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ARE MONOJETS DUE TO UNUSUAL Z^0 DECAYS?

Jonathan L. Rosner

CERN - Geneva
and

Enrico Fermi Institute and Department of Physics
University of Chicago, Chicago, IL 60637

A B S T R A C T

We examine and compare implications of several recent suggestions that events of the form $p\bar{p} \rightarrow \text{jet} + (\text{missing transverse momentum})$ could be due to unusual Z^0 decays. Two possibilities are noted: a) $Z^0 \rightarrow N\bar{N}$, where N (or $\bar{N}$) is a neutral heavy lepton decaying to three neutrinos with a 10% branching ratio, and b) $Z^0 \rightarrow h_1 h_2$, where h_1 and h_2 are two distinct spinless particles, and only the decay of h_1 is seen in the detector. Early tests of both possibilities are noted.

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The events consisting of $\bar{p}p \rightarrow \text{jet} + (\text{missing transverse energy})$ ("monojets") first observed by the UA1 collaboration at the CERN collider¹⁾ apparently have appeared at a similar rate in the 1984 run.²⁾ It is likely that one will be dealing with a total sample of some two dozen of these events once analysis is completed.³⁾

The kinematics of these events are consistent with Z^0 decays.⁴⁻⁶⁾, F1
The typical jet momenta and missing transverse energies are both about half a Z^0 mass, suggesting a Jacobian peak structure in the decay

$$Z \longrightarrow A + B \quad (1)$$

where

$$A \longrightarrow \text{unseen products} \quad (2)$$

and

$$B \longrightarrow \text{jet} \quad (3)$$

Suggestions for A and B include various types of neutral leptons^{4,5)} or scalar particles.⁶⁾

It has been pointed out⁶⁾ that if monojets are due to unusual Z decays of the form (1), the reaction

$$e^+ e^- \longrightarrow Z_{\text{virtual}} \longrightarrow A + B \quad (4)$$

will occur with a cross section which is measurable at present energies. In this note we wish to elaborate further upon that suggestion, and show how a distinction can be drawn (both in $e^+ e^-$ and in $\bar{p}p$ collisions) between the possibilities^{4,5)}

$$Z \longrightarrow \begin{array}{c} N \\ \downarrow \\ 3 \text{ neutrinos} \end{array} + \begin{array}{c} N \\ \downarrow \\ \text{jet} \end{array} \quad (5)$$

and

$$Z \longrightarrow \begin{array}{c} h_1 \\ \downarrow \\ \text{jet} \end{array} + \begin{array}{c} h_2 \\ \downarrow \\ \text{unseen} \end{array}, \quad (6)$$

where h_1 and h_2 are spinless particles.

The cross section for the process (4) is

$$\begin{aligned} \sigma(e^+ e^- \rightarrow Z_{\text{virtual}} \rightarrow A + B) \\ = \frac{G_F M_Z \Gamma_Z s}{\sqrt{2} (M_Z^2 - s)^2} \mathcal{B}(Z \rightarrow A + B) (1 - 4x + 8x^2), \quad (7) \end{aligned}$$

where $G_F = 1.166 \times 10^{-5} \text{ GeV}^{-2}$, $M_Z = 94 \text{ GeV}/c^2$, $\Gamma_Z = 3 \text{ GeV}$, s is the squared c.m. energy, $\mathcal{B}(Z \rightarrow A + B)$ is the branching ratio for the decay (1), and $x \equiv \sin^2 \theta = 0.22$.

The branching ratio $\mathcal{B}$ we estimate conservatively to lie between 1% and 6% if the process (1) is to account for the observed events.¹⁾ With this range of branching ratios we then predict the cross sections and numbers of events shown in Table 1. At least 12 events of the form (4) are expected in each typical PEP experiment with $\sqrt{s} = 29 \text{ GeV}$ and⁷⁾ $\int \mathcal{L} dt = 200 \text{ pb}^{-1}$, and at least 19 in each PETRA experiment with $\sqrt{s} = 44 \text{ GeV}$ and $\int \mathcal{L} dt = 100 \text{ pb}^{-1}$. (Such high integrated luminosities have yet to be accumulated at this energy.)

We now turn to distinctions between the models (5) and (6). The most natural branching ratio for the simulation of a monojet event by $Z \rightarrow N + \bar{N}$ is $\mathcal{B} \approx 1\%$. This number is the product of the intrinsic branching ratio $\mathcal{B}(Z \rightarrow \nu \bar{\nu}) \approx 6\%$ and the estimate⁸⁾ $\mathcal{B}(N \rightarrow 3 \text{ neutrinos}) \approx 10\%$, multiplied by two since either neutral lepton can decay into three neutrinos.^{F2} The 10% figure occurs naturally in models without suppression of flavor-changing neutral currents. The cross section for $f\bar{f} \rightarrow Z \rightarrow N\bar{N}$ in the Z c.m.s., where f is any fermion, is proportional to $1 + \cos^2 \theta^*$, where θ^* is the angle of N or $\bar{N}$ with respect to the beam. (Here we assume no experimental distinction is made between N and $\bar{N}$.)

If monojets are due to $Z \rightarrow h_1 h_2$, where h_1 and h_2 are two distinct spinless particles, a natural branching ratio for this process is^{6),9)} $\mathcal{B}(Z \rightarrow h_1 h_2) \approx \mathcal{B}(Z \rightarrow e^+ e^-) \approx \frac{1}{2} \mathcal{B}(Z \rightarrow \nu \bar{\nu}) \approx 3\%$. This occurs in the limit that h_1 and h_2 belong to a weak isodoublet ϕ_i whose vacuum expectation value does not contribute substantially to the longitudinal

component of the Z: $\langle \phi_i \rangle = v_i \ll G_F^{-1/2} 2^{-1/4} \simeq 246 \text{ GeV}$. The angular distribution for $f\bar{f} \rightarrow Z \rightarrow h_1 h_2$ is proportional to $\sin^2 \theta^*$.

The different c.m. angular distributions for $Z \rightarrow N\bar{N}$ and $Z \rightarrow h_1 h_2$ are reflected in laboratory angle and transverse momentum distributions in $\bar{p}p$ collisions. The Jacobian peak at $x^\perp \equiv 2p^\perp / M_Z = 1$ is more pronounced for $Z \rightarrow h_1 h_2$ than for $Z \rightarrow N\bar{N}$. An illustrative prediction is shown in Fig. 1 for $\sqrt{s} = 540 \text{ GeV}$. A substantial fraction of $Z \rightarrow N\bar{N}$ events occur at fairly low $x^\perp$. These also tend to make small angles with respect to the beam. A central detector (with, e.g., $50^\circ \leq \theta \leq 130^\circ$) is more efficient at picking up $Z \rightarrow h_1 h_2$ than $Z \rightarrow N\bar{N}$ events, as shown in Fig. 1b. Distributions of similar shape are obtained at $\sqrt{s} = 630$ and 1600 GeV . Here we have assumed structure functions $u_V(x) = 2.19 x^{-1/2} (1-x)^3$, $d_V(x) = 1.23 x^{-1/2} (1-x)^4$, $\bar{S}(x) = 0.24 x^{-1} (1-x)^7$, corresponding to valence u, valence d, and sea quarks.

Table 2 displays the effects of cuts designed to enhance a $Z \rightarrow h_1 h_2$ signal relative to backgrounds which might not be so centrally distributed. At CERN collider energies, more than half the $h_1 h_2$ signal survives the cuts $50^\circ \leq \theta \leq 130^\circ$ (which selects events in the central detector) and $0.8 \leq x^\perp \leq 1$ (which favors the most energetic jets in the signal). However, only about 1/3 the $Z \rightarrow N\bar{N}$ signal survives such cuts.

Our crude model for structure functions probably underestimates the energy dependence of the production cross section. Nonetheless, we trust the predicted trend of both $N\bar{N}$ and $h_1 h_2$ production away from the central region at higher energies. Experiments at the Tevatron will have to pay close attention to the forward detector region to study monojets if these events are really due to unusual Z decays.

Signatures of unusual Z decays at PEP and PETRA might not be as dramatic as the CERN monojets, since the momenta of the decaying particles leading to the jet are considerably less. The jets could consequently spread out somewhat, depending on the mass of the particles giving rise to them. If these new particles are neutral leptons, their decays will contain leptons (charged or neutral). If the decays involve new spinless particles, the decays of the visible particle could be enriched with

heavy quark fragments, as long as the visible particle h_1 is behaving at all like a Higgs boson. In any case, dedicated searches are already under way, and useful bounds on specific models can be expected soon.¹⁰⁾

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FOOTNOTES

- F1. One of the published events ("A") has too large a transverse mass.
- F2. A further reduction by two comes if we demand no neutrinos in the N decay, which must then always yield a charged lepton.

Table 1. Numbers of events corresponding to monojet physics at a typical PEP, PETRA, or TRISTAN experiment if monojets are due to Z decays with branching ratio $\mathcal{B}$.

	PEP ($\sqrt{s} = 29$ GeV)	PETRA ($\sqrt{s} = 44$ GeV)	TRISTAN ($\sqrt{s} = 60$ GeV)	($\sqrt{s} = 70$ GeV)
$\frac{\sigma}{\mathcal{B}}$ (pb)	6	19	61	148
Typical $\int \mathcal{L} dt$ (pb $^{-1}$) assumed	200	100	100	100
No. of events:				
$\mathcal{B} = 1\%$	12	19	61	148
$\mathcal{B} = 6\%$	72	112	366	888

Table 2. Cross sections in pb for $\bar{p}p \rightarrow Z \rightarrow N\bar{N}$ (fermion pairs) and $\bar{p}p \rightarrow Z \rightarrow h_1 h_2$ (spinless bosons), assuming a 3% branching ratio of the Z into either final state.

	$\sqrt{s} = 540$ GeV N $\bar{N}$ $h_1 h_2$	$\sqrt{s} = 630$ GeV N $\bar{N}$ $h_1 h_2$	$\sqrt{s} = 1600$ GeV N $\bar{N}$ $h_1 h_2$
Total	49	59	115
$\left\{ \begin{array}{l} 50^\circ \leq \theta \leq 130^\circ \\ 0.8 \leq x^\perp \leq 1 \end{array} \right\}$	16 25	19 29	26 40

Fig. 1. Differential cross section with respect to $x^\perp \equiv 2 p^\perp / M_Z$ for jet production in $\bar{p}p \rightarrow Z \rightarrow \text{jet} + (\text{missing transverse energy})$, for $\sqrt{s} = 540$ GeV. Dashed lines: $Z \rightarrow N\bar{N}$ (fermion pairs); solid lines: $Z \rightarrow h_1 h_2$ (spinless boson pairs). a) All laboratory angles θ with respect to beams; b) $50^\circ \leq \theta \leq 130^\circ$. Here we take $\mathcal{B}(N\bar{N}) = \mathcal{B}(h_1 h_2) = 3\%$.