High-Level Trigger Studies

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CMS has a multi-tiered trigger system:

- **L1** reduces rate from 40 MHz to 100 kHz
  - Custom hardware processes calorimeter and muon data to select $e$, $\gamma$, muon, jet, $E_T$, $\not{E}_T$ above threshold

- **L2, L3, ... (HLT)** reduces rate from 100 kHz to 100 Hz
  - Commercial CPU farm runs online programs to select *physics channels*

The CPU farm is fed by an Event Builder composed of readout buffers and a large network switch.
The DAQ/HLT Challenge

DAQ hardware needs sufficient bandwidth
- Total event size is 1 MB, event rate is 100 kHz
- Bandwidth limited by switch and link technology

HLT selection algorithms must keep only 1 event per 1000
- Limited by ability to filter a L1 data sample which is already rich in physics

These two needs are coupled. The needs of HLT drive the hardware, but hardware limitations drive the HLT algorithms

Require “On-Demand” Reconstruction \(\Rightarrow\) ORCA
- Pull data through switch only as needed (partial event reconstruction), and process only what is needed to keep the HLT latency low
The Physics Groups

Four Physics Reconstruction and Selection (PRS) groups were established by CMS in April, 1999

- Electron/Photon: C. Seez
- Muon: U. Gasparini
- Jet/Missing $E_T$: S. Eno
- $b/\tau$: A. Caner

Overall coordination by P. Sphicas

US-CMS has substantial involvement in the Electron/Photon, Jet/Met and Muon groups

- Focus of the Calorimeter, Endcap Muon, and TriDAS construction project communities

The charge is to evaluate the full chain from L1 to offline on the physics capability of CMS

- Design and implement the algorithms and software to provide the necessary rejection in the L1 and HLT triggers and to keep the efficiency high for the CMS physics plan
The L1 Trigger TDR is targeted for November, 2000

- Still to need to pin down some parameters of the Muon and Calorimeter triggers based on these studies

The DAQ TDR is targeted for November, 2001

- Need to understand the rejection capability of the HLT triggers and the amount of data each step requires to validate possible hardware solutions

A Physics TDR is planned for ~2003

- It was actually delayed to allow for the transition to object-oriented software

In all cases, we need to validate the algorithms for the CMS physics plan, taking into account all possible backgrounds
Collaboration decided to deploy Object-Oriented software ⇒ ORCA

⇒ HLT studies should be performed in this environment
⇒ ORCA provides “On-Demand” reconstruction
⇒ No reason in principle why online code should differ from offline code (other than source of data), except that CPU farm has fixed time constraints

First HLT milestone for Physics Groups:

⇒ For November 1999, show that we can get a factor of 10 rejection of the L1 triggers using only 25% of the event data
  □ Calorimeter and muon data can be used, but only a tiny fraction of tracker data
Work Plan from April to Nov. ‘99

- Write software for ORCA (in C++ as much as possible)
  - Hit generation, digitization, L1 trigger, reconstruction
- Produce large Monte Carlo samples
  - Fortran CMSIM package provides GEANT3 hits to ORCA
  - Must coordinate the CPU resources of many institutes
- Make them persistent
  - Store digitized hits in an Objectivity database
- Write user analysis jobs and produce Ntuples
- Determine L1 rates and efficiencies
  - Set the baseline
- Develop L2 algorithms
  - See what HLT can do

This was an aggressive plan for 6 months time!
Trigger and Physics Challenges

Electron/Photon:
- Primary background from $\pi^0$s
- After threshold, further rate reduction from
  - Isolation (L1–L2), track match and E/p cuts (L3)

Muon:
- Rate primarily from real muons! ($\pi$/K and leptonic b,c decays)
- After threshold, further rate reduction from
  - Isolation, topology (L1–L2)

Jet/MET:
- Rate from jet production
- After threshold, further rate reduction from
  - Refined jet algorithms, $\eta$ coverage, granularity (L1–L2)

B/tau:
- Rate reduction from tracking (L3)
- Principal challenge is how to design L1 trigger without it
Technical Challenges for U.S. Groups

Jet/MET and Electron/Photon

- Basic calorimetry code existed for the ECAL at the outset (Apr.99)
- Needed to be extended to HCAL in a unified way
- Detailed simulation for pile-up had to be introduced

(Endcap) Muon

- Basic code existed for barrel muon system at outset (Apr.99)
- Code for endcap muon system had to be written from scratch
  - Detector technology and organization is completely different, as is the entire L1 trigger chain

In All Groups

- Working environments had to be established in the U.S.
  - Manpower had to found
  - Regular meetings were arranged
  - User facility was established at Fermilab
- Data handling facilities had to be set up
  - Caltech, Florida, UC Davis
U.S. makes up a large fraction of the Physics Groups

Jet/MET Physics Group:

- Substantial U.S. contribution from 10 in all areas
  - R.Wilkinson (Caltech), D.Green & W.Wu (FNAL), E.McCliment (Iowa), S.Eno & S.Kunori (Maryland), P.Sphicas (MIT), D.Stickland & C.Tully (Princeton), S.Dasu (Wisconsin)

Electron/Photon Physics Group:

- Substantial U.S. contribution from 6 in all areas
  - S.Shevchenko & R.Wilkinson (Caltech), P.Vikas (Minnesota), P.Sphicas (MIT), D.Stickland & C.Tully (Princeton)

Muon Physics Group:

- Substantial contribution from 7 in all areas
  - R.Wilkinson (Caltech), P.Sphicas (MIT), R.Breedon & T.Cox(UCDavis), B.Tannenbaum (UCLA), D.Acosta & S.M.Wang (UFllorida),

A unique opportunity to have lead role in CMS physics studies
Jet/MET and $e/\gamma$ HLT Accomplishments

- A complete simulation, reconstruction, and analysis chain in ORCA was set up by the Nov. 1999 milestone
  - Considerable U.S. involvement in meeting this milestone
  - U.S. needs software engineering support for training and guidance

- Large MC data sets generated by Caltech
  - Installed into Objectivity database at CERN
  - Being made available at FNAL user facility (limited by manpower and resources)

- L1 Trigger rates and efficiencies determined

- L2 algorithms developed
  - EM clustering, isolation, $\pi^0$ rejection, bremsstrahlung recovery
  - Jet algorithms, $\tau$ identification
  - Typical rejection factors in 3-10 range
# L1 Jet Trigger Rates

## L1 Rates Verification with ORCA at $L=10^{34}\text{cm}^{-2}\text{s}^{-1}$

<table>
<thead>
<tr>
<th>Triggers</th>
<th>ORCA, Individual rates, (cum. rates) kHz</th>
<th>CMS TN 1998/027 cmslm111, Ind. rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 J, $\text{Et thr} &gt; 100 \text{ GeV}$</td>
<td>1.7 (1.7)</td>
<td>1.5</td>
</tr>
<tr>
<td>2 J, $\text{Et thr} &gt; 60 \text{ GeV}$</td>
<td>1.8 (2.7)</td>
<td>1.2</td>
</tr>
<tr>
<td>3 J, $\text{Et thr} &gt; 30 \text{ GeV}$</td>
<td>2.8 (4.4)</td>
<td>2.3</td>
</tr>
<tr>
<td>4 J, $\text{Et thr} &gt; 20 \text{ GeV}$</td>
<td>2.9 (5.5)</td>
<td>2.6</td>
</tr>
<tr>
<td>$\text{miss Et &gt; 80 GeV}$</td>
<td>1.1 (6.2)</td>
<td>1.2</td>
</tr>
<tr>
<td>Scalar $\text{Et &gt; 400 GeV}$</td>
<td>2.2 (7.1)</td>
<td>0.3</td>
</tr>
</tbody>
</table>
L2 Single e/γ Trigger Rate

- Rejection factor in range 3-10
- Efficiency about 94%
- Higher statistics needed
Muon HLT Accomplishments

- A complete simulation, reconstruction, and analysis chain in ORCA was set up for (barrel) muon studies by the Nov. 1999 milestone (but just barely…)

- About 100,000 background events (min. bias and W/Z) were generated

  - Single muon weighting scheme developed at CERN
    - Reduces colossal data sets, but slight bug found later…
  - Florida, UC Davis, and Italian groups produced samples

- Objectivity database at CERN filled with digitized hits

- Standard analysis Ntuples created

- Preliminary results on L1 and L2 rates and efficiencies were obtained
Muon L1 and L2 Rates

Using only \( \mu \)-chamber data (barrel)

<table>
<thead>
<tr>
<th>( p_t^{thr} )</th>
<th>L1 rate</th>
<th>L2.1 rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 GeV</td>
<td>28 kHz</td>
<td>12 kHz</td>
</tr>
<tr>
<td>20 GeV</td>
<td>8 kHz</td>
<td>2.6 kHz</td>
</tr>
<tr>
<td>30 GeV</td>
<td>5 kHz</td>
<td>1 kHz</td>
</tr>
<tr>
<td>40 GeV</td>
<td>3 kHz</td>
<td>550 Hz</td>
</tr>
<tr>
<td>50 GeV</td>
<td>2 kHz</td>
<td>320 Hz</td>
</tr>
</tbody>
</table>

Factor 2–6 rejection from improved \( p_T \) resolution
Endcap Muon Accomplishments

- First release of core reconstruction software for endcap muon system was completed by Nov. 1999
  - Includes geometry, digitization, persistency, L1 trigger
  - But the integration of all these packages is still ongoing…
  - Offline OO track reconstruction is under development now

- HLT studies were hampered by the need to get the reconstruction software written despite a small (and inexperienced) group

- Endcap Muon community needs software engineering support to help guide this development and make it more robust and efficient

- Nevertheless, preliminary physics results on the endcap L1 trigger performance were derived from CMSIM and non-ORCA software for the Nov. 1999 milestone
  - Needed for L1 Trigger TDR to validate scheme
Rate is for $L=10^{34}$

Target rate of 1kHz per unit rapidity can be met with a threshold of 15 GeV only for a 3-station sagitta measurement

L1 hardware needs to be modified to include this feature
Conclusions

U.S. took a lead role in HLT studies, and in a short period of time delivered software and results

- Very preliminary results show an L2 rejection factor of $\approx 5$

Although substantial progress shown, the DAQ-HLT milestone was not met

- Needed more time for code to stabilize, and to develop HLT algorithms
- Lacked sufficient manpower and resources
- Completion of first milestone is expected by June 2000
- Future milestones should demonstrate that 100 Hz DAQ rate is feasible with high physics efficiency (June 2001)

User facilities and software/computing support is essential for U.S. physicists to maintain prominent role