Nuclear Effect in Single Pion Production

M. Sakuda (KEK)

14 December 2002 @ NuInt02

Outline

- Single pion production model and data
- Pauli exclusion effect in $\nu N \rightarrow \mu^- \Delta$ production (single pion production)
- For better single pion production models
- Summary

Collab. E.Paschos

1. Single pion production models and Data

- Models for single pion production

Different models give a different cross section and different Q^2 distributions even if the same M_A value is used.

- Rein-Sehgal model, Ann.Phys.(NY)133('81)79.

  Rein, Z.Phys.C35('87)43

This model is most commonly used by many groups (NuInt01).

But, this (original) model does not consider nuclear effects.

- Schreiner-von Hippel('73)/Adler ('68) model

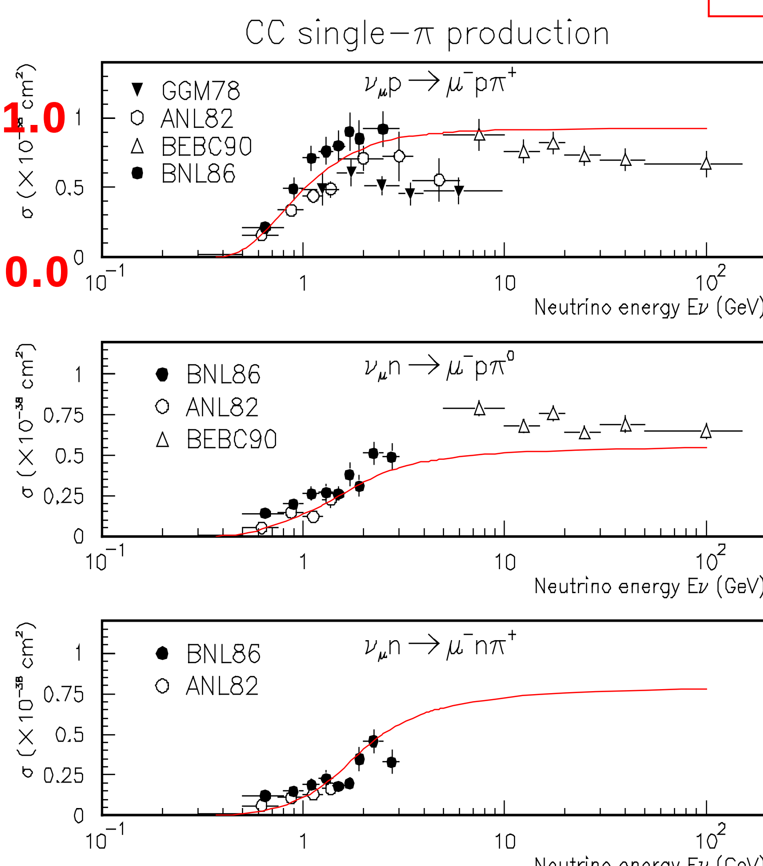
(→Singh, Paschos@nuint01)

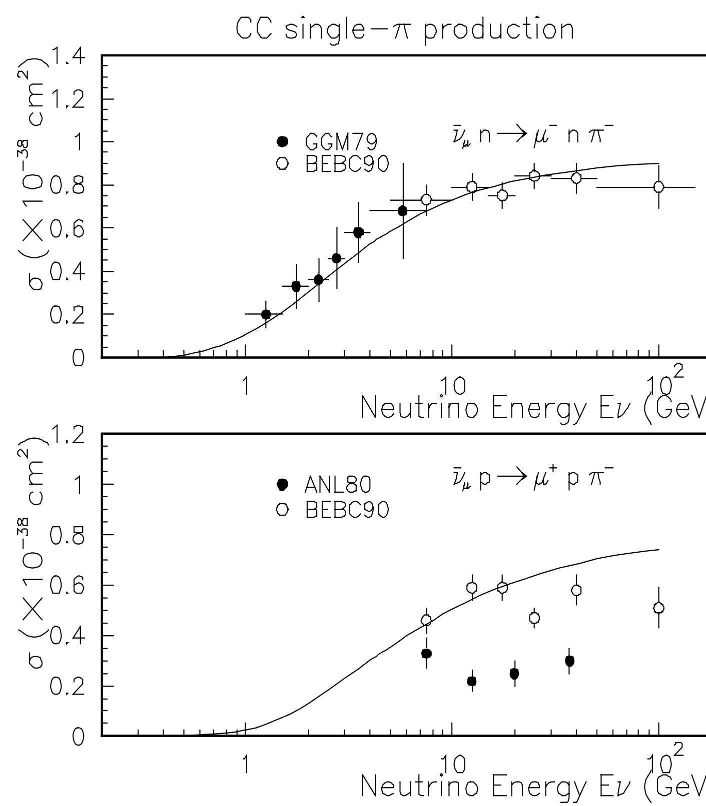
Single Pion Production Cross Section

Prediction = Rein-Sehgal M_A=1.2 GeV/c^2

1×10^{-38} → 1.0 (cm^2)

0.0

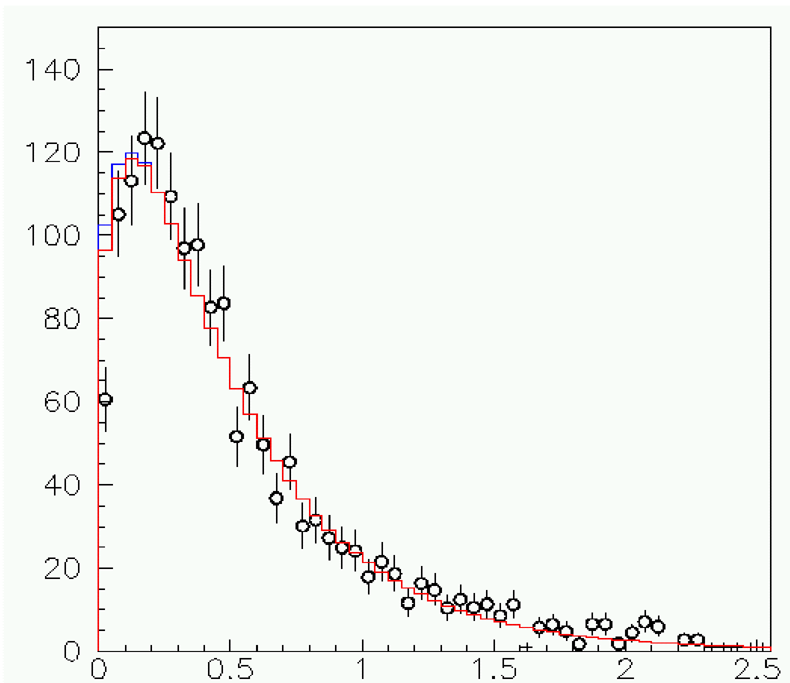




BNL $\mu^- p \pi^+$ Q^2 distribution

Furuno@nuint02

$\mu^- p \pi^+ n_s$



M_A=1.2 GeV/c^2

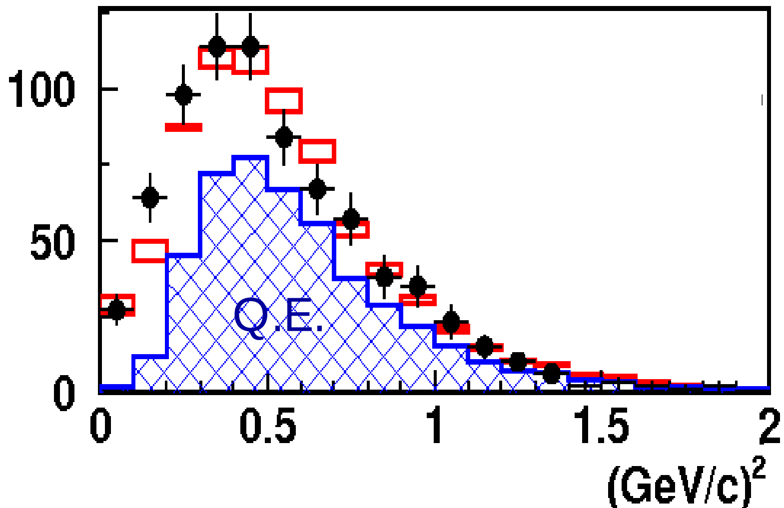
Normalized by the entries

Q^2(GeV)

- Q^2 distributions of 2-track samples (K2K)

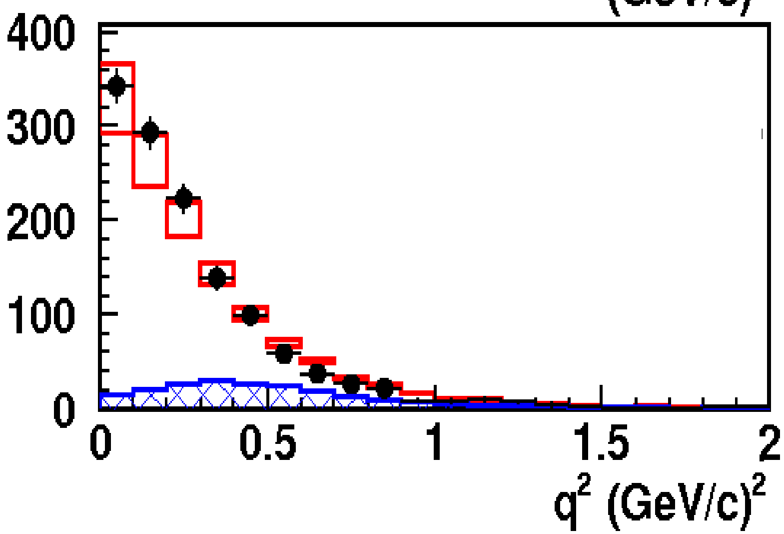
T.Ishida@nuint02

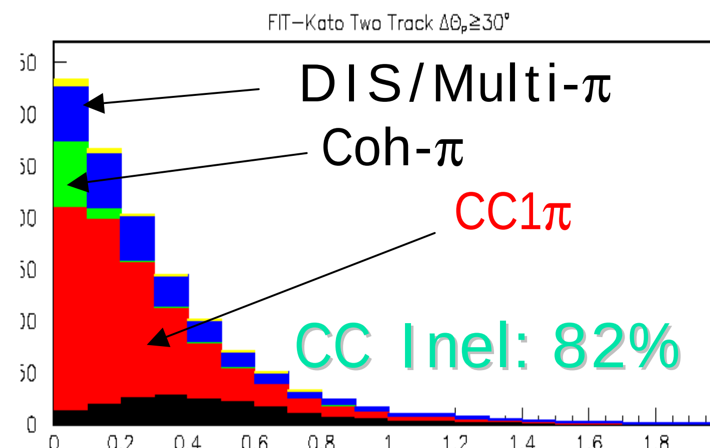
(2) 2-track
$\Delta\Theta_P \leq 25^o$



Single pion dominates Inelastic distributions.

(3) 2-track
$\Delta\Theta_P \geq 30^o$





2. Pauli suppression in $\nu N \rightarrow \mu^- \Delta$

- Adler-Nussinov-Paschos, PRD9('74)2125, give the formula for Pauli suppression $G(W,Q^2,k_F)$ in $\nu N \rightarrow \mu^- \Delta$ reaction.

$q=(q_0,|q|)$, $q_0=(W^2-M^2-Q^2)/2W$,

$E_\pi= (W^2+m_\pi^2 - M^2)/2W$,

$p_\pi=(E_\pi^2-m_\pi^2)^{1/2}$

$R=0.226$ GeV $=k_F$

(1) $2R>|q|+p_\pi>|q|-p_\pi$

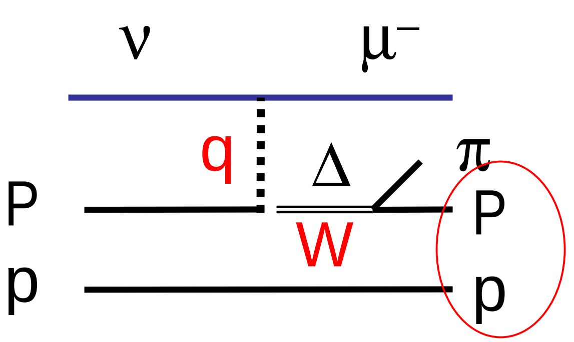
$\mathbf{G}=1/2|q|[(3|q|^2+p_\pi^2)/2R-(5|q|^4+ p_\pi^4 +10 |q|^2 p_\pi^2)/30R^3]$

(2) $|q|+p_\pi > 2R >|q|-p_\pi$

$\mathbf{G}=1/4\, p_\pi|q|[(|q|+p_\pi)^2 - 4/5R^2 -(|q|-p_\pi)^3/2R +(|q|-p_\pi)^5/40R^3]$

(3) $|q|-p_\pi > 2R$

$\mathbf{G}=1.$

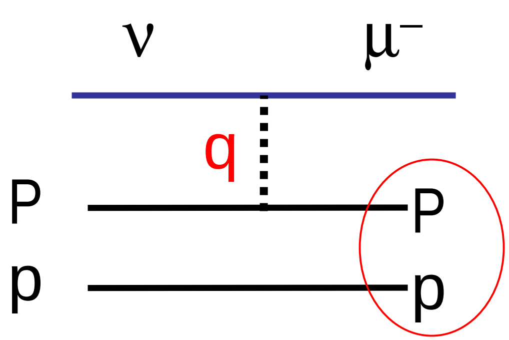


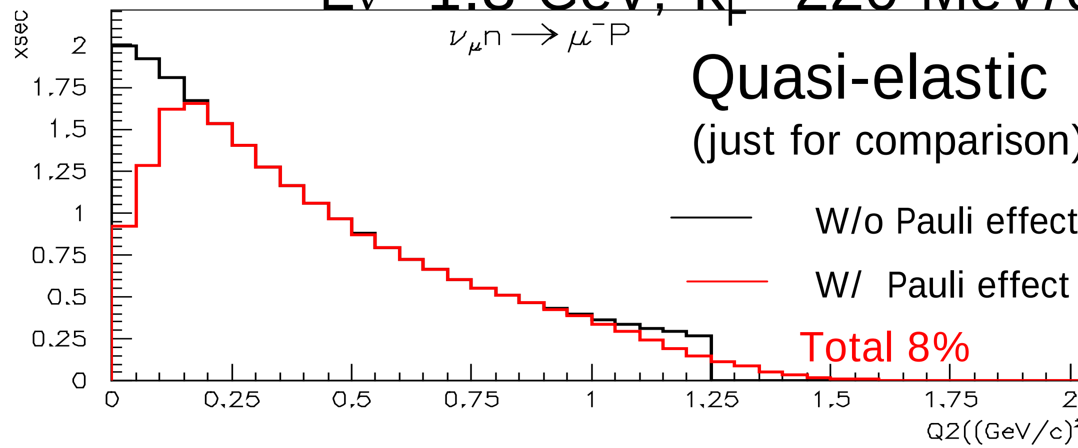
P $<k_F$, suppressed.

At $E\nu=1.3$ GeV, the suppresion factor $G(W,Q^2,k_F)$ is about 10-15% at low $Q^2 < 0.2$ (GeV/c^2) for kF=~0.220 GeV.

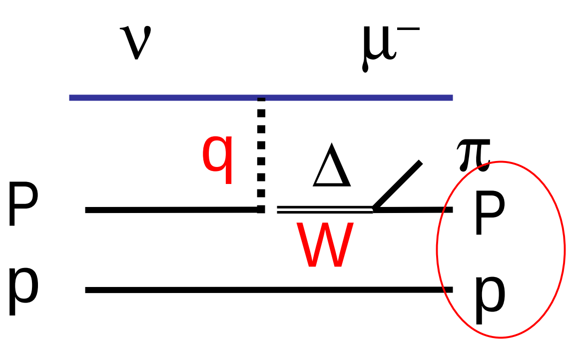
Pauli exclusion effect in Δ production

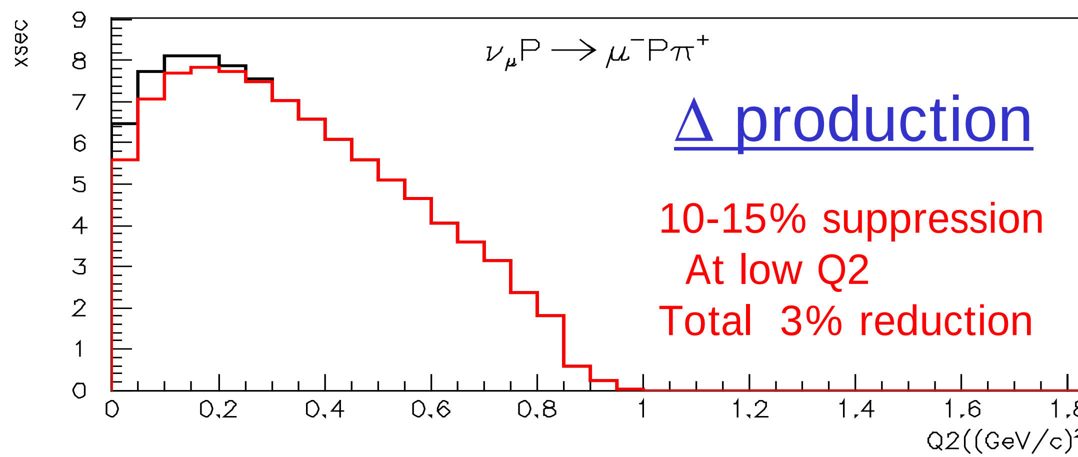
$E_\nu = 1.3$ GeV, $k_F = 220$ MeV/c





If $P < k_F$, suppressed.

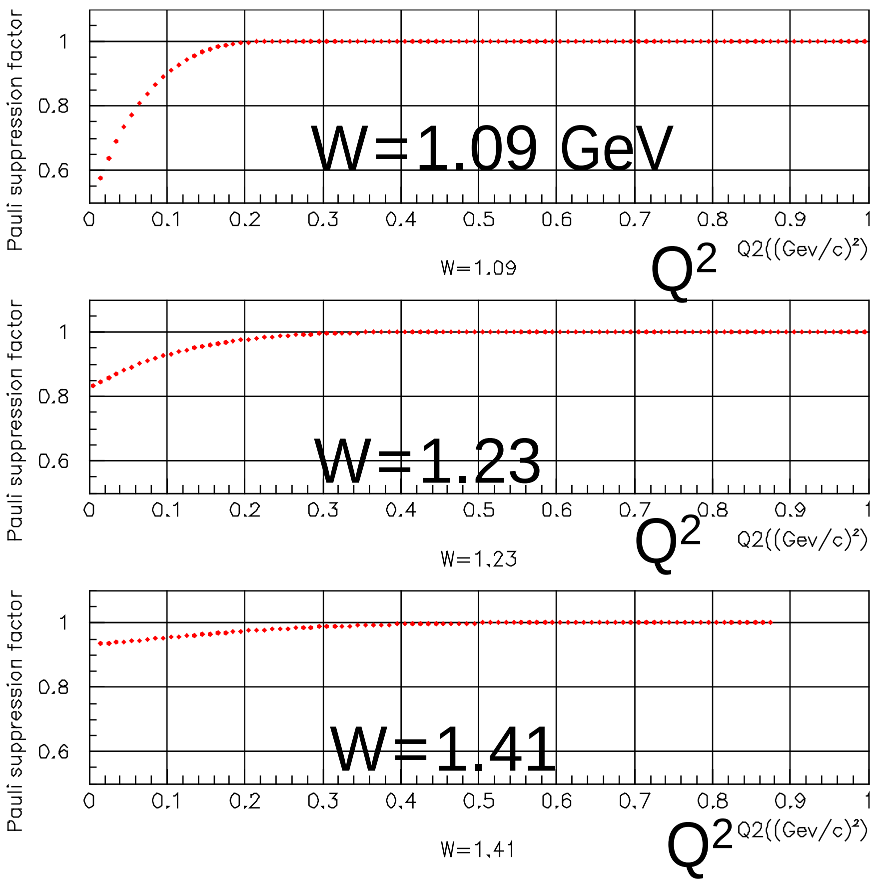


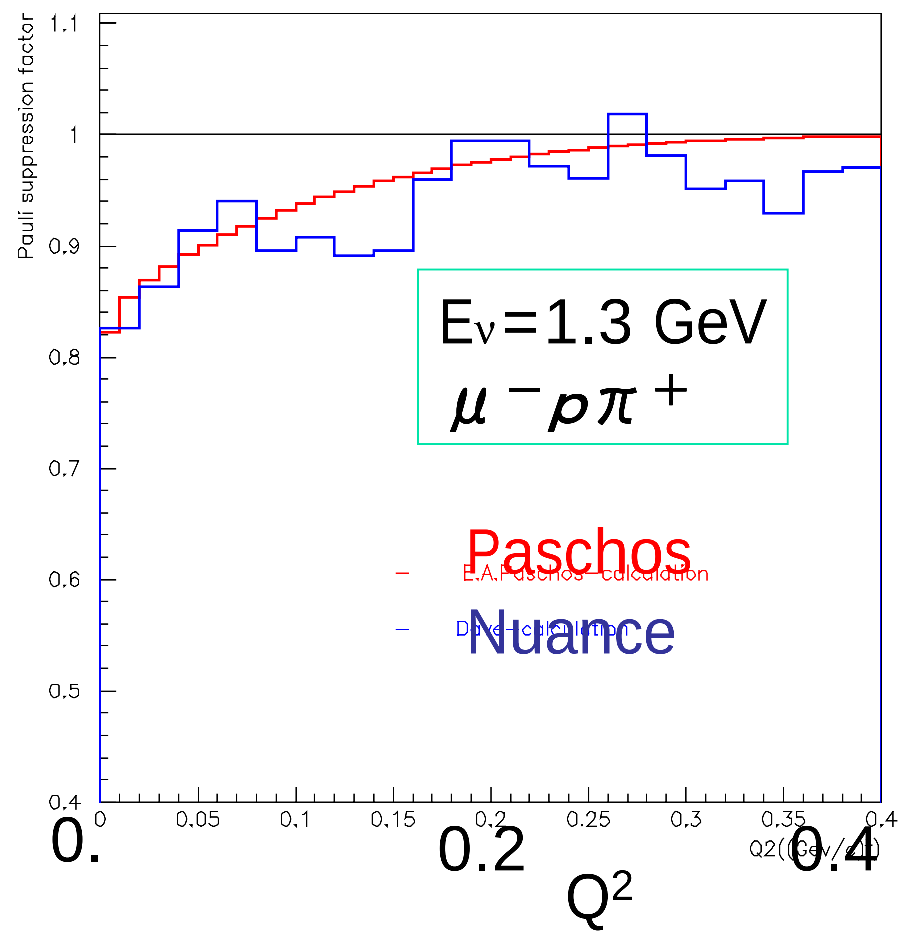


Comparison between G(W,Q^2 ,k_F) and NUANCE

-Consistent with each other.

Pauli suppression G(W,Q^2 ,k_F) depends much on W and Q^2. kF~220 MeV.





3. For better single pion production models

- Rein-Sehgal model

$$C_i^{A,V} = C_i^{A,V}(0)\underline{(1-q^2/4M_N^2)^{\frac{1}{2}(1-N)}} / (1-q^2/M_A^2)^2$$

The factor is introduced from harmonic oscillator model.

Model uses 18 resonances and their interference.

- Schreiner-vonHippel ('73)/Adler ('68) for Δ production model (Singh, Paschos@nuint01)

Vector form factors C_i^V are determined from γN and eN data. Axial form factors are determined using PCAC and ANL Bubble Chamber data (νH '73, 121 events). M_A=0.96 GeV/c^2.

$$C_i^A = C_i^A(0)\underline{(1+1.21q^2/(2-q^2))}/(1-q^2/M_A^2)^2$$

. $\sim 1-0.6|q^2|$ at low q^2. i=3,4,5. →

- It is natural that we get different q^2 distributions and different cross section for the same M_A value.

Schreiner-von Hippel('73)/Adler ('68) model

Form factors $C_i^{V,A}$ (i=1,6) for $\nu N \rightarrow \mu^- \Delta$

- Vector form factors

$C_3^V(Q^2) = 2.05/(1+Q^2/0.54)^2$,

$C_4^V(Q^2) = -M/M_\Delta \, C_3^V(Q^2)$,

$C_5^V(Q^2) = 0.$

$C_6^V(Q^2) = 0.$ (CVC)

- Axial form factors

$C_i^A(Q^2) = C_i^A(0)(1-1.21Q^2/(2+Q^2))/(1+Q^2/M_A^2)^2$, (i=3,4,5)

$C_6^A(Q^2) = C_5^A(Q^2) \, M^2/(m_\pi^2+Q^2)$ [PCAC]

$C_3^A(0) = 0.$

$C_4^A(0) = -0.3$,

$C_5^A(0) = 1.2$

Proposal for single pion production model

- Below for $W<1.6$ GeV/c^2, Δ model with Schreiner parameters and three resonances may be used.

$$C_i^{A,V} = C_i^{A,V}(0)\, G(W,Q^2,k_F)^{1/2} / (1-q^2/M_A^2)^2$$

  - $G(W,Q^2,k_F)$ should be different for different target.
  - Non-resonant contribution, $<20\%$, may be added.

  For $W>1.6$, Bodek's DIS may be used. →

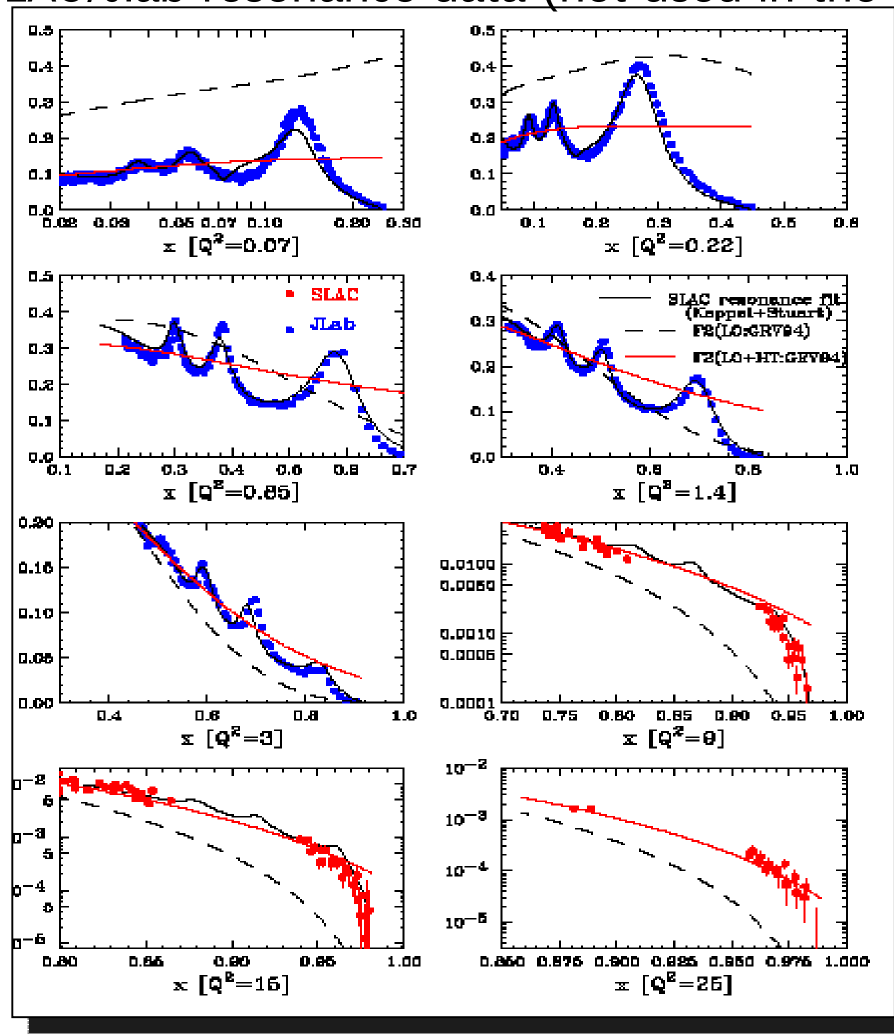
- Do we need an extra factor $(1-aq^2/(b-q^2))$??
- Paschos-Pasquali-Yu, NPB588('00)263, already

show that this scheme may work.

- We must tune our Q^2 distributions with correct nuclear effects.

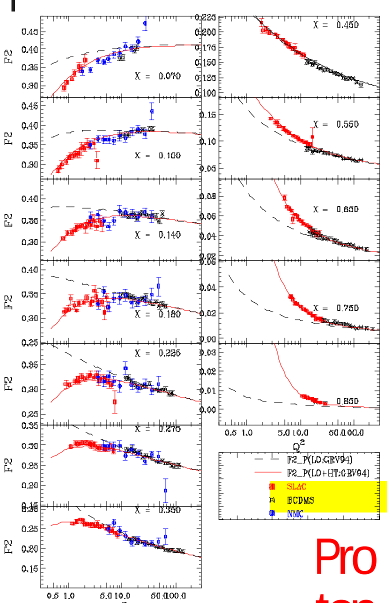
GRV94 + LO (Bodek-Yang at NuInt01)

SLAC/Jlab resonance data (not used in the fit)

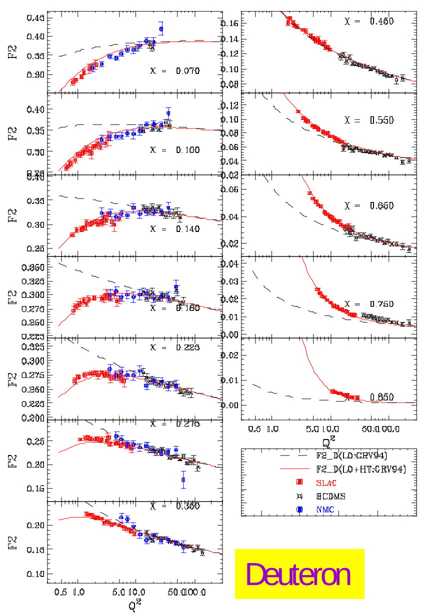


LO+HT fit Comparison with DIS F_2 (H, D) data

[These SLAC/BCDMS/NMC are used in the Xw fit]



Pro ton



Deuteron

Summary

- Nuclear effects in Δ production in nucleus are being studied in the framework of Adler-Nussinov-Paschos. The effect is 10-15% at low Q^2 region (<0.2 GeV/c^2) and the total effect in the cross section is 3% for kF=220MeV (C,O). This will effectively lower M_A (Δ). Such known corrections should be included. Comparison of M_A with data should be done consistently with correct nuclear effects.

- Future direction: A simpler model with nuclear effects which describes the resonance region is being worked on. Three resonances+some multi-pions (W<1.6) + DIS (w/ Bodek) (W>1.6GeV)

  (Rein-Sehgal + nuclear effect is ok, untill we get a better model.)

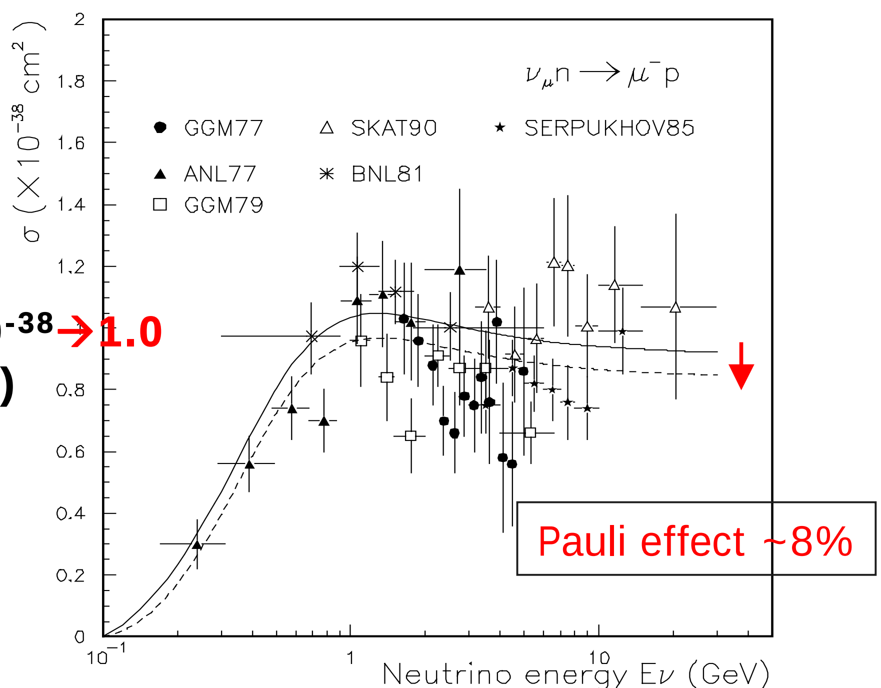
- It will be extremely useful if we can eastimate the nuclear effects in electron-nucleus Δ production data at JLAB (CLAS). Quasi-elastic also. (e,e') dN/dQ^2(Carbon) vs. dN/dQ^2(Hydrogen) → gives $G(W,Q^2, k_F)$.

  It is good if the common Δ model (vector form factors) will be used and developed in the neutrino and electron physics community.

Charged-Current Quasi-elastic Scattering

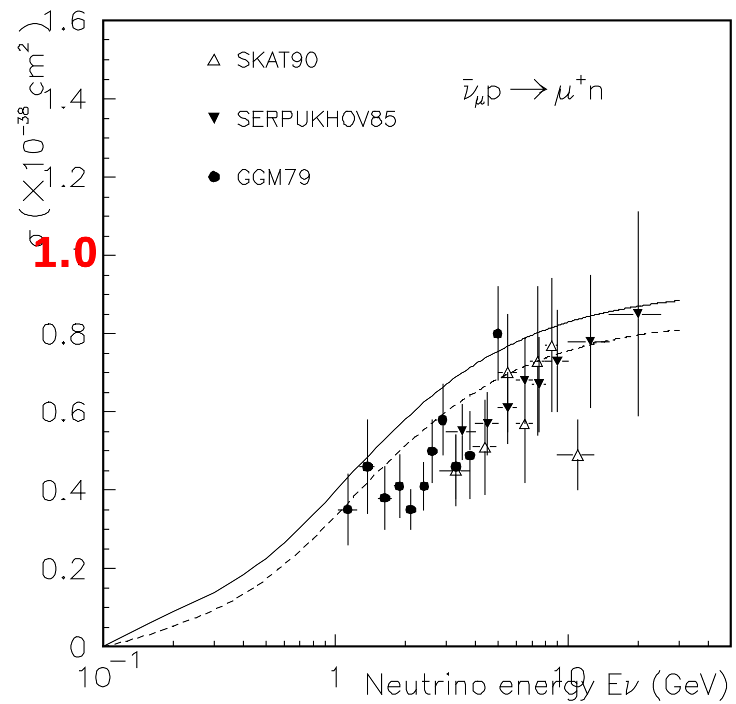
$\sigma(\nu_\mu\, n \rightarrow \mu^- p)$

1x10^{-38} → 1.0 (cm^2)



0.1 1.0 10. 50.

$\sigma(\bar{\nu}_\mu\, p \rightarrow \mu^+ n)$

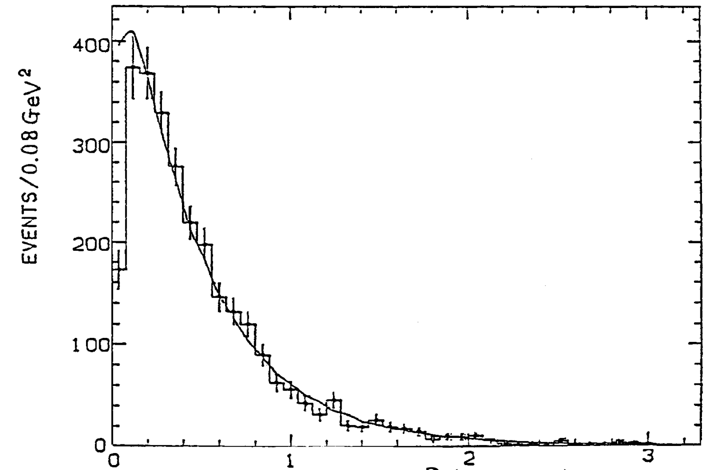


0.1 1. 10.

Dipole M_A for Quasi-elastic scattering

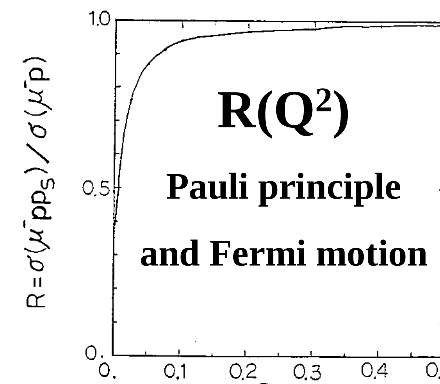
H.Sagawa, PhD thesis, Tohoku U., 1985
T.Kitagaki et al., PRD34,2554(1986), PRD42,1331(1990)

M_A = 1.10±0.05 is fitted to over all Q^2 distribution in $0.08 < Q^2 < 3GeV^2$



Q^2(GeV)

Deuteron correction factor



Q^2(GeV)

σ_H ; C.H.Llewellyn Smith, Phys.Rep.C3,261(1971)

$R(Q^2)$; S.K.Singh, NPB36,419(1972)