Development of Neutrino-Nucleus Interactions In the Few-GeV Region
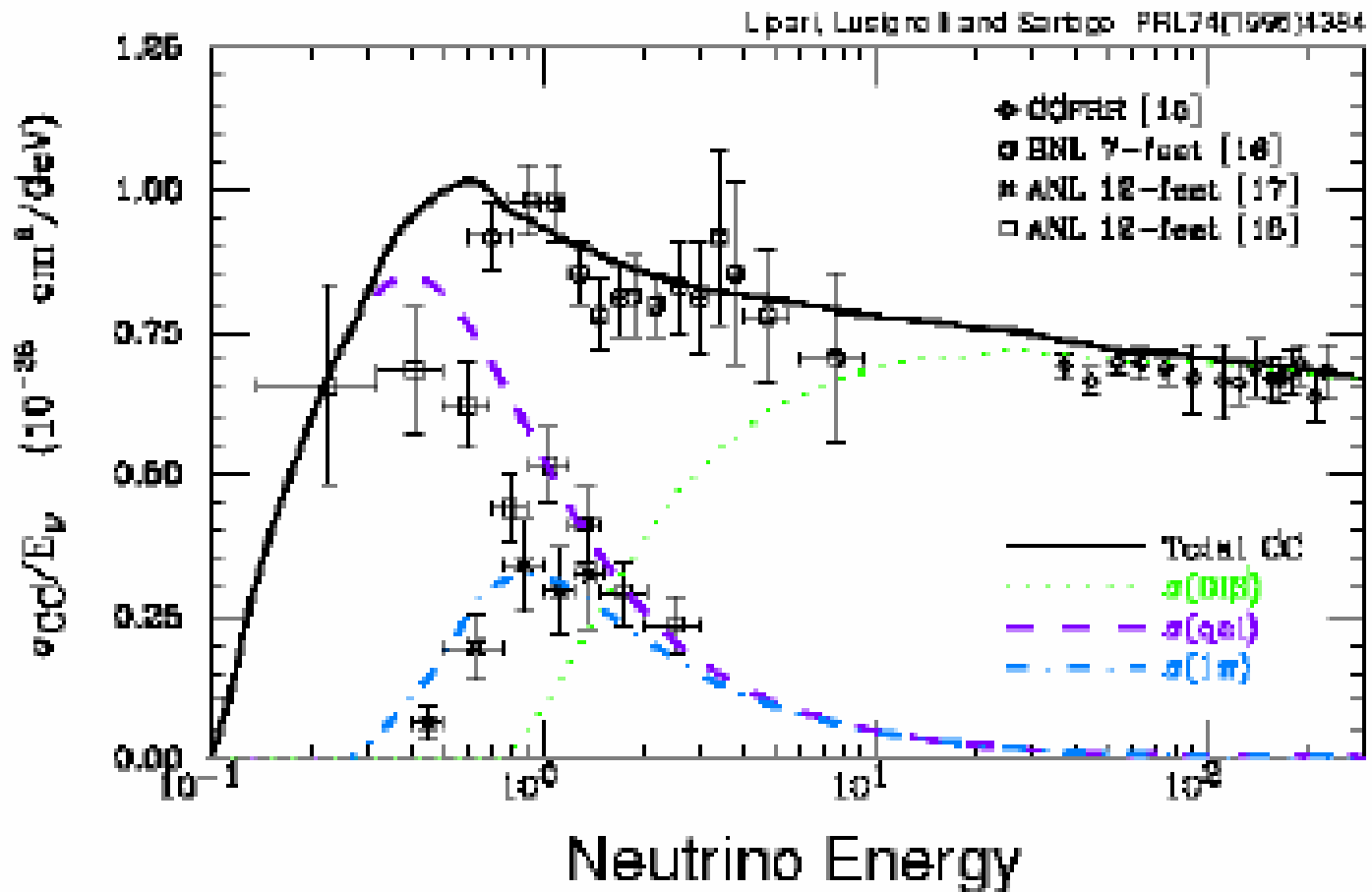
Makoto Sakuda (Okayama Univ)
1 December 2005 @ JPARC05

Outline

1. Motivations and Goals of NuInt Workshop

2. Some highlights and Tasks

3. One subject relevant to JPARC-HS05 besides Δs

→ SN related experiement

Neutrino Cross Sections (by Lipari '90)

- They are old and not very accurate at GeV region.

Study of Neutrino-Nucleus Interactions in the Few-GeV Region (NuInt Workshop)

We started the first workshop (NuInt01) in 2001 with the prospect that knowledge of the neutrino cross sections would become more important as the contribution of the systematic errors due to these cross sections and nuclear effects become more significant in the second-generation neutrino-oscillation experiments.

Through this series of workshops, we have established a working collaboration between the elementary particle physics community and the nuclear physics community, between experimentalists and theorists, and developed the field of neutrino-nucleus interactions. MINERvA (FNAL) and JUPITER (JLAB) are experimental examples of this growing collaboration.

Goal of NuInt Workshop

- **Goal (Theoretical)**

  We would like to etablish a canonical method to treat them and to quantify the accuracy. We need to unify the formulation among nuclear physics and neutrino physics.

- **Goal (Experimental)**

  We like to measure the electron- and neutrino-nucleus cross sections with better accuracy.

Workshop on Neutrino-Nucleus Interactions in the Few-GeV Region

(1) NuInt01

(KEK, Dec.13-16, 2001)

Nucl.Phys.B(Proc.Suppl.)112, 2002

(2) NuInt02

(UC Irvine, Dec.12-15, 2002)

(3) NuInt04

(Gran Sasso, March 17-21, 2004)

Nucl.Phys.B(Proc.Suppl.)139, 2005

NuInt05 (Okayama, Sep.26-29, 2005)
http://fphy.hep.okayama-u.ac.jp/NuInt05/

Quote From the APS Neutrino Study "Neutrino Matrix" 2004

Section 4 Recommendations

"The precise determination of neutrino cross sections is an essential ingredient in the interpretation of neutrino experiments…

Interpretation of atmospheric and long-baseline accelerator-based neutrino experiments, understanding the role of neutrinos in Supernova explosions, and predicting the abundances of the elements produced in those explosions all require knowledge of neutrino cross sections. New facilities, such as the Spallation Neutron Source and existing neutrino beams can be used to meet this essential need."

Highlights of NuInt05

- Supernova related talks.
- The first result of ICARUS proto-type detector (Liq.Ar TPC, 50litters) exposed with the CERN neutrino beam in 1997. where 61 clean quasi-elastic events are selected and compared with the FLUKA Monte Carlo Model.
- Latest reports on the neutrino interactions from K2K, MiniBOONE, NOMAD, and MINOS experiments.
- Latest reports (G0, JUPITER) on the electron-nucleus interactions from JLAB, which are related to the neutrino-nucleus interactions.
- Detailed discussion on the neurino-nucleus interaction
  - Quasi-elastic interaction and the final state interaction
  - Resonance production
  - Deep Inelastic Scattering
- Future experiments for neutrino cross section measurements etc.

Neutrino Oscillations

Atmospheric Neutrino Oscillations have been established

- Atmospheric Neutrino Oscillation ($\nu_\mu - \nu_\tau$) discovered by SK in 1998 has been confirmed by K2K in 2004 at 99.99% CL.
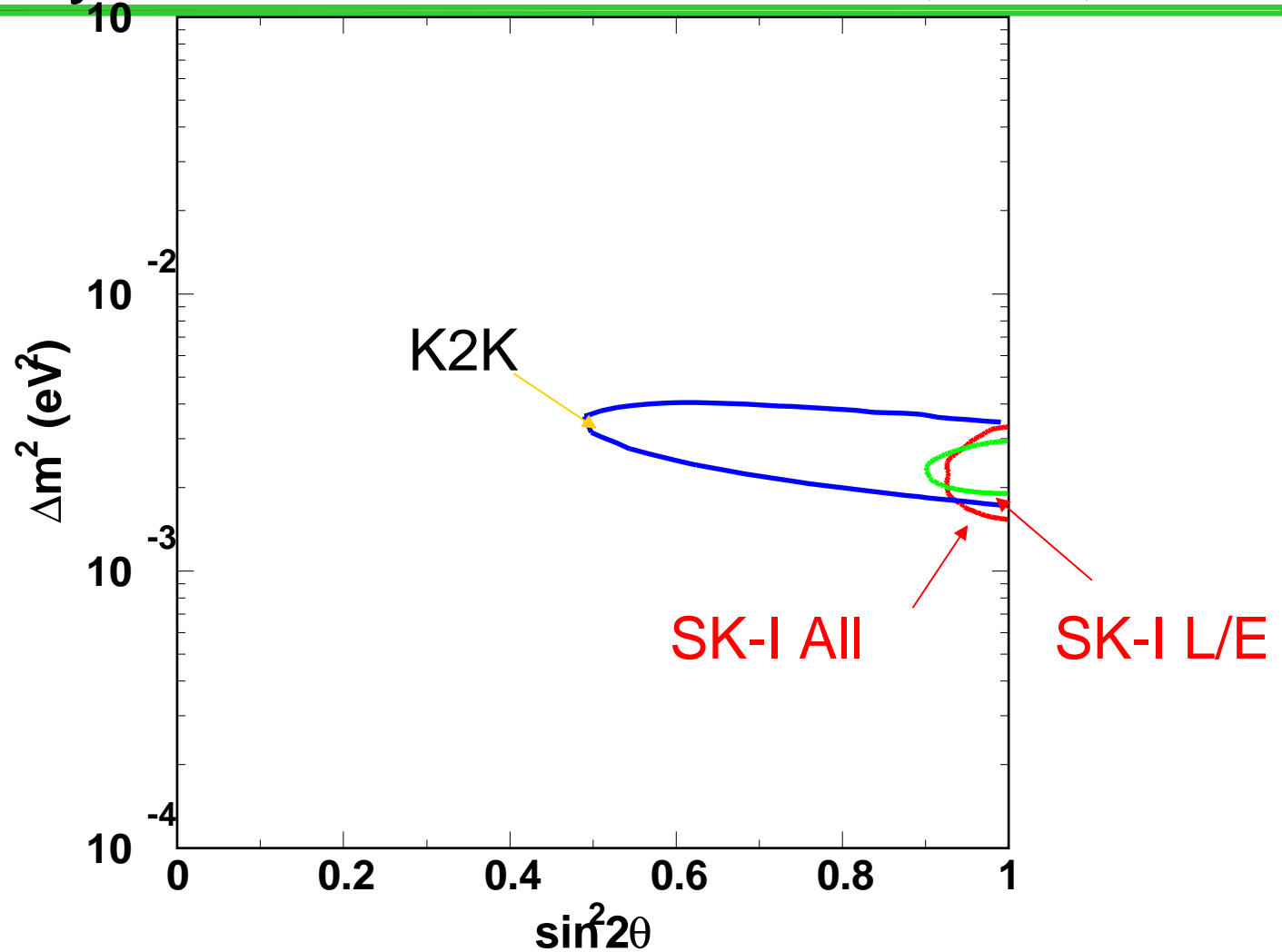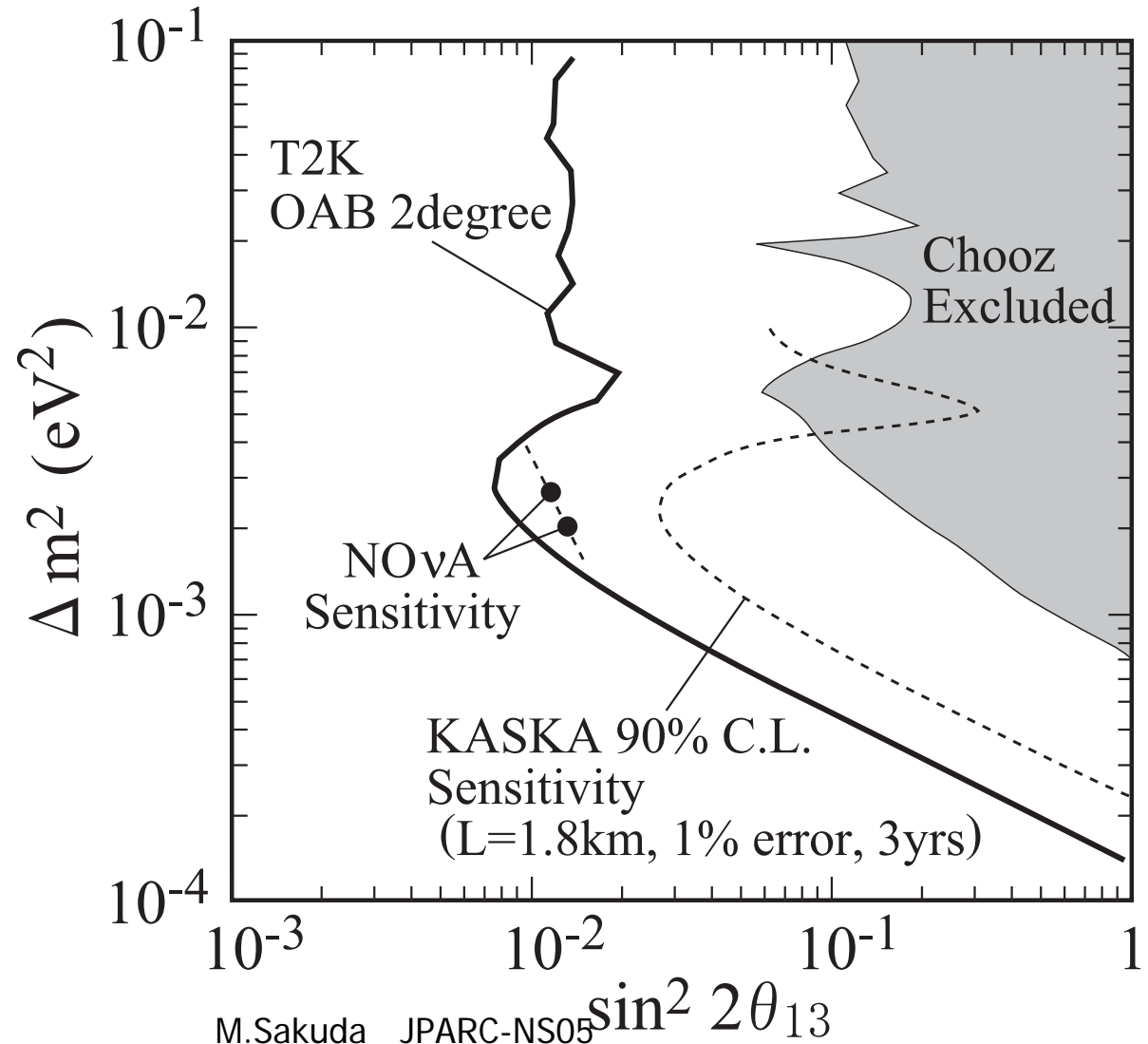
Super-K atmospheric neutrinos

K2K
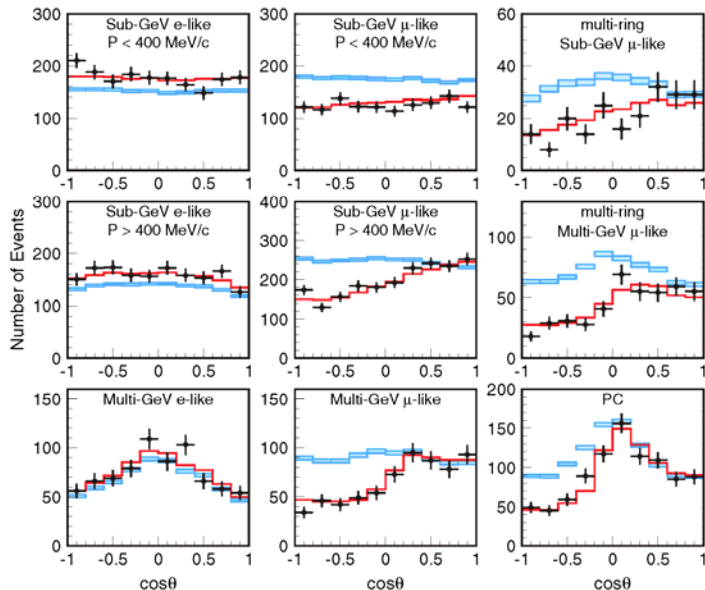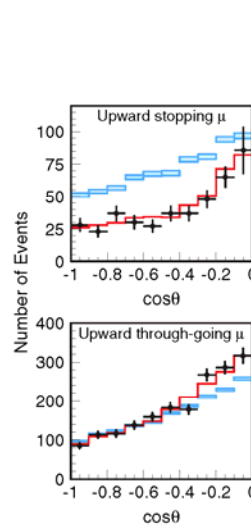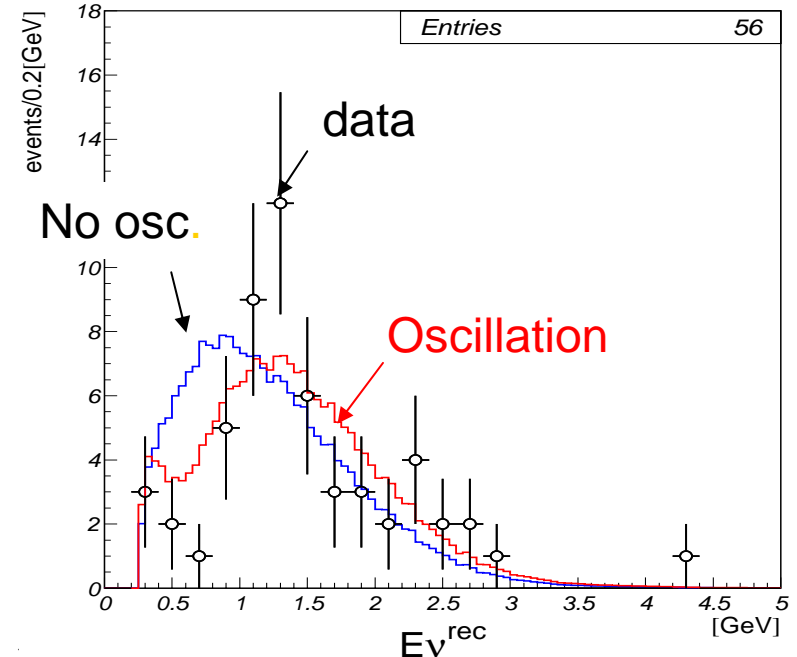
ν_μ-ν_τ oscillations established by SK and K2K at 90%CL (2004)

Next : $\nu_e-\nu_\tau$ or $\nu_e-\nu_\mu$ oscillation at 1% or less by T2K,NOvA and Reactors in 2009-2015
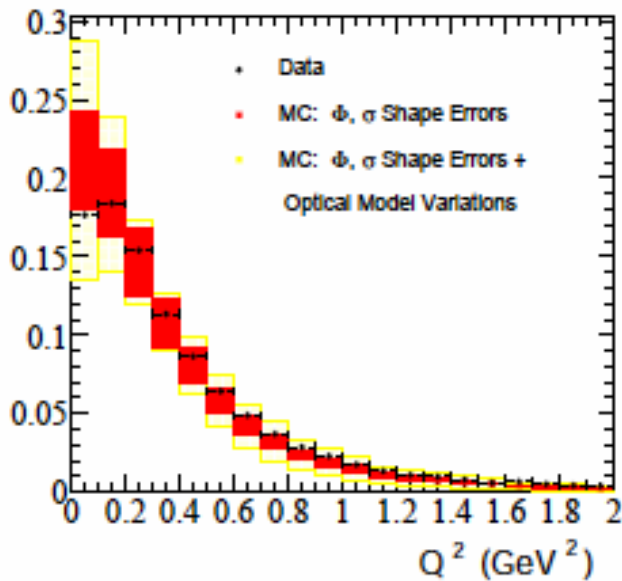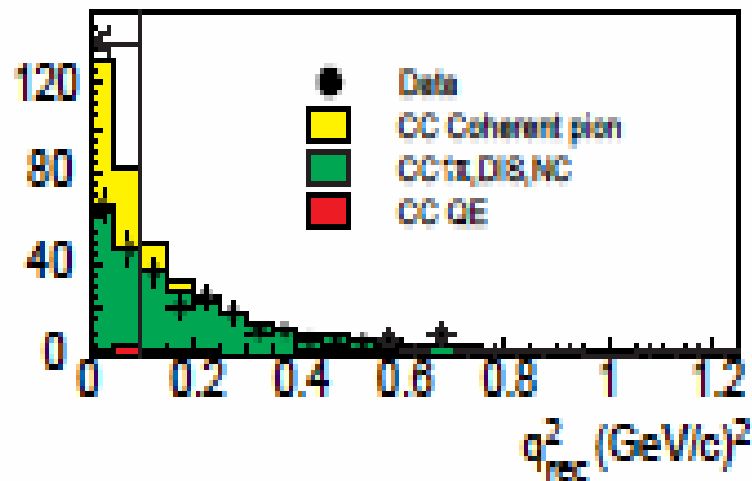
Neutrino-Nulceus Interactions

●MiniBOONE and K2K Q² deficit
Then, JUPITER at JLAB

•K2K SciBar result suggests the reduced Coherent Pion Production. M.Hasegawa et al.(K2K), Hep-ex/0506008.

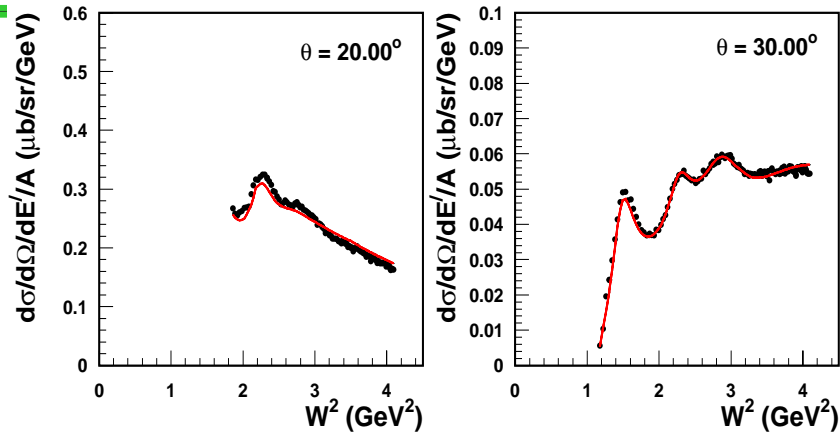MiniBOONE QE sample

K2K SciBar Inelastic sample

•Low-Q^2 C(e,e') data have been taken by JUPITER experiment at JLAB. Consistecy with MiniBOONE data will be interesting.
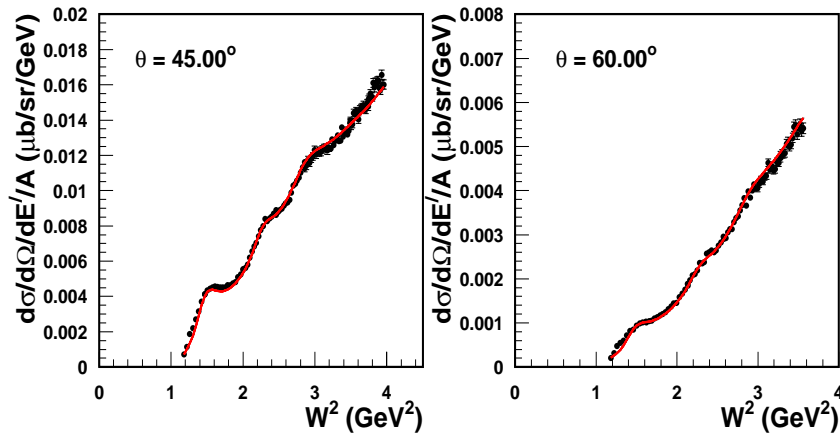NB: Neutrino physicists need accuracy in low-Q2, while Nuclear physicists go to high-Q2.

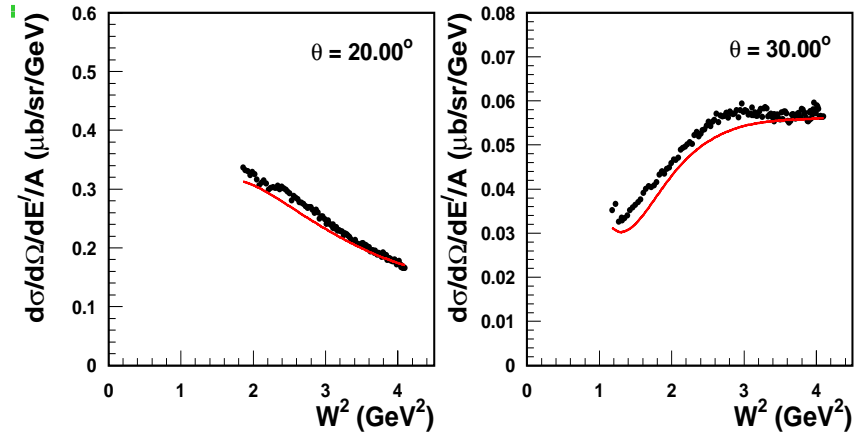**E_{Beam} = 2.3 GeV, Target = D**

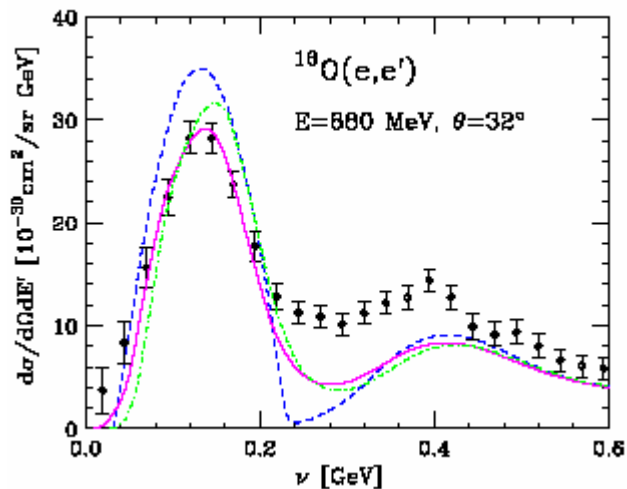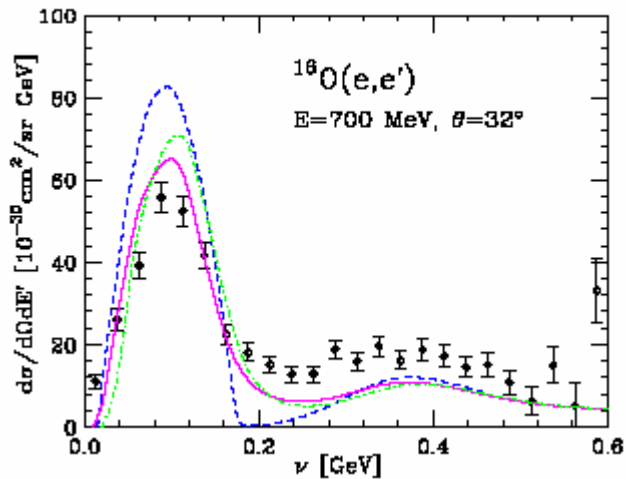**E_{Beam} = 2.3 GeV, Target = C**
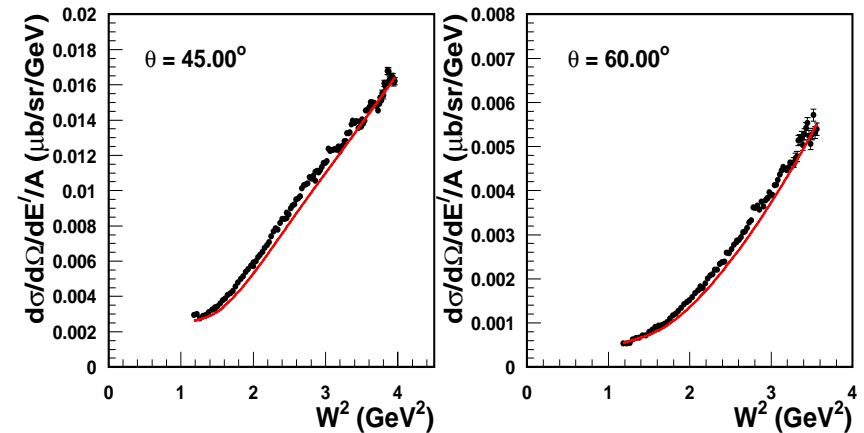
----- **Input models for RCs, etc.**

Deuterium: Fits to previous JLab & SLAC resonance region data.

Heavy targets: fits to DIS data (F_2 & R) + y-scaling QE model.

➤ Error bars are statistical only.

➤ Only inelastic data shown. Elastic under way.

akuda

● Quasi-elastic Interaction

-Comparison of FG, SP, SP+<u>FSI</u> validated by electron scattering data

O(e,e')

Benhar,MS et al, PRD72,053005,2005

O(ν,e)

FG

SP

SP+FSI

$\nu_e + {}^{16}O \rightarrow e + X$

$E_\nu = 1$ GeV
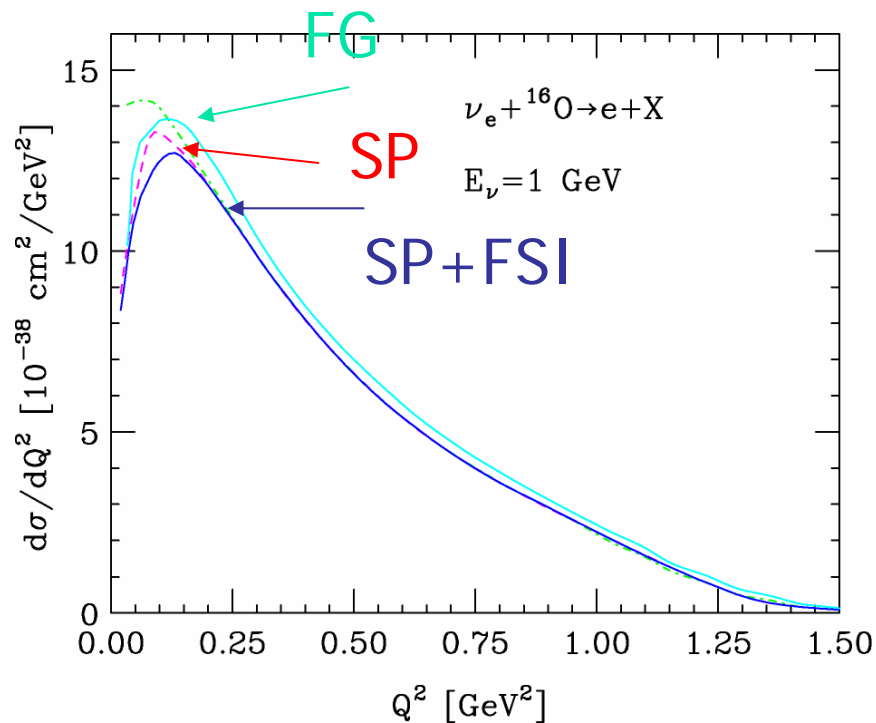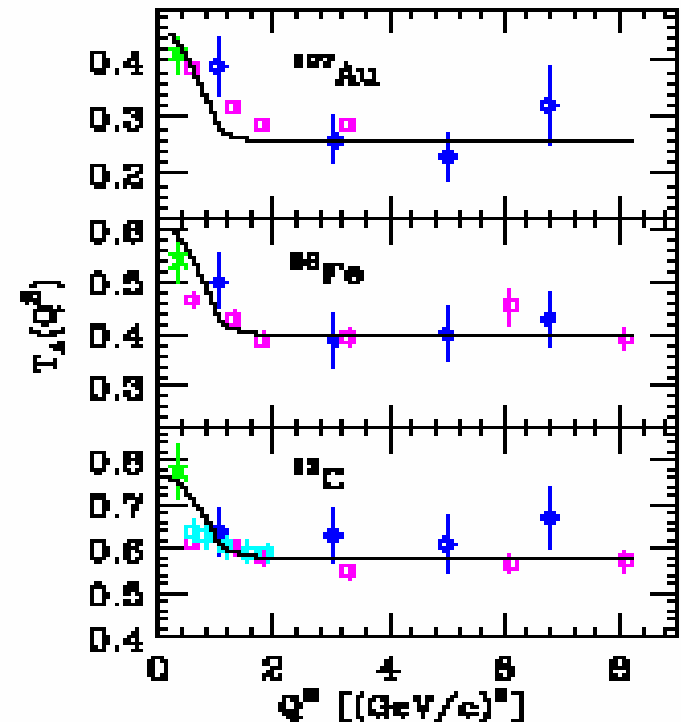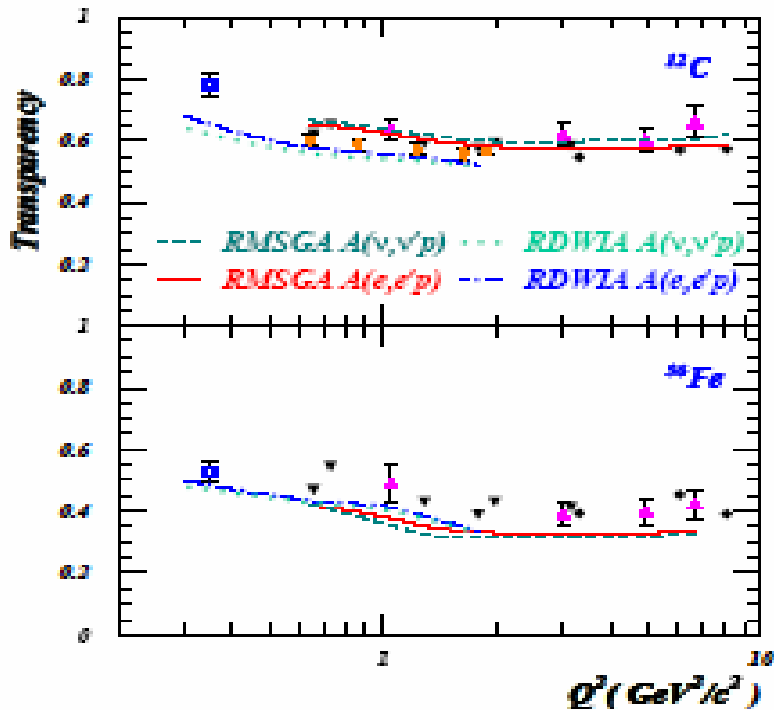
Validation of FSI effect: Calculated transparency compared to data

Transparency= Probability that a nucleon can escape from
the nucleus without being subject to any interaction.
i.e. T=1.0 = Completely transparent=No interaction

Jachowicz et al., nucl-th/0505008   Benhar,MS et al., PRD72,053005,2005

●Improved Δ production model

Paschos MS et.al PRD69('04)
Sato-Lee, PRC67('03)

- Pauli effect $G(W, Q^2, k_F)$
- Correct N-Δ form factor
- 3-4 resonances
- e-p data look good.

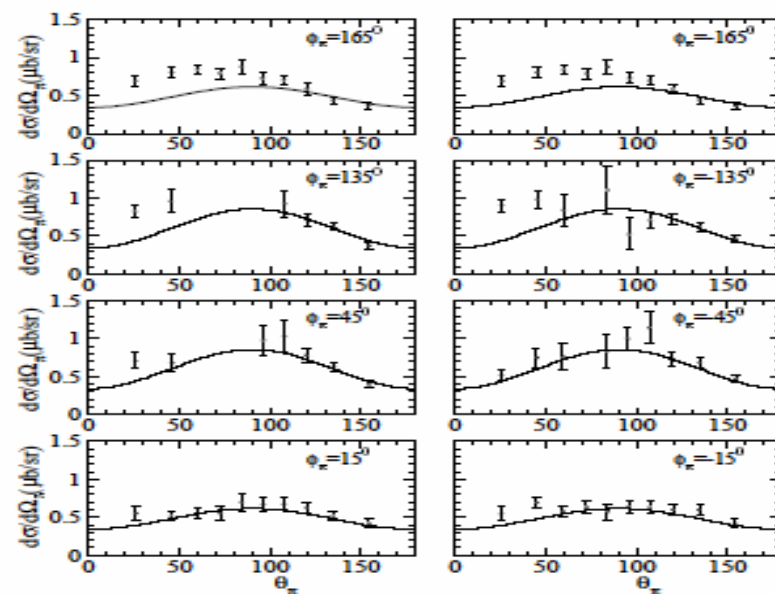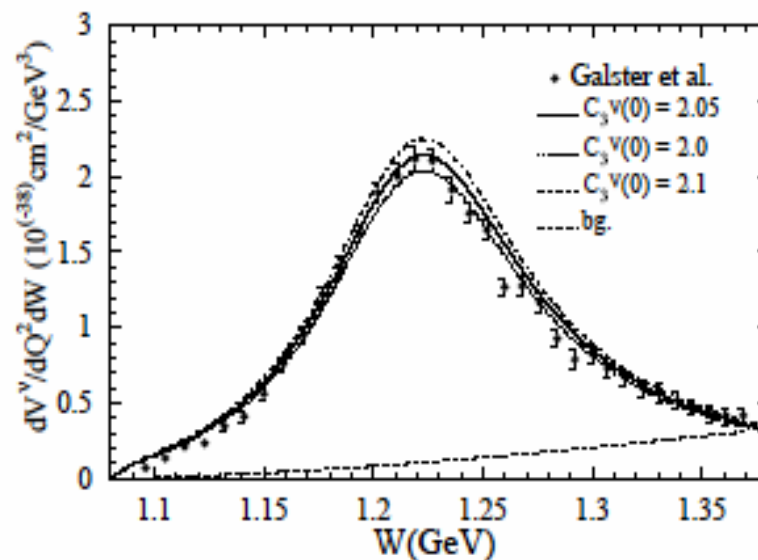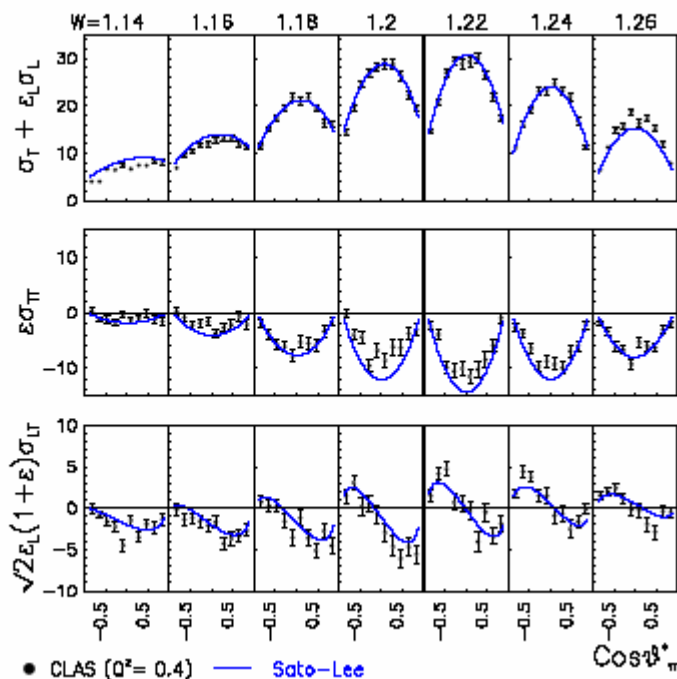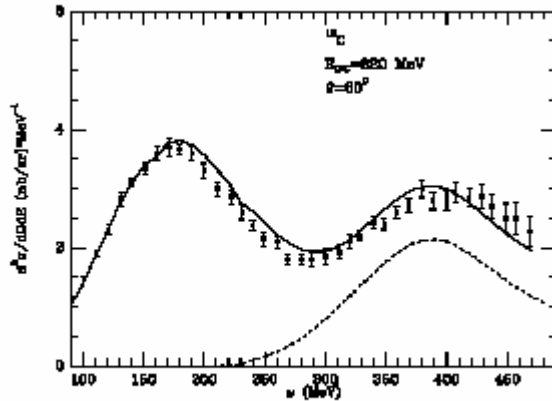$e + p \rightarrow e' + \pi^0 + p$ (Unpol)

● CLAS ($Q^2 = 0.4$) —— Sato-Lee

FIG. 10: Electroproduction data [25] for the reaction $e + p \rightarrow e + p + \pi^0$.

Δ production –Some differences in e-C (Nucleus). Dip region must be understood. Nieves et al. looks good.
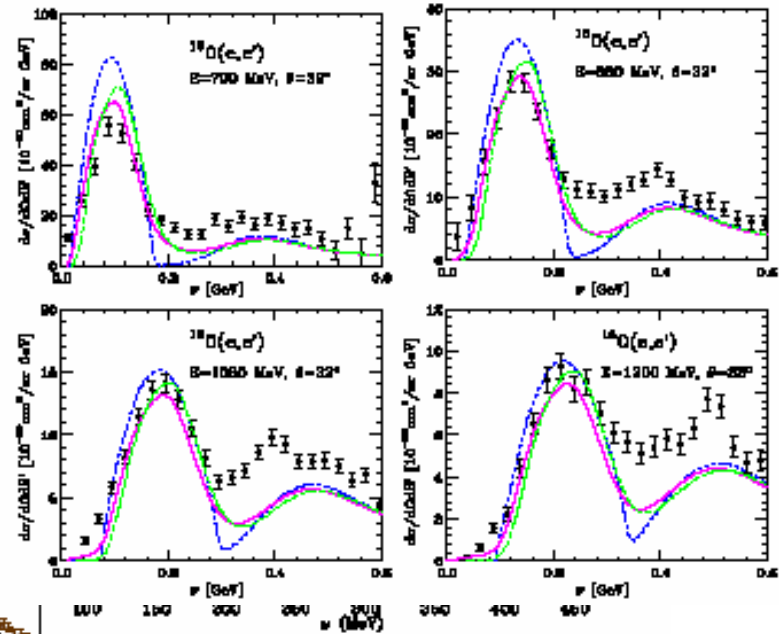
Nieves et al.,PRC70('04)

Benhar,MS et al.

$$e + {}^{12}C \rightarrow e' + X$$

A.Gil, J.Nieves and E.Oset, Nucl.Phys. A627:543,(1997)

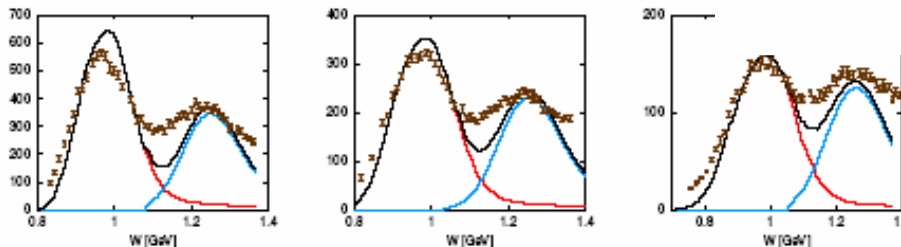### Sato-Lee

$$e + {}^{12}C$$

$E_e = 0.96 GeV$ $E_e = 1.1 GeV$ $E_e = 1.3 GeV$
$\theta = 37.5°$

- spectral function $P(k, E)$ (O. Benhar et al.)

Comparison to Frascati ^{16}O (e, e') data

E.Oset, Nucl.Phys. A627:543,(1997)

•Nuclear PDF and its effect on the DIS cross section

-Kumano@NuInt04
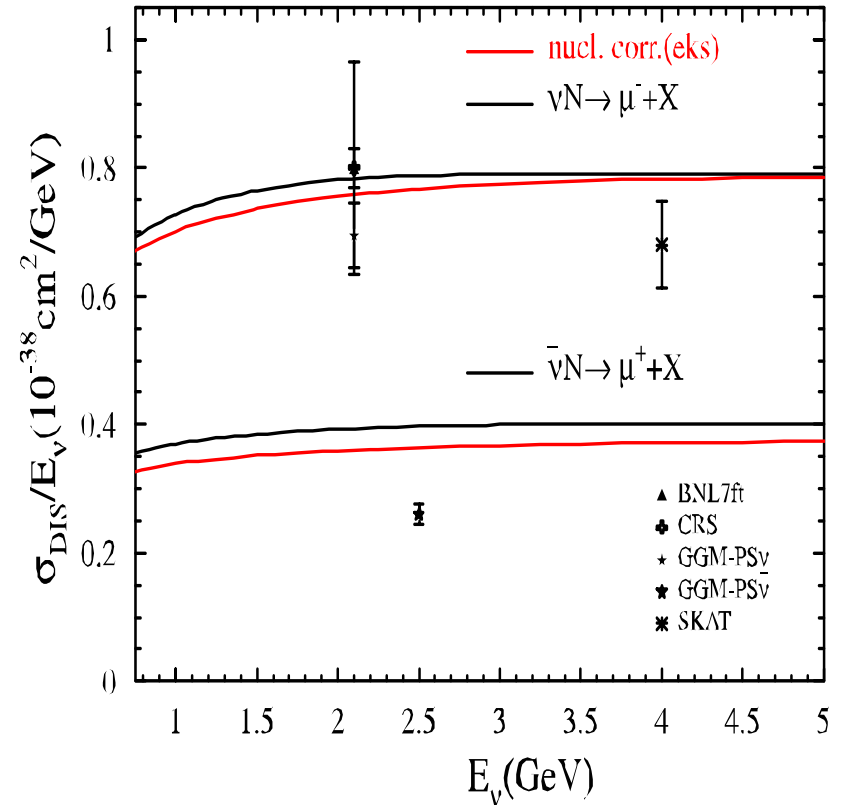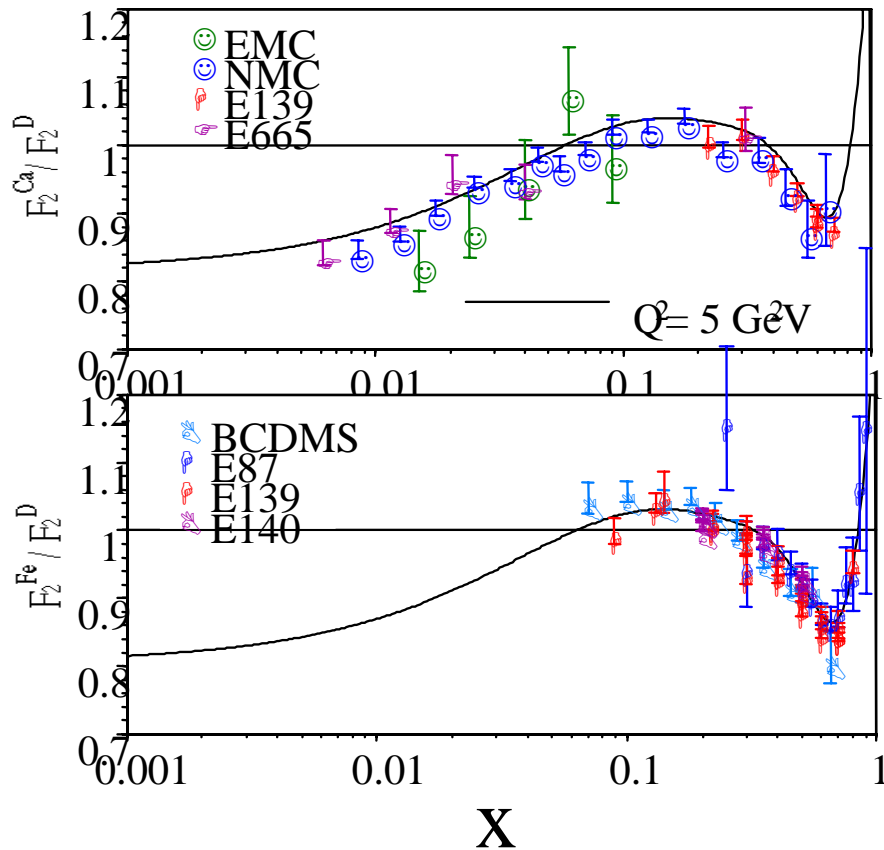
Resonance to DIS (Bodek-Yang at NuInt01/02)

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

Dashed: GRV94
Red: Bodek-Yang

We heard more details.
→Melnitchouk's talk,
Phys.Rep.406,2005.

•Resonance to DIS (Bodek-Yang at NuInt01/02)
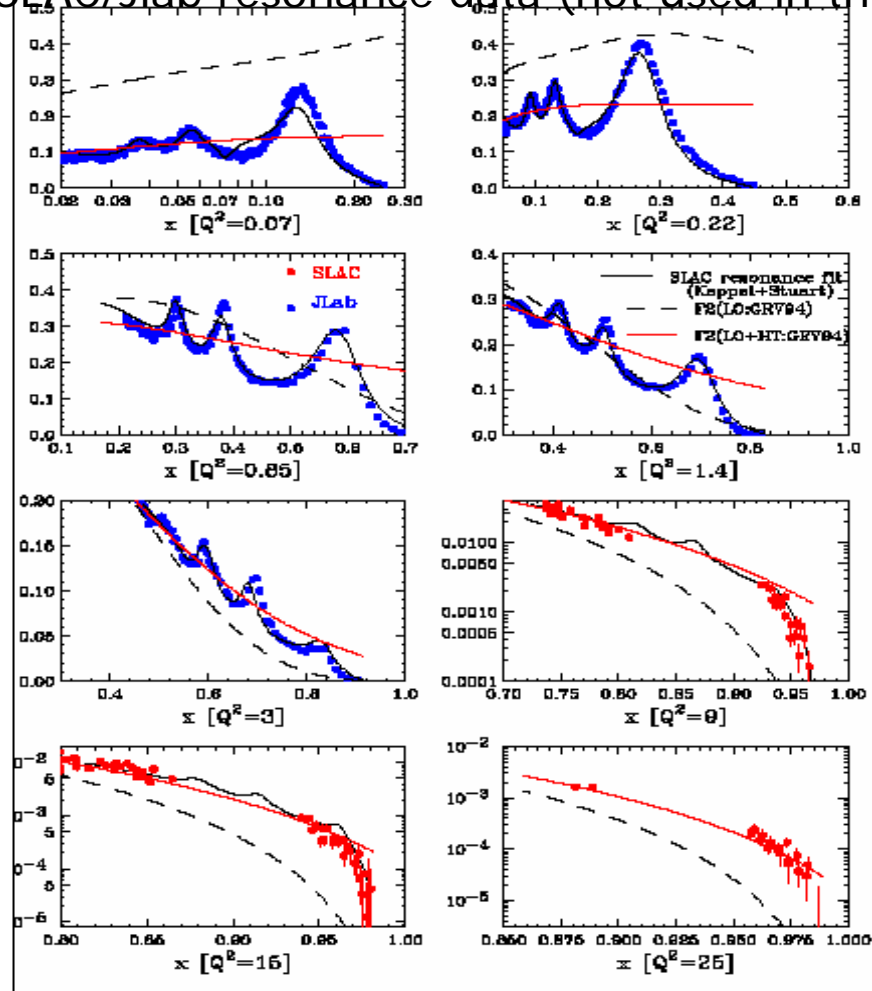
$$F_2(x) = \sum_i e_i^2 \left(xq_i(x) + x\overline{q_i(x)} \right)$$
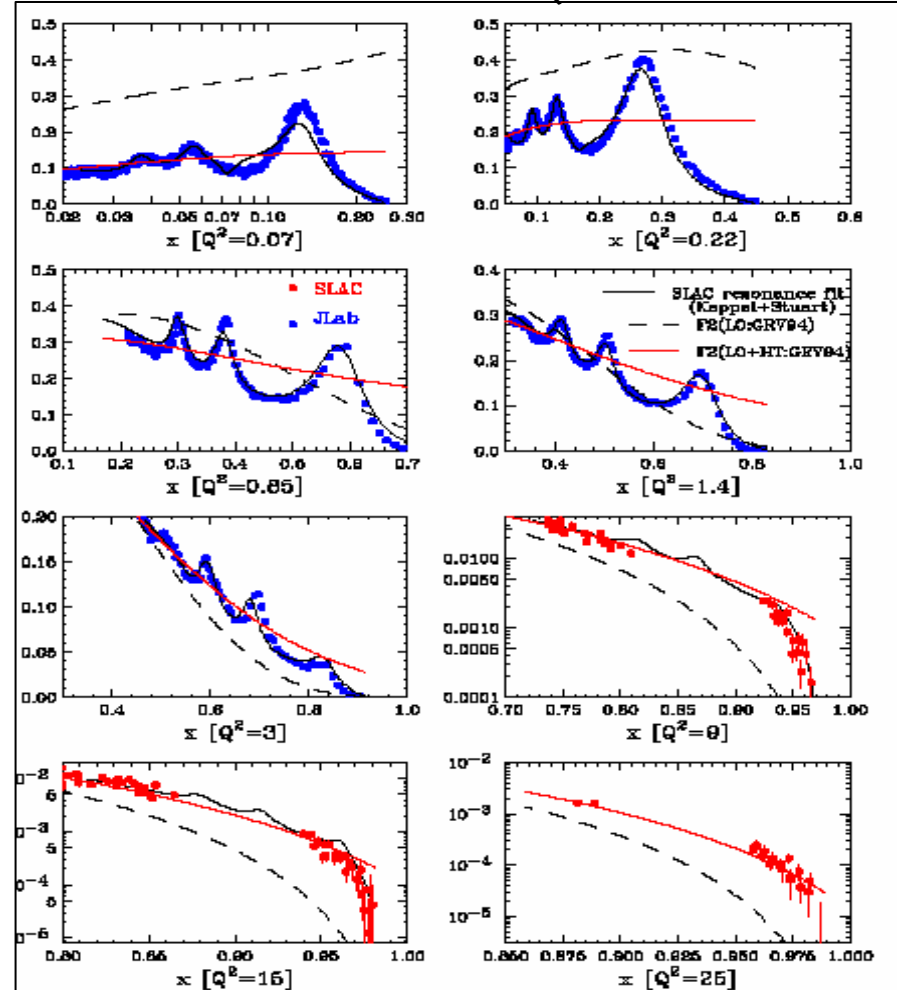
$$F_2(x) = \frac{Q^2}{Q^2 + 0.188} F_2(x_w)$$

$$where \; x_w = x(Q^2 + 0.624)/(Q^2 + 1.735x).$$

Dashed: GRV94
Red:Bodek-Yang
This correction is significant
at low Q2 region.

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

New at NuInt05
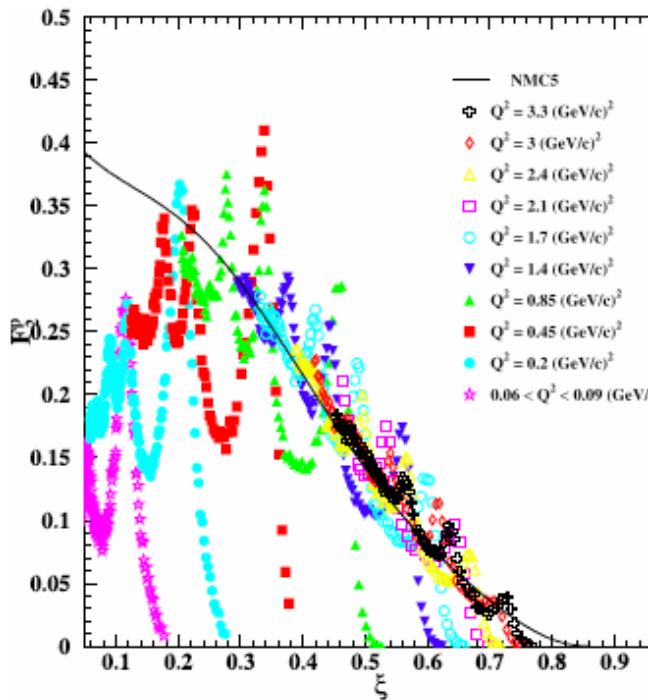
Resonance-DIS transition and low Q^2 phenomena

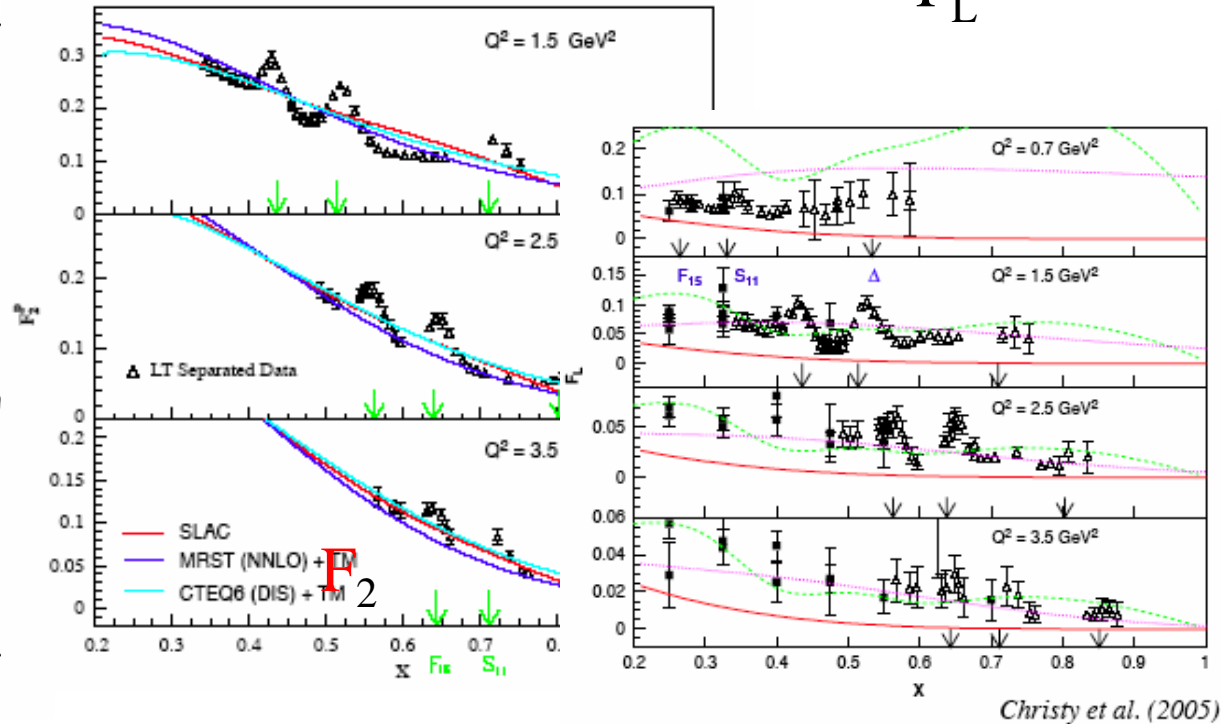*Wally Melnitchouk*

Jefferson Lab

+ *F. Close (Oxford), O. Lalakulich & E. Paschos (Dortmund)*

F_2

F_L

Duality in F_L not as well demonstrated but large errors on measured values

●SuperNova

- Detection of neutrinos from the past SuperNova explosions (Relic Supernova Neutrinos) is one of the main topics at SuperKamiokande in the next 5 years.→Fig

  There, Neutrino-Nucleus interactions in 10-200 MeV region need precision to understand Signal (SNν) and background (ATMν).

- SN models want to understand why they do not explode.

→Experimental proposal (ν-SNS) to measure neutrino-nucleus cross sections in the MeV region.

In 2003, Super-Kamiokande published the world's best limits on this so-far unseen flux (Relic SNν) [M.Malek *et al.*, *Phys. Rev. Lett.* **90** 061101 (2003)].
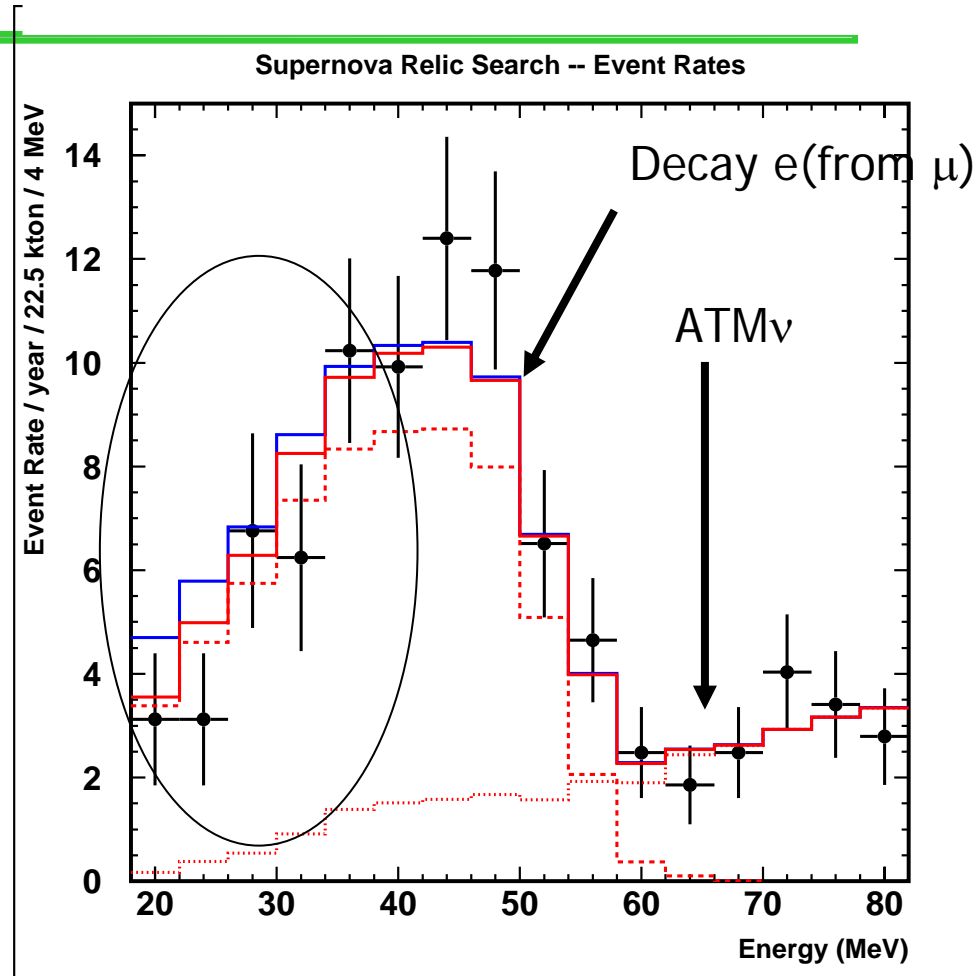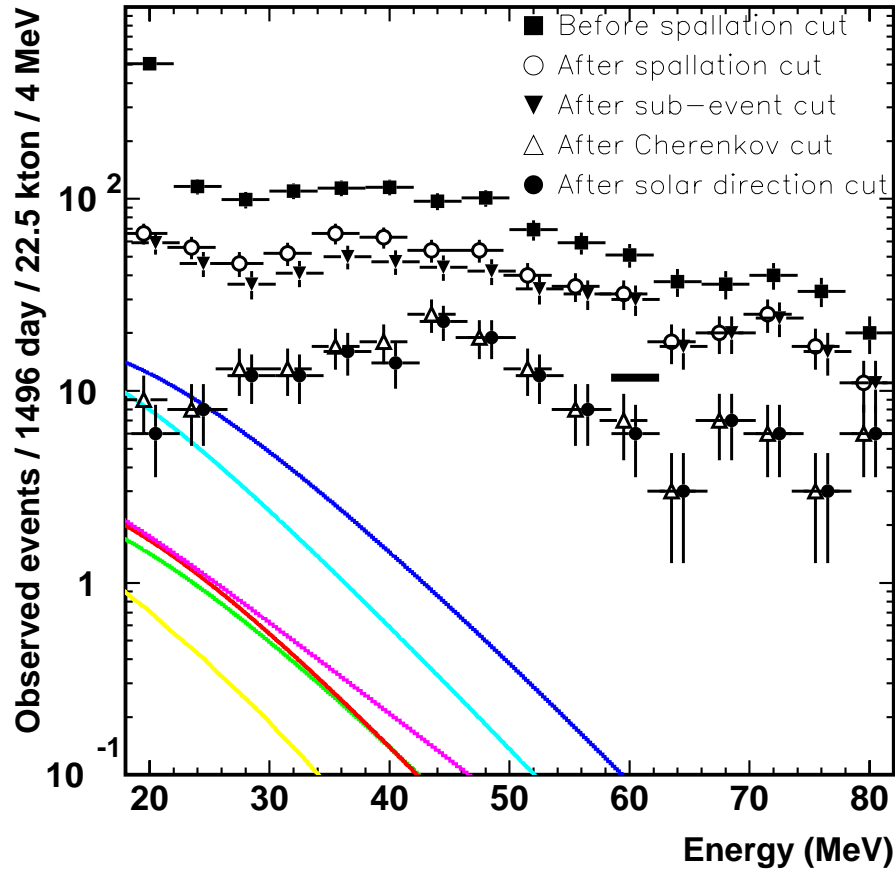
SK need more statistics and reduce backgrounds in order to see clear excess.
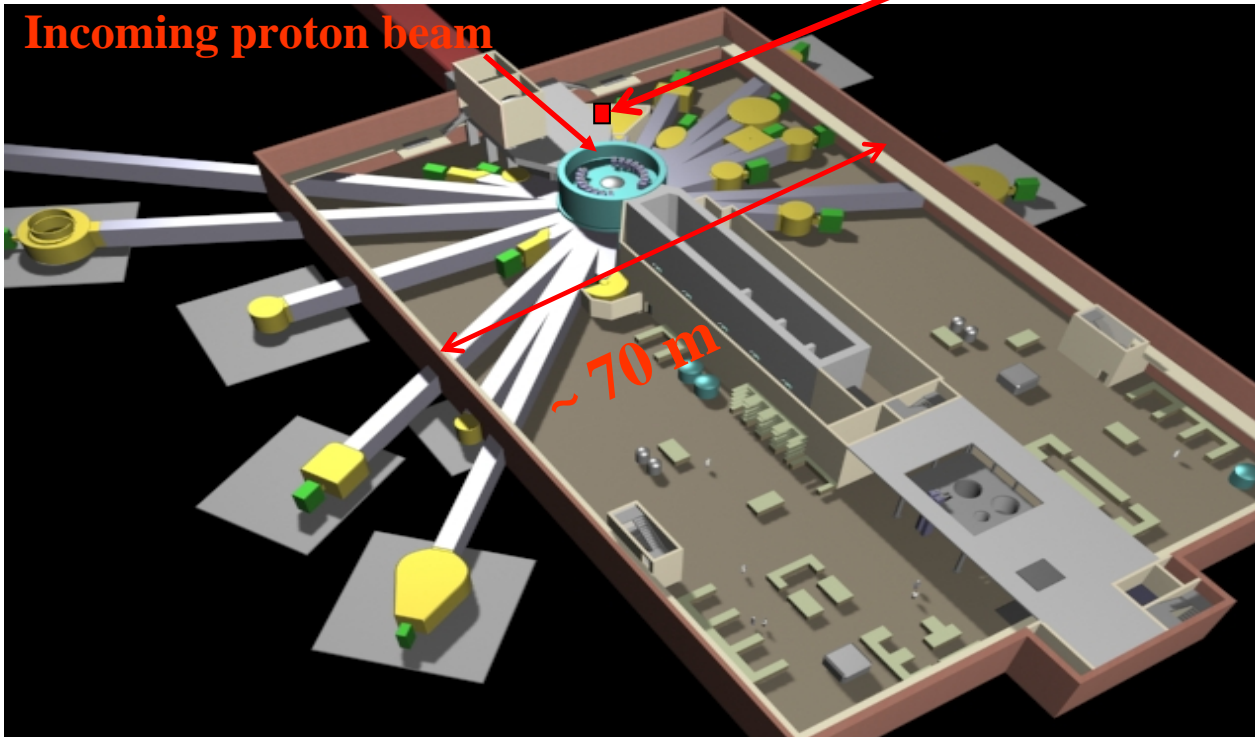
Potential Location

SNS Target Building is a big and busy place !!!

Identified location
~ 20 m

Incoming proton beam

~ 70 m

To explore full potential of SNS we need to locate neutrino detectors as close to the target as reasonably achievable !!!

Backward location has some advantage because most of energetic neutrons are going in forward direction

ν-SNS

Summary

- NuInt Workshop is a unique workshop which develops the neutrino-nucleus interactions. We, neutrino physicists and nuclear physicists, are working together.

- We extend our energy region down to 10-500MeV region, where SuperNova neutrinos, Sub-GeV atmospheric neutrinos and solar/reactor neutrinos are relevant.

- Neutrino experiments at Neutron Spallation Facility at JPARC may be interesting like ν-SNS.

Electron-Nucleus and Neutrino-Nucleus quasi-elastic interactions

- Electromagnetic current (J_a^{em}) and weak hadronic charged current ($J_a^{CC}=V_a^{1+i2}-A_a^{1+i2}$) is written in terms of form factors:
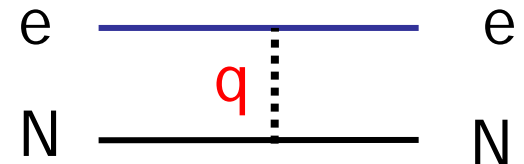
$$< N(p')\,|\,J_\alpha^{em}\,|\,N(p)> = \bar{u}(p')\left[\gamma_\alpha F_1^N(Q^2) + \frac{i}{2M}\sigma_{\alpha\beta}q^\beta F_2^N(Q^2)\right]u(p),$$

$$< p(p')\,|\,V_\alpha^{1+i2}\,|\,n(p)> = \bar{u}(p')\left[\gamma_\alpha F_1^V(Q^2) + \frac{i}{2M}\sigma_{\alpha\beta}q^\beta F_2^V(Q^2)\right]u(p),$$

$$< p(p')\,|\,A_\alpha^{1+i2}\,|\,n(p)> = \bar{u}(p')\left[\gamma_\alpha\gamma_5 F_A(Q^2) + q_\alpha F_p(Q^2)\right]u(p),$$

$$G_E^N(Q^2) = F_1^N(Q^2) - \tau F_2^N(Q^2)$$

$$G_M^N(Q^2) = F_1^N(Q^2) + F_2^N(Q^2) \qquad with \quad \tau = \frac{Q^2}{4M^2}$$

$$G_{E,M}^{V(}(Q^2) = \frac{1}{2}\left[G_{E,M}^p(Q^2) - G_{E,M}^n(Q^2)\right]$$

$$F_1^V(Q^2) = \frac{G_E^V(Q^2) + \tau G_M^V(Q^2)}{1+\tau} \quad and \quad F_2^V(Q^2) = \frac{G_M^V(Q^2) - G_E^V(Q^2)}{1+\tau}$$

e ———————————— e

q

N ———————————— N