G. Girardi, and P. Sorba, Phys. Lett. 91B, 77 (1980); M. B. Gavela, A. Le Yaouanc, L. Oliver, O. Pene, and J. C. Raynal, Phys. Lett. 98B, 51 (1981), and Phys. Rev. D 23, 1580 (1981).
[5]D. Silverman and A. Soni, Phys. Lett. 100B, 131 (1981).
[6]T. J. Goldman and D. A. Ross, Phys. Lett. 84B, 208 (1979); W. Marciano, Phys. Rev. D 20, 274 (1979); N. P. Chang, A. Das, and J. Pérez-Mercader, Phys. Lett. 93B, 137 (1980).
[7]H. Georgi and S. L. Glashow, Phys. Rev. Lett. 32, 438 (1974).
[8]S. Weinberg, Phys. Rev. Lett. 43, 1566 (1979); F. Wilczek and A. Zee, Phys. Rev. Lett. 43, 1571 (1979).
[9]The $A^{2/3}$ scaling law would be valid if $\bar{p}$ was on the mass shell. If $\bar{p}$ was very off shell, we would rather have an A scaling law. In our case, and for medium nuclei ($A \sim 10$ to 100) one would expect something in between. We choose the $A^{2/3}$ law to be on the conservative side.
[10]R. Phillips, Rev. Mod. Phys. 39, 681 (1967); R. A. Bryan and R. Phillips, Nucl. Phys. B5, 201 (1968); P. Pascual and F. J. Yndurâin, Nuovo Cimento 61A, 225 (1969).
[11]C. Schmid, Phys. Lett. 66B, 353 (1977); A. Le Yaouanc, L. Oliver, O. Pene, and J. C. Raynal, Phys. Lett. 72B, 53 (1977).

Higher-Twist Ambiguities in the Determination of $\sin^2\theta_W$

M. Glück and E. Reya
Institut für Physik, Universität Dortmund, 4600 Dortmund 50, West Germany
(Received 11 August 1981)

It is shown how present measurements of $\sin^2\theta_W$ are hampered by contributions of higher-twist operators, which are even more important than recently calculated electroweak radiative corrections. The resulting limit of accuracy for measurements of $\sin^2\theta_W$ is estimated to be of the order of 5% at presently available energies.

PACS numbers: 12.20.Hx, 12.30.Cx

Interest in the accurate determination of $\sin^2\theta_W$ is largely motivated nowadays by the fact that this quantity is predicted in grand unified theories (GUT's). Therefore a great effort has recently gone into improving both the accuracy of the predictions of GUT's and the theoretical analysis of the experiments. We refer the reader to Marciano and Sirlin[1] for a summary of the relevant activity. In particular the theoretical analysis of the data was improved to the level of radiative QED corrections which were found to modify $\sin^2\theta_W$ by at most 5%. On the other hand no corrections for possible departures from the quark-parton model are available except for the parity-nonconserving left-right asymmetry in deep-inelastic electron-deuteron scattering.[2] It is our purpose to extend this investigation to the more accurate neutrino data presently available[3] and thus draw some conclusions on the ultimate accuracy expected for measuring $\sin^2\theta_W$ at presently available energies.

It should be stressed at this point that while the nonperturbative $O(\mu^2/Q^2)$ corrections due to the higher-twist contributions are of minor importance, even with $\mu^2 \simeq 0.5$ GeV^2, in studying quantum chromodynamic scaling violations[4] where they are to be compared essentially with $\alpha_s \simeq 0.2$, they can, however, turn out to be quite important when compared to quantities pretended to be theoretically understood to the level of $\alpha \simeq 1/137$.

To understand the appearance of higher-twist terms in neutrino reactions, recall that the Gla-

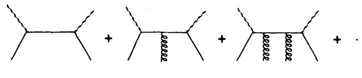

FIG. 1. Handbaglike diagrams.

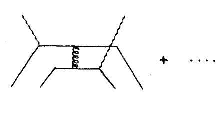

FIG. 2. Flavor-changing non-handbaglike higher-twist diagrams contributing to ϵ.

show-Weinberg-Salam hadronic weak neutral current is given by

$$J_\mu^{\rm NC}=(\tfrac{1}{2}-\tfrac{4}{3}\sin^2\theta_{\rm W})\bar{u}\gamma_\mu u-\tfrac{1}{2}\bar{u}\gamma_\mu\gamma_5 u-(\tfrac{1}{2}-\tfrac{2}{3}\sin^2\theta_{\rm W})\bar{d}\gamma_\mu d+\tfrac{1}{2}\bar{d}\gamma_\mu\gamma_5 d \tag{1}$$

and that in the quark-parton model only the flavor diagonal pieces in $J_\mu^{\rm NC}J_\nu^{\rm NC}$, e.g., $\bar{u}\gamma_\mu u\bar{u}\gamma_\nu u$ or $\bar{u}\gamma_\mu u\bar{u}\gamma_\nu\gamma_5 u$, are considered since their nucleon expectation value is dominant. This is because the flavor diagonal terms get contributions from handbaglike diagrams (Fig. 1) which, among others, include the dominant parton (i.e., twist-2) piece. The flavor off-diagonal terms in $J_\mu^{\rm NC}J_\nu^{\rm NC}$, like $\bar{u}\gamma_\mu u\bar{d}\gamma_\nu d$, for example, are, on the other hand, suppressed by the factor $|\epsilon_n|=n\mu^2/Q^2+\cdots$ relative to the dominant flavor-diagonal terms; here n refers to the usual moment of a structure function. This is because off-diagonal terms only appear as higher-twist, i.e., nonhandbag (Fig. 2), contributions to ratios of cross sections, for example. With the parameter ϵ_n it is now straightforward to evalaute the modification of the standard quark-parton model formulas for $\sin^2\theta_{\rm W}$. One just has to repeat the standard calculations[5] and keep all off-diagonal terms. The results thus obtained, dropping all sea contributions, are

$$R^\nu\equiv\sigma_{\rm NC}{}^{\nu N}/\sigma_{\rm CC}{}^{\nu N}=(\tfrac{1}{2}-\sin^2\theta_{\rm W}+\tfrac{20}{27}\sin^4\theta_{\rm W})(1+\epsilon_2)-\tfrac{4}{27}\epsilon_2\sin^4\theta_{\rm W}, \tag{2}$$

$$R^{\bar\nu}\equiv\sigma_{\rm NC}{}^{\bar\nu N}/\sigma_{\rm CC}{}^{\bar\nu N}=(\tfrac{1}{2}-\sin^2\theta_{\rm W}+\tfrac{20}{9}\sin^4\theta_{\rm W})(1+\epsilon_2)-\tfrac{4}{9}\epsilon_2\sin^4\theta_{\rm W}, \tag{3}$$

$$D\equiv\frac{\sigma_{\rm NC}{}^{\nu N}-\sigma_{\rm NC}{}^{\bar\nu N}}{\sigma_{\rm CC}{}^{\nu N}-\sigma_{\rm CC}{}^{\bar\nu N}}=(\tfrac{1}{2}-\sin^2\theta_{\rm W})(1+\epsilon_2). \tag{4}$$

With the measured values[3] for R^ν, $R^{\bar\nu}$, and D, and the results (2)–(4), one concludes that $\sin^2\theta_{\rm W}$ is essentially modified by the factor ϵ_2. This should be contrasted with the corresponding result[2] for the parity-nonconserving left-right asymmetry A^{ed} in deep-inelastic scattering of longitudinally polarized electrons off nucleons,

$$A^{ed}=-\frac{G_{\rm F}Q^2}{2\sqrt{2}\pi\alpha}\frac{9}{10}\left[\left(1-\frac{20}{9}\sin^2\theta_{\rm W}\right)K+(1-4\sin^2\theta_{\rm W})\frac{1-(1-y)^2}{1+(1-y)^2}\right] \tag{5}$$

with

$$K\simeq 1+[2\sin^2\theta_{\rm W}/(9-20\sin^2\theta_{\rm W})+\tfrac{1}{10}]2\epsilon(x), \tag{6}$$

which implies that higher-twist terms modify $\sin^2\theta_{\rm W}$ only by a factor of about $\frac{1}{2}\times 0.4\epsilon(x)$ for $\sin^2\theta_{\rm W}=0.2$ to 0.25 where $|\epsilon(x)|\simeq\mu^2/Q^2(1-x)$. Thus in spite of the fact that these parity-nonconservation experiments[6] are carried out at *low* Q^2 ($\simeq 2$ GeV^2) the correction to $\sin^2\theta_{\rm W}$ at $x=0.2$ is still only about ±3% for $\mu^2\simeq\langle k_T{}^2\rangle_{\rm intrinsic}\simeq 0.2$ GeV^2 (or ±7% for[7] $\mu^2\simeq 0.5$ GeV^2) which is quite a reasonable value consistent[4] with present data on scaling violations. The same value of μ^2 also implies a ±3% uncertainty in the *high*-Q^2 ($\simeq 20$ GeV^2) measurements[3] of $\sin^2\theta_{\rm W}$ in neutrino experiments because the ϵ terms in Eqs. (2)–(4) now *appear in full strength*! Obviously the corrections are proportional to μ^2 and uncertainties up to ±10% in $\sin^2\theta_{\rm W}$, corresponding to $\mu^2\simeq 1$ GeV^2, due to higher-twist contributions *cannot* be *strictly* excluded, say, from our present knowledge[8] about scaling violations in deep-inelastic scattering.

[1]W. J. Marciano and A. Sirlin, in Proceedings of the Second Workshop on Grand Unification, Ann Arbor, Michigan, April 1981 (to be published), and Phys. Rev. Lett. 46, 163 (1981).

[2]J. D. Bjorken, Phys. Rev. D 18, 3239 (1978); L. Wolfenstein, Nucl. Phys. B146, 477 (1978).

[3]C. Geweniger, in *Neutrino '79,* Proceedings of the International Conference on Neutrinos, Weak Interactions, and Cosmology, Bergen, Norway, 1979, edited by A. Haatuft and C. Jarlskog (University of Bergen, Bergen, 1980), Vol. 2, p. 392; F. Dydak, in *Proceedings of the EPS International Conference on High Energy Physics* (CERN, Geneva, 1979), Vol. 1, p. 25; M. Jonker *et al.*, Phys. Lett. 99B, 265 (1981).

[4]M. R. Pennington and G. G. Ross, Nucl. Phys. B179, 324 (1981); D. W. Duke and R. G. Roberts, Phys. Lett. 94B, 417 (1980); M. Glück and E. Reya, Universität Dortmund Report No. DO-TH 80/7 (unpublished), and to be published; F. Eisele (CERN–Universität Dortmund–Universität Heidelberg–Centre d'Etudes Nucléaires de Saclay collaboration), in Proceedings of the Fourth Symposium on Elementary Particle Physics, Kasimierz, Poland, 1981 (unpublished), and Universität Dortmund Report No. DO-EXP 6/81 (unpublished).

[5]L. M. Sehgal, Nucl. Phys. B65, 141 (1973); C. H. Albright, Phys. Rev. D 8, 3162 (1973); A. Pais and S. Treiman, Phys. Rev. D 6, 2700 (1972); E. A. Paschos and L. Wolfenstein, Phys. Rev. D 7, 91 (1973).

[6]C. Prescott *et al.*, Phys. Lett. 77B, 347 (1978), and

84B, 524 (1979).
[7]L. F. Abbott, W. B. Atwood, and R. M. Barnett, Phys. Rev. D 22, 582 (1980); L. F. Abbott, E. L. Berger, R. Blankenbecler, and G. L. Kane, Phys. Lett. 88B, 157 (1979).
[8]Note that the nucleon expectation values of some of the higher-twist operators contributing to neutral-current cross sections are *not* necessarily the same as of those entering deep-inelastic electroproduction and weak-charged-current structure functions.

Observation of Levels in ${}^{13}_{\Lambda}$C, ${}^{14}_{\Lambda}$N, and ${}^{18}_{\Lambda}$O Hypernuclei

M. May, H. Piekarz, R. E. Chrien, S. Chen,[(a)] D. Maurizio, H. Palevsky, R. Sutter, and Y. Xu[(b)]
Brookhaven National Laboratory, Upton, New York 11973

and

P. Barnes, B. Bassalleck, N. J. Colella, R. Eisenstein, R. Grace, P. Pile, F. Takeutchi, and W. Wharton
Carnegie-Mellon University, Pittsburgh, Pennsylvania 15213

and

M. Deutsch and J. Piekarz
Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

and

S. Bart, R. Hackenburg, E. V. Hungerford, B. Mayes, and L. Pinsky
University of Houston, Houston, Texas 77001

and

R. Cester
University of Torino, Torino, Italy

and

R. L. Stearns
Vassar College, Poughkeepsie, New York 12601
(Received 29 June 1981)

The spectra of levels in the hypernuclei ${}^{13}_{\Lambda}$C, ${}^{14}_{\Lambda}$N, and ${}^{18}_{\Lambda}$O, excited by 800-MeV/c kaons in the (K^-, π^-) reaction, have been observed at the Brookhaven alternating-gradient synchrotron. Data were recorded for scattering angles from 0° to 25°, corresponding to momentum transfers from 50 to 330 MeV/c. The levels are interpreted in terms of a Λ hyperon coupled to a strangeness-zero nuclear core. The results provide insights into the properties of the Λ-nucleon and Λ-nucleus interactions.

PACS numbers: 21.80.+a, 25.80.+f

Through use of the strangeness-exchanging (K^-, π^-) reaction, levels of the hypernuclei ${}^{13}_{\Lambda}$C, ${}^{14}_{\Lambda}$N, and ${}^{18}_{\Lambda}$O have been studied for the first time in an experiment done at the Brookhaven alternating-gradient synchrotron. A schematic description of the structure of these states is given in this paper. A comprehensive theoretical treatment of the structure of the levels in ${}^{13}_{\Lambda}$C and their excitation is presented in the accompanying Letter.[1]

The experimental apparatus used the hypernuclear spectrometer which has been previously described.[2] The momentum of the incident kaon beam was ~800 MeV/c. Approximately 10^4 kaons/sec were incident on the target, where the π/K ratio was approximately 15 to 1. For the ~2-g/cm^2 targets used in these experiments the energy resolution for the observed hypernuclear states was approximately 2.5 MeV. The pion spectrometer is rotatable up to angles of 35° with respect to the beam direction, and the resulting angular distributions are useful in establishing the character of the states observed.

For the ${}^{13}_{\Lambda}$C measurement, the target was a liquid scintillator of benzene containing ^{13}C enriched to 99%. The target signal due to hyper-

