CMS Status Report

Run II Performance and Recent Physics Highlights

Anne E. Dabrowski (CERN)

On Behalf of the CMS Collaboration
LHCC Open session, December 2\textsuperscript{nd} 2015
2015 - What a year!

Asymmetric di-jet event PbPb
Robustness of Cryogenic system for CMS Magnet

• **Much has been understood** about the erratic behavior but mysteries remain.

• The first focus of the joint CMS-CERN TE task force has been **increasing tolerance** to contamination to **maximise the “Up-Time”** of the CMS magnet for Physics
  – Changes to cold-box absorbers, filters & turbines plus regular elective regeneration/maintenance of the filters, absorbers and first heat exchanger

• This effort has resulted in:
  – ~3/4 of the 13 TeV luminosity delivered with the magnetic field ON
  – All reference p-p and all Pb-Pb (except today) luminosity delivered so far, with the magnetic field ON

• **For improved stability in 2016**, the task force is implementing a detailed program to consolidate the system by changing or cleaning components. This plan is compatible with the agreed schedule for **YETS 2015/2016**.

• CMS Magnet risk review 7-8th December
  – Review YETS plan & future risks to magnet

CMS thanks CERN TE and EN departments for their exceptional efforts
Data validated for Physics @ 13 TeV

2.7 fb⁻¹ validated for physics @ 13 TeV with B=3.8 T

CMS Integrated Luminosity, pp, 2015, $\sqrt{s} = 13$ TeV

Data included from 2015-06-03 08:41 to 2015-11-03 06:25 UTC

LHC Delivered: 4.0 fb⁻¹
CMS Recorded: 3.6 fb⁻¹

B=3.8 T, recorded for physics: 2.8 fb⁻¹
B=3.8 T, validated: 2.7 fb⁻¹

Preliminary Offline Luminosity

✓ CMS appreciates the effort of the LHC and the other experiments in adjusting the beam schedule to minimize data taking periods without the CMS magnetic field
Proton-Proton reference run @ 5.02 TeV

- **28 pb\(^{-1}\) of data recorded for physics - all with B=3.8 T in 5 days!**

- **Crucial for HI physics run**

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![Z+Jet event](image)

- ✓ excellent availability of the LHC to maximise delivered luminosity to the experiments! Thank you and congratulations to LHC crew!

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Data Quality Proton-Proton reference run @ 5.02 TeV

**D⁰ mesons peak** from D⁰ mesons online trigger

$|y| < 1.0$

$8.0 < p_T < 20.0 \text{ GeV/c}$

**B⁺ meson peak** from dimuon triggered sample

$B^+ \rightarrow J/\psi K^+ \rightarrow \mu^+ \mu^- K^+$

2.5 billion minimum-bias events recorded for low $p_T$ D meson analysis
Today’s Peak activity Pb-Pb @ 5.02 TeV/nucleon

- 143 $ub^{-1}$ of data delivered for physics – all (except this morning’s fill) with magnet ON
Quarkonia production in **pp and Pb-Pb @ 5.02 TeV/nucleon**

**Charmonia**

![Charmonia Graph](image1)

**Bottomonia**

![Bottomonia Graph](image2)
Active channels throughout the $\sqrt{s}=13$ TeV p-p run

Excellent availability of the CMS detector
Preparing CMS data-sets

• New release of offline software available since November

• First MC samples for winter conferences have been submitted
  – 2.8 billion events in the queue
  – Target 3-4 billion events

• Inputs before re-reconstruction of Run-II data being collected:
  – Final alignment
  – Calibration corrections
  – Reconstruction algorithms
  – ...

• On track for launching re-reconstruction of Run II data before Christmas
Tracker alignment & resolution

- **Prompt reconstruction**
  - Compensate for effect of magnet cycles
- **Final alignment** at the module level
  - Performance is close to ideal case (MC)
  - Ready for data reprocessing

Pixel Detector Resolution:
- Transverse to the beam: $\sigma_\phi=10.64 \, \mu m$
- Parallel to the beam: $\sigma_z=29.09 \, \mu m$

As good or better than Run-1
Excellent Hit efficiency

- Slightly better performance than in Run-I
- Dynamic inefficiency most visible on layer 1
- Efficiency above 99% on all layers/disks
Tracking performance

Tracking efficiency excellent for both “inside-out” and “outside-in” reconstructions

“Inside-out” reconstruction efficiency

“outside-in” reconstruction efficiency

- Small ~2% inefficiency in data in region $1 < \phi < 3$ due to absence of modules in layer 2 of Pixel BMO_3
- Now included in MC description for winter conferences
Muon Detectors

Excellent performance in 2015 p-p run

- New CSC ME4 and RPC RE4 muon stations
- Upgrades to forward inner CSC readout electronics
  - hit resolutions improves by 20% wrt. Run I
- DT Trigger primitives efficiency improved in 2015
- Good stability of RPC cluster size, important for L1 $p_T$ assignment

map of efficiency of CSC local trigger.
Excellent stability achieved in the prompt reconstruction of ECAL data using laser measurement

- Stability of response is comparable to 2012 data

Multi-fit algorithm for amplitude reconstruction optimized for high pileup and deployed as default

- Isolated colliding bunch was useful to provide data sample for pulse distributions
Level-1 and High-Level Triggers

Successful operation of trigger for physics data-taking during 2015 pp run

- Menus put in place targeting different scenarios:
  - 50 ns runs: peak luminosity of $5 \times 10^{33} \text{cm}^{-2}\text{s}^{-1}$ (PU ~ 30)
  - 25 ns runs: peak luminosities of $3.6 \times 10^{33} - 1 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$ (PU 20 – 40)
  - Deployed special menus: VDM scan and low pileup runs for FSQ/HIN
  - Dedicated menus for the Heavy Ions Pb-Pb run and p-p reference run
  - Also collected data for detector calibration/alignment & commissioning

- Menus included significant improvements in trigger algorithms:
  - Handle the expected increases in rate (due to the increase in center of mass energy)
  - Handle pileup

- Significant improvements made to online rate monitoring
  - Continuing to monitor performance of triggers with data

- Multi-threading validated and deployed online since the previous LHCC
Trigger Performance

From start of 25ns running period switched to the “Stage-1” calorimeter upgrade

New L1 single isolated Tau hadronic trigger efficiency \( p_T > 28 \text{GeV} \) compared to legacy

L1+HLT efficiency as a function of offline tau \( p_T \) for isolated double tau hadronic trigger with \( p_T > 35 \text{ GeV} \)
Offline and Computing in Run-2

Exploited in Run-2:

- Threaded framework
- SIM & RECO code improvements
- Less Tier boundaries in the Comp. model
- More automation in Comp. operations

Global Pool for job submission management to better handle overall priorities:

- Reached ~150k jobs running in parallel
- Can operate all T1/T2/opportunistic resources in a single pool
- MC for 2.8 billion events started
Luminosity calibration

CMS sends online per-bunch luminosity to the LHC at a frequency of 0.5 Hz.
- **Multiple detectors** are useful to understand beam and detector systematics
  - PLT, HF-lumi, BCM1F, pixel cluster counting

Each Luminometer calibrated offline using the Van der Meer (VDM) scan technique

VDM-calibrated-BCM1F used as primary offline luminometer for physics for 50 ns recorded data.

<table>
<thead>
<tr>
<th>Source</th>
<th>Uncertainty [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>VDM calibration using fill 4266</td>
<td>2.6</td>
</tr>
<tr>
<td>Uncertainty from VDM</td>
<td>2.6</td>
</tr>
<tr>
<td>Detector behavior during 50 ns</td>
<td>4</td>
</tr>
<tr>
<td>Linearity and stability</td>
<td>4</td>
</tr>
<tr>
<td>TOTAL uncertainty (for 50 ns)</td>
<td>4.8</td>
</tr>
</tbody>
</table>

Work ongoing for 25 ns offline luminosity uncertainty (presently 12%)
CMS Publications

485 CMS Submitted papers:
- 445 physics papers
- 24 papers based on cosmic ray data
- 15 detector performance papers
- 1 CMS detector paper

17 papers submitted since the September LHCC meeting

# CMS Publications - Run II data

## Run 2 Publications

<table>
<thead>
<tr>
<th>Publication Code</th>
<th>Title</th>
<th>Status</th>
<th>Submission Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOP-15-003</td>
<td>Measurement of the top quark pair production cross section in proton-proton collisions at $\sqrt{s} = 13$ TeV</td>
<td>Submitted to PRL</td>
<td>18th October 2015</td>
</tr>
<tr>
<td>SMP-15-004</td>
<td>Measurement of inclusive W and Z boson production cross sections in pp collisions at $\sqrt{s} = 13$ TeV</td>
<td>CMS approved</td>
<td></td>
</tr>
<tr>
<td>FSQ-15-007</td>
<td>Underlying Event Measurements with Leading Particles and Jets in pp collisions at $\sqrt{s} = 13$ TeV</td>
<td>CMS approved</td>
<td></td>
</tr>
<tr>
<td>EXO-15-001</td>
<td>Search for narrow resonances using the dijet mass spectrum with $2.4$ fb$^{-1}$ of pp collisions at $\sqrt{s} = 13$ TeV</td>
<td>CMS approved</td>
<td></td>
</tr>
</tbody>
</table>

**Additional analyses in the pipeline for LHC Physics Jamboree, 15th December 2015**
Inclusive W/Z boson cross section

*Commissioning muon ID, electron ID & missing transverse energy with novel methods*

- 8 TeV analysis done at low pileup special run conditions
- 13 TeV done in high pileup environment using 50 ns data sample

- PUPPI MET* for pileup mitigation, becomes essential in the W case to improve resolution and signal/background separation at low values of MET

![Graph showing CMS Preliminary data and expected values for W/Z boson cross section at 13 TeV.](https://cds.cern.ch/record/2051942/)
Inclusive W/Z boson cross section

- Consistent results between electron and muon channels
- Agreement with SM
  - Precision tests on next-to-next leading order QCD calculations
- Uncertainties expected to reduce before final publication

### CMS Preliminary

<table>
<thead>
<tr>
<th>Process</th>
<th>Theory: FEWZ (NNLO), NNPDF3.0</th>
<th>Observation: NNPDF3.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>$W\rightarrow l\nu$</td>
<td>$11370 \pm 50_{\text{stat}} \pm 230_{\text{syst}} \pm 550_{\text{lum}} \text{ pb}$</td>
<td>$11330 \pm 300 \text{ pb}$</td>
</tr>
<tr>
<td>$W\rightarrow l\nu$</td>
<td>$8580 \pm 50_{\text{stat}} \pm 160_{\text{syst}} \pm 410_{\text{lum}} \text{ pb}$</td>
<td>$8370 \pm 230 \text{ pb}$</td>
</tr>
<tr>
<td>$W\rightarrow l\nu$</td>
<td>$19950 \pm 70_{\text{stat}} \pm 360_{\text{syst}} \pm 960_{\text{lum}} \text{ pb}$</td>
<td>$19700 \pm 520 \text{ pb}$</td>
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<tr>
<td>$Z\rightarrow l\nu$</td>
<td>$1910 \pm 10_{\text{stat}} \pm 40_{\text{syst}} \pm 90_{\text{lum}} \text{ pb}$</td>
<td>$1870 \pm 50 \text{ pb}$</td>
</tr>
<tr>
<td>$W\rightarrow l\nu / W\rightarrow l\nu$</td>
<td>$1.323 \pm 0.010_{\text{stat}} \pm 0.021_{\text{syst}}$</td>
<td>$1.354 \pm 0.011$</td>
</tr>
<tr>
<td>$W\rightarrow l\nu / Z\rightarrow l\nu$</td>
<td>$5.96 \pm 0.04_{\text{stat}} \pm 0.10_{\text{syst}}$</td>
<td>$6.06 \pm 0.05$</td>
</tr>
<tr>
<td>$W\rightarrow l\nu / Z\rightarrow l\nu$</td>
<td>$4.50 \pm 0.03_{\text{stat}} \pm 0.08_{\text{syst}}$</td>
<td>$4.48 \pm 0.02$</td>
</tr>
<tr>
<td>$W\rightarrow l\nu / Z\rightarrow l\nu$</td>
<td>$10.46 \pm 0.06_{\text{stat}} \pm 0.16_{\text{syst}}$</td>
<td>$10.55 \pm 0.07$</td>
</tr>
</tbody>
</table>
Dijet resonance search @ 13 TeV

- Model independent search for narrow $qq$, $qg$, or $gg$ resonances
  - Uses 2.4 fb$^{-1}$ of Run II data
  - Various models considered
    - For example, CMS can exclude string resonances ($q$-$g$) with masses below 7.0 TeV
  - Surpass Run 1 limits for resonances above 2 TeV

![Graph showing dijet mass distribution and resonance search results](image-url)
Underlying Event (UE) @ 13 TeV

Key measurement to improve our current MC tunes at 13 TeV

- Study of the **average multiplicity** density and **scalar transverse momentum** density in the **orthogonal direction** to the thrust of the leading event activity
- Compare quantities in the transverse region as a function of track or jet $P_T$ of leading particle with various MC models (Phythia8, Herwig++, EPOS) with various tunes.
- Data is in reasonable agreement (10-20%) with all tunes
- “Monash PYTHIA8” gives the best agreement among all studied tunes

![Diagram](image)

- **TransMAX**: density in region of maximum activity
- **TransMIN**: density in region of minimum activity
- TransDIF: $\text{TransMAX} - \text{TransMIN}$
- TransAVE: $(\text{TransMAX} + \text{TransMIN})/2$
RUN I RESULTS
Data-scouring & search for low-mass dijet resonances @ 8TeV

Data-scouring => save additional events with lower than typical HLT thresholds

- Standard HLT triggers:
  - Typically 500kB/event
- Scouring:
  - 10 kB/event, saving only the 4-momenta of jets and lepton
- No offline reconstruction of data possible, but for many analyses, the HLT online resolution is sufficient
- Run 1, Saved with high rate (~1kHz) hadronic triggers > 250 GeV
  - Window to low mass resonances > 500 GeV

Exclusion limit on the coupling strength $g_B$ of a hypothetical baryonic $Z'_B$ that decays to a final state of 2 jets, as a function of the $Z'_B$ mass

CMS-PAS-EXO-14-005
http://cds.cern.ch/record/2063491
Run 1: Higgs $\rightarrow$ invisible combination @ 8TeV

- Predicted by SM at very low rate BR (H$\rightarrow$ZZ$\rightarrow$4$\nu$) $\sim$0.1%
- Complementary to Dark Matter searches.
- Signatures of missing transverse energy tagged in the follow channels:
  - $qqH$ (VBF): two forward/backward jets with large $\Delta\eta_{jj}$ & $m_{jj}$
  - $Z(\rightarrow ll)H$: two lepton compatible with a Z boson
  - $Z(\rightarrow bb)H$: two b-jets compatible with a Z boson
- Updated to also include
  - $Z/W(\rightarrow qq)H$: resolved and merged jets compatible with $Z/W$ boson
  - $gg \rightarrow H+jet$: one high $p_T$ jet

- 30% improvement in sensitivity.
- Observed (expected) upper limit set on BR(H$\rightarrow$inv) for $m_H$=125 GeV is 0.36 (0.30) at 95% CL
Charm-tagged jet production in p-Pb @ 5.02 TeV & p-p @ 2.76 TeV

- b-jets tagged at CMS by selecting on displaced vertices
- Charm jets have smaller displacement, therefore trickier to tag
  - Developed a set of variables that provide discrimination power to extract c-jets

**3+ Body Secondary Vertex Tagging**

- **Separation of Heavy + Light**
- Feed into template shapes – charm jet contribution extracted

**Corrected Secondary Vertex Mass**

- **Separation of Charm + Bottom**
Charm-tagged jet production in pPb @ 5.02 TeV & pp @ 2.76 TeV

• First charm jet measurement in heavy-ion collisions!
  – pPb and pp tackled so far – both consistent with PYTHIA predictions
    - pPb: $1.00 \pm 0.19$ (stat.+syst.)
    - pp: $1.15 \pm 0.27$ (stat.+syst.)
  – Charm jet fraction (not shown) also consistent with PYTHIA

CMS-PAS-HIN-15-012
Conclusions

• Up-time of the CMS magnet was the main limitation in 2015
  • A plan is in place for maintenance in 2015/2016 YETS and CMS appreciates all parties for their efforts

• CMS took high good quality data with high efficiency during Run 2
  – Improved detectors, trigger and data-acquisition
  – Event reconstruction robust against 25 ns pile-up conditions

• Computing and software algorithms much improved for Run 2
  – Multi-threading already deployed is online HLT framework and also offline software (MC and data-RECO)
  – Data-reco on schedule for submission before the Christmas break

• Run 2 Physics analyses are moving forward
  • New analyses in the wings for the jamboree

• HI data taking and prompt analyses are at the highest level of activity
  – Looking forward to what is in store for physics
EXTRA SLIDES
DETECTOR PERFORMANCE
Apart from Theta SL's in MB1 stations of external wheels (where in any case the track inclination and the transverse component of magnetic field bias the residual distributions and make the Gaussian fit unstable), the resolution observed this year is compatible or slightly better than the one obtained with 2012 data.
Muon Identification

Muon ID robust against pileup and in good agreement with MC

Muon ID with loose isolation vs number of primary vertices

\[
\text{Efficiency vs } N(\text{primary vertices})
\]

1280 pb\(^{-1}\) (13 TeV)

P\(T > 20\) GeV \(|\eta| < 2.4\)

Z line shape in data and MC

After data driven \(P_T\) calibration correction
Pixel volume sufficiently dry to run Trackers cold in 2015

- Dew point excellent
  - “originally” Pixel volumes and Bulkhead not sufficiently well sealed for lower temperature
    - Major work during LS1
  - < -40 °C for both ends of CMS
  - All gas systems ran without downtime
    - Redundancy available in case of failures

Dew point temperature in pixel detector volume

Final intervention on sealing of pixel detector volume before closing CMS

-- Positive end
-- Negative end
Tracker Operations

**Excellent performance at -10 degrees (pixels) -15 (silicon strip) throughout 2015**

- Both detectors running smoothly
- Minor Pixel sector problem limited to only 1 layer out of 3
  - Negligible effect on track seeding and b-tagging and will be taken into account in MC

- Reading out prototype Phase I upgrade modules installed in FPIX
  - firmware development in realistic data taking conditions
  - Ensure CMS has fully debugged readout with new Phase I detector (2017)
Pixel movements during magnet cycles

Tracker Alignment in 2015 Data Taking Used as Reference

CMS Preliminary

3.16 fb\(^{-1}\) (13 TeV)

[Graph showing pixel movements during magnet cycles]
Pixel movements during magnet cycles

Tracker Alignment in 2015 Data Taking
Used as Reference

$\Delta z$ [\mu m]

Run

CMS Preliminary

3.16 fb$^{-1}$ (13 TeV)
LUMINOSITY
Luminosity – detector performance - linearity

CMS sends per bunch luminosity to the LHC at 0.5 Hz from 3 online luminosity systems

- Below example from BCM1F, where the contribution of luminosity products in the bunch crossing after the colliding bunch is measured to be less than 1.5%
Luminosity – detector performance

Scan 2: Y-plane BCID 1711

<table>
<thead>
<tr>
<th>CMS Preliminary</th>
<th>VdM Scan: Fill 4266</th>
<th>BCM1F</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\chi^2 / \text{ndf}$</td>
<td>36.27 / 19</td>
<td></td>
</tr>
<tr>
<td>$\Sigma$</td>
<td>0.1146 ± 0.0005</td>
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</tr>
<tr>
<td>$\alpha / \sigma$</td>
<td>1.4 ± 0.2</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>-0.0072 ± 0.0005</td>
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</tr>
<tr>
<td>Amp</td>
<td>0.00272 ± 2e-05</td>
<td></td>
</tr>
<tr>
<td>Frac</td>
<td>0.06 ± 0.07</td>
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<tr>
<td>Const</td>
<td>3.9e-06 ± 7e-07</td>
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</table>

Scan 1: X-plane BCID 1711

<table>
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<th>BCM1F</th>
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<tbody>
<tr>
<td>$\chi^2 / \text{ndf}$</td>
<td>30.26 / 19</td>
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</tr>
<tr>
<td>$\Sigma$</td>
<td>0.1237 ± 0.0006</td>
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</tr>
<tr>
<td>$\alpha / \sigma$</td>
<td>1.33 ± 0.03</td>
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<tr>
<td>Mean</td>
<td>-0.004 ± 0.0006</td>
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<tr>
<td>Amp</td>
<td>0.00271 ± 2e-05</td>
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<tr>
<td>Frac</td>
<td>0.3 ± 0.2</td>
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<tr>
<td>Const</td>
<td>4.2e-06 ± 8e-07</td>
<td></td>
</tr>
</tbody>
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Luminosity calibration using BQM for current normalisation

![Graph showing data for CMS Preliminary and Fill 4266, $\sqrt{s} = 13$ TeV]
The ratio of luminosity measured from the BCM1F diamond array to that estimated from the rate of muon trigger candidates measured with Drift Tube barrel muon detector and associated trigger electronics (DTLumi) for all Lumi Section periods (~23.3 s) of the 50 ns 2015 pp run, as well as the profile of the same ratio across lumi sections. The group of low points corresponds to the low pileup data (end of fill 3996), where the bias comes from DTLumi, which is less sensitive at low luminosity values. Fill boundaries are visible as slight discontinuities; these variations are within the current uncertainty on the luminosity. The stability of BCM1F in this data is confirmed comparing to other luminometers (not shown). The large excursions come from Lumi Sections at the beginning of the fill not used for physics, where the imperfect synchronization of the time periods between the two luminometers plays a role.
The ratio of BCM1F luminosity to Pixel Cluster Counting (PCC) luminosity is flat over a wide range of instantaneous luminosity, for isolated, leading, and in-train bunch crossings. The value plotted is the average ratio of the points falling into a given instantaneous luminosity bin; the error bars represent the standard error on the mean. The co-linearity of these two detector systems is used to quantify the linearity components of the systematic uncertainty in luminosity measurement for the 50ns data.
The stability of CMS Offline luminosity is measured using yields of Z bosons decaying into two Muons during the 50ns data-taking period. Muons are required to have a transverse momentum higher than 25 GeV and to be within 2.4 absolute pseudorapidity. The plot shows the relative difference of Z cross-section measurements performed in 7 successive 50ns data-taking periods with respect to the average cross-section. The statistical uncertainties of the reconstruction, selection and trigger efficiency estimates for Z bosons decaying into two Muons and the statistical uncertainty of the yields themselves are added in quadrature and correspond to the error bars in this plot. CMS offline luminosity is measured with BCM1f with a precision of 4.8%. 

\[
\frac{\sigma^Z_{\text{avg}} - \sigma^Z_{\text{(RunRange)}}}{\sigma^Z_{\text{avg}}}
\]
Luminosity calibration

CMS sends online per-bunch luminosity to the LHC at a frequency of 0.5 Hz.
- Multiple detectors useful to understand beam and detector systematics
  - PLT, HF-lumi, BCM1F, pixel cluster counting

Each Luminometer calibrated offline using the Van der Meer (VDM) scan technique

VDM-calibrated-BCM1F used as primary offline luminometer for physics for 50 ns recorded data.

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<td></td>
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<tr>
<td>BCID variations</td>
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<tr>
<td>Reproducibility between scans</td>
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<td>Length scale</td>
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<td>Beam-beam corrections</td>
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<tr>
<td>Bunch current</td>
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<tr>
<td>Ghosts, Satellites</td>
<td>0.2</td>
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<tr>
<td>Detector behavior during 50 ns</td>
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</tr>
<tr>
<td>Linearity and stability</td>
<td>4</td>
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<tr>
<td>TOTAL uncertainty (for 50 ns)</td>
<td>4.8</td>
</tr>
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HI AND LOW ENERGY P-P
Proton-Proton reference run @ 5.02 TeV

28 pb-1 of data recorded for physics @ 5.02 TeV with B=3.8 T

√s = 5 TeV

Data included from 2015-11-19 14:39 to 2015-11-23 06:28 UTC

Preliminary Offline Luminosity

✓ 94 % efficient in recording data for Pb-Pb reference run ... excellent availability of the LHC to maximise delivered luminosity to the experiments! Congrats to LHC crew!

Quick look at data quality from di-muon spectrum from express stream

pp [Express 262163-262328] √s = 5.02 TeV

J/ψ
ψ(2S)
γ(1,2,3S)
Z

Events/(GeV/c²)

m_{μμ} (GeV/c²)
Event displays from PbPb collisions

Head-on collision

The first dijet event

The first Upsilon Candidate

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CMS Status Report
PbPb: first upsilon candidate
Z boson event in PbPb collision at 5 TeV
PbPb: first Z candidate

- Dimuon mass 92GeV
- 2 back-to-back muons, pt=22 and 27GeV/c
2.5 billion minimum-bias events recorded!!

Important reference for low $p_T$ heavy flavor mesons
Z boson event in PbPb collision at 5 TeV
Z boson event in PbPb collision at 5 TeV
Event displays from PbPb collisions
Corrected secondary vertex mass

**Differences between b-jet and c-jet tagging**

- **Corrected Secondary Vertex Mass**
  
  \[ M_{corr}(\text{min}) = \sqrt{M_1^2 + p_1^2 \sin^2 \theta_1 + p_1 \sin \theta_1} \]

  - Partially corrects for neutrals/invisibles in the secondary vertex decay via comparing the reconstructed particle momentum to the vertex decay length vector.
  
  - This variable calculates the minimum possible missing energy of the decay.

- **Secondary Vertex “High Purity” Working Point**
  
  - Requires a 3+ body decay from the reconstructed secondary vertex.
  
  - Reduction of the light jet fraction in the tagged sample: 3x -> more precise charm jet template fitting.
Pre-QM Heavy Flavored Jet Status

CMS showed b-jets in PbPb (and pPb) are modified to a similar extent as light jets

Can we say anything about charm jets? (yes)
Claim c Jet fraction is consistent with PYTHIA to within systematic uncertainties both in pA and pp.
Calculating the Heavy Flavour Jet fraction

\[ E_c = \frac{C_c f_c \frac{N_{c\text{tagged}}}{N_{\text{jets}}}}{f_c_{\text{untagged}} \frac{N_{\text{untagged}}}{N_{\text{jets}}}} \]  

\[ N_{c\text{jets}} = N_{\text{jets}} \frac{f_c}{E_c} \]  

- Purity \( f_c \) is found via fitting distribution of \( M_{\text{corr}} \)
- Efficiency \( E_c \) is found in MC and via the tagging and anti-tagging purity [eq. 1]
Jet tagging efficiency

Figure 1: Efficiency curves are plotted for the high purity (HP), and high efficiency (HE) versions of the simple secondary vertex (SSV) tagger for both bottom (left) and light (right) jets as a function of c jet tagging efficiency. The charm-to-bottom discrimination power is virtually unchanged between the SSVHE and SSVHP taggers, while the light jet mistag rate is reduced by a factor of three at the SSVHP working point, shown as the closed red cross on the plot.
Dijet resonance search @13 TeV

<table>
<thead>
<tr>
<th>Narrow Resonance</th>
<th>CMS Run 1 (20 fb⁻¹)</th>
<th>CMS Run 2 (2.4 fb⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>Observed</td>
<td>Expected</td>
</tr>
<tr>
<td>String Resonance (S)</td>
<td>5.0</td>
<td>4.9</td>
</tr>
<tr>
<td>Scalar Diquark (D)</td>
<td>4.7</td>
<td>4.4</td>
</tr>
<tr>
<td>Axigluon (A)/Coloron (C)</td>
<td>3.7</td>
<td>3.9</td>
</tr>
<tr>
<td>Excited Quark (q*)</td>
<td>3.5</td>
<td>3.7</td>
</tr>
<tr>
<td>Color Octet Scalar (S8)</td>
<td>2.7</td>
<td>2.6</td>
</tr>
<tr>
<td>Heavy W (W')</td>
<td>1.9, 2.0-2.2</td>
<td>2.2</td>
</tr>
<tr>
<td>Heavy Z (Z')</td>
<td>1.7</td>
<td>1.8</td>
</tr>
<tr>
<td>RS Graviton (G)</td>
<td>1.6</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Set upper limits at 95% CL on cross section of qq, qg and gg resonances and compare them with predictions from 8 models of new physics

- String Resonances, Excited Quarks, Axigluons/Colorons, Scalar Diquarks, Color Octet Scalars, W', Z', and Randall-Sundrum Gravitons
- CMS limits extend above 7.0 TeV in dijet mass for the first time
Results dijet resonance and comparison standard analysis

Upper limits on various production cross sections as a function of the resonance mass

Example on limits on Randall-Sundrum graviton decaying into q-qbar

Comparison shows that the expected limits with scouting agrees well with the limits from standard analysis within the uncertainty band.
Monash tune of Pythia8 best describes the energy dependence of the leading jet $p_T$
UE results – Multiplicity density vs leading jet $p_T$

Comparisons of corrected

(a) transAVE,
(b) transDIF,
(c) transMAX, and
(d) trans-MIN average particle densities with the various simulations as a function of $p_{jet_T}$. 
MET resolution, Particle flow with PUPPI

Most effective for low MET and high pileup

https://cds.cern.ch/record/2051942?ln=en
CMS Upgrades during LS1

All upgrades contributed to improved performance during 2015

- Data acquisition: new architecture, hardware, software
- Trigger Control and Distribution System: new (uTCA)
- Level-1 trigger: new calorimeter trigger (uTCA)
- Electromagnetic calorimeter: new trigger optical links
- Hadronic calorimeter: new SiPMs (HO), new PMTs (HF), HF back-end (uTCA)
- Drift Tube chambers: new trigger electronics
- Resistive Plate Chambers: new chambers
- Cathode Strip Chambers: new chambers & electronics
- Silicon pixels: lower temperature (–10°C) and recovered channels
- Silicon tracker: lower temperature (–15°C)
- Luminosity & Beam monitoring: new pixel luminosity telescope, fast beams conditions monitor and beam halo monitor, bril-daq software
New DAQ fabric and HLT
Tracker and Pixel running at -20°C
4th muon station (CSC +RPC), CSC electronics upgrade
HF new PMT & backend
New Beampipe
New Silicon LUMI telescope and improved FE for BCM1f
New beam halo monitors
HO new SiPM