"Preparation and commissioning of CMS for the run-II of LHC"

jean-louis Faure

CEA-Saclay: DSM/IRFU/SPP

on behalf of CMS collaboration

in

13th Pisa Meeting on Advanced Detectors
The CMS Detector

Total weight 14,000 t
Overall diameter 15 m
Overall length 28.7 m

- Pixel Tracker
- ECAL
- HCAL
- Muons
- Solenoid coil

- Pixels & Tracker
  - Pixels (100x150 μm²)
  - 1 m² ~66M ch
  - Si Strips (80-180 μm)
  - ~200 m² ~9.6M ch

- 3.8T Solenoid
- 76k scintillating PbWO₄ crystals
- Scintillator/brass Interleaved ~7k ch

MUON END CAPS
- 473 Cathode Strip Chambers (CSC)
- 432 Resistive Plate Chambers (RPC)

IRON YOKE
- Preshower
  - Si Strips ~16 m² 
  - ~137k ch

Forward Cal
- Steel + quartz
- Fibers 2-k ch

MUON BARREL
- 250 Drift Tubes (DT) and
- 480 Resistive Plate Chambers (RPC)
CMS Upgrade Program

LS1 Projects
- Complete muon coverage (ME4)
- Improve muon operation (ME1), DT electronics
- Replace HCAL photo-detectors in Forward (new PMTs) and Outer (HPD $\rightarrow$ SiPM)
- BRIL
- Tracker operation at $-15^\circ$ C
- DAQ1 $\rightarrow$ DAQ2

Phase 1 Upgrades
- New L1-trigger systems (Calorimeter – Muons – Global) (ready for 2016)
- New pixel detector (ready for installation in 2016/2017 Year End Technical Stop)
- HCAL upgrade: photodetectors and electronics (HF 2015/2016 YETS, HB/HE during LS2)

- Preparatory work during LS1
  - New beam pipe
  - Install test slices (Pixel, HCAL, L1-trigger)

Phase 2 Upgrades: Technical Proposal this fall
- Tracker Replacement, Track Trigger
- Endcap Calorimeter replacement
- Barrel ECAL Electronics upgrade
- Trigger/DAQ upgrade
  - Tracker & possible endcap Calorimeter, Muon extension
    - From $|\eta| = 3$ to $|\eta| \sim 4$

Current LHC schedule
LS1: January 2013 – December 2014 (24 mos)
Extended Year End Technical Stop (EYETS): December 2016-April 2017 (19 weeks)
LS2: July 2018 – December 2019 (18 mos)
LS3: January 2023 – June 2025 (30 mos)
**CMS Upgrade Program In Elba Meeting**

**Phase 1 Upgrades**
- New L1-trigger systems (Calorimeter – Muons – Gobal) (ready for 2016)
- New pixel detector (ready for installation in 2016/2017 Year End Technical Stop)
- HCAL upgrade: photodetectors and electronics (HF 2015/2016 YETS, HB/HE during LS2)

**Phase 2 Upgrades: Technical Proposal this fall**
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Talk of Fabio Ravera, Poster Paola Tropea

Talk of Davide Cieri
Talk of Geoff Hall

Poster Nicola Pozzobon

Gilles De Lentdecker, Ilaria Vai, Alice Magnani, Luigi Benussi

Poster: Sophie Mallows : Monte Carlo simulations of the radiation environment for the CMS Experiment
CMS during LS1

- **New detectors / components**
  - **RPC**: installation of new RE4 chambers
  - **CSC**: installation of new ME4/2 chambers and new on and off chamber electronics for ME1/1
  - **Trigger**: new hardware, moving on path to full trigger upgrade
  - **DAQ**: new DAQ2 (hardware and software) and new Trigger and Clock Distribution System
    - New beam pipe with smaller diameter: prepare for new pixel detector
    - New YE4 shielding

- **Detector repairs and improvements**
  - Pixels removed to repair faulty channels
  - Tracker sealing to operate at $-20^\circ$C (4C during run 1)
  - DT: readout electronics moved
  - HCAL: replacing HO HPDs with SiPMs, replacing HF PMTs, new Clock Control Modules
  - ECAL: new serial links for trigger, new laser, DAQ upgrades
General Consolidation

<table>
<thead>
<tr>
<th>Operative Channels %</th>
<th>Start of Run2 versus end of Run1</th>
</tr>
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<tbody>
<tr>
<td>CASTOR</td>
<td>97.5</td>
</tr>
<tr>
<td>CSC</td>
<td>96.24</td>
</tr>
<tr>
<td>RPC</td>
<td>97.82</td>
</tr>
<tr>
<td>DT</td>
<td>98.3</td>
</tr>
<tr>
<td>HO</td>
<td>98.6</td>
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<tr>
<td>HF</td>
<td>99.53</td>
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<tr>
<td>HE</td>
<td>99.95</td>
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<tr>
<td>HB</td>
<td>100</td>
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<tr>
<td>HCAL</td>
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<tr>
<td>ES</td>
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<td>EB</td>
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<td>Pixel</td>
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<td>97.61</td>
</tr>
<tr>
<td></td>
<td>99.39</td>
</tr>
</tbody>
</table>

94 96 98 100
Muon System in Run 2

- CMS Muon System has three sub-systems: Drift Tubes (DT), Cathode Strip Chambers (CSC), Resistive Plate Chambers (RPC)
- Removal, revision, re-installation of ME1/1 chambers
- 4th muon station added: 72 (144) new CSC (RPC) chambers
Drift Tubes for Run2

- **250 chambers**
- **172200 drift tubes**

**Chamber HV**: 312 channels recovered

**Chamber Minicrates**: 3200 channels recovered

**Sector Collector (Read-Out and Trigger)** relocated out of UXC: installed 3500 optical links that make single outputs of all 250 chambers available in USC
CSC consolidation

Present system consolidation, maintenance and repair
Repair system faults from Run 1 → recover highest efficiency. Improve system reliability (HV, LV, racks, detector infrastructure)

Completion of station 4 (ME4/2 ring 1.2<|\eta|<1.8)
Re-establish 4-station redundancy over all 0.9<|\eta|<2.4 range. Improve muon-ID efficiency and sustain high-Lumi L1 rates at a reasonably low pT threshold

ME1/1 refurbishment lab in SX5
ME1/1 chamber electronics upgrade
72 chambers extracted, refurbished and reinstalled in CMS. Increase capacity for data rate and exploit full chamber segmentation in 2.1<|\eta|<2.4 to enhance rate capability (including @ HL-LHC) and improve muon reconstruction

ME1/1 installation

ME4/2 chamber factory in B904
ME4/2 installation
RPC (RE4) for Run2

144 chambers installed

CMS CERN LHC-P5
May 2014 Cessy / France

photo by michael.hoch@cern.ch
LS1: Muon performance improvements

Trigger performance: significantly lower threshold for same rate
CSC and RPC: ME4/2 (1.25<|\eta|<1.8)
More hits, lower rates
CSC: ME1/1 (2.1<|\eta|<2.4) new digital boards and trigger cards: higher strip granularity
Electronics reliability
DT: new trigger readout board and relocation of sector collector from UXC55 to USC55 (new optical links)
Tracker running cold (-20 degrees)

Si tracker operation at -15 C commissioned (tested to -20), Pixel -20 C (tested -25)

New dry gas plant

Bulkhead with insulation

More detail in Poster of Lorenzo Viliani
New beampipe

New reduced Diam. Pipe ready for installation of upgraded pixel in 2017
HO: replacement of HPDs by SiPMs

HBHE: control modules
Replacement and misc repairs

HF: switch to multi-anode PMTs and uTCA BE electronics

New Thin window, dual-anode to reduce Cherenkov noise from punch through muons
Beam Radiation Instrumentation and Luminosity measure backgrounds, protect the experiment and measure luminosity

**BCM2L:**
- 4 pCVD diamond (inner) – beam abort
- 8 pCVD diamond (outer) - monitoring

**Si-PLT:**
- 48 si-pixel sensors
- special 40 MHz readout

**BCM1F:**
- 48 single crystal diamond sensors
- fast MIP counter, triggerless readout

**BCM1L:**
- 4 pCVD diamond – beam abort

**HF Luminosity:**
- Photo-detectors
- backend electronics

**HF Neutron RADMON:**
- Polyethylene moderator & ionization chamber

**BHM:**
- Fast PMTs, directionality
- Backend electronics

**Medipix**
- Hybrid pixelated silicon
Beam Radiation Instrumentation and Luminosity

measure backgrounds, protect the experiment and measure luminosity

**BCM2L:**
- 4 pCVD diamond (inner) – beam abort
- 8 pCVD diamond (outer) - monitoring

**HC Luminosity:**
- Photo-detectors
- Backend electronics

**Si-PLT:**
- 48 si-pixel sensors
- special 40 MHz readout

**BCM1F:**
- 48 single crystal diamond sensors
- fast MIP counter, triggerless readout

**BCM1L:**
- 4 pCVD diamond – beam abort

**Medipix:**
- Hybrid pixelated silicon

**BHM:**
- Fast PMTs, directionality
- Backend electronics

**HF Neutron RADMON:**
- Polyethylene moderator & ionization chamber

See poster Stella Orfanelli
See poster Andreas Kornmayer,
See poster Olena Karacheban
DAQ

&

Triggers
Event size up to 1MB

100 kHz L1 rate

100 GB/s

13000 core filter farm

max. 1.2 GB/s to storage

Event size up to 2MB (large margin)

100 kHz L1 rate

10/40 Gb/s Ethernet

56 Gb/s Infiniband

200 GB/s

15000+ core filter farm

~ 2 GB/s to storage
New or upgraded detectors in CMS

- Several detectors / online-systems being upgraded to cope with higher luminosity
- Increase of event size
- Readout electronics of upgraded systems based on μTCA

<table>
<thead>
<tr>
<th>Year</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>New Trigger Control and Distribution System</td>
</tr>
<tr>
<td>2014</td>
<td>Stage-1 calorimeter trigger upgrade</td>
</tr>
<tr>
<td>2014/15</td>
<td>new HCAL readout electronics</td>
</tr>
<tr>
<td>2016</td>
<td>Full trigger upgrade</td>
</tr>
<tr>
<td>2017</td>
<td>New pixel detector and readout electronics</td>
</tr>
</tbody>
</table>

SLINK sender mezzanine plugged onto VME electronics

- Fragment size 1..4 kB

SLINK-64 copper cable
- 400 MB/s

Myrinet NIC

Frontend-Readout Link

640 Legacy Links: SLINK-64
- (600 after pixel upgrade)

+ 50 new Links: SLINK-express
- (170 after pixel upgrade)

SLINK express sender = IP-core μTCA electronics

- "AMC-13" card used by many subsystems
- Fragment size 2..8 kB

Optical SLINK-express
- 4 Gb/s (soon 10 Gb/s)
- retransmit

Frontend-Readout Optical Link
DAQ2 for Run2

**Legacy readout link**
- SLINK-64

**Optical readout link**
- SLINK express

**Frontend Readout Optical Links**
- 4 Gbs
- 400 MBs

**Data Concentrator: Individual 10/40 Gb/s Ethernet switches**
- 48 x 12 (10/40 Gbe)
- 40 Gbe
- 56 Gbe IB-FDR
- 84x64 (56 Gbe)

**Core Event Builder:**
- 56 Gb/s FDR Infiniband

**Event Filter**
- attached by 1/10/40 Gb/s Ethernet

**Storage:**
- Cluster file system

**Core Event Builder (FEL):**
- Event Filter with 15000 cores
- 54 BU-FU appliances

**Surface Counting room**
- 2 x 1 Gbe FUUs
- 36 x 40 Gbe
- 10 Gbe
- FU PCs

**Optical readout link**
- 4 Gbs
- 10 Gbs

**Clos network**
- 576 Front-End Readout Optical Link (FEROL-PCix)

**Event Filter attached by 1/10/40 Gb/s Ethernet**
- 54 BU-FU appliances
- 6 x 40 Gbe
- 36 x 40 Gbe

**Storage:**
- Cluster file system
Motivation:
– New partitions required for upgrade and future detector
– Merging logically different components: L1 trigger and Timing and Control system
L1 Trigger Upgrade Calorimeters

- **Upgrade to ECAL Level-1 trigger:** change links between ECAL Trigger Concentrator Cards (TCC) and Regional Calorimeter Trigger (RCT)
L1 Trigger Upgrade: Muon Trigger

- Build up new Muon Track Finders in 2015 and commission in parallel (ready for physics by 2016)
- **Full split** of CSC signals installed and tested
- Split a **slice** of the DT and RPC signals to commission the new trigger

Also in Poster
Pierluigi Bortignon
Improvements of High Level Trigger [HLT]

8 TeV → 13 TeV
Factor ~2 in cross-section from the increased energy
Factor > 2 for multiple object triggers (due to combinatorial)

50 ns → 25 ns bunch spacing
Increased level of out of time pileup

Peak luminosity from ~7e33 cm⁻²s⁻¹ to 1.4e34 cm⁻²s⁻¹ Factor 2 in rate

Rate x 4 (at least)
In time pileup from <PU> ~ 25 (Run1) up to <PU> ~ 40 (Run2)
Out of time pileup has a much larger impact than at Run1

Reminder L1 ~ 100 kHz and HLT output rate ~1 kHz

Use of Particle Flow (PF) at the HLT level

Major directions driving the developments were:
pileup mitigation, both for in-time and out-of-time pileup
improved efficiency for high-pt

general improvements to the algorithms building on experience in Run 1
Improvements of HLT exemple_1

Tracking improvements

Effect of pileup subtraction on the 2015 “PF cluster based” isolation, and comparison of performance with the one used at Run1
ECAL
New “multifit” method of local reconstruction validated on simulation and Run I data
- Improved performance with high pileup
- Will be used offline for 50ns & 25ns running; in HLT for 25ns running

In words: A relative improvement is achieved in the $E_{5x5}/E_{\text{true}}$ energy measured using the multifit method w.r.t. the 3+5 weights, of about 10% (7%) for photons in EB (EE) with $E_T$ in (30, 100) GeV and of $\approx 50\%$ ($\approx 34\%$) for photons in EB (EE) with $E_T$ in (5-10)
Improvements of HLT exemple_3 Muon

L1 updates for 2015

- Additional muon chambers in the endcaps
- Increased granularity of the CSC (endcap muon) readout

Main updates to the Level_3 algorithm for Run2:
- Use $\chi^2$ measurement to assign hits to tracker tracks
- Quality filters on tracker tracks become part of the L3
CMS READY FOR RUN 2

Splash event April

First low energy proton-proton collisions after LS1 (900 GeV)
This di-jet event produced from proton-proton collisions was detected in the CMS detector. The total energy is approximately 30 GeV in each jet.

13 TeV proton-proton collisions after LS1
May, 21st

Thank You & Stay tuned
Some Glossary

BRIL : Beam Radiation Instrumentation and Luminosity
BHM: Beam Halo Monitor
PLT: (Si) Pixel Luminosity Telescope
BCMxx: Beam Condition Monitor