ANALYSIS OF EFFECTIVE COUPLINGS FROM NEUTRINO-HADRON SCATTERING

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ABSTRACT

We present an updated fit to the model independent parameters entering the effective neutrino-quark interaction Lagrangian, using all relevant data from neutrino-hadron scattering. For the theoretical evaluations we employ the most recent parton distribution functions.

INTRODUCTION

In this work, we present a modern global analysis of ν-hadron scattering experiments. The major complication arises from the reduction of the measured hadronic cross sections to the quark-level effective charged current (CC) and neutral current (NC) Lagrangians,

$$\mathcal{L}^{\nu q}_{\text{CC}} = -\frac{2}{v^2}\overline{\nu_L}\gamma^\mu\nu_L[\epsilon_L(u)\overline{u_L}\gamma_\mu u_L + \epsilon_R(u)\overline{u_R}\gamma_\mu u_R + \epsilon_L(d)\overline{d_L}\gamma_\mu d_L + \epsilon_R(d)\overline{u_R}\gamma_\mu d_R] \tag{1}$$

where we suppressed family indices, where $v \equiv [\sqrt{2}G_F]^{-1/2} = 246.22$ GeV is the EW scale. In the SM one can also other parametrizations involving,

$$g_L^2 \equiv \epsilon_L(u)^2 + \epsilon_L(d)^2 = -0.3053 \simeq -\frac{1}{2} - \hat{s}_Z^2 + \frac{5}{9}\hat{s}_Z^4, \tag{2}$$

$$g_R^2 \equiv \epsilon_R(u)^2 + \epsilon_R(d)^2 = -0.0295 \simeq -\frac{1}{2} - \hat{s}_Z^2 + \frac{5}{9}\hat{s}_Z^4, \tag{3}$$

$$\tan\theta_L \equiv \frac{\epsilon_L(u)}{\epsilon_L(d)} = -0.8080 \simeq -2 + [1 - \frac{3}{2}\hat{s}_Z^2]^{-1}, \tag{4}$$

$$\tan\theta_R \equiv \frac{\epsilon_R(u)}{\epsilon_R(d)} = -1.9976 = -2 + \frac{3\hat{\alpha}_Z}{4\pi\hat{\kappa}^{\nu N}\hat{c}_Z^2}, \tag{5}$$

Where $\hat{s}_Z^2$ is the sine of the Weinber angle ($\hat{s}_Z^2 = 0.23126$).

χ^2 FUNCTION

The χ^2 is given by

$$\chi^2 = \sum_{j\in\text{observables}} \frac{\left(O_j^{\text{exp}} - O_j^{\text{th}}\right)^2}{\sigma^2_{O_j^{\text{exp}}}} + \sum_{k=1}^{28}\frac{(x_k - \bar{x}_k)^2}{\sigma^2_{x_k}} + \chi^2_{\text{E734}} + \chi^2_{\text{corr}}, \tag{6}$$

where O^{exp} and $\sigma_{O_j^{\text{exp}}}$ are given in column 2 Tables 2–4, σ_{x_k} are the x_k uncertainties, "observables" stand for observables that have no correlation with any other and χ^2_{E734} is the sum of Eq. 7 plus the constraint for M_A.

$$\chi^2 = (O^{\text{th}} - O^{\text{ex}})_i(\text{Cov}^{-1})_{ij}(O^{\text{th}} - O^{\text{ex}})_j, \tag{7}$$

where the O is the differential cross-section $d\Sigma_\nu/dQ_i^2$ for i =1,7 and $d\Sigma_{\bar{\nu}}/dQ_i^2$ for $i = 7,14$. The χ-square for deep inelastic observables having correlations is $\chi^2_{\text{corr}} = \Delta\chi^2_{3,4} + \Delta\chi^2_{5,6} + \Delta\chi^2_{14,15} + \Delta\chi^2_{27,28} + \Delta\chi^2_{31,32} + \Delta\chi^2_{42,43}$, where

$$\Delta\chi^2_{i,j} = \frac{(\text{pull}(i)^2 + \text{pull}(j)^2 - 2\rho_{i,j}\text{pull}(i)\text{pull}(j))}{\sqrt{1-\rho^2_{i,j}}}, \tag{8}$$

i,j	3,4	5,6	14,15	27,28	31,32	42,43
$\rho_{i,j}$	(-0.634)	(-0.780)	(+0.313)	(-0.017)	(+0.339)	(+0.163)

Table 1 – correlation parameters

the correlation parameters $\rho_{i,j}$ are shown in Tabe 1 and

$$\text{pull}(j) = \left(O_j^{\text{exp}} - O_j^{\text{th}}\right)/(\sigma_{O_j^{\text{exp}}}). \tag{9}$$

DATA TREATMENT

O_{exp}	Experimental value	E_ν	$E_{h\text{-cut}}$	η^*	Collaboration
O_1	R_ν =0.3072± 0.0032	85	10	0.082	CDHS (Abramowicz)
O_2	R_ν =0.3093± 0.0031	85	4	0.000	CHARM (Allaby)
O_3	g_L^2 =0.2917± 0.0093	60	20	0.010	CCFRR (Reutens)
O_4	g_R^2 =0.0298± 0.0087	60	20	0.010	CCFRR (Reutens)
O_5	g_L^2 =0.2820± 0.0142	61	9	0.010	FMM (Bogert)
O_6	g_R^2 =0.0440± 0.0136	61	9	0.010	FMM (Bogert)
O_7	R_ν =0.3010± 0.0070	70	10	0.069	CDHS (Abramowicz)

Table 2 – Deep inelastic scattering from isoscalar targets. Here $R_\nu = \sigma_\nu^{NC}/\sigma_\nu^{CC}$ and$R_{\bar{\nu}} = \sigma_{\bar{\nu}}^{NC}/\sigma_{\bar{\nu}}^{\overline{CC}}$ are the ratios of the neutral current cross-section to the charged current cross-section for neutrinos and antineutrinos respectively. g_L^2 and g_R^2 are the neutral current electroweak couplings at $Q_0^2 = 20$ GeV^2. E_ν is the average neutrino energy in the beam, $E_{h\text{-cut}}$ is the lower hadronic energy and $\eta^* = (n-p)/(n+p)$. Where n and p represent the number of neutrons and protons inside the nucleon.

O_{exp}	Experimental value	E_ν	$E_{h\text{-cut}}$	η^*	Collaboration
O_{31}	R_ν^p= 0.3840± 0.0283	20	8	-1	BBCIMOU(Jones)
O_{32}	$R_{\bar{\nu}}^p$= 0.3380± 0.0213	20	8	-1	BBCIMOU(Jones)
O_{33}	R_ν^p= 0.4700± 0.0400	28	10	-1	BEBC-TST(Armenise)
O_{34}	$R_{\bar{\nu}}^p$= 0.3300± 0.0400	24	10	-1	BEBC-TST(Armenise)
O_{35}	R_ν^p= 0.4900± 0.0600	20	0	-1	SIMTT(Kafka)
O_{36}	R_ν^n= 0.2200± 0.0300	20	0	1	SIMTT(Kafka)
O_{37}	$R_{\bar{\nu}}^p$= 0.3600± 0.0600	25	0	-1	PAC(Carmony)
O_{38}	R_ν^p= 0.5100± 0.0400	37	5	-1	ABCMO(Blietschau)
O_{39}	R_ν^p= 0.4800± 0.1700	25	10	-1	FLHM(Harris)
O_{40}	$R_{\bar{\nu}}^{(n/p)}$= 0.8800± 0.1700	15	0	1/-1	FIIM(Gorichev)
O_{41}	$R_\nu^{(n/p)}$= 1.0800± 0.1900	18	5	1/-1	LW(Marriner)
O_{42}	r_ν= 0.0600± 0.0583	20	5	-	ABBPPST(Allasia)
O_{43}	$r_{\bar{\nu}}$= 0.0200± 0.0949	25	5	-	ABBPPST(Allasia)

Table 3 – Deep inelastic scattering from non-isoscalar targets. Here $R_\nu^p = \sigma_{\nu p}^{NC}/\sigma_{\nu p}^{CC}$, $R_{\bar{\nu}}^p = \sigma_{\bar{\nu}p}^{\overline{NC}}/\sigma_{\bar{\nu}p}^{\overline{CC}}$ $R_\nu^n = \sigma_{\nu n}^{NC}/\sigma_{\nu n}^{CC}$, $R_{\bar{\nu}}^n = \sigma_{\bar{\nu}n}^{\overline{NC}}/\sigma_{\bar{\nu}n}^{\overline{CC}}$, $r_\nu = (\sigma_{\nu n}^{NC} - \sigma_{\nu p}^{NC})/(\sigma_{\nu n}^{CC} - \sigma_{\nu p}^{CC})$ and $r_{\bar{\nu}} = (\sigma_{\bar{\nu}n}^{\overline{NC}} - \sigma_{\bar{\nu}p}^{\overline{NC}})/(\sigma_{\bar{\nu}n}^{\overline{CC}} - \sigma_{\bar{\nu}p}^{\overline{CC}})$, where $\sigma_{\bar{\nu}p(n)}^{\overline{NC}}$ and $\sigma_{\bar{\nu}n(p)}^{\overline{CC}}$ are the neutral and charged current cross-sections on protons (neutrons) respectively. E_ν is the average neutrino energy in the beam, $E_{h\text{-cut}}$ is the lower hadronic energy and $\eta^* = (n-p)/(n+p)$, with n and p represent the number of neutrons and protons inside the nucleon.

O_{exp}	Experimental value	Collaboration
O_{49}	β^2 = 0.9300± 0.1400	NOMAD(Kullenberg)
O_{50}	β^2 = 0.9300± 0.3700	SKAT(Grabosch)
O_{51}	β^2 = 1.0800± 0.5400	CHARM(Bergsma)
O_{52}	β^2 = 0.9300± 0.3800	CHARM(Vilain)
14 Q^2 values	$d\Sigma/dQ^2$	E734(Ahrens)

Table 4 – The O_{49}-O_{52} observables comes from coherent pion production $\nu N \longrightarrow \nu\pi^0 N$. In the standard model $1 = \beta = \epsilon_L(u) - \epsilon_R(u) - \epsilon_L(d) + \epsilon_R(d)$. In the E734 experiment there was seven $d\Sigma_\nu/dQ_i^2$ observables and seven $d\Sigma_{\bar{\nu}}/dQ_i^2$ for elastic scattering of neutrinos and antineutrinos from protons respectively.

RESULTS

Quantity	Amaldi	Erler	SM-Q_0^2=20 GeV^2	SM-$Q_0^2 = 2.2$ GeV^2
g_L^2	0.2996 ± 0.0044	0.3009 ± 0.0028	0.3038	0.3034
g_R^2	0.0298 ± 0.0038	0.0328 ± 0.0030	0.0300	0.0302
θ_L	2.47 ± 0.04	2.50 ± 0.035	2.46	2.46
θ_R	$4.65^{+0.48}_{-0.32}$	$4.56^{+0.42}_{-0.27}$	5.18	5.18

Table 5 – Model independent electroweak parameters in previous fits at $Q_0^2 = 20$ GeV^2. The last two columns are the standard model predictions at $Q_0^2 = 20$ GeV^2 and $Q_0^2 = 2.2$ GeV^2 respectively.

	AMALDI	+CCFR	+NUTEV	Erler
d.o.f	22.00/49	27.34/53	27.62/55	
g_L^2	$0.2991^{+0.0040}_{-0.0041}$	$0.2992^{+0.0038}_{-0.0040}$	$0.3003^{+0.0025}_{-0.0024}$	0.3034
g_R^2	$0.0292^{+0.0047}_{-0.0043}$	$0.0332^{+0.0045}_{-0.0041}$	$0.0311^{+0.0011}_{-0.0011}$	0.0302
θ_L	$2.45^{+0.05}_{-0.05}$	$2.46^{+0.05}_{-0.05}$	$2.46^{+0.04}_{-0.05}$	2.46
θ_R	$4.87^{+0.40}_{-0.30}$	$4.76^{+0.46}_{-0.27}$	$4.82^{+0.44}_{-0.28}$	5.18
m_c	$1.30^{+0.23}_{-0.24}$	$1.26^{+0.23}_{-0.23}$	$1.27^{+0.23}_{-0.23}$	
R_L	$0.10^{+0.09}_{-0.09}$	$0.12^{+0.09}_{-0.09}$	$0.10^{+0.08}_{-0.07}$	
M_A	$1.028^{+0.025}_{-0.025}$	$1.024^{+0.026}_{-0.025}$	$1.026^{+0.026}_{-0.024}$	

Table 6 – Best fit values of the electroweak parameters at $Q_0^2 = 2.2$ GeV^2. The second column corresponds to the best position when we only consider the ν_μ-hadron experiments quoted in(Amaldi). The third column is the result when we exclude Nutev from our data, this result is consistent with the best fit just before Nutev experiment (Erler), the fourth column is the best fit position taking into account all the data. Except for g_L^2 it is consistent with the SM predictions in Table 5.

CONCLUSIONS

Our analysis reproduce the classical results of Amaldi et al. We also elaborate a proposal to include the NuTev análisis in the global fit, although there are several questions to be resolved regarding the inclusion of this experiment with a different PDF set than the one used by NuTeV.