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Rapid Communications

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Method for counting the neutrino species from $\bar{p}p \to Z^0\ (\to \sum_\nu \nu\bar{\nu}) + \text{jet} + \text{anything}$

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We emphasize the usefulness of the method for determining the number of neutrino species from the reaction $\bar{p}p \to Z^0\ (\to \sum_\nu \nu\bar{\nu}) + \text{jet} + \text{anything}$, where the hadronic jet has a large transverse momentum.

One of the most important open problems in particle physics is that of the number of fermion generations, which is equal to the number of neutrino species N_ν under the assumption that each generation has one and only one neutrino. Besides having important implications in particle physics, the number of neutrino species plays an important role in the cosmological models of the development of the early universe. Cosmological arguments place an upper limit on N_ν (Ref. 1): $N_\nu \leq 7$. In terrestrial experiments the limit $N_\nu < 1400$ has been obtained from the study of the decay $K \to \pi\nu\bar{\nu}$ (Ref. 2) and the limit $N_\nu < 137$ has been obtained from a study of the neutrino effects in the radiative corrections to the ρ parameter and the $e^+e^- \to \mu^+\mu^-$ cross section.[3] The bound $N_\nu \leq 38$ can be derived if we use the recent results[4] of UA1 experiments on

$$R_{\text{expt}} = \frac{\sigma_{Z^0} B(Z^0 \to e^+e^-)}{\sigma_{W^+} B(W^+ \to e^+\nu) + \sigma_{W^-} B(W^- \to e^-\bar{\nu})} \tag{1}$$

and the method of Ref. 5. Two other methods have been proposed for determining N_ν. One is the method of studying the following reaction, where a single hard photon is produced:[6]

$$e^+e^- \to \gamma Z^0,\quad Z^0 \to \sum_\nu \nu\bar{\nu}\ . \tag{2}$$

The other one is to use the weak production of (nearly massless) $\nu\bar{\nu}$ pairs in $\bar{p}p$ collisions via[7]

$$\bar{p}p \to Z^0 + \text{anything}\ ,\quad Z^0 \to \sum_\nu \nu\bar{\nu} \tag{3}$$

The feasibility of using the missing-hadronic-energy spectrum $d\sigma/dE_m$ and the missing-hadronic-transverse-momentum spectrum $d\sigma/dp_\perp$ of reaction (3) has been discussed in Ref. 7. In his calculations, however, Dunbar studied the reaction within the Drell-Yan model, introducing the transverse momentum of the produced pairs $\nu\bar{\nu}$ in a phenomenological way.

In this Rapid Communication we reexamine the method of determining N_ν through Z^0-boson production in the hadronic reaction

$$\bar{p}p \to Z^0 + \text{jet} + \text{anything}\ ,\quad Z^0 \to \sum_\nu \nu\bar{\nu} \tag{4}$$

In such a reaction the neutrino pairs produced can be identified by the presence of a gluon or quark jet with a transverse momentum p_{jT} which is equal to the missing (antiparallel) transverse momentum of the $\nu\bar{\nu}$ pairs. We calculate the transverse-momentum spectrum of the produced jet $d\sigma/dp_{jT}$ within the first order (in α_s) of perturbative QCD, taking into account two types of subprocesses [quark-antiquark annihilation and a gluon-(anti)quark Compton process, Fig. 1] contributing to the reaction (4).

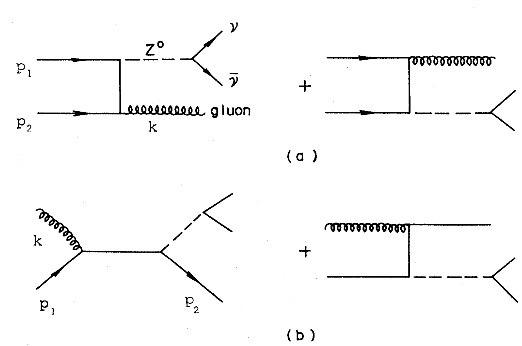

FIG. 1. (a) The quark-antiquark annihilation diagrams. (b) The quark-gluon Compton diagrams.

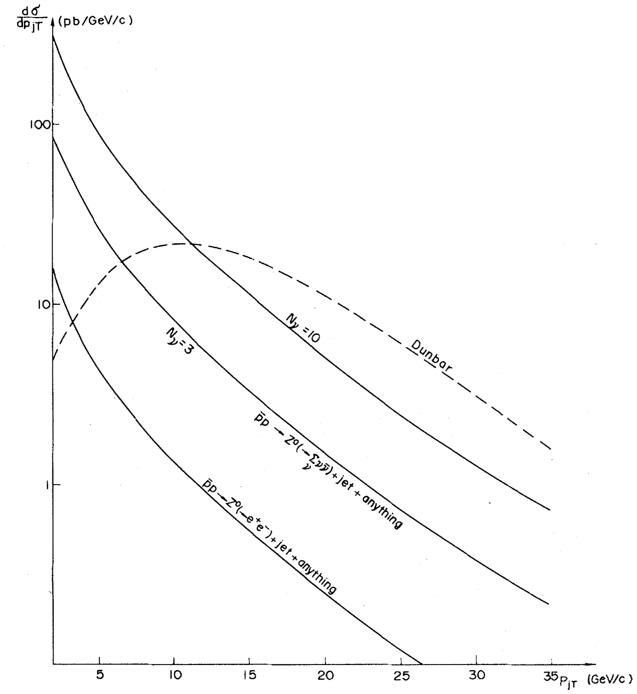

FIG. 2. Transverse-momentum spectrum $d\sigma/dp_{jT}$ for the reaction $\bar{p}p \to Z^0\ (\to \sum_\nu \nu\bar{\nu}) + \text{jet} + \text{anything}$ with $N_\nu = 3, 10$ and $d\sigma/dp_{jT}$ for the reaction $\bar{p}p \to Z^0\ (\to e^+e^-) + \text{jet} + \text{anything}$ at $\sqrt{s} = 540$ GeV, as a function of jet transverse momentum p_{jT}. The curve obtained by Dunbar (Ref. 7) for $d\sigma/dp_{jT}$ for the reaction $\bar{p}p \to Z^0\ (\to \sum_\nu \nu\bar{\nu}) + \text{jet} + \text{anything}$ with $N_\nu = 3$ is also shown by the dashed curve.

We have

$$\frac{d\sigma}{dp_{jT}}(\bar{p}p \to Z^0 + \text{jet} + \text{anything})_{Z^0 \to \sum_\nu \nu\bar{\nu}} = N_\nu \frac{B(Z^0 \to \nu\bar{\nu})}{B(Z^0 \to e^+e^-)} \times \frac{d\sigma}{dp_{jT}}(\bar{p}p \to Z^0 + \text{jet} + \text{anything})_{Z^0 \to e^+e^-} , \quad (5)$$

where in the Weinberg-Salam model with $\sin^2\theta_W = 0.226$,

$$\frac{B(Z^0 \to \nu\bar{\nu})}{B(Z^0 \to e^+e^-)} = \frac{1}{1 - 4\sin^2\theta_W + 8\sin^4\theta_W} = 1.98 \ . \quad (6)$$

In order to give some estimate of the size of the cross section, we calculated $d\sigma/dp_{jT}$, adopting the standard method.[8] The results of the calculations for $\bar{p}p$ collisions at $\sqrt{s} = 540$ GeV for the reaction $\bar{p}p \to Z^0\ (\to \sum_\nu \nu\bar{\nu}) + \text{jet} + \text{anything}$ with $N_\nu = 3$ and 10, employing the parametrizations of Glück, Hoffman, and Reya[9] for the parton structure functions, are presented as a function of p_{jT} in Fig. 2, where for the sake of comparison, the curve obtained by Dunbar and the one for $\bar{p}p \to Z^0\ (\to e^+e^-) + \text{jet} + \text{anything}$ are also shown. It is clear from the figure that the missing-transverse-momentum spectra can provide important information toward determining the number of neutrino species. More detailed numerical studies on reaction (4) and as well the estimate of the background would be needed before comparison with the experimental data is performed.

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