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AN ANALYSIS OF THE CDF MONOJET DATA

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ABSTRACT

An analysis is presented of events with a single jet and significant missing transverse energy selected from 4.7 pb^{-1} of $p\bar{p}$ data at $\sqrt{s} = 1800$ GeV. The goal is to identify events of the type $p\bar{p} \to Z^0 + \text{jet}$; $Z^0 \to \nu\bar{\nu}$. Event selection and backgrounds are discussed. The number of observed monojet events is compared to the number of observed $Z^0 \to e^+e^-$ events in which the Z^0 is accompanied by a jet. We measure the number of light neutrino species to be $N_\nu = 2.2 \pm 1.5$ and we place an upper limit on the cross section for new physics of 8.3 pb (95% C.L.).

1. Introduction

The missing energy technique can be applied to the analysis of $p\bar{p}$ collisions to observe the so-called "invisible" decays of the Z^0 boson into neutrinos, and to search for new physics that might produce a monojet signal.

The CDF detector is described in detail in Reference 1. We briefly mention the features of the detector most important to this study. Electromagnetic and hadronic calorimetery covered the region in polar angle $2° < \theta < 178°$ or $|\eta| < 4.2$, where η is pseudorapidity. The Central Tracking Chamber (CTC) covered the region $|\eta| < 1.1$ and measured charged particle trajectories and transverse momenta in an axial 1.5 T magnetic field. The Vertex Time Projection Chambers (VTPC) provided tracking information down to $\theta = 3.5°$ ($|\eta| < 3.5$). Muon coverage was also present in the region $|\eta| < 0.7$.

2. Data Sample and Event Selection

The data were collected with a trigger that required the missing transverse energy, $\not{E}_t$, to be at least 25 GeV, and that the leading energy cluster (defined as the highest E_t cluster in the event) be in the region $|\eta| < 1.2$. The leading cluster was further required to have at least 8 GeV of energy deposited in the EM calorimeters. About 2.7×10^5 events came in on this trigger. We have measured the efficiency of the missing E_t trigger to be 89% for events that have $\not{E}_t > 30$ GeV.

In the offline analysis, we applied the following cuts to the data sample:

- Timing information from the central hadron calorimeters was used to reject events that contained cosmic rays not in coincidence with a beam crossing.

*See Reference 3 for the author list.

- The $\not{E}_t$ was required to be at least 30 GeV.
- The quantity $\sigma_{\rm MET}$, called the the "missing E_t significance" and defined as $\sigma_{\rm MET} = \not{E}_t / \sqrt{\sum E_t}$ (where $\sum E_t$ is the scalar sum of E_t over all calorimeters), was required to be at least $2.4\,{\rm GeV}^{\frac{1}{2}}$.
- We rejected events containing an energy cluster with $E_t > 5$ GeV within a $30°$ wedge opposite in azimuth to the leading cluster. This cut removed most of the background from dijet events in which one jet was poorly measured.
- There had to be one and only one energy cluster with $E_t > 15$ GeV.
- The scalar sum of the transverse momenta of the charged particles associated with the leading cluster had to be at least 10% of the E_t of the cluster. This cut eliminated most of the remaining cosmic ray and beam gas events.
- We required the leading cluster to have $0.1 <$ EM fraction < 0.85, where the EM fraction was defined as the ratio of the E_t in the EM calorimeters to the E_t in the hadronic calorimeters. Detector noise was removed by the lower bound on the EM fraction, and $W \rightarrow e\nu$ events were rejected by the upper bound.
- We required the event vertex to be within 60 cm of the center of the detector along the beam axis. This cut improved the hermeticity of the detector.

A sample of 510 monojet candidates survive the above cuts. However, a substantial portion of these events are of the type $W \rightarrow \ell\nu$, where the W is accompanied by a jet and the lepton was undetected. Some events are also $W \rightarrow \tau\nu$ where the τ decayed hadronically and was mistaken for a jet. We therefore applied further cuts to eliminate events with high-p_t muons or electrons and events containing narrow, low-multiplicity energy clusters that resemble τ decays. These W cuts rejected a total of 262 events. We next applied further cuts designed to reduce the background from cosmic rays, beam gas, and QCD dijets. These cuts were based on the characteristics of the leading cluster and the data from the CTC, and removed 22 events from the sample. We are left with a final data set consisting of 226 events.

Figure 1 shows the missing E_t distribution for the final monojet data set. Also shown is the expected $\not{E}_t$ spectrum of the $Z^0 \rightarrow \nu\bar{\nu}$ signal, from Monte Carlo simulations. Figure 1 shows that a large fraction of the monojet sample is background.

3. Background Estimates

In Table 1 we present a list of the possible sources of monojet backgrounds and the estimated contribution from each background source to the final data set.

To estimate the residual monojet backgrounds from vector boson decays, we relied on a Monte Carlo program based on the PAPAGENO[2] event generator. For the case of hadronic decays of $W \rightarrow \tau$, we used a $W \rightarrow \tau\nu$ simulation based on 2664 $W \rightarrow e\nu$ events from the CDF data. For each real $W \rightarrow e\nu$ event, we replaced

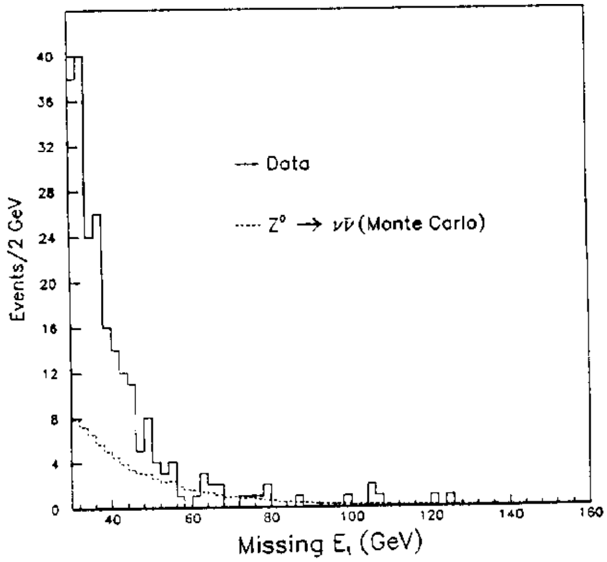

Fig. 1 $\not\!E_t$ distribution for the 226 events that pass the monojet cuts. Also shown is the estimated $\not\!E_t$ distribution for the expected $Z^0 \rightarrow \nu\bar{\nu}$ signal.

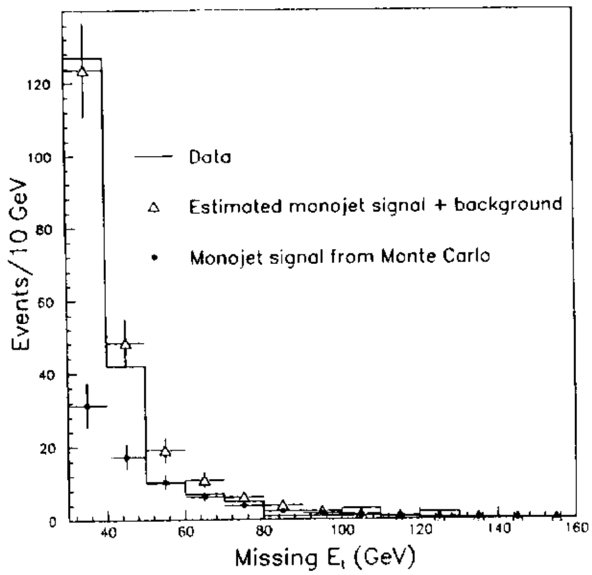

Fig. 2 The $\not\!E_t$ distribution all estimated components of the monojet sample compared to the data, after events with energy clusters near calorimeter cracks have been removed.

the electron track and calorimeter cluster with a simulated τ lepton with the same momentum.

Information from the CTC and VTPC tracking detectors was used to estimate the residual background from QCD dijet events with one jet lost through calorimeter leakage. Multijet QCD background was estimated by examining the energy deposition in the calorimeter regions near known cracks, and by looking for correlations between the azimuthal coordinates of the missing E_t vector and any secondary energy clusters.

The CDF detector is unable to discriminate, on an event by event basis, between EM showers produced by single prompt photons and showers caused by multiple photons from decays of neutral mesons. For this reason we group these two sources of background together. Our methods for estimating direct photon and neutral hadron backgrounds are based on studies of both a sample of real CDF photon candidates[3] and Monte Carlo simulations.

4. Conclusions

Our total background estimate for the monojet data set is 177 ± 18 events. Subtracting this number from the 226 events in the data yields a $Z^0 \rightarrow \nu\bar{\nu}$ signal of 49 ± 24 events. This is consistent with our Monte Carlo prediction of 78 ± 15 events.

Figure 2 shows the $\not\!E_t$ spectrum of the sum of the estimated components of the monojet sample and the spectrum observed in the data. Since we do not have

Table 1: The estimated contribution to the monojet sample from each source of background, and the estimated number of invisible Z^0 decays in the monojet sample.

Process	Estimated Number of Events
$p\bar{p} \to W^{\pm} + \text{jet};\ W^{\pm} \to \ell^{\pm}\nu_{\ell}$	57 ± 11
$p\bar{p} \to W^{\pm};\ W^{\pm} \to \tau^{\pm}\nu_{\tau};\ \tau \to \text{hadrons}$	26 ± 5
$p\bar{p} \to Z^0 + \text{jet};\ Z^0 \to \ell^{+}\ell^{-}$	1 ± 0.2
QCD dijets	31 ± 11
Multijet events with ≥ 2 jets lost or mismeasured	18 ± 7
Multijet events with one jet lost or mismeasured	4 ± 4
Prompt photons and isolated neutral hadrons	31 ± 2
Cosmic rays and beam gas	9 ± 4
Total Background Estimate:	177 ± 18
Number of events in the final sample:	226
Extracted $Z^0 \to \nu\bar{\nu}$ Signal:	49 ± 23

knowledge of the $\not\!\!E_t$ spectrum of the multijet QCD background, the data of Figure 2 do not include events with secondary energy clusters near known calorimeter crack regions. We also neglected the contributions to the monojet sample from multijet QCD events with one jet lost or mismeasured and from cosmic ray/beam gas backgrounds. The data set contains 198 events after events with clusters in crack regions are removed. The sum of the signal plus background estimates give a sample size of 217 ± 15 events.

We can test the size of the extracted $Z^0 \to \nu\bar{\nu}$ signal against the predictions of the Standard Model by comparing it to the number of $Z^0 \to e^+e^-$ events found in the CDF data[4] in which the Z^0 is accompanied by a jet. We measure the ratio of the branching fraction $BR(Z^0 \to \nu\bar{\nu})$ to $BR(Z^0 \to e^+e^-)$ to be equal to 4.4 ± 3.0. The Standard Model value for this ratio is 5.962 (assuming $N_\nu = 3$ and $\sin^2\theta_W = 0.23$). Expressing this result in terms of the number of light neutrino species, $N_\nu = 2.2 \pm 1.5$.

5.1. Limits on New Physics

Using the method described in Reference 5, we calculate an upper limit on the possible cross section for hitherto unknown processes that produce events with a single high-E_t jet ($E_t > 15$ GeV) with the jet in the central region ($|\eta| < 1.2$) and missing E_t greater than 30 GeV. This limit is $\sigma_{new} < 8.3$ pb (95% C.L.). The limit on the number of neutrino species is $N_\nu < 5$ at the 90% confidence level.

6. References

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