Calorimeter Trigger* -- W. Smith

• Simulation Results
• Hardware Developments

Common Projects -- R. Loveless

Muon Project -- D. Reeder
Wisconsin Senior Personnel Responsibilities

D. Reeder
• Acting US CMS Spokesman
• CMS Management Board
• US CMS Collaboration Board Chair
• US CMS Steering Committee
• US CMS Project Management Group
• US CMS Executive Committee

W. Smith
• CMS Trigger Project Manager
• CMS Steering Committee & Management Board
• US CMS Trigger Level 2 Manager
• US CMS Steering Committee
• US CMS Project Management Group
• LHC Electronics Board

R. Loveless
• US CMS Common Projects Level 2 Manager
• Endcap Muon System Technical Coordinator
• CMS Technical Board
• US CMS Steering Committee
• US CMS Project Management Group
U. S. Trigger Organization

W. Smith,
Wisconsin
CMS Trig. PM
Level 2
Manager

J. Hauser,
UCLA
Level 3
Manager
Muon Trigger

P. Padley
Rice
Port Cards
Clock &
Control

J. Hauser
UCLA
Sector
Receiver

D. Acosta
U. Florida
Sector
Processor

J. Lackey
Wisconsin
Engineering

W. Badgett
S. Dasu
Wisconsin
Simulation
Trigger Project Management

CMS Annual Reviews

- **April: TriDAS Status**
  - Progress, draft R&D plans & expenses for next year
- **November: TriDAS Internal Review**
  - R&D Plans/Progress, Cost & Schedule, Milestones
  - Finalize R&D plans & expenses for next year
  - Internal CMS Review w/CMS referees
- **Internal Electronics Reviews by LHC Electronics Board CMS Reps.**
  - G. Hall (Imperial), G. Stefanini (CERN), W. Smith (Wisc.)
  - Reports to CMS Management Board (next trigger review in Fall '98)

US Reviews/Reporting

- **Monthly Video Conferences:**
  - Florida, Rice, UCLA, Wisconsin, Davis (sim)
  - Review Progress, milestones, simulation activities
- **Integration Meetings:**
  - Calorimeter Trigger: FNAL, Maryland, Wisconsin
  - Muon Trigger: Ohio, Florida, Rice, UCLA, Wisconsin, others.
- **Annual Site Visits:** Florida, Rice, UCLA
CMS Task Support

Infrastructure Grant
- HP-RISC Processor Farm
- Scopes
- Pulse Generators
- Test Equipment
- (augmented by SSC equipment)

Mentor Graphics Grant
- Full CAD Software Suite

UW 95-96 Support of Personnel
- J. Lackey
- S. Dasu
- PSL Engineering

UW Equipment Support
- Teleconference Equipment
- Video Room Remodeling
- CAD Printers

UW CAD support
- Purchase of Visula PCB Suite
- Includes specialized high speed router
- New version of Zeus trigger design suite
CMS Trigger Levels

Level-1. Specialized processors
- Particle ID: electron/γ, muon, jets, missing $E_T$
- Coarse granularity to reduce data volume
- Local pattern recognition and energy sums

High trigger levels. CPU farms
- Clean particle signature (Z, W, quarks..)
- Finer granularity precise measurement
- Kinematics. Effective mass cuts and topology
- Track reconstruction and detector matching
- Event reconstruction and analysis
Calorimeter Triggers
(Wisconsin Design)

**Electron:**

Shower Profile Cuts:
- HAC Veto
- Neighbor $E_t$ Veto

**Jet:**

- $\Delta \eta, \Delta \phi = 0.348$

**Jet $E_t$ from sum of ECAL & HCAL trigger tower $E_t$ in non-overlapping 4x4 regions (also used for $E_x, E_y, E_t, E_t^{\text{Miss}}$)**

Use multijet triggers
Jet candidates are sorted to find highest energy jets

**3 x 3 sliding window centered on ECAL/HCAL trigger tower pairs**

Tower count = $72 \phi \times 54 \eta \times 2 = 7776$
Simulation programs

**FASTSIM - Fast simulation of event response**
- Simplified CMS geometry, uniform tracking medium, meson decays & parameterized calorimeter showers

**CMSIM - Version 111**
- CMS standard GEANT based detector simulation
- Detailed calorimeter geometry, average tracker

**PYTHIA - common for FASTSIM/CMSIM**
- QCD background events are used for rate studies.
- High $P_t$ signal events, e.g., top, Higgs and SUSY particle decays, are used for efficiency studies.
- Noise hits are superposed with high $P_t$ events.
- Minimum bias included - FASTSIM minbias is added for both CMSIM and FASTSIM.

**Trigger simulation - common for FASTSIM/CMSIM**
- Various digital scales with limited resolution and dynamic range involved in the trigger system are fully implemented.
- Algorithms are performed in integer arithmetic using memory lookup tables when needed.

**Wisconsin Role:**
- FASTSIM & CMSIM Trigger Code Author: S. Dasu
- Upgrade of FASTSIM & New CMSIM: W. Badgett
Integrated rate above $E_t$ cut is plotted versus $E_t$ cut. All four, i.e., finegrain, HAC veto, neighbor HAC veto and quiet neighborhood, cuts are included.

For 25 GeV $E_t$ cut, CMSIM rate is 9 kHz versus to 4 kHz in FASTSIM.
Electron/photon Efficiency

Efficiency for triggering top to electron decay events is plotted versus the P_t of the electron for various cuts.

Identical values for the four cut parameters yield similar efficiencies - custom tuning was not necessary.

All efficiencies are over 90%.

Note: drop at high E_t is artificial. Actual trigger removes conditions at high E_t.
Physics at high luminosity
Wisconsin Simulation for Luminosity = $10^{34}$ cm$^{-2}$ s$^{-1}$

<table>
<thead>
<tr>
<th>Trigger Type</th>
<th>Trigger Et Cutoff (GeV)</th>
<th>Rate (kHz)</th>
<th>Process</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>CMSIM</td>
<td>FASTSIM</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Individual</td>
<td>Incremental</td>
<td>Individual</td>
<td>Incremental</td>
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<tr>
<td>Sum Et</td>
<td>400</td>
<td>0.3</td>
<td>0.3</td>
<td>0.4</td>
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<td>Missing Et</td>
<td>80</td>
<td>1.2</td>
<td>0.9</td>
<td>1.7</td>
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<tr>
<td>Electron</td>
<td>25</td>
<td>11.4</td>
<td>9.3</td>
<td>4.5</td>
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<tr>
<td>DiElectron</td>
<td>12</td>
<td>2.1</td>
<td>1.8</td>
<td>1.0</td>
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<tr>
<td>Single jet</td>
<td>100</td>
<td>1.5</td>
<td>1.0</td>
<td>2.0</td>
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<tr>
<td>Dijet</td>
<td>60</td>
<td>1.2</td>
<td>0.7</td>
<td>1.9</td>
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<tr>
<td>Trijet</td>
<td>30</td>
<td>2.3</td>
<td>1.3</td>
<td>3.1</td>
</tr>
<tr>
<td>Quadjet</td>
<td>20</td>
<td>2.6</td>
<td>1.1</td>
<td>3.3</td>
</tr>
<tr>
<td>Jet+Electn</td>
<td>50 &amp; 12</td>
<td>1.3</td>
<td>0.3</td>
<td>0.7</td>
</tr>
<tr>
<td>Cumulative Rate</td>
<td></td>
<td>16.7</td>
<td></td>
<td>12.4</td>
</tr>
</tbody>
</table>

**QCD Background**

The sum & missing $E_t$ cutoffs chosen to yield 2 kHz rate.

Electron/photon triggers are emphasized, ~8 kHz rate out of total available 15 kHz.

Remaining 5 kHz available for jet triggers.

**Signal Efficiency** (no offline cuts)

High efficiency for all channels with electrons and photons.

The difficult-to-trigger top decay events have high efficiency, enabling studies of associated Higgs production.

*Inclusion of muon trigger gives full efficiency.
Calorimeter Trigger Overview
Wisconsin Responsibility Circled

4K 1 Gb/s serial links with:
2 x (8 bits EM or HAC Energy) + 5 bits error detection code
(+ fine grain isolation (or H1) bit)
72 φ x 54 η Towers (.087x.087ea.) every 25 ns.

US CMS HCAL:
FNAL/ Maryland

Calorimeter Electronics Interface

CMS ECAL:
Lisbon/ Palaiseau

US CMS HCAL:
U. Nebraska

US CMS HCAL:
U. Nebraska

US CMS Trigger:
U. Wisconsin

Calorimeter Regional Trigger
(WBS 3.1.2)
Receiver
Electron Isolation
Jet/Summary

Copper 40 MHz Parallel
4 Highest E_{t_{e/γ}}
4 Highest jets E_{x,y}
from each crate

E_{t_{sums}}

Cal. Global Trigger
Sorting, E_{t_{Miss}}, \Sigma E_{t}

Luminosity Monitor

Global Trigger Processor

Muon Global Trigger
Iso Mu Minlon Tag

Luminosity Monitor

Minlon Tag for
each 4φ x 4η region
Data from calorimeter FE on Cu links @ 1.2 Gbaud

- Into 152 rear-mounted Receiver Cards (proto. being built)

160 MHz point to point backplane (proto. built)

- 19 Clock&Control (proto. built), 152 Electron Identification, 19 Jet/Summary Cards & Receivers operate @ 160 MHz
3.1.2.8: Receiver Card
(prototype being built by U. Wisconsin)

Rear:
32 Channels =
4 Ch. x 8 mezzanine cards
1.2 GBAud copper rcvrs
18 bit (2x9) data + 5 bit error
Vitesse Chip:
  Converts Serial to Parallel

Front: Data from Rear @ 120 MHz TTL
Phase ASIC: Deskew,Mux @ 160MHz
  Error bit for each 4x4, Test Vectors
Memory LUT @ 160 MHz
Adder ASIC:
  8 inputs @ 160 MHz in 25 ns. (built!)
Differential Output@160 MHz
Vitesse 0.6\(\mu\) H-GaAs Process: ECL I/O

- 13 bits per operand x 8 operands
- Single thirteen bit output
- Latency: 25 ns @ 160 MHz
- Full Boundary Scan support

Technical analysis by Vitesse

- ~11,000 cells
- 4 Watts
- 308 MHz

Status:

- 5 tested devices delivered
- select nets exceed simulation speed by 10%

- J. Lackey
Receiver Card Prototype

Card built, assembly next
Monolithic 9U High Backplane

- Incorporates std. 32 bit VME in top connector position
  - Single 128 pin DIN in Trigger Processor Card area
  - Two 96 pin DIN connectors in left most slot positions
- Data sharing on backplane
  - Reduces the number of receivers, serial to parallel convertors, and synchronizing circuits
- Stripline construction w/ five ground and power planes
  - 50 Ω impedance to match connectors and boards
  - 1 oz. copper with multiple power points
- Five signal layers
  - Handles routing density thru connector pins
  - Differential pairs are held to the same layer
  - Point to point on high speed data paths @ 160 MHz
Prototype Clock Board

switches to set delay lines

synch & reset

clock

Delay Lines

Drivers

1: Rcvr-E.I. 2: clk-sync 3: clk-reset

4 Recvr Cards, 4 Electron Iso, 1 Jet/Sum

- J. Lackey & M. Jaworski
U. Wisconsin
Display 3 of 5 signal layers:
(most signals are hidden by top layer)

Board layout:
(Alternate connectors on opposite sides)
Backplane Test Setup

Top rear view of crate & backplane with power supplies

Front view of crate & backplane with clock board installed
Conclusions:

- Output of backplane rise 820 ps
- Output of backplane fall 840 ps
- Measured 20% to 80%

*one side of differential pair
CMS Cal. Trigger '98/'99

**Full dataflow tests**
- Receiver Card Prototype
- Backplane Prototype
- Electron Identification Card Prototype

**Electron Isolation ASIC**
- Design in Vitesse GaAs
- Produce Prototype

**Prototype Jet Summary Board**
- Trigger data summary generation
- Data transmission to global cal. trig.

**Intercrate data transfer**
- Second crate & backplane
- Test transmit/align techniques

**System Design**
- Interfaces to HCAL & ECAL (Geometry)

**Detailed Simulation**
- Update/improve full GEANT - CMSIM
- Verify against fast simulation results
- Study processing of level 1 by higher levels
- study b-physics triggers
- use of quiet regions by muon triggers
TRIDAS:

"The U.S. CMS Trigger and Data Acquisition groups have made excellent progress since the previous Lehman Review. The effort has strong leadership in place and is capable of meeting their obligations to CMS."

Trigger:

"The Trigger group is well advanced in design and has a clearly defined path to completion"

Simulation:

"The trigger simulation studies...provided estimates of the overall Level 1 trigger rate which are important for justifying the reduction in the Level 1 trigger rate and associated DAQ bandwidth from 100 kHz to 75 kHz."

Technical, Cost & Schedule:

"The Trigger project is well advanced and have developed detailed planning and reference documentation...the Trigger and DAQ groups are well managed and have clear mechanisms in place for decision-making and for reporting and monitoring expenses."
Conclusions

CMS Regional Calorimeter Trigger

• Inputs on 1.2 Gbaud Cu serial links
  • 8-bits energy & 1 bit fine grain/trigger tower
  • Careful mapping of calorimeter towers into trigger logic

• Receiver Card scales, sums, preprocessed
  • Prototype being manufactured
  • Designed to receive data from serial links
  • Designed to operate @ 160 MHz
  • 13 x 8 bit Adder ASIC tested > 160 MHz

• Backplane for VME & trigger data
  • Prototype constructed/tested
  • Prototype Clock Card constructed/tested
  • Signal performance excellent @ 160 MHz
  • Confirmation of design feasibility

• Electron Isolation & Jet Summary Cards
  • Receive data from Backplane
  • Algorithms matched to data & physics
  • Next on development plan

• Simulation & Hardware Plans for '98/'99
  • Comprehensive program