DELPHI Collaboration

DELPHI 2001-107 CONF 534
15 May, 2001

Particle correlations in $e^+e^- \rightarrow W^+W^-$ events with the DELPHI detector

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Abstract

A mixing method with improved sensitivity was used to investigate particle correlations between the decay products from different W's in $e^+e^- \rightarrow W^+W^-$ interactions at energies from 189–209 GeV, recorded by the DELPHI detector in 1998, '99 and 2000. These 3 years of running correspond to a collected luminosity of 153, 219, and 159 pb^{-1}, respectively. No significant evidence for inter-W correlations was found.

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1 Introduction

The DELPHI analysis of Bose-Einstein correlations between pions from different W's has been recently revised, including the new statistics taken during the 2000 run. A total luminosity of 531 pb^{-1} was collected in the energy range from 189 to 209 GeV. The particle and event selections have changed slightly both in the fully hadronic and semileptonic decay channel. The particles used in the Bose-Einstein analysis itself were subjected to more strict selection criteria than before [1]. The purity of the tracks with respect to the content of primary tracks has been increased to 95.3%. The purity and efficiency of the event selection amount to 84% and 71%, respectively, for the fully hadronic channel and to 94% and 53% for the semi leptonic channel. The understanding of the Bose-Einstein effect is still far from complete, although there are many recent theoretical reviews [2, 3, 4].

2 Analysis Method

DELPHI studied the presence of two-particle correlations using two-particle densities defined in terms of the four momentum transfer $Q = \sqrt{-(p_1 - p_2)^2}$, where p_1, p_2 are the momenta of the two particles. The formalism described in [5] and [6] was used, with slightly modified notations. In this formalism one studies essentially the validity of the following relation:

$$\rho^{WW}(1,2) = 2\rho^{W}(1,2) + \rho^{WW}_{mix}, \tag{1}$$

where $\rho^{WW}(1,2)$, $\rho^{W}(1,2)$ and ρ^{WW}_{mix} represent the two-particle densities for particle pairs coming from a fully hadronic event, the hadronic part of a semi-leptonic event and pairs from 2 different semi-leptonic events which are combined to look like a fully hadronic event. One can either study a deviation from zero of:

$$\Delta\rho(Q) = \rho_2^{WW}(Q) - 2\rho_2^{W}(Q) - \rho_2^{mix}(Q), \tag{2}$$

or, alternatively, a deviation from one of

$$D(Q) = \frac{\rho_2^{WW}(Q)}{2\rho_2^{W}(Q) + \rho^{mix}(Q)}. \tag{3}$$

In order to construct the reference sample ρ^{WW}_{mix}, pairs of semileptonic events were combined to construct a fully hadronic event. Particles identified as lepton or belonging to the leptonic jet were removed. The remaining hadronic parts of both events were matched according to the fitted W momenta (one of the bosons was rotated opposite to the direction of the other W boson, and both were boosted to the nominal $E_{cm}/2$ with balanced momentum). Since the detector effects are not propagated through the rotation and boost, for mixing only pairs of W bosons which already have well balanced momentum were accepted:

$$\sqrt{(\overrightarrow{p_1} + \overrightarrow{p_2})^2 + (E_{cm} - E_1 - E_2)^2} < 50 \text{ GeV} \tag{4}$$

and the maximal number of re-uses of a single event was limited to 10. After mixing, the fully-hadronic selection was applied to the sample of mixed events. The balance cut discarded 76% of all possible mixed combinations. The hadronic event selection cuts rejected an additional 15% from the mixed sample. The mixing procedure was checked by comparing the relevant event shapes and single particle spectra for mixed events with the corresponding shapes and spectra of the hadronic events using EXCALIBUR simulation without Bose-Einstein correlations. In all cases a good agreement was found.

3 Background subtraction and modeling

Background subtraction requires special attention since one must rely on the use of a model to correct for the residual Z^0/γ background. The correct estimate of the uncertainty associated with the background subtraction is important especially in the fully hadronic channel, where the 4-jet background events can mimic the signal for inter-W correlations to some extent. In the present study, background Z^0/γ events were simulated with PYTHIA and PYBOEI model (version BE32). The model reshuffles the momenta of the final particles in order to reproduce the desired enhancement of the correlation function for pairs of close bosons. A gaussian parametrisation was used with parameters (PARJ(92) = 1.35, PARJ(93) = 0.34).

Three sources of possible bias of the background Q distribution were studied:

- uncertainty related to the number of background events
- uncertainty related to the difference in the charged particle multiplicity between data and MC
- uncertainty related to the shape of the Q distribution.

For the estimate of the systematics originating from the number of 4-jet background events, the background content was increased by 20%. The overall difference in the charge multiplicity between data and MC simulation, of the order of 1.5-2.5% in single particle distributions, 3-5% in 2-particle distributions, was taken into account in the subtraction by a correction factor 0.96 applied on the subtracted terms in expression 2. The bias of the modeling of the 2-particle distributions was studied in Z^0 4-jet events at the peak energy and in a high energy sample dominated by Z^0/γ events. The discrepancies observed in the shape of two-particle densities do not exceed 10%. The correction factors fitting the data/MC ratio in the peak sample were used to estimate the systematic error associated with the background subtraction. The study of the systematic uncertainty due to the background and other sources is still ongoing but the actual status is summarised in Table 1.

4 Results

All the terms of Equation 1 were computed using the combined statistics of 3 years of data taking. From these terms the variables $D(Q)$ and $\Delta\rho(Q)$ were computed. The expected background content was subtracted from the selection of fully hadronic events using PYBOEI(BE32) model with parameters (PARJ(92) = 1.35,PARJ(93) = 0.34) as

Source	Systematic error on measured variables	
	Λ	δ
mixing procedure	0.02	0.003
background subtraction (hadronic sel.)	0.05	0.003
background subtraction (mixed sample)	0.003	0.0003
reconstruction of close pairs	0.015	0.0003
Total	0.055	0.004

Table 1: The main sources of systematic uncertainty and the associated systematic errors described in the text.

discussed in Section 3. The correlations between bins as well as bin errors were computed from the data using the covariance matrix. The distributions of the variables $D(Q)$ and $\Delta\rho(Q)$ for like-sign pairs are shown in Fig.1.

The data were compared with model predictions from the PYTHIA WW sample using the BE32 model with the same parameters as mentioned above, for two scenarios: one with intra-W correlations only and one with both inter- and intra-W correlations. As can be seen from Fig. 1, the scenario where both intra- and inter-W correlations are present shows an enhancement at low Q values for the variable $D(Q)$ ($\Delta\rho(Q)$), while both data and the model without inter-W correlations agree between themselves and with the straight line equal 1 (0). Note that the model predictions are plotted just for illustration, and that our measurement is *absolute* and *model independent* except for the background subtraction. In order to quantify any possible inter-W correlations, the $D(Q)$ distribution for like sign pairs was fitted with an exponential parametrisation:

$$D(Q) = N(1 + \delta Q)(1 + \Lambda e^{-RQ}). \tag{5}$$

First, the prediction of the model with the full correlation scenario was fitted with results:

$$\begin{aligned}\Lambda(full\ BE) &= 0.24 \pm 0.03\\ R(full\ BE) &= 1.01 \pm 0.14 \text{ fm}\\ \delta(full\ BE) &= 0.003 \pm 0.004\\ N &= 0.997 \pm 0.006\end{aligned}$$

with the $\chi^2/\text{ndf} = 41.1/46$.

As the data agree very well with a straight line, a multi-parameter exponential fit with free R and Λ is extremely unstable. For this reason we take the dampening parameter R from the model including all correlations ($R = 1.01$ fm) and the fit was repeated for the data and the model without inter-W correlations.

The fit of the $D(Q)$ for the data yielded:

$$\begin{aligned}\Lambda(data) &= -0.037 \pm 0.055 \text{ (stat)} \pm 0.055 \text{ (syst)}\\ R &= 1.01 \text{ fm(fixed)}\\ \delta(data) &= -0.009 \pm 0.007 \text{ (stat)} \pm 0.004 \text{ (syst)}\\ N(data) &= 1.017 \pm 0.012\end{aligned}$$

distribution	data	BE32 inside	BE32 full
$\int \Delta\rho$	0.012 ± 0.015	0.007 ± 0.006	0.052 ± 0.006

Table 2: The integral of the distribution in the region 0 – 1 GeV/c^2 to be compared with the absolute prediction for the absence of inter-W correlations, $\int \Delta\rho = 0$. Errors are statistical only.

with χ^2/ndf= 44.5/47, and the model without inter-W correlations gave

$$\begin{gathered}\Lambda(BEin) = -0.021 \pm 0.021 \\ R = 1.01 \text{ fm(fixed)} \\ \delta(BEin) = 0.002 \pm 0.003 \\ N(BEin) = 1.005 \pm 0.004\end{gathered}$$

with χ^2/ndf= 29.8/47.

In order to give a further quantification of possible inter-W correlations, the integral of the $\Delta\rho(Q)$ distributions for like-sign pairs was calculated in the Q region between 0 and 1 GeV/c^2. The results for the data and both models are shown in Table 2.

5 Conclusions

The presence of inter-W correlations has been investigated using the data collected by DELPHI for 3 years of data taking, amounting in a total used luminosity of 530 pb^{-1}. No significant indication of the presence of the inter-W correlations was found.

References

[1] DELPHI COLL., *Correlations between particles in* $e^+e^- \rightarrow W^+W^-$ *events* , DELPHI 00 – 115 OSAKA CONF 414.

[2] B. Andersson and M. Ringnér, *Nucl. Phys.* B **513**, 627 (1998).

[3] B. Andersson, *Coherence and Incoherence in Bose-Einstein Correlations* Proc. XXXth Int. Symp. on Multiparticle Dynamics, edts. T.Csörgő et al. (World Scientific, Singapore, 2001) p.364 (to be publ.)

[4] K. Zalewski, *Physics from Bose-Einstein correlations in high energy multiparticle production*, hep-ph/0009122.

[5] S.V. Chekanov, E.A. De Wolf, W. Kittel, *Eur. Phys. J.* C **6**, 403 (1999).

[6] E.A. De Wolf, *Correlations in* $e^+e^- \rightarrow W^+W^-$ *hadronic decays*, hep-ph/0101243.

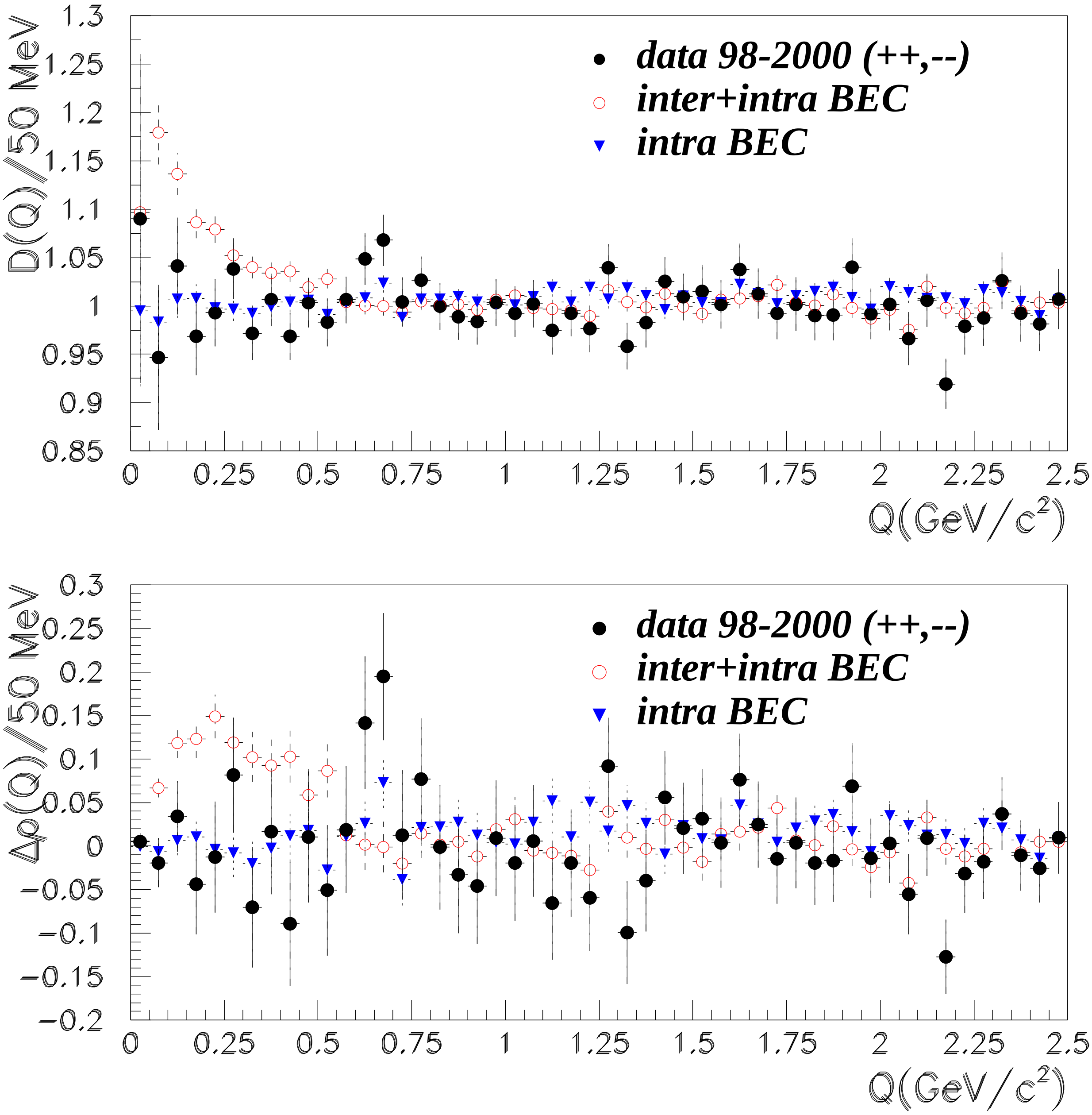

Figure 1: Upper plot: The $D(\mathrm{Q})$ variable for like-sign combinations. Lower plot: The $\Delta\rho(\mathrm{Q})$ variable for like-sign combinations