

CMS status report

LHCC open session
3 March 2025

C. Asawatangtrakuldee (Chulalongkorn University, Bangkok)

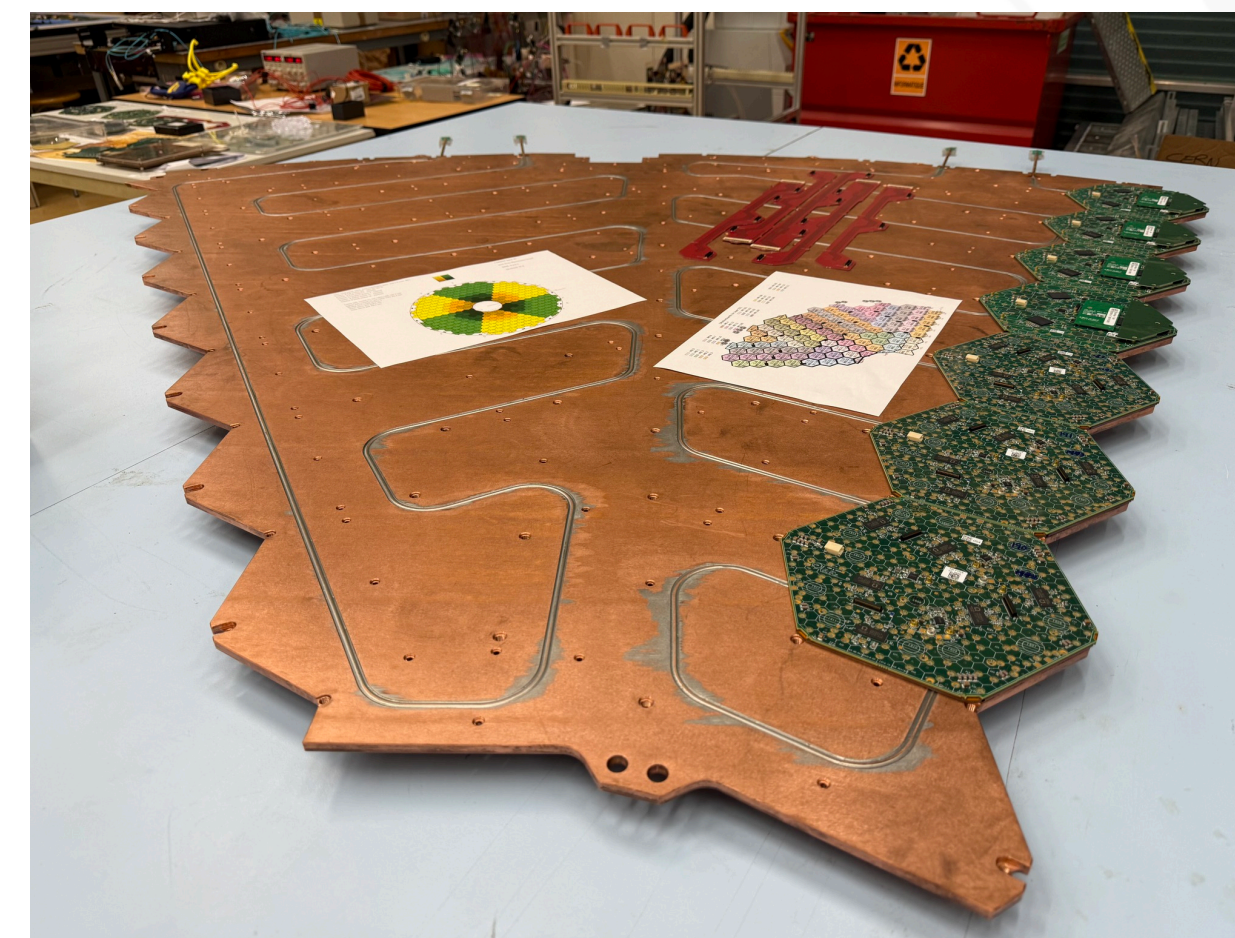
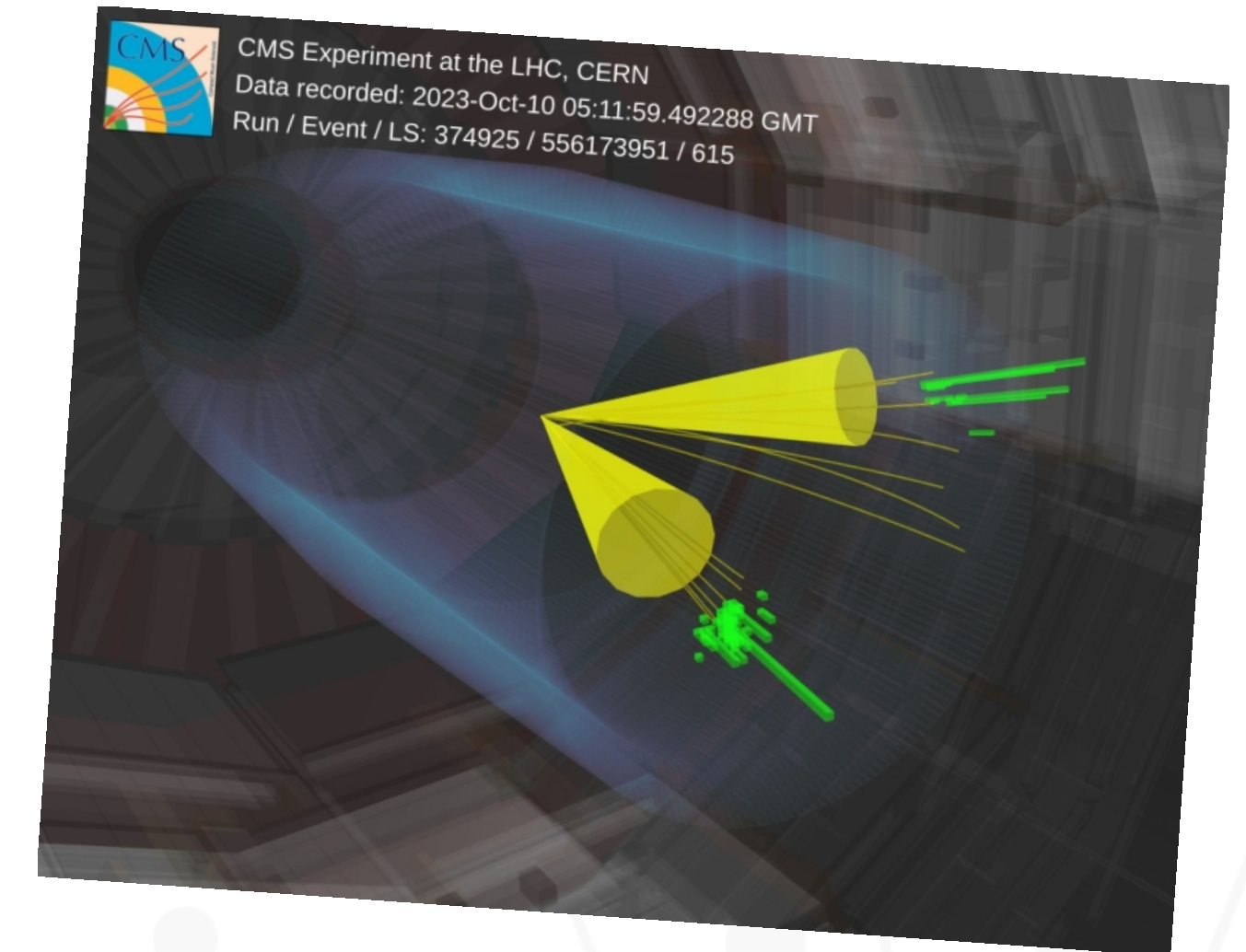
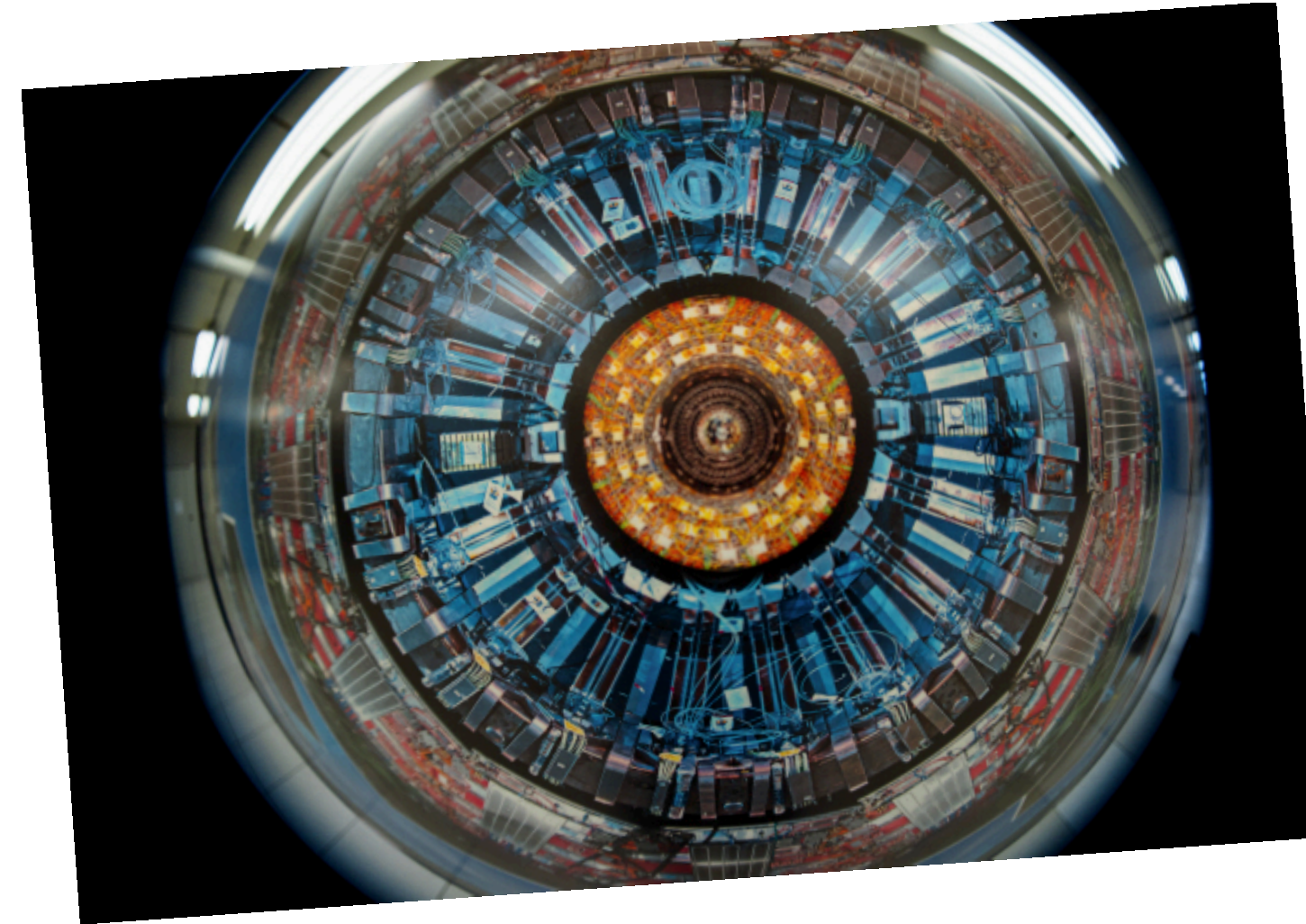
on behalf of the CMS Collaboration

📌 2024 Achievements

📌 Physics Highlights

📌 Readiness for 2025 Data-taking

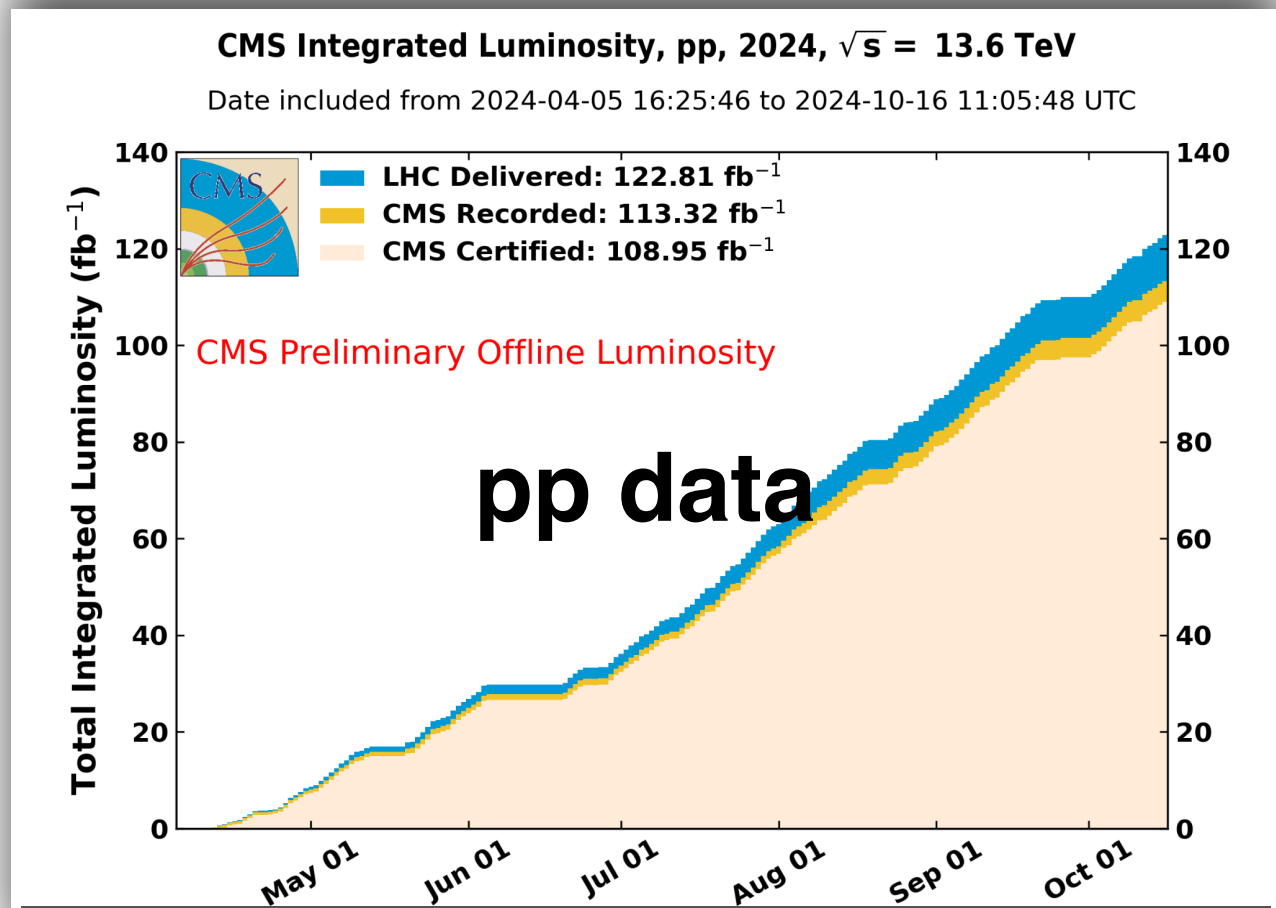
📌 Towards HL-LHC



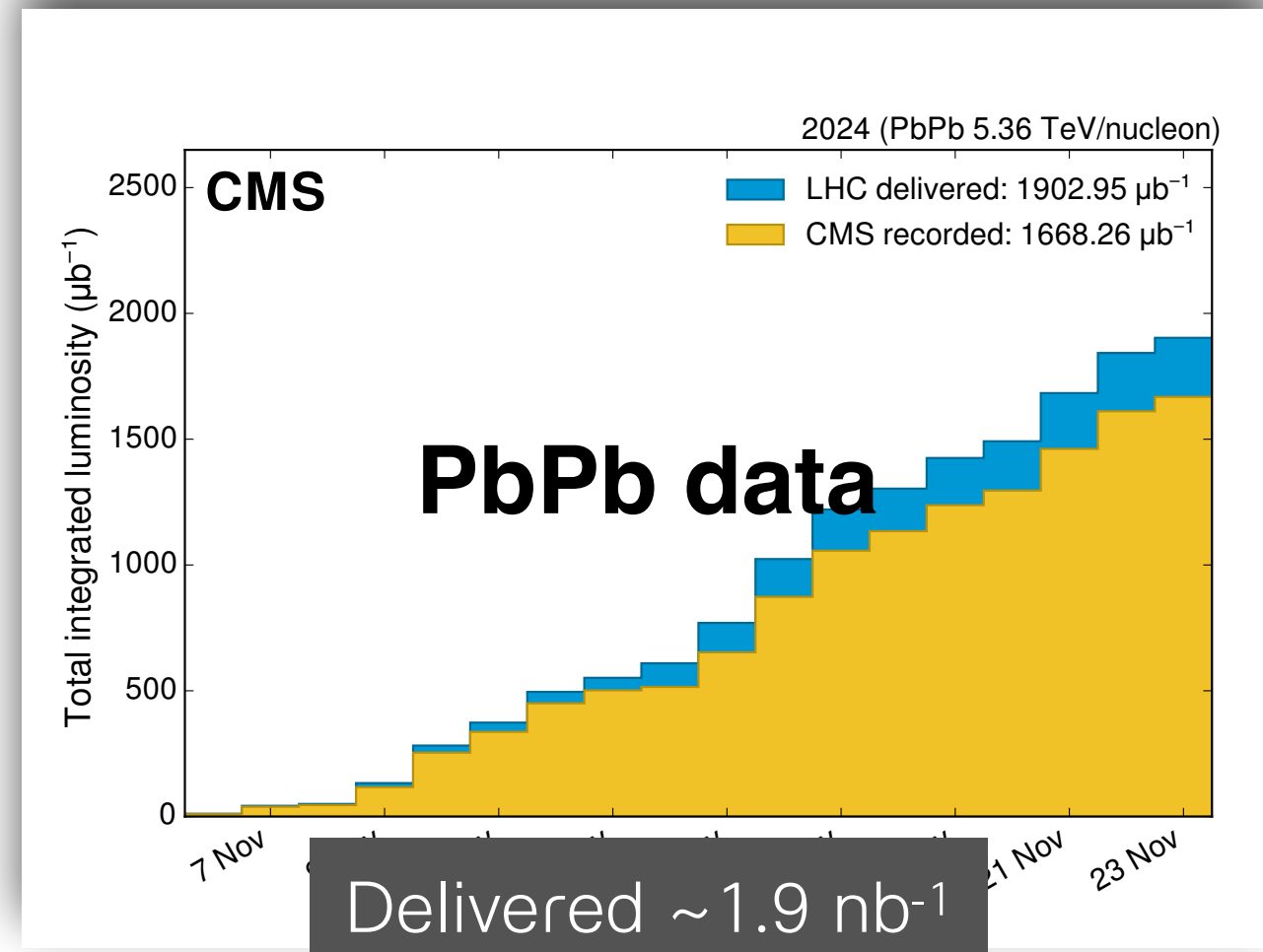
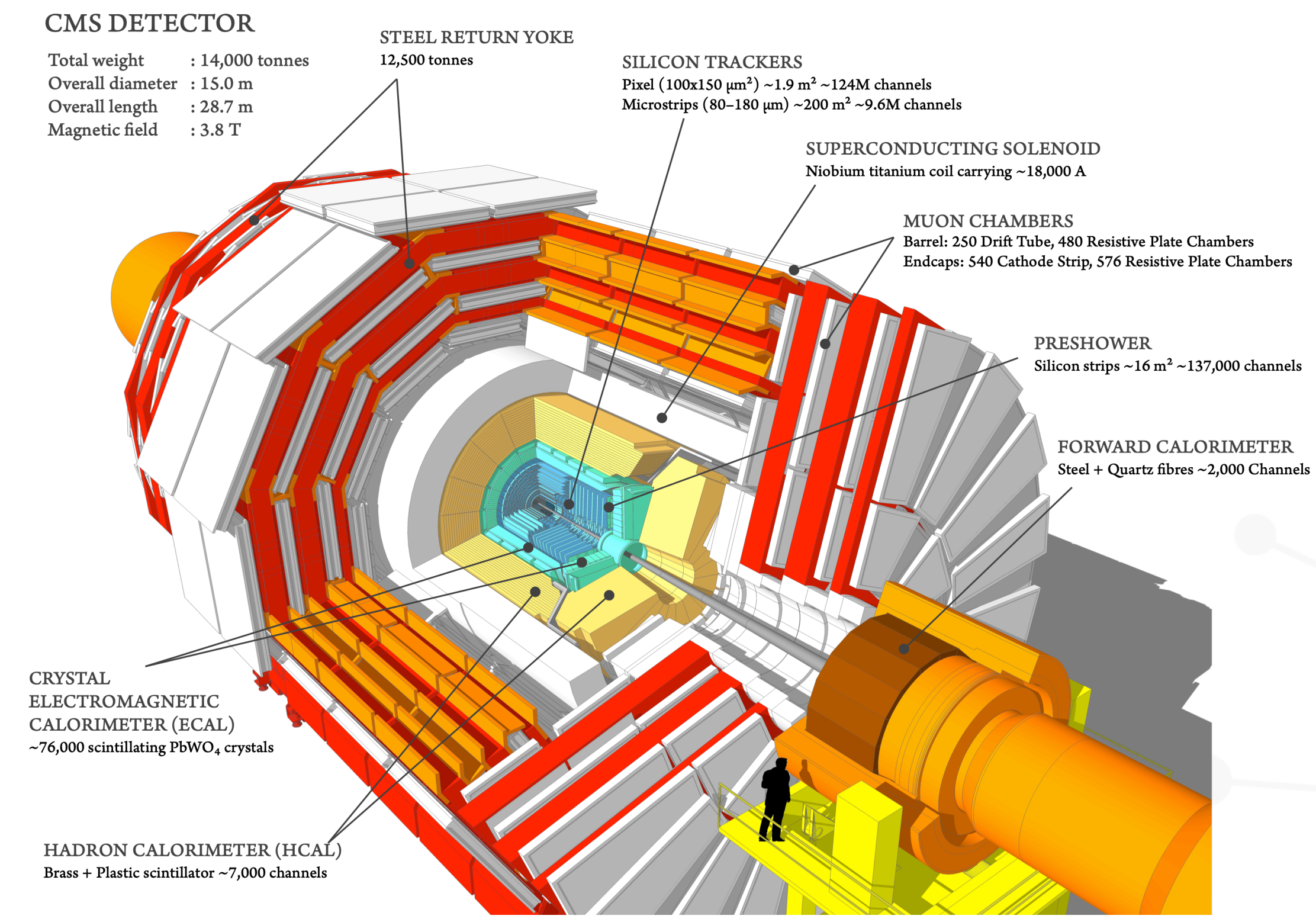
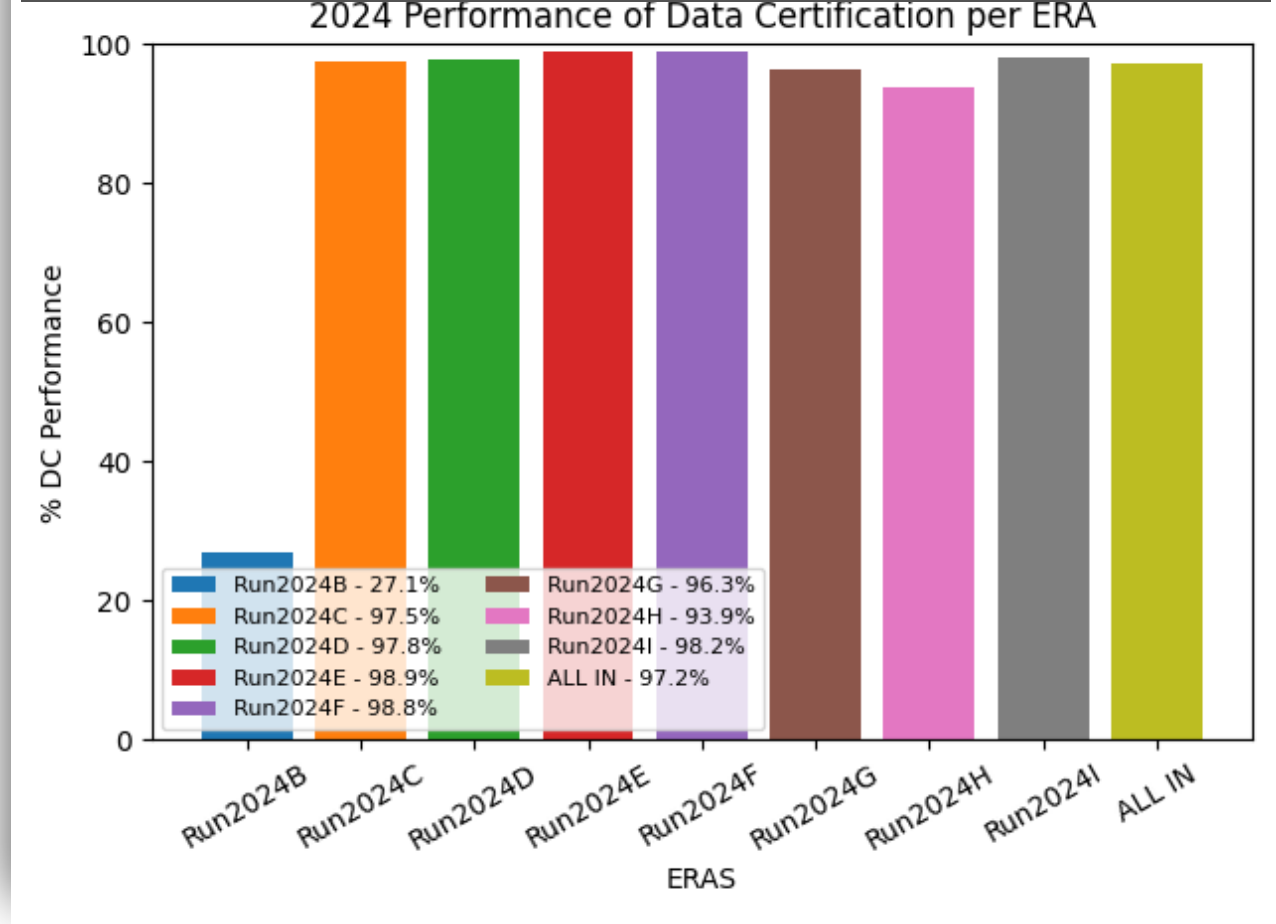
2024 Achievements – Detector Performance



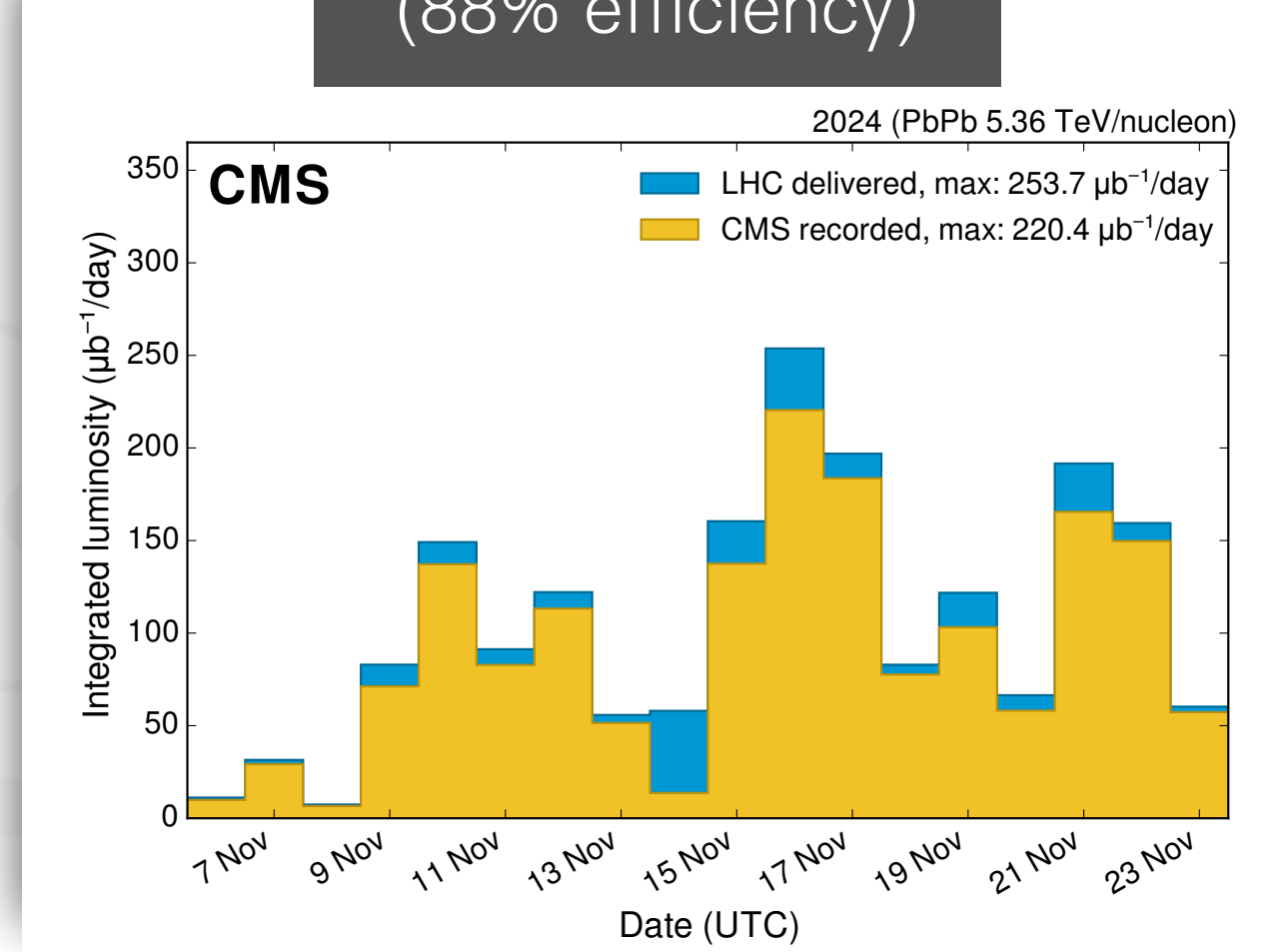
Very smooth operations from all detector systems during pp and PbPb data taking in 2024



Data Certification efficiency (certified/DC processed) up to 97.2%



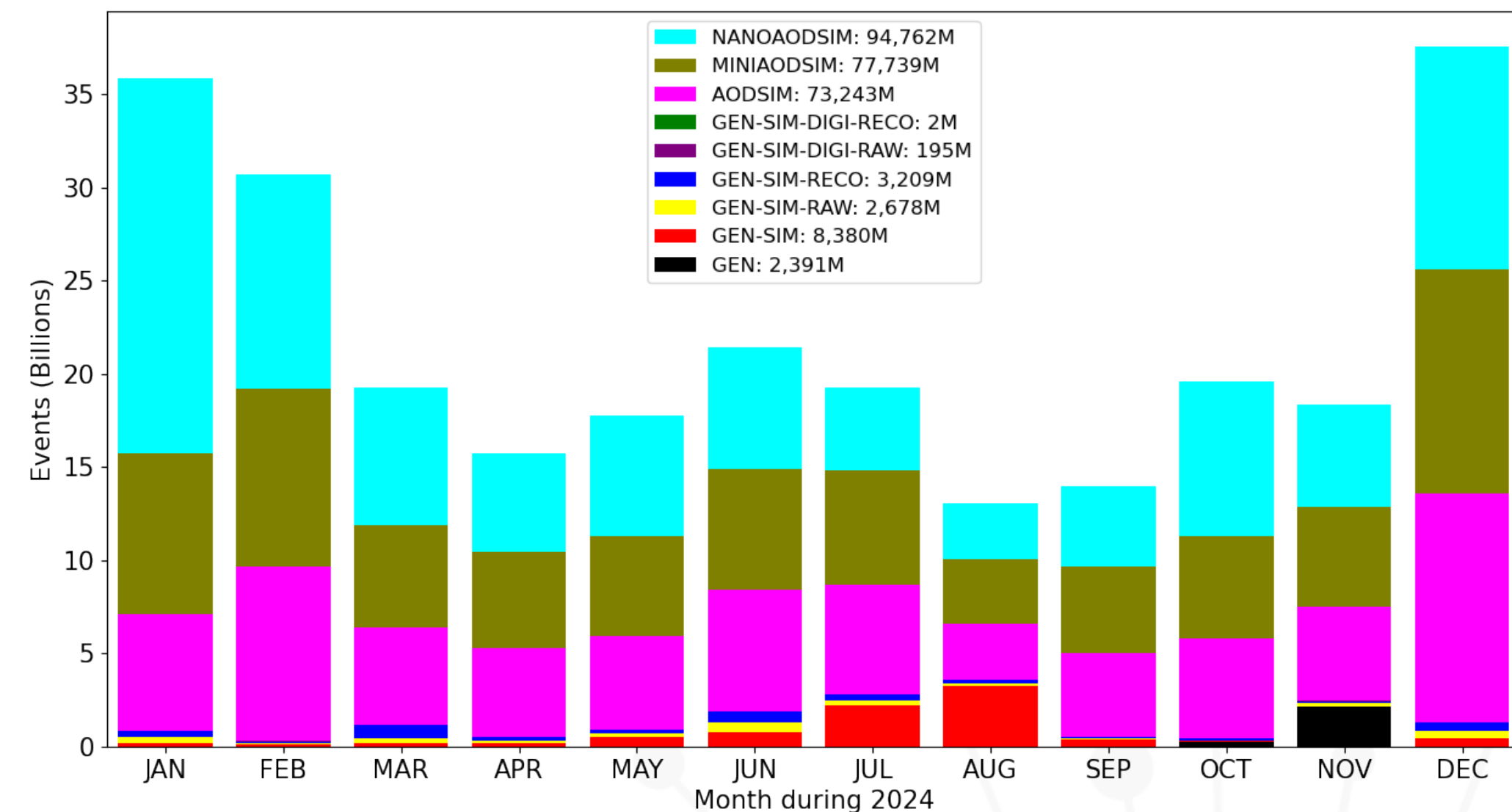
Delivered ~1.9 nb⁻¹
Recorded ~1.7 nb⁻¹
(88% efficiency)



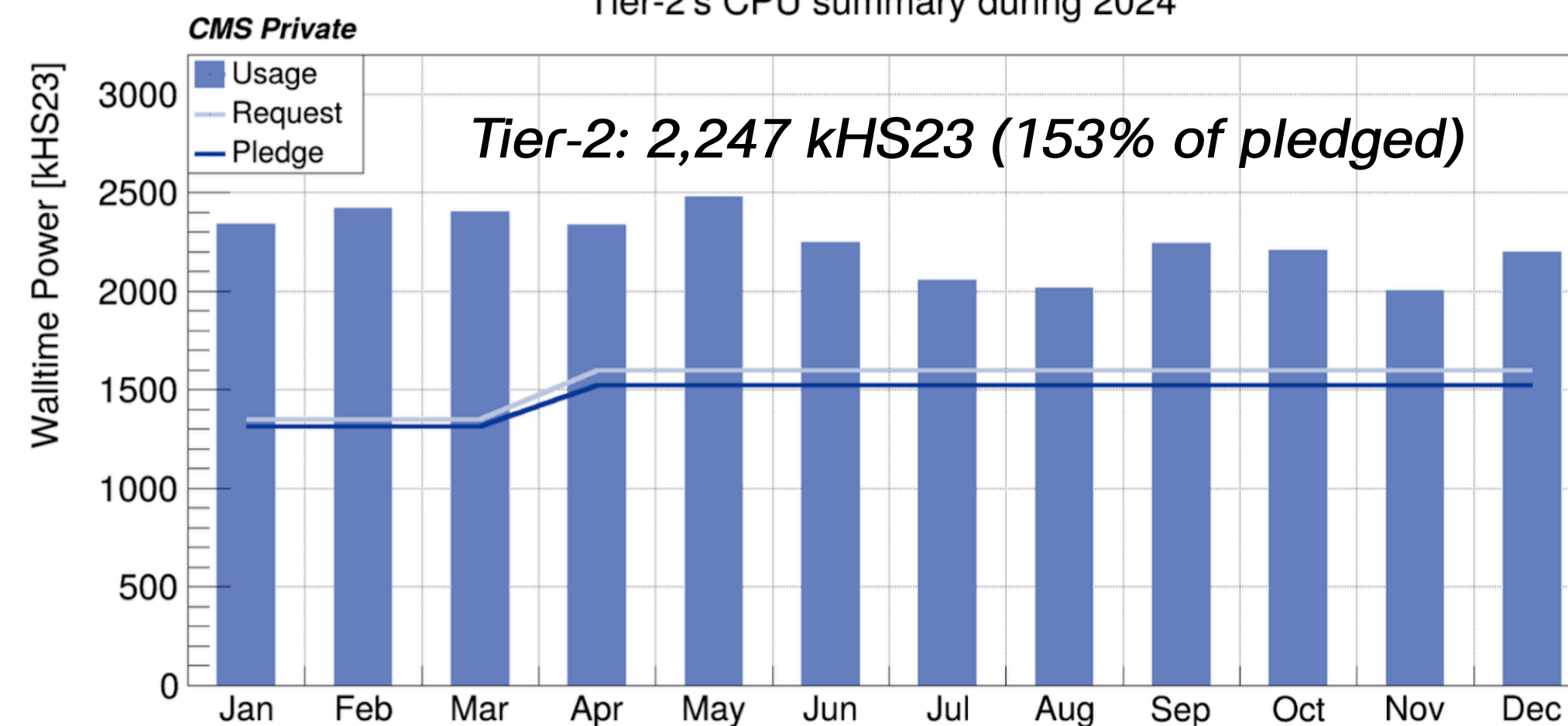
2024 Achievements – Data Reprocessing & MC Production



- CMS is following the plan proposed in the Spring 2023 Scrutiny.
 - Tier-1 resources and Run 2 HLT are being used for parked data processing in real time.
 - Overpledged and opportunistic resources have contributed significantly to MC production, with 73.2 billion events generated from scratch (1.4 billion events per week!).
 - Run 2 Ultra Legacy
 - Run 3 2023
 - Phase 2 samples for trigger study
- We would like to thank all funding agencies and site support teams for providing the essential computing resources.



Tier-2's CPU summary during 2024



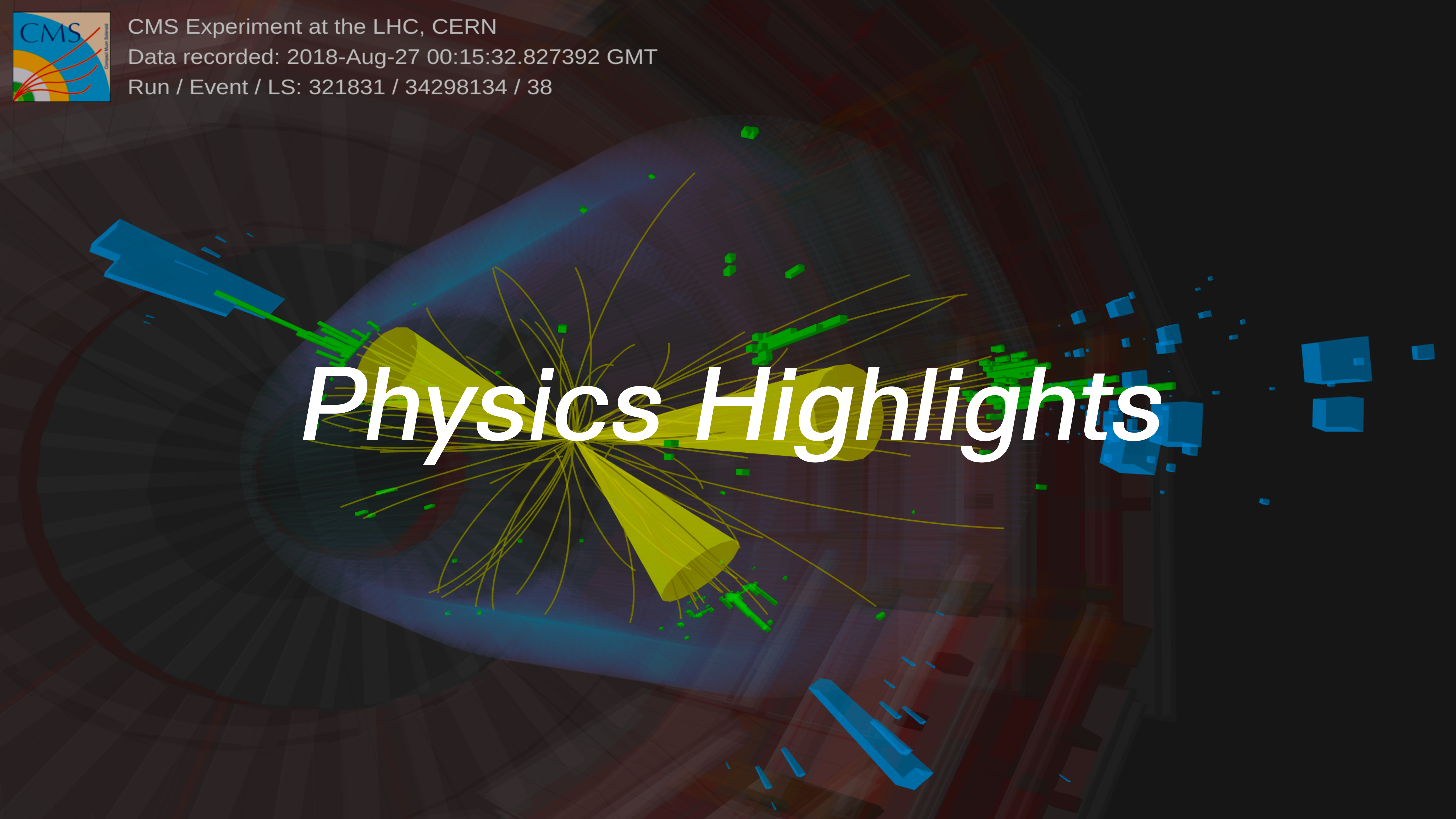


CMS Experiment at the LHC, CERN

Data recorded: 2018-Aug-27 00:15:32.827392 GMT





Run / Event / LS: 321831 / 34298134 / 38

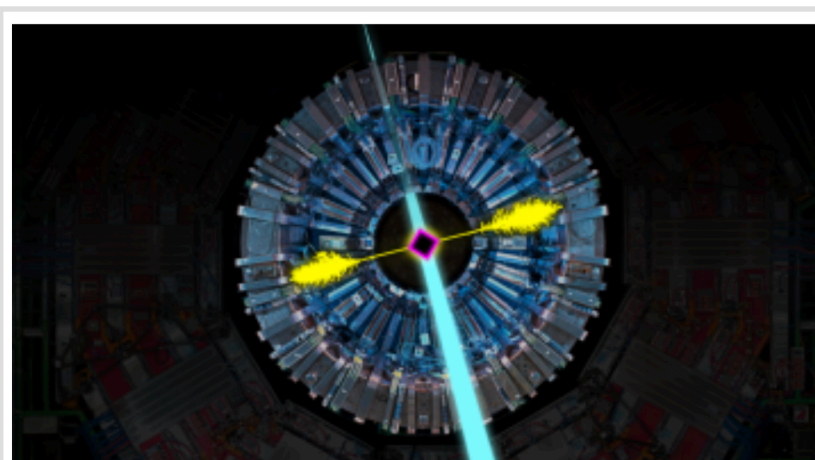
Physics Highlights



New results since last LHCC

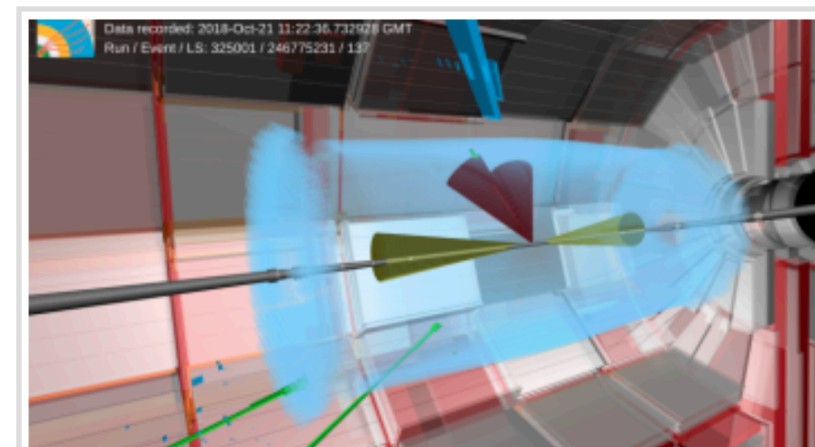


-  [8 new public results](#)
-  [24 submitted papers](#)
-  [18 new DPS notes](#)
-  [3 new physics briefings](#)



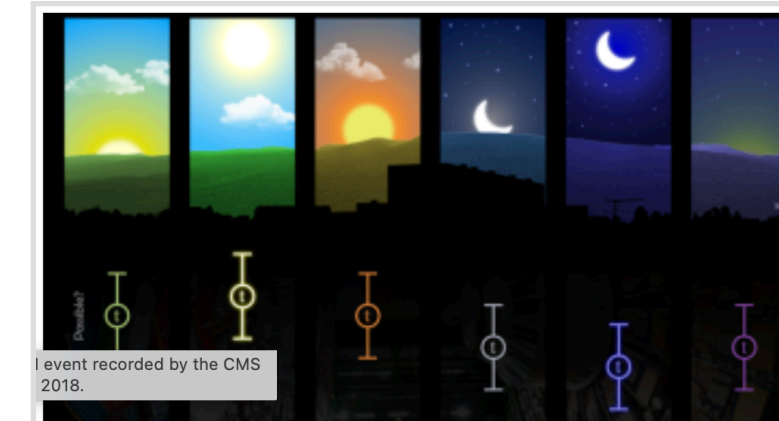
THE "LARGE PHOTON COLLIDER": CMS OBSERVES SCATTERING OF LIGHT BY LIGHT AT THE LHC

13 JAN 2025








A TALE OF TWO HIGGS: THE QUEST FOR PRODUCTION OF HIGGS BOSON PAIRS AT CMS

02 DEC 2024



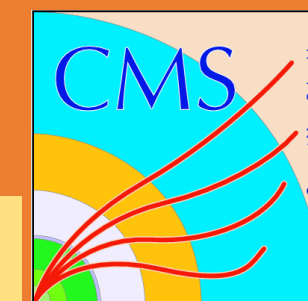
CLOCKING NATURE'S HEAVIEST ELEMENTARY PARTICLE: DO TOP QUARKS PLAY BY EINSTEIN'S RULES THE WHOLE DAY AND NIGHT?

27 NOV 2024

	CMS PAS SMP-23-003	Search for Z LFV decays with Run2 data	Search
	CMS PAS HIG-23-015	Differential cross section measurement of ttH production in proton-proton collisions at 13 TeV in CMS	Measurement
	CMS PAS BPH-23-007	Measurements of the $\Upsilon(1S)$ meson production in association with a Z boson in proton-proton collisions at 13 TeV	Flavor Physics
	CMS PAS HIN-24-004	Characterizing the Initial State in XeXe and PbPb Collisions using Multiparticle Cumulants	Heavy Ions
	CMS PAS HIN-24-014	Constraining nPDFs using dijet production in pPb collisions at 8.16 TeV with the CMS experiment	
	CMS PAS HIN-24-016	First k_T scan of the Lund jet plane in heavy-ion collisions to test the factorization of the vacuum and medium parton shower	
	CMS PAS JME-23-001	A new method for correcting the substructure of multi-prong jets using Lund jet plane reweighting in the CMS experiment	Tools
	CMS PAS MUO-24-001	Identification of low-momentum muons in the CMS detector using multivariate techniques in proton-proton collisions at 13.6 TeV	

Search for charged LFV Z and Z' boson decays

SMP-23-003

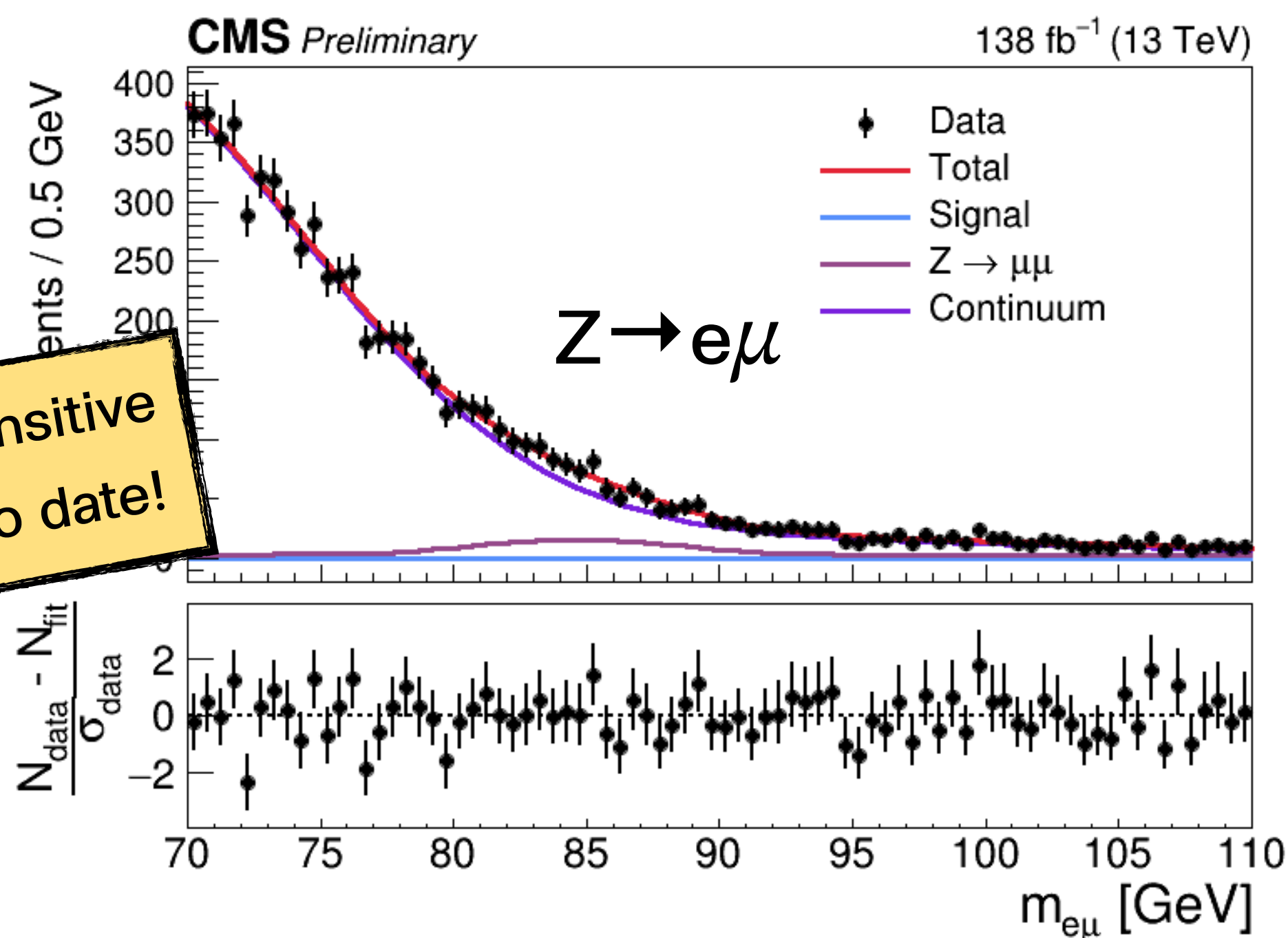


In SM, Z boson charged lepton flavor-violating BFs are $O(10^{-50})$ from neutrino loops

Run 2

Search for $Z \rightarrow e\mu$, $Z \rightarrow e\tau$, $Z \rightarrow \mu\tau$

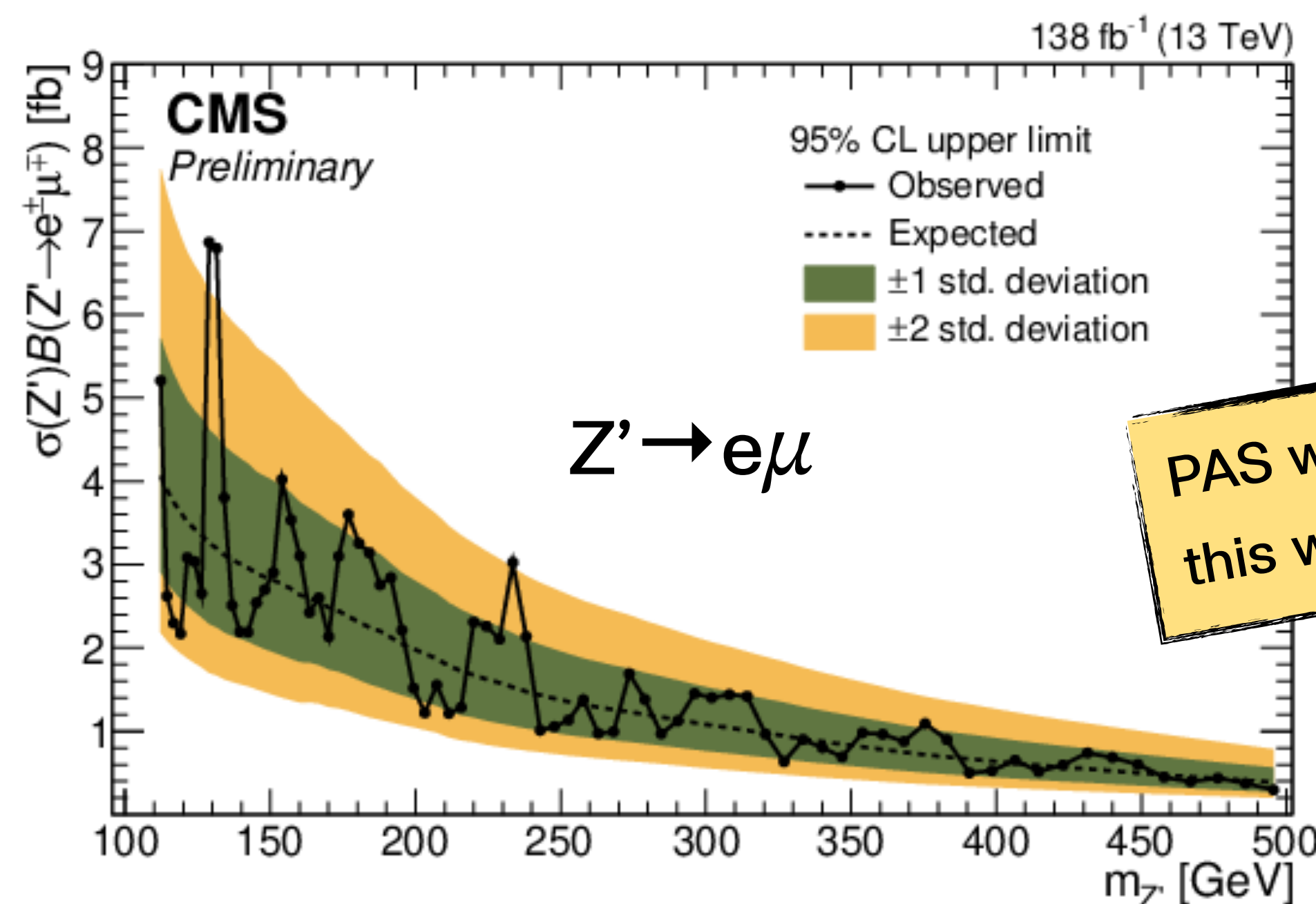
Search for a heavier $Z' \rightarrow e\mu$



most sensitive result to date!

For $Z \rightarrow e\mu$, upper observed (expected) limits

$$BR(Z \rightarrow e\mu) < 1.9 \ (2.0^{+0.8}_{-0.6}) \times 10^{-7}$$



PAS will be released this week for LHCC!

For $Z' \rightarrow e\mu$, upper limits cross section times BFs range from

0.3 to 7 fb in the Z' mass range of 110-500 GeV

Measurements of $\Upsilon(1S)$ production with a Z boson

BPH-23-007

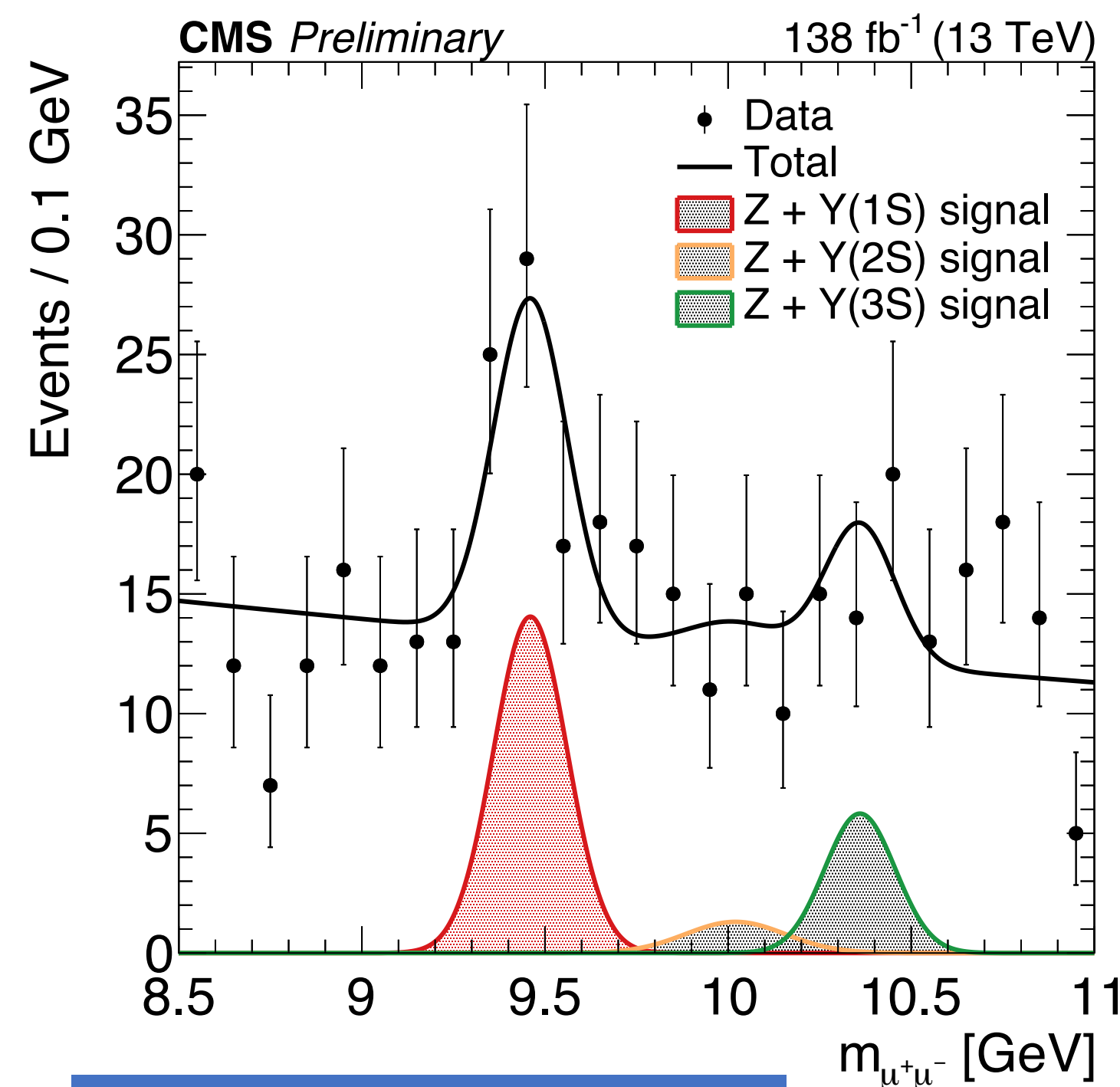
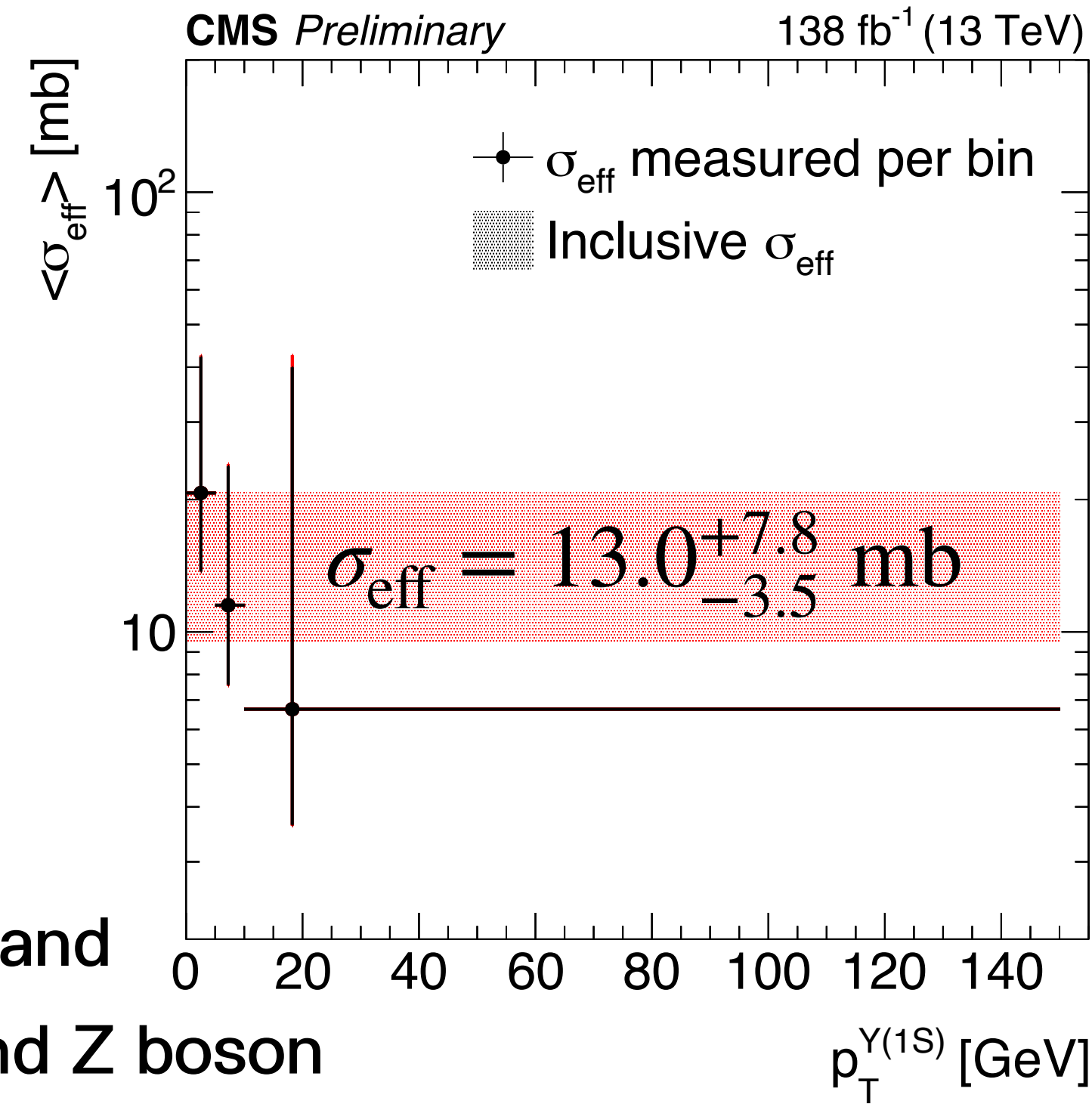
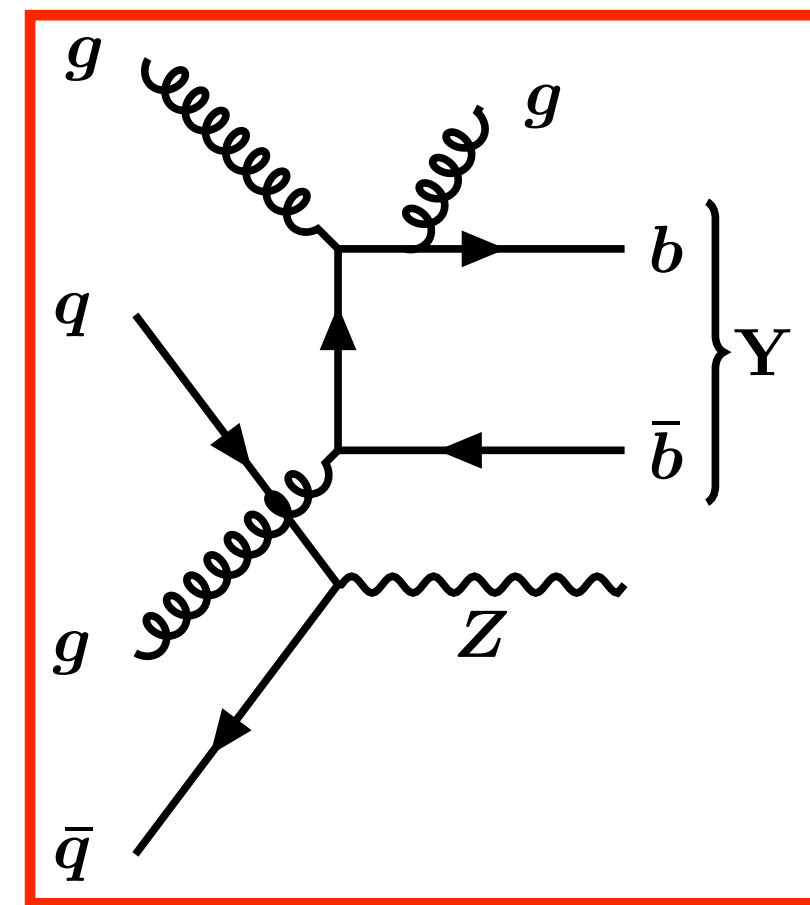
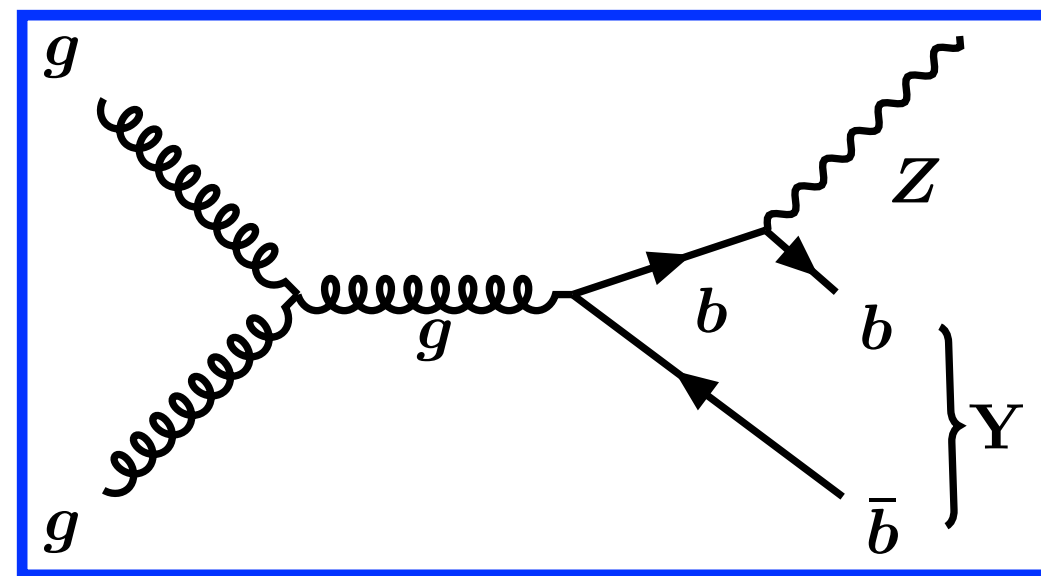


Run 2

The production of heavy quarkonia is not completely understood, involving pQCD in creation step and a complex non-perturbative binding process.

Further complicated when produced with electroweak bosons due to competing **SPS** and **DPS** processes

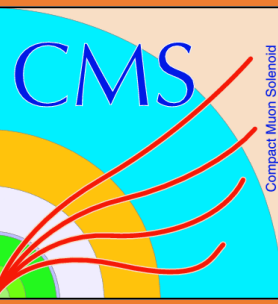
The first measurement using 4-muon final state



Effective **DPS** cross section obtained and measured differentially in p_T bins of $\Upsilon(1S)$ and Z boson

observed Z+ $\Upsilon(1S)$
 34.6 ± 9.0 events (5.3σ)

Lund jet plane in PbPb collisions



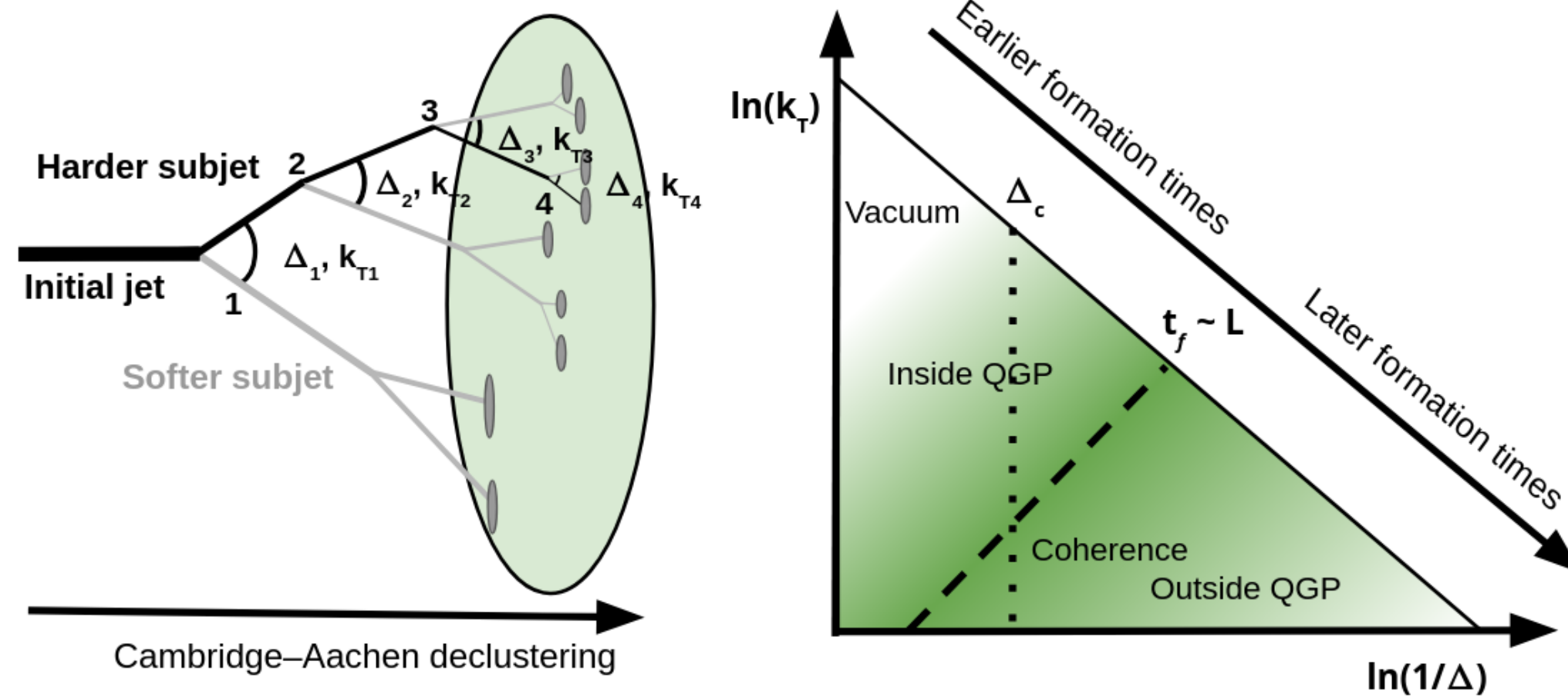
HIN-24-016

First momentum scale (k_T) scan of the Lund jet plane in PbPb collisions to characterize QGP

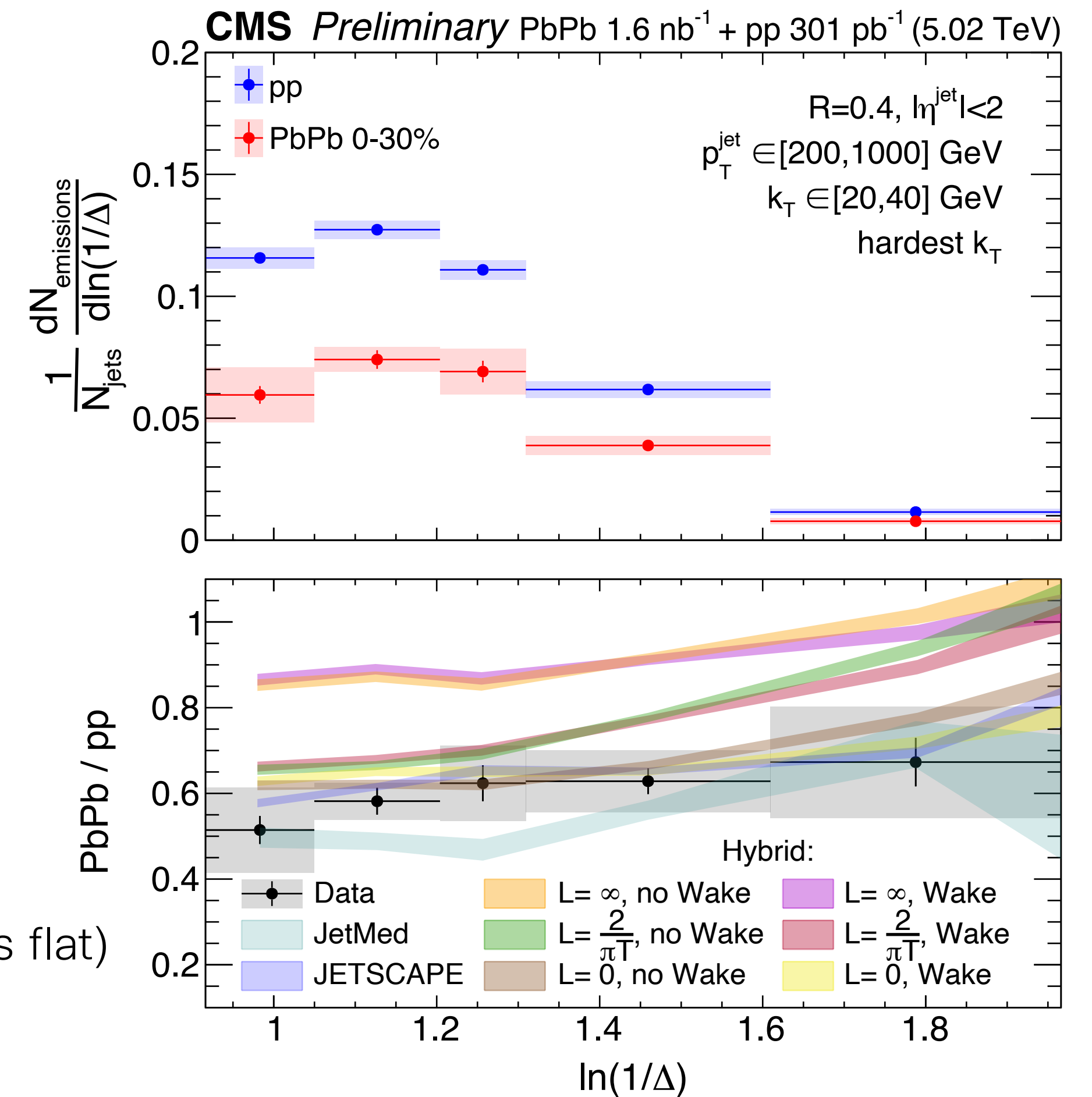
Run 2

CERN Seminar
18 Feb 2025

To test the factorization hypothesis between vacuum-like (high k_T) and in-medium jet cascades
Key element in the modeling of jets in heavy ions



- Two k_T intervals are tested, **PbPb** and **pp** results are compared.
- At high k_T , the emission angle θ has the same shape in **PbPb** and **pp** (**ratio** is flat)
- The **ratio** is compared with various jet quenching model predictions.



Jet substructure correction using Lund plane reweighting

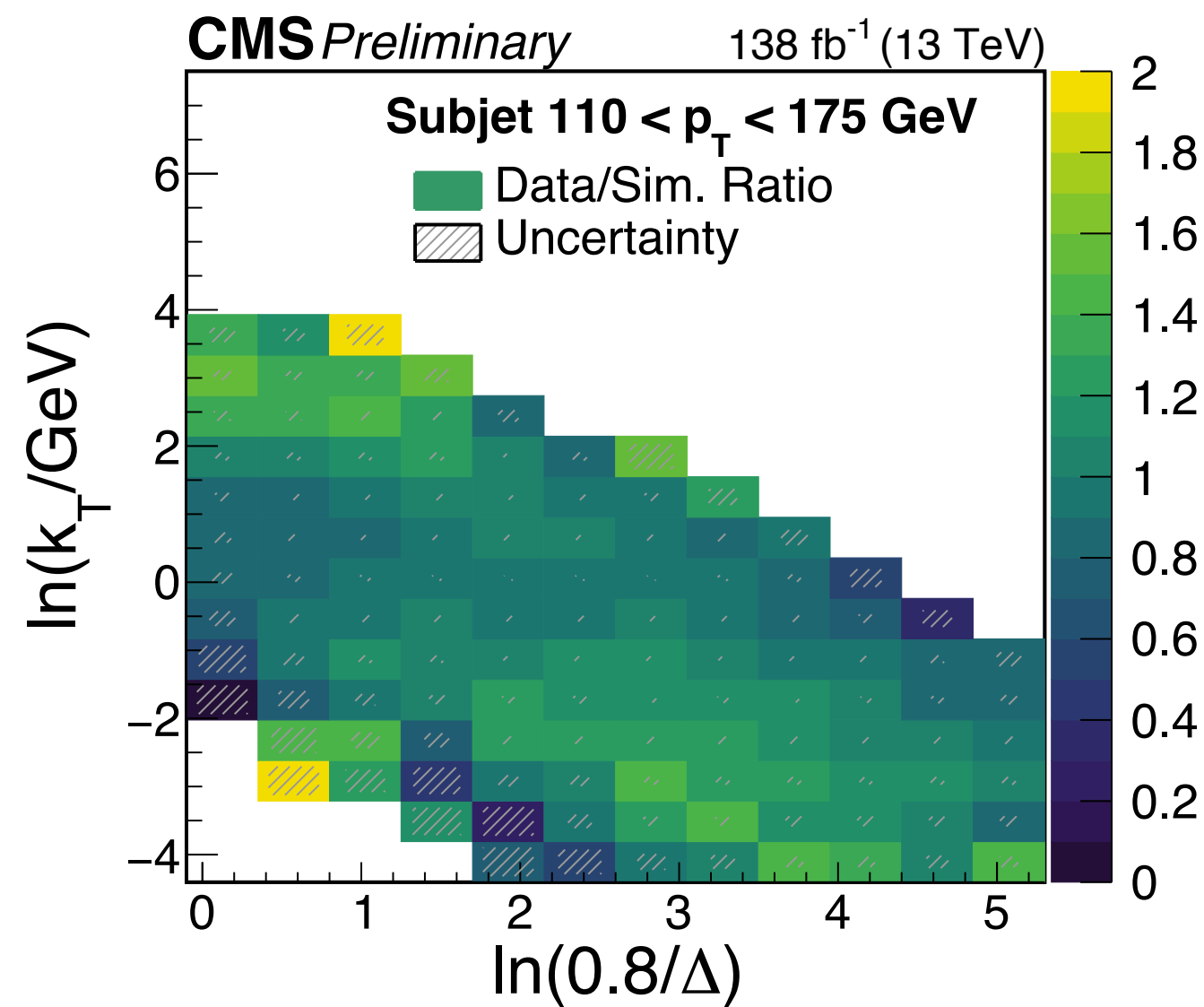
JME-23-001



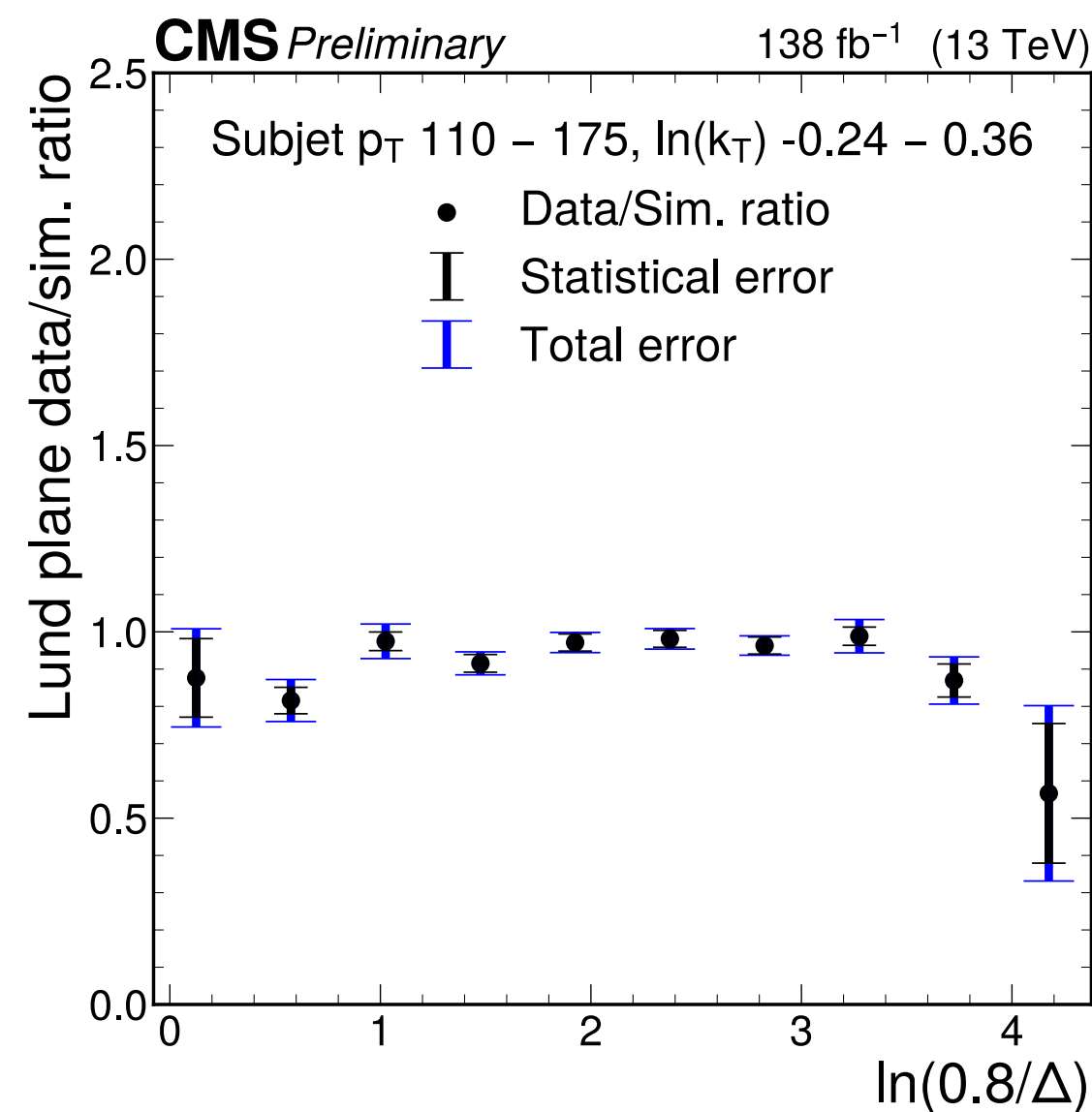
CERN Seminar
18 Feb 2025

A new technique for correcting the substructure of simulated large-radius jets from multi-prong decays.

Run 2

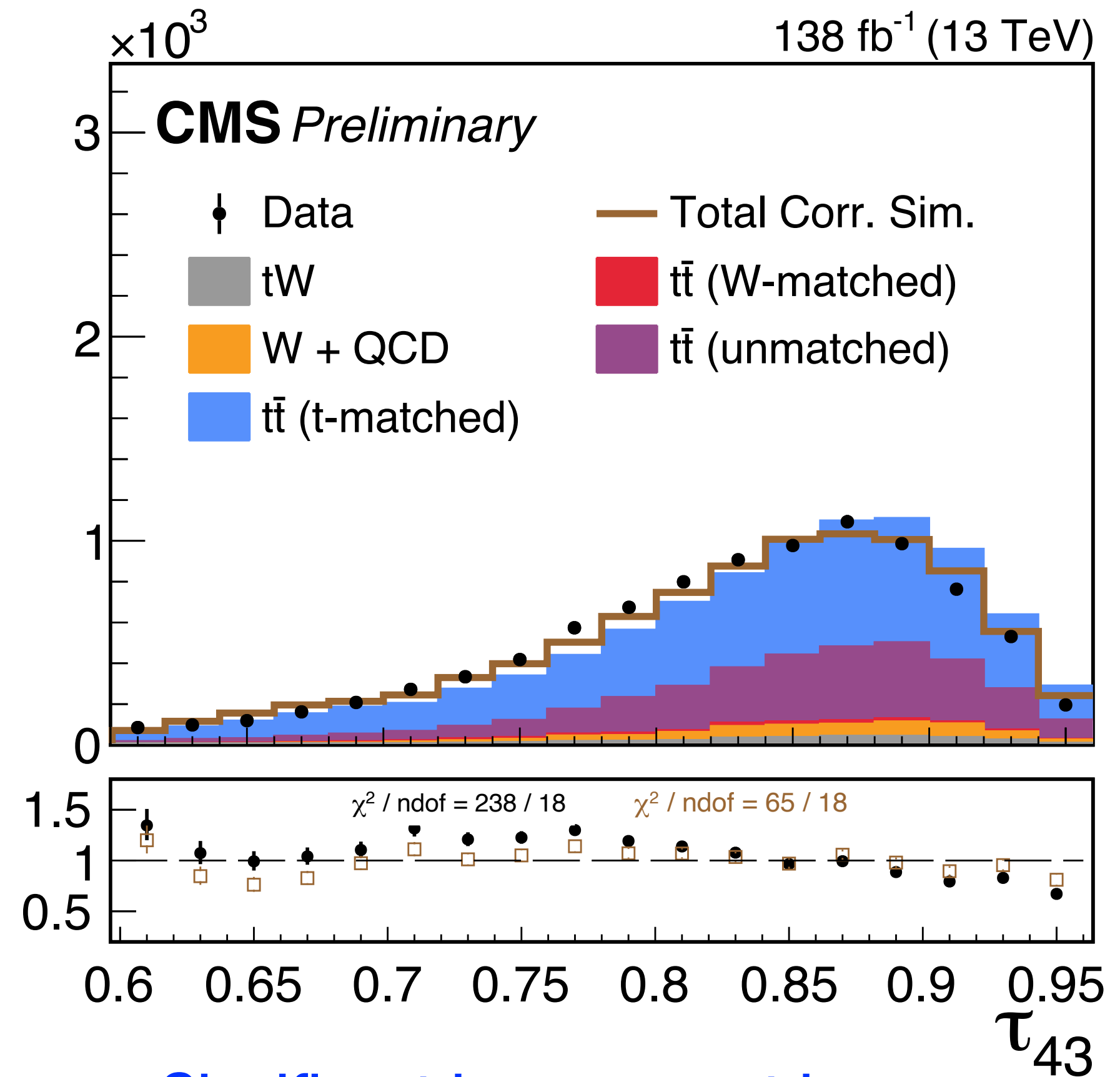


Ratios of the LJP densities in the subjet p_T bins (6 bins)



Ratios of the LJP densities between data and MC projected into one dimension

Events / 0.02



Significant improvement in data/MC agreement

Characterizing the initial state in XeXe and PbPb

HIN-24-004



Run 3

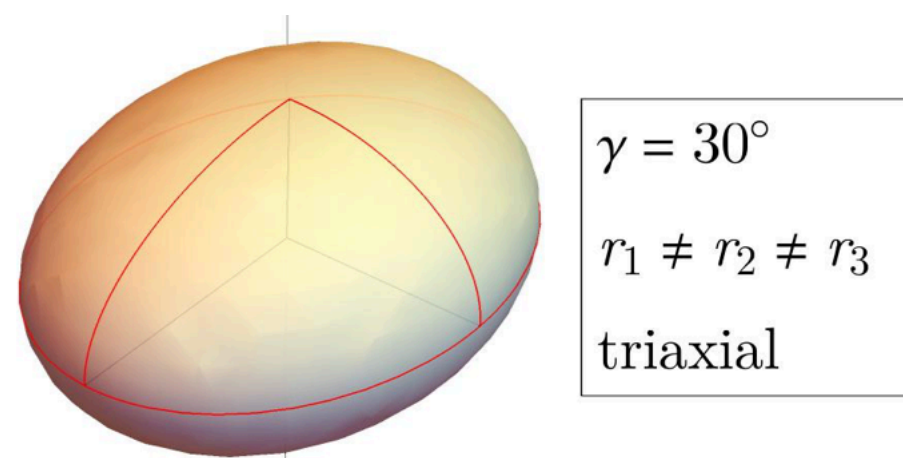
New methods to perform imaging of the collective structure of atomic nuclei

XeXe (2017 @ 5.44 TeV)

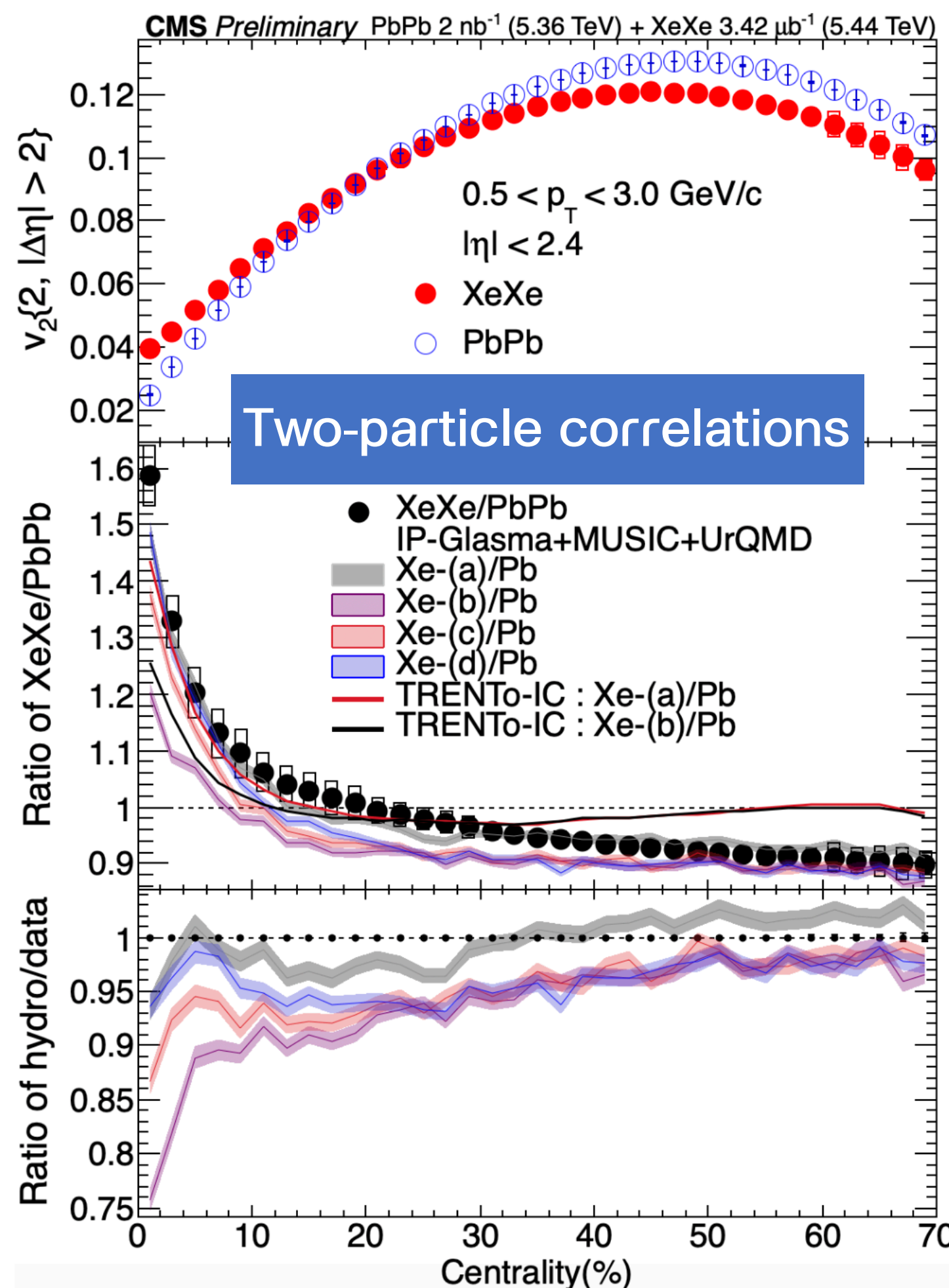
PbPb (2023 @ 5.36 TeV)

Comparison of XeXe/PbPb with various theoretical models to the data

Xe-(a)/Pb is best match



XeXe predicted to have deformed and **triaxial structure** ([arXiv:2108.09578](https://arxiv.org/abs/2108.09578))



First look at higher-power moments of the flow harmonics which show a strong departure from the pre-equilibrium conditions due to the hydrodynamical evolution.

- Sensitivity to nuclear deformation parameters in XeXe
- Looking forward to OO collisions this year!

An aerial, high-angle photograph of a large, complex industrial facility, likely a particle accelerator or a large-scale data center. The central area is dominated by a circular structure with a complex arrangement of pipes, cables, and machinery. The surrounding area is filled with green metal walkways and railings, providing access to various levels of the facility. The floor is a mix of grey concrete and yellow safety markings. In the foreground, there are several large, cylindrical objects wrapped in silver insulation, with labels like 'HE-RBX 04', 'HE-RBX 05', 'HE-RBX 06', and 'HE-RBX 07'. A yellow forklift is visible on the right side. The overall scene is one of a highly organized and technologically advanced environment.

Readiness for 2025
Data-taking

YETS 2024-2025 Highlights



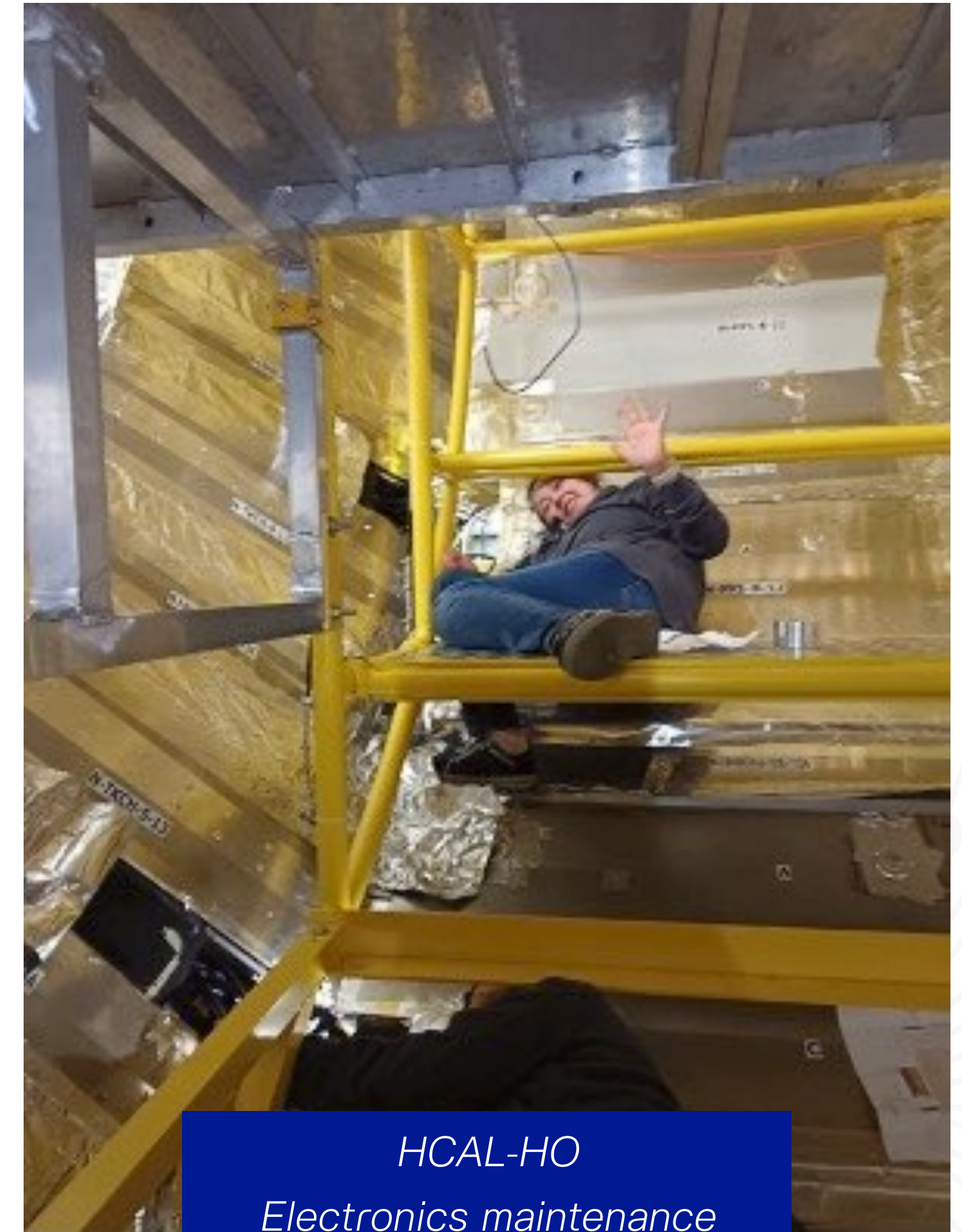
Tracker: successful opening of the bulkhead and cleaning of Pixel fibers



BRIL: Pixel Luminosity Telescope and Beam Conditions monitors replacement -Z end

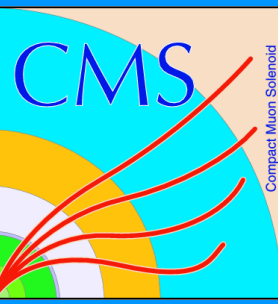


CMS status report: LHCC open session



HCAL-HO Electronics maintenance

YETS 2024-2025 Highlights

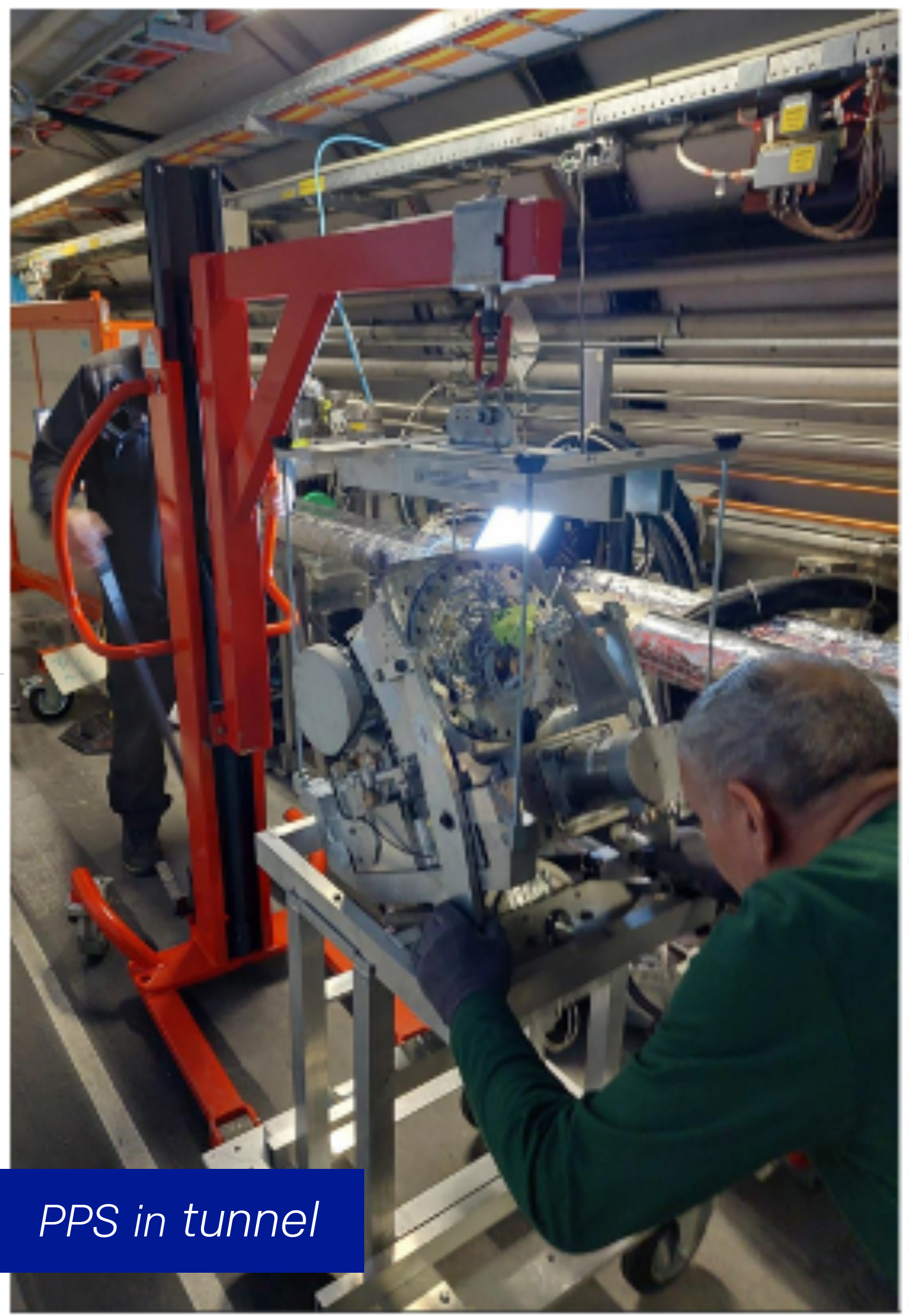
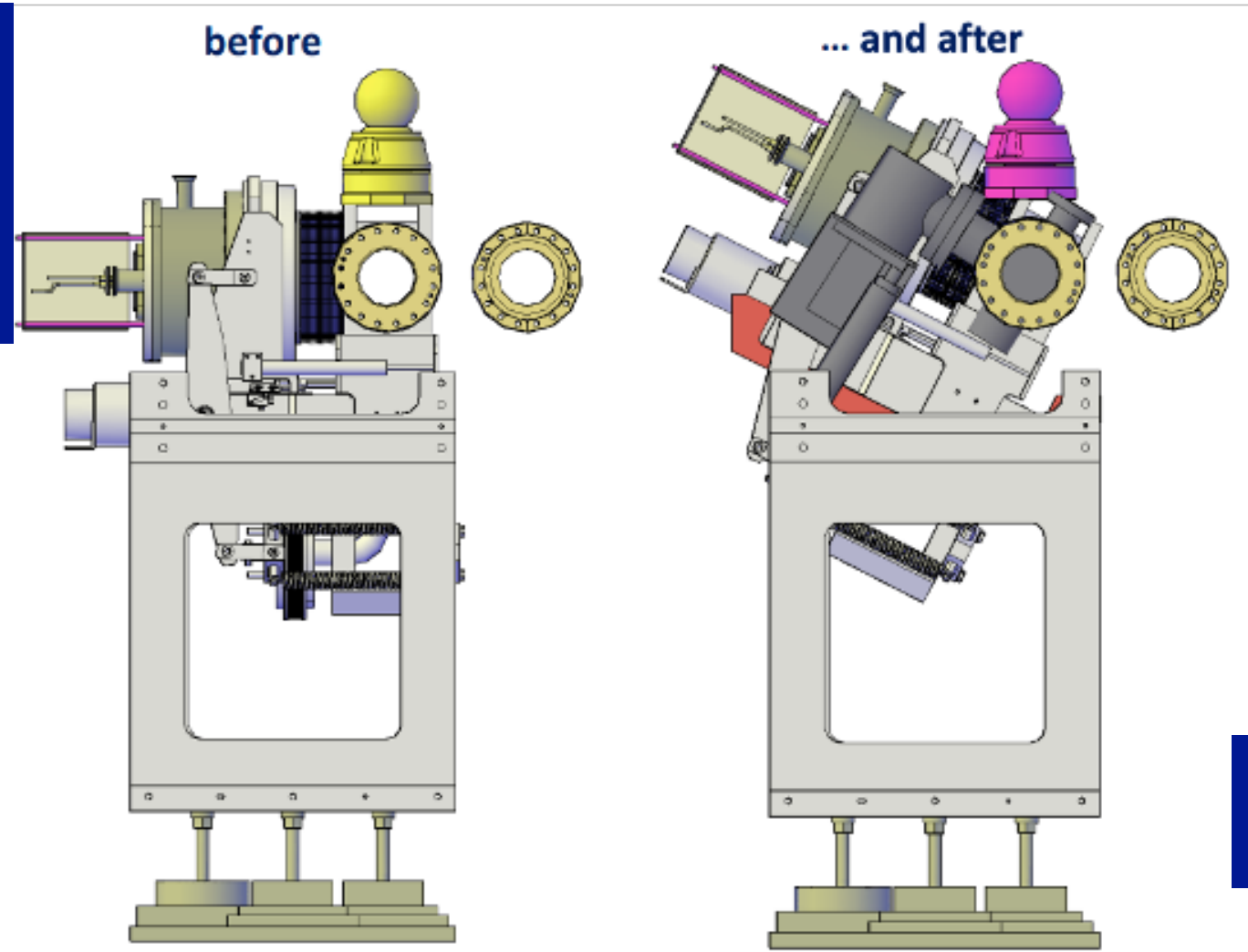


Opening with push back system for Installation of RE-4/1 chamber



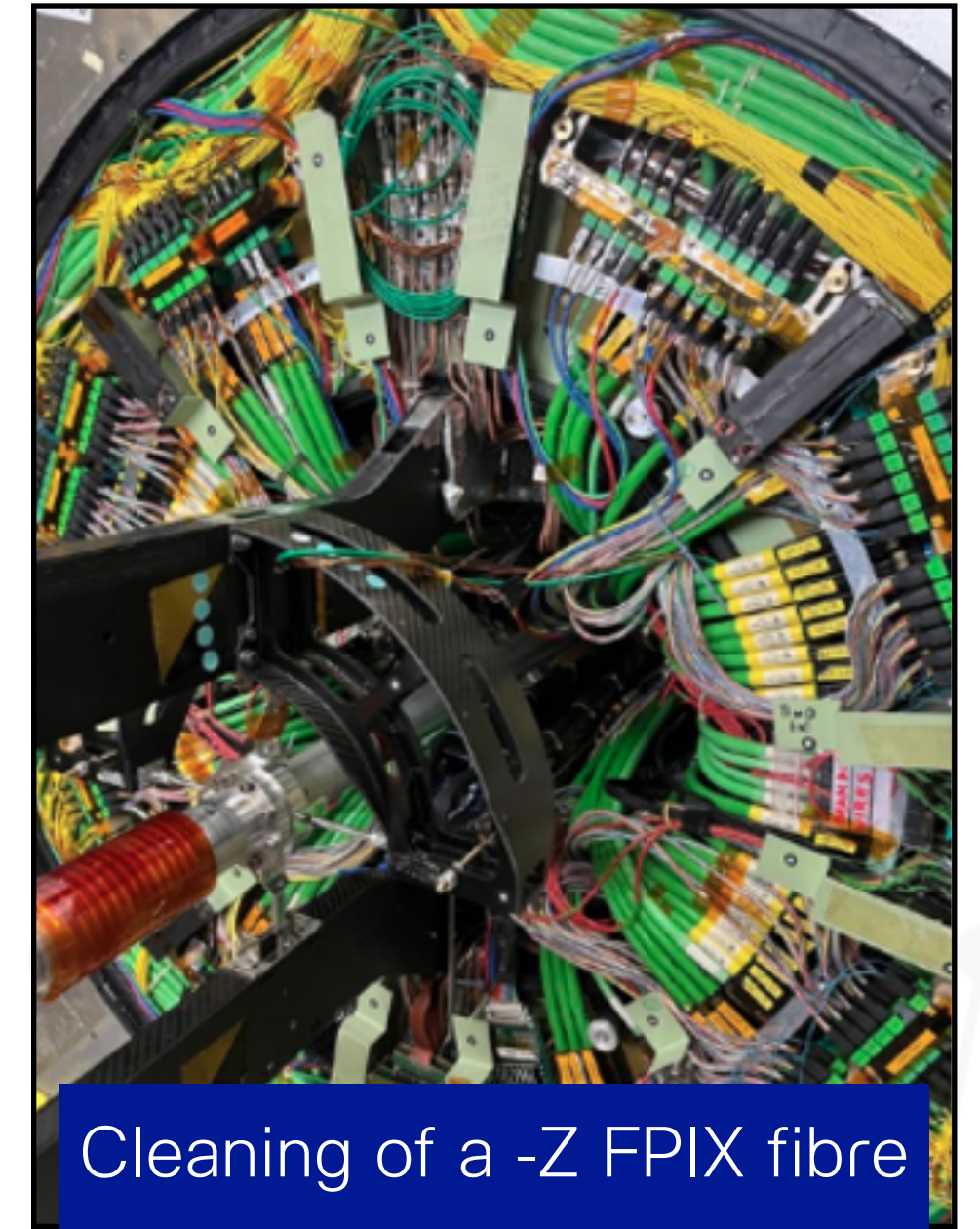
RPC (Barrel) Leak Repair

PPS: Rotation by 27 degrees of all horizontal Roman Pots



PPS in tunnel

- Smooth operations during data taking in 2024
- Maintenance projects conducted during YETS 2024-2025
 - Opening of the -Z pixel bulkhead for BRIL work and opportunistic cleaning of a -Z FPIX fibre
 - Bulkhead region since flushed and now resealed
 - Humidity is now under control. Dew points are back to nominal.
- Further activities during YETS 2024-2025
 - Pumps replaced in both strips cooling plants (SS1/2)
 - An SS2 pneumatic line unclogged
 - EP/DT replacement of all I/O cards of BPIX & FPIX cooling plants
 - Refurbishment of strips VME controllers

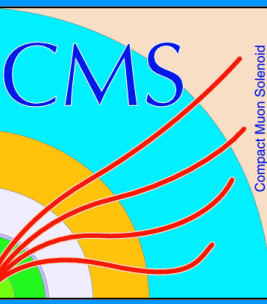


Cleaning of a -Z FPIX fibre



VME controllers

Electromagnetic Calorimeter (ECAL)

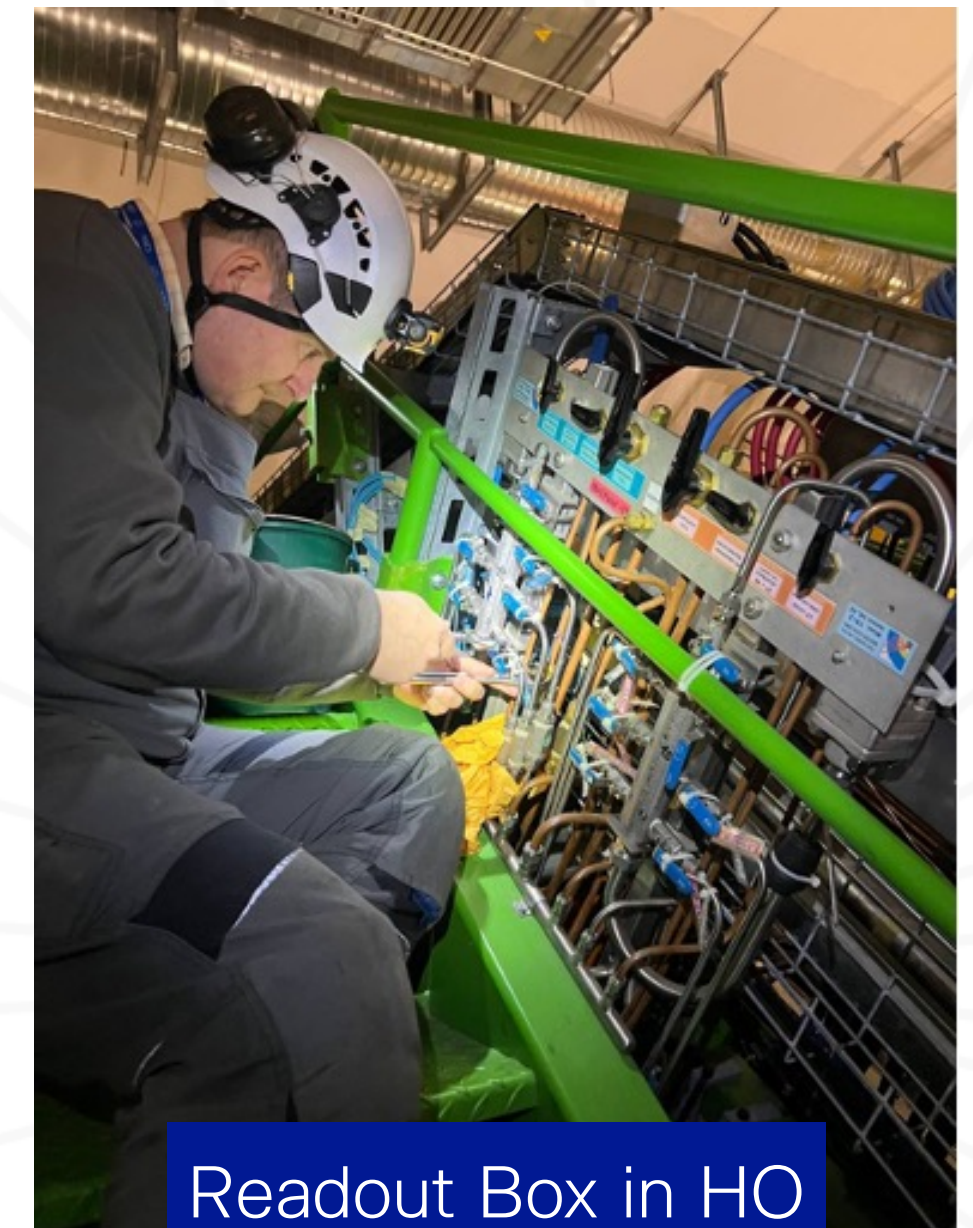


- Smooth operations during data taking in 2024
- Preparations for 2025 data taking in full swing
 - ECAL Barrel HV calibration finished, extensive unmasking campaign
- Improvements to cope with increasing noise and ensure smooth operations in 2025
 - Updated noise prediction for 2025 — well understood
 - Increased ECAL Barrel zero suppression (ZS) thresholds, updating Spike Killer threshold, and new L1 Zero-Suppression threshold on ECAL trigger primitives at 1 GeV
- Plan to continue frequent conditions & calibration updates to maintain stable performance
 - Improvements in automation workflow planned



ECAL shifts during 2024

- **Smooth operations during data taking in 2024**
 - Automatic recovery mechanism for solving minor issues worked effectively reducing data loss due to HCAL compare to previous years.
 - New laser data were taken and HB and HE radiation damage studies resumed.
 - The ZDC system collected PbPb data with improved capabilities to observe 1n/2n peaks.
- **YETS 2024-2025, efficiently follow up a list of issues registered during 2024**
 - Focus on replacing some next generation Clock & Control Modules (ngCCMs) and Readout Modules (RM) on HB-M side as well as for HF.
 - Cooling issue of one of the Readout Box (RBX) in HO is still being investigated.
 - ZDC* and QIE* crates were moved to the surface as planned.



Readout Box in HO

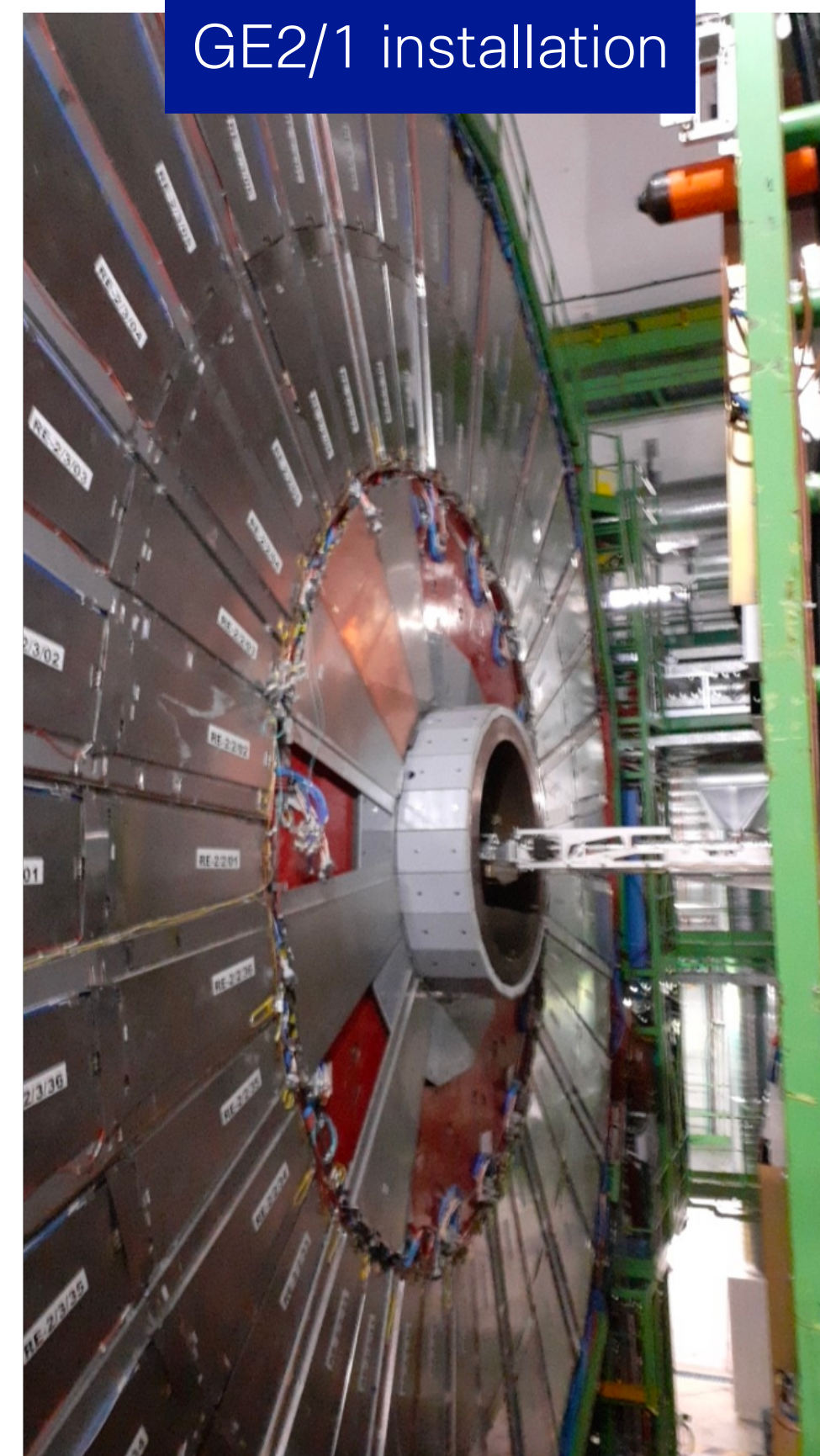
- Smooth operations during data taking in 2024
- New chambers in the high eta region during YETS:
 - 4 GE2/1 chambers installed and commissioned
 - Two iRPC stations installed (details later)
- OTMB optical upgrade for ME3/1 and ME4/1 stations completed



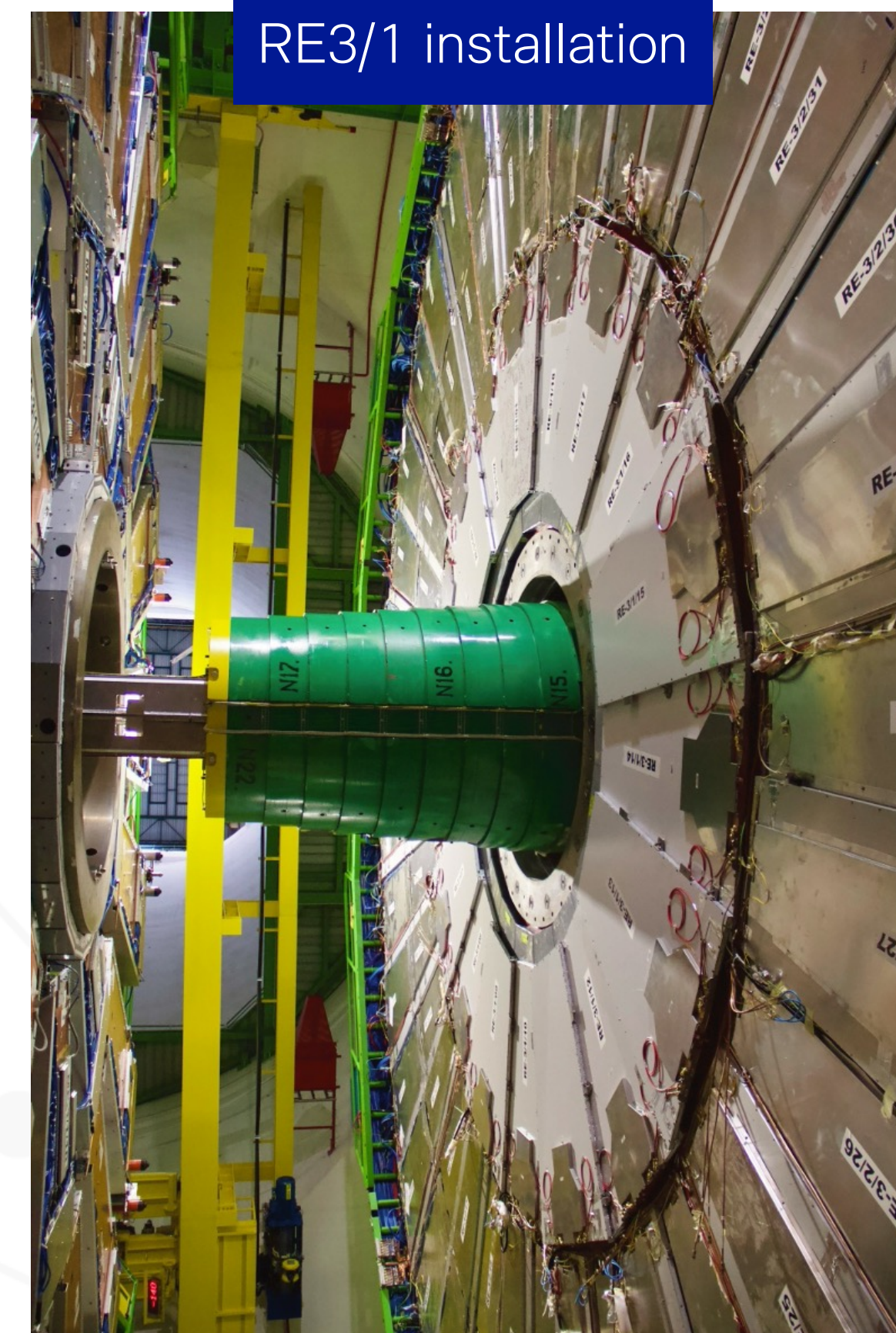
OTMB optical upgrade

- Maintenance during YETS

- 6 leaking RPC chambers repaired and 20 chambers recovered
- 1 DT chamber repaired addressing the gas connector issue left unplugged last year



GE2/1 installation

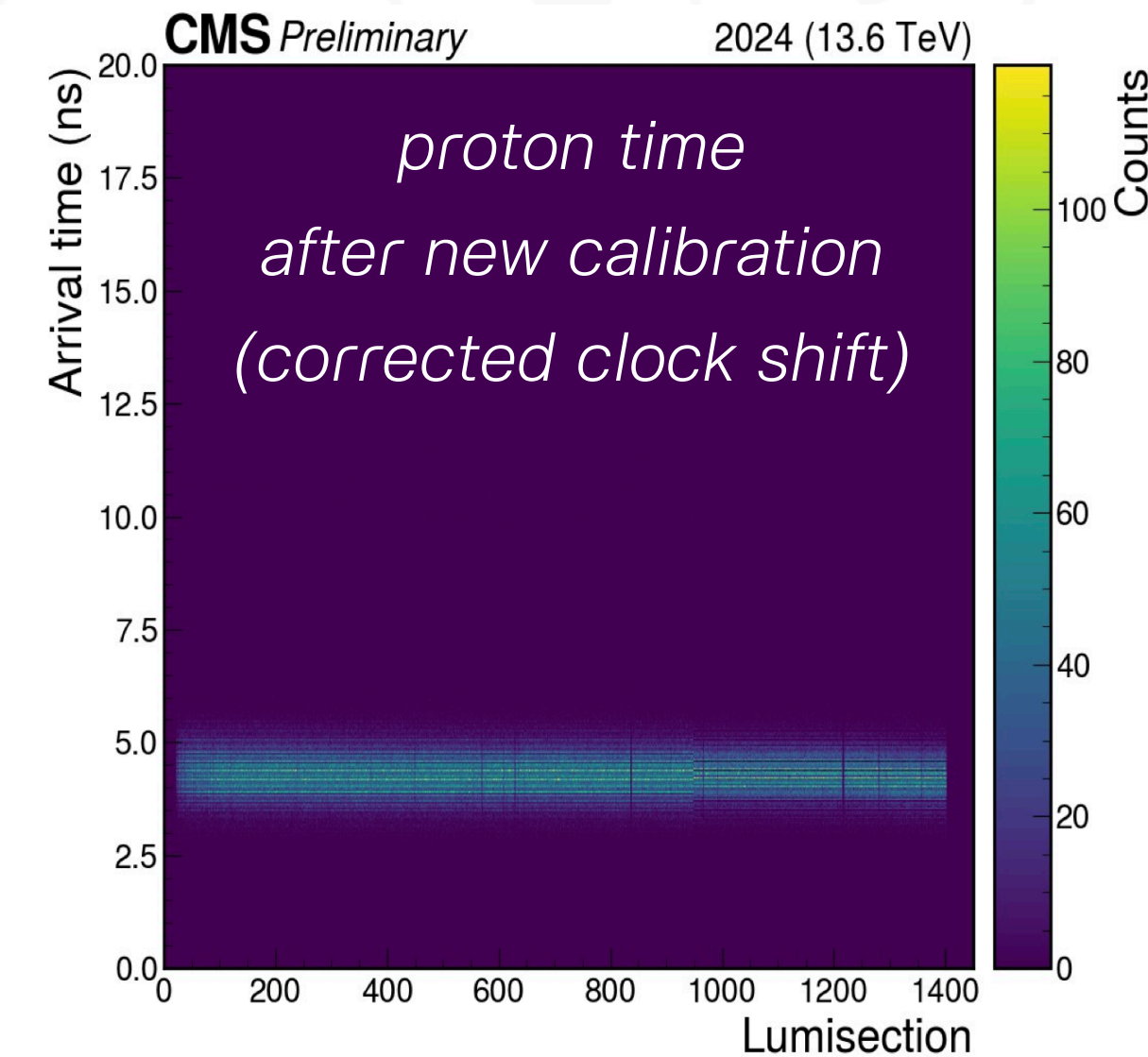
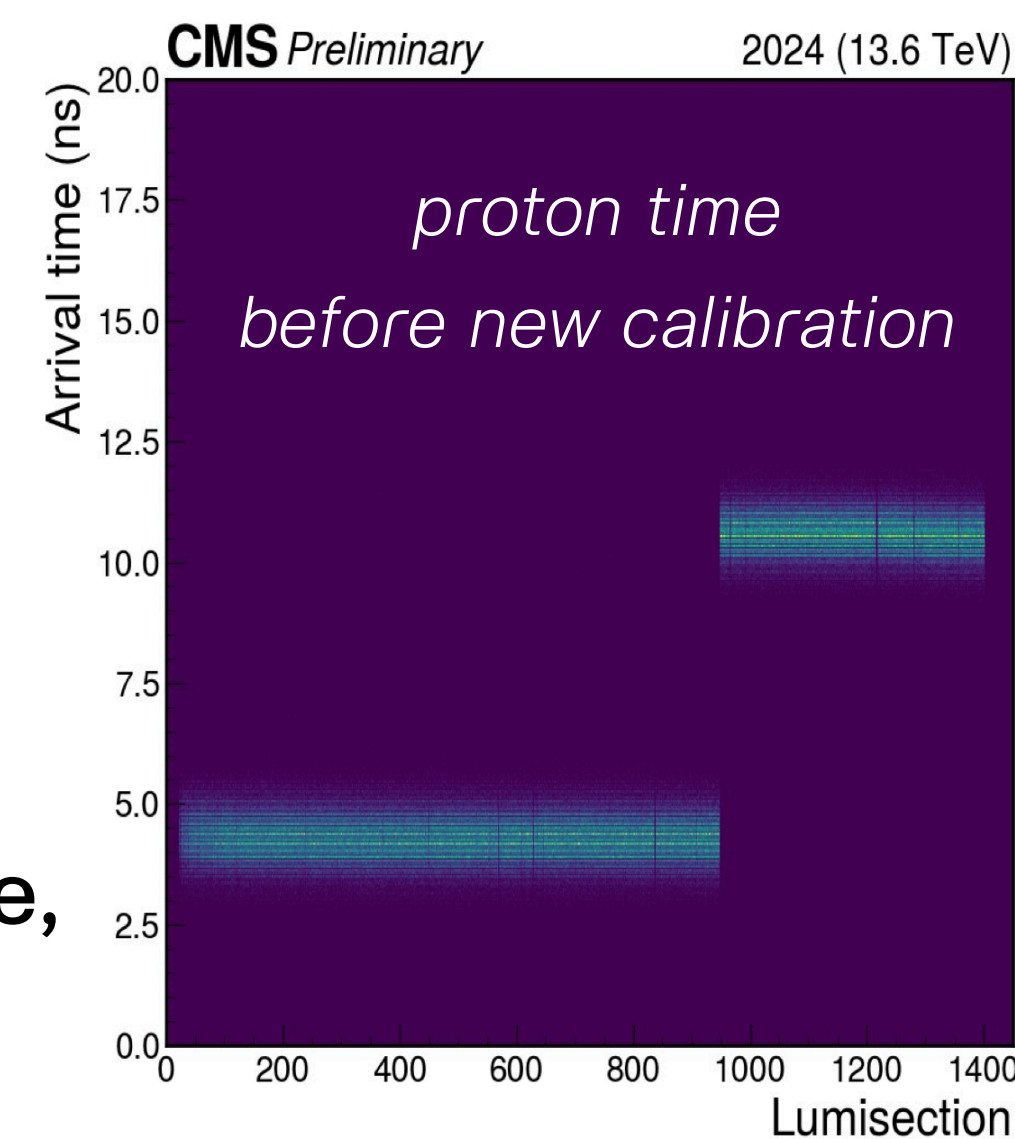
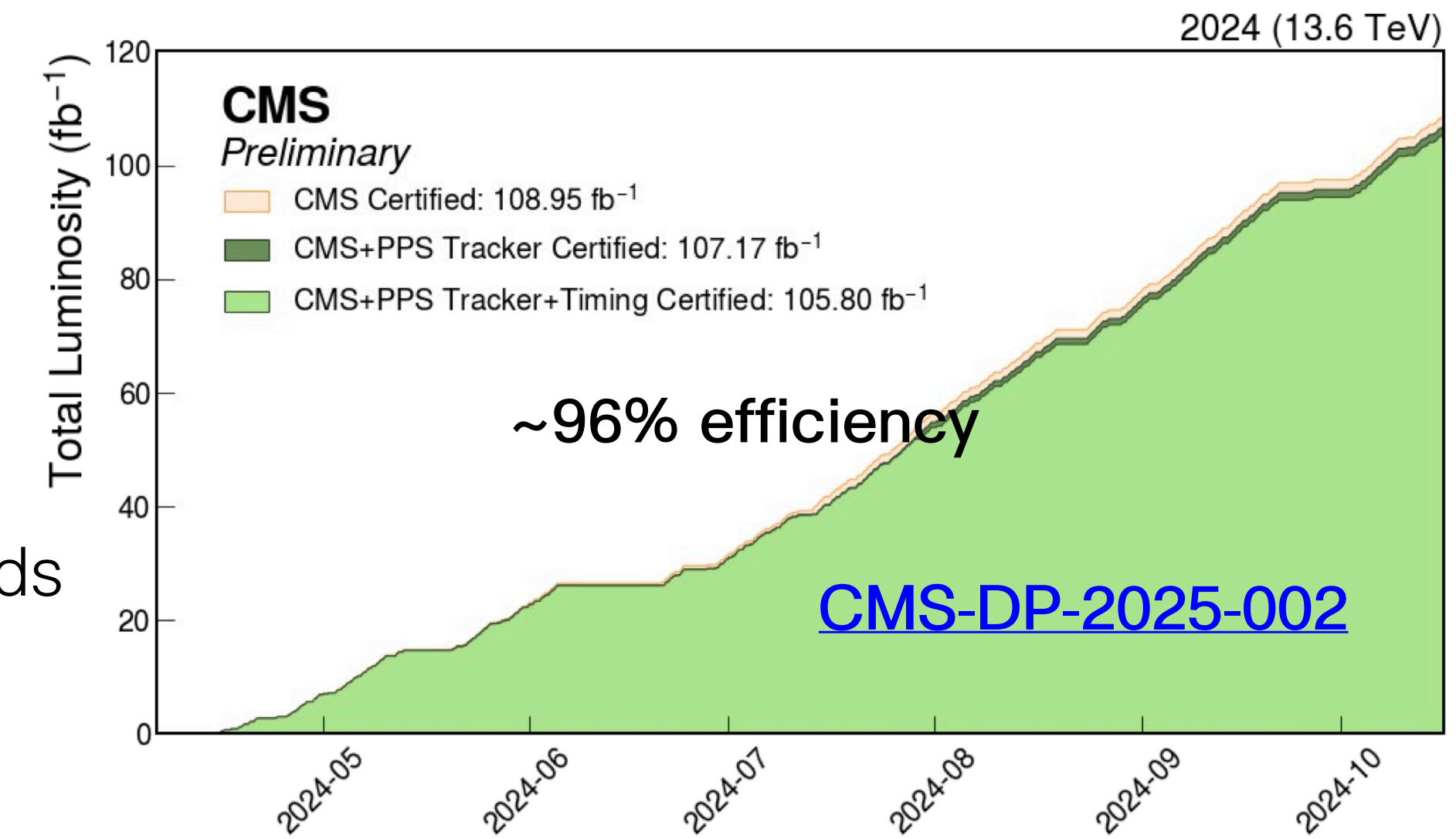


RE3/1 installation

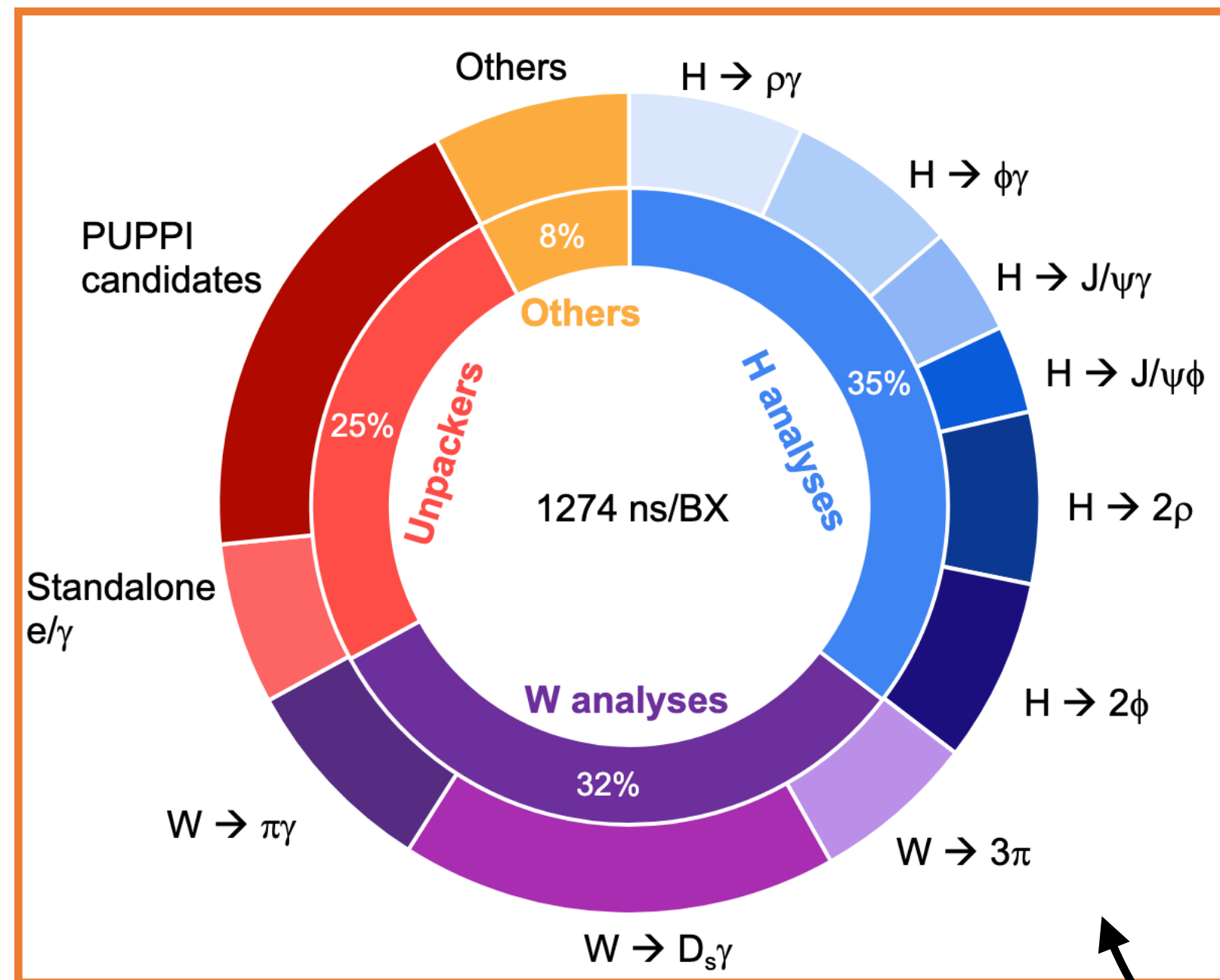
Precision Proton Spectrometer (PPS)



- PPS detector performance in 2024
 - $>105 \text{ fb}^{-1}$ with Roman Pots inserted in certified runs in 2024
- Extensive work on timing detectors
 - LEDs used to mitigate inefficiencies due to polarization in diamonds
 - Automated calibration procedure improved, taking into account occasional clock shifts
 - Measured 47 ps/proton resolution in special calibration runs
- Major effort to prepare for vertical crossing angle
 - Rotation of RPs to 27 degrees angle required to preserve acceptance
- New geometry implemented in reconstruction software, in preparation for start of 2025 run



Level-1 Trigger (L1T)

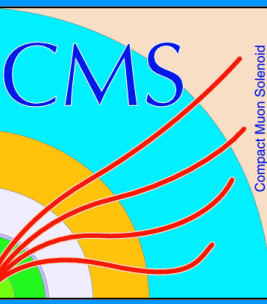


Phase 2 L1 Scouting Demonstrator System

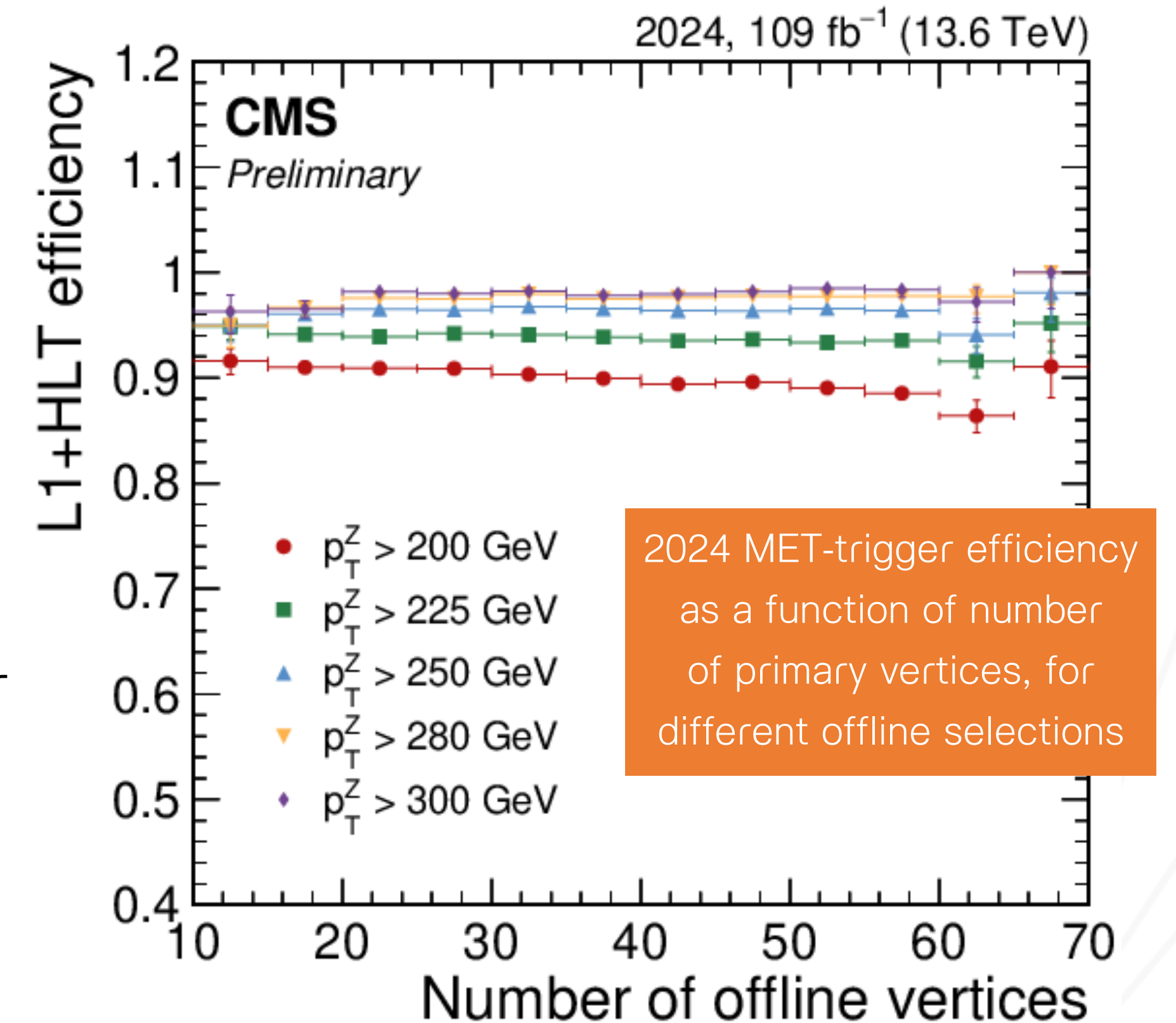
Distribution of the CPU time to run analyses of Higgs and W rare decays on AMD EPYC 9654 processor

- **CMS L1 Trigger (L1T) worked smoothly throughout 2024**, with very low data losses, even when including issues linked to other subsystems
- **Only minor changes are planned for 2025**, mainly to update calibrations for better stability
- **Anomaly detection triggers (CICADA and AXOL1TL)** are being improved to handle pileup and detector changes better, while still catching a wide range of physics signals
- **New MLOps and Calibrations teams** are being set up to keep performance high in the last years of Run 3 and get ready for Phase 2
- Full integration of Next Generation Trigger (NGT) workforce in the group through both core roles and R&D towards **Phase 2**:
 - [MLOps pipelines for AXOL1TL](#)
 - [Demonstrators of real-time analysis for scouting system](#)
 - New ML-based algorithms for objects/events reconstruction and identification in CTL2 (including anomaly detection)
 - Investigation of novel AI accelerators (e.g., AMD Versal AI Engines) to augment scouting system

High Level Trigger (HLT)

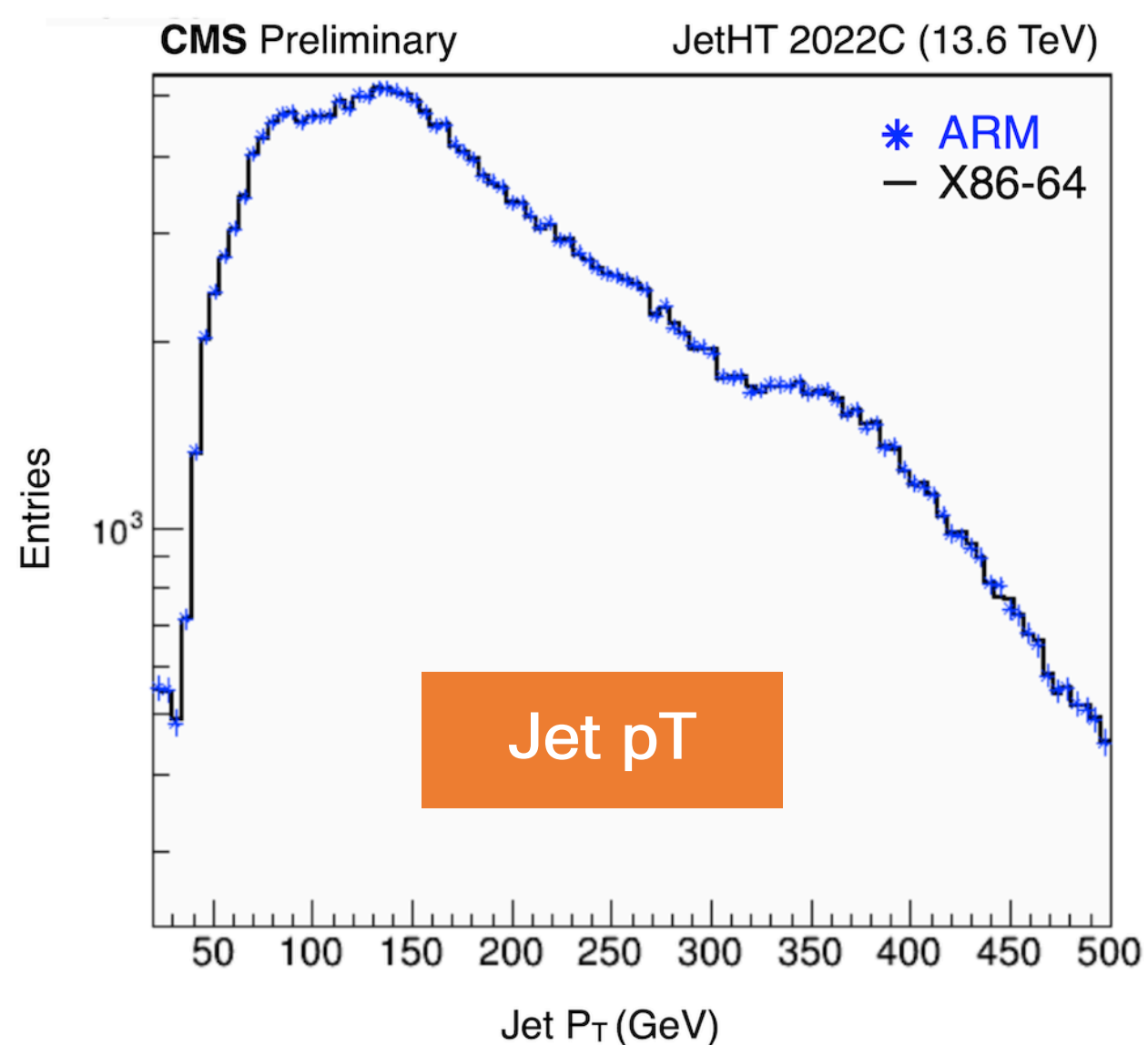
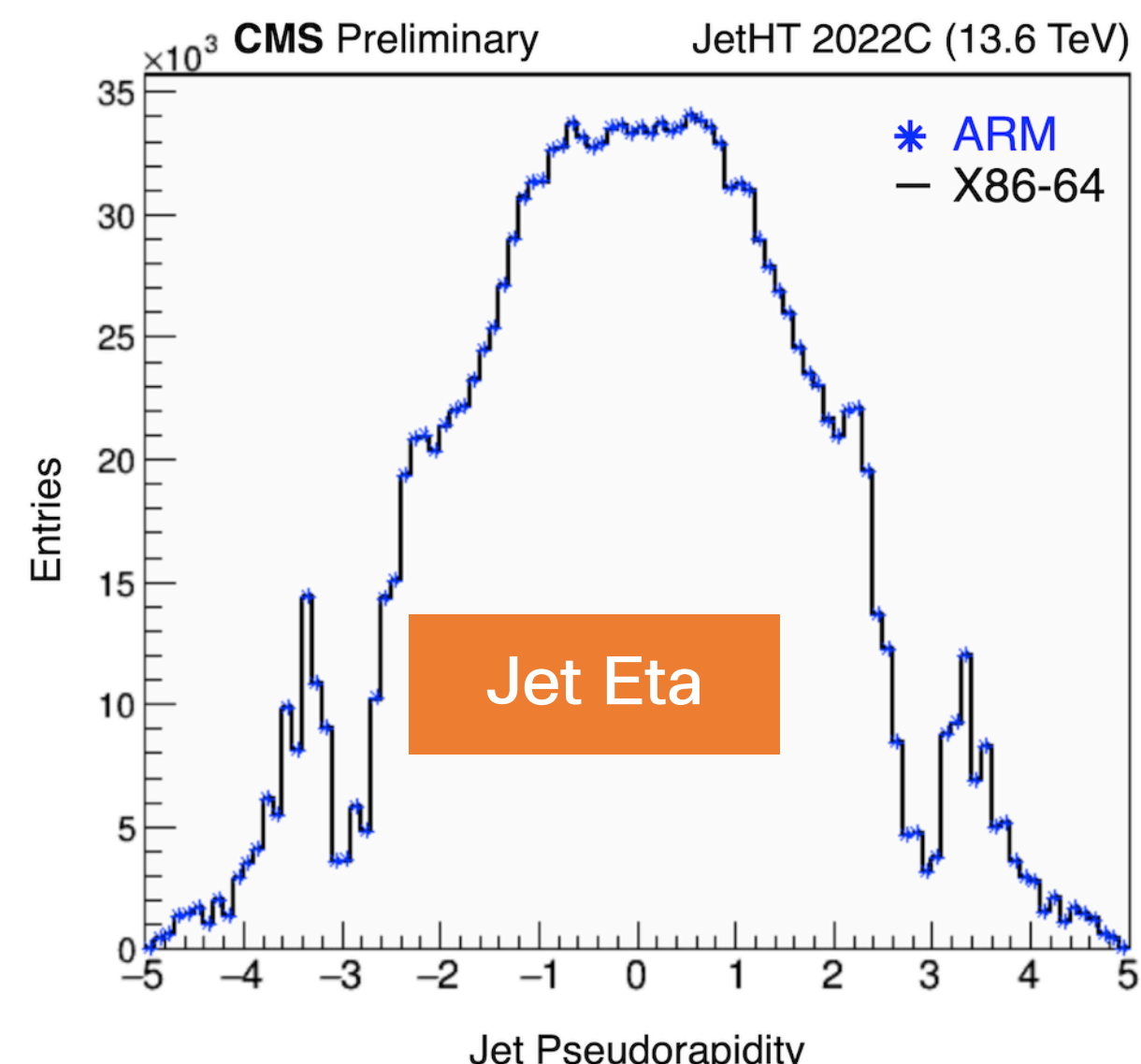


- Smooth data-taking at HLT throughout 2024
- Good performance of the online reconstruction in 2024
- Preparations for the 2025 pp trigger menus well underway
 - Trigger strategy similar to 2024
 - Several improvements to the online reconstruction to further improve performance under 2025 conditions
 - Work ongoing to offload to GPUs more parts of the online reconstruction
- Paper on the HLT performance in Run 2 published in JINST in late 2024 ([CMS-TRG-19-001](#))



Performance of missing energy (MET) triggers in 2022, 2023 and 2024 ([CMS-DP-2025-007](#))

CMS Computing with ARM CPUs



*ARM = Advanced RISC Machine

*RISC = Reduced Instruction Set Computing

- **Why is CMS interested in ARM* CPUs?**

- ARM offers a **cost-effective, energy-efficient alternative** for computing.
- Surveys indicate its growing adoption in HPCs and commercial clouds, with increasing interest from WLCG sites.
- CMSSW must adapt to this transition and fully utilize this architecture.

- **Validation Status:**

- Last validation in October 2024 using 2022–2023 data reprocessing at CNAF ARM.
- Excellent agreement observed across all detector and physics groups.
- CMS approved ARM in November 2024.

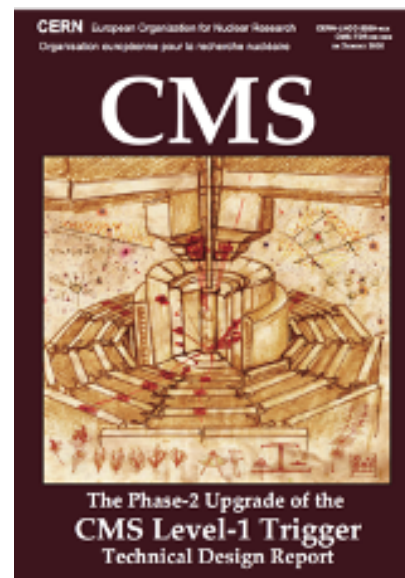
- **Future Plans:**

- ARM pledges plan to be accepted in 2026 with the new ROOT version (6.34+).
- Large-scale testing to continue using opportunistic resources.

A photograph showing two technicians in white hard hats and safety gear working inside a large, circular particle accelerator tunnel. They are positioned on a green scissor lift platform. The tunnel walls are metallic and feature various labels, including 'RE-4/1/11' and 'RE-4/1/14'. A large, clear, cylindrical component is visible in the upper left. The scene is brightly lit, and the overall atmosphere is one of industrial precision and technical work.

Towards HL-LHC

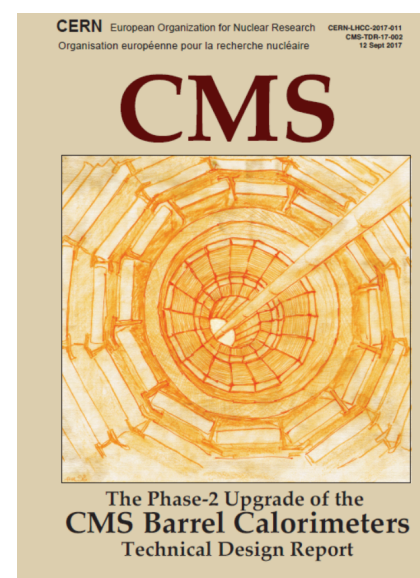
CMS Upgrade Catalogs



L1-Trigger

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

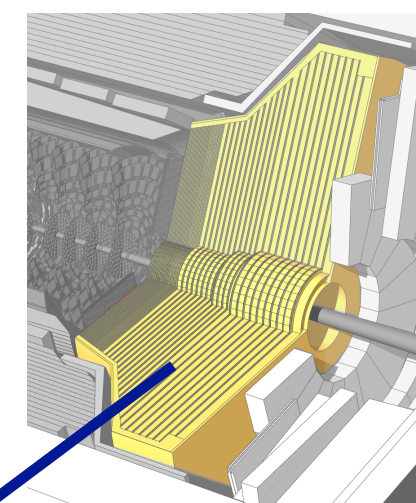
- Tracks in L1-Trigger at 40 MHz
- Particle Flow selection
- 750 kHz L1 output
- 40 MHz data scouting



Barrel Calorimeters

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

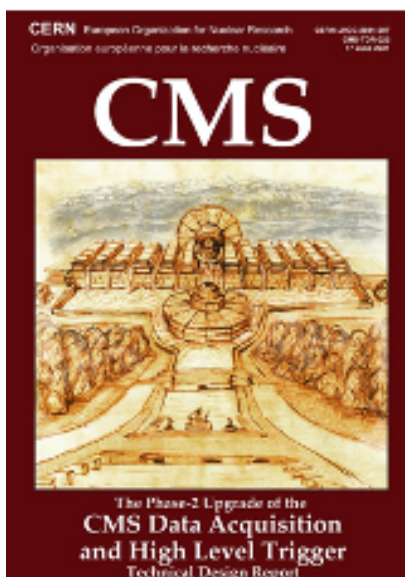
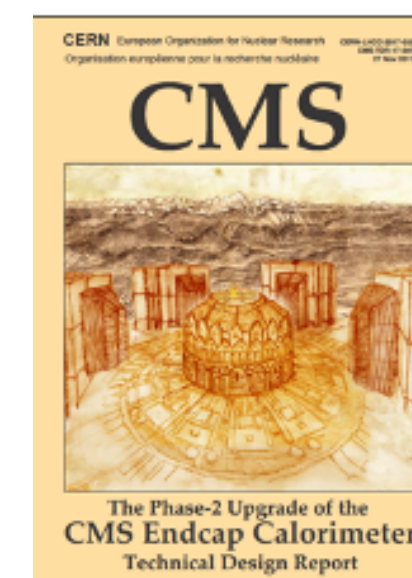
- ECAL crystal granularity readout at 40 MHz with precise timing for e/γ at 30 GeV
- ECAL and HCAL new Back-End boards



Calorimeter Endcap

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

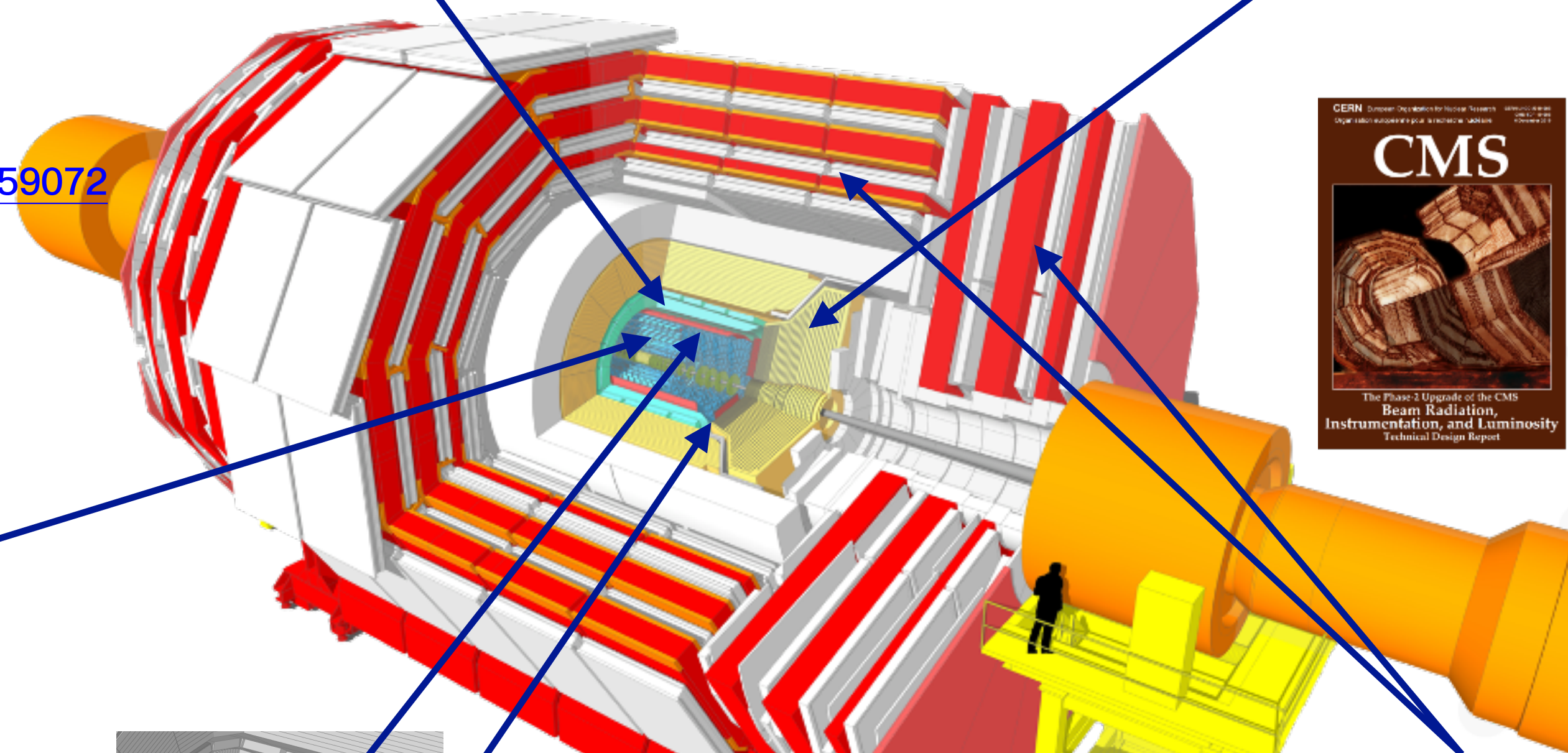
- 3D showers and precise timing
- Si, Scint+SiPM in Pb/W-SS



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



Beam Radiation Instr. and Luminosity

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

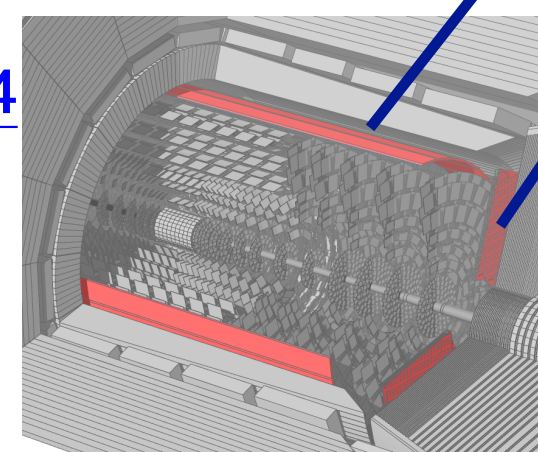
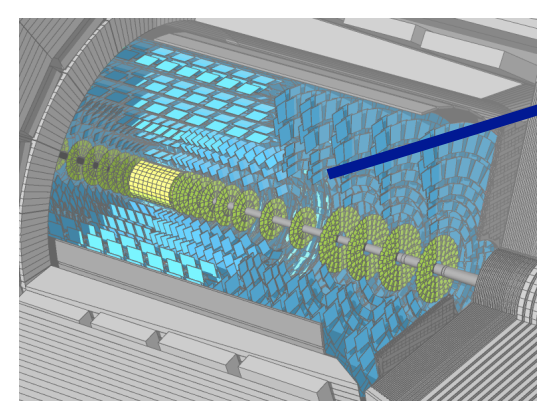
- Beam abort & timing
- Beam-induced background
- Bunch-by-bunch lumi: 1% offline, 2% online
- Neutron and mixed-field radiation monitors



Tracker

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

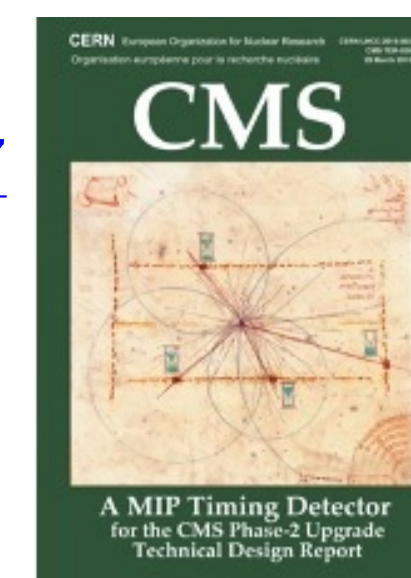
- Si-Strip and Pixels increased granularity
- Design for tracking in L1T
- Extended coverage to $\eta \approx 3.8$



MIP Timing Detector

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

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

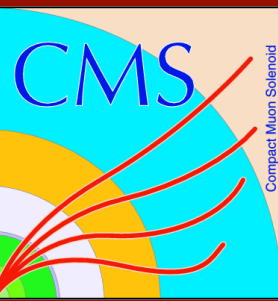


Muon systems

<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 $\eta \approx 3$

Infrastructure Highlights



Focus on the installation of the CO₂ cooling infrastructure and the Main Transfer Lines (MTL)

- Already installed: two 2PACL units, five accumulators, nine distributions manifolds
- However, manifolds were removed and sent back to company for improved cleaning



IKEA2 storage hub & crane



New hypoxic air plant @ SXS5



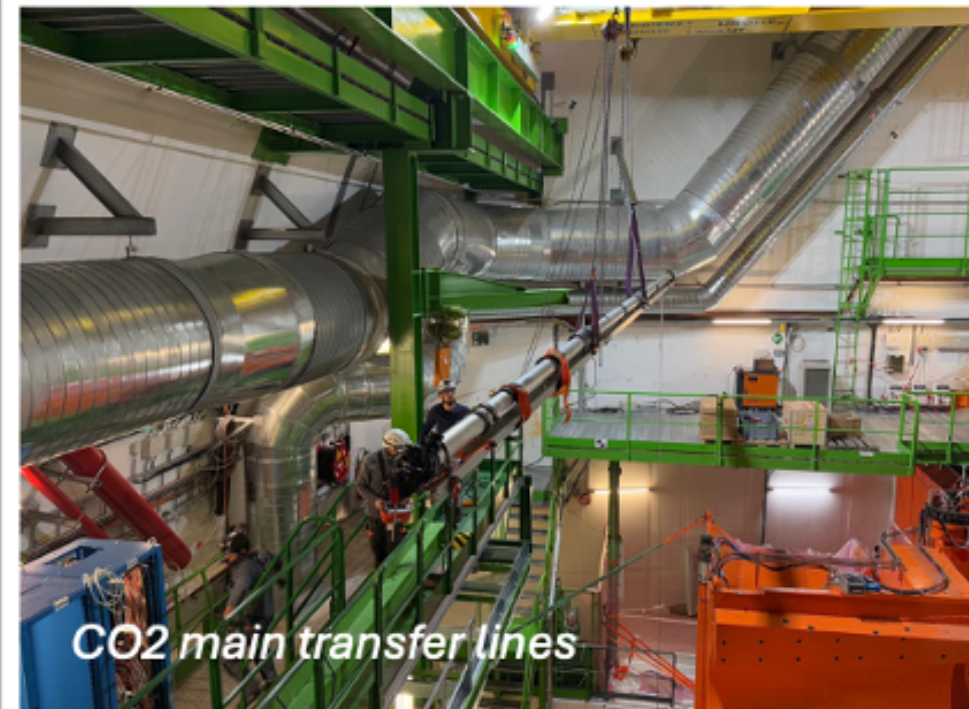
New DAQ room



2PACL CO₂ plant #2



Accumulator for 2PACL CO₂ #1

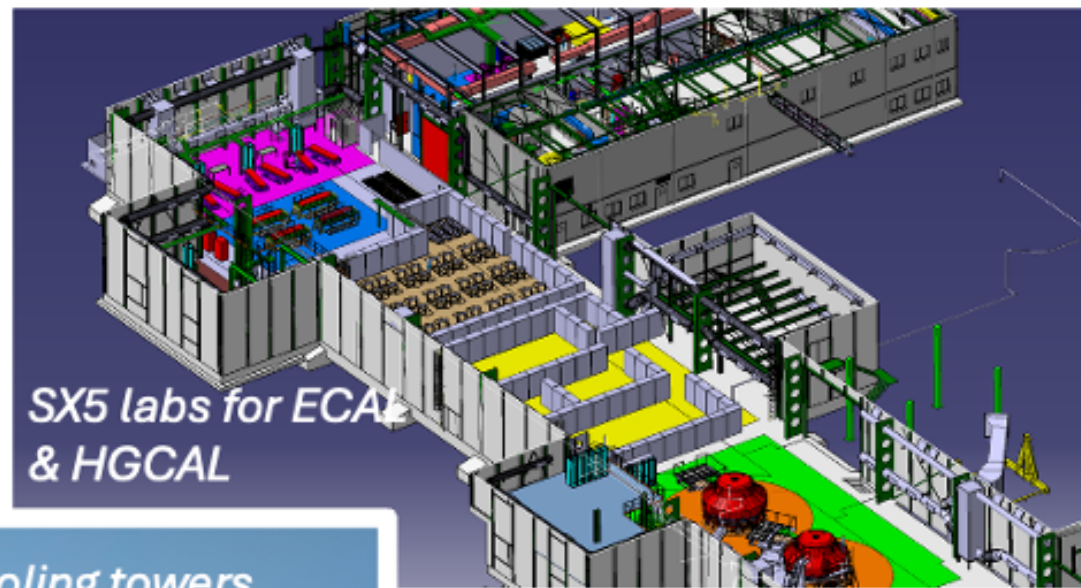


CO₂ main transfer lines



West Slab & RP building -> design-completed

YETS 24-25



SX5 labs for ECAL & HGCAL



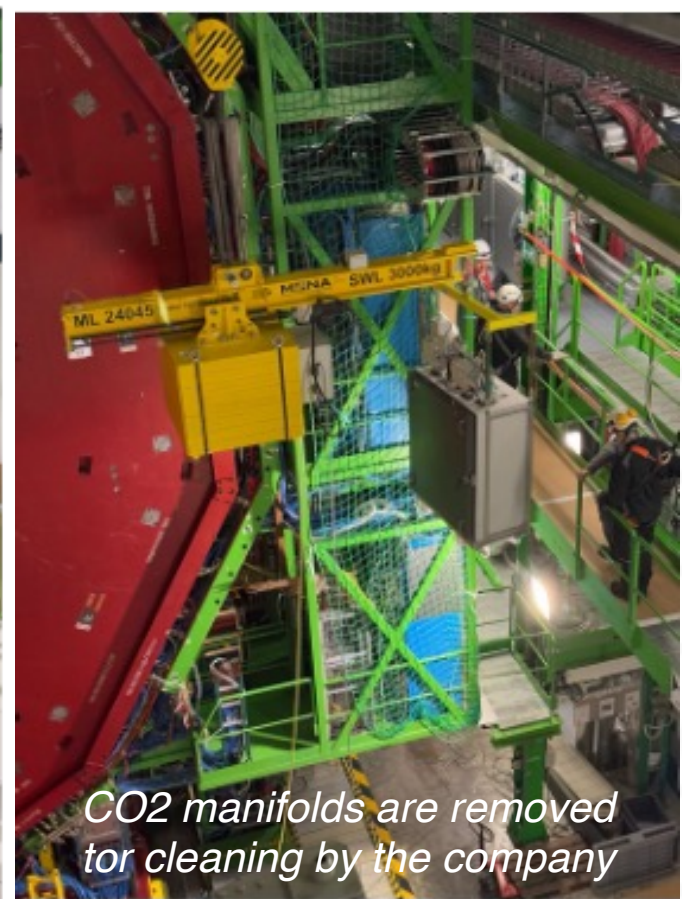
New CMS cooling towers



R744 - 11 slices @ SXS5

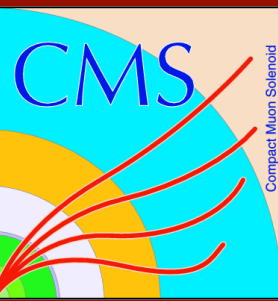


CO₂ main transfer lines

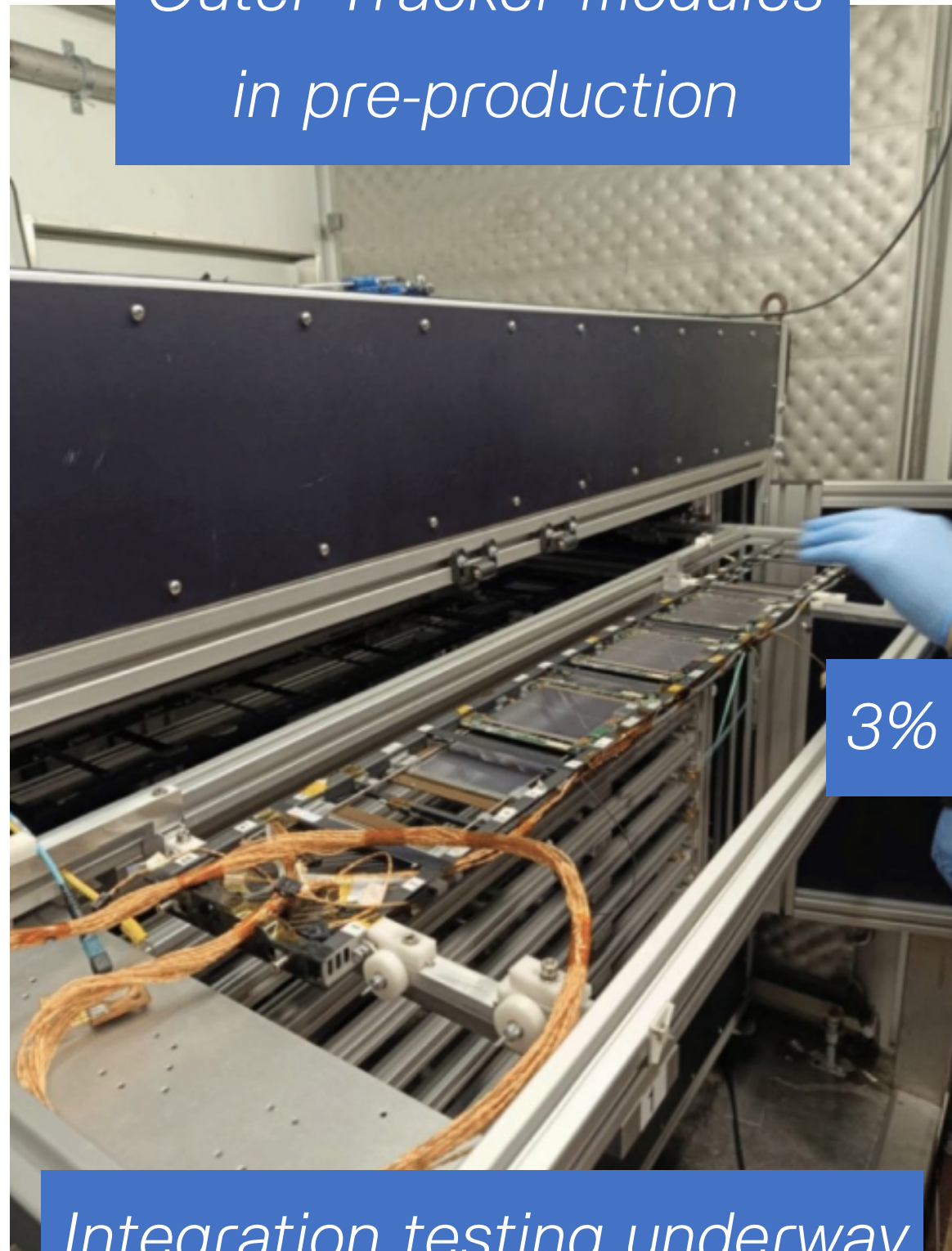


CO₂ manifolds are removed for cleaning by the company

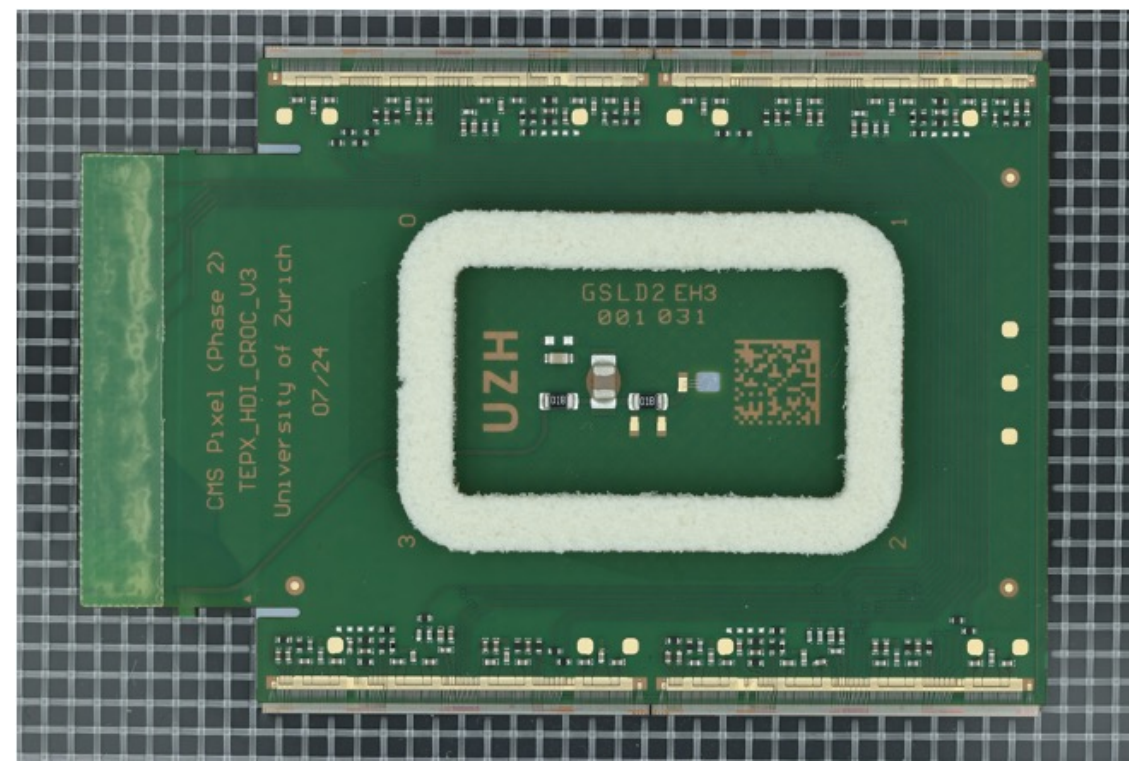
Tracker and MTD Phase 2 Highlights



Outer Tracker modules
in pre-production



Starting Pixel module production



3% of bare bump bonded modules in hand



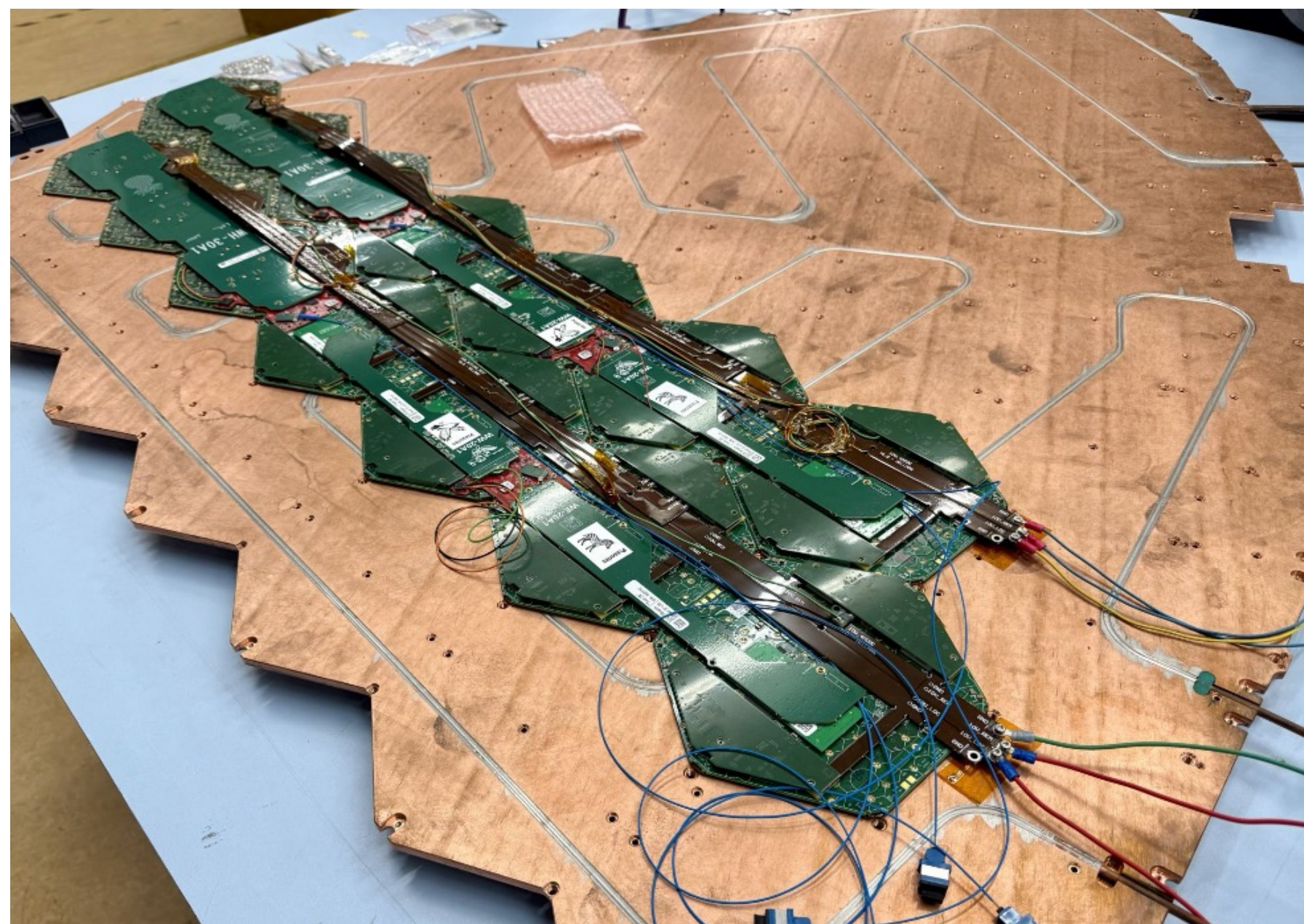
BTL-Tracker Support Tube heating foil gluing
Ready for BTL installation early March

Integration testing underway

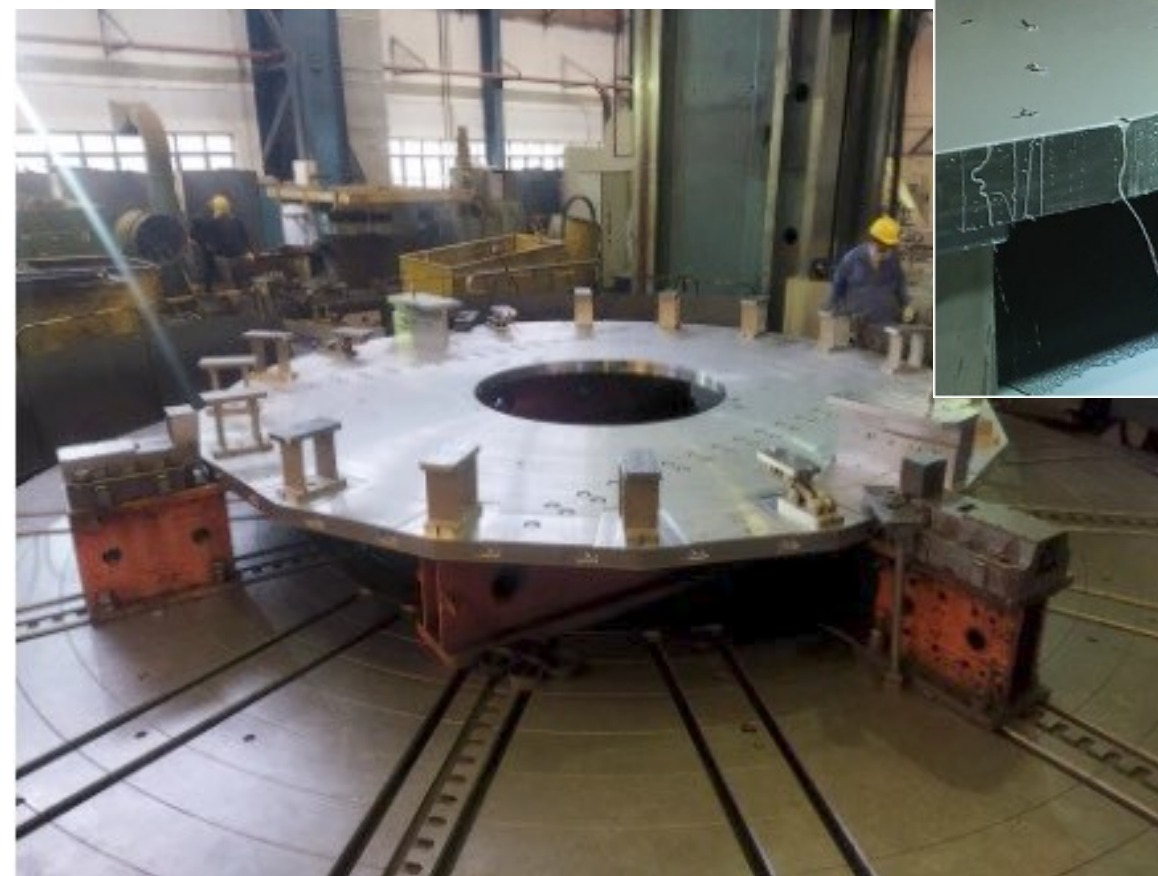


30% of BTL modules done



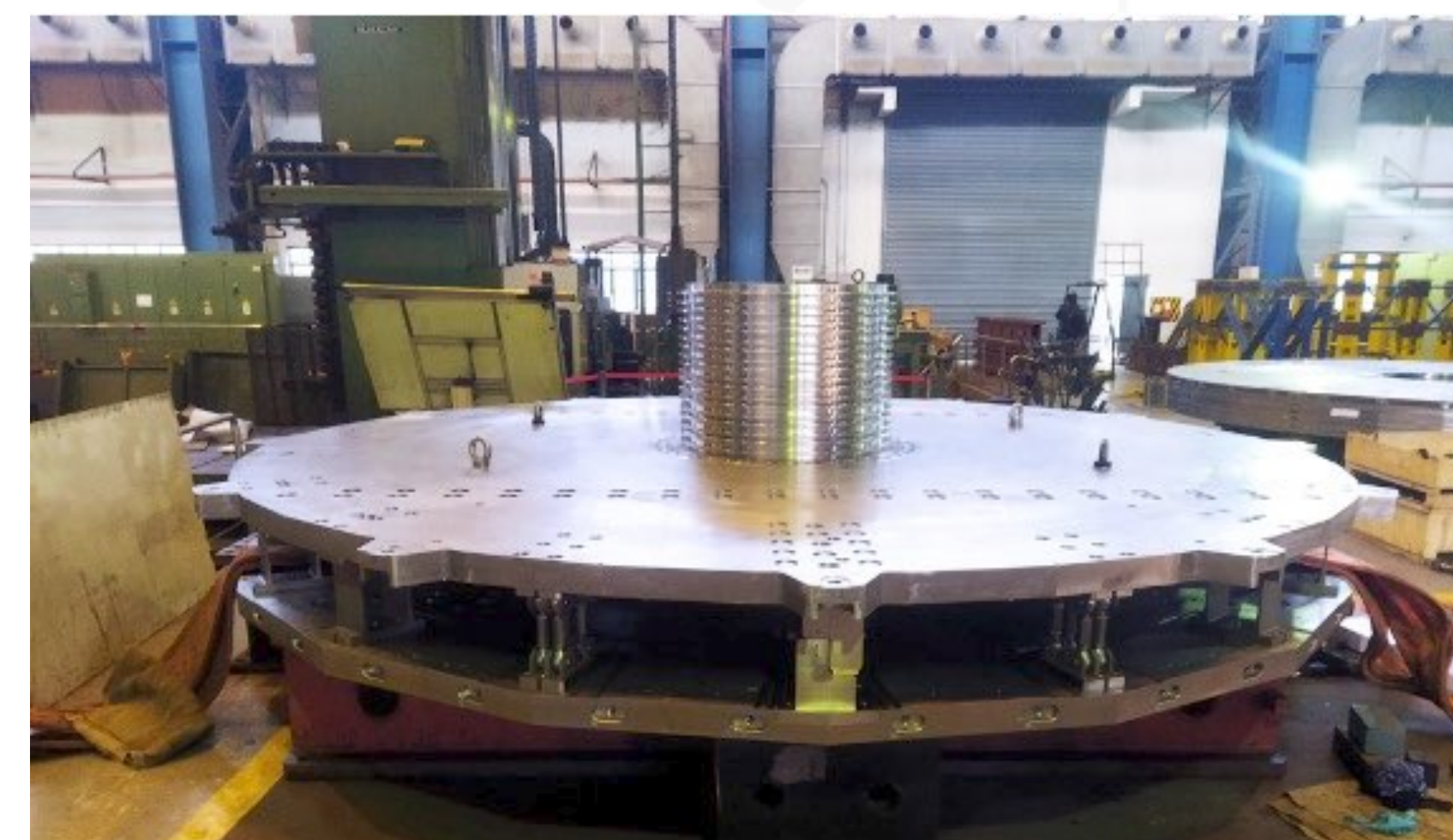


CE-H Absorber



- *For the first time two silicon Low and two High Density trains on a cooling plate*
- *Big step towards integration and system evaluation*

- Machining of full set of one CE-H endcap absorber disks completed in Pakistan
- Pre-assembly of absorber stack underway



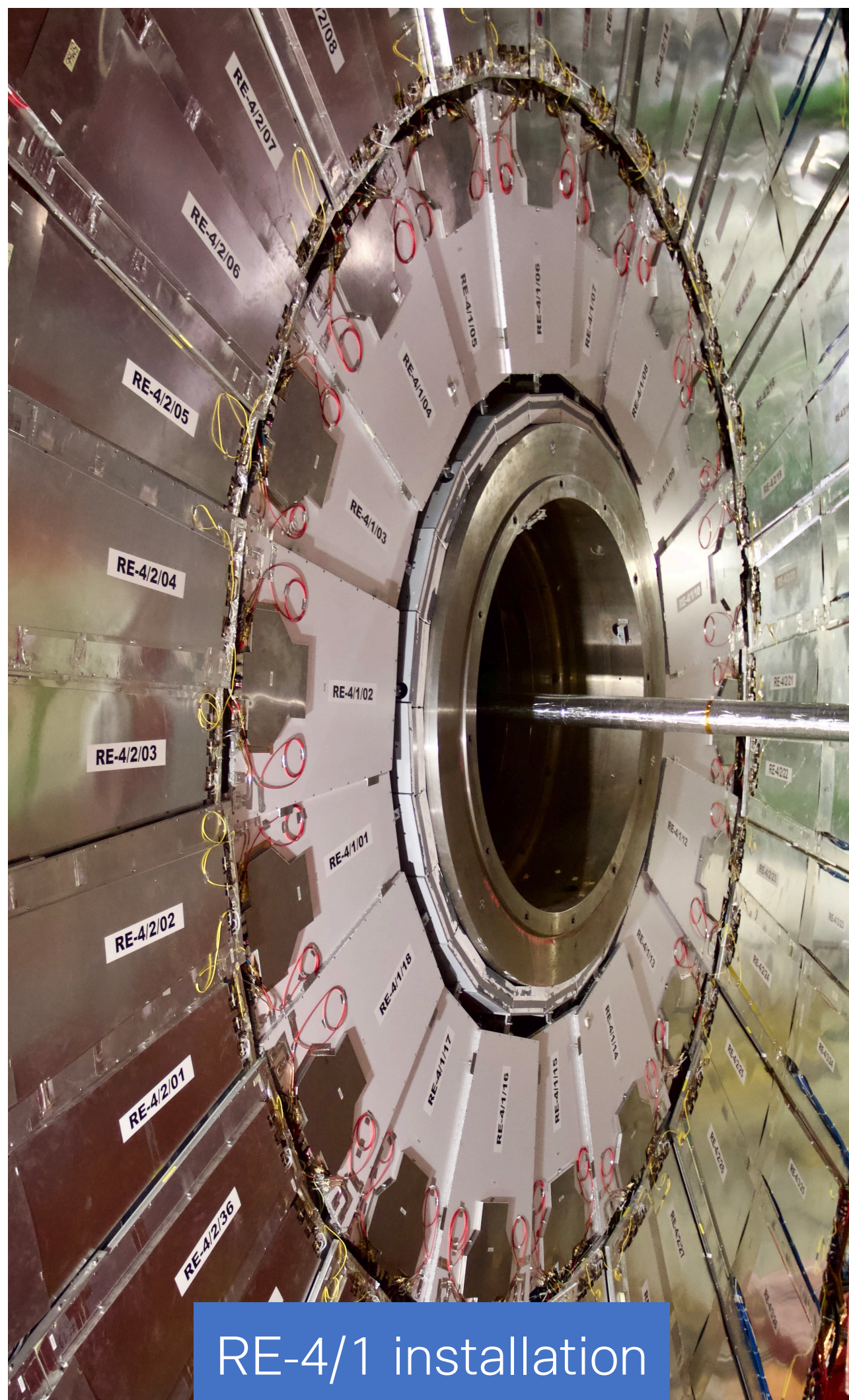
Stacking of back-flange and back-disk with attachment of wedges and support cylinder

Muon Phase 2 Highlights



Installation of the two improved-RPCs (iRPCs) stations on the minus end during YETS 2024-2025

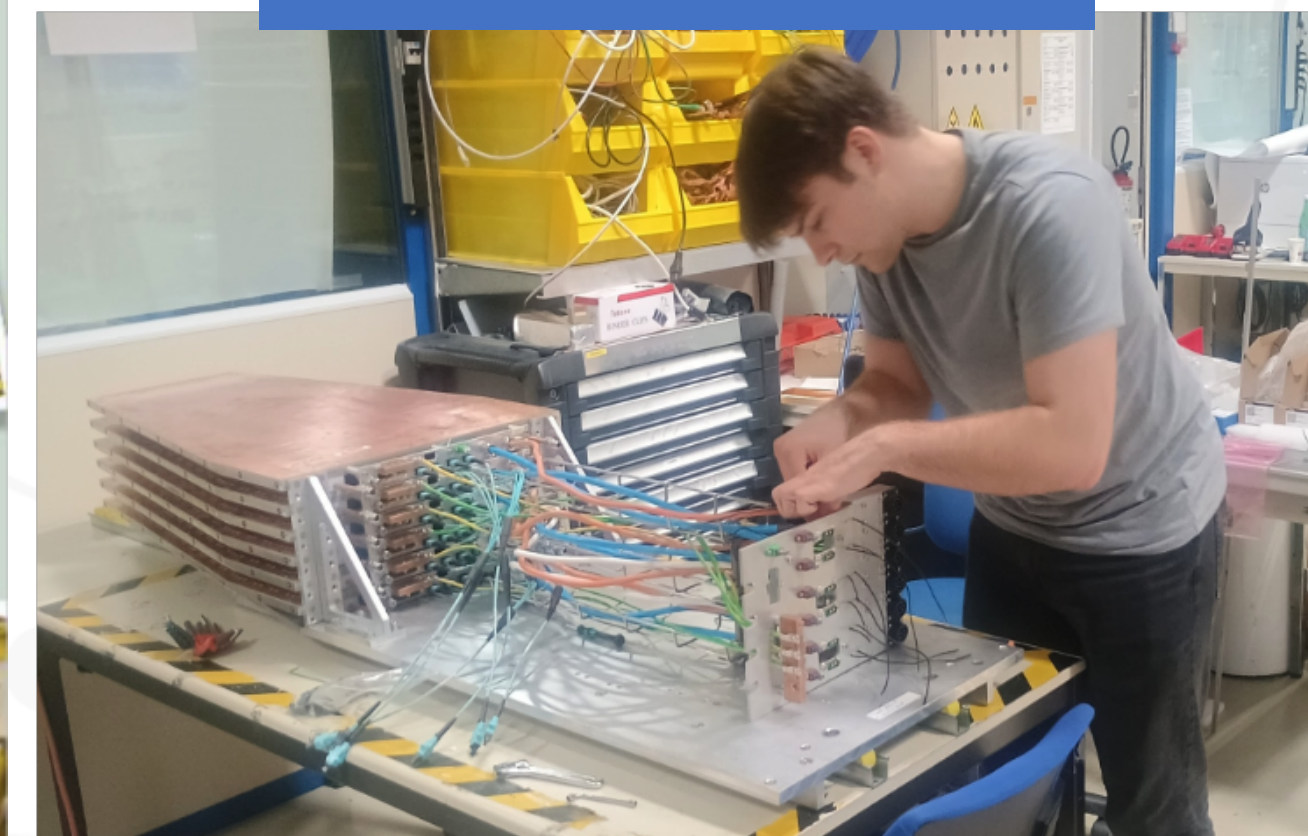
- RE-3/1 chambers installation completed and commissioned
- RE-4/1 chambers installation completed and commissioned



RE-4/1 installation



2nd ME0 (GEM) stack



RE-3/1 installation



The Year Ahead

Thanks to the LHC for outstanding continuous efforts in delivering Run 3 data

Run 3

Maintain best operations throughout the last full year of Run 3

Analysis

Use Run 3 data to continue precision measurements and searches

Hi-Lumi

Prepare for LS3 and hi-Lumi CMS, putting as much in place as possible during 2025

People

Maintain and grow a collaboration of over 6000 people through maximal engagement

Backup



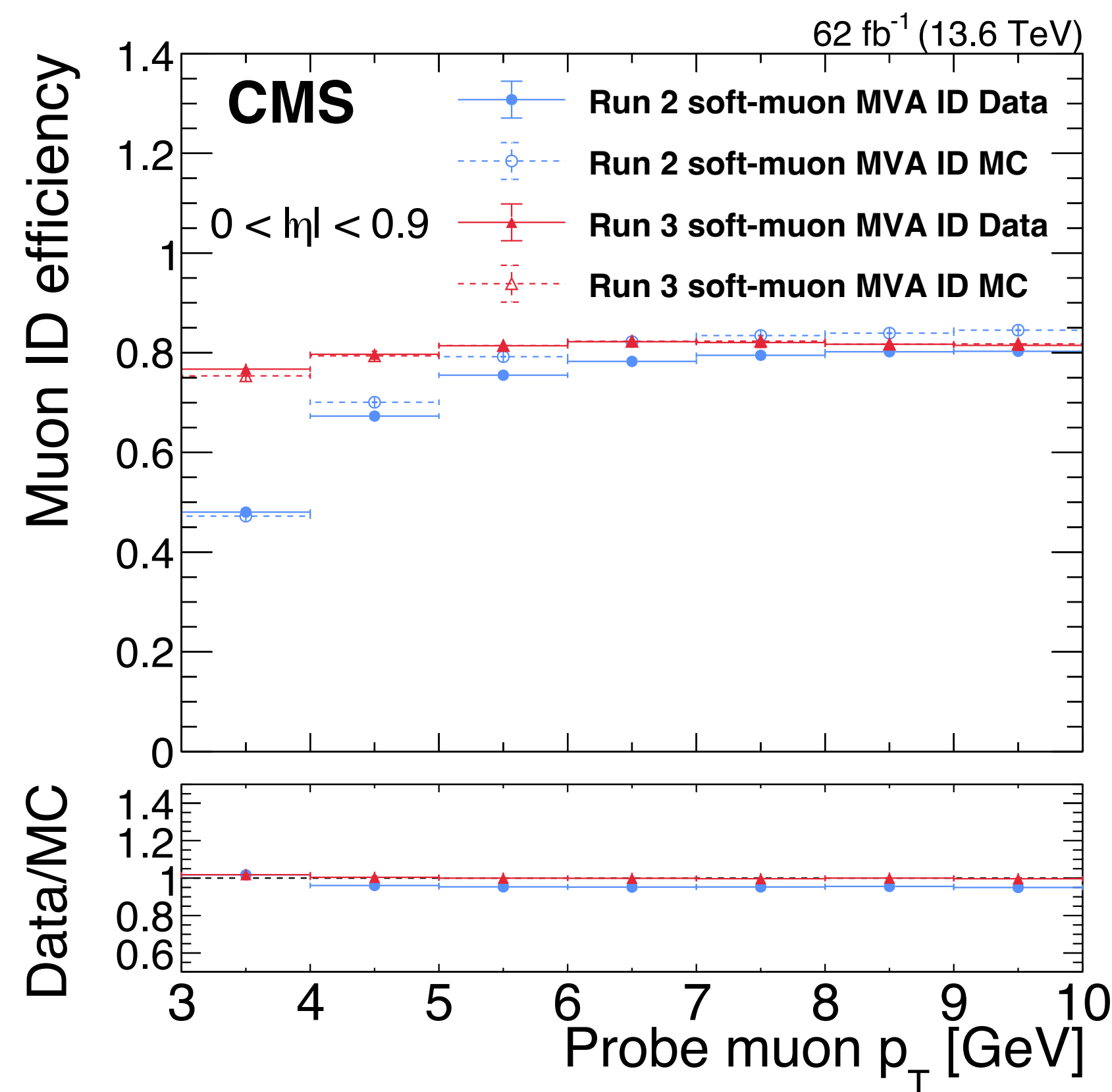
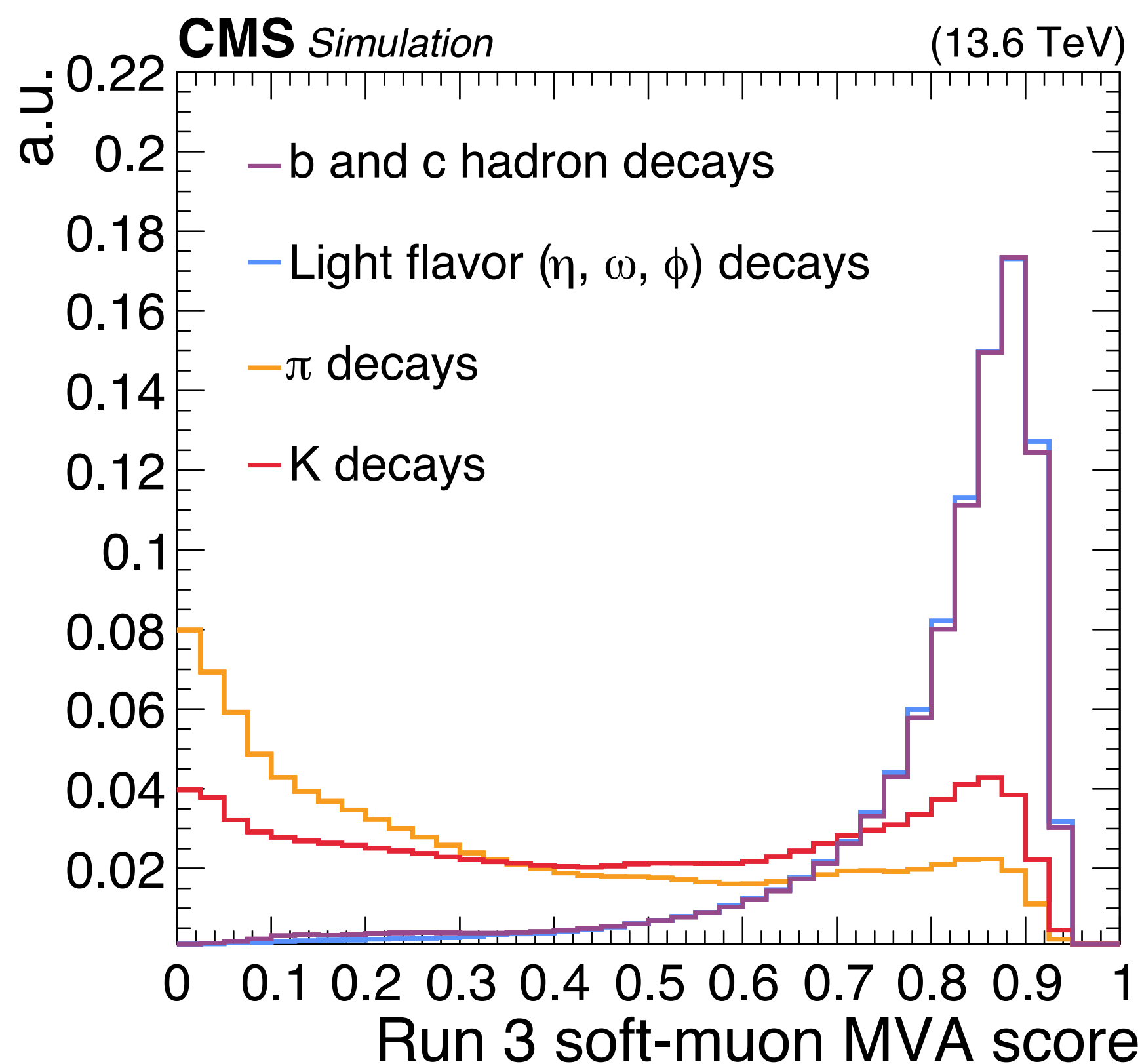
ID of low-momentum muons using MVA technique

MUO-24-001



Identification studies for **soft muons** with $p_T < 10$ GeV

They are featured in many processes such as decays of heavy-flavor hadrons or rare tau lepton decays



Run 3
2022 + 2023 data

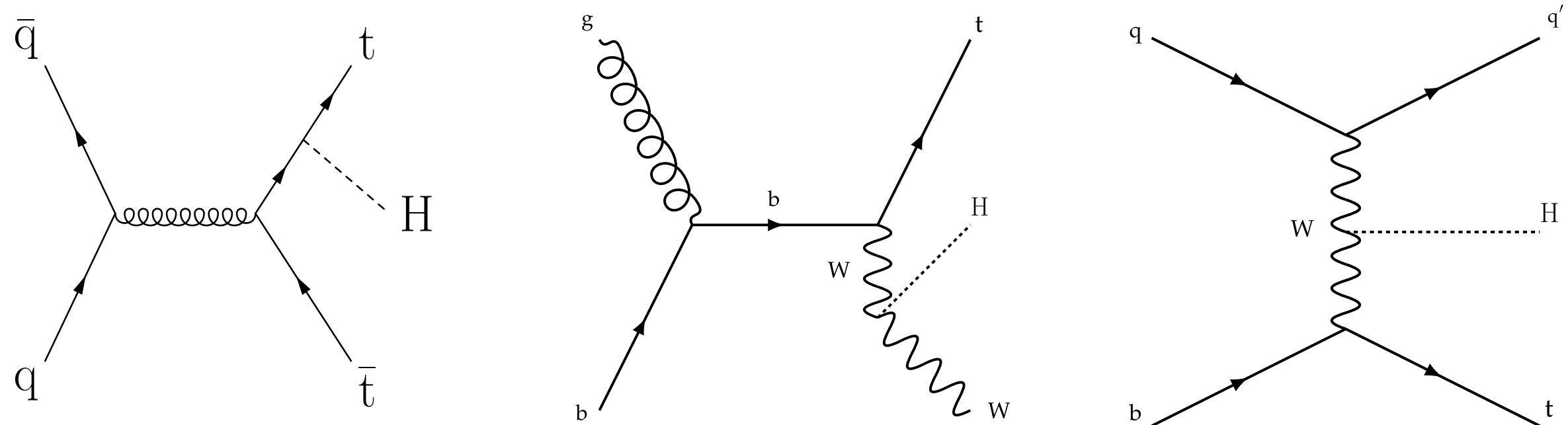
Significant improvements wrt Run 2 MVA ID for a working point with a similar background rate

Differential cross section of ttH production

HIG-23-015

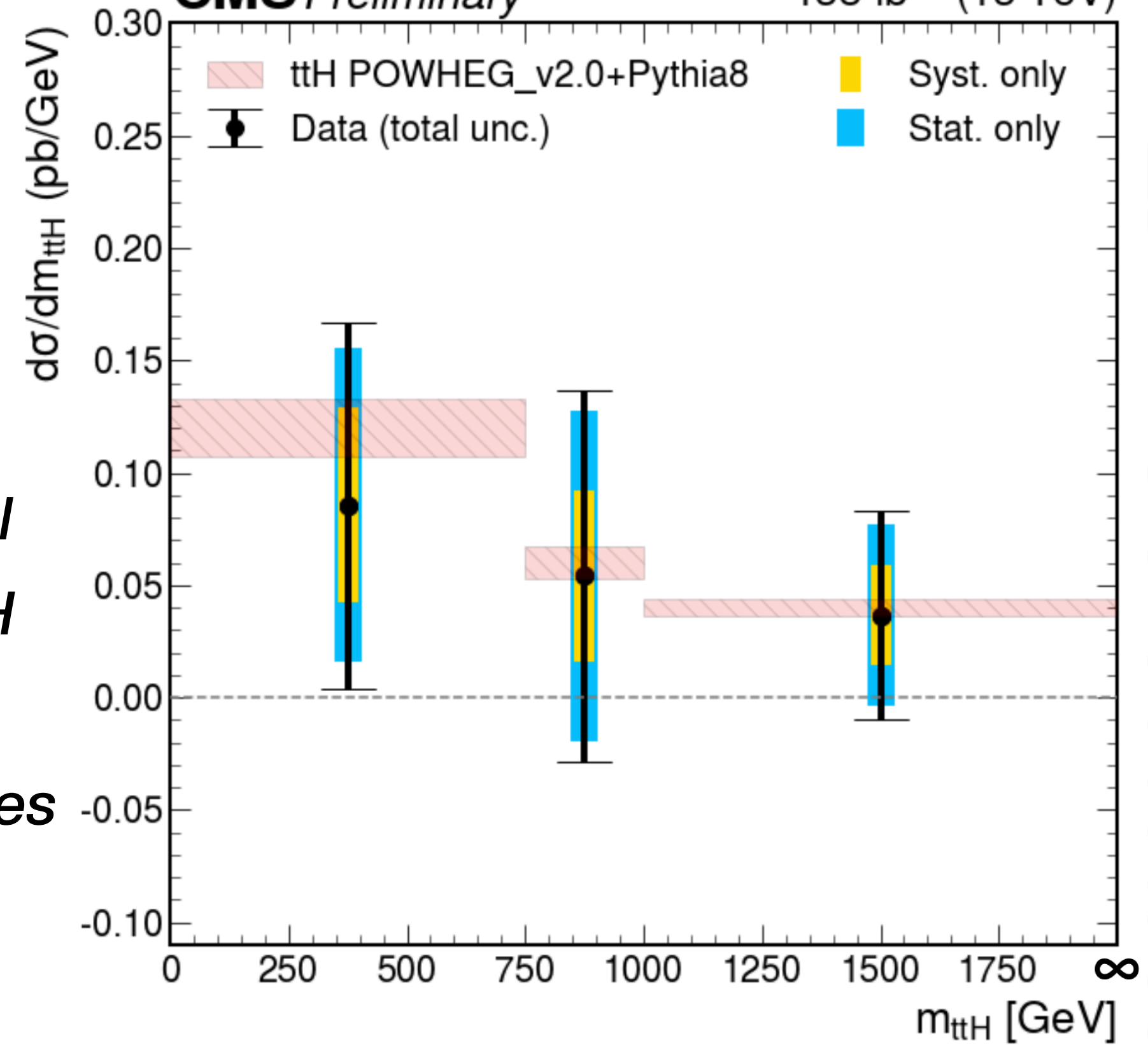


Differential production rates from ttH productions are measured in $H \rightarrow WW$ and $H \rightarrow \tau\tau$ final states by maximizing the sensitivity with lepton multiplicities

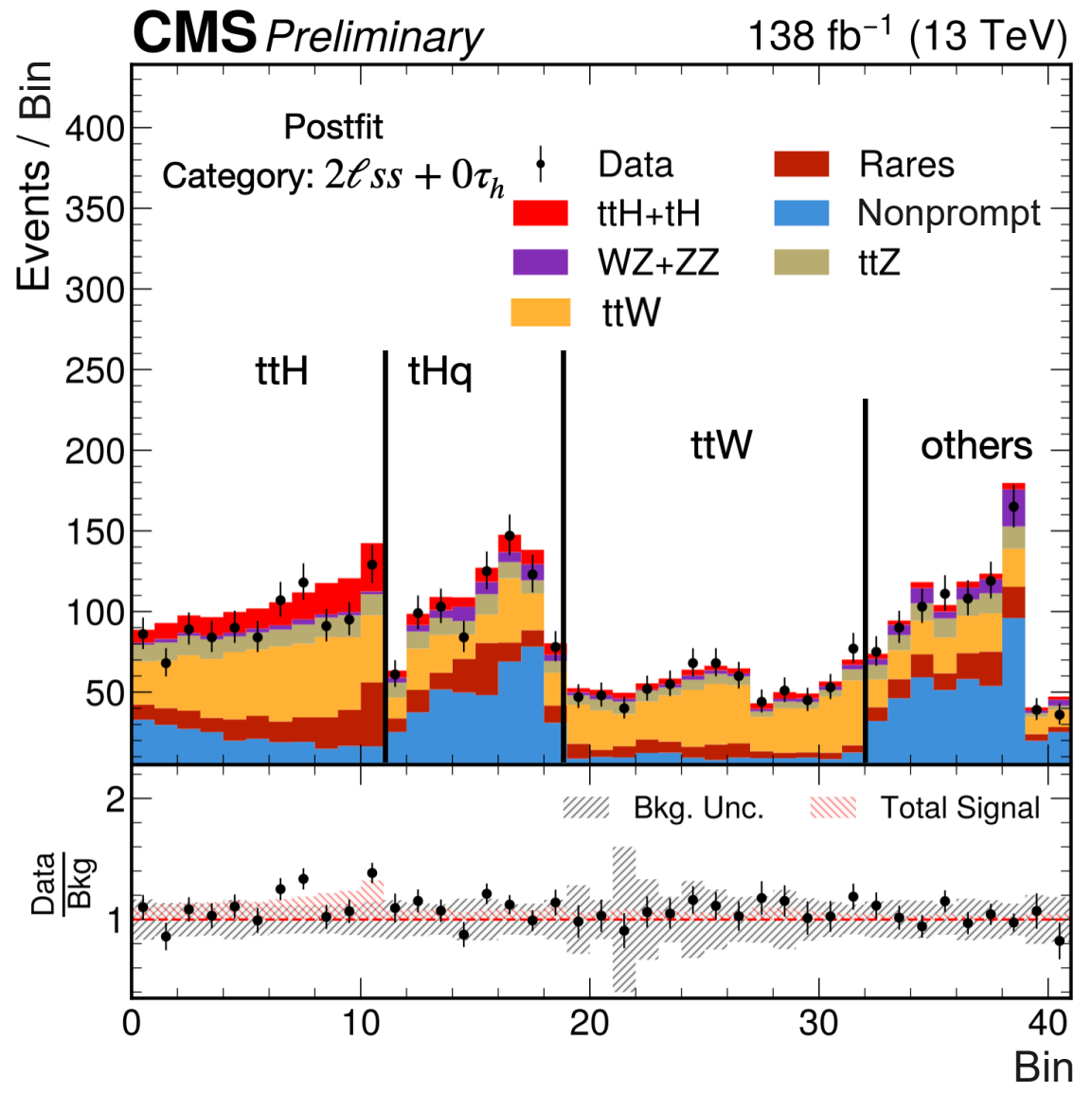
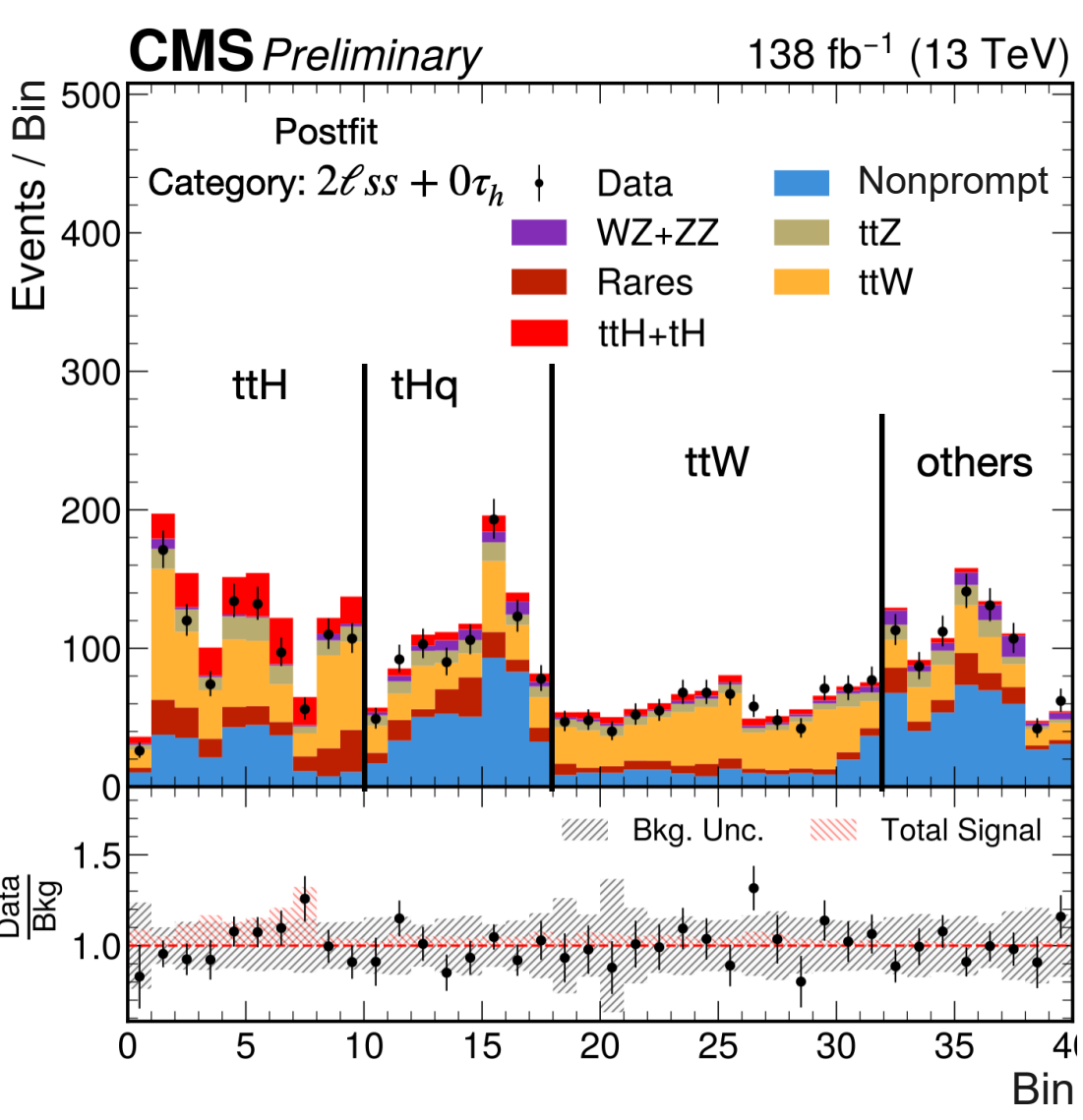


Run 2

CMS Preliminary 138 fb⁻¹ (13 TeV)



The first differential measurement of ttH production in CMS with DNN techniques



3 March 2025

CMS status report: LHCC open session

Constraining nPDFs using dijet production in pPb

HIN-24-014



Run 2

First measurement of dijet pseudo-rapidity distributions in pPb collisions at 8.16 TeV

Dijet pseudo-rapidity distribution across various average transverse momentum (p_T^{avg}) intervals from 50 to 500 GeV

accessing a previously unconstrained region of the gluon nPDF and new constraints on existing nPDF models via dijet final states

