CMS Status Report

A. Tapper for the CMS collaboration
Outline

• Run 3 performance
• Physics analysis highlights
• Upgrade status
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• Physics analysis highlights

• Upgrade status
Run 3 so far …

- Teething problems fixed promptly
- Similar efficiency to Run 2 (2015)
- Big thanks to LHC!!

- In numbers:
  - Over 10 fb$^{-1}$ delivered @13.6 TeV
  - 90.2% data taking efficiency

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4  Open Session, 151st LHCC Meeting, September 14th 2022.
Run 3 so far …

- Improvement of tools and procedures for calibrations and data certification in many areas
  - For example, PCL (Prompt Calibration Loop) workflows ↓
    - PCL workflows in Run 2 (end of 2018)
      - BeamSpot (4 wfs)
      - SiStrip Quality
      - SiStrip Gains
      - ECAL pedestals
      - SiPixel Alignment
      - SiPixel Quality
      - Lumi PCC
      - SiStripGainsAAG
    - During LS2 most of these workflows were consolidated/improved and new ones were added for Run 3
      - BeamSpot (4 wfs)
      - SiStrip Quality
      - SiStrip Gains
      - ECAL pedestals
      - SiPixel Alignment
      - SiPixel Quality
      - Lumi PCC
      - SiStripGainsAAG
      - SiStrip HitEff
      - SiPixel LA
      - SiPixel Ali HG
      - PPS Timing
      - PPS Sampilc

- In numbers:
  - Over 10 fb\(^{-1}\) delivered @13.6 TeV
  - 90.2% data taking efficiency
  - 67% - 83% certification efficiency (improving)
Luminosity & beam monitoring

- Luminometers showing excellent performance
  - BCM1F, PLT, HFOC, HFET “calibrated” in emittance scans
  - RAMSES, DT cross calibrated
  - PCC in progress
- Background and abort systems all operational
  - Good progress with Beam Halo Monitor
  - BPTX operational — upgrade being commissioned
- Awaiting a VDM scan for better systematics

Over full running period all luminometers within ± 2%
• **Level-1 Trigger highlights**
  - New triggers: displaced/delayed muons/jets, low $E_T$ double $E/\gamma$ for b-physics, …
  - Impact of updates from the detectors (new pulse shape filter for HCAL, endcap muon reconstruction and shower trigger, ECAL spike noise cleaning, Kalman filter for muons…)

• **HLT highlights**
  - GPU offload 40% of evt. processing
  - Yields 70% increase in throughput
  - Consistent results CPU vs GPU
  - Graph Neural Network for jet tagging
• New B physics triggers (parking)
  ‣ New **di-muon** triggers for $B \rightarrow \mu \mu X$
    optimised requirement for different phase space
  ‣ Also for searches $\tau \rightarrow \mu \mu \mu$, resonances etc.
  ‣ New **di-electron** triggers for $B \rightarrow eeX$
  ‣ Low thresholds @L1: ID and mass @HLT

\[ \text{Reduced mass: } m(B) - m(e,e) + m(J/\Psi) \]

• Jet tagging @HLT
  ‣ Triggers developed for $HH \rightarrow 4b$ resolved, for boosted $H \rightarrow bb$ and boosted $H \rightarrow \tau_h \tau_h$
  ‣ Measure the efficiency of the Particle-NET $b$-tag or Particle-NET $bb$-tag based selection in a control region **in data** in which events have two real $b$-jets
  ‣ The monitoring runs in on-line DQM
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**Offline & computing**

- So far *Standard and Parking* streams successfully promptly processed at the Tier-0
  - Run 3 peak processing rates > 5 kHz
    - Run 4 like
- Introduced new compression algorithm for RAW data:
  - LZMA replaced GZIP thanks to ROOT
  - 10% smaller RAW event size
- Huge tape deletion campaign
  - 70 PB (20% of all data on tape) deleted
  - Using RUCIO for the first time for tape deletion

Successful prompt processing @ > 5 kHz
Offline & computing

- Record CPU utilisation since May: 386K CPU cores average, peak: 466K
  - Large contributions from HPCs, Run-2 HLT Cloud, and beyond-pledge contributions from our sites
- Excellent support and availability from all our sites
- Continuous growth of capacity used at HPCs
  - Transparent site extensions (e.g. RWTH, HOREKA, Marconi)
  - Allocations accessed through a service (e.g. HEPCloud, OSG)
- Full Physics Validation of samples created on the M100 HPC (Power CPUs) started last week.
  - If successful, production will start on the machine
  - Done by objects and detector experts

Record usage of compute capacity, usage of HPCs continues to grow.
Tracker

- Pixel and strip tracker running well in 13.6 TeV collisions
  - Timing and other scans for commissioning have been performed successfully →
  - **Reminder**: new Barrel Pixel Layer 1 installed in LS2 — working well
  - Number of active channels stable since last year
  - Beam spot position after LSS5 realignment well centred in \( y \) (vertical), will likely ask for small shift in \( x \) during YETS →
Electromagnetic calorimeter

- ECAL was successfully commissioned for Run 3, with updates to pedestals, pulse shapes, calibrations, timing, etc.

- The new laser workflow, which allows updates to HLT conditions once per fill, has been successfully deployed.

- The automation of calibration workflows is also being commissioned.
Electromagnetic calorimeter

- Alignment and energy calibration are ongoing, with excellent results already

The Z peak in EB and EE. The groups are in the process of updating conditions for Run3: Noise, pedestals, pulse shapes, timing, intercalibration and energy scale.
• **Reminder**: new HCAL barrel readout in LS2

• Successfully started Run 3 with timing and conditions derived using splash events and machine commissioning runs
  › Collision data to be used for channel-by-channel corrections

• Some hiccups during runs with high data volume, addressed by operations crew

• Deployed trigger algorithm that includes pile-up subtraction
  › Achieved 100% matching between data and emulation →
Muon detectors

• The muon system is running smoothly
  ‣ Online and offline analyses show detector performance in agreement with Run 2 results

• Drift Tube Phase-2 slice demonstrator, equipped with both the legacy system and the new Phase-2 on-board electronics
  ‣ Inter-channel response synchronised to few ns precision
  ‣ Phase-1 and Phase-2 hit efficiency are in agreement
  ‣ Phase-2 trigger primitive timing resolution comparable to the offline reconstruction
Muon detectors: GEM

- **Reminder**: Early partial installation of GEM detectors for Phase-2 upgrade
- High number of trips in several chambers observed with the first Run 3 fills
  - Immediate response: lower HV working point and induction gap off — decreased spike rate
  - HV scan was performed to fine tune the HV working point, chamber by chamber
  - Preliminary results obtained for HV working point at 690 µA (nominal value 700 µA)
  - Further optimisation expected to recover efficiency

New back-propagation method for GEM alignment applied, consisting of six misalignment parameters, 6 DOF alignment, significantly improves accuracy of relative alignment between GEM and CSC chambers.
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Physics results & publications

- **1159 papers** on collider data published or submitted to a journal

Since last LHCC:

- **26 new publications**
- **20 papers submitted**
- **18 analyses** in Collaboration Wide Review (CWR) or beyond – final journal submission or publication expected soon
- **6 approved results** released as Physics Analysis Summaries (PAS)

**Analysis in progress**
- Run 2 data analysis continues >100 analysis efforts ongoing
- Run 3 early data analysis foresee ~100 analyses in the first couple of years
- First preliminary result with Run 3 data presented at TOP2022 — more to come

Ten years of the Higgs

- Combination of multiple results fitting for coupling modifiers
- Combination of HH results for the three most sensitive channels (4b, 2b2τ, 2b2γ)
  - Reaching ~3x SM sensitivity, expect SM sensitivity with HL-LHC

All details in our Nature paper
Higgs coupling to charm

- Coupling to charm is extremely challenging to measure at SM value
- CMS developed new charm tagging techniques based on Graph Neural Networks
- Sizeable sensitivity improvement (~10x SM sensitivity)
- Calibration candle is the $Z\rightarrow cc$ decay (bonus 5σ observation of $Z\rightarrow cc$)
Searches with $\tau$ and $b$-quarks

- Final states with $\tau+\nu$, $\tau+b$ and $\tau\tau$ are investigated
- Good probe of models related to $b$-anomalies (e.g. leptoquark)
- Sensitivity approaching the preferred region from $b$-anomalies in some LQ models
- Some sizeable excess in non-resonant $\tau\tau$ final state
$\mathcal{B}(B_S^0 \to \mu^+ \mu^-) = [3.95^{+0.39}_{-0.37}\text{ (stat)} + 0.29\text{ (syst)}] \times 10^{-9}$

- **Updated results with full Run 2 dataset**
  - Most precise single experiment measurement to date
  - Highly compatible with SM prediction
  - Most precise **measurement** of lifetime $\tau = 1.83^{+0.23}_{-0.20}\text{ (stat)} + 0.03\text{ (syst)}$ ps
First Run 3 physics result!

- First measurement of the top-quark pair-production cross section in proton-proton collisions at 13.6 TeV

- Result presented at TOP2022 workshop
  - Combination of five channels, eμ, ee, μμ, e+jets, μ+jets which allows determination of efficiencies in situ
  - Measurement in good agreement with the standard model prediction

\[ \sigma_{tt} = 887^{+43}_{-41} \text{ (stat + syst) } \pm 53 \text{ (lumi) pb} \]

Theory prediction: \( 921^{+29}_{-37} \text{ pb} \)
Briefings since last LHCC:

**Hunting for New Particles with Light from the Higgs Boson**

Have you heard of sector-like quarks? They are hypothetical particles which would provide an explanation to the value of the Higgs boson mass, which is a mystery. Vector-like quarks are predicted by a variety of theories beyond the Standard...

**New Study of Rare B Meson Decays to Two Pions**

Rare events, such as a total solar eclipse or a supernova explosion, are fascinating and stimulate our imagination. In addition, such events may lead to discoveries expanding our knowledge horizon. At the Large Hadron Collider (LHC), studies of...

**Jet Qones with Top Flavour**

CMS has developed a new method to measure the properties of the top quark with high precision. It relies on an innovative way to study particles into jets. The top quark is the most massive elementary particle we have discovered so far. Due to...

**Protons That Do Not Break Up at the LHC**

The processes that are mostly studied at the LHC are caused by energetic collisions where the protons break up into their constituents, the quarks and gluons, which reassemble to form composite hadrons. However, many proton-proton interactions result...

**The Higgs Boson Turns 10: Results from the CMS Experiment**

Exactly ten years ago, on the 4th of July 2012, the ATLAS and CMS experiments announced the discovery of a new particle compatible with the long sought Higgs boson. This discovery takes us back to the events occurring in our early universe, just a...

**The LHC as a W-Photon Collider**

The LHC can be viewed not only as a hadron collider, but also as a boson collider. With the highest energies and collision rates ever, the LHC is pushing the limits of our understanding of rare processes such as W-photon scattering. The W...

**Fitting Together the Silicon Tracker**

The LHC's silicon detector, illustrated in Fig. 1, is centred around the largest and highest granularity silicon tracker ever built, including around twenty thousand detector units structured in thin cylindrical layers that extend over nearly 6 metres along...

**Two Collisions for the Price of One**

The Large Hadron Collider (LHC) offers a unique opportunity to probe the internal structure of protons, with great precision and unprecedented energies. According to Feynman's parton model, protons are made up of three quarks: two "up" quarks...

More details at: https://cms.cern/tags/physics-briefing
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Phase-2 Upgrade — scope

**L1-Trigger HLT/DAQ**
https://cds.cern.ch/record/2714892
https://cds.cern.ch/record/2759072
- Tracks in L1-Trigger at 40 MHz
- PFlow selection 750 kHz L1 output
- HLT output 7.5 kHz
- 40 MHz data scouting

**Barrel Calorimeters**
https://cds.cern.ch/record/2283187
- ECAL crystal granularity readout at 40 MHz with precise timing for e/γ at 30 GeV
- ECAL and HCAL new Back-End boards

**Tracker**
https://cds.cern.ch/record/2272264
- Si-Strip and Pixels increased granularity
- Design for tracking in L1-Trigger
- Extended coverage to η ≃ 3.8

**Calorimeter Endcap**
https://cds.cern.ch/record/2293646
- 3D showers and precise timing
- Si, Scint+SiPM in Pb/W-SS

**Muon systems**
https://cds.cern.ch/record/2283189
- DT & CSC new FE/BE readout
- RPC back-end electronics
- New GEM/RPC 1.6 < η < 2.4
- Extended coverage to η ≃ 3

**Beam Radiation Instr. and Luminosity**
http://cds.cern.ch/record/2759074
- Bunch-by-bunch luminosity measurement: 1% offline, 2% online

**MIP Timing Detector**
https://cds.cern.ch/record/2667167
Precision timing with:
- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes
Phase-2 Upgrade — highlights

- All projects continue to make remarkable progress
  - Transition from final prototyping to pre-production or production in many areas
  - All this in an environment of worldwide strain on resources, which continues to be felt
- High Granularity Calorimeter HGCAL:
  - Silicon sensors Production Readiness Review successfully passed
  - Five module assembly centers fully qualified for pre-series modules
  - Concentrator ASICs - on critical path – progressing but tight schedule
    - Trigger version under test – data version and design and verification
  - SiPM-on-Tile-module assembly centers also on track, and pre-series SiPMs are under test
- Inner Tracker:
  - IT planar sensor tender completed and contract(s) in preparation
  - Irradiation and test beam of 3D and planar modules completed
  - Delay in RD53 submissions
- Outer Tracker:
  - Sensor production continues
  - Hybrid contract signed
  - Final PS and 2S module prototypes built, in use in multiple tests
Phase-2 Upgrade — highlights

- **MIP Timing Detector MTD:**
  - Test beam performed with optimized Barrel BTL module (packaging, new ASIC, SiPM)
  - Validated final prototype of BTL module thermal performance in full populated tray
  - Endcap ETL sensors: market survey nearly complete with several vendors satisfying specs

- **Barrel Calorimeter:**
  - ASICs: CATIA and LiTE-DTU final prototypes meet specs
  - Components on schedule for test beam with ‘spare’ supermodule 36 in Nov 22

- **Muons:**
  - RPC: started production
  - GEM GE2/1 production progressing on track

- **BRIL:**
  - Commissioning of Run-3 demonstrators advancing (muon slice, L1 scouting)
  - Future detectors: progress on ongoing R&D activities, incl. Fast Beam Conditions Monitor mechanical design and frontend ASIC

- **Level-1 Trigger:**
  - All pre-production milestones reached for all families of boards, pilot production designs in progress. Integration tests advancing
Summary

• Strong start to Run 3 — CMS is taking good quality data with high efficiency

• Many interesting physics results still to come from Run 2 data and first result from Run 3 data presented

• Upgrade making good progress in all areas

• Looking forward to the restart of collisions!