NEUTRAL CURRENT INTERACTION

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This is a report of part of the work of the group which considered neutrino physics at Tevatron II. The remainder of its work is reported by G. Conforto.

Participants in the working group included:

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While the Glashow-Salam-Weinberg model has so far been extremely successful in its neutral current predictions, many questions about the neutral weak interactions remain open. These questions, some of which are rather basic, include the following:

1. Is there a single Z^0, with the mass and couplings predicted by Glashow, Salam, and Weinberg (GSW), or are there several (or perhaps no) neutral weak bosons? If there are several, and the GSW model is only the low $-q^2$ limit of the correct one, do sizeable deviations from the GSW predictions appear as one approaches the $q^2 \sim M_Z{}^2$ domain? Additional Z^0's corresponding to additional U(1) groups, could affect greatly our understanding of grand unification.

2. What are the neutral current interactions of the heavier quarks (s, c, b, ...), or ν_e, and of the muon? Does the behavior of the fermions we have studied so far [left-handed particles in doublets, right-handed ones in singlets of $SU(2)_{weak}$] get replicated as expected? Are the neutral weak interactions of ν_e and ν_μ precisely the same? Similarly, are those of e and μ the same?

3. Are quark flavor-changing neutral weak interactions absent except for the small higher-order effects expected in the standard model?

4. Does the space-time structure of the neutral weak interactions (and of the charged ones, for that matter) continue to be at high energies what it has been at low energies?

5. When probed by neutral current weak interactions, does the nucleon have the same quark structure function as when probed by charged current weak or electromagnetic interactions?

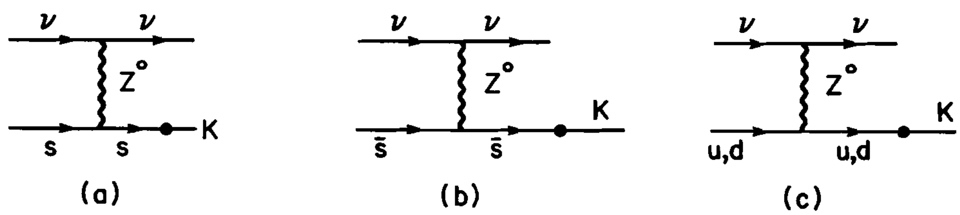
6. Can QCD-induced modifications of the neutral weak interactions of hadrons be studied?

Here we shall focus on a few possible experiments which have not been discussed before, or which appear to us to be particularly interesting, or particularly well-suited to Tevatron II.

We consider first the question of the neutral currents of the heavier quarks. We suggest that the neutral current of the strange quark s could perhaps be measured by studying

$$\nu + N \xrightarrow[x]{\text{small}} \nu + K(\text{large } Z) + X. \qquad (1)$$

Here $Z = P_K/P_K^{max}$, and it is helpful to know the momentum of the expected additional strange particle in X. The diagrams which lead to reaction (1) are (the dot • stands for quark fragmentation):



Diagrams (a) and (b) are the ones of interest. They obviously depend on the s, $\bar{s}$ content of the quark sea in the nucleon. Our unchecked estimate is that they will account for (5-10)% of the total event rate at small x. Diagram (c) can occur via valence quarks and is a background which we estimate to be comparable, in general, to the signal coming from the diagrams where the Z^0 strikes an s or $\bar{s}$ quark. However, this background can be cut down by going to large Z. Although this will decrease the event rate from all three diagrams, the ratio of diagrams (a) and (b) to diagram (c) will be enhanced because of the behavior of the quark fragmentation functions. This is illustrated in Table I, where $D_d^{K^0}$ is the $d \to K^0$ fragmentation function, etc.

Table I.

Z	$Z(D_d^{K^0} + D_d^{\bar{K}^0})$	$ZD_s^{K^0}$	$ZD_s^{\bar{K}^0}$	$\dfrac{D_s^{K^0} + D_s^{\bar{K}^0}}{D_d^{K^0} + D_d^{\bar{K}^0}}$
0.6	0.040	0.008	0.089	2.42
0.8	0.030	0.003	0.083	2.87
0.9	0.027	0.001	0.082	3.08
0.99	0.025	0	0.082	3.28

In addition, since u or d quark fragmentation leads to a non-strange hadronic state, one can further reduce the background from diagram (c) by rejecting events in which there is an additional strange particle in the final state with its momentum close (suitably defined) to that of the K.

Once the contribution of diagrams (a) and (b) has been experimentally determined, the coupling strength $S_L^2 + S_R^2$ can be inferred. Here, S_L and S_R are, respectively, the neutral weak couplings of left-handed and right-handed s quarks to neutrinos. In extracting $S_L^2 + S_R^2$ from the measure (a) and (b) contribution, one uses the knowledge of the s and $\bar{s}$ content of the nucleon sea, gained from the analysis of $\nu(\bar{\nu})N \to \mu^+\mu^-X$ experiments in terms of charm. One also uses knowledge of the $s \to K$ fragmentation functions, which are measurable if not already measured. (This suggested method of studying the neutral current of the s quark was worked out in discussions involving J. Morfin, B. Roe, and B. Kayser.)

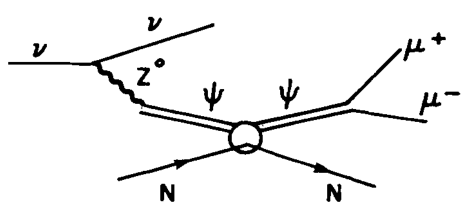
If the detector detects only neutral kaons and cannot tell K^0 from $\bar{K}^0$, $S_L^2 + S_R^2$ can be found separately. This is accomplished by studying the y distribution of events which include a high Z K^- and then of those which include a high Z K^+. For a ν (not $\bar{\nu}$) beam

$$d\sigma_{K^-} \propto S_L^2 + (1-y)^2 S_R^2$$

$$d\sigma_{K^+} \propto S_R^2 + (1-y)^2 S_L^2$$

Interestingly, in the GSW model, S_L^2 is approximately 25 times larger then S_R^2.

Another way to probe the neutral currents of heavy quarks is through the diffractive production of vector mesons made of these quarks. This idea was proposed several years ago by a number of authors.[2] To study the charmed quark, for example, one would look for the reaction



The signature of the reaction would be a low-momentum proton (one is looking for a diffractive event with small-momentum transfer, a muon pair reconstructing to the mass of a ψ, and nothing else. Now the diffractive ψP cross section may be inferred from the cross section for $\nu P \to \nu\psi P$, one may extract the coupling of the

Z^0 to the vector neutral current of the charmed quark. (The axial vector current does not contribute to the process because the ψ, being a vector particle, has no axial vector current.) In a similar way, one may measure the couplings of the Z^0 to the vector neutral currents of the s and b quarks by studying diffractive ϕ and γ production. In the case of the ϕ, one would search for three-prong events containing a low momentum p, and a K^+K^- pair whose invariant mass is that of the ϕ.

As illustrated in Fig. 1 from R. Brown et al.,[2] the cross sections for diffractive vector meson production are steeply rising functions of neutrino energy. Thus, the higher neutrino energies that will be available at Tevatron II will make the study of these processes much less difficult.

We turn next to the question of how many neutral weak bosons, and how many charged ones, there are. Conceivably, a Z^0 and/or a $W^\pm$ with the mass predicted by the GSW model will have been discovered in colliding-beam experiments before the beginning of the Tevatron II fixed-target program. Or, a Z^0 lighter than that of the GSW model may be found.[3] In either case, there would be less interest in looking for effects of the Z^0 or $W^\pm$ propagator in neutrino-induced processes at Tev II. If no weak boson had yet been found, there would be considerable interest in searching for such effects, but it would not be easy. Figure 2, taken from a study made by C. Baltay, illustrates the effects which would be produced by a $W^\pm$ with a mass of 70 GeV (in the GSW model the mass is 80 GeV). To our knowledge, QCD effects, which, like the W propagator, would also cause a decrease in the cross section of the large -x region to which the graph refers, have not been taken into account in the Baltay study. These effects must be considered before assessing any proposed experiment.

Related to the question of the number of neutral weak bosons is that of the low-q^2 properties of neutral current interactions. It is important to search for deviations from the GSW predictions in precision measurements of the neutral current properties of u and d quarks, and of the light leptons. (High precision measurements of $\sin^2\theta_W$ are also important, especially since the value of this parameter has implications for grand unified theories.) However, many of the gauge theoretic alternatives to the GSW model are very difficult to distinguish from that model experimentally.

Another alternative to the GSW model, motivated by consideration of grand unified theories, has recently been discussed by Deshpande.[5] This alternative also illustrates the point that in many experiments, particularly those involving neutrinos, there can be little or no difference between the alternative and the GSW predictions. For one version of the model considered by Deshpande, the only sensitive experiment involving interactions between leptons and quarks is the measurement of parity-violation in heavy atoms. While it is important to make precision tests of

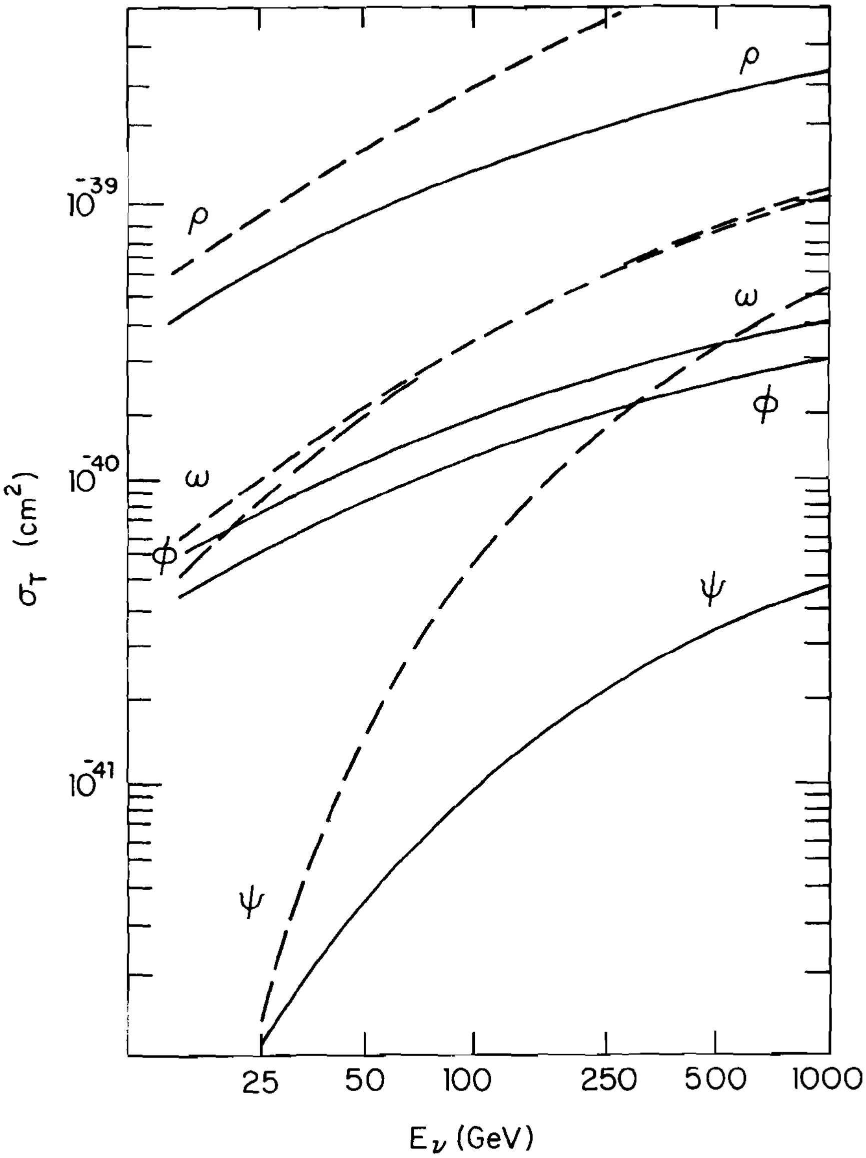


Fig. 1. Total cross sections as functions of beam energy for $\nu p \to \nu p V^0$. The mass of the neutral intermediate boson is taken to be 5 (75.5) GeV/c^2 for the solid (dashed) curves.

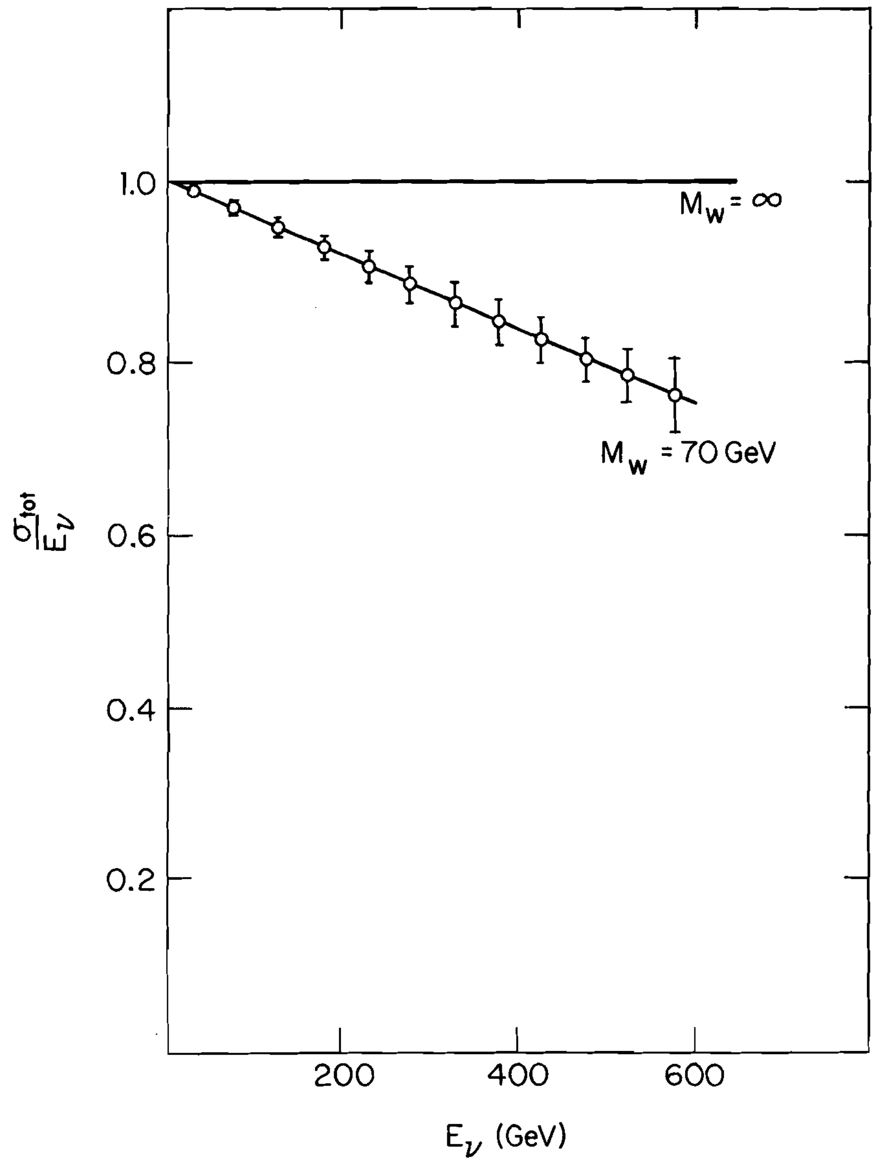


Fig. 2. σ_{tot}/E_ν. $x > 0.8$; $y > 0.8$. 1000 ton detector, 2×10^{18} protons. $\langle q^2 \rangle \approx 1.6\ E_\nu$. (About 10^5 events). For these statistics the limiting considerations will be systematic + other effects.

the GSW model, the search for any deviations from this model in neutrino physics will be difficult. However, if deviations occur their implications could be comparable to finding proton decay.

References

1. The table entries correspond to the model fragmentation functions given by L. Sehgal in the Proceedings of the 1977 International Symposium on Lepton and Photon Interactions at High Energies, Hamburg.

2. M. Chen, F. Henyey, and G. Kane, Nucl. Phys. **B118**, 345 (1977); M. K. Gaillard, S. Jackson, and D. Nanopoulos, Nucl. Phys. **B102**, 326 (1976); R. Brown, L. Gordon, J. Smith, and K. Mikaelian, Phys. Rev. **D13**, 1856 (1976).

3. Using recent PETRA data, N. Wright and J. J. Sakurai, Phys. Rev. **D22**, 220 (1980), have shown that if there is but one Z^0 constrained to give the same low q^2 physics as the GSW model, then $M_{Z^0} > 36$ GeV. Also using PETRA data, R. Marshall, Rutherford preprint RL-80-029, has found that in two illustrative two-Z^0 models, the mass of the lighter Z^0 must exceed 30 GeV.

4. R. Mohapatra and G. Senjanovic, Fermilab preprint, and references therein.

5. N. Deshpande, University of Oregon preprint OITS-141.