

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

ALEPH 2001-064

CONF 2001-044

July 10, 2001

PRELIMINARY

**Further studies on  
Bose-Einstein correlations  
in W-pair decays**

**The ALEPH Collaboration**

**Abstract**

Bose-Einstein correlations in W-pair decays are studied using data collected by the ALEPH detector at centre-of-mass energies up to 208 GeV. The analysis presented is based on the comparison of selected  $WW \rightarrow q\bar{q}q\bar{q}$  events to “mixed” events constructed from the hadronic parts of selected  $WW \rightarrow q\bar{q}\ell\nu$  events using the  $\Delta\rho$  distribution. The data distribution is consistent with  $\Delta\rho = 0$  predicted when the Bose-Einstein correlations are present only for pions coming from the same W. The JETSET model with the Bose-Einstein correlations between pions from different W’s is disfavoured.

*Contribution to the International Europhysics Conference on High Energy Physics  
July 12-18, 2001, Budapest, Hungary*

*and*

*XX International Symposium on Lepton and Photon Interactions at High Energies  
23rd-28th July 2001, Rome Italy*

Contact person: B. Pietrzyk (pietrzyk@lapp.in2p3.fr)

# 1 Introduction

The ALEPH analysis of Bose-Einstein correlations (BEC) in  $W$ -pair decays based on the comparison of like-sign and unlike-sign pion pairs is described in detail in Ref. [1, 2]. Further ALEPH studies using the so-called “mixed” method [3, 4] have been described for energies up to 202 GeV in Ref. [2, 5], where results have been presented using the ratio of the two-pion densities measured for selected fully hadronic  $W$ -pair decays and for events constructed by mixing the hadronic parts of two selected semileptonic decays. The comparison is sensitive to the Bose-Einstein enhancement of the two-particle differential cross-section for pairs of pions coming from two different  $W$ 's in  $WW \rightarrow q\bar{q}q\bar{q}$  events, since, by construction, these “mixed” events have BEC between pions from the decay of the same  $W$ , but no BEC between pions from different  $W$ 's. This effect may influence the  $W$  mass measurement in fully hadronic  $W$ -pair decays [6].

In this note, a new analysis of BEC in  $W$ -pair decays using the mixed method is presented. The main differences with respect to Ref. [2, 5] are that all data collected at LEP2 energies between 183 and 208 GeV have been analysed, and that results are presented in terms of the difference  $\Delta\rho$  [3, 7] between the two-pion densities for fully hadronic and “mixed” semileptonic events, rather than in terms of their ratio. The event selection is described in [1] for the 183 GeV and 189 GeV data. For the data recorded in 1999 between 192 and 202 GeV, the event selections are those used for the  $W$  mass measurement at 189 GeV [6], and for the data recorded in 2000 above 202 GeV the event selections are those used for the  $W$  mass measurement at 192–208 GeV [8]. The total integrated luminosity used for the analysis is  $683 \text{ pb}^{-1}$ : this represents an increase of  $217 \text{ pb}^{-1}$  with respect to the analysis of Ref. [2, 5], coming from the data collected above 202 GeV. For this additional data sample only semileptonic events with electrons and muons are used to construct mixed events, while also the tau channel had been used for the lower energies.

The event mixing technique and Monte Carlo simulation used in the analysis are described in Ref. [2, 5]. Bose-Einstein correlations for both  $WW$  and  $q\bar{q}$  events are simulated according to the JETSET model of Ref. [9]. Signal events from fully hadronic  $WW$  decays have been simulated under three hypotheses: in the absence of BEC, with BEC only for pions coming from the same  $W$ , and with BEC also for pions coming from two different  $W$ 's. The last two models are referred to as BEI (BEC Inside each  $W$ ) and BEB (BEC also Between  $W$ 's) in the following.

## 2 Analysis method, Monte Carlo studies and results

Bose-Einstein correlations occur for identical bosons of the same charge that are close in momentum space. In this analysis, BEC are studied for like-sign pairs of reconstructed charged pions as a function of their distance  $Q$  in momentum space, defined as

$$Q = \sqrt{(\vec{p}_1 - \vec{p}_2)^2 - (E_1 - E_2)^2}, \quad (1)$$

where  $(E_1, \vec{p}_1)$  and  $(E_2, \vec{p}_2)$  are the four-momenta of the two pions. The selection of pions is described in detail in Ref. [1].

The Bose-Einstein enhancement in pair production of identical pions was studied in [5] using a two-particle correlation function, derived from the ratio of the number of like-sign pion pairs in events selected as  $WW \rightarrow q\bar{q}q\bar{q}$  decays ( $N_{\text{Sel. } 4q}^{++,--}$ ) to the number of like-sign pion pairs in mixed events ( $N_{\text{Mixed}}^{++,--}$ ). Here, the ratio is replaced by the difference and the so called  $\Delta\rho$  distribution [3] is obtained. Since the event mixing technique could introduce systematic distortions to the distribution of this variable, the difference for data is corrected by the same difference obtained from the Monte Carlo without any Bose-Einstein correlations. The resulting double difference is given by

$$\Delta\rho^{\text{back. incl.}}(Q) = \left(N_{\text{Sel. } 4q}^{++,--} - N_{\text{Mixed}}^{++,--}\right)^{\text{data}} - \left(N_{\text{Sel. } 4q}^{++,--} - N_{\text{Mixed}}^{++,--}\right)^{\text{MC}(WW+q\bar{q}, \text{ no BEC})} \quad (2)$$

Each of the four distributions  $N(Q)$  in Eq. 2 are normalised to one selected event for the respective category of events, so that the integral of each  $N(Q)$  between 0 and infinity is a function of the pion multiplicity observed for that category. The same formula is used with the first difference computed for Monte Carlo distributions where BEC in the WW signal are simulated according to the BEI and BEB models (see [5]) and where BEC are also included for the selected  $q\bar{q}$  background events. This allows to compare the distribution of  $\Delta\rho$  predicted by the Monte Carlo to that observed in the data, providing evidence for or against the two BEC models considered.

The inclusion of background in the analysis is essential to ensure that the comparison of the data to the two MC models is meaningful. In Eq. 2, the large ( $\sim 20\%$ )  $q\bar{q}$  background contamination to the selection of fully hadronic WW events is thus included in the  $N_{\text{Sel. } 4q}^{++,--}$  terms for both data and MC, while the background contamination to mixed events has been neglected because the purity of the semileptonic W selection is very high.

The distribution of  $\Delta\rho^{\text{back. incl.}}$  is shown in Fig. 1 for all data collected between 183 and 208 GeV. The distributions predicted by the Monte Carlo are also shown on the same plot, for the two cases where BEI or BEB is included in the WW signal. The data distribution is in good agreement with the Monte Carlo BEI distribution, and disfavours BEB distribution in which BEC between pions from different W's are allowed.

The analysis has been repeated using another definition of  $\Delta\rho$

$$\Delta\rho^{\text{back. subt.}}(Q) = \left(N_{\text{Sel. } 4q}^{++,--} - N_{\text{Mixed}}^{++,--}\right)^{\text{data-MC}(q\bar{q}, \text{BEC})} - \left(N_{\text{Sel. } 4q}^{++,--} - N_{\text{Mixed}}^{++,--}\right)^{\text{MC}(WW, \text{ no BEC})} \quad (3)$$

where the contribution from  $q\bar{q}$  backgrounds, including BEC as simulated by the MC, is subtracted from the data distribution for fully hadronic events. The distribution of  $\Delta\rho^{\text{back. subt.}}$  is shown in Fig. 2.

In the absence of backgrounds,  $\Delta\rho(Q)$  is defined in Ref.[3] in such a way that it should be equal to zero for all values of Q in case of no Bose-Einstein correlation between pions from different W's for data and, by construction, for the BEI Monte Carlo distribution – as it should have been equal to 1 for the ratios studied in [5]. The data distribution in Fig. 2 is consistent with 0, the value expected in case of absence of BEC between pions from different W's. This is also true for the MC BEI distribution. The JETSET model BEB allowing these correlations predicts positive values of  $\Delta\rho$  at low Q values. This prediction is disfavoured by the data.

### 3 Conclusions

Bose-Einstein correlations in  $W$ -pair decays are studied by comparing  $WW \rightarrow q\bar{q}q\bar{q}$  decays to events constructed by mixing the hadronic parts of two selected  $WW \rightarrow q\bar{q}\ell\nu$  decays using the  $\Delta\rho$  distribution. The data distribution is consistent with  $\Delta\rho = 0$  predicted when the Bose-Einstein correlations are present only for pions coming from the same  $W$ . The JETSET model [9] with the Bose-Einstein correlations between pions from different  $W$ 's is disfavoured. This is in agreement with and provides complementary information to the preliminary results previously obtained in Ref. [2, 5] in terms of double ratio for hadronic and mixed events. This is also in agreement with previously published results for BEC in  $W$ -pair decays based on the comparison of like-sign and unlike-sign pion pairs [1].

### References

- [1] ALEPH Collaboration, *Bose-Einstein correlations in  $W$ -pair decays*, Phys. Lett. B478 (2000) 50.
- [2] ALEPH Collaboration, *Update on Bose-Einstein correlations in  $W$ -pair decays*, ALEPH note ALEPH 2000-024 CONF 2000-020, contributed to the 2000 winter conferences.
- [3] S.V. Chekanov, E.A. De Wolf and W. Kittel, *Bose-Einstein correlations and color reconnection in  $W$ -pair production*, Eur. Phys. J. C6 (1999) 403.
- [4] DELPHI Collaboration, *Bose-Einstein Correlations Between Particles from Different  $W$ 's in  $e^+e^- \rightarrow W^+W^-$  Events*, DELPHI notes DELPHI 99-22 CONF 221 and DELPHI 99-159 CONF 330.
- [5] ALEPH Collaboration, *Further studies on Bose-Einstein correlations in  $W$ -pair decays* ALEPH note ALEPH 2000-039 CONF 2000-059, contributed to the ICHEP, Osaka, 2000.
- [6] ALEPH Collaboration, *Measurement of the  $W$  Mass and Width in  $e^+e^-$  Collisions at 189 GeV*, Eur. Phys. J. C17 (2000) 241.
- [7] L3 Collaboration, *Measurement of Bose-Einstein Correlations in  $e^+e^- \rightarrow W^+W^-$  at  $\sqrt{s} = 189$  GeV*, Phys. Lett. B493 (2000) 233.
- [8] ALEPH Collaboration, *Measurement of the  $W$  Mass and Width in  $e^+e^-$  Collisions at  $\sqrt{s}$  between 192 and 208 GeV* ALEPH note ALEPH 2001-020 CONF 2001-017, contributed to the 2001 winter conferences.
- [9] L. Lönnblad and T. Sjöstrand, Eur. Phys. J. C2 (1998) 165.

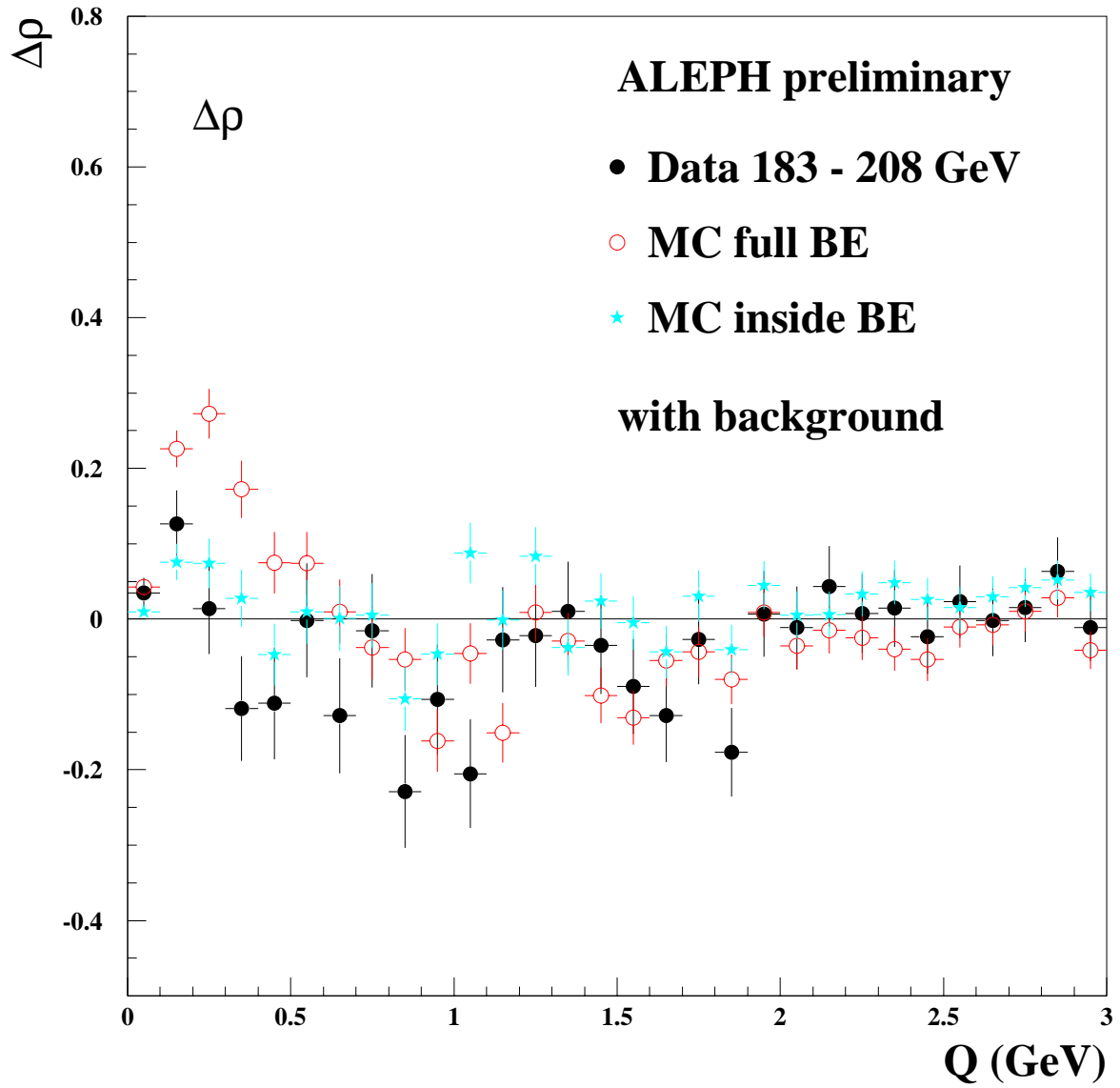


Figure 1:  $\Delta\rho(Q)$  distributions for data and Monte Carlo with Bose-Einstein correlations. Only statistical errors are shown.

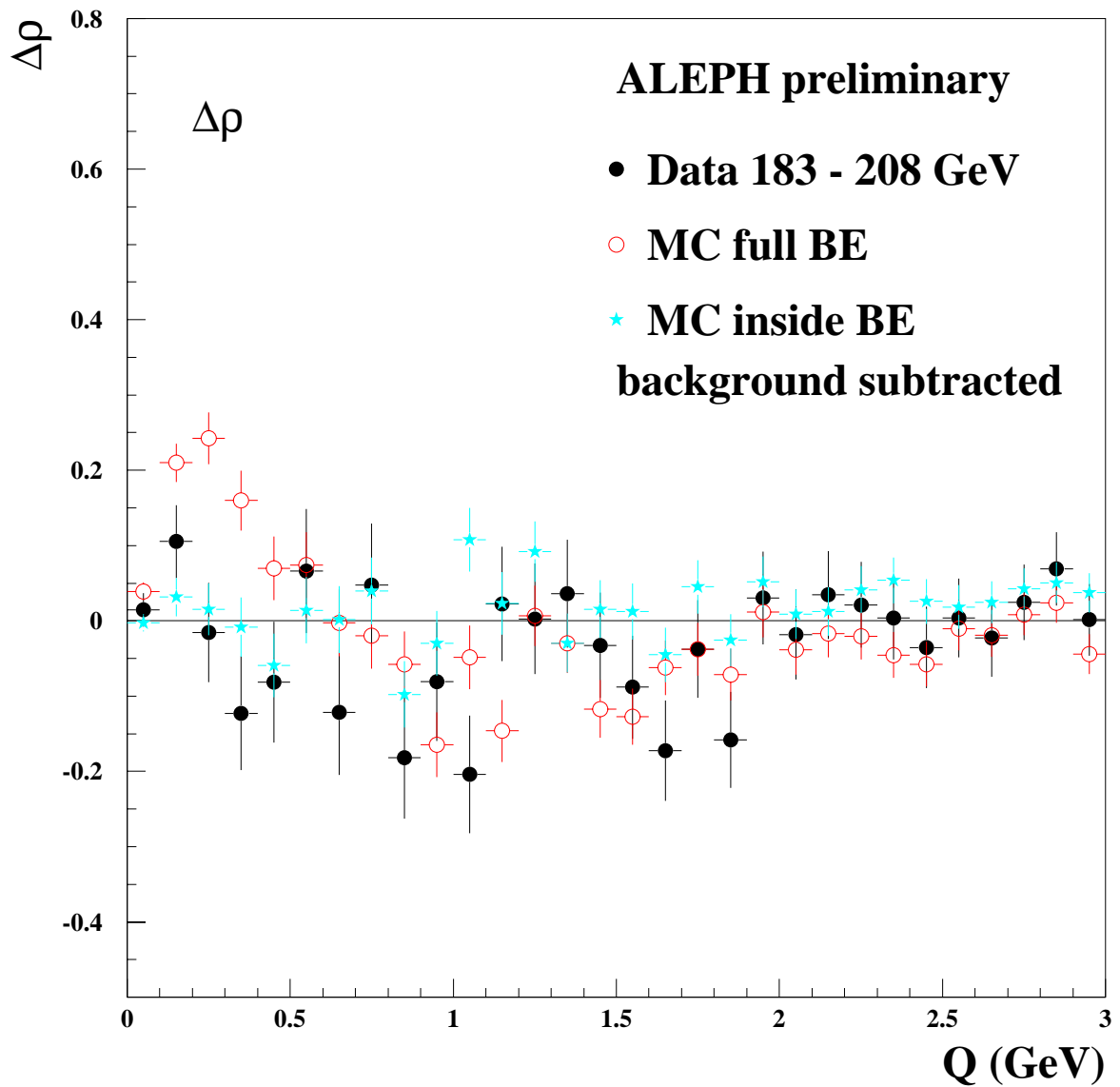


Figure 2:  $\Delta\rho(Q)$  distributions for data and Monte Carlo with Bose-Einstein correlations after background subtraction. Only statistical errors are shown.