CMS status report

30\textsuperscript{th} November 2022

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on behalf of the CMS collaboration

152\textsuperscript{nd} LHCC meeting - open session
https://indico.cern.ch/event/1219913/
Outline

- Run 3 data taking and performance
- Physics analysis highlights
- Phase 2 upgrade status
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- Run 3 data taking and performance
- Physics analysis highlights
- Phase 2 upgrade status
Successful and fruitful year of data taking after ~3 years of shutdown

- Commissioning of new detectors (including Phase 2 prototypes), new electronics, new triggers, new DAQ, …
- Back to operation
- Excellent start: 3 more years of Run 3 ahead of us!
- LHC performed superbly providing more than 40/fb to CMS
- Heavy Ion data taking → fruitful head start of the operation with HI for next year
- Tests with different filling schemes in preparation of next years → positive feedback from CMS
- Successful data taking with very high pileup
  - Analysis of these data ongoing
Averaged data taking efficiency ~ 91.7% (increasing with time, last month ~ 92.2%)

Averaged data certification efficiency ~ 89% (increasing with time, last month ~ 95%)

2022 is both a commissioning year and a pp-production year

commissioned upgrades in the first months of 2022

Pile up

Average pileup of 2022: 44

CMS efficiently and routinely operating at lumi-level pileup 55

We have also taken a fill entirely leveled at pileup 60 without any problems
Heavy Ion in 2022

- Commissioned:
  - L1 + HLT triggers
  - ECAL and tracker readout configuration for HI
  - 0.4 ub\(^{-1}\) delivered luminosity
  - very useful dataset to prepare for 2023
Several systems for
- beam loss (abort)
- beam timing
- beam induced background
- luminosity
- radiation monitoring

operated smoothly in 2022

Preliminary luminosity calibration of 13.6 TeV pp data aimed for 03/2023

Took various non-standard beam separation scans in 2022 September (fill dedicated to LHCf) to study possible improvements in methodology for future luminosity measurements to reach the precision goal of 1%
Generally smooth data taking

- Successful heavy ion test
- No particular problems observed also during a test fill with instantaneous luminosity reaching $2.6 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$

Barrel pixel innermost layer performance routinely monitored and operational parameters updated

Work for the YETS under preparation
ECAL performed well during the run, with an exception

- During the second week of September 2022, low voltage instabilities and HV channel trips started to develop in the ECAL positive Endcap

- By sequential opening and closing of supply and return valves, while monitoring the humidity levels, it was possible to link these symptoms to a water leak connected to supply line 7

- This supply line is connected to cooling block 7, that serves 491 channels, about 7% of the positive encap

- These channels are off since then, while the rest of EE+ is working as expected after the humidity has dried

The consequences are:

- **Trigger**: slight reduction in electron and photon trigger efficiency (-5% in the affected \( \eta \) region once integrated over \( \phi \)) and an increased MET trigger rate (+10%)

- Within the affected area, impact to physics object is limited to a loss of \( \gamma \) and \( e^\pm \) and a degraded jet performance. Due to the modest size, the global impact to physics is small
- Very smooth running after September shutdown
  - No outstanding issue affecting operations
- Operating trigger algorithm with included pile-up subtraction
  - Stable energy reconstruction vs pileup
- Recent updates, and ongoing activities
  - Long-Lived Particle trigger: performed phase scan to further tune the detector timing
  - Detector timing: deployed channel-by-channel adjustments in all detector
  - Implementing procedures to automatize detector calibration
Muons

- Muon system was **smoothly** participating in 2022 Run 3 pp collision runs
- Online and offline analyses are showing detector performance in agreement with Run 2 results
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- Stability vs integrated luminosity

**First measurements of GE1/1-ME1/1 bending angle using GEM RecHits:** data match expectations from simulation
Many **special menus** deployed online and smooth running in the HLT farm

- 2022 full commissioning of **GPU HLT farm**
- **Prescale** columns (L1 rate management) are now selected according to the **L1 rate** (instead of instantaneous luminosity)
  - 102 kHz considered as max pre-deadtime L1 rate for 2022
- New method to measure online the **maximum throughput of the HLT farm**
  - At $1.8 \times 10^{34}$ cm$^{-2}$s$^{-1}$ (PU~53), we established some margin in the HLT farm capacity
- Frequent validation and deployment of updated **conditions** for the HLT
  - eg. pixel HV, tracker alignment, HCAL gain, ECAL timing, new L1 trigger calibrations …
Offline and computing

- Record CMS Computing resource utilization
- Record peak CPU utilization:
  - 524K CPU cores, >400K average since the last LHCC Week, recently driven by very high utilization of HPCs at NERSC, and continued efficient use of our sites

Full physics validation of the POWER9 architecture was successful, opening sites like Marconi 100 at CINECA-INFN to production (seamlessly accessed through the Tier-1 at CNAF)

- It opens the door for other power machines such as Summit@ORNL
Successful Heavy-Ion Test Run Offline

- Major improvements since Run 2:
  - Offline reconstruction time 1/3 faster compared to Run 2
  - Introduction of approximated SiStrip clusters into the RAW data format (the so-called RAWprime): both streams successfully processed at the Tier-0 for later study
  - Substantial event size savings will allow CMS to take more HI data
  - Sustained data volume to offline: 6 GB/s over ~6 h after ramping up

CMS was well-prepared for heavy-ion running and is looking forward for next year

35% speedup and years of new features integrated!
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Publication statistics


- 1170 papers on collider data published or submitted to a journal

- Analysis of Run 3 data started and more Run 2 results will come
HH → WWγγ

- Search for HH production in WWγγ final state: part of the suite of HH results that was released in the last years
  - Considers 0 lepton, 1 lepton, and 2 leptons final states for the WW system
  - Deep NNs to separate signal from background (mll for dilepton final state)
  - Use $m_{γγ}$ distribution to extract signal
  - Sensitivity $\sim x100$ Standard Model
  - Result interpreted in terms of BSM enhancement scenarios and EFT
Search for light scalar partners of the Higgs, produced in Higgs decays

Preferential coupling to 3rd and 2\textsuperscript{nd} generation quarks → searched for in μμbb

Search runs in 15 GeV < m\textsubscript{a} < m\textsubscript{H/2}

Used χ\textsubscript{2} compatibility between μμ and bb system and μμbb system to m\textsubscript{H} to separate signal and background

No signal observed

Limit on decay-chain BR set as a function of m\textsubscript{a}

\begin{align*}
χ\textsubscript{bb} &= \frac{(m\textsubscript{bb} - m\textsubscript{μμ})}{σ\textsubscript{bb}}, \quad \text{and} \quad χ\textsubscript{H} = \frac{(m\textsubscript{μμbb} - 125)}{σ\textsubscript{H}}
\end{align*}
- **Legacy Run 2 paper** on Higgs properties from the 4l golden channel
- (As usual) exploit angular and kinematic distributions from the final state to characterize the decay and extract sensitive parameters (e.g., coupling modifiers via loop effects)
- Determined inclusive and differential cross section
Three new **physics briefing** released

- [https://cms.cern/tags/physics-briefing](https://cms.cern/tags/physics-briefing)

First **Run 3** physics result (more will come):


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**MEASURING THE HIGGS BOSON DECAY TO WW IS 90% PHYSICS. THE OTHER HALF IS TEAMWORK!**

04 NOV 2022

It was a bit more than 10 years ago that together with our colleagues from the ATLAS experiment, we at CMS announced the discovery of this new (and quite amazing) particle. Now, detecting a new fundamental particle is no easy feat; in these 10 years...

**TOP QUARKS FAST TO ARRIVE AT NEW ENERGY FRONTIER**

24 OCT 2022

On 5 July 2022, the LHC surpassed the previous energy limits of experimental particle physics, breaking its own record by achieving stable proton-proton collisions at a center-of-mass energy of $\sqrt{s} = 13.6$ TeV. This marked the start of Run 3, the...

**SEARCHING FOR TOP SQUARKS WITH CMS DATA**

14 OCT 2022

What is the Universe made of? Searching for the answer to this question has been the main quest of particle physicists. Part of the answer is provided by the highly-successful Standard Model (SM) of particle physics, whose last achievement is the...
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- Run 3 data taking and performance
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Phase 2 upgrade

- All projects continue to make remarkable progress

**L1-Trigger**
- Tracks in L1-Trigger at 40 MHz
- Particle Flow selection
- 750 kHz L1 output
- 40 MHz data scouting

**Calorimeter Endcap**
- 3D showers and precise timing
- Si, Scint+SiPM in Pb/W-SS

**DAQ & High-Level Trigger**
- Full optical readout
- Heterogenous architecture
- 60 TB/s event network
- 7.5 kHz HLT output

**Barrel Calorimeters**
- ECAL crystal granularity readout at 40 MHz with precise timing for e/y at 30 GeV
- ECAL and HCAL new Back-End boards

**Muon systems**
- DT & CSC new FE/BE readout
- RPC back-end electronics
- New GEM/RPC 1.6 < η < 2.4
- Extended coverage to η ≈ 3

**Tracker**
- Si-Strip and Pixels increased granularity
- Design for tracking in L1-Trigger
- Extended coverage to η ≈ 4.0

**MIP Timing Detector**
- Precision timing with:
  - Barrel layer: Crystals + SiPMs
  - Endcap layer: Low Gain Avalanche Diodes

**Beam Radiation Instr. and Luminosity**
- Beam abort & timing
- Beam-induced background
- Bunch-by-bunch luminosity: 1% offline, 2% online
- Neutron and mixed-field radiation monitors
All projects continue to make **remarkable progress**

- **L1-Trigger**
  - [L1-Trigger](https://cds.cern.ch/record/2714892)
  - Tracks in L1-Trigger at 40 MHz
  - Particle Flow selection
  - 750 kHz L1 output
  - 40 MHz data scouting

- **DAQ & High-Level Trigger**
  - [DAQ & High-Level Trigger](https://cds.cern.ch/record/2759072)
  - Full optical readout
  - Heterogenous architecture
  - 60 TB/s event network
  - 7.5 kHz HLT output

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

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

- **Muon systems**
  - [Muon systems](https://cds.cern.ch/record/2283189)
  - DT & CSC new FE/BE readout
  - RPC back-end electronics
  - New GEM/RPC 1.6 < $\eta$ < 2.4
  - Extended coverage to $\eta \approx 3$

- **Tracker**
  - [Tracker](https://cds.cern.ch/record/2272264)
  - Si-Strip and Pixels increased granularity
  - Design for tracking in L1-Trigger
  - Extended coverage to $\eta \approx 4.0$

- **MIP Timing Detector**
  - [MIP Timing Detector](https://cds.cern.ch/record/2667167)
  - Precision timing with:
    - Barrel layer: Crystals + SiPMs
    - Endcap layer: Low Gain Avalanche Diodes

- **Beam Radiation Instr. and Luminosity**
  - [Beam Radiation Instr. and Luminosity](https://cds.cern.ch/record/2759074)
  - Beam abort & timing
  - Beam-induced background
  - Bunch-by-bunch luminosity: 1% offline, 2% online
  - Neutron and mixed-field radiation monitors
The EDR/ESR (Engineering Design / Electronics Systems Review) took place Oct 18/19\textsuperscript{th}

- They were successfully passed and marked an important milestone for the start of the production for the upgrades, which is foreseen for early 2023

**Supermodule 36 (SM36)**

- equipped with Phase 2 electronics: 400 channels
- **TestBeam in H4** with SM36 on Nov 2-14
- First Vertical Integration Test from Very Front End (VFE) to backend boards (BCP)

**SuperModule 36 in H4**

**Signal in SM36 from 150 GeV electrons**
**Production** of the Low Density (LD) full-size silicon sensors **started**

- Close to final version HD-Hexaboards (V3) design
- **Testbeam** with Si Module very successful
- CE-H stainless steel raw absorber manufacturing ongoing
- Procurement process of thermal screen started
- Steady progress in the concentrator ASICs

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**HGCAL**

![HD V3 hexaboard](image1)

Excellent progress on reconstruction

![LD v3 HGCAL silicon module in test beam](image2)

CE-H stainless steel absorber

Trial installation on mockup of thermal screen rails and panels
**Tracker**

**Inner Tracker**
- CMS Readout chips (CROC) submission delayed
- **CMS is very appreciative of all RD53 work** for/with CMS since the ASIC drives the inner tracker critical path
- Converged on module design: cooling plate, nominal position, HDI design

**Outer Tracker (OT)**
- HPK sensor production at a higher rate than agreed
- OT ASICs started production
- Pre-production of mechanical structures started
Summary

- CMS wishes to congratulate to LHC for the excellent start of Run 3
- CMS in 2022
  - Commissioning and pp-production year
- Run 2 and Run 3 analyses ongoing
- Phase 2 upgrade towards HL-LHC is progressing steadily

Comments (28-Nov-2022 06:07:12)

No Beam for the next few months!
End of 2022 RUN
40 fb$^{-1}$
DELIVERED TO ATLAS & CMS in 2022!
Backup
ECAL: EE+ water leak
Highlights of the projects

Outer Tracker: hybrid pre-production test system PCBs

Inner Tracker: two 3D Single Chips composing the 3D double module

Gantry assembly

Jig-based assembly

MIP Timing detector – ETL

Gantry for module assembly

BRIL: FBCM Mechanics

HGCAL: Mixed CE-H cassette preparations

Muons: DT frontend electronics boards pre-series production using halogen free materials

Muons: RPC link system card packs

HGCAL: System test chain including 3 live Si-modules

Outer Tracker: Magnet test of power supplies with MNP17 magnet
Release and production plan

- **Feb 2022**
  - CMSSW 12_3_0
  - Data-taking for early collisions and ramp-up
  - Trigger: first menu

- **Mar 2022**
  - CMSSW 12_4_0
  - POG and PAG samples: Run3Summer22(EE)
  - Trigger: final menu

- **Apr 2022**
  - CMSSW 12_5_0
  - HIN release
  - Phase 2

- **May 2022**
  - Physics Collisions
  - Physics Collisions

- **Jun 2022**
  - CMSSW 12_6_0
  - Possible re-nano
  - Improved mtf
  - Used for early 2023 cosmic runs
  - HLT (CUDA -> Alpaka)
  - Geant 10.7.2+Pi

- **Jul 2022**
  - CMSSW 13_0_0
  - Data-taking for 2023 collisions
  - MC production
  - Phase 2: start of integration of GPU code
  - Geant 11.1.1

- **Aug 2022**
  - Run 3 trigger, DPG, POG, PAG samples (CMSSW 12_X)

- **Sep 2022**
  - 12.2: pp 0.5k events
  - Custom-Nano (JME) Run 3

- **Oct 2022**
  - 12.5: Phase 2 MC

- **Nov 2022**
  - Run 3 Summer22(EE) with Nanov10 + Re-Nano later

- **Dec 2022**
  - Run 3 NanoAODv11

- **Jan 2023**
  - Run 2 Legacy MC 16/17/18 (Summer20UL) MiniAODv2 / NanoAODv9 default. Possibly Re-Nano v11

- **Feb 2023**
  - Reprocessing of ERAs ABCDEF

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**Run-2 Legacy**
- Produced ~90 Billion unique MC events
- Re-NanoAOD v11 in 12_6 or 13_0
- Custom-NanoAOD: establish for JME
- High-precision calibration and SF
- B-parking reprocessing in 10_6 completed

**Run-3 DATA and MC operation**
- Prompt Calibration Loop for promptReco Alignment & Calibration
- Skims
- Analysis MC with Run3Summer22(EE) for 2022 DATA
- SF derivation for Run3Summer22(EE) MC Campaigns
- HI commissioning run
- Migration from HLT modules from CUDA to Alpaka
- Reprocessing of the ERAs ABCDEF

**Phase-2 Preparation**
- New MC campaign in 12_5
- GPU integration from 13_0
• The Laser Lab cabin is being built, initial occupation by ECAL foreseen by second week of December

• Previous location in USC (underground service cavern) → USC space needed for Phase 2
First Run 3 Result: $\sigma_{tt} = 887^{+38}_{-42} \text{ pb} (\text{stat+syst}) (\pm 55 \text{ (lumi)}) \text{ pb}$

Theory prediction: $921^{+29}_{-37} \text{ pb} – \text{consistent with SM}$

- First measurement of the **top quark pair production cross section** in proton-proton collisions at **13.6 TeV**
- Measurement in good agreement with the standard model prediction
- Aiming at publication with full 2022 dataset
Run 3 data taking strategy

Parking Stream:
- ~3 KHz
- ~1.5 MB/evt
- Stored on tape and reconstructed when resources are available

Standard Stream:
- ~1 KHz
- ~1.5 MB/evt
- Processed in real-time @TO

Scouting Stream:
- event size reduced by about x100 wrt Standard Stream
- Rate increased by about x30 wrt Standard Stream
- Based on reconstruction @HLT (i.e., no offline reconstruction)

40 MHz → L1 trigger → 100 KHz → High-Level Trigger farm → Parking Stream, Standard Stream, Scouting Stream
New B physics triggers for Data Parking

**New dimuon triggers** for $B(s) \rightarrow \mu\mu$ and more

- New dimuon triggers at low mass with different requirements, covering different regions of the interesting phase space
- Serving BPH beyond $B(s) \rightarrow \mu\mu$ (e.g., $B \rightarrow \mu\mu X$ and similar, spectroscopy)
- To be exploited for searches (e.g., $\tau \rightarrow \mu\mu\mu$ and low-mass new resonance searches)

**New strategy for Run 3 parking:** low-$p_T$ dielectron triggers for $B \rightarrow eeX$

- Restrict to central detector (to fill the available bandwidth with our best electrons)
- Different $p_T$ threshold, to operate at different peak luminosity
- Electron ID and $m_{ee}$ upper cut @HLT

Triggers successfully **commissioned**

- We see the **J/psi control-region peak**
- Obviously, signal region is blind
- Because of low stat integrated in 2022, any analysis result will wait for **2023 data** (not enough luminosity in 2022)
Upgrade highlights

**MIP Timing Detectors – Barrel (BTL) and Endcap (ETL)**

- **Sensors:**
  - BTL: LYSO - tender being finalized; SiPMs - last prototypes arriving
  - ETL: Full size LGAD sensors meetings specs in testbeam

- **ASICs:**
  - BTL: TOFHIR production ASIC submission
  - ETL: ETROC2 (full-size and full-functionality) ASIC prototype submitted

- General good progress with integration, e.g. cooling tests

**Muons**

- Three Phase-2 demonstrators operating at P5
  - Drift Tubes, Resistive Plate Chambers, GEMs (GE 2.1)

**L1T:**

- Great progress on the algorithm development for the various subsystems, global track trigger and the global trigger

**HLT**

- Steady progress speeding up algorithms