Commissioning and performance of the ATLAS Trigger with proton collisions at the LHC

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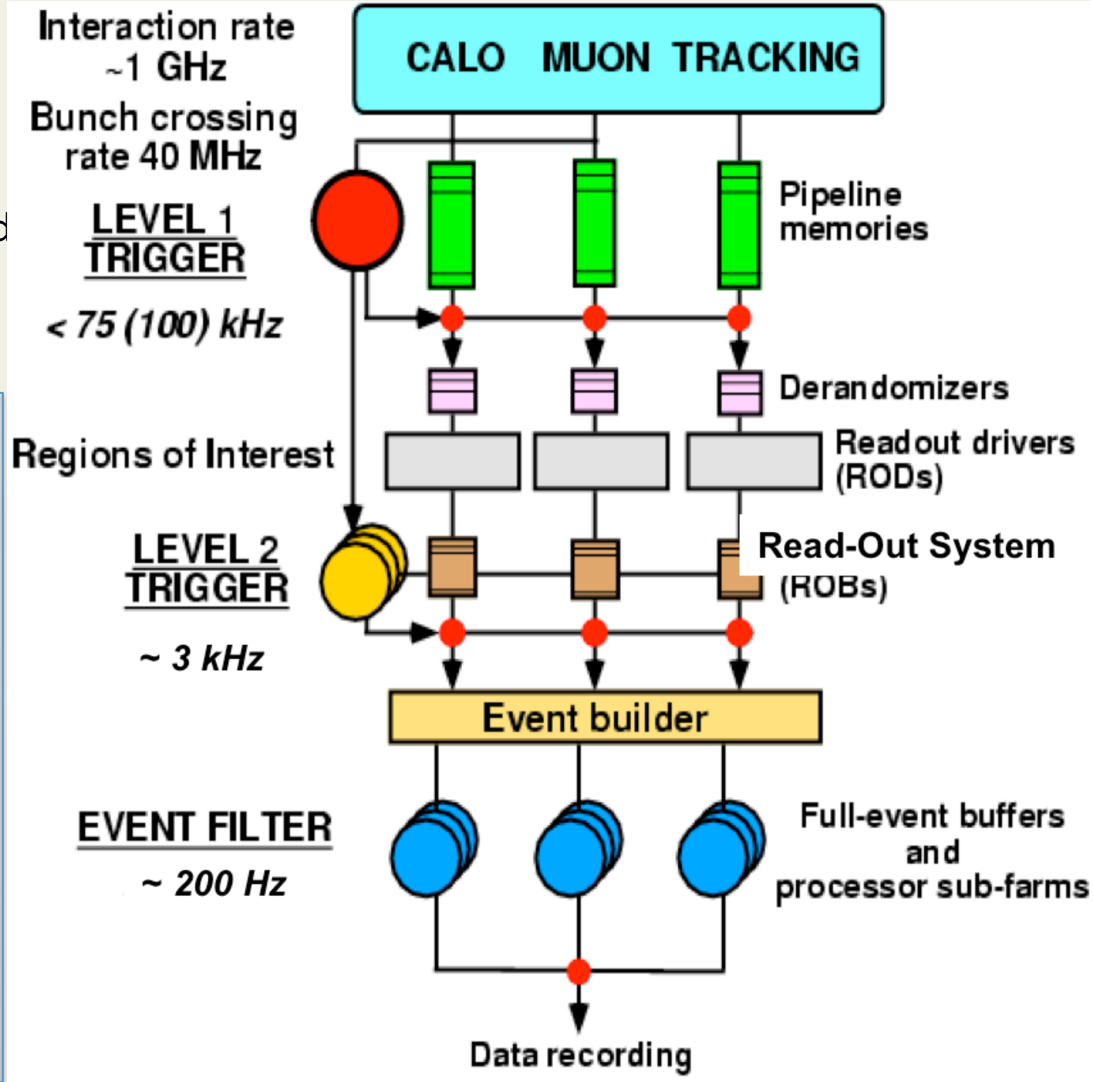
Outline

- Introduction
  - ATLAS trigger and DAQ system
  - Trigger selection
- Trigger commissioning strategy
- Results from 2009-2010 data
  - LVL1 timing and calibration
  - Performance of tracking, calorimeter and muon tracking trigger reconstruction
    - Physics trigger objects (i.e. electrons, photons, muons etc) not discussed in detail here:
      - Dedicated talk by R.Mackeprang on June 8^{th}
- Summary and outlook

ATLAS Trigger/DAQ System

- Three level system
- Level 1 (LVL1)
  - Fast custom-build electronics,
  - Trigger decision based on muon and calorimeter information only,
  - Coarse resolution,
  - Latency: <2.5μs,
- Level 2 (LVL2)
  - Large PC farm (O(1000) cores)
  - Software based reconstruction and selection,
  - Dedicated fast algorithms,
  - Limited data access (Region-Of-Interest - RoI),
  - <Processing time>= 40 ms,
- Level 3 – Event Filter (EF)
  - Large PC farm (O(5000) cores),
  - Offline software reused in RoI,
  - Full event information available,
  - <Processing time>= 4s

High Level Trigger (HLT)



Trigger selection

<u>Trigger chain:</u>

- sequence of reconstruction and selection algorithms,
- typically 2-10 algorithms per chain,
- possible event rejection at each step in the chain,

<u>Trigger menu:</u>

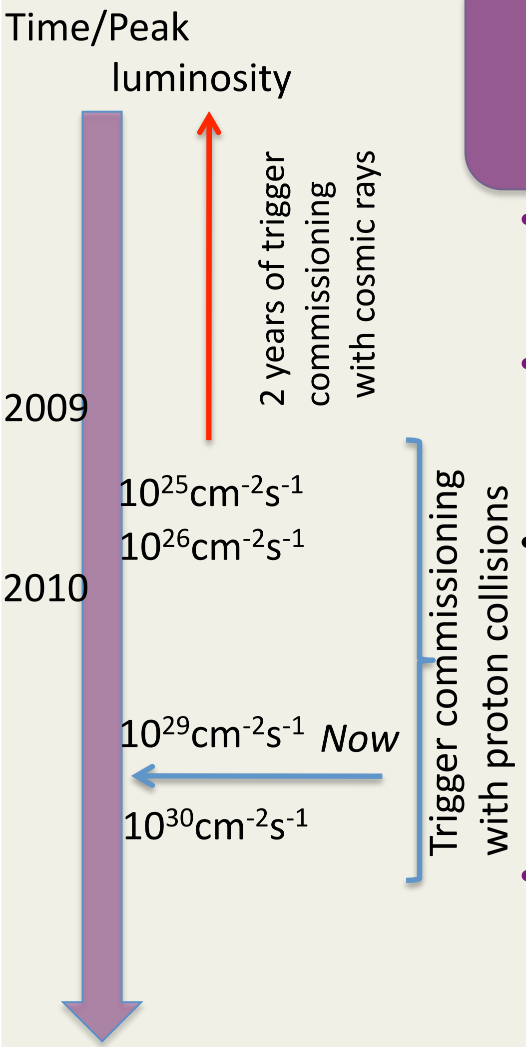
- collection of trigger chains,
- luminosity dependent,
- typically had 200-500 chains so far.

Trigger physics objects	LVL1 lowest thresholds (GeV)	HLT lowest thresholds (GeV)
Electron/photon	2	3
Tau	5	12
Muon	4	4
Missing energy	10	20
Jet	5	20
Total energy	10	90

Example: e3 chain

- LVL1: EM2
- LVL2: Calo
- LVL2: tracking
- LVL2: matching
- EF: Calo
- EF: tracking
- EF: matching
- 3 GeV electron

Trigger commissioning strategy

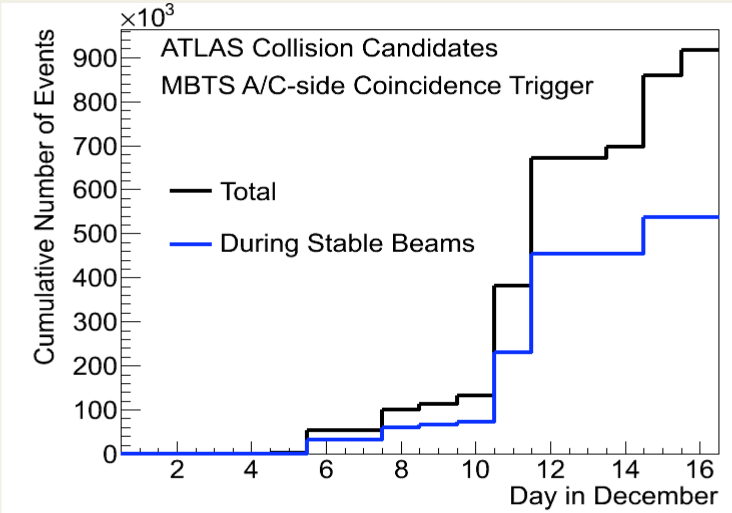


Rely on LVL1 during the initial phase of running when a data-recorded rate < 200 Hz i.e. below $10^{29}cm^{-2}s^{-1}$. Write to tape all LVL1-triggered physics events, the rest of bandwidth is filled in with a min bias sample.

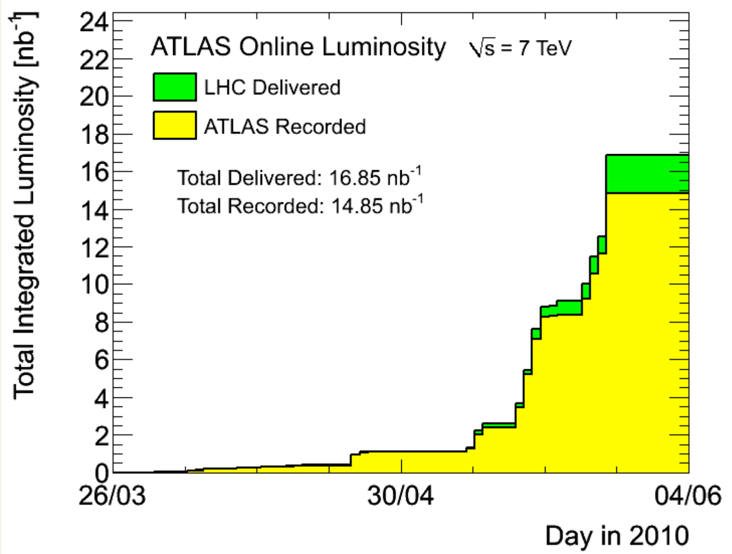
- HLT algorithms turned off for very first collisions
  - Run offline instead – no impact on data-taking,
  - Check for possible errors, crashes, timeouts, etc.
- HLT running online in monitoring mode for commissioning
  - HLT decisions recorded but not used for rejection,
  - Detailed offline analysis of the online decision – many results shown in this talk,
- Gradually activate HLT physics chains (above $10^{29}cm^{-2}s^{-1}$)
  - First ensure their performance is fully understood and satisfactory w.r.t. offline event selection,
  - One cannot afford to write to tape all LVL1-triggered physics events, therefore rejecting HLT chains will help reduce an output rate and provide higher purity events,
  - This can be done during an ongoing run by means of LVL1 and HLT pre-scale changes,
- Full HLT active, switch to a “physics menu” (few $10^{30}cm^{-2}s^{-1}$)
  - All high-p_T HLT chains are active.

2009/2010 data samples

- 2009 run
  - √s= 0.9 TeV or 2.36 TeV,
  - About 0.5M collision events written to tape,
  - Peak luminosity: 7x10^{26}cm^{-2}s^{-1},
  - Integrated luminosity: 12 μb^{-1},

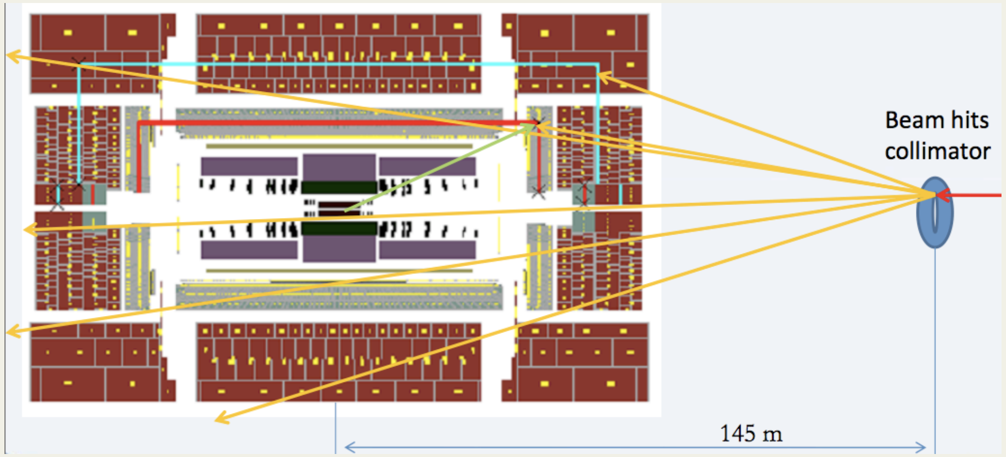


- 2010 run (ongoing)
  - √s=7 TeV,
  - More than 800M collision events observed,
  - Peak luminosity: 2x10^{29}cm^{-2}s^{-1},
  - Integrated luminosity > 14.8nb^{-1}

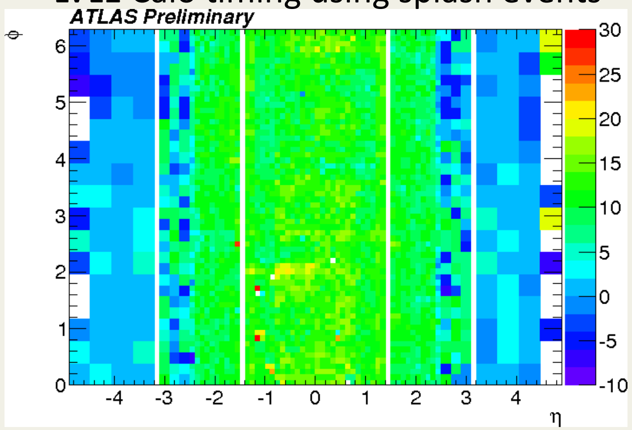


LVL1 commissioning with beam

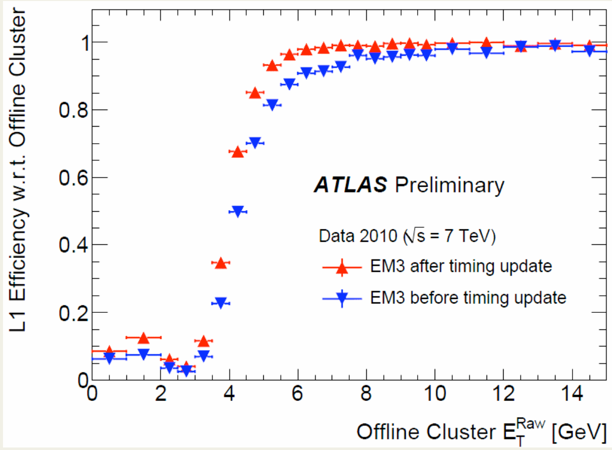
- Timing of LVL1 calorimeter triggers determined with splash events
  - Corrections for time-of-flight to estimate collision timing,
  - z-axis: nanosecond relative peak position for the EM layer (similar for hadronic),
  - Timing accuracy with splashes: 5-10 ns,



LVL1 Calo timing using splash events

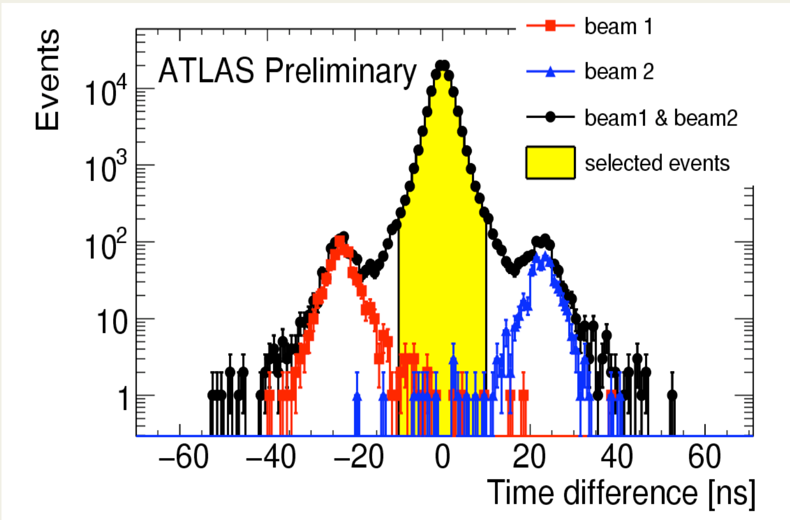


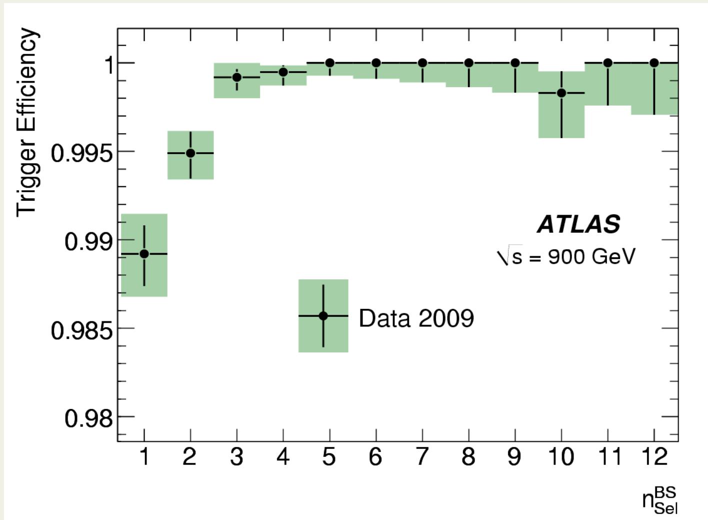
  - Final LVL1 calo timing adjustments with collisions will be at 2 ns level,
- LVL1 muon timing: the forward trigger is completely timed-in to ~2-3 ns, not enough data in the central region yet,
- Energy calibration of LVL1 calo using splash events established at 5-10% accuracy.



Min Bias triggers

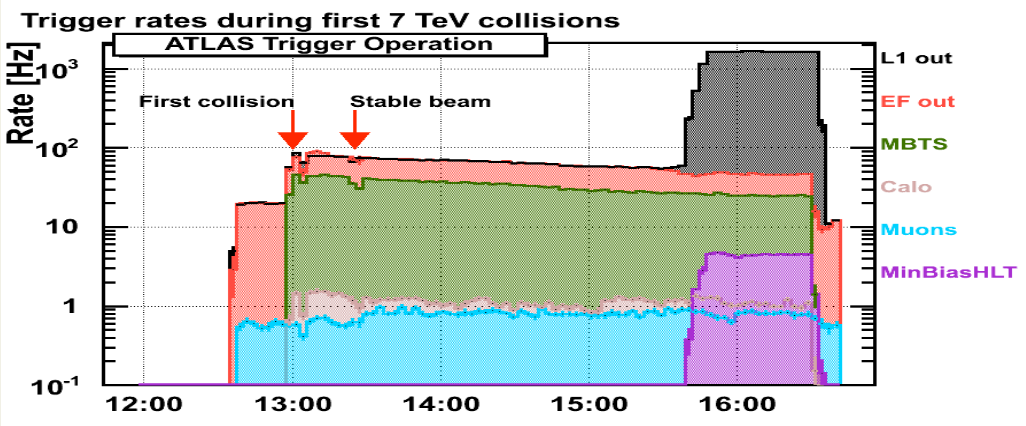
- Minimum Bias Trigger Scintilator (MBTS_1) was a main physics trigger in 2009
  - 16x2 scintillator paddles installed in front of the calorimeter cryostat on both sides ,
  - Used in first charge-particles multiplicity studies for 900 GeV,
  - Efficiencies derived from running a high-rate random trigger at LVL1 and performing HLT selection (MinBias triggers in rejection mode already in Dec 2009)

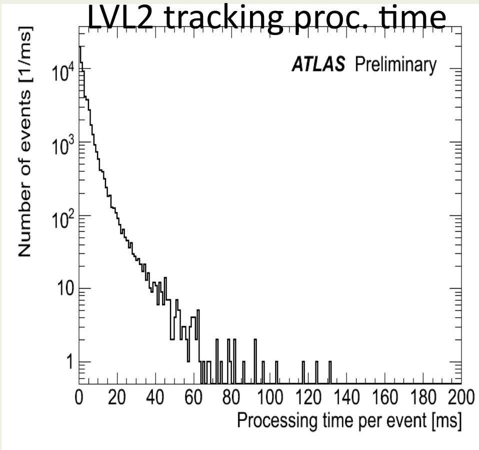


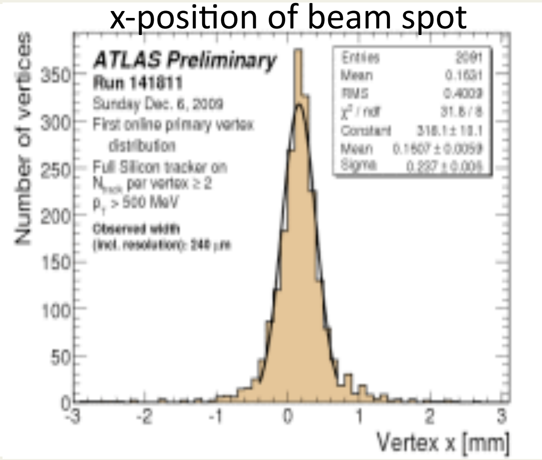


Trigger operations

- Trigger running very smoothly during single beam and collision periods
  - Monitoring and shift operations exercised 24/7,
  - No algorithm crashes so far,
  - Rare timeouts for massive cosmic showers (<20 timeouts per day),
    - Each timeout is analyzed carefully,
  - Feature of enabling/disabling/pre-scaling triggers without affecting an ongoing run maximizes data-taking efficiency,
  - Very detailed online monitoring of global trigger features and also detailed trigger chain output is very helpful,
  - Offline monitoring of trigger performance w.r.t. physics objects also in place.

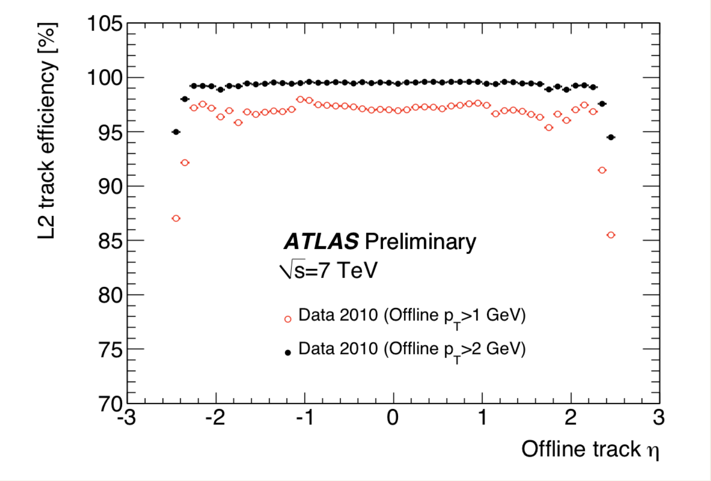


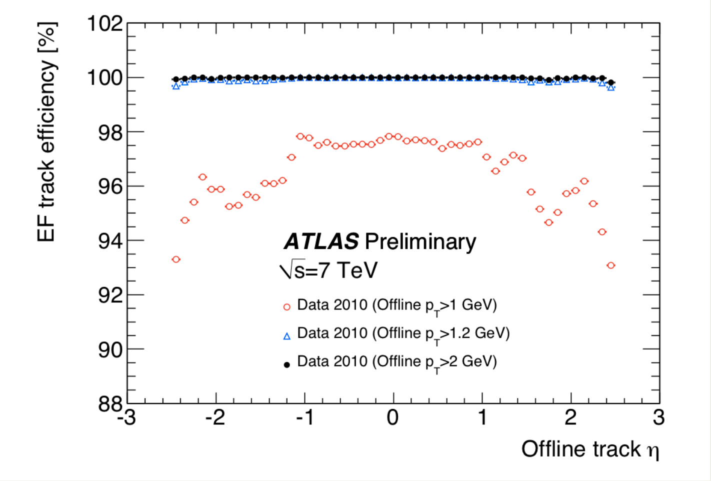


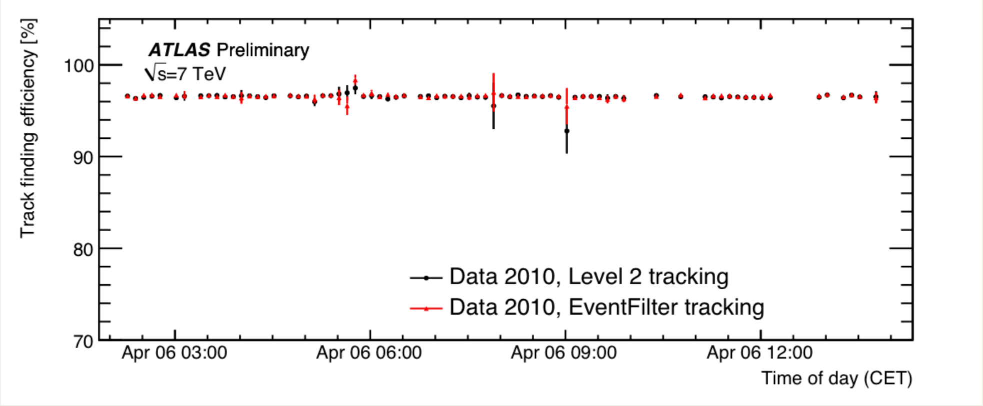


HLT tracking performance

- At √s=0.9TeV rate of RoI-based tracks was very small, therefore most studies done in full scan (i.e. scanning the entire detector) mode
  - Performance w.r.t. offline objects,
  - Slight fall of LVL2 efficiency at high p_T for the forward region,
  - The central region is flat for large p_T,
  - EF plateau near 100%
- Commissioning of RoI-based objects started up at √s=7TeV

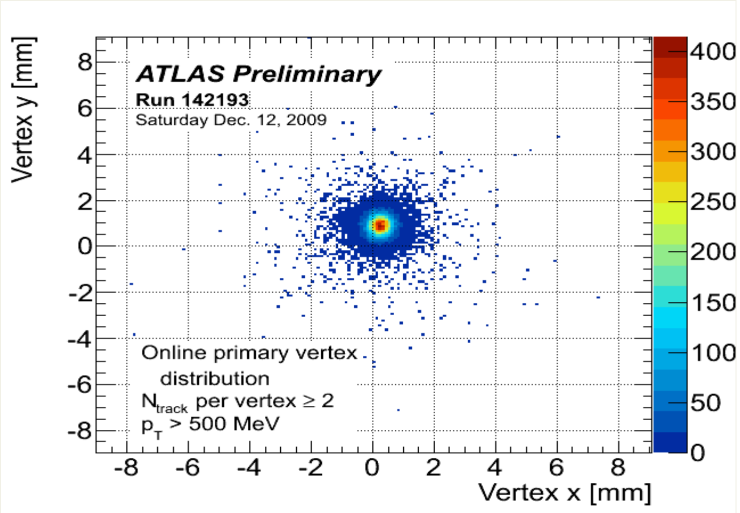


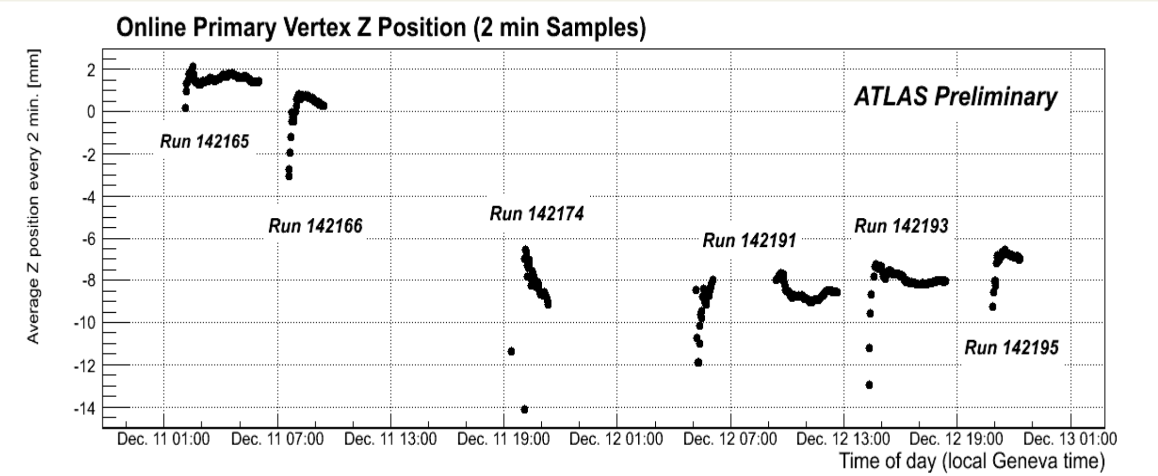


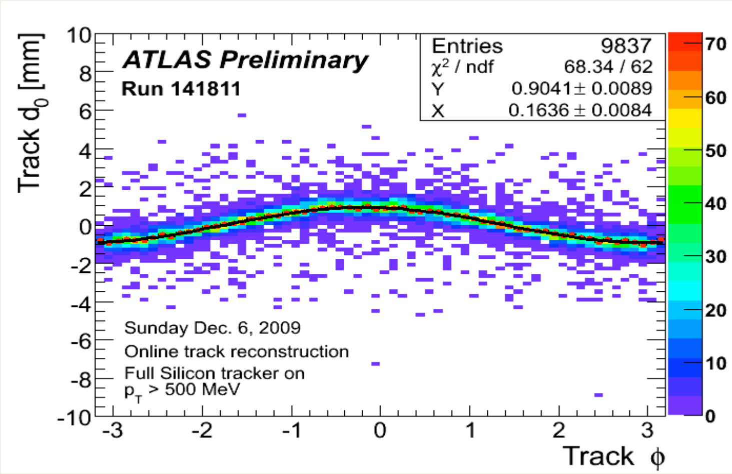


Transverse beam position

- Accurate online measurements of the interaction region,
  - Full-scan tracking reconstruction at LVL2, results available whenever HLT is running,
  - Available to the LHC machine and soon to HLT algorithms



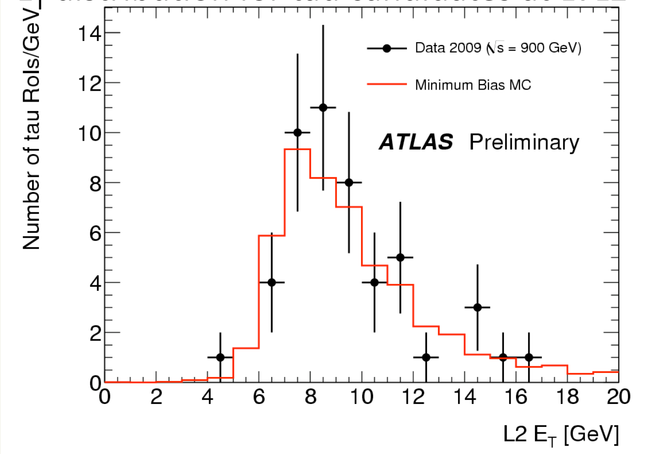




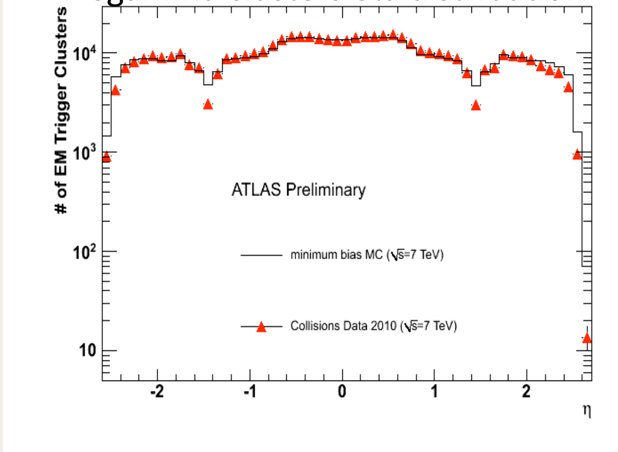
Calorimeter triggers

- Calorimeter reconstruction is a starting point for many physics objects
  - Electrons, photons, jets, taus etc
- Distributions generally agree well with simulation,
  - Data is absolutely needed to derive corrections for transition regions

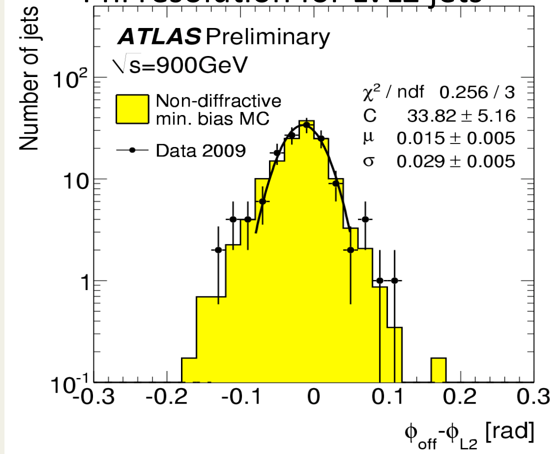
E_T distribution for tau candidates at LVL2



EF egamma clusters eta distribution



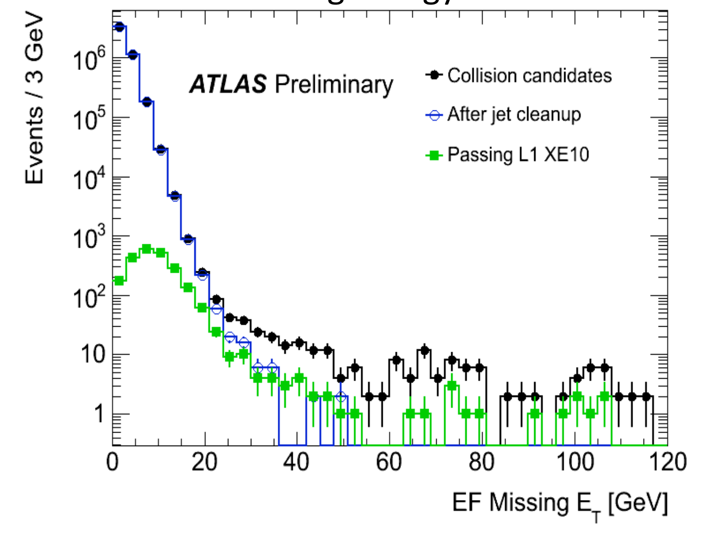
Phi resolution for LVL2 jets



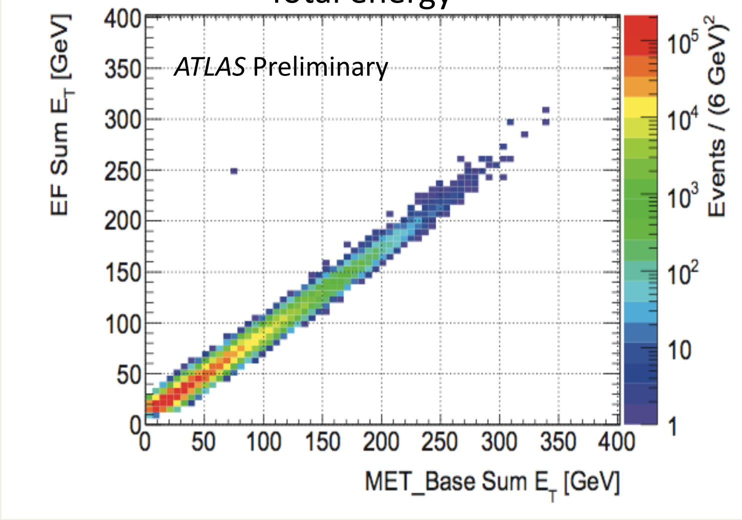
Missing energy and total energy

- Missing energy is a global feature of heavy, non-interacting particles being evidence of new physics – use missing energy to trigger on them,
- This trigger is non-RoI-based,
  - Sum E_T over all calorimeter channels requiring some noise suppression at EF ($|E_T|>2\sigma_{noise}$),
  - Correct LVL2 and EF for high-p_T muons,
- Total energy trigger also available
  - Used for exotic searches

Missing energy



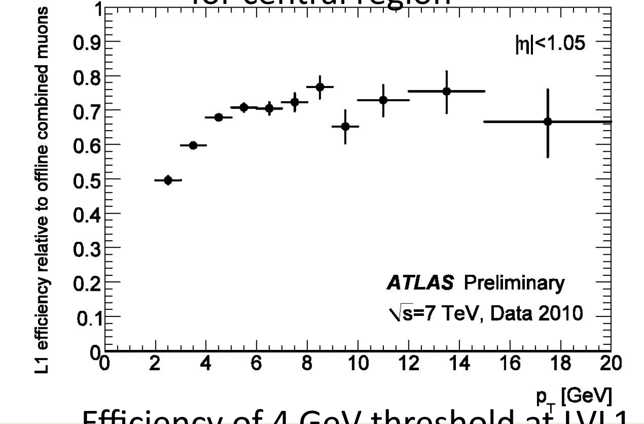
Total energy



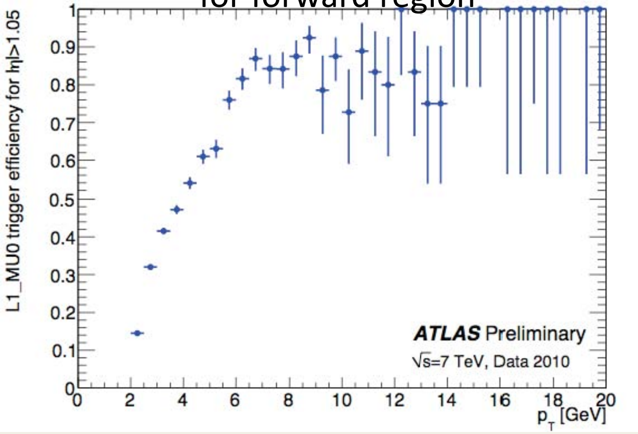
Muon triggers

- LVL1 muon trigger not fully timed-in in the central region yet , more data needed,
  - LVL1 inefficiency at plateau is mainly due to the detector geometrical acceptance, with future timing adjustments it is expected to reach 84%,
- LVL2 and EF confirm LVL1 muons with standalone (muon system only) and combined (muon system +Inner Detector) reconstructions,
- Slow turn-on for standalone muon due to non-optimized p_T resolution

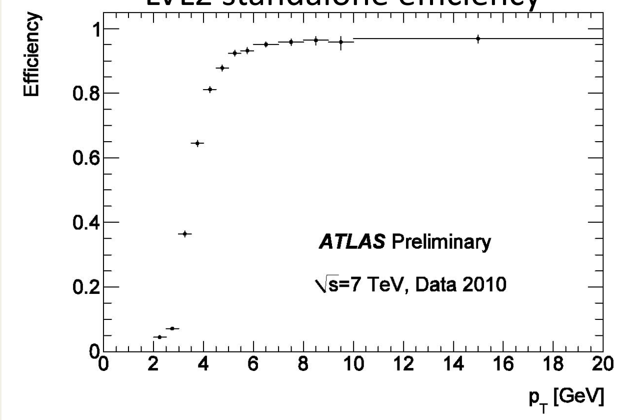
Efficiency of 4 GeV threshold at LVL1 for central region



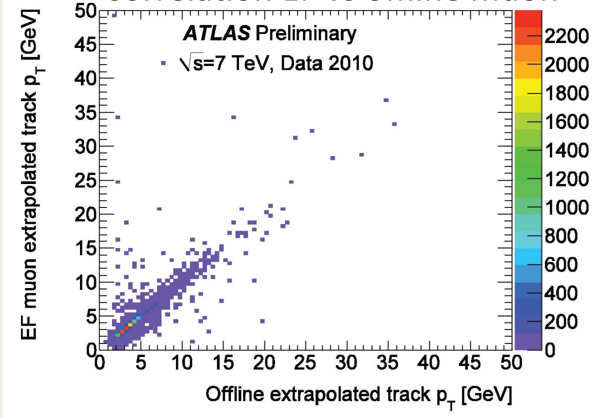
Efficiency of 4 GeV threshold at LVL1 for forward region



LVL2 standalone efficiency



Correlation EF vs offline muon



Summary and Outlook

- ATLAS trigger has worked extremely well since the very beginning writing to disk event rates following LHC operation needs (fraction of Hz-350 Hz),
- Trigger commissioning menu is very flexible to select physics events based on either LVL1 or HLT decision

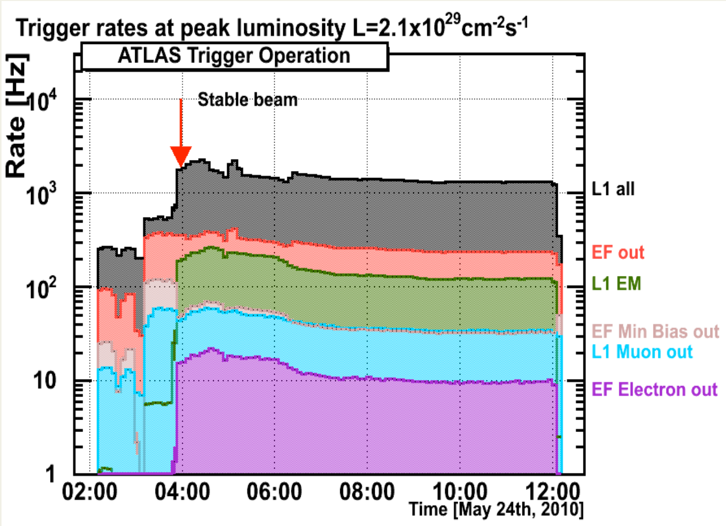
• Trigger commissioning follows the plan:

• All HLT algorithms run online in monitoring mode, some also running in rejection mode,

- HLT rejection enabled for Min Bias and the lowest-p_T egamma thresholds,

• Trigger performance monitored online and offline,

• First results as expected, also remarkably well described by the simulation



• Next steps:

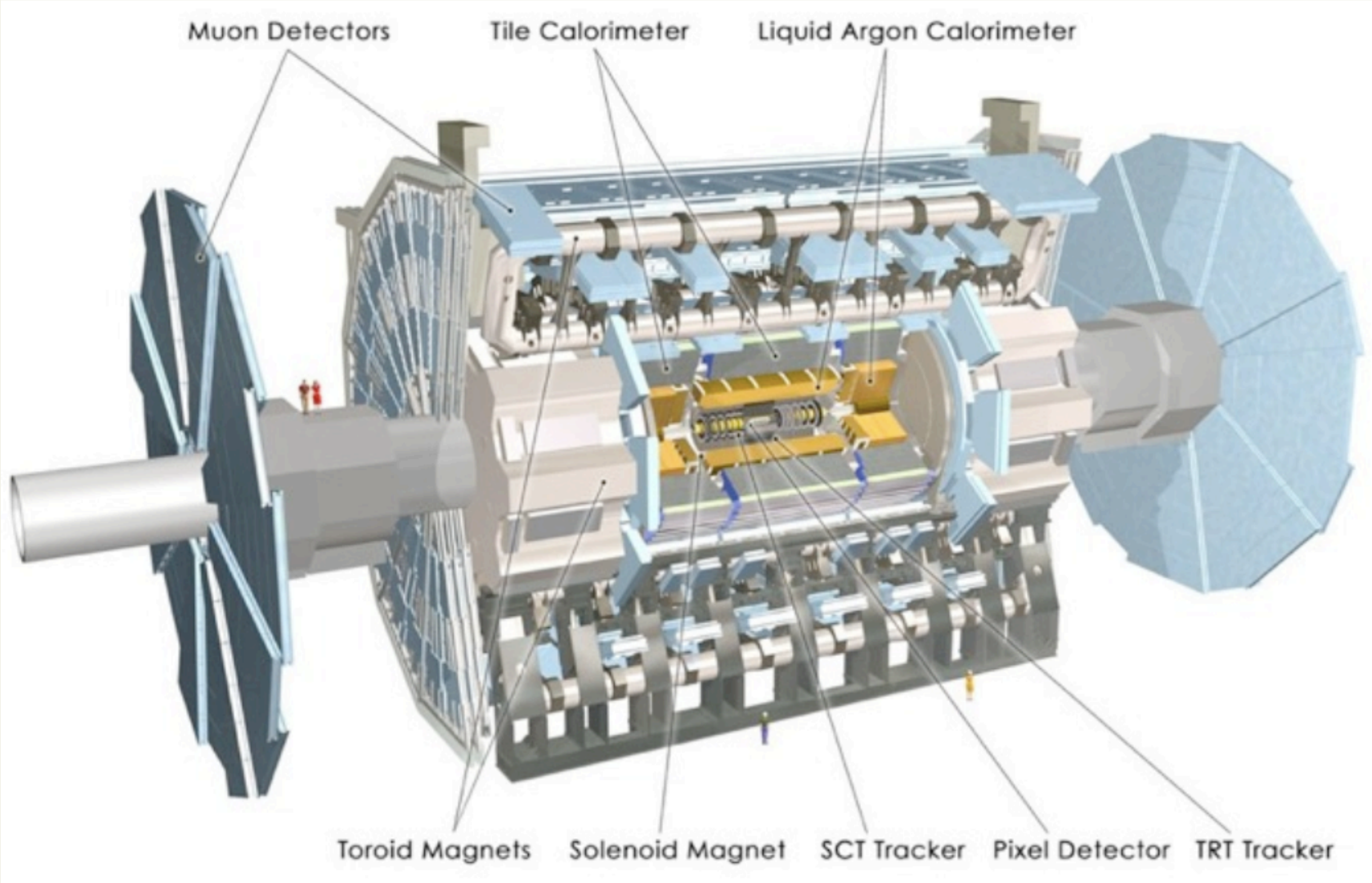
• Luminosity will gradually increase over the coming months until it reaches few 10^{32} $cm^{-2}s^{-1}$,

- Other trigger objects (taus, muons, etc.) will enter into rejection mode soon,

• Trigger menu will switch from a commissioning to "physics" one at few $10^{30}cm^{-2}s^{-1}$ (all triggers in rejection mode).

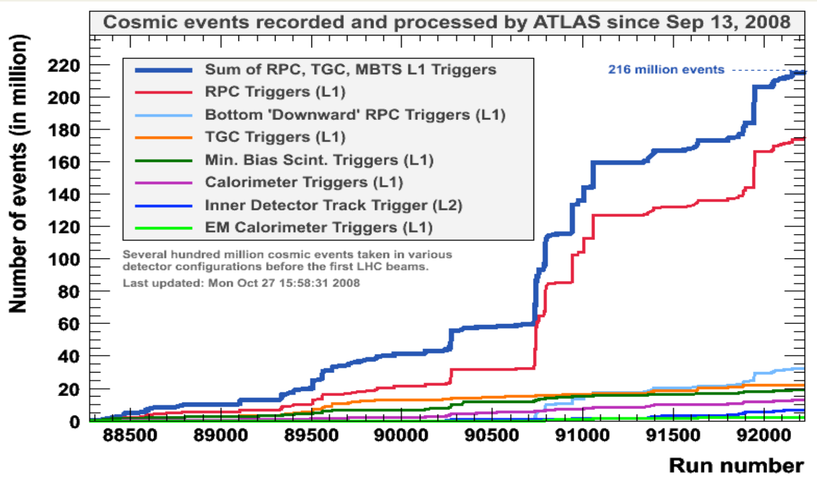
Back-up slides

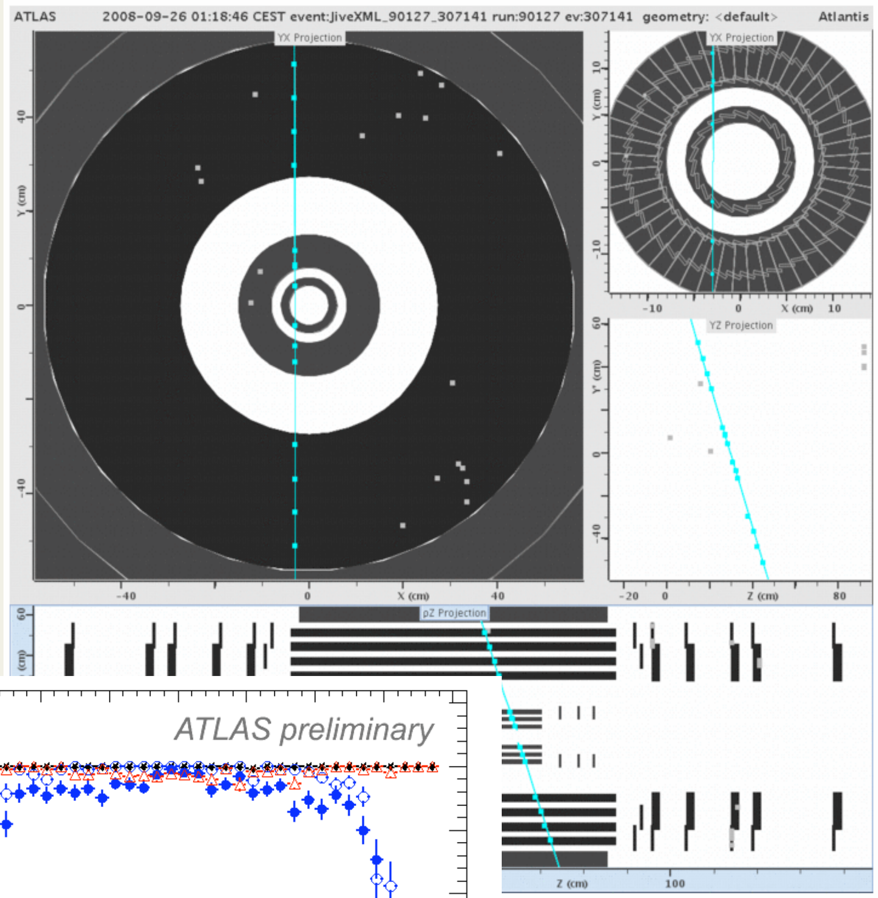
ATLAS detector

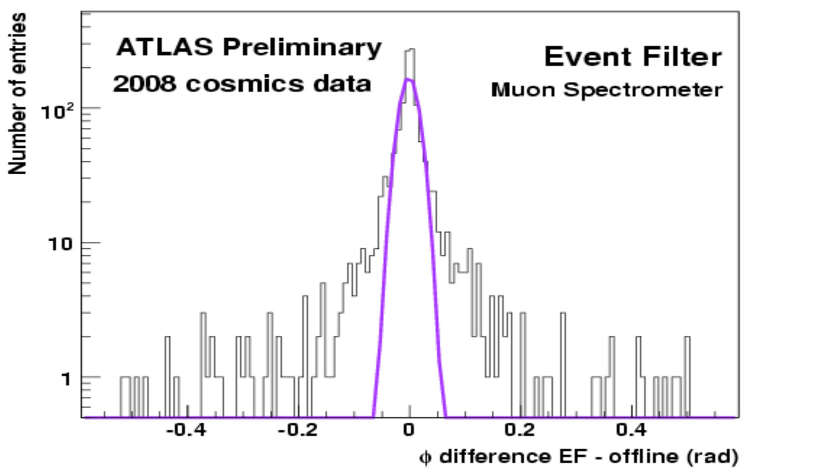


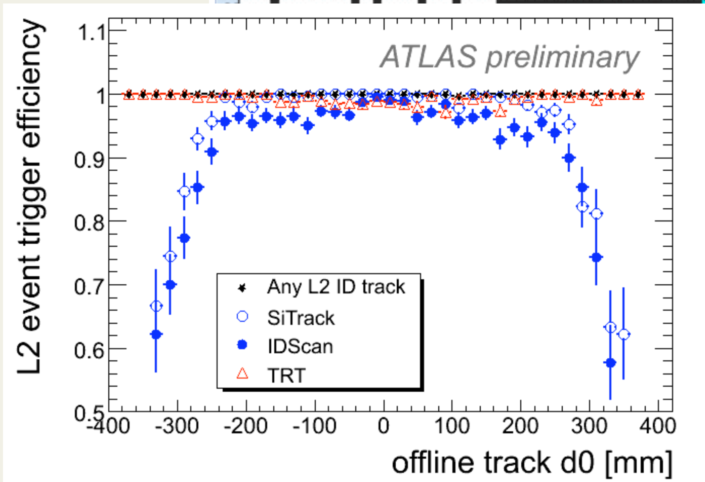
Trigger commissioning with cosmic rays

- Trigger commissioning was started more than 2 years ago,
- Cosmic runs provided very useful samples for first performance studies







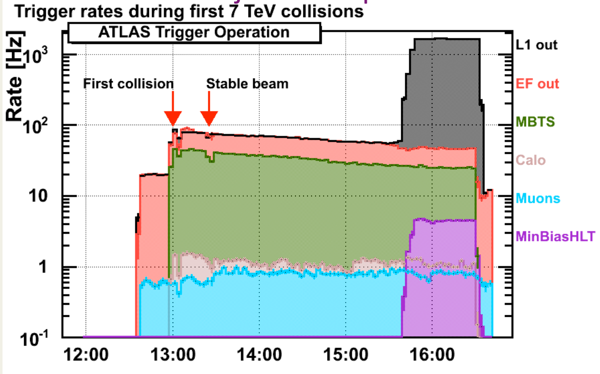


Status and next steps

- Trigger menu needs to evolve constantly following a luminosity increase accompanying LHC commissioning
  - Strategy: enable HLT rejection before pre-scaling to keep output rates within allocated bandwidth. If it does not help, tighten selection to collect most of data with un-pre-scaled triggers,
  - Output rates controlled via LVL1 and HLT pre-scale factors which can be fine-tuned on the fly.

Trigger objects	LVL1 lowest thresholds (GeV)	HLT lowest thresholds (GeV)	HLT rejection enabled
Minimum Bias			~10^{26} (Dec 2009)
Electron/ photon	2	3	2×10^{29} (May 24th, 2010)
Tau	5	12	soon
Muon	4	4	
Missing energy	10	20	
Jet	5	20	
Total energy	10	90	

Min Bias HLT rejection in place



Electron/photon HLT rejection enabled