ATLAS Trigger System

2011-2012 Performance and Evolution

Brian Petersen, CERN
On behalf of the ATLAS collaboration

ICHEP
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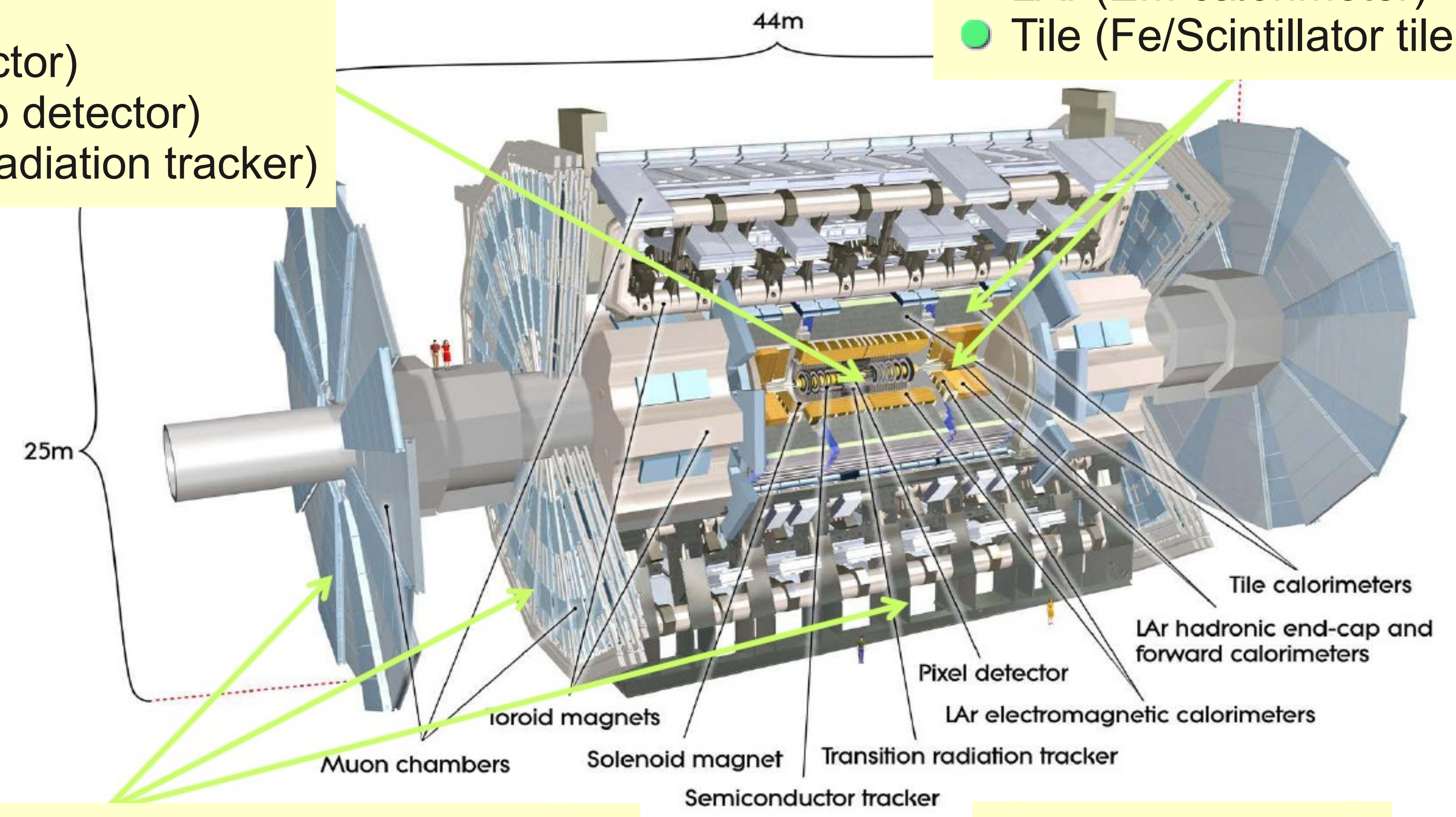
The ATLAS Experiment



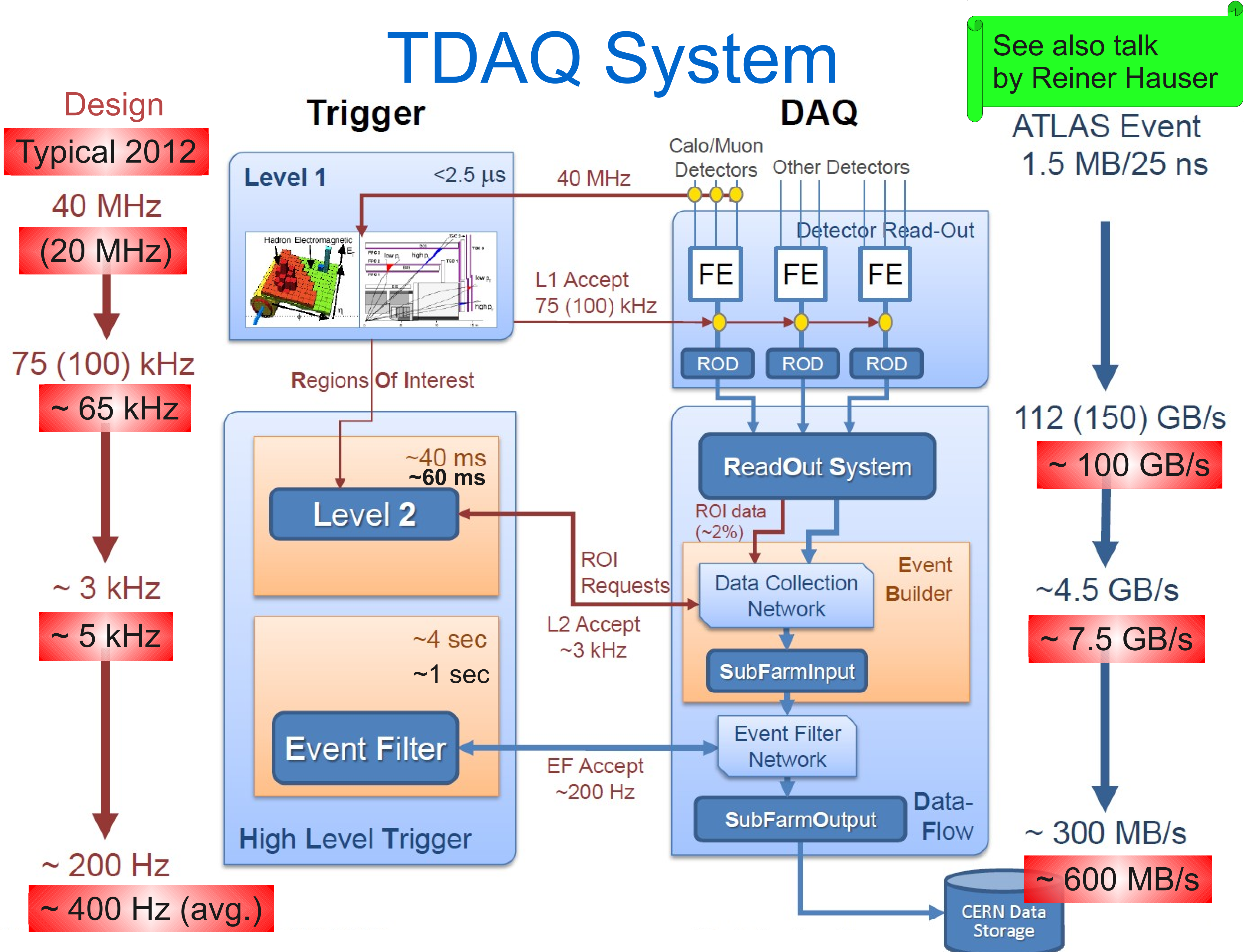
Inner Detector
- Pixel (pixel detector)
- SCT (silicon strip detector)
- TRT (transition radiation tracker)

Calorimeter
- LAr (EM calorimeter)
- Tile (Fe/Scintillator tile)

Muon Spectrometer
- MDT,CSC (precise momentum measurement)
- RPC,TGC (trigger chambers)

Magnet System
- 2 T solenoid
- 0.5 T toroid

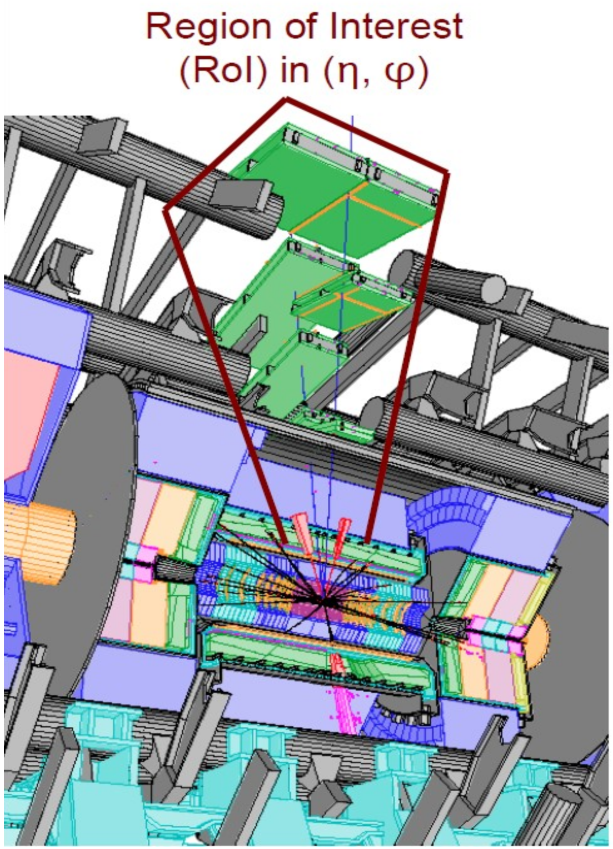
TDAQ System



See also talk
by Reiner Hauser
Design
Typical 2012
40 MHz
(20 MHz)
75 (100) kHz
~ 65 kHz
~ 3 kHz
~ 5 kHz
~ 200 Hz
~ 400 Hz (avg.)
Trigger
DAQ
Level 1
<2.5 μs
40 MHz
Calo/Muon
Detectors
Other Detectors
Detector Read-Out
FE
FE
FE
L1 Accept
75 (100) kHz
ROD
ROD
ROD
Regions Of Interest
ReadOut System
~40 ms
~60 ms
Level 2
ROI data
(~2%)
ROI
Requests
Event
Builder
Data Collection
Network
L2 Accept
~3 kHz
SubFarmInput
~4 sec
~1 sec
Event Filter
Event Filter
Network
EF Accept
~200 Hz
Data-
Flow
SubFarmOutput
High Level Trigger
CERN Data
Storage
ATLAS Event
1.5 MB/25 ns
112 (150) GB/s
~ 100 GB/s
~4.5 GB/s
~ 7.5 GB/s
~ 300 MB/s
~ 600 MB/s

The ATLAS Trigger System

Three level trigger system
Based on Region of Interest (RoI) concept



Level 1:

- Fast, custom-build electronics finds and defines RoIs
- Muon and Calorimeters only
- Coarse resolution

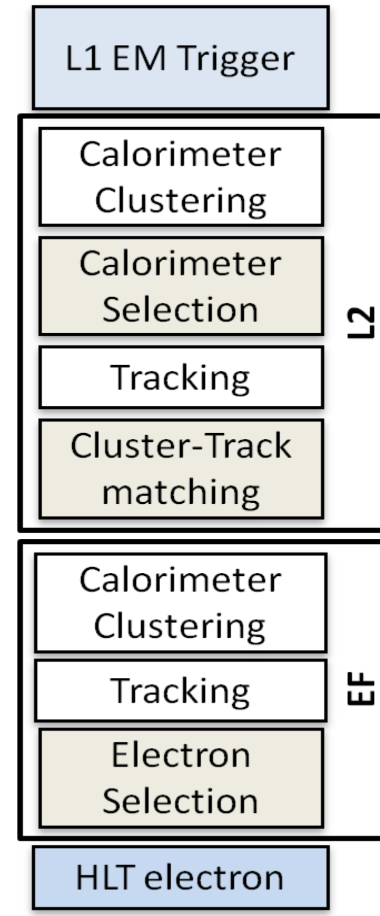
Level 2:

- Dedicated, fast software algorithms
- Works on full-granularity RoI data

Level 3 (Event Filter):

- Software reused from offline
- Full event information available, but partly still RoI based

Electron chain



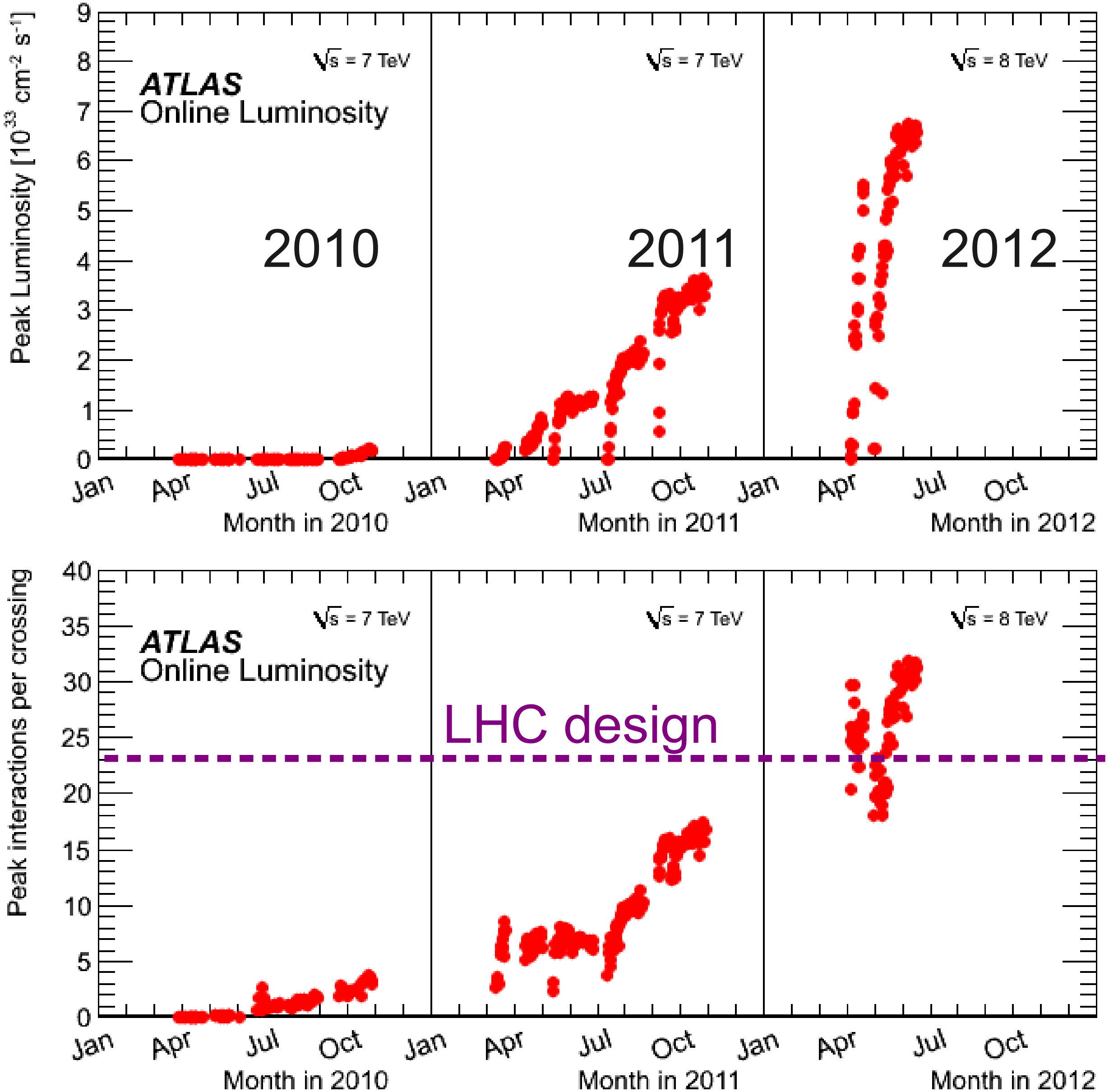
Nomenclature:

- *Chain:* one full L1→EF selection sequence
- *Menu:* full set of chains and prescale factors

Typical menu has ~500 chains

Luminosity Challenge

LHC has had an extremely successful luminosity ramp up



Rapid changes in trigger to follow six orders of magnitude changes in luminosity during first years

In the last year luminosity increased mostly from more bunch luminosity

Challenge for trigger to keep efficiency and rejection stable in high pileup conditions

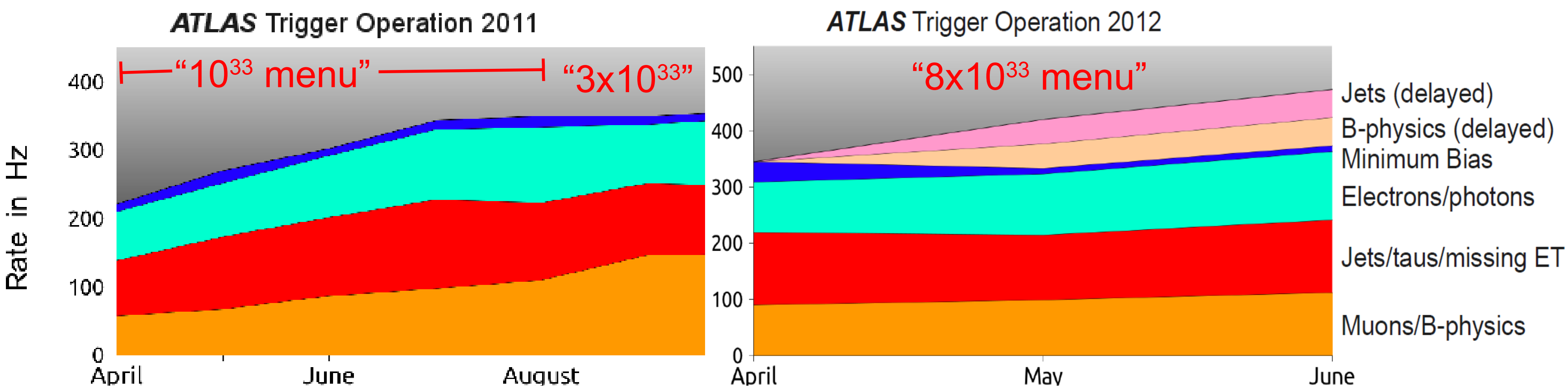
Trigger Menu Strategy & Evolution

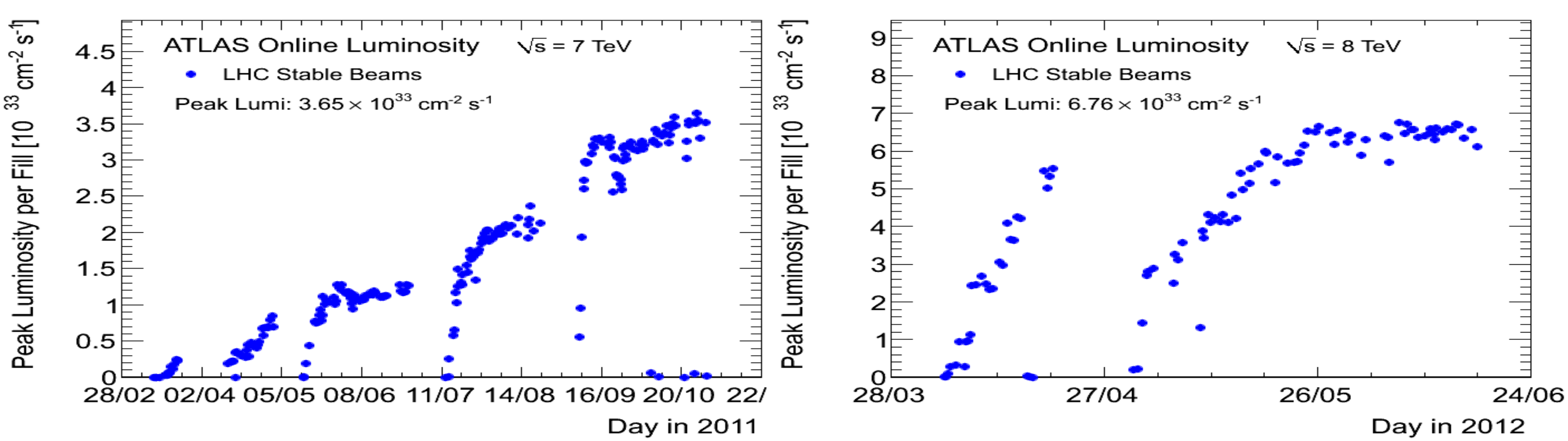
Frequent trigger changes complicate physics analyses

For 2011-2012 managed to run with just 3 base menus for p-p

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

Separate trigger menu for Heavy-Ion running





Trigger Menu Design and Rates

Optimal distribution of available bandwidth is critical
Driven by physics requirements and priorities
– extensive consultations with physics sub-groups
Most bandwidth given to most generic triggers

Approximate EF bandwidth assignment

- Single leptons (e/μ): ~50 Hz each
- Generic triggers: 5-15 Hz each
  examples: multi-jet, di-muon, ...
- Specialized triggers: ~1 Hz
  examples: long-lived particles, ...
- Supporting triggers: 20%

L1 and L2 bandwidth constraints also need to be considered

Rate distribution for $L_{peak}=7\times10^{33}\ cm^{-2}s^{-1}$

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

New 2012

About 150 Hz of additional B-physics and jet triggers recorded for later processing in 2013

Group overlap accounted for in the sum

Muon Triggers

See also poster by Takashi Kubota

Muon trigger at p_T>18 GeV in 2011

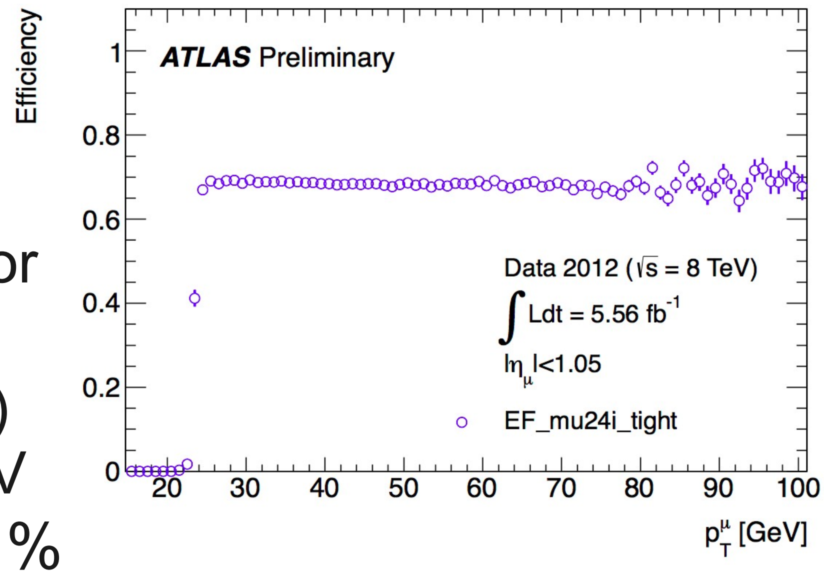
Tightened L1 trigger mid 2011 due to out-of-time hits with 50ns beam

Changes for 2012:

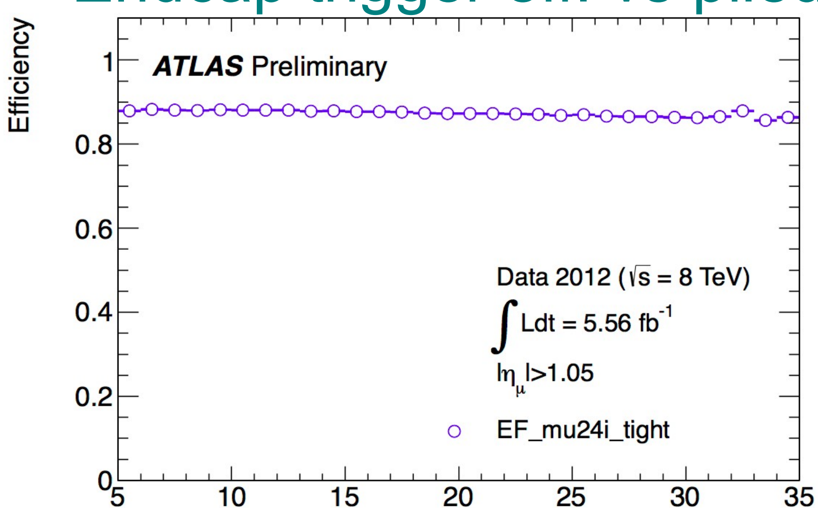
- Additional shielding installed in detector
- Raise to p_T>24 GeV
- Track isolation required (pileup robust)
- Di-muon raised from 2x10 to 2x13 GeV

Efficiencies measured in $Z \rightarrow \mu\mu$ to <1%

Barrel trigger eff. vs p_T

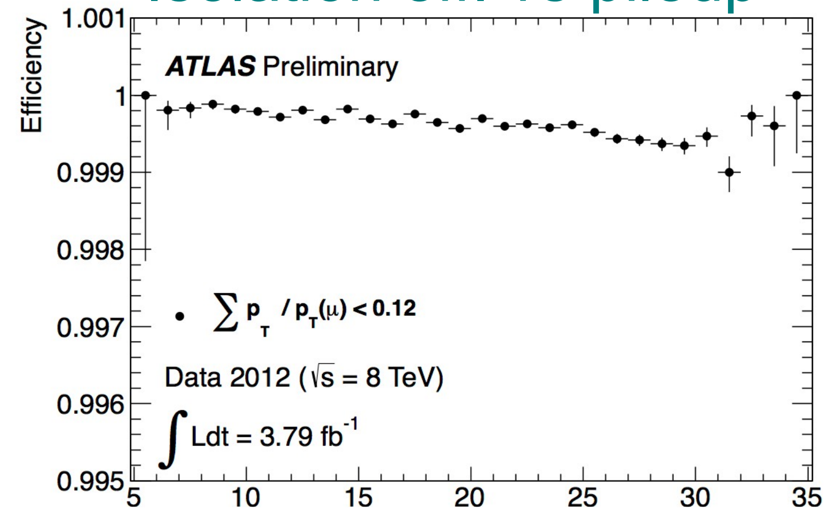


Endcap trigger eff. vs pileup



Average interactions per bunch crossing (pileup)

Isolation eff. vs pileup



Average interactions per bunch crossing (pileup)

Electron Triggers

Design: Inclusive 25 GeV and 2x15 GeV electron triggers
– Requires HLT ~ offline

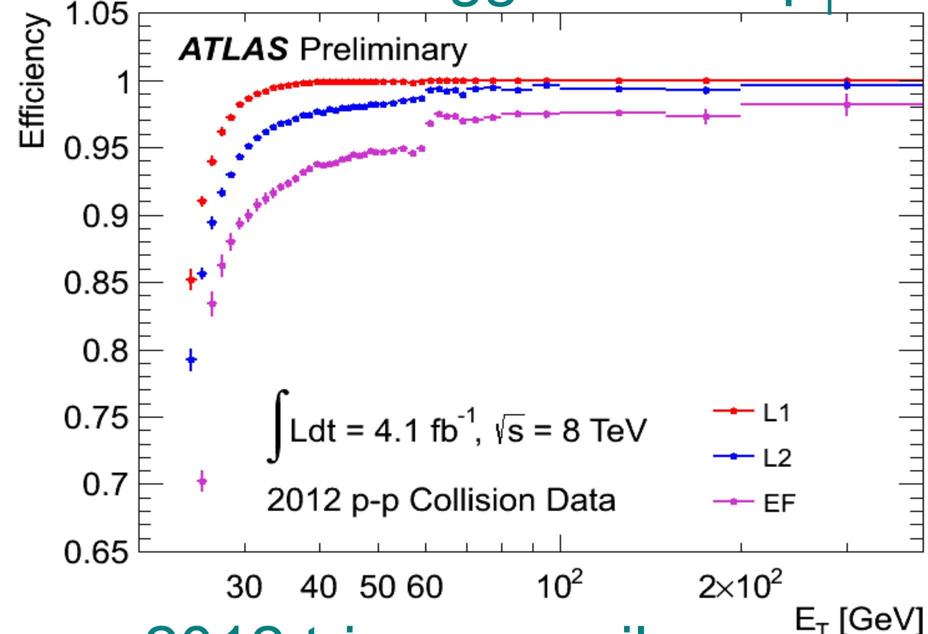
Changes during 2011:

- Hadronic veto at L1
- Retuned HLT&Offline electron ID

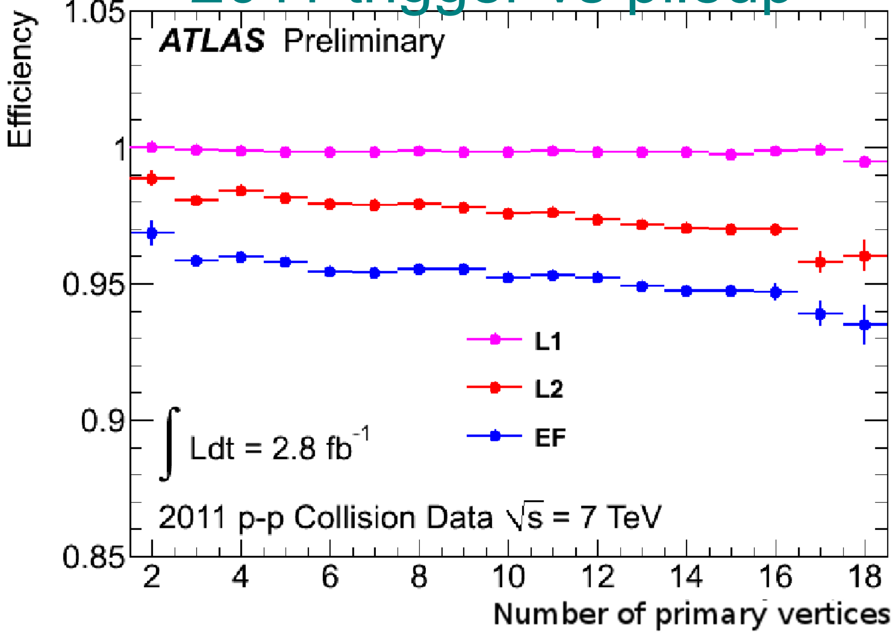
Changes for 2012:

- Raised L1 threshold
- Retuned electron ID for high pileup
- Track isolation required (pileup robust)

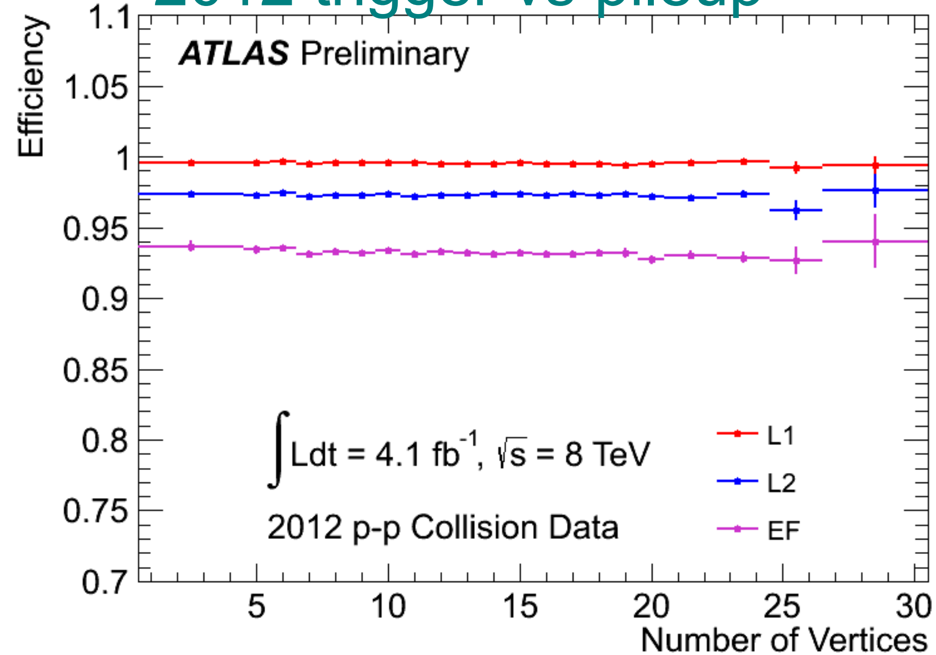
Electron trigger eff. vs p_T



2011 trigger vs pileup



2012 trigger vs pileup



Hadronic τ Triggers

See also poster by Curtis Black

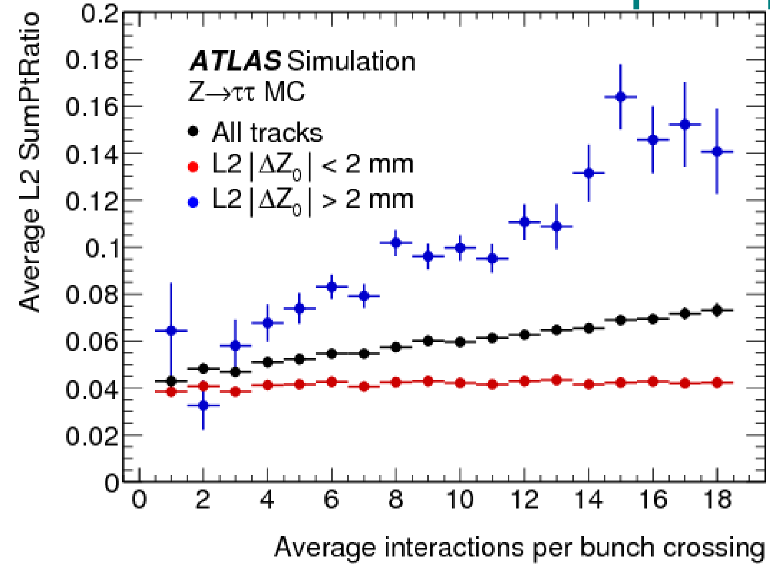
τ triggers mostly used in combination with 2nd τ (had/lep) or MET trigger

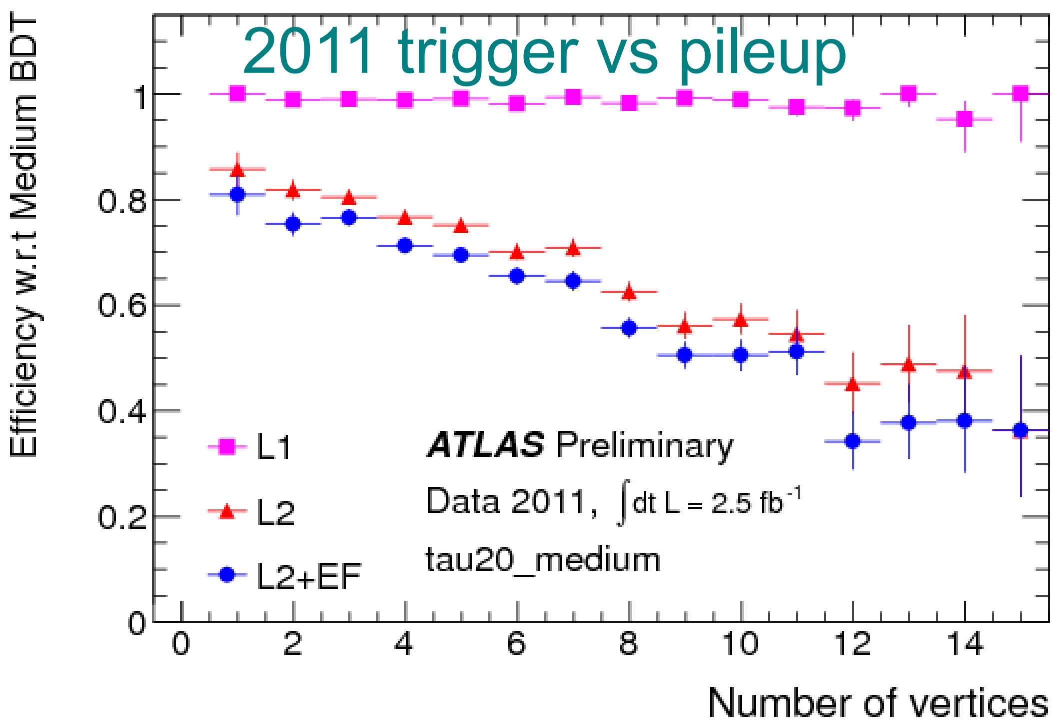
Tuned for $H\to\tau\tau$ and $H^+\to\tau\nu$

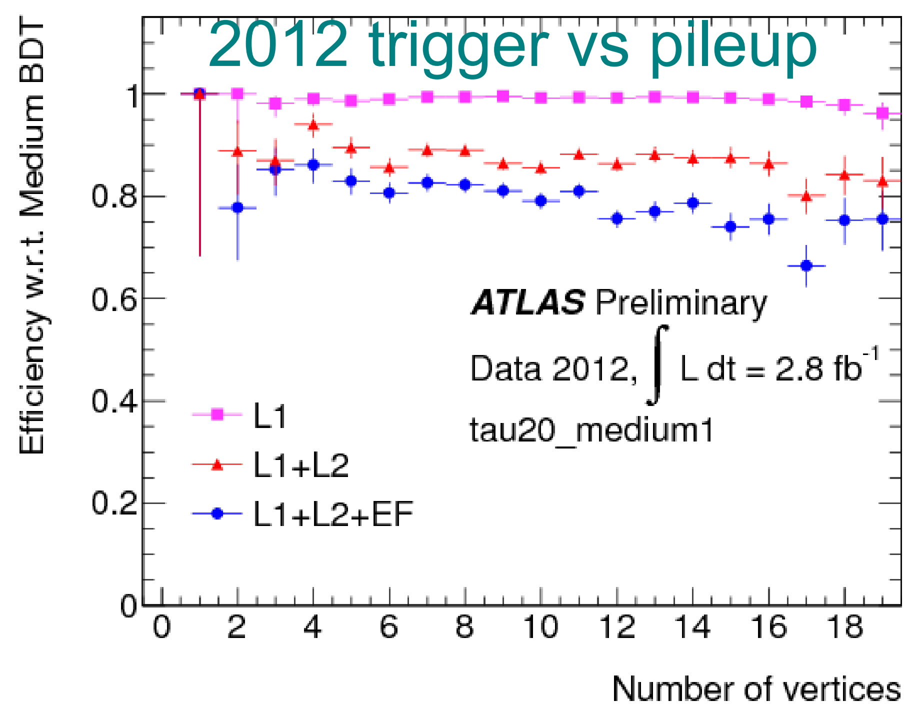
Significant improvements for 2012:

- Much improved pileup robustness
  Smaller cone sizes, Δz track cuts
- EF now uses multi-variate selection to increase rejection power significantly

τ track isolation vs pileup





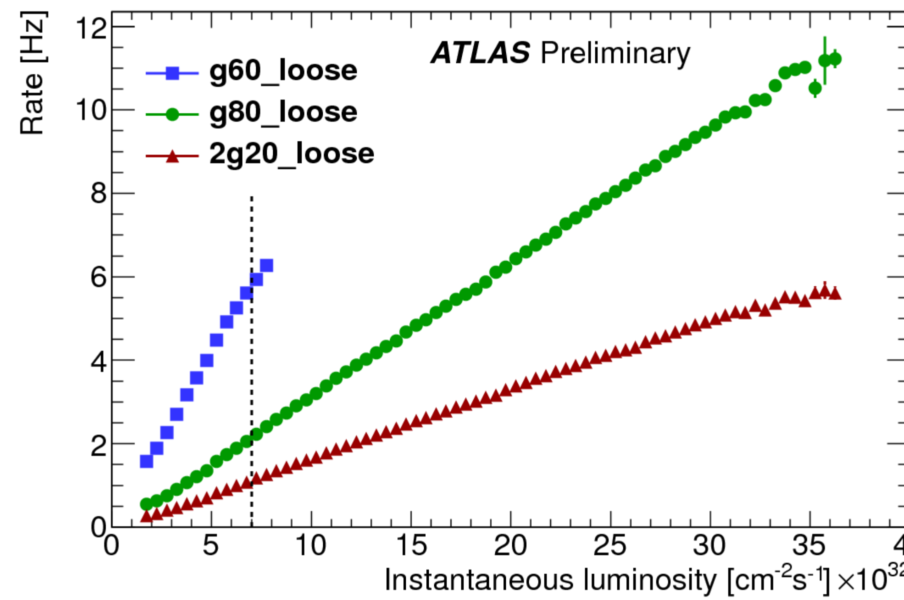


Photon Triggers

Many users of photon triggers

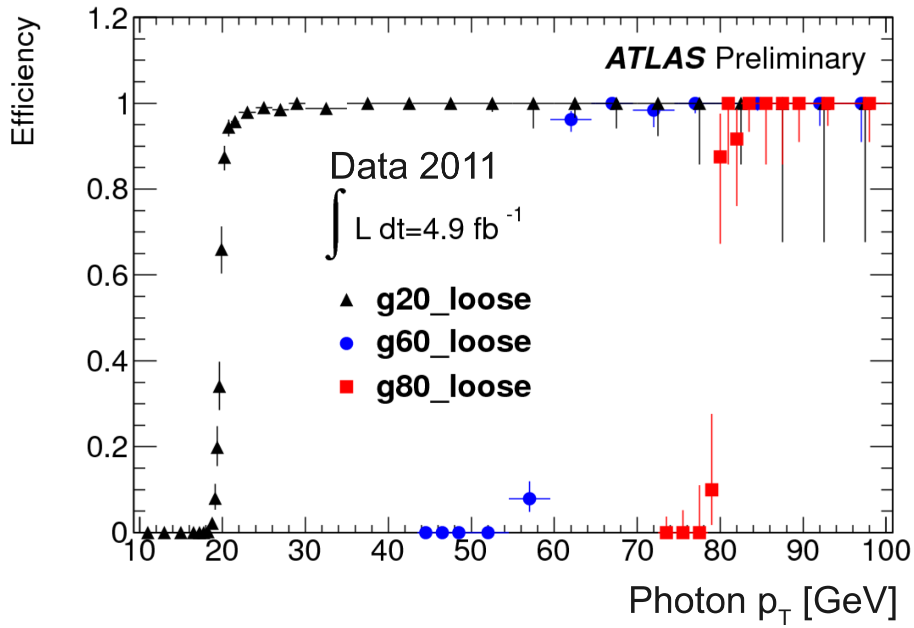
- Di-photon (2x20 GeV) trigger essential for $H \rightarrow \gamma\gamma$, at >99% eff.

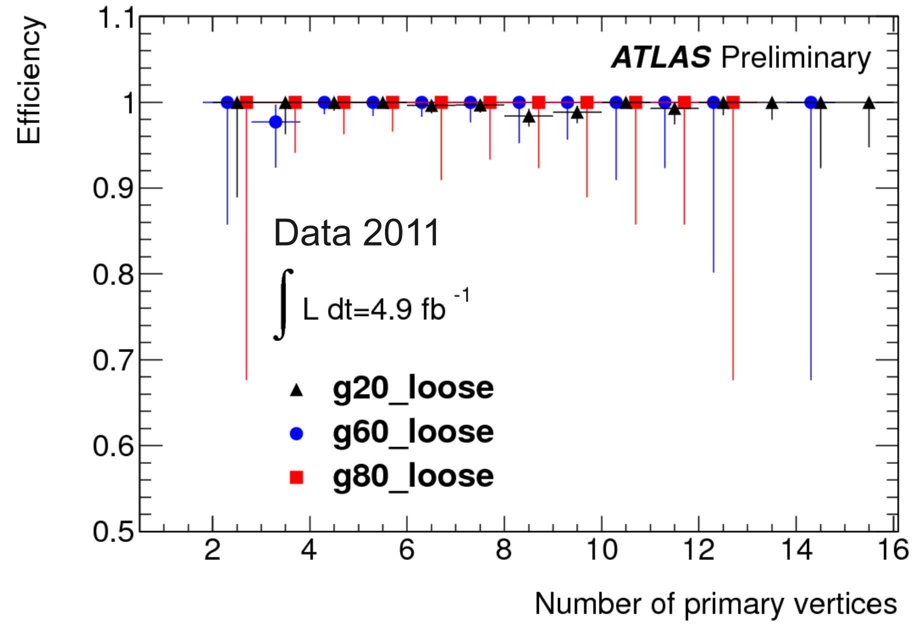
Kept stable during 2011



Retuned for 2012:

- Loosened pileup sensitive selection, but raised p_T thresholds
- 2x20 GeV trigger with somewhat tighter photon identification
- Added 3-photon triggers





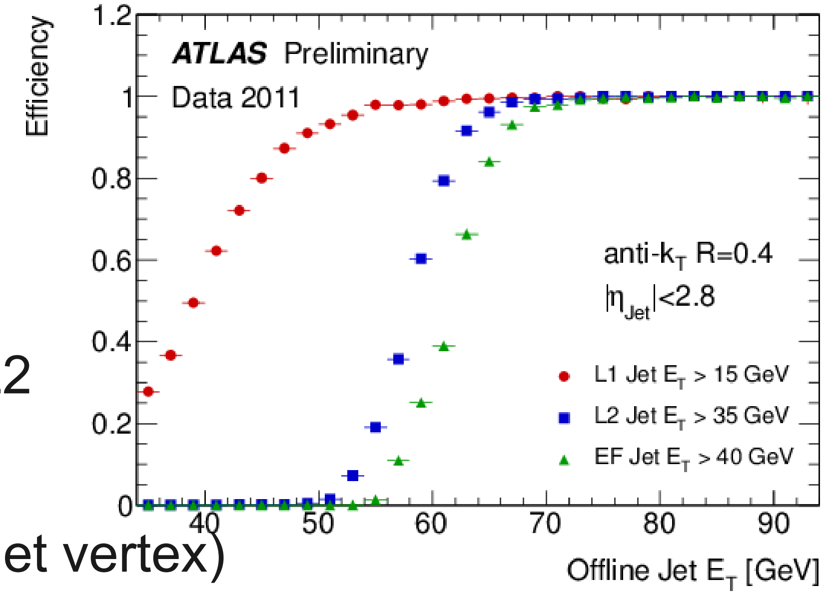
Jet Triggers

Many signals rely on jet triggers
Have triggers for various sizes of jets and both with and without b-tag
Evolution away from RoI based triggers

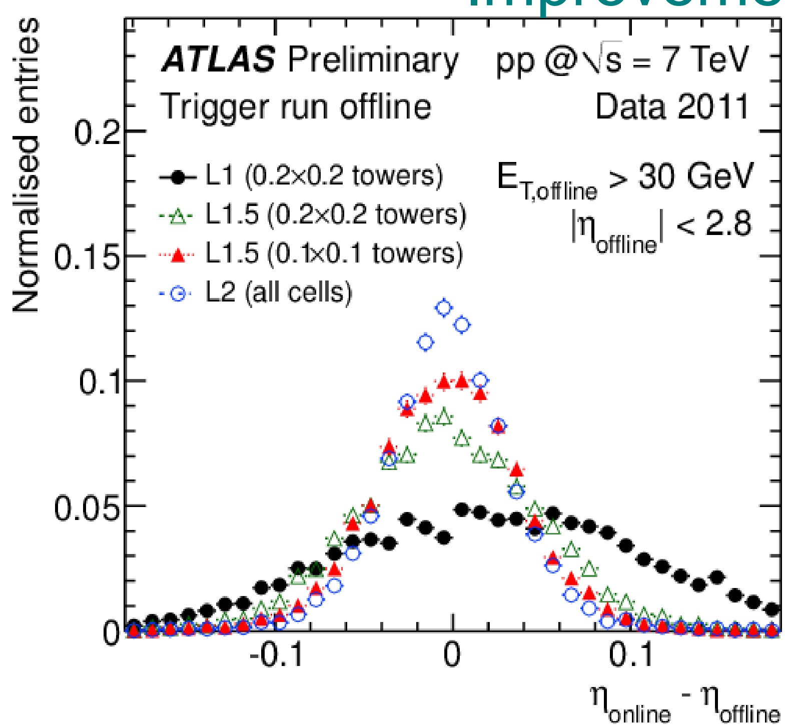
Improvements for 2012:

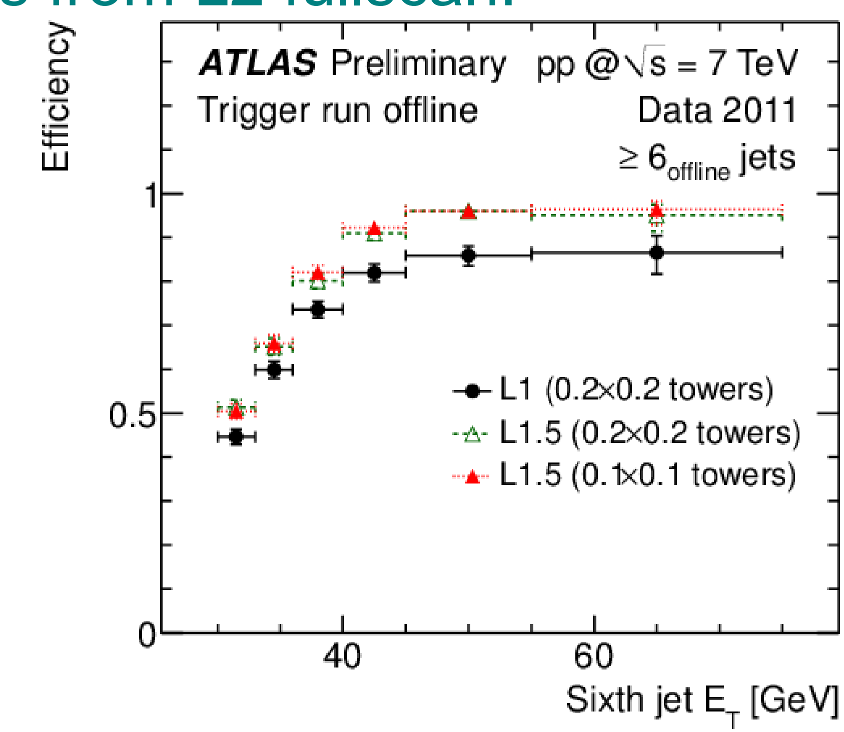
- Full scan reco of L1 towers for anti-kt jets at L2
- Hadronic scale for HLT jets
- Noise thresholds adjusted for high pileup
- More advanced b-tagger (Multi-variate, multi-jet vertex)

Jet efficiency vs p_T



Improvements from L2 fullscan:

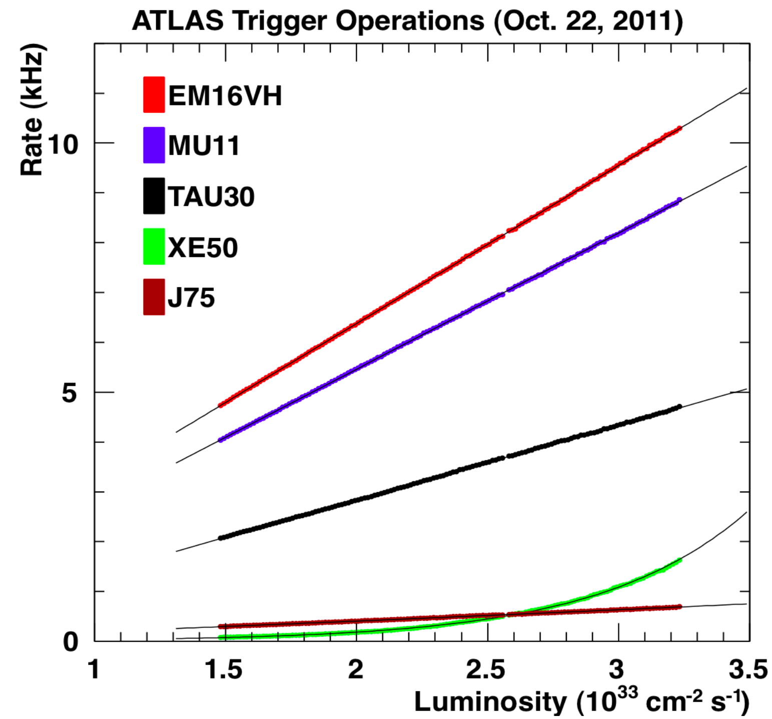




Missing Energy Triggers

Trigger MET sums over calorimeter cells above noise threshold

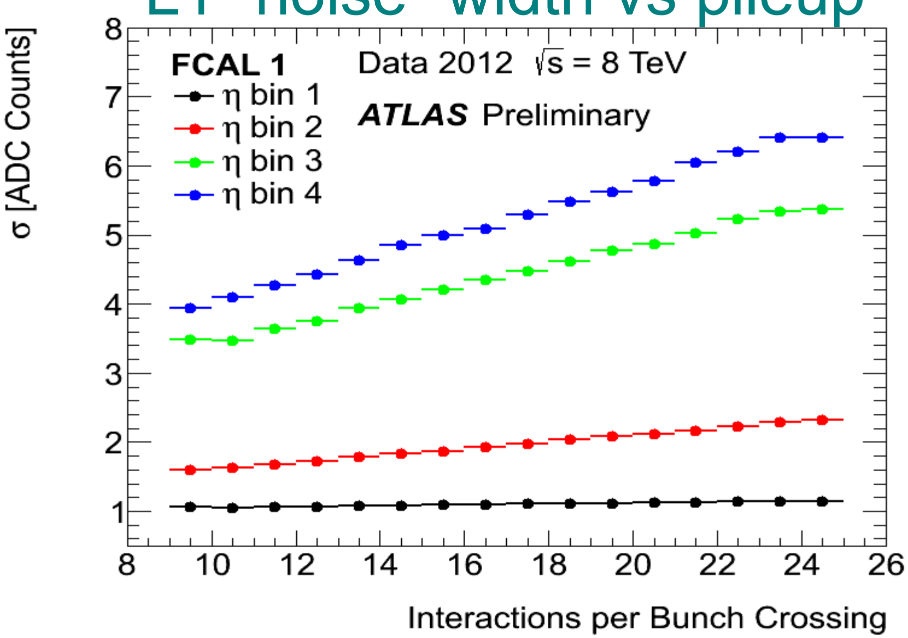
Strong pileup effect seen in 2011

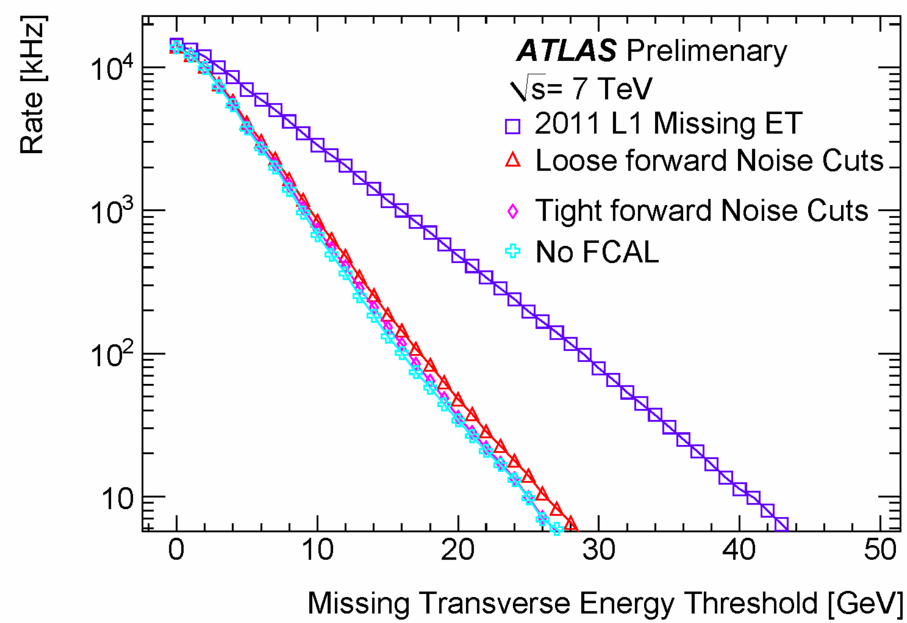


L1 improvements for 2012:

- Pileup effectively increases noise, particularly in the forward calorimeters → noise threshold per tower was raised
- L1 rate reduced by factor 10-20
- Little effect on resolution seen

L1 “noise” width vs pileup



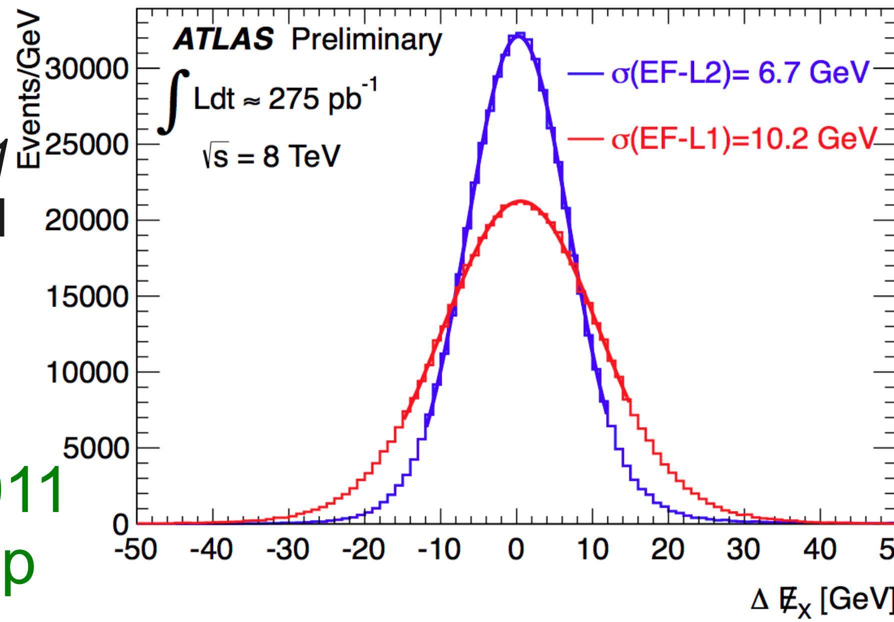


Missing Energy Triggers

HLT improvements for 2012:

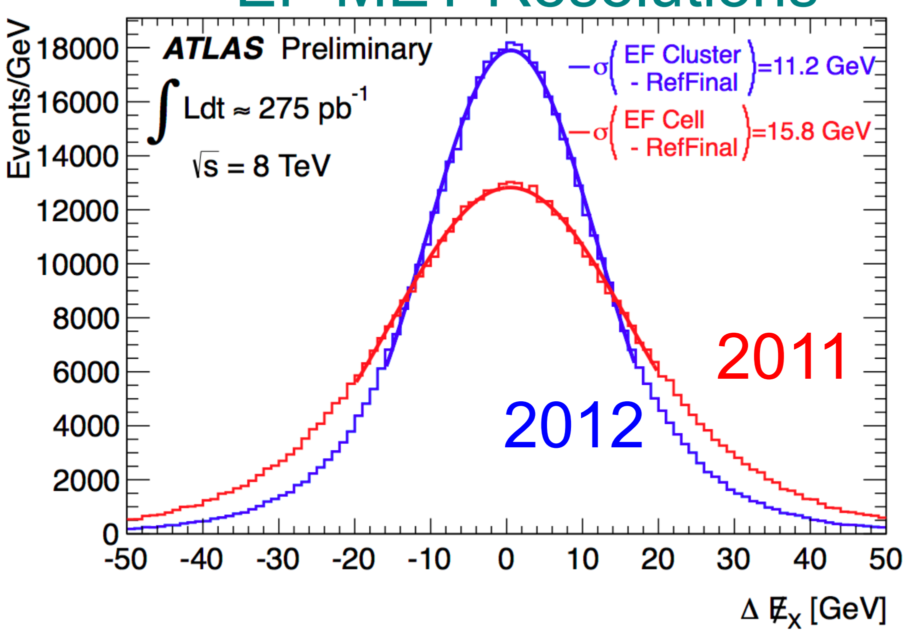
- Cell-based MET sum implemented in readout system for fast L2 decision
  Factor ~5 L2 rejection vs none in 2011
- New EF algorithm summing calibrated clusters instead of all cell energies (closer to offline definition as well)
- Noise cuts adjusted for high pileup

L1 vs L2 MET Resolution

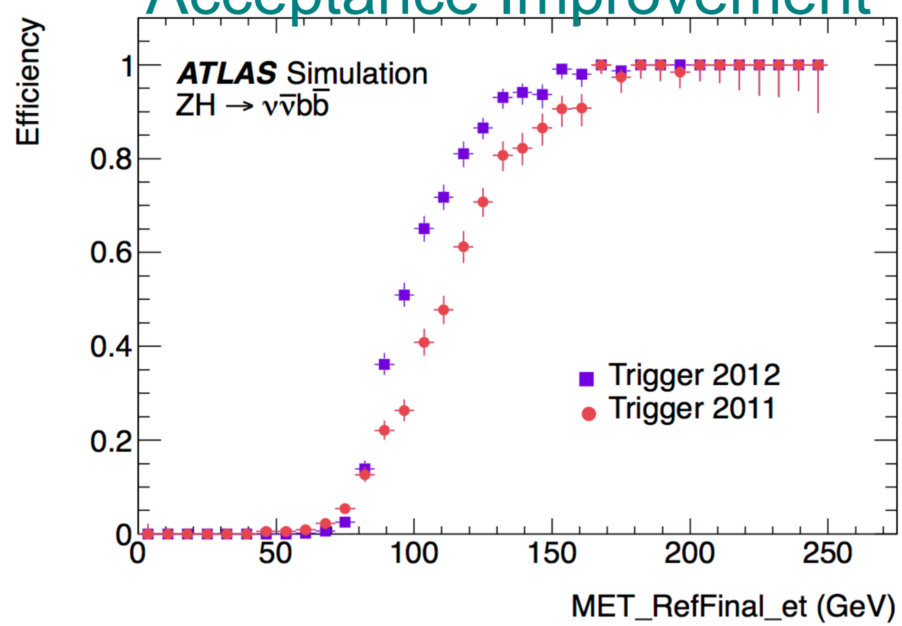


MET trigger looser in 2012 than 2011 despite higher luminosity and pileup

EF MET Resolutions



Acceptance Improvement



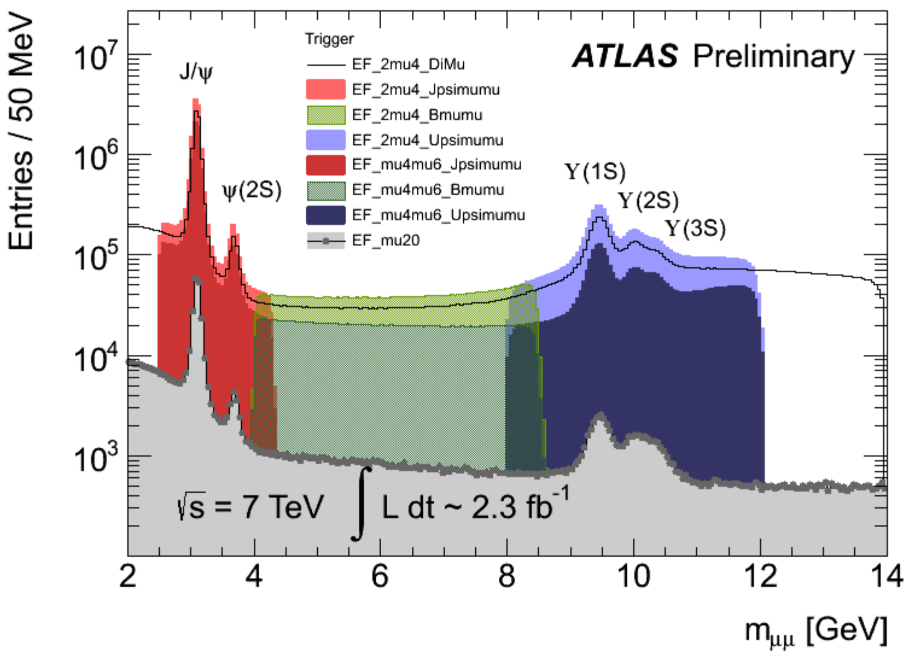
Summary and Outlook

- The ATLAS trigger operating successfully in 2011-2012
  - Efficiency losses due to the trigger are typically less than few %
  - Efficiencies are measured accurately using data
- Handling challenge of excellent LHC performance
  - Luminosity increased by factor 30 since end of 2010
  - Pileup increase by almost a factor 10 since end of 2010
- Significant improvements deployed for 2012
  - Retuned selection for high pileup conditions
  - More advanced HLT selection algorithms
  - Trigger thresholds only raised minimally w.r.t. 2011 despite twice the luminosity and beyond design pileup conditions
- Now planning for $\sqrt{s}$=13-14 TeV and L>10^{34} $cm^{-2}s^{-1}$

Backup

B-physics Triggers

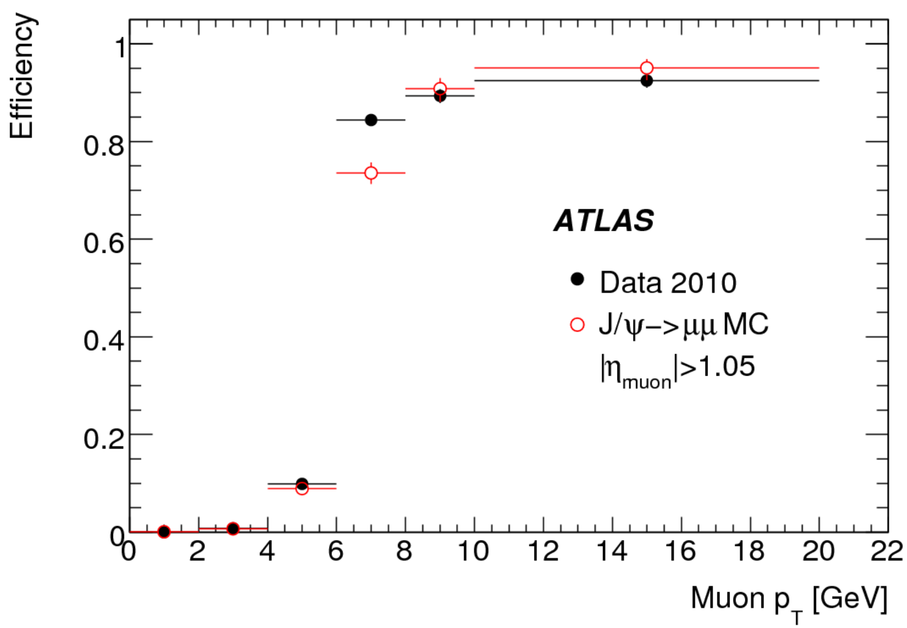
Large sample of low-p_T di-muon events collected for B-physics
Main trigger: di-muon with mass cut



Improvements for 2012:

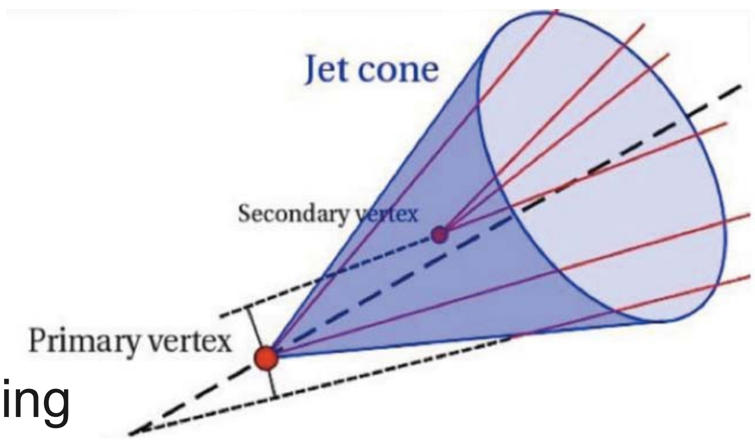
- New "Barrel-only" low-pt muons at L1 keeps lowest threshold for best muons
- Delayed processing stream (lifts EF output limit)

Low-pt muon efficiency



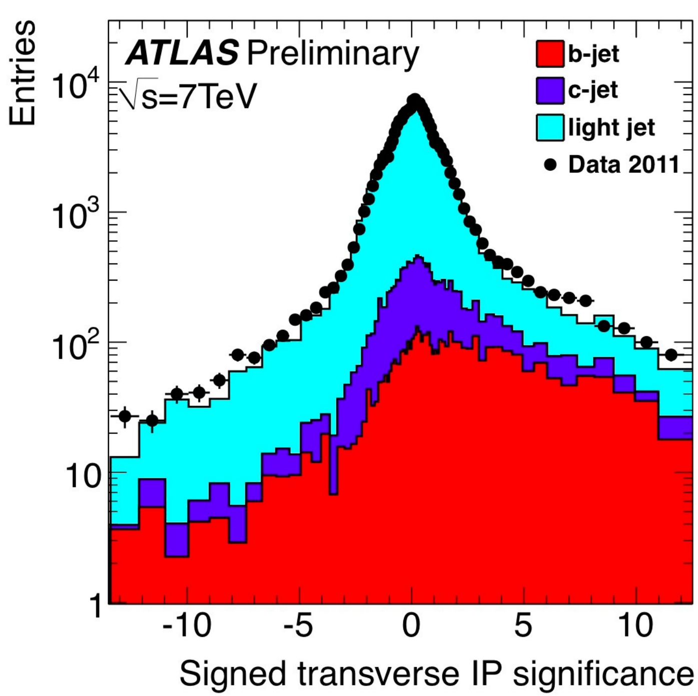
B-jet Triggers

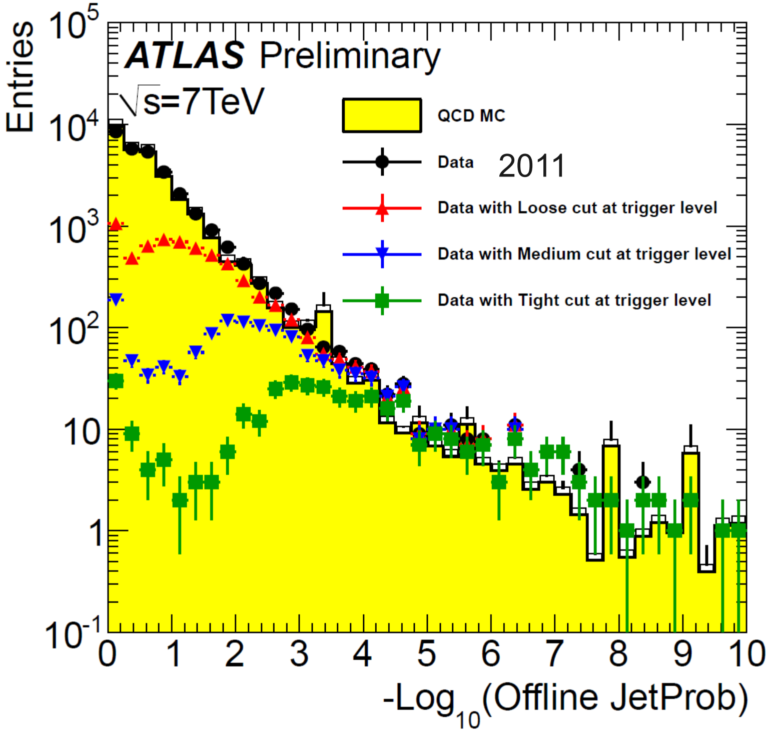
B-tagging of jets available in the trigger
Mostly used in multi-jet triggers
Can reduce trigger rates by factor 10-50



Improvements for 2012:

- More advanced tagger incl. secondary vtx finding
  Factor 4-5 better light jet rejection
- Pileup robust primary vertex determination
- Full use of HLT jets





Main Unprescaled Triggers

	Offline Selection	Trigger Selection L1	EF	L1 Peak (kHz) $L_{peak} = 7x10^{33}$	EF Ave (Hz) $L_{ave} = 5x10^{33}$
Single leptons	Single muon p_T > 25 GeV	15 GeV	24 GeV	8	45
	Single electron p_T > 25 GeV	18 GeV	24 GeV	17	70
Two leptons	2 muons p_T >15 2 muons p_T > 20,10 GeV	2x10 GeV 15 GeV	2 x 13 GeV 18,8 GeV	1 8	5 8
	2 electrons, each p_T > 15 GeV	2x10 GeV	2x12 GeV	6	8
	2 taus p_T > 45, 30GeV	15,11 GeV	29,20 GeV	12	12
Two photons	2 photons, each p_T > 25 GeV 2 loose photons, p_T > 40,30 GeV	2 x10 GeV 12,16 GeV	2 x 20 GeV 35, 25 GeV	6 6	10 7
Single jet	Jet p_T > 360 GeV	75 GeV	360 GeV	2	5
MET	MET > 120 GeV	40 GeV	80 GeV	2	17
Multi-jets	5 jets, each p_T > 55 GeV	4x15 GeV	5x55 GeV	1	8
b-jets	b + 3 other jets p_T > 45 GeV	4x15 GeV	4x45 GeV+btag	1	4
TOTAL				**<75**	**~400 (mean)**