GAUGE BOSON SELF COUPLINGS
AND FOUR FERMION FINAL STATES
AT LEP

PAOLO AZZURRI

Scuola Normale Superiore, Piazza dei Cavalieri 7, 56100 Pisa, Italy

Abstract

Four-fermion productions measured in the LEP2 data are reviewed. The total and differential cross-section yields represent the first clear evidence for the existence of gauge boson self couplings, in support of the non-abelian SU(2)$\otimes$U(1) structure of the electroweak model, at the percent level.

1 Introduction

A striking feature of the Standard Model (SM) of electroweak interactions $\mathcal{M}$, is the presence of gauge bosons self-couplings (GC) due to
the non-abelian nature of the SU(2) group leading to three-line (TGC) and four-line (QGC) boson vertices shown in Fig. 1.

Gauge self couplings influence directly the pair-production of weak bosons, and in particular of W-bosons, so that the LEP2 represents an ideal data sample to verify their structure, through the detection of the resulting four-fermion final states.

2 W-pair and Z-pair productions

The LEP2 data sample of 700pb$^{-1}$ per experiment at $\sqrt{s}$=161-207 GeV allowed to collect about $10^4$ W-pairs and 500 Z-pairs per experiment, identifying these events in all their visible final states. The combined total cross sections, measured as a function of the centre-of-mass energy are shown in Fig. 2. The overall precision of the measured productions rates is at the level of 1% for W-pairs and 5% for Z-pairs, and in agreement with the SM predictions. As it can be seen in Fig. 2 the W-pair cross section measurement represents alone a stunning proof of the presence of both the WWZ and WW$\gamma$ couplings dictated by the electroweak SU(2)$\otimes$U(1) gauge structure.

![Graph of total W-pair and Z-pair cross-sections](image)

**Figure 2:** Total W-pair and Z-pair cross-sections measured at LEP at $\sqrt{s}$=161-207 GeV, compared to SM predictions. The two dashed curves show the predicted W-pair cross section in the absence of the WWZ and WW$\gamma$ couplings.

The LEP2 W-pair sample has also proven valuable to provide
the first direct measurement of all leptonic and hadronic W decay branching ratios, resulting in a test of the lepton family universality of charged currents at the level of 1% \( g_\mu/g_e = 1.000 \pm 0.010, g_\tau/g_e = 1.026 \pm 0.014, g_\tau/g_\mu = 1.026 \pm 0.014 \), and of the lepton-quark universality of charged currents at the level of 0.7% \( g_\mu/g_\tau = 1.010 \pm 0.007 \).

## 3 Single W and single Z productions

Four-fermion final states arising from single W and Z productions have also been measured in the LEP2 data \([2]\), and are shown in Fig. 3. Results are in agreement with SM expectations within the combined experimental precision of 7-8%.

![Figure 3: Single W and single Z cross-sections measured at LEP at \( \sqrt{s} = 161-207 \text{ GeV} \), compared to SM predictions.](image)

## 4 Constraints on Gauge Self Couplings

The structure of charged TGC vertices WWZ and WW\(\gamma\) have been studied using W-pair, single W and single \(\gamma\) events, and possible deviations from SM expectations have been searched for. The most common set of parameters to describe the two vertices is \(g_1^Z, \lambda_\gamma\) and \(\kappa_\gamma\), which
conserve both C and P, and obey the SM gauge structure. The combined LEP2 data yields $g_1^Z = 0.991 \pm 0.022$, $\lambda_\gamma = -0.016 \pm 0.022$ and $\kappa_\gamma = 0.984 \pm 0.045$, therefore in agreement with the SM expectations $\lambda_\gamma = 0$ and $\kappa_\gamma = g_1^Z = 1$ at the 2-5% level [2].

Charged QGC as WWZZ, WWZ$\gamma$ and WW$\gamma\gamma$ are predicted in the SM but are beyond the sensitivity of the LEP2 data. Larger anomalous contributions have been searched for in WW$\gamma$ and $\nu\nu\gamma\gamma$ final states, leading to limits on the new physics scale of the anomalous contributions $\Lambda > 5-10$ GeV at 95% confidence level [2].

Neutral TGC as ZZZ, ZZ$\gamma$ and Z$\gamma\gamma$ do not exist in the SM but possible contributions have been searched for in Z pair, Zee and Z$\gamma$ events. No evidence for neutral TGC has been found and parameterizing the vertices with the $h_i^V$ and $f_i^V$ ($i = 1, 4$ and $V = \gamma, Z$) couplings, limits have been set at the level $h_i^V, f_i^V < 0.05-0.20$ at 95% confidence level [2].

Neutral QGC also do not exist in the SM, but possible contributions of a ZZ$\gamma\gamma$ vertex have been searched for in the LEP2 data. Here the study of ZZ$\gamma$ and $\nu\nu\gamma\gamma$ events allows to set limits on the new physics scale of the anomalous contributions again with $\Lambda > 5-10$ GeV at 95% confidence level [2].

References

[1] S.L. Glashow, *Nucl. Phys.* 22, 579 (1961); A. Salam and J.C. Ward, *Phys. Lett.* 13, 168 (1964); S. Weinberg, *Phys. Rev. Lett.* 19, 1264 (1967); A. Salam, in *Elementary Particle Theory: Relativistic groups and Analyticity* (Nobel Symposium 8) p.367 (Stockholm,1968).

[2] LEP Collaborations ALEPH, DELPHI, L3, OPAL and Electroweak Working Group, *A Combination of Preliminary Electroweak Measurements and Constraints on the Standard Model*, hep-ex 0312023 and references therein.