CMS HCAL Phase1 Upgrade

Seth I. Cooper (Alabama)
for the CMS HCAL group

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CMS Hadron Calorimeters

CMS in Run 1: 5/fb at 7 TeV, 20/fb at 8 TeV; 50 ns bunch spacing; up to 30 vertices/pileup

Plan for Run 2: ~13 TeV, up to 3000/fb; 25 ns bunch spacing; up to 100 vertices/pileup. Upgrade to maintain (even improve) high performance.
HB/HE/HO Performance

HB, HE, HO use HPD photodetector
- Operates in strong B-field (3.8 T CMS solenoid)
- Gain > 2000

Drawbacks:
- Requires large E-field (8 kV over 3 mm gap)
- Electrical discharges in B-field
- QE*gain drifting

Issues particularly affect HO (fringe field)

HPDs discharge regularly (this is a good/typical HPD)

Ion Feedback
- HPD in 4T B-field, self triggered in lab

HB/HE HPD gain drift

![HPD](image.png)
HF uses PMTs to capture Cherenkov light
However, anomalous signals were observed even before Run 1.
• Hits of particles on PMT windows from in-flight decays or shower particles
• Early arrival: 5 ns before Cerenkov light
In Run 1 at 50 ns bunch spacing, the HF readout phase was adjusted to move these signals to the previous, empty bunch crossing.
During Run 2, at 25 ns bunch spacing, each crossing will potentially contain real signals, so this strategy no longer works.
Phase 1 Upgrade

Replace HPDs with SiPMs (HB/HE/HO)
- Reduce background, pre-empt potential failures, better signal to noise (allow increased longitudinal segmentation)

Upgrade PMTs to new models
- Reduce anomalous signals

New front-end electronics
- Include TDC capability (background rejection)
- Faster data link, more channels
- Better radiation hardness
- Increase redundancy of control path

New back-end electronics
- Handle increased data-volume
- Move from VME to uTCA architecture
Timeline


HBHE: 2014-2016

HF: LS1 (2013-14)

YETS (2015/16)

LS1 (2013-14)
SiPM Performance (HB/HE/HO)

Array of Geiger-mode operated micron-size APD pixels

Voltage under 100 V, gain 10000

Compact, B-field insensitive

Recovery time < 10 ns (no response shift vs. pileup)

Radiation tolerant

- Requirement is 100 Gray, $7 \times 10^{11}/\text{cm}^2$ neutron
- Expected dose is 14 Gray, $2 \times 10^{12}/\text{cm}^2$ neutron
- Neutrons: bulk damage, dark current increase. Tolerate up to 200 µA for 2.2 x 2.2 mm SiPM array

Gain depends on temperature

Prototype SiPM module
Increase number of channels and longitudinal segmentation with SiPMs
- Improve suppression of pileup particles (inner layers)
- Recalibrate gain losses due to radiation damage (inner layers)
- Finer granularity of shower development
Upgraded PMTs (HF)

Multi-anode readout
- 4 anodes read out into 2 channels allows identification of anomalous signals

Thinner glass windows
- 4x decrease in anomalous signals

Cherenkov light from showers fires all channels

Anomalous signals fire one channel

Recover signal from unaffected channel.
Front-end: HB/HE/HF QIE

Integration and digitization of charge in 25 ns time slices

- No dead time, specialized ASIC
- TDC with sub-ns resolution
- Large dynamic range (3 fC to 330 pC, 17 bits)
- Digitization error (~2%) less than calorimeter resolution, 4 gain ranges (6 bit mantissa + 2 bit exponent)
- Radiation tolerant: 1.5 Gray expected, 100 Gray required
  - Neutrons: $2 \times 10^{11}$/cm$^2$ expected, $2 \times 10^{12}$/cm$^2$ required
  - Hadrons: $6 \times 10^8$/cm$^2$ expected, $10 \times 10^{10}$/cm$^2$ required
- 2 versions for input impedance matching:
  - QIE10 for HF PMTs (negative signals)
  - QIE11 for HBHE SiPMs (positive signals)
Front-end: Other components

FPGA: rad tolerant Microsemi ProASIC3E
- Handle data from several QIEs (sync.+formatting)

Control: next-generation CCM
- Deliver clock and controls (orbit, reset, etc.)
- Increase redundancy: each ngCCM also linked to its neighbor
Back-end

Read out both current and upgraded front-ends

Main components
- μHTR
  - Receive front-end data
  - Compute L1 trigger information, send to central calo. trigger
- AMC13
  - “13th” card in the μTCA crate
  - Build events and send to DAQ

Tested in 2013 during p-Pb collisions
Production ramping up now
Installation in 2014 for HF, 2015 for HBHE
Wrap-Up

The CMS Phase1 HCAL Upgrade will improve HCAL performance for Run 2

- Photodetectors: increase reliability, reduce anomalous signals
- Front-end: include signal timing, higher radiation tolerance, better redundancy
- Increase depth segmentation: better coping with pileup, radiation damage
- Back-end: handle increased data volume

Installation and commissioning:
HF PMTs/backend: 2013-14 (LS1)
HF front-end: 2015-16 (YETS)
HBHE backend: 2014-16
HBHE frontend+SiPMs: 2018 (LS2)
Backup
SiPM Dark Current with Neutron Irradiation

CERN IRRAD
Hamamatsu SiPMs with 15 μm cells have 25 μA/mm² dark current, (120 μA for 2.2 x 2.2 mm array) at 2x10^{12}/cm² neutrons.
Dark current → Voltage drop in HV filter resistor, gain drop
Apparent 20% gain loss for 2x10^{12}/cm² neutrons.
Remaining HF Anomalous Signals

Anomalous signals remain in new PMTs.

Need new FE with TDC to measure arrival times with resolution < 1 ns.

Level 1 calorimeter trigger rate based on anomalous signals. Derived from 24 upgraded PMTs included during 2012 run at 8 TeV using minimum bias events.
HO SiPM Readout Module

control board
light mixer
I2C bus
ADC cards
bias board
mounting board
SiPMs