

# MOMENTS OF THE CHARGED-PARTICLE MULTIPLICITY DISTRIBUTION IN Z DECAYS AT LEP

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The charged-particle multiplicity distribution and its moments have been measured, for all hadronic as well as for light-quark and b-quark events in  $e^+e^-$  collisions at the Z mass. The  $H_q$  moments derived from the charged-particle multiplicity distribution are known to exhibit quasi-oscillations when plotted versus the order of the moment. This behavior is predicted by the NNLLA of perturbative QCD for the parton level and, under the assumption of LPHD, also for the hadron level. Using the jet multiplicity distributions in order to vary the dependence on the LPHD hypothesis, we find, however, that at our energy the oscillations only appear for non-perturbative scales. In the absence of confirmation of pQCD, we investigate a more phenomenological answer in the possibility that the features seen in the  $H_q$  behavior could be due to the fact that the charged-particle multiplicity derives from a superposition of final states related to the topology of the events. Therefore, the analysis is repeated using charged-particle multiplicity distributions originating from 2-jet and 3-jet events for the full, light- and b-quark samples.

## 1 Introduction

Although the number of charged particles is only a global measure of the characteristics of the final state of a high-energy collision, it has proved a fundamental tool in the study of particle production. Independent emission of single particles leads to a Poissonian multiplicity distribution. Deviations from this shape, therefore, reveal correlations<sup>1</sup>. The shape of the charged-particle multiplicity distribution analysed with the ratio of cumulant factorial moments to factorial moments<sup>2</sup>,  $H_q$ , is known to reveal quasi-oscillations<sup>3</sup>, when plotted versus the order  $q$ , with a first minimum at  $q = 5$ .

The usual way to interpret this result is to refer to perturbative QCD, which provides us with calculations for the  $H_q$  of the parton multiplicity distribution<sup>4</sup>. The Next to Next to Leading Logarithm Approximation (NNLLA), which has the most accurate treatment of energy-momentum conservation, predicts for the  $H_q$  a negative first minimum near 5 followed by quasi-oscillations. This behavior may be expected for the charged-particle multiplicity distribution under the Local Parton-Hadron Duality (LPHD) hy-

pothesis, which assumes that the hadronization does not distort the shape of the multiplicity distribution.

However, this result can also be interpreted in a more phenomenological way by viewing the shape of the charged-particle multiplicity distribution as a superposition of different types of event like 2-jet and 3-jet events<sup>5</sup>. This can be investigated using rather simple parametrizations, as a weighted sum of two Negative Binomial Distributions (NBD), each NBD carrying parameters (mean,  $\bar{n}$  and dispersion,  $D$ ) taken from the experimental 2-jet or 3-jet charged-particle multiplicity distributions and using as relative weight the 2-jet fraction ( $\alpha_{2\text{jet}}$ ),  $2\text{NBD}_{\text{fullsample}} = \alpha_{2\text{jet}}\text{NBD}_{2\text{jet}} + (1 - \alpha_{2\text{jet}})\text{NBD}_{3\text{jet}}$ . A similar parametrization can also be tested using light- and b-quark events<sup>6</sup>, instead of 2-jet and 3-jet events.

The test of the two approaches is done by measuring charged-particle multiplicity distributions and their moments for the full, light- and b-quark samples. These samples were also subdivided into 2-jet and 3-jet events obtained from various  $y_{\text{cut}}$  values.

This analysis is based on data collected by the L3 detector<sup>7</sup> in 1994 and 1995 at the energy of the Z. The data sample corresponds to approximately one million selected hadronic events. A b-tag algorithm is used to discriminate between light-(udsc) and b-quark events<sup>8</sup>. Furthermore, the resulting multiplicity distributions are fully corrected for selection, detector inefficiencies<sup>9,10,12</sup> and light- or b-quark purity. It has been shown that the  $H_q$  moments are very sensitive to truncation<sup>13</sup>. Since we want to compare a large variety of multiplicity distributions, we have to make sure that all distributions are affected by the truncation in the same way. Therefore, the truncation is defined as the fraction of events removed in the tail of the charged-particle multiplicity distribution of the full sample (events with multiplicity larger than 48 are removed), and the same fraction of events is then removed in all charged-particle multiplicity distributions studied.

## 2 Test of the pQCD approach

The  $H_q$  for the charged-particle multiplicity distribution of the full, light- and b-quark samples (figure 1) exhibit a first negative minimum at  $q = 5$  and quasi-oscillation for greater  $q$ . The  $H_q$  measured from the light-quark sample are found to agree very well with those of the full sample, while slight differences exist, mainly at low  $q$ , for the  $H_q$  measured from the b-quark sample. The observed behavior is similar to that predicted by the NNLLA. However, also JETSET<sup>14</sup> agrees very well with all the data samples, even though the parton shower of JETSET does not use NNLLA. The same behaviour is found when

[width=5.8cm,height=6cm]hqk0tag\_c\_ol\_p\_relim.eps [width = 5.8cm, height =

6cm]mc\_new.eps Figure 1.  $H_q$  of the charged particle mul- Figure 2.  $H_q$  for various Monte Carlo op-  
multiplicity distribution. tions  
[width=5.8cm,height=6cm]pn\_btag\_2nbd\_fit.eps [width = 5.8cm, height =

6cm]hq\_fit\_btag.eps Figure 3. Charged-particle multiplicity Figure 4.  $H_q$  of the charged-particle mul-  
distributions for b-quark events and 2-jettiplicity distribution for b-quark with  
and 3-jet b-quark events, together with the  $H_q$  calculated from the 2NBD  
their parametrizations. parametrizations

using other parton generation and fragmentation models and even when we use matrix element production of  $q\bar{q}$  only, even with independent fragmentation. This shows us that the  $H_q$  behavior can be reproduced without the need for the NNLLA of pQCD.

Furthermore, our analysis of jet multiplicity obtained at perturbative energy scales ( $\gtrsim 1$  GeV), where pQCD predictions for the behaviour of  $H_q$  should be directly accessible, did not show any of the pQCD predictions made for the  $H_q$ <sup>15</sup>. Therefore, the  $H_q$  behavior seen for the charged-particle and jet multiplicity distribution at non-perturbative energy scales only, appears unrelated to the behavior of the  $H_q$  calculated in NNLLA.

### 3 The phenomenological approach

This approach relies on the assumption that we can view the charged-particle multiplicity distribution as a superposition of distributions originating from various processes related to the topology of the event, as 2-jet, 3-jet, light- or heavy-quark events. Assuming that each of these processes can by itself be described by a relatively simple parametrization as the NBD, the charged-particle multiplicity distribution of the full sample would then be a weighted sum of all the contributions. All together, these various contributions would explain the shape of the charged-particle multiplicity distribution and, hence, the  $H_q$  behavior. We checked mainly two hypotheses with this parametrization.

1. The first assumes that the shape of the charged-particle multiplicity distribution of the full sample arises from the superposition of 2-jet and 3-jet events. Our 2-jet and 3-jet samples were obtained using the Durham algorithm<sup>16</sup> for a set of six  $y_{\text{cut}}$  values. As parameters for the NBD's, we used the means and dispersions calculated from the experimental 2-jet and 3-jet charged-particle multiplicity distributions. The relative weight between the two NBD's was taken to be the fraction of 2-jet events for a given  $y_{\text{cut}}$  value. This gives us a fully constrained 2NBD parametrization of the full sample. The resulting  $\chi^2$  are given in the left half of table 1. Since the  $H_q$

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Figure 5.  $H_q$  of the charged-particle mul- Figure 6. Evolution of  $H_7$  as a function of  
multiplicity distribution, for all events and for  $y_{cut}$  for 2-jet and 3-jet, light- and b-quark  
2-jet and 3-jet events ( $y_{cut} = 0.015$ ) events

moments from charged-particle multiplicity distributions of full, light- and b-quark samples are very similar, we also tested this hypothesis on light and b-quark samples separately, isolating in these cases the 2-jet and 3-jet events from the light- and b-quark samples. The resulting  $\chi^2$  for the b-quark sample are given in the right half of table 1. We find amazingly good  $\chi^2$  for the 2NBD parametrizations of the full (column 2 of table 1), light- (not shown) and b-quark (column 5 of table 1) samples. (see also figure 3 for the case of the b-quark sample). We calculated the  $H_q$  from the parametrizations and also these are found to be in good agreement with the  $H_q$  measured for the full, light and b-quark samples (figure 4 for the b-quark sample). However, none of the NBD parametrizations are able to describe any of the individual 2- or 3-jet charged-particle multiplicity distributions themselves, even though the  $\chi^2$  is seen to decrease when the purity increases. 2. We also attempted to parametrize the 2-jet and 3-jet charged-particle multiplicity distributions, and as a consistency check the full sample, by a superposition of light and b-quark events, using in that case as relative weight between the two NBD's, the fraction of b-quark events,  $R_b$ <sup>17</sup>. Results are summarized in table 2. We don't find any agreement at all, neither for 2NBD parametrization of the full sample which has a  $\chi^2/\text{dof}$  near 13. This constitutes by its failure a good check of the method, since it shows that not all combinations of two NBD's agree with the data. We extended the study of the 2-jet and 3-jet samples to the measurement of their  $H_q$  moments. We find that, even if the oscillations are still there, their amplitudes are far smaller than for the full sample (figure 5). Furthermore the size of the oscillations decreases when the purity in 2 jet (3 jet) in the 2-jet (3-jet) sample increases. Differences at low  $q$  (mainly for  $q < 8$ ) are found between the  $H_q$  of 2-jet and 3-jet events, and also large differences are seen for fixed  $q$  when the  $H_7$  moment is plotted versus  $y_{cut}$  (figure 6). We see differences between  $H_q$  of 2-jet and 3-jet events of the light- and b-quark samples, however the oscillations are comparable to those of 2-jet or 3-jet events of the full samples. All together, this supports the phenomenological approach when we assume that the shape of the charged-particle multiplicity distribution arises from a superposition of 2-jet and 3-jet events.

Table 1.  $\chi^2$  between the 2-jet, 3-jet parametrization and their experimental counterpart

$y_{\text{cut}}$	$\chi^2/\text{dof}$ for the full sample			$\chi^2/\text{dof}$ for the b-quark sample		
	2NBD <sub>all</sub>	NBD <sub>2jet</sub>	NBD <sub>3jet</sub>	2NBD <sub>all</sub>	NBD <sub>2jet</sub>	NBD <sub>3jet</sub>
0.03	1.4	56	8.5	2.6	19	2.2
0.015	0.6	36	15	1.4	13	3.4
0.01	20.4	8	6.3	0.93	9.8	4.4
0.006	0.7	16	36	0.53	5.5	6.4
0.004	1.5	9.4	57	0.53	3.5	8.5
0.002	5.	5.5	119	3	0.8	15

Table 2.  $\chi^2$  between the light-, b-quark parametrization and their experimental counterpart

$y_{\text{cut}}$	$\chi^2/\text{dof}$	
	2NBD <sub>2jet</sub>	2NBD <sub>3jet</sub>
0.03	74	8
0.015	46	14
0.01	39	9
0.006	23	33
0.004	14	48
0.002	5	100

#### 4 Conclusions

The oscillatory behavior of the  $H_q$  moments of the charged-particle multiplicity distribution is usually interpreted as a confirmation of NNLLA, but investigations performed on different models of parton generation and for different fragmentation models have shown similar oscillatory behavior in all cases. Furthermore, the analysis of the  $H_q$  of the jet multiplicity distributions reveals that this behavior appears only for very small  $y_{\text{cut}}$ , corresponding to energy scales  $\lesssim 100$  MeV, far from the perturbative region. This gives us strong indications that the oscillatory behavior is not related to the behavior predicted by the NNLLA. In search of an alternative origin of this  $H_q$  behavior we have, therefore, investigated a more phenomenological answer which assumes that the shape of the multiplicity distribution results from the superposition of 2-jet and 3-jet events. Using a weighted sum of 2 NBD's as a parametrization, we found very good agreement for both the charged-particle multiplicity distribution and its  $H_q$  moment. This supports the idea that the main feature in the shape of the charged-particle multiplicity still visible in the final states are due to the presence of hard gluon radiation and to the hadronization.

## References

1. E.A. De Wolf, I.M. Dremin, W. Kittel, *Phys. Rep.* **270**, 1996 (1).
2. I.M. Dremin, *Physics-Uspekhi* **37**, 1994 (715).
3. SLD Collab., K. Abe *et al.*, *Phys. Lett. B* **371**, 1996 (149).
4. I.M. Dremin, *Phys. Lett. B* **313**, 1993 (209);  
I.M. Dremin and V.A. Nechitailo, *JETP Lett.* **58**, 1993 (881).
5. A. Giovannini, S. Lupia, R. Ugoccioni, *Phys. Lett. B* **374**, 1996 (231).
6. A. Giovannini, S. Lupia, R. Ugoccioni, *Phys. Lett. B* **388**, 1996 (639).
7. L3 Collab., B. Adeva *et al.*, *Nucl. Instrum. Methods A* **289**, 1990 (35);  
J.A. Bakken *et al.*, *Nucl. Instrum. Methods A* **275**, 1989 (81);  
O. Adriani *et al.*, *Nucl. Instrum. Methods A* **302**, 1991 (53);  
B. Adeva *et al.*, *Nucl. Instrum. Methods A* **323**, 1992 (109) ;  
K. Deiters *et al.*, *Nucl. Instrum. Methods A* **323**, 1992 (162);  
B. Acciari *et al.*, *Nucl. Instrum. Methods A* **351**, 1994 (300);  
A. Adam *et al.*, *Nucl. Instrum. Methods A* **383**, 1996 (342).
8. J.G. Branson, A. Dominguez, I. Fisk, G. Raven, L3 Note 2108 (1997);  
L3 Collab., M. Acciarri *et al.*, *Phys. Lett. B* **411**, 1997 (373);  
A. Dominguez, Ph.D. thesis, University of California at San Diego (1998).
9. S. Banerjee, D. Duchesneau, S. Sarkar, L3 Note 1818 (1995);  
J. Casaus, L3 Note 1946 (1996);  
L3 Collab., B. Adeva *et al.*, *Z. Phys. C* **55**, 1992 (39).
10. The L3 detector simulation is based on GEANT, see R. Brun *et al.*,  
CERN report CERN DD/EE/84-1 (Revised), 1987, and uses GHEISHA  
to simulate hadronic interactions, see<sup>11</sup>.
11. H. Fesefeldt, RWTH Aachen report PITHA 85/02, 1985.
12. G. Susinno, L3 Note 1996 (1996).
13. A. Giovannini, S. Lupia, R. Ugoccioni, *Phys. Lett. B* **342**, 1995 (387).
14. T. Sjöstrand, *Comp. Phys. Comm.* **39**, 1986 (347);  
T. Sjöstrand and M. Bengtsson, *Comp. Phys. Comm.* **43**, 1987 (367).
15. W. Kittel, S.V. Chekanov, D.J. Mangeol, W. Metzger, Proc. XXVII Int.  
Symp. on Multiparticle Dynamics, eds G. Capon *et al.* (North-Holland,  
1998) p.30  
D.J. Mangeol, Proc. 8th Int. Workshop on Multiparticle Production,  
eds. T. Csörgö *et al.* (World Scientific, Singapore, 1999) p.342  
W.J. Metzger, Proc. XXIX Int. Symp. on Multiparticle Dynamics, eds  
I. Sarcevic *et al.* (World Scientific, Singapore, 2000) p.238
16. S. Bethke, *et al.*, *Nucl. Phys. B* **370**, 1992 (310).
17. The LEP/SLD heavy flavour working group, D. Abbaneo *et al.*,  
LEPHF/99-01.