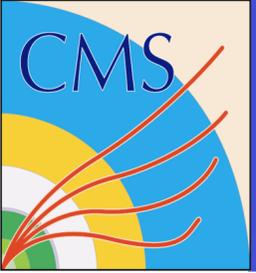


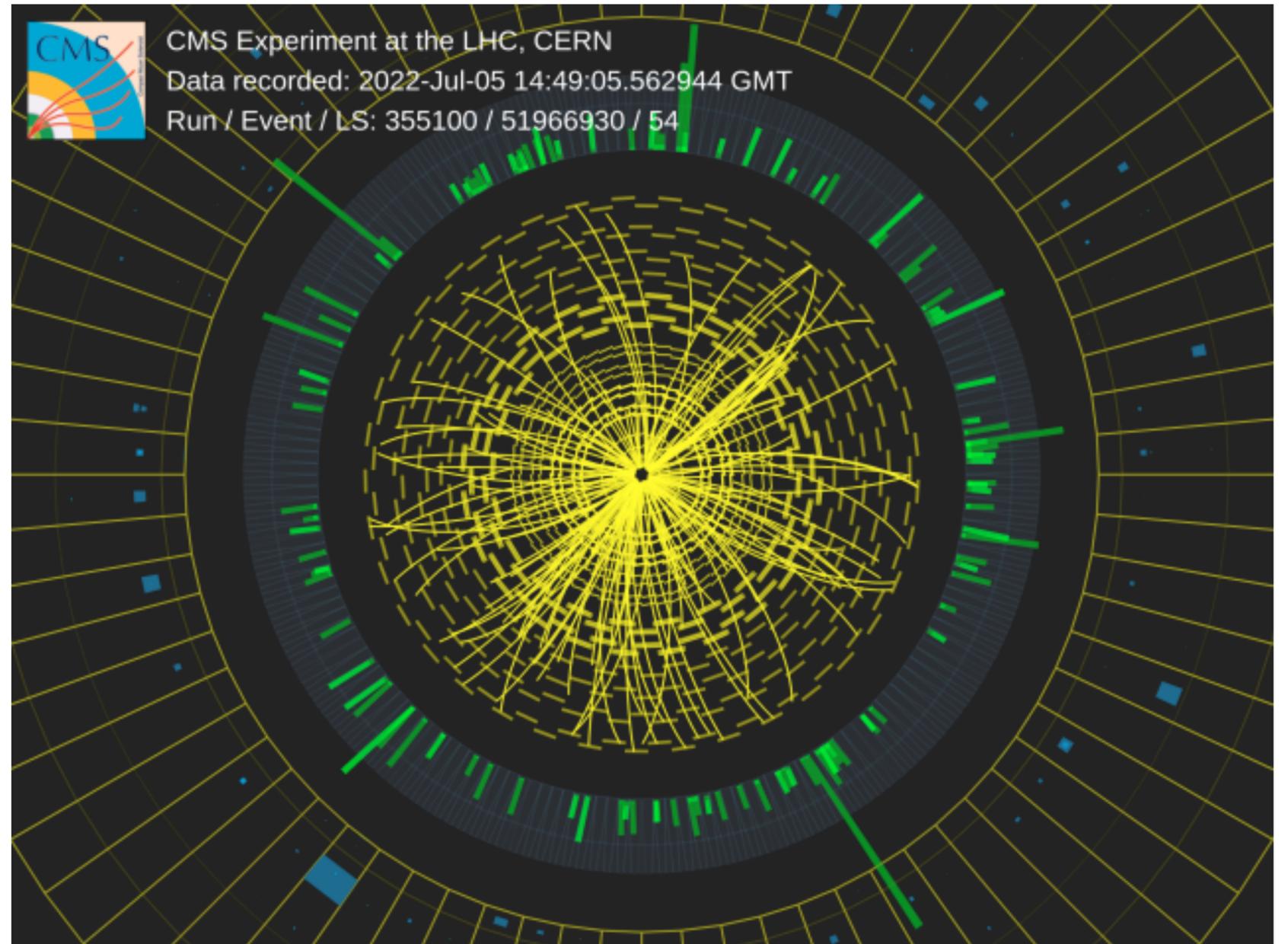
CMS Status Report

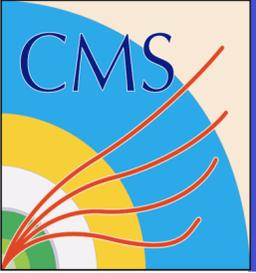
A. Tapper for the CMS collaboration



Outline

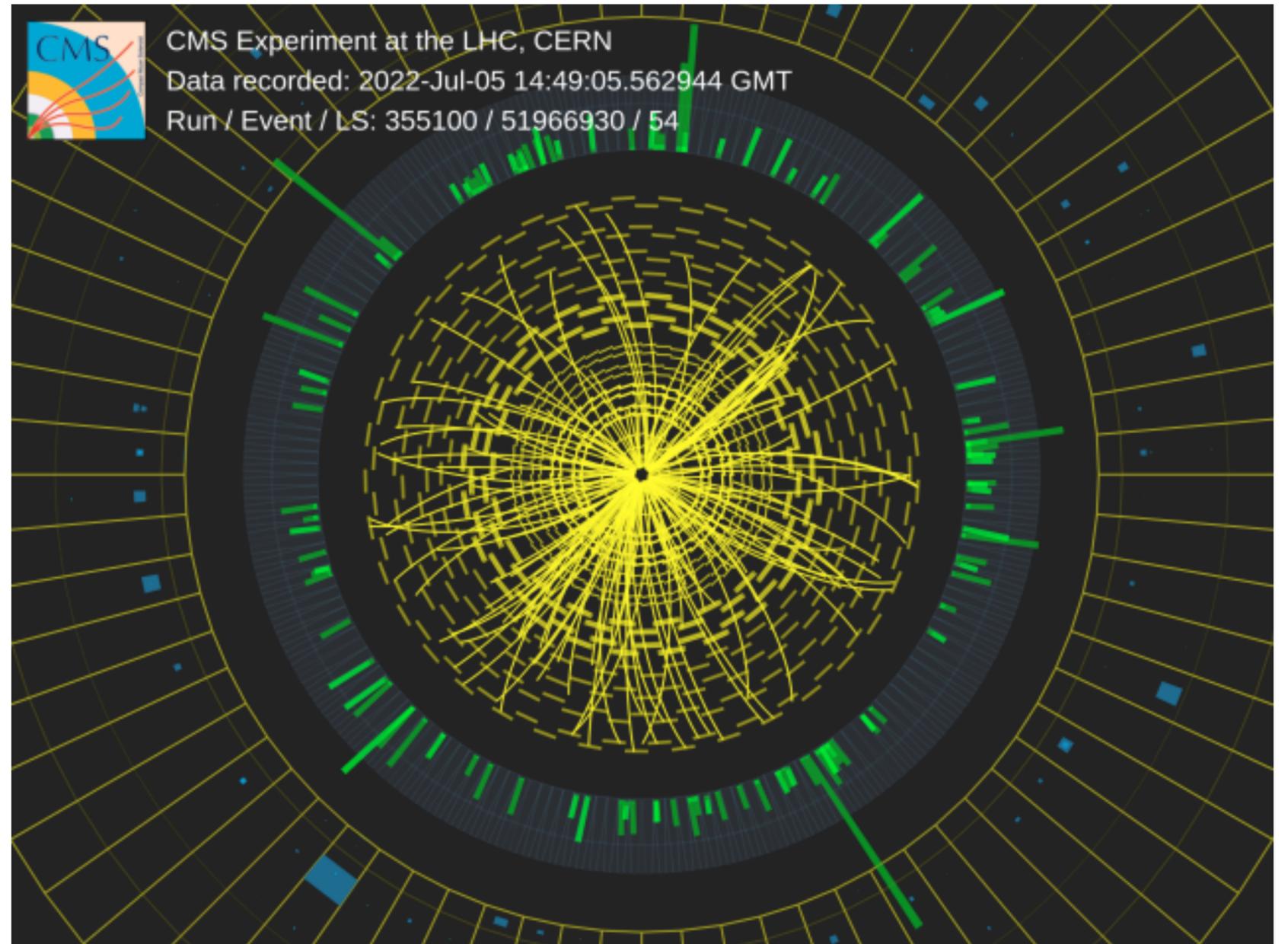
- Run 3 performance
- Physics analysis highlights
- Upgrade status

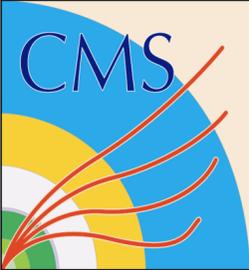




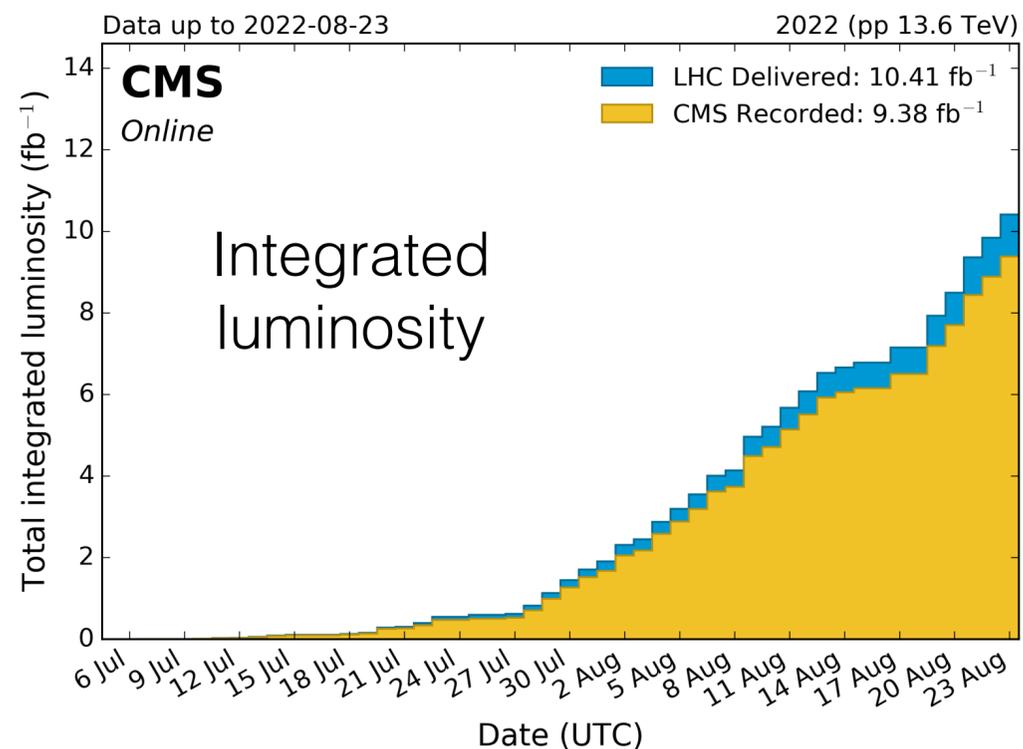
Outline

- Run 3 performance
- Physics analysis highlights
- Upgrade status





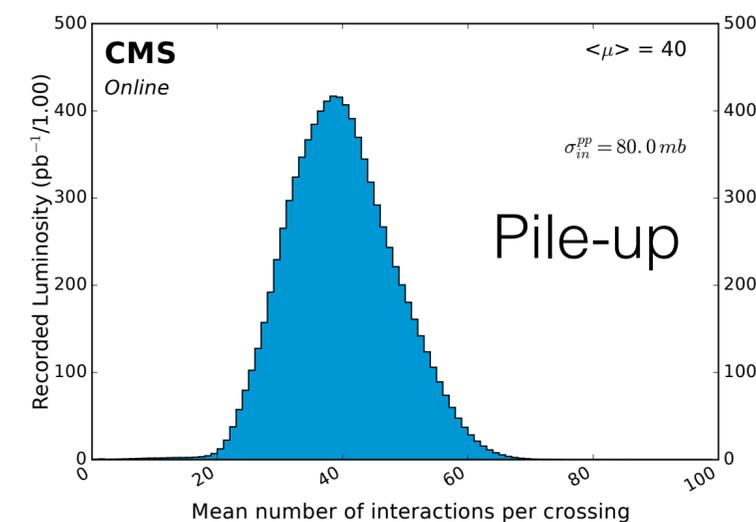
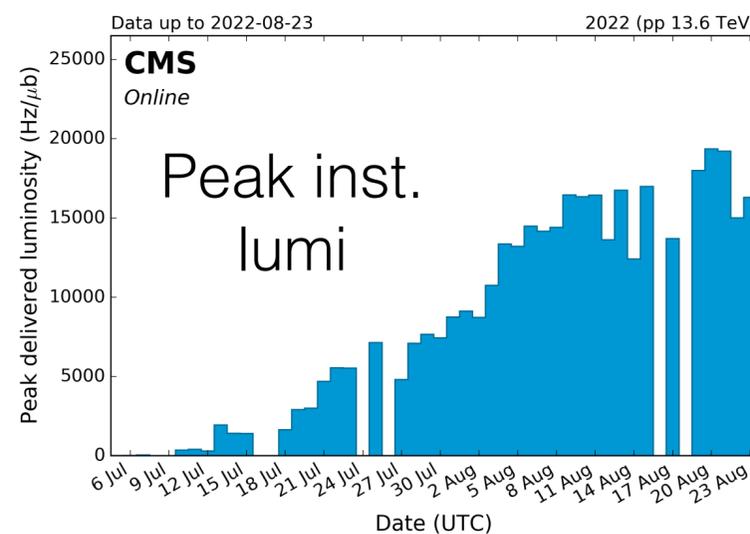
Run 3 so far ...

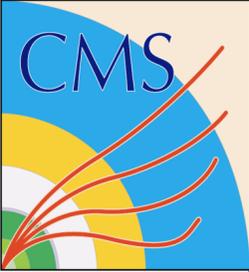


- Teething problems fixed promptly
- Similar efficiency to Run 2 (2015)
- Big thanks to LHC!!

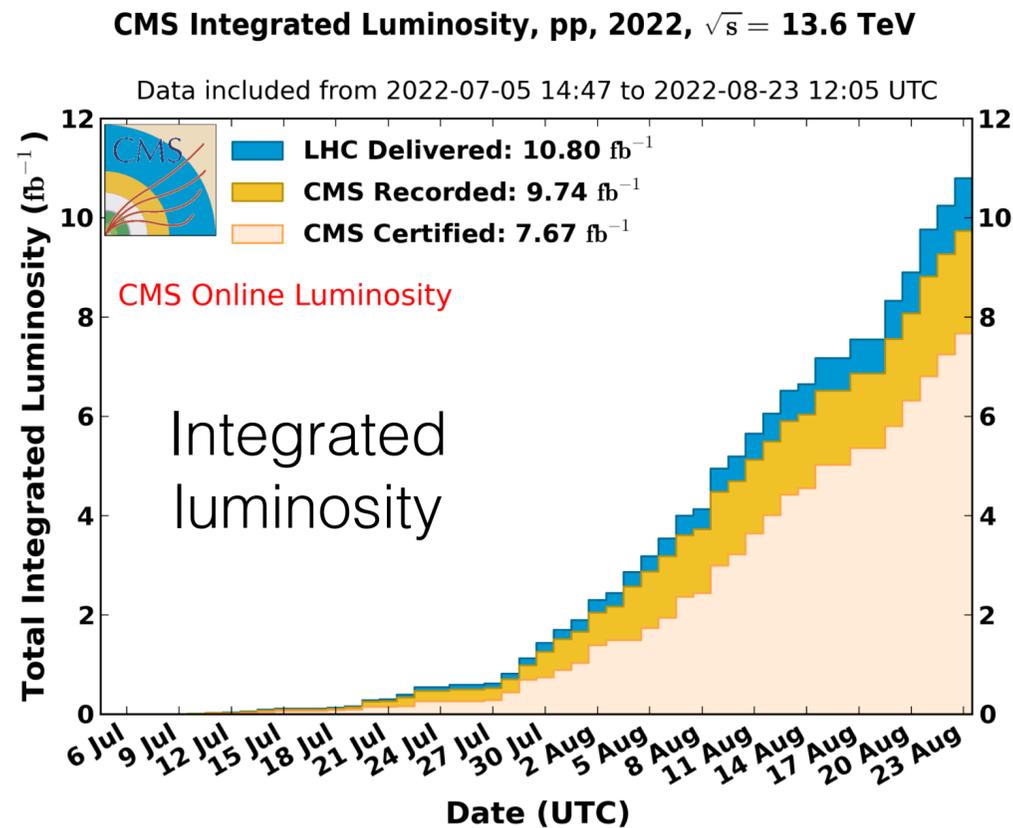
- In numbers:

- ▶ Over 10 fb⁻¹ delivered @13.6 TeV
- ▶ 90.2% data taking efficiency





Run 3 so far ...



- In numbers:

- ▶ Over 10 fb⁻¹ delivered @13.6 TeV
- ▶ 90.2% data taking efficiency
- ▶ 67% - 83% certification efficiency (improving)

- Improvement of tools and procedures for calibrations and data certification in many areas

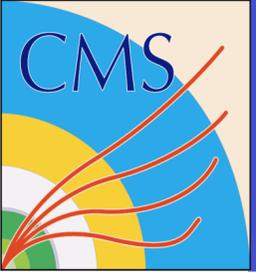
- ▶ For example, PCL (Prompt Calibration Loop) workflows ↓

- PCL workflows in Run 2 (end of 2018)

BeamSpot (4 wfs)	SiStrips Quality	SiStrips Gains	ECAL pedestals
SiPixel Alignment	SiPixel Quality	Lumi PCC	SiStripGainsAAG

- During LS2 most of these workflows were consolidated/improved and new ones were added for Run 3

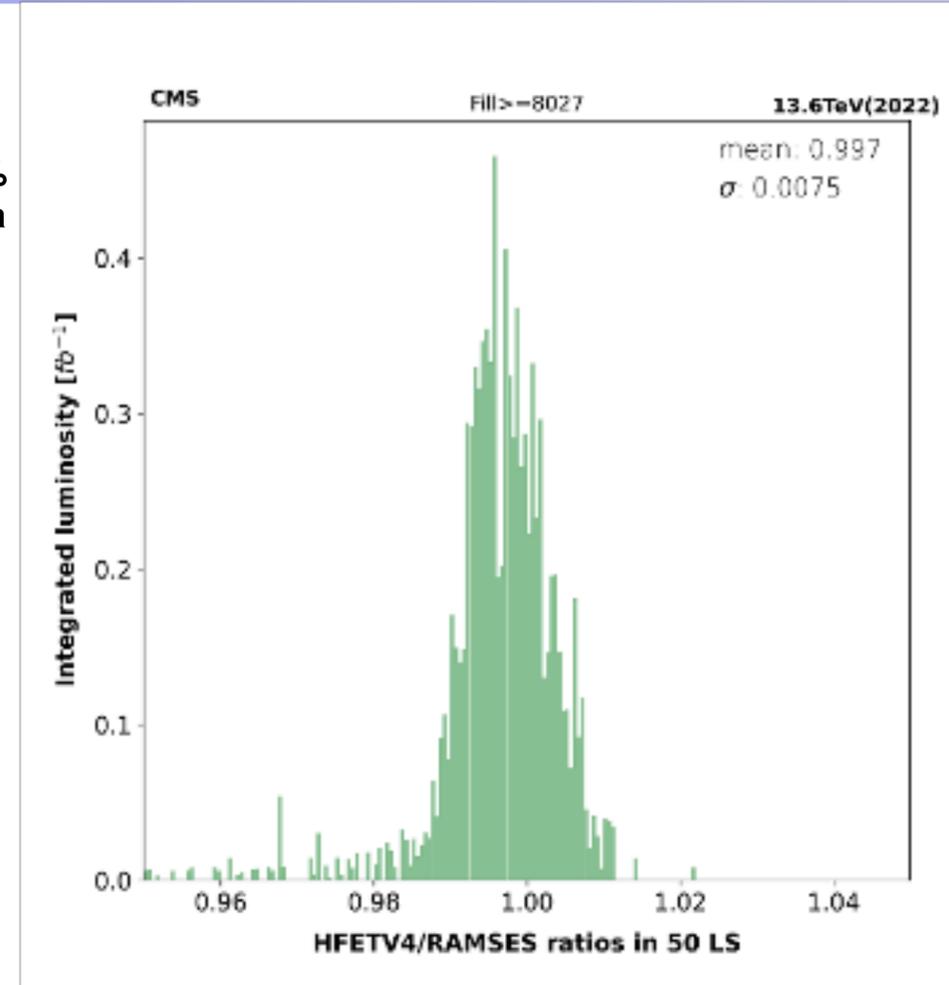
BeamSpot (4 wfs)	SiStrips Quality	SiStrips Gains	ECAL pedestals
SiPixel Alignment	SiPixel Quality	Lumi PCC	SiStripGainsAAG
SiStrip HitEff	SiPixel LA	SiPixel Ali HG	PPS Timing
PPS Sampic	PPS Alignment		



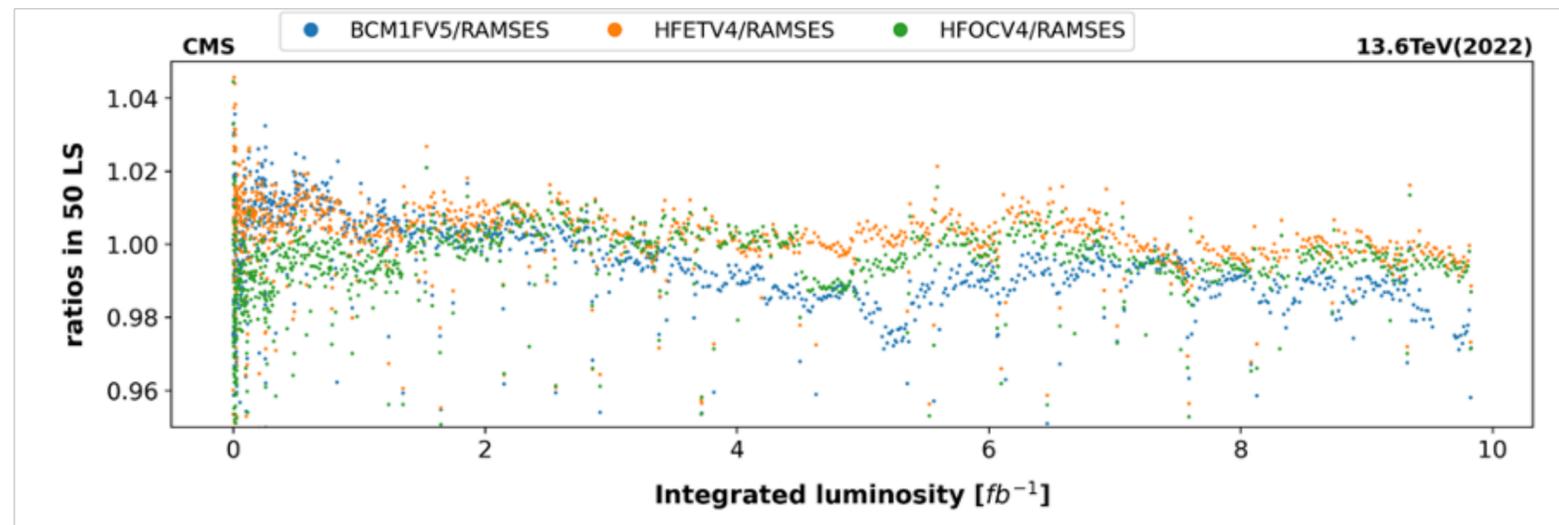
Luminosity & beam monitoring

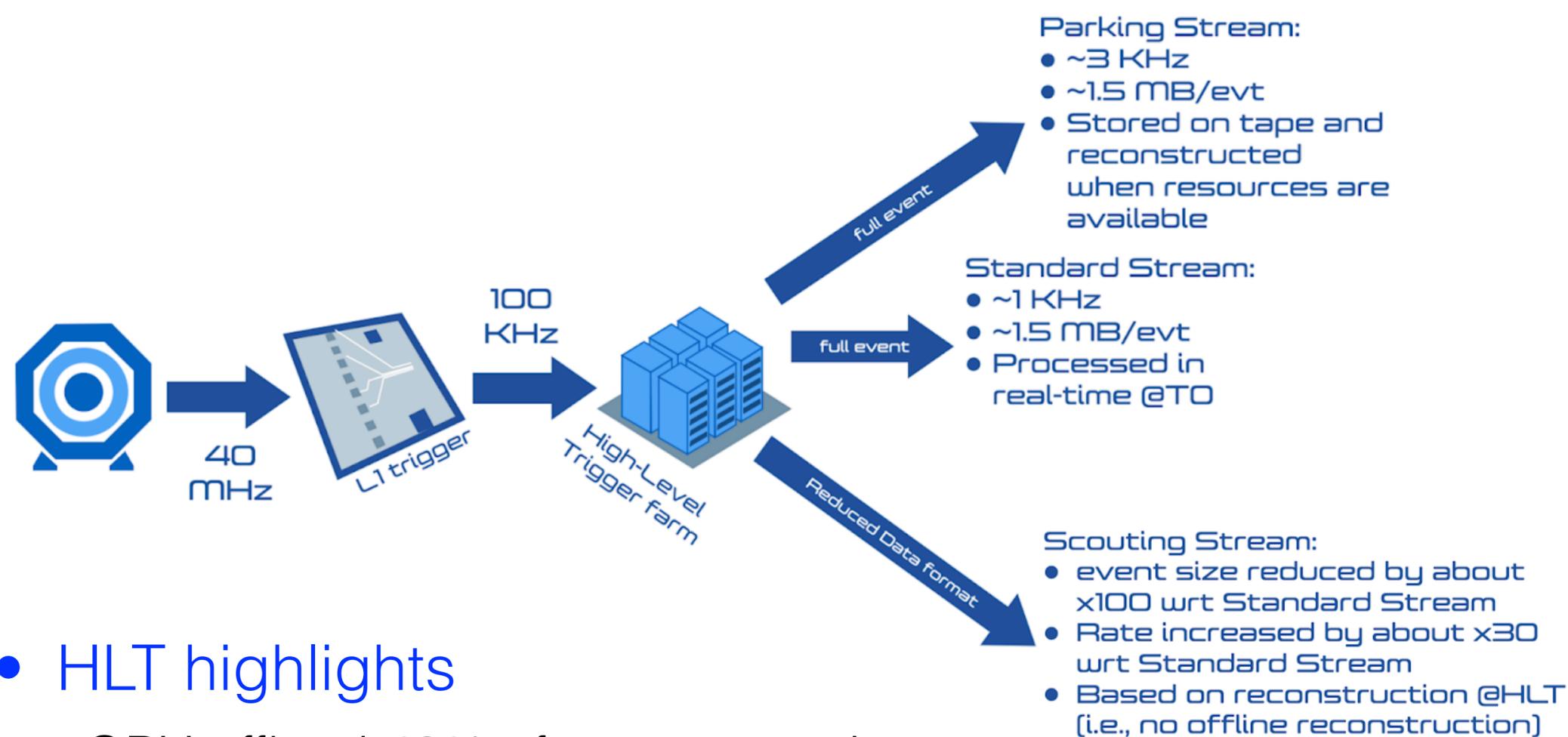
- Luminometers showing excellent performance
 - ▶ BCM1F, PLT, HFOC, HFET “calibrated” in emittance scans
 - ▶ RAMSES, DT cross calibrated
 - ▶ PCC in progress
- Background and abort systems all operational
 - ▶ Good progress with Beam Halo Monitor
 - ▶ BPTX operational — upgrade being commissioned
- Awaiting a VDM scan for better systematics

RMS better than 1%
over the Run 3 data



Over full running period all
luminometers within $\pm 2\%$



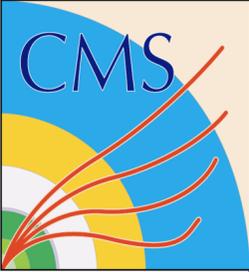


- **HLT highlights**

- ▶ GPU offload 40% of evt. processing
- ▶ Yields 70% increase in throughput
- ▶ Consistent results CPU vs GPU
- ▶ Graph Neural Network for jet tagging

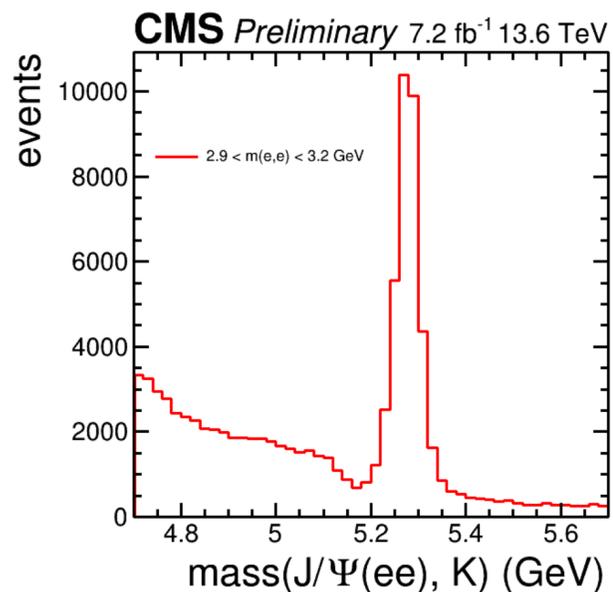
- **Level-1 Trigger highlights**

- ▶ New triggers: displaced/delayed muons/jets, low E_T double E/γ for b-physics, ...
- ▶ Impact of updates from the detectors (new pulse shape filter for HCAL, endcap muon reconstruction and shower trigger, ECAL spike noise cleaning, Kalman filter for muons...)



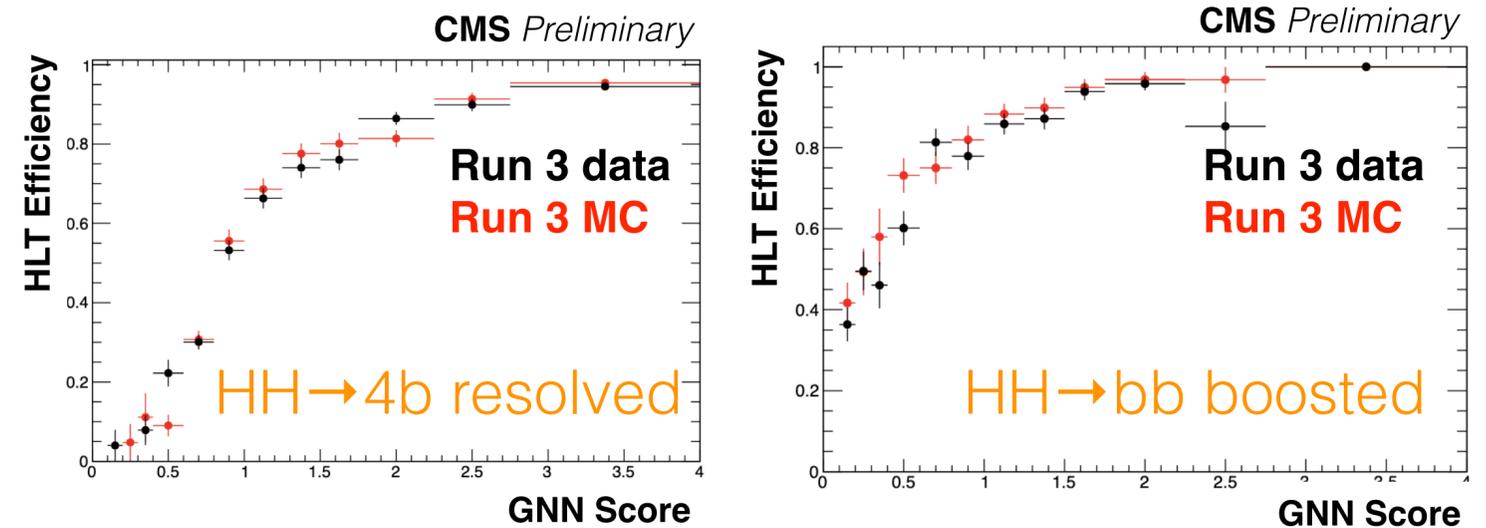
Trigger

- New B physics triggers (parking)
 - ▶ New **di-muon** triggers for $B \rightarrow \mu\mu X$ optimised requirement for different phase space
 - ▶ Also for searches $\tau \rightarrow \mu\mu\mu$, resonances etc.
 - ▶ New **di-electron** triggers for $B \rightarrow eeX$
 - ▶ Low thresholds @L1: ID and mass @HLT

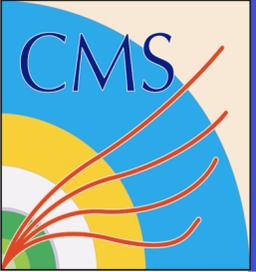


Reduced mass:
 $m(B) - m(e,e) + m(J/\Psi)$

- Jet tagging @HLT

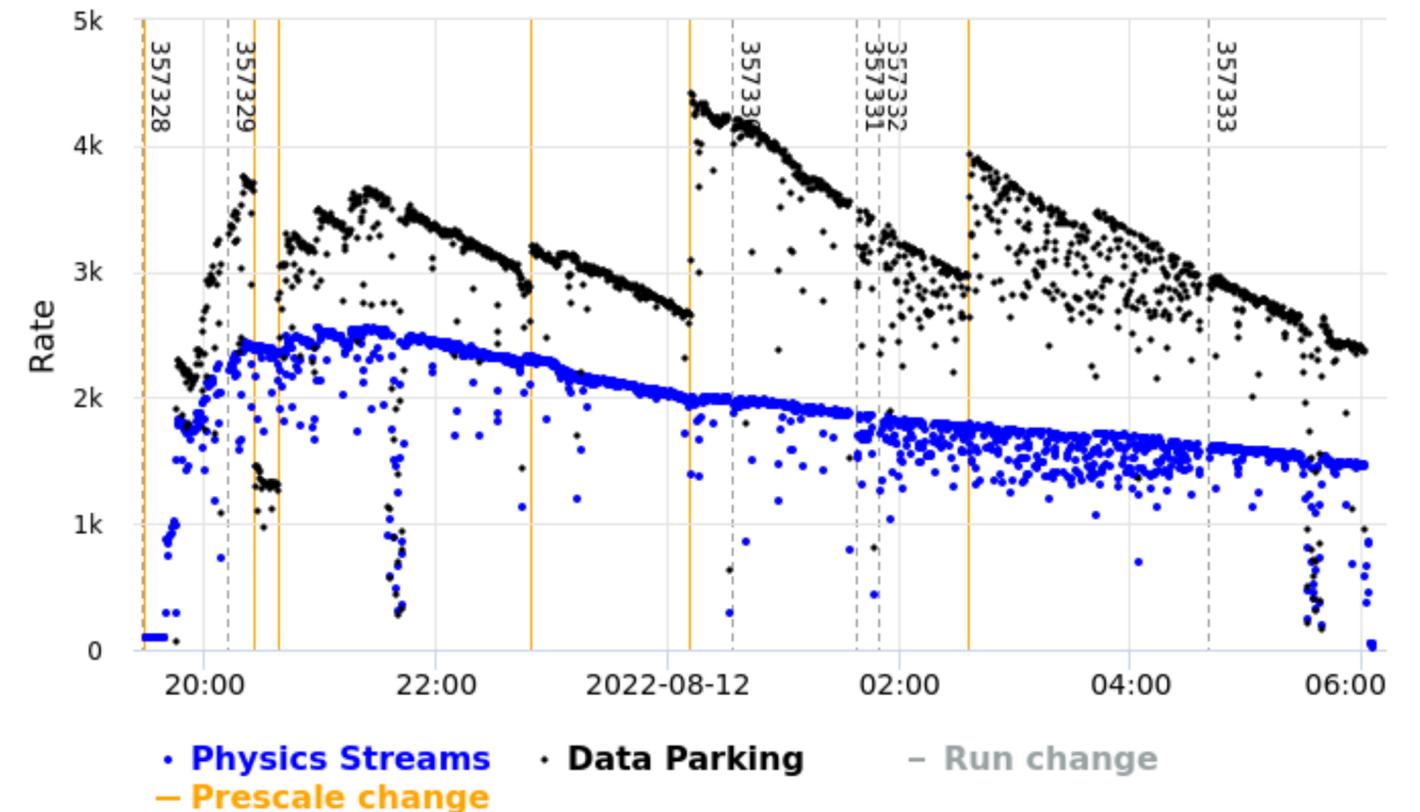


- ▶ Triggers developed for $HH \rightarrow 4b$ resolved, for boosted $H \rightarrow bb$ and boosted $H \rightarrow \tau_h \tau_h$
- ▶ Measure the efficiency of the Particle-NET b-tag or Particle-NET bb-tag based selection in a control region **in data** in which events have two real b-jets
- ▶ The monitoring runs in on-line DQM

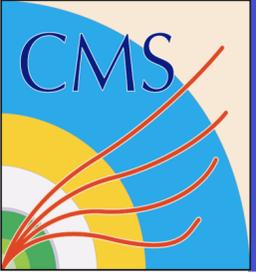


Offline & computing

- So far *Standard* and *Parking* streams successfully promptly processed at the Tier-0
 - ▶ Run 3 peak processing rates > 5 kHz
 - Run 4 like
- Introduced new compression algorithm for RAW data:
 - ▶ LZMA replaced GZIP thanks to ROOT
 - ▶ 10% smaller RAW event size
- Huge tape deletion campaign
 - ▶ 70 PB (20% of all data on tape) deleted
 - ▶ Using RUCIO for the first time for tape deletion

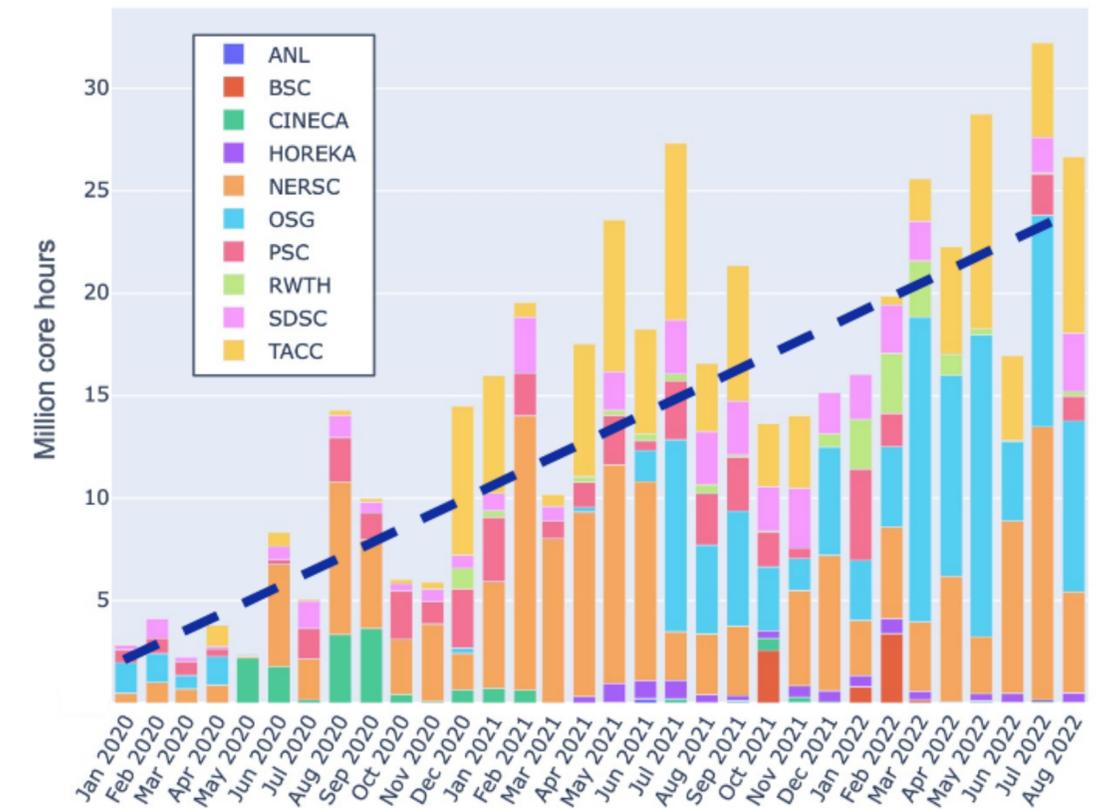


Successful prompt processing @ > 5 kHz

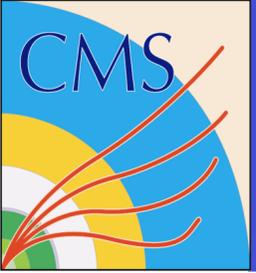


Offline & computing

- Record CPU utilisation since May: 386K CPU cores average, peak: 466K
 - ▶ Large contributions from HPCs, Run-2 HLT Cloud, and beyond-pledge contributions from our sites
- Excellent support and availability from all our sites
- Continuous growth of capacity used at HPCs
 - ▶ Transparent site extensions (e.g. RWTH, HOREKA, Marconi)
 - ▶ Allocations accessed through a service (e.g. HEPCloud, OSG)
- Full Physics Validation of samples created on the M100 HPC (Power CPUs) started last week.
 - ▶ If successful, production will start on the machine
 - ▶ Done by objects and detector experts

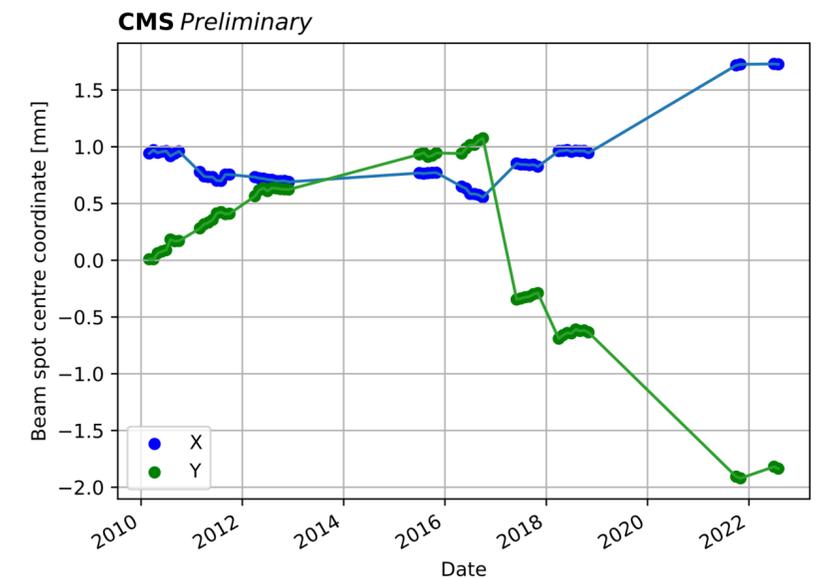
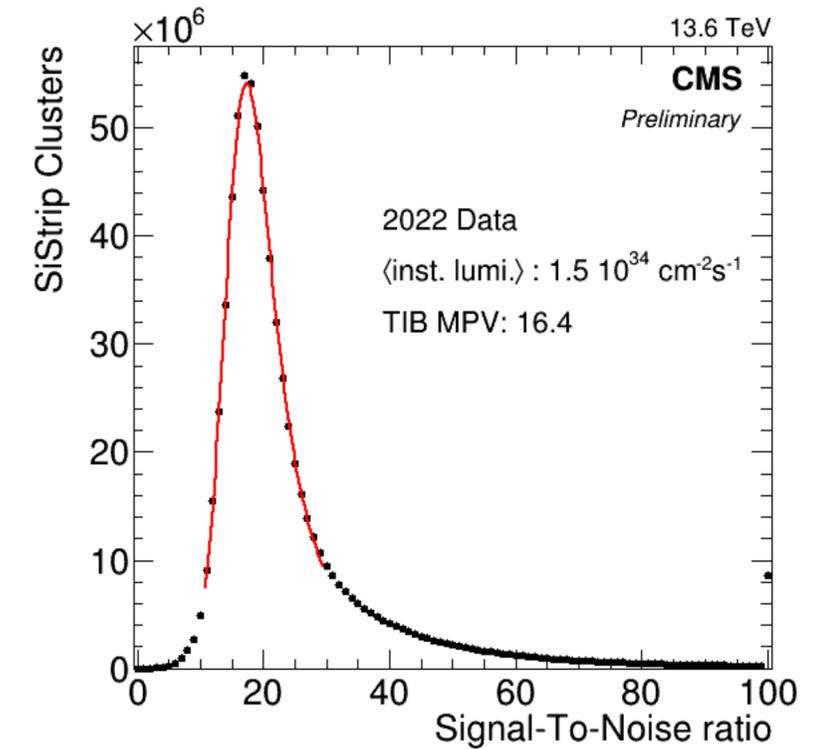


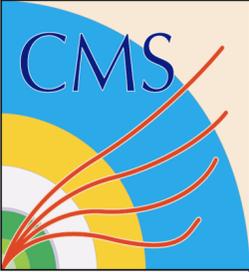
Record usage of compute capacity, usage of HPCs continues to grow.



Tracker

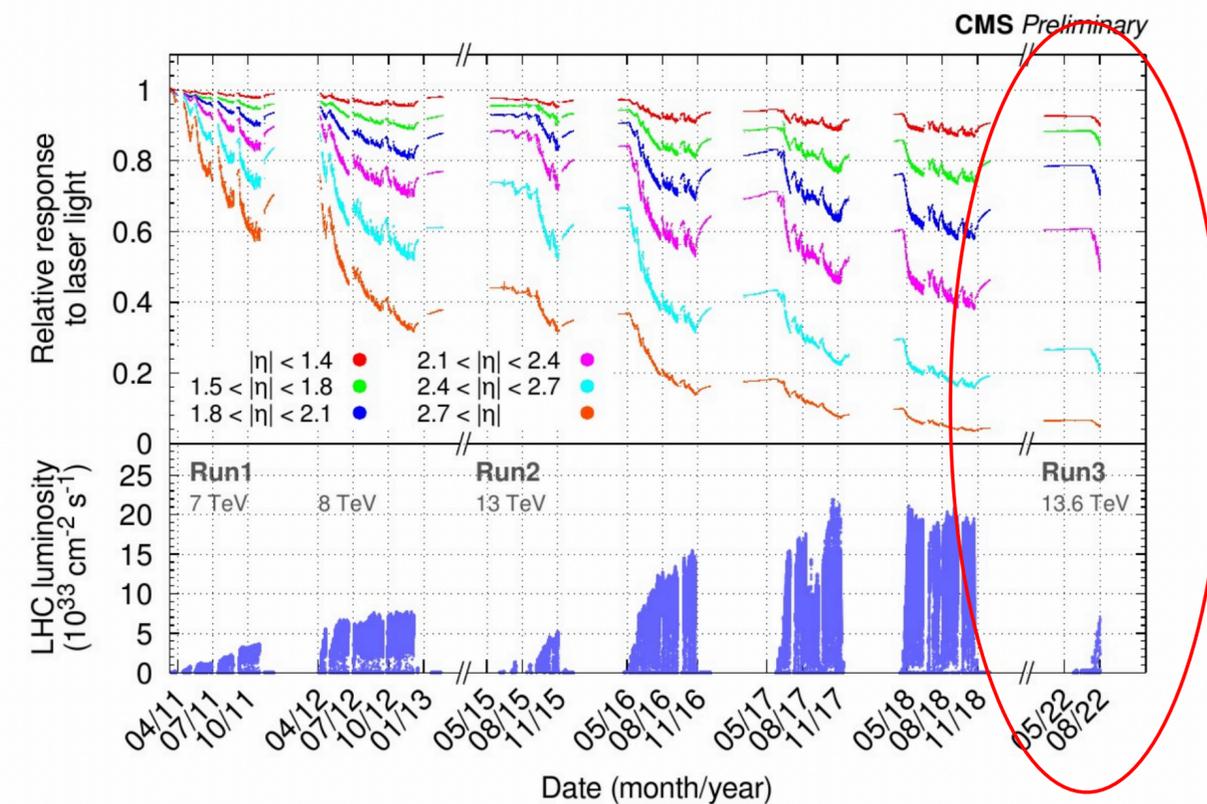
- Pixel and strip tracker running well in 13.6 TeV collisions
 - ▶ Timing and other scans for commissioning have been performed successfully →
 - ▶ **Reminder:** new Barrel Pixel Layer 1 installed in LS2 — working well
 - ▶ Number of active channels stable since last year
 - ▶ Beam spot position after LSS5 realignment well centred in **y** (vertical), will likely ask for small shift in **x** during YETS →



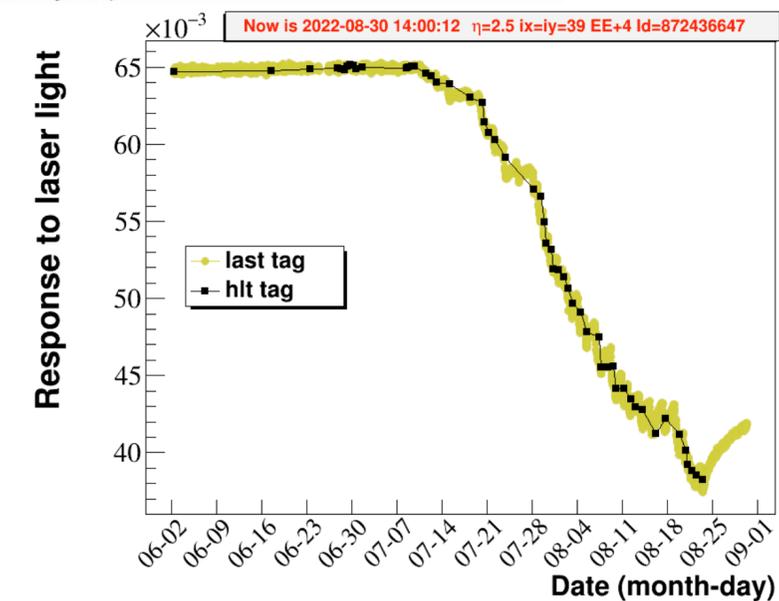


Electromagnetic calorimeter

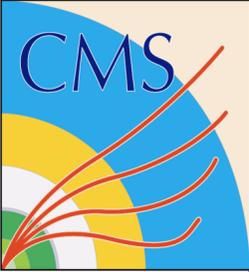
- ECAL was successfully commissioned for Run 3, with updates to pedestals, pulse shapes, calibrations, timing, etc.
- The new laser workflow, which allows updates to HLT conditions once per fill, has been successfully deployed
- The automation of calibration workflows is also being commissioned



The updated laser transparency plot, that shows the transparency at turn-on in April and the effect of collisions in Run 3

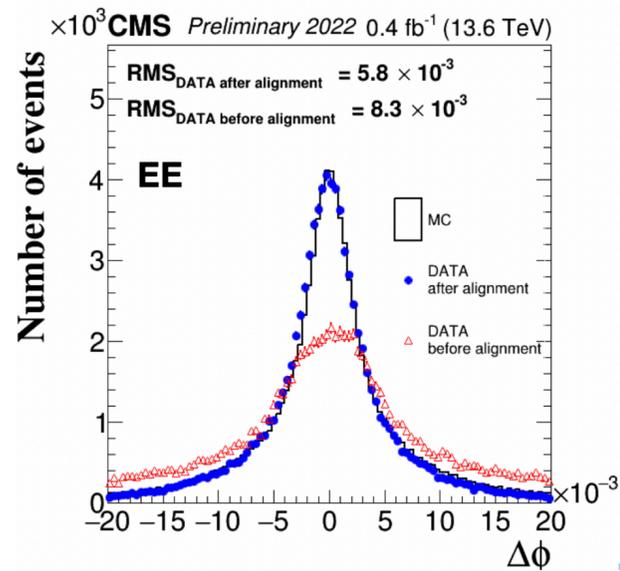


The 2022 history of one channel in EE, showing that the per-fill update of the HLT tag (which is not performed in no-collision periods) follows closely the system response.

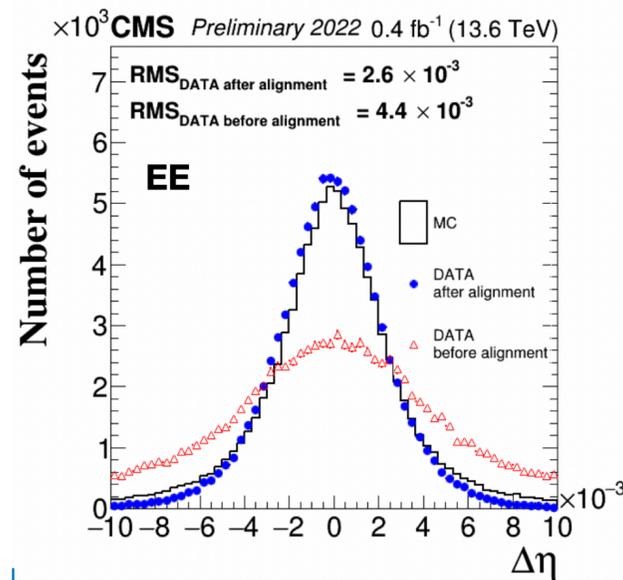


Electromagnetic calorimeter

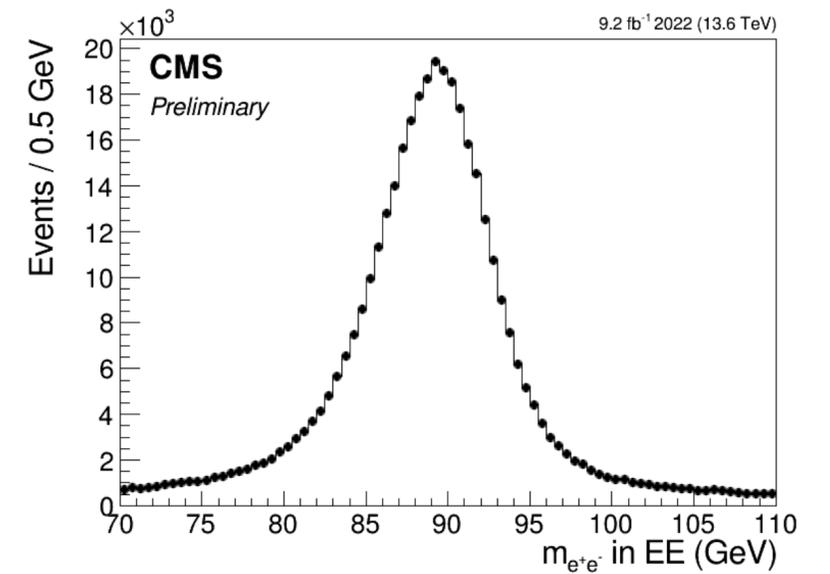
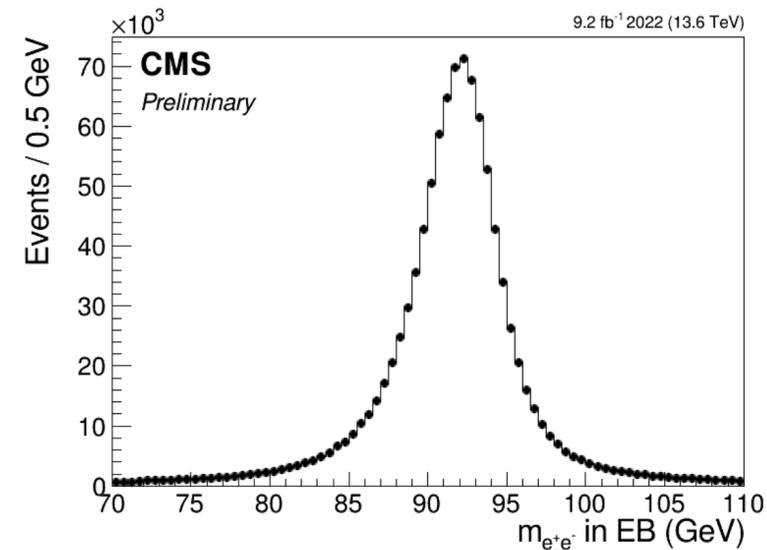
- Alignment and energy calibration are ongoing, with excellent results already

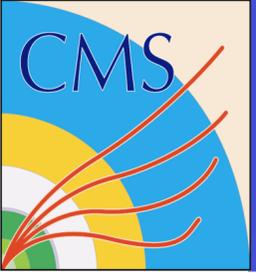


Results from alignment in ϕ and η



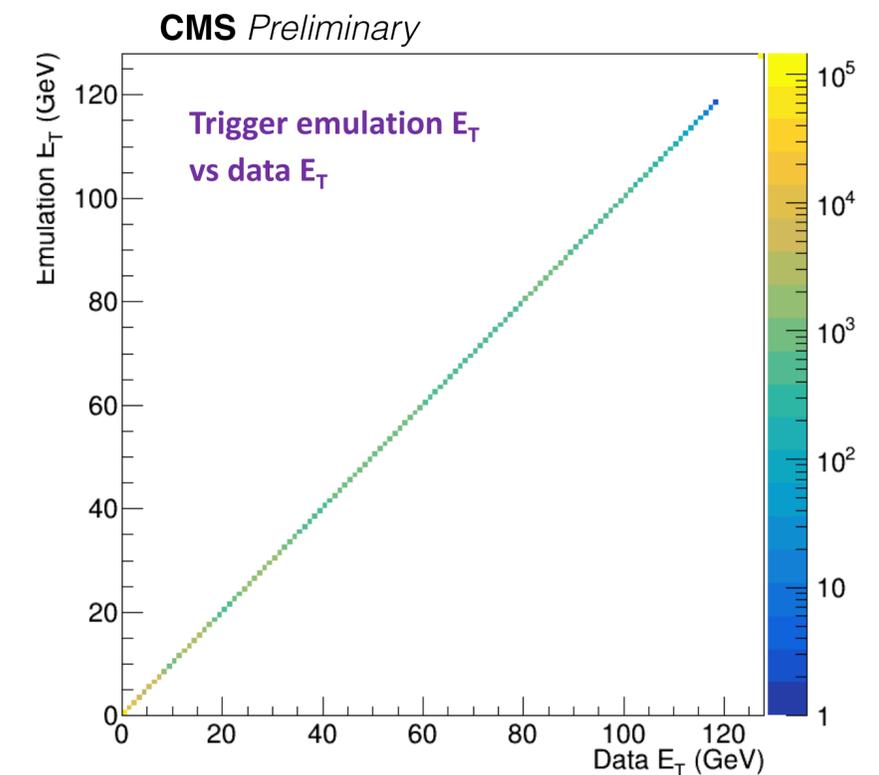
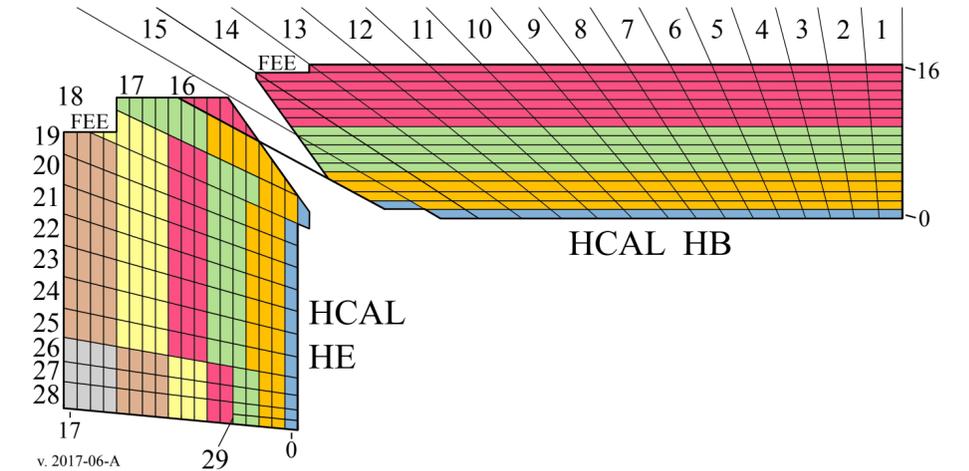
The Z peak in EB and EE. The groups are in the process of updating conditions for Run3: Noise, pedestals, pulse shapes, timing, intercalibration and energy scale

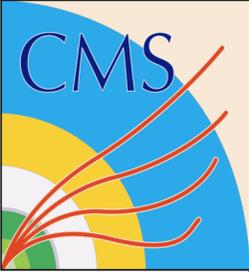




Hadronic calorimeter

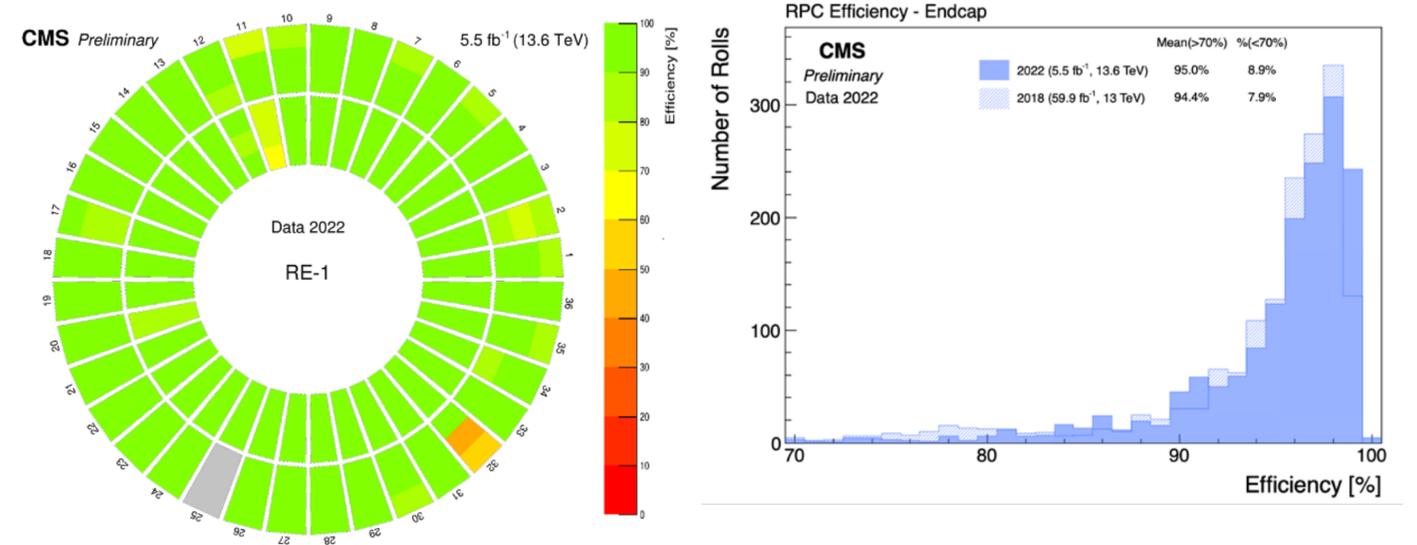
- **Reminder:** new HCAL barrel readout in LS2
- Successfully started Run 3 with timing and conditions derived using splash events and machine commissioning runs
 - ▶ Collision data to be used for channel-by-channel corrections
- Some hiccups during runs with high data volume, addressed by operations crew
- Deployed trigger algorithm that includes pile-up subtraction
 - ▶ Achieved 100% matching between data and emulation →





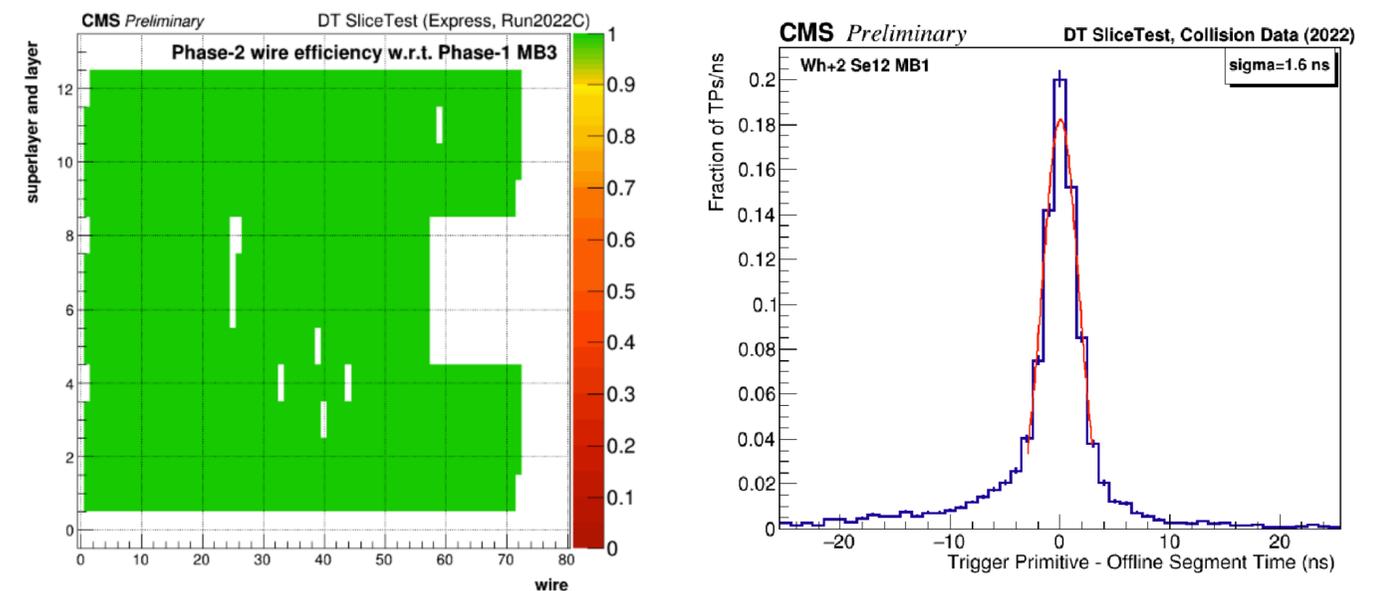
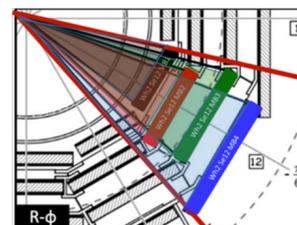
Muon detectors

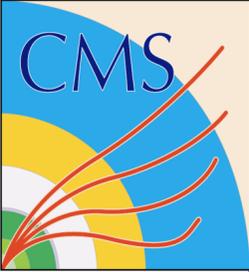
- The muon system is running smoothly
 - ▶ Online and offline analyses show detector performance in agreement with Run 2 results



Endcap RPC efficiency

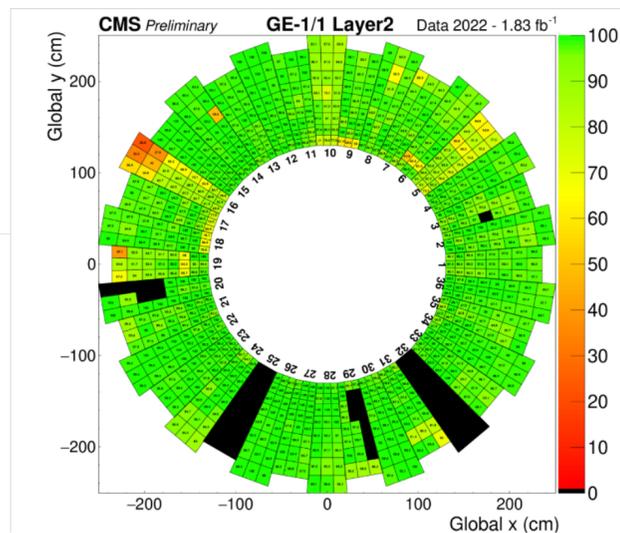
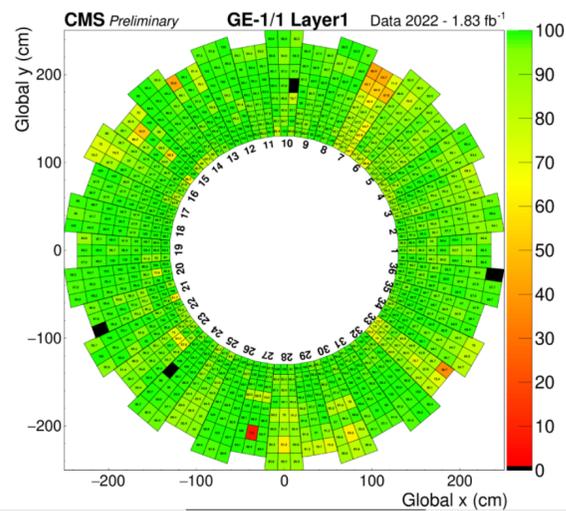
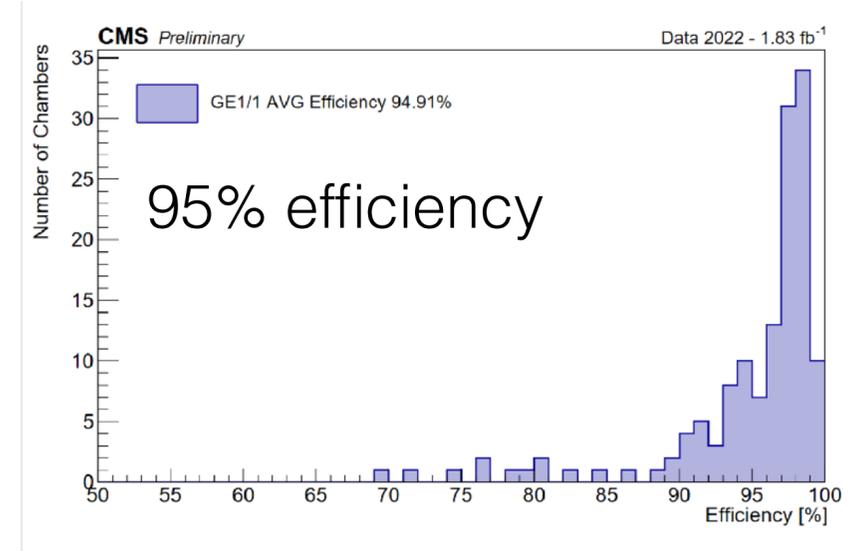
- Drift Tube Phase-2 slice demonstrator, equipped with both the legacy system and the new Phase-2 on-board electronics
 - ▶ Inter-channel response synchronised to few ns precision
 - ▶ Phase-1 and Phase-2 hit efficiency are in agreement
 - ▶ Phase-2 trigger primitive timing resolution comparable to the offline reconstruction



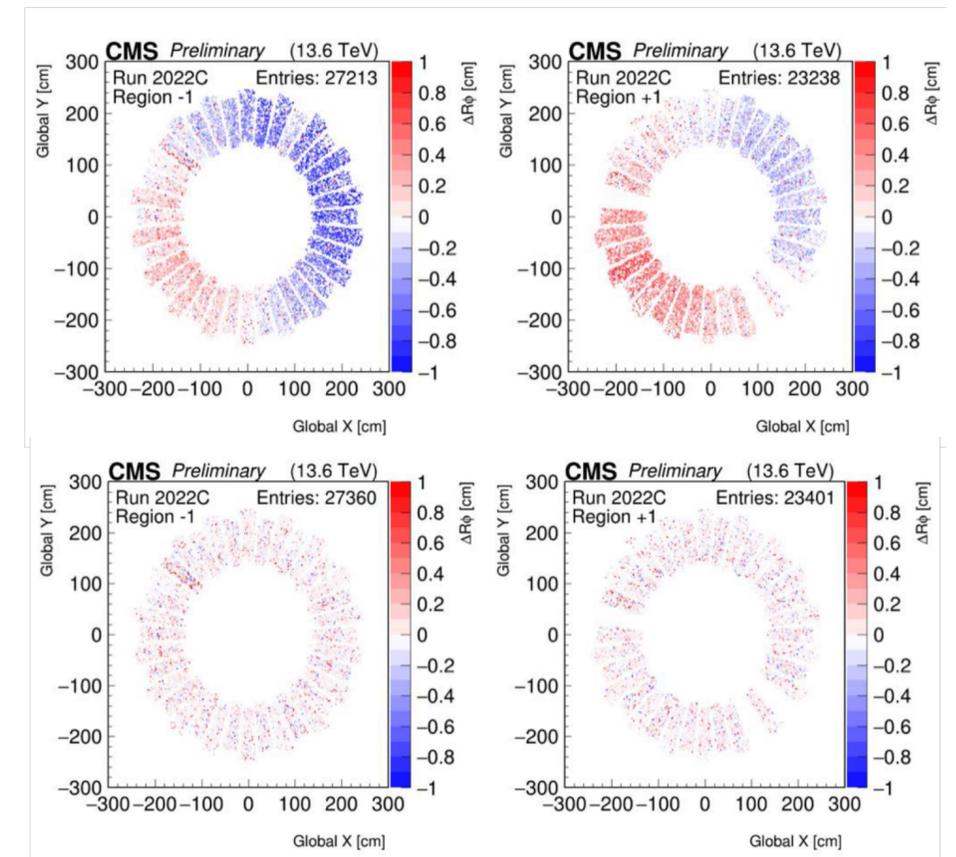
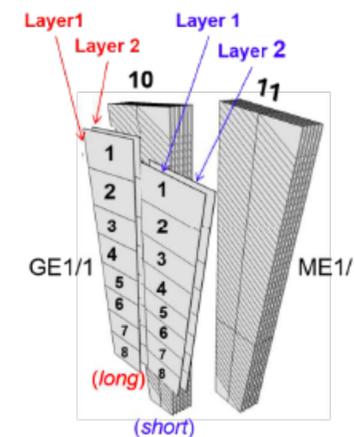


Muon detectors: GEM

- **Reminder:** Early partial installation of GEM detectors for Phase-2 upgrade
- High number of trips in several chambers observed with the first Run 3 fills
 - ▶ Immediate response: lower HV working point and induction gap off — decreased spike rate
 - ▶ HV scan was performed to fine tune the HV working point, chamber by chamber
 - ▶ Preliminary results obtained for HV working point at 690 μA (nominal value 700 μA)
 - ▶ Further optimisation expected to recover efficiency

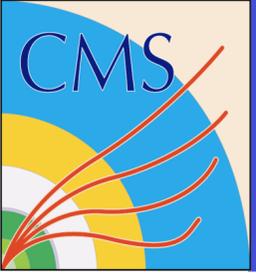


New back-propagation method for GEM alignment applied, consisting of six misalignment parameters, 6 DOF alignment, significantly improves accuracy of relative alignment between GEM and CSC chambers



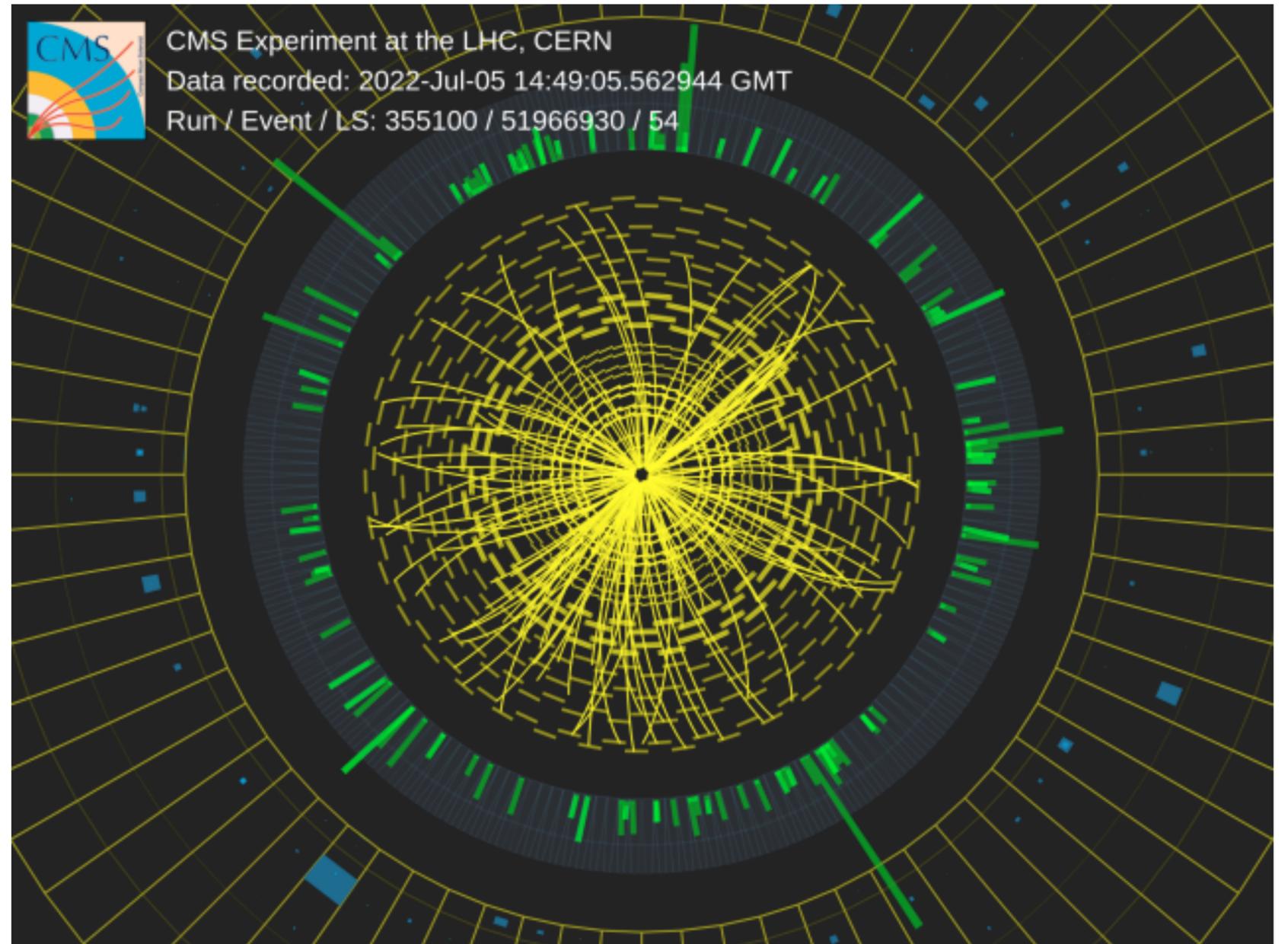
Before

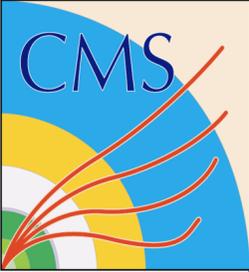
After



Outline

- Run 3 performance
- Physics analysis highlights
- Upgrade status



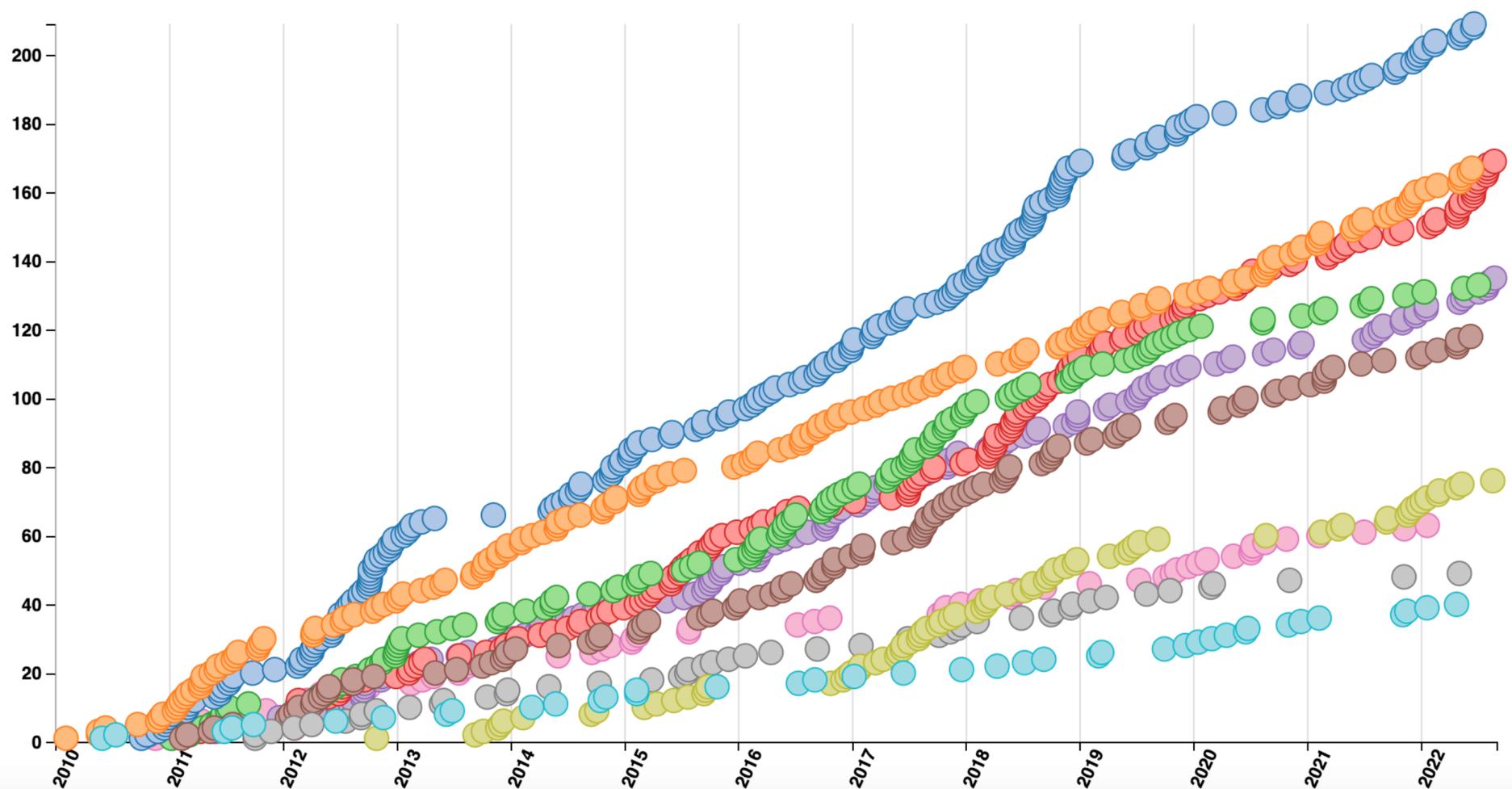


Physics results & publications

Show all Total Exotica Standard Model Supersymmetry Higgs Top Heavy Ions

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

1159 collider data papers submitted as of 2022-08-27



<http://cms-results.web.cern.ch/cms-results/public-results/publications-vs-time/>

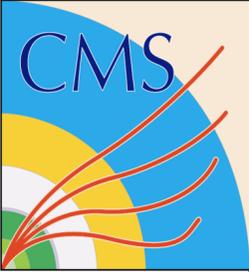
- **1159 papers** on collider data published or submitted to a journal

Since last LHCC:

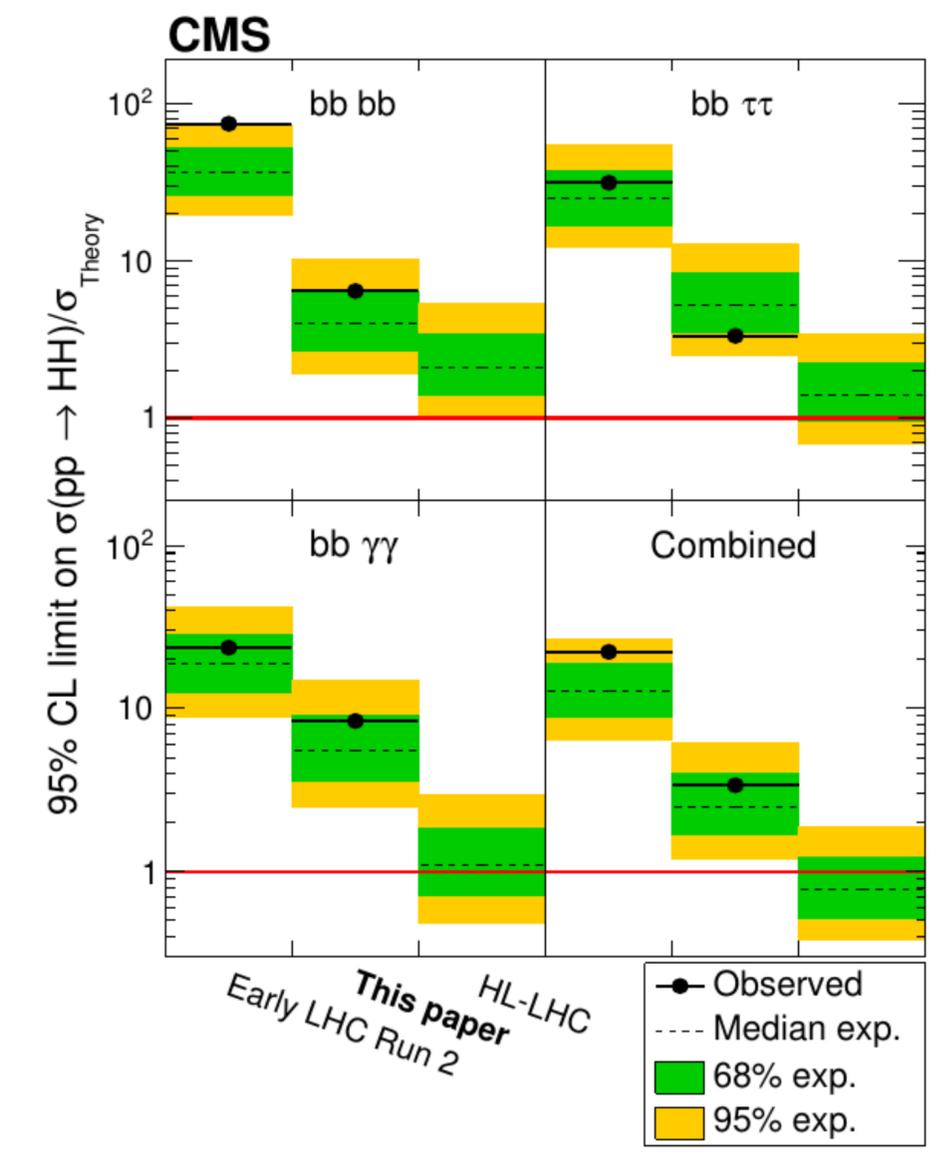
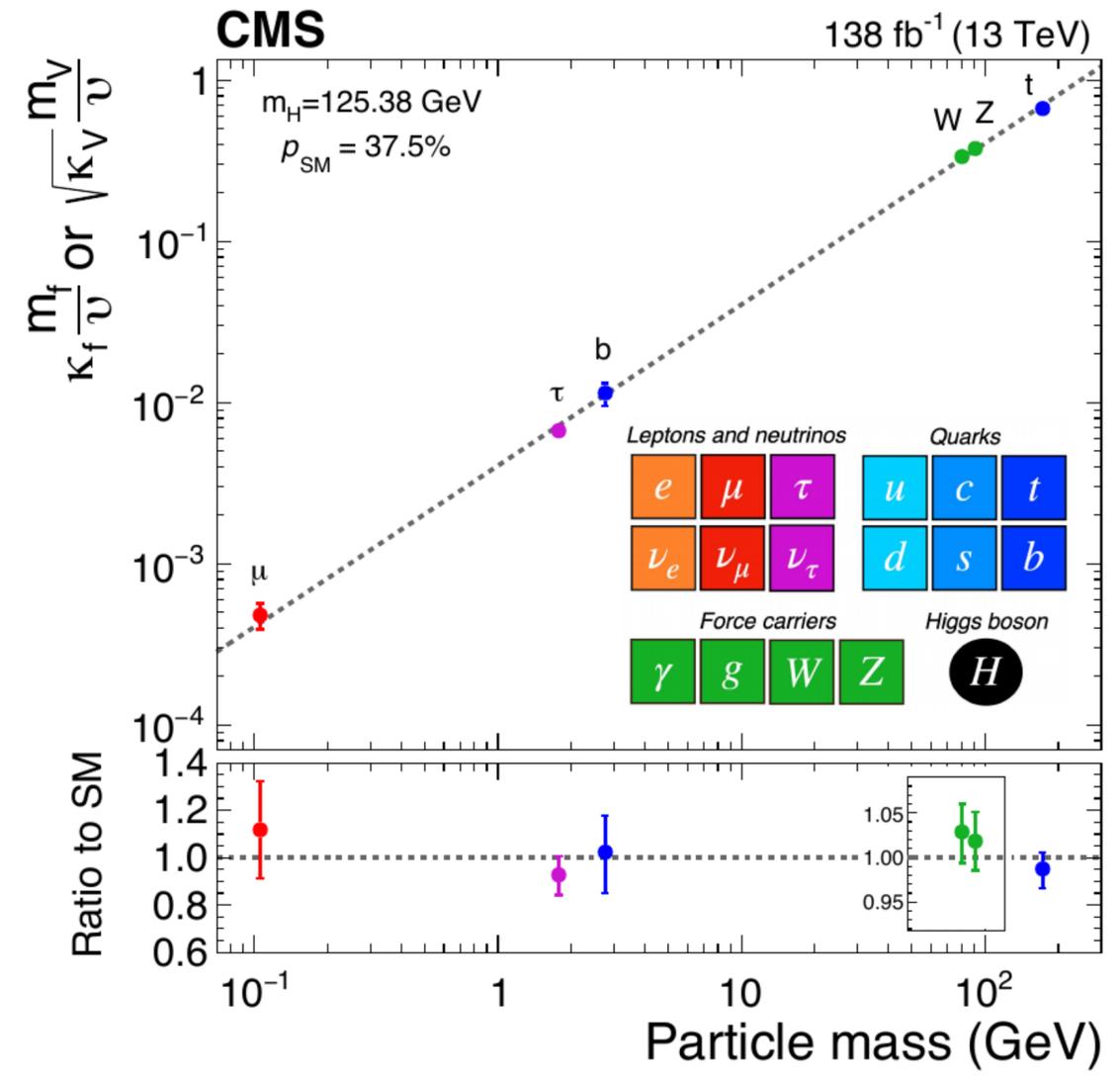
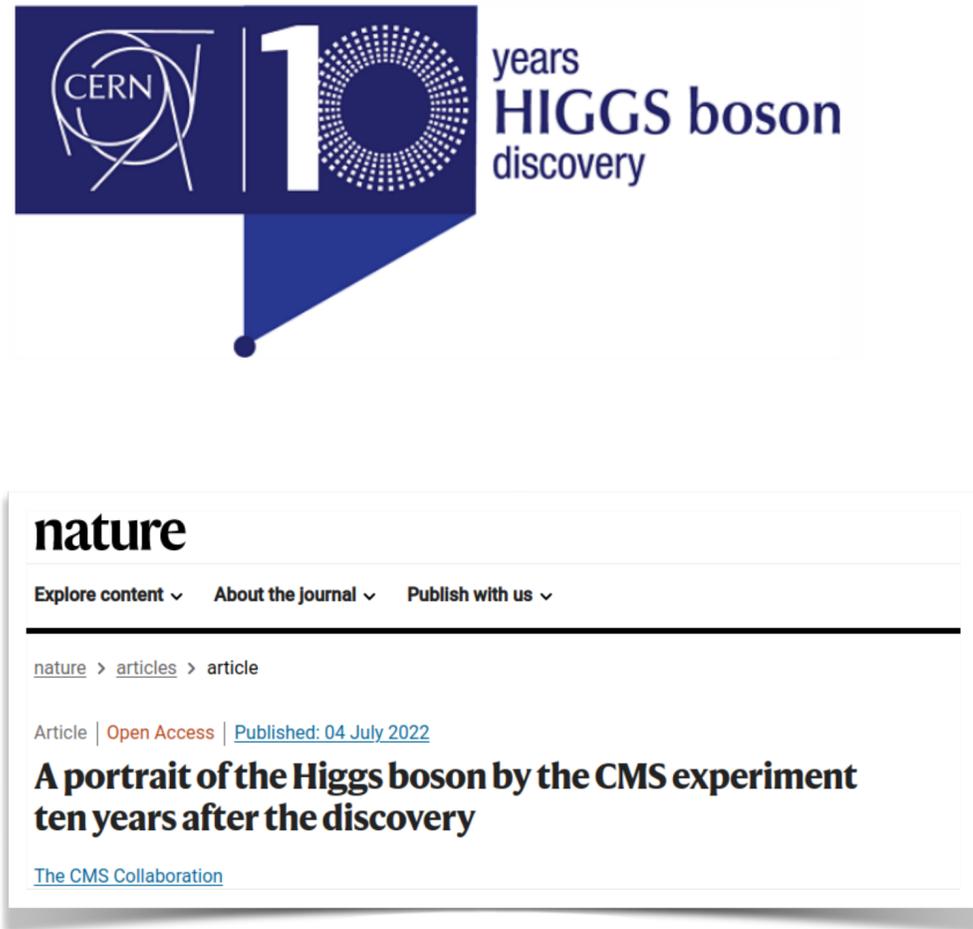
- **26 new publications**
- **20 papers submitted**
- **18 analyses** in Collaboration Wide Review (CWR) or beyond – final journal submission or publication expected soon
- **6 approved results** released as Physics Analysis Summaries (PAS)

Analysis in progress

- Run 2 data analysis continues >100 analysis efforts ongoing
- Run 3 early data analysis foresee ~100 analyses in the first couple of years
- First preliminary result with Run 3 data presented at TOP2022 — more to come

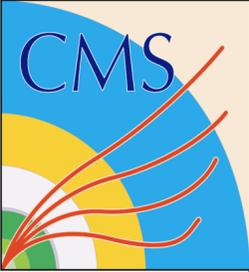


Ten years of the Higgs



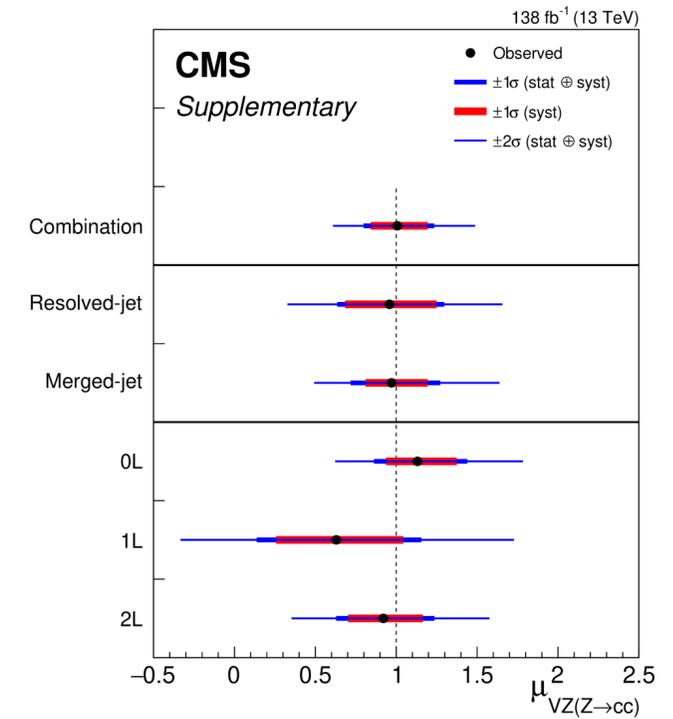
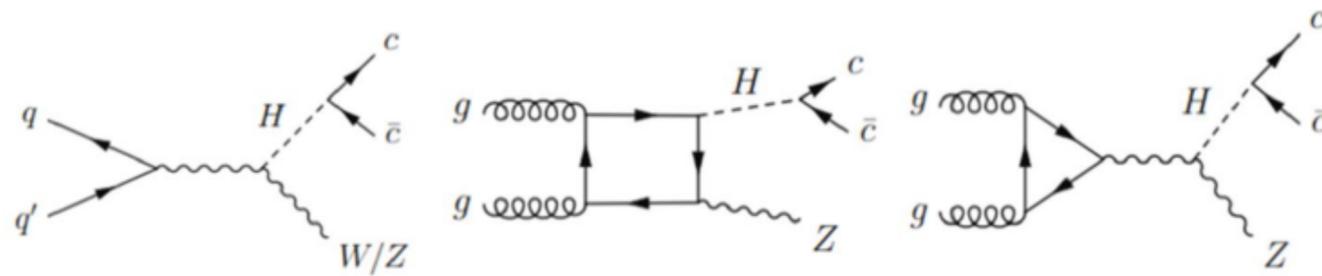
- Combination of multiple results fitting for coupling modifiers
- Combination of HH results for the three most sensitive channels (4b, 2b2τ, 2b2γ)
 - Reaching ~3x SM sensitivity, expect SM sensitivity with HL-LHC

All details in [our Nature paper](#)

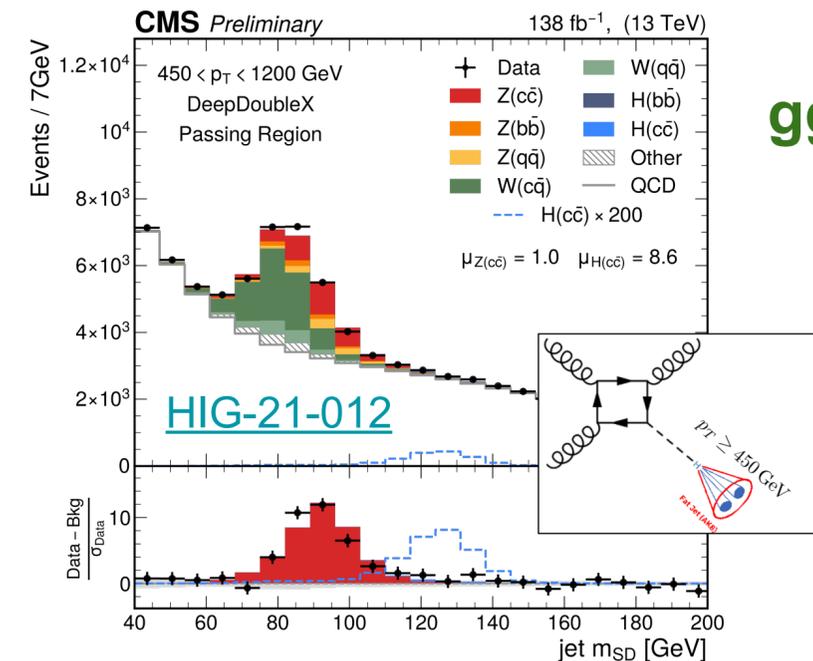
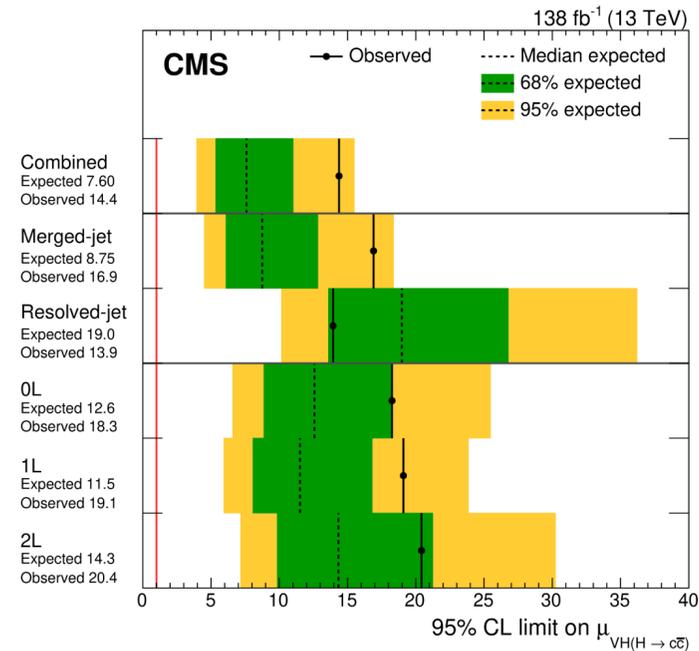
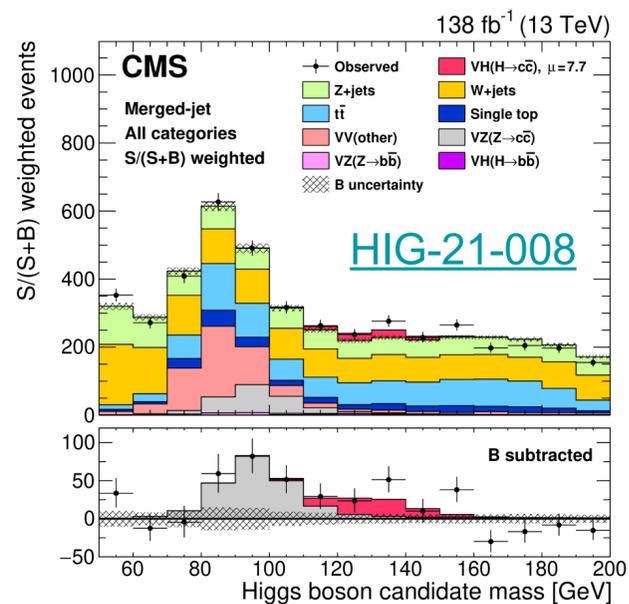


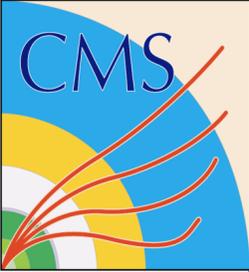
Higgs coupling to charm

- Coupling to charm is **extremely challenging** to measure at SM value
- CMS developed **new charm tagging techniques** based on Graph Neural Networks
- Sizeable sensitivity improvement ($\sim 10\times$ SM sensitivity)
- Calibration candle is the $Z \rightarrow cc$ decay (bonus 5σ observation of $Z \rightarrow cc$) \rightarrow

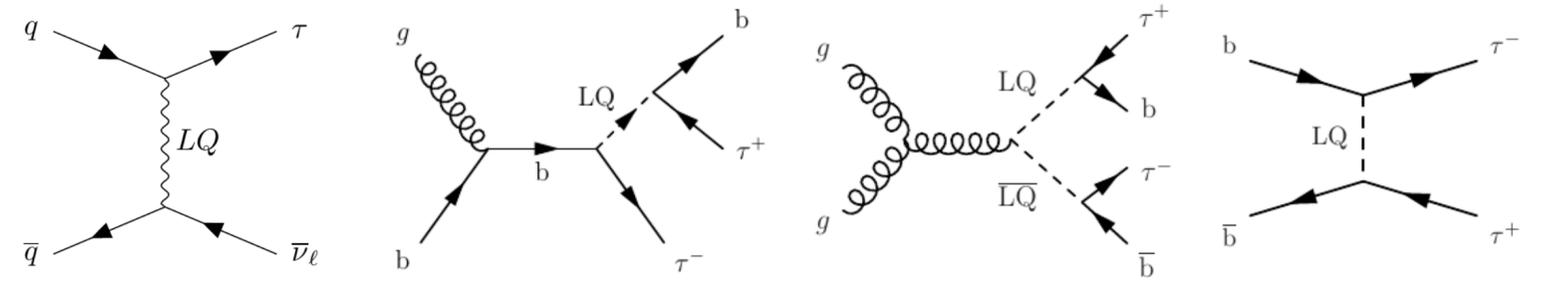
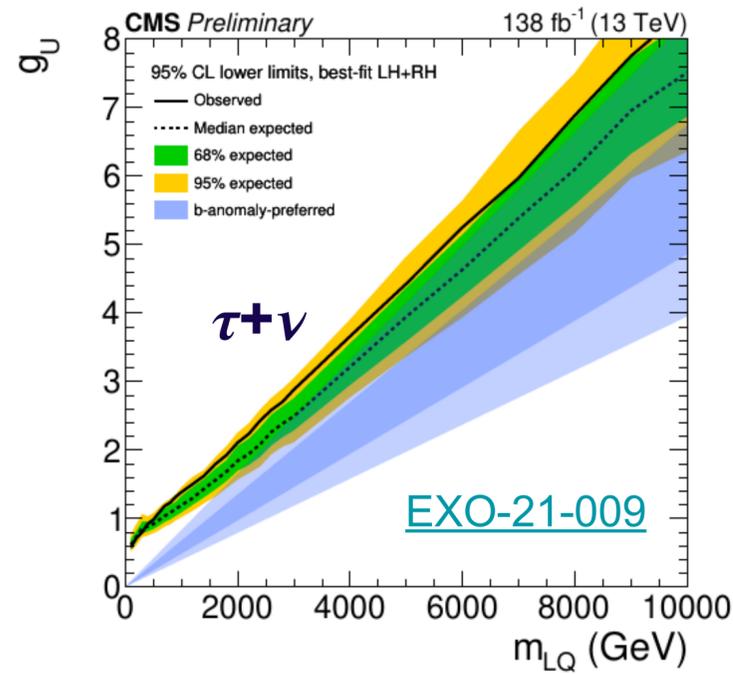
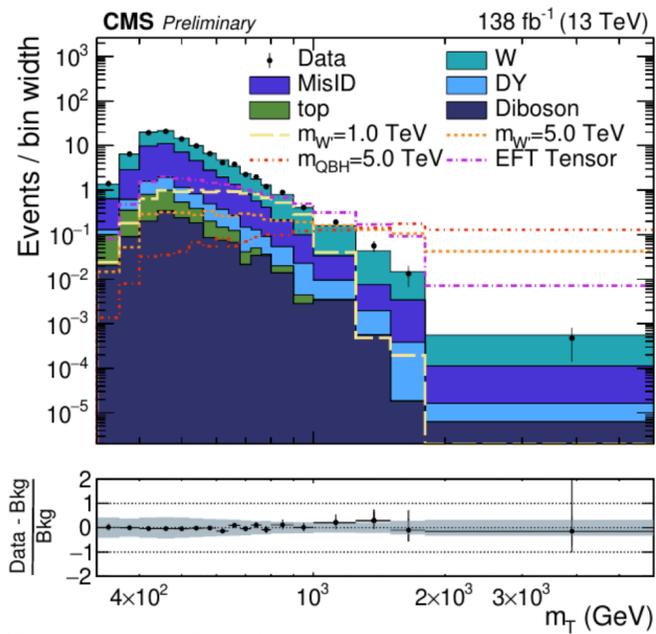


VH

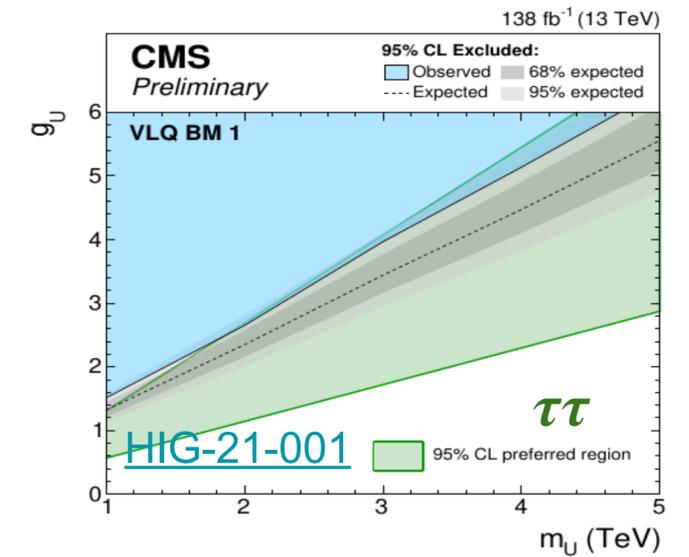
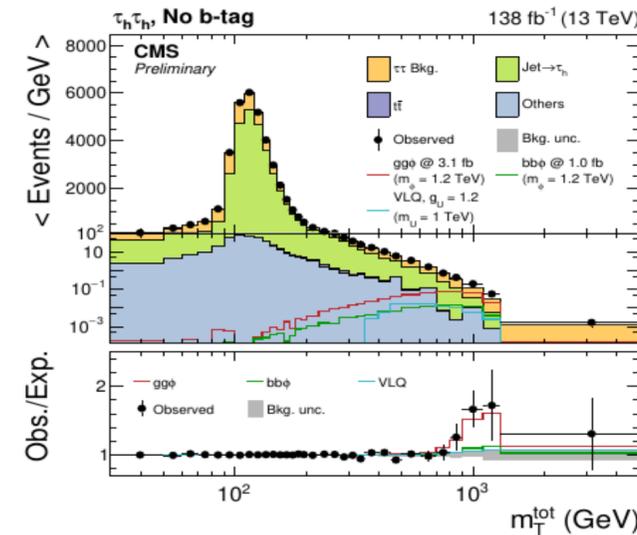
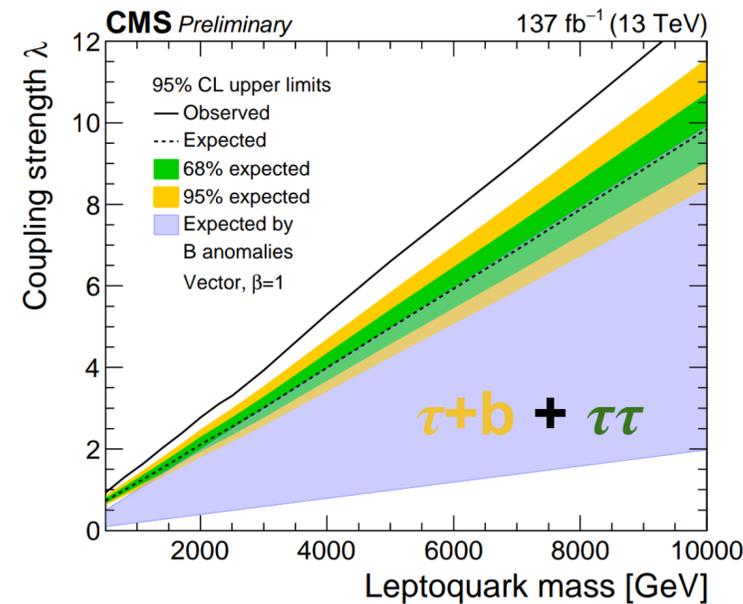
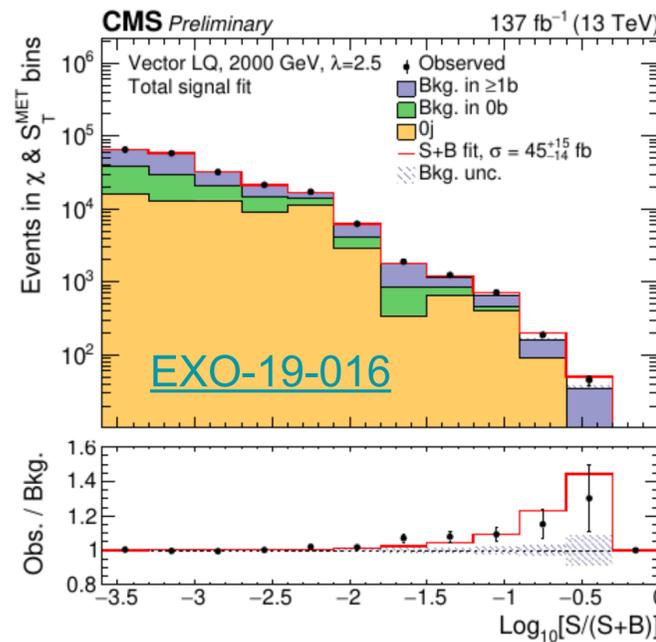


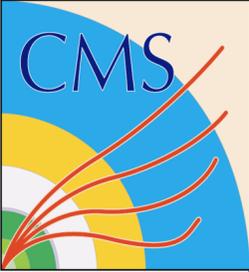


Searches with τ and b-quarks

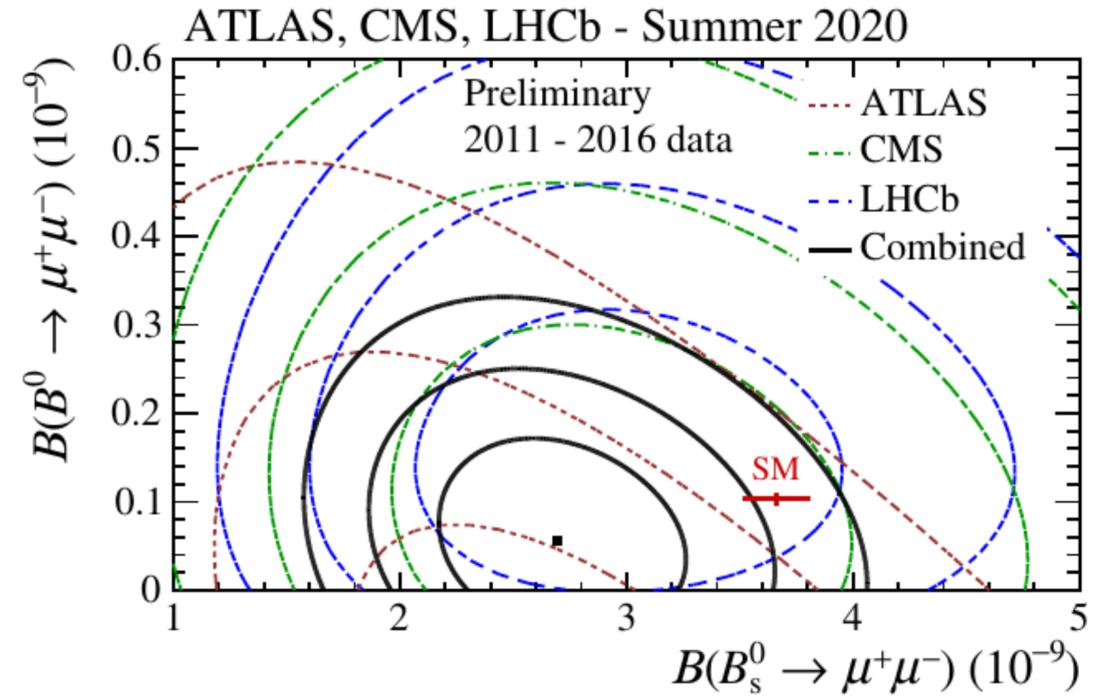
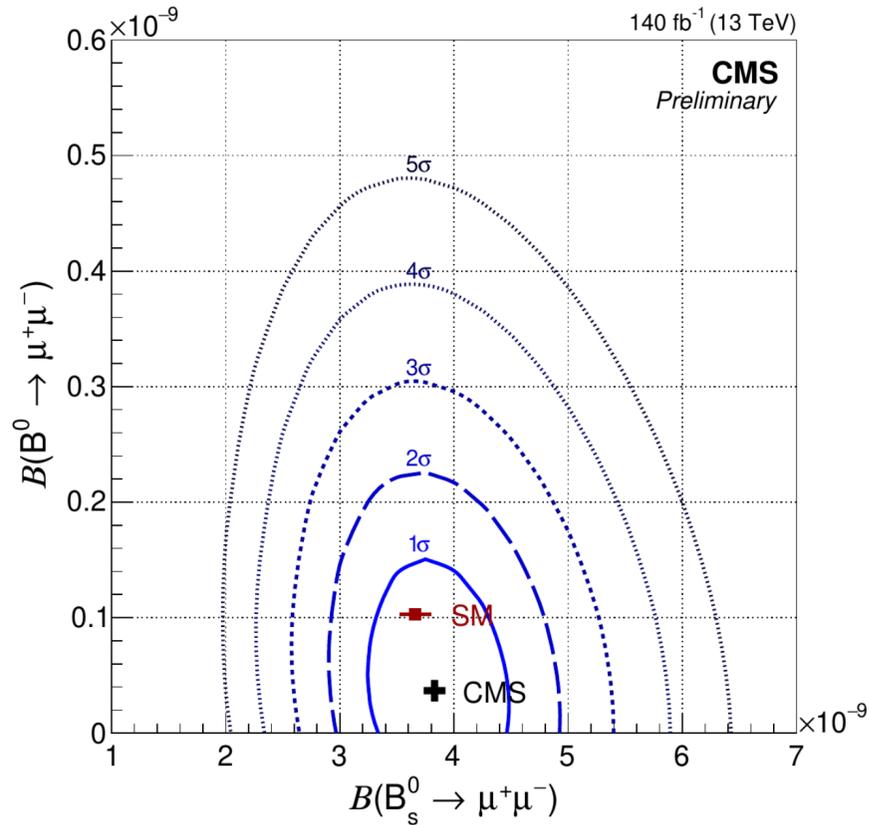
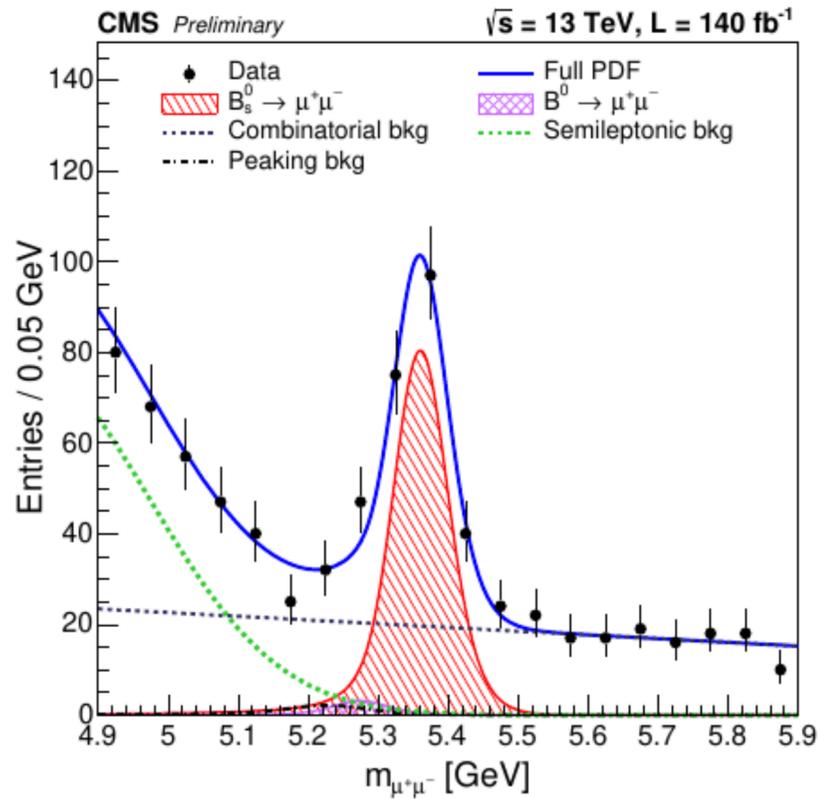


- Final states with $\tau+\nu$, $\tau+b$ and $\tau\tau$ are investigated
- Good probe of models related to b-anomalies (e.g. leptoquark)
- Sensitivity approaching the *preferred* region from b-anomalies in some LQ models
- Some sizeable excess in non-resonant $\tau\tau$ final state





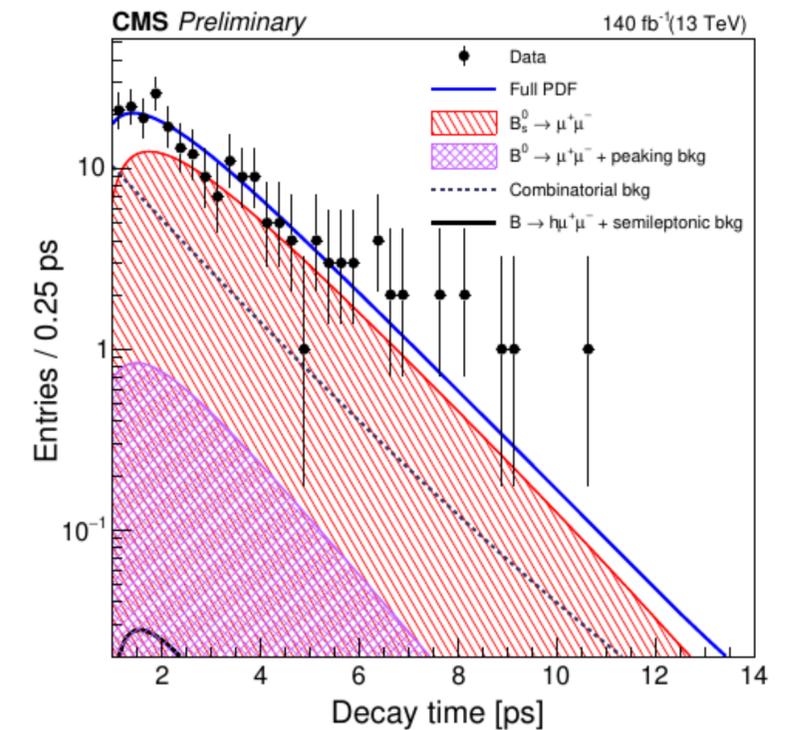
Full Run 2 $B_s \rightarrow \mu\mu$

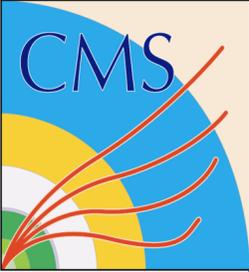


$$\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-) = [3.95^{+0.39}_{-0.37} (\text{stat})^{+0.29}_{-0.24} (\text{syst})] \times 10^{-9}$$

- Updated results with full Run 2 dataset

- ▶ Most precise single experiment measurement to date
- ▶ Highly compatible with SM prediction
- ▶ Most precise **measurement** of lifetime $\tau = 1.83^{+0.23}_{-0.20} (\text{stat})^{+0.03}_{-0.03} (\text{syst}) \text{ ps}$.



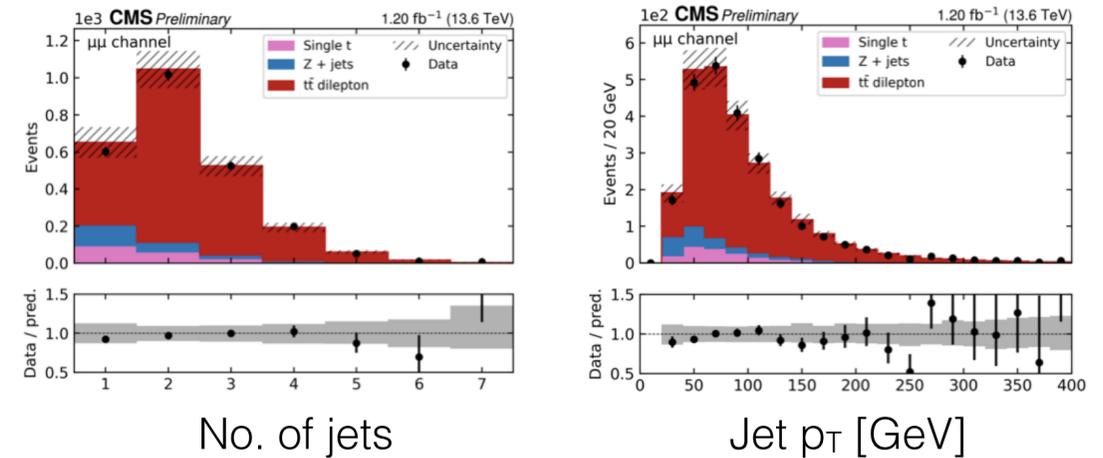


First Run 3 physics result!

- First measurement of the top-quark pair-production cross section in proton-proton collisions at 13.6 TeV

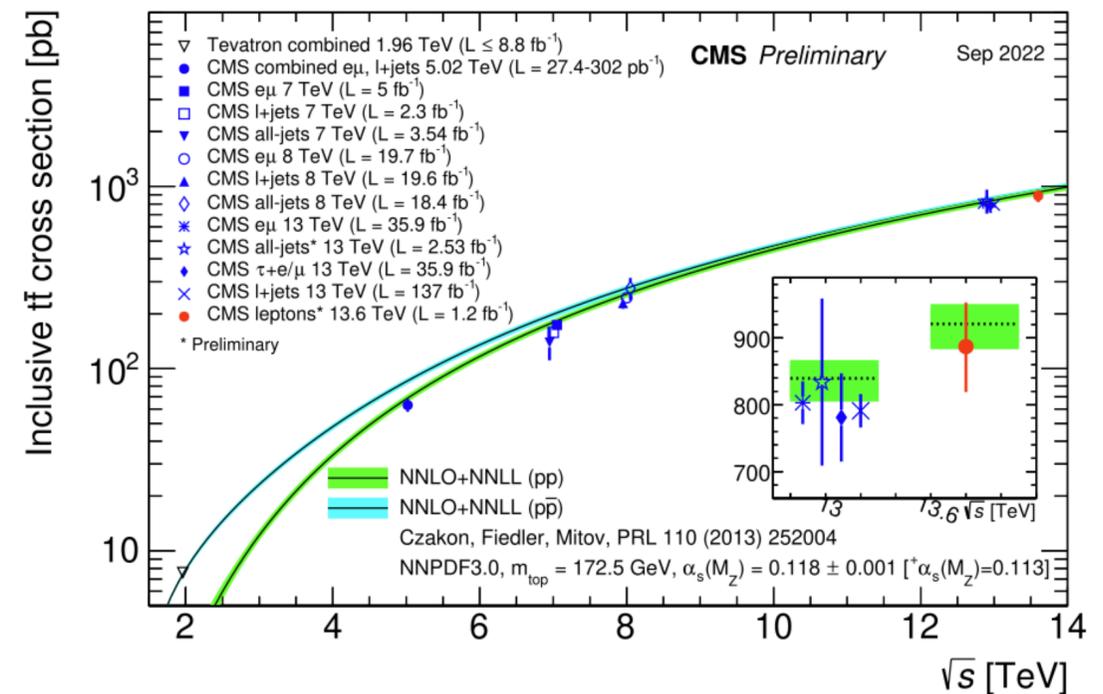
- Result presented at TOP2022 workshop

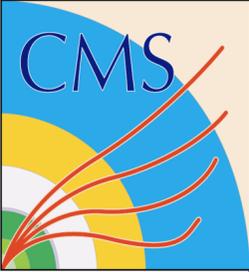
- ▶ Combination of five channels, $e\mu$, ee , $\mu\mu$, e +jets, μ +jets which allows determination of efficiencies in situ
- ▶ Measurement in good agreement with the standard model prediction



$$\sigma_{tt} = 887^{+43}_{-41} \text{ (stat + syst)} \pm 53 \text{ (lumi) pb}$$

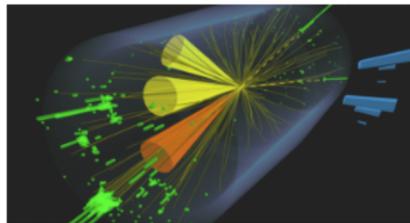
Theory prediction: $921^{+29}_{-37} \text{ pb}$





Physics communications

Briefings since last LHCC:

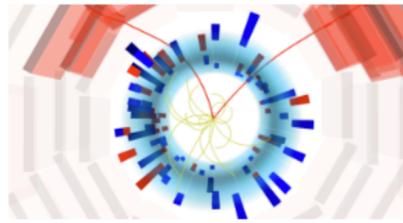


HUNTING FOR NEW PARTICLES WITH LIGHT FROM THE HIGGS BOSON

12 JUL 2022

Have you heard of vector-like quarks? They are hypothetical particles which would provide an explanation to the value of the Higgs boson mass, which is still a mystery. Vector-like quarks are predicted by a variety of theories beyond the Standard...

[READ MORE](#)

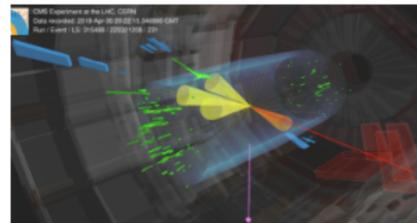


NEW STUDY OF RARE B MESON DECAYS TO TWO MUONS

11 JUL 2022

Rare events, such as a total solar eclipse or a supernova explosion, are fascinating and stimulate our imagination. In addition, such events may lead to discoveries expanding our knowledge horizon. At the Large Hadron Collider (LHC), studies of...

[READ MORE](#)

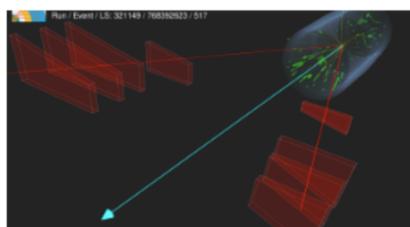


JET CONES WITH TOP FLAVOUR

08 JUL 2022

CMS has developed a new method to measure the properties of the top quark with high precision. It relies on an innovative way to cluster particles into jets. The top quark is the most massive elementary particle we have discovered so far. Due to...

[READ MORE](#)

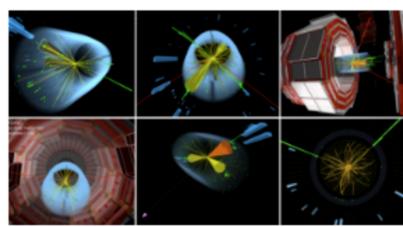


PROTONS THAT DO NOT BREAK UP AT THE LHC

07 JUL 2022

The processes that are mostly studied at the LHC are caused by energetic collisions where the protons break up into their constituents, the quarks and gluons, which recombine to form composite hadrons. However, many proton-proton interactions result...

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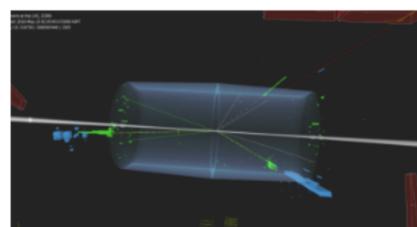


THE HIGGS BOSON TURNS 10: RESULTS FROM THE CMS EXPERIMENT

04 JUL 2022

Exactly ten years ago, on the 4th of July 2012, the ATLAS and CMS experiments announced the discovery of a new particle compatible with the long-sought Higgs boson. This discovery takes us back to the events occurring in our early universe, just a...

[READ MORE](#)



THE LHC AS A W-PHOTON COLLIDER

22 JUN 2022

The LHC can be viewed not only as a hadron collider, but also as a boson collider. With the highest energies and collision rates ever, the LHC is pushing the limits of our understanding of rare processes such as W-photon scattering. The W bosons and...

[READ MORE](#)

CERN COURIER
Reports from the Large Hadron Collider experiments
CMS
Jet-energy corrections blaze a trail
Understanding hadronic final states is key to a successful physics program.

CERN COURIER | Reporting on international high-energy physics
Physics Technology Community In focus Magazine

STRONG INTERACTIONS | NEWS
Upsilon suppression in heavy-ion collisions
30 June 2022
A report from the CMS experiment.

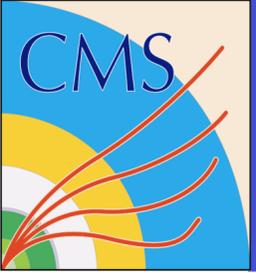
The bound states of a heavy quark and its antiquark, called quarkonia, have long been regarded as ideal probes to study the quark-gluon plasma (QGP) formed in high-energy heavy-ion collisions. The golden signature is the suppression of their production yield in lead-lead (PbPb) collisions with respect to

FITTING TOGETHER THE SILICON TRACKER
21 JUN 2022
The CMS detector, illustrated in Fig. 1, is centred around the largest and highest granularity silicon tracker ever built, including around twenty thousand detector units structured in thin cylindrical layers that extend over nearly 6 metres along...

HOW ARE THE QUARKS MOVING?
13 JUN 2022
The Large Hadron Collider, LHC, collides protons at an energy of 13 TeV — thirteen thousand times the mass of a proton. The high energy of the accelerator allows searching for (and maybe finding) new particles, but also in-depth studies of the...

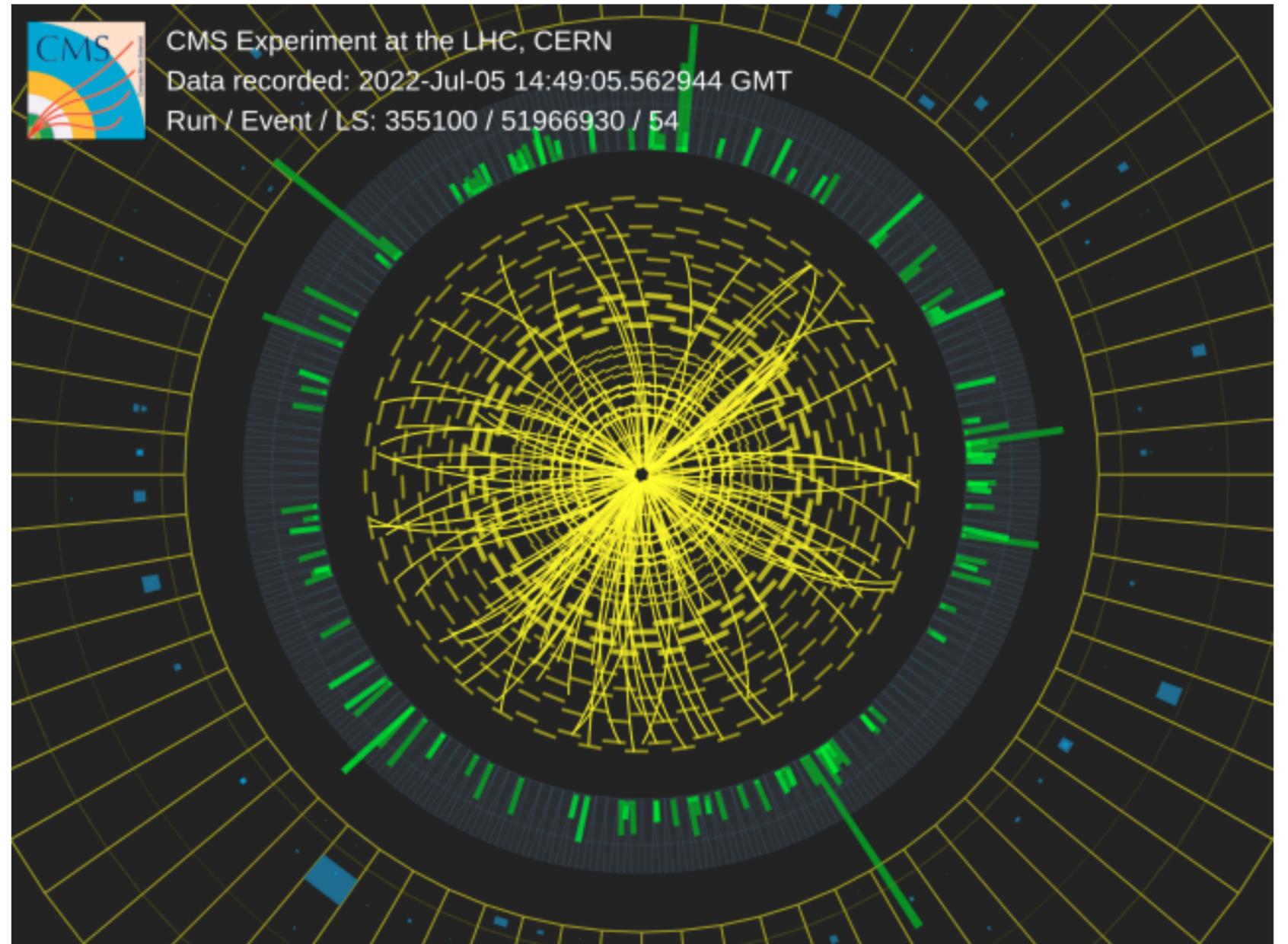
TWO COLLISIONS FOR THE PRICE OF ONE
07 JUN 2022
The Large Hadron Collider (LHC) offers a unique opportunity to probe the internal structure of protons, with great precision and at unprecedented energies. According to Feynman's parton model, protons are made up of three quarks, two "up" quarks...

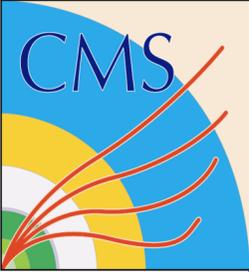
<https://cms.cern/tags/physics-briefing>



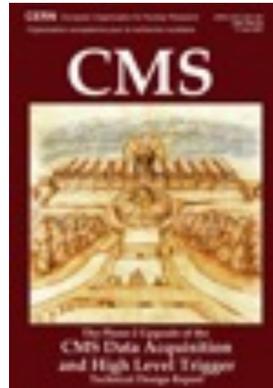
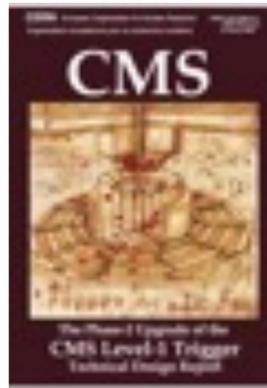
Outline

- Run 3 performance
- Physics analysis highlights
- Upgrade status





Phase-2 Upgrade — scope



L1-Trigger HLT/DAQ

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

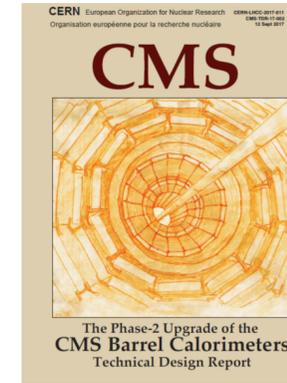
<https://cds.cern.ch/record/2759072>

- Tracks in L1-Trigger at 40 MHz
- PFlow selection 750 kHz L1 output
- HLT output 7.5 kHz
- 40 MHz data scouting

Barrel Calorimeters

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

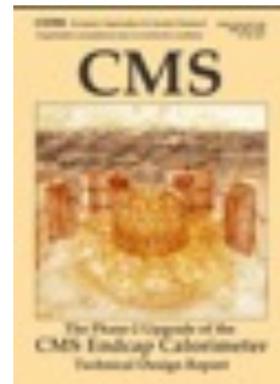
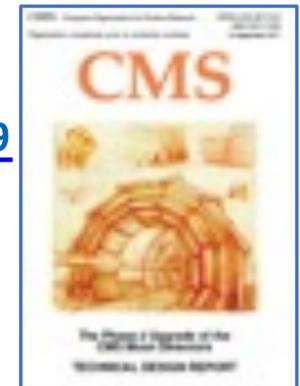
- ECAL crystal granularity readout at 40 MHz with precise timing for e/γ at 30 GeV
- ECAL and HCAL new Back-End boards



Muon systems

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

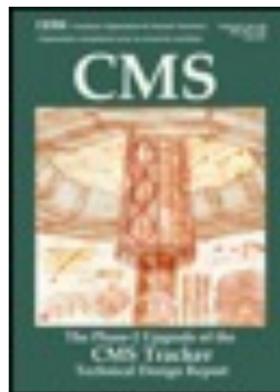
- DT & CSC new FE/BE readout
- RPC back-end electronics
- New GEM/RPC $1.6 < \eta < 2.4$
- Extended coverage to $\eta \approx 3$



Calorimeter Endcap

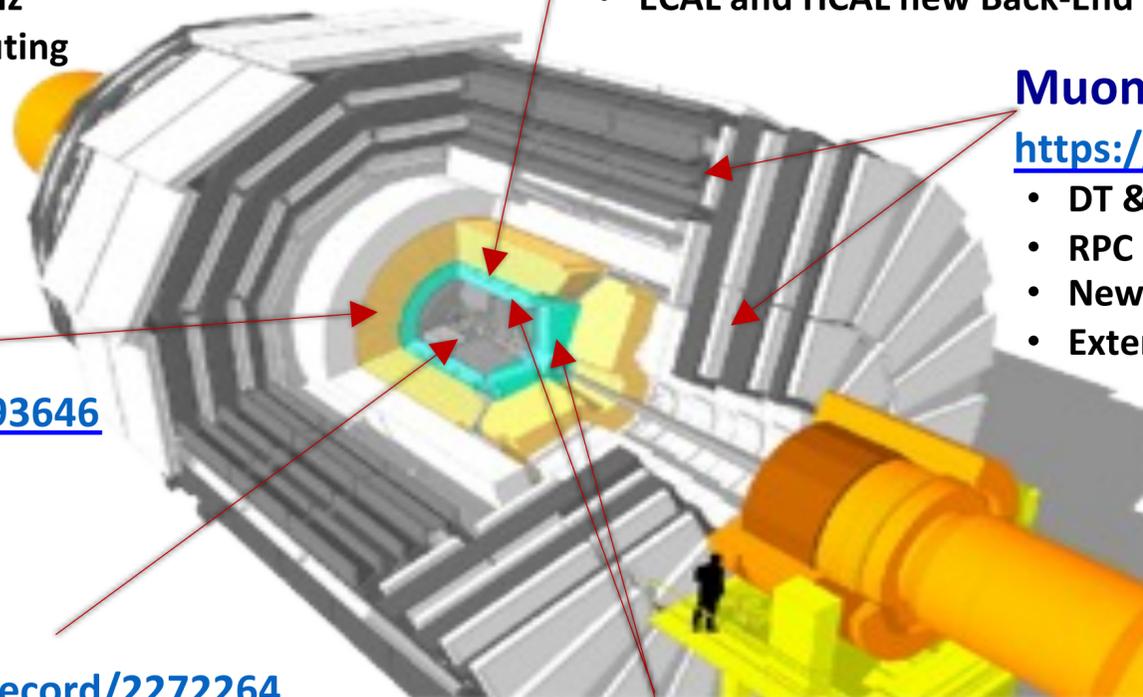
<https://cds.cern.ch/record/2293646>

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



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

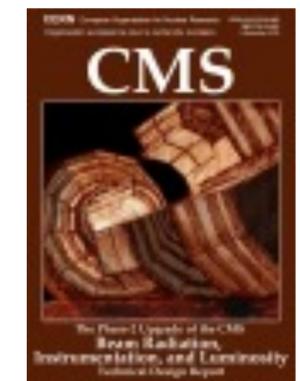
- Si-Strip and Pixels increased granularity
- Design for tracking in L1-Trigger
- Extended coverage to $\eta \approx 3.8$



Beam Radiation Instr. and Luminosity

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

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

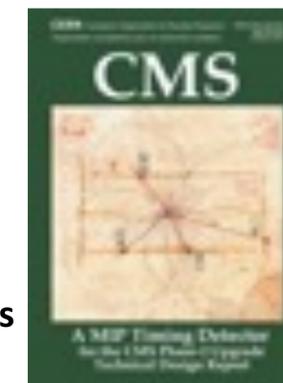


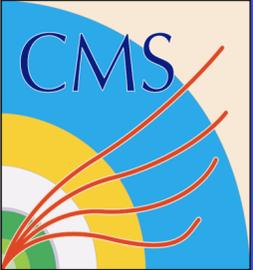
MIP Timing Detector

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

Precision timing with:

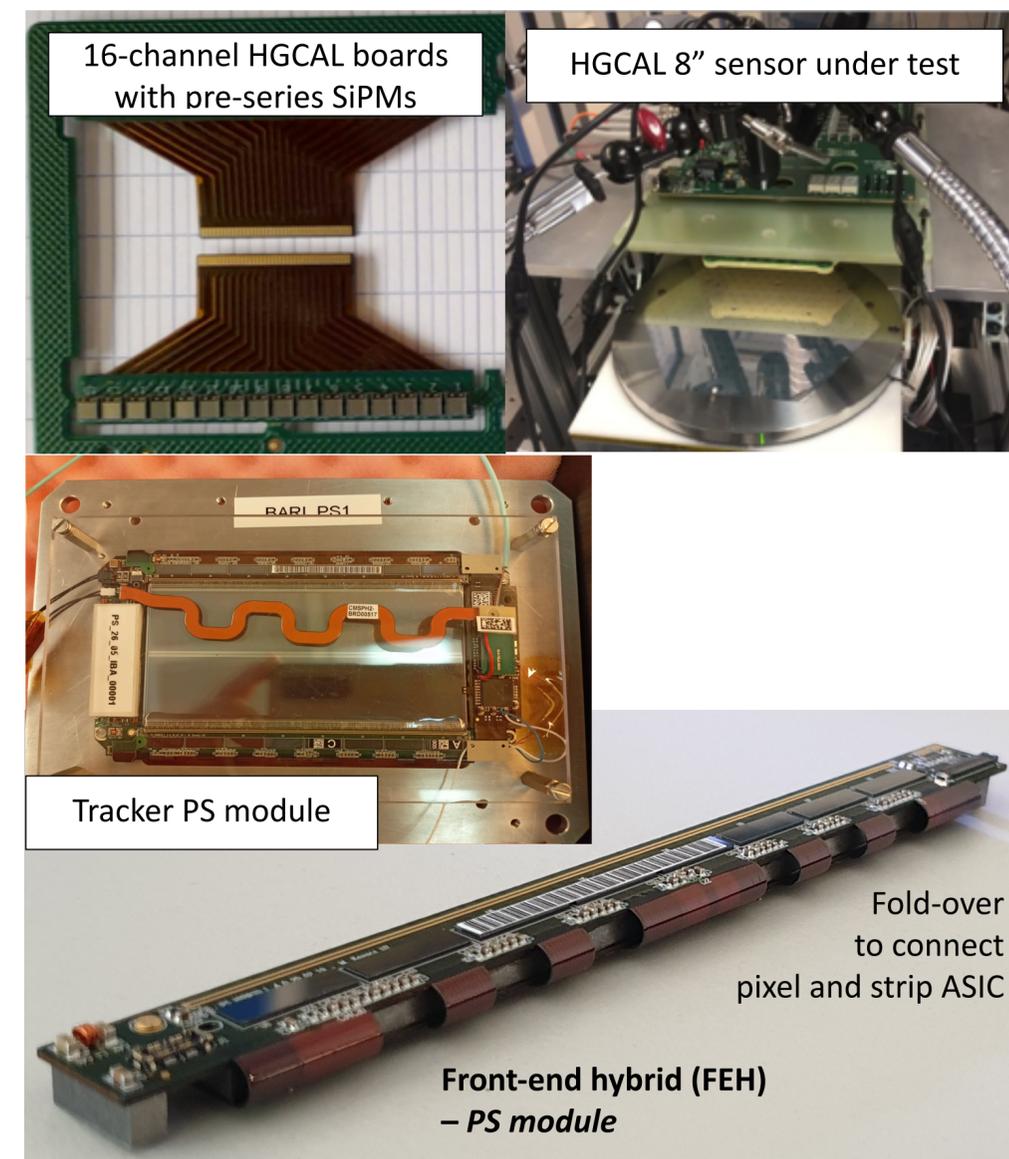
- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes

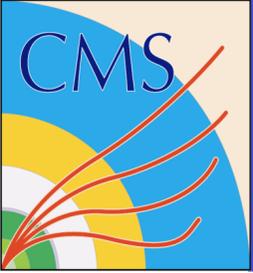




Phase-2 Upgrade — highlights

- All projects continue to make remarkable progress
 - ▶ Transition from final prototyping to pre-production or production in many areas
 - ▶ All this in an environment of worldwide strain on resources, which continues to be felt
- High Granularity Calorimeter HGICAL:
 - ▶ Silicon sensors Production Readiness Review successfully passed
 - ▶ Five module assembly centers fully qualified for pre-series modules
 - ▶ Concentrator ASICs - on critical path – progressing but tight schedule
 - ▶ Trigger version under test – data version and design and verification
 - ▶ SiPM-on-Tile-module assembly centers also on track, and pre-series SiPMs are under test
- Inner Tracker:
 - ▶ IT planar sensor tender completed and contract(s) in preparation
 - ▶ Irradiation and test beam of 3D and planar modules completed
 - ▶ Delay in RD53 submissions
- Outer Tracker:
 - ▶ Sensor production continues
 - ▶ Hybrid contract signed
 - ▶ Final PS and 2S module prototypes built, in use in multiple tests





Phase-2 Upgrade — highlights

- **MIP Timing Detector MTD:**

- ▶ Test beam performed with optimized Barrel BTL module (packaging, new ASIC, SiPM)
- ▶ Validated final prototype of BTL module thermal performance in full populated tray
- ▶ Endcap ETL sensors: market survey nearly complete with several vendors satisfying specs

- **Barrel Calorimeter:**

- ▶ ASICs: CATIA and LiTE-DTU final prototypes meet specs
- ▶ Components on schedule for test beam with 'spare' supermodule 36 in Nov 22

- **Muons:**

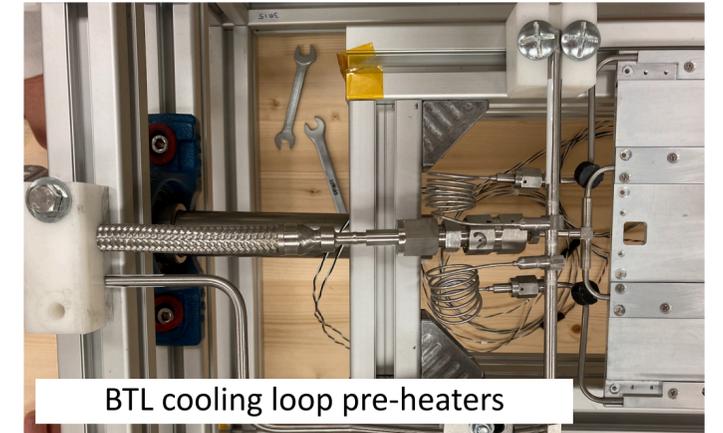
- ▶ RPC: started production
- ▶ GEM GE2/1 production progressing on track

- **BRIL:**

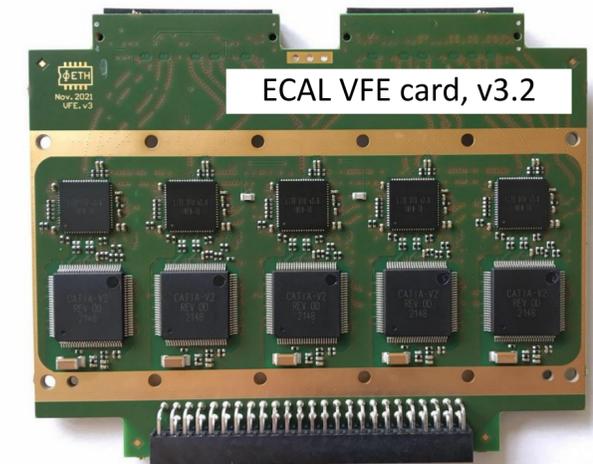
- ▶ Commissioning of Run-3 demonstrators advancing (muon slice, L1 scouting)
- ▶ Future detectors: progress on ongoing R&D activities, incl. Fast Beam Conditions Monitor mechanical design and frontend ASIC

- **Level-1 Trigger:**

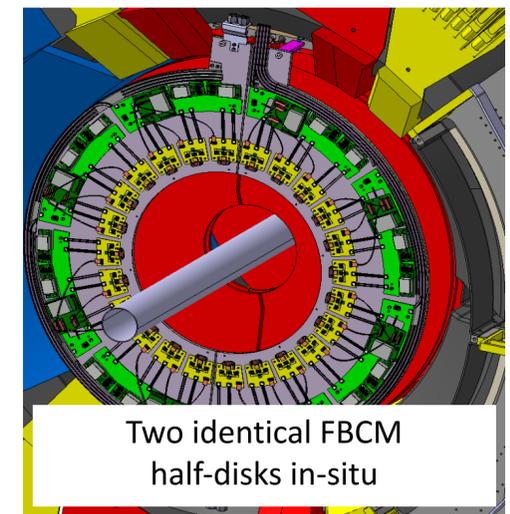
- ▶ All pre-production milestones reached for all families of boards, pilot production designs in progress. Integration tests advancing



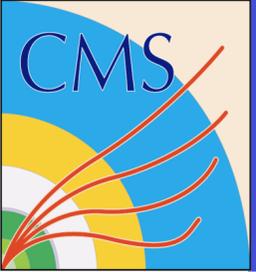
BTL cooling loop pre-heaters



ECAL VFE card, v3.2



Two identical FBCM half-disks in-situ



Summary

- Strong start to Run 3 — CMS is taking good quality data with high efficiency
- Many interesting physics results still to come from Run 2 data and first result from Run 3 data presented
- Upgrade making good progress in all areas
- Looking forward to the restart of collisions!

