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# Chapter 1

# Prospects for Neutral MSSM Higgs Search Improvement

The neutral MSSM Higgs search, described in the previous chapter, suffers strongly of poor jet reconstruction efficiency and b-tagging performance due to the particular phase space required, this bound the potential of this search, improoving b-tagging would result in a major improvement of the search sensitivity. This chapter investigates an alternative to the commonly used calorimeter jets in ATLAS, which is trackjets b-tagging. The prospects for successfully use trackjets b-tagging in the future neutral MSSM Higgs searches are reported, b-tagging on trackjets was never attempted before. Section**??** describes this and that...

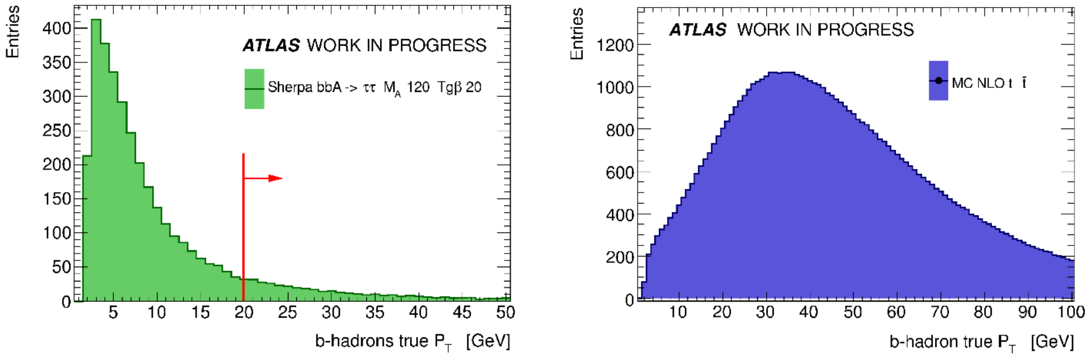


Figure 1.1: Cormparison of simulated b-hadron distribution for signal b-associated production events (left) and $t\bar{t}$ events (right). The red line in the figure shows the acceptance region due to calibrated jet $p_t$ requirements.

## 1.1 Introduction to Trackjets

This problematic has two sources: - The ATLAS calorimeter is not a sampling calorimeter, this means that responses differently for Hadrons and for leptons, has different responses to electromagnetic and hadronic shower. The Calorimeter cells are calibrated in energy using response to electromagnetic showers, to know the energy of the original parton that initiated the jet there are different procedure to calibrate the Jets offline which are called in short Jet Energy Scale (JES) corrections [], which make use of MC simulation. Due to the high amount of pileup and ambient energy density in the events, jets are calibrated from 20 GeV in $p_t$, this means that currently is not possible with calorimeter jets to access the low transverse momentum phase space.

The neutral MSSM Higgs search, as described in chapter **??**, splits the dataset in two category by means of the presence or the absence of a b-tagged jet, the b-tagged category is optimized for the b-associated production mechanism, in which the Higgs is produced in association with two b-jets. Figure 1.1 shows a comparison between $p_t$ spectrum of simulated b-hadron in b-associated Higgs and $t\bar{t}$ events, the signal prefers b-hadron with relatively low transverse momentum, jet calibration invoqe jet $p_t > 20$ GeV removing a large fraction of possible signal candidate, many of the b-associated production signal events falls in fact in the b-veto category, making the separation not so effective. The low $p_t$ spectrum is actually quite challenging, jet reconstruction efficiency and calibration set then a lower limit to the signal sensitivity in the b-tag category. Another challenge to this search are the poor b-tagging performance at low transverse momentum, for the a fixed tagging point of the MV1 tagger the b-tagging efficiency drops, in fact, rapidly with jet $p_t$ reacing a minimum of 50% at 20 GeV [65, 66] (using as tagging point the 70% point).

A solution to the jet reconstruction efficiency is to use, instead of calorimetric jets (calo-jet), track-jet , which are as well anti-kt object (see chapter**??**) but constructed using inner detector tracks as building blocks, not calorimeter cells. Jets in the ATLAS reconstruction software are reconstructed by clustering four vector objects (calorimeter energy cluster, tracks, truth particle, etc.) in the $\eta - \phi$ plane. In the case of clustering tracks, however, it is possible to take advantege of the longitudinal ($z$) impact parameter information provided by the inner detector and build track-jets in three dimensions $\eta - \phi - z$. Track-jets will then contains only tracks originating from the same interaction point (reconstructed vertex). Even thoug for calorimeter jet is possible to use the JVF, track-jets result to be more resistant to decrease in performance in the presence of pile-up, thus particolarly important in b-tagging, which depends on the determination of the jet-axis. B-tagging has been never tested before on track-jets, in the following, the first study of b-tagging over track-jets performances is reported.

Trackjets are builded by running the anti-kt clustering algorithm on a subset of tracks with respect to the total tracks in the event, this subsample is chosen by means of the TrackZTool this will return only tracks that are associated with the primary vertex of the event (vertex with higher transverse momentum tracks associated), furthermore, to be allowed in the collection, tracks need to pass the following quality selection criteria:

- $|z_{PV} * sin(\theta)| < 1.5$ mm, which the distance between the primary vertex and the extrapolation of the track to the plane ortogonal to the beam axis, and is a measure of how much the track is pointing to the PV in the plane that contain the beam axis.

- $d_{PV} < 1.5$ mm where $d$ is the minimum distance between the track and the primary vertex in the plane ortogonal to the beam axis.

- At least one pixel hit and at least 5 SCT hits.

- No b-layer hit requiremets

- $|\eta| < 2.5$

- $p_t > 300$ MeV

- To build a trackjets is necessary to cluster at least two tracks

- A trackjet is produced and stored if the sum of its tracks has $p_t > 2$ GeV.

it has been shown that those selections, togheter with a maximum cone size for clustering of $\Delta R = 0.6$, are the best compromise between quality requirements, to control "fakes" i.e. tracks from random association of hits or badly reconstructed tracks, and b-hadron reconstruction efficiency.

For the purpose of studying performance of trackjets the trackject building algorithm, with the specifications previously described, the following ATLAS standard MC simulation samples are produced with trackjets and b-tagging by means of ad-hoc implemented software within the ATLAS NTUPLE production software framework. Table 1.1 report a summary of the produced samples and their purpose of use.

| Process | MC Generator | Purpose |
|---|---|---|
| Minimum bias | Pythia | Systematics study |
| $b\bar{b}$ | Alpgen | Performance for low $p_t$ b-tagging |
| $Z \to \tau\tau$ | Pythia | Impact on the analysis |
| $t\bar{t}$ | MC@NLO | Impact on the analysis |
| MSSM $bb/A/h/H$ | Sherpa | Impact on the analysis |

Table 1.1: Monte Carlo simulation sample produced for the sudies reported in this chapter.

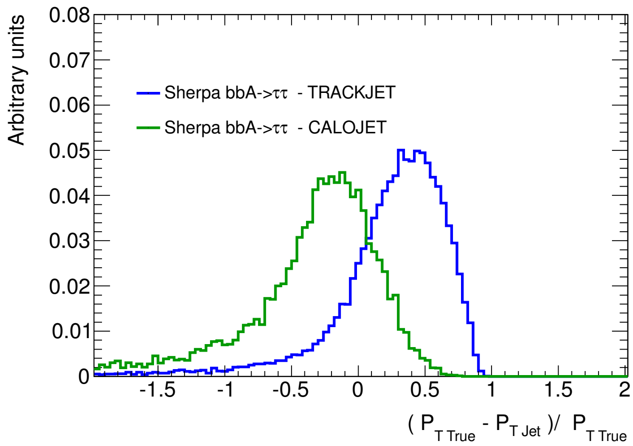


Figure 1.2: Residuals comparison of track-jet and calo-jet $p_t$ with respect simulated jet $p_t$.

## 1.2 Trackjet Performance

### 1.2.1 B-tagging Performance

Many analysis could profit from an enhanced b-jet reconstruction efficiency at low $p_t$, the study presented in this section is aimed to compare performance of common b-tagging algorithm and b-jet reconstruction efficiency between calorimeter jets (calo-jet) and track-jets, the study is specially focused on low transverse momentum jets. Due to the high precision of the inner detector track-jets are robust agaist pileup and is possible possible to reconstruct them up to very low transverse momentum, if they are used for the only purpose of b-tagging then calibration is also not needed, however, track-jets can only reconstruct the charged part of the jet, the neutral part is lost, according to isospin invariance the expected neutral fraction in a jet is roughly 2/3 of the total. This implies that the momentum and of the track-jet will be shifted and the direction will have a larger uncertainty, figure 1.2 shows a comparison of track-jet and calo-jet $p_t$ residuals with respect to true jet $p_t$, this effect may be critical for b-tagging algorithm since some of them strongly rely on the maesurement of jet axis and jet $p_t$.

To compare performance of track-jet and calo-jet, a cone size anti-kt 0.4 is choosen, if a reconstructed jets lais up to a distance in $\Delta R$ ¡ 0.3 from a simulated b-hadron in the event, this jet is said to *match with a b-hadron*. Reconstruction

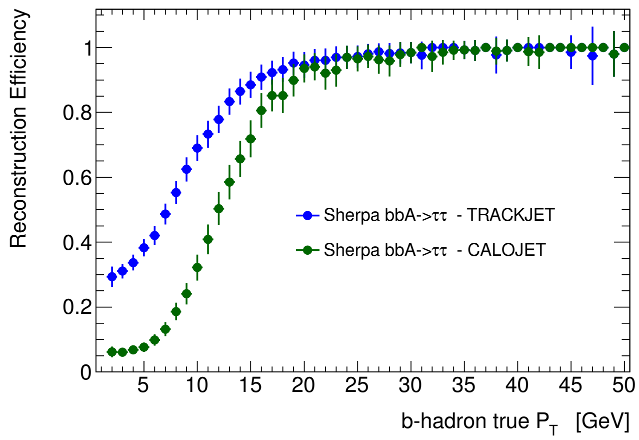


Figure 1.3: Comparison of b-hadron reconstruction efficiency for track-jet and calo-jet as a function of the simulated b-hadron $p_t$. Note that calo-jet and track-jet has a requirement at production level to be respectively with $p_t > 7$ and 2 GeV, a fair comparison is only possible above 8 GeV in $p_t$.

efficiency is then defined as the ratio between the number of matched b-hadron and the total number of b-hadron. Figure 1.3 compare b-hadron reconstruction efficiency between calo-jet and track-jets, the latter shows a higher reconstruction efficiency for low transverse momentum due to their robustness to pileup.

To exploit the performance of b-tagging on trackjets other two definitions are usefull: the tagging efficiency and the rejection power. The *tagging efficiency* is the fraction of *matched* jets wich passes a determined selection on a tagging algorithm, i.e. which are *tagged*. The rejection is the inverse of the misidentifying rate, i.e. the inverse of the fraction of the jets which are not matched with a b-hadron or c-hadron, but are tagged. Fixing the selection value for a given tagging algorithm will fix a point in the efficiency-rejection plane, this is a common way in ATLAS to determine the performance of b-tagging and is shown in figure 1.4, figure 1.5 instead shows the rejection as a function of the $p_t$ of the trackjet for the tagging point which gives 50% efficiency for that $p_t$ value. Mistagging rate is rapidly increasing for low transverse momentum trackjets, revealing the necessity of a dedicated tagging algorithm for low $p_t$ jets.

The previously introduced definitions do not allow a fair comparison between trackjets and calojets, due to the fact that calojets can be reconstructed also in case no tracks are associated with them, in this particular case any tagging algorithm would likely fail, altering the rejection distribution. It is convinient to use instead the following quantities, *effective rejection*, which is the inverse of the number of mistagged jets per event, and the b-hadron *reconstruction efficiency*, which is defined above. Figure 1.6 shows a comparison between calojets and trackjets for the two variables just defined, for a given b-hadron reconstruction efficiency trackjets can achieve higher rejection, for a fair comparison in this plot trackjets are selected in the transverse momentum range between 4 and 25 GeV, while calojets between 8 and 50 GeV, this follow from figure 1.2. This demonstrates that thackjets are more suitable than calojets for low transverse momentum b-tagging.

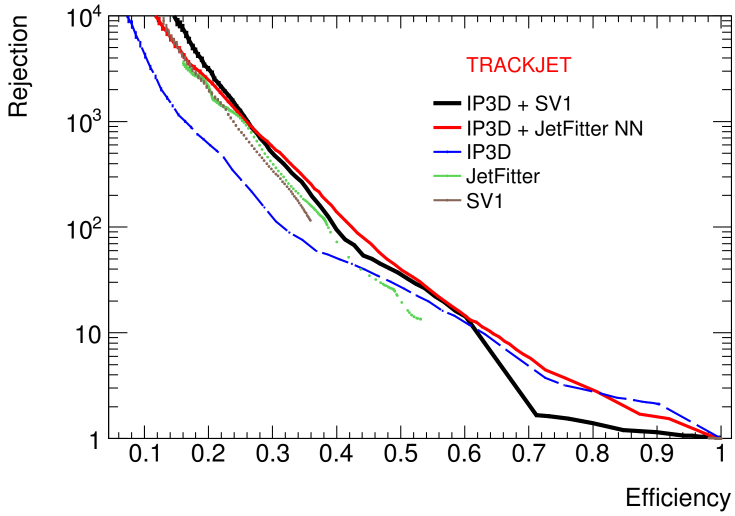


Figure 1.4: Rejection as a function of the tagging efficiency for different ATLAS tagging algorithm.

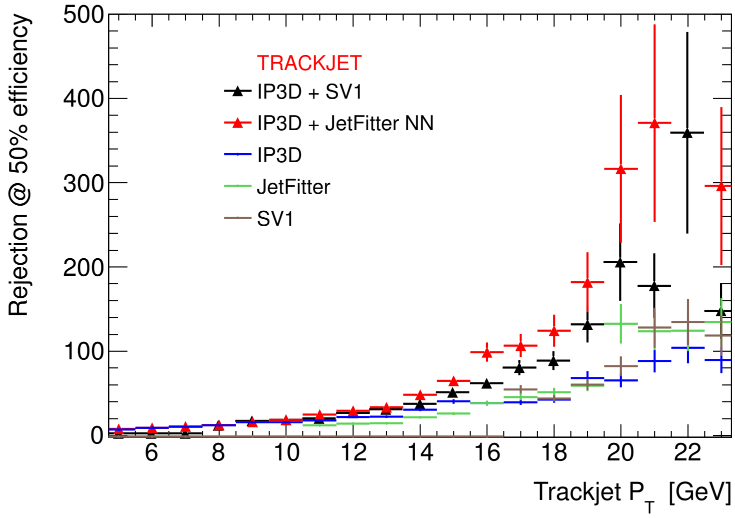


Figure 1.5: Rejection as a function of the transverse momentum of the trackjet for the tagging point which gives 50% efficiency for that $p_t$ value. Different ATLAS tagging algorithm are reported.

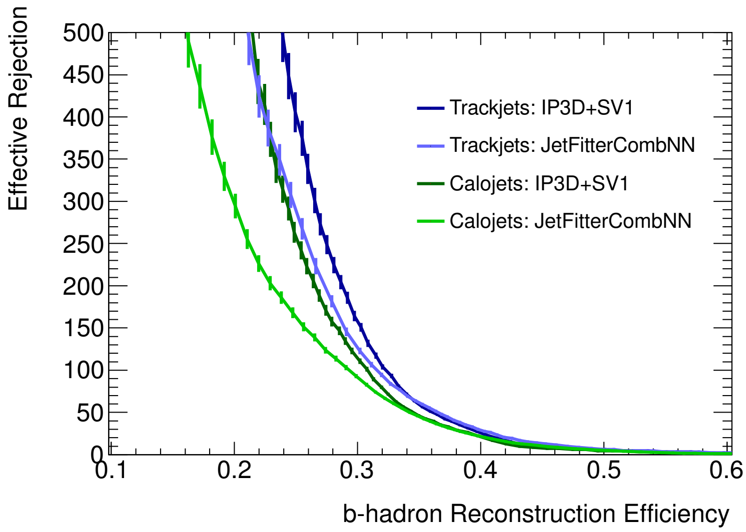


Figure 1.6: Effective rejection as a function of b-hadron reconstruction efficiency, trackjet and calo jets are compared for two different ATLAS tagging algorithms. Trackjets are selected in the transverse momentum range between 4 and 25 GeV, while calojets between 8 and 50 GeV.

The impact of trackjets on the analysis is tested in a preliminary study, the yield of signal and for the most significant backgrounds is compared in table 1.2, where preselection is defined in a very similar[1] way to what has been discuss in section **??** with the following exeption on the definition of taggable jets:

- Calorimeter taggable jets should have $|\eta| < 2.5$ and $20 < p_t < 50$ GeV
- Track taggable jets should have $|\eta| < 2.5$ and $5 < p_t < 33$ GeV, this correspond to the same range as for calojets above, figure 1.2 in fact is only valid for low $p_t$ jets and the fraction of momentum lost appreciate 1/3 for high $p_t$ trackjets.

## 1.3 Systematic Uncertainties on Trackjets

### 1.3.1 General discussion

### 1.3.2 Track Subtraction Method

### 1.3.3 Track Subtraction Validation

### 1.3.4 Track Subtraction Results

[1]This study has not been updated with the newest version of the object reconstruction selections and corrections, a difference of the order of 10% is expected with respect the numbers in table **??**.

| Selection | Signal $bbA/H/h$ | | $Z \to \tau\tau$ | | $t\bar{t}$ | |
|---|---|---|---|---|---|---|
| Preselection | $127.2 \pm 2.2$ | | $3017 \pm 8$ | | $2066 \pm 5$ | |
| | Calojet | Trackjet | Calojet | Trackjet | Calojet | Trackjet |
| At least one taggable jet | $47.3 \pm 0.8$ | $106.9 \pm 1.8$ | $1146 \pm 3$ | $2513 \pm 7$ | $1804 \pm 4$ | $2014 \pm 5$ |
| Exactly one jet matched b-hadron | $18.4 \pm 0.3$ | $46.7 \pm 0.8$ | $4.5 \pm 0.3$ | $18.2 \pm 0.5$ | $1054 \pm 3$ | $959.1 \pm 2.3$ |
| Exactly one tagged jet | $10.2 \pm 0.1$ | $21.0 \pm 0.6$ | $37.3 \pm 0.5$ | $107 \pm 1$ | $777 \pm 4$ | $630 \pm 4$ |

Table 1.2: Impact of tracjets on the analysis, the event yield is compared between tracjets and calojets. As a signal b-associated production is simulated for $\tan\beta = 20$ is assumed. The yields are normalized to an integrated luminosity of 1 $fb^{-1}$.

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