Study of 5-Jet Events in W Pair Decays

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One of the channels used to determine the W mass at LEP is the process $e^+e^- \to W^+W^- \to q\bar{q}q\bar{q}$. In approximately 46% of all cases the two produced W bosons decay into four quarks. These events consist of four energetic hadronic jets with little or no undetected energy and momentum.

The aim of this study is to reconstruct the W mass from the jet information and to optimize the actual analysis, which is based on a 4-jet reconstruction [1,2], by examining the influence of 5-jet events (due to hard gluon radiation) on the mass resolution.

After a preselection to reduce most of the dominant background $\left(Z^0/\gamma\right)^* \to q\bar{q}$ [3] a jet algorithm combines the detected particles and forces them to four jets. To extract the W mass from each event one has to know which two jets originate from the same W boson, i. e. one has to find the best out of the three different possibilities of associating two jet pairs with four jets.

A kinematic fit provides the probability that the four jets and their association to the two W bosons are consistent with energy and momentum conservation and the assumption of equal mass of the two W bosons. This probability is calculated for each combination separately. Together with additional kinematic information it is used to determine which combination is most likely the correct one [1].

However, the 4-jet mass reconstruction can be biased or wrong if an initial parton radiates an energetic gluon and (part of) the momentum of the latter is not associated to the jet it belongs to: Either the event is rejected due to a small probability to fulfil the constraints mentioned above, or it provides worse mass information and degrades the mass resolution of the analysis.

A possible solution to this problem is to treat the events as five jets rather than four jets to avoid that the jet algorithm adds gluon energy to a wrong jet. The idea is to recover otherwise rejected 4-jet events on the one side and improve the mass reconstruction of events with a hard gluon on the other side.

The disadvantage of treating WW events as five jets comes from the greater number of possibilities of jet combinations: There are ten different ways of associating two jets out of five to one W. This can in general lead to a bigger combinatorical background, i. e. $WW \to q\bar{q}q\bar{q}$ events that provide no useful mass information due to a wrong jet-W association, and a loss of signal events for which the 4-jet analysis would have picked the right combination.

The aim of this analysis is to improve the existing 4-jet analysis by dividing all events into two groups with respect to the parameter

$$Y_{45} = 2min_{ij}\left(min\left[E_i^2, E_j^2\right]\frac{1-cos(\theta_{ij})}{s}\right) \qquad (1)$$

where the subscripts i and j denote two jets and s is the square of the center of mass energy. $E_{i,j}$ are the energies of the i^{th} and j^{th} jet while θ_{ij} denotes the angle between these two jets. The minimum is taken with respect to all combinations of two out of the 5 jets. Y_{45} is a measure for the smallest separation of two jets of a 5-jet event. This is the same parameter that is already been used in the jet algorithm mentioned above: The jet algorithm adds iteratively the 4-momenta of those two particles together which have the smallest $Y_{n,n+1}$ in order to reduce the number of jets of the event from $n+1$ to n. This process is repeated until the final number of jets, either four or five, is reached.

In order to quantify the effect of mixing the energy from both W bosons in one jet one can use the incorrectly associated W energy (E_{wrong}) to each of the five jets.

Fig.1a) shows the fraction of 4-jet (5-jet) events in bins of $\log(Y_{45})$ which have at least one jet with wrongly associated W energy E^{max}_{wrong} exceeding 10 GeV. For small $\log(Y_{45})$ E^{max}_{wrong} is similar for 4 and 5 jet events but with increasing $\log(Y_{45})$ it becomes much worse for 4 jet events. This indicates that an improvement by 5 jet reconstruction can mainly be expected for events with a large $\log(Y_{45})$.

This is further illustrated in fig.1b) by the distribution of the wrongly associated W energy E^{max}_{wrong} for the "worst" jet for both four and five jets just for those events with $\log(Y_{45})$ exceeding -6.0. This distribution shows that it is worth trying to recover 4-jet events with a high amount of wrongly associated W energy by treating events with large $\log(Y_{45})$ as five jets.

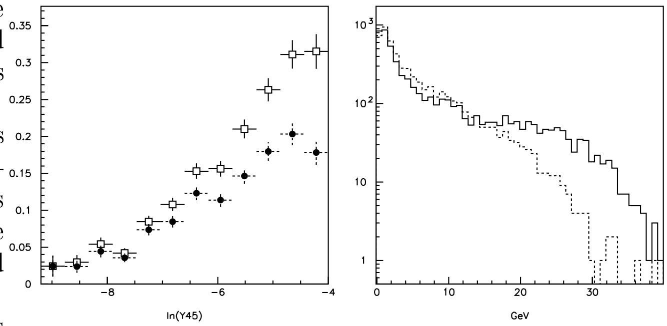

Fig. 1: a) Fraction of Events with wrongly associated energy that is bigger than 10 GeV for each bin in $\log(Y_{45})$ for 4-jet (empty squares and solid bars) and 5-jet events (filled circles and dashed bars).
b) Distribution of the wrongly associated energy E^{max}_{wrong} for the "worst" jet for 4-jet (solid line) and 5-jet events (dashed line) with $\log(Y_{45}) > -6.0$.

References

[1] The OPAL Collaboration, G. Abbiendi et al., *Measurement of the W Mass and Width in e^+e^- Collisions at 183 GeV*, Phys. Lett. **B453** (1999) 138

[2] The OPAL Collaboration, K. Ackerstaff et al., *Measurement of the W Boson Mass and W^+W^- Production and Decay Properties in e^+e^- Collisions at $\sqrt{s} = 172$ GeV*, Eur. Phys. J. **C1** (1998) 395

[3] The OPAL Collaboration, G. Abbiendi et al., *W^+W^- production and triple gauge boson couplings at LEP energies up to 183 GeV*, Eur. Phys. J. **C8** (1999) 191