Search for Exotica

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Searches for *exotic processes and particles* have been performed in the data collected at LEP by the four collaborations (`Aleph,Delphi,L3 and Opal`) at centre-of-mass energies up tp 208 GeV corresponding typically to a total luminosity of ≈ 600 pb^{-1} per experiment. Good agreement is observed with the SM expectation in all channels studied.

1. Introduction

LEP has provided data samples to look for new physics beyond the Standard Model (SM) allowing investigation of a great variety of new phenomena and search for new particles.

Some of the topics covered at LEP within *exotic* searches were, flavour changing neutral currents that could be observed from single top production, possible observation of leptoquarks, gravity in extra dimensions, compositeness leading to the presence of excited fermions, and particles predicted by Technicolor models [1].

Here the last topic will be reported in detail, as the others were covered in detail at this conference not only from LEP results but also in combination with results from detectors at HERA and the Tevatron.

2. The Technicolor model

The technicolor model provides an elegant scheme to generate W/Z masses. These bosons are seen as condensates of a new family of quarks (the techniquarks) which obey a QCD-like interaction with an effective scale Λ_{TC} much larger than Λ_{QCD}. It also predicts heavy (> 1 TeV) vector mesons which cannot be observed at LEP2.

It is well known, however, that this scheme encounters several problems. It cannot correctly generate fermion masses and, in its simplest version, it contradicts the LEP1 precision measurements since it gives positive contributions to the S parameter. In technicolor models with QCD-like dynamics, $S \sim 0.45$ is expected for an isodoublet of technifermions, while the precise measurements give: $S = -0.07 \pm 0.11$ [2].

Extensions [3] have been worked out which solve these problems at the price of losing predictive power. These schemes depart from the straightforward analogy with QCD, with the usual asymptotic freedom behaviour. It turns out that perturbative calculations do not work ("walking technicolor"), and therefore the theory cannot be fully tested by precision measurements.

These extensions call for a large number N_D of technidoublets [4], and therefore for additional scalar (π_T, π'_T) and vector (ρ_T, ω_T) mesons. These can be light enough to be observed at LEP2 or the Tevatron. The searches for technicolor production assume the theoretical model given in [5].

The main ρ_T decay modes are $\rho_T \to \pi_T\pi_T$, $W_L\pi_T$, W_LW_L, $f_i\bar{f}_i$ and $\pi^0_T\gamma$, where W_L is the longitudinal component of the W boson. For $M_{\rho_T} > 2M_{\pi_T}$ the decay $\rho_T \to \pi_T\pi_T$ is dominant, while for $M_{\rho_T} < 2M_{\pi_T}$ the decay rates depend on many model parameters. In all cases the total ρ_T width for $M_{\rho_T} < 200$ GeV/c^2 is predicted to be of the order of 10 GeV if any of the channels $\rho_T \to \pi_T\pi_T$, π_TW_L, W_LW_L is open, and below 1 GeV if all of them are closed. For ω_T the main decay modes are $\omega_T \to \pi_T\pi_T\pi_T$, $\pi_T\pi_TW_L$, etc. If these decay modes are forbidden kinematically, then its dominant decay is $\omega_T \to \pi^0_T\gamma$. By analogy with QCD it is supposed that $M_{\rho_T} \simeq M_{\omega_T}$ and $M_{\pi^0_T} \simeq M_{\pi^\pm_T}$.

Following [5], technipions are assumed to decay as $\pi_T^+ \to c\bar{b}$, $c\bar{s}$ and $\tau^+\nu_\tau$; and $\pi_T^0 \to b\bar{b}$, $c\bar{c}$ and $\tau^+\tau^-$. The width $\Gamma(\pi_T \to \bar{f}'f)$ is proportional to $(m_f + m_{f'})^2$, therefore the b-quark is produced in $\sim 90\%$ of π_T decays. The total π_T width is less than 1 GeV. These properties are extensively used in the search presented here.

The ρ_T coupling to the photon and Z^0 is proportional to $Q_U - Q_D$, where Q_U and Q_D are the charges of U and D techniquarks. The value $Q_U - Q_D$ has to be one to avoid triangle anomalies. Therefore, for $M_{\rho_T} < \sqrt{s}$, it can be produced on mass shell in e^+e^- interactions through the radiative return process and its production cross-section is independent of the values chosen for Q_U and Q_D. It can then be observed as a narrow resonance in the corresponding mass distribution.

Technipions can also be produced at LEP through virtual ρ_T exchange. At LEP the off-shell processes $e^+e^- \to \rho_T^* \to (\pi_T^+\pi_T^-,\ \pi_T^+W_L^-)$ and $e^+e^- \to (\rho_T^*, \omega_T^*) \to \pi_T^0\gamma$ to search for virtual ρ_T production if $M_{\rho_T} > \sqrt{s}$ were used. The processes $e^+e^- \to \rho_T^* \to (\pi_T^+\pi_T^-,\ \pi_T^+W_L^-)$ depend on 3 quantities, namely M_{π_T}, M_{ρ_T} and N_D. Three additional parameters, namely the technicolor coupling constant α_{ρ_T}, the sum of charges of the technicolor doublet $Q_U + Q_D$, and the mass scale M_V are introduced to describe $e^+e^- \to (\rho_T^*, \omega_T^*) \to \pi_T^0\gamma$. Figure 1 shows the cross-sections of the mentioned processes for some typical parameter values proposed in [5]: $M_{\pi_T} = 90$ GeV/c^2, $M_V = 200$ GeV/c^2, $N_D = 9$, $(Q_U + Q_D) = 4/3$. It is assumed that the symmetry group, under which the technifermions transform as fundamental, is $SU(N_{TC})$ with $N_{TC} = 4$ and that $\alpha_{\rho_T} = 2.91(3/N_{TC})$.

It can be seen that the production cross-section of technicolor objects is expected to be reasonably high for a wide range of M_{ρ_T} values, making the search at LEP possible, but that the process giving the $\pi_T^0\gamma$ final state, depends strongly on the three additional parameters, and can even become zero for $(Q_U + Q_D) = 0$.

`Delphi` and `Opal` [1] collaborations have performed searches for ρ_T with $M_{\rho_T} < \sqrt{s}$ in all decay modes, for $\pi_T^+\pi_T^-$ and $\pi_T^+W_L^-$ final states, and for $\pi_T\gamma$. It is assumed that $M_{\rho_T} > 90$ GeV/c^2 and $M_{\pi_T} > 45$ GeV/c^2, supposing that the ρ_T and π_T with smaller masses would be detected in precise measurements at LEP1. The CDF experiment at the Tevatron [7] has already published results of a search for these particles.

[1] at centre-of-mass energies of ≈ 189 GeV `L3` [6] had performed a similar analysis

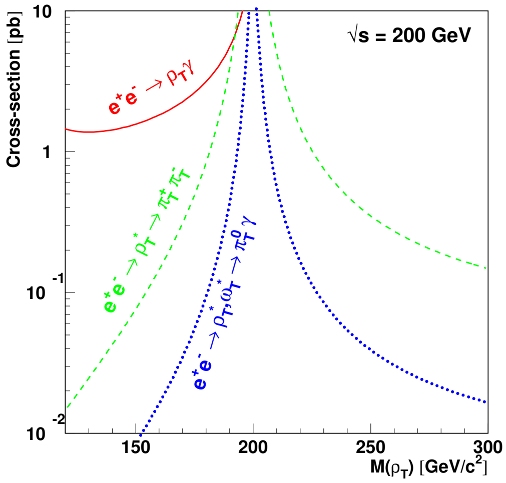

Figure 1. Technicolor production cross-sections at LEP for some typical parameter values: $M_{\pi_T} = 90$ GeV/c^2, $M_V = 200$ GeV/c^2, $N_D = 9$, $(Q_U + Q_D) = 4/3$, and $\alpha_{\rho_T} = 2.91(3/N_{TC})$ with $N_{TC} = 4$.

3. Search for π_T in $e^+e^- \to \rho_T^* \to (W_L\pi_T, \pi_T\pi_T)$

If the π_T is light enough, $W_L^+\pi_T^-$ or even $\pi_T^+\pi_T^-$ final states can be produced through the decay of ρ_T^*. These can provide striking signatures because technipions are expected [5] to decay into the heaviest fermions. Charged technipions therefore prefer final states with a b quark, which can be separated from the W bosons by applying b-tagging.

The `Delphi` analysis will be described here, while results will be presented also for `Opal` analysis.

3.1. Search in the 4-jet Final State

Events originating from the signal contain mainly one or two b-quarks and one or two c-quarks, while the background from W^+W^- contains very few b-quarks. This situation is similar to that in the Higgs search in 4 jet final states, therefore the same jet clustering algorithm using the DURHAM method [8] and the same b-tagging procedure [9] are applied. The analysis starts with the four-jet preselection described in [10], which aims at eliminating the radiative and $\gamma\gamma$ events and to reduce the QCD and $Z^0\gamma^*$ background.

The $q\bar{q}(\gamma)$ and 4-fermion backgrounds remaining after the preselection have to be reduced further. For this purpose different shape and b-tagging variables have been investigated, assuming that the analysis should be sensitive and keep a reasonable efficiency for a wide range of the π_T mass from $\sim$ 45 GeV/c^2 up to the kinematical limit.

12 variables are selected for this analysis and the final discriminant variable is defined as the output of a neural network (NN). The resulting NN output provides good background suppression and high selection efficiency over a wide range of M_{π_T}.

The mass M_{5C} of the jet pair after the 5C fit for the pairing with the smallest χ^2_{5C} is used as the π_T mass estimator. The possible contribution of $\pi_T\pi_T$ production would be seen as a narrow peak. The channel $W_L\pi_T$ would give a slightly wider peak shifted towards the mass of the W. The form of the mass spectrum of the sum of these two channels depends on the ρ_t mass and the mixing angle χ.

Figure 2 shows the expected spectrum of $W_L\pi_T$ and $\pi_T\pi_T$ production for M_{π_T}=99 GeV/c^2, M_{ρ_T}=220 GeV/c^2 and $N_D = 9$ normalised to the collected luminosity. For these model parameters the signal to background ratio for events with $M_{5C} > 96$ GeV/c^2 is about 6.

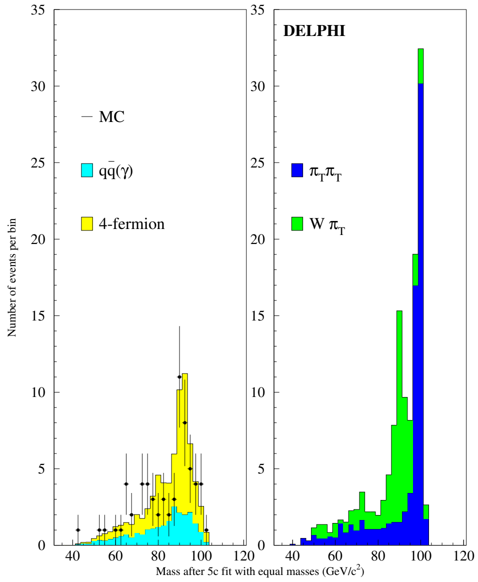

Figure 2. Delphi search in the 4-jet final state: M_{5C} mass distributions for the NN analysis with the cut on NN output > 0.30.

3.2. Search in the Semileptonic Final State

The search for the technipion is also performed in channels containing two quarks, a lepton and a neutrino, corresponding to the decays $W_L^+\pi_T^- \to l^+\nu q\bar{q}$ and $\pi_T^+\pi_T^- \to \tau\bar{\nu}q\bar{q}$. This final state is selected in two steps.

Since the topology searched for is very close to that of semileptonic W^+W^- decays, a similar selection [11] is applied at the first step. However, variables strongly correlated with the boson mass are not used, making the analysis efficient for a wide range of π_T^- masses.

An isolated lepton candidate has to be found. Depending on the flavour of the isolated lepton candidate, different neural networks are then used to reduce the background further. For tau candidates, the missing momentum and visible energy are less discriminant and are replaced by four new variables: the thrust, the angle between the lepton and hadronic system, and the acoplanarity and acollinearity of the hadronic jets. The second

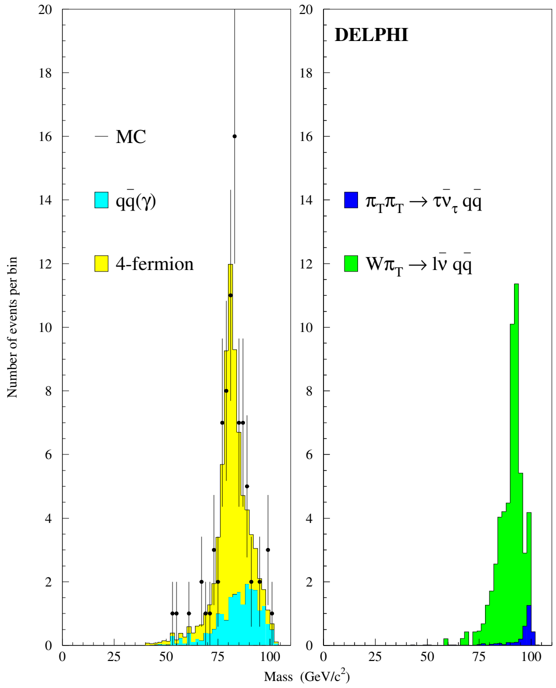

Figure 3. Delphi search in the semileptonic final state: Estimated π_T mass distributions for NN output > 0.10.

step exploits the specific properties of the signal, such as the presence of b-quarks or the production angle, to distinguish it from the W pairs. This is done using another neural network which uses four input variables: the b-tagging variables of the two hadronic jets, $q \cdot \cos\theta_{prod}$ and $|\cos\theta_{miss}|$. The charge q is defined according to that of the lepton, and the production polar angle θ_{prod} is built from the hadronic jets.

This analysis provides good background suppression and a reasonable selection efficiency of the $W_L\pi_T$ final state. The $\pi_T\pi_T$ efficiency is limited by the small $\pi_T \rightarrow \tau\bar{\nu}$ decay rate.

The M_{π_T} mass estimator is the same as in the hadronic channel. The constrained fit is done with three additional free parameters coming from undetected neutrino for electron and muon, and with four parameters for tau, since also its energy is not known. Figure 3 shows the π_T mass spectrum for events with the NN output greater than 0.1 for the full statistics collected at $\sqrt{s}$=192-208 GeV. This figure also shows the expected spectrum of $W_L\pi_T$ and $\pi_T\pi_T$ production for M_{π_T}=100 GeV/c^2, M_{ρ_T}=220 GeV/c^2 and $N_D = 9$ normalised to the collected luminosity. A good agreement between data and the SM prediction is observed.

No contribution from technicolor production is observed.

3.3. Combined result of the π_T search

Since good agreement between data and the Standard Model expectation is observed, the results are used to set limits on technicolor production, which are presented as a 95% CL exclusion region in the (M_{ρ_T}, M_{π_T}) plane.

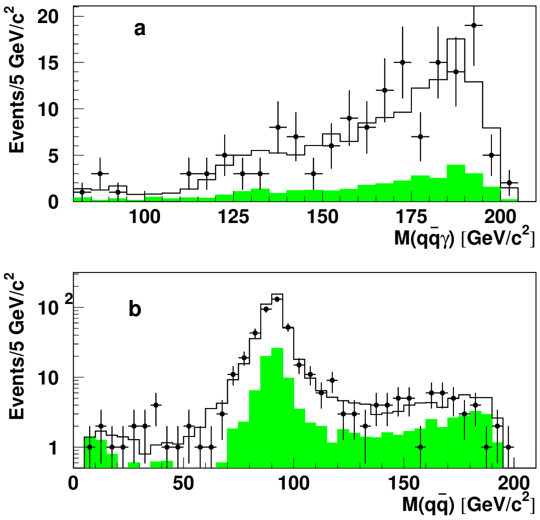

Figure 4. $\pi_T^0\gamma$ analysis: **a)** distribution of the mass of the hadronic system plus the isolated photon; **b)** distribution of the hadronic mass.

The observed and expected limits quoted are based on the confidence level for signal, CL_s, as described in [13]. The test statistic used is a likelihood ratio, based on comparing the observed and expected rates and distributions as a function of mass and NN output. The statistical and systematic errors on the expected background and signal distributions are taken into account.

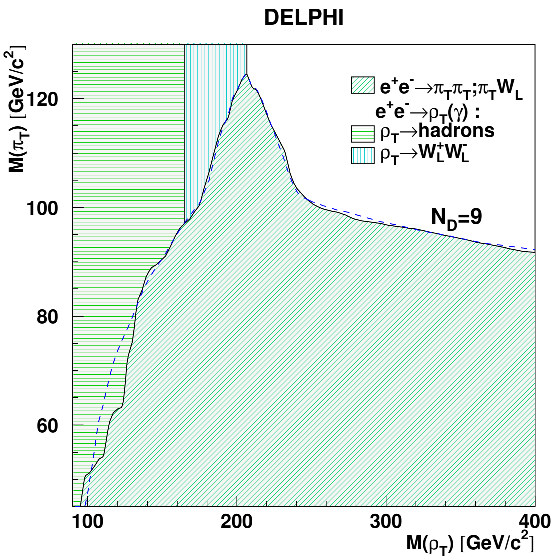

Figure 5. The region in the $(M_{\rho_T} - M_{\pi_T})$ plane (filled area) excluded at 95% CL for $N_D = 9$ (theoretically preferred W_L - π_T mixing). The dashed line shows the expected limit for the $e^+e^- \to \pi_T\pi_T, \pi_T W_L$ search.

Two cases are considered separately, $N_D = 2$ (maximal mixing), and $N_D = 9$ (theoretically preferred [5]), see Fig. 5. The regions excluded by this analysis are shown by the diagonal hatching.

In the limit of infinite ρ_T mass and assuming a point-like coupling of the gauge bosons to $\pi_T^+\pi_T^-$, the DELPHI data set 95% CL lower limits on the charged technipion mass of $M_{\pi_T} = 79.8$ GeV/c^2 (81.1 GeV/c^2 expected) for $N_D = 2$, and $M_{\pi_T} = 89.1$ GeV/c^2 (88.1 GeV/c^2 expected) for $N_D = 9$.

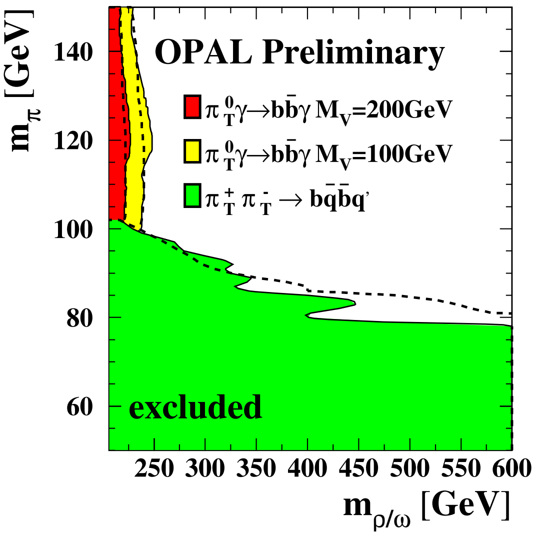

Figure 6. The 95% CL excluded region in the $(m_{\rho_T/\omega_T}, m_{\pi_T})$ plane from the combination of the $\pi_T\pi_T \to b\bar{q}\bar{b}q'$ search and the $\pi_T^0\gamma \to b\bar{b}\gamma$ search.

Search for $\boldsymbol{\rho_T}$ with $\boldsymbol{M_{\rho_T} < \sqrt{s}}$ was also performed. A $\boldsymbol{\rho_T}$ with mass below $\boldsymbol{\sqrt{s}}$ can be produced on mass shell in the radiative return process $\boldsymbol{e^+e^- \to \rho_T(\gamma)}$ with subsequent decay into different final states. It is based on a special search for the $\boldsymbol{\pi_T\gamma}$ channel and on previous DELPHI measurements [11,12] of the $\boldsymbol{WW}$ and $\boldsymbol{q\bar{q}}$ production cross-sections. The decay $\boldsymbol{\rho_T \to \pi_T^0\gamma}$ is more favourable kinematically than charged $\boldsymbol{\pi_T}$ pair production and the dominant decay of $\boldsymbol{\pi_T^0}$ into $\boldsymbol{b\bar{b}}$ (∼90 %) allows a clean experimental signature. The result of this search is shown in Fig. 4.

Similar results were obtained by `Opal` [**14**] using the data collected in the year 2000 at $\boldsymbol{\sqrt{s} \approx 200 - 209\ GeV}$ in the processes $\boldsymbol{e^+e^- \to}$

$\rho_T^0/\omega_T^0 \rightarrow \pi_T\pi_T \rightarrow b\bar{q}\bar{b}q'$ and $e^+e^- \rightarrow \rho_T^0/\omega_T^0 \rightarrow \pi_T^0\gamma \rightarrow b\bar{b}\gamma$. No excess over the expectation from Standard Model processes was observed, and upper limits for the production cross-sections as a function of the technipion mass were derived.

4. Conclusions

A good agreement between data and the Standard Model expectation is observed in all channels studied.

The combined region in the (M_{ρ_T}, M_{π_T}) plane excluded by the `Delphi` analysis at a 95% CL is shown in Fig. 5. A 95% CL lower mass limit of 79.8 GeV/c^2 is set independently of other parameters of the technicolor model, supposing its point-like coupling with gauge bosons (see section 3.3). The ρ_T production is excluded at 95% CL for $90 < M_{\rho_T} < 206.7$ GeV/c^2 independently of the π_T mass and all other model parameters.

These results significantly improve on the exclusion limits on technicolor production obtained by the CDF experiment [7].

An absolute lower limit was set by the `Opal` [**14**] analysis on the π_T mass to 62 **GeV**at 95 % CL, independently of other parameters in the Technicolor Straw Man Model.

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