Achievements and plans

Petra Van Mulders
on behalf of the CMS collaboration

LHCC open session - 21st of September 2016
CMS is efficiently collecting data

Thanks to our LHC colleagues for the extremely smooth accelerator operation!

- Around 30/fb of data: 24M ttbar events and 1.5M Higgs boson events produced

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

- Last year’s issue with the cryogenic system of the magnet fully resolved

- Data collection efficiency: 92.5%

- Data certification efficiency: 92%

Last year's issue with the cryogenic system of the magnet fully resolved
Computing highlights

Computing resources are heavily used:

- Average CPU usage at T1 level is ~103% of the pledges
  - T1s are under-pledged in CPU/Disk/Tape
- Average CPU usage at T2 level is ~122% of the pledges

Improved the transfer rates out of CERN

![Graph showing transfer rates from May to July 2016 with 6 GB/s transfer rate in June 2016.]
Achievements in 2016 and plans

- Continue to ensure smooth operation
- **Status of detector systems**
  - L1 trigger successfully upgraded
  - High-Level Trigger
  - Muon system
  - Calorimeters
  - Silicon strip inefficiency and solution
  - CT-PPS runs together with CMS at high luminosity
- Object reconstruction and identification performance
- Selection of recent physics highlights
- Future plans: Phase 1
L1 trigger successfully upgraded

- Moved to regional muon track finders using redundancy of muon detector systems
- For the calorimeter system the data from one event is streamed into a single FPGA
- Global L1 trigger modified to allow more sophisticated triggering conditions

- Taking high quality data since May 2016 at higher luminosity running
HLT rates and extrapolation

The peak luminosity observed at CMS is $1.33 \times 10^{34} \text{ cm}^{-2} \text{s}^{-1}$

- the current HLT menu and CMS software release are able to cope with at least up to $1.5 \times 10^{34} \text{ cm}^{-2} \text{s}^{-1}$
- further improvements:
  - 10% CPU reduction from new CMS software release used from this week onwards
  - +10~15% capacity from HyperThreading

Excellent DAQ performance!
Gain of CSC chambers optimized

- The muon system is performing well
- Tuning of high voltages of CSC chambers to better equalize their gains
- This equalization should improve the efficiency of low-gain chambers and reduce the ageing effects in high-gain chambers
HCAL operating stably

- HCAL behaves very stably during data taking (~98% fully available)

- Overall less than 0.2% of dead channels

- Backend electronics for HCAL successfully migrated to μTCA
- Perfect agreement between trigger primitives for old (VME) and new backend electronics
- VME now turned off
ECAL is performing well

- Updates deployed in DAQ firmware and software to improve data taking efficiency

- Readout settings tuned for high luminosity running, can handle $1.5 \times 10^{34}$ cm$^{-2}$ s$^{-1}$

- The energy resolution in prompt reconstruction is comparable to the best performance obtained from the legacy reprocessing of the Run 1 data
Issue with silicon strip tracker solved

- During late 2015 and early 2016 we observed a decrease in the signal to noise for the strip tracker associated also with a loss of hits on tracks
- Problem was initially believed to be due to heavily ionizing particles (HIPs)
- Later traced to saturation effects in the pre-amplifier of the APV25 readout chip
- Early August the drain speed of the pre-amplifier was changed to allow for faster recovery
  → signal to noise ratio improved and fully recovered hit efficiency
Silicon strip inefficiency: mitigation

- Around 20/fb of data was collected with the old setting for the pre-amplifier
- Largest impact on b-tagging → mitigation strategies developed

Dedicated mitigation recovers most of the efficiency loss
The affected dataset will be reprocessed

Tracking + b-tag mitigation together for e.g. ttH with 4 b-tags results in a signal efficiency change of a factor 1.8 (11% absolute efficiency improvement)
CMS Totem Precision Proton Spectrometer (CT-PPS)

- Fully integrated in readout and trigger
- Deflected protons are tracked using silicon strips [in 2017: 3D pixels a la Phase 2]
- Precise timing using diamond detectors [in 2017: adding ultra fast silicon]
- Recorded ~11/fb of data

- Detector aligned w.r.t. beam
- Determined beam optics parameters
- Measured the energy fraction lost by protons
Achievements in 2016 and plans

- Continue to ensure smooth operation
- Status of detector systems
- **Object reconstruction and identification performance**
  - Missing transverse energy tails
  - Charm jet identification algorithm
- Selection of recent physics highlights
- Future plans: Phase 1
Various cleaning algorithms have been developed to deal with anomalous noise causing high tails for the missing transverse energy.

After the cleaning the simulation describes the data quite well.
Identification of charm quark jets

- A charm tagger was developed

- Two separate discriminators are constructed, one optimized for \( c \) against light-jet and one for \( c \) against b-jet discrimination

- Scale factors correcting for the difference between simulation and data are derived using W+c and top quark pair events
Achievements in 2016 and plans

- Continue to ensure smooth operation
- Status of detector systems
- Object reconstruction and identification performance
- **Selection of recent physics highlights**
  - Top quark pair production
  - Higgs boson production
  - ttH production
  - Searches for supersymmetry
  - Dark matter searches
- Future plans: Phase 1
Physics results

- Over 90 new results presented at the Summer conferences
- Covering a broad range of physics topics
  - Scrutinizing the standard model (both at Run 1 and Run 2)
  - Searching for (exotic) phenomena of physics beyond the standard model

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Top quark production cross section

- The top quark pair production cross section at 8 TeV is measured with a precision of 3.7% (uncertainty on the theoretical prediction is 5.7%)
- Precision measurements of top quark production in association with other particles are becoming available at 13 TeV

Direct measurement of the top quark width: $0.6 < \Gamma_t < 2.5$ GeV @ 95% C.L.

All results at: [https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP](https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP)

**CMS-PAS-TOP-16-019**
Higgs boson @13TeV, e.g. $H \rightarrow ZZ (4l)$

- $H \rightarrow ZZ$ just as example, also $H \rightarrow \gamma\gamma$ results available
- Much more than measuring mass and signal strength
- Fiducial cross section as a function of the center-of-mass energy

In 2016 explore differential cross section measurements and detailed measurements of the Higgs boson properties
Top quark Yukawa coupling: $ttH$

- Direct measurement of top Yukawa coupling through observation of $ttH$ process
- $ttH \rightarrow$ multileptons

- Multiple MVA-discriminators
- Used to define bins of different signal-to-backgrounds ratios

limits at 95% C.L:
- Obs.: 3.4
- Exp.: $1.3^{+0.6}_{-0.4}$
Huge jump in sensitivity for SUSY

- 21 SUSY searches updated for ICHEP covering a wide variety of topologies
  https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

- Direct stop production decaying to top and neutralino (LSP)
  \[ pp \to \tilde{t}\tilde{t}, \tilde{t} \to t \tilde{\chi}_1^0 \]  
  ICHEP 2016

- Direct electroweak production of charginos and neutralinos
  \[ pp \to \tilde{\chi}_2^0 \tilde{\chi}_1^\pm \]  
  ICHEP 2016

- For a massless LSP, limit on stop quark mass is 150 GeV higher compared to LHC Run 1

- Over 100 search regions!

- For a massless LSP, limit on the chargino mass is already 300 GeV higher
Looking for signatures of dark matter

- Searches for MET+X with X = j, γ, Z, H, tt, bb
- Low-/high-mass dijet resonance searches
- Sensitive to the spin of the mediator
Achievements in 2016 and plans

- Continue to ensure smooth operation
- Status of detector systems
- Object reconstruction and identification performance
- Selection of recent physics highlights
- Future plans: Phase 1
  - High luminosity and pile up
  - Phase 1 silicon pixel tracker
  - HF/HE
Higher luminosity and PU for 2017 run

The peak luminosity in 2016 is already above the LHC design luminosity!

- Upgrades to be installed will allow us to handle up to $\sim 2 \times 10^{34}$ cm$^{-2}$s$^{-1}$
  - Especially the new silicon pixel tracker with four barrel pixel layers
    - e.g. huge impact for b-tagging

peak luminosity = $1.33 \times 10^{34}$ cm$^2$ s$^{-1}$
Phase 1 upgrade: pixel tracker

- Module production in its last phase
- Integration in progress
- On track for installation during the end of year technical stop

- “Pilot blades” regularly included in runs
- Installation of the services being prepared
- Offline software is being developed
- On track for collisions in 2016
Phase 1 upgrade: HCAL Forward (HF)

- Front-end electronics will be updated to suppress anomalous noise
  - Exploit early arrival time for anomalous signals using QIE10 chip
  - Dual anode readout of the PMTs to identify anomalous signals

- Result of pilot Phase-1 setup

Anomalous signals result in charge asymmetry in dual anodes

On track for installation during the end of year technical stop
Phase 1 upgrade: HCAL endcap (HE)

- Radiation damage: signal reduction up to 18% ($|\eta|=1.79$) to 55% ($|\eta|=2.93$) → accelerated the phase-1 upgrade for the HE w.r.t. the original schedule
- Hybrid Photodiodes (HPD) will be replaced by Silicon Photomultipliers (SiPM)
  - More channels → finer depth segmentation (recalibration of radiation damage)
  - 3x higher photodetection efficiency w.r.t. HPD
- New front-end electronics (QIE11 chip)
  - Add timing information
- Burn-in and assembly of readout modules has started
  
  On track for installation during the end of year technical stop
Summary

- Excellent detector operation
- We are continuously improving object identification techniques
- Working hard on the detector upgrades for Phase 1 (and Phase 2)
- Many new results for the Summer conferences
- So far no sign for new physics in the data but we are prepared to see the first glimpses

Many thanks to our LHC colleagues for the many nice collisions!
Summary

- Excellent detector operation
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Many thanks to our LHC colleagues for the many nice collisions!
No sign of an excess in the 2016 data around 750 GeV

“Search for high-mass diphoton resonances in proton-proton collisions at 13 TeV and combination with 8 TeV search” submitted to Phys. Lett. B
Top quark Yukawa coupling: tHq/tHW

- Important to determine the sign of the top coupling
- \(H \rightarrow bb\), 2 signal regions: 3 and 4 b-tagged jets
- BDTs for jet assignment under \(tt\) and tHq hypothesis (for different couplings)

A different BDT to discriminate \(tt(H)\) from tHq (for different couplings)

95% CL limits on production rate for the various coupling scenarios

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<th>Region</th>
<th>Observed Limit</th>
<th>Expected Limit</th>
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<td>Combination</td>
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<td>6.0</td>
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</table>
Looking for signatures of dark matter

- Searches for MET+X with X = j, γ, Z, H, tt, bb
- Sensitive to low-mass dark matter
- Particularly powerful for spin-dependent searches
- Complementary to direct detection experiments
New indications for jet quenching

- CMS has a very rich heavy ion program and there are many Run-2 results!
- Modification of jet splitting function
- Momentum imbalance of di-b-jets

- More new Run-2 results to be presented at Hard Probes 2016
- Currently large focus on preparation of the 2016 pPb run
Boosted W-tagging

- Identification of boosted $W \to qq$ reconstructed in a single fat jet
- Efficiencies are evaluated using simulated Graviton $\to WW$ samples
- W-tagging algorithms with PUPPI are more robust against pile up
- Algorithms with n-subjettiness reduce the misidentification probability with a factor $\sim 5$ (while keeping over 60% of the signal)
Identification of hadronic tau leptons

- The MVA-based hadronic tau discriminator was optimized for Run 2
- The MVA-based approach shows a reduction of a factor 2 for the misidentification probability w.r.t. the cut-based approach at a similar efficiency.

- Identification of boosted $H \rightarrow \tau \tau$
- Important for e.g. heavy resonances decaying to $HH$
- A reconstruction technique for boosted $\tau$ was developed and outperforms the standard reconstruction at high Higgs $p_T$
Double-b tagging

- Identification of boosted $H \rightarrow bb$
- Important for e.g. heavy resonances decaying to $HH$

In case of the boosted double-b jet we exploit the presence of 2 $b$ jets in a single fat jet
The performance of the double-b tagger is compared to subject $b$-tagging and fat jet $b$-tagging using our standard CSVv2 tagger
The performance and resolution of the MET reconstruction is measured by comparing the momentum of the Z boson to that of the hadronic recoil system. Our “pile up per particle identification” (Puppi) makes the resolution more stable against pile up.
Diboson production cross section

- Already 3 measurements at 13 TeV (WW, WZ and ZZ)
- No significant deviations from the NNLO predictions

![Graph showing diboson production cross section ratios with CMS measurements vs. NNLO (NLO) theory.](http://cern.ch/go/pNj7)
HLT extrapolation to $1.5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$
HLT performance

Efficiency of the PFMET100_PFMHT100 triggers as a function of offline ETmiss

Efficiency of the HLT_PFHT800 trigger as a function of offline HT

Online b-tagging performance for Particle Flow jets

Efficiency for the di-τ trigger for the $H \rightarrow \tau\tau$ analysis
Migration of the CMS analysis tool for remote jobs

Successfully completed the migration to CRAB3 for analysis jobs

![Bar chart showing 3 million jobs per week from Sep 2014 to Jun 2016](image)

Silicon pixel tracker performance

- Despite the increase in luminosity, pileup and trigger rate, the current pixel detector still behaves reasonably well.

- The limit of the pixel tracker bandwidth will be around $1.5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ and 50 pile up collisions

- The dynamic inefficiency is increasing, we expect 6% efficiency loss at the luminosity and pile up mentioned above → serious impact on e.g. b-tagging

- For the remainder of data taking in 2016, we can deal with the current situation

- Also, a better simulation of the pixel dynamic inefficiency is available in the next CMS software releases (for physics results with the full 2016 dataset)
Pixel alignment

- Pixel tracker may move due to changes in temperature and magnet cycles
- Automatic procedure measures the movement relative to geometry used in data taking using 20k events online
- Movements during magnet-off periods:
  - < 50 μm in x and y
  - < 150 μm in z
Pixel hit reconstruction

- Lorentz angle (LA) measured using tracks with shallow impact angle
- $\tan(\text{LA})$ is the slope of the function relating the average drift of charges with their creation depth in the silicon
- Irradiation damages silicon causing a shift in the cluster position
- Corrections are applied to the cluster position and the global module alignment
Silicon strip inefficiency: mitigation

- Around 20/ fb of data collected with the old setting for the pre-amplifier
- Impact mostly visible for tracking, muon identification and b-tagging
- Mitigation strategies were developed: recovering most of the efficiency loss

- The data collected before the change in the pre-amplifier settings is about to be reprocessed with mitigation for tracking and b-tagging including also updated alignment and calibration conditions
Muon detector efficiency and timing

Single Hit efficiency

DT

RPC barrel

RPC endcap

Times from reconstructed segments

CSC

DT
CT-PPS integrated in CMS data taking

Note: silicon strips replaced last week
Water leak in CSC last December

- Regarding the water leak from a faulty brazed joint in the cooling circuit on one CSC chamber in the ME1/1 station that occurred last December:
  - No additional leaks were encountered, so it is possible that this was a one-time occurrence
  - Nonetheless, a method for reliably reinforcing the joints in situ during a YETS was developed and tested, in case such replacement were to become necessary

![Epoxy over the joint](image1)

![Protection of epoxy against mechanical stress](image2)
HCAL energy calibration

- The ratio between track momentum and HCAL energy is typically kept within 5%
  - Thanks to a more robust selection for isolated charged hadrons to cope with higher PU

- In 2015 we were not able to measure this because the selection for isolated charged hadrons needed tuning for higher PU

- Intrinsic uncertainty of the method is 2% (aiming for this precision with the legacy reprocessing)
Phase 2 time line

Illustrating different phases of the project and approval process (TDRs and EDRs).

Detector design, Technology R&D, specification and demonstration of major component feasibility
Engineering, prototyping and validation of final components, assemblies and systems
Pre-production of final grade components, assemblies and systems
Production, Integration and commissioning of detector and systems
Installation at P5, cabling and commissioning of detectors and systems

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M: Phase 1; D: Phase 2; B: Phase 3; L: Long shutdown; R: Refill; P: P5; C: Phase 4; I: Installation; Comm: Commissioning; LS2: Long Shutdown 2; LS3: Long Shutdown 3

Legend:
- **Design** - Design phase
- **Demo** - Demonstration phase
- **Engin** - Engineering phase
- **Proto** - Prototype phase
- **Pre-prod** - Pre-production phase
- **Prod** - Production phase
- **Inte** - Integration phase
- **Intcal** - Integration and calibration phase
- **Install** - Installation phase
- **Comm** - Commissioning phase
- **Ready to install** - Ready to install phase
- **Float** - Floating phase
Phase 2 muon upgrade

- Irradiation and muon performance tests on all types of chambers at the GIF++
- Schedule and milestones for the Phase 2 muon upgrade are being prepared
- GEM chambers and electronics continue to be produced for installation in CMS during early 2017 of a four-“superchamber” slice test, integration tests
- Work on writing the TDR will start soon

Draft schedule and milestones for muon upgrade

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GE1/1 integration with ME1/1 at CERN