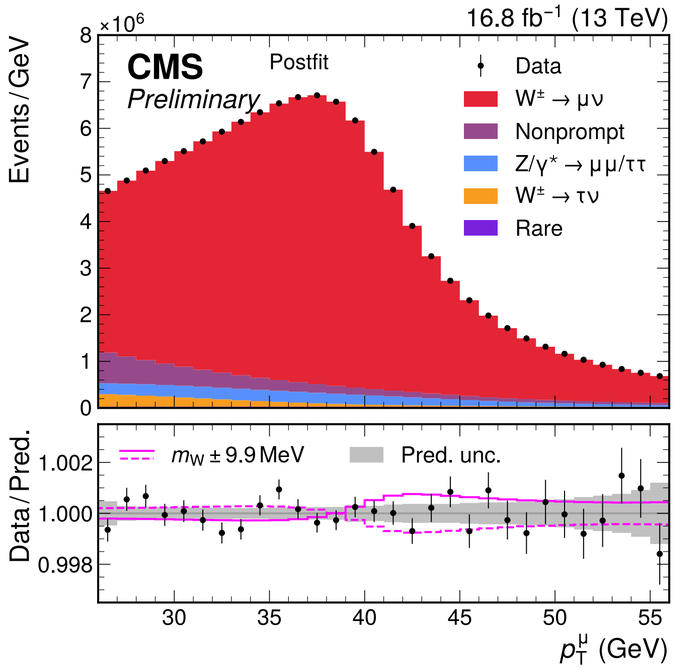
# CMS status report

## LHCC open session
## 18/11/2024

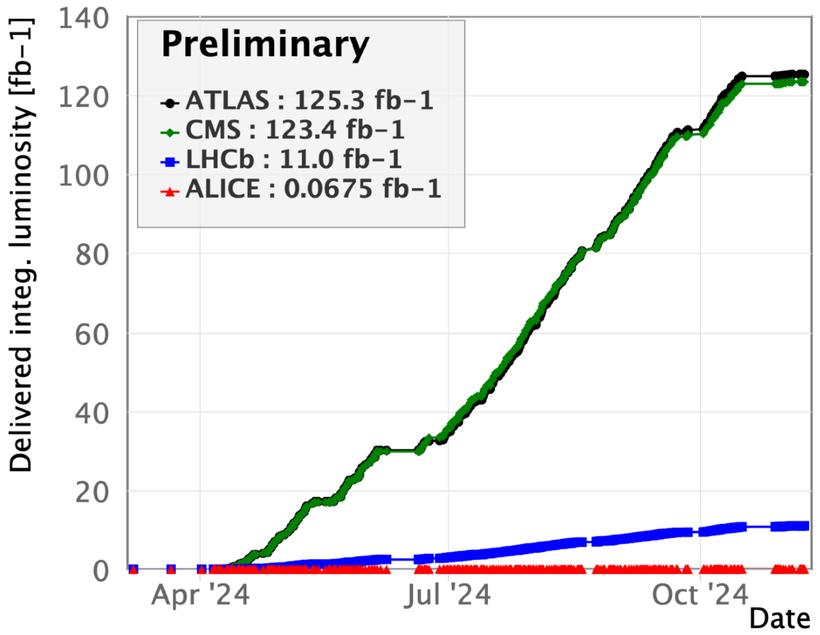
A. de Wit (CNRS/IN2P3, LLR, École Polytechnique) on behalf of the CMS Collaboration

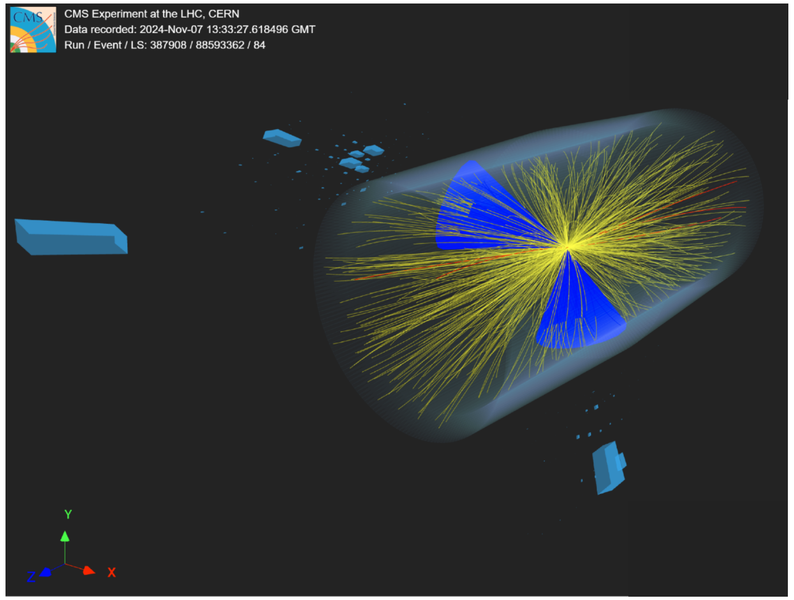
# Outline




**New physics results since last LHCC**

Delivered Luminosity 2024




**2024 pp & PbPb data taking**

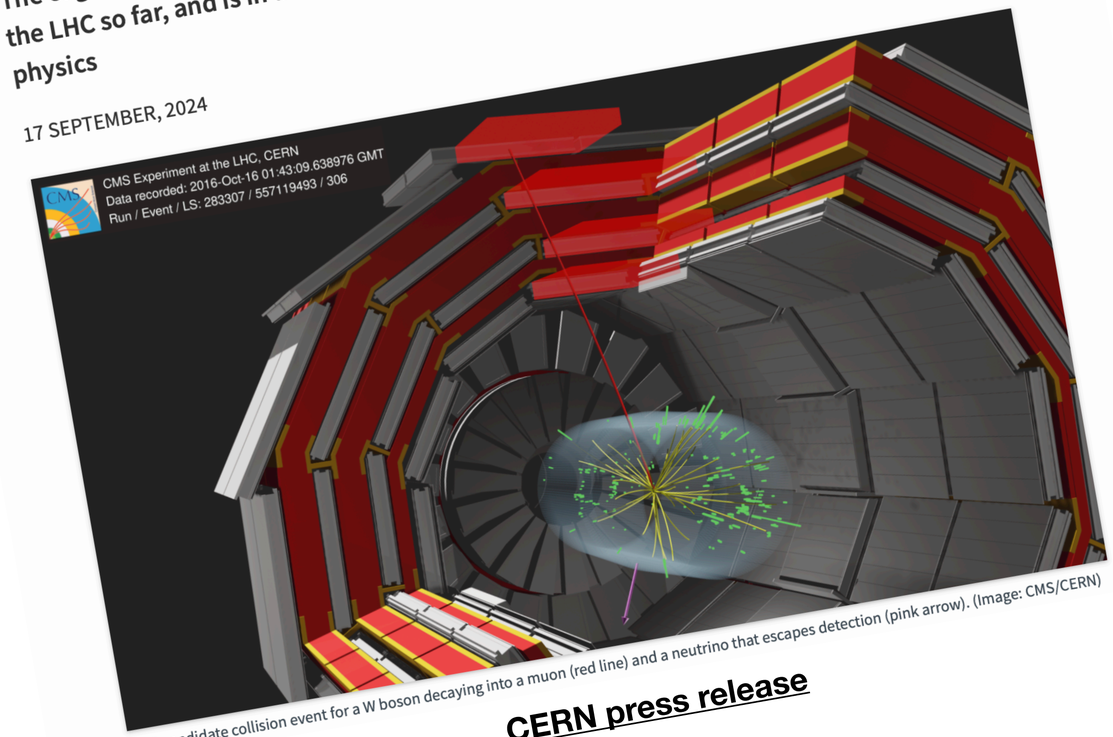
**Upgrade status**

# W mass measurement

## CMS experiment at CERN weighs in on the W boson mass

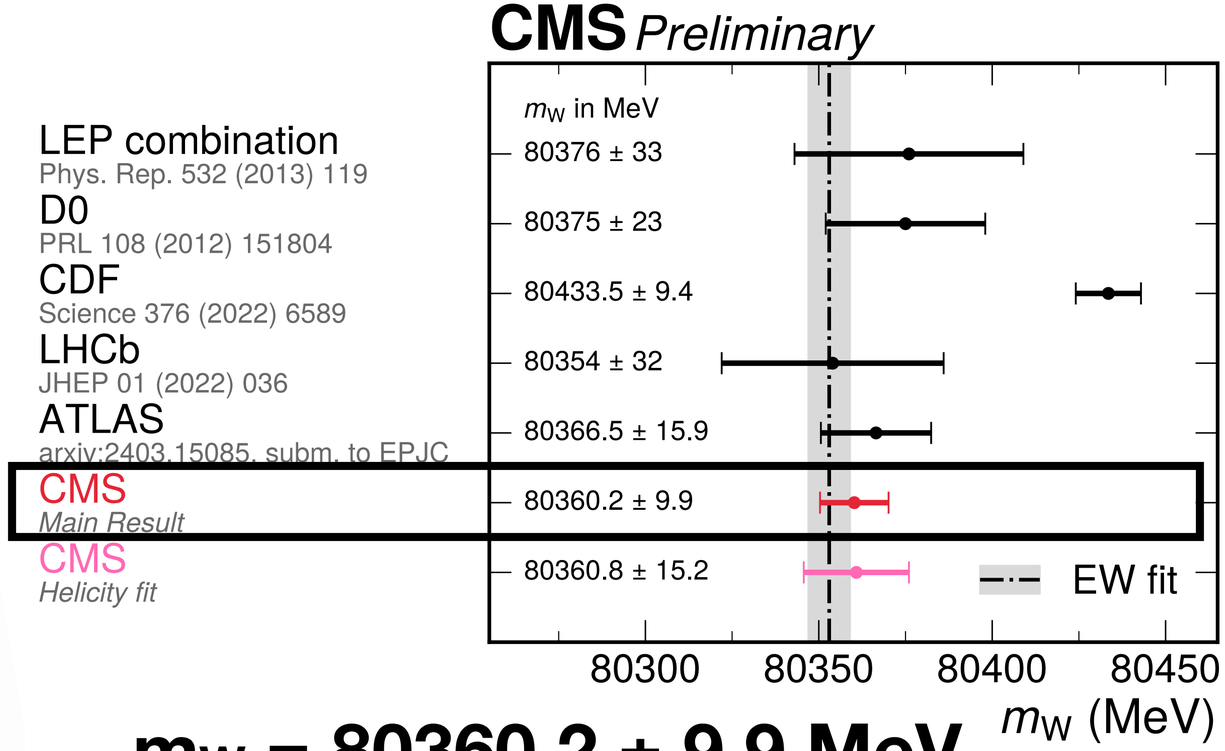
**The eagerly awaited result is the most precise measurement of the W mass made at the LHC so far, and is in line with the prediction from the Standard Model of particle physics**

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**




**mw = 80360.2 ± 9.9 MeV**

Major, long-awaited, news since the last LHCC

# New results since last LHCC

| | |
|---|---|
| SMP-23-002 | Measurement of the W boson mass |
| HIG-23-015 | Measurement of differental ttH cross sections in multilepton final state |
| HIG-23-016 | Constraints on SMEFT from VH, H→bb |
| SMP-24-007 | The strong coupling constant and its running from inclusive jet production |
| SMP-24-003 | Combined EFT interpretation |
| HIG-20-011 | Combined measurements of di-Higgs production |
| HIG-22-013 | Search for A/H→tt |
| HIG-20-012 | Search for X→HY→4b |
| HIG-23-011 | Search for γH production |
| SUS-24-002 | Search for light pseudoscalars in H→aa→4τ/2τ2μ |
| MLG-24-002 | Wasserstein normalized autoencoder |
| HIN-23-006 | Evidence for medium response to hard probes with Z-hadron correlations |
| HIN-24-003 | Measurement of $D^0$ photoproduction in heavy-ion collisions |
| HIN-24-011 | Measurement of τ g-2 in ultraperipheral PbPb collisions |
| HIN-24-008 | Jet shapes based on two-particle angular correlations in PbPb collisions |
| HIN-24-010 | Search for medium-induced jet axis decorrelations with inclusive jets in PbPb collisions |
| HIN-23-010 | Search for jet quenching using transverse momentum balance in pPb collisions |
| HIN-23-009 | Bjorken-x evolution of gluon fields via J/ψ photoproduction in PbPb collisions |

Measurement
Combination (measurements)
Search
Tools
Heavy-ion physics

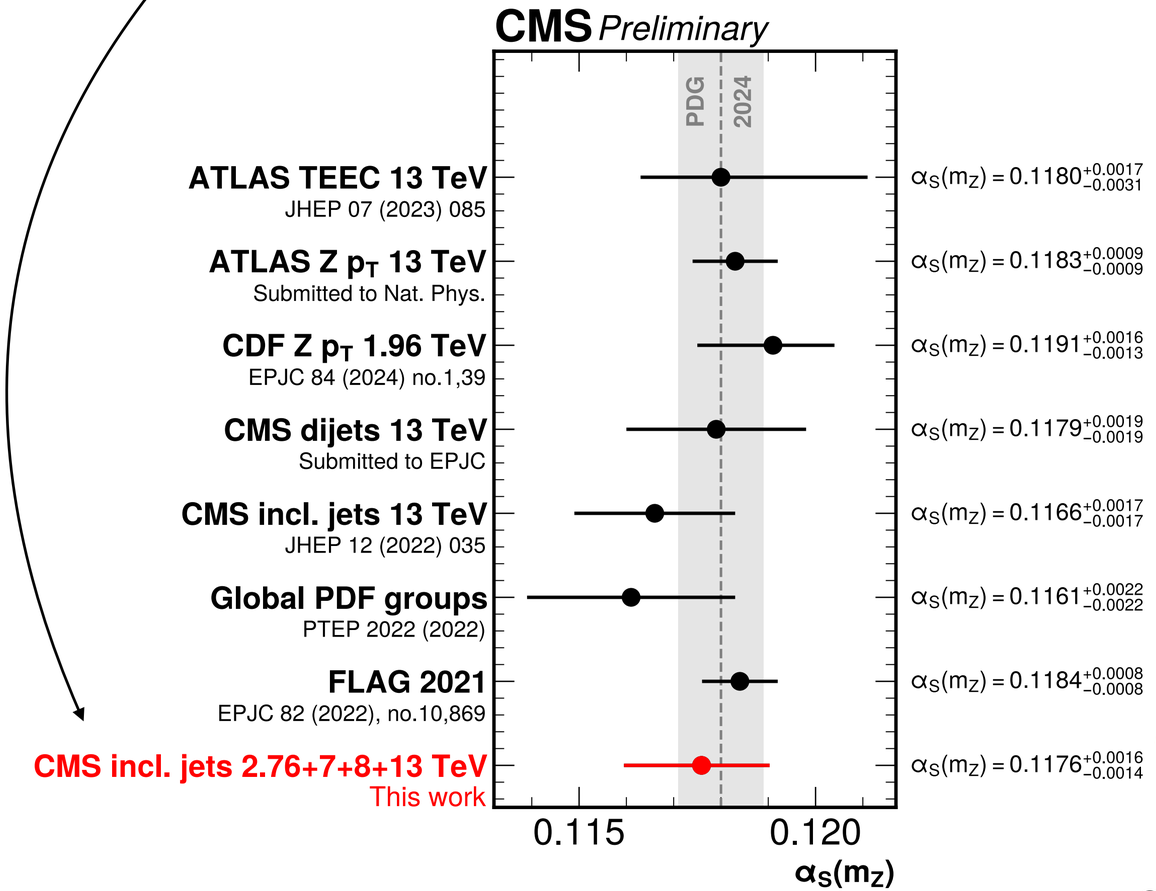
**18 new physics results** and **39 new DPS notes** since the last LHCC

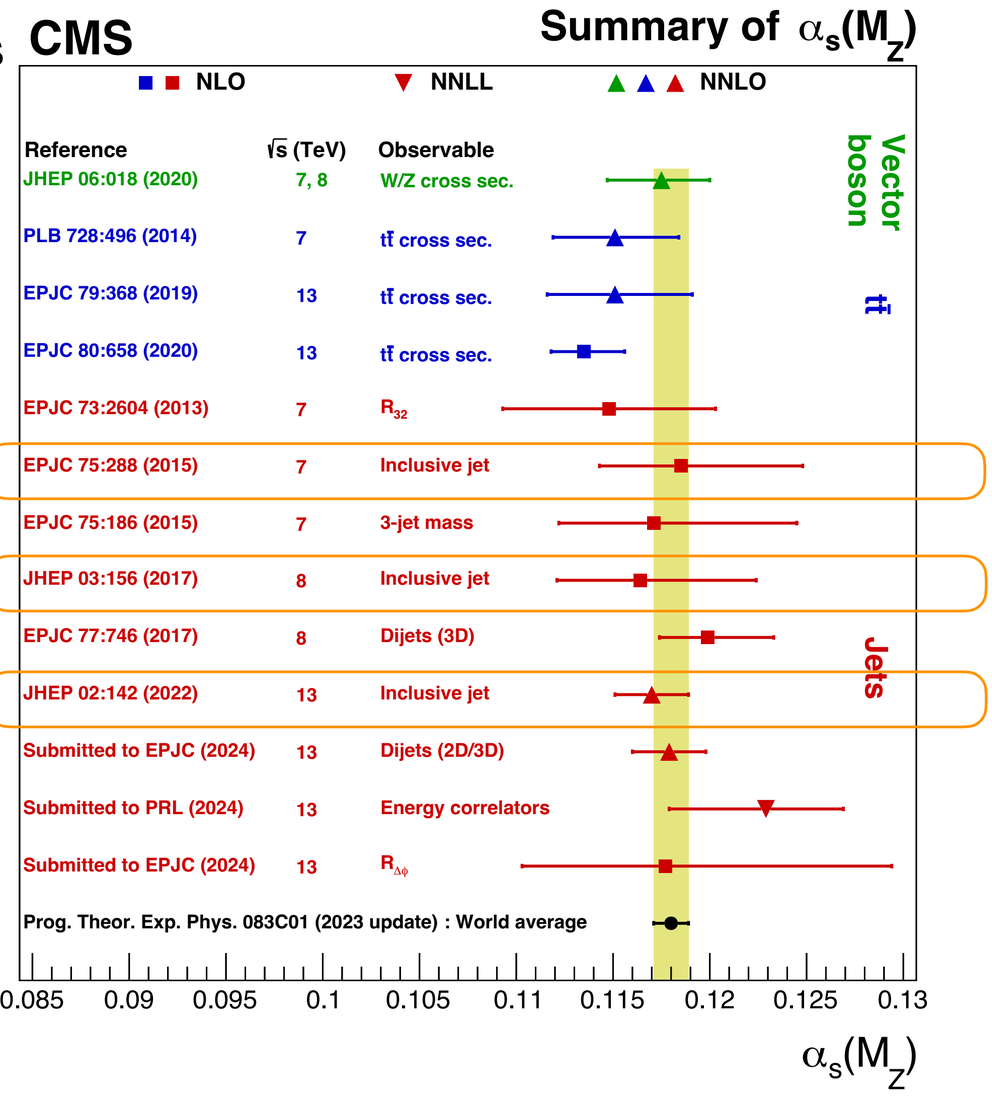
Results highlighted in **blue**: discussed today

# $\alpha_s$ and its running from inclusive jet combination

Analysis at NNLO in QCD, simultaneous extraction of $\alpha_s$ & PDFs

Most **precise** measurement of $\alpha_s$ from jet cross sections



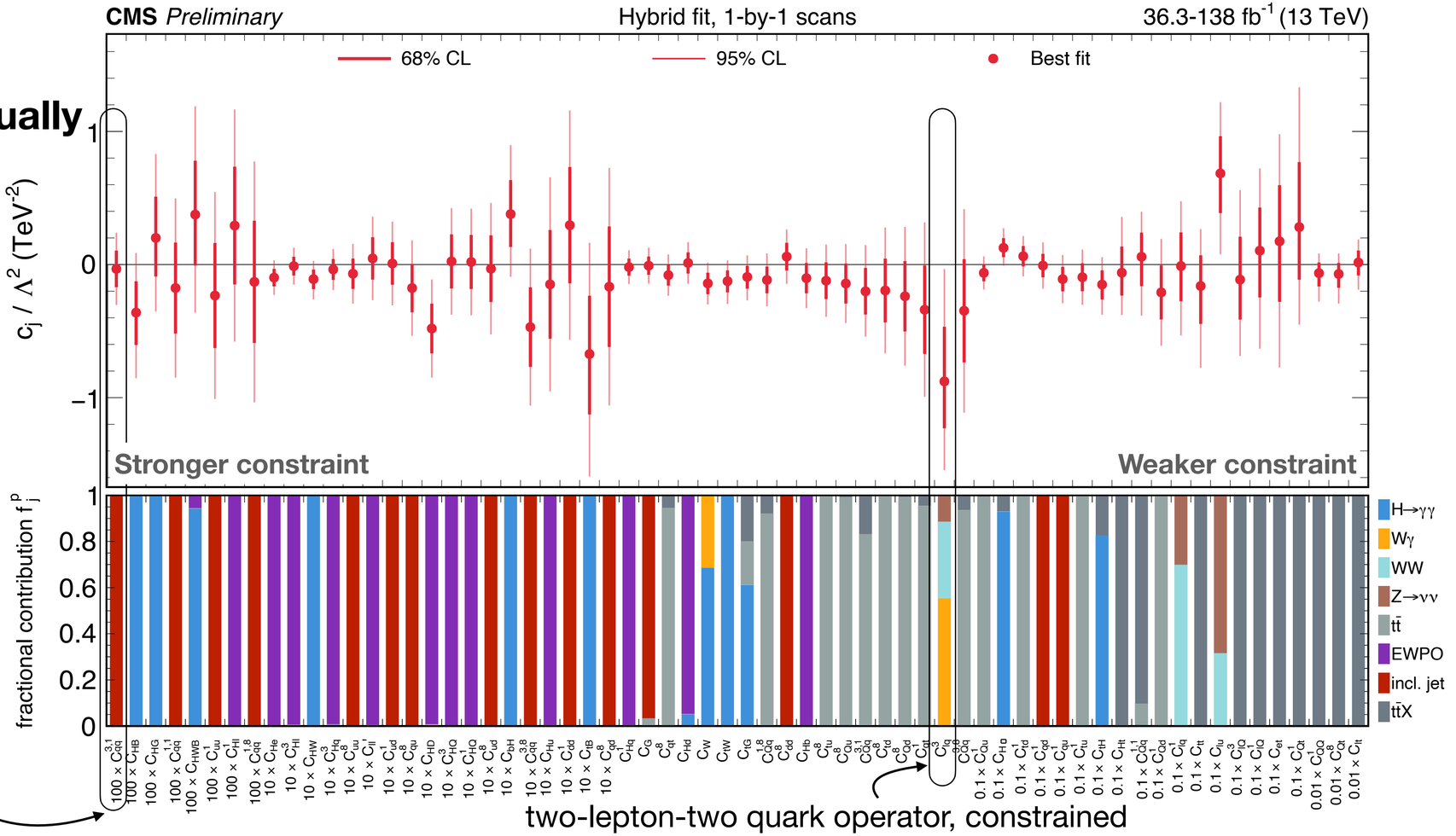




$$\alpha_s(m_Z) = 0.1176\ ^{+0.0016}_{-0.0014}$$

# Combined EFT interpretation of Higgs, EW, strong, and top measurements

**Global EFT effort, correlating different sectors**. First combination across physics analysis groups. Combined interpretation of H→γγ, tt, ttX, WW, Wγ, Z→νν and inclusive jet production measurements + EWPO from LEP+SLC.

**Constraints on 64 WCs individually (42 linear combinations of WCs constrained simultaneously) → gain from complementarity of different measurements**



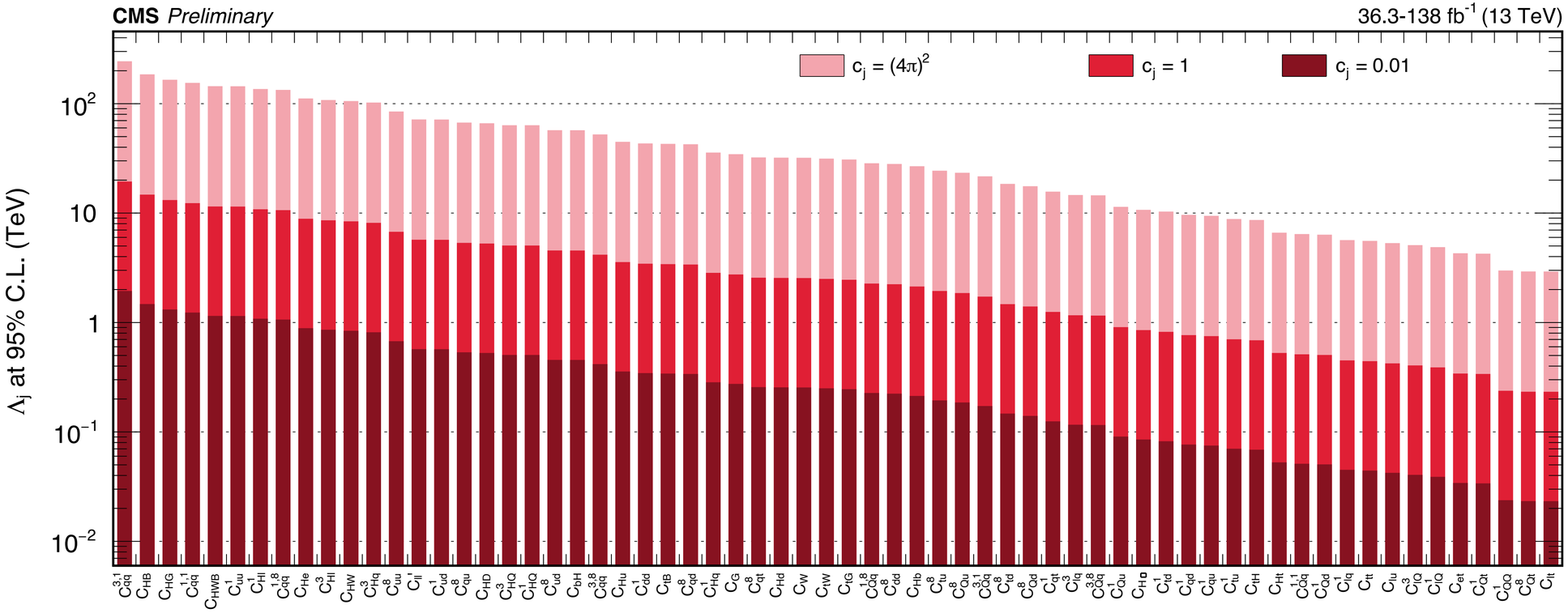

Four-quark operator, constraint multiplied by 100. Constrained by jet measurements

two-lepton-two quark operator, constrained by Wγ, Z→νν and WW

# Combined EFT interpretation of Higgs, EW, strong, and top measurements

**Global EFT effort, correlating different sectors**. First combination across physics analysis groups. Combined interpretation of H→γγ, tt, ttX, WW, Wγ, Z→νν and inclusive jet production measurements + EWPO from LEP+SLC.

$c_j/\Lambda^2$ constraints translated to 95% CL lower limits on NP energy scale, for values of $c_j$ of $(4\pi)^2$, 1 and 0.001

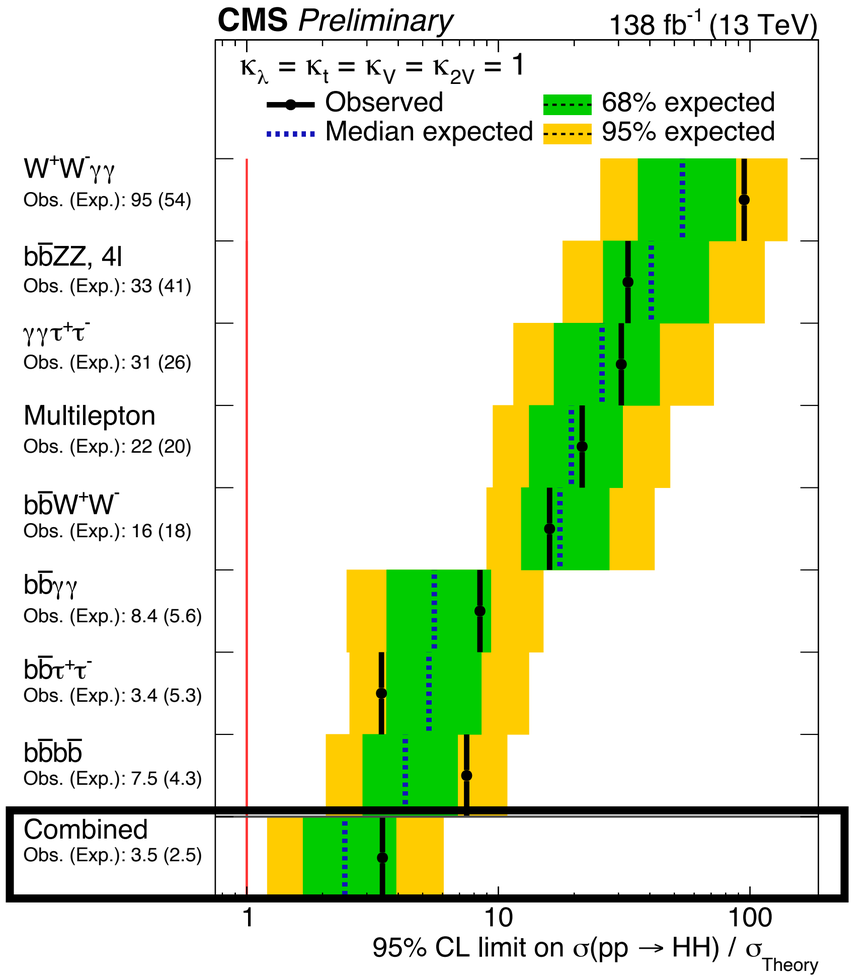


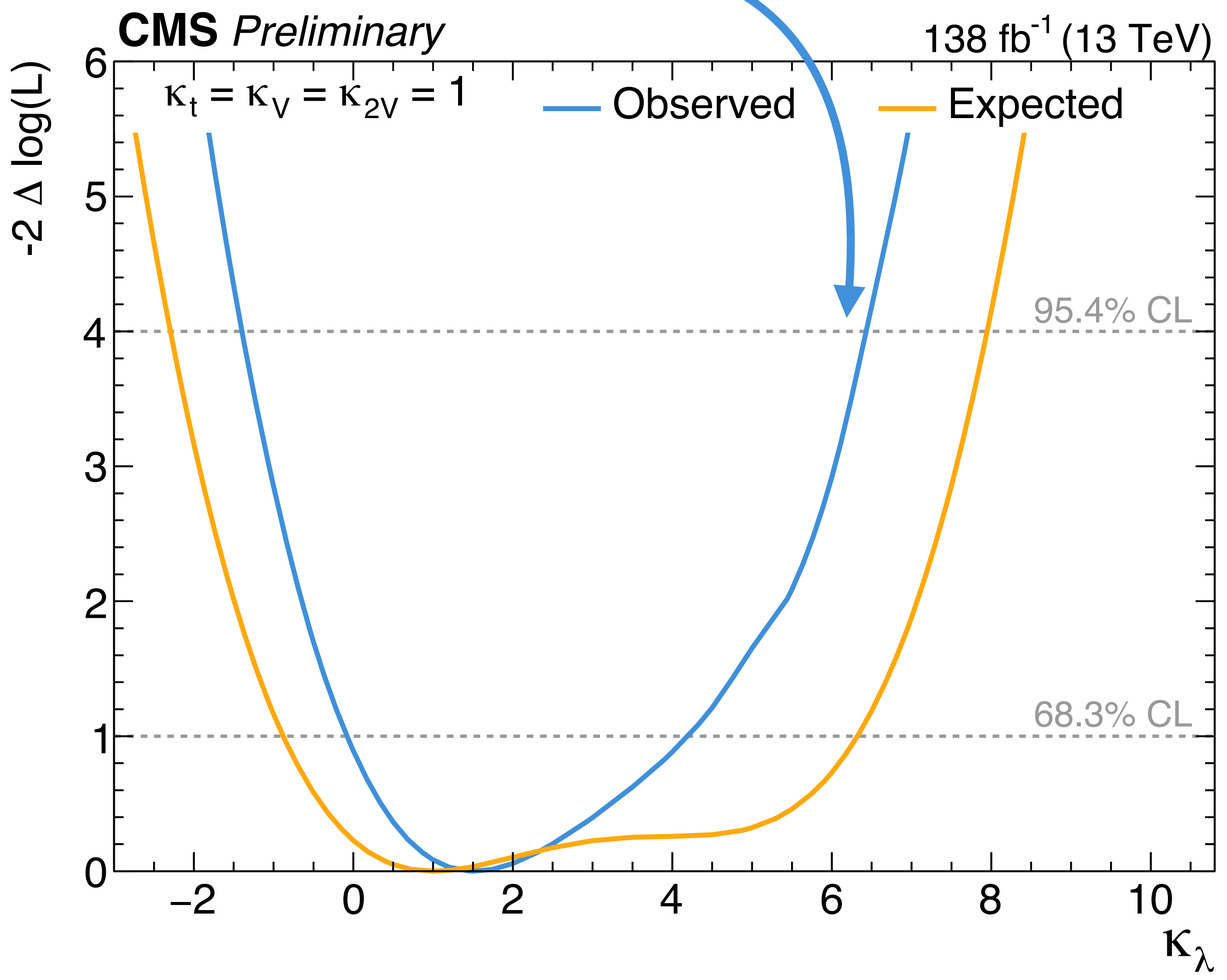

Energy scales upward of **100 TeV** probed, depending on Wilson coefficient and assumed coupling

# Combined di-Higgs measurements

**Combined di-Higgs measurement using Run 2 inputs in 8 HH decay channels**

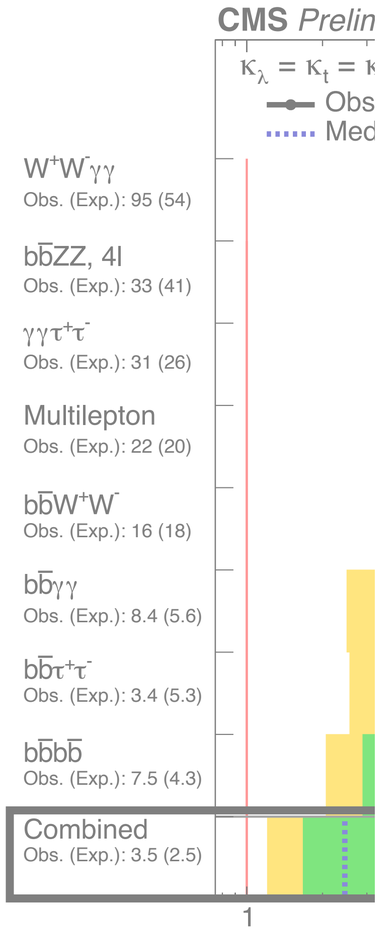
- Observed (expected) 95% CL upper limit on HH production: **3.5 x SM σ (2.5x SM σ)**
- Constraint on Higgs self-coupling: $-1.4 < \kappa_\lambda < 6.4$ (95% CL)

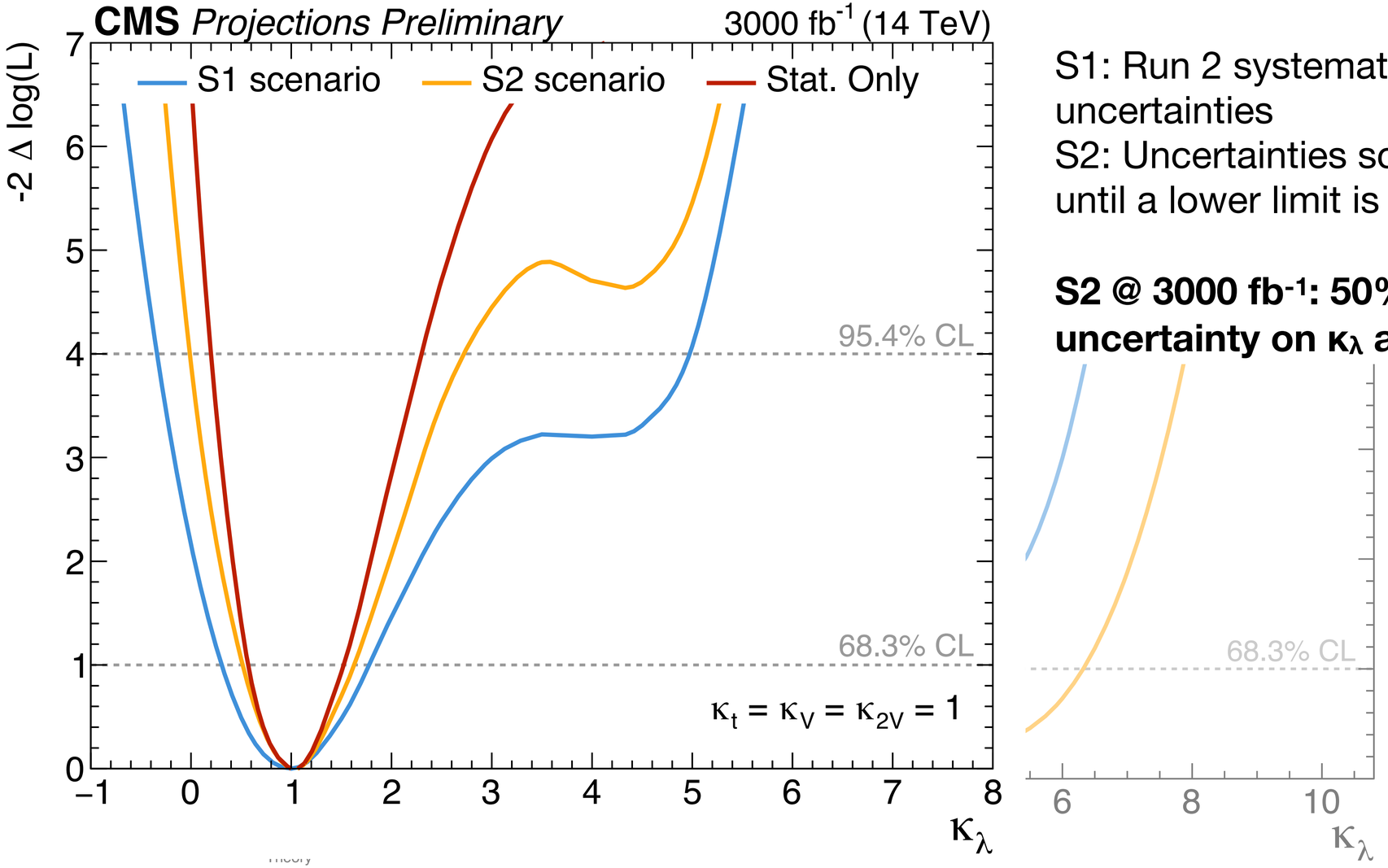


# Combined di-Higgs measurements

**Includes projections for high-luminosity LHC**

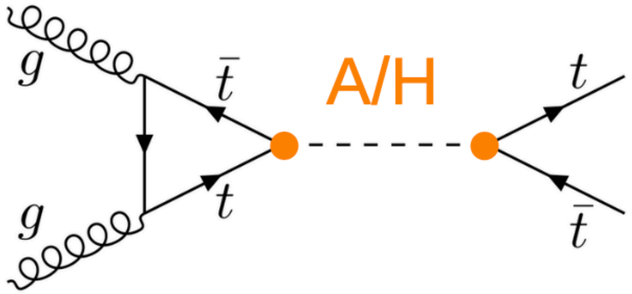



S1: Run 2 systematic uncertainties
S2: Uncertainties scaled down until a lower limit is reached

**S2 @ 3000 fb$^{-1}$: 50% uncertainty on $\kappa_\lambda$ at 68% CL**

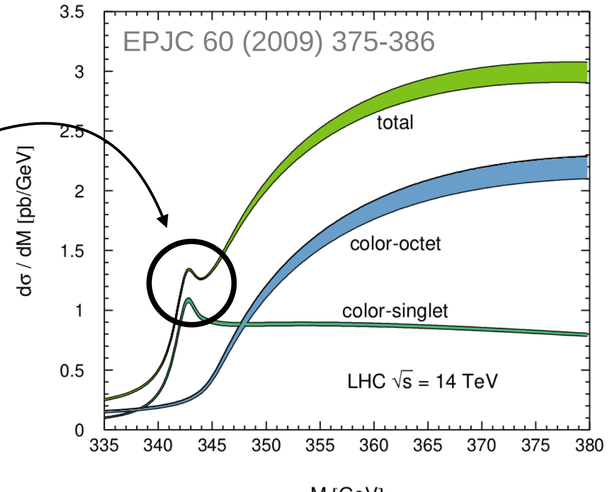
# Search for A/H→tt̄

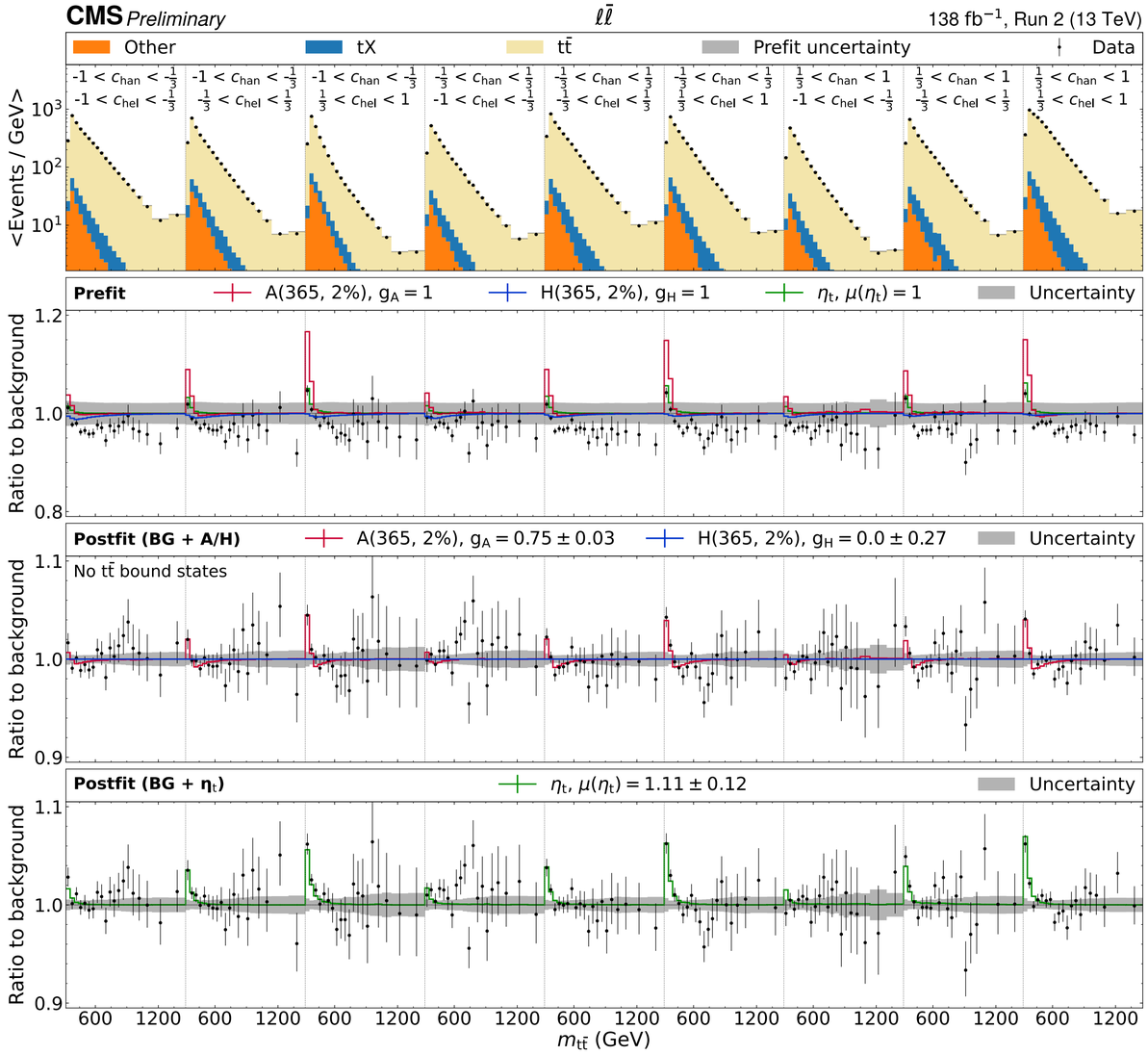



**Spin correlation observables used to distinguish between $0^+$ and $0^-$ hypotheses**

**Test A, H, and $\eta_t$ ($t\bar{t}$ pseudoscalar bound state) hypotheses**

$t\bar{t}$ bound state at threshold




**Excess observed in $t\bar{t}$ threshold region**

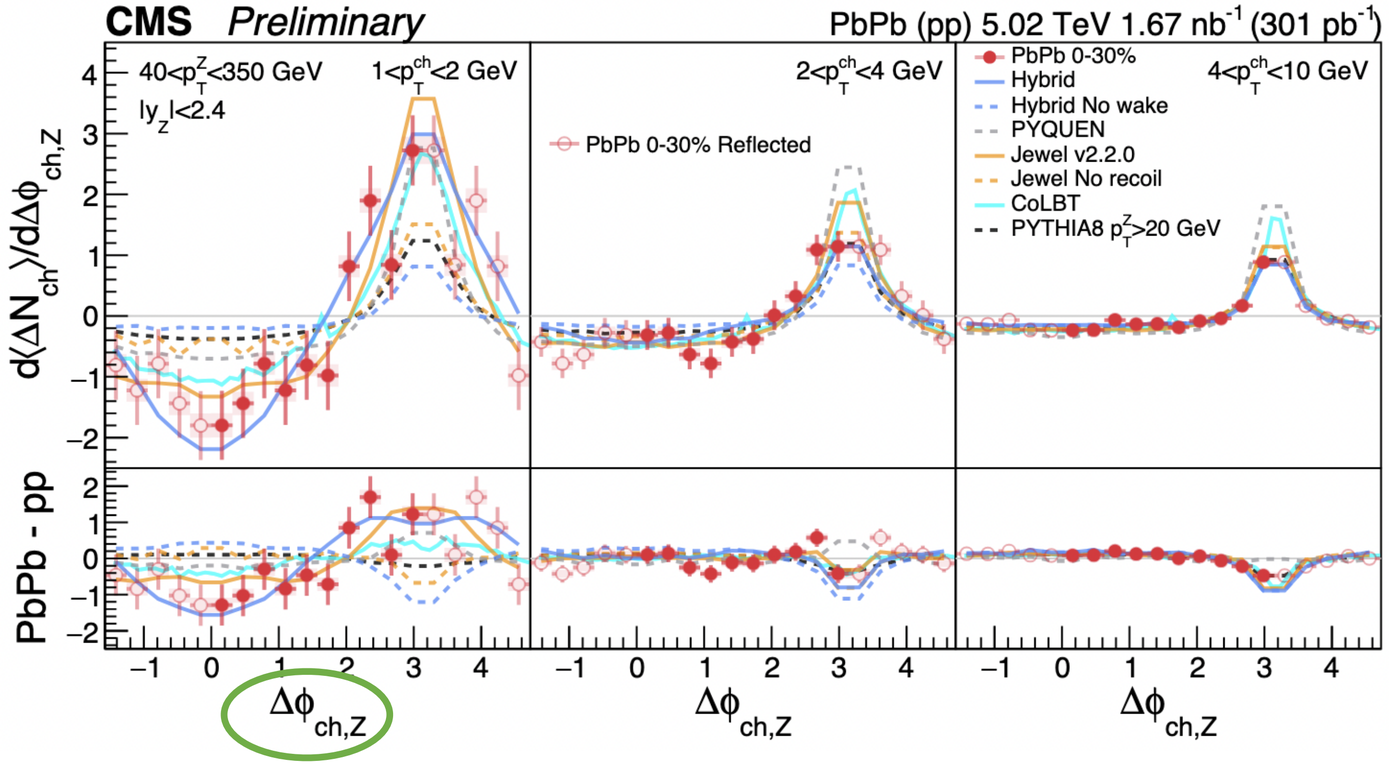
significance > 5σ

pseudoscalar hypothesis favoured, $\sigma_{\eta t}$ = 7.1 pb, 11% uncertainty

# Unveiling the medium response with Z-hadron correlations

**First measurement of the Z-hadron two-particle correlation function in bins of hadron $p_T$**

Focus: charged hadrons associated with the Z boson, study possible medium-induced modifications

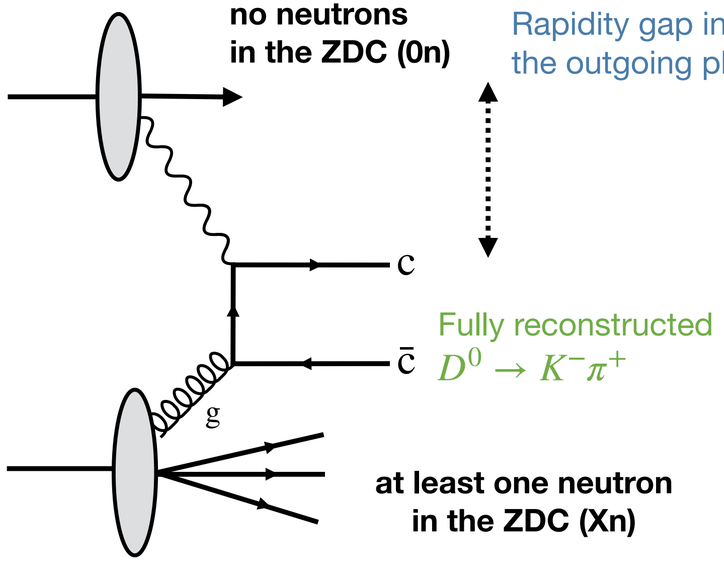


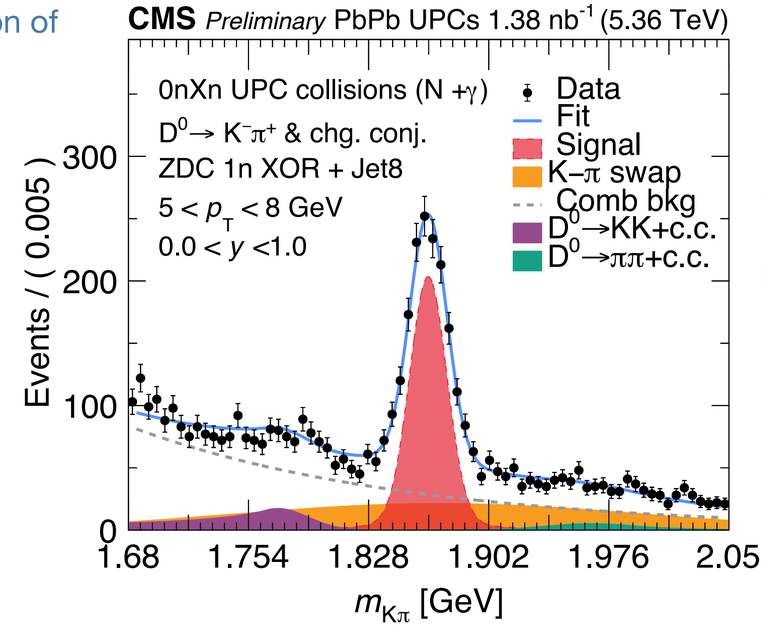

Charged hadron spectra vs $\Delta\phi_{ch,Z}$

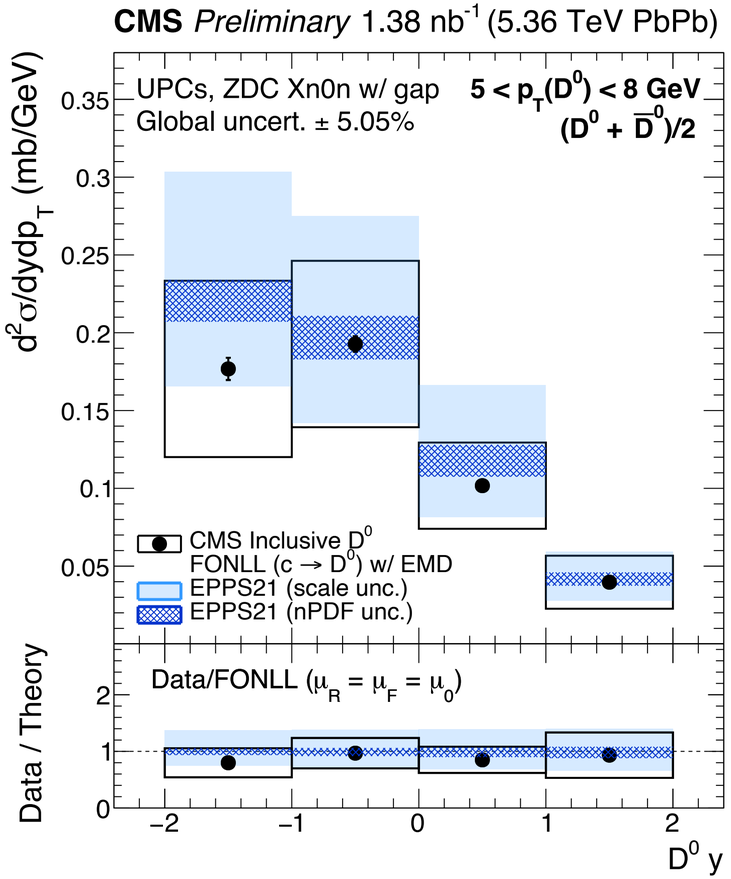
New information about the correlation between hard and soft particles in heavy-ion collisions

**First evidence of a negative QGP wake produced by a fast-moving parton**

# $D^0$ photoproduction in UPC, measured in 0nXn events with a rapidity gap



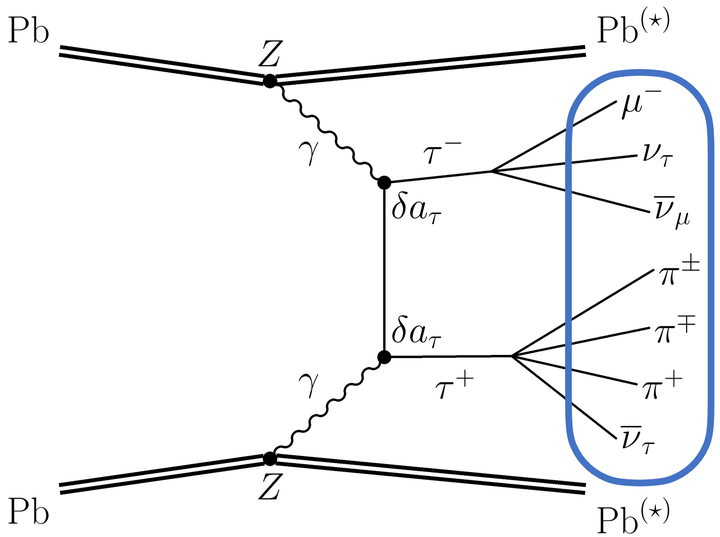

Measured cross section as a function of $D^0$ $p_T$ and y

**First measurement of this process**

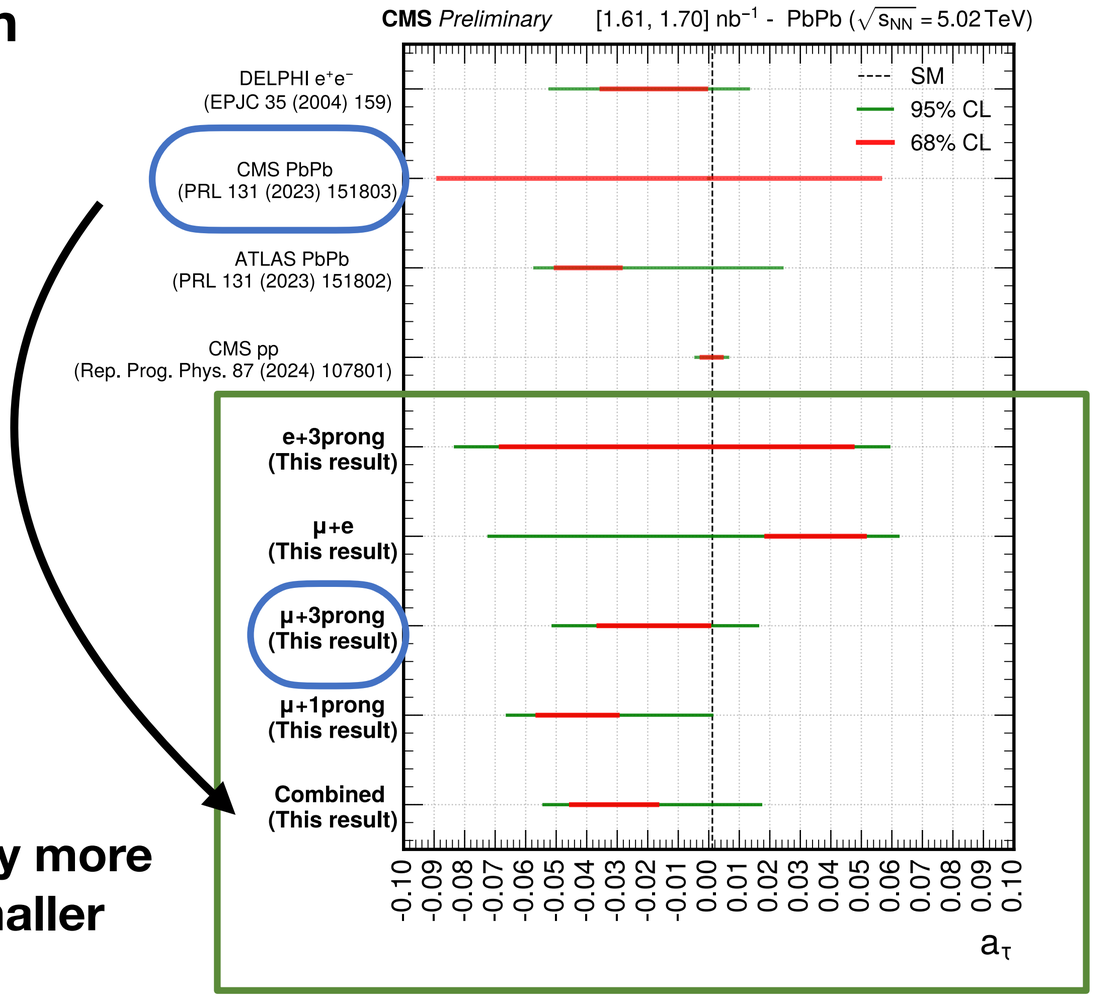
**Run 3 data collected in 2023**

# Measurement of τ g-2 in UPC

**Using 4 ττ decay channels, cross section information and kinematic distributions to determine g-2**




**μ+3-prong τ decay channel** (used in first observation of this process)



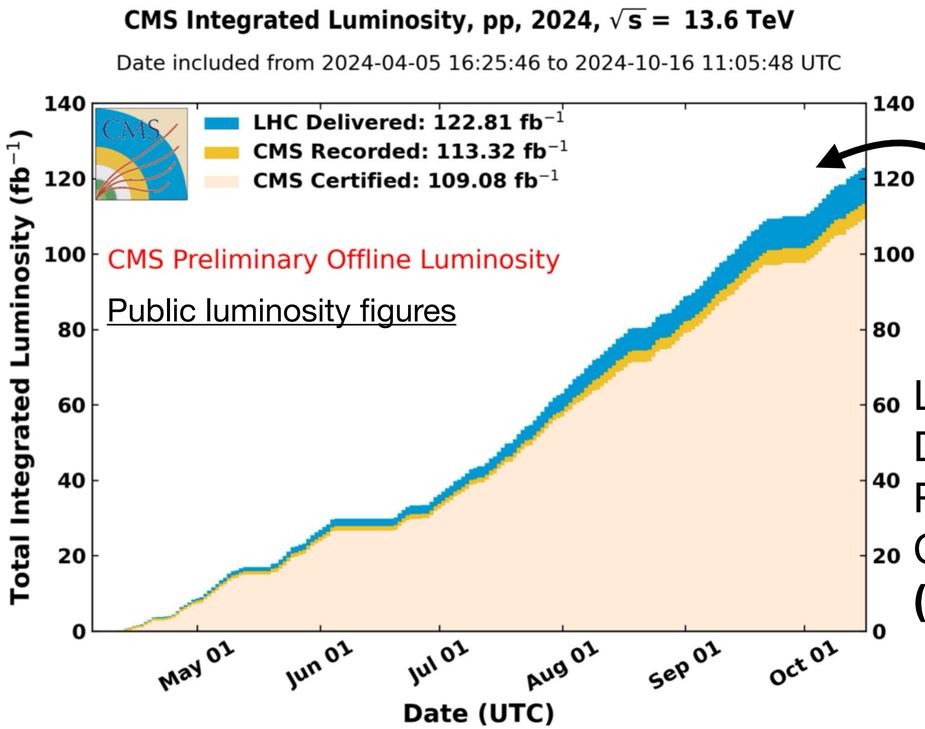

**Uncertainty more than 4x smaller**


# 2024 Data taking

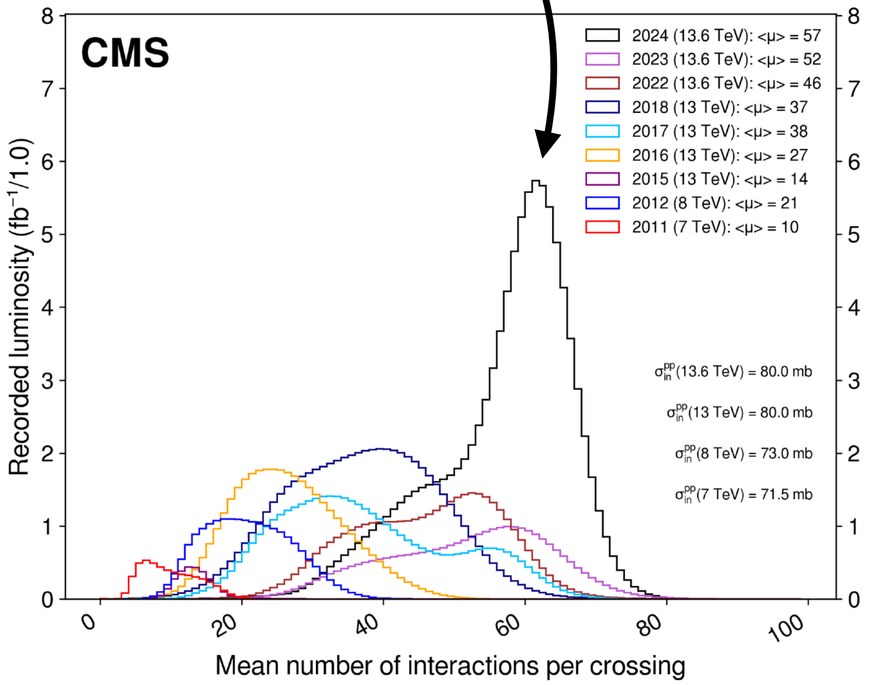
# 2024 pp data taking

- Smooth data taking during the last part of the pp run - 92.3% data taking efficiency by lumi

- Levelled at **PU 62-64** during the year
  - 3-6% deadtime
  - 105-115 kHz of L1 trigger rate
  - Measures needed to control rate/dead time caused by ECAL noise evolution

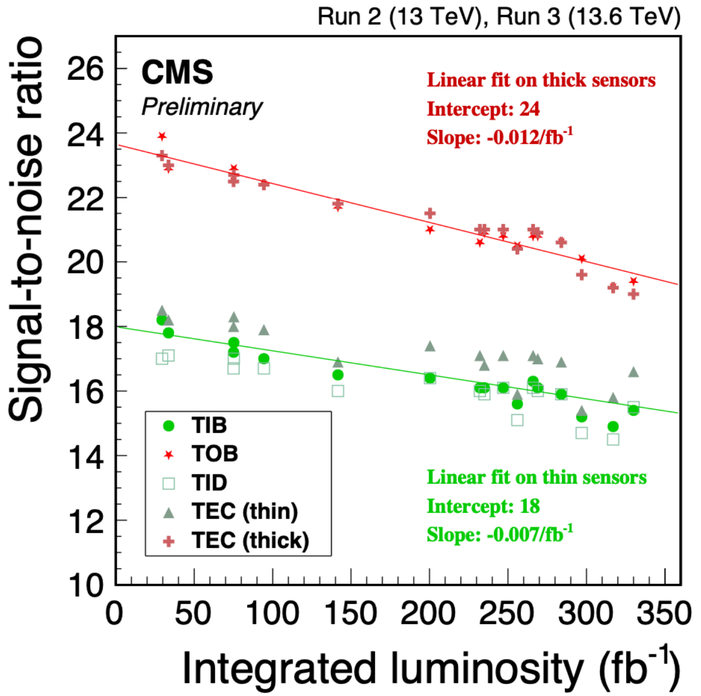



Luminosity:
Delivered: **122.8 fb$^{-1}$**
Recorded**: 113.3 fb$^{-1}$ (92.3%)**
Certified for phys: **109.1 fb$^{-1}$ (96.3%)**



# Tracker

- **Smooth operation of pixel and strip detectors at the end of pp running**
- **Minor data-taking issues have been addressed without further problem**
- **Strip detector**:
  - Current limit reached for 13 HV channels
    - Excessive leakage currents from radiation damage, but rate so far in line with expectations
- **Pixel detector**:
  - HV raised to 550V in September (degraded charge collection efficiency)
  - Layer 1 auto-masking rates stable at ~5%




**CMS-DP-2024/101**
Signal-to-noise ratio in strip tracker well above 10, and will stay like this until 500 $fb^{-1}$

# ECAL

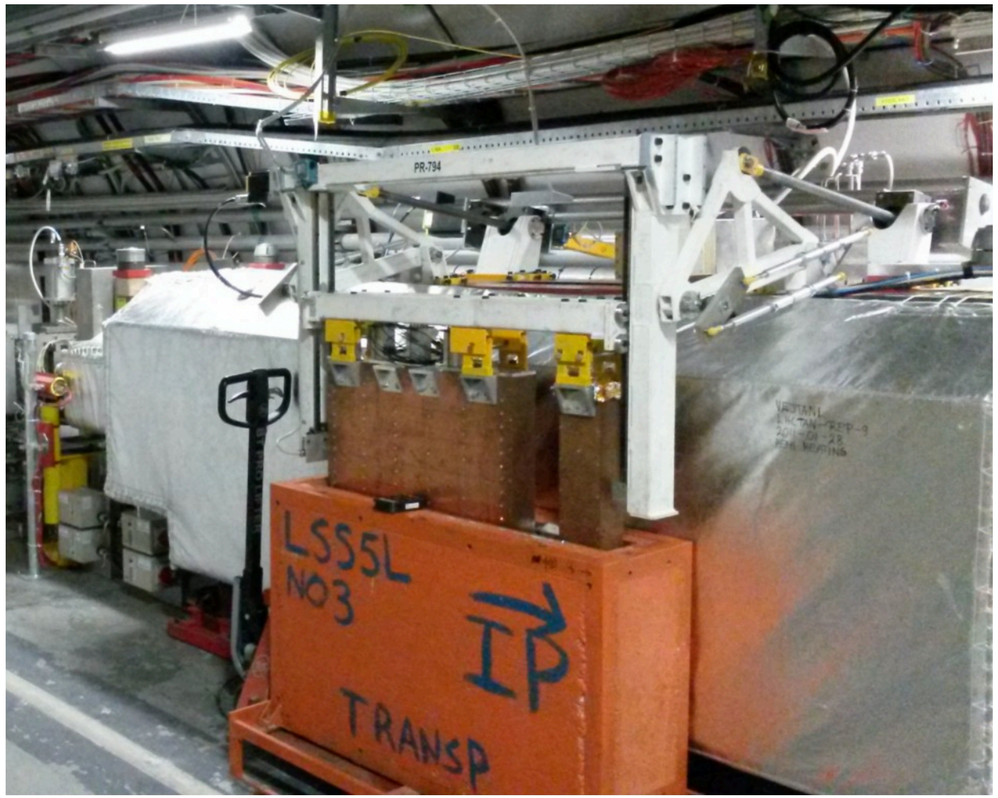
- **Smooth operations in 2024**
  - Regular pedestal checks, mitigate effect of APD noise
  - HI operations going well; zero suppression threshold adjusted
- **Dead time under control after taking mitigating actions**
- **Conditions being prepared to guarantee smooth operation in 2025**
  - e.g. raising zero suppression thresholds
- **Detector performance activities**
  - Progress with calibration, alignment and simulation conditions

# HCAL

- **Smooth HCAL operation through the end of pp data taking**
  - **Effective automatic recovery for minor issues**
  - HBHE SiPM annealing during MD before pp reference run
  - New pedestals w/ cosmics, more suitable for HI data
  - New laser signal strength aligned between different HCAL sections

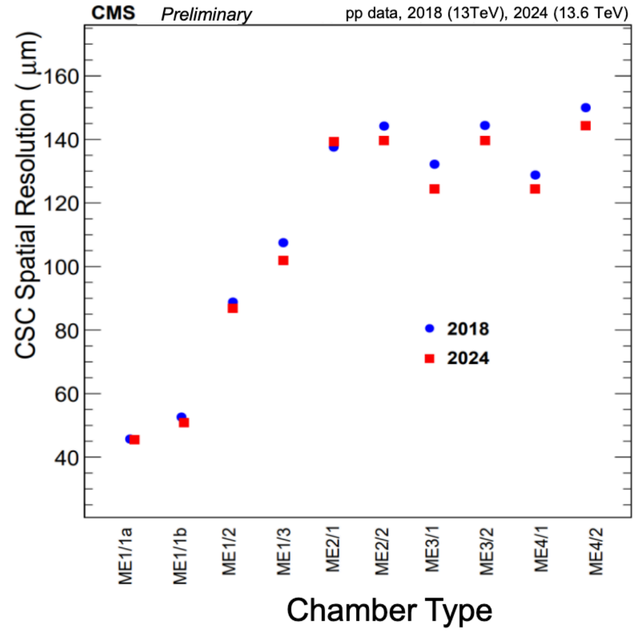
- **Progress on detector performance**
  - Pedestals, zero-suppression thresholds updated automatically every 5-7 days
  - Regular data and MC condition updates ➔ best performance in physics analyses

- **ZDC system successfully repaired after the accident at the beginning of the year**
  - Installed and commissioned at the end of pp run
  - Much progress on ZDC-related software, geometry, and conditions implementations

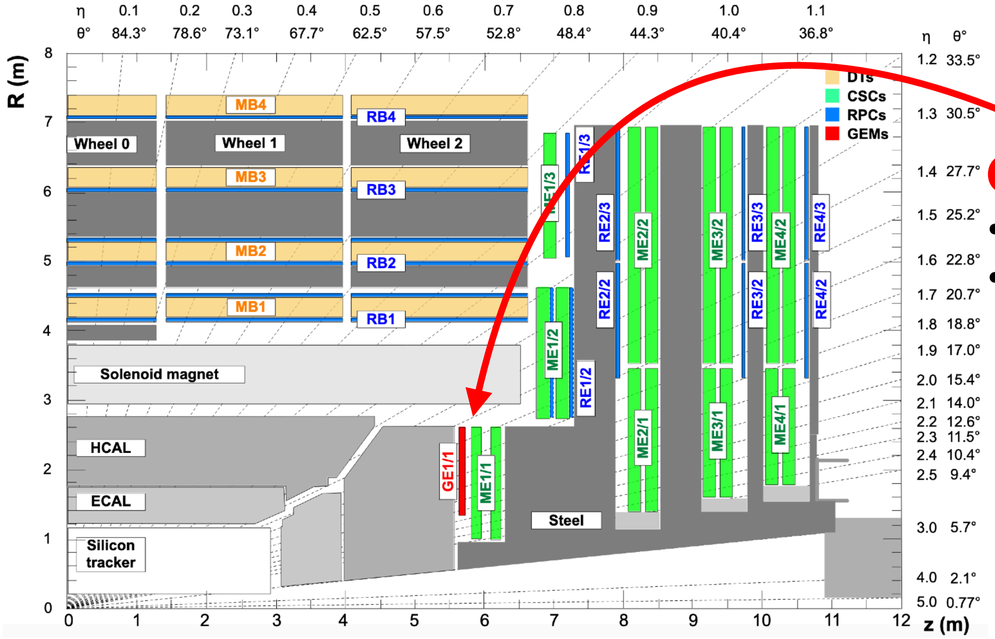


# Muon systems

- **Smooth operation of the muon system**
- **Smooth data certification**
- **Stable performance over time**

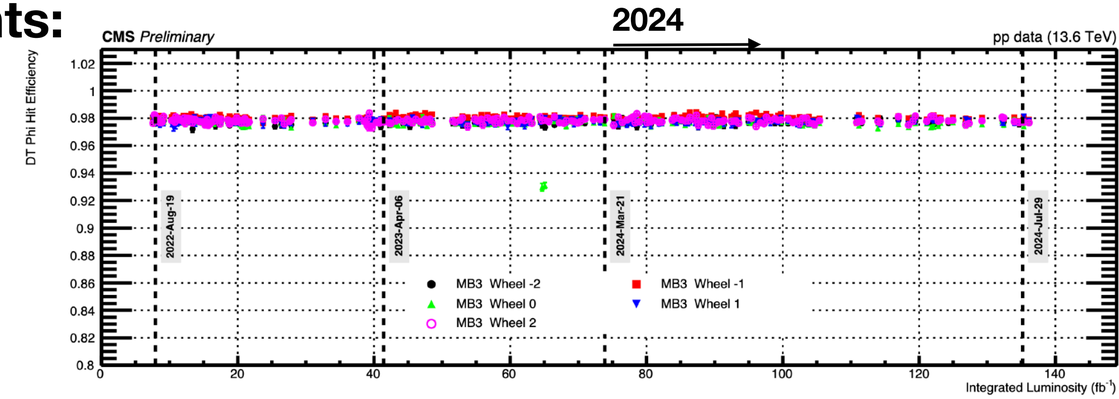



CSC Spatial resolution measured with 2018 (Run 2) and 2024 (Run 3) pp collisions (CMS-DP-2024/093)




## GE1/1 improvements:

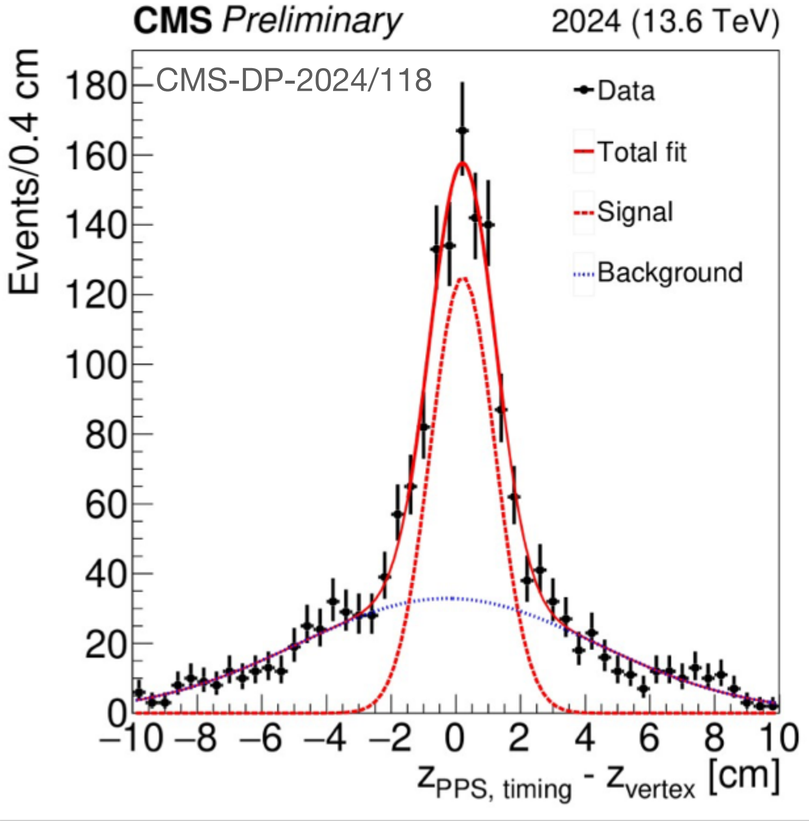
- Time res: ~15 ➔ 12 ns
- GE1/1 successfully included in Level-1 trigger




DT phi hit efficiency measured in Run 3 CMS-DP-2024/106

# PPS

- **PPS roman pots included for ~all high-lumi fills in 2024**
  - >100 $fb^{-1}$ collected, Run 3 data set > Run 2 data set
  - No operation during HI run: detector extracted for EOY maintenance
- **Timing performance in 2024**
  - 47 ps/proton resolution (low-PU calibration run)
  - Efficiency losses from polarization at high PU partly mitigated
    - Work ongoing to improve in 2025
- **Tracking performance in 2024**
  - Vertical movement system used to mitigate non-uniform radiation damage (shifting every 10$fb^{-1}$)
  - PPS tracking information in HLT for the first time in 2024

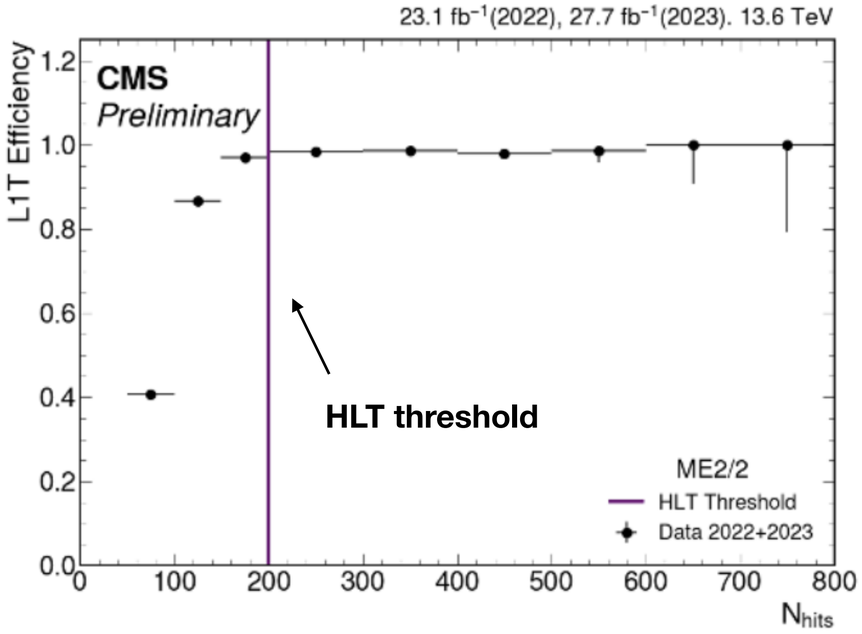



Vertex resolution from PPS proton timing

**Preparing for vertical crossing angle change (requires rotation) in 2025**

# L1 trigger

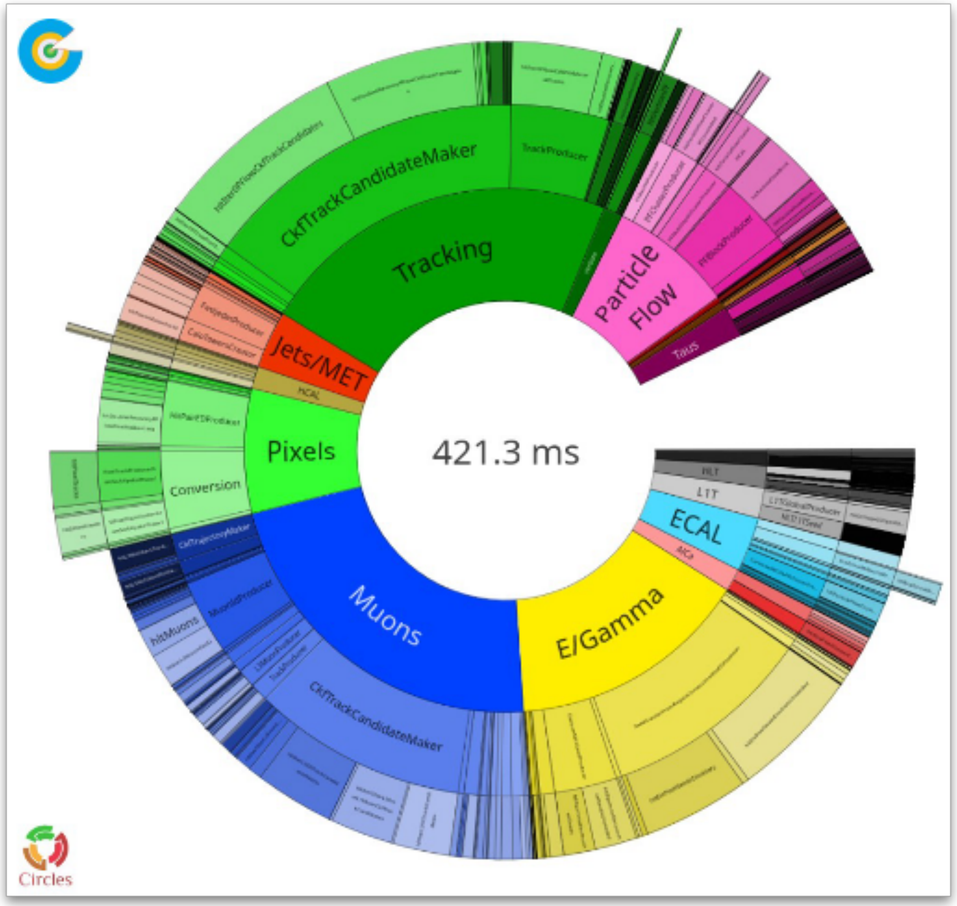
- **Stable operations of CMS L1 trigger, good performance until end of pp run**
  - Per-mille level data losses associated with L1T, best so far
- **After commissioning, CICADA enabled for physics data-taking at end of 2024 pp run**
  - Calorimeter-based AI anomaly-detection algorithm
- **New trigger menus 2024 pp reference and HI runs deployed in time**
- **Four new DPS notes for CHEP conference**



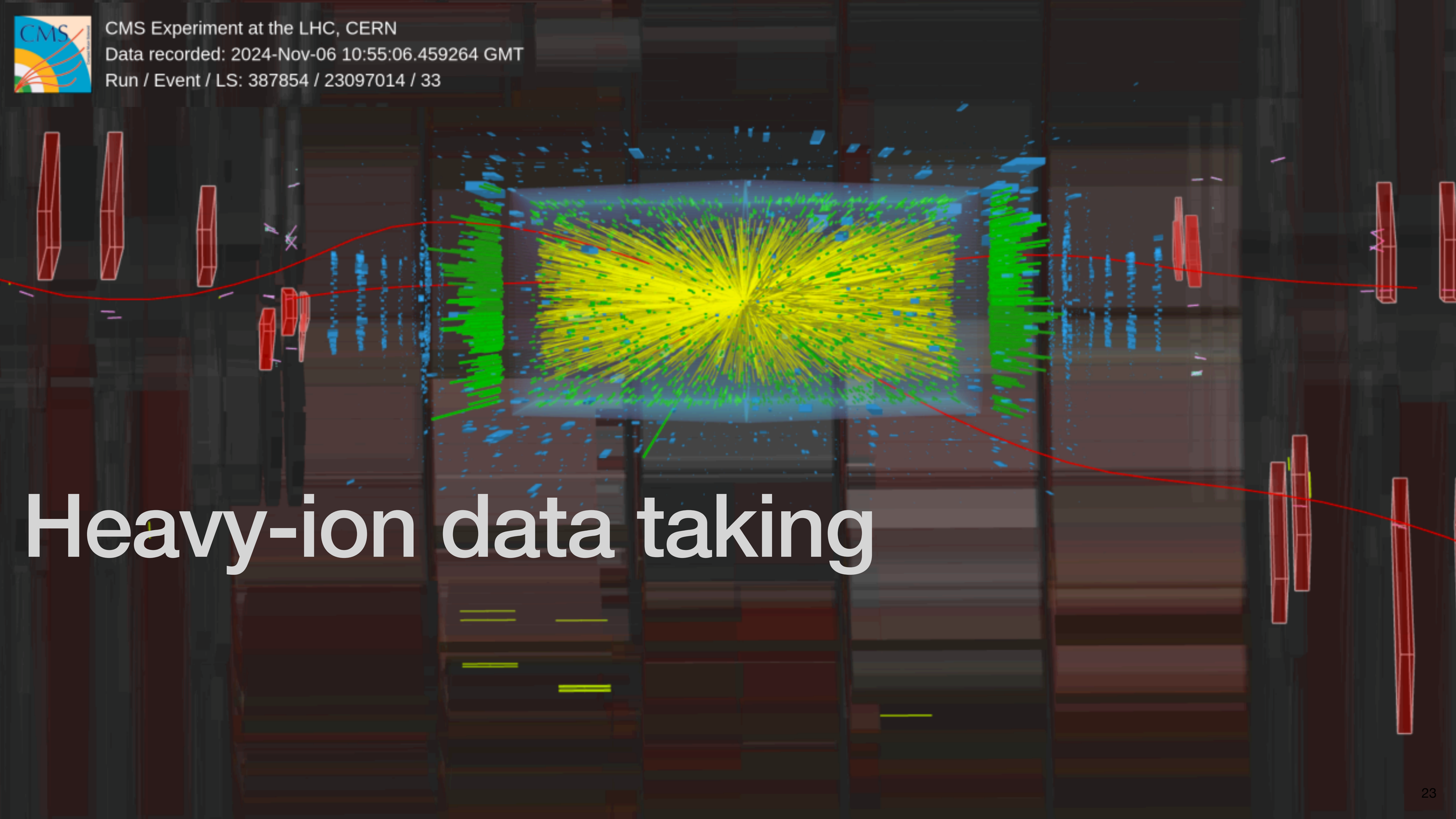

Measurement of the high-multiplicity muon detector shower trigger efficiency in CSC station ring ME2/2
CMS-DP-2024-099

# High-level trigger

- **Smooth pp data-taking at HLT throughout 2024**
  - Average rates: ~2kHz prompt, ~5kHz parking, ~26 kHz HLT scouting
  - Heterogeneous (CPU+GPU) reco software used at HLT ported to Alpaka portability library
  - CPU usage under control (DP note on HLT throughput and power consumption)
- **Dedicated trigger menus deployed for pp reference and PbPb run, no data-taking issues**
- **Preparations for 2025 trigger menus starting**




Average HLT processing time per event on 2024 pp data (CMS-DP-2024-082)




# Heavy-ion data taking

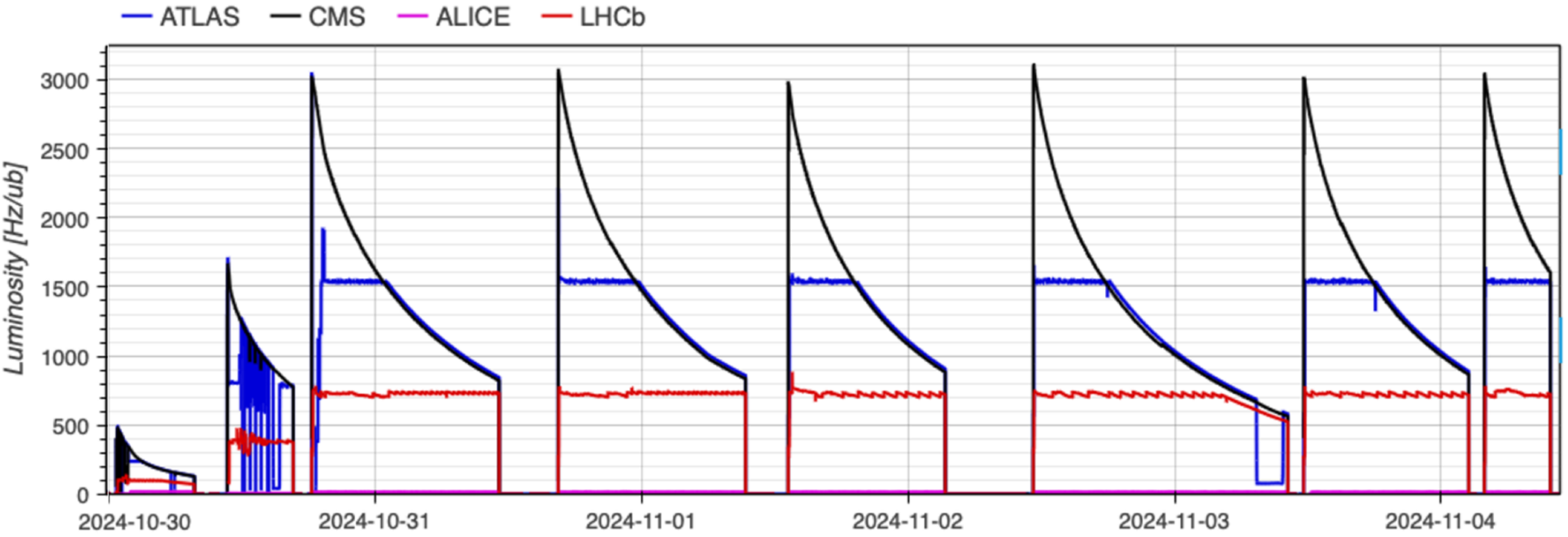
# pp reference run

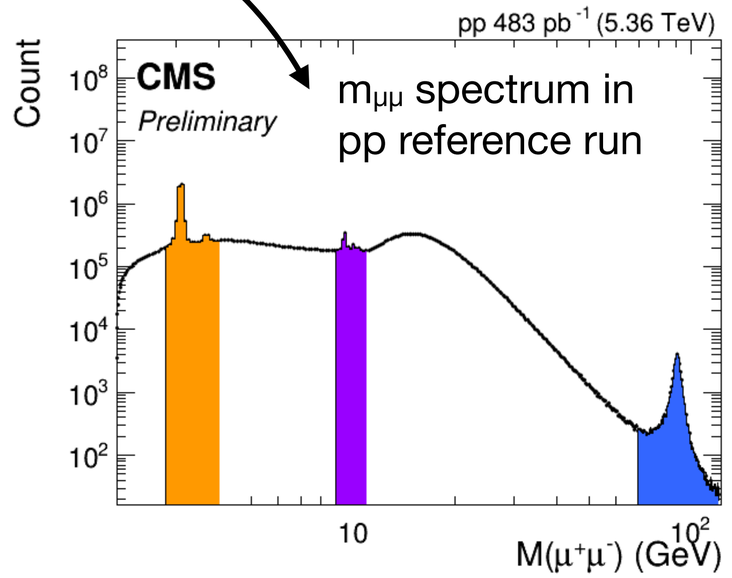
**Very efficient pp reference run at 5.36 TeV and smooth VdM session**

Long fills starting at PU=8 and then decaying to PU 1-2

For CMS, half the fill duration would have been optimal

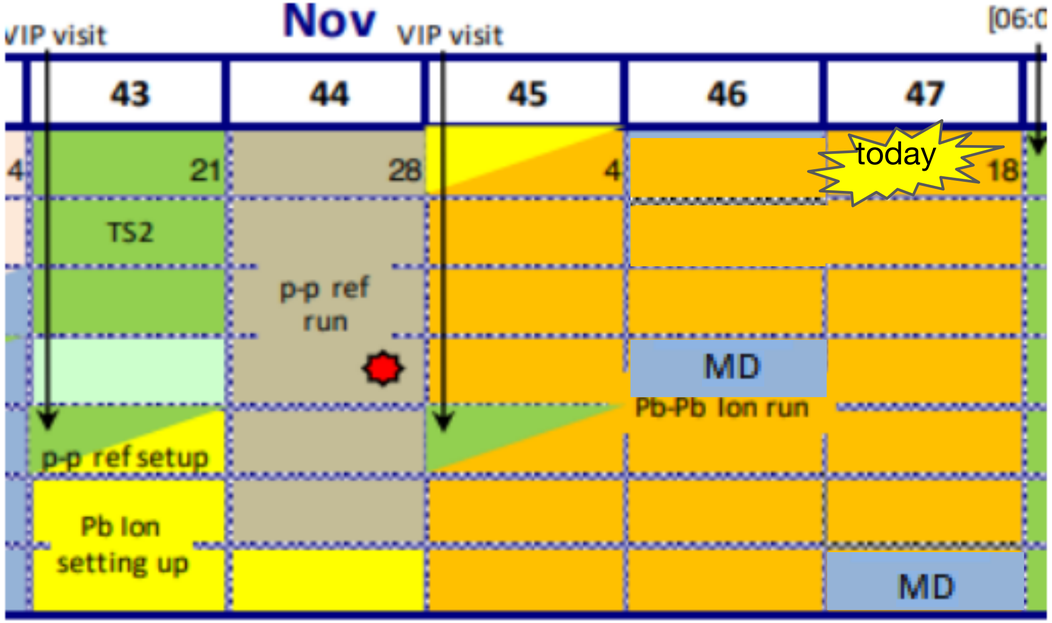
520 $pb^{-1}$ delivered to CMS, **92.3%** efficiency (~480 $pb^{-1}$ recorded )

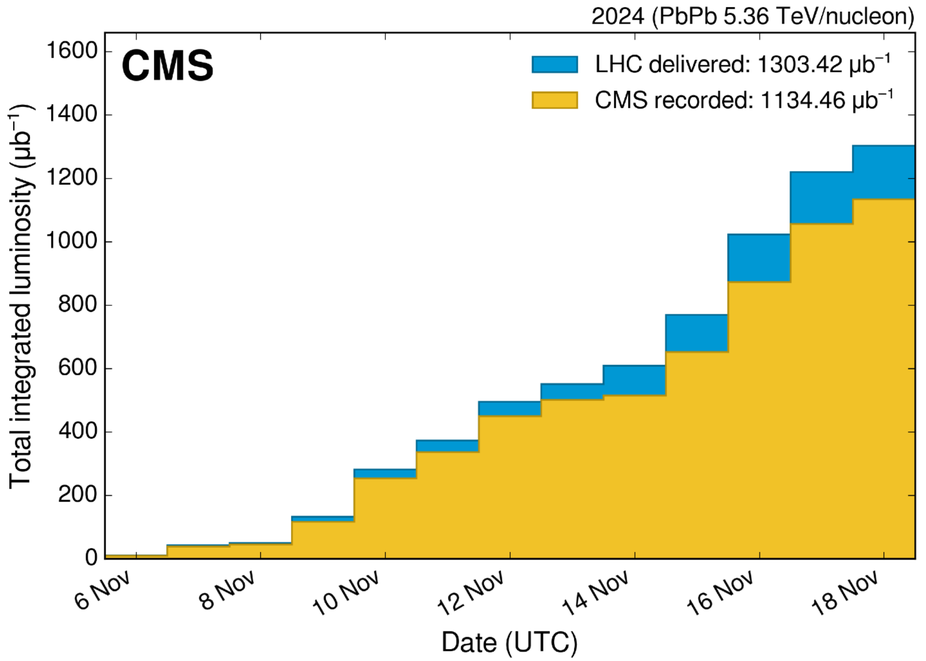


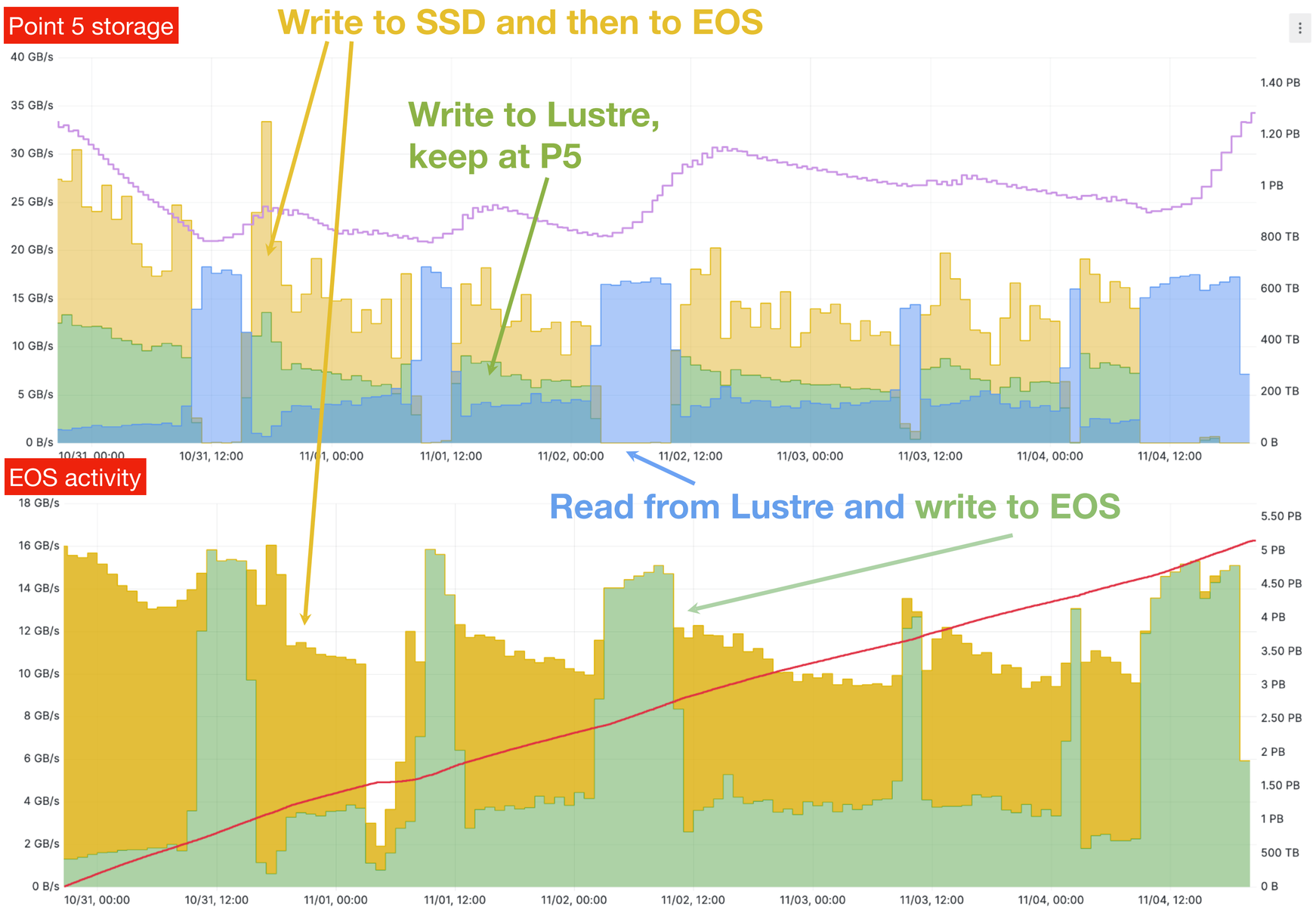
# 2024 PbPb run

- Ion setup started November 4th - first stable beams on Wednesday November 6th
- VdM sessions successfully completed
- **Current status: 1.32 nb$^{-1}$ delivered,1.16 nb$^{-1}$ recorded by CMS**



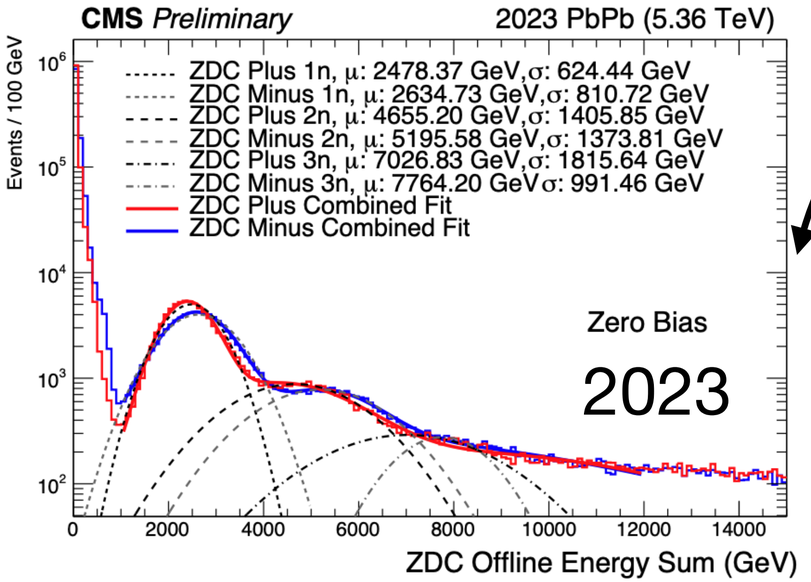




# Improved DAQ data flow for PbPb run



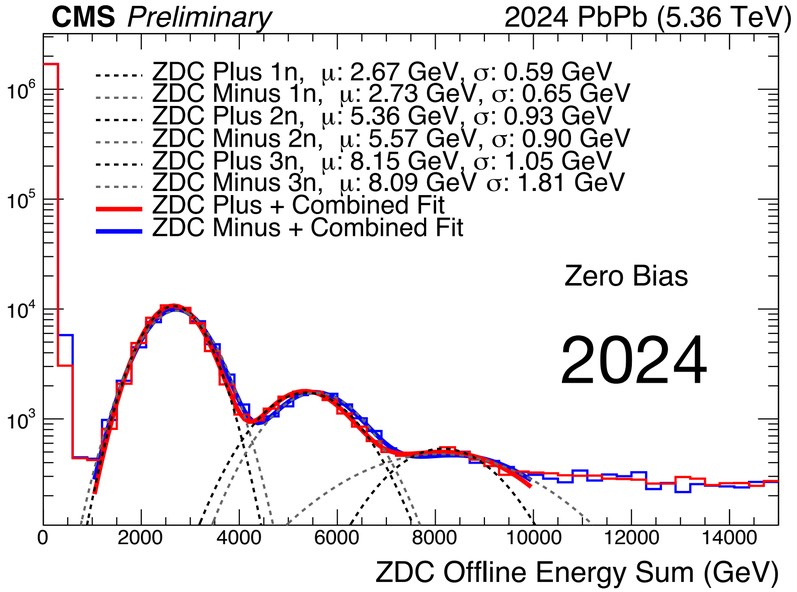

- **During HI run, CMS collecting data at up to 32 GB/s (up from max. 20 GB/s) ;** HLT output divided into two streams (Lustre, SSD)
- **Only SSD to EOS during fill.** In interfill: Lustre read and sent to EOS
- **Continuous writing to EOS (+tape) with constant ~15 GB/s rate**
- **All PbPb minimum-bias data recorded**

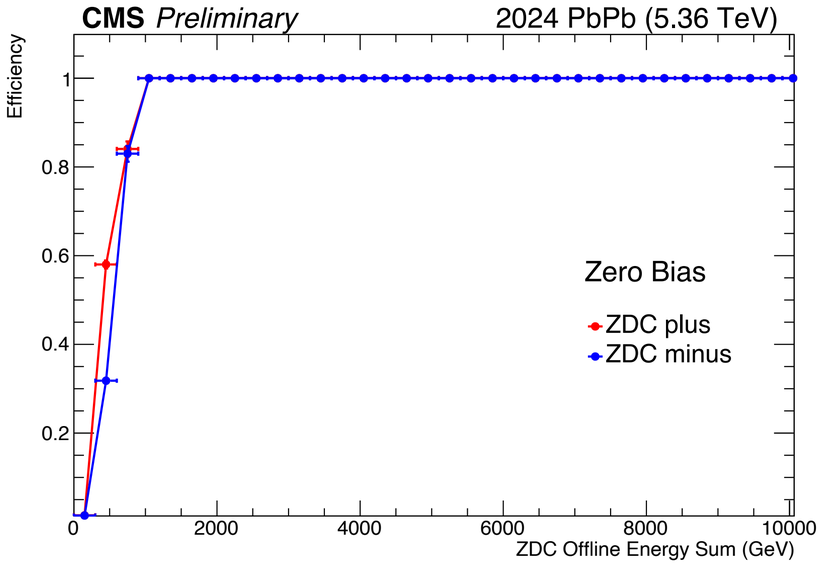
# PbPb performance in 2024

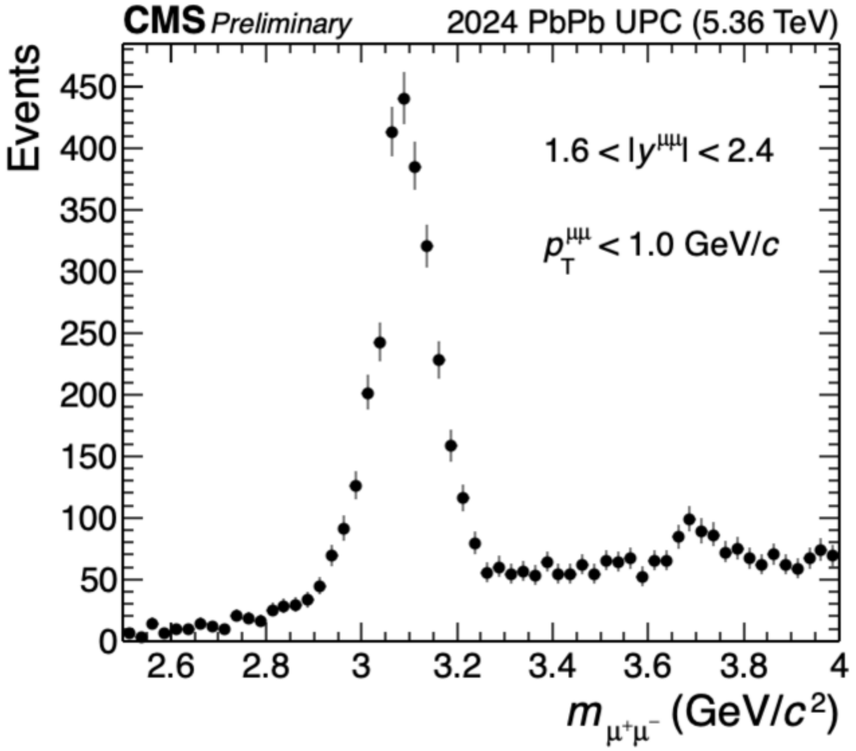



**Much better ZDC performance compared with 2023**

**Minimum-bias trigger efficiency significantly improved**

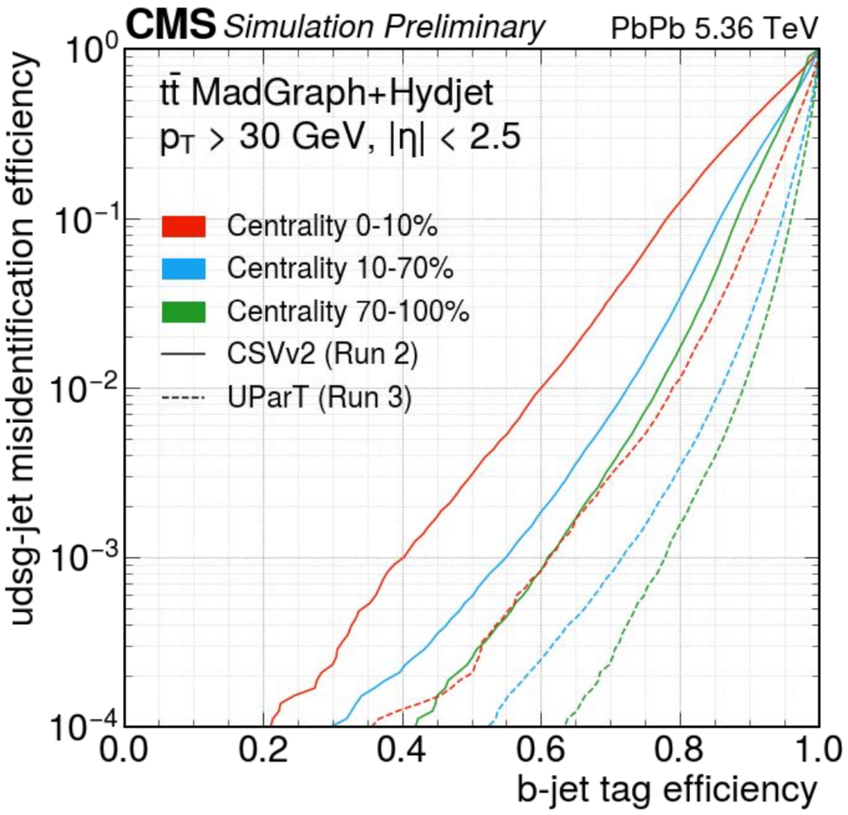


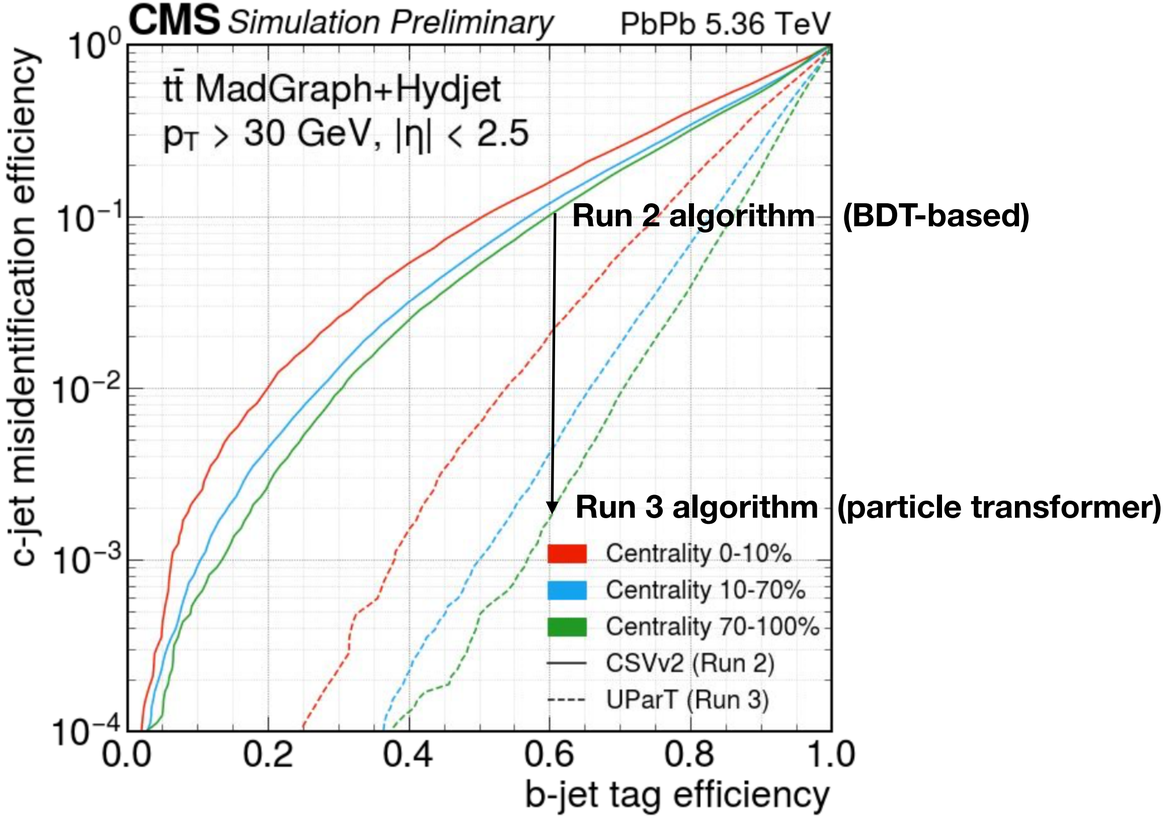




**$m_{\mu\mu}$ performance in ultra-peripheral collisions**

# B-tagging performance in 2023 PbPb data

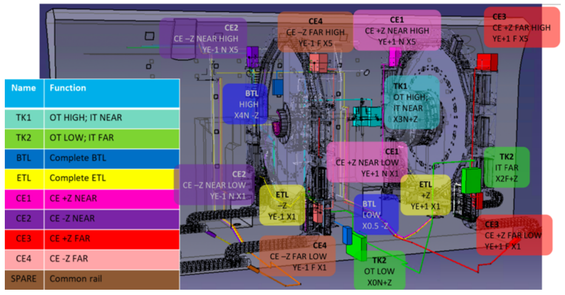



**Significantly improved b-jet tagging performance in Run 3 (2023) PbPb collisions compared with Run 2**

# YETS 24-25

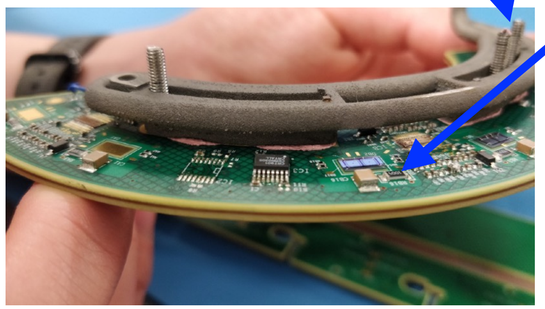
**Many activities planned during the 24-25 YETS**

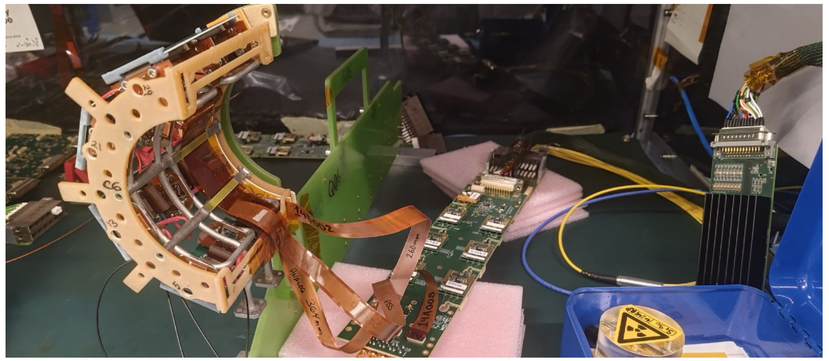



**Cooling manifold installation**

BCM1F cooling circuit

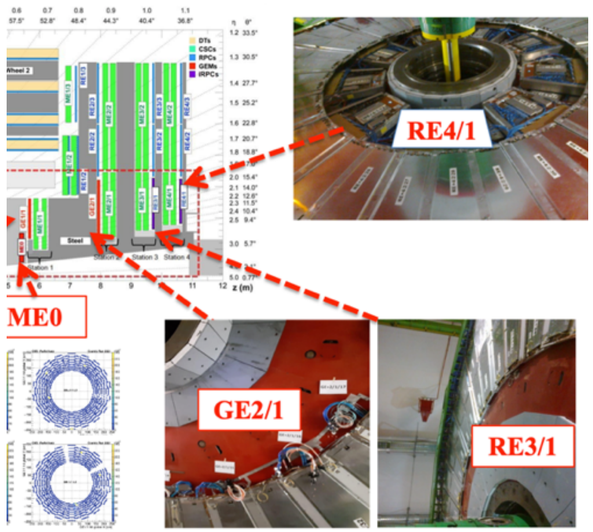
BCM1F double sensors



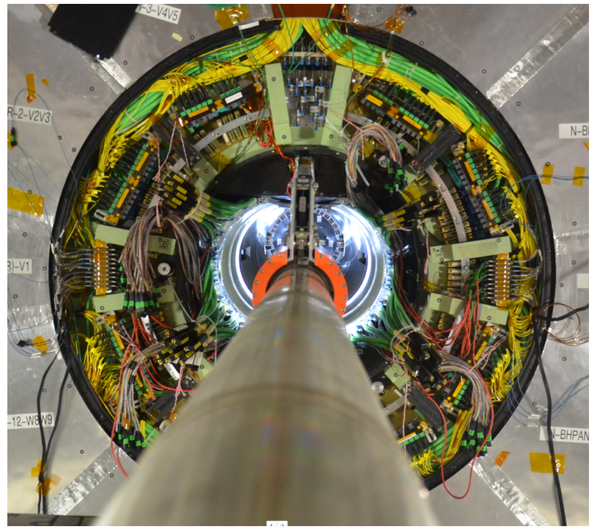


**Replacement of BCM1F, PLT, BCML luminosity detectors at -Z**

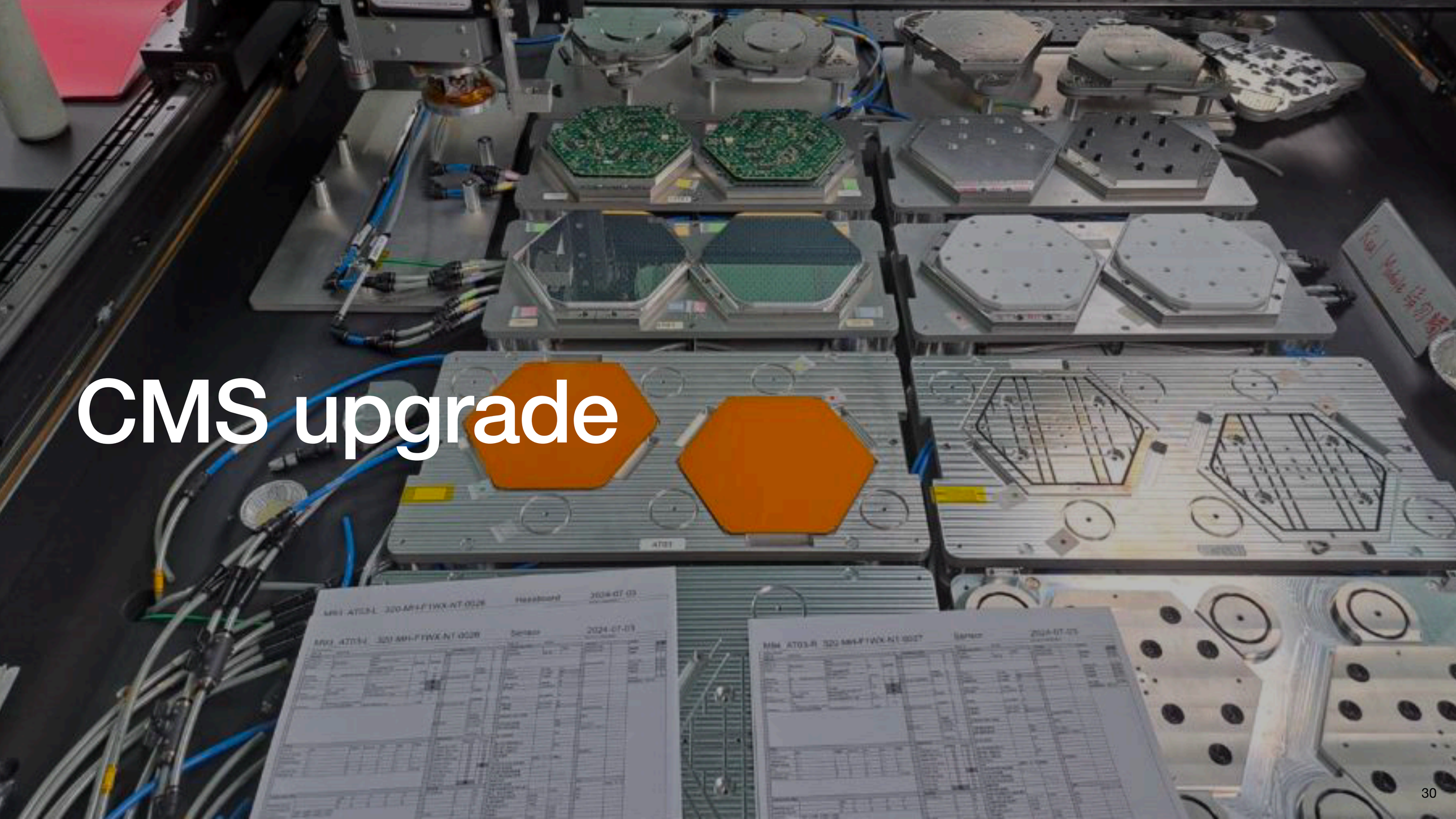
Retesting and reintegration of spare modules produced during LS2 ongoing to be ready for installation in January




**Muon system upgrade and maintenance**

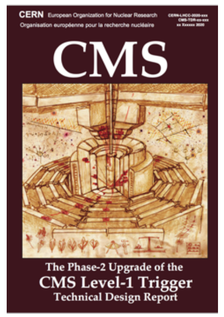


**Pixel fiber inspection at patch panels outside detector volume**



# CMS upgrade

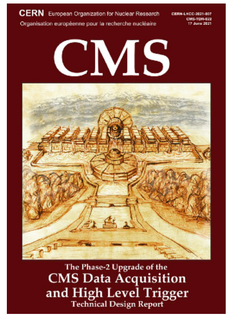
# CMS upgrade overview




## 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

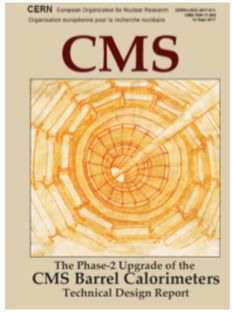
https://cds.cern.ch/record/2759072

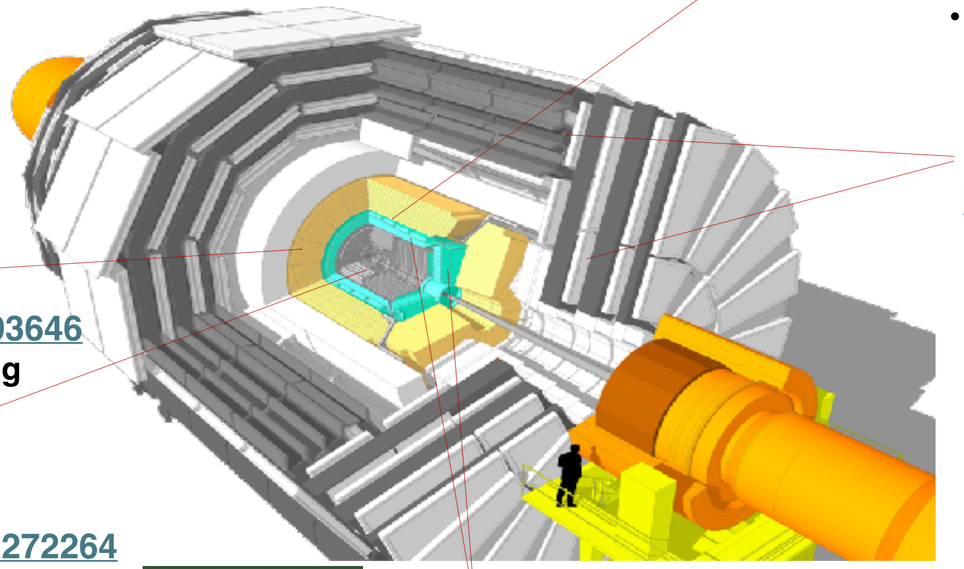
- Full optical readout
- Heterogenous architecture
- 60 TB/s event network
- 7.5 kHz HLT output

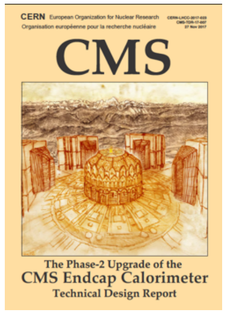
## Barrel Calorimeters

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

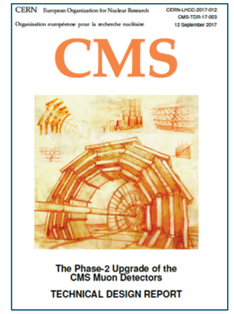
https://cds.cern.ch/record/2293646

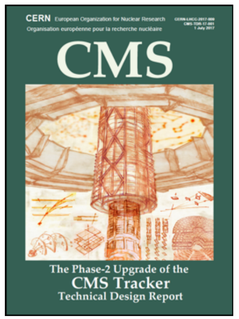
- 3D showers and precise timing
- Si, Scint+SiPM in Pb/W-SS

## Muon systems

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

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

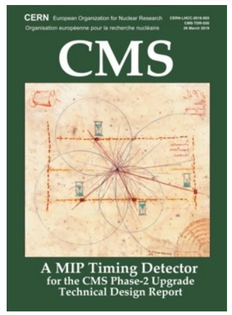



## Tracker

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

- Si-Strip and Pixels increased granularity
- Design for tracking in L1-Trigger
- Extended coverage to η ≃ 3.8




## MIP Timing Detector

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

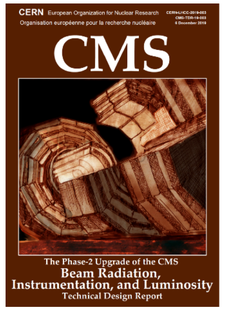
Precision timing with:

- 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



# 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)
  - **Control through optical link fails** (≥1%, can be identified with testing + selecting)

- **Work ongoing**
  - Radiation campaign with v1 to guarantee no detrimental evolution (change, but no increase in population)
  - Bug-free submission (lpGBTv2): Submission happened, expect substantial amount early summer

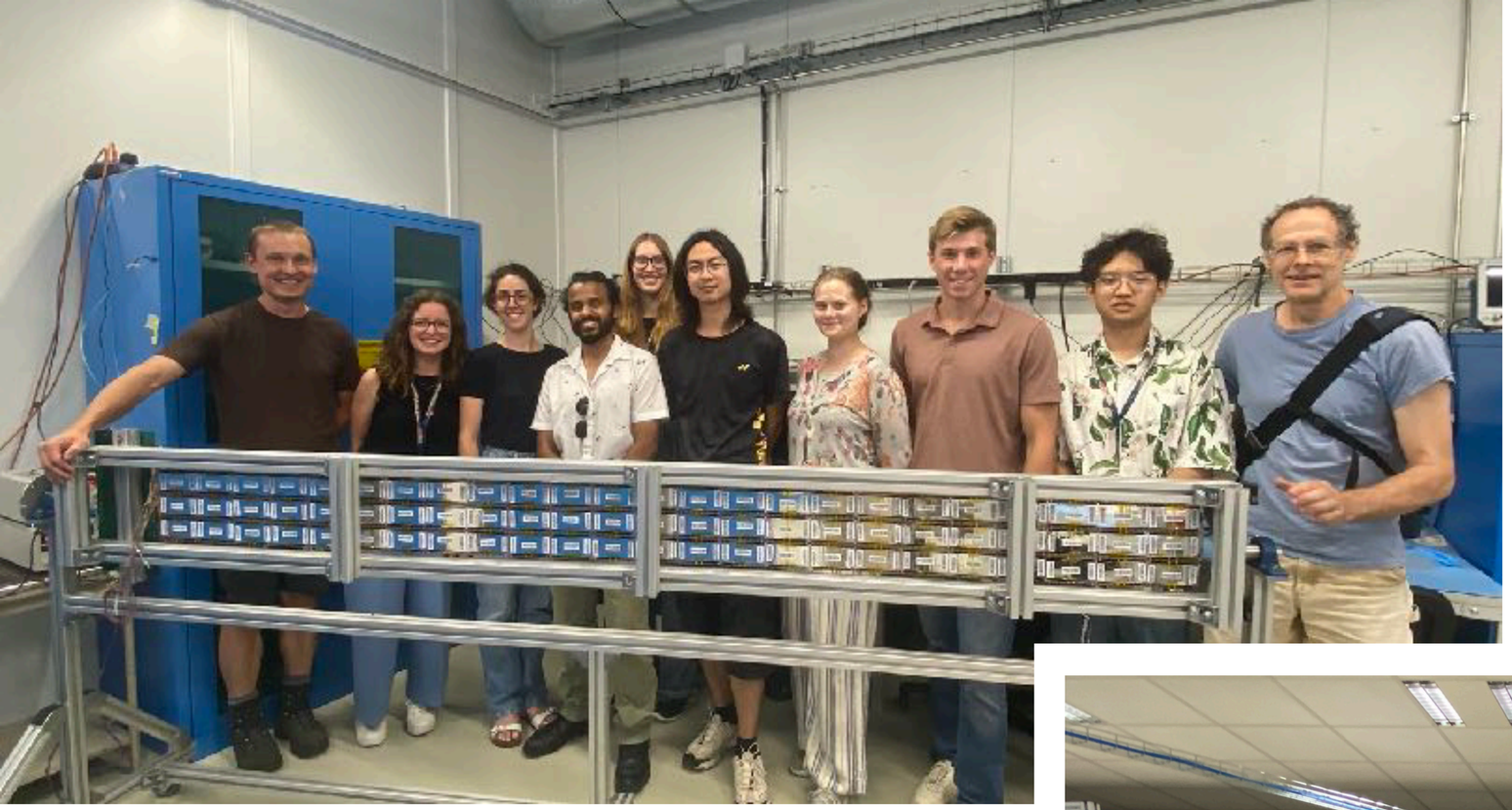
**CMS applauds CERN Microelectronics for the fast pace**

CMS continues large-scale testing with lpGBTv1 **and is assessing the risk of using v1 rather than v2**

**This will decrease our schedule float**

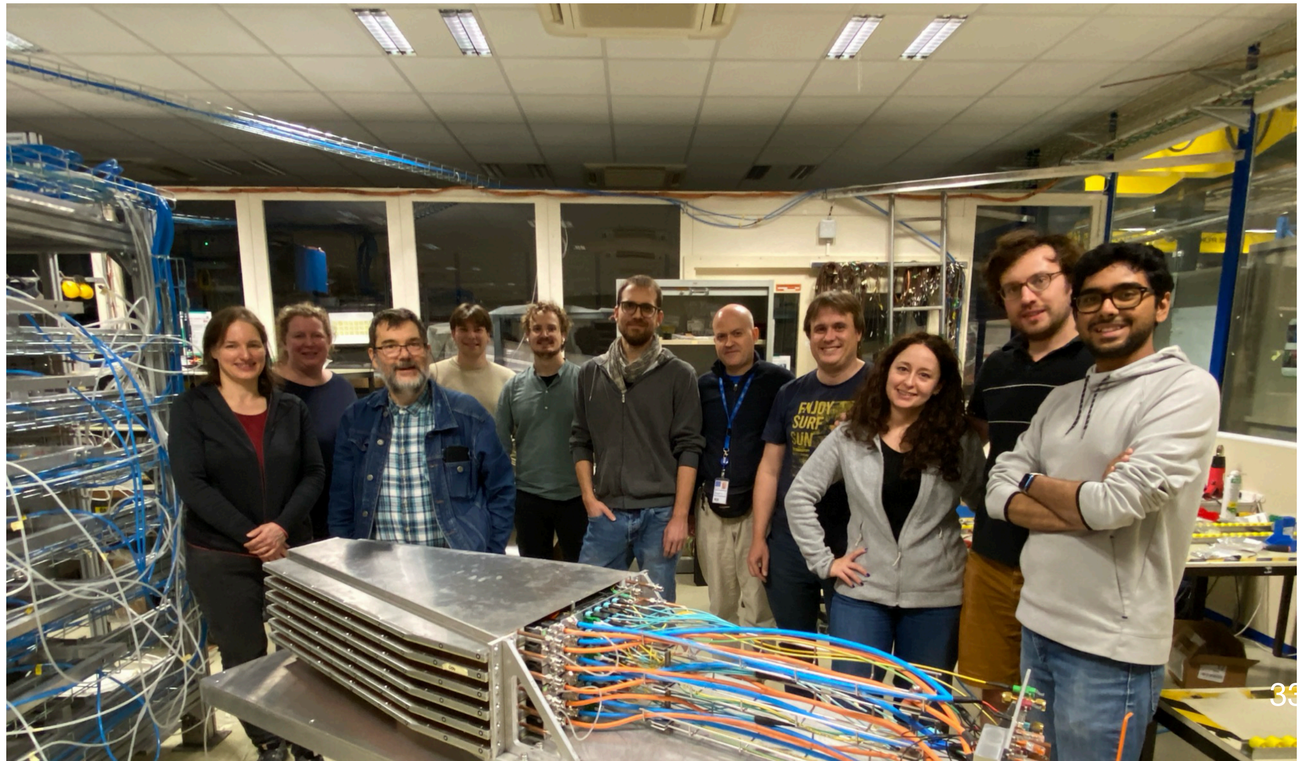
| Subsystem | Total # | |
|---|---|---|
| **Inner Tracker** | 4k | on electronics boards ‘portcards’ |
| **Outer Tracker** | 14k | on hybrids, integral part to every **module** |
| **HGCAL** | 26k | on electronic boards ‘engines’, integral part of **cassette** |
| **BCAL** | 14k | on upper electronics 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 |

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



1st ME0 production stack

BTL: 1st production tray assembled



**Steady production of all BTL and ME0 ingredients and structures**

# HGCAL mechanics in production

end-flange wedge

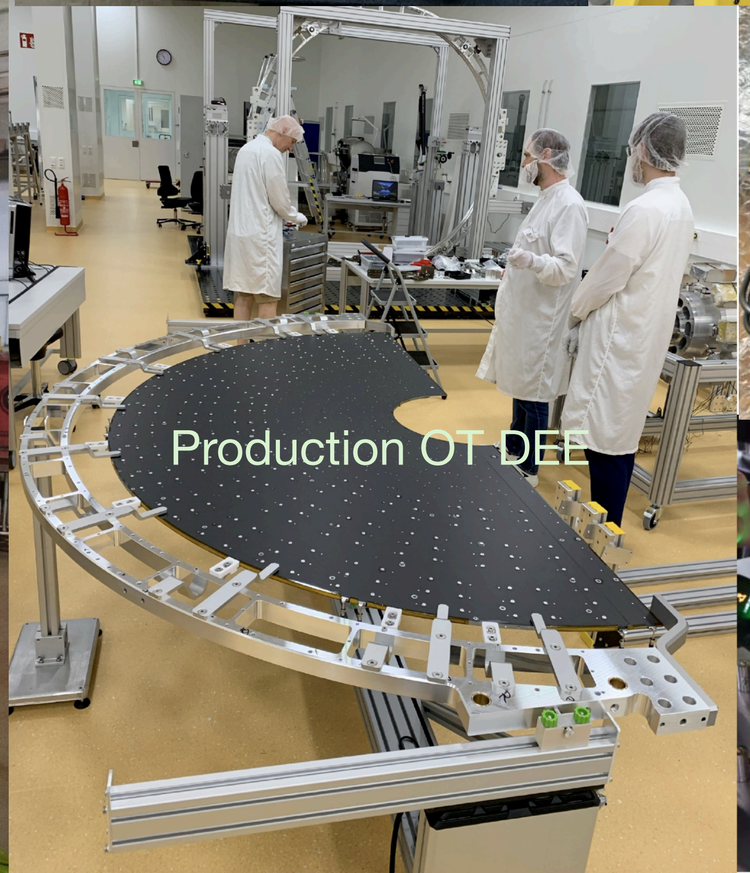
pre-production cooling plate QC

# Tracker mechanics in production

IT : Carbon foam cured to carbon fiber sheets

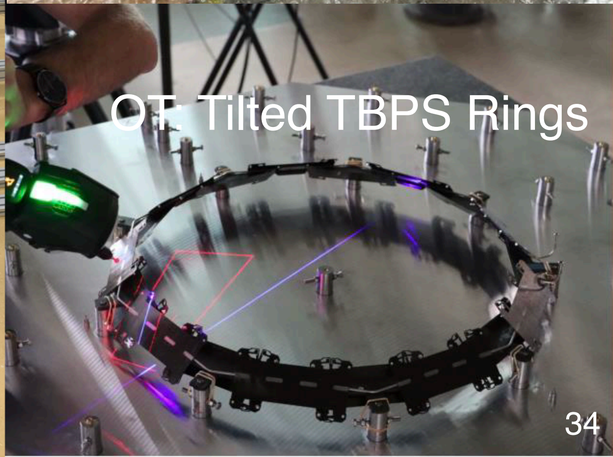

BTST load test after transport incident – All OK

**This marks the official starting date of the HGCAL structure assembly in Pakistan**



Production OT DEE

IT: Bent Titanium pipes



OT: Tilted TBPS Rings

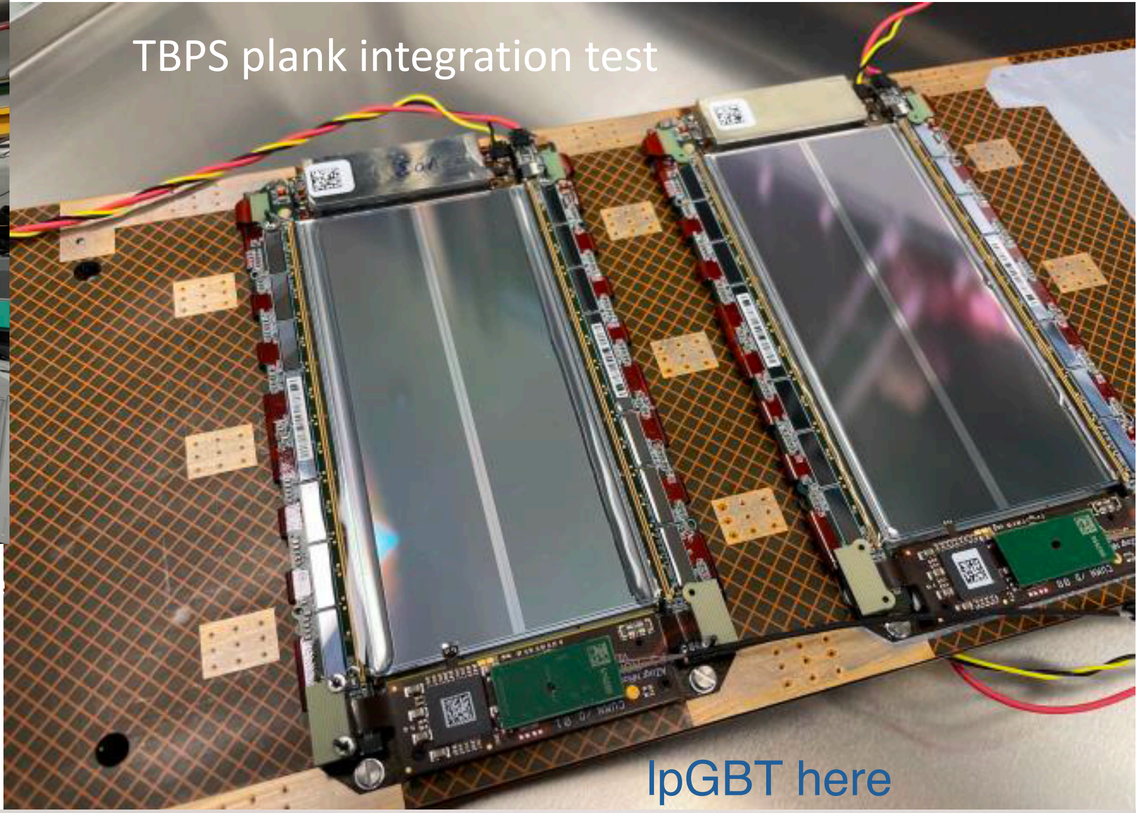

HGCAL Cast Scintillator Tiles


HGCAL SiPMs


HGCAL Molded Tile production

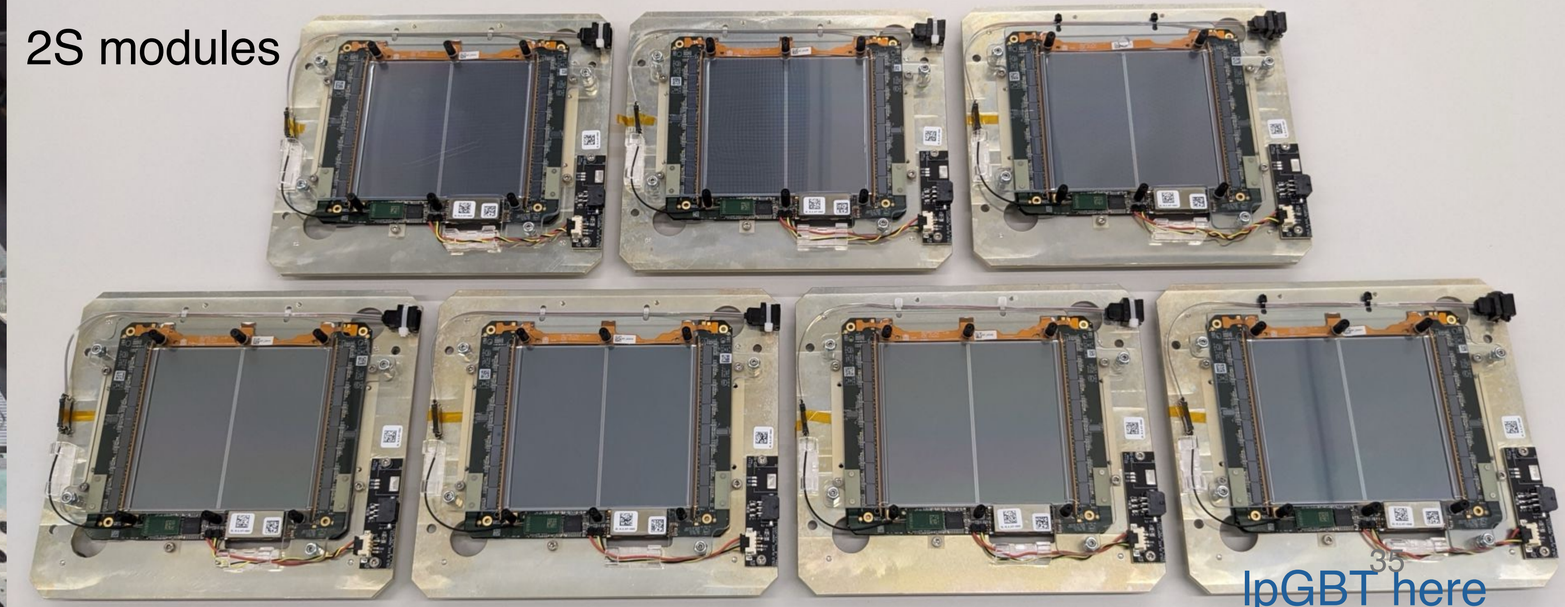
# HGCAL and Tracker in production

IT: High Density Interface


TBPS plank integration test

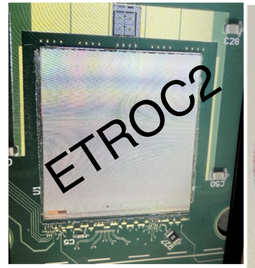
lpGBT here

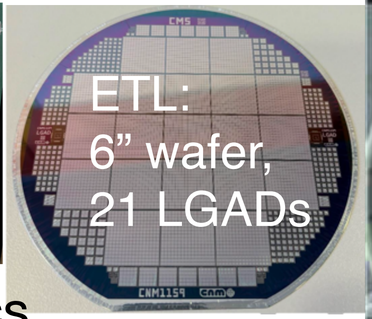

HGCAL: Gantry tooling at NTU
ready for pre-production of full-HD

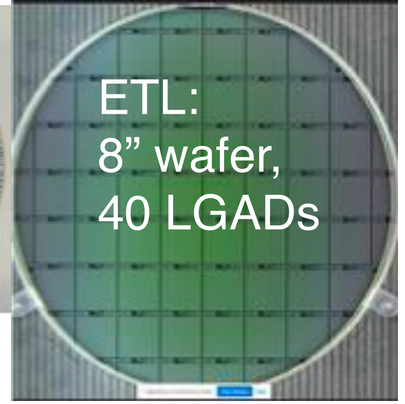

2S modules

lpGBT here

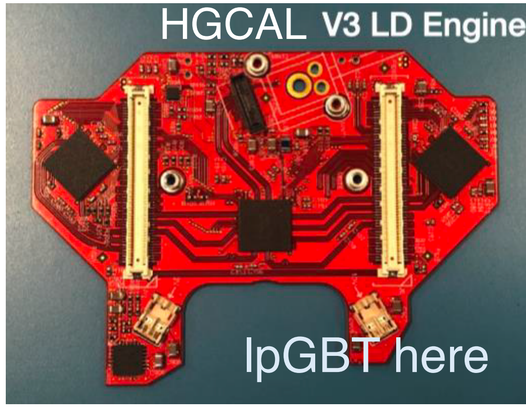
# Upgrade status overview

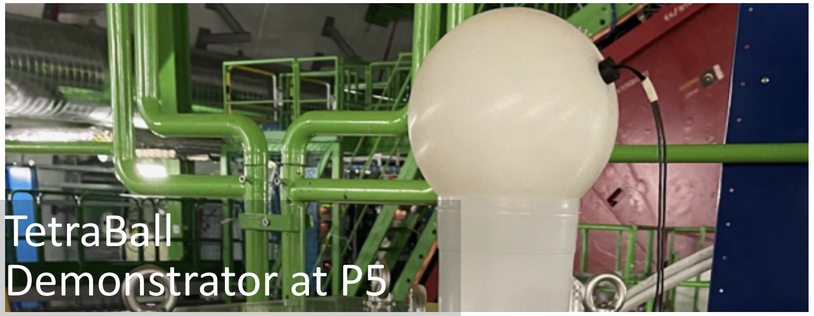


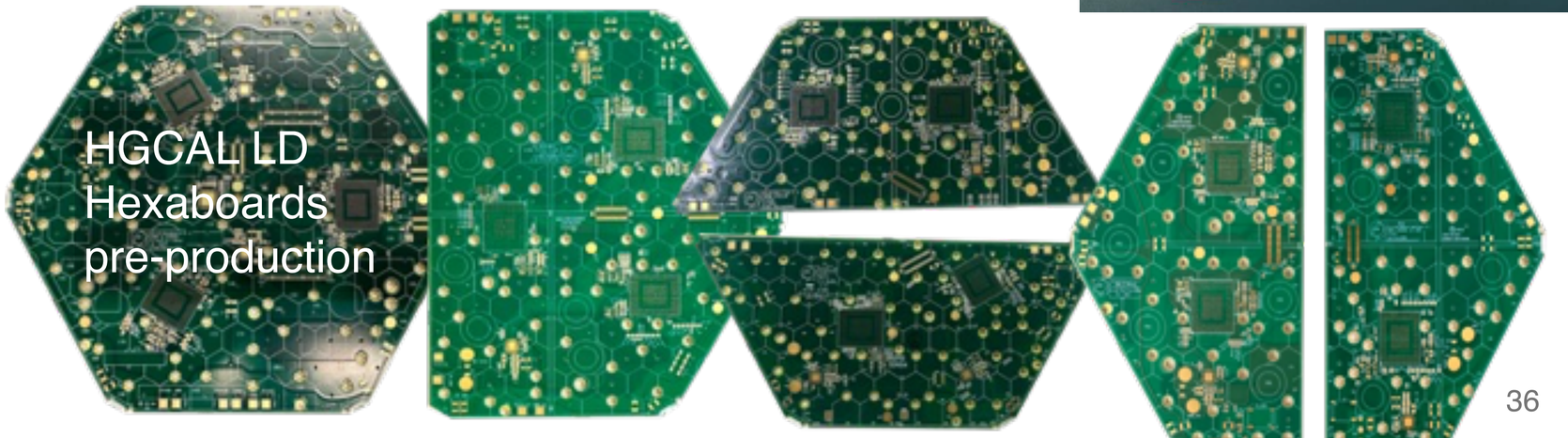




- **Barrel Timing Layer, GEM ME0, CSC, DTs** in production
- **Endcap Timing Layer**: final ASICS & sensor in hand. Progress on electronics
- **L1 Trigger**: Boards ready for production, waiting for SAMTEC Firefly12
- **Barrel Calorimeter** all designs ready, ASICs boards, etc. Prod start 2025
- **Tracker**: All component procurements have been launched. Module production started
- **HGCAL**: more designs finished since last LHCC - *not all done YET*.
  Many parts in full production. Waiting eagerly for HGROC3c from packaging stage.
  - Module Assembly centres ready and eagerly waiting for parts
- **BRIL**: Successful testbeam, learnt a lot: first neutron monitor demonstrator at P5
- **Next complex steps: Module assembly and structure integration**



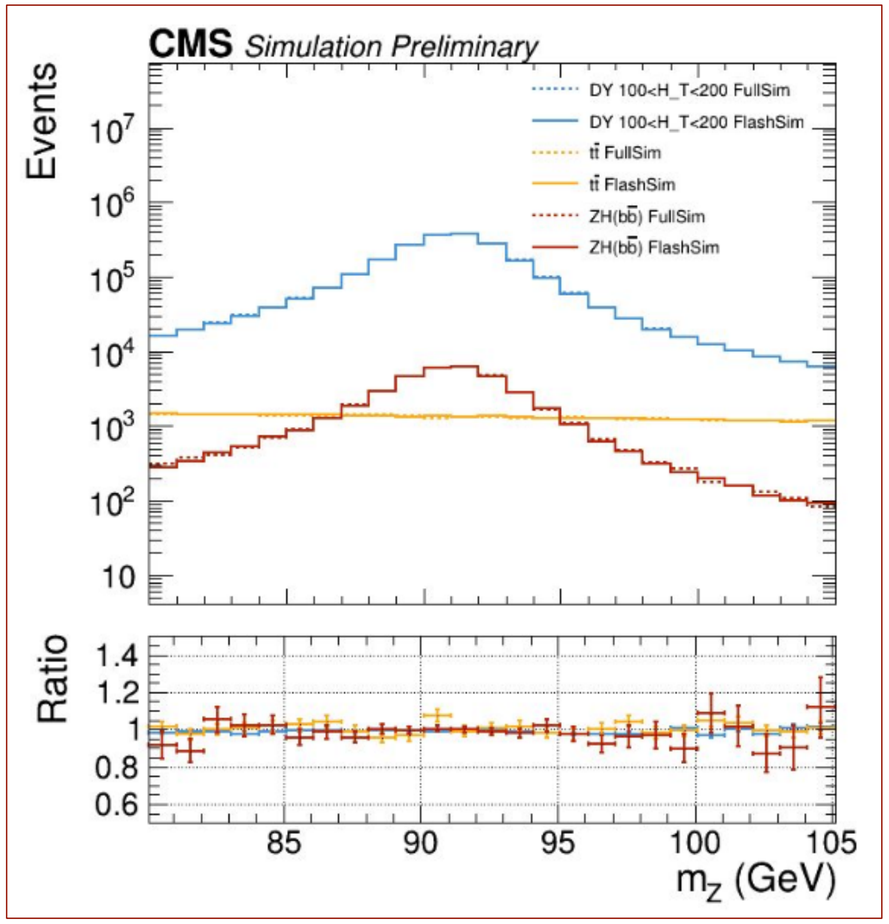




BRIL Beam Radiation Instrumentation Luminosity

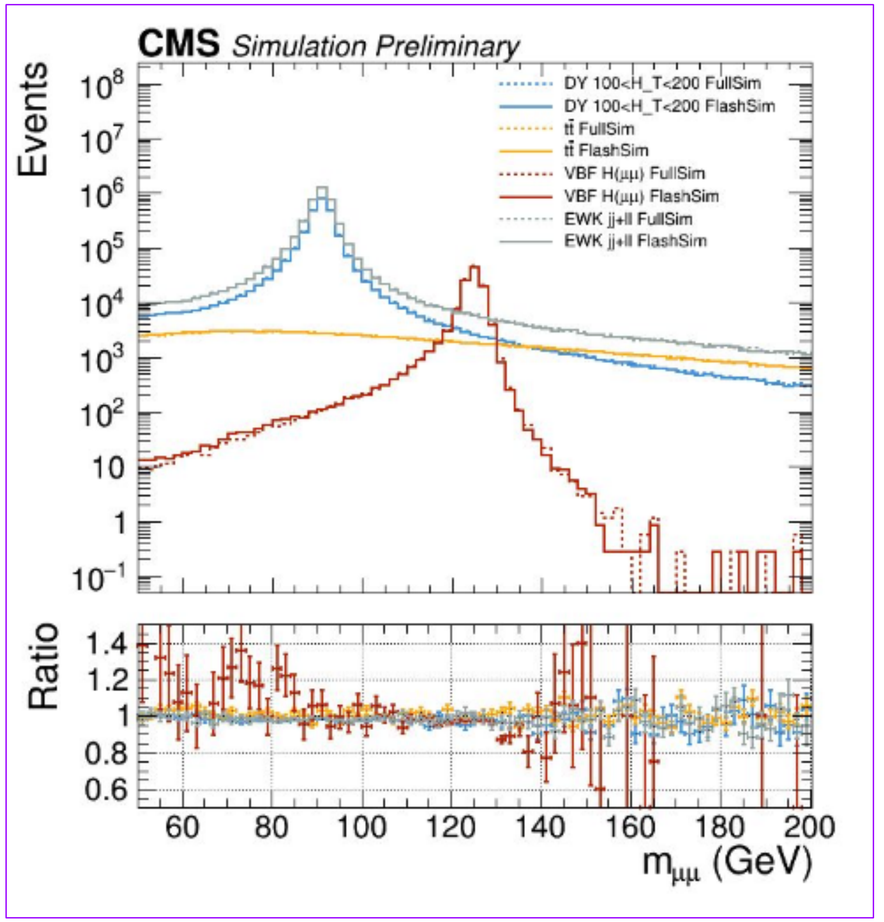
# Summary

- **Many new physics results released by CMS since the last LHCC**
  - 18 new searches, measurements, and combinations; using pp, pPb, PbPb data
- **Generally smooth 2024 pp data taking with good availability of the detectors**
  - 92.3% data-taking efficiency; 113.3 $fb^{-1}$ recorded by CMS
- **Heavy-ion data taking off to a very good start**
- **Progress on upgrades**
  - Many items in production
  - lpGBTv1 ASIC issues affecting schedule float

# FlashSim performance




Z(μμ)H(bb)

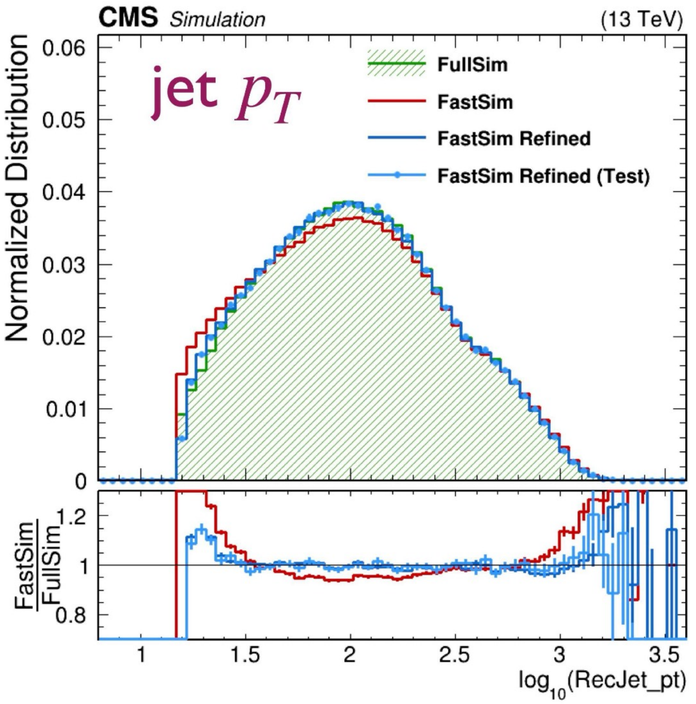


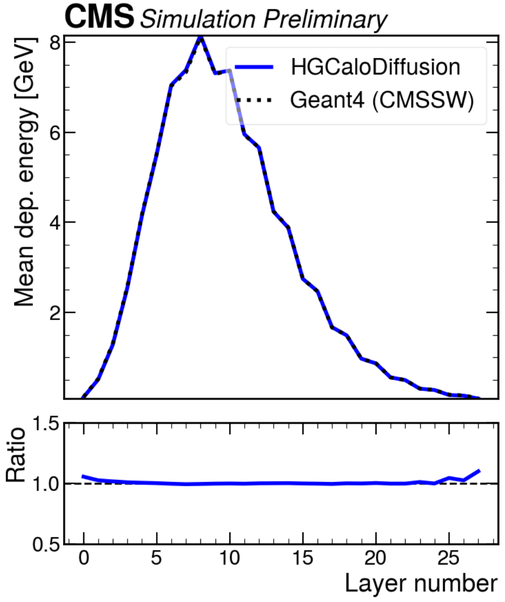

VBF H→μμ

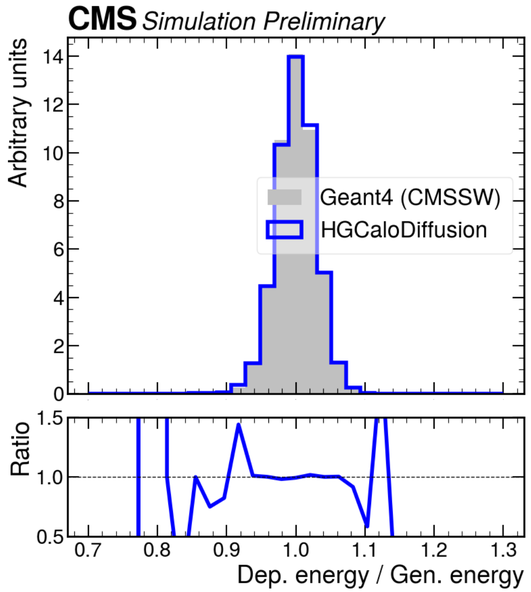
# Offline software & computing

## Improving fast simulation results

- CMS FastSim: simplified geometry, fast particle propagation and tracking, analytical interaction models
- Apply ML to FastSim to get better agreement with full simulation
  - Use same scale factors for both simulations; large MC samples simulated 10x faster
- Prototype in place for Run 3 production



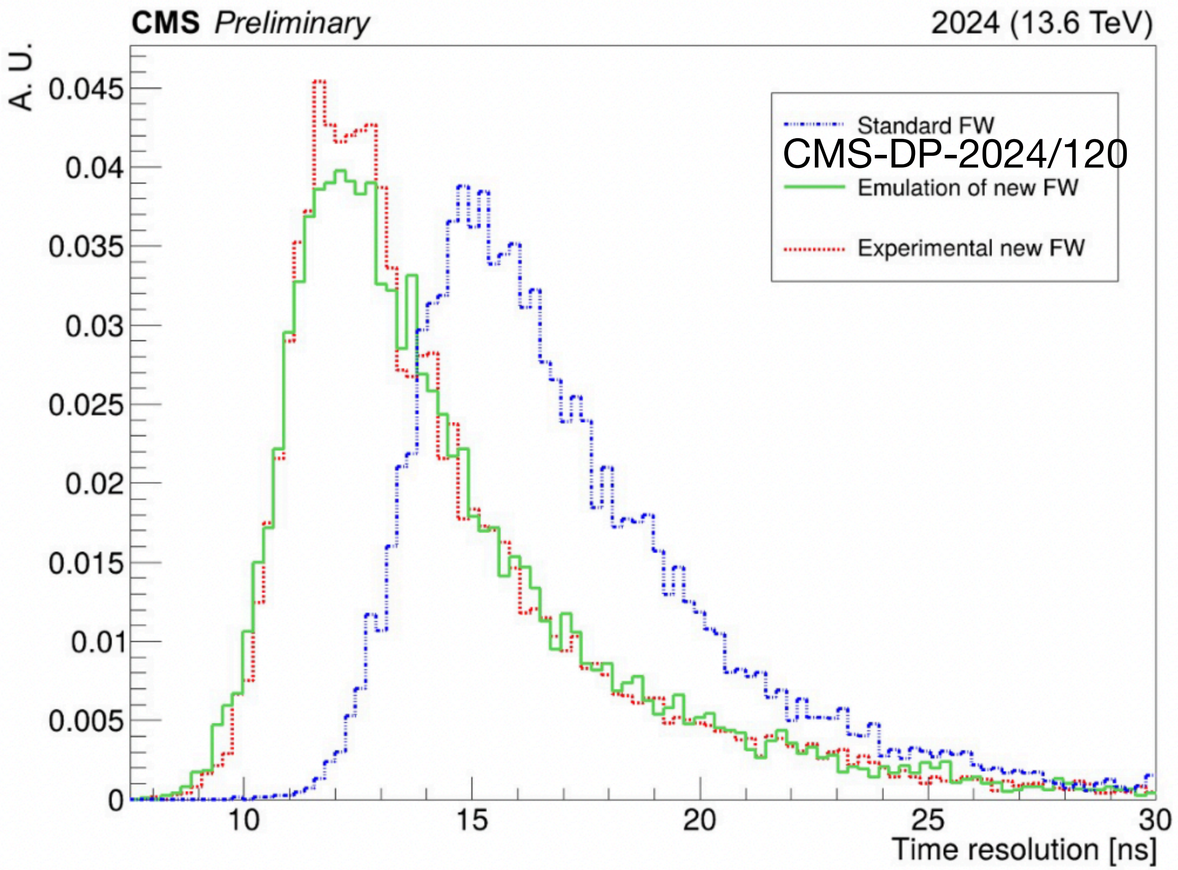




## Simulating HGCAL with ML

- Full simulation of HGCAL: twice as slow as current calo
- Use of CaloDiffusion model (Phys. Rev. D 108 (2023) 072014) with adjustments for HGCAL to generate calorimeter showers
- Preliminary results: good agreement in several variables

# GE1/1 time resolution

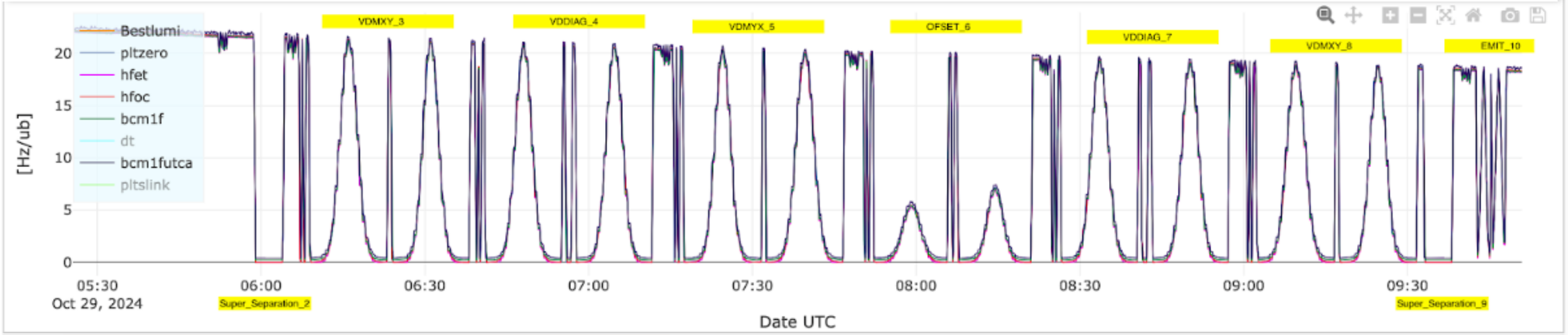
- **Significant improvement in GE1/1 time resolution (~15 → ~12 ns)**
- **New FPGA firmware for on-chamber electronics, suppressing inter-readout-strip crosstalk**



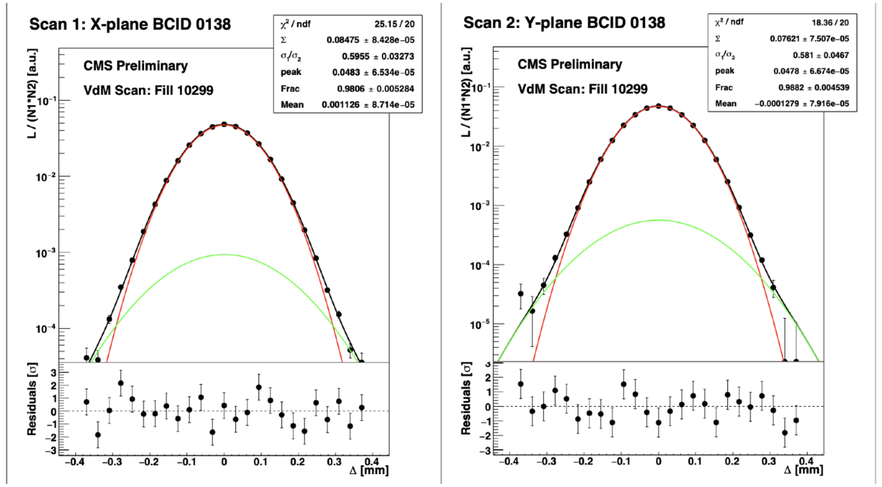

Collision runs, GEM hits matched to muon track w/ $p_T$>10 GeV, with standard FW, new FW, and emulation of the new FW

# Successful VdM scans for ppRef and PbPb

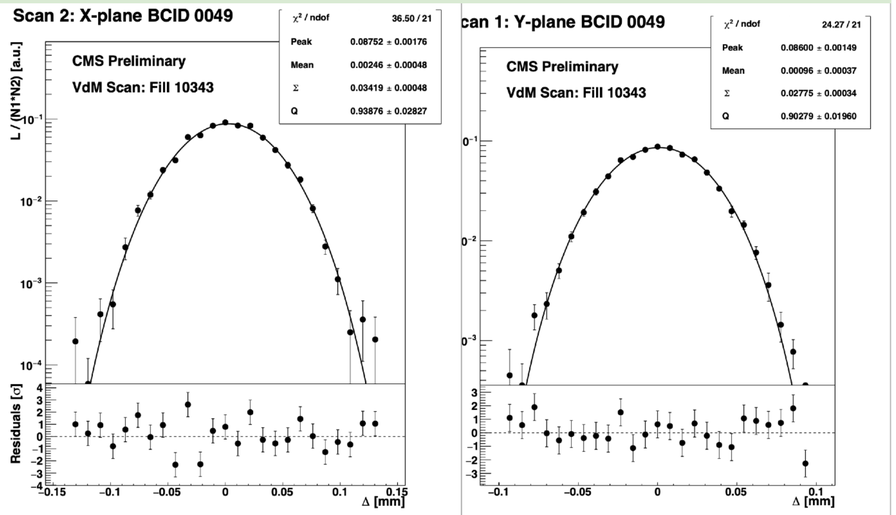
Essentially identical programs lasting about 6 hours were run for both ppRef and PbPb




## ppRef Example Fit




## PbPb Example Fit

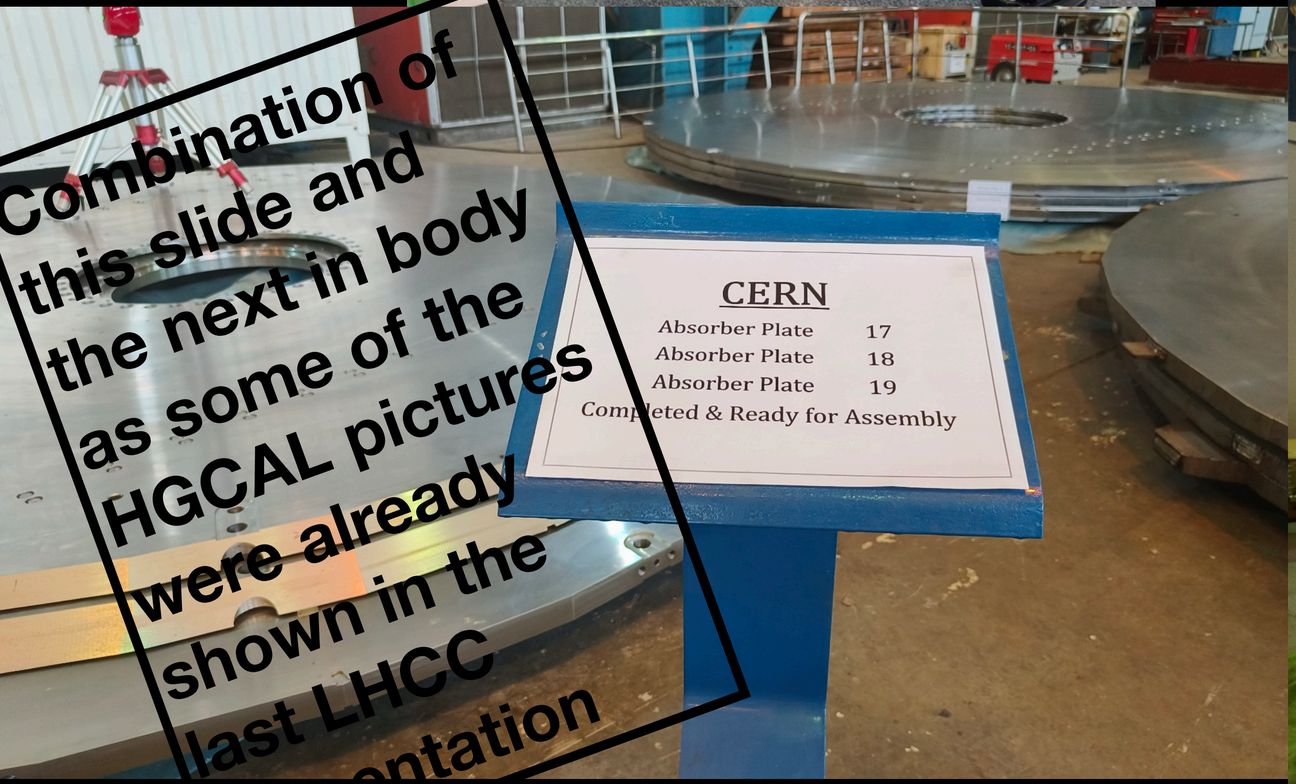


# HGCAL mechanics in production

end-flange wedge

Inner Cylinder Pack at QC

pre-production cooling plate QC




Combination of this slide and the next in body as some of the HGCAL pictures were already shown in the last LHCC entation

Absorber plate machining on track

**This marks the official starting date of the HGCAL structure assembly in Pakistan**

# Tracker mechanics in production

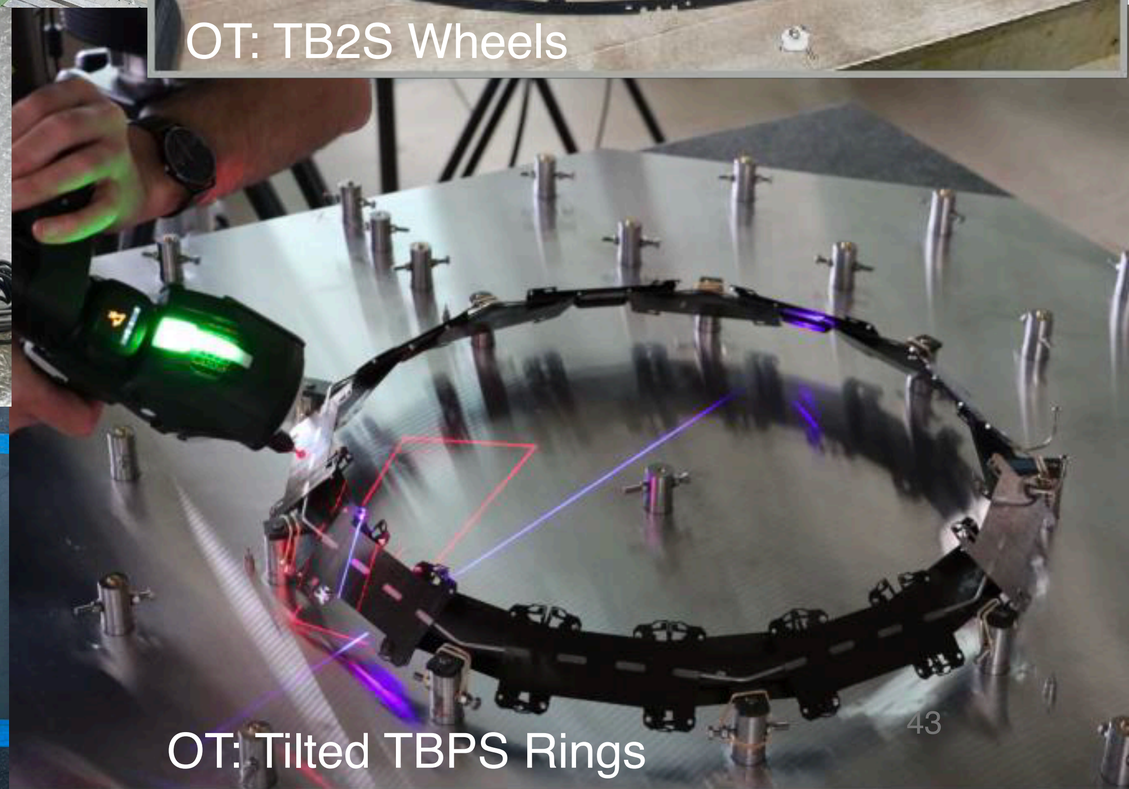

Production OT DEE

BTST load test after transport incident – All OK


OT: TB2S Wheels


IT: Bent Titanium pipes


IT : Carbon foam cured to carbon fiber sheets


OT: Tilted TBPS Rings