Interconnection phenomena in W pair production at LEP2

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In this paper the status of the experimental analysis on interconnection effects between W pairs hadronically decaying at LEP 2 is reviewed.

1. INTRODUCTION

Interactions between the products of the hadronic decays of different Ws in WW events can happen due to the fact that the lifetime of the W ($\tau_W \simeq \hbar/\Gamma_W \simeq 0.1$ fm/c) is one order of magnitude smaller than the typical hadronization times. Such interactions can occur at several stages: from the colour rearrangement between the quarks coming from the primary branching and the gluon exchange during the parton cascade (Color Reconnection), to the mixing of identical pions due to Bose-Einstein Correlations (BEC). Besides the intrinsic interest of their study related to the understanding of the multiparticle production mechanisms, these phenomena can affect the ultimate accuracy in the W mass measurement by LEP 2 [1]. The characteristics of the W hadronic decays when both Ws decay in fully hadronic modes (WW $\rightarrow 4jets$) can be compared with the case in which one W decays semileptonically (WW $\rightarrow 2jets\,\ell\bar{\nu}$). These should be equal in the absence of interference between the products of the hadronic decay of the Ws.

- The effect of Color Reconnection (CR) between the decay products of different Ws could lead to a charge multiplicity for $4jets$-events that is 1-2 % smaller than twice the multiplicity of $2jets$-events.
- The main experimental observable sensitive to BEC is the two-particle correlation function.

2. EXPERIMENTAL RESULTS

The present experimental results are based on the data collected at LEP at $\sqrt{s} = 172$, 183 and 189 GeV; the total number of W decays collected by the four experiments was about 7000 in the fully hadronic channel, and about 5000 in the semileptonic one.

2.1. QCD effects

Charge multiplicity in WW $\rightarrow 4jets$ and WW $\rightarrow 2jets\,\ell\bar{\nu}$ events has been studied by ALEPH [2], DELPHI [3], OPAL [4] and L3 [5], looking for possible effects of correlations on the fully hadronic sample. The quantity

$$\Delta <n> = <n>^{(4jets)} - 2 <n>^{(2jets)} \quad (1)$$

has been measured by all four experiments (Table 1).

Table 1
Mean difference in charge multiplicities between the $4jets$ and twice the $2jets$ channels.

	Energy (GeV)	$\Delta < n >$
ALEPH *preliminary [2]*	189	0.47±0.44±0.26
DELPHI *preliminary [3]*	183-189	-0.96±0.54±0.23
L3 *preliminary [5]*	189	-0.23±0.40±0.52
OPAL [4]	183	0.7±0.8±0.6
Average		-0.07±0.32

From these measurements one can extract a 95% CL upper limit

$$\frac{< \Delta n >}{< n >^{(4jets)}} < 1.7\% \,. \tag{2}$$

Inclusive distributions of charged particles from the decay of the W in WW events have also been studied. Fig. 1 shows the ratio between the $-\ln x_p$ (where $x_p = 2p/\sqrt{s}$) distribution for charged particles in $4jets$ and twice $2jets$ events, as measured by ALEPH [2]. Effects of correlations on the WW $\rightarrow 4jets$ sample are not seen; similar results have been published by OPAL [4].

One could be more sensitive to interconnection effects by studying inclusive particle distributions "oriented" by the event axis (like thrust or rapidity), or by looking at heavy particle distributions: $K^{\pm}$ and p average multiplicities measured by DELPHI [3] do not show (at 8% level) deviations from models with CR.

A different method has been tried by L3 [5], looking at the inter-jet activity in a WW $\rightarrow 4jets$ sample. Results are shown in Fig. 2 together with the model predictions.

2.2. Bose-Einstein correlations

BEC manifest themselves in an enhancement in the production of pairs of identical bosons close in phase space.

To study the enhanced probability for the emission of two identical bosons, the correlation function R is used as a probe. For pairs of particles, it is defined as

$$R(p_1, p_2) = \frac{P(p_1, p_2)}{P_0(p_1, p_2)} \,, \tag{3}$$

where $P(p_1, p_2)$ is the two-particle probability density, subject to Bose-Einstein symmetrization, p_i is the four-momentum of particle i, and $P_0(p_1, p_2)$ is a reference two-particle distribution which, ideally, resembles $P(p_1, p_2)$ in all respects, apart from the lack of Bose-Einstein symmetrization. It is frequently parametrized by the function

$$R(Q) = 1 + \lambda e^{-r^2 Q^2} \tag{4}$$

where the parameter r gives the RMS radius source, and λ is the strength of the correlation between the pions.

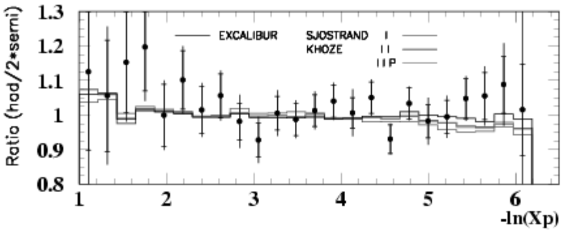

Figure 1. The ratio between $4jets$ and twice $2jets$ $-\ln x_p$ distribution as measured by ALEPH.

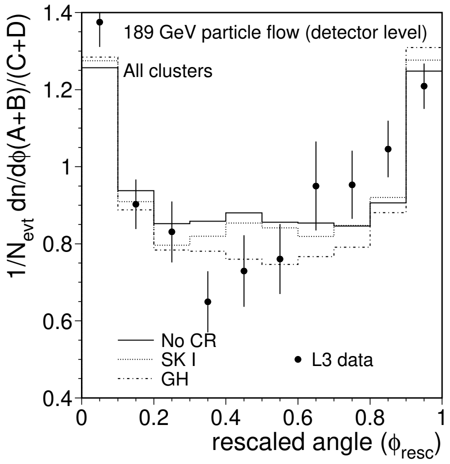

Figure 2. Particle flow between 2 jets from the same W divided by the same quantity between 2 jets from different Ws as measured by L3.

In a simultaneous fit to three event samples, each dominated by one of the processes WW $\to$ $4jets$, WW $\to$ $2jets\,\ell\bar{\nu}$, or $(Z/\gamma)^* \to q\bar{q}$, OPAL [8] has measured the BEC parameters for pions originated from the same and from different W bosons (Fig. 3). Taking into account the lifetimes of the W bosons, a strength $\lambda^{diff} = 0.05 \pm 0.67 \pm 0.35$ has been extracted for pions coming from different Ws.

In the method used by L3 [9], a function sensitive to inter-W BEC only is defined directly from the experimental data. No evidence for such an inter-W Bose-Einstein correlation is found.

After tuning of the Monte Carlo to the Z data, ALEPH [6] has compared a model with BEC between decay products of different Ws with the WW $\to$ $4jets$ distribution: this model is disfavoured at 2.7σ, while data agree with the simulation without inter-W BEC.

DELPHI [7] compares the WW $\to$ $4jets$ distribution with a reference sample built by pairing WW $\to$ $2jets\,\ell\bar{\nu}$; Fig. 4 shows that BEC between pions from different Ws seem favoured at 2σ level.

3. CONCLUSIONS

The studies of charge multiplicity and inclusive particle distributions do not indicate at the present level of statistics the presence of color reconnection effects.

Although experiments employ different techniques and there is contradiction between measurements, there is no evidence for Bose-Einstein correlations between pions originating from different Ws in WW $\to$ $4jets$ events.

Improvements of statistic with new data (LEP run at 192-200 GeV), more cooperative experimental effort and theoretical progress will give new input to this research, which is still an important point for the W mass measurement and *per se*.

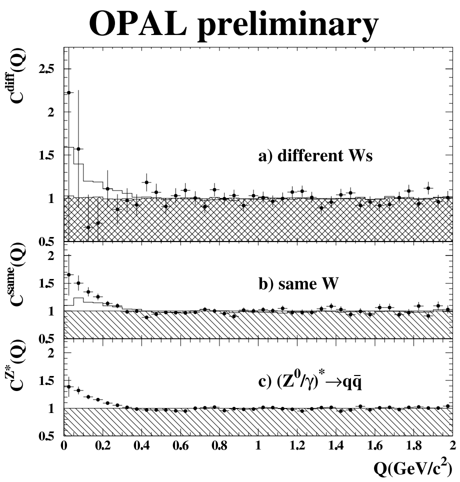

Figure 3. Correlation functions for a) pions from different Ws, b) pions from the same W, c) pions from $q\bar{q}$ events.

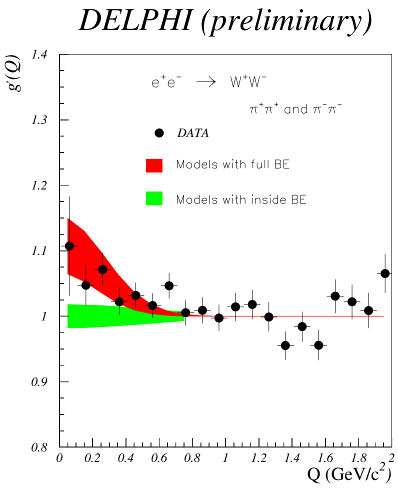

Figure 4. Correlation function for like-sign pion pairs, using a mixed reference sample.

ACKNOWLEDGMENTS

I wish to thank A. De Angelis and L. Vitale for their help in preparing this talk.

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