

CMS Experiment Status and Perspectives

COMHEP

7th Colombian Meeting on High Energy Physics 2022

Camilo Carrillo



COMHEP



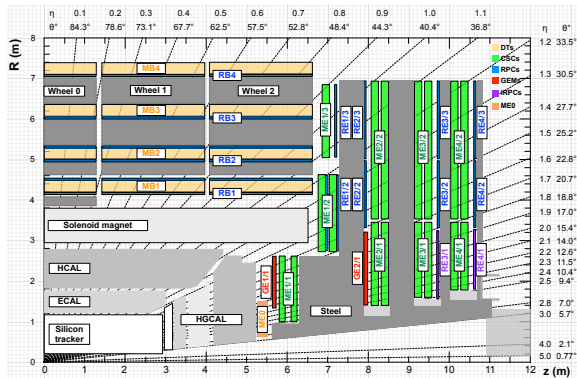
Imperial College UK/CERN

29/11/22

In this talk:

- 1 CMS description
- 2 CMS data flow and Trigger
- 3 Physics results
- 4 Phase-2 upgrade
- 5 Conclusions

The Compact Muon Solenoid

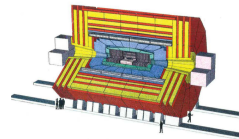


CERN/LHC/02-03
LHC/02/1
1 October 1992

LABORATOIRE EUROPÉEN POUR LA PHYSIQUE DES PARTICULES
CERN EUROPEAN LABORATORY FOR PARTICLE PHYSICS

CMS

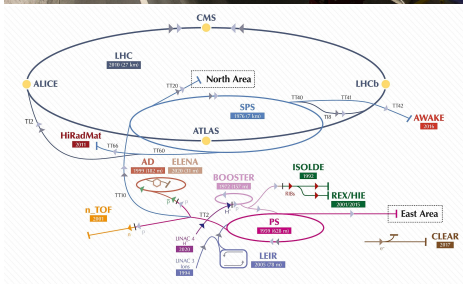
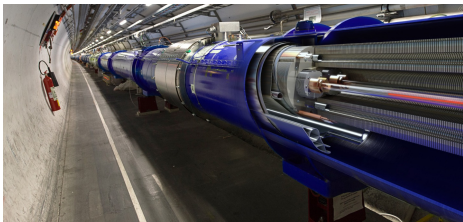
The Compact Muon Solenoid



Letter of Intent

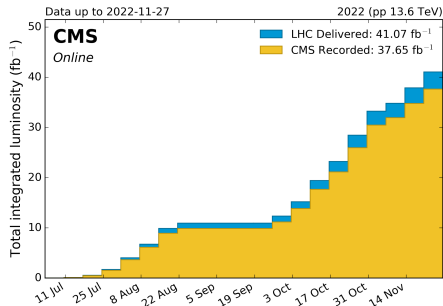
- In 2022 CMS is celebrating 30 years. CMS was born with this **letter of intent 05/10/1992**
- This will be the central topic during the next CMS week (next week)

The LHC



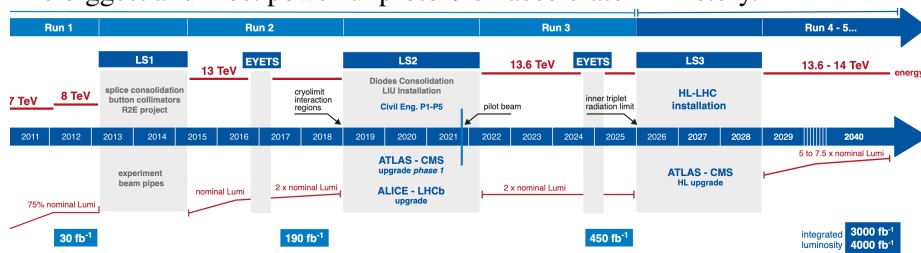
We will Not to repeat what the LHC is. Just, few points with the latest news, November 2022:

- Record energy with Pb ions: 6.8 TeV/Z
- Record peak luminosity with protons: $> 2.5 \times 10^{34}$
- Record stored energy per beam: ≈ 400 MJ
- Record peak loss rate during Quench Test (still without quench): ≈ 700 kW



The Compact Muon Solenoid

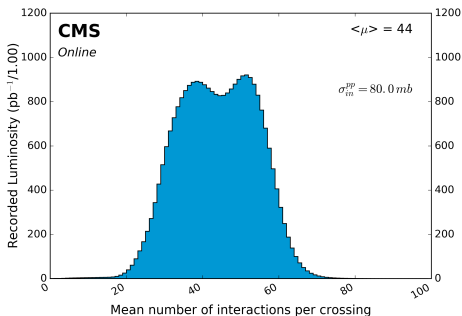
- **CMS** is one of the two general purposes experiments of the **L**arge **H**adron **C**ollider **LHC**, The biggest and most powerful proton/ion accelerator in history.



- Yesterday morning at 6:00am CET, LHC dumped the last beam for 2022/Run-3. LHC has delivered $\approx 40 \text{ fb}^{-1}$ so far. This third campaign of data collection has started in July 2022 and is expected to last 4 years.
- **Only 10% of the expected integrated luminosity for the full life of the LHC has been seen by the experiments**

Goals of CMS

- Take a “photo” of every LHC pp/HI collision, **every 25 ns**
- Then, try to understand fundamental laws of physics



<https://twiki.cern.ch/twiki/bin/view/CMSPublic/LumiPublicResults>

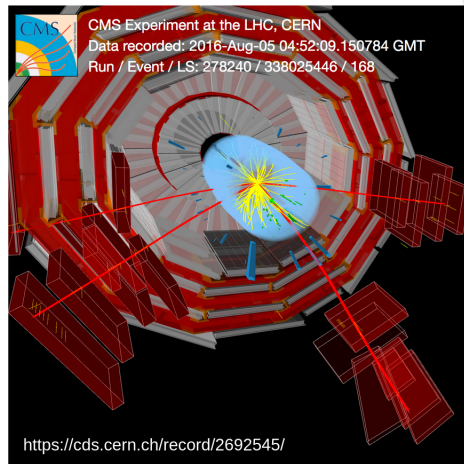
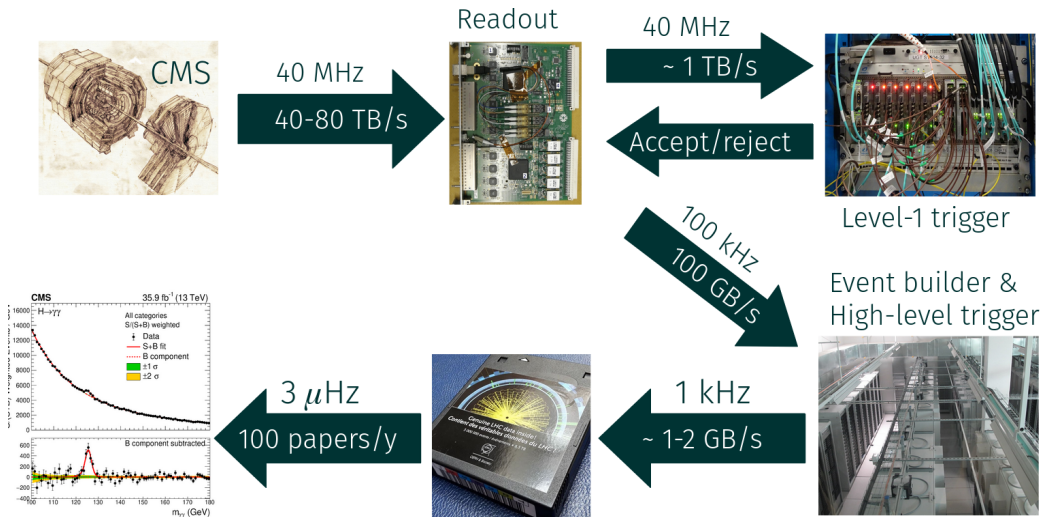


Fig: 4μ final state topology or..

A Higgs boson with a given probability

How data flows in CMS

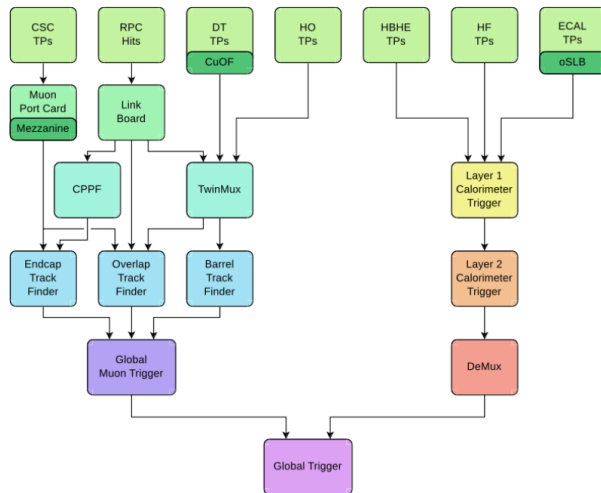


The L1 Trigger and Online Software

- Trigger recognizes interesting activity in the detector
- Online Software is responsible for:
 - Configuration
 - Control
 - Monitoring
- Each LHC collision is precious. If an event isn't accepted by the trigger, it's **lost forever**.
 - L1T online SW: Critical role in data taking — must be designed carefully to:
 - Ensure reliable and robust behavior
 - Guide on-call experts to rapidly resolve problems
 - Maintain high uptime
 - Achieve the above despite complexity of the level-1 trigger (& upstream systems)

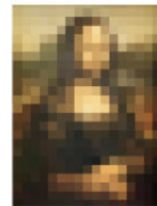
The L1 Trigger and Online Software

- ~ 150 boards
- ~ 3000 optical links
 - Up to 10Gbps
- Complex system
 - Input from 5 detector systems
 - 9 subsystems → different data-processing algorithms (calo clusters, local μ reco ...)
 - **5 different board designs**

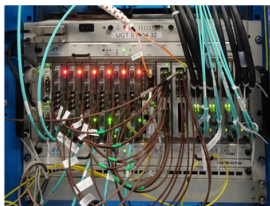


The L1 Trigger and Online Software

- Level-1 trigger, HW-based
- High-level trigger, SW based
- Successive selections of finer granularity



L1T

HLT

Level-1 trigger



High-level trigger

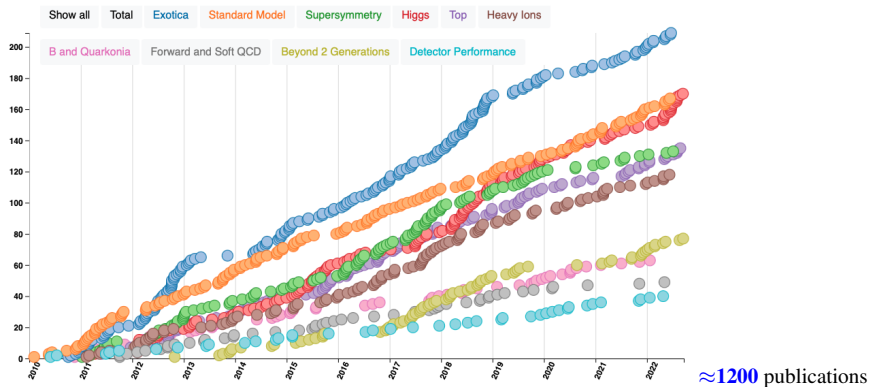


prometheus.io



Grafana
grafana.com

What do we do with these data? We do physics!

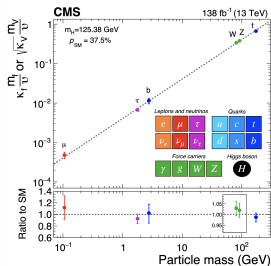


<http://cms-results.web.cern.ch/cms-results/public-results/publications-vs-time/> by CMS covering a very wide range of particle physics and detector performance/technology. Among those the first experimental observation of the famous Higgs Boson (together with ATLAS).

The Higgs Boson was observed in 2012. We are celebrating 10 years!

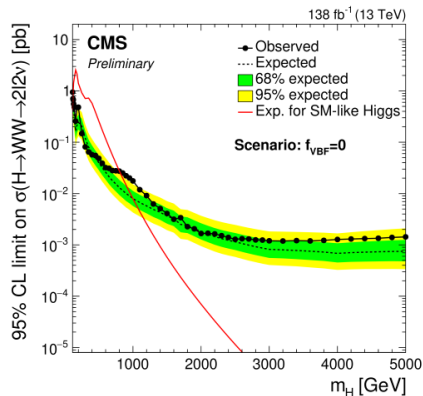
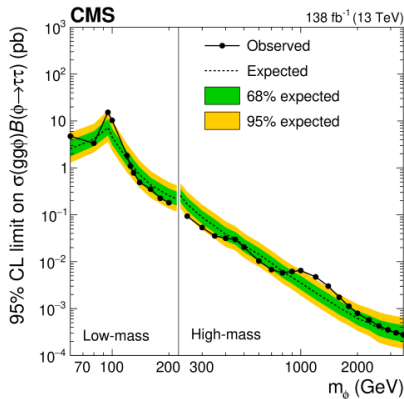


- CMS Nature publication: **A portrait of the Higgs boson by the CMS experiment ten years after the discovery** <https://www.nature.com/articles/s41586-022-04892-x>
- The Higgs Boson is not only a new observed particle. It is a tool for new discoveries.
- $m_H = 125.38 \pm 0.14 \text{ GeV}$ (**0.11%!**)
- Coupling to charm quarks has been also observed. Unthinkable for an Hadron collider experiment some years ago!
- Small but very interesting deviations from the SM observed in some couplings.
- We have the tool. We need to keep studying in depth the Higgs Boson \rightarrow HL-LHC



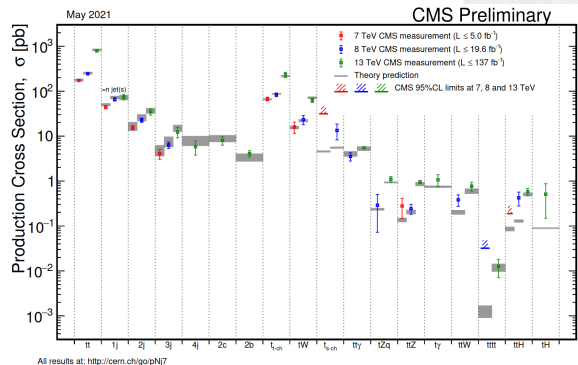
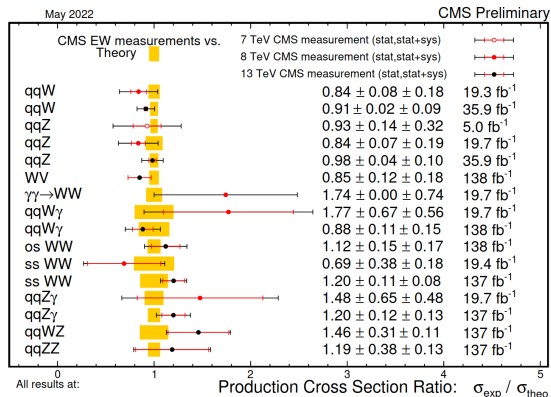
Some H^0 ints

Looking for more Higgses:



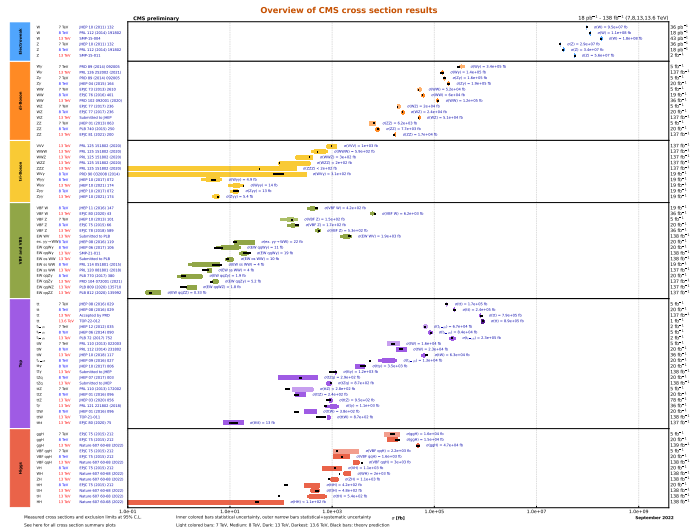
- $H \rightarrow \tau\tau$ 3.1 σ excess, @ $m_\phi \approx 95$ GeV, CMS-HIG-21-001
- $H \rightarrow WW$ 3.8 σ excess, @ $m_H \approx 650$ GeV, CMS-PAS-HIG-20-016

CMS Physics results combined



<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsCombined>

CMS Physics results, x-sections summary



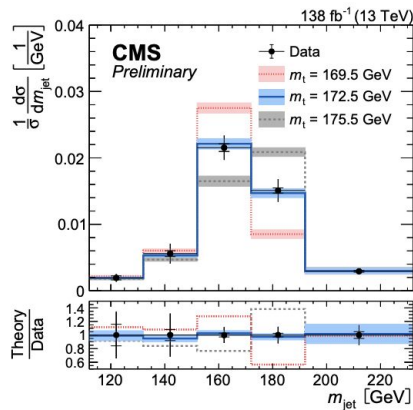
- BSM CMS Physics will be covered on Thursday by Andrés Florez.

- Clickable chart
<https://twiki.cern.ch/twiki/pub/CMSPublic/PhysicsResultsCombined/CMSCrossSectionSummaryBar.pdf>

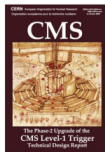
CMS Physics results, t for top

The top quark is **the most massive elementary particle** we have discovered so far.
 “Several top masses” have been measured with unprecedented precision by CMS check our physics briefing: [1](#), [2](#)]

- Direct measurement with 5D fit, constraining jet uncertainty from W peak:
 $m_t = 171.77 \pm 0.38 \text{ GeV}$ (0.22%!)
- Measurement from $t\bar{t}$ +jet cross section:
 $m_t^{\text{pole}} = 172.94 \pm 1.37 \text{ GeV}$
- Measurement of mass distribution and m_t in hadronic decay to boosted jets:
 $m_t = 172.76 \pm 0.81 \text{ GeV}$



CMS and the Phase-2 upgrade

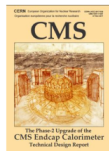


L1-Trigger HLT/DAQ

<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



Calorimeter Endcap

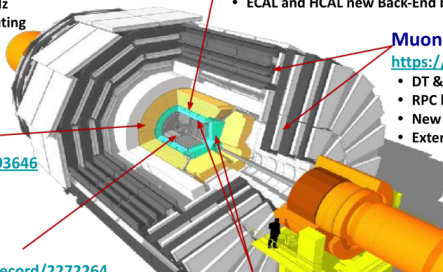
<https://cds.cern.ch/record/2293646>

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



Tracker <https://cds.cern.ch/record/2272264>

- Si-Strip and Pixels increased granularity
- Design for tracking in L1-Trigger
- Extended coverage to $\eta \approx 3.8$



Barrel Calorimeters

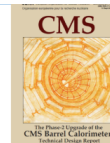
<https://cds.cern.ch/record/2283187>

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

Muon systems

<https://cds.cern.ch/record/2283189>

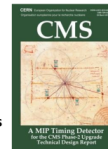
- DT & CSC new FE/BE readout
- RPC back-end electronics
- New GEM/RPC $1.6 < \eta < 2.4$
- Extended coverage to $\eta \approx 3$



Beam Radiation Instr. and Luminosity

<http://cds.cern.ch/record/2759074>

- Bunch-by-bunch luminosity measurement: 1% offline, 2% online



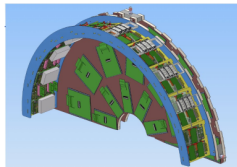
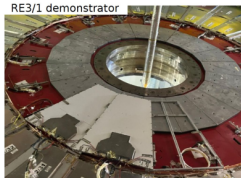
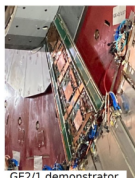
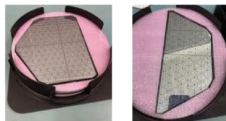
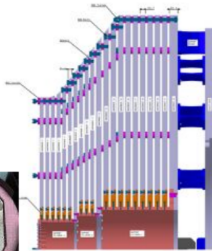
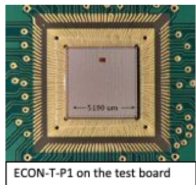
MIP Timing Detector

<https://cds.cern.ch/record/2667167>

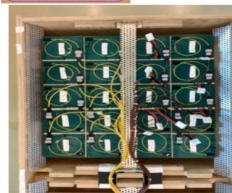
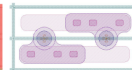
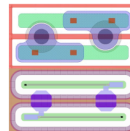
Precision timing with:

- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes

CMS and the Phase-2 upgrade



TRACKER INTEGRATION & SERVICES: BTST



Conclusions

- The LHC is performing very well. Several new records broken this year.
- CMS is ready for the rest of Run-3. 2022 data taking has finished with $\approx 40 \text{ fb}^{-1}$ delivered.
- After ten years of the discovery, Higgs physics is still very interesting (including some of the tensions).
- CMS subdetectors are performing as expected.
- Preparing for HL-LHC: a lot of new detectors to finalize, prototype, build and test

Backup

Backup



CMS Quadrant

