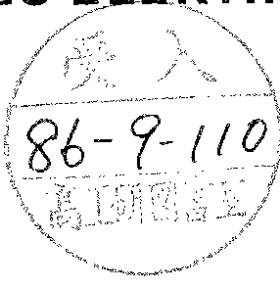


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SEARCH FOR LIGHT LEPTOQUARK BOSONS

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CELLO Collaboration

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Hamburg, August 12, 1986

Search for light leptoquark bosons

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Search for light leptoquark bosons

CELLO Collaboration

Abstract

A search for light leptoquarks decaying into a lepton and a quark has been performed using the CELLO detector at the storage ring PETRA. We have looked for decay modes where the lepton is either a muon or a neutrino, the latter being detected by a high missing transverse momentum. Except for one event previously reported no further jet events with two isolated muons were observed. No evidence for pair production of these particles has been found in other final states configurations. Our results are interpreted within a model where leptoquarks appear as a coloured Goldstone multiplet of charge 2/3. We set a 95% C.L. upper limit of 0.30 pb on the pair production cross section of such leptoquarks, thus excluding masses between 7 and 20.5 GeV.

An unusual two jet event with two isolated muons previously reported by our collaboration^{1/1} was rather difficult to understand in terms of conventional electroweak processes. Some models^{2/2} accounting for this event and similar ones observed in $\bar{p}p$ collisions^{3/3, 4/4} suggest the production of a pair of leptoquark bosons^{3/3, 4/4} which decay subsequently into a muon and a jet. Leptoquarks with spin 0 and fractional charge occur naturally in some technicolour schemes^{5/5} or in composite models as bound states of preons^{6/6}, but their masses cannot be reliably estimated.

Pair production of low mass spinless leptoquarks X of charge Q can be detected in e^+e^- collisions through electromagnetic interactions. The cross section for the process $e^+e^- \rightarrow X\bar{X}$ can be written as

$$\frac{d\sigma}{d\cos\theta} (e^+e^- \rightarrow X\bar{X}) = \frac{3\pi\alpha^2 \cdot Q^2}{4s} \cdot \beta^3 \cdot \sin^2\theta$$

where θ is the polar angle of the leptoquark momentum p with respect to the electron beam direction, \sqrt{s} denotes the centre of mass energy and $\beta = 2p/\sqrt{s}$. Due to the β^3 factor, the cross section is slowly rising above the production threshold, which makes it difficult to detect the contribution of leptoquark production to the total hadronic cross section. Therefore we have looked for leptoquark signals via decay modes $X \rightarrow \ell q$, where the lepton (ℓ) can be either a muon or a neutrino, the latter being detected by a high missing transverse momentum $p_{T, \text{miss}}$. This leads to the following event signatures:

- + $\mu^- + \text{hadrons}$ (2a)
- + $\mu^- + \text{hadrons} + p_{T, \text{miss}}$ (2b)
- + $\mu^- + \text{hadrons} + p_{T, \text{miss}} + \tau$ (2c)

We did not search for decays into electrons since a large background is expected from deep inelastic e^+e^- scattering, i.e. high Q^2 photon-photon interactions. The decays into τ leptons are difficult to detect.

Our results are interpreted within a specific model of B-Schrempp and F. Schrempp^{4/4} where three leptoquarks, one per generation family, appear as coloured pseudo-Goldstone boson multiplets of charge 2/3. In our

analysis we consider the leptoquarks of the second family decaying either into $s\bar{q}$ or $c\bar{q}$, i.e. $\text{Br}(X \rightarrow s\bar{q}) + \text{Br}(X \rightarrow c\bar{q}) = 1$.

The search for the leptoquark X was performed with the CELLO detector at the storage ring PEPII. The analysis is based on a total integrated luminosity of 47.8 pb^{-1} of data collected at $\sqrt{s} = 43.0$ GeV. Most of the data were taken at fixed $C.M.$ energies of 44.2 GeV, 43.6 GeV and 38.2 GeV with luminosities of 8.9 pb^{-1} , 16.7 pb^{-1} and 8.7 pb^{-1} respectively. The remaining data were taken at energies equally distributed between 40 and 46. GeV.

The CELLO detector has been described elsewhere^{7/7}. Here we briefly mention the main elements important for this analysis. The central tracking detector, consisting of interleaved drift and proportional chambers, measures charged particle momenta in the range of polar angles $|\cos\theta| \leq 0.91$. In the forward and backward directions the tracking is complemented by two pairs of end cap proportional chambers perpendicular to the beam direction. The barrel liquid argon calorimeter covers the range of $|\cos\theta| \leq 0.86$ and consists of lead strips in three orientations. The energy deposition is sampled in 7 layers up to a maximum depth of 20 radiation lengths at 90° providing an energy resolution of electromagnetic showers of $\Delta(E)/E = 5\% + 10\%/\sqrt{E}$. In addition the end cap liquid argon calorimeter detects showers with $0.925 \leq \cos\theta \leq 0.99$. The acceptance gap between the barrel and the end cap calorimeter is closed by a segmented two layer lead scintillator (hole tagger). Muons are detected by a system of large wire chambers covering 92% of the solid angle placed behind an iron hadron absorber 80cm thick.

The trigger relevant for this search required at least 2 GeV energy deposited in the central calorimeter and at least one charged particle with a transverse momentum greater than 650 MeV.

After processing all the events through the standard CELLO reconstruction programs, multihadronic events were selected by requiring at least 5 charged tracks with transverse momenta $p_{T, \text{ch}}$ larger than 120 MeV/c coming from the point and a total visible energy of the charged particles larger than 0.15 \sqrt{s} .

A total of 11647 events were selected in this way. Additional criteria were imposed to reduce background from several sources such as annihilation into $q\bar{q}$ (g), two gamma mediated processes, pair production of τ leptons and inelastic Compton scattering. To determine the number of background events and to estimate the acceptances of the leptoquark pair production, a Monte Carlo simulation of various processes^{8/8} our detector was carried out. The Lund string fragmentation scheme^{9/9} was used to generate^{9/9} the hadrons. Initial state photon radiation has been taken into account.

In the events corresponding to topologies (2a) and (2b), muon candidates are identified according to the following criteria:

- (1) A charged particle of momentum ≥ 4 GeV detected in the central

38% to 3.9% for leptoquark masses ranging from 20 GeV to 4 GeV. The 95% C.L. limit on the $Br(X \rightarrow \mu^+ s)$ for this topology is plotted in Fig.1.

The signature of events (2c) is a high missing momentum carried away by neutrinos. The event selection can be performed by looking either for acoplanar jets or for isolated missing momentum. The latter possibility was included in our selection criteria:

- (a) Total energy in the barrel calorimeter $E_{cal} \geq 0.07\sqrt{s}$.
- (b) Missing energy $\geq 0.45\sqrt{s}$.
- (c) Transverse missing momentum $\geq 0.18\sqrt{s}$.
- (d) Only those events with missing momentum and sphericity axis pointing in the barrel region were taken into account, i.e.
 - $|\cos\theta_{miss}| \leq 0.8$, $|\cos\theta_{sph}| \leq 0.8$.
- (e) Opening angle between p_{miss} and the transverse momentum of any charged particle or nonlinked shower greater than 30° .

Cuts (b) and (c) efficiently reduce the background from τ pair production, from inelastic Compton scattering and from annihilations into $q\bar{q}$ (g). Cut (c) rejects events from $\tau\tau$ interactions, cut (d) removes radiative events and cut (e) rejects events from τ pair production and from annihilation into $q\bar{q}$.

Events satisfying the above cuts were scanned and beam gas and beam pipe interactions were removed. Of the remaining 4 events, two have jet-jet topology with several unreconstructed tracks in the direction of the missing momentum and cannot be considered as candidates for the signature (2c). The last one is monojet like and most likely arises from $q\bar{q}$ production with hard initial state radiation with the hard photon escaping in the gap between two stacks. We expect a total of 0.5 events of this type.

Before estimating the number of background events we checked our simulation programs by comparing a subsample of multihadronic events with Monte Carlo events simulating the annihilation into $q\bar{q}$ (g). For this purpose we applied loose cuts on x_{VIS} (≥ 0.23) and on the number of charged tracks (≥ 6) in order to reject events from two photon scattering. No further special cleaning of data was made. The distributions of x_{VIS} and the total transverse momentum of charged tracks are shown in Fig.2 a,b. The agreement is reasonable in spite of a slight excess of simulated data at $x_{VIS} \approx 0.5$. The simulation of showers in the calorimeter was verified by comparing the ratios of E^0/E^{\pm} , where E^0 is the total energy of neutral showers linked to the charged tracks and E^{\pm} is the sum of the energies of the corresponding charged tracks (Fig.2c).

The detection efficiency for topology (2c) decreases from 35% to 2% for the leptoquark masses in the range from 20 GeV to 8 GeV. From the observed candidate we calculate a conservative 95% C.L. limit of 4.7 events and deduce from this the limits on the mass and the branching ratio as shown in Fig.1.

tracking detector.

- (2) The transverse energy deposited by this track in the barrel calorimeter ≤ 0.6 GeV.
- (3) At least one reconstructed hit in a muon chamber, which has to match the position of the track extrapolated through the iron filter.

Moreover at least one muon candidate has to be isolated, i.e. the angle between its transverse momentum and that of any other charged particle had to be greater than 30° .

For the final states (2b) and (2c) the missing momentum has to be determined. Besides the momenta of the charged particles, the showers in the barrel and end calorimeter are taken into account if they are not linked to any charged track and had energies above 400 MeV. Since the hole tagger has a poor resolution it is used only as a veto to eliminate events with photons emitted into the corresponding angular range.

In the following we discuss the event selection criteria for the different topologies.

To select events with signature (2a) we require that two muons be detected. Furthermore, the invariant mass of all charged particles except the muons has to be larger than 5 GeV. This cut rejects events from α electromagnetic processes $e^- e^+ \rightarrow q\bar{q} \mu^+ \mu^-$

One event already observed in the CELLO detector^{1/1} passes our cuts. From the values of the invariant masses of the combinations muon-jet we deduce that the lowest mass which can be attributed to the leptoquarks is 14 GeV. A detailed study of background sources which could account for this event can be found in ref. 1/1. For our total luminosity of 47.8 pb^{-1} the numbers of predicted events from the reactions $e^- e^+ \rightarrow q\bar{q}$ (g) and $e^- e^+ \rightarrow \mu^+ \mu^- q\bar{q}$ were found to be less than 9.5×10^{-3} and 2.3×10^{-3} . These estimates correspond to invariant masses, scaled to s, larger than or equal to those observed in this particular event.

The acceptance for $X\bar{X}$ production varies from 35% to 4.3% for leptoquark masses between 20 GeV and 4 GeV. With one observed event we obtain a 95% C.L. limit on the branching ratios $X \rightarrow \mu^+ s$ as a function of the X mass (see Fig.1).

Events of topology (2b) are selected by requiring only one muon to be identified. The following cuts are applied:

- (i) Transverse missing momentum larger than $0.07\sqrt{s}$.
- (ii) Polar angle of the missing momentum within the acceptance of the central detector, i.e. $|\cos\theta_{miss}| \leq 0.87$.
- (iii) Opening angle between the muon momentum and the missing momentum larger than 30° .

Cut (ii) eliminates radiative events, while cut (iii) eliminates events from τ pair production. No event has been found and none is expected from background sources. The detection efficiency varies from

To conclude, we have searched for evidence of pair production of scalar leptons of the Goldstone boson type in e^+e^- annihilations between C.M. energies of 38.3 GeV and 46.8 GeV. Except for the CELLO event previously reported we have not found any other multihadronic event with isolated muons in spite of a tenfold increase of the integrated luminosity. No event with one muon and missing energy was observed. One candidate for the pair production of leptons decaying both into $(\nu\bar{\nu})$ pairs is compatible with the number of background events. The total of two candidates put an 95% C.L. limit on the XX production cross section of 0.30 pb. Combining the 95% C.L. limits on the cross sections for the three topologies we the X mass region from 7 to 20.5 GeV for any value of the branching ratio of $X \rightarrow \mu\bar{\mu}$.

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Figure captions

Fig. 1. 95% C.L. limit contours for the leptons masses as a function of the branching ratio $X \rightarrow \mu\bar{\mu}$ for the signatures $\mu^+\mu^-$ + hadrons (full line), $\mu^+\mu^-$ + hadrons + p_{miss} (dotted line) and hadrons + p_{miss} (dashed-dotted line).

Fig. 2. A comparison of Monte Carlo and data for the distributions of the total transverse momentum of charge tracks (a) and of the total normalized charged energy (b). The ratio of the sum of energies of linked showers E_{μ}^0 to the sum of energies of the corresponding tracks E^+ vs the energy E^+ (c).

- hadrons + p_{miss}
- $\mu^+\mu^-$ + hadrons
- - - μ^+ + hadrons + p_{miss}

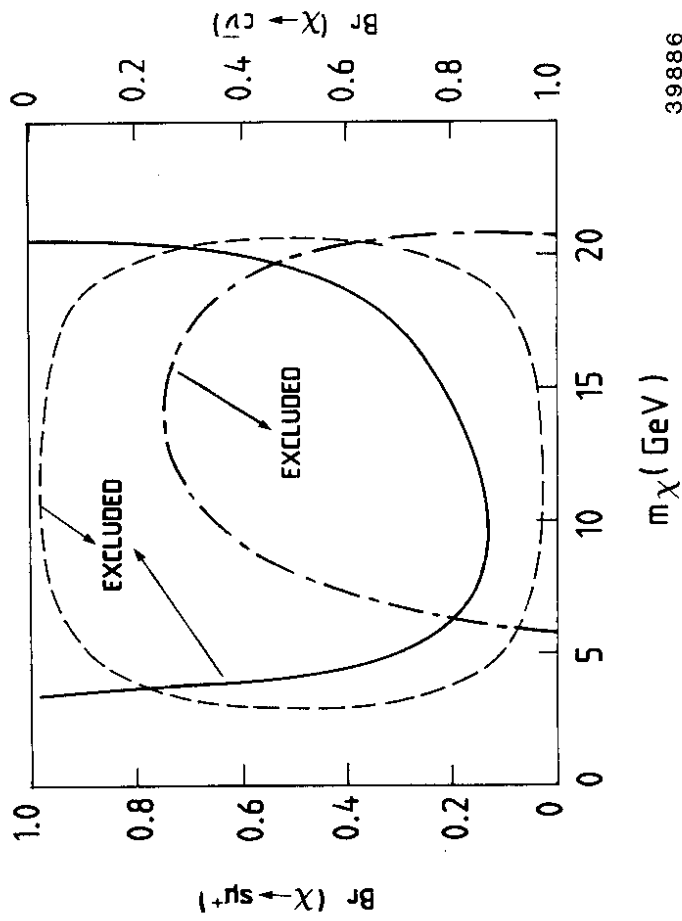


Fig. 1

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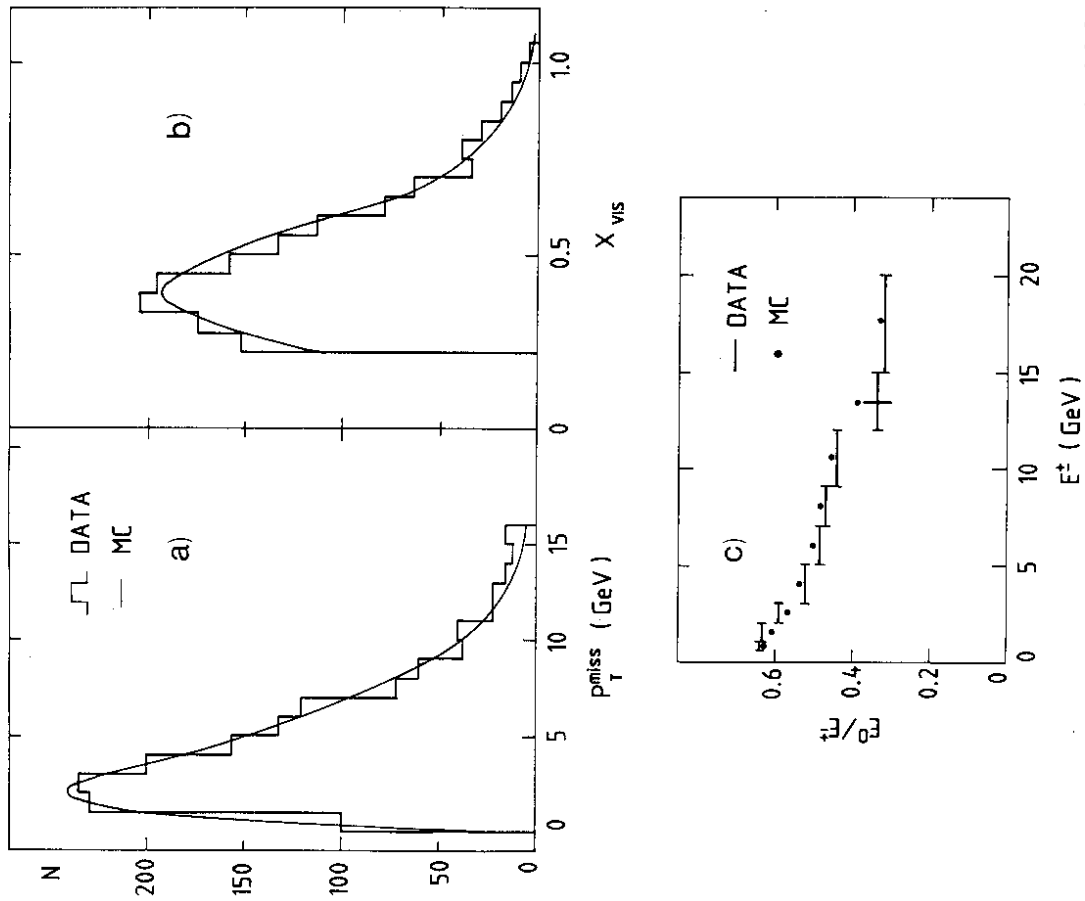


Fig. 2

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