CMS Status Report

- Looking back at 2017 data taking
- Recent Run 2 physics highlights
- Preparing for 2018 data taking
- Preparing for the future

Lea Caminada (PSI and Universität Zürich) on behalf of the CMS Collaboration

LHCC Open Session | February 28, 2018
2017 data taking

- LHC showed excellent performance and delivered luminosity of 51 fb$^{-1}$
  - 20% more than in 2016
- CMS kept up with increasing luminosity and took high quality physics data
  - 46 fb$^{-1}$ recorded
  - 90.3% average data-taking efficiency
  - After challenging start-up phase (accommodating the Phase 1 upgrades) data-taking efficiency improved over the course of the year
CMS detector in 2017

**Muon system**
- Active channel fraction >98%
- Excellent performance
- Demonstrator GEM detectors for Phase 2 upgrade integrated and successful collision data taking

**Strip Tracker**
- Active channel fraction stable at 96%
- Very good performance with ~99% hit efficiency with average pileup of 45

**Pixel Detector**
- New Phase 1 system installed in EYETS16/17
- Improved performance up until after TS2, then degraded due to "DCDC issue"

**HCAL**
- Active channel fraction >99%
- HF Phase 1 upgrade successful in noise suppression
- HE Phase 1 upgrade for one 20° phi wedge shows promising results, finalized during YETS17/18

**ECAL**
- Active channel fraction 99%
- Excellent performance
Phase 1 Pixel Detector Operation

- New 4-layer/2x3-disk pixel system
  - Twice number of channels & active area
  - More tracking layers, but less material
  - New readout chips to reduce dynamic inefficiency at high instantaneous luminosity

- Achieved good performance despite initial challenges in operation
  - Timing adjustment, SEU recovery, reset rate

- Until...
Pixel Detector: DCDC Converter Issue

- DCDC converters that provide LV (VA/VD) for pixel detector modules started failing on October 5, 2017
  - Damage accumulated, leading to a total of about 50 broken DCDC converters (5% of the detector, BPIX+FPIX)
  - Affected channels during data-taking larger (up to 10%) since power-cycling for module SEU recovery was only done rarely as a precaution

- While impact on 2017 data still bearable, with no action taken, 2018 data-taking would have been endangered
  - Asked for extension of YETS (BIG THANKS!!!) to allow for pixel detector intervention
  - Goals: 1) investigate the issue, 2) replace DCDC converters
Impact on tracking and b-tagging in 2017

• Many studies performed to assess data quality in last period of the run

• Simulation studies with 2017 detector scenarios based on actual pattern of disabled pixel modules show that tracking efficiency losses are small and data quality is good for physics

• Impact on b-tagging performance is small
  – Achieve performance at least as good as in 2016
Physics with 2017 data

• Data analysis ongoing
• Studies with full data set show that physics object reconstruction performance is good and well-modeled by simulation
• First physics results with 2017 data will be shown at upcoming conferences... stay tuned!
Luminosity Monitoring in 2017 – Fill-by-fill!

- Online measurements of per-bunch visible cross section for each luminometer
- Online measurements of bunch position & emittance

Example uncorrected $\sigma_{\text{vis}}$ measured by PLT fill-by-fill

Emittance measured during fill

→ Input to LHC machine performance studies and beam-beam simulations
Run 2 Physics Results

• In 8 years CMS submitted for publication 743 physics papers
  – 714 papers with collision data out of which 156 with Run 2 data
  – 132 papers in 2017 (record year for CMS!)
  – 29 papers since last LHCC (see list in backup)

Only a few selected highlights presented in the following
Higgs bosons as probe for new physics

- Exploit complex final states with Higgs boson to probe new physics models (SUSY, extended Higgs sectors, etc)
- Employing advanced experimental techniques as for instance
  - efficient b-tagging at trigger level
  - jet substructure techniques with flavor tagging

CMS-PAS-HIG-16-018
arXiv:1712.08501
Search for heavy neutral leptons

- Adding sterile neutrinos to SM solves a range of questions
  - smallness of neutrino masses
  - baryon asymmetry
  - nature of dark matter
- LHC just started to probe mass range left open by EW precision measurements
- New approach targets leptonic decay of N produced in $W^\pm \to Ne^\pm/N\mu^\pm$
  - first constraints at $m_N > 500$ GeV
  - improved over LEP results at low $m_N$

Significantly lower masses will become available when exploiting also displaced signatures!
Search for Leptoquarks (LQ)

- Models with leptoquarks that preferentially couple to 3\textsuperscript{rd} generation can explain $R_{D^*}$ anomaly reported by B-factories and LHCb
- Predict LQ at TeV scale that can be probed at LHC
- Search for decay $LQ \rightarrow t\tau$ in LQLQ pair production
  - using final state of $l+\tau+\text{jets}$
  - achieved best limits in this channel excluding masses below 900 GeV
Charm and strange in Heavy Ion collisions

- Heavy quarks produced in early stages of the collision → probe properties of QGP through entire evolution
- Measurement of D mesons compared to strange hadrons
  - mass ordering for strange hadrons similar in pPb and PbPb
  - Smaller elliptic flow for charm in pPb
- May suggest weaker collective behavior for charm quarks in small systems → Looking forward to theoretical calculations
Preparing for 2018 data taking

- Started as soon as 2017 run was over...

**LHC**
- End of run
- YETS
- Machine checkout & re-commissioning
- Ramp up
- 2018 physics run

**CMS**
- Opening CMS
- Closing CMS
- Magnet Ramp

**HE**
- Phase 1 upgrade
- \(+z\)
- \(-z\)

**Pixel**
- FPIX- to surface
- FPIX+/BPIX to surface
- Repair
- FPIX/BPIX re-installed
- Commissioning & calibration

**Data taking**
- pp 2017
- MWGR
- MWGR
- MWGR
- CRUZET
- CRAFT
- pp 2018
HE Phase 1 Upgrade

- Phase 1 upgrade of HE front-end electronics completed!
  - Intense but smooth operation, confirming excellent experience with pilot system
  - All HE HPDs replaced by SiPMs
  - Eliminated dominant source of HE signal loss
  - Increased longitudinal segmentation and added time information (TDC)

**HE response loss** vs integrated luminosity in 2017 (channels at same eta+layer, different phi):

- For 2018 we expect a very moderate loss in all HE channels!
Summary of HE commissioning

• Cobalt-60 calibration campaign completed
• All HE front-end channels are working
  – Pedestals and SiPM bias voltage tuned
  – Commissioning and calibrations well underway
• Already participating in global run!

SiPM gain calibration verified in-situ using single PE peaks from low intensity LED data
Pixel detector repair

- FPIX+ extracted before lab closure to get access to problematic converters ASAP
  - work continued every day during holiday season and new year
  - heroic common effort of chip designers, DCDC-, pixel-, DCS- and cooling-experts

- Replaced all DCDC converters on FPIX and BPIX (>1000)

- Huge effort in testing, diagnostic and forensics
Current understanding of DCDC issue

• Thanks to the effort of the chip designers, we know on transistor-level where the problem in FEAST2 ASIC is located
  – Behavior of broken converters can be reproduced in simulation by drain-gate breakdown in clamp transistors in under voltage protection circuit
  – Additionally found "high-current" converters (early stage of failure?)
  – what causes this damage is not understood

• FEAST2 IV characteristics measured on several samples
  – Phase 1 pixel extracted/spare/new production, pixel pilot system, HCAL, FEAST2 chips on CERN module, irradiated samples, ...

• Modules with "high-current" found in
  – 30% of Phase 1 pixel detector after 2017 operation
  – 9/33 converters (on CERN module) irradiated in 2014 (tested in 2018)
  – few modules of new production (tested ok in Q&A)

→ "High-current" behavior not limited to CMS module/environment
→ Large effort in community to investigate and resolve this issue
→ Measurement program being set up
Collateral damage to pixel detector modules

- Since HV granularity is lower than granularity of DCDC converters, modules behind broken DCDC converters were run with LV off, but HV on during 2017 operation.
- This condition caused damage to pixel pre-amplifier:
  - Leakage current leads to too high voltage at pre-amp input.
  - Amount of damage depends on time and leakage current.
- Damage most severe in BPIX L1.

→ 6 out of 8 affected modules replaced in L1.
Pixel detector status

• Pixel detector re-installed into CMS mid February
• First checkout successfully completed
  – re-established working fraction of ~97-98%
• Cold operation at -22°C starting this week
  – re-commissioning and calibration
  – participate in CRUZET/CRAFT crucial for alignment
• Operation in 2018 will depend on performance of DCDC converters
  – Learn how to optimize operation procedure to minimize DCDC failures
• Prepare to replace all DCDC converters with new, improved converters in LS2
  – Designers are working on new FEAST version
Other YETS activities

• Muon DT Phase 1 upgrade successfully completed
  – Upgrade of DT VME ROS to mTCA ROS (uROS)
  – Comparison with legacy system shows excellent results

• Operation temperature for Si strip tracker and pre-shower detector lowered
  – in order to decrease leakage current

• Detector brought up smoothly for cosmic data-taking starting at the end of January
  – All subsystems (except pixels) run in Mid-Week Global Runs (MWGR)
  – DAQ runs efficient and stable
Trigger development

- Aim is to keep a trigger menu for collision data-taking with the same physics content as at the end of 2017: similar thresholds and rates
  - Target an instantaneous luminosity of $2 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ with 48b (25ns) bunch trains
  - L1 menu with improvements in object reconstruction and algorithms
  - HLT technical improvements
    - More refined algorithms to mitigate possible pixel detector inefficiencies
    - Adapt to HE upgrade

- Review of scouting and parking strategy to best exploit this last year of Run 2

→ Physics case:
  - low $p_T$ muons
  - complement di-jet mass spectrum at low mass
Software & Computing

• From mid November on, focus on 2017 data and MC re-RECO – at the same time preparing for next run
  – Overall, processed almost 50 B events (!!) in 2017

• During Christmas break production utilized the full Tier-0 plus a sizeable fraction of HLT cores
  – Important test for 2019, when we plan to do this all year long
  – Test under full load successful, no problems spotted

• Study new data format for event size reduction (NanoAOD)
  – Should enable >50% of analyses, down to 800B/event (factor 50 reduction wrt MINIAOD)

peak utilization of HLT reached 50k cores in a dedicated test
Challenges for 2018 and beyond

• Take high-quality physics data with increasing luminosity
  – pp and HI
  – Effort in detector operation to keep up performance

• Process and analyze full Run 2 data set
  – Do precision SM physics and search for new physics

• Prepare for various activities scheduled during LS2
  – Muon system upgrade (new CSC FE, new GEM layer GE1/1)
  – HB Phase 1 upgrade
  – Pixel Layer 1 replacement (& DCDC repair)
  – Preparation of infrastructure for LS3 (incl. beampipe replacement)

← GEM chamber production proceeding smoothly
Upgrade for HL-LHC

• Very active time for upgrade preparation producing:
  – 4 TDRs (Tracker, Muons, Barrel and Endcap Calorimeter)
    • https://cds.cern.ch/record/2293646
    • https://cds.cern.ch/record/2272264
    • https://cds.cern.ch/record/2283187
    • https://cds.cern.ch/record/2283189
  – 2 Interim Design Reports (Trigger, DAQ/HLT)
    • https://cds.cern.ch/record/2283192
    • https://cds.cern.ch/record/2283193
  – 1 Technical Proposal (MIP Timing)
    • https://cds.cern.ch/record/2296612
Summary

- Physics results continue to be excellent in exploring new phase space
- Analysis of 2017 data ongoing, first results to be shown at upcoming conferences
- Used YETS for important repair and upgrade work
  - Pixel detector extracted, major effort in repair (all DCDC converter replaced, 6/8 affected L1 modules replaced), detector re-installed, commissioning in progress
  - Located problem in FEAST2 ASIC, cause not understood yet → setting up measurement program
  - HE Phase 1 upgrade completed (HPD → SiPMT)
  - Muon DT Phase 1 upgrade completed (uROS)
- CMS detector preparation on track for 2018 data taking
- Upgrade projects for LS2 and beyond well underway
Backup
## CMS Paper submitted since last LHCC meeting (1/3)

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<tr>
<th>CMS Publications</th>
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<td><strong>B2G-16-029</strong></td>
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<td><strong>EXO-16-057</strong></td>
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## CMS Paper submitted since last LHCC meeting (2/3)

<table>
<thead>
<tr>
<th>ID</th>
<th>Title</th>
<th>Journal</th>
<th>Date</th>
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<tbody>
<tr>
<td>733</td>
<td>Combined search for electroweak production of charginos and neutralinos in proton-proton collisions at $\sqrt{s} = 13$ TeV</td>
<td>Submitted to JHEP</td>
<td>11 January 2018</td>
</tr>
<tr>
<td>732</td>
<td>Measurement of the $Z\gamma^* \rightarrow \tau\tau$ cross section in pp collisions at $\sqrt{s} = 13$ TeV and validation of $\tau$ lepton analysis techniques</td>
<td>Submitted to EPJC</td>
<td>10 January 2018</td>
</tr>
<tr>
<td>731</td>
<td>Search for new physics in events with two soft oppositely charged leptons and missing transverse momentum in proton-proton collisions at $\sqrt{s} = 13$ TeV</td>
<td>Submitted to PLB</td>
<td>5 January 2018</td>
</tr>
<tr>
<td>730</td>
<td>Search for decays of stopped exotic long-lived particles produced in proton-proton collisions at $\sqrt{s} = 13$ TeV</td>
<td>Submitted to JHEP</td>
<td>31 December 2017</td>
</tr>
<tr>
<td>729</td>
<td>Electroweak production of two jets in association with a Z boson in proton-proton collisions at $\sqrt{s} = 13$ TeV</td>
<td>Submitted to EPJC</td>
<td>28 December 2017</td>
</tr>
<tr>
<td>728</td>
<td>Search for $R'$-parity violating supersymmetry in pp collisions at $\sqrt{s} = 13$ TeV using $b$ jets in a final state with a single lepton, many jets, and high sum of large-radius jet masses</td>
<td>Submitted to PLB</td>
<td>24 December 2017</td>
</tr>
<tr>
<td>727</td>
<td>Measurement of prompt and nonprompt charmonium suppression in PbPb collisions at 5.02 TeV</td>
<td>Submitted to EPJC</td>
<td>24 December 2017</td>
</tr>
<tr>
<td>726</td>
<td>Search for physics beyond the standard model in events with high-momentum Higgs bosons and missing transverse momentum in proton-proton collisions at 13 TeV</td>
<td>Submitted to PRL</td>
<td>22 December 2017</td>
</tr>
<tr>
<td>725</td>
<td>Search for lepton flavour violating decays of the Higgs boson to $\mu\tau$ and $e\tau$ in proton-proton collisions at $\sqrt{s} = 13$ TeV</td>
<td>Submitted to JHEP</td>
<td>20 December 2017</td>
</tr>
<tr>
<td>724</td>
<td>Study of Bose-Einstein correlations in pp, pPb, and PbPb collisions at the LHC</td>
<td>Submitted to PRC</td>
<td>20 December 2017</td>
</tr>
<tr>
<td>Paper ID</td>
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<tr>
<td>BTV-16-002</td>
<td>Identification of heavy-flavour jets with the CMS detector in pp collisions at 13 TeV</td>
<td>Submitted to JINST</td>
<td>19 December 2017</td>
</tr>
<tr>
<td>BPH-16-002</td>
<td>Search for the X(5568) state decaying into $B_s^0 \pi^\pm$ in proton-proton collisions at $\sqrt{s} = 8$ TeV</td>
<td>Submitted to PRL</td>
<td>17 December 2017</td>
</tr>
<tr>
<td>SMP-16-014</td>
<td>Azimuthal correlations for inclusive 2-jet, 3-jet, and 4-jet events in pp collisions at $\sqrt{s} = 13$ TeV</td>
<td>Submitted to EPJC</td>
<td>14 December 2017</td>
</tr>
<tr>
<td>EXO-17-005</td>
<td>Search for $Z\gamma$ resonances using leptonic and hadronic final states in proton-proton collisions at $\sqrt{s} = 13$ TeV</td>
<td>Submitted to JHEP</td>
<td>9 December 2017</td>
</tr>
<tr>
<td>TOP-16-020</td>
<td>Measurement of the associated production of a single top quark and a Z boson in pp collisions at $\sqrt{s} = 13$ TeV</td>
<td>Accepted by PLB</td>
<td>8 December 2017</td>
</tr>
<tr>
<td>TOP-17-003</td>
<td>Search for the flavor-changing neutral current interactions of the top quark and the Higgs boson which decays into a pair of b quarks at $\sqrt{s} = 13$ TeV</td>
<td>Submitted to JHEP</td>
<td>6 December 2017</td>
</tr>
<tr>
<td>FSQ-16-005</td>
<td>Constraints on the double-parton scattering cross section from same-sign W boson pair production in proton-proton collisions at $\sqrt{s} = 8$ TeV</td>
<td>JHEP 02 (2018) 032</td>
<td>6 December 2017</td>
</tr>
<tr>
<td>EXO-16-048</td>
<td>Search for new physics in final states with an energetic jet or a hadronically decaying W or Z boson and transverse momentum imbalance at $\sqrt{s} = 13$ TeV</td>
<td>Submitted to PRD</td>
<td>6 December 2017</td>
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CMS PAS since last LHCC meeting

- **SUS-17-002** Search for supersymmetry in events with tau leptons and missing transverse momentum in proton-proton collisions at $\sqrt{s}=13$ TeV
- **SUS-17-009** Search for selectrons and smuons at $\sqrt{s}=13$ TeV
- **B2G-16-028** Search for third-generation scalar leptoquarks decaying to a top quark and a tau lepton at $\sqrt{s}=13$ TeV
- **B2G-17-006** Search for heavy resonances decaying into two Higgs bosons or into a Higgs and a vector boson in proton-proton collisions at 13 TeV
- **B2G-17-013** Search for new heavy resonances decaying into a Z boson and a massive vector boson in the $2\ell2q$ final state at $\sqrt{s}=13$ TeV
- **EXO-17-011** Search for a heavy right-handed W boson and a heavy neutrino in events with two same-flavor leptons and two jets
- **HIG-16-018** Search for Higgs bosons produced in association with b quarks and decaying into a b-quark pair with 13 TeV data
- **HIG-17-012** Search for a new scalar resonance decaying to a pair of Z bosons in proton-proton collisions at $s^{\sqrt{}}=13$ TeV
- **HIG-17-020** Inclusive search for the standard model Higgs boson produced in pp collisions at $\sqrt{s}=13$ TeV using $H\rightarrow bb$ decays
- **HIN-17-003** Elliptic flow of charm and strange hadrons in high-multiplicity pPb collisions at $\sqrt{s_{NN}}=8.16$ TeV
Hadron Calorimeter performance

Forward Hadron Calorimeter:
- Steel absorber, quartz fibers, PMT readout

Phase-1 upgrade to address beam-induced PMT anomalous noise:
- Upgrade completed in EYETS 2016/17
- All new handles to achieve noise suppression are in use
- Substantial rate reduction for MET achieved
Pixel Detector: DCDC converter issue

% of Dead ROCs Pixel

October 5
stable at ~5%
rapidly increasing
Strip Tracker and Muon System Status

- No major intervention during YETS
- Strip tracker
  - kept cold during whole period
  - Operation temperature lately lowered from $-15^0\text{C}$ to $-20^0\text{C}$ to decreases leakage current (needed for individual modules)
- Muon system
  - Fixed water leak in YE1 that appeared in May 2017 and verified that there is no collateral damage
  - Annual system maintenance (gas system, hardware, firmware, software) in progress
  - DAQ upgrade (VME→uTCA) successfully completed
Calorimeter Status

- No major intervention during YETS (except for HE)
- ECAL
  - Pre-shower operation temperature lowered (-7\(^\circ\)C to -15\(^\circ\)C)
  - Firmware and software upgrades to improve efficiency and reliability, in particular in view of high PU (up to 60)
  - Estimation of expected noise and light output until LS3

- HCAL
  - HB and HO: fixed one data fiber each that were lost during the year
  - HB and HE: faster software algorithm allowed to unify the online and offline local reconstruction
  - HF front-end firmware updated to better handle (rare) beam induced low voltage power supply cycles
  - MC simulation: an improved description of the front-end electronics time slew was implemented