DELPHI Collaboration

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A study on collinear events in the framework of the Higgs analysis

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Abstract

In the search for the Higgs boson in the missing energy channels, collinear jets can easily fake a signal. In this note we report a study on collinear jets in missing energy events.

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1 Introduction

Two different diagrams contribute to the Higgs production in the missing energy channel: the Higgsstrahlung process and the WW fusion process as shown in figure 1. The two processes interfere positively. The Higgsstrahlung mechanism dominates for m(H)$\leq \sqrt{s}$-m(Z) (the so-called Higgsstrahlung wall) while the WW-fusion mechanism is our only possibility to go beyond. Figure 2 shows the various contributions to the cross section of the process $e^+e^- \to$H $\nu\bar{\nu}$ as a function of the Higgs mass for a centre of mass energy of 206 GeV. At $E_{\rm cm}$ =206 GeV and for a Higgs of 115 GeV, about 40% of the cross section is due to the fusion process and interference. This means that the kinematic distributions are quite different from the ones expected from the Higgsstrahlung process alone.

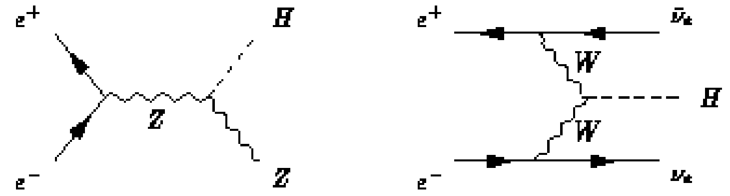

Figure 1: The two Feynmann diagrams describing the Higgs production: the Higgsstrahlung process and the WW-fusion process.

In figure 3 the acollinearity of the two jets from the Higgs decay is shown at generator level using the `WPHACT` generator [2] for the total signal (bottom), and for Higgsstrahlung (top) and WW-fusion (center) only. The different behaviour in acollinearity of these two contributions is evident and the net result on the signal distribution (Higgsstrahlung + WW-fusion + interference) is that the jets tend to have an angle in space quite different from 180 degrees. The fraction of events with acollinearity lower than 5 degrees is 5% and it is 15% for an angle smaller than 10 degrees. One may also notice that, even if one considers the Higgsstrahlung contribution alone, the two jets do not tend to be collinear. This corresponds to the fact that, even if we are at the kinematic limit for production of an Higgs and a Z, they are not produced at rest. One can see from figure 4 (top) that the highest differential cross section dσ/dm($\nu\bar{\nu}$) is about 1 GeV lower than that of the Z mass. This may be understood as the result of two competing mechanisms: the Z Breit-Wigner which tends to put m($\nu\bar{\nu}$) as close as possible to m(Z) and the steep decrease near the kinematic limit of the production cross section $e^+e^- \to$HZ as a function of m(Z), which on the contrary tends to produce a much lower m($\nu\bar{\nu}$). With a mass m($\nu\bar{\nu}$) of, say, 90 GeV, the Higgs of 115 GeV gets at this energy a boost of 10 GeV. This behaviour is confirmed by the exact differential cross section dσ/d(boost) of figure 4 (bottom) which has a peak around 10 GeV for the Higgsstrahlung and around 15 GeV for the total signal.

In this note we study the characteristics of these events and the background composition.

1.1 The event selection

The events are selected as in the DELPHI official H$\nu\bar{\nu}$ analysis, (see [1]) except that few of the cuts were not applied in order not to suppress collinear event. As already stated in

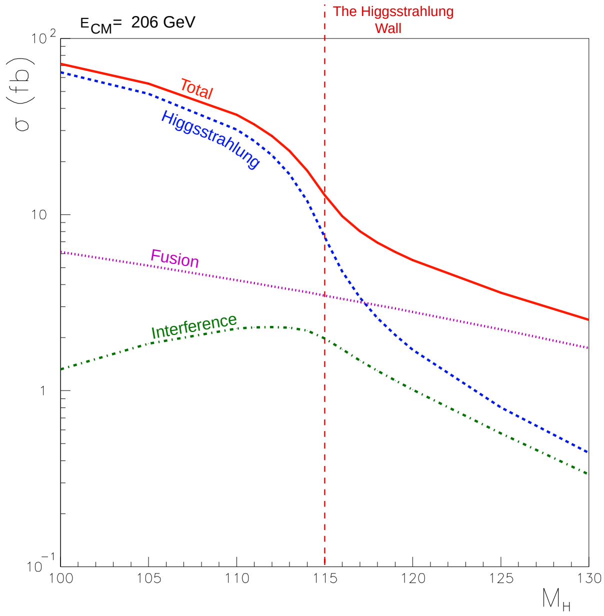

Figure 2: The cross section for Higgs production at E_{cm} =206 GeV as function of the Higgs mass for the different production processes.

[1] we expect very few events integrated over all years since the cross section for a high mass Higgs is very small. The only chance to see them is to work in an environment free of background.

The following cuts (applied in the standard $H\nu\bar{\nu}$ analysis) are *not used* in the present analysis:

- the acoplanarity (of the event forced to 2 jets) should be larger than 6° and the missing transverse momentum should be larger than 6 GeV (the missing transverse momentum is defined as the total momentum in the plane perpendicular to the beam direction).
- two coplanar jets (acoplanarity $\leq 10°$) should not go both in the region of polar angle $\theta = 40° \pm 5°$ and should be above 20° in θ.
- $\sqrt{s}' \leq 0.96 \times E_{\rm cm}$
- Events defined by this two-dimensional cut in the $\theta(p_{mis})$ (degree) vs. $\sqrt{s}'$ (GeV) plane are excluded:

$$\theta_{\rm p_{mis}} < 40°\textbf{:}\ \sqrt{\rm s}' < (-0.6 \times \theta_{\rm p_{mis}} + 115)\ \rm GeV$$
$$\theta_{\rm p_{mis}} > 140°\textbf{:}\ \sqrt{\rm s}' < (+0.6 \times \theta_{\rm p_{mis}} + 7)\ \rm GeV$$

These last two cuts suppress collinear events as it is shown in figure 5 for the selected events with a cut on the btag larger than 0 (the btag is defined as in [1]).

Finally the collinearity of the 2 jets is required to be less than 10 degrees for this study.

Two kinds of background dominate: the full energy $q\bar{q}$ events and the double radiative return to the Z, $Z\gamma\gamma$. In the first case the 2 quarks are the only energetic particles in

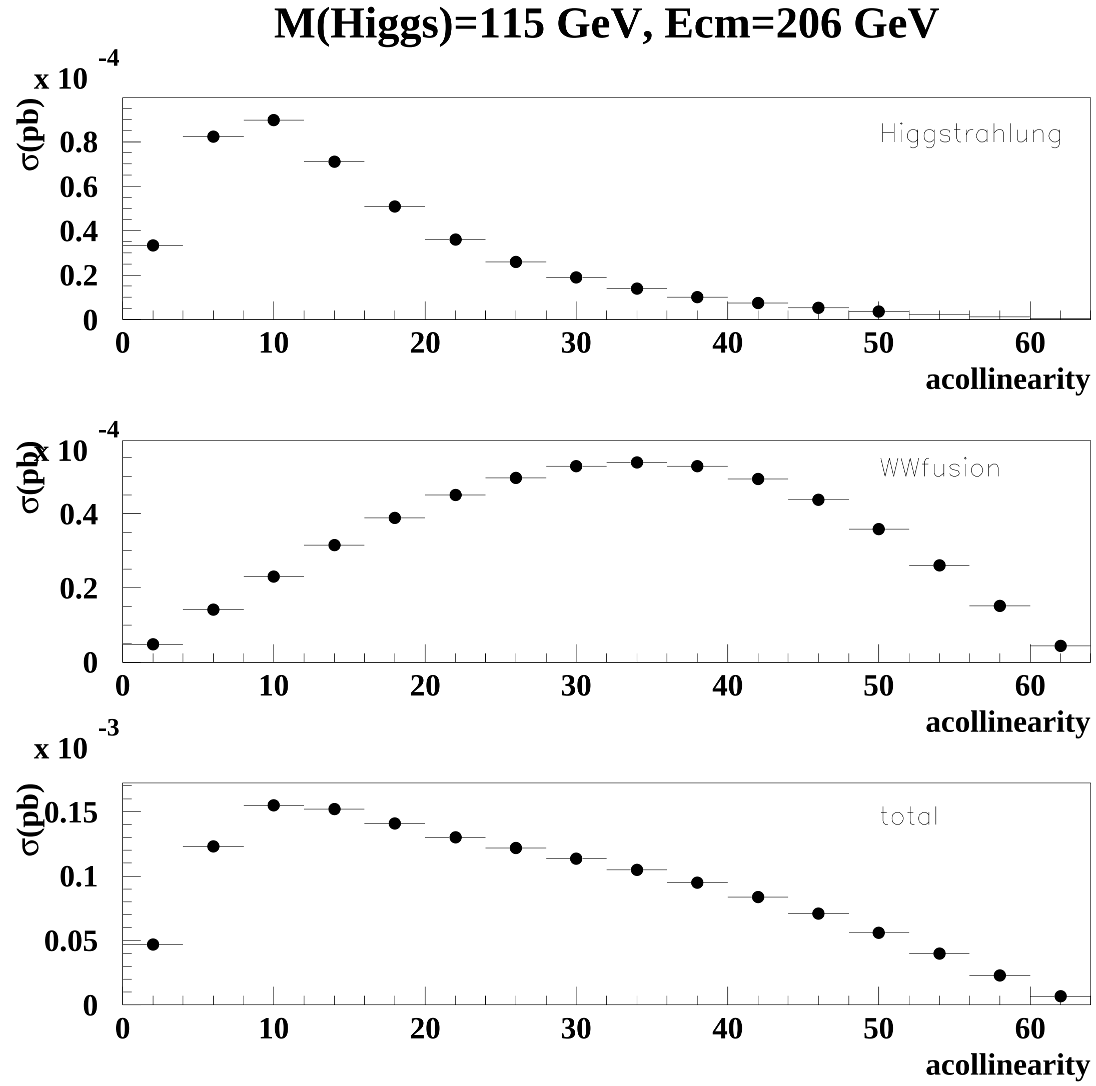

Figure 3: Acollinearity distribution for the two b-quarks coming from a Higgs of 115 GeV/c^2 at E_{cm} =206 GeV, produced with `WPHACT`.

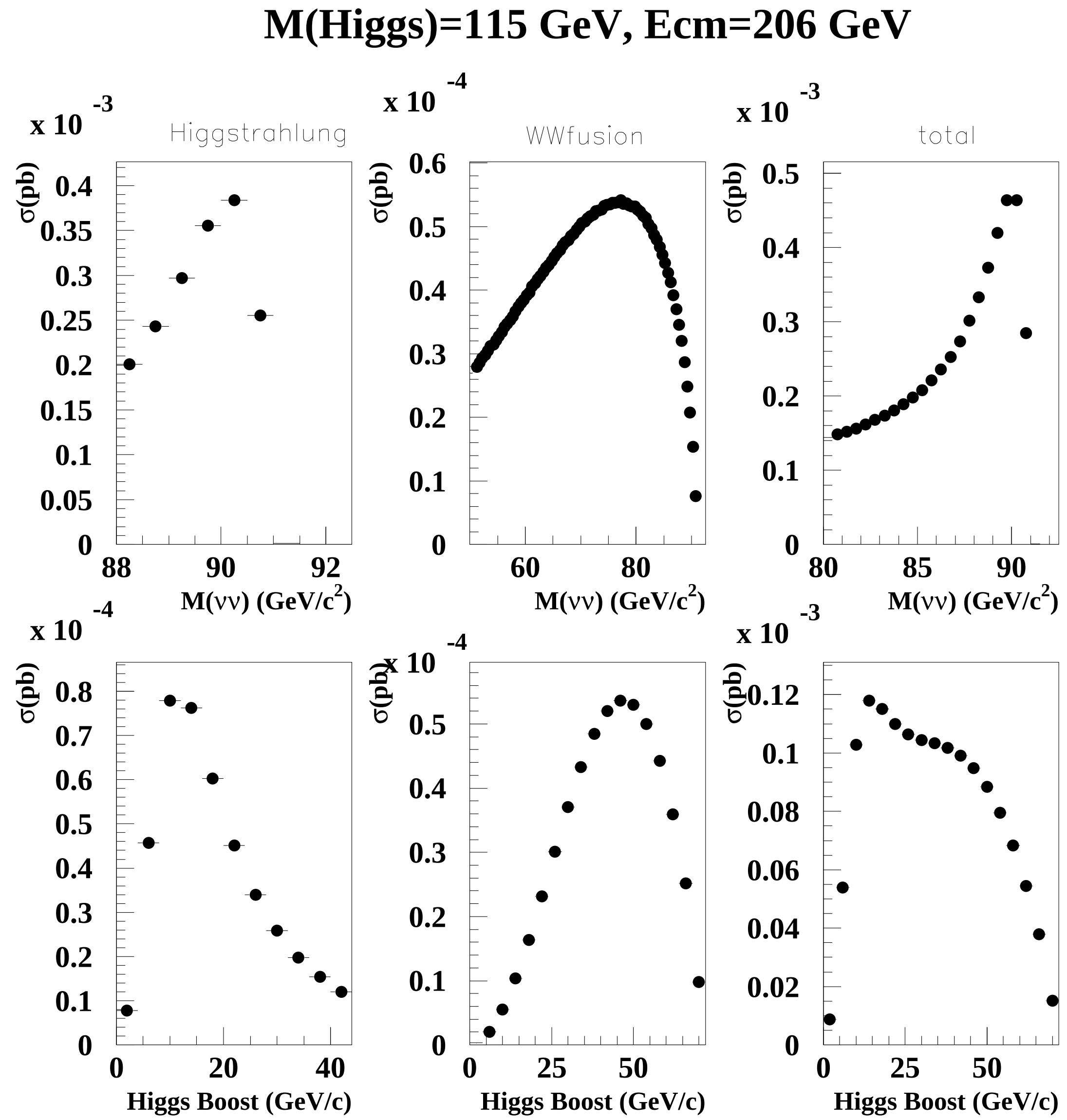

Figure 4: Distribution of the invariant neutrino mass and the Higgs boost for a Higgs of 115 GeV/c^2 at E_{cm} =206 GeV, produced with `WPHACT`

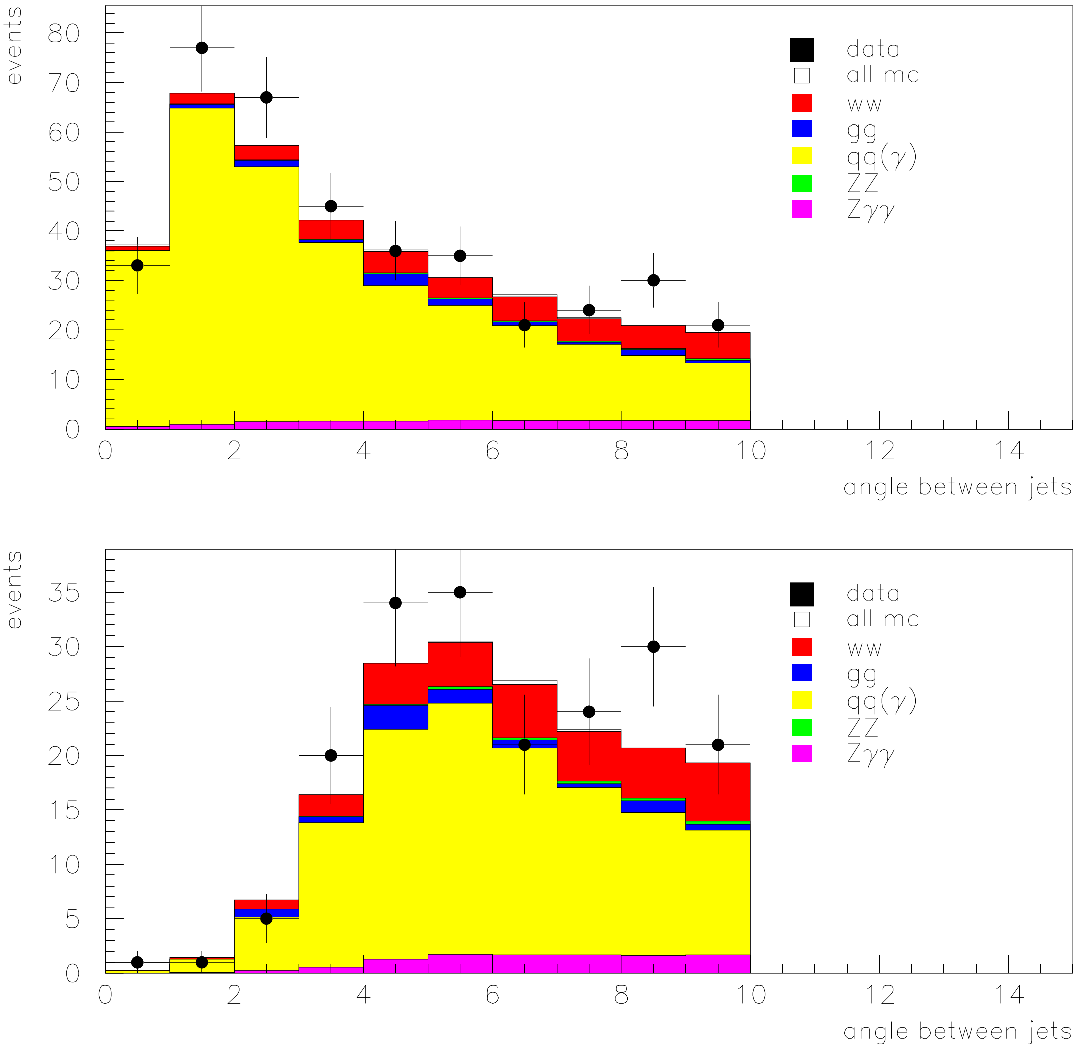

Figure 5: The angle (in degrees) between the 2 jets (top) when not applying the cuts on $\sqrt{s}'$ and on the polar angle of the missing momentum, (bottom) applying them.

the final state; of these events the “dangerous” ones are those where only about half of the energy is reconstructed due to detector effects and/or the presence of neutrinos in semileptonic decays.

After these cuts, the efficiency for a Higgs of 115 GeV of mass is reduced to 16%, and it drops to 5% if one requires an acollinearity cut at 5 degrees. In the standard Higgs analysis the efficiency after event selection is 75%.

2 The results

The visible mass (M_{vis}) spectra for the selected events is shown in figure 6: with a btag larger than 0 (top), 1 (bottom left) and 3 (bottom right). The Higgs efficiency after the 3 btag cuts is respectively 10%, 8% and 4%. A 1 σ excess of data with respect to simulation is observed. The dark grey (purple) histogram is the contribution in the simulation coming from $Z\gamma\gamma$ events [3], while the light grey (yellow) part is the one due to non resonant $q\bar{q}$ (γ).

If one forces the missing mass to be M_Z, the events will have a recoiling mass to the Z in the highest kinematically accessible bins i.e. $\sqrt{s}$-M_Z, as shown in figure 7 for btag$\geq$0. We focus on the next on the events with a visible mass in the range 95-120 GeV/c^2 which are compatible with a high mass Higgs boson.

The θ distribution of the jets and the acoplanarity (i.e. the angle between the jets in the $R\phi$ projection) are shown in figure 8 for the events in the region $95\leq M_{vis} \leq 120$ GeV/c^2 and with a btag$\geq$ 0. From these plots there is no evidence that the events are concentrated in detector areas of poor energy resolution or lacking hermeticity (i.e. 40°,90°.) The background from double radiative return events is reduced almost completely with the cut on the visible di-jet mass. The only background remaining is from the $q\bar{q}$ (γ) events. Because of the cuts on the btag, 90% of the simulated events have b-quarks in the final state. About 80% of the events originate from a M($q\bar{q}$) $\sim E_{\rm cm}$, about 20% originate from M($q\bar{q}$) $\sim$ 120-180 GeV/c^2, and less than 1% are still Z with two or many photon emitted, not recognised as a double radiative return, or with photons inside one of the jets thus increasing the visible mass.

In figure 9 the visible mass spectra and the recoiling mass to the Z are shown for the selected collinear events (with acollinearity $\leq 10°$), asking a btag$\geq$1 (corresponding to a Higgs efficiency of 10%) for the different centre of mass energies: going from the top to the bottom of the page respectively for 189 GeV, 196 GeV, 200+202 GeV and for the 2000 data and 206.7 GeV simulation. It is obvious that the recoiling mass shifts with centre-of-mass energy and that a discrepancy between data and simulation, or a statistical fluctuation, could fake a Higgs signal at the kinematic limit. The number of events in data and simulation are the following: at $E_{\rm cm}$ =189 GeV 33 in data and 28.6 in MC, at $E_{\rm cm}$ =196 GeV 18 in data and 13.2 in MC, at $E_{\rm cm}$ =200+202 GeV 18 in data and 21.1 in MC and for the year 2000 38 in data and 33 in MC.

3 Energy carried away by neutrinos

In the full energy 2 quarks final state events, where only half of the energy is reconstructed in the detector, the loss is largely due to detector effects. However, the fraction of events

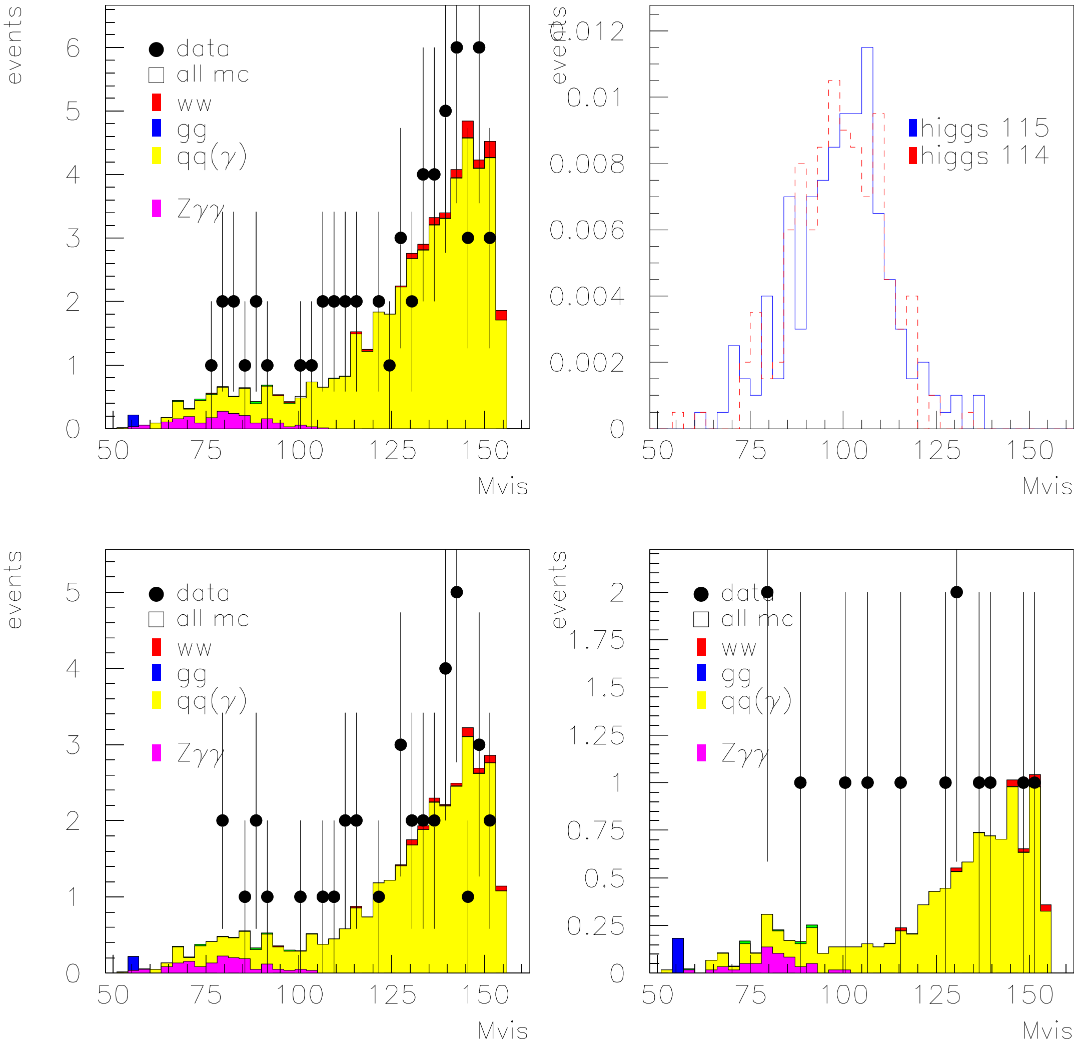

Figure 6: The visible mass distribution for the selected events for three different btag cuts, ≥ 0 (top left plots for data and simulation; top right plot for the Higgs signal) and btag$\geq$ 1 and 3 on the bottom. The simulation is at E_{cm} =206.7 GeV. The spectra end at about M_{vis}=160 GeV because of the cut on the visible energy $\leq 0.75 \times E_{\text{cm}}$. The full line (blue) on the top-right plot is for a Higgs of 115 GeV of mass; the dashed line (red) is for a Higgs of 114 GeV of mass.

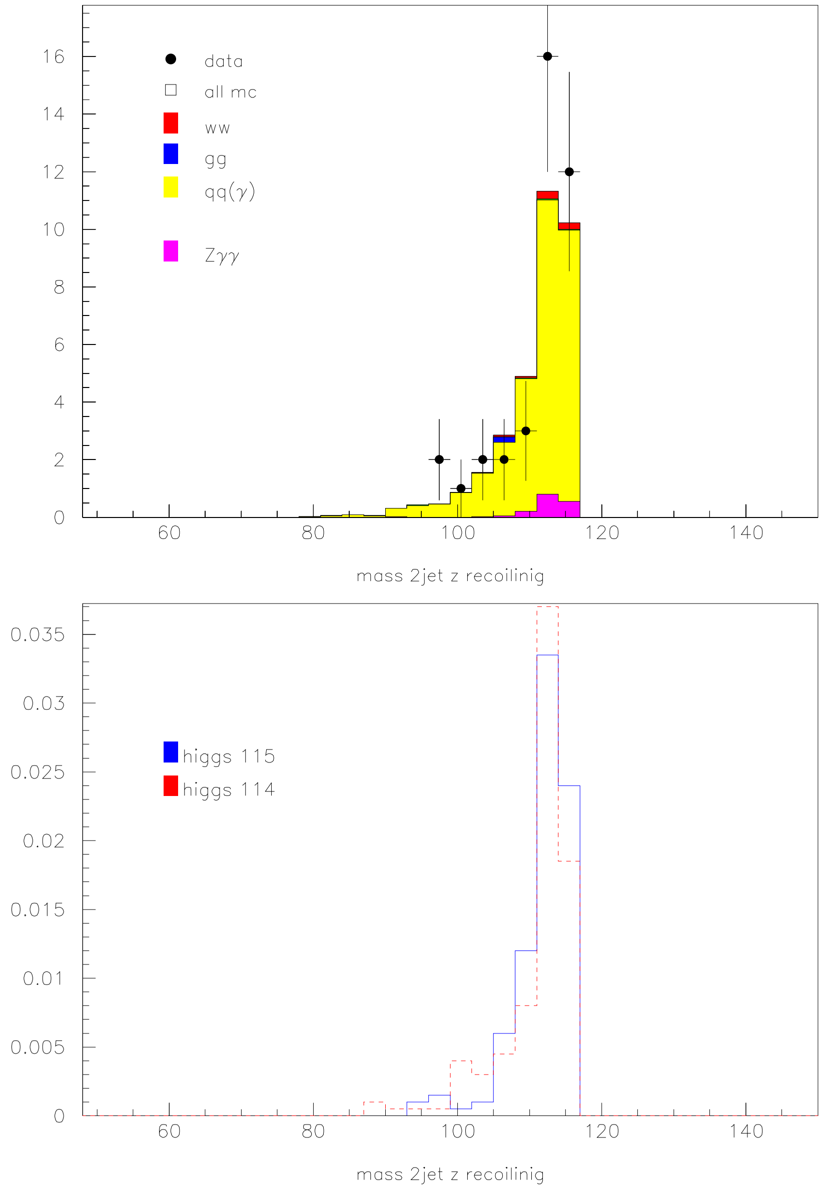

Figure 7: The recoiling mass to the Z→$\nu\bar{\nu}$, for btag ≥1. The simulation is at E_{cm} =206.7 GeV. In the bottom plot the full line (blue) is for a Higgs of 115 GeV of mass; the dashed line (red) is for a Higgs of 114 GeV of mass.

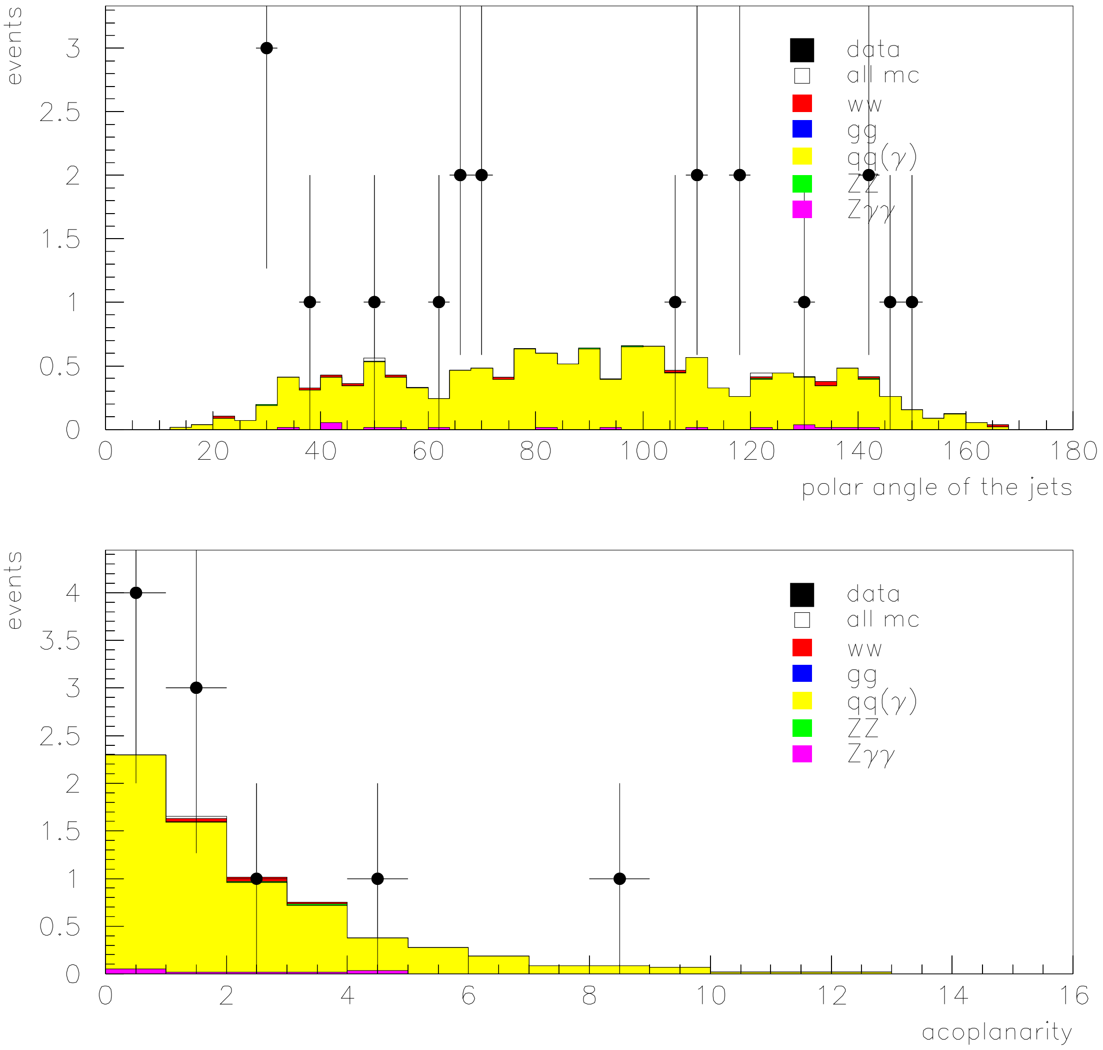

Figure 8: The polar angle distribution of the jets and the acoplanarity of the selected events and with 95$\geq M_{vis} \geq$120 GeV/c^2 and btag $\geq$0.

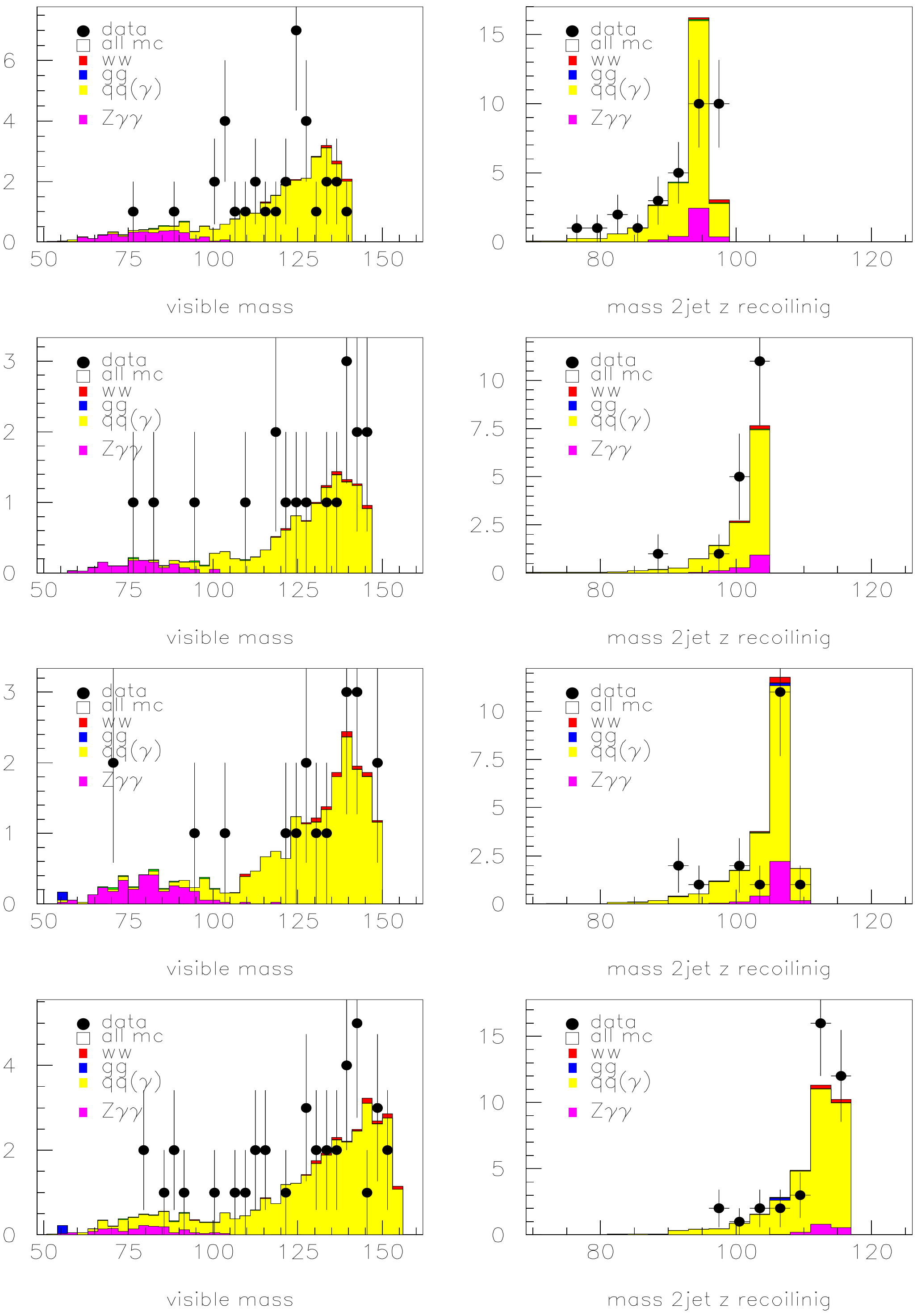

Figure 9: The visible mass and the recoiling mass spectra for collinear selected events and for a btag ≥ 1 for 189 GeV, 196 GeV, 200+202 GeV and 2000 year data respectively going from the top to the bottom.

in which the main loss is due to neutrinos from semileptonic decays is not negligible and it is detector independent.

The percentage of events that loose more than 30% of their energy in neutrinos from semileptonic decays has been estimated using generated MC events. 371000 $e^+e^-\to q\bar{q}$ events have been generated at $E_{\rm cm}$ =206 GeV; of these 91000 have E($q\bar{q}$)$\geq$ 200 GeV. For 217 of them, more than 60 GeV of energy has been carried away by the neutrinos: i.e. 6×10^{-4} of the total $q\bar{q}$ events. If b-quark events are selected, 172 have lost more than 60 GeV of energy in neutrinos: i.e. 5×10^{-4} of the total $q\bar{q}$ events.

This means that in each experiment we expect, in the 2000 run only (i.e. for an integrated luminosity of 220 pb^{-1} at $E_{\rm cm}$ =206 GeV), that about 10 events have lost at least 60 GeV of their energy in neutrinos (i.e. neglecting detector effects). In figure 10 the energy carried away by neutrinos for $e^+e^-\to q\bar{q}$ events and $e^+e^-\to b\bar{b}$ events is shown for events generated at $E_{\rm cm}$ =206 GeV and with E($f\bar{f}$)$\geq$ 200 GeV. Similar results are obtained at the Z [4].

Figure 11 shows the acollinearity of events that have lost at least 60 GeV of energy in neutrinos for $e^+e^-\to q\bar{q}$ events and $e^+e^-\to b\bar{b}$ events (events generated at $E_{\rm cm}$ =206 GeV and with E($f\bar{f}$)$\geq$ 200 GeV): 70% have acollinearity $\leq 5^\circ$, 90% acollinearity $\leq 10^\circ$.

Of the $\tilde{1}0$ events expected in each detector during the 2000 run, 55% will remain at the end of the analysis described in this note, while only 14% would survive the $H\nu\bar{\nu}$ DELPHI standard analysis [1] (after event selection, i.e. for an Higgs efficiency of 75%).

Trying to characterise the event categories where more than 60 GeV of energy is lost in neutrinos, one can see that:

- for 85% of the events, there are neutrinos in both hemispheres as both the B (or D) hadrons decay semileptonically.
- The total number of events with at least one τ lepton is 72 (of which 5 with two τ). Looking more in details; the sample is enriched in $B\to\tau\nu_\tau$ as one gets twice as many as one would expect from the relative branching ratios.
- In half of the events, the B decays semileptonically into a D hadron that decays semileptonically as well.
- The leptons in these events are quite soft and with a small transverse momentum with respect to the thrust axis. In total, 70% of these events *do not* have at least one lepton of high momentum (i.e. $\geq$ 5 GeV/c) and high p_T (i.e. $\geq$ 2 GeV/c).

4 Conclusion

Higgs at the kinematic limits are always produced with a sufficient boost that allows to cut away collinear events without a serious loss in the number of expected signal events. We have shown in this note that collinear events can easily fake a high mass Higgs signal in case of a discrepancy between data and simulation. The most dangerous irreducible background in this case is that of 2 fermions events produced at full energy that loose almost half of their energy in neutrinos.

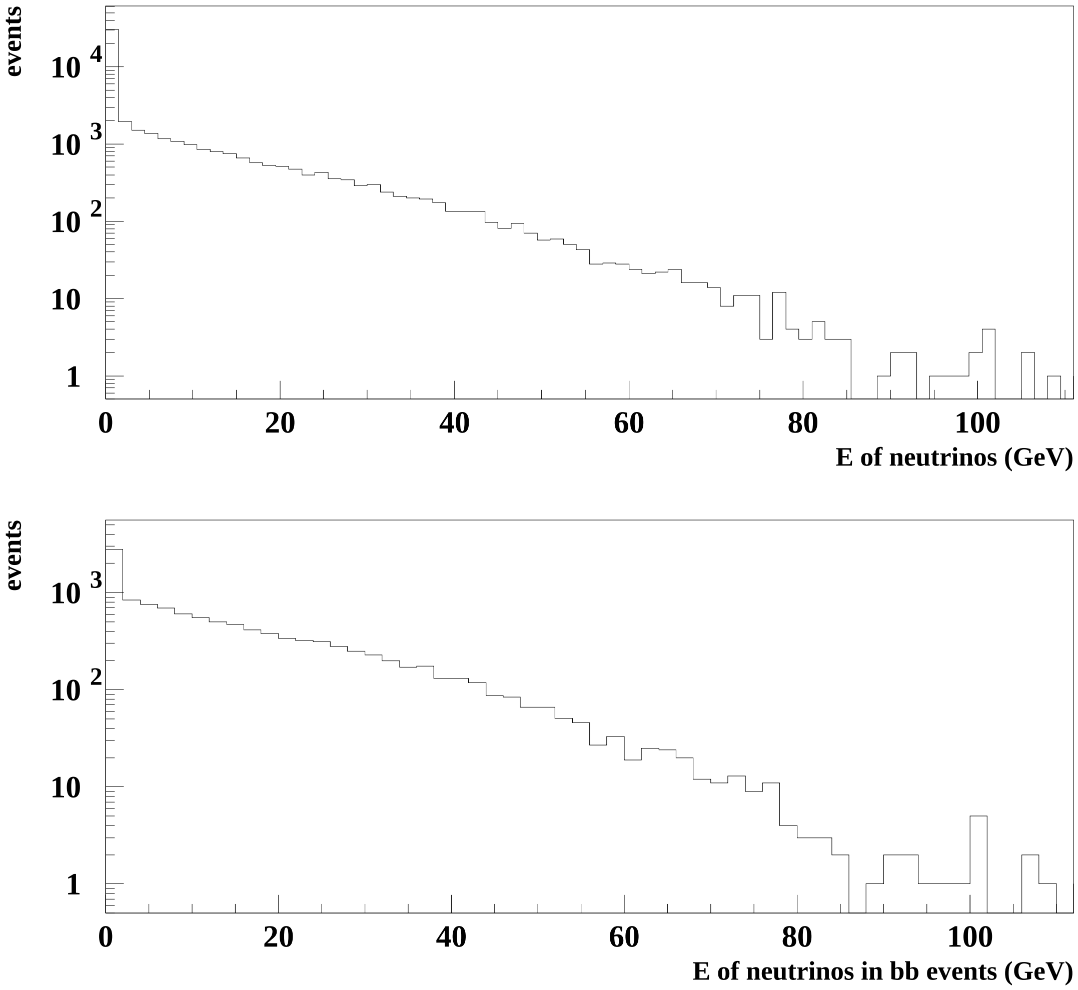

Figure 10: The energy carried away from neutrinos in (top) $q\bar{q}$ generated events at $E_{\rm cm}$ =206 GeV and in (bottom) $b\bar{b}$. The only request is that the energy of the 2 quark should be larger than 200 GeV.

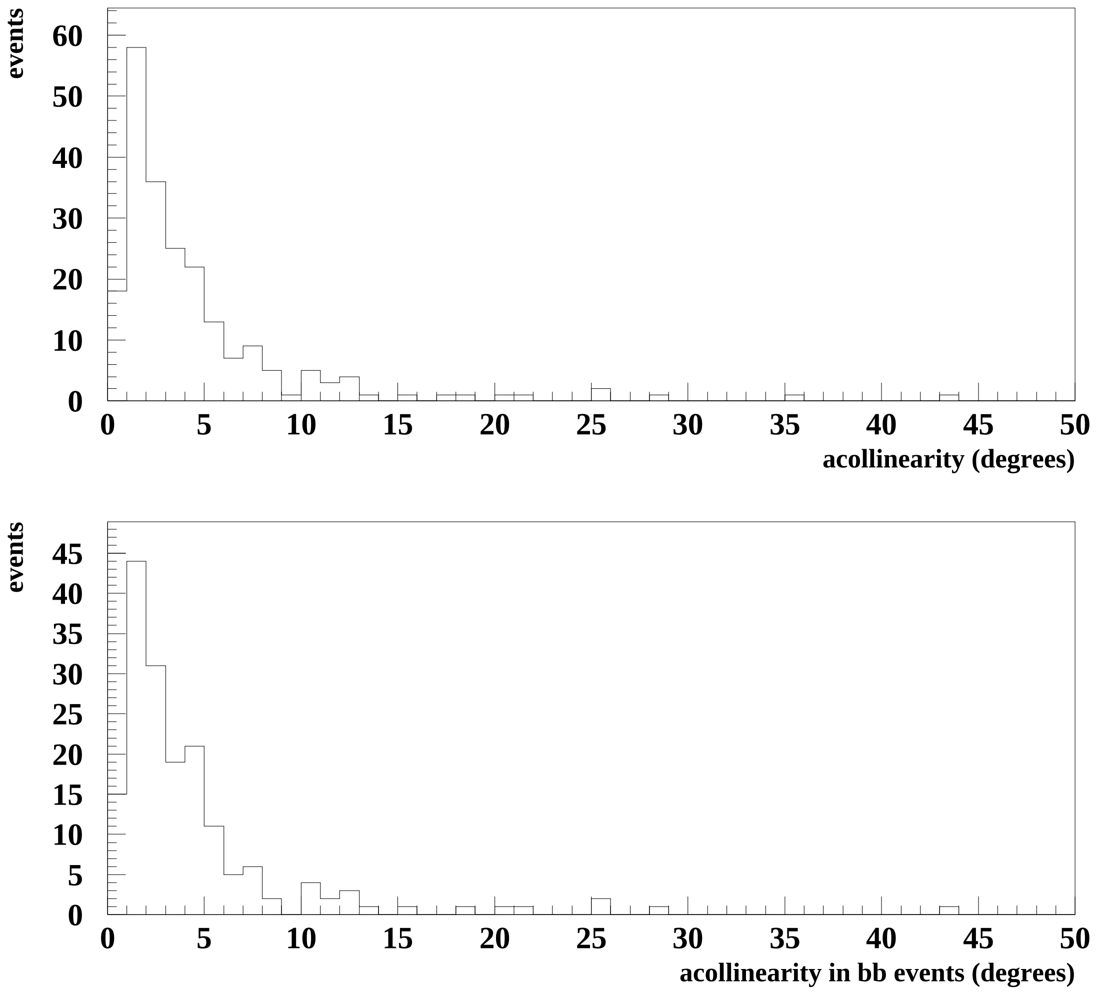

Figure 11: The acollinearity of the events in which more than 60 GeV of energy has been carried away by neutrinos. Upper plot: $q\bar{q}$ generated events at E_{cm} =206 GeV asking E($q\bar{q}$)≥200 GeV; lower plot: $b\bar{b}$ events asking E($b\bar{b}$)≥200 GeV.

References

[1] P. Abreu *et al.* [DELPHI Collaboration], *"Search for the standard model Higgs boson at LEP in the year 2000,"* Phys. Lett. B **499** (2001) 23.

[2] E. Accomando and A. Ballestrero, Comp. Phys. Comm. **99** (1997) 270.

[3] C. Mariotti, E. Piotto,"*Symmetric double radiative return with Z* $\rightarrow q\bar{q}$ *final state*", 2000-132 OSAKA CONF 431.

[4] A.DeAngelis (DELPHI), private comunications.