

CMS Run3 Triggering For Long Lived Particles

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on behalf of the CMS collaboration

Searching for long-lived particles at the LHC:
Seventh workshop of the LHC LLP Community

27/05/20

The CMS Trigger System

two level trigger system: L1 + HLT

- L1 has limited input:
 - ECAL, HCAL, Muon chambers only
 - limited information sent
 - 5x5 ecal towers, max 2 stubs per muon chamber, data quantized into 25ns steps
 - possibly some room to adjust the muon information sent within the trigger system
 - has hard limit of 100kHz
- HLT has complete information
 - HLT only lacks final calibrations and time
 - all information from detectors is available
 - however CPU limitations means can't run things like tracking on every event and the tracking that can run has to be quicker than offline
 - eg: tracking is pixel seeded with the exceptions of muons, no non-pixel iterations except for a few specific LL triggers
 - HLT output limited by the disk space & CPU time necessary to process data offline

In general, L1 is the constraint here as limited ways to distinguish prompt particles from long lived



Summary Current Long Lived Particle Triggers in CMS

Long Lived Triggers at CMS

three strategies for LL triggering at CMS

- use MET triggers
 - disappearing tracks, delayed jets
- use standard triggers
 - displaced vertices, emerging jets , HSCP
 - standard photon triggers can be used for ele/phos
 - analyses can also trigger on prompt objects in the event using these triggers
- use dedicated long lived triggers
 - displaced jet
 - displaced photon
 - displaced muons
 - stopped particles
 - disappearing tracks

when you can't trigger on the object, usually due to L1

signal is not sufficiently exotic that standard triggers work
note: often these triggers have higher rate budgets

dedicated triggers that either reject prompt background or adjust reconstruction to avoid use of tracker

Specific Long Lived Triggers (I)

note by default, CMS jets are particle flow jets, i.e. use the tracker, many displaced triggers use Calo jets instead

- displaced jet ([EXO-19-021](#))
 - Calo HT > 430 GeV with at least two jets with
 - ≤ 2 prompt tracks ($d_0 < 1\text{mm}$)
 - one associated displaced track ($d_0 > 0.5$, impact param sig > 5.0)
 - *runs dedicated displaced track iteration on candidate jets*
 - Calo HT > 650 GeV with at least two jets with
 - ≤ 2 prompt tracks ($d_0 < 0.5$)
 - for reference, inclusive PF HT trigger is > 1050 GeV
- displaced photon + HT ([EXO-19-005](#))
 - pho $E_T > 60$ GeV, PF HT > 350 GeV
 - standard EG with LL specific showershape and track veto
- stopped particles ([EXO-16-004](#))
 - veto bxs with colliding bunches
 - the L1 seeds with bx vetos are the only specific LL seeds in CMS

Specific Long Lived Triggers (II)

- displaced muons ([EXO-16-022](#))
 - use tracking and muon stations as normal triggers
 - no vertex constraint, no max d0 cuts
 - later versions have a min d0 cut to reduce rates
 - sensitive to displacements up to 0.1cm
 - dimuon > 43 GeV, e-mu > 38 GeV (ele uses pho trigger)
- very displaced muons ([CMS-DP-2019-028](#))
 - uses muon system only, no tracking
 - no vertex constraint at HLT
 - two muons with $p_T > 23$ GeV
- disappearing tracks ([EXO-19-010](#)):
 - Calo MET trigger > 105 GeV + isolated track with $p_T > 50$ GeV
 - otherwise PFMET > 120 GeV

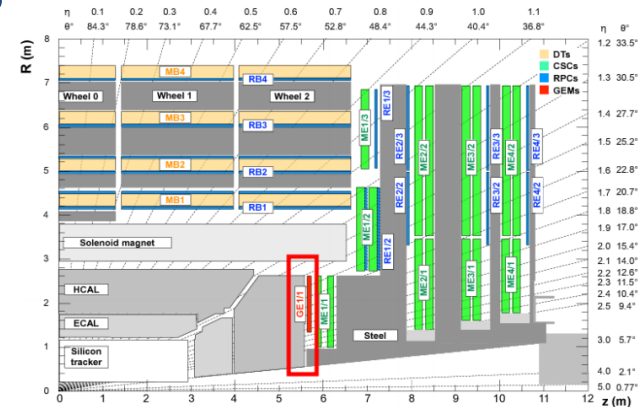


Summary of Improvements possible for Run3

CMS Detector Upgrades for Run3

- GEM detectors to supplement muons

- limited $|\eta|$ coverage
- might be able with CSC to provide pointing angle to ID displaced tracks
 - under study



- HCAL electronics upgrade

- most relevant to long lived searches, adds significant timing and depth information

- GPU based tracking*

- pixel tracks can be produced for a significant fraction of HLT events
- could be useful for vetos?

Run 3 HCAL

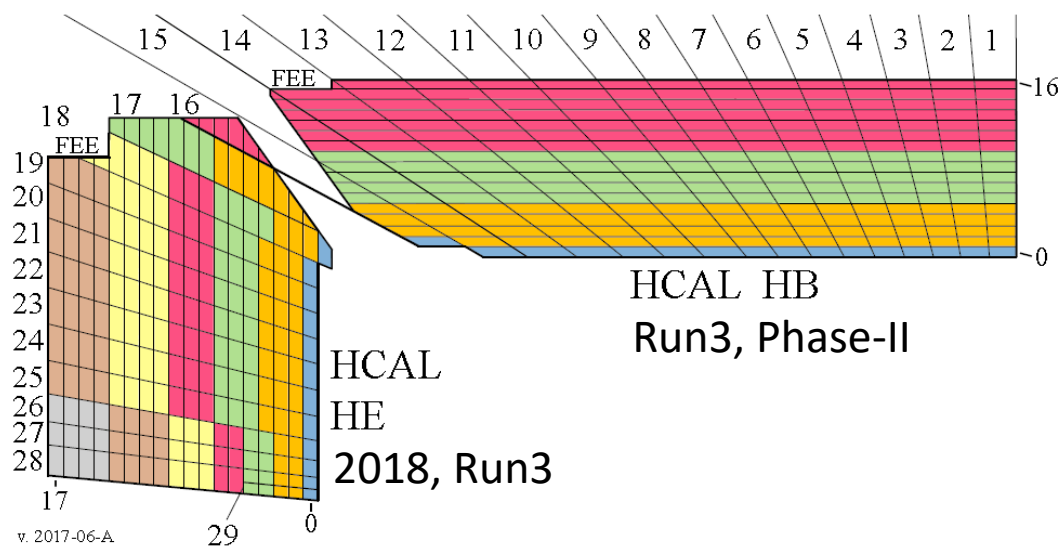
CMS HCAL has had its detector electronics upgraded

- now read out in 4 depths (barrel) and up to 7 (endcap)
 - endcap was in place 2018 but so far not exploited in the trigger

- new TDC with 0.5ns resolution -> timing at the HCAL
 - so far this has only been possible for the ECAL
- much lower noise

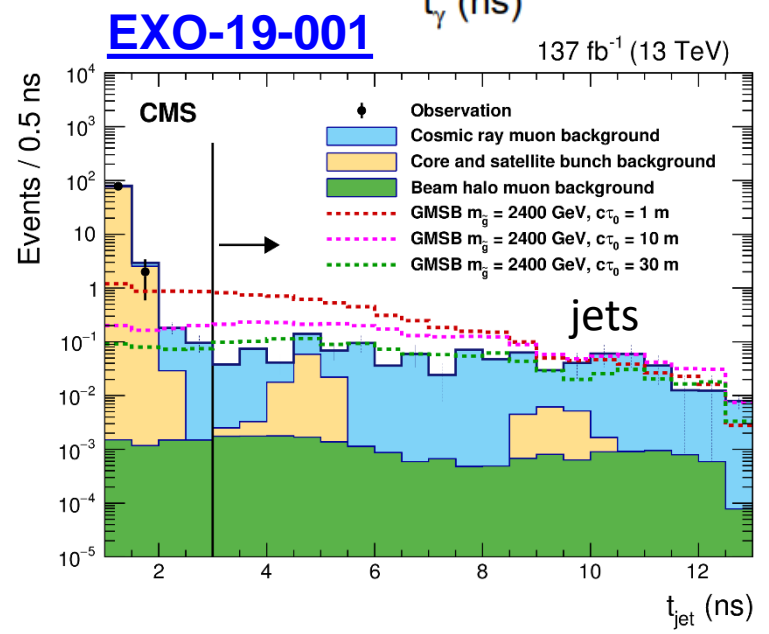
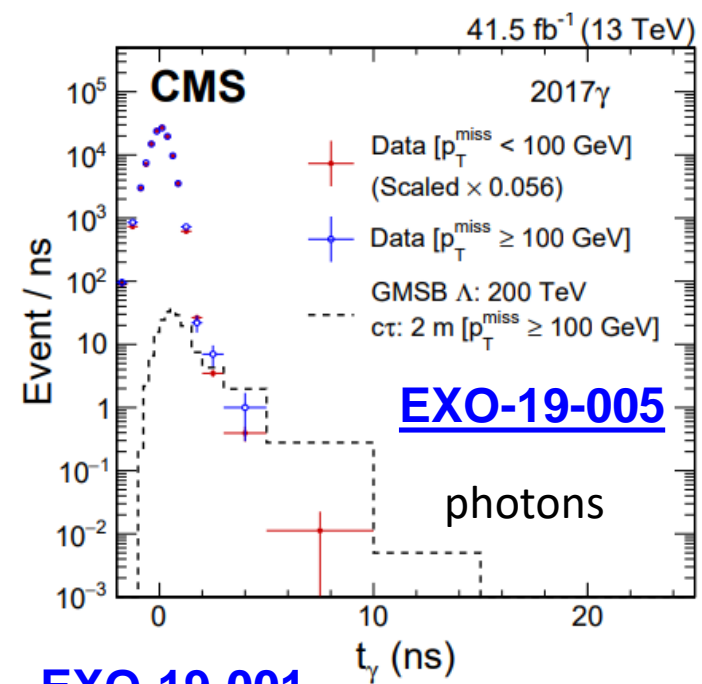
this information is also available at the L1 with limited precision

- could be very useful for long lived triggers



ECAL Timing

- used offline extensively
 - default reco has timing cuts in place to reject out of time events, dedicated LL reco offline without these cuts so it can be used as a discriminating variable
- not currently available in HLT for three reasons
 - in Run1, it was unclear how stable this would be in the HLT
 - we can now of course test this
 - didn't significantly reduce rate of prompt triggers and risk of damaging EXO program was too great
 - never put a cut on the trigger unless you *need* that cut
 - nobody requesting it...
- note: ECAL timing not available in L1



Muon Triggers

L1 muon system limited in two ways:

- pt measurement is 2 stations + vertex constraint
 - means long lived particles pt can be reconstructed low
 - currently investigating how / if this constraint can be removed as well as using more muon stations for p_T
- only two stubs per CSC/DT muon station sent
 - no jet decays in muon system as ATLAS has
 - looking at how to overcome this limitation -> see S. Dildick's talk earlier



HLT is much less of a bottleneck here and can happily just do standard alone (ie no tracker) muon reconstruction with no vertex constraint

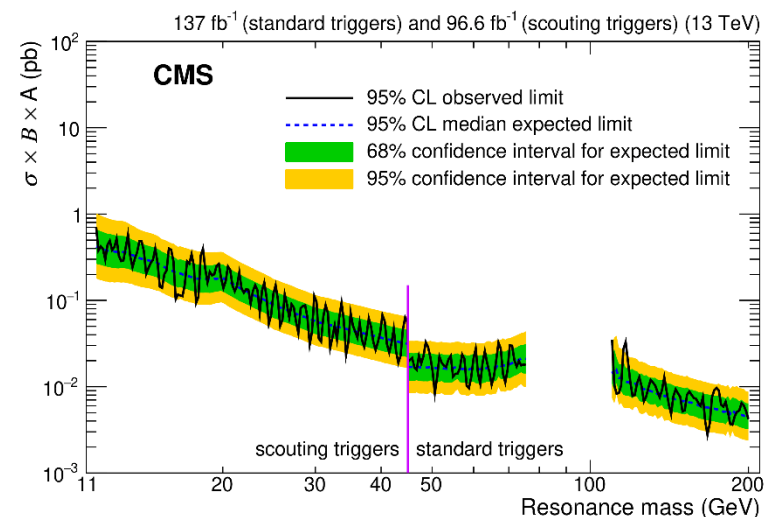
Summary for Object Improvements

- **Jets: significant L1 + HLT improvements possible**
 - new HCAL will increase CMS sensitivity to delayed or displaced particles with **depth and timing** information now available even at L1
- **Muons: significant L1 improvements being worked on**
 - L1 vertex constraint is an issue and work is ongoing to investigate if this can be mitigated
 - work ongoing to allow the L1 to detect showers in the muon system
- **E/gamma:**
 - ECAL timing could be attempted at the HLT if it is seen as useful

- **Taus:**
 - so far not a priority and it's a hard problem so would need strong motivation

EXO-19-018

- **Scouting / Parking:**
 - for prompt searches, CMS lowers the threshold of selected objects significantly by only writing out the HLT quantities and not the RAW data
 - same could be expanded to LLP searches if L1 is not limiting factor



Outlook

- perfect time for long lived trigger development at CMS
 - HCAL upgrade brings new long lived triggering capabilities to CMS
 - with beam over a year away, sufficient time to develop new triggers although work needs to be underway soon
- a wish list of topologies would be highly useful
 - limited person power in the trigger but help could be available if a well defined target is in place
 - crazy ideas are welcome
- the stronger the physics case the easier it is to assign a higher HLT bandwidth to a search



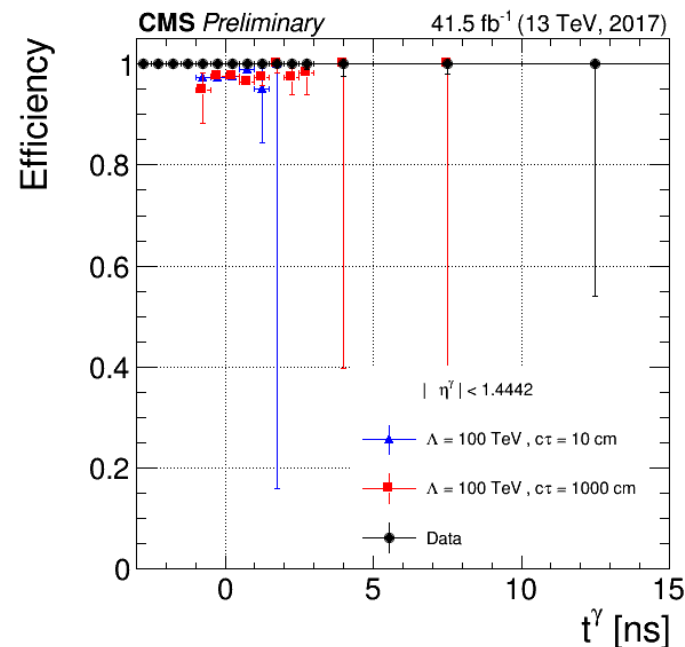
backups

Jet Triggers

- standard Particle Flow HT triggers
 - displaced vertices
- Calo HT triggers + prompt jet veto
 - displaced jets
 - uses tracking to veto on prompt jets, allows significant reduction of HT threshold
- note in both cases key limitation is L1, there is currently no way to distinguish prompt from long lived jets at L1 so we are stuck with high L1 thresholds

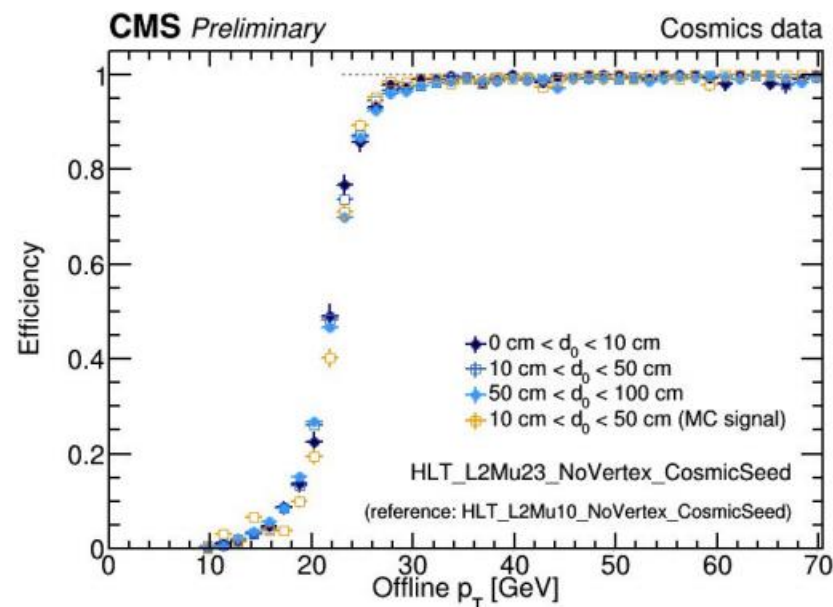
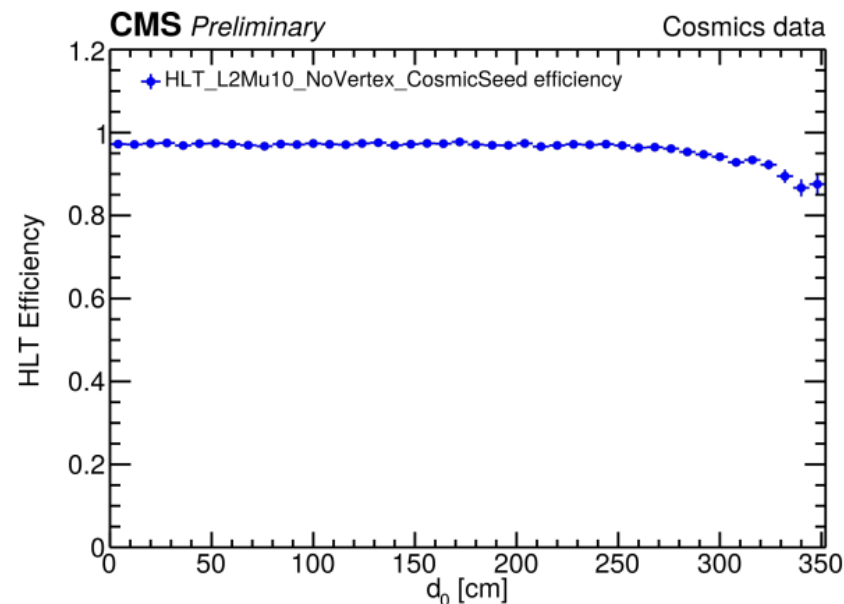
E/gamma Triggers

- no dedicated electron triggers
 - use generic or long lived specific photon triggers (ele, pho reco at L1 + HLT is identical except any track requirements)
- displaced photon trigger:
 - standard photon reco + specific displaced object ID
 - ID is based on showershape and isolation, so far does not use timing

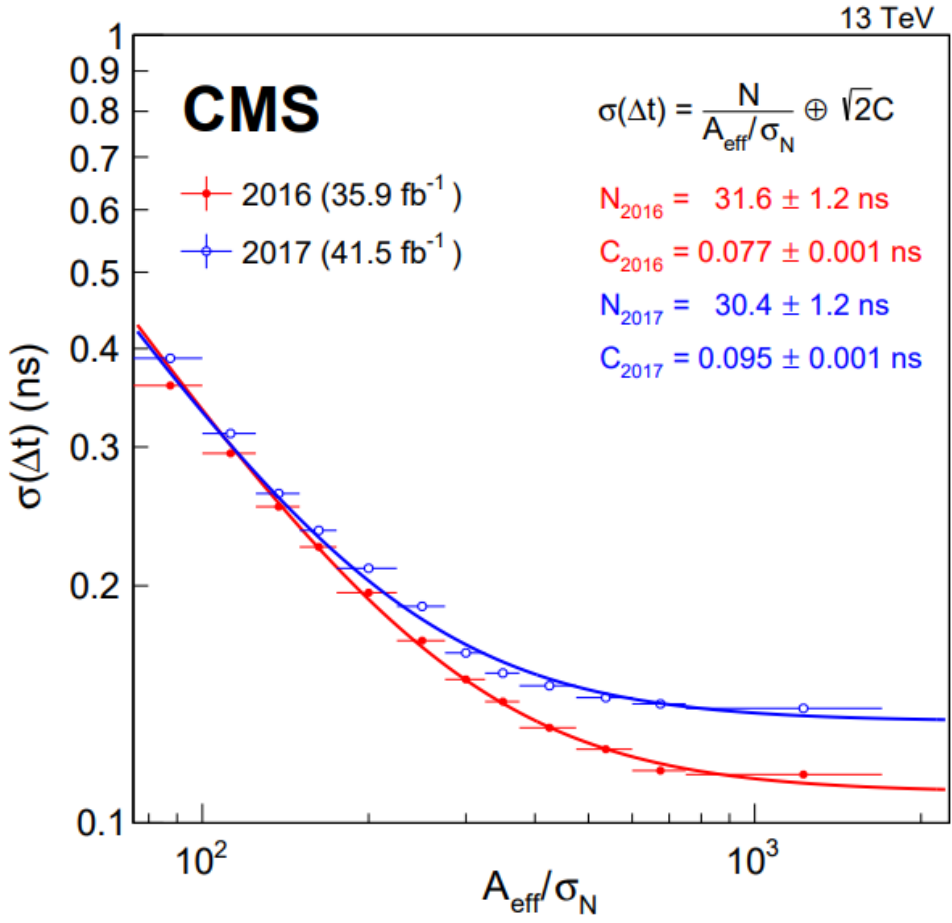


Muon Triggers

- Several dedicated displaced muon triggers at CMS
- have both triggers solely use the muon system (L2 in CMS speak) and triggers that run looser selections but with tracking
- cross triggers exist with photons
- major issue: although well above L1 thresholds, L1 pt measurement is vertex constrained which means displaced muons can be measured to be a much lower pt
 - looking into this



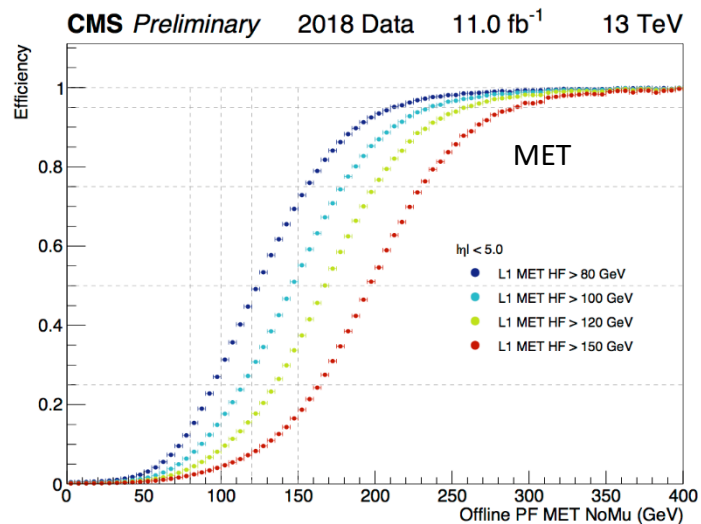
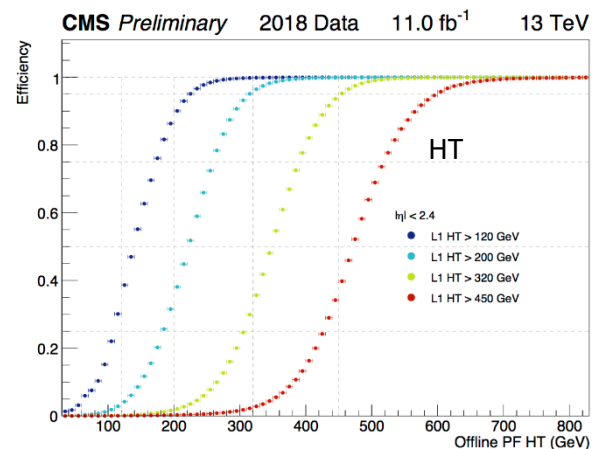
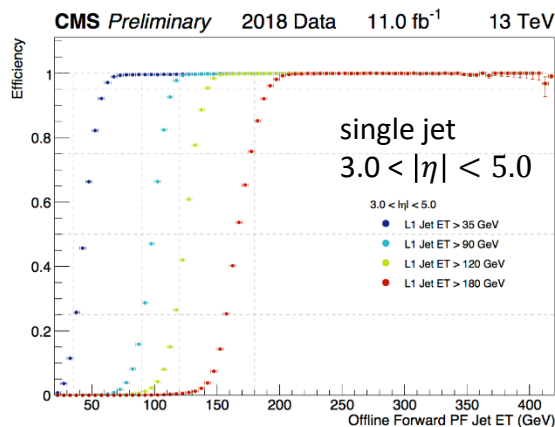
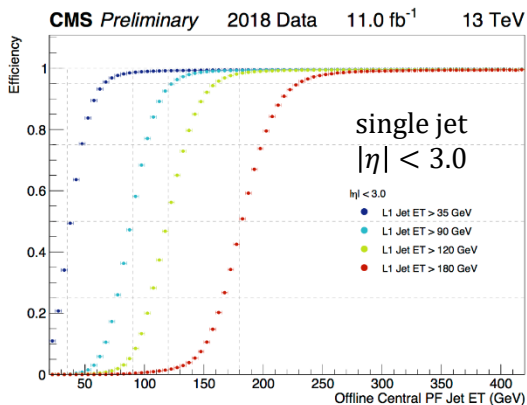
ECAL Time Resolution vs Amplitude



[EXO-19-005](#)

L1 Turn ons: DP-2018/40

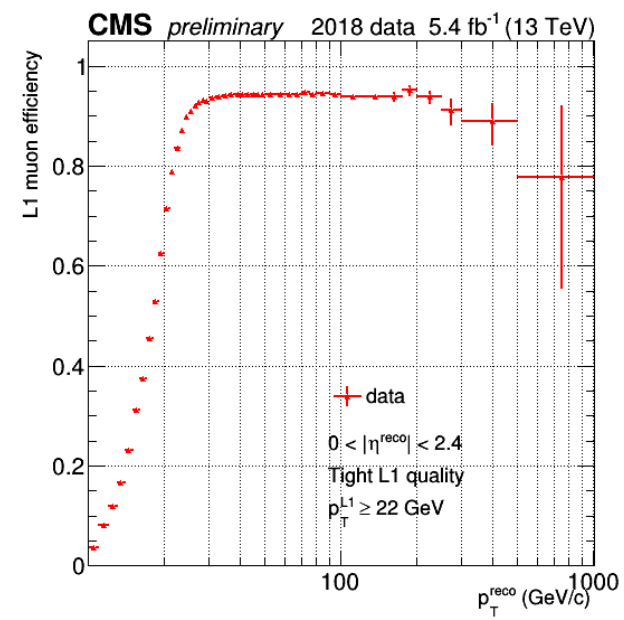
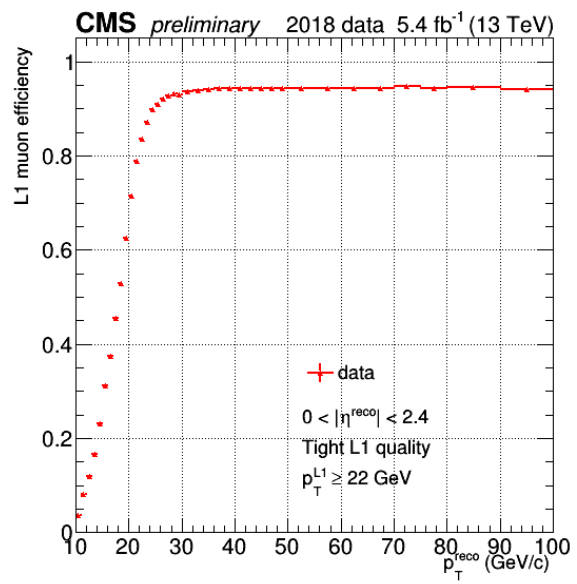
<https://twiki.cern.ch/twiki/bin/view/CMSPublic/Level1TriggerJetsAndSumsPerformance2018>



- L1 jet turn ons

L1 Turn ons: DP-2018/44

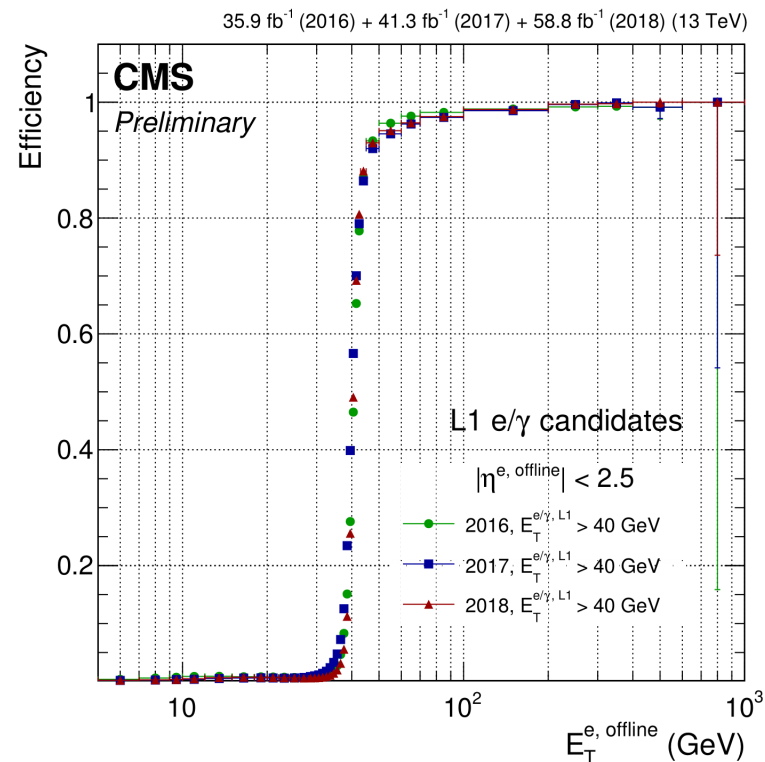
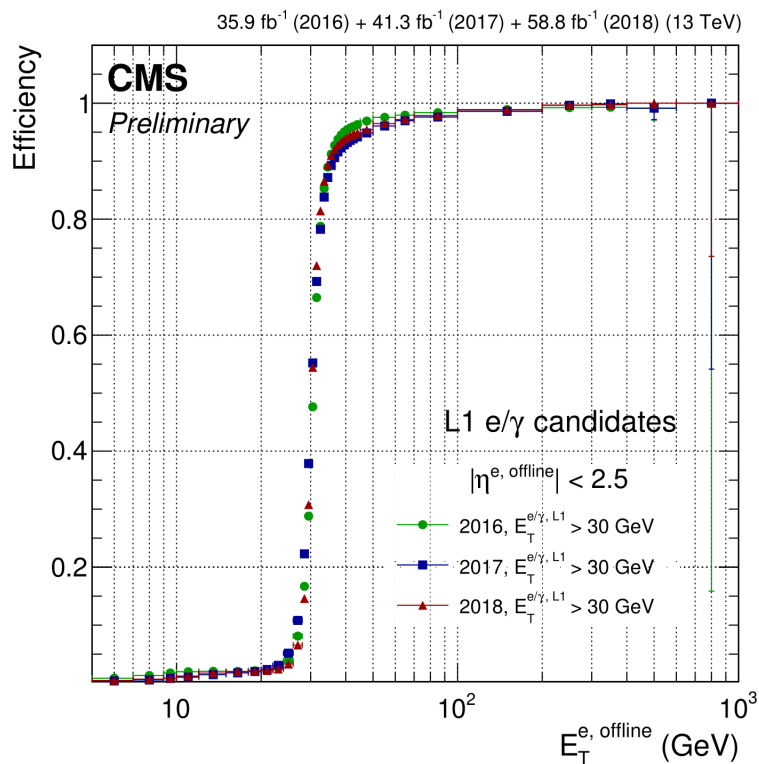
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- L1 Muon Turn ons (prompt)

L1 Turn ons: DP-2019/20

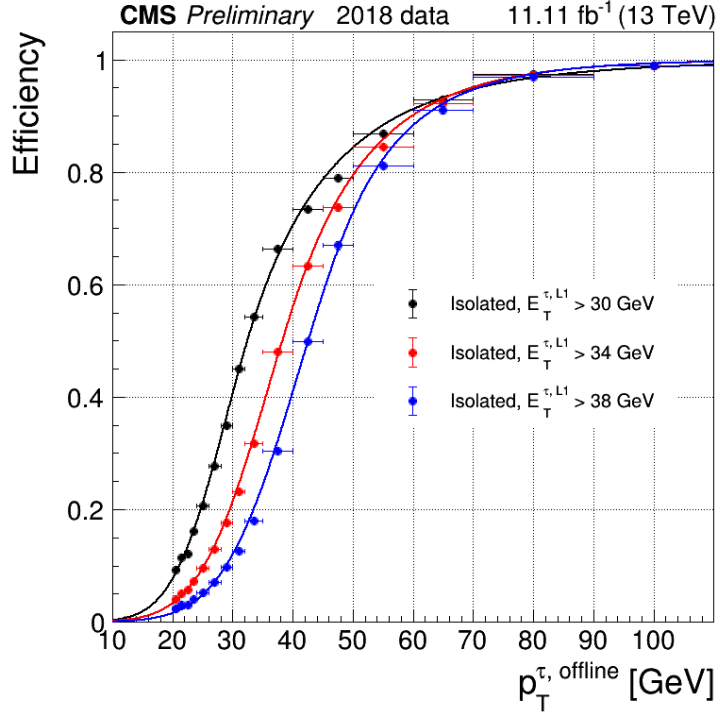
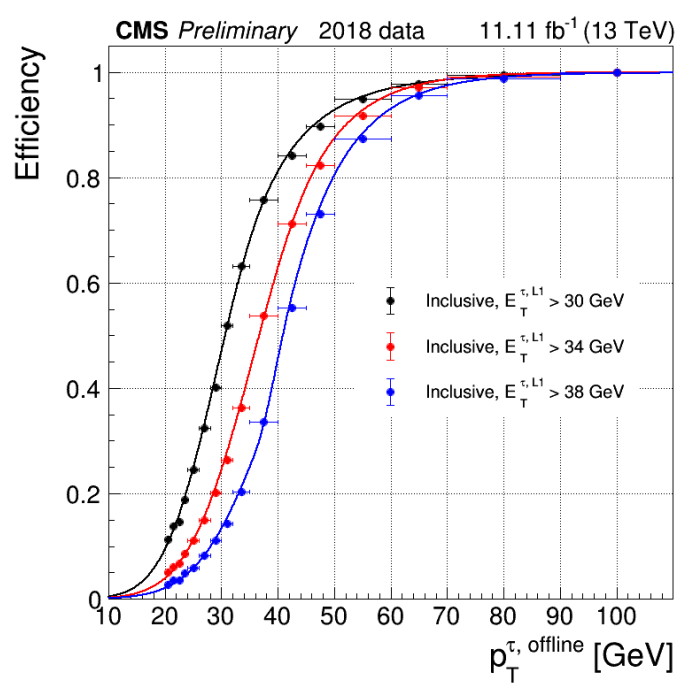
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- L1 EG Turn ons (prompt)

L1 Turn ons: DP-2018/40

<https://twiki.cern.ch/twiki/bin/view/CMSPublic/Level1TriggerTauPerformance2018>



- L1 Tau Turn ons (prompt)