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 $e^+e^- \rightarrow f\bar{f}$ EVENTS**

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DELPHI RESULTS ON THE STUDY OF HIGH ENERGY PHOTONS IN $e^+e^- \rightarrow f\bar{f}$ EVENTS

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ABSTRACT

Thanks to our deep knowledge of the photon couplings in QED, the emission of hard electromagnetic radiation in e^+e^- collisions at LEP can be assumed as a reference process when probing different sectors of the Standard Model or in the search for new physics. In the following we briefly review the DELPHI results on the analysis of radiative $e^+e^- \rightarrow f\bar{f}$ events obtained during the first three years of operation at the Z^0 peak.

processes, $e^+e^- \rightarrow \mu^+\mu^-$ events are an ideal laboratory as in this case one can safely apply constraints based on energy and momentum conservation. These constraints can be used not only to cross-check the photon energy as measured by the forward calorimeters, but also to reconstruct undetected radiation along the beam axis. The DELPHI result⁽⁸⁾, based on the analysis of 46,000 muon-pair events at Z^0 energies, is compared to DYMU3⁽⁹⁾ Monte Carlo predictions in Figure 3.

2 SEARCH FOR NEW PHYSICS

Anomalous contributions to the prompt photon yield at LEP can arise from the decay of excited fermions, from the existence of non-standard three-boson couplings ($ZZ\gamma$, $ZH\gamma$ and $H\gamma\gamma$) or from the production of new particles decaying into photons⁽¹⁰⁾. Most of these processes are expected in a large class of models, known as *composite models*, in which quarks, leptons and gauge bosons are interpreted as bound states of more elementary strongly-interacting subconstituents (*preons*). In this context weak interactions are explained as residual forces between these bound states.

A direct search for singly produced excited fermions ($Z^0 \rightarrow f^*\bar{f}$) has been made in both the hadronic⁽⁶⁾ and the leptonic⁽¹¹⁾ sample assuming the f^* to decay into its ground state through photon emission. From the absence of resonance effects in the $\gamma - lepton$ and $\gamma - jet$ invariant mass distributions lower limits of a few TeV have been obtained for the energy scale (Λ) of compositeness. If $m_{f^*} < m_Z/2$ the production of excited fermions at LEP could also take place in pairs, through the reaction $Z^0 \rightarrow f^*\bar{f}^*$. Such process is however excluded by the precise measurement of the total Z^0 width⁽¹²⁾ if standard couplings are assumed between the excited fermion and the Z^0 boson.

The possibility of anomalous three-boson couplings opens interesting prospects in the search for new physics. For instance the $Z^0 \rightarrow H\gamma$ decay, which in the Standard Model is suppressed by the absence of the corresponding tree-level coupling⁽¹³⁾, could be largely enhanced and be detectable at LEP above the large background produced by FSR. As the Higgs boson is assumed to decay prevalently into $b\bar{b}$ pairs, the hadronic events with an isolated photon have been analysed by looking for a resonance peak in the mass distribution of the jets recoiling against the photon. The mass spectrum corresponding to the events collected by DELPHI up to the end of 1991 is shown in Figure 4. From the absence of any significative peak, an upper limit on $\sigma(e^+e^- \rightarrow H\gamma)$ at the Z^0 peak has been derived, as reported in Figure 5. In the same figure the rates predicted by composite models for different values of the Λ parameter⁽¹⁴⁾ and by the Standard Model are also displayed. The present limit on the MSM Higgs mass, as obtained from DELPHI data, is $m_H \geq 54.7 GeV$ ⁽¹⁵⁾ at 95% confidence level.

The existence of a massive particle (X) decaying into photons at LEP was first investigated by the L3 Collaboration who detected a slight excess of $l^+l^-\gamma\gamma$ events with $m_{\gamma\gamma} \simeq 59 GeV$ ⁽¹⁶⁾. Although no real excess has been observed in DELPHI data, two leptonic ($l^+l^-\gamma\gamma$) and one hadronic ($q\bar{q}\gamma\gamma$)

1 PROBING THE STANDARD MODEL

In $e^+e^- \rightarrow f\bar{f}$ events the main standard sources of high energy photons are generally classified as final state radiation (FSR), initial state radiation (ISR) and secondary decays of neutral mesons (such as π^0 's or η 's).

In $Z^0 \rightarrow q\bar{q}$ decays, high energy photons radiated from the final state have shown to be unique probes in world of parton interactions and can provide a measurement of the electro-weak coupling of *up* and *down* quarks to the Z^0 ⁽¹⁾. Events with hard FSR radiation are extracted from the hadronic sample by requiring the presence of a well isolated energetic photon in the barrel region of the detector. The isolation request suppresses the huge background of non-prompt photons which populates the hadronic jets. Typical values for the minimum photon energy and isolation cone are respectively $E_{min}^\gamma = 7.5 \text{ GeV}$ and $\delta_{cone}^\gamma = 20^\circ$.

A valuable test of QCD consists in applying standard clustering algorithms (such as the JADE E0 algorithm⁽²⁾) to these radiative events and comparing the obtained jet multiplicity with exact matrix element predictions. In this way one verifies that our knowledge of the parton interactions in hadronic cascades is capable of describing at the same time electro-magnetic and gluon radiation from quarks. A comparison between DELPHI data and $O(\alpha_s)$ predictions for the process $Z^0 \rightarrow q\bar{q}(g)\gamma$ ⁽³⁾ as function of the JADE resolution parameter $YCUT = \frac{m_{ij}^2}{M_Z^2}$ is reported in Figure 1⁽⁴⁾.

As recently suggested⁽⁵⁾, the measurement of the FSR yield at LEP also provides the determination of the electro-weak coupling of quarks. The rate of final state emission in hadronic Z^0 decays ($\Gamma_{qq\gamma}$) is in fact proportional to:

$$\Gamma_{qq\gamma} \propto S_{qq\gamma} = 2c_u(q_u)^2 + 3c_d(q_d)^2,$$

where $c_i = v_i^2 + a_i^2$ and q_i are, respectively, the electro-weak coupling and the electric charge of *up* and *down* quarks. By combining this result with a measurement of the total hadronic width,

$$\Gamma_{qq} \propto S_{qq} = 2c_u + 3c_d,$$

the values $c_u = 1.65 \pm 0.43$ and $c_d = 1.13 \pm 0.29$ have been extracted⁽⁶⁾. The constraints coming from the two relations and the final result are also displayed in Figure 2.

Initial state radiation represents the emission of photons from the incoming electrons in e^+e^- collisions. Because ISR tends to be collinear with the beam direction, these photons are mostly detected in the forward part of the e.m. calorimeter and are thus experimentally distinguishable from FSR photons. As the emission of radiation from the initial state shifts the effective interaction energy to lower values, the analysis of the emitted spectrum provides a measurement of the cross-section $\sigma(e^+e^- \rightarrow f\bar{f})$ at energies below the nominal collision energy. To study such

candidates with $m_{\gamma\gamma}$ in the same mass region as the L3 events have been detected in a data sample corresponding to more than one million Z^0 decays⁽¹⁷⁾. The hadronic candidate is displayed in Figure 6. In the wait for new data, which should clarify the origin of such events, a limit of order:

$$BR(Z^0 \rightarrow X f \bar{f}) \times BR(X \rightarrow \gamma\gamma) \leq 10^{-5}$$

has been set in the mass region $m_X \simeq 59 \text{ GeV}$.

Finally, a detailed analysis of radiative $\tau^+\tau^-$ pairs from Z^0 decays⁽¹⁸⁾ has shown good agreement with Standard Model predictions. Thus the constraints (at 95% c.l.) $F_2(q^2 = 0) \leq 0.078 \tau \text{ Bohr Magnetons}$ and $F_{EDM}(q^2 = 0) \leq 4.3 \times 10^{-16} e \cdot \text{cm}$ have been set on the anomalous magnetic and electric dipole moment of the τ lepton.

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FIGURE CAPTIONS

Figure 1 : Jet multiplicity distribution as function of the resolution parameter $YCUT = \frac{m_{ij}^2}{M_Z^2}$ in hadronic events with hard final state radiation. Superimposed to the figure are the $O(\alpha_s)$ predictions for the process $Z^0 \rightarrow q\bar{q}\gamma$.

Figure 2 : Constraints on the electro-weak coupling of *up* and *down* quarks to the Z^0 obtained from the measurement of the partial decay widths $\Gamma_{qq\gamma}$ and Γ_{qq} .

Figure 3 : Reconstruction of the $e^+e^- \rightarrow \mu^+\mu^-$ line-shape at energies below the Z^0 mass as obtained from the analysis of muon-pair events with hard initial state radiation.

Figure 4 : Mass distribution of the hadrons recoiling against isolated photons. A peak in the mass distribution would be a signature of the $Z^0 \rightarrow H\gamma$ decay.

Figure 5 : Upper limits on the cross section $\sigma(e^+e^- \rightarrow S\gamma)$ at the Z^0 peak, where S is a scalar resonance decaying into hadrons. The curves show the Standard Model and Compositeness (depending on the Λ parameter) predictions for the case in which the S particle is identified with the Higgs boson.

Figure 6 : The only hadronic event with a well isolated high mass photon pair detected out of more than one million Z^0 decays. The $\gamma\gamma$ mass in this event has been estimated to be $56.8 \pm 1.7 \text{ GeV}$.

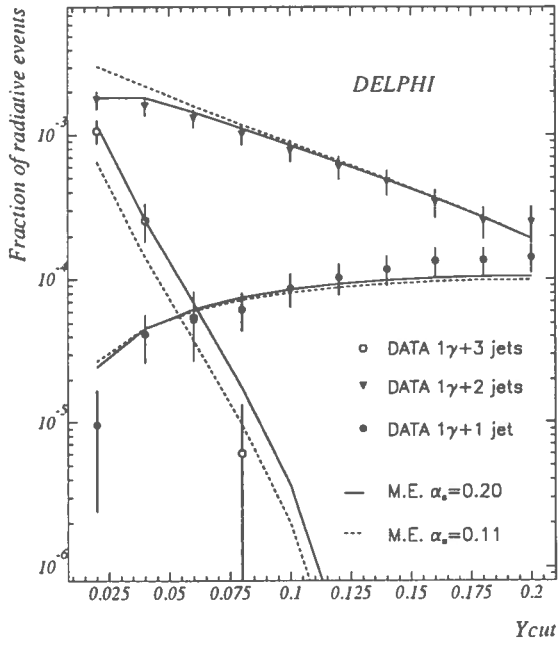


Figure 1

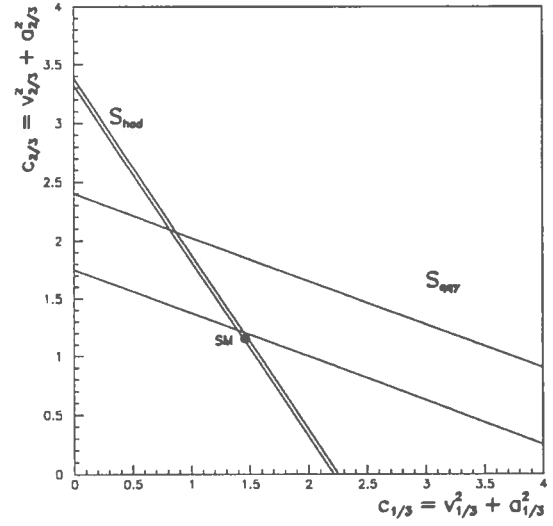


Figure 2

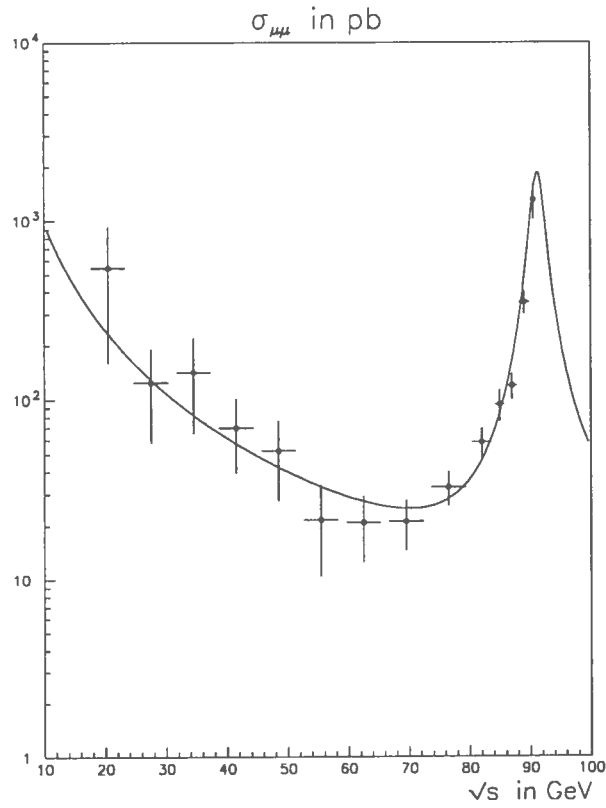


Figure 3

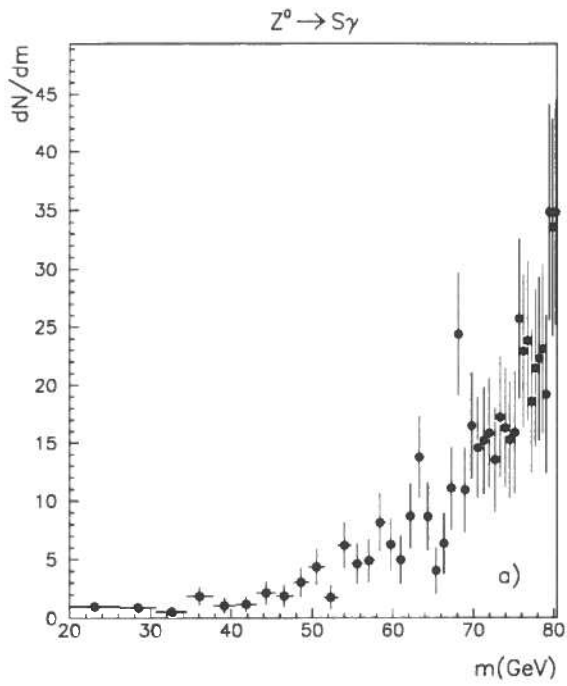


Figure 4

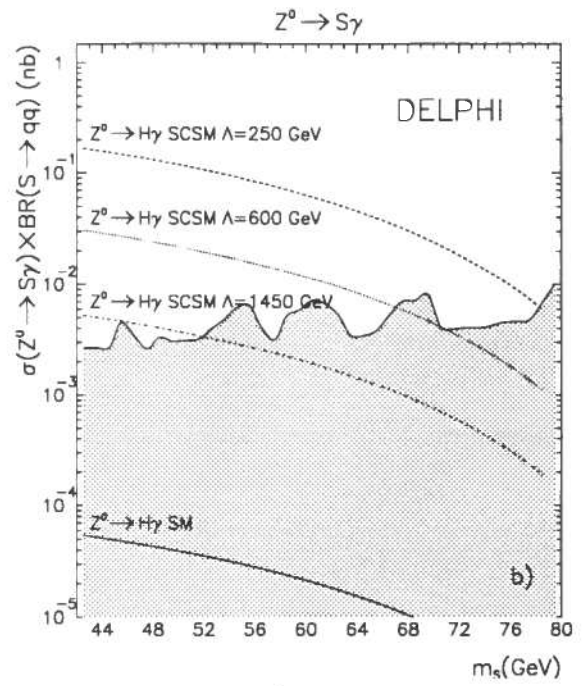


Figure 5

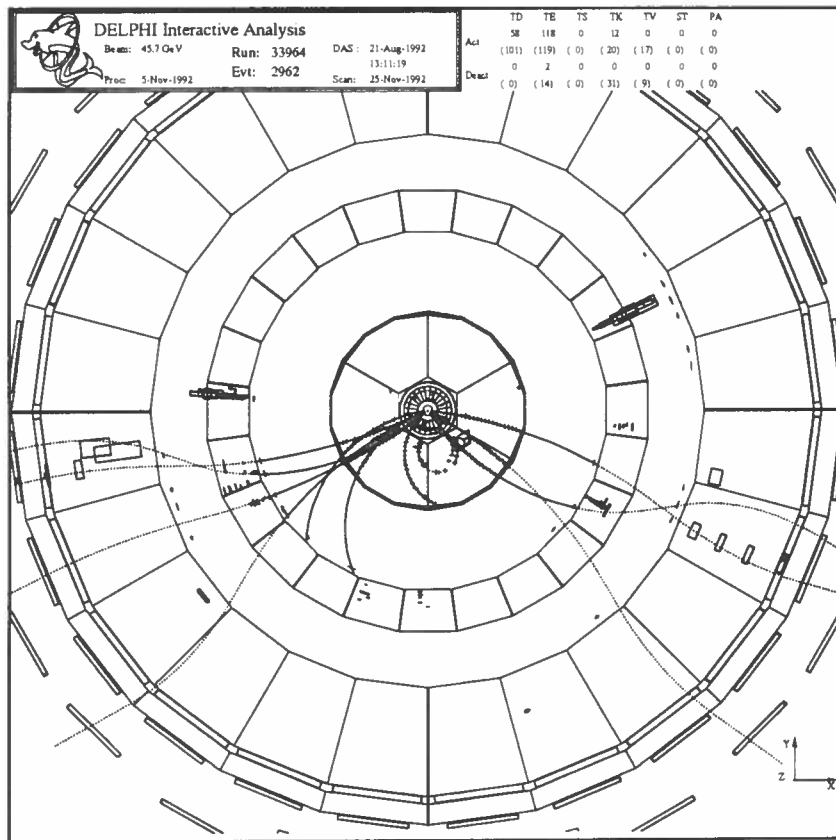


Figure 6