Algorithms, performance, and development of the ATLAS High-level Trigger

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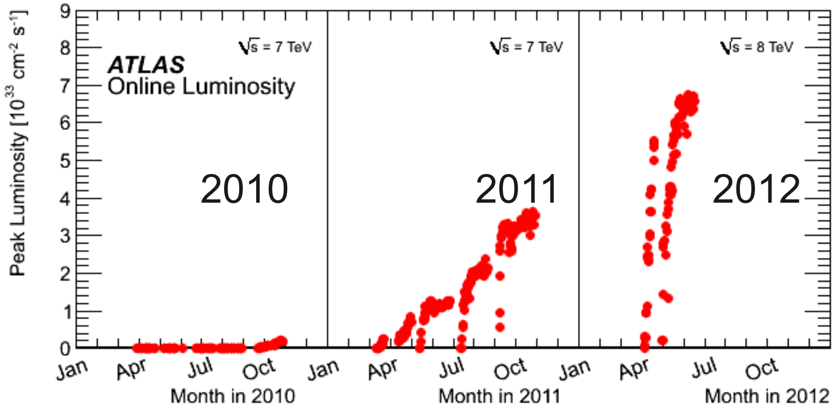
Challenging days for Trigger

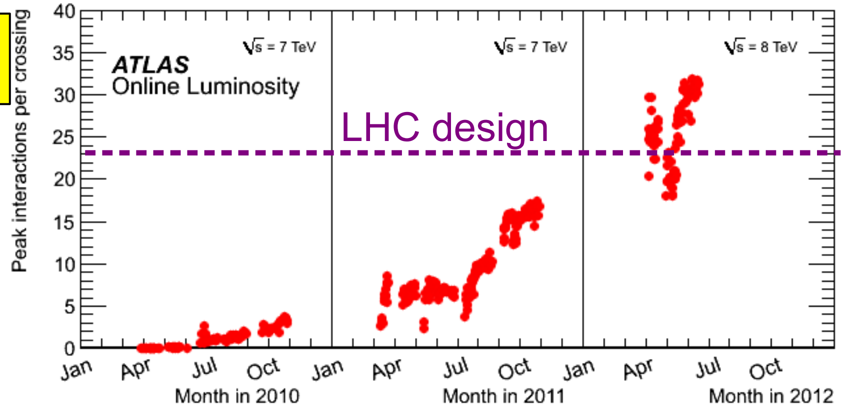
LHC had an extremely successful operation and luminosity ramp up!

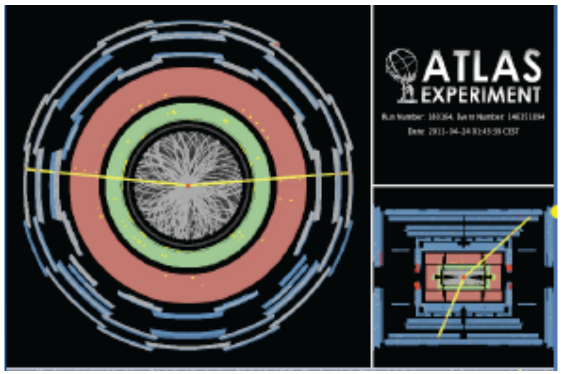
- Luminosity increase
  - -- Changes in trigger had to follow six orders of magnitude of changes in luminosity
- Pileup increase
  - -- In-time (overlapping p-p collision events within a same BC) and out-of-time (from previous BC)
  - -- Luminosity increase in the past years mostly by increase of bunch luminosity
    → Larger pileup than design
  - -- Challenge of trigger to keep efficiency and rejection stable in high pileup conditions

Peak Luminosity

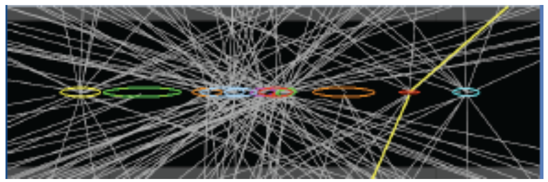


Peak Interactions per crossing





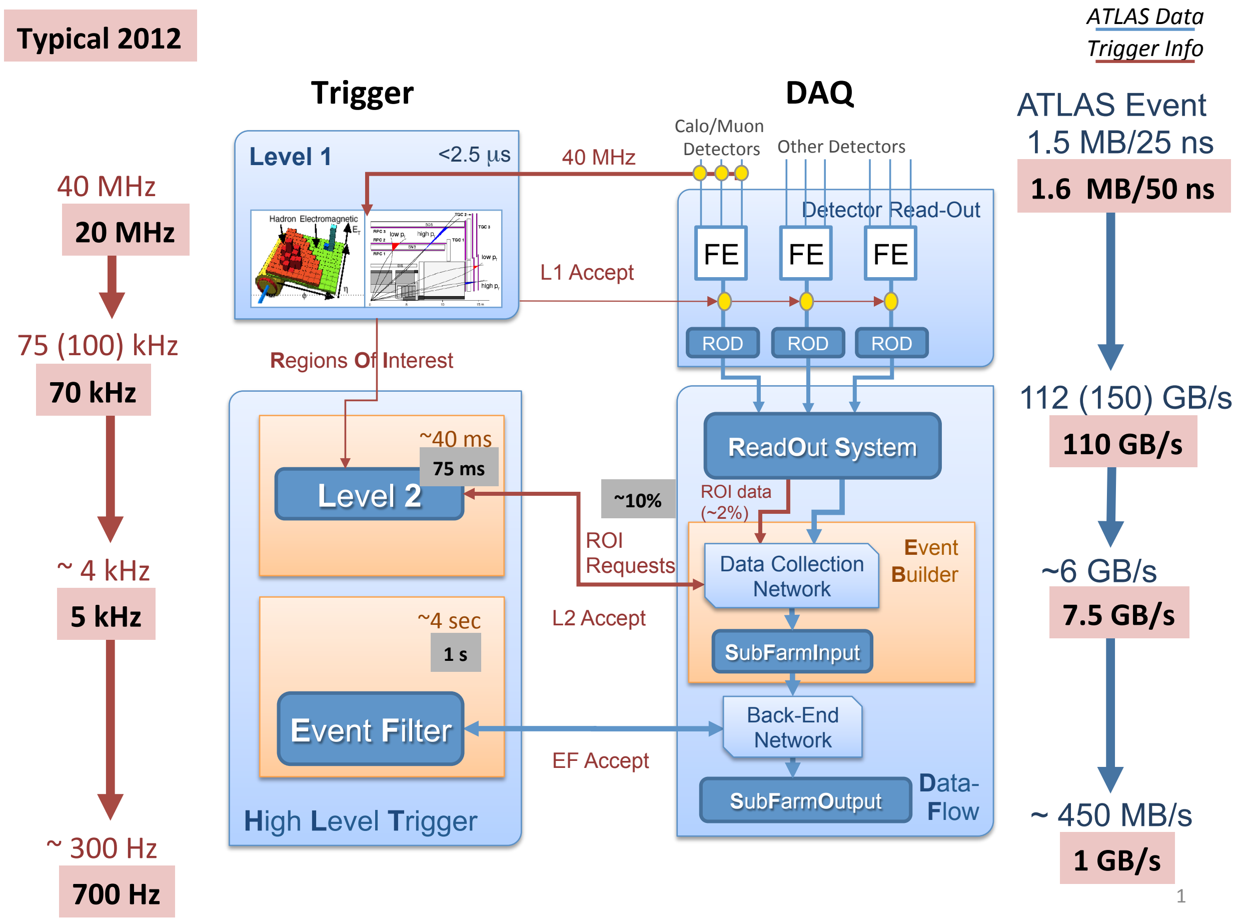
11 vertices with 1 Z→μμ



ATLAS Trigger and DAQ

- Dead-time free, multi-level trigger
  - Next collision before trigger decision
    → Pipeline
  - Low S/N
    → Multi-level

- Output rates
  - Recording rate (~700 Hz in 2012)
    ∗ Need to reduce from bunch crossing rate (20 MHz in 2012)
    → Rejection : ~30000



- Based on identified object thresholds and counts
  - Electron, photon muon, jet, b, τ, etc. …

ATLAS Trigger

Typical 2012

- Level-1 (<2.5 μs)
  - -- Calorimeter and Muon detectors
  - -- Processed with custom made electronics
  - -- Fully-synchronized

40 MHz
20 MHz

75 (100) kHz
70 kHz

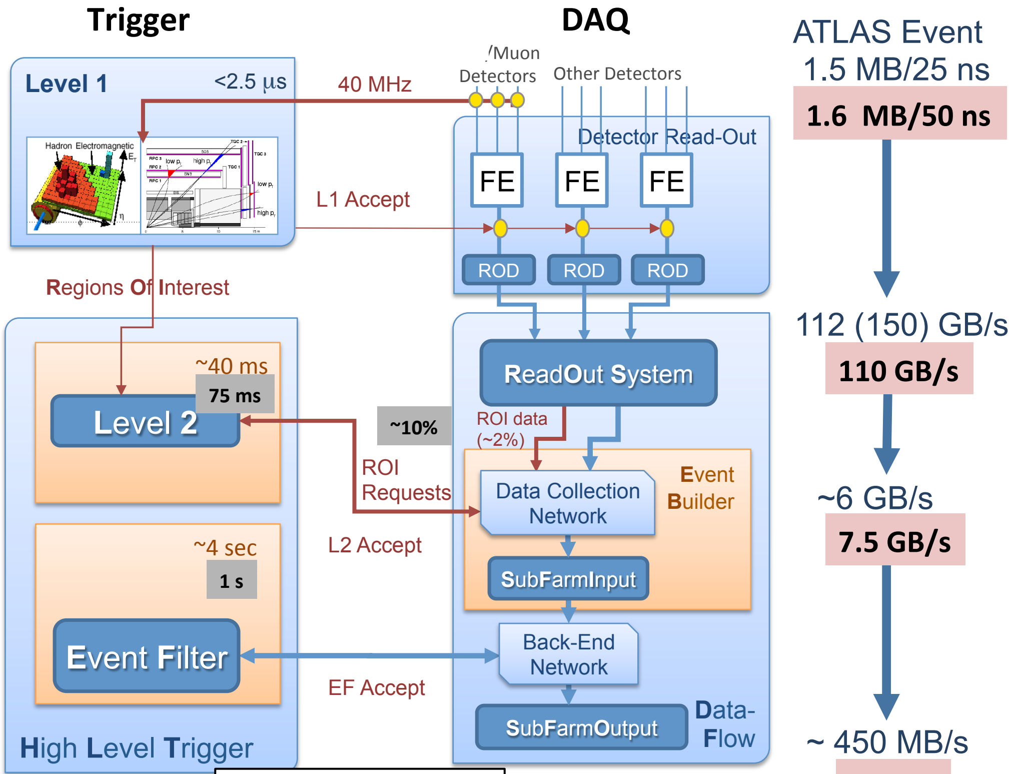
- Level-2 (<t>~75 ms)
  - -- More precise calculation by reading out only the region around the position of L1's identified trigger signature ("Region of Interest"; RoI)

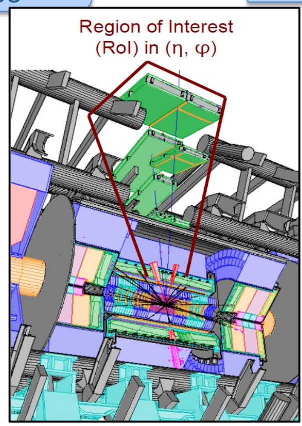
~ 4 kHz
5 kHz

~ 300 Hz
700 Hz

HLT
(Higher level trigger)

- Event Filter (<t>~1 s)
  - -- Make use of full detector info as running after event building.
  - -- Software reused from offline.

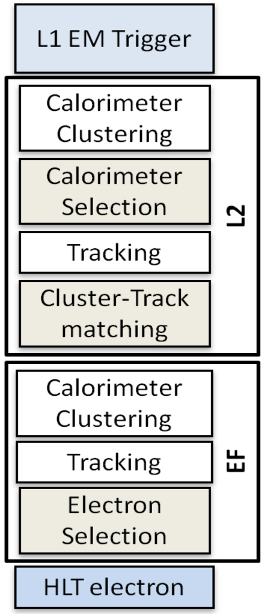




Trigger Menu Strategy and Evolution

- Chain: one full L1→L2→EF selection sequence
  - -- E.g.: "e24i" chain = single electron trigger with $E_T > 24$ GeV
- Menu: full set of chains and prescale factors
  - -- Prescale factor = reduction factor to issue a trigger
  - -- A typical menu contains ~500 chains, to meet a large variety of physics goals at LHC, and also to contain sufficient supporting triggers (for background estimations, detector performances etc.)

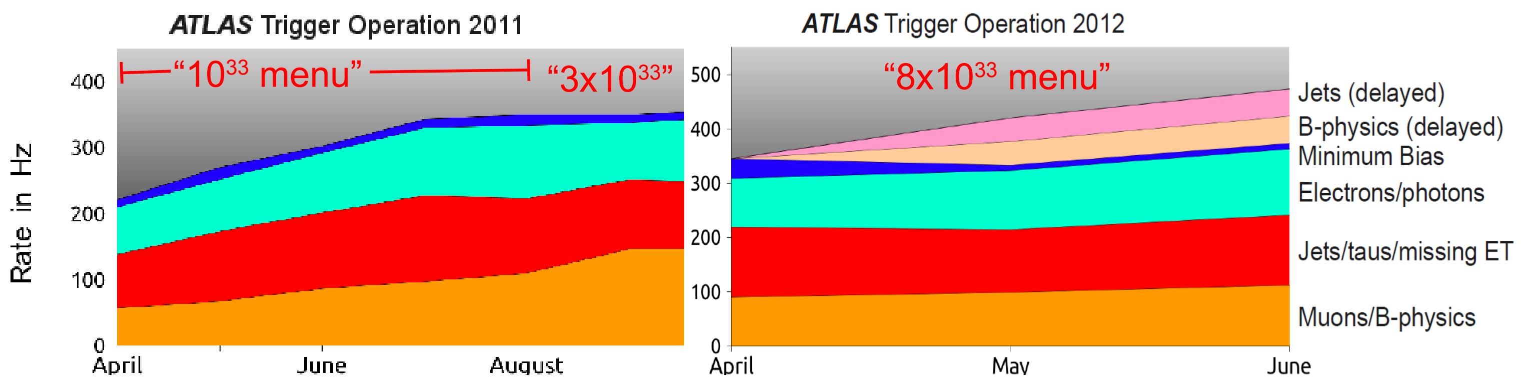
Electron chain



❑ For 2011-12: managed to run with just 3 base menus for p-p

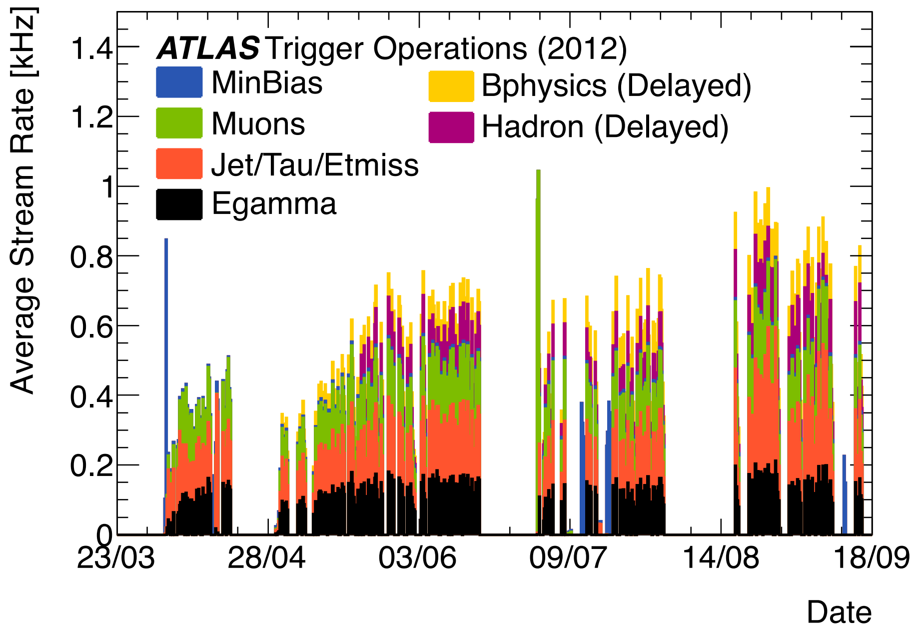
-- Some chains designed as extras in each menu dropped as luminosity increases to keep bandwidth under control

-- Avoid complication in physics analyses due to frequent trigger changes



Trigger Rates

Optimal distribution of available bandwidth is driven by physics requirements and priorities
Most bandwidth given to most generic triggers



Group	Peak L1 rate	Peak L2 rate	Average EF rate
E/gamma	30000	2000	140
Muon	14000	1200	100
Tau	24000	800	35
Jets	3000	1000	35
MET	4000	800	30
B-jets	5000	900	45
B-physics	7000	50	20
Total	65000	5500	400

Special data at low pileup
-- Low p_T jets for calibration
-- MinBias data at <μ>=0.01
Delayed streams
-- About 150 Hz of additional recording for later processing
-- Low pT b-physics triggers and low pT jet triggers (for SUSY, boosted objects searches)

See also poster by: M. Woudstra

Muon Trigger

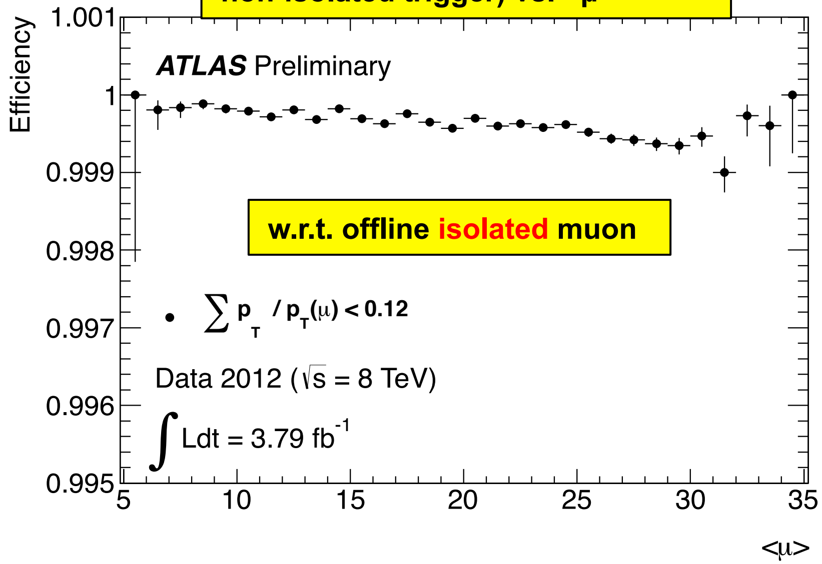
Multi-purpose single muon trigger with $p_T > 24$ (18) GeV
Di-muon trigger with $p_T > 15$ (10) GeV
() in 2011

- Changes in 2011
  - -- L1 tightened during 2011 due to out-of-time backgrounds in 50 ns beams

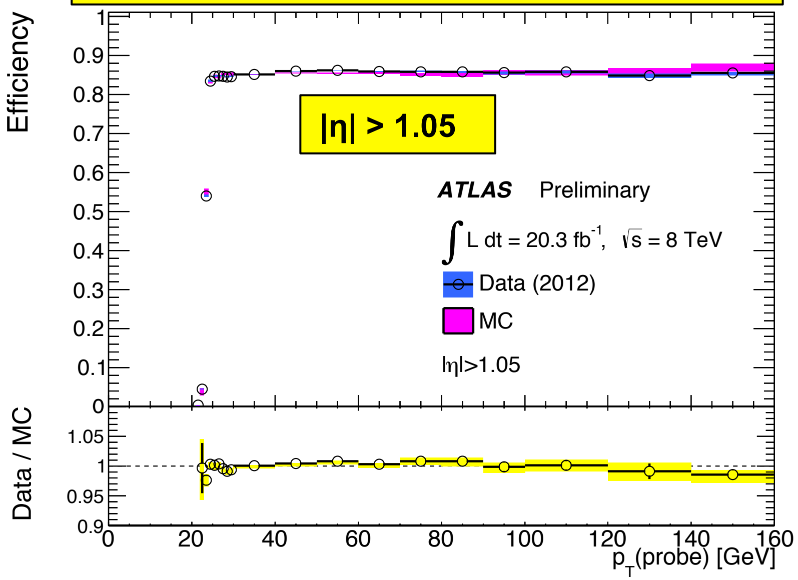
- Changes & Improvements in 2012
  - -- Track isolation applied for single muon, robust against pileup
  - -- A new unified EF algorithm merging two independent reconstruction methods
  - -- A new di-muon trigger with 2nd muon found by full-scan at EF

◆ Efficiency ~86 (70)% at plateau in endcap (barrel), mostly due L1 detector coverage
◆ Robust against pileup

Isolation efficiency (relative to non-isolated trigger) vs. <μ>



Single muon chain (L1→L2→EF) efficiency vs. p_T



Electron Trigger

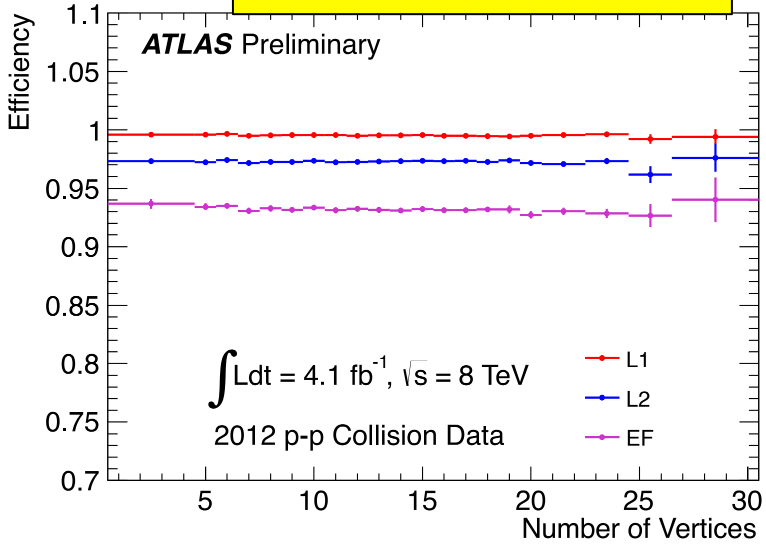
Multi-purpose single electron trigger with E_T > 24 GeV (22 GeV in 2011)
Di-electron trigger with E_T > 12 GeV

- Changes in 2011
  - -- Hadronic veto applied at L1
  - -- HLT & offline ID retuned

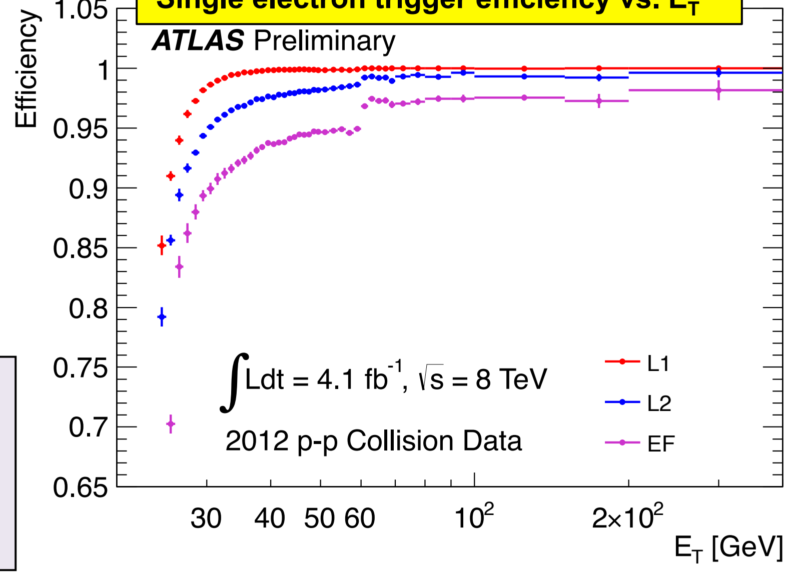
- Changes & Improvements in 2012
  - -- Track isolation applied for single electron
  - -- Electron PID cut optimized for pileup: loosen cuts on pileup sensitive quantities (radial shower sizes)

- Efficiency ~95 % at plateau, recovering 2-3 % by relaxing isolation at E_T > 60 GeV
- Robust against pileup

Single electron trigger efficiency vs. nr of vtx



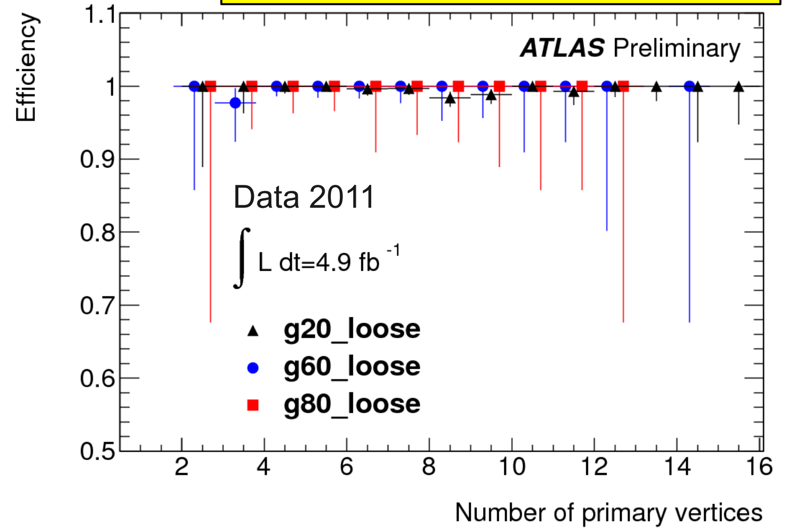
Single electron trigger efficiency vs. E_T



Photon Trigger

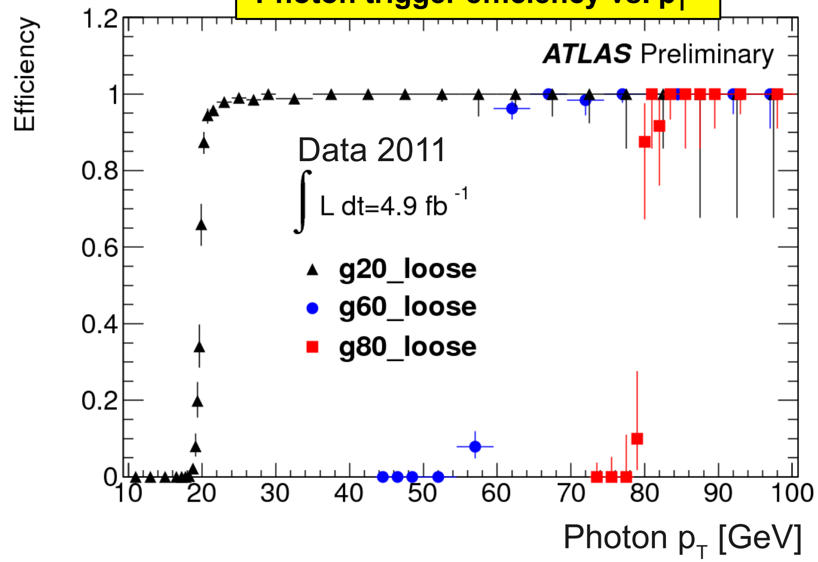
Di-photon trigger with asymmetric
E_T > 30, 20 GeV
→ Mandatory e.g. for H→γγ
Single photon trigger with E_T > 120 GeV

Photon trigger efficiency vs. nr of vtx



- <u>Changes & Improvements in 2012</u>
  - -- PID cut optimized for pileup as same as electron PID
  - -- Raised E_T threshold for single photon, while tightened PID somewhat to keep E_T threshold for di-photon.

Photon trigger efficiency vs. p_T



◆ Efficiency ~100% at plateau
◆ Robust against pileup

See also poster by: J. Mahlstedt

Hadronic Tau Trigger

τ triggers mostly used in combination with 2^{nd} τ (had/lep) or missing transverse energy (MET)
Crucial e.g. for H→ττ and SUSY searches

❑ **Significant improvements in 2012**

-- Much improved pileup robustness

* Reduce calo cone size ΔR < 0.4 → 0.2
* Limit tracks with $|z_0| < 2$ mm
* Remove pileup-sensitive shower radius

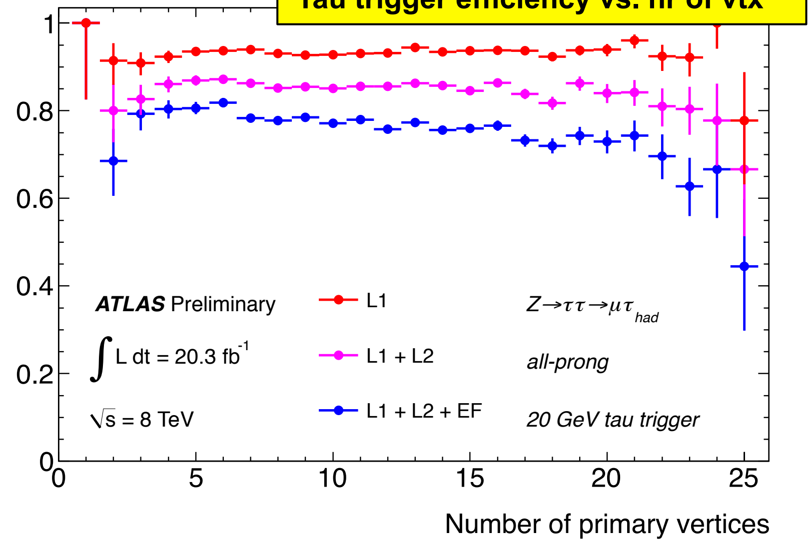
-- MVA PID introduced at EF

BDT as default, LLH as backup
Rejection power significantly improved

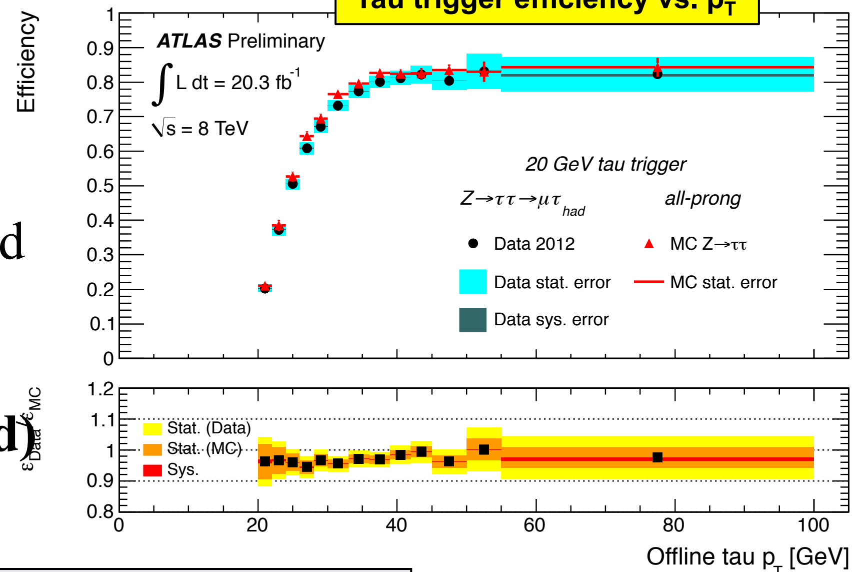
-- Topological triggers to maximize sensitivity to H→ττ (~5 fb^{-1} collected)

* Di-hadronic tau with looser tau ID
extra rate suppressed by Δn(ττ)<2.5
* VBF specific triggers

Tau trigger efficiency vs. nr of vtx



Tau trigger efficiency vs. p_T



◆ Efficiency ~80% at plateau

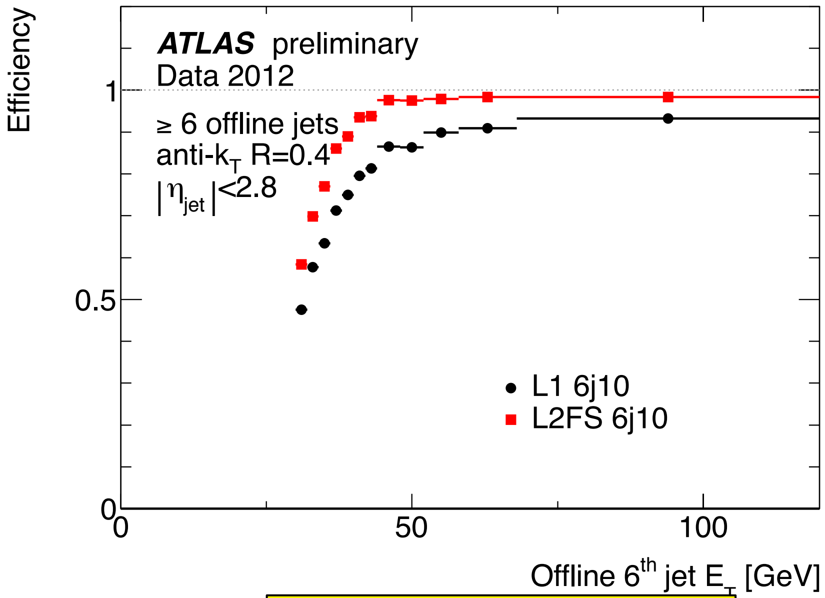
See also poster by: S. Shimizu

Jet Trigger

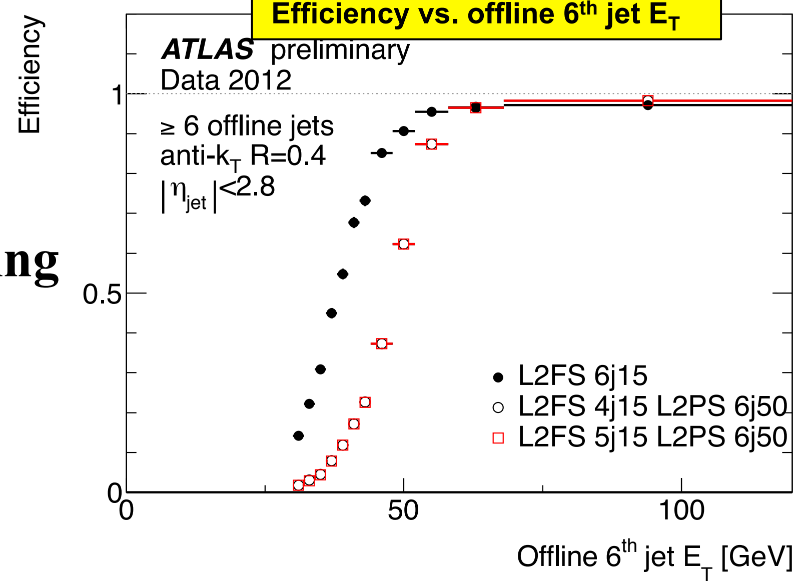
Large variety of triggers e.g. for various sizes of jets and both with and without b-tagging
Evolution away from RoI-based triggers

- **Significant improvements in 2012**
  - **-- L2 anti-k_T full-scan (L2FS) jet finding on L1Calo trigger towers**
    Much higher efficiency than requiring multi-jet at L1
    → L2FS used for all multi-jet trigger based on L1 4J15
  - **-- L2 anti-k_T partial-scan (L2PS) jet finding on calo data read-out from all L1 RoIs**
    Improves E_T resolution
  - **-- Hadronic energy scale, as well as LC correction to selected chains**

Efficiency vs. offline 6th jet E_T



Efficiency vs. offline 6th jet E_T

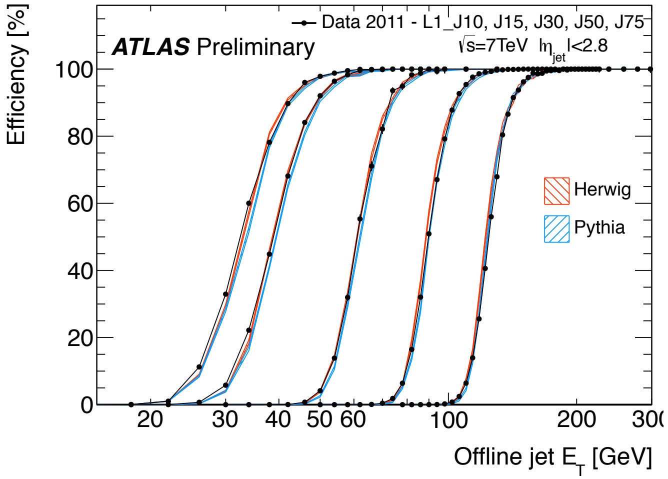


See also poster by: S. Shimizu, A. Buzatu

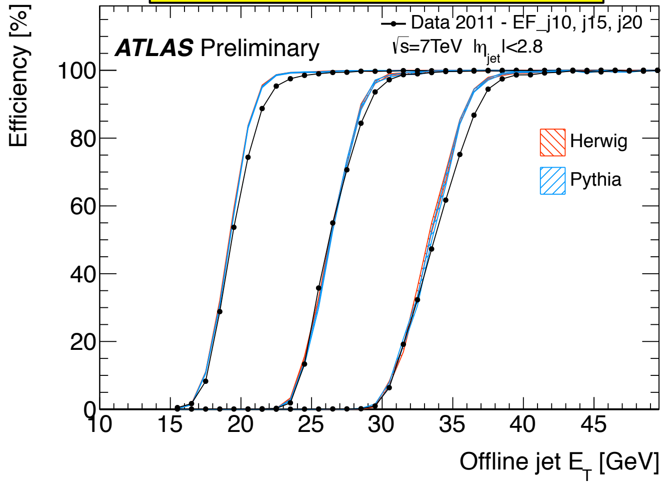
Jet Trigger -cont'd-

- Efficiency ~100% at plateau
- Measurement possible down to jet p_T ~ 20 (40) GeV at EF (L1)

L1 Efficiency vs. offline jet E_T



EF relative (wrt L2) efficiency vs. offline jet E_T

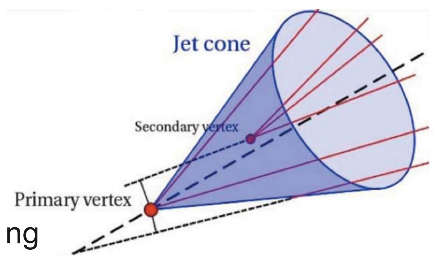


Significant improvements in 2012

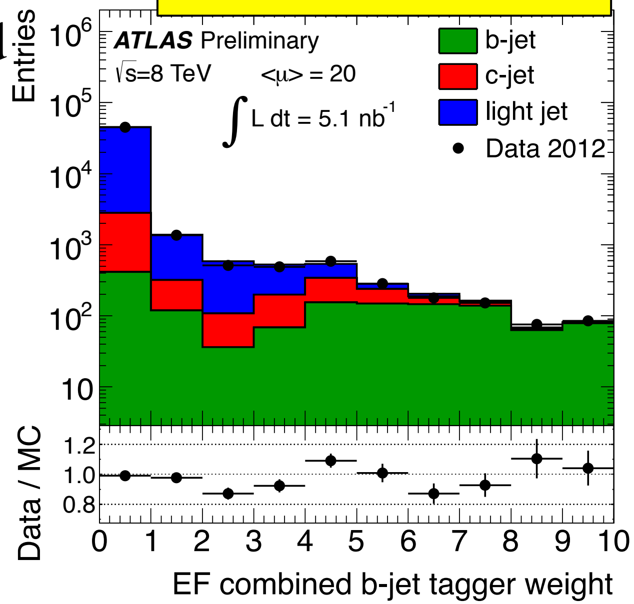
-- More advanced b-tagging

Combined between impact parameter based and secondary vertex finding based

Pileup robust primary vertex determination



Combined b-jet tagger weight distributions at EF



Missing Energy Trigger

Mandatory for various new physics searches, however, challenging quantity: pileup sensitive as trigger MET sums over calorimeter cells above threshold

❑ **Significant improvements in 2012**

-- L1 improvements

① **Noise threshold optimized per tower**

Pileup effectively increases noise, particularly in the forward calorimeter

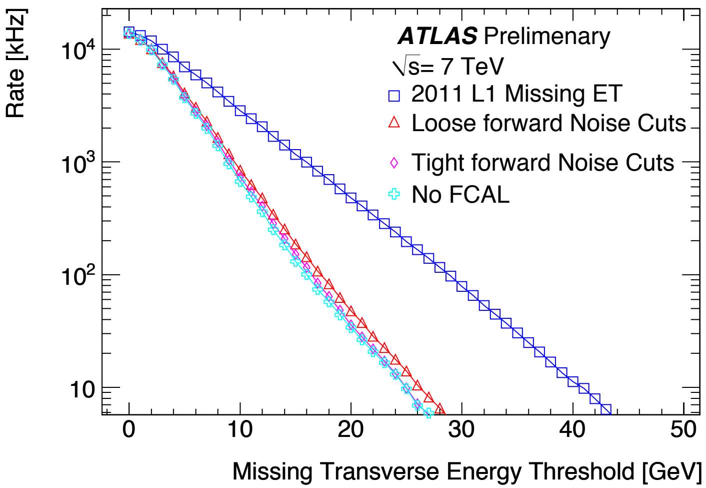
→ Little effect on resolution seen

→ **L1 threshold lowered in 2012 !**

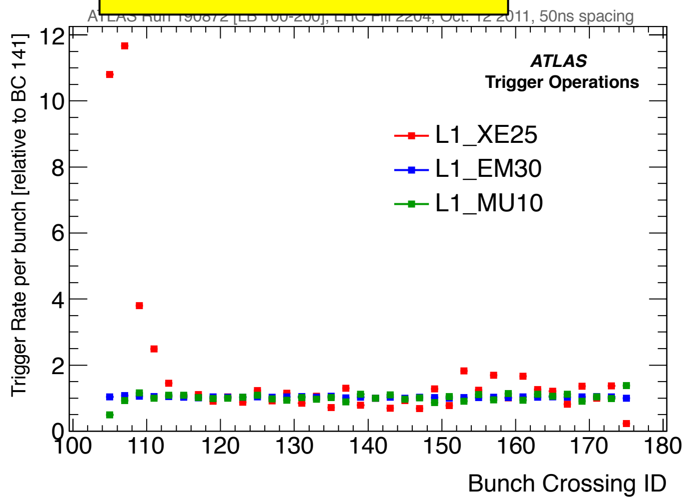
② **First 3 bunch-crossings were vetoed in some triggers to further lower threshold**

Unbalanced overlaying of out-of-time pileups from neighboring bunches cause spike in missing energy

Rate vs. L1 MET threshold

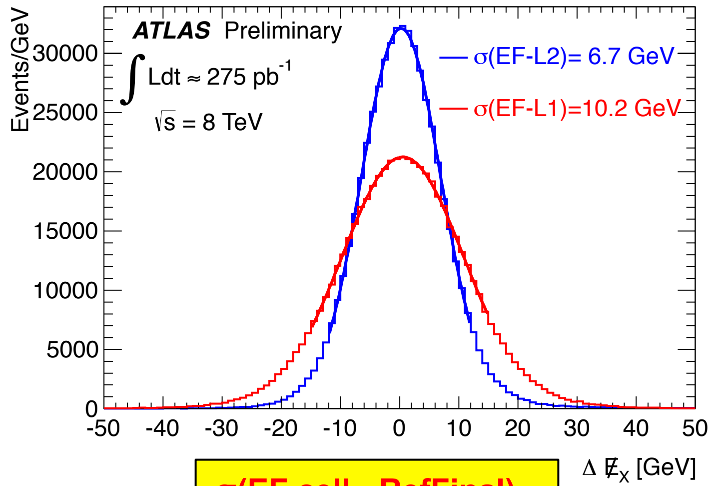


Rate as a function of BCID



Missing Energy Trigger -cont'd-

σ(EF-L1) = σ(EF-L2) in 2011
σ(EF-L2) = σ(EF-L2) in 2012



- **Significant improvements in 2012**
  - **-- L2 improvement: "FEB" MET**

    Up to 2011: L2 = L1, as "RoI" scheme gives least benefits to global quantities…

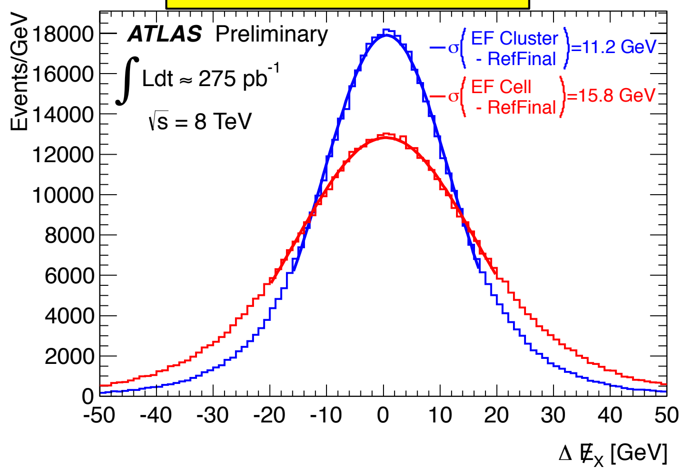
    Makes use of special "summary data" stored in LAr/Tile front-end-buffer (FEB)

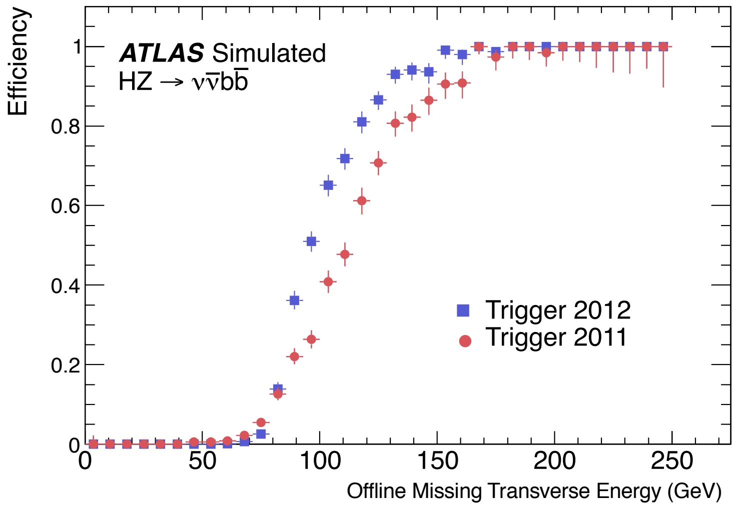
    → Resolution improves by about 50%.
  - **-- EF improvement**

    Cluster-based MET / hadronic calibration (shared with Jet triggers)

    → Resolution improved by about 40%

σ(EF cell - RefFinal)
σ(EF topo – RefFinal)





◆ Higher signal efficiency in 2012 !

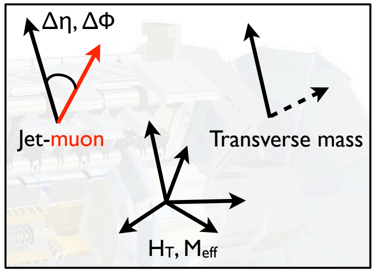
See talk by: N.Galleri

Developments for "Run2"

Parameter	E_{cm} [TeV]	# of bunches	Bunch separation [ns]	Peak lumi. [$cm^{-2}s^{-1}$]	Pile-up	Event size
Run 1	8	1380	50	~7×10^{33}	~35	~1.5 MB
Run 2	~13	1380 - 2700	25 - 50	$1.5\text{-}2\times10^{34}$	up to 80	1.7 - 2.1 MB

- Physics goals require triggers with similar low p_T at Run 2
  -- E.g. for precision measurements of Higgs in various production and decay channels

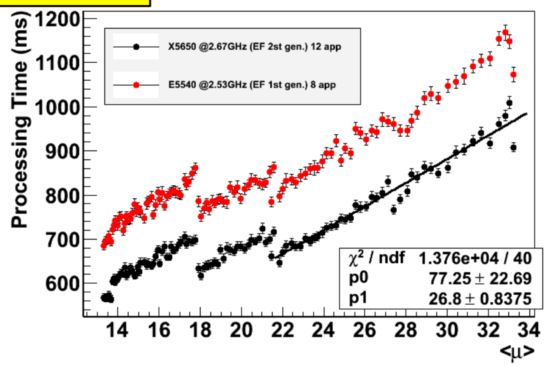
- While, as cross-sections grow by ~2 (due to increased cms energy) and luminosity grows by ~3; the demand on the trigger grows by ~6 !
  -- Most severe constraint is L1
    * The L1 limit from go from 65 kHz to 100 kHz
    * L1 Topological trigger processor will be introduced
    → See talk by N.Galleri



  -- HLT also needs big improvements
    * Speed-up of algorithm to overcome CPU increases due to high pileup and L1 inputs
    * More selective power in particular at earlier processing
    * Optimization of processing sequences, data access
    * Recording rate from 400 to 500-1000 Hz limited by offline computing costs.

FTK Merged HLT (next slides)

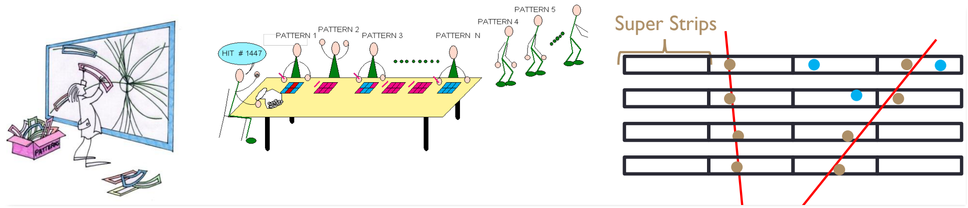
Processing time vs. <μ>



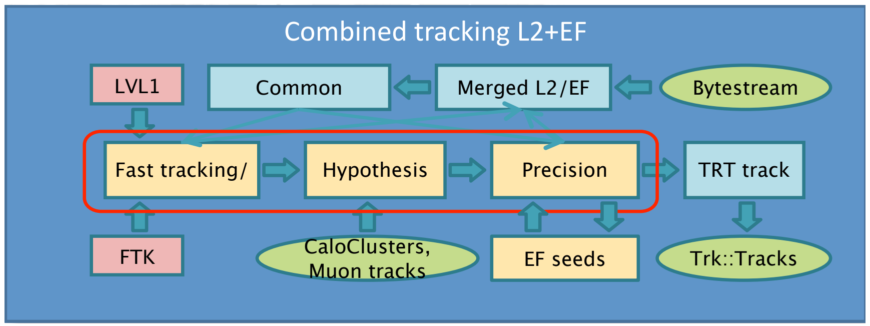
See talk by: N.Galleri,
poster by: S Martin-Haugh

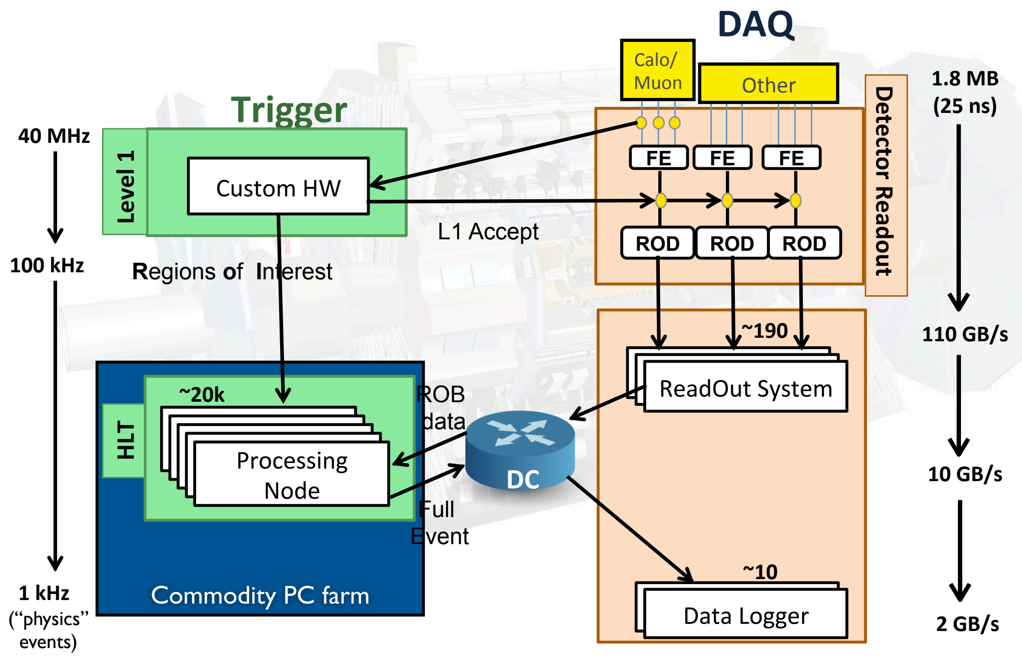
Developments for Run 2 -cont'd-

- Fast Tracker (FTK)
  - -- Special hardware receives a copy of all silicon data at each L1 accept.
  - -- Full detector tracking for all events accepted by L1 using patterns banked in memory
  - -- Expected to be very useful for HLT
    - * Seed track finding at HLT
    - * Improve b-tagging and τ id



- Merged L2 & EF
  - -- L2 data access cached for EF
  - -- Flexible event building point
  - -- No hardware limit on algorithm seeding, re-use of previous step calculation
  - → Opportunity for re-optimization of algorithms





Summary

◆ The ATLAS Trigger operated successfully in 2011-12.
  -- Efficiency loss due to trigger is typically a few %.
  -- Efficiencies are accurately measured using data.

◆ Many new improvements in trigger 2012 were successfully made, which preserves and even improves trigger efficiency for various physics targets
  -- e.g. in MET trigger, we could use even lower L1/L2 threshold

◆ Development for Run 2 is on-going. Many changes are planned to cope with challenging conditions.