WG2 Summary

Masashi Yokoyama (U. Tokyo)

on behalf of WG2 conveners
Kendall Mahn(TRIUMF)
Luis Alvarez Ruso(U. Valencia)

WG2 statistics this year

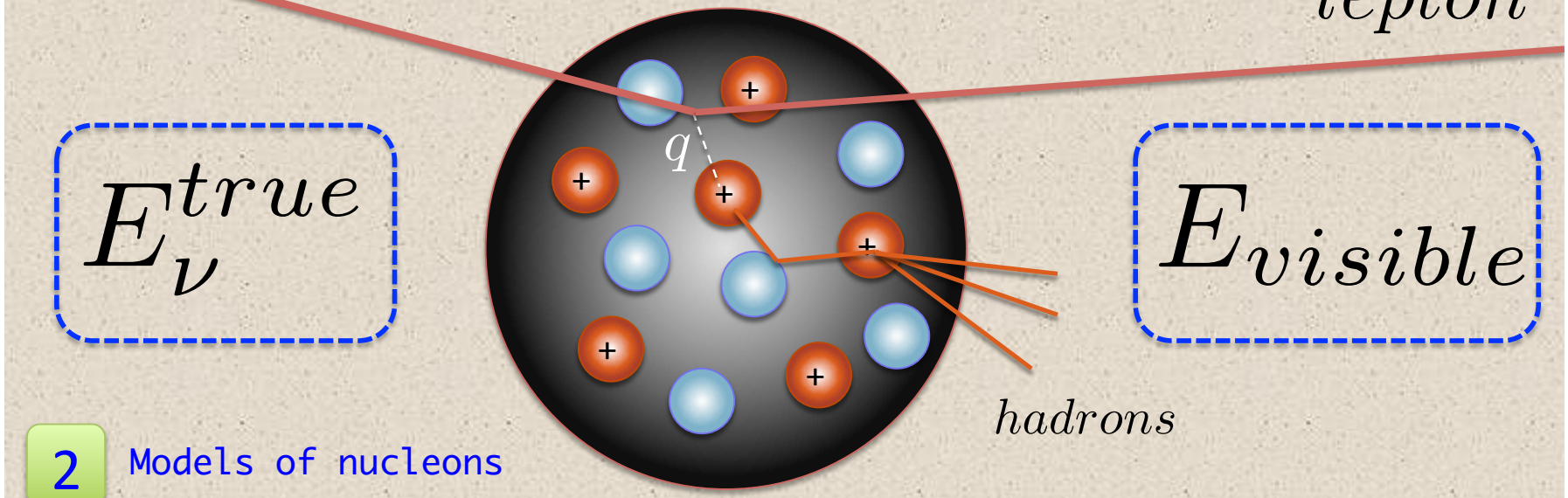
- 3 related plenary talks
- 4 talks in joint WG1+2 session
- 27 talks in WG2 sessions

Thank you for all speakers and participants!

Dave Schmitz, Plenary talk

Physics of GeV ν-N Interactions

1 Cross section models for all exclusive ν-nucleon interaction channels (elastics, resonance productions, DIS …)



2 Models of nucleons within the nucleus (Relativist Fermi Gas, spectral functions, nucleon correlations, …)

3 Final state interaction models which alter the hadronic final state (rescattering, absorption, charge exchange, …)

Where are we?

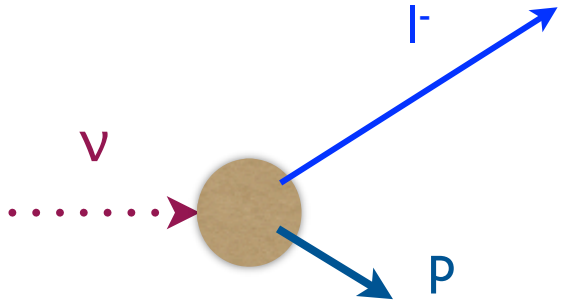
Map at Great Wall

CCQE

Charged current quasielastic (CCQE)

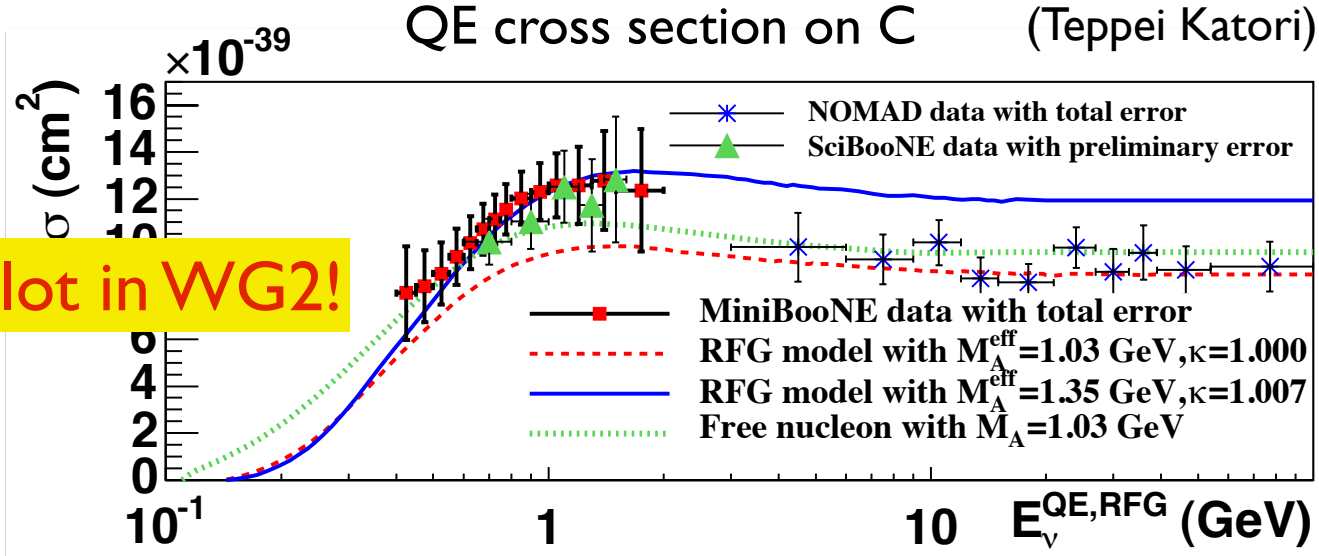
- The 'simplest' channel:

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



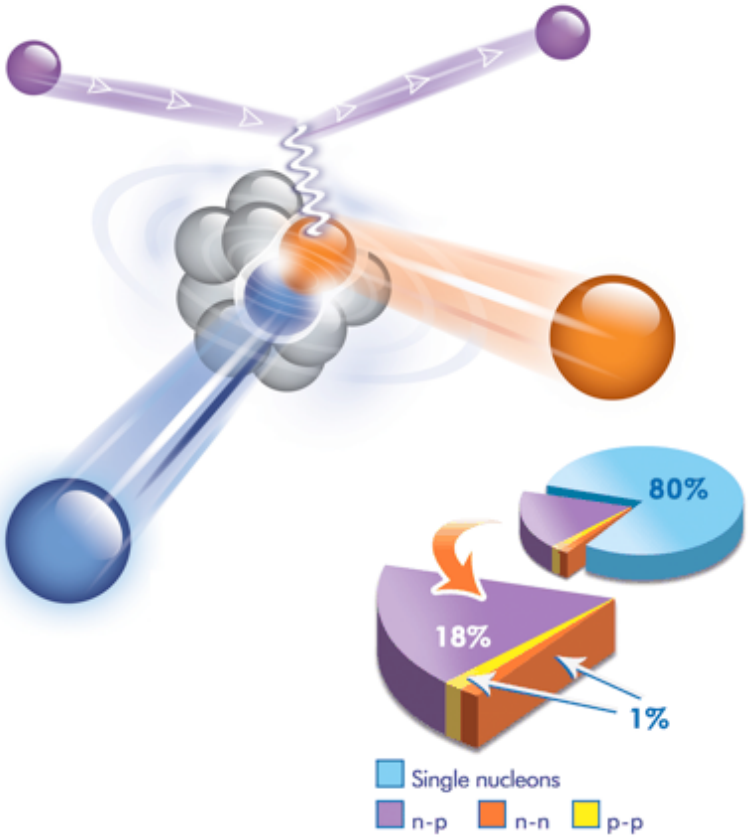
- Dominant interaction in <~1GeV
  - Energy reconstruction from lepton kinematics
- Found to be far more complex than thought
  - One of hot topics for past few years..

Most cited plot in WG2!



Multi-nucleon effects

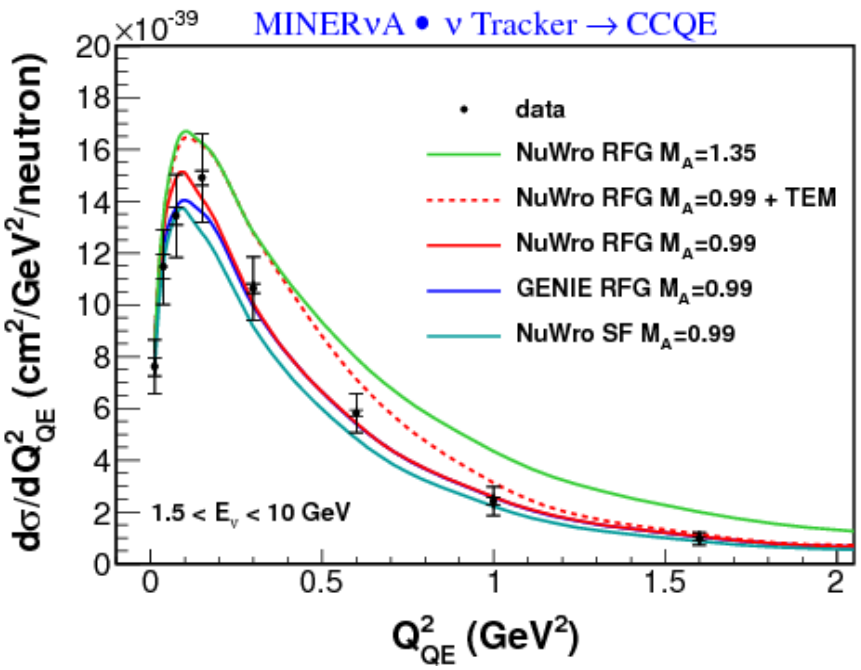
- Short range correlation (SRC) seen in e-N scattering, for ~20% of nucleons
- Meson exchange current (MEC) also contributes
- Can affect energy reconstruction
  → effect on oscillation measurements?



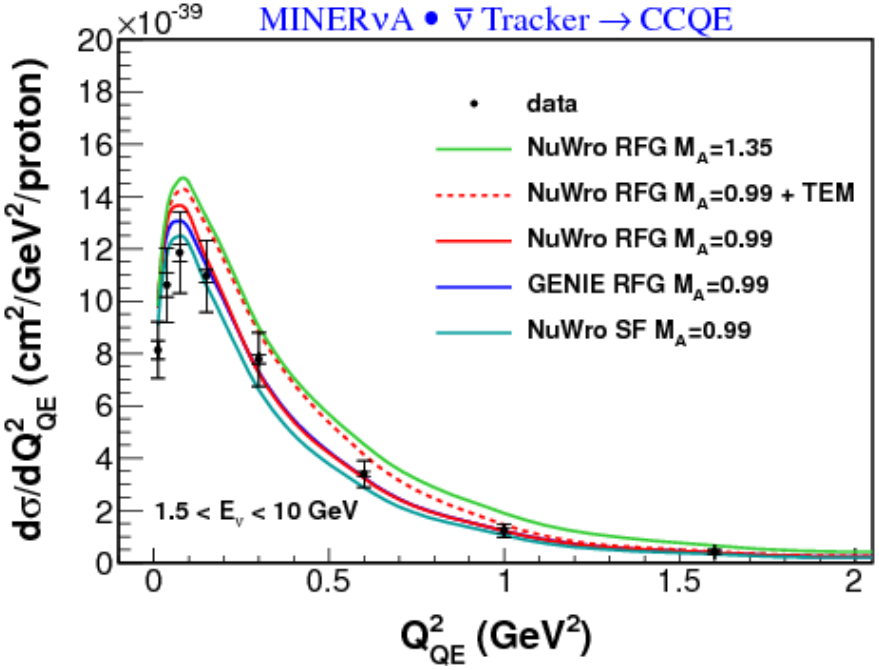
R. Subedi et al., Science 320, 1476 (2008)

MINERvA CCQE

Neutrino



Anti-neutrino



M_A = 1.35 ——— best fit to MiniBooNE data

TEM - - - - - - - - empirical model based on electron scattering data

GENIE ——— independent nucleons in mean field

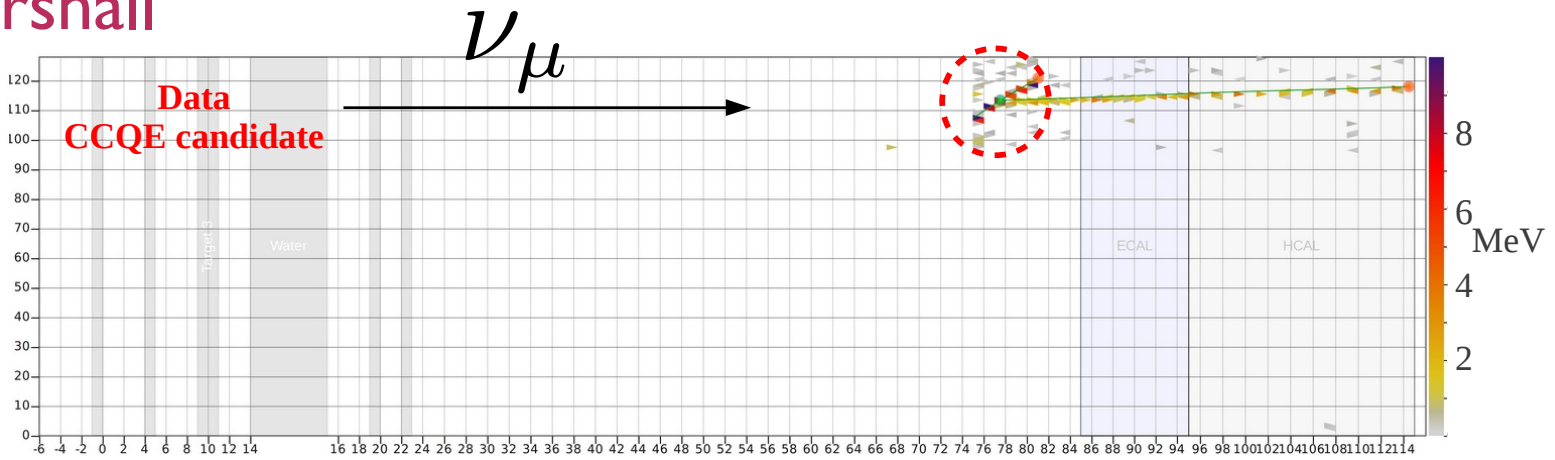
SF ——— more realistic nucleon momentum-energy relation

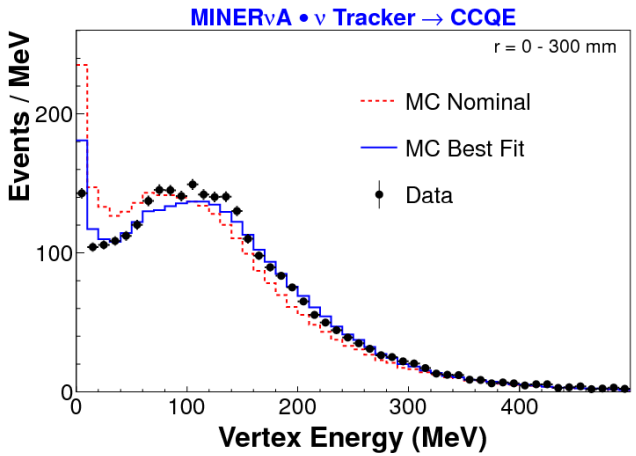
C.Marshall

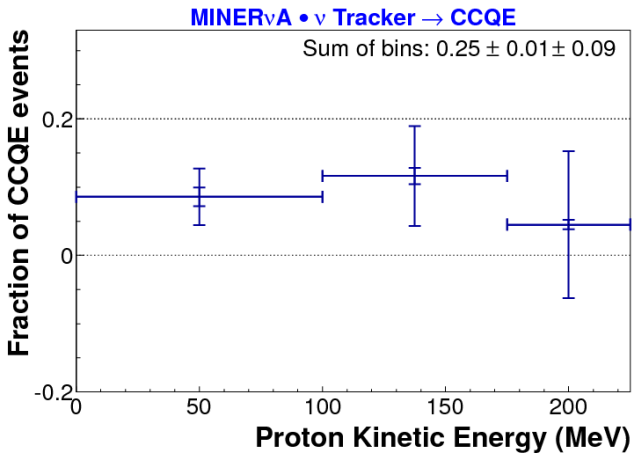
Discrimination of models

Vertex activity study at MINERvA

C.Marshall







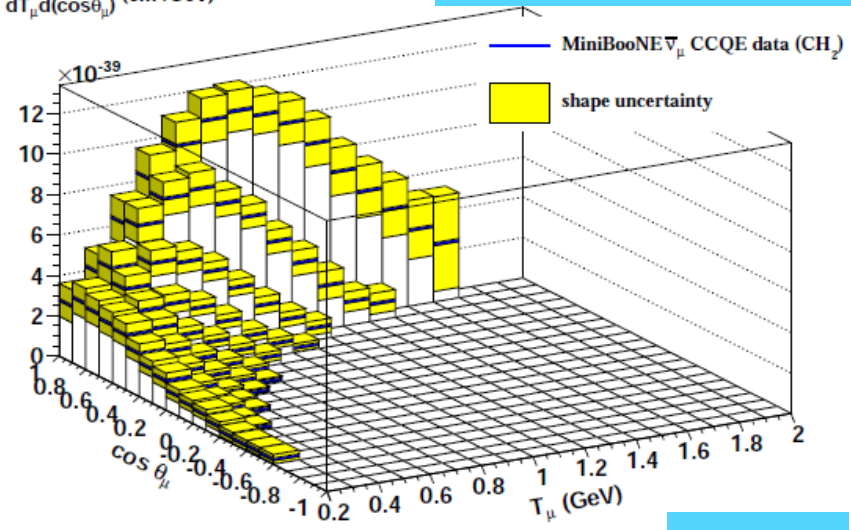
- Fit wants to add low-energy protons to (25 ± 10)% of CCQE events

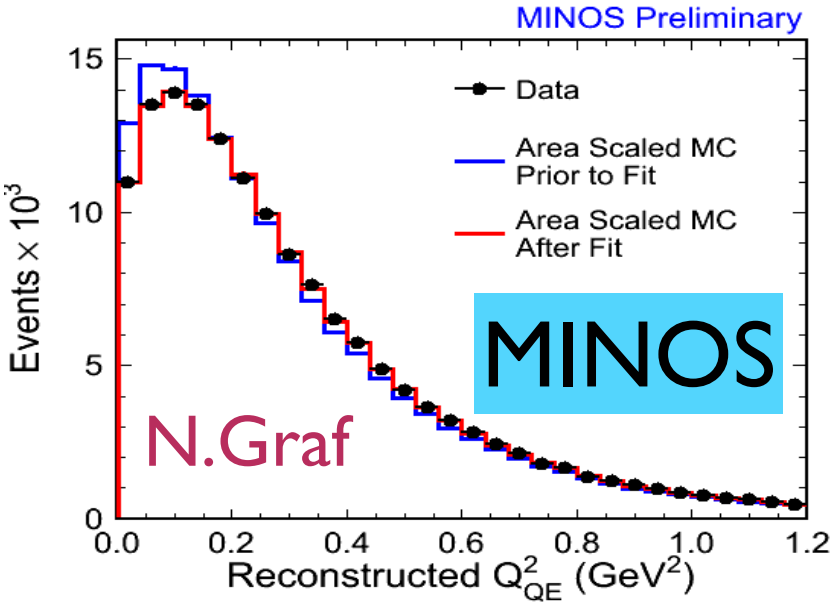
hint of multi-nucleon effect?

Other CCQE measurements

Z. Pavlovic

MiniBooNE $\bar{\nu}$





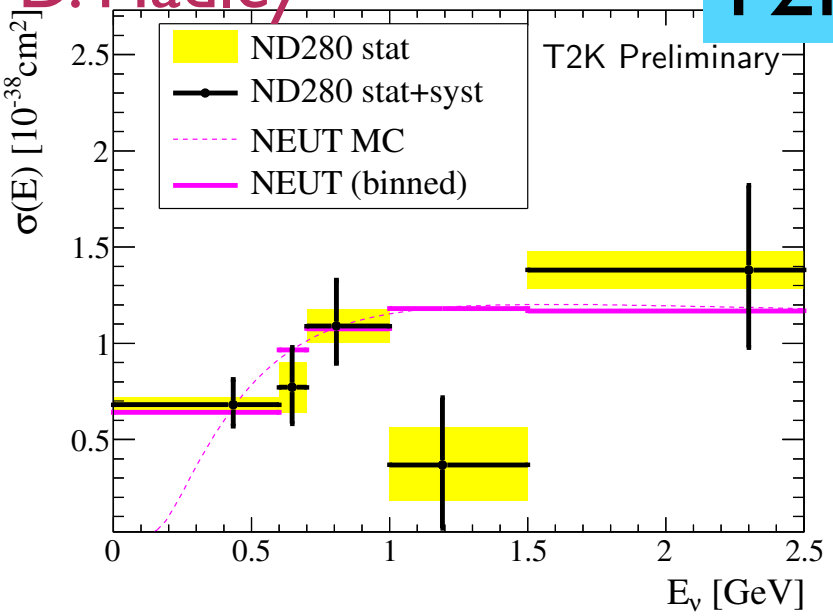
MINOS

N.Graf

$$M_A^{QE} = 1.21^{+0.18}_{-0.10}(fit)^{+0.13}_{-0.15}(syst)\,GeV$$

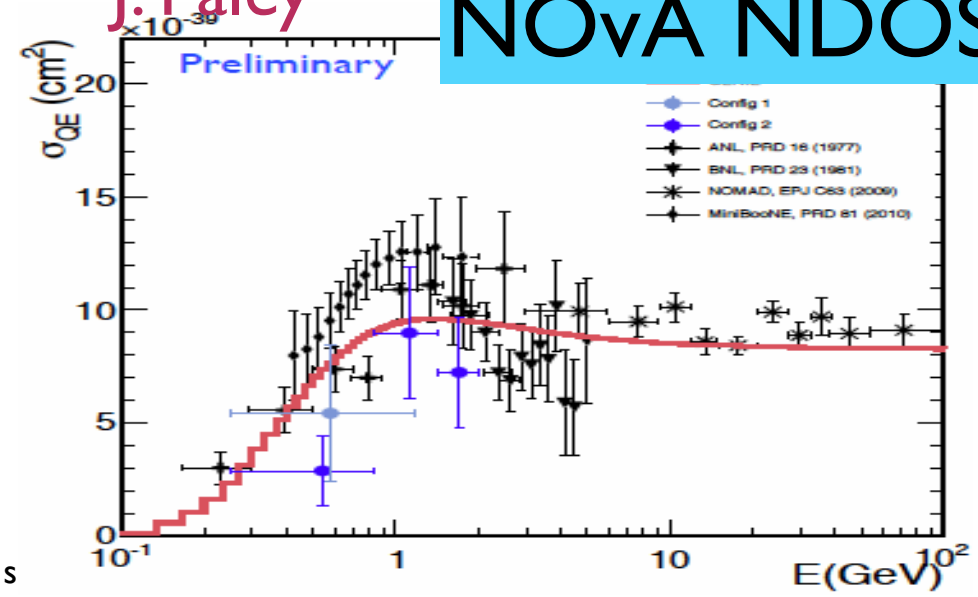
D. Hadley

T2K



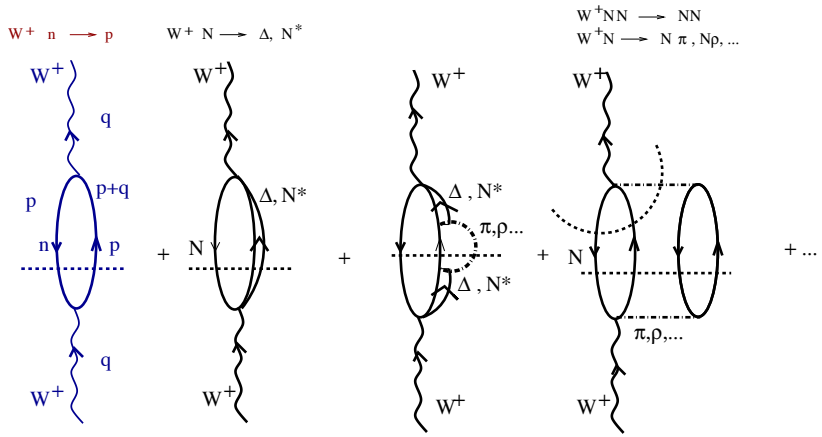
J. Paley

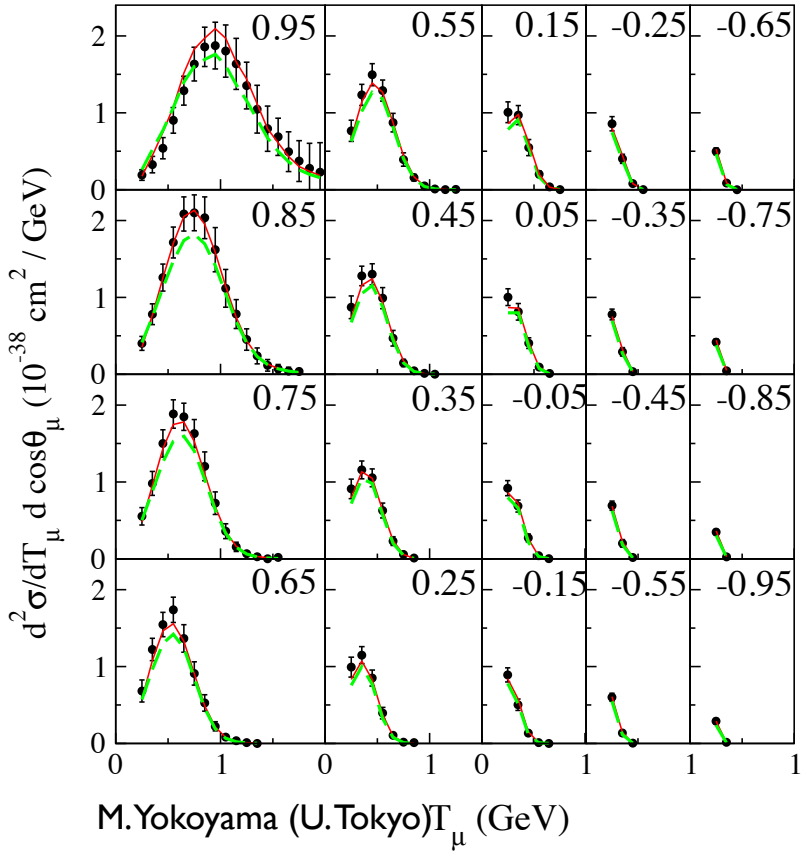
NOvA NDOS



WG2 s

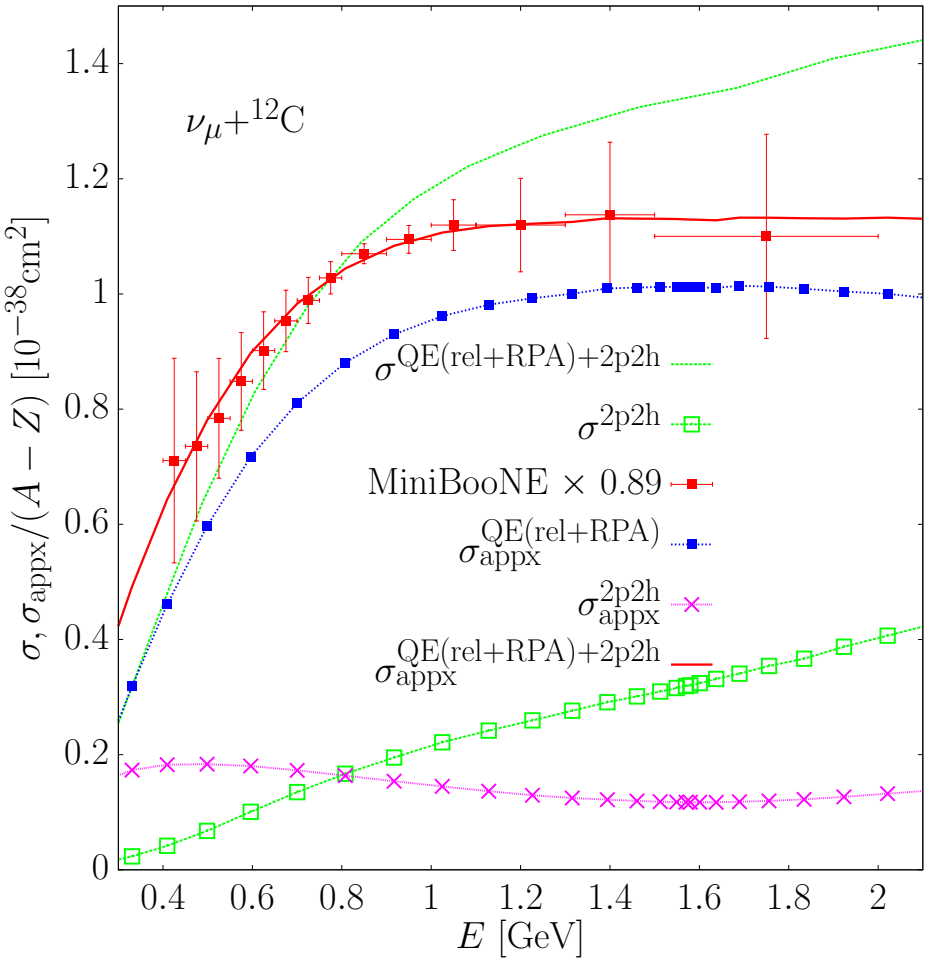
Microscopic calculation of CCQE





M. Yokoyama (U. Tokyo)

J. Nieves

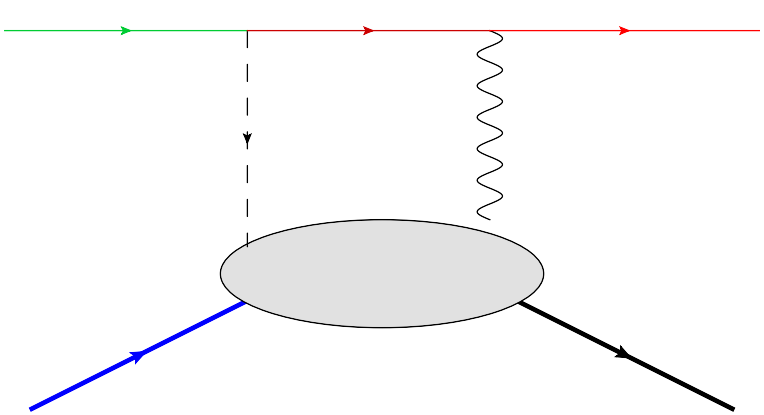


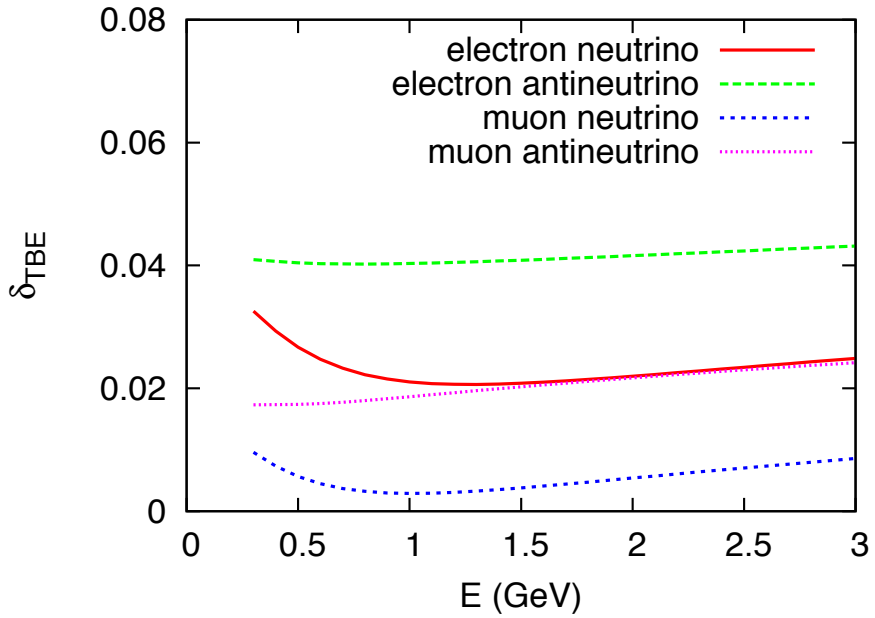
Reconstructed E_ν can be significantly affected

Radiation correction in CCQE

K. M.Graczyk

Two boson exchange correction





ν_e/ν_μ difference ~2%

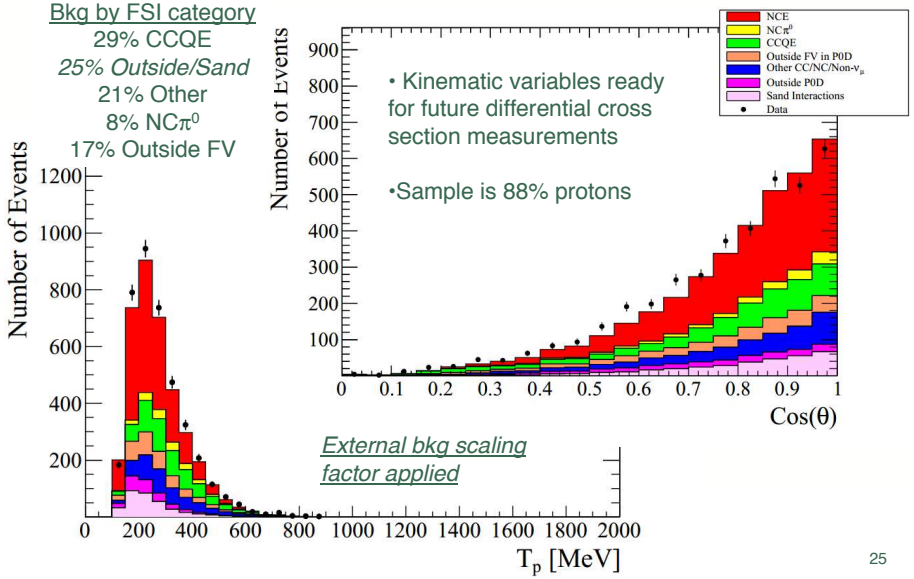
Neutral current elastic scattering

T2K

T2K

Final Sample

Bkg by FSI category
29% CCQE
25% Outside/Sand
21% Other
8% NCπ^0
17% Outside FV

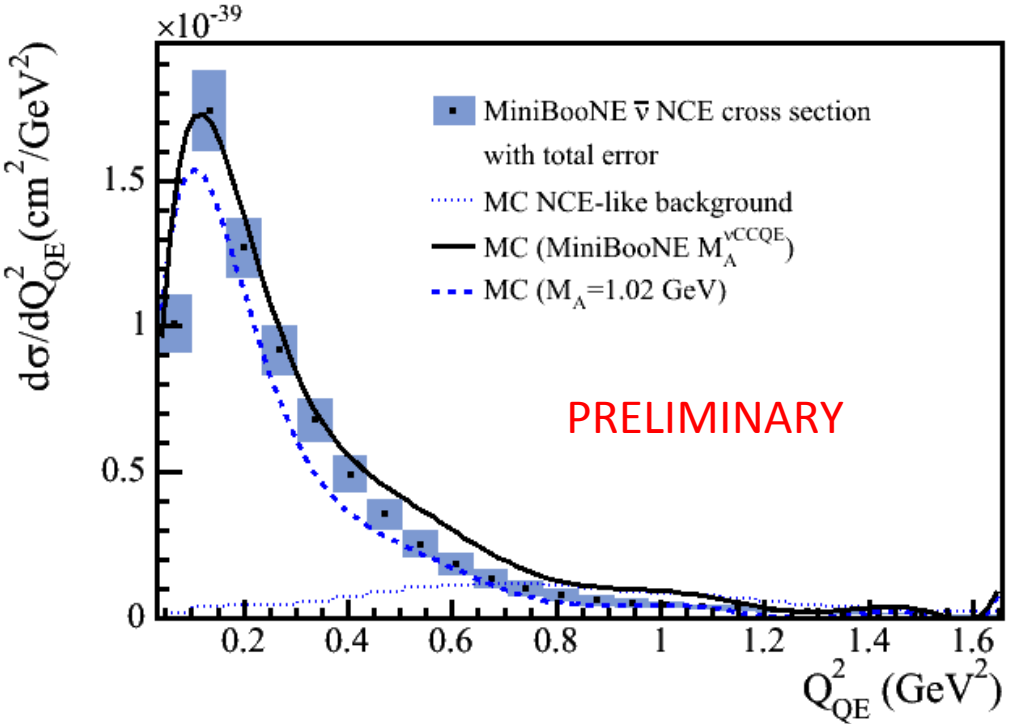


25

D. Ruterbories

MiniBooNE $\bar{\nu}$

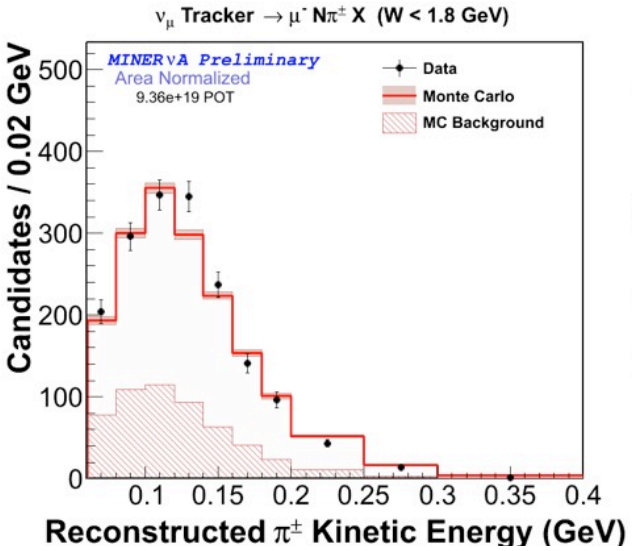
Z. Pavlovic

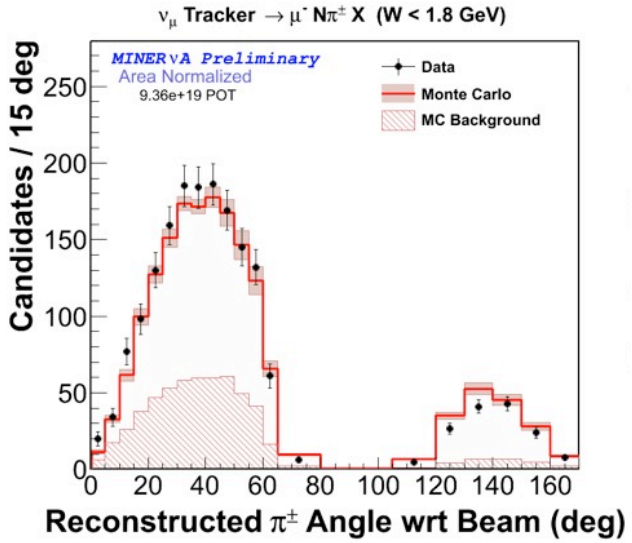


Meson/γ production

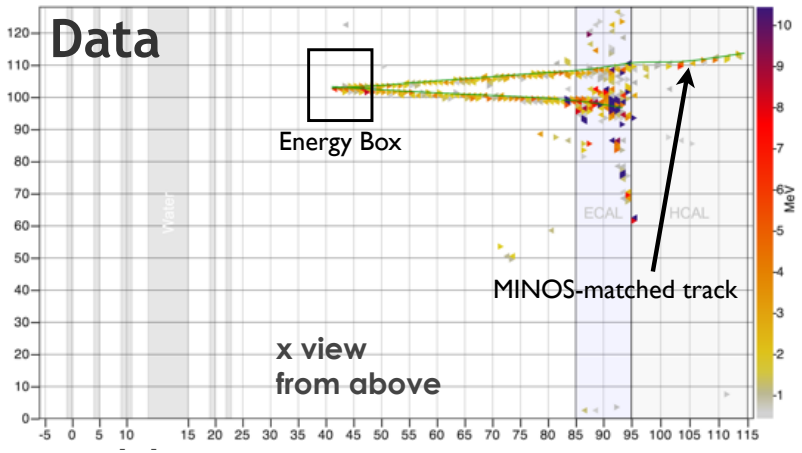
MINERvA pion production

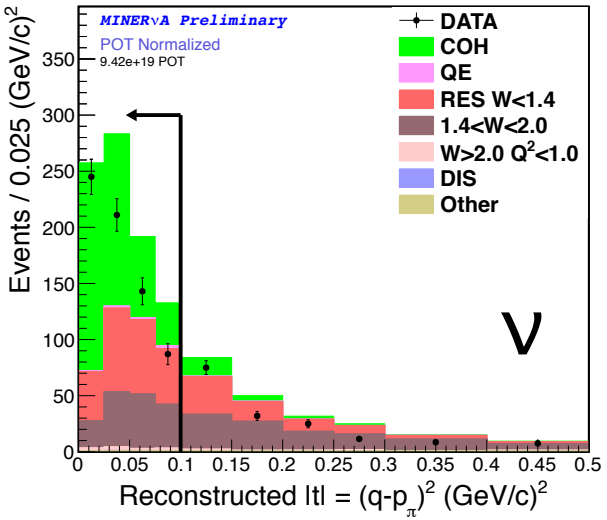
inclusive π production

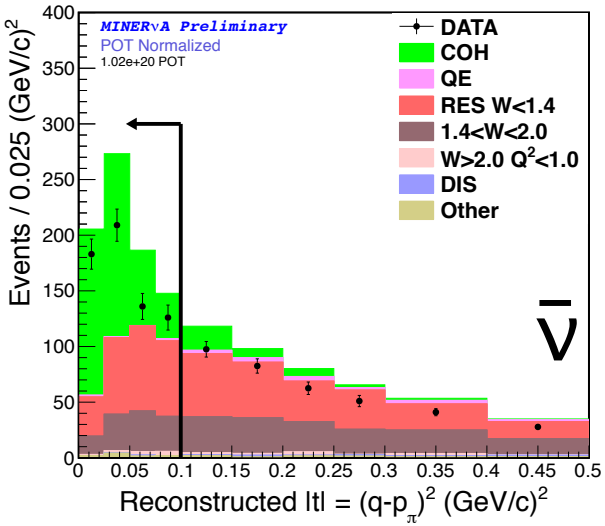




coherent pion production



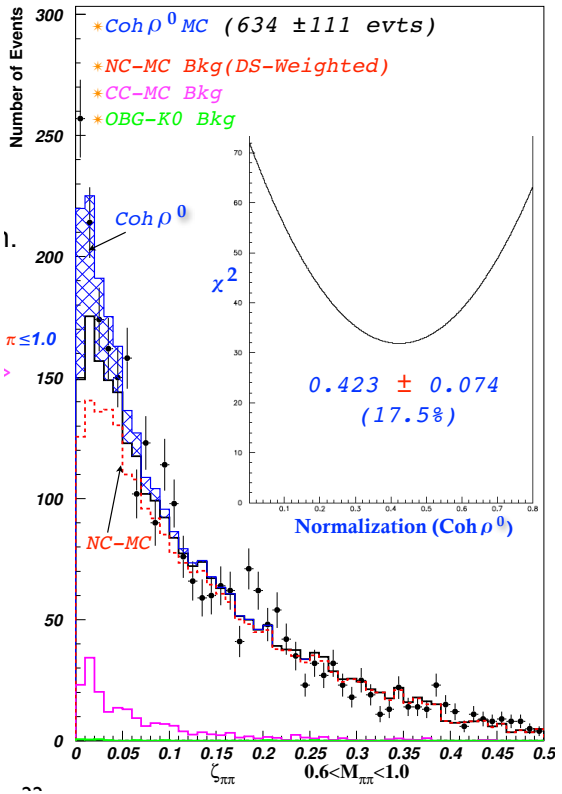


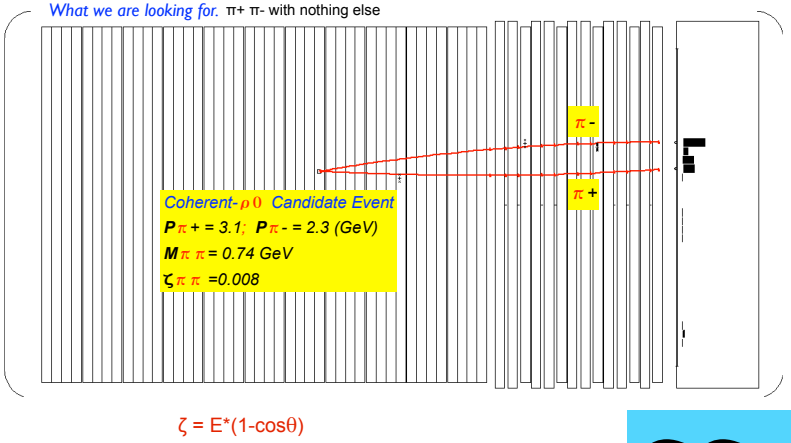


A. Higuera

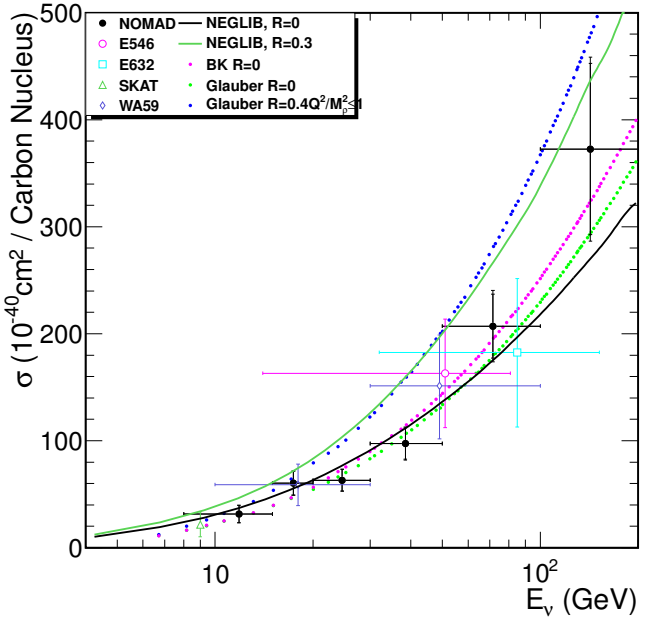
Coherent ρ production (NOMAD)

NC ρ^0 H. Duyang





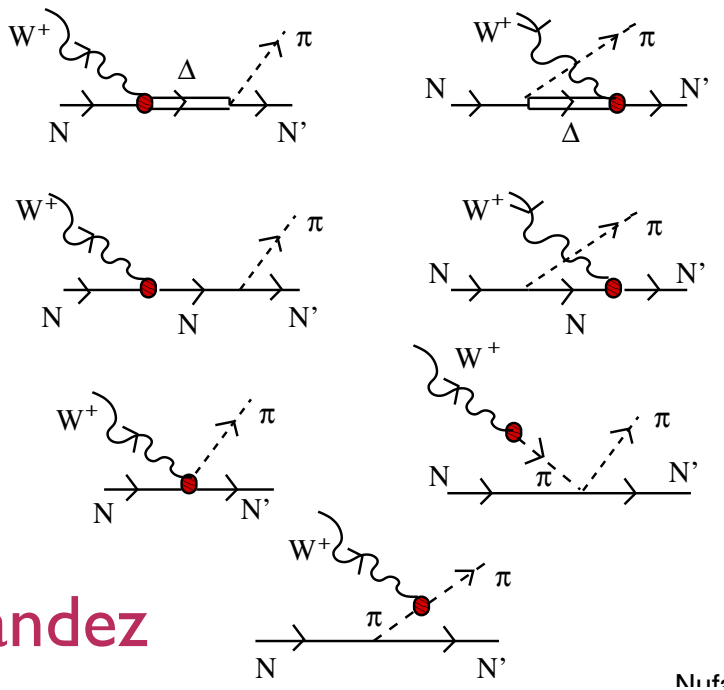
CC ρ^+ X. Tian



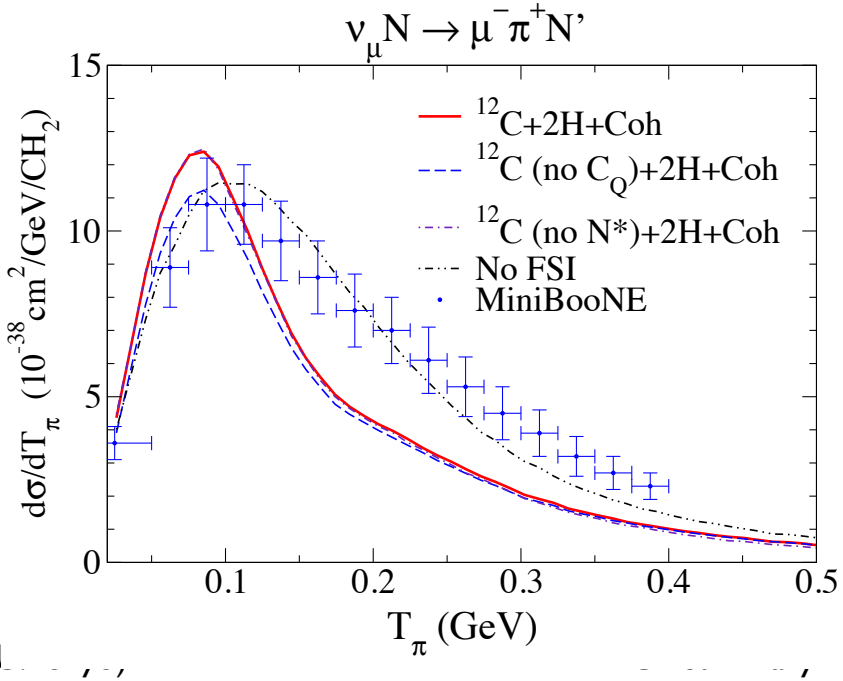
First observation!

Useful exercise for LBNE-ND

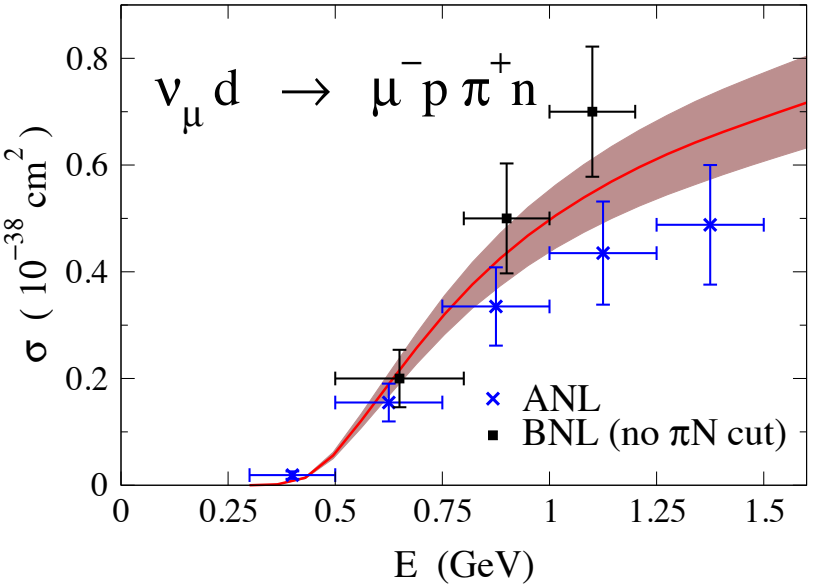
Pion production calculation



E. Hernandez



Can fit ANL/BNL results



$$C_5^A(0) = 1.00 \pm 0.11,$$
$$M_{A\Delta} = 0.93 \pm 0.07\,\mathrm{GeV}$$

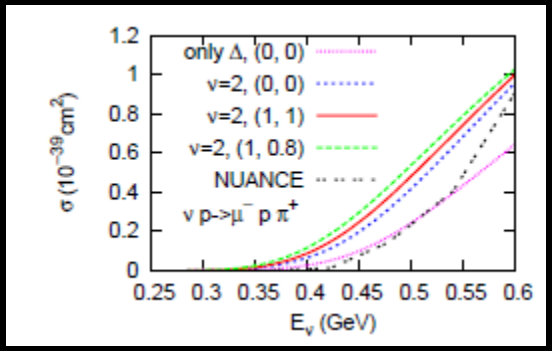
MiniBooNE data agree with NO FSI?

→ need something else

π/γ emission with a chiral EFT

X. Zhang

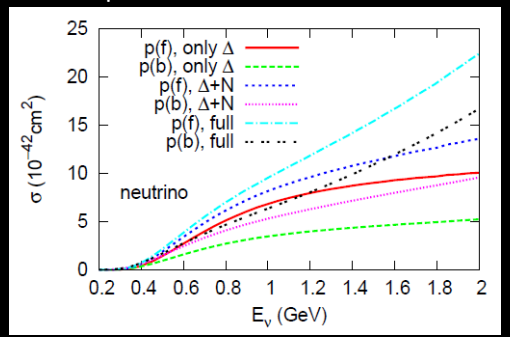
Incoherent neutrinoproduction of pion from C12

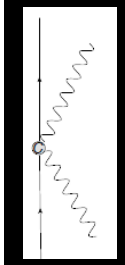


MiniBooNE NC photon

X.Z. and B. Serot, PLB 719, 409 (2013) (arXiv: 1210.3210)

Extrapolation of previous results to higher energy



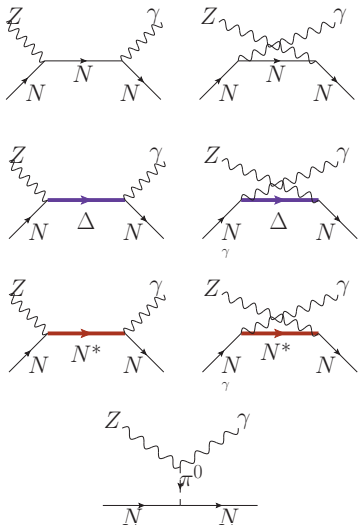


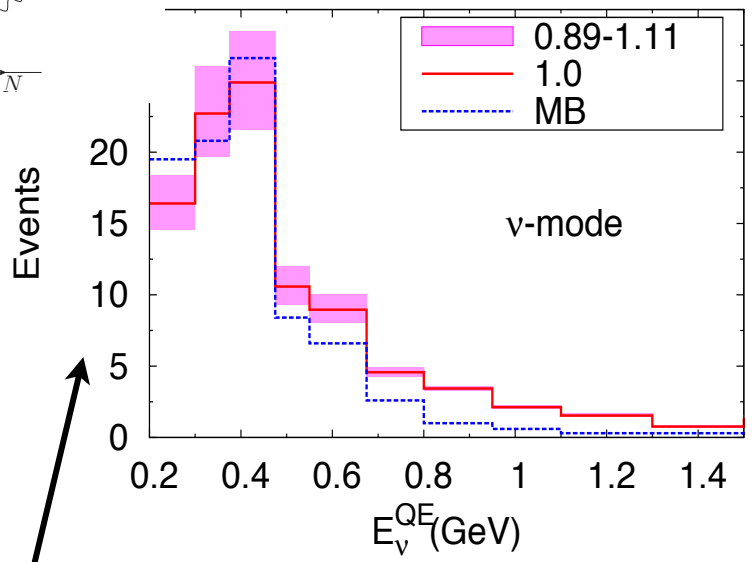
$\frac{c_1}{M^2}\overline{N}\gamma^\mu N\,\mathrm{Tr}(\tilde{a}^\nu \overline{F}^{(+)}_{\mu\nu})$, $\frac{e_1}{M^2}\overline{N}\gamma^\mu\tilde{a}^\nu N\overline{f}_{s\mu\nu}$

Interesting direction; extension to other processes?

NC γ emission

E. Wang

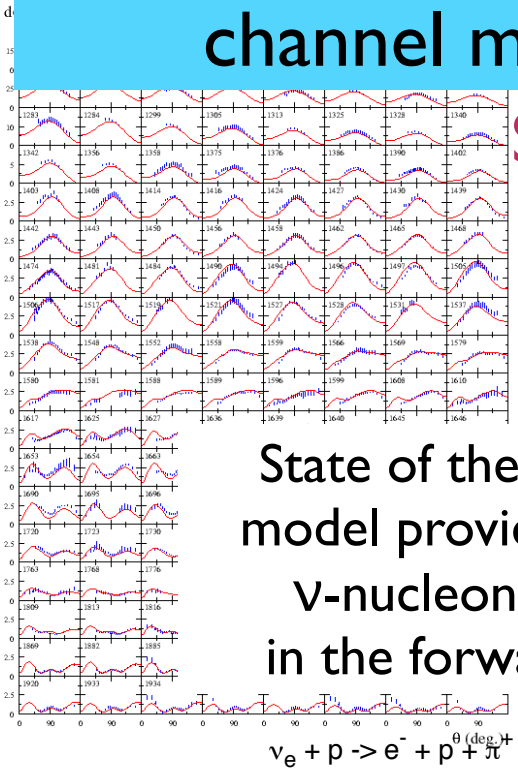




Both consistent with MiniBooNE estimate and cannot explain excess

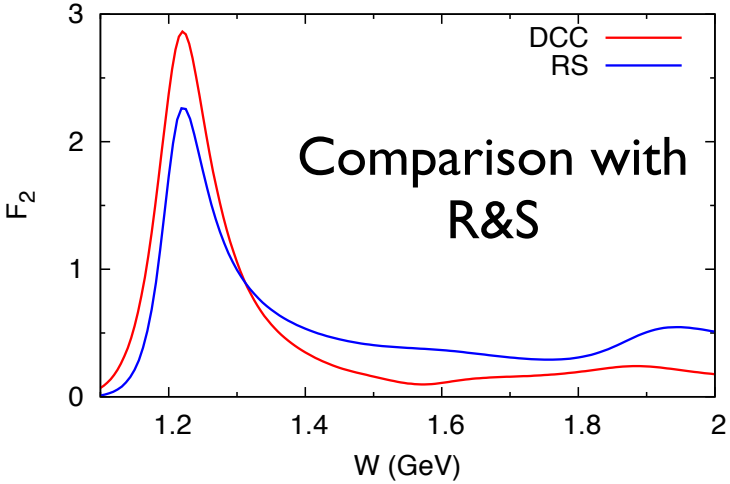
π production with dynamical coupled-channel model

S. Nakamura



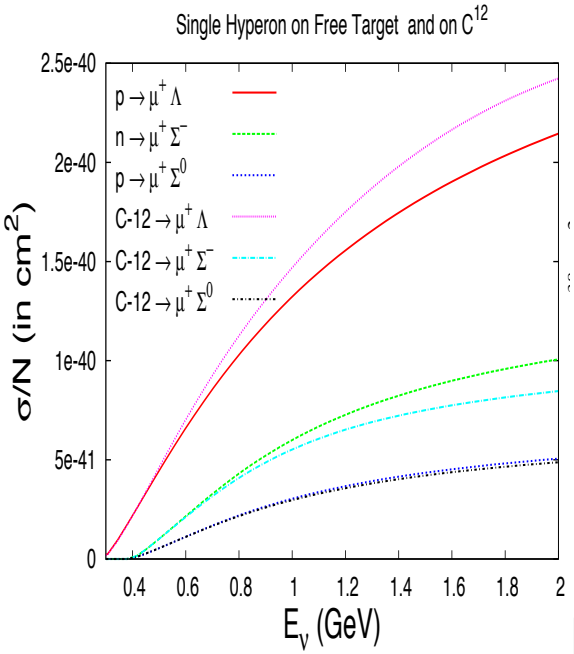
State of the art hadronic model provides info about ν-nucleon interaction in the forward direction

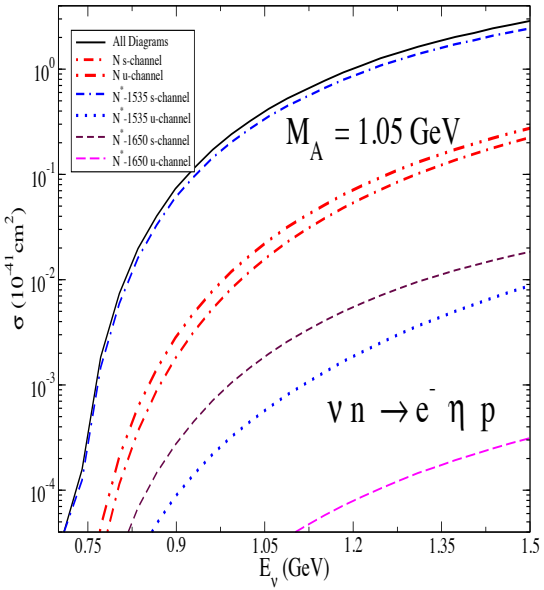
$\nu_e + p \rightarrow e^- + p + \pi^+$



Strangeness/eta production

M. Rafi Alam

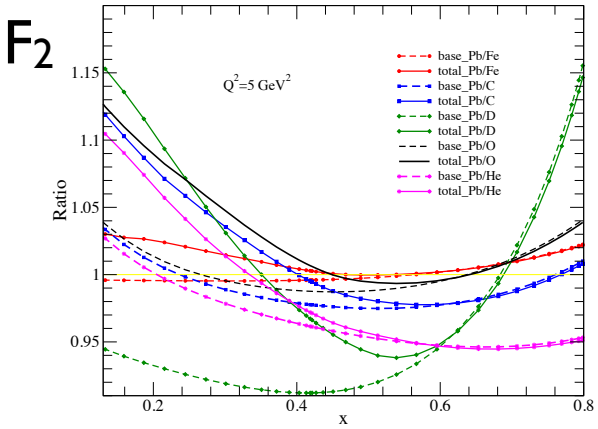


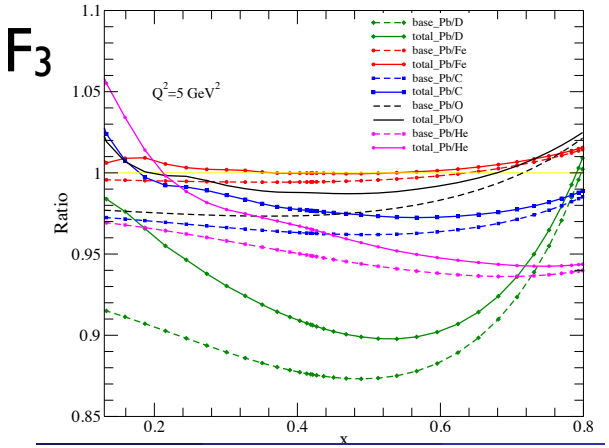


Understanding nuclear structure

Nuclear effects and DIS

Calculation for various nuclei

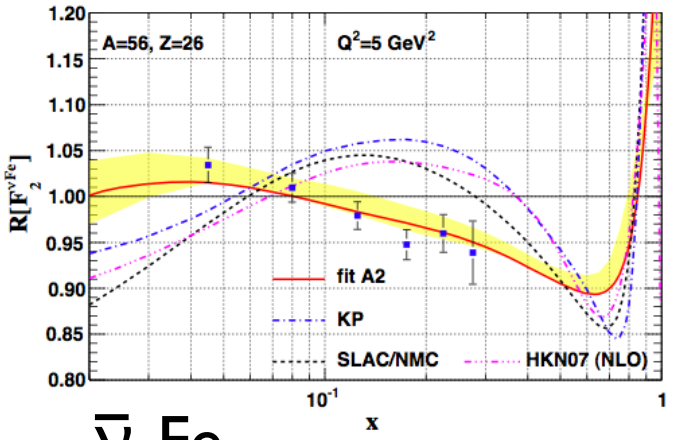




M. Sajjad Athar

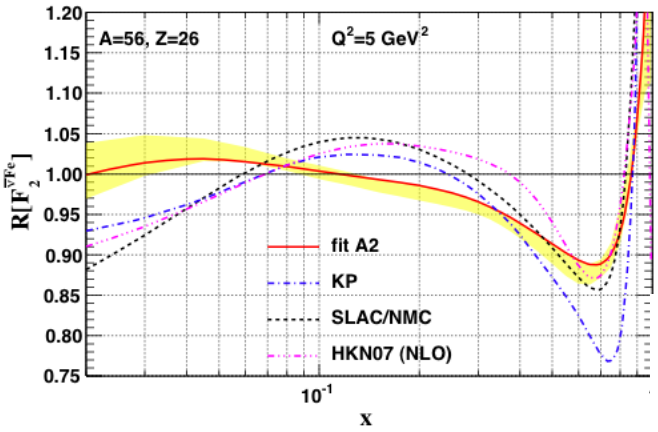
CTEQ nPDF

ν-Fe



J. Morfin

$\bar{\nu}$-Fe



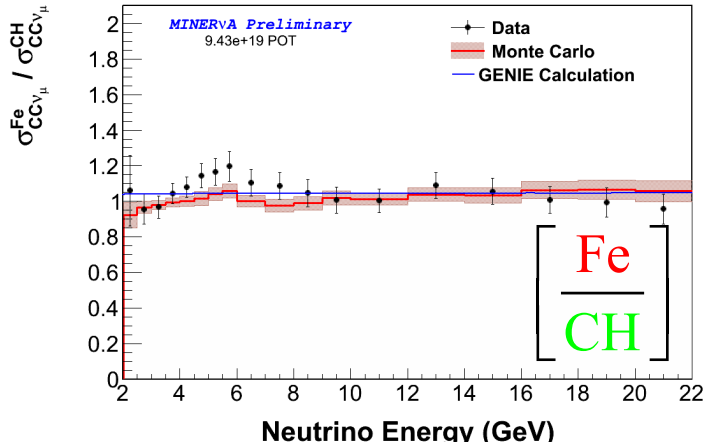
Effect on $\sin^2\theta_W$ measurement?

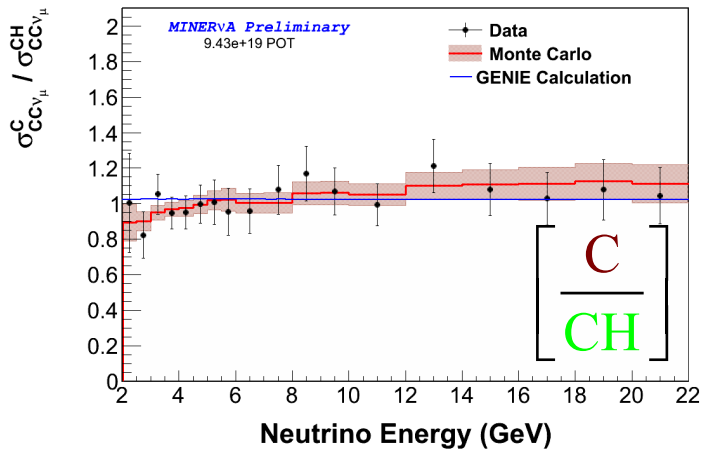
ν induced parton-level nuclear effects may be different from $l^{\pm}$

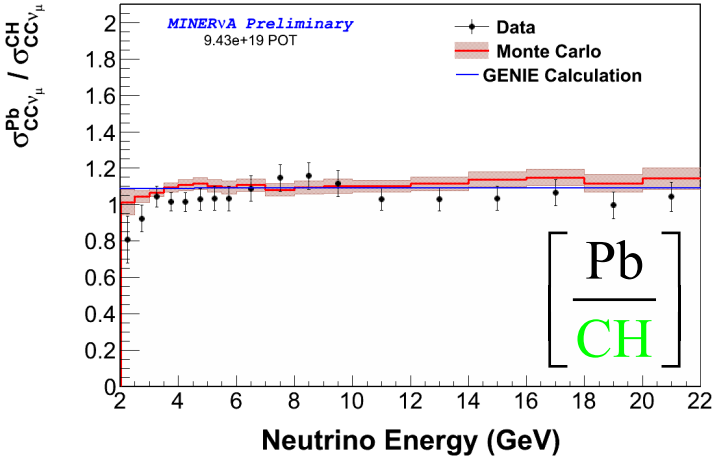
MINERvA inclusive cross sections

various nuclear targets → nuclear structure

Ratio (E_ν) of Fe, C, Pb to CH Cross Sections







isoscalar correction not applied to these ratios

higher statistics

→ x, Q^2 in bins of ν energy

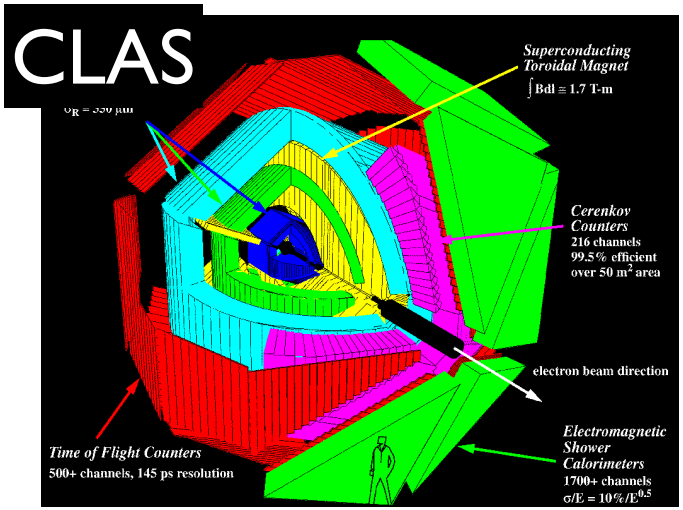
→ remove elastic and resonant contributions

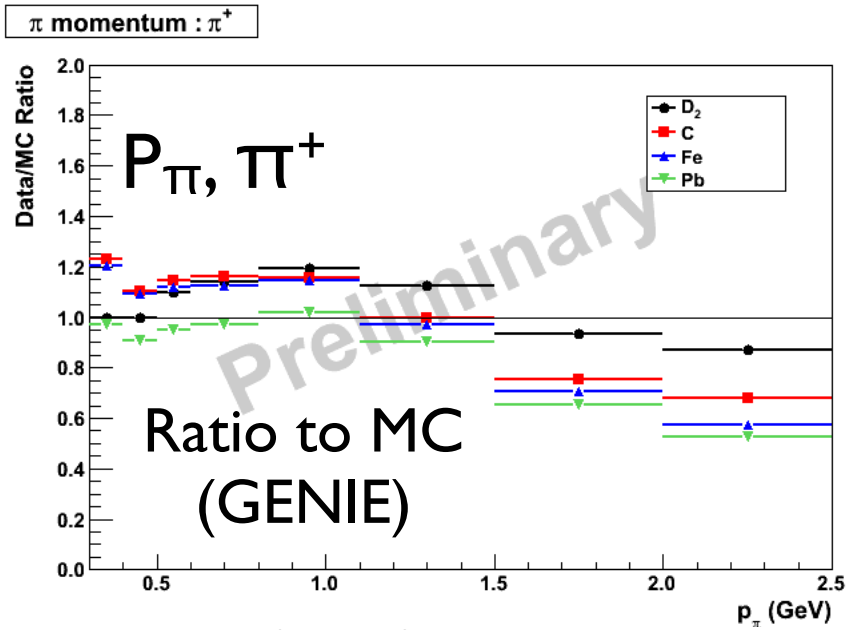
A. Bravar

Non-ν scattering

π production in e-A scattering

S. Manly

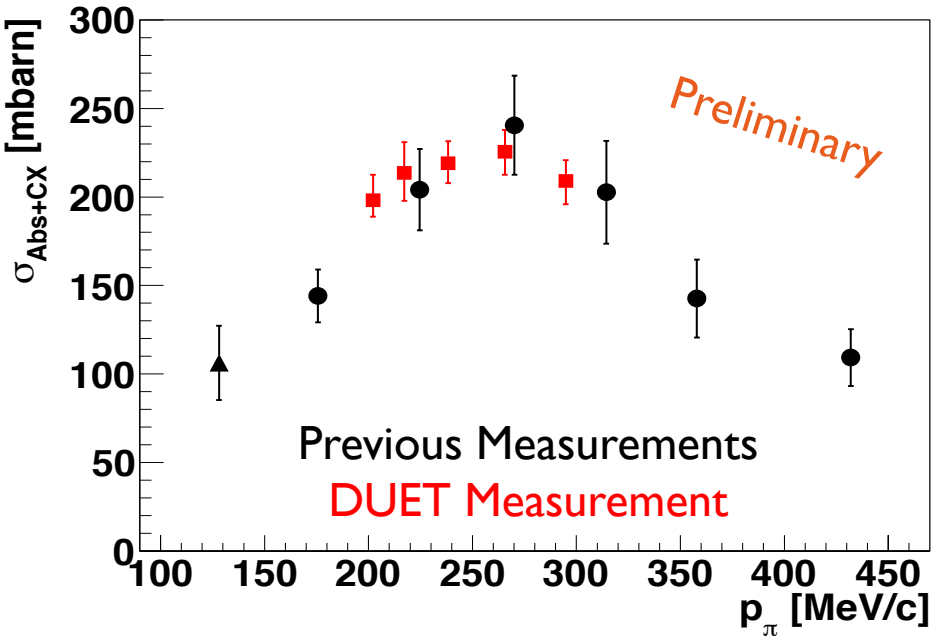




π absorption/ charge exchange in nuclei

E. Pinzon

Measurement with
1.5mm fiber tracker



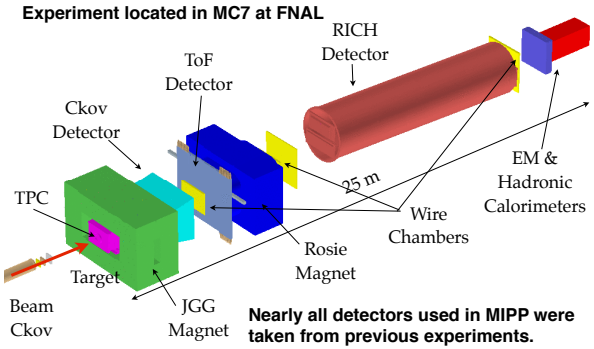
Important for constraining FSI

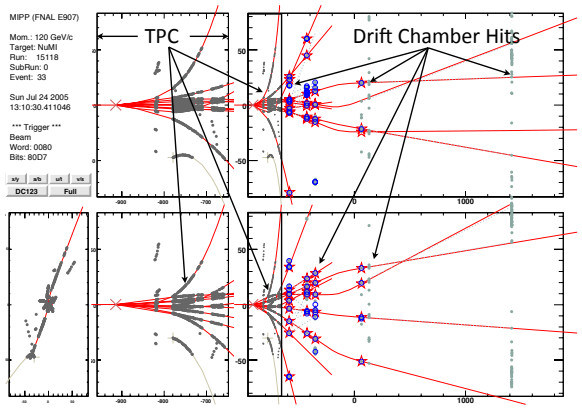
Understanding ν flux

Hadron production

Future opportunity

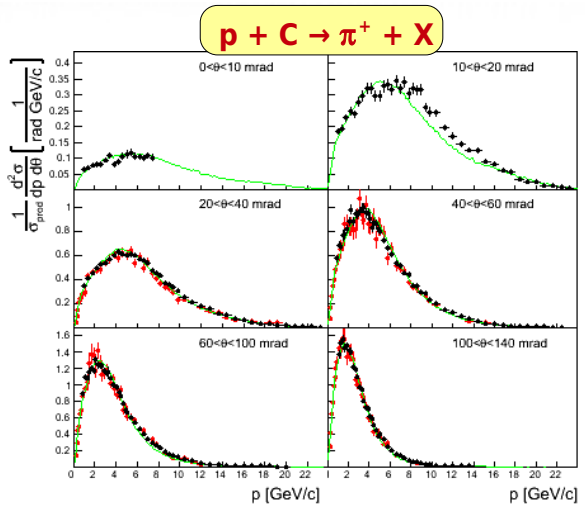
MIPP J. Paley

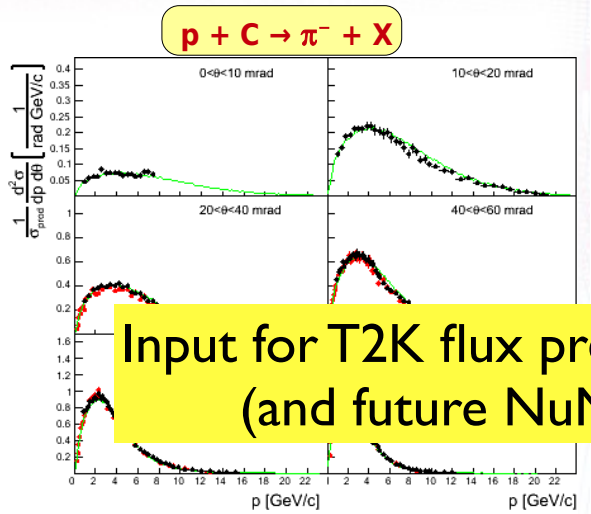




NuMI target analysis

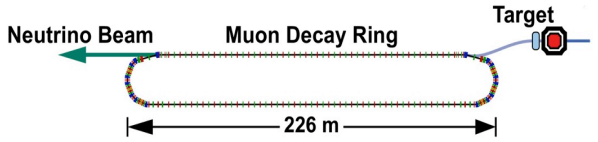
NA61/SHINE A. Korzenev

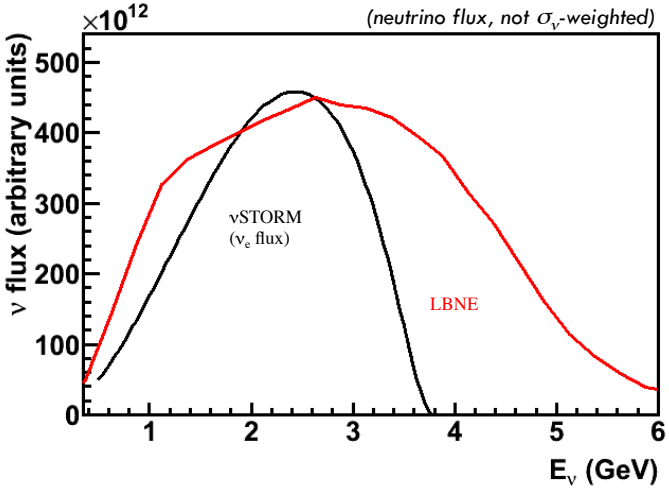




Input for T2K flux prediction (and future NuMI)

nuSTORM J. Morfin



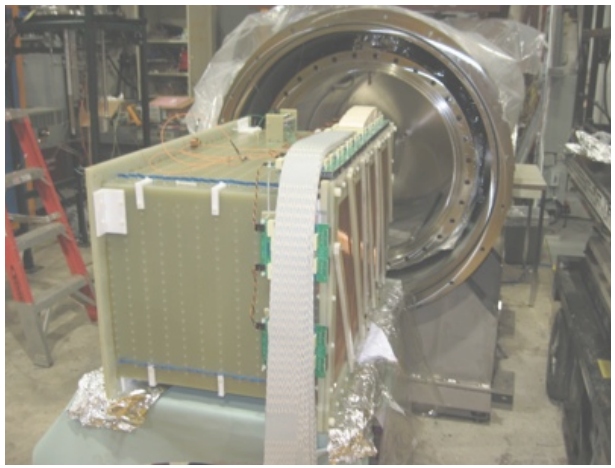


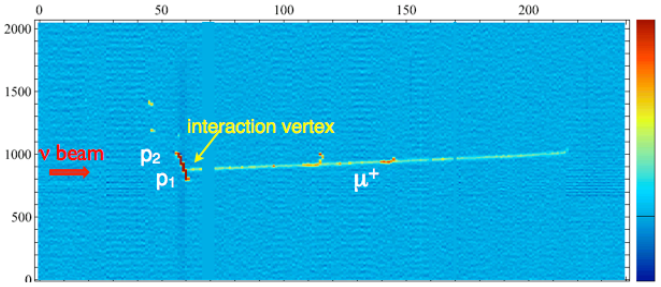
Precision ν flux
νe scattering

LAr development

ArgoNeuT

T. Yang



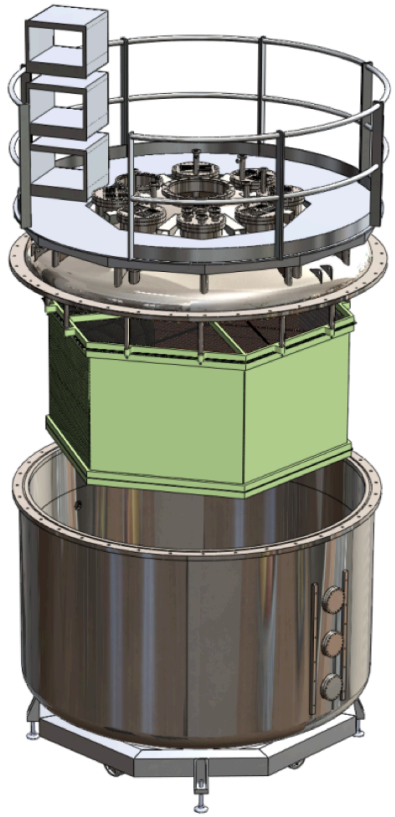


MicroBooNE

J. St. John

CAPTAIN

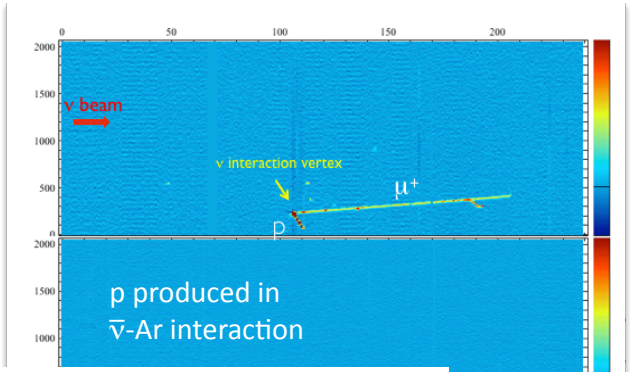
C. Taylor

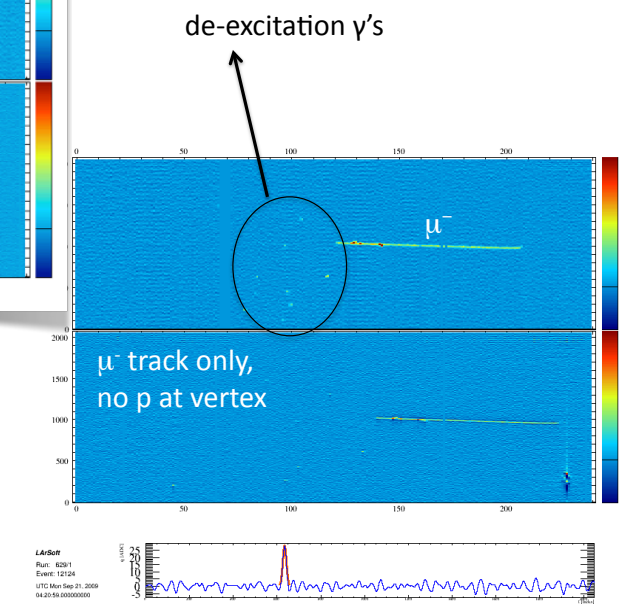


Intensive effort, especially in US

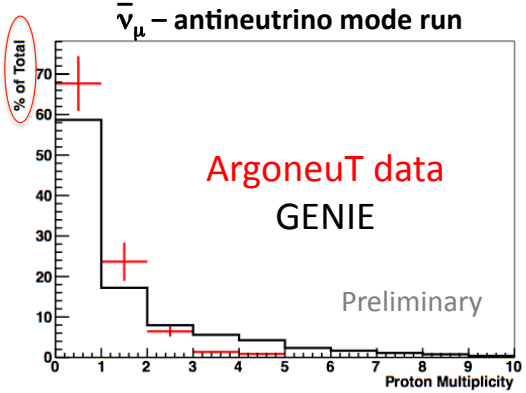
Hints for Nuclear Effects

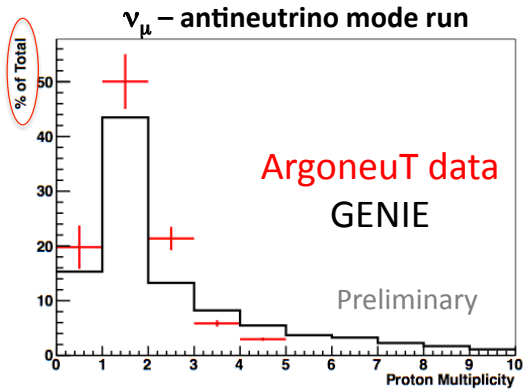
Real physics output from ArgoNeuT!



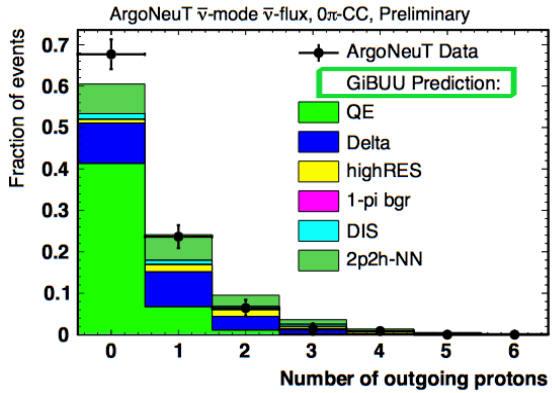


Proton Multiplicity





proton threshold:T_p>21 MeV



- LAr data can provide an important discriminator among models

T.Yang


FROM
NUFACT2013
August 19-24
TO NUFACT 2014

WG2: Forum for discussion

MY, introduction

- Need close communication and interplay between
  - Experimentalists and theorists
  - Neutrino physicists and nuclear physicists
  - People having different ideas
- NuFact WG2 is (together with NuINT workshop) at heart of this field to have discussions for further progress
  - Many ideas from discussions in past NuFACT

Jan Sobczyk, Plenary talk

There is nothing more practical than a good theory (Kurt Lewin)

OK, but what is a *good theory*?

From experimentalist's point of view, it must:

be validated with data
be implemented in MC code
be able to assign associated uncertainties

to be useful in an experiment.

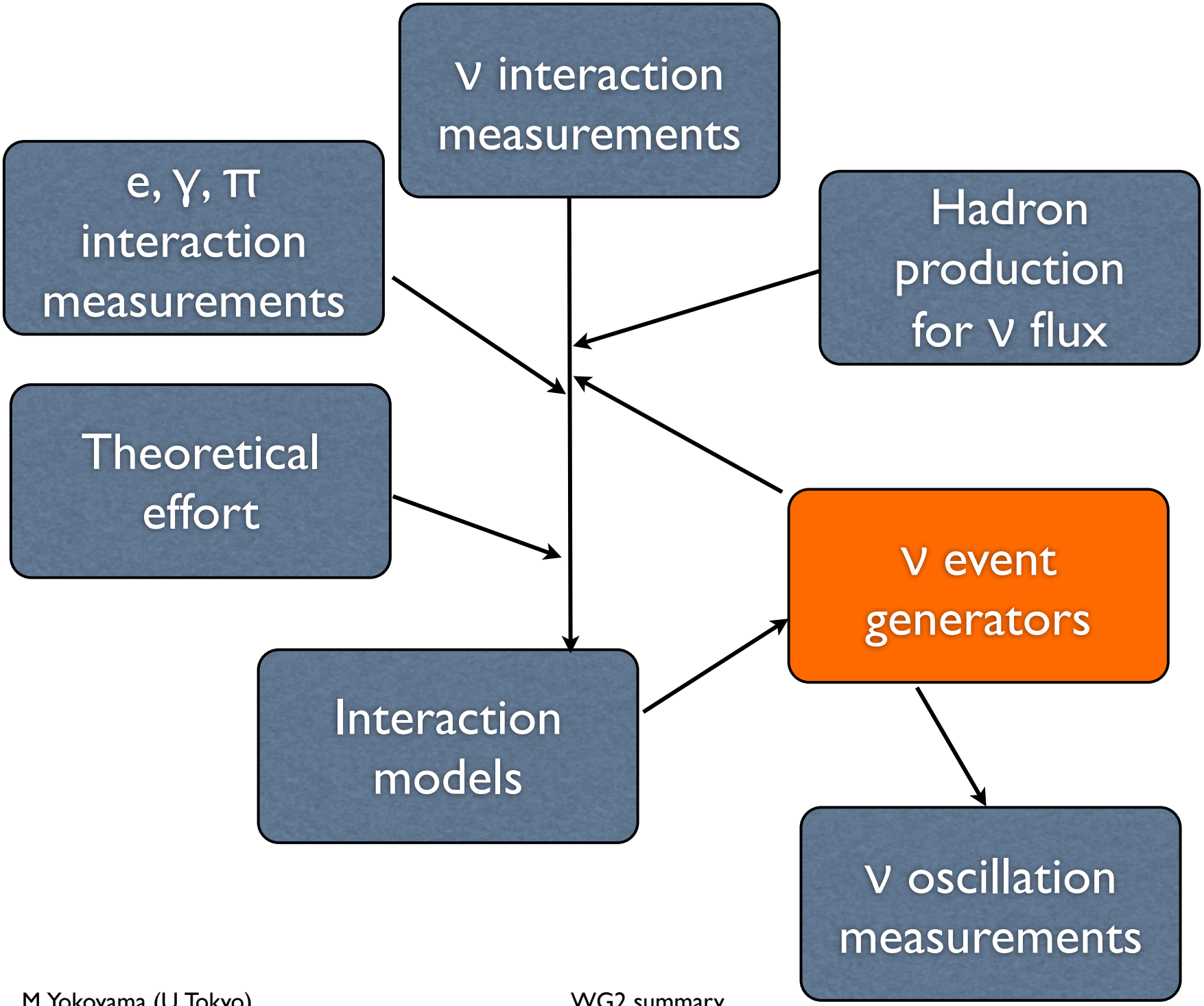
Dave Schmitz, Plenary talk

In Summary: Nuclear Physics Meets Neutrino Physics

Dave Schmitz, Plenary talk

In Summary: Nuclear Physics Meets Neutrino Physics

Nuclear Physics Meets Particle Physics


ν interaction measurements
e, γ, π interaction measurements
Hadron production for ν flux
Theoretical effort
ν event generators
Interaction models
ν oscillation measurements

Questions for 2014 (draft)

1. Multi-nucleon effects; SRC, MEC, ...
   - How do we experimentally identify those effects?
   - How do we implement the effect in MC generators?
   - How to evaluate the uncertainties?
2. How can we help MC code development?
   - What is necessary input from experiments, theorists, and generator code developers?
   - Can we have a common event format?
3. What kind of cross section experimental and theoretical program is needed for future experiments?
4. How can we invite more theorists to the field?

Many steps to go.
Keep climbing!

Backup

So many acronyms...

- CCQE (Charged Current Quasi Elastic)
- RES (RESonance pion production)
- DIS (Deep Inelastic Scattering
- MEC (Meson Exchange Current)
- SRC (Short Range Correlation)
- TBE (Two Boson Exchange)
- RPA (Random Phase Approximation)
- IA (Impulse Approximation)
- FSI (Final State Interaction)
- SF (Spectrum Function)
- FG (Fermi Gas)
- MF (Mean Field)
- QHD EFT (Quantum HadronDynamics Effective Field Theory)
- .....

WG2: "ν scattering physics"

- Understanding of neutrino interaction ever more important in the era of *precision measurement*

Example: T2K νe appearance systematics (2013)

Systematic uncertainties

Error source	$\sin^2 2\theta_{13}=0.0$	$\sin^2 2\theta_{13}=0.1$
Beam flux + ν int.	4.9 %	3.0 %
w/ND constraint		
ν int. (from other exp.)	6.7 %	7.5 %
Far detector (+FSI+SI+PN)	7.3 %	3.5 %
Total	11.1 %	8.8 %
[Total (2012)	(13.0 %)	(9.9 %)]

T.Ishida, KEK seminar July 2013

Note: T2K will continue to reduce systematic uncertainties in future analysis.
→ benchmark for future projects