Performance of the ATLAS High Level Trigger in the 2011 and 2012 run

Catrin Bernius
Louisiana Tech University

On behalf of the ATLAS TDAQ Collaboration

CHEF 2013
Calorimetry for the High Energy Frontier

Paris, France
April 22-25, 2013

LOUISIANA TECH UNIVERSITY

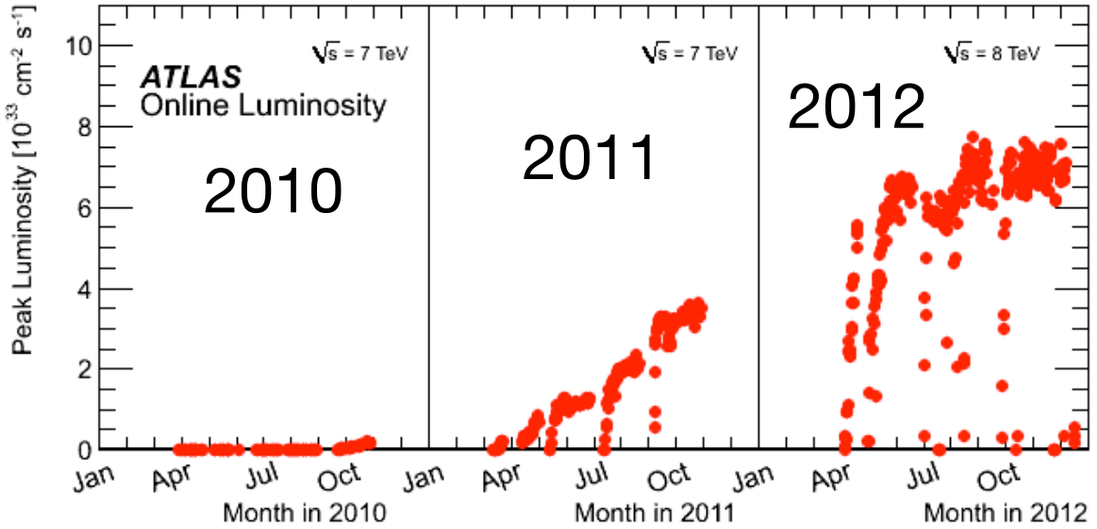
Outline

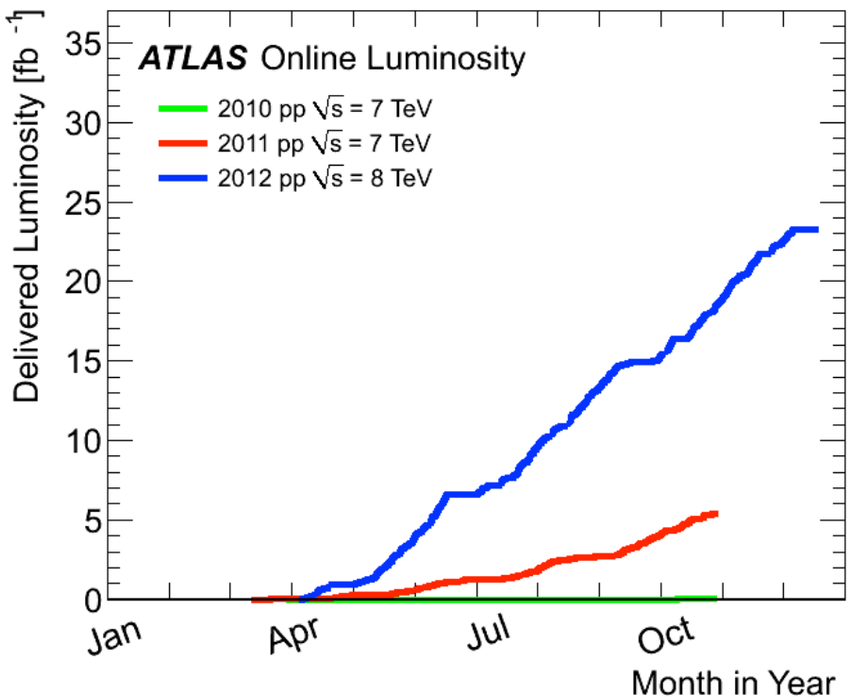
- Introduction
  - LHC Luminosity Challenge
  - The ATLAS Trigger System
- HLT Trigger Performance
  - τ trigger
  - Transverse momentum trigger (MET trigger)
  - Jet trigger

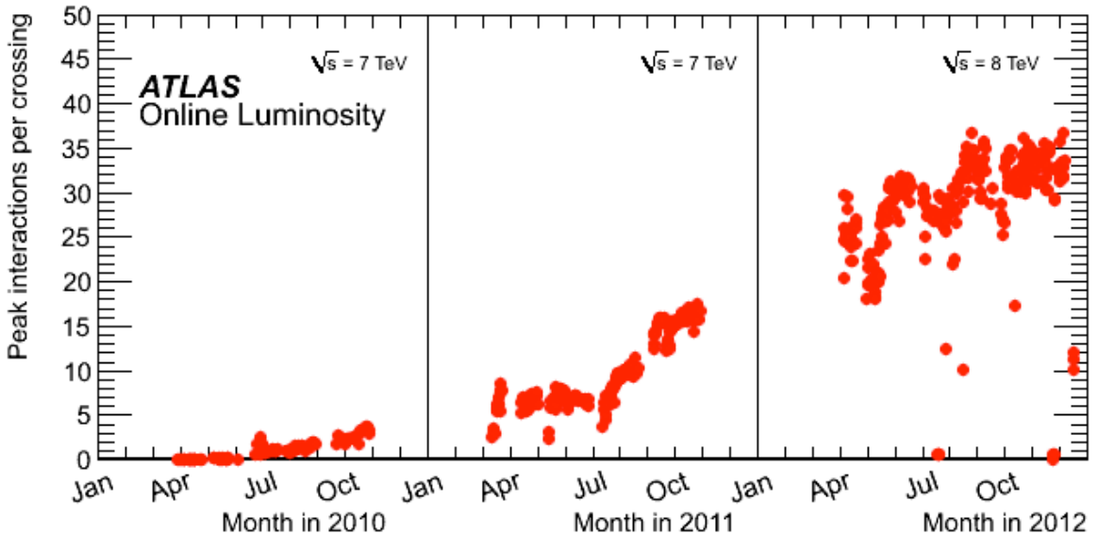
The LHC Luminosity Challenge

LHC had an extremely successful luminosity ramp up

- Rapid changes in trigger to follow six orders of magnitude changes in luminosity during first 3 years
- In 2011, the luminosity increase came mostly from more bunch luminosity
- Challenge for trigger to keep efficiency and improve rejection with the increasing high pile-up conditions



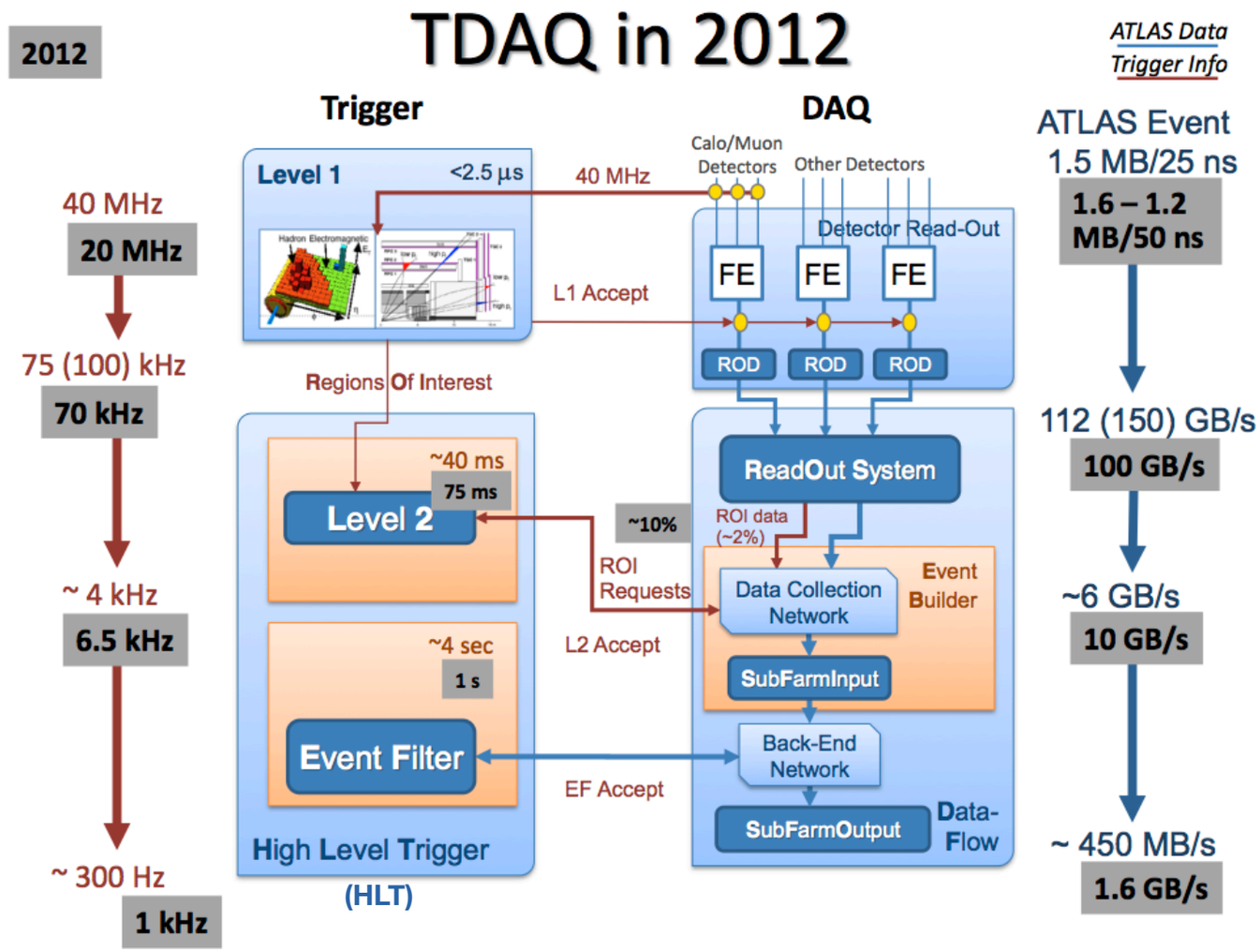




The ATLAS Trigger System

Three-tiered system designed to select events of interest for the diverse ATLAS physics program:

- Level 1 (L1):
  - hardware trigger
  - uses coarse granularity data from calorimeter and muon detectors
  - identifies Region-of-Interest (RoI)
- Level 2 (L2):
  - fast software algorithms
  - accesses full granularity data within RoI (2% of total event size)
  - adds tracking and topological cuts
- Event Filter (EF):
  - offline algorithms
  - exploits the seed from L2 using full event data



Nomenclature:

- Chain: one full L1 → EF selection sequence
- Menu: full set of chains and prescale factors, typical menu has ~500 chains

Tau Trigger Performance

ATLAS-CONF-2013-006

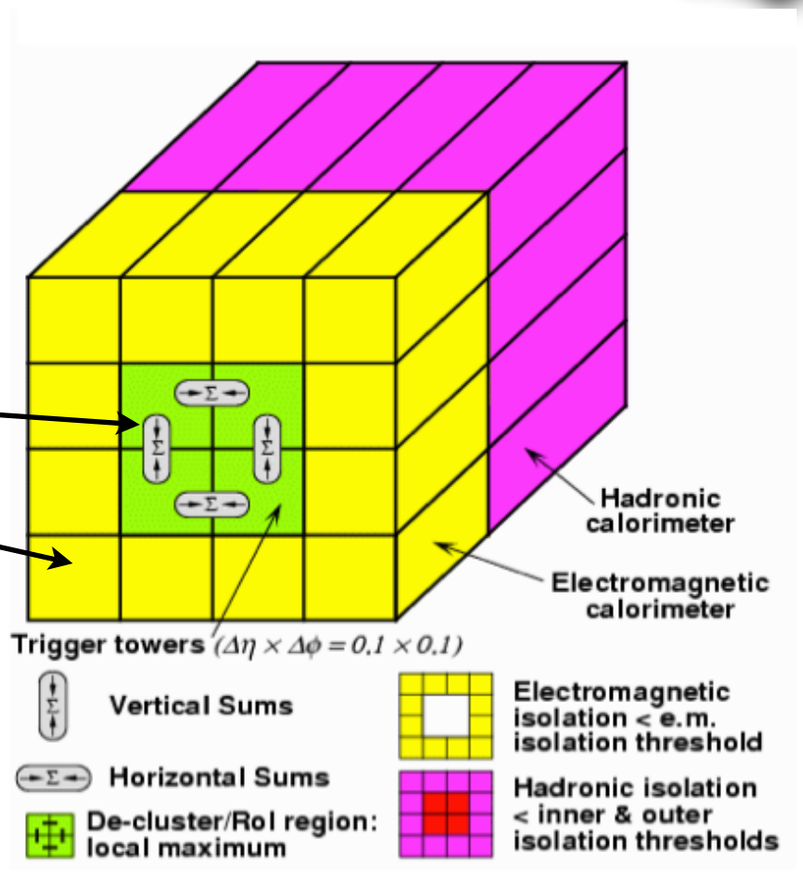
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TauTriggerPublicResults

ATLAS EXPERIMENT

LOUISIANA TECH UNIVERSITY

The ATLAS Tau Trigger System

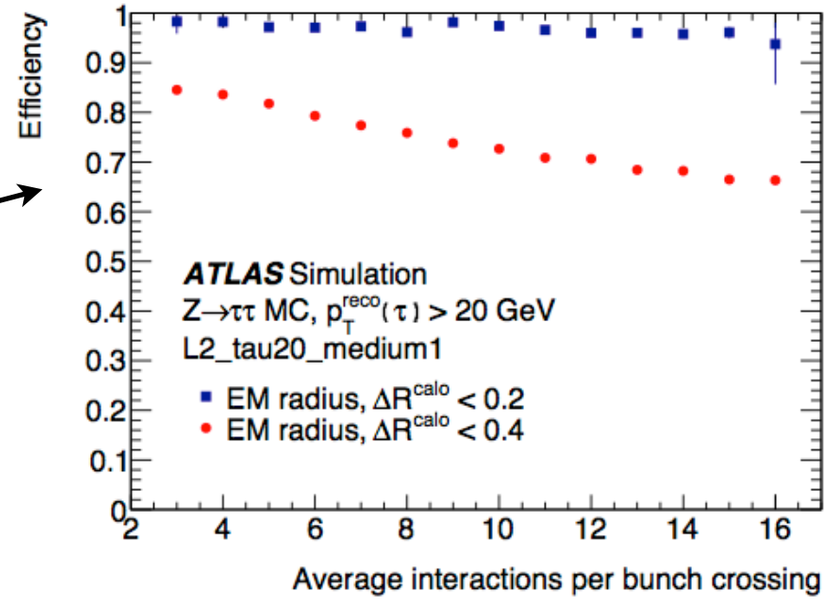
- Level 1
  - using electromagnetic (EM) and hadronic (HAD) calorimeter towers to calculate
    - energy in core region
    - isolation region around the core
- Level 2:
  - tracking and calorimeter-based information used to exploit hadronic τ characteristics and discriminate from multi-jet background
    - low track multiplicity
    - narrow collimated jet
    - isolation in surrounding region



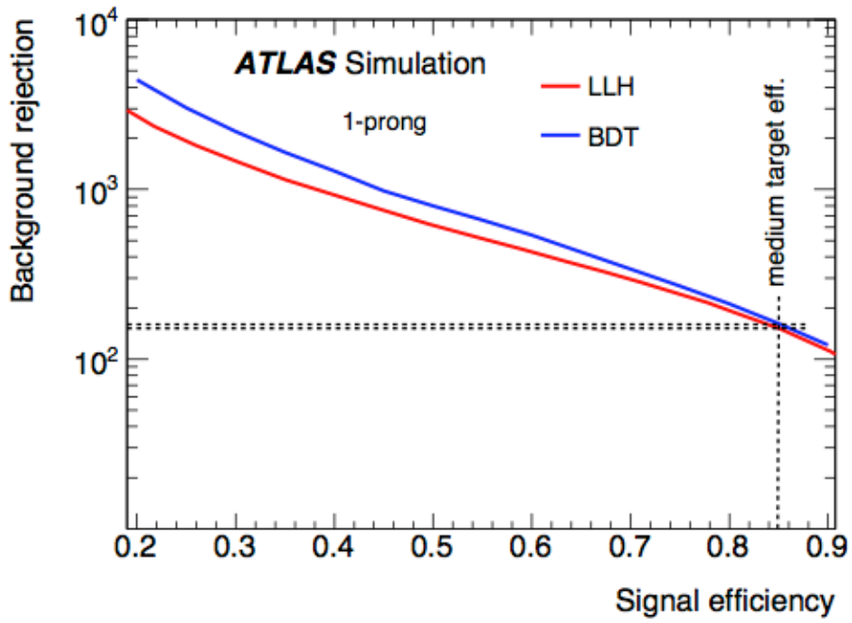
- Event Filter:
  - complete event information for full reconstruction of τ candidates with algorithms similar to those used offline

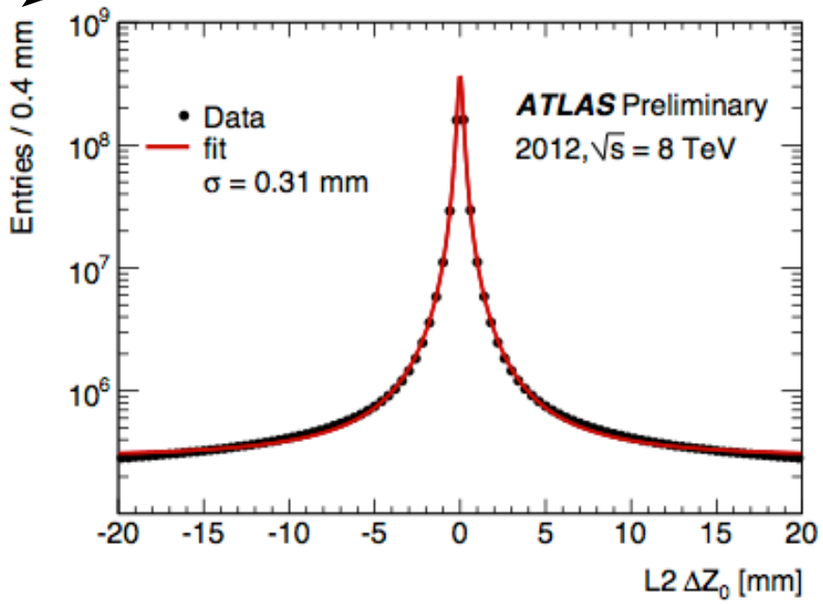
Improvements for 2012

- L2 improvements made for 2012 data taking period w.r.t. pile-up robustness
  - Calorimeter based selections:
    - Reduced cone size definition (from 0.4 to 0.2)
      → almost no pile-up dependence
    - Variables to apply selection on e.g. total transverse energy
  - Tracking based selections:
    - Threshold of $\Delta z_0 < 2$mm measured with respect to leading track at L2 and EF → removes contributions of tracks not coming from the same vertex
    - Addition of new selection variables



- EF Improvements
  - Traditional cut-based triggers replaced with multivariate triggers (Boosted Decision Trees (BDTs), Log Likelihood (LLH))

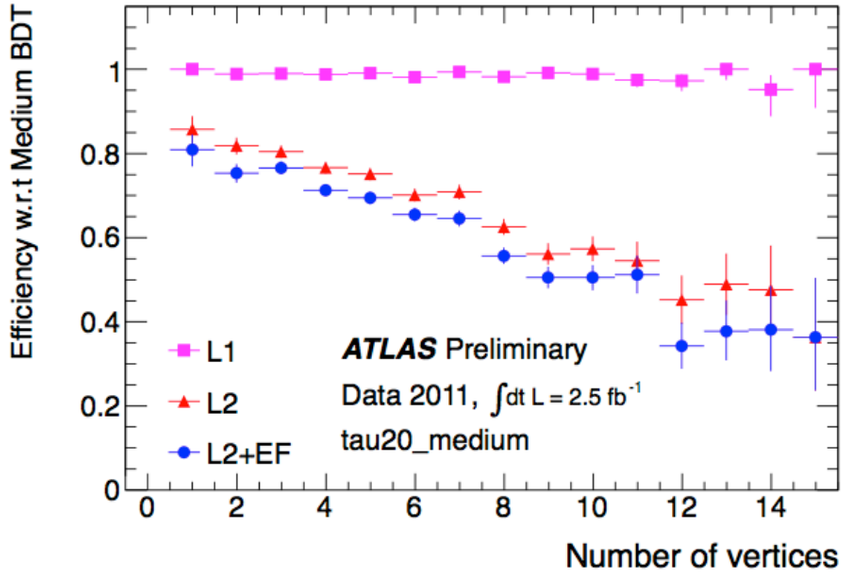


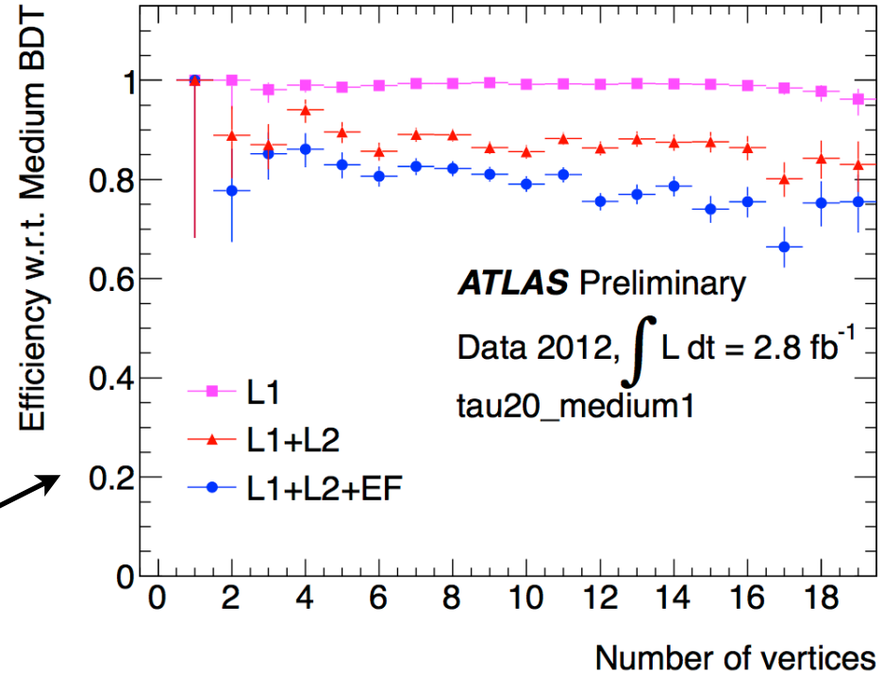


Performance in 2012

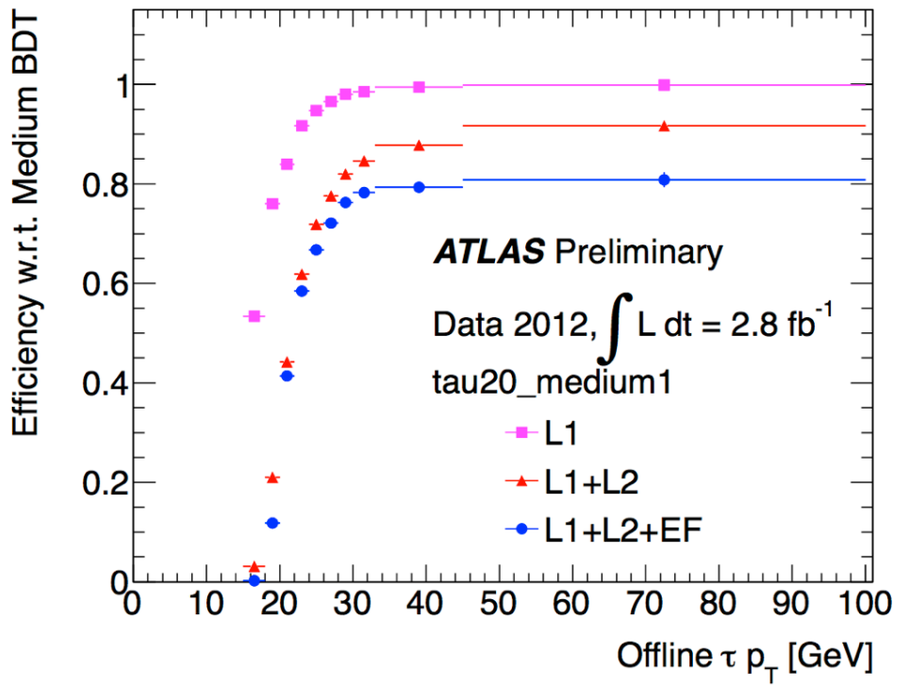
- Pile-up dependence dramatically reduced
- Loss of efficiency recovered
  - τ trigger studies in 2011 showed a degradation of efficiency with increasing pile-up

Efficiency of trigger with 20 GeV threshold (medium selections requires ~80% efficiency w.r.t. taus reconstructed and identified by offline algorithms (Boosted Decision Tree (BDT))





- Performance of τ trigger has been measured in 2012
  - Efficiency w.r.t. p_T of offline τ candidates identified by BDT algorithm
  - $Z \rightarrow \tau\tau \rightarrow \mu\tau_{had}$ tag and probe method



MET Trigger Performance

ATLAS-CONF-2011-072

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TriggerOperationPublicResults

LOUISIANA TECH
UNIVERSITY®

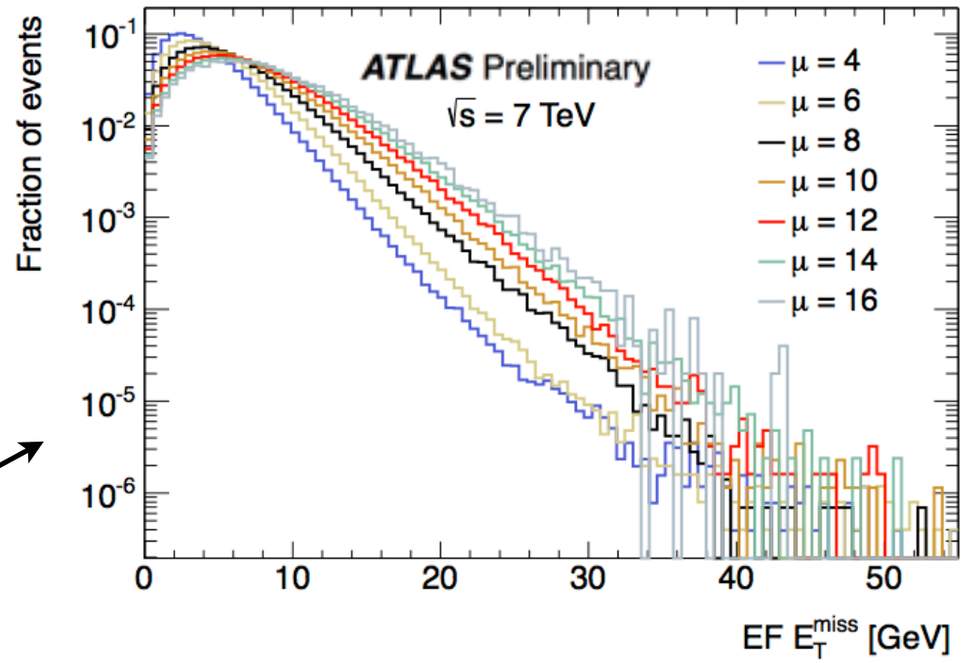
MET Trigger

- Triggers use global sums over calorimeter
  - sensitive to measurement fluctuations and systematic changes anywhere in detector
  - during 2011-2012 running with increase of pile-up:
    - increase of average energy deposit in calorimeter
    - increase in energy-measurement fluctuations
  - changes in beam conditions
    - necessity of changes in calorimeter noise-suppression schemes

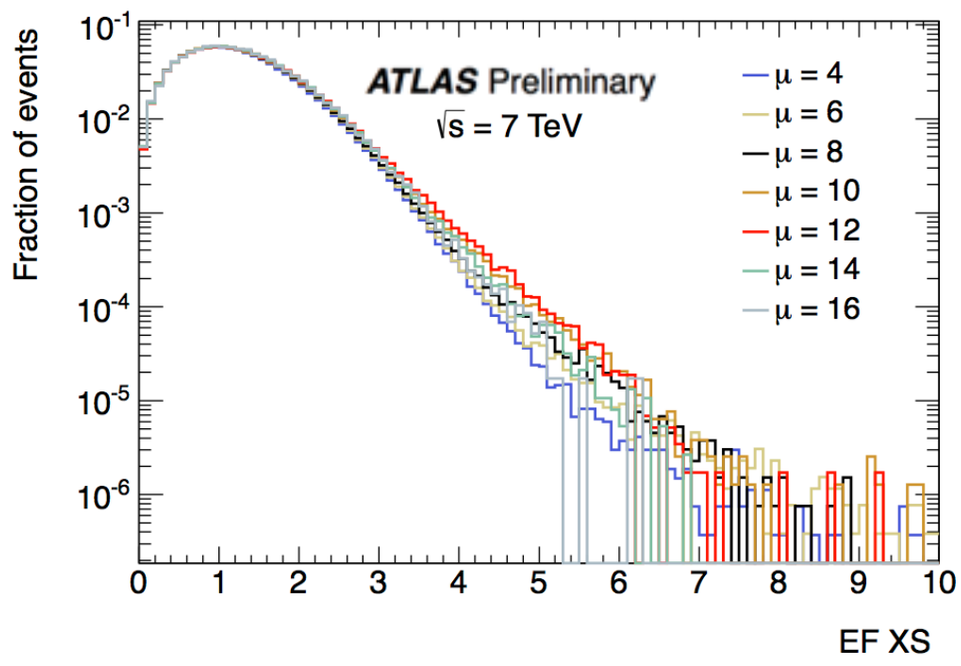
→ transverse momentum distributions and transverse momentum triggers affected

→ E_T^{miss} thresholds or prescales to be increased OR new trigger type to be introduced

- Therefore: In 2011, introduction of missing momentum significance trigger (XS)
  - trigger criterion is ratio of E_T^{miss} to its resolution
  - select events whose E_T^{miss} is unlikely to come from overall calorimeter energy measurement fluctuations
  - allows triggering on some events with E_T^{miss} below the threshold possible for E_T^{miss} triggers



Sensitivity of E_T^{miss} threshold rates to beam conditions in EF E_T^{miss} distribution for various pile-up values.

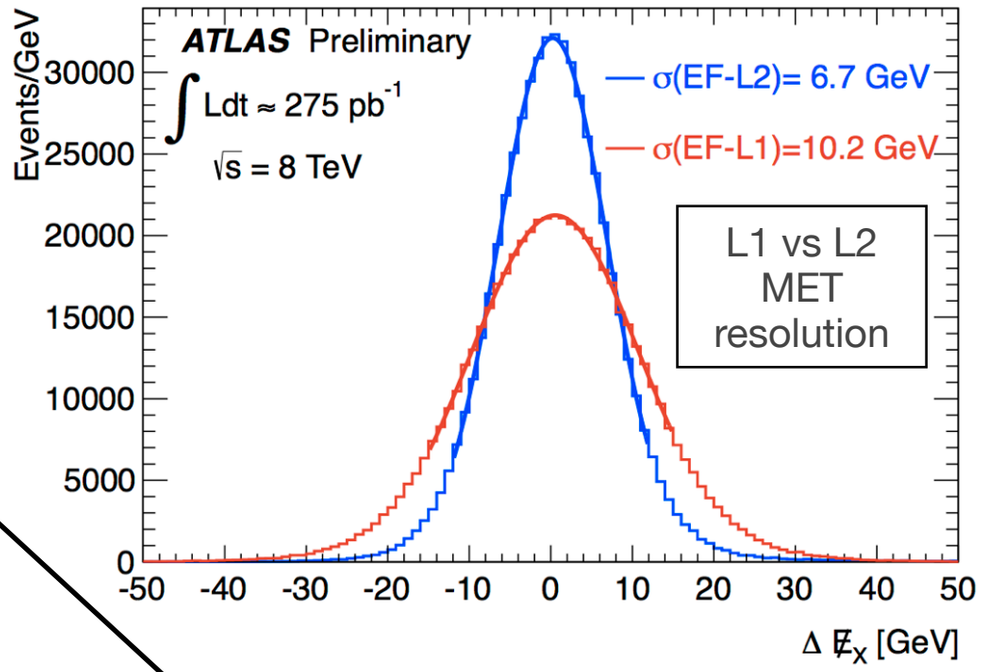


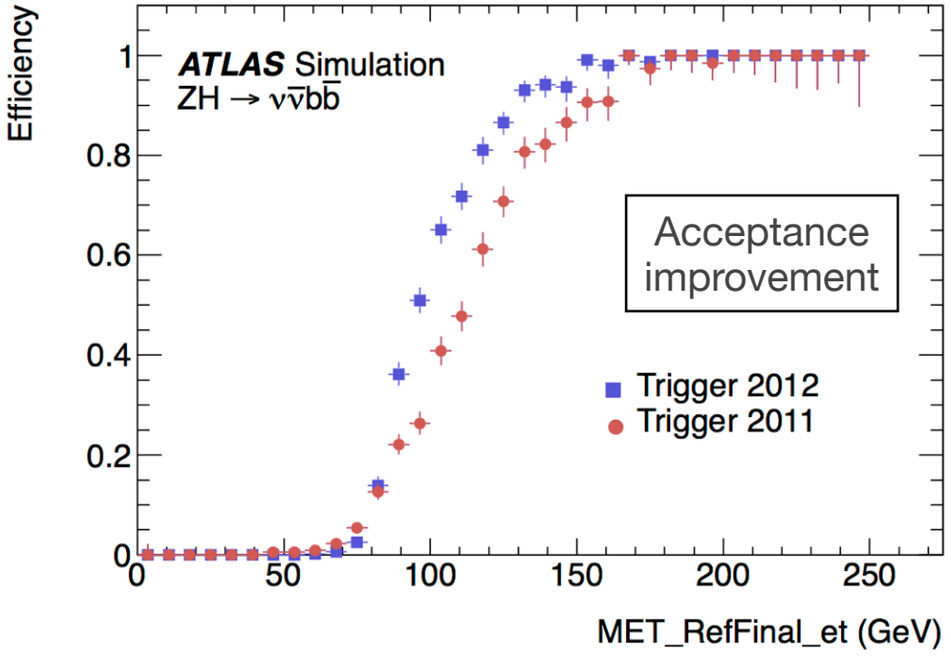
XS distributions for various values of pile-up. Events with calo noise bursts or badly measured jets have been removed.

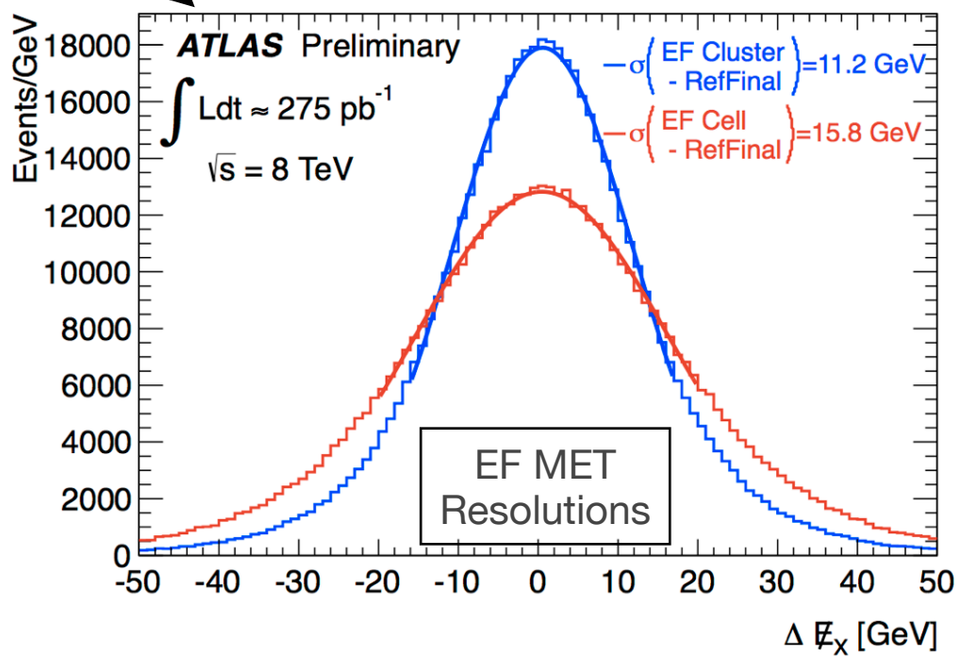
MET HLT improvements

- HLT improvements for 2012
  - cell-based MET sum implemented in calo readout system for fast L2 decision, breaking RoI concept
    → factor of ~5 in L2 rejection vs none in 2011
  - new EF algorithm summing calibrated topological clusters instead of all cell energies (closer to offline definition too)
  - noise cuts adjusted for high pile-up, applied commonly for MET and jets (see following slides)
  - using a 2-sided noise cut

→ MET trigger looser in 2012 than 2011 despite higher luminosity and pile-up



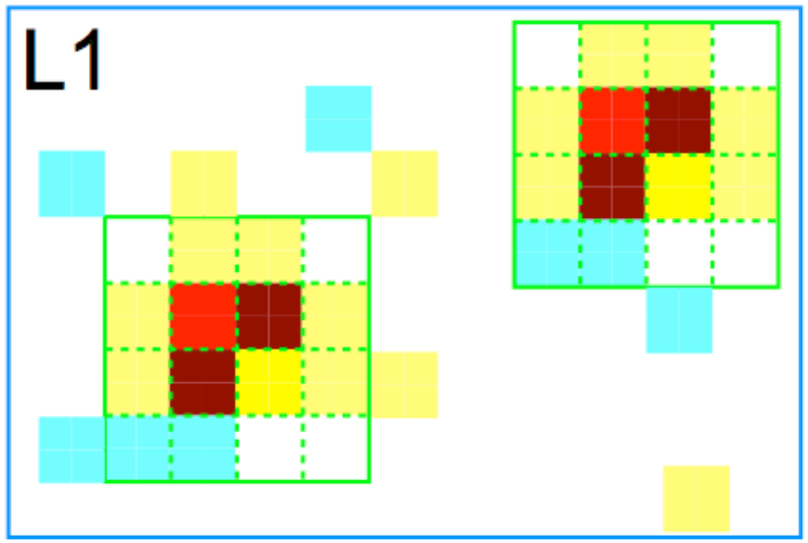


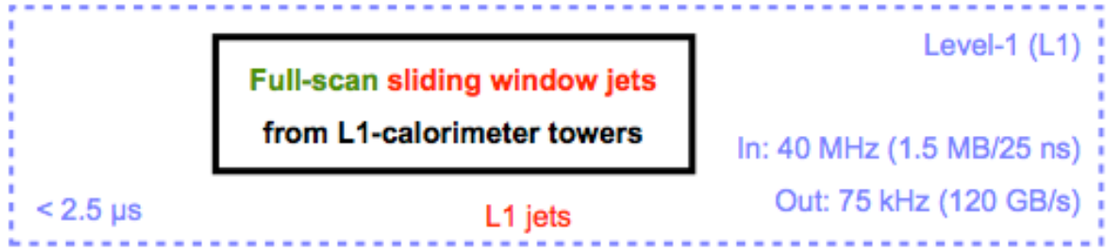


Jet Trigger Performance

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/JetTriggerPublicResults

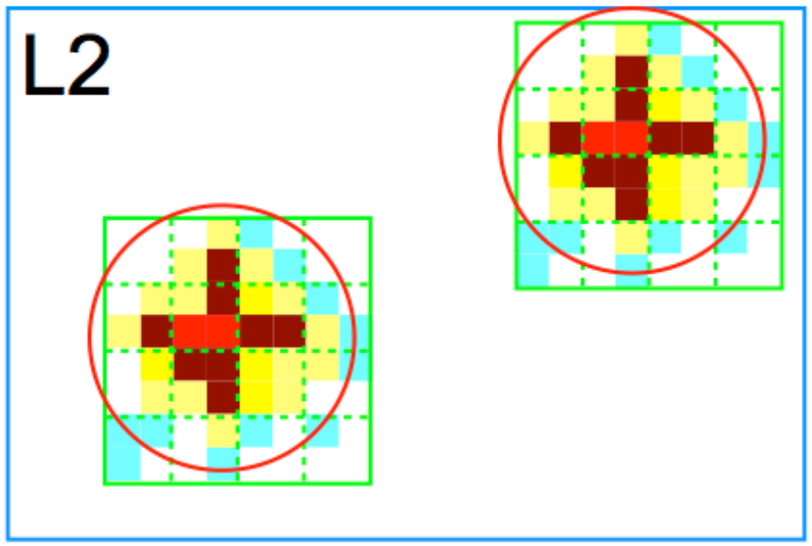
Jet Trigger System: Level 1

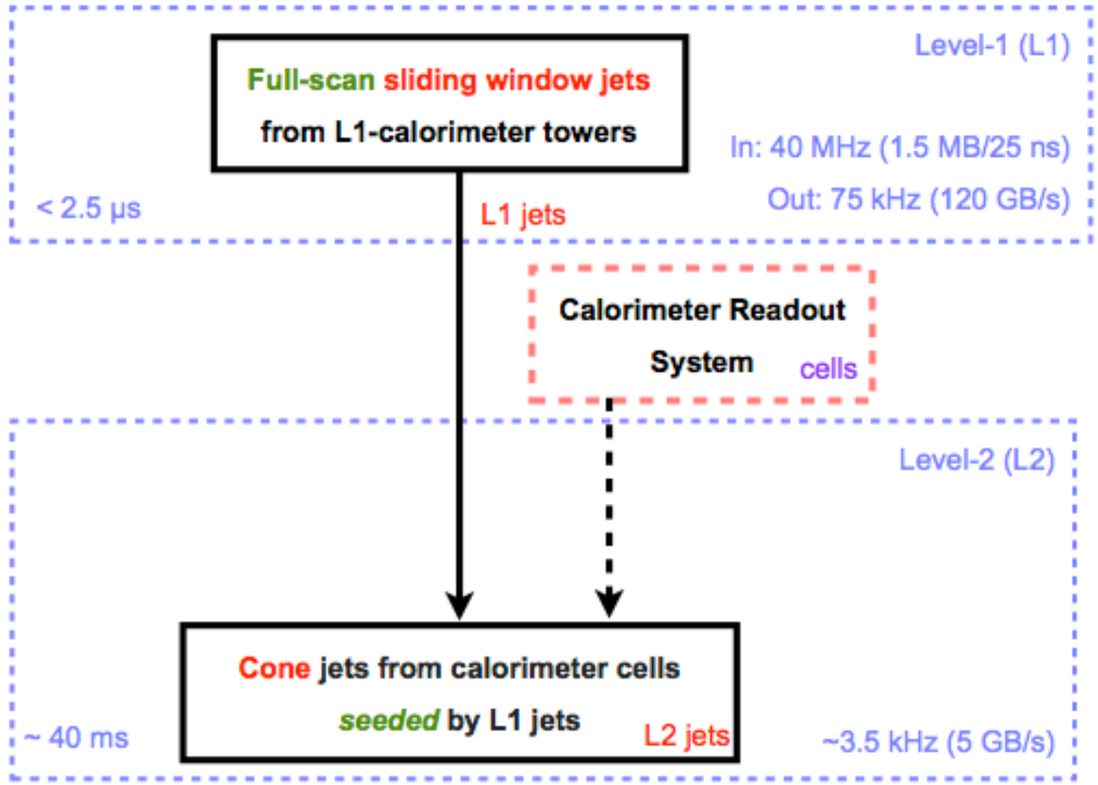




- Level 1:
  - Search for local maxima using overlapping, sliding windows on calorimeter towers of 0.2x0.2 in ηxϕ
  - Poor energy resolution
    - L1_J15 not fully efficient until ~50GeV
  - Efficiency losses for nearby jets
    - due to jet algorithm differences

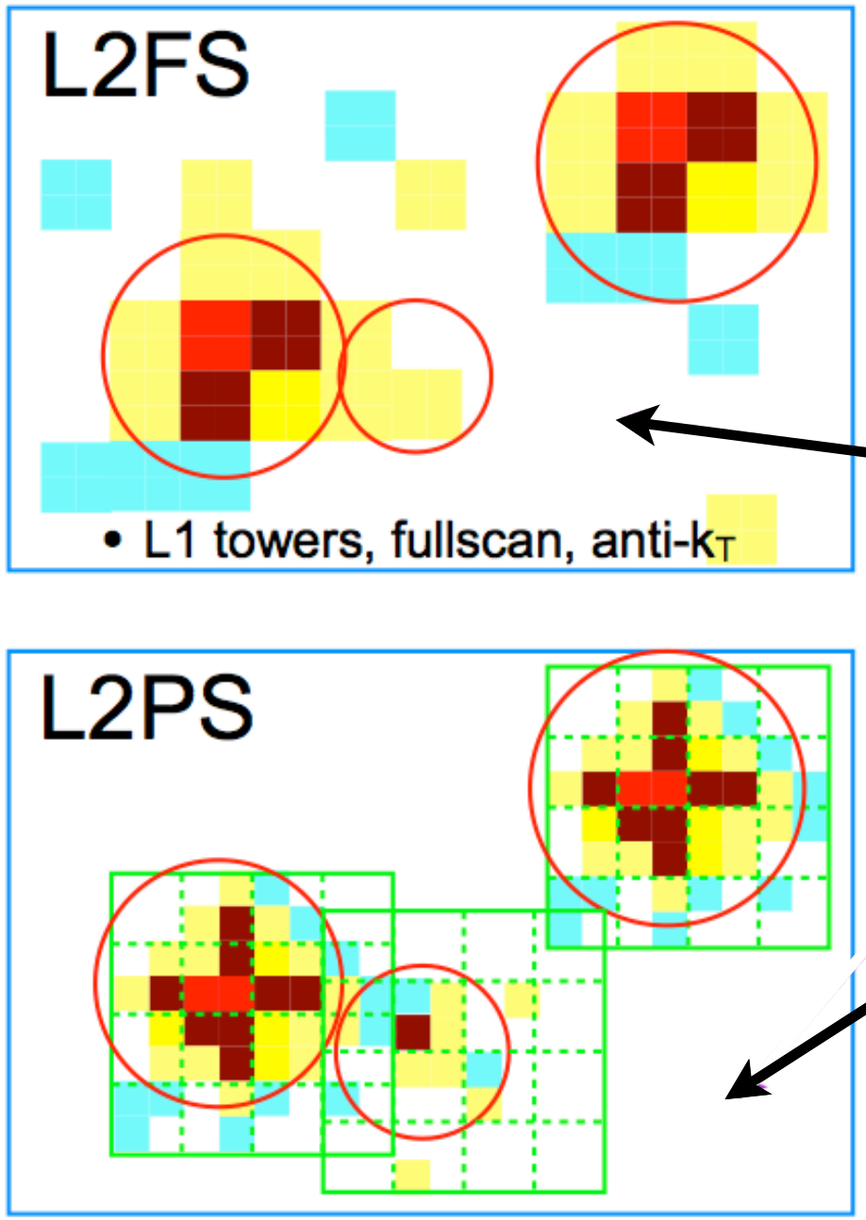
Jet Trigger System: Level 2 (single jet)

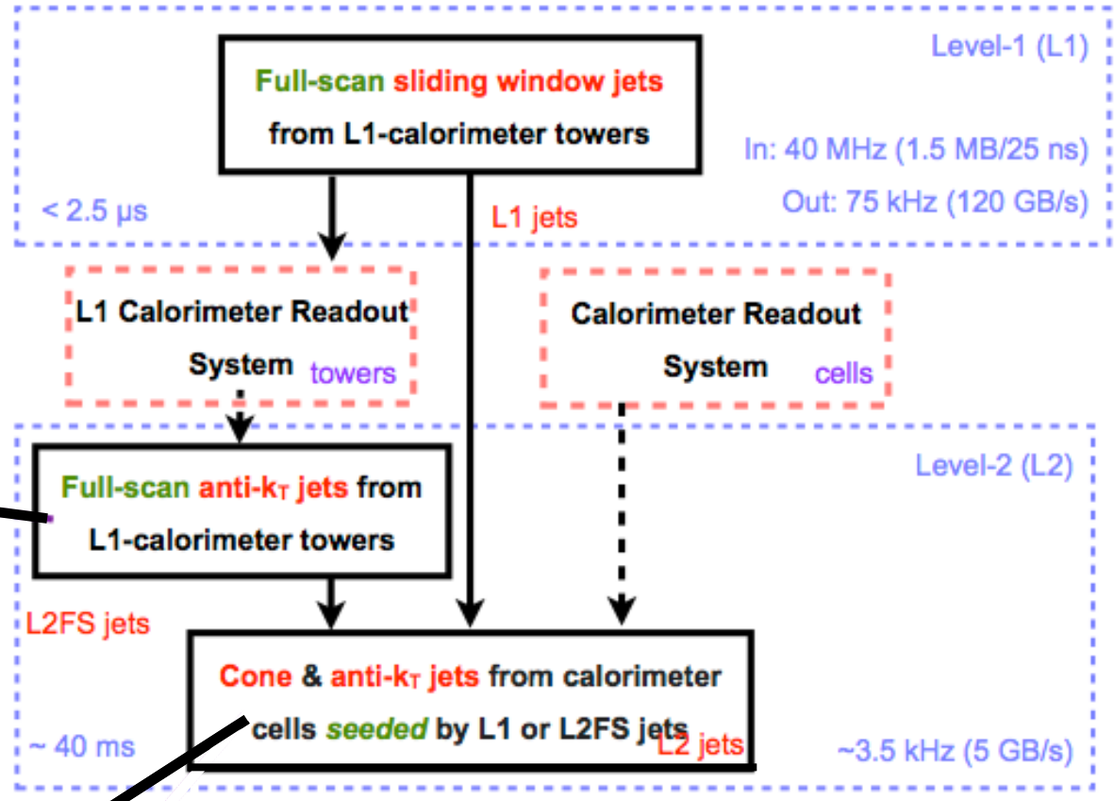




- Level 2: single jet trigger
  - RoI based cone jets
  - Each RoI considered separately
  - Good energy resolution
  - Efficiency limited by L1

Jet Trigger System: Level 2 (multijet)



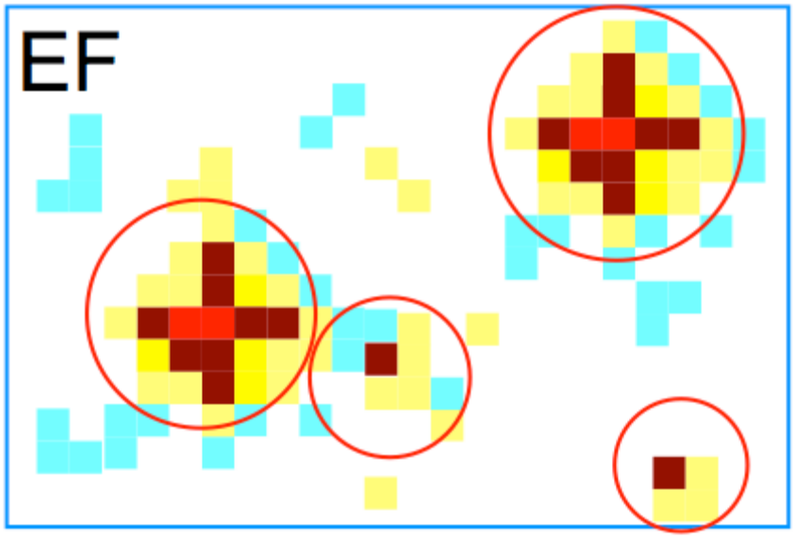


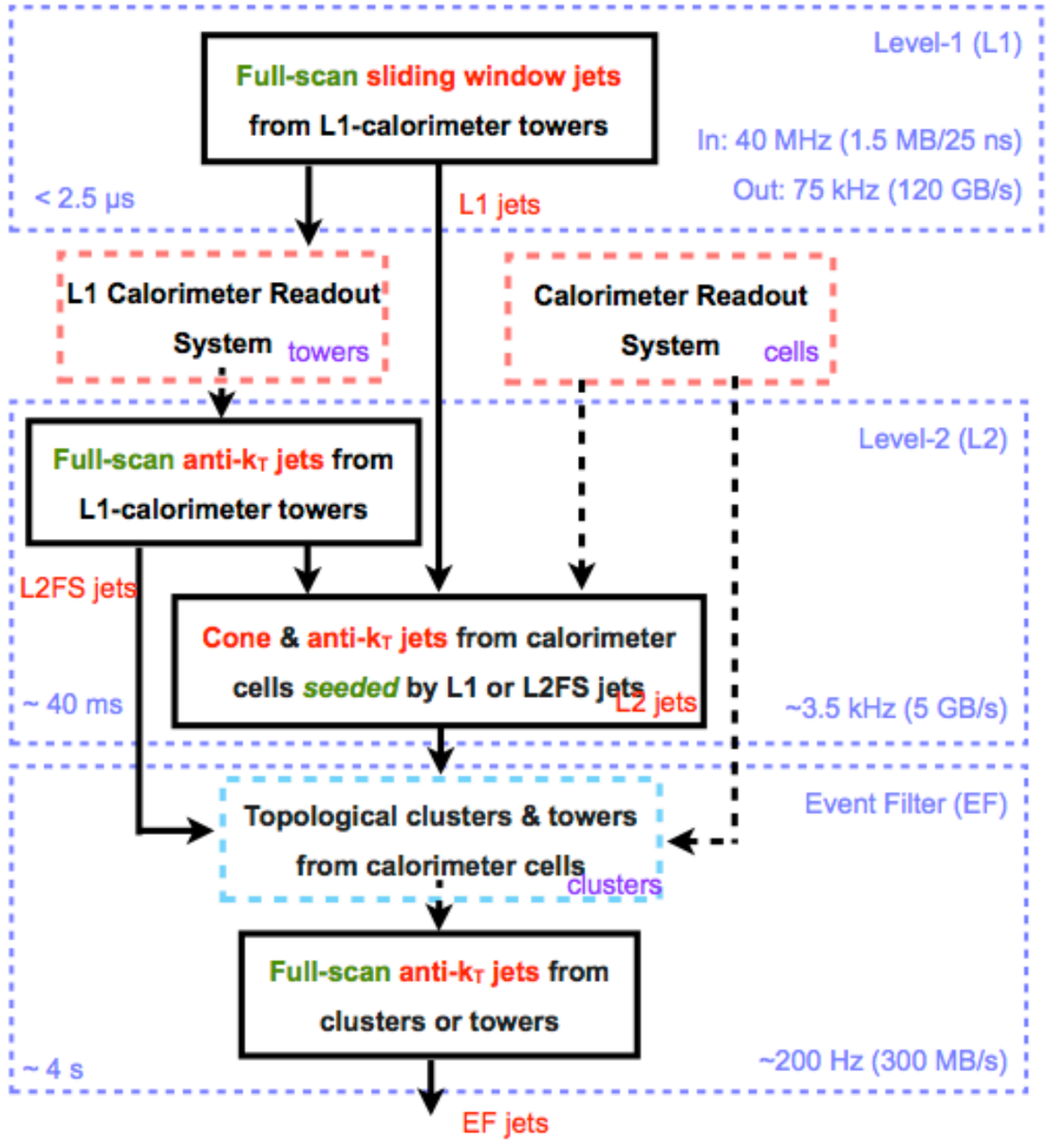
- Level 2: multijet trigger
  - Anti-k_T jets from L1 calorimeter towers
  - Calorimeter cells merged geometrically
  - All RoIs considered at once

Jet Trigger System: Event Filter

- Event Filter
  - Full-scan offline algorithms
    - very flexible
  - Topological clusters of cells, same as used for MET
  - Excellent resolution and efficiency

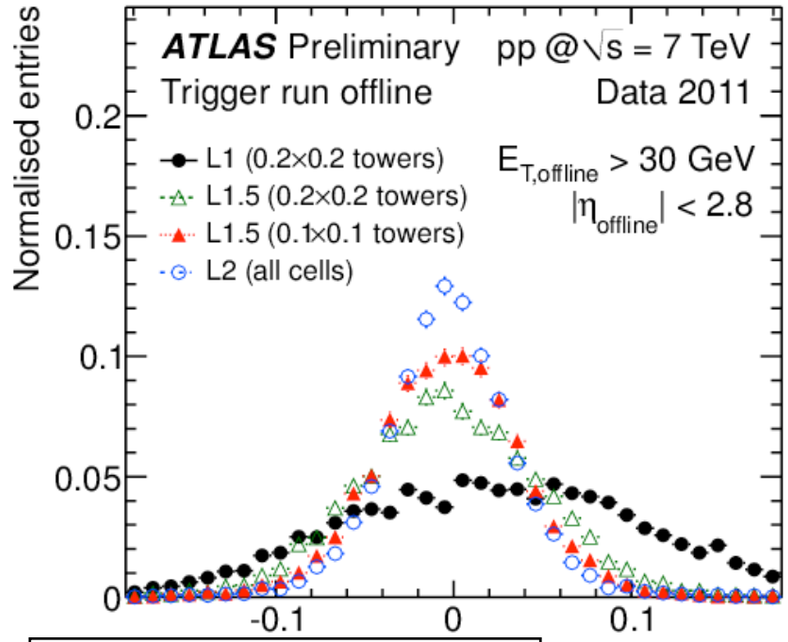
- Overall a highly flexible, configurable and well working system!



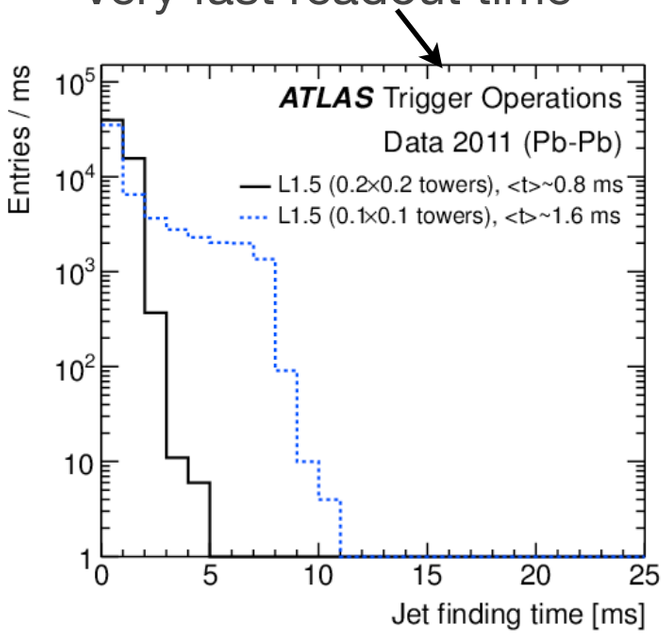


L2 Full Scan

- L2 full-scan (L2FS or L1.5) jet trigger uses trigger towers to reconstruct jets across the entire detector
- Provides several key enhancements to the jet trigger functionality:
  - ability to study the entire detector at L2 (breaking the RoI concept again)
  - ability to run the same jet algorithms as used in offline analysis such as anti-k_T
  - increased flexibility of the trigger system (no need for lower level RoI)
  - ability to apply jet specific calibrations to L1 calorimeter based jets to further improve the rejection
  - Very fast readout time

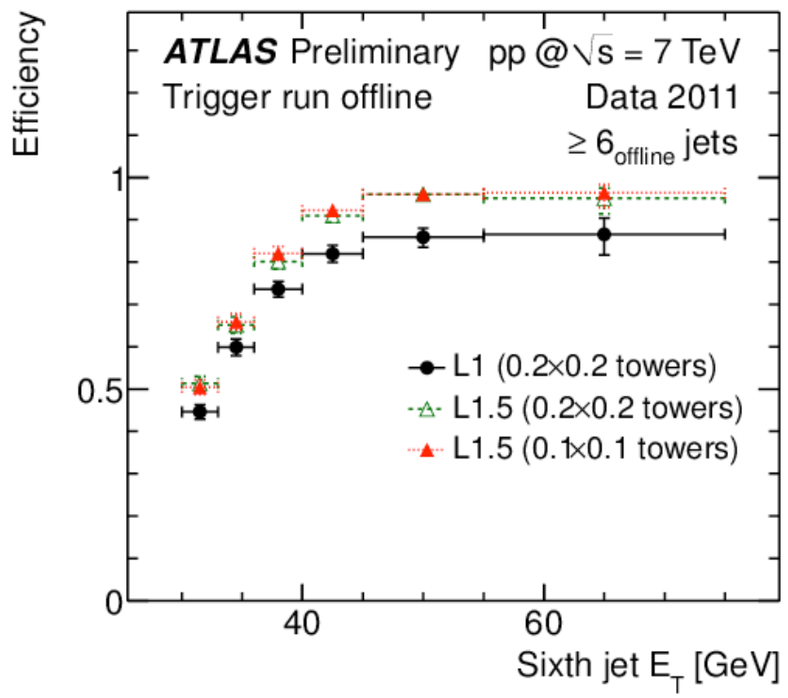


Jet position resolution of L1, L1.5, L2 jet triggers



Time to find L1.5 jets using the anti-k_T with R=0.4

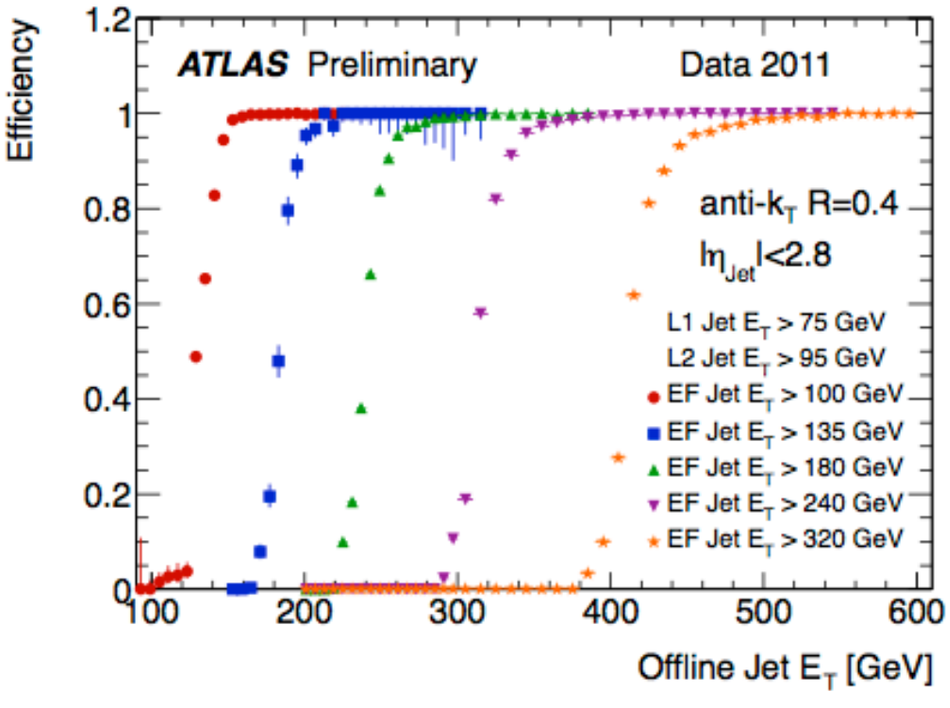
Efficiency for L1 (sliding window) and L1.5 (anti-kT R=0.4) jets to satisfy a six jet trigger in events where at least six jets have been identified online



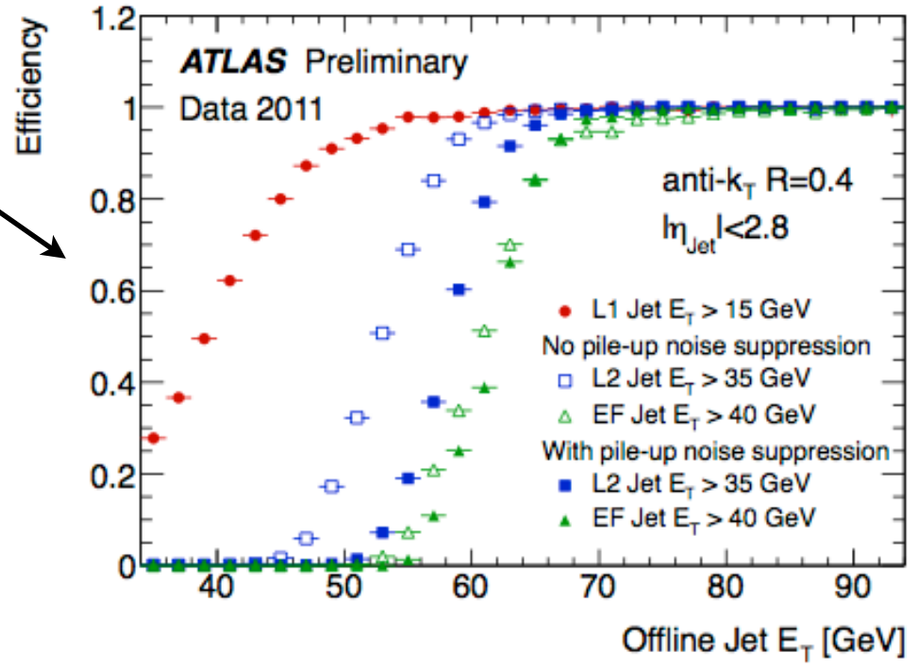
Pile-up Noise Suppression

- Event consists of a interesting collision with additional pile-up interactions and signals from particles generated a few bunch crossings before or after
- Noise suppression tool implemented at L2 and EF in 2011
  - considers electronics and pile-up noise
  - combined noise level is used to determine the threshold energies for calorimeter cells considered in jet reconstruction

  → results in more precise measurement of jet energy
  → improvement in resolution and efficiency of turn-on curve
  → jet trigger efficient over a wide range of E_T
  → lower thresholds without increasing rate possible



Trigger efficiencies of EF inclusive jet trigger for 5 different thresholds using full scan at EF and noise suppression at L2 and EF. Jets at EF were reconstructed using the anti-k_T algorithm with R=0.4



Trigger efficiencies of an inclusive jet trigger chain for anti-k_T jets for two different data-taking scenarios: before and after pile-up noise suppression was applied

Summary

- Overall extremely successful trigger operation in last 3 years
  - Efficiency losses due to trigger are less than a few %
  - Luminosity increased by a factor of 30 since end of 2010
  - Pile-up increase by almost a factor 10 since end of 2010

- Significant improvements have been made for 2012
  - Shown for τ, MET and jet trigger, not show for eγ triggers (time constraints)
  - Retuned selections for high pile-up conditions
  - More advanced HLT selection algorithms
  - Trigger thresholds only raised minimally w.r.t. 2011 despite twice the luminosity and pile-up conditions

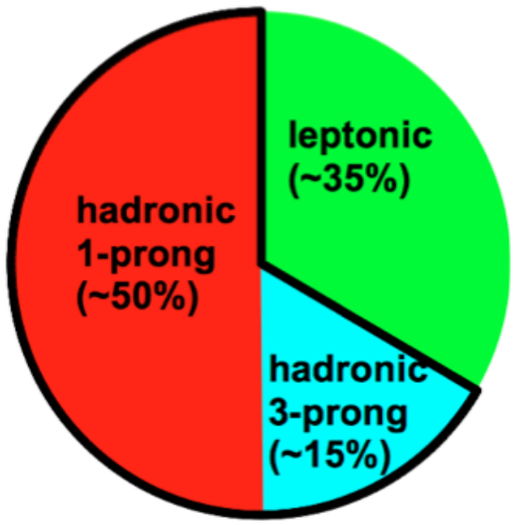
- Now planning for $\sqrt{s}$ = 13-14 TeV and luminosities > 10^{34} $cm^{-2}s^{-1}$
  - Increase compatibility of HLT with offline algorithms
  - Preparation of more flexible and efficient HLT (partial merging of L2/EF)

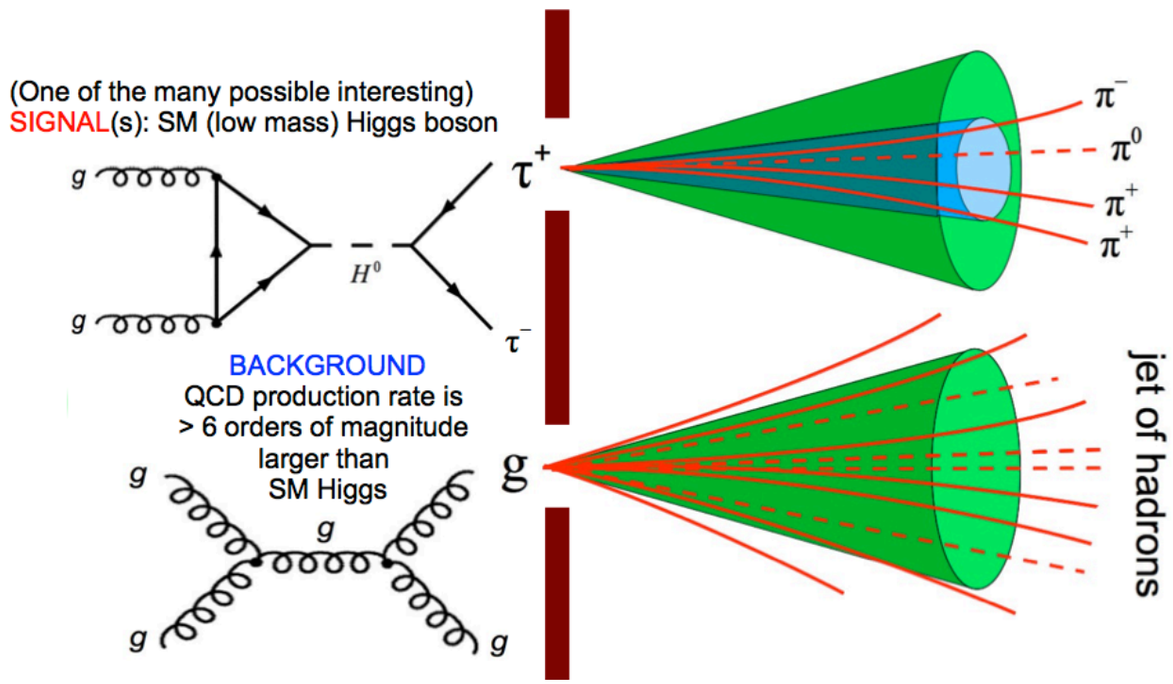
Backup Slides

LOUISIANA TECH
UNIVERSITY®

Motivation

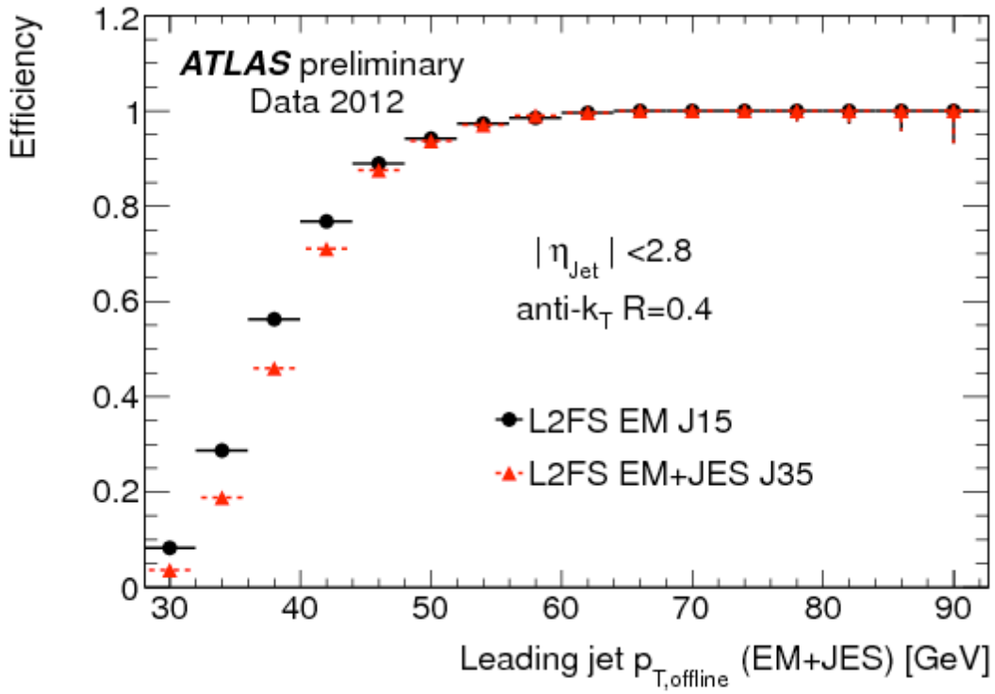
- Hadronic τ decays play essential role in Standard Model (SM) physics and Beyond the SM (BSM), including H→ττ, charged Higgs searches, Z‘ searches
  - τ leptons are observed via their decay products
  - hadronic decays account for 65% of τ decay modes
  - QCD jets present a significant and challenging background
  - hadronic τ decay signatures are distinguished by:
    - low track multiplicity
    - narrow collimated jet
    - isolation in surrounding region



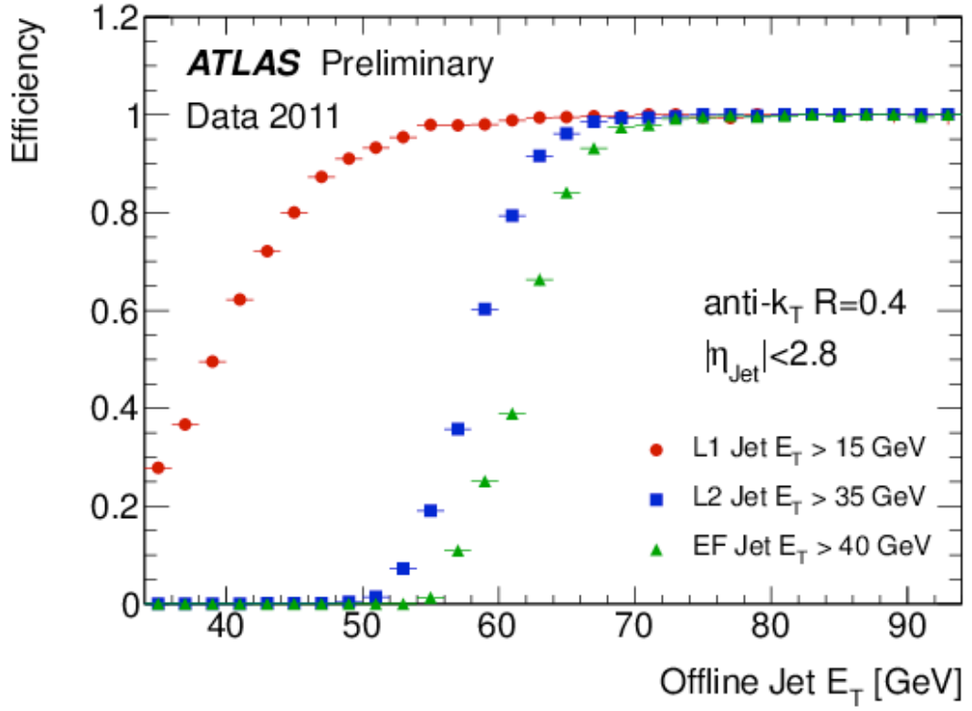


Jet Trigger Performance in 2011 and 2012

- Impressive jet trigger performance in 2011 and 2012
- Major improvements for 2012
  - full scan reconstruction of L1 towers for anti-kT at L2
  - Hadronic scale for HLT jets
  - Noise thresholds adjusted for high pile-up



Efficiency for L2 full scan at electromagnetic (EM) and hadronic (EM+JES) calibration scale vs leading offline jet p_T. Minimum jet ET thresholds are 15GeV for EM-scale trigger and 35 GeV for the EM+JES scale trigger.



Efficiency for anti-kT jets with R=0.4 to for a jet trigger chain. Different thresholds are applied at each level of the trigger to increase rejection while keeping acceptance for events with high probability of satisfying the overall jet trigger. Results are shown with pile-up noise suppression.