Studies of single and double electron triggers at the ATLAS experiment

Maciej Misiura, University of Warsaw, Poland

September 7, 2011

Abstract

This report describes work that has been done under supervision of Wolfgang Ehrenfeld and Milan Zvolský during the Summer Students Program 2011 at DESY. The main subject of the project was the study of single and double electron triggers at the ATLAS experiment. Results for trigger efficiencies obtained from selected data sample, Standard Model and SUSY Monte Carlo samples are presented. A more detailed study of estimating dielectron trigger efficiencies with single-electron trigger efficiency is described.

Contents

1 Introduction

This section gives the motivation for the project topic choice, a brief introduction to the ATLAS detector, the trigger system, theoretical aspects of calculating trigger efficiencies and information on data/MC samples used in the analysis.

1.1 Motivation

The project was done in the ATLAS SUSY group at DESY. Supersymetry (SUSY) is a theory that may be successor of the Standard Model (SM). It assigns for each SM particle a superpartner. Assuming so called R-parity conservation, each SUSY particle decays into another SUSY particle and at least one SM particle. The decay chain will end with the decay to the lightest supersymetric particle (LSP), that will escape the detector unobserved. Therefore one of the SUSY signatures would be missing-E_T, but also leptons from SUSY particle decays. So far for SUSY analyses at ATLAS single lepton triggers have been used to obtain events with two leptons. Now, due to rapidly increasing instantaneous luminosity and data acquisition (DAQ) system constraints, the unprescaled single electron trigger with the lowest threshold is the one with $p_T >$ 25 GeV requirement. To have dielectron events with lower p_T one should use dielectron triggers that have requirements also on the subleading electron. Studies of dielectron trigger efficiencies, partially covered by the project, may be important for further studies.

1.2 The ATLAS experiment

ATLAS [1] and CMS are two general-purpose experiments installed at the Large Hadron Collider (LHC). Their task is to search for "new physic", to test known theories, like QCD and to discover the last missing particle of the Standard Model - the Higgs boson. The ATLAS detector (A Toroidal LHC ApparatuS) has cylindrical and forward-backward symmetry. The general overview of the ATLAS experiment is given in Figure 1. The interaction point is surrounded by the inner tracking detector that consists of a silicon pixel detector, a silicon microstrip tracker and a transition radiation detector. Outside the inner detector one can find a superconducting solenoid that provides 2 T magnetic field for the measurement of the charged particle's momentum. The energy and spacial position of electromagnetic showers are measured by a high-granularity lead-liquid-Argon (LAr) calorimeter. In the barrel region hadronic showers are measured by a iron-scintillator calorimeter while in the endcap region by a LAr calorimeter. The calorimeters are surrounded by a muon system that consists of three superconducting toroids, eight coils each, a system of tracking chambers and some specific detectors for triggering.

1.2.1 The ATLAS coordinate system

The nominal interaction point (IP) is the origin of the ATLAS coordinate system. The beam direction defines the z-axis of the coordinate system, the x axis is in the direction from the nominal interaction point to the center of the accelerator ring. The y axis is

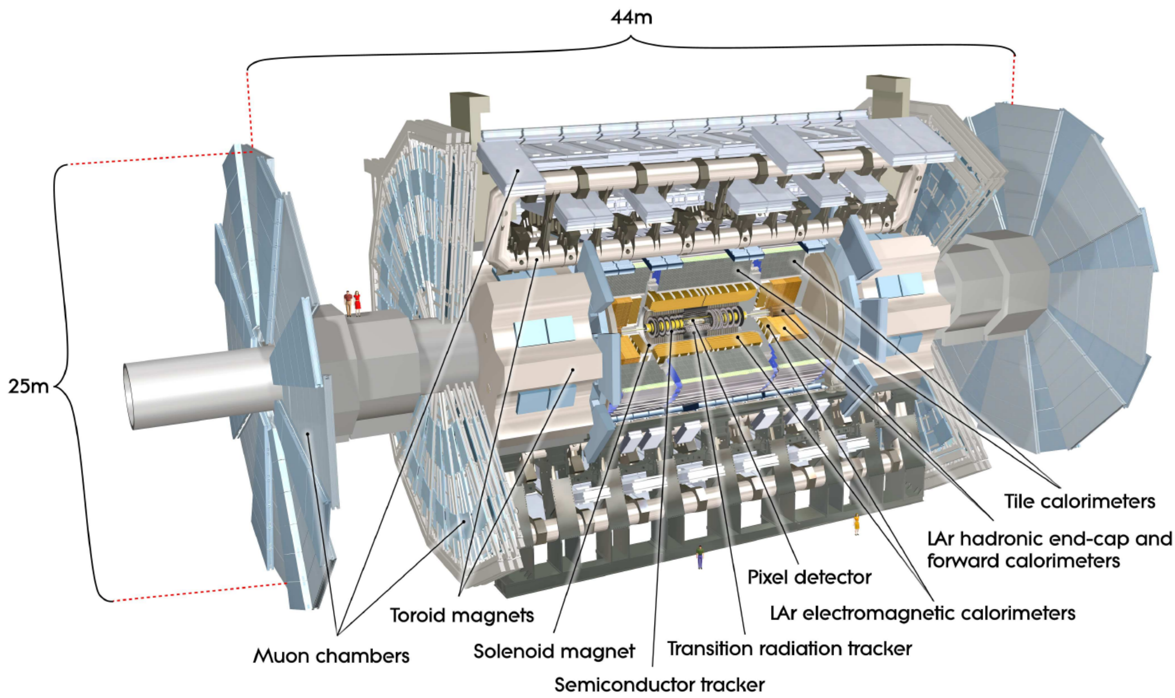

Figure 1: General overview of the ATLAS experiment [1].

perpendicular to both x and z axis. The x-y plane is called transverse. The azimuthal angle is measured with respect to the positive x axis. The pseudorapidity is defined as follows:

$$\eta = -\ln \tan\left(\frac{\theta}{2}\right), \tag{1}$$

where θ is the polar angle, defined from the beam line. Pseudorapidity equal to 0 corresponds to the transverse plane, while large $|\eta|$ values correspond to the forward-backward region (near the beam). The distance in the detector is defined as:

$$\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2}, \tag{2}$$

where ϕ is the azimuthal angle, around the beam axis.

1.3 ATLAS trigger system

The ATLAS trigger system consists of three levels: Level 1 (L1), Level 2 (L2) and Event Filter (EF). L1 trigger is implemented using custom-made hardware. L2 and EF are called High Level Trigger (HLT) and are software algorithms running on computers connected via network [1].

1.3.1 L1 trigger

Level 1 trigger looks for signatures of interesting processes using measurements of muons, electrons/gamma particles or jets. It can also select events using information about E_T^{miss}. L1 uses only reduced detector information from the calorimeter and from muon detectors designed for the triggering.
The L1 Calorimeter Trigger (L1Calo) identifies high-E_T objects (photons, electrons, jets, taus) as well as missing transverse momentum. Isolation may be applied - then it is checked if the energy deposit around the considered cone is not larger than a given threshold.
The information from the muon detectors; i.e. RPC (Resistive Plate Chambers) in the barrel and TGC (Thin-Gap Chambers) in the end-caps, are used for muon-based triggers. There are six independent muon p_T thresholds. Muons should point back to the interaction point and at least one of them should be over given threshold. Muon double counting in the region of overlaping detectors is resolved.
The final trigger decision (accept/reject) for every event is made by the Central Trigger Processor (CPT) which combines information from the different subsystems. While the L1 decision is based only on the multiplicity of objects that passed a given requirement, the information about the spacial position of the objects is saved as Regions of Interests (RoI) and passed to the HLT. The output rate from L1 is about 75 kHz and the decision from L1 reaches the front-end electronics after 2.5 μs.

1.3.2 HLT trigger

During the L1 2.5 μs latency the detector readout is stored in the buffer of each specific detector subsystem. If the event is accepted by the L1, the data is transferred through Readout Links to the HLT. But before, information from L1 subsystems is merged by the RoI builder into a single data structure. Each subsystem provides also information about the RoI. Further selections are applied at the L2, that uses information from all subdetectors (including the tracker) around RoI. The main part of the L2 trigger is a processing farm that consists of 500 processors. The output rate is about 3.5 kHz. Events accepted by L2 are processed by the Event Filter that consists of 1600 processors. EF incorporates alignment and the full detector readout is available. Events that pass all three levels of the trigger system are saved to the mass storage. The final output rate is about 200 Hz.

1.4 Trigger efficiency

The trigger efficiency is mandatory for almost every physics analysis. One of them, for which the efficiency is crucial, is the measurement of the cross section. "Trigger efficiency" has no meaning itself, one has to define the trigger requirement T, the sample with respect to which the efficiency is calculated. One can determine the efficiency as a function of some variable x, the transverse momentum p_T, for instance. The efficiency

$\epsilon_{\mathrm{T}}(x;\mathrm{A})$ is a probability as a function of x that event from sample A passes the trigger selection T [2]. It is simply the conditional probability:

$$\epsilon_{\mathrm{T}}(x;\mathrm{A}) = P(\mathrm{T}|\mathrm{A},x). \tag{3}$$

First, let's assume that we do no take into account the x-dependence of the efficiency. What we want to estimate is $\epsilon_{\mathrm{T}}(\mathrm{A}) = P(\mathrm{T}|\mathrm{A})$. The easiest procedure would be to count the initial number of events in the sample A (n), count the final number of events that pass the trigger T (k) and calculate:

$$\epsilon_{\mathrm{T}}(\mathrm{A}) \approx \frac{k}{n}. \tag{4}$$

Considering the x dependence, we want to estimate $\epsilon_{\mathrm{T}}(x;\mathrm{A})$. It would be possible to fill two histograms with value x, the first for events from sample A passing trigger T (the counts in i bin would be k_i) and the second for all events from sample A (n_i for i-bin). The estimate of the efficiency as a function of x would be the ratio of these two histograms bin-by-bin.
To calculate the uncertainity of the efficiency we consider triggering as a Bernulli's process. Then the probability distribution would be binominal. The uncertainity of the ratio $\epsilon = \frac{k}{n}$ is given by:

$$V = \frac{\epsilon(1-\epsilon)}{n}. \tag{5}$$

There are two cases $\epsilon \to 0$ and $\epsilon \to 1$ when the uncertainity is always equal to 0 and does not depend on n. Other solutions are needed. To calculate the uncertainity TEfficiency class from ROOT has been used. More details, both about the class and the way the uncertainties are calculated can be found in [4].

1.5 Data and MC samples, cuts

The following samples have been used for the analysis:

- Data - Period J and also two runs from period I2: 185761 and 185823.
- Monte Carlo from production mc10b.

Concerning the Monte Carlo samples:

- SUSY MC - mSUGRA model with $\tan\beta = 10$. All grid points (for different m_0 and $m_{1/2}$) have been merged to obtain higher statistics. The generator used was HERWIG++.
- $\mathrm{Z}^0 \to \mathrm{e}^+\mathrm{e}^-$ - generator used was Alpgen+Jimmy $\mathrm{Z} \to \mathrm{ee}$.

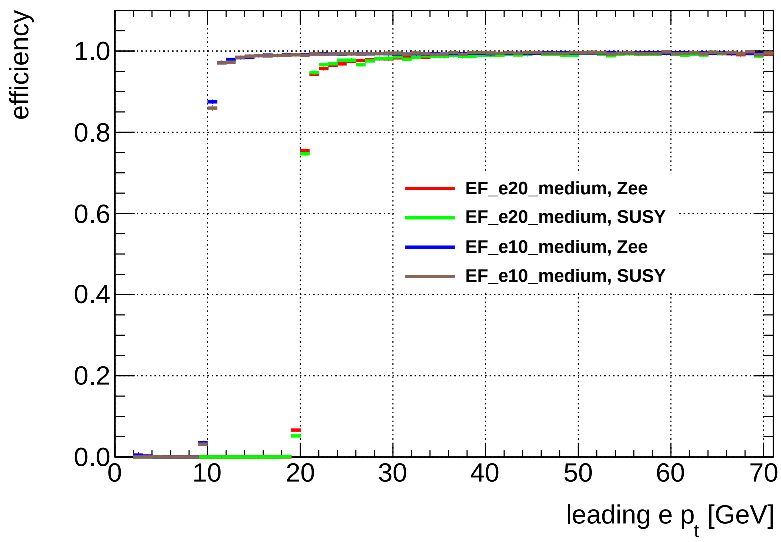

Figure 2: The efficiency of EF_e10_medium and EF_e20_medium as a function of leading electron p_T for SUSY and Z $\rightarrow$ ee MC samples.

To analyze data a three step workflow has been used. In the first step (that was run over all events in the sample) some specific information was saved and passed to the second step: number of electrons, electrons p_T, triggers decisions, etc. Only electrons with $p_T > 5$ GeV and $\eta < 2.47$ were taken into account. The η cut was due to tracker acceptance range. In the second step a tree was created and only information important for further analysis was saved. The final analysis was done using ROOT. To calculate efficiencies the TEfficiency class from ROOT was used. The analysis was based on "tight" electrons after the following overlap removal procedure: if any jet overlapped within $\Delta R < 0.2$ with an electron then the jet was removed. Afterwards if an electron overlapped with a jet ($0.2 < \Delta R < 0.4$), then the electron was rejected.

2 Absolute efficiencies

2.1 Single electron triggers

The first part of the analysis was the calculation of absolute efficiencies of single electron trigger. The study was performed for two MC samples: SUSY and Z $\rightarrow$ ee and for two single electron EF triggers: EF_e10_medium and EF_e20_medium. The p_T threshold for medium electron is 10 GeV and 20 GeV, respectively. The EF_e10_medium will be used for further analysis of dielectron trigger efficiency estimation, the EF_e20_medium was taken as a comparison. The efficiency was calculated with respect to the sample of at least one tight electron in the event. The efficiency plots are shown in Figure 2.
There is no big difference between the efficiencies for the two MC samples. One can see the characteristic turn-on curve: inefficiency region for low-p_T and plateau level.

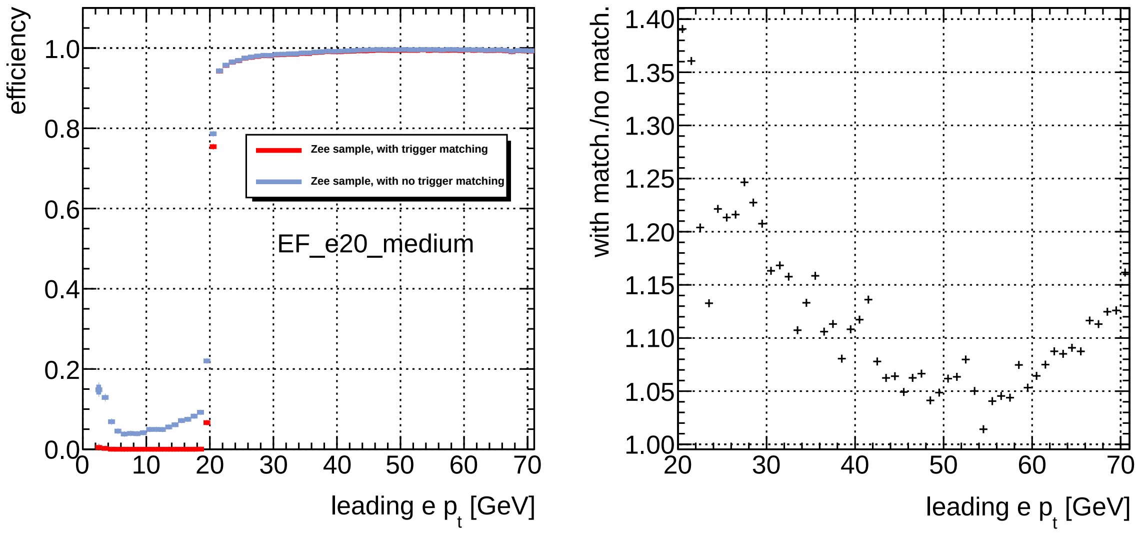

Figure 3: The effect of the trigger matching on the single trigger efficiency. Right plot is a ratio of efficiencies for sample with/without the trigger matching.

The plateau region is reached for $p_T \approx p_{\mathrm{th}} + 5$ GeV for both triggers, where p_{th} is the trigger threshold. The plateau regions mean efficiencies are: for EF_e20_medium - (0.992±0.005) and for EF_e10_medium - (0.994±0.003).

2.2 Trigger matching

For plots shown in Figure 2 so called trigger matching was applied. This procedure drops electrons which did not trigger the event, e.g. gammas that were misidentified as electrons during the reconstruction process. The idea is to match offline electrons to trigger objects with p_T over given trigger threshold using minimization of the ΔR distance, defined by Equation 2. Only offline electrons with a trigger object matched in $\Delta R < 0.2$ cone were considered.
One can see the effect of the trigger matching in Figure 3. After applying trigger matching there is no artifact in the low-p_T region that is caused by fake electrons. The efficiency in general is a little bit lower, but comparing the mean plateau efficiencies the efficiencies are the same when taking into account the statistical uncertainity (without trigger matching (0.993±0.005), with trigger matching (0.992±0.005)).

2.3 Absolute dielectron trigger efficiency

The next topic was the study of dielectron trigger absolute efficiency as a function of leading and subleading electron p_T. The study has been done for two MC samples - $Z \rightarrow$ ee and SUSY, the efficiency was calculated with respect to the sample of events with at least two tight electrons. The efficiency plot is presented in Figure 4.

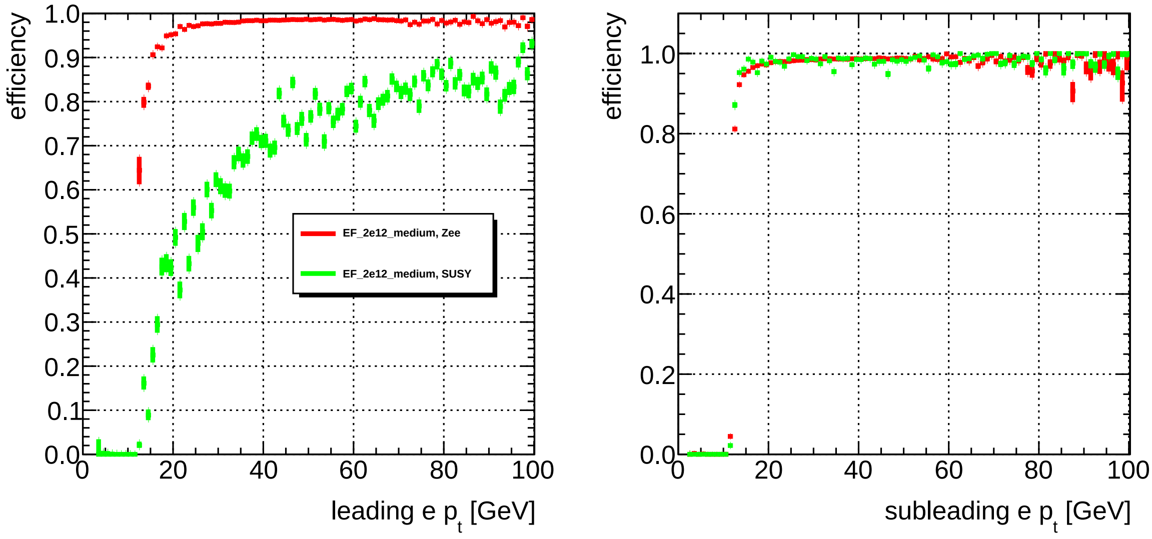

Figure 4: The absolute efficiency of EF_2e12_medium as a function of leading (left) and subleading (right) electron p_T for SUSY and Z $\rightarrow$ ee MC samples.

One can see that there is a significant difference between the two samples, especially for the leading electron. But one should remember that the dielectron trigger efficiency is a two-dimensional problem and if we look just for one of the electrons p_T we can only see:

$$\epsilon_{2\mathrm{e}}(p_T^1) = \int \epsilon_{2\mathrm{e}}(p_T^1, p_T^2) \cdot f(p_T^2; p_T^1)\ \mathrm{d}p_T^2, \tag{6}$$

where $\epsilon_{2\mathrm{e}}$ stands for dielectron trigger efficiency and $f(p_T^2; p_T^1)$ is the probability distribution for having a subleading electron with p_T^2 for a given p_T^1. For two different MC samples the f function is different - one can see it in Figure 5, where the scatter plot of leading and subleading electron p_T is presented. In the Z $\rightarrow$ ee MC one can see a peak at half of the Z boson mass, that is not present in the SUSY sample.
The decrease of the efficiency for the Z $\rightarrow$ ee sample for higher p_T is caused by the smaller number of subleading electrons with p_T over the trigger threshold (see Figure 5). If the cut $p_T > 12$ GeV is applied on both electrons we can observe the plateau region - Figure 6.

3 Relative efficiency

EF_2e12T_medium is a new trigger with lower rate comparing to EF_2e12_medium due to tighter selection, what is important concerning the DAQ system constraints. The only difference between these triggers is at L1: EF_2e12 seeded by L1_2EM7 and EF_2e12T by L1_2EM10. The relative efficiency of EF_2e12T_medium with resp. to EF_2e12_medium measured as a function of leading and subleading electron p_T is described in this section.

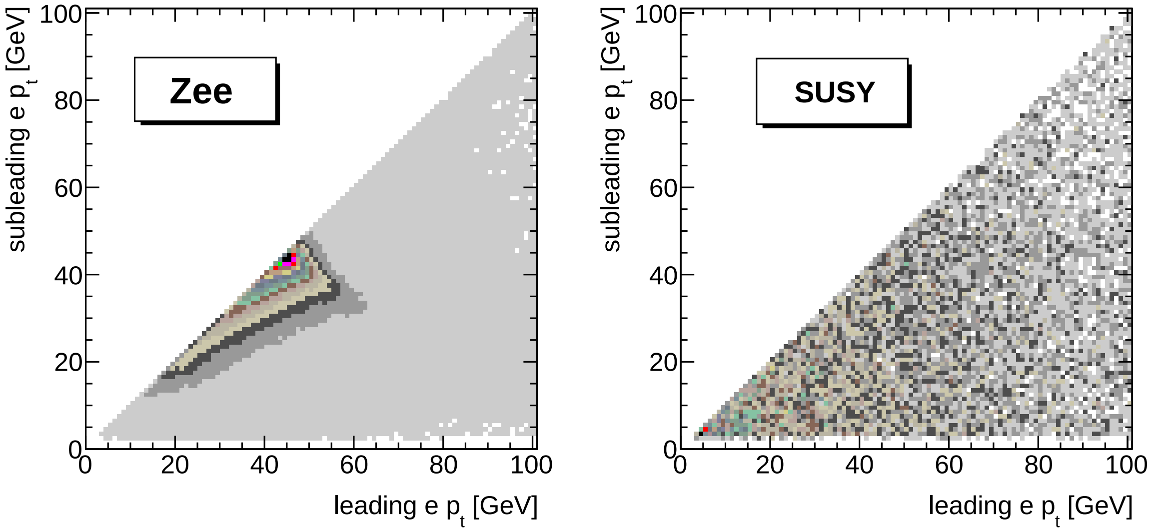

Figure 5: Two dimensional distributions of (p_T^1, p_T^2) for Z $\rightarrow$ ee (left) and SUSY MC samples.

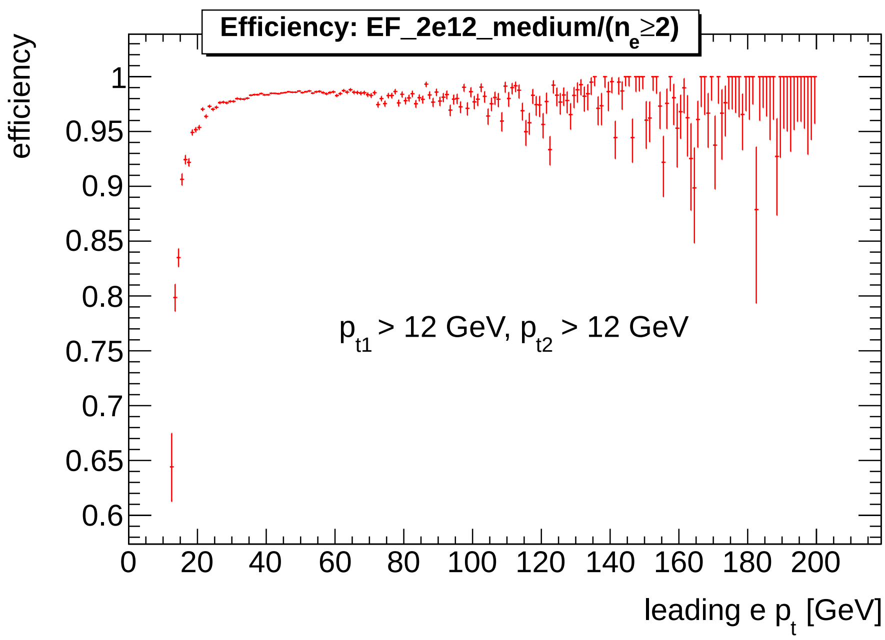

Figure 6: The absolute efficiency of EF_2e12_medium as a function of leading electron p_T for Z $\rightarrow$ ee sample with $p_T > 12$ GeV cut.

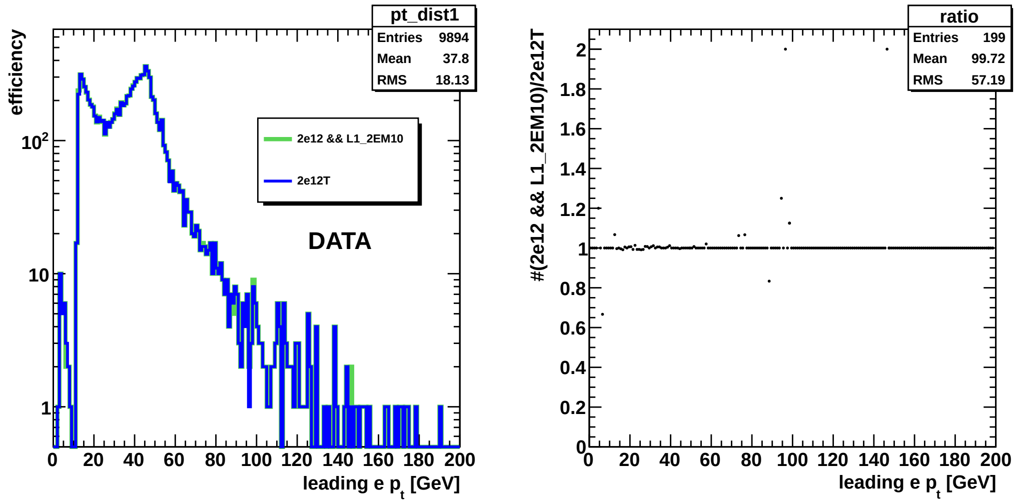

Figure 7: Comparison of p_T distributions for events with (L1_2EM10 and EF_2e12) and with EF_2e12T_medium (left). On the right plot the ratio of these two distributions is shown.

The problem in the analysis was the fact that there was no EF_2e12T_medium in the produced MC samples. The following approximation has been used: EF_2e12T_medium $\approx$ (L1_2EM10 and EF_2e12_medium). It was checked using a small data subsample (runs 185761 and 185823, period I2) that this approximation works good. The deviation in the number of events was about 0.2%. The comparison for the p_T distributions for events with (L1_2EM10 and EF_2e12) and with EF_2e12T_medium can be seen in Figure 7.
The first step was the calculation of the relative efficiency for a small data sample (runs 185761 and 185823) and its comparison to Z $\rightarrow$ ee MC sample. The cut on the leading and subleading electron p_T was 12 GeV. The result is shown Figure 8. One can see the inefficiency in the low-p_T region due to difference between L1 triggers. The results for data and MC are consistent within the statistical uncertainity.
Furthermore, data from period J has been used, where both, EF_2e12T_medium and EF_2e12_medium were present. The efficiency has been calculated for two cuts on p_T of leading and subleading electrons: 12 GeV and 15 GeV. The result is presented in Figure 9. One can see the inefficiency in the low-p_T region due to difference between L1 triggers.

4 Dielectron efficiency

4.1 Introduction

The interesting question is how good can we estimate the double electron trigger efficiency using the known efficiency of a single electron trigger. This might be an important topic, because it is possible to obtain single trigger efficiency from data using for instance

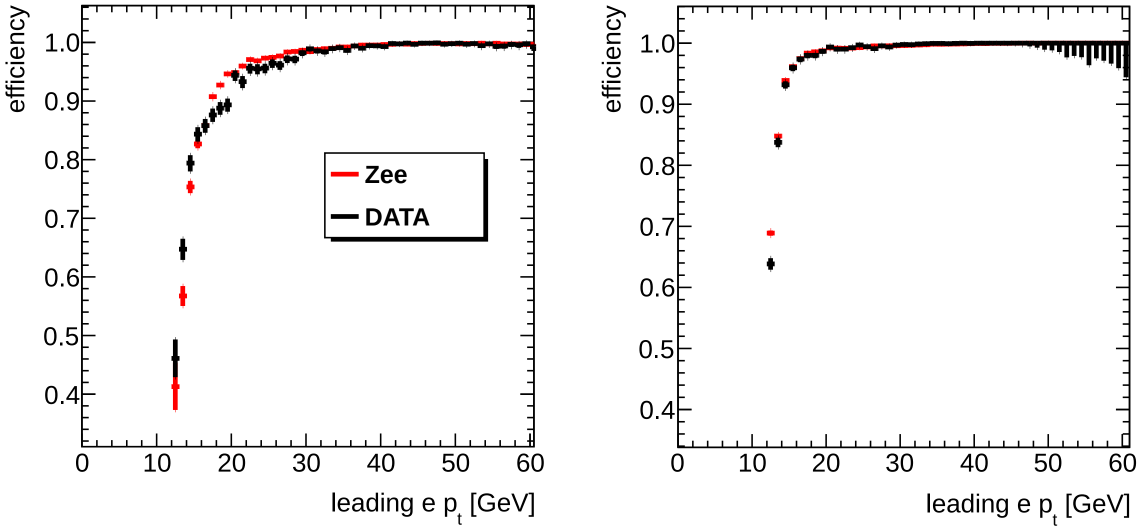

Figure 8: Relative efficiency of EF_2e12T_medium as a function of leading (left) and subleading (right) electron p_T for Z → ee sample and data from two runs from period I2.

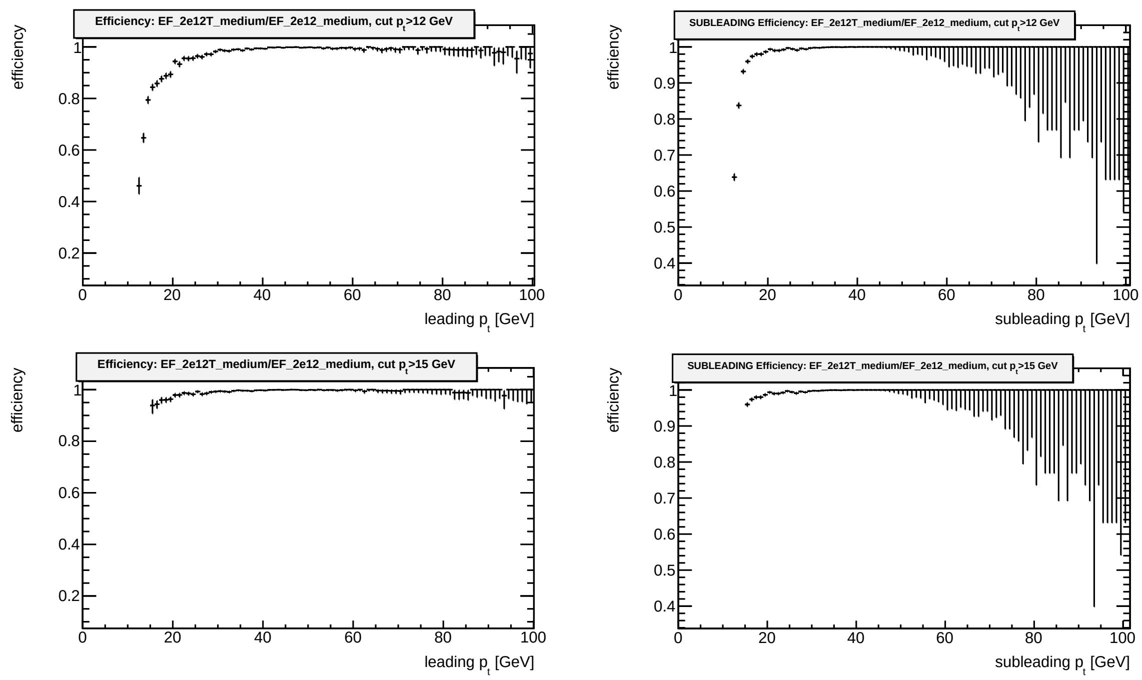

Figure 9: Relative efficiency of EF_2e12T_medium as a function of leading (left) and subleading (right) electron p_T for data from J period for two p_T cuts.

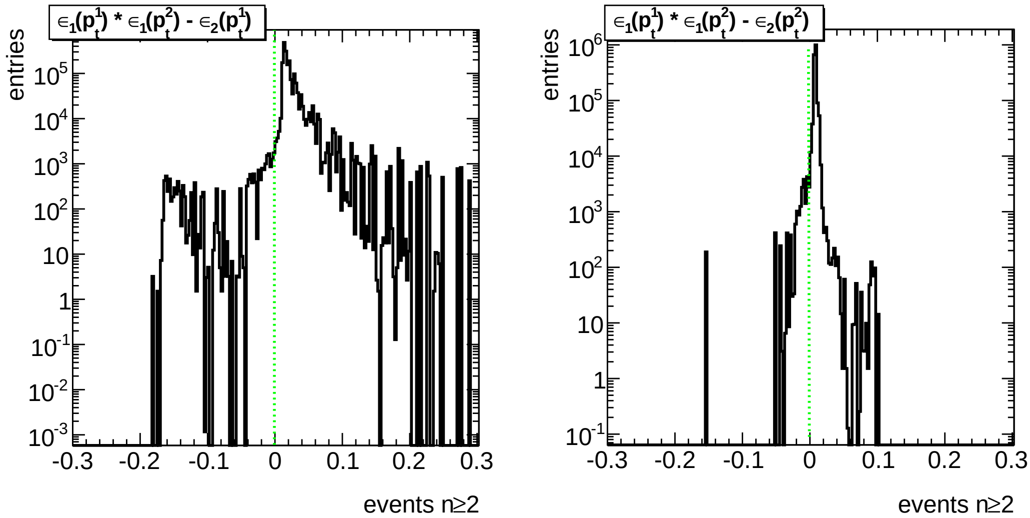

Figure 10: Distributions of ξ_1 and ξ_2 for Z $\rightarrow$ ee sample.

a tag-and-probe method: Z bosons decaying to electron-positron pair are used, one of them is used as tag, to have an unbiased sample, and the other as probe, for which we calculate the single trigger efficiency. Efficiency calculated with this method might be used to obtain the efficiency of a double electron trigger. The easiest idea is to "square" the efficiency of a single trigger or rather by multiplying the efficiencies of a single electrons for given p_T^1 and p_T^2.
For this study on SUSY and Z $\rightarrow$ ee MC, two triggers were used: EF_2e10_medium and EF_e10_medium.

4.2 Method 1

First distributions of the following quantities were checked:

$$\xi_1 = \epsilon_{1\mathrm{e}}(p_T^1) \cdot \epsilon_{1\mathrm{e}}(p_T^2) - \epsilon_{2\mathrm{e}}(p_T^1),$$

and

$$\xi_2 = \epsilon_{1\mathrm{e}}(p_T^1) \cdot \epsilon_{1\mathrm{e}}(p_T^2) - \epsilon_{2\mathrm{e}}(p_T^2).$$

Efficiencies of a single electron trigger $\epsilon_{1\mathrm{e}}$ and double electron trigger $\epsilon_{2\mathrm{e}}$ were calculated with the methods described in the previous sections. Then for each event ξ_1 and ξ_2 were calculated using p_T^1 and p_T^2 for a given event. If by the expression $\epsilon_{1\mathrm{e}}(p_T^1) \cdot \epsilon_{1\mathrm{e}}(p_T^2)$ the efficiency of a double electron trigger as a function of p_T^2 was described, then the distribution of ξ_1 should be narrow and centered at 0. This also applies to $\epsilon_{1\mathrm{e}}(p_T^1) \cdot \epsilon_{1\mathrm{e}}(p_T^2) - \epsilon_{2\mathrm{e}}(p_T^2)$ and the ξ_2 distribution. In Figure 10 these distributions are presented. One can see that the distribution of ξ_1 is wider - $\epsilon_{2\mathrm{e}}(p_T^1)$ is not described well by the efficiency calculated this way. Distribution of ξ_2 is not so wide, but for both cases we have a bias - both distributions are not centered at zero.

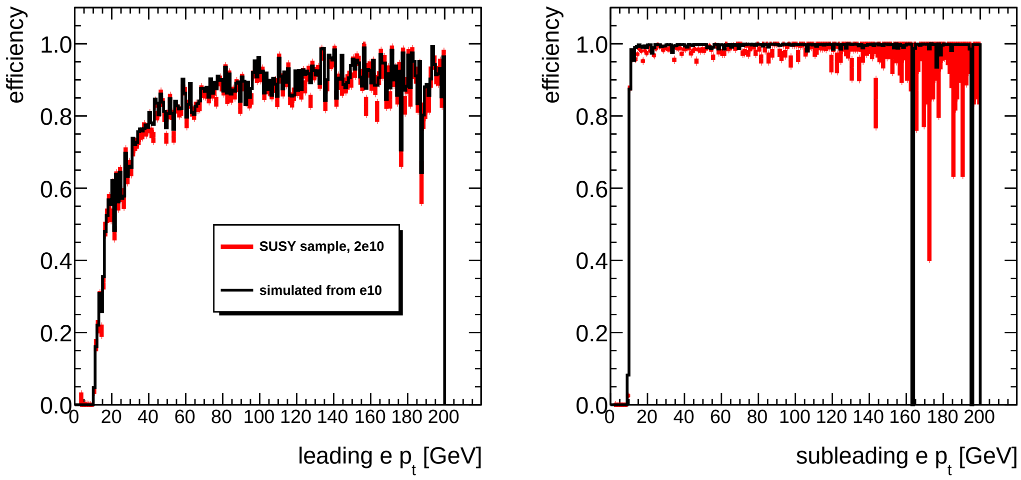

Figure 11: Results for simulation of double electron efficiency as a function of p_T^1 (left) and p_T^2 (right) using efficiency of single electron trigger.

4.3 Method 2

The next step is to check if we can determine $\epsilon_{2e}(p_T^1)$ using information from a single trigger. It might be estimated by:

$$\epsilon_{2e}(p_T^1) = \epsilon_{1e}(p_T^1) \cdot \zeta,$$

where:

$$\zeta = \int \epsilon_{1e}(p_T^2) \cdot f(p_T^2; p_T^1) \mathrm{d}p_T^2.$$

The correction factor for SUSY MC is calculated using the ROOT TProfile class, that returns the bin-wise mean of $\epsilon_{1e}(p_T^2)$. Afterward the efficiency $\epsilon_{1e}(p_T^2)$ is multiplied bin-by-bin with ζ. The result is ploted with efficiency $\epsilon_{2e}(p_T^1)$ in the Figure 11. The same procedure can be performed for simulation of $\epsilon_{2e}(p_T^2)$, the result is also in Figure 11. Results of simulation are satisfying - the efficiency of double electron trigger can be estimated using efficiency of single electron trigger.

5 Summary

Absolute trigger efficiencies using MC for single electron and double electron triggers have been presented. The plateau efficiencies from Z $\rightarrow$ ee samples are: for EF_e20_medium - (0.992±0.005) and for EF_e10_medium - (0.994±0.003). Relative efficiencies between EF_2e12_medium and EF_2e12T_medium have been calculated. There is an inefficiency in the low-p_T region coming from different L1 triggers as seed. It was checked that one can estimate the efficiency of double electron trigger using single electron trigger.

References

[1] ATLAS, G. Aad et al., The ATLAS Experiment at the CERN Large Hadron Collider, JINST 3, S08003 (2008)

[2] D. Casadei, Efficiency measurement: Bayesian approach, (2010), arXiv:0908.0130v5.

[3] M. Paterno, Calculating efficiencies and their uncertainties, (2004), `http://home.fnal.gov/paterno/images/effic.pdf`.

[4] `http://root.cern.ch/root/html/TEfficiency.html`.