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JET ENERGY MEASUREMENT WITH THE ALEPH DETECTOR AT LEP2

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The impact of the jet energy and direction measurement performances is studied through the 4 jets (W pair production) at LEP2. Emphasis is put on the sensitivity of the algorithms to the calibration of the jet component and to the the jet fragmentation modelling. The implication upon the systematics for the main physics channels are derived.

1. Introduction

One of the main evolution between LEP1 and LEP2 concerns the way the jet are used in the analysis. At LEP1, topological studies on jets were used in QCD related analysis as well as the analysis of their content, jets were also used for flavor tagging either by identifying their content or from their lifetime; at LEP2 in addition to the LEP1 studies, jets are heavily used to identify and measure 2 or 4 jet final state. Among the subject of interest at LEP2, one of the most challenging one is the precise W mass measurement, reconstructed from jets, for which the expected statistical error from the 4 LEP experiment, using the whole LEP2 statistic, will be about 22 MeV. Therefore particular care is given to the evaluation of the systematic errors. Among systematic error sources those issued from the uncertainties on the jet reconstruction covers several aspects:

(1) the absolute calorimeter calibration.
(2) the jet direction and mass determination
(3) the jet hadronization scheme
(4) the quality of the detector simulation
(5) the choice of the the jet algorithm

To achieved the best measurement from the 4 LEP experiments, the sensitivity of jet algorithm upon the final state modelling, which concerns effects correlated between experiment, has to be evaluated and minimized.

2. Hadronic jets

As mentioned above, at LEP2, physical processes involve jets in their final state as W^+W^- pair production inducing 4 jets when both W decay in quarks or 2 jet when one of the W decays semi-leptonically, or Higgs production in association with a Z boson. A crucial point in those analysis is to determine the di-jet invariant mass. The determination of both energy and direction with the best accuracy relies upon a precise measurements of all its components; using the Aleph energy flow algorithm technique, 60% of the jet energy is carried out by charged tracks, the remaining 40% coming from neutral particles, photons or neutral hadrons, can only be measured by the calorimeters[3].

2.1. *Calorimeters calibration*

The Aleph electromagnetic calorimeter is made of 36 modules (12 covering the central region, and 12 in each of the 2 endcaps), of 45 layers of lead and proportional tube, finely segmented, each element covering a solid angle of about 1 degree in polar and azimuthal dimension and achieving a resolution of $\sigma(E)/E = 0.18/\sqrt{E} + 0.009$. The gain of the gas in the proportional tubes is monitored by an Fe^{55} source, which allow to correct for time variation due to pressure or temperature fluctuations. The intercalibration of the 36 modules is done with electron in the range from 2 to 15 GeV issued from $\gamma\gamma$ processes taken during the Aleph running. This procedure allows to reach a 0.3% precision upon the module intercalibration and take in account shower leakage and saturation effects measured in test beam data. The absolute calibration is performed with events recorded when the LEP operate at the Z, and controlled with bhabhas from high energy running; the quoted overall uncertainty upon the electromagnetic calorimeter is of 0.7%.

The hadron calorimeter has 36 modules where iron layers are interleaved with streamer tubes, the whole arranged in projective towers with a granularity of 3.7x3.7. Analog readout on towers and digital one on cathode strips along the streamers tubes give a two dimensional information used for muon tracking. The energy resolution for charged pions measured in test beam was measured to be $\sigma(E)/E = 0.85/\sqrt{E}$. The gas monitoring system[1] allow to correct for time dependence due to temperature or pressure fluctuations, the level of the correction can reach 10%. The overall calibration comes from the energy deposited by a muon crossing the calorimeter at normal incidence normalized to test beam energy response. The residual time dependence is monitored from $\gamma\gamma$ events during the high energy run and found to be kept within 1.5%. To derived systematics due to calibration uncertainties, calorimeter response for both electromagnetic and hadronic calorimeter are compared to Monte-Carlo;

the Monte Carlo is re-scaled to the data taking in account the polar dependence and the response of each calorimeter element and is shaken according to the resolution.

2.2. *Energy flow algorithm*

Tuned at LEP1, the Aleph energy flow algorithm[2] has been designed to optimize the total energy measurement and intensively used at LEP1 for the Higgs search; it uses the good performance upon the track momentum measurement and takes advantage of the finely segmented calorimeters to disentangle the different contributions:

(1) charged tracks and identified leptons contributions are taken from their tracking measurement
(2) γ and π^0 from the electromagnetic calorimetry
(3) neutral hadron from both calorimeter measurement
(4) the last component being the residual from charged hadrons or γ which should be kept at the lowest level

The performance of this algorithm has been tested at LEP1 using Z decays into 2 acoplanar jets accompanied by an high energy photon. The invariant di-jet mass reconstructed from the energy flow objects can be compared to the recoil mass against the high energy photon. This method allows to measure the jet resolution as a function of the jet energy to be:

$$\sigma(E)/E = (0.59 + -0.03)/\sqrt{E} + (0.6 + -0.03) \text{ GeV}$$

The dependence upon the jet energy is shown on Figure 1 and the expected resolution at high energy is derived from this measurement. For Z events among 60% of reconstructed energy comes from tracking measurement, 32% from the electromagnetic calorimetry; from LEP2 study the sharing of the energy remains identical.

2.3. *Jet reconstruction performance*

To reconstruct jet the energy flow objects are clustered using Durham algorithm where objects for which the distance $y_{ij} = 2min(E_i^2, E_j^2)(1-cos\theta_{ij})/E_{cm}^2$ is smaller than a certain threshold are assigned to the same jet. According to the topic studied either the maximal distance is fixed or adjusted in order to force the event into a certain number of jets (for exemple 4 in the case of W pair production decaying into 4 quarks). The jet performance resolution in term of energy and direction has been studied with Z data. The jet energy resolution behave as $\sigma(E_{jet})/E_{jet} = 0.67/\sqrt{E}_{jet}$, which correspond to 10% at 45 GeV where a 6-7% resolution is expected for a perfect detector measured from

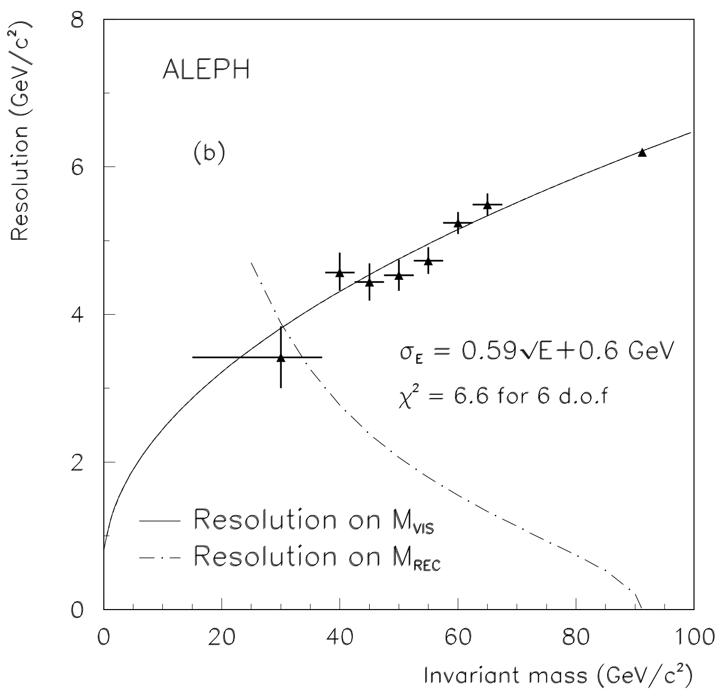

Figure 1. Measured resolution on $q\bar{q}\gamma$ from Z decays

Monte Carlo parton shower. The angular resolution is studied from Z data where the 2 jets are expected to be back to back, an angular resolution of 0.9 is observed for energy flow jets in good agreement with Monte-Carlo expectations which represents a large improvement compare to the 1.6 and 1.4degree obtained respectively for jets build from charged tracks and calorimeter objects.

3. W mass reconstruction

W mass measurement is based on a precise reconstruction of the jet-jet mass. The whole method uses large simulated events inputs and requires a fine and detailed matching between all the components; therefore the understanding of detector effect as well as the physics modelling of parton shower will allow to improve the measurement precision.

3.1. *W Reconstruction method*

In the case of W pair production where both pair decays into quarks, the event is forced into 4 jets and the procedure used takes advantage of the kinematical constraints from the known total energy available in the center of mass, re-scaling the jets energy and momentum as $\Sigma\beta_i E_i = E_{cm}$, with the momentum balance constraint $\Sigma\vec{u_i}\beta_i p_i = 0$, leaving the jet direction unchanged. In a more elaborate recursive fitting procedure the jets direction and momentum are allowed to vary within their expected errors while a 4 momentum conservation constraint is applied (4C-fit), jet masses can be forced to be equal in a 5C-fit procedure. By using kinematic fitting procedure the resolution improves as shown on Figure 2 The fitting procedure implies a large use of Monte-Carlo

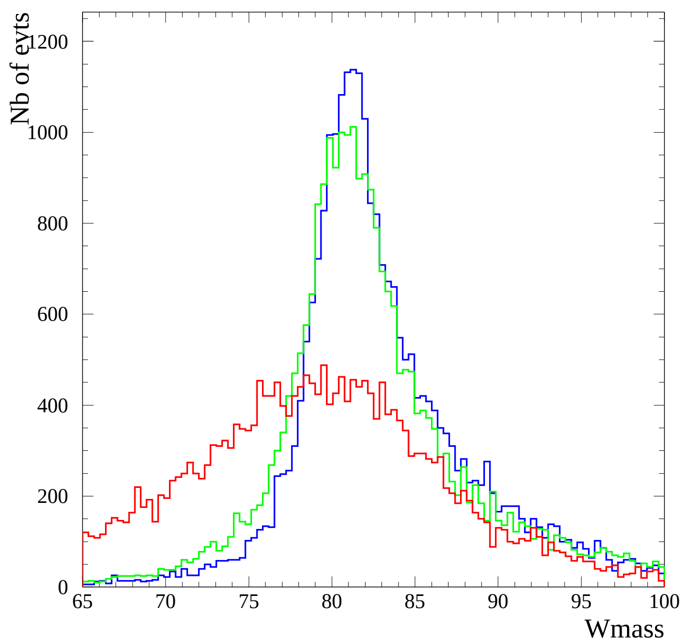

Figure 2. Reconstructed W mass from raw jets (dashed), energy re-scaled jet (dot), and 4C fit (full).

samples, the di-jet mass is fitted by changing the underlying W mass parameter and applying weights calculated from the matrix element ratio when changing the W mass parameters. The accuracy of the method is based on the control of the agreement between simulated and real events.

3.2. *Jet mass dependence*

For massless partons the invariant mass of 2 of them is defined as $M_{if} = 2E_iE_j(1 - cos\theta_{ij}$, therefore the energy of each of the jets and the angle determination are important feature. The uncertainty linked to a jet energy mea-

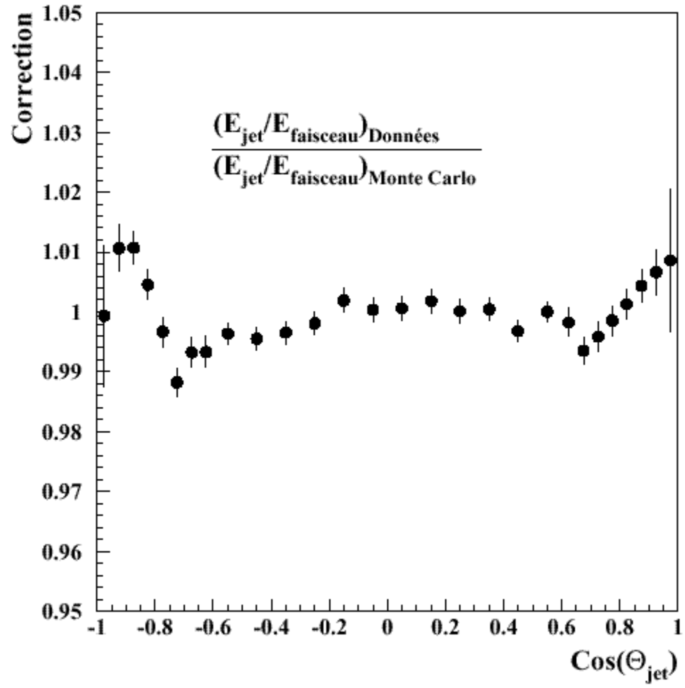

Figure 3. The correction factor to the jet energy determined from jet energy comparison at the Z is plotted as a function of the polar angle

surement difference between data and Monte-Carlo is estimated by re-scaling the jet energy taking in account the angular dependence shown on Figure 3

As mentioned above the jet angular resolution is in good agreement between data and Monte-Carlo[4]. But the hypothesis of massless parton is too trivial, and reconstructed jets have a mass which is sensitive to several effects:

(1) jet multiplicity due to fragmentation scheme or induced by detector effects
(2) particles not assigned to the right jet
(3) final state modelling and among them color reconnection effect

One should notice that systematic differences in jet mass between real and simulated events will induce systematic upon W mass determination : $\delta(M_W) = m_i/M_W \delta(m_i^{data} - m_i^{MC})\theta_{ij}$, typically a 100 MeV shift in the jet mass determination will induce a 40 MeV systematic effect on the W mass. To estimate the corresponding systematics detailed Monte-Carlo/Data comparison are conducted in order to only use for the mass determination the component for which a good agreement between simulated and real data is achieved. Detailed comparison of simulated and real jets had been done, on the energy spectrum and multiplicity of their different energy flow components, it as shown that at low energy the multiplicity of energy flow objects coming from hadron and photon residuals in Monte-Carlo poorly match the data (a factor 1.3 for element below 1 GeV). Removing from the jet definition such energy range for this type object does not affect the expected mass resolution as shown in Figure 4 and still improve the determination compare to a massless hypothesis for which the expected error will 122MeV.

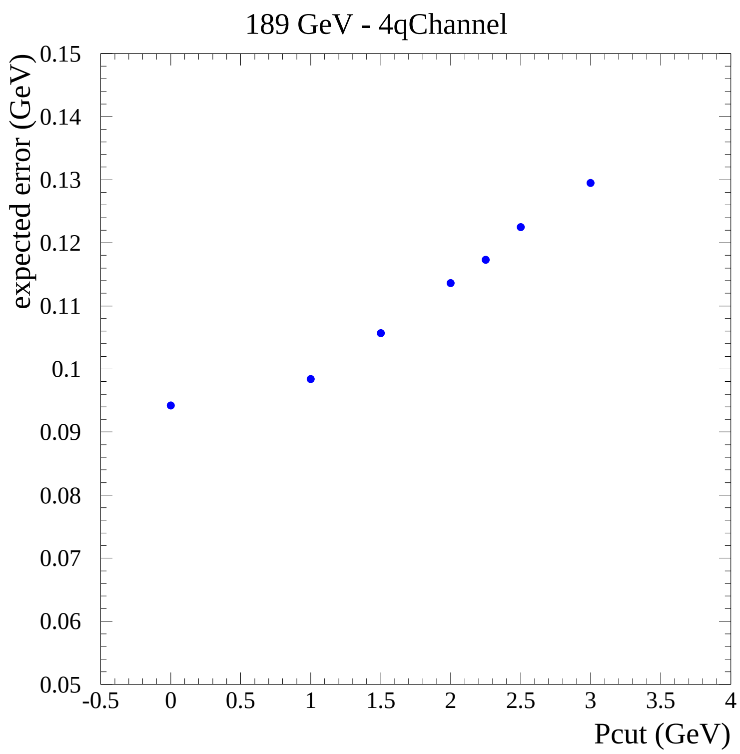

Figure 4. W mass resolution evolution as a function of the an energy cut upon the energy flow object. In addition the expected uncertainty for a massless hypothesis is quoted

The systematics uncertainties derived from the above studies are summarized in Table 1. The uncertainty quoted for the calorimeter simulation is expected to decrease with the improvement in the understanding of the jet energy flow component.

The last line of this table concerns the uncertainties arising from hadronic scheme, it concerns: the fragmentation scheme for which the associated uncer-

Table 1. Systematics uncertainties for W mass measurement for fully hadronic W pair and for events where one of the W decay semileptonically.

	4q	$l\nu q\bar{q}$
Calorimeter calibration	4 MeV	5 MeV
Jet calibration	7MeV	10MeV
Jet angle	5 MeV	4 MeV
Calorimeter simulation	10 MeV	15 MeV
FSI(CR,BE,Fragm)	48 MeV	20 MeV

tainty is derived using several scheme (Ariadne-Herwig-Jetset).

(1) the fragmentation scheme for which the associated uncertainty is derived using several scheme (Ariadne-Herwig-Jetset).
(2) the jet particle association.
(3) the bose-einstein effect
(4) color reconnection level for W pair going to 4 quarks

These effects lead to a low weight in the W mass determination of the 4-quarks channel (27%). This uncertainty should be reduce using alternative jet algorithm designed to be less sensitive to the final state interaction.

4. Conclusions

At LEP2 the use of energy flow technique for the jet measurement allows physics measurements involving two and four hadronic jets final state. On top of it the use of kinematic fitting procedure requires a good matching between real and simulated data, leading to a more demanding understanding of the detector feature. Recent progress in this field will allow improved and more robust uncertainties determination for the W mass measurement.

Acknowledgments

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