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Calibration of Monte Carlo jets for the fixed cone algorithm in ATLAS experiment

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Abstract

An optimization of the jet calibration implemented in the Monte Carlo simulation package for ATLAS experiment has been proposed. A set of Z + 1 jet events have been simulated to get a new parameterization, and to complete the calibration the W bosons produced in $t\bar{t}$ events have been reconstructed. A simple fixed cone algorithm commonly used for the jet reconstruction in various experiments has been tested for different values of the cone size and p_T^{jet} threshold, and also for different processes such as $WH(H \to b\bar{b})$ and W+jets. The important features of the algorithm were noted and correspondent recommendations have been worked out.

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1 Introduction

Several parameterizations for the jet energy calibration in ATLAS [1] have been developed in the ATLFAST framework [2]. In particular, there are sets of parameters from the *atlfast-b* [3] code and a recently proposed alternative calibration based on a neural net approach [4]. Another set of parameters was presented in the paper [5] devoted to the *top* quark mass measurement in ATLAS. For the latter a sample of 8 million Z + 1 jet events was generated with Pythia 6.115 [6] and the CTEQ4$\overline{MS}$ set of parton distribution functions. The hard process was generated with a minimum p_T = 20 GeV/c, and a p_T^{jet}-threshold of 15 GeV/c was applied for the jets selection. The calibration (energy scale) was obtained by fitting the ratio $R = p_T^Z/p_T^{jet}$ as a function of the raw p_T^{jet} for jets of two different types (*b*-jets and others). This calibration was used to reconstruct the mass of $W(W \to jj)$ boson in semi-leptonic $t\bar{t}$ events and define the global correction coefficient $C_{mass} = M_W/M_{jj}$ (mass scale) which could be applied to all jets. The mass scale was checked for p_T^{jet} > 40 GeV/c. In all approaches above the jets were reconstructed by means of the fixed cone algorithm with the radius ΔR_{cone} = 0.4 (where $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$).

There were several motivations for a new attempt which is presented in this Note. The "standard" (fixed cone) parameterization [3] is not described in full details yet, and its direct application to the continuum background (e.g. W + jets) gives a low mass peak in the jet + jet invariant mass spectra (see, namely, $Wb\bar{b}$ ntuples used for TDR [7]). This could be corrected either by implementing a cut to separate two jets or by increasing the cone size and so making a new parameterization. In addition, we have attempted to calibrate the low p_T jets more accurately and included a new "standard" set of *p.d.f.* (CTEQ5L).

The Note is organized as follow. First we recall how the jet calibration was obtained for the commonly used value of the jet cone size ΔR_{cone} = 0.4. We analyze Z + 1 jet events to get the energy correction for raw p_T^{jet} and apply the obtained calibration to $t\bar{t}$ processes to define the mass scale. The differences from the reference analyses are noted. Then the calibration is applied to the light SM Higgs boson study (WH) and some details are pointed out. The analysis for W+jets processes is presented in more detail for various cone size values. Finally, the "optimal" value ΔR_{cone} = 0.6 is proposed and checked reconstructing the masses of W boson and top quark produced in $t\bar{t}$ events and the Higgs masses from WH reactions.

2 Jet calibration for $\Delta R_{cone} = 0.4$

The method we used in our analysis is similar to [5]. We used Pythia 6.157 Monte Carlo generator but with a different set of *p.d.f.* (CTEQ5L) and a lower p_T-threshold for jets. A hard process was generated with minimum p_T of 10 GeV/c defined by the PYTHIA parameter CKIN(3). Increasing the minimum p_T from 10 to 20 GeV/c is not desirable as it would cost about 8% of the cross section for Higgs production in WH processes (the difference in the cross section for these values of CKIN(3) parameters). Although the p_T-threshold of 15 GeV/c for calibrated jets will be applied in the future analysis of WH, an increase of the combinatorial background however needs to be taken into account.

Three types of jets can be identified by default in the ATLFAST package: *b*, *c* and others ("*light*") jets, so we tried calibrating each type of jets separately. Jets from τ-decays were not considered. We have started with the fixed cone size of ΔR_{cone}= 0.4 for the jets reconstruction and the "quark" option for b, c labelling in ATLFAST. We have used a default setting for a simple ATLFAST algorithm of the jet reconstruction.

2.1 Energy scale

In Z + 1 jet events only $Z \to \mu^+\mu^-$ decays were considered and effects like initial and final state radiation, hadronization and multiple interaction were included. For the event selection we have applied the criteria similar to [5], but with lower jet p_T-thresholds:

- two muons with $p_T^\mu \geq 10$ GeV/c and $|\eta^\mu| \leq 2.5$. Their invariant mass has to satisfy $| M_{\mu\mu} - M_Z | \leq 10$ GeV/c^2.
- only one jet with raw $p_T^{jet} \geq 10$ GeV/c and $|\eta^{jet}| \leq 2.5$ for $b-$jets, or $|\eta^{jet}| \leq 5$ for other jets.
- additional cut to the angle between the transverse momenta of Z and jet: $|\Delta\phi_{Z-jet} - \pi| \leq 0.1$.

In Fig. 1 the result of the analysis is presented for three samples of Z + 1 jet events corresponding to the selected types of jet: b, c and other ("*light*") jets. The p_T-spectra of Z bosons and yet "uncalibrated" jets are shown in Fig. 1 a) and b). The spectra are different for p_T below 40 GeV/c for the various quarks. This is, in particular, due to the different quark masses. Fig. 1 c) shows the distributions on the value of the angle $\Delta\phi_{Z-jet}$. As one may expect the back-to-back configuration is dominant in Z + 1 jet events (note the log-scale). The dashed area shows the fraction of $c-$jet events passing the additional cut which was applied to provide

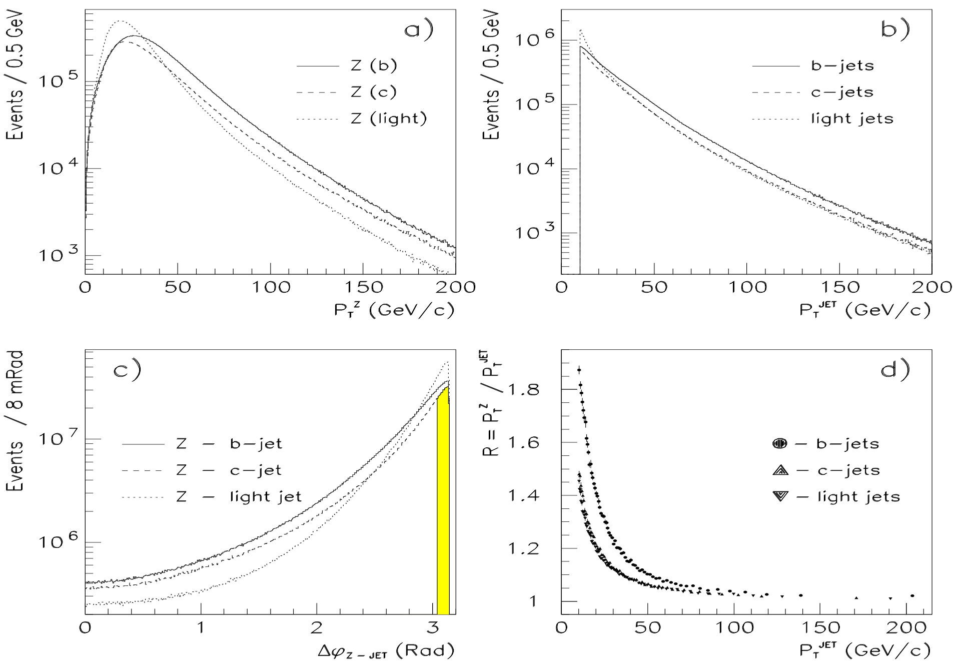

Figure 1: *For three samples of Z + 1 jet events with b, c and light jets shown are the transverse momentum spectra of (a) Z bosons and (b) "uncalibrated" jets of various types, (c) the distributions on the value of the angle between the transverse momenta of the Z and the jet, and (d) the ratio* $R = p_T^Z/p_T^{jet}$ *as a function of raw* p_T^{jet}.

better back-to-back p_T-balance in the Z + 1 jet event. After all selection criteria were applied each sample contained about 3 million events.

To correct the raw value of jet p_T, the ratio $R = p_T^Z/p_T^{jet}$ was calculated within the various p_T^{jet}-intervals. The interval's boundaries were selected so that each interval contained about 50K events. The spectra of the ratio value are broad for low p_T^{jet} region. The peak positions were fitted to a Gaussian and then plotted in Fig. 1 d) as a function of raw p_T^{jet}. The corrections for *light* jets and $c-$jets are very similar (the maximal difference is about 4%). The correction factor for $b-$jets is much higher.

The ratio was fitted to the following function of raw p_T^{jet}:

$$R = f(p_T^{jet}) = exp(A + B \cdot p_T^{jet}) + exp(C + D \cdot p_T^{jet}) + E \tag{1}$$

and the results of the fit are presented in Table 1.

Table 1: *Fit results for the ratio* $R = p_T^Z/p_T^{jet}$ *as a function of raw* p_T^{jet} *(1). Fit was performed for* p_T^{jet} *above 10 GeV/c. The jets were reconstructed with the cone size* ΔR_{cone} *= 0.4.*

Jet type	A	B	C	D	E	χ^2/df
light jets	0.17± 0.07	-0.157± 0.008	-1.39± 0.06	-0.032± 0.001	1.012± 0.001	73/64
$c-$ jets	0.17± 0.06	-0.140± 0.007	-1.39± 0.07	-0.032± 0.002	1.013± 0.001	55/56
$b-$ jets	0.60± 0.03	-0.114± 0.004	-0.93± 0.07	-0.032± 0.002	1.020± 0.002	63/61

In Fig. 2 the correction factor for p_T^{jet} obtained in this analysis is compared with the two others mentioned above (shown by dashed [5] and dashed-dotted [3] lines). Our results for $b-$jets are shown in Fig. 2 a) by solid line. In Fig. 2 b) our parameterizations for the light jets (solid line) and $c-$jets (dotted line) are compared with the referenced analyses for the light jets (i.e. all non-b-jets). We note a big difference in the value of our correction factor and those from the reference analyses. Our corrections for the light jets at low p_T-region are much smaller. This is due to the additional cut applied to the angle $\Delta\phi_{Z-jet}$ giving better back-to-back balance for Z and jet transverse momenta, although we used lower p_T-threshold for selection of the one jet events.

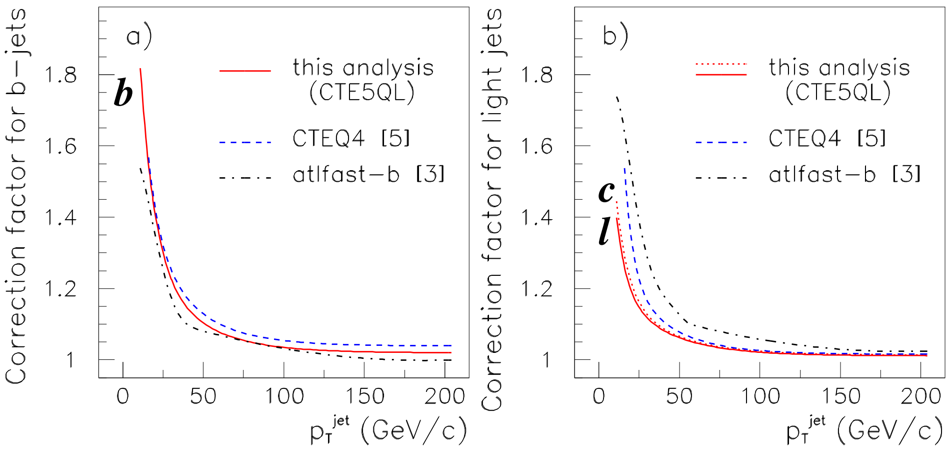

Figure 2: *Correction factors for jets of different types obtained in this analysis (solid and dotted lines, labelled) and earlier (dashed and dashed-dotted lines) for (a) b-jets and (b) for c- and light jets, which are compared with the earlier parameterizations for non-b (light) jets. Corrections are shown as a function of the raw p_T^{jet}.*

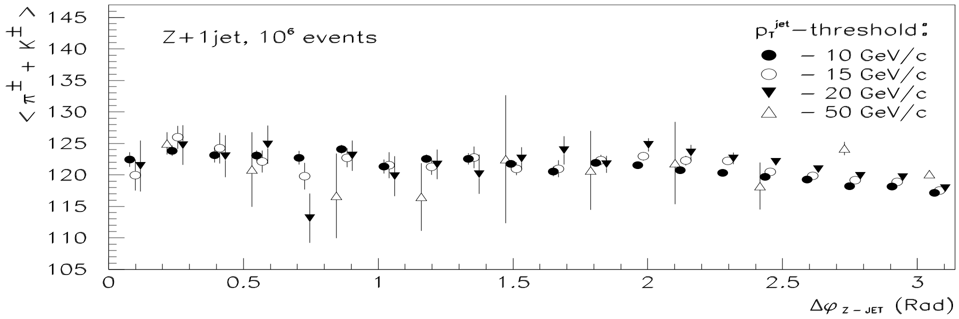

Figure 3: *Average multiplicity of charged pions and kaons for different values of the angle between the transverse momenta of Z and jet and various thresholds for the raw p_T^{jet} in Z + 1 jet events.*

In order to understand how significant our selection cuts influence the properties of events (in particular, their "hadronic activity") we have analysed the average multiplicity of secondary particles in the PYTHIA events. It was seen from Fig. 1 c) that the major bulk of selected events (~80%) have $\Delta\phi_{Z-jet} \geq 2.5$, i.e. the transverse momenta of Z boson and jet are almost balanced. The multiplicity of secondary hadrons produced in these events reveals the activity of the processes of initial and final state radiation. One million Z + 1 jet events were generated and 10 GeV/c^2 constraint for the mass of two muons was applied (see above). The results are presented in Fig. 3 for different p_T^{jet}-threshold values as a function of the $\Delta\phi_{Z-jet}$. For the region $\Delta\phi_{Z-jet} \geq$ 2.5 all the changes are within ±1%. So we may conclude that both lower p_T^{jet}-threshold and a new $\Delta\phi_{Z-jet}$ cuts does not influence significantly the properties of selected jets.

2.2 Mass scale

When the corrections obtained in the previous sections were applied for reconstruction of the masses of known reconances we realized that an additional correction is required to set a proper mass scale, similarly to what proposed in [5]. In this section a global calibration constant will be determined as $C_{mass} = M_W/M_{jj}$, where M_{jj} is fitted peak position in the invariant mass spectra of two reconstructed jets from W boson decay. It will be applied globally to all types of jets for the final correction of their transverse momenta.

A sample of $W \to jet + jet$ decays was selected from 20 million simulated $t\bar{t}$ semi-leptonic events.At this stage the raw values of p_T^{jet} were already corrected using the parameters from Table 1. The event selection requires:

- at least one muon with $p_T^{\mu} \geq 20$ GeV/c and $\mid \eta^{\mu} \mid \leq 2.5$.
- total missing energy in the event $\not{E}_T \geq 20$ GeV/c.
- at least four jets with $p_T^{jet} \geq 15$ GeV/c and $\mid \eta^{jet} \mid \leq 2.5$, from which at least two are $b-$jets as identified in ATLFAST. We assumed 100% efficiency for the b-tagging in this analysis, although the results for more realistic p_T-dependent values will be shown in the last section.

The W boson was reconstructed with the pair of two light non-b jets (*two jets* sample) which had the highest p_T in the event. For higher "purity" of the selected sample the *top* was also formed by adding the b−jet which combined with the two jets gave the highest p_T of the *top*. To suppress the influence of the background to the fitted value of the W mass, M_{jj}, an assignment between the jets and quarks was performed [5]. The quark was considered as the origin of the jet if the distance $\Delta R^{q-jet} = \sqrt{\Delta\eta^2 + \Delta\phi^2}$ between the jet and the quark was minimal from all the jet+quark combinations in the event and satisfies the condition $\Delta R^{q-jet} \leq \Delta R^{q-jet}_{max}$. Ideally, two non-$b$-jets have to match two quarks from the W decay and the two selected b-jets have to originate from the initial $t\bar{t}$ pair ("perfect" assignment).

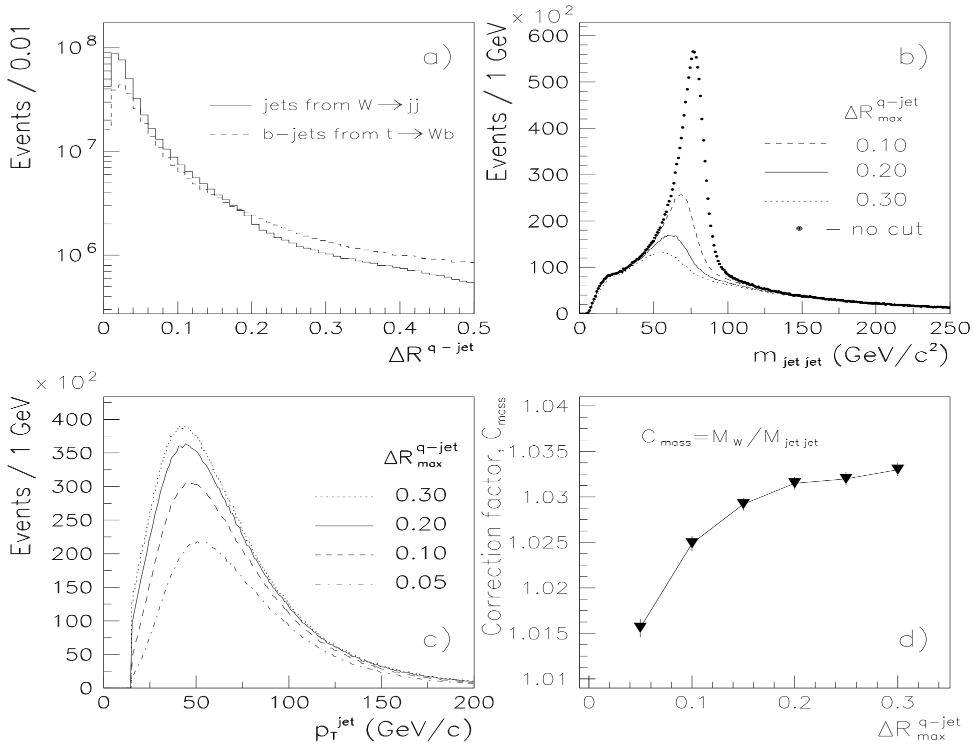

Figure 4: *(a) The distribution on the minimal distance ΔR^{q-jet} between the jet and the quark for jets from the* two jets *sample (W decays) and for the b-jets. (b) The invariant mass spectra of two jets from the* two jets *sample (dots) and various backgrounds (lines), i.e. the jets which have a minimal value of ΔR^{q-jet} in the event but failed the condition $\Delta R^{q-jet} \leq \Delta R^{q-jet}_{max}$. (c) - p_T-spectra for all jets from the* two jets *samples selected by various values of the matching parameter ΔR^{q-jet}_{max} and (d) - the correction factor for the mass distribution (black triangles) obtained as the ratio of the expected peak position to the fitted one as a function of the matching parameter value.*

In Fig. 4 a) the distribution on the minimal distance ΔR^{q-jet} is presented for the jets selected for the W reconstruction (*two jets* sample) and for the b−jets. The distributions are slightly different which means that an optimal value of the matching parameter ΔR^{q-jet}_{max} could be different for various types of jets. The invariant mass spectra of two jets from the *two jets* sample is shown in Fig. 4 b) by dots. The jets which have failed the condition $\Delta R^{q-jet} \leq \Delta R^{q-jet}_{max}$ made up the background. The correspondent background distributions obtained for ΔR^{q-jet}_{max} equals 0.1, 0.2 and 0.3 are also presented in Fig. 4 b). The chosen maximal value of the matching parameter ΔR^{q-jet}_{max} changes the position of the "real" W peak, M_{jj} as seen in Fig. 4 d).

For the better choice of the matching parameter value we have analysed the p_T-spectra of jets from *two jets* combinations shown in Fig. 4 c) for different values of ΔR^{q-jet}_{max}. We note from Fig. 4 c) that matching acts similarly to a p_T-cut, i.e. smaller values of the matching parameter suppress the contribution from the low p_T jets (and reduce probability of mismatching). The low values of ΔR^{q-jet}_{max} give high "purity" of the *two jet* sample for W reconstruction, but the contribution from the jets with low p_T is not high enough to be used to get a proper jet calibration. The values of $\Delta R^{q-jet}_{max} > 0.2$ provide a representative sample of the jet p_T values, but result in a higher contribution from the false *two jets* combinations.

The "perfect" assignment between the jets and quarks was performed for various values of ΔR^{q-jet}_{max} and the peak position in the two jets invariant mass spectrum was fitted with a Gaussian[1)]. The ratio of the expected

[1)] We have applied an asymmetrical Gaussian function within $\pm 1\sigma$ around the peak position to account for a low mass "tail" which is likely to be the "feature" of a fixed cone algorithm used for the jet reconstruction. An acceptable fit to the standard Gaussian was possible only within a $\pm 0.5\sigma$ interval around the peak with the results differing by $\sim 0.5\%$.

mass M_W=80.33 GeV/c^2 to the fitted value M_{jj}, which we will use as the global correction factor, is presented in Fig. 4 d) by black triangles. It varies by 2% from 1.014 to 1.033 when changing ΔR^{q-jet}_{max} from 0.05 to 0.3. As the ΔR^{q-jet}_{max} is correlated with the jet p_T, the global correction factor obtained in this way (and so the jet calibration in general) could be different for various values of the p_T^{jet}-threshold used for the jet selection.

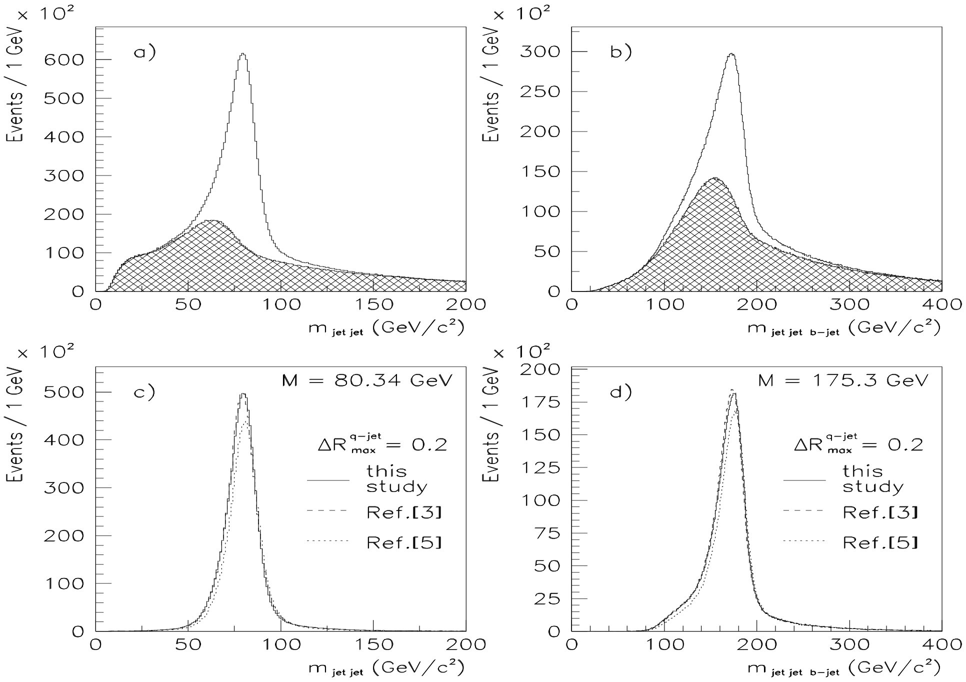

Figure 5: *Invariant mass spectra of (a)* two jets *and (b)* two jets + b-jet *combinations after all jet energy corrections and (c and d) corresponding spectra for the jet combinations obtained due to the "perfect" assignment of jets to quarks with* $\Delta R^{q-jet}_{max} = 0.2$. *The shaded area in a) and b) shows the background distribution (at least one jet from the selected combination does not match the initial quark).*

The value ΔR^{q-jet}_{max}=0.2 has been selected as an optimal compromise for matching the jet candidates to W decays, and $M_{jj} = (77.91 \pm 0.03)$ GeV/c^2 was determined by fitting the invariant mass distributions of the "optimal" *two jets* sample. It was then scaled to the W mass with the constant

$$C_{mass}(\Delta R_{cone} = 0.4) = M_W/M_{jj} = 1.031 \qquad (2)$$

which was used in the following analysis as a global correction factor in addition to those obtained in the previous section.

The invariant mass spectra for *two jets* and *two jets + b-jet* combinations obtained after all corrections are presented in Fig. 5 a) and b) correspondently. Twenty million semi-leptonic $t\bar{t}$ events were generated. The mass distributions for the jets passing the matching criterium ΔR^{q-jet}_{max}=0.2 are shown in the Fig. 5 c) and d). The validity of the proposed calibration for all types of jets is confirmed by the fit of peak positions, M, which gives the values of (80.34±0.07) GeV/c^2 for the W boson and (175.3±0.2) GeV/c^2 for the *top* quark mass. When applying C_{mass}=1.031 to the whole mass spectra with no background subtraction, the correspondent masses are lower - 79.9 GeV/c^2 and 173.9 GeV/c^2.

To compare the invariant mass distributions with the reference analyses [3] and [5] the corresponding jet calibrations were applied to the same sample of generated events. The results are presented in Fig. 5 c) and d). We have obtained lower values for the masses of W and *top* candidates (79.45 GeV/c^2 and 173.7 GeV/c^2) using the calibration from [3] and higher values (80.72 GeV/c^2 and 176.6 GeV/c^2) for the jet calibration from [5]. In general, the results of all three approaches are similar.

2.3 Results for the Higgs mass (WH process)

The calibration parameters obtained (Table 1 and (2)) were used for jet energy reconstruction in WH processes. Ten million WH events were generated for different values of the Higgs mass, M_H, varying from 100 to 150 GeV/c^2. We used the "standard" criteria for the event selection [7]:

- the threshold of 20 GeV/c for p_T of isolated electron and muon, both with $|\eta| < 2.5$, events with a second lepton within the same interval of pseudorapidity and with $p_T > 6$ GeV/c were vetoed;

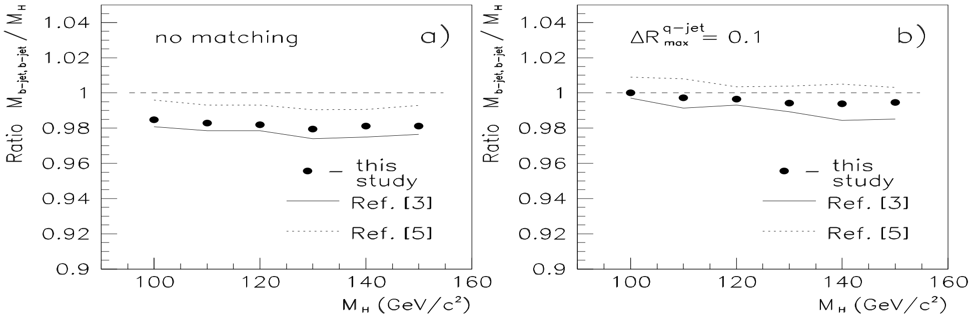

Figure 6: *The ratio of mass values, $M_{b-jet,b-jet}/M_H$, obtained from the invariant mass spectra of two b-jets (black dots) as a function of the Higgs mass, M_H: for (a) the jet pairs without jet-to-quark matching and (b) the jets which satisfied the matching parameter ΔR^{q-jet}_{max} = 0.1. For the WH events generation the Higgs masses from 100 to 150 GeV/c^2 have been used. Solid and dashed lines show the results for the reference calibrations [3] and [5].*

- 15 GeV/c threshold to the "calibrated" transverse momenta used for the jet reconstruction in the cone of $\Delta R_{cone} = 0.4$;
- only two jets ($b-$*tagged* jets) in the event are allowed, events with additional jets in the pseudorapidity interval $\mid \eta \mid < 5$ and with $p_T > 30$ GeV/c were vetoed.

The value of the mass, $M_{b-jet,b-jet}$ was obtained by fitting the peak in the invariant mass spectrum of two $b-$jets (within $\pm 1\sigma$) to the asymmetrical Gaussian. The ratio M_{jj}/M_H is presented in Fig. 6 by black dots as a function of M_H. The fitted values are lower than those expected by $\sim$2% (Fig. 6 a). This is due to the presence of the background. When the jet-to-quark matching was applied to the selected events the masses became closer to the given values. As only the b-jets have been involved in the Higgs reconstruction, the optimal matching parameter ΔR^{q-jet}_{max} could be lower than for other jets (see dotted line in Fig. 4 a). We were able to get a good agreement with the expected values only for a small matching parameter $\Delta R^{q-jet}_{max} = 0.1$ as shown in Fig. 6 b).

The corresponding results for reference calibrations are also presented in Fig. 6. We note the agreement between the various approaches: the difference in reconstructed Higgs masses is about 1%.

3 W + jets sample for various ΔR_{cone} values

As we have already mentioned ΔR_{cone}= 0.4 gives a low mass peak in the jet + jet invariant mass spectra in W + jets sample. This is an important background for the low mass Higgs searches, so it has to be simulated carefully. In particular, in [8] the W + jets events have been generated for different intervals of the transverse momenta of the hard process, e.g. p_T^{hard}= 10 – 30, 30 – 50, 50 – 100, 100 – 200 GeV/c and greater than 200 GeV/c.

The results for the interval p_T^{hard}=30 – 50 GeV/c are presented in Fig. 7 for various values of ΔR_{cone} = 0.4 – 0.7. Ten million W + jets events were generated for each cone size. Only two jets events with $p_T^{jet} >$ 10 GeV/c and $\mid \eta \mid < 2.5$ were selected. For this particular analysis no corrections were applied to the raw transverse momenta of the jets. In Fig. 7 a) the invariant mass distribution of two jets is shown for ΔR_{cone}= 0.4. We note a "fake" peak at low masses using $\Delta R_{cone} = 0.4$ with a low p_T^{jet}-threshold and no jet separation cut, the jet reconstruction algorithm often splits one low energy jet into two jets (and these two jets are more likely to be eliminated by the p_T^{jet}-threshold, see below). An additional cut for the distance between the jets, ΔR_{jj}, is usually applied to separate jets (the value of ΔR_{jj}= 0.7 was explored in paper [4] for ΔR_{cone}= 0.4). The shaded area in Fig. 7 a) shows that ΔR_{jj}= 0.7 removes a "fake" peak at low masses and does not change the invariant mass spectra at high masses.

One has to consider also other possibility to deal with the "fake" peak like the optimization of the jet cone size. In Fig. 7 b) the invariant mass distributions are presented for different values of the cone size from 0.4 to 0.7. The low mass peak becomes less significant for higher ΔR_{cone} though the jet separation cut should still be applied. But, a more important observation is the increase of the background in general. The integral increase of the number of selected two jets events over the data for $\Delta R_{cone} = 0.4$ is shown in Fig. 7 c) as a function of the cone size (black dots). The maximal excess is about 3% for $\Delta R_{cone} = 0.6$ (no jet separation cut was applied). But it is more significant in the interesting invariant mass interval for search for the light Standard Model Higgs boson ($m_{jet,jet}$ = (100 – 150) Gev/c^2) and is shown in Fig. 7 c) by open circles. For the cone sizes of 0.6 and 0.7 the increase is higher than 10% (partially due to the cone size increase). This indicates the

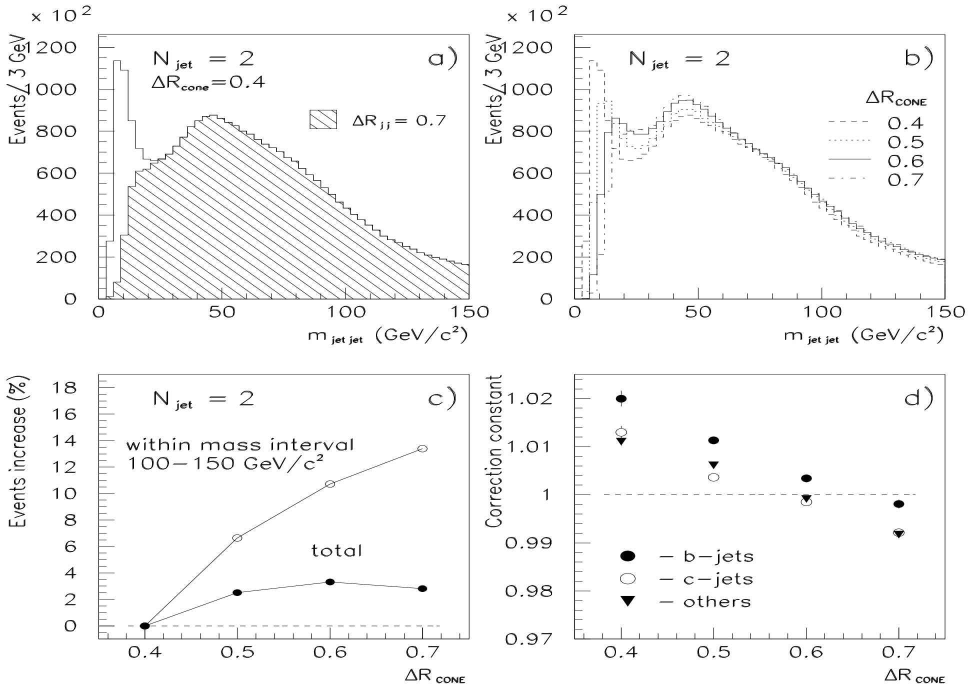

Figure 7: *(a) The jet+jet invariant mass distribution for W + jets events generated for the* p_T^{hard}*= 30 - 50 GeV/c interval of the transverse momenta of the hard process. The jets were reconstructed with the cone size of* ΔR_{cone}*= 0.4. The shaded area shows the result of the jet separation cut* ΔR_{jj}*= 0.7. (b) The invariant mass distributions for different cone size values* ΔR_{cone} *varying from 0.4 to 0.7. (c) Increase of the number of selected two jets events as a function of* ΔR_{cone}*. The total increase is shown by the black dots. The open circles present the increase within the invariant mass interval of 100 - 150 GeV/c*^{2}*. (d) The constant term, E, of the correction factor (1), which provides jet calibration for high* p_T^{jet} *(e.g.* p_T^{jet} *>100 GeV/c), is shown for jets of different types as a function of* ΔR_{cone}*.*

uncertainty of the background level from W+jets events for the WH process due to the selection of the jet cone size (W+jets and $t\bar{t}$ backgrounds dominate for SM Higgs signal [9], and so contribute about 5% uncertainty in the value of S/$\sqrt{B}$).

We conclude that values of the jet cone sizes above 0.5 are better for the reconstruction of the low p_T jets. The jet energy parameterization 1, described in section 2.1, was obtained for different jet cone size values ΔR_{cone}= 0.4 - 0.7. In Fig. 7 d) the constant term, E, of the parameterization (1), which provides calibration of the high p_T jets (the p_T-region where both exponentials from 1 are not important, e.g. p_T^{jet}¿100 GeV/c), is presented for jets of various types as a function of ΔR_{cone}. For $\Delta R_{cone} = 0.7$ the term is below the unity for all types of jets. This means that the fixed cone algorithm with ΔR_{cone}= 0.7 overestimates the jet transverse momentum for high p_T^{jet}.

4 Results for $\Delta R_{cone} = 0.6$

Based on the data presented in the previous sections we used a cone size of $\Delta R_{cone} = 0.6$ for the jet reconstruction in the whole p_T^{jet}-region. The coefficients of the corresponding parameterization (1) are presented in Table 2. We used these parameters for calibration of jets from decays of W produced in $t\bar{t}$ events. The “perfect” assignment between jets and quarks with the matching parameter $\Delta R_{max}^{q-jet} = 0.2$ was performed at this stage in order to reconstruct the mass of W boson and thus define the mass scale of the jet calibration (see section 2.2) obtaining

$$C_{mass}(\Delta R_{cone} = 0.6) = 1.036. \quad (3)$$

These calibration parameters for $\Delta R_{cone} = 0.6$ were applied then for the analysis of the $t\bar{t}$ processes and Higgs production in WH reactions. The results are summarized in Fig. 8.

The reconstructed invariant mass spectra for W boson and *top* quark (with $\Delta R_{max}^{q-jet} = 0.2$) are presented in Fig. 8 a) and Fig. 8 b), respectively. The spectra are compared with those obtained for $\Delta R_{cone} = 0.4$ (dashed line, see fig. 5). The results are similar. The larger value of the cone size provides ∼10% narrower peak in the mass distributions, although the reconstructed mass of the *top*-quark is higher by ∼1%. This value characterizes the uncertainty of the proposed jet calibration. We note that with no background subtraction the fitted masses are 80.1 GeV/c^2 (for W) and 175.1 GeV/c^2 (for *top*), which is better than for $\Delta R_{cone} = 0.4$.

Table 2: *Fit results for the ratio $R = p_T^Z/p_T^{jet}$ as a function (1) of the jet p_T for various jet samples. Fit was performed for raw p_T^{jet} values above 10 GeV/c. The jets were reconstructed with the cone size ΔR_{cone} = 0.6. Each sample of jets contained more than one million jets.*

Jet type	A	B	C	D	E	χ^2/df
light jets	1.58± 0.23	-0.346± 0.032	-1.46± 0.06	-0.051± 0.002	0.9991± 0.0005	38/21
$c-$ jets	1.47± 0.23	-0.307± 0.022	-1.57± 0.06	-0.046± 0.002	0.9985± 0.0006	21/20
$b-$ jets	0.47± 0.06	-0.153± 0.008	-1.14± 0.09	-0.041± 0.002	1.0034± 0.0008	32/32

Fig. 8 c) represents the values of the global correction factor, C_{mass}, obtained from the analysis of $t\bar{t}$ events simulated with different p_T-thresholds for the jet selection. As we have seen in Section 2.2 the reconstructed mass of W boson is closer to the expected value for the jets with higher transverse momentum. That is why the global correction factor is smaller if the high p_T-threshold is applied for jets selection. For the interval of p_T-threshold from 15 to 45 GeV/c the factor changes by ~0.5%.

In Fig. 8 d) the ratio M_{jj}/M_H as a function of Higgs mass M_H is shown by black dots (five million events were generated for each mass value). The obtained masses are by ~2% closer to the expected ones than it was for $\Delta R_{cone} = 0.4$ (shown by dotted line) although no jet-to-quark matching was applied. The open circles show results for more realistic p_T-dependent b-tagging efficiency [3] which are also close to the expected values of the Higgs mass.

An application of the jet separation cut does not affect significantly the results for the Higgs mass, but is useful for the W+jet events analysis. The optimal cut value for the jet cone size of ΔR_{cone}= 0.6 was found based on the jet+jet invariant mass distributions for W+jet events for different intervals of the transverse momenta of hard process. These spectra obtained for ΔR_{jj}= 0.7 and 1.0 are presented in Fig. 9 for W+jet events with only two reconstructed jets. The same number, 10^8, of generated events was used for each interval of the p_T^{hard}. A smooth shape of the mass spectra with tiny traces of the "fake" peak at low masses was observed for the jet separation cut value of ΔR_{jj}= 1.0 for all intervals of the transverse momenta of hard process.

5 Conclusion

A simple fixed cone algorithm of the jet reconstruction has been checked for various ΔR_{cone} from 0.4 to 0.7 in WH, $t\bar{t}$ and W+jets processes. Some problems for commonly used cone size values of 0.4 and 0.7 have been indicated. Namely, it was shown that a small cone size underestimates the number of events with only two jets, whereas a big value of ΔR_{cone} overestimates the jet energy. Our results were compared with other parameterizations of the jet energy calibration used in ATLAS. A more accurate parameterization has been proposed based on the analysis of Z + 1 jet (for the energy scale) and $t\bar{t}$ samples (mass scale) of the Monte Carlo events.

The value of ΔR_{cone} = 0.6 was selected as a suitable compromise for reconstruction of jets at low and high p_T^{jet}'s. It allows a better reconstruction of the resonance masses in WH processes and a more realistic shape of the continuum background such as that from W+jets events.

We recommend to use ΔR_{cone} = 0.6 for the jet reconstruction based on the fixed cone algorithm in ATLFAST when working with the low p_T^{jet}-threshold (e.g. for the light SM Higgs boson). The parameters for the jet energy calibration (1) are presented in the Table 2. The mass scale can be set with the global correction factor, C_{mass}, taking into account its dependence on the p_T-threshold for the jets selection.

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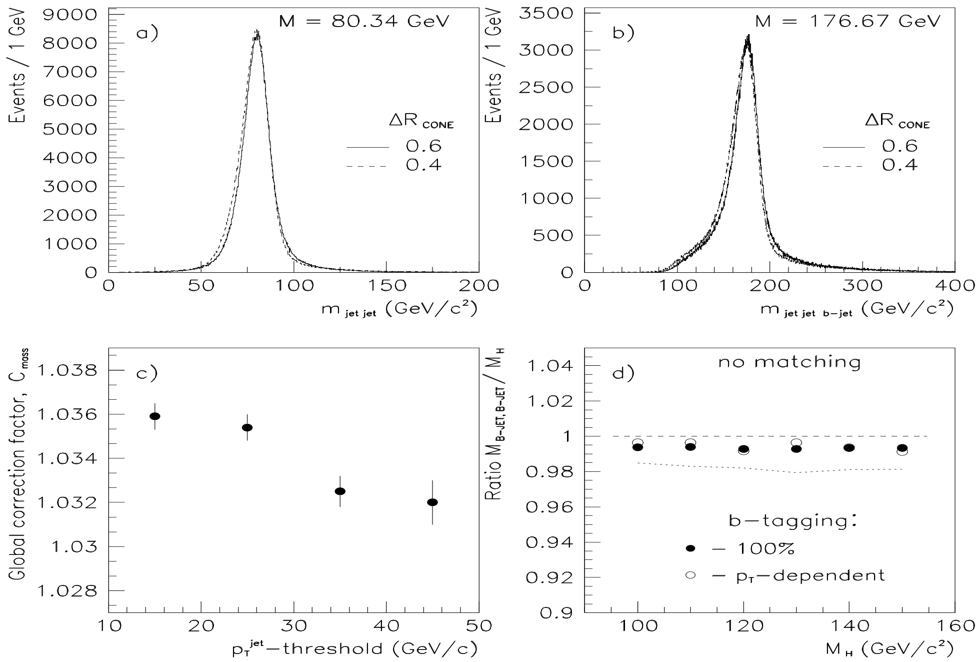

Figure 8: *Invariant mass spectra of (a)* two jets *and (b)* two jets + b-jet *combinations after the jet energy corrections and the "perfect" jet-to-quark assignment with* ΔR^{q-jet}_{max}*=0.2. Jets are reconstructed with* ΔR_{cone}*=0.6. The spectra are compared with the results obtained for* ΔR_{cone}*=0.4 shown by the dashed line. (c) Global correction factor,* C_{mass}*, obtained from the analysis of* $t\bar{t}$ *events simulated for various values of the jet* p_T*-threshold. (d) The ratio of mass values,* $M_{j,j}/M_H$*, obtained from the invariant mass spectra of two b-jets as a function of the Higgs mass,* M_H*, for "ideal" (black dots) and "realistic" b-tagging. The results from section 3 for* ΔR_{cone}*=0.4 are shown by the dotted line for comparison.*

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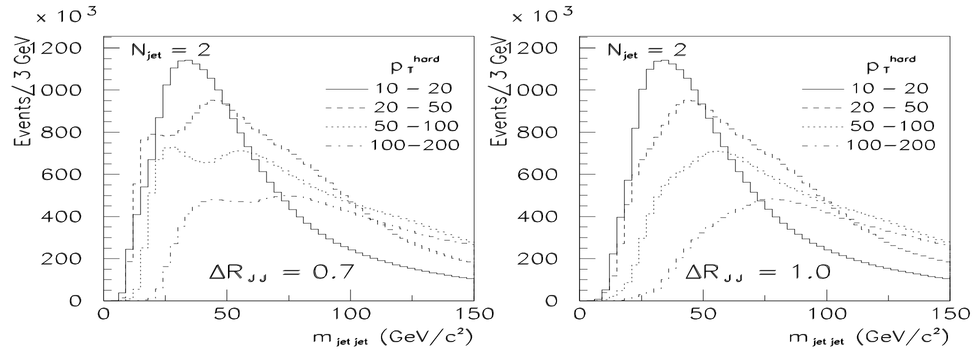

Figure 9: *The jet+jet invariant mass distribution for W + jets events generated for different intervals of the transverse momenta of hard process, p_T^{hard}. The jets were reconstructed with the cone size of ΔR_{cone}= 0.6 and the spectra are shown for two values of the jet separation cut: (a) ΔR_{jj}= 0.7 and (b) ΔR_{jj}= 1.0.*