Dynamical coupled-channels approach to Resonance Region beyond $\Delta(1232)$

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Introduction

Challenges in resonance region beyond $\Delta(1232)$

Neutrino interactions in resonance region beyond $\Delta(1232)$ are highly relevant to future neutrino oscillation experiments

T. Katori and M. Martini, J. Phys. G 45 (2017)

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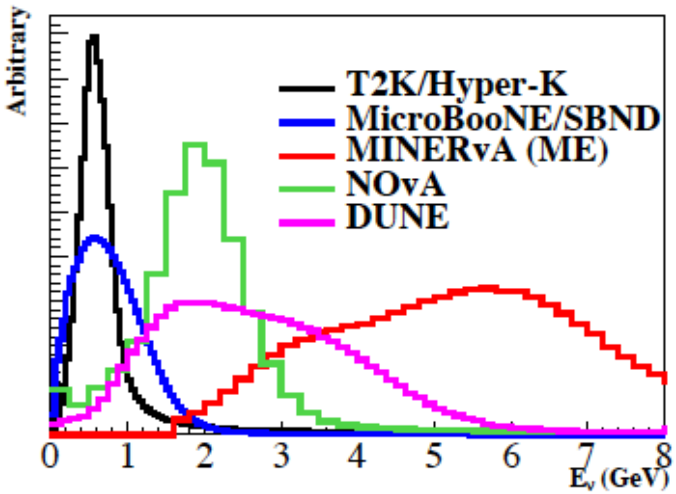

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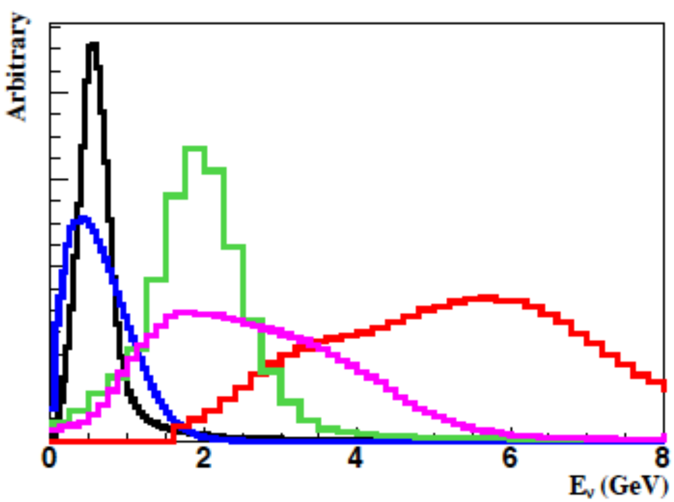

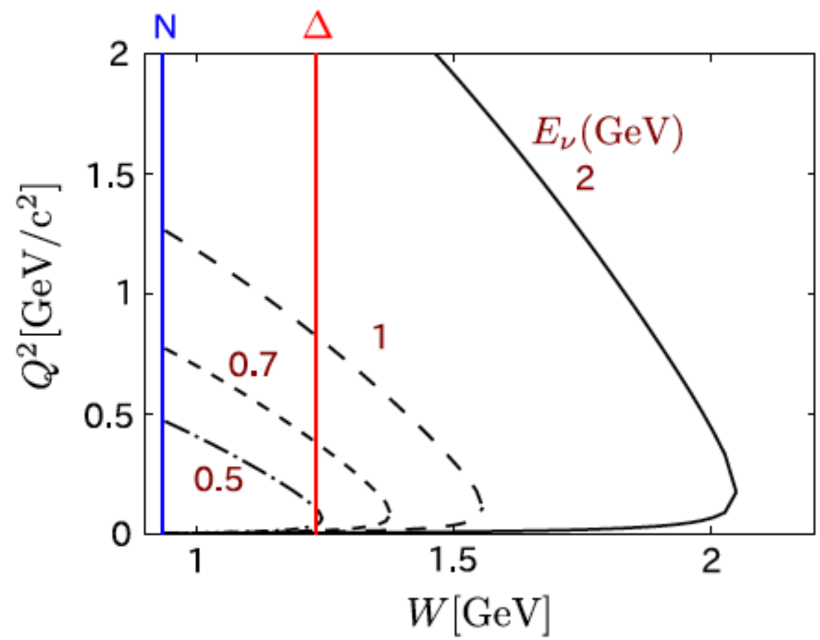

BAD NEWS ! (?)

Neutrino interactions in resonance region beyond $\Delta(1232)$ are much more difficult to understand than in $\Delta(1232)$ region

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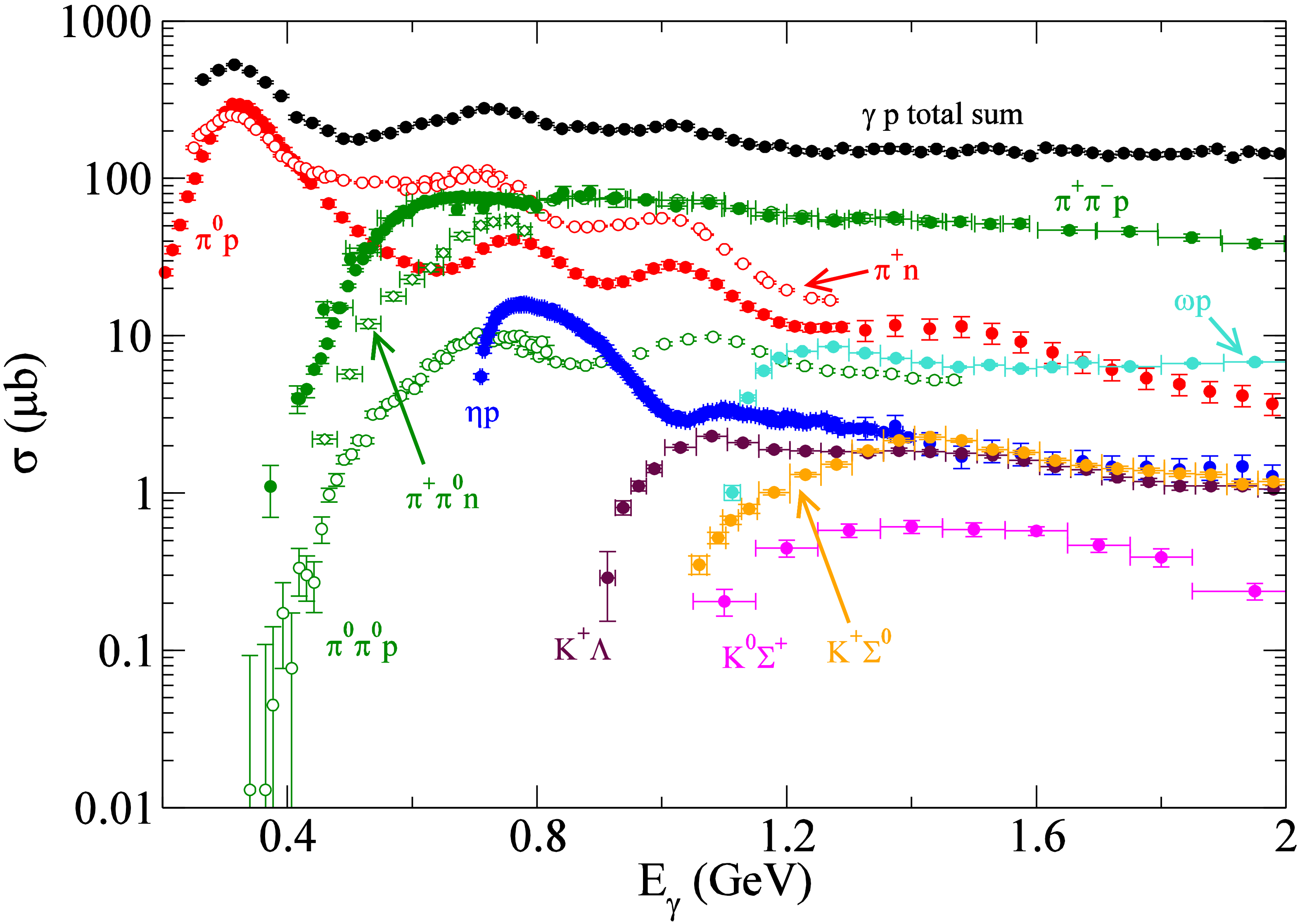
	$\Delta(1232)$ region	Beyond $\Delta(1232)$ region ($W \lesssim$ 2 GeV)
Resonance	$\Delta(1232)$ dominates No other resonances	No single resonance dominate Several comparable resonances overlap

Resonance region (single nucleon)

$\gamma N \rightarrow X$



Several resonances overlap to form characteristic peaks

Resonance region (single nucleon)

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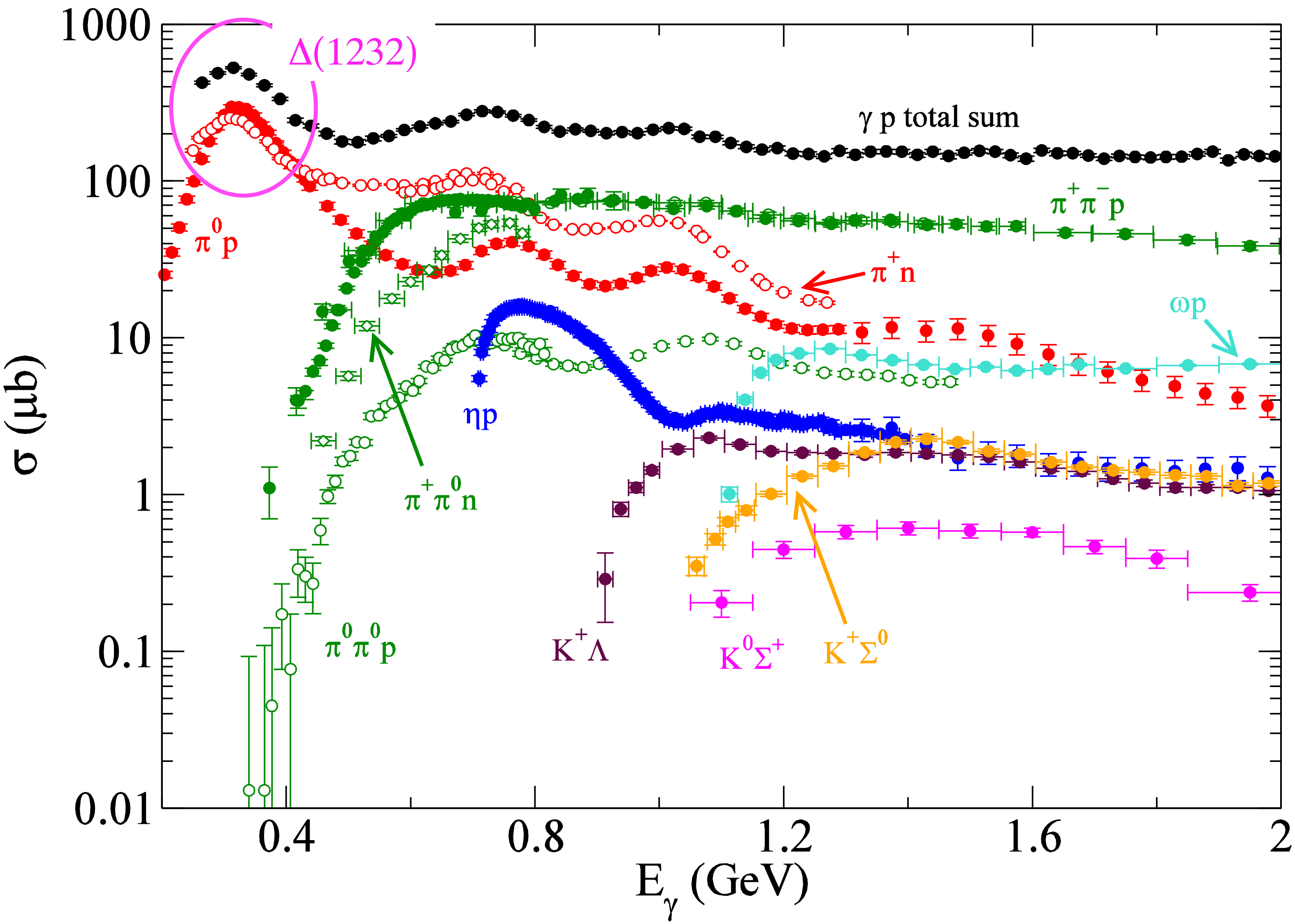

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Resonance region (single nucleon)

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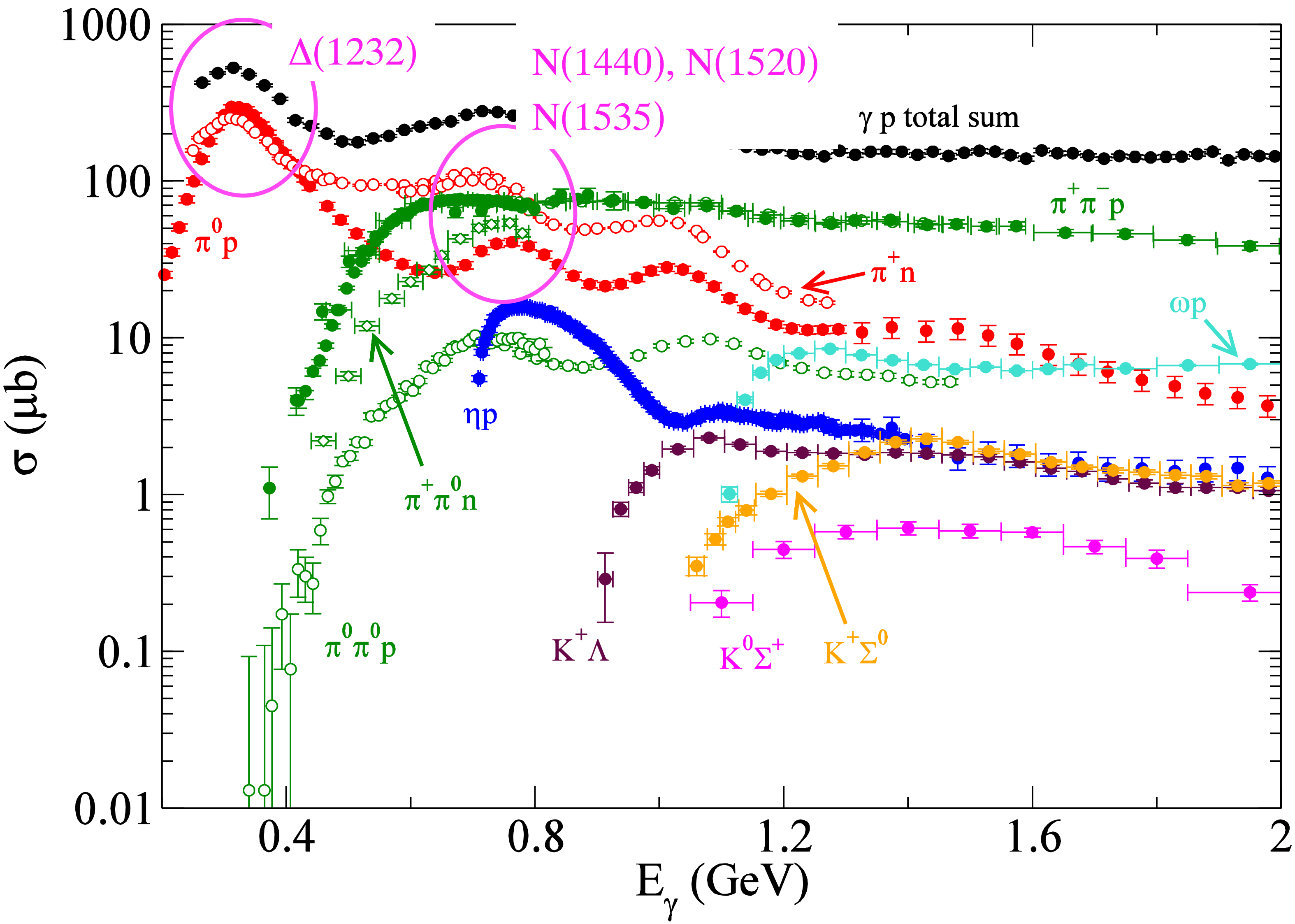


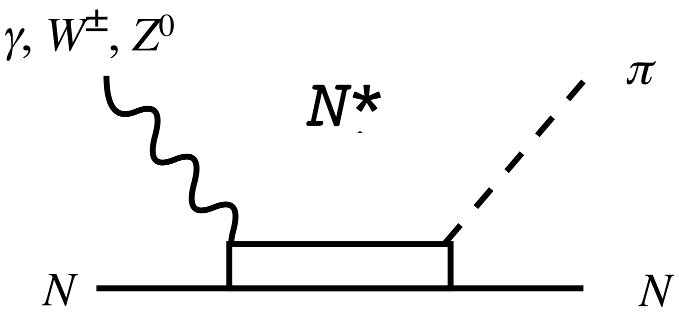
Several resonances overlap to form characteristic peaks

Neutrino interactions in resonance region beyond $\Delta(1232)$ is much more difficult to understand than in $\Delta(1232)$ region

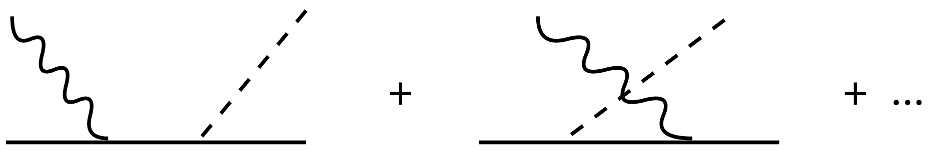
	$\Delta(1232)$ region	Beyond $\Delta(1232)$ region ($W \lesssim 2$ GeV)
Resonance	$\Delta(1232)$ dominates No other resonances	No single resonance dominate Several comparable resonances overlap
Non-resonant	Much smaller than $\Delta(1232)$ ChPT works → well-controlled	Comparable to resonant contributions ChPT not work

Resonance region

(Main) reaction mechanism : resonance excitations



(Sub-leading) non-resonant mechanisms

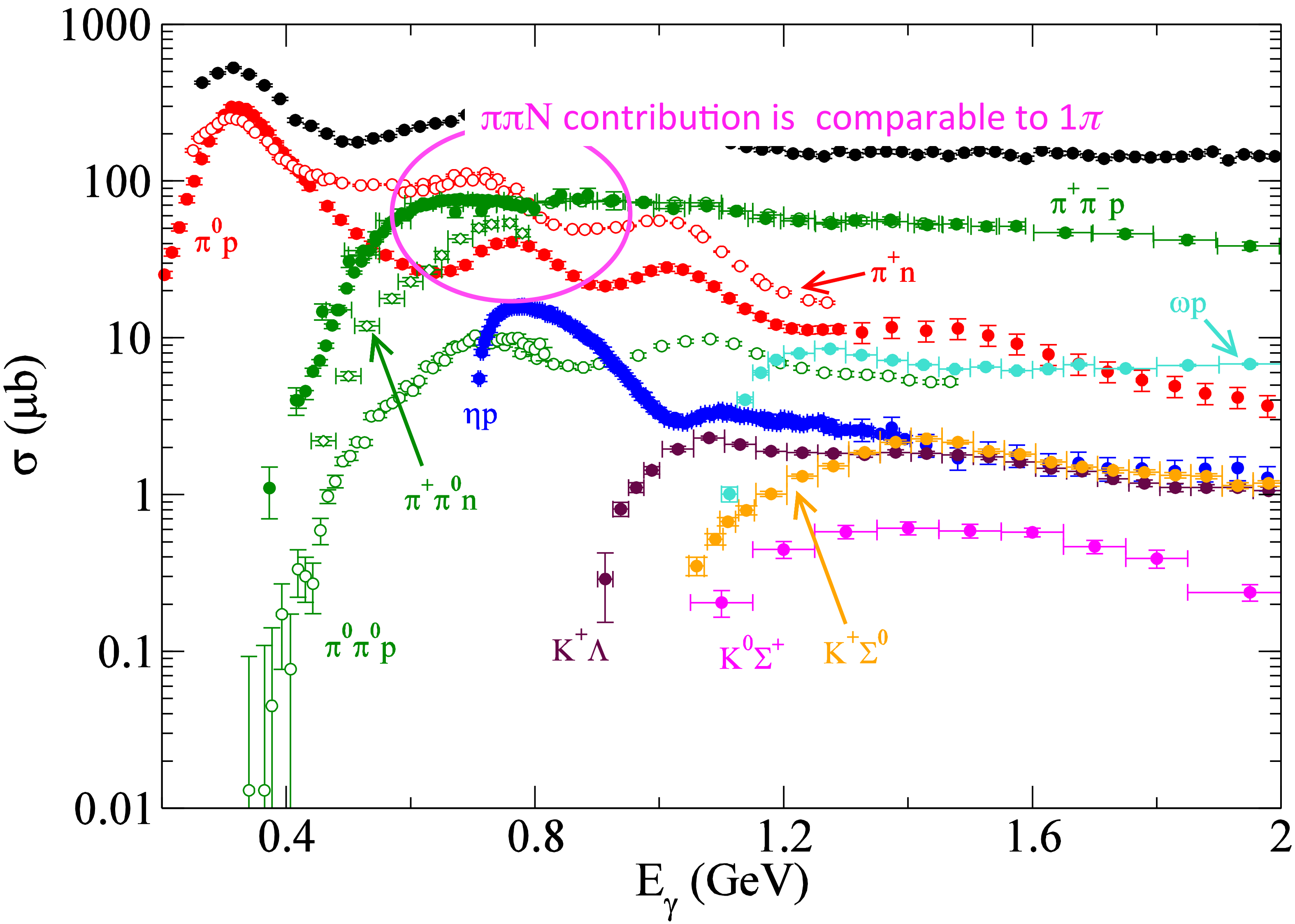


Neutrino interactions in resonance region beyond $\Delta(1232)$ is much more difficult to understand than in $\Delta(1232)$ region

	$\Delta(1232)$ region	Beyond $\Delta(1232)$ region ($W \lesssim$ 2 GeV)
Resonance	$\Delta(1232)$ dominates No other resonances	No single resonance dominate Several comparable resonances overlap
Non-resonant	Much smaller than $\Delta(1232)$ ChPT works → well-controlled	Comparable to resonant contributions ChPT not work
Relative phases among mechanisms	(fairly) well-controlled	Crucially important but not easy to control
Coupled-channels	Only πN	πN and $\pi\pi N$ are comparable and strongly coupled ηN, $K\Lambda$, $K\Sigma$ channels are also coupled

Resonance region (single nucleon)

$\gamma N \rightarrow X$



Strategy to tackle neutrino reactions beyond $\Delta(1232)$

Vector current

1. EM couplings and Q^2-dependence ← Analysis of electron-induced reaction data (1π production and inclusive)

2. Isospin separation : $V_{CC} = V_{isovector} = V^{EM}_{proton} - V^{EM}_{neutron}$

Both proton- and neutron-target electron data need to be analyzed

Strategy to tackle neutrino reactions beyond $\Delta(1232)$

Axial current

Useful data are not available to determine axial current in this kinematical region

→ Guiding principle to derive the axial current : PCAC relation with πN reaction amplitude

$$< X \mid q \cdot A(Q^2 \sim 0) \mid N > \sim i f_\pi < X \mid T \mid \pi N >$$

Through a model $g_{AN\to N^*}(Q^2 \sim 0) \propto g_{\pi N\to N^*}$ for a dominant axial form factor

If $g_{\pi N\to N^*}$ is available (including its phase) , $g_{AN\to N^*}(Q^2 \sim 0)$ is obtained (including its phase)

Both πN → πN and AN → πN reaction models need to be developed consistently with PCAC

Common procedure : $\Gamma(N^* \to \pi N)$ from PDG ➔ $g_{AN\to N^*}(Q^2 \sim 0) \propto \mid g_{\pi N\to N^*} \mid$

No information about phase is available

Axial current for $Q^2 \neq 0$

To determine axial form factors (Q^2-dependence), we need

neutrino data or parity-violating electron scattering data

No useful data is available beyond $\Delta(1232)$ region to determine Q^2-dependence

→ we need to assume it, dipole form is often used

$F_A(Q^2)$: axial form factors

non-resonant mechanisms $$F_A(Q^2) = \left(\frac{1}{1+Q^2/M_A^2}\right)^2$$ M_A=1.02 GeV

resonant mechanisms $$F_A(Q^2) = \left(\frac{1}{1+Q^2/M_A^2}\right)^2$$

Dynamical coupled-channels approach in and beyond $\Delta(1232)$ region

- ✔ Both proton- and neutron-target electron data need to be analyzed
- ✔ Both $\pi N \rightarrow \pi N$ and $AN \rightarrow \pi N$ reaction models developed consistently with PCAC
- ✔ Channel-couplings among $\pi N, \pi\pi N, \eta N, K\Lambda, K\Sigma$ required by unitarity

Dynamical Coupled-Channels model
for meson productions
in and beyond $\Delta(1232)$ region

DCC (Dynamical Coupled-Channel) model

Matsuyama et al., Phys. Rep. **439**, 193 (2007)

Kamano et al., PRC 88, 035209 (2013)

Coupled-channel Lippmann-Schwinger equation for meson-baryon scattering

$$T_{ab} = V_{ab} + \sum_c V_{ac} G_c T_{cb}$$

$$\{a, b, c\} = \pi N,\ \eta N,\ \pi\pi N,\ \pi\Delta, \sigma N, \rho N,\ K\Lambda,\ K\Sigma$$

By solving the LS equation, coupled-channel unitarity is fully taken into account

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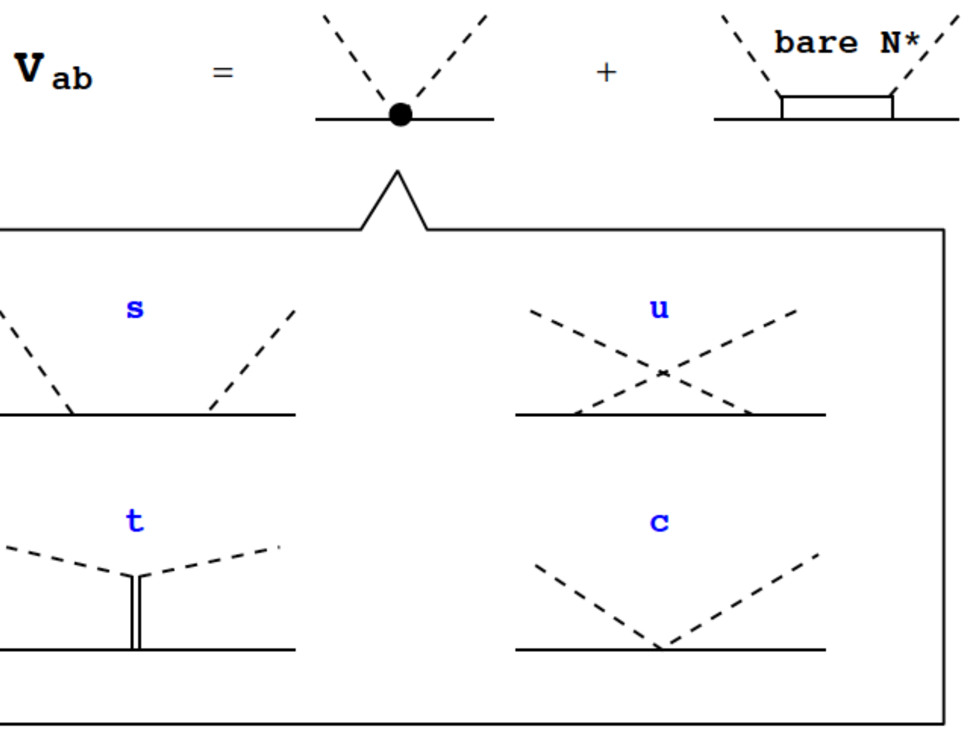

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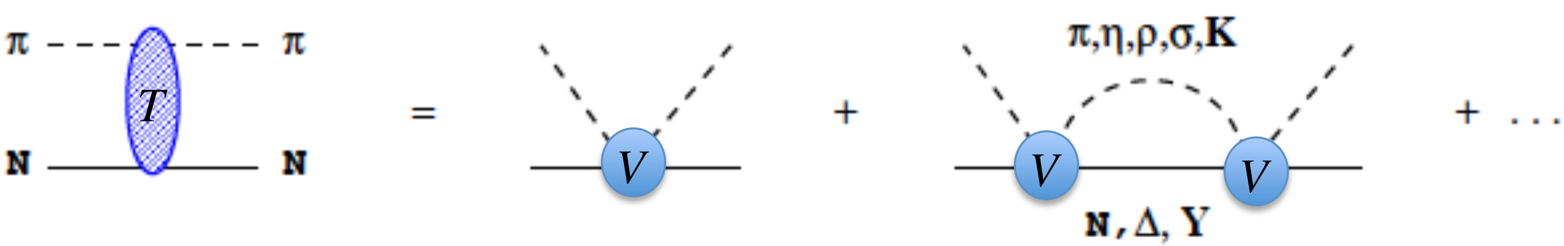
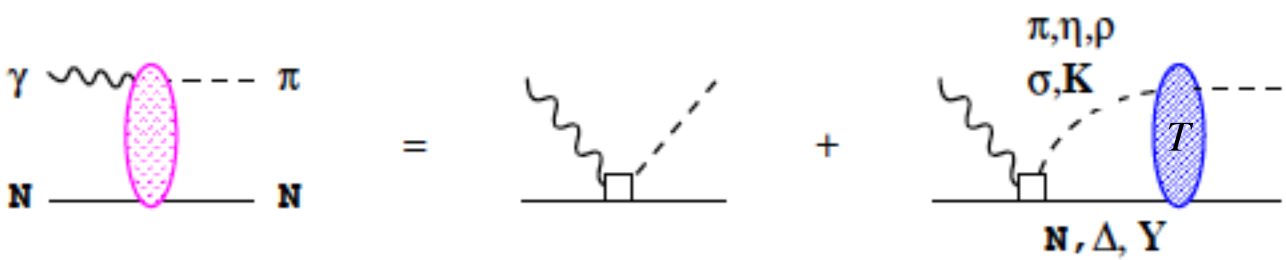


In addition, γN, $W^{\pm}N$, ZN channels are included perturbatively



DCC analysis of $\gamma N, \pi N \rightarrow \pi N, \eta N, K\Lambda, K\Sigma$

and electron scattering data

DCC analysis of meson production data

Kamano, Nakamura, Lee, Sato, PRC 88 (2013)

Fully combined analysis of $\gamma N, \pi N \rightarrow \pi N, \eta N, K\Lambda, K\Sigma$ data

$d\sigma / d\Omega$ and polarization observables (W ≤ 2.1 GeV)

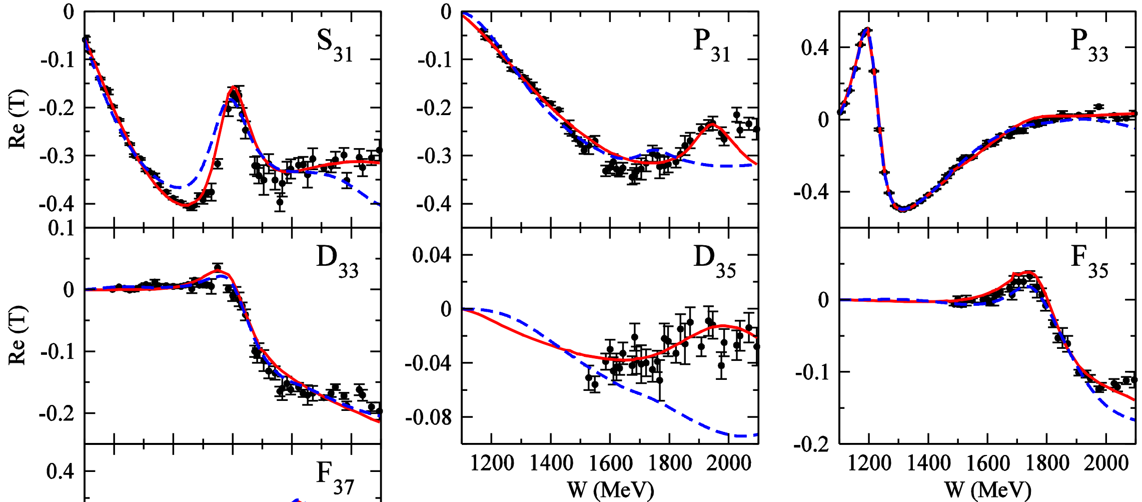
~ 27,000 data points are fitted

by adjusting parameters (N^* mass, $N^* \rightarrow MB$ couplings, cutoffs)

Data for electron scattering on proton and neutron are analyzed by adjusting

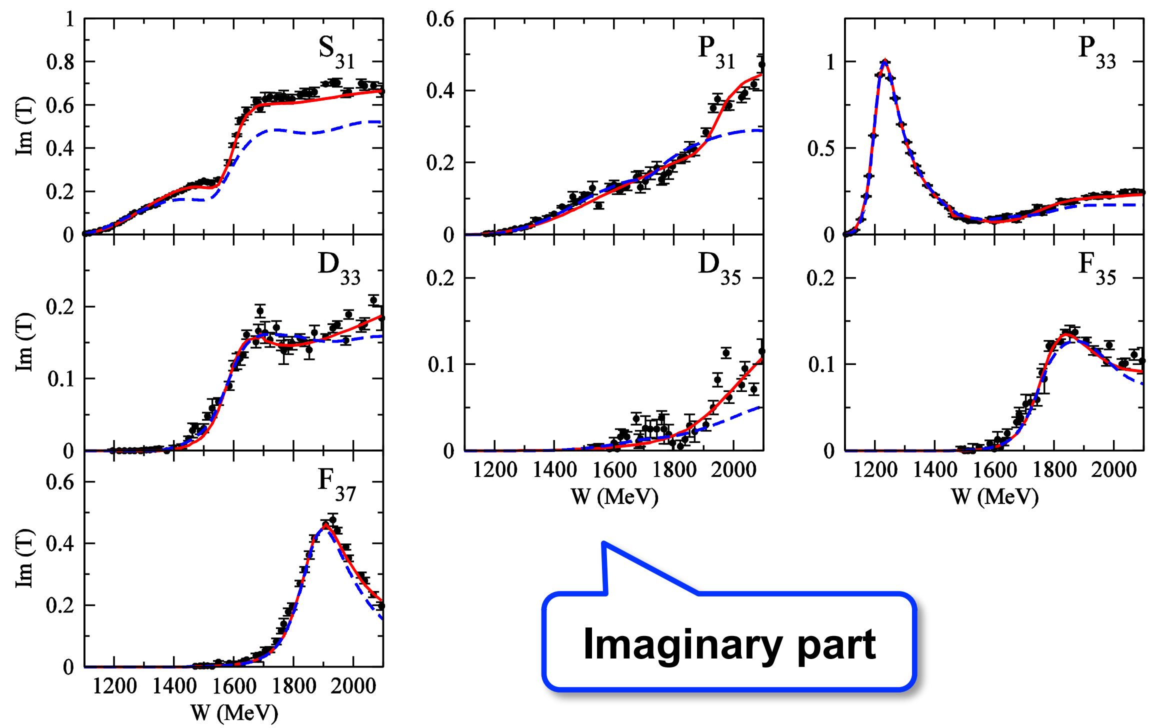
$\gamma^* N \rightarrow N^*$ coupling strength at different Q^2 values ($Q^2 \leq 3\ (\mathrm{GeV}/c)^2$)

Partial wave amplitudes of π N scattering



Real part

$$I = \frac{3}{2}$$



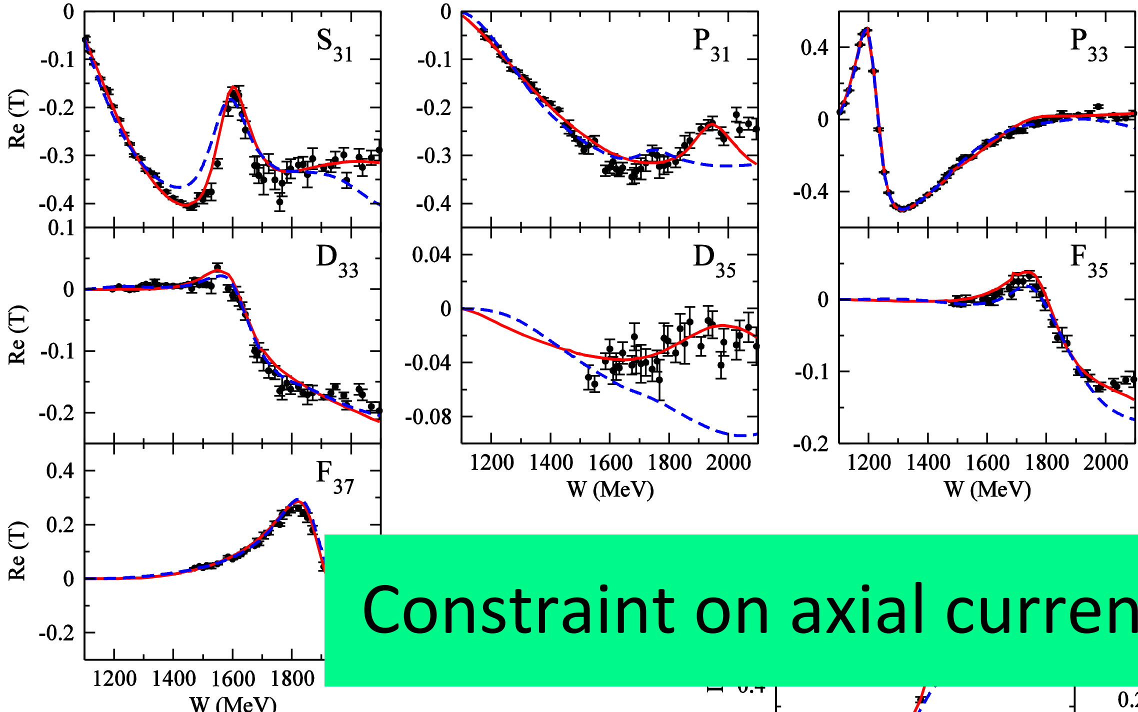
Imaginary part

Kamano, Nakamura, Lee, Sato, PRC 88 (2013)

Previous model (fitted to πN → πN data only) [PRC76 065201 (2007)]

Data: SAID πN amplitude

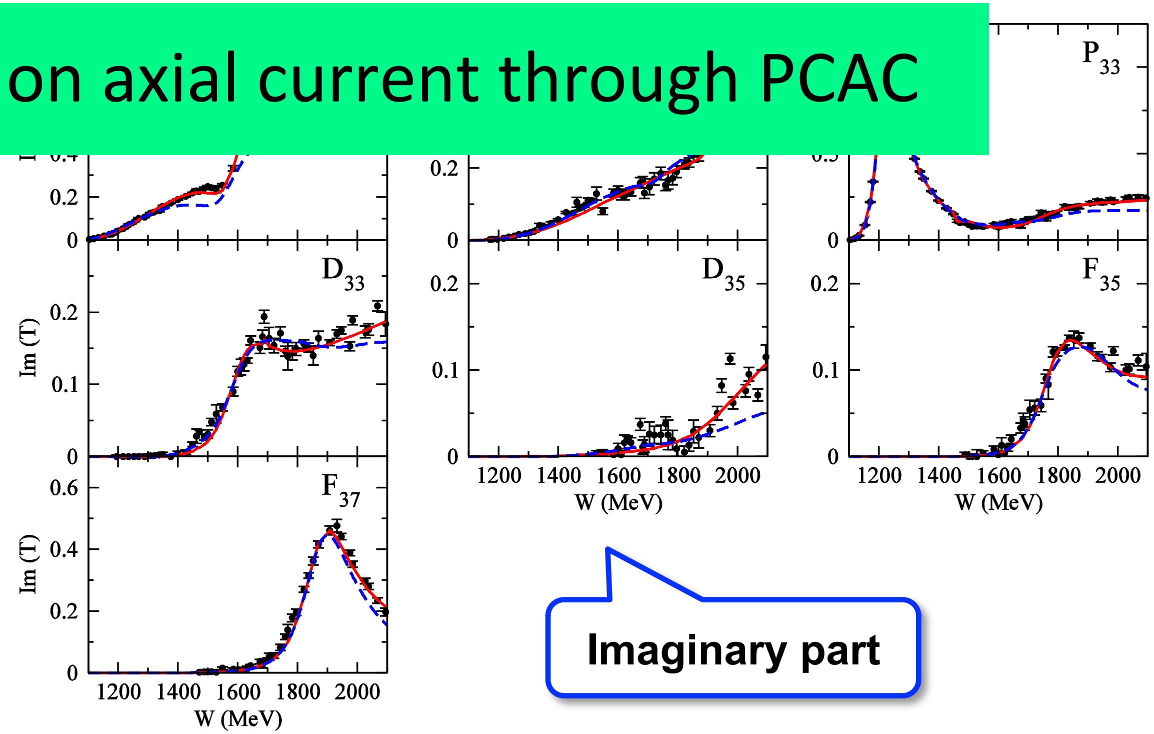
Partial wave amplitudes of π N scattering



Real part

$$I = \frac{3}{2}$$

Constraint on axial current through PCAC



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Kamano, Nakamura, Lee, Sato, PRC 88 (2013)

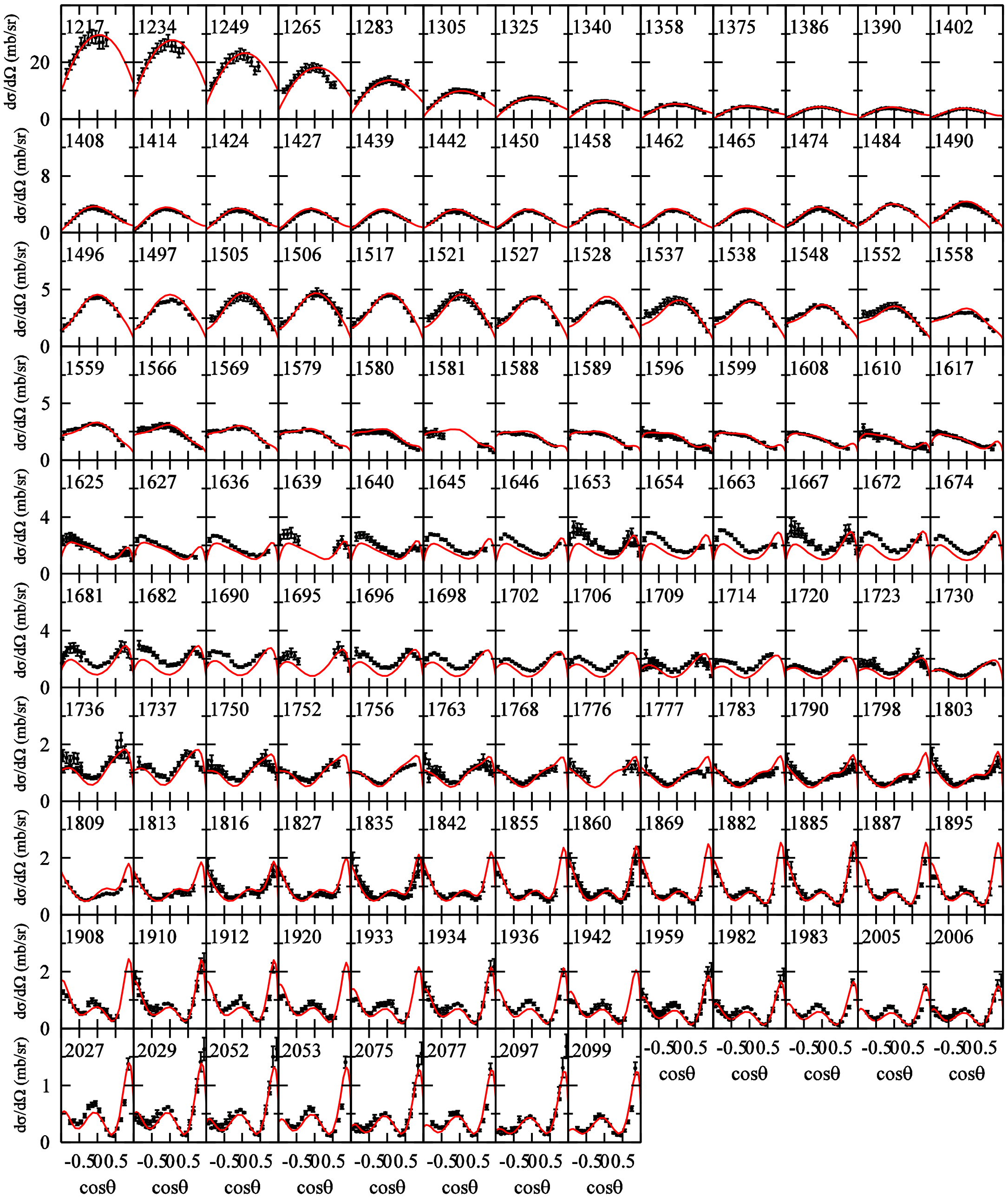
Previous model
(fitted to πN → πN data only)
[PRC76 065201 (2007)]

Data: SAID πN amplitude

$\gamma p \rightarrow \pi^0 p$

$d\sigma/d\Omega$ for W < 2.1 GeV

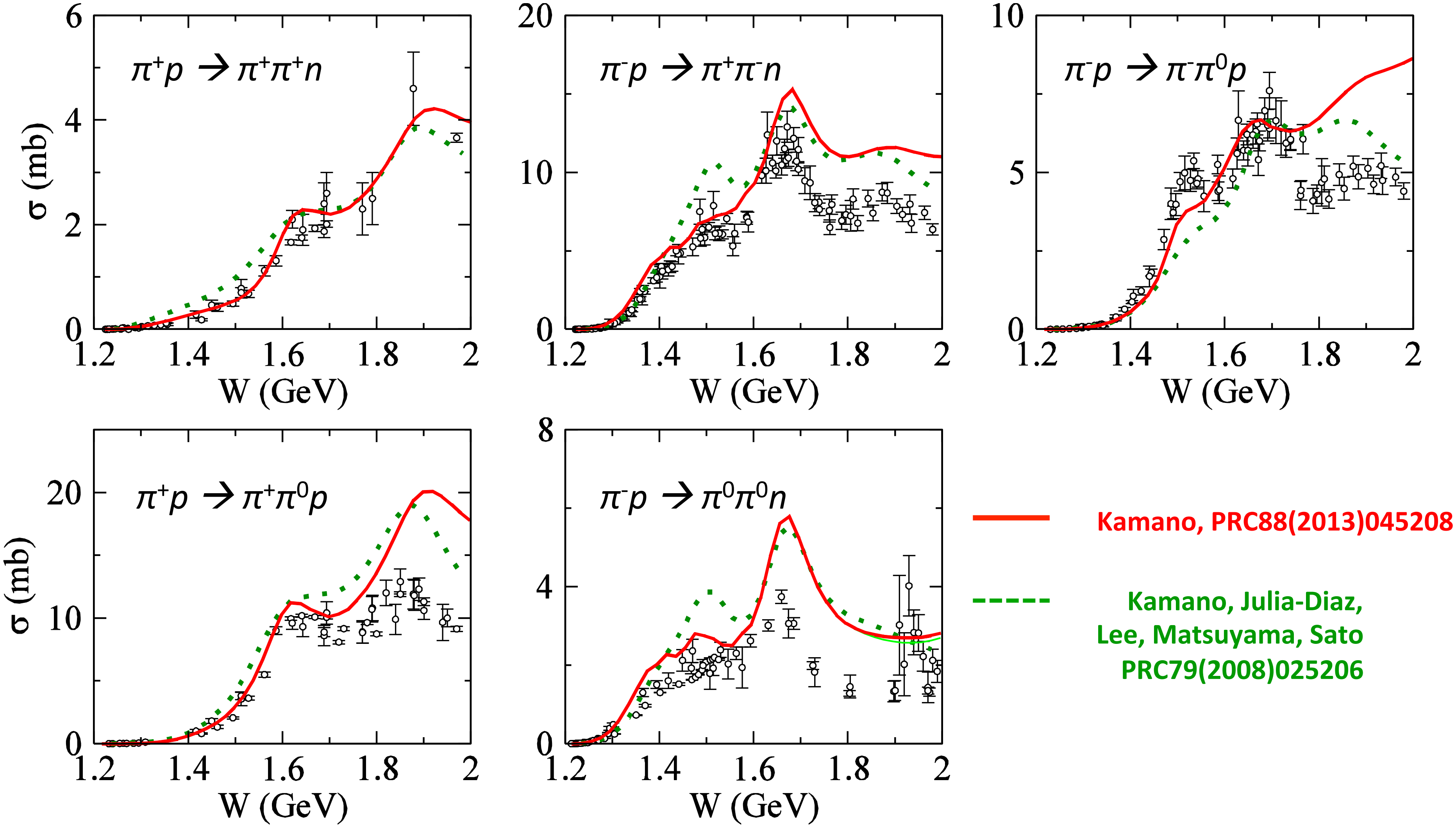
Kamano, Nakamura, Lee, Sato, PRC 88 (2013)



Vector current (Q^2=0) for 1π

Production is well-tested by data

Predicted πN → ππN total cross sections with our DCC model

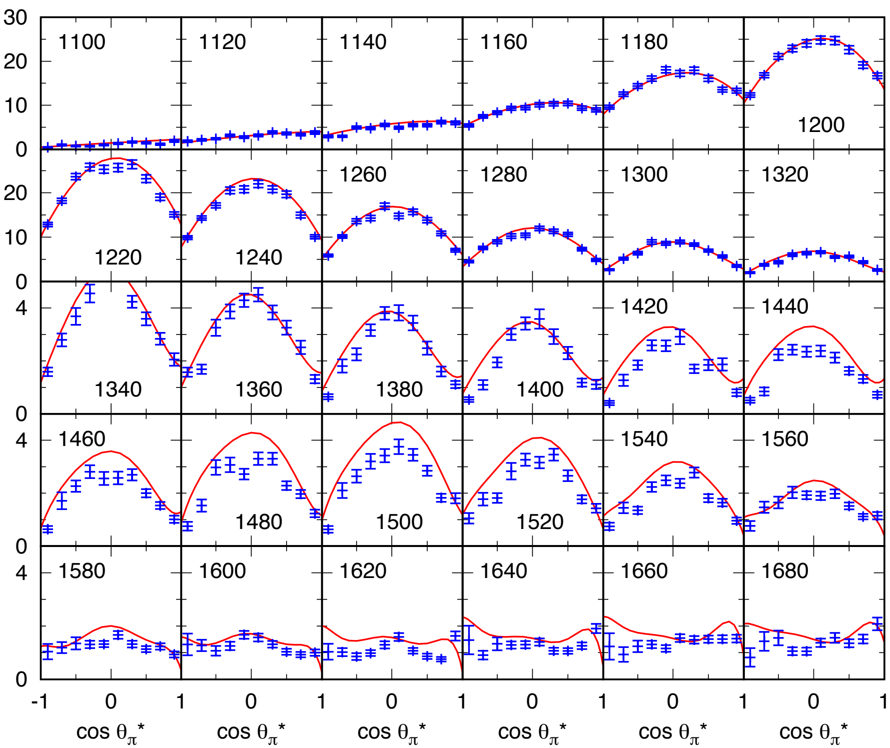


Single π production in electron-proton scattering

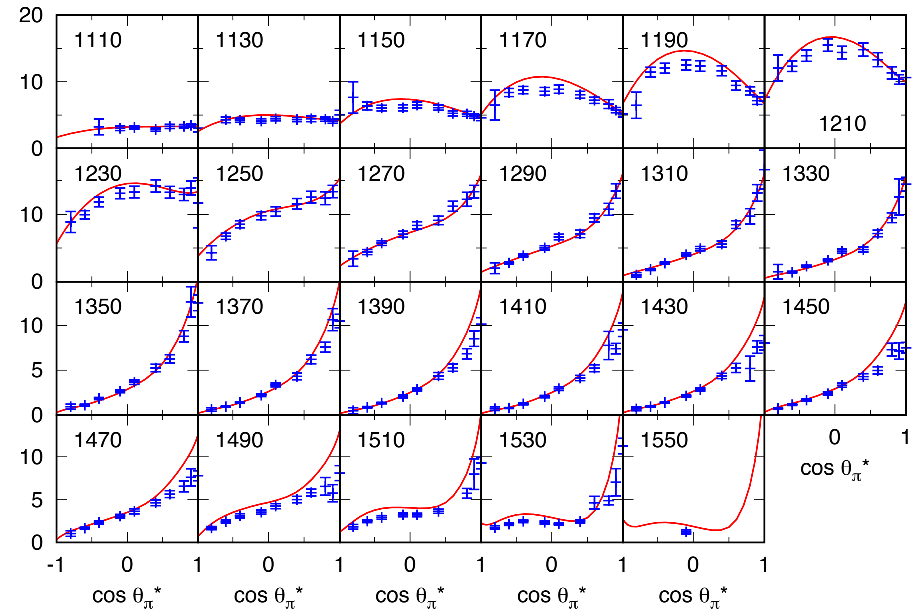
Purpose : Determine Q^2 –dependence of vector coupling of p-N^* : $VpN^*(Q^2)$

$\sigma_T + \varepsilon\, \sigma_L$ for Q^2=0.40 (GeV/c)^2 and W=1.1 – 1.68 GeV

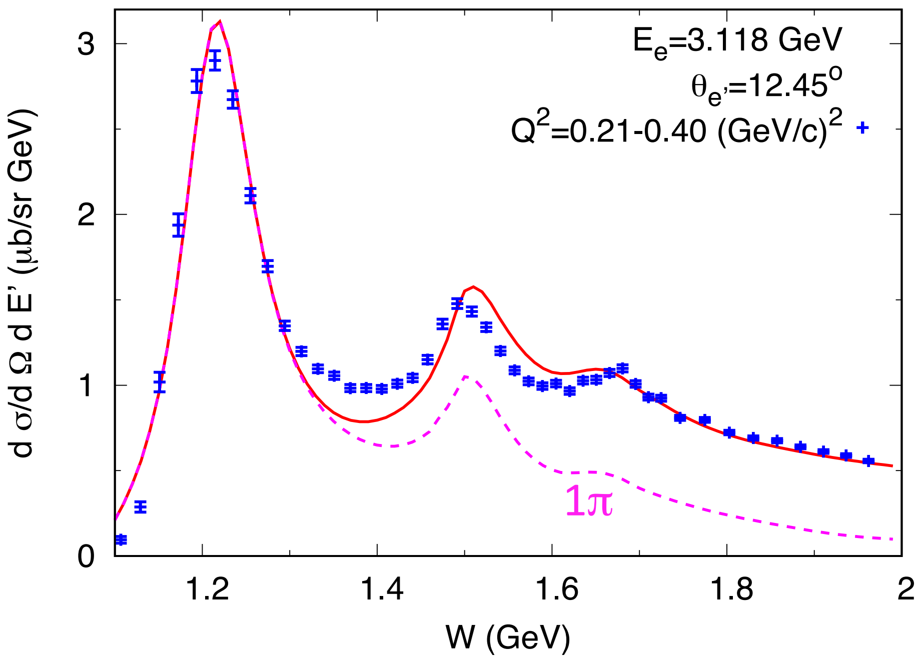
$p(e,e'\pi^0)p$

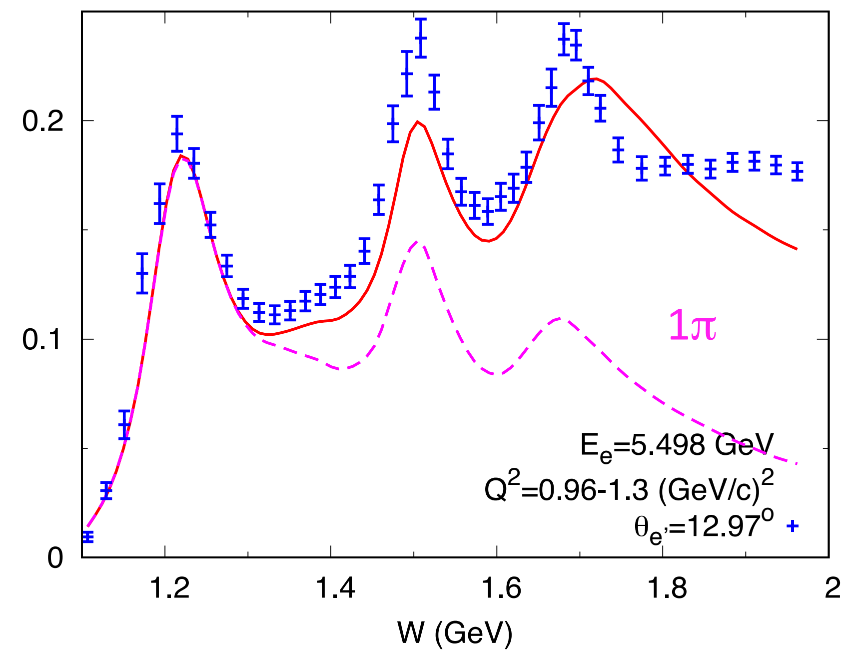


$p(e,e'\pi^+)n$



Inclusive electron-proton scattering





Data: JLab E00-002 (preliminary)

- Reasonable fit to data for application to neutrino interactions
- Important 2π contributions for high W region

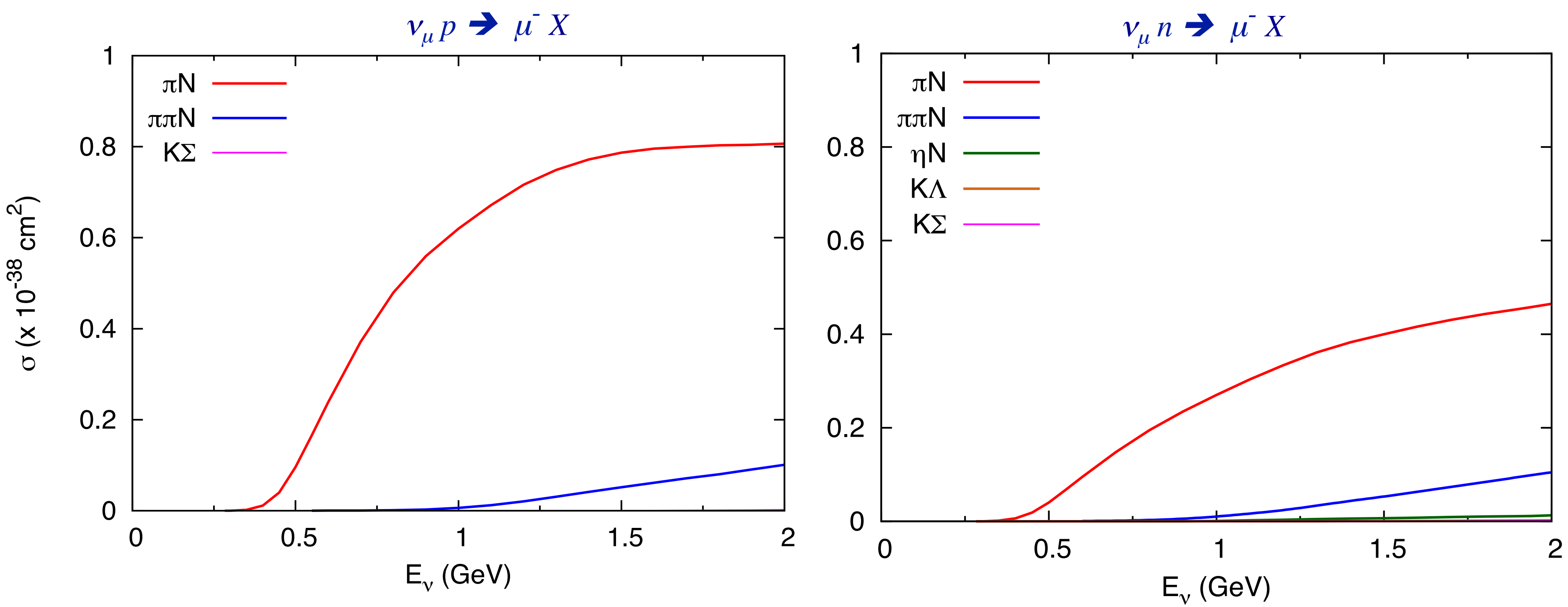
Similar analysis of electron-neutron scattering data has also been done

DCC vector currents has been tested by data for whole kinematical region relevant to neutrino interactions of $E_\nu \leq 2$ GeV

Neutrino Results

SXN et al., Phys. Rev. D **92**, 074024 (2015)

Cross section for $\nu_\mu N \rightarrow \mu^- X$



- πN & $\pi\pi N$ are main channels in few-GeV region
- DCC model gives predictions for all final states
- ηN, KY cross sections are $10^{-1} - 10^{-2}$ smaller

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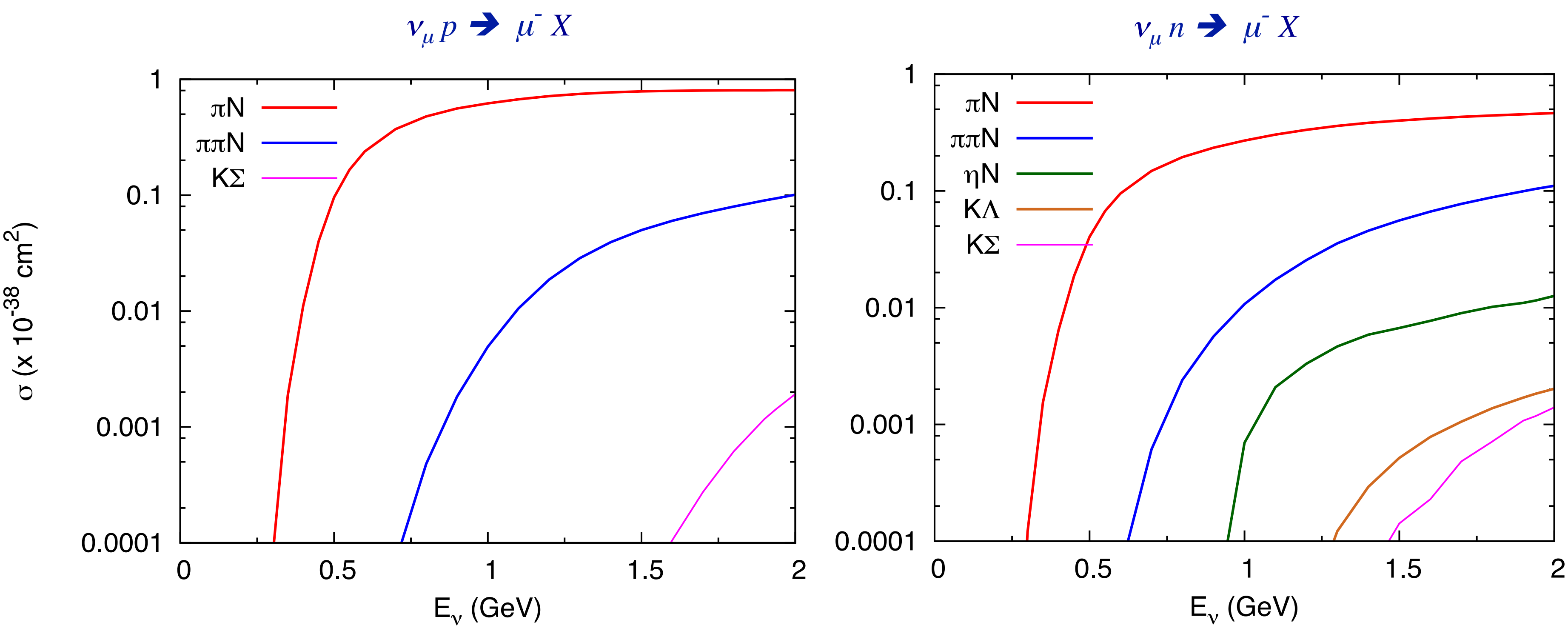

- πN & $\pi\pi N$ are main channels in few-GeV region
- DCC model gives predictions for all final states
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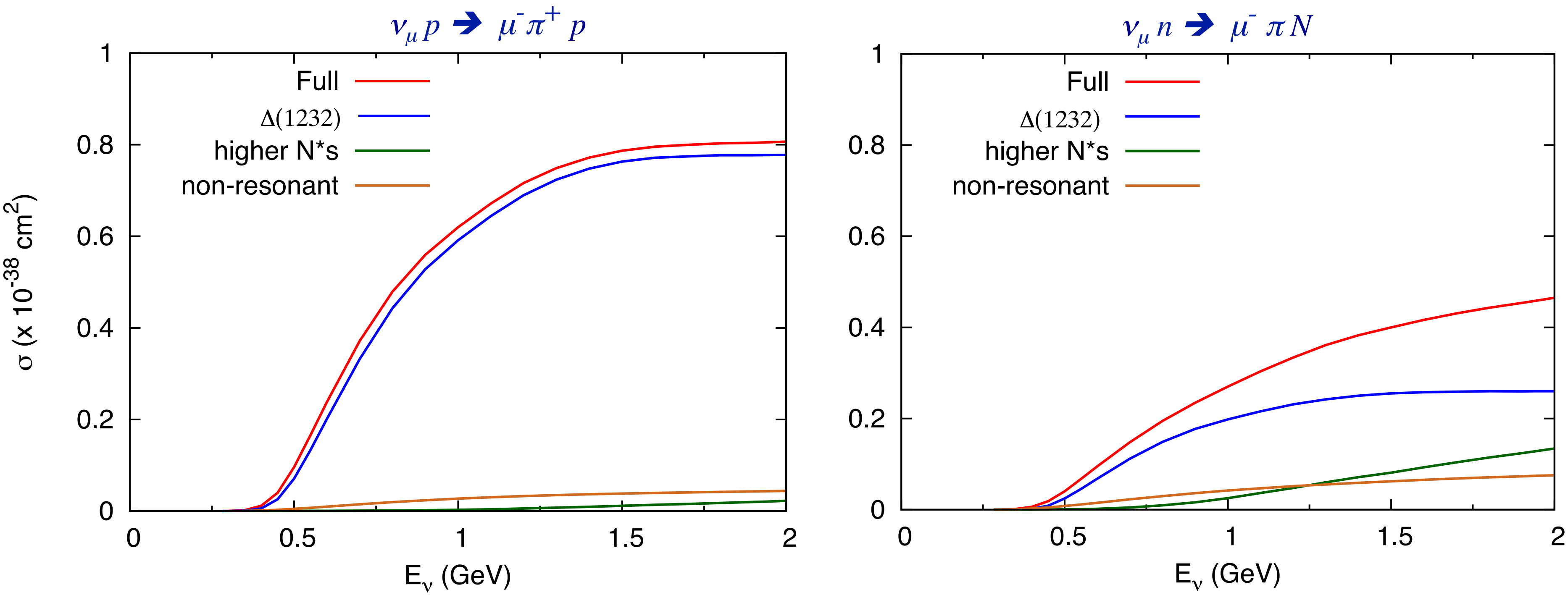
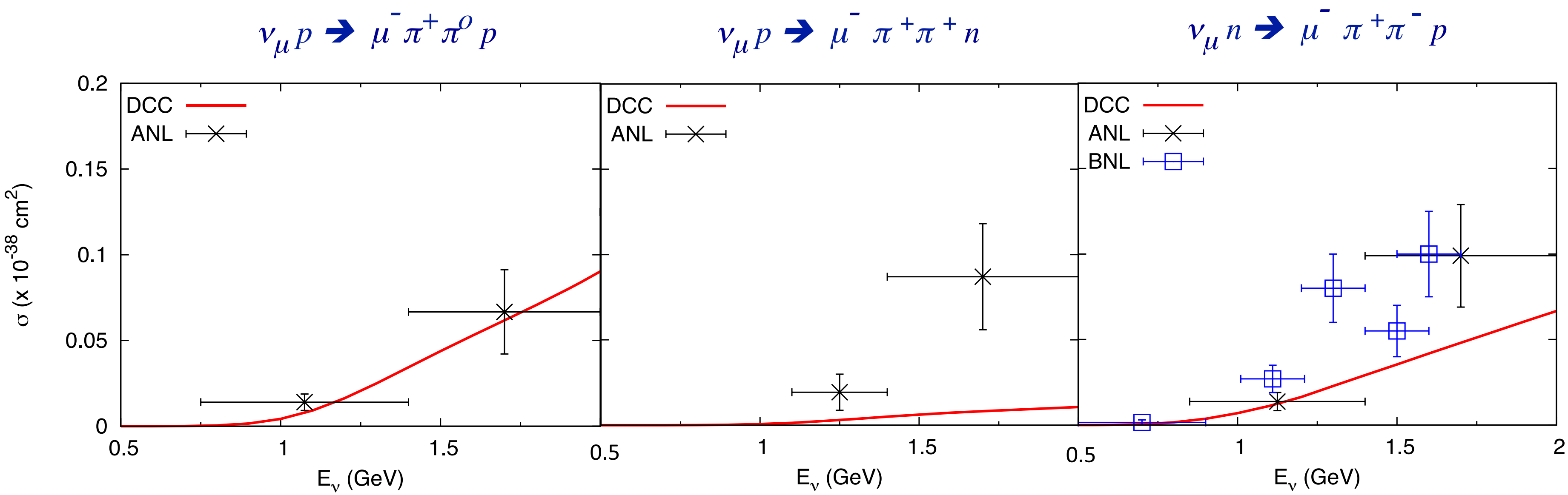
Mechanisms for $\nu_\mu N \rightarrow \mu^- \pi N$



- Δ(1232) dominates for $\nu_\mu p \rightarrow \mu^- \pi^+ p$ $(I=3/2)$ for $E_\nu \leq 2$ GeV
- Non-resonant mechanisms contribute significantly
- Higher N^*s becomes important towards $E_\nu \approx 2$ GeV for $\nu_\mu n \rightarrow \mu^- \pi N$

Comparison with double pion data



Fairly good DCC predication

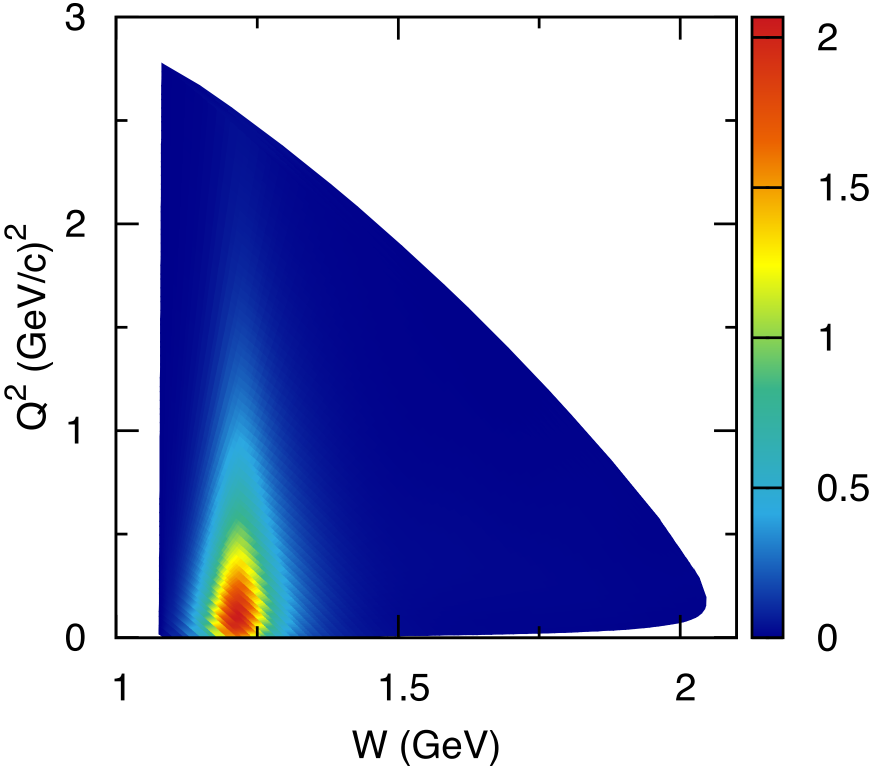
ANL Data : PRD **28**, 2714 (1983)
BNL Data : PRD **34**, 2554 (1986)

First dynamical model for 2 π production in resonance region

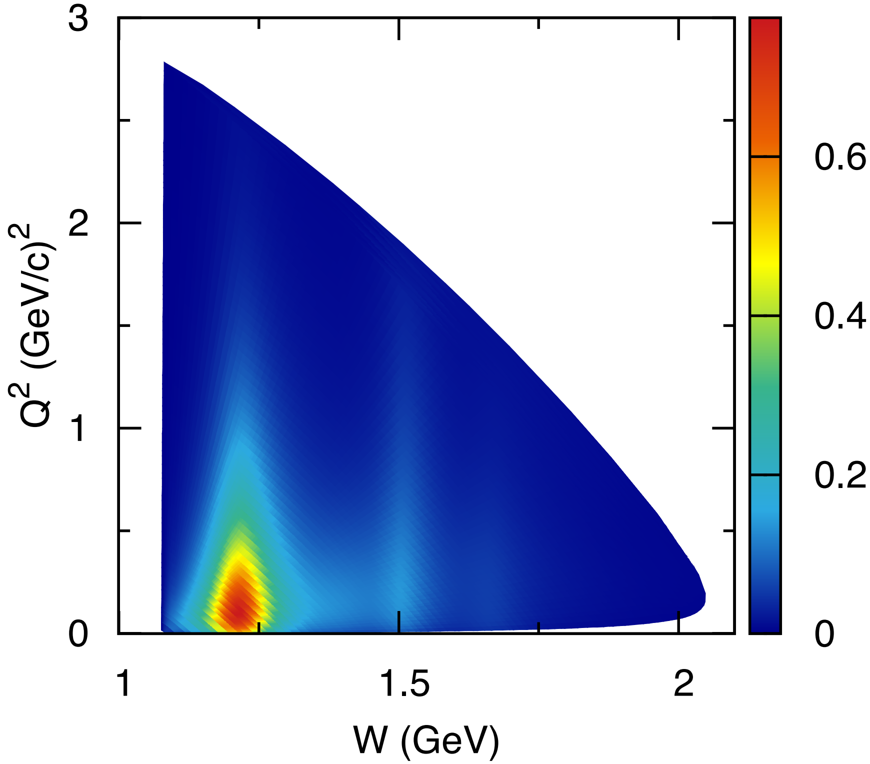
$d\sigma / dW\, dQ^2$ ($\times 10^{-38}$ cm^2 / GeV^2)

E_ν = 2 GeV

$\nu_\mu p \rightarrow \mu^- \pi^+ p$



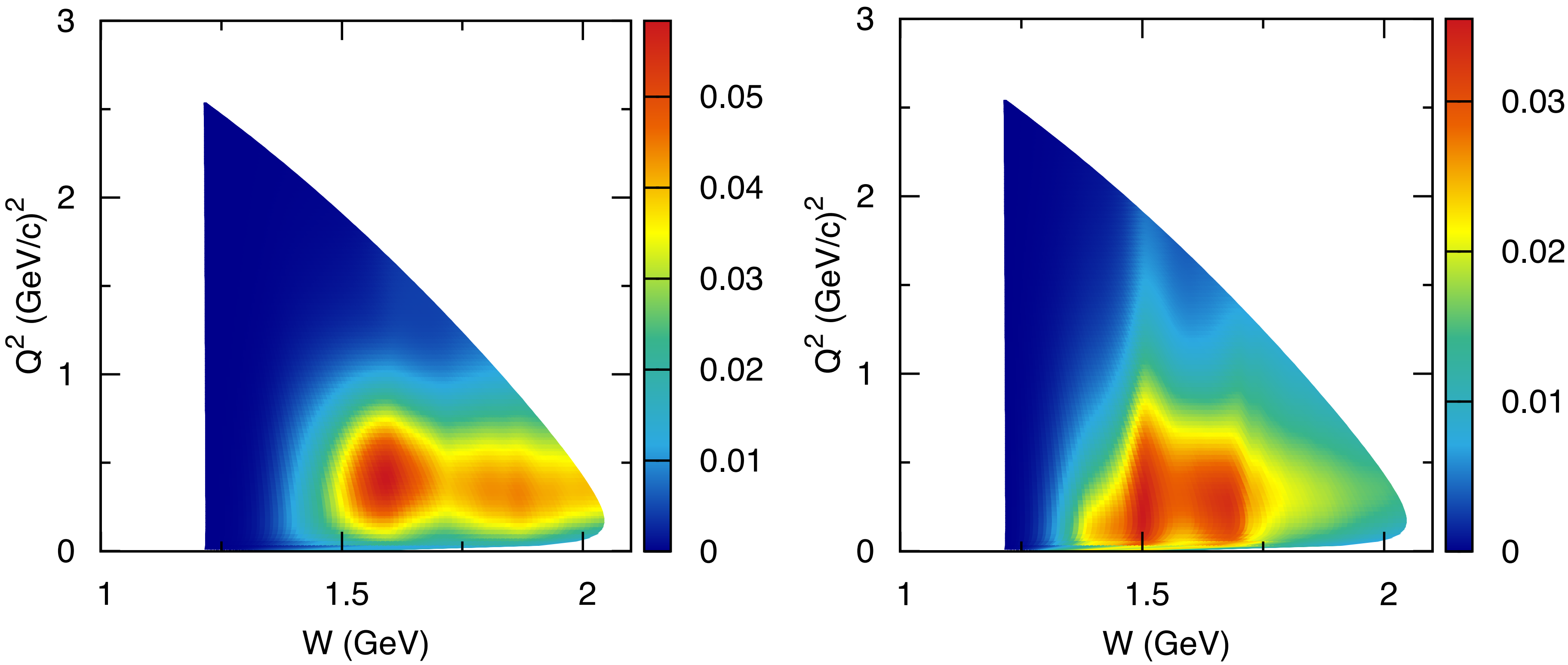
$\nu_\mu n \rightarrow \mu^- \pi N$



$d\sigma / dW\, dQ^2$ ($\times 10^{-38}$ cm^2 / GeV^2)

E_ν = 2 GeV

$\nu_\mu p \rightarrow \mu^- \pi^+ \pi^0 p$ $\qquad$ $\nu_\mu n \rightarrow \mu^- \pi^+ \pi^- p$

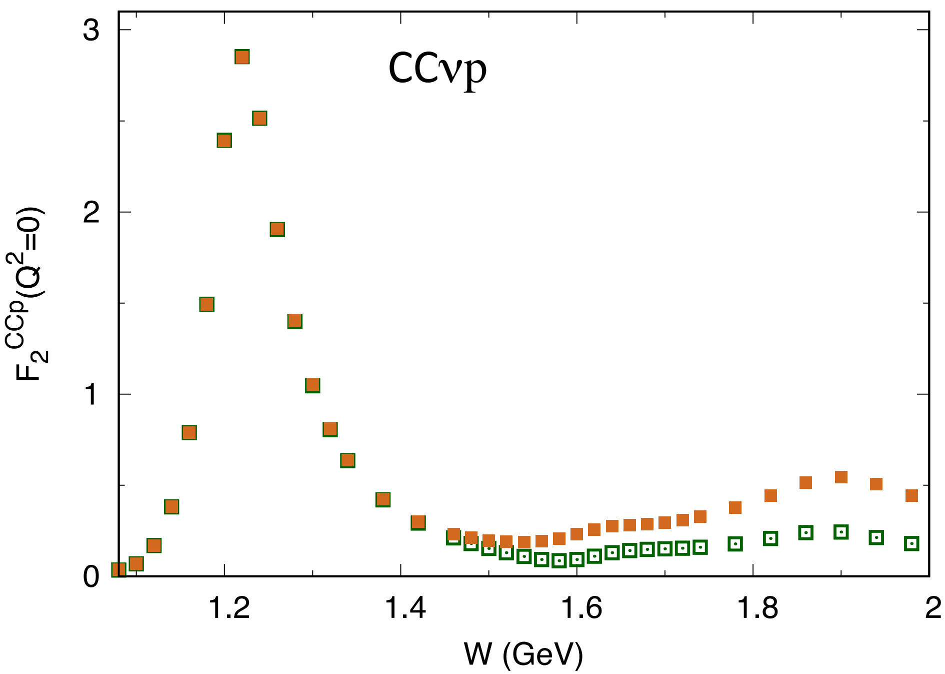


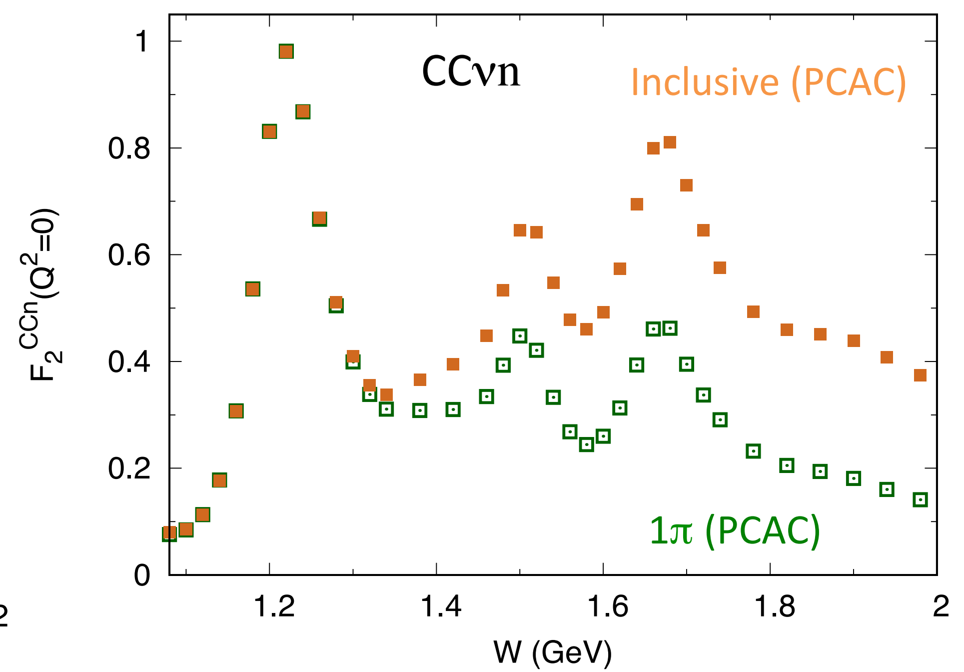
Neutrino-nucleon cross section at Q^2=0 (m_μ=0)

$$\frac{d\sigma^{CC}}{dE_l d\Omega_l} = \frac{G_F^2 V_{ud}^2}{2\pi^2}\frac{E'^2}{E-E'}F_2,$$

PCAC

$$F_2 = \frac{2f_\pi^2}{\pi}\sigma_{tot}(\pi+N)$$



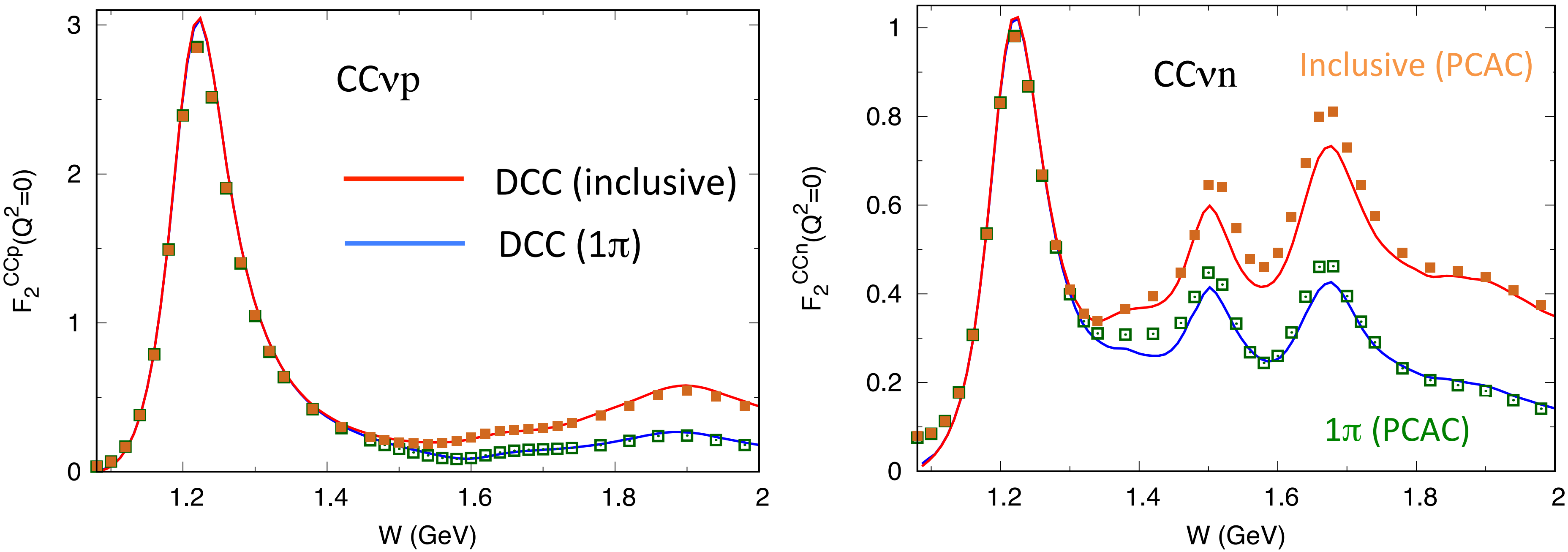


So far in this workshop, no model for resonance region beyond Δ(1232) has not been validated by neutrino-nucleon data ← ANL and BNL data are not very sensitive to this energy region

Suggestion: Validate all models for resonance region beyond Δ(1232) with this useful "data"

Cross section at Q^2=0 and $m_\mu=0$

$$\frac{d\sigma^{CC}}{dE_l d\Omega_l} = \frac{G_F^2 V_{ud}^2}{2\pi^2}\frac{E'^2}{E-E'}F_2, \qquad F_2 \overset{\text{PCAC}}{=} \frac{2f_\pi^2}{\pi}\sigma_{tot}(\pi+N)$$



- F_2 (Q^2=0) from DCC model agrees with PCAC values (∝ πN cross sections)

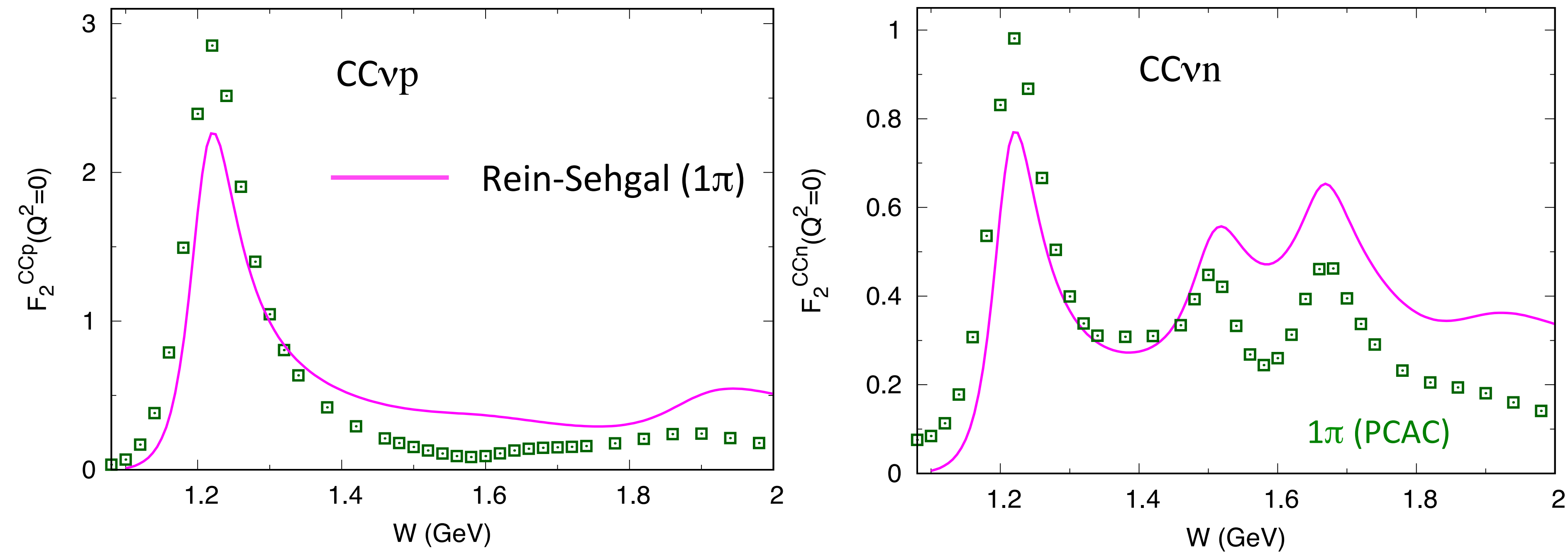
  ← DCC axial current and πN amplitude are consistent with PCAC relation

Cross section at Q^2=0 and m_μ=0

$$\frac{d\sigma^{CC}}{dE_l d\Omega_l} = \frac{G_F^2 V_{ud}^2}{2\pi^2} \frac{E'^2}{E - E'} F_2,$$

PCAC

$$F_2 = \frac{2 f_\pi^2}{\pi} \sigma_{tot}(\pi + N)$$



Rein and Sehgal, Annals Phys. 133 (1981)

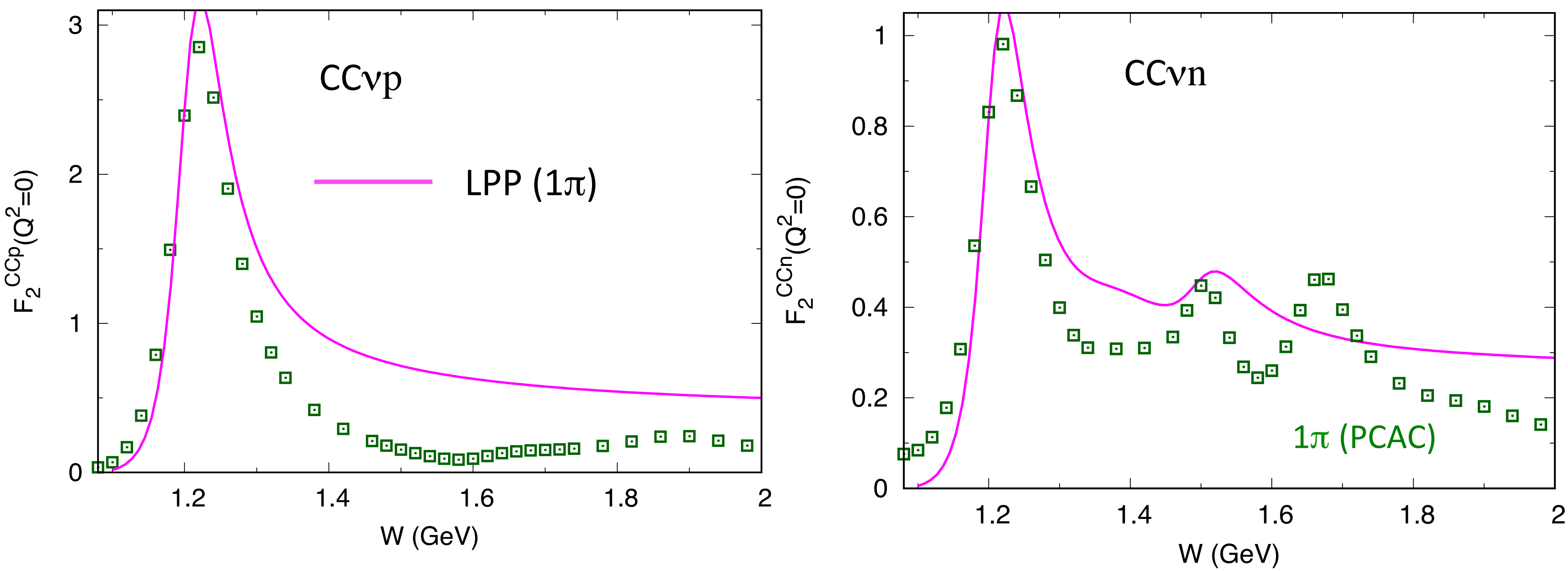
F_2 (Q^2=0) from RS model significantly overshoot PCAC values beyond $\Delta(1232)$ region

Cross section at Q^2=0 and m_μ=0

$$\frac{d\sigma^{CC}}{dE_l d\Omega_l} = \frac{G_F^2 V_{ud}^2}{2\pi^2} \frac{E'^2}{E-E'} F_2,$$

PCAC

$$F_2 = \frac{2f_\pi^2}{\pi}\sigma_{tot}(\pi+N)$$



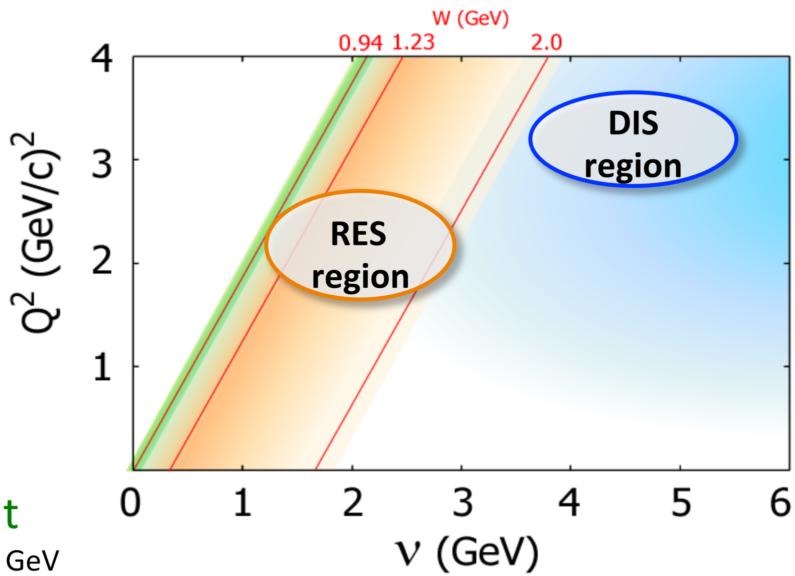
LPP: Lalakulich et al., PRD 74 (2006)

LPP model includes $\Delta(1232)$, $P_{11}(1440)$, $D_{13}(1520)$, $S_{11}(1535)$

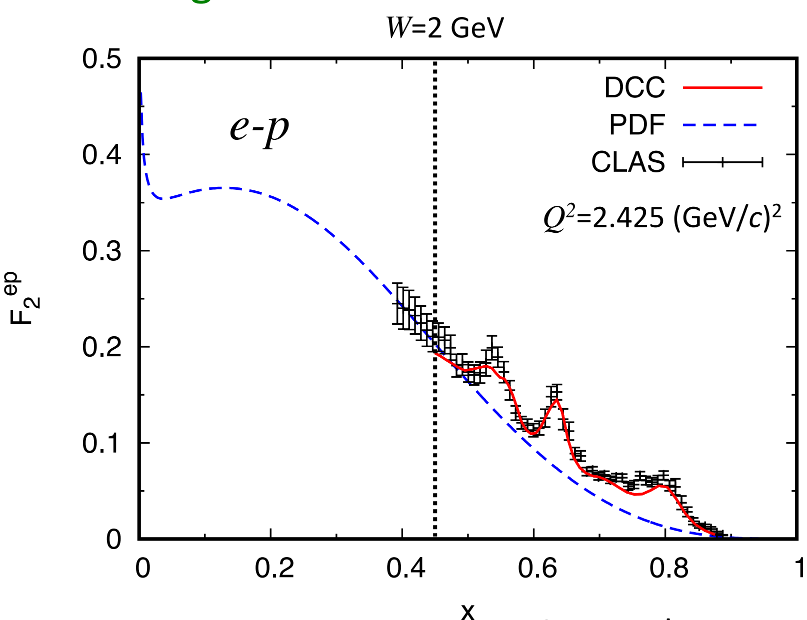
F_2 (Q^2=0) from LPP model significantly overshoot PCAC values beyond $\Delta(1232)$ region

A remaining issue

Matching with DIS region



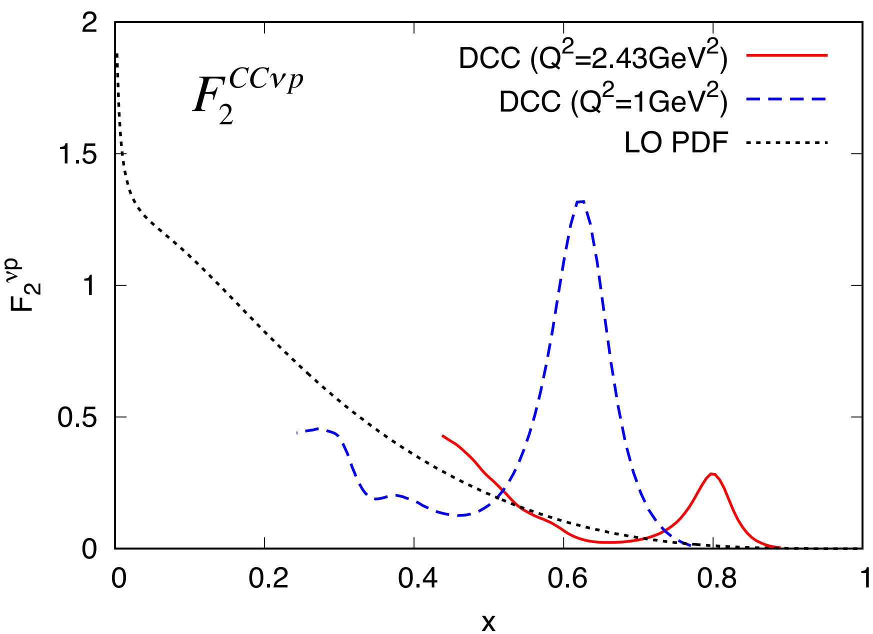
Electromagnetic current

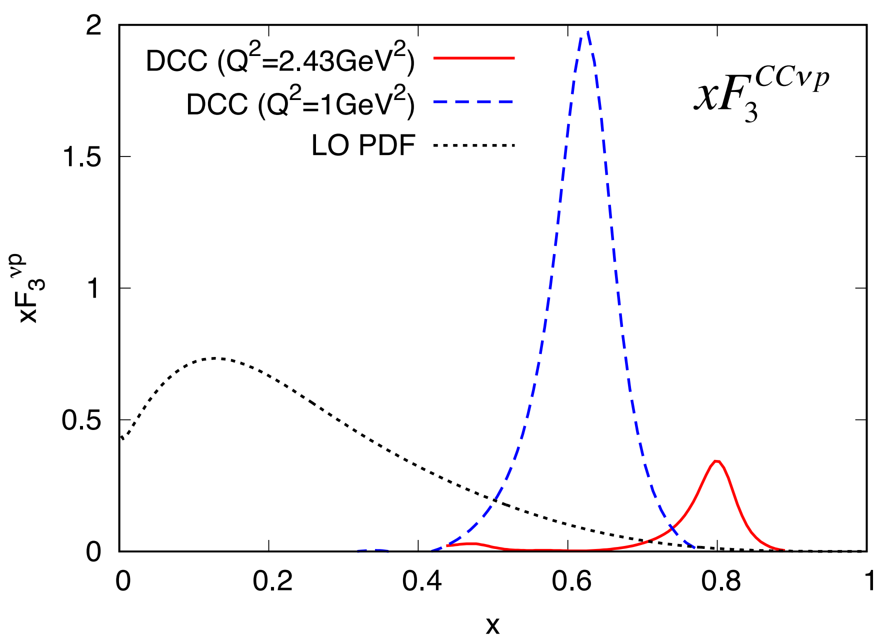


DCC smoothly connect to DIS region

SXN et al., Rept. Prog Phys. 80 (2017)

Matching with DIS region





$$F_2^{CC} \sim |V|^2 + |A|^2$$

$$F_3^{CC} \sim \mathrm{Re}(V A^*)$$

DCC axial current seems too weak in the matching region

→ Dipole axial form factor may be causing too much damp

→ Improvement is needed to fully cover high-Q^2 resonance region

neutrino data, parity-violating electron data, fitting to PDF, etc.

Conclusion

DCC approach to resonance region beyond $\Delta(1232)$

Difficult problems that we must manage

- (several) Δ, N^*s, non-resonant overlap with comparable strengths

  ➔ essential to understand interference pattern among them

- πN and $\pi\pi N$ channels are comparably important and are strongly coupled

Conclusion : DCC approach is promising

Extensively tested by $\gamma^{(*)}N,\ \pi N$ ➔ $\pi N,\ \pi\pi N,\ \eta N,\ K\Lambda,\ K\Sigma$ data

➔ Well-validated vector current

➔ Axial current consistent with the PCAC relation to πN interaction

interferences among different mechanisms are unambiguously fixed

➔ Two-pion productions are calculated with all relevant resonance contributions

Should address remaining issues (high-Q^2 behavior of axial current, etc.)

BACKUP

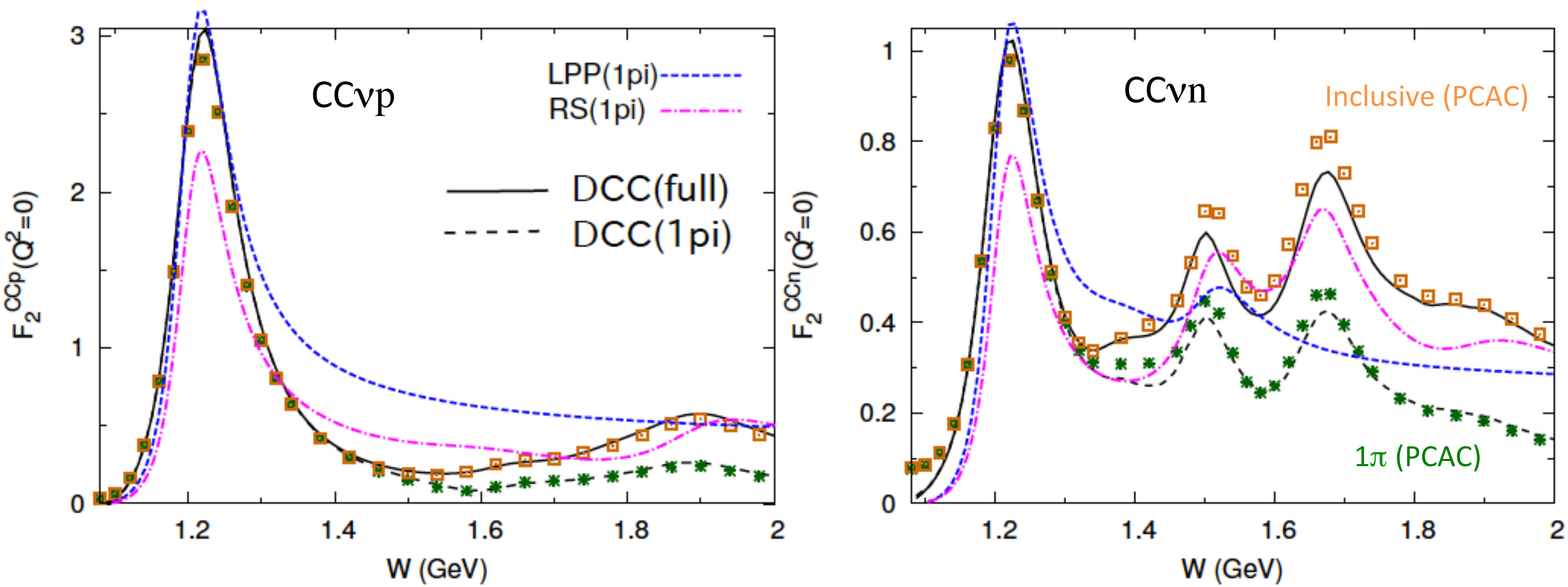
Cross section at Q^2=0 and $m_\mu=0$

LPP: Lalakulich et al., PRD 74 (2006)
RS: Rein and Sehgal, Annals Phys. 133 (1981)

$$\frac{d\sigma^{CC}}{dE_l d\Omega_l} = \frac{G_F^2 V_{ud}^2}{2\pi^2}\frac{E'^2}{E-E'}F_2,$$

PCAC

$$F_2 = \frac{2f_\pi^2}{\pi}\sigma_{tot}(\pi + N)$$

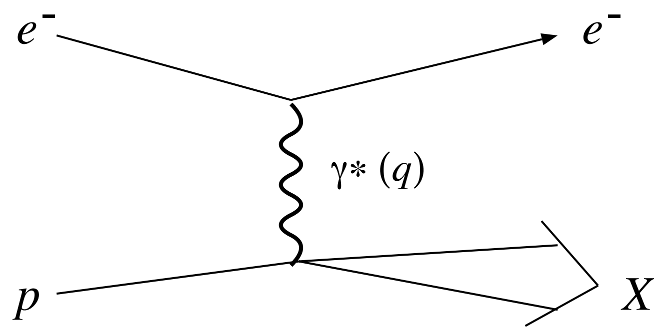


Useful quantity to check soundness of a model for energy region beyond Δ(1232)

- F_2 from DCC model agrees with PCAC values (∝ πN cross sections)
  ← DCC axial current and πN amplitude are consistent with PCAC relation
- F_2 from LPP and RS models deviate from PCAC values

Parity-violating electron-nucleon scattering and axial form factors

Inclusive electron-proton scattering ($e^- p \rightarrow e^- X$)



Differential cross section with respect to lepton kinematics

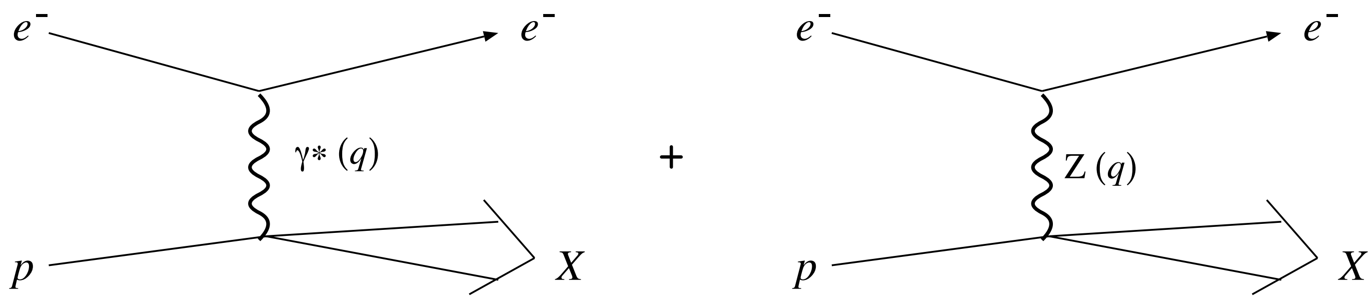
$$\frac{d\sigma}{d\Omega dE'} = \frac{4\alpha^2 E'^2}{Q^4}\left[2W_1^{\text{em}} \sin^2\frac{\theta}{2} + W_2^{\text{em}} \cos^2\frac{\theta}{2}\right]$$

$W_i^{\text{em}}(W, Q^2)$: structure functions (all information of hadron dynamics encoded in)

$$W_1^{\text{em}} = \frac{1}{2}\bar{\sum_i}\sum_f \left(\left|\langle f|J_x^{\text{em}}|i\rangle\right|^2 + \left|\langle f|J_y^{\text{em}}|i\rangle\right|^2 \right) \delta^{(4)}(p_i + q - p_f)$$

$$W_2^{\text{em}} = \frac{Q^2}{|\vec{q}|^2} W_1^{\text{em}} + \frac{Q^2}{|\vec{q}|^2}\frac{Q^2}{|\vec{q}_c|^2}\bar{\sum_i}\sum_f \left|\langle f|J_0^{\text{em}}|i\rangle\right|^2 \delta^{(4)}(p_i + q - p_f)$$

Parity-violating inclusive electron-proton scattering



Parity-violating asymmetry

$$A = \frac{d\sigma(h_e = +1) - d\sigma(h_e = -1)}{d\sigma(h_e = +1) + d\sigma(h_e = -1)} \quad = -\frac{Q^2 G_F}{\sqrt{2}(4\pi\alpha)} \frac{N}{D}$$

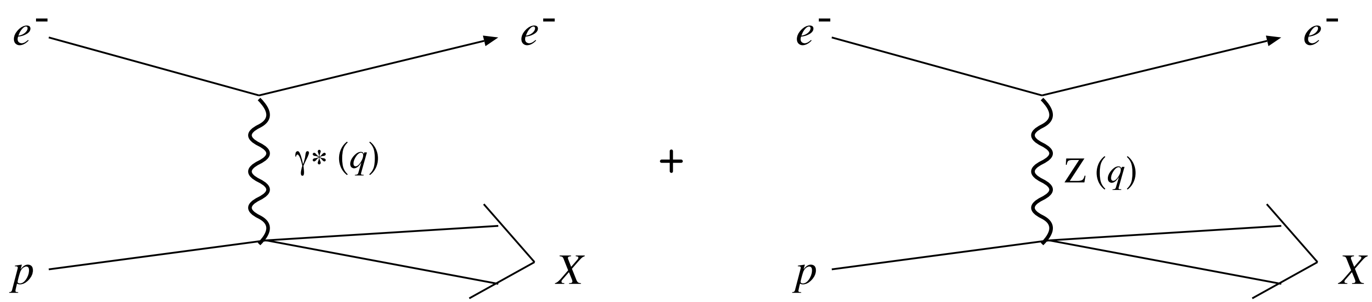
$$D = \cos^2\frac{\theta}{2} W_2^{\text{em}} \quad + 2\sin^2\frac{\theta}{2} W_1^{\text{em}}$$

$$N = \cos^2\frac{\theta}{2} W_2^{\text{em-nc}} + 2\sin^2\frac{\theta}{2} W_1^{\text{em-nc}} \quad + \sin^2\frac{\theta}{2}(1 - 4\sin^2\theta_W)\frac{E + E'}{M} W_3^{\text{em-nc}}$$

$$J^\mu_{\text{nc}} = (1 - 2\sin^2\theta_W) J^\mu_{\text{em}} - V^\mu_{\text{isoscalar}} - A^\mu_3$$

$$\rightarrow (1 - 2\sin^2\theta_W) D + \left(\cos^2\frac{\theta}{2} W_2^{\text{em-is}} + 2\sin^2\frac{\theta}{2} W_1^{\text{em-is}}\right)$$

Parity-violating inclusive electron-proton scattering



Parity-violating asymmetry

$$A = -Q^2 \frac{G_F}{\sqrt{2}\, 4\pi\alpha} \left(2 - 4\sin^2\theta_W + \Delta_V + \Delta_A \right)$$

$\approx 8.99 \times 10^{-5}$ (GeV^{-2})

≈ 1.075 (main term)

$$\Delta_V = \frac{\cos^2\frac{\theta}{2} W_2^{\text{em-is}} + 2\sin^2\frac{\theta}{2} W_1^{\text{em-is}}}{D}$$

$$\Delta_A = \frac{\sin^2\frac{\theta}{2}(1 - 4\sin^2\theta_W)\frac{E+E'}{M} W_3^{\text{em-nc}}}{D}$$

$$1 - 4\sin^2\theta_W \approx 0.08$$

- $2W_3^{\text{em-nc}} = W_3^{\text{CC}}$
  $\propto \langle f | V_{\text{iso-vector}} | i \rangle \langle f | A_{\text{iso-vector}} | i \rangle^*$

→ PV asymmetry data for backward electron kinematics can measure W_3 for neutrino CC process and axial matrix element (form factors)

- Δ_V is proportional to isoscalar current
  → small in $\Delta(1232)$ region

Δ_V , Δ_A contributions from SL model

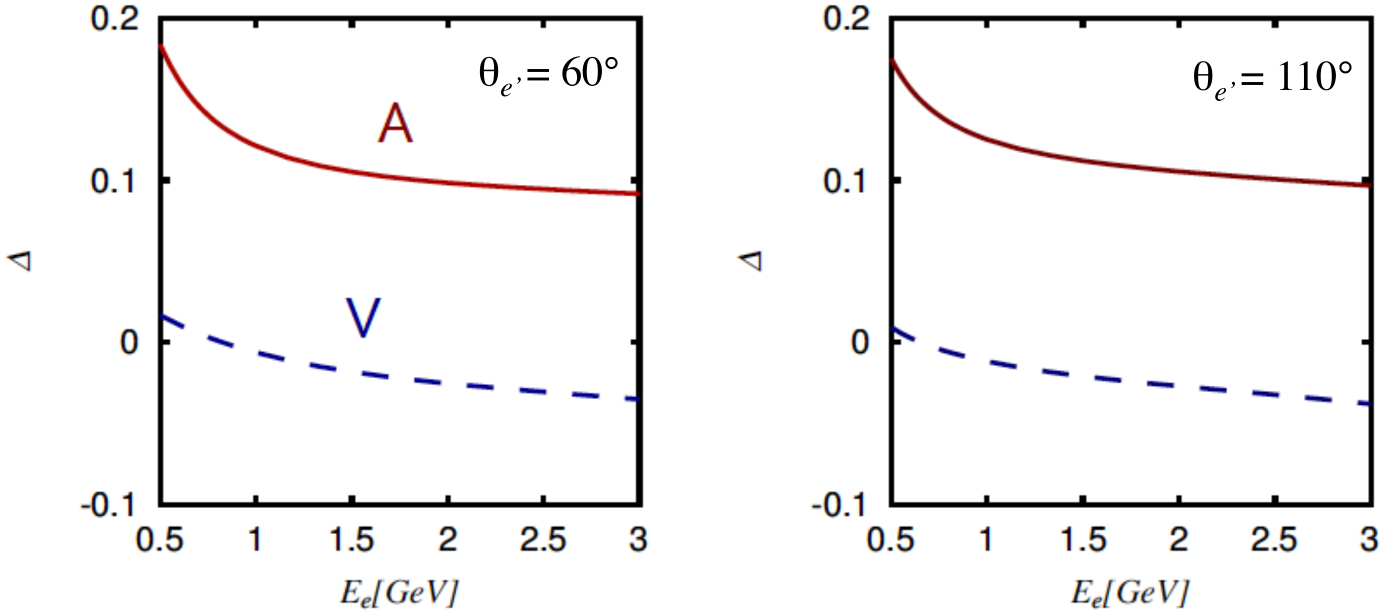
Matsui, Sato, Lee, PRC 72, 025204 (2005)

$$A/Q^2 = -89.9 \times 10^{-6} \left(1.075 + \Delta_V + \Delta_A \right)$$

[1/GeV²]

$$\Delta_V = \frac{\cos^2 \frac{\theta}{2} W_2^{\text{em-is}} + 2 \sin^2 \frac{\theta}{2} W_1^{\text{em-is}}}{D},$$

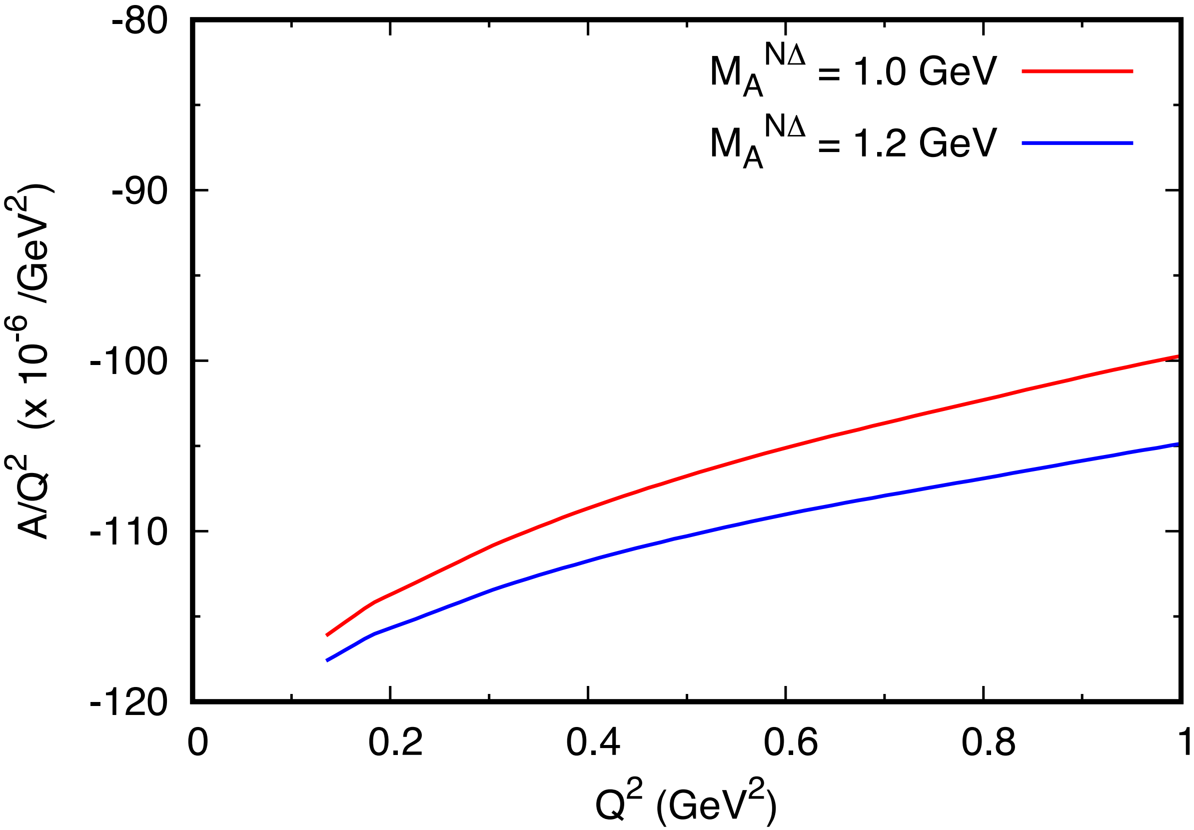
$$\Delta_A = \frac{\sin^2 \frac{\theta}{2} (1 - 4 \sin^2 \theta_W) \frac{E+E'}{M} W_3^{\text{em-nc}}}{D}$$



$p(\vec{e}, e'), W = 1.232 GeV$

Δ_A gives ~10% correction to A

Sensitivity of PV asymmetry to $N \rightarrow \Delta(1232)$ axial form factor



$W = 1232$ MeV, $\theta_{e'} = 110°$

$$A/Q^2 = -89.9\left(1.075 + \Delta_V + \Delta_A\right)$$

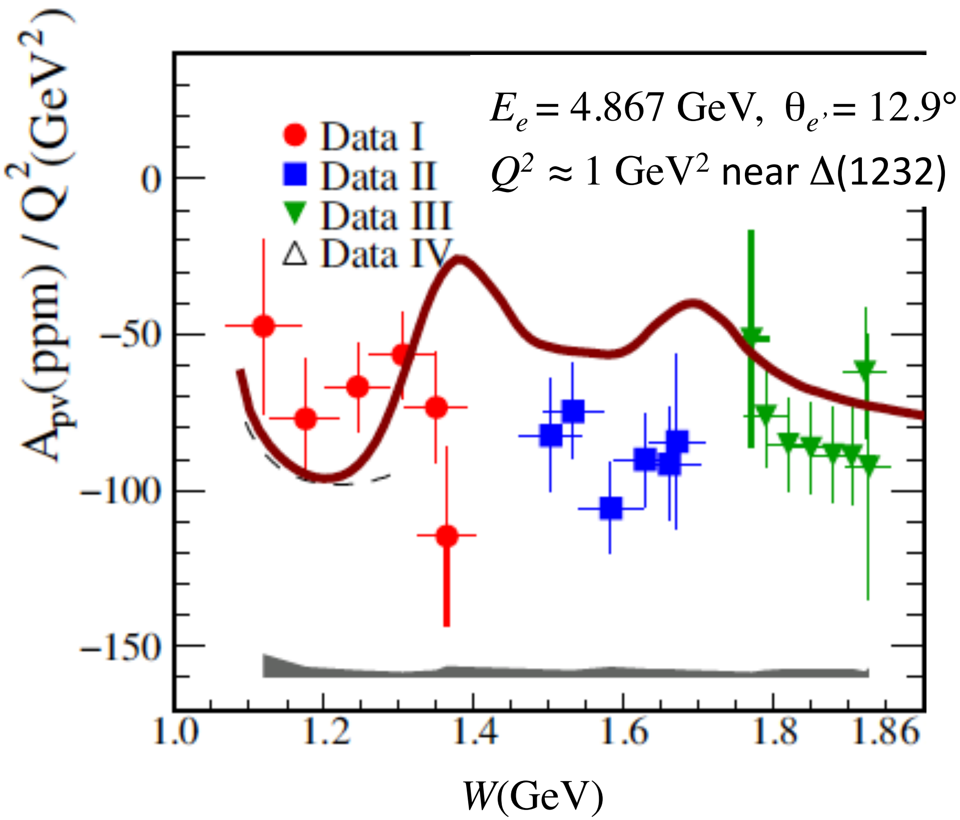
[10^{-6}/GeV^2]

$N \rightarrow \Delta(1232)$ dipole form factor with $M_A^{N\Delta}$

- 5% precision PV asymmetry data may discriminate 0.2 GeV difference in the axial mass
- Sensitivity to $N \rightarrow N^*, \Delta^*$ (higher resonances) transition axial form factors can be studied with the DCC model

Comparison with PV asymmetry data from JLab

The PVDIS Collaboration, PRC 91 045506 (2015)



$$A = \frac{d\sigma(h_e = +1) - d\sigma(h_e = -1)}{d\sigma(h_e = +1) + d\sigma(h_e = -1)}$$

$$A / Q^2 = -\ 89.9 \times \left(1.075 + \Delta_V + \Delta_A \right)$$

[10^{-6}/GeV^2]

30-50% precision data for A already exist

→ Event rate measured at 0.3% precision

Deuteron target data

→ proton and neutron cross sections are simply summed in calculation

- Forward electron kinematics → axial current hardly contribute
- Deviation from data in Δ(1232) may be from nuclear effects (FSI, Fermi motion, etc.)
- Deviations in higher W region → calling improvement on the model (isospin separation)

Relation between neutrino and electron (photon) interactions

Charged-current (CC) interaction (e.g. $\nu_\mu + n \rightarrow \mu^- + p$)

$$L^{cc} = \frac{G_F V_{ud}}{\sqrt{2}} [J_\lambda^{cc} \ell_{cc}^\lambda + h.c.\,] \qquad J_\lambda^{cc} = V_\lambda - A_\lambda \qquad \ell_{cc}^\lambda = \bar{\psi}_\mu \gamma^\lambda (1-\gamma_5)\psi_\nu$$

Electromagnetic interaction (e.g. $\gamma^{(*)} + p \rightarrow p$)

$$L^{em} = e\, J_\lambda^{em} A_{em}^\lambda \qquad J_\lambda^{em} = V_\lambda + V_\lambda^{IS}$$

V and V^{IS} in J^{em} can be separately determined by analyzing photon ($Q^2=0$) and electron reaction ($Q^2 \neq 0$) data on both proton and neutron targets, because:

$$< p | V_\lambda | p > = - < n | V_\lambda | n > \qquad < p | V_\lambda^{IS} | p > = < n | V_\lambda^{IS} | n >$$

Matrix element for the weak vector current is obtained from analyzing electromagnetic processes

$$< p | V_\lambda | n > = \sqrt{2} < p | V_\lambda | p >$$

DCC model for axial current

Because neutrino reaction data are scarce, axial current cannot be determined phenomenologically

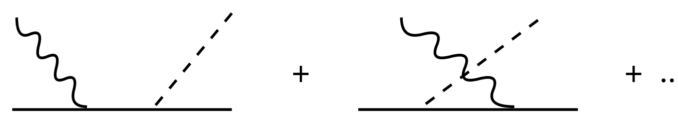
→ Chiral symmetry and PCAC (partially conserved axial current) are guiding principle

PCAC relation $< X' | q \cdot A | X > \sim i f_\pi < X' | T | \pi X >$

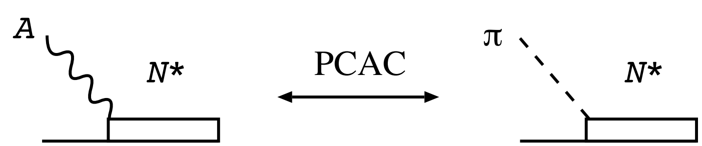
Q^2=0

non-resonant mechanisms

$$\partial_\mu \pi \to f_\pi A_\mu^{external}$$

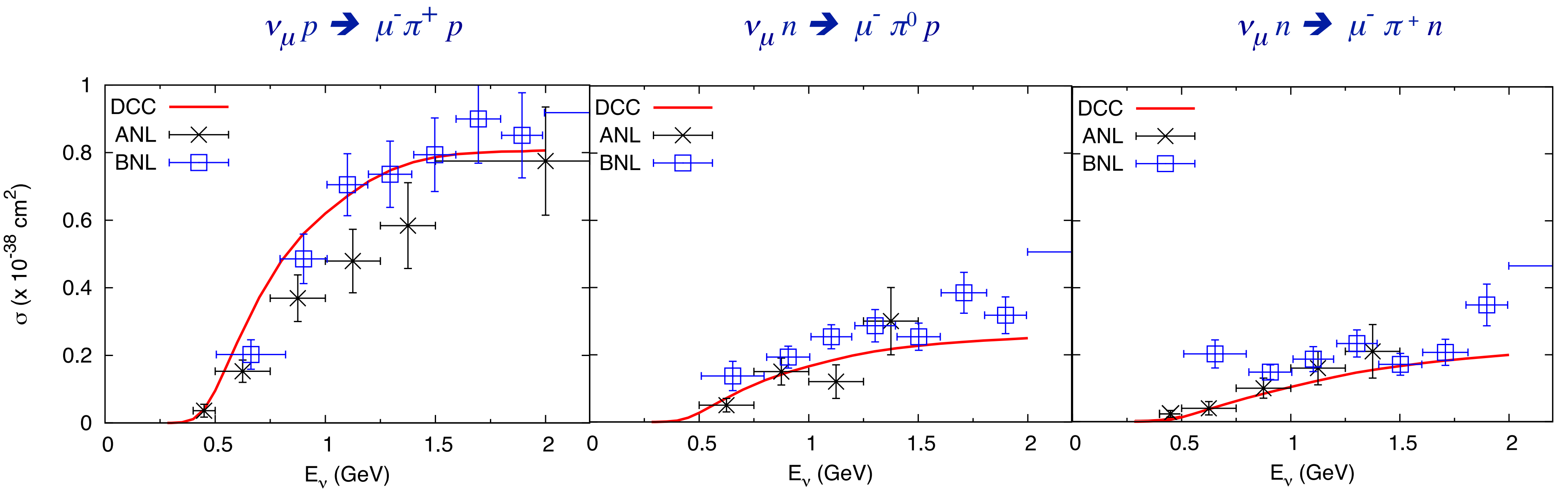


resonant mechanisms



Interference among resonances and background can be uniquely fixed within DCC model

Comparison with single pion data



DCC model prediction is consistent with data

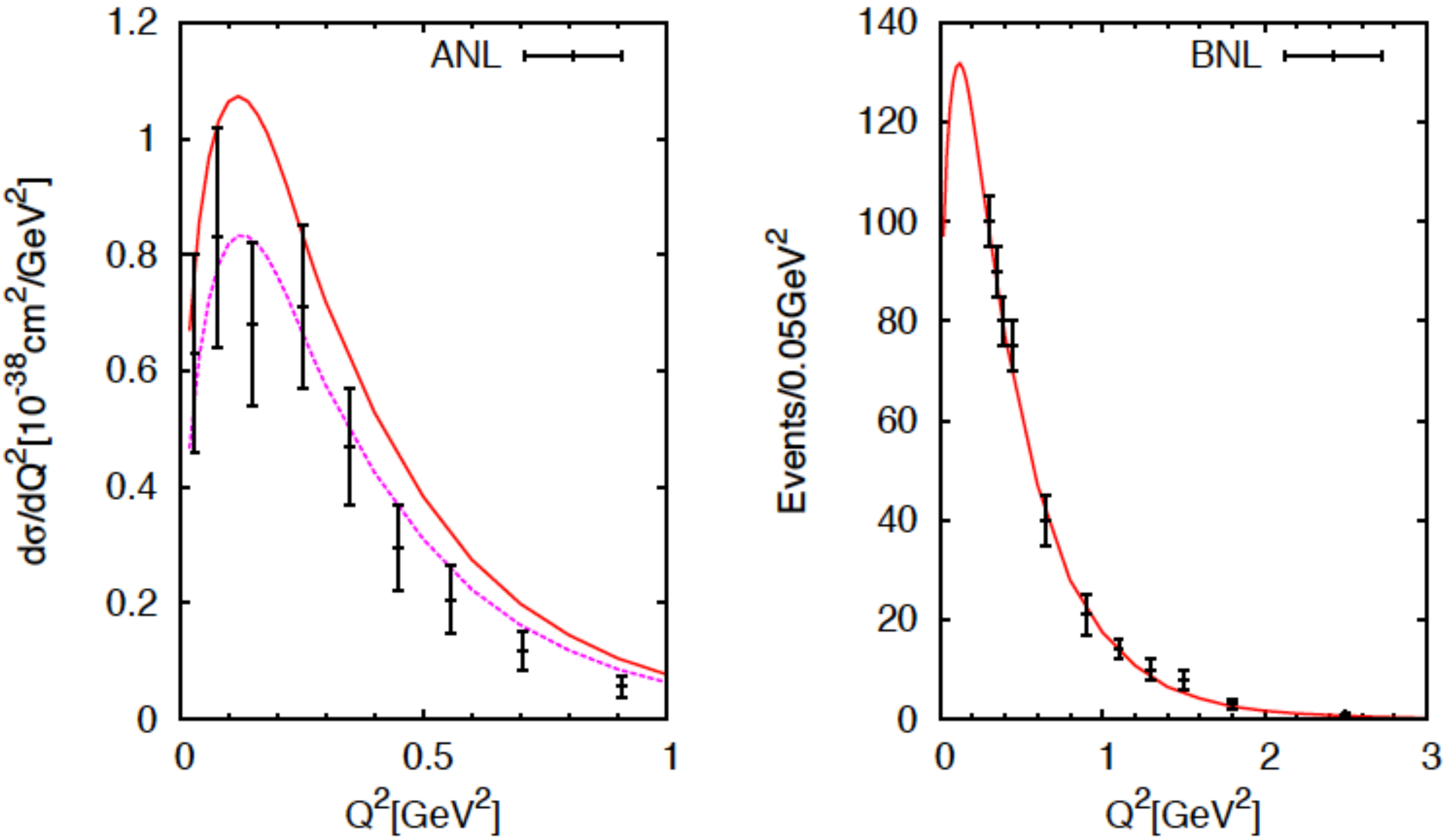
ANL Data : PRD **19**, 2521 (1979)
BNL Data : PRD **34**, 2554 (1986)

- DCC model has flexibility to fit data ($ANN^*(Q^2)$)
- Data should be analyzed with nuclear effects

(Wu et al. , PRC91, 035203 (2015); to be discussed later)

Q^2 – dependence

$\nu_\mu p \rightarrow \mu^- \pi^+ p$

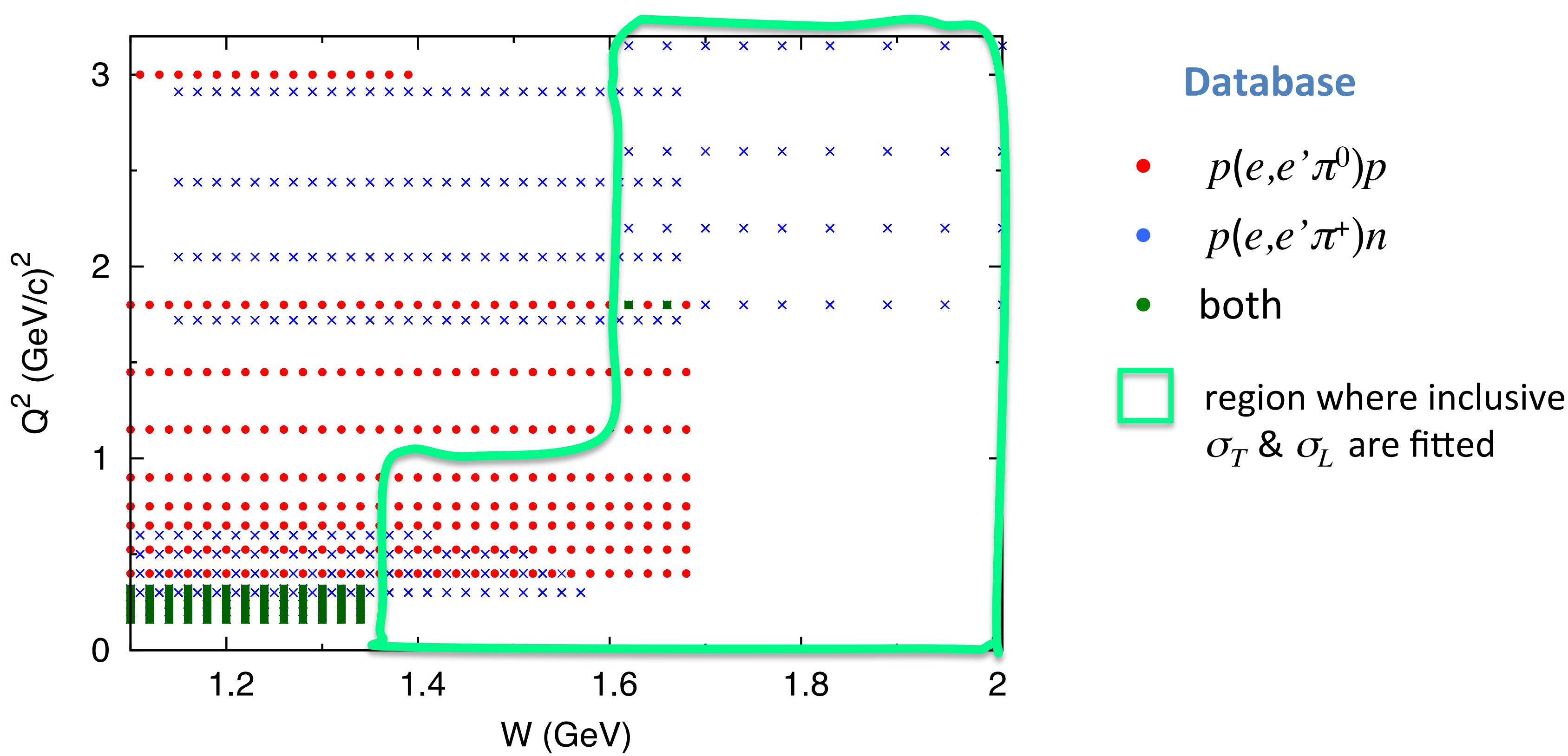


Analysis of electron-proton scattering data

Purpose : Determine Q^2 –dependence of vector coupling of p-N^* : $VpN^*(Q^2)$

Data : * 1π electroproduction

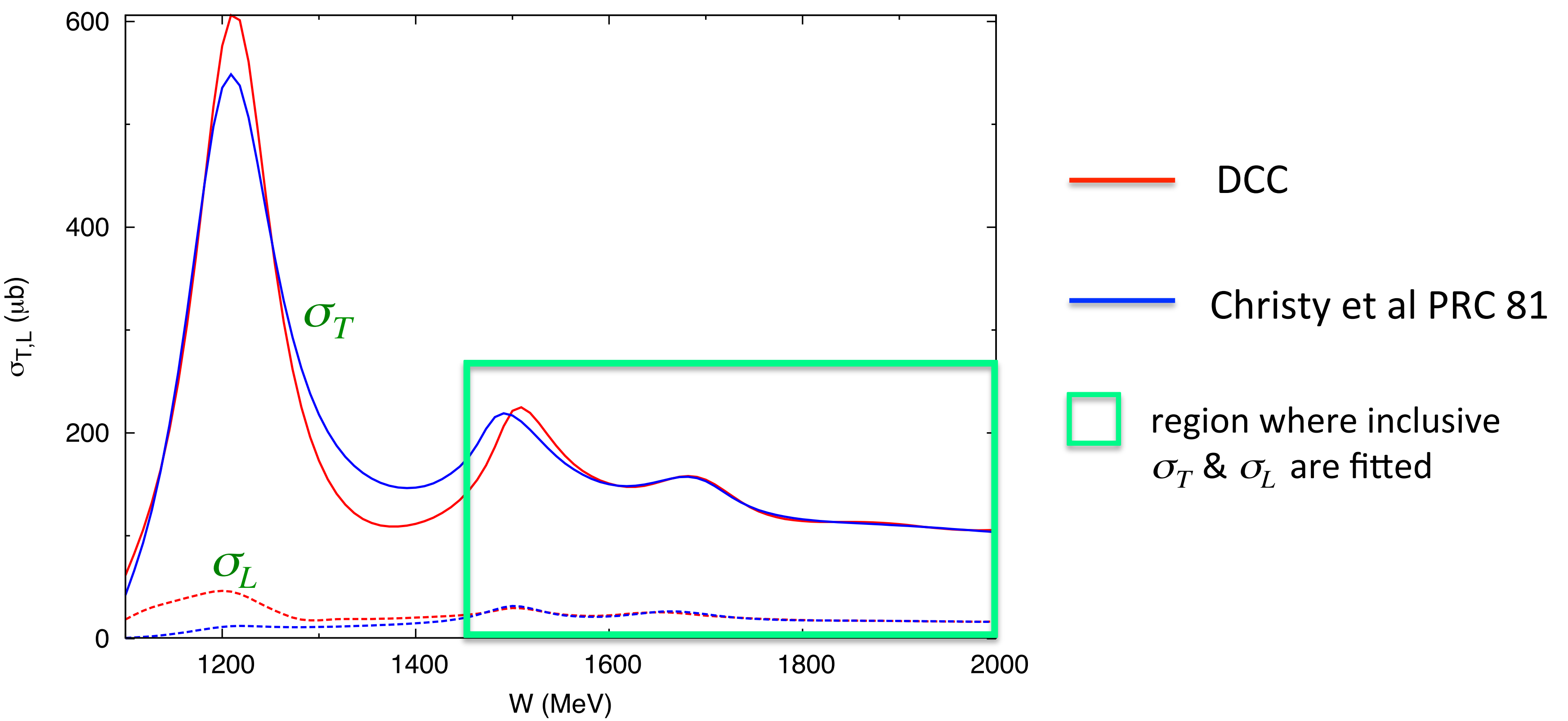
* Empirical inclusive inelastic structure functions σ_T, σ_L ← Christy et al, PRC 81 (2010)



Analysis result

Q^2=0.16 (GeV/c)^2

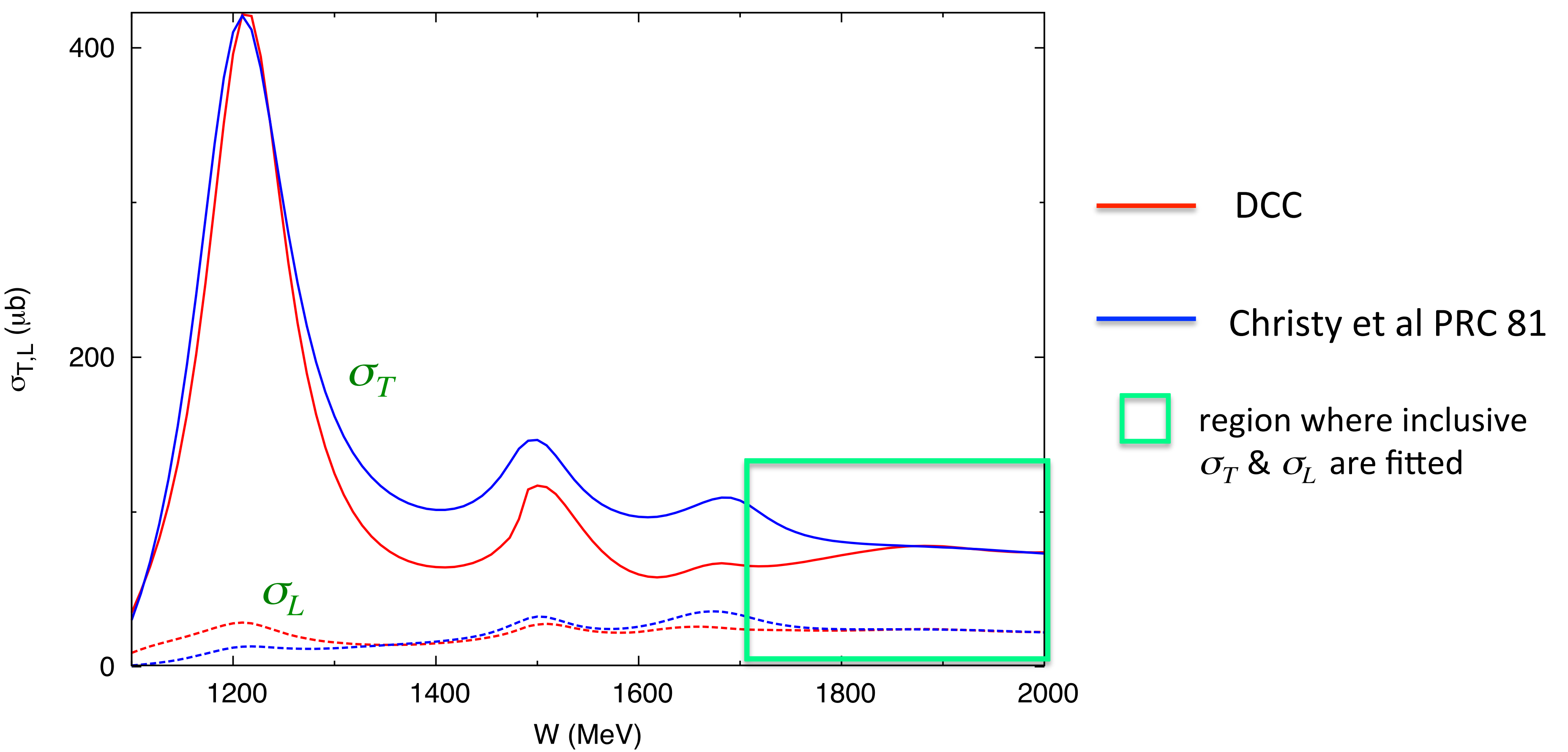
σ_T & σ_L (inclusive inelastic)



Analysis result

Q^2=0.40 (GeV/c)^2

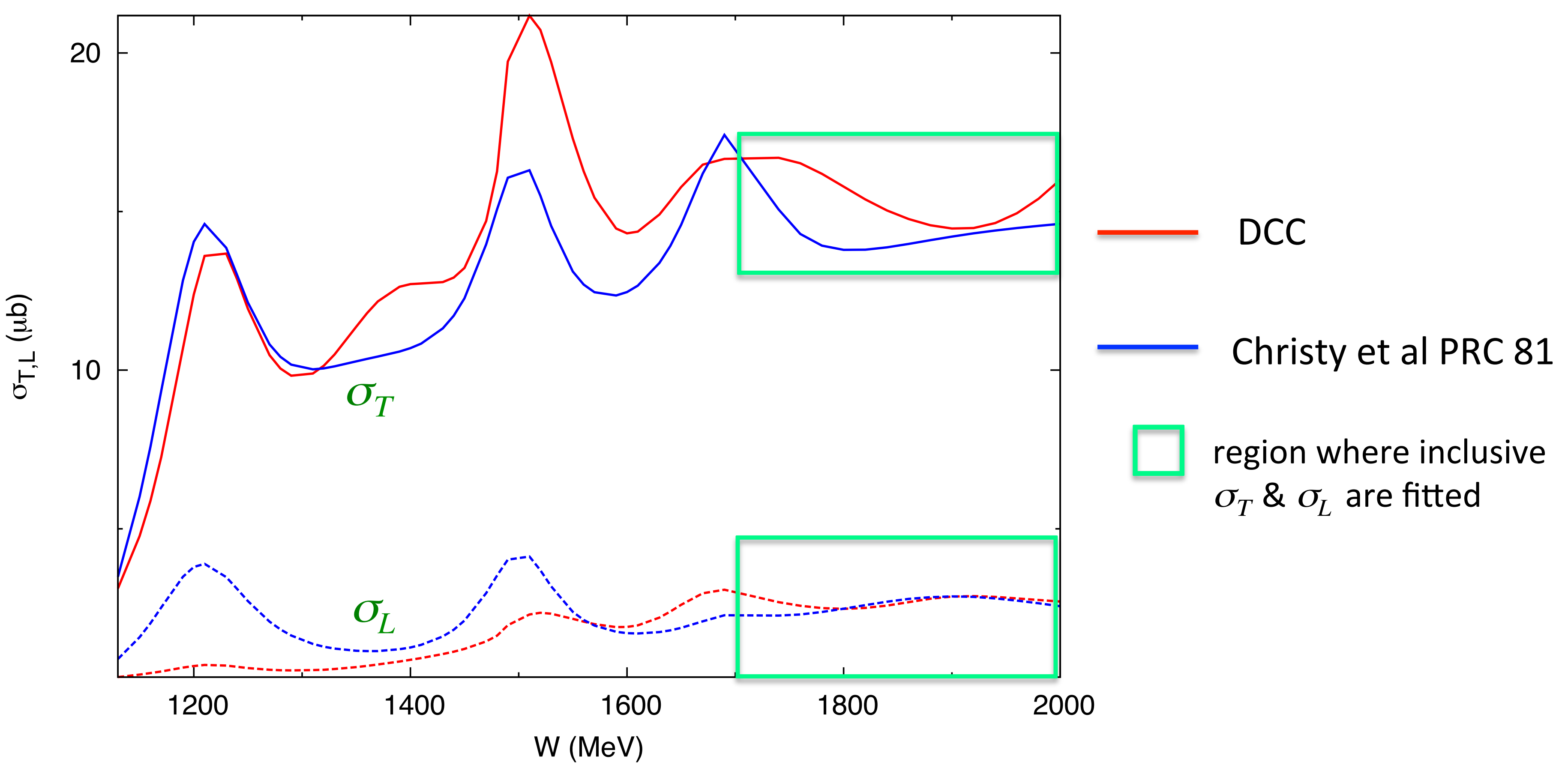
σ_T & σ_L (inclusive inelastic)



Analysis result

Q^2=2.95 (GeV/c)^2

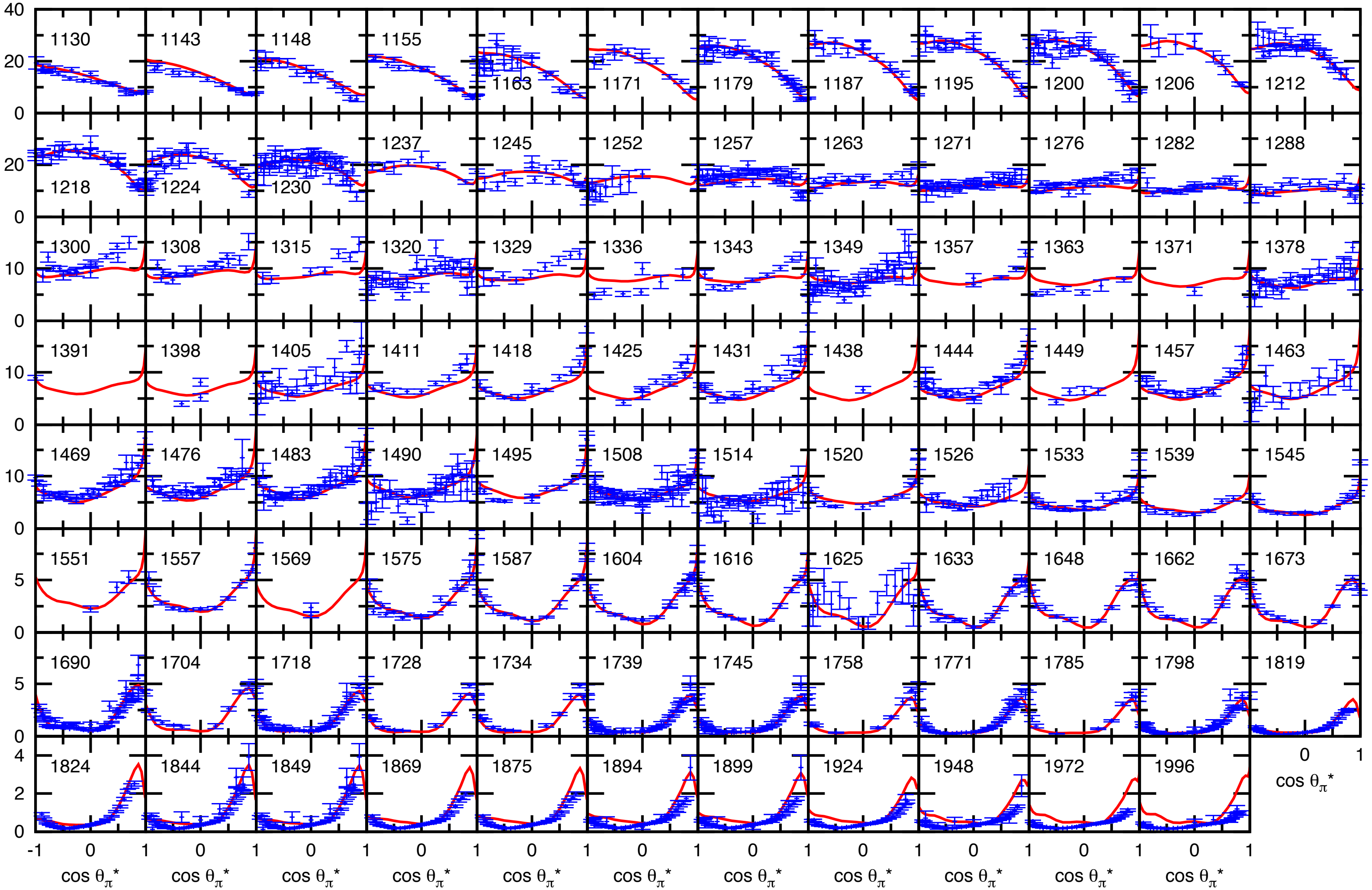
σ_T & σ_L (inclusive inelastic)



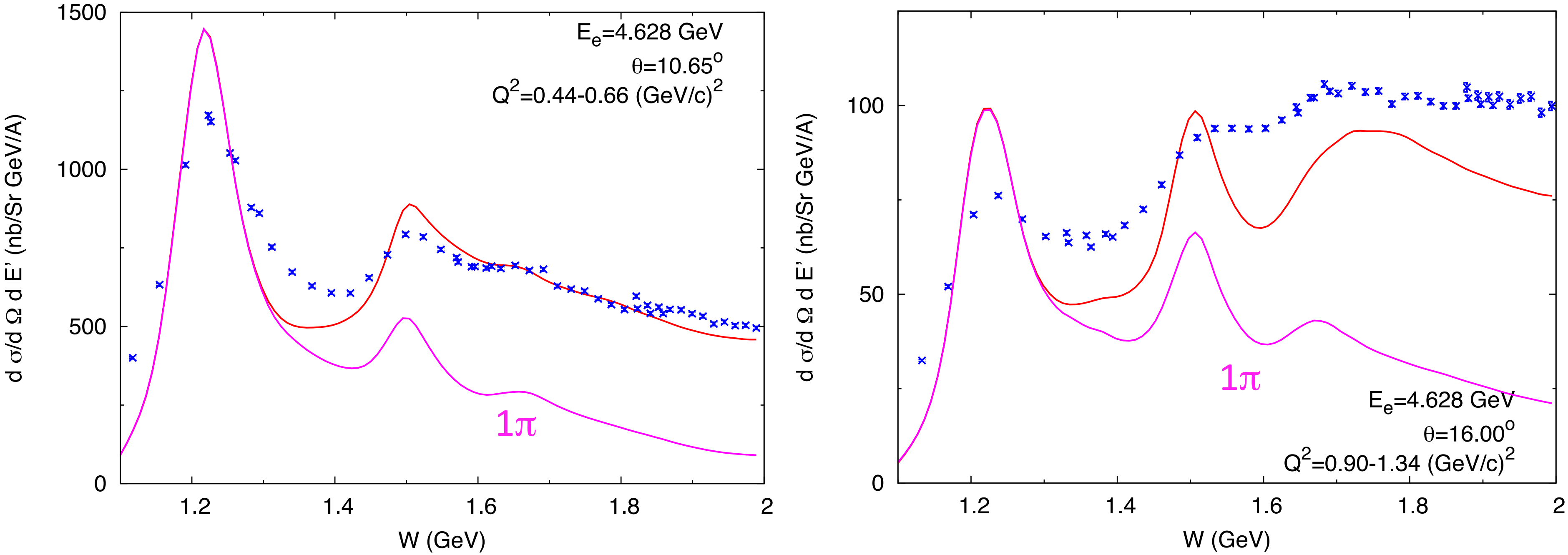
Analysis result (single π)

Q^2=0

$d\sigma / d\Omega$ $(\gamma n \rightarrow \pi^- p)$ for W=1.1 – 2.0 GeV



Analysis result (inclusive e^{-}-d)



Data: NP Proc. Suppl. 159, 163 (2006)

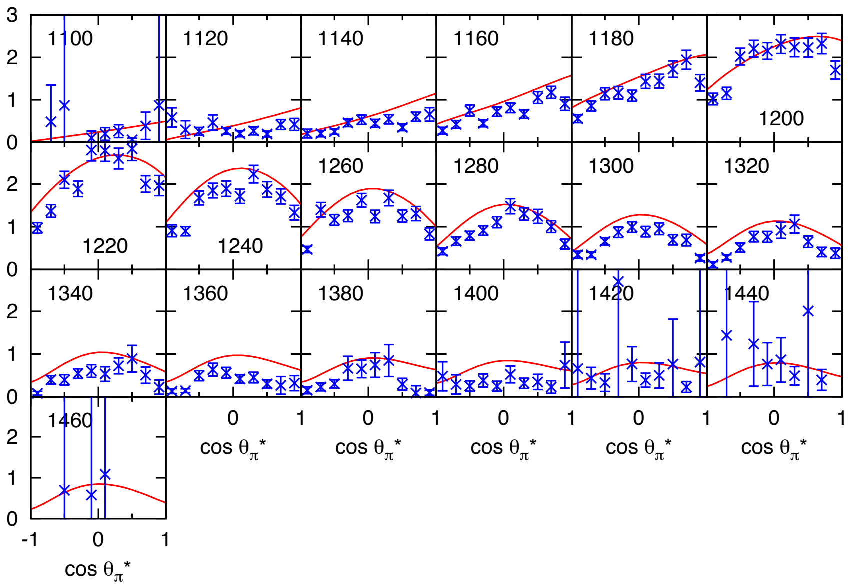
- Our calculation : $[\ \sigma(e^{-}\text{-}p) + \sigma(e^{-}\text{-}n)\ ] / 2$
- Too sharp resonant peaks → fermi motion smearing, other nuclear effects needed
- Reasonable starting point for application to neutrino interactions

Analysis result (single π)

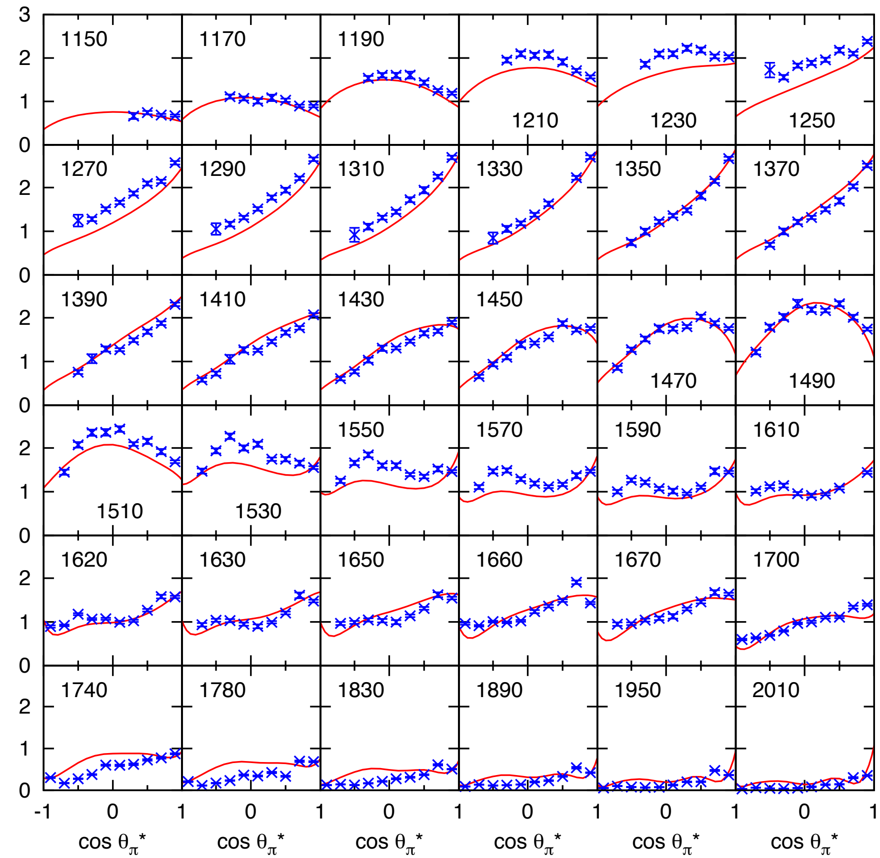
Q^2=1.76 (GeV/c)^2

$\sigma_T + \varepsilon\, \sigma_L$ for W=1.10 – 2.01 GeV

$p(e,e'\pi^0)p$



$p(e,e'\pi^+)n$

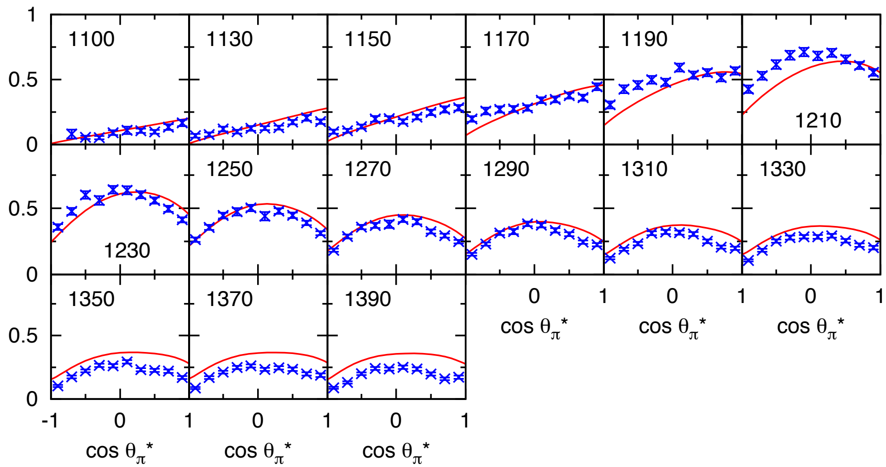


Analysis result (single π)

Q^2=2.91-3.00 (GeV/c)^2

$\sigma_T + \varepsilon\, \sigma_L$ for W=1.10 – 1.67 GeV

$p(e,e'\pi^0)p$



$p(e,e'\pi^+)n$