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Four fermion final states and photoproduction at LEP2

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Abstract. Four fermion processes have been measured at LEP2 in e^+e^- collisions up to $\sqrt{s} = 209$ GeV. Combination of results from the four LEP experiments allows stringent tests on Standard Model (SM) predictions and to model backgrounds for Higgs bosons and new physics searches.

PACS. 14.70.-e Gauge bosons – 12.15.-y Electroweak interactions

1 Introduction

Four fermion (4f) production encompass a large set of processes, that can proceed via two, one or non-resonant boson exchange, such as $e^+e^- \to W^+W^-, ZZ, Z\gamma^*, eeZ/\gamma^*$ and $e\nu W$. Cross sections at LEP2 are shown in Fig. 1, as taken from reference [1].

Usually many diagrams can contribute to the chosen final state. LEP experiments have agreed on common signal definitions for the diagrams to be included and the phase space regions of interest, to combine measurements [2]. With a collected luminosity of about 700 pb^{-1} per experiment, most of the measured 4f final states result from processes seen at LEP2 for the first time. These measurements are useful to check SM predictions on cross sections and study triple gauge boson couplings (such as κ_γ from $WW\gamma$, in single W production). In addition, processes such as $e\nu W$ are important in the modelling of the background to the search for the Higgs boson in the $H\nu\bar{\nu}$ channel and for physics beyond the SM. In the following, only $Z\gamma^*$ production (where the measurement of a ZZ pair is extended to include an off-shell photon instead of a Z) and single boson production ($e\nu W, eeZ/\gamma^*$) will be covered. The production of boson pairs (WW, ZZ) and the measurement of trilinear gauge couplings (TGC's) are the subject of separate presentations at this conference [1]. The effort to match the experimental accuracy of the combined LEP experiments in the 4f field has triggered a lot of theoretical activity, in the form of detailed event generators such as GRC4F and WPHACT [3]. Theoretical predictions, for the 4f processes covered in this talk, have reached an accuracy level of $\sim 5\%$, while the measurements are mainly statistics limited. In addition, 4f states such as $e^+e^-l^+l^-$ can be produced by photon-photon collisions. These processes are a good test of QED and can allow the extraction of limits on the anomalous magnetic and electric dipole moments a_τ, d_τ of the tau lepton.

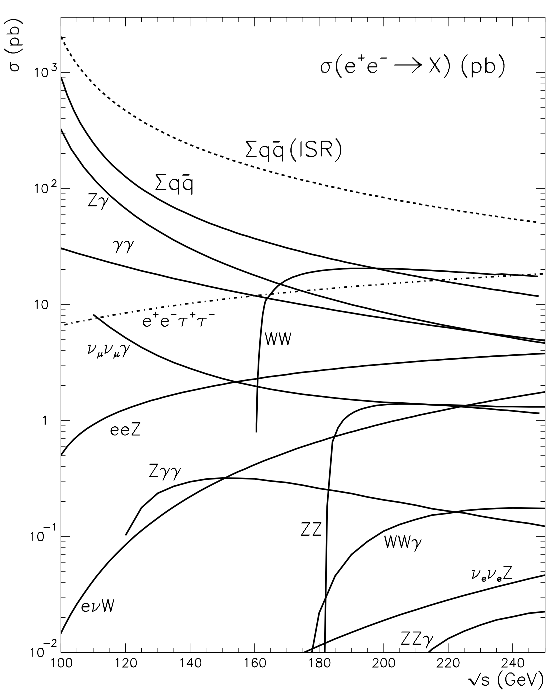

Fig. 1. Cross sections for some typical 4f and 2f SM processes

2 $Z\gamma^*$ production

The extension of measurements of neutral boson pairs to include an off-shell photon (γ^*) instead of a Z gives events with a distinctive topology: a characteristic forward-peaked production and a quasi mono-energetic γ^* at the lower masses. OPAL has analyzed $\mu\mu q\bar{q}$ and $eeq\bar{q}$ final states [4], while DELPHI included also $\nu\bar{\nu}q\bar{q}$ (monojet topology) and $llll$, $qq\bar{q}\bar{q}$ states [5]. The OPAL analysis

[1] see the contributions by S. Natale and R. Bruneliere

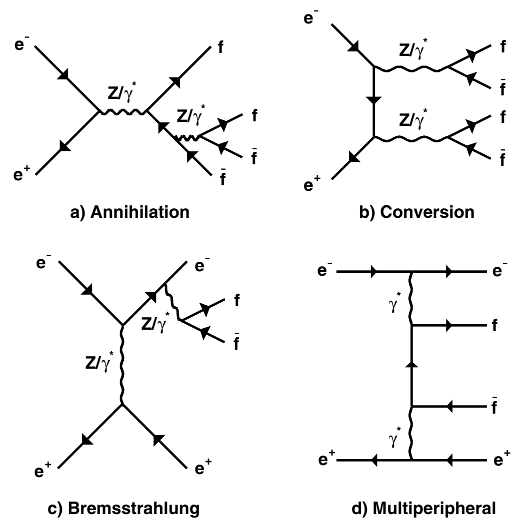

Fig. 2. Diagrams responsible of 4f NC production in e^+e^- collisions. Events stemming from d) (multiperipheral) are regarded as background

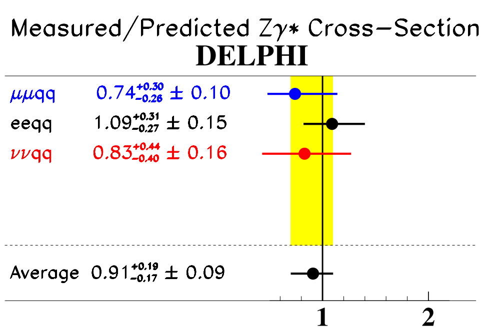

Fig. 3. Ratio of measured over predicted cross sections for $Z\gamma^*$ production, according to the LEP common signal definition

considered all graphs of Fig. 2, except the multiperipheral ones, while DELPHI considered only the conversion graphs (NC08). A subsequent common LEP signal definition has been agreed to combine all results. Depending on the final state, it requires the following kinematical cuts:

$$\mid \cos\theta_{l^\pm} \mid \leq 0.95, M_{q\bar{q}} > 10\ GeV/c^2, M_{l^+l^-} > 5\ GeV/c^2$$

to avoid the difficult regions of low di-fermion masses. In addition only one fermion pair can have an invariant mass compatible with a Z boson. DELPHI presented at this conference results with the common LEP definition, that are reported in Fig. 3 and give a combined value :

$$\sigma_{Z\gamma^*} = 0.137^{+0.029}_{-0.026} \pm 0.014\ pb$$

for the luminosity-weighted cross section.

3 Single boson production

Single vector bosons production in e^+e^- collisions ($e^+e^- \to e^-\overline{\nu_e}W^+$, $e^+e^- \to e^-e^+Z/\gamma^*$) proceeds via EW Compton scattering ($\gamma e^+ \to \overline{\nu_e}W^+$, $\gamma e^+ \to e^+Z$) of a quasi real photon ($q^2_\gamma \sim 0$) radiated from the incoming e^- on the e^+ from the other beam. The e^-, radiating the quasi real photon, is predominantly lost along the beampipe.

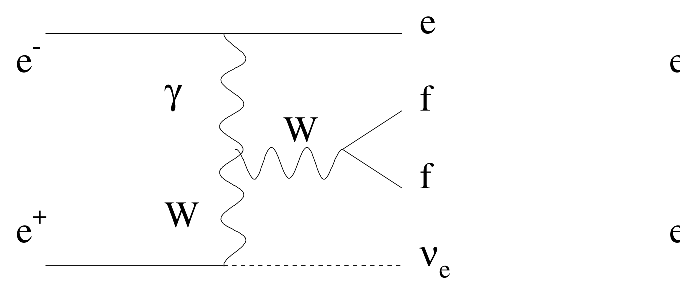

Fig. 4. Feynman diagrams contributing to $e^+e^- \to e\nu_e W$ at lowest order

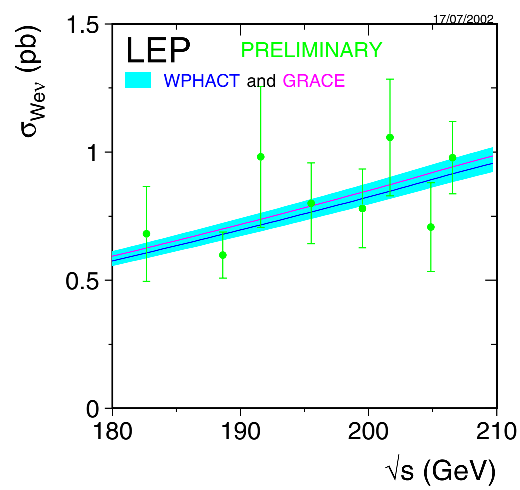

Fig. 5. Combined LEP cross-sections (ADLO) as a function of $\sqrt{s}$ for the $We\nu$ channel

3.1 Single W production

Single W bosons can be produced at tree level by the diagrams shown in Fig. 4. This process is important for the measurement of the trilinear gauge coupling κ_γ ($\kappa_\gamma = 1$ in the SM), through the $WW\gamma$ vertex. All final states $e\nu_e q\bar{q}, e\nu_e l\nu_l (l = e, \mu, \tau)$ have been measured by the LEP experiments [6,7,8,9]. Results were combined through a common signal definition, requiring t-channel graphs only and suitable kinematical cuts to reduce the contribution of the multiperipheral diagrams ($m_{q\overline{q'}} \geq 45\ GeV/c^2$ for $e\nu_e q\overline{q'}$, $E_l \geq 20\ GeV$ for $e\nu_e l\nu_l$ and $E_{e^+} \geq 20\ GeV$, $\mid \cos\theta_{e^+} \mid \leq 0.95$, $\mid \cos\theta_{e^-} \mid \geq 0.95$ for the $e\nu e\nu$ channel, vetoing on the e^-). Data selection required for the hadronic channel a pair of acoplanar jets (for the leptonic channel one high energy lepton) and a large missing energy. Figure 5 reports the combined result from the LEP experiments, as a function of $\sqrt{s}$. Averaging on all energies gives:

$$R_{e\nu_e W} = \frac{\sigma_{meas}}{\sigma_{WPHACT}} = 0.978 \pm 0.080$$

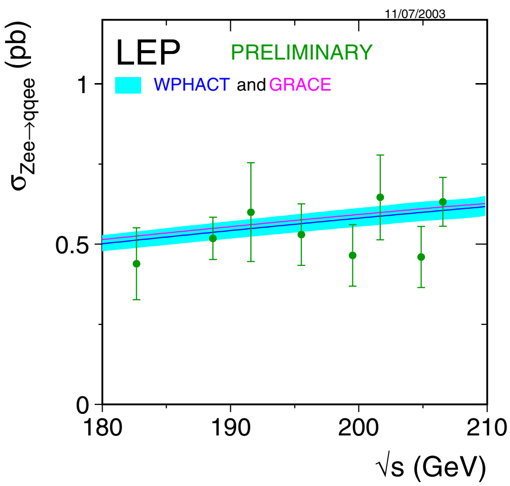

Fig. 6. Combined LEP cross-sections (ADL) as a function of $\sqrt{s}$ for the $Zee \to e^+e^-q\bar{q}$ channel

3.2 eeZ/γ^* production

The signature of such events is a low energy electron in the detector, recoiling against the Z/γ^* system, while the other electron is usually lost in the beampipe. The common LEP signal definition is based on kinematical cuts to enhance the single-Z contribution: $m_{ff'} \geq 60\ GeV/c^2$ and $cos\theta_{e^-} \geq 0.98, -0.5 \leq \cos\theta_{e^+} \leq 0.98$ and $E_{e^+} \geq 3\ GeV$ for a visible positron. Results have been obtained by ALEPH [10], DELPHI [6] and L3 [11] for $eeq\bar{q}$, $ee\mu\mu$ final states. Data selection required a jet pair (μ pair) from Z/γ^* decay, an isolated electron, missing momentum along the beamline and e^+/e^- symmetric cuts using signed variables ($Q_e \times \cos\theta_e, Q_e \times \cos\theta_{p_{miss}}$). Figure 6 reports the combined LEP result as a function of $\sqrt{s}$, updated for this conference. Averaging over all energies gives:

$$R_{Zee} = \frac{\sigma_{meas}}{\sigma_{WPHACT}} = 0.932 \pm 0.068$$

4 $\gamma\gamma \to \tau\tau$ production

The process $e^+e^- \to e^+e^-l^+l^-(l = \mu, \tau)$, via photon-photon production, is a dominant channel at LEP2 and can be used to study QED computations to order $O(\alpha^4)$. As an example, the cross section $\sigma(e^+e^- \to e^+e^-\tau^+\tau^-)$ as a function of $\sqrt{s}$ (from L3) is compared to QED calculations from DIAG36 [14] in Fig. 7. For $\gamma\gamma \to \tau\tau$ the average cross sections measured from L3 [12] ($189 \leq \sqrt{s} \leq 208$ GeV) and DELPHI [13] ($183 \leq \sqrt{s} \leq 208$ GeV) at LEP2 are 457 ± 58 pb and 428.9 ± 17.1 pb, respectively, to be compared with SM expectations of 452.3 and 447.7 pb. The process $\gamma\gamma \to \tau^+\tau^-$ can also be used to measure the anomalous magnetic moment a_τ and electric dipole moment d_τ of the τ lepton ($a_\tau = 0, d_\tau = 0$ at tree level in the SM). The measured $e^+e^- \to e^+e^-\tau^+\tau^-$ cross sections can be compared to theoretical expectations for various values of a_τ, d_τ to extract limits on the anomalous e.m. couplings of the τ lepton. The 95 % CL limits as quoted by DELPHI

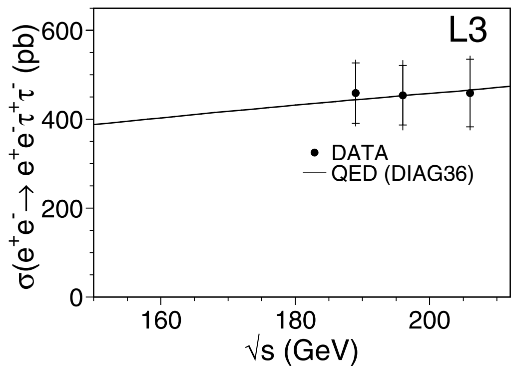

Fig. 7. The cross section $\sigma(e^+e^- \to e^+e^-\tau^+\tau^-)$ as a function of $\sqrt{s}$. The data are compared to the QED calculations of DIAG36 [14]

(L3) at this conference are:

$$-0.052 \leq a_\tau \leq 0.013 \quad (\mid a_\tau \mid \leq 0.107)$$

$$\mid d_\tau \mid \leq 3.7 \times 10^{-16}\ e \cdot cm\ (\mid d_\tau \mid \leq 1.14 \times 10^{-15}\ e \cdot cm)$$

5 Conclusions

4f physics at LEP2 has reached, for the reported cross section measurements, a final accuracy of $\sim 7\%$ matched by precise theoretical predictions (at 5% level). In many cases, it was the first measurement of processes that will be dominant at the next linear collider (LC) for precise SM physics and are a relevant background for new physics searches at LEP2.

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References

1. G. Altarelli et al.: "Physics at LEP2", CERN 96-01, 1996
2. LEP Collaborations: CERN-EP/2002-091
3. J. Fujimoto et al.: Comp. Phys. Comm. **100**, 128 (1997); E. Accomando et al.: Comp. Phys. Comm. **99**, 270 (1997); E. Accomando et al.: Comp. Phys. Comm. **150**, 166 (2003)
4. OPAL Collaboration: Phys. Lett. B **544**, 259 (2002)
5. A. Lipniacka et al.: DELPHI Collaboration: DELPHI 2003-060 CONF 680, 27 June 2003
6. H.M. Blom et al., DELPHI Collaboration: DELPHI 2003-055, CONF 675, 12 June 2003
7. ALEPH Collaboration: ALEPH 2001-017, 8 March 2001
8. OPAL Collaboration: OPAL Note PN427, March 2000
9. L3 Collaboration: Phys. Lett. B **426**, 417 (1998); L3 Collaboration: Phys. Lett. B **487**, 229 (2000)
10. ALEPH Collaboration: ALEPH 2002-029, 18 July 2002
11. L3 Collaboration: Phys. Lett. B **561**, 73 (2003)
12. L3 Collaboration: L3 Note 2815, 30 June 2003
13. I. Boyko, V. Zhuravlov, and DELPHI Collaboration: DELPHI 2003-027 CONF 647, 15 June 2003
14. F.A. Berends, P.H. Daverveldt, and R. Kleiss: Comp. Phys. Comm **40**, 285 (1986)