Correlations Between Particles from Ws in $e^+e^- \to$ W$^+$W$^-$ Events

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OUTLINE

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Way? BEC

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CONCLUSION

The precise measurement of the correlations between particles became important for $e^+e^- \rightarrow$ W$^+$W$^-$ events due to possible large impact of these correlations on the measure W mass.

The data used for the present analysis were collected with the DELPHI detector during the 1998-2000 years at centre-of-mass energies ranging from 189 to 209 GeV.

Combining all data, a total luminosity of 550 pb^{-1} was analyzed. Events required for the WW BEC analysis were selected using Neural Networks.

3250 fully hadronic events were selected.

The purity and efficiency were 92% and 63%, respectively.

2570 mixed hadronic and leptonic events were selected.

The purity and efficiency were 96% and 58%, respectively.

DELPHI - DEtector with Lepton, Photon and Hadron Identification - is a detector, with special emphasis on powerful particle identification, three-dimensional information, high granulity and precise vertex determination. It was installed at LEP at CERN where it has operated since 1989. The detector has a central cylindrical section and two end-caps. Overall length and diameter are over 10 m and total weight is 3500 tons. A superconducting solenoid produces magnetic field - 1.23 Tesla - parrallel to the beam pipe. Design and construction of the DELPHI detector took 7 years.

Main parts of detector are:

- Tracking Detectors
- Electromagnetic calorimeters
- Hadron calorimeter

Bose-Einstein Effects

The Hanburi-Brown-Twiss (HBT) effect originated in astronomy where one uses the interference pattern of the photons to learn angular sizes of stellar objects. In high energy physics it has provided information on the space-time evolution of expanding hadronic systems created in particle collisions.

Statistical fluctuations of a chaotic system consisting of non interacting identical bosons in the six-dimensional phase-space are not Poissonian, like for macroscopic particles, but Bose-Einstein type. So we have two “names” of one effect: HBT or BEC. The effect can be described as an enhancement of the two-particle correlation function that occur when the two particles are identical bosons and have similar energy-momenta.

We measured the correlation function for WW fully hadronic and semi-leptonic events, defined as

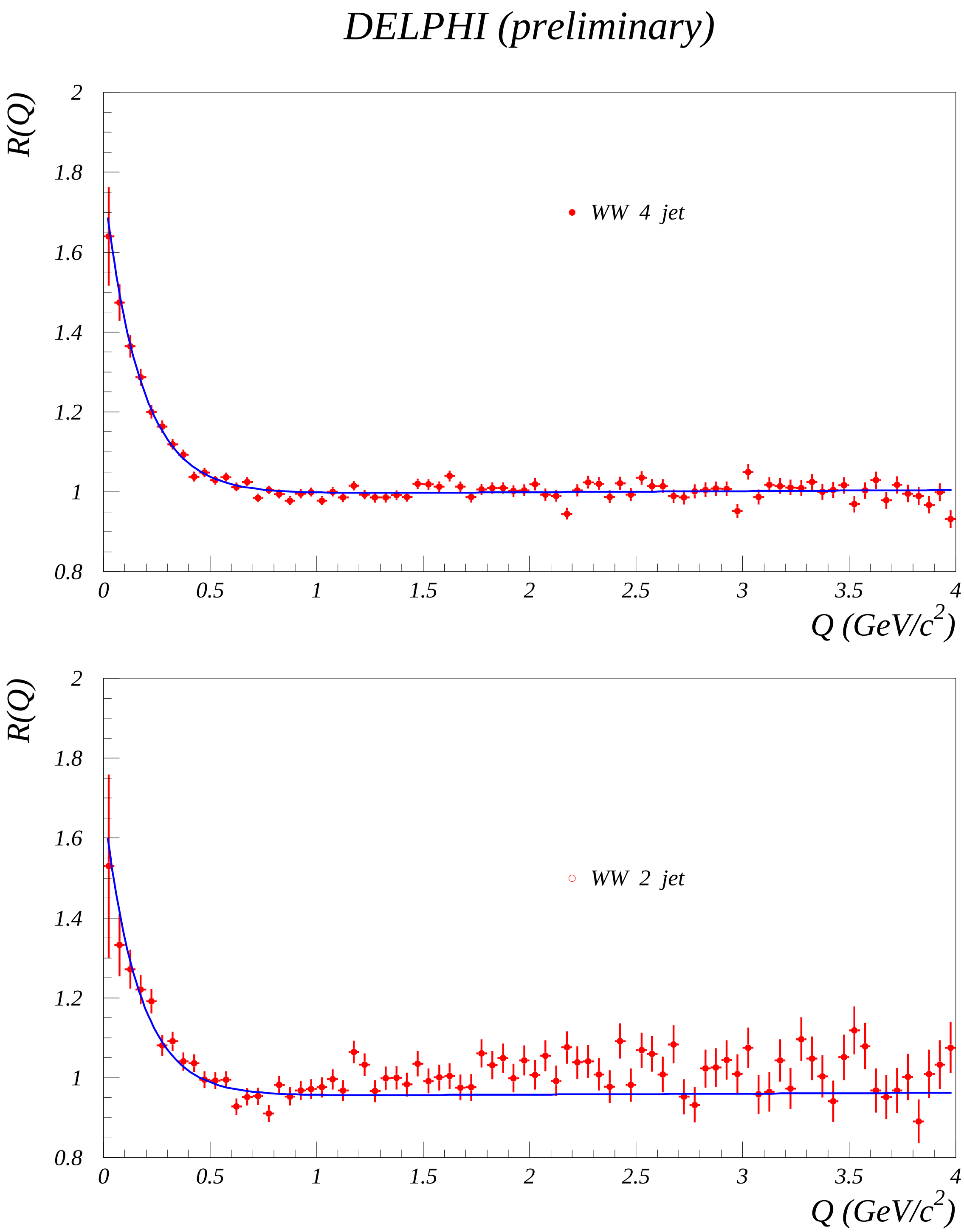
$$R(Q) = \frac{P(Q)}{P_0(Q)}, \qquad (1)$$

where $P(Q)$ is the two-particle probability density, subject to BE simmetrization. The variable Q is defined as $Q^2 = -(p_1 - p_2)^2 = M^2(\pi\pi) - 4m_\pi^2$, 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

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

In the above equation, in the hypothesis of a spherically symmetric pion source, the parameter r gives the radius of the source and λ is the strength of the correlation between the pions.

Correlation Functions for WW$\rightarrow 4j$ and WW$\rightarrow 2jl\nu$



Covariance matrix method

The usual calculations of statistical errors for entries in histograms and the use of these errors in the fitting procedure can bias the measurements if there are several entries from the same event. Traditionally, in the past this problem was ignored. The effect is small for low multiplicity events. However, for LEP and especially for the future LHC, RHIC, etc... experiments this effect is not small at all. These entries are correlated creating bin-to-bin and inside bin correlations. Neglecting these correlations, leads to a remarkable underestimation of the errors in the measured quantities and less precise estimation of the quantities themselves.

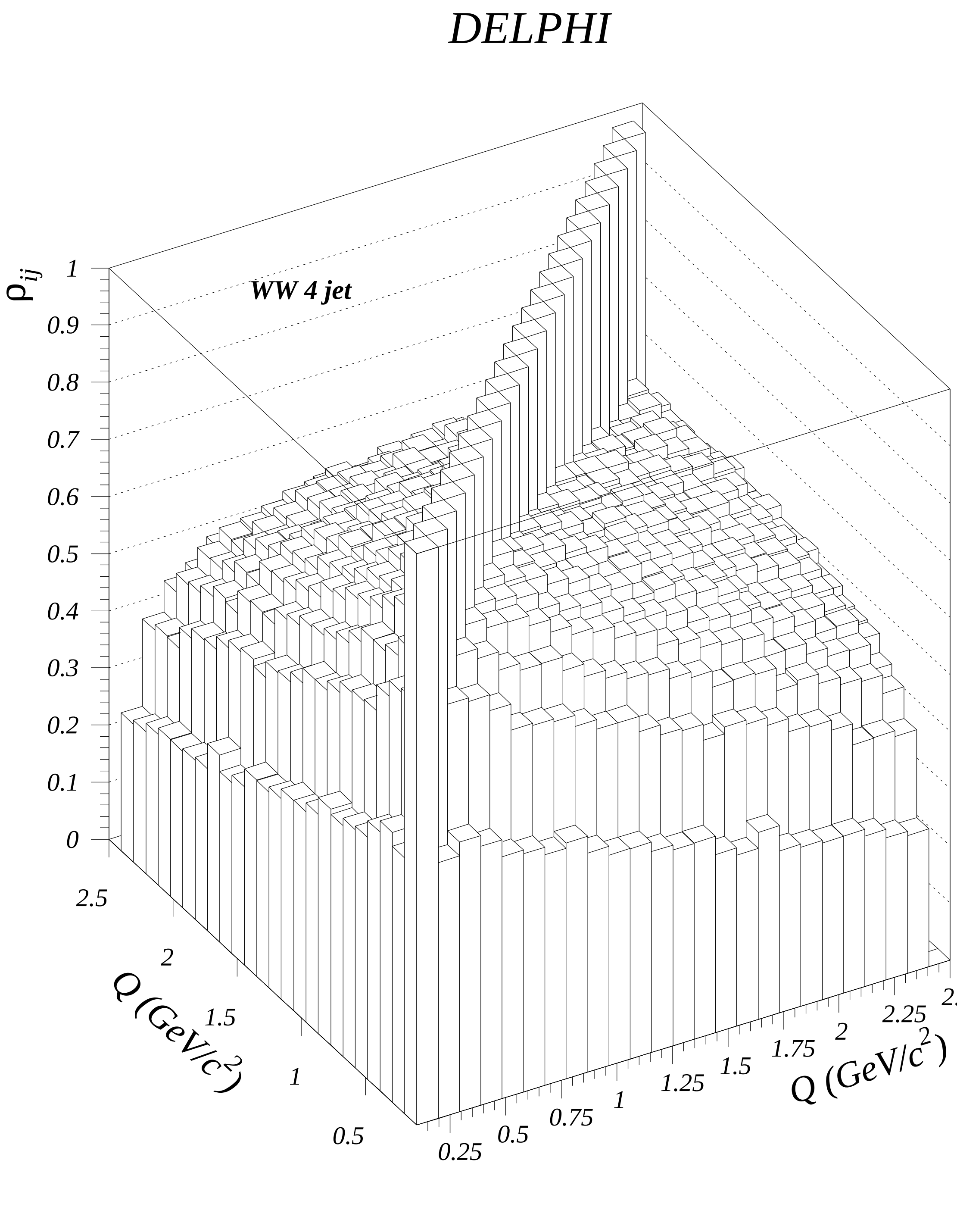
If there are N positive tracks in the events, each of them has $(N-1)$ entries in the two-particle density P, contributing to different bins of the histogram. Also, due to the finite bin width, the same track can also enter several times in the same bin, which is a source of inside bin correlations. Our method is based on classical statistics. Let us consider for each i-th event from the set of n events, two particle density P is presented in the histogram h^i with N_p bins.

The histogram $H = \sum_{i=1}^{n} h^i$ and values

$$c_{jk} = \sum_{i=1}^{n} (h^i_j - H_j/n)(h^i_k - H_k/n)(1 + 1/n)$$

were calculated event by event. Here j and k are the bin numbers for the histograms. For all events we have the resulting histogram H for the two-particle density P and $V_{jk} = c_{jk} \cdot n/(n-1)$ covariance matrix for this histogram.

Correlation matrix $\rho_{jk} = V_{jk}/(\sigma_j \sigma_k)$ for WW fully hadronic channel



A fit to the correlation functions $R(Q)$ by the expression:

$$R(Q) = N\,(1+\delta Q)\,\left(1+\lambda e^{-rQ}\right) \quad (3)$$

using the inverted V_{jk} matrix yielded the following values for

$$\lambda_{2q} = 0.280 \pm 0.037(stat) \pm 0.010(syst) \quad (4)$$

$$r_{2q} = 0.581 \pm 0.052(stat) \pm 0.016(syst) \text{ fm} \quad (5)$$

for the semi-leptonic channel and

$$\lambda_{4q} = 0.306 \pm 0.021(stat) \pm 0.013(syst) \quad (6)$$

$$r_{4q} = 0.616 \pm 0.032(stat) \pm 0.016(syst) \text{ fm} \quad (7)$$

for fully hadronic channel. The value of radius r is comparable for 4q and 2q events, but the correlation strength λ is larger in the case of 4q. It stimulates to look for the correlations between particles from different Ws.

Direct Measurements of Correlations Between Particles from Different Ws

To perform a direct measurement of correlations between particles from different Ws, sensitive to BEC, we used a reference sample which contains only BEC for particles coming from a single W boson, but not for particle pairs from different Ws. Such reference samples were constructed using an event mixing method.

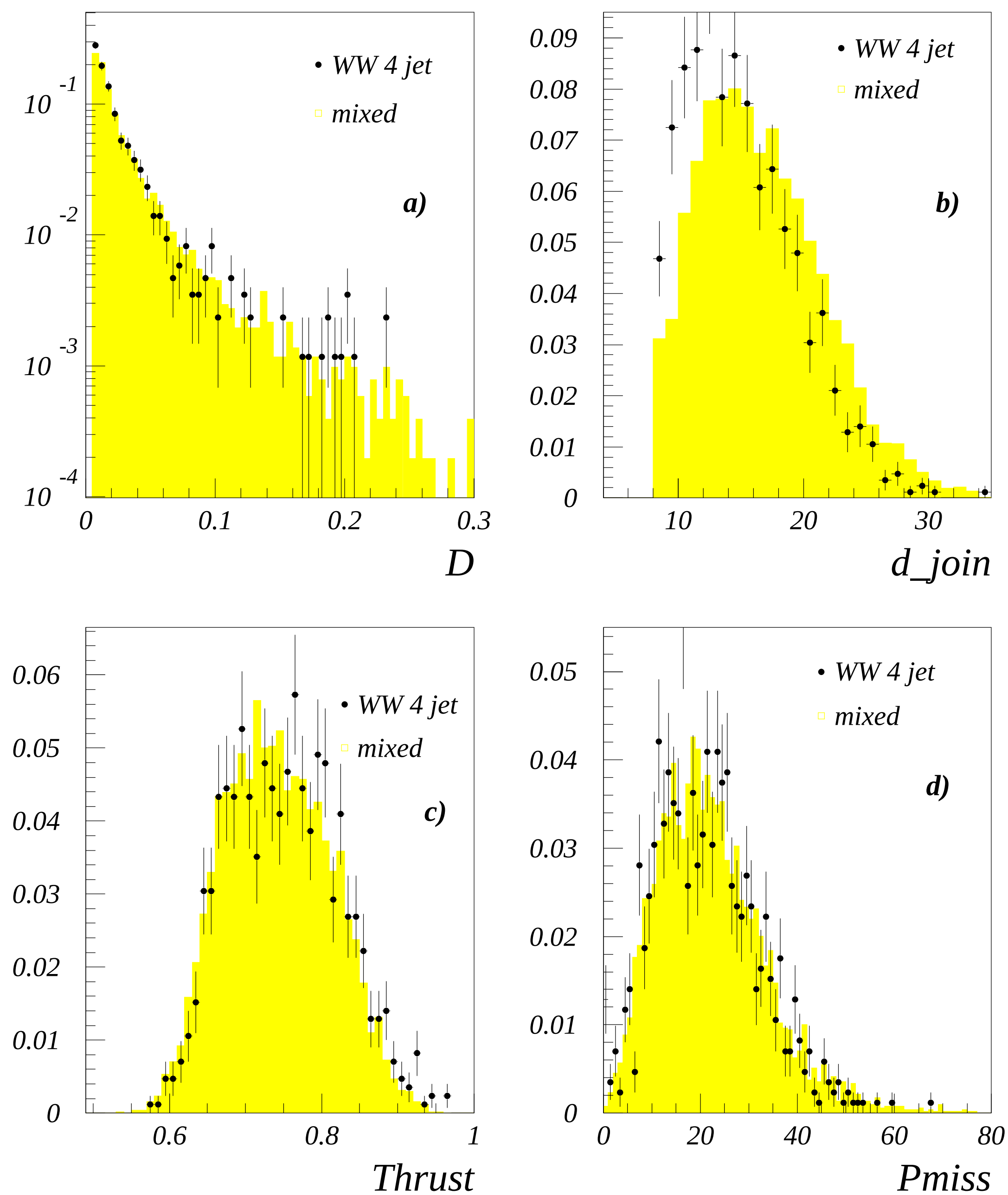
Event Mixing Technique

A reference sample of $(4q)$-like events was constructed by mixing of two $(2q)$ events if they had momentum balance $\mid \overrightarrow{P}_1 + \overrightarrow{P}_2 \mid <$ 25 GeV. From each selected semi-leptonic event, the hadronic part was boosted to the rest frame of the W candidate. The rest frames of the W candidates were determined using the energy and momenta of the Ws obtained from the kinematical fits. The mixed event was then constructed from two W candidates by boosting the particles of the individual Ws in opposite directions. The boost vectors were determined taking into account energy-momentum conservation and the fitted mass of W candidate.

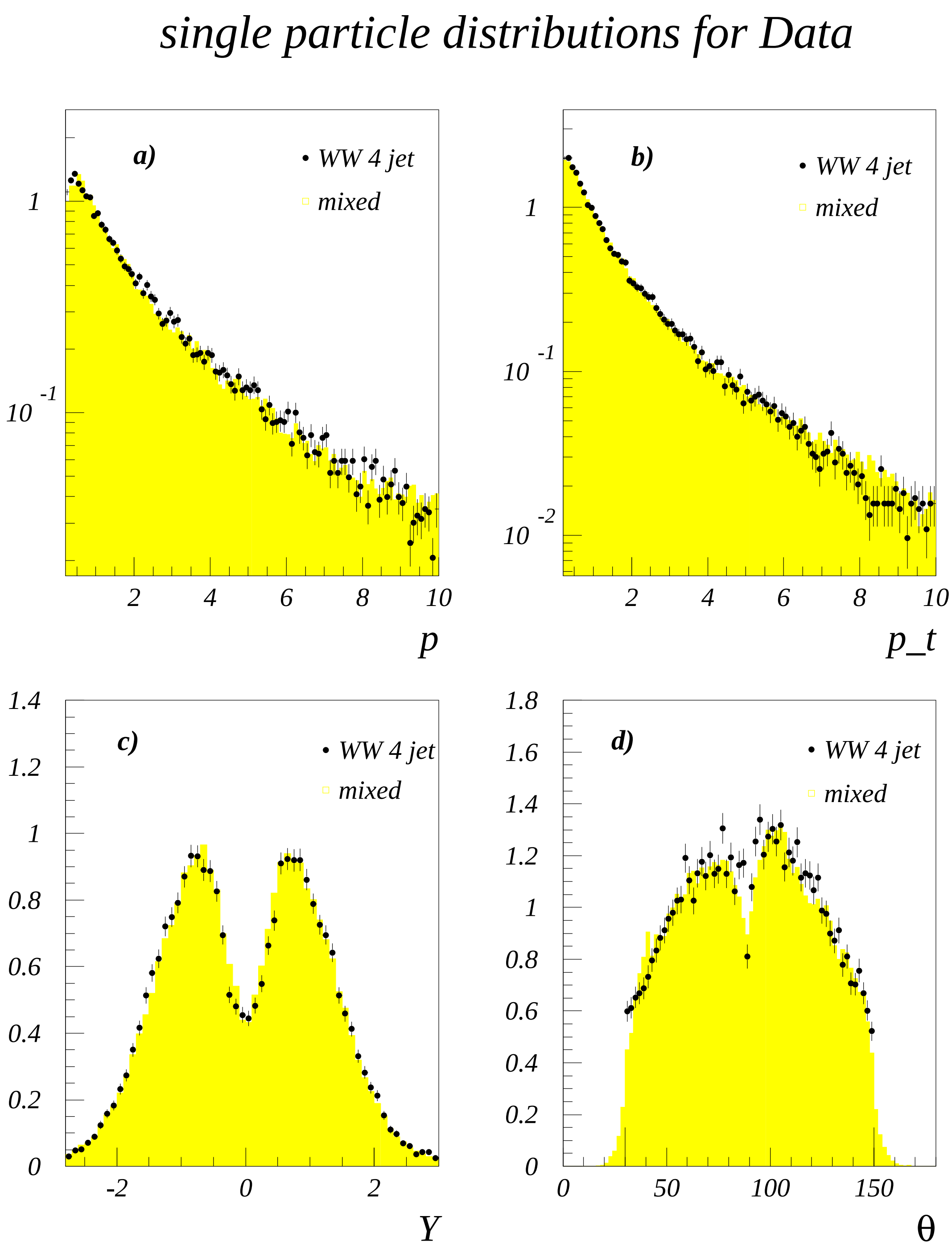
The R_{4q} in case of no correlations between Ws can be written as

$$R_{4q}(Q)(const) = \frac{[P_{2q}(Q) + P_{mix}(Q)]\ data}{[P_{2q}(Q) + P_{mix}(Q)]\ MC\ no\ BE}, \tag{8}$$

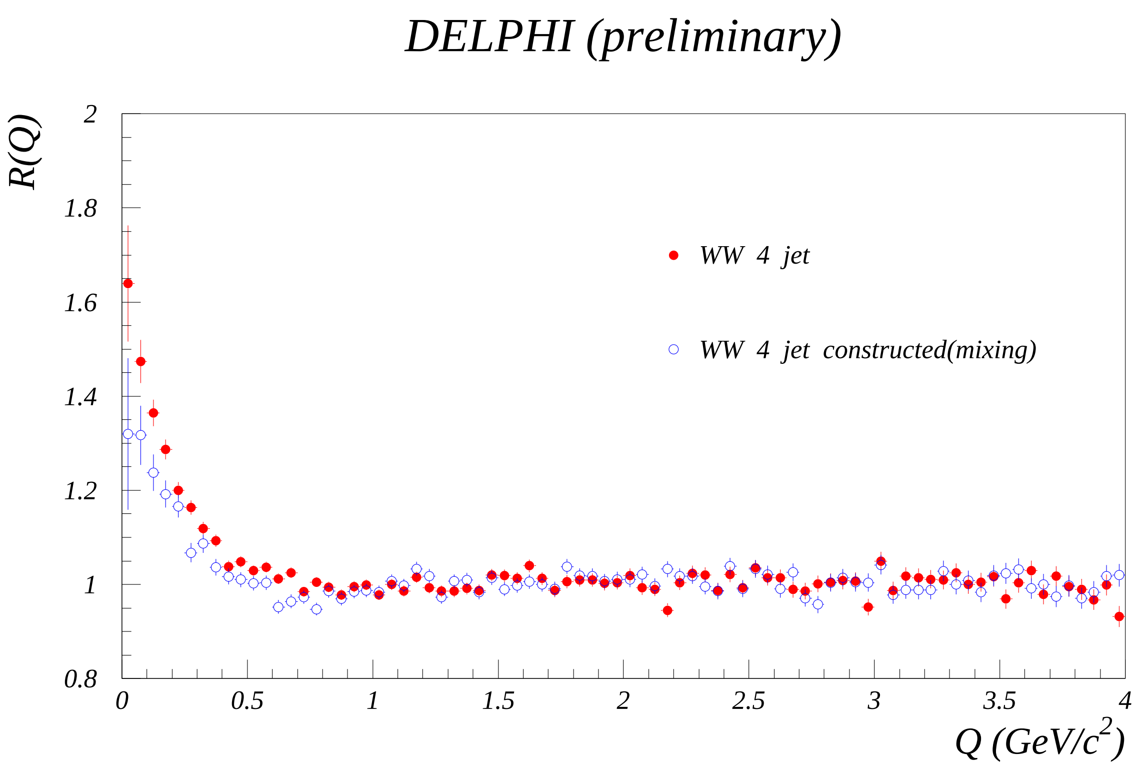
Comparison of event shape variables for (4q) and mixed events for real 1998 data.



Comparison of single particle distributions for (4q) and mixed events for real 1998 data.



Correlation Functions for WW$\rightarrow$ $4j$ $data$ and WW$\rightarrow$ $4j$ $const.$



We define the difference

$$\Delta\lambda = \lambda_{4q}(data) - \lambda_{4q}(const). \tag{9}$$

A difference of $\Delta\lambda$ from zero would indicate the presence of correlations between particles from different Ws in real $(4q)$ events.

The fit yielded:

$$\lambda_{4q}(const) = 0.214 \pm 0.029(stat) \pm 0.008(syst) \tag{10}$$

$$\lambda_{4q}(data) = 0.302 \pm 0.021(stat) \pm 0.013(syst) \tag{11}$$

$$\Delta\lambda = \lambda_{4q}(data) - \lambda_{4q}(const) = \\ = 0.088 \pm 0.036(stat) \pm 0.015(syst)\,. \tag{12}$$

Using the BEC model with LUBOEI, tuned to the data at the Z-peak(Aleph method) we obtain:

$$\Delta\lambda = \lambda_{4q}(data) - \lambda_{4q}(const;\ MC\ inside) = \\ = 0.073 \pm 0.025(stat) \pm 0.013(syst). \tag{13}$$

To perform model independent measurements of correlations between particles from different Ws, the ratio which is independent of any Monte-Carlo model:

$$D(Q) \equiv \frac{P_{4q}(Q)}{2\,P_{2q}(Q) + 2\,P_{mix}(Q)}\,, \qquad (14)$$

was used. This was fitted by the expression:

$$D(Q) = N\,(1 + \delta Q)\left(1 + \Lambda e^{-RQ}\right)\,. \qquad (15)$$

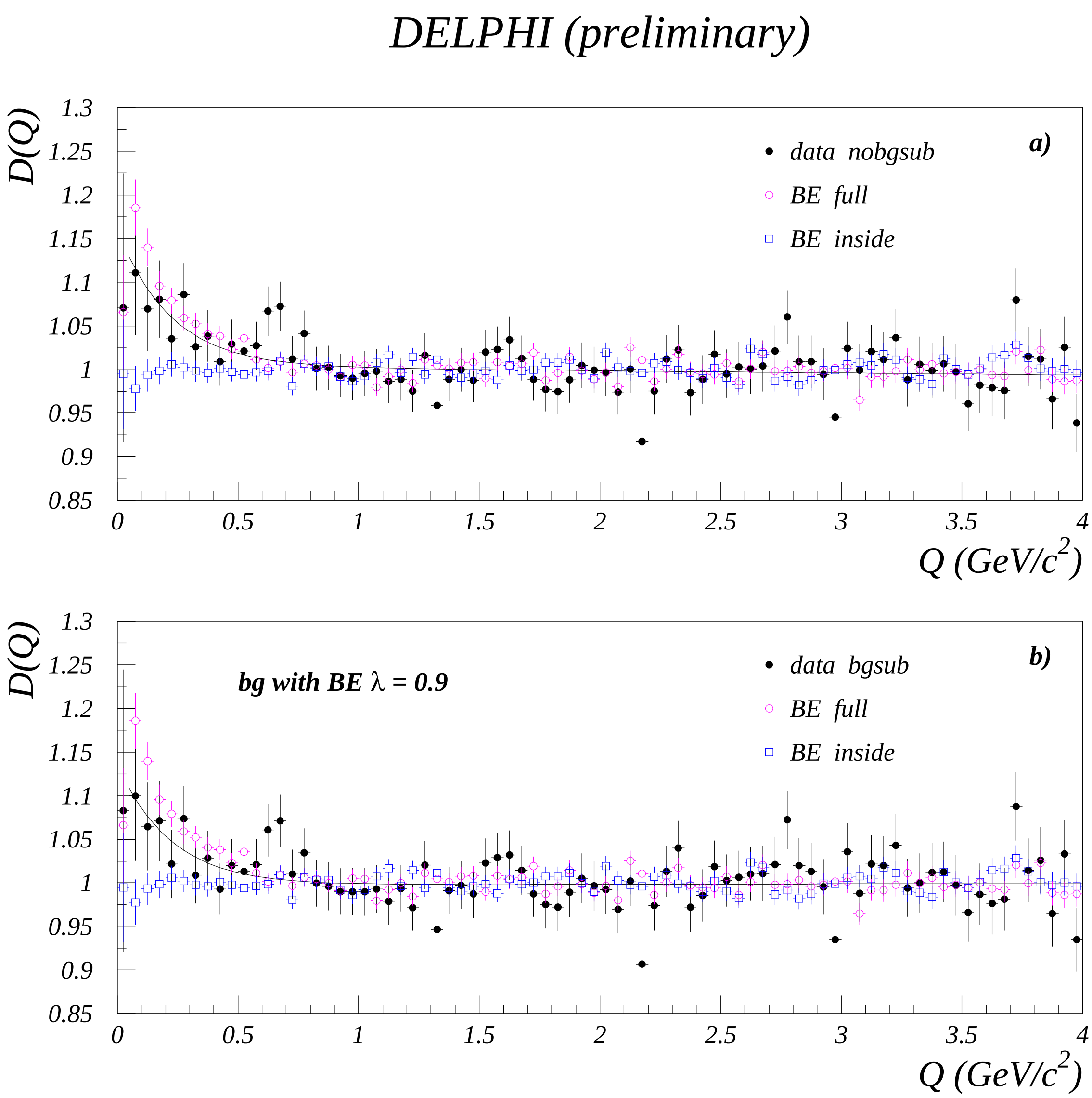
The fits yielded:

$$\Lambda(full\ BE) = 0.227 \pm 0.026(stat) \qquad (16)$$

$$\Lambda(inside\ BE) = -0.002 \pm 0.016(stat) \qquad (17)$$

$$\Lambda(data) = 0.149 \pm 0.045(stat)^{+0.025}_{-0.020}(syst) \qquad (18)$$

The ratio $D(Q)$ of full hadronic to mixed events for data and MC.



Summary:

A model independent method for measuring the quantities influenced by bin-to-bin and inside bin correlations are presented. The correlation functions for like-sign particles were measured for semi-leptonic and for fully hadronic WW channels using data collected with the DELPHI detector during the 1998-2000 years with integrated luminosity of $550\ \mathrm{pb}^{-1}$ at centre-of-mass energies ranging from 183 to 209 GeV. The values of the correlation strength λ between the pions were

$$\lambda_{4q} = 0.306 \pm 0.021(stat) \pm 0.013(syst) \quad (19)$$

$$\lambda_{2q} = 0.280 \pm 0.037(stat) \pm 0.010(syst)\,. \quad (20)$$

A direct measurement of correlations between pions from different Ws was performed using an event mixing technique. The difference between the correlation strength of like-sign pairs for real WW $(4q)$ events and for a sample which contains only correlations coming from the same W boson was

$$\Delta\lambda = 0.088 \pm 0.036(stat) \pm 0.015(syst)\,. \quad (21)$$

Another measurement of $\Delta\lambda$, obtained using a MC reference sample with BEC according to LUBOEI, tuned and corrected at the Z peak was

$$\Delta\lambda = 0.073 \pm 0.025(stat) \pm 0.013(syst)\,. \qquad (22)$$

The value of parameter $\Lambda(data)$ characterizing the correlations between like–sign particles coming from different Ws was found to be

$$\Lambda(data) = 0.149 \pm 0.045(stat)^{+0.025}_{-0.020}(syst) \qquad (23)$$

The methods explored prefer the hypothesis of correlations between pions coming from different Ws at the level of 2.4 standard deviations.