Performance studies of the Run 3 jFEX algorithms in the ATLAS calorimeter trigger

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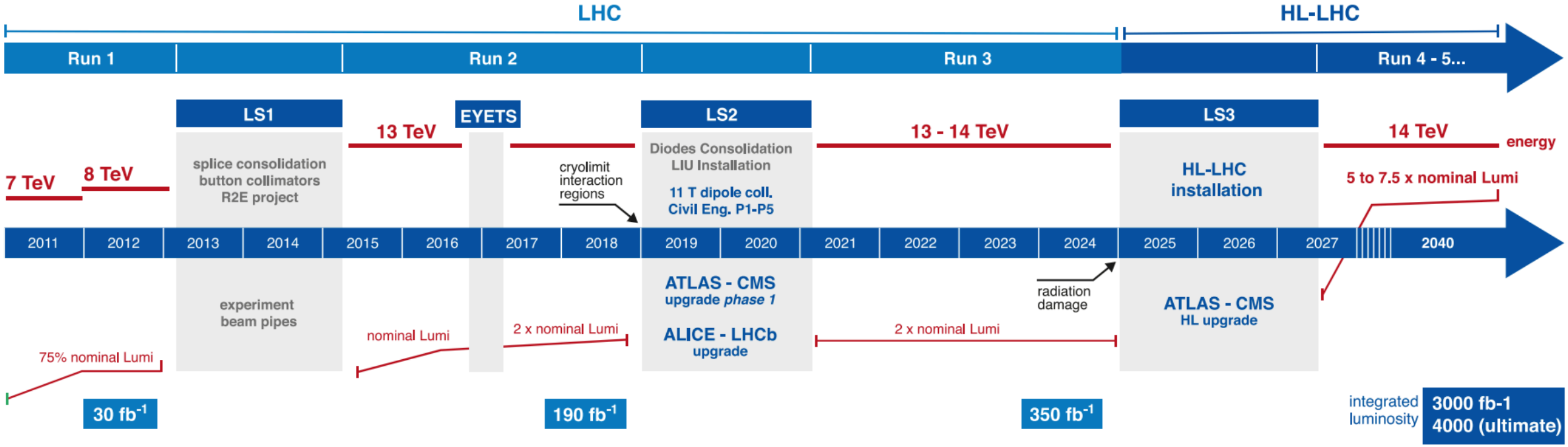
ATLAS Upgrade timescale and Motivation

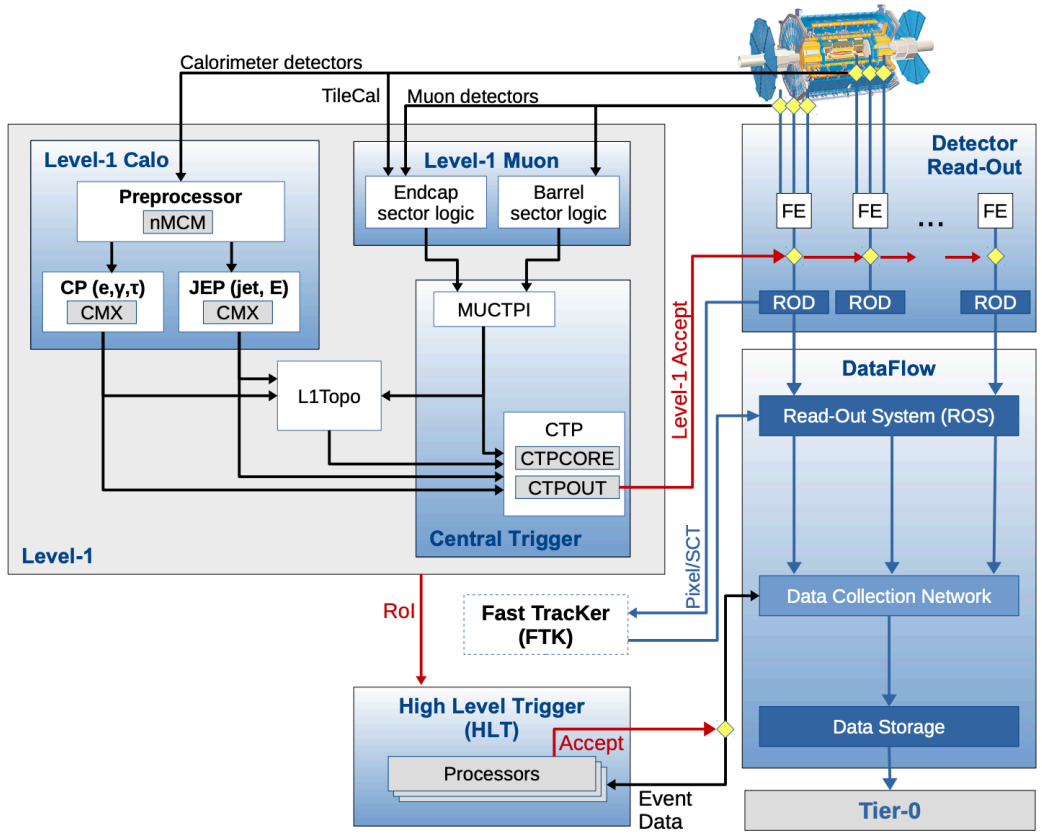
- ATLAS is utilizing the LHC Long Shutdown 2 shutdown from 2018 – 2021 to implement upgrades for TDAQ, the new small wheel, the Liquid Argon (LAr) calorimeter, and the Level-1 (L1) calorimeter trigger
- Motivation for Upgrade
  - Accommodate increase in luminosity
  - Improve detector performance



https://project-hl-lhc-industry.web.cern.ch/sites/project-hl-lhc-industry.web.cern.ch/files/inline-images/HL-LHC-plan-2020-Plan-1.pdf

ATLAS L1 Calo System in Run 2

- The Run 2 ATLAS trigger system is comprised of two levels: a hardware based Level-1 (L1) and a software High Level Trigger (HLT). Between late 2018 and early 2021, the ATLAS trigger system is undergoing upgrades to allow for an increase in luminosity and to improve the performance



Run 2

- L1Calo receives information from tile and LAr
- Jet Energy Processor (JEP) looks for missing energy, total energy, and jets
- Cluster Processor looks for electrons, taus, and photons
- Central Trigger Processor (CTP) and the topological trigger (L1 Topo) then receive the information
- High level trigger (HLT) receives events that pass selection
- Accepted events are saved to permanent storage

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

ATLAS L1 Calo System in Run 3

https://cds.cern.ch/record/1602235/files/ATLAS-TDR-023.pdf

https://arxiv.org/pdf/1806.09207.pdf

Two major sets of upgrades to the ATLAS L1 trigger system:

- The increase in read-out granularity in the Liquid Argon (LAr) detectors ("supercells")
  - 7k towers (Run 2) to 36k supercells (Run 3)

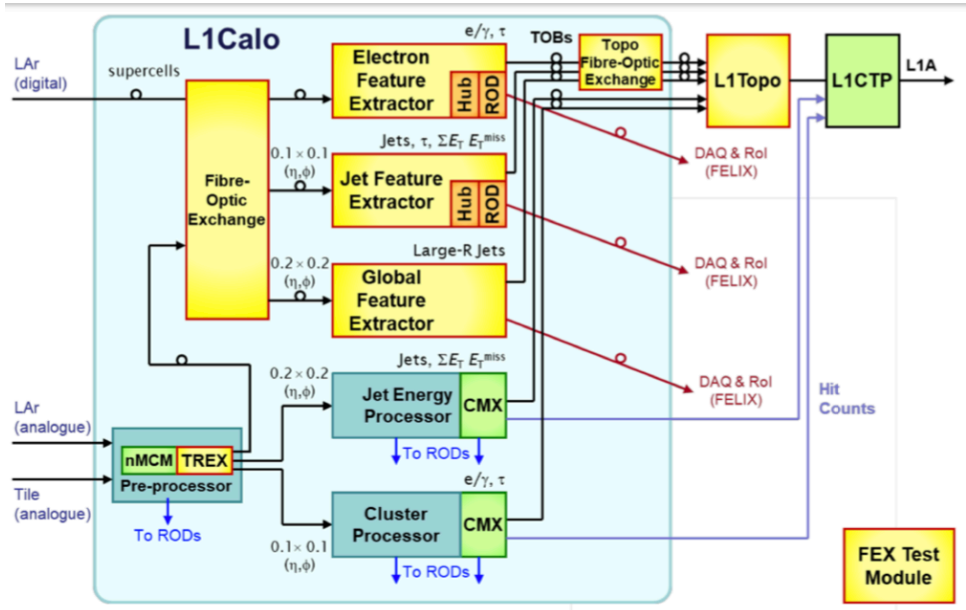
- The addition of new Feature EXtractors (FEXs):
  - Global FEX (gFEX) - identifies large radius jets
  - Electromagnetic FEX (eFEX) - Finds electron, photon, and tau clusters
  - Jet FEX (jFEX) - identifies jets and calculates missing transverse momentum and other energy sums

jFEX

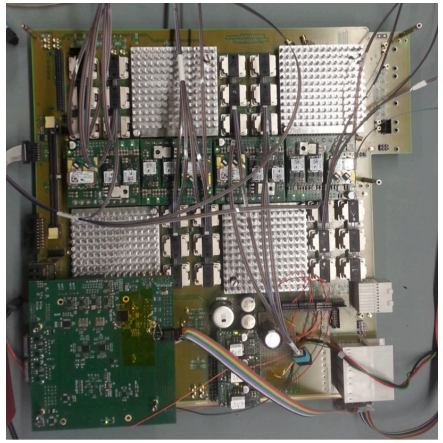
- Six jFEX modules
- Each jFEX module is a ATCA (Advanced Telecommunication Computing Architecture) board with 4 processor Xilinx **UltraScale+** FPGAs (field-programmable gate array) and can process a total input data rate of ~3.6 Tb/s
- Eta coverage of 4.9
- The new jFex jets are much finer granularity in eta phi than current L1 jets
- Opportunities for pileup mitigation via pileup subtraction
- Identifies jets and calculates missing transverse momentum and other energy sums

Run 3 system

- New components for Run 3 are in highlighted in orange and yellow



jFEX

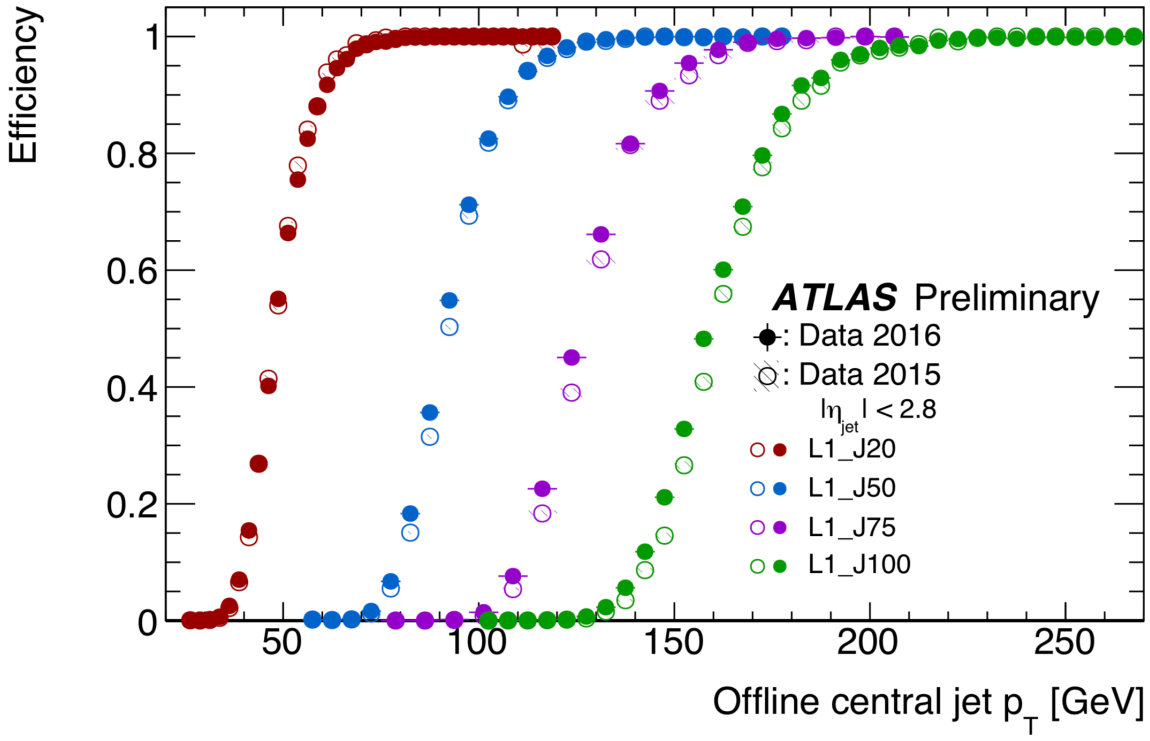


Run 2 L1 jets

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

Formation of a Run 2 L1 jet

- Reconstructed using a 0.8 x 0.8 sliding window algorithm with a 0.2 x 0.2 tower and a 0.4 x 0.4 seed

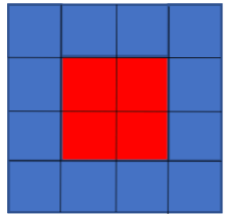


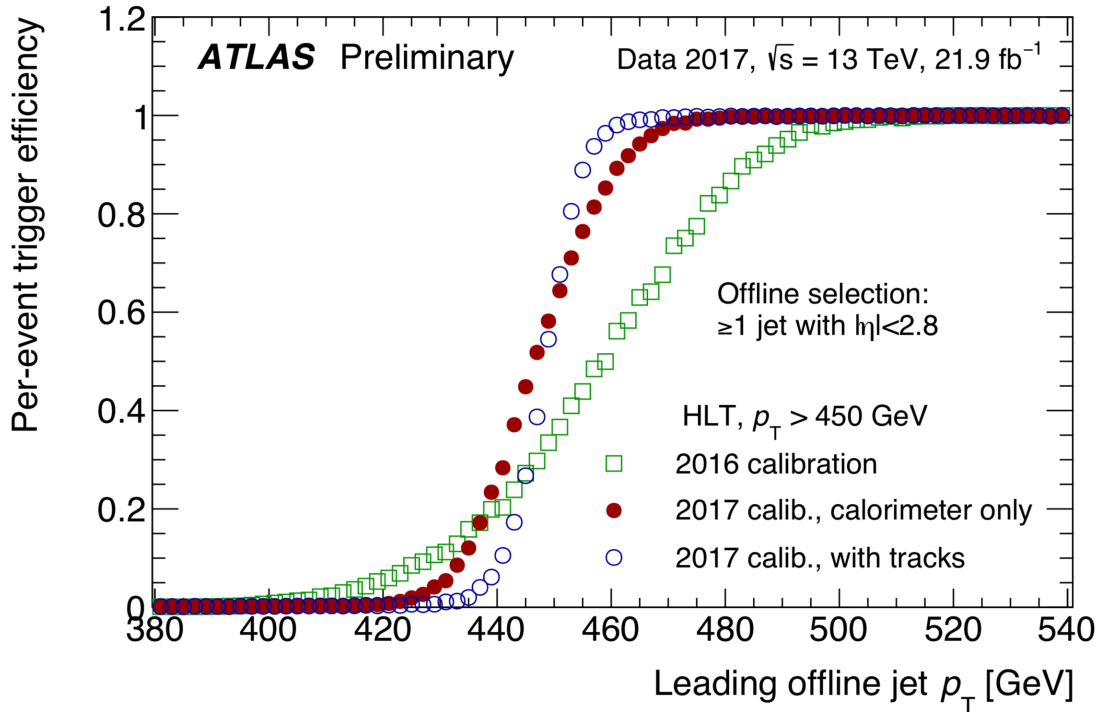
Trigger efficiencies for single jet L1 triggers for 2015 and 2016

- L1_JX means single jet trigger that accepts an event if a jet has ET > X GeV
- L1 single jet triggers in 2015 and 2016 become fully efficient at same point
- L1_J100 is the lowest unprescaled trigger

L1 jet ROI (0.8 x 0.8)

- **0.2 x 0.2 tower**
- **0.4 x 0.4 seed**

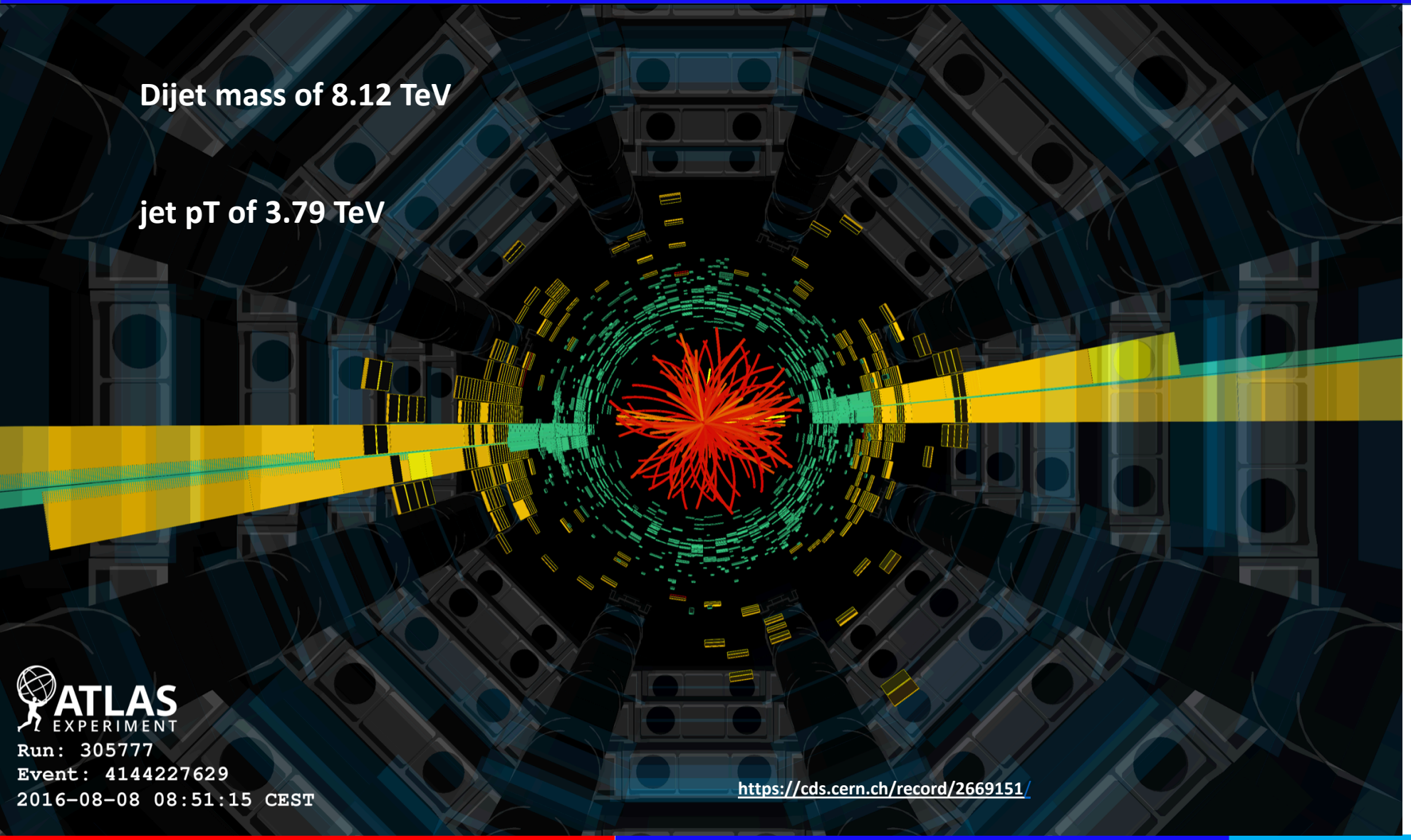




Trigger efficiencies for a single jet trigger with 3 different calibrations applied to jets in the high-level trigger (HLT)

- Large HLT rate serves as a limitation
- Offline threshold is at 440 GeV, L1_J100 is 100 % efficient at 200 GeV

Dijet Event: Potential for Dark Matter

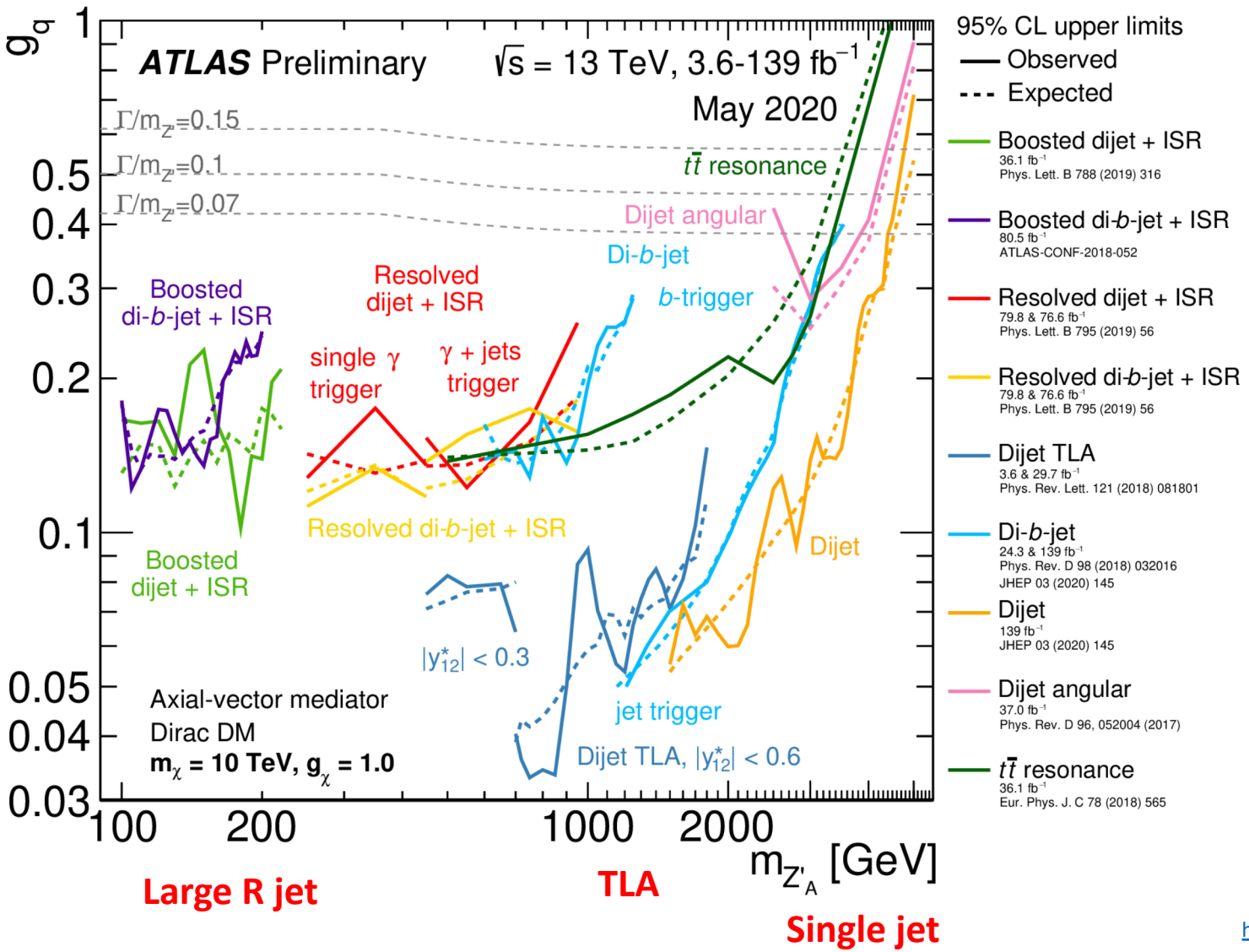


- Single jets triggers are used for dijet events above 1.5 TeV
- Dijet events offer opportunity to search for dark matter

Dark matter process:

$$z' \longrightarrow qq$$

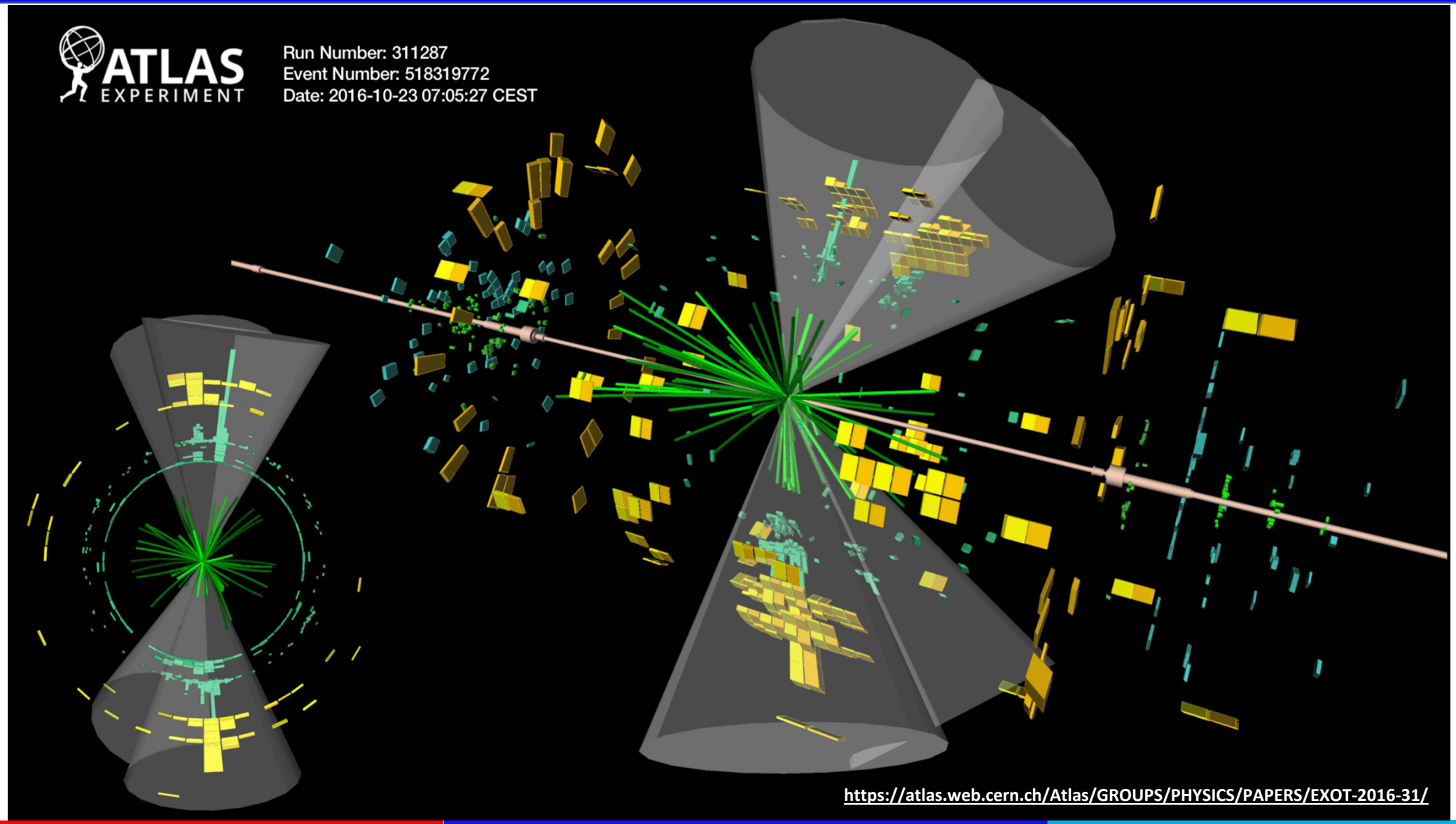
Dark Matter Summary



- TLA (trigger-level analysis) combats limitation from HLT and extends sensitivity to lower masses
  - Recovers some events from HLT that would have been lost
- Large R jets has sensitivity in lower masses
  - Improvements for large R jets would allow for increased sensitivities for lower masses

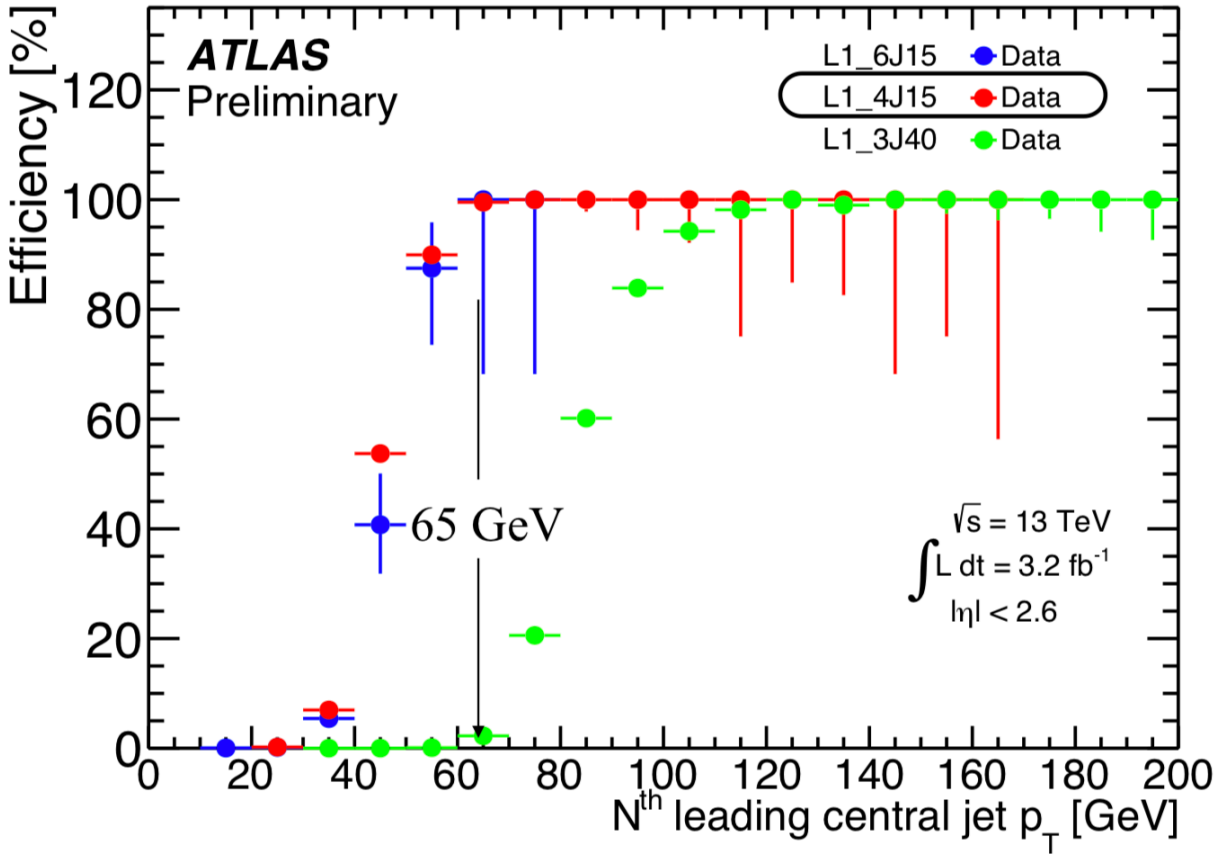
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/EXOTICS/

4 Jet Event: Potential for Dark Matter



Multijet trigger for HH searches

- Primary decay channels of HH: bbbb and bbττ
- HH -> bbbb search using L4J15 and 2 b-tags in HLT



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

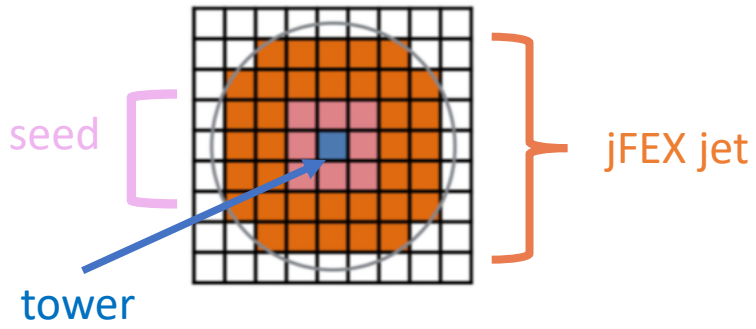
- 15 GeV at L1 correlates to 65 GeV in the HLT and in offline analysis
  - Serves as a limitation
- Room for improvement for triggers for HH searches

Run 3 jFEX jet Algorithms

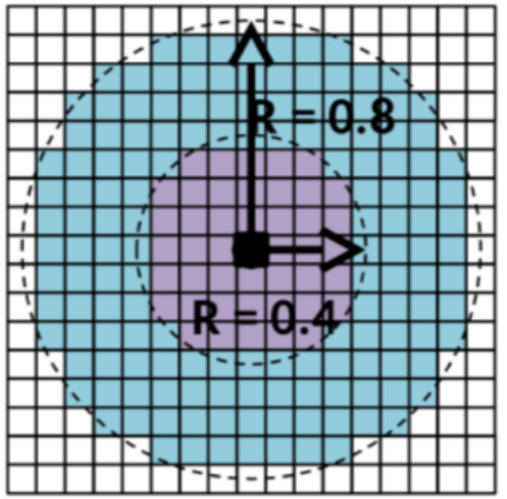
Small-R jFEX jet:

- Reconstructed using 0.9 x 0.9 sliding window algorithm
- Noise threshold of 2 GeV is required for any jTower
  - ET of jTower is set to 0 if noise cut fails
- Each 0.1 x 0.1 jTower is surrounded by a 0.3 x 0.3 seed that consists of 3 x 3 jTowers
- The “local maximum”, seed with the highest ET, is determined by scanning all seeds that exist within a range of 5 x 5 jTowers and finding the seed with highest ET
- Small-R jet is defined as a cone of $\Delta R = 0.4$, where $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$ and is computed with respect to the local maximum
- Jet ET = sum of ET of each tower

Small R jFEX jet (0.7 x 0.7 rounded-off square), 0.1 x 0.1 tower, 0.3 x 0.3 seed



Large R jFEX jet



Large-R jFEX jet:

- Uses same algorithm as Small-R jFEX jets, but with an increased cone size of $\Delta R = 0.8$

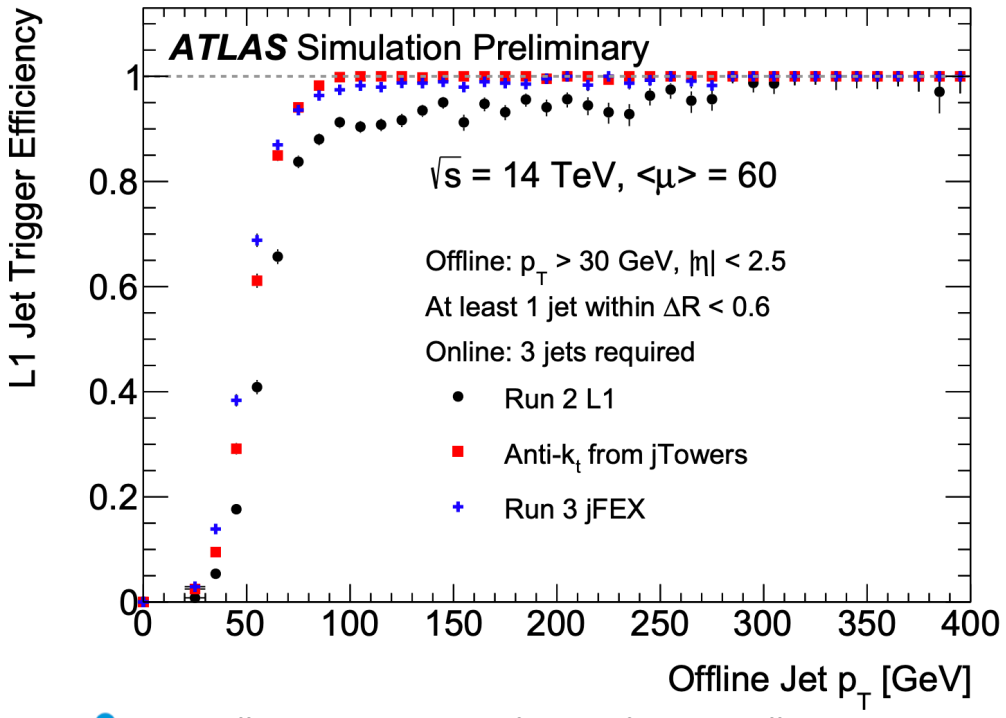
Run 3 jFEX L1 Jet Trigger Efficiencies

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/L1CaloTriggerPublicResults

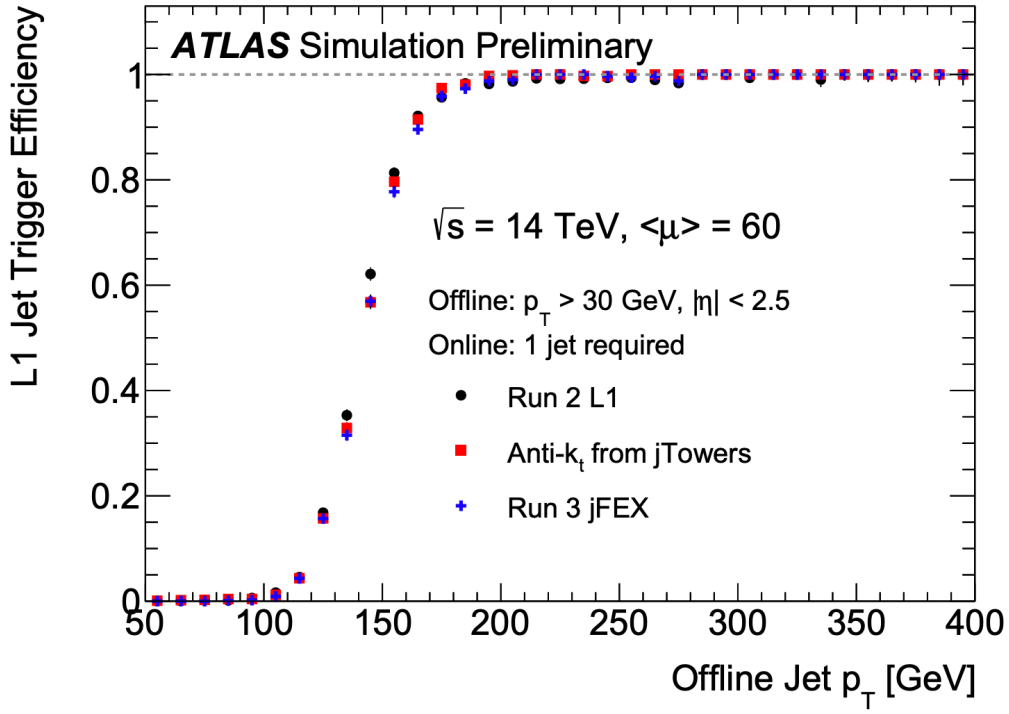
- Plots of per jet trigger efficiencies in HH->bb(bb) Monte Carlo samples for Run 2 L1 jets, Run 3 jFEX jets, and the offline Anti-kt reconstruction algorithm running over R = 0.4 jTowers
  - Run 3 jFEX algorithm and offline Anti-kt reconstruction algorithm apply 2 GeV noise cut to jTowers
    - "AntikT from jTowers" does not actually run the anti-kT algorithm in the hardware
  - Thresholds for all three approaches were tuned to have equivalent rates

Conclusion

- **The new algorithm performs better for nearby jets**
- **Run 2 L1 jets and the new algorithm perform similarly for online single-jet events**



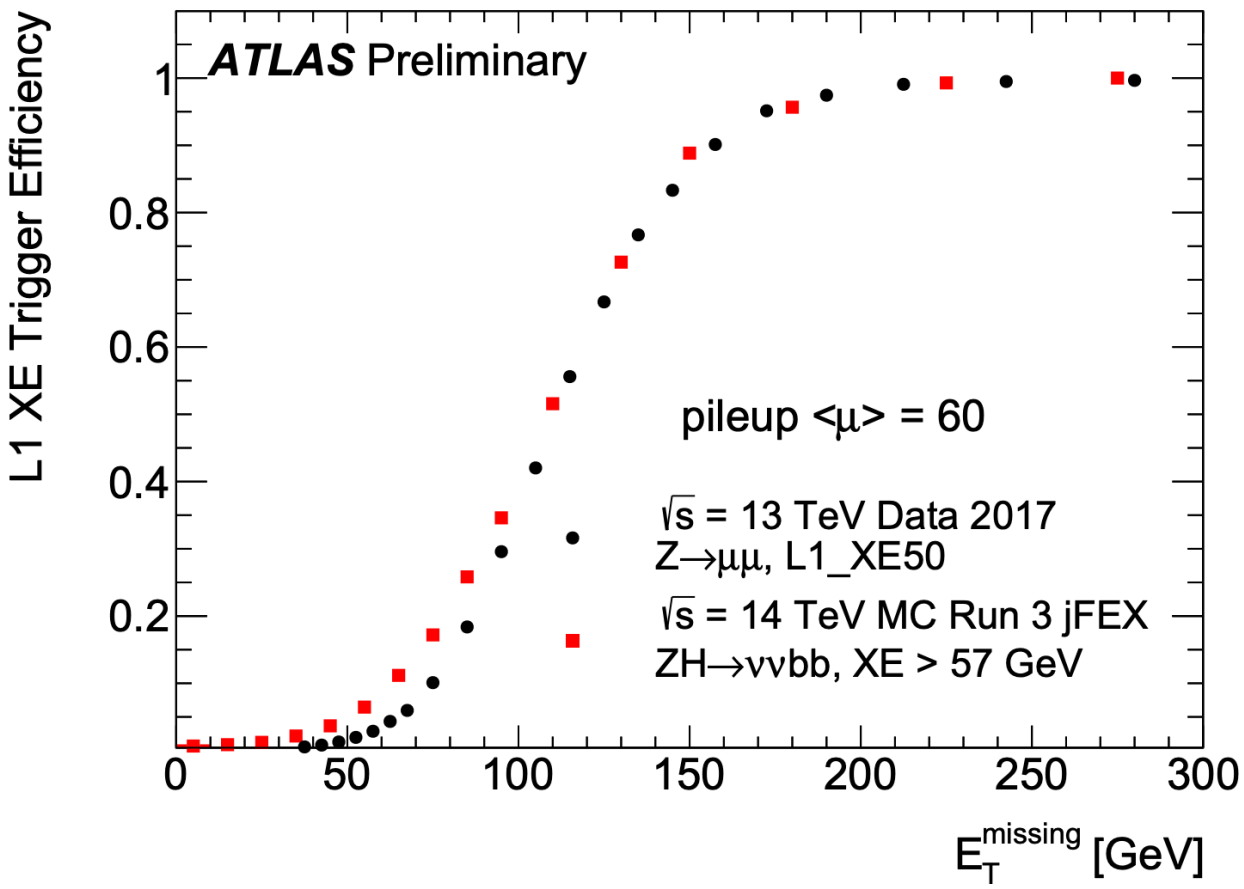
- Trigger efficiencies computed as a function of calibrated offline jets where
  - pT> 30 GeV
  - |η| < 2.5
  - At least one jet is > 30 pT and is < Δ R = 0.6 of the probe jet
  - 3 online jets required



- Trigger efficiencies computed as a function of calibrated offline jets where
  - pT> 30 GeV
  - |η| < 2.5
  - 1 online jet required

jFEX MET algorithms

jFEX MET Trigger Efficiences



https://twiki.cern.ch/twiki/bin/view/AtlasPublic/L1CaloTriggerPublicResults

- Efficiency of jFEX MET algorithm versus truth MET in a ZH->ννbb Monte Carlo simulation
- jFEX MET is calculated as the vector sum of all towers with ET greater than an η-dependent threshold
- Threshold cuts noise and ranges from 0 – 5 GeV
- jFEX MET algorithm in ZH->ννbb compared to Run 2 MET threshold L1_XE50 in Z->μμ events
- This plot is shown as a proof of principle and is the same algorithm as Run 2, hence the performance is the same

jFEX MET algorithms

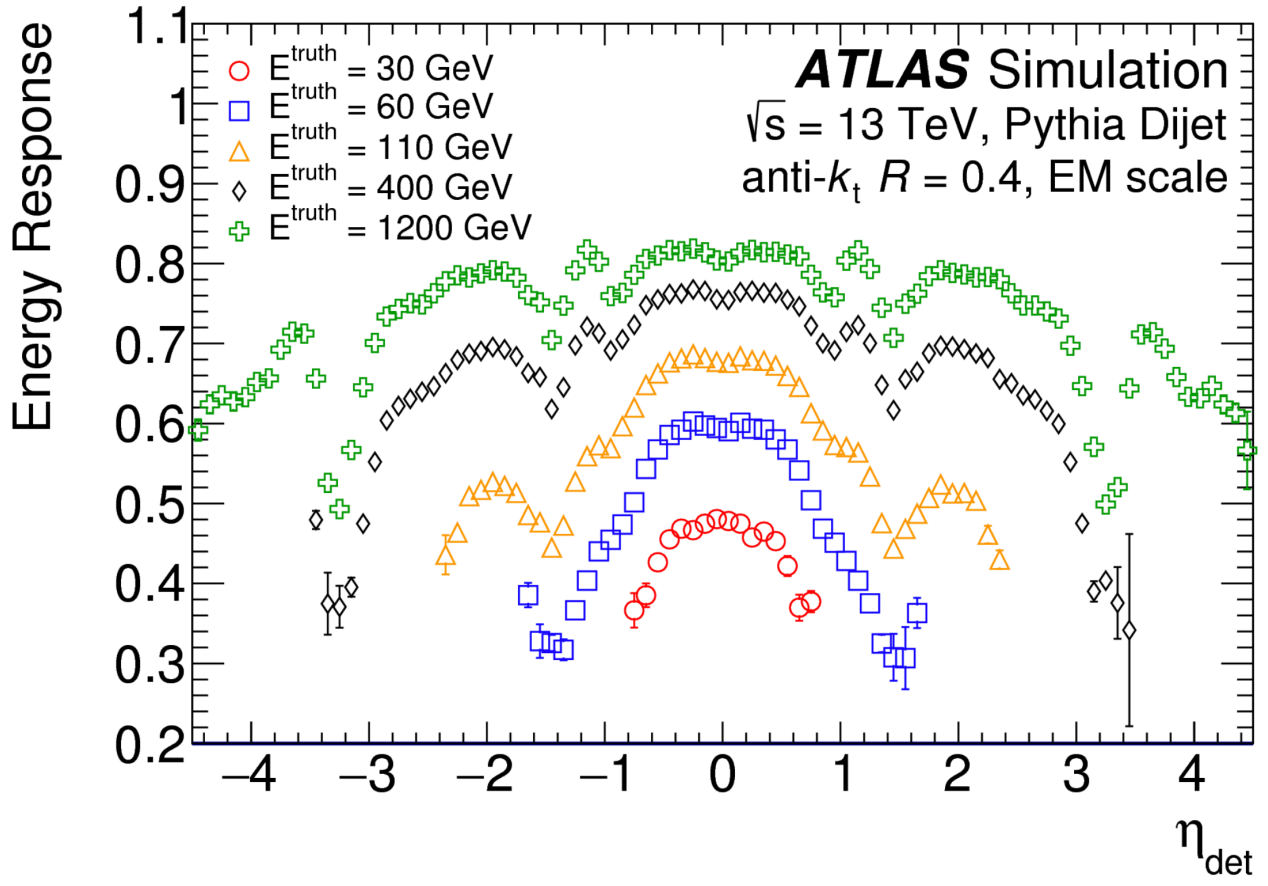
- jFEX MET algorithms aim to achieve better pileup mitigation
  - Intend to implement **rho-subtracted MET calculation** in which the average energy (from in-time pile-up) is calculated event-by-event and subtract energy from all towers, then sum over all towers with positive energy

Potential improvement: utilize jet calibrations

The Need to Calibrate

- The ATLAS detector is not uniform in eta, so the response to jets is not uniform in eta
- Goal: remove the eta-dependence in energy response to improve the jet resolution via calibration
  - Energy response = reconstructed energy / true energy

- Goal for trigger: select all jets that had true pT above X
- For a response, R, that is constant everywhere, the L1 selection would be at X*R
- If R is a function of eta, a cut at a single value X*R will select truth jets at different pT across eta
- A calibration can be derived to make calibrated jFex jets have a flat response in eta



https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/PERF-2016-04/

Summary

- ATLAS upgrades for Run 3 are in full swing
- Performance studies have shown improvements for jFEX jets over Run 2 L1 jets
- Further studies to help pileup mitigation via improvements in jFEX MET and to help improve performance with better jets, taus, and photons