ATLAS Trigger Status and Results from Commissioning Operations

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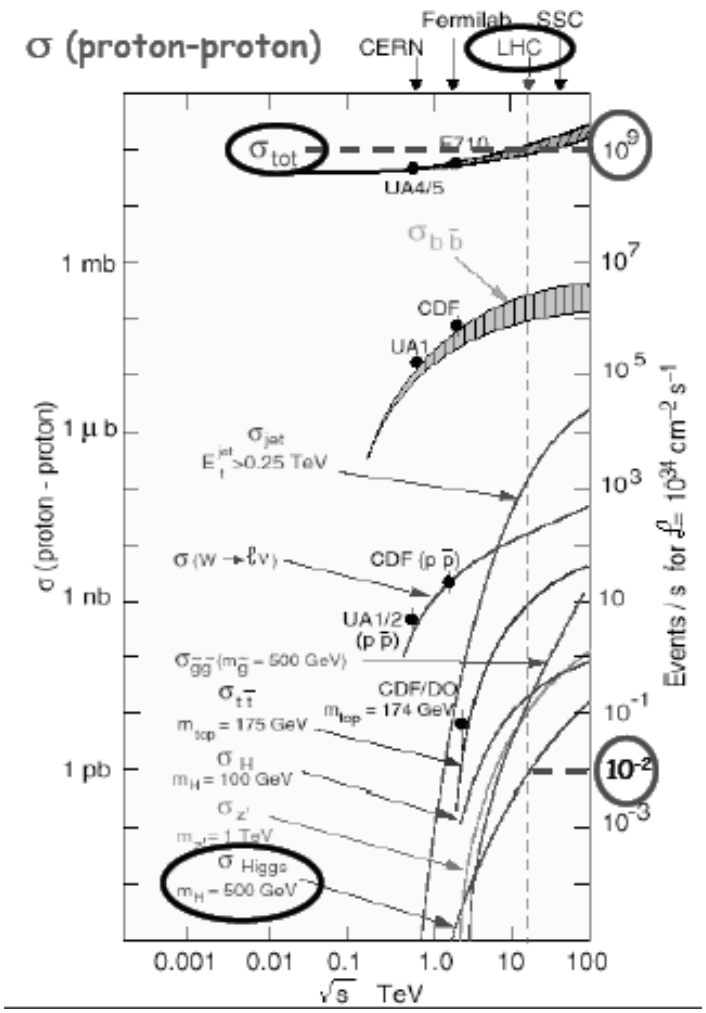
Trigger Requirements at LHC



- pp collisions at √s=14 TeV
- Total cross section ~70mb
  - Interesting physics, cross section < 1 nb
- 40 MHz bunch crossing rate
- 25 interaction / bc @ $L=10^{34}$ $cm^{-2}s^{-1}$

→ Input rate 1 GHz

- event size ~1.5 MB → input rate ~1PB/s !
- ... but we can write ~300 MB/s
- Need to reduce the rate to ~200Hz

Trigger must efficiently cover ATLAS physics programme for SM precision measurements and for new physics searches

The ATLAS Detector

high occupancy →high granularity needed → 10^8 electronic channels

4 super-conducting magnets: solenoid + 3 toroids

Silicon Pixel detector

80 M channels, intrinsic resolution 10 x 110 μm

Solenoid field 2T in inner detector region

toroid field peak strength 4T

Muon spectrometer

~1200 precision chambers for track reconstruction

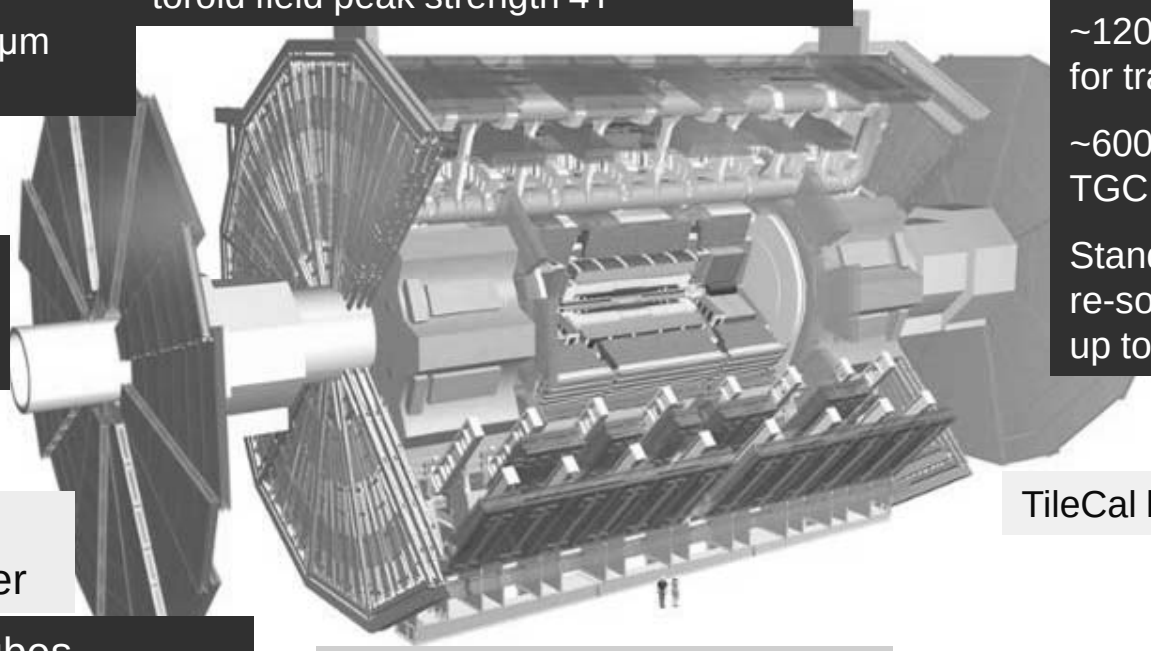
~600 RPC and ~3600 TGC trigger chambers

Stand-alone momentum re-solution Δpt/pt < 10% up to 1 TeV

Silicon tracker

~ 6 ·10^6 channels

80 μm wide strips



Transition Radiation Tracker

Xe filled straw tubes, electron – pion separation

~ 35 hits/track for track reconstruction

TileCal hadronic calorimeter

Sandwich structure: iron absorber + scintillator tiles

~ 10000 channels

LAr calorimeters (EMC, HC)

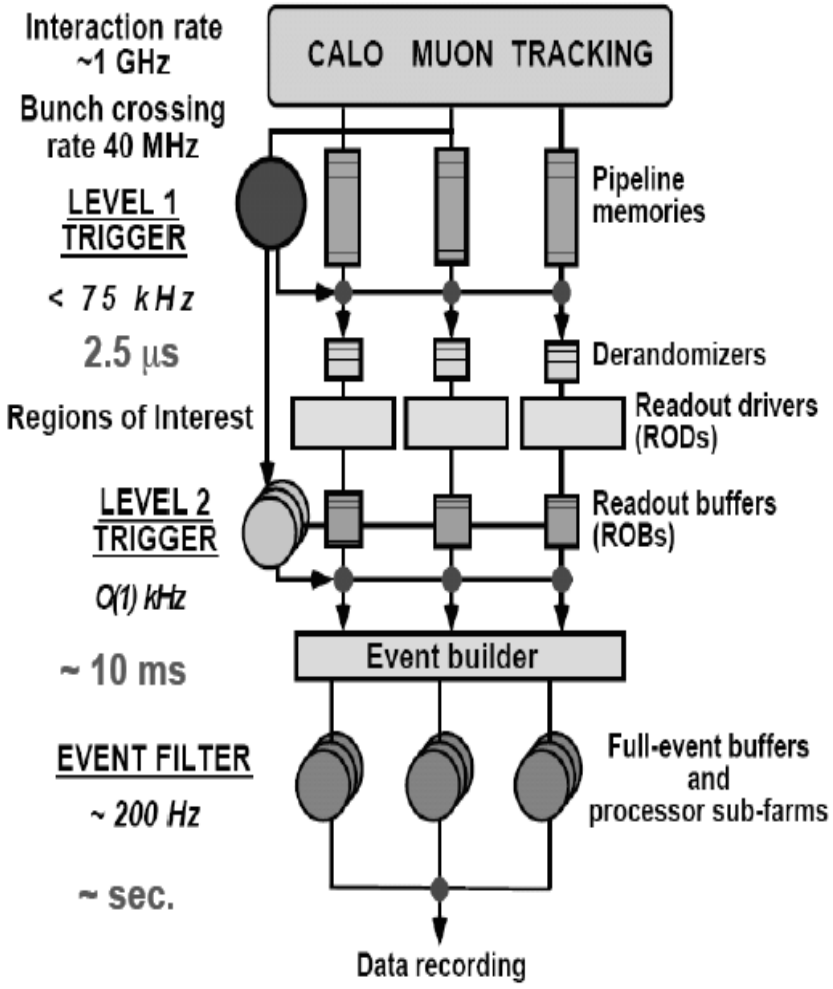
~ 160000 + 10000 channels (EMC,HC)

10%/√E energy resolution for e,γ

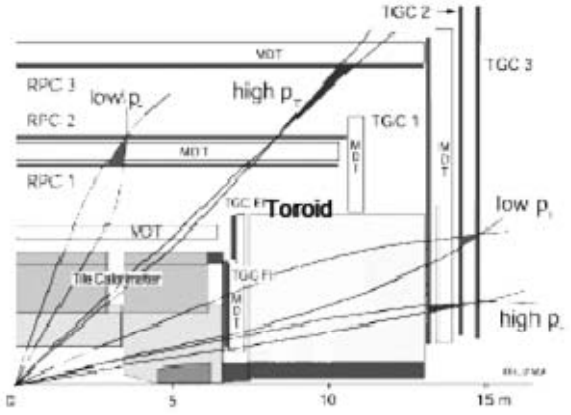
Trigger for electrons, photons and jets

ATLAS Trigger

- **Three trigger levels:**
- **Level 1:**
  - **Hardware based**
  - **Calorimeter and muons only**
  - **Latency 2.5 μs**
  - **Output rate ~75 kHz**
- **Level 2:**
  - **Only detector "Regions of Interest" (RoI) processed (< 10% of full event with full granularity from all detectors)**
  - **Fast reconstruction**
  - **Processing time per event ~40 ms**
  - **Output rate up to ~2 kHz**
- **Event Filter (EF):**
  - **Seeded by level 2**
  - **Potential full event access**
  - **Offline algorithms**
  - **Processing time per event ~4 s**
  - **Output rate up to ~200 Hz**



LVL1 : Muons & Calorimetry



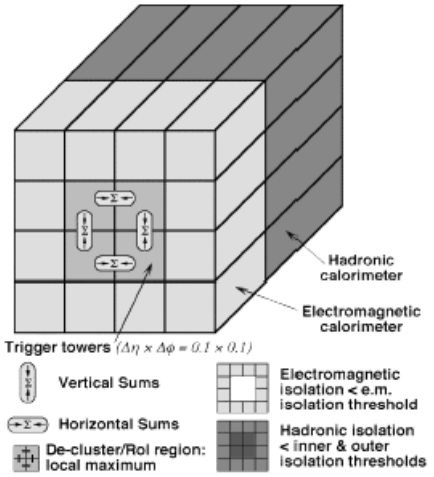
Muon Trigger looking for coincidences in muon trigger chambers

HLT/DAQ

L1A

Central Trigger Processor (CTP)

Rols



Calorimetry Trigger looking for e/γ/τ+ jets+ETmiss/sumET

- **Various combinations of cluster sums and isolation criteria**

Barrel (RPC)

Endcaps (TGC)

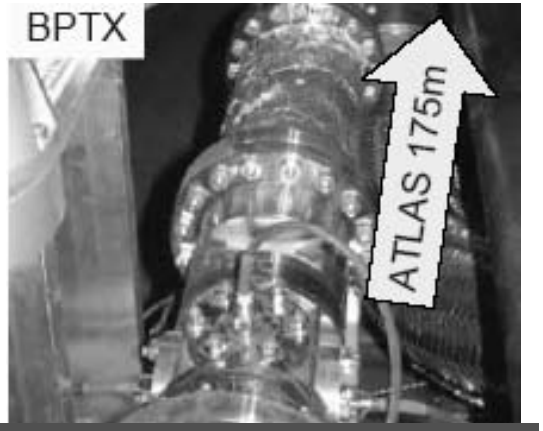
muon central trigger processor interface (μCTPi)

clusters (e/γ and τ/h)

Jet/Energy

Other Detector Components

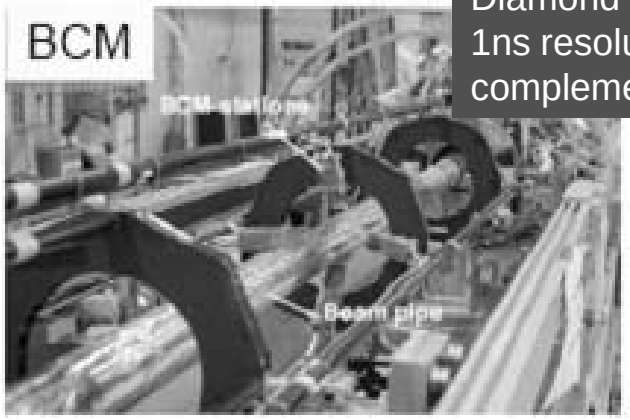
Additional inputs to the CTP



Beam Pickup: at ± 175m from ATLAS
Trigger on filled bunch
Provide the reference timing

Minbias Trigger Scintillator:
32 sectors on LAr cryostat
Main trigger for initial running
η coverage 2.1 to 3.8

Luminosity Monitor
within forward shielding (η~6)
can complement MBTS

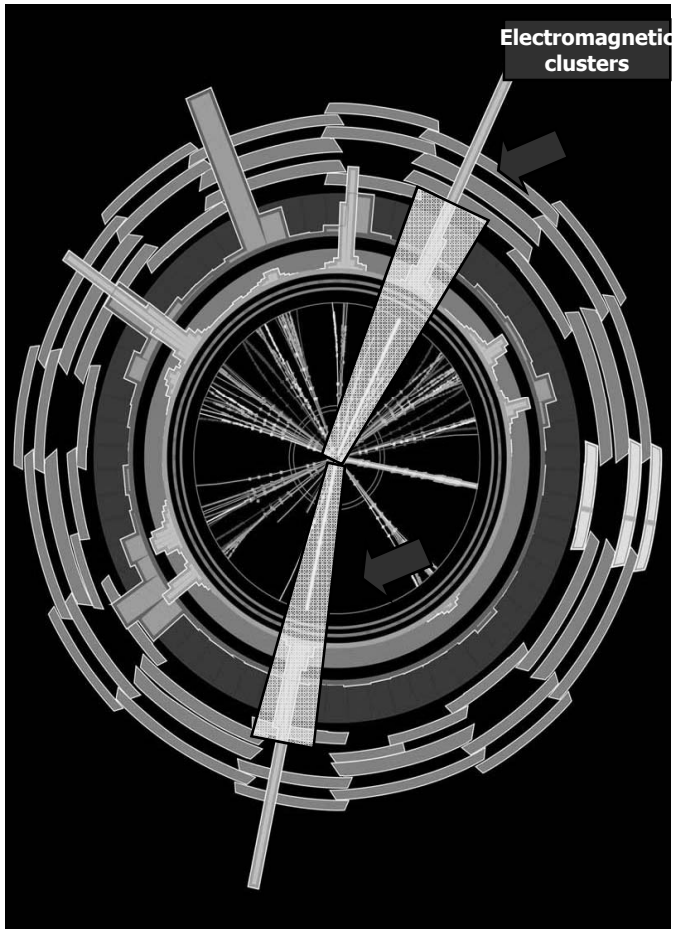


Beam Condition Monitor
Diamond sensors next to Pixel
1ns resolution
complements MBTS

Important role during the LHC early running

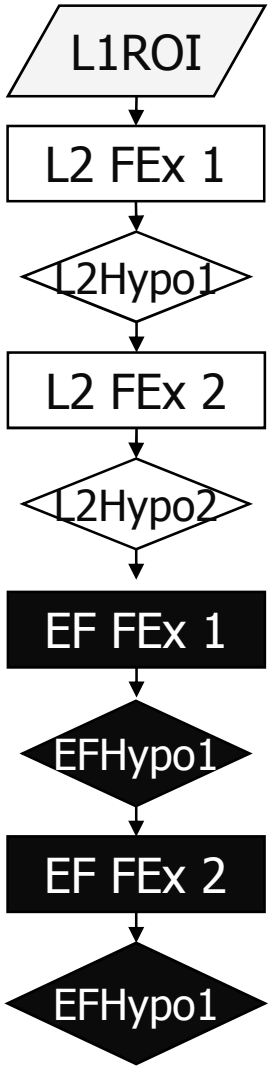
High Level Triggers

- The HLT algorithms are either specific to on-line (L2) or wrap off-line tools (EF)
  - Re-use many elements of the offline software
- Processing is done RoI-wise
  - i.e. HLT algorithms are driven to Region of Interest (RoI) by the framework
  - request and process as little data as possible (~2% of the detector)
- Miniminze CPU usage and bandwidth but add complexity



HLT Algorithms

- Events are processed chain-wise (i.e. at the end we have many decisions)
  - reject events as soon as possible
- Full set of algorithms available for collision running, "slices"
  - Muon, electron, photon, tau, jet, MET, B-physics,Cosmics etc
- Processing is configured and archived in on-line TriggerDB
  - Which keeps menus (HLT chains and L1 items), algorithms properties
- Very extensive studies performed on simulated events
- Rate, efficiency and timing performance consistent with computing resources for initial running



Trigger Menu

- **Tables of trigger items that incorporate the signatures for physics objects at each level**
  - **Each L1/HLT item is a logical combination of one or more of the configured L1/HLT thresholds.**
  - **Include additional triggers for validation, monitoring, calibration and measuring the performance of the physics triggers.**

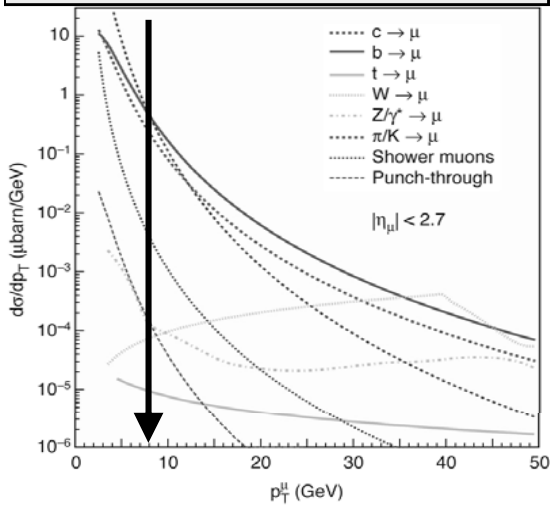
- **Many versions …**
  - **Commissioning and early runnig : Cosmics, Single Beam, first collisions**
    - **Flexible HLT algorithm configuration, adapted for the required selection type**
  - **Physics : Trigger menus defined and studied for $L=10^{31}\ cm^{-2}s^{-1}$ and beyond**
  - **Will evolve with understanding of the trigger and increasing luminosity**

- **… many L1→L2→EF chains**
  - **Sequence of algorithms and hypotheses to test input**
  - **Event passes if at least one chain is successful**
  - **Prescales and special bits (passthrough)**
    - **it can be adjusted to keep the output bandwidth saturated without stopping and restarting a data-taking run**

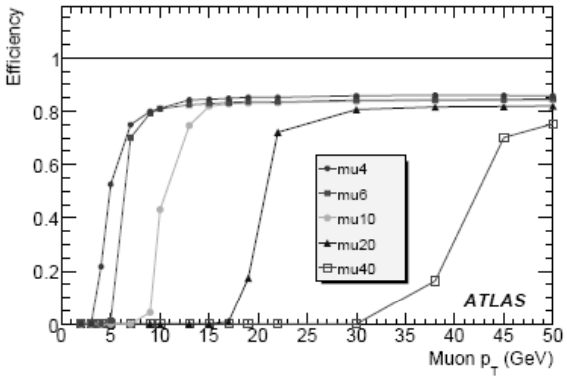
- **Data Streaming to ease offline analysis**
  - **inclusive streaming model whereby raw data events can be streamed to one or more files based on the trigger decision**

Example : Lepton Trigger Selection

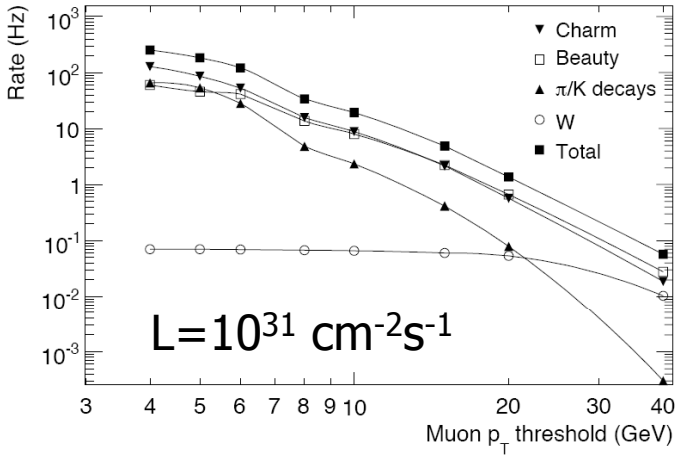
muon inclusive cross sections



High cross sections at low energy → threshold cuts to limit the rates and select interesting physics

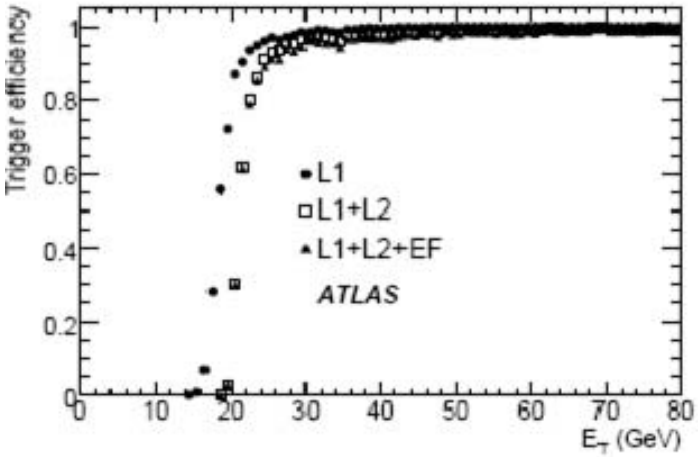


Level-1 muon efficiency
barrel ~ 80%
endcap ~ 94%
Almost exclusively due to geometrical acceptance



MUONS : overall trigger efficiency (L1 + L2 + EF) for different thresholds

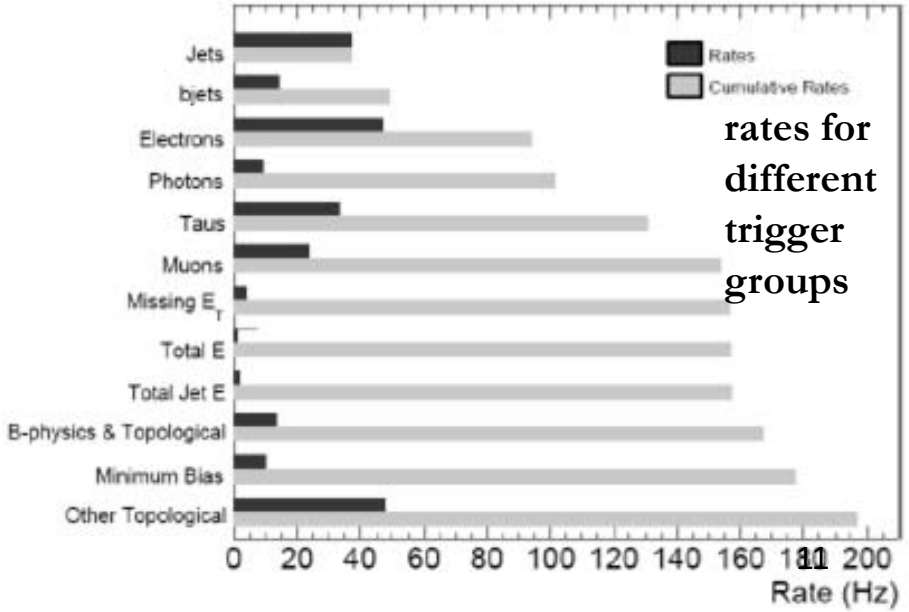
e/γ: e20 electron trigger efficiency wrt offline selection



Trigger Rates at $L=10^{31}\ cm^{-2}\ s^{-1}$

- The initial LHC startup luminosity with a low number of bunches
- → Ideal for commissioning the trigger and detector systems and for the initial data taking, which will be dedicated to high cross section SM signatures.
- Menu with combination of low p_T thresholds and loose selection criteria.
- Triggers at higher selection stages will be operated in pass-through mode wherever possible

Menu
• Contains ~130 Level-1 items and ~180 HLT selection chains
•e/γ and μ triggers mostly unprescaled



rates for different trigger groups

Evolution to higher luminosities

- As the LHC ramps up to its design luminosity, complex trigger signatures with multiple observables, higher p_T thresholds and tighter selections will be deployed
- The trigger and detector will be better understood, the full ATLAS physics programme should be covered by the trigger
- the Trigger software and selection must be robust against high detector occupancies, pile-up effects and cavern backgrounds

Trigger menus will evolve continuously with time to reflect our best knowledge of the physics and the detector

Preliminary rate studies suggest that of the 200 Hz bandwidth

- 30% will be available for electron and photon triggers
- 25% for muon triggers
- 15% for jet triggers
- 15% for taus and /*E T* .
- 5% for *B*-physics

$L = 10^{33}\ cm^{-2}\ s^{-1}$

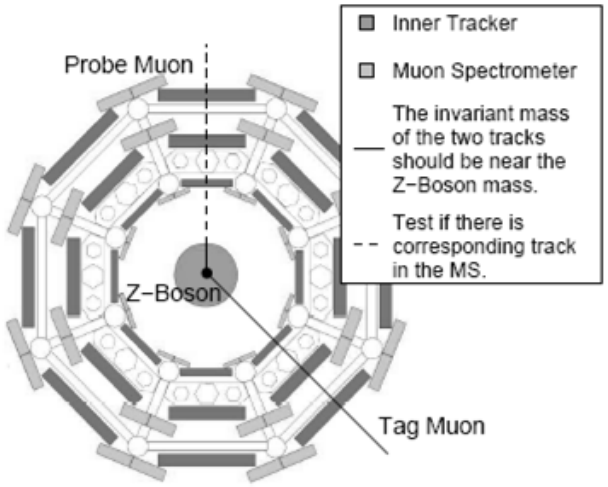
L1 item	Rate (kHz)
EM18I	12.0
2EM11I	4.0
MU20	0.8
2MU6	0.2
J140	0.2
3J60	0.2
4J40	0.2
J36_XE60	0.4
tau16I_XE30	2.0
MU10_EM11I	0.1
Others	5.0

HLT item	Rate (Hz)
e22i	40
2e12i	< 1
g55i	25
2g17i	2
MU20i	40
2MU10	10
J370	10
4J90	10
J65_XE70	20
tau35i_XE45	5
2MU6 for *B*-physics	10

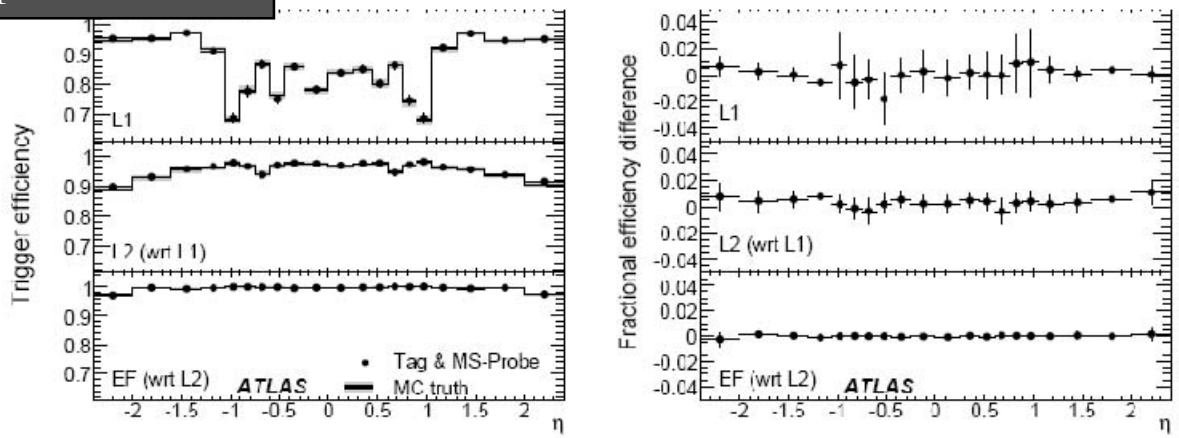
trigger items without prescale fasctors

Trigger Efficiency from data

- For electrons and muons use the "Tag & Probe" method
  - Use clean signal sample (Z, J/ψ → l^+l^-)
  - Select track that triggered the event ("Tag")
  - Find other track using offline criteria ("Probe")
  - Determine efficiency by applying trigger selection on Probe



pT > 20 GeV



$Z \rightarrow \mu^+\mu^-$

Study with ~50 pb^{-1}
Use inner detector (ID-Probe) or muon spectrometer (MS-Probe) as probe system
Overall efficiency (77.4 ± 0.4) %
Very good agreement between Tag&Probe and MC truth (~99%)

The efficiencies determined with the Tag and Probe method are compared to those calculated in a Monte Carlo truth-based analysis.

Commissioning the ATLAS Trigger

- **Different strategies and complexity levels**
  - **relying on LVL1 selection only**
    - **Streams mainly based on L1 trigger type**
  - **HLT menu integrated in stages, running in pass through mode to exercise and validate the algorithms.**
  - **Physics chains + specialized streams for detector studies**
  - **different detector setups**
  - **Magnetic field (toroid and solenoid) ON/OFF**

Different phases :

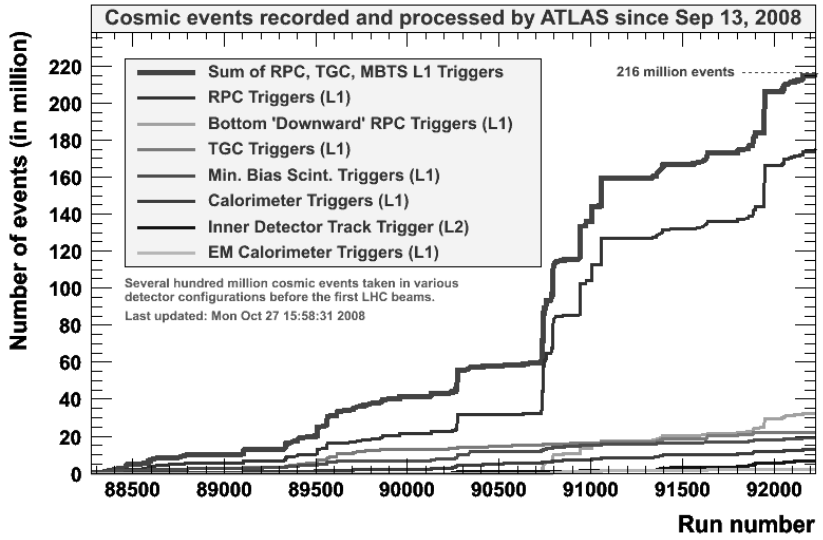
•Standalone 'cosmics' menu to be used in data taking
•L1 : low energy thresholds & muon thresholds with loose coincidences
• HLT cosmic algorithms
•Cosmic-ray selection to enhance purity of data samples for detector studies (ID...)
• efficient for barrel

•Adding simple beam triggers (BPTX/BCM/LUCID/MBTS)
•HLT "HALO" algorithms
•full commssiong of endcaps
•detector timing alignments

Enable higher thresholds in L1 Muon and Calo
Multiobject signatures
Full L2/EF menu (mostly pass through)
Check rates

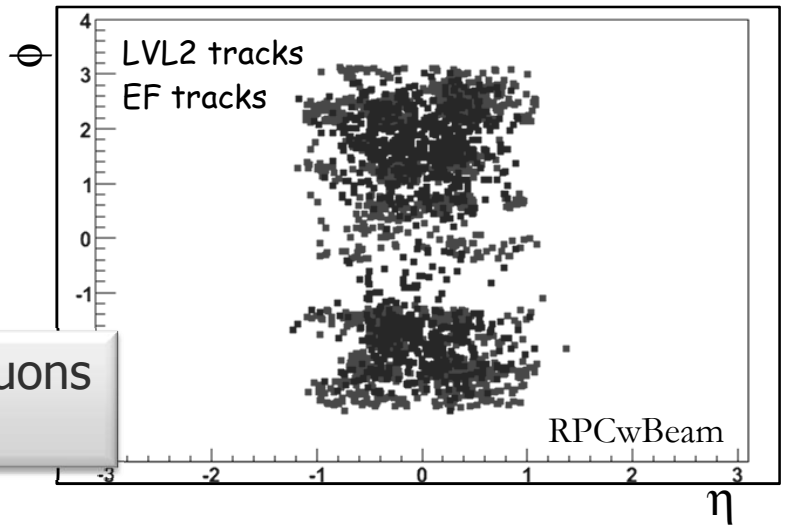
Cosmic Runs

ATLAS Trigger selected milions of events



- HLT is in pass through mode, useful for
  - Test functionalities (selection, algorithms, infrastructure)
  - Validate releases and "beam" algorithms
    - Some problems are rare enough to never show off-line
  - Detector studies

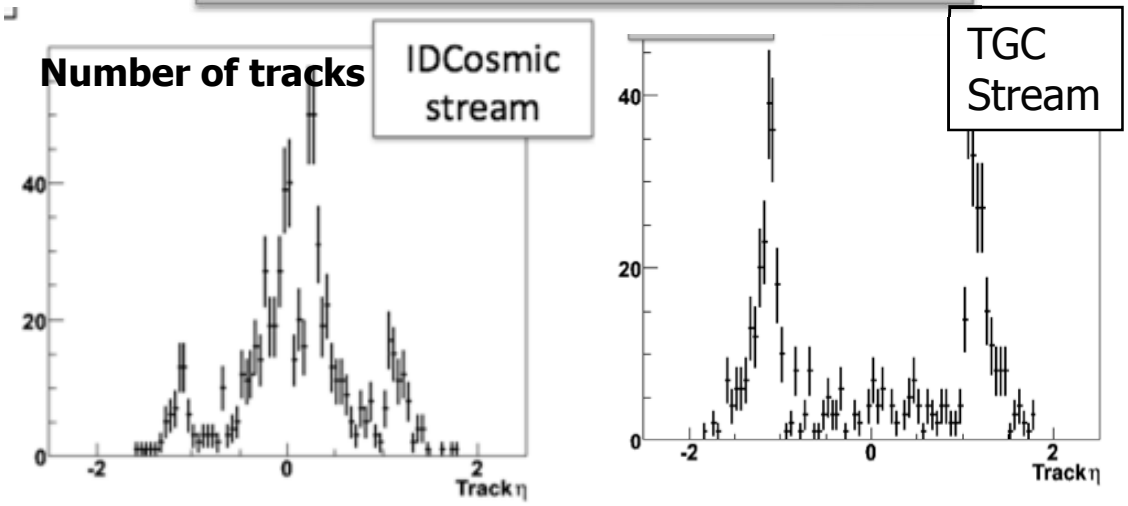
HLT Reconstructed muons in L1 RPC stream

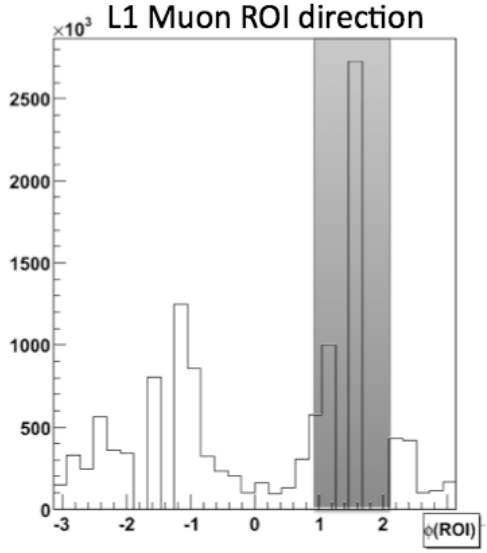


Cosmic Runs

- HLT also flagging events for specific studies, examples:
  - IDCosmic Stream:
    - ID track enriched events
    - Run full ID reconstruction @ L2
    - Accommodate any (TRT, SCT, Pixel) combination with good efficiency
  - Selection to provide samples enriched with pointing muons for timing studies
    - Only bottom half of the cosmic ray has the same timing as beam events
    - Select events @LVL2, based on L1 ROI

ID illuminated by different triggers



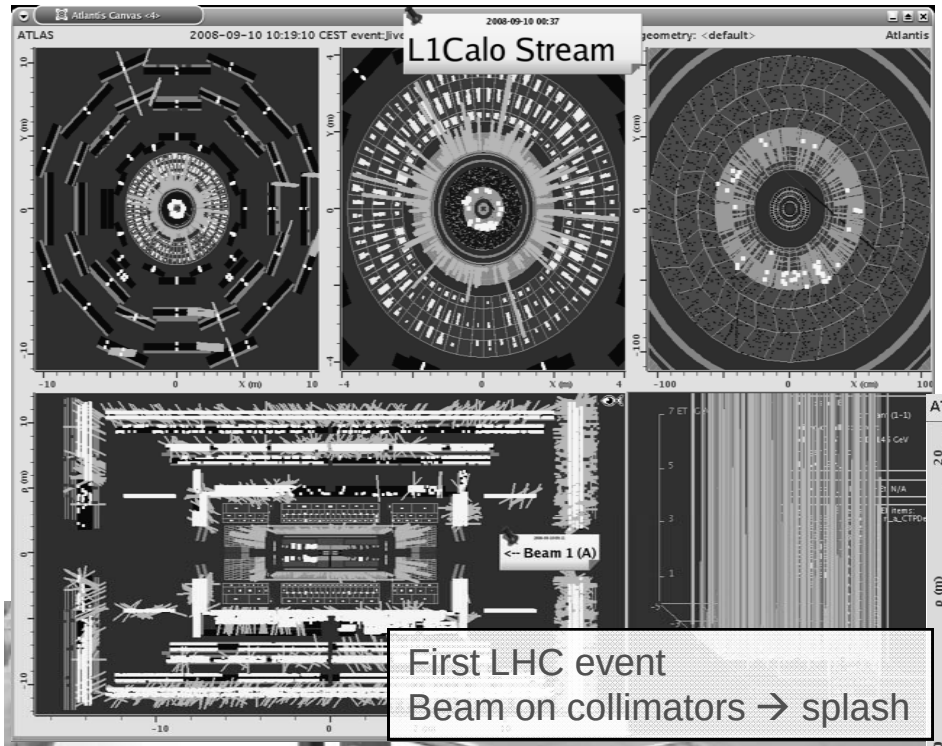


Commissioning during LHC startup

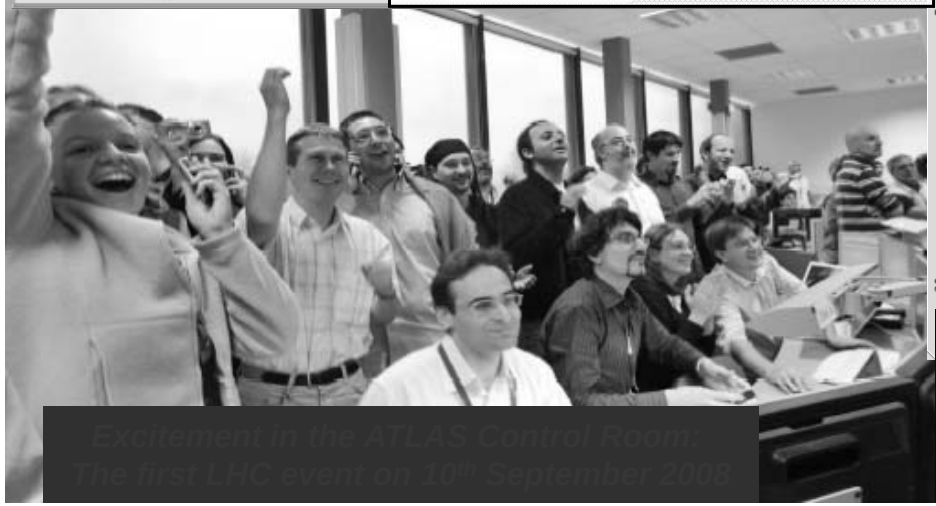
- Many requirements to the trigger
  - Timing-in of detector channels, trigger and DAQ
  - Commissioning of detectors
  - LVL1 trigger and HLT commissioning
  - Provide samples for initial physics studies
  - Provide calibration and alignment samples

- Different LHC beam conditions
  - single beam clockwise/counter-clockwise
  - beam on collimator → splash events
    - exceptionally high multiplicity events
    - L1Calo, MBTS
  - beam through ATLAS
    - one turn/many turns
    - trigger on the beam pick-ups
  - two colliding beams

First experience with LHC single beams

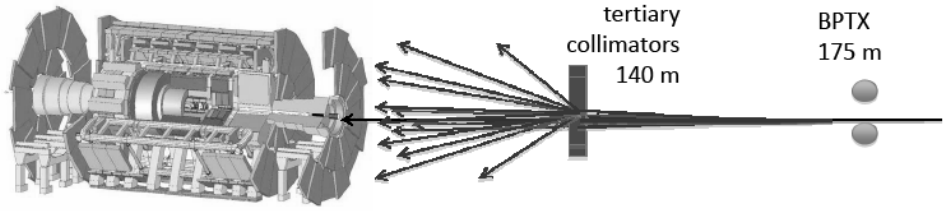


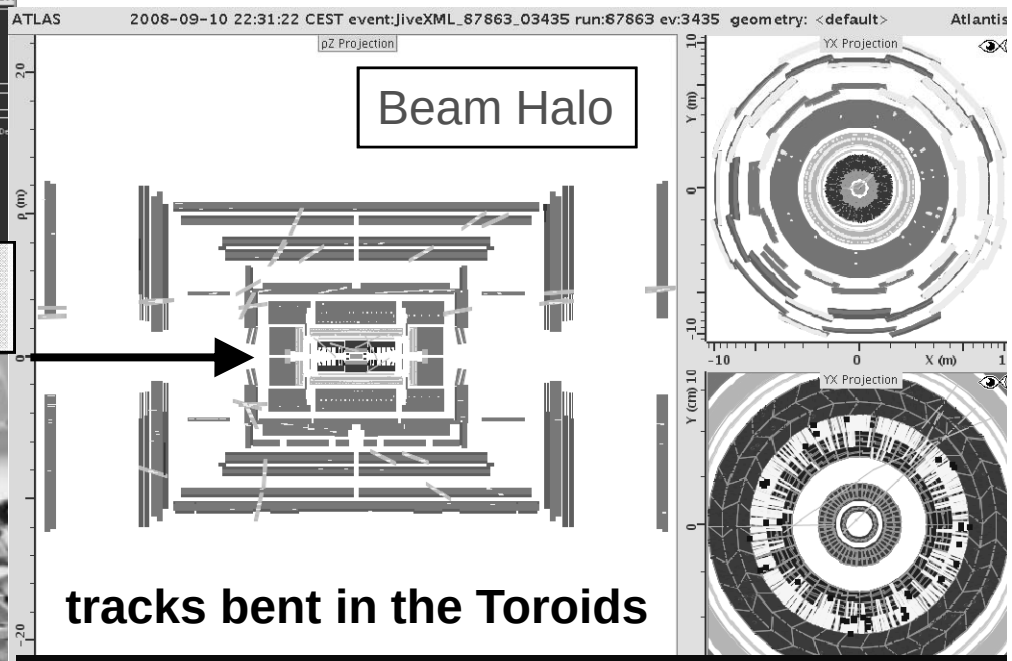
First LHC event
Beam on collimators → splash



Excitement in the ATLAS Control Room: The first LHC event on 10th September 2008

From the LHC start-up day (10 Sep.)

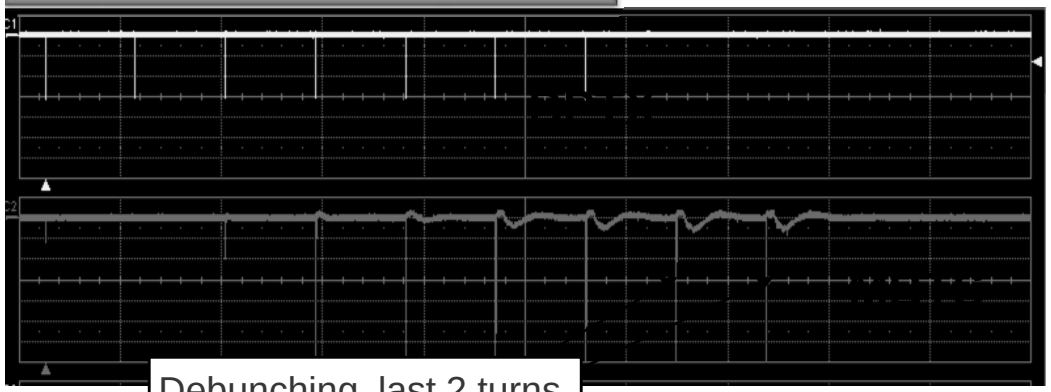




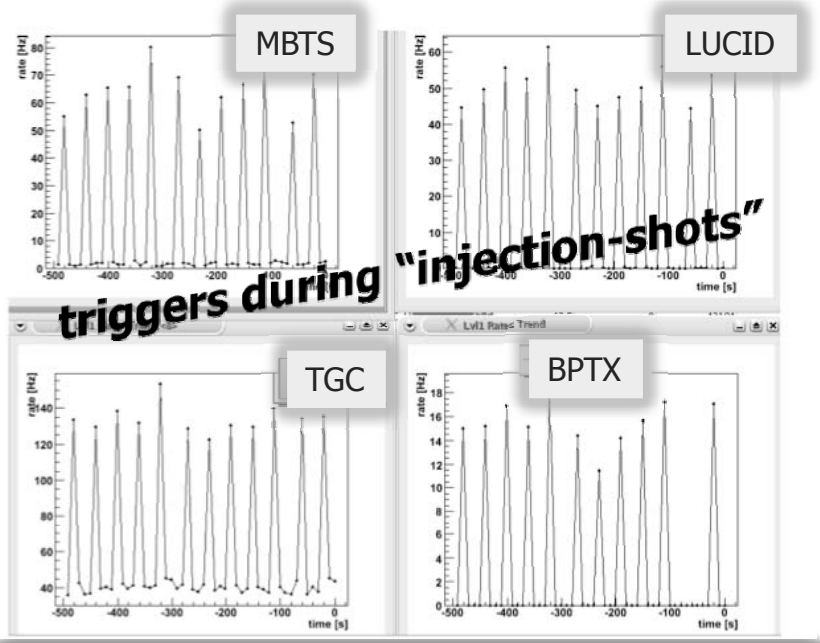
A more readable event collected later (a "halo" event, with the beam passing through the experimental area)

Experience with LHC single beams

Trigger of circulating beam

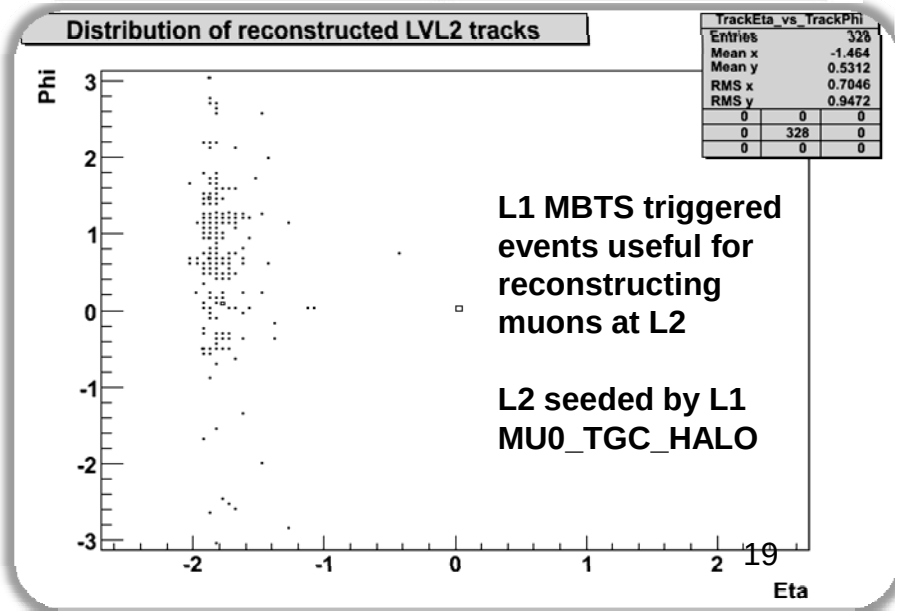


Debunching, last 2 turns seen by MBTS, not any more by BPTX



BPTX defines the time when a bunch is going through the detector.
Adjust delay of each trigger input to be aligned with the trigger that fired the L1A

The High Level Trigger system was not on-line during the single beam period
Raw data were passed, offline, through HLT algorithms in a quasi online fashion



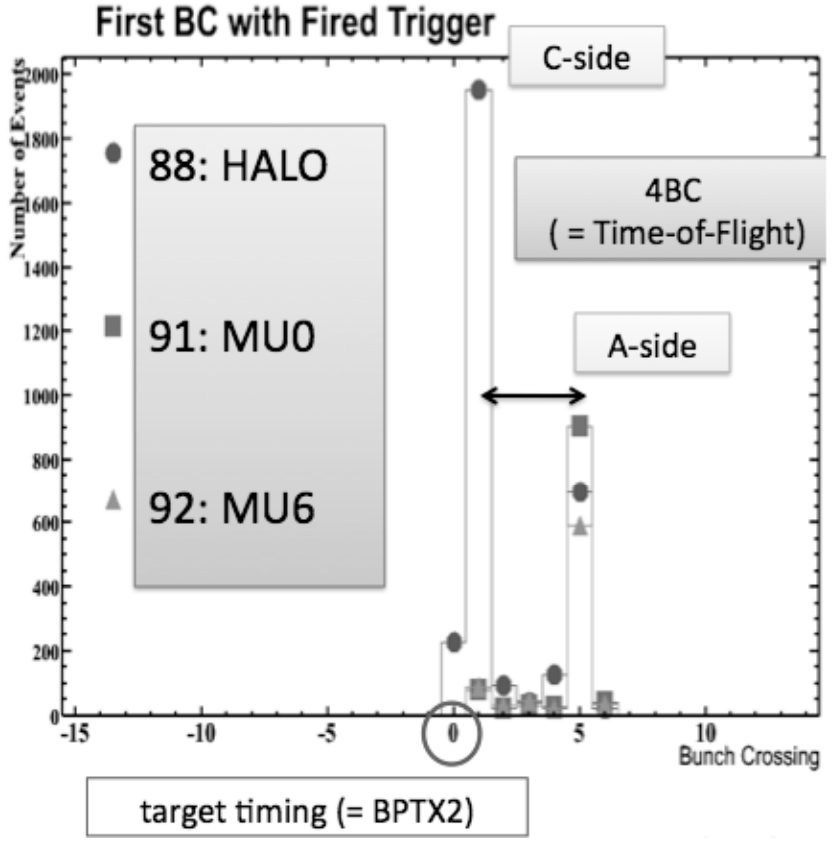
Timing-in the Trigger

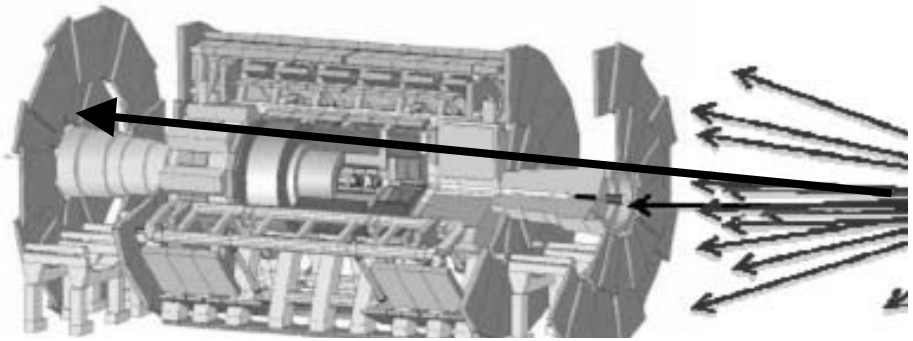
Example of TGCs

- **MU0_TGC_HALO**
  - **2 stations coincidence full Open (maximizing single beam acceptance)**
- **MU0_TGC**
  - **3 stations coincidence full open**
- **MU6_TGC**
  - **3 stations coincidence with road**

- **Beam halo data allow to measure the timing of the trigger wrt BPTX**

- **The difference of the two peaks (4 bc) indicates the TOF of the proton beam between endcaps (~30 m)**





Conclusions

- **The ATLAS Trigger is getting ready to face LHC data**
- **Trigger menus**
  - **Trigger menus defined and studied for cosmics, single beams, L = 10^{31} and beyond**
  - **Will be adjusted as soon as we get first collisions**
- **LVL1 and HLT selection studied in detail on both simulated and real data (cosmics)**
- **Preparation for online running is being assessed: for example methods to determine trigger efficiency from data are available**
- **Commissioning of the ATLAS trigger**
  - **Selection and rates controlled by Level-1 prescales until HLT algorithms under control**
  - **High-Level Trigger algorithms took part in cosmics test runs**
  - **A complete physics strategy has been developed for early running and is ongoing for higher luminosities**