WG2 Summary

~ Neutrino interactions ~

WG2 Conveners
Y.Hayato
K. McFarland
J. Nives

Please refer to the following two plenary talks together with the presentations in WG2 session

- Summary of Theoretical Challenges Coming from NuInt09
  (Luis Alvarez Ruso, Universidad de Murcia)
- Review of Current and Future Neutrino Cross-Section Experiments
  (David Schmitz, Fermilab)

Outline

- Introduction
  - Energy spectrum of various neutrino beams
    - ~ Hadron production experiments ~
  - Requirements from the experiments

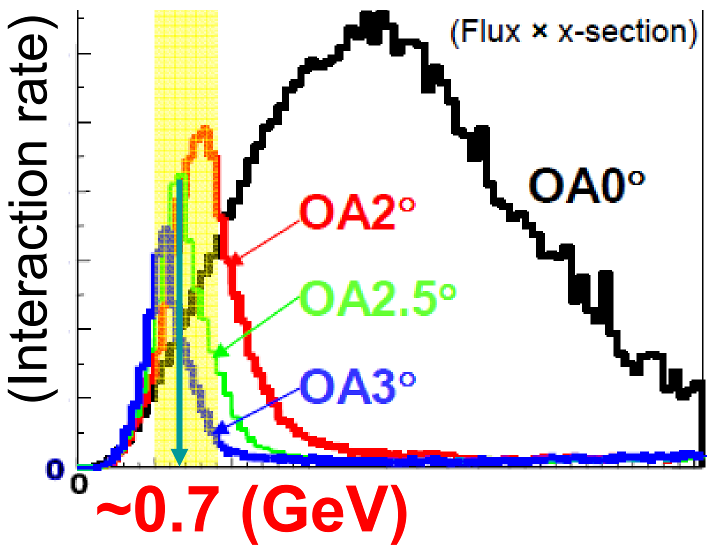
- Quasi-elastic scattering
- Single pion productions
- Coherent pion productions
- Deep inelastic scattering

- New experiments to measure cross-sections
- Flux measurements ~ hadron production ~
- Other related topics
  - Deeply virtual neutrino production of π^0
  - Application to the other experiments
    - ~ Cross-section of Dark matter ~

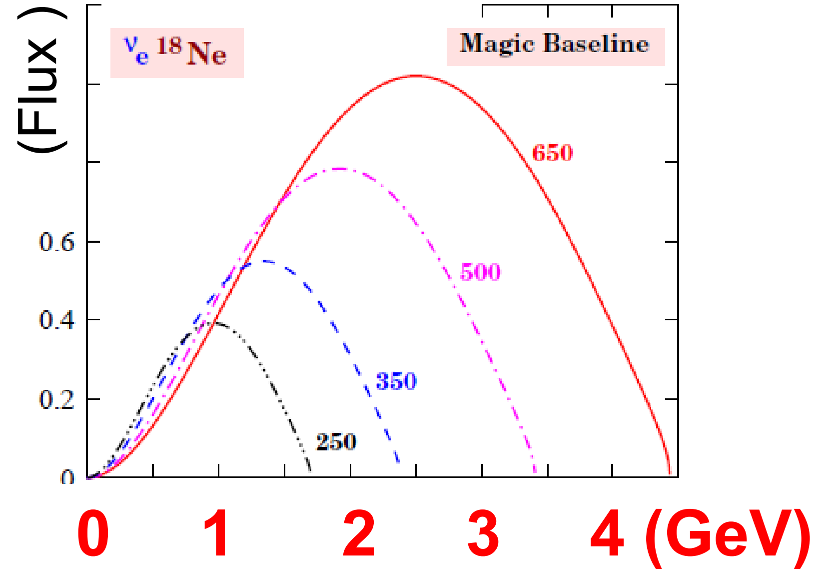
Energy spectrum of various neutrino beams

(D. Harris)

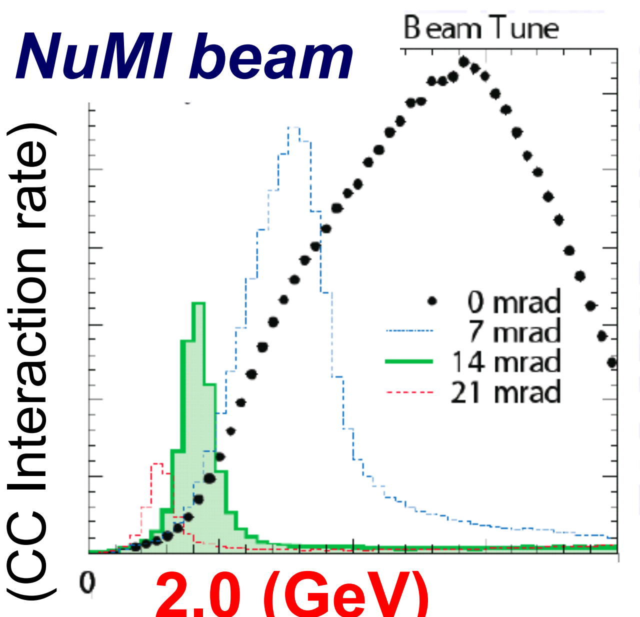
T2K beam



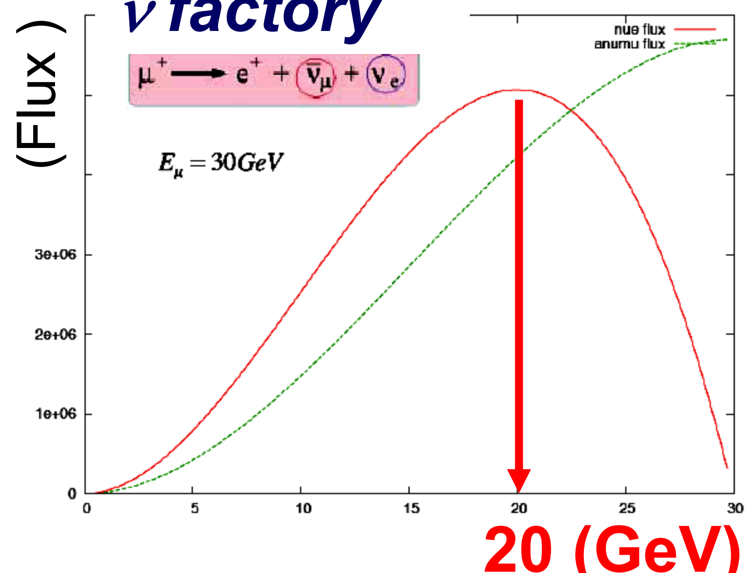
Beta beam



NuMI beam



ν factory



Hadron production experiments

(R. Schroeter)

Important to reduce systematic uncertainties in the neutrino oscillation experiments.

Estimate flux at the near and the far detectors.

Also essential input to extract ν cross-section.

		HARP 2-15 GeV/c p, π^+, π^-	MIPP 5-120 GeV/c p, $\pi^\pm$, $K^\pm$	NA61 31 GeV/c p
Accelerator-based Neutrino Beams	K2K, MiniBooNE	X		
	MINOS		X	
	T2K off-axis			X
Neutrino Factory		X	(X)	
Atmospheric Neutrinos		X	X	X
Systematic Target Studies		H, D, Be, C, N, O, Al, Cu, Sn, Ta, Pb		
			H, Be, C, Bi, U	
				C

Hadron production experiments

(R. Schroeter)

- Hadron production knowledge is limiting factor in understanding and optimization of a variety of neutrino sources (accelerator-based neutrino beams, atmospheric neutrinos)
- Search for smaller effects: characterization of actual neutrino beam targets to reduce MC extrapolation to the minimum
- HARP
  - Useful results for conventional ν beams study, NuFact design, EAS, atmospheric ν studies and for general MC tuning (G4, FLUKA, etc.)
  - Data taken with the same detector for a wide range of nuclear target: systematic effects are minimized
  - Lots of results!
- MIPP
  - Multi-GeV neutrinos (MINOS, atmospheric neutrinos, NuMI future: Noνa, MINERνA)
  - Detector performances well understood, physics analysis well underway, first hadron production cross section by september 2009
- NA61
  - Good quality of 2007 data, about to release π^- spectra

See also A. Bravar poster contribution for full experiment description and analysis status

Requirements ~ neutrino oscillation experiments ~

Need to understand the neutrino interactions from 0.5 GeV to 30GeV

- Next generation experiments (θ_{13} measurements)
  ~10 % (might be 15~20%?) of uncertainty is allowed.
  (depends on the parameter, of course)

- In CP violation studies, error should be **less than a few %.**

Current understanding of interactions is not sufficient especially to study the CP violation.

Also we need appropriate prescriptions to simulate events.

(Fast enough to generate millions of simulated events in reasonable amount of time.)

Quasi-elastic scattering

(R. Taylor)

M_A from CCQE

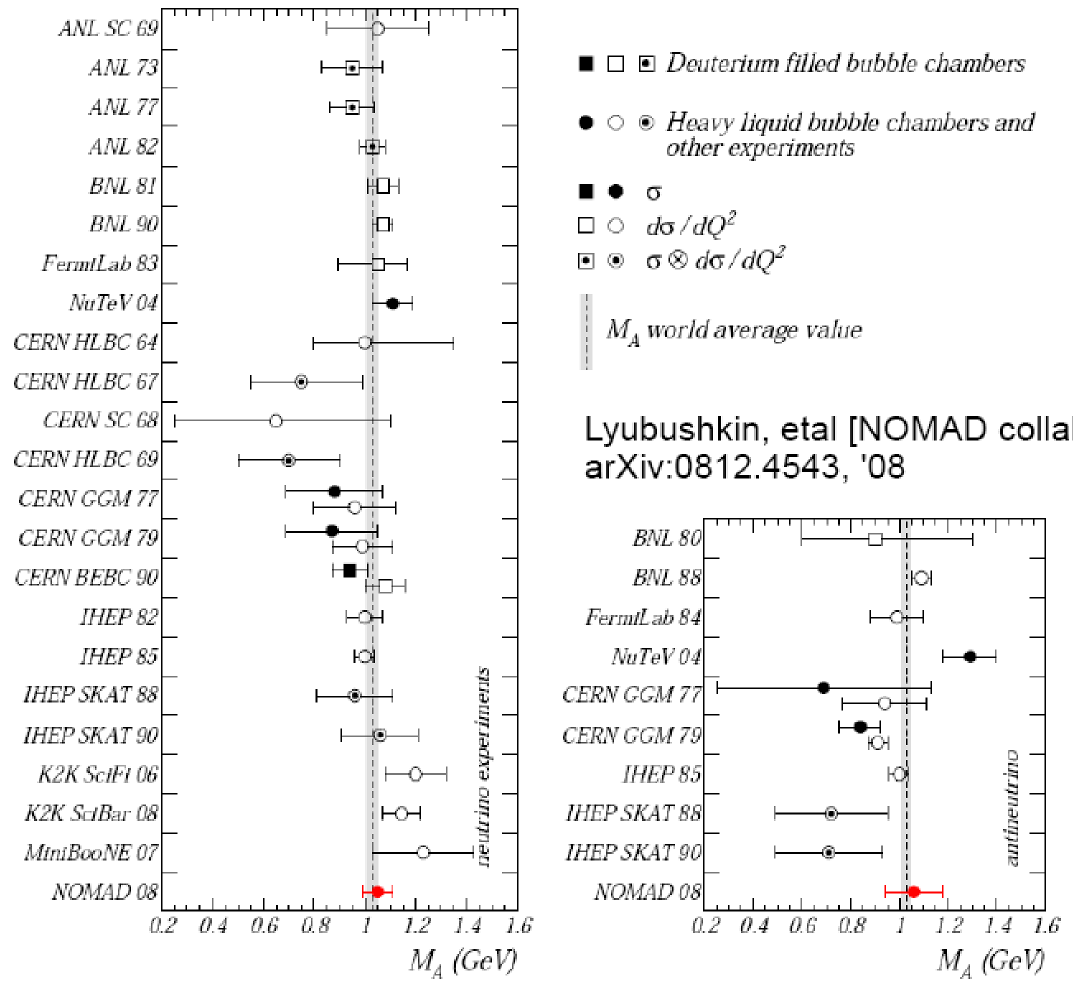
- M_A measurments, from Lyubushkin, etal (NOMAD collab, arXiv:0812.4543)

- different targets/energies

- world average from Bernard, etal, JPhysG28, 2002: M_A=1.026±0.021 (also, M_A from π photo-production similar)

- However, recent data from some high-stats experiments not well-described with this M_A and/or the simple model described on previous page

summary of ν, $\bar{\nu}$ measurements of M_A



Lyubushkin, etal [NOMAD collab], arXiv:0812.4543, '08

Fig. 18. A summary of existing experimental data: the axial mass M_A as measured in neutrino (left) and antineutrino (right) experiments. Points show results obtained both from deuterium filled BC (squares) and from heavy liquid BC and other experiments (circles). Dashed line corresponds to the so-called world average value $M_A = 1.026 \pm 0.021$ GeV (see review [33]).

Quasi-elastic scattering
Low energy experiments

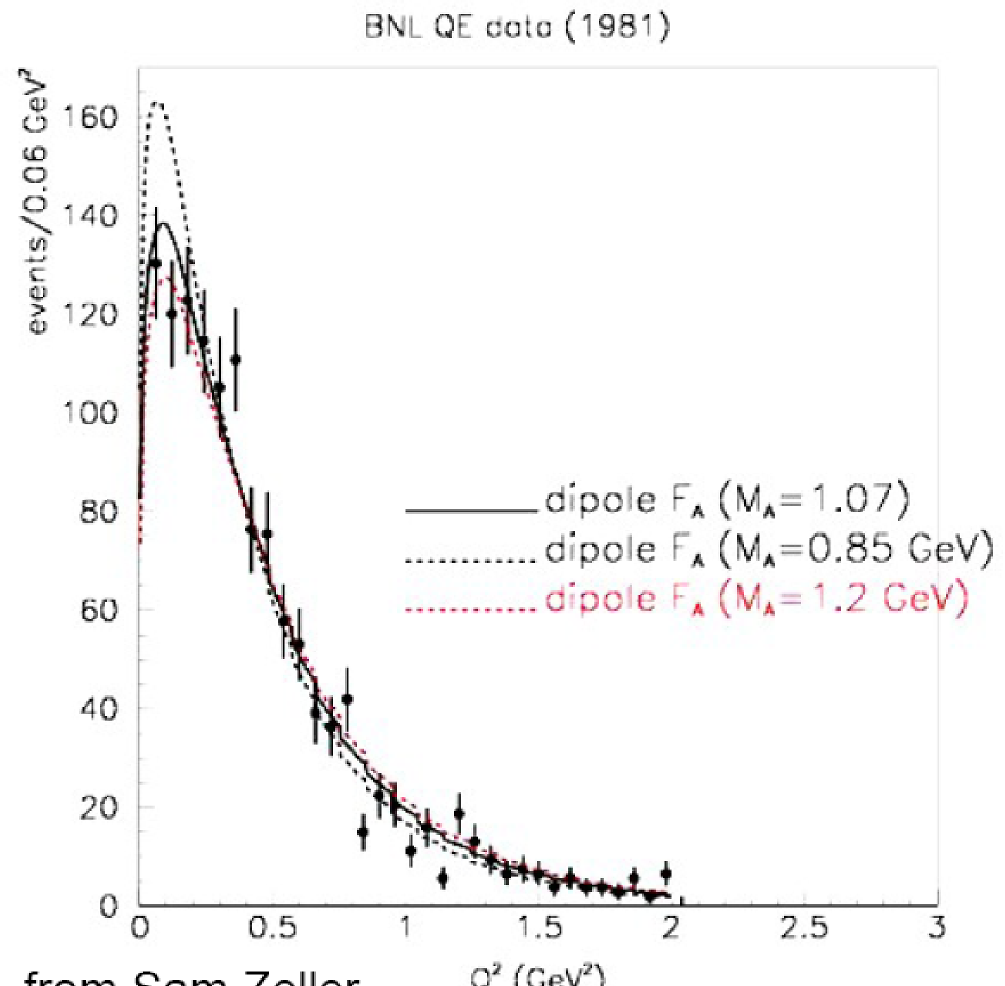
(R. Tayloe)

BNL QE data:
- Baker, PRD 23, 2499 (1981)
- data on D_2
- M_A=1.07 +/- 0.06 GeV

1,236 ν_μ QE events

- curves with diff M_A values, relatively norm'd, overlaid.
- M_A extracted from the shape of this data in Q^2

$$F_A(Q^2) = -\frac{g_A}{\left(1+\frac{Q^2}{M_A^2}\right)^2}$$



from Sam Zeller

Quasi-elastic scattering

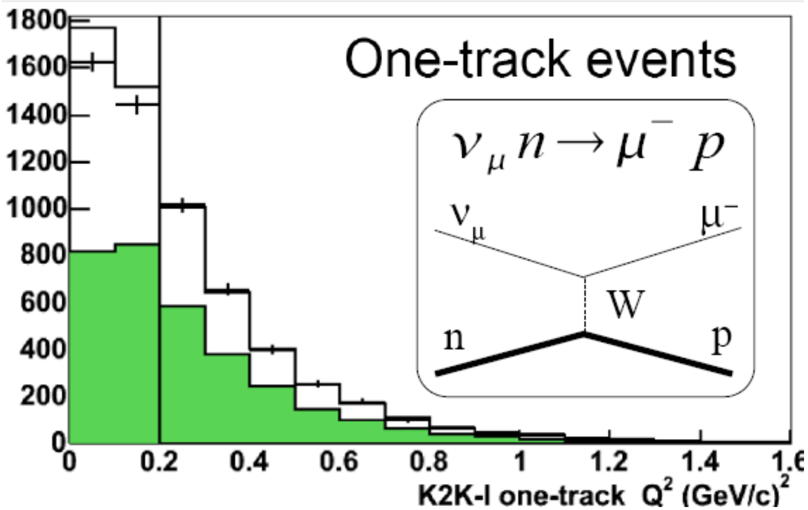
(R. Tayloe)

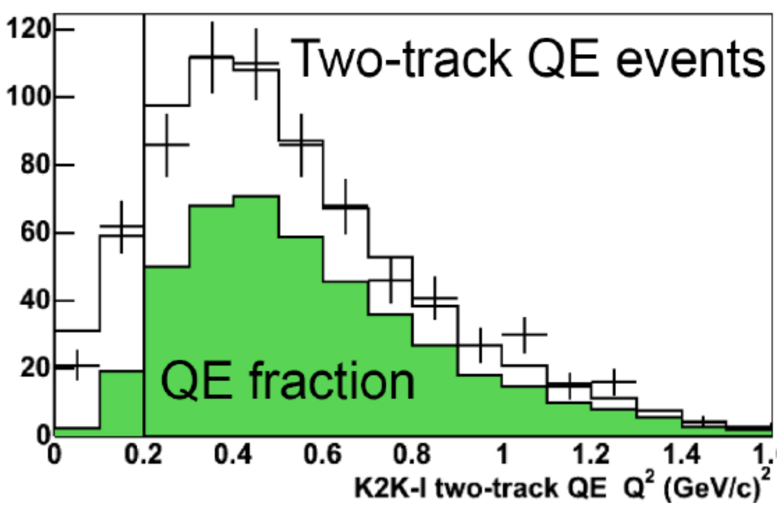
Recent results in low energy experiments

K2K SciFi

shape only fits $Q^2 > 0.2 (GeV/c)^2$

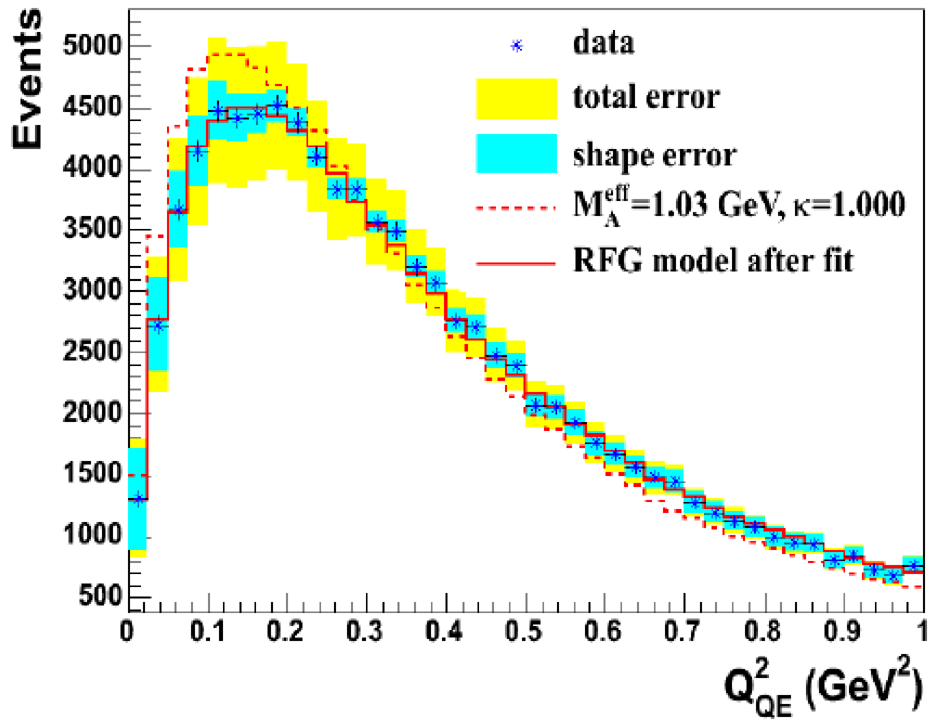
$\mathbf{M_A = 1.20 \pm 0.12\ (GeV/c^2)}$





MiniBooNE

$\mathbf{M_A^{eff} = 1.35 \pm 0.17}$



Preliminary SciBooNE results also indicates larger M_A

Quasi-elastic scattering

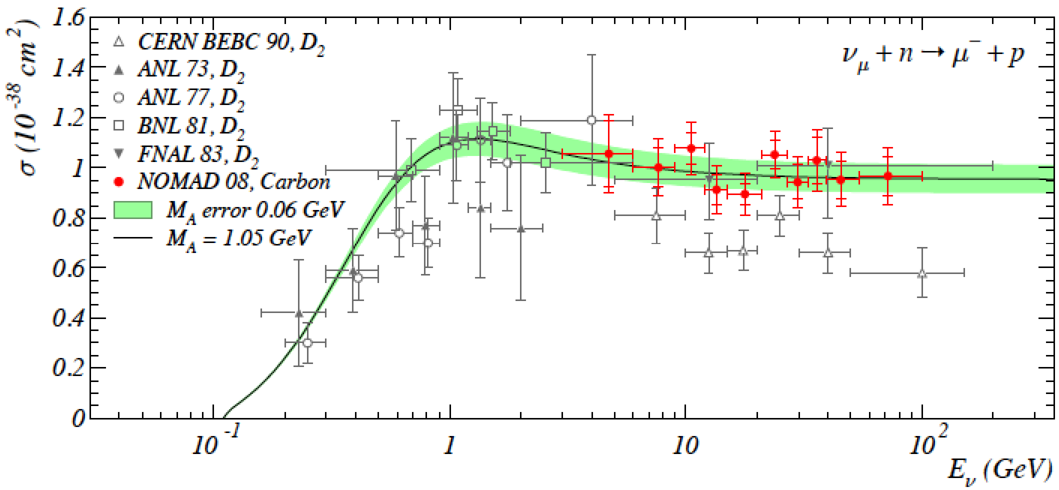
(R. Gran)

Recent results in high energy experiments

NOMAD

normalization to deep inelastic scattering and inverse muon decay

$$M_A = 1.05 \pm 0.02 (\text{stat.}) \pm 0.06 (\text{syst.})\ (\text{GeV}/c^2)$$



Results from shape Q2 fit

$$M_A = 1.07 \pm 0.06 (\text{stat.}) \pm 0.07 (\text{syst.})\ (\text{GeV}/c^2)$$

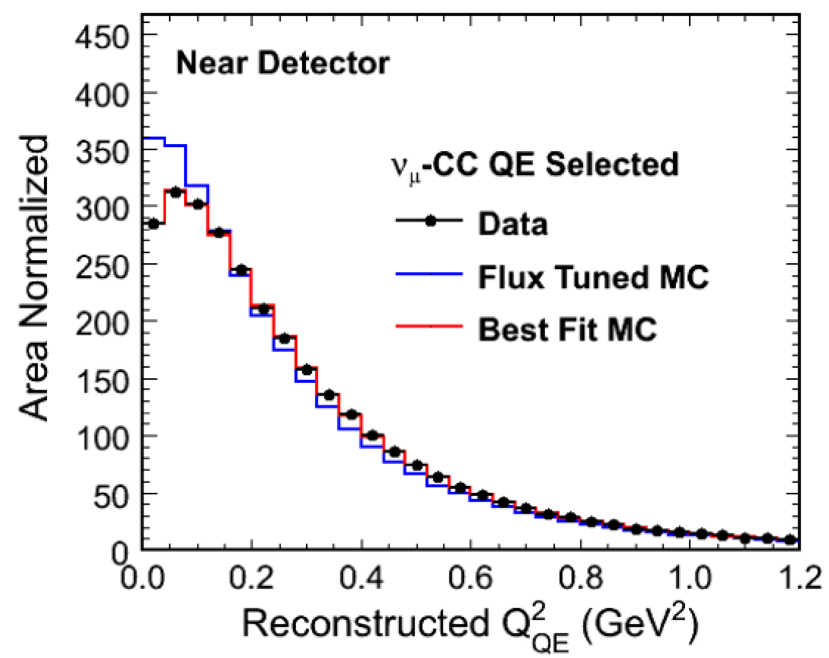
MINOS preliminary

Shape fit (all Q^2 region)

$$M_A = 1.19 \pm^{0.09}_{0.10} (\text{fit.}) \pm^{0.12}_{0.14} (\text{syst.})$$

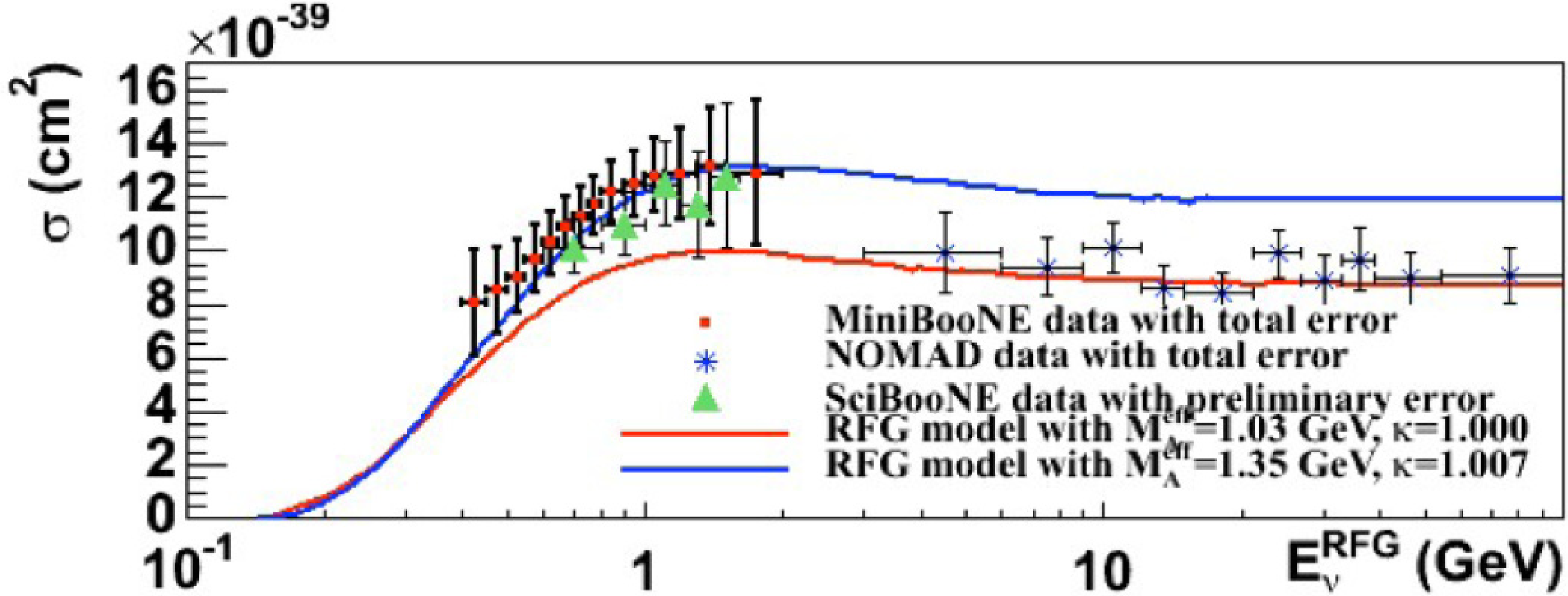
Shape fit ($Q^2 > 0.3\ (\text{GeV}/c)^2$)

$$M_A = 1.26 \pm^{0.12}_{0.10} (\text{fit.}) \pm^{0.08}_{0.12} (\text{syst.})$$



Quasi-elastic scattering

Also, the interaction rate (~ cross-section) seems to be larger for the experiments with larger M_A?



Somewhat inconsistent?

Quasi-elastic scattering ~ Theory ~

(M. Valverde)

More careful treatments of nuclear effects is essential

~ Beyond the simple Fermi-gas model ~

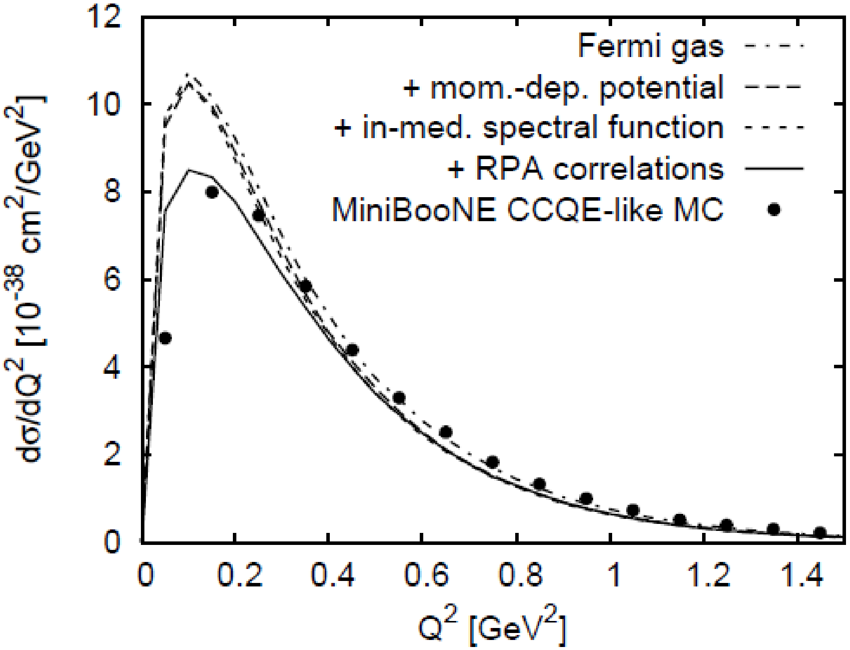
- Pauli blocking
  - Fermi Gas
- Fermi motion
  - Fermi Gas
- Correlations in excited states
  - RPA
- Nucleon binding
  - Nucleon spectral functions (hole states)
- Final State Interactions
  - Nucleon spectral functions (particle states)
- Nucleon rescattering
  - MonteCarlo cascade models
  - GiBUU

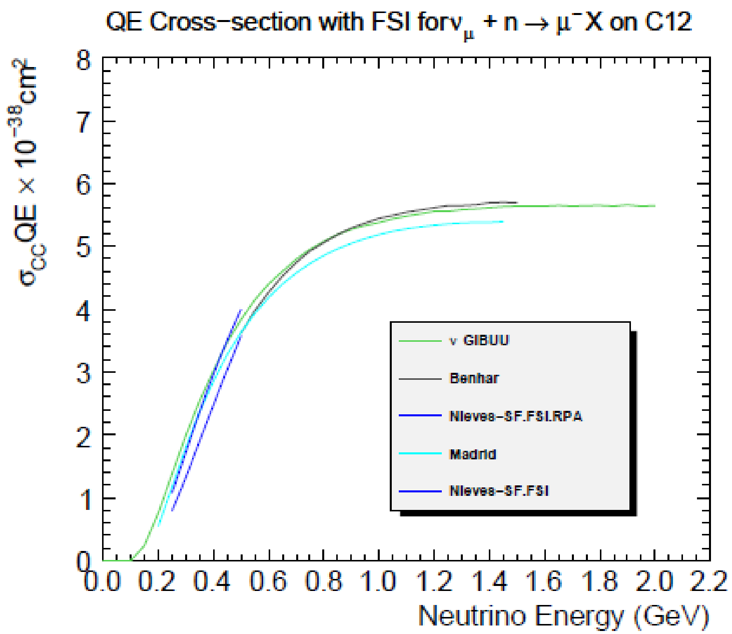
Quasi-elastic scattering ~ Theory ~

(M. Valverde)

RPA is important effect for MiniBoone

Models including spectral functions seem consistent





- Qualitative agreement on which nuclear effects are relevant ... and how they affect cross sections
- Quantitative agreement between different theoretical models (specially differential cross sections) not so good

Quasi-elastic scattering

To resolve the existing inconsistencies,

- **Need more careful analyses (of existing data)**

  Need to understand background in the CCQE measurements.
  Need to know (estimate) the flux correctly.

- **Need data from 1 GeV to several GeV for various material.**

  → ***MINERvA***

- **Need another experiments**

  → ***T2K-Near detectors (Scintillator + TPC)***
  Lq. Ar TPCs (ArgoNeut, MicroBooNE)

Another important thing (for the future experiment)

Measurement of the anti-neutrino cross-sections

Another type of difficulties

- Final state nucleon is neutral (neutron)
  Identification is more difficult.
- Usual beam contains fair amount of neutrinos
  in the anti-neutrino beam.

→ ***Correct understanding of neutrino cross-section is essential.***

Single pion productions

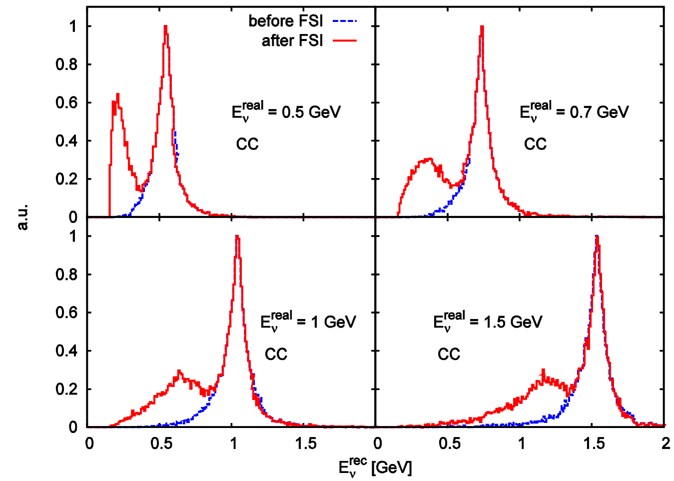
In the θ_{13} measurement experiments

- Background to search for the ν_e appearance signal.

In the Δm_{23} & θ_{23} precise measurement experiments

- Bias in the energy estimation
  using the charged current quasi-elastic scattering.
- Background in the number of events estimation (energy bin)
  using the charged current quasi-elastic scattering.

Possible bias in the energy reconstruction
(U. Mosel)



→ Important to understand this interaction.

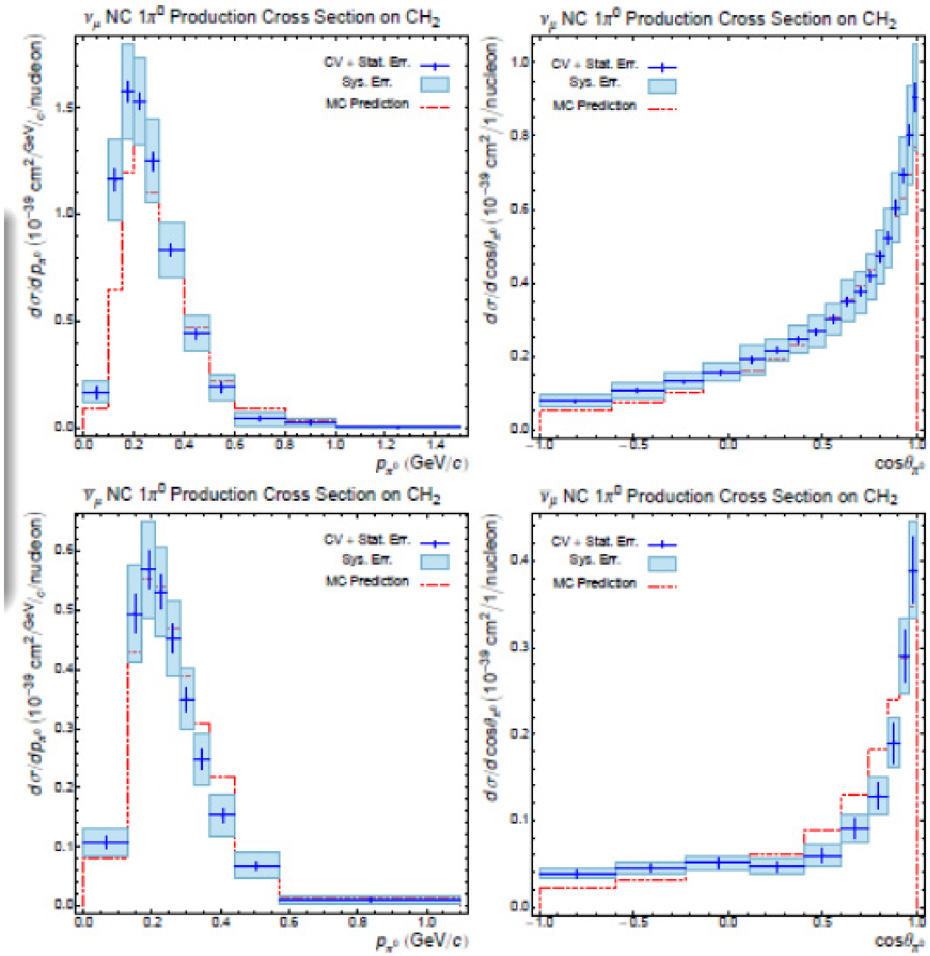
Single pion productions ~ experiments ~ (J. Catala)

MiniBooNE NC π^0 production

Signal definition:
Neutral Current events with a π^0 exiting from the target nucleus and no other mesons.

Event selection similar to K2K 1KT one.

First absolute differential xsec measured for NC-pi0 production using neutrinos and antineutrinos.



C. Anderson - NuInt09

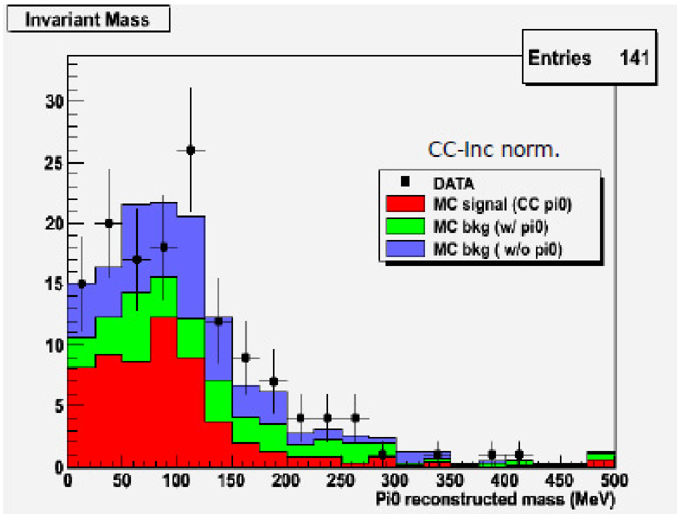
$$\nu - induced\ \sigma = (4.54 \pm 0.04_{stat.} \pm 0.71_{sys}) \times 10^{-40}\, cm^2 / nucleon$$

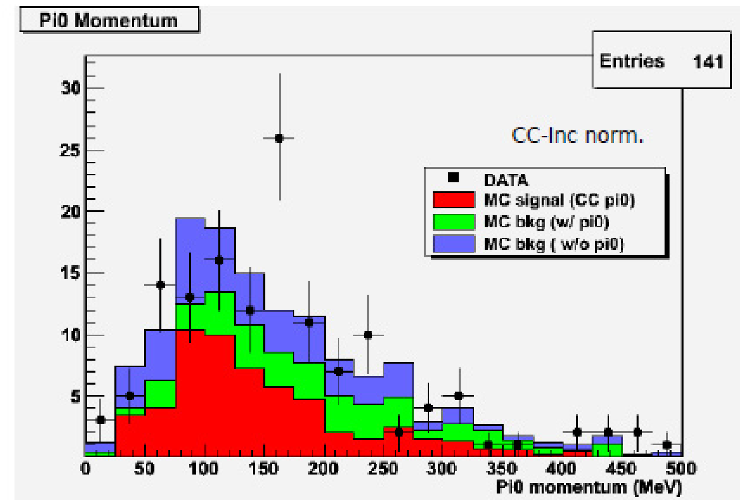
$$\bar{\nu} - induced\ \sigma = (1.43 \pm 0.03_{stat.} \pm 0.23_{sys}) \times 10^{-40}\, cm^2 / nucleon$$

Single pion productions ~ experiments ~ (J. Catala)

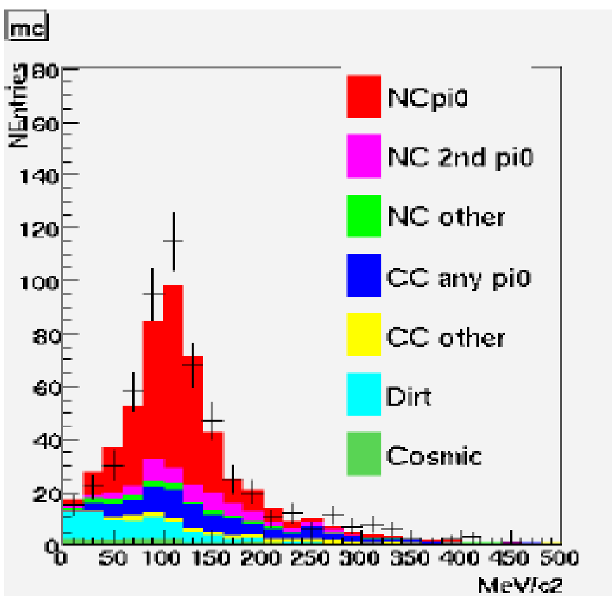
SciBooNE CC & NC π^0 production ~ Analysis is ongoing

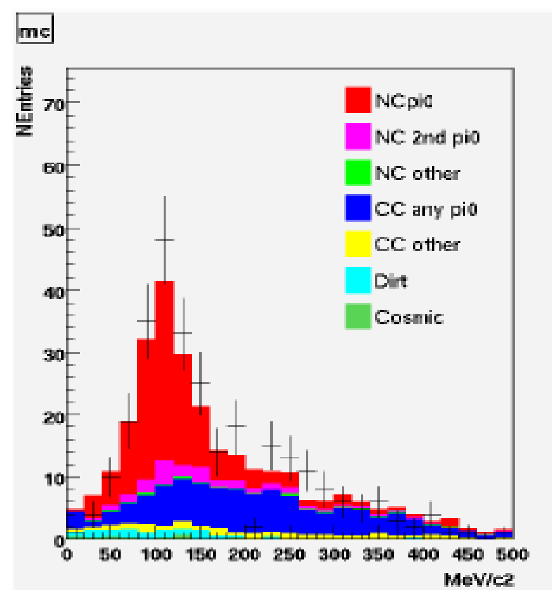
CC





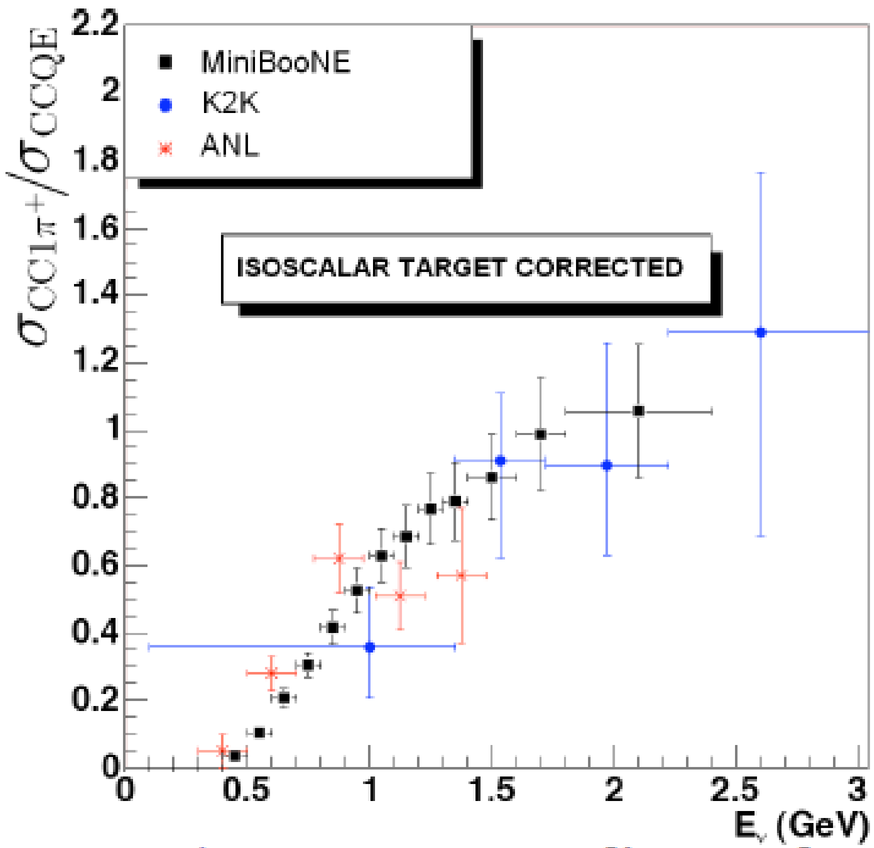
NC





Single pion productions ~ experiments ~ (J. Catala)

CC π^+ cross-sections ANL, K2K and MiniBooNE



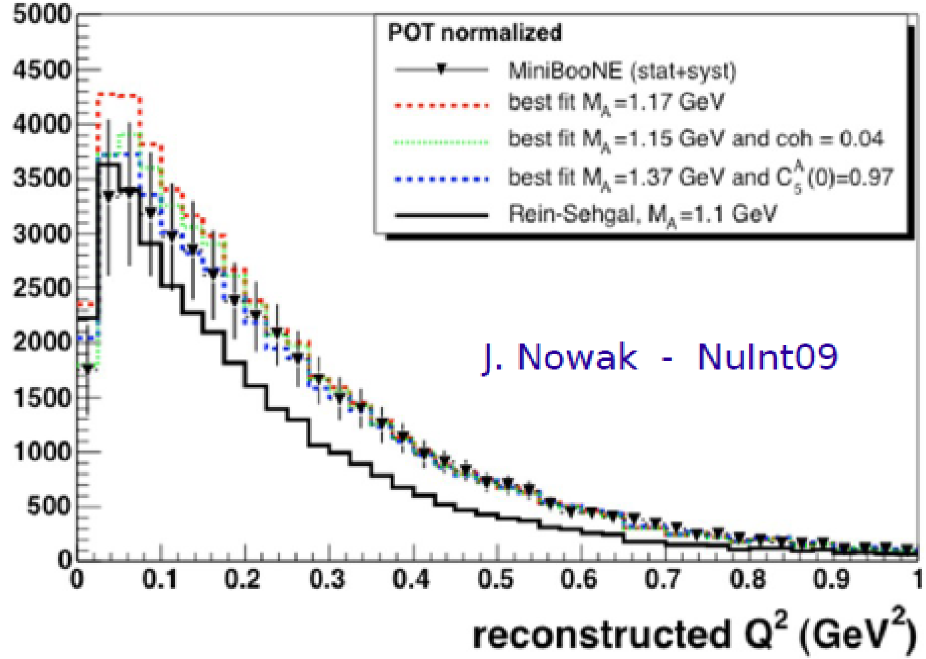
arXiv:0904.3159v1 [hep-ex]

CC π^+ Q^2 distribution from MiniBooNE

MiniBooNE gives rather large M_A

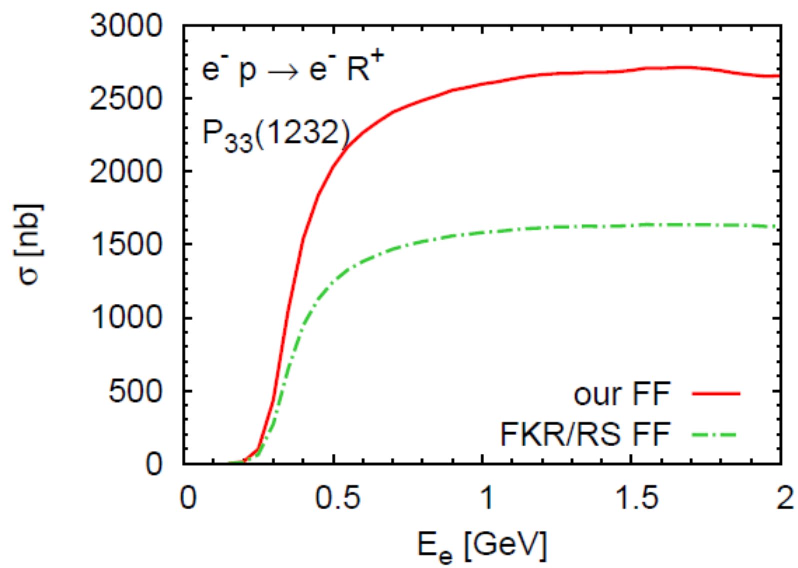
$M_A^{1\pi}$ for Q^2>0.2GeV

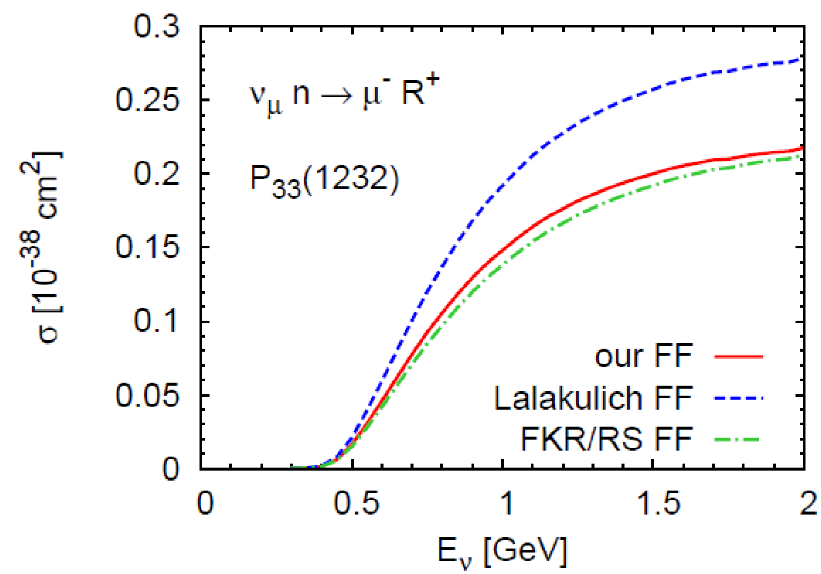
- $M_A^{1\pi} = 1.17 \pm 0.13$ GeV



Single pion productions ~ Theoretical ~ (U. Mosel)

Take look at the presentation by U.Mosel
Instructive for the experimentalists.





Rein-Segal formfactors bad in vector sector,
but reasonable in neutrino X-sect
➔ Fortunate cancellation of vector and axial contribs

We (experimentalists) need to use more appropriate models.

(U. Mosel)

Medium modifications

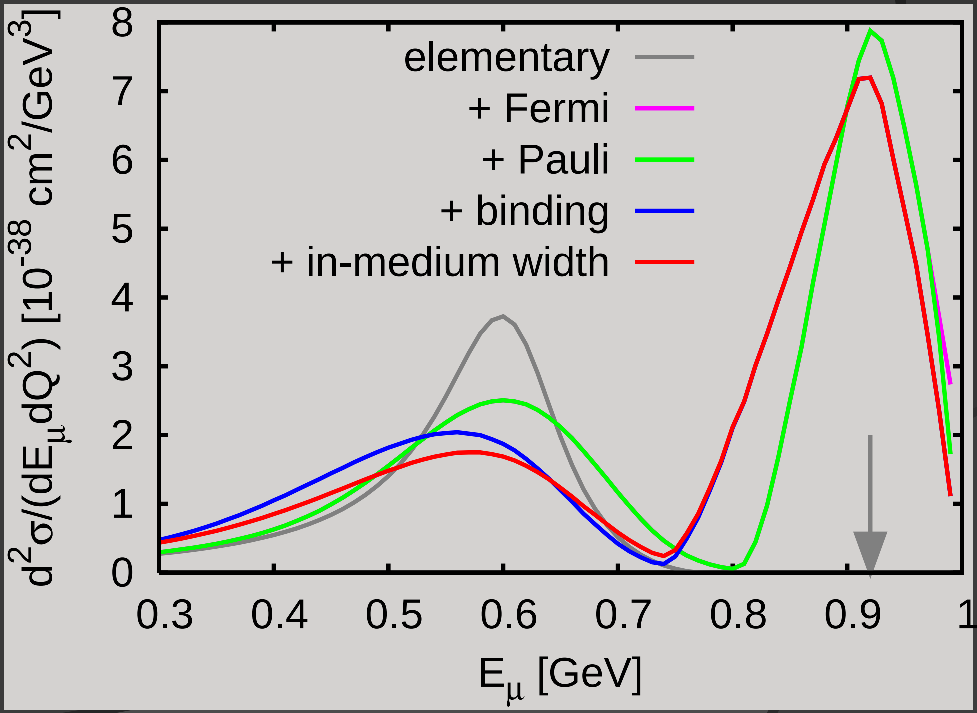
- All cross sections Fermi smeared
- Δ cross section is further modified in the nuclear medium:
  - π decay might be Pauli blocked: decrease of the free width $\Gamma \to \Gamma_P$
  - additional "decay" channels in the medium: collisional width Γ_{coll}

$\Delta N \to NN$
$\Delta NN \to NNN$
"pion-less decay"
$\Delta N \to \pi NN$
$\Delta N \to \Delta N$

overall effect:
increase of width

$\Gamma \to \Gamma^{med} = \Gamma_P + \Gamma_{coll}$

collisional broadening



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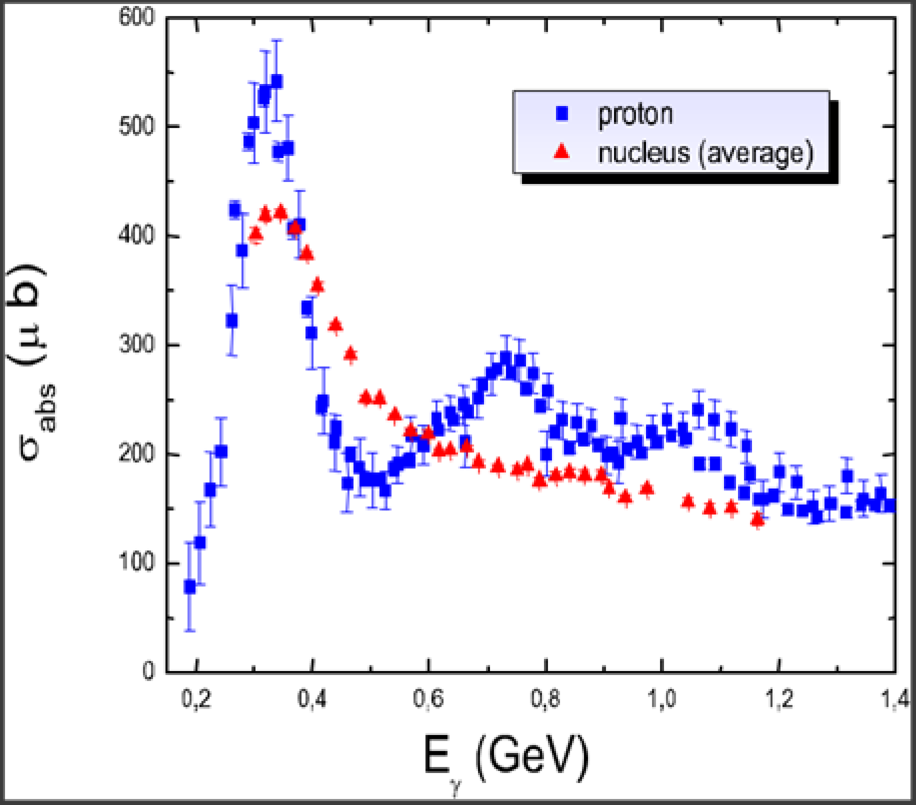
(U. Mosel)

Higher Resonances

Photoabsorption X-section



- Δ nearly unchanged
- 2nd resonances vanish
- 3rd resonances vanish

3rd resonance region disappears by Fermi-motion

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Coherent pion productions

Initially, the K2K experiment gives smaller cross-section
for the charged current coherent π production
compared to the original Rein-Sehgal model.

→ Correcting the model to apply low energy region,
there seems to be a solution.

- Wait for the anti-nu data from SciBooNE
  together with detailed analysis of neutrino data.
- Another precise measurements from MINERvA.

As for the neutral current cross-section,
we need to check the “new” models
using the MiniBooNE data.

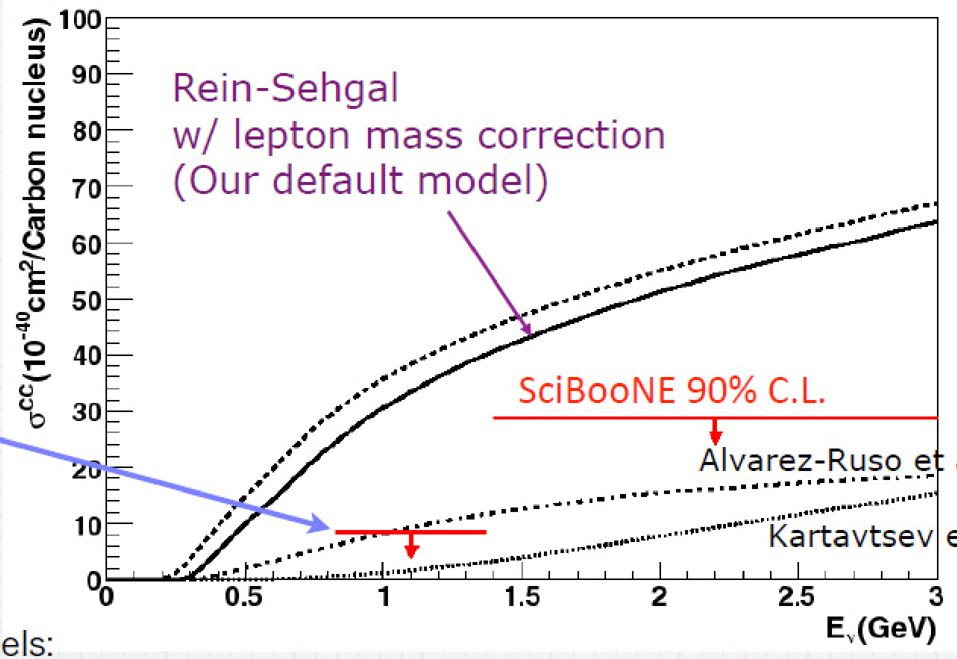
(Their data indicates the existing of enhancement
in the forward going π^0.)

Of course,
correct understanding of resonance production is required.

Coherent pion productions ~ Experiments ~

(H.Tanaka)

Upper limit on cross section



Upper limit: 33% of the prediction

Measured upper limits on $\sigma(\text{CC coherent } \pi)/\sigma(\text{CC})$ ratios are converted to upper limits on absolute cross sections by using $\sigma(\text{CC})$ predicted by MC simulation.

New coherent π models:

- Singh et al., Phys Rev. Lett. 96:241801 (2006).
- Paschos and Kartavtsev, Phys. Rev D74:054007 (2006).
- Alvarez-Ruso et al., Phys. Rev C75:05501 (2007).
- Nakamura et al. arXiv:0901.2366
- Hernandez et al. Phys. ReV D76, 033005 (2007), D79, 013002 (2009)
- ...

Recently proposed CC coherent π models predict production of CC coherent π events just below our upper limit.

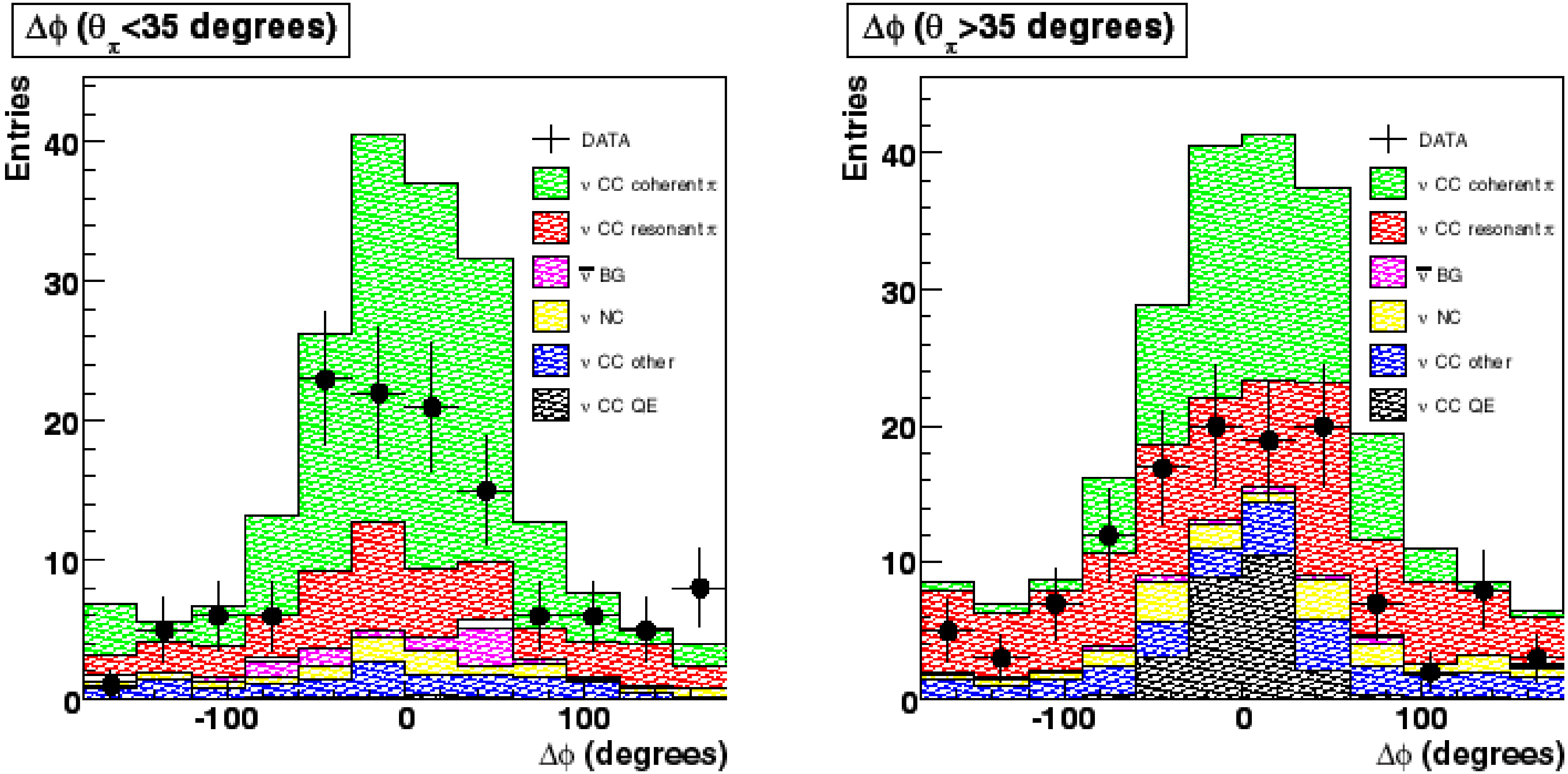
➜ Search for $\bar{\nu}$ CC coherent pion production, since $\bar{\nu}$ data is expected to be more sensitive to look at CC coherent π production than ν data.

Coherent pion productions ~ Experiments ~

(H.Tanaka)

Further analysis in SciBooNE

Some excess in the forward going pion?



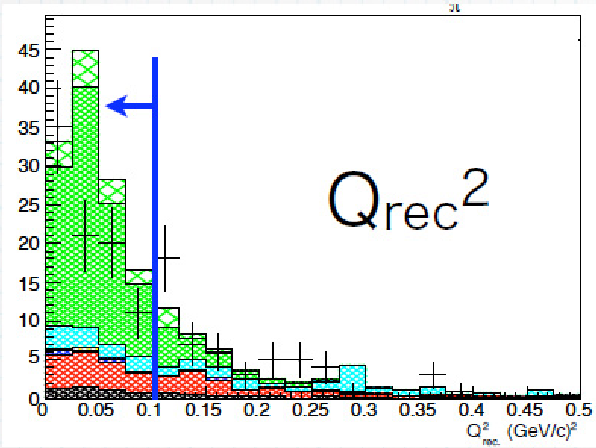
(K. Hiraide @ NuINT09)

Coherent pion productions ~ Experiments ~

(H.Tanaka)

$\bar{\nu}$ CC coherent π

$\bar{\nu}$ coh-π, θπ < 35°



Preliminary & stat. error only

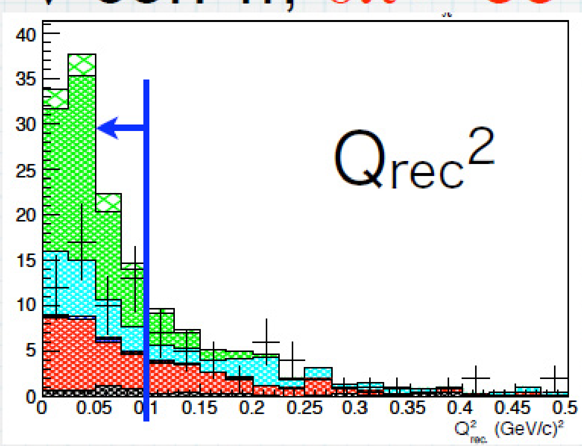
Signal region: $Q^2<0.1$

- 87 events observed
- 31 non-coherent π events (BG)

➜ Data - BG: 56±11 (stat)

NEUT (R&S) prediction: 92 ($\nu+\bar{\nu}$)

$\bar{\nu}$ coh-π, θπ > 35°



Signal region: $Q^2<0.1$

- 52 events observed
- 49 non-coherent π events (BG)

➜ Data - BG: 2.6±8.5 (stat)

NEUT (R&S) prediction: 59 ($\nu+\bar{\nu}$)

CC coherent π component at small θ_π region.

Coherent pion productions ~ Experiments ~

(H.Tanaka)

More NC-π^0 from MiniBooNE

C.E. Anderson at NuInt09

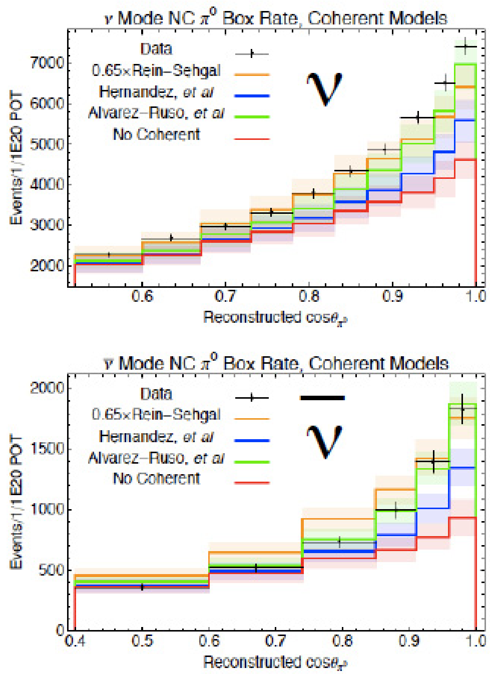
Coherent Production Models

- Models for NC coherent π^0 production demonstrate wide variabilities in their predictions
- Forward angular distribution (particularly for antineutrino mode) is very sensitive to predictions
- MiniBooNE uses the Rein–Sehgal[a] prediction scaled by 0.65 by default in MC; also incorporated predictions from Hernandez, *et al*[b], and Alvarez-Ruso, *et al*[c]

[a] Nucl. Phys. **B223**, 29, (1983)

[b] arXiv:0903.5285v1; thanks to Juan Nieves for predictions

[c] Phys. Rev. C **76**, 068501 (2007); thanks to Luis Alvarez-Ruso for predictions

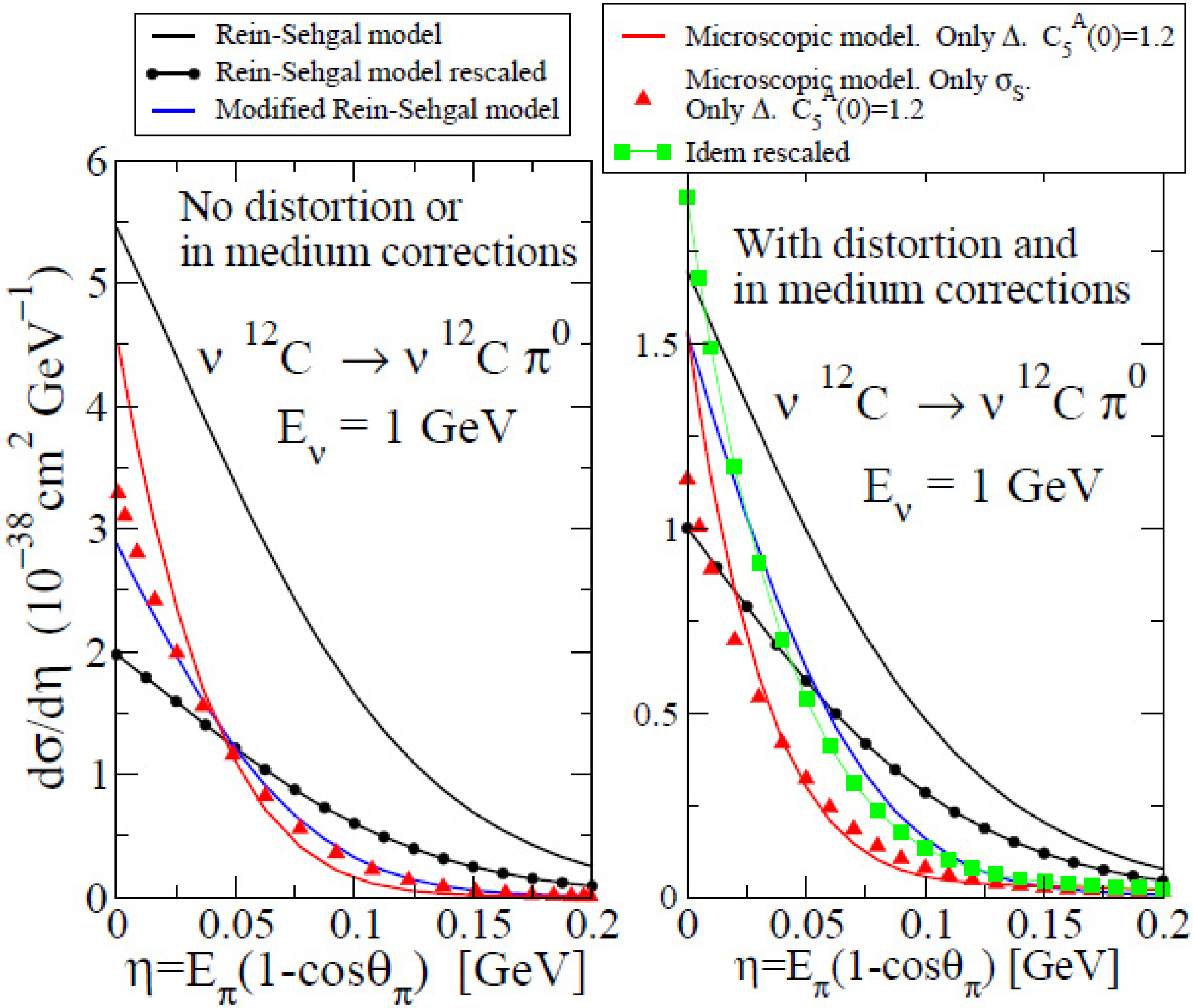


- New NC-π^0 results for both ν and $\bar{\nu}$ beam modes.
- Demonstrated comparison between data and models
- ν and $\bar{\nu}$ data suggest:
  - Clear evidence of non-zero NC coh-π
  - Forward angular distribution is sensitive to model predictions

NOTE: MC distributions are absolutely normalized

Coherent pion productions ~ Theory ~

(E. Hernandez)

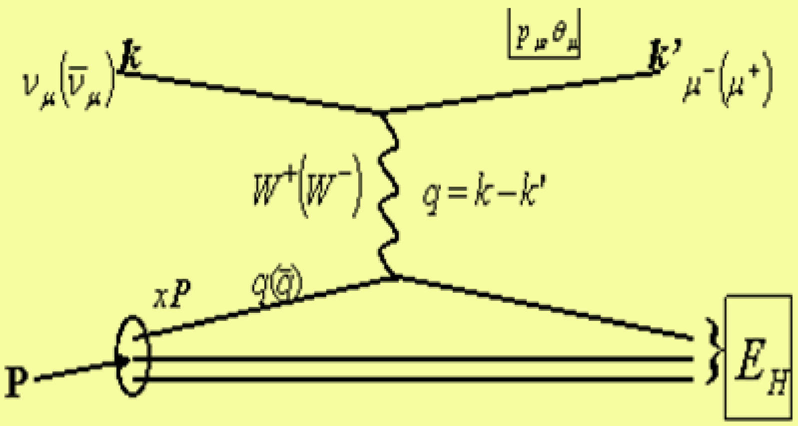


Recent models / corrected model seems to have better agreement with data in the directional distribution

Deep inelastic scattering

Neutrino DIS

(M. Tzanov)



$$Q^2 = 4E_\nu E_\mu \sin^2\frac{\theta}{2},$$ Squared 4-momentum transferred to hadronic system

$$x = \frac{Q^2}{2ME_{HAD}},$$ Fraction of momentum carried by the struck quark

$$y = \frac{\nu}{E_\nu} = \frac{E_{HAD}}{E_\nu},$$ Inelasticity

Differential cross section in terms of structure functions:

$$\frac{1}{E_\nu}\frac{d^2\sigma^{\nu(\bar{\nu})}}{dxdy} = \frac{G_F^2 M}{\pi\left(1+Q^2/M_W^2\right)^2}\left[\left(1-y-\frac{Mxy}{2E_\nu}+\frac{y^2}{2}\frac{1+4M^2x^2/Q^2}{1+R(x,Q^2)}\right)F_2^{\nu(\bar{\nu})} \pm \left(y-\frac{y^2}{2}\right)xF_3^{\nu(\bar{\nu})}\right]$$

Structure Functions in terms of parton distributions

$$F_2^{\nu(\bar{\nu})N} = \sum\left[xq^{\nu(\bar{\nu})N}(x) + x\bar{q}^{\nu(\bar{\nu})N}(x) + 2xk^{\nu(\bar{\nu})N}(x)\right],$$

$$xF_3^{\nu(\bar{\nu})N} = \sum\left[xq^{\nu(\bar{\nu})N}(x) - x\bar{q}^{\nu(\bar{\nu})N}(x)\right] = x\left(d_V(x)+u_V(x)\right) \pm 2x\left(s(x)-c(x)\right),$$ **ν-scattering only**

$$R = \frac{\sigma_L}{\sigma_T}$$

Rather well understood compared to the other interactions. (at least to me)

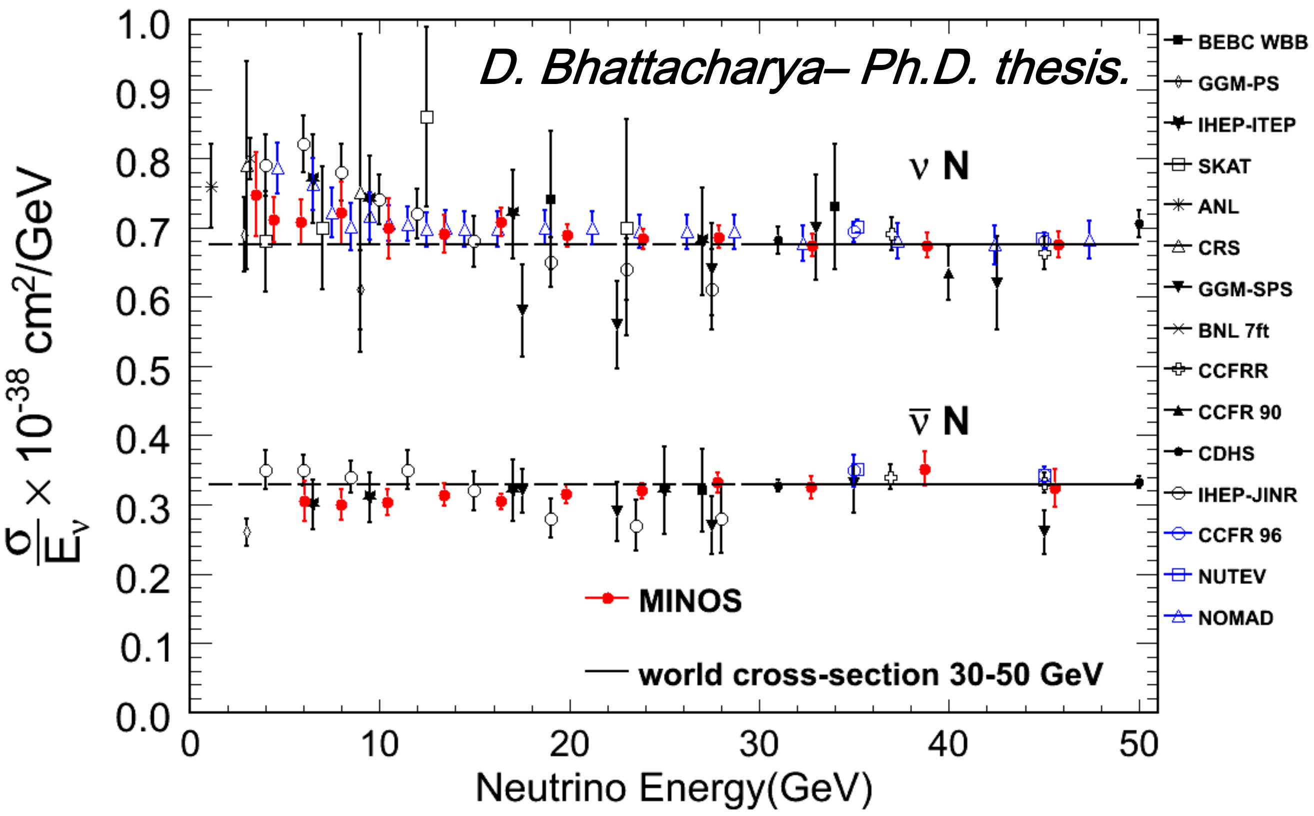
Deep inelastic scattering

(M. Tzanov)

- Several high stat. & high precision measurements

NuTeV, NOMAD, CHORUS, MINOS

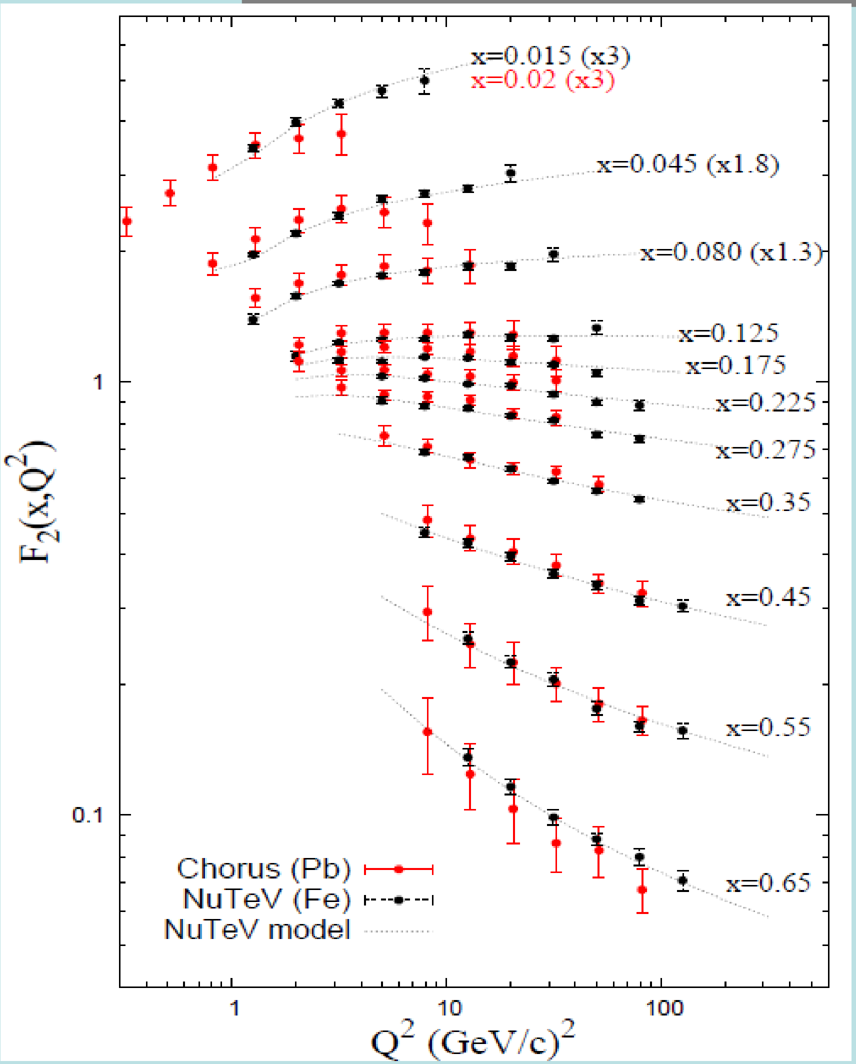
NuTeV & MINOS	: **<u>Fe</u>**
NOMAD	: **<u>C</u>**, Al, Fe
CHORUS	: **<u>Pb</u>**, Fe, Ca, C

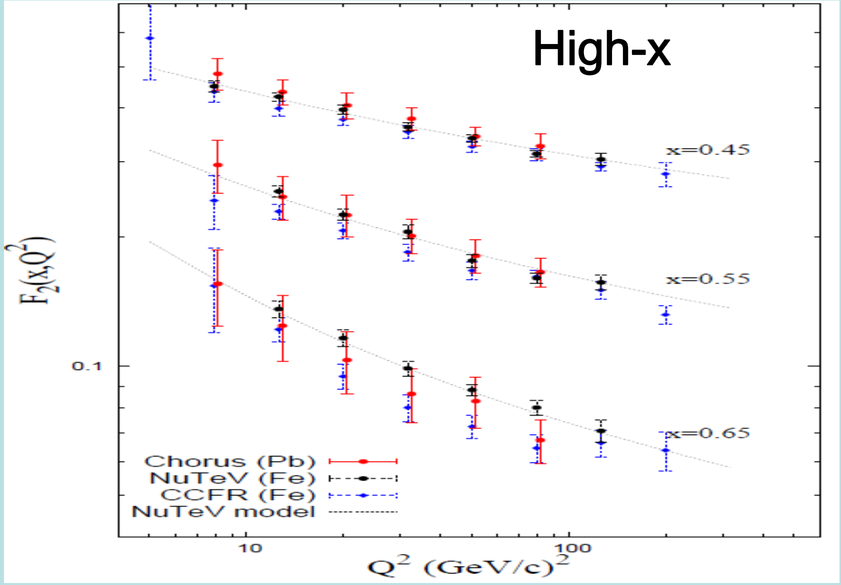


Deep inelastic scattering

(M. Tzanov)

CHORUS, NuTeV and CCFR Comparison





D. Naples – NuInt07

- not as precise,
- agrees well with NuTeV over the whole range,
- hint of a different Q^2 shape at low-x

- assuming nuclear corrections similar for Fe and Pb.

(J. Morfin)

How do Neutrino Scattering Results Influence Parton Distribution Function Fits?

Summary

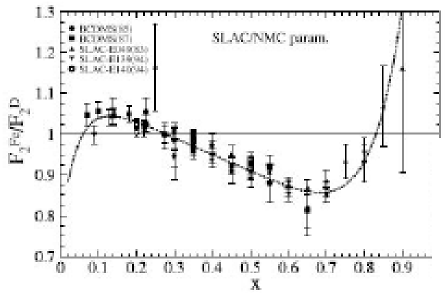
- **Neutrino scattering could be a powerful tool to determine PDFs particularly the strange and high-x valence quarks**
- $(\bar{d} - \bar{u}) / (\bar{d} + \bar{u})$ reasonably constrained out to $x \approx 0.4$.
- $\kappa = (s + \bar{s}) / (\bar{u} + \bar{d})$ seems to be increasing with x.
- $(s - \bar{s}) / (s + \bar{s})$ and heavy quarks need further clarification.
- The valence u-quark is reasonable out to $x = 0.5$, while the d-quark uncertainty blows up around $x = 0.3$.
- d/u at high-x still uncertain due to spread in deuteron correction.
- There is a serious need for new input to global QCD fits at HIGH X
- **The Cleanest Way To Measure d/u: ν + p Scattering**
- **UNKNOWN nuclear corrections in neutrino scattering are keeping the special abilities of neutrinos out of global fits for PDFs**

Deep inelastic scattering (J. Morfin)

How do Neutrino Scattering Results Influence Parton Distribution Function Fits?

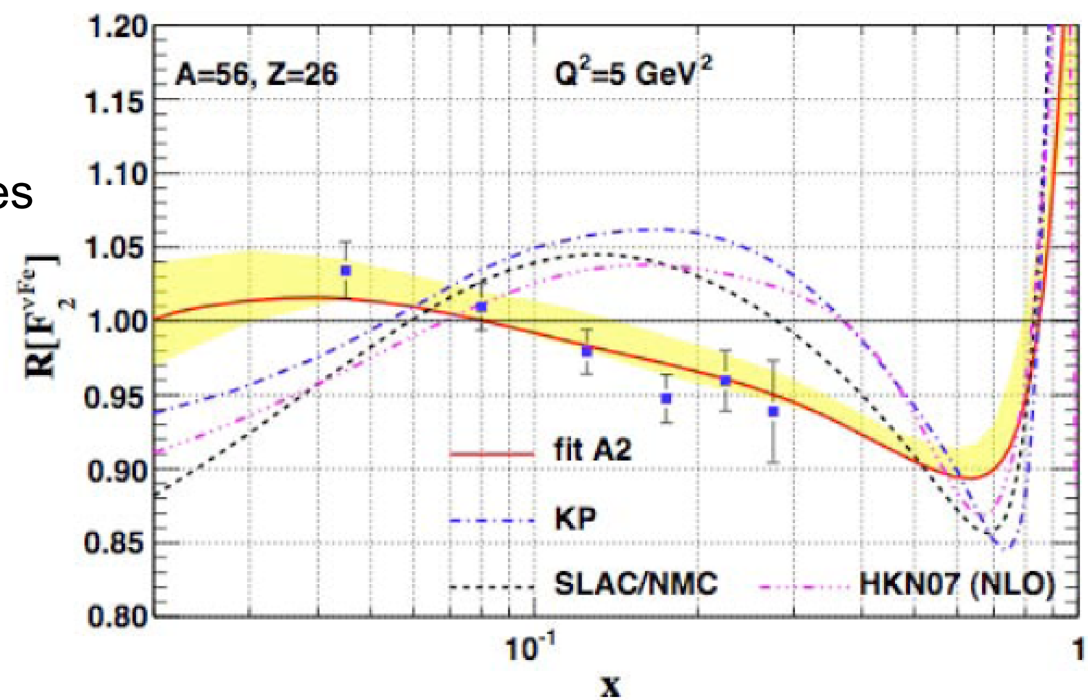
F_2 Structure Function Ratios: NuTeV ν-Iron

See NuFact08 Proceedings for Details



I. Schienbein, J-Y. Yu, C. Keppel, J.G.M., F. Olness, J.F.Owens

Estimated nuclear effects differences
μ/e-A vs ν-A



Deep inelastic scattering ~ duality

(A. Bodek)

There have been some difficulties in handling the transition region from resonance to safe DIS.

Fit existing charged lepton scattering data and obtain correction factors for the neutrino scattering.

Bodek -Yang Effective LO PDF model - 2003

(A. Bodek)

Seems to work well.

1. Start with GRV98 LO (Q^2_{min}=0.80 GeV^2)
   - dashed line- describe F2 data at high Q^2
2. Replace the Xbj with a new scaling, ξ_w
3. Multiply all PDFs by K factors for photo prod. limit and higher twist
   $[\sigma(\gamma) = 4\pi\alpha/Q^2 * F_2(x, Q^2)]$
   $Ksea = Q^2/[Q^2+Csea]$
   $Kval = [1- G_D{}^2 (Q^2)] * [Q^2+C2V] / [Q^2+C1V]$ motivated by Adler Sum rule
   where $G_D{}^2 (Q^2) = 1/ [1+Q^2 / 0.71]^4$
4. Freeze the evolution at $Q^2 = Q^2_{min}$
   - $F_2(x, Q^2 < 0.8) = K(Q^2) * F_2(Xw, Q^2=0.8)$

➢ Fit to all DIS F2 P/D (with low x HERA data)
A=0.418, B=0.222

Csea = 0.381, C1V = 0.604, C2V= 0.485
χ^2/DOF = 1268 / 1200 Solid Line

Fit only precise charged lepton scattering data.
No neutrino data and No Resonance data included in the fit.

2004 update:
Separate K factors for uv, dv,us,ds

A : initial binding/TM effect+ higher order
B : final state mass m_f^2, Δm^2,
K Factor: Photo-prod limit (Q^2 =0), Adler sum rule

$$\xi_w = \frac{Q^2+m_f^2+O(m_f^2-m_i^2)+A}{M\nu\,(1+(1+Q^2/\nu^2))^{1/2}+B}$$

$Xbj = Q^2 / 2M\nu$

Summary and Discussions

- We updated our Effective LO model with ξw and K(Q2) factors.
- (1) Updated to include a low nu K factor to describe all charged lepton inelastic continuum as well as resonance data including photo-production data. The vector part of the neutrino cross section is now modeled very well. Note: By Gauge Invariance, the vector structure functions must go to zero at Q2=0 for both resonances and inelastic continuum.
- (2) Updated to account for the difference in the higher order QCD corrections between F2 and XF3. This is accounted for with a H(x) factor Therefore, the axial part is also well described for Q2>1 GeV2, where axial and vector are expected to be the same
- (3) Updated to use K_axial (Q^2)=1 for both the resonance and inelastic continuum region. This is expected since we know that neutrino quasielastic and resonance production form factor are not zero at Q2=0.
- The lowest Q2 bins in the neutrino and antineutrino measured differential cross sections favor K_axial (Q^2)=1 . Needs to be studied in more detail
- The total cross section as measured in high energy neutrino scattering favors K_axial (Q^2)=1 .

Quark- Hadron Duality

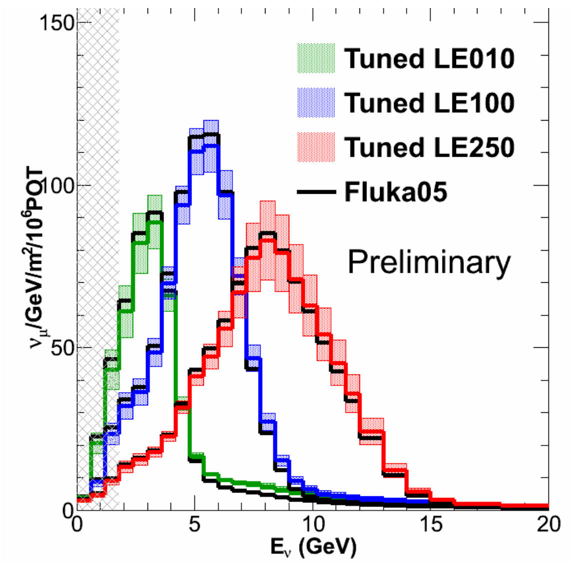
(Krzysztof M. Graczyk)

Summary from his slide:

- the Bloom-Gilman duality is confirmed experimentally for the electron scattering off nucleon and nucleus
  - BG duality is violated below $Q^2=0.3$ GeV^2
- BG duality can help to fine tune the magnitude of **nonresonant** contribution
- **Neutrino-nucleon**
  - **phenomenological models suggest appearance of the duality in neutrino scattering off deuteron-like target**
  - **for *charged current* and *neutral current* structure functions with W < 1.6/1.8 GeV**
    - **xF1 and xF3 (with 1σ level of accuracy), for the F2 (with 2σ level of accuracy)**
    - **violation below Q^2=0.3 GeV**
    - **the experimental verification is required (waiting for Minerνa measurements)**
- **duality in neutrino scattering off nucleus waits for more comprehensive studies**

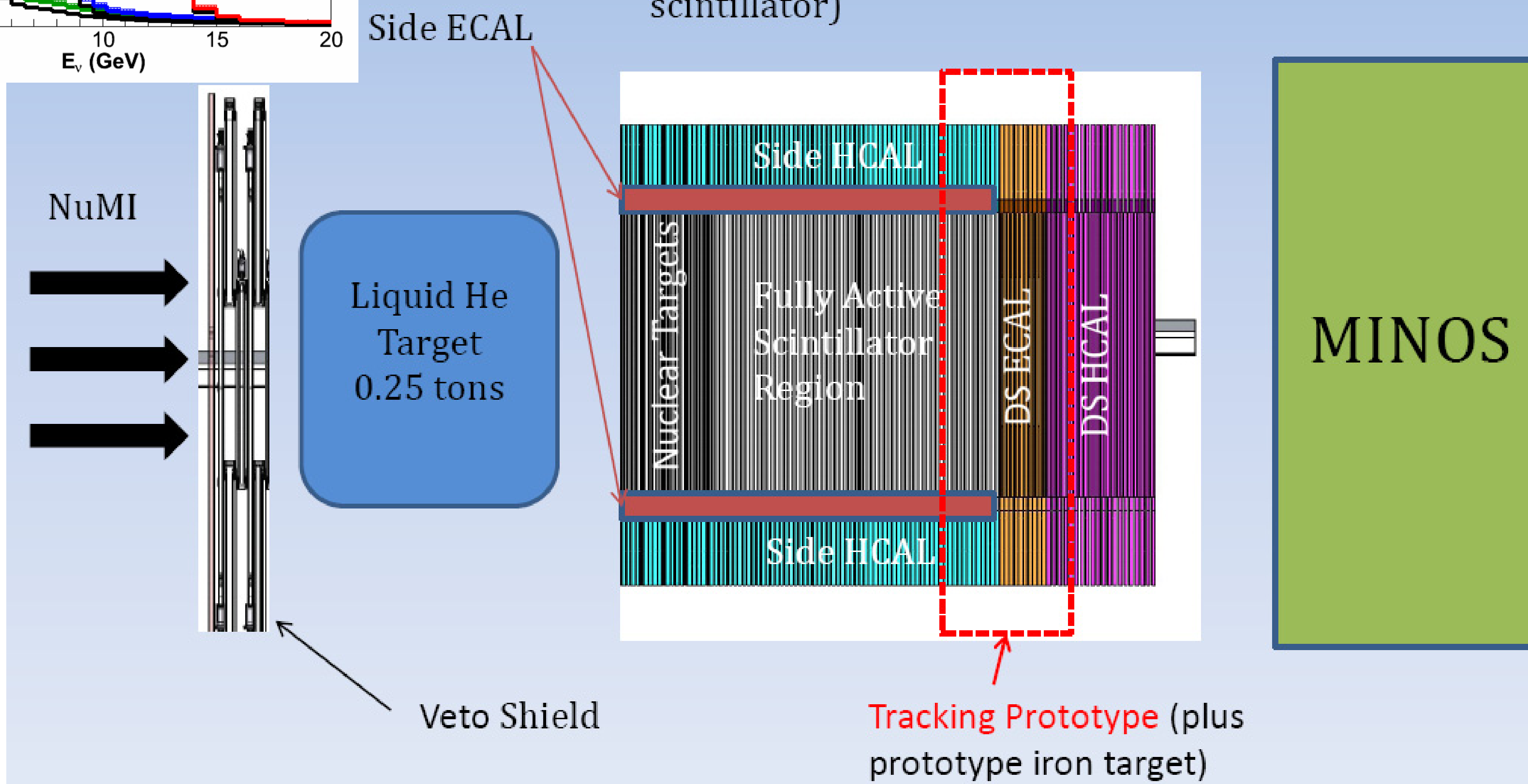
MINERνA

(B. Eberly)



Use MINOS beamline to measure cross-sections with various target material

- Scintillator Region: 8.3 tons (~3 tons fiducial)
- Solid Nuclear Target Region: 6.2 tons (40% scintillator)

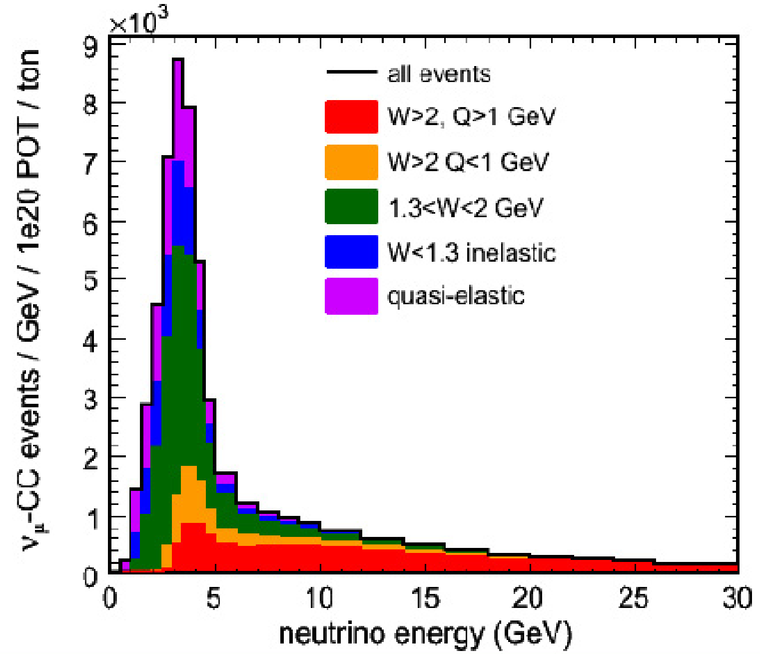


MINERνA

(B. Eberly)

- If assume a standard run:
  - 4×10^{20} POT LE
  - 12×10^{20} POT ME
- Results in ~14 million CC events
  - ~9 million on scintillator
  - ~5 million on nuclear targets

CC Process Type (on scint.)	Number of Events
Quasi-elastic	0.8M
Resonance Production	1.7M
Res-DIS Transition Region	2.1M
DIS Low Q2 & Structure Functions	4.3M
Coherent Pion	89k CC, 44k NC
Charm/Strange	230k



Nuclear Target	Number of Events
He	0.6M
C	0.4M
Fe	2.0M
Pb	2.5M

Aiming to reduce cross-section uncertainties

QE	5%	DIS	5%
Resonance	5% (CC) / 10% (NC)	Coherent	20%

ArgoNeuT

(M. Antonello)

Lq. Ar detector in the MINOS beamline

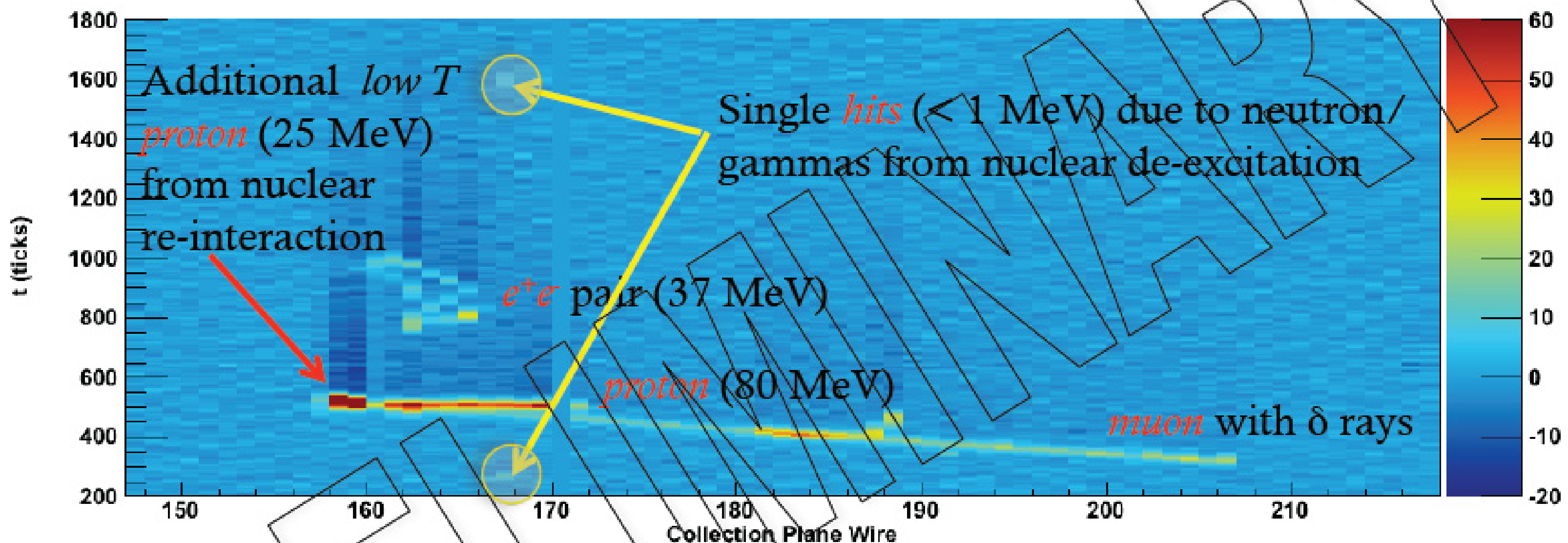
170 L active volume (~235kg)

- ArgoNeuT will address some of the hardware and physics R&D issues on the way toward massive LAr TPC detectors (MicroBooNE, LAr20 etc..) in terms of:
  - Argon purity, electronics, detector design and construction, etc.
  - Development of MC Simulation and off line reconstruction
- Demonstrate **particle ID** capabilities of LArTPCs with **dE/dx and Range** measurements
- Physics:
  - Study CC and NC neutrino events in the "few GeV range" in LAr
  - Precise CC QE ν_μ cross section measurement in Argon

Already in operation!

Event Type	# of events in 180 days (1.4×10^{20} POT) – ν mode	# of events in 180 days (1.4×10^{20} POT) – anti-ν mode
ν_μCC	19337	6109
anti-ν_μCC	1692	5490
ν_eCC	362	118
NC	6526	4015
Total	27917	15732

ArgoNeuT: Reconstructed CC ν Event



This event reconstruction is still preliminary.

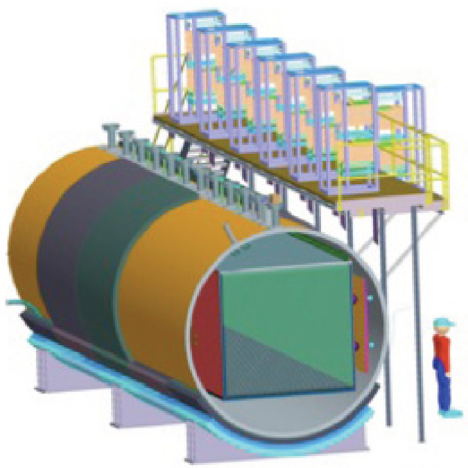
A full and detailed MC simulation including nuclear effects is required for validation. A preliminary FLUKA MC simulation support the possibility to detect such nuclear effects in LAr TPC.

MicroBooNE

(M. Antonello)

MicroBooNE

- MicroBooNE is a proposed LArTPC detector to run in the on-axis Booster and off-axis NuMI beam on the surface at Fermilab.
- MicroBooNE intend to combine hardware R&D with a relevant physics program in the way toward massive LAr TPC detectors.
- Hardware goals:
  - Cold electronics
  - Long Drift (high level purity required)
  - Purity through detector purging with GAr before filling (without evacuating)
- Physics goals
  - Investigate the MiniBooNE low energy excess
  - Measure low energy Cross-section
- Software goals:
  - Develop automated 3D and calorimetric reconstruction and Particle ID



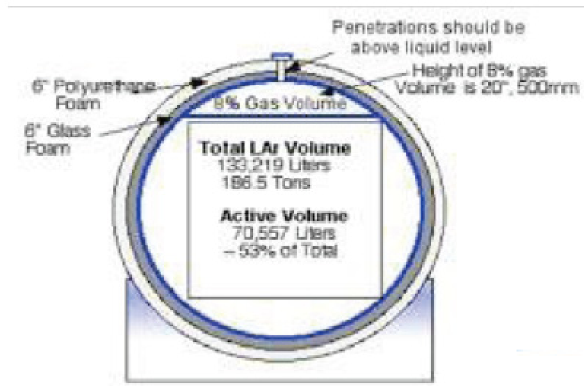
Jun 2008 → Fermilab Directorate Stage I approval
NSF MRI and DOE funded

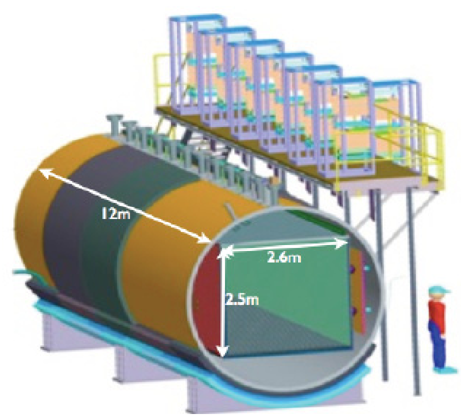
MicroBooNE

(M. Antonello)

MicroBooNE Design

- Cryostat (170 Tons LAr) as large as can be built commercially and trucked to site; Single wall, mechanically insulated (glass and polyurethane foam)
- TPC parameters:
  - 100 (70) Tons active (fiducial) volume
  - 2.6 m drift @ 500V/cm → 1.6ms drift time
  - ~10.000 channels (using cold preamplifier)
  - 3 Readout planes (±60° Induction, vertical Collection planes)
- ~30 PMT for triggering;
- Purification/Recirculation system





Total request

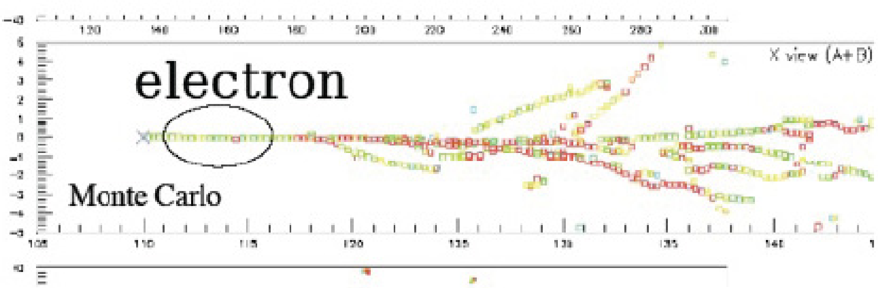
	BNB	NuMI
POT	$6\mathrm{x}10^{20}$	$8\mathrm{x}10^{20}$
ν_μ CCQE	68k	25k
NC π^0	8k	3k
ν_e CCQE	0.4k	1.2k
Total	145k	60k

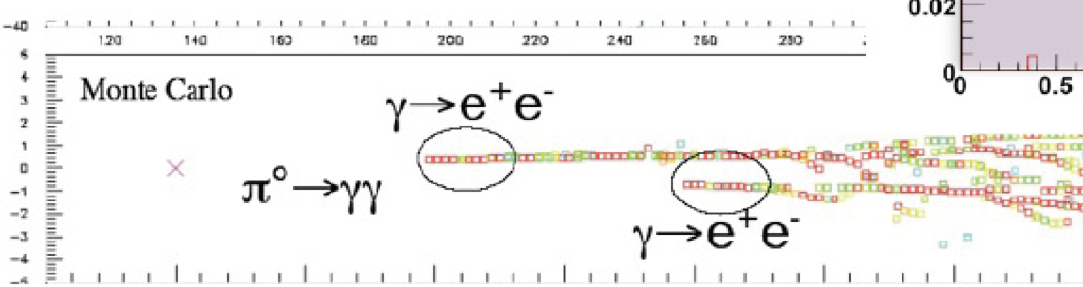
MicroBooNE

(M. Antonello)

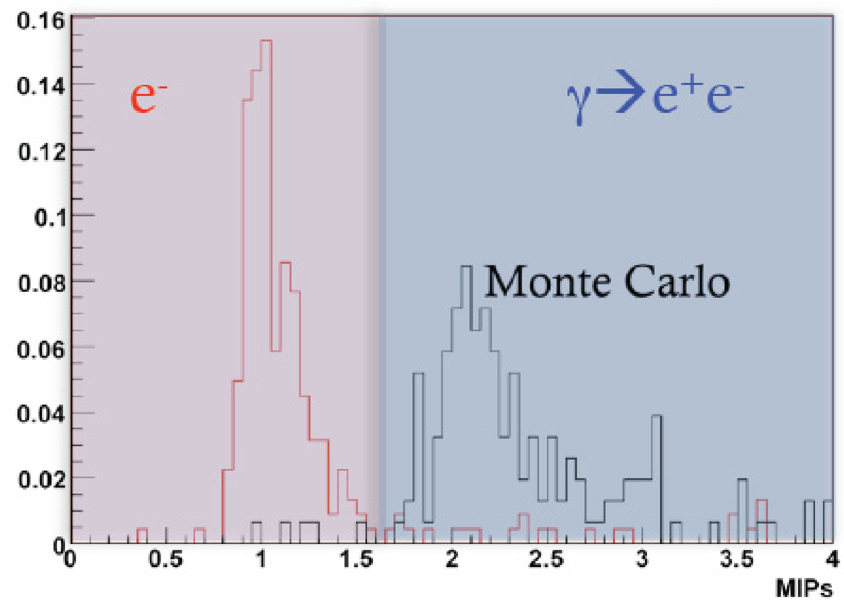
LAr TPC e/$\pi^0(\gamma\gamma)$ separation

- LAr TPC can separate e/gamma through topological analysis and calorimetric measurement of the first cm of track (1mip for e , 2 mip's for gamma) (MC→efficiency>90%)
- This allows to reject BG events like $\nu_\mu NC\pi^0$ from signal (ν_e CC)
- → very important for $\nu_\mu \rightarrow \nu_e$ oscillation experiments





1GeV e⁻'s vs 1GeV γ's



M.Antonello LNGS

Importance of the neutrino scattering experiments

(Vassili Papavassiliou)

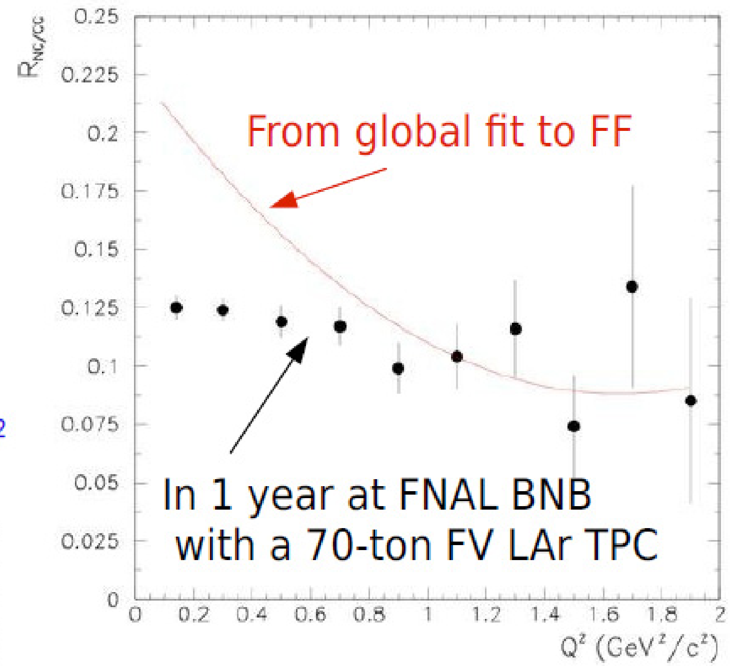
Measuring Δ*s* in Elastic ν*N* Scattering in Liquid Ar

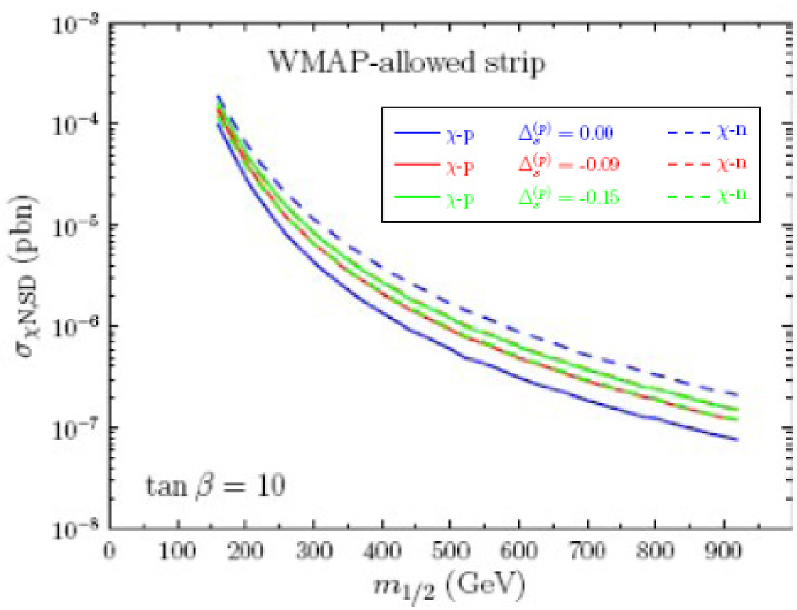
$$R_{NC/CC} \equiv \sigma(\nu p \to \nu p) / \sigma(\nu n \to \mu^- p)$$

Numerator sensitive to Δ*s*

- Contribution to proton spin from strange quarks
- From DIS: Δ*s* = −0.09±0.03
  - Indirect measurement
  - Some model uncertainty

Requires measurement at very low Q^2





Uncertainty affects direct searches for supersymmetric cold dark matter

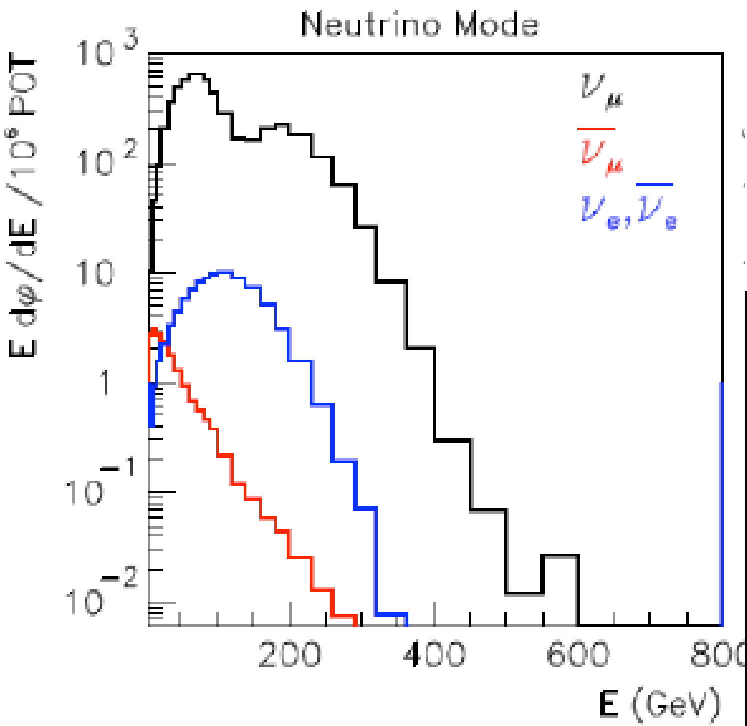
Neutralino-nucleon elastic-scattering cross section very sensitive to Δ*s*

Will affect choice of detector material

NuSOnG

(J. Conrad)

High energy neutrino beam
to study new physics
and for the high precision measurements.



Process	Rate	Physics
$\nu_\mu + e^- \rightarrow \mu^- + \nu_e$ [IMD] $\bar{\nu}_\mu + e^- \rightarrow \mu^- + \bar{\nu}_e$	700k 0	normalization, "WSIMD", non-standard interactions
$\nu_\mu + e^- \rightarrow \nu_\mu + e^-$ [ES] $\bar{\nu}_\mu + e^- \rightarrow \bar{\nu}_\mu + e^-$	75k 7k	new "heavy" physics (Z', ν mixing with heavy singlets), new "light" physics, modified couplings, $\sin^2\theta_w$, ρ, R-parity, extended Higgs
$\nu_\mu + q \rightarrow \nu_\mu + X$ [DIS] $\bar{\nu}_\mu + q \rightarrow \bar{\nu}_\mu + X$ $\nu_\mu + q \rightarrow \mu^- + X$ $\bar{\nu}_\mu + q \rightarrow \mu^+ + X$	190M 12M 600M 33M	ν-q non-standard interactions, $\sin^2\theta_w$, ΔxF_3, F_2, isospin violation, heavy quarks, nuclear effects
decays in low density decay regions	*60??*	new long-lived heavy neutral particles

NuSOnG

(J. Conrad)

What makes NuSOnG special?

1) We have an accurate flux measurement! (via IMD events)
2) We have an enormous number of DIS events!

Method: Pick an x and Q^2 bin
Plot the data as a function of y
Vary the structure functions to get the same y-distribution

$$\frac{d^2\sigma^{\nu(\overline{\nu})N}}{dxdy} = \frac{G_F^2 M E_\nu}{\pi\left(1+Q^2/M_W^2\right)^2}\left[F_2^{\nu(\overline{\nu})N}(x,Q^2)\left(\frac{y^2+(2Mxy/Q)^2}{2+2R_L^{\nu(\overline{\nu})N}(x,Q^2)}+1-y-\frac{Mxy}{2E_\nu}\right)\pm xF_3^{\nu(\overline{\nu})N}y\left(1-\frac{y}{2}\right)\right]$$

Bin-by-bin, minimize:

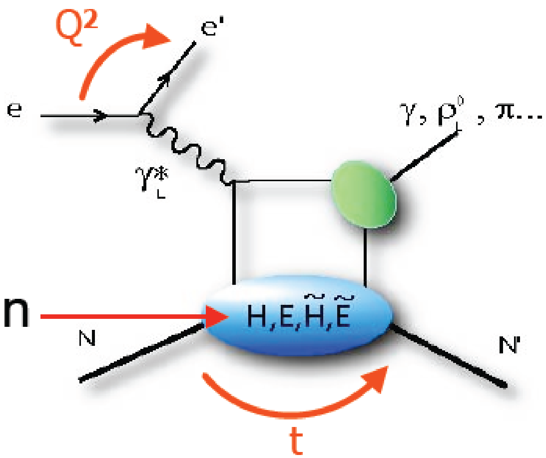
$$\chi^2 = \sum_{\nu,\overline{\nu}}\sum_{y-\mathrm{bins}}\frac{\left(N_{data}^{\nu(\overline{\nu})} - N_{MC,pred}^{\nu(\overline{\nu})}\left(SF_{fit}\right)\right)^2}{N_{data}^{\nu(\overline{\nu})}}$$

Deeply Virtual Neutrino Production of π^0 from Nucleon & Nuclear Targets

(G. Goldstein, S. Liuti)

Spin dependent GPDs upon insertion of T product into nucleon matrix elements

Chiral even



Spin dependence relates H,E to E.M.: $F_1(t)$, $F_2(t)$ & $f_1(x,Q^2)$, $g_1(x,Q^2)$
H_T to $h_1(x,Q^2)$

Chiral odd → $H_T, E_T, \tilde{H}_T, \tilde{E}_T$

Parity violating V-A coupling doubles the number of helicty amps from 6 to 12.

Neutrino (antineutrino) cross section

$$\frac{d^4\sigma}{d\Omega d\varepsilon_2 d\phi dt} = \Gamma\left\{\frac{d\sigma_T}{dt} + \varepsilon_L \frac{d\sigma_L}{dt} + \varepsilon\cos 2\phi \frac{d\sigma_{TT}}{dt} + \sqrt{2\varepsilon_L(\varepsilon+1)}\cos\phi \frac{d\sigma_{LT}}{dt}\right.$$

$$\left. \pm(\varepsilon \text{ factor})\sin\phi \frac{d\sigma_{L'T}}{dt} + (\varepsilon \text{ factor})\sin 2\phi \frac{d\sigma_{T'T}}{dt}\right\}$$

Measure ϕ dependence using $\nu N \to \mu^- \pi^+ N$

I’d like to thank all the speakers
and the participants in WG2.