TileCal Trigger Towers studies considering additional segmentation on the ATLAS upgrade for the high luminosity LHC

L. March on behalf of the ATLAS Tile Calorimeter System

IFIC (University of Valencia - CSIC)

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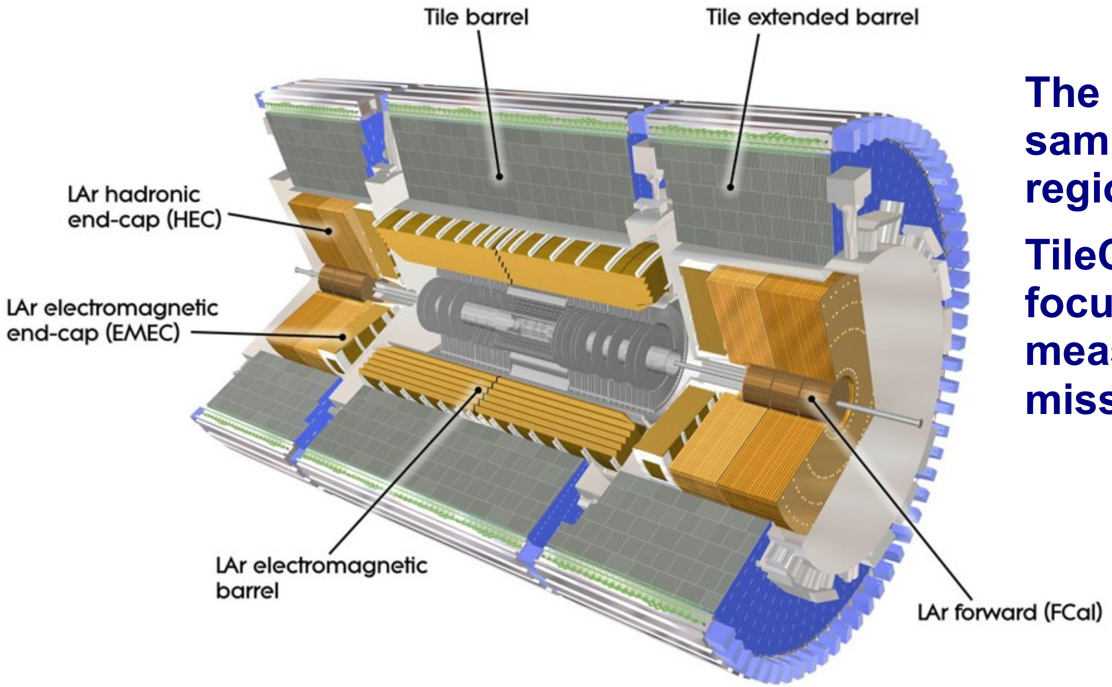
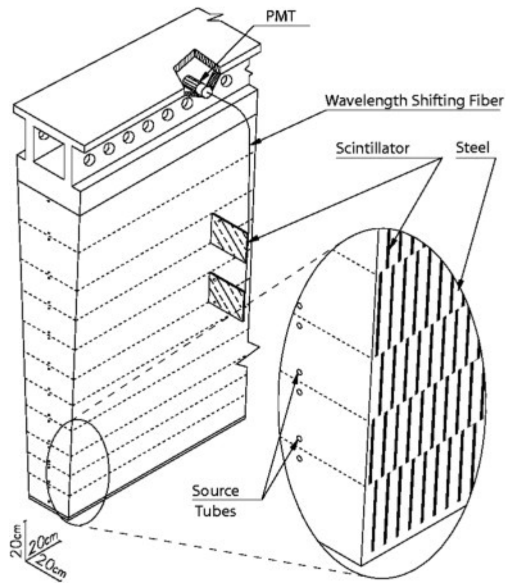
ATLAS hadronic Tile Calorimeter (TileCal)



The Tile Calorimeter (TileCal) is the hadronic sampling calorimeter covering most central region of the ATLAS detector at LHC.

TileCal (with the ATLAS EM Calorimeter) focuses on precise energy and position measurements of hadrons, jets, taus and missing transverse energy (E_T^{miss}).

	Channels	Cells	Trigger Outputs
Long barrel	5760	2880	1152
Extended barrel	3564	1790	768
Gap and crack	480	480	128
MBTS	32	32	32
Total	9836	5182	2080



Absorber: Iron plates & active medium: plastic scintillator tiles

$|\eta|<1.7$: Tile (long) barrel ($|\eta|<1.0$) and extended barrel ($0.8<|\eta|<1.7$)

Designed energy resolution for jets: $\frac{\Delta E}{E} = \frac{50\%}{\sqrt{E(GeV)}} \oplus 3\%$

Segmented into 64 modules in ϕ: $\Delta\phi \sim 0.1$ rad

Each module is segmented into 3 longitudinal layers

The ϕ, η and radial segmentation define the 3D TileCal cells

2 PMTs per cell and 2 gains per PMT

TileCal Trigger Tower geometry

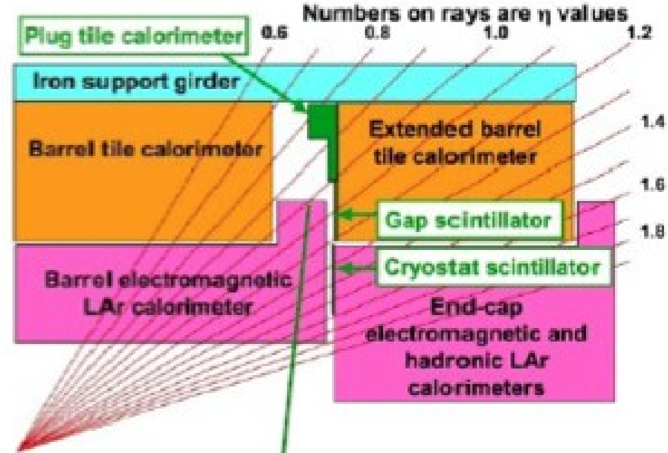
The trigger signal corresponding to a "tower" of cells with ΔηxΔΦ = 0.1x0.1 is formed by an analogue sum of the input signals and are sent via long cables to the Level-1 (L1) calorimeter trigger system to identify jets, taus, total calorimeter energy and E_T^{miss} signatures.

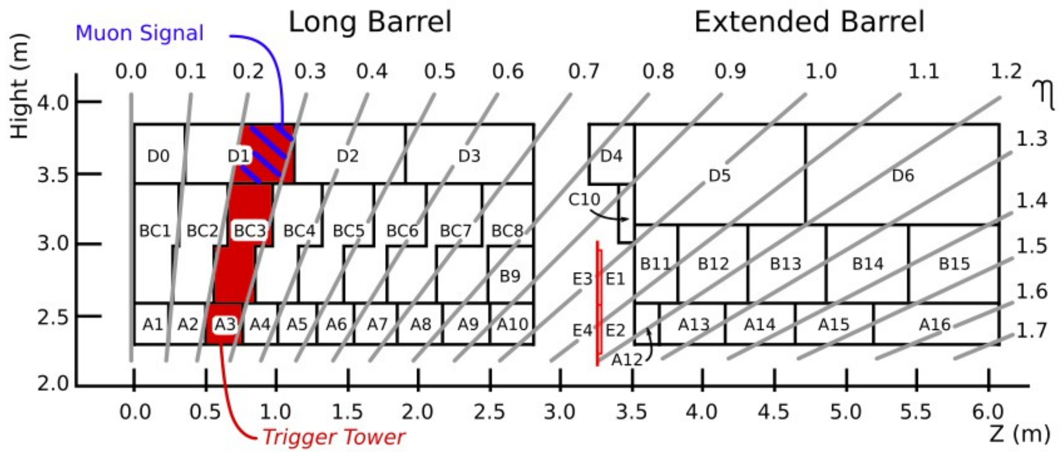
The L1 trigger is fully implemented in hardware and receives information from the muon chambers and the calorimeters with a coarse granularity.

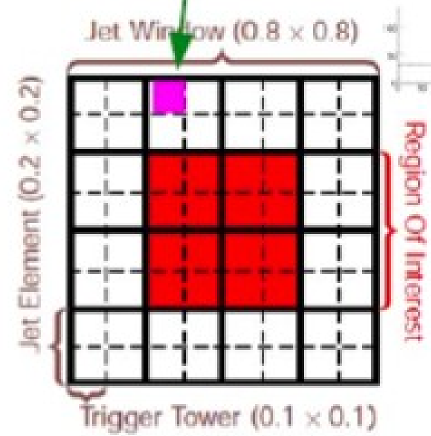
There are ~2000 TileCal Trigger Tower (TT) signals.

L1 is responsible for selecting Regions of Interest (RoI) to be used by next level of triggers.

A second output, so-called muon output, that can be added at a later stage to reduce the muon background rates, contains only the signal from cells of the outermost calorimeter layer.







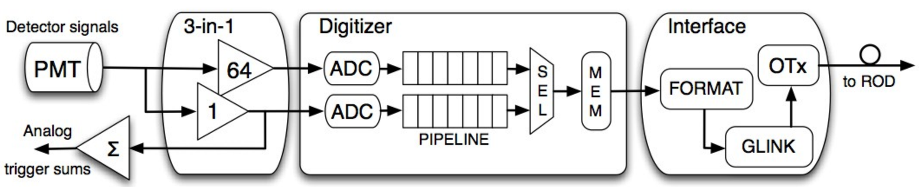
Window of 8x8 jet towers for L1 jet trigger

LHC and TileCal upgrades

- **The LHC upgrade program is divided into 3 phases:**
  - **Phase-0: Long Shutdown 1 (LS1, on-going 2013-2014) → peak luminosity: 10^{34} cm^2s^{-1}**
  - **Phase-1: LS2 (2018-2019) → peak luminosity: 2-3 10^{34} cm^2s^{-1} (pile-up: <μ>~55-80, 25 ns bunch spacing)**
  - **Phase-2: LS3 (foreseen 2022-2023) → peak luminosity: ~ 10^{35} cm^2s^{-1} (<μ> up to ~200)**

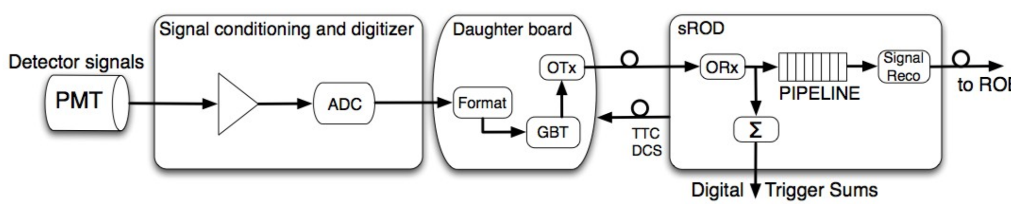
- **The ATLAS TileCal upgrade program at phase-1:**
  - **Energy measurements can assist in rejecting muon background rates coming from non-collision particles**
  - **Current TT energy precision can be better: Least Significant Bit (LSB) from 1024 to 512 or 256 MeV**
  - **Improve jet energy resolution comparing with the current system reconstruction**

- **The ATLAS TileCal upgrade program at phase-2:**
  - **Electronics upgrade: digitize all the calorimeter signals at 25 ns (LHC bunch crossing)**
  - **The trigger will profit from the full radial granularity and resolution of the detector to deal with pile-up**



Current TileCal front-end electronics

LSB = 1024 MeV → Analogue TT energy precision



Upgraded TileCal front-end electronics

LSB = Digital cell energy precision (~ 20 MeV)

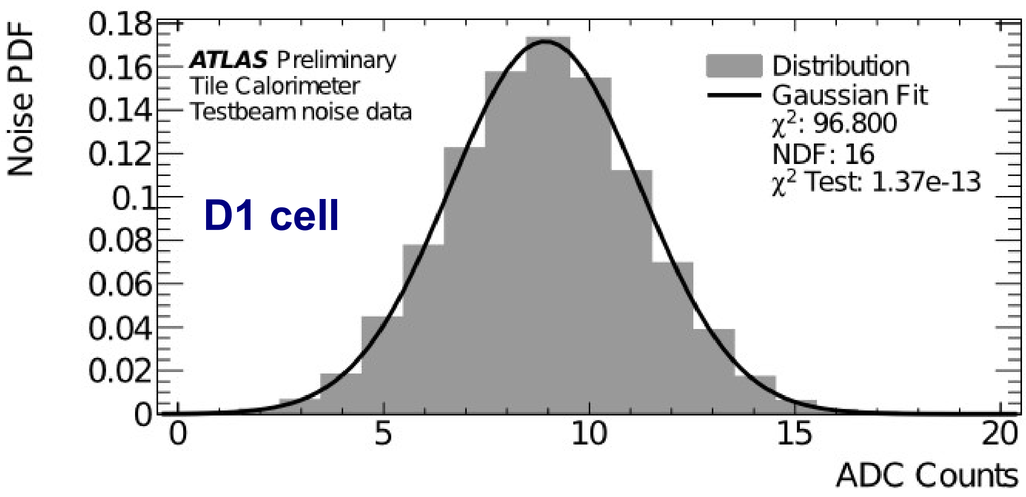
Results on these topics, planned for the upgrade phases, are shown in the next slides

Phase-1: Reduction of muon background trigger rate

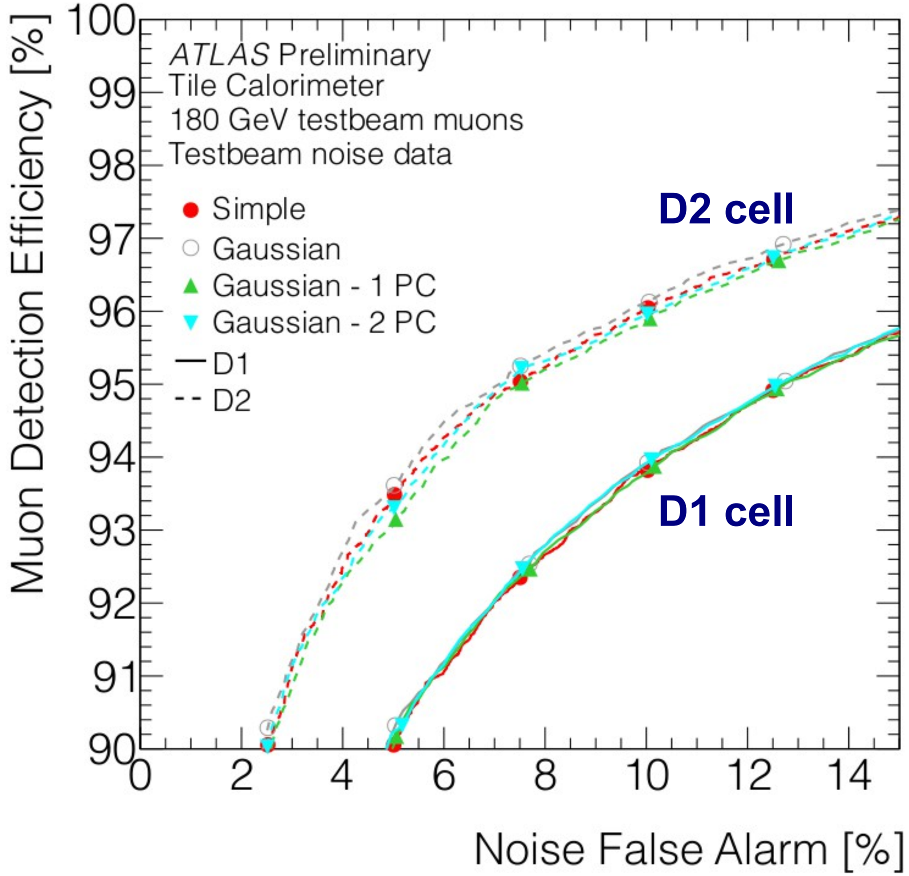
- Studies performed with test-beam data and MC simulations
- Studied on the barrel detector: $|\eta| < 0.7$

Phase-1: Reduction of muon fake trigger rate (1)

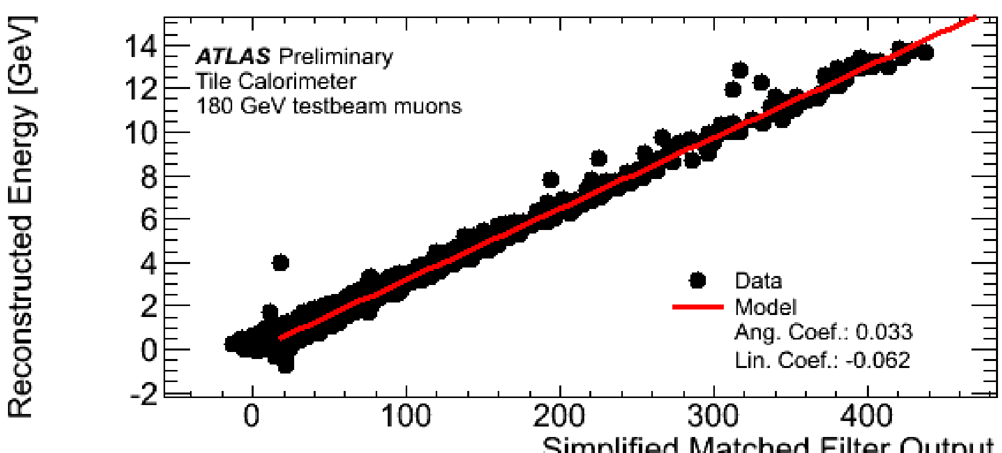
- **TileCal muon signal: formed by the amplification of the last radial layer (D cells) readout**
  - **Combining TileCal and muon system, the L1 muon background rate can be reduced**
  - **Currently not used by L1, but available and being considered for a L1 upgrade**
- **Two main sources of fake triggers degrade the L1 performance for muons:**
  1) **Beam-associated photon and neutron fluxes in the ATLAS cavern**
  2) **Muons from in-flight decays of pions and kaons**
- **A prototype receiver for the TileCal muon signals has been developed to extract information from the signals and to discriminate them from noise**
  - **The final signals have a very low Signal-to-Noise Ratio (SNR)**
  - **Summing both PMT signals from the same D-cell increases the SNR by a factor of ~1.414**
- **The matched filter technique is the optimal linear fitter for maximizing the SNR in the presence of additive stochastic noise**
- **Two signal discriminators:**
  - **A simplified approach: mean value over all the events of the muon signal**
  - **A full stochastic signal discriminator: considering both muon and noise signals to be gaussian random processes**



Phase-1: Reduction of muon fake trigger rate (2)



- The discrimination performance is evaluated for the two signal discriminators: Simplified approach & gaussian
- Data analysis performed on 2 D cells: D1 and D2, from one TileCal module
- Results are derived from circuit simulations using measurements with 180 GeV muon test-beams
- Really similar results for both signal discriminators
- The simplified approach is considered the most appropriate, due to its simplicity and speed



(Simplified approach:ADC counts)

- The energy deposited in the D1 cell by muons can be estimated with a linear fit from the output of the simplified signal discriminator approach
- This study has been performed for the TileCal barrel detector, it continues with proton-proton collisions data from 2010 and it will be expanded to the extended barrel (0.9<|η|<1.3)

Phase-1: Studies on trigger towers

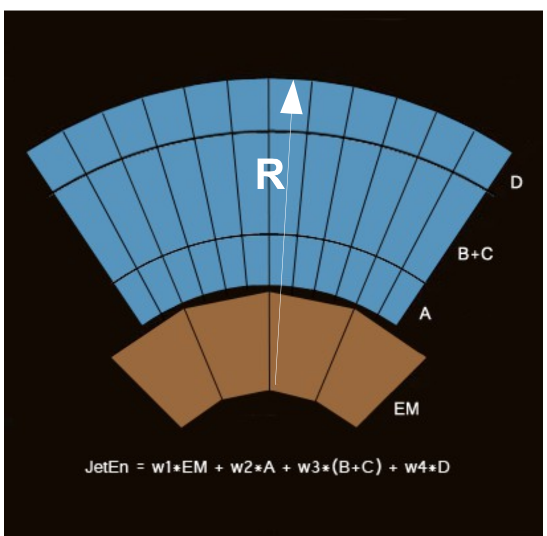
- Jet energy reconstruction algorithms
- Better TT energy precisions: 512 and 256 MeV
- High pile-up MC dataset used for this study:
  mc10_14TeV.105568.ttbar_Pythia.recon.ESD.e662_s1107_d459_r2037
  which contains 10k events with $\langle\mu\rangle \sim 46$, 25 ns bunch interval

Phase-1: Jet energy reconstruction algorithms

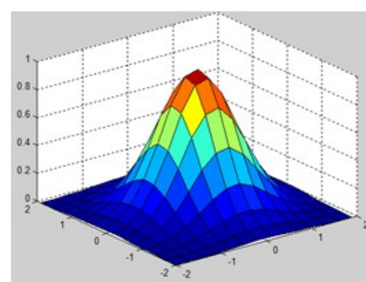
- **Two energy reconstruction methods studied on the L1 trigger performance with jets**
  - **Depth segmentation (R direction)**
    - **Energy sum over the jet RoI (Region of Interest): ΔηxΔΦ=0.45x0.45**
    - **Least Square (LS) based optimization algorithm to find the weights**

$$JetEne = w_1 \sum_{\eta,\phi} Larg + w_2 \sum_{\eta,\phi} TileA + w_3 \sum_{\eta,\phi} TileBC + w_4 \sum_{\eta,\phi} TileD$$

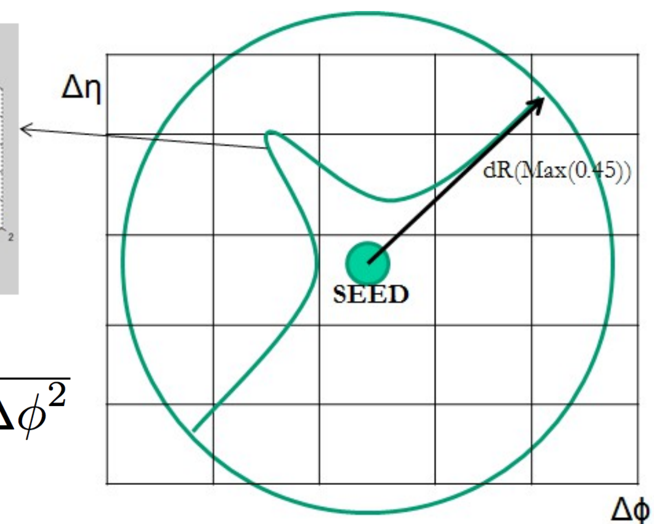
    - **At phase-1, only D layer segmentation can be added and not too much gained**
    - **At phase-2, full radial segmentation will be available. It could be implemented at L1**
  - **Gaussian fit**
    - **Reduction of pile-up effect: Fit the jet energy seeded at η,Φ (avoid further cells)**
    - **No additional segmentation required, but not easy implementation**



Depth segmentation (LS)



$$\Delta R \equiv \sqrt{\Delta\eta^2 + \Delta\phi^2}$$



Gaussian fit

Phase-1: Trigger Tower precision studies

- The current Level-1 online trigger system will profit from full detector granularity (at cell level) at phase-2, but at phase-1 a higher precision of the Trigger Towers (LSB) can be used:
  - Phase-1: Ideal laboratory to make precision measurements of the Higgs boson properties and, in particular its couplings to fermions and bosons
  - Motivation: Improving the present Level-1 trigger of the ATLAS experiment, to be able to keep an acceptable trigger rate, while keeping current p_T thresholds for single and isolated objects
  - ATLAS EM (LAr) calorimeter will use 256 MeV, instead of the current 1 GeV granularity
  - TileCal is evaluating if using 256 or 512 MeV, due to TT noise (only cell noise considered in the present results)

EM LAr TT signal granularity (MeV)	Had TileCal TT signal granularity (MeV)	10-90% rise on jet trigger efficiency (GeV)	Relative difference with current system (%)
1000	1000	18.8	--
256	256	15.0	- 20
256	512	16.1	- 14
256	1000	16.8	- 11

↳ And jet energy with gaussian fit method

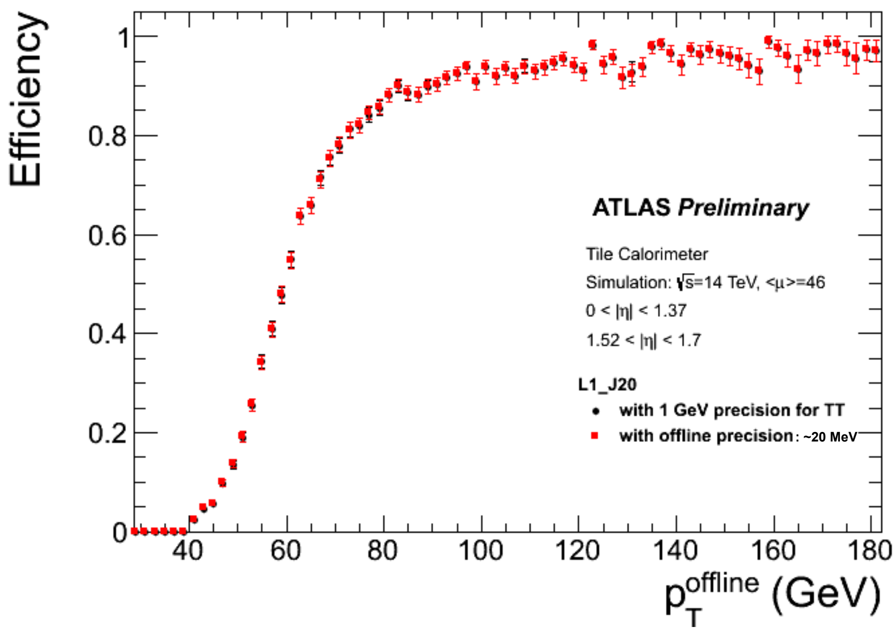
Phase-2: Studies on trigger towers

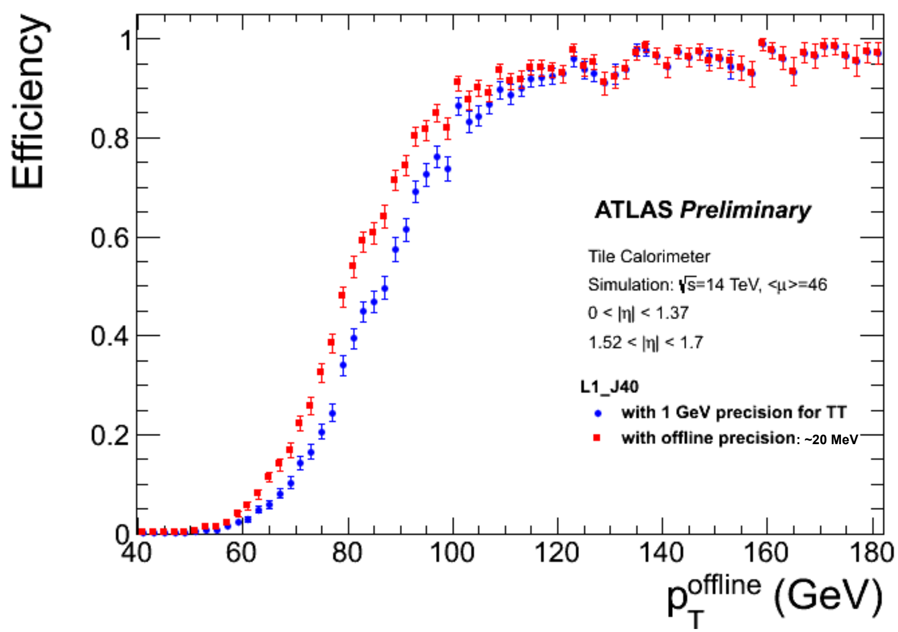
- Electronics upgrade
- TileCal detector full granularity (at cell level)
- Digital signal read-out: full energy resolution (cell noise: ~20 MeV)
- High pile-up MC dataset used for this study:

  mc10_14TeV.105568.ttbar_Pythia.recon.ESD.e662_s1107_d459_r2037
  which contains 10k events with <μ> ~ 46, 25 ns bunch interval

  Same MC, up to a factor 4 less pile-up than expected because MC not available yet

Phase-2: Trigger Tower precision studies (1)





L1_J20 (L1_J40): Jet window of 8x8 TTs and E_T>20 (E_T>40) GeV

EM calorimeter TTs with 1 GeV precision: TileCal better precision impact on current system

Jet selection cuts and trigger matching
- **Reconstructed jet: p_T > 30 GeV, 0 < |η| < 1.37 & 1.52 < |η| < 1.7**
- **L3 (Event Filter) jet trigger: ΔR (reco jet, L3 trigger)<0.4 & p_T>40 GeV**
- **L1 jet trigger: ΔR (reco jet, L1 trigger)<0.4 & E_T (8x8 TTs) > 70 GeV**

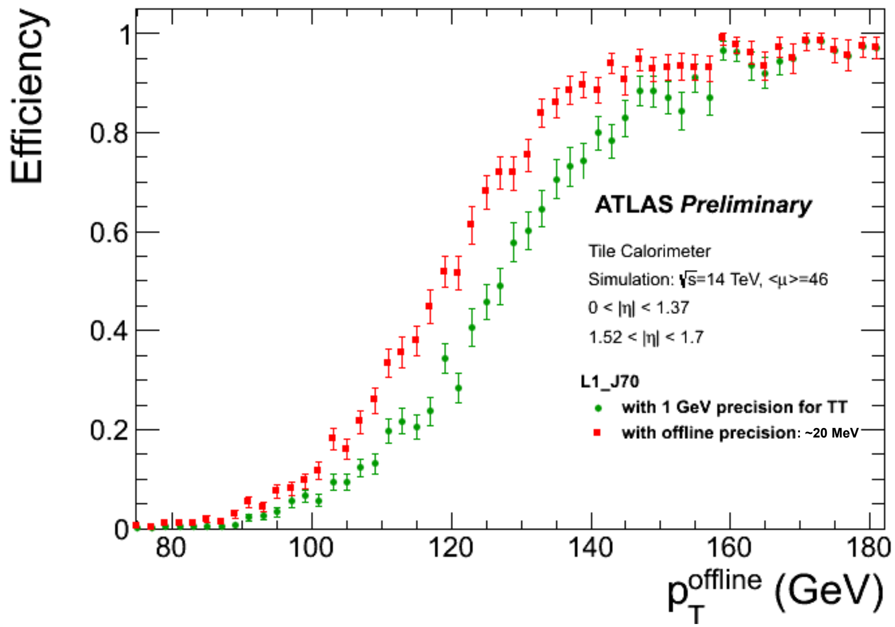
- **Difference between L1_J20 and L1_J40:**
  - **Low jet energies with L1_J20, low energy deposition at TileCal → Dominated by EM calorimeter**
  - **The L1_J40 turn-on curve with offline cell energy precision (planned for phase-2) from 10% to 90% efficiency is ~9% more narrow than with the current system**

$\Delta p_T = p_T^{offline}$(Jet Eff = 90%) - $p_T^{offline}$(Jet Eff = 10%):

L1_J20
- **With 1 GeV precision: Δp_T = 45 GeV**
- **With offline precision: Δp_T = 45 GeV**

L1_J40
- **1 GeV: Δp_T = 44 GeV**
- **Offline: Δp_T = 36 GeV**

Phase-2: Trigger Tower precision studies (2)



L1_J70: Jet window of 8x8 TTs and E_T>70 GeV

EM TTs with 1 GeV precision: TileCal impact

$\Delta p_T = p_T^{offline}$(Jet Eff = 90%) - $p_T^{offline}$(Jet Eff = 10%):

L1_J70 1 GeV precision: Δp_T = 48 GeV

L1_J70 with offline precision: Δp_T = 38 GeV

Jet selection cuts and trigger matching
- **Reconstructed jet: p_T > 30 GeV, 0 < |η| < 1.37 & 1.52 < |η| < 1.7**
- **L3 jet trigger: ΔR (reco jet, L3 trigger)<0.4 & p_T>40 GeV**
- **L1 jet trigger: ΔR (reco jet, L1 trigger)<0.4 & E_T (8x8 TTs) > 70 GeV**

- **Higher difference for L1_J70 than L1_J40:**
  - **Larger jet energies, larger deposition of energies at TileCal → Higher impact**
  - **The L1_J70 turn-on curve with offline cell energy precision (planned for phase-2) from 10% to 90% efficiency is ~12.5% more narrow than with the current system**
  - **Promising results, but need further checks to be completed, such as the impact on the trigger rates**

Conclusions

- **The LHC upgrade for high luminosity will increase the amount of interactions per bunch crossing**
- **ATLAS and its trigger system will upgrade components and algorithms to deal with pile-up**
- **These studies address the issue of improving the present Level-1 trigger of the ATLAS experiment, to be able to keep an acceptable trigger rate, while keeping present p_T thresholds for single and isolated physics objects**
- **Currently, the TileCal muon signals are not being used by L1 to reduce the muon background trigger rate, but they are available and being considered for a L1 upgrade**
- **TileCal could profit from an additional granularity in comparison with the current L1 trigger system**
- **The L1 trigger system will profit from full detector granularity (at cell level) and resolution at phase-2**