Trigger Strategies

- **e⁺e⁻ colliders**: low total cross section, low rates
  - Trigger pretty much on everything, perhaps with the exception of very forward processes (low-angle Bhabha)
- **Hadron colliders**: enormous cross section, unattainable rates
  - Trigger is very selective
  - Only small fraction of collisions is written to tape
  - Additional complications due to pile-up
- **LHC**:
  - $\sigma_{\text{tot}} = 110 \text{ mb}$, $\sigma_{\text{in}} \sim 70 \text{ mb}$
  - $L = 10^{34} \text{ cm}^{-2}\text{s}^{-1} = 10 \text{ nb}^{-1}\text{s}^{-1}$
  - Total rate: $\sim 10^9 \text{ s}^{-1}$ or $\sim 25$/crossing

[Block, Halzen, hep-ph/0510238]

[PDG]
More Trigger Challenges

- **LHC Physics Demands**
  - EWSB in SM (Higgs, W, Z)
    - Lepton/photons $E_T \sim 50$ GeV
    - High rate (10 Hz of top events!)
  - TeV scale supersymmetry, UED
    - Multiple leptons, jets and LSPs (missing $E_T$), $E_T < 100$ GeV

- **QCD Background**
  - Jet $E_T \sim 250$ GeV, rate $\sim 1$ kHz
  - Jet fluctuations $\Rightarrow$ electron BG
  - Decays of p, k, B $\Rightarrow$ muon BG

- **Technical challenges**
  - 40 MHz input $\Rightarrow$ fast processing
  - 100 Hz output $\Rightarrow$ physics selection
  - $10^9$ events per year $\Rightarrow \leq 10^2$ higgs events
Trigger Architecture

- Must reduce 1 GHz of input interactions to 100 Hz
  - Do it in steps/successive approximations: “Trigger Levels”

Recent progress in networking/switching has justified CMS choice
CMS Trigger & Data Acquisition

• CMS has a two-tiered system to handle LHC challenge:
  – Level-1 trigger reduces rate from 40 MHz to 100 kHz (max)
    • Custom electronic boards and chips process calorimeter and muon data to select objects
  – High-Level triggers reduce rate from 100 kHz to O(100 Hz)
    • Filter farm runs online programs to select physics channels
    • No custom Level-2 hardware

Large switching network (~Tbit/s)
O(1000) node PC cluster

40 TB/s
100 MB/s
• **Level-1 Trigger**  
  Technical Design Report:  
  – CERN/LHCC 2000-038

• **DAQ and High-Level Trigger**  
  Technical Design Report:  
  – CERN/LHCC 2002-026  
  pp. 528

• **Physics Technical Design Report - Volume 1**  
  – Will have a trigger chapter and is due out this year  
  pp. 630
## Tevatron & LHC: Quick Comparison

<table>
<thead>
<tr>
<th></th>
<th>CDF/DØ</th>
<th>CMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inst. Luminosity</td>
<td>$10^{32}$</td>
<td>$10^{34}$</td>
</tr>
<tr>
<td>Bunch crossing freq.</td>
<td>2.5 MHz</td>
<td>40 MHz</td>
</tr>
<tr>
<td>Pileup</td>
<td>$\approx2$ events</td>
<td>$\approx20$ events</td>
</tr>
<tr>
<td>L1 output rate</td>
<td>2-10 kHz</td>
<td>100 kHz</td>
</tr>
<tr>
<td>L2 output / HLT input</td>
<td>$\approx500$ Hz</td>
<td>100,000 Hz</td>
</tr>
<tr>
<td>L3 output rate</td>
<td>50 Hz</td>
<td>100 Hz</td>
</tr>
<tr>
<td>Event size</td>
<td>$\approx0.1$ MB</td>
<td>1 MB</td>
</tr>
<tr>
<td>Filter Farm</td>
<td>$\approx100$ nodes</td>
<td>$\approx1000$ nodes</td>
</tr>
</tbody>
</table>
The CMS Level-1 Trigger

- Reduce data rate from 40 MHz to 100 kHz while keeping high-$p_T$ physics
  - Custom electronic hardware, some of which must be radiation hard
  - Algorithms are pipelined at 40 MHz for deadtime-free operation
  - Total decision latency: 3.2 $\mu$s
- Only muon and calorimeter systems participate
  - Silicon tracker data is unavailable until the High-Level Trigger
    - Significant handicap compared to the Tevatron experiments
    - Resembles UA1 or DØ in Run I
    - On a positive side, makes L1 trigger logic simpler
Level-1 Trigger Scheme

Electrons, Photons, Jets, $\text{MET}_T$

- $3 < |\eta| < 5$
- $|\eta| < 3$
- $|\eta| < 3$
- $|\eta| < 2.1$
- $0.9 < |\eta| < 2.4$
- $|\eta| < 1.2$

Muons

- $|\eta| < 2.1$
- $0.9 < |\eta| < 2.4$
- $|\eta| < 1.2$
Calorimeter Trigger Geometry

EB, EE, HB, HE map to 18 RCT crates
Provide $e/\gamma$ and jet, $\tau$, $E_T$ triggers

Trigger towers: $\Delta \eta = \Delta \phi = 0.087$
Level-1 EM Calorimeter Trigger

- **Electron (Hit Tower + Max)**
  - 2-tower $\Sigma E_T >$ threshold
  - Hit tower $H/E < 5%$
  - Hit tower 2x5-crystal strips >90-95% of tower $E_T$ in 5x5 (Fine Grain)

- **Isolated Electron (3x3 Towers)**
  - Quiet neighbors: all towers pass Fine Grain & $H/E$
  - One group of 5 EM corners has $E_T <$ threshold (~1 GeV)

Sum $E_T$ of the central hit tower (pink) and the nearest neighbor w/ the highest $E_T$ (one of the yellow towers)
Level-1 Jet Calorimeter Trigger

• Jet or \( \tau E_T \)
  – 12x12 trig. tower \( \Sigma E_T \) sliding in 4x4 steps w/central 4x4 \( E_T > \) others

• \( \tau \): isolated narrow energy deposits
  – Energy spread outside \( \tau \) veto pattern sets veto
  – Jet \( \equiv \tau \) if all 9 4x4 region \( \tau \) vetoes off
Level-1 Global Calorimeter Trigger

• Implements sliding window jet cluster algorithm
• Sorts electron and jet objects
• Computes energy and missing $E_T$ sums
• Forwards Calorimeter Quiet bits and MIP (minimum-ionizing particle) bits to Global Muon Trigger for each 4x4 tower Calorimeter region.
• Output to Global Trigger (sorted in $E_T$):
  – $E_T$ and location in detector
    • 4 non-isolated $e/\gamma$
    • 4 isolated $e/\gamma$
    • 4 central jets
    • 4 forward jets
    • 4 $\tau$ objects
  – Total $E_T$
  – Missing $E_T$ and $\phi$ angle
  – Jet Counts
Level-1 Electron Efficiency and Rate

Response to electrons

Rate from QCD background

Graph showing electron efficiency and rate as a function of electron transverse momentum (Electron Pt) and Level-1 $E_T(95\%)$ (GeV).
Muon Trigger Geometry

- RPC: resistive plate chamber system
- CSC: cathode strip chamber system
- DT: drift-tube system

Initial coverage of RPC is staged to $\eta<1.6$
Initial coverage of CSC 1st station is staged to $\eta<2.1$

4 Stations in the barrel and each endcap
Muon Trigger Overview

- **DT hits**
  - local trigger track segments \((\phi, \delta\phi, \eta, \delta\eta)\)
  - regional trigger Barrel Track Finder
    - \(\leq 4\) muon candidates \((p_T, \eta, \phi, \text{quality})\)

- **CSC hits**
  - local trigger track segments \((\phi, \delta\phi, \eta, \delta\eta)\)
  - regional trigger Endcap Track Finder
    - \(\leq 4\) muon candidates \((p_T, \eta, \phi, \text{quality})\)

- **RPC hits**
  - PAtern Comparator Trigger
    - \(\leq 4\) barrel + \(\leq 4\) endcap muon candidates
      - \((p_T, \eta, \phi, \text{quality})\)

- **Global Muon Trigger**
  - \(\leq 4\) muons
    - \((p_T, \eta, \phi, \text{quality})\)
DT and CSC Local Triggers

Both are multi-layer detectors

Bunch & Track Identifier (BTI) uses shift registers to search for patterns in drift tubes ($\phi$ and $\theta$) and to assign correct BX.

Local Charged Track (LCT) logic identifies track stubs in CSCs (in $\phi$ and $\eta$) and assigns BX.
Track-Finding

Austria (DT), Poland (RPC), U.S. (CSC)

- DT and CSC Track-Finders link local track segments into distinct tracks
- RPC Pattern Comparator
  Trigger applies coincidence logic along roads in $\eta$ and $\phi$ with $\Delta\eta \times \Delta\phi = 0.1 \times 0.005$
- Standalone momentum measurement using B-field in yoke
- Highest quality candidates sent to Global Muon Trigger
Global Muon Trigger

- Combines/matches muons from all 3 systems:
  - Maximize efficiency
  - Minimize rate
  - Cancel duplicates
  - Apply calorimeter isolation or MIP
  - Programmable $P_T$ thresholds from 1 to 140 GeV/c

**Inputs:**
- 8 bit $\phi$, 6 bit $\eta$, 5 bit $p_T$
- 2 bits charge, 3 bit quality, 1 bit halo/$\eta$ fine-coarse

**Outputs:**
- 8 bit $\phi$, 6 bit $\eta$, 5 bit $p_T$
- 2 bits charge/synch, 3 bit quality, MIP bit, Isolation bit

- 252 MIP bits
- 252 Quiet bits
- 4 $\mu$ RPC brl
- 4 $\mu$ DT
- 4 $\mu$ CSC
- 4 $\mu$ RPC fwd
Muon rates and efficiencies

L = $2 \times 10^{33}$ cm$^{-1}$s$^{-1}$

L = $10^{34}$ cm$^{-1}$s$^{-1}$
Level-1 Global Trigger

- Receives Trigger Objects:
  - 4 forward and 4 central jet, 4 $\tau$-jets, 4 isolated and 4 non-isolated $e/\gamma$, total $E_T$, $\text{MET}_T$ and position information from global calorimeter trigger
  - 4 $\mu$, $\mu$ position, sign, and quality information from global muon trigger
- 128 different conditions (thresholds, topological cuts) can be combined to make 128 physics triggers
- Forwards Level-1 accept to DAQ and Trigger Timing and Control (TTC) system for data collection.
- Level-1 decision is transmitted to the Trigger Throttle System, which in turn transmits a Level-1 Accept via the Trigger Timing and Control system to the detector front-end read-out electronics.
**Crude Level-1 Trigger Table**

<table>
<thead>
<tr>
<th>Trigger</th>
<th>Low Luminosity (50 kHz Startup DAQ)</th>
<th>High Luminosity (100 kHz Full DAQ)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>95% Eff. Thr. (GeV)</td>
<td>Rate (kHz)</td>
</tr>
<tr>
<td>e</td>
<td>29</td>
<td>3.3</td>
</tr>
<tr>
<td>ee</td>
<td>17</td>
<td>1.3</td>
</tr>
<tr>
<td>μ</td>
<td>14</td>
<td>2.7</td>
</tr>
<tr>
<td>μμ</td>
<td>3</td>
<td>0.9</td>
</tr>
<tr>
<td>τ</td>
<td>86</td>
<td>2.2</td>
</tr>
<tr>
<td>ττ</td>
<td>59</td>
<td>1.0</td>
</tr>
<tr>
<td>j•jj•jjjj</td>
<td>177,86,70</td>
<td>3.0</td>
</tr>
<tr>
<td>j*E_{Tmiss}</td>
<td>88*46</td>
<td>2.3</td>
</tr>
<tr>
<td>e*j</td>
<td>21*45</td>
<td>0.8</td>
</tr>
<tr>
<td>μ*jet</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Min. bias</td>
<td>-</td>
<td>0.9</td>
</tr>
<tr>
<td>TOTAL</td>
<td>-</td>
<td>16.0</td>
</tr>
</tbody>
</table>

× 3 safety factor
CMS Trigger/DAQ Evolution

- CMS DAQ is a number of functionally identical, parallel, small DAQ systems
  - Build up 512×512 switch from 8 64×64 switches (1/8th DAQ slice)
- Turn-on in 2007 expected to have 4 such slices (US contributes one slice), yielding 50 kHz maximum Level-1 input rate to HLT
  - L1 fully scoped to deliver up to 100 kHz rate, and front-ends able to absorb 100 kHz rate
• A Filter Farm with commodity PCs does everything beyond Level-1
• HLT does partial event reconstruction “on demand” using full detector resolution
• Historically: Level-2 uses only calorimeter + muon
  Level-3 uses tracker (90% of data volume)
High-Level Triggers

- Reduces the rate from 100 kHz to O(100 Hz)
  - Final rate will depend on data bandwidth, storage capability, and background rejection capability
  - Deployed as software filters running in an online computer farm (~1000 year 2007 PCs)
  - Software is in principle the same as used offline
- Starts with a data sample already enriched in physics!
  - Level-1 already applied a factor 400 background rejection
- What can be done:
  - Electrons: require high-$p_T$ track match to veto $\pi^0$ fakes, recover bremsstrahlung
  - Photons: veto tracks
  - Muons: require high-$p_T$ track match to improve $p_T$ resolution
  - Jets: run standard jet algorithms
  - Tracks: improve measurement of impact parameter, $p_T$, and charge
  - Quality: Apply isolation criteria to all leptons
  - Event shape: Apply topological and invariant mass cuts
## Crude HLT Trigger Table

<table>
<thead>
<tr>
<th>Trigger</th>
<th>Threshold (GeV)</th>
<th>Rate (Hz)</th>
<th>Cumulative Rate (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inclusive Electron</td>
<td>29</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td>Di-electrons</td>
<td>17</td>
<td>1</td>
<td>34</td>
</tr>
<tr>
<td>Inclusive Photon</td>
<td>80</td>
<td>4</td>
<td>38</td>
</tr>
<tr>
<td>Di-photons</td>
<td>40, 25</td>
<td>5</td>
<td>43</td>
</tr>
<tr>
<td>Inclusive Muon</td>
<td>19</td>
<td>25</td>
<td>68</td>
</tr>
<tr>
<td>Di-muons</td>
<td>7</td>
<td>4</td>
<td>72</td>
</tr>
<tr>
<td>Inclusive $\tau$-jets</td>
<td>83</td>
<td>3</td>
<td>75</td>
</tr>
<tr>
<td>Di-$\tau$-jets</td>
<td>59</td>
<td>1</td>
<td>76</td>
</tr>
<tr>
<td>1-jet $* E_T^{\text{miss}}$</td>
<td>$180 * 123$</td>
<td>5</td>
<td>81</td>
</tr>
<tr>
<td>1-jet OR 3-jets OR 4-jets</td>
<td>$657, 247, 113$</td>
<td>9</td>
<td>89</td>
</tr>
<tr>
<td>Electron $* $ Jet</td>
<td>$19 * 45$</td>
<td>2</td>
<td>90</td>
</tr>
<tr>
<td>Inclusive b-jets</td>
<td>237</td>
<td>5</td>
<td>95</td>
</tr>
<tr>
<td>Calibration etc. (10%)</td>
<td>-</td>
<td>10</td>
<td>105</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>-</td>
<td>-</td>
<td>105</td>
</tr>
</tbody>
</table>

"Low" Luminosity ($2\times10^{33}$ cm$^{-2}$ s$^{-1}$)
LPC Trigger Group Logistics

• Conveners:
  – Kaori Maeshima & GL

• LPC Trigger Group Mailing List:
  – lpc_trig@fnal.gov; to subscribe, send an e-mail to listserv@fnal.gov with a single line in the body: SUBSCRIBE lpc_trig Jane Doe ← (replace with your name!)

• LPC Trigger Group Web Site:
  – http://www.uscms.org/LPC/lpc_trig/index.html, linked from the LPC Working Group page

• Trigger Meeting Schedule:
  – Every other Thursday, 2:30-4pm, Sunrise
    • Ad-Hoc video is available via 82-TRIG
    • There is a meeting later TODAY!
LPC Trigger Group Web Site

Conveners: Greg Landsberg and Kaori Maeshima

Send e-mail to conveners:

LPC Trigger Group:

Welcome to the Trigger Group of the LHC Physics Center (LPC)! The LHC Physics Center is located at Fermilab. The goal of the LPC is to provide a center inside the United States and assist the high energy physics groups of the US that collaborate on the Compact Muon Solenoid (CMS) experiment in the preparation and analysis of LHC data. The trigger group of the LPC started in summer 2004. We have outlined goals for software development in the near term (within 2005). We are also contributing to the Volume I of CMS Physics TDR.

News:

LPC "Triggers for Physics" Workshop: October 6, 2:30-6:00pm, WH11 Sunrise room. AdHoc Video-Conferencing is available via 82-TRIG (82-8744)

Please, contact the conveners if you plan to participate

This page has been last updated on 09/30/2005 by Greg Landsberg
LPC Trigger Group Mission

• Play a leading role in the development, tuning, monitoring, and commissioning of Level 1 Triggers (LOT), High-Level Triggers (HLT), and related tools for the CMS experiment

• Develop a well-defined and realistic trigger table tailored for high-priority physics topics, commissioning, and calibration of the CMS detector by summer 2007

• Take a leading role in the ongoing effort of setting-up, commissioning, and operation of the CMS Remote Operation Center (ROC) at Fermilab

• All these efforts are pursued with close coordination with other working groups, e.g., OSG (online selection), EVF/DQM (Event filtering/Data Quality Monitoring), Trigger/DAQ, Detector-Sub-Groups, Offline, PRS, etc
Summary

- CMS Trigger system reduces the rate by an overall factor of roughly $10^6$ while maintaining good efficiency
- Level-1:
  - First factor of 1000
  - Hadronic $\tau$ trigger implemented
  - Sliding window jet triggers
  - Isolated and non-isolated lepton triggers (without central tracking)
  - 128 trigger lines available
- HLT:
  - Second factor of 1000
  - Access to full event information
  - Partial reconstruction based on the calorimeter and muon systems initially (verify and improve Level-1 decision), followed by pixel + tracker information for final rejection
- Lots of flexibility in both Level-1 and HLT; lots of work to do!