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BOSE–EINSTEIN CORRELATIONS IN $e^+e^- \to W^+W^- \to q\bar{q}q\bar{q}$*

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A model independent method of measurement of correlations between particles belonging to close, partially overlapping hadronic systems is used by LEP collaborations to study $e^+e^- \to W^+W^- \to$ hadrons. The strategy of the combination of the results is discussed.

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1. Introduction

The production of the pair of W bosons at LEP2 energies represents a unique opportunity to study the cross-talk between particles belonging to two close hadronic systems, and in particular, the correlations resulting from the quantum-mechanical interference in the final state, so called Bose-Einstein (BE) effect. The measurement, outlined in [1], takes advantage of the possibility to construct the 'ideal' reference sample from the data itself. Hadronic parts of 2 measured $W^+W^- \to q\bar{q}l\nu_l$ events are (after removal of the lepton track) mixed in order to reproduce the $W^+W^- \to q\bar{q}q\bar{q}$ sample in the hypothesis of a completely independent decay of W bosons. The reference sample is then compared to the genuine hadronic W^+W^- events. Any significant discrepancy between the two samples implies some kind of interference/correlations in the final state. The method minimizes the direct dependence of the measurement on the modeling of interference effects (only the background subtraction requires a decent simulation), and provides a basis for an absolute measurement of the inter-W correlations.

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2. Observables

The analysis of data is based on measured charged tracks, with selection criteria proper to each experiment (for details, see references). These tracks are used to construct the 2-particle density $\rho_2(Q) = dN_{\rm pairs}/dQ/N_{\rm events}$ as function of the momentum transfer $Q = \sqrt{-(p_i - p_j)^2}$, where p_i, p_j are particle 4-momenta (all accepted particles are assumed to be pions).

As mentioned above, the central idea of the measurement is the direct comparison of $\rho_2^{{\rm mix}\,WW}$ obtained from mixed WW events (reference sample) and of $\rho_2^{{\rm hadr}\,WW}$ from measured hadronic WW events (after background subtraction). This comparison can be done either via a ratio, or a difference of the two distributions:

$$\begin{aligned} \Delta\rho(Q) &= \rho_2^{{\rm hadr}\,WW}(Q) - \rho_2^{{\rm mix}\,WW}(Q)\,, && (2.1)\\ D(Q) &= \rho_2^{{\rm hadr}\,WW}(Q)/\rho_2^{{\rm mix}\,WW}(Q)\,. && (2.2) \end{aligned}$$

The following variable reflects the strength of the inter-W BE correlations in close analogy with usual definition of the correlation function

$$\delta_I(Q) = \frac{\Delta\rho(Q)}{\rho^{\rm mix\,pairs}(Q)}\,. \qquad (2.3)$$

It should be mentioned at this point that the observables in Eq. (2.1)–(2.3) have different experimental properties (for example, the measurement of correlations through the ratio D is much less sensitive to statistical fluctuations in the multiplicity of charged particles, while the integral of the difference $\Delta\rho$ offers a model independent quantification of the measurement). This leads to a large variety of optimized results from LEP experiments, which will be briefly recounted in the next section.

The presence of the BE effect would manifest itself by an enhancement of the like-sign 2-particle density at low Q. However, a question arises which part of the effect is due to the genuine BE correlations, and which has a different origin. It is therefore useful to look at the combination of the above mentioned variables for particle pairs with like-sign($\pm\pm$) and unlike-sign($+-$) charge:

$$\begin{aligned} \delta\rho(Q) &= \Delta\rho(\pm\pm) - \Delta\rho(+-)\,, && (2.4)\\ d(Q) &= D(\pm\pm)/D(+-)\,, && (2.5)\\ \Delta_I(Q) &= \delta_I(\pm\pm) - \delta_I(+-)\,. && (2.6) \end{aligned}$$

These variables are also more robust with respect to eventual bias in the mixing procedure.

3. Experimental results

For the first time, the results of measurements of inter-W correlations from all 4 LEP experiments (based on the mixing technique, and using the entire LEP2 data samples), are presented here. The measurements are compared with the expectations of the PYTHIA model BE32 [2], tuned to the inclusive ($b\bar{b}$ depleted) Z0 sample within each experiment. The most significant numerical results are listed in Table I and compared with the model expectations.

The latest contribution came recently from the OPAL Collaboration [4]. OPAL has analysed all the variables in Eq. (2.1)–(2.6), the measured $\Delta\rho$ is shown in Fig. 1. The data prefer the scenario without inter-W correlations, but due to the relatively low sensitivity of the measurement, one cannot rule out the scenario with inter-W BEC, either.

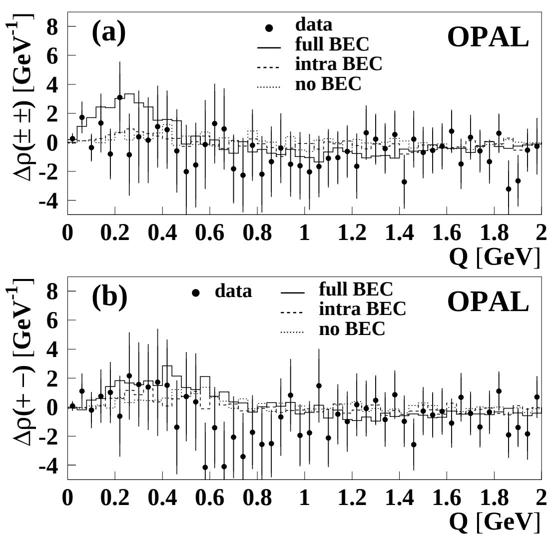

Fig. 1. $\Delta\rho$ (Eq. (2.1)) measured by OPAL [4] for like-sign and unlike-sign pairs.

The intriguing measurement of the L3 Collaboration [3], here illustrated by Fig. 2, suggests a strong suppression of inter-W correlations as expected from the model (data are 3.6 σ below the full BEC MC in the sample of like-sign charge pairs).

Similar observation is reported by the ALEPH Collaboration [5], in somewhat modified analysis, where the mixed WW sample is 'calibrated' by the MC sample without inter-W correlations. The fit of the double ratio $D'(\pm\pm) = D(\pm\pm)/D(\pm\pm)_{\rm MC}$ with function $f = \kappa * 1 + \lambda \exp(-\sigma^2 Q^2)$, with σ fixed to the fit of full BEC, yields result consistent with the absence of inter-W correlations, 3.7σ below the full BE scenario.

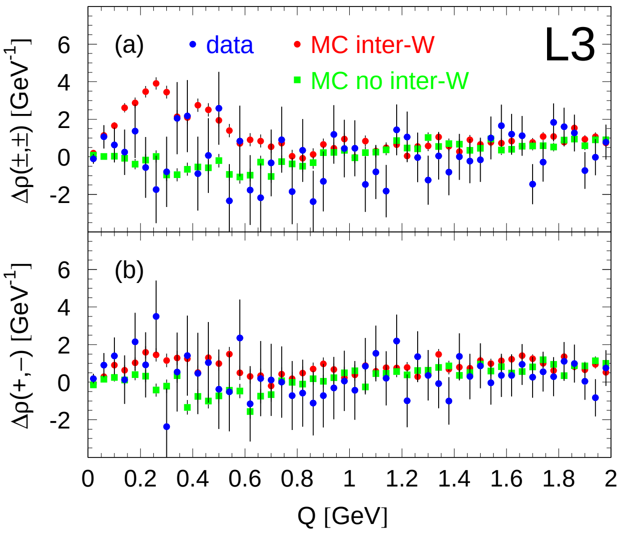

Fig. 2. $\Delta\rho$ (Eq. (2.1)) measured by L3 [3] for like-sign and unlike-sign pairs.

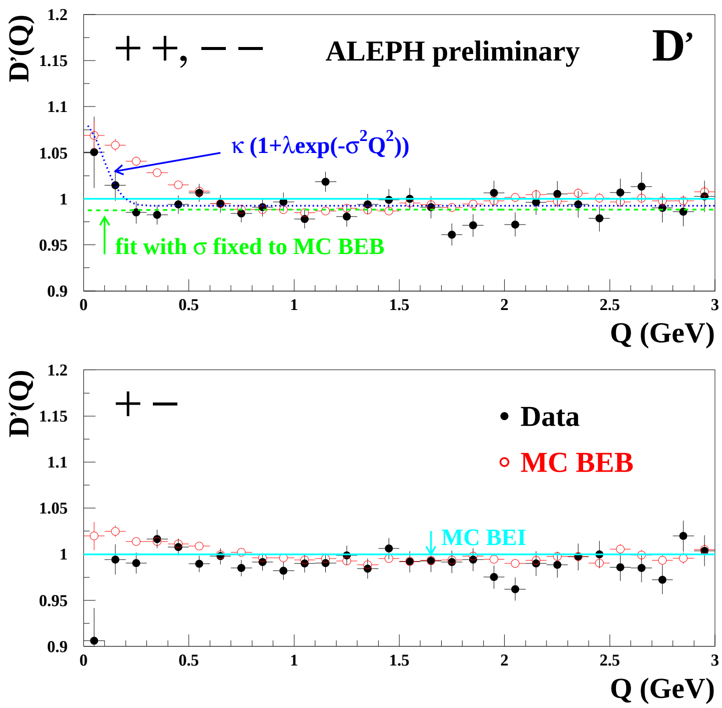

Fig. 3. D' measured by ALEPH Coll. [5] for like-sign and unlike-sign pairs.

The only non-zero effect is measured by the DELPHI Collaboration [6], Fig. 4, in the most sensitive analysis presented (see the reference for more details), at the level of 2.4 σ (2.0σ below the full BEC scenario). However, the analysis also sees relatively strong correlations in the unlike-sign sample (0.3σ *above* full BEC), which suggest a contribution of non-BE origin to this result.

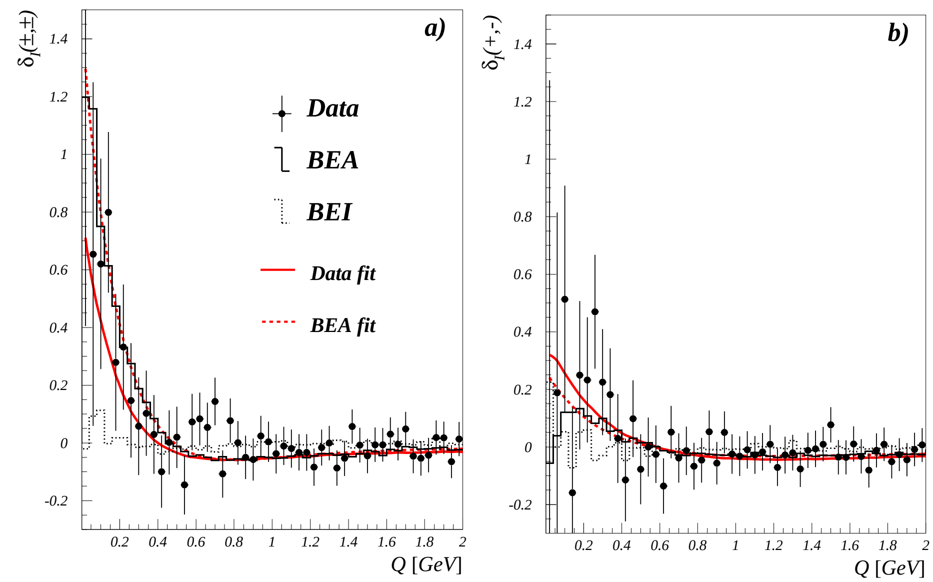

Fig. 4. δ_I (Eq.2.3) measured by DELPHI [6] for like-sign and unlike-sign pairs.

4. LEP-wide combination of results

4.1. Model dependent combination

Since all the measurements are provided at the detector level, the direct comparison of absolute numbers is rather confusing. A simple and straightforward method of the comparison and combination of different measurements consists in recalculation of results in terms of a fraction of the amount of correlations expected in a given BE model, as indicated in Table I. Such a combination is particularly suitable for the estimation of systematic errors related to the presence of inter-W correlations. A preliminary combination of this type is described in [7]. The minor problem encountered there is related to small differences between tunings of the model in each collaboration, and can be fixed with help of common reference sample (ongoing work). However, a major disadvantage of this method lies in its dependence on existing BE modeling, which is not reliable.

TABLE I

Overview of main results scaled by the model.

Experiment	Method	Range	Fraction of model measured ($\pm\pm$)	Fraction of model measured ($+-$)
ALEPH	fit of D'	$0 < Q < 3$ GeV	-0.01 ± 0.27	~ 0
DELPHI	fit of δ_I	$0 < Q < 4$ GeV	0.55 ± 0.22	1.33 ± 0.71
L3	integral of $\Delta\rho$	$0 < Q < 0.68$ GeV	0.02 ± 0.26	~ 0
OPAL	integral of $\Delta\rho$	$0 < Q < 0.48$ GeV	0.18 ± 0.37	0.57 ± 0.58

4.2. Model independent combination

It was mentioned already that the experimental method has the potential to provide an absolute measurement of the inter-W correlations. To achieve that, it is however mandatory to correct the data for the detector effects (to 'unfold' the data). Relatively simple recipe for unfolding is based on the parameterization

$$\rho_2^{\rm exp}(Q) = \epsilon(Q)\rho_2^{\rm true}(Q) + n(Q)\,, \tag{4.1}$$

where $\rho_2^{\rm exp}$ stands for the measured (detector level) 2-particle density, $\rho_2^{\rm true}$ is the unfolded 2-particle density, $\epsilon(Q)$ is the reconstruction efficiency and $n(Q)$ represents the 'noise' due to the interaction with the material of the detector. MC study shows that correction functions $\epsilon(Q), n(Q)$, which can be found with help of simulated WW samples, practically do not depend on the amount of BE correlations present in the sample, thus allowing a model independent unfolding of the data. The success of the unfolding is of course determined by the quality of the detector description in simulated samples.

The combination of unfolded data between experiments requires additional correction to the common acceptance region, which is again shown to be model independent. No particular bias is expected due to the differences in the WW event selection among LEP experiments.

5. Conclusions

The measurement of the inter-W correlations was done by 4 LEP experiments using the mixing technique to build the reference (uncorrelated) WW sample. The results suggest a strong suppression of inter-W correlations with respect to the naive expectation, and their combination allows to reduce the systematic error in the direct reconstruction of the W mass. The absolute measurement of the effect depends on the capability of experiments to correct the data for the detector influence.

REFERENCES

[1] S.V. Chekanov, E.A. De Wolf, W. Kittel, *Eur. Phys. J.* **C6**, 403 (1999).
[2] L. Lönnblad, T. Sjöstrand, *Eur. Phys. J.* **C2**, 165 (1998).
[3] L3 Coll., *Phys. Lett.* **B547**, 139 (2002).
[4] OPAL Coll., *Eur. Phys. J.* **C36**, 297 (2004).
[5] ALEPH Coll., ALEPH 2003-013, CONF 2003-009.
[6] DELPHI Coll., DELPHI 2004-026-CONF-701.
[7] CERN-LEPEWWG-2002-02 (Chapter 13).