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by

B. Klima

Deutsches Elektronen-Synchrotron DESY, Hamburg

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Analysis of e^+e^- Annihilation in terms of the Webber Model*

BOAZ KLIMA
DESY, HAMBURG, GERMANY

ABSTRACT. e^+e^- annihilation data obtained at a c.m. energy of 34.6 GeV is compared with a modified version 2.2 of Webber Monte Carlo that has been developed. The model is found to reproduce well the gross features of the data, including the fraction of multijet events and the "string" effect in 3-jet events. The modified version's best parameters are : $\Lambda_{Webber} = 200 \pm 90 MeV$ and $M_c = 4.2 \pm 0.5 GeV$ where Λ_{Webber} is the QCD scale in this model and M_c is the maximum cluster mass.

1. Introduction

The Webber model (1), the cluster model with interfering soft gluons, is one of the two successful fragmentation models, the other being the Lund model (2). The Webber model does very well with very few parameters which is a particular success. It reproduces the "string" effect, the inclusive spectra and even a few higher order aspects which were studied so far. Its main failure up to now was that it could not give the correct fraction of 3-jet events. This in general has prevented a thorough overall comparison between model and data since no good fit to the data was obtained. The studies published so far concern the 3-jet analysis (3,4), but the model was used with the parameter set of the original version. These parameters did not reproduce the data satisfactorily. therefore one should first of all solve the 3-jet fraction problem, then find the model's best parameters and only then proceed with detailed comparisons.

A modified version 2.2 of the model has been developed which corrects this problem. This note describes briefly the features of the modified model in comparison with data from e^+e^- annihilations taken with the TASSO detector at PETRA.[1]

2. Modified Version 2.2 of Webber Model

In order to improve the model (1) two changes were made. The first one deals with the value of the boost. As it was explained in detail previously (1) the lack of manifest covariance means that it is incorrect to simulate multijet production by combining single cascades generated in different frames. This difficulty is avoided by requiring that all branching will take place in a single hemisphere, i.e. in e^+e^- annihilation the entire final state must be generated first of all as a "photon jet" and subsequently be transformed to its rest frame after computing the exact Q^2 of the virtual photon. The minimal boost, γ , required in order to have the initial quark - antiquark at 90 degrees is $\sqrt{2}$, but any larger value is also acceptable. Even though the calculations are performed in a non-infinite momentum frame it makes little effect both on most of the event distributions and on the fraction of multijet events. In the original version a value of 1.5 was chosen assuming that the physics results will not depend on this value. Unfortunately this is not the case and one better look for that value for which the Q^2 distribution is peaked exactly at E^2_{cm},the square of the c.m. energy. The value which gives that requirement was found to be $\gamma = 1.465$.

The second improvement deals with the energy distribution of the initial quark and antiquark. The energy of the quark in the boosted frame is

$$E_q = m_q + z(\gamma E_{cm} - 2m_q)$$

where m_q is the mass of the quark, E_{cm} is the c.m. energy, γ is the boost and z is a random number between 0 and 1. The energy of the antiquark in this frame is

$$E_{\bar{q}} = \gamma E_{cm} - E_q$$

In the original version it was assumed that the z distribution does not affect the physics results and a flat distribution was taken. However, since one deals with the virtual photon which is a vector rather than a scalar source one better uses the Altarelli - Parisi type distribution function $z^2 + (1-z)^2$ instead of a flat one . Using the Altarelli - Parisi distribution function however results in harder gluons and consequently in a larger 3-jet rate.

3. Tuning of the Parameters

3.1 Assumptions

Using the modified version of Webber Monte Carlo described above there are few parameters which either should be tuned or should be chosen according to certain physics assumptions.

Assuming that the hadronizaion of the clusters is due to phase space and spin factors only, there are the following parameters : Λ_{Webber}, the QCD scale in this model, which is not identical to the commonly used $\Lambda_{\overline{MS}}$, M_c, the maximum cluster mass above which fission occurs, m_g, the gluon virtual mass cut-off and the quark masses, m_q's. These parameters have been explained in detail previously (1).

One has to remember that there are some constraints on these parameters which are built into the model which affect our choice. The constraints are : (1) $m_g \geq 2m_{u,d}$. (2) $m_{u,d} > 1.1\Lambda_{Webber}$. (3) $m_q > M_P$ where P is the lightest pseudoscalar which contains the quark q, e.q. $m_{u,d} > M_\pi$, $m_s > M_K$, $m_c > M_D$, $m_b > M_B$ etc.

Since the masses of the quarks were pushed up by the third constraint, at least for the heavy ones, the minimal values for the s, c and b quark mass were chosen.

A reasonable value for the light quark mass was taken and the virtual gluon mass which is the cut-off where the perturbative part is being stopped was chosen to have exactly twice the previously mentioned value, $m_g = 2m_{u,d}$. The value for the gluon virtual mass is the minimal available according to the first constraint. However the physics results turned out to be almost insensitive to reasonable changes in this value.

3.2 Event Selection

The experiment was performed with the TASSO detector at PETRA. The data used for this analysis were taken at c.m. energies in the range $32 < E_{cm} < 36 GeV$. Details of the detector are described elsewhere (5). Hadronic final states from e^+e^- annihilation were selected using the information on charged particle momenta measured in the central detector. The selection criteria for charged particles and for multihadron events were identical to those described previously (6). A total of 21567 events were accepted. The experimental distributions were corrected for the effect of acceptance and for QED radiative effects (7).

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3.3 Fit Procedure

Following the procedure of a previous analysis (8) the determination of the two remaining parameters, namely Λ_{Webber} and M_c, was done using a simulteneous fit to the following set of three distributions :$1/\sigma_{tot}d\sigma/dx_p$, $1/\sigma_{tot}d\sigma/dP_T^{in}$ and $1/\sigma_{tot}d\sigma/dP_T^{out}$ where x_p is the scaled momentum of the charged particles $x_p = 2|p|/E_{cm}$ and P_T^{in}, P_T^{out} are the transverse momenta in and out of the event plane which is determined by diagonalizing the momentum tensor of second rank.

A lattice of 4x4 points in the Λ_{Webber} and M_c space was considered. For each lattice point about 3700 Monte Carlo events were generated and the distributions were calculated according to our definition (Sect. 3.1). The content of each bin of each distribution was parametrized by a 2nd order polynomial in Λ_{Webber} and M_c which gave a good description of the Monte Carlo data. The best values for Λ_{Webber} and M_c were obtained by a combined fit of these parametrizations to the corrected data using the computer code MINUIT (9).

3.4 The Best Parameters of the Model

Using the following values for the untuned parameters :

$$m_g = 2m_{u,d} = 0.70GeV$$
$$m_s = 0.50GeV$$
$$m_c = 1.87GeV$$
$$m_b = 5.30GeV$$

the modified Webber Monte Carlo best parameters are

$$\Lambda_{Webber} = 200 \pm 90 MeV$$
$$M_c = 4.2 \pm 0.5 GeV$$

The relatively big errors, especially in Λ_{Webber}, reflect two facts : (1) Λ_{Webber} always appears logarithmically in physics expressions so that they are not very sensitive to slight changes in this parameter. (2) The Monte Carlo distributions are not in a good agreement with the data. For very high momenta the model deviates from the data.

3.5 The Interpretation of Λ_{Webber} in the Webber model

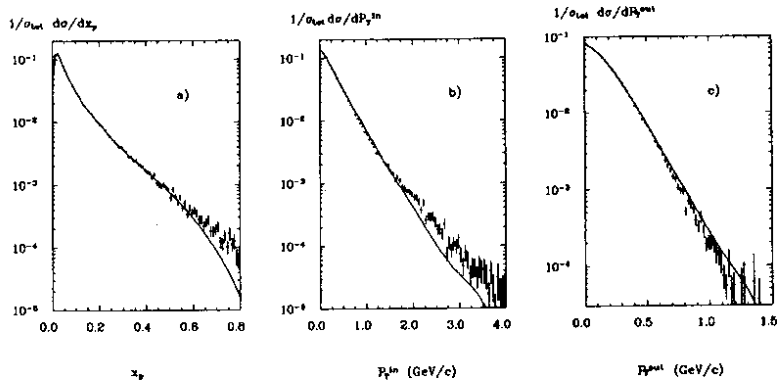
It is very important to emphasize that Λ_{Webber} in this model is not the commonly used one, namely $\Lambda_{\overline{MS}}$. In order to compare our result with other experiments using different models one needs to know what is the connection between these two Λ's.

A recent theoretical publication (10) which might define and prove the connection between these parameters deals only with moments of multiplicity distributions so it cannot be applied to the present study. A more general theoretical proof is required in order to be able to interpret our result.

4. Comparison with the Data and with the Original Version

4.1 Results of Distributions

The χ^2/N_{DOF} of the fit, bearing in mind that it was done using the statistical errors only, is reasonably good. For the three different distributions χ^2/N_{DOF} values of 4.3 for x_p distribution, 4.5 for the P_T^{in} one, 3.2 for the P_T^{out} and 4.0 for all these three distributions were obtained. The quality of the fit is comparable to that of 2nd order Lund model (8).



Figs. 1a-c: Webber model fit. The normalized distributions $1/\sigma_{tot}d\sigma/dY$,where Y is the quantity indicated on the horizontal scale, for the corrected data (+) and for the best fit predictions of Webber model (−). a) The scaled momentum distribution $x_p = 2p/E_{cm}$. b,c) The single particle inclusive $P_T^{in}$and P_T^{out} distributions.

In figures 1a-c one can see that up to certain values of P_T^{in} and P_T^{out} the fit results describe well the data. For relatively high values the fit is worse, even though one has to remember that the systematical errors which are much larger in this region were not included. Since these distributions were plotted using a logarithmic scale one should realize that the fit is good up to two orders of magnitude, i.e. the integrated deviation from the data is much less than one percent. In the x_p distribution it seems as if from a value of 0.5 on the model's curve deviates from the data points. This might reflect an intrinsic problem in the model (14). Once again since one is dealing with a logarithmic plot it should be emphasized that the integrated deviation from the data in the x_p distribution is less than 0.1 percent.

4.2 The Fraction of Multijet Events

Since the fraction of multi (≥ 3) jet events was the main problem in the original version, the modified version's results are compared both with the original ones and with the data.

In table 1 the percentage of multi (≥ 3) jet events was summarized using two different methods. The first method, the angular cluster algorithm (11), was used in order to find the number of jets of charged particles while in the second one the generalized sphericity method(12) was used. In the first method any other cuts besides those which exist in that algorithm were not applied . The parameters $(\alpha, \beta, \epsilon_1, \epsilon_2)$ as defined previously (11) were chosen to be $(30^\circ, 45^\circ, 0.1, 0.11)$. In the second method exactly the same cuts as was done in the previous analysis (13) were applied.

The two methods might give a hint about possible systematic errors. Nevertheless, in both cases it is very clear that the modified version reproduces the data well.

4.3 The "String" effect in Webber model

Using the method of generalized sphericity (12) and applying exactly the same cuts as

	Method 1	Method 2
Data	23.8±0.6	11.1±0.4
Original Version	18.9±0.4	10.0±0.3
Modified Version	22.9±0.4	11.7±0.3

Table 1: Percentage of multi (≥ 3) jet events in the Original and Modified versions of Webber Monte Carlo in comparison with the Data

was done previously (13) a multi (≥ 3) jet event sample was obtained. This sample was studied with and without removing the 4 and 5 jet events. In table 2 the ratios of particle flow into the gap regions between jets for data and for the modified version 2.2 of Webber model were summarized.

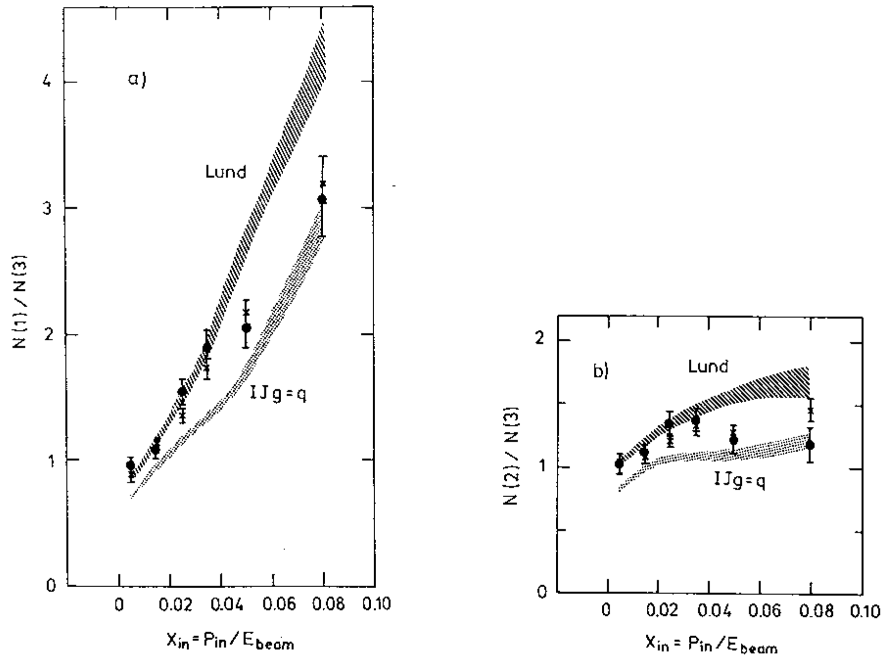
	N(2)/N(3)		N(1)/N(3)	
	≥ 3 jets	3 jets	≥ 3 jets	3 jets
Data	1.19±0.03	1.26±0.04	1.51±0.04	1.64±0.05
Webber model	1.16±0.02	1.20±0.02	1.46±0.02	1.56±0.03

Table 2: The ratios of particle flow into the gap regions between jets for data and for the Webber modified version 2.2

In both cases, with and without removing the 4 and 5 jet events, it seems as if the "string" effect is reproduced in the Webber model even though its strength, the above mentioned ratios of particle flow into the gap regions between jets, might be a bit too small. Nevertheless our results are still compatible with previous studies (3,4) done using the original version's parameters.

Another investigation which was done using this sample concerned the momentum dependence of the density ratios. Figs. 2a and b show N(1)/N(3) and N(2)/N(3) in intervals

of $x_{in} = p_{in}/E_{beam}$ where p_{in} is the particle momentum projected into the event plane. We limit the analysis to $x_{in} < 0.1$ for reasons of statistics. In both ratios the Webber model reproduces the data reasonably well.



Figs. 2a,b: Ratios of particle densities in angular gaps between jet axes as a function of x_{in}. Superimposed on the data (↕) are the Webber model (↕) calculations. The Lund and Independent Jet models predictions are taken from reference (13).

5. Conclusions

A modified version 2.2 of Webber Monte Carlo which well reproduces the gross features of the data, including the fraction of multijet events and the "string" effect in 3-jet events, was developed. The two improvements included in this version gave a better description for the initial quark-antiquark energy distribution.

Using this model the best fit to e^+e^- data yields the values :

$$\Lambda_{Webber} = 200 \pm 90 MeV$$

$$M_c = 4.2^+_-0.5 GeV$$

The interpretation of Λ_{Webber} in this model or the connection between this parameter and the commonly used $\Lambda_{\overline{MS}}$ needs some more theoretical understanding.

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