

“Set the scene”

WG2: Neutrino cross-section

WG2 conveners:
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NUFACT 11, Aug 1-6 2011, Geneva

Neutrinos and interaction

- Neutrinos interact only through weak interaction
- Theory of weak interaction: WEAK established
- Electroweak theory: triumph of Standard Model

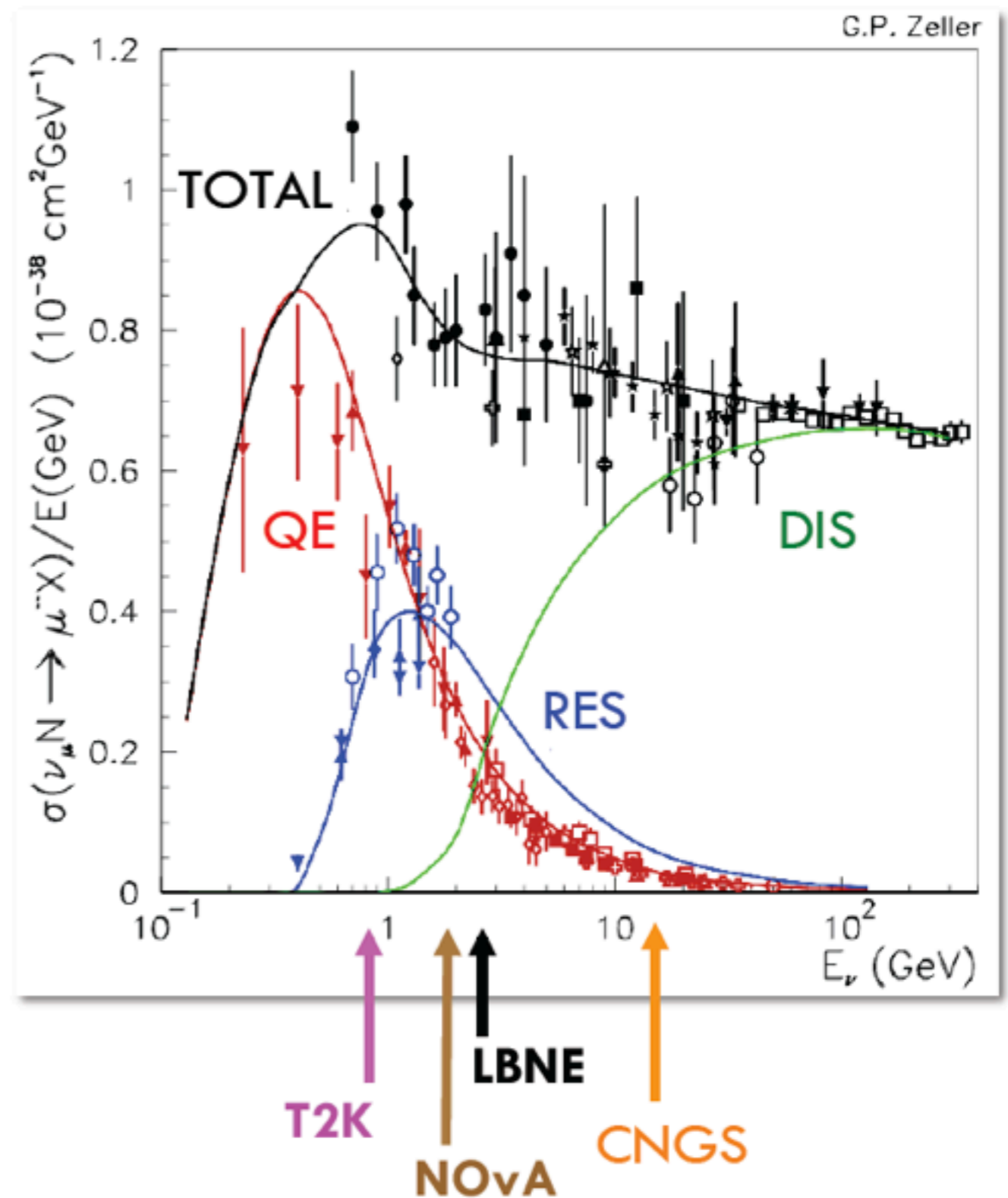
$$\mathcal{L}_N = eJ_\mu^{em} A^\mu + \frac{g}{\cos\theta_W} (J_\mu^3 - \sin^2\theta_W J_\mu^{em}) Z^\mu$$
$$\mathcal{L}_C = -\frac{g}{\sqrt{2}} \left[\bar{u}_i \gamma^\mu \frac{1-\gamma^5}{2} M_{ij}^{CKM} d_j + \bar{\nu}_i \gamma^\mu \frac{1-\gamma^5}{2} e_i \right] W_\mu^+ + h.c.$$

(from Wikipedia)

- Why need to worry?

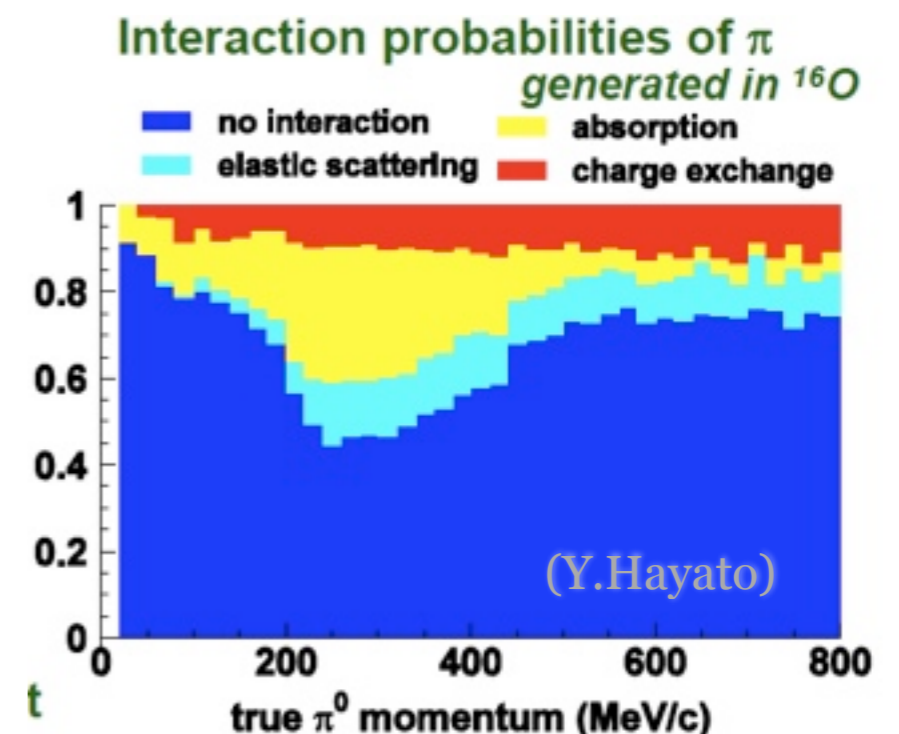
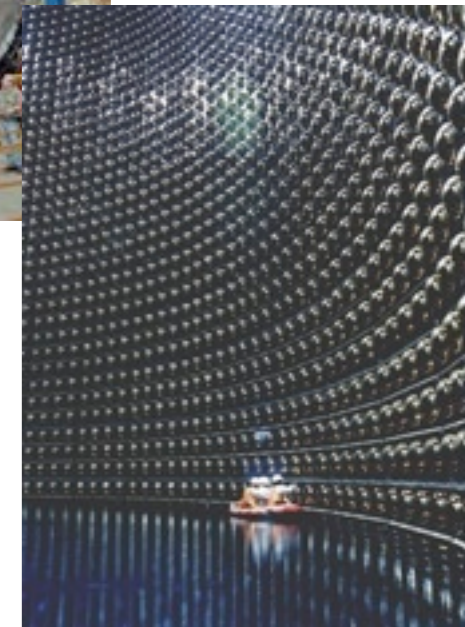
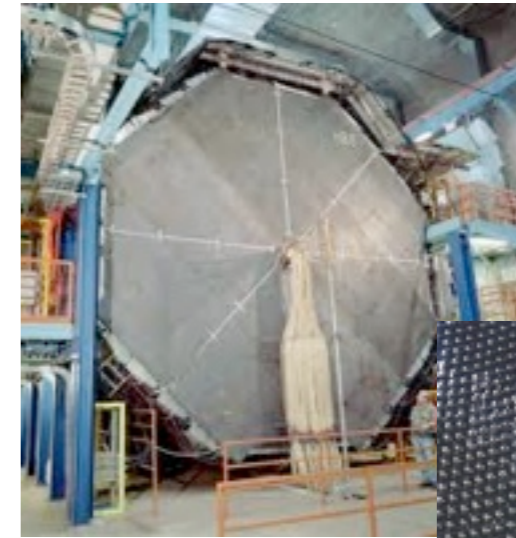
Why do we care ν cross section

- Motivated by neutrino oscillation experiments
- atmospheric and long baseline
- $\Delta m^2 \sim 10^{-3} \text{eV}^2$ with 100-1000km baseline
→ $E_\nu \sim \text{GeV}$
- ν -N interaction
- Contribution from multiple channels
- Limited knowledge from old experiments



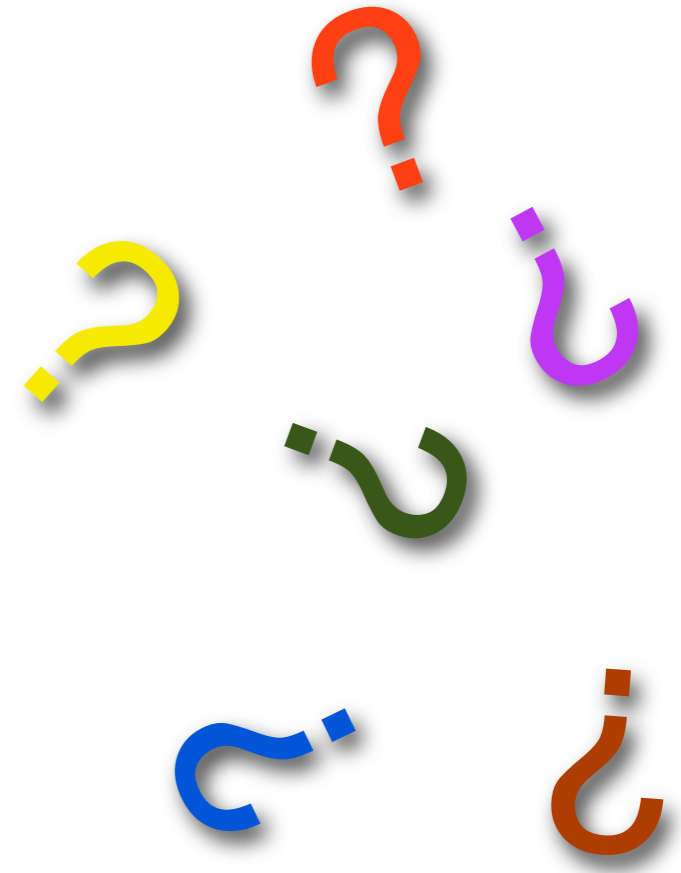
Why do we care V cross section

- Massive detector with *heavy* material
 - C, O, Ar, Fe, Pb, ... not H, D
- Interaction with bound nucleon
 - Modification to cross section
- FSI effect in nucleus
- Hadron interaction in nuclear matter



Uncertainties combo

- Neutrino flux / energy spectrum
 - Normalization
 - Energy dependence
- Nuclear effects
 - Cross-section modification
 - Migration between channels
- Limited detector acceptance / resolution



Experimentally not easy to untangle in many cases

Importance of neutrino interaction: an example

T2K first result on ν_e appearance

PRL 107, 041801 (2011)

Source	$\sin^2 2\theta_{13} = 0$	$\sin^2 2\theta_{13} = 0.1$
(1) neutrino flux	$\pm 8.5\%$	$\pm 8.5\%$
(2) near detector	$+5.6\%$ -5.2%	$+5.6\%$ -5.2%
(3) near det. statistics	$\pm 2.7\%$	$\pm 2.7\%$
(4) cross-section	$\pm 14.0\%$	$\pm 10.5\%$
(5) far detector	$\pm 14.7\%$	$\pm 9.4\%$
Total $\delta N_{SK}^{\text{exp}} / N_{SK}^{\text{exp}}$	$+22.8\%$ -22.7%	$+17.6\%$ -17.5%

- Need to reduce uncertainty
 - ← *better* knowledge of cross section
- Will continue to be true for future measurements
(anti-neutrino, ν_e vs ν_μ , and more ..)

Growth of field over past decade

- In situ measurement with oscillation expt's
 - K2K, MiniBooNE, NOMAD, MINOS, T2K, ..
- Dedicated experiments
 - SciBooNE, MINERvA, ArgoNeuT, ..
- Hadron production (reducing flux error)
 - HARP, MIPP, SHINE, ...
- Pion scattering (nuclear FSI) measurements
- Theoretical developments

Near detectors of LBL exp'ts



K2K-ND



@KEK



MINOS

@FNAL



T2K-ND

@J-PARC



SBL exp'ts



@CERN

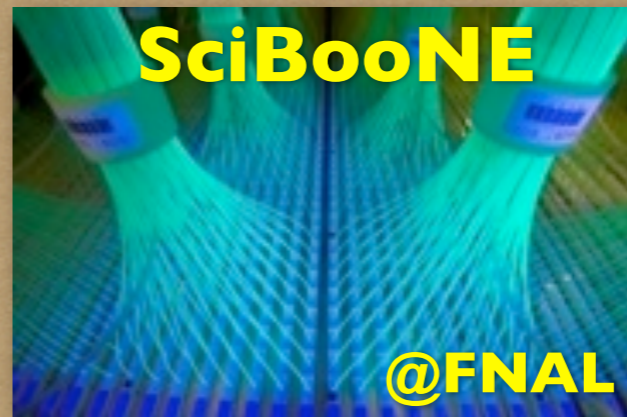
NOMAD



MiniBooNE

@FNAL

Dedicated exp'ts



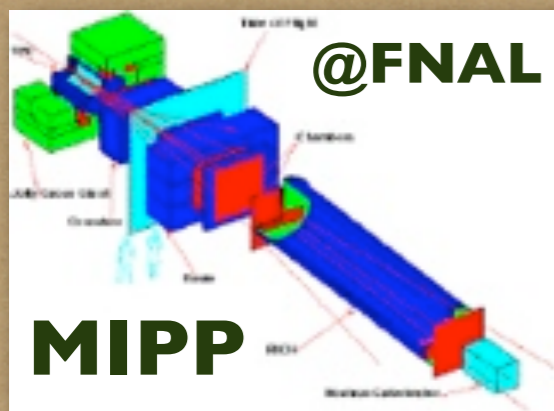
SciBooNE

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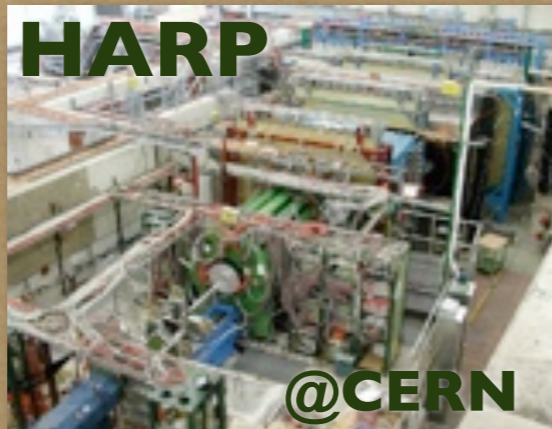
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MINERvA



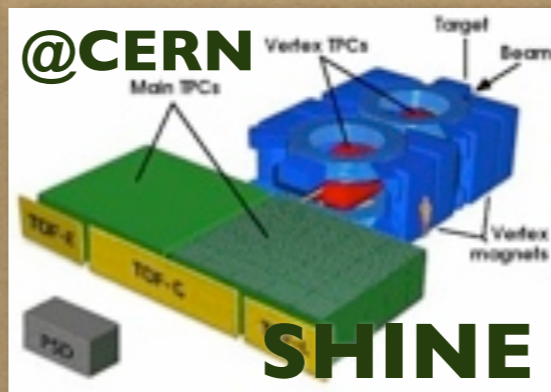
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MIPP



HARP

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SHINE

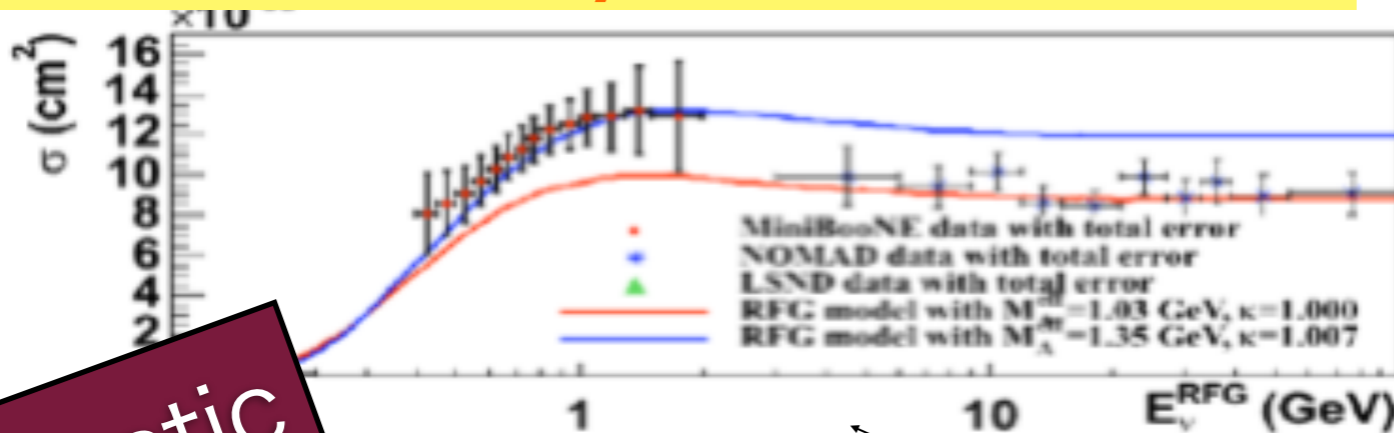


ArgoNeuT

@FNAL

Hadron production experiments

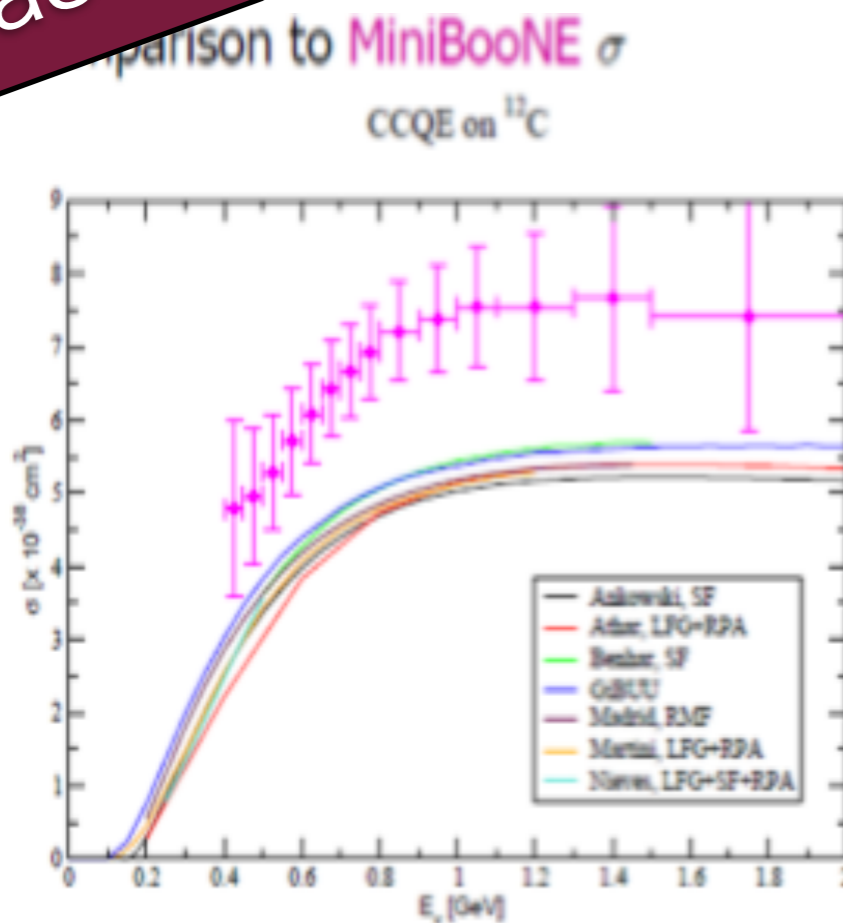
From WG2 summary @ NUFACT10



“Puzzles”

Quasi Elastic

Objectives for NuFACT11



We get $\frac{\sigma(\text{CCcoh}\pi^+)}{\sigma(\text{NCcoh}\pi^0)} \Big|_{0.8\text{GeV}} = 1.45 \pm 0.03$

to be compared with the value reported by the SciBooNE Collaboration [Y. Kurimoto et al., Phys. Rev. D 81,111102 (2010)]

$\frac{\sigma(\text{CCcoh}\pi^+)}{\sigma(\text{NCcoh}\pi^0)} \Big|_{\text{SciBooNE}} = 0.14^{+0.30}_{-0.2}$

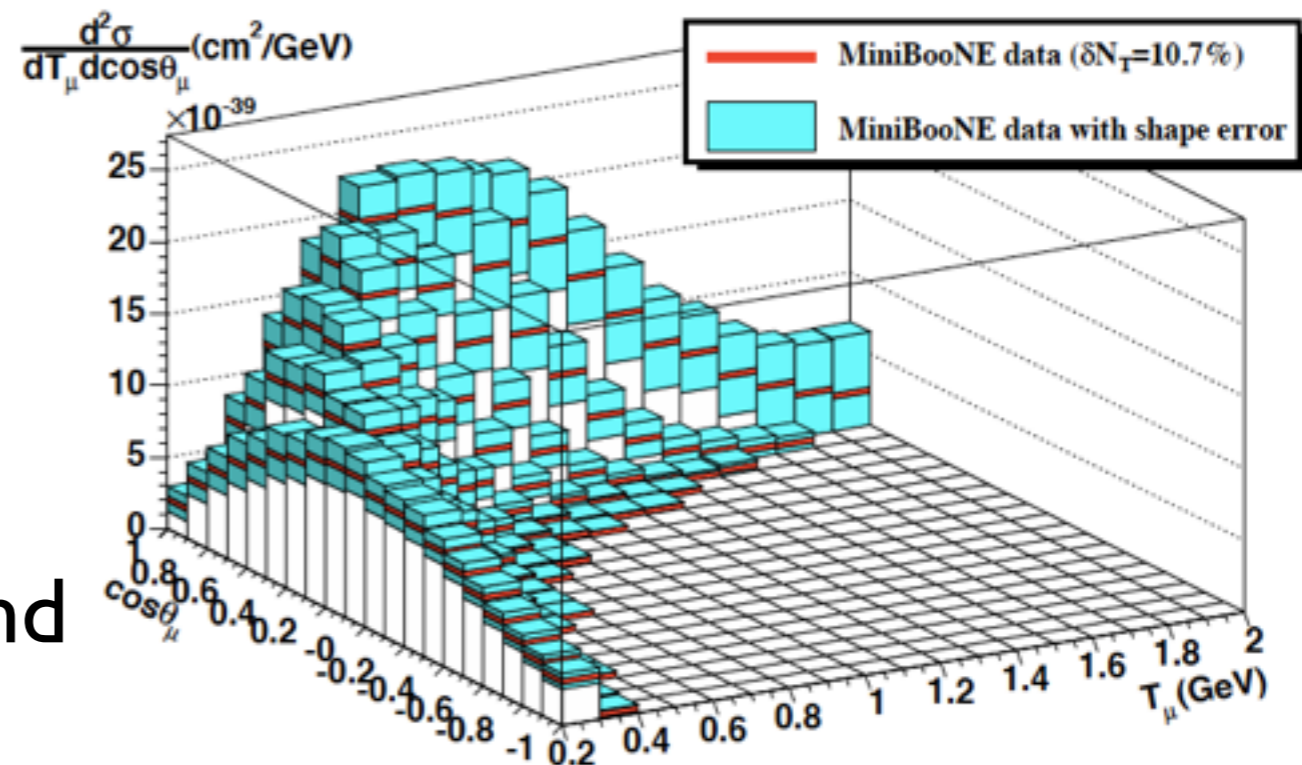
A huge factor of 10 discrepancy!

Coherent π

- It's much more complex than we thought..
- We learned a lot, but at the same time many questions have been raised.

What do we need to go further?

- Need a joint effort of
 - Experimentalist and theorist
 - Particle physics and nuclear physicists
- Recently growing consensus from close discussion: model independent (as much as possible) presentation of data
 - Example: MiniBooNE double differential cross section (observed muon kinematics).
- NuFact WG2 is one of central forums to exchange new info and ideas for further progress!



WG2 program

- Latest results from experiments
 - **New** for this year:
MINERvA, T2K, ArgoNEUT
- Latest theoretical developments
- Interaction simulation
- Flux determination
- Detector technology (joint with WG1)

+ Plenary talks on Thursday morning

Looking forward to lively discussion during sessions!

- Session #1 (Mon 14:00-)
 - MiniBooNE cross-section results
 - SciBooNE
- Session #2 (Tue 13:30-)
 - M_A from MiniBooNE CCQE double differential cross section data
 - The role of 2p2h in CCQE
 - Electron vs Neutrino-Nucleus Scattering
 - Axial and Vector Structure Functions for Lepton-Nucleon Scattering

- Session #3 (Wed 11:00-)
 - CC and NC coherent pi production
 - NuWro: Monte Carlo generator of neutrino interactions
 - Monte Carlo generators: NEUT and GENIE
- Session #4 (Wed 14:00-)
 - Measurement of π -N interaction: PIAvO-Harpsichord
 - Performance of T2K Near Detectors
 - MINERvA reconstruction & performance

- Session #5 (Thu 11:00-)
 - Neutrino interaction measurements using T2K Near Detectors
 - MINERvA Elastic Scattering
 - MINERvA CC inclusive & nuclear target
- Session #6 (Thu 14:00-)
 - NA61: pion production cross-sections and plans
 - NA61: Strange particle production
 - NA61: Long target results
 - FLUKA: hadron production simulation
 - Predicting neutrino flux for T2K
 - NuMI (MINERvA) flux prediction

- Session #7 (Fri 13:40-)
 - Neutrino nucleus reactions at high energies within the GiBUU model
 - Nuclear corrections in neutrino-nucleus DIS and their compatibility with global NPDF analyses
 - Gamma-ray production in NC interactions
 - Argoneut
- Session #8 (Fri 16:00-)
 - Joint detector session w/ WGI

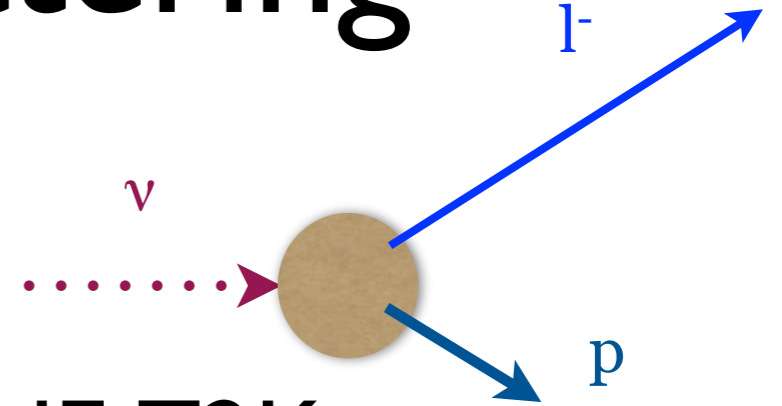
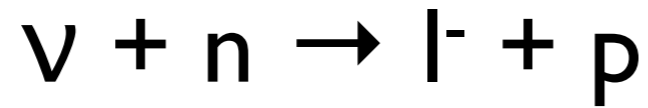
**Let's come up with
new ideas.**

See you at WVG2!

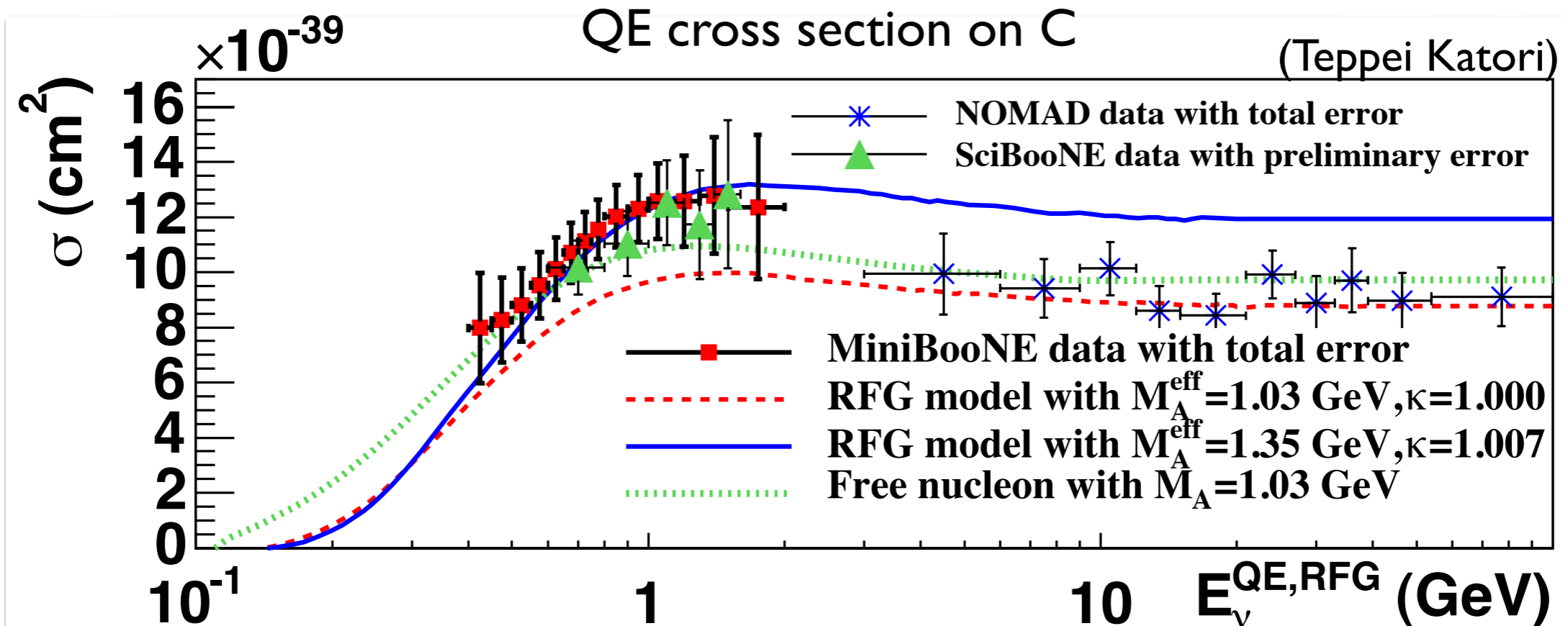
Backup

Quasi elastic scattering

- The simplest channel:

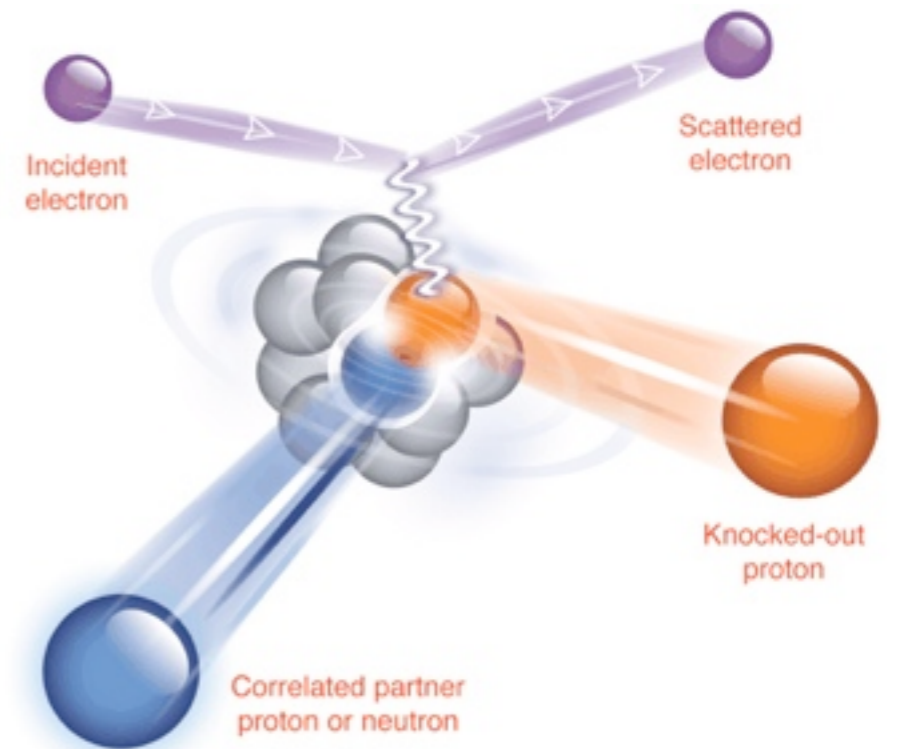


- Dominant interaction for MiniBooNE, T2K
 - Energy reconstruction from lepton kinematics
- Thought as ‘robust’ channel, however...



Quasi elastic scattering

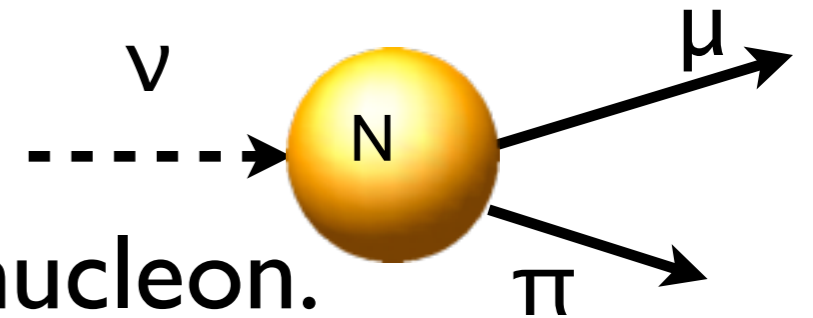
- Much effort to explain by changing form factor (e.g. M_A).
- Recent realization: contribution from multi-nucleon correlations?
- Effect seen in e-N scattering
- Can be as large to explain MB/NOMAD discrepancy.
- What we call “QE” may depend on detector/analysis.



Science 320 1476(2008)

Coherent pion production

- Neutrino interaction with whole nucleus rather than each nucleon.
- Experiments with higher energy well described with a model by Rein and Sehgal
- Recent measurements in \sim GeV have revealed some puzzle..
- K2K, SciBooNE, MiniBooNE, NOMAD
- CC/NC ratio \ll model prediction at \sim 1 GeV



Discussion over past 5 years, still a mystery..