Single π production in NEUT

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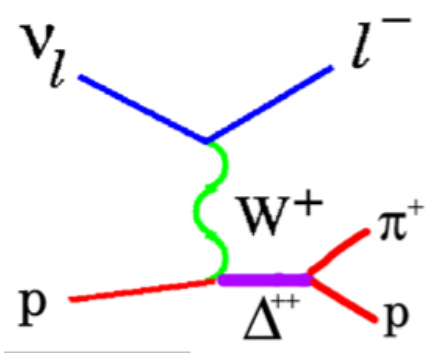
Single π production in NEUT

Based on D.Rein, and L.M.Sehgal, Ann. of Phys. 133(1981),
and D.Rein, Z.Phys. C35 (1987) 43-64

$\nu + N \rightarrow l + \Delta(N^*)$

$\Delta(N^*) \rightarrow \pi + N'$



"Relativistic harmonic oscillator model"
by Feynman, Kislinger and Ravndal
(Feynman et al. Phys. Rev. D3 (1971) 2706)

Initial helicity amplitude code was provided by one of the authors.

The interferences between the resonances are taken into account as appeared in the original paper.

Total cross-section : Integrated over the allowed kinematic region of W and q^2. (=Consider mass of the lepton)

Single π production in NEUT

Further corrections (improvements)

- Lepton mass and spin correction

  Kuzmin et al. Mod.Phys.Lett. A19 (2004) 2815-2829
  Phys.Part.Nucl. 35 (2004) S133-S138

- Lepton mass correction

  Berger & Sehgal Phys.Rev.D76:113004,2007

Form factors

1) Original

Axial vector mass is set to 1.21 GeV/c^2 by default.

(1.01, 1.11 and 1.31 GeV/c^2 are supported.)

2) Graczyk-Sobczyk

Phys.Rev. D77 (2008) 053001

(Nowak Arxiv:0909.3659)

Parameters are fixed by re-fitting the ANL and BNL data.

Single π production in NEUT

Determination of kinematics in nucleus

1) Select nucleon momentum
2) Determine lepton kinematics in nucleon rest frame
3) Determine pion and nucleon kinematics in Adler frame

Pion distribution from $\Delta(1232)$

Follow prescription by Rein (1981)

Pion from the other resonance

Isotropic in resonance rest frame.

Determination of original resonance

$\sigma(D(1232))/\sigma(\text{All resonances})$

4) If the momentum of nucleon is below the Fermi-surface momentum, this event is suppressed.

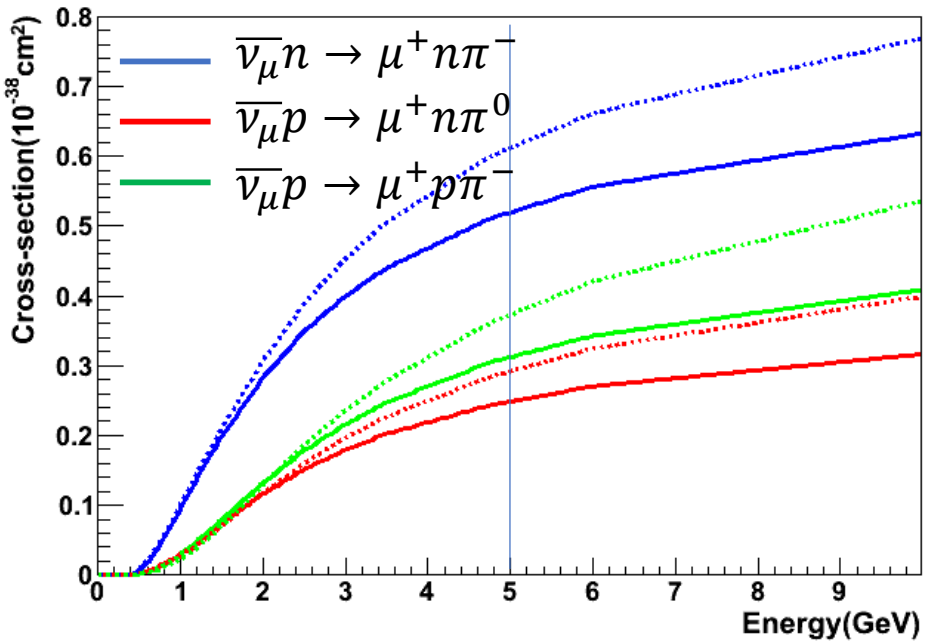
(~ a few % of events are discarded ~ suppressed)

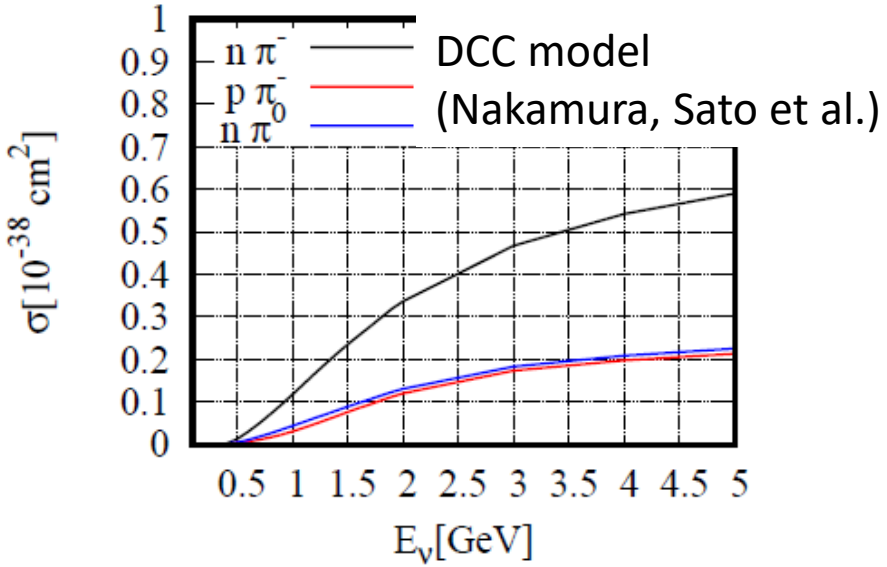
5) X % of pions are not emitted at all. (Delta-absorption)

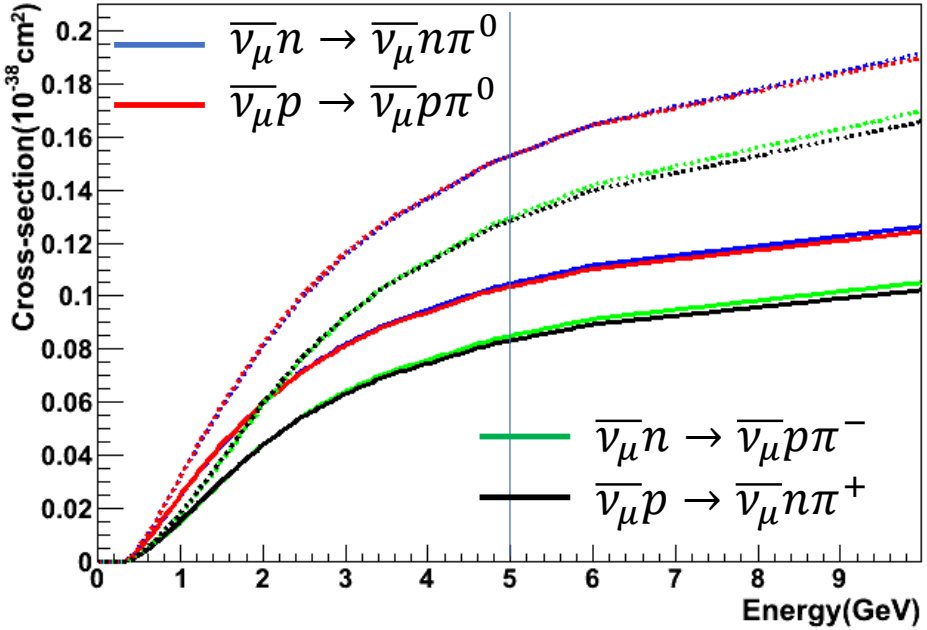
X was 20% before introducing 2p2h. Now X is set to 0%.

Single π production cross-section (W<2GeV)

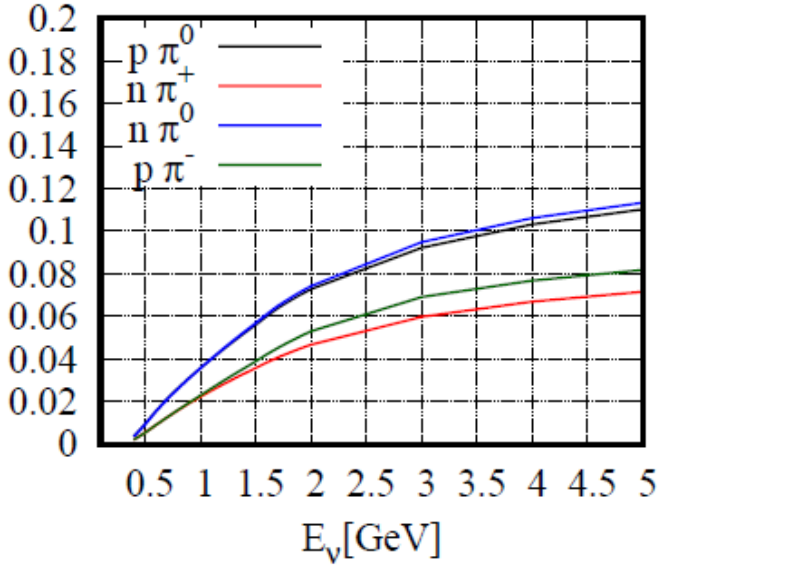
CC anti-ν_μ







NC anti-ν

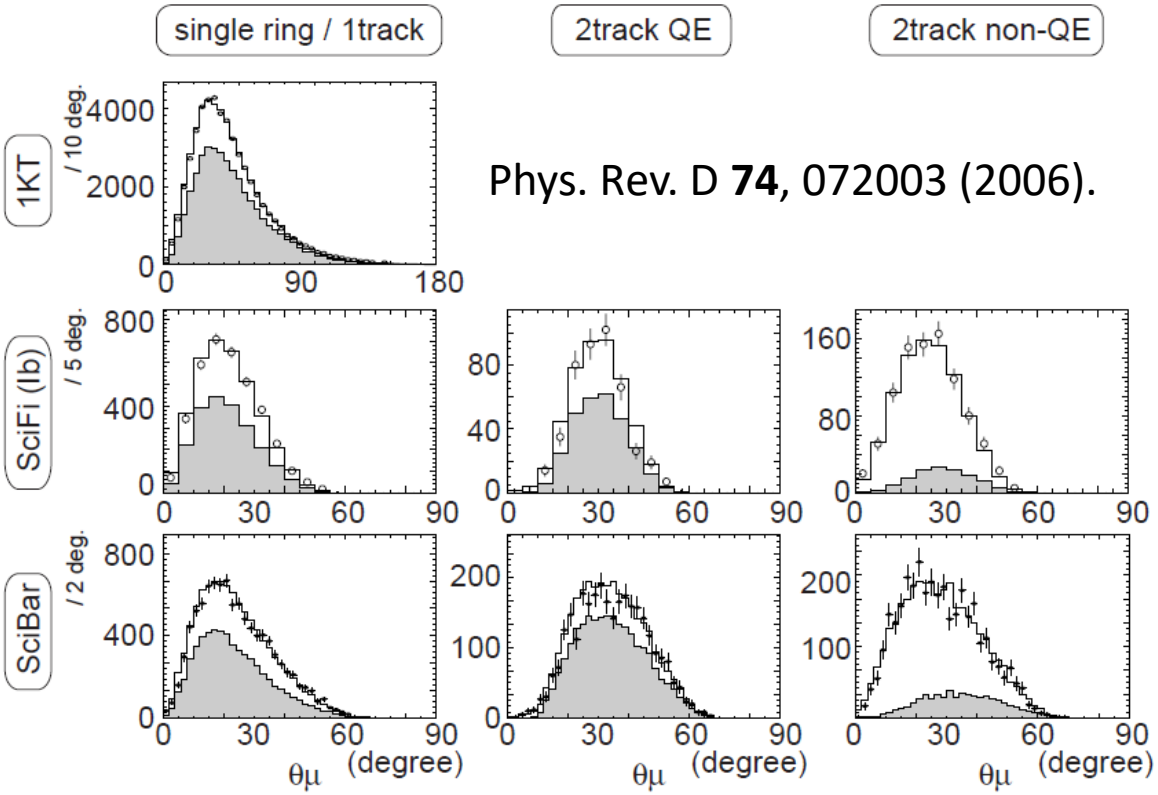


Single π production in NEUT

Axial vector mass 1.21 GeV/c^2

1) Suppression of forward going μ in inclusive sample (K2K)
Larger M_A for CCQE + Bodek-Yang correction
were not sufficient.

(K2K oscillation analysis : M_A=1.1 GeV/c^2 for CCQE & 1π production)



Phys. Rev. D **74**, 072003 (2006).

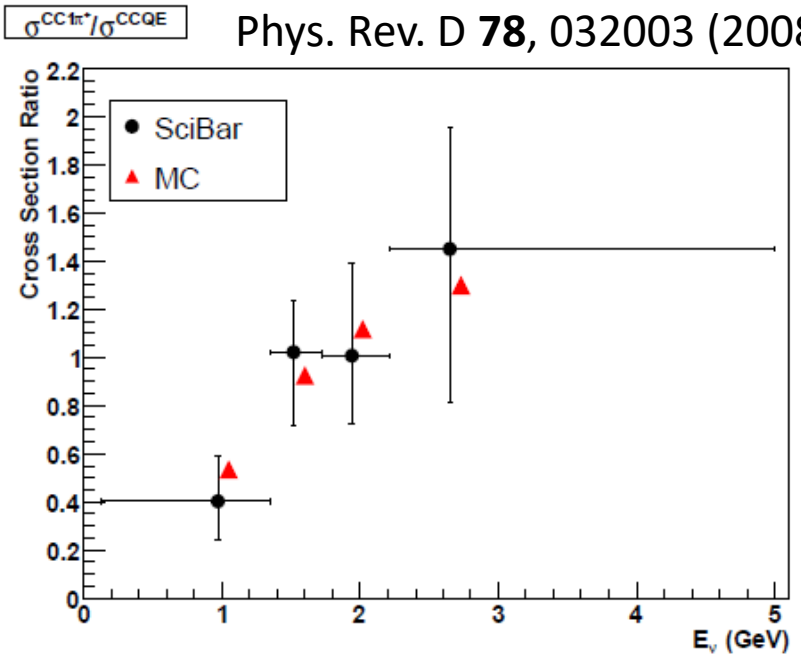
Shaded area : CCQE

Single π production in NEUT

Axial vector mass 1.21 GeV/c^2

2) CC1π^+ to CCQE ratio and NCπ^0 to CCQE @ K2K is almost unity

CC1π^+ to CCQE ratio



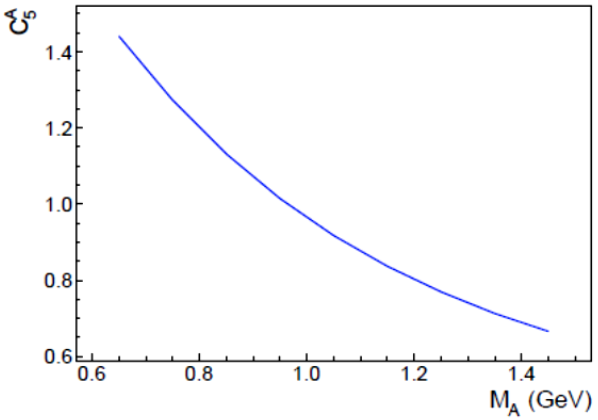
Phys. Rev. D **78**, 032003 (2008)

3) CCQE M_A seemed to be 1.21 GeV/c^2 @K2K (from shape)

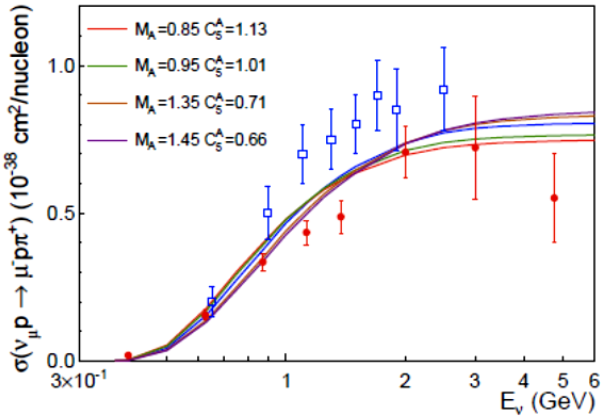
4) # of π^0 (mainly from NC 1 π^0 production) in atmospheric ν sample agrees quite well.

Single π production in NEUT

- Alternative form factor
  Graczyk-Sobczyk Phys.Rev. D77 (2008) 053001
  Nowak Arxiv:0909.3659



M_A^{res} vs $C_5^A(0)$ for const xsec

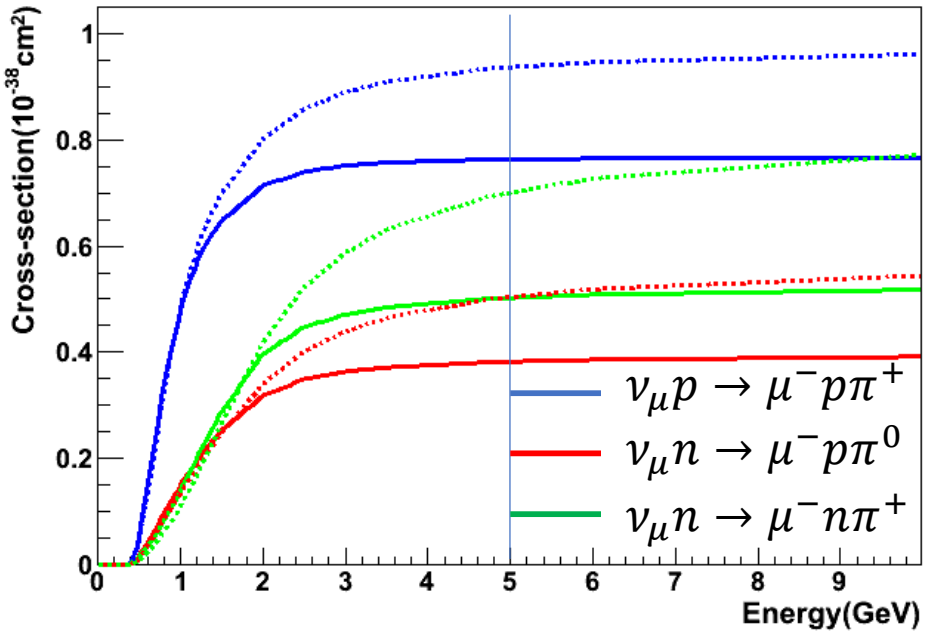


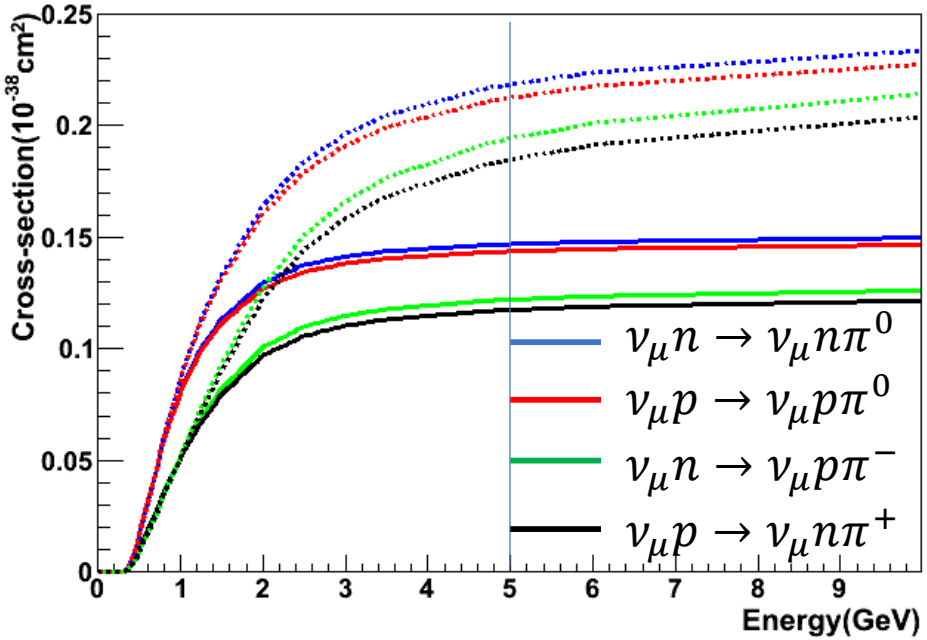
Samples from the curve: nearly const

A. Bercellie, P. Rodrigues et al.

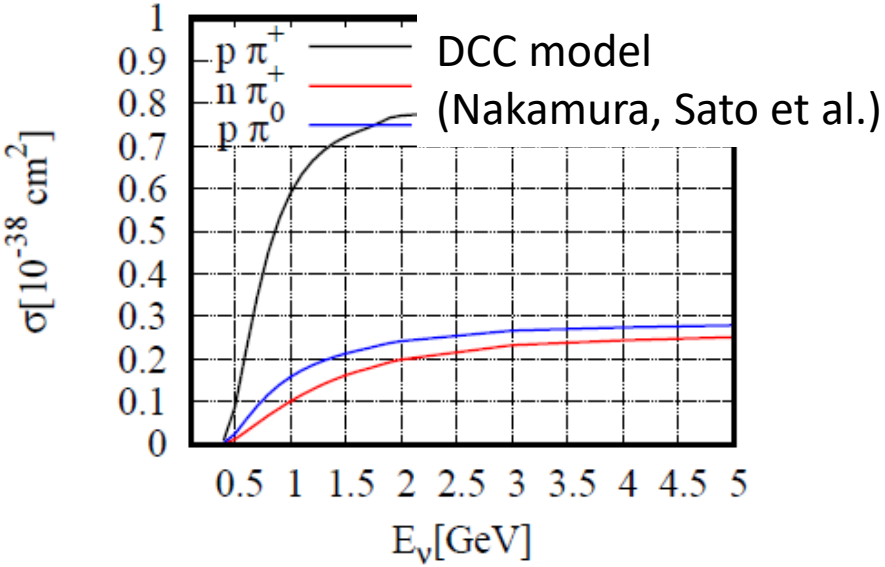
- Parameters in nucleon model:
  - $C_5^A(0)$ Value of axial FF at $Q^2 = 0$. Main effect is normalization of total xsec
  - M_A^{res} Mass parameter in axial FF. Affects both shape of $d\sigma/dQ^2$ and overall normalization.
  - BG Scale of $J = 1/2$ nonresonant background terms
- Try to reparametrize $(M_A^{res}, C_5^A(0))$ into (shape, norm) for convenience
- Best fit: $M_A^{res} = 0.95$, $C_5^A(0) = 1.01$ Choose BG scale 1.3 ± 0.2

Single π production cross-section (W<2GeV)

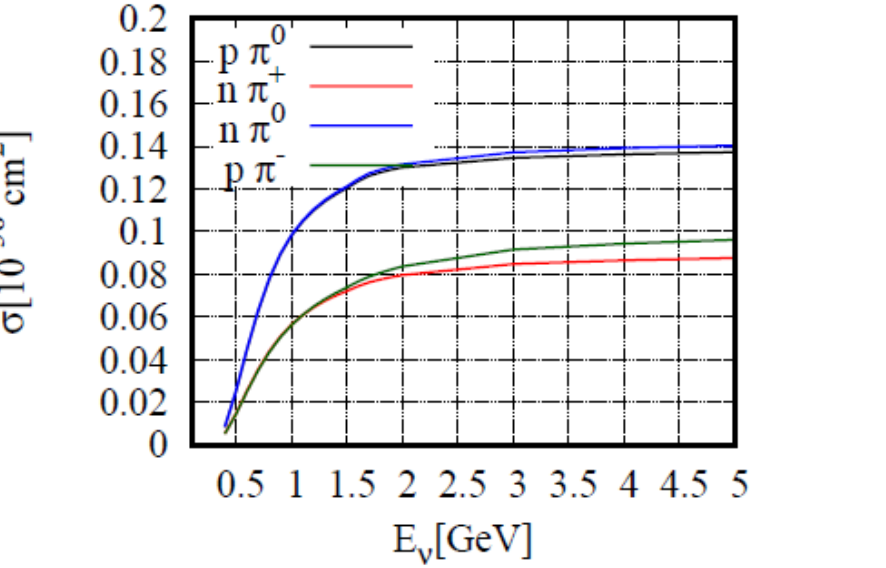




CC ν_μ



NC ν

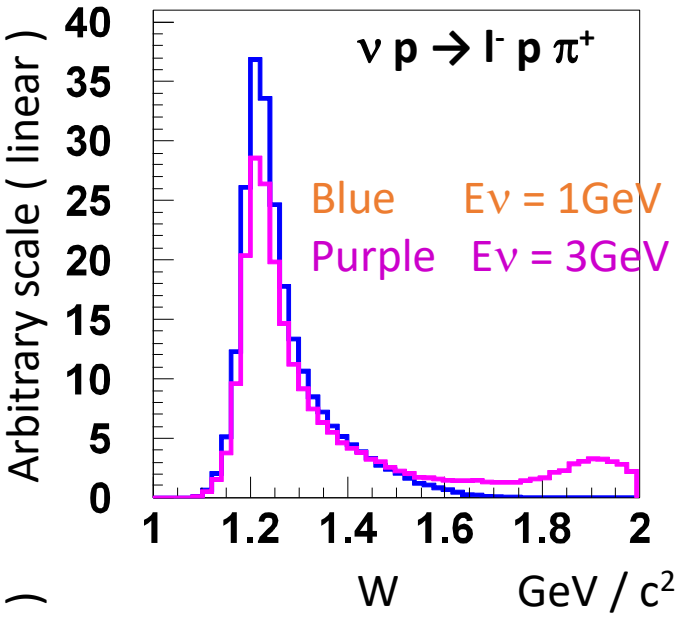


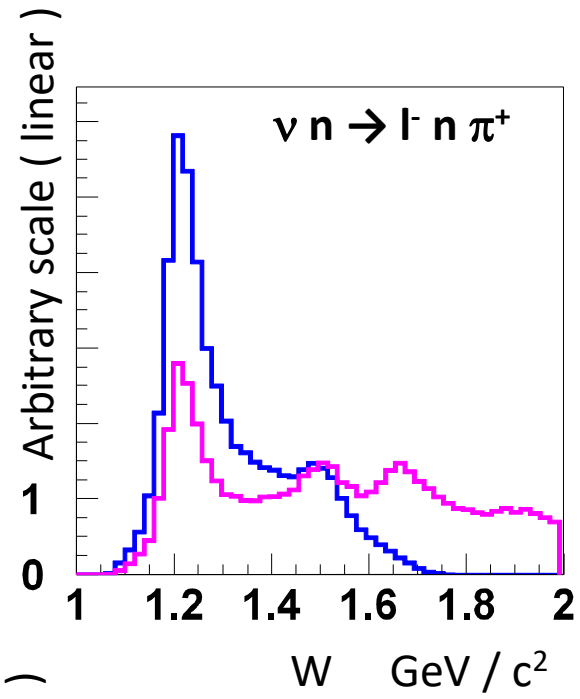
Single π production distributions

Invariant mass of resonance (W)

$\nu p \rightarrow l^- p \pi^+$

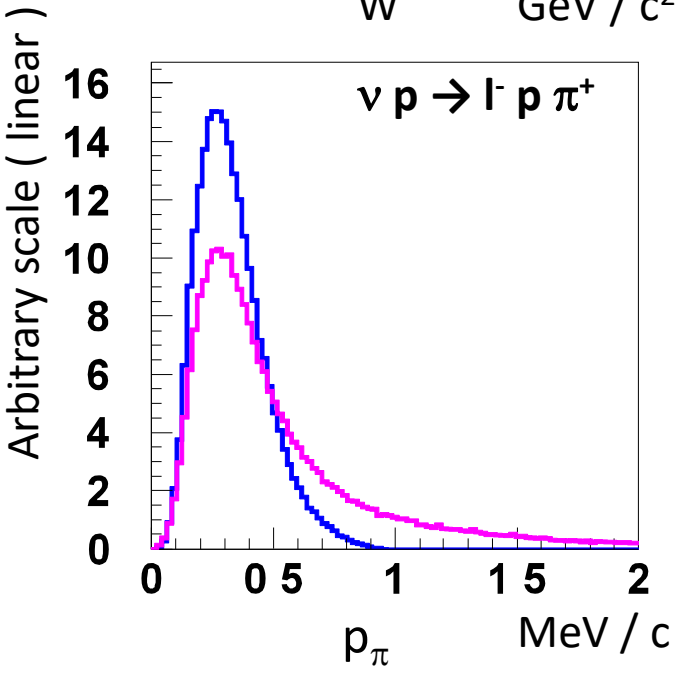
Δ^{++} **(1232) dominant**

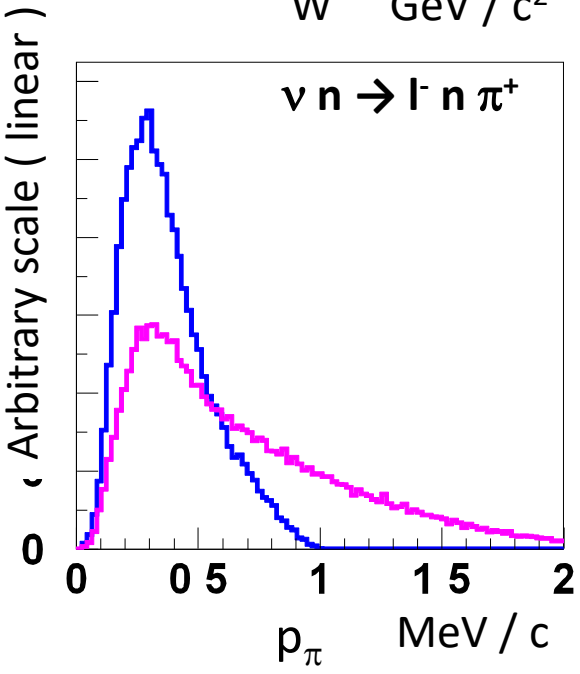




momentum of π

first order :
determined by resonance masses

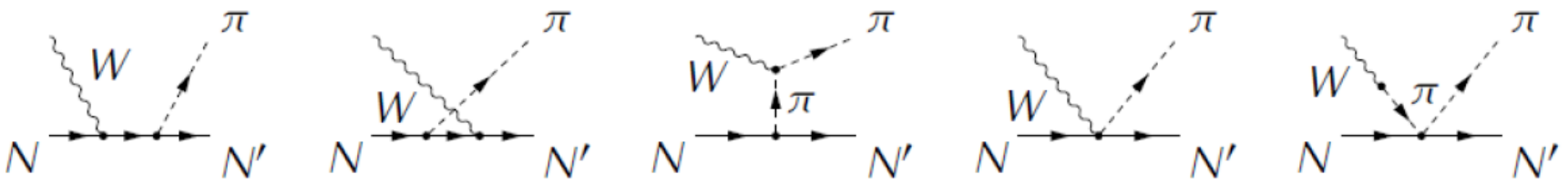




Single pion production ~ New model

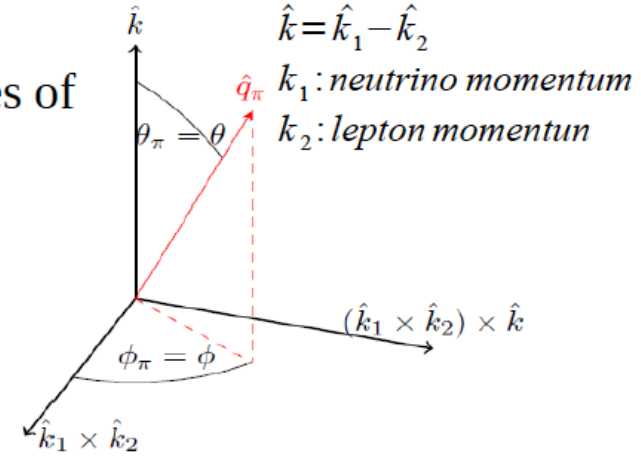
Model is implemented by M. Kabirnezhad
Adapt for Neut by C. Wret

- **The new model includes resonant (Rein-Sehgal model) and non-resonant interactions (5 diagrams from Hernandez et.al) coherently!**



E. Hernandez, J. Nieves and M. Valverde, Phys. Rev. D 76 (2007) 033005

- We need to define a common framework to calculate the helicity amplitudes, Isobaric system.
- The main challenge is to calculate helicity amplitudes of the above diagrams in this frame.
- It is suitable for neutrino generators.
- The new model output is $d\sigma / dW\, dQ^2\, d\Omega_\pi$ pion angles are part of cross-section!



The main effects of nonresonant bkg is for pion angles due to the interference terms with resonances!

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(Slide by M. Kabirnezhad)

Single pion production ~ New model

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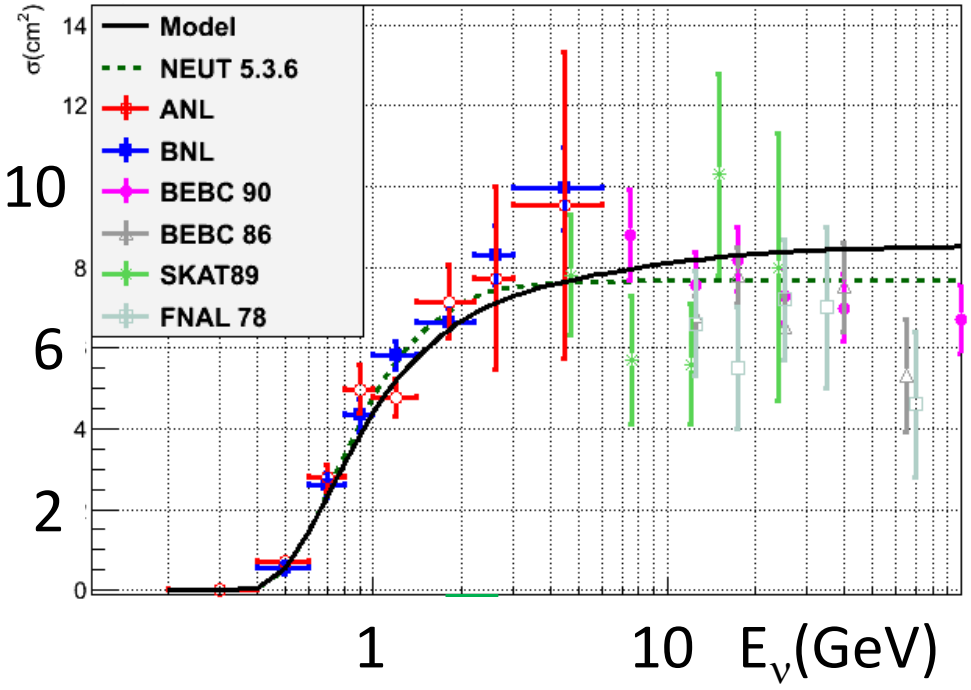
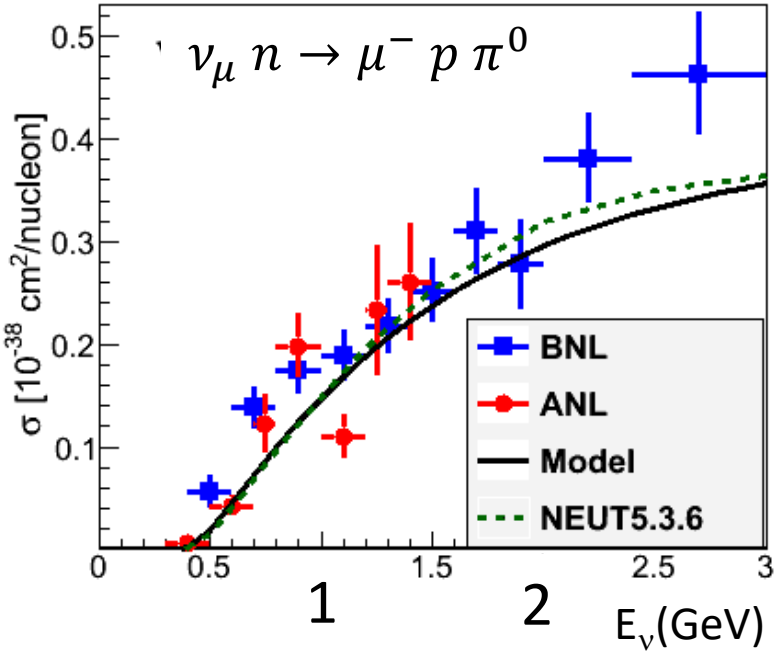
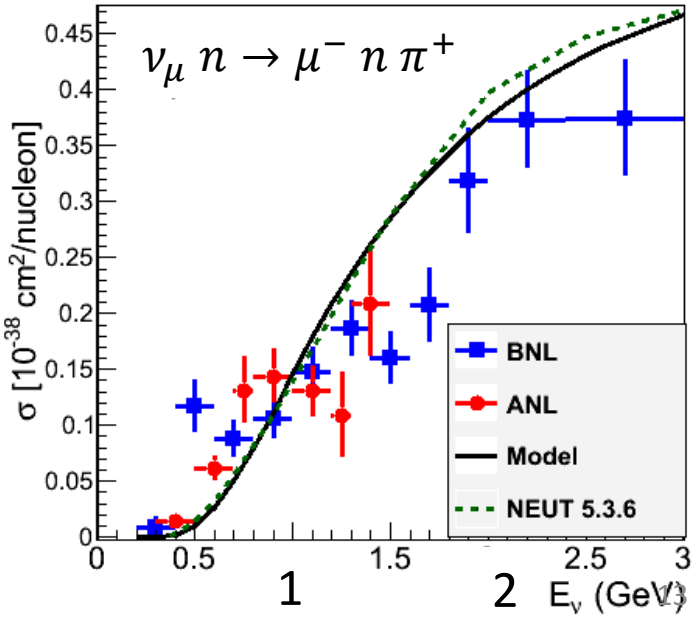
Interaction cross-sections

$10^{-39}(cm^2)$ $\nu_\mu\, p \rightarrow \mu^-\, p\, \pi^+$ (W < 2GeV/c²)







Figures by M. Kabirnezhad,
ANL & BNL data is reanalyzed by C. Wilkinson et al.

Single pion production ~ New model

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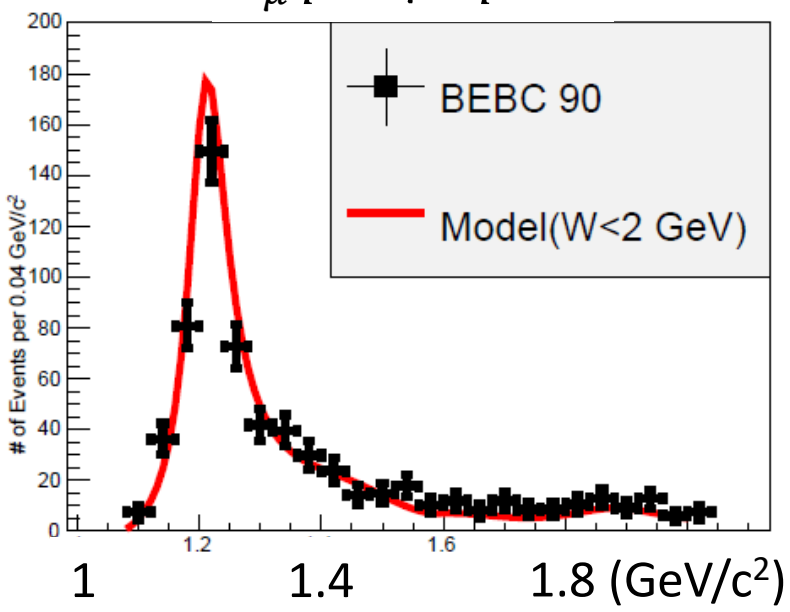
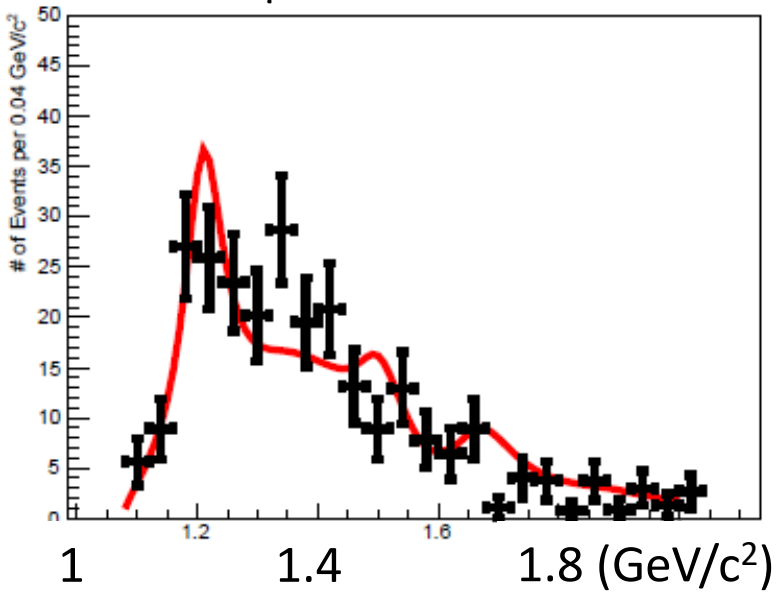
Intermediate resonance
Invariant mass distributions

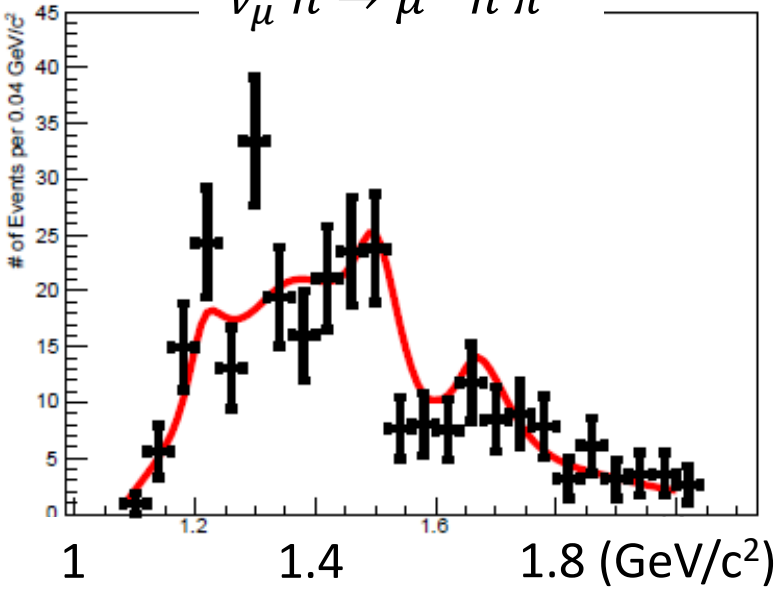
$\nu_\mu\, p \rightarrow \mu^-\, p\, \pi^+$



$\nu_\mu\, n \rightarrow \mu^-\, p\, \pi^0$



$\nu_\mu\, n \rightarrow \mu^-\, n\, \pi^+$



(Figures by M. Kabirnezhad)

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Angular distribution of π in the Adler frame

T2K ND280 neutrino flux