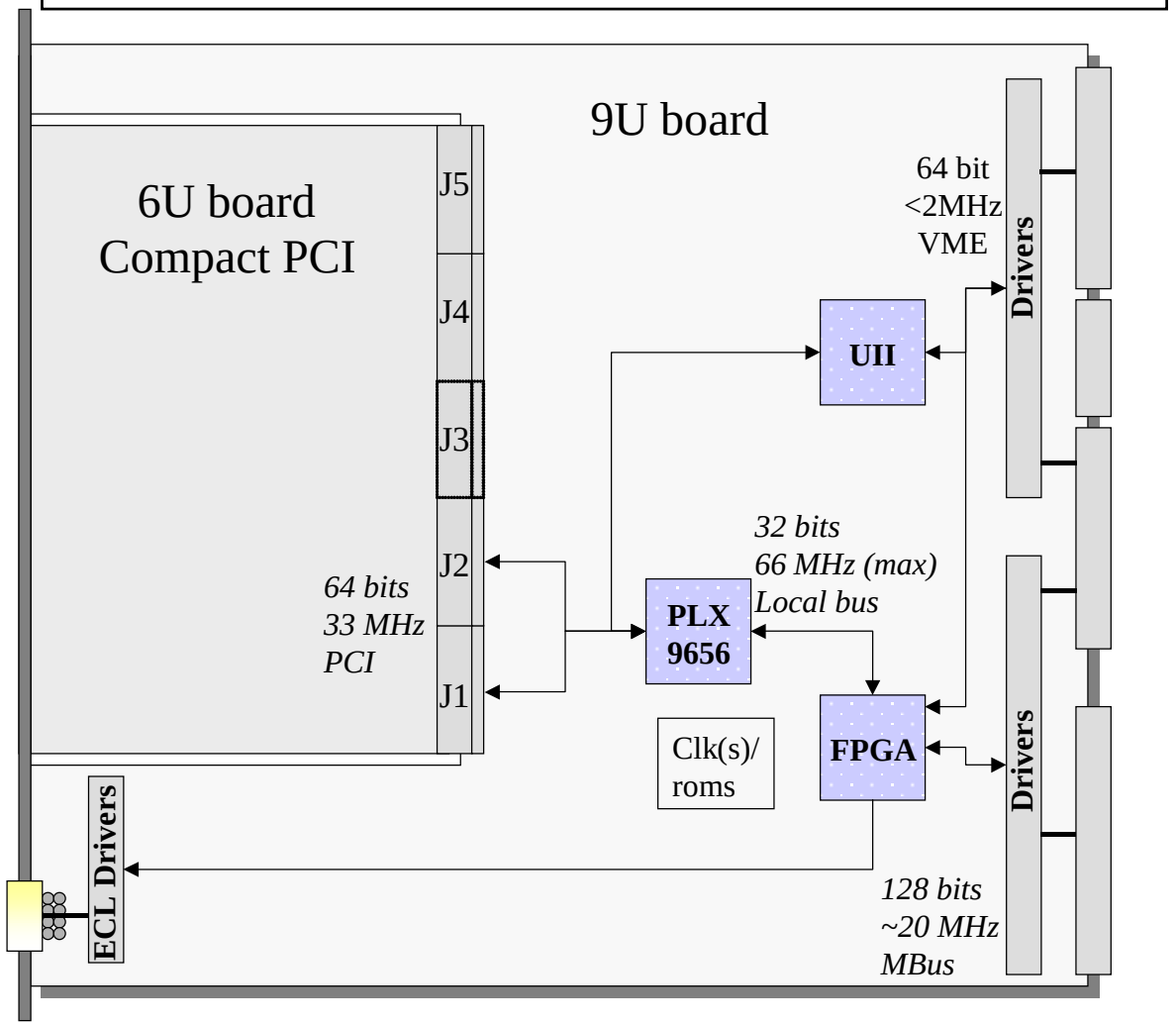


SMT layers used	N_{mb}	rejection for 65% efficiency
012345	0	22
012345	7.5	11
01235	7.5	9
12345	7.5	6
0245	7.5	6

WBS 1.2.4: L2βeta Upgrade

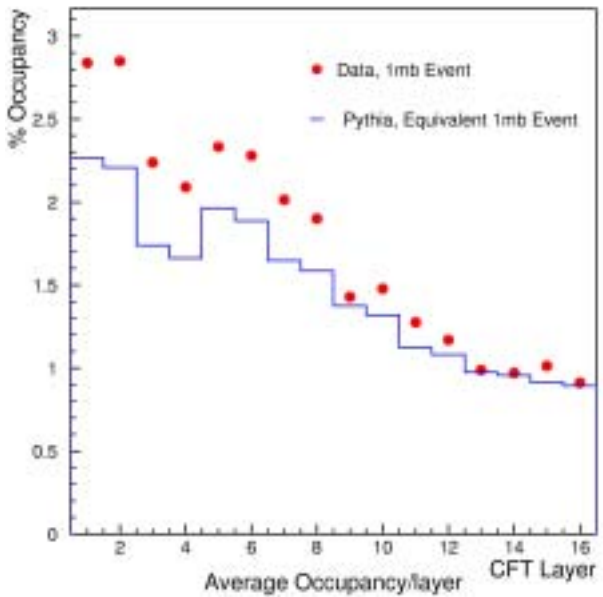
- In Run IIa, 24 beta processors replace existing Alpha processors
  - installation in early 2003
- Add 12 additional processors for higher RunIIb luminosity
  - processors only; use Run IIa adapter boards
- provide processing power (X 2-3 increase over RunIIa) needed to take advantage of the increased power at L1

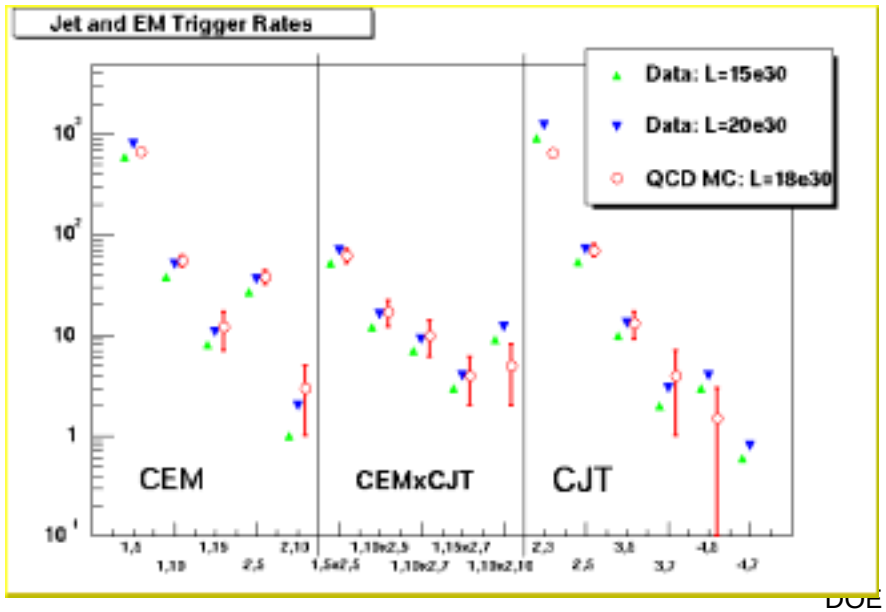
WBS 1.2.4: L3 manager: R. Hirosky (Virginia)



Trigger Simulations: Methods and Reality Checks

- Background rates: PYTHIA QCD Monte Carlo, plus Poisson distribution of PYTHIA min. bias events
- Benchmarks with current data
  - Central Fiber Tracker occupancy vs. layer for real vs. simulated minimum bias
  - Calorimeter trigger rates at low luminosity for real vs. simulated QCD background





Trigger Rates

- **Core trigger menu, simulated at L=2e32, Δt=396 ns**

Trigger	Example Physics Channels	L1 Rate (kHz) (no upgrade)	L1 Rate (kHz) (with upgrade)
EM (1 EM TT > 10 GeV)	$W \to e\nu$ $WH \to e\nu jj$	1.3	0.7
Di-EM (1 EM TT > 7 GeV, 2 EM TT > 5 GeV)	$Z \to ee$ $ZH \to eejj$	0.5	0.1
Muon (muon p_T > 11 GeV + CFT Track)	$W \to \mu\nu$ $WH \to \mu\nu jj$	6	1.1
Di-Muons (2 muons p_T > 3 GeV + CFT Tracks)	$Z \to \mu\mu$, $J/\Psi \to \mu\mu$ $ZH \to \mu\mu jj$	0.4	< 0.1
Electron + Jets (1 EM TT > 7 GeV, 2 Had TT > 5 GeV)	$WH \to e\nu$+jets $tt \to e\nu$+jets	0.8	0.2
Muon + Jet (muon p_T > 3 GeV, 1 Had TT > 5 GeV)	$WH \to \mu\nu$+jets $tt \to \mu\nu$+jets	< 0.1	< 0.1
Jet+MET (2 TT > 5 GeV, Missing E_T> 10 GeV)	$ZH \to \nu\bar{\nu}b\bar{b}$	2.1	0.8
Muon + EM (muons p_T > 3 GeV+ CFT track + 1 EM TT > 5 GeV)	$H \to WW, ZZ$	< 0.1	< 0.1
Single Isolated Track (1 Isolated CFT track, p_T > 10 GeV)	$H \to \tau\tau$, $W \to \mu\nu$	17	1.0
Di-Track (1 isolated tracks p_T > 10 GeV, 2 tracks p_T > 5 GeV, 1 matched with EM energy)	$H \to \tau\tau$	0.6	<0.1
Total rate:		**~30 kHz**	**3.9 kHz**

Total L1 bandwidth = 5 kHz

Additional headroom available from

- **topological cuts available in upgraded L1cal**
- **Higher mu p_T threshold with upgraded CTT**

Trigger upgrade:Limited scope

- Studied and eliminated several upgrade options in favor of lower schedule-risk and/or cost:
  - Level 1 stereo tracking
  - Preshower as 9th tracking layer
  - Finer granularity of calorimeter towers (0.1x0.2)
  - 6-layer Silicon Track Trigger
- Use existing hardware (or minor modifications thereof) for new applications
  - Muon Trigger Cards for calorimeter-track matching
  - Existing DFE motherboards with daughter board replacement for tracking upgrade
  - Reuse L2Beta interface boards
  - Increase RunIIa STT production order to accommodate upgrade

Trigger Upgrade Project

- **Task Force Study:** Summer 2001, DØ Trigger Task force studies upgrade options for trigger
- **Technical Design:**
  - first draft TDR presented in April 2002
  - substantially revised to reflect significant process in developing detailed design, August 2002
- **Trigger Upgrade Project:**
  - responsible institutions identified by January 2002
  - all WBS Level 3 managers in place by March 2002
  - Biweekly full group meetings, plus subproject meetings
  - Planning with fully resource-loaded schedule (341 tasks)
- **NSF MRI award:** Trigger MRI submitted in January 2002, received in July 2002
  - $456k + $113k matching for L1 tracking subproject
  - Complements ~$400k Saclay in-kind contribution for L1cal
- **Reviews:** PAC (Oct 01, April 02), Technical Review Committee(Dec 01), Director's Review Committee (April 02), DRC/TRC (August 02)
  - June 02 PAC recommends stage 1 approval
  - August 02 DRC/TRC recommends all D0 Trigger upgrades ready for baselining.

Trigger Upgrade Project Institutions

Sub-project	Institution(s)
Calorimeter: ADF	Saclay, MSU
Calorimeter: TAB	Columbia
Track trigger	Boston U., FNAL
Cal-Track match	U. of Arizona
Simulation & algorithms	Notre Dame, Saclay, Kansas, Manchester, Brown
Online software & integration	MSU, Northeastern, FSU,Langston
Level 2β	Orsay, Virginia, MSU
STT upgrade	Boston, Columbia, Stony Brook, FSU

- Strong, active institutions
- Largely University-driven
- Combination of RunIIa experience and new ideas
- Engineering, technical and physicist manpower identified for delivering upgraded trigger
- Other institutions expressing interest

M&S Cost Estimates ($k)

FY02 k$

total cost = 2,871 (+ 48% contingency)

Project	M&S equip	Labor	Total	Contin-gency
WBS 1.2.1: L1 calorimeter	457	928	1385	45%
WBS 1.2.2: L1 cal-track match	177	71	248	40%
WBS 1.2.3: L1 tracking	569	301	870	51%
WBS 1.2.4: L2 Beta	49	44	93	80%
WBS 1.2.5: L2 STT	172	63	235	43%

Note: much of labor is covered by in-kind contributions from French laboratories ($587k) and US Universities ($398k)

(Detailed cost estimate provided to committee)

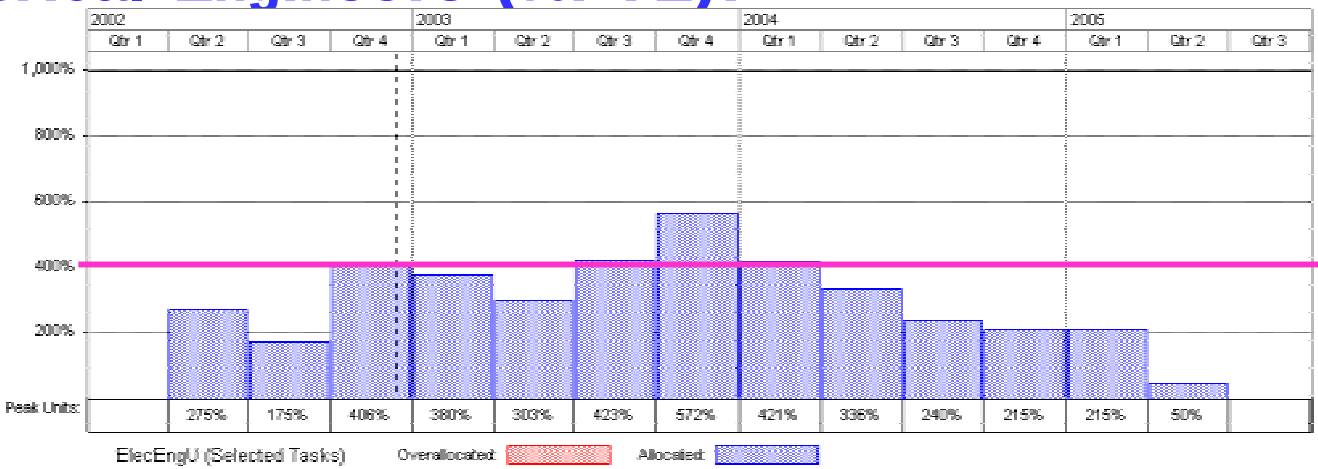
Baseline Schedule: Level 1

project	Selected milestones
WBS 1.2.1: L1 calorimeter	
•ADF prototype shipped to Fermilab	5/03
•TAB prototype complete	5/03
•Production & Testing complete	2/05
WBS 1.2.2: L1 cal-track match	
•Prototype MTFB complete	5/03
•Production & Testing complete	7/04
WBS 1.2.3: L1 tracking	
•Target FPGA algorithm coded	7/03
•Prototype tested at Fermilab	4/04
•Production & Testing complete	3/05

- Detailed resource-loaded schedule included in material provided
- Installation begins after start of shutdown (5/25/05)

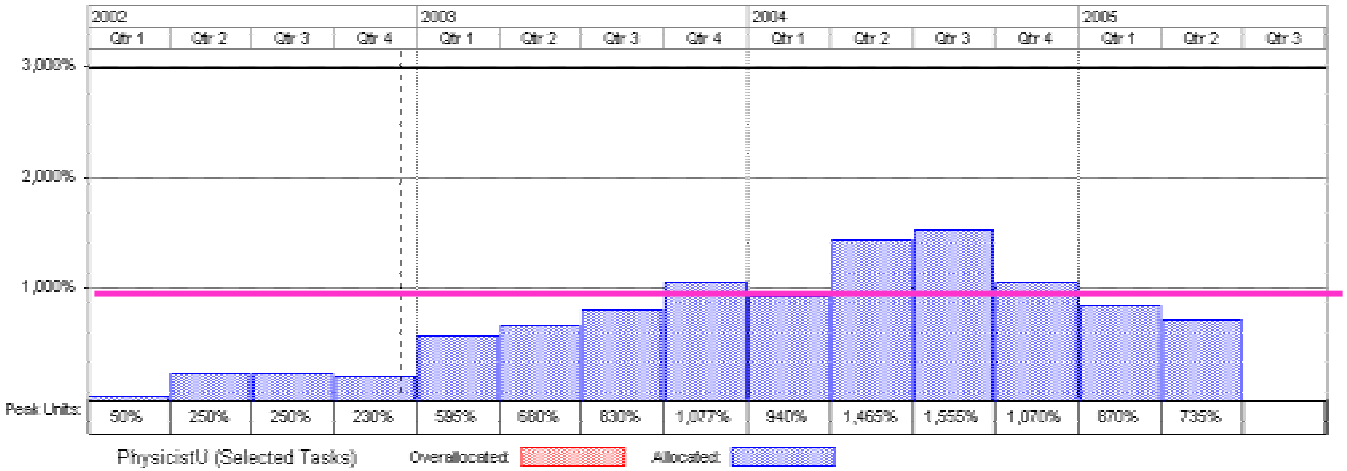
Trigger Labor Profiles

- **Electrical Engineers (%FTE):**



4 FTE

- **Physicists (%FTE):**



10 FTE

Level 1 Schedule Sensitivity

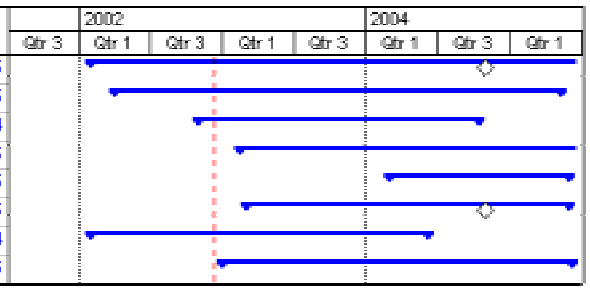
scenario	All production and testing complete	Trigger slippage (days)
default	3/16/05	0
extra ADF prototype revision & test	5/2/05	47
extra TAB prototype revision & test	6/8/05	84
extra GAB prototype revision & test	3/9/05	0
double time for all in-situ and integration tests	4/12/05	27
3rd prototype cycle for DFEAs	7/7/05	113
Cal-trk redesign after internal review	3/9/05	0
All of the above	8/4/05	148

Note: Shutdown period = 5/25/05 – 12/21/05
All scenarios leave at least 4 months for installation and commissioning

Baseline Schedule: Run IIb Level 2

project	Milestone Date
WBS 1.2.4: L2 RunIIb beta	
•L2 beta prototype testing complete	10/04
•L2 beta Production Complete	2/05
WBS 1.2.5: L2 Run IIb STT	
•Place parts order	4/03
•Production & Testing complete	2/05

ID	WBS	Task Name	Marked	Duration	Start	Finish
1	1.2	Run IIb Trigger Upgrade	No	166.4 w	Thu 11/1/01	Wed 3/16/05
2	1.2.1	Level 1 Calorimeter Trigger	No	154 w	Wed 1/2/02	Mon 2/7/05
92	1.2.2	Level 1 Calorimeter Track Matching	No	96.8 w	Thu 8/1/02	Wed 7/14/04
141	1.2.3	Level 1 Tracking	No	115 w	Tue 11/12/02	Wed 3/16/05
200	1.2.4	Level 2 Beta Processor	No	61 w	Mon 12/1/03	Mon 2/28/05
234	1.2.5	Silicon Track Trigger Upgrade	No	110.4 w	Mon 12/2/02	Mon 2/28/05
319	1.2.6	Trigger Simulation	No	115.4 w	Thu 11/1/01	Fri 3/5/04
336	1.2.7	Administration	No	120 w	Tue 10/1/02	Tue 3/8/05



- Detailed resource-loaded schedule included in material provided
- L2 beta processors could be ordered up to 2 years earlier—virtually no schedule risk

Summary

- DØ trigger upgrade
  - preserves trigger capabilities for critical physics processes at high-luminosity operation
  - Baseline design complete and documented in TDR
  - System design progressing rapidly
    - only modest design work necessary for several subsystems
    - prototypes expected in early 2003 for other subsystems
  - Detailed schedule shows completion compatible with shutdown for installation of silicon detectors
  - Strong collaboration in place for prototyping, production, simulation, installation and commissioning
- Much more technical detail available in breakout sessions