PROCEEDINGS

International Europhysics Conference on HEP

W-pair and single-W production at LEP

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Abstract: This article summarises the LEP combinations of published and preliminary results on W-pair and single-W production cross-sections and on W decay branching fractions, based on data collected up to a centre-of-mass energy of 209 GeV. The results are compared with the most recent theoretical predictions.

1. Introduction

Since the first run above the W-pair production threshold in 1996, LEP has guaranteed more than 700 pb^{-1} per experiment at e$^+$e$^-$ centre-of-mass energies up to 209 GeV. The largest statistics have been collected at 189 GeV and at about 207 GeV, with a luminosity of 180 and 140 pb^{-1}, respectively. In the regime of four-fermion physics the processes mediated by charged currents are of particular importance for precision electroweak measurements. In what follows, the determination of their cross-section at LEP will be briefly reviewed.

The signals are defined on a diagrammatic basis, since many Feynman diagrams can contribute to the same final state. W-pair production is unambiguously defined as the so-called CC03 set of diagrams [1], whereas for single-W production, characterised by only one resonant propagator, a more complex definition must be adopted. At LEP a common definition was agreed, which considers single-W production as the complete t-channel subset of Feynman diagrams contributing to $e\nu_e f\bar{f}'$ final states, with additional phase space cuts in order to exclude those regions dominated by multiperipheral diagrams, where the cross-section calculation is much more uncertain. These cuts are: $m_{q\bar{q}}$ >45 GeV/c^2 for the $e\nu_e q\bar{q}$ final states, E_l >20 GeV for the $e\nu_e l\nu_l$ final states with $l = \mu, \tau$ and, finally, $|cos\theta_{e^-}|$ >0.95, $|cos\theta_{e^+}|$ <0.95 and E_{e^+} >20 GeV (or the charge conjugate cuts) for the $e\nu_e e\nu_e$ final states.

2. Production cross-section measurements

The signatures of single-W or W-pair production depend upon the decay of the bosons and the observed multiplicity ranges from a fully hadronic final state with four or more jets in

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the detector in the case of $WW \to q\bar{q}q\bar{q}$ to a single detected lepton in the case of $We\nu_e \to l\nu_l e\nu_e$ where the initial state electron is lost in the beam pipe. The main backgrounds for the signals can be either due to four-fermion or 2-fermion processes. In table 1 the final states, their Branching Ratios (BRs), the typical signatures and backgrounds are summarised.

Channel	BR$_{SM}$	Signature	Backgrounds
$WW \to q\bar{q}q\bar{q}$	0.456	>3 jets, high E$_{vis}$, low $\not{p}_T$	$q\bar{q}(\gamma)$, ZZ
$WW \to q\bar{q}l\nu$	0.439	isolated lepton with jets, high $\not{p}_T$	$q\bar{q}(\gamma)$
$WW \to l_1\nu_{l_1}l_2\nu_{l_2}$	0.105	two acoplanar, acollinear leptons	$l^+l^-(\gamma)$, $\gamma\gamma$
$We\nu_e \to q\bar{q}e\nu_e$	0.676	two high mass jets, high $\not{p}_T$ e $\not{p}_{\parallel}$	$q\bar{q}(\gamma)$, WW, other 4-f
$We\nu_e \to l\nu_l e\nu_e$	0.324	isolated, high p_T lepton	$l^+l^-(\gamma)$, WW, $\gamma\gamma$

Table 1: Signal final states, their Standard Model BRs, typical signatures and backgrounds. p_T and $p_{\parallel}$ are defined with respect to the beam, E$_{vis}$ indicates the visible energy.

For the event selections the experiments adopt either a sequential cuts approach, cutting on kinematical variables to enhance the signal, or Neural Networks are used, and final cuts are applied to their output. For the WW selection, typical efficiencies range from 85 to 90% for the fully hadronic channel, from 75 to 90% for the mixed hadronic-leptonic channel with e or μ, from 50 to 80% for the $q\bar{q}\tau\nu_\tau$ final state, and from 50 to 80% for the fully leptonic channel. Performances, of course, depend upon the analysis and the detector coverage and efficiency. The purest channels are the mixed hadronic-leptonic ones, with purities greater than 90%. Concerning the single-W selections, the techniques are very similar to those of the WW selection, though a performance comparison between experiments is still difficult due to different signal definitions. Conversion factors to the measured cross-section are then provided by each experiment in order to adhere to the LEP common signal definition.

Cross-sections are determined through a likelihood fit to the observed number of events in each sub-channel, assuming a Poissonian distribution for the number of observed events and the Standard Model (SM) BRs.

Systematic uncertainties on the measurements include the modelling of the jet fragmentation (both for signal and backgrounds), considered as fully correlated between years and experiments in the LEP combination, the luminosity determination and the theory errors on the SM cross-sections, both considered as year-by-year correlated. Other sources, uncorrelated in the LEP combination, comprise detector calibration, track reconstruction and lepton identification efficiencies and the statistics of simulated events.

The results from 1996 onwards are shown in figure 1. They are all preliminary with the exception of the published WW cross-section results for centre-of-mass energies below 190 GeV. The W-pair results are compared with the most recent calculations which include $\mathcal{O}(\alpha)$ electroweak radiative corrections in the so called Double Pole Approximation [2] (DPA). All results are in excellent agreement with the expectations.

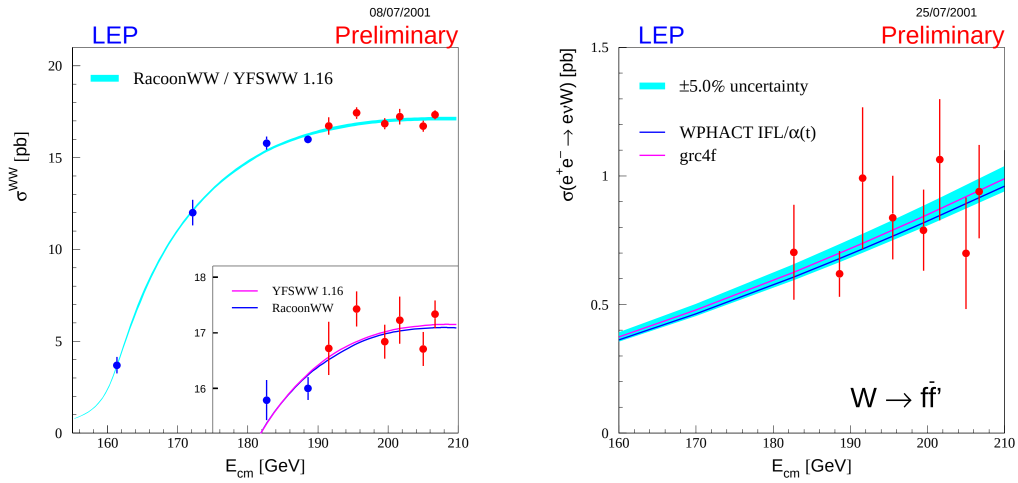

Figure 1: W-pair and single-W cross-section measurements compared with theory expectations. The error bars include total statistical and systematic errors.

3. Derived quantities

From the partial WW cross-sections it is possible to extract information about the W BRs. Assuming unitarity in such a way that $\mathrm{Br}_{e\nu}$+$\mathrm{Br}_{\mu\nu}$+$\mathrm{Br}_{\tau\nu}$+$\mathrm{Br}_{q\bar{q}}$=1, the leptonic branching fractions can be fitted. If one also assumes lepton universality the hadronic branching ratio can be determined. The preliminary combined LEP results with the full data sets are shown in figure 2, where the errors include both statistics and systematics. Good agreement with the predicted values is found.

The leptonic branching fraction can also be written as:

$$\frac{1}{Br_{l\nu}} = 3\left(1 + \left(1 + \frac{\alpha_s(m_W)}{\pi}\right) \sum_{(u,c)(d,s,b)} |V_{ij}|^2\right) \tag{3.1}$$

Given the good knowledge of the sum of the squares of the CKM matrix elements which do not involve V_{cs} and of α_s [3], it is possible to extract V_{cs} from the measurement of $\mathrm{Br}_{l\nu}$. The LEP combined value turns out to be V_{cs}=0.996±0.013, compatible with 1, as expected.

Another useful quantity that can be defined is $\mathrm{R}_{WW} = \sigma_{WW}(EXP)/\sigma_{WW}(TH)$, which represents our ability to test the SM through the WW cross-section measurement. Taking into account year-by-year correlations of the systematics it is possible to combine all LEP data providing a single result. This is shown in figure 3, where as theoretical predictions a standard LEP2 generator (left) and one which includes more precise radiative corrections (right) have been used. KoralW [4] was chosen as the standard generator; it includes ISR LL $\mathcal{O}(\alpha^3)$ via YFS and FSR LL $\mathcal{O}(\alpha^2)$ via PHOTOS. The generator with DPA is RacoonWW, but very similar results are found by using YFSWW instead. The combined results on R_{WW} are reported below, where statistical and systematic contributions are

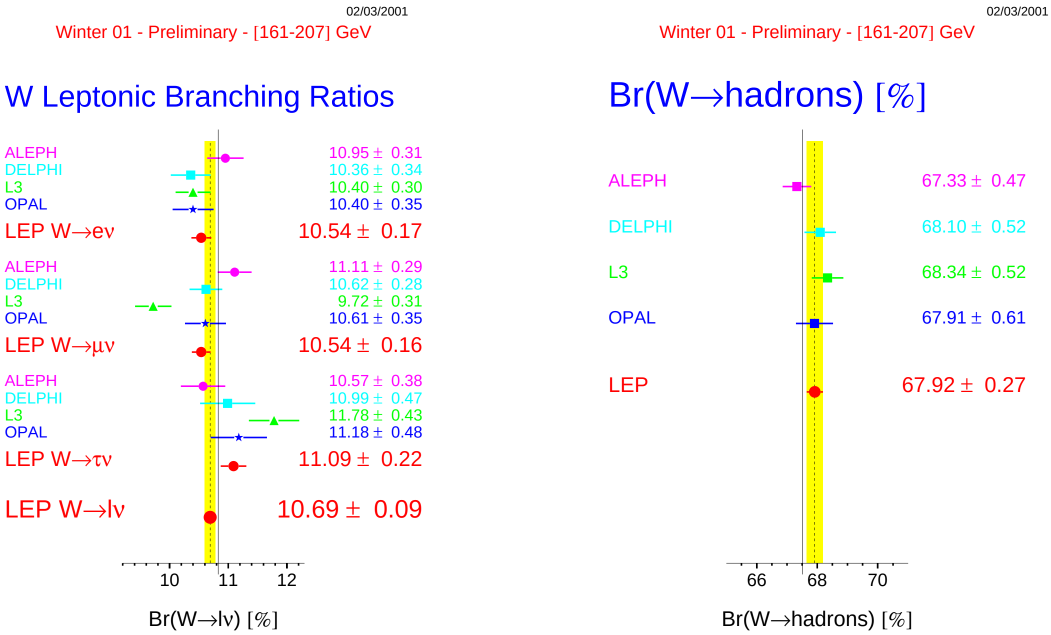

Figure 2: LEP combined leptonic and hadronic BRs, compared with the SM predictions.

given separately.

$$R_{WW}(KoralW) = 0.9788 \pm 0.0060(stat.) \pm 0.0067(syst.)$$
$$R_{WW}(RacoonWW) = 1.0000 \pm 0.0061(stat.) \pm 0.0069(syst.)$$

The data seem to prefer the DPA calculations, disfavouring the program not including full $\mathcal{O}(\alpha)$ by almost 2.5σ. This is an important result which tells us that at LEP2 we are able to test the SM at the one loop level. From the results on R_{WW} it is also clear that, in the final combination, the systematic error starts to be comparable to the statistical one, mostly because of the size of the correlated errors.

4. Conclusions and Outlook

The excellent performance of the LEP accelerator in the last five years has allowed the collection of a large amount of data and high quality studies of four-fermion physics. In particular the cross-section measurements of charged currents mediated processes have shown a very good agreement with the SM expectations at all energies. Derived quantities, like V_{cs} or the W branching fractions, are in agreement with predictions as well. The measured value of the ratio R_{WW} using the RacoonWW generator is 1.0000±0.0092, precision of the same order of magnitude of the theory error on the cross-section which allows us to test the validity of SM calculation at the loop level.

LEP collaborations are working towards finalising their results and developping a more refined way of combining LEP results. In particular a better understanding of the correlated

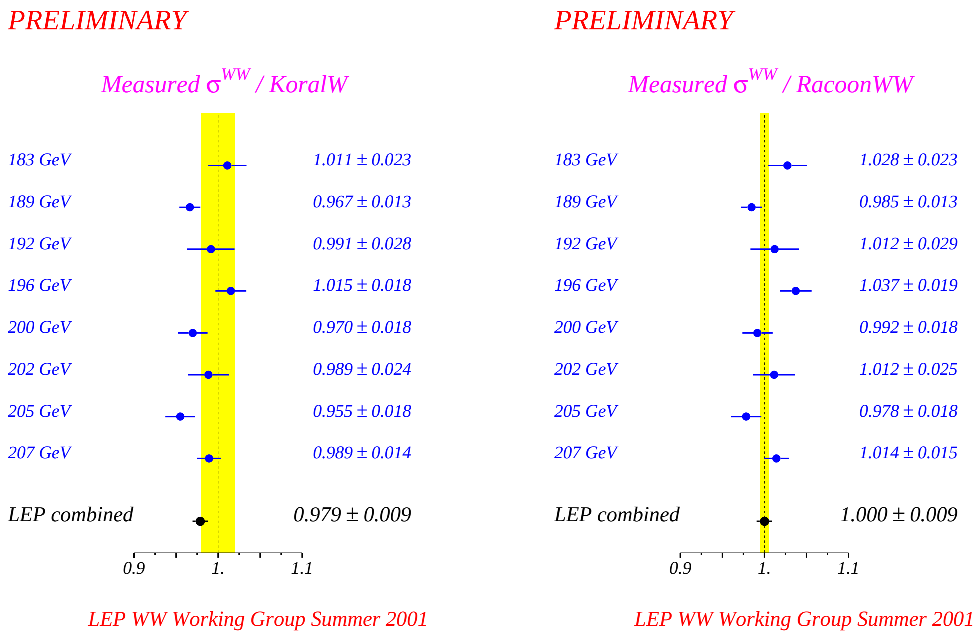

Figure 3: R_{WW} from LEP for LEP2 standard EW radiative corrections and $\mathcal{O}(\alpha)$ corrections in DPA.

part of the systematic errors, mostly due to fragmentation, could result in a significative reduction of the combined systematic error, now of the same order of the statistical one.

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