Resonances with different spins in neutrinoproduction

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Outline

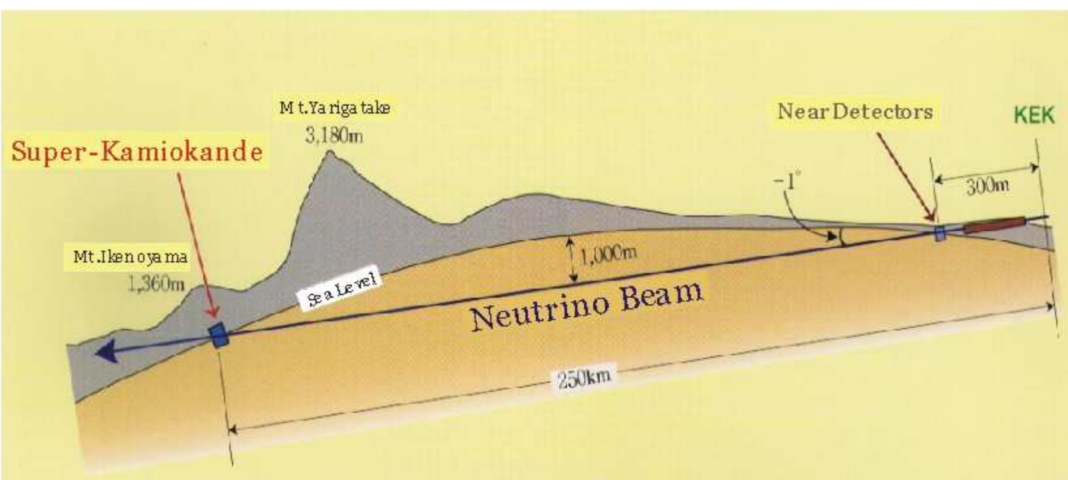
- Phenomenological way to describe the resonances production: vector and axial formfactors, the general form for the spin-1/2 and spin-3/2 resonances
- General ways to determine the form factors from the experiments and theoretical principles
- Form factors for $P_{33}(1232)$, $P_{11}(1440)$, $D_{13}(1520)$ and $S_{11}(1535)$
- The role of the second resonance region in the neutrino cross section at different energies (cross sections)
- Conclusions

Why to study one pion production

The first evidence about the neutrino oscillations came from SuperKamiokande, where the $\mu-$deficit was observed for atmospheric neutrinos. Then evidences came for solar neutrinos from SNO.

It became clear that for the subsequent measurements of the mixing matrix elements more precise measurements are needed. Thus one comes to the idea of ”artificial” neutrino sources and long baseline exepriments.

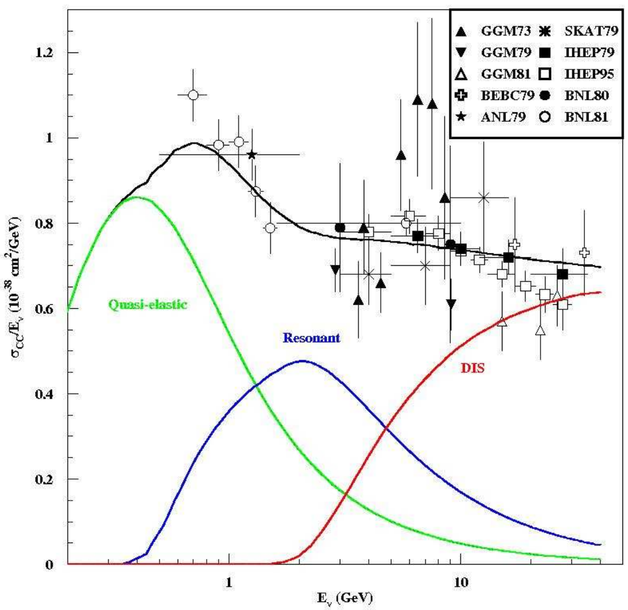
Among the artificial neutrinos there are ”reactor neutrinos”, which are $\bar{\nu}_e$ with the energy of few MeV. We are mainly interested in the $accelerator\ \ neutrinos$, 99% of which are ν_μ with the energy $few\ \mathrm{GeV}$.



neutrino.kek.jp/news/

2004.06.10/index-e.html

Resonance production



$\sigma_{tot} = \sigma_{\mathrm{QE}} + \sigma_{\mathrm{RES}} + \sigma_{\mathrm{DIS}}$

1) quasi-elastic (QE)

$\nu_\mu n \rightarrow \mu^- p$

2) one-pion-production $\equiv$

resonance production (RES)

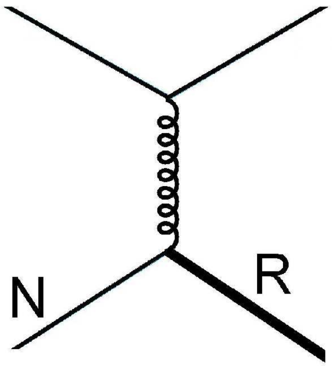
$\nu_\mu N \rightarrow \mu^- R \rightarrow \mu^- N' \pi$

3) deep inelastic scattering (DIS)

$\nu_\mu N \rightarrow \mu^- X$

R	M_R, GeV	$\Gamma_{R(tot)}$, GeV	elasticity $\Gamma_R(R \rightarrow \pi N)/\Gamma_{R(tot)}$
$P_{33}(1232)(\Delta^{++}, \Delta^{+}, \Delta^{0}, \Delta^{-})$	1.232	0.114	0.995
$P_{11}(1440)(P_{11}^{+}, P_{11}^{0})$	1.440	$0.350(250-450)$	$0.6(0.6-0.7)$
$D_{13}(1520)(D_{13}^{+}, D_{13}^{0})$	1.520	$0.125(110-135)$	$0.5(0.5-0.6)$
$S_{11}(1535)(S_{11}^{+}, S_{11}^{0})$	1.535	$0.150(100-250)$	$0.4(0.35-0.55)$

Phenomenological description



For $E_\nu \sim few\,\mathrm{GeV}$, $2m_N E_\nu << m_W^2$, so the weak vertex is described as Fermi 4-fermion intreraction (current-current interaction)

$$\frac{G_F}{\sqrt{2}} J^\nu_{(\mathrm{hadronic})} j_\nu^{(\mathrm{leptonic})}, \qquad J^\nu_{(\mathrm{hadronic})} = V^\nu - A^\nu$$

The hadronic current is parametrized in terms of the

nucleon-resonance form factors (vector and axial)

which depend on the transfered momentum

These form factors are independent of the flavor of the incoming nutrino (and correspondingly outgoing muon). So one can simulate them for ν_μ and then use for ν_e and ν_τ.

Form factors for $P_{33}(1232)$ $(J^P = \frac{3}{2}^+)$

Earlier articles in this notation: Dufner, Tsai, PR 168, 1801; Lewellyn Smith, PR 3 (1972) 261; Schreiner, von Hippel, NPB58 (1983) 333; Paschos, Sakuda, Yu, PRD 69 (2004) 014013; Singh, Athar, Ahmad, hep-ph/0507016;

The resonance field is described by a Rarita-Schwinger spinor $\psi_\lambda^{(R)}$. Quite generally the weak vertex for the resonance production may be written as

$$\langle\Delta|V^\nu|N\rangle = \bar{\psi}_\lambda^{(R)}\left[\frac{C_3^V}{m_N}(\not{q}g^{\lambda\nu} - q^\lambda\gamma^\nu) + \frac{C_4^V}{m_N^2}(q\cdot p g^{\lambda\nu} - q^\lambda p^\nu) + \frac{C_5^V}{m_N^2}(q\cdot p' g^{\lambda\nu} - q^\lambda p'^\nu) + C_6^V g^{\lambda\nu}\right]\gamma_5 u_{(N)}$$

$$\langle\Delta|A^\nu|N\rangle = \bar{\psi}_\lambda\left[\frac{C_3^A}{m_N}(\not{q}g^{\lambda\nu} - q^\lambda\gamma^\nu) + \frac{C_4^A}{m_N^2}(q\cdot p g^{\lambda\nu} - q^\lambda p^\nu) + C_5^A g^{\lambda\nu} + \frac{C_6^A}{m_N^2}q^\lambda q^\nu\right]u_{(N)}$$

dictated by gauge invariance

How the form factors can be determined

CVC: $q^\mu J_\mu = 0 \quad \Longrightarrow \quad C_6^V = 0$,

PCAC: $i\overline{\Delta_\mu^+} q^\mu \left[C_5^A + \frac{C_6^A}{m_N^2} q^2 \right] u_N, = -i\sqrt{\frac{1}{3}} \frac{m_\pi^2 f_\pi}{q^2 - m_\pi^2} \overline{\Delta_\mu^+} g_\Delta q^\mu u_N.$ Other FF can be

$$\Longrightarrow C_5^A(Q^2 = 0) = \frac{g_\Delta f_\pi}{\sqrt{3}} = 1.2 \qquad C_6^A = m_N^2 \frac{C_5^A}{m_\pi^2 + Q^2}$$

fixed theoretically only within a certain model.

Helicity amplitudes evaluated from the electroproduction data at $W = M_R$ Tiator et al., EPJA 19 (2004) 55; Burkert, Lee, IJMPE(2004)

The relations to C_i^V are calculated by our group

$$A_{3/2} = \sqrt{\frac{\pi\alpha}{m_N(W^2 - m_N^2)}} \langle R, +\tfrac{3}{2} | J_{em} \cdot \varepsilon^{(R)} | N, +\tfrac{1}{2} \rangle = A_{3/2}(C_i^V)$$

$$A_{1/2} = \sqrt{\frac{\pi\alpha}{m_N(W^2 - m_N^2)}} \langle R, +\tfrac{1}{2} | J_{em} \cdot \varepsilon^{(R)} | N, -\tfrac{1}{2} \rangle = A_{1/2}(C_i^V)$$

$$S_{1/2} = \sqrt{\frac{\pi\alpha}{m_N(W^2 - m_N^2)}} \frac{q_z}{\sqrt{Q^2}} \langle R, +\frac{1}{2} | J_{em} \cdot \varepsilon^{(S)} | N, +\frac{1}{2} \rangle = S_{1/2}(C_i^V)$$

Vector form factors for $P_{33}(1232)$

- comparison with electroproduction cross section (1968 - 1971) $C_3^V(0) = 2.05 \pm 0.04$, and magnetic multipole dominance leads to $C_4^V(0) = -\frac{m_N}{W} C_3^V, \quad C_5^V = 0$
- FF fall down with Q^2 faster than dipole $\frac{1}{(1+\frac{Q^2}{M_V^2})^2} \equiv \frac{1}{D}$ with $M_V = 0.84$ GeV

  different parametrizations for C_3^V, which give approximately the same

$$\frac{C_3^V(0)}{D} \frac{1}{1+\frac{Q^2}{4M_V^2}} \qquad \frac{C_3^V(0)}{(1+\frac{Q^2}{0.54\ \mathrm{GeV}^2})^2} \qquad \left[(C_3^V(0))^2(1+9\sqrt{Q^2})e^{-6.3\sqrt{Q^2}}\right]^{1/2}$$

Paschos, Sakuda, Yu — Dufner, Tsai

- beyond the magnetic dominance

  2001: unambigious evidences from the JLAB for the contribution of the electric $E2 \sim -2.5\%$, of scalar multipoles $S2 \sim -5\%$. They are taken into account by extracting the form factors from the helicity amplitudes Lalakulich.,Paschos,G.P.,2005

$$C_3^V = \frac{2.1}{D} \cdot \frac{1}{1+Q^2/4M_V^2}, \qquad C_4^V = \frac{-1.4}{D} \cdot \frac{1}{1+Q^2/6M_V^2}, \qquad C_5^V = \frac{-0.25}{D} \cdot \frac{1}{1+Q^2/M_V^2}$$

$P_{33}(1232)$, axial form factors

From PCAC $C_5^A = 1.2, \quad C_6^A = m_N^2 \frac{C_5^A}{m_\pi^2 + Q^2}$.

Other form factors C_3^A, C_4^A cannot be determined form general principles.

$C_4^A = -C_5^A/4, \quad C_3^A = 0$ is favoured by Adler's model and gives good agreement with the experiment.

As Q^2 increases, axial form factors also fall down steeper than dipole.

$\frac{1}{D_A} = \frac{C^A(0)}{\left(1 + \frac{Q^2}{{M_A}^2}\right)^2}$ with $M_A \approx 1.0 \text{ GeV}$

Summary:

1) axial form factor C_5 is determined through PCAC and expressed through the decay width

2) vector form factor are determined from electroproduction data

The same procedure will be applied to higher resonances

$D_{13}(1520)$: $J^P = 3/2^-$

The parametrization of weak vertex for this resonance are similar to that for P_{33} with the γ_5 appeared in axial part instead of vector one: there are 3 independent vector form factors and 3 independent axial form factors.

Vector form factors are extracted from photoproduction helicity amplitudes:

$C_i^{V(iV)} = \frac{1}{2}\left(C_i^{V(p)} - C_i^{V(n)}\right)$

$$C_3^{(iV)} = \frac{2.2}{D} \cdot \frac{1}{1 + Q^2/5.3M_V^2}, C_4^{(iV)} = \frac{-0.89}{D}, \quad C_5^{(iV)} = \frac{-0.11}{D}.$$

Axial form factors:

From PCAC $C_6^A(D_{13}) = m_N^2 \frac{C_5^A(D_{13})}{m_\pi^2 + Q^2}$, $\quad C_5^A(D_{13}) = \sqrt{\frac{2}{3}} g_{\pi NR} f_{D13} = 2.1$ and we do not know the Q^2–dependence

We also do not know C_3^A, C_4^A

We take arbitrarily $C_3^A(0) = 0$, $C_4^A(0) = 0$, $C_i^A(Q^2) = \frac{C_i^A(0)}{D_A} \frac{1}{1 + Q^2/3/M_A^2}$

with the axial mass common for all the resonances $M_A = 1.05$ GeV

$P_{11}(1440)$, $J^P = \frac{1}{2}^+$ and $S_{11}(1535)$, $J^P = \frac{1}{2}^-$

For the spin-1/2 resonances all formulas are simpler

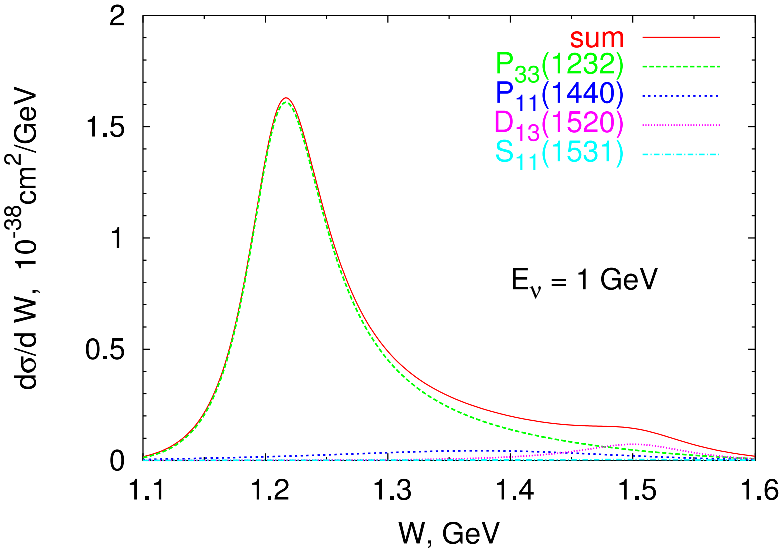
$$\langle P_{11}|V^\nu|N\rangle = \bar{u}^{(P_{11})}\left[g_1^V\gamma^\nu + \frac{i}{M_P + m_N} g_2^V\sigma^{\nu\lambda}q_\lambda + g_3^V q^\nu\right]\gamma_5 u_{(N)}$$

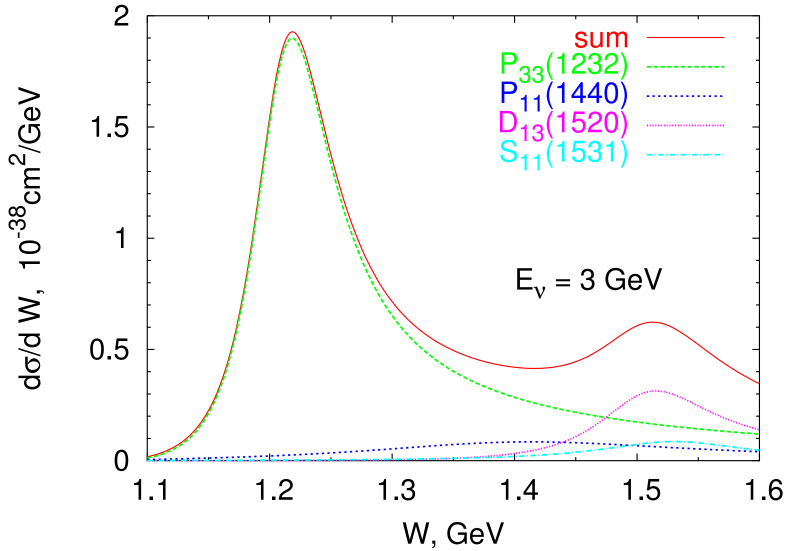
$$\langle P_{11}|A^\nu|N\rangle = \bar{u}^{(P_{11})}\left[g_1^A\gamma^\nu + \frac{i}{M_P + m_N} g_2^A\sigma^{\nu\lambda}q_\lambda + g_3^A q^\nu\right] u_{(N)}$$

$$\langle S_{11}|V^\nu|N\rangle = \bar{u}^{(S_{11})}\left[g_1^V\gamma^\nu + \frac{i}{M_P + m_N} g_2^V\sigma^{\nu\lambda}q_\lambda + g_3^V q^\nu\right] u_{(N)}$$

$$\langle S_{11}|A^\nu|N\rangle = \bar{u}^{(S_{11})}\left[g_1^A\gamma^\nu + \frac{i}{M_P + m_N} g_2^A\sigma^{\nu\lambda}q_\lambda + g_3^A q^\nu\right]\gamma_5 u_{(N)}$$

Neutrinoproduction at different E_ν

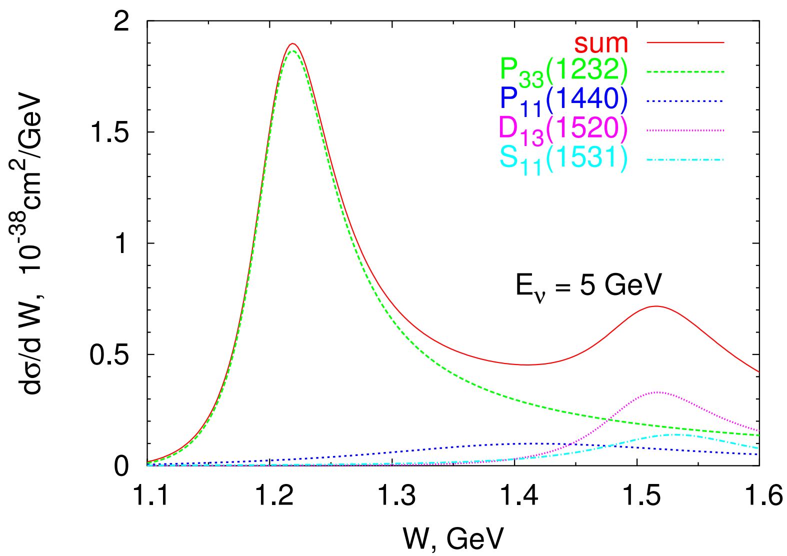




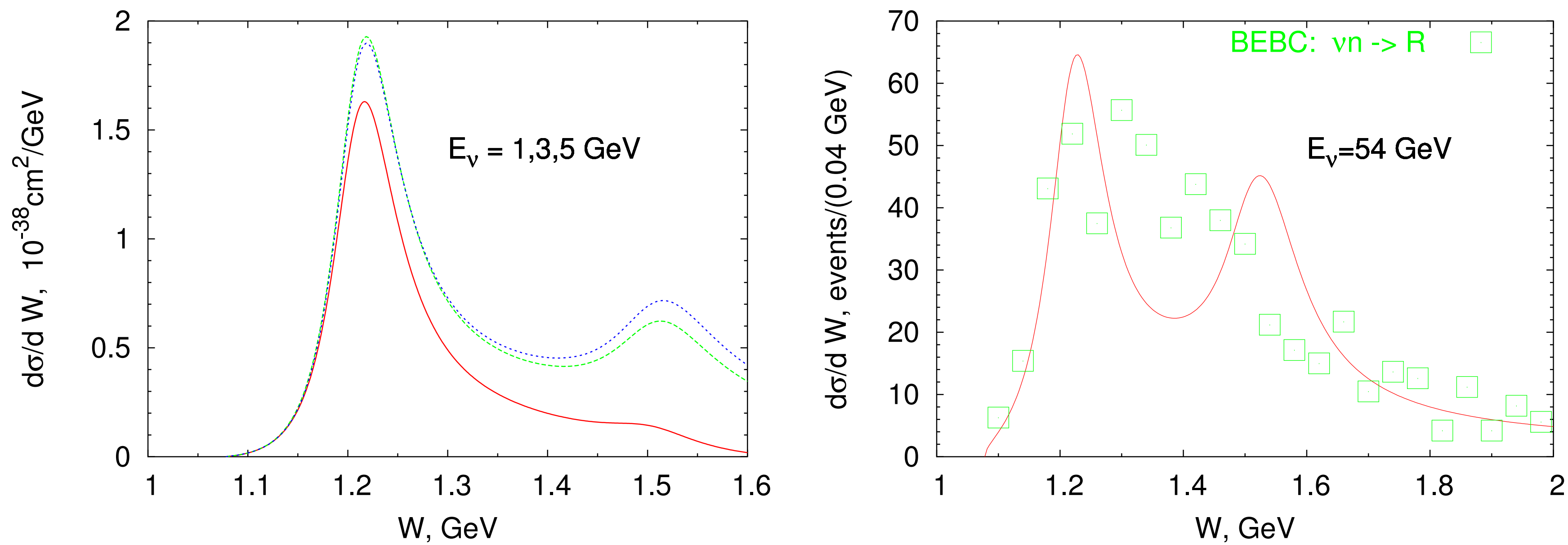
P_{11} is too small to be seen as separate peak

D_{13} and S_{11} are seen as one peak

the second resonance region become more pronounce as neutrino energy increases



Neutrinoproduction at different E_ν



- At $E_\nu < 1$ GeV the second resonance region is negligible in neutrino scattering. It will not be seen in K2K and MiniBOONE.
- At $E_\nu \sim 50$ GeV the two peaks are clearly seen. However, BEBC experiment Allasia et al, NPB 343 (1990) 285 didn't resolve them.

Summary

- The new experimental data of resonance electroproduction are available. It helps to investigate second resonance region($P_{11}(1440)$,$D_{13}(1520)$,$S_{11}(1535)$).
- The form factors of neutrinoproduction of resonances $P_{11}(1440)$, $D_{13}(1520)$, $S_{11}(1535)$ are produced firstly.
- For the isospin-1/2 resonances the form factors fall down not so fast as for the Δ. For $P_{11}(1440)$ and $S_{11}(1535)$ decreasing at small Q^2 is even slower than dipole.
- The contribution of the isospin-1/2 resonances to the cross section grows with the increasing energy of the incoming neutrinos.