We report the correction from the asymmetric strange-antistrange sea of the nucleon by using both the light-cone baryon-meson fluctuation model and the chiral quark model, and show that a significant part of the NuTeV anomaly can be explained by the strange-antistrange asymmetry. We also show that the calculated $s$/$\bar{s}$ asymmetry are compatible with the NuTeV data by including some additional symmetric $s$/$\bar{s}$ quark contribution.

Keywords: strange-antistrange asymmetry; chiral quark model; NuTeV anomaly.

The NuTeV Collaboration at Fermilab measured the value of the Weinberg angle (weak mixing angle) $\sin^2 \theta_w$ in deep inelastic scattering (DIS) on nuclear target with both neutrino and antineutrino beams. Having considered and examined various source of systematic errors, the NuTeV Collaboration reported the value: $\sin^2 \theta_w = 0.2277 \pm 0.0013 \text{ (stat)} \pm 0.0009 \text{ (syst)}$, which is three standard deviations from the value $\sin^2 \theta_w = 0.2227 \pm 0.0004$ measured in other electroweak processes. As $\theta_w$ is one of the important quantities in the standard model, this observation by NuTeV has received attention by the physics society. This deviation, or NuTeV anomaly as people called, could be an indication for new physics beyond standard model, if it cannot be understood by a reasonable effect within the standard model.

The NuTeV Collaboration measured the value of $\sin^2 \theta_w$ by using the ratio of neutrino neutral-current and charged-current cross sections on iron. This procedure is closely related to the Paschos-Wolfenstein (PW) relation:

$$R^+ = \sigma_{NC}^\nu - \sigma_{NC}^\bar{\nu} \over \sigma_{CC}^\nu - \sigma_{CC}^\bar{\nu} = \frac{1}{2} - \sin^2 \theta_w,$$

(1)

which is based on the assumptions of charge symmetry, isoscalar target, and strange-antistrange symmetry of the nucleon sea. It is necessary to pay particular attention to the strange-antistrange asymmetry, i.e., $s(x) \neq \bar{s}(x)$, which brings the correction to the PW relation:

$$R_N^- = \sigma_{NC}^\nu - \sigma_{NC}^\bar{\nu} \over \sigma_{CC}^\nu - \sigma_{CC}^\bar{\nu} = R^- - \delta R_s^-,$$

(2)

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where $\delta R_s$ is the correction term
\[
\delta R_s = (1 - \frac{7}{3} \sin^2 \theta_w) \frac{S^-}{Q_v + 3S^-},
\]
where $S^- \equiv \int_0^1 x[s(x) - \bar{s}(x)]dx$ and $Q_v \equiv \int_0^1 x[u_v(x) + d_v(x)]dx$. I will show in this talk that the effect due to the strange-antistrange asymmetry is able to explain a significant part of the NuTeV anomaly by using both the light-cone baryon-meson fluctuation model \cite{3} and the chiral model model \cite{5,6}, based on the collaborated works with Ding \cite{4} and also with Ding and Xu \cite{7,8}.

In the light-cone formalism, the hadronic wave function can be expressed by a series of light-cone wave functions multiplied by the Fock states, for example, the proton wave function can be written as
\[
|p\rangle = |uud\rangle \Psi_{uud/p} + |uudg\rangle \Psi_{uudg/p} + \sum_q |uudq\rangle \Psi_{uudq/p} + \cdots.
\]

Brodsky and I made an approximation \cite{3}, which suggests that the intrinsic sea part of the proton function can be expressed as a sum of meson-baryon Fock states. For example:
\[
P(uds\bar{s}) = K^+ + \Lambda(uds) \quad \text{for the intrinsic strange sea,}
\]
the higher Fock states are less important, the $ud$ in $\Lambda$ serves as a spectator in the quark-spectator model \cite{9}. The momentum distribution of the intrinsic $s$ and $\bar{s}$ in the $K^+\Lambda$ state can be modelled from the two-level convolution formula:
\[
s(x) = \int_x^1 \frac{dy}{y} f_{\Lambda/K^+\Lambda}(y) q_s/\Lambda(x/y),
\]
\[
\bar{s}(x) = \int_x^1 \frac{dy}{y} f_{K^+/K^+\Lambda}(y) q_s/K^+(x/y),
\]
where $f_{\Lambda/K^+\Lambda}(y)$, $f_{K^+/K^+\Lambda}(y)$ are the probabilities of finding $\Lambda$, $K^+$ in the $K^+\Lambda$ state with the light-cone momentum fraction $y$, and $q_s/\Lambda(x/y)$, $q_s/K^+(x/y)$ are the probabilities of finding $s$, $\bar{s}$ quarks in $\Lambda$, $K^+$ state with the light-cone momentum fraction $x/y$. Two wave function models, the Gaussian type and the power-law type, are adopted \cite{3} to evaluate the asymmetry of strange-antistrange sea, and almost identical distributions of $s-\bar{s}$ are obtained in the nucleon sea. Thus, using this model, we can obtain the distributions of $s$ and $\bar{s}$ in the nucleon state. The result of our calculation is $0.0042 < S^- < 0.0106$ (0.0035 $< S^- < 0.0087$) for the Gaussian wave function (for the power-law wave function), which corresponds to $P_{K^+\Lambda} = 4\%$, 10\%. Hence, $0.0017 < \delta R_s^- < 0.0041$ (0.0014 $< \delta R_s^- < 0.0034$), for the Gaussian wave function (the power-law wave function). The shift in $\sin^2 \theta_w$ can reduce the NuTeV discrepancy from 0.005 to 0.0033 (0.0036) ($P_{K^+\Lambda} = 4\%$) or 0.0009 (0.0016) ($P_{K^+\Lambda} = 10\%$). Thus the $s-\bar{s}$ asymmetry can remove the NuTeV anomaly by about 30–80\% in this model.

A further study by Ding, Xu and I by using chiral quark model also shows that this strange-antistrange asymmetry has a significant contribution to the PW relation and can explain the anomaly without sensitivity to input parameters. The chiral
symmetry at high energy scale and it breaking at low energy scale are the basic properties of QCD. The chiral quark model, established by Weinberg and developed by Manohar and Georgi, has been widely accepted by the hadron physics society as an effective theory of QCD at low energy scale. This model has also a number of phenomenological applications, such as to explain the light-flavor sea asymmetry of $u$ and $d$ sea quarks, and also to understand the proton spin problem. In the new analysis, we provide a new success to understand the NuTeV anomaly with the chiral quark model without sensitivity on parameters. We find that the effect due to strange-antistrange asymmetry can bring a significant contribution to the NuTeV anomaly of about 60–100% with reasonable parameters without sensitivity to different inputs of constituent quark distributions. This may imply that the NuTeV anomaly can be considered as a phenomenological support to the strange-antistrange asymmetry of the nucleon sea. There also similar studies which give similar conclusion as ours.

Besides, we also calculated the strange sea distributions of $x(s(x) + \overline{s}(x))$ and $x(s(x) - \overline{s}(x))$ within this model, and notice that the results of the effective chiral quark model calculations are lower than the parametrization of NuTeV data at arbitrary $x$, which may be caused by the non-considered symmetric strange sea content. This means that there should be a significant symmetric $s/\overline{s}$ contribution which is not included in the model calculation. We find that the distribution of $s(x)/\overline{s}(x)$ matches well with the experimental data when additional symmetric sea contributions being considered effectively by taking into account the difference between model results and data parametrization. Thus the calculated $s(x)/\overline{s}(x)$ asymmetry are compatible with the data by including some additional symmetric strange quark contribution, as can be seen from Fig. 1.

Gao and I also analyzed the possible light-quark fragmentation effect from prompt like-sign dimuon data and studied its influence on the measurement of strange asymmetry by NuTeV. Our result is that the light-quark fragmentation may be an important source that reduces the effect of strange asymmetry from opposite sign dimuon studies. The difference for the $D(c\overline{q})$ and $D(c\overline{q})$ meson production cross sections in neutrino and antineutrino induced charged current deep inelastic scattering is illustrated to be sensitive to the nucleon strange asymmetry. There is also a suggestion to measure the strange asymmetry by $D_s$ asymmetry in photoproduction.

Finally, we give our conclusions as follows:

- The effect due to strange-antistrange asymmetry might be important to explain the NuTeV anomaly or the NuTeV anomaly could be served as an evidence for the $s/\overline{s}$ asymmetry.
- The calculated $s/\overline{s}$ asymmetry are compatible with the available data by including some additional symmetric strange quark contribution.
- Reliable precision measurements are needed to make a crucial test of $s/\overline{s}$ asymmetry.
Fig. 1. Distributions of $s(x)/T(x)$, where the shadowing area is the error range of NuTeV. The thick and thin curves are the effective chiral quark model results with different inputs. The left side is the prediction by the effective chiral quark model only and the right side is the result by including both the prediction of the effective chiral quark model and the symmetric sea contribution estimated by the difference between the NuTeV data parametrization and the effective chiral quark model result.

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