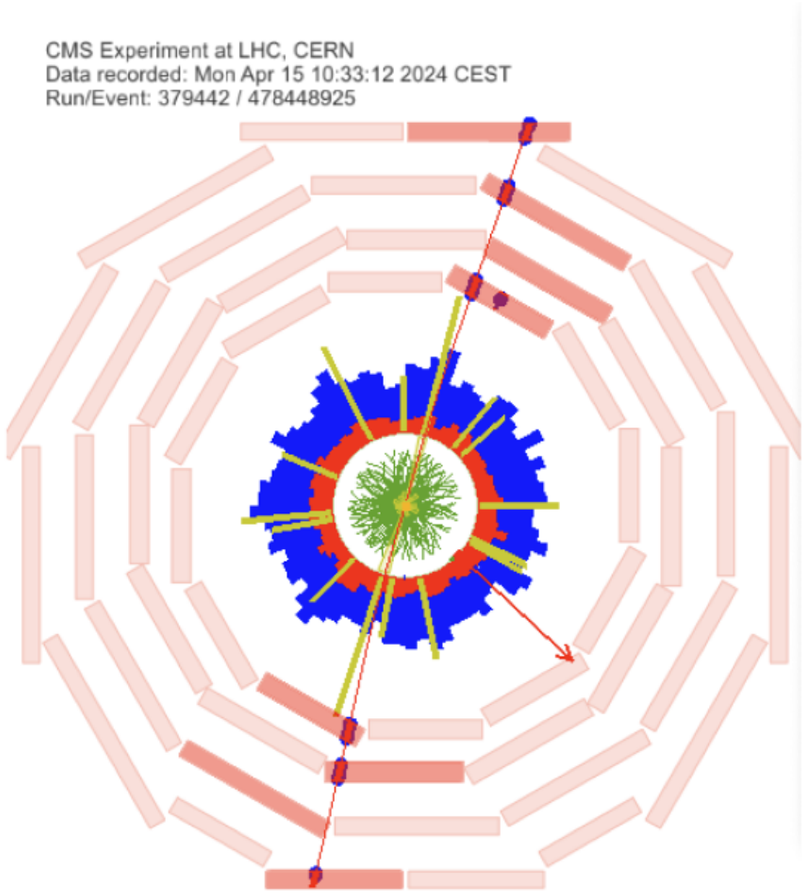
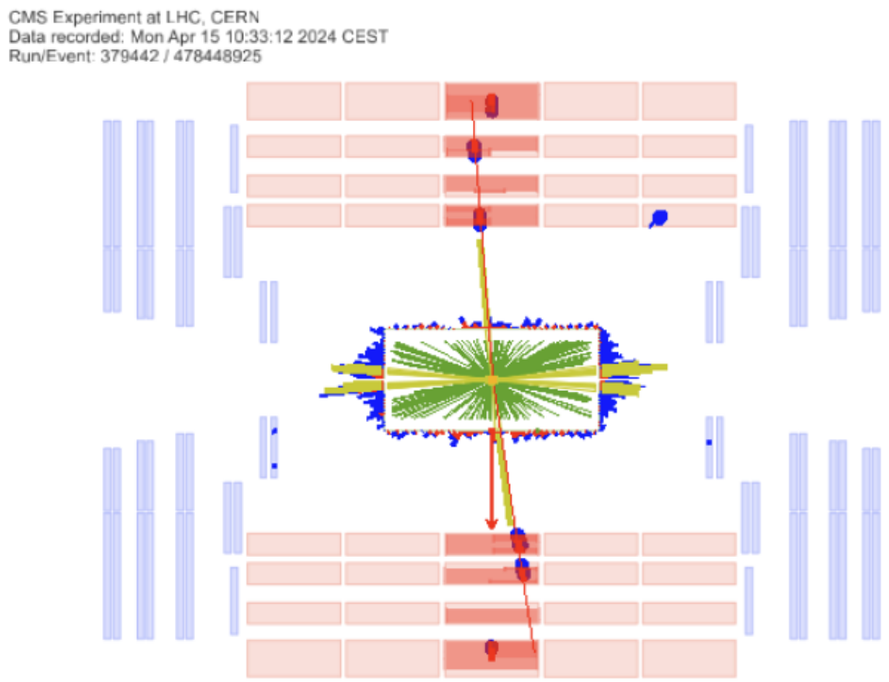
CMS Status Report

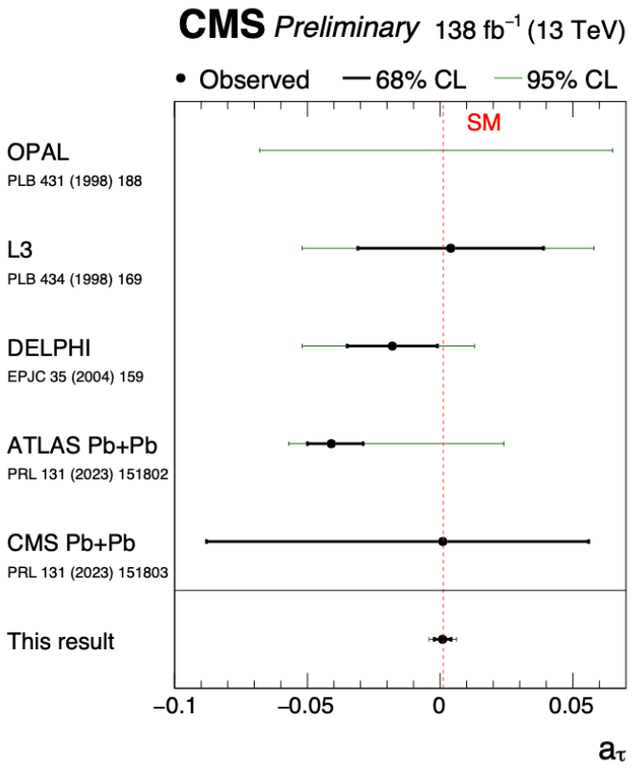
Anna Benecke (UCLouvain)
on behalf of the CMS Collaboration





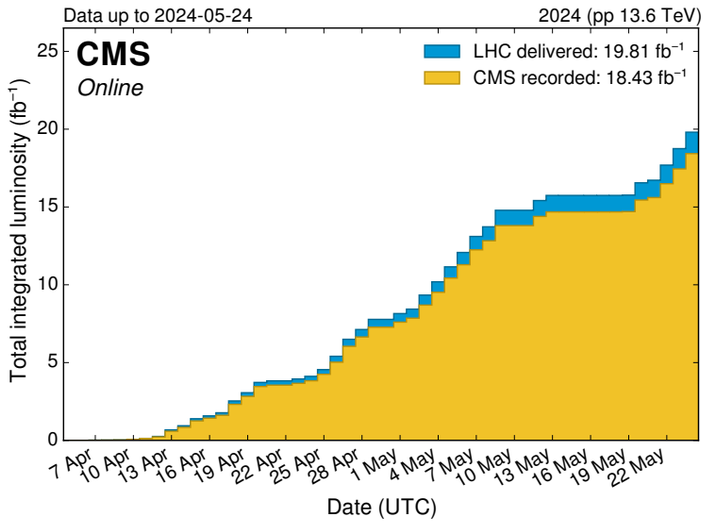
Outline

38 results made public since last LHCC



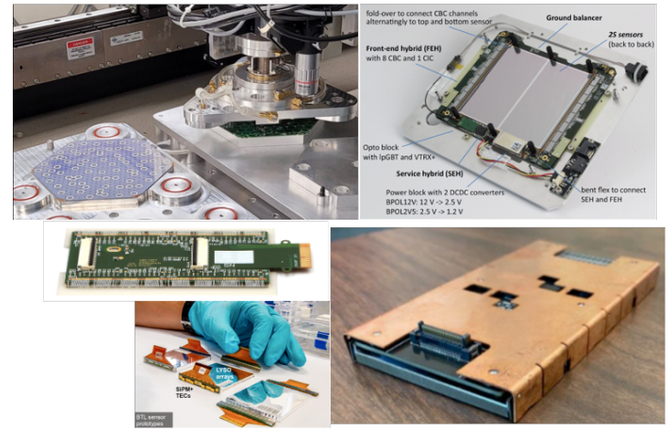
- 14 searches for new particles
- 13 precision SM & Higgs physics
- 8 heavy quark physics
- 1 heavy ion
- 2 tools & generators

Object and detector performance in Run 3

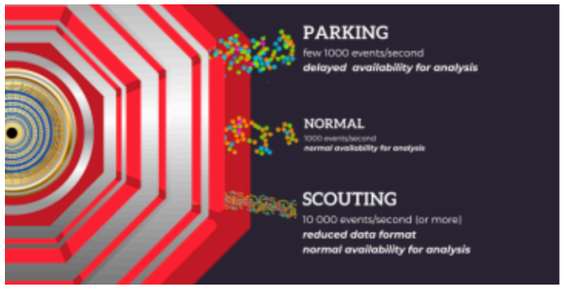


- Excellent performance in prompt data
- Smooth start-up of 2024 data-taking
- Successful commissioning and calibration

CMS Phase-2 Upgrade

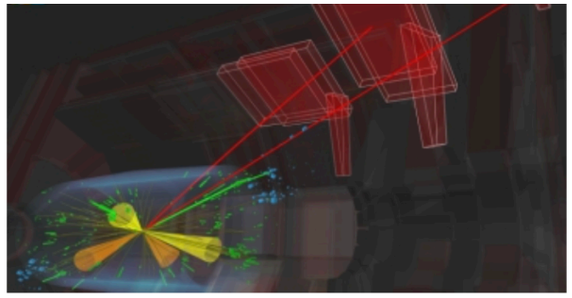


- Transitioning into production
- Planning assembly and integration
- Improvement in simulation timing



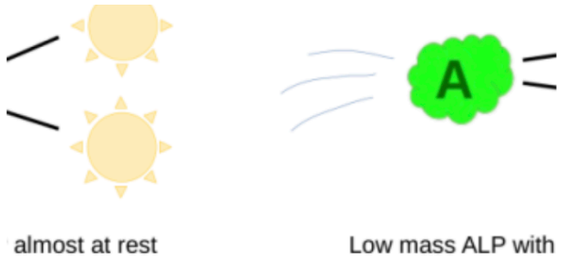
SAME LHC, SAME CMS, MORE PHYSICS

29 MAR 2024



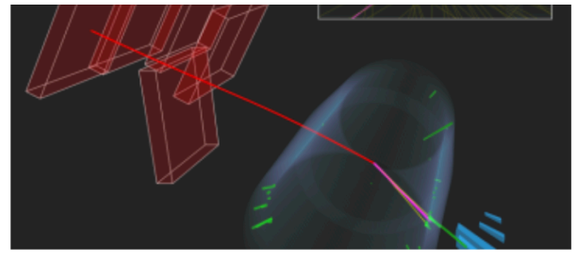
A NOVEL TRAIL: SIMULTANEOUS PROBE OF RARE TOP QUARK EVENTS

26 MAR 2024



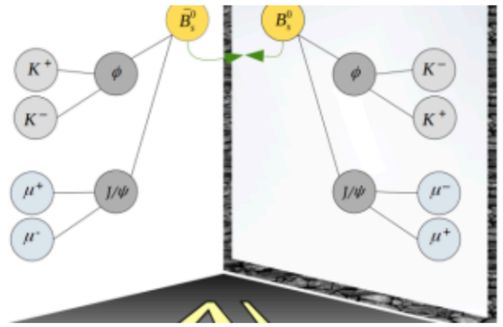
THE HIGGS WINDOW TO NEW PHENOMENA: ALPS THIS TIME!

24 MAR 2024



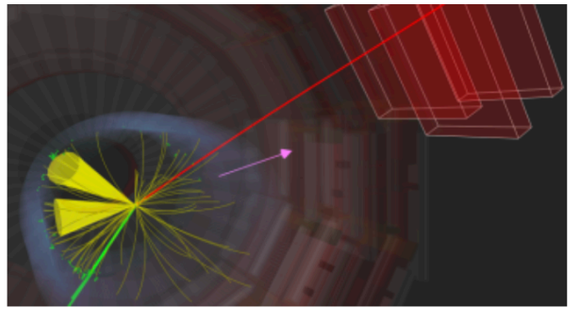
DISCLOSING QUANTUM CORRECTIONS TO ELECTROMAGNETIC INTERACTIONS OF TAU LEPTONS

25 MAR 2024



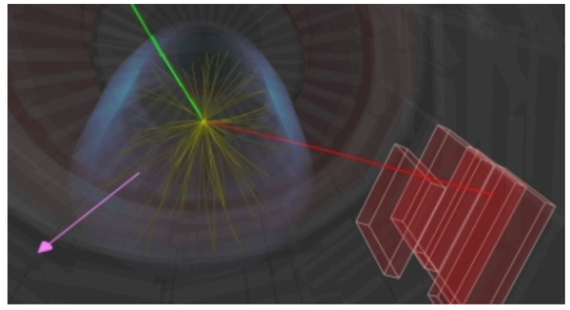
PROBING MATTER-ANTIMATTER ASYMMETRY WITH ARTIFICIAL INTELLIGENCE

30 APR 2024



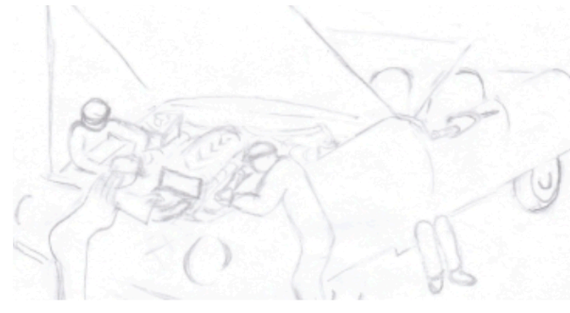
ENTANGLED TITANS: UNRAVELING THE MYSTERIES OF QUANTUM MECHANICS WITH TOP QUARKS

27 MAR 2024



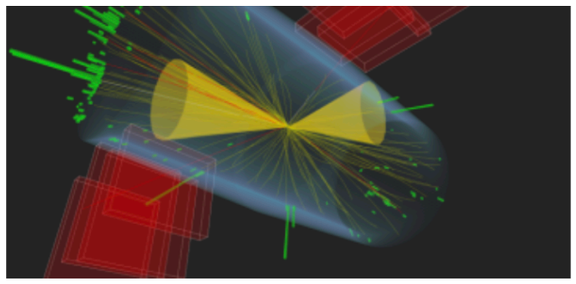
RUN 3 PROVIDES THE STANDARD MODEL WITH A NEW VICTORY AT THE ENERGY FRONTIER

28 MAR 2024



USING MUONS TO CHECK UP ON THE CMS DETECTOR IN THE TOUGHEST CONDITIONS

29 APR 2024

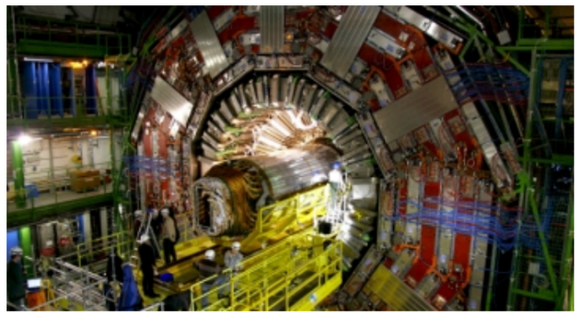


NEW HIGGS BOSONS TO PIN DOWN THE G-2 PUZZLE

21 MAY 2024

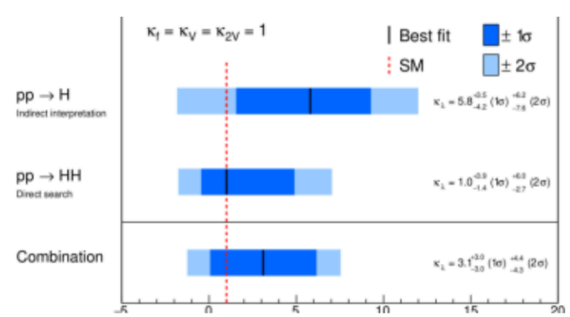
MISSING PIECE TO THE HIGGS PRODUCTION

25 MAR 2024



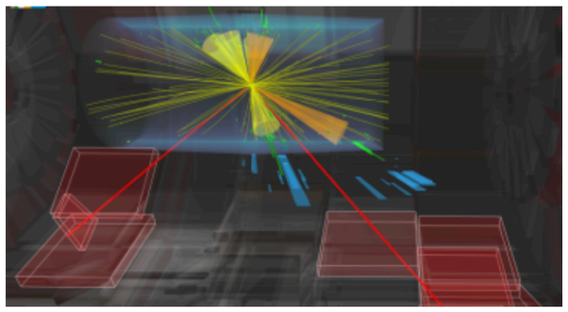
A BEAUTY PATH TOWARD HEAVY NEUTRINOS

13 MAY 2024



THE HIGGS BOSON, AS IT INTRACTS WITH ITSELF

28 MAR 2024

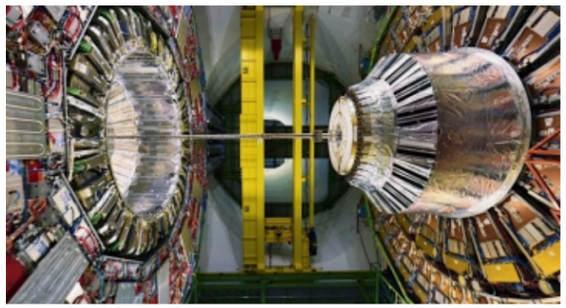


CMS FIRED A SHOT TO HEAVY HIGGS PARTICLES… AND THE GUN IS SMOKING

29 MAR 2024

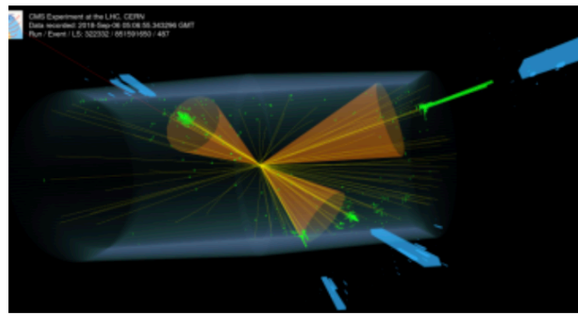
CMS COMMITMENT TO OPEN SCIENCE TAKES THE NEXT STEP

16 APR 2024



TOWARDS A NEW PRECISION ERA IN THE STUDY OF ELECTROWEAK INTERACTIONS

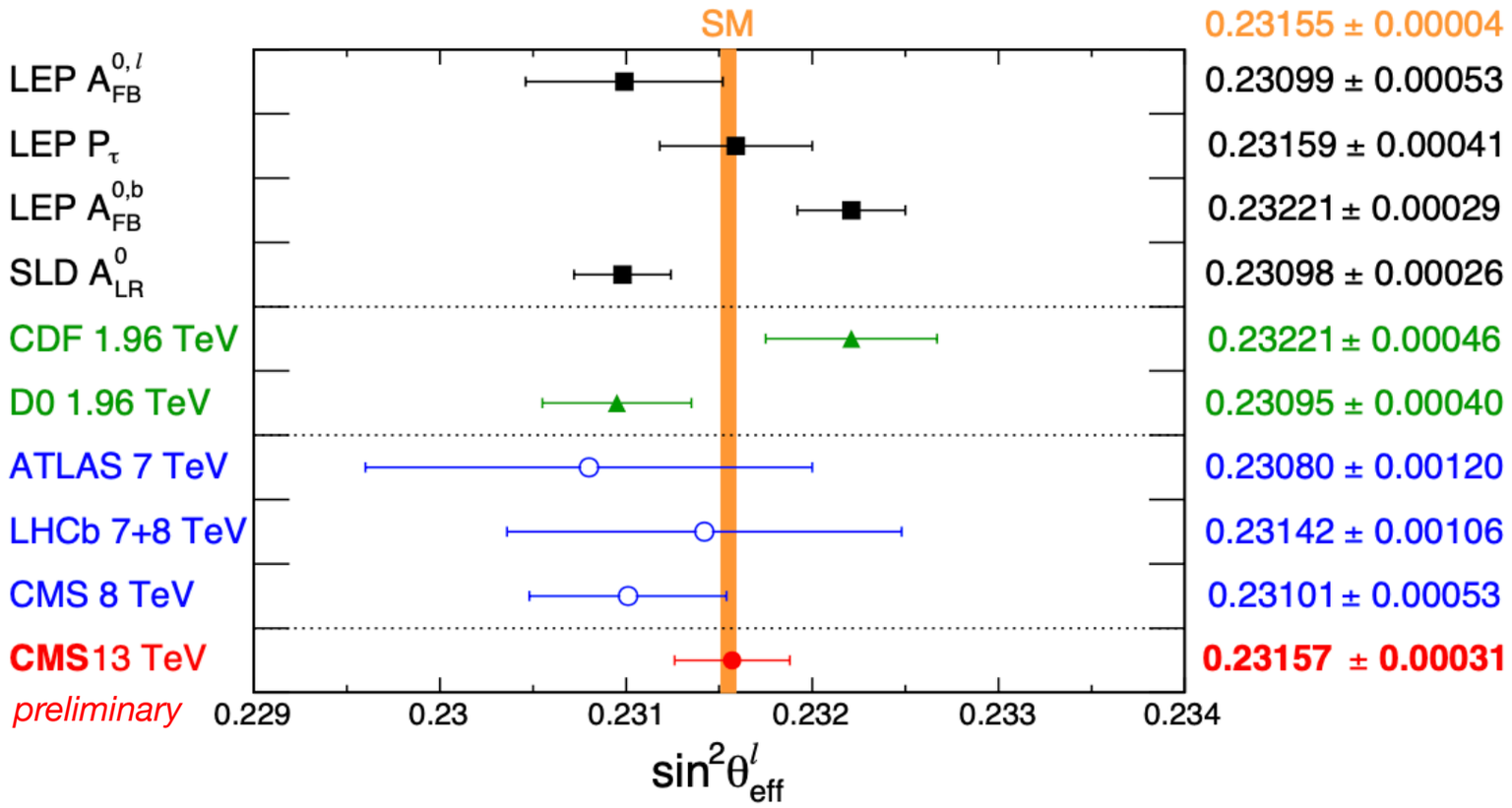
03 APR 2024



CAN AI FIND NEW PARTICLES ON ITS OWN?

26 MAR 2024

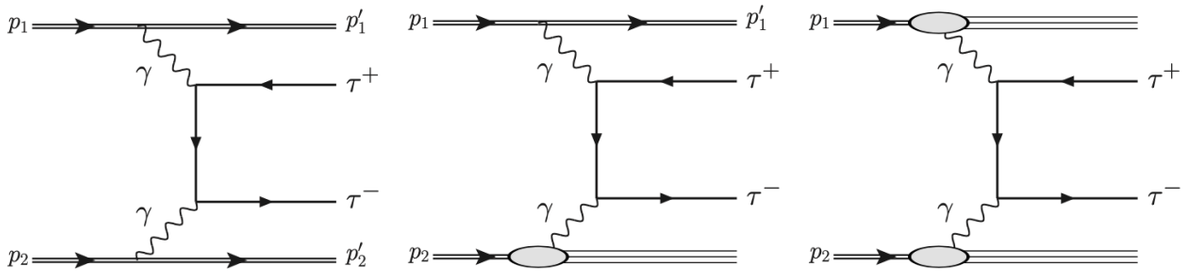
Measurement of the Drell-Yan forward-backward asymmetry and of $\sin^2\theta_{\text{eff}}$ using pp collisions at 13 TeV

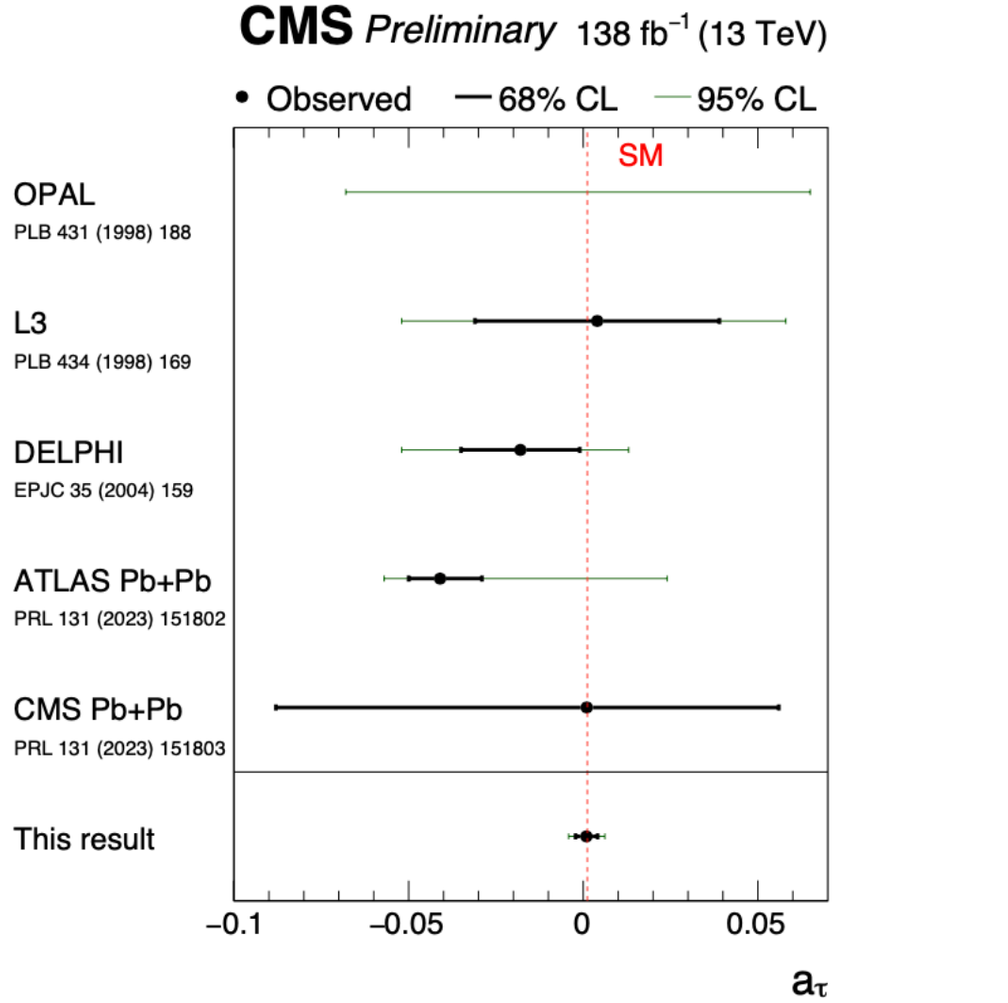


- Forward-backward asymmetry in DY events: $\sin^2\theta_{\text{eff}}$ extracted
- Including central-forward combination of electrons improved the final result
- Performed measurement vs dilepton mass and rapidity
- CMS measurement aligns with SM prediction

Observation of $\gamma\gamma \rightarrow \tau\tau$ in pp collisions & limits on g-2 of the τ lepton

- Experimentally challenging in pp collisions due to high pileup
- Isolate α sample enriched in photon collisions by selecting low-multiplicity vertices
- Data-driven corrections to account for discrepancies in PV description, pileup track multiplicity, etc.
- Observed process for the first time in pp collisions





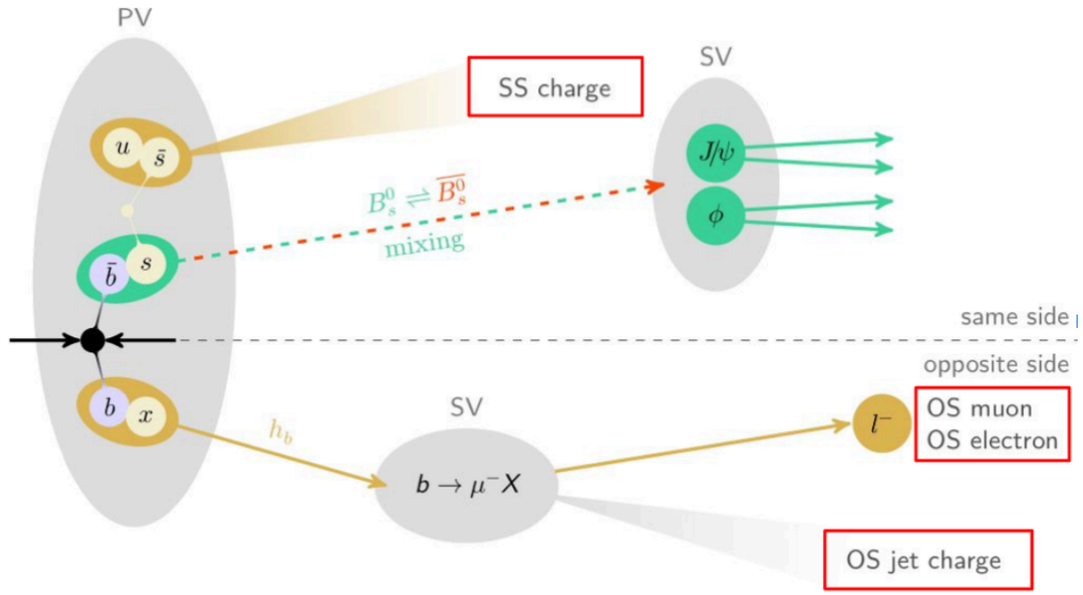
LHC seminar | Physics Briefing | CERN News

Measurement of time-dependent CP violation in $B_S^0 \to J/\Psi\phi(1020)$ decays with the CMS detector

Flavor physics in CMS:

+ Excellent tracking
+ Lot of statistics

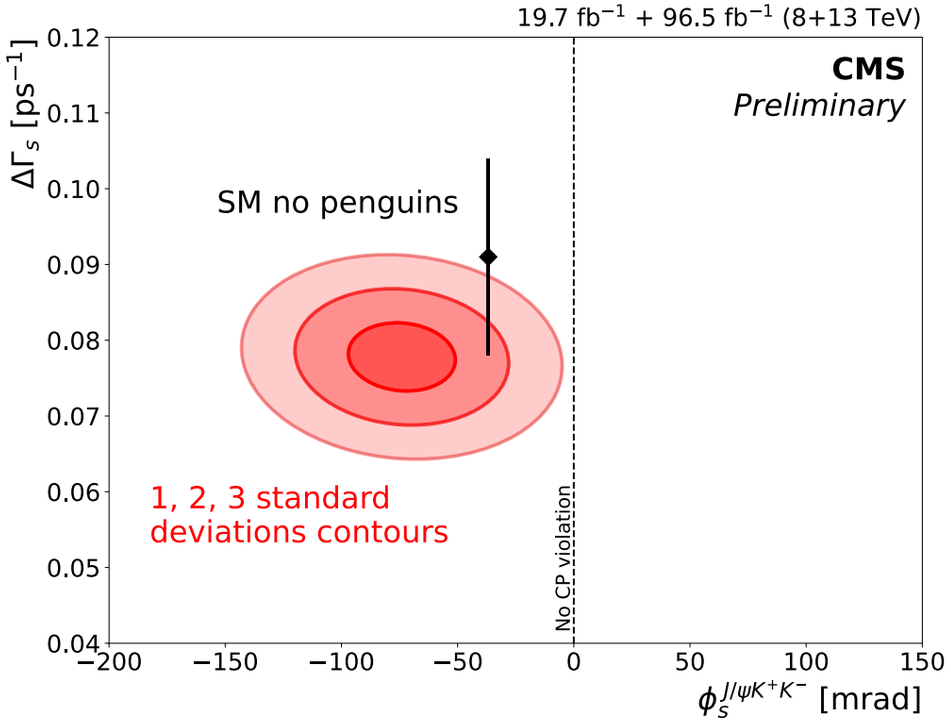
− High pileup
− Hadron particle identification



- 4 different ML techniques used:
  - OS muon/electron
  - OS jet charge
  - Same-sign charge

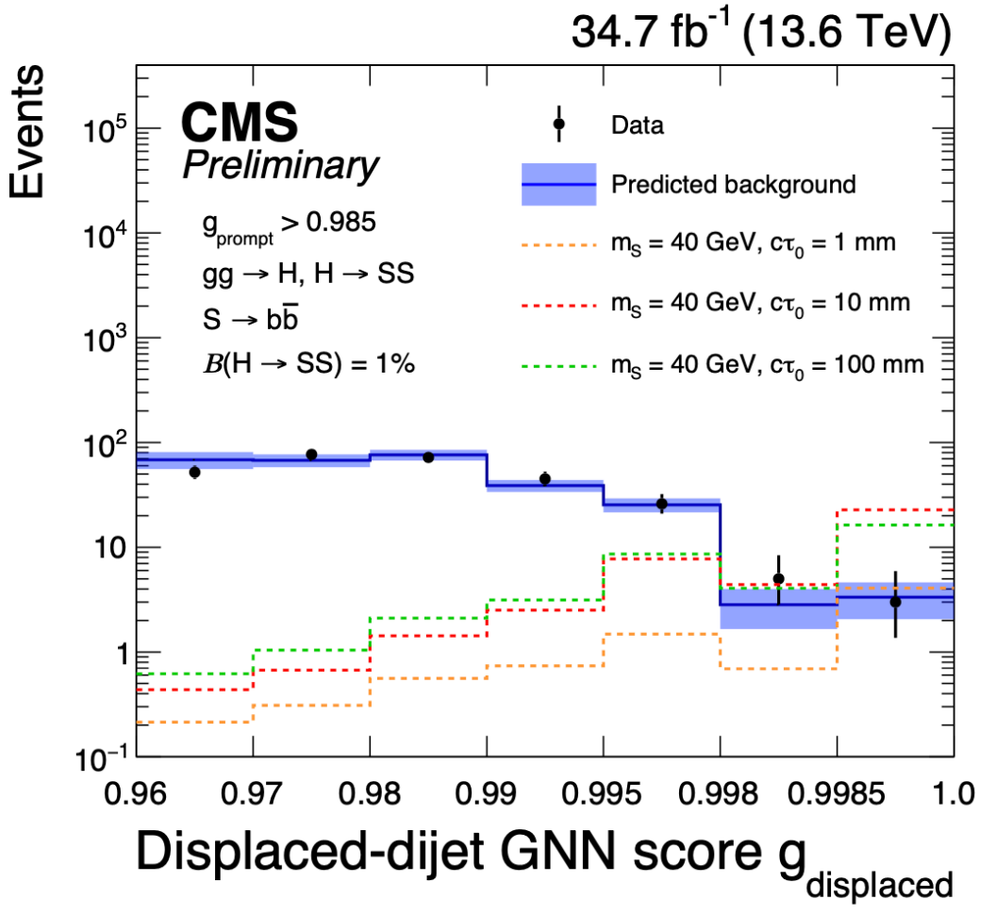
- Extracts 5 parameters of interest, among which the weak phase, $\Delta\Gamma_s$, and Δm_s

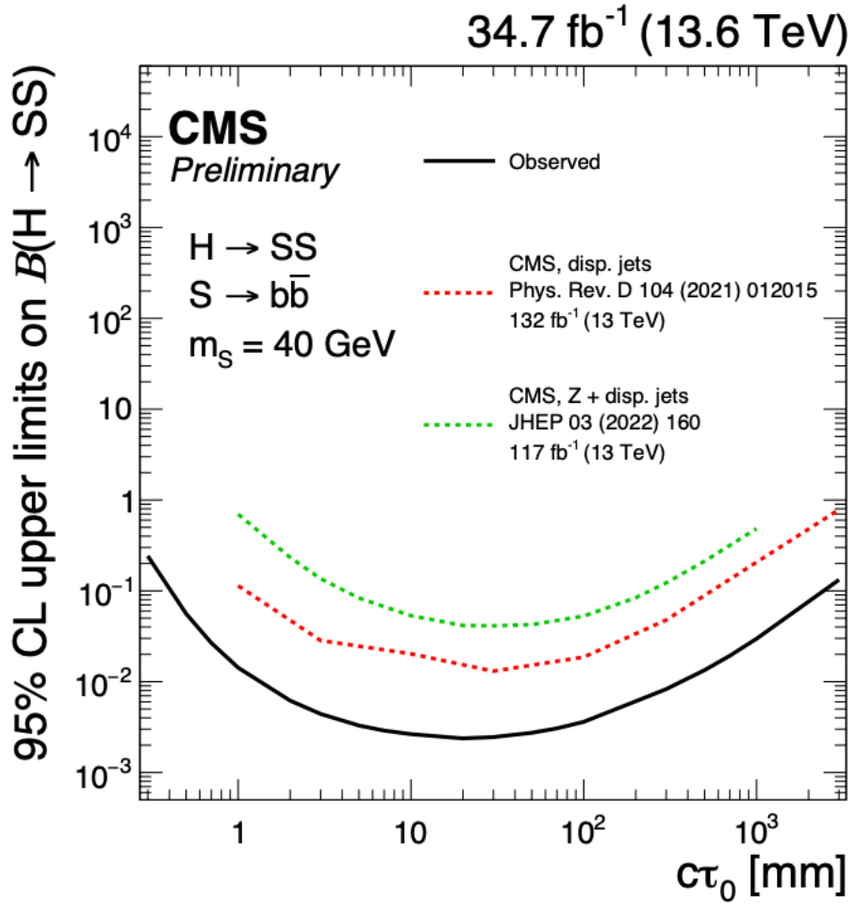
- First evidence of CP violation in this decay mode!



LHC seminar | Physics Briefing | CERN News

Search for low-mass long-lived particles decaying to displaced jets in pp collisions at $\sqrt{s} = 13.6$ TeV

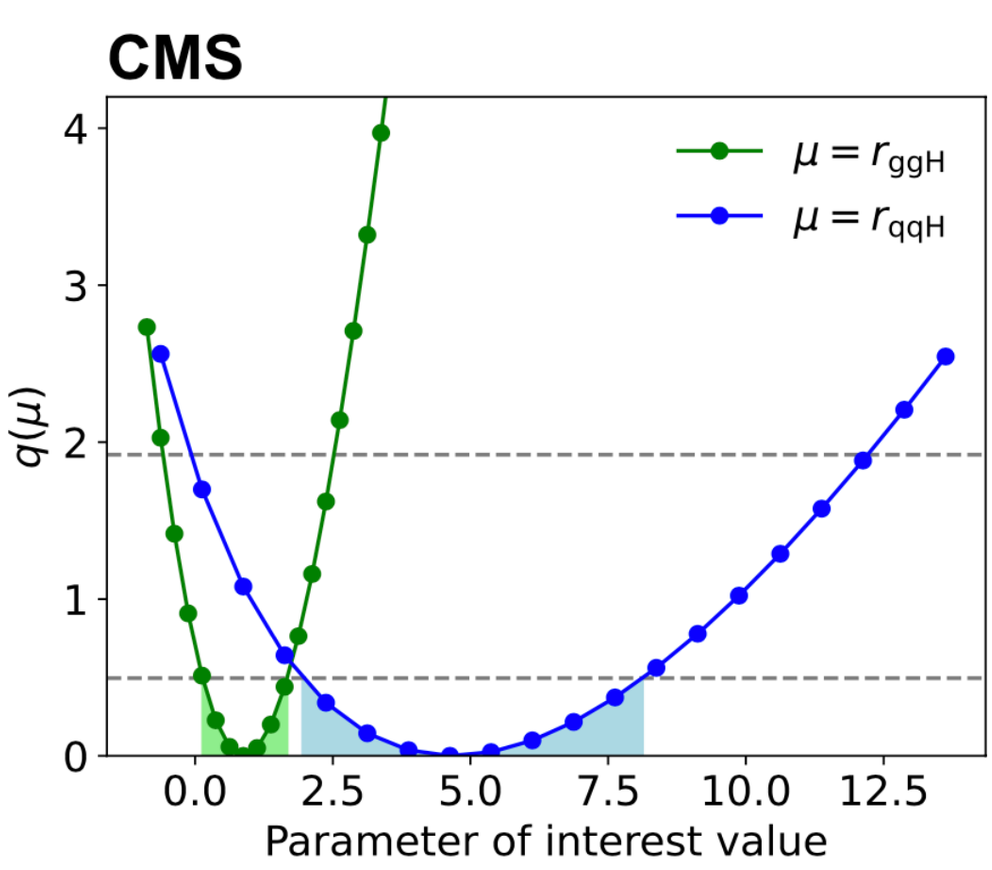


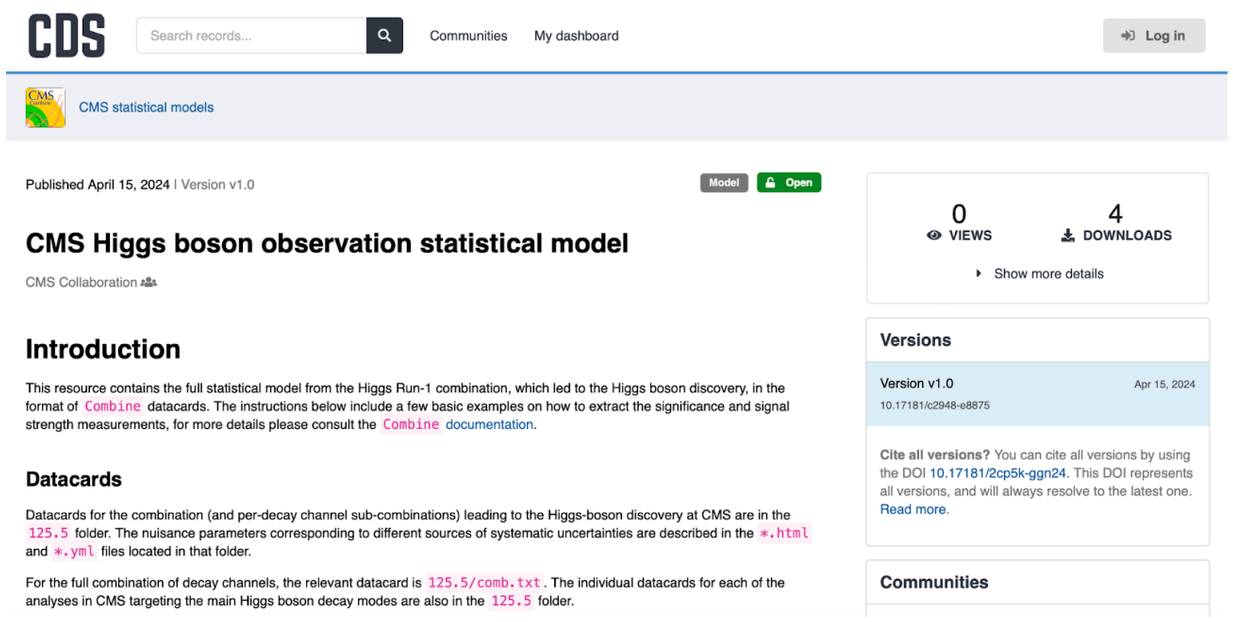


- Improved displaced jet triggers
- Novel displaced dijet ID based on graph NNs
- Improved on Run2 sensitivity, with only 2022 data

The CMS statistical analysis & combination tool: COMBINE

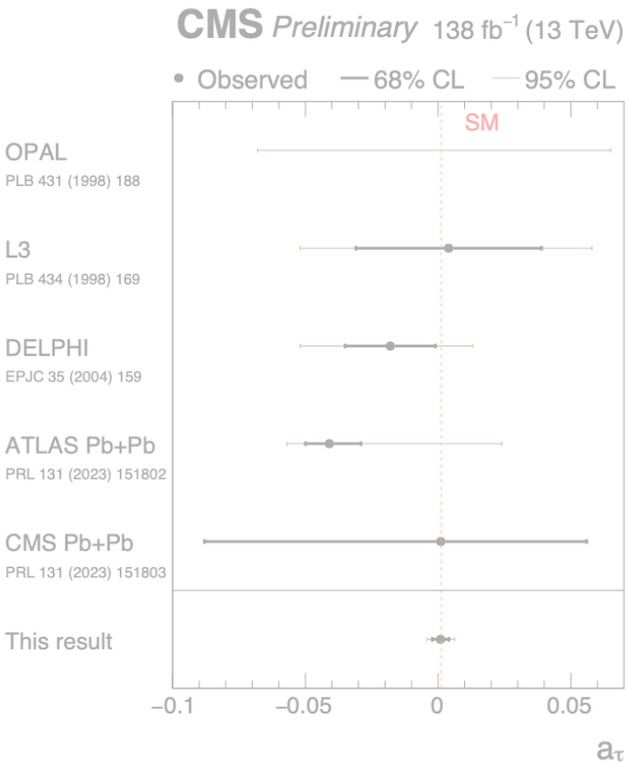
- Following the recommendation from CERN: Publishing statistical models: Getting the most out of particle physics experiments
- Full documentation of our statistical procedures and their implementation in the Combine library
- “Ready to use” container image (Check it out!)
- Open access to science: full Higgs discovery likelihood released!





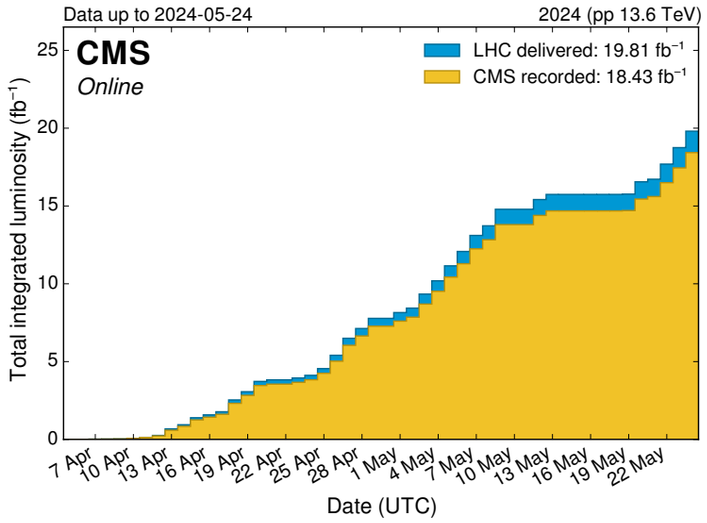
Outline

38 results made public since last LHCC



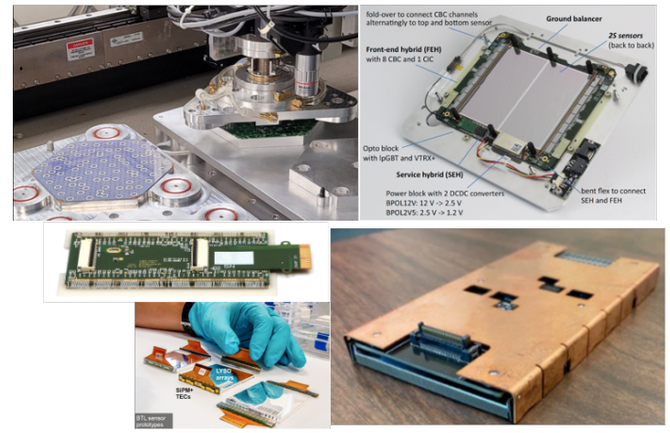
- 14 searches for new particles
- 13 precision SM & higgs physics
- 8 heavy quark physics
- 1 heavy ion
- 2 tools & generators

Object and detector performance in Run 3



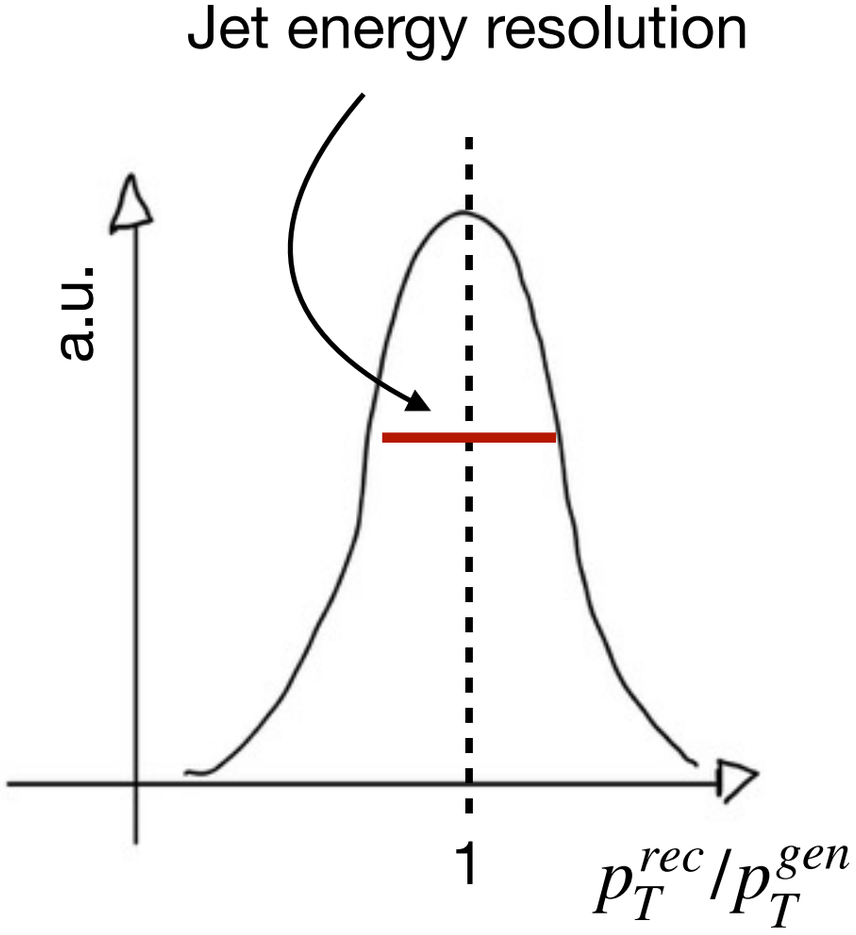
- Excellent performance in prompt data
- Smooth start-up of 2024 data-taking
- Successful commissioning and calibration

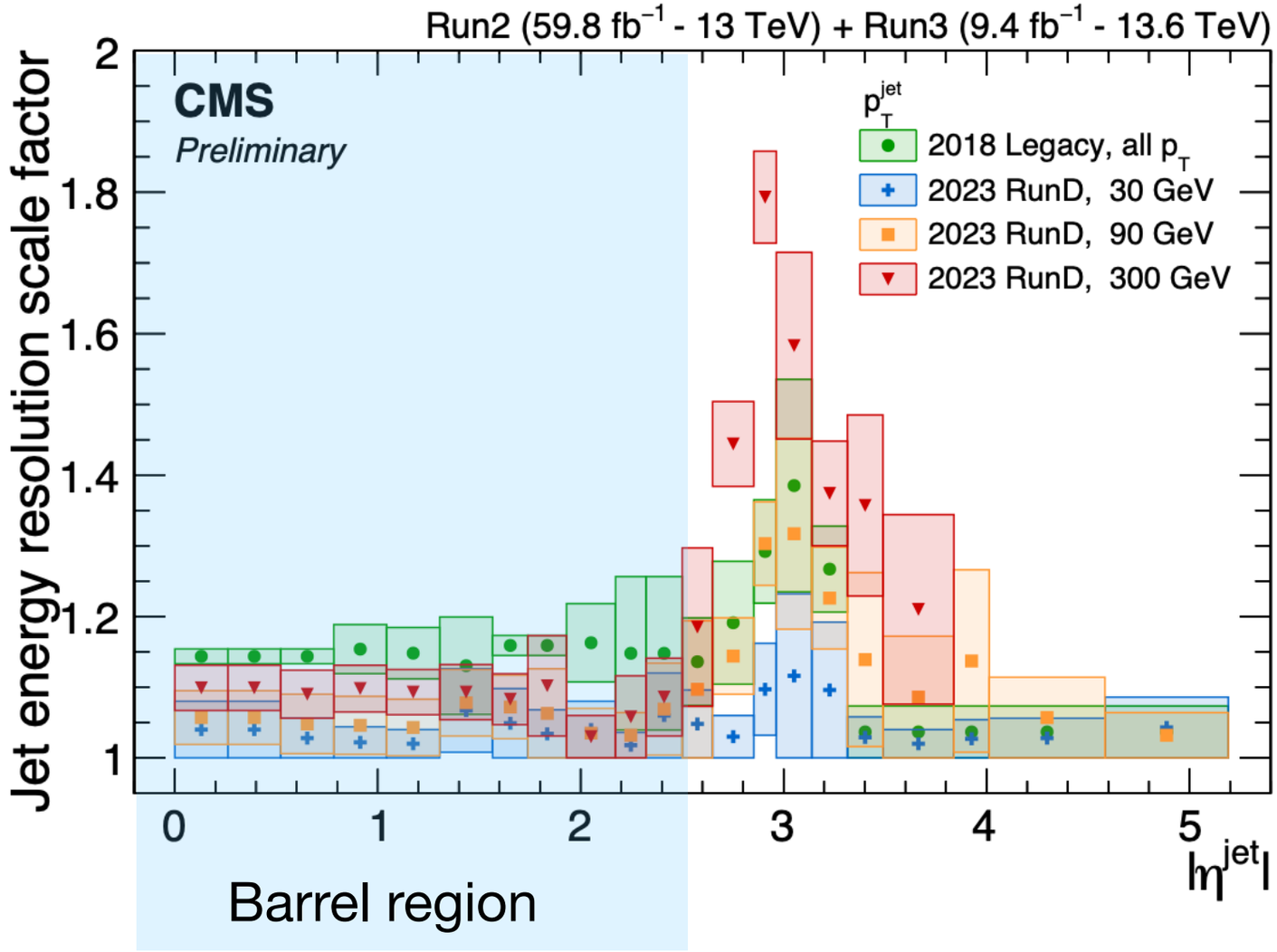
CMS Phase-2 Upgrade



- Transitioning into production
- Planning assembly and integration
- Improvement in simulation timing

Prompt reconstruction of data in Run3



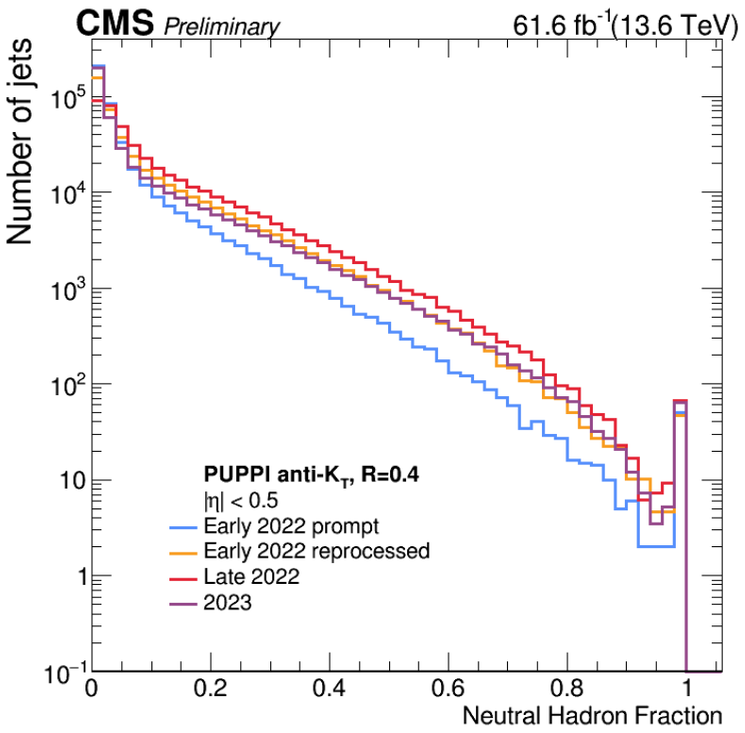


The jet energy resolution of prompt reconstructed data in 2023 is

- as good as legacy reconstruction in Run2 in the barrel region ($|\eta| < 2.5$)
- compatible for low p_T in the endcap ($2.5 < |\eta| < 3$)

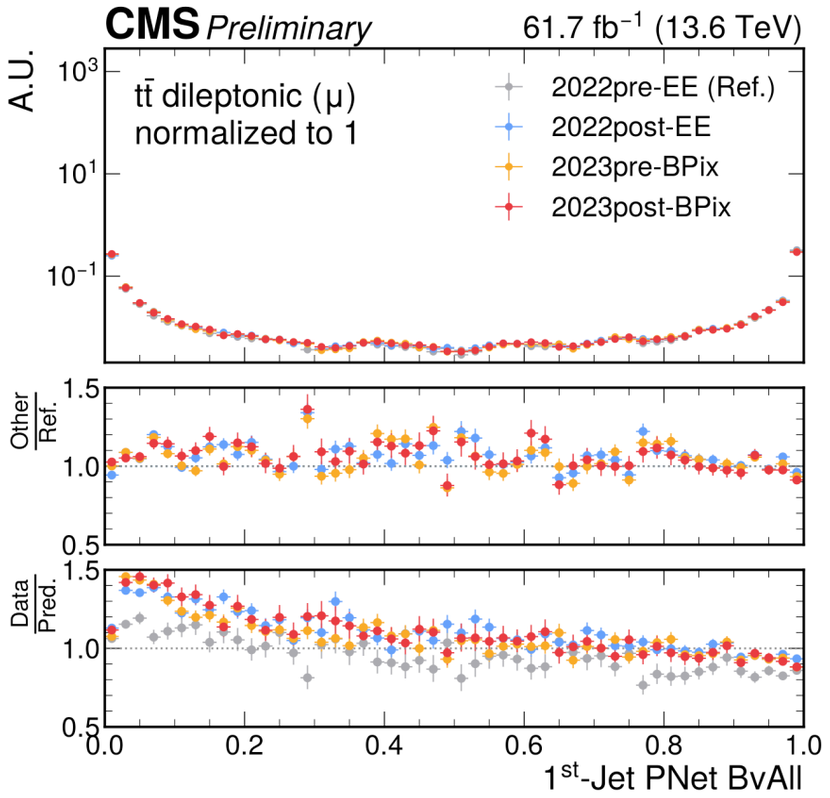
Time stability of object performance in Run3

CMS DP-2024/024



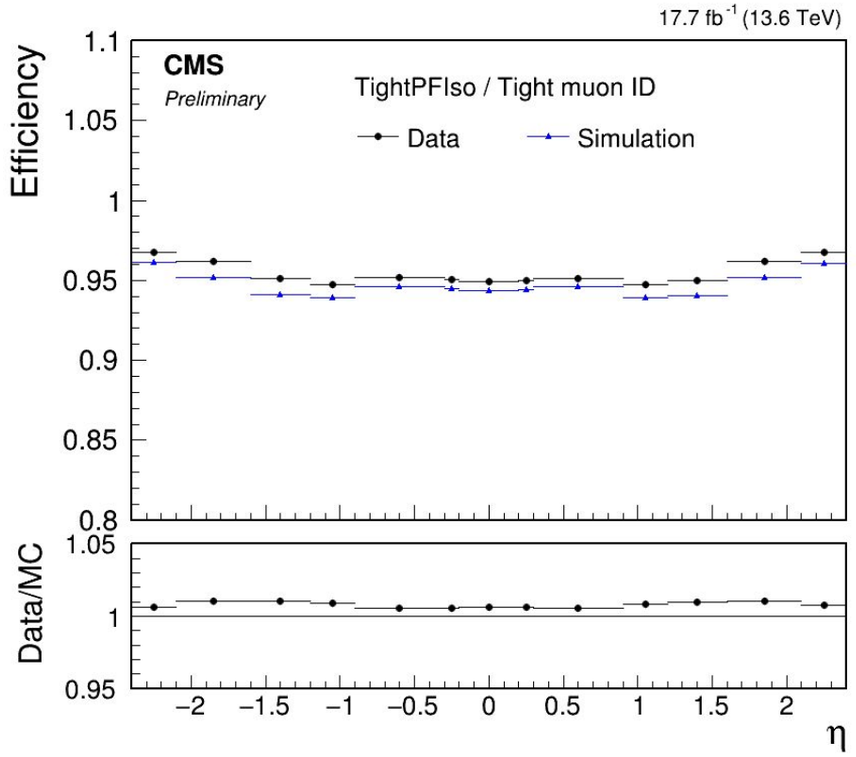
Only small differences in **neutral hadron fraction** for different data-taking periods

CMS DP-2024/024



Only small differences in the **b-identification score** for different data-taking periods

CMS-DP-2024-023

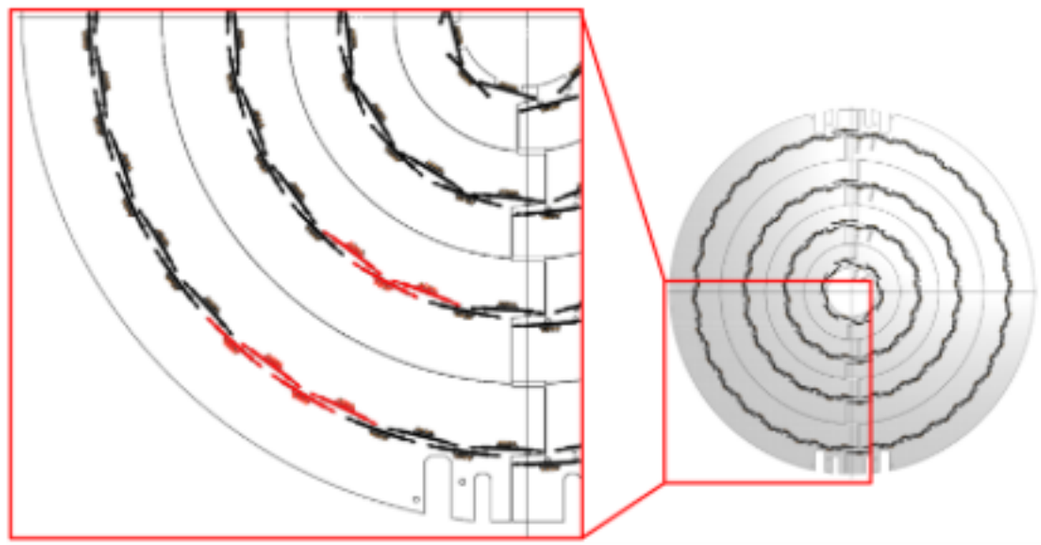


Good data-to-simulation performance for **muon identification**

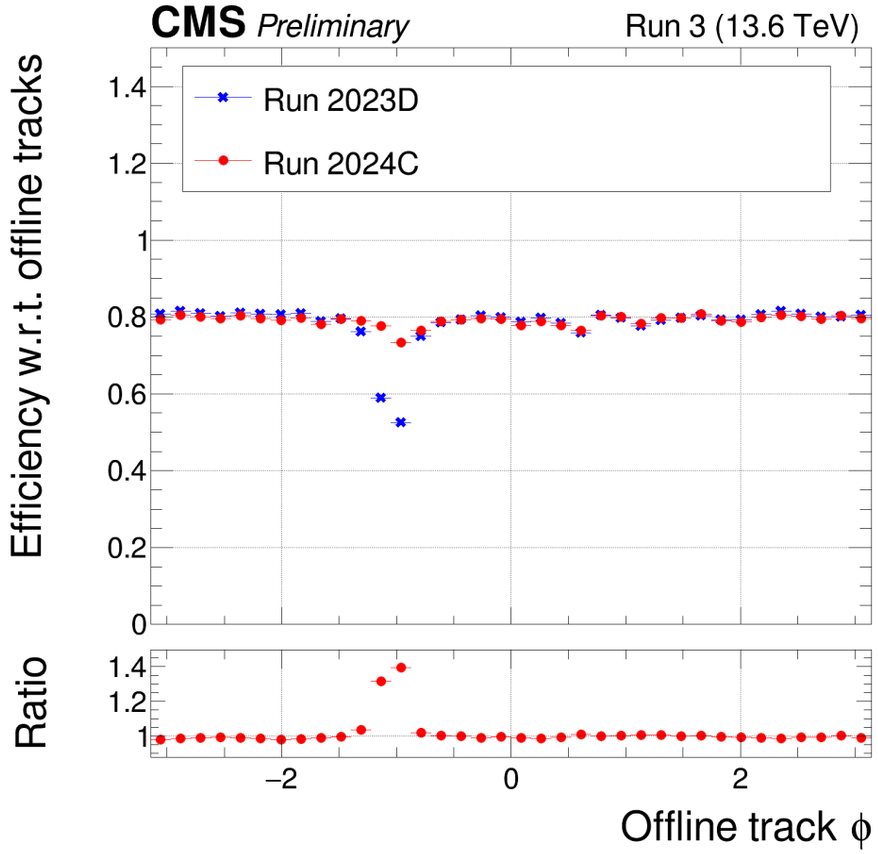
2022pre-EE = early 2022 data, 2022post-EE = late 2022 data,
2023pre-Bpix = early 2023 data, 2023post-Bpix = late 2023 data

Barrel Pixel layer 3 & 4

After TS1 of 2023 (June 19-24): 27 modules* in the Barrel Pixel Layers 3 & 4 became inoperable (issue in distributing the LHC clock signals). They cover a sector spanning approximately 0.4 radians (~23 degrees) in ϕ at negative pseudorapidity.



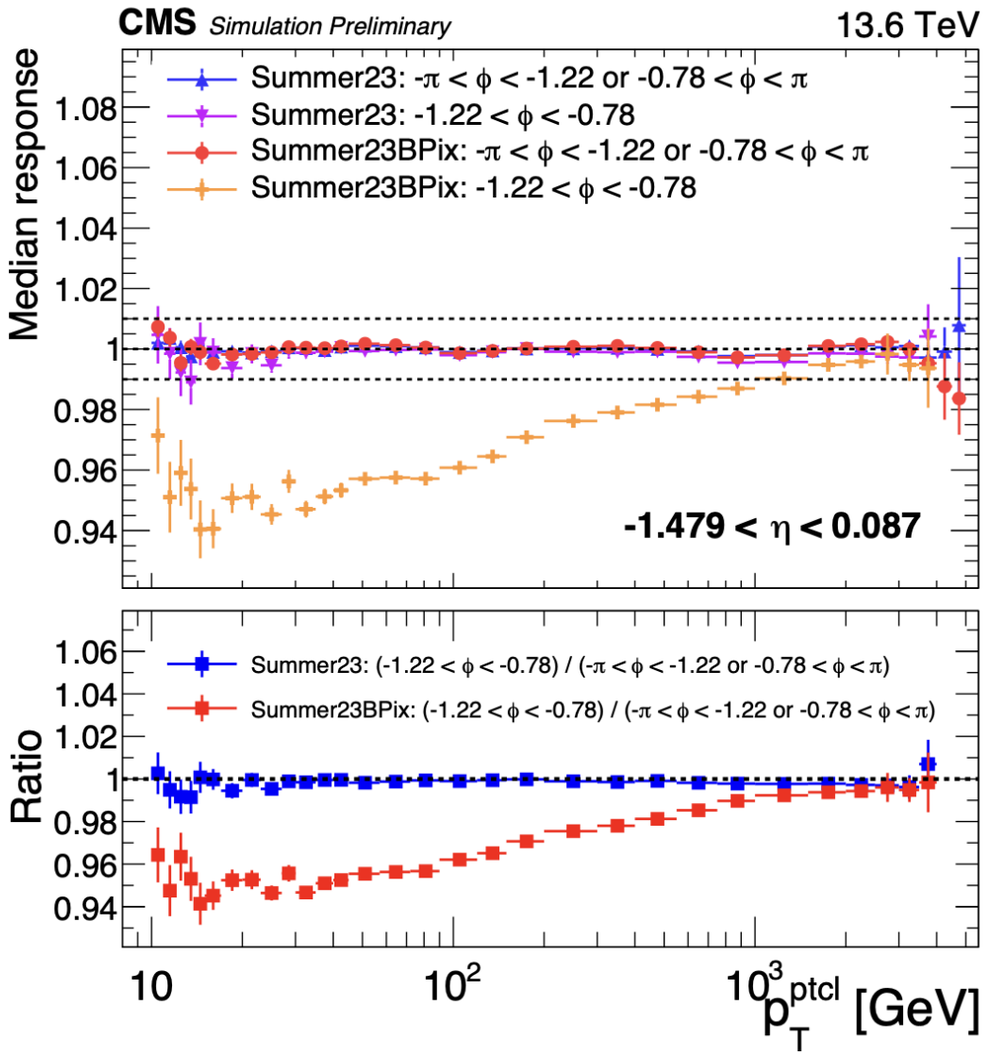
A small region in the detector has reduced efficiency in tracking

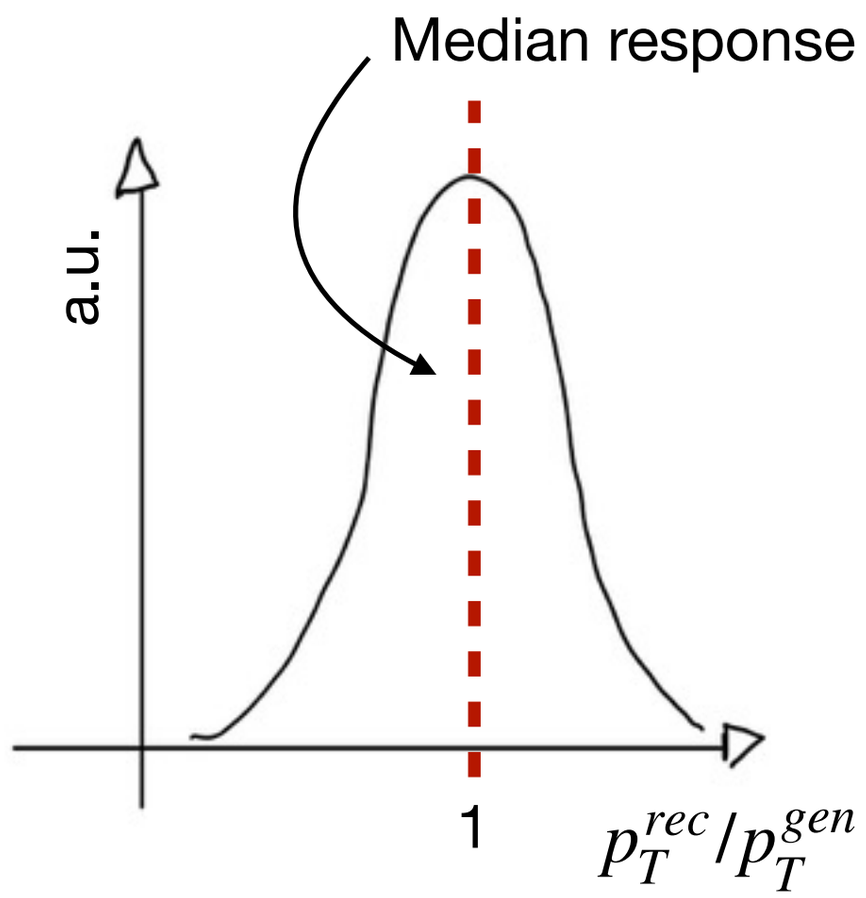


Doublet recovery for High-Level Trigger tracking to recover efficiency

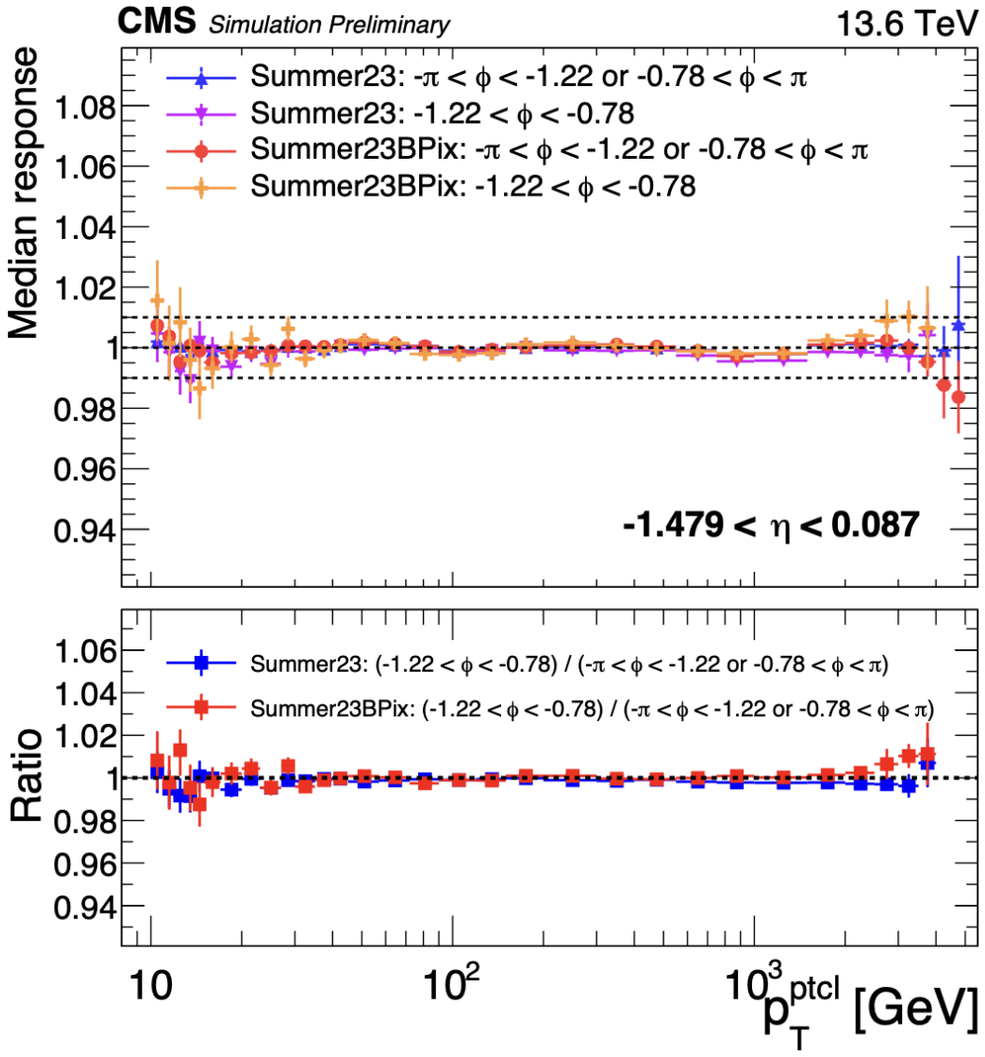
* representing about 1.5 % of the total modules in the pixel detector

Barrel Pixel layer 3 & 4
- offline reconstruction -

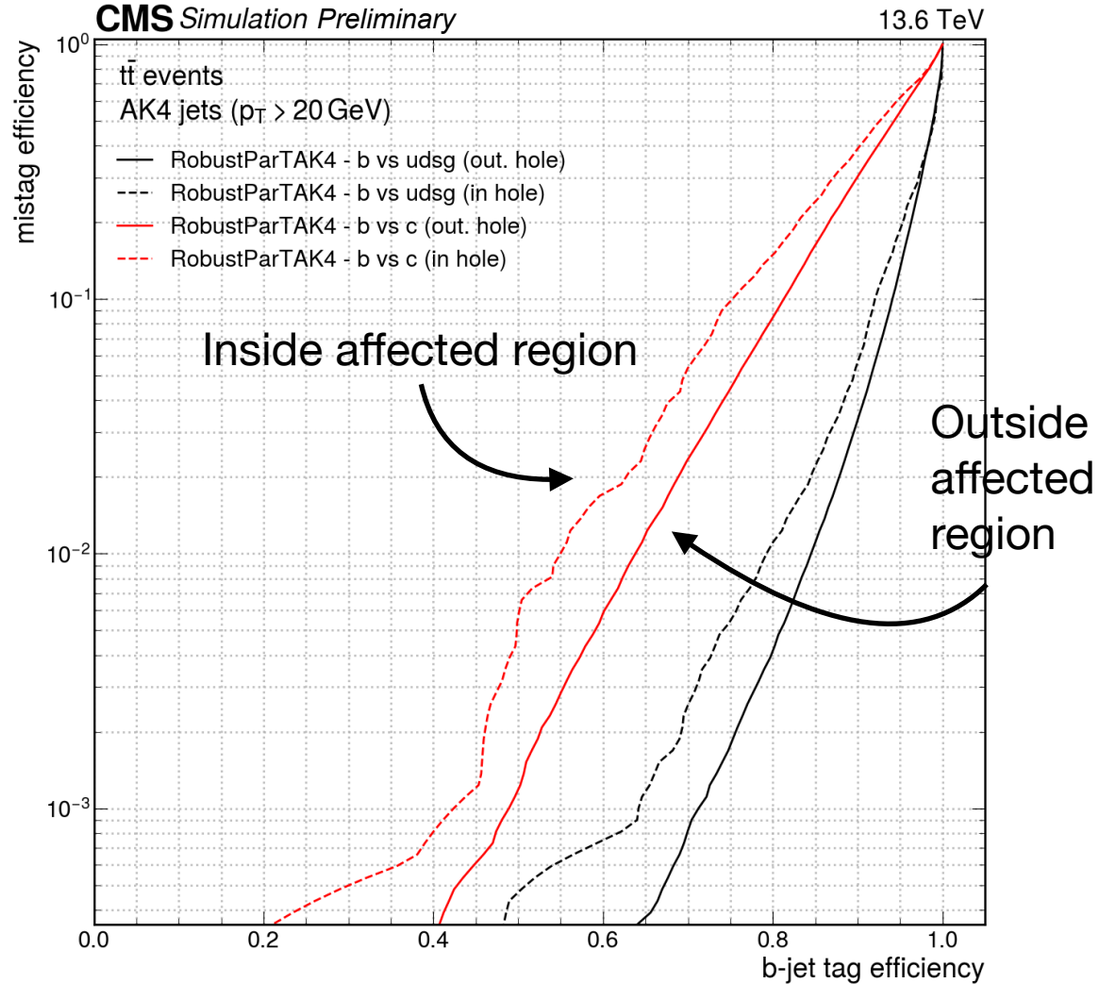




Barrel Pixel layer 3 & 4
- offline reconstruction -

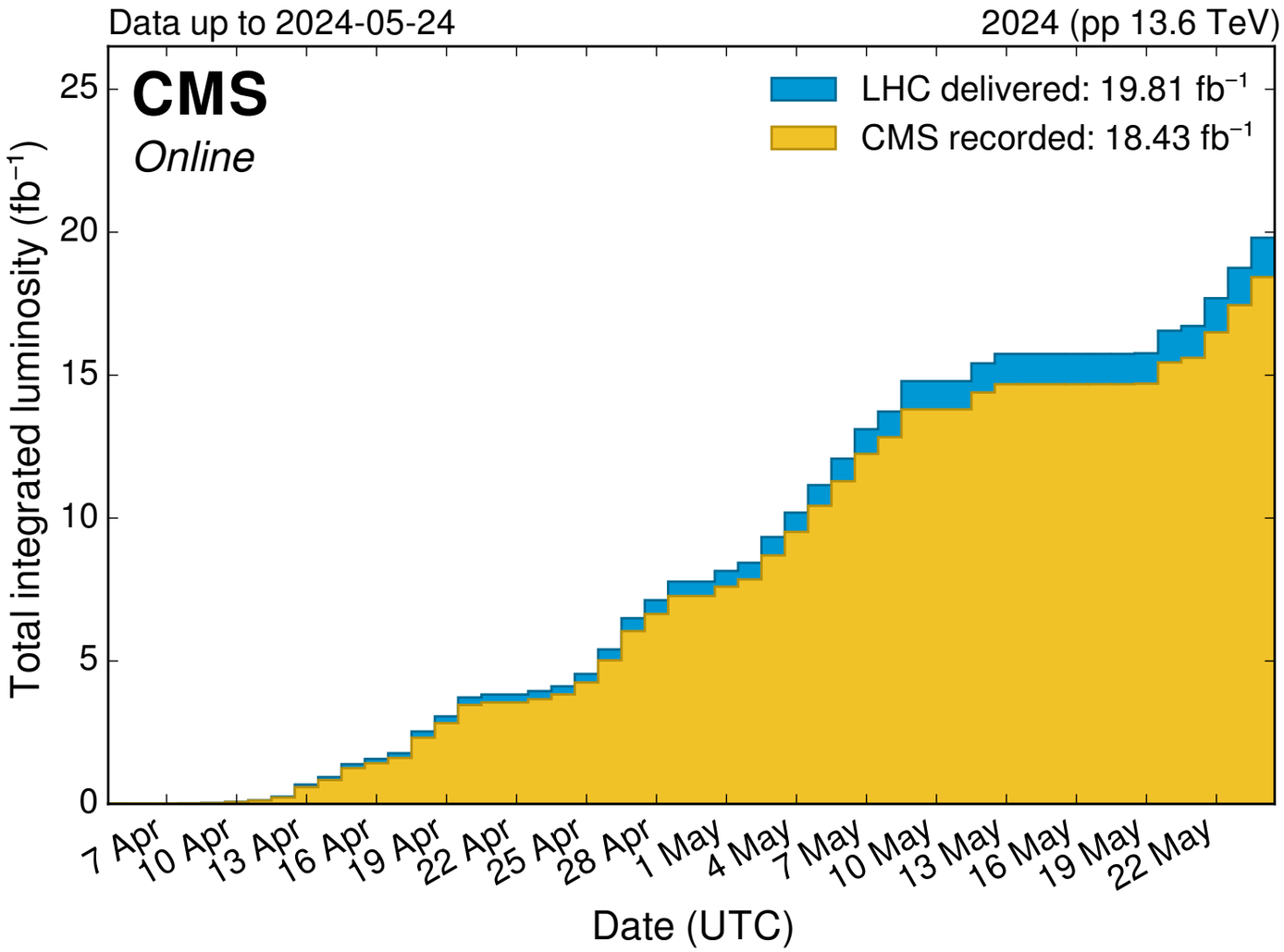


Dedicated **jet energy corrections** in the region to recover energy loss



Around 5% loss in **heavy flavor identification** efficiency in the affected region

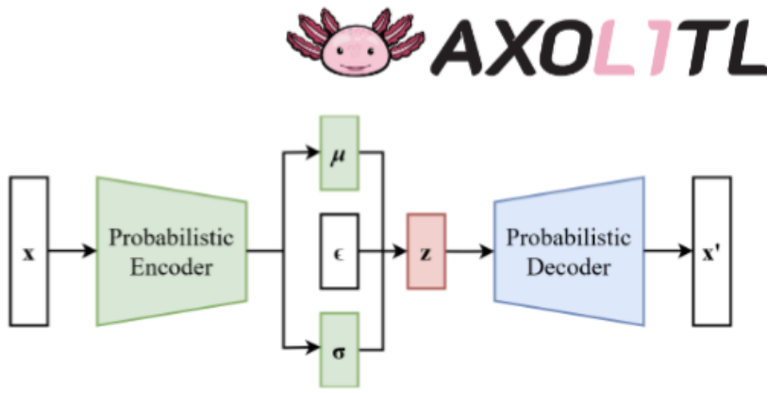
2024 data taking



- Successful detector commissioning
- Smooth data taking
- Excellent data certification > 97% in physics collisions

Level-1 Trigger

Higher target rate & optimizations of existing seeds:
→ add many new seeds to the L1 menu in 2024



- New **anomaly detection trigger**

- New low p_T single muons seed for barrel region
  → extremely valuable for **CMS B-physics program**

- Extend the coverage of displaced muon seeds for **LLP searches**

- New seeds targeting single lepton channel of **HH→bbWW**

L1 scouting: new VCU128

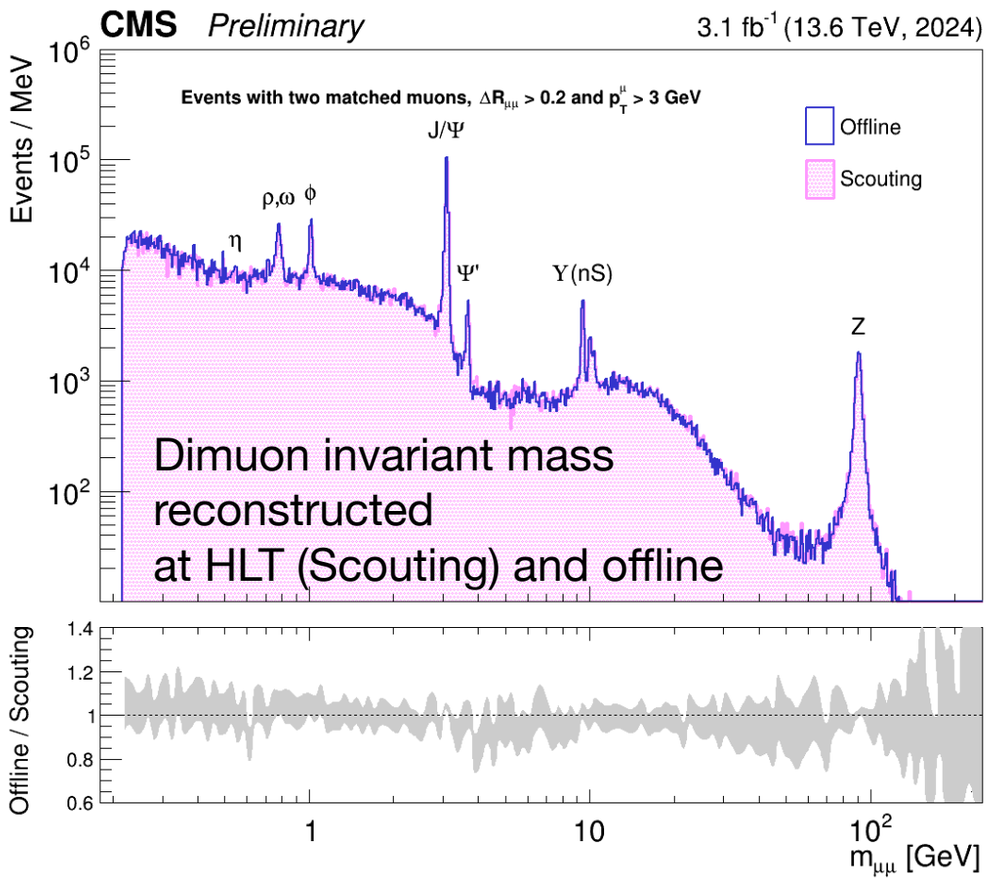
High-Level Trigger

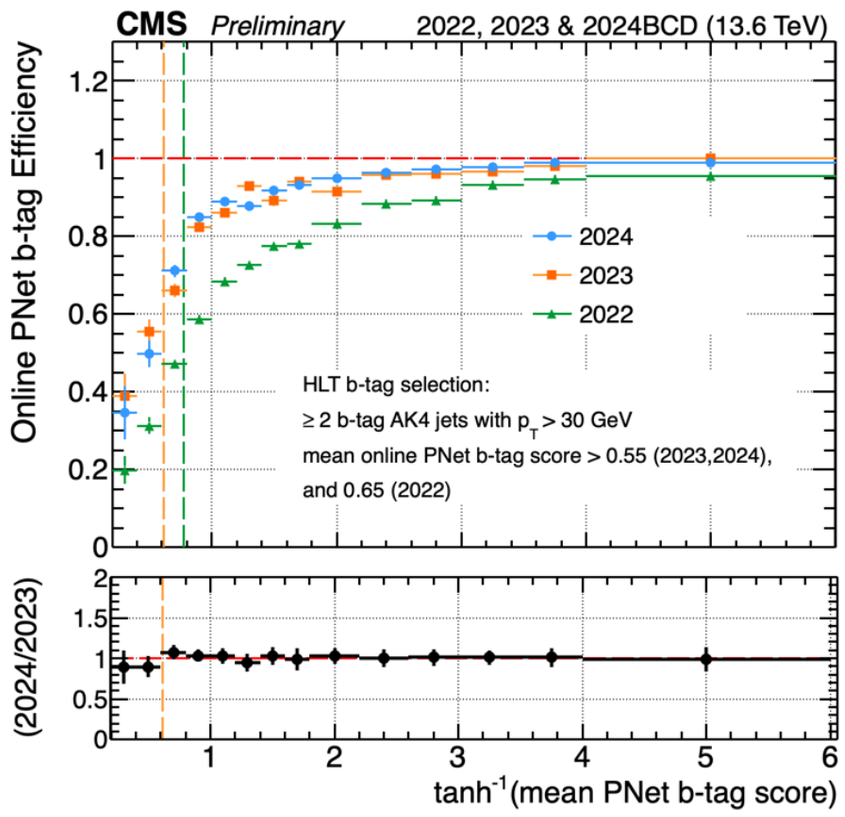
Many improvements deployed at HLT in 2024:

CMS-DP-2024-013

CMS-DP-2024-016

- New triggers (e.g. low-pT single muon)
- Improvements in the HLT reconstruction, and extended event content for HLT scouting
- More reconstruction is offloaded to GPUs, and heterogeneous code is ported to Alpaka portability library (CMS-DP-2024-026)
- Good physics performance in the first 2024 data



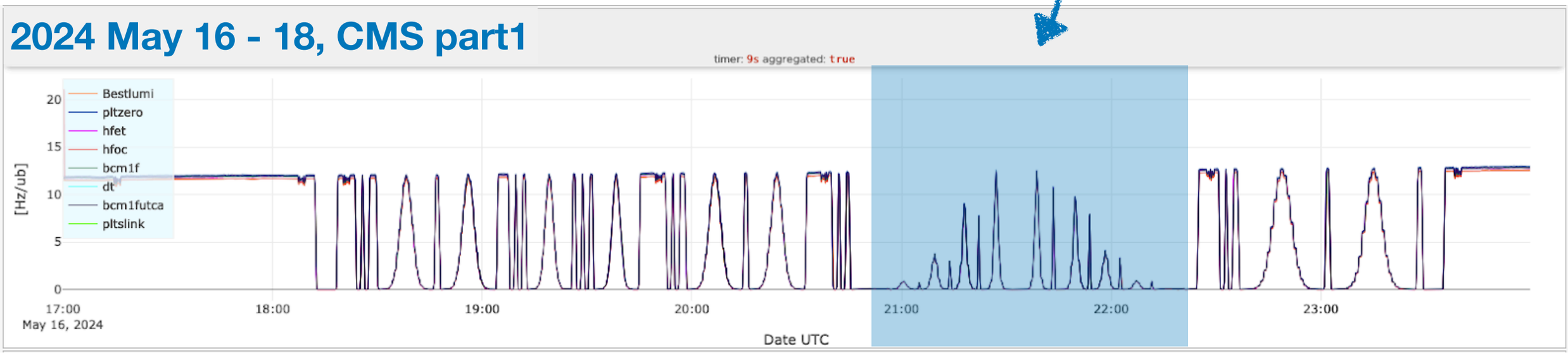


Increased b-tagging efficiency at HLT in ttbar events

Beam Radiation Instr. & Luminosity

- Finalizing 2023 luminosity calibration (expected precision < 2%)
- Consistency of 5 independently calibrated luminometers in 2023 vdM fill better than 0.3%
- Leading uncertainty in 2022+2023 due to bunch proton density distribution

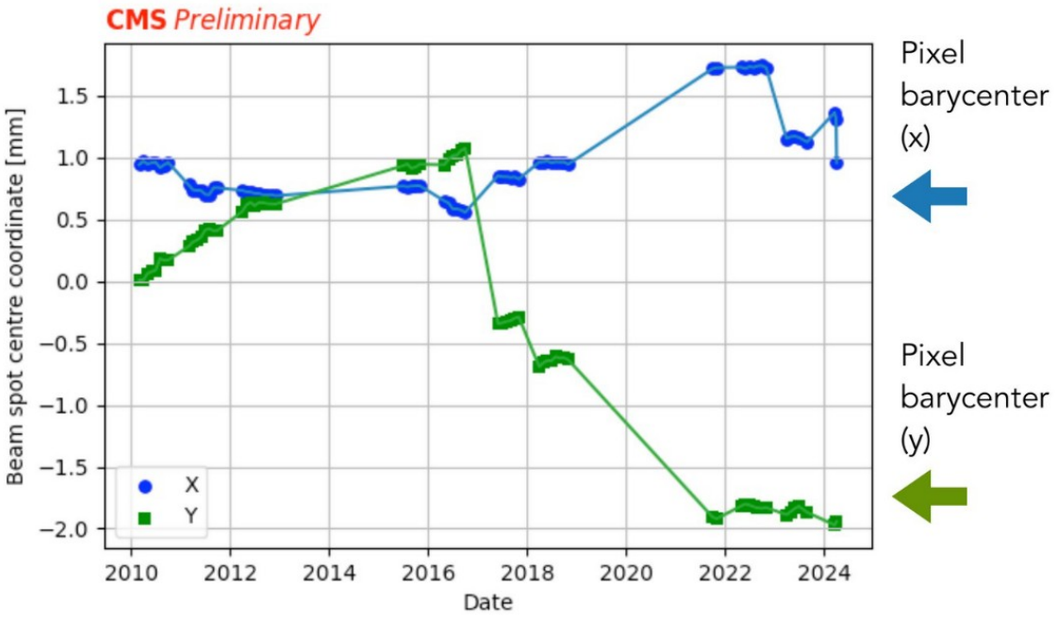
→ Recent vdM campaign with emphasis on XY-factorization measurement



Tracker

Thanks to the machine team for the quick action!

Beam spot movement



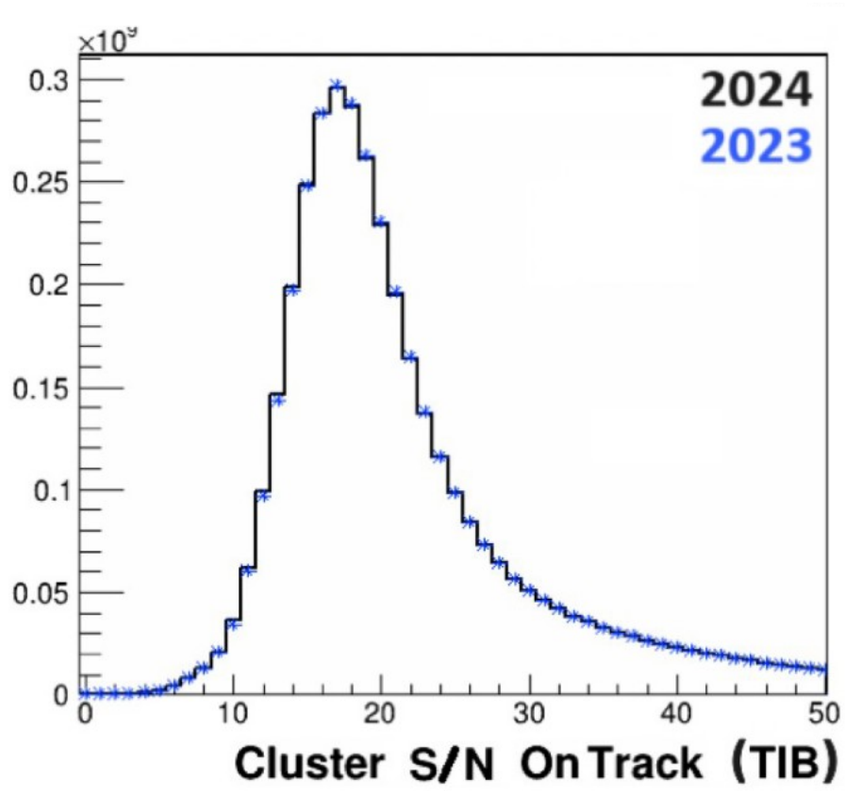
- 200 - 300 μm shift further away from barycenter observed in 900 GeV running

→ detector lifetime concerns

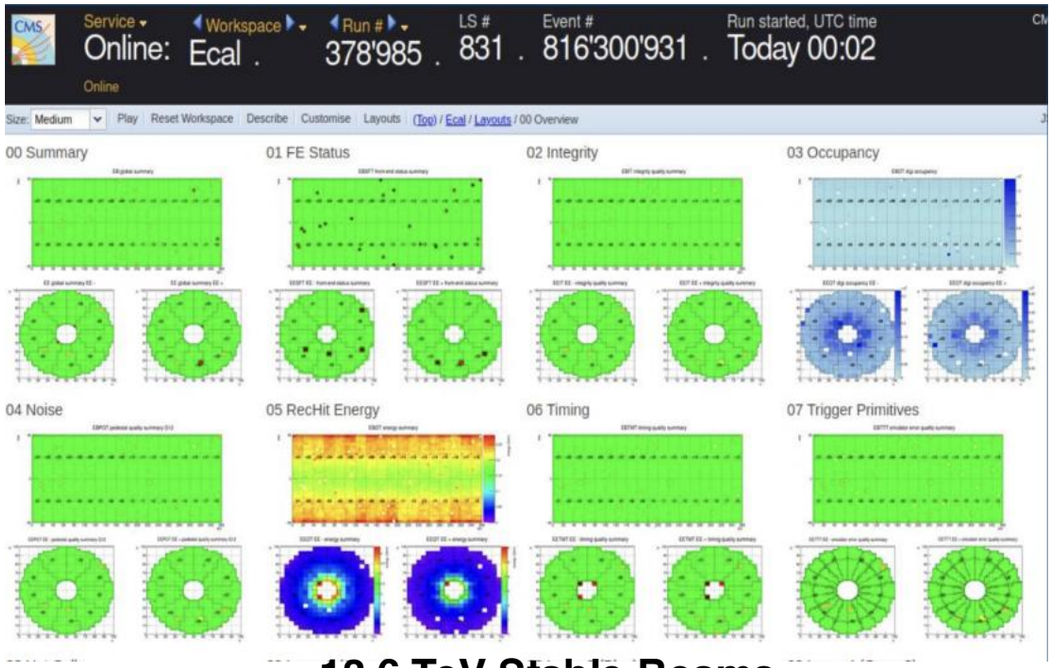
- LHC updated optics for 13.6 TeV running
- Now excellent overall radial displacement

Data quality for both strips and pixels

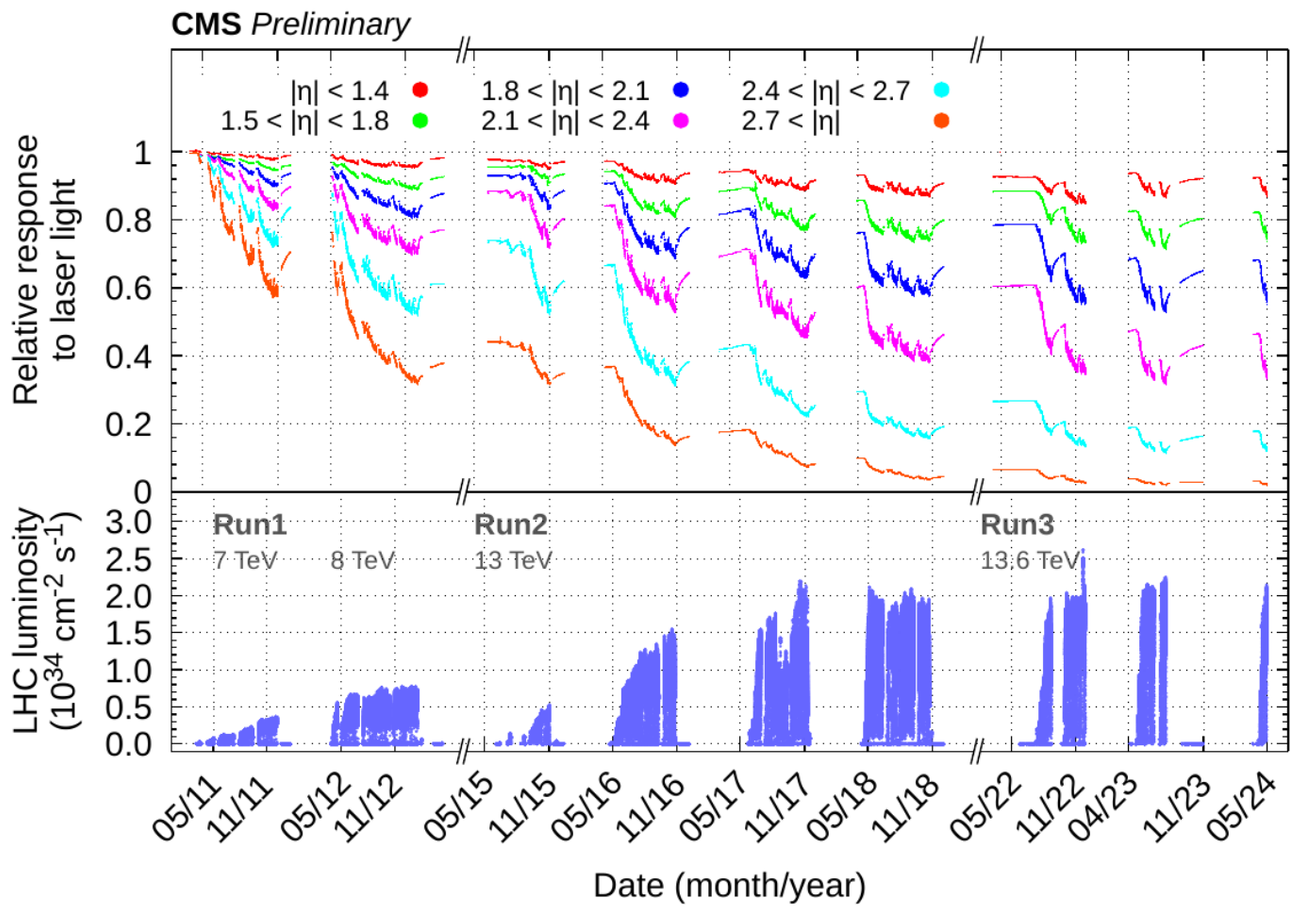
- Good-channel fractions of 96% (pixel) and 97% (strips)
- Signal-to-noise cluster charge well behave and compatible with 2023



Electromagnetic Calorimeter



13.6 TeV Stable Beams



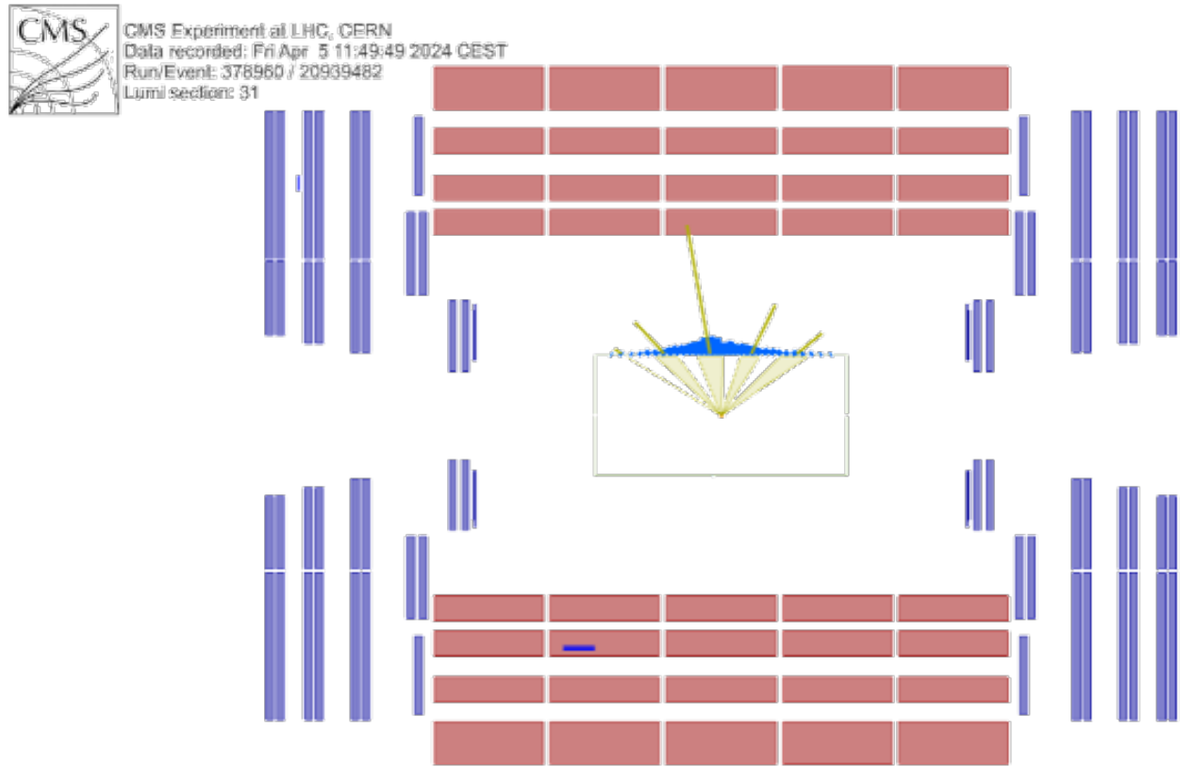
CMS-DP-2024-022

- ECAL Run Readiness Review (5 March): to ensure smooth startup
- Beam commissioning: ECAL ran smoothly during beam splashes, unstable beams, and cosmics
- Two ECAL Papers: ML4DQM paper accepted & Run 2 Performance paper submitted
- Inter-calibration: new conditions deployed for 2024 data taking

Hadronic Calorimeter

Smooth start of 2024 data taking after successfully completing the preparation of detector using commissioning data

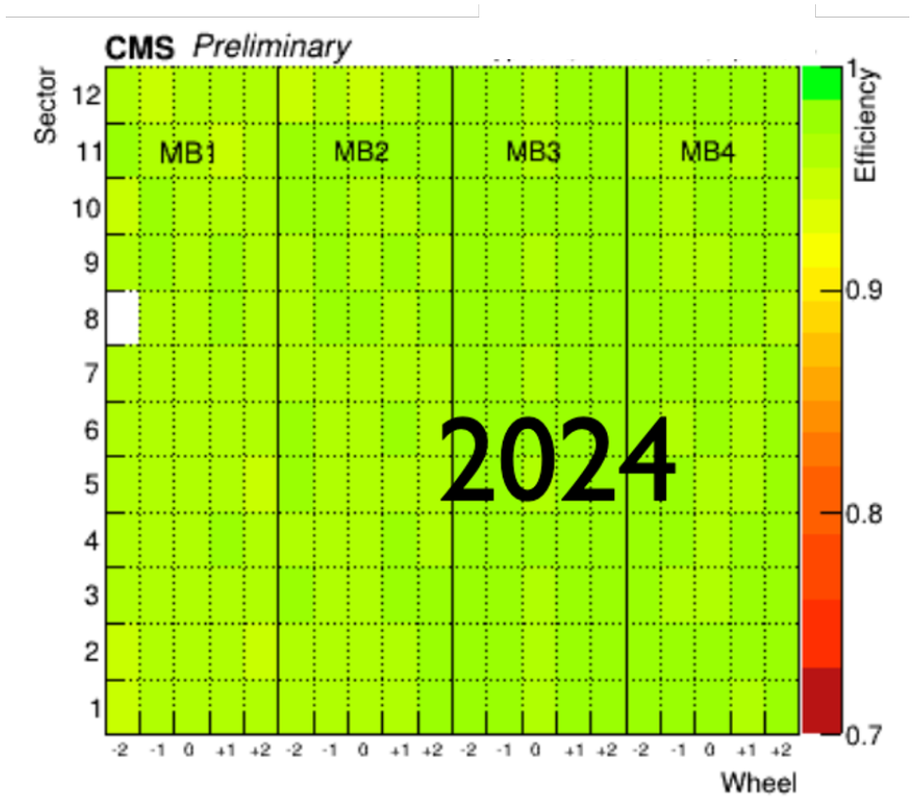
- Phase-scan run allowed for fine-tuning of detector timing
- Completed framework to automatically (and frequently!) update the detector conditions (radiation-induced evolution)
- Prepared depth- and pseudorapidity-dependent pulse shapes for a better reconstruction of calorimeter energy



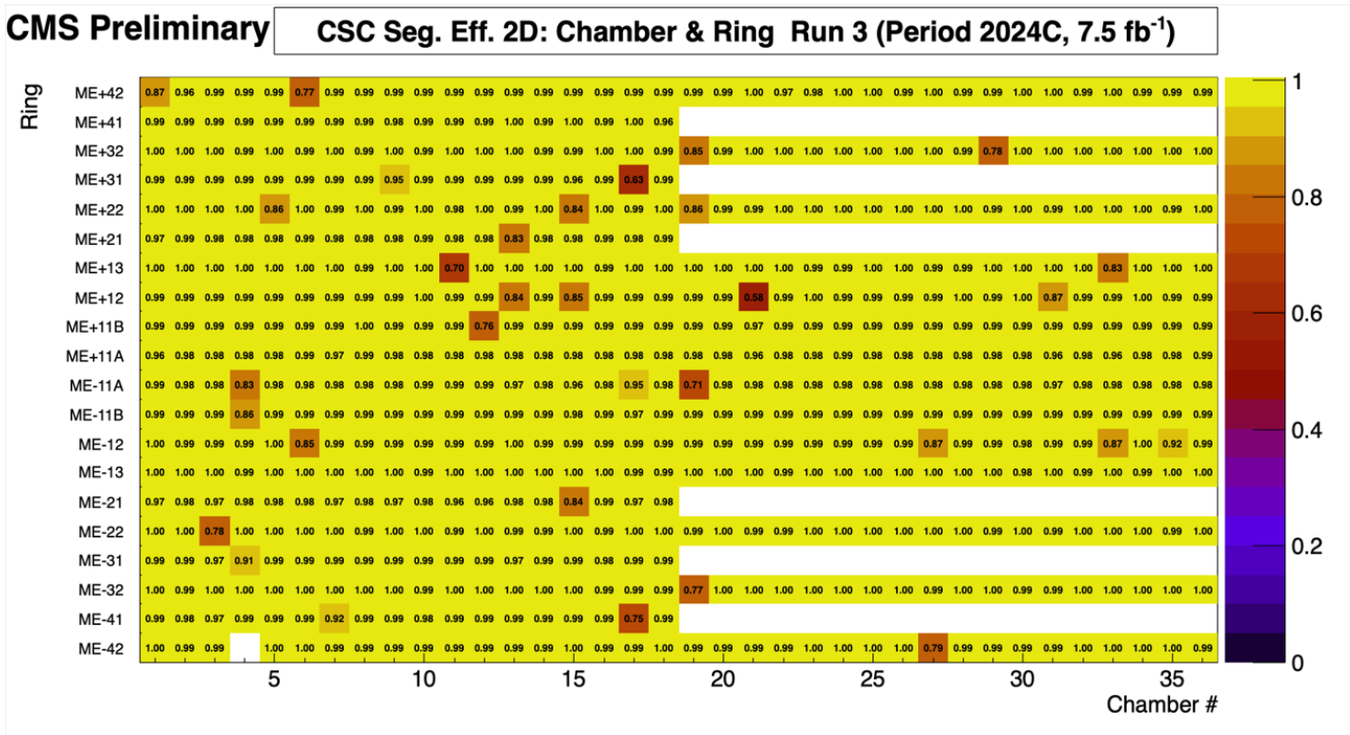
Before collisions: HCAL LED Run
Injecting light in the HCAL photosensors to test the backend electronics firmware produces unusual event displays

Muon System

✓Muon System is running smoothly
✓Good detector performance



2024 DT efficiencies
One DT chamber is off due to a hardware issue that will be solved during YETS24-25



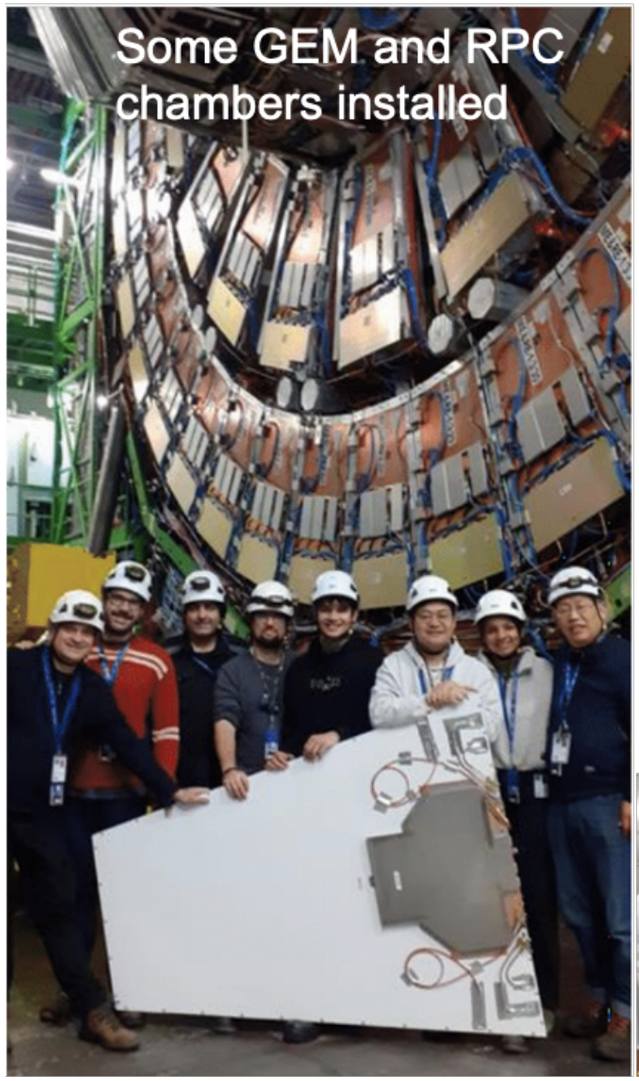
2024 CSC segment efficiencies
Few chambers with lower efficiency are due to known reasons (electronics board failures, occasional temporary failures)

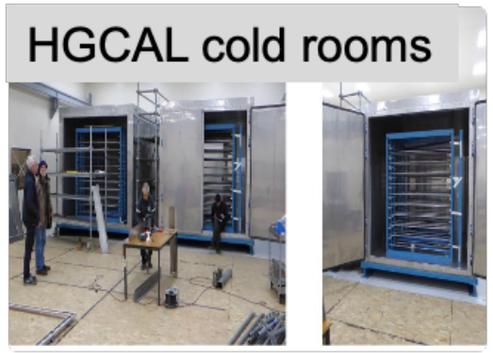
Precision Proton Spectrometer

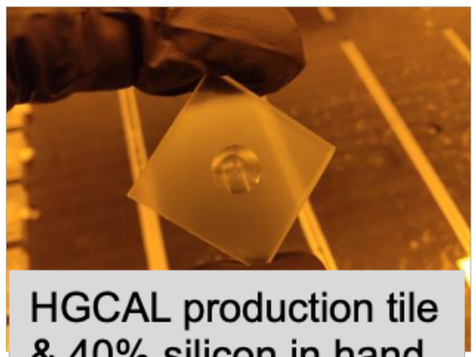
- Roman Pots are in and detectors take data for every high-luminosity fill of 2024
- Pixel tracking detectors show excellent efficiency (2 new detector packages installed)
- Vertically shift detectors every 100/fb for mitigation of non-uniform radiation
- First high-level-trigger using PPS data
- Mitigation of radiation effects in 2024: Improved resolution of diamon timing detectors
- “Beam-based” alignment fill completed → alignment constants underway

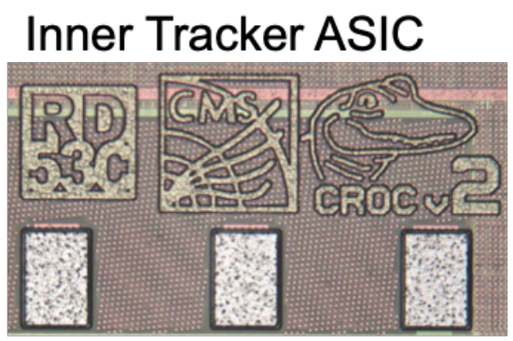
Phase-2 Upgrade

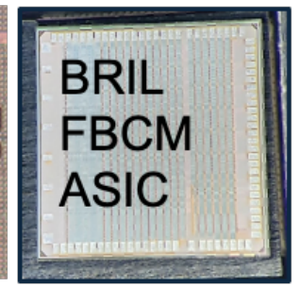
CMS Upgrade transitioning into production

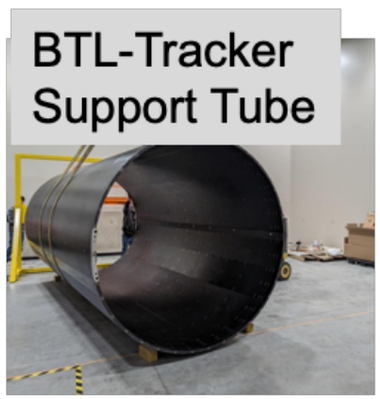


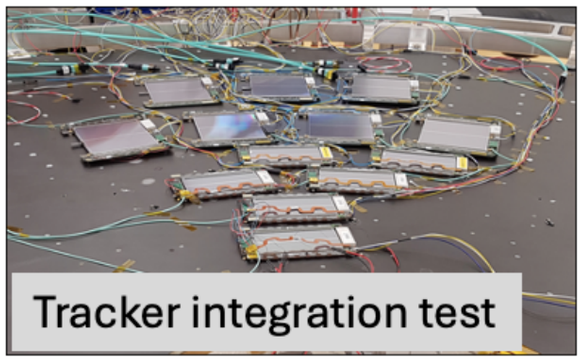




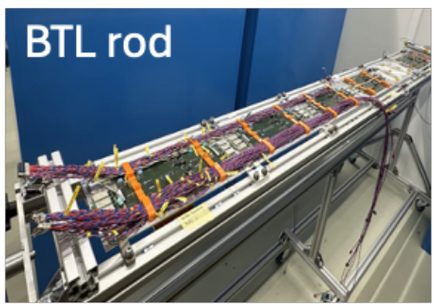






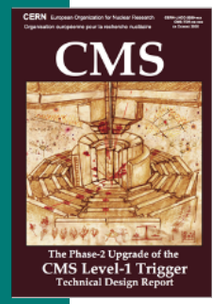


Barrel Calo insertion tool - enfourneur



CMS Upgrade planning on assembly and integration

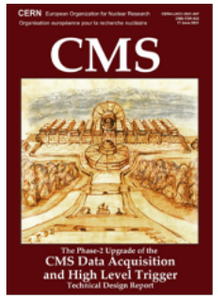
Phase-2 Upgrade



L1-Trigger

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

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



DAQ & High-Level Trigger

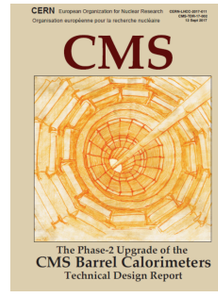
https://cds.cern.ch/record/2759072

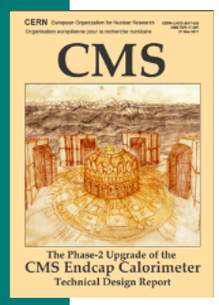
- Full optical readout
- Heterogenous architecture
- 60 TB/s event network
- 7.5 kHz HLT output

Barrel Calorimeters

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

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

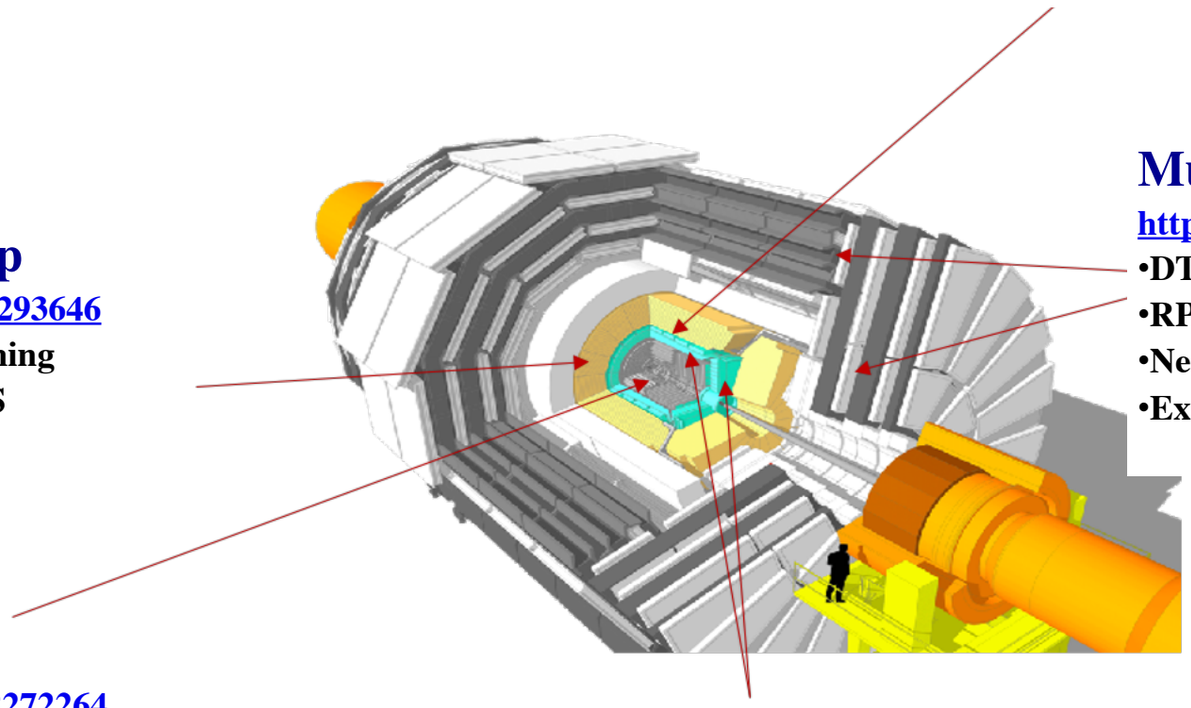




Calorimeter Endcap

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

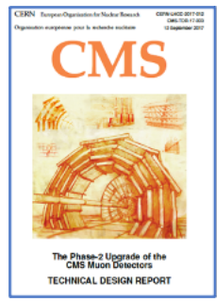
- 3D showers and precise timing
- Si, Scint+SiPM in Pb/W-SS

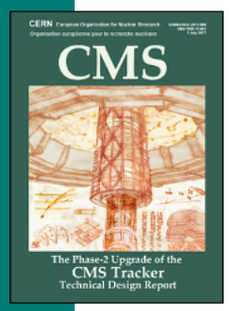


Muon systems

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 $\eta \simeq 3$

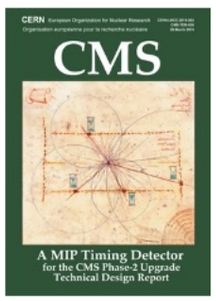




Tracker

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:

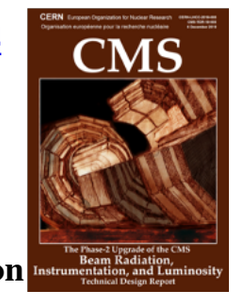
- Barrel layer: Crystals + SiPMs
- Endcap layer:

Low Gain Avalanche Diodes

Beam Radiation Instr. & 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



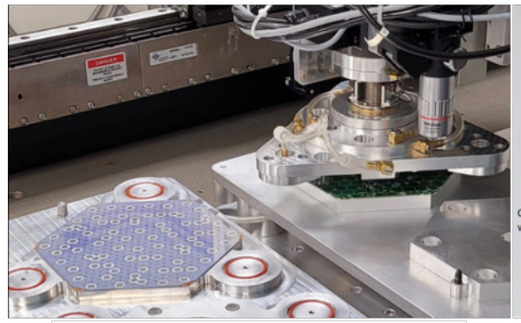
The CMS Upgrade

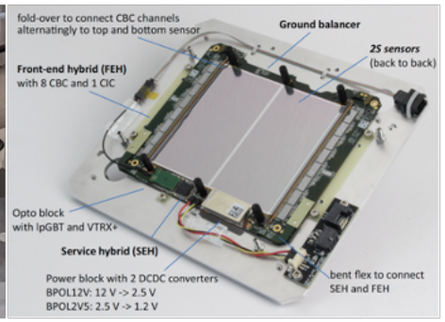
- CMS conducted most EDR/ESR – recently the complete back-end systems ESR
  - finalising prototyping of HGCAL electronics and MTD/ETL components for reviews in the near future
- Two more ASIC submissions to go
- **Schedule end float *just* positive**
  - Delays also due to resource limitation
  - Lots of work behind and ahead

But no steady-state module production YET

Many basic items are in production

•Tracker inner (IT) & outer (OT): All ASICs, all sensors, OT hybrids, MAPSA,
mechanics, IT hybridization
•HGCAL: Some ASICs, sensors, SiPMs, tiles, some mechanics, hexaboards
•BTL: ASICs, LYSO, SIPMs
•BCAL: ASICs, some electronics boards
•MUONs: GEM and iRPC chambers, DT and CSC electronics boards
•DAQ: DTH400 and DAQ800 electronic cards - ready for series production
•CO_2 systems

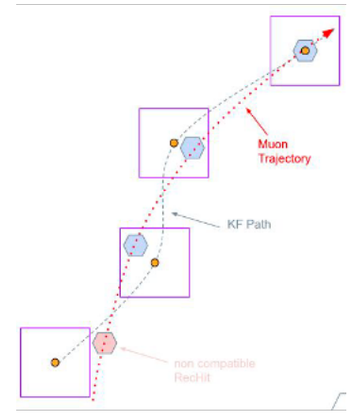




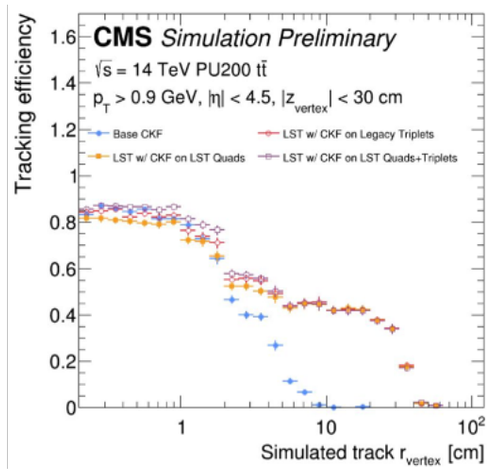
Recent highlights

- **Great progress in detector performance & high-level trigger:**
  - Kalman Filter for Muons in HGCAL & Line Segment Tracking in high-level trigger
- **Tracker:**
  - About to start Outer Tracker module production
  - Inner Tracker ASIC final and in production
- **MTD, Barrel BTL:** about to start module production
- **MTD, Endcap ETL:** sensor review in July, ASICs – full functionality proven
- **Muon:** RPC and GEM chamber production ongoing
- **HGCAL:**
  - Great progress with mechanics
  - A couple of HGROC bugs were found, studied, and understood, fix possible in metal layer. Studies ongoing.
  - SiPM, Scintilator production started & more than 40% of silicon sensors received

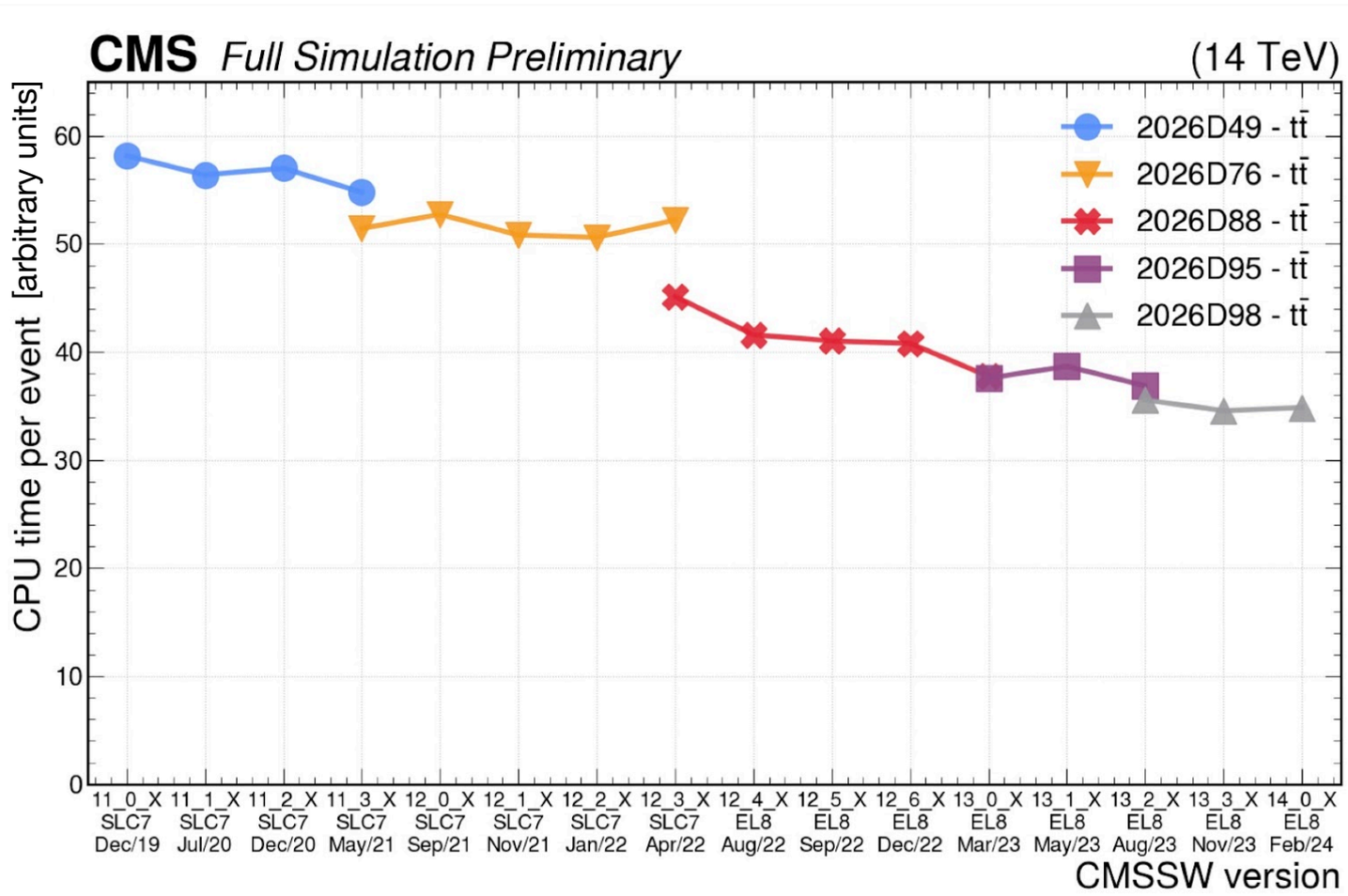
Kalman Filter in HGCal



Line Segment Tracking @ HLT



Evolution of Phase-2 simulation timing



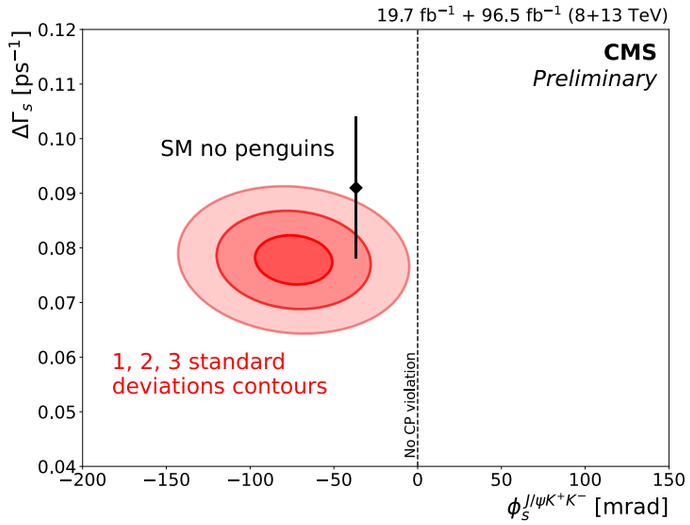
- Improving the full Geant4 Phase-2 Simulation over 5 years
- CMS aspired to 10% year-over-year improvements in the simulation timing
- Similar trend for reconstruction timing

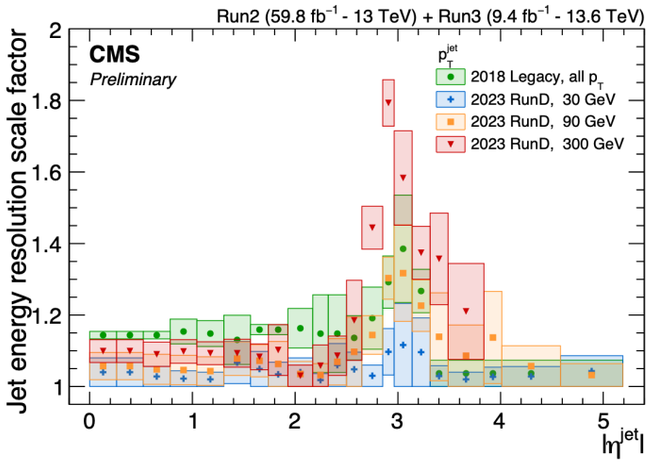
Summary

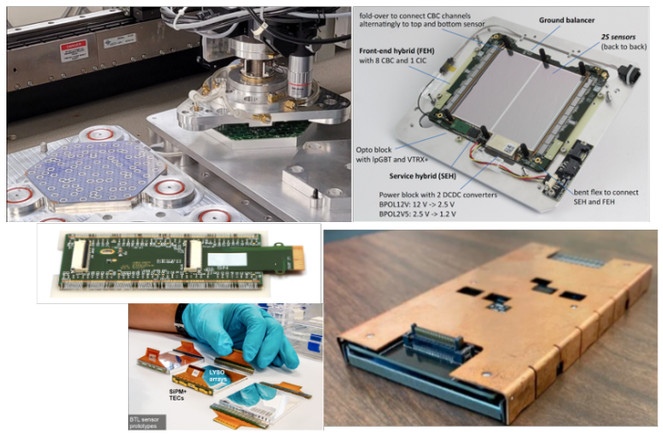
With a good understanding and calibration of the physics objects and innovative machine learning techniques, we can move the boundaries of what is assumed to be possible!

We learned a lot about our detector in Run2 resulting in excellent performance of physics objects in prompt data reconstruction in Run3.

In the CMS Phase-2 Upgrade, we are transitioning into production and some great developments in the software area.



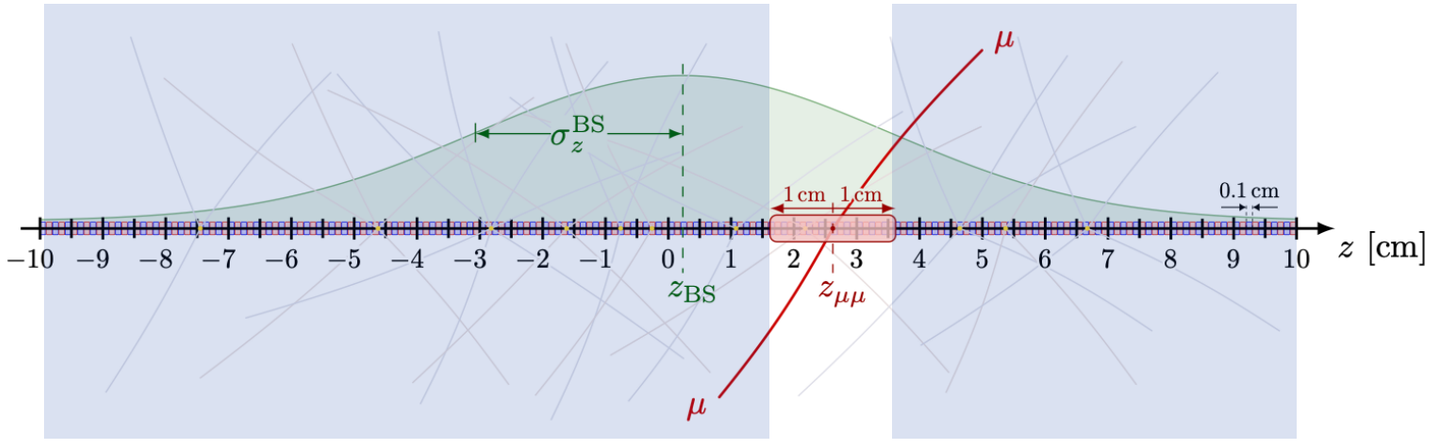


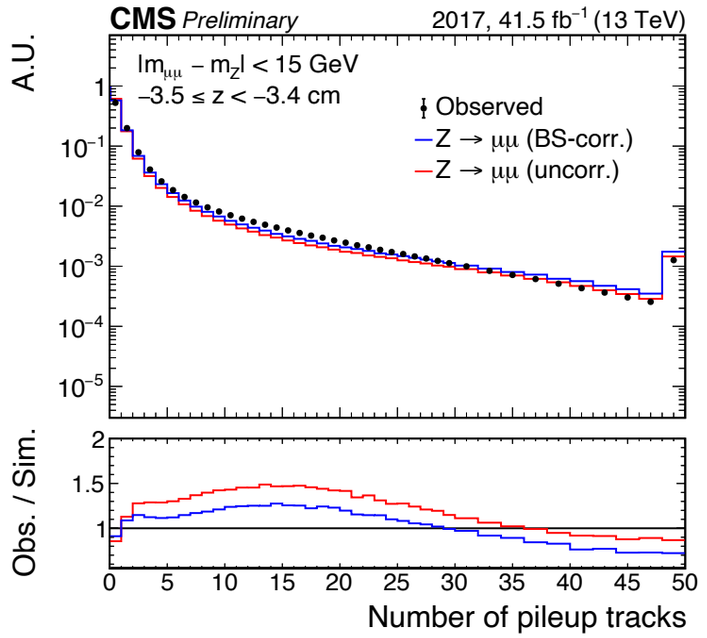


Backup

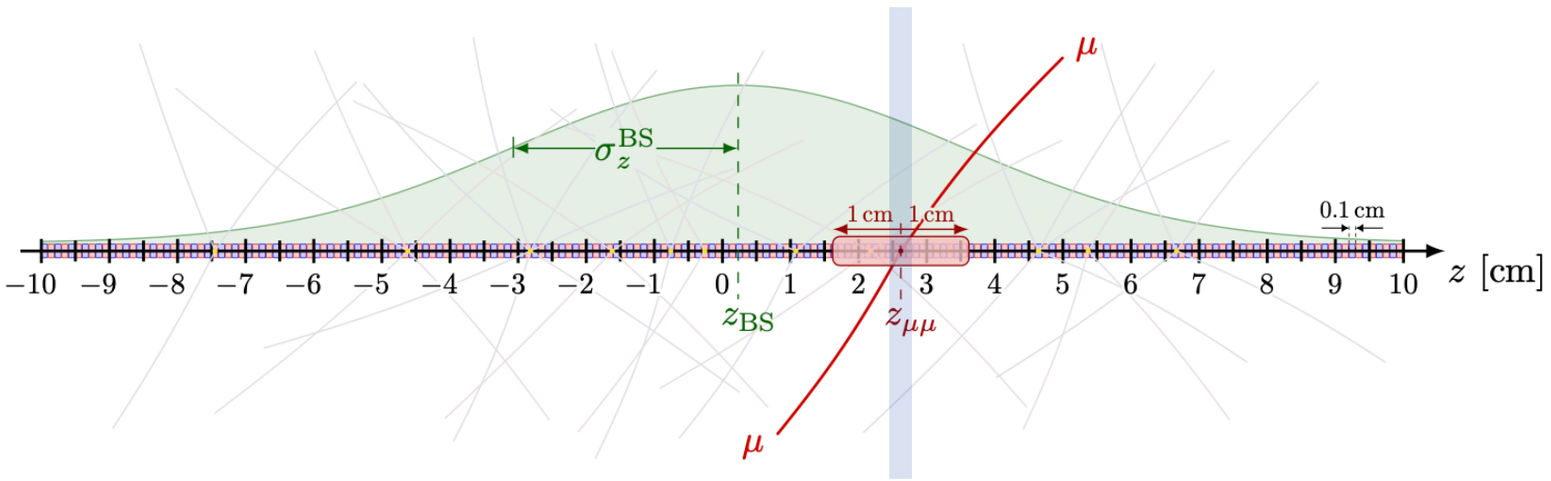
Observation of $\gamma\gamma \to \tau\tau$ in pp collisions & limits on g-2 of the τ lepton

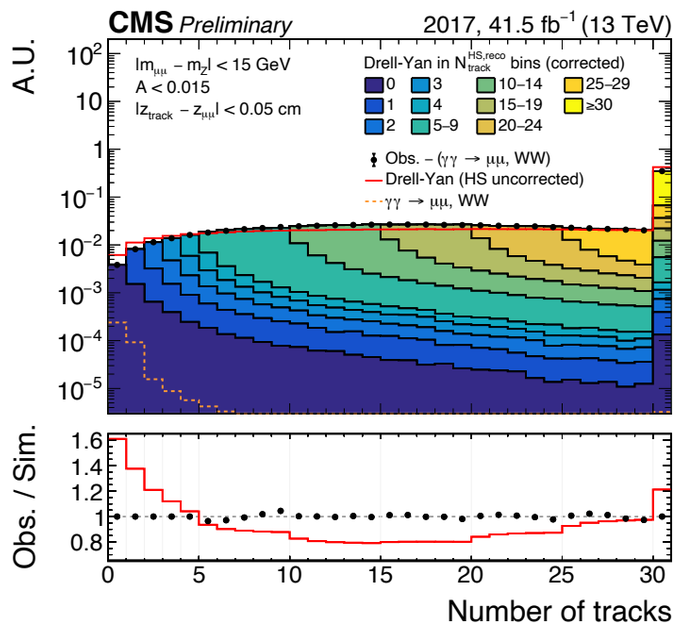
Pileup track multiplicity correction





Hard scattering track multiplicity correction





Line Segment Tracking in HLT

CMS-DP-2024-014

- During HL-LHC increased combinatorics for the pattern recognition algorithms of charged particles

- Parallelize track finding as much as possible → line segment tracking

- Throughput at GPUs 3% better for LST + Legacy triplets and 35% better for LST+LST Quads

- LST + Legacy triplets higher efficiency than LST+LST Quads

- All variants with LST offer acceptance to displaced tracks