CMS: Present Status, Limitations, and Upgrade Plans

Harry W. K. Cheung
for
The CMS Collaboration
Rediscovering the Standard Model at 7 TeV

- Great performance of the CMS Detector so far
Rediscovering the Standard Model at 7 TeV

- Of course nothing is perfect...
The CMS Experiment

- Current status and review of performance given in Ettore Focardi’s talk on Friday 14:00
Of course, the normal expected problems

- Usual: Not all channels are working, e.g. for pixel detector

  - One ROC no-signal: 1/192 (0.5%)
    Recoverable.
  - Too Low signal amplitude (TBM): 1/192 (0.5%)
  - No signal output: 1/192 (0.5%)
  - Slow panels: 5/192
  - No I2C communication with AOH: 6/192 (3.1%)
Some less expected problems

- Beam gas interactions in the straight session of the LHC close to the experiment generates shower of particles that enter the pixel detector along the beam line. (“PKAM events”)
  
  - Large number of pixels above threshold in the barrel if the track hits the sensor, generating many hits in a single readout channel causing timeouts.
  
  - Visible since early 900 GeV collisions and scales with beam intensity.
  
  - Implemented new FED firmware to dump the long events and holdoff triggers. Initially took some time to understand the problem.
Some less expected problems

- **Anomalous ECAL Signals**
  - In collision data we observe anomalous signals in barrel ECAL where the readout is by APD (avalanche photodiode), having the appearance of large energy deposits in a single crystal.
  - The origin of the signal is energy deposited by heavily ionizing particles in the APD.
  - At the cluster level the anomalous signals appear as energy in a single crystal, while in e.m. showers the energy is typically shared between neighbouring crystals. This fact is used to tag anomalous signals.

MC without recording interactions in the APD as hits
Focus on issues relevant to upgrades for Phase 1

- Old 10 year plan: luminosity profile (from July 2010)
  - 2/3rd of data collected in Phase 1 will be with $>10^{34}$ cm$^{-2}$s$^{-1}$
  - CMS designed for $10^{34}$ cm$^{-2}$s$^{-1}$; Limitations operating above this
  - Upgrade to CMS to maintain performance

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Phase 1
Upgrade with constraints imposed by running experiment, maybe with “discovery in progress”

Phase 2
Upgrade to Muon Systems

- Upgrade driven by effect of peak instantaneous luminosity on muon trigger and by maintenance

Work on DT trigger boards:
Replace failing ASICs in theta boards with FPGAs (improves resolution); recover ASICs for spares; move parts of trigger to low radiation/magnetic field region

New RE4 RPC

New ME4/2 CSC

Work on ME1/1 and trigger

Extend eta range of RPC
L1 Muon Rate Limitations at High Luminosity

- Need 3 hits to reduce L1 rates (better $p_T$ resolution), need 4 chambers to keep high efficiency
- Remove 3-to-1 ganging of ME1/1 to lower L1 rates
- Replace CSC trigger board (FPGA) to increase efficiency over all CSC eta range
Upgrade to Muon CSC and RPC Endcaps

- Additional 4\textsuperscript{th} chamber for RPC increases RPC trigger efficiency
- Projected improvement in muon L1 trigger for \(2 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}\)
  - RPC Trigger optimized for high efficiency

R&D for GEM extension of RPC eta range see talks: Paul Karchin and Tania Moulik on Monday
Upgrade to Hadron Calorimeters

- Upgrade driven by effect of peak instantaneous luminosity, robustness, efficiency, trigger

- Replace HPD in HB/HE/HO with SiPM
- Add timing (TDC) to HB/HE
- Replace PMT with MAPMT in HF
- Replace PMT with more radiation tolerant PMTs in CASTOR

Depth segmentation in HB/HE

TIPP 2011 - H.W.K.Cheung
Anomalous/Noise Signals in HB/HE/HO

- Electronics noise from the Hybrid PhotoDiode (HPD) and Readout Box (RBX) used for HB, HE, and HO, (worse in HO due to 0.2-0.3T region, need to run at lower HV)
- The HPD has 18 channels/device; There are 4 HPDs in a RBX
  - HPD and RBX noise is random and the overlap with physics is very low, and HPD/RBX noise produce distinct patterns in HCAL
  - Filters have been developed making use of hit patterns, timing, pulse shape, and EM fraction
- Replace HPD with Silicon PhotoMultiplier (SiPM)
  - Essential for HO; Enables HB/HE upgrade for robust and efficient operation
Upgrades to HB and HE

- See Jake Anderson’s SiPM HO upgrade talk on Friday
- SiPM provides much better S/N to deal with increased occupancy (poorer timing determination and isolation)
  - Can split signal to TDC (reduce background/noise contributions)
  - Can give longitudinal segmentation (x4) for readout
    - Electron isolation (e/π) and triggering; muon isolation and id
    - Compensate for radiation damage in front/inner part of HE

Using timing to clean MET in CDF
Upgrades to HB and HE

- R&D still needed
- SiPM specifications (esp. rate for HE/HB)
- Optimization of FE/electronics (readout, trigger, infrastructure)
- Simulation studies

Isolation efficiency for background jet sample at low lumi (2 segments)
Anomalous Signals in HF (Forward Calorimeter)

- HF Extends eta coverage from 3 to 5; For tagging jets, missing $E_T$, and determining luminosity (e.g. VBF Higgs, 70% of signal have a jet >30GeV in HF)

- Quartz fibers in iron. Long fibers: extends for the full length of HF. Short fibers: start at a depth of 22cm from the front of HF (separate readout)

- Low amount of Cherenkov light from quartz readout fibers. Cherenkov light produced by interactions in the window of the HF PMTs

- Glass window thickness in the center is ~1mm increasing to ~6.1mm on the edge

150 GeV muon looks like a 120 GeV jet; seen in test beam

In collision running, can get “1 TeV jet” PMT events.

Dominant sources are muons from decays in flight and hadron shower punch through
Anomalous Signals in HF (Forward Calorimeter)

- Most of the HF PMT hits can be identified based on the energy sharing between the Long and Short fibers. Filters have been developed to effectively remove anomalous signals with little impact on real energy deposits.

- Can tag PMT events offline but only with 80% efficiency, not sufficient for very rare processes.

- Replace with thinner window (<1mm) MAPMT (4 anodes); pattern of light used to eject PMT events with 96% efficiency in test beam.

Other anomalous HF pulses from scintillation in mirror sleeve; sleeves replaced Jan. 2011. New connection with non-scintillating material for upgrade.
Upgraded Pixel Detector Replacement

- Upgrade driven by instantaneous luminosity, robustness, efficiency
  - Pixel readout chip (ROC) just adequate for $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ with 4% (16%) dynamic data loss at 25ns (50ns) crossing time (due to readout latency and buffer)
    - At $2 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ data loss is 15% (50%) for crossing time of 25ns (50ns)
  - Three hit coverage not hermetic, leading to 10-15% inefficiency when requiring 3-of-3 hits in high luminosity environment. This limits HLT tracking trigger efficiencies and slows tracking algorithm
  - Inner regions need replacement before the end of Phase 1 when $\sim 350 \text{ fb}^{-1}$ data will have been collected
Upgraded Pixel Detector Replacement

- Replace with new pixel detector with additional layer using redesigned ROC, and higher BW readout and DC-DC converters to reuse current cables and fibers
- Reduce material by using CO$_2$ cooling instead of C$_6$F$_{14}$, lighter construction, and relocating services out of tracking volume
- Smaller diameter beampipe; first layer closer to IP

4$^{th}$ barrel layer closer to strip detector to help mitigate any losses for inner strip layer
Simulations of Upgraded Pixel Detector

- Simulations with Geant4 for $2 \times 10^{34}$ cm$^{-2}$s$^{-1}$ @ 25ns including data losses in ROC

Tracking efficiency and track fake rates

b-tagging performance

20% gain in tagging b-jets at same 1% light quark mistag

See poster by Pratima Jindal, Friday/Monday in room Chicago 6&7 for more details
Reduce Material in Upgraded Pixel Detector

- Affects track resolutions and photon conversions

Can see effect of 18 cooling pipes in resolution of low momentum tracks

R&D involved for all components:
ROC itself and digital readout; CO$_2$ cooling components and system; ASIC for rad-hard DC-DC converter; rad-hard sensors; simulation of layout
Phase 1 Trigger Upgrade

- Upgrade driven by instantaneous luminosity, other subdetectors, robustness
- Keep L1 at 100 KHz, so extra data to be handled by DAQ
  - Regional calorimeter trigger to use full granularity for internal processing, and more sophisticated clustering and isolation algorithms to handle higher rates and complex events (e.g. improved position resolution and trigger performance)
  - New infrastructure based on μTCA for increased BW, maintenance, and flexibility
  - Upgrade to muon trigger to handle addition channels, plus faster FPGA
Other Subsystem Upgrades

• Upgrade to DAQ to address larger data sizes and readout channels, additional HLT processing resources, reliability

• See talk from Frans Meijers on Saturday

• Additional upgrades
  - Beam instrumentation and luminosity monitoring, includes R&D on suitable detectors, and updates to cavern simulation
  - Lots of work on CMS common systems, infrastructure and facilities
    - E.g. experimental beam pipe, safety systems, utilities, shielding
  - We have produced a Phase 1 Technical Proposal document with some details
Some Words on the Schedule

- “Old” 10 year technical Plan from July 2010
- Real schedule likely to change a number of times
Schedule will be Driven by Physics

- New draft 10 year plan (Steve Myers, 3/8/2011 SLHC-PP)

- LS1 (Long Shutdown 1)
  - New beampipe, PLT DT electronics relocation, Fwd mu (CSC4,RE4, ME1/1), HO SiPM, HF PMT, CASTOR

- LS2 (Long Shutdown 2)
  - "driven by expts" (2019?) HB/HE SiPM and segmentation, Pixel replacement, Trigger, DAQ

- LS3 (Long Shutdown 3)
  - Also expect to use technical stops (winter shutdowns)
Phase 2 Upgrade R&D

- Builds on Phase 1 upgrade work
- Replace tracking system to handle $5 \times 10^{34}$ cm$^{-2}$s$^{-1}$ and 3000 fb$^{-1}$; includes producing L1 track trigger
- R&D on sensors, ASICs, data links, power distribution, CO$_2$ cooling, trigger functionality

Talks from Selcuk Cihangir, Lenny Spiegel, Giuseppe Broccolo; and posters by Stefano Mersi, Pramod Lamichhane

- Work on EB; and forward EE, HE, HF
- New muon electronics, MPGDs for RPC
- Trigger electronics upgrade, increase L1 latency X2, integrate L1 tracking trigger

Single muon L1 trigger at $5 \times 10^{35}$ cm$^{-2}$s$^{-1}$ needs tracking information; motivates L1 tracking trigger
Summary

- CMS is working well and expectations are great for making the most of the LHC luminosity *(as we have done so far)*
  - There have of course been some problems; many of which are expected for a new experiment
  - We had our share of more interesting problems which we have solved/managed, a few were presented
  - Some of these, and some others will be relevant at Phase 1 luminosities and require upgrades
- Described the proposed upgrades for CMS during Phase 1: covering the driving factors, the proposal of changes, constraints, and R&D needed
  - See the other talks/posters at this conference for more details
- We have produced a Phase 1 upgrade technical proposal document
- The proposed changes should prepare the CMS detector for coming challenges and (additional) discovery opportunities to come!