One–pion production in neutrino induced reactions

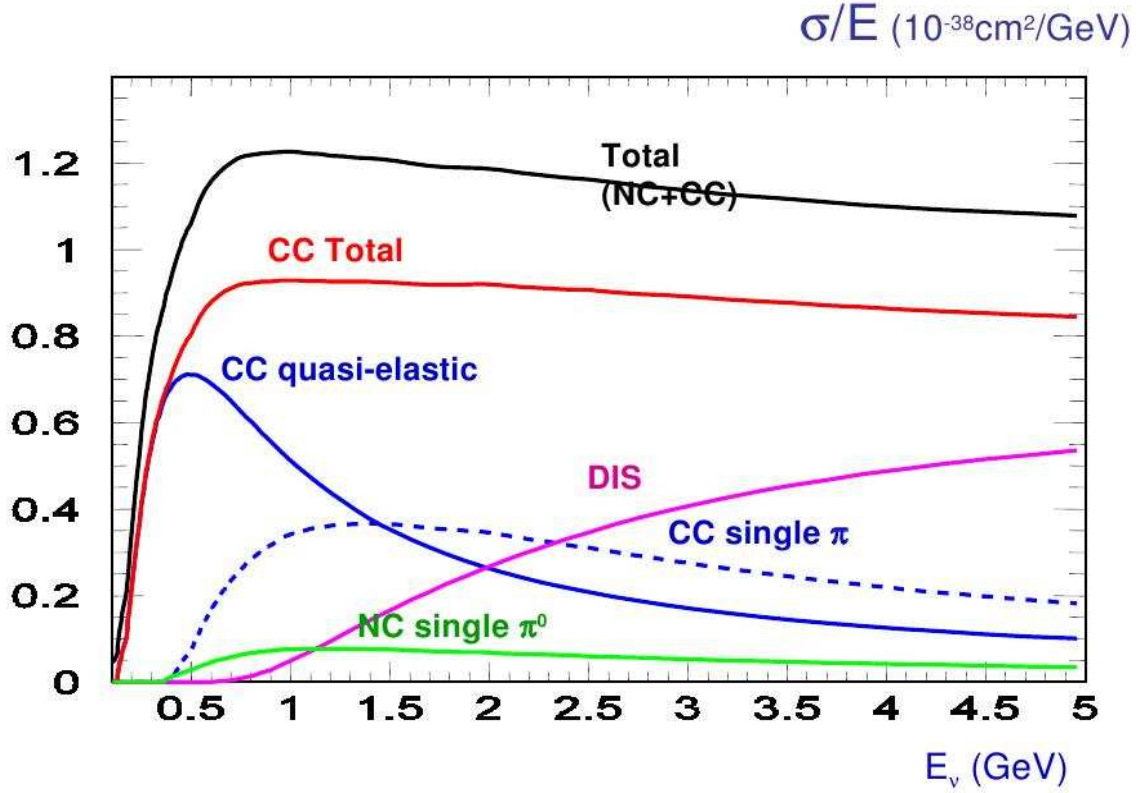
O. Lalakulich, O. Buss, T. Leitner, U. Mosel

Justus–Liebig University Giessen, Germany

Outline

1. One–pion production as resonance production + background
2. Neutrinoproduction: Phenomenological models of the background
3. Diagram approach to the 1-pion production
4. 7 diagrams: neutrino–nucleon interactions

The total cross section



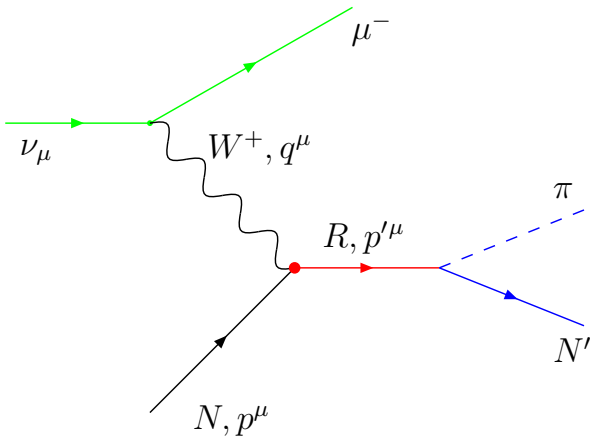
$\sigma_{tot} = \sigma_{\rm QE} + \sigma_{1\pi} + \sigma_{\rm DIS}$

- quasi-elastic (QE)
  $\nu_l n \to l^- p$
- one-pion-production
  $\nu_l N \to l^-(\nu_l)\pi N'$
- deep inelastic (DIS)
  $\nu_l N \to l^- X$

One–pion production as resonance production $+$ background

- Resonance production (RES) — peak in W distribution
  $\nu_l N \to l^- R \to l^- N'\pi$ (Charged Current)
  $\nu_l N \to \nu_l R \to \nu_l N'\pi$ (Neutral Current)
- background — smooth function of W (or ν) (Walker, 1969)
- resonance–background interference

Isobar model for resonance production



isobar diagram = resonance pole

The hadronic vertex is parametrized in terms of the *vector* and *axial* nucleon-resonance (transition) form factors

$R_{isospin,\,spin}$	M_R, GeV	$\Gamma_{R(tot)}$, GeV	elasticity $\Gamma_R(R \to \pi N)/\Gamma_{R(tot)}$
$P_{33}(1232)(\Delta^{++}, \Delta^+, \Delta^0, \Delta^-)$	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	$0.150(100-250)$	$0.4(0.35-0.55)$
+15 more with raiting 4*			

Leptonic vertex is known — independent on the resonance being produced

Theoretical model for *each resonance production vertex* is needed

Electroproduction is a benchmark for neutrinoproduction

Detailed multipole analysis of pion-, photon-, eta- electroproduction (40 years of experience), taking into account interfering resonant and non-resonant contributions
1) JLab model (Aznauryan et. al.)
2) MAID — A Unitary Isobar Model for Pion Photo- and Electroproduction on the Nucleon (Tiator et. al.)

Can one do the same theoretical model for neutrinoproduction?

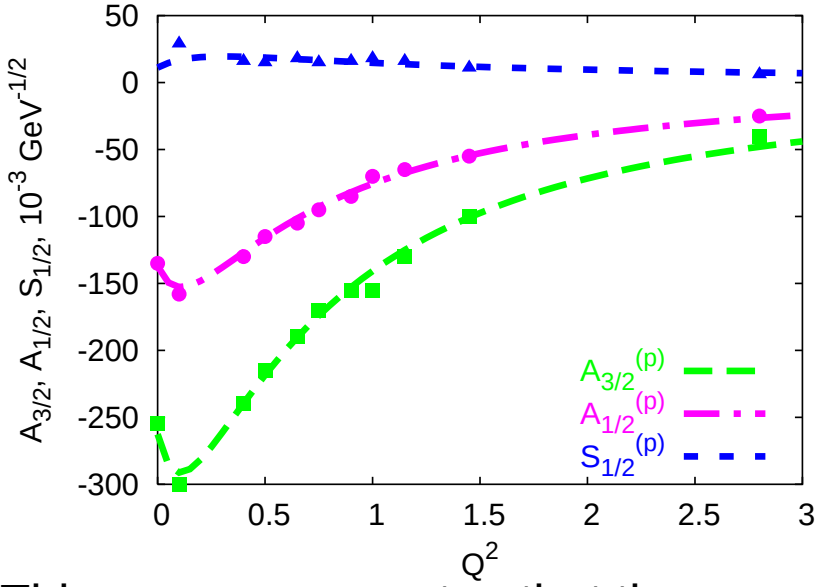
- the same level of difficulty for vector part
- plus conserved part of the axial current
- plus vector–axial interference
- plus extra for non–conserved part of the axial current

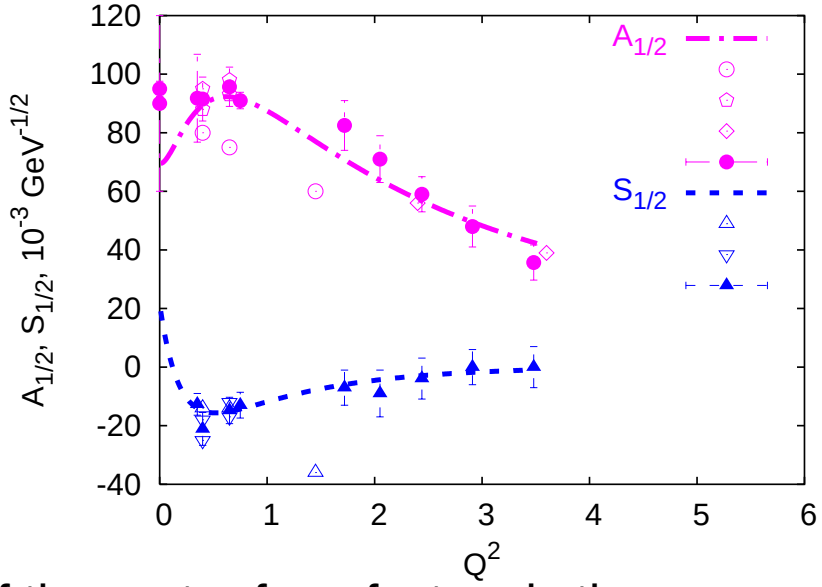
None did ... yet.

How can we use electroproduction analysis

What can we extract from electroproduction analysis without being experts in it?

- Helicity amplitudes $A_{3/2}$, $A_{1/2}$, $S_{1/2}$ describe resonace production
  We relate them to electromagentic transition (nucleon–resonance) form factors and perform a fit.





  This way we guarantee that the accuracy of the vector form factors is the same as the accuracy of the helity amplitudes (different for different resonances)

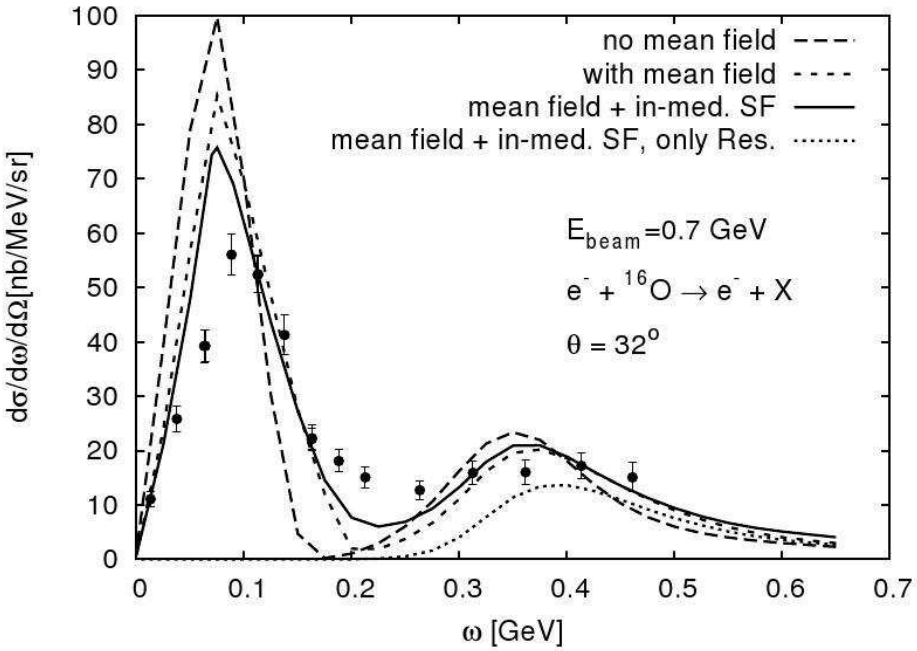
- nonresonant background = 1-pion xsec (exper) - resonance contribution

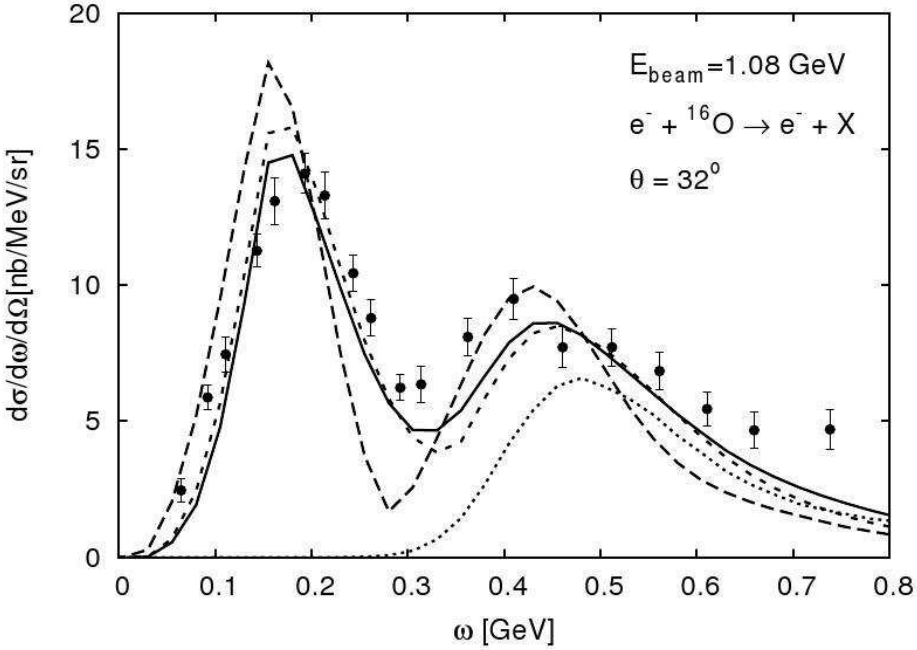
Pure phenomenological background

Buss, Leitner, Mosel, Alvarez-Ruso, PRC 76

background = MAID tot x-sec - resonance contribution

background is important for filling the gap between the QE and RES peak





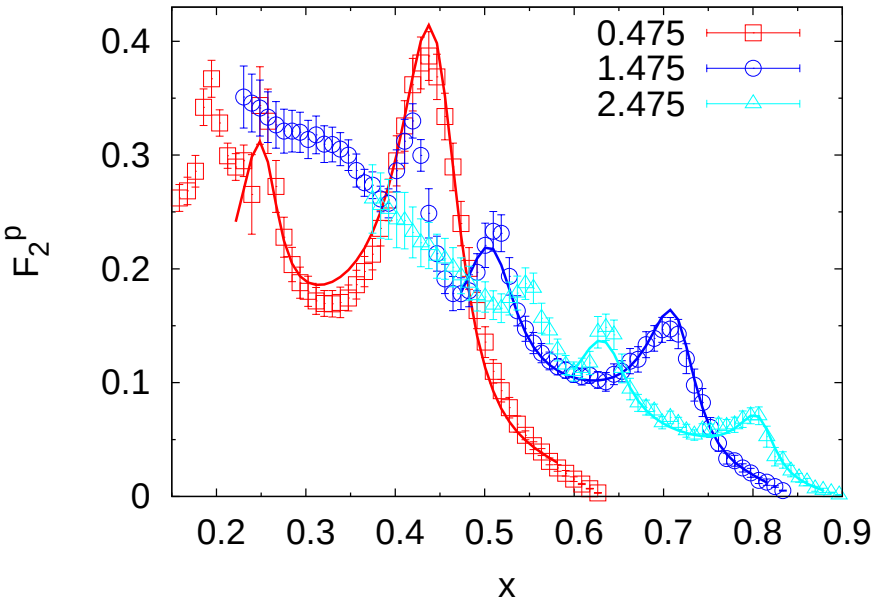
Pure phenomenological background

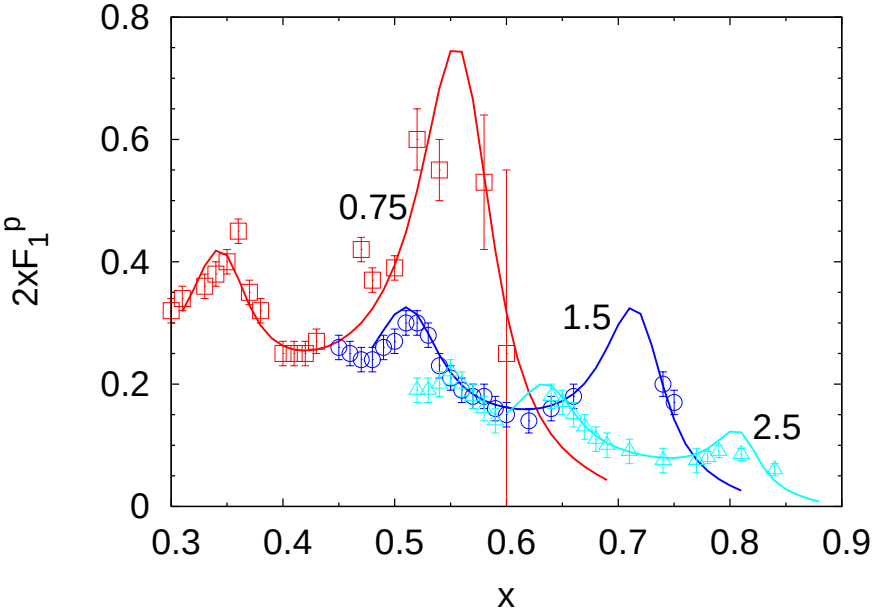
OL: fitting the JLab electroproduction data on F_2 and $2xF_1$ for different Q^2 as the first four resonances (within the Dortmund model) + noninterfering background

$$F_2^{(p)bgr} = \frac{\nu Q^2}{Q^2+\nu^2}\frac{a_2(W-W_{th})^{n_2}}{(Q^2+b_2)^3} \qquad 2xF_1^{(p)bgr} = \frac{\nu Q^2}{Q^2+\nu^2}\frac{a_1(W-W_{th})^{n_1}}{(Q^2+b_1)^3}$$

$a_1 = a_2$ and $n_1 = n_2$ from the requirement $F_2 - 2xF_1 \sim 1/Q^4$ as $Q^2 \to \infty$

$$W_{th} = m_N + m_\pi \quad a_1 = a_2 = 37.4 \quad n_1 = n_2 = 0.35 + 0.22Q^2 \quad b_2 = 3.88 \quad b_1 = 3.2$$

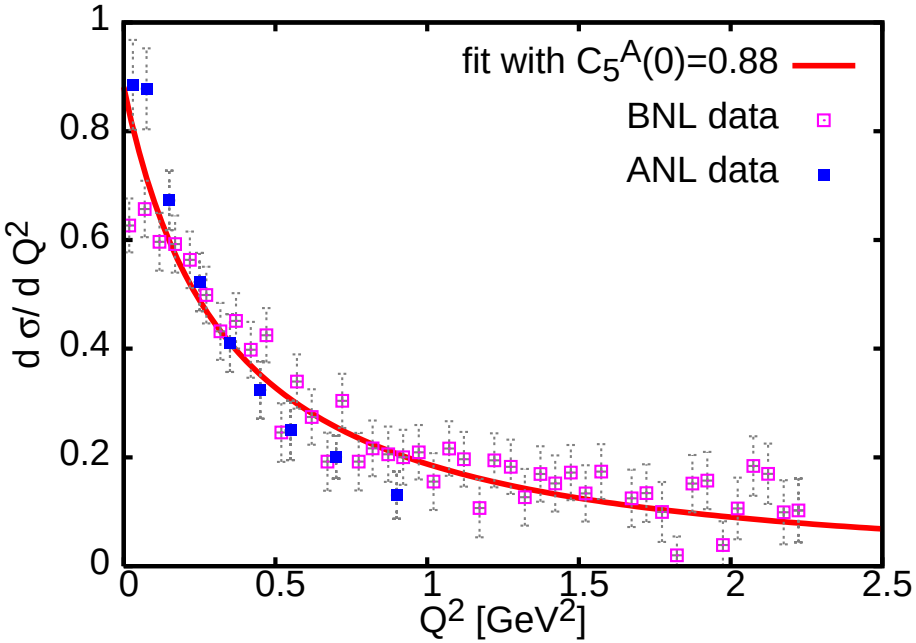




suitable for two–, one–fold and integrated x-sec

Do we really need background in neutrinoproduction?

The best measured channel $\nu p \to \mu^- \Delta^{++} \to \mu^- p \pi^+$
We CAN fit the data with pure isobar diagram and adjust axial form factors
The accuracy of axial form factors is never better than the accuracy of the experiments we fit



ANL data show a steeper Q^2 dependence and lower x-sec than BNL

$$C_5^A = \frac{0.88}{\left(1+Q^2/9.71\ \mathrm{GeV}^2\right)^2} \times \frac{1}{\left(1+Q^2/0.35\ \mathrm{GeV}^2\right)}$$

simultaneous fit of ANL and BNL data

Graczyk, Sobczyk, PRD77 combination of phenomenological (for Δ) and theoretical (Rein–Sehgal model for other resonances) arguments, recently improved analysis (this school, talk of K. Graczyk)

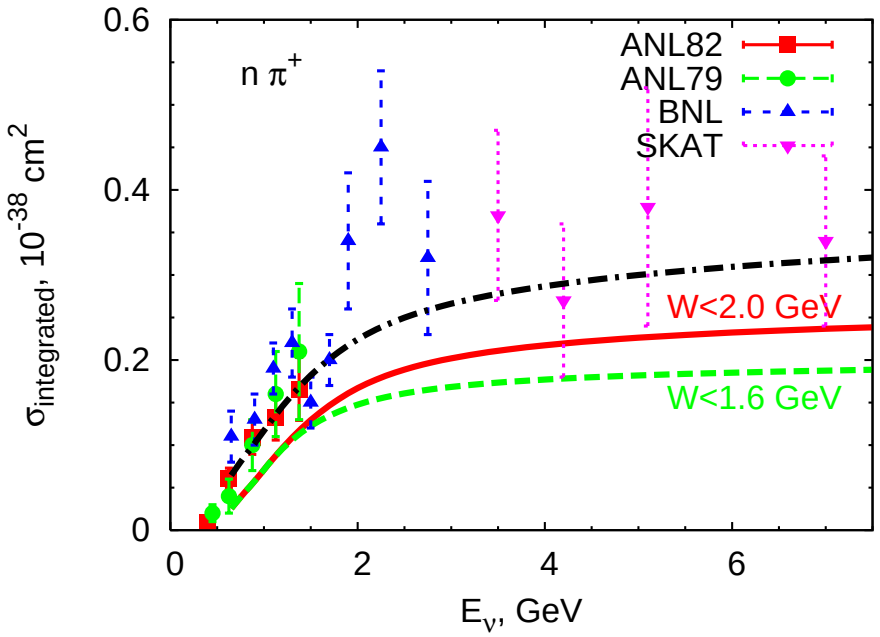
Do we really need background in neutrinoproduction?

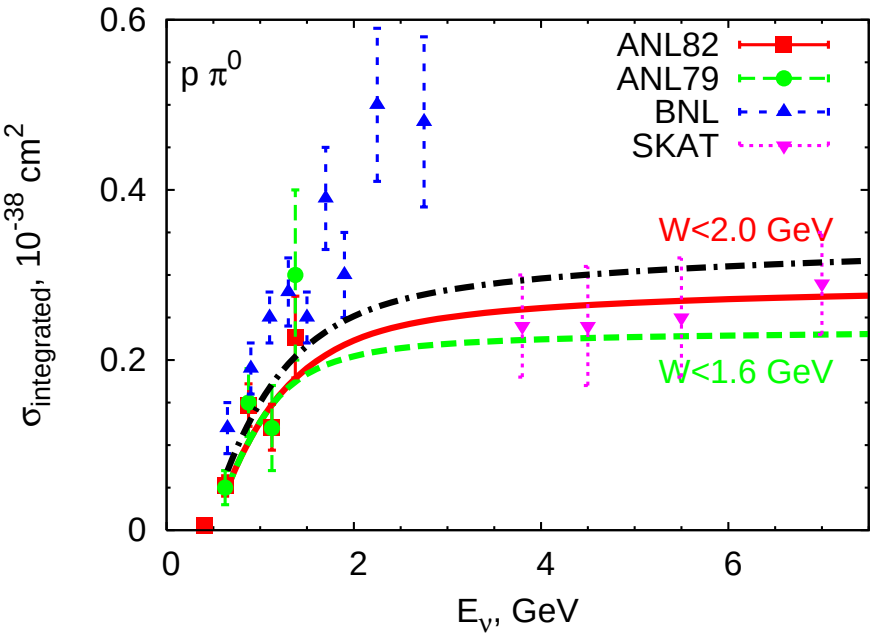
Two other channels $\nu n \to \mu^- R^+ \to \mu^- p \pi^0$, $\nu n \to \mu^- R^+ \to \mu^- n \pi^+$

1) Isospin-3/2 (Δ): $\frac{\sigma(p\pi^0)}{\sigma(n\pi^+)}_{theor} = 2$ Experimentally: $\frac{\sigma(p\pi^0)}{\sigma(n\pi^+)}_{exp} \approx 1$

2) Can other high–lying resonances help? Isospin-1/2: $\frac{\sigma(p\pi^0)}{\sigma(n\pi^+)}_{theor} = \frac{1}{2}$

3) Theoretical curves are still lying below the experimental data





Conclusion. We DO need background

Phenomenological models of the background

Step 1. Suppose there background for $\nu p \to \Delta^{++} \to p\pi^+$ is negligible

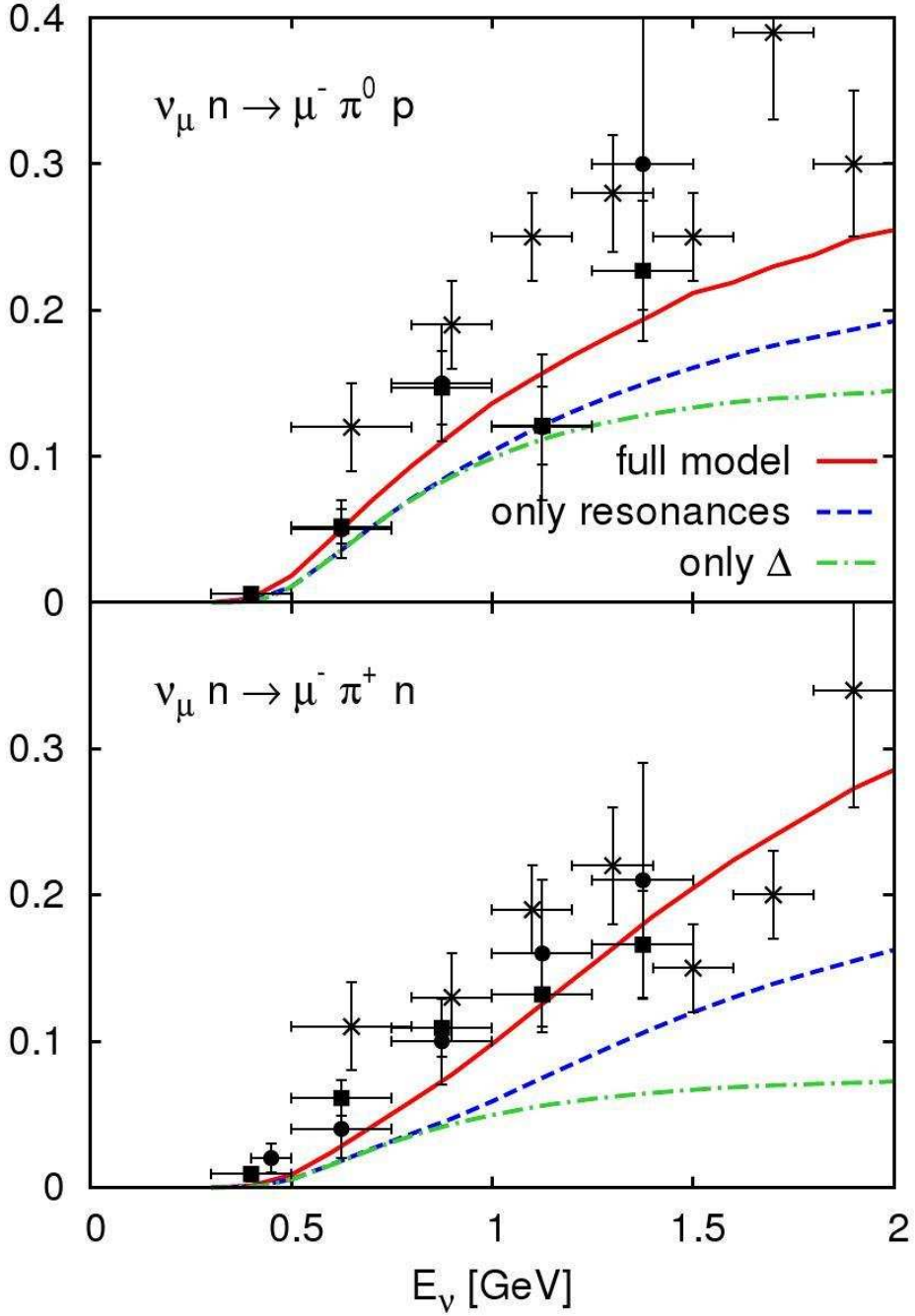
Step 2. Fit the data on $\nu p \to \Delta^{++} \to p\pi^+$ to determine axial form factors.

Step 3. Suppose backround for $\nu p \to \Delta^+$ is isospin-1/2, that is

$$\frac{\sigma_{\rm bgr}(\nu p \to p\pi^0)}{\sigma_{\rm bgr}(\nu p \to n\pi^+)} = \frac{1}{2}$$

Step 4. Fit the neutrinoproduction data on these two channels to determine background

Results of the Giessen group

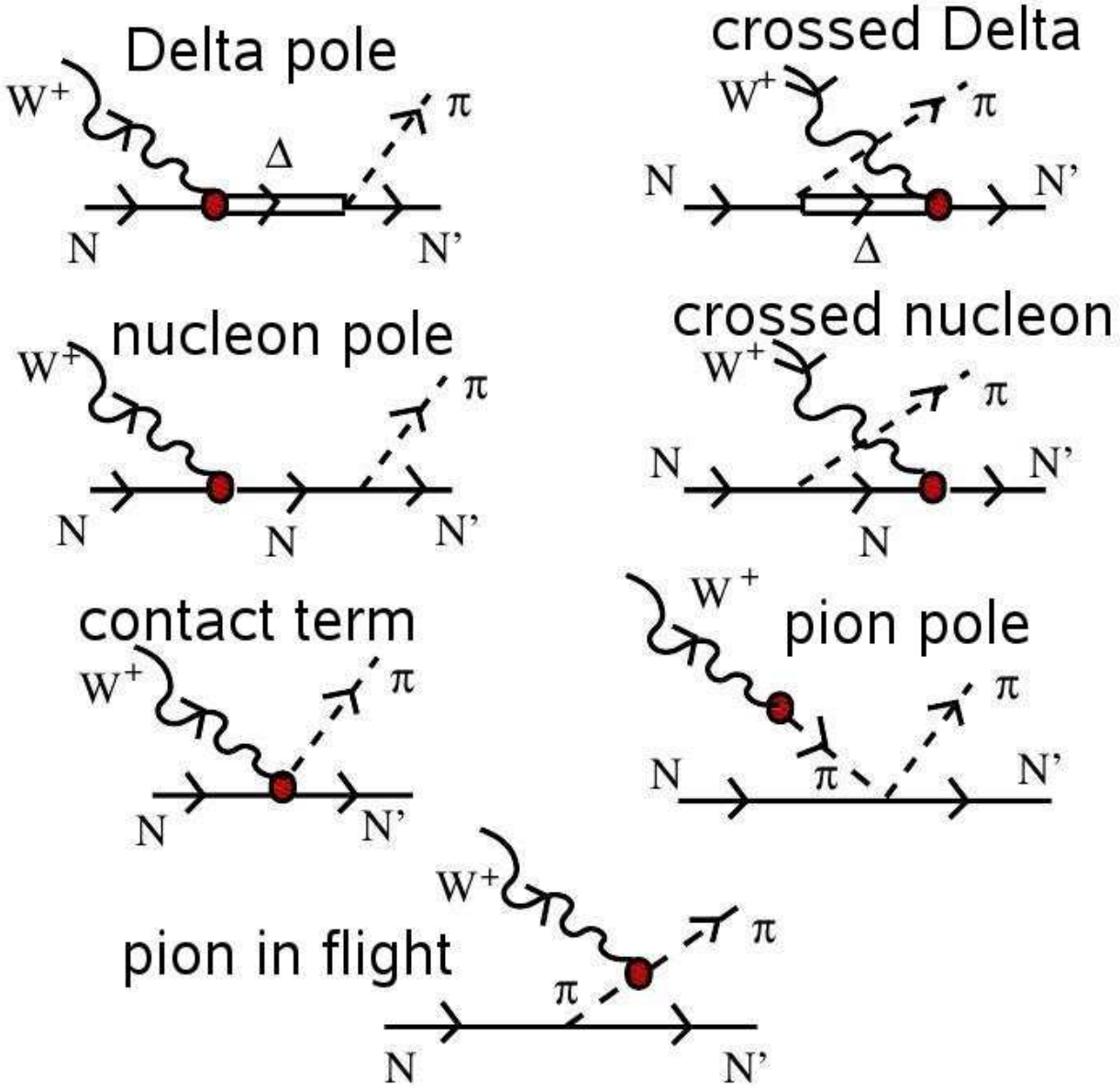


Leitner et. al, arXiv:0812.0587

$$d\sigma_{BG} = d\sigma_{BG}^{V} + d\sigma_{BG}^{\text{non-V}} = (1 + b^{N\pi})\, d\sigma_{BG}^{V}\,, \qquad (62)$$

FIG. 4: Total CC pion production cross sections for the mixed isospin channels as a function of the neutrino energy compared to the pion production data of of ANL (Refs. [50] (•) and [51] (■)) and BNL ([52] (×)). The solid lines denote the our full result including the non-resonant background following Eq. (62) with $b^{p\pi^0} = 3$ and $b^{n\pi^+} = 1.5$. Furthermore, we show the results for pion production only through the excitation and the subsequent decay of all resonances (dashed lines) or through the Δ alone (dash-dotted lines). No cut on the invariant mass is applied.

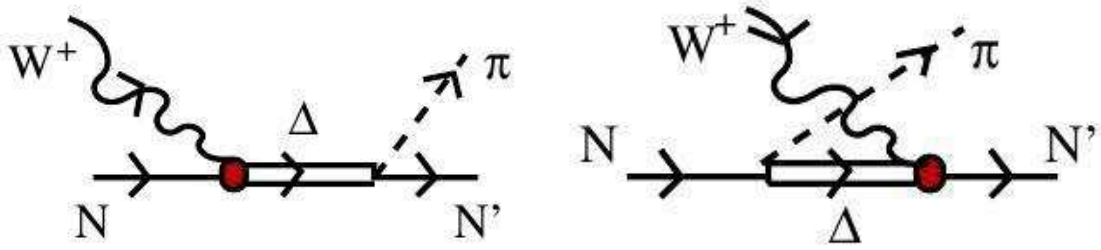
Diagram approach to the 1-pion production



Hernandez, Nieves, Valverdo, PRC 76 (2007) 033005
Sato-Lee PRC 67 (2003)

Parameterization of vertices

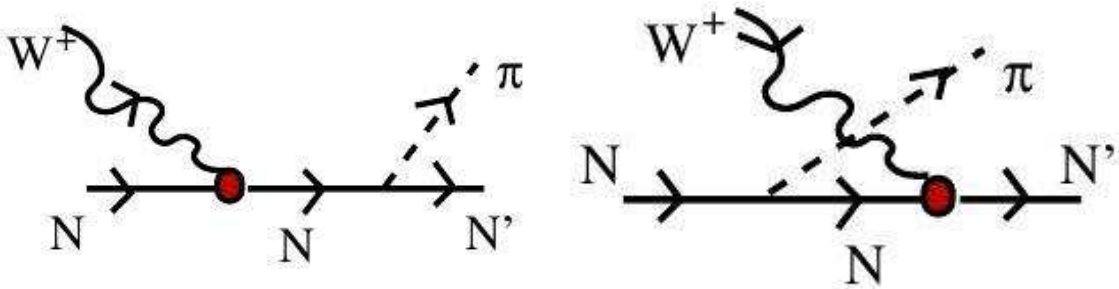
Dp, cDp



$WN\Delta$: standard parameterization with the form factors

$\Delta N\pi$: standard parameterization
with the the coupling constant determined from the Γ_{tot}

Np, cNp



WNN': standard parameterization with the QE form factors

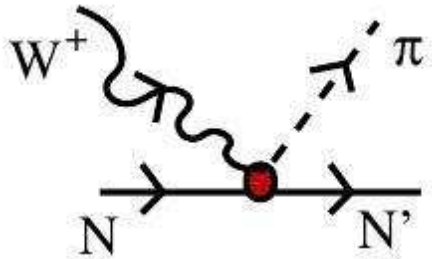
$NN'\pi$: $\mathcal{L} = \frac{g_A}{2f_\pi}\bar{N}\gamma^\mu\gamma^5\tau_a\partial_\mu\pi_a N$
from $SU(2)$ non–linear σ–model

Hernandez, Nieves, Valverdo, PRC 76 (2007) 033005

Vertices from non-linear sigma-model

Constants $g_A = 1.23$, $f_\pi = 0.097\ \mathrm{GeV}$, phenomenological form factors F_{CT}, F_ρ, F_{pF}

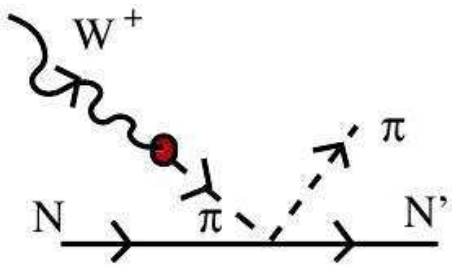
CT (contact term)



including *rho*-dominance

$WNN'\pi$: $\mathcal{L} = \frac{1}{2f_\pi}\bar{N}\gamma^\mu W^a_\mu \varepsilon_{abc}\pi_b\tau_c N \cdot F_\rho - \frac{g_A}{2f_\pi}\bar{N}\gamma^\mu\gamma^5 W^a_\mu \varepsilon_{abc}\pi_b\tau_c N \cdot F_{\mathrm{CT}}$

pp (pion pole)

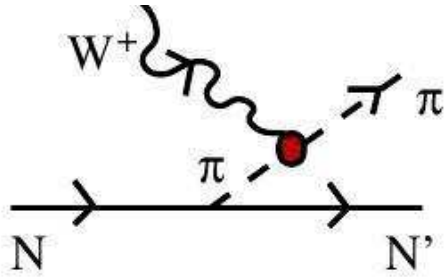


including *rho*-dominance

$WNN'\pi$: $\mathcal{L} = -W^\mu_a f_\pi \partial_\mu \pi^a$

$NN'\pi\pi'$: $\mathcal{L} = -\frac{1}{4f_\pi^2}\bar{N}\gamma^\mu \varepsilon_{abc}\tau_a\pi_b\partial_\mu\pi_c N \cdot F_\rho$

pF (pion in Flight)



$W\pi\pi'$: $\mathcal{L} = W^\mu_a \varepsilon_{abc}\pi_b\partial_\mu\pi_c \cdot F_{pF}$

$NN'\pi'$: as in nucleon pole

This model introduces nonzero ($\sim 10\%$ — HNV PRC 76) background for the $\nu p \to \mu^- p \pi^+$, 6 of 7 diagrams contribute

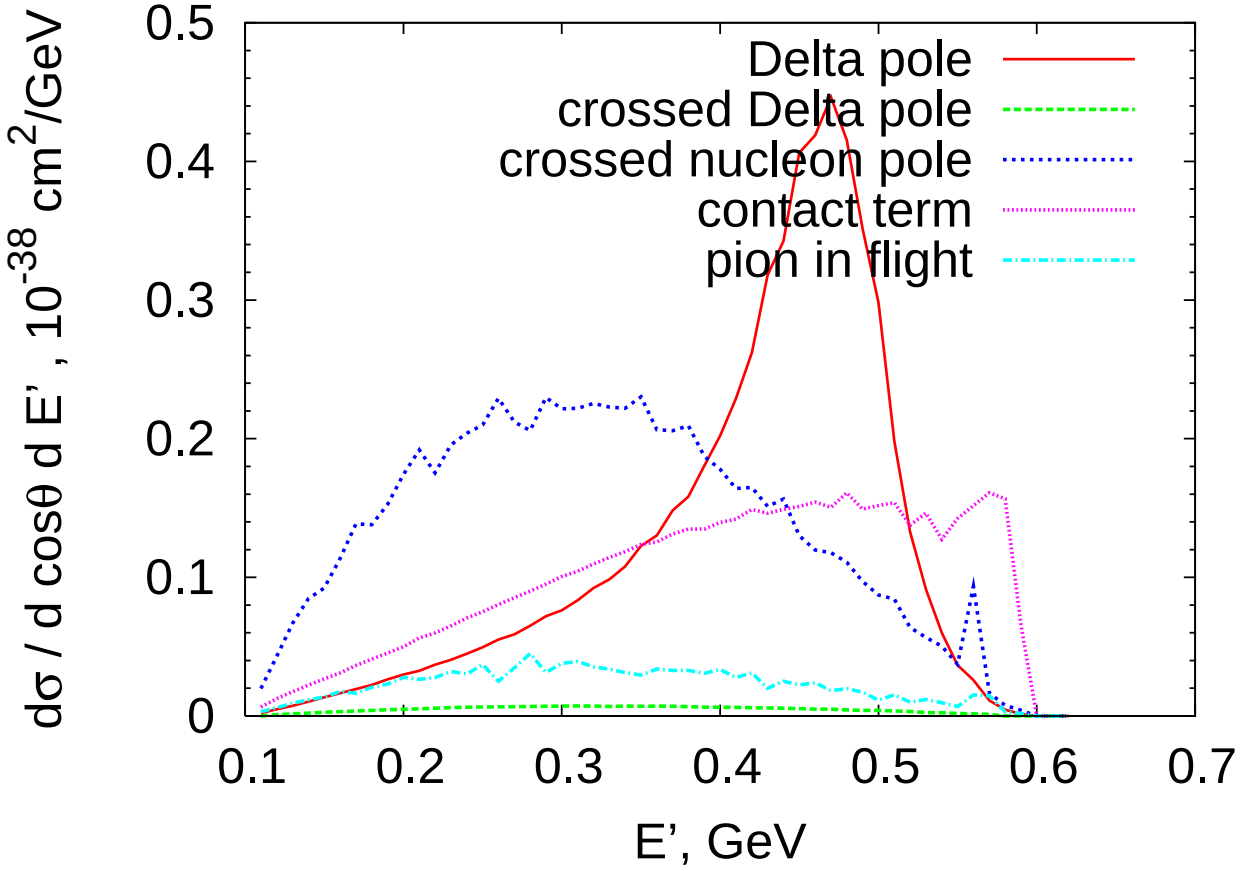
The model is being implemented into GiBUU code, which fixes the elementary vertices

Detailed dynamics of each contribution and the interference of different diagram can be investigated

Nuclear effects can be treated within the GiBUU transport model

Double differential x-sec $\nu p \to \mu^- p \pi^+$

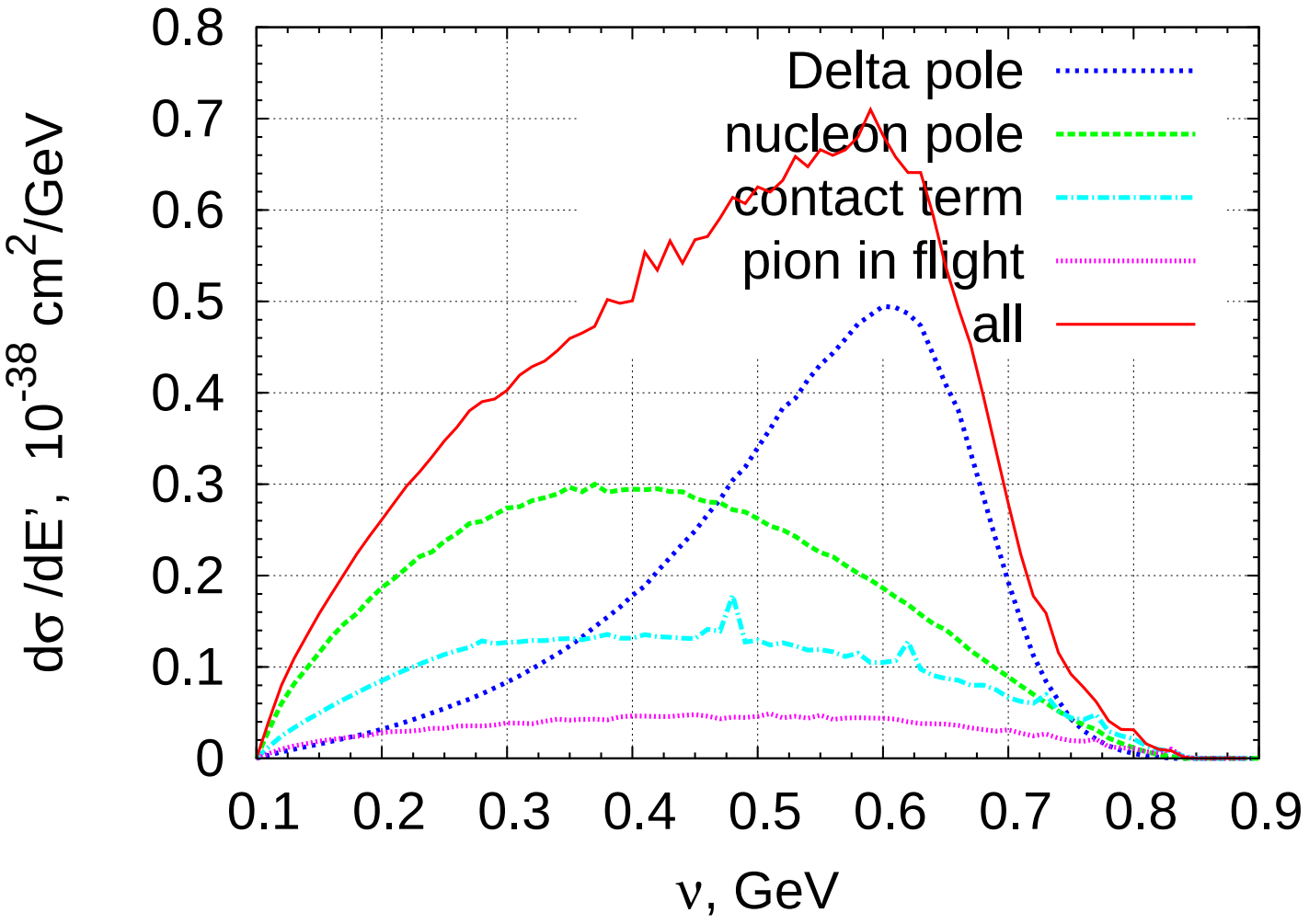
... to be checked ...



$E_\nu = 1$ GeV, $\cos\theta = 0.6$

One differential x-sec $\nu p \to \mu^- p \pi^+$

... to be checked ...



negative interference of various diagrams

Conclusion and plans

- Understanding of the nonresonant backgeound is required for understanding of various neutrinoproduction channels
- Phenomenological background is simple, but highly dependent on the resonance contribution used; no predictive power
- Background model (Hernandez, Nieves, Valverdo, PRC 76) based on nonlinear $SU(2)$ sigma-model is being implemented in the GiBUU code; can be used for any type of x-sec, any reaction channel
- Within GiBUU model we can investigate this background for both neutrinos and antineutrinos, CC and NC, for nucleons and nuclei, initial and final state intereactions are automatically included