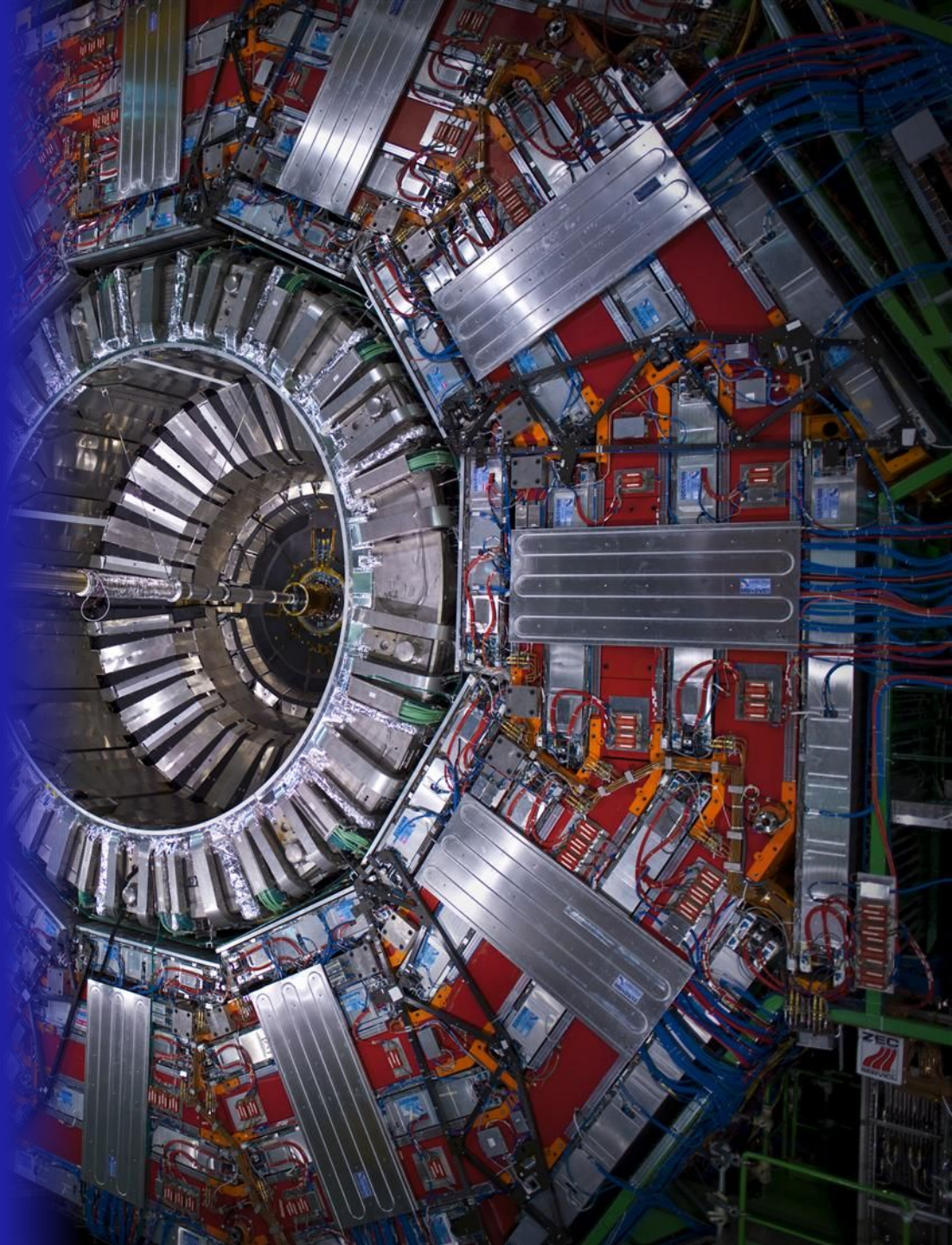
CMS status report

Jordan Martins - Rio-UERJ - on behalf of CMS Collaboration

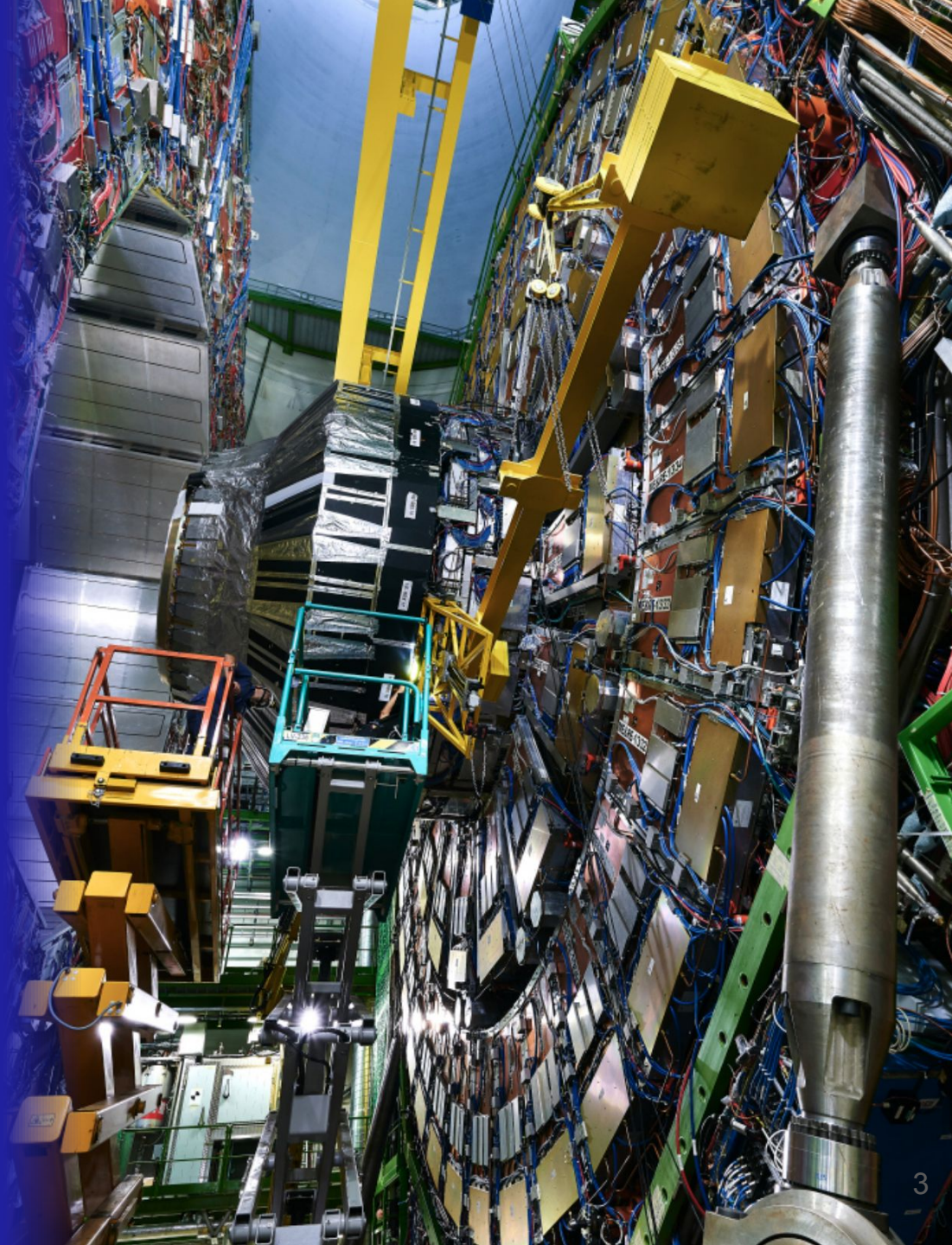
8th March 2023 - 153rd LHCC

Outline

- Run 3 2023 Preparation
- Phase 2 Upgrade Status
- Physics Analyses Highlights



Run 3 2023 Preparation

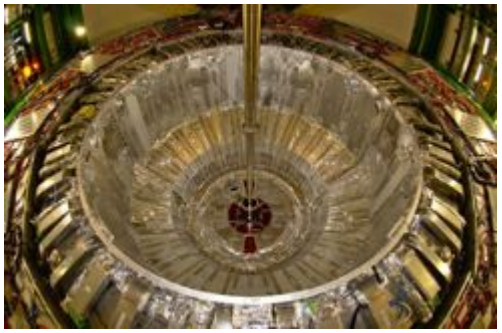


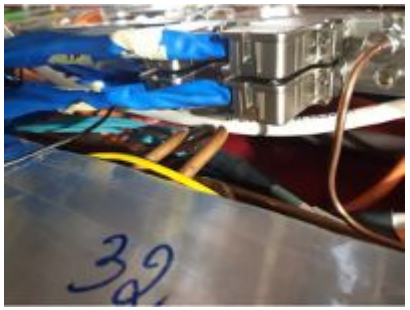
CMS News

- The Year End Technical Stop (YETS) was successful
  - CMS is closed; magnet commissioning soon
- Studies ongoing to establish running conditions for 2023
  - In 2022, the LHC established that PU > 60 is possible during the Run 3
  - CMS has been studying the optimum running conditions for the CMS Physics program
- Re-Commissioning for 2023 run ongoing
- The CMS Phase 2 upgrade displays excellent progress with subsystems moving towards production

CMS - Year End Technical Stop (YETS)

- Tracker:
  - Improved humidity sealing of the tracker volume inside the vactank on both ends
- ECAL:
  - +z-Endcap water leak repaired, all channels recovered (LHCC session Nov 30, 2022)
- MUON:
  - Detectors maintenance and repair
  - Muon +z-Endcap: all services were prepared for installation of new Phase 2 detectors GE2/1, RE3/1, RE4/1
  - Installed 2nd demonstrator for the Drift Tubes (DT) Phase 2 readout in the barrel



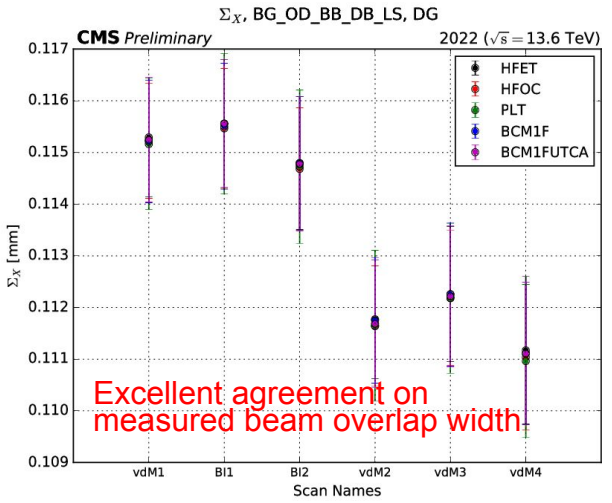


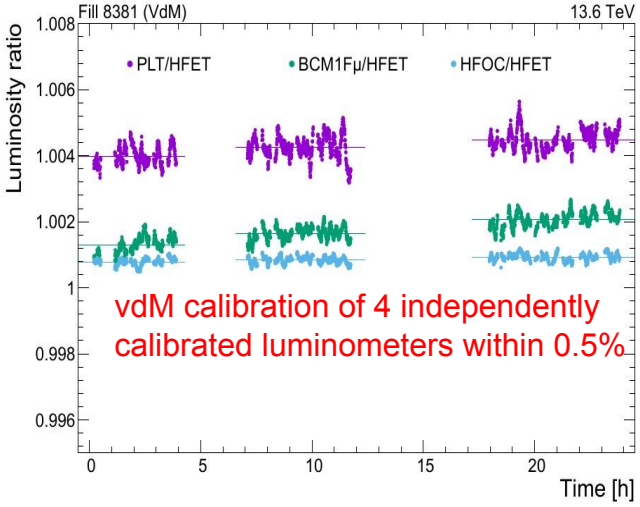
CMS - (Re-)Commissioning

- The Global Runs (Middle Week Global Run - MWGR) with cosmic rays trigger for commissioning/calibration of the CMS detector is ongoing
- CMS is ready for the beam at the end of March, with first stable beam in April

Beam Radiation Instrumentation and Luminosity (BRIL) - Towards preliminary 2022 luminosity calibration

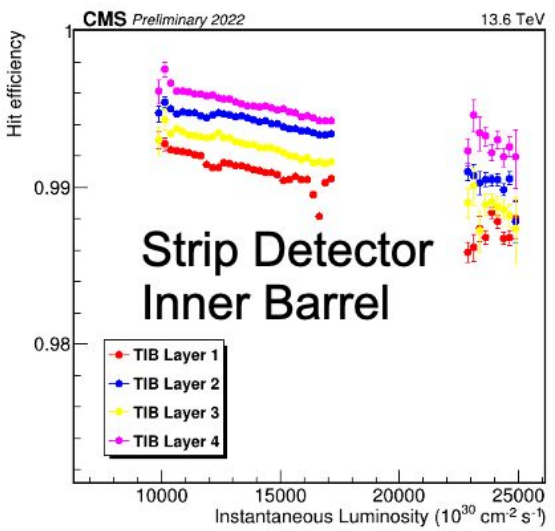
- Online (real-time) Luminometers:
  - PLT: Pixel Luminosity Telescope
  - BCM1F: Beam Condition Monitor - Fast
  - HFET: Hadron Forward calorimeter - sum_ET method
  - HFOC: Hadron Forward calorimeter - tower counting (occupancy) method
- Data-driven Corrections for each luminometer derived - excellent agreement between them
- Independently calibrated, bunch-by-bunch
- Total uncertainty of O(2%) with potential to improve (analysis still ongoing)

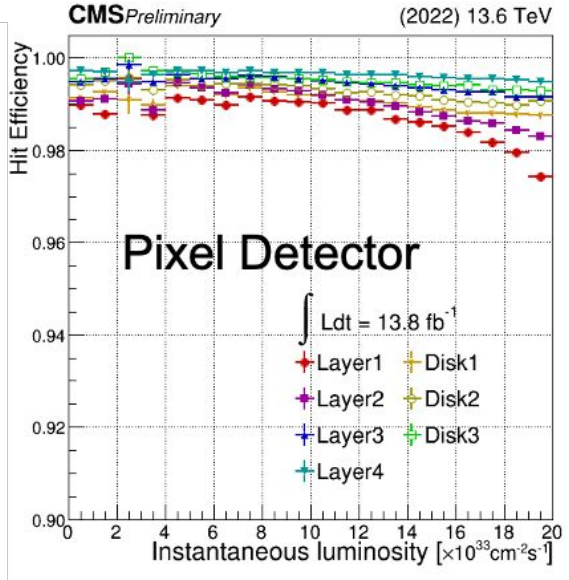




Tracker

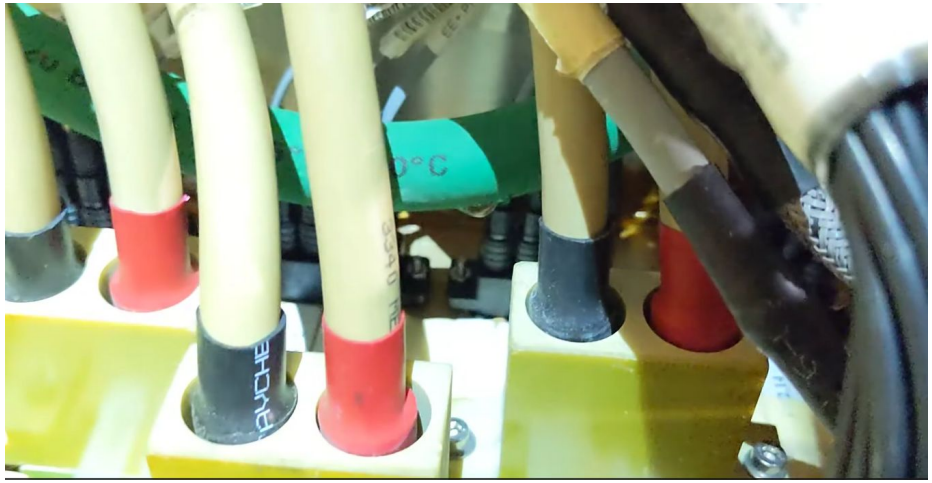
- Tracker YETS program finished
  - Detector check-out at low temperature has been done: both systems (pixels and strips) in good shape
- Beam position for 2023:
  - First stage of correction in horizontal plane successfully finished: many thanks to all the teams involved!
  - The new beam position to be verified during first stable beams
- Analysis of hit efficiencies with respect to the instantaneous luminosity:
  - Pixel layer 1 is more affected, though well behaved up to the designed luminosity
  - Strips display linear behaviour





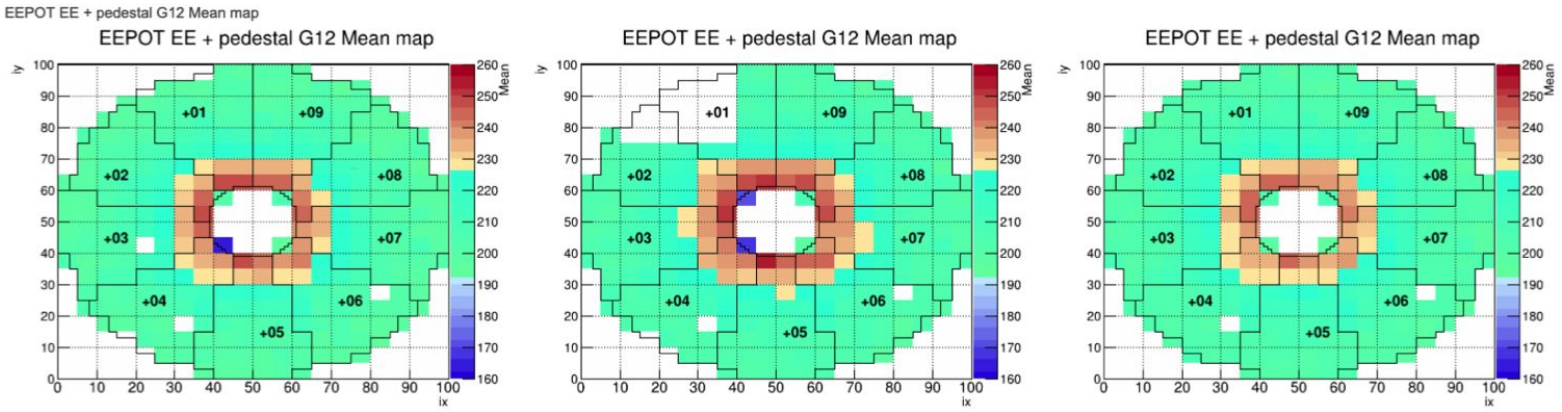
ECAL

- ECAL water leak repaired during the YETS
- The flexible pipe was replaced
- Further analyses on the damaged pipe did not revealed any systematic issue



Before the incident | After the incident | After the fix - YETS

Pedestals

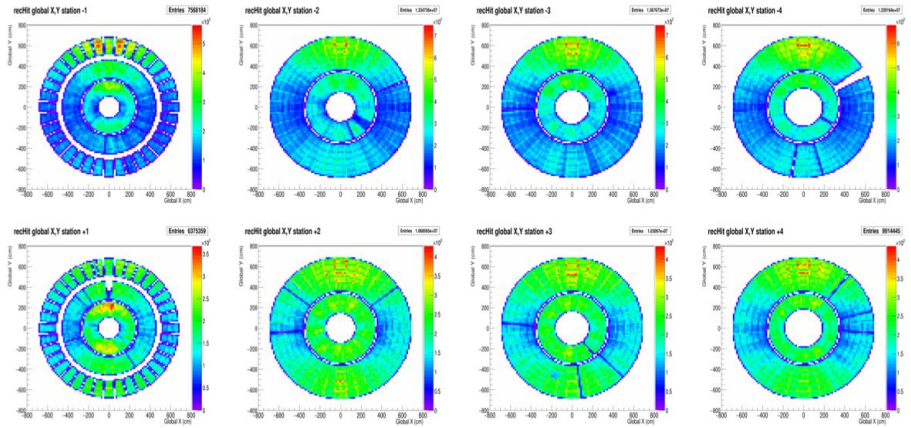


HCAL

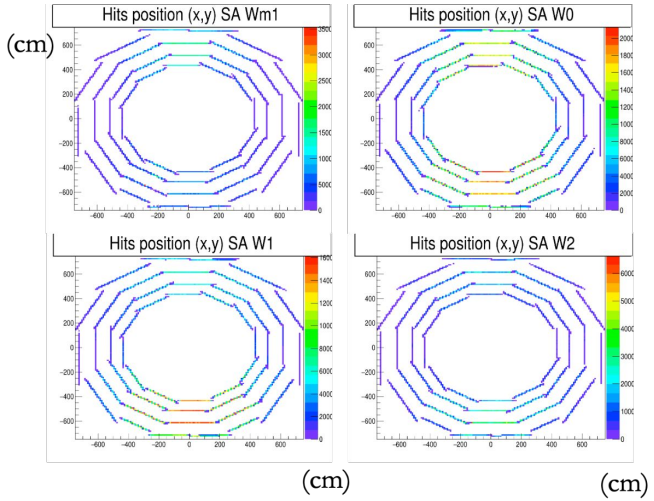
- Successful restart of detector after break
  - Completed replacement of faulty frontend components
- Commission for 2023
  - Significant update in automatization of detector calibration
  - Further improvements on the detector timing (leading-edge TDC measurements from new HB electronics)
  - Enabled orbit-gap calibration sequence with HF radiation-damage monitoring

Muons

- Muon detector commissioning ongoing:
  - Cathode Strip Chambers (CSC) and Drift Tubes (DT) systems joined the first Middle Week Global Run (MWGR#1) of 2023: overall good performance, in agreement with expectations
  - Gas Electron Multiplier (GEM): completed the GE1.1 HV trainings both in pure CO_2 gas and Ar/CO_2 final gas mixture. System successfully joined the MWGR#2



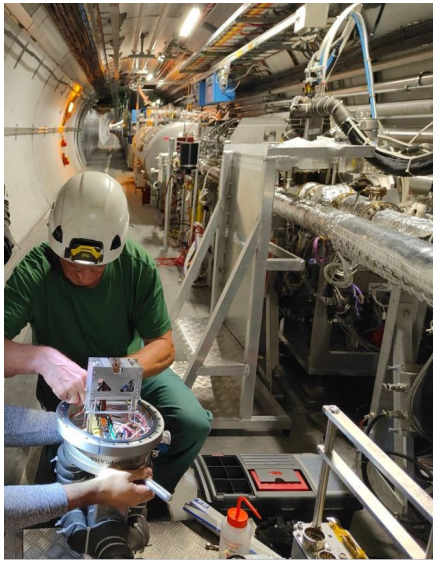
CSC reconstructed hit position

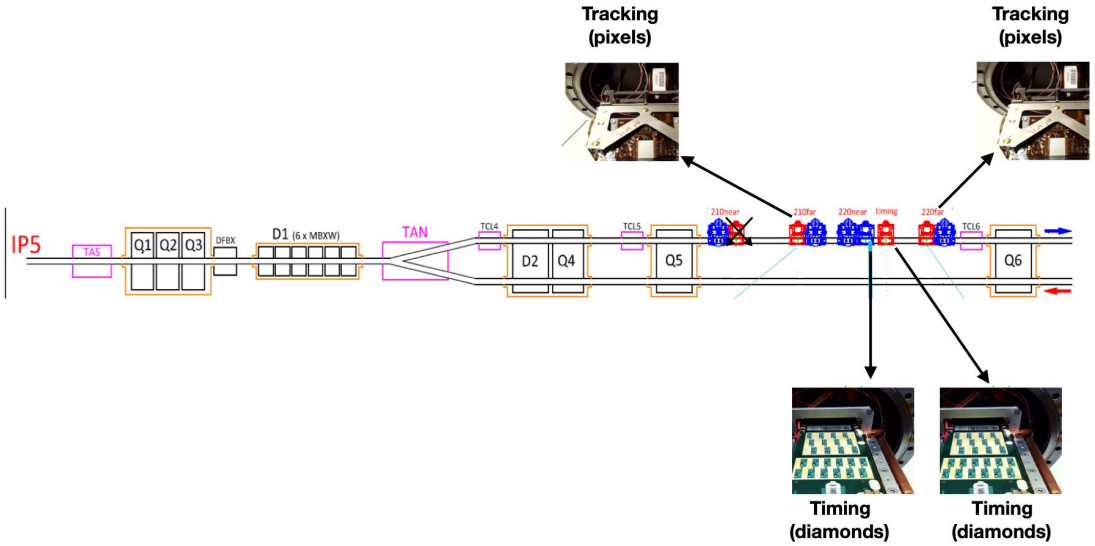


DT reconstructed hit position

PPS

- Tracking
  - Four refurbished pixel detector packages reassembled and installed in Roman Pots
- Timing
  - Diamonds for the second timing station on each arm installed
  - Installation of additional DAQ electronics completed to sustain L1T increased rates for the 2023 running conditions



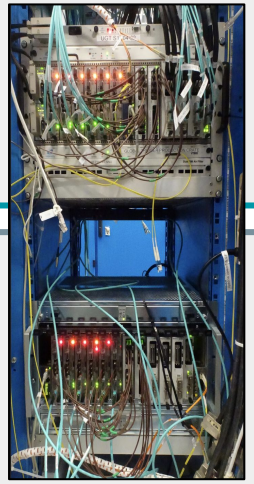


Trigger - Level 1 (L1T)

- Development of the 2023 menu
  - Adjustment for higher PU scenario
  - 2022 menu is the starting point
  - Dead time studies to probe the maximum capability
- L1T Scouting: ongoing development of demonstrators that will allow to explore online analyses

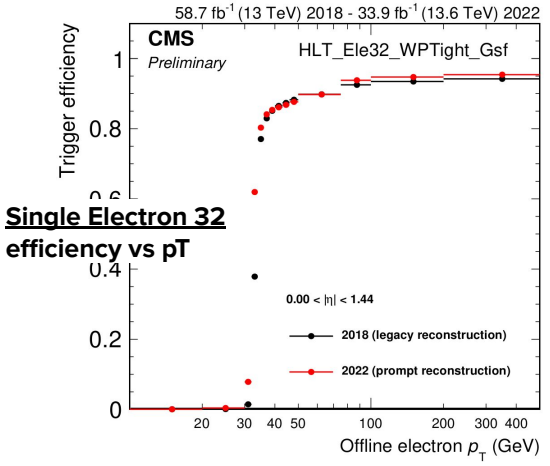
uGT (Level-1 Global Trigger) ***production crate*** *hosting the L1 Physics Menu*

uGT (Level-1 Global Trigger) ***test crate*** *(functional replicate of the production crate fully operational) can be used to test menus, firmware and new Phase-2 algorithms*

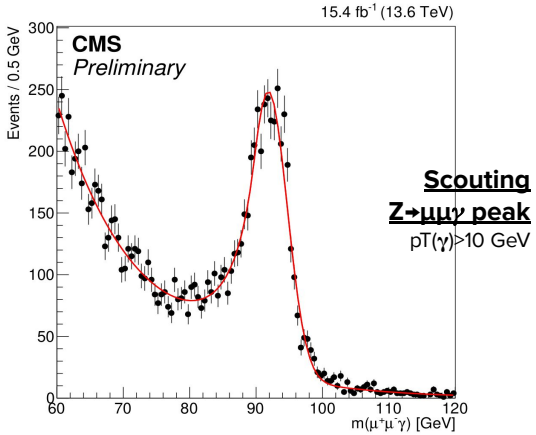


Trigger - High Level Trigger (HLT)

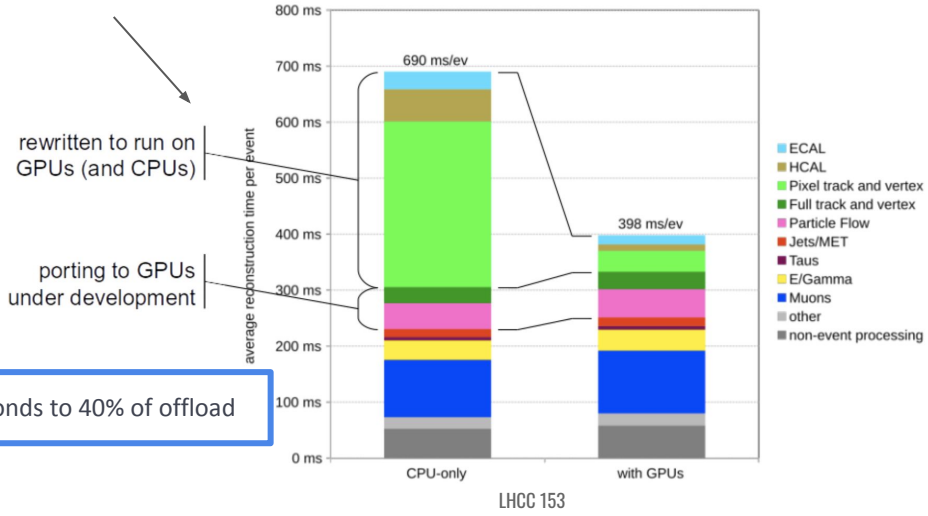
- Measurement of the trigger performance using 2022 data
  - Especially for the new object reconstruction (eg. long-lived particle)
  - Overall very good performance observed
- Improved version of data scouting
  - Very high rate (30 kHz) - GPU-accelerated reconstruction
  - Small event content (~6 kB/event) including muons, electrons/photons, jets, tracks, vertex
- Towards heterogeneous computing environment: migration of the GPU reconstruction code from CUDA to Alpaka (portability library) in progress



Single Electron 32 efficiency vs pT



Scouting Z→μμγ peak
pT(γ)>10 GeV



- GPUs corresponds to 40% of offload

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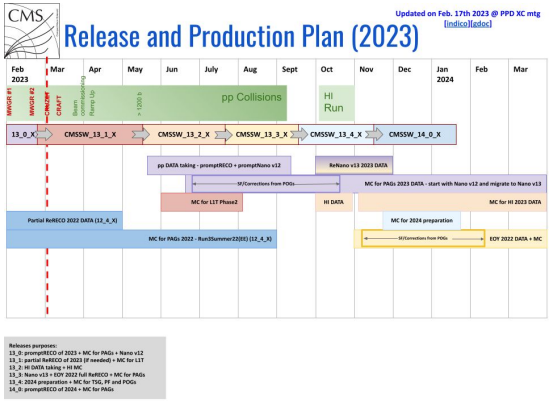
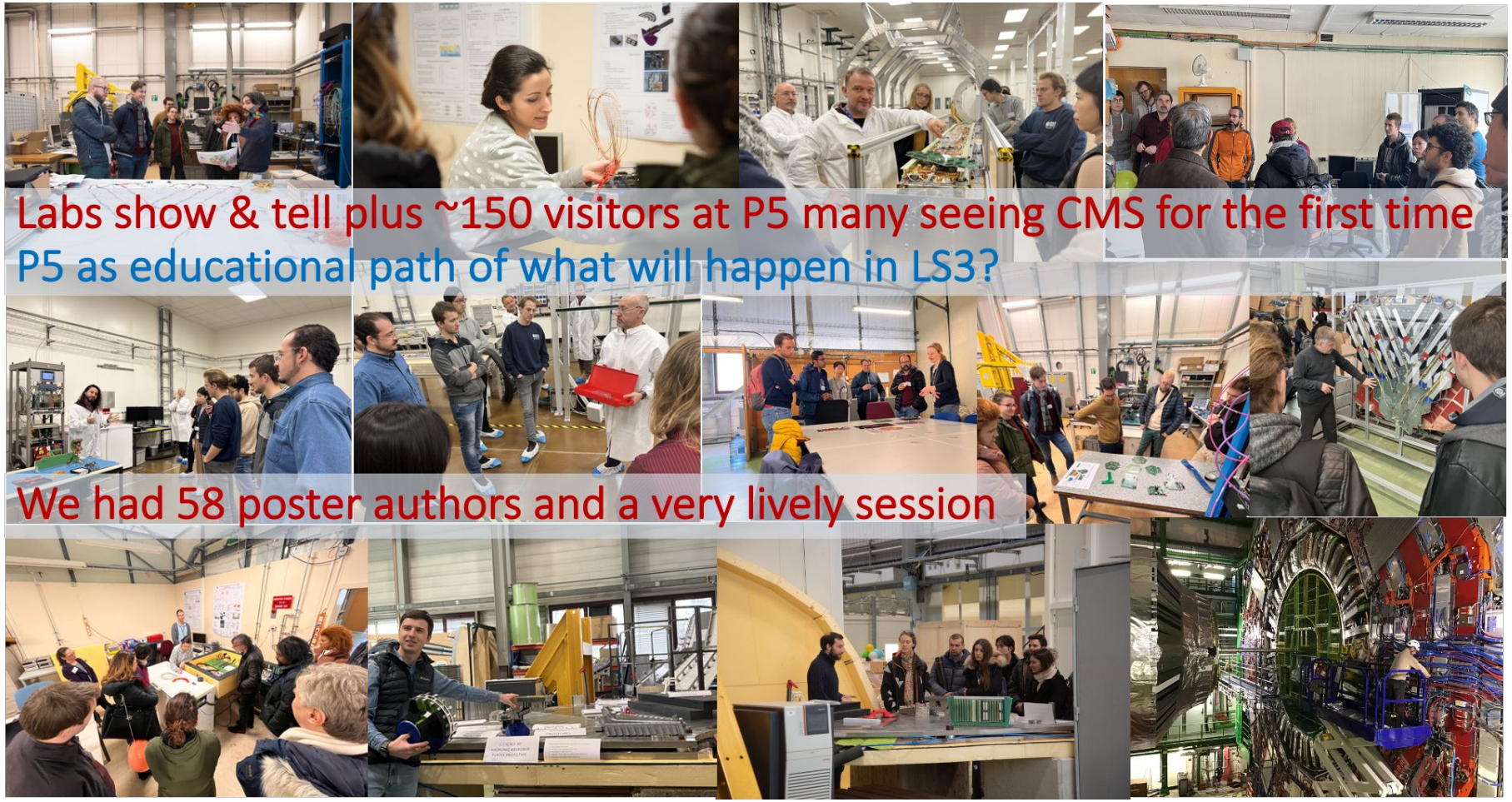
Offline and Computing

- CMS software ready for 2023 DATA taking:
  - Physics validation and software integration of bleeding edge technologies
  - Reconstruction algorithms improvements with respect to 2022 DATA taking
  - Link Time Optimization (LTO) compiler option used in production for our software for the first time
    - About 5% improvement of runtime performance across the board, HLT, simulation, reconstruction
- Most compute capacity at HPCs is located in the U.S. so far: ongoing effort to increase HPC usage in Europe



Phase 2 Upgrade Status

Upgrade days (Feb. 2023) - A great success!



Labs show & tell plus ~150 visitors at P5 many seeing CMS for the first time

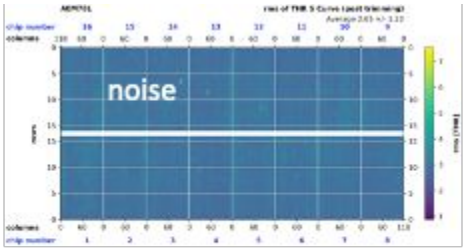
P5 as educational path of what will happen in LS3?

We had 58 poster authors and a very lively session

The CMS Phase 2 Upgrade

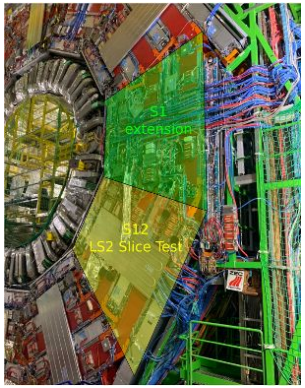
- Tracker:
  - Outer Tracker sensors > 60% received
  - Outer Tracker ASICs in production
  - The contract for testing ***1000+*** 65nm wafers (3 ASICs) has been signed
  - Inner Tracker: sensor contracts ready
  - Inner Track system integration: thermal, electrical, and mechanical - OK
- Muons:
  - Drift Tubes (DT): extension of a slice test with final Phase 2 on board electronics
  - iRPC and GEM: chamber production ongoing - on track

First PS modules with final ASICs



MaPSA final prototype campaign completed – we need 25m²

First ladder fully equipped with 12 functional 2S modules



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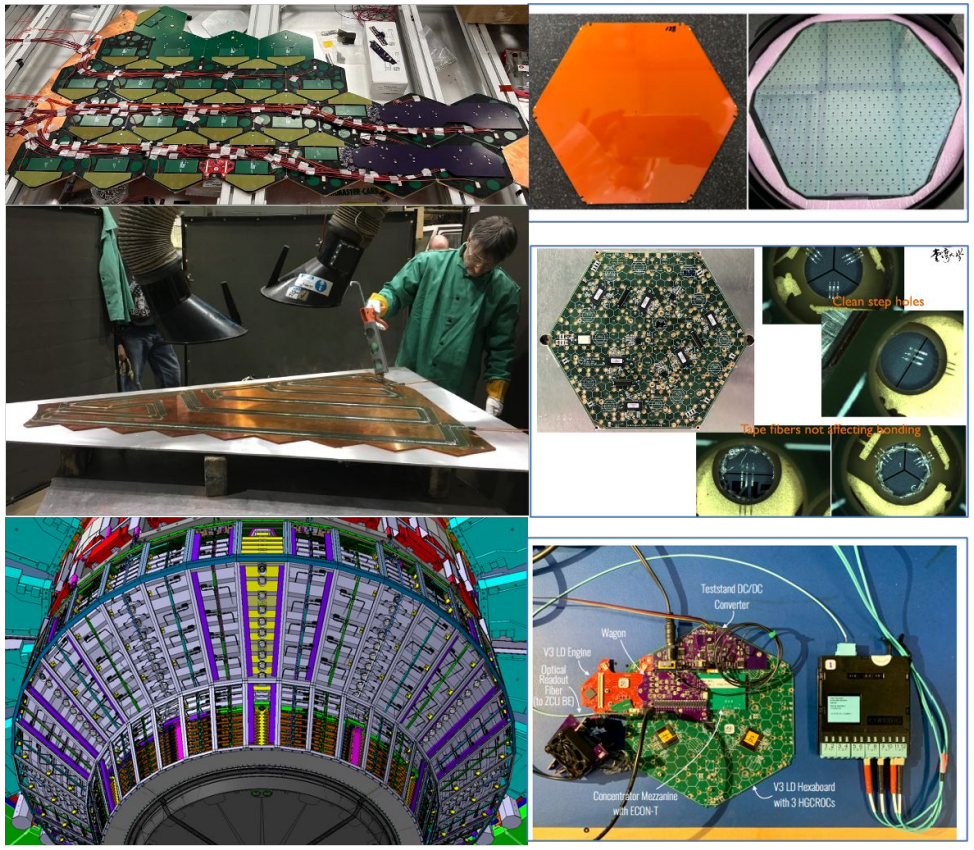
iRPC: Improved Resistive Plate Chambers
GEM: Gas Electron Multiplier
MaPSA: pixel-slip (ps) sensor & MPA ASICs

The CMS Phase 2 Upgrade

- High Granularity Calorimeter (HGCAL):
  - Production silicon sensors arriving
  - **ASICs: HGCAL ECON-D (on critical path) - submitted**
  - Latest prototype modules perform well
  - Mechanics are going very well:
    - Engineering Design Review (EDR) done in February
    - All pre-production steel plates have arrived in Pakistan

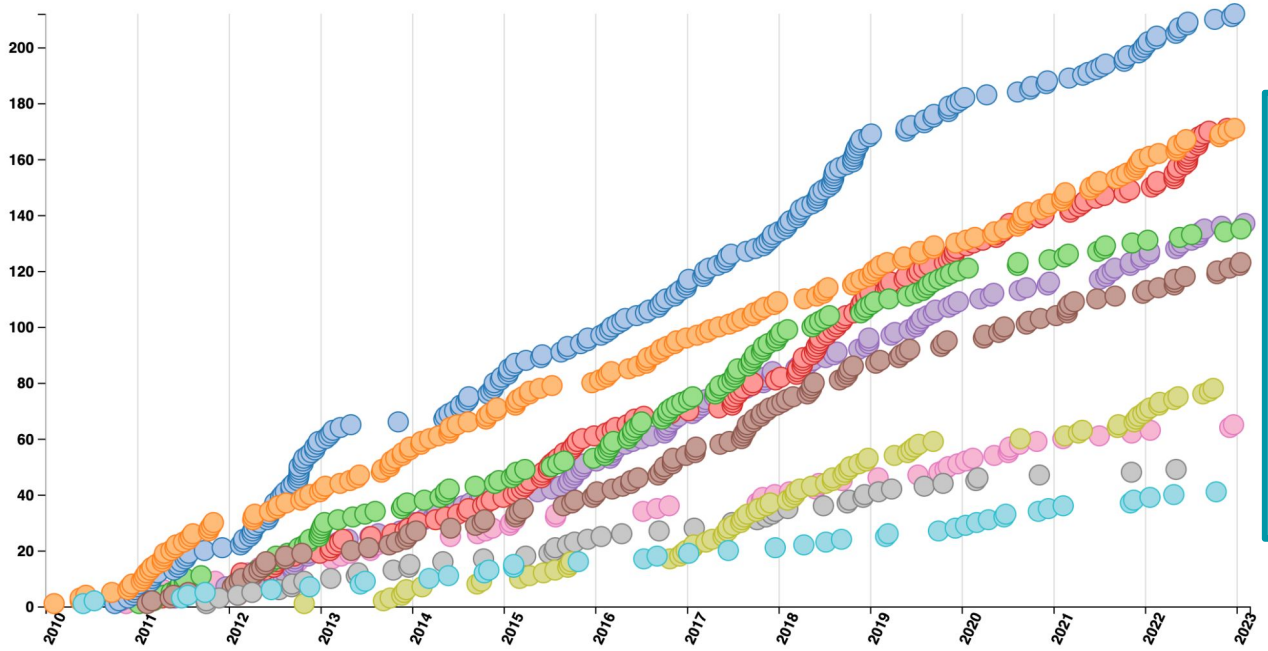


ECON-D: Concentrator ASIC (data version)

Physics Analyses Highlights

Physics Statistics

CMS Publications



Show all | Total | Exotica | Standard Model | Supersymmetry | Higgs | Top | Heavy Ions

B and Quarkonia | Forward and Soft QCD | Beyond 2 Generations | Detector Performance

- ***1184 papers*** on collider data published or submitted to a journal

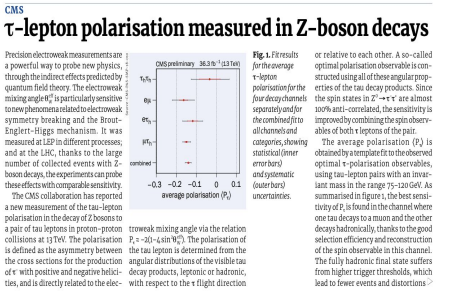
Since last LHCC

- ***11 analyses*** approved
- ***12 results*** submitted to publication
- ***17 accepted*** for publication

Measurement of the tau polarization in Z decays - [SMP-18-010]

- Tau polarization determined from the angular distributions of the visible τ decay products in $Z \rightarrow \tau\,\tau$ (leptonic or hadronic) with respect to the τ flight direction or relative to each other and combines the spin observables of both leptons.
- The average polarization $\langle P_\tau \rangle$ is extracted from a template fit to the observed optimal τ polarization observables in an invariant mass interval of the τ lepton pairs of 75-120 GeV
- Major uncertainties come from the hadronically decaying tau leptons mode reconstruction

CERNCOURIER [Link]


CMS

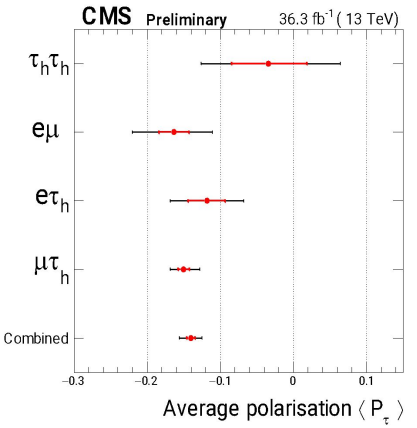
τ-lepton polarisation measured in Z-boson decays

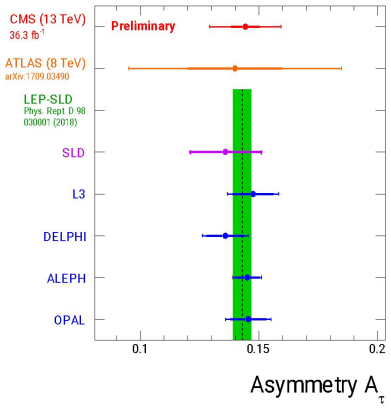
Precision electroweak measurements are a powerful way to probe new physics, through the indirect effects predicted by quantum field theory. The electroweak mixing angle θ_W^{eff} is particularly sensitive to new phenomena related to electroweak symmetry breaking and the Brout–Englert–Higgs mechanism. It was measured at LEP in different processes; and at the LHC, thanks to the large number of collected events with Z-boson decays, the experiments can probe these effects with comparable sensitivity.

The CMS collaboration has reported a new measurement of the tau–lepton polarisation in the decay of Z bosons to a pair of tau leptons in proton–proton collisions at 13 TeV. The polarisation is defined as the asymmetry between the cross sections for the production of τ^+ with positive and negative helicities, and is directly related to the electroweak mixing angle via the relation $P_\tau = -\mathcal{A}_\ell = -4(\sin^2\theta_W^{\text{eff}})$. The polarisation of the tau lepton is determined from the angular distributions of the visible tau decay products, leptonic or hadronic, with respect to the τ flight direction or relative to each other. A so-called optimal polarisation observable is constructed using all of these angular properties of the tau decay products. Since the spin states in $Z \rightarrow \tau^+\tau^-$ are almost 100% anti-correlated, the sensitivity is improved by combining the spin observables of both τ leptons of the pair.

The average polarisation (P_τ) is obtained by a template fit to the observed optimal τ-polarisation observables, using tau–lepton pairs with an invariant mass in the range 75–120 GeV. As summarised in figure 1, the best sensitivity of P_τ is found in the channel where one tau decays to a muon and the other decays hadronically, thanks to the good selection efficiency and reconstruction of the spin observable in this channel. The fully hadronic final state suffers from higher trigger thresholds, which lead to fewer events and distortions

Fig. 1. *Fit results for the average τ–lepton polarisation for the four decay channels separately and for the combined fit to all channels and categories, showing statistical (inner error bars) and systematic (outer bars) uncertainties.*





$\mathcal{P}_\tau\,(Z) = -0.144 \pm 0.006(\text{stat}) \pm 0.014(\text{syst})$

(SM $A_l = 0.1468 \pm 0.0003$)

And the effective weak mixing angle is measured

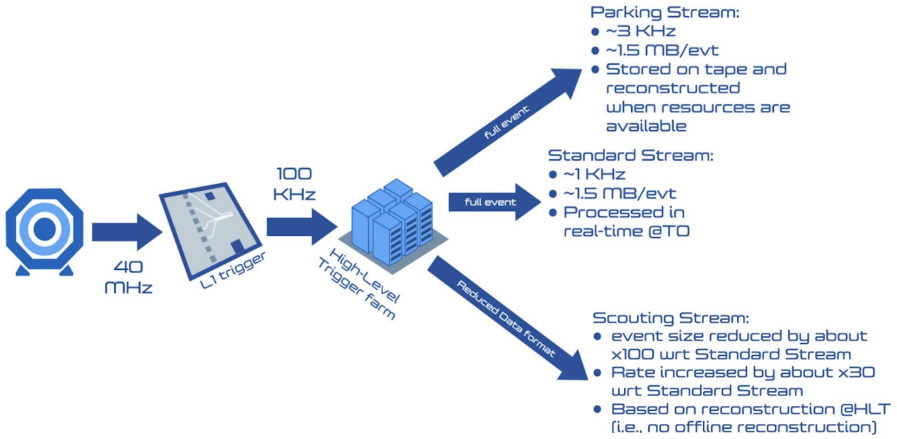
$\sin^2\theta_W^{\text{eff}} = 0.2319 \pm 0.0008(\text{stat}) \pm 0.0018(\text{syst})$

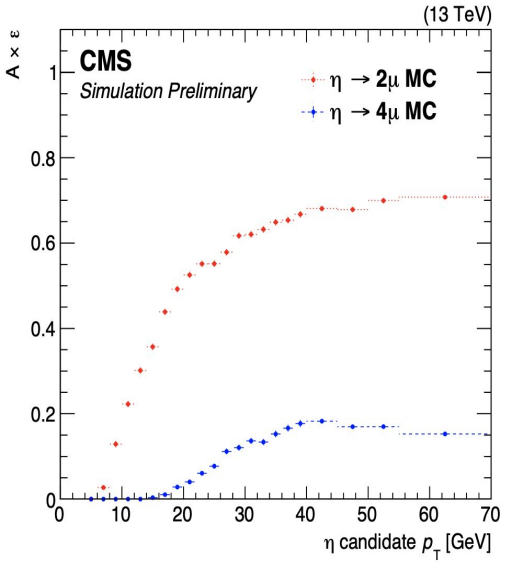
Reached same precision as SLD Experiment

Observation of $\eta \to 4\mu$ decay - [BPH-22-003]

Probe low-mass 4μ region using HLT scouting DATA

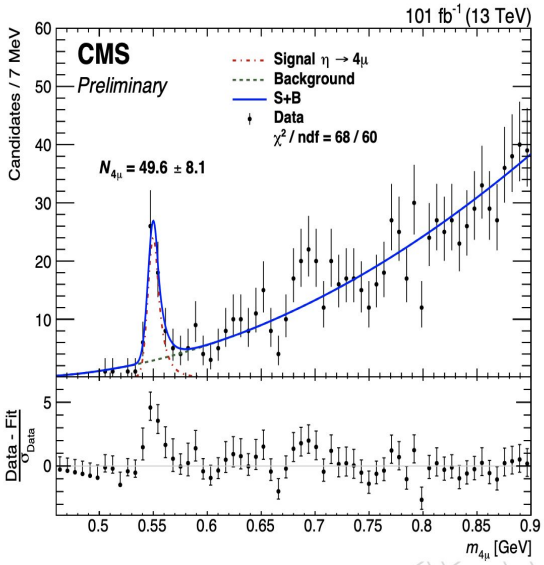
- BR measured wrt $\eta \to 2\mu$ (known with 13% precision)
- DATA filtered with loose triggers: two muons with transverse momenta as low as 3 GeV





First observation of this decay

Measured BR compatible with SM expectation (central value is 25% higher)



$$\mathcal{B}(\eta \to 4\mu) = (5.0 \pm 0.8\,(\text{stat}) \pm 0.7\,(\text{syst}) \pm 0.7\,(\mathcal{B})) \times 10^{-9}$$

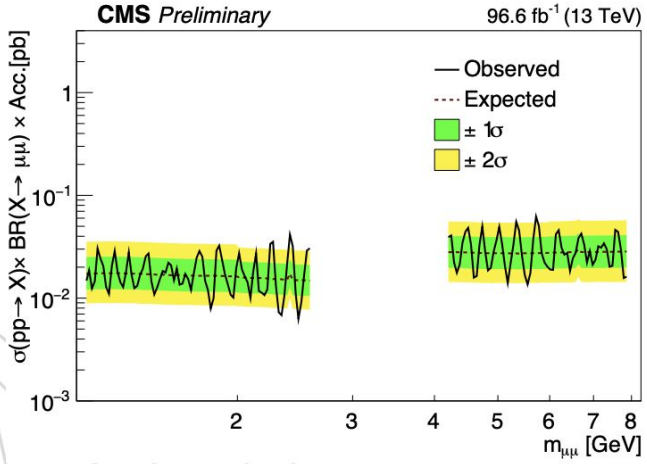
Search for prompt low-mass dimuon resonances with scouting - [EXO-21-005]

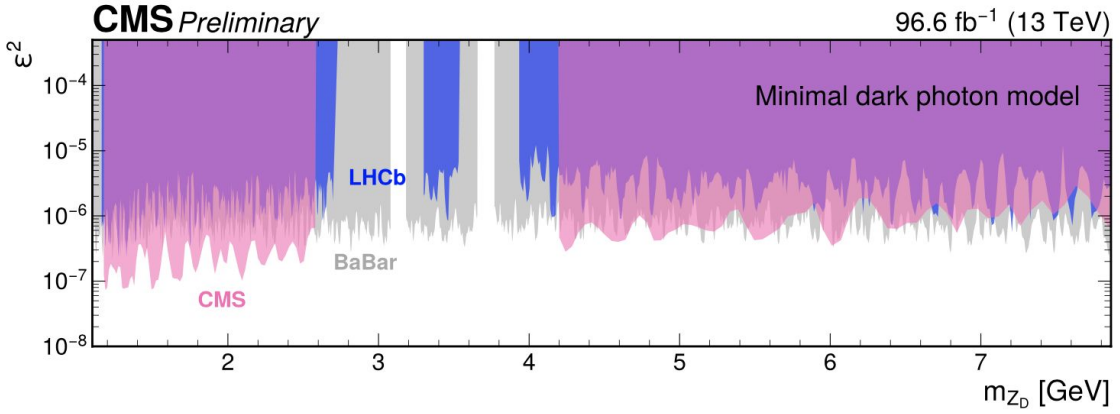
LHC Seminar : Feb 28, 2022
https://indico.cern.ch/event/1231795/

Use HLT scouting DATA to select light dimuon pairs

- High trigger efficiency at small di-muon angle separation (low ΔR), with some efficiency retained at larger values
- Two MVA analysis to select muons, trained on J/ψ and Y
- An excess is observed in high-pT selection at 2.41 GeV - local (global) significance of 3.2σ (1.3σ)

Perform a bump hunt outside the J/ψ, ψ' region, and Y(1S)





Search for charged lepton flavor violation in the top quark sector in tri-lepton final states - [TOP-22-005]

- Considering both modifications in top production and decay
- Define signal and control regions through loose cuts and object counting
- No signal observed. Limit on C/Λ^2

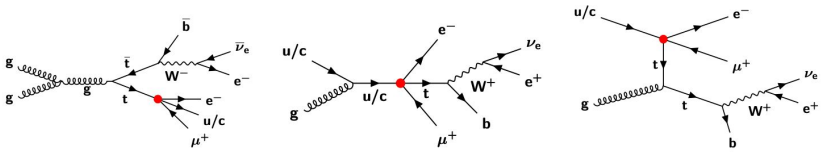
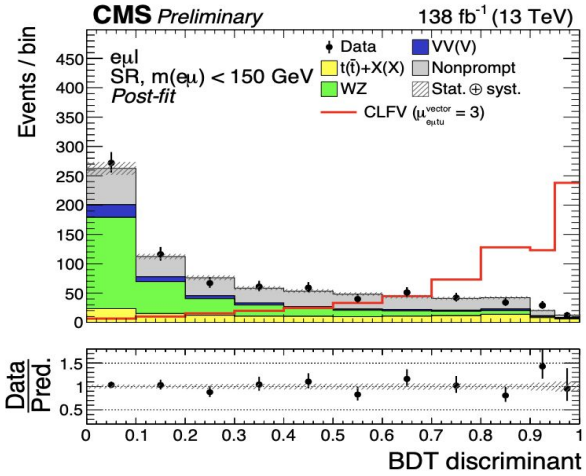
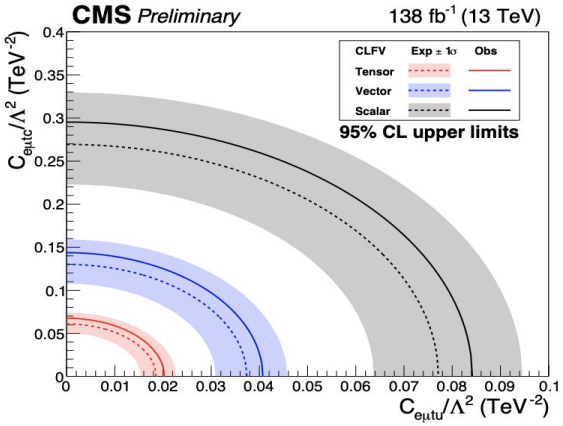


Table 2: Summary of the selection criteria used to define different event regions.

Channel	Region	OnZ	OffZ	$p_T^{miss} > 20$ GeV	# jets ≥ 1	# b jets ≤ 1
$eee/\mu\mu\mu$	VR	-	-	-	-	-
	WZ CR	✓	-	✓	✓	✓
$e\mu l$	SR	-	✓	✓	✓	✓
	VR	✓	-	-	-	-
	WZ CR	✓	-	✓	✓	✓



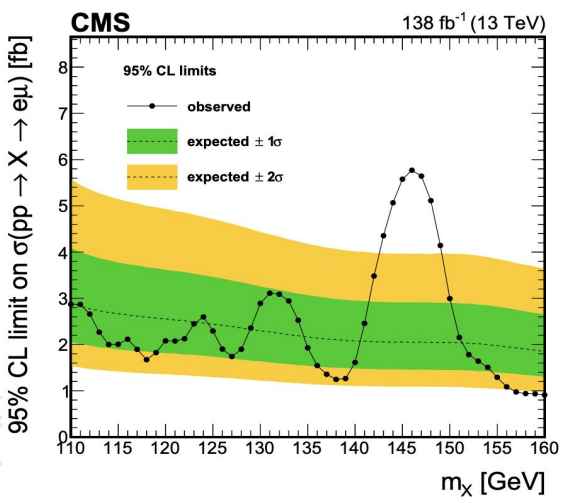


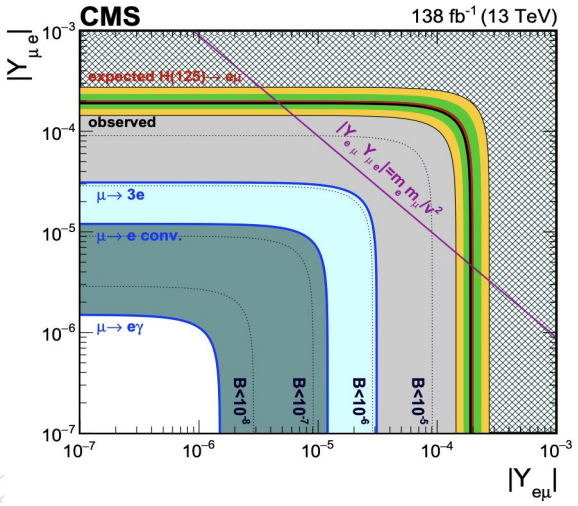
Search for H → eμ and X → eμ - [HIG-22-002]

Search for lepton-flavor violating decay of a Higgs boson with a rest mass between 110 to 160 GeV to an eμ pair

- Strongest direct bound on BR(H(125) → eμ): observed (expected) upper limit set to be 4.4×10^{-5} (4.7×10^{-5}) at 95% CL
- Indirect limit on BR(H(125) → eμ)< 10^{-8} derived from the null result of μ → eγ

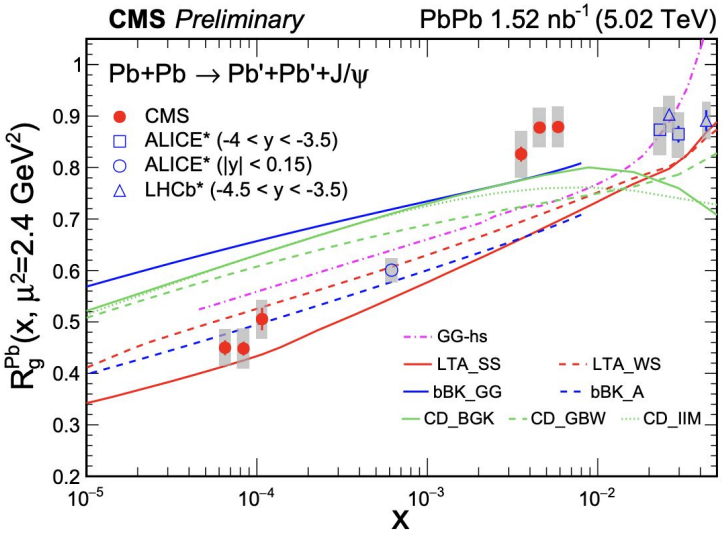
Observed excess of events over the expected background around 146 GeV with a global (local) significance of 2.8σ (3.8σ)

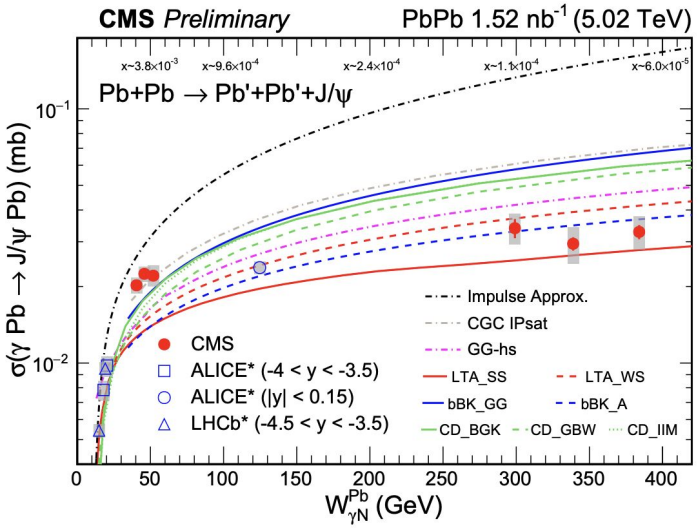




Charmonium photoproduction with 5.02 TeV PbPb UPC - [HIN-22-002]

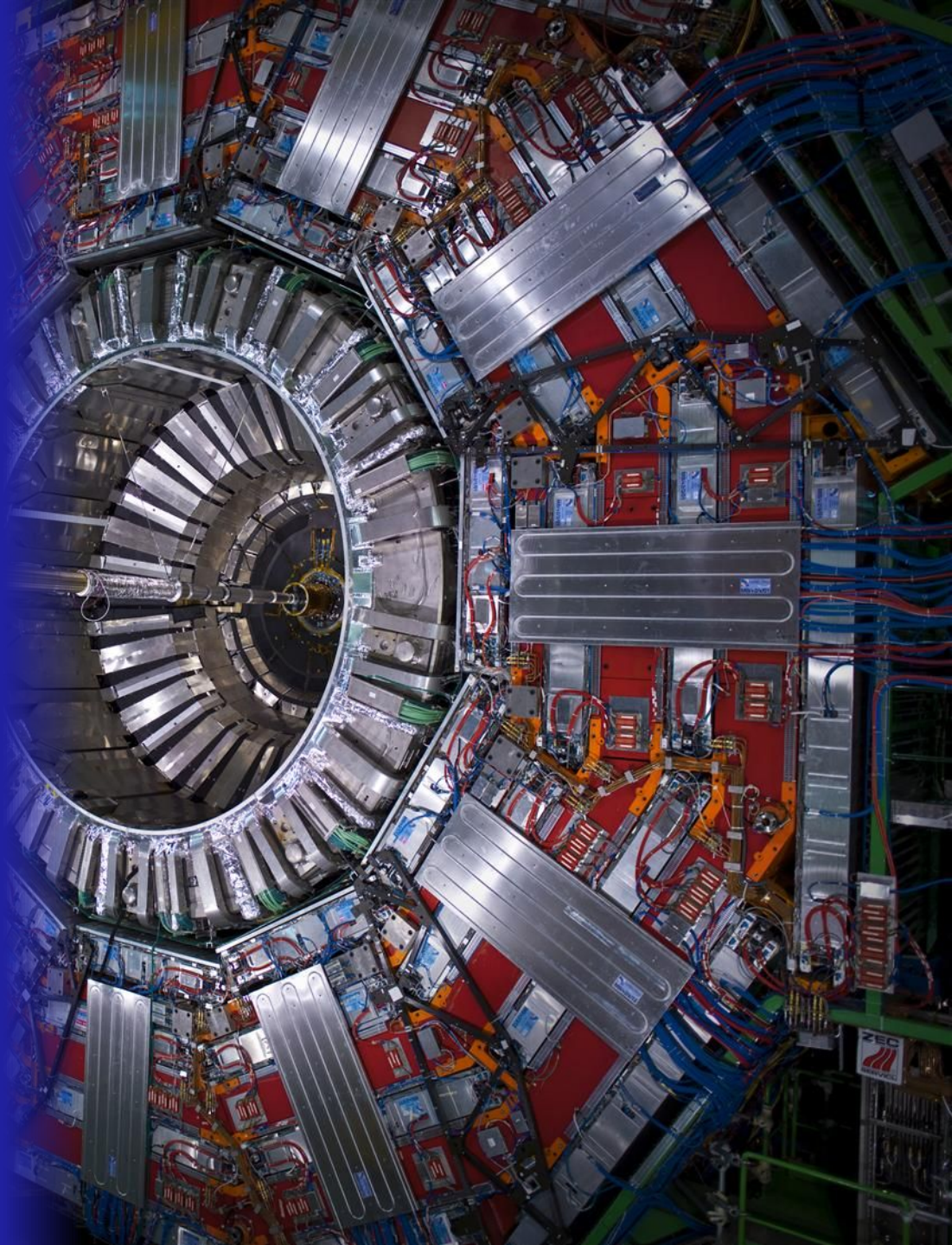
- First measurement of the nuclear gluonic structure probed by high-energy photons
- For the first time, disentangled the low and high γ energy contributions to coherent J/Ψ
- CMS measured coherent J/Ψ at a new unprecedentedly low-x gluon regime (10^{-4}-10^{-5})
- Flattening of coherent σ(J/Ψ) vs. W not predicted by state of the art models
  - ***Gluon saturation? or black disk limit? or other physics effects?***





Summary

- Year End Technical Stop was important for CMS maintenance
- CMS is ramping up for 2023 DATA taking
- Adapting to higher 2023 PU scenario with respect to 2022
- Phase 2 program is moving towards production
- Run 2 Physics analyses are still yielding new results while shifting priority towards the Run 3 DATA



Backup

Public results since last LHCC

SMP-18-010: Measurement of the tau polarization in Z decays

TOP-22-005: Search for charged lepton flavor violation in the top quark sector in trilepton final states with the CMS detector at s√=13 TeV

TOP-22-006: Search for new physics in top quark production with additional leptons in the context of effective field theory using 138 fb−1 of proton-proton collisions at √s = 13 TeV

HIG-22-002: Search for the lepton flavor violating decay of a Higgs boson in the eμ final state in proton-proton collisions at √s = 13 TeV

B2G-21-005: Search for a heavy resonance decaying into a top quark and a W boson in the lepton+jets final state at √s=13 TeV

EXO-21-005: Search for prompt production of a GeV scale resonance decaying to a pair of muons in proton-proton collisions at s√=13 TeV

EXO-20-010: Search for inelastic dark matter in events with two displaced muons and missing transverse momentum in proton-proton collisions at s√=13 TeV

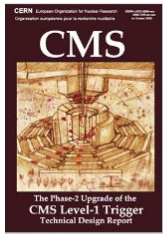
EXO-21-012: Search for dark matter in DarkHiggs(WW)+MET final state

HIN-22-002: Photon-nucleus energy dependence of coherent J/ψ cross session in ultraperipheral PbPb collisions at 5.02 TeV with CMS

BPH-21-001: Measurement of the dependence of the hadron production fraction ratio fs/fu on B meson kinematic variables in proton-proton collisions at √s= 13 TeV

BPH-22-003: First observation of the rare 4μ decay of the η meson

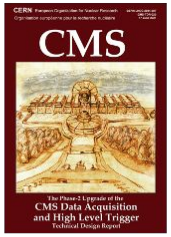
The CMS Phase 2 Upgrade



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

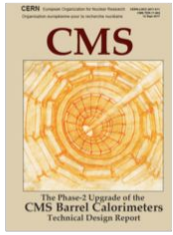
https://cds.cern.ch/record/2759072

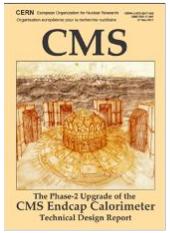
- Full optical readout
- Heterogenous architecture
- 60 TB/s event network
- 7.5 kHz HLT output

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

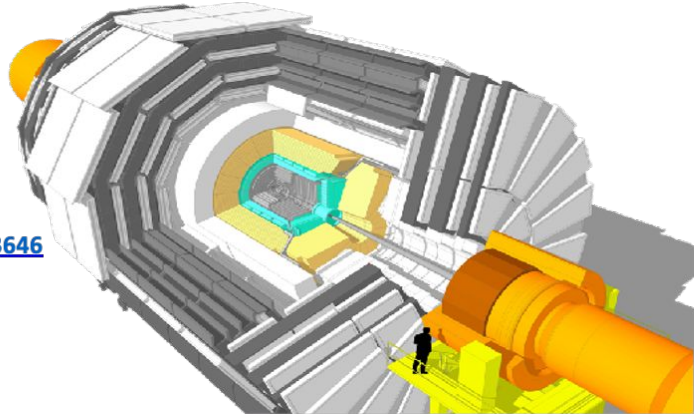




Calorimeter Endcap

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

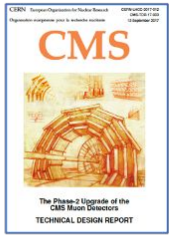
- 3D showers and precise timing
- Si, Scint+SiPM in Pb/W-SS

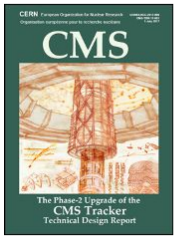


Muon systems

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

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

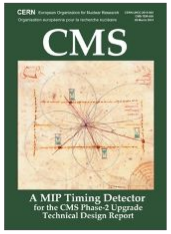




Tracker

https://cds.cern.ch/record/2272264

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



MIP Timing Detector

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

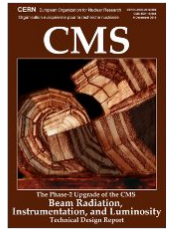
Precision timing with:

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

Beam Radiation Instr. and Luminosity

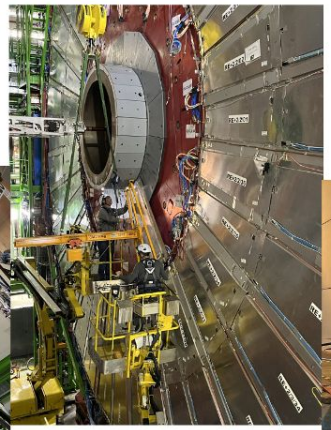
http://cds.cern.ch/record/2759074

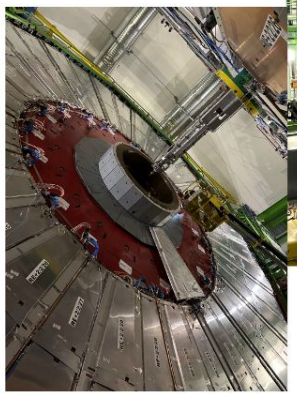
- Beam abort & timing
- Beam-induced background
- Bunch-by-bunch luminosity:
  1% offline, 2% online
- Neutron and mixed-field radiation monitors



CERN Courier - Jan./Feb. 2023

- Magazine link
- Front page featuring iRPC 2022 demonstrator installation (new muon forward station)



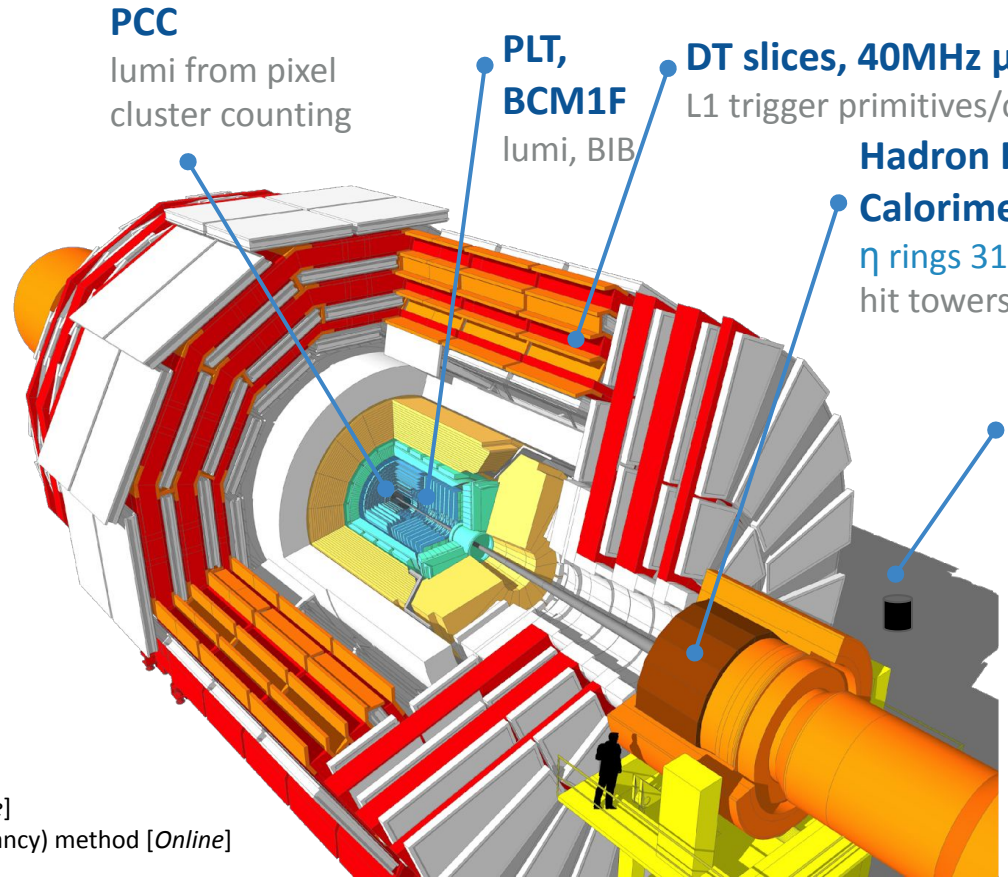


CMS Lumi detectors

Multiple independent systems used online:

- **BCM1F uTCA**, **BCM1F VME**, **HFET**, **HFOC**, **PLT**
  - *independently calibrated*
- **REMUS**, **DT**
  - *cross-calibrated*

PCC (Pixel cluster counting) is used after offline processing



HFET: Hadron Forward calorimeter - sum(ET) method [*Online*]
HFOC: Hadron Forward calorimeter - tower counting (occupancy) method [*Online*]
PCC: Pixel Cluster Counting [*Offline*]
PLT: Pixel Luminosity Telescope (3-fold coincidence counting) [*Online*]
BCM1F: Beam Condition Monitor - Fast (hit counting) [*Online*]
DT: Muon Drift Tubes (level-1 muon stub counting) [*Online*]
REMUS: Radiation and Environment Monitoring Unified Supervision (ambient dose equivalent rate measured by gas-filled ionization chambers) [*Online*]

Photos PLT & BCM1F - Run3