Status of CMS

Giovanni Petrucciani (CERN)
Last LHCC

Quark Matter

Feb

Mar

New Pixel Installation completed

Moriond, Aspen

Mar

CMS closure begins

Apr

Pixel in global runs

May

Magnet at 3.8 T

600th CMS paper on collider data

Today

first beam splashes

LHCP
Outline

Focusing on what’s new since last LHCC:

• Harvesting 2016 data: highlights of CMS physics results from winter conferences
• 2017 CMS detector startup
• Preparation for 2017 running at higher instantaneous luminosity
> 600 papers submitted

39 new results released for Moriond 2017 conferences
Searches for new physics in di-jets

- Event reconstruction in High Level Trigger allows to cover low mass range (*data scouting*)
- Dark Matter interpretation
  - complementary sensitivity to direct searches
Searches with boosted objects

• Search for resonances that decay into heavy bosons: \( X \rightarrow VV, VH, qV \)
  – Use jet substructure & boosted double-b tag
Searches with boosted objects

- Background fitted directly from data using analytic functions
- Sensitivity to diboson resonances up to ~3 TeV
Supersymmetry searches

Broad program: 19 searches completed with full 2016 CMS data, several already submitted to journals for publication:

- probing different models (inclusive production, electroweak production, 3rd generation sparticles)
- relying on different final states (e.g. leptonic or hadronic) and analysis methods (generic or more model specific)

- gluinos (inclusive)
  \[ pp \rightarrow \tilde{g}\tilde{g}, \tilde{t}\tilde{\chi}_1^0 \]

- electroweakinos
  \[ pp \rightarrow \tilde{\chi}_2^0\tilde{\chi}_1^\pm \]

- stops (3rd gen)
  \[ pp \rightarrow \tilde{t}\tilde{t}, \tilde{t}\tilde{\chi}_1^0 \]
Higgs boson measurements

- Fiducial and differential cross sections from $H \rightarrow ZZ^* \rightarrow 4\ell$ and $H \rightarrow \gamma\gamma$ on full 2016 data
  - $\Delta\sigma_{\text{fid}}/\sigma_{\text{fid}} = 18\% (4\ell), 15\% (\gamma\gamma)$, good agreement with theory predictions (YR4, NLO MC) also on $p_T(H)$ and $N(\text{jet})$ distribution
- Mass measurement: $125.26 \pm 0.21 \text{ GeV} (4\ell)$
  - More precise than LHC Run 1 combination
Higgs boson measurements

- \( ttH \) searches in leptonic final states
  - direct probe of top Yukawa coupling

- reoptimized analyses on full 2016 dataset
  - \( 3.3\sigma \) evidence for \( ttH \) (2.5\( \sigma \) expected)
  - also dedicated effort for \( H \rightarrow \tau\tau \) decays
SM measurements at 13 TeV

Electroweak Z+jj production study with full 2016 data:

• Main QCD Z+jets background suppressed with a BDT using jet quark-gluon likelihood and event kinematics
• Measured $\sigma_{EW}(\ell\ell jj) = 552 \pm 58$ fb (SM pred.: $543 \pm 24$ fb)
• Validate MC modelling of VBF variables (e.g. 3rd jet $p_T$)
Run 1 measurements: $d\sigma(t\bar{t})$

- double-differential measurement of $t\bar{t}$ production vs $p_T(t)$, $y(t)$, $p_T(t\bar{t})$, $y(t\bar{t})$, $M(t\bar{t})$, $\Delta\eta(t,\bar{t})$, $\Delta\phi(t,\bar{t})$
  - $e\mu$ final state, reconstruct $v$ kinematic imposing $m_t$ value
  - approx NNLO predictions with latest PDFs show improved agreement with $[p_T(t), y(t)]$ data wrt existing NLO MCs
  - measurement yields improved constraints on gluon PDF
Run 1 measurements: \(B^0 \rightarrow K^{*0} \mu^+\mu^-\)

- **4D unbinned fit for angular parameters in \(B^0\) decay**
  - Try to address the tension between P5′ measurements in LHCb & Belle and the a-priori SM predictions (DHMV)
  - CMS result more SM-like, but compatible with both

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**Image:**

- Graph showing data and fit curves for the invariant masses in the range of \(q^2\) from 2.00 to 4.30 GeV\(^2\) and from 4.30 to 6.00 GeV\(^2\). The CMS Preliminary fit for each range is compared with the SM predictions (DHMV and HEPfit) and other experiments like LHCb and Belle.

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**10/05/17 G. Petrucciani (CERN)**

**CMS PAS BPH-15-008**
Heavy Ion physics: B mesons

- First measurement of B mesons in Pb Pb collisions
  - suppression by a factor ~2 with respect to pp collisions
  - updated result w/ improved uncertainties and comparison to more theoretical models

![Graph showing CMS data on B mesons](image)

351 μb⁻¹ (PbPb 5.02 TeV)

**CMS**

- **B⁺ + B⁻**
  - 10 < \( p_T \) < 15 GeV/c
  - |y| < 2.4

![Plot comparing CMS data and theoretical models](image)

28.0 pb⁻¹ (pp 5.02 TeV) + 351μb⁻¹ (PbPb 5.02 TeV)

- **Data**
- **Fit**
- **Signal**
- **Combinatorial**
- **B → J/ψ X**

![Comparison of R_AA values](image)

- **TAMU**
- **Correlated syst. uncert.**
- **CUJET3.0**
- **AdS/CFT HH D(p)**
- **Global uncert.**

**B⁺, |y| < 2.4**

- **p_T (GeV/c)**
- **R_AA**

- **CMS**
  - Updated result with improved uncertainties and comparison to more theoretical models.
2017 CMS DETECTOR STARTUP
CMS detector: what’s new in 2017

- new pixel detector
- one HCal endcap readout 20° sector upgraded
- HF readout upgraded
- GEM GE1/1 slice installed (5×10°)
CMS Phase I Pixel Detector

- 4 layers / 3 disks
- CO$_2$ cooling
- DCDC converters
  → reduced material budget

- New readout ASIC & back-end electronics (μTCA)
  → Readout inefficiency negligible up to PU 100 at 100 kHz L1 rate
    → Old detector had ~5% inefficiency in Barrel Layer 1 at PU ~ 40
CMS Phase I Pixel Detector

- Increased tracking efficiency, especially at high $|\eta|$, and reduction of fake rate
- Improvement in impact parameter resolution and, consequently, $b$-tagging performance

Performance of tracking on simulated $t\bar{t}$ events at $\langle PU \rangle = 35$, for 2016 and 2017 detector

Performance of $b$-jet identification with 2016 and 2017 pixel detector
Pixel detector: installation

Started Feb 28th
Completed Mar 9th

Following commissioning steps:
• Connection checkout Mar 5th-12th
• Sealed & running cold Mar 18th
• Ready to close CMS Mar 24th
HF Phase-I upgrade completed

• Completed the upgrade program to discriminate good physics signals from anomalous ones (particles hitting PMT windows)
• EYETS 16/17: PMT boxes reworked and Front-end upgraded:
  – Add TDC to improve PMT hit discrimination
  – Dual-anode readout for further discrimination & hit recovery
• Detector fully re-commissioned using laser/LED/pedestal runs, $^{60}$Co source and beam splash events

All HF channels are working
Green: good channel (blue: unused slot)

Example of $^{60}$Co source signals for 4 readout channels in one HF tower
• Long and Short fibers
• Each with dual anode readout
Phase-I Upgrade of an HE Sector

- A 20° φ sector (HEP17) of HCAL Endcap has been upgraded as demonstrator:
  - Replaced Hybrid Photo-Detectors (HPD) with Silicon Photo-Multipliers (SiPM)
    - Eliminate high amplitude noise and drifting response of HPDs
    - Mitigate effects of radiation damage
    - Increased longitudinal segmentation of readout
- Provides important feedback for upgrades of full HCal Endcap (likely in YETS17/18) and Barrel (scheduled for LS2)
  - Upgrade procedure validated
  - Commissioning: LED/Laser, ⁶⁰Co source, cosmic
- Phase 1 depth segmentation collapsed in software to emulate legacy system readout
Commissioning: other detectors

- **Strips**: standard calibration and alignment done with cosmics, stable and high signal/noise
- **ECal & ES**: stably running after refurbishment of LV power supplies, laser monitoring hardware and full recalibration of 1224 Ecal Barrel HV channels
- **Muons**: various repairs & updates to chambers and services, commissioning of GEM GE1/1 5×10° φ slice
Commissioning: active channels

- Upgraded Pixel detector has ~twice the number of channels of the old one.
- Endcap RPC being brought back to HV on after flushing Argon gas from EYETS, expect to have all restored in 1-2 weeks
Cosmics: pixel

- Pixel detector in global runs for cosmic data taking since mid-April.
- The thresholds are already comparable (or better) to the ones of the previous detector.
- Coarse time alignment achieved: $\pm12$ ns — to be completed with collisions.
Cosmics: Pixel alignment

- Pixel detector aligned at module level using cosmics:
  - Barrel and Forward pixel aligned at 50-100μm precision
  - Very good starting point for alignment with collisions

\[ \text{HL} = \text{alignment of high level structures only}; \quad \text{ML} = \text{module-level alignment} \]
Cosmics: HCAL HEP17

- Analysis of cosmic events confirms beautiful performance of HE Phase1
  - muon signals clearly seen in HEP17
  - timing also correctly measured
  - substantial reduction of coherent noise compared to old readout
Cosmics: Muon detectors

- Overall, good state of muon systems demonstrated in first cosmic running:
  - DT, CSC & Barrel RPC fully ready for data
  - Endcap RPC HV being brought back on after flushing Argon gas from EYETS
Beam Splashes: ECAL

**Energy**
- Upstream: up to 1 TeV energy deposited per crystal in endcaps

**Timing**
- Consistent with time of flight from +ve side of CMS to -ve side

Splash events used to successfully validate ECAL readout/trigger status and timing synchronisation
Beam Splashes: HCAL

- Validate energy response of the upgraded HEP17 (SiPMs) w.r.t legacy detector (HPDs), readout and trigger timing
- Reconstructed energy in HEP17 consistent with measurement in neighboring legacy system
  - NB: phi-symmetry not expected to be perfect for splash events due to ‘LHC floor shadow’

Energy (GeV) in HE (legacy) depth1 vs iphi/ieta (for HEP17, depths are summed to emulate legacy system)

Signal Time for a Beam2 splash event (from −z to +z)

\[ \Delta t = t_{\text{HEP17}} - t_{\text{HEP18}} \approx 7 \text{ ns} \]
PREPARATION FOR 2017 RUN AT HIGHER LUMINOSITY
2017 detector re-tuning

Preparation for high luminosity & high rate running:

- **Pixel**: increased bandwidth from detectors to FEDs, new 10 Gb/s links allowing 100 kHz L1 rate at PU 100
- **Ecal**: optimized readout settings (zero suppression), DAQ improvements to reduce downtime.
- **DAQ/HLT**: increased number of sub-detector channels (esp. for new Pixel) and event building throughput. Planning for increased HLT processing capability.

*All CMS subsystems ready for 2017 luminosity*
Level 1 Trigger development

• Data from 2016 high pile-up run being used in preparation for 2017 running
  – Improvements in algorithms and calibrations, to better cope with PU (sizeable gains esp. for $E_T^{\text{miss}}$ & $H_T$)

• Extended L1 trigger menu allowing for more complex algorithms *a la* HLT:
  – e.g. 2 jets w/ VBF cuts + 2 central jets or taus, or di-muon triggers in exclusive mass bins for b-physics
  – can have up to 512 different L1 seeds

• Good progress in integrating RPC data into the endcap muon track finder (last step of L1 trigger Phase 1 upgrade)
  – should increase efficiency in CSC ring gaps

• Operational improvements on automatic data quality monitoring, validation & shifter tools.
High Level Trigger development

- HLT preparation for 2017 running:
  - reconstruction updated to 2017 detector: upgraded pixel detector, HCal HEP17, HF
  - improvements to bring HLT objects closer to offline ones: higher purity & plateau efficiency
  - code and algorithm optimizations to reduce CPU usage, to allow running at higher PU

- HLT menu being defined for 2017 luminosity
  - main goal of ~1 kHz average physics rate for LHC fills with peak instantaneous luminosity of ~2E34
Software & Computing

• MC production & 2016 data processing for 2017 winter conferences successfully completed (~20B events)
  – Resources now mainly devoted to MC for 2017 run preparation and phase 2 upgrade TDRs
  – Also, final 2016 data re-reco. with best calibrations and consolidation of analysis object developments for precision measurements and future 2016+2017 analyses

• Working to review and optimize overall computing model for Run 2 & Run 3
  – First outcome are strategies now being put in place to improve disk usage efficiency:
    • Improved MiniAOD (~40 kb/evt): larger analysis coverage, to reduce amount of AOD (~300 kb/ev) needed on T2 disks
    • Improving dynamic data management policies
Conclusions

• Following up successful 2016 datataking with impressive set of new physics results.
  – and more precision physics measurements on earlier run 1 and run 2 datasets

• Upgraded Pixel detector and Hcal readout installed and integrated

• Successful 2017 detector commissioning, cosmics and beam splash data taking

• Completing preparations for 2017 running at higher luminosity and pileup
Higgs boson measurements

- Mass measurement in $H \rightarrow ZZ^* \rightarrow 4\ell$ decays:
  - New technique combining event-by-event errors, Matrix Element and kinematic refit of the $Z \rightarrow \ell\ell$ decay
  - Full 2016 data analyzed
- $m_H = 125.26 \pm 0.21$ GeV
  - better obs precision than LHC run 1 combination
Higgs boson measurements

- Fiducial and differential cross sections from $H \rightarrow ZZ^* \rightarrow 4\ell$ and $H \rightarrow \gamma\gamma$ on full 2016 data
  - $\Delta\sigma_{\text{fid}}/\sigma_{\text{fid}} = 18\%$ ($4\ell$), 15\% ($\gamma\gamma$), good agreement with theory predictions (YR4, NLO MC)
Pixel detector: commissioning

• Pixel detector integration timeline:
  – Installation in CMS: Feb 28\(^{th}\)-Mar 9\(^{th}\)
  – Connection checkout: Mar 5\(^{th}\)-Mar 12\(^{th}\)
    • cooling, power, control, readout
  – Sealing and start of cold operations: Mar 18\(^{th}\)
  – Green light to close CMS: Mar 24\(^{th}\)
  – In cosmic global runs since mid April
    • Coarse time alignment achieved: ± 12 ns
HCal Commissioning and Calibration

- The fraction of active channels is ~99.9% overall
- Coherent noise
  - The rate is much reduced in the upgraded wedge as expected (monitored in cosmic data taking)
- Trigger primitives
  - commissioned for the upgraded HF
  - finalizing those for HEP17 (the upgraded HE wedge)

<table>
<thead>
<tr>
<th>HB (%)</th>
<th>HE (%)</th>
<th>HF (%)</th>
<th>HO (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>99.88</td>
<td>99.96</td>
<td>100</td>
<td>99.72</td>
</tr>
</tbody>
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- Initial gains for the upgrade wedge HEP17
  - are being set using the $^{60}$Co source data taken before & after the HEP17 upgrade (HPD $\rightarrow$ SiPM)
  - To be further refined using phi symmetry and isolated tracks in collision data
HF Phase-I upgrade completed

- Completed the upgrade program to further discriminate physics signals from ‘PMT hits’
  - Beam-induced anomalous signals are due to particles directly hitting PMT windows
  - New, thin-window PMTs installed during LS1 are less sensitive to anomalous hits
- EYETS 16/17: PMT boxes reworked and Front-end upgraded in order to:
  - Add TDC to improve PMT hit discrimination (anomalous signals arise 2-7 ns earlier)
  - Implement dual-anode readout as further discrimination, as spurious signals often affect one anode only, enabling recovering the energy measurement from the other anode
- Detector recommissioned using laser/LED/pedestal runs, and $^{60}$Co source
  - Also, splash events being used to adjust HF readout and trigger timing

Example of $^{60}$Co source signals for 4 readout channels in one HF tower
- Long and Short fibers
- Each with dual anode readout

All HF channels are working
Green: good channel (blue: unused slot)
Pixel reconstruction and performance

- Trigger timing of the pixel detector was successfully adjusted to the Strip tracker and the Muon system
  - Subsequently, efficient data-taking in CMS global runs

- Observed uniform data-taking efficiency across the whole detector
  - Inefficient regions expected from detector calibration is confirmed by data
  - No observable signs of relative misalignment in time or space for any partition of the detector

- Reconstruction geometry and online-to-offline cabling map has been verified

- Gain calibration for first collisions being processed
  - Cluster properties already look reasonable, final confirmation needed with magnetic field

- Ready for first collisions
Tracker alignment of the pixel in oT cosmics

- Processed ~2M CRUZET events (more is available)
- FPix detector was timed earlier → good alignment available
  - ~3 mm difference of Z-minus side w.r.t ideal geometry
  - few 100 microns in transverse plane
- Monte Carlo with estimated misalignment was prepared earlier this year
  - Observed misalignment is consistent with expectations
  - Observed cosmics tracks rate dead-on with expectations
- Expected average accuracy of module-level alignment from available cosmics:
  BPix ~15-30 um, FPix ~150-200 um
- Observed pulls in FPix suggests better alignment than expected
- 3.8T cosmics are still going to be useful
- Ready for alignment in collisions starting with smaller misalignment than expected!

Agreement with default geometry (FPix):

Track-rate improvement after applying alignment (3 mm correction of Z-minus in global Z)
GEM Muon Upgrade R&D to Demonstrator Slice

Small Prototypes
10x10 cm² triple-GEMs, 1D or 2D readout, 128 or 256 channels:
Standard double-mask triple-GEM - "Timing GEM"

http://indico.cern.ch/event/159247/

S. Colafranceschi
A. Marinov

From 904 to TIF
Micro-pattern gaseous detectors for Upgrade of the CMS Muon System

https://indico.cern.ch/event/484223

Archana Sharma  Detector Seminar CERN Feb 5, 2016

New handle: bending angle

Forward trigger for $|\eta| > 1.6$ relies entirely on the CSC system:
- Measurement driven by internal chambers: least scattering, strong B field.

GEM detector in front of CSC can measure muon bending angle in magnetic field and add redundancy

[Graph and diagram showing CMS Phasell Simulation]

- Maintain 15 GeV online threshold, keep < 5 kHz rate, high efficiency
MUON GEM GE11 SLICE at P5

Overview of Standard HV and LV

Further DCS, DB work on going for monitoring
DPG just starting work on real data!
DQM needs to be set up

First report in CMS Run Meeting – 14.3.2017

DCS Operational Trending HV, $I_{\text{mon}}$, Gas parameters continuously monitored

Good progress in DSS h/w
Insert in Action Matrix Plan 10.4

Planning for combined run with CSC for latency scan
Eventually muon detection with GEM soon
Detectors installation status

5 GEMINIs (2 layers ea.) were installed on the YE-1 endcap disk during this EYETS:
• 4 GEMINIs are powered with the standard HV divider, the 5th one with the multichannel power supply

The HV and LV system has been commissioned and is operational. The gas system and the cooling system have been completed and are running as expected.

Stability tests are ongoing for HV, LV and gas to verify the performance of the detectors before the first beam.
The GEM DCS is running locally and actually allows the shifter to:
• Control/Monitor the standard HV
• Control/Monitor the multichannel HV
• Control/Monitor the LV
• Monitor the gas system and the environmental parameters
• Monitor the RadMon sensors

The development of the GEM Finite State Machine, which is the first step towards the inclusion on the GEM DCS in Central, is ongoing
Already deployed and tested scan scripts that allow to configure the system and perform noise studies. (S-curves, threshold scan, latency scan.

Good understanding of noise in our system. Currently optimizing the system to lower down the noise.

Deploying XDAQ infrastructure at P5.

Developing the Function Manager to be able to have miniDAQ for DOC shifter and to enter global CMS DAQ.

DOC#1 already started in March. We are filling the shiftlist

First evidence of muons in our GEM system!!!

Waiting for internal review on readiness of DQM, DCS (central), Global DAQ