Topics in W^+W^- Physics Measurements with DELPHI

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Abstract

LEP2 collider proves to be an excellent scientific environment for $W^\pm$ physics measurements. Analyses and recent results on production cross-section, branching ratios, mass reconstruction and triple gauge boson couplings obtained on data recorded by the DELPHI experiment are presented.

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1 Introduction

Large Electron Positron Collider (LEP) operating in European Organization for Nuclear Research (CERN) delivered in 1998 to the four adjoint experiments an integrated luminosity of about 150 pb^{-1} of data at the centre-of-mass energy $E_{\text{CMS}} \approx 189 \text{ GeV}$. A $W^\pm$ pair production proceeds through the processes shown in fig. 1. From the recorded e^+e^-

Figure 1: Processes contributing to $W^\pm$ pair production in e^+e^- collisions at LEP energies.

collisions, the DELPHI experiment[1] reconstructed about 2400 W^+W^- pairs decaying into 4 fermions. Generally these events are divided into three categories, depending on the subsequent $W^\pm$ boson decays: hadronic events with both $W^\pm$ decaying into quarks, semileptonic events with one $W^\pm$ decaying into quarks and the other into leptons and leptonic events, where both bosons decay into leptons. In 1999 the integrated luminosity raised to approximately 230 pb^{-1} collected at energies between 192 GeV and 204 GeV. A large sample of reconstructed $W^\pm$ pair events in a clean e^+e^- collision environment enables a number of precision measurements and tests of the Standard Model. Results presented in next sections are mostly based on data collected by DELPHI in 1998 and 1999 and are to be considered preliminary.

2 Cross-section and branching ratios

Selection of W^+W^- events exploits topological and kinematical properties of different decay channels mentioned in section 1. For hadronic events a neural net was fed by several observables discriminating the signal from the background. For semileptonic and leptonic events sequential cut analyses were used[2]. Selection criteria were optimized to obtain the best possible efficiency $\times$ purity. The output of the neural net for signal and background events is shown in fig. 2.

A maximum likelihood fit to the binned neural net output distribution (hadronic channel) and to the number of observed events (semileptonic and leptonic channel) was performed leaving the total $\sigma(e^+e^- \rightarrow W^+W^-)$ production cross-section and individual leptonic branching ratios of $W^\pm$ boson as free parameters. The results[2] are consistent with lepton universality. For data at $E_{\text{CMS}} \leq 189 \text{ GeV}$ measurements yield a value $Br(W^\pm \rightarrow \ell\nu) = 10.71 \pm 0.24(\text{stat.}) \pm 0.14(\text{syst.}) \%$, in good agreement with the SM prediction of 10.8%. The hadronic branching ratio, calculated as $1 - 3Br(W^\pm \rightarrow \ell\nu)$, obtained at different e^+e^- collision energies is shown in fig.3. $\sigma(e^+e^- \rightarrow W^+W^-)$ was obtained by fixing $Br(W^\pm \rightarrow \ell\nu)$ to the SM value. At 189 GeV the cross-section amounts to $15.83 \pm 0.38(\text{stat.}) \pm 0.20(\text{syst.}) \text{ pb}$, and its energy dependence is compared to the SM prediction in fig.3. Systematic uncertainties receive contributions from the efficiency and background determination, and from the measurement of luminosity.

Figure 2: Output of the neural network used for $W^+W^- \rightarrow 4q$ events selection. Dots with error bars represent the data and histograms the simulated data for signal and different sources of background at $E_{\text{CMS}}=189$ GeV[2].

Figure 3: $W^\pm$ hadronic branching ratio (left) and total $W^\pm$ pair production cross-section (right) obtained from the fit to the data at different e^+e^- centre-of-mass energies. The shaded band is the SM prediction[3].

3 $W^\pm$ mass measurements

The invariant mass reconstruction of $W^\pm$ boson decay products enables tests of the SM (through comparison with indirect measurements of this quantity). M_W is also sensitive to the mass of the SM Higgs boson. Hadronic and semileptonic events were used in the performed analysis, while leptonic events have a lower sensitivity due to a presence of at least two undetected neutrinos.

The invariant mass was calculated from the measured momenta of hadronic jets and leptons, after a kinematically constrained fit requiring a 4-momentum conservation[4]. In

Figure 4: Ideogram, giving a probability density for a certain configuration of four (left) or five (right) jets in hadronic events to arise from two objects with masses m_x and m_y .

Figure 5: Results on M_W obtained at different e^+e^- CMS energies. The top most data point shows an indirect measurement derived from the total W^+W^- production cross-section just above the threshold. Errors include statistical and systematical uncertainties. Dark shaded band is the combination of all results.

the semileptonic sample the mass extraction method consisted of event-by-event likelihood function optimization, which was constructed as a convolution of the theoretical signal mass distribution with the resolution function plus the simulated background distribution. For $W^+W^- \rightarrow 4q$ decays the ideogram technique was adopted [5][6]. In the constrained fit masses of the two produced heavy objects were fixed to a certain value (m_x, m_y) . By scanning the (m_x, m_y) plane and repeating the fit one obtains a probability (ideogram) for a given reconstructed kinematics of an event to be a product of two objects with masses m_x and m_y . An example of the ideogram is shown in fig. 4. The likelihood function is then constructed as a convolution of this ideogram with the expected signal and background mass distributions.

The obtained $W^\pm$ mass value has to be corrected for a small systematic shift, arising

from the initial state radiation, which is not properly taken into account in the fit. The bias was estimated using the MC sample and amounts to around 400 MeV/c² in semileptonic and around 150 MeV/c² in hadronic channel.

Figure 6: Results of direct (dotted line) and indirect (full line) M_W and top quark mass reconstruction compared to the SM Higgs boson mass prediction [7].

Combining measurements at $E_{\text{CMS}} \leq 189$ GeV, the $W^\pm$ mass was found to be [6] $M_W = 80.316 \pm 0.076(\text{stat.}) \pm 0.047(\text{syst.}) \pm 0.017(\text{LEP})$ GeV/c², where the last error comes from the uncertainty of the LEP collision energy. The largest contribution to the systematic error in hadronic channel arises from the modeling of final state interactions, while for the semileptonic events the contribution from the jet energy uncertainty is dominating. Fixing the value of $W^\pm$ mass and varying the width of the boson in the likelihood fit yields $\Gamma_W = 2.48 \pm 0.40(\text{stat.}) \pm 0.10(\text{syst.})$ GeV/c².

Values of M_W obtained at different E_{CMS} are summarized in fig. 5. Fig. 6 illustrates the limits on the SM Higgs boson mass imposed by direct measurements of M_W and top quark mass [7].

4 TGC measurements

Since the processes, leading to a $W^\pm$ boson production at LEP, include vertices with three gauge bosons (W^+W^-V ; $V \equiv \gamma, Z^0$) it is possible to measure the triple gauge couplings (TGC's). Beside the diagrams, shown in fig.1, also single $W^\pm$ and γ productions are exploited. Under reasonable assumptions [8] TGC's can be described with three parameters: an overall $W^+W^-Z^0$ coupling g_1^Z , dipole $W^+W^-\gamma$ coupling κ_γ and quadrupole $W^+W^-\gamma$ coupling λ_γ . Results for these parameters are presented in the form of deviations from the SM predictions ($\Delta g_1^Z = 0$, $\Delta \kappa_\gamma = 0$, $\lambda_\gamma = 0$).

TGC parameters affect the total $W^\pm$ pair production cross-section, the $W^\pm$ production angle distribution, as well as the polarization of charged gauge bosons and by that angular distribution of final state fermions. In hadronic and semileptonic W^+W^- events two observables with maximal sensitivity to the TGC's were constructed (Optimal Observables - OO [9]) using the quadratic dependence of differential cross-section on a given coupling

Figure 7: Left: OO_1 distribution for Δg_1^Z in hadronic channel at 183 GeV. Points represent the data and histogram the best fit. Background contribution is shaded [10]. Right: Results of TGC measurements combining all decay channels used on data at $E_{CMS} \leq 189$ GeV.

α :

$$\frac{d\sigma(\vec{\Omega}, \alpha)}{d\vec{\Omega}} = c_0(\vec{\Omega}) + c_1(\vec{\Omega})\alpha + c_2(\vec{\Omega})\alpha^2, \quad OO_1 \equiv \frac{c_1(\vec{\Omega})}{c_0(\vec{\Omega})}, \quad OO_2 \equiv \frac{c_2(\vec{\Omega})}{c_0(\vec{\Omega})}$$

TGC's were extracted from the comparison of the two measured OO distributions (fig. 7) to the expected ones, leaving one of the parameters in the fit free and fixing the other two to the SM values. In leptonic $W^\pm$ pair decays and in single $W^\pm$ and γ events only a single most sensitive variable was used in the fit (total cross-section, inter-jet angle and the photon energy, respectively). Results [10] are presented in fig. 7 and show no significant deviations from the SM.

5 Conclusion

A large variety of measurements in the field of $W^\pm$ boson physics is performed with the DELPHI detector at LEP, many of them not covered in the presented short overview. Unknown parameters of the SM are measured with a high precision and results show no deviations from the SM predictions.

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