CMS HIGHLIGHTS

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**SETTING THE SCENE**

**The Lord of the Rings**

27 km long “ring”, (mainly) pp collider at the Swiss-French border

**LHC**

CMS: A general purpose detector

Co-axial layers of tracker, calorimeters, muon detectors.

**CMS has a broad physics program**

I’ll try to give a glimpse of that in this talk

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**CMS DETECTOR**
- Total weight: 14,000 tonnes
- Overall diameter: 15.0 m
- Overall length: 28.7 m
- Magnetic field: 3.8 T

**STEEL RETURN YOKE**
- 12,500 tonnes

**SILICON TRACKERS**
- Pixel (100x150 μm) - 16 m² ~6M channels
- Microstrips (40x180 μm) - 200 m² ~9.6 M channels

**SUPERCONDUCTING SOLENOID**
- Niobium-titanium coil carrying ~18,000 A

**MUON CHAMBERS**
- Barrel: 260 Drift Tube, 480 Resistor Plate Chambers
- Endcaps: 400 Cathode Strip, 432 Resistor Plate Chambers

**PRESHOWER**
- Silicon strips = 16 m² ~137,000 channels

**FORWARD CALORIMETER**
- Steel + Quartz fibres ~2,000 channels

**CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)**
- ~76,000 scintillating PbWO₄ crystals

**HADRON CALORIMETER (HCAL)**
- Brass + Plastic scintillator ~7,000 channels
INTRODUCTION

➤ LHC started running in 2010 with two major focus
  ➤ Find a Higgs boson, which was the last missing piece of Standard Model (SM)
  ➤ Find new physics beyond the Standard Model (BSM)
➤ A Higgs boson was discovered in 2012. Its properties look SM-like.
➤ Next obvious question is: Where is new physics hiding?
  ➤ Two avenues to address the question
    ➤ Directly search for new particles in various final states
    ➤ Measure known quantities precisely and look for deviation w.r.t SM prediction

Run2 data taken during 2015-2018

We are here
CURRENT ACTIVITIES IN CMS

➤ Run2 data-taking ended in 2018.


➤ Run3 will start in 2022.

➤ Currently we are:
  ➤ Making the most out of Run2 data
  ➤ Continuing to produce Physics results from Run 2
  ➤ Gearing up for near future (Run3)
  ➤ Detector upgrade activities, planned for LS2, almost fully completed
  ➤ Gearing up for far future (HL-LHC aka Phase2)
  ➤ Finalizing the last two technical design reports (TDR)

Data collected until now

This talk will show highlights of just a few of a large number of CMS results, with personal bias

Link to all CMS results:
**CMS Trigger System**

- **Two-level trigger system** to bring down huge rate to a manageable value.
  - **First level:** L1, hardware-based.
    - Ongoing developments for Run3 to aid long-lived new particle searches, which is a major focus for Run3 physics program.
    - Increase efficiency for displaced muons
    - Capability to trigger on hadronic particles in muon system
    - Exploit timing measurement of calorimeters
    - Usage of HCAL longitudinal depth information
  - **Second level:** High level trigger (HLT), software-based.
    - Transitioning to a **heterogeneous HLT farm** (deploy CPU and GPU)
      - Great to have it in Run3, critical requirement for HL-LHC. Impressive speed-up due to offloading of reconstruction code to GPUs.
      - Opens new possibilities for trigger algorithms leveraging on GPUs.

More in this talk

*Trigger (CMS)* by Pallabi Das
Impressive dielectron mass resolution during all years of Run2.

Most challenging part is far-endcap due to higher noise, more radiation damage.

Excellent performance of muon triggers during Run2.

Used in many physics analyses.

Usage of advanced Machine-learning technique to identify jets initiated by charm quark.
DATA SCOUTING @HLT

Relaxed trigger thresholds, and perform physics analysis with objects reconstructed @HLT.

No RAW data saved. No offline reconstruction.

Save HLT objects in “scouting datasets”. Minimal event content.

High rate HLT paths, but very low bandwidth needed due to small event size.

Search for a narrow long-lived dimuon resonance

First search for long-lived BSM signatures using scouting data

Interaction with SM through Higgs (h) portal via Higgs mixing $\kappa$

CMS-PAS-EXO-20-014
Idea of data parking: collect data using a trigger, but do not reconstruct promptly. Reconstruct during technical-stop / shutdown.

In 2018, CMS used low pT muon triggers to save a sample of unbiased B hadron decays recoiling against the triggering muon.

Main goal of B-parking is to make CMS competitive with LHCb in the $R(K)/R(K^*)$ measurements.

Several ongoing analysis on lepton flavour universality violation (LFUV).

Developed dedicated low-pT electron reconstruction for such analyses.
HUNTING THE HIGGSINOS

Signature: HH(4b) + MET
Search performed in 2 scenarios: resolved and boosted

Gauge mediated SUSY breaking
Boost to cross section from different production channels
Parameter of interest: NLSP mass

Simplified SUSY model
Mass degenerate NLSP, bino LSP
Parameters of interest: LSP and NLSP masses

More on SUSY in this talk
SUSY (CMS) by Koushik Mandal

CMS-PAS-SUS-20-004
EXTENDED HIGGS SECTOR

Jet substructure and flavor identification techniques are used.

$X \rightarrow aa$ and $a \rightarrow bb$ branching fractions are assumed to be 100%.

CMS Preliminary

95% CL limits:
- observed
- expected
- expected ± 1σ
- expected ± 2σ

90 fb$^{-1}$ (13 TeV)

More on BSM in this talk

Dark Matter (CMS) by Siqi Yuan
LONG LIVED HEAVY NEUTRAL LEPTON

2 leptons from a displaced vertex, and a 3rd lepton from the primary vertex.

No excess was found in data.
Search for HH(4b)

Gluon fusion and vector boson fusion production modes investigated.

DNN-based b-jet tagger used in this analysis

Observed upper limit on the HH production cross section: 3.6 times the SM prediction

Latest Higgs results in this talk

Overview of the latest Higgs physics results from the CMS experiment by Angela Taliercio
The differential cross section distributions are measured as a function of various kinematic observables.

Present measurements can be used as an input for the further optimization of the simulation parameters.

Important precision tests of the perturbative QCD predictions.

More in this talk

Standard Model (CMS) by Patrick Connor
Flavor changing neutral currents (FCNC) allow for transitions between quarks of different flavor but same electric charge.

Highly suppressed in the SM due to the GIM mechanism.

Only small contributions appear at one loop level.

Many extensions of the SM predict the presence of FCNC and give rise to detectable FCNC amplitude.

Any evidence of FCNC will indicate the existence of new physics.

Search for tHq (q = u,c), H→bb, usage of DNN to associate the reconstructed objects to the matrix-element partonic final state.
Telling the world what we do, in easy & understandable language.
Mostly aimed at non-expert and young people.

Physics briefings generally shared in social media to reach a broader audience.
DETECTOR ACTIVITIES DURING LS2

- New GEM detector GE1/1 integrated in CMS
- New CMS beam pipe installed, fully aligned and leak tested
- CMS pixel tracker reinstallation after extensive repair and upgrade
- CMS on track for the Pilot Beam Test (Oct 2021) and for the start of Run3 (Feb 2022)
CMS detector upgrade in HL-LHC is a critical necessity, ensuring:
- Radiation hardness
- Mitigation of physics impact of high pileup

**L1-Trigger**
- L1 tracks at 40 MHz
- Regional ParticleFlow 750 kHz output

**Barrel Calorimeters**
- ECAL+HCAL: New electronics
- ECAL: Lower operating temperature to mitigate radiation-induced noise

**HLT/DAQ**
- Heterogeneous (CPU+GPU) 7.5 kHz output

**Tracker**
- Increased granularity
- Extended coverage in η

**Endcap Calorimeter (HGCAL)**
- Radiation tolerant
- High granularity
- 5D (x,y,z,Energy,time) measurement

**Muon systems**
- DT, CSC: new FE/BE readout
- New GEM and RPC chambers
- Extended coverage in η

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

**Beam Radiation Instrumentation and Luminosity (BRIL)**
- Improved precision of luminosity measurement
HL-LHC UPGRADE

More in this talk
The Phase-2 upgrade of the CMS experiment at LHC
by Davide Zuolo

The TDRs!

L1-Trigger

Barrel Calorimeters

HLT/DAQ

Tracker

Endcap Calorimeter (HGCAL)

Muon systems

MIP Timing Detector

Beam Radiation Instrumentation and Luminosity (BRIL)
**PHASE2 HLT TDR: SOME HIGHLIGHTS**

Prepared simplified but realistic HLT menu for HL-LHC

- **Taus@HLT**: CNN-based tau identification
- **Workhorse single electron HLT**: (~1 kHz rate)
- **DeepCSV b-jet tagging @HLT**: Run2-like efficiency & thresholds
- **PF+PUPPI MET**: Stable MET response after corrections
- **Sharp turn-on for muons**: Thanks to tracking@L1.
SUMMARY

Wealth of new results analysing Run 2 data.
Several new models/signatures explored for the first time.
We still have many years and luminosity in front of us…
Up to now, LHC delivered $\sim5\%$ of the total expected
CMS activities span in several different areas:

- Physics analysis
- Development of new techniques which are needed to exploit the huge amount of data
- Preparation and upgrades for the coming Run3 & HL-LHC

Stay tuned!
EXTRA SLIDES