Photon reconstruction, trigger performance, and future applications with heavy ions at CMS

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Introduction

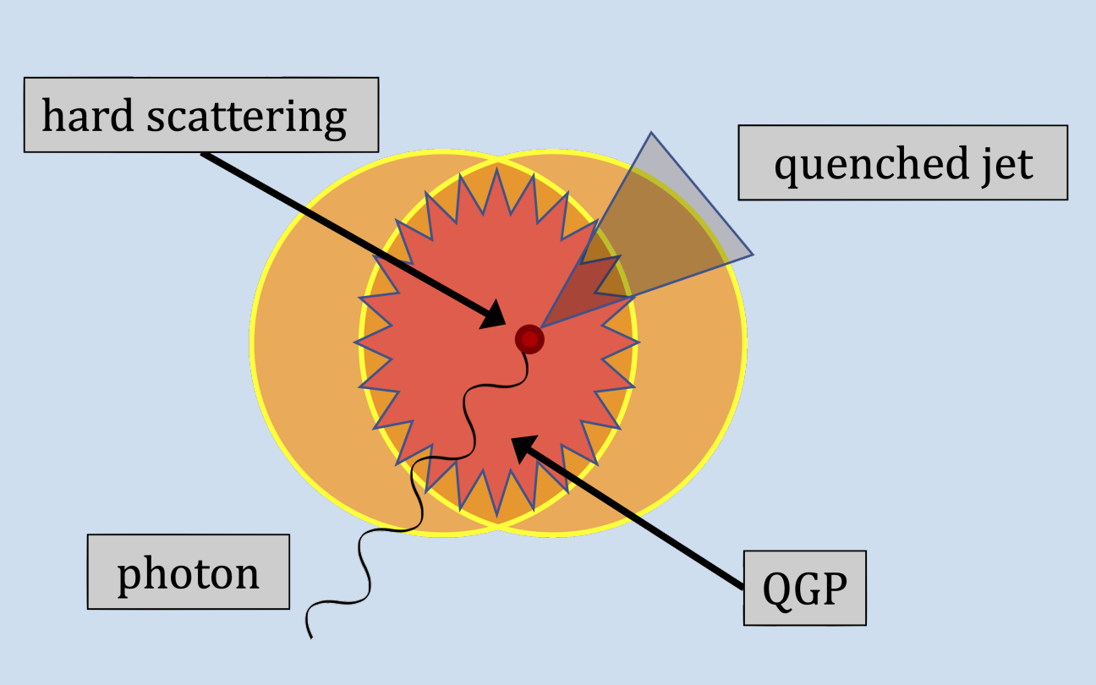

Figure 1. Heavy ion collision

When heavy ions collide, a quark-gluon plasma (QGP) is formed. Hard-scattered partons lose energy through interacting with the QGP, and can serve as non-trivial colored probes. Photons do not interact with QGP strongly, and thus they are able to tag the initial p_{T} of the recoiled partons.

The Compact Muon Solenoid (CMS) detector

CMS detector is one of the two general-purpose cylindrical detectors hosted at the LHC, which is located at IP5.

Photons are reconstructed and identified using the silicon tracker, the electromagnetic calorimeter (ECAL), and distinguished against hadrons based on the hadron calorimeter (HCAL).

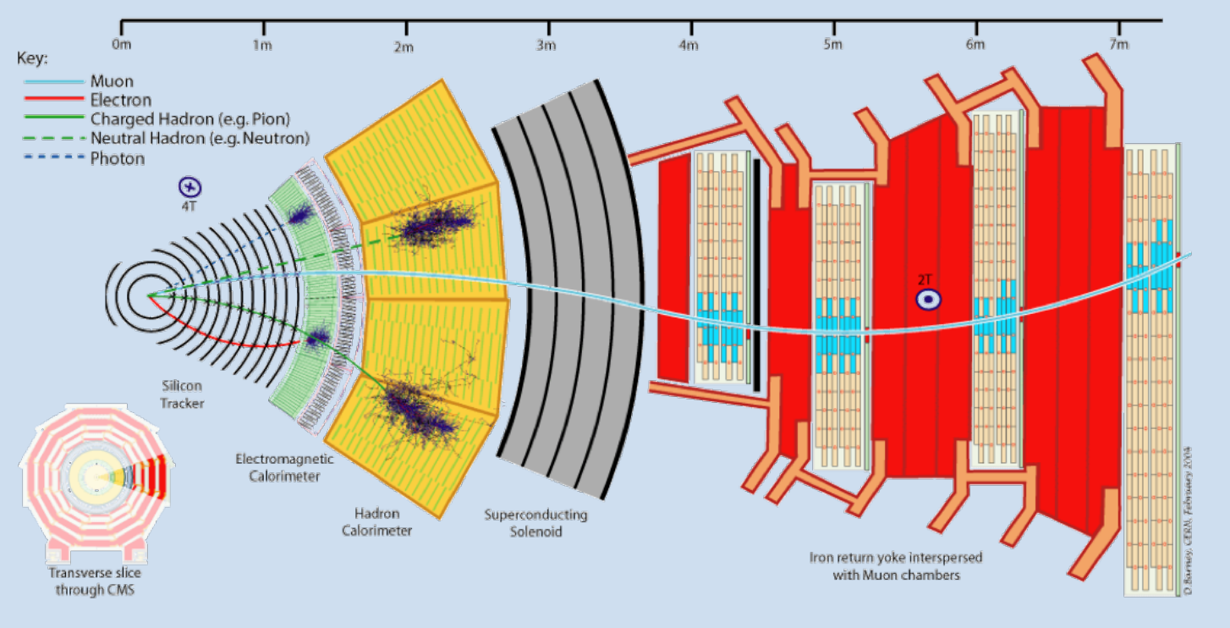

Figure 2. CMS cross-sectional slice [1]

Level-1 and high-level triggers

Heavy ion collision in LHC is dense (corresponding pp pile-up: ~ 200), and thousands of tracks are created in an average event. Also, tracking consumes significant amount of time, and therefore it is a challenge to design efficient triggers to record events with only high energy photons due to the limited resources available in the trigger systems.

CMS has a two-stage trigger system [2] consisting of the **level-1 (L1) trigger** (first level) and the **high-level trigger (HLT)** (second level). The hardware-based L1 trigger provides a fast trigger decision based on less-detailed information. After the L1 trigger accepts an event, the event is passed to the software-based HLT system which uses information from the whole detector and performs event reconstruction. If the HLT system accepts an event, the event will then be recorded for offline reconstruction.

The L1 trigger employs information from the ECAL, where the ECAL crystals are combined into arrays of 5×5 trigger towers (TTs). By combining with information from neighboring TTs and HCAL energy deposits, the TTs are then filtered and refined to form 'EG' objects. If the E_{T} of an EG object is above a certain threshold depending on the deposit location, the event is accepted and passed to the HLT system.

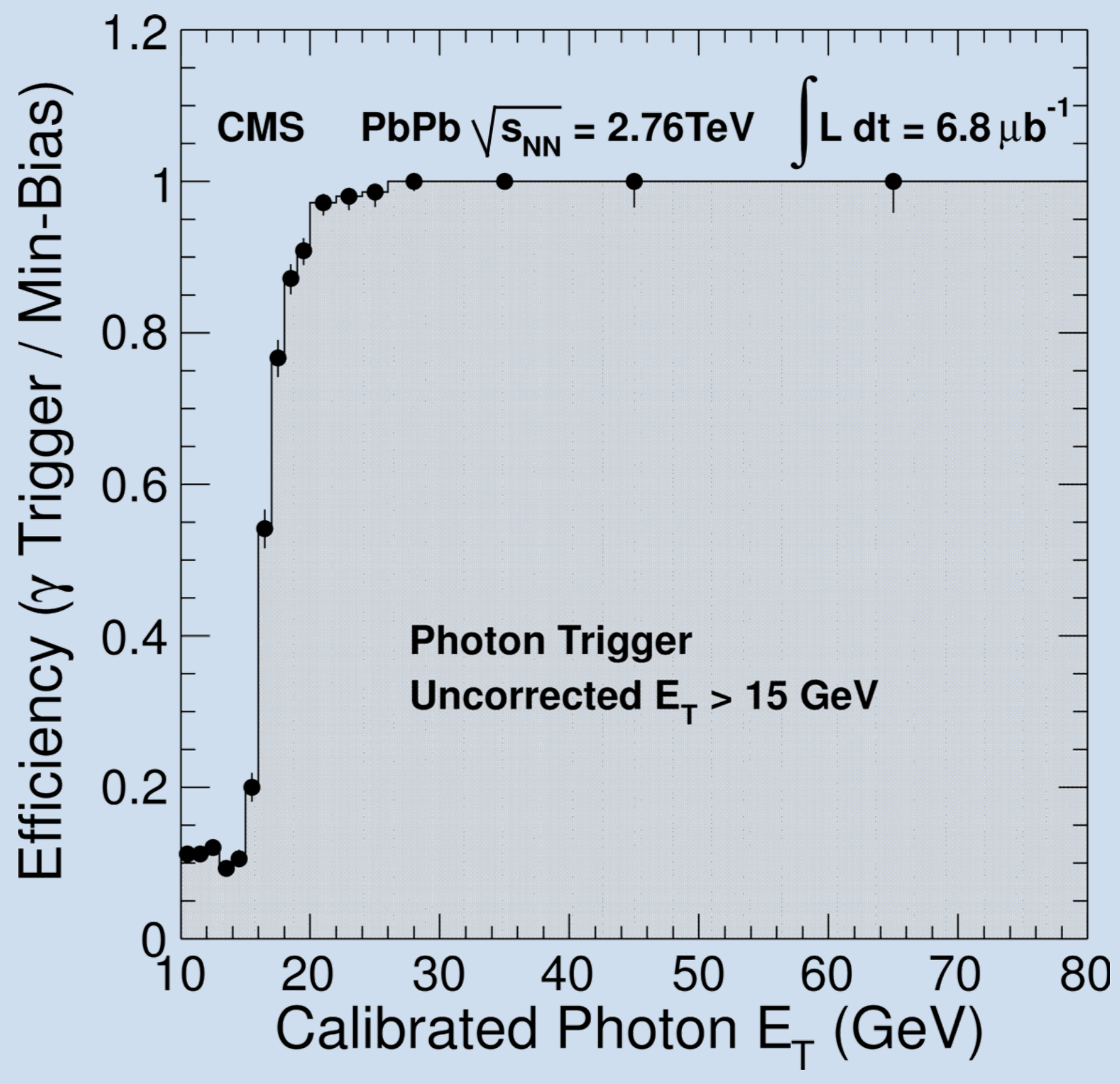

Figure 3. An HLT photon trigger turn-on curve [3].

The HLT system, on the other hand, employs algorithms similar to offline reconstruction which are faster but less precise. Comparing to those used in offline reconstruction (see below), the ECAL clustering in the HLT is regional, energy calibration is less accurate, H/E and isolation requirements are looser, and the momentum and angle of the objects are calculated with respect to the CMS origin rather than the primary collision vertex.

Figure 3 shows a trigger turn-on curve as efficiency with respect to corrected photon transverse energy measured with a Run 1 minimum-bias sample for the HLT photon trigger at 15 GeV being $\geq 90\%$ efficient already at 20 GeV. In order to prepare for the future heavy ion run in Run 3, we have emulated the responses of the photon triggers of the HLT system with QCD photon Monte-Carlo samples.

Photon reconstruction

There are many challenges to reconstruct high quality photons in the heavy ion environment due to the large amount of energy and fluctuations caused by the QGP itself.

A 3×3 (5×5) matrix of ECAL crystals contains about 95% (98%) of the energy of a photon reaching ECAL. However, if a photon is converted to electrons before reaching the ECAL, its energy spreads, causing a 5×5 matrix to miss $\sim 25\%$ of the energy, and the clustering algorithms help recover the true energy of the photon.

ECAL crystals with significant energy deposits are grouped to form "clusters". Crystals with energy above certain threshold are identified as seed crystals for clusters and sorted in decreasing order of energy. A crystal is added to a cluster if it has enough energy and is next to the cluster. Seed clusters are identified and superclusters (SCs) are grouped similarly, and the SCs which meet the photon compatibility requirements are recognized as photon candidates. More details may be found in Ref. [4].

Two algorithms are used in photon reconstruction: the Island Algorithm [5] and the Global Event Description (GED) Algorithm [6]. Reconstruction performance can be evaluated by the energy scale and resolution, the reconstruction and selection efficiency, and the misidentification (fake) rate.

The reconstructed energy can be further corrected by employing the regression analysis in the Toolkit for Multivariate Data (TMVA). Training variables including the photon SC raw energy, SC shape, and underlying event activity (see Figures 4 and 5 for example). More details may be found in Ref. [4].

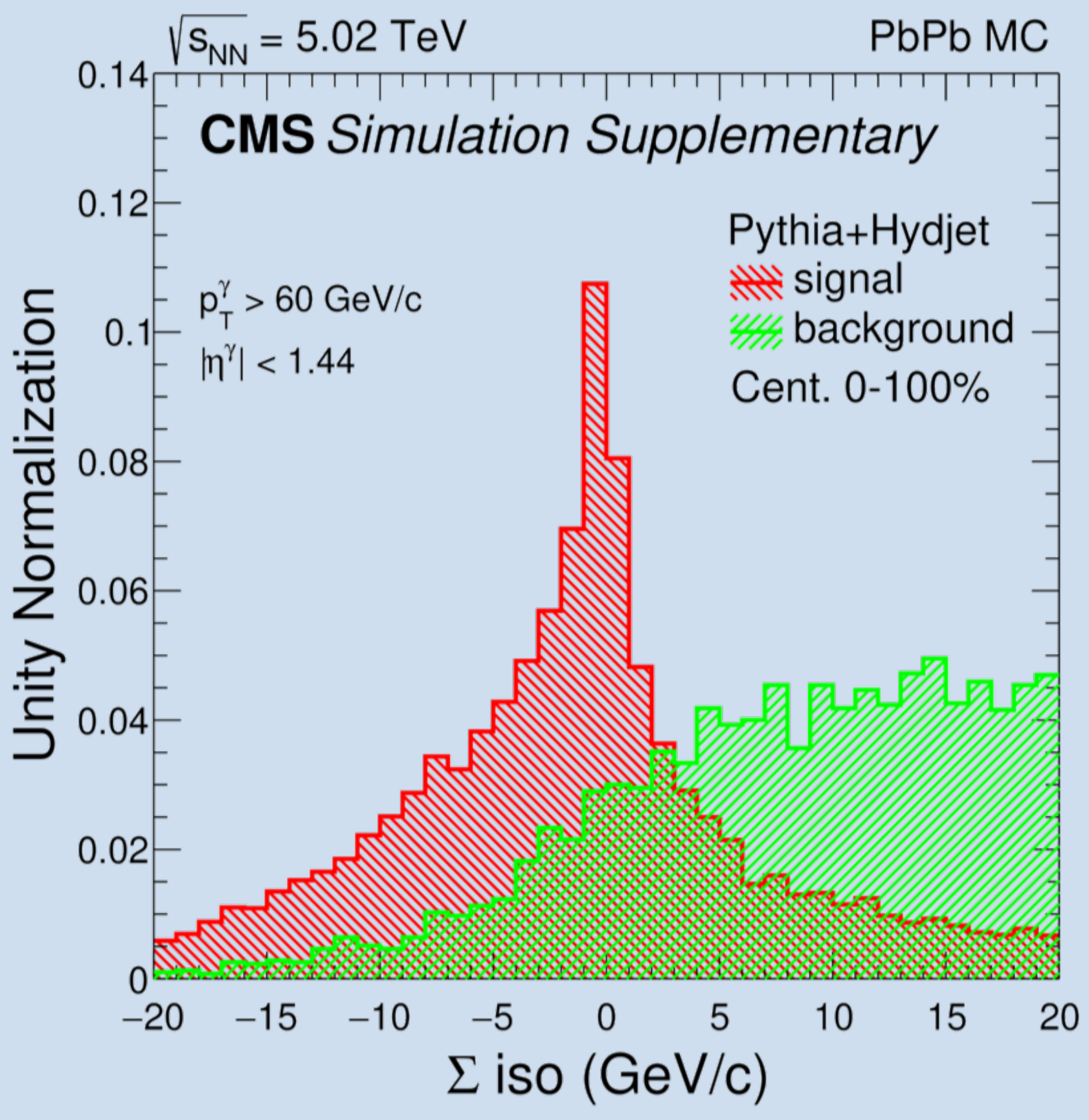

Figure 4. Distribution of the photon isolation variables sum [7].

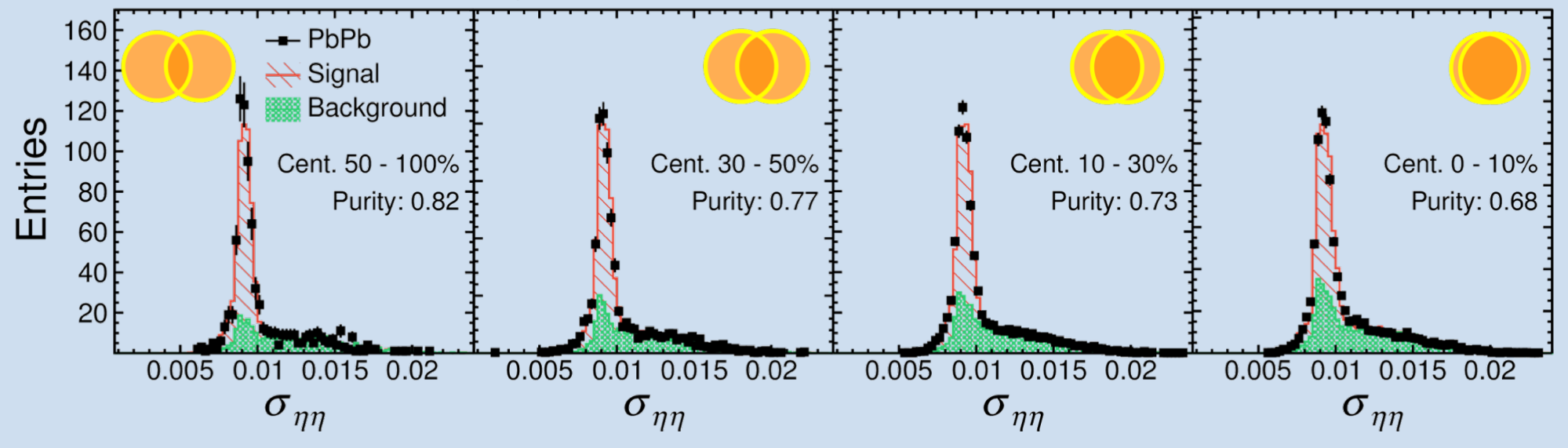

Figure 5. Centrality dependence of the shower shape variable $\sigma_{\eta\eta}$ [8].

Future prospects

Successful reconstruction and triggering on the photons allow measurements of photon-jet observables such as the photon-jet imbalance, and we can learn about medium response of the QGP from photon-jet analyses.

Now we are working on other photon-jet observables such as $\Delta\phi_{j\gamma}$ and jet-axis decorrelation δ_{jj} (measure of the angular difference between the Winner-Take-All and E-Scheme jet axes). Stay tuned!

References

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