Report on the LHC re-start: Compact Muon Solenoid (CMS) experiment

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HEPAP
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Outline

• LHC: expectations for Run-2

• CMS: work during Long Shutdown 1

• Successes & issues during 2015 running

• Plan for 2015-2016 Year-End Technical Stop
Run-1 peak performance numbers

- Max. inst. lumi = $7.7 \times 10^{33}/\text{cm}^2/\text{s}$ (design = $1 \times 10^{34}$)
- Number of bunches = 1380 (design ~ 2200)
- Bunch spacing = 50ns (design = 25ns)

From the point of view of peak instantaneous luminosity per bunch, LHC Run-1 exceeded the specs by ~140%
Changes from Run-1 → Run-2

From M. Solfaroli (CERN) at LHCC 23 Sept 2015 (https://indico.cern.ch/event/443017/)

• 160% larger collision energy → \( \sqrt{s}=13 \) TeV
• 50% smaller bunch spacing → 25ns
• 200% larger number of bunches → 2800 bunches
• 200% larger pileup → 40 interactions/crossing
• 66% smaller \( \beta^* \) → 40cm
• 170-220% larger peak lumi → (13-17)x10\(^{33}\)cm\(^{-2}\)s\(^{-1}\)

“Priority for 2015 is to prepare 2016 as a ‘physics production run’ at 25ns” – M. Solfaroli (CERN)
Step-by-step approach

To bring up machine safely in 2015, LHC took it step-by-step

R. Bruce (CERN) at Chamonix ‘14 ([http://indico.cern.ch/event/315665/](http://indico.cern.ch/event/315665/))

1. “Scrub” to reduce e-cloud
2. $\sqrt{s}=13$ TeV with 50ns bunch spacing (as in Run-1)
3. Scrub to reduce e-cloud
4. Try 25ns bunch spacing
5. Increase # of bunches

Variable running conditions made 2015 a dynamic year both for LHC and for CMS
Recall CMS plan: upgrade detector to match the LHC performance

- CMS “Phase-1” upgrade (2014-2019): handle increased pileup...
  - Add another layer of silicon tracking
  - Add processing power to the Level-1 trigger
  - Refine granularity of the hadron calorimeter

- Long-Shutdown 1 (2013-2014): complete and maintain detector; lay foundation for Phase-1...
  - Next page ➔
CMS work during Long Shutdown 1

- Data acquisition: new architecture, hardware, software
- Trigger Control and Distribution System: new (uTCA)
- Level-1 trigger: new calorimeter trigger (uTCA)
- Silicon pixels: new modules
- Silicon tracker: new lower temperature (−15°C)
- Electromagnetic calorimeter: new trigger optical links
- Hadronic calo: new SiPMs, back-end electronics (uTCA)
- Drift Tube chambers: new trigger electronics
- Resistive Plate Chambers: new chambers
- Cathode Strip Chambers: new chambers & electronics
- Beam Radiation Instr. and Luminosity: new detectors

Coming into 2015, CMS was a ~new detector
3 June 2015: first “Stable Beams” (collisions) at $\sqrt{s}=13$ TeV


Large Hadron Collider turns on 'data tap'

By Paul Rincon
Science editor, BBC News website

3 June 2015 | Science & Environment

The CMS experiment team celebrated when the first collisions occurred
Appreciating the success of hard work

The CMS experiment team celebrated when the first collisions occurred
Examples of improvements for 2015 (1/4):
new Cathode Strip Chambers

Increased coverage from new chambers increases purity of triggers on high momentum muons
Examples of improvements for 2015 (2/4): “Stage-1” trigger upgrade

First stage of the CMS calorimeter trigger upgrade in use for 97% of the 2015 run

- Transition to the full trigger upgrade for the 2016 run
- Note: have regularly run with new trigger boards during 2015 collisions

Major improvement in $\tau$ trigger efficiency due to upgraded calo trigger
Examples of improvements for 2015 (3/4): event reconstruction

Updates to event reconstruction reduces processing time to manageable levels in a high pileup environment
Examples of improvements for 2015 (4/4): multi-threading framework

Updating to a multi-threaded framework reduces memory footprint needed to reconstruct events.

Important for Heavy Ion jobs targeted on central events.
Some unforeseen obstacles in 2015

• Rare 3ns timing steps in clock tree
  – Fixed by resetting PLLs according to Xilinx specs

• Occasional trigger rate steps in calo optical links
  – Effect mitigated with automatic masking
  – Will not be an issue with 2016 trigger

• Rare link loss in forward Hadronic calorimeter electronics
  – Effect minimized w/automatic alarm/expert reaction
  – Data will require special handling for these cases
Another unforeseen obstacle in 2015

These are the times when CMS must be fully operational.

= LHC collisions

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<th>June 2015</th>
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- 50ns setup
- 25ns operations
- 25ns setup
- Heavy Ions
- = LHC collisions

HEPAP - 10 Dec 2015  
G. Rakness (FNAL)
Another unforeseen obstacle in 2015

CERN cryo experts and CMS Technical Coordination worked extremely hard to maximize overlap of CMS magnet B=3.8T with LHC collisions

See talk by F. Bordry (CERN)
Integrated luminosity $\sqrt{s}=13$ TeV

https://twiki.cern.ch/twiki/bin/view/CMSPublic/LumiPublicResults

B=3.8T: 3.0 fb$^{-1}$ delivered, 2.8 fb$^{-1}$ recorded (93%)
B≠3.8T: 1.0 fb$^{-1}$ delivered, 0.8 fb$^{-1}$ recorded (80%)
Efficient data collection throughout 2015

Lumi recorded / delivered (%)

Time

→ Steady state recording efficiency > 90% ←
Overview of CMS work plan during the 2015-2016 Year-End Technical Stop

• Clean cold box
  – See talk by F. Bordry (CERN)

• Commission new items
  – Trigger: on tight schedule (must be ready on day 1)
  – Hadronic Calorimeter: all electronics move to uTCA (coupled with Trigger)
  – Pixel: include new Pixel blade (for 2017) in 2016 running

• Set goal to minimize data lost at certification
  – Review data monitoring to catch problems online
CMS commissioning plan

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<tr>
<td><strong>Cooling work</strong></td>
<td><strong>CRUZET/CRAFT</strong></td>
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**January**
- 15/16/17
- 22/23/24
- 29/30/31

**April**
- 4/5/6/7/8/9/10
- 11/12/13/14/15/16/17
- 18/19/20/21/22/23/24
- 25/26/27/28/29/30/1

**Legend**
- **RED** = 1st beams in
- **STAR** = Stable Beams
- **WHITE** = Cooling work
- **GREEN** = Local commissioning
- **GREEN** = “Global” runs

**CMS commissioning plan**
- Use mix with previously established track record of success...
  - Short “global” runs
  - Interface tests (not shown)
  - Extended running campaigns
- ... to prepare for LHC collisions in 2016...
Expectedations for 2016

We are expecting that 2016 will be a production year as was 2012...

2015 had a slow steady ramp-up similar to the 2011 ramp-up...
Summary

• LHC Run-2 promises higher luminosity and pileup
  – 2015 successfully laid the groundwork for these conditions

• CMS is on-track with its upgrade program
  – (Long-Shutdown 1 + 2015 run) made a solid step forward

• 2015 was a productive year of data collection
  – ... including dealing with issues both expected and unexpected

• 2015-2016 Year-End Technical Stop will put CMS in a good position to reap the harvest from high intensity collisions

CMS is looking forward to LHC collisions in 2016
Backup
1. Begin lumi ramp-up with 50ns bunch spacing
2. Low pileup (PU≈0.01-0.4)
3. Scrub for 50ns operation
4. Continue 50ns ramp-up
5. Scrub for 25ns operation
6. Lumi ramp-up @ 25ns
7. Van der Meer scan
8. Physics production with 25ns spacing
9. TOTEM run
10. pp “reference” run
11. Ion run

https://espace.cern.ch/be-dep/default.aspx