Search for $ZX \rightarrow \nu\bar{\nu}b\bar{b}$ Events in the DØ Detector

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Abstract

We report on a search for a new particle, X, decaying via $X \rightarrow b\bar{b}$, made through associated production with a Z boson. We use data collected with the DØ detector operating at the Fermilab Tevatron $p\bar{p}$ collider with $\sqrt{s} = 1.8$ TeV. We utilize muon-tagged jets to identify b-quarks and the $\nu\bar{\nu}$ channel to detect Z bosons. Preliminary results on cross section limits for X masses between 90 GeV/c^2 and 180 GeV/c^2 are presented.

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We have searched for the production of a new particle, X, in association with a Z boson using the signatures $Z \rightarrow \nu\bar{\nu}$ and $X \rightarrow b\bar{b}$. The b-quarks are identified through their decays to muons while missing energy in the detector indicates the presence of neutrinos. The final state particles, $\nu\bar{\nu}b\bar{b}$, are identical to that in our charge 1/3 third generation leptoquark search. We use the same data samples and event selection for the ZX search reported here [1]. This paper gives preliminary limits on production cross section times β, the branching ratio for $X \rightarrow b\bar{b}$, for masses of X (M_X) between 90 GeV/c^2 and 180 GeV/c^2.

The data used for this search was collected by the DØ detector operating at the Fermilab Tevatron during the 1993-1996 period with $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV. The DØ detector, described in detail elsewhere [2], is composed of three major systems: an inner detector for tracking charged particles, a uranium-liquid argon calorimeter for measuring electromagnetic and hadronic showers, and a muon spectrometer. The calorimeter has 0.1 segmentation in both pseudorapidity η and azimuth ϕ and measures the energy of jets with a resolution of approximately $\sigma/E = 0.8/\sqrt{E}$ (E in GeV) [3]. The muon spectrometer consists of three layers of proportional drift tubes with a magnetized iron toroid between the first two layers. This provides a measurement of muon momentum with a resolution of $\delta p/p = [(\frac{0.18(p-2)}{p})^2 + (0.003p)^2]^{1/2}$ (p in GeV/c). The total thickness of the calorimeter plus the toroid varies from 13 to 15 interaction lengths and reduces the hadron punchthrough to a negligible level. The presence of neutrinos in the final state is inferred from missing transverse energy ($\not\!\!E_T$). This is defined as the negative of the vector sum of the calorimeter cell transverse energies and the p_T of detected muons.

Candidate ZX events were collected using three triggers, each requiring at least one muon in the trigger [4]. A dimuon sample required two muons at both hardware and software trigger levels, with $p_T > 3.5$ GeV/c. The second trigger required a muon with $p_T > 1.0$ GeV/c and a calorimeter hardware-only jet trigger with an E_T threshold of 10 GeV. The third trigger required a muon with $p_T > 15$ GeV/c and a jet with $E_T > 15$ GeV. Integrated luminosities of 60.1 pb^{-1}, 19.5 pb^{-1}, and 92.4 pb^{-1} respectively were collected with these three triggers.

B-quark decay is indicated by the presence of a muon associated with a jet. The offline analysis required muon tracks in the pseudorapidity range $|\eta_\mu| < 1.0$ and $p_T > 3.5$ GeV/c. Muon trajectories are required to be consistent with the reconstructed vertex position and have at least 1 GeV energy deposition in the calorimeter. For events with either single muon trigger, the muon is required to have hits in all three layers of the muon detector, a matching track in the central detector, and a good fit when these elements are combined. At least one of the muons in dimuon trigger events must satisfy these additional requirements. Jets are reconstructed using a cone algorithm with $R = 0.7$ where $R = \sqrt{(d\phi)^2 + (d\eta)^2}$ about the jet's direction. Each jet was required to statisfy the following quality criteria: (1) 0.05 < electromagnetic fraction of the jet $E_T < 0.90$, (2) the ratio of the highest cell energy to the next highest < 10, and (3) the fraction of E_T deposited in the outermost calorimeter layer < 0.4. To reduce multi-jet QCD and top backgrounds, events with 6 or more jets ($E_T > 10$ GeV) are rejected. For the dimuon trigger, we require the dimuon invariant mass be greater than 8 GeV/c^2 thereby rejecting low mass resonances, and that both muons have a unique jet with ΔR($\mu -$ jet) < 0.5 and $E_T > 10$ GeV. The remaining events are dominated by $b\bar{b}$ decays [5]. Single muon triggers require a jet be associated with the muon using the same ΔR and and E_T requirements. Single muon events must have an additional jet, with $E_T > 25$ GeV and $|\eta| < 1.5$. Events with only a single muon-tagged jet have contributions from W+jet events where $W \to \mu\nu$ [6]. Due to the neutrino, W decays have significant $\not\!\!E_T$, and therefore can contribute to our signal. To reduce the W acceptance, we use two variables to improve the b-quark identification.

We define $Z_\mu = p_{T\mu}/H_T$ with H_T being the scalar sum of the E_T of the jets and muons in the event. Z_μ will be large if the muon energy dominates the event. A requirement that $Z_\mu < 0.20$ removes about 90% of the $W \to \mu\nu$ events with a signal efficiency of about 82%. We also use the pattern of energy deposition around the muon to reduce the W contribution. We define $E_{46} = E(R_\mu \leq 0.4)/E(R_\mu \leq 0.6)$ as the ratio of energy in a R-cone of 0.4 about the muon's direction to that in a R-cone of 0.6. B-decays will have the majority of their hadronic energy well-associated with the muon. A requirement that $E_{46} > 0.80$ removes about 84% of the $W \to \mu\nu$ events with a signal efficiency of about 80%.

The high-p_T muon trigger channel has a significant contribution from $t\bar{t}$ events. The scalar sum of jet E_T, H_T, was used to identify the top quark [8]. In this analysis, we use H_T, including muon energies, to reduce the top contribution. We require $H_T < 240$ GeV for those events satisfying the high-p_T muon trigger; this removes about one-third of $t\bar{t}$ events with an efficiency of about 93% for signal channels.

We use the missing energy in the event to identify neutrinos. Fig. 1 gives the $\not\!\!E_T$ distributions with $M_X = 90$ GeV/c^2; it is essentially the p_T of the Z. To aid in eliminating events where the $\not\!\!E_T$ is mismeasured, we reject events where the azimuthal angular separation between the missing energy direction and the nearest jet, $d\phi$, is less than 0.7. We also reject events where the vector sum of the jet and muon transverse energies is consistent with zero; these events were found to have significant contributions to the missing energy from the part of calorimeter near the main ring of the accelerator, and from individual calorimeter cells. The resulting $\not\!\!E_T$ distribution combining all three trigger channels is given in Fig. 2. A requirement that $\not\!\!E_T > 35$ GeV leaves 2 events.

We have considered background contributions from $t\bar{t}$ production, W and Z bosons, and QCD-produced $b\bar{b}$ and $c\bar{c}$ events. Top events have multiple b-quarks and $\not\!\!E_T$, but with extra, energetic jets. We use Monte Carlo, and a production cross section of 5.5 ± 1.8 pb [9], to estimate that $t\bar{t}$ contributes 1.5 ± 0.5 events to our sample. W and Z events produce $\not\!\!E_T$ through the decays $W \to l\nu$ and $Z \to \nu\nu$. Also, either a prompt muon has to overlap a jet or a jet itself needs to fragment into a muon usually by a c-quark or a π/K decay. We again use Monte Carlo to calculate their contributions, with production cross sections of 21.2 ± 1.3 nb and 6.5 ± 0.5 nb [10] yielding 1.0 ± 0.5 W events and 0.1 ± 0.1 Z events in our sample. QCD-produced $b\bar{b}$ and $c\bar{c}$ events do not have energetic neutrinos and are effectively eliminated by the $\not\!\!E_T$ and $d\phi$ cuts. Estimates of their contribution using data and Monte Carlo are imprecise but consistent with 0, and we use a value of 0 from this source in our limit calculation as it gives the most conservative results. Our total background estimate is therefore 2.6 ± 0.7 events.

We calculate the acceptances for ZX events by assuming that the X particle has identical properties to the Higgs boson. The use of a central muon to tag b-decays limits the acceptance to values under 3%. We combine the three trigger channels to set limits. Errors on the acceptance include contributions from trigger and reconstruction efficiency, effects of muon momentum resolution and jet energy scale, our understanding of the E_{46} cut, and

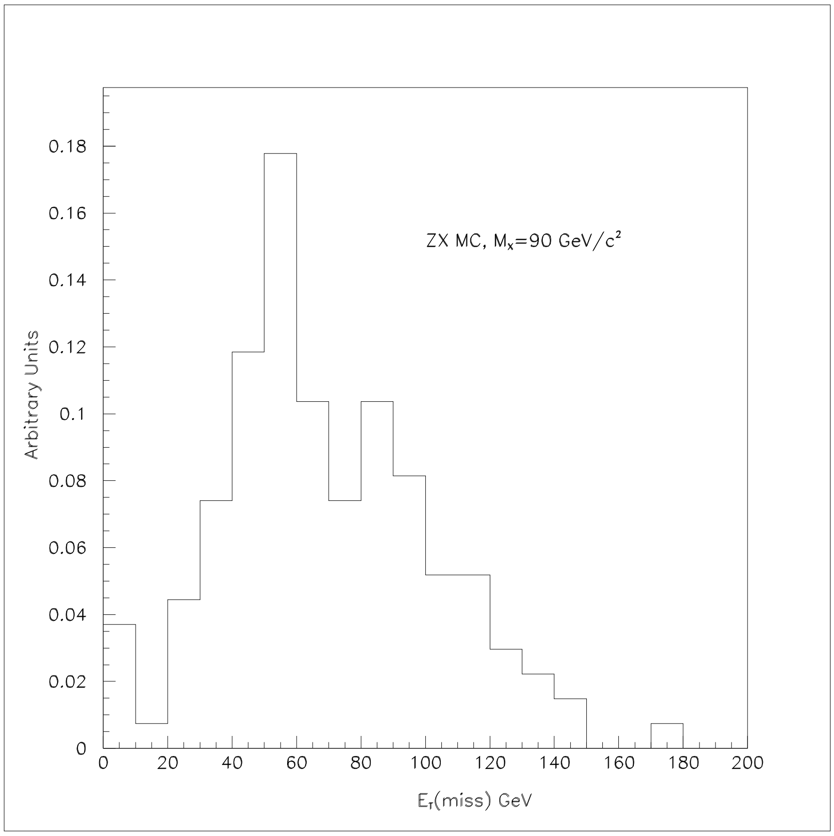

FIG. 1. The distributions of $\not\!\!E_T$ for ZX events with $M_X = 90$ GeV/c^2.

Monte Carlo statistics. The three trigger channels have different systematic errors since their selection criteria and average muon p_T differ, but most errors are correlated. The total systematic error on the combined acceptance for the preliminary results reported here is about 14%. We anticipate this being lowered to about 10% in the near future.

The 95% confidence level (C.L.) limits on the production cross section are obtained using a Bayesian approach [11] and include the systematic uncertainties on the acceptance and a 5.3% uncertainty on the integrated luminosity. Preliminary limits on the cross section times β, the branching ratio for $X \to b\bar{b}$, as a function of M_X are shown in Fig. 3. Limits range from 84 pb for $M_X = 90$ GeV/c^2 to 37 pb for $M_X = 180$ GeV/c^2.

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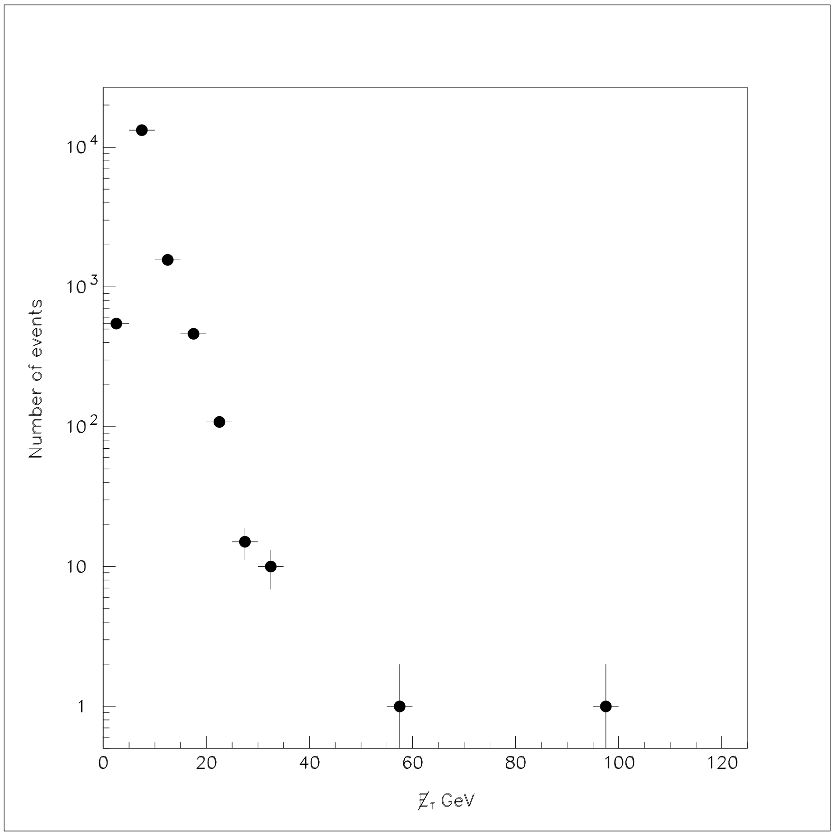

FIG. 2. The distribution of $\not{E}_T$ for data events after all other requirements.

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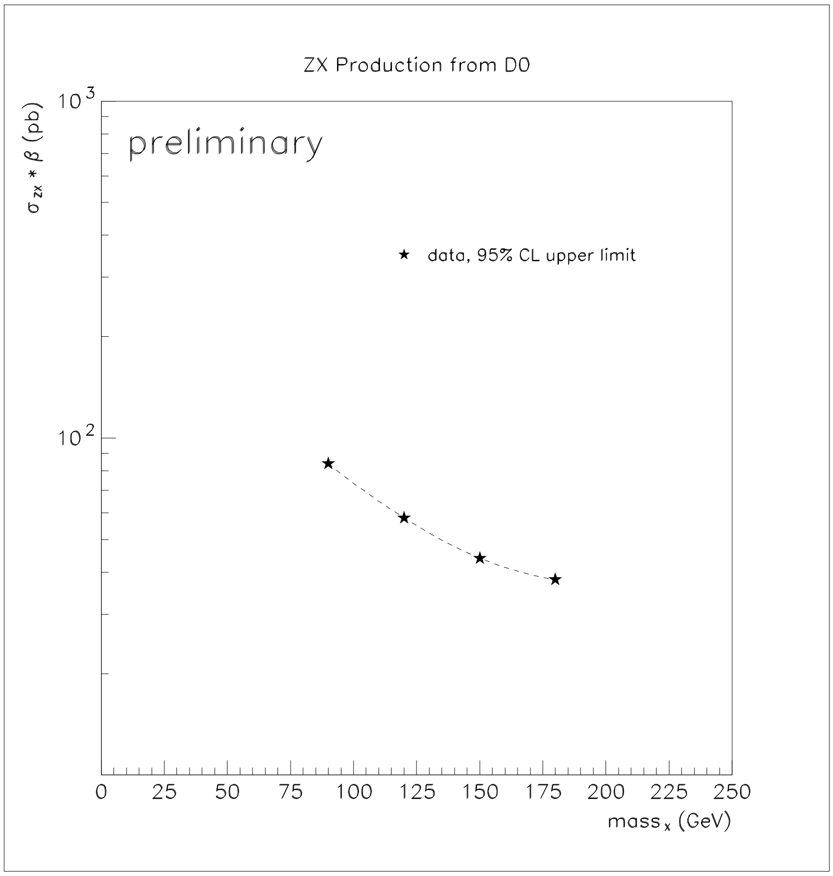

FIG. 3. 95% CL cross section limit for ZX production versus M_X.

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