Study of Final State Interactions in $e^+e^- \to W^+W^-$ events

DELPHI Collaboration

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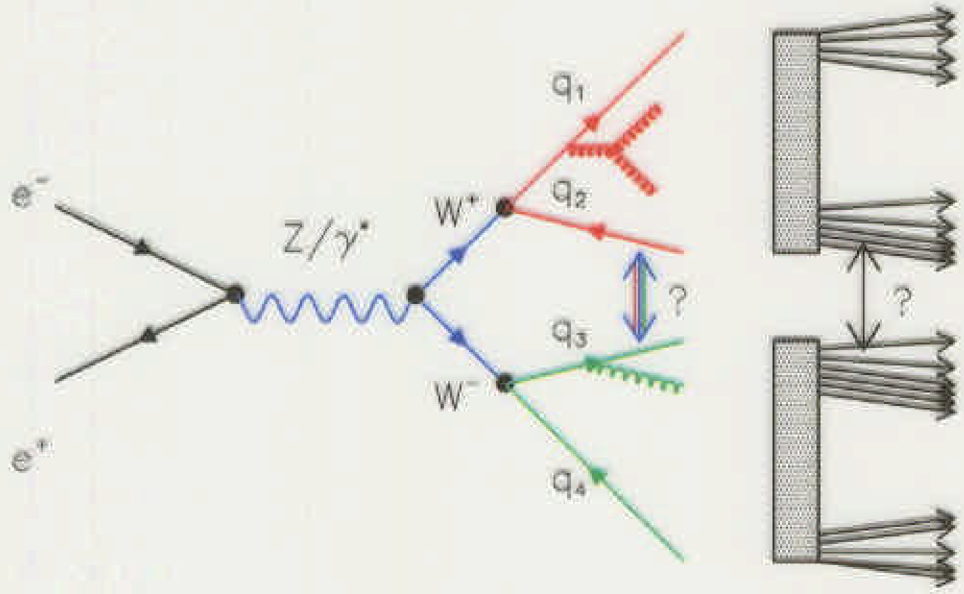
Outline

We investigated

- Correlations Between Particles in $e^+e^- \to W^+W^-$ events
- Colour Reconnection effects in $e^+e^- \to W^+W^-$ events

WW pair production and decays for fully hadronic events



The question :

are there correlation between quarks or particles coming from different Ws ?

It is important

- to understand better fragmentation proccess
- to estimate systematic in W-mass measurement due to interconnection effects.

Correlation Functions

We measured the correlation functions defined as

$$R(Q) = \frac{P(Q)}{P_0(Q)},$$

where $P(Q)$ is the two-particle probability density. The variable Q is the four-momentum difference of two particles, defined by $Q^2 = -(p_1 - p_2)^2 = M^2(\pi\pi) - 4m_\pi^2$, where M is the invariant mass of the two pions, and $P_0(Q)$ is reference two-particle distribution without Bose-Einstein correlations. We used the Monte-Carlo events (without BEC) after full detector simulation to calculate $P_0(Q)$. The $R(Q)$ distributions were parametrized by the function

$$R(Q) = \gamma\,(1 + \delta Q)\left(1 + \lambda e^{-r^2 Q^2}\right).$$

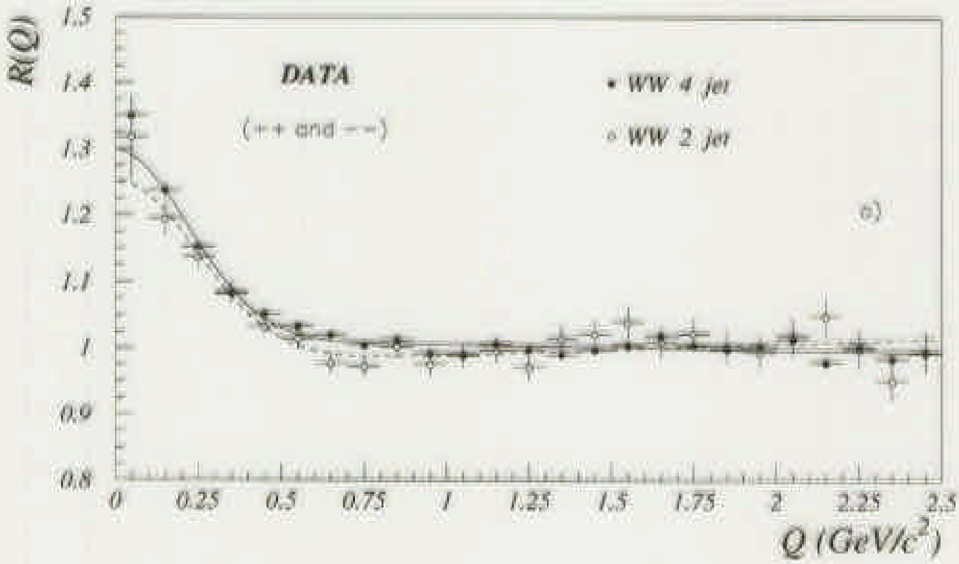
where λ and r are BEC parameters, γ is a parameter for normalisation, and the term $(1 + \delta Q)$ takes into account possible long range correlations.

The data used for the analysis were collected with the DELPHI detector at LEP in 1997, 1998 and 1999 at centre-of-mass energies from 183 to 202 GeV with integrated luminosity of 437 pb^{-1}

We selected:	pur	eff
2891 Fully Hadronic Events	82%	69%
1449 Mixed Hadronic-Leptonic Events	95%	44%

Correlation Functions for WW$\rightarrow 2ql\nu$ and WW$\rightarrow 4q$ Events

DELPHI(preliminary)



A fit to the correlation functions yielded the values:

$$\lambda_{2q} = 0.288 \pm 0.038(stat)$$
$$r_{2q} = 0.569 \pm 0.055(stat)\text{fm}$$

for the semileptonic channel and

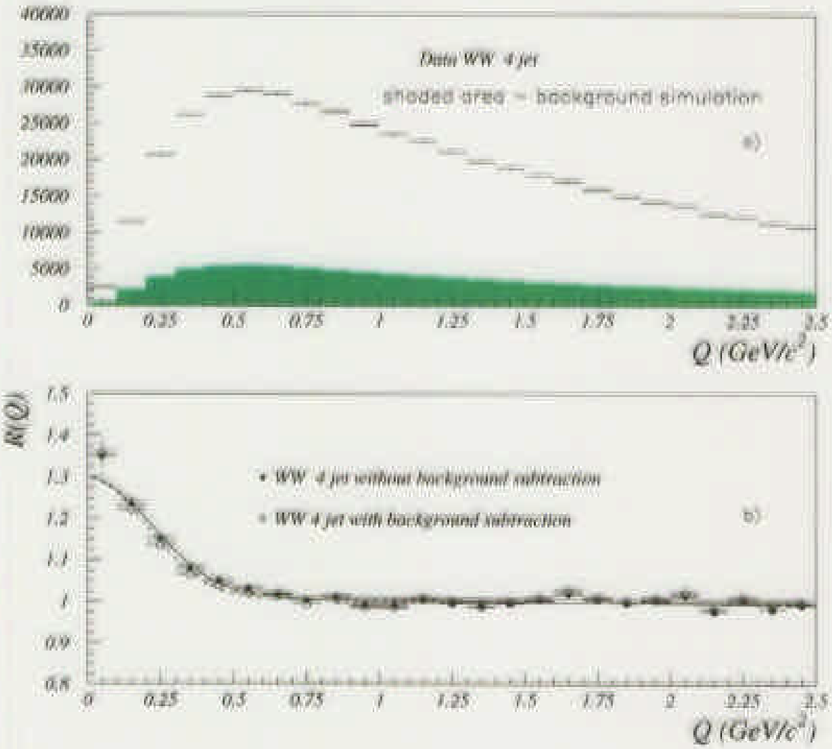
$$\lambda_{4q} = 0.281 \pm 0.020(stat)$$
$$r_{4q} = 0.634 \pm 0.030(stat)\text{fm}$$

for the fully hadronic decay channel.

Correction for the Background Contributions to the Fully Hadronic Sample

The background in the selected WW fully hadronic events contained 13% of high energy $q\bar{q}$ events and 5% of ZZ events.
We obtained the Q-distributions for $q\bar{q}$ and ZZ events using simulated events with BEC included which passed WW selections and these distributions were subtracted from the Q-distribution of real WW fully hadronic events.

DELPHI(preliminary)



The BEC parameters after background subtraction were:

$$\lambda_{4q} = 0.290 \pm 0.027(stat)$$
$$r_{4q} = 0.709 \pm 0.064(stat)\text{fm}$$

Correlations Between Particles from Different Ws

To perform direct measurements sensitive to BEC between particles from different Ws, analyses were made using comparison samples which contain only BEC for particle pairs coming from a single W boson, but not for particle pairs from different Ws.

Such comparison samples were constructed by the following two techniques:

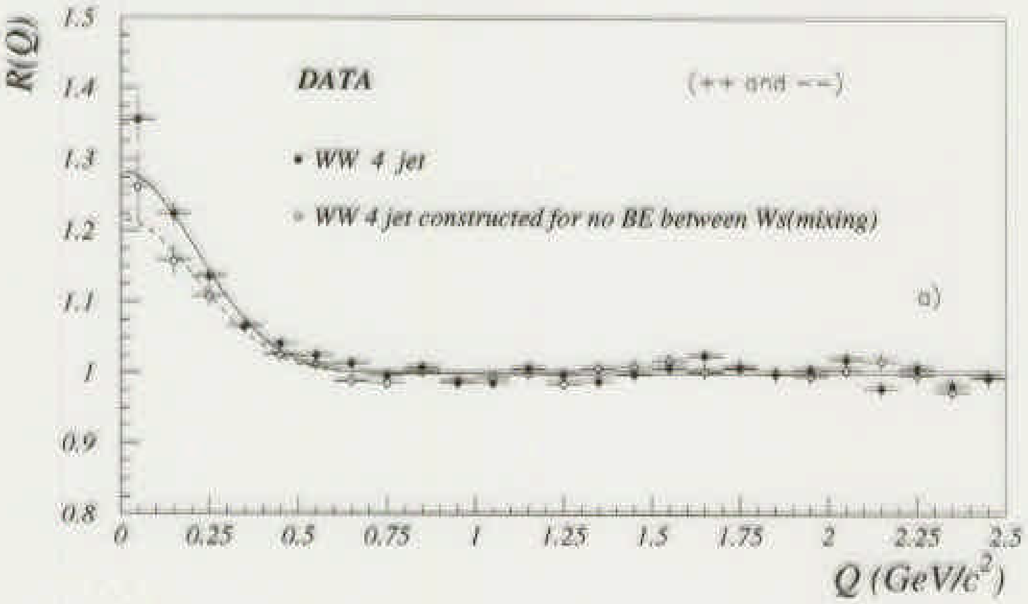
1. using an event mixing method;
2. using a correlation function calculated from R_{2q} (called the Linear Scenario);

Event Mixing Technique

The R_{4q} in case of no correlations between Ws can be written as

$$R_{4q}(Q)(mixing) = \frac{[2P_{2q}(Q) + P_{mix}(Q)]\ data}{[2P_{2q}(Q) + P_{mix}(Q)]\ MC\ no\ BE}$$

DELPHI(preliminary)



We define the difference

$$\Delta\lambda = \lambda_{4q} - \lambda_{4q}(mixing)$$

The difference of $\Delta\lambda$ from zero indicates the presence of correlations between particles from different Ws.
We measured:

$$\Delta\lambda(mixing) = 0.062 \pm 0.025(stat) \pm 0.021(syst)$$

Systematics for Event Mixing Technique

The systematic error on the measured value of $\Delta\lambda_{4q}(mixing)$ is the sum in quadrature of the following contributions:

- Due to the event mixing technique. The systematic error was estimated to be 0.017.
- Due to background events. Half the difference of the $\Delta\lambda$ obtained with the two background subtraction methods, i.e. 0.006 was used.
- A systematic error of 0.010 was assigned due to the fitting procedure.

Linear Scenario

In case of no correlations between Ws we can write

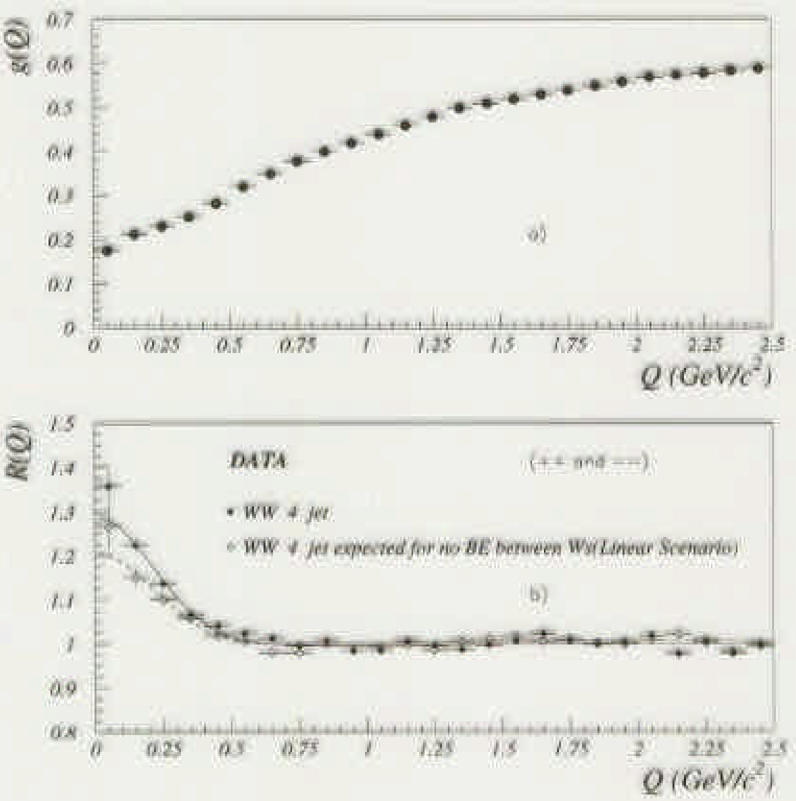
$$R_{4q}(Q)(linear) \;=\; R_{2q}(Q) - g(Q)\,(R_{2q}(Q) - 1)\;,$$

where

$$g(Q) \;=\; \left(\frac{P_{4q}^{(0d)}(Q)}{P_{4q}^{(0s)}(Q) + P_{4q}^{(0d)}(Q)}\right),$$

$g(Q)$ represents the fraction of pairs coming from different Ws.

DELPHI(preliminary)



We measured:

$$\Delta\lambda(linear) \;=\; 0.077 \pm 0.026(stat) \pm 0.020(syst)$$

Systematics for Linear Scenario

The systematic error on the measured value of $\Delta\lambda_{4q}(linear)$ is the sum in quadrature of the following contributions:

- Due to the linear technique used. The systematic error assigned was 0.011.
- The systematic error due to background events was 0.006.
- A systematic error of 0.012 was estimated for the uncertainty on the model dependence of the function $g(Q)$.
- A systematic error of 0.010 was assigned due to the fitting procedure, as for the previous method.

Analysis of Colour Reconnection Effects Using Charged Particle Multiplicity and Inclusive Distributions

Most models predict that, in case of colour reconnection, the ratio between the multiplicity in $(4q)$ events and twice the multiplicity in $(2q)$ events would be smaller than 1; the difference is expected to be at the percent level.

In the presence of interconnection, the deficit of multiplicity is expected to be concentrated in the region of low momentum.

Such deplection is not observed in the full momentum range:

$$\left(\frac{\langle n^{(4q)}\rangle}{2\langle n^{(2q)}\rangle}\right) = 0.990 \pm 0.015(stat) \pm 0.011(syst)\,,$$

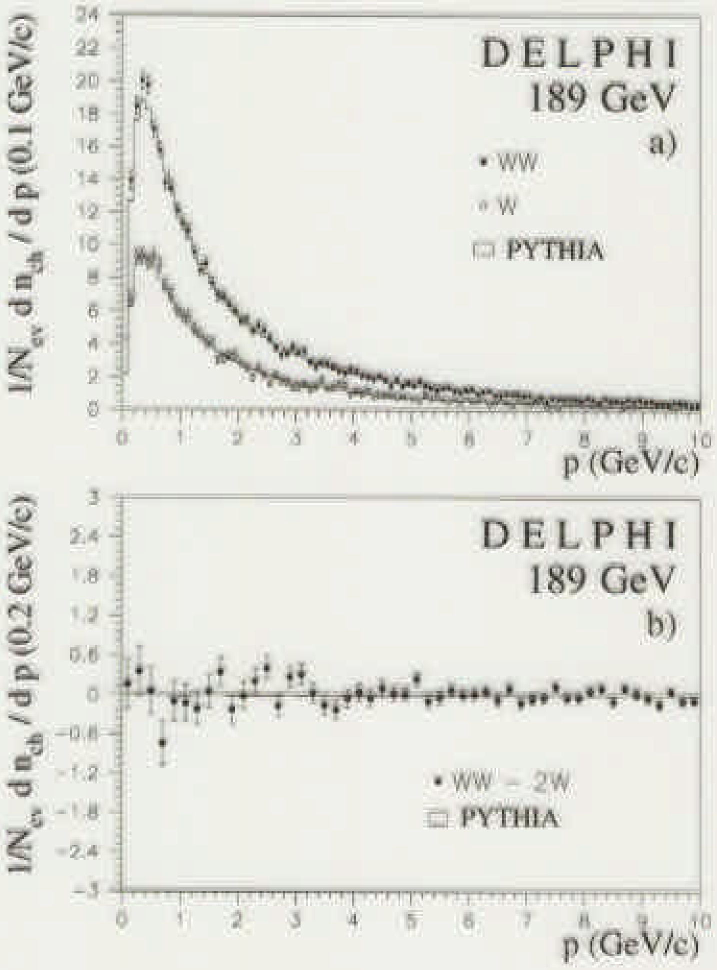
nor in the momentum range $0.1 < p < 1.0$ GeV/c:

$$\left.\frac{\langle n^{(4q)}\rangle}{2\langle n^{(2q)}\rangle}\right|^{0.1<p<1\,GeV/c} = 0.980 \pm 0.024(stat) \pm 0.011(syst).$$

Also, the ratio of the multiplicities of identified heavy hadrons in (4q) events to twice those in (2q) events is compatible with unity, both for the full momentum range and for momenta between 0.2 and 1.25 GeV/c:

Particle	All p	0.2 GeV/c $< p <$ 1.25 GeV/c
$K^{\pm}$	$0.98 \pm 0.17 \pm 0.08$	$0.96 \pm 0.38 \pm 0.08$
$p(\bar{p})$	$0.97 \pm 0.28 \pm 0.11$	$0.72 \pm 0.57 \pm 0.08$.

The momentum distributions in the $(4q)$ and in the $(2q)$ cases are:



Summary

Using a model independent event mixing technique, the difference between the correlation strengths of like-sign pairs for real WW $(4q)$ events and for a sample which contains only correlations coming from the same W boson was

$$\Delta\lambda(mixing) = 0.062 \pm 0.025(stat) \pm 0.021(syst)$$

Another measurement of $\Delta\lambda$ obtained using a comparison of R_{4q} and R_{2q} (the linear scenario) makes use of more model dependent input, in particular the fraction of pairs from different Ws as a function of Q, yielding

$$\Delta\lambda(linear) = 0.077 \pm 0.026(stat) \pm 0.020(syst)$$

Both measurements yield compatible results. Our conclusion is that our data support the hypothesis of correlations between like-sign pions coming from different Ws at the level of about two standard deviations.

No depletion of the multiplicity in fully hadronic WW events with respect to twice the semileptonic events, as predicted by most colour reconnection models, was observed.