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COLOUR RECONNECTION AND BOSE-EINSTEIN CORRELATIONS IN WW DECAYS

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In the reaction $e^+e^- \to W^+W^- \to q_1\bar{q}_2q_3\bar{q}_4$, cross-talk between the two evolving hadronic systems may be possible, trough Colour Reconnection or Bose-Einstein Correlations. The present status of the study of these effects in the DELPHI experiment at LEP2 is presented.

1 Introduction

In the study of fully hadronic decay of W pairs, interference between the two hadronic systems arising from the decay of each W is in itself a study of interest In the WW events produced at LEP2, trough the reaction $e^+e^- \to W^+W^- \to q_1\bar{q}_2q_3\bar{q}_4$, the distance travelled by the W bosons before decaying is around $\tau_W \sim 1/\Gamma_W \simeq 0.1$ fm, one order of magnitude smaller than the typical fragmentation scale of the W boson. Hence there is a significant space-time overlap of both W hadronization regions, where their decay products can interact.

Cross-talk between both W systems can occur trough gluon exchanges between the the partons stemming from each W , resulting in a colour rearrangement between the systems. This effect is known as *Colour Reconnection* (CR). But cross-talk can also occur between final state hadrons trough quantum mechanical interference, mainly due to Bose-Einstein effects between identical bosons. In this case we talk of Inter-W *Bose-Einstein Correlations* (BEC). Both these effects can spoil the measurement of the W mass (m_W) in the full hadronic channel, because hadrons can no longer be uniquely assigned to one W boson.

Between 1996 and 1999 the LEP machine at CERN worked at centre-of-mass energies above the WW threshold. During this period the DELPHI experiment collected about 10000 WW events, for a total luminosity of more than 600 pb^{-1}. These events provide the basis for the studies here reported. The studies of CR, performed using both the particle flow and the Δm_W methods, are detailed in [1], while the study of Inter-W BEC is described in [2]. Here they are reviewed very briefly. All results are preliminary.

2 Colour Reconnection

CR between the primary quarks or the hard partons from different W bosons is supressed at perturbative level, but, at the non-perturbative level, colour exchanges between soft partons coexisting in space and time could lead to large effects . The effects of CR are estimated from phenomenological models. The studies presented here are based in the SKI [3], AR2 [4] and HERWIG models[5].

In the SKI model, implemented in JETSET, the colour field strings, spanned between the primary quarks coming from each W, are treated as flux tubes, with a transverse dimension. The strings can cross in space-time, with a overlap volume V_{overlap}. The probability of CR in one event is then given by $P_{\text{reco}} = 1 - e^{-k_I V_{\text{overlap}}}$, where k_I is a free parameter that allows to vary the percentage of reconnected events. In the AR2 model, implemented in ARIADNE , CR is allowed when the string lenght after reconnection is shorter than the original one. Moreover, CR can only occur bellow a fixed energy scale, usually Γ_W. Within the framework of cluster fragmentation, implemented in HERWIG, CR is allowed with a fixed probability ($\simeq 1/9$) when it reduces the size of the clusters.

2.1 The Particle Flow Method

CR predicts an increase in the number of particles produced between the jets originating from the same W decay (Inside-W region), and a corresponding decrease of particle production between jets from different W decays (Outside-W region). Tight angular event selection criteria enable the proper definition of the regions, at the cost of low efficiency (15%−22%). Particles in the Inside-W and Outside-W regions are counted, and after background subtraction, the ratio R of the integrated particle flow Inside-W to the same integral Outside-W is calculated. Simulation shows this observable to be sensitive to CR. The R values measured at each centre-of-mass energy are rescaled to 189 GeV using simulation, and their average is calculated to be $\langle R \rangle = 0.979 \pm 0.032(\text{stat}) \pm 0.030(\text{syst})$. The systematic uncertainties considered were the modelling of fragmentation in signal and background, possible BEC effects in the signal, background subtraction, and the extrapolation to 189 GeV.

In Fig. 1 (left) the R measured in data is compared with the R values estimated for several simulated samples. There is sensitivity only to the SKI model. By varying the κ_I parameter of SKI, it is possible to plot a χ^2 distribution for the particle flow measurement, presented in Fig. 1 (right).

2.2 The Δm_w Method

The standard m_W estimator, $m_W(\text{std})$, based on the direct reconstruction of WW fully hadronic decays, can be affected by CR. It is possible to construct estimators of m_W with less sensitivity to CR by negleting the low momentum particles between the jets, which are the main participants in CR. A cone is defined around the jet axis, and the particles laying outside it are removed. The jet axis is recalculated and the procedure is repeated until a stable direction is reached, which is then used to estimate $m_W(\text{cone})$. The true value of m_W is unknown, but it must be invariant for the different estimators, so the difference $\Delta m_W = m_W(\text{std}) - m_W(\text{std})$ is an observable for CR. For a cone radius of 0.5 rad, this difference was determined to be $\Delta m_W(\text{std}, \text{cone}) = 59 \pm 35(\text{stat}) \pm 21(\text{syst})$. The main systematic uncertainties are possible problems in jet reconstruction, fragmentation modelling and BEC effects.

The Δm_W observable was found to be sensitive to the SK1 model, but not to HERWIG, and not enough to AR2. Again in Fig. 1 (right), the χ^2 for the SKI κ_I

is ploted, now using the Δm_w method. A combination with the particle flow χ^2 is also performed, resulting in a measurement of $\kappa_I = 1.02^{+1.66}_{-1.01}$.

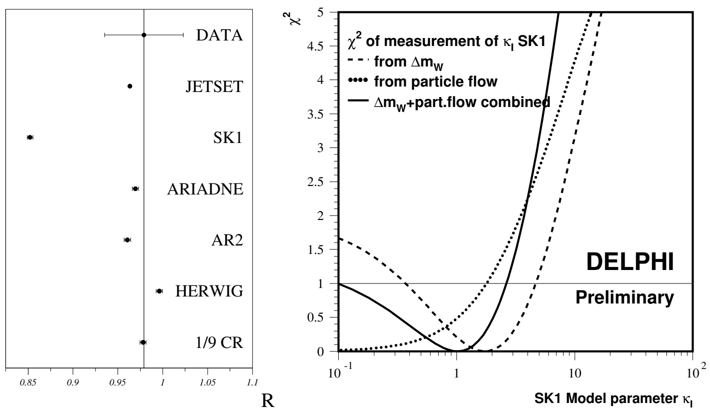

Figure 1. Left: The particle flow R measured in data, compared with simulated signals with CR (SK1, AR2, HERWIG 1/9 CR) and without CR for the given models . Right: The χ^2 distributions for the κ_I parameter, from the particle flow (dotted line) and the Δm_W methods, (dashed line) and the combined χ^2 (solid line) .

3 Bose-Einstein Correlations

Correlations between pairs of particles are studied by defining the inclusive two-particle density $\rho(Q) = (1/N_{ev})(dn_{pairs}/dQ)$ where $Q = \sqrt{-(p_1 - p_2)^2} = \sqrt{M^2 - 4m_\pi^2}$, M being the invariant mass of the particle pairs (taken to be pions). Assuming independent W decays, the two-particle density for a fully hadronic WW decay, ρ^{WW}, is related to the two-particle density for a sigle W decay, ρ^W (measured from semi-leptonic WW decays) trough the expression $\rho^{WW}(Q) = 2\rho^W(Q)+2\rho^{WW}_{\text{mix}}(Q)$. The two-particle density ρ^{WW}_{mix} is obtained by combining particles from two hadronic decays taken from different WW semi-leptonic events. The test variable $D(Q) = \rho^{WW}(Q)/(2\rho^W(Q) + 2\rho^{WW}_{\text{mix}}(Q))$ is defined, and any deviation from one indicates the presence of Inter-W BEC.

Fully hadronic and semi-leptonic WW decays are selected using a neural network. The qq background in the fullly hadronic events is subtracted using simulation, while the hadronic ZZ events are taken as signal. From the $WW \to q\bar{q}l\bar{\nu}_l$ decays, the $l\bar{\nu}_l$ parts are removed, and a sample of mixed events is build using the remaining hadronic parts. A comparison between the mixed events and the fully hadronic events confirms the consistency of the mixing procedure. A possible Inter-W BEC signal is simulated using the BE_{32} variant of the LUBOEI model [6]. In fully hadronic WW decays, this model allows the simulation of BEC between particles from the same W (BE-ins), or from different W bosons (BE-full).

The $D(Q)$ distribution of the like-sign pairs in the data is ploted in Fig. 2 (left), together with the distributions for the BE-ins and BE-full models. The phenomenological expression $D(Q) = N(1 + \Lambda e^{-RQ})(1 + \delta Q)$ was fited to the data, with the R parameter fixed to the value from BE-full, resulting in a value of $\Lambda = 0.241 \pm 0.075(\text{stat}) \pm 0.038(\text{syst})$, that is 2.9 σ away from zero. The same fit was performed without fixing R, and the result is presented in Fig. 2 (right). The presence of BEC in the background or CR in the signal, the variation of the fixed fit parameter R and the selection of the mixed events were studied as sources of systematic uncertainties.

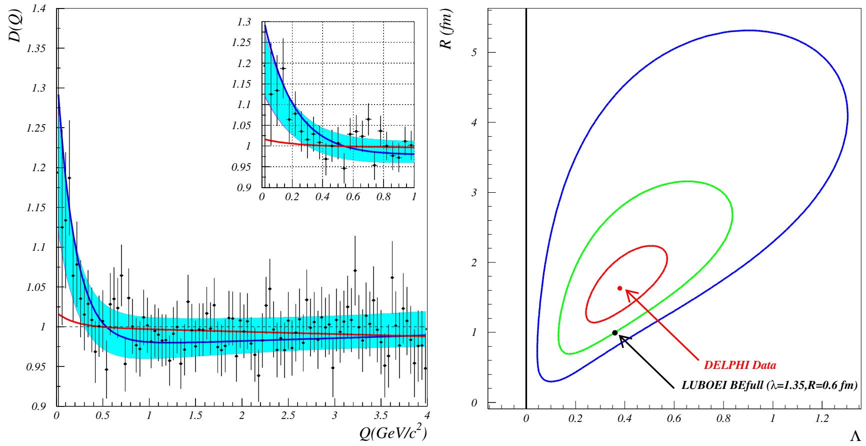

Figure 2. Left: The D(Q) distribution for data (points), BE-full (curved line) and BE-ins (flatter line); the band accounts for the correlation between the other fit parameters. Right: The 1, 2 and 3 σ contours for a fit with the R parameter free with the result for the BE-full model also given.

4 Summary

Studies of CR and of Inter-W BEC effects in $e^+e^- \to W^+W^- \to q_1\bar{q}_2q_3\bar{q}_4$ events collected by DELPHI were performed. The preliminary results indicate a small amount of CR, while evidence of Inter-W BEC was found at the 2.9 σ level.

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