Triggering on PbPb collisions with CMS in 2015

Kaya Tatar[1] and Krisztián Krajczár[1] on behalf of the CMS Collaboration
[1] Massachusetts Institute of Technology, Cambridge, Massachusetts, USA

Introduction: For the 2015 PbPb runs, the instantaneous luminosity provided by LHC increased by a factor of ~6 compared to the 2011 PbPb data taking period. This increase of collision rate required a significant re-work of the triggering strategy in CMS, both at the Level-1 (L1) and at the High Level Trigger (HLT) level. At L1, a trigger algorithm for selecting events of specific centralities was developed. This algorithm was used in concert with the requirement of the presence of hard objects (jets, photons, muons, high-p_T tracks) in the event to record high-statistics central and peripheral data containing hard probes. A new L1 jet trigger algorithm was also developed, which was capable of performing underlying event subtraction already at L1. At HLT, minimum-bias triggers had the largest fraction of bandwidth allocated. The trigger menu also included high-rate photon, muon, and jet triggers, as well as special triggers for central events, for events with large and small azimuthal anisotropy, for events containing J/ψ and Upsilon states, Z bosons, for ultra-peripheral collisions, for high-p_T tracks, for b-jets, and for D-mesons.

PbPb physics with CMS: CMS detector has already proven its excellent physics potential in PbPb collisions. The silicon tracker, located in the 3.8 T magnetic field, allows for precise charged particle tracking in $|\eta|<2.5$ with a momentum resolution of 1.5% at 100 GeV/c. Inside the solenoid, a sampling hadron calorimeter (HCAL) resides covering $|\eta|<3.0$. The forward calorimeters (HF) extend the coverage up to $|\eta|=5.2$ and are used to determine the collision centrality. CMS also has excellent electromagnetic calorimeters (ECAL) within $|\eta|<3.0$ and muon detection capabilities in $|\eta|<2.5$.

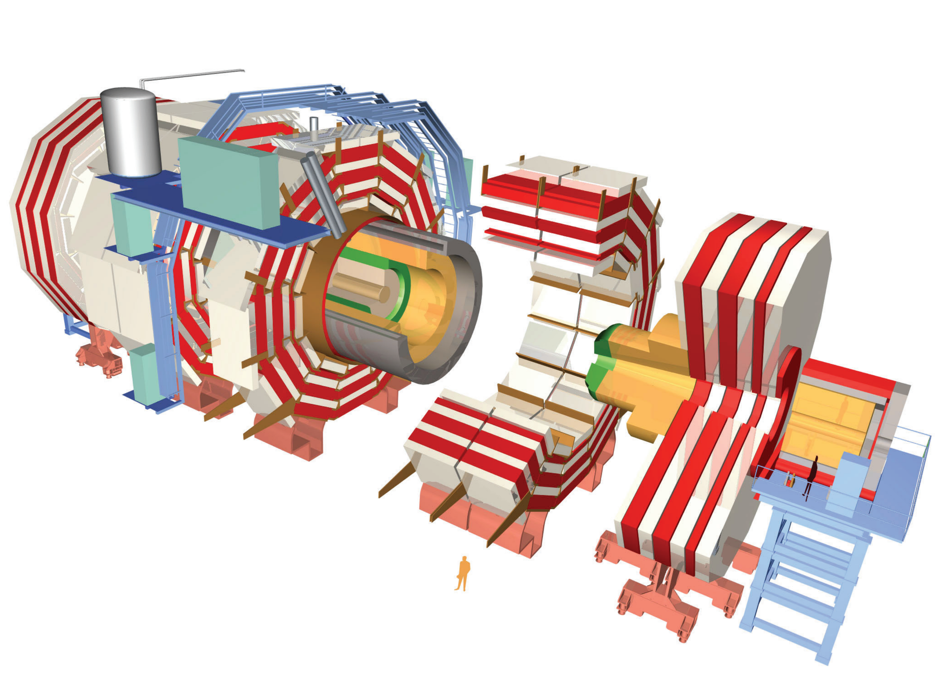


Fig. 1: Schematic view of the CMS detector

Triggering with CMS: CMS has a two-stage triggering system. The hardware-based L1 system provides fast trigger decisions to the HLT software, which is capable of running full offline-like event reconstruction online.

Upgrade of L1 calorimeter trigger for 2015: The L1 calorimeter trigger consists of the Regional (RCT) and the Global Calorimeter Triggers (Stage-1). The RCT only has access to information from parts of the calorimeters, while the Stage-1 board (new in 2015) has information from the whole calorimeter. This allowed for the development of new L1 algorithms with high discrimination power.

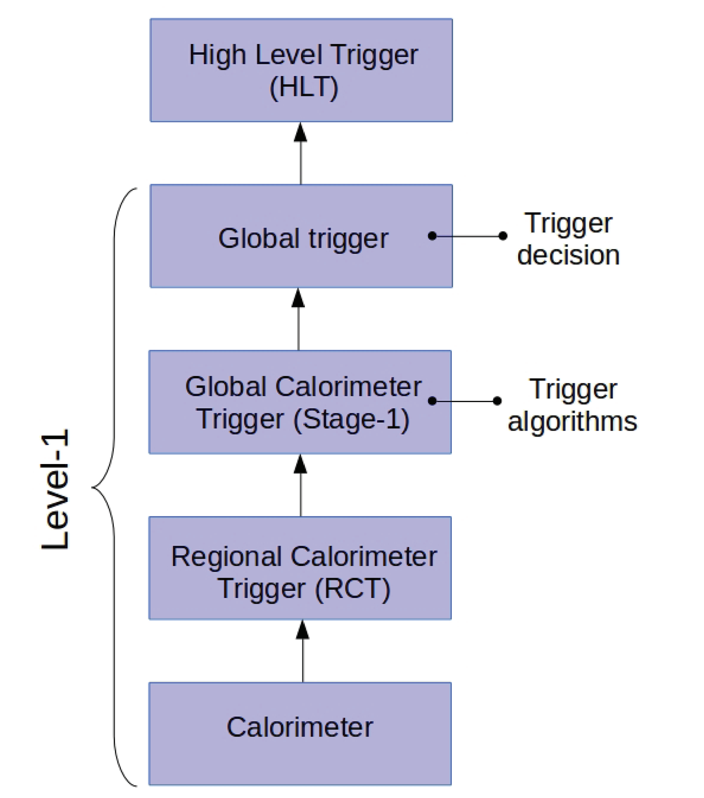


Fig. 2: Scatch of triggering system of CMS

Triggering on jets: In PbPb collisions, the jets reside over a large underlying-event background. Thus simple triggers based on energy deposited in the calorimeters are not responsive to changes in the trigger threshold; an underlying-event subtraction algorithm is to be applied already at L1. As the pp pile-up subtraction was shown to be inadequate in PbPb collisions, a PbPb-specific algorithm was written, which estimates the energy to be subtracted by averaging the energy of calorimeter regions in rings of ϕ. The resulting L1 "seeds" are used in HLT in an offline-like jet reconstruction algorithm, performing the "PU" subtraction. The collected data contains jets up to 1 TeV of E_T.

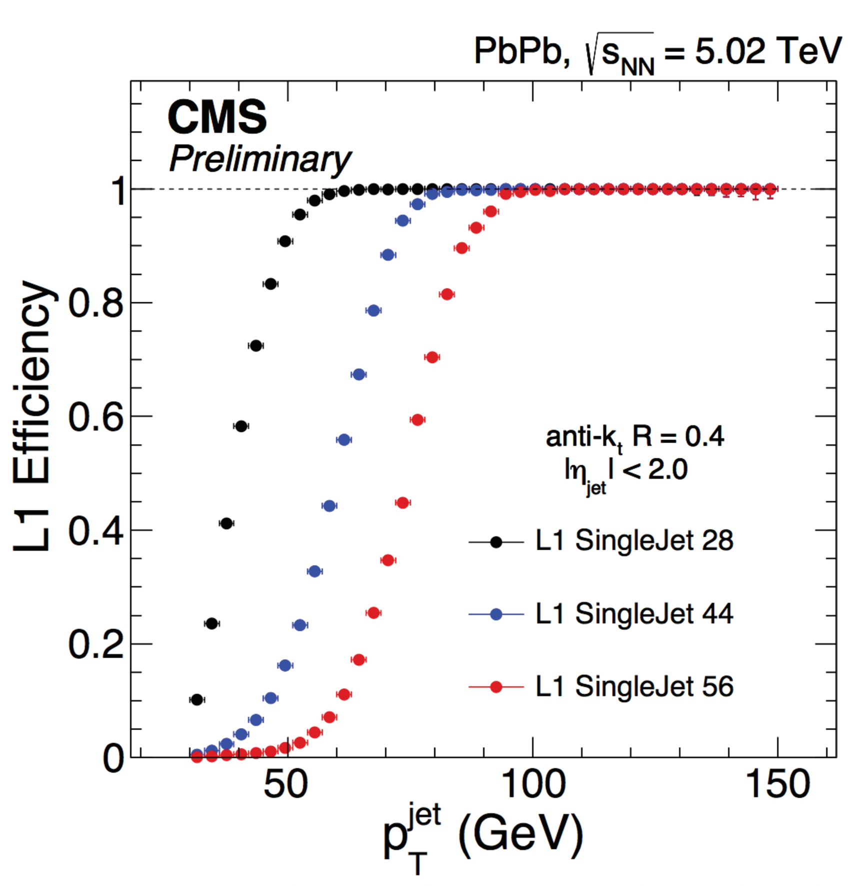


Fig. 3: L1 efficiency of jet triggeres. The L1 algorithm performs underlying event subtraction in rings of ϕ. The thresholds refer to the uncalibrated E_T of L1 jets.

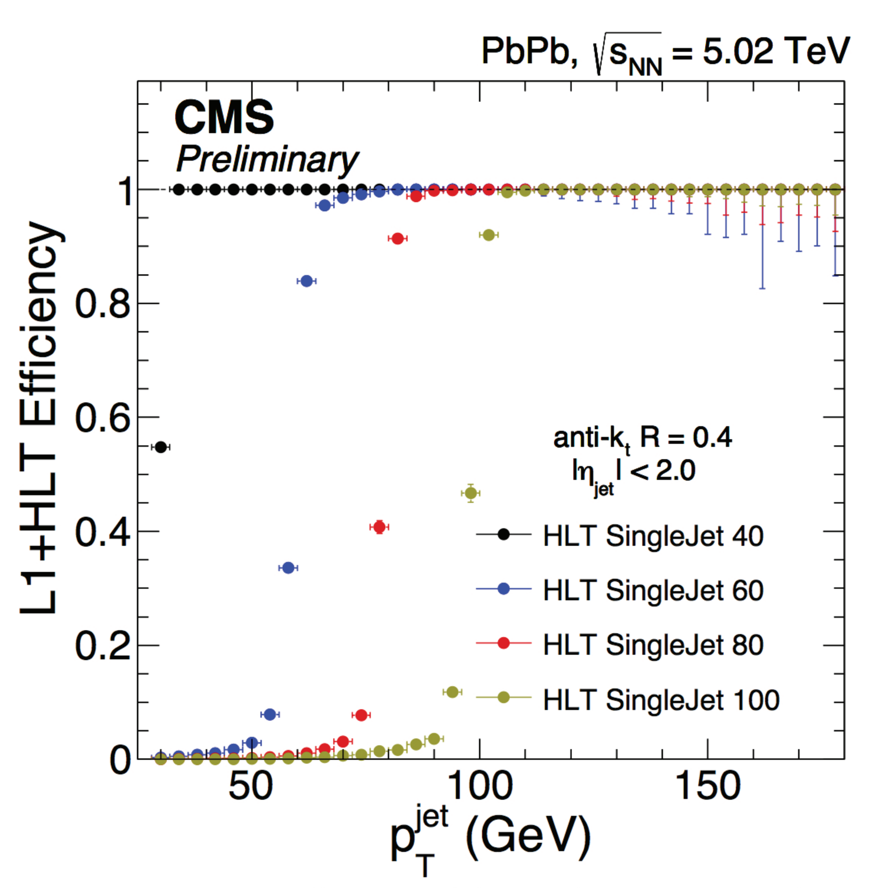


Fig. 4: L1+HLT efficiency of the single-jet triggers. The HLT paths employ the anti-k_T algorithm, and are based on calorimeter towers. The "PU" subtraction is used.

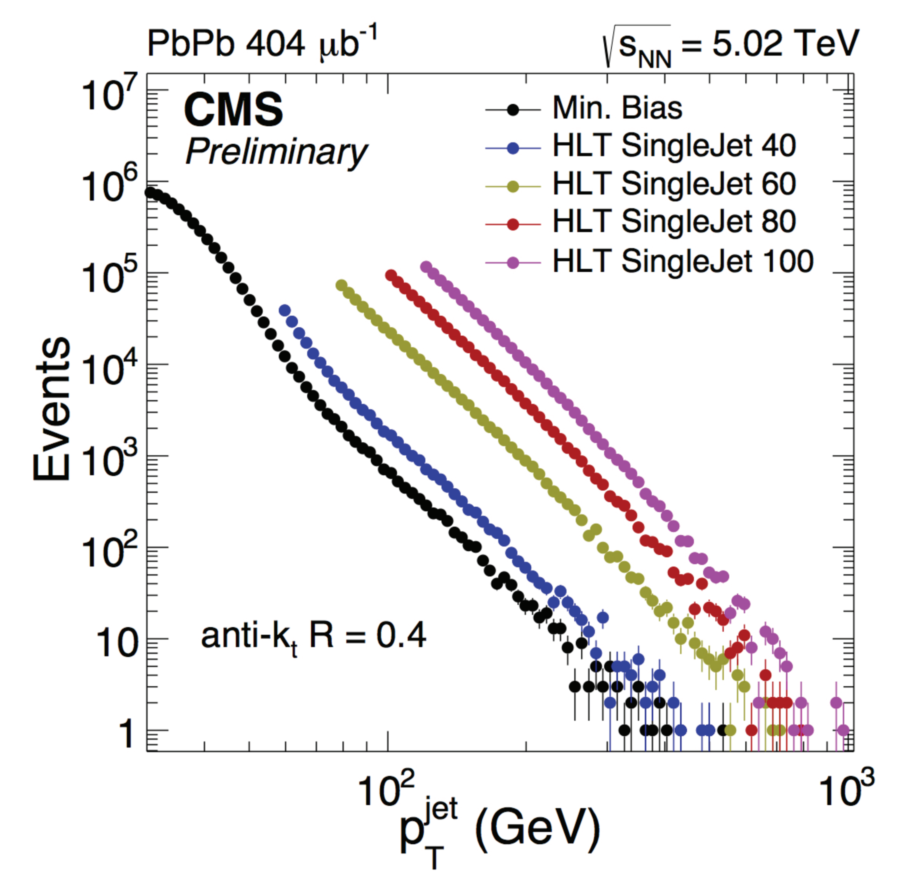
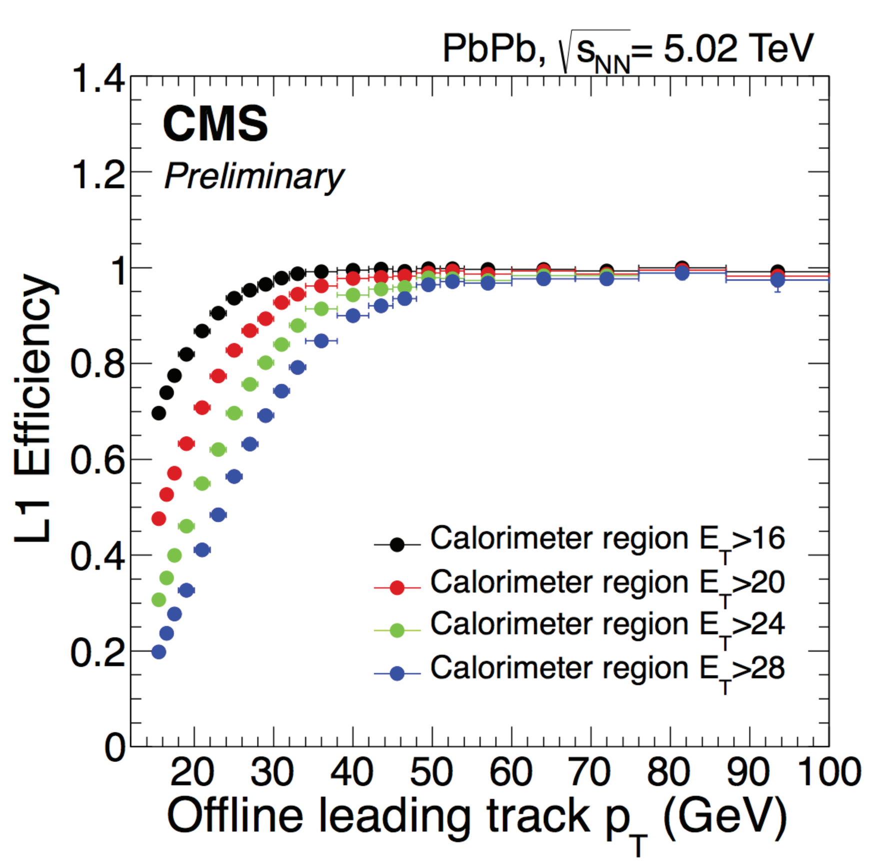
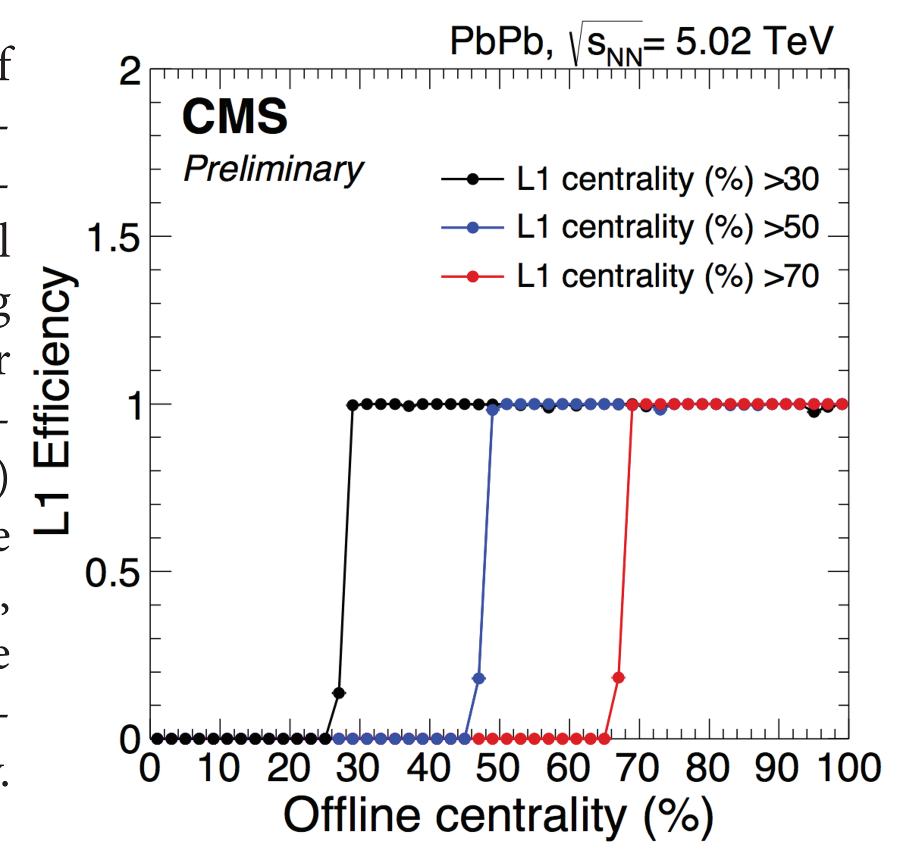


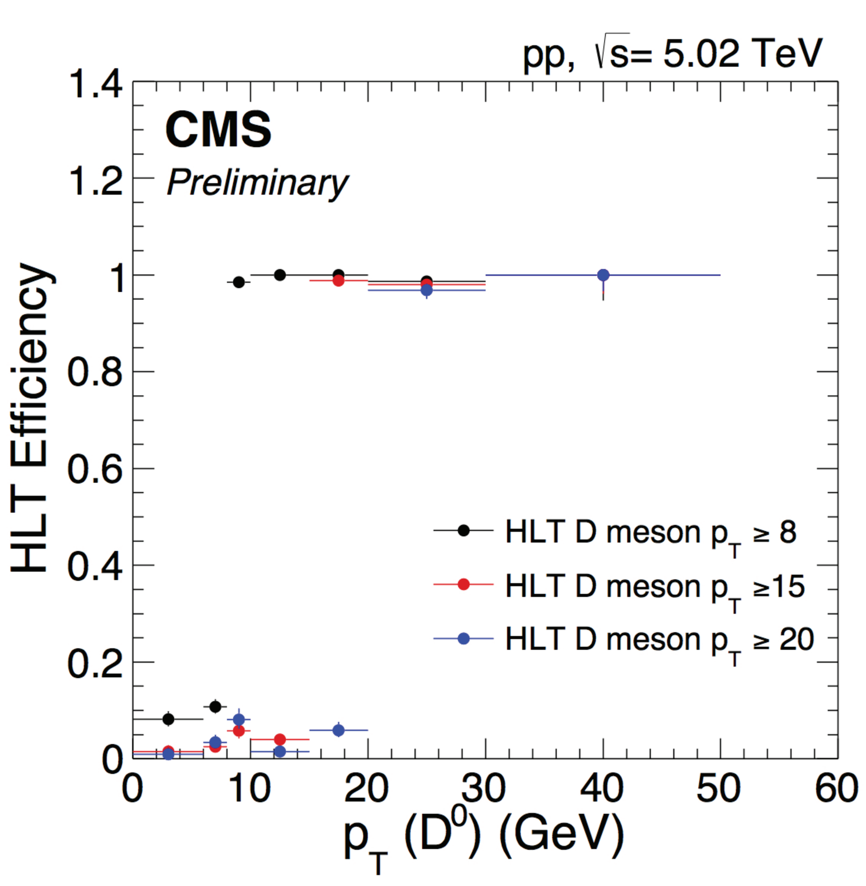
Fig. 5: p_T distribution of leading underlying-event subtracted, R=0.4 anti-k_T calorimeter jets. Statistics from triggers of different thresholds are shown.

Triggering on high-p_T tracks: With the L1 upgrade, CMS could trigger on the highest-E_T calorimeter region of the full detector. High-p_T tracks usually leave such signals. Seeding the HLT track triggers by such L1 bits was found to give a better performance than seeding by L1 jet objects. At HLT, a global track reconstruction is performed using an online version of the iterative tracking algorithm with smaller number of iterations and stricter track selections. The plot on the right shows the efficiency of the described L1 triggers as a function of the leading-track p_T.

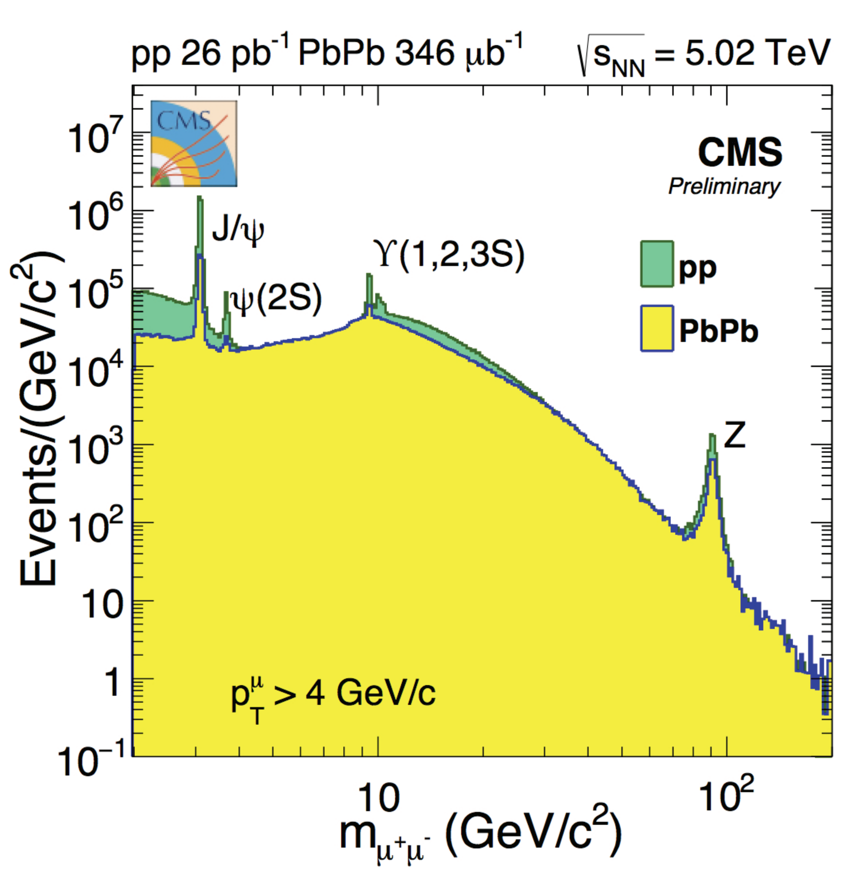


Triggering on event centrality: Production of hard probes scale with the number of binary nucleon-nucleon collisions. To keep low-threshold hard objects coming from peripheral collisions unprescaled, an L1 trigger selecting specific centralities was designed. The trigger computes the sum of the E_T of the HF calorimeter regions, and uses a Look-Up Table (LUT) to associate the sums to event centralities. The LUT was first derived from simulated events, then it was updated based on the first data. The plot on the right shows the efficiency of the centrality trigger as a function of offline centrality.





Triggering on D mesons: Probing the energy loss of heavy-flavour quarks in the quark-gluon plasma is an important physics program of the CMS HI program. During the 2015 PbPb and pp reference runs, both b-jet and D-meson triggers were deployed. At L1, the triggers relied on minimum bias and jet seeds. At HLT, the D meson trigger ran global track reconstruction, including the reconstruction of displaced tracks of secondary origin. Events were saved if the mass of the D-meson candidates were compatible with the expected mass. The plot on the left shows the HLT efficiency of the D-meson triggers in the pp reference data.



Triggering on muons: A multi-layered trigger strategy was applied to trigger on di-muon events. The inclusive trigger, with no p_T requirement on the muons, was run prescaled for most of the time. To keep the di-muon signal events unprescaled, triggers selecting specific centralities and performing global reconstruction of muons (using signals both from the muon and from the tracking detectors) were employed. The good momentum resolution of globally reconstructed muons allowed for filtering the dimuon events based on the invariant mass of the muon pair.