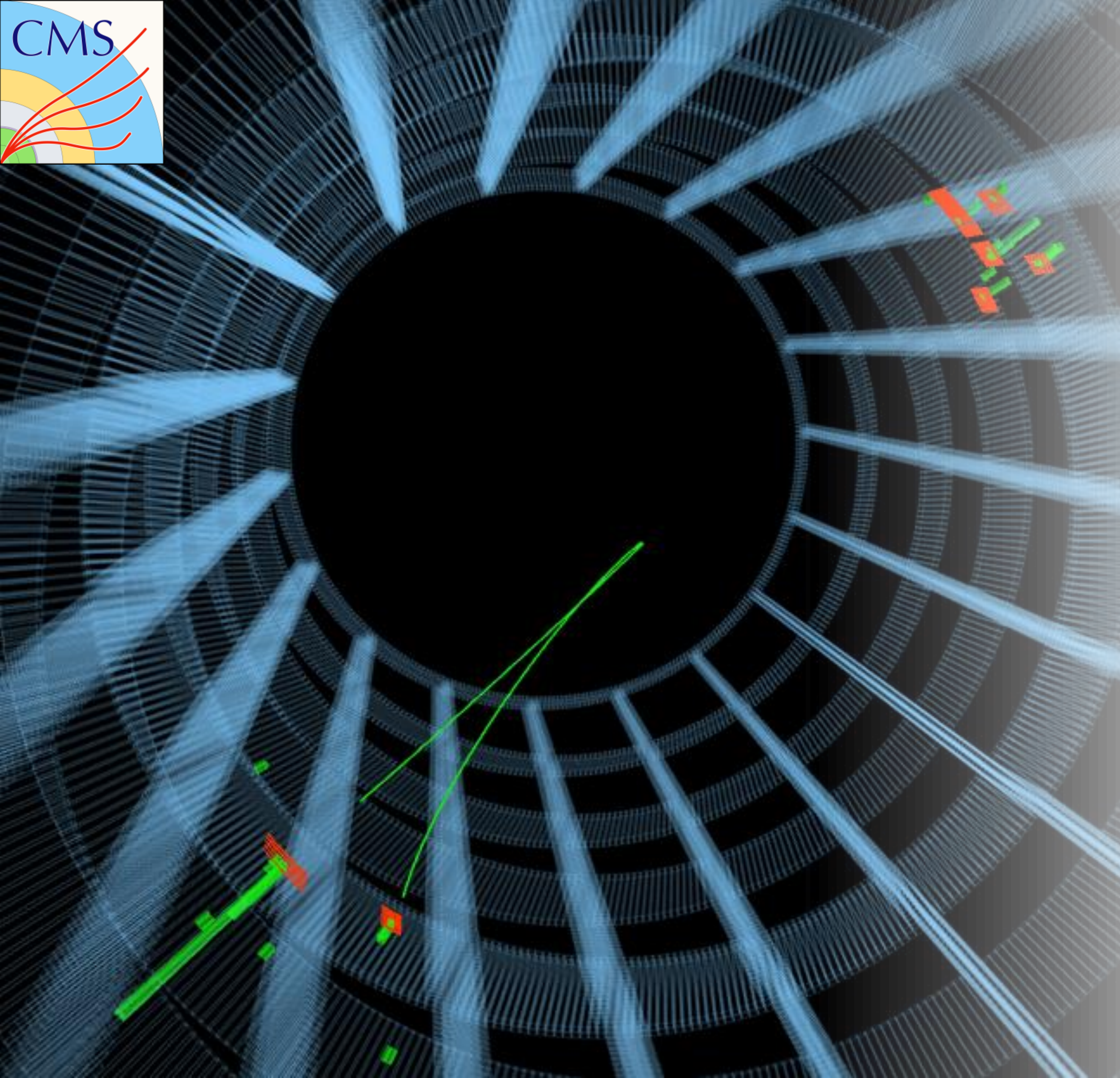

Performance of electrons and photons in Run3 at the CMS experiment

Focusing mainly on trigger performance

Anshul Kapoor

For the CMS experiment

19/11/2023

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Focus on these public results

- CMS DP -2023/076

Trigger efficiency studies of the CMS Run-3 Data Scouting

- CMS-DP-2023-055, CMS-DP-2023-008

Performance of Level-1 Trigger e/gamma and tau in Run 3

- CMS-DP-2023-029

Performance of Level-1 EGamma Trigger On 2022 pp Collisions at 13.6 TeV

- CMS-DP-2023-015

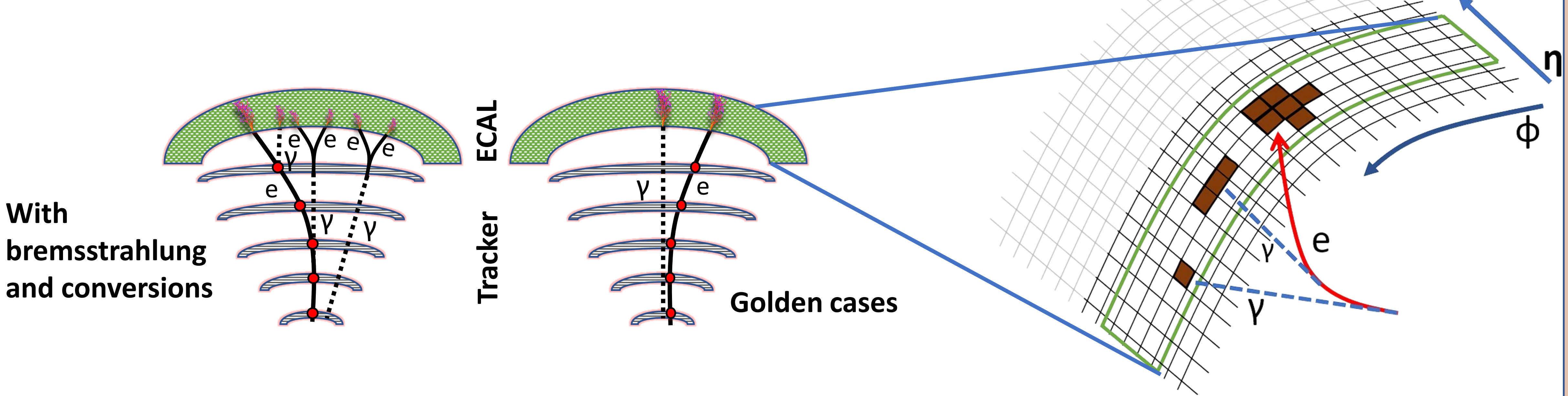
Performance of electron reconstruction at High Level Trigger using data collected at the CMS experiment at CERN in 2022

- CMS-DP-2023-081 Bonus

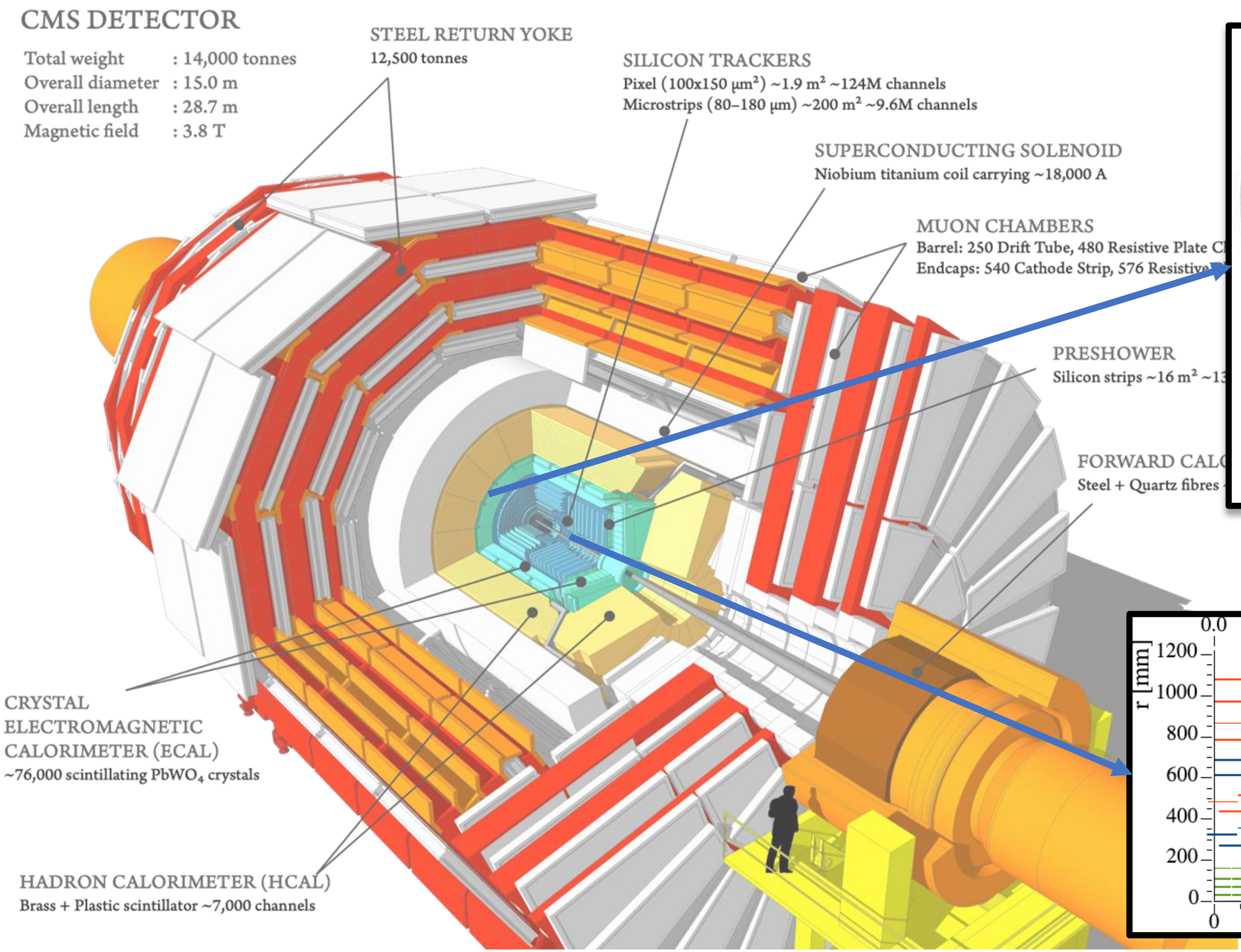
Low-pT Electron ID scale factors from CMS in proton-proton collisions at $\sqrt{s}$ =13 TeV using J/ψ events

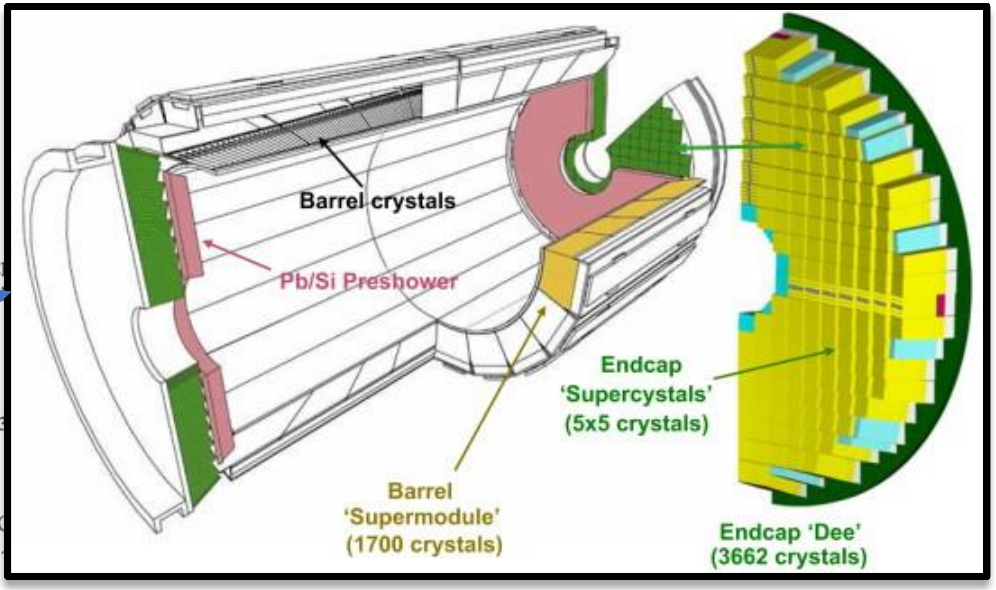
Some quick introduction before that

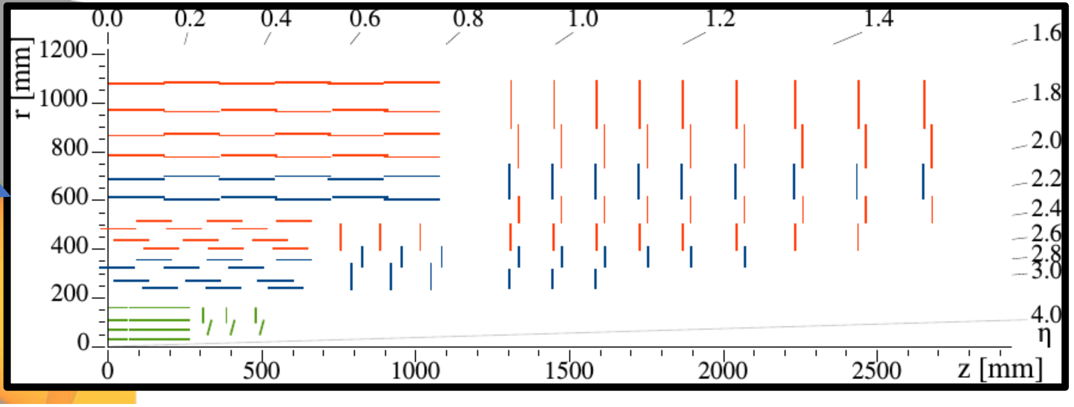
- **Electrons** (e) **and photons** (γ) are critical to the experimental high energy physics program at the LHC
- e **&** γ appear in several new physics signatures
- Also critical to standard model measurements
- At CMS, **Reconstruction** & **Identification** of e **&** γ is done primarily using information from silicon tracker & electromagnetic calorimeter (ECAL)high-energy



The CMS detector







The LHC Runs in 2016-2023

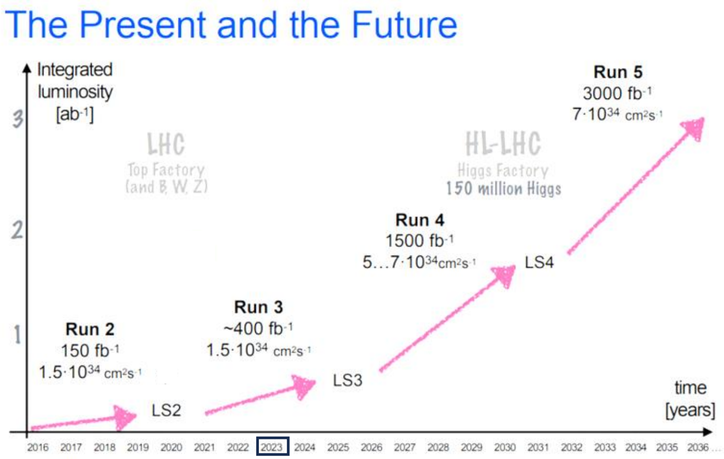


image credit: Andreas B. Meyer

Run 2

- Run 2 of the LHC wrapped up in 2018, capping off three years of amazing science.
- The LHC’s accelerator, detectors, and computing systems were all ticking along like clockwork.
- The LHC showed off its adaptability with a bunch of special runs.
- The total integrated luminosity of pp collisions in Run 2 was just a little over 150 fb^-1.

Run 3

- Run 3 of the LHC kicked off in July 2022.
- The LHC is set to run for nearly four years at a whopping collision energy of 13.6 trillion electronvolts (TeV).
- The data readout and selection systems of the four big LHC experiments got some major upgrades.
- The ATLAS and CMS detectors are gearing up to record more collisions during Run 3 than the two previous LHC physics runs combined.
- With more data samples and higher collision energy, Run 3 is set to broaden the LHC’s already diverse physics program even further.

Electrons and photons with Scouting in Run 3

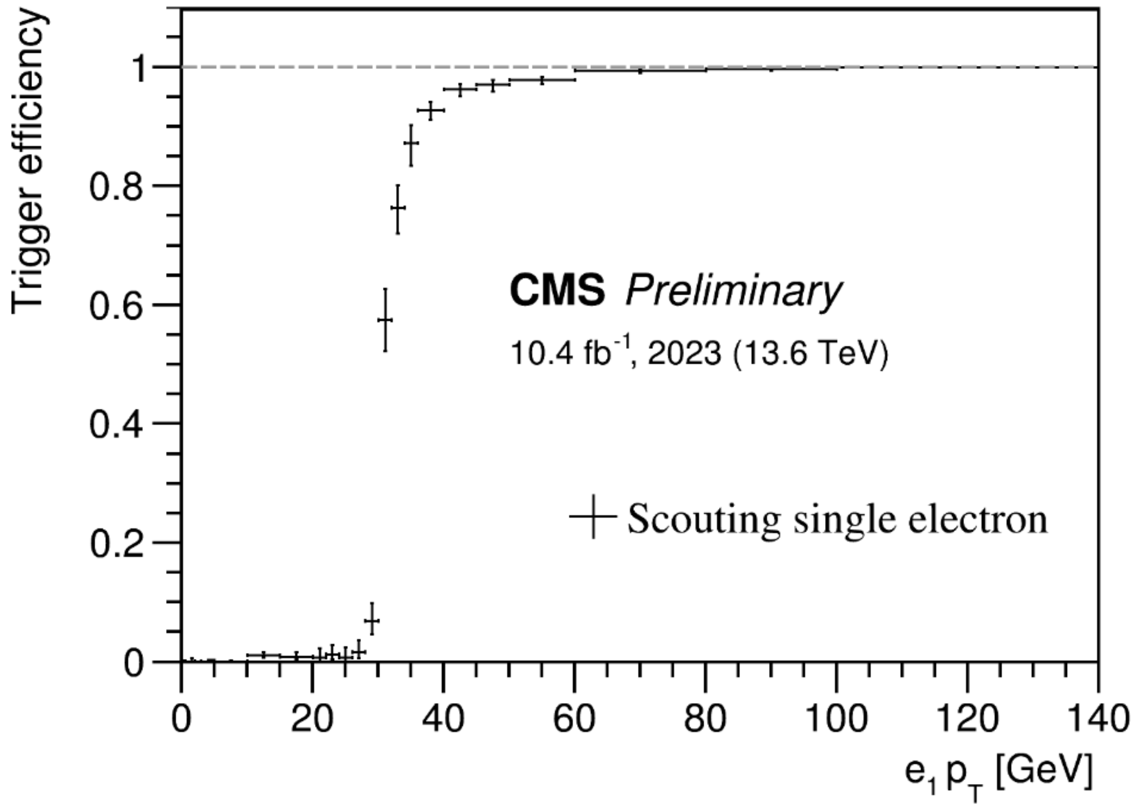
[CMS DP -2023/076](CMS DP -2023/076)

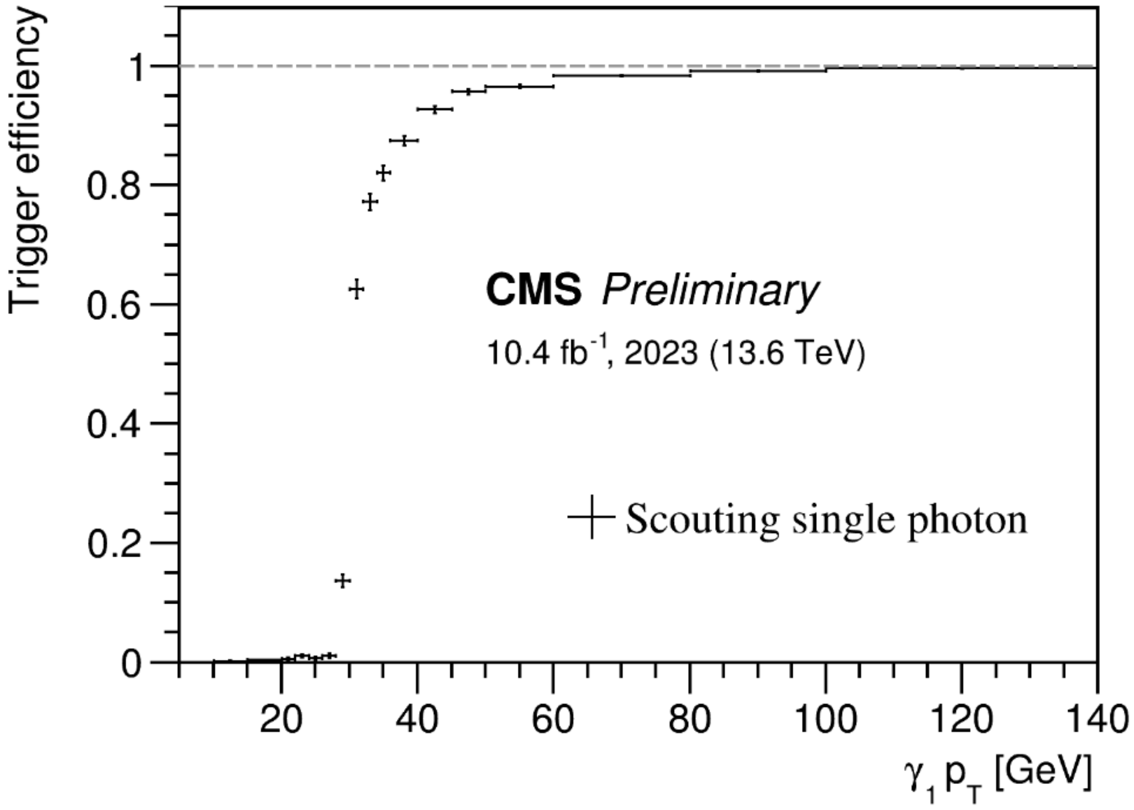
- Data scouting is a new approach for data analysis at CMS
- It's based on trigger-level reconstruction and serves as a complement to the traditional strategy of analyzing physics objects reconstructed offline.
- Events are reconstructed online by the High-Level Trigger (HLT) and selected based on the kinematic quantities of the reconstructed objects.
- This method applies looser energy and momentum thresholds than the traditional strategy.

- To compute the trigger efficiency of data scouting as a function of offline reconstructed objects, a study was performed on recorded data.
- This study used a dataset that records the raw detector output with a prescaled version of the data scouting trigger condition.

Electrons and photons with Scouting in Run 3

CMS DP -2023/076





What is efficiency here?

Numerator: Number of events that fired the reference and target trigger

Denominator: Number of events that fired the reference trigger

The scouting single e/γ trigger is efficient in selecting events with e/gamma pT > 30 GeV and $|\eta| < 1.44$.

Electrons and photons with L1 trigger in Run 3

CMS-DP-2023-055, CMS-DP-2023-008 CMS-DP-2023-029

- Electrons and photons can't be told apart by the L1 trigger, so they're generally referred to together.
- Efficiency is defined as the ratio between the number of probe objects with a matched L1 object passing a specific transverse energy threshold and the total number of tagged offline objects.
- The transverse energy, pseudorapidity, and azimuthal angle responses of the L1 trigger are computed with respect to the offline reconstructed objects.
- The performance of the L1 objects is studied with respect to the offline reconstructed ECAL superclusters.
- **Method Definitions:**

The studies were done using the full dataset recorded in 2022, which had an integrated luminosity of 34 fb-1.

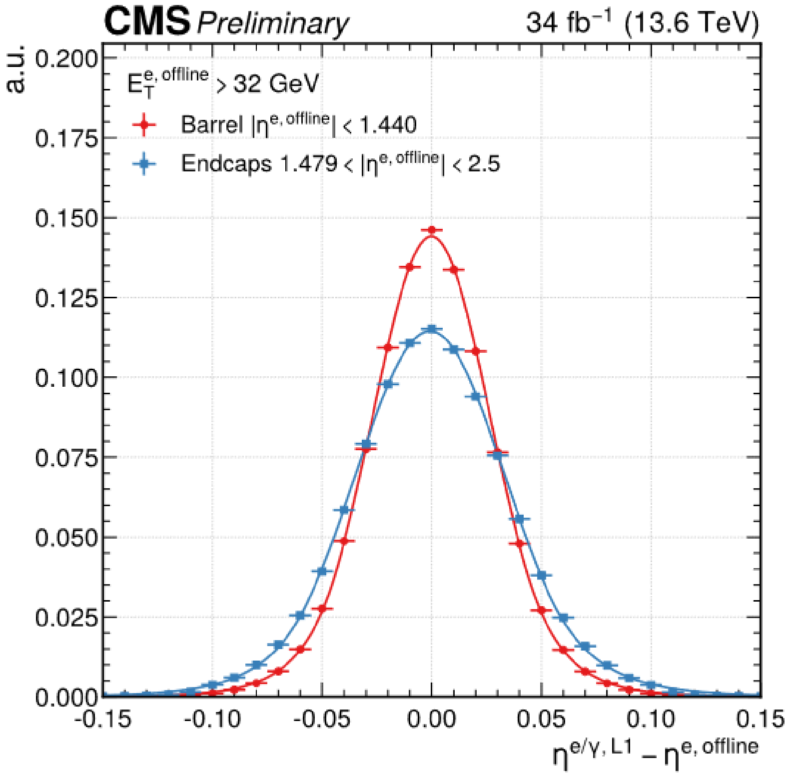
A tag-and-probe technique was used for evaluating the performance of certain objects in the L1 trigger.

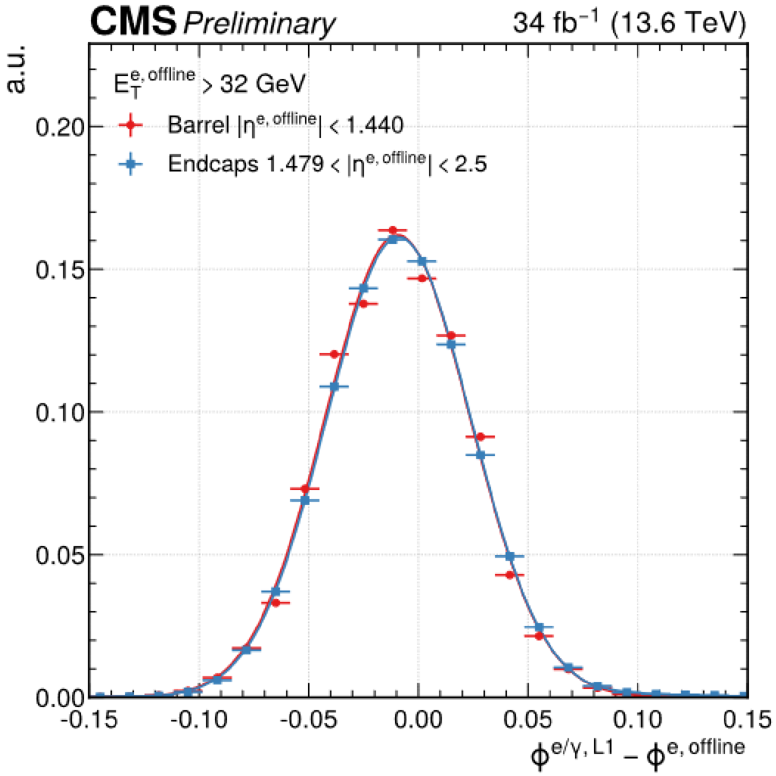
The object triggering the event was chosen as the tag object. It had to be inside the fiducial volume of the detector and had to meet strict offline identification requirements.

The second object in the pair was chosen as the probe. It was used as an unbiased set for evaluating the L1 trigger performance by applying a geometrical match between offline and L1 objects.

Electrons and photons with L1 trigger in Run 3

CMS-DP-2023-055, CMS-DP-2023-008 CMS-DP-2023-029

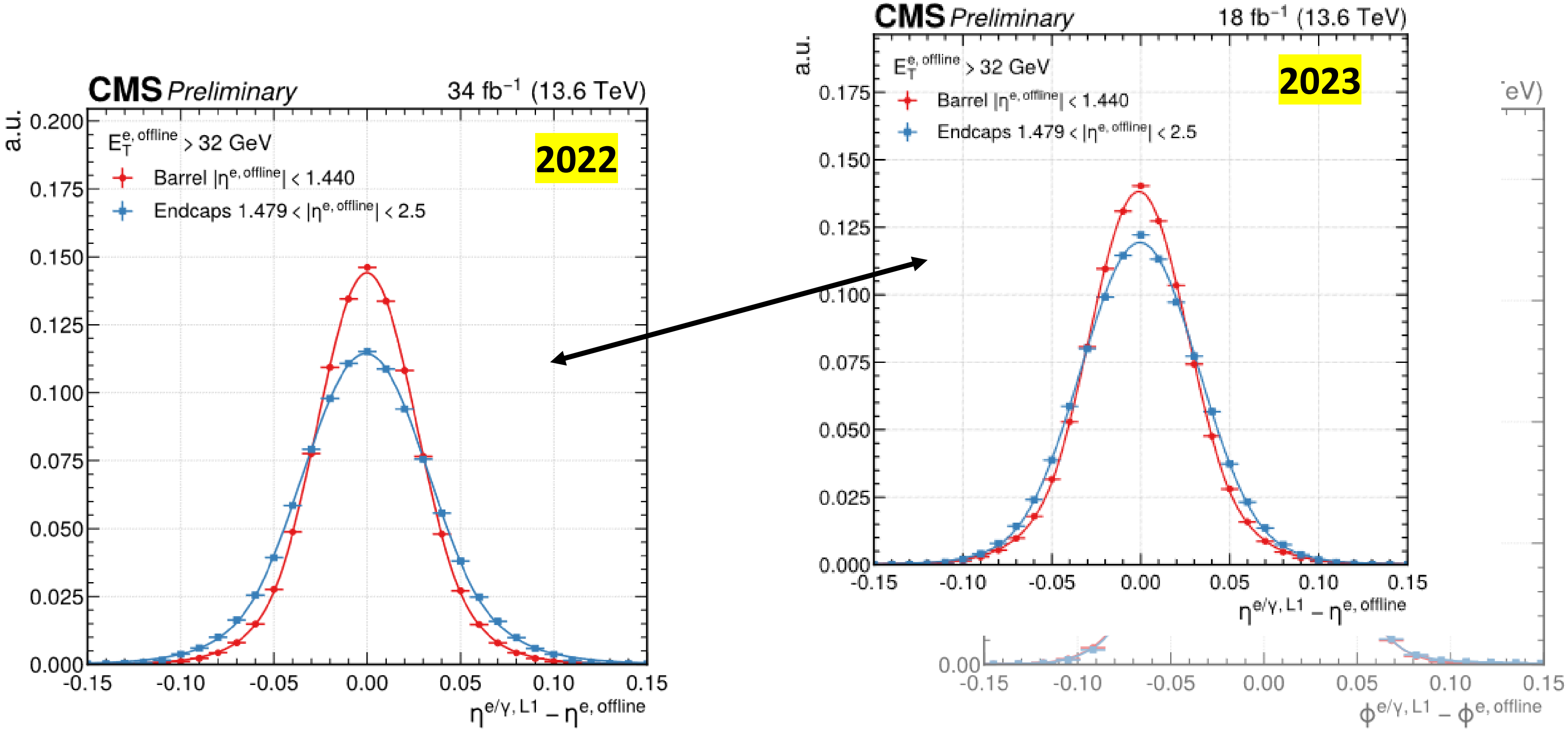




The pseudorapidity (left), and azimuthal angle (right) positions of Level-1 e/γ candidates with respect to the offline reconstructed position, separately for the barrel and endcap regions. The functional form of the fits consists of a two-sided tail asymmetric Crystal Ball function.

Electrons and photons with L1 trigger in Run 3

CMS-DP-2023-055, CMS-DP-2023-008 CMS-DP-2023-029



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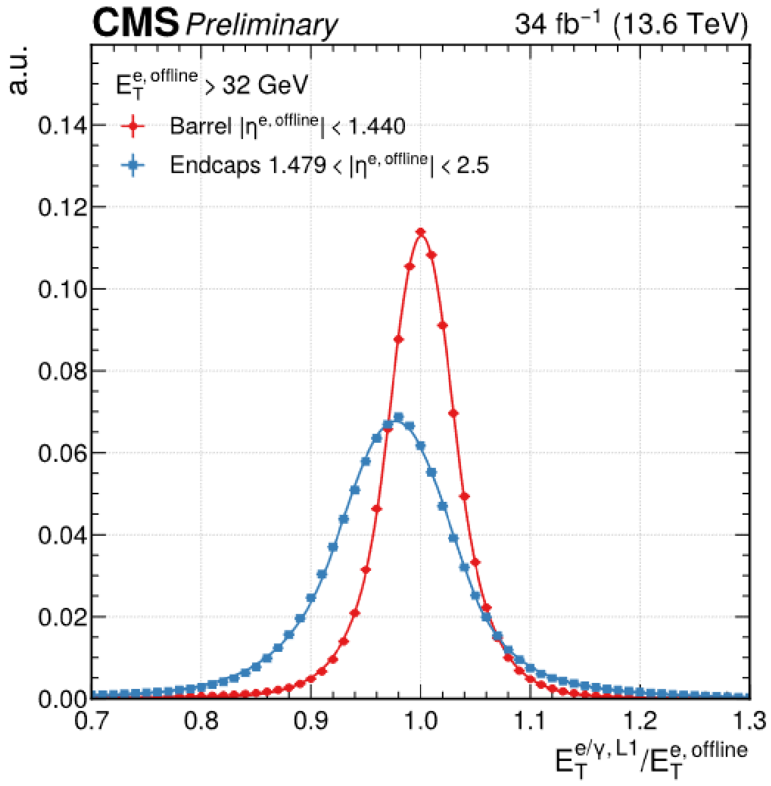
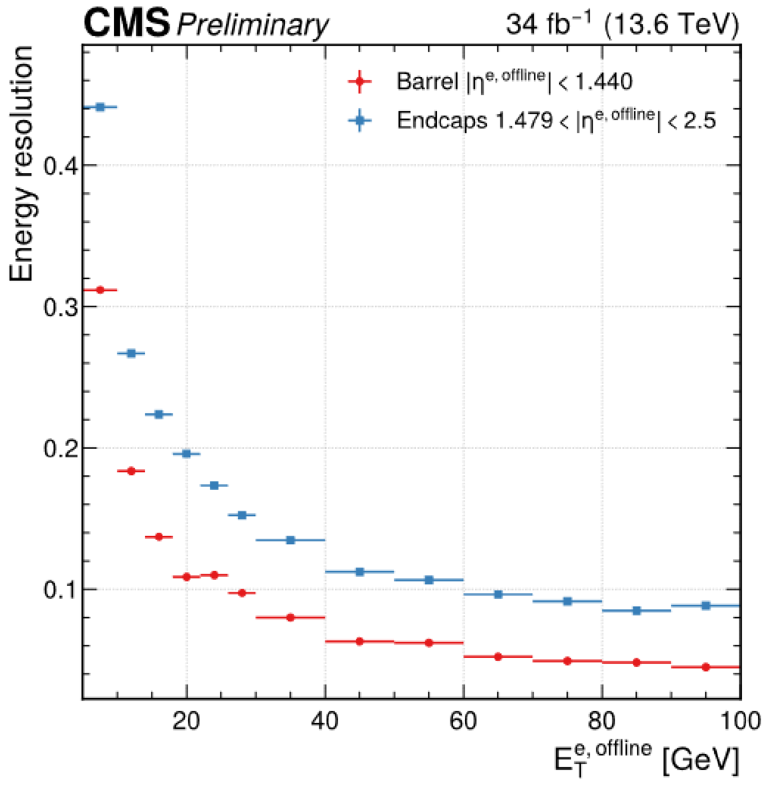
Electrons and photons with L1 trigger in Run 3

[CMS-DP-2023-055](), [CMS-DP-2023-008]()





The Level-1 e/γ trigger energy response with respect to the offline reconstructed E_T, separately for the barrel and endcap regions; the functional form of the fits consists of a two-sided tail asymmetric Crystal Ball function (left). The Level-1 e/γ trigger energy resolution, as a function of the offline E_T (right).

Electrons and photons with L1 trigger in Run 3

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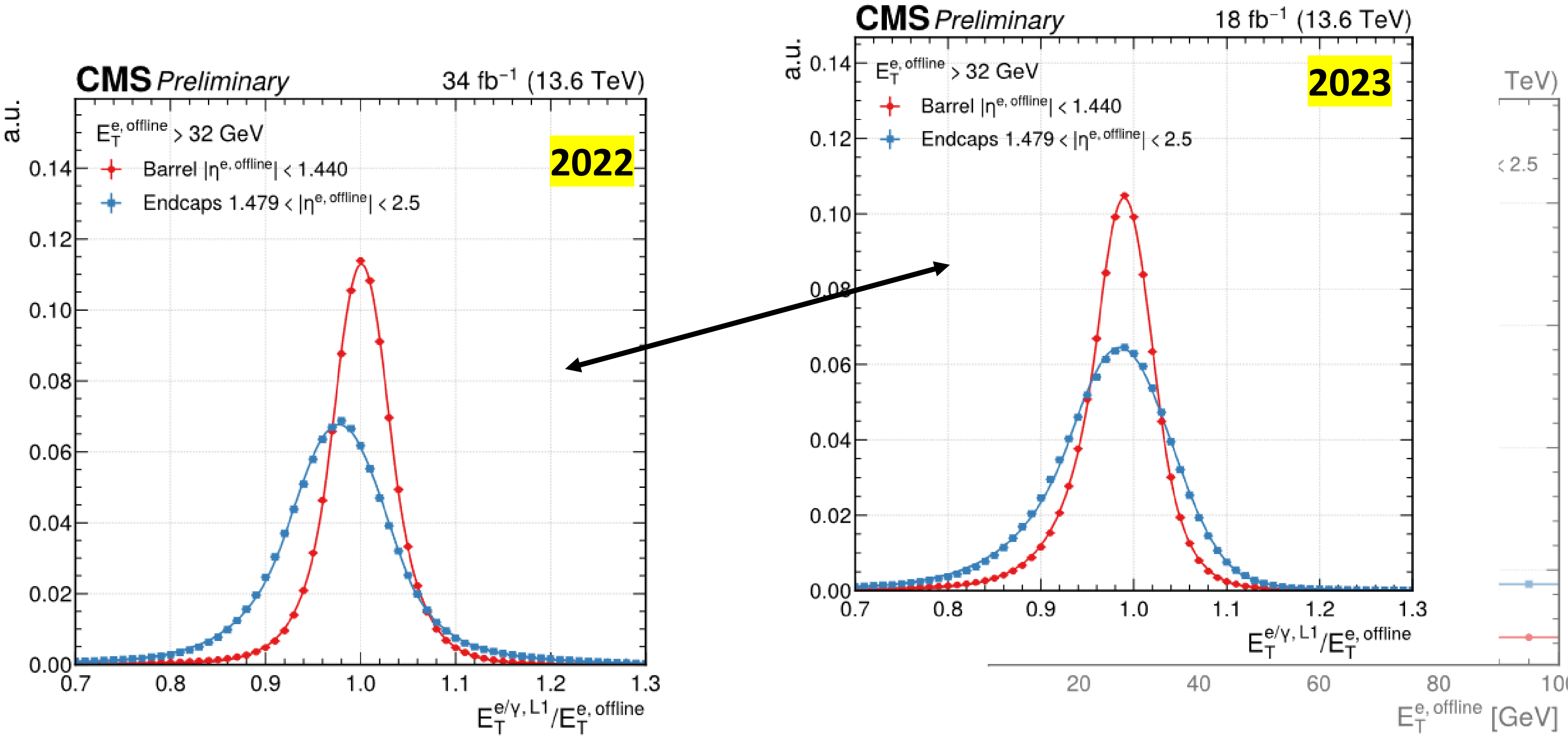

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Electrons and photons with L1 trigger in Run 3

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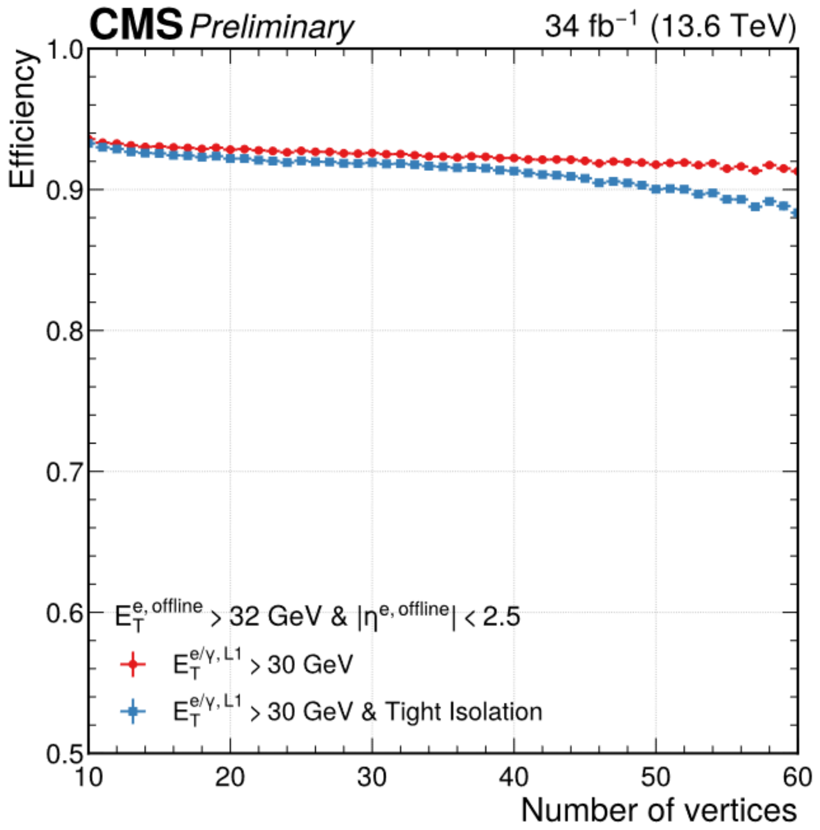
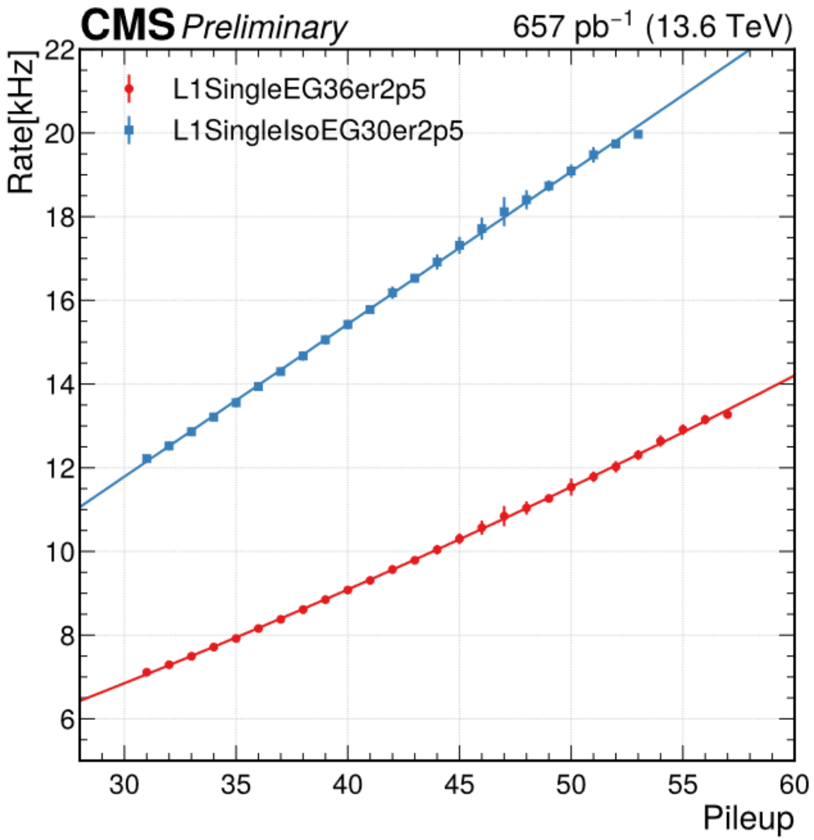


The Level-1 e/γ trigger efficiency as a function of the number of offline reconstructed vertices, for both isolated and non-isolated candidates.



Level-1 trigger rates as a function of pileup, evaluated in a single LHC fill, for 2 L1 trigger algorithms

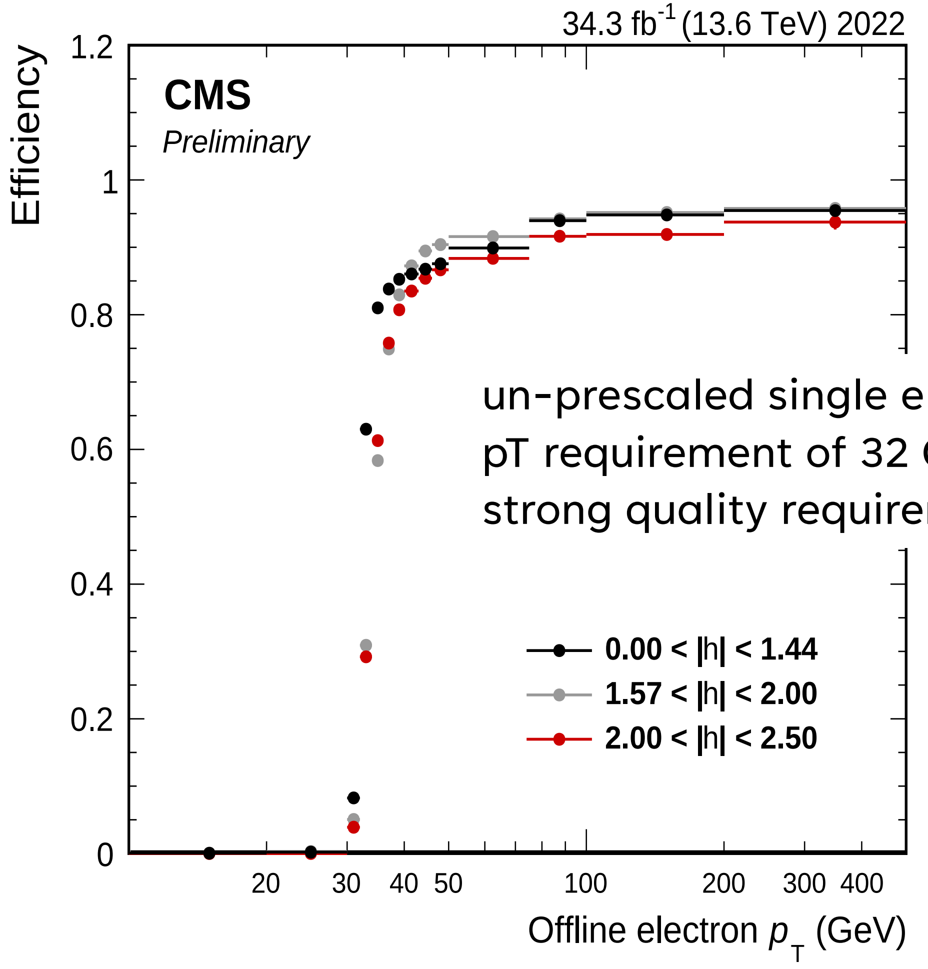
Electrons and photons at HLT in Run 3

CMS-DP-2023-015

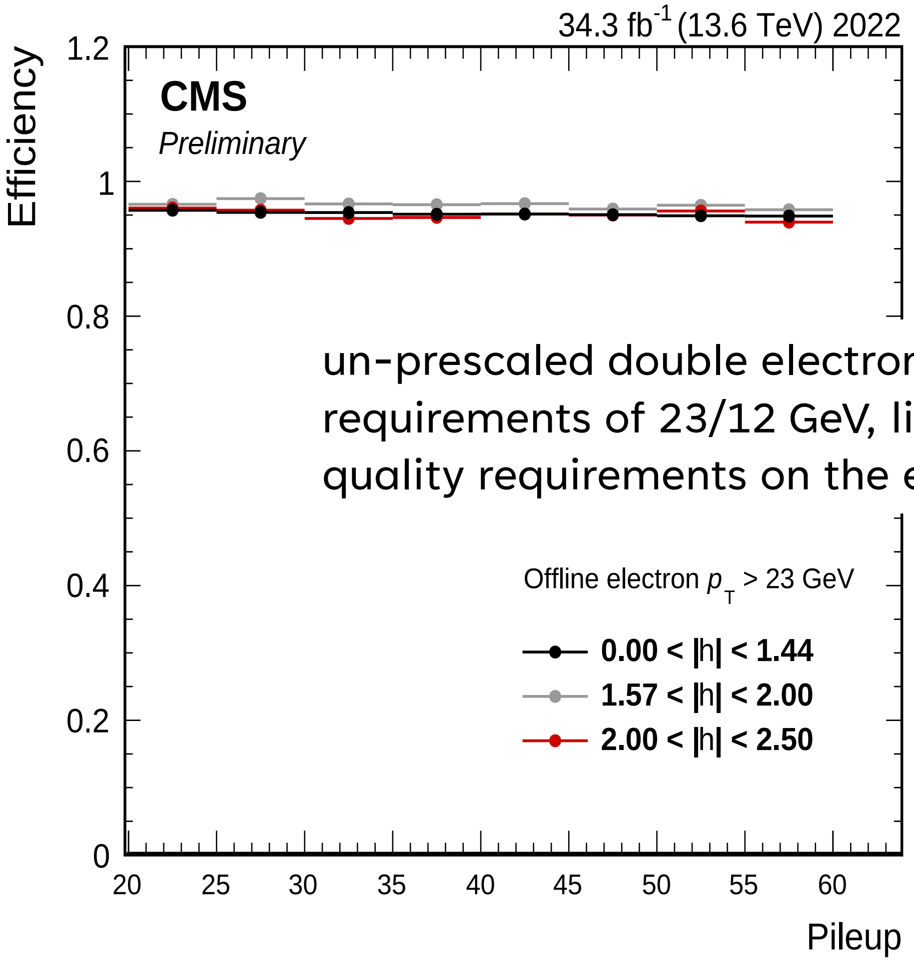
- We're looking at how well single and double-electron high-level trigger (HLT) algorithms perform..
- The data we're using is from 2022 proton-proton collisions at 13.6 TeV. The data corresponds to an integrated luminosity of 34.3 fb-1.
- We're only keeping events that have two particles reconstructed as electrons and with a mass between 50 and 130 GeV. This is to capture Z → ee decays.
- We define a tag electron if it:
  - is selected by the HLT algorithm HLT_Ele32_WPTight_Gsf (this means it's an isolated electron with a transverse momentum $p"$ > 32 GeV);
  - has pT > 32 GeV, has pseudorapidity $|\eta|$ < 2.17;
  - is identified as an electron using an offline cut-based ID with high purity
- We then measure the efficiency of the desired HLT algorithm using the probe electron. The probe electron must also:
  - have the opposite charge sign compared to the tag;
  - be identified as an electron using the same offline cut-based ID as the tag;
  - be matched with the trigger object using a ΔR < 0.1 criterion;
  - not fall within 1.44 < η < 1.57. This is the transition region between the central and forward electromagnetic calorimeters, where the electron and photon reconstruction isn't the best.

Electrons and photons at HLT & Offline in Run 3

CMS-DP-2023-015



un-prescaled single electron, pT requirement of 32 GeV, strong quality requirements

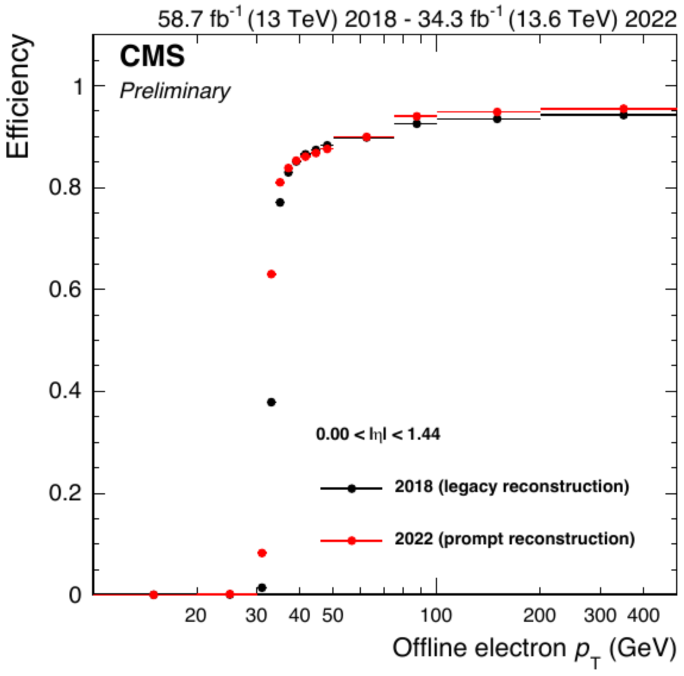


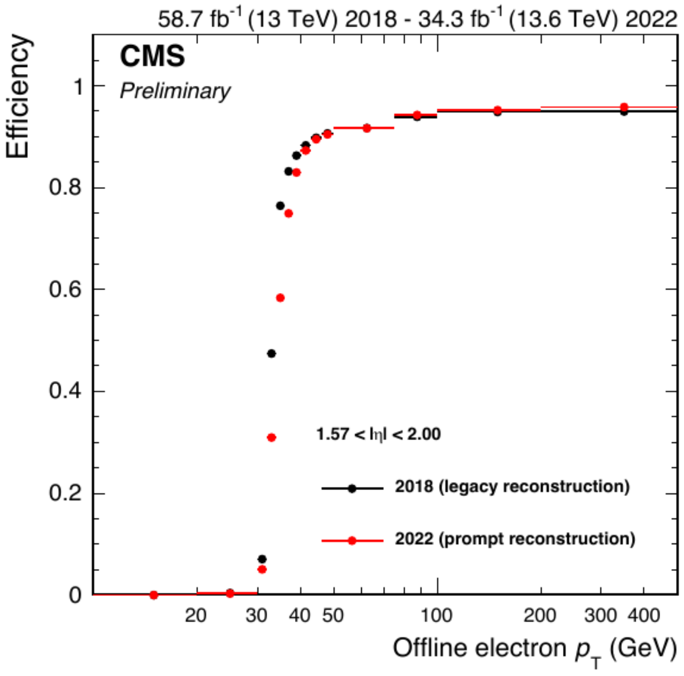
un-prescaled double electron, pT requirements of 23/12 GeV, lighter quality requirements on the electrons

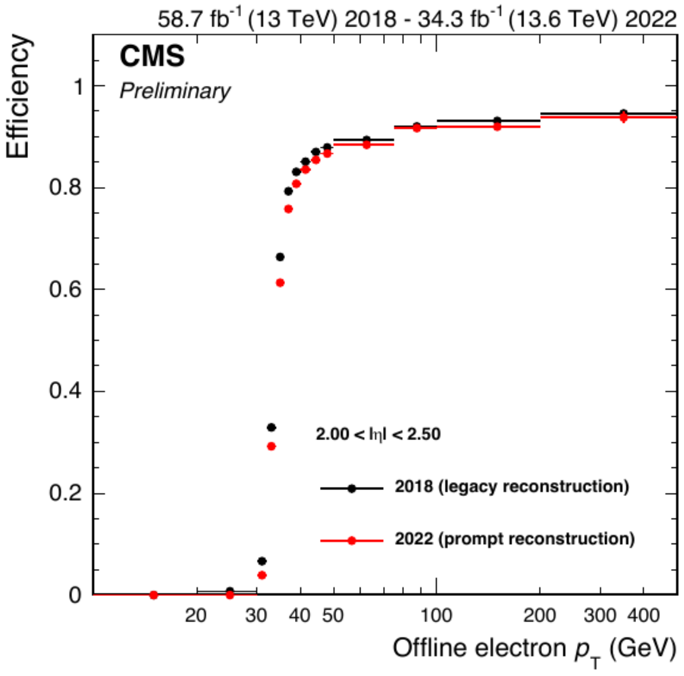
Electrons and photons at HLT & Offline in Run 3

CMS-DP-2023-015

- Comparison with Run2
- **Better performance of HLT_Ele32_WPTight_Gsf in 2022 than in 2018 in barrel**



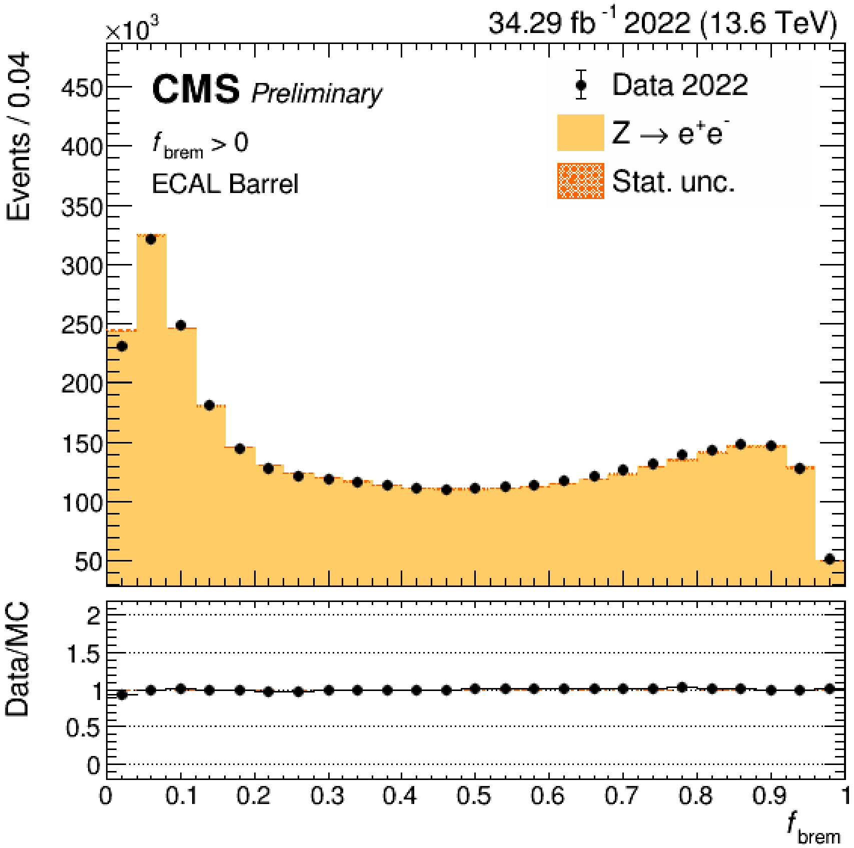




Electrons and photons at HLT & Offline in Run 3

CMS-DP-2023-015

- Already after the startup of the machine, experiments at LHC have seen an excellent performance of the detectors and.
- **This is here demonstrated by the ability to model momentum loss due to bremsstrahlung from electrons (shown for CMS) in Z→ee.**



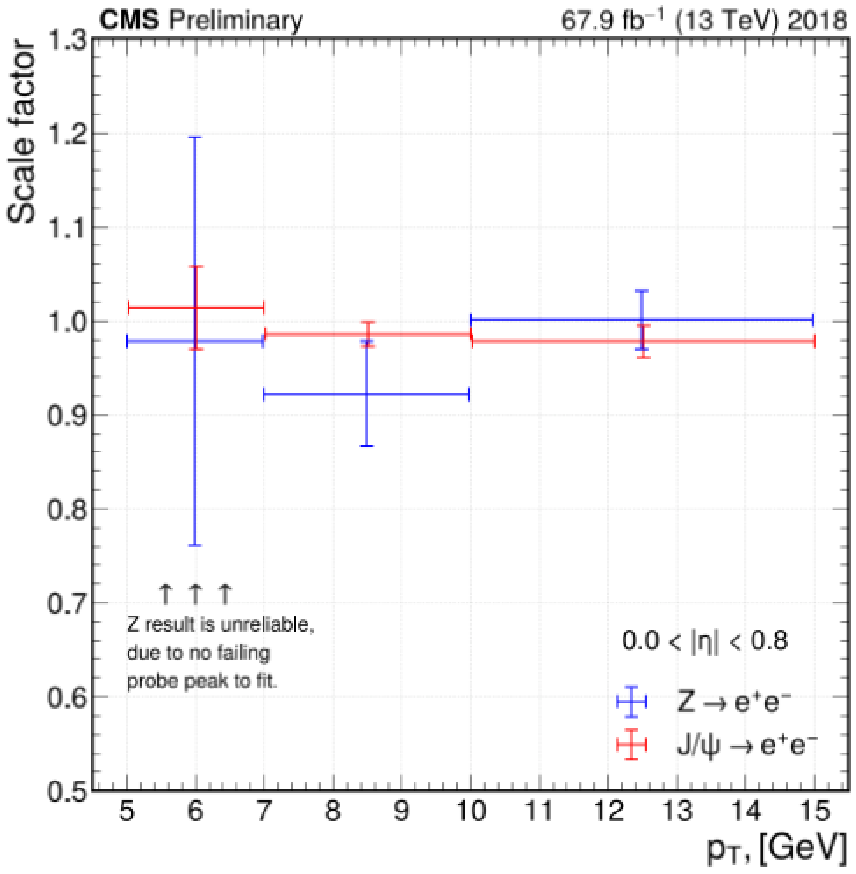
Low-pT Electron ID scale factors using J/ψ events

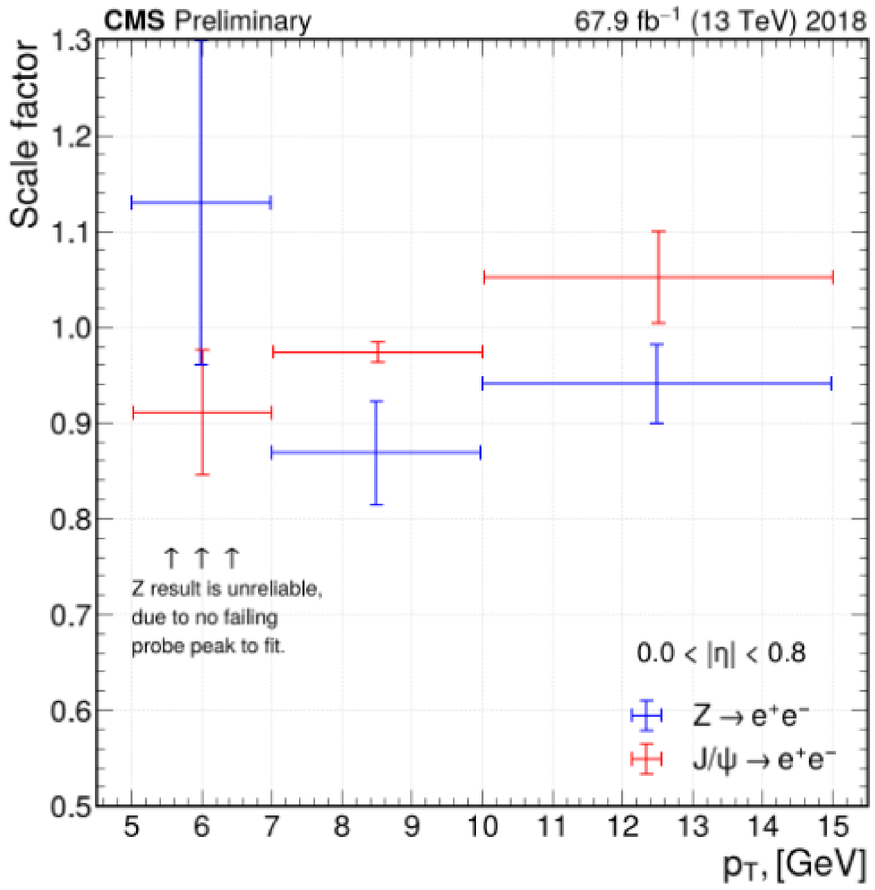
CMS-DP-2023-081

- Low-pT electrons (5 < pT < 15 GeV) pop up in several CMS (Compact Muon Solenoid) analyses.
- Their interaction with the tracker material and the CMS magnetic field makes efficiency measurement tricky.
- We've devised a new method to measure their ID efficiency using the CMS particle flow algorithm. This uses $J/\psi \rightarrow e^+e^-$ decays from the Run 2 parking dataset.
- This gives us more signal statistics in the low-pT region than the Z boson resonance.
- We can now measure electron ID scale factors more precisely in the 7 < pT < 15 GeV range, & even in the 5 < pT < 7 GeV range. This will the default technique for Run 3.
- We're also suggesting a new method to derive electron efficiencies based on their relative isolation.

Low-pT Electron ID scale factors using J/ψ events

CMS-DP-2023-081





High-efficiency electron ID scale factors measured using the Tag&Probe method in J/ψ→e+e- or Z→e+e- events for 0.0 < |η| < 0.8. Without (left) and with (right) isolation. As one can see J/ψ→e+e- provides an equivalent and mostly a statistically better estimate of scale factors. This is also true for other regions in |η|. Plots can be found in CMS-DP-2023-081

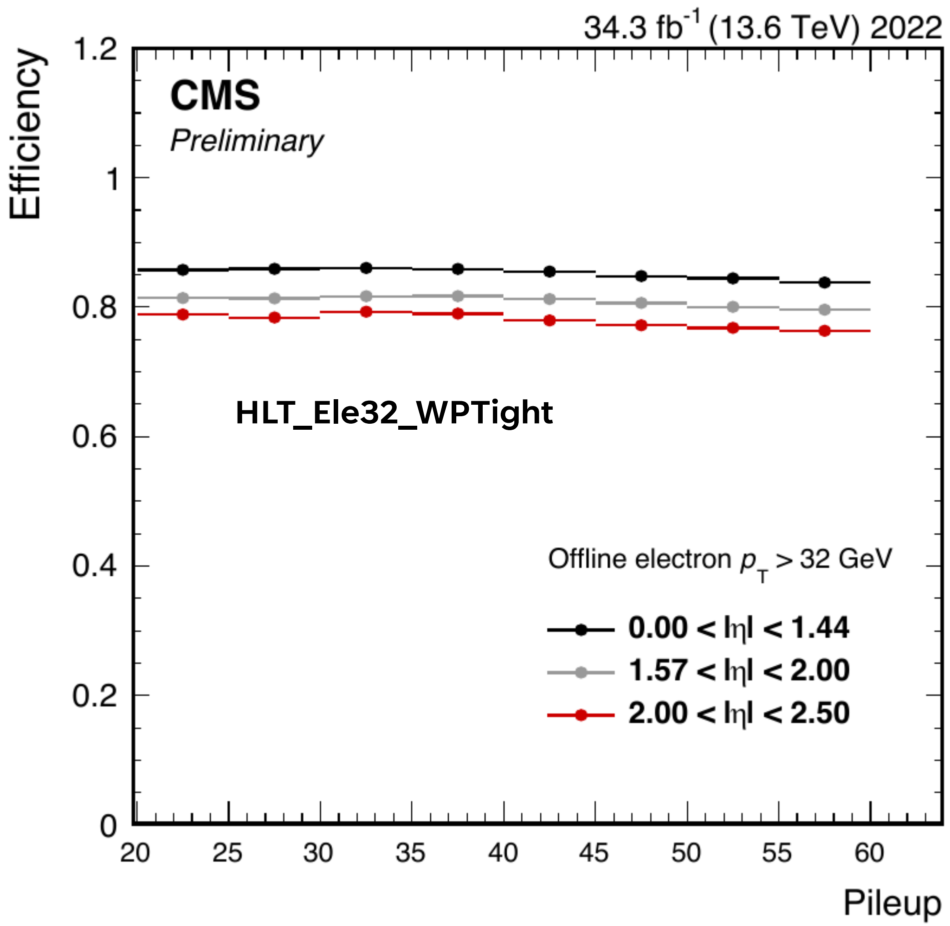
Conclusion

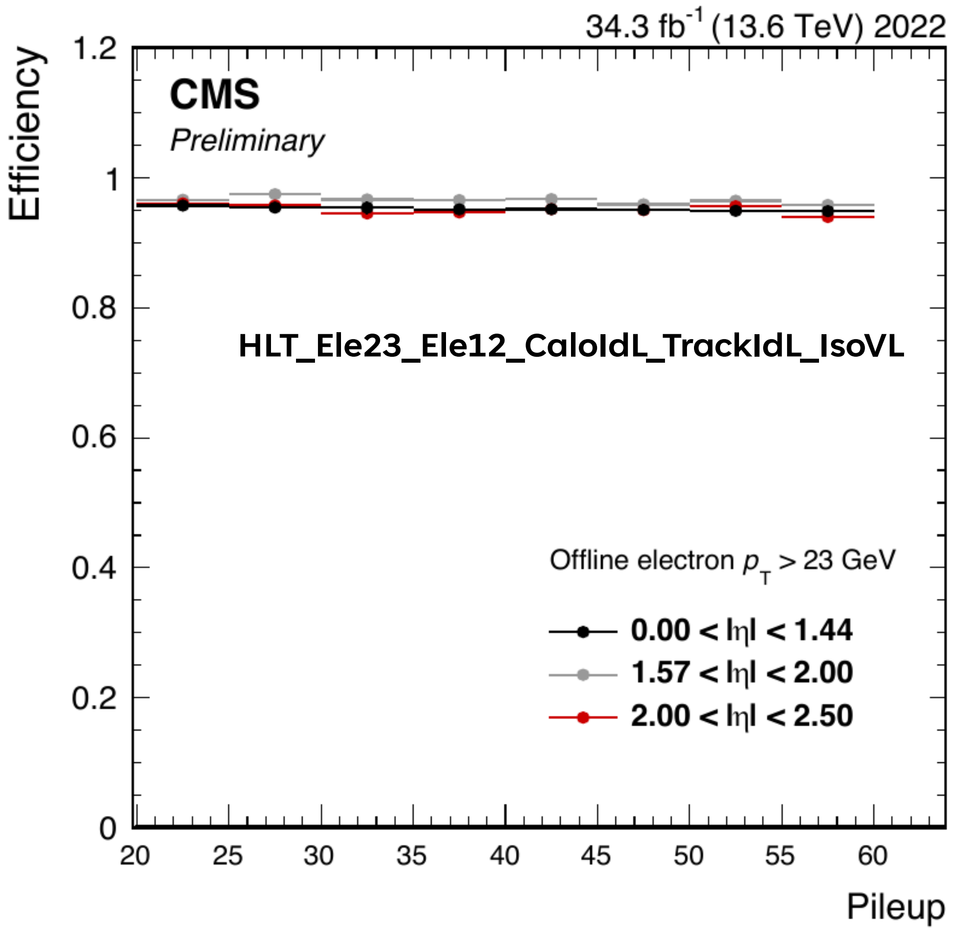
- Run 3 lepton and photon performance for triggers and offline reconstruction looks excellent for the CMS experiment.
- After a successful Run 2 of the LHC, CMS is now ready for Run 3 of the LHC, with the detector having already collected data for the 2022 and 2023 parts of the Run.
- Several new developments in the area of triggers and offline reconstruction have resulted in improved performance of lepton and photon reconstruction.
- Overall, electrons and photons are displaying excellent performance both at the online and offline levels.
- Newer and improved methods, developed with the Run 2 dataset will now be used in Run 3.

BACKUP

E/Gamma: HLT

- Vs Pileup





Level-1 e/γ triggers energy response with respect to offline reconstructed transverse energy (E_T)

nt_Gsf in 2022 than in 2018 in barrel