CERN SUMMER STUDENT REPORT

ATLAS Tile Calorimeter performance for the phase II upgrade

Kevissen Sellapillay - University of Strasbourg

Under the supervision of :

Priscilla Pani - CERN, ATLAS

Arely Cortes Gonzalez - CERN, ATLAS

Abstract

The first part of the internship is focused on trying to assess the performance of the upgraded geometry of the ATLAS Tile Calorimeter. To do this, we use Monte Carlo generated samples for the upgraded geometry and from the current geometry, then we derive the p_T response and resolution. The second part of the study is an analysis of the sensitivity of the two different geometries to a new heavy boson that would decay into a top quark pair : $Z' \to t\bar{t}$.

1.Introduction

The LHC (Large Hadron Collider) is a particle accelerator that has a circumference of 27 km and hosts particle physics experiments such as ALICE, ATLAS, CMS, LHCb and many others. This study was done on the ATLAS (A Toroidal LHC ApparatuS, Fig.1) detector which is a general-purpose detector. It is a cylinder of 25 meters diameter, 46 meters long, sits in a cavern 100 meters below ground and weighs around 7 000 tonnes.

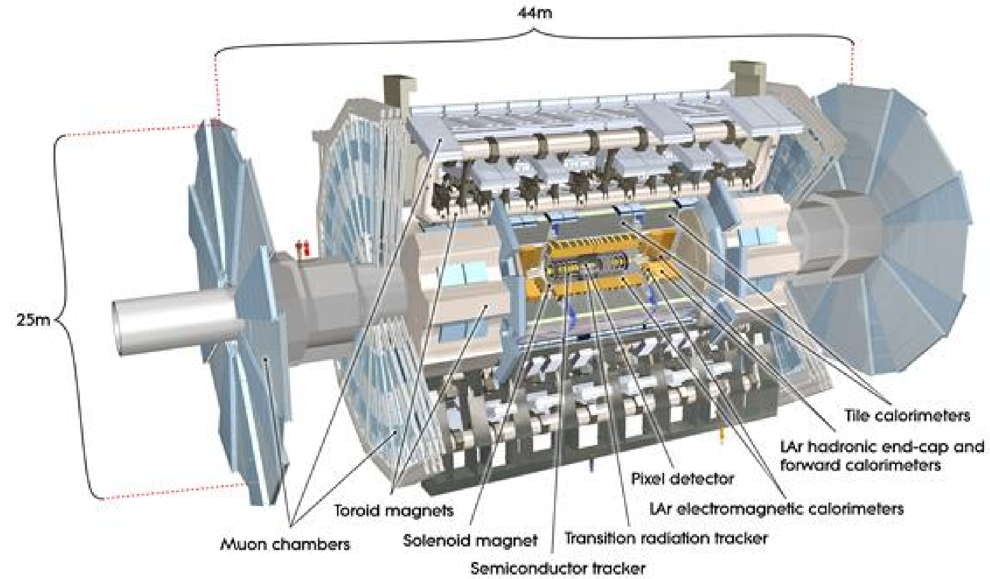


Figure 1: Computer generated image of the whole ATLAS detector, CERN

Like several other particle physics experiments, the ATLAS detector is composed of layers : the inner detector, the muon chamber or the calorimeters are some of them. Each of these layers serve a different purpose. This study is about the upgrade of the Tile Calorimeter which provides important information for reconstruction of hadrons, jets, hadronic decays of tau leptons and missing transverse energy..
The upgrade of the Tile Calorimeter is a consequence of the fact that the LHC itself is going to be upgraded into the High Luminosity LHC in the upcoming years. A high number of collisions per crossing (up to 200 pile-up events compared to around 30 curently) is to be expected in the upgraded LHC, and to avoid degrading the performance of the detector, some parts of ATLAS will need to be upgraded. The Phase II upgrade follows three guidelines : Electronic update, ITK tracker upgrade and increase of granularity. The first part of this study focuses on the performance change due to the ITK tracker upgrade. The second part is about the sensitivity of the detector to a new heavy boson. We present the method and definitions used in this study and we then show the results we obtained and discuss them.

2.Method and definitions

One of the most important tool in particle phyics that allows physicists to test QCD (quantum chromodynamics) predictions and to identify particles produced during massive particle decays is the notion of jet. A jet can be defined as a bunch of signals following the detection of high transverse momentum particles produced by strong decay in hard scattering process. The theory predicts that the energetic partons (gluons and quarks) produced in collisions create showers of other partons which will then create other composite particles (this process is called hadronization). There are several algorithms that analyse the data and according to criterias like colinearity and energy, try to extract jets out of them. These jets then go into several pocesses of calibration (EM, LCW, GSC and others) to get the calibrated jets.
It is important to note the fact that the calibration used to produce the sample for the upgraded geomerty is the calibration derived for the current geometry. As a consequence, this study might be biased for the upgraded geometry.

To assess the performance of the ITK tracker upgrade, we want to measure the p_T response and p_T resolution. We calculate these variables on the uncalibrated and calibrated jets for the current geometry and the ITK upgrade. Those quantities are defined as follow :
The p_T response is defined in [1] as the mean value extracted from the gaussian fit of the $\frac{p_T}{p_T^{truth}}$ ditribution within range of 1.6 standard deviation.
The p_T resolution is defined as $\frac{sigma}{mean}$ where sigma is the standard deviation of the same gaussian fit as before.

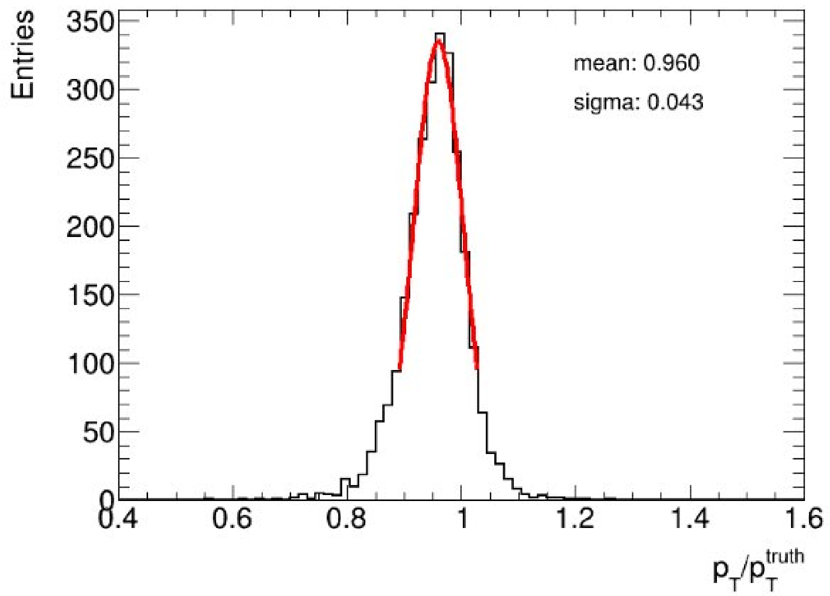


Figure 2: Example of Gaussian fit from jet pefomance studies, the binning and ranges choices are done by eye to ensure the fit function is working properly

We calculate the response and resolution as functions of the jet energy fraction deposited in each TileCal layer (Fig.3).

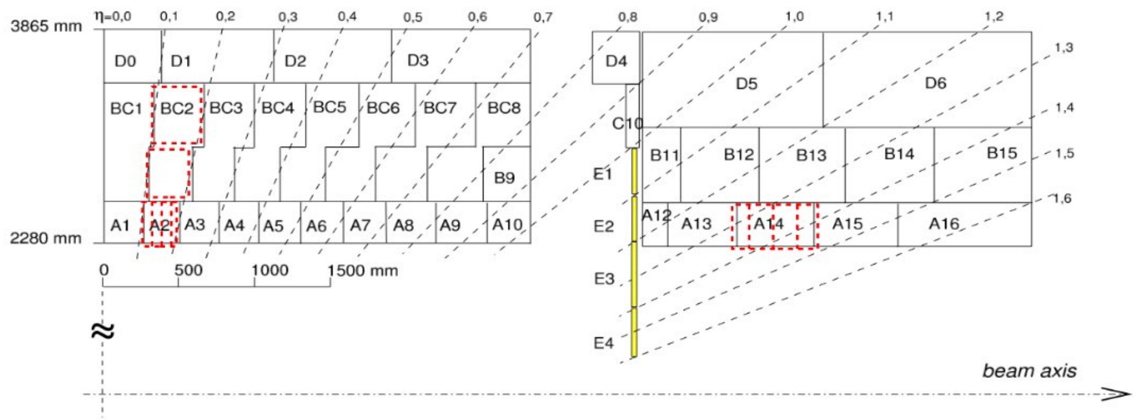


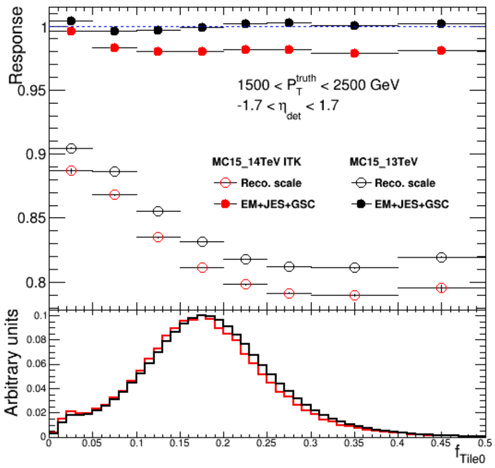
Figure 3: Tile Calorimeter configuration. The p_T response and resolution plots are functions of fTile0, fTile1 or fTile2 depending on which part of the detector we want to study. fTile0 is the jet energy fraction in layer A, fTile1 the one for layer BC and fTile2 the one for layer D. We can also see the pseudorapidity represented here. CERN

For the second part of the study, we also calculate the mass resolution which is defined in [3] as half of the 68% interquantile range divided by the median.

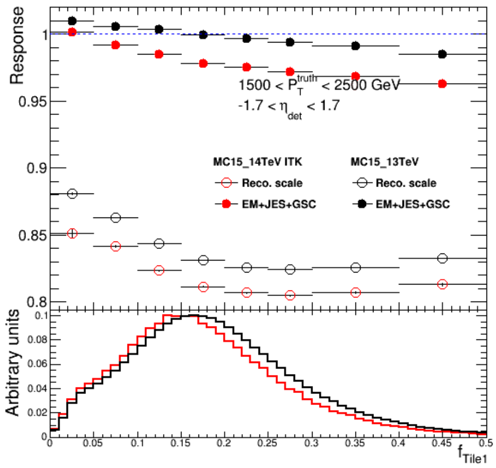
3.Results and discussions

For the first part of the study we use Monte Carlo generated QCD dijet samples (current geometry 13 TeV and new geometry 14 TeV ITK) and we calculate the quantities needed to assess the performance.

We calculate the response (Fig.4) and resolution (Fig.5) and restrict our study to high p_T jets (1500 GeV $< p_T <$ 2500 GeV). We also apply a cut on η_{det}, the pseudorapidity, which limits the jets we use in the analysis to a certain fraction of the detector. We observe a clear loss of response in the ITK upgrade compared to the current geometry. The same is observed with the resolution (the ITK points are higher than the curent geometry one which means the resolution is worse because of the definition being $\frac{sigma}{mean}$).
We made sure that the statistical error is small enough for each point so that those results are significant.

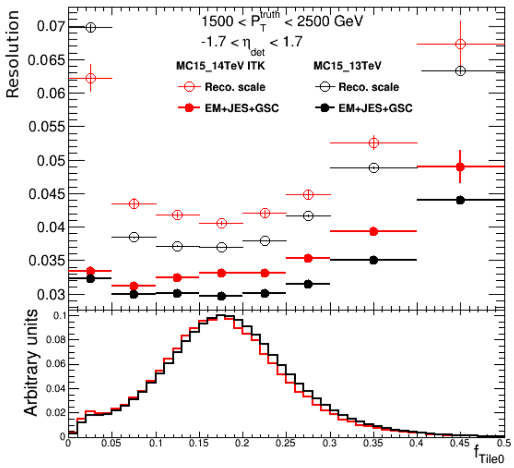


p_T response as a function of fTile0

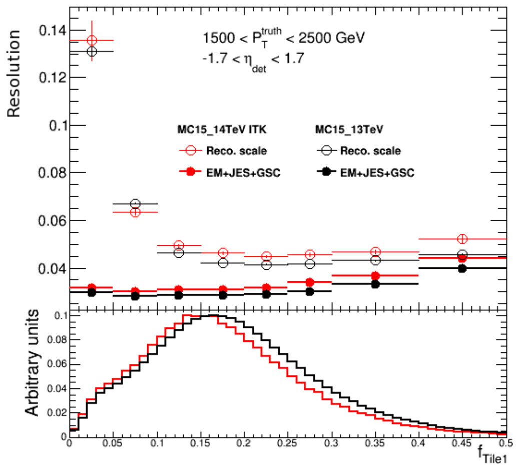


p_T response as a function of fTile1

Figure 4: p_T responses. Each point has a X-width which is the range of the energy fraction in layer A (fTile0) or layer BC (fTile1) on which the $\frac{p_T}{p_T^{truth}}$ data is taken to be fitted with a gaussian just like Fig.2 (in this quotient p_T is either the reconstructed data, which is the uncalibrated data, or EM+JES+GSC, the calibrated data, and p_T^{truth} is the raw data). The mean of each gaussian is extracted to get the coresponding point. The bottom pad represents the energy fraction distributions (with η and p_T cuts applied) deposited in layer A (left figure) or layer BC (right figure), for current geometry in black, and upgraded one in red.



p_T resolution as a function of fTile0



p_T resolution as a function of fTile1

Figure 5: p_T resolutions. Each point has a X-width which is the range of the energy fraction in layer A (fTile0) or layer BC (fTile1) on which the $\frac{p_T}{p_T^{truth}}$ data is taken to be fitted with a gaussian just like Fig.2 (in this quotient p_T is either the reconstructed data, which is the uncalibrated data, or EM+JES+GSC, the calibrated data, and p_T^{truth} is the raw data). The standard deviation sigma and the mean of each gaussian is extracted and we calculate $\frac{sigma}{mean}$ to get the coresponding point. The bottom pad represent the energy fraction distributions (with η and p_T cuts applied) deposited in layer A (left figure) or layer BC (right figure), for current geometry in black, and upgraded one in red.

The same general trend of ITK being worse than the current geometry was seen in the plots that were functions of fTile2 and are not shown here.

We mention here that someone from ATLAS already did this study [1] on the same Ntuple. Even tough some discrepancies from his results were observed, the conclusion is the same, there is a loss of performance on the upgraded geometry.
This is thought to be the reason of the loss of response and resolution. There is currently a search for other possible reasons for the loss in response and resolution.

We then went on to assess the sensitivity of the ITK upgrade to new physics by analysing samples that are made specifically to allow this kind of study (the jet algorithm uses larger R to create the jets, which is the radius of the cone used to identify jets).
This time, we plotted the quantities as functions of p_T^{truth} and applied a cut on η_{truth}. We also took the highest p_T jet.

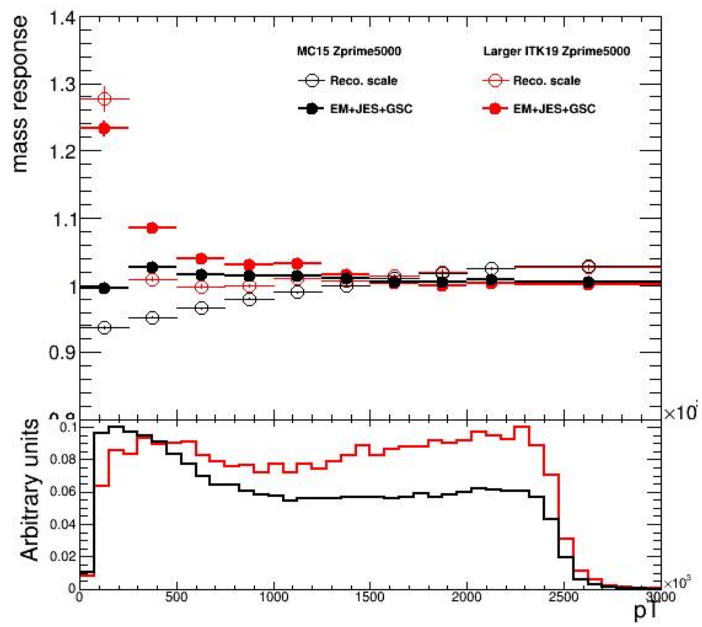


Figure 6: Mass response. The definition is the mean value of the $\frac{m}{m^{truth}}$ ditribution extracted from the gaussian fit within standard range of 1.6 σ. Each point has a X-width which is the range of p_T^{truth} on which the data is taken to be fitted with a gaussian, we also take the highest p_T jet for each entry and apply the cut $|\eta| < 1.7$. In the quotient m is either the reconstructed data or EM+JES+GSC, and m^{truth} is the raw data. The bottom pad represents the p_T^{truth} distributions with the cuts for current geometry, in black, and upgraded one, in red.

There is still some work to do to have an interpretation of the results for the mass response (Fig.6) and the mass resolution (Fig.7).

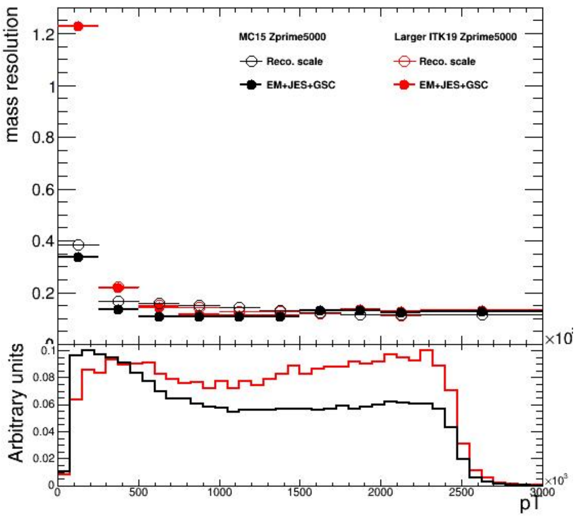
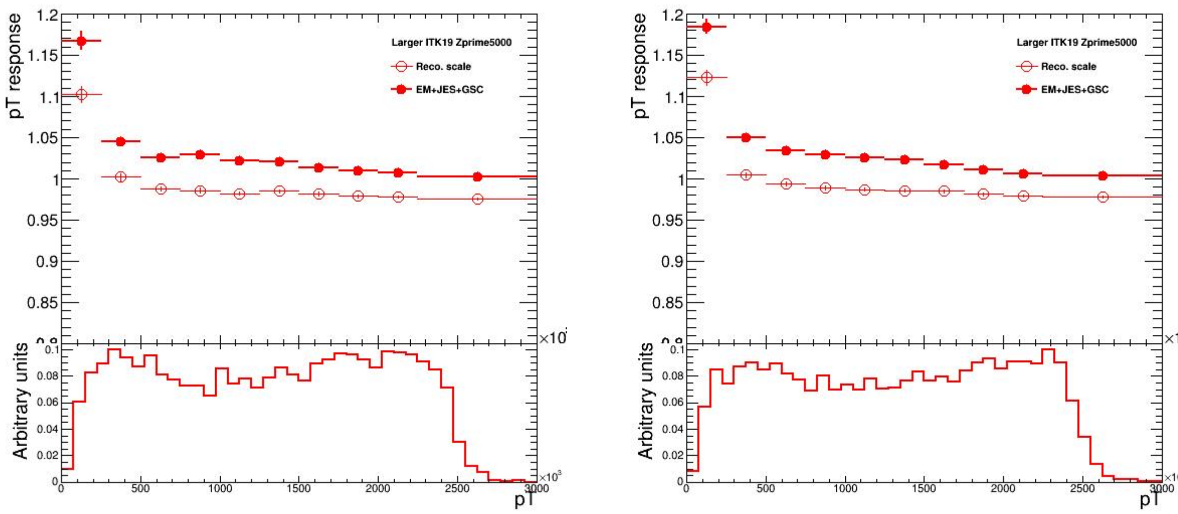


Figure 7: Mass resolution. The bottom pad represents the p_T^{truth} distributions with the cuts for current geometry, in black, and upgraded one, in red.

We also plotted the p_T response for these samples but this time with either low pileup (Fig.8) or high pileup (Fig.9). We did this on the ITK upgrade sample only since it's the one we want to study the new physics on. There is no strong dependance on the pileup for the p_T response. The same conclusion was obtained for the resolution. Further studies on the sensitivity of the ITK upgrade to new physics are needed to have more insights on these plots.



p_T response, low pileup : $190 <$ number of collisions< 195

p_T response, high pileup : $205 <$ number of collisions< 210

Figure 8: p_T responses with different pileup values for ITK sample. The bottom pads represent the p_T^{truth} distributions with the cuts for the upgraded geometry.

4.Conclusion

During this summer at CERN, we studied the perfomance of the ITK upgraded geometry for the ATLAS Tile Calorimeter. By calculating the response and resolution we observed a significant loss of performance on the upgraded geometry believed to be due to the fact that the calibration used isn't the correct one. However we still need to understand what causes the calibration to change so much that the peformance would be affected significantly.
We then studied the sensivity of the new geometry to new physics but we didn't obtained anything striking, further studies are needed on the subject.
The work done by another summer student Vincent Cecchini about jet substructure for the new physics samples is complementary to this one.

Bibliography

[1] B. Chargeishvili, https://indico.cern.ch/event/646088/contributions/2627390/attachments/1477649/2289727/Upgrade_Jet_Perf_ITK_1.9_15Jun17.pdf

[2] The ATLAS collaboration, https://arxiv.org/pdf/1411.1855.pdf

[3] The ATLAS collaboration, https://cds.cern.ch/record/2200211/files/ATLAS-CONF-2016-035.pdf