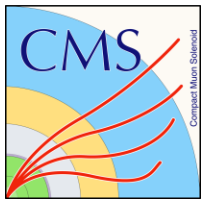
UCLA



CMS Status Report

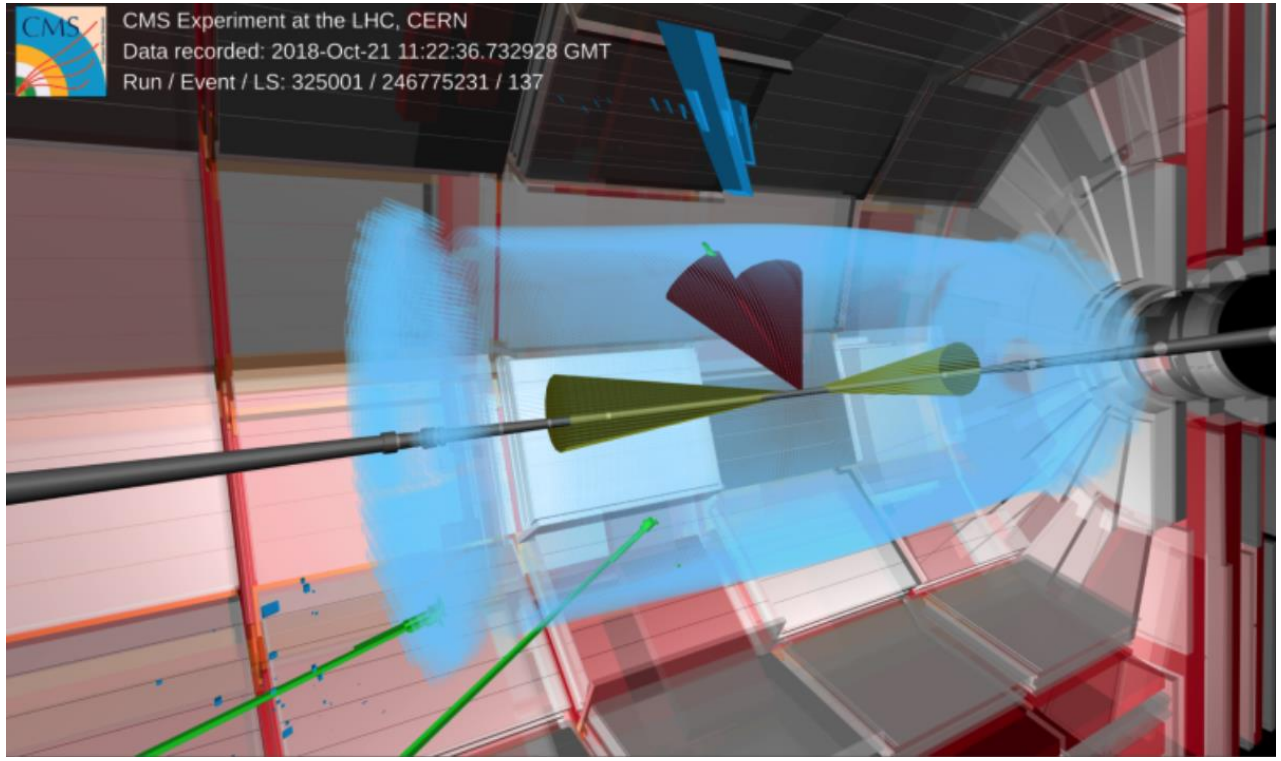
ABHISEK DATTA

ON BEHALF OF THE CMS COLLABORATION

US LHC USERS ASSOCIATION ANNUAL MEETING

Overview

- 2024 Data Taking and Performance
- Highlights of Physics Results
- Status of Phase-2 Upgrades

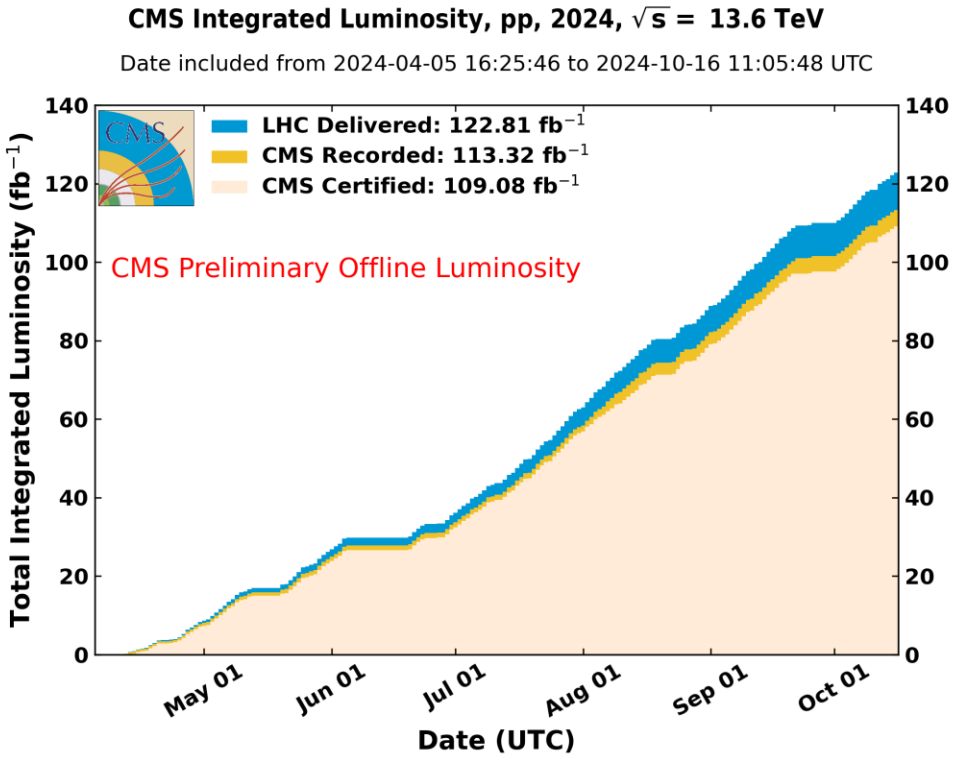


2024 Data Taking and Performance

2024 pp Data Taking

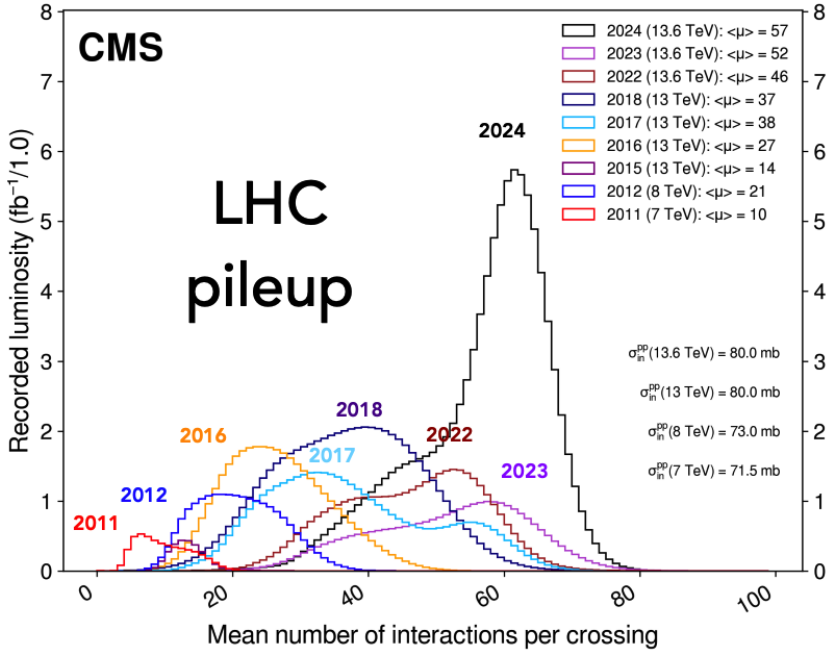
Smooth data taking in 2024:

- Delivered luminosity in 2024: 122.8 fb^{-1}
- Recorded integrated luminosity in 2024: 113.3 fb^{-1} (92.3%)
- Certified for physics: 109.1 fb^{-1} (96.3%)



Pileup (PU) levelled at 62-64 during the year:

- 105-115 kHz of L1 trigger rate
- 3-6% deadtime
- Mitigation measures to control dead time caused by ECAL noise evolution
  - Minimal effect on physics performance and uniformity



2024 Heavy Ion Data Taking

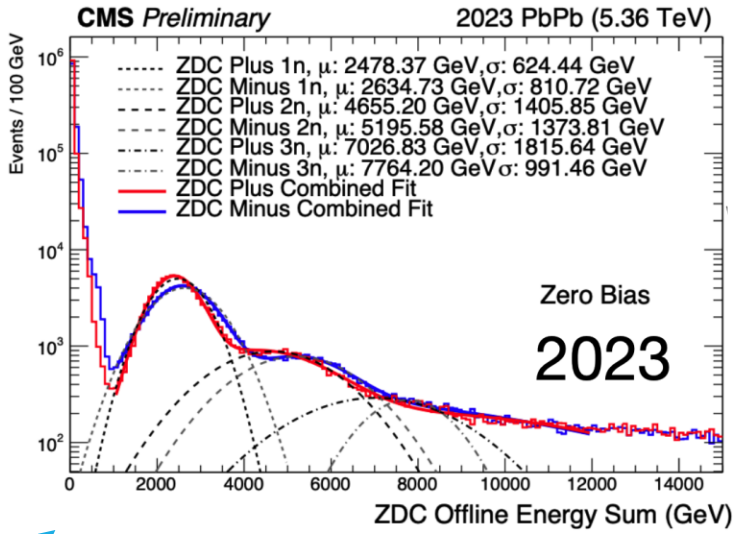
Successful heavy ion run in 2024:

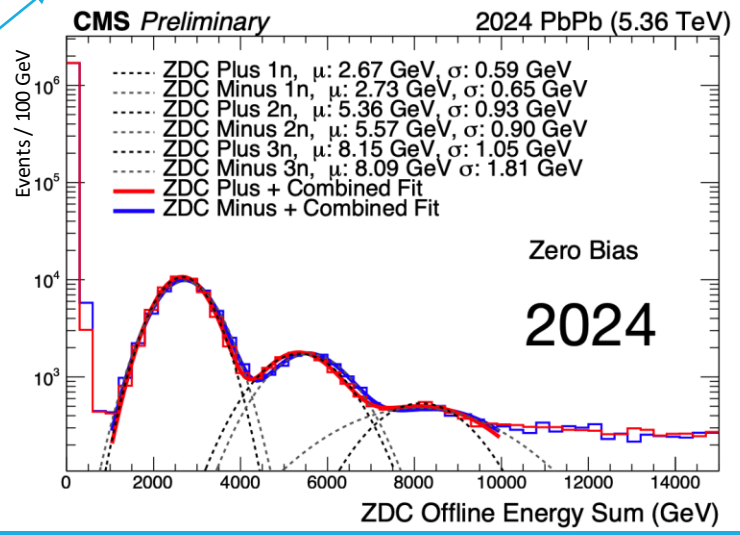
- PbPb @ 5.36 TeV/nucleon
- Delivered luminosity in 2024: 1.90 nb^{-1}
- Recorded integrated luminosity: 1.67 nb^{-1}
- Good machine performance but availability impacted by 3 quench events
- Downtime from some hardware issues
- "Good-for-physics" efficiency ~80-85%

PbPb Performance in 2024:

- Improved Zero Degree Calorimeters (ZDC) performance compared with 2023
- Minimum-bias trigger efficiency significantly improved

Also, significantly improved b-jet tagging performance in Run-3 PbPb collisions as compared to Run 2





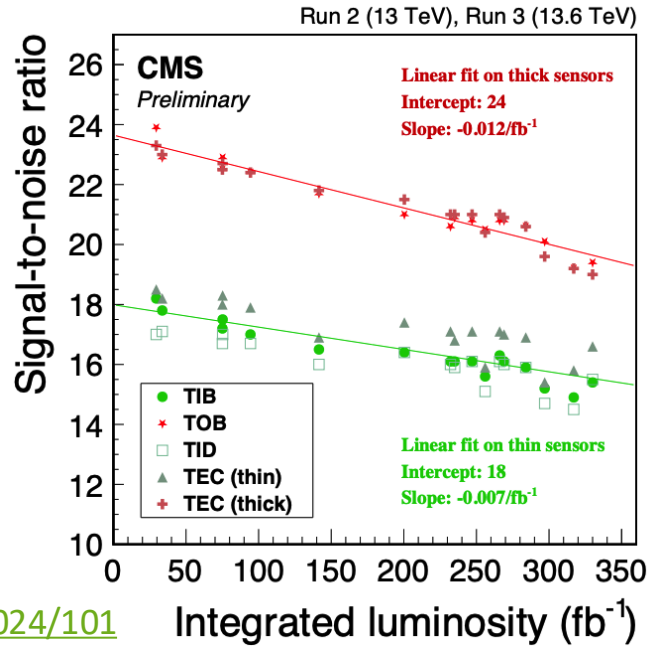
Performance of Sub-Detectors

Tracker:

- Smooth operation of both pixel and strip detectors
- Current limit reached for several strip HV channels, but fully consistent with expectations

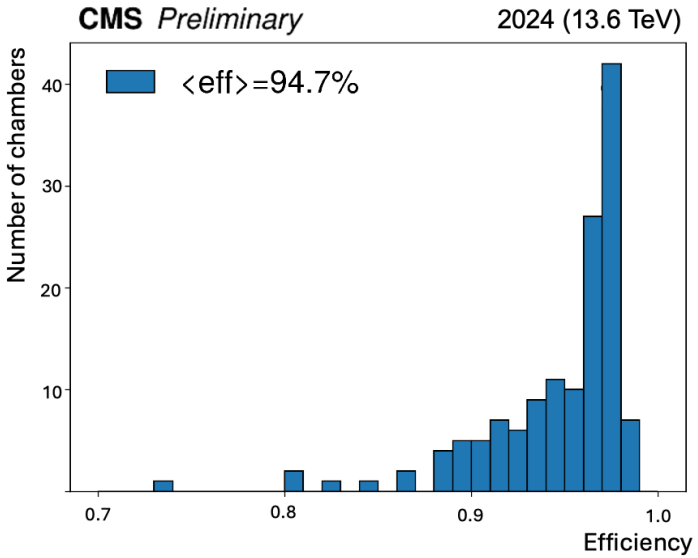
Muons:

- Excellent performance in both Barrel and Endcap regions
- Significant improvement in time resolution in GE1/1 (successfully included in Level-1 trigger)

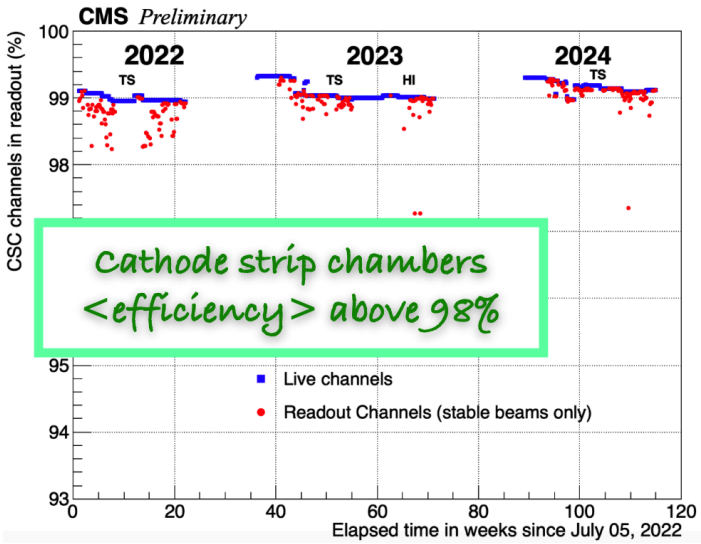


CMS-DP-2024/101

Signal-to-noise ratio in strip tracker well above 10, and will stay like this until 500 fb^{-1}



GE1/1 efficiency in 2024

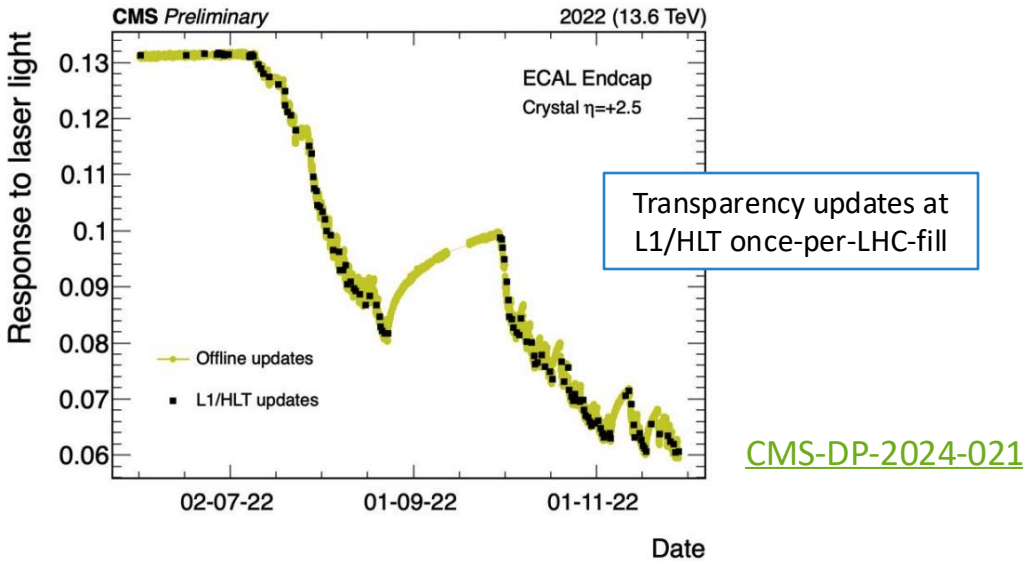


CSC active channel in Run 3

Performance of Sub-Detectors

ECAL:

- Smooth operation in 2024, despite challenging conditions with high rate and PU
- Dead time, due to increasing APD noise, under control after mitigation measures
  - Plan to raise zero suppression (ZS) thresholds in 2025
- Continuous effort in improving automatization in calibrations (e.g. transparency updates)



Transparency updates at L1/HLT once-per-LHC-fill

CMS-DP-2024-021

HCAL:

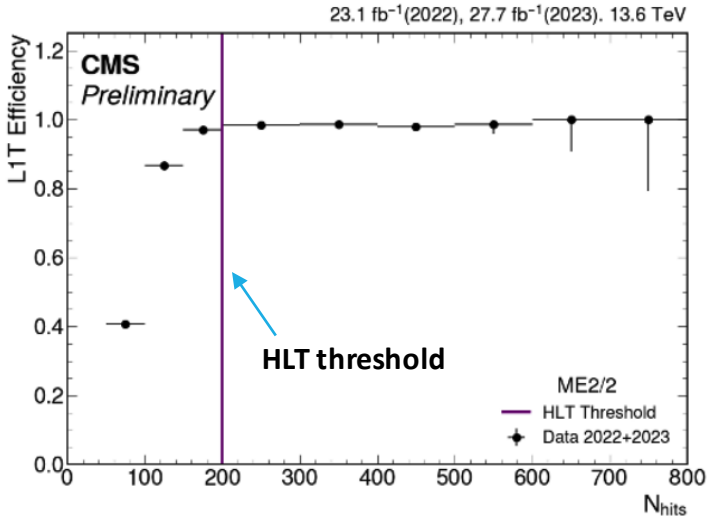
- Smooth HCAL operation through the end of data taking
- Effective automatic recovery for minor issues
- New laser setup: radiation damage studies resumed
- Excellent operations of ZDC during pp-ref and HI runs
  - Successfully repaired after accident at the start of the year
  - Installed and commissioned at the end of pp run

Trigger System

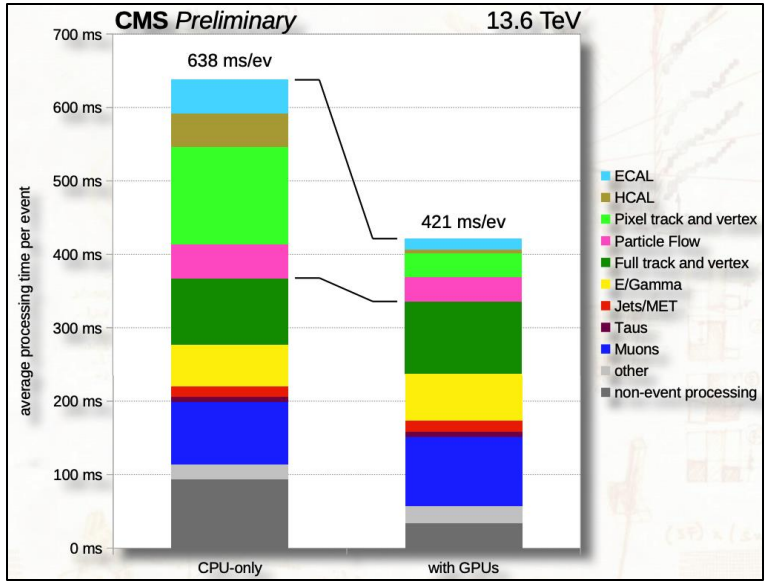
Stable operations and good performance for both L1 trigger and HLT throughout 2024

- Smooth data taking with several new triggers added in 2024:
  - New neural network based anomaly detection triggers (AXOL1TL and CICADA)
  - Low p_T single muon triggers in barrel (extremely valuable for CMS B-physics program)
  - Low p_T lepton + jet cross-triggers
- Improvements in the HLT reconstruction, and extended event content for HLT scouting
- Heterogeneous (CPU+GPU) reconstruction software used at HLT ported to Alpaka portability library

Average rates:
- ~2 kHz prompt
- ~5 kHz parking
- ~26 kHz HLT scouting



Measurement of the high-multiplicity muon detector shower trigger efficiency in CSC station ring ME2/2
CMS-DP-2024-099

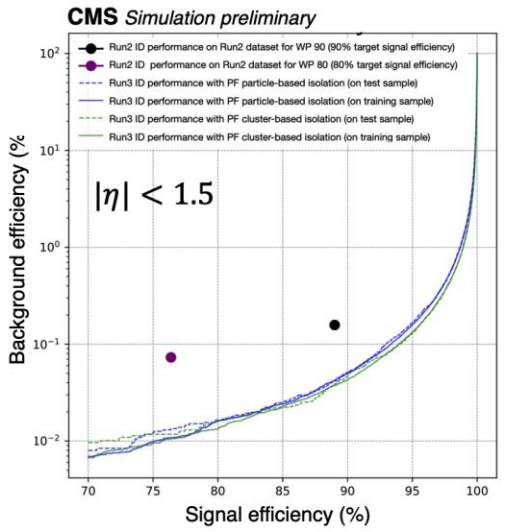


Large improvement in HLT processing time using GPUs
CMS-DP-2024-082

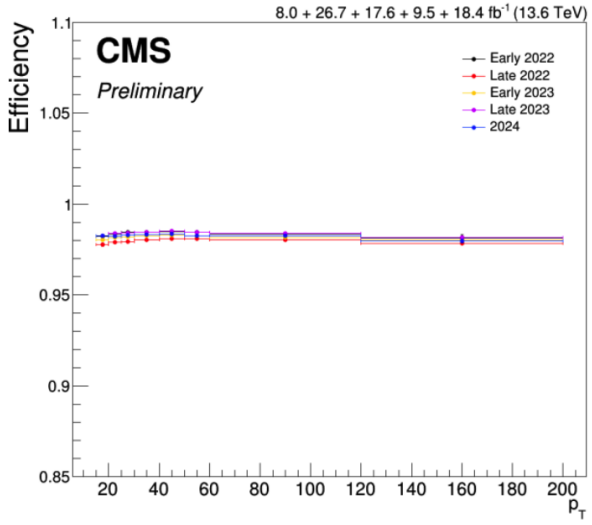
Physics Object Performance in Run 3

- Stable physics performance of electrons, photons, muons, taus, jets
- Improvements in jet tagging performance using machine learning
  - Latest algorithms using graph-nets and transformers
  - Extended to multiple kinds of jets (also τ_h)

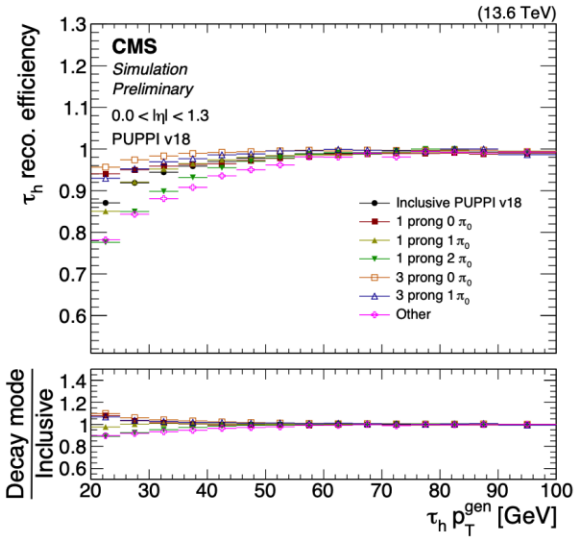
Electron and photon in Run-3
CMS-DP-2024-052



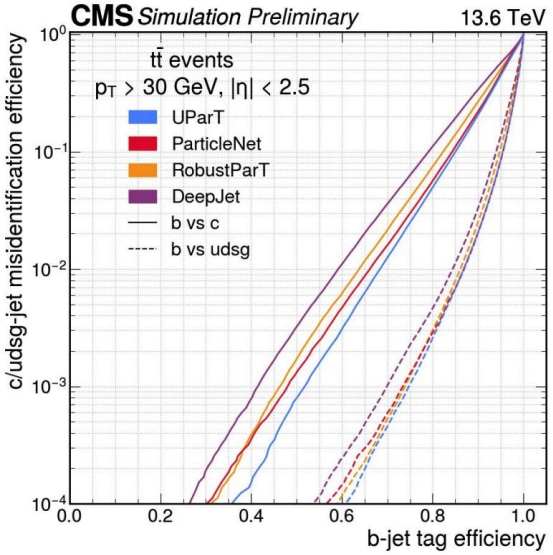
Global Muon Reconstruction in Run 3
CMS-DP-2024-067



PU mitigation for tau tagging
CMS-DP-2024-043



b-tagging for Run 3
CMS-DP-2024-066



Highlights of Physics Results

W Mass Measurement

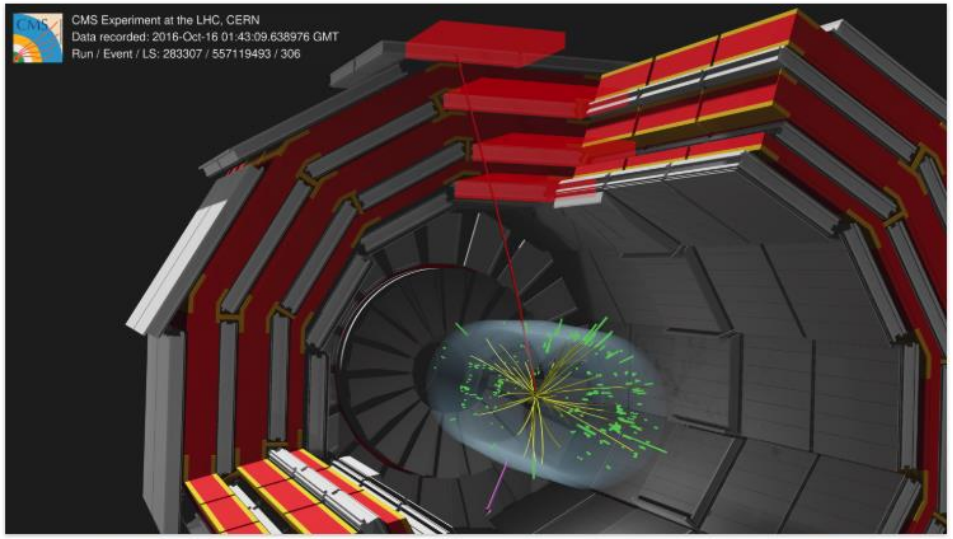
Major, long-awaited result from CMS

CMS-PAS-SMP-23-002

CMS experiment at CERN weighs in on the W boson mass

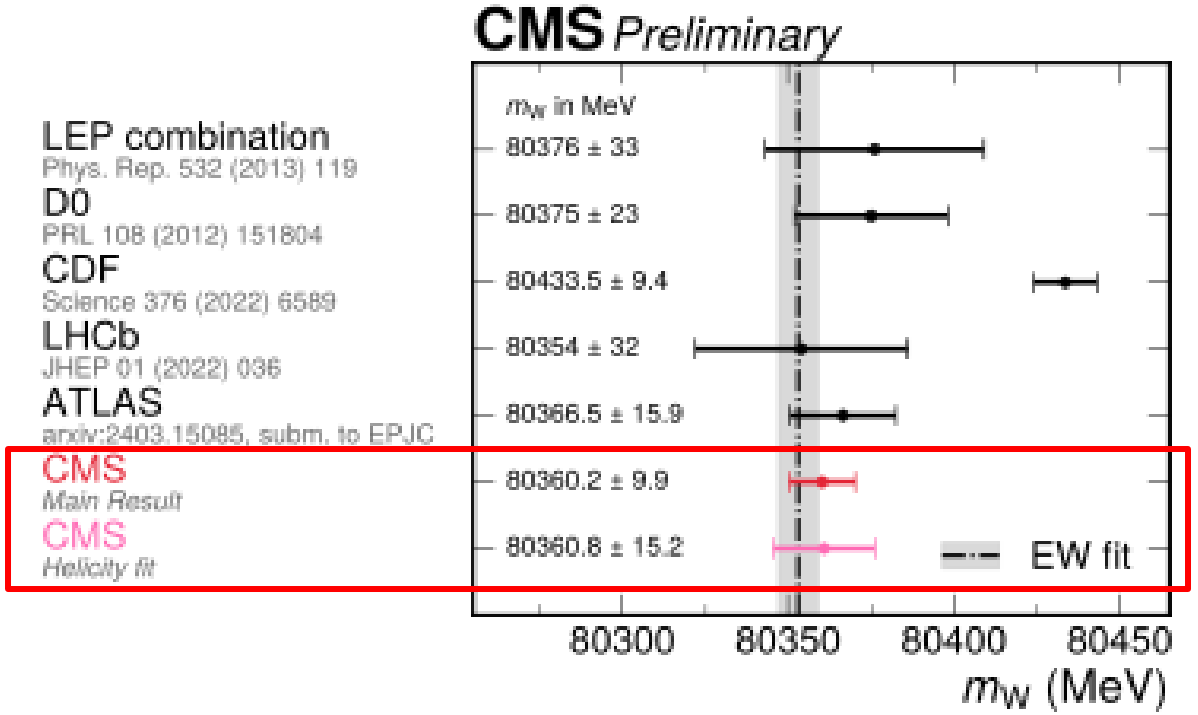
The eagerly awaited result is the most precise measurement of the W mass made at the LHC so far, and is in line with the prediction from the Standard Model of particle physics

17 SEPTEMBER, 2024



CMS candidate collision event for a W boson decaying into a muon (red line) and a neutrino that escapes detection (pink arrow). (Image: CMS/CERN)

CERN press release



$$m_W = 80360.2 \pm 9.9 \text{ MeV}$$

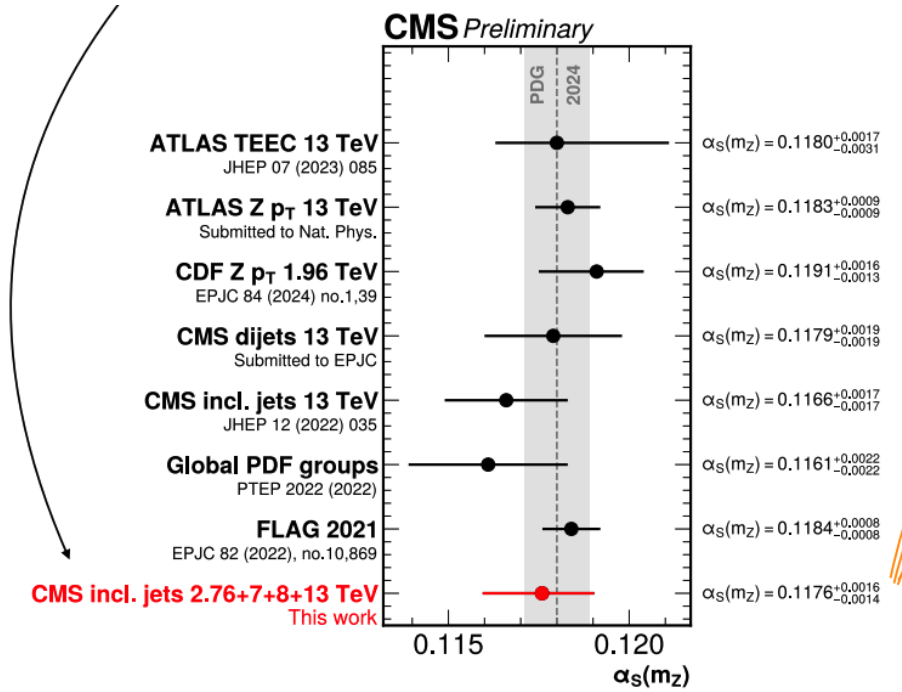
Results consistent with the Standard Model prediction

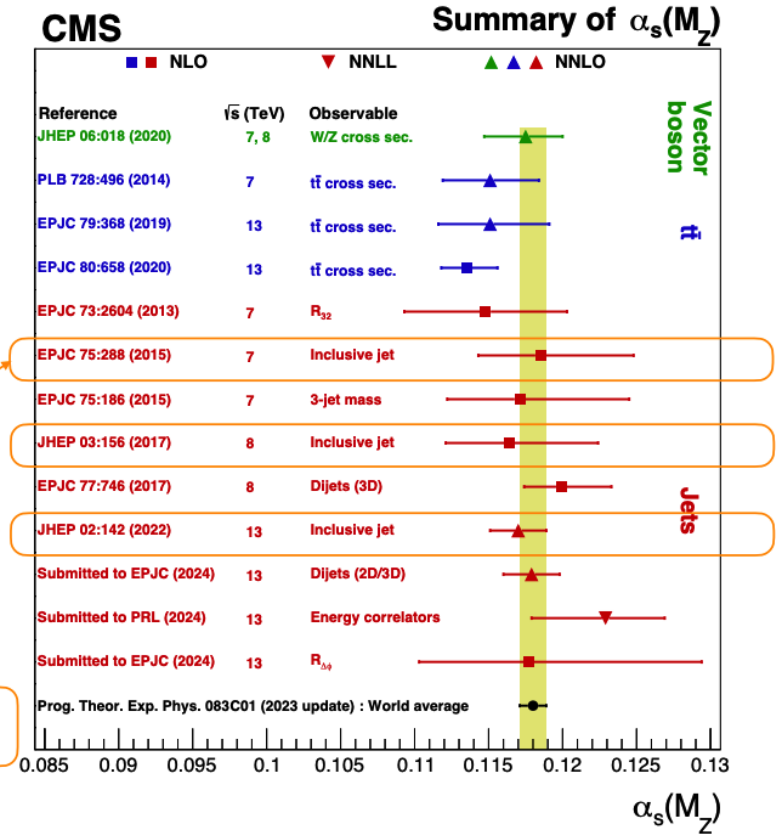
α_S Measurement from Jets

- Analysis at NNLO in QCD
- α_S extracted together with the PDFs of the proton

CMS-PAS-SMP-24-007

Most precise measurement of α_S from jet cross sections



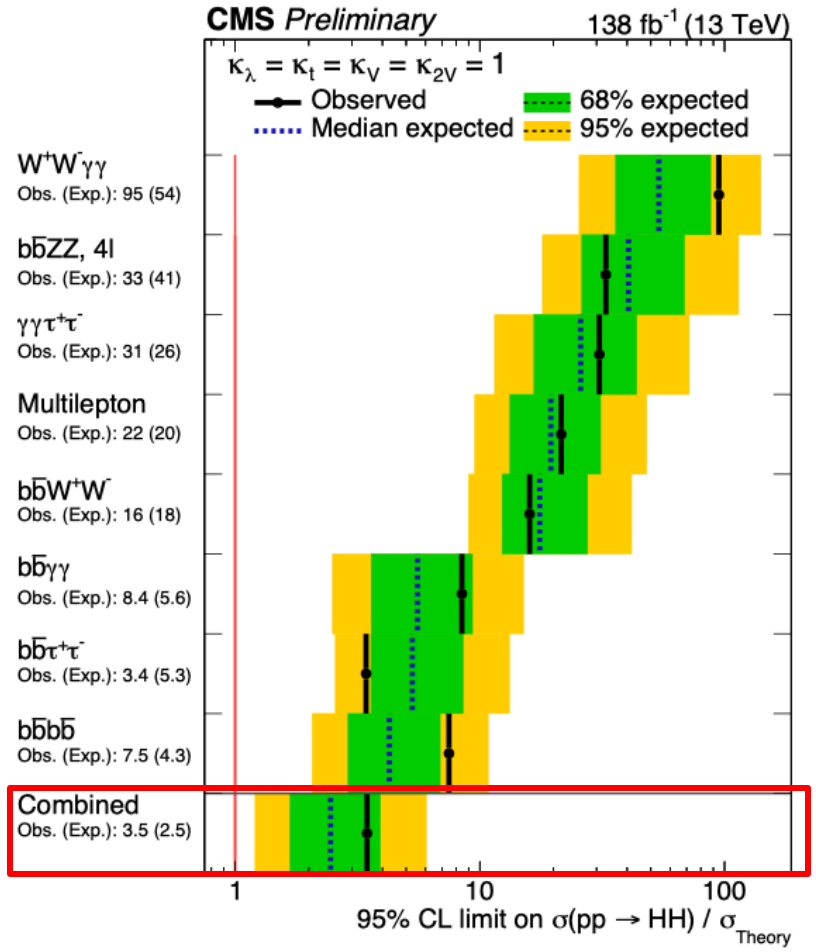


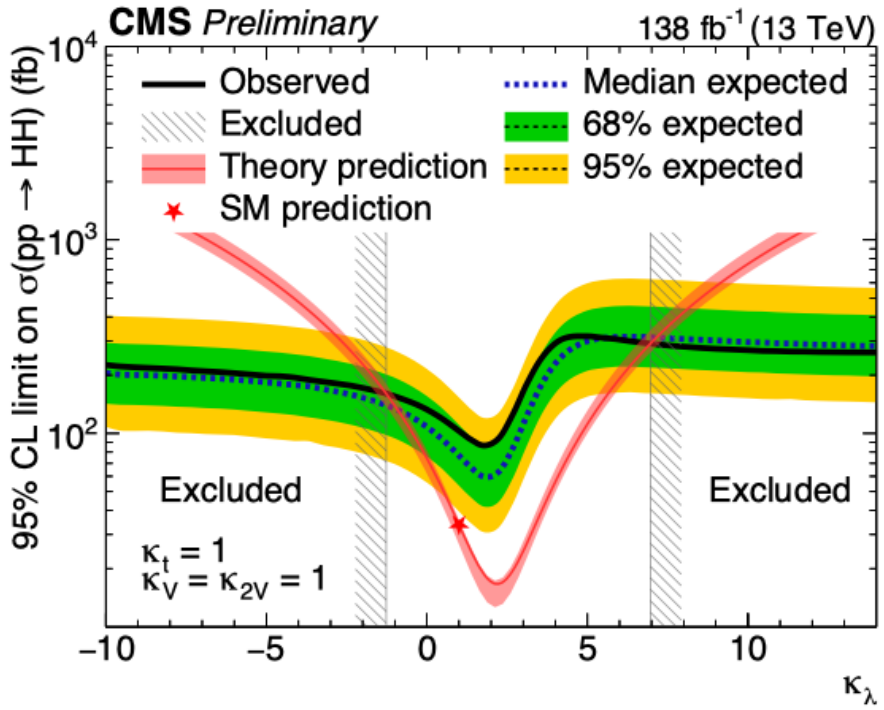
$$\alpha_S(m_Z) = 0.1176^{+0.0016}_{-0.0014}$$

Combined di-Higgs Measurements

Combined HH measurement using 8 HH decay channels with Run-2 data

CMS-PAS-HIG-20-011





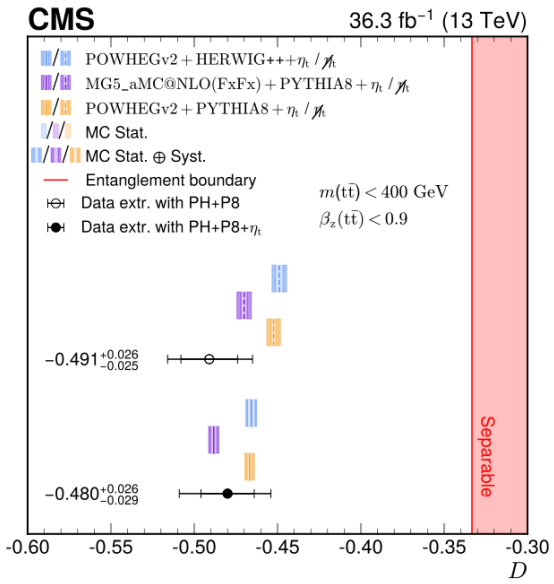
- Observed (expected) upper limit on HH production: **3.5 (2.5)** × **SM** $\boldsymbol{\sigma}$
- Constraint on Higgs boson self-coupling: $\boldsymbol{-1.3 < \kappa_\lambda < 7.02}$ **(95% CL)**

Spin Correlation in $t\bar{t}$ Production

Entanglement in $t\bar{t}$ pair probed via spin correlation matrix:

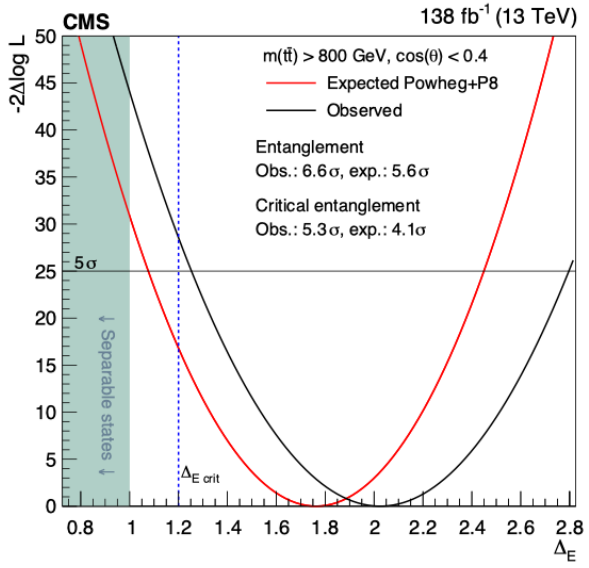
Dilepton analysis

Done at $t\bar{t}$ threshold $m_{t\bar{t}} \sim 400$ GeV



Lepton + jets analysis

Observed at high $m_{t\bar{t}}$ > 800 GeV



CMS-TOP-23-001

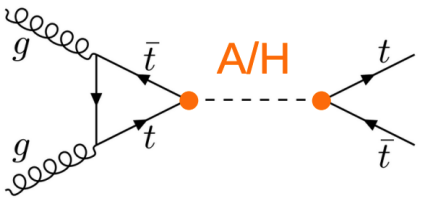
2024 *Rep. Prog. Phys.* **87** 117801

CMS-TOP-23-007

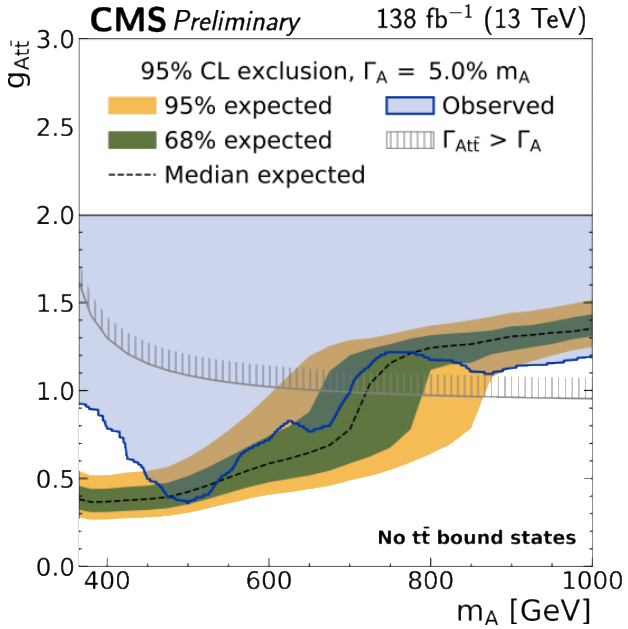
Entanglement observed with high significance

CERN press release

Search for heavy pseudoscalar/scalar bosons decaying to $t\bar{t}$:



- Make use of $m_{t\bar{t}}$ and spin correlation variables
- Spin correlation observables used to distinguish between scalar and pseudoscalar hypotheses

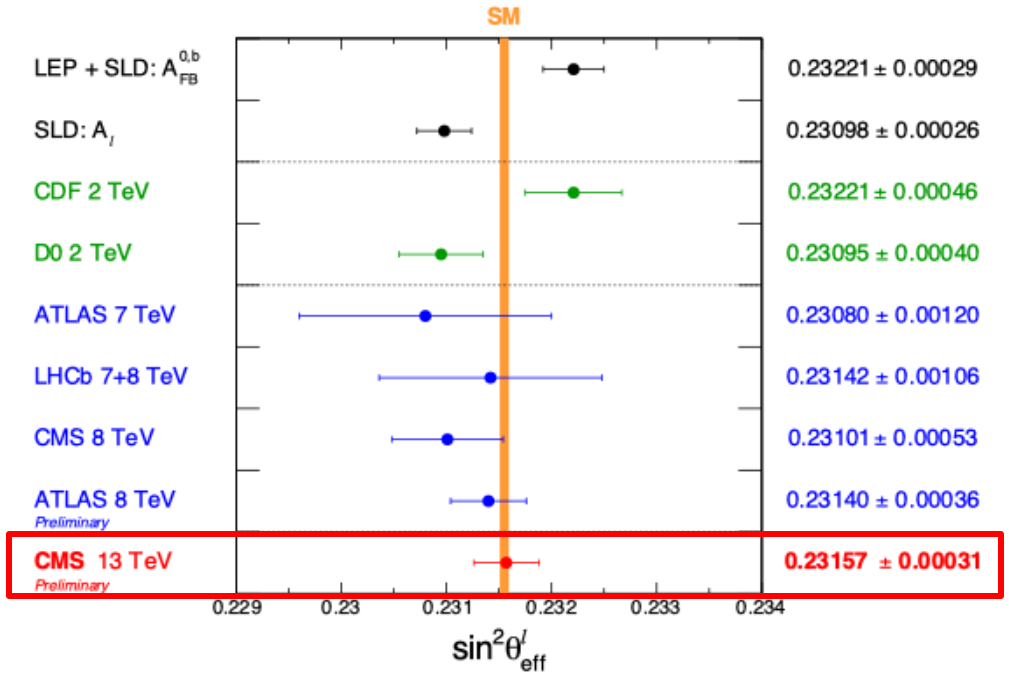


- **Excess observed in $t\bar{t}$ threshold region**
- Pseudoscalar hypothesis favored
- Compatible with production of a ${}^1S_0^{[1]}$ $t\bar{t}$ bound state η_t
  - $\sigma_{\eta_t} = 7.1 \pm 0.8$ pb
  - $> 5\sigma$ significance

CMS-PAS-HIG-22-013

Measurement of $\sin^2\theta^l_{\text{eff}}$

- Measurement of the Drell-Yan forward-backward asymmetry and the effective leptonic electroweak mixing angle (θ^l_{eff})
- Performed measurement vs dilepton mass and rapidity



In the SM:
$\sin^2\theta^l_{\text{eff}} = \kappa(1 - m_W^2/m_Z^2)$
with $\kappa \approx 1.037$

$$\sin^2\theta^l_{\text{eff}} = 0.23157 \pm 0.00031$$

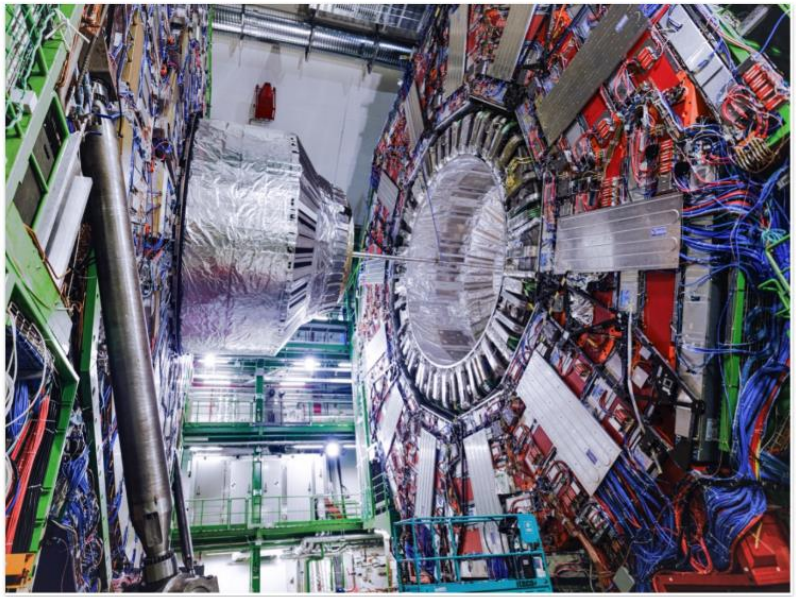
Consistent with SM prediction

CMS-PAS-SMP-22-010

The CMS experiment at CERN measures a key parameter of the Standard Model

With this measurement the LHC is again demonstrating its ability to provide very high-precision measurements and bringing new insights into an old mystery

3 APRIL, 2024



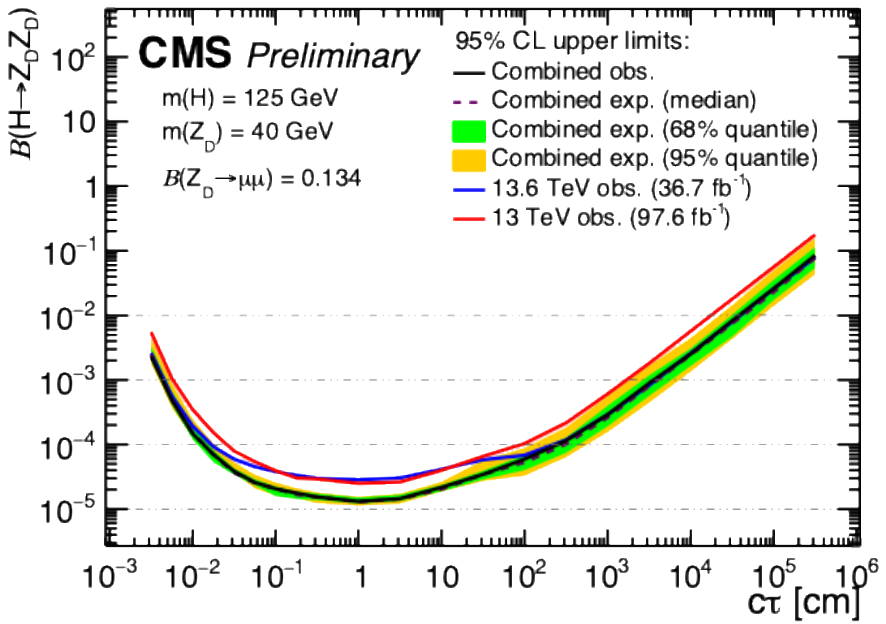
The CMS experiment (image: CERN)

CERN press release

Search for Long-Lived Particles in Run 3

Multiple searches for long-lived particles (LLP) using displaced objects in Run 3 at $\sqrt{s} = 13.6$ TeV

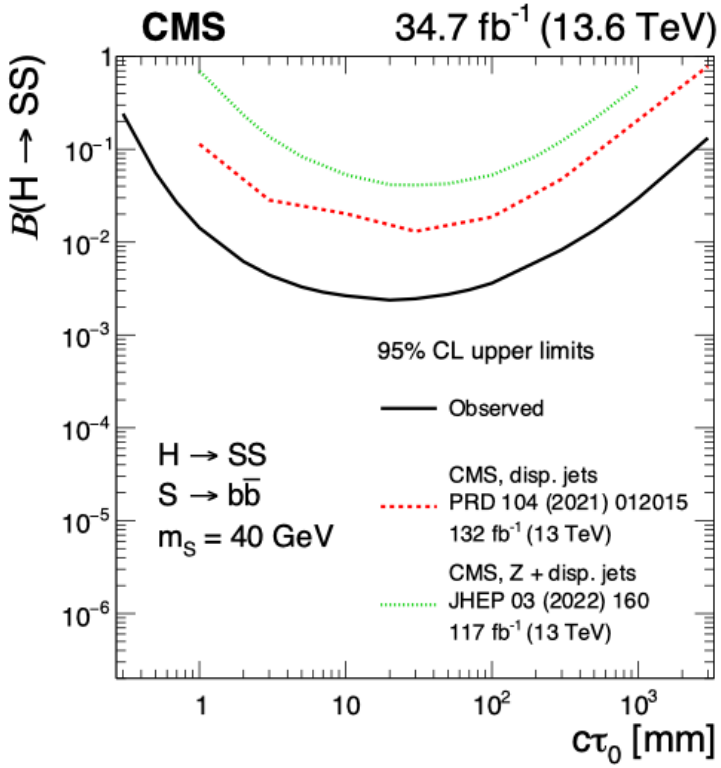
LLPs decaying to displaced muons



CMS-PAS-EXO-23-014
J. High Energ. Phys. **2024**, 47 (2024)

- Benefit from new triggers for displaced objects in Run 3
- Better sensitivity than Run-2 with only 2022 data

LLPs decaying to displaced jets



CMS-PAS-EXO-23-013

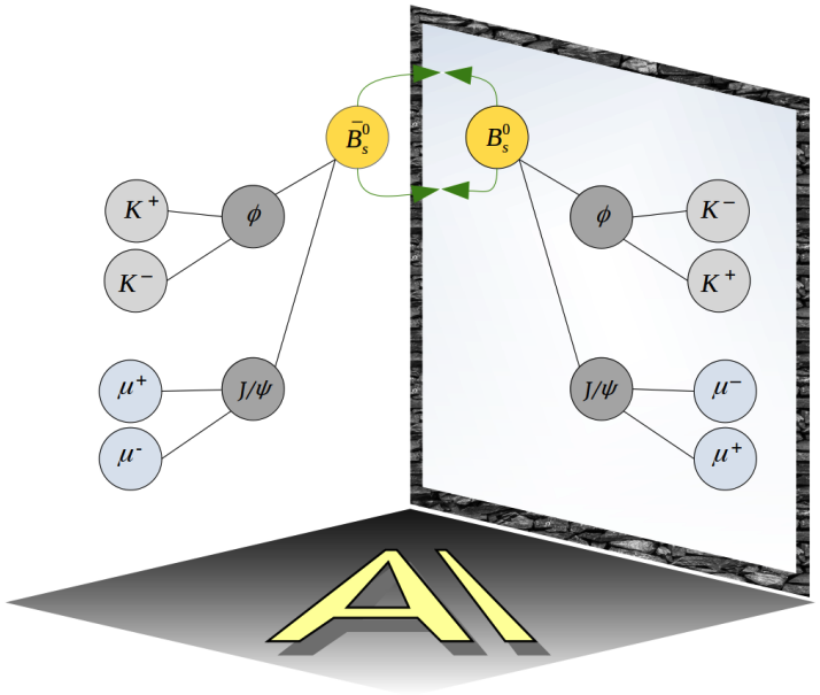
Measurement of CP Violation in B_S^0 decays

Measurement of time-dependent CP violation in $B_S^0 \to J/\psi\,\phi(1020)$ decays

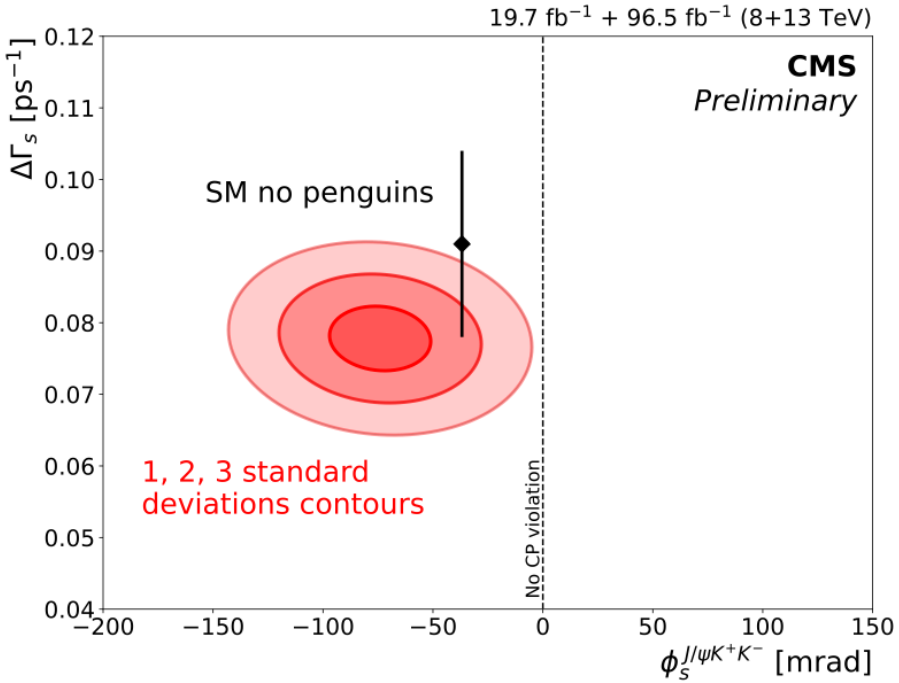
CMS-PAS-BPH-23-004

Flavor physics in CMS:

- Take advantage of excellent tracking and lots of statistics
- Challenges due to high pileup and hadron particle identification



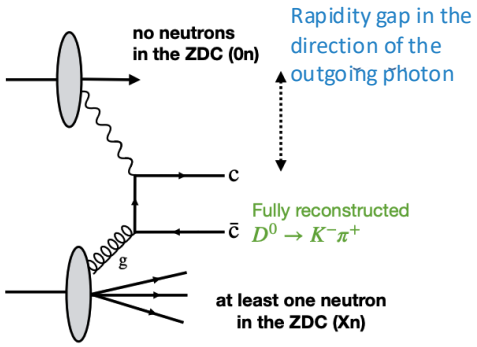
- Measurement driven by machine learning techniques
- Extracts 5 parameters of interests, among which the CP-violating weak phase, $\Delta\Gamma_S$, Δm_S



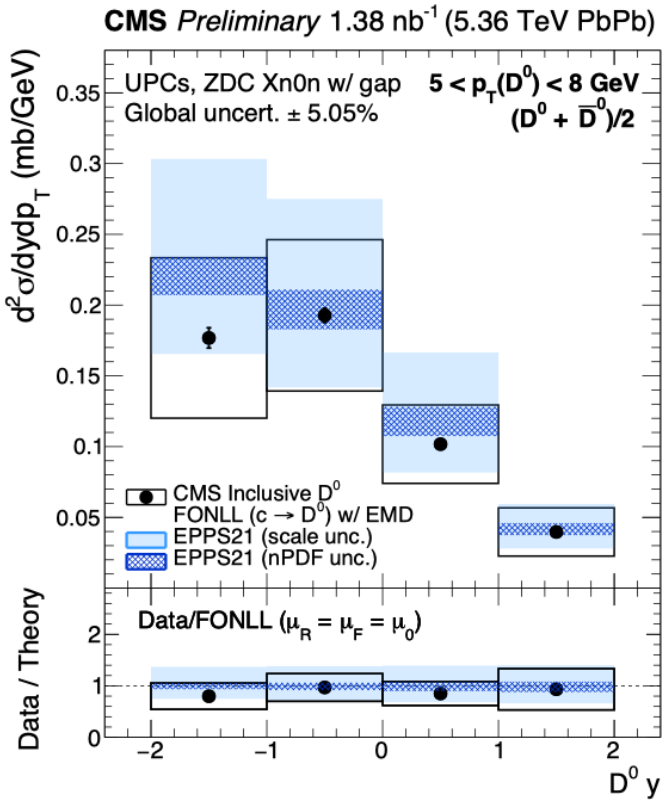
First evidence of CP violation in this decay mode

Heavy Ion Physics

D^0 photoproduction in UPC



- First measurement of this process
- Run-3 data collected in 2023

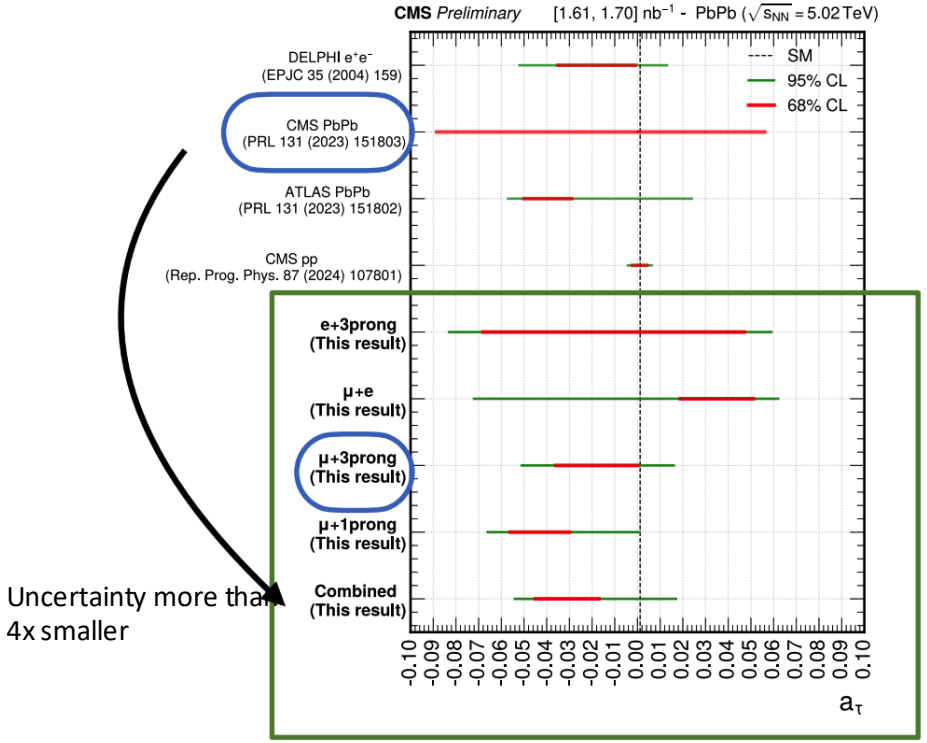


Measured cross section as a function of D^0 p_T and y

[CMS-PAS-HIN-24-003]

Measurement of τ g-2 in UPC

Using 4 $\tau\tau$ decay channels, cross section information and kinematic distributions to determine g-2



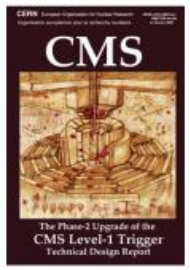
Uncertainty more than 4x smaller

[CMS-PAS-HIN-24-011]

UPC: Ultraperipheral Collisions

Status of Phase-2 Upgrades

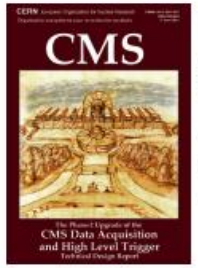
CMS Phase-2 Upgrade Overview



L1-Trigger

https://cds.cern.ch/record/2714892

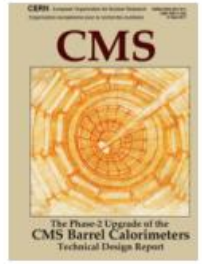
- Tracks in L1-Trigger at 40 MHz
- Particle Flow selection
- 750 kHz L1 output
- 40 MHz data scouting



DAQ & High-Level Trigger

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

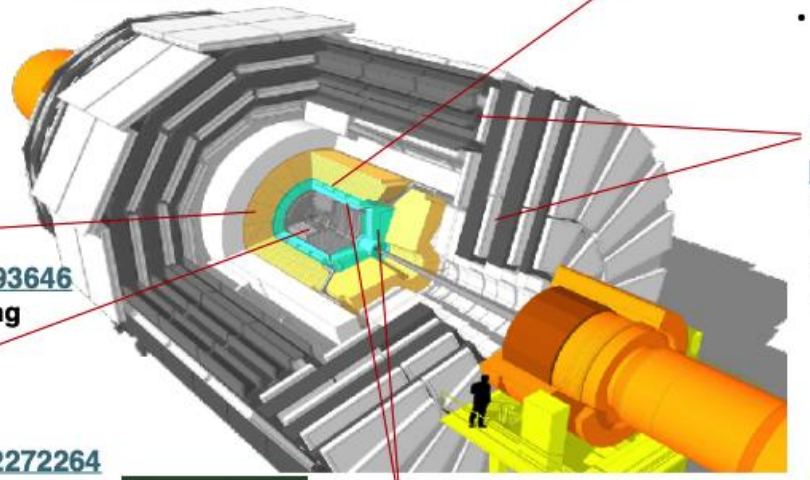
- Full optical readout
- Heterogenous architecture
- 60 TB/s event network
- 7.5 kHz HLT output

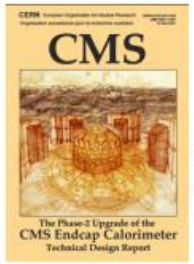


Barrel Calorimeters

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

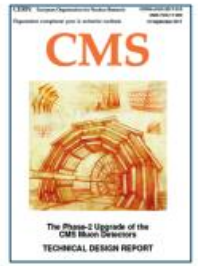




Calorimeter Endcap

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

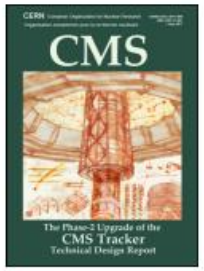
- 3D showers and precise timing
- Si, Scint+SiPM in Pb/W-SS



Muon systems

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

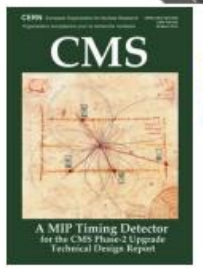
- DT & CSC new FE/BE readout
- RPC back-end electronics
- New GEM/RPC $1.6 < \eta < 2.4$
- Extended coverage to $\eta \simeq 3$



Tracker

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

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

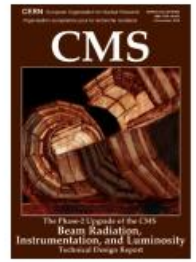


MIP Timing Detector

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

Precision timing with:

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

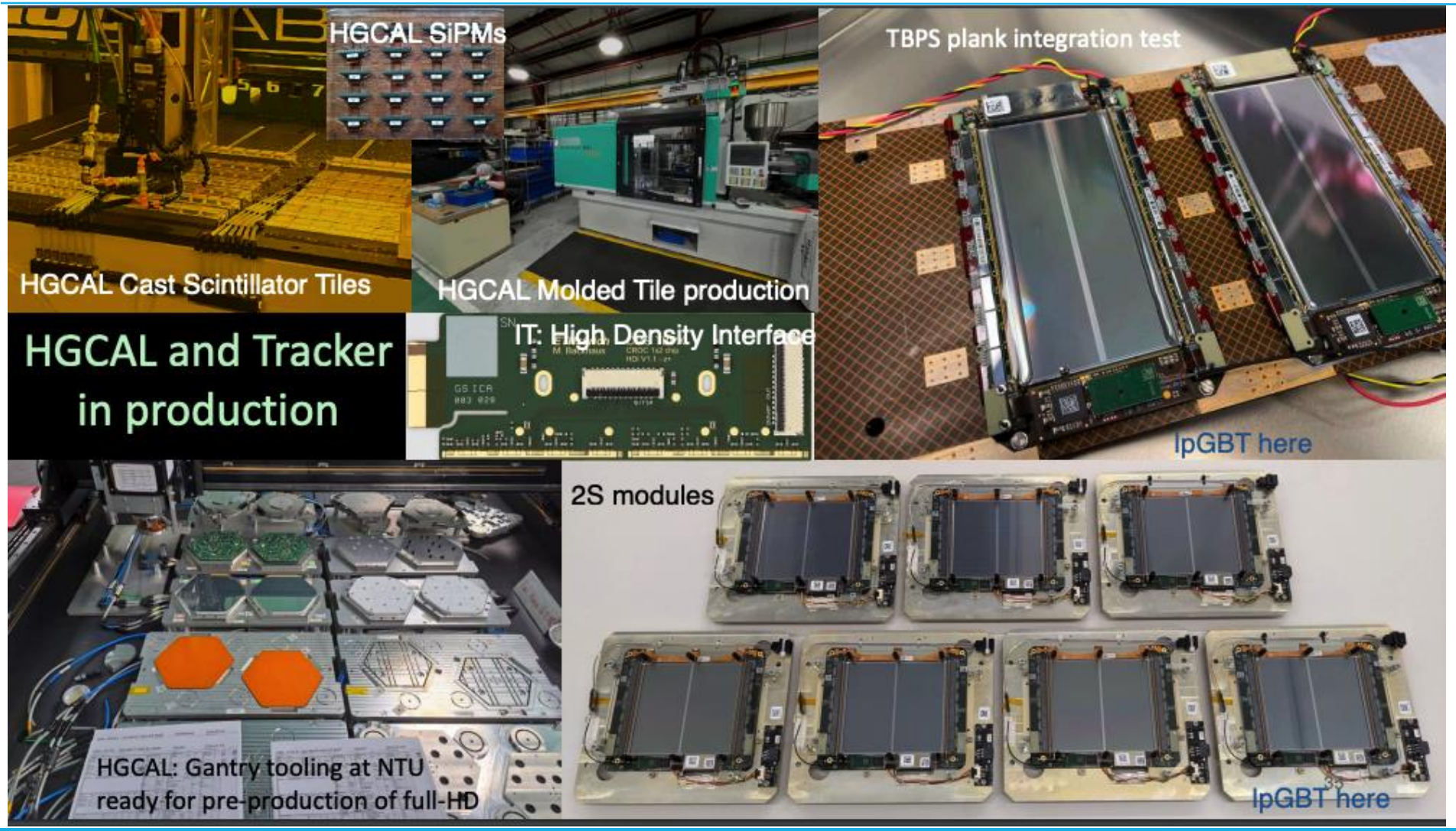


Beam Radiation Instr. and Luminosity

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

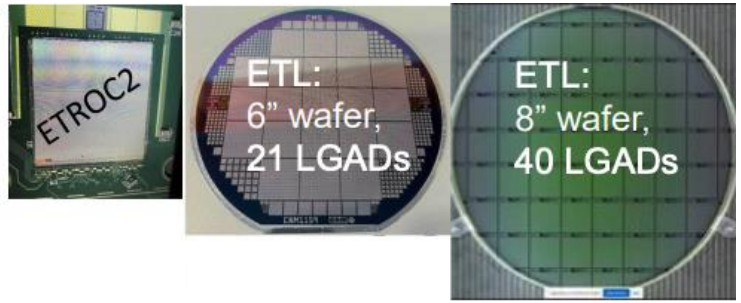
Upgrade Projects in Progress

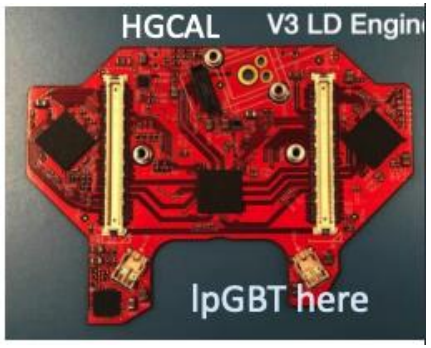


Upgrade Projects in Progress

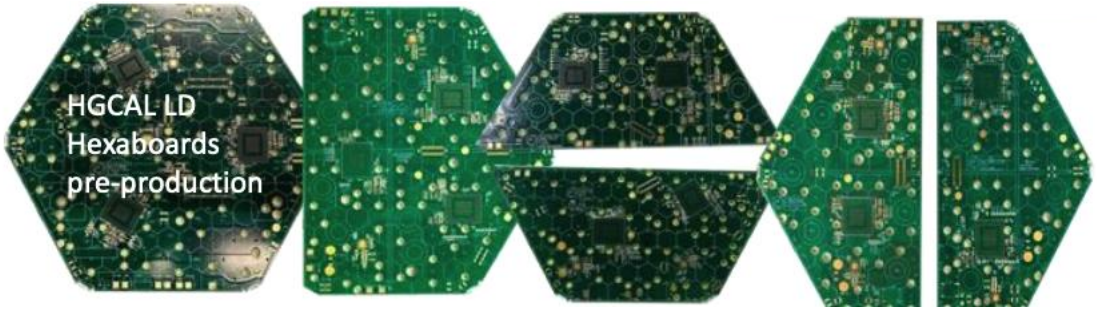
Upgrade Status Overview

- **BTL, GEM ME0, CSC, RPC, DT**: in production
- **Tracker**: All component procurements have been launched. Module production started
- **L1 Trigger**: Boards ready for production, waiting for SAMTEC Firefly12
- **Barrel Calorimeter**: all designs ready, ASICs boards, etc. Prod start 2025
- **HGCAL**: more designs finished - not all done yet. Many parts in full production. Packaged HGCROC3C received – under testing
  - Module assembly centers ready and eagerly waiting for parts
- **BRIL**: Successful test beam, learnt a lot, BCML EDR conducted, TetraBall demonstrator at P5
- **ETL**: final ASICS & sensor in hand. Progress on electronics
- Next complex steps: Module assembly and structure integration

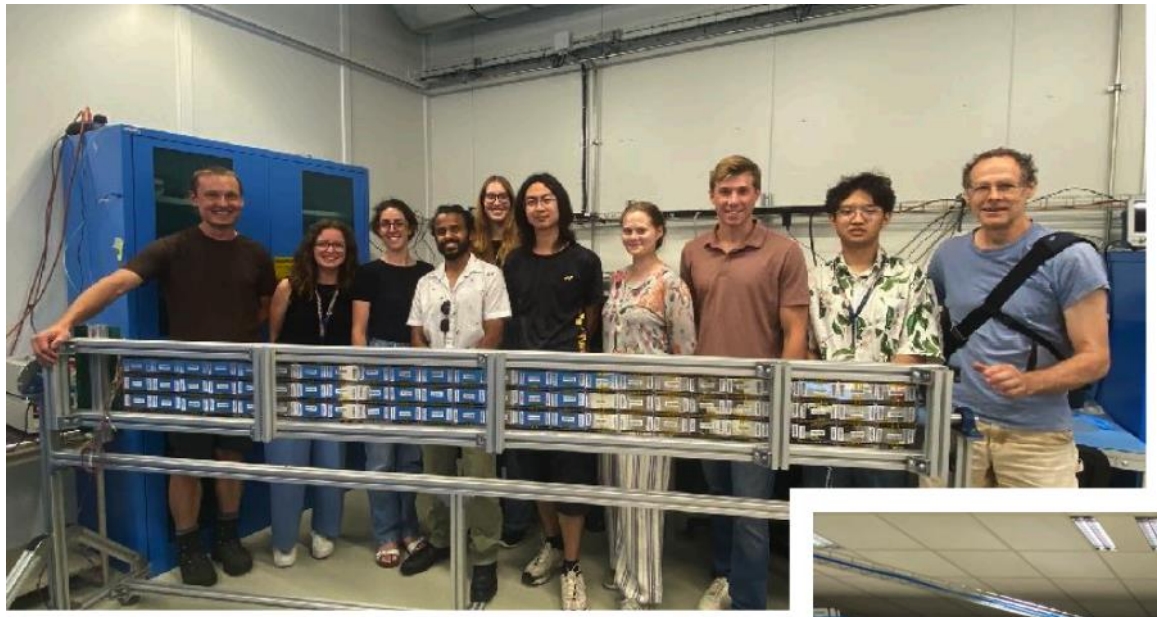




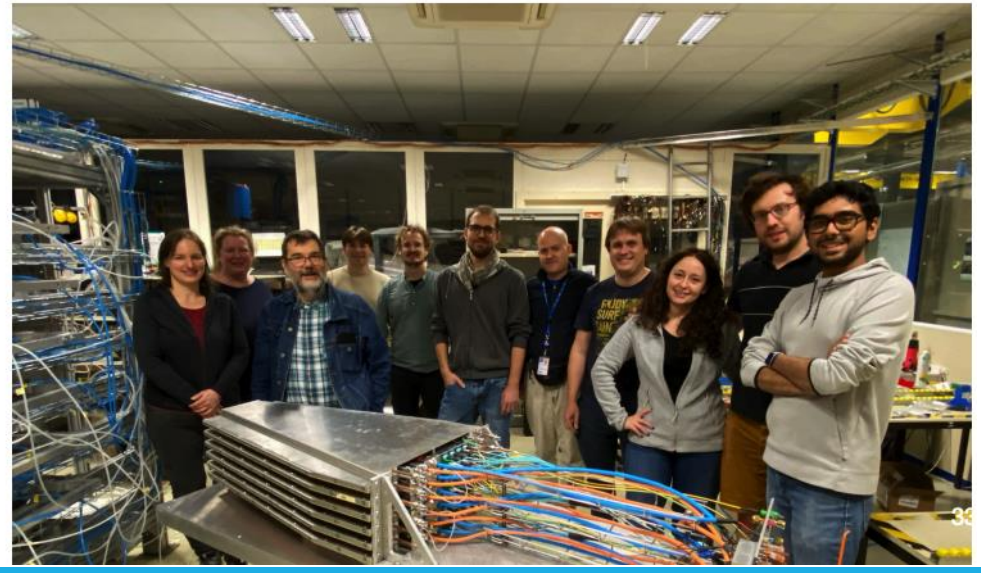
BRIL Beam Radiation Instrumentation Luminosity



Production of BTL and ME0



Steady production of all BTL and ME0 ingredients and structures



1st ME0 Production Stack

BTL: 1st Production Tray Assembled

News on Global ASIC - lpGBT

- **Two separate issues** discovered in lpGBTv1 ASIC during larger scale system testing:
  - Stuck at power-up: 1%, different population depending on environment (temp, power rise time, TID)
  - Control through optical link fails: ≥1%, can be identified with testing + screening, yield not fully clear

- **Work ongoing:**
  - Radiation campaign with v1 to guarantee no detrimental evolution (change in population, but not increase)
  - Submission of lpGBTv2 with bug-fixes: progressing well, expect substantial amount early summer 2025

- CMS continues large scale testing with v1 and assessing the risks, will try to minimize usage of v1 as much as possible

Subsystem	Total #	
Inner Tracker	4k	on electronics boards 'portcards'
Outer Tracker	14k	on hybrids, integral part to every **module**
HGCAL	26k	on electronic boards 'engines', integral part of **cassette**
BCAL	14k	on upper electronics boards 'FE', *ECAL single layer*
BTL	1k	board manufacture complete with v1, but lpGBT **redundant**, *single layer*
ETL	4k	on electronics boards 'readout board', integral part of **dee**
ME0	2k	on optoboard situated on modules, integral part of **stack**
DT	1k	OBDTs
BRIL	130	On FBCM optoboards

This will decrease our schedule float

A plan is in place for handling the issue in all affected subdetectors

Summary

- **Successful data taking by CMS in 2024 with good detector availability:**
  - Both for pp and Heavy Ion collisions
  - 92.3% data-taking efficiency in pp collisions; 113.3 fb^{-1} recorded by CMS
  - 1.67 nb^{-1} recorded for PbPb collisions
- **A year full of spectacular new physics results:**
  - > 110 approved new results and > 100 papers submitted
  - Many exciting results exploiting Run-2 data, Run-3 results also ramping up
  - Several physics reports, from SM measurements to dark matter searches, published by CMS this year
- **Excellent progress on Phase-2 Upgrade projects for HL-LHC:**
  - Many of the subprojects already in production
  - Positive feedback from P2UG and LHCC