Improvement of the ATLAS Muon Trigger for HL-LHC Using the Muon Drift Tube Chambers

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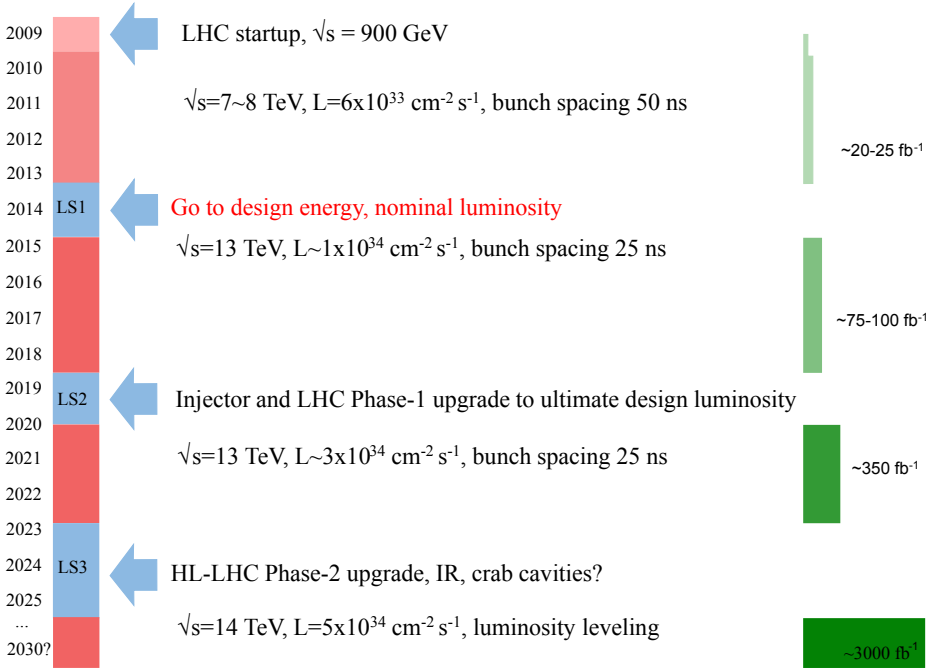
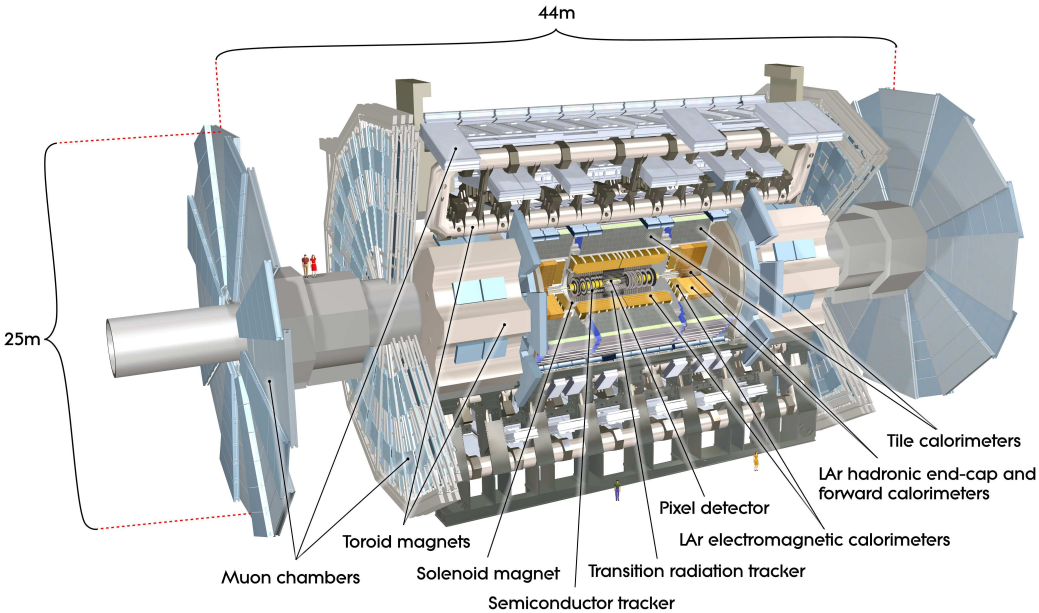
LHC Timeline

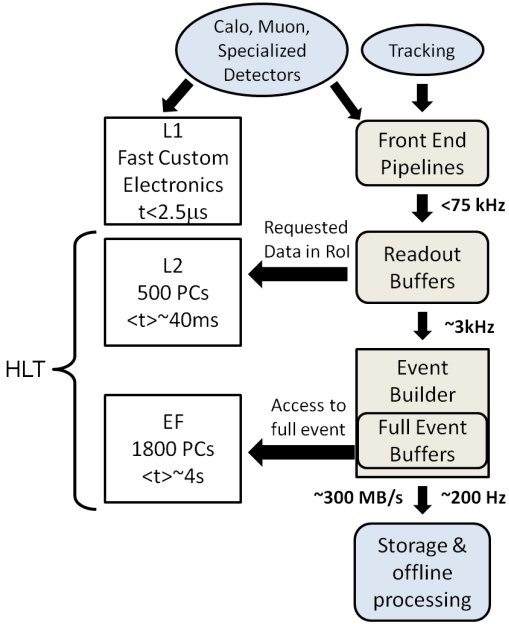


The ATLAS Detector



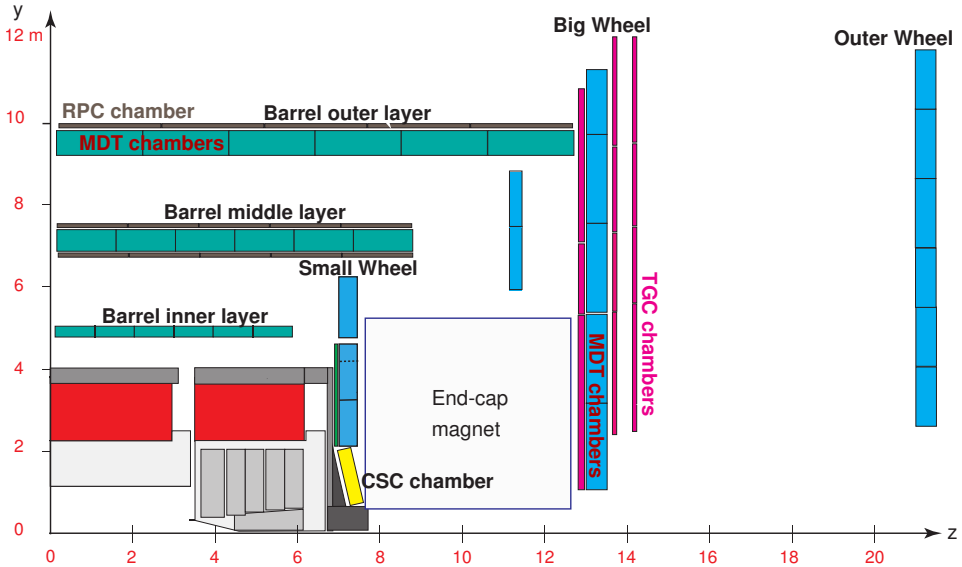
Overview Trigger System

Selection of rare events out of extremely high background → Realized in a multi level trigger



- Level 1 (L1):
  muon and calorimeter signals used to define "Regions of Interest" (RoI)
- Level 2 (L2):
  L1 candidates used to find physics objects (e, γ, μ, jets, ...) with reduced event information within RoI
- Event Filter (EF):
  full event information, fast data analysis, storage after filtering

The present ATLAS Muon Spectrometer

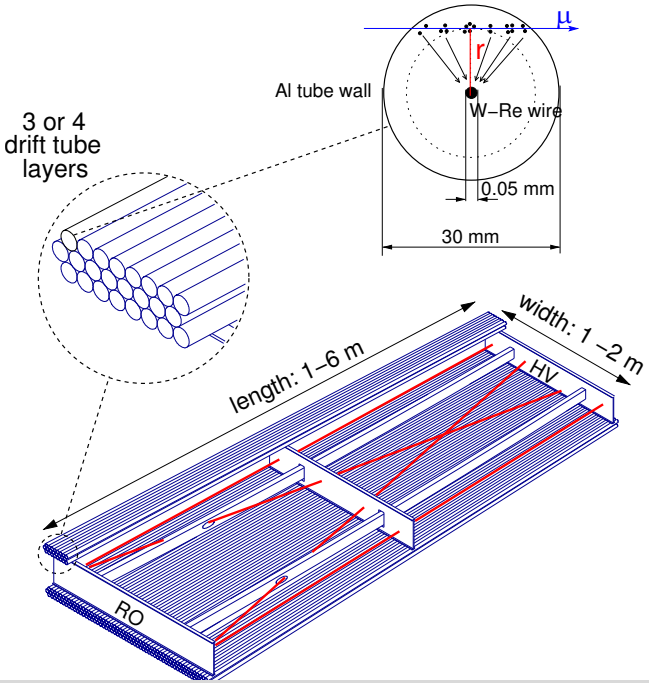


Spatial resolution:

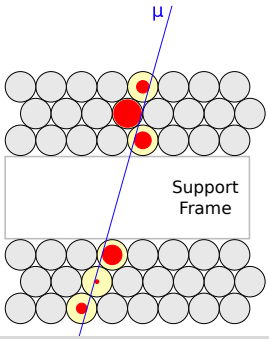
Monitored Drift Tube chamber: $\sim 40\ \mu m$

Trigger chamber (Resistive Plate and Thin Gap Chamber) : ~ 3 cm

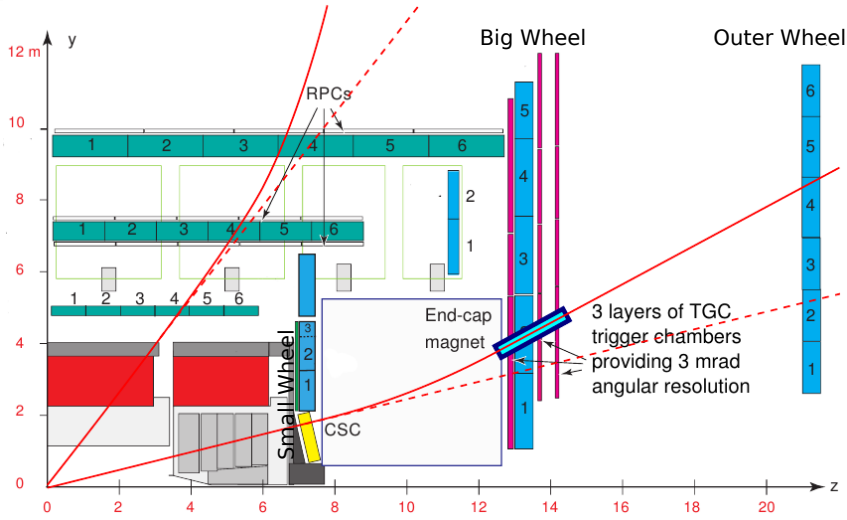
The ATLAS MDT chambers



- Gas mixture: Ar/CO_2 $(93/7)$
- 3 bar absolute pressure
- Max. drift time: $\approx 700ns$
- Single tube resolution: $80\mu m$
- Wire positioning accuracy: $\approx 20\mu m$
- Chamber tracking resolution: $\approx 40\mu m$



Current Level-1 end-cap muon trigger



- Muon momentum measurement from slope of the muon track in the Big Wheel assuming the muons emerging from the nominal beam spot

Level-1 trigger scheme for HL-LHC (MDT based)

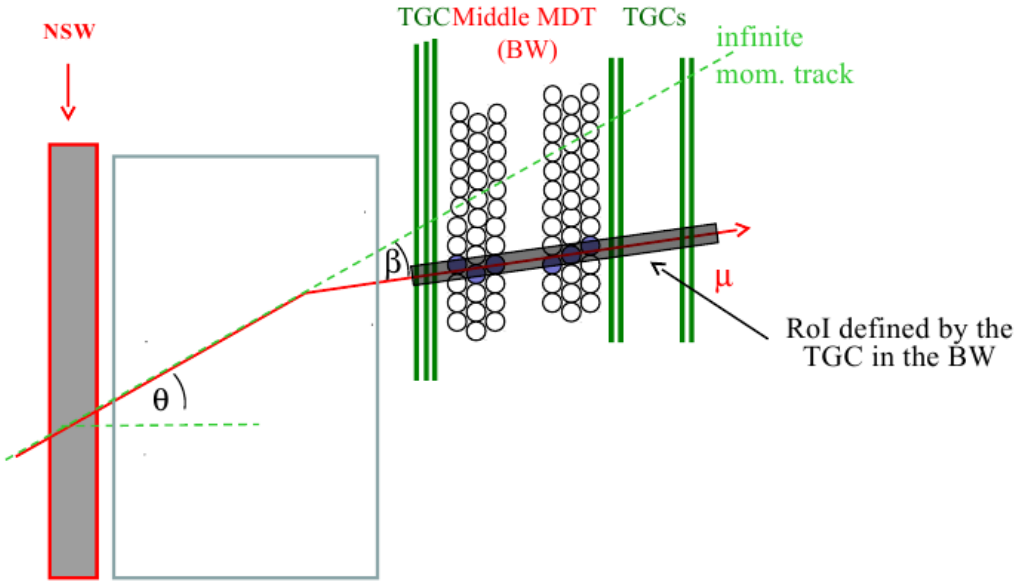
- Use direction measurement of the New Small Wheel and the Big Wheel to measure the deflection of the muon trajectory in the end-cap toroid

$\Rightarrow$ NSW (Phase I): $\sim$50% Level-1 trigger rate reduction

$\Rightarrow$ MDT in trigger: Additional rate reduction of $\sim$ 50% (20 GeV threshold)

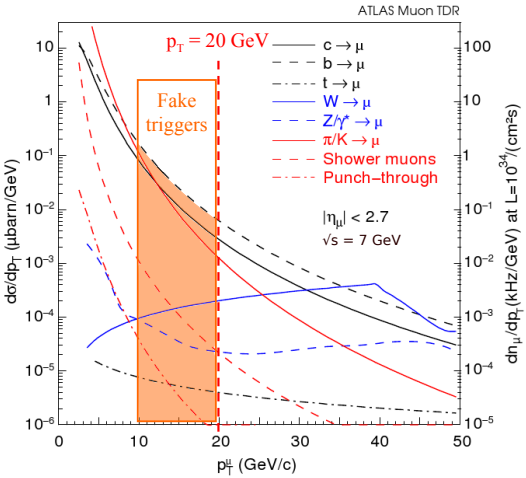
- $\sim$ 10% MDT occupancy in Big Wheel due to expected background

Trigger scheme for HL-LHC (MDT based)

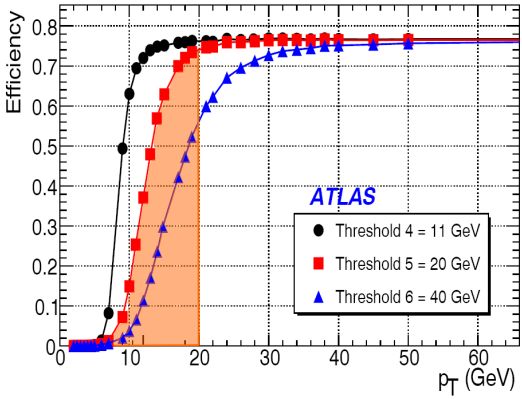


Performance of the present ATLAS Level-1 muon trigger

Inclusive muon cross section



Muon Level-1 trigger efficiencies

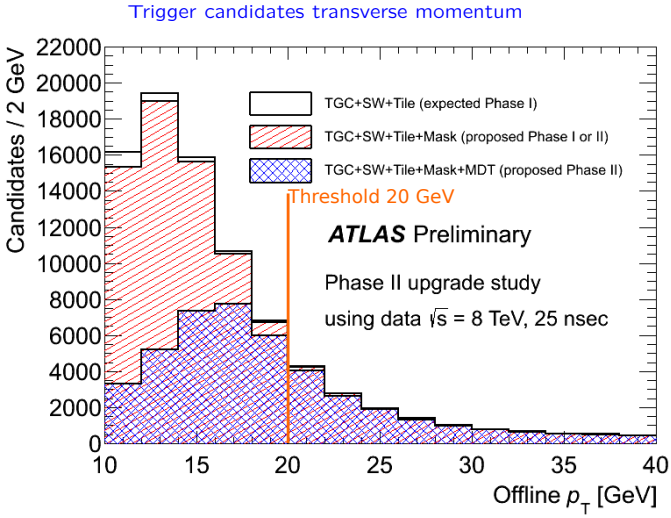


- Steepness of the Level-1 trigger turn-on limited by the spatial resolution/granularity of the trigger chambers ($\sim$ 3 cm)

$\Rightarrow$ Single muon Level-1 trigger rate dominated by muons with p_{T} below the threshold

- Upgrade task: “Sharpening” of the Level-1 threshold

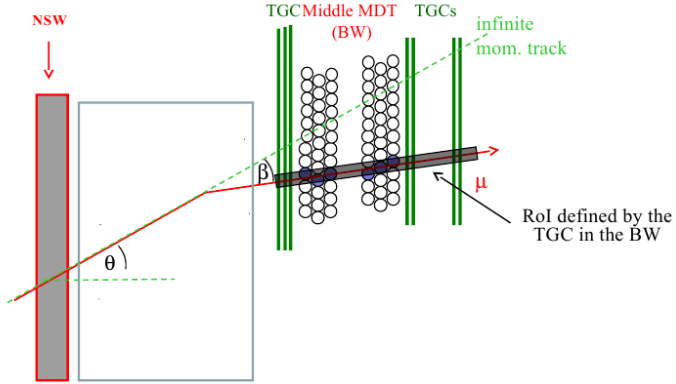
Muon trigger candidates in the end-cap from real data



- White: All trigger candidates
- Red: High quality trigger candidates
- Blue: Additional MDT based trigger requirements

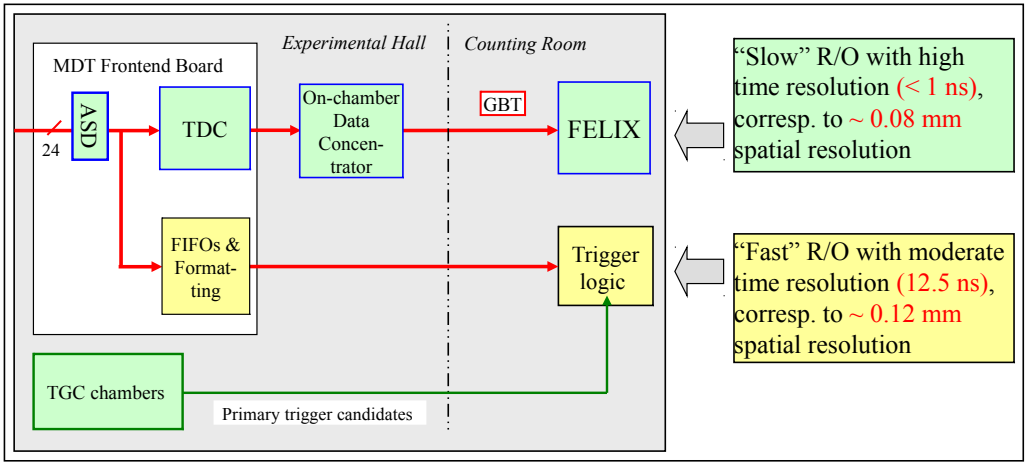
Based on data taken with ATLAS in 2012
Event selection: Level-1 muon trigger with 20 GeV transverse momentum threshold

Basic concept of an MDT-based Level-1 trigger



- TGC trigger chambers provide:
  - Bunch crossing identification
  - Region of interest (ROI)
  - Slope of the muon track in the Big Wheel with 3 mrad resolution
- Fast track reconstruction from the MDT hits in the ROI
  $\rightarrow$ resulting in < 1 mrad angular resolution
- Confirmation or rejection of the TGC trigger candidate

Technical implementation



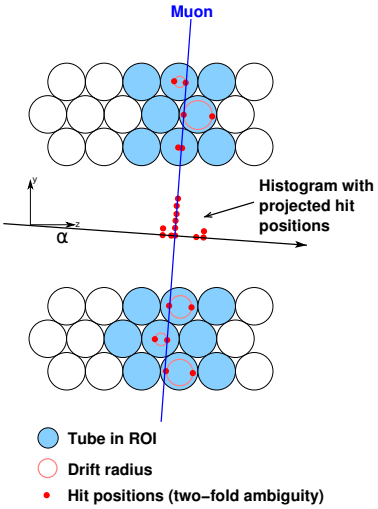
ASD: Amplifier Shaper Discriminator → Analog read-out chip
TDC: Time to Digital Converter → Drift time measurement
GBT: Gigabit Transceiver → Optical link
FELIX: Front-End Link Interface eXchange → Interface to data processing

Two parallel read-out paths for precision tracking and contribution to the trigger decision

Available Level-1 latency: 30μs

Fast track reconstruction of MDT hits for trigger confirmation

Histogram based pattern recognition and track reconstruction



- Use ROI as starting point of pattern recognition
- Incident angle α is known from trigger chambers (with 3 mrad resolution)
- Project hits into the plane perpendicular to the trigger chamber track
- The highest peak in the histogram corresponds to the triggering track discarding hits due the left-right ambiguity
- Straight line fitted to points in the histogram peak

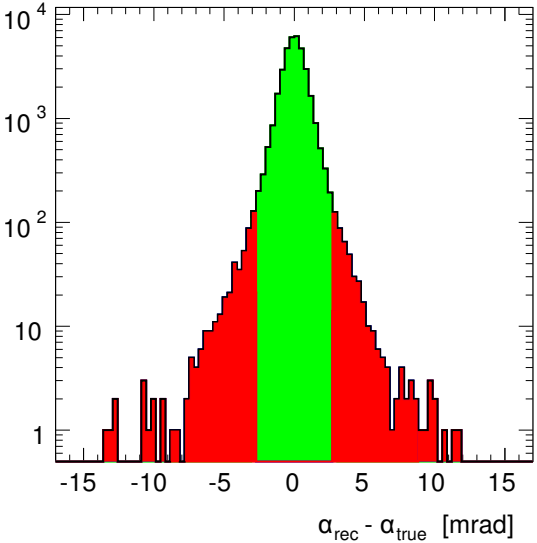
Loss of hits due δ-rays and background hits resulting in different hit quality

χ^2 per degrees of freedom of the reconstructed track $\rightarrow$ measure of fit quality

Performance of the algorithm in simulated data

- Simulation with single muons and uncorrelated background
- Quality of reconstructed tracks defined by the deviation of the reconstructed slope (α_{rec}) from the true one (α_{true})

Occupancy due to uncorrelated background: 10%



Defining two categories:

- Good: $|\alpha_{rec} - \alpha_{true}| < 3$ mrad
- Poor: $|\alpha_{rec} - \alpha_{true}| \geq 3$ mrad

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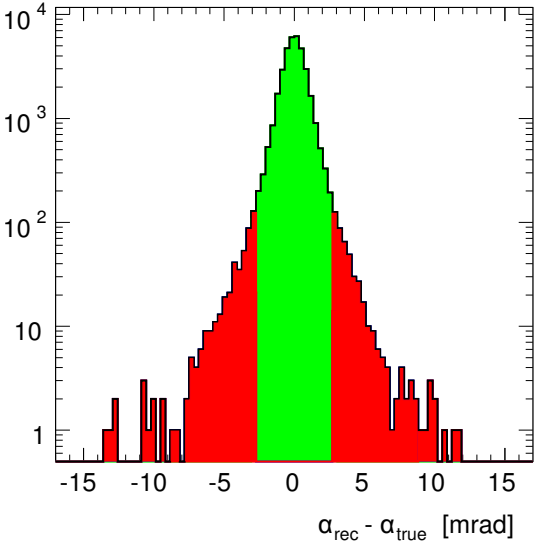


Defining two categories:

- Good: $|\alpha_{rec} - \alpha_{true}| < 3$ mrad
- Poor: $|\alpha_{rec} - \alpha_{true}| \geq 3$ mrad

	fraction of generated tracks	
	without χ^2-cut	with χ^2-cut
Good	95.7%	90.1%
Poor	2.5%	0.94%

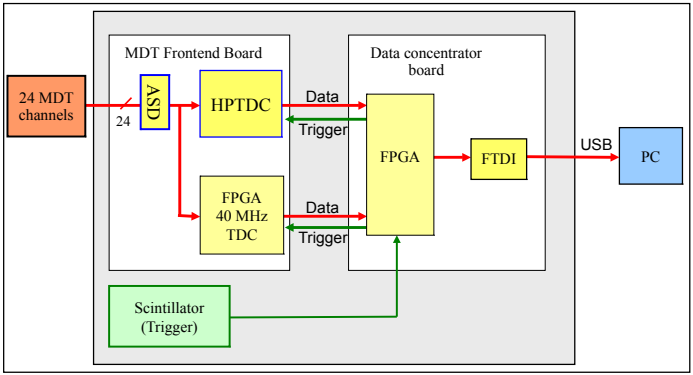
- If no track fulfilling all requirements can be reconstructed → confirm the primary trigger (prevent loss of high p_{T} muons)

Hardware demonstrator

Hardware demonstrator

Goals

- Demonstrate feasibility of additional fast read-out path
- Study resolution and efficiency of fast tracking algorithm with real data



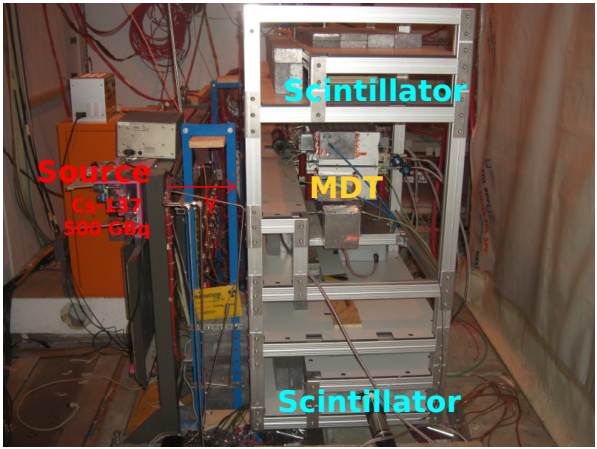
ASD: Amplifier Shaper Discriminator
→ Analog read-out chip

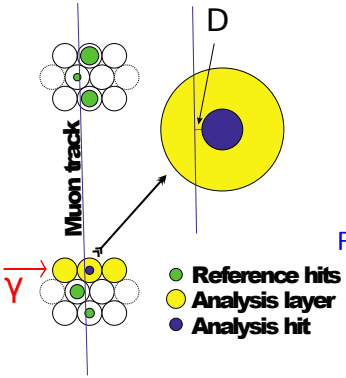
HPTDC: High Performance Time to Digital Converter (CERN)

FTDI: USB interface

Test of hardware demonstrator with cosmic muons

CERN Gamma Irradiation Facility (GIF) - 2013/2014

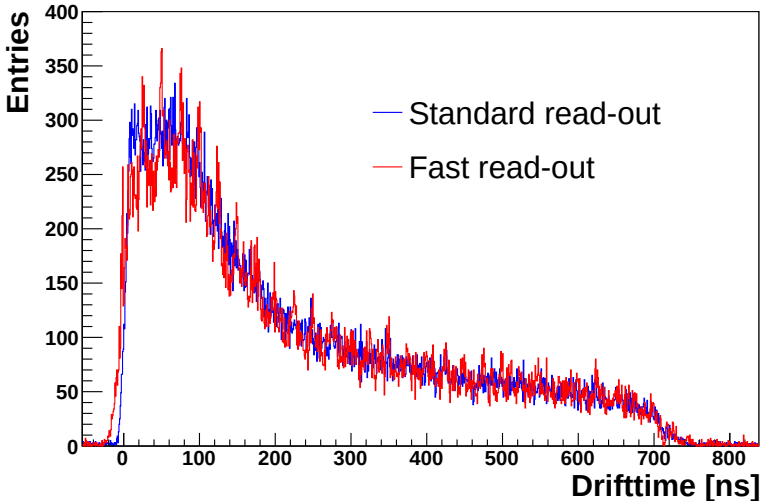




Resolution:

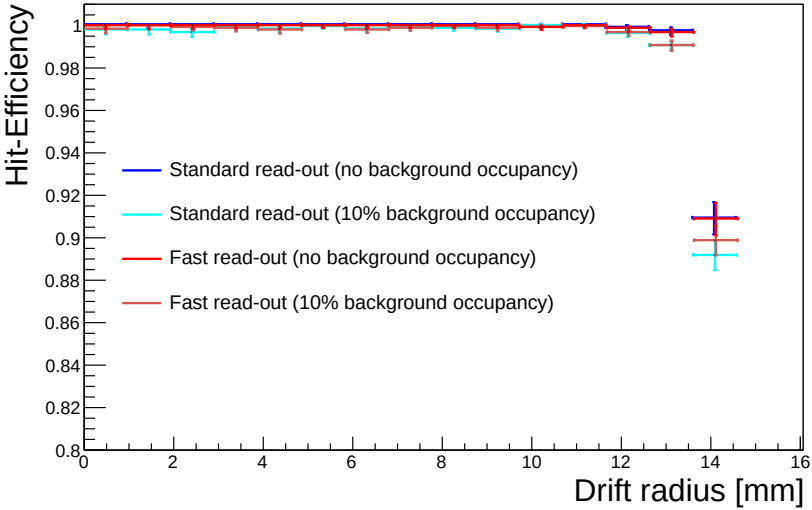
- Use 5 out of 6 layers for track fitting
- Use distance between track and hit as basis for resolution determination

Comparison of drift time spectra



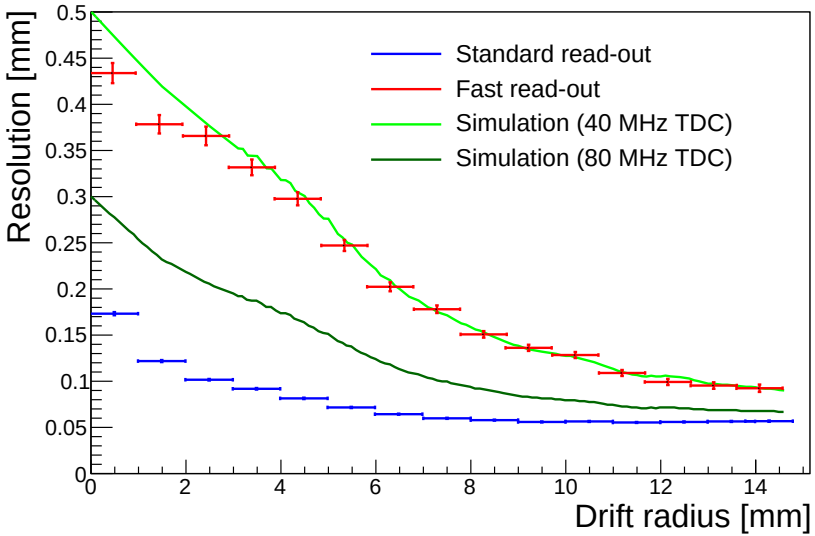
- Fast read-out shows expected behavior

Efficiency of new fast read-out



- Fast read-out shows expected hit efficiency
- Hit efficiency is independent of background occupancy

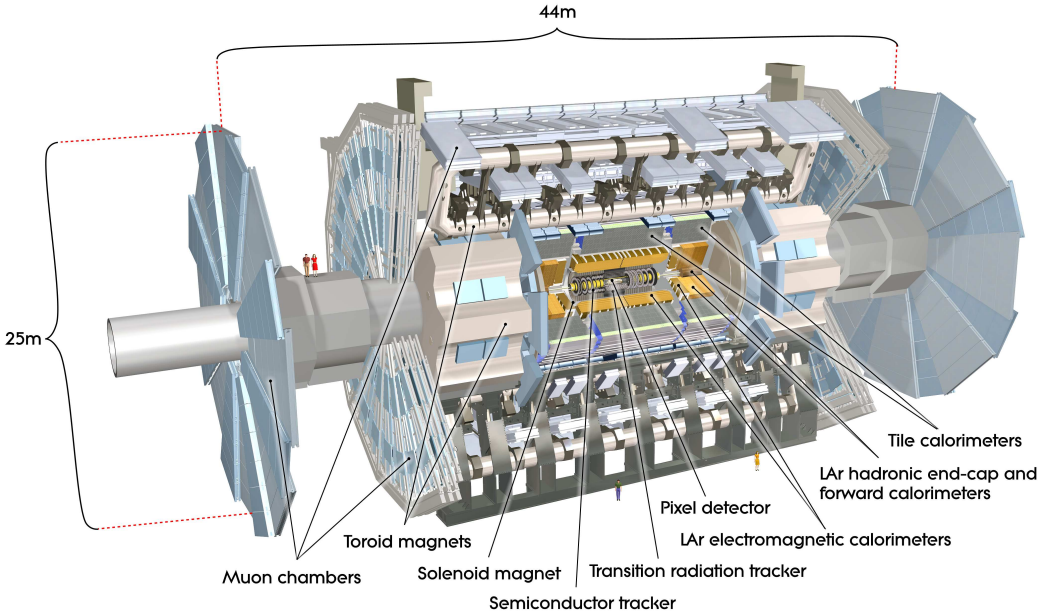
Resolution of new fast read-out



- Fast read-out shows expected resolution

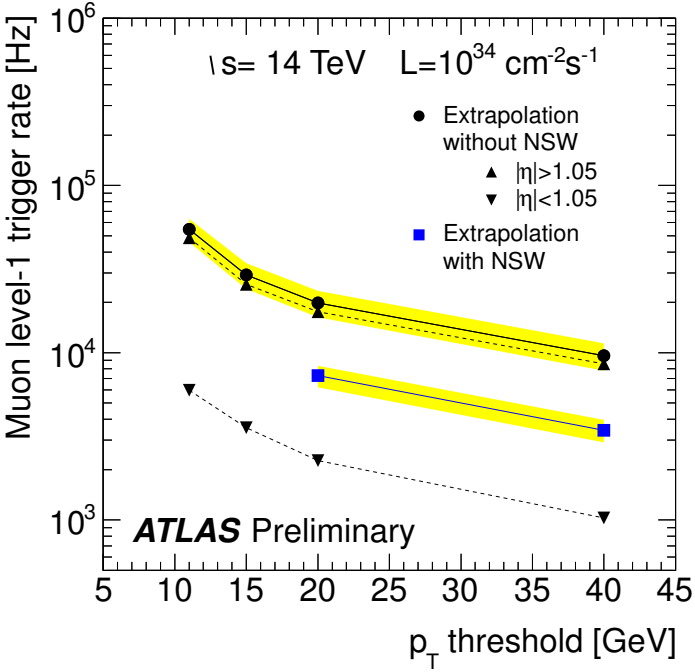
Summary

- The implementation of a more selective Level-1 muon trigger for HL-LHC using the precision Muon Drift Tube (MDT) chambers has been studied
- Simulation shows reduction of the ATLAS Level-1 trigger rate below the nominal 20 GeV threshold by a factor of 2 without loss of efficiency
- Demonstrator setup of additional fast MDT read-out showed expected resolution and efficiency


44m
25m
Tile calorimeters
LAr hadronic end-cap and
forward calorimeters
Pixel detector
LAr electromagnetic calorimeters
Toroid magnets
Muon chambers
Solenoid magnet
Transition radiation tracker
Semiconductor tracker

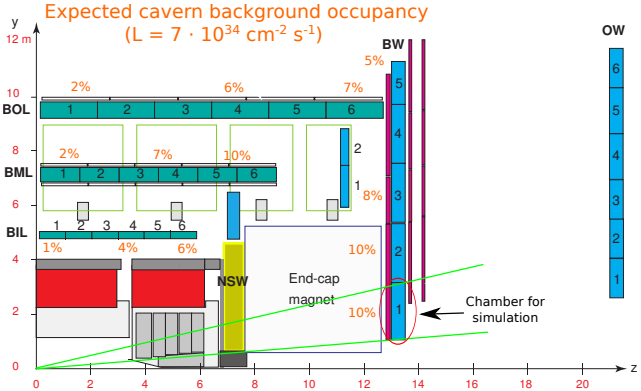
Backup

Level-1 muon trigger rate extrapolation to 14 TeV



Simulation studies of the fast track reconstruction

Operating conditions



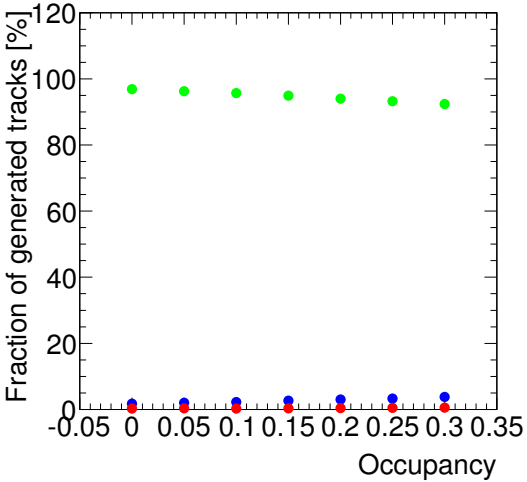
- The muon spectrometer is operated within a high background of thermal neutrons and gamma radiation
- This background is the main difficulty at HL-LHC
- $\sim 10\%$ occupancy in the MDT chambers of the middle layer

Parameters of the simulation studies

- Dead time in MDT electronics: 200 ns
- Read-out TDC time resolution: 12.5 ns (80 MHz clock)
- Occupancies: 0-10%, δ electrons present
- TGC angular resolution: 3 mrad
- Bin width: 2 mm
- Number of hits in peaks ≥ 4

Quality category fractions versus occupancy

- Quantify the track quality as the fraction of generated tracks to which a track of a given category is reconstructed.

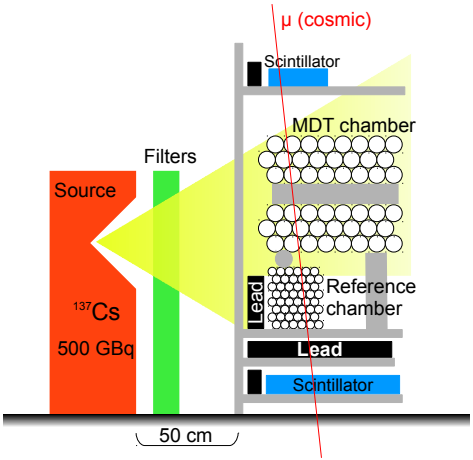


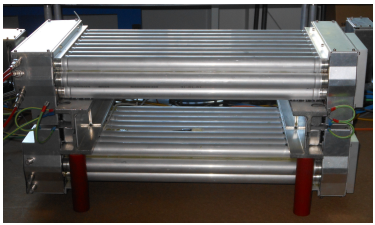
- "Good": More than 90% of the generated tracks are reconstructed with required accuracy of 1 mrad for occupancies up to 30%
- "Like L0": $\sim 2\%$ of the generated tracks are reconstructed with a slope accuracy that provide a moderate or no improvement to the TGC precision
- "Poor:" $\ll 1\%$ of the generated tracks is poorly reconstructed

Test of new hardware and fast tracking algorithm

CERN Gamma Irradiation Facility (GIF) - 2013/2014

Goal: Measurement of efficiency and resolution





MDT chamber used for test
6 tube layers, 50 cm length

- No muon beam in the GIF $\rightarrow$ use cosmic muons
- Fast read-out and normal read-out are triggered by scintillators
- Angle seed according to reference chamber: 4.7 mrad

Full prototype