CMS Experiment at the LHC, CERN
Data recorded: 2022-Jul-22 04:58:42.084736 GMT
Run / Event / LS: 356005 / 100747617 / 114

CMS Status Report

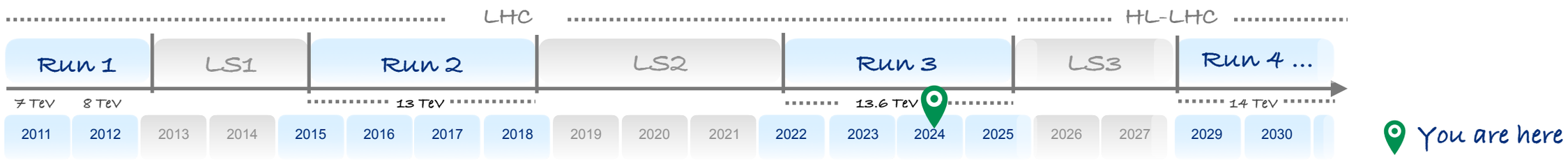
Deborah Pinna
(University of Wisconsin-Madison)

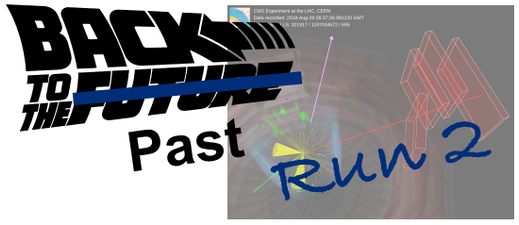
on behalf of the *CMS Collaboration*

LHCC Open Session

11 September 2024

Outline





- 48 results made public since last LHCC
  - 18 searches for new particles
  - 18 precision SM & Higgs physics (*)
  - 9 heavy ion physics
  - 3 tools & generators

(*) 3 new results from Run 3

Physics communication: 21 briefings, news for LHCP and ICHEP

- Smooth on-going 2024 data-taking
  - excellent performance in prompt data

more than 50 notes on detector performance since last LHCC

- Upgrade project continues to progress on all fronts
  - many items in full production & preparing for assembly and integration

CMS Experiment at the LHC, CERN
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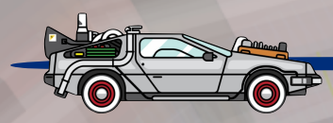
Run / Event / LS: 321917 / 1197034672 / 655

Physics with Run 2



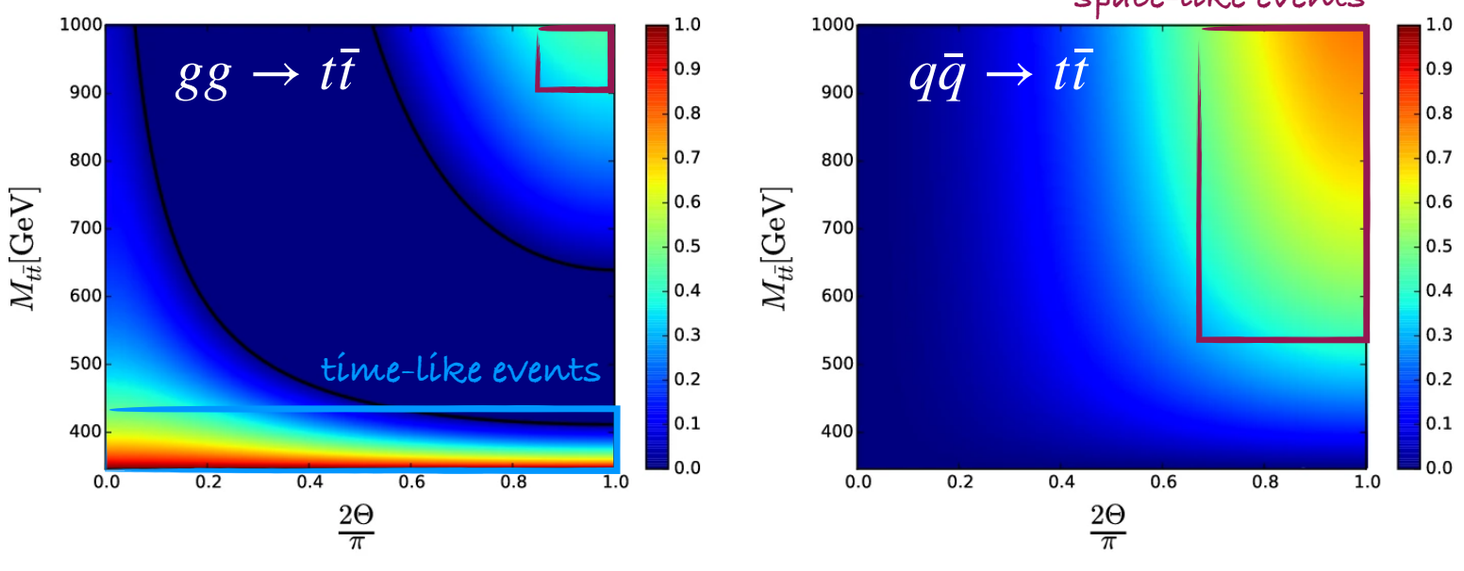
BACK TO THE FUTURE *Past*

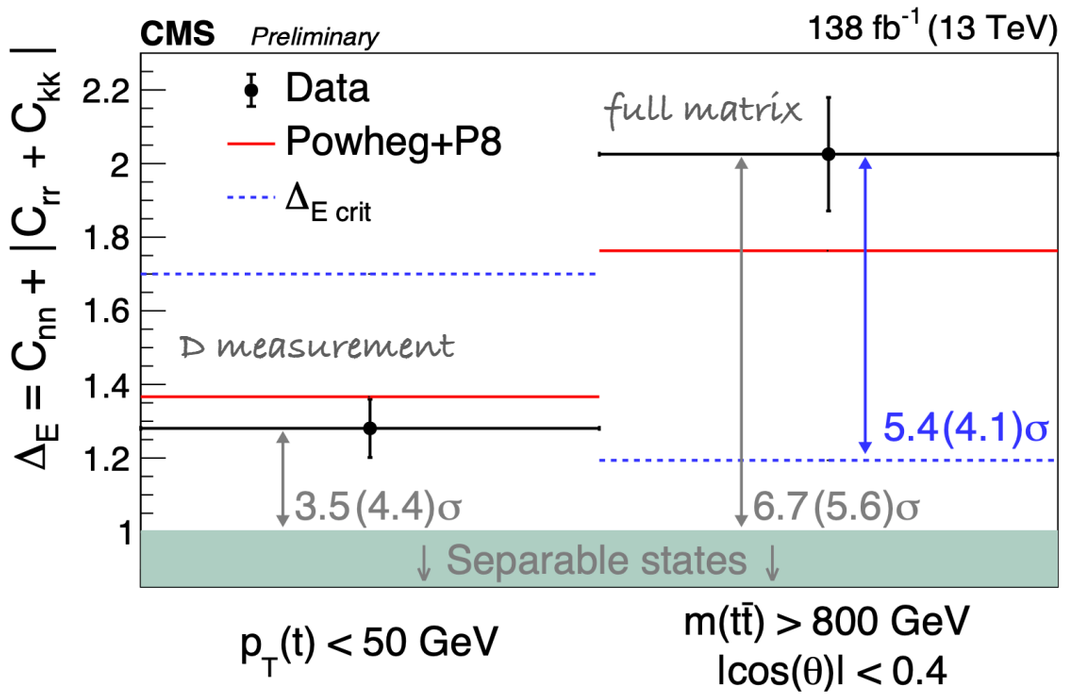
CMS a probe for Quantum Entanglement

- LHC high-energies allow large production of $t\bar{t}$ events
- allow SM test and new opportunities for QM tests at high energies
- Probe entanglement via spin correlation matrix
  - from fit to two decay products angles
  - m_{tt}~400 GeV: $t\bar{t} \to bl\nu bl\nu$
    spin transmitted to leptons, higher eff at threshold, dominated by time-like events
  - high m_{tt}: $t\bar{t} \to bl\nu bjj$
    higher BR, higher m_{tt} resolution dominated by space-like events

Entanglement observed with high significance

space-like events

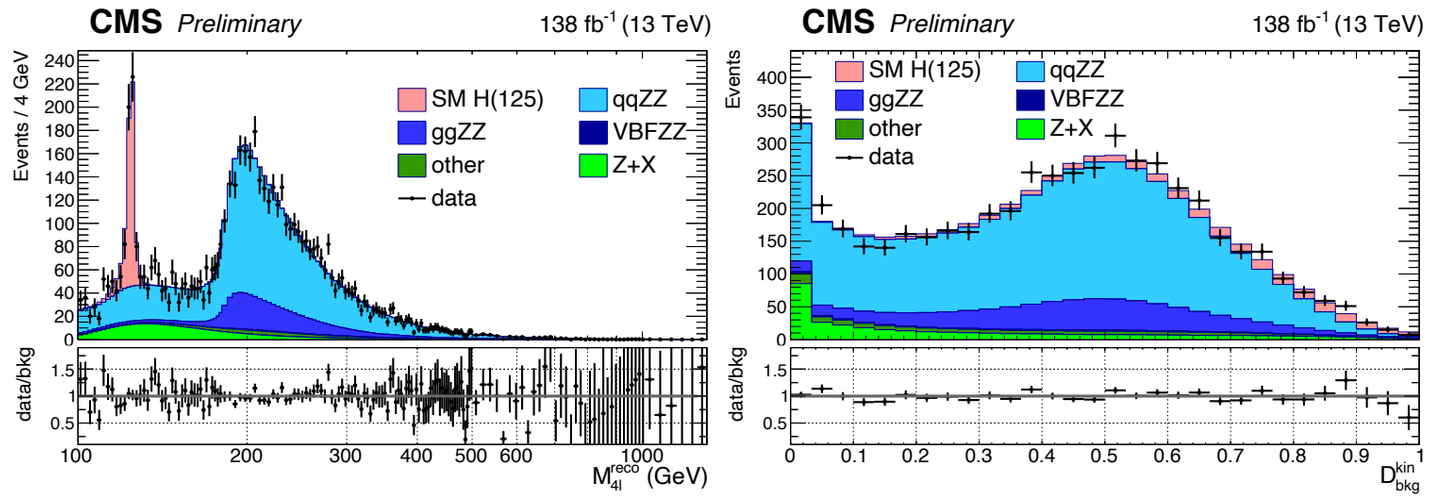


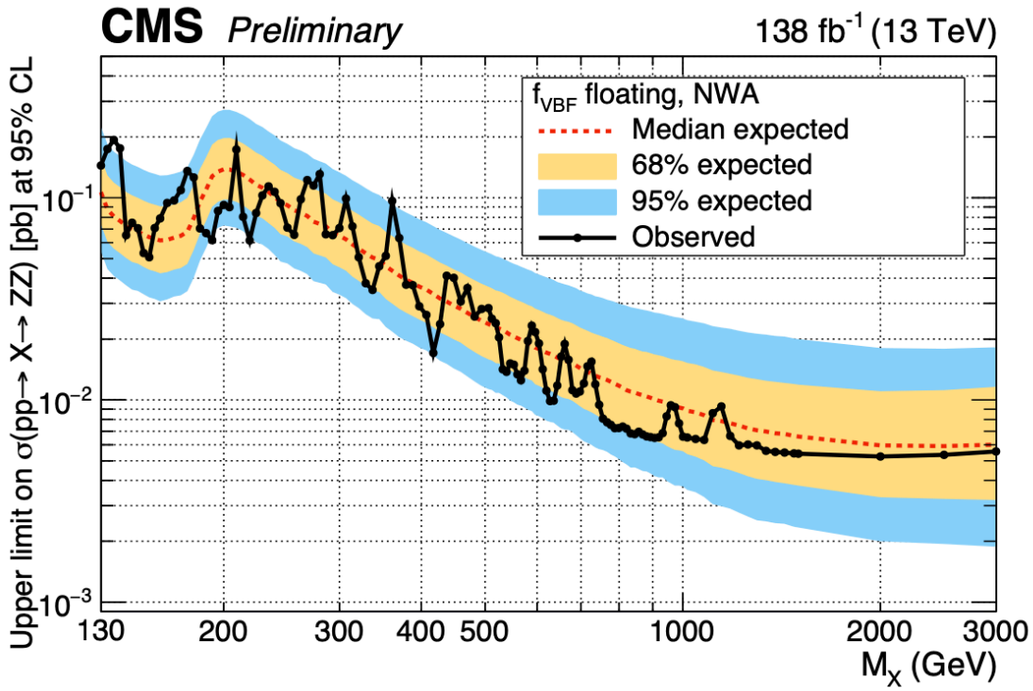


CMS energy frontier: searches at the TeV scale

- SM open questions drive searches for new physics, *eg.* additional scalar resonances
- Search for high-mass scalars (up to 3TeV) decaying to $ZZ \to 4l$
  - addressing claims for new boson in 650-680 GeV (based on ATLAS data)
  - 4l final state: good energy resolution of electrons and muons
  - enhanced sensitivity by 2D approach: invariant mass m_{4l} vs matrix element discriminant D_{bkg}^{kin}
  - model-independent analysis: parametric approach to describe processes
- Results compatible with SM

No excess observed in 650-680 GeV





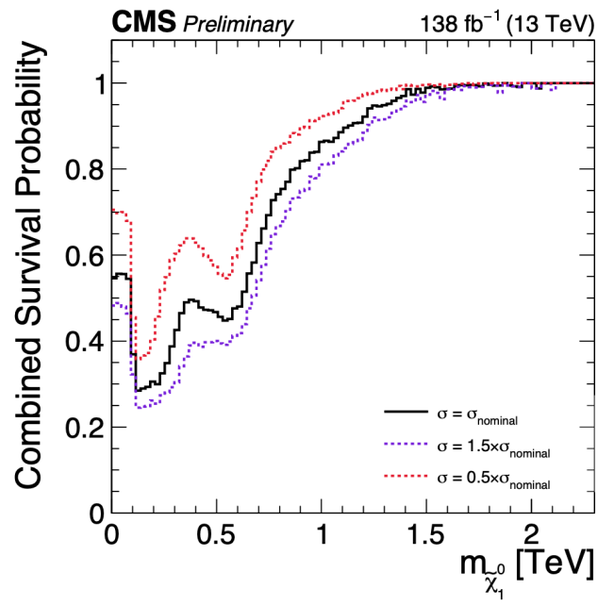
CMS energy frontier: searches at the TeV scale

- First statistical combination of CMS SUSY searches with full Run 2 data
- Interpretation in terms of 19-parameter realization of phenomenological MSSM (pMSSM)
  - highlight interesting or uncovered regions as roadmap for future searches
  - demonstrate complementarity of search program
- Gives us a big picture:
  - evaluate models fraction surviving CMS constraints out of all models (surviving probability)

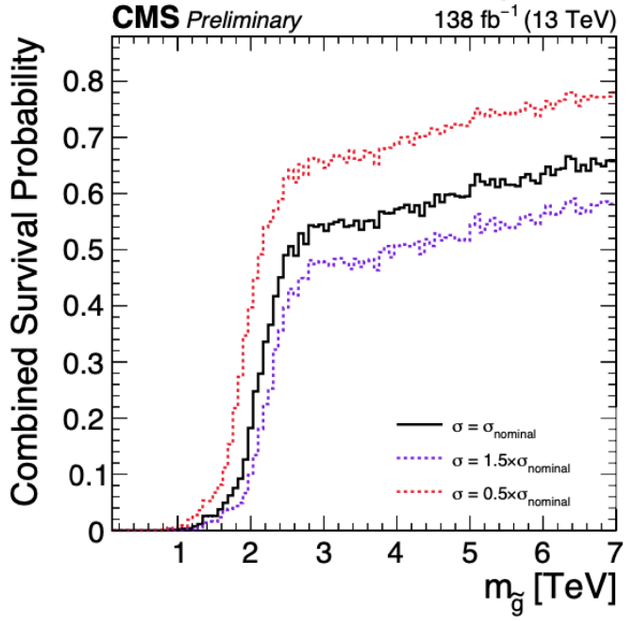
Light EWkinos still allowed

Colored superpartners are heavily disfavored with masses below 800 GeV

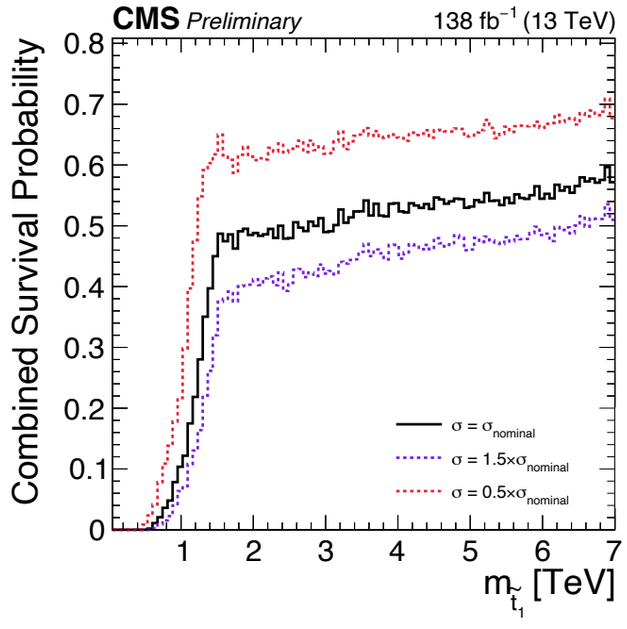
lightest electroweakino



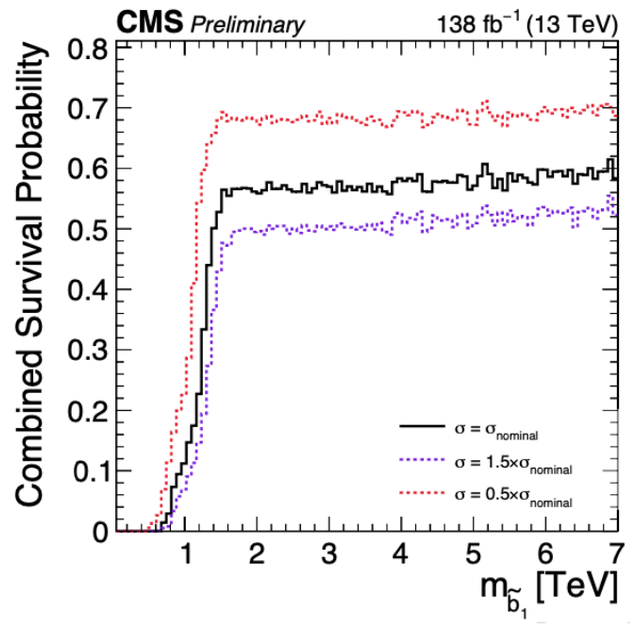
gluino



top squark

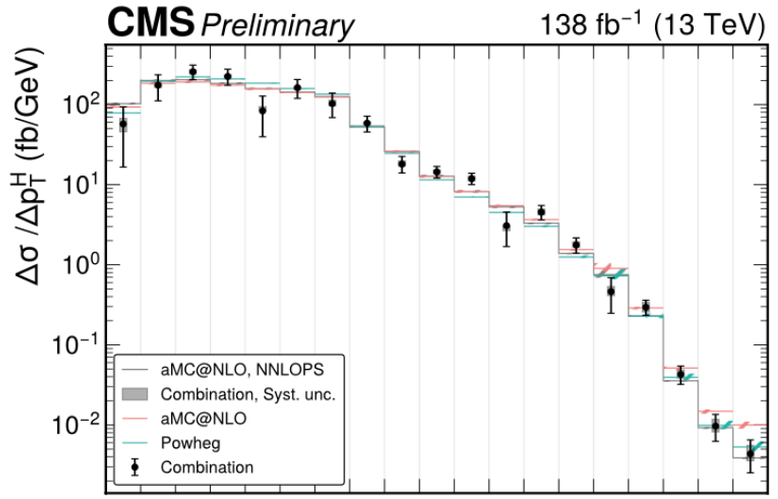


bottom squark



CMS intensity frontier: Higgs boson physics

- Combination of fiducial differential Higgs production cross section
  - combination across various final state (WW, ZZ, $\gamma\gamma$, $\tau\tau$)
    (all production modes considered)
  - most precise determination of Higgs boson cross section as a function of quantities eg. Higgs boson p_T

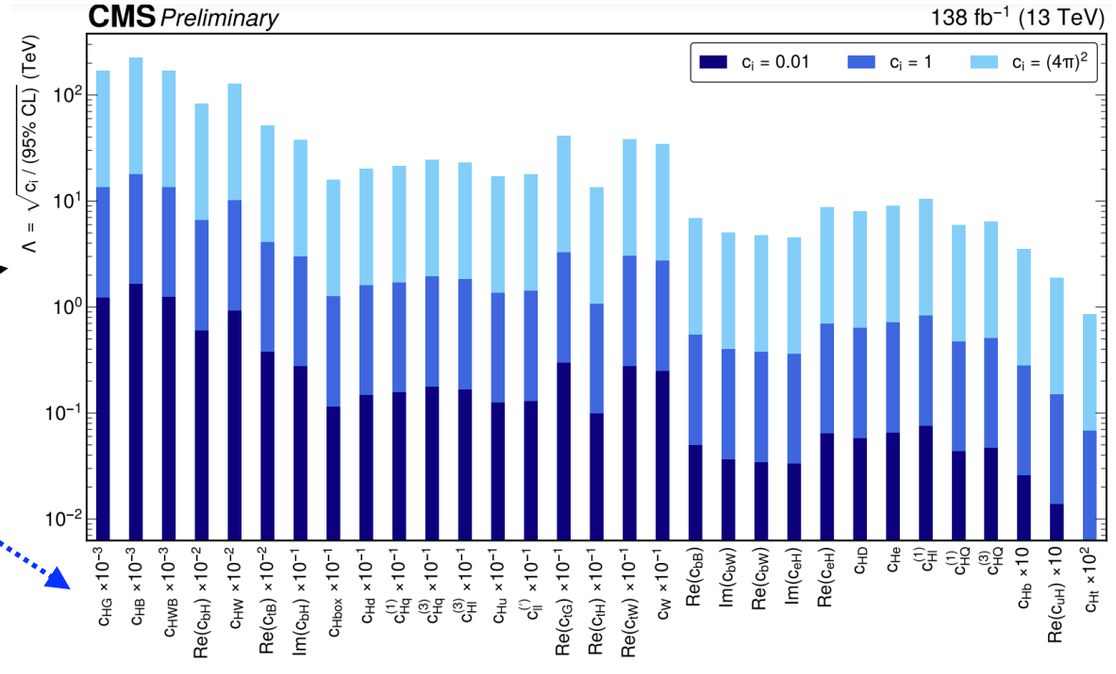


- Higgs differential production cross section as complementary probe to new physics
  - modified couplings could appear as distortions in the spectra

- Result interpreted in terms of SM Effective Field Theory

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_j \frac{c_j}{\Lambda^2} \cdot \mathcal{O}_j^{(6)}$$

Limits for each Wilson coefficient c_i in terms of the energy scale Λ for different assumptions of c_i

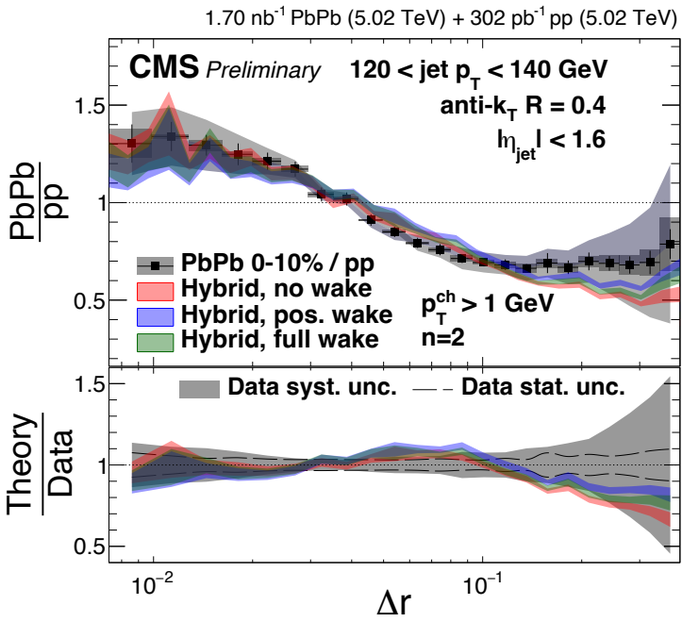


CMS as heavy ion experiment: probing QGP

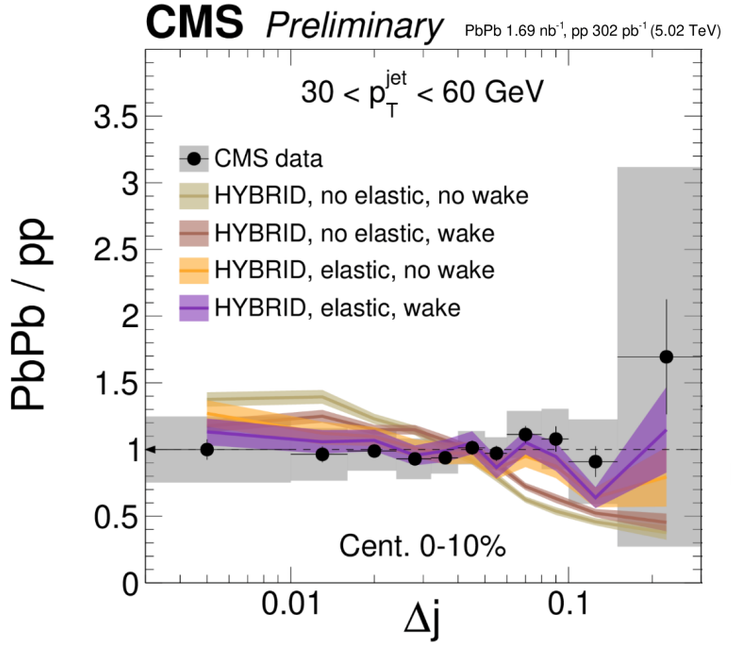
- Probing Quark-Gluon-Plasma interaction with jets emerging from collisions
  - new tools to improve our understanding of QGP dynamics

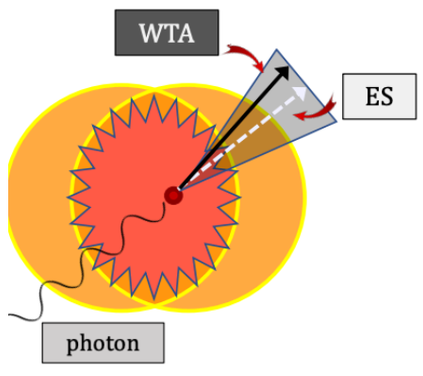
- Jet studies
  - provide complementary observable to understand energy loss mechanisms in QGP
  - energy-energy correlators measured in PbPb collisions for first time

- γ+jet studies
  - decorrelation of jet axis from photon momentum, sensitive to large-angle scattering effects in QGP
  - photon transparent to QGP, while jet interacts



Energy-energy correlators PbPb to pp ratio compared to predictions with different loos mechanism





Jet axis decorrelation PbPb to pp ratio compared to predictions

CMS Experiment at the LHC, CERN
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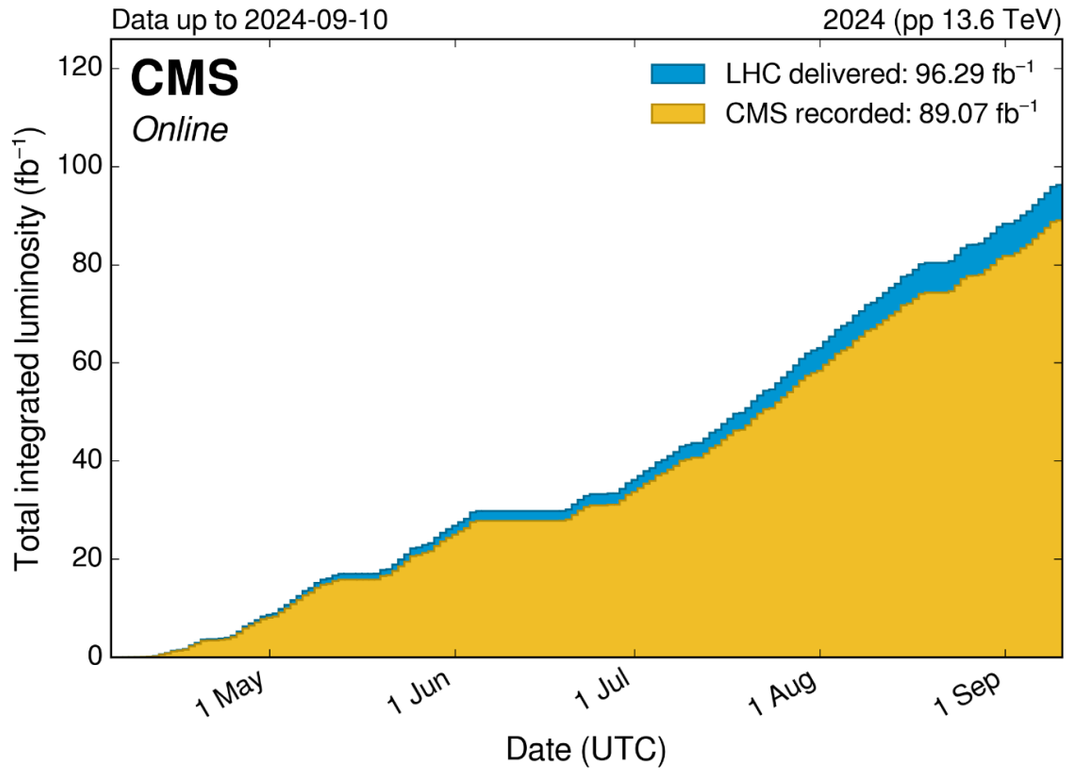
Run / Event / LS: 357900 / 188884112 / 142

Performances and Physics with Run 3

Run3 data taking and processing

- Run 3 data taking
  - ~63 fb^{-1} good for physics in 2022+2023
  - already recorded ~90 fb^{-1} out of 95 fb^{-1} delivered in 2024
    - Run 3 already surpassed luminosity from Run 2, still >4 weeks of pp running to go!
  - working towards fully AI-based Data Quality Monitoring Data Certification (done in parallel with human-based one)
    - will allow to recover even more Data for analyses!



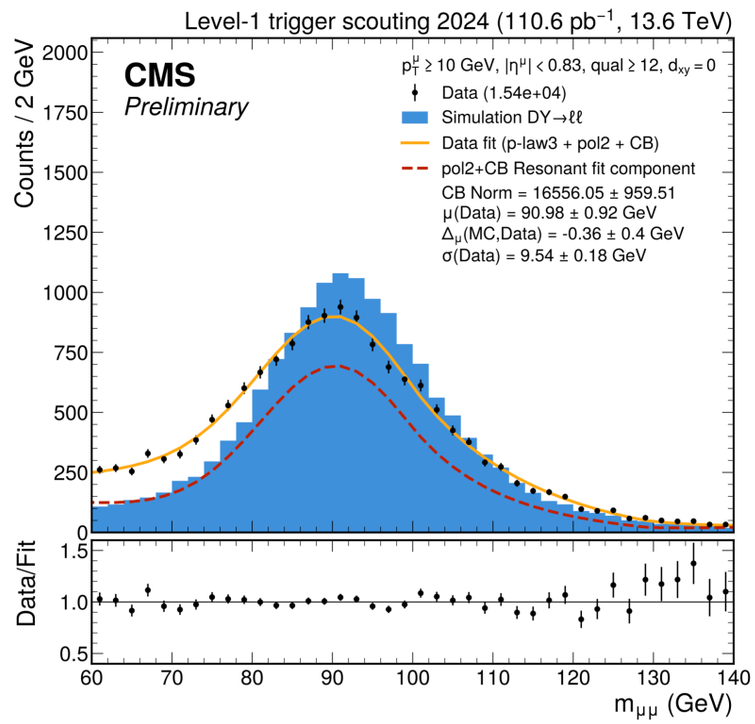
- ~93% of the delivered data are collected (same as Run 2)
- above 94% of collected data good for physics (higher than Run 2)

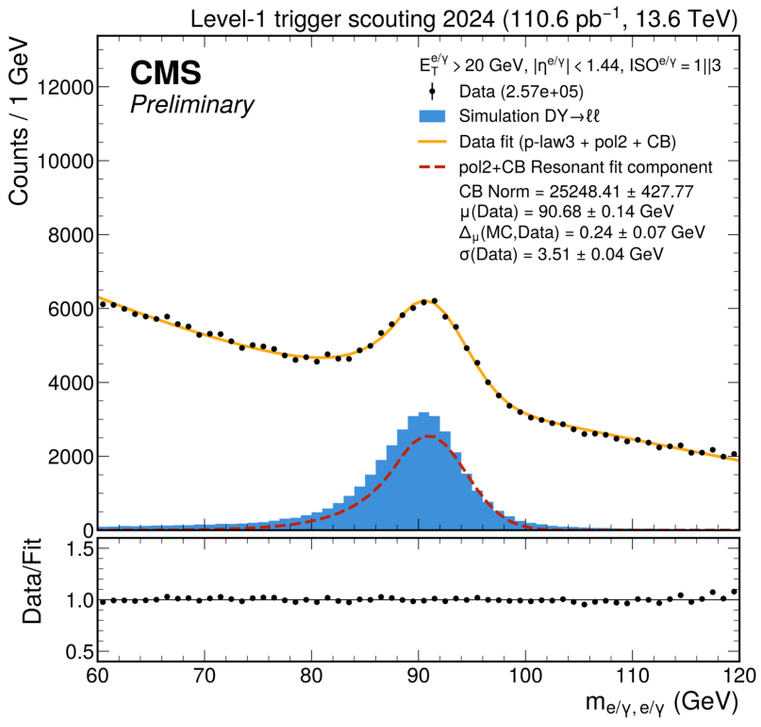
- Run 3 data processing
  - Tier-0 continued to perform well during 2024
  - CMS effectively extended Tier-0 processing capacity to include Run 2 HLT Cloud resources at Point 5 and Tier-1
  - heterogeneous software and HPC opportunistic resources
  - continues efforts to incorporate GPUs into workflows

Level-1 Trigger

- Stable operations throughout 2024
  - collecting pp collision data up to 115 kHz
  - recording up to 64 simultaneous collisions/event (2.5x CMS design, 45% of HL-LHC)
- Associated data losses at a record low
  - lumi losses at ‰ level even when counting the ones correlated with other subsystems
- Good performance of all standard Level-1 Trigger Objects
- Level-1 scouting
  - data vs simulation comparison of reconstructed Z invariant mass using Level-1 muons and electrons/photons
  - work ongoing in defining new streams for Level-1 Trigger scouting to be used in physics analyses in 2025

Level-1 scouting already showing potential for physics measurement!





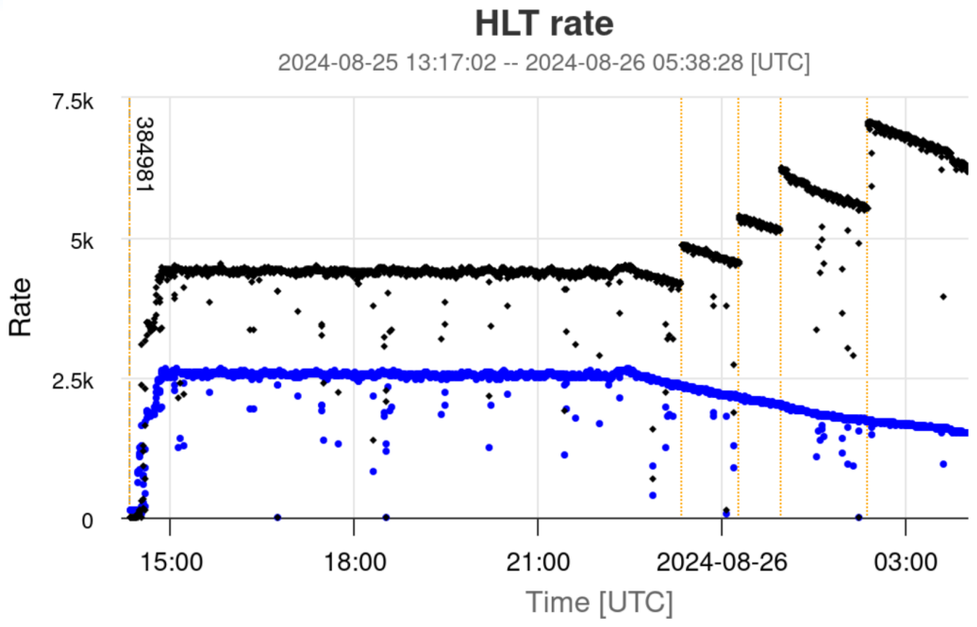
High-Level Trigger

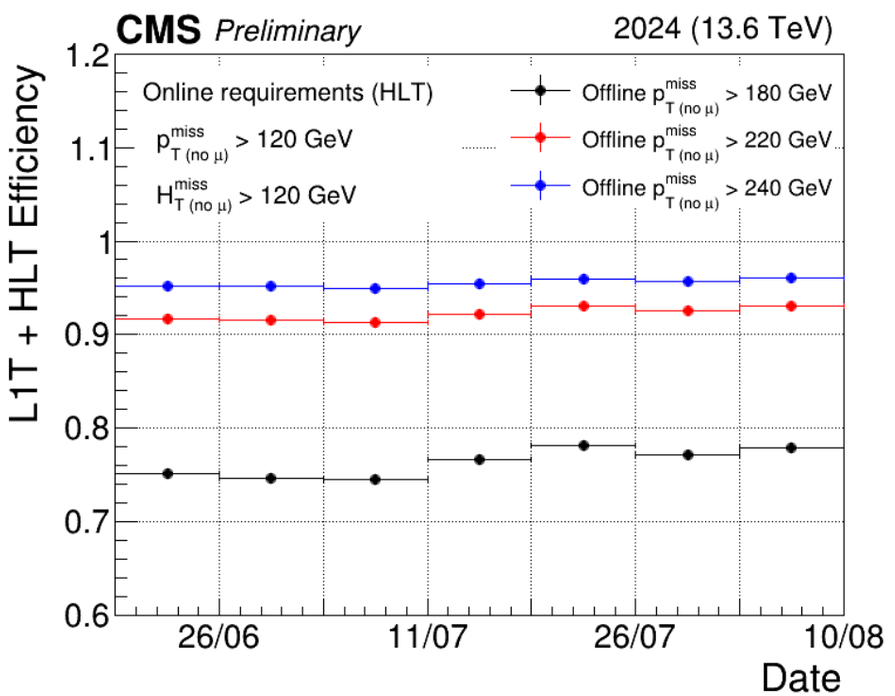
- Smooth data-taking at HLT
  - average HLT rates: ~2 kHz Promptly reconstructed, ~5 kHz Parked data, ~27 kHz HLT-Scouting

- CPU usage under control
  - +20% processing power after new nodes deployment in June 2024

- Heterogeneous (CPU+GPU) software
  - GPU-enabled reconstruction (Pixel, ECAL, HCAL, PFClustering) has been ported to the Alpaka portability library

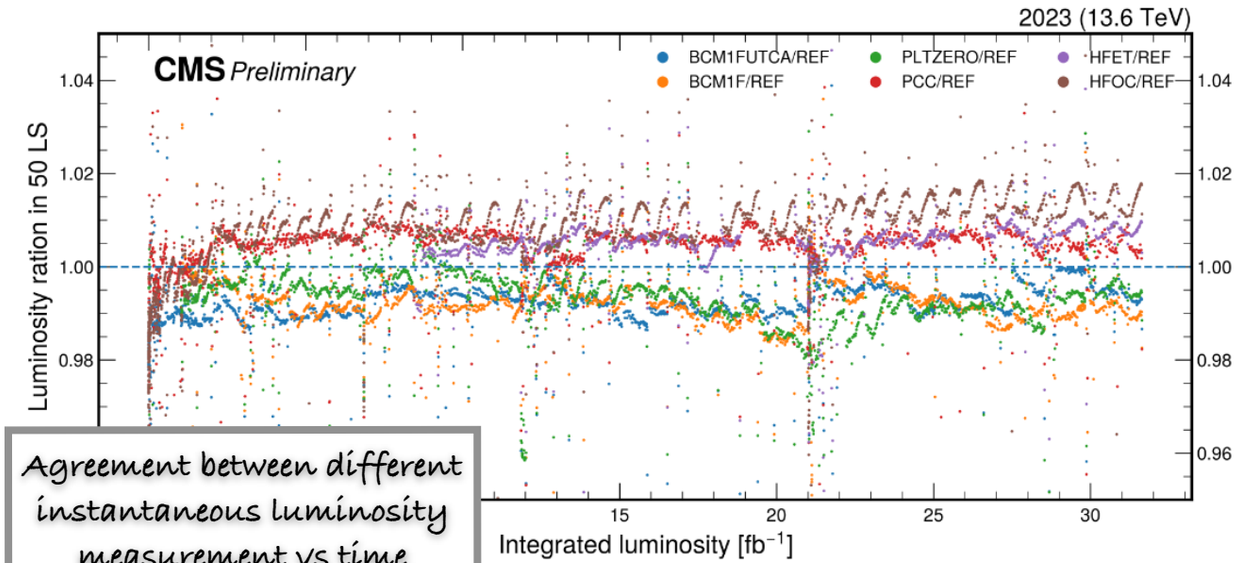
- Stable physics performance of HLT reconstruction in 2024



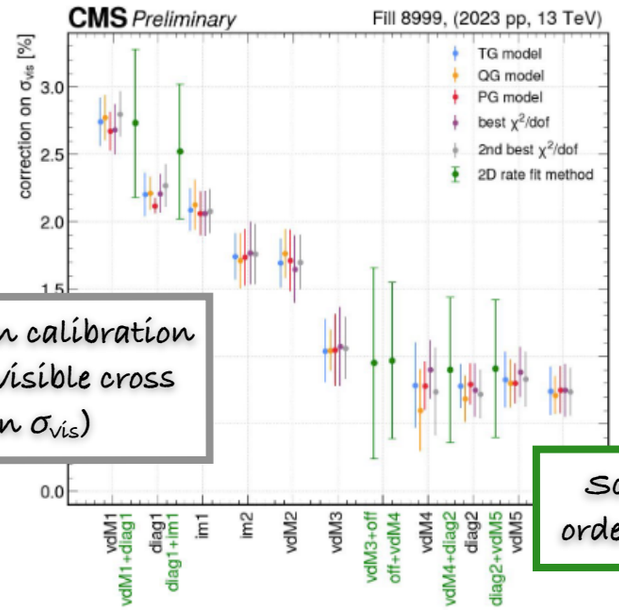


Beam Radiation Instr. & Luminosity

- Overall smooth data taking in 2024
- Preliminary 2023 luminosity calibration out: 1.28% precision, best ever preliminary!



Agreement between different instantaneous luminosity measurement vs time



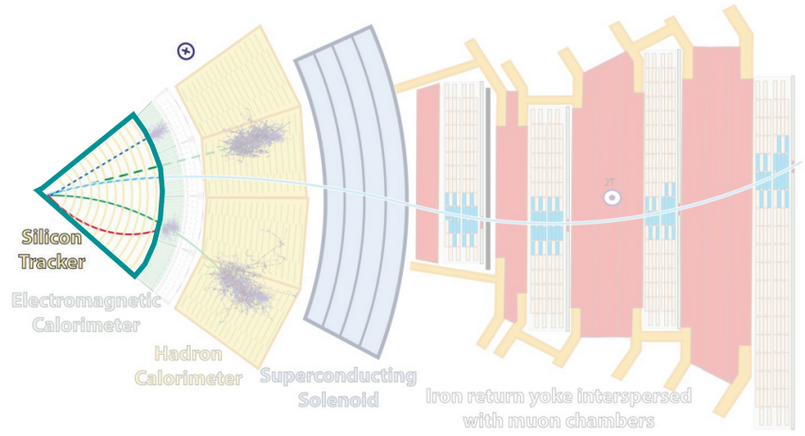
Correction on calibration constant (visible cross section σ_{vis})

Scans in order of time

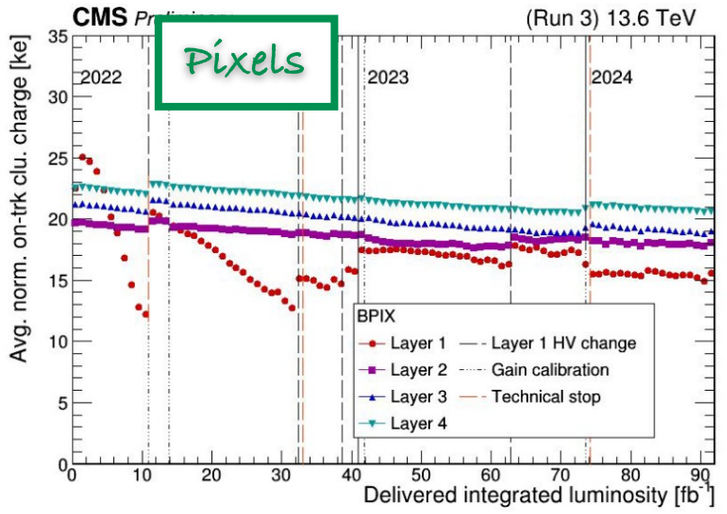
- 6 independently calibrated luminometers
  - cross-detector stability 0.71% uncertainty
  - cross-detector linearity 0.59% uncertainty

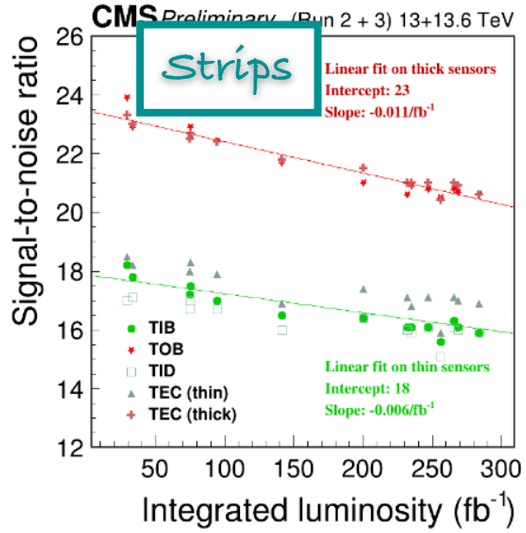
- Excellent compatibility with independent measurement (in green)
  - beam shape related 0.67% uncertainty

Tracker



- Pixels: 96% (BPix), 98% (FPix) operational channels
  - good performances: cluster charge, hit efficiency, etc.
  - Barrel Layer 1 replaced in LS2, condition stabilized
- Strips: ~96% good detector fraction
  - temp to -25 C during TS1 to mitigate leakage currents
  - sign/noise, hit efficiency, etc continues to be good





✱ Recent cooling issues

- June site-wide power glitch: stopped primary chiller and both strip cooling plants (SS1/2) → recovered
- SS2 stopped in Aug: issue with motor's electrical connections
  Rapid repair, connection box replaced during weekend interfill by EN-CV
- more thoroughly repair/replace during YETS

Thank you!

- Tracker alignments: many developments
  - improved prompt calibration, including Z mass constraint
  - deploy high quality prompt alignment condition with "Rolling Calibration"
  - exact solution method (Lapack) used for data/MC reprocessing
    - excellent performance, soon be deployed for prompt

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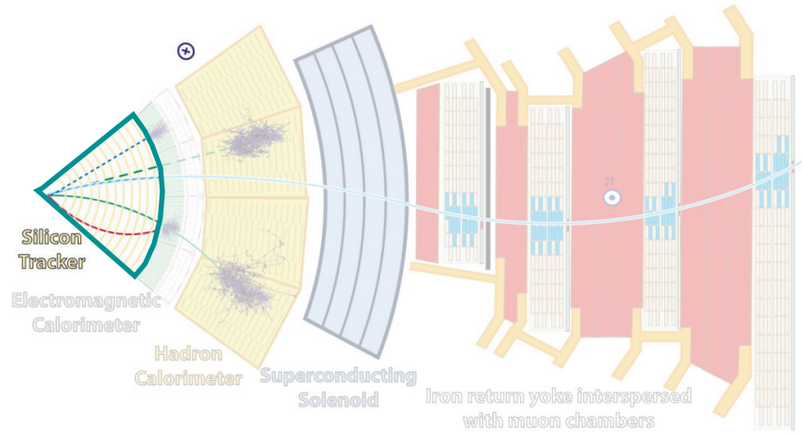

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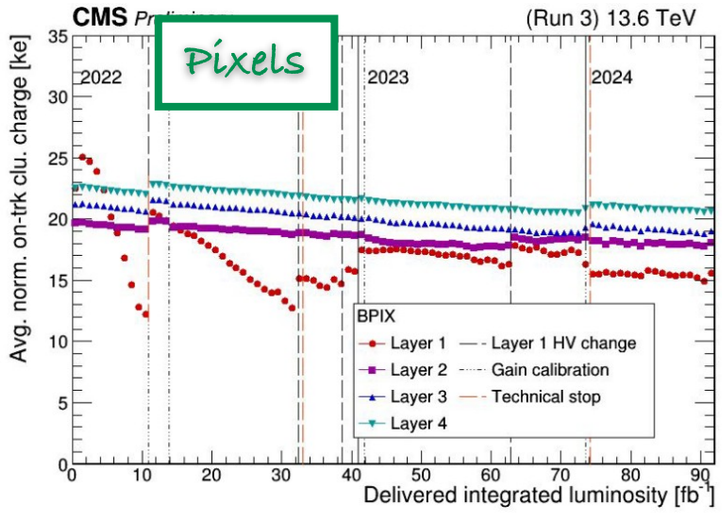

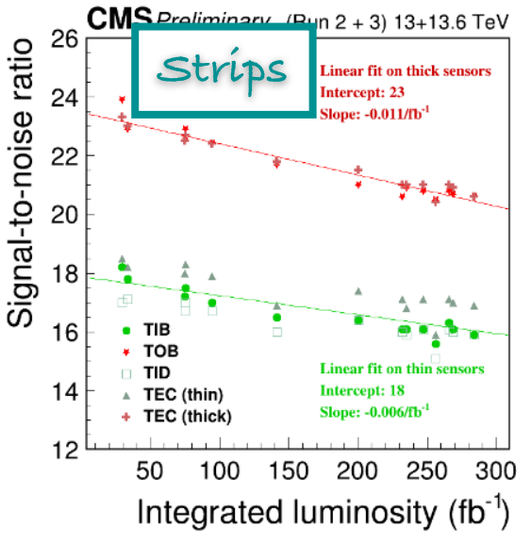

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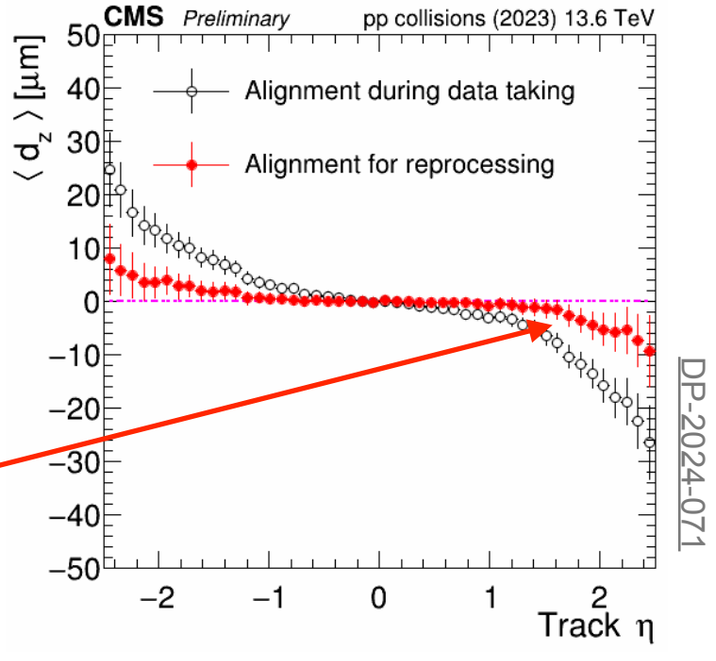
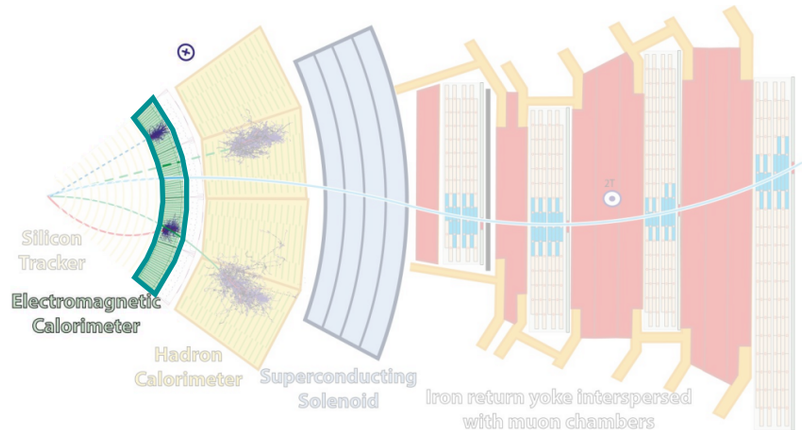
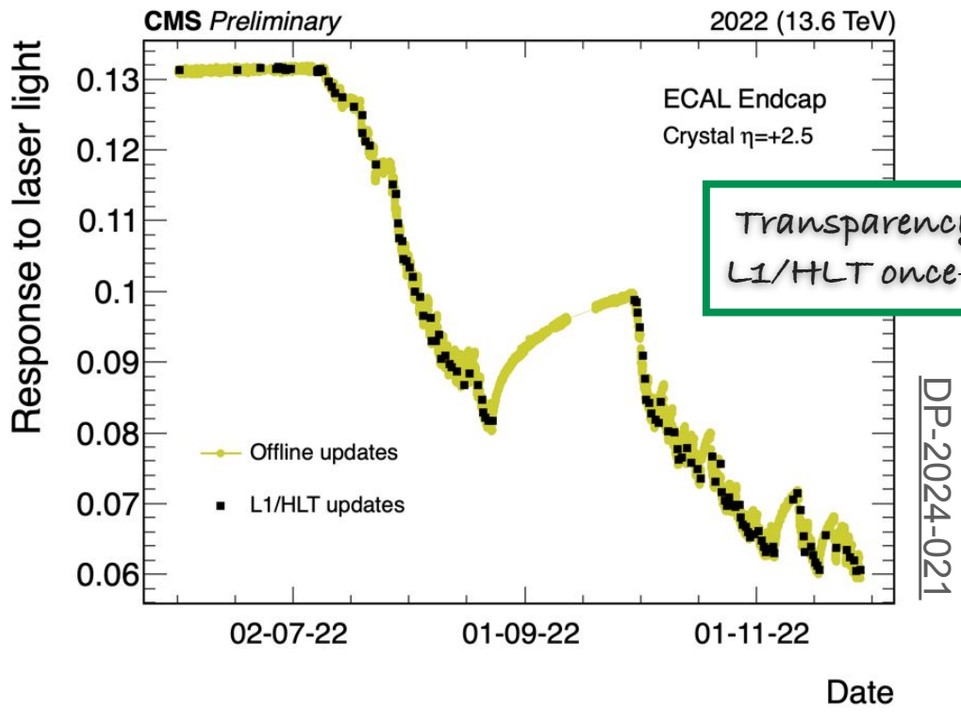


DP-2024-071

Electromagnetic Calorimeter



- Operations generally smooth
  - despite challenging conditions with high rate and PU
- Detector Performance
  - ✱ Calibrations:
    - new regional calibration deployed in prompt, per crystal calibration also prepared
    - continuous effort in improving automatization (eg. transparency updates)
    - prompt performances similar to re-reco Run 2



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


EUROPEAN ORGANIZATION FOR NU

CMS-EGM-18-002

Performance of the CMS electromagnetic calorimeter in pp collisions at $\sqrt{s} = 13$ TeV

The CMS Collaboration*

Abstract

The operation and performance of the Compact Muon Solenoid (CMS) electromagnetic calorimeter (ECAL) are presented, based on data collected in pp collisions at $\sqrt{s} = 13$ TeV at the CERN LHC, in the years from 2015 to 2018 (LHC Run 2), corresponding to an integrated luminosity of 151 fb^{-1}. The CMS ECAL is a scintillating lead-tungstate crystal calorimeter, with a silicon strip preshower detector in the forward region that provides precise measurements of the energy and the time-of-arrival of electrons and photons. The successful operation of the ECAL is crucial for a broad range of physics goals, ranging from observing the Higgs boson and measuring its properties, to other standard model measurements and searches for new phenomena. Precise calibration, alignment, and monitoring of the ECAL response are important ingredients to achieve these goals. To face the challenges posed by the higher luminosity, which characterized the operation of the LHC in Run 2, the procedures established during the 2011–2012 run of the LHC have been revisited and new methods have been developed for the energy measurement and for the ECAL calibration. The energy resolution of the calorimeter, for electrons from Z boson decays reaching the ECAL without significant loss of energy by bremsstrahlung, was better than 1.8%, 3.0%, and 4.5% in the $|\eta|$ intervals [0.0, 0.8], [0.8, 1.5], [1.5, 2.5], respectively. This resulting performance is similar to that achieved during Run 1 in 2011–2012, in spite of the more severe running conditions.

Submitted to the Journal of Instrumentation

arXiv:2403.15518v1 [physics.ins-det] 22 Mar 2024

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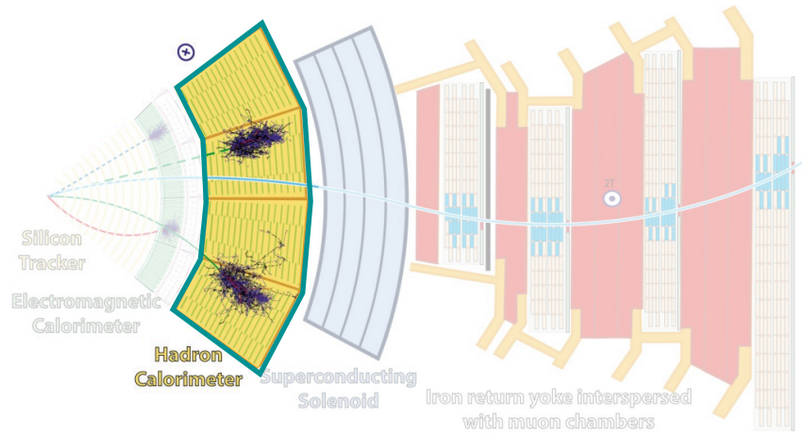
*See Appendix E for the list of collaboration members

just published in JINST 19 P09004

✱ Recent public results: ECAL Run 2 Performance, published in JINST

Hadronic Calorimeter

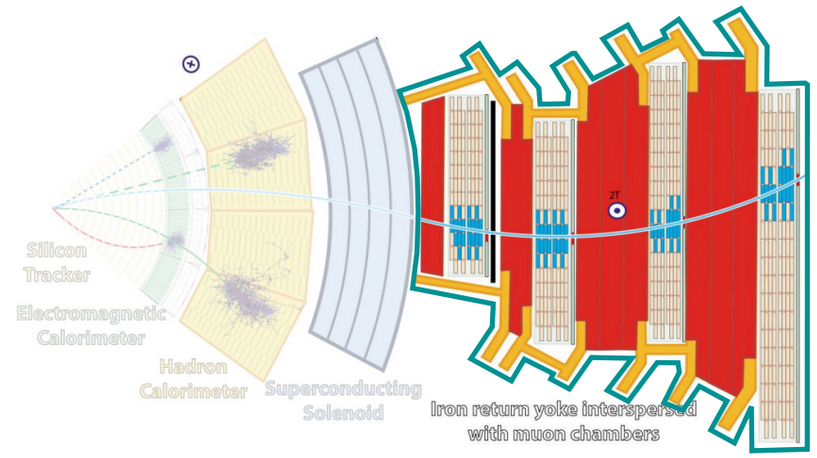


- Smooth participation in 2024 operations ongoing
  - automatic recovery mechanism for solving minor issues related to bad data errors in place
  - new Laser box operational for first time since winter, being tuned to provide uniform and strong pulse in all sub-sections of HCAL

- Significant progress on detector performance
  - framework for automatic pedestal updates fully tested and operational allows to deploy updated pedestals every couple of days
  - conditions for data and MC simulation updated regularly for achieving best performance in physics analyses

- The Zero Degree Calorimeter system is getting ready for the heavy ion Run
  - on February 1st baked out incident affecting ZDC: reparation and improvements successful!
  - ZDC now integrated in global run and DQM successfully displaying ZDC data

Muon system



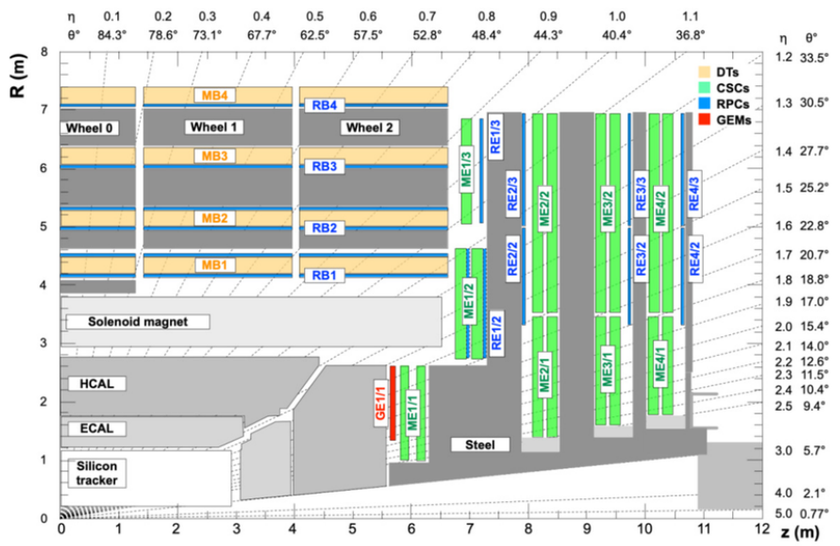
- Smooth running
  - minor contribution to luminosity loss (~4%)
- Stable performance over time and with instantaneous luminosity increases
- Improved GE1/1 performance
  - thanks to the High Voltage and electronics calibration performed earlier this year

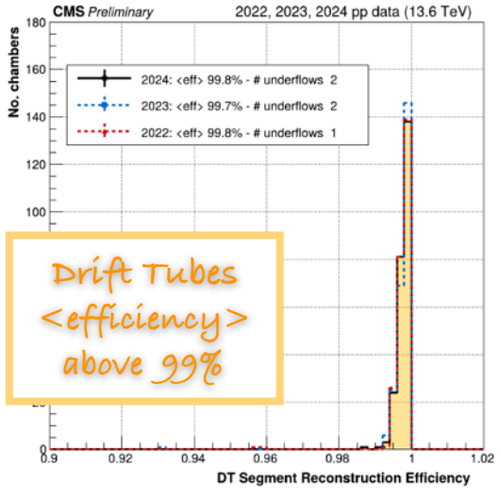
Drift Tubes

Resistive plate chambers

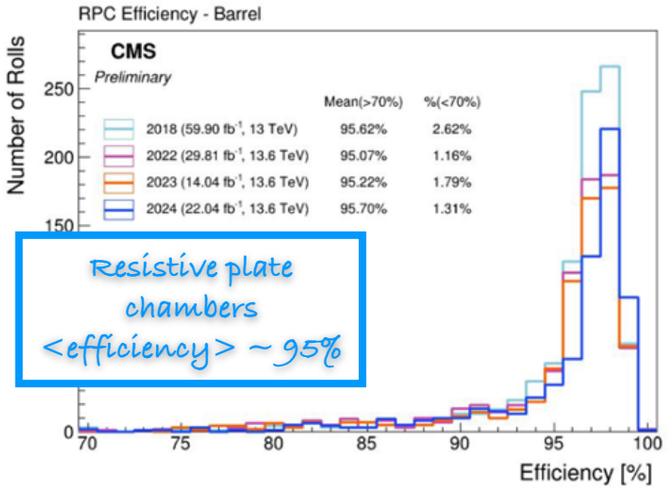
Cathode strip chambers

GE 1/1

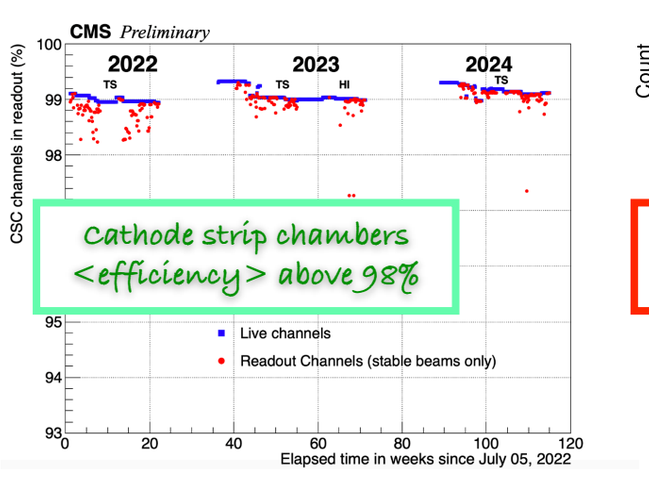




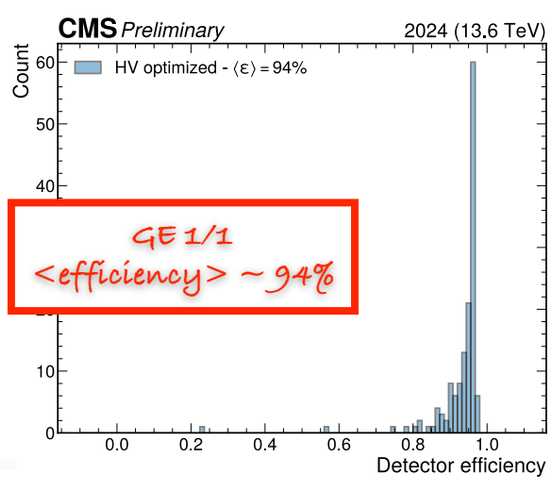
DT segment efficiency in Run 3 (2022, 2023, 2024)



Barrel RPC efficiency in Run 3 (2022, 2023, 2024) and Run 2 (2018)



CSC active channel in Run 3



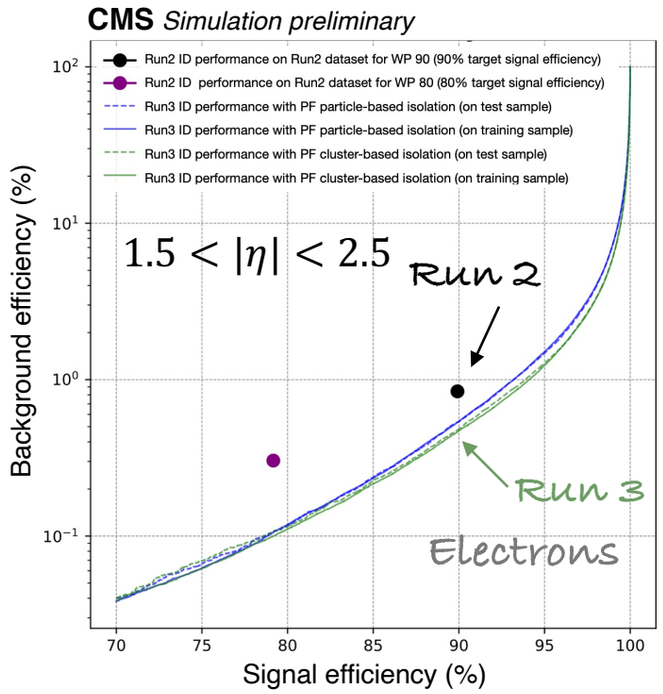
GE1/1 efficiency in 2024
(first detector from Phase 2 in CMS)

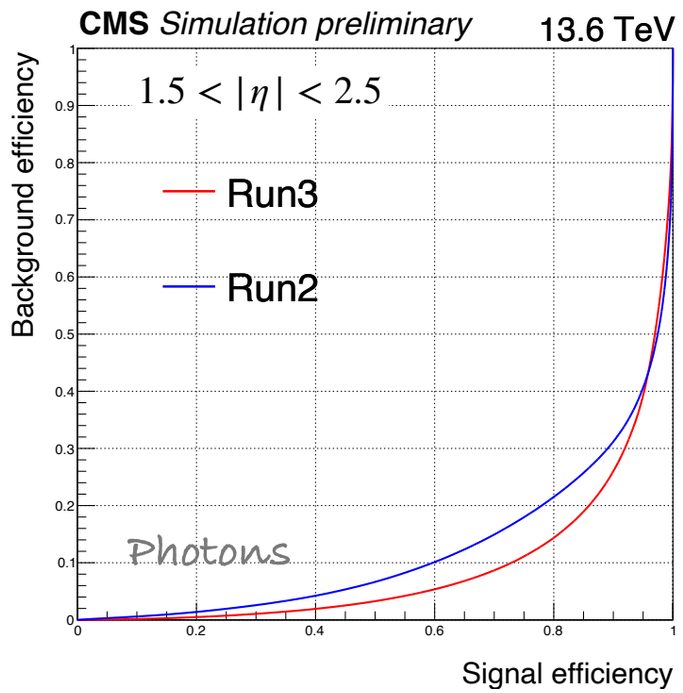
Objects performance in Run 3

Identification

Electrons, Photons

- Stable physics performance during Run 3 data taking
- Well understood precision objects: high quality prompt calibration & reconstruction → (new with Run 3)





Jets

- AI solutions to improve performance eg. jet tagging
  - b-tagging revolution from rule-based to graph-nets and transformers
  - extended to multiple kinds of jets (also τ_h)
  - combined with flavor-aware jet energy and resolution estimation

Bkg discrimination for 70% efficient b tagging

Objects performance in Run 3

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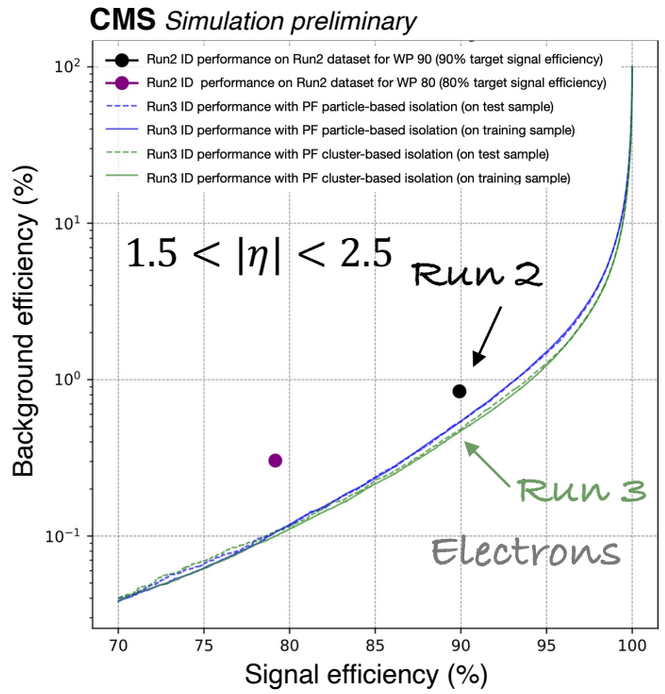

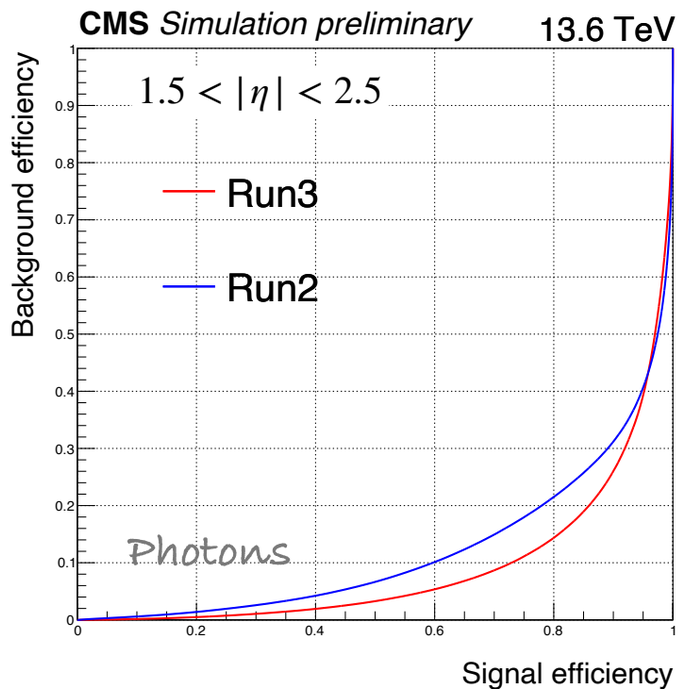

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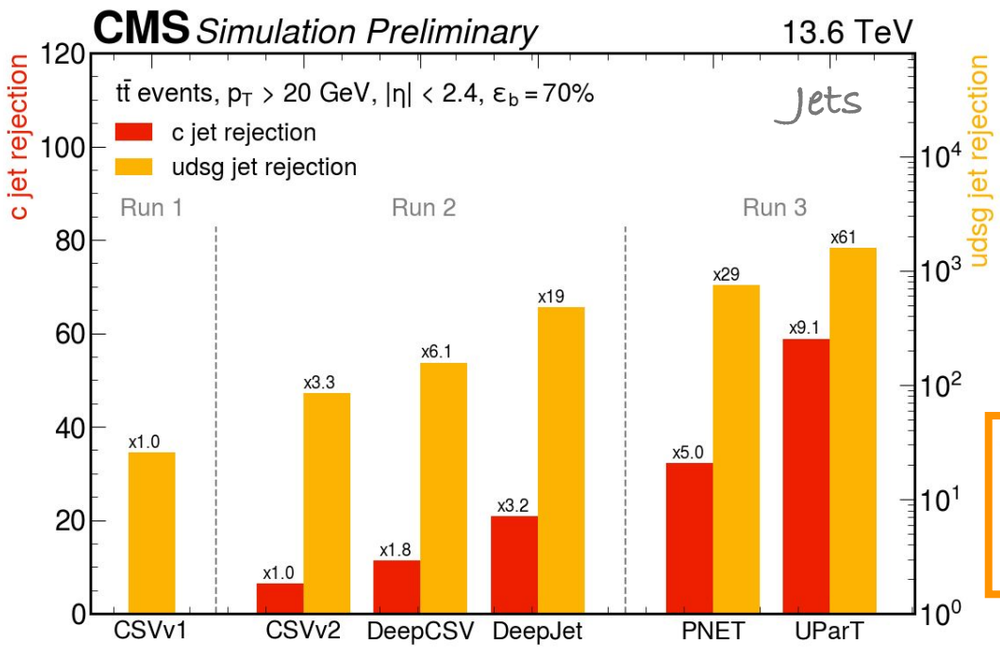


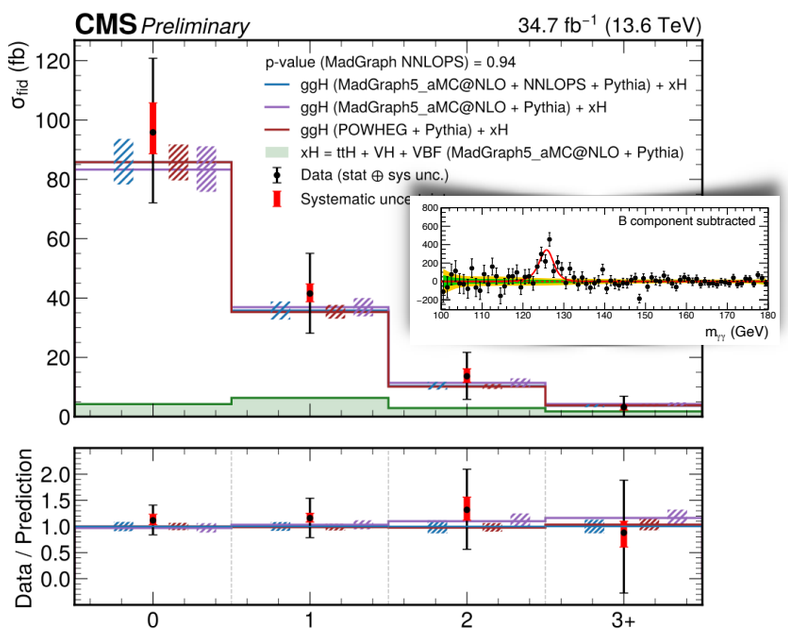
Bkg discrimination for 70% efficient b tagging

CMS intensity frontier: Higgs boson physics

Run 3

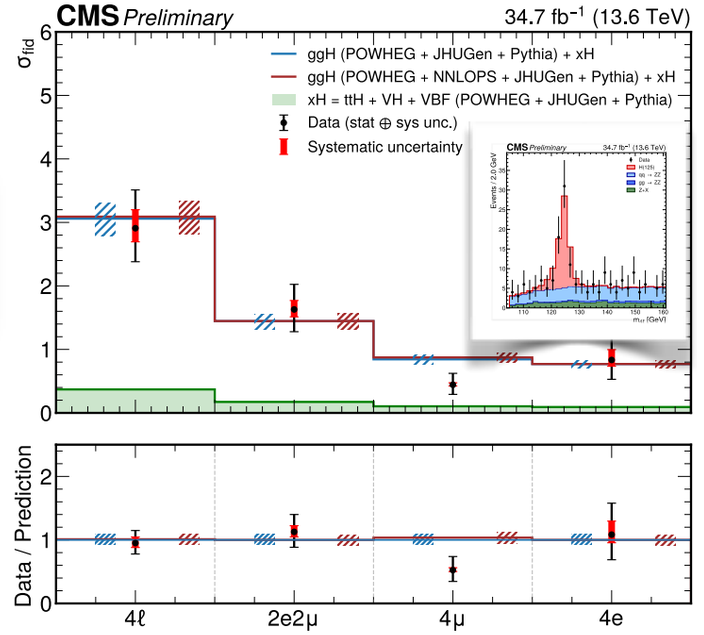
- New cross section measurements at 13.6 TeV for different Higgs decays

* $H \to \gamma\gamma$:
  - γ mismodeling in simulation non-negligible source of systematic, eg. per-photon energy resolution estimate σ_E
  - AI method (normalizing flow) introduced to correct simulation of σ_E (γ) with data control samples



Inclusive, differential cross section

$\sigma_{fid} = 2.94 \pm 11(\text{stat}) \pm 6(\text{sys})\text{fb}$

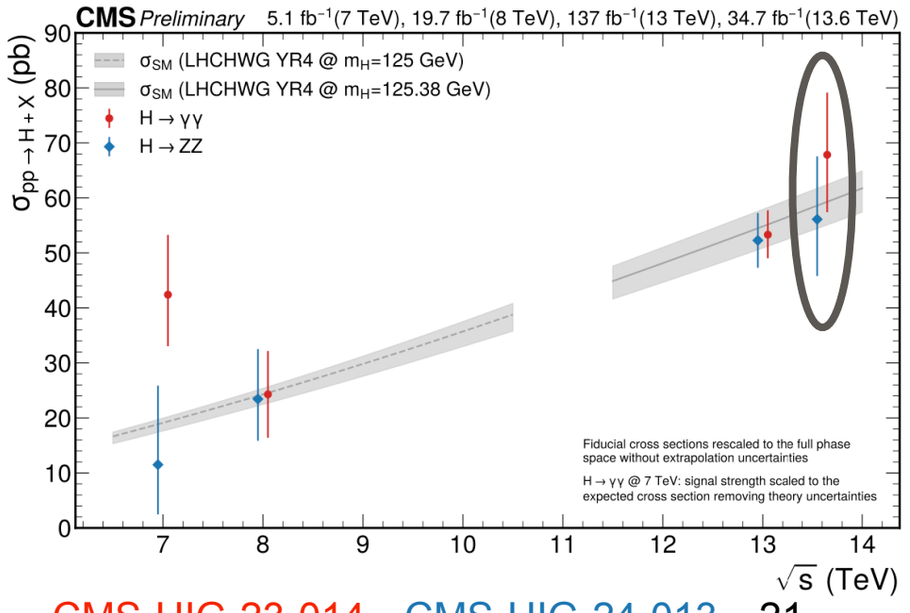


Inclusive, differential cross section

$\sigma_{fid} = 2.94^{+0.53}_{-0.49}(\text{stat})^{+0.29}_{-0.22}(\text{sys})\text{fb}$

* $H \to ZZ(4l)$
  - low branching ratio clean four lepton signature, large signal-to-bkg ratio

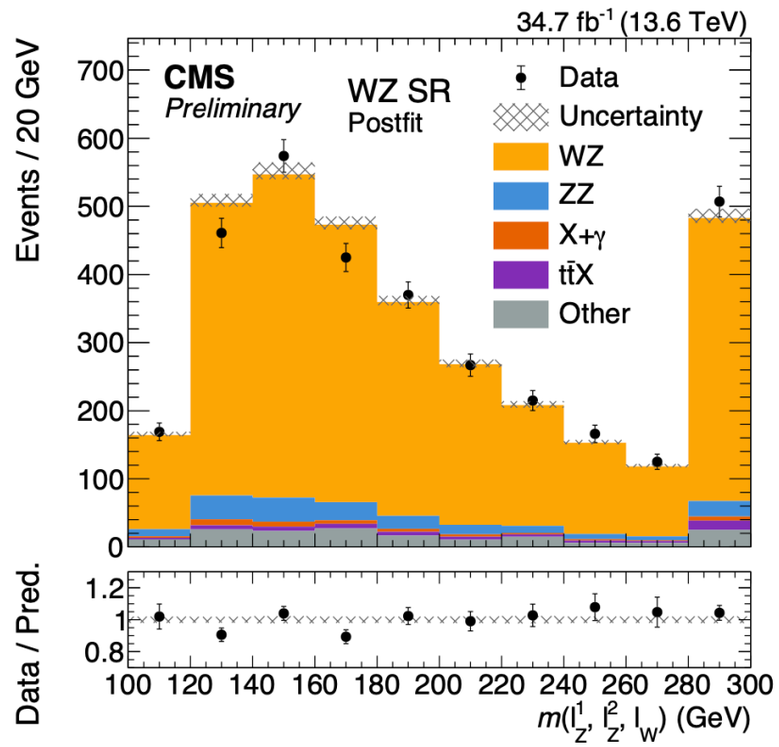
Consistent with SM expectations



CMS intensity frontier: Standard Model physics

Run 3

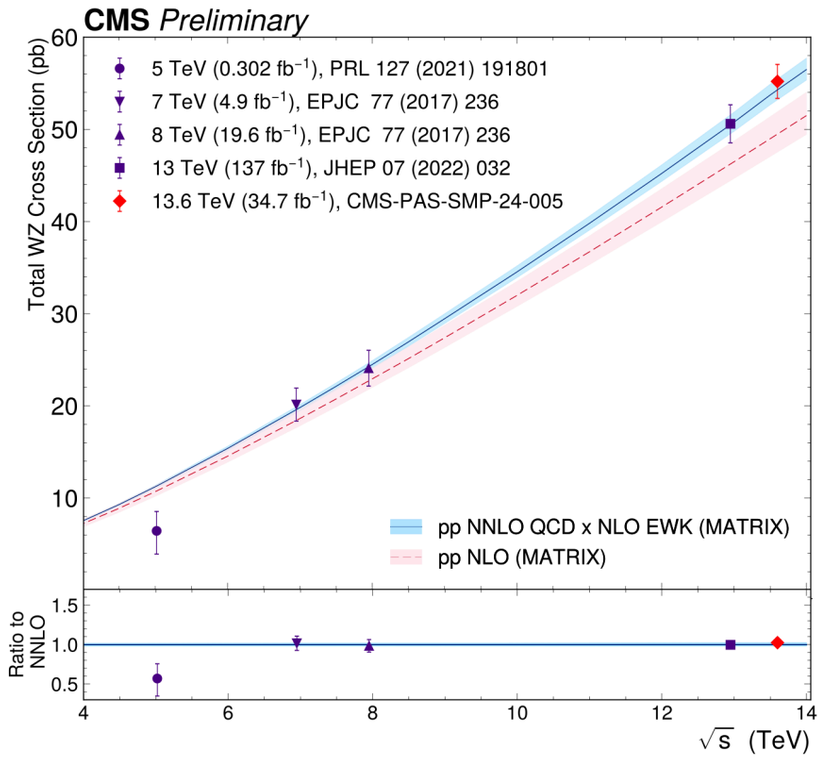
- Diboson production WZ
  - large event yields, high purity in multileptonic final states
  - sensitivity to variations in the SM trilinear gauge couplings
- Use of new training for lepton ID MVA based on Run 3 simulation
  - further separate prompt and non-prompt contributions



Inclusive cross section pp→WZ

$\sigma = 55.4 \pm 1.2(\text{stat}) \pm 1.4(\text{sys}) \pm 0.1(\text{th})\text{fb}$

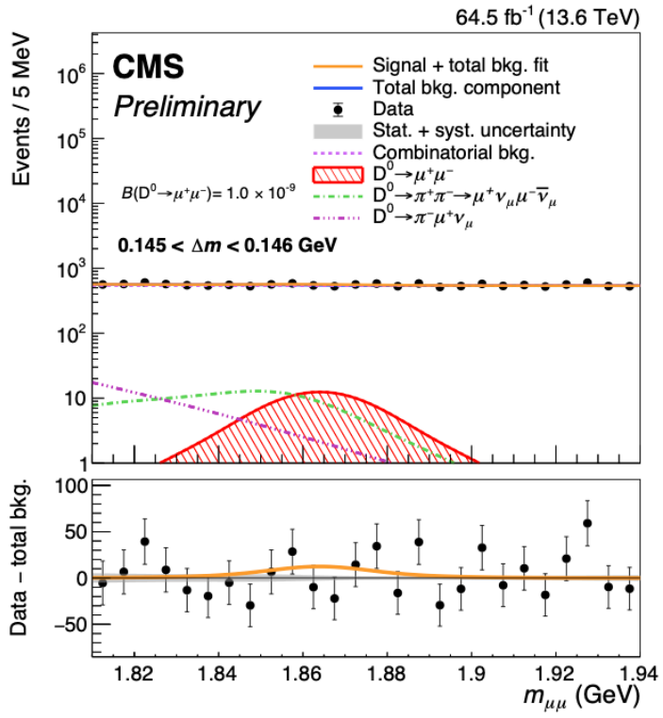
The relative uncertainty is competitive with Run 2!

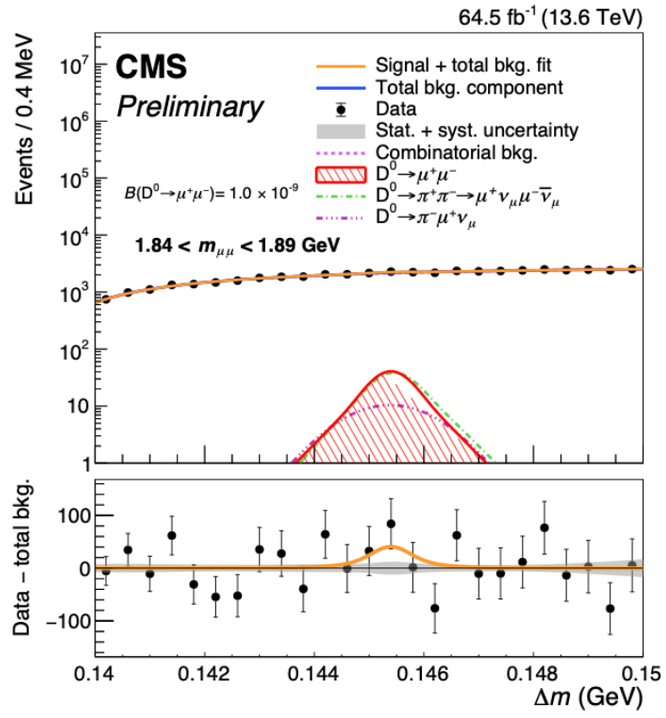


CMS Parking: Search for rare charm decays

Run 3

- First Run 3 results with double muon parking trigger
  - double-muon trigger for flavor & CP violation program (low p_T)
- First BR($D^0 \to \mu^+\mu^-$) CMS result
  - new physics predict decay rate enhancements
  - use cascade decays of $D^{*+} \to D^0\pi^+$, $D^0 \to \mu^+\mu^-$, allows for 2D fit of m_{D^0} and Δm, improves the background rejection
  - branching fraction estimated wrt normalization channel $D^{*+} \to D^0\pi^+$, $D^0 \to \pi^+\pi^-$





$$\mathcal{B}(\mathrm{D}^0 \to \mu^+\mu^-) < 2.6 \times 10^{-9} \text{ at } 95\% \text{ CL}$$

Most sensitive measurement to date

Improved by 35% over previous best limit

CMS Scouting: Low p_T taus reconstruction

- New physics at low masses? → traditional data acquisition requires high thresholds for manageable trigger rates

Parking Stream

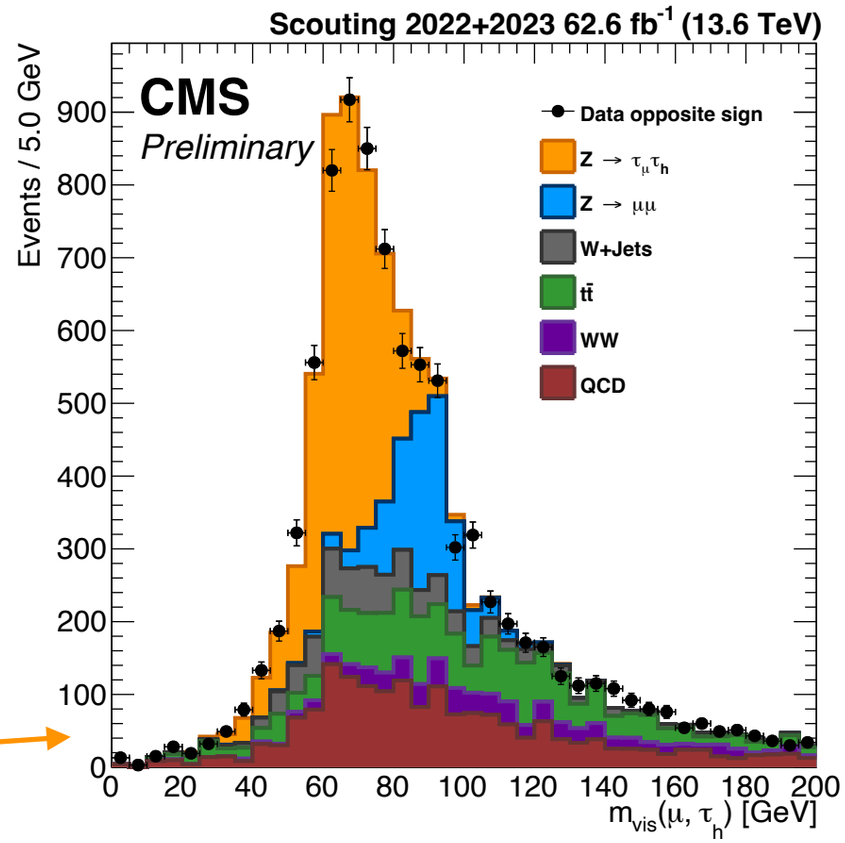
- kept in raw format until extra computing resources are available
- trigger menu extended to cover topics beyond flavor physics: bb+X, Vector Boson Fusion, LLP triggers

Scouting Stream

- reduced event information (only HLT reco objets)
- excellent HLT online reconstruction, ~ offline-like resolution
- in Run 3 generalized to all objets: photons, electrons, hadrons, taus

Scouting taus

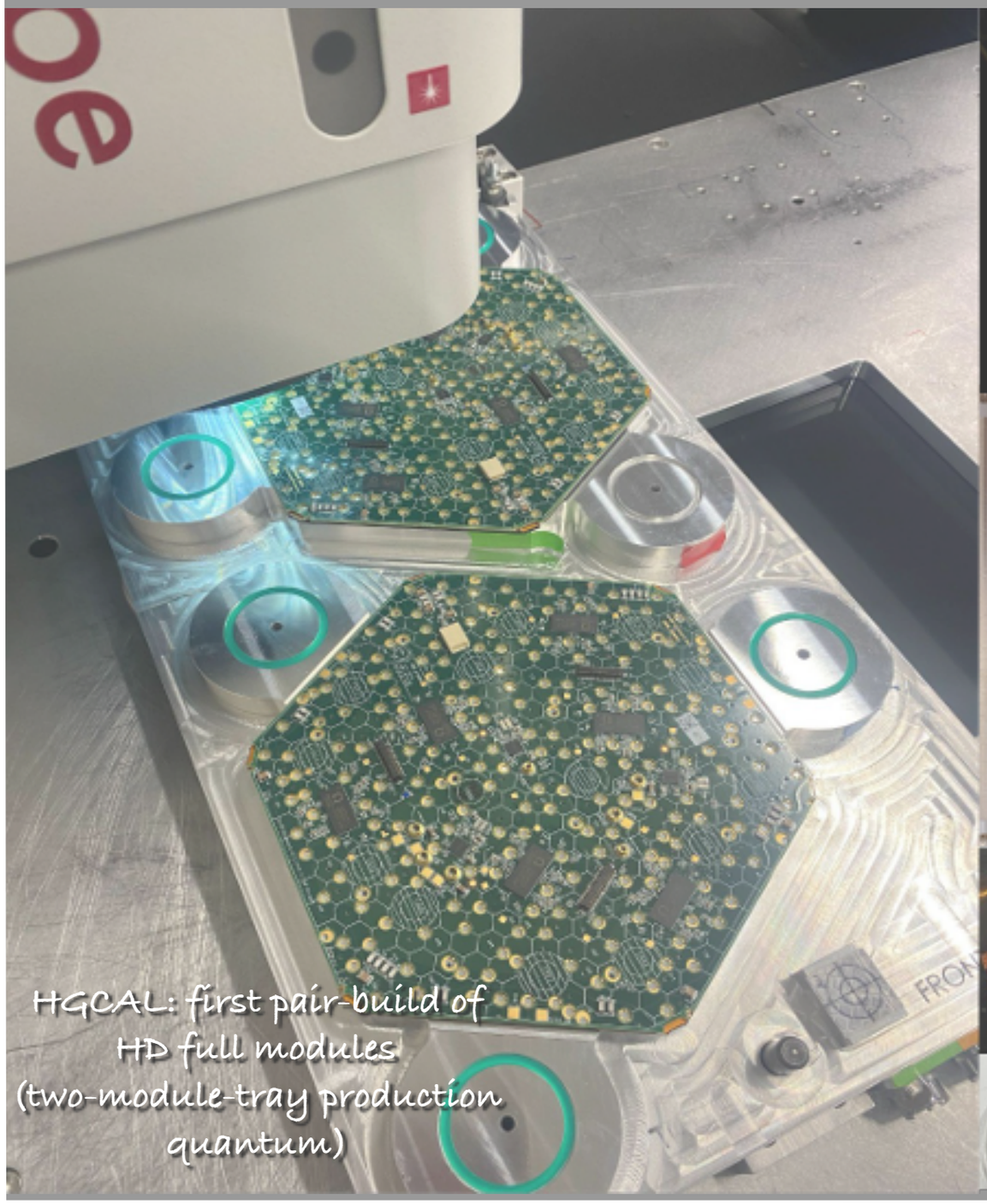
- adapts standard reconstruction for low p_T τ_h using HLT objects
- p_T ~5 GeV compared to ~20 GeV in standard offline reconstruction



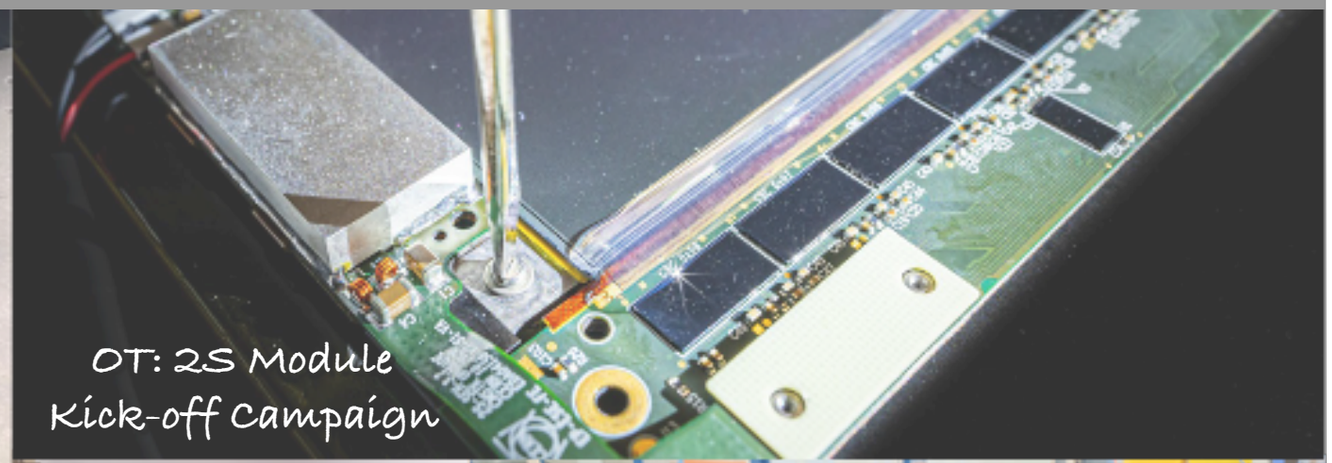
Observation of $Z \to \tau_\mu \tau_h$ process with expected cross section using Scouting data. Confirms successful τ_h identification and reconstruction

CMS Upgrade

BACK TO THE FUTURE HL-LHC

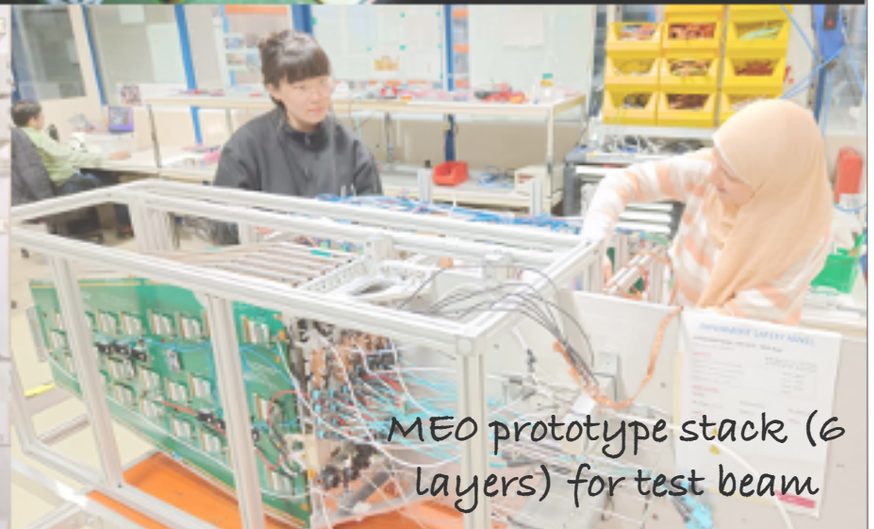


HGCAL: first pair-build of HD full modules (two-module-tray production quantum)



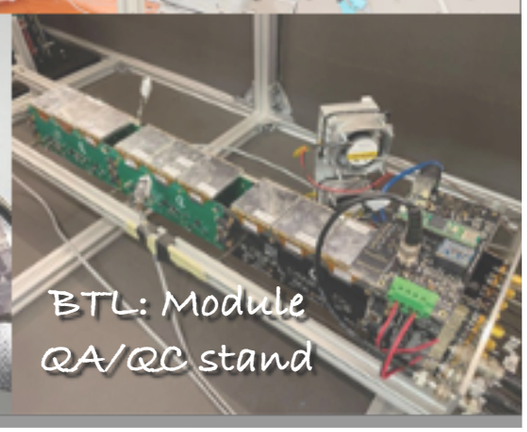
OT: 2S Module Kick-off Campaign

DAQ-800 first (and last) prototype



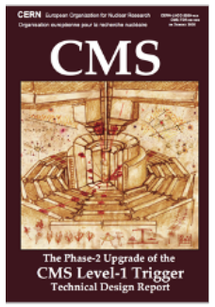
MEO prototype stack (6 layers) for test beam

BRIL: FBCM mockup and ASIC



BTL: Module QA/QC stand

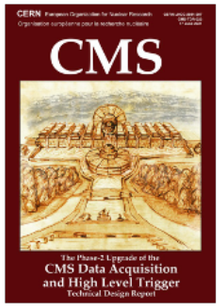
CMS bold innovative beautiful upgrade



L1-Trigger

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

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



DAQ & High-Level Trigger

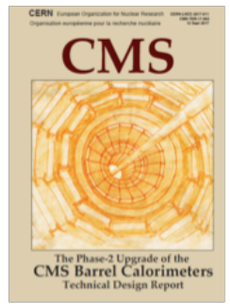
https://cds.cern.ch/record/2759072

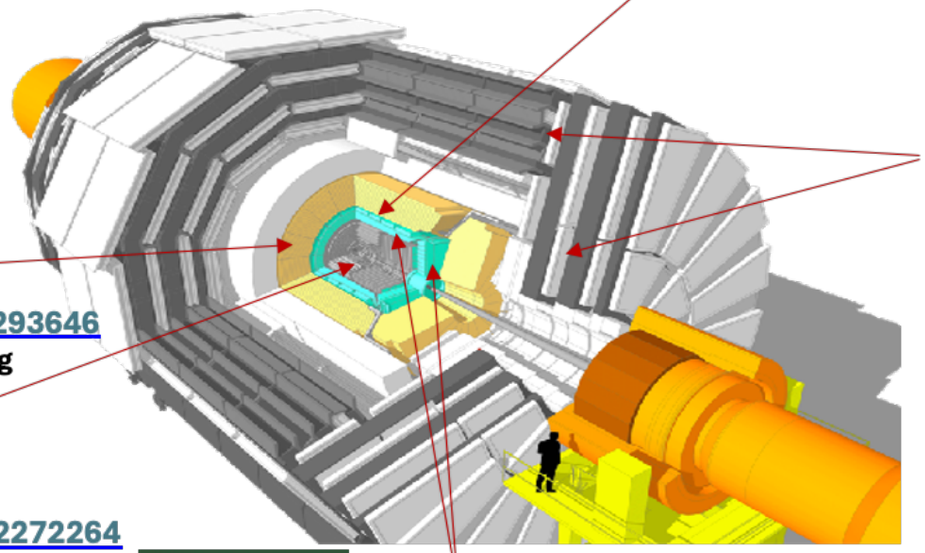
- Full optical readout
- Heterogenous architecture
- 60 TB/s event network
- 7.5 kHz HLT output

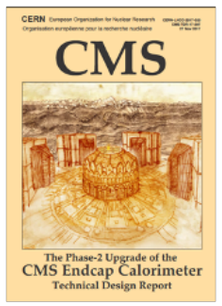
Barrel Calorimeters

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

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







Calorimeter Endcap

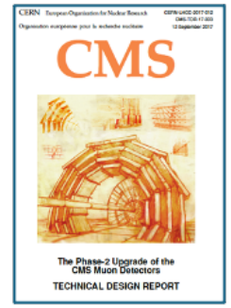
https://cds.cern.ch/record/2293646

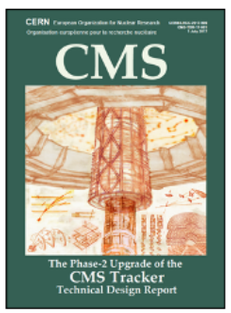
- 3D showers and precise timing
- Si, Scint+SiPM in Pb/W-SS

Muon systems

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

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

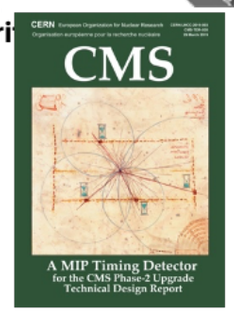




Tracker

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

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



MIP Timing Detector

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

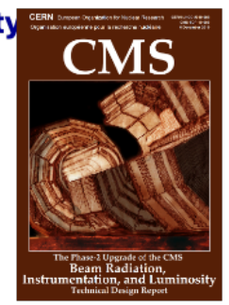
Precision timing with:

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

Beam Radiation Instr. and Luminosity

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

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



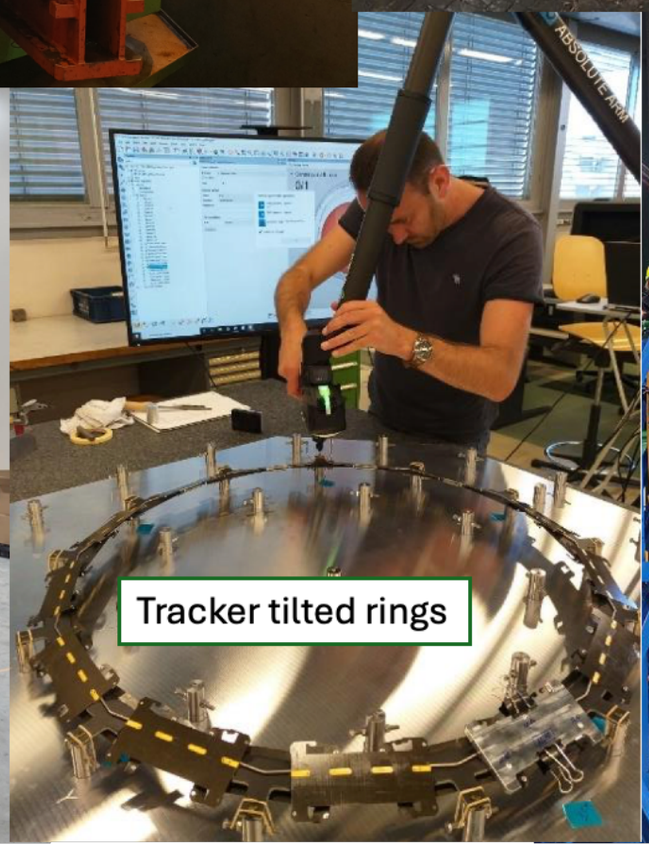
Many items in production


HGCAL Hadron Absorber plate

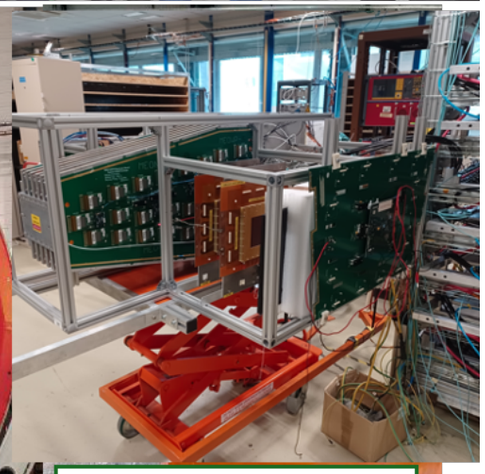

HGCAL inner cylinders

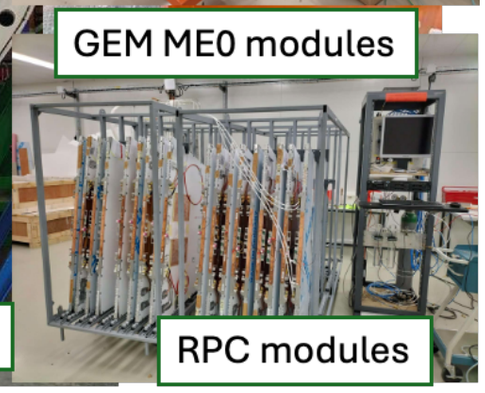

CSC boards


BTL Tracker Support Tube


Tracker tilted rings

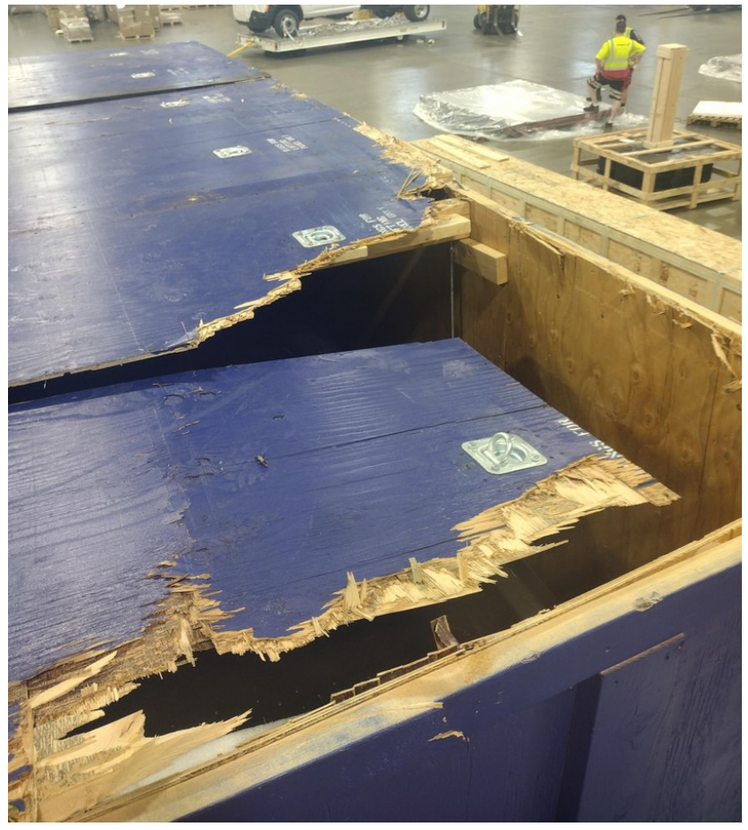

Barrel Calo installation platform


GEM ME0 modules


RPC modules

The Barrel Timing Layer tracker support tube

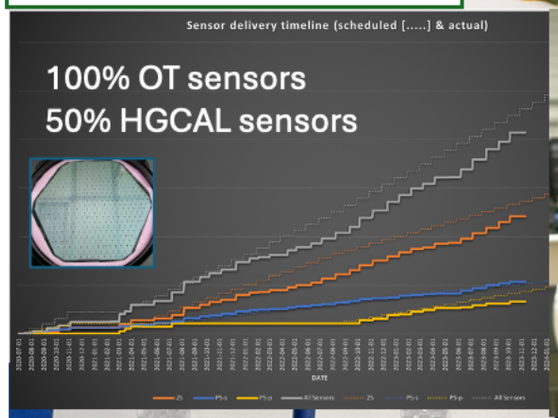
- Barrel Timing Support Tube was successfully shipped from California to Purdue in May
- Accident in June during delivery from Purdue to Chicago O'Hare airport (~150 miles) en route to CERN
- Support tube back at Purdue since July for assessment
  - experts panel involved: mechanical/aeronautic engineering at Purdue, the vendor, CERN EP-Detect&Techn, etc
  - laser scans, metrology, non-destructive testing
  - ultrasound scanning of entire support tube with ~1 cm^2 windows
- Only a few minor defects found!
  - no apparent show-stoppers
- Final evaluation (load testing) now on-going
  - fitness-for-purpose to be determined though comparison with finite element analysis

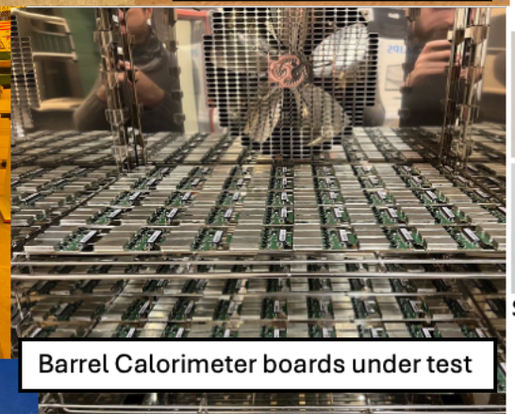


Many more items in production

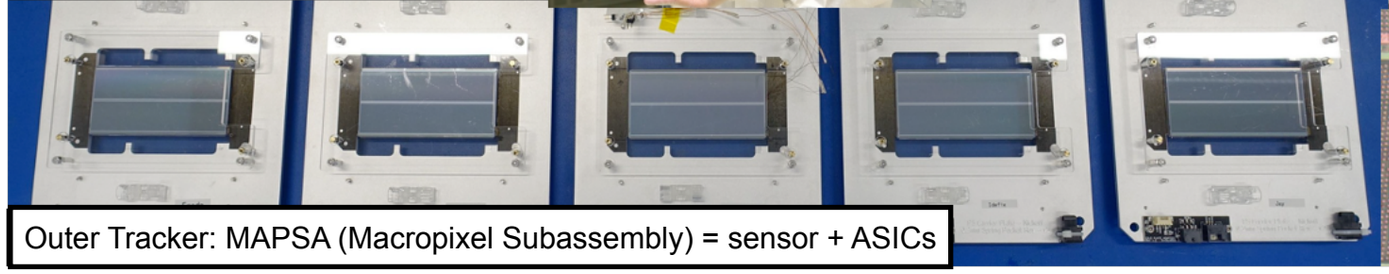
BTL SiPM and LYSO crystals

Inner Tracker sensors





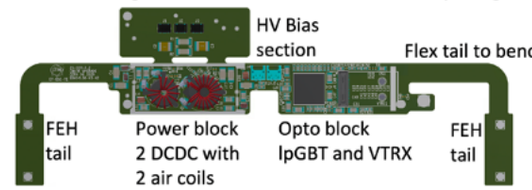
Barrel Calorimeter boards under test

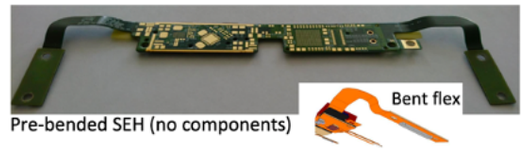


Outer Tracker: MAPSA (Macropixel Subassembly) = sensor + ASICs

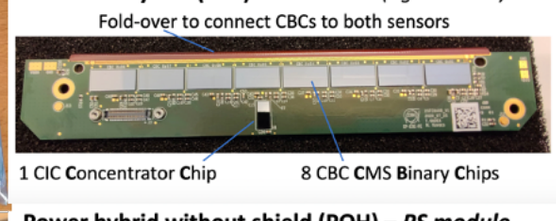
Service hybrid (SEH) - *2S module* *unbended view*

Common design for 1.8 mm and 4.0 mm sensor spacings



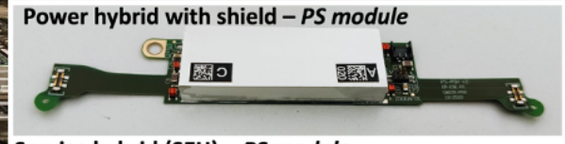


Front-end hybrid (FEH) - *2S module* *(right version)*



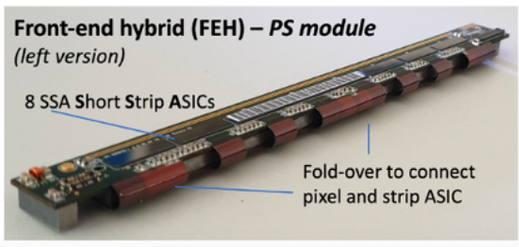
Power hybrid without shield (POH) – *PS module*

Power hybrid with shield – *PS module*



Service hybrid (SEH) – *PS module*

Front-end hybrid (FEH) – *PS module*
(left version)



Recent Highlights

CMS intensity frontier: measurement of W boson mass

LHC Seminar

High-precision measurement of the W boson mass at CMS

by Josh Bendavid (Massachusetts Inst. of Technology (US))

Tuesday 17 Sept 2024, 11:00 → 12:00 Europe/Zurich

500/1-001 - Main Auditorium (CERN)

Description: The W boson mass is measured using proton-proton collision data at corresponding to an integrated luminosity of 16.8 inverse fb recorded during 2016 by the CMS experiment. The W boson mass is obtained from a fit of the two-dimensional pT-η distribution in a sample of W→μν decays, categorized by charge, yielding one of the most precise measurements of the W mass to date.

Refreshments will be served at 10:30

Organised by: Tancredi Carli, Jan Fiete Grosse-Oetringhaus and Michelangelo Mangano

Videoconference: LHC Seminar - 17 September 2024 — Join

Webcast: There is a live webcast for this event — Watch

Contact: EP-seminars.colloquia@cern.ch

No spoilers
Stay tuned for next week's LHC Seminar!

Summary

Thanks to LHC for outstanding continuous effort in delivering Run 3 data!

- CMS is many experiments at once: intensity and energy frontier, flavor and heavy ion experiment, ...
  - cutting edge results on all fronts of collider physics: Higgs, Electroweak, QCD, Top, Flavor, Heavy Ions, and search for new physics
- We are pushing the detector performance beyond design limits rethinking the way we operate it
  - e.g., with novel data taking strategies
  - smooth on-going 2024 data-taking and excellent performance of physics objects
- CMS is a technology driver: reconstruction on GPUs, real-time analysis, AI applications, ...
  - good understanding and calibration of the physics objects, and these innovations allow to move boundaries of what assumed to be possible!
- A major upgrade is ahead, that will extend our physics reach even further!
  - upgrade project continues to progress on all fronts
  - many items in full production & preparing for assembly and integration

CMS Experiment at the LHC, CERN
Data recorded: 2022-Jul-22 04:58:42.084736 GMT
Run / Event / LS: 356005 / 100747617 / 114

Thank you!

Upgrade: progress on all fronts

- Outer Tracker
  - **In full production:** ASICs, Sensors, hybrids, mechanics, etc.
  - **Module** production starting right now
- Inner Tracker
  - **In full production:** ASICs, Sensors, bare modules
  - Good progress on **mechanics**
- HGCAL
  - **In full production:** Sensors, SiPM, scintilators, mechanics, many boards
  - Submitted final ASIC in July with all bug fixes
  - Finishing designs of last electronic components, and some mechanics
- Muons
  - GEM ME0 (priority) **in full production**
  - CSC, DT on track, **in full production**
  - RPC chambers **in full production**
- MTD, BTL
  - **All ingredients in full production**
  - Module & Tray production starting
- MTD, ETL
  - LGAD sensors conducted the PRR
  - ETROC ASIC jumped a submission
- BCAL
  - Electronics in very good shape, readying for production early 2025
- DAQ
  - Boards finalised and in procurement
- L1T
  - All four board families making more pieces for slice tests
  - As usual, excellent progress on firmware
- BRIL
  - FBCM ASIC final in a single submission