Forward Tagging and Jet Veto Studies for Higgs Events Produced via Vector Boson Fusion.

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Abstract

The discovery potential for an intermediate mass Higgs boson produced by vector boson fusion is presently under investigation by the ATLAS Higgs group. The signature for this process is the presence of two forward jets, which are used to tag the events, and low hadronic activity in the region between those two jets. In this work the jet reconstruction is performed with a full simulation of the ATLAS detector and it is compared to the fast simulation to extract a set of corrections to be applied in the Higgs analyses. The effect of pile-up is also studied for two different luminosity scenarios showing that the reconstruction of very low P_T ($<$ 20 GeV) jets can be a critical issue at the highest LHC design luminosity.

Contents

1 Introduction

Since the publication of the physics TDR [1] a large effort was dedicated to the search for the Higgs boson in the so-called intermediate mass range, i.e. in the mass interval between 130 and 180 GeV. In this range precision channels, like the 4-lepton or the 2-photon decays, can not be used for a fast discovery of the Higgs as their inclusive production rate is too low. Thus, other production and decay mechanisms have to be investigated to enhance the Higgs visibility.

It has been suggested [2] that the Higgs can be searched for in the events produced through Vector Boson Fusion (VBF) whose cross section, in the intermediate mass range, is about 4-5 times lower than the gluon fusion one. However, events produced through VBF, have a distinctive signature with two quarks emitted in the forward region of the detector which can be tagged to strongly reject the backgrounds. Moreover the Higgs production is essentially electroweak, so no other hadronic activity is expected, therefore a jet veto can be applied in the rapidity region in between the two forward jets.

These signatures have already been exploited to study the discovery potential of a heavy Higgs boson (M_H >600 GeV) and extended down to a mass of 300 GeV [3, 4]. Presently VBF is being studied in ATLAS for the intermediate mass range, selecting as a decay channel $H \to WW$ [5, 6], or $H \to \tau\tau$ [7, 8]. All these ongoing studies are performed using the ATLFAST [9] fast simulation program of the detector.

The forward jet tagging and the central jet veto play a critical role in these analyses, and it is of key importance to verify their efficiencies with a detailed simulation of ATLAS. In this work the forward tagging and jet veto performance is studied using a full GEANT simulation of the ATLAS detector [10] for different values of the luminosity. The results are then compared to the ATLFAST predictions to extract the appropriate correction factors to the ATLFAST results and to obtain a more realistic response.

2 The ATLAS Full Simulation Data Sample and Event Reconstruction

2.1 Data Samples

A sample of 23,000 fully simulated events of $H \to WW \to 2l2\nu$ is used to study the forward tagging and the jet veto efficiencies. The mass of the Higgs is 160 GeV and l stands for electron or muon. This sample was simulated by the Alberta group using DICE on a pc farm[1].

For comparison a sample of events of the same type, simulated using Atlfast for the Higgs group[2], is used. To verify that the kinematics of the two samples is the same, some relevant distribution have been compared and no relevant difference was found.

The full simulation events are analyzed using the combined ntuples in the ATRECON framework [11]. The calibration constants of the forward calorimeter have been changed with respect to the default ones in the *calibf.age* routine, as suggested by [12] and set to

[1]Courtesy of Jim Pinfold and Jeff DeJong.

[2]Events produced by M. Klute. Information at http://klute.home.cern.ch/klute/higgs/mcarlo/r5000.html

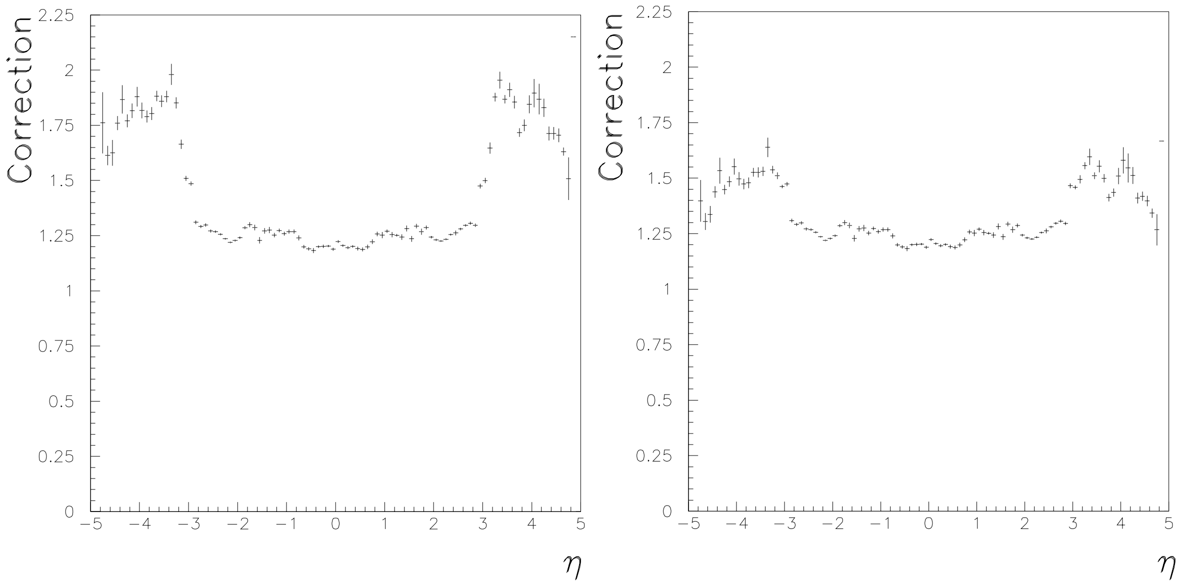

Figure 1: *Correction coefficient, as a function of η, which is applied to recover the correct energy scale of fully simulated jets. The plot on the left is referring to the default setting of ATRECON, while on the right the setting used in this work is shown.*

Forward Sample	Old Parameter	New Parameter
FCAL-1	68.4	89
FCAL-2	134.4	137
FCAL-3	103.9	113

Table 1: *Calibration constant used for the forward calorimeter.*

the values given in table 1. Pile-up at low/high luminosity is added at ATRECON level, by using the CLPILE routine [13].

The comparison with ATLFAST is carried out using different reconstruction schemes, namely:

1. No pile-up added and standard ATRECON calorimeter calibrations;
2. No pile-up added and calorimeter calibrations modified for the forward region;
3. Low luminosity pile-up and modified calibration constants;
4. High luminosity pile-up and modified calibration constants.

A proper reconstruction of the charged leptons is beyond the aim of this work, so a faster approach was taken for the electron and muon reconstruction. Two charged leptons (electrons or muons) with $P_T > 20$ GeV and $|\eta| < 2.5$ are required at the parton level, i.e. in the KINE banks, and all the jets within a cone of radius $\Delta R = 0.2$ around the leptons are removed from the list of jets.

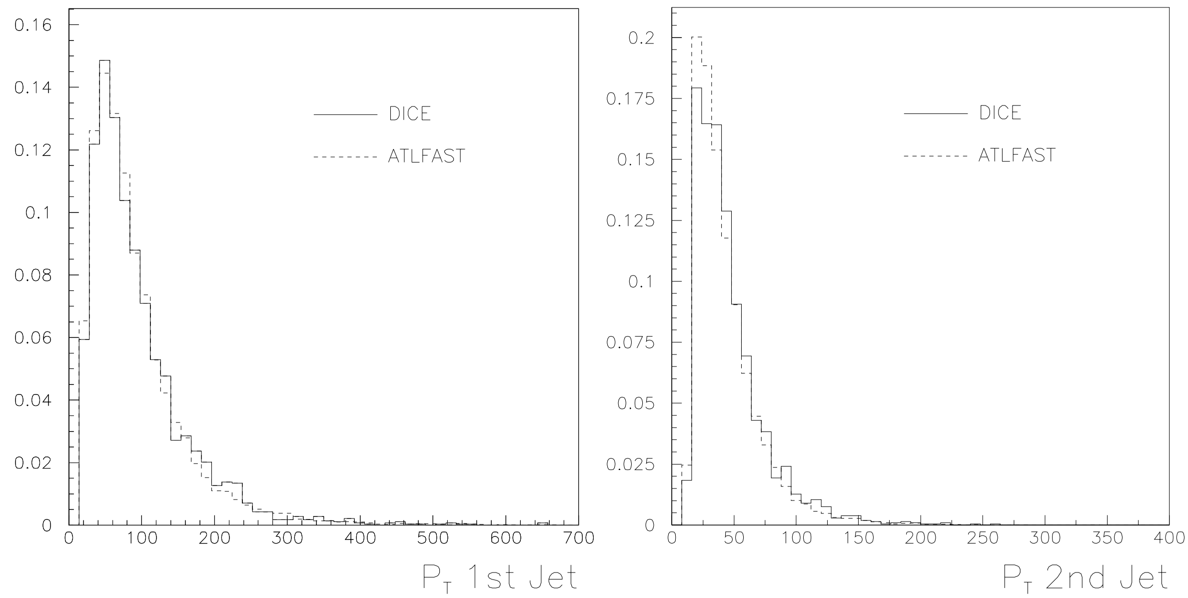

Figure 2: *Transverse momentum of the leading (left) and second to leading (right) jet. DICE and ATLFAST simulations are compared.*

2.2 Jet Energy Calibration

After running ATRECON the jets have still to be calibrated in order to take into account detector inhomogeneties, and to recover the correct energy scale. A routine to achieve this has been provided by the Jet/ETmiss group (*calv6jet.f*) and the correction coefficient which is applied is plotted in figure 1 as a function of the pseudorapidity of the jets. On the left the correction coefficient is plotted using the default ATRECON settings, while on the right the parameter setting of the leftmost side of table 1 is used. This correction is particularly significative in the forward calorimeter region, however, with the new set of ATRECON parameters, the correction coefficient for the forward region is closer to one than in the default case.

After this rescaling, the P_T distribution of the jets should be similar for the full simulation and the fast simulation, the reconstructed transverse momentum of the two leading jets is compared in figure 2 for the two different approaches. However the P_T of the jet is not yet matching the P_T of the originating parton, as a further correction to recover the effect of initial- and final-state radiation has to be applied. This correction is provided for the ATLFAST simulation (*atlfcal*), but it can be used also for the full simulation events after the correct energy scale is defined. Finally, the ratio between the jet energy and the parent parton energy is plotted in figure 3 as a function of η for DICE (left) and ATLFAST (right), showing that the reconstruction and calibration procedures discussed in this section restore the original parton energy at the level of a few percent in the full pseudorapidity range covered by ATLAS.

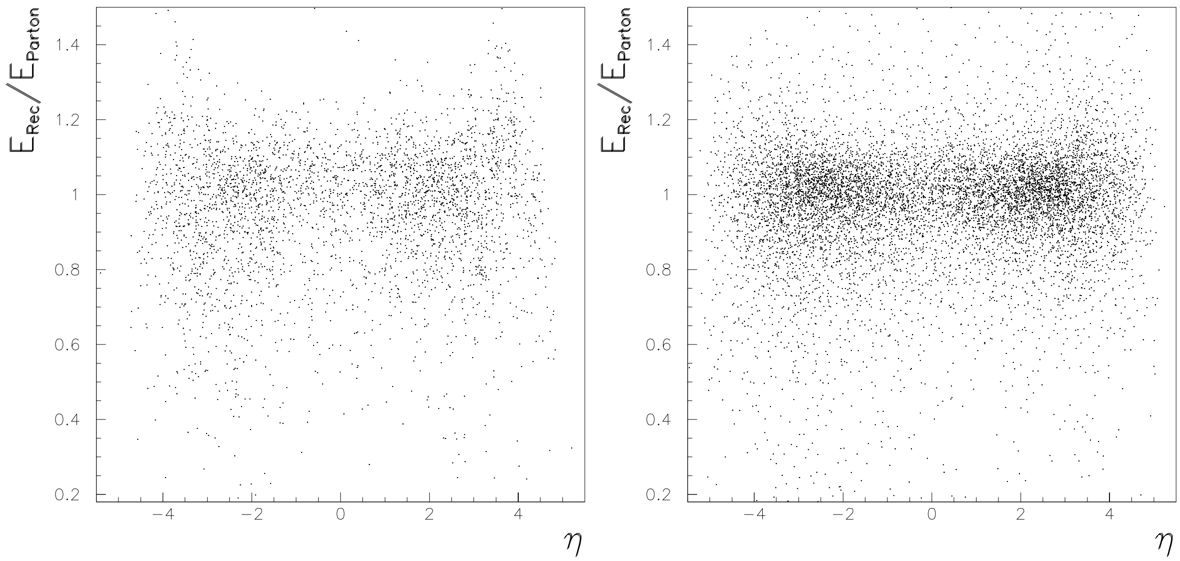

Figure 3: *Ratio between the reconstructed jet energy and the matching parton energy as a function of η for the full simulation (left) and ATLFAST (right).*

3 Forward Tagging and Jet Veto without Pile-up

The first comparison between ATRECON and ATLFAST is performed assuming that there is no minimun bias pile-up. This situation is not realistic, as some pile-up is expected also when LHC will run at $10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$. However pile-up events are not included in the fast simulation, so this comparison is useful to understand the role of the interaction of the particles with the detector.

3.1 Matching Efficiency

A parton which fragments into a jet, depending on the detector performance and jet algorithms, is reconstructed with a given efficiency. To quantify this efficiency in figure 4 (left) the probability for a parton with $P_T > 15$ GeV to match a jet within a cone of radius 0.2 (the jet angular resolution) as a function of η is shown. On the right side of figure 4 the ratio between the full simulation and the particle level matching efficiencies is plotted for three different ranges of the jet transverse momentum. It can be noted that there is a drop in the efficiency in the region around $|\eta| = 3$ due to the forward crack. This drop is particularly evident for jets with $15 < P_T < 30$ GeV. The efficiency finally drops at the edge of the detector, as jets are no longer contained.

The matching efficiency is the main difference between the particle level and the full simulation, and should be taken into account in all VBF analyses to obtain a more realistic response of the detector. To account for this a fortran function (*dicecorr.f*) is provided which, for a jet with a given η and P_T, returns the probability for the jet to be identified

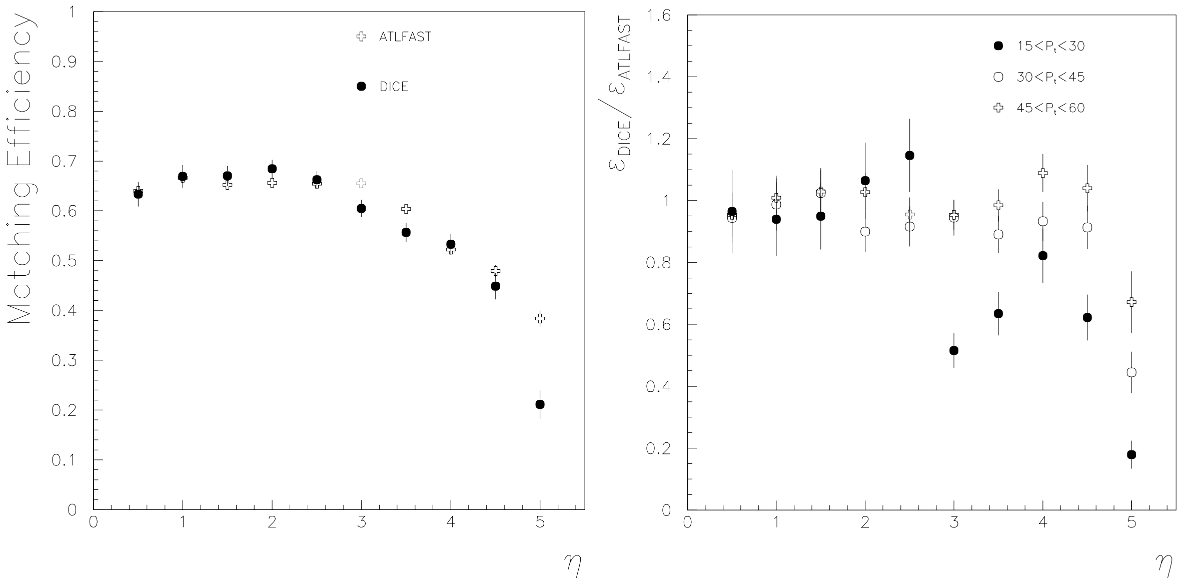

Figure 4: *Matching efficiency between partons and jets as a function of η. On the left DICE and ATLFAST are compared, while on the right their ratio is shown for different P_T bins, evidencing the inhomogeneties of the detector.*

by the full simulation[3].

3.2 Forward Tagging and Veto on Extra Jet Activity

An event is defined as forward tagged if two jets above a given threshold are present, one in the forward ($\eta > 2$) and one in the backward ($\eta < -2$) direction. The efficiency for this (double) forward tagging is plotted in figure 5 (left) as a function of the P_T threshold applied. The full simulation results are compared to ATLFAST, before and after applying the correction for the detector efficiency described in the previous section.

Higgs events are also expected to have a low hadronic activity in the region between the two forward jets, due to the color structure of the events. For this reason a veto can be applied on the presence of a jet in this region, resulting in a further enhancement of the signal compared to the backgrounds. However this veto to be efficient, requires the reconstruction of jets with a P_T as low as 15 GeV, which suffers from detector inefficiencies and from the presence of fake jets coming from pile-up events, as it will be discussed in the next section.

[3]This routine and the other routines needed by the Higgs group to correct the particle level results can be found on the web at *http://www.pi.infn.it/atlas/physics/soft.html*

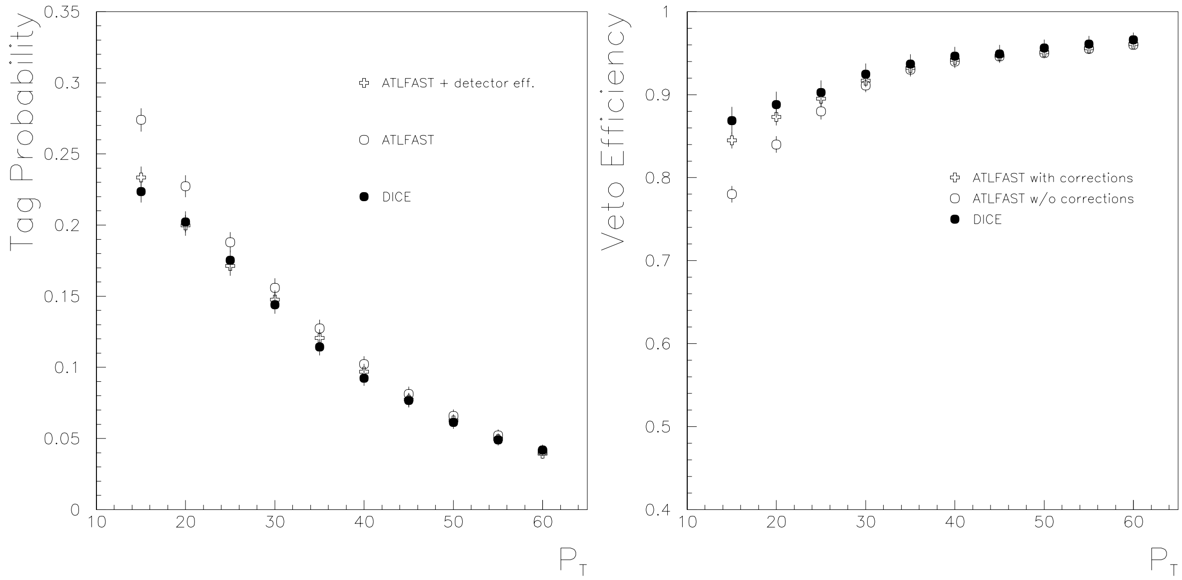

Figure 5: *Forward tagging (left) and central veto (right) efficiencies as a function of the P_T threshold applied. The full simulation is compared with ATLFAST, before and after applying the jet efficiency correction defined in section 3.1.*

4 The effect of Pile-up

At LHC more than one interaction will occur during the same bunch-crossing, with the exact number depending on the instantaneous luminosity of the machine. Two scenarios are usually investigated, one low-luminosity scenario at $10^{33}\text{cm}^{-2}\text{s}^{-1}$ and one high-luminosity scenario at $10^{34}\text{cm}^{-2}\text{s}^{-1}$. Moreover the integration time of the ATLAS sub-detectors will be longer than the 25 ns inter-bunch time. The minimum-bias pile-up contributes with different weights over 10-20 bunch crossings. This is simulated using ATLAS standard routines as described in section 2.1. Due to the bi-polar shaping of the LAr calorimeter electronics, the presence of pile-up results in an extra noise introduced in the calorimeter towers.

The distribution of the deposited transverse energy in the calorimeter cells is shown in the histograms in figure 6, and their RMS values are reported in table 2. Each histogram refers to a different η region, and the two luminosity scenarios are superimposed, the width of those distributions slightly depends on the pseudorapidity. As a first approach, a threshold cut of 0.2 (1.0) GeV for the low- (high-) luminosity scenarios has been applied on the transverse momentum deposited in each calorimeter cell to remove this noise.

The probability of reconstructing an extra jet due to the minimum bias contribution in the central region of the detector is plotted in figure 7 as a function of the P_T of the jets for a sample of pile-up only events. The two different operation luminosities are considered as well as different sizes for the central region definition.

The effect of pile-up on jet veto and on forward tagging is shown in figure 8. The efficiency is decreasing due to the presence of pile-up when threshold cuts on jets below

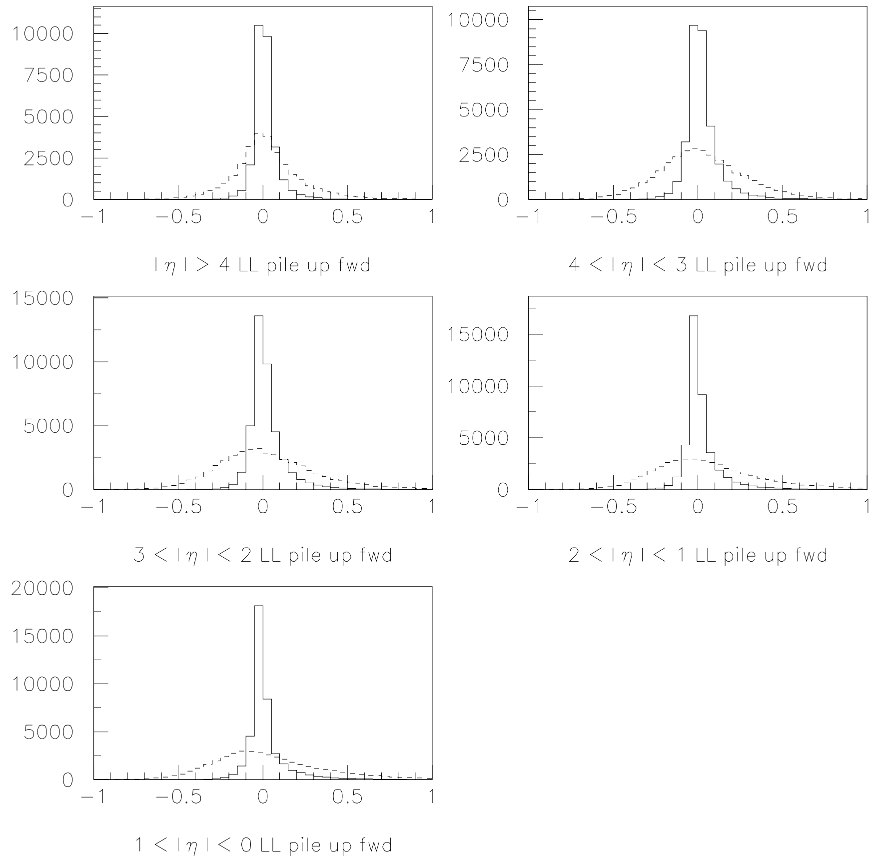

Figure 6: *Transverse energy (in GeV) released in a single cell, for low luminosity pile-up (full line) and high luminosity pile-up (dashed line), and for different η bins.*

30 GeV are applied. In figure 8 (right) we see that the forward tagging efficiency is reduced for high P_T threshold, as a cut on cells transverse energy is reducing the total reconstructed energy of jets. For lower P_T thresholds, the forward tagging efficiency is higher in presence of pile-up, due to the contribution from fake jets.

The effect of the cell E_T threshold on the tagging and veto efficiencies is shown in figure 9, for a 15 GeV and a 30 GeV cut on veto and tagging jets. The results are stable when a 30 GeV threshold is considered, while there is a dependence on the cell threshold for low P_T jet cuts.

Conclusions

The forward tagging efficiency and the veto efficiency for $H \to WW$ events have been studied with a full simulation of the ATLAS detector. The results were compared to the

η region	Low Luminosity Noise (MeV)	High Luminosity Noise (MeV)
$\|\eta\| > 4$	80	210
$4 < \|\eta\| < 3$	110	270
$3 < \|\eta\| < 2$	120	280
$2 < \|\eta\| < 1$	120	290
$0 < \|\eta\| < 1$	130	310

Table 2: *RMS of the histograms in figure 6, i.e. noise from the minumum-bias contribution for low and high luminosity and for different pseudorapidity region.*

ATLFAST simulation and a routine to correct the reconstruction efficiency as a function of P_T and η of the jet is provided, for a cell E_T threshold of 0.2 (1.0) GeV for low- (high-) luminosity.

The effect of the pile-up noise is studied as well and a threshold cut on the transverse energy of the calorimeter cells is applied to cut it. The dependence of the efficiency on this threshold cut is also investigated.

In conclusion the veto efficiency and the forward tagging probability are reliably estimated by ATLFAST if a 30 GeV cut is applied on the transverse energy of jets in the high luminosity scenario.

Acknowledgements

We would like to thank Jim Pinfold and Jeff Dejong from the Alberta group for providing us the DICE simulated events with which this analysis is done. Jeff Dejong also for the help on all the technical aspects of the full simulation. We thank Andrei Kiryunin, Martine Bosman and Peter Loch for the suggestions on the jet simulation, Georges Azuelos and Stefan Simion for the pile-up addition, and Karl Jakobs for useful discussions.

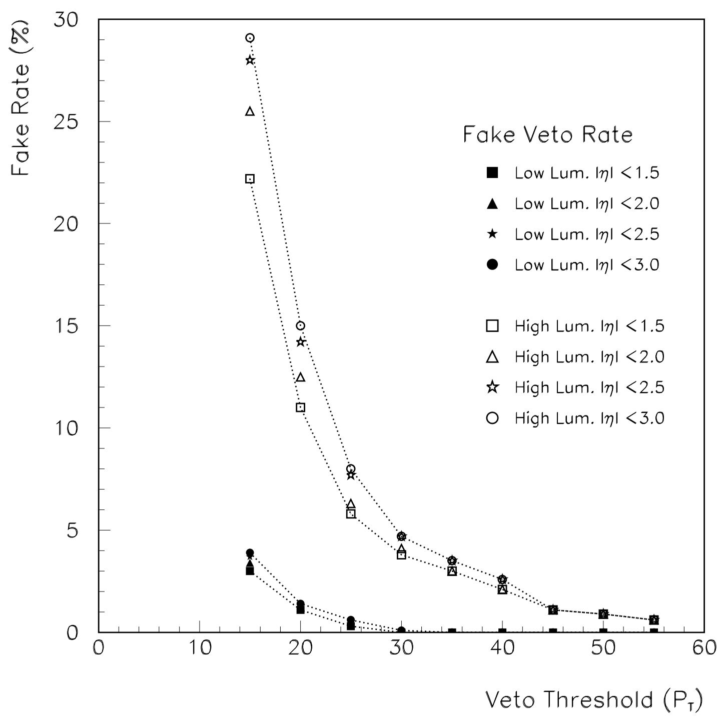

Figure 7: *Probabilty to reconstruct a jet in the central region of the detector due to the presence of pile-up. The results are plotted for two different luminosity operation scenarios of the LHC and for different sizes of the central pseudorapidity region of ATLAS.*

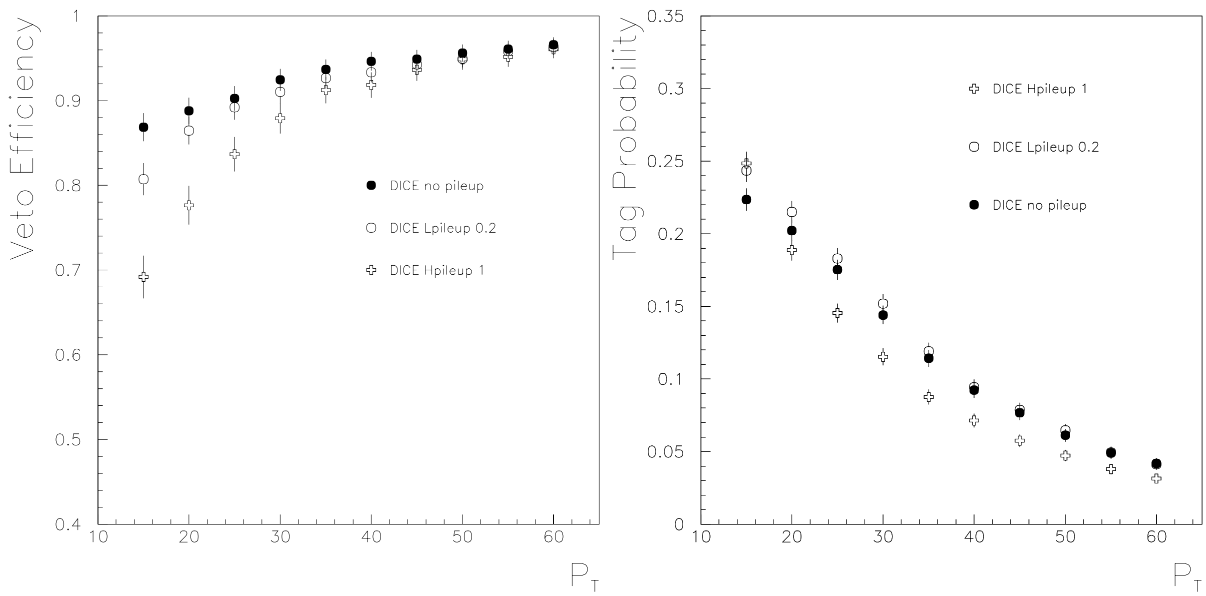

Figure 8: *Effect of the pile-up noise on the veto (left) and forward tagging (right) efficiencies, the low and high luminosity pile-up scenarios are compared to the ideal situation when no pile-up is included.*

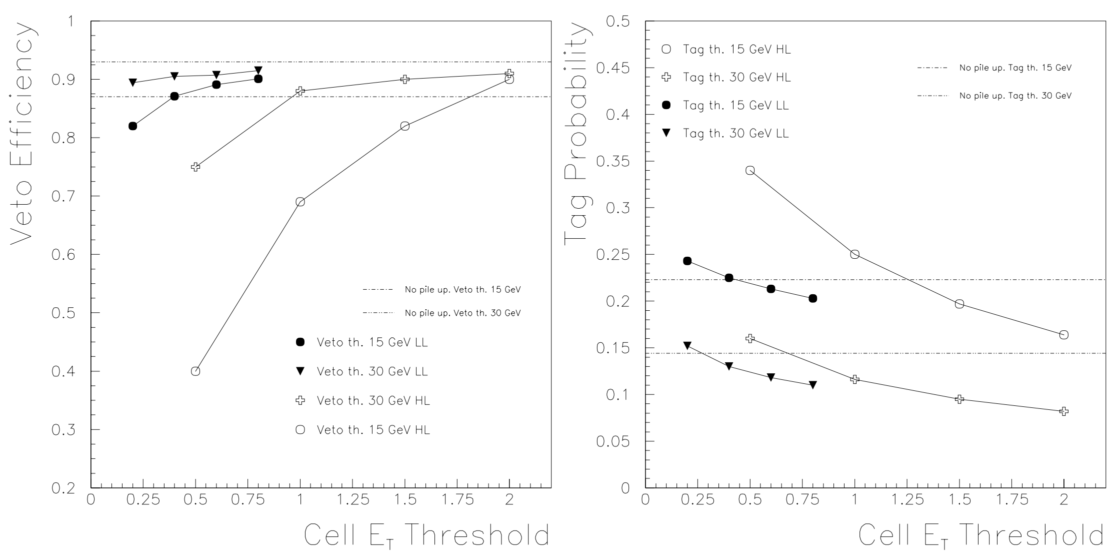

Figure 9: *Effect of cell E_T threshold on the veto (left) and forward tagging (right) efficiencies. The veto and forward tagging efficiency for a cut of 15GeV and of 30 Gev on jet P_T are plotted as a function of the E_T threshold applied on calorimeter towers. The horizontal lines show the values for the no-pileup situation. Low and high luminosity situations are considered.*

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