The ATLAS Trigger & Data AcQuisition (TDAQ) System

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on behalf of the Trigger Group

ATLAS Induction Day
21. October 2019

U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Who are we?

https://twiki.cern.ch/twiki/bin/view/Atlas/AtlasTrigger

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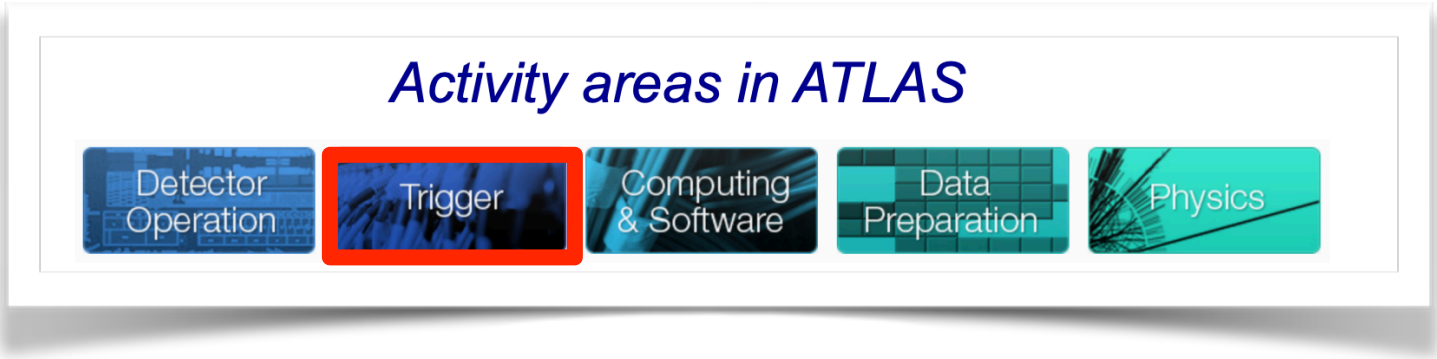


- Trigger Group is one out of five *Activity Areas* covering a diverse range of work
  - **Menu & performance** related work within **signatures** (egamma, muons, taus, jets, met etc) and **detector software** (tracking, calorimeter) maintaining close contact to physics groups and offline reconstruction groups
  - (Core) **software**-related work include analysis tools, conditions, data model and online related activities
  - **Releases and validation**
  - Exciting **on-call/online** work as part of **trigger operations** including data quality & monitoring

https://twiki.cern.ch/twiki/bin/view/Atlas/AtlasTrigger

Trigger Coordination Group

https://twiki.cern.ch/twiki/bin/view/Atlas/TriggerOrganisation

Trigger Coordinators

L1 Operations

- L1Topo algorithm commissioning
- L1 software

Trigger Operation & DQ

- Monitoring, DQ & Tools
- Debug Stream & Offline Reprocessing
- On-call crew

Trigger Core Software

- Analysis Tools
- Trigger Tool & Configuration
- HLT Integration

Trigger Menus & Performance

- Signature Groups
- Trigger Detector Software
- Rates & Cost Monitoring
- Heavy Ion Forum
- Online Beamspot Forum
- Menu Coordination Group

Releases & Validation

- Release Coordination Rota
- Validation Rota
- RTT& Validation Tools

Contacts to other groups

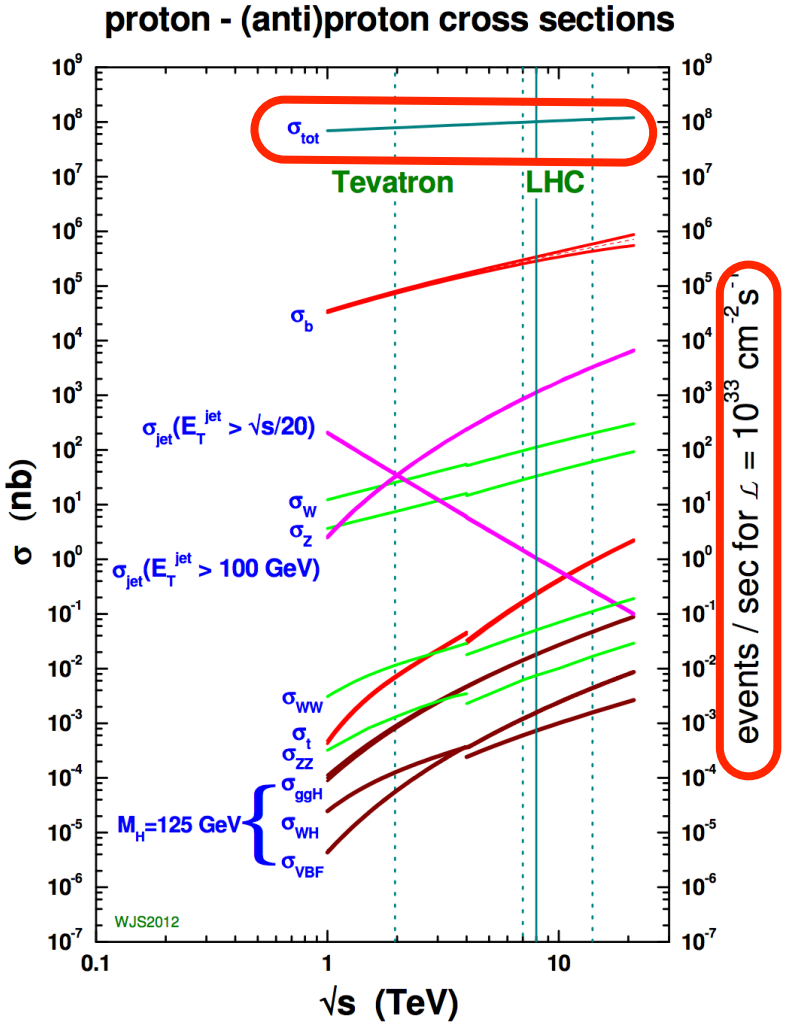
- EDM
- Non-collision Background
- Simulation
- DAQ/HLT

Activity
Group of People
Activity belongs to group
Activity also reports to indicated group

Why Trigger? - Physics at the LHC

- Typical collision at LHC not necessarily that interesting
  - 1 GHz @ 10^{34} cm^{-2} s^{-1}
- Interesting physics is 6-8 orders of magnitude rarer
  - Electro-weak (W/Z) and Top physics
- LHC was built to explore even more rare physics
  - e.g. Higgs produced in about 1 out of 10^9 collisions
    - Detection rate is even lower

Even if we could, saving all events at LHC is not useful!



Trigger & Data Acquisition (TDAQ) System

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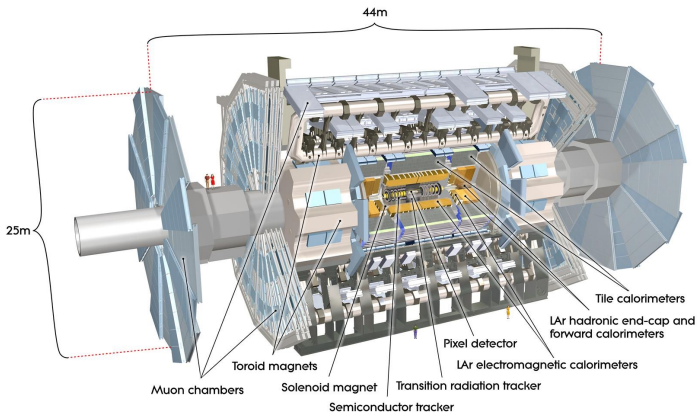
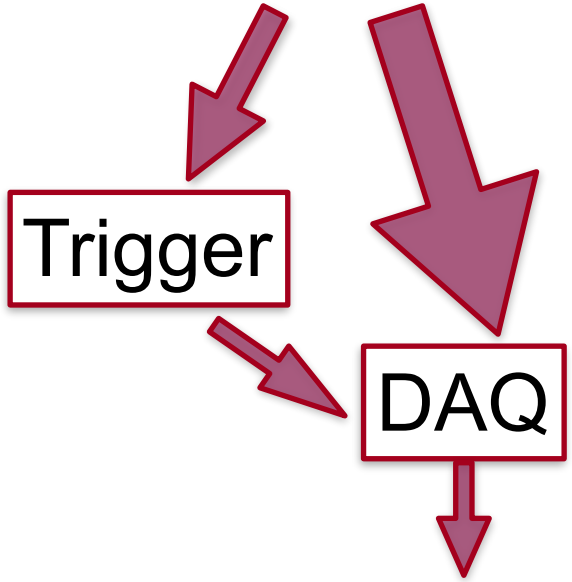
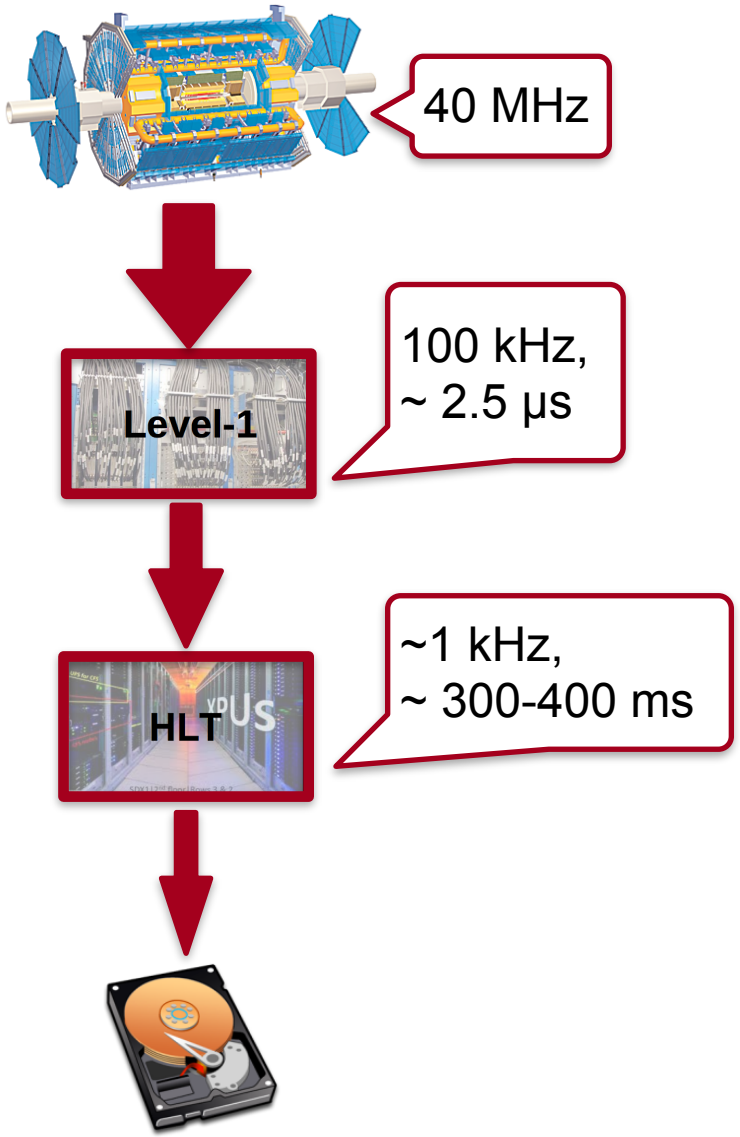
- Recording the interesting physics is a challenge
  - **ATLAS detector is BIG**
    - ~100 million channels
    - 1 MB of RAW data per event
  - **Rate of delivered collisions is high**
    - 40 MHz measurement rate (every 25 ns)



- **Data Acquisition (DAQ)** is responsible for
  - collecting data from detector systems (detector read-out),
  - digital conversion and
  - recording them to mass storage for offline analysis (data flow)
- **Trigger** is responsible for **real-time (online) selection** of the subset of events to be recorded

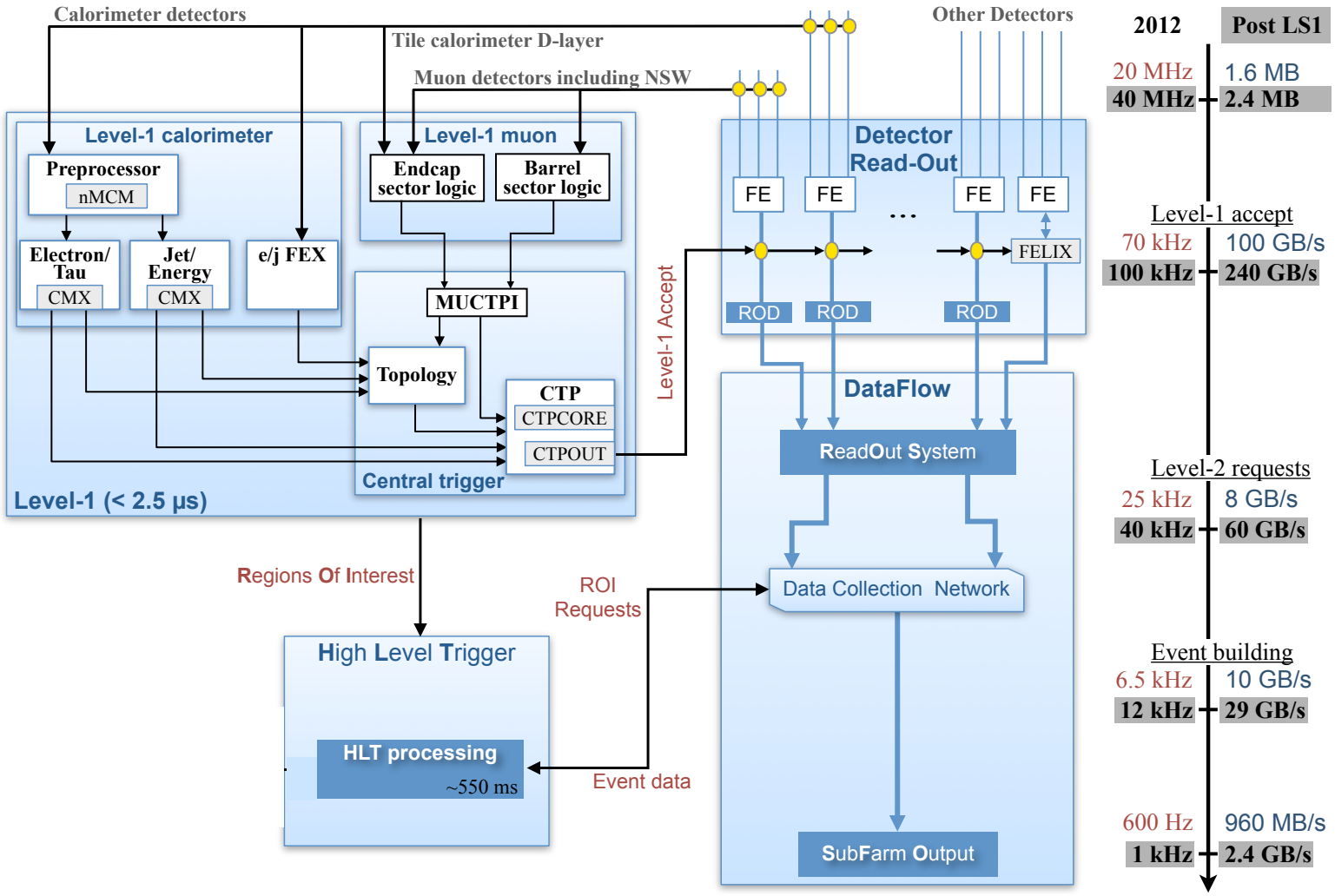


The ATLAS Trigger System



- **Level-1**
  - **Hardware-based**
  - Coarse selection based on limited input from **calorimeter & muon** systems
  - Rate and latency limit set by detector & trigger hardware
- **High Level Trigger (HLT):**
  - **Software-based**
  - Average processing time set by HLT farm size
    - Commodity hardware; ~40k processing units (PUs)
    - Expected to be 59k (68k) processing units (PUs) in 2021 (2022); 40k PUs
  - ~1 kHz **average** output rate

More Complex Overview of the Run 3 TDAQ System



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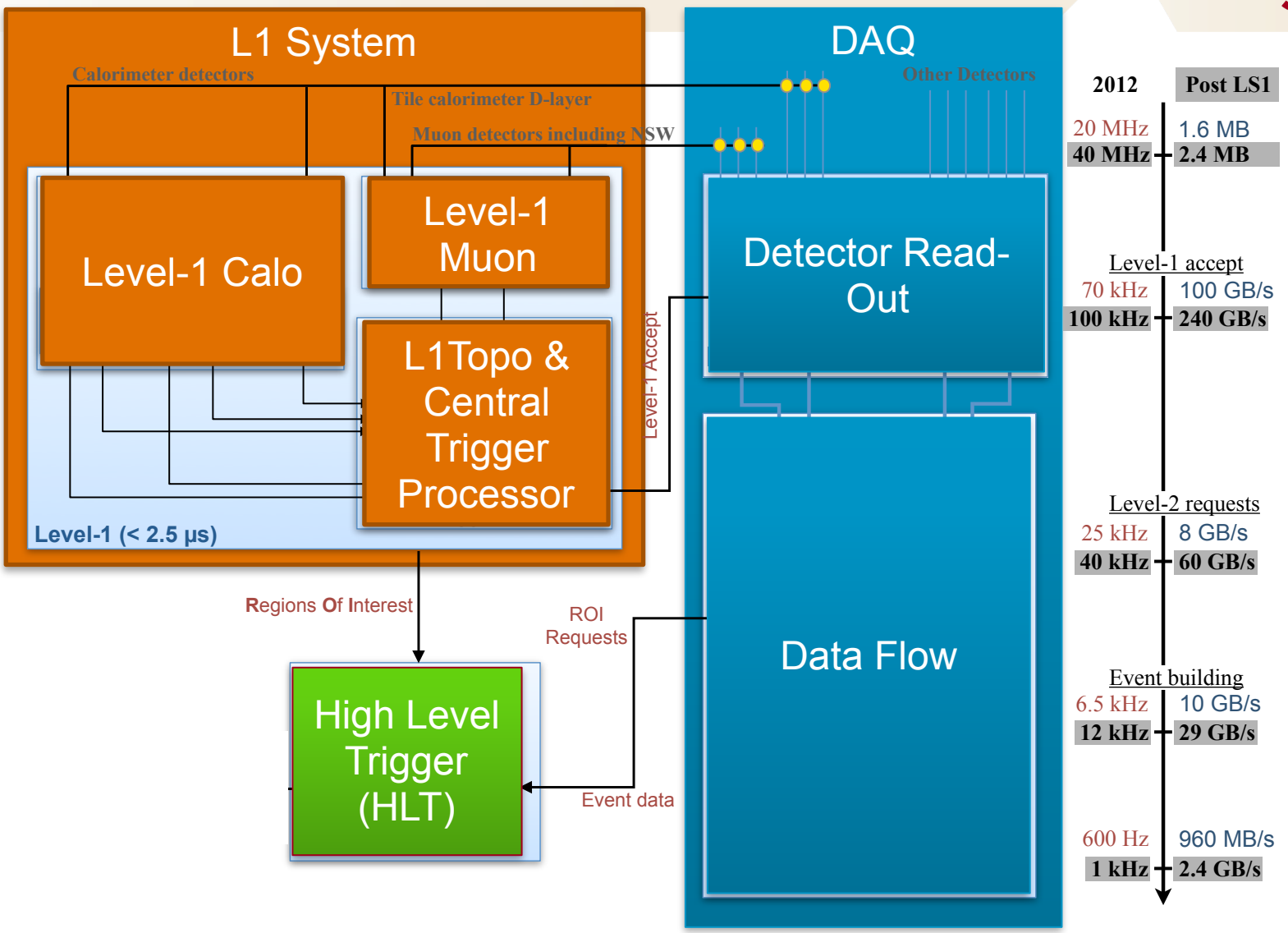
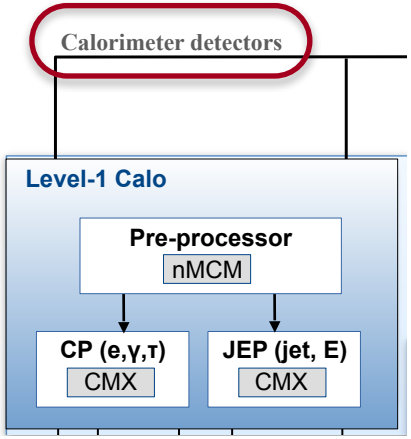
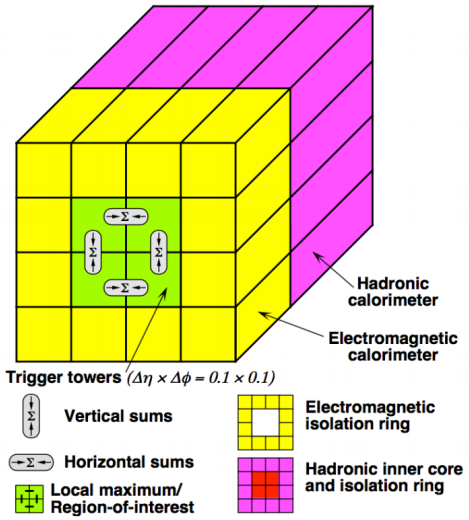


L1Calo - Run 2

- **For triggering on any EM object**
  - **Electrons, Photons, Jets, Taus**
  - **Global event quantities (ME_T)**

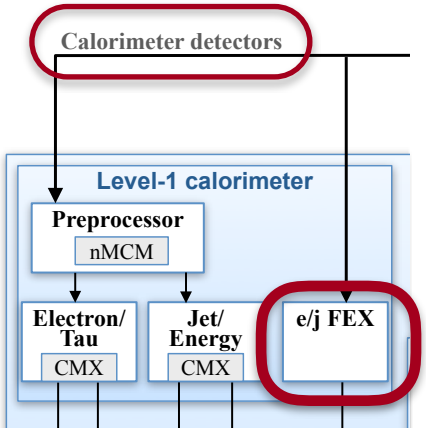
- Run 2 Pre-processor
  - Several **calorimeter cells are summed into trigger towers**
  - Resulting in towers of reduced granularity, e.g. η x Φ = 0.1 x 0.1
    - ~7000 calorimeter trigger towers
- Run 2 Cluster Processor (CP), Jet-Energy Sum Processor (JEP): **Object reconstruction for e, γ, τ, jet, (E)**
  - Find local maximum via sliding window algorithms
    - Apply energy selection based on sum in towers
    - Window size depending on object
    - Electron/Photon 0.2 x 0.2, Jets 0.4 x 0.4
  - Can apply additional selections
    - EM isolation (ring around core)
    - Hadronic isolation (no activity in hadronic layer)

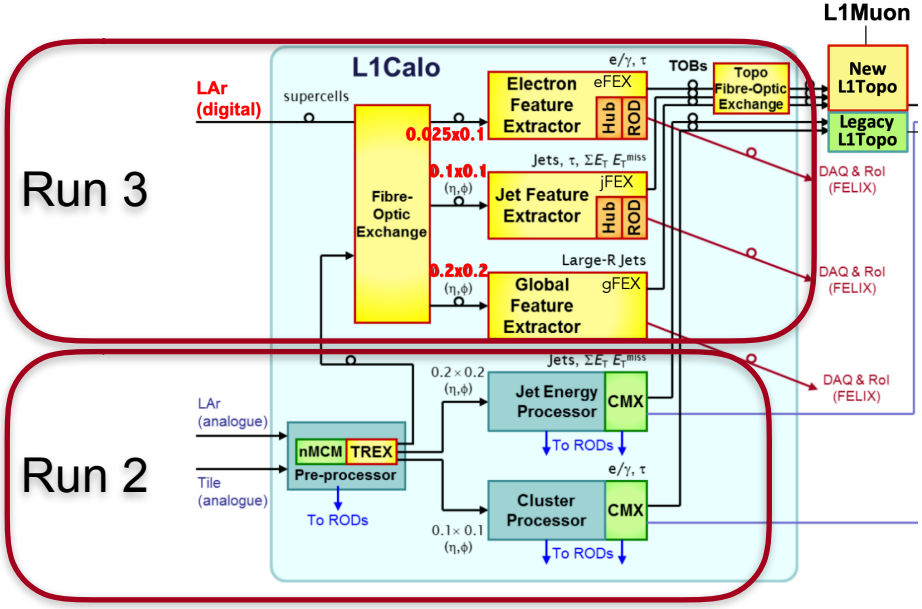


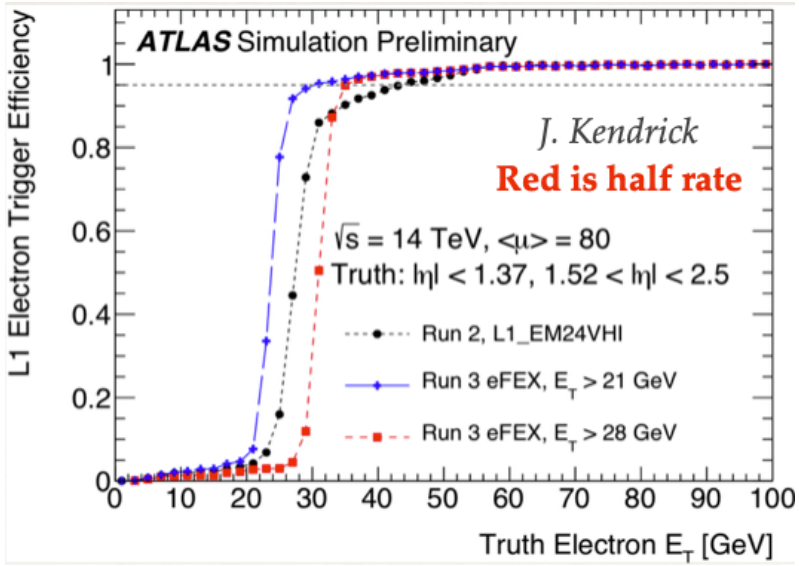


L1Calo - Run 3

- L1Calo Run 3 upgrade with **digital processors (FEXs)** to take full advantage of the digital LAr higher granularity and longitudinal shower information
  - **better isolation**
  - **better pile-up and background rejection**
- Will **free up** part of the **L1 bandwidth** to be used by other triggers
  - Example of higher granularity in the eFEX (electron trigger)
- Challenge to commission the new L1Calo (and L1Topo) system in the beginning of Run 3 with the Run 2 system running in parallel

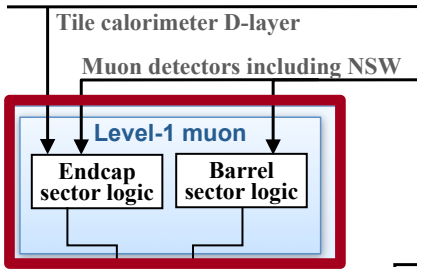


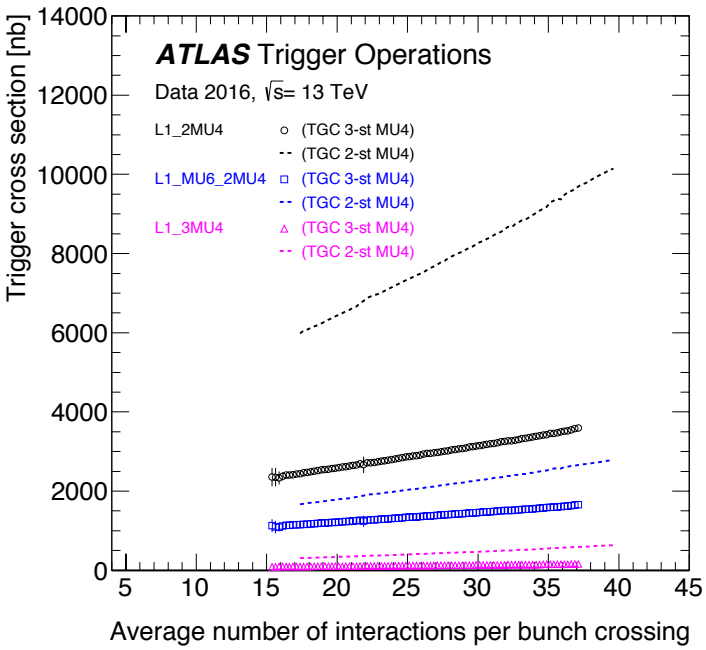


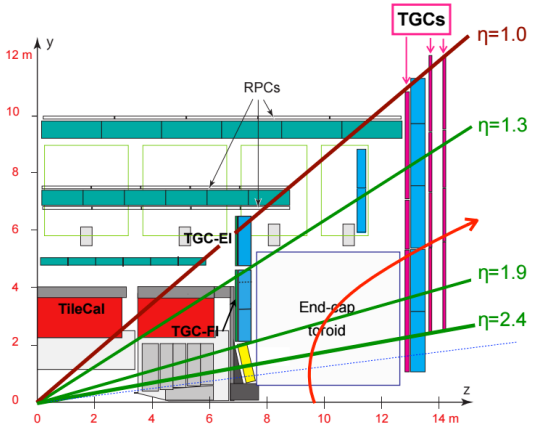


L1Muon System

- **Barrel (RPC, |η| < 1.05)**
  - Extra coverage increases acceptance (few %, new in 2016)
- **Endcaps (TGC, 1.05 < |η| < 2.4)**
  - Two- (low-p_T) and three-station (hight-p_T) coincidence triggers
  - Extra coincidence between chambers to reduce fakes (up to 60%)
- **Coincidence:**
  - New in 2016: moved from two to three-station coincidence MU4 → reduced rate from background particles and **improved the rate dependence on the number of pile-up interactions significantly** while efficiency was only reduced by a few %
- **For Run 3: New Small Wheel (NSW)**
  - L1 rate reduction expected already with only one working NSW

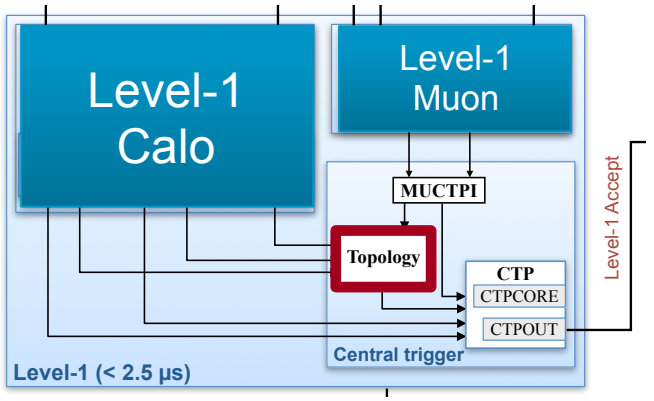


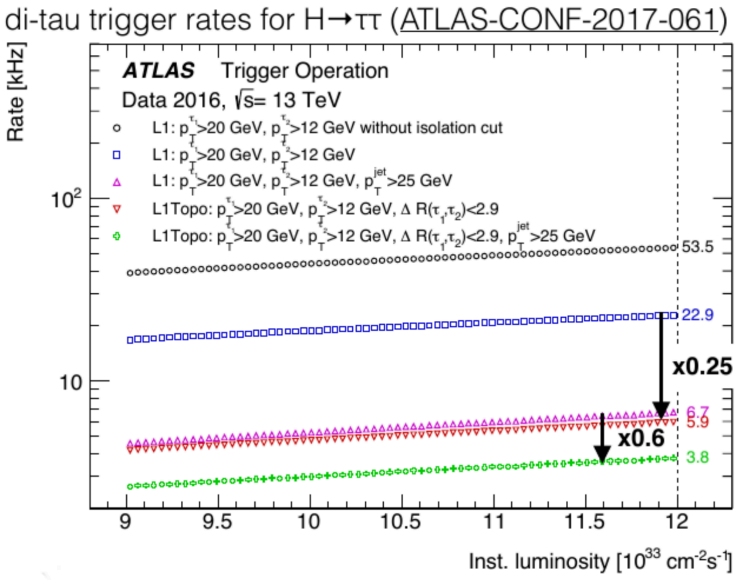




L1Topo

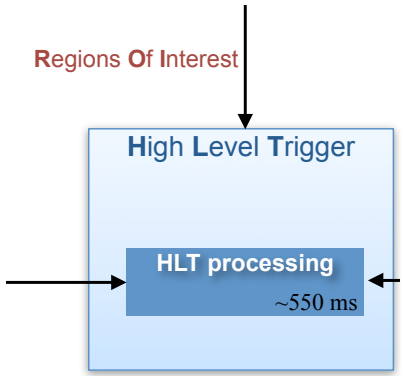
- Combines information from **L1Calo and/or L1Muon** into variables that are used for additional L1 selections
  - **Topological, angular kinematic selections, sums**
  - Significant **rate reduction,** increased **signal purity,** no impact in physics acceptance
  - Key feature for **high-luminosity** running
  - Example: di-tau trigger rates for H → ττ

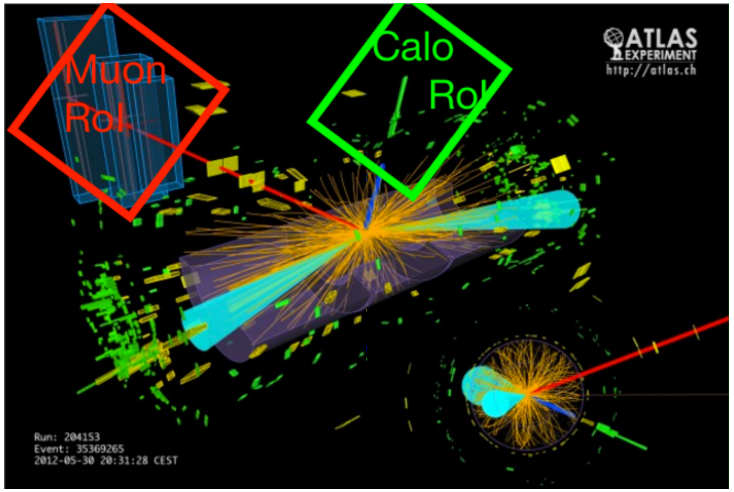




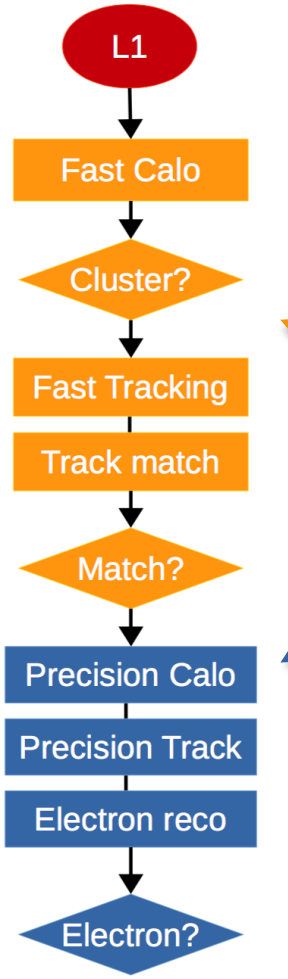
High-Level Trigger (HLT)

- High Level Trigger (HLT)
  - Input from Level-1 is regional information, the so-called **Region-of-Interest (RoI)**
    - RoI is a geometrical region in η x Φ with information about type of object (EM, MU, TAU,…) and thresholds passed (p_T, E_T)
    - RoI is the place where more CPU/time expensive reconstruction algorithms can be run, e.g. tracking
  - Decision about the final event accept is made





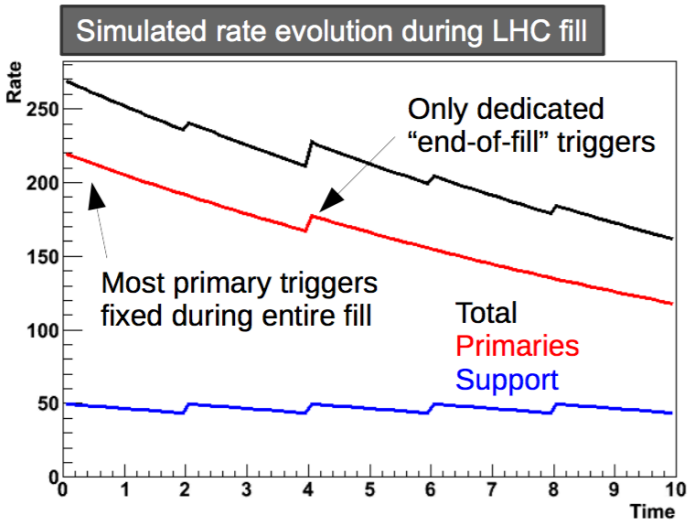
Reconstruction in the HLT

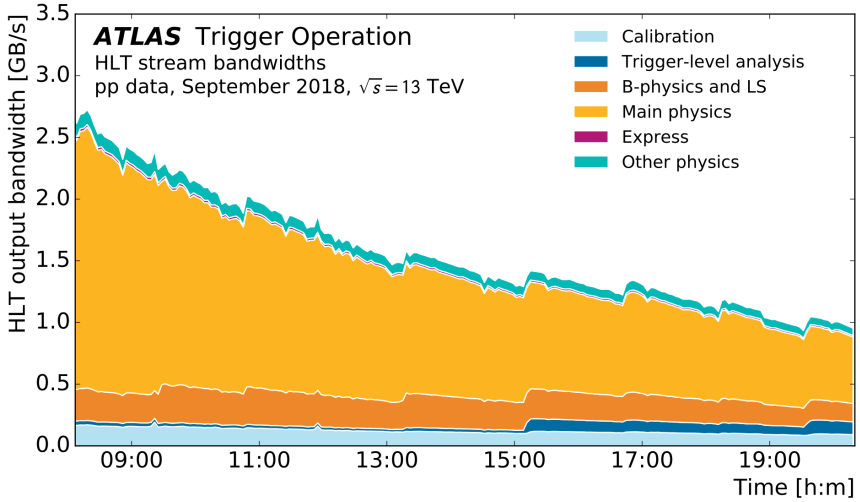


- Offline reconstruction in Run-2 too slow to be used directly
  - Takes > 10s per event but HLT needs < 1s
  - Make use of offline reconstruction tools and trigger specific code to stay in the CPU budget
- Requires **step-wise** processing with **early rejection** to save CPU time
  - Fast reconstruction with algorithms that are either trigger-specific or a special configuration of offline algorithms, guided by L1 RoI
  - Precision reconstruction with offline (or very close to) algorithms with the full detector data being available to increase rejection
- Reconstruction is organised in trigger chains
  - Feature extraction algorithms followed by hypotheses algorithms
- Optimisation of algorithm ordering
  - Tracking runs only after a cluster was found successfully

Trigger Menu

- Implementation of the physics program of ATLAS
  - **Trigger menu is the collection of *trigger chains***
    - Contains primary physics triggers, support and backup triggers (e.g. for efficiency measurement) and triggers for detector calibration and monitoring
    - Triggers are run within agreed **allocated rates** and within **agreed bandwidth** (limited by storage, transfer bandwidth, Tier0 processing constraints)
  - **Trigger menu varies with luminosity and time**
    - Constantly fine-tuned according to running conditions

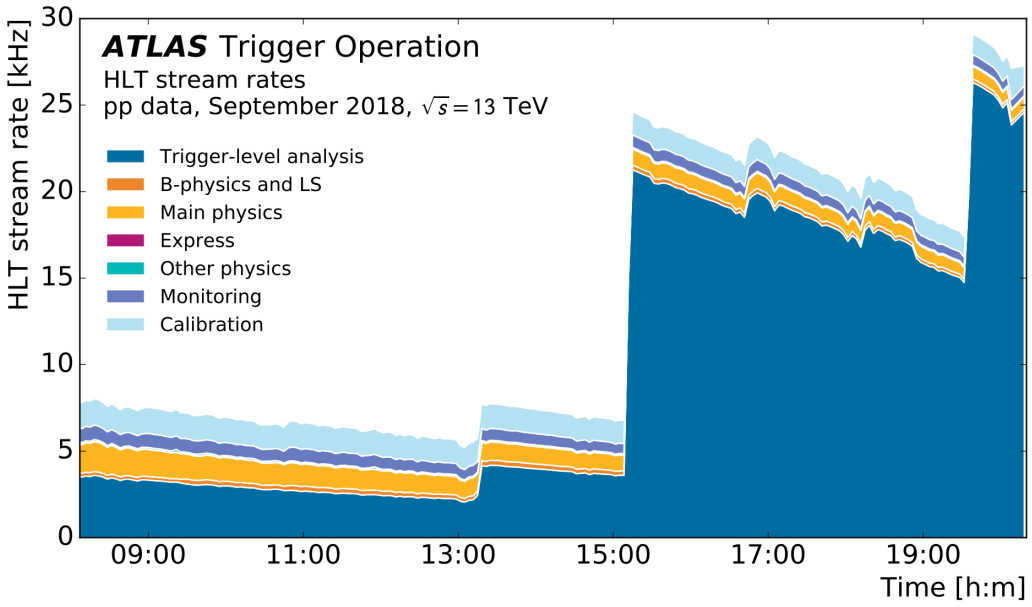




Streaming

- If any trigger chain passes, events are accepted and are written out to **streams** depending on the trigger that passed

  - **physics_Main** (single stream used for most physics analyses)
  - **Debug** (events that could not be processed at the HLT)
  - **Express** (prompt reconstruction for monitoring/quick validation)
  - **Delayed** (not promptly reconstructed, only when Tier0 resources allow it)
  - **Partial Event Building (PEB)** stream (only relevant part of the detector information is written out), used in **Trigger-Level Analysis (TLA)**
  - Calibration and Monitoring streams



Trigger Menu for Run 3

Proposal for the Run 3 baseline menu has been circulated

- https://cds.cern.ch/record/2683881

- **This does not mean that everything is fixed! If you have a bright idea for a new trigger, this can still be considered!!**
- Trigger Request Policy twiki

Contents

New HLT Framework for Run 3

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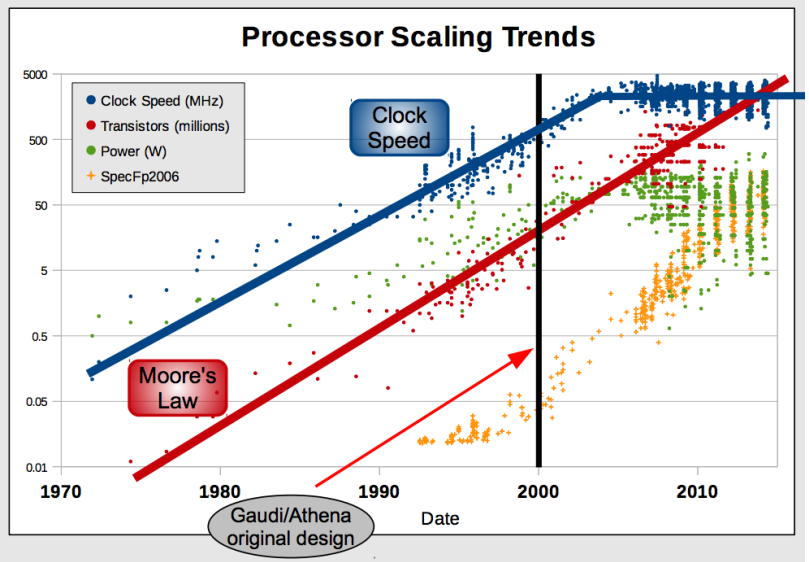
- ATLAS reconstruction uses lots of memory → even more the higher the luminosity gets
- CPUs aren't getting faster: core density increasing but memory/core ration continues to decrease
- Either can't afford to fully populate all nodes with enough memory or physically can't
  - AthenaMP (MultiProcessing) won't save us forever

  → **Have to think of other ways to use memory more efficiently**



- Run 3 software is based on Multi-Threading (MT) which means **algorithms using data from one event can be parallelized** and multi-events can also run in parallel (**AthenaMT/release 22/master**)
- **Trigger framework is being re-implemented for Run 3** to benefit from more general scheduler
  - Also easier to run offline reconstruction in trigger

- Lots of development and integration work to be completed during this Long Shut-down (LS2):

https://twiki.cern.ch/twiki/bin/viewauth/Atlas/TriggerLS2AthenaMTDeliverables

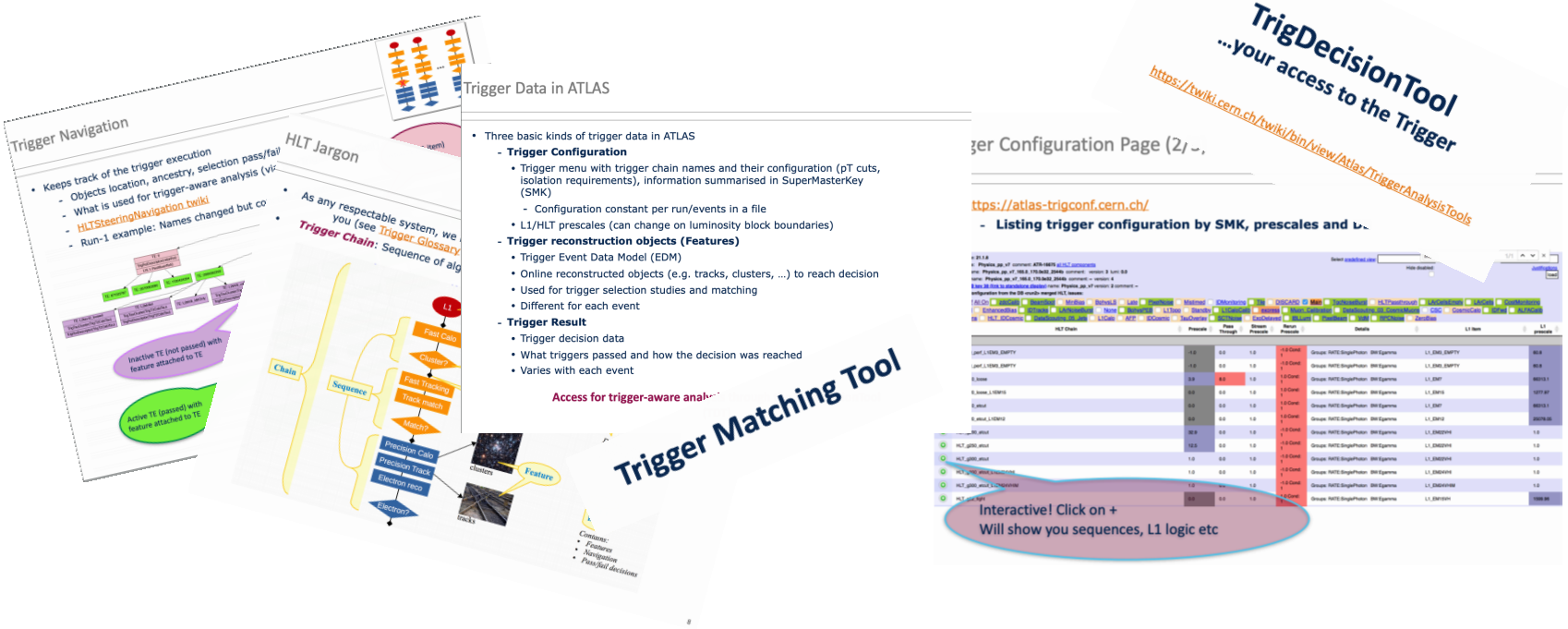
https://its.cern.ch/jira/secure/WBSGanttMain.jspa?filter=BOARD_26

https://its.cern.ch/jira/secure/Dashboard.jspa?selectPageId=19338

How to Make Use of the Trigger Decision

Trigger stores HLTResult object in the recorded data

- Reconstructed objects and decisions can be used for analysis of the trigger performance as well as in your favourite physics analysis!
- **Marcus Morgenstern will in his "Trigger for Analysis" talk explain how you can make use of this!**



Outlook

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Currently in the middle of the long shutdown 2 (LS2)

- Complete rewrite of the HLT software for better utilisation of future computer resources
- Addition/Upgrade of hardware components (L1Calo/L1Topo/NSW)
- Design and optimisation of the trigger menu for Run 3

Great opportunity for newcomers to make significant contributions and impact to the success of the trigger and therefore data-taking and ultimately physics in Run 3!! Everybody is welcome!

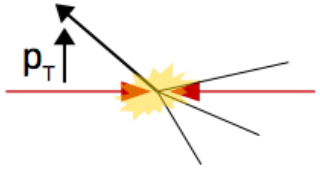
Email Jiří Masik (jiri.Masik@cern.ch) and Catrin Bernius (catrin.Bernius@cern.ch) if you're interested, we're happy to chat with you!

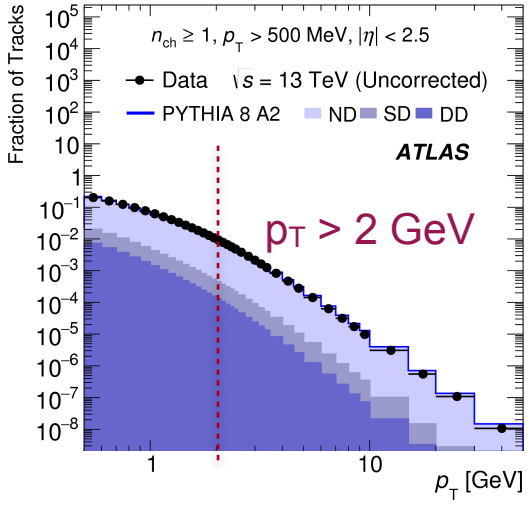
https://twiki.cern.ch/twiki/bin/view/Atlas/TriggerServiceTasks

Backup

Identifying the "Interesting" Events

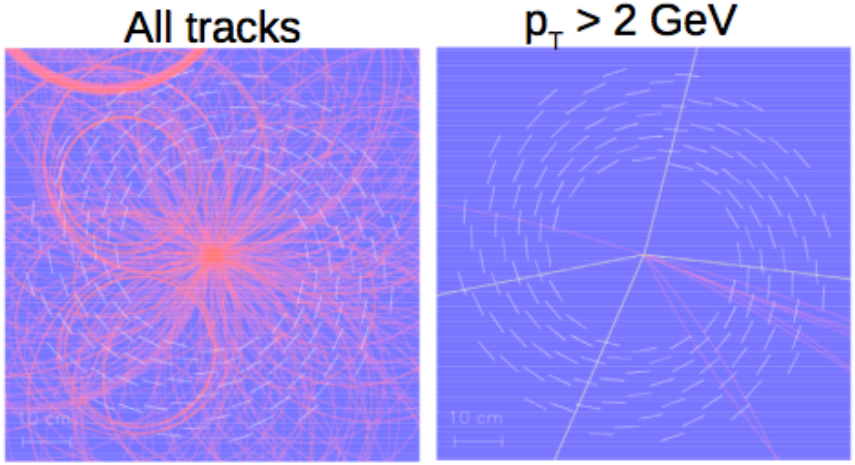
- Proton collisions produce mainly hadrons with low transverse momentum
  - Only 2% of all tracks have p_T > 2 GeV





- Interesting physics is usually **high-p_T**
  - H → γγ, p_T(**γ**) ~ 50-60 GeV
  - W → eu, p_T(**e**) ~ 30-40 GeV
  - Obvious signatures to use in the trigger
    - Single e/μ triggers used in most analyses

- What if new physics is "soft"?
  - This is where triggering becomes a challenge
  - Upgraded and new features in TDAQ system as well as ideas necessary!



Simulated $H \to 4\mu$ + 17 minbias events

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