Test of fundamental symmetries in the $A = 12$ nuclei

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It is shown in a model-independent fashion that, even without the conserved vector current test by extracting the shape factors from the observed $e^{\mp}$ energy spectra in the beta decays of ^{12}B and ^{12}N, the validity of conservation of vector current and partial conservation of axial vector current and the absence of second-class axial currents have now been *individually* confirmed by the combination of the muon capture data and the results of the recent asymmetry measurements. On the other hand, it is found that the presence of appreciable meson-exchange corrections does not cause a serious discrepancy between the asymmetry data and the Cohen-Kurath nuclear model after the spin-quadrupole-moment term (from the $L = 2$ component of the lepton wave functions) and all the theoretical uncertainties are also taken into account.

[RADIOACTIVITY CVC, PCAC, and no second-class axial vector current, tested individually; meson-exchange corrections, compatibility with the Cohen-Kurath nuclear wave functions.]

Recently, several beautiful experiments have been performed to measure the variation with energy of the asymmetry coefficients $\alpha_{\mp}$ on the nuclear β decays: $^{12}B \to {}^{12}C\, e^- \bar{\nu}_e$ and $^{12}N \to {}^{12}C\, e^+ \nu_e$. These measurements yield

$$\alpha_- = -(0.07 \pm 0.20)/\text{GeV (Lebrun } et\ al.^1),$$
$$= +(0.24 \pm 0.44)/\text{GeV (Brandle } et\ al.^2),$$
$$= +(0.25 \pm 0.34)/\text{GeV (Sugimoto } et\ al.^3),$$
$$\alpha_+ = -(2.77 \pm 0.52)/\text{GeV (Sugimoto } et\ al.^3),$$
$$= -(2.73 \pm 0.39)/\text{GeV (Brandle } et\ al.^4)$$

which are in excellent agreement with the values predicted by the validity of conservation of vector current (CVC) and the absence of second-class axial vector currents[5]:

$$\alpha_- = (0.08 \pm 0.03)/\text{GeV},$$
$$\alpha_+ = -(2.75 \pm 0.03)/\text{GeV}.$$

With "suitably-corrected" partial conservation of axial vector current (PCAC) as an additional input,[5] the same hypothesis results in the predicted muon capture rate by ^{12}C and the predicted polarization of recoil ^{12}B in agreement with the observed values.[6,7] In view of these highly successful accomplishments, most of us are willing to accept, without any further challenge, the *standard* theoretical picture in which the validity of CVC and PCAC and the absence of second-class axial vector currents are suitably implemented.

However, if the standard theoretical picture can always be adopted as the starting point in the investigation of flavor-conserving charge weak interactions, it is of utmost importance to verify the *converse* of the statement that such a standard picture results in many experimentally confirmed predictions. In other words, we need to ask if the existing data have verified individually the basic ingredients of the standard picture. This particular question is, of course, familiar to many of us[8] but, strictly speaking, a completely model-independent answer remains to be assessed.

To explain why it is difficult to arrive at a completely model-independent answer to the question addressed above, we review briefly the current status on the other cases where the standard picture has been favorably involved. In the $A = 8$ case, we note that, in addition to the measurement[9] on the $e^{\mp}$-α angular correlation in the β decays of ^8Li and ^8B (and the α decays of the daughter $^8Be^*$), the radiative width of the 16.6-16.9 MeV doublet has been measured recently by Bowles and Garvey.[10] In view of the fact that, without the validity of (strong) CVC, the electromagnetic ($M1$ and $E2$) transition form factors can bear no significance on the determination of the *weak* magnetism form factor, the genuine model-independent conclusion drawn from the combination of the angular correlation and radiative width measurements should be stated as follows: "The validity of CVC is confirmed if and only if the second-class axial current is absent." Obviously, such conclusion is by no means equivalent to the assertion that both the validity of CVC and the absence of second-class axial vector currents are confirmed. On the other hand, it was pointed out[11] that, in the $A = 6$ case, an early measurement[12] on the angular correlation between the electron and neutrino momenta in the β decay of ^6He can allow us to draw some conclusion on the size of second-class axial vector currents. However, the conclusion regarding the absence of second-class axial vector currents suffers from the fact[13] that, apart from the large experimental error, the first-class contribution to the weak-electricity form factor, which is indispensable for the conclusion to be drawn, is sensitive to the nuclear wave functions of ^{6}He and ^{6}Li. Further, the model-dependent nature of the conclusion in this particular case is a formidable task to remove.

Therefore, it is not surprising that, although the existing data in the $A = 12$ case agree with those predicted by the standard picture, the question addressed above remains to be analyzed. In particular, we note that overall consistency was attained within the standard picture since the first-class weak electricity form factor $F_E^{(I)}$ was calculated from Cohen-Kurath nuclear wave functions[14] without appreciable meson-exchange corrections (MEC). However, it was pointed out by Kubodera, Delorme, and Rho[15] that the value of $F_E^{(I)}$ could be substantially different from that calculated from the connection[5,16] between the "elementary-particle" treatment (EPT) and nucleon-only impulse approximation (NOIA). Their preliminary estimate indicated that a 30–50% increase on the value of $F_E^{(I)}$ might be required by the inclusion of MEC. Recently, Noble[17] confirmed quantitatively their estimate (he obtained a result of about 30% which is quite insensitive to the nuclear wave functions used) by calculating the MEC in the σ model, which explains successfully a variety of nucleon-scattering data. The new value of $F_E^{(I)}$, with the inclusion of MEC, induces a discrepancy between theory and experiment of about two standard deviations. Such discrepancy, if it persists, indicates *either* (1) the Cohen-Kurath nuclear wave functions are not adequate, *or* (2) the experimental values of $a_\mp$ are in question once again. Clearly, it would be very much welcome if the discrepancy caused by the inclusion of MEC could be removed in a simple and intuitive manner.

It is well known that the validity of CVC was confirmed in the early experiment of Lee, Mo, and Wu[18] by measuring the $e^\mp$ energy spectra in the decays of ^{12}B and ^{12}N and extracting the shape factors $a_\mp$ from the observed spectra. However, the original analysis of the data was questioned by Calaprice and Holstein,[19] reanalyzed by Wu, Lee, and Mo themselves,[20] and recently reinvestigated by Koshigiri, Nishimura, Ohtsubo, and Morita.[20] Although the final consensus favors the validity of CVC, the complicated nature of the whole program could still have kept some of us feeling reserved toward the conclusion. Such reservations may grow even stronger if one observes that the individual values of $a_\mp$ obtained recently by Kaina *et al.*[21] show small discrepancies with the theory although the difference $a_- - a_+$ is indeed in accord with CVC. Therefore, an independent test of CVC, if it can be extracted from the existing data, should be extremely helpful in establishing our confidence toward the standard picture.

It is the purpose of this paper to present the following results: The basic ingredients of the standard picture, namely, the validity of CVC and PCAC and the absence of second-class axial vector currents, can be confirmed individually in the $A = 12$ nuclei without an invocation of the experiment of Lee, Mo, and Wu[18,20] or Kaina *et al.*[21] The additional test of CVC comes from a combination of the observed muon capture rate[6] *either* with the recent measurement on the polarization of recoil ^{12}B (Ref. 7) *or* with the recent asymmetry measurements (Refs. 1–4). Finally, it is shown that, after the small correction due to the nuclear spin-quadrupole-moment matrix element $\mathfrak{M}_{\sigma Q}$ is taken into account, the discrepancy caused by the inclusion of MEC can be resolved to a reasonable extent.

In this paper, the notations and the formulas, if unspecified, are the same as those of Ref. 5. We now note that the nuclear weak magnetism (M), axial (A), pseudoscalar (P), and weak electricity (E) form factors $F^\mp_{M,A,P,E}(q^2)$ can be represented by

$$F^\mp_{M,A,P,E} = \{F_{M,A,P,E}\}_{\rm NOIA} + \{F_{M,A,P,E}\}_{\rm MEC} + \{F^\mp_{M,A,P,E}\}_{\rm EM}\,. \tag{1}$$

Here, as already described in Ref. 5, $\{F_{M,A,P,E}\}_{\rm NOIA}$ can be expressed in terms of the nucleon form factors $f^{(I)}_{V,M,A,P}, f^{(II)}_{S,E}$, and the nuclear matrix elements $\mathfrak{M}_{\rm GT}$, $\mathfrak{M}_L$, $\mathfrak{M}_{\sigma pz}$, and $\mathfrak{M}_{\sigma Q}$. The standard procedure[22] also enables us to write down explicit formulas for $\{F_{M,A,P,E}\}_{\rm MEC}$ if meson-exchange corrections are characterized in a way similar to that used by Chemtob and Rho.[23] (Note that the procedure used by Noble in his evaluation of MEC is similar.[17]) Finally, $\{F^\mp_{M,A,P,E}\}_{\rm EM}$, which account for the difference between $F^-_{M,A,P,E}$ and $F^+_{M,A,P,E}$, represent the *residual* electromagnetic corrections which have not been taken into account by the Fermi functions $F_\mp(Z, E_e)$ (for the final-state Coulomb interactions) or by the multiplication factor $1 + (\alpha/2\pi) \times g_\mp(E_e)$ (for the radiative corrections.)[24] In the analysis of Ref. 5, the factor $1 + (\alpha/2\pi)g_\mp(E_e)$ is already absorbed in the definition of the Fermi functions $F_\mp(Z, E_e)$.[25] Slightly different values for $F^-_{M,A,P,E}$ and $F^+_{M,A,P,E}$ are always required since neither Coulomb interactions nor radiative corrections can be factored out completely. (In fact, radiative corrections cannot be calculated unambiguously in the phenomenological theory. Apart from the so-called ultraviolet divergences, a sum of a finite number of Feynman diagrams does not preserve the salient features, such as gauge invariance, CVC, or PCAC, of the lowest-order phenomenological theory.) Nevertheless, the ratios $F_M^+(0)/F_M^-(0)$, $F_A^+(0)/F_A^-(0)$, $F_E^{(\mathrm{I})+}(0)/F_E^{(\mathrm{I})-}(0)$, and $F_E^{(\mathrm{II})+}(0)/F_E^{(\mathrm{II})-}(0)$ are expected to be almost identical if all the contributions listed in Eq. (1) are taken into account.[26] Therefore, we eliminate $F_{M,A,E}^+(0)$ from the expressions of $\alpha_\mp$ (see Ref. 5) and obtain from the observed values of $\alpha_\mp$ (Refs. 1–4)

$$\frac{F_E^{(\mathrm{I})-}(0)}{F_A^-(0)} = -\tfrac{3}{2} m_p(\alpha_- + \alpha_+) = 3.67 \pm 0.44 \,, \tag{2a}$$

$$\frac{F_M^-(0)}{F_A^-(0)} + \frac{F_E^{(\mathrm{II})-}(0)}{F_A^-(0)} = \tfrac{3}{2} m_p(\alpha_- - \alpha_+) = 4.07 \pm 0.44 \,. \tag{2b}$$

To use the muon capture data as additional inputs, we adopt the assumption that the q^2 dependence of the weak form factors $F_{M,A,E}^-(q^2)$ and the magnetic transition form factor $\mu(q^2)$ is similar in the q^2 regime of our interest:

$$\frac{\mu(q^2)}{\mu(0)} = \frac{F_A^-(q^2)}{F_A^-(0)} = \frac{F_M^-(q^2)}{F_M^-(0)} = \frac{F_E^-(q^2)}{F_E^-(0)} \,. \tag{3}$$

As already elucidated in detail by Ref. 5, Eq. (3) can be regarded as a consequence of the following three statements, viz.: (1) The small difference in the q^2 dependence of the nuclear matrix elements $\mathfrak{M}_{\mathrm{GT}}(q^2;{}^{12}\mathrm{B}\to{}^{12}\mathrm{C})$, $\mathfrak{M}_L(q^2;{}^{12}\mathrm{B}\to{}^{12}\mathrm{C})$, $\mathfrak{M}_{\sigma p z}(q^2;{}^{12}\mathrm{B}\to{}^{12}\mathrm{C})$, $(m_\pi^2/q^2)\mathfrak{M}_{\sigma Q}(q^2;{}^{12}\mathrm{B}\to{}^{12}\mathrm{C})$, and $\mathfrak{M}_{\mathrm{GT}}(q^2;{}^{12}\mathrm{C}^*\to{}^{12}\mathrm{C})$, $\mathfrak{M}_L(q^2;{}^{12}\mathrm{C}^*\to{}^{12}\mathrm{C})$ can be safely neglected in the q^2 regime of our interest; (2) The small isospin-symmetry breaking between ^{12}B (g.s.) and ^{12}C* (15.110) gives rise to a modification of the equality between $\mathfrak{M}_{\mathrm{GT}}(0;{}^{12}\mathrm{B}\to{}^{12}\mathrm{C})$ and $\mathfrak{M}_{\mathrm{GT}}(0;{}^{12}\mathrm{C}^*\to{}^{12}\mathrm{C})$ [or between $\mathfrak{M}_L(0;{}^{12}\mathrm{B}\to{}^{12}\mathrm{C})$ and $\mathfrak{M}_L(0;{}^{12}\mathrm{C}^*\to{}^{12}\mathrm{C})$] but induces only a negligible effect on the similarity of their q^2-dependence characteristics; and (3) the validity of Eq. (3), as extracted mainly from the EPT-NOIA connection, is affected little by the inclusion of small MEC. Using the first equality of Eq. (3), with the attribution of a 3–5% theoretical uncertainty, and factorizing the initial-state Coulomb interaction in the standard manner, we obtained in Ref. 5

$$\Gamma(\mu^- \,{}^{12}\mathrm{C} \to \nu_\mu \,{}^{12}\mathrm{B}) = (2.0 \pm 0.1) R(q_m^2) \times 10^3\ \mathrm{sec}^{-1} \tag{4a}$$

with

$$R(q_m^2) \equiv 2\left(1 + \frac{F_M^-(q_m^2)}{F_A^-(q_m^2)}\frac{E_\nu}{2m_p}\right)^2 + \left(1 + \frac{F_P^-(q_m^2)}{F_A^-(q_m^2)}\frac{m_\mu E_\nu}{m_\pi^2} - \frac{F_E^-(q_m^2)}{F_A^-(q_m^2)}\frac{E_\nu}{2m_p}\right)^2 \tag{4b}$$

and

$$q_m^2 = 0.740\, m_\mu^2, \quad E_\nu = 91.41\ \mathrm{MeV} \,. \tag{4c}$$

Experimentally, we have[6]

$$[\Gamma(\mu^- \,{}^{12}\mathrm{C} \to \nu_\mu \,{}^{12}\mathrm{B})]_{\exp} = (6.2 \pm 0.3) \times 10^3\ \mathrm{sec}^{-1} \,, \tag{4d}$$

so that

$$R(q_m^2) = 3.1 \pm 0.2 \,. \tag{4e}$$

Further, the recoil ^{12}B polarization in $\mu^-\,{}^{12}\mathrm{C} \to \nu_\mu\,{}^{12}\mathrm{B}$ is given by[8,5]

$$P_{\mathrm{av}} = \tfrac{2}{3}[1 - P(q_m^2)/R(q_m^2)] \tag{5a}$$

with

$$P(q_m^2) \equiv \left[\frac{F_P^-(q_m^2)}{F_A^-(q_m^2)}\frac{m_\mu E_\nu}{m_\pi^2} - \left(\frac{F_M^-(q_m^2)}{F_A^-(q_m^2)} + \frac{F_E^-(q_m^2)}{F_A^-(q_m^2)}\right)\frac{E_\nu}{2m_p}\right]^2 . \tag{5b}$$

Experimentally, Possoz *et al.*[7] measured the "apparent" average polarization of the recoil ^{12}B (g.s.) from polarized-muon capture by ^{12}C (g.s.) and subtracted the contribution due to those recoil ^{12}B (g.s.) which were produced *indirectly*, e.g., $\mu^-\,{}^{12}\mathrm{C}$ (g.s.) $\to \nu_\mu\,{}^{12}\mathrm{B}^* \to \nu_\mu\,{}^{12}\mathrm{B}$ (g.s.)γ. More careful analysis on the subtraction of the background in their experiment were performed by Kobayashi *et al.*[7] and by Hwang.[7] The final model-independent result for the average polarization of ^{12}B (g.s.) produced directly from $\mu^-\,{}^{12}\mathrm{C}$ (g.s.) $\to \nu_\mu\,{}^{12}\mathrm{B}$(g.s.) is given by

$$(P_{\mathrm{av}})_{\exp} = 0.47 \pm 0.05 \,, \tag{5c}$$

so that, using Eq. (4e) as an input,

$$P(q_m^2) = 0.91 \pm 0.23 \,. \tag{5d}$$

As already noticed by Pascual,[8] a test of CVC can be achieved by solving $F_M^-(q_m^2)/F_A^-(q_m^2)$ from Eqs. (4e) and (5d). In view of Eq. (3), we obtain in this way

$$F_M^-(0)/F_A^-(0) = 4.73 \pm 1.16 \,. \tag{6}$$

Here the following plausible choice of the signs has been made:

$$1 + \frac{F_M^-(q_m^2)}{F_A^-(q_m^2)}\frac{E_\nu}{2m_p} > 0 \,,$$
$$\frac{F_P^-(q_m^2)}{F_A^-(q_m^2)}\frac{m_\mu E_\nu}{m_\pi^2} - \left(\frac{F_M^-(q_m^2)}{F_A^-(q_m^2)} + \frac{F_E^-(q_m^2)}{F_A^-(q_m^2)}\right)\frac{E_\nu}{2m_p} < 0 \,. \tag{7}$$

Further, we note that Eqs. (6), (5d), (2a), and (2b) yield

$$\frac{F_E^{(\mathrm{II})-}(0)}{F_A^-(0)} = -(0.66 \pm 1.24)\,, \tag{8a}$$

$$\frac{F_P^-(q_m^2)}{F_A^-(q_m^2)} = -(1.02 \pm 0.29)\,. \tag{8b}$$

On the other hand, the observed β and γ decay rates[27] of ^{12}B and its isospin analog ^{12}C* yield

$$\left(\frac{F_M^-(0)}{F_A^-(0)}\right)_{\mathrm{CVC}} = 3.86 \pm 0.12\,, \tag{9a}$$

which agrees fairly well with Eq. (6). Meanwhile, the NOIA calculation, as illustrated below by Eqs. (11b) and (12b), gives rise to

$$\left(\frac{F_P^-(q_m^2)}{F_A^-(q_m^2)}\right)_{\mathrm{NOIA}} = -1.02\left(1+\frac{q_m^2}{m_\pi^2}\right)^{-1} + \delta$$
$$= -0.99\,. \tag{9b}$$

Here the small difference in the q^2 dependence of $\mathfrak{M}_{\mathrm{GT}}(q^2)$ and $(m_\pi^2/q^2)\mathfrak{M}_{\sigma Q}(q^2)$ has been neglected again. The small nonpole term δ in Eq. (9b) signals a deviation from naive PCAC for nuclei.[28] Therefore, the basic ingredients of the standard picture, namely, CVC [Eqs. (6) and (9a)], PCAC [Eqs. (8b) and (9b)], and the absence of second-class axial currents [Eq. (8a)] are now individually confirmed in a completely model-independent fashion.

Alternatively, using Eqs. (9b) and (3), we can solve $F_M^-(0)/F_A^-(0)$ and $F_E^{(\mathrm{II})-}(0)/F_A^-(0)$ from Eqs. (4e), (2a), and (2b). In this way, we obtain

$$\frac{F_M^-(0)}{F_A^-(0)} = 4.73 \pm 0.95\,, \tag{10a}$$

$$\frac{F_E^{(\mathrm{II})-}(0)}{F_A^-(0)} = -(0.66 \pm 1.05)\,. \tag{10b}$$

Thus, as long as the validity of PCAC [Eq. (9b)] is reasonably justified, the results of the recent asymmetry measurements (Refs. 1–4) together with the observed muon capture rate[6] imply both the validity of CVC and the absence of second-class axial vector currents. The sensitivity to the validity of PCAC can be reflected by the fact that, if we attribute an unlikely large uncertainty of about 40% to Eq. (9a), then the errors quoted in Eqs. (10a) and (10b) need to be doubled. Nevertheless, Eq. (10a) provides an additional test of CVC and the validity of such a new argument is less sensitive to the observed recoil ^{12}B polarization.[7] Clearly, using Eqs. (10a), (10b), (2a), and (5d), the observed value of P_{av} [Eq. (5c)] yields

$$\frac{F_P^-(q_m^2)}{F_A^-(q_m^2)} = -(1.02 \pm 0.28) \tag{10c}$$

which can be viewed as a consistency check of using Eq. (9b) as an input in the derivation of Eqs. (10a) and (10b).

Either of Eqs. (6) and (10a) confirms the experiment of testing CVC by measuring the $e^{\mp}$ energy spectra and extracting the shape factors.[18,20,21] It is indeed remarkable to note that, in the $A=12$ case (and so far only in this case), the basic ingredients of the standard picture, namely, the validity of CVC and PCAC and the absence of second-class axial vector currents, have now been *individually* confirmed by the experimental data. Apart from the desire to improve the experimental errors, what remains is the theoretical calculation of the nuclear form factors $F^{\mp}_{M,A,P,E}(q^2)$. The purpose of such theoretical manipulations is to test the nuclear models rather than to challenge the fundamental principles (CVC, PCAC, and no second-class currents). Clearly, a consistent, and yet convincing, formulation to calculate $\{F_{M,A,P,E}\}_{\mathrm{MEC}}$ and $\{F^{\mp}_{M,A,P,E}\}_{\mathrm{EM}}$ is very desirable. Unfortunately, the values of $\{F_{M,A,P,E}\}_{\mathrm{NOIA}}$ are already sensitive to the details of nuclear wave functions. To illustrate this last statement, we obtain, from the formulas in Ref. 5,

$$\frac{\{F_E^{(\mathrm{I})}(0)\}_{\mathrm{NOIA}}}{\{F_A(0)\}_{\mathrm{NOIA}}} = 1 + 2\frac{\mathfrak{M}_{\sigma p z}(0)}{\mathfrak{M}_{\mathrm{GT}}(0)} + \frac{2m_p\Delta^-}{m_\pi^2}\,\delta\,, \tag{11a}$$

$$\frac{\{F_P(q_m^2)\}_{\mathrm{NOIA}}}{\{F_A(q_m^2)\}_{\mathrm{NOIA}}} = -1.02\left(1+\frac{q_m^2}{m_\pi^2}\right)^{-1} + \delta \tag{11b}$$

with

$$\delta \equiv \frac{1}{4}\lim_{q^2\to 0}\frac{m_\pi^2}{q^2}\frac{\mathfrak{M}_{\sigma Q}(q^2)}{\mathfrak{M}_{\mathrm{GT}}(q^2)}\,.$$

Both the values of $\mathfrak{M}_{\sigma p z}(0)$ and δ depend sensitively on the details of nuclear wave functions. In the analysis of Ref. 5, the terms in δ were neglected since the corrections due to these terms are not expected to be more appreciable than $\{F_{M,A,P,E}\}_{\mathrm{MEC}}$ or $\{F^{\mp}_{M,A,P,E}\}_{\mathrm{EM}}$ (which were neglected already). In view of the presence of an appreciable MEC,[15,17] more accurate results are desirable and the terms in δ must also be included. In particular, if the Cohen-Kurath wave functions of ^{12}C(g.s.) and ^{12}B(g.s.) are used, we have $\delta=-0.28$ (Ref. 29). Accordingly, we obtain

$$\frac{\{F_E^{(\mathrm{I})}(0)\}_{\mathrm{NOIA}}}{\{F_A(0)\}_{\mathrm{NOIA}}} = 3.25 \pm 0.08\,, \tag{12a}$$

$$\frac{\{F_P(0)\}_{\mathrm{NOIA}}}{\{F_A(0)\}_{\mathrm{NOIA}}} = -1.30\,,$$

$$\frac{\{F_P(q_m^2)\}_{\mathrm{NOIA}}}{\{F_A(q_m^2)\}_{\mathrm{NOIA}}} = -0.99\,. \tag{12b}$$

To clarify the situation regarding the legitimacy of using the Cohen-Kurath wave functions, we first quote the MEC result obtained by Noble[17] and, to compensate our ignorance of the EM corrections (isospin-symmetry breaking), we attribute an uncertainty to the final result of as large as $[F_A^-(0) - F_A^+(0)]/F_A^-(0)$. Thus we obtain

$$\left(\frac{F_E^{(1)-}(0)}{F_A^-(0)}\right)_{\text{theory}} = 4.5 \pm 0.5\,. \qquad (12c)$$

Here the theoretical uncertainties attributed to the NOIA and MEC contributions are taken, respectively, as ±0.1 and ±0.2. The uncertainity of the NOIA contribution arises mainly from the fact that at least three slightly different sets of Cohen-Kurath nuclear wave functions are at stake. The quoted uncertainty for the MEC contribution is probably too small since not only the existing procedures[15,17,22,23] to calculate the MEC remain to be confirmed experimentally but the parameters (coupling constants, etc.) involved in these calculations are not known very well. Clearly, after the terms in δ and all the theoretical uncertainties are put together, it becomes not clear whether a discrepancy between theory [Eq. (12c)] and experiment [Eq. (2a)] indeed exists. On the other hand, the experimental value of P_{av} (0.47 ± 0.05) is in excellent agreement with the NOIA prediction of the standard picture, in which the Cohen-Kurath wave functions are invoked. Nonetheless, any MEC (to PCAC) of ordinary size can still be tolerated in view of the large experimental error [Eqs. (5c) and (8b)]. In any event, it should be very interesting to elaborate the work of Ref. 28, although a drastic departure from PCAC is unlikely.

In summary, we have shown in a model-independent fashion that, even without the CVC test by extracting the shape factors from the observed $e^{\mp}$ energy spectra[18-21] in the β decays of ^{12}B and ^{12}N, the basic ingredients of the standard picture, namely, CVC, PCAC, and the absence of second-class axial vector currents, have now been *individually* confirmed by the combination of the muon capture data[6,7] and the results of the asymmetry measurements.[1-4] Further, the presence of appreciable meson-exchange corrections[15,17] does not cause any serious discrepancy between the data [Eq. (2a)] and the Cohen-Kurath model[14] after the spin-quadrupole-moment term and all the theoretical uncertainties are also taken into account.

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