The ATLAS Level-1 Topological Processor: experience and upgrade plans

Carlos Moreno-Martínez (IFAE-BIST Barcelona)
on behalf of the ATLAS Collaboration

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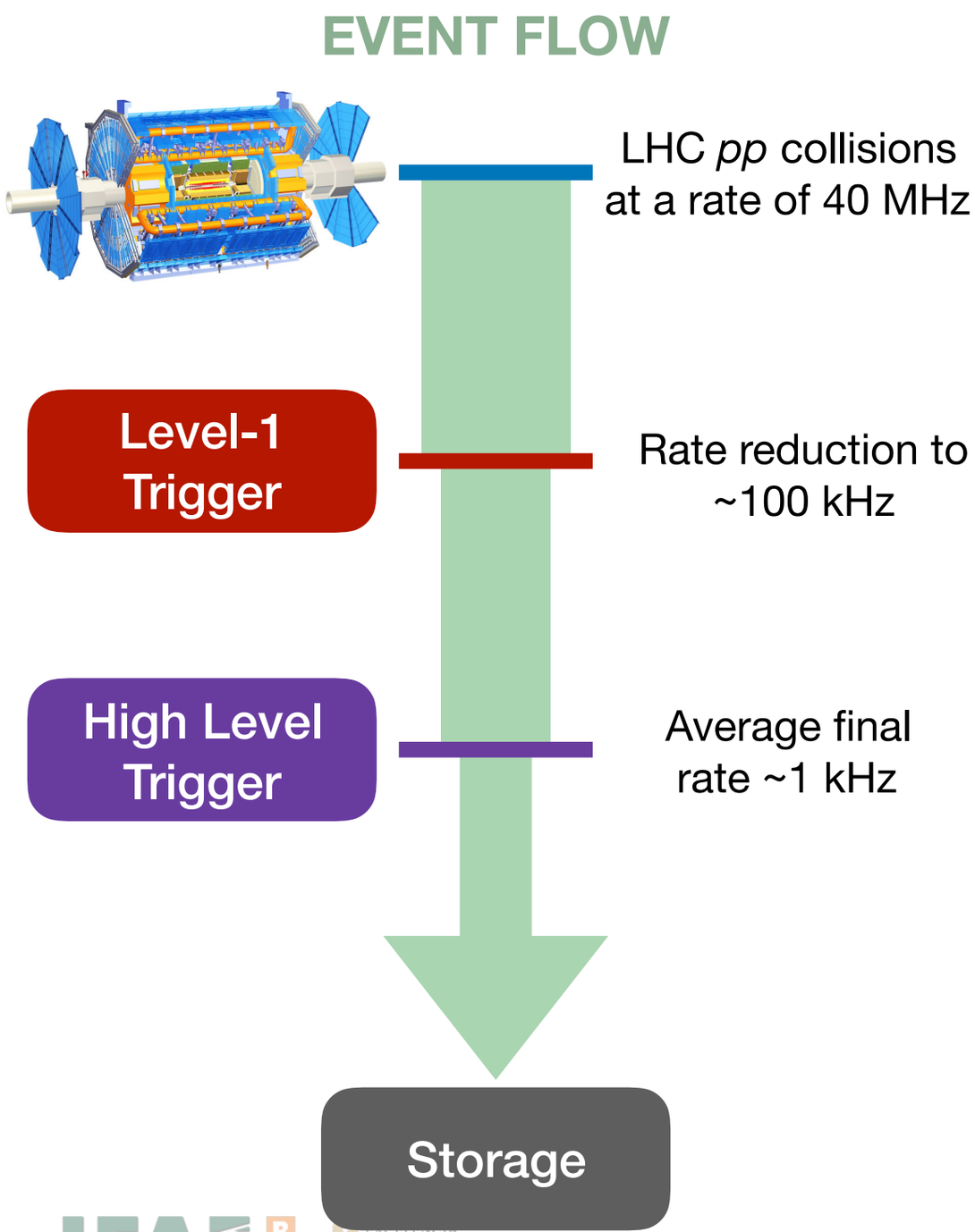
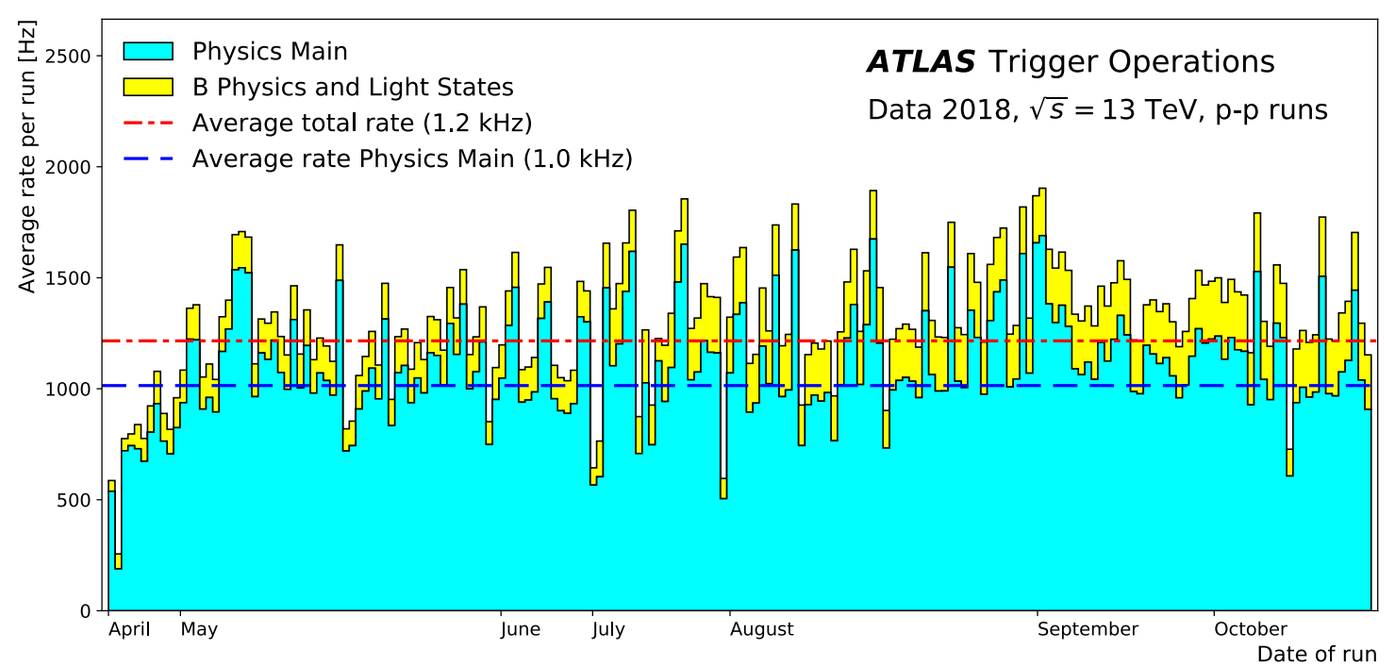
Institut de Física d'Altes Energies
EXCELENCIA SEVERO OCHOA
BIST Barcelona Institute of Science and Technology

ATLAS EXPERIMENT

ATLAS Trigger System in Run-2

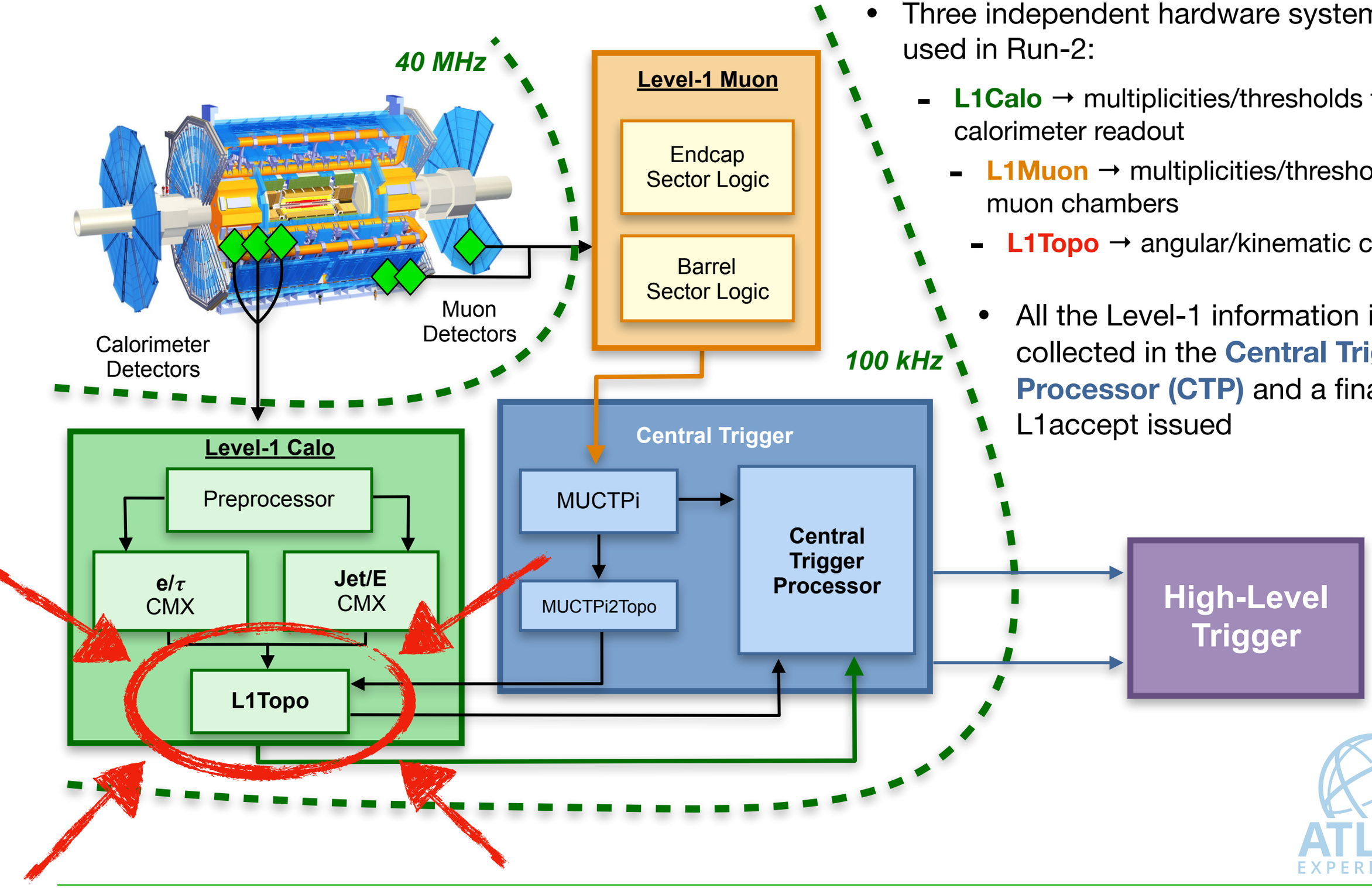


- The trigger system efficiently reduces the event rate by recording the *interesting* ones
- This selection is done in two levels:
  - **Level-1 Trigger (L1)**: hardware-based system using only the calorimeter and muon information
  - **High Level Trigger (HLT)**: software-based system applying offline-based reconstruction criteria
- Efficient ways of reducing background:
  - Minimum energy and multiplicity objects
  - Kinematic and angular cuts: *Topological trigger*



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

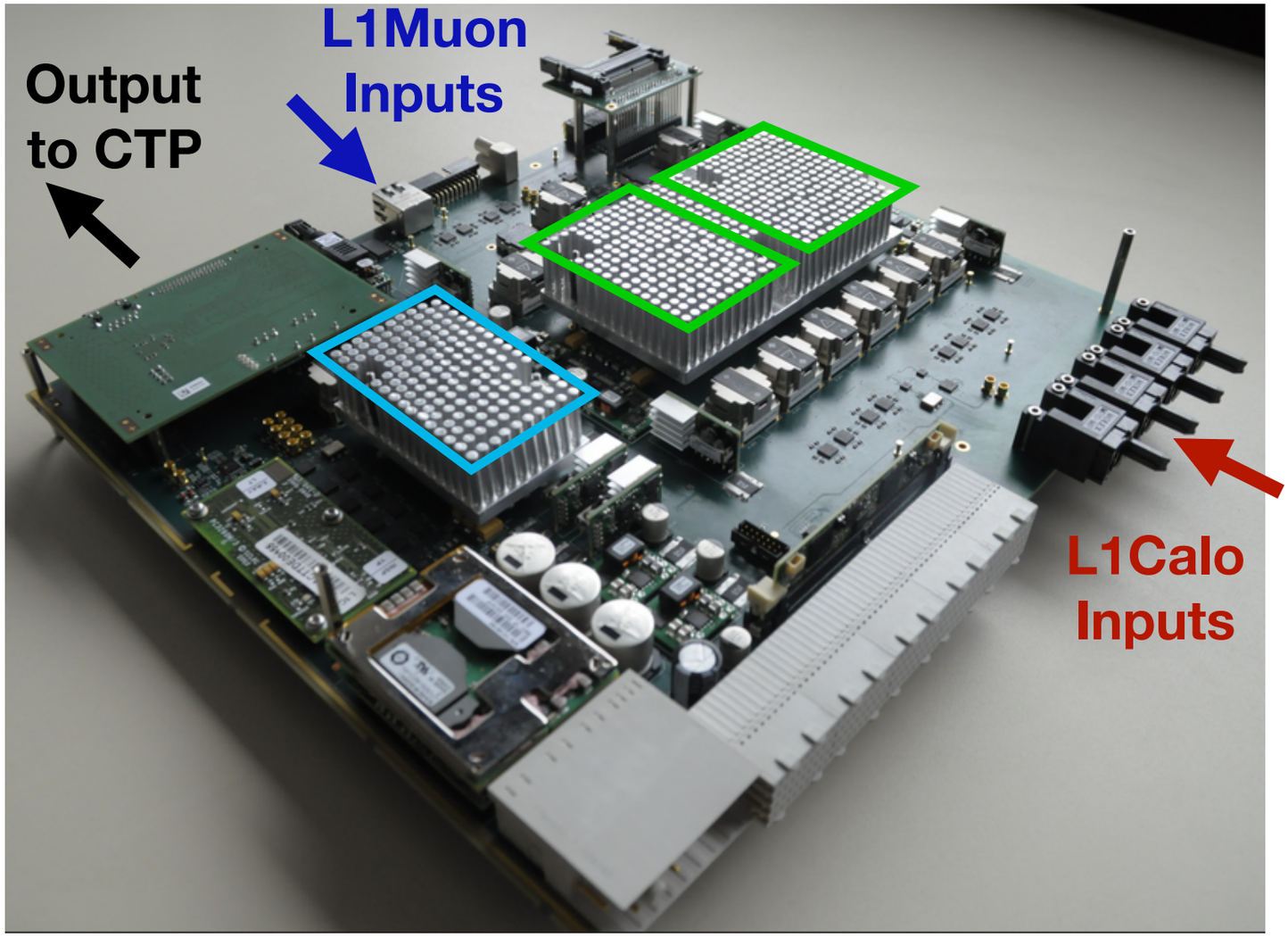
ATLAS Level-1 Trigger in Run-2



- Three independent hardware systems were used in Run-2:
  - **L1Calo** → multiplicities/thresholds from calorimeter readout
  - **L1Muon** → multiplicities/thresholds from muon chambers
  - **L1Topo** → angular/kinematic cuts
- All the Level-1 information is collected in the **Central Trigger Processor (CTP)** and a final L1accept issued

Level-1 Topological (L1Topo) Trigger in Run-2

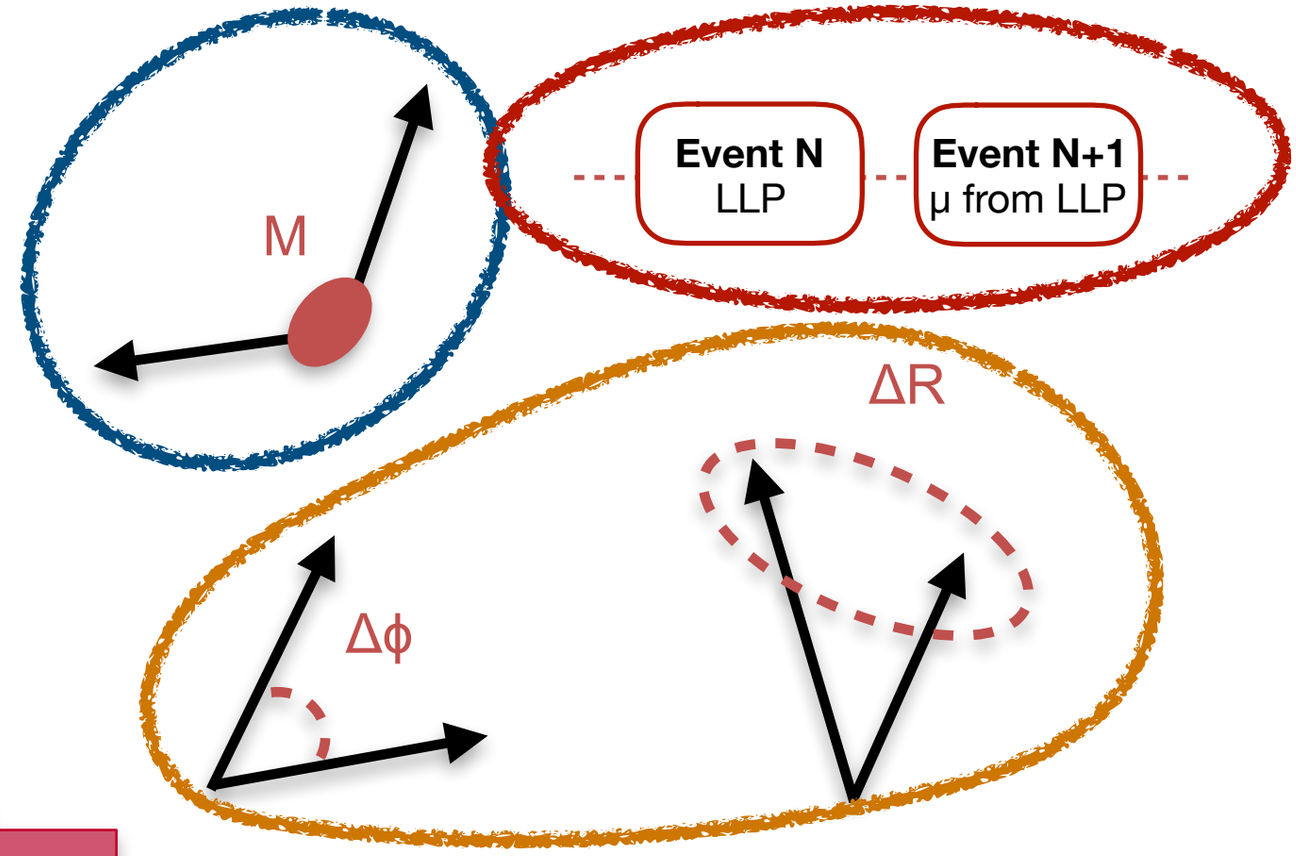
- L1Topo was installed and commissioned in Run-2
- **IN:** Receives information from *L1Calo* and *L1Muon*
- **OUT:** Provides trigger decisions based on topological variables
  - Up to 128 decisions available
  - Sent directly to *CTP*
- Consists of two boards, each with:
  - 2 Virtex 7 FPGAs to compute algorithms
  - 1 Kintex 7 FPGA for communication and readout
- High input bandwidth (~1Tb/s)
- High speed inter-FPGA communication (238Gb/s)

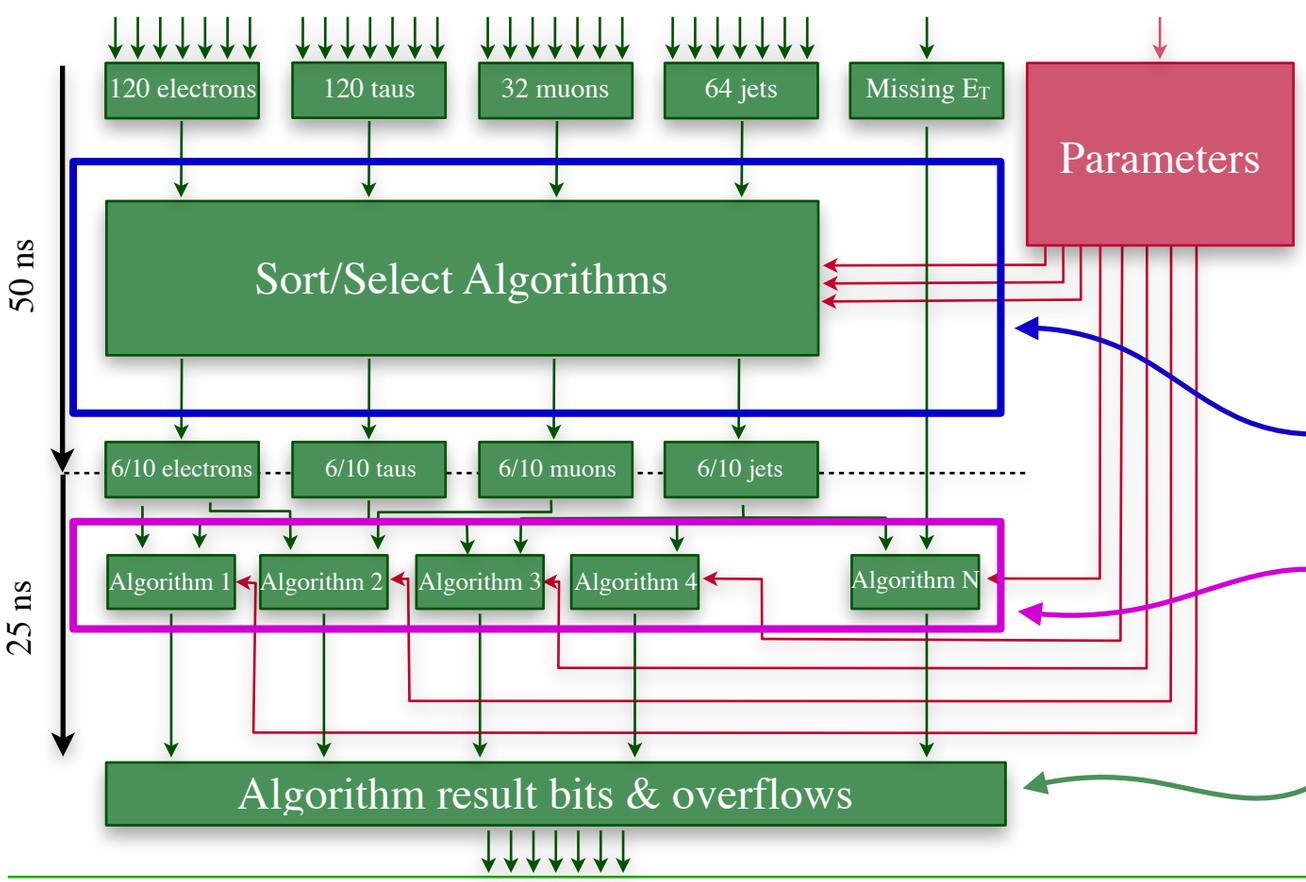


L1Topo Board in Run-2

L1Topo functionality and implementation

- Combination of calorimeter and muon detectors information
- Angular selections:
  - Δϕ, ΔR, Δη, angular window, objects disambiguation
- Mass selections:
  - Invariant and transverse mass
- Access to trigger objects from different bunch crossings





Implementation

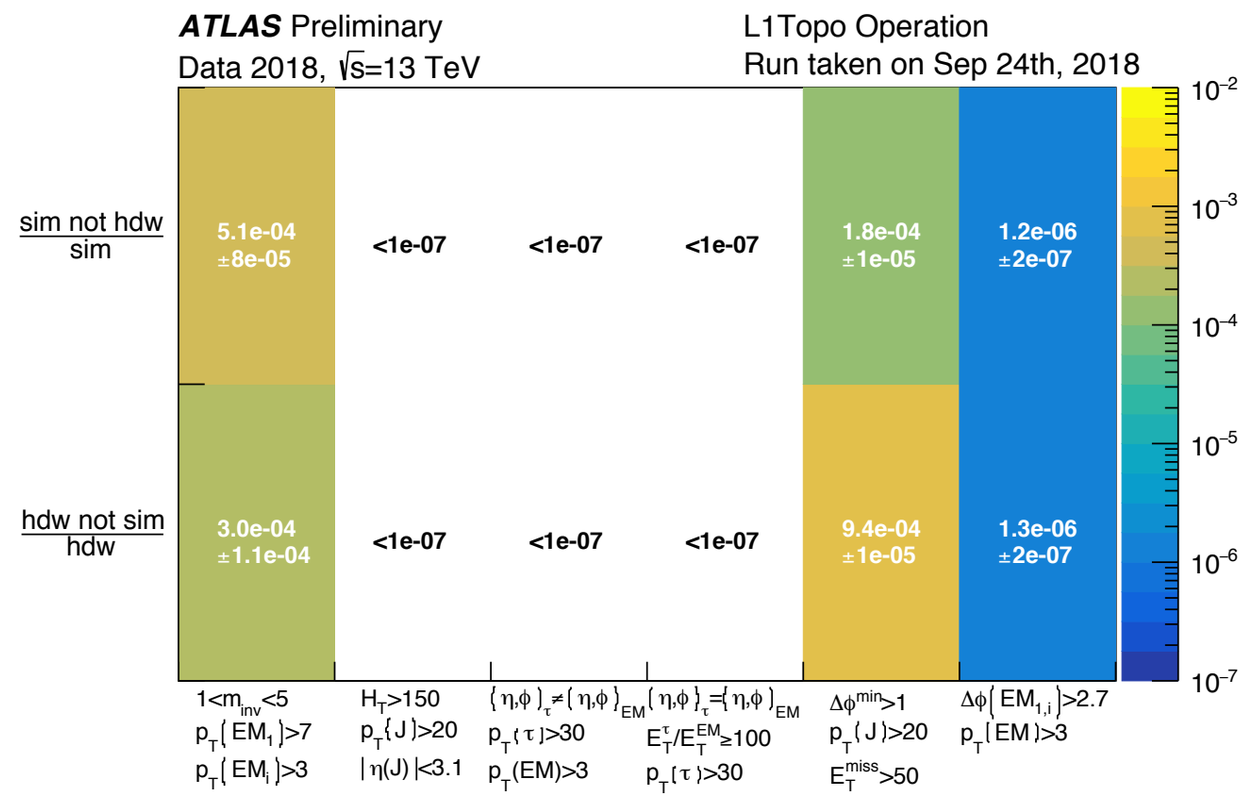
- ~75 ns used for algorithms
- L1Topo receives energy and position of all **trigger objects** (TOBs) → reduced into lists
- TOBs are processed by algorithms producing up to 128 trigger decisions
- Final decisions are sent to the CTP

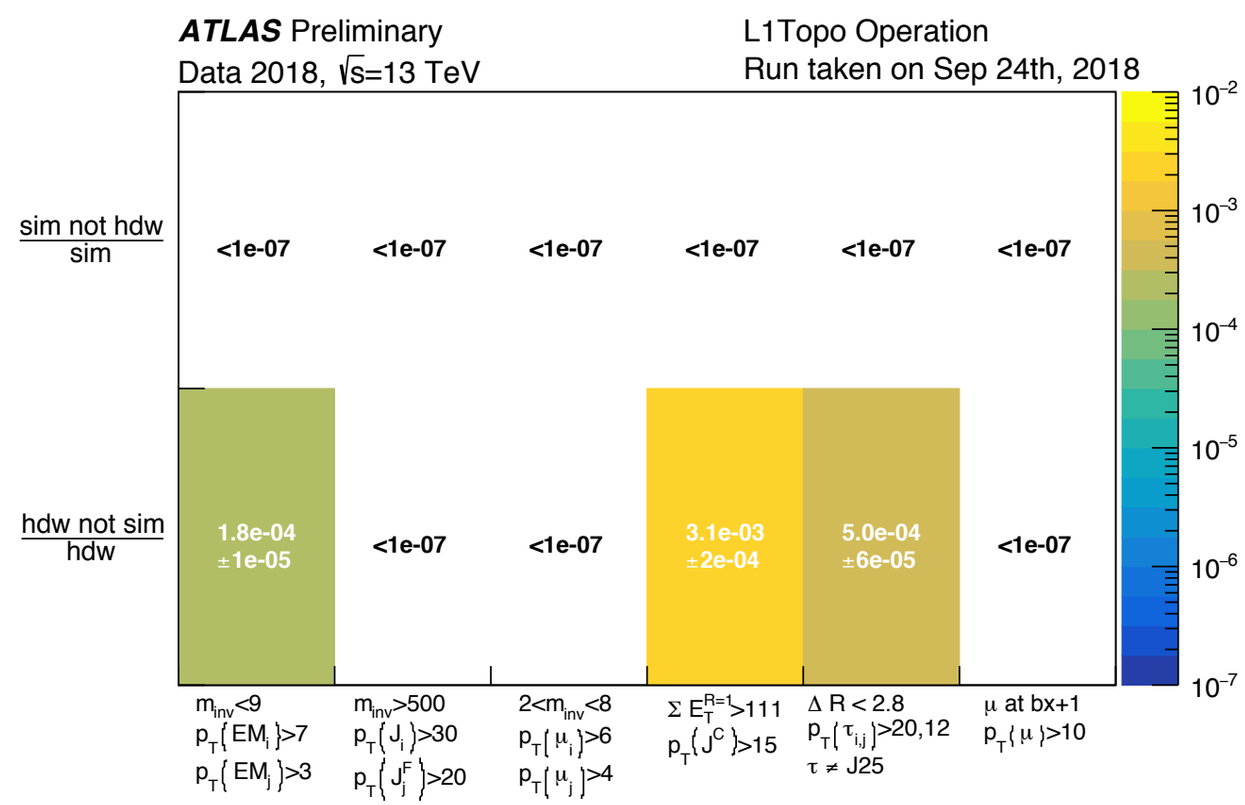
Validation Process

- Different ways to validate L1Topo performance:
  - Standalone VHDL simulation
  - Using well defined data and studying the algorithm outputs
- One of the most powerful methods: **integrated simulation in HLT**
  - Runs online for almost every accepted event
  - Reproduces bitwise all the L1Topo decisions
  - *Both hardware and simulation decisions are stored*
- The rates of simulation false positives/negatives are computed for each L1Topo trigger
  - Events showing hardware-simulation discrepancies are studied in detail offline
  - Can be used to understand unexpected behaviour of different triggers

Hardware-simulation discrepancy rates lower than 10^{-3}

False positive/negative rates for L1Topo triggers

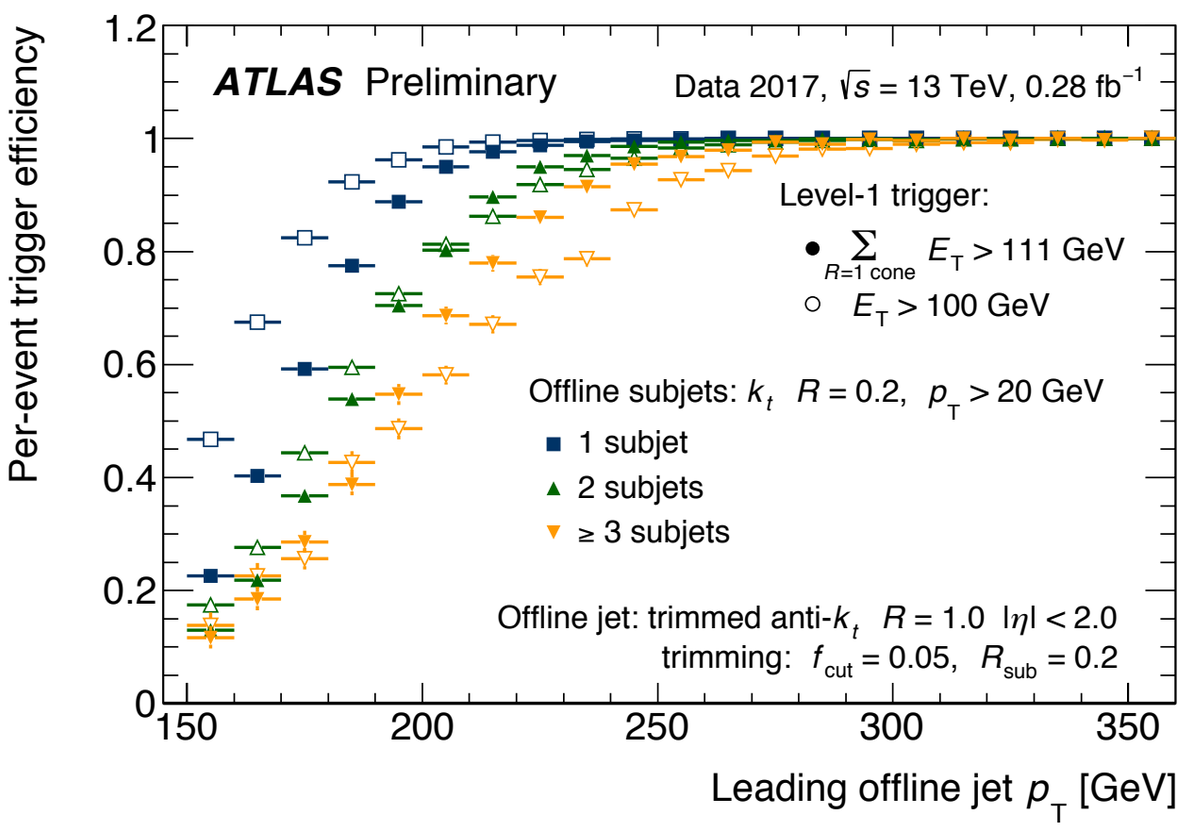




https://twiki.cern.ch/twiki/bin/view/AtlasPublic/L1CaloTriggerPublicResults

Physics Motivation

- Used in a variety of physics searches
  - Helps to keep trigger rates low by rejecting background events
  - Very useful to target challenging signatures
  - Equivalent to cut-based analysis results at L1!
- Helpful in the commissioning of new systems
  - FastTracker system



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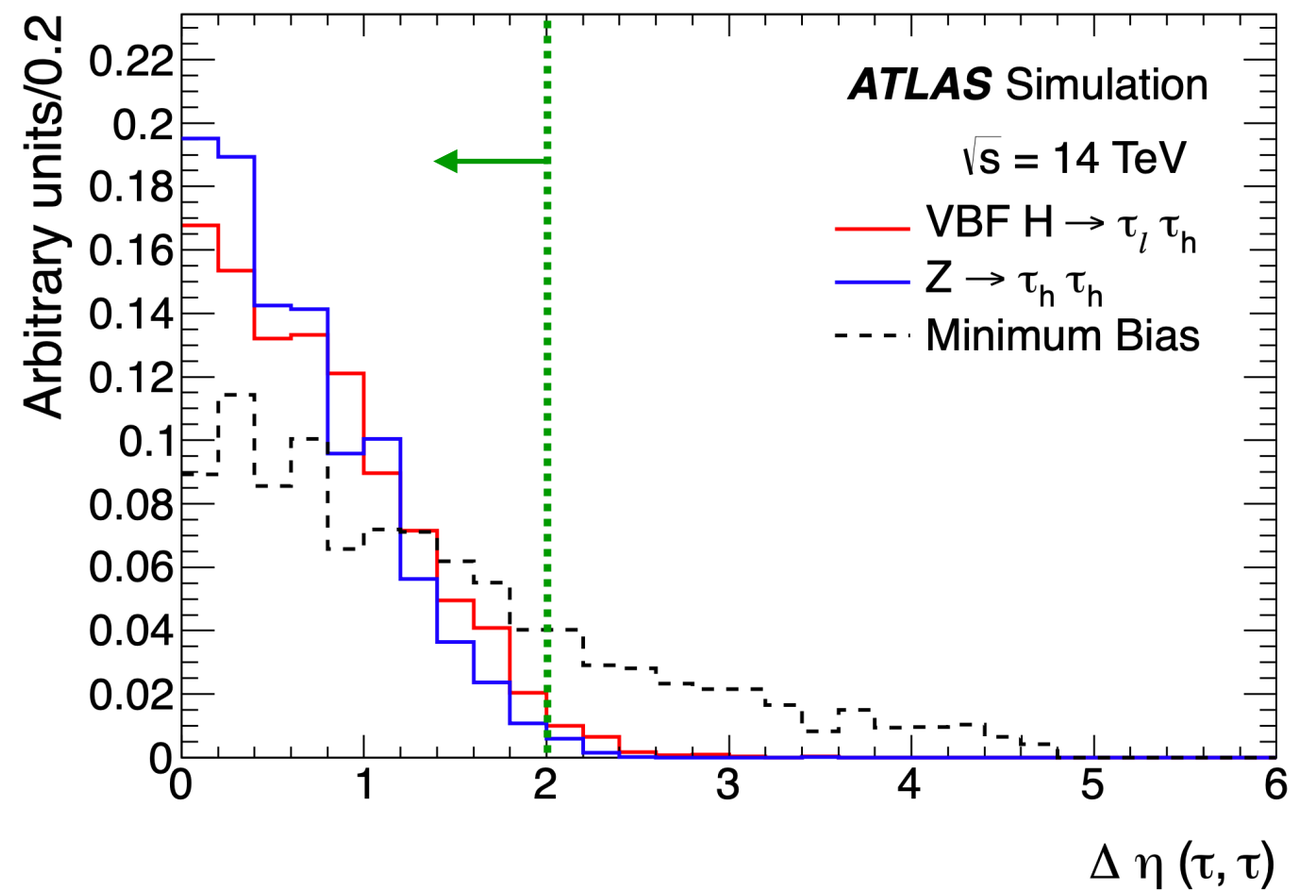
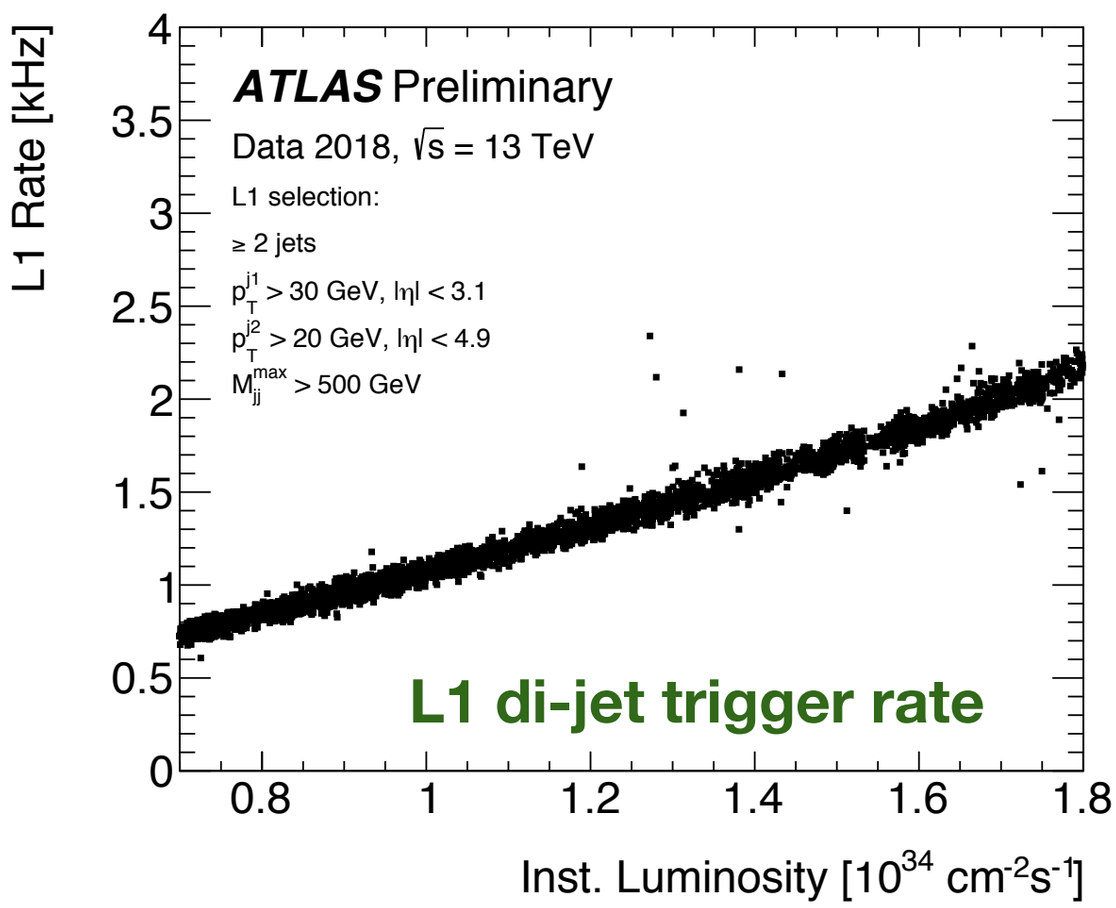
Angular separation between taus ATLAS-TDR-023

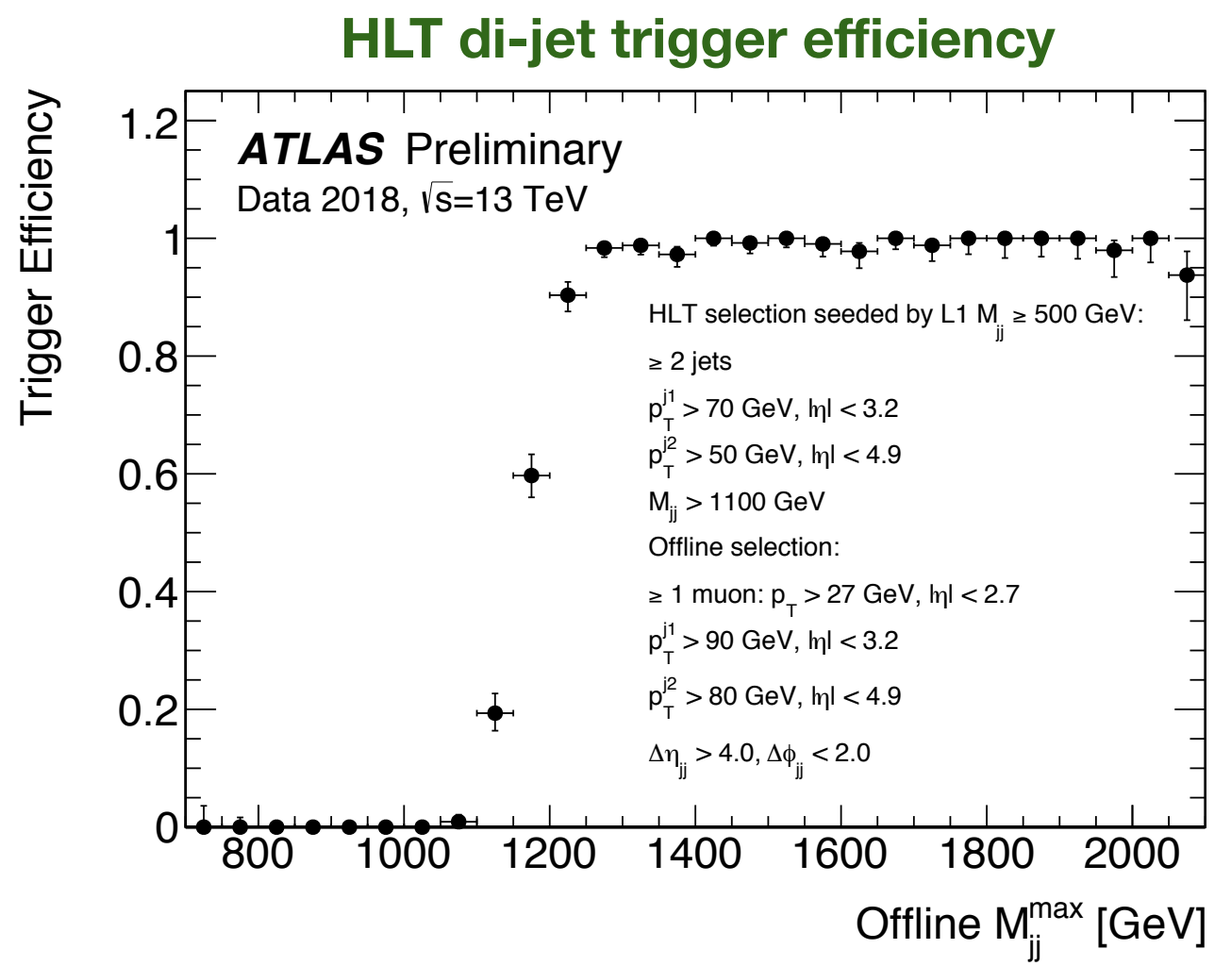


- L1Topo efficiently identifies jet sub-structure
- Comparison of two algorithms
  - ● Energy inside a cone higher than 111 GeV (L1Topo)
  - ○ Energy inside a square window higher than 100 GeV (non-topo)
- High number of subjets → energy is more spread
  - L1Topo shows higher efficiency

Physics Performance: di-jet triggers

- Di-jet triggers have high rates at low jet momentum
  - Cut on invariant mass helps to keep low thresholds
- High trigger efficiency for M_{jj} >1.3 TeV
  - Designed to reduce trigger rate while enhancing signal over background
- Combined with lepton triggers in different physics analysis
  - Higgs to di-τ
  - VBF Higgsino production





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Physics Performance: di-muon triggers

- Very useful for final states with low momentum leptons
  - Di-muon triggers used in B-physics analyses
- Topological cuts result in rate reduction of **~4x**
  - Region optimized for high signal acceptance
  - Large background rejection already at L1!
- Comparison of invariant mass distribution for **topo** and **non-topo** triggers
  - No bias introduced by L1Topo trigger
  - No significant loss in efficiency

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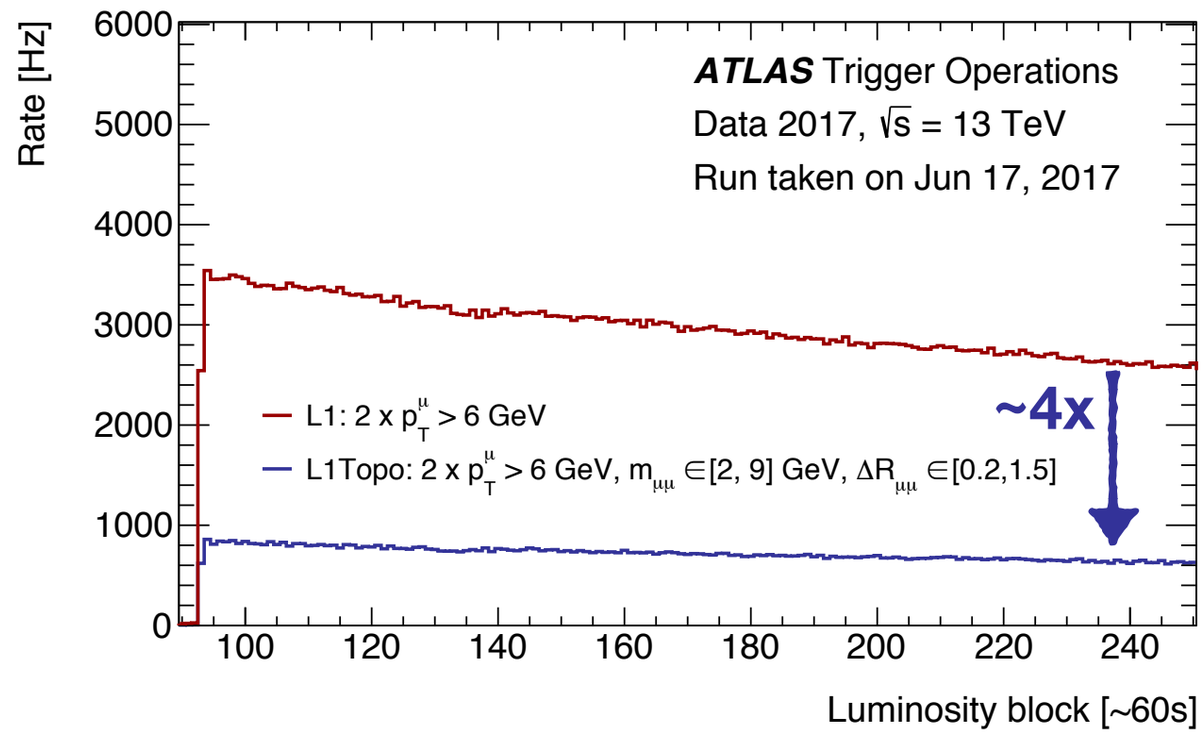
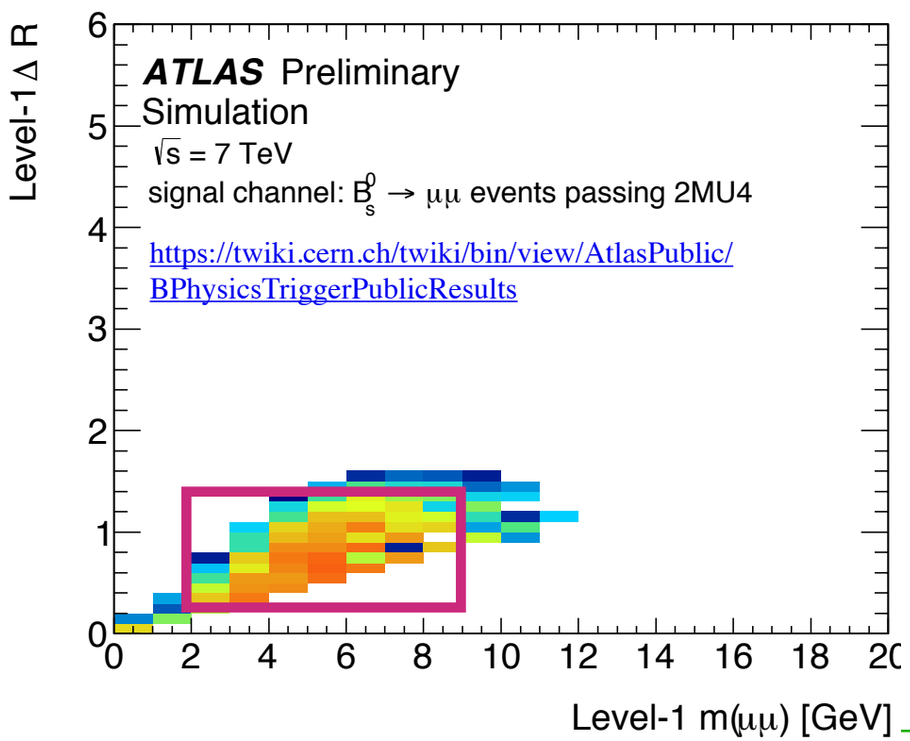
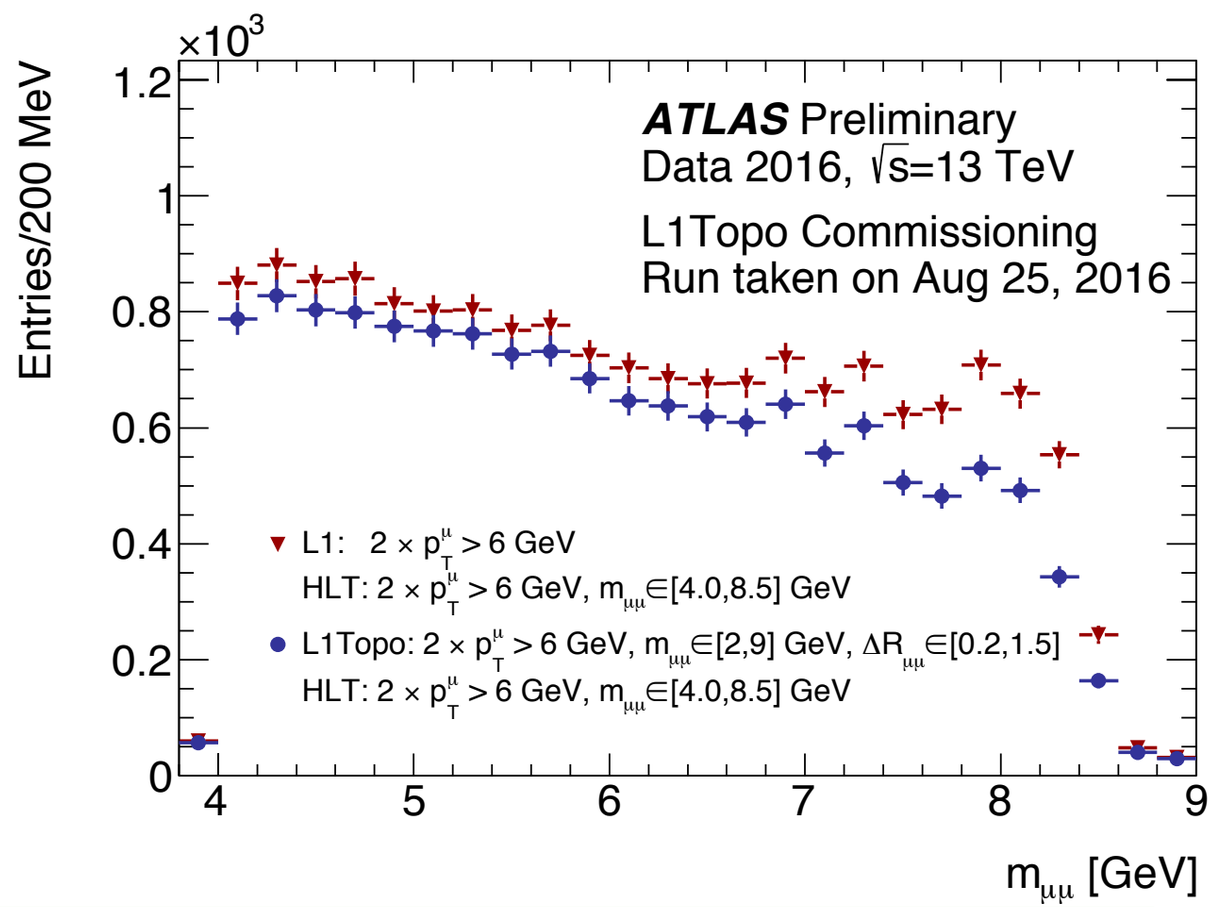
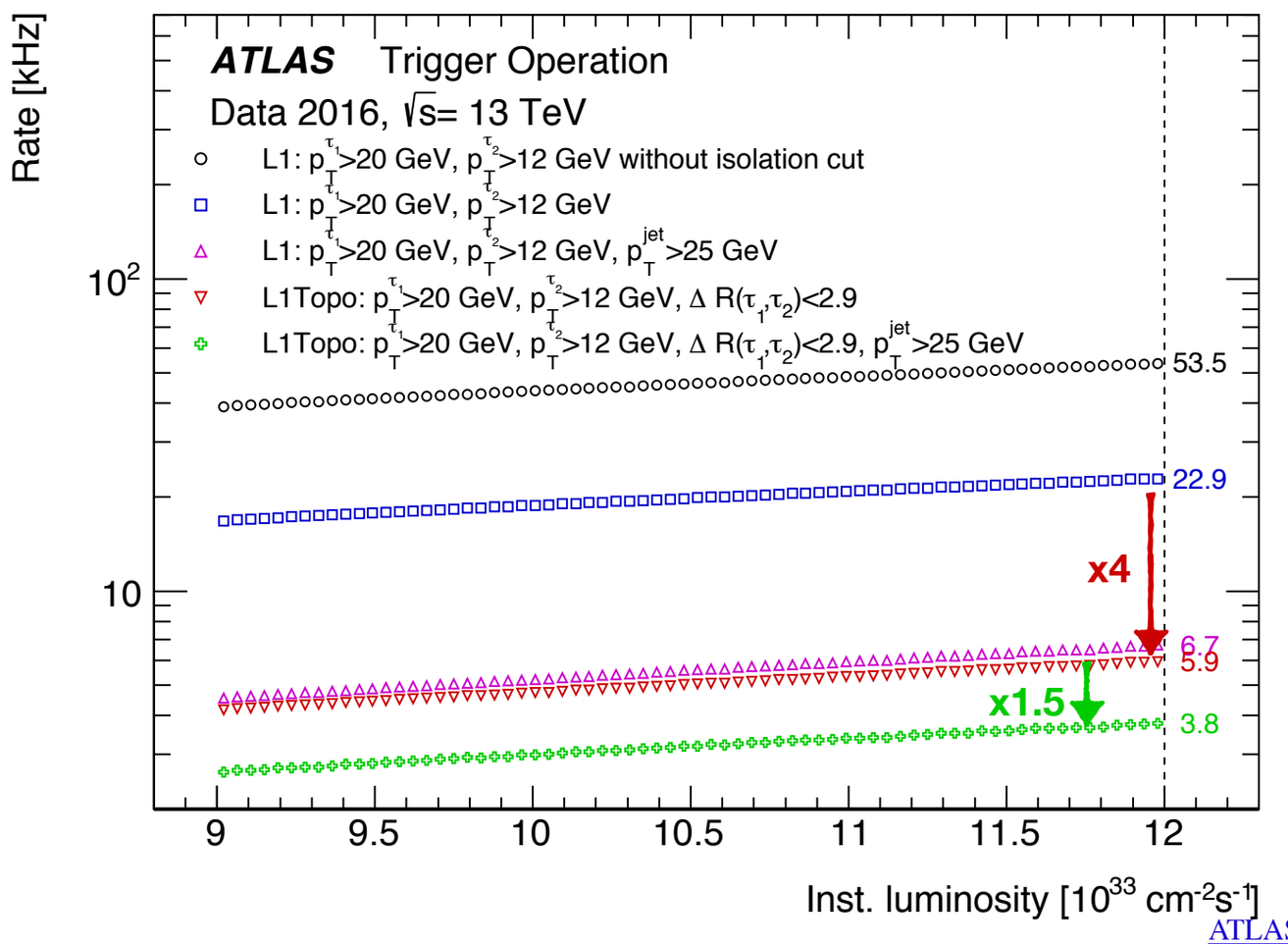


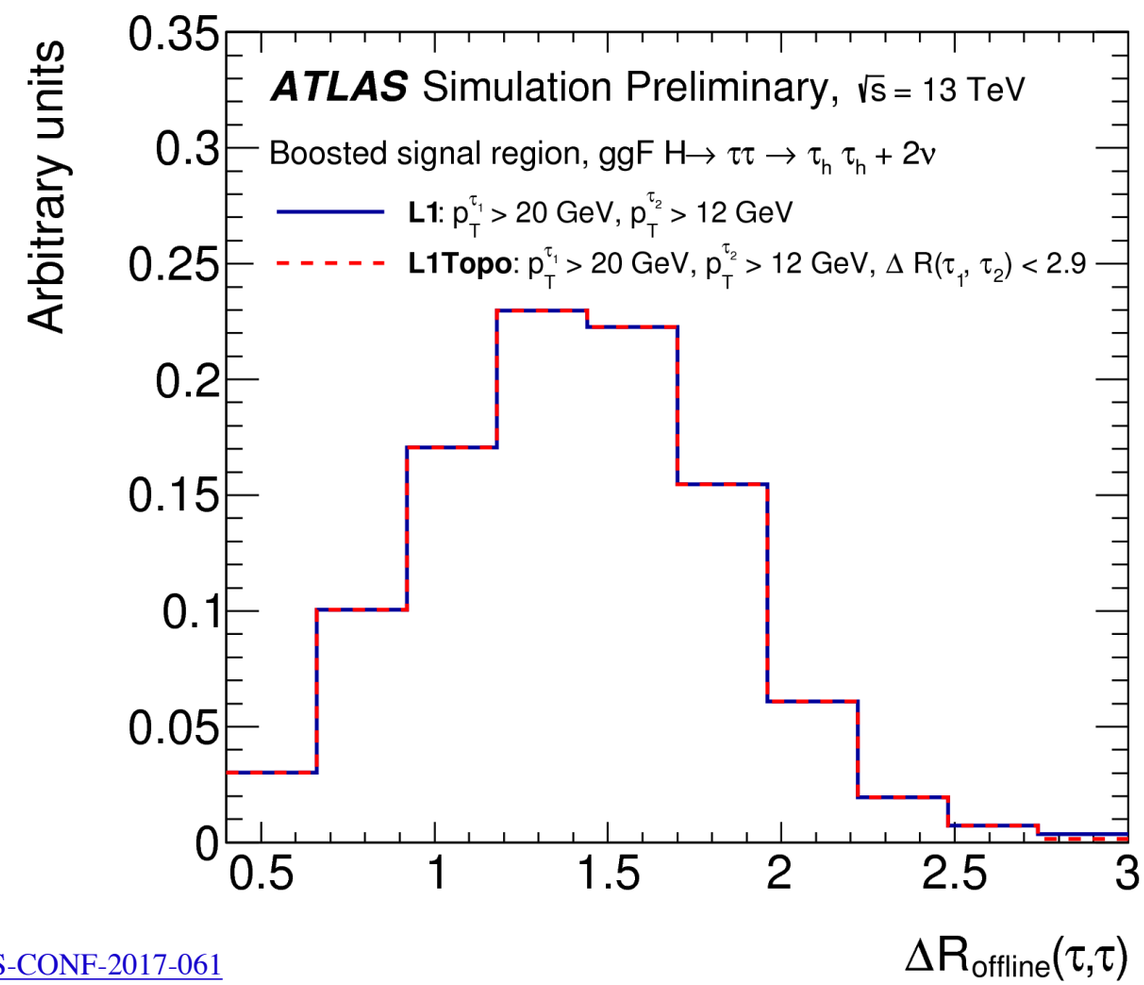




Physics Performance: di-tau triggers

- Critical use in analyses targeting di-τ final states: **H→τ τ**, **Z→τ τ**
  - High rate signature, L1Calo triggers need higher energy thresholds
- Including topological cuts reduces trigger rate while rejecting background
- For **H→τ τ** analysis: ΔR selection and extra jet requirement
  - Extra jet not overlapping with **τ** → possible only in L1Topo!
  - Large rate reduction
  - No efficiency loss





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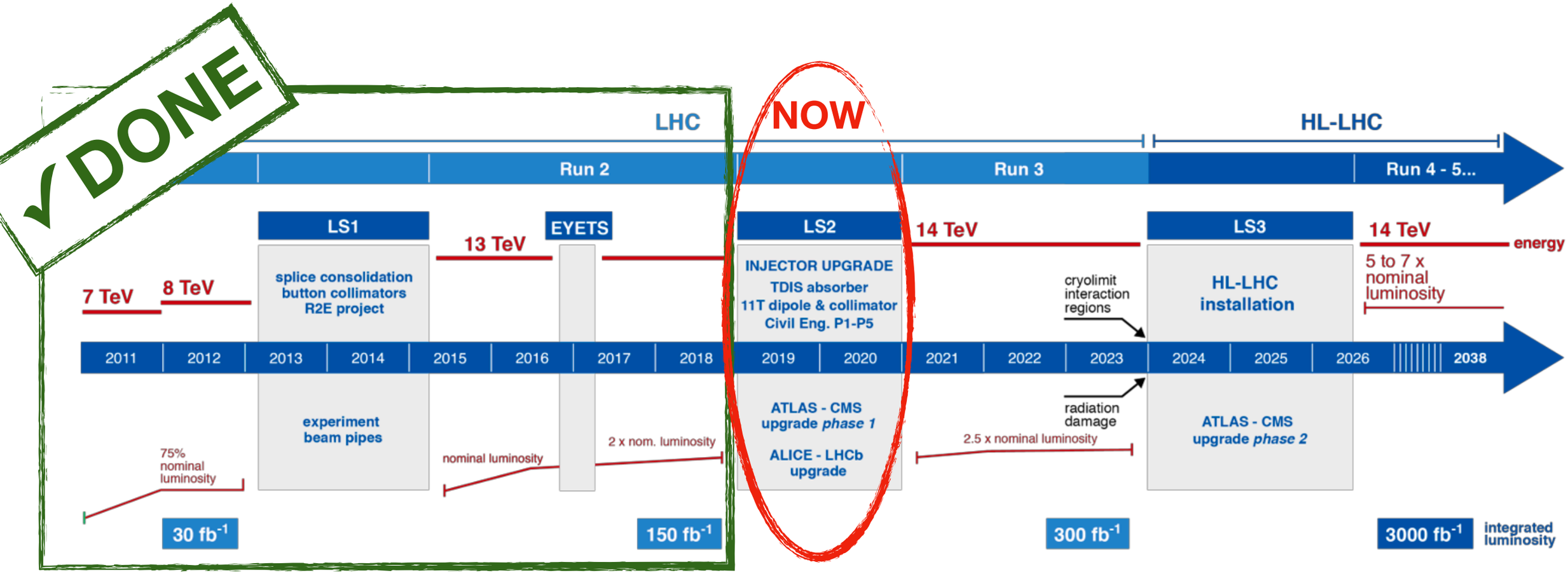
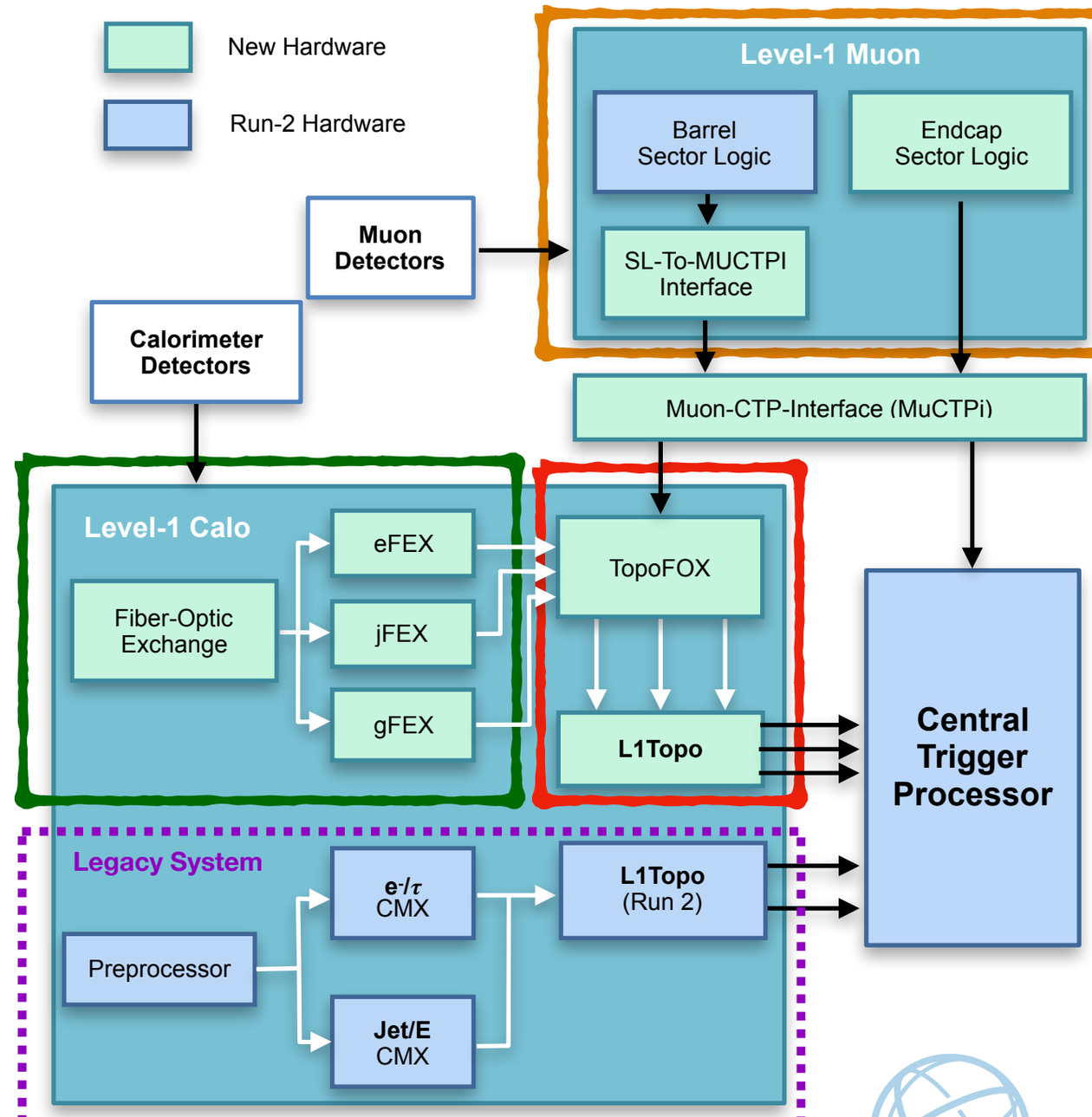
Moving towards LHC Run-3



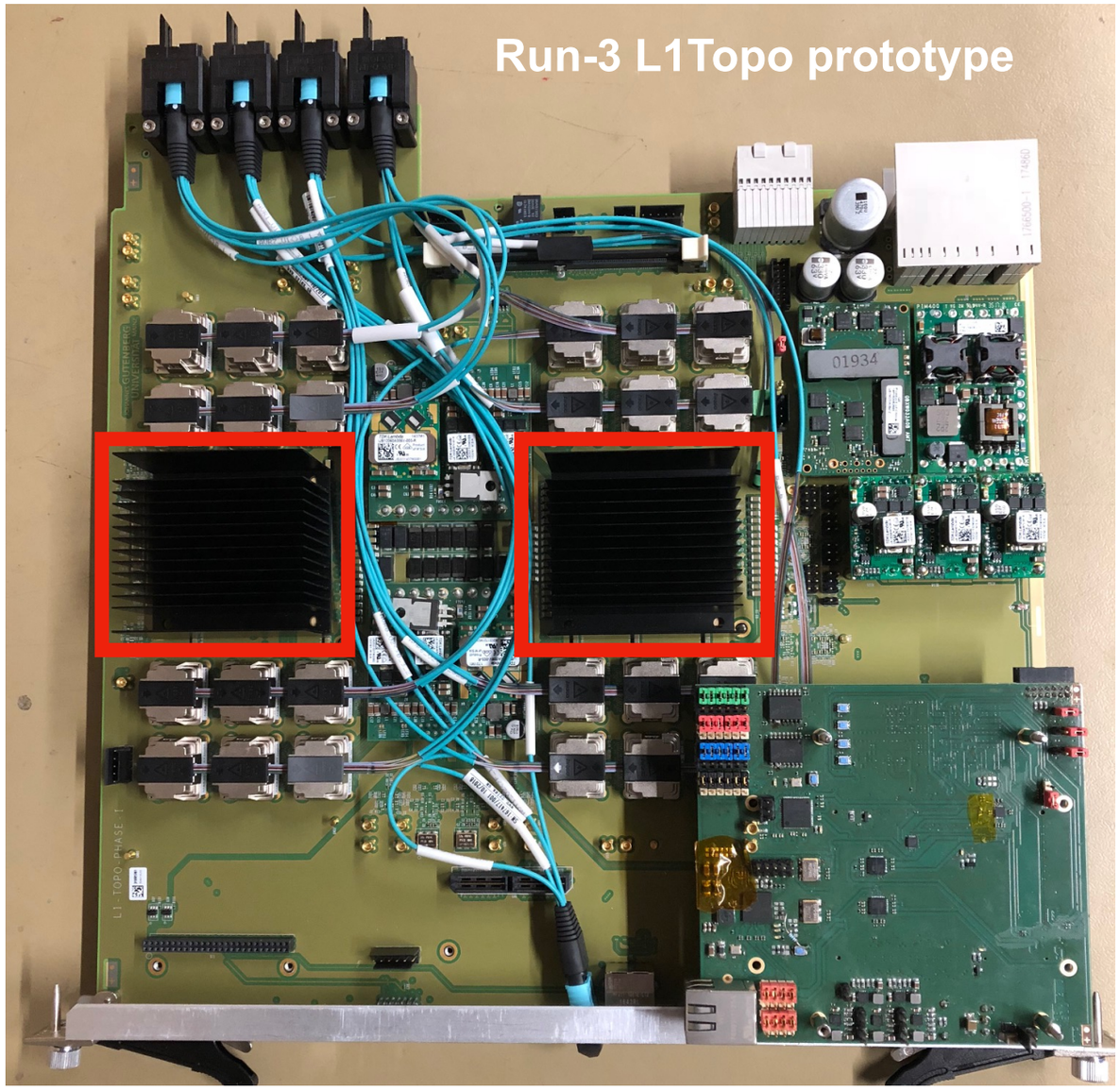
- Successful data taking during Run-2
- Next milestone: get ready for Run-3 during Long-Shutdown-2 (LS2)
- LHC will be upgraded: different conditions during Run-3
  - Higher pileup → lower calorimeter resolution and harder particle isolation
  - Higher trigger rates
- ATLAS calorimeters, muon spectrometer and trigger systems will be upgraded
  - Try to keep trigger thresholds as low as possible

Level-1 Trigger in Run-3

- ➡ Changes in **L1Muon**:
  - End-cap Sector Logic enhanced
  - New MuCTPi with extra bandwidth
    - Sends more information to L1Topo and CTP
- ➡ **L1Calo** → Feature Extractor boards (FEX):
  - Electron Feature Extractor (eFEX)
  - Jet Feature Extractor (jFEX)
  - Global Feature Extractor (gFEX)
- ➡ **L1Topo** → new hardware
- ➡ Run-2 hardware will be kept during the commissioning phase → **Legacy**

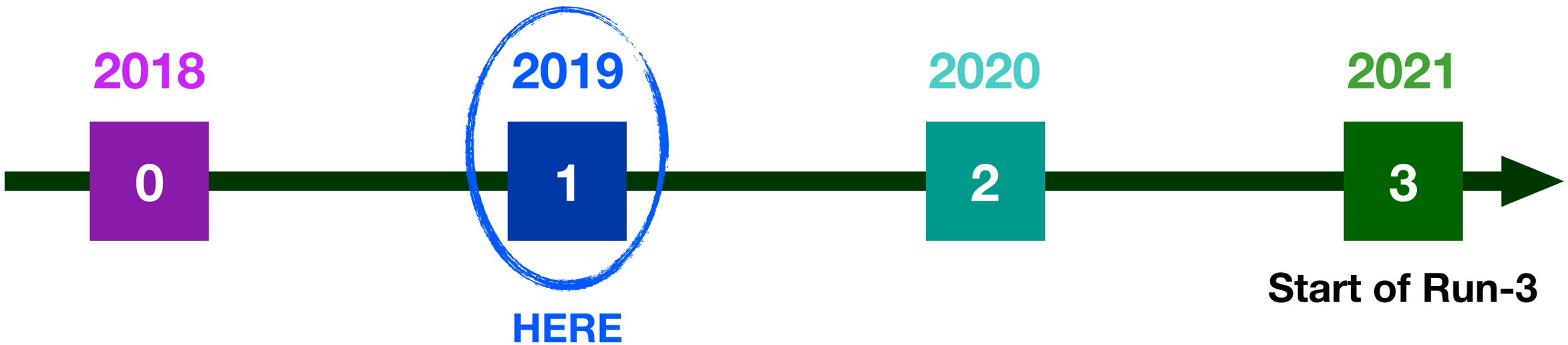


L1Topo in Run-3



- Consists of **three new hardware boards** with
  - 2 Xilinx UltraScale+ FPGAs for algorithm computation
  - 118 input fibers per FPGA
  - 24 output fibers per FPGA
- L1Calo threshold/multiplicity triggers will be formed in L1Topo
- Higher granularity from L1Calo and L1Muon
- Enhanced processing power for higher algorithm complexity, e.g.
  - Invariant mass of three objects
  - Simultaneous cuts in invariant mass and angular variables
  - Use of muon charge in computations
- Prototypes delivered and tested with good results
- Production of final boards starting soon!

L1Topo Commissioning Plan



0 **Pre-commissioning** ✔

- First tests with prototype

1 **Commissioning of integrated system**

- System-level tests and communication with neighbouring systems

2 **Pre-beam commissioning**

- Use calorimeter tower patterns and cosmic rays and compare with simulation

3 **Commissioning with LHC beam**

- First year of data taking
- Legacy system and new hardware will run in parallel
- Trigger menu adaptation is needed

Data taking with new L1Topo

- Legacy system will be removed once commissioning is done
- Online simulation will run at the HLT

Conclusions

- Successful commissioning and routine operation of Level-1 Topological Trigger during Run-2
- Increased signal acceptance in analysis targeting challenging signatures with high trigger rates
  - Useful to discriminate between signal and background already at the trigger level!
- Performance continuously validated with online simulation
  - Achieved an agreement level between simulation and hardware of better than 99%!
- Upgraded L1Topo system in Run-3 will allow higher complexity in topological algorithms
  - Parallel commissioning with the new upgraded L1Calo and L1Muon systems