Low-energy nu cross sections, and implications (with Ulrich Mosel)

Hisakazu Minakata

U. Sao Paulo

Japan & Santa Barbara (Wiki)

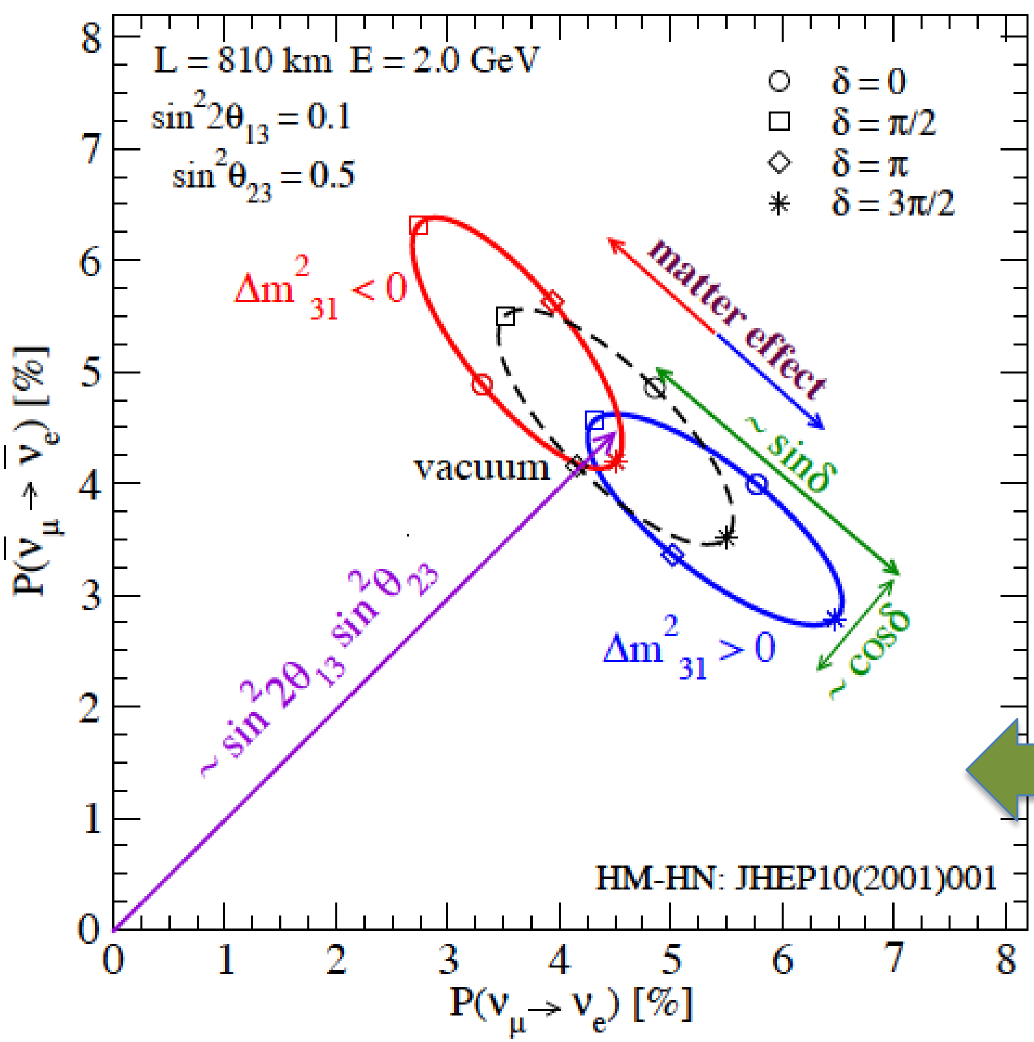
During World War II, Santa Barbara was home to Marine Corps Air Station Santa Barbara; Naval Reserve Center Santa Barbara at the harbor; was near to the Army's Camp Cook, present-day Vandenberg Air Force Base; and contained a hospital for treating servicemen wounded in the Pacific Theatre. On February 23, 1942, not long after the outbreak of war in the Pacific, the Japanese submarine *I-17* surfaced offshore and lobbed 16 shells at the Ellwood Oil Field, about 10 miles (16 km) west of Santa Barbara, in the first wartime attack by an enemy power on the U.S. mainland since the War of 1812. Although the shelling was inaccurate and only caused about $500 damage to a catwalk, panic was immediate. Many Santa Barbara residents fled, and land values plummeted to historic lows.

CP violation: warning

- Not possible to carry out unambiguous CPV detection: "$K_l \rightarrow 2\pi$□ does not appear to be possible (T-Violation would do, but ..)
- One cannot avoid CPV mimicking by other cause, matter effect, cross section errors, etc.
- May be we (theorists) should spend more time to think about possible mechanism which can mimic "CP phase effect"

Motivating for ν cross sections: CP

CP, matter effect, and all that



Use P – P-bar asymmetry + spectral modulation to measure CP phase δ

Plot first made in UNICAMP Brazil

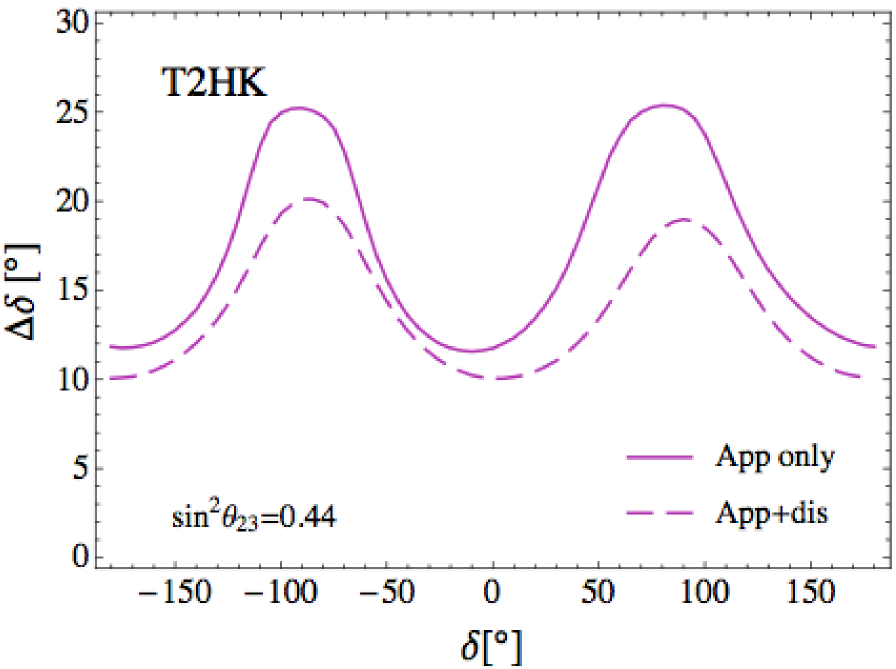
CP measurement: basics 1

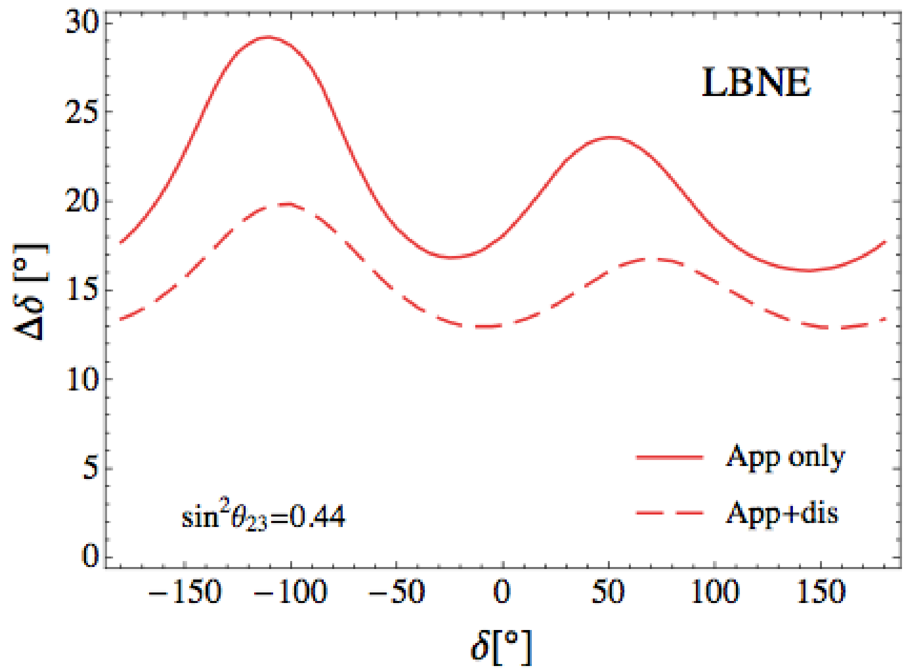
- For narrow band beam (T2K, NOVA) a set of measurement of (P, bar-P) determines δ
- However, effect of δ (cosine and sine) has to be tiny
- Because it is suppressed by two small numbers: $\Delta m^2_{21}/\Delta m^2_{31} \sim 0.031$, $J_r = c_{12}s_{12}c_{23}s_{23}s_{13} \sim 0.035$
- Altogether it is $P_{\mu e} \sim 10^{-3}$ → we need big detector/intense neutrino beam

CP measurement: basics 2

- For narrow band beam (T2K, NOVA) a set of measurement of (P, bar-P) determines δ
- There might be issues like, degeneracy etc. but let's ignore them
- Probably the most crucial issues are:
- To know nu and bar-nu flux accurately
- To know nu and nu-bar cross sections accurately

Expected CP sensitivity: $\Delta\delta \sim 10\text{-}20^{o}$





P.Coloma, HM, S.J.Parke
1406.2551

T2HK: 7.5 MW year
LBNE: 20 MW year
(year = 10^7 sec)

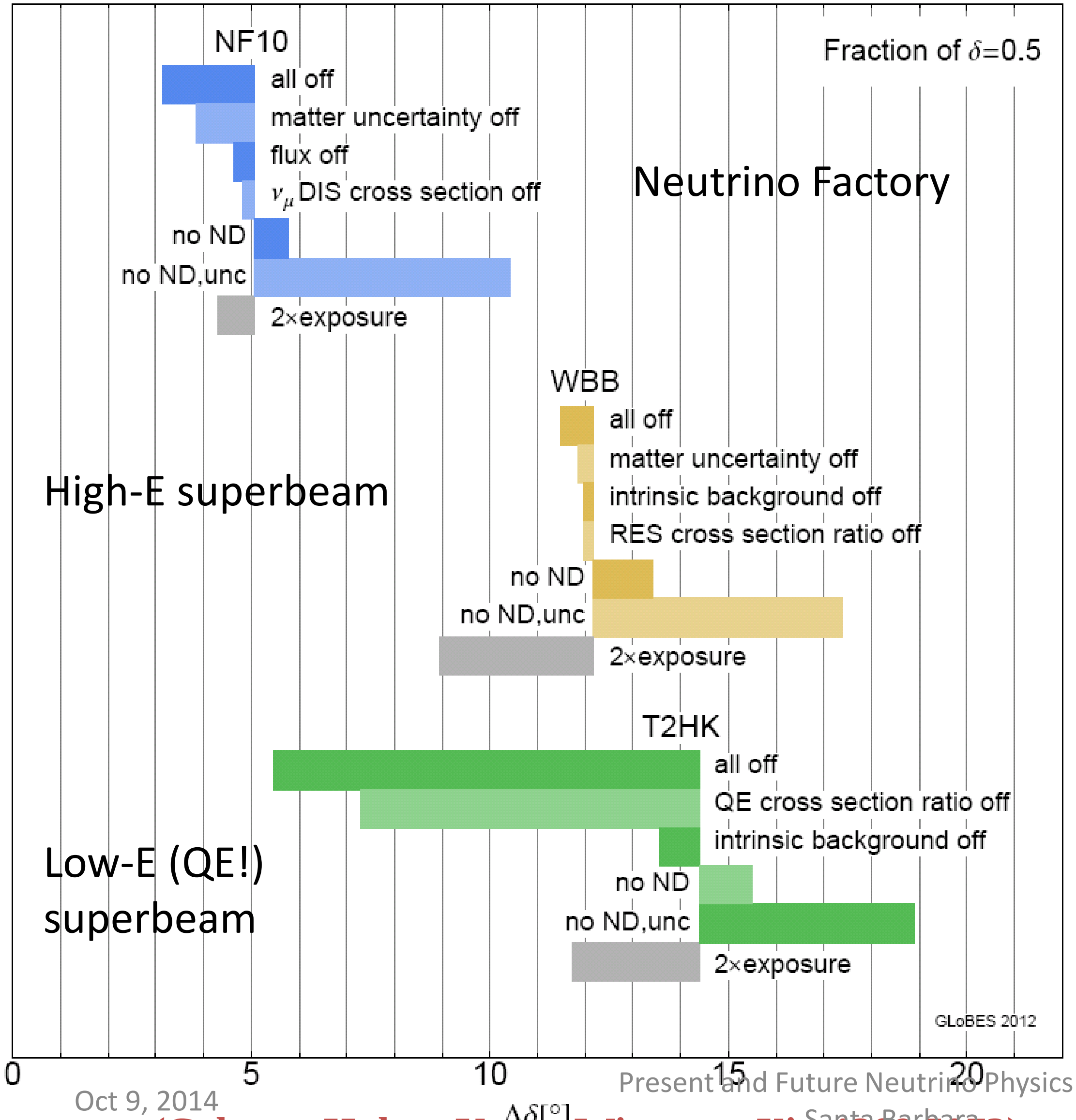
Let us examine some of them

	L (km)	Detector (kton)	Beam Power	E_p (GeV)	Flux peak	$(t_\nu, t_{\bar{\nu}})^\dagger \times 10^7 s$
LBNE	1300	LAr - 34	1.2 MW	120	3 GeV	(8.25, 8.25)
T2HK	295	WC - 560	0.75 MW	30	0.6 GeV	(3, 7)
ESSνSB	540	WC - 500	5 MW	2.5	0.3 GeV	(3.4, 13.6)
IDS-NF	2000	MIND - 100	10^{21} $\mu^\pm/10^7$ sec	NA	6 (9) GeV	$(10, 10)^\ddagger$

	Energy range	ν app.	$\bar{\nu}$ app.	ν dis.	$\bar{\nu}$ dis.
LBNE	0.5 - 8.0 GeV	1095/314	324/208	7340/82	3873/27
T2HK	0.4 - 1.2 GeV	3984/1705	2161/1928	26237/716	19232/735
ESSνSB	0.1 - 1.0 GeV	270/85	244/82	6198/113	4128/79
IDS-NF	0.1 - 9.0 GeV	20241/476	5257/269	171133/7370	106077/3279

P. Coloma, HM, & S.Parke, Note it's a very balanced collaboration! arXiv:1406.2551

Main cause of error for CP (slide borrowed from Walter, modified)



Robust wrt systematics
Main impact:
Matter density uncertainty

Operate in statistics-limited regime

Exposure more important than near detector

QE ν_e X-sec critical:
no self-consistent measurement

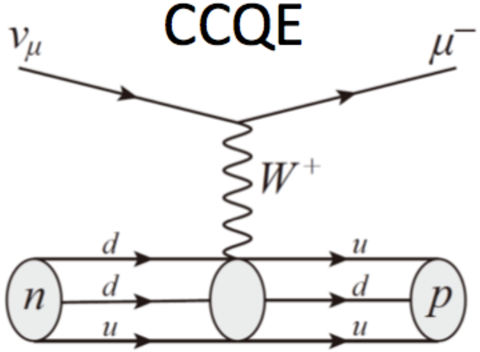
Theory: ν_e/ν_μ ratio?
Experiment: νSTORM?

(Coloma, Huber, Kopp, Winter, arXiv:1209.5973)

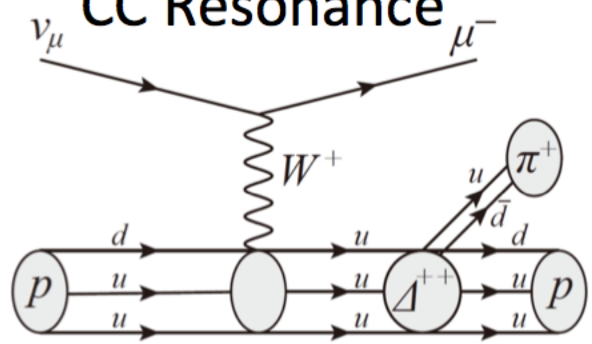
Measuring cross section must be easy

ND280 Tracker Event Selection

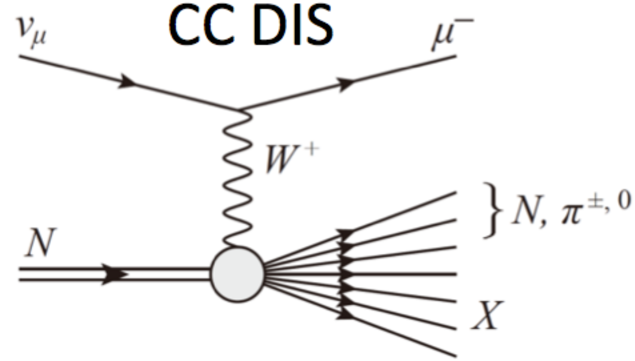
CCQE



CC Resonance

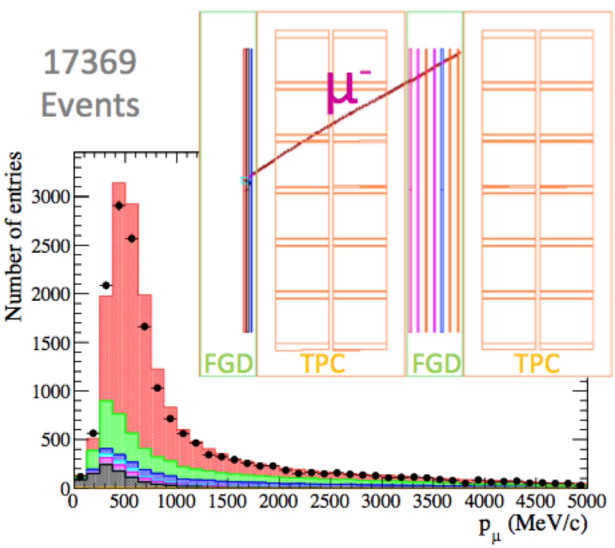


CC DIS



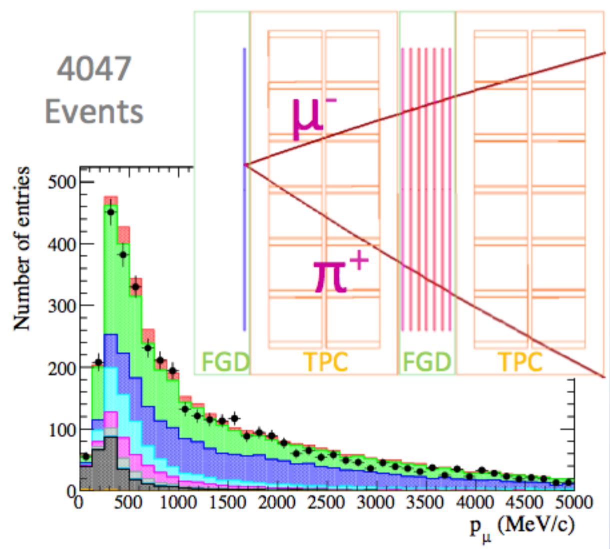
CC 0π Enriched

(CCQE Purity: 63%)



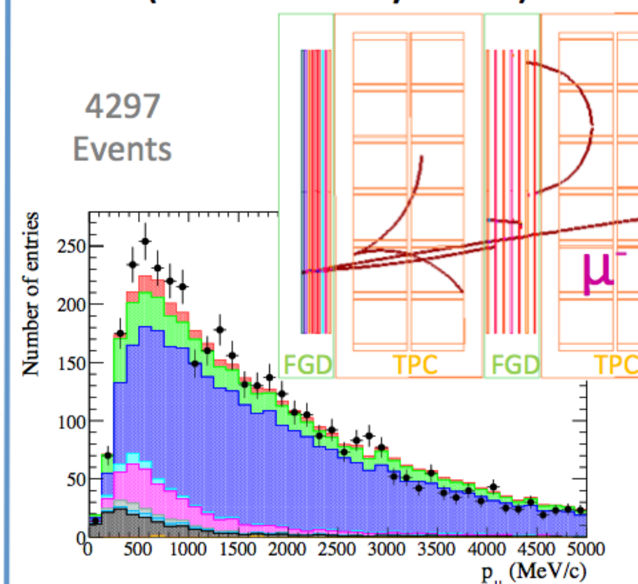
CC 1π⁺ Enriched

(CC Res. Purity: 39%)



CC Other Enriched

(CC DIS Purity: 68%)

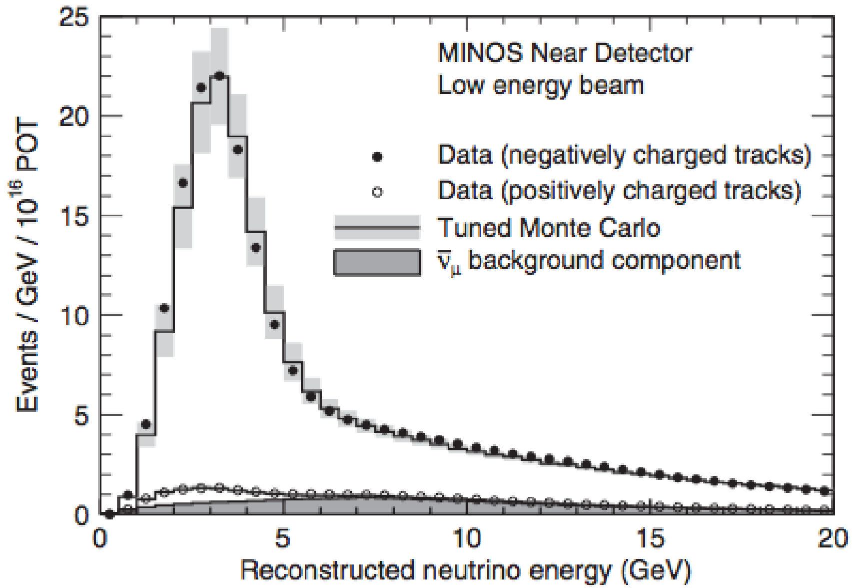


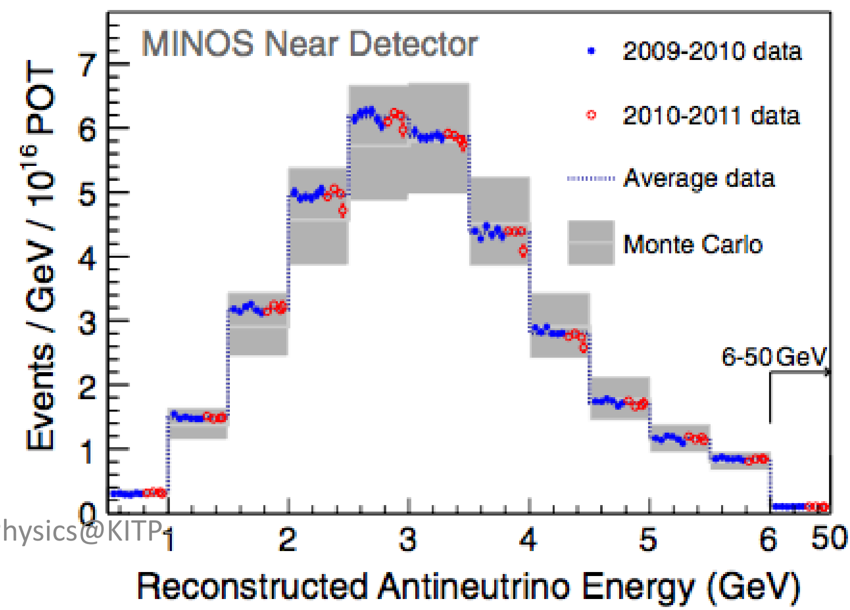
MC Legend: CCQE | Out-of-FGD | CC Coherent | CC Res. | NC | CC DIS

Do you know ν flux? No!

To measure neutrino nucleus cross section

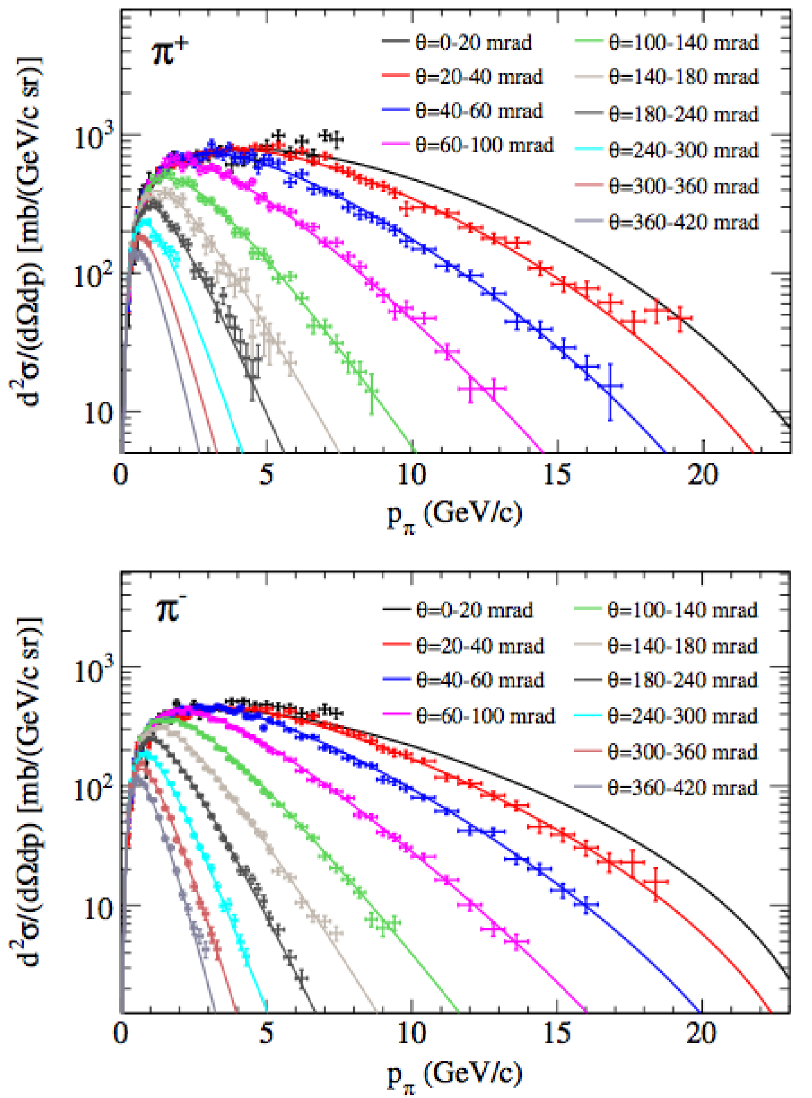
- To measure neutrino nucleus cross section one has to know neutrino flux
- To determine nu flux one has to carry out hadron production experiments (preferably with replica target) to know pion (kaon) momentum distribution as accurately as possible





For T2K: NA61/SHINE @ CERN

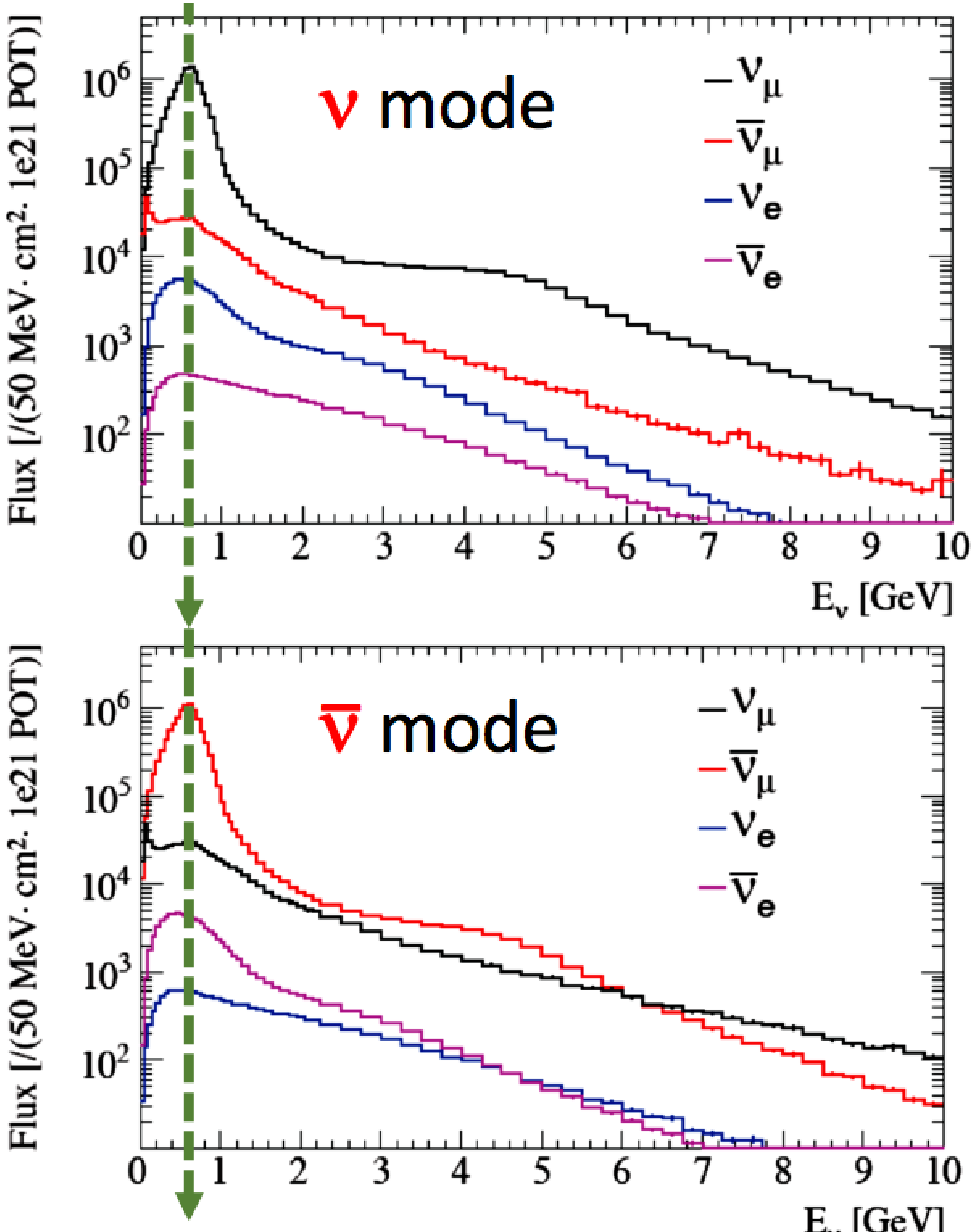
PHYSICAL REVIEW D **87,** 012001 (2013)



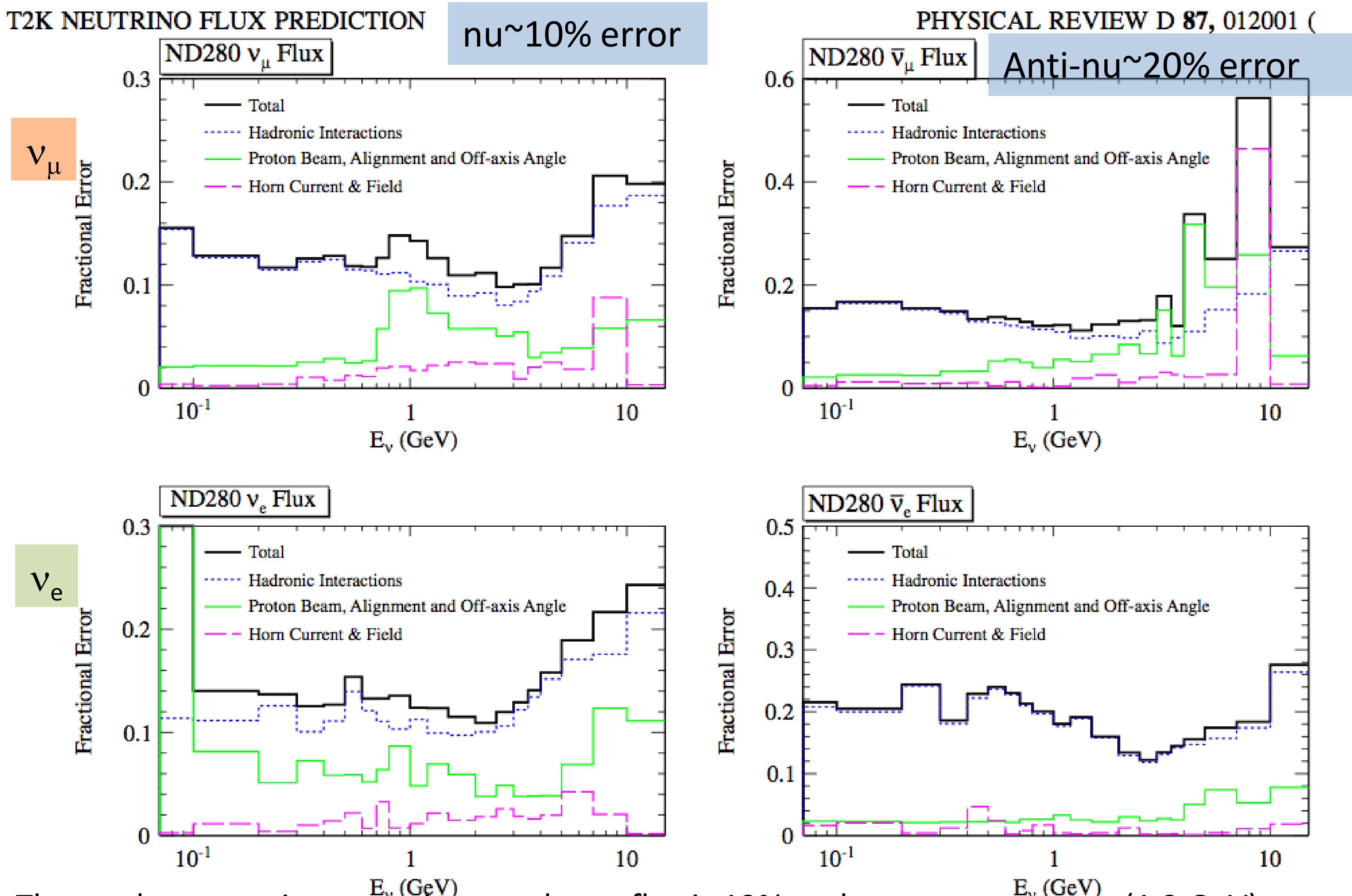
Thin target

FIG. 28 (color online). The BMPT fits to the NA61/SHINE pion production data.

T2K flux prediction: ν and anti-ν

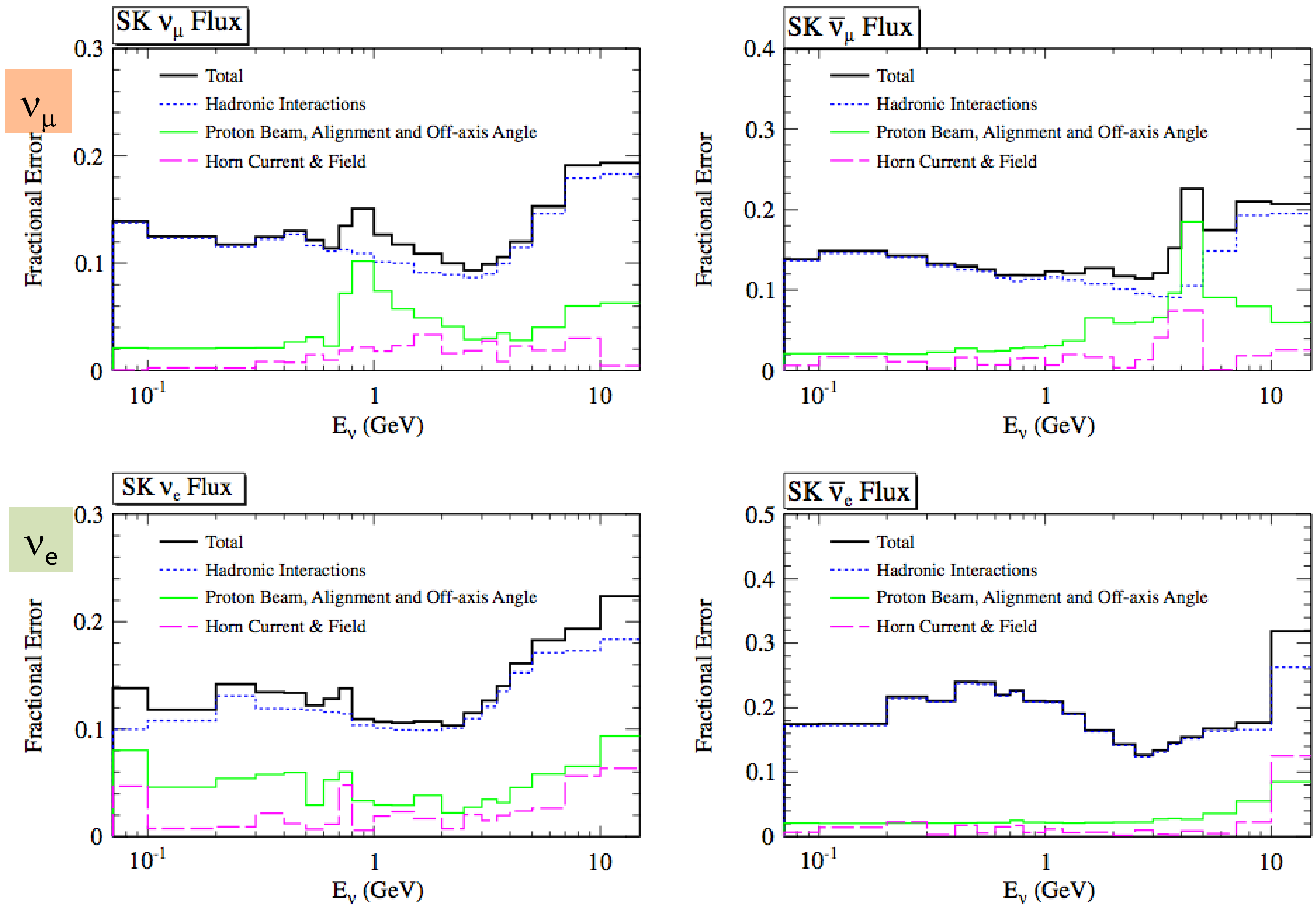


nu flux error at ND280

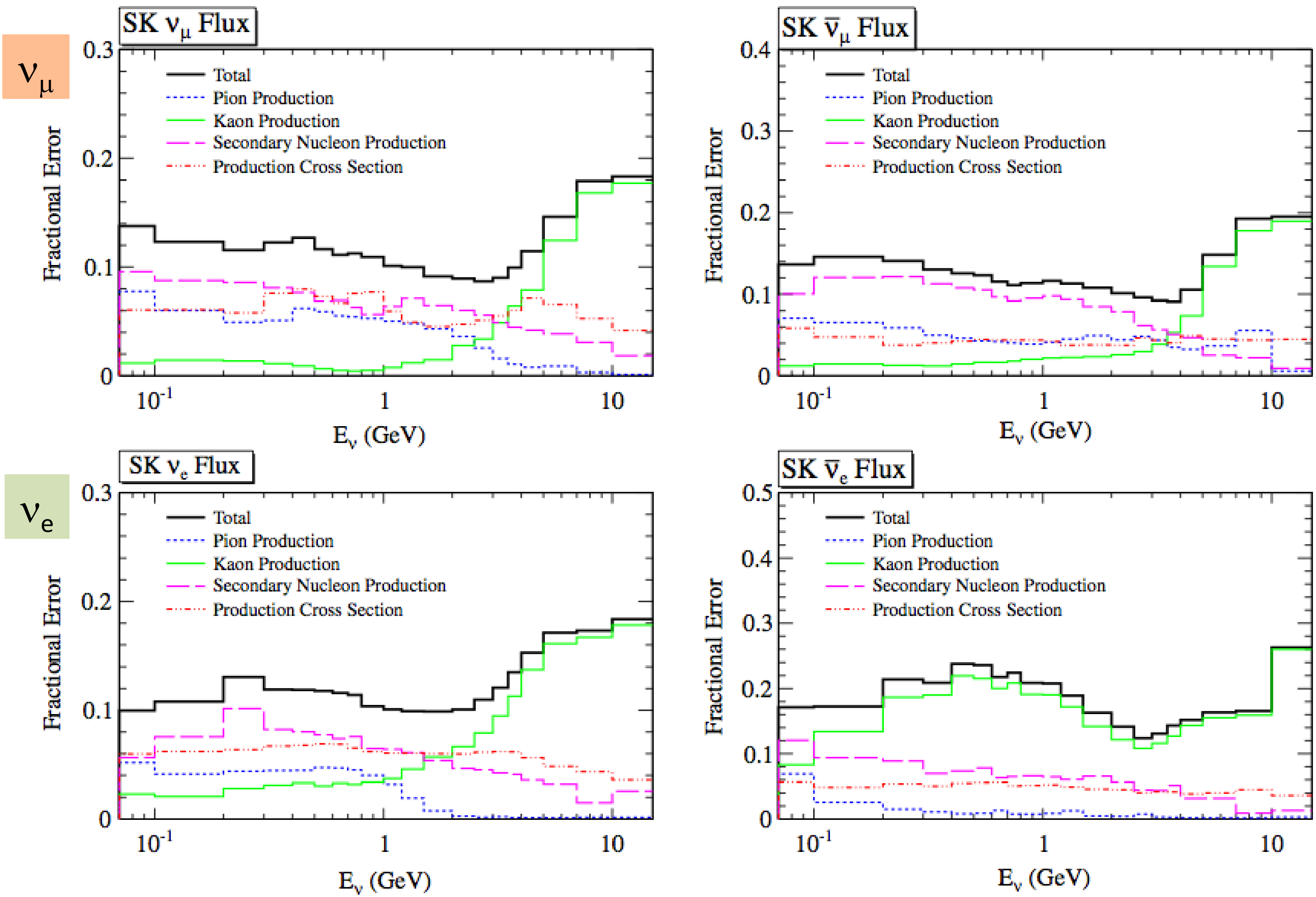


The total systematic uncertainty on the ve flux is 13% at the mean ve energy (1.3 GeV).

nu flux error at SK



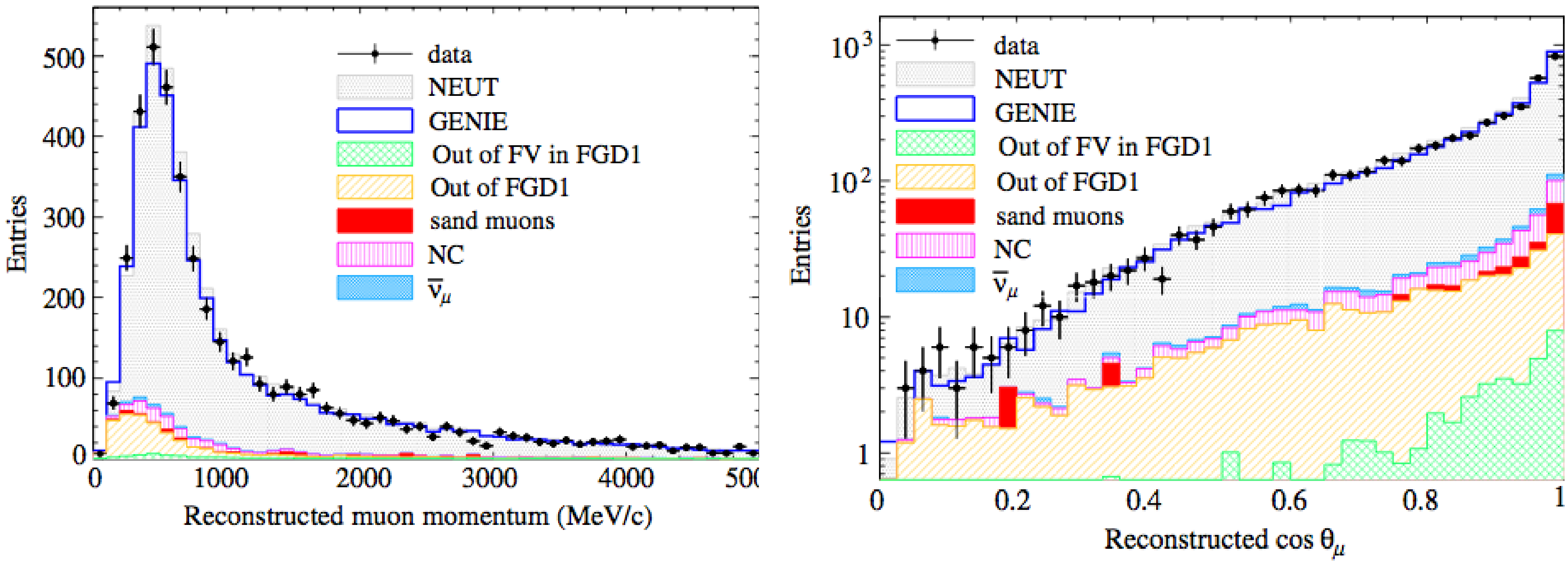
Uncertainty: Hadron production dominates



C

FIG. 38 (color online). Fractional flux error due to hadron production uncertainties.

T2K ν_μ CC inclusive



PRD D 87, 092003 (2013)

FIG. 9 (color online). The muon momentum and angle distribution for the selected events in the data and MC. The GENIE prediction is shown by the solid blue line, while the backgrounds and signal as derived from NEUT are shown in filled colors.

T2K flux-averaged ν_μ CC cross section

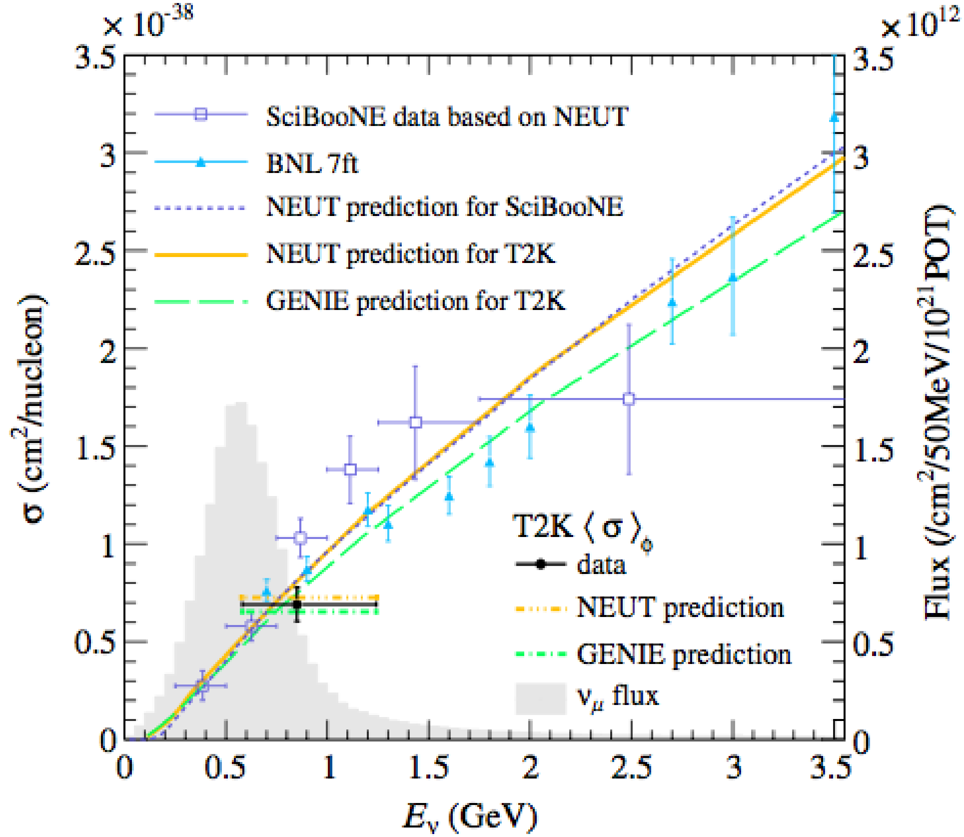
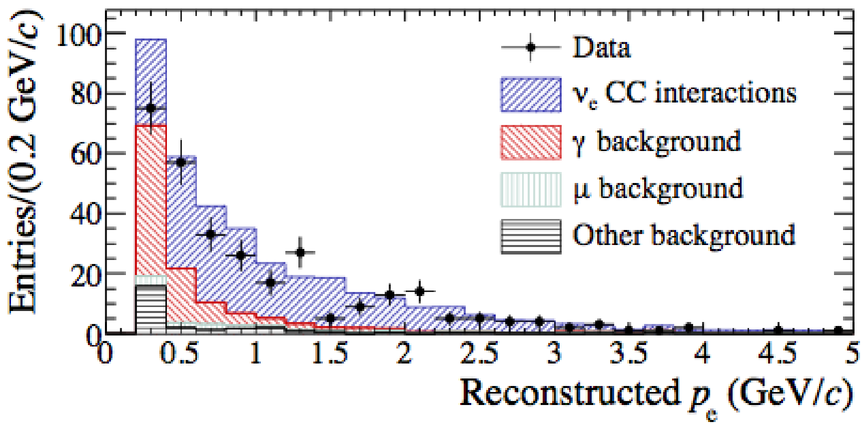
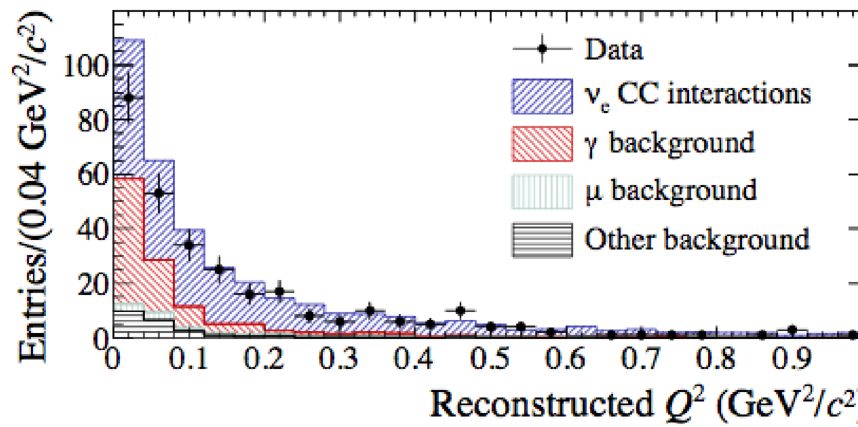


FIG. 13 (color online). The T2K total flux-averaged cross section with the NEUT and the GENIE prediction for T2K and SciBooNE. The T2K data point is placed at the flux mean energy. The vertical error represents the total (statistical and systematic) uncertainty, and the horizontal bar represent 68% of the flux at each side of the mean energy. The T2K flux distribution is shown in grey. The predictions for SciBooNE have been done for a C_8H_8 target [52] which is comparable to the mixed T2K target. BNL data has been measured on deuterium [53].

T2K ν_e CC





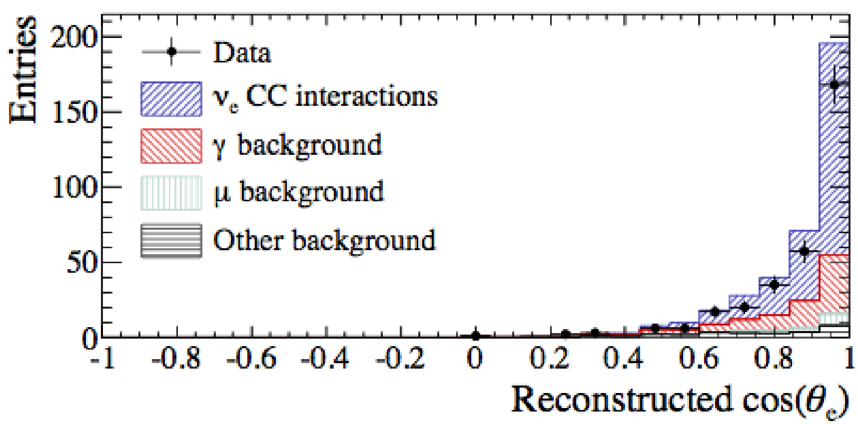


FIG. 1. Reconstructed p_e (top), $\cos(\theta_e)$ (middle) and Q^2 (bottom) distributions of ν_e event candidates. The NEUT Monte Carlo prediction is separated into the ν_e CC interaction signal, background from $\gamma \to e^+e^-$ conversions, background from μ^- tracks and all other backgrounds. The last bins in the top and bottom plots do not include the overflow of events.

T2K ν_e CC

1407.7389
315 ve CC interaction candidates are selected, with an expected purity of 65%.

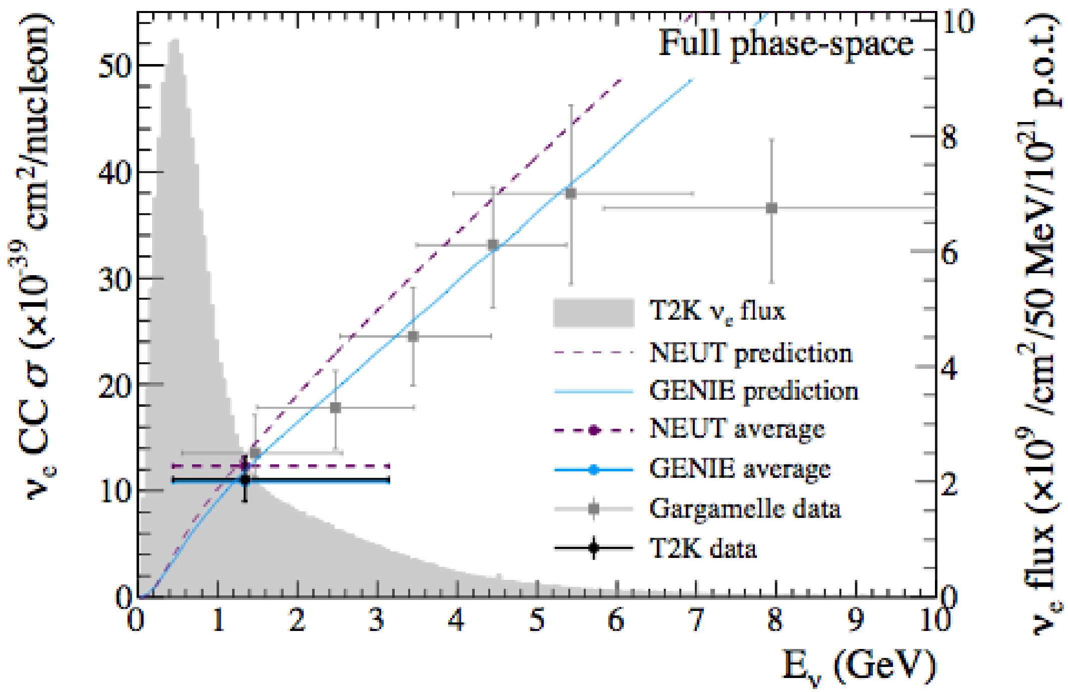


FIG. 3. Total ν_e CC inclusive cross-section when unfolding through Q^2. The T2K data point is placed at the ν_e flux mean energy. The vertical error represents the total uncertainty, and the horizontal bar represents 68% of the flux each side of the mean. The T2K flux distribution is shown in grey. The NEUT and GENIE predictions are the total ν_e CC inclusive predictions as a function of neutrino energy. The NEUT and GENIE averages are the flux-averaged predictions. The Gargamelle data is taken from Ref. [9].

How to deal with ν_e cross section?

T2K ne flux is mostly from muon decay

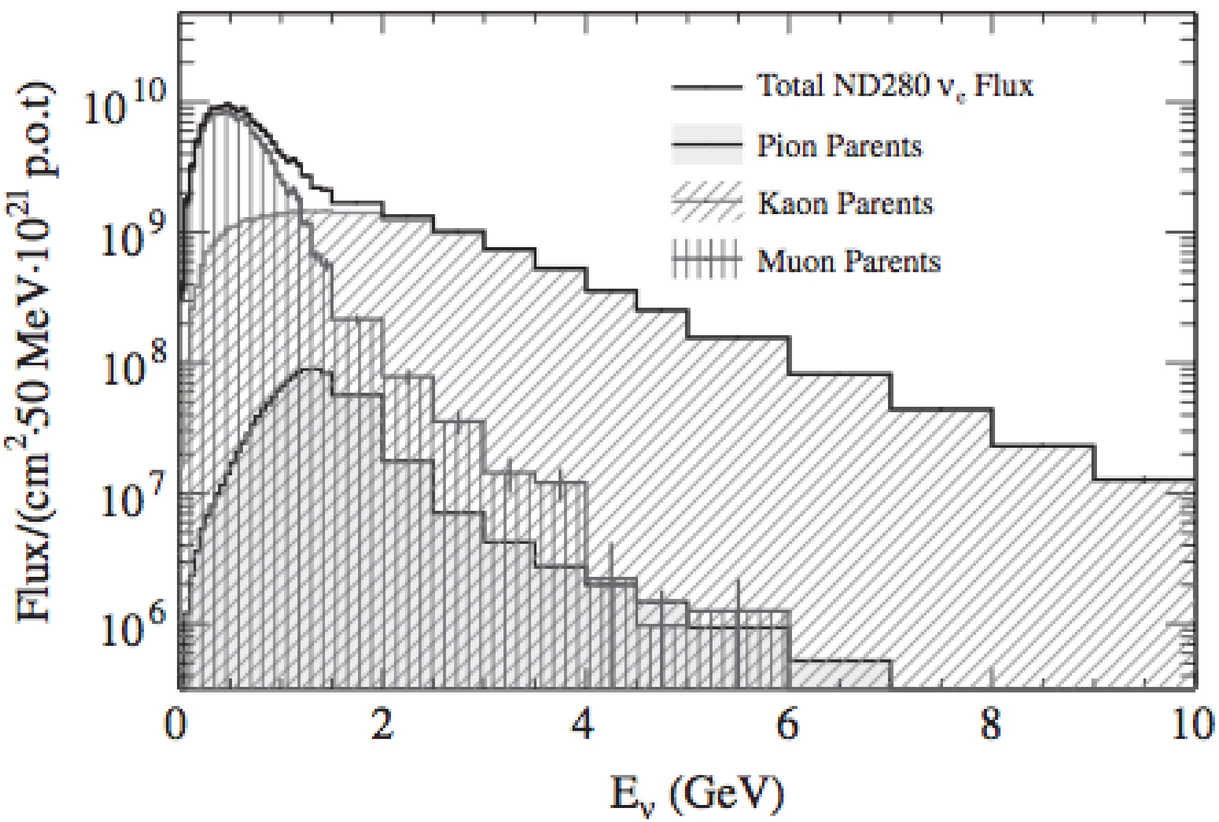


FIG. 1. The prediction of the ν_e flux at ND280 broken down by the neutrino parent particle type [4].

TABLE VI: The parameters used to vary the NEUT cross section model along with the values used in the ND280 fit (input value) and uncertainties prior to the ND280 and SK data fits.

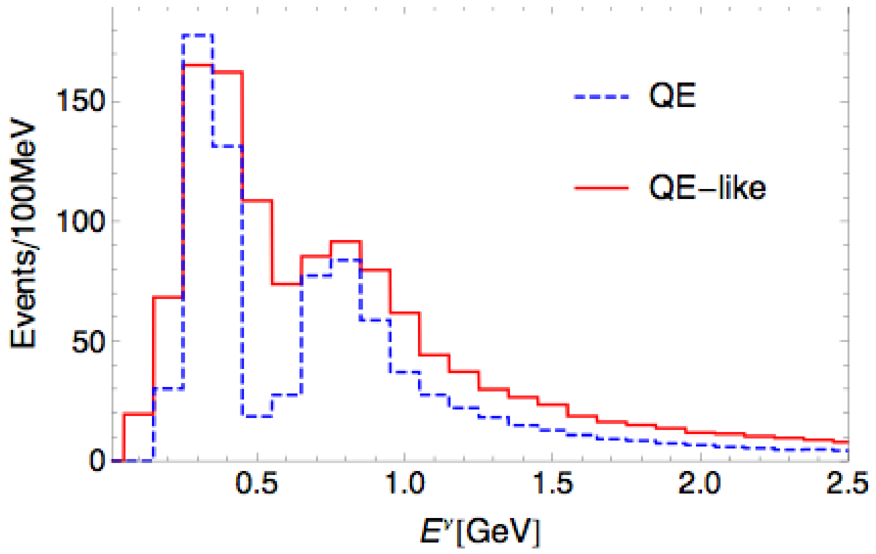
Parameter	Input Value	Uncertainty
M_A^{QE} (GeV)	1.21	0.43
x_1^{QE}	1.00	0.11
x_2^{QE}	1.00	0.30
x_3^{QE}	1.00	0.30
x_{SF}	0.0	1.0
$p_F(^{12}C)$ (MeV/c)	217	30
$p_F(^{16}O)$ (MeV/c)	225	30
M_A^{RES} (GeV)	1.16	0.11
$x_1^{CC1\pi}$	1.63	0.43
$x_2^{CC1\pi}$	1.00	0.40
$x^{NC1\pi^0}$	1.19	0.43
$x_{1\pi E_\nu}$	off	on
W_{eff}	1.0	0.51
$x_{\pi-less}$	0.2	0.2
$x^{CCcoh.}$	1.0	1.0
$x^{NCcoh.}$	1.0	0.3
$x^{NCother}$	1.0	0.3
$x_{CCother}$ (GeV)	0.0	0.4
x_{ν_e/ν_μ}	1.0	0.03

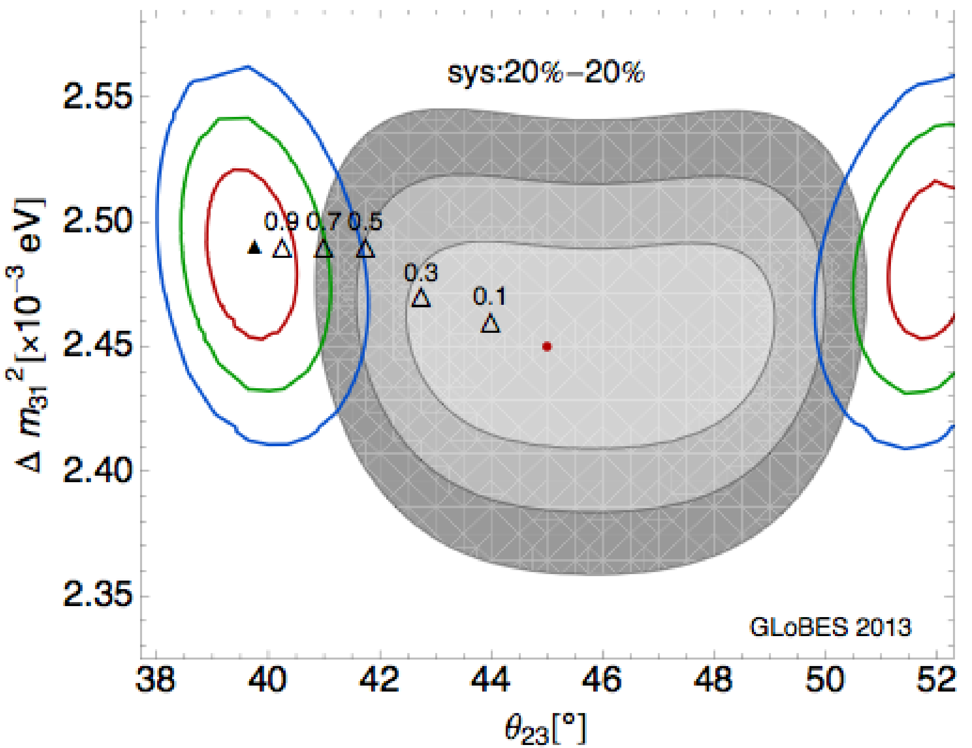
ν_e/ν_μ determined at 3% error

arXiv:1304.0841

Effect on θ_{23}

If QE and non-QE are not separated appropriately …





P.Coloma-P.Huber, 1307.1243

ArgoNeuT sees nucleon correlations

ArgoNeut saw SRC in nuclei

240 Kg active volume

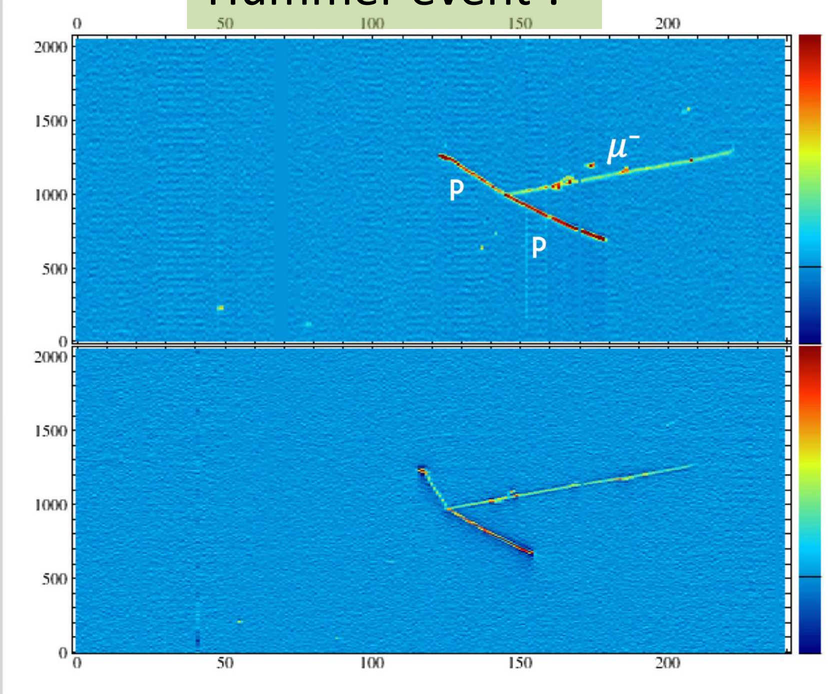
47×40×90 cm^3, wire spacing 4 mm

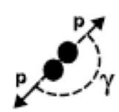
LAr TPC

~7000 CC events

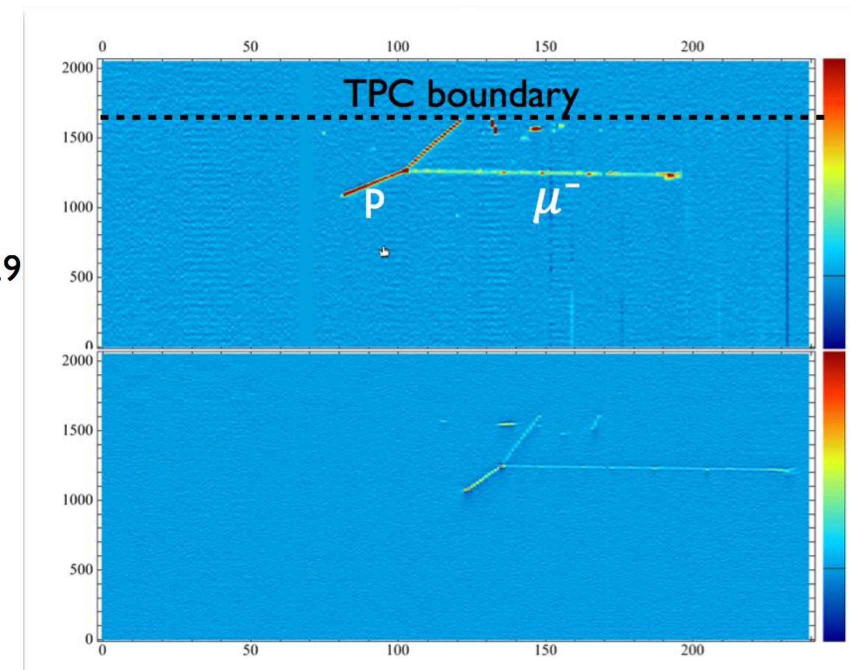
(μ-+2p) triple coincidence topology events 30 (19 collected in the anti-neutrino mode run and 11 in the neutrino mode run) fully reconstructed events

Hummer event !

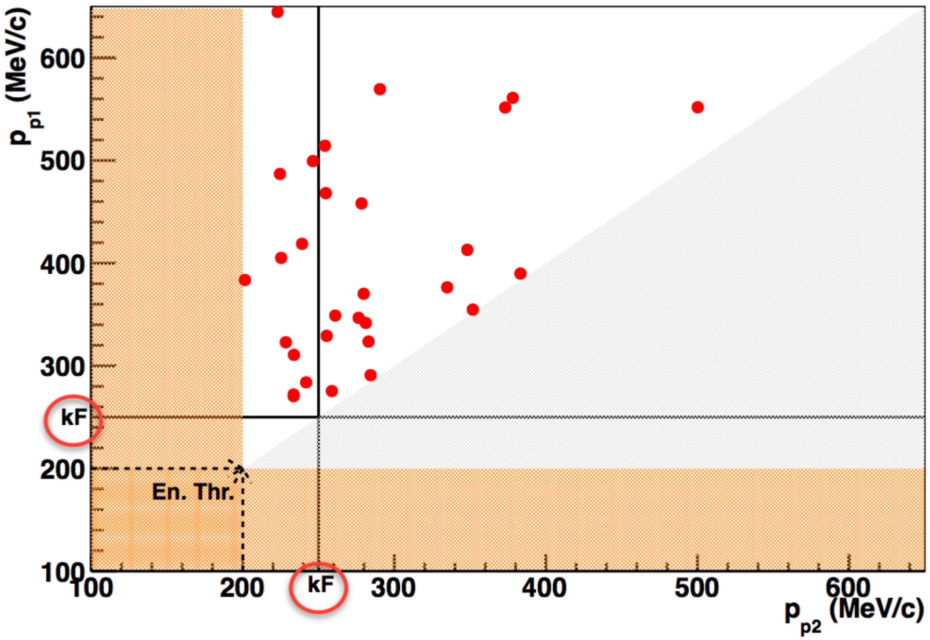




cos(γ)<-0.9

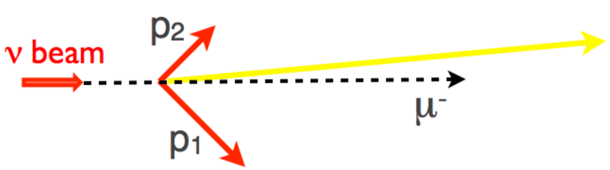


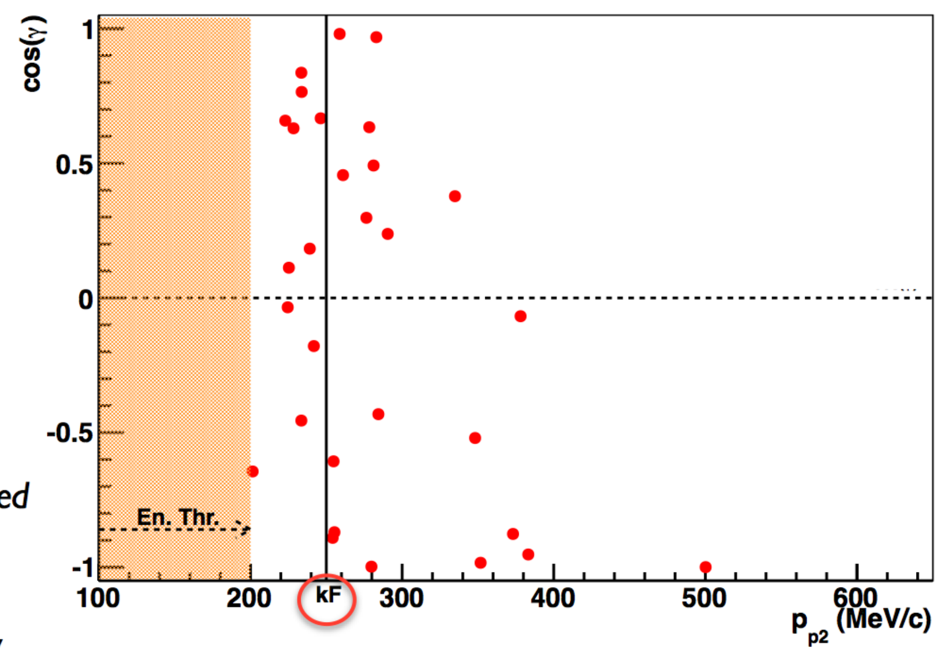
(μ⁻+2p) data sample



Momentum of the more energetic proton p_{p1} in the pair vs. momentum of the other (less energetic) proton p_{p2}

Most of the events (19 out of 30) have both protons above Fermi momentum of the Ar nucleus ($k_F \simeq 250$ MeV/c)





cos(γ) vs momentum of the least energetic proton p_{p2} in the pair

*γ=angle in space between the two detected proton tracks in the **Lab reference frame***

Fermi gas model tends to overestimate cross sections

E. Fernandez Martinez, D. Meloni / Physics Letters B 697 (2011) 477–481 4

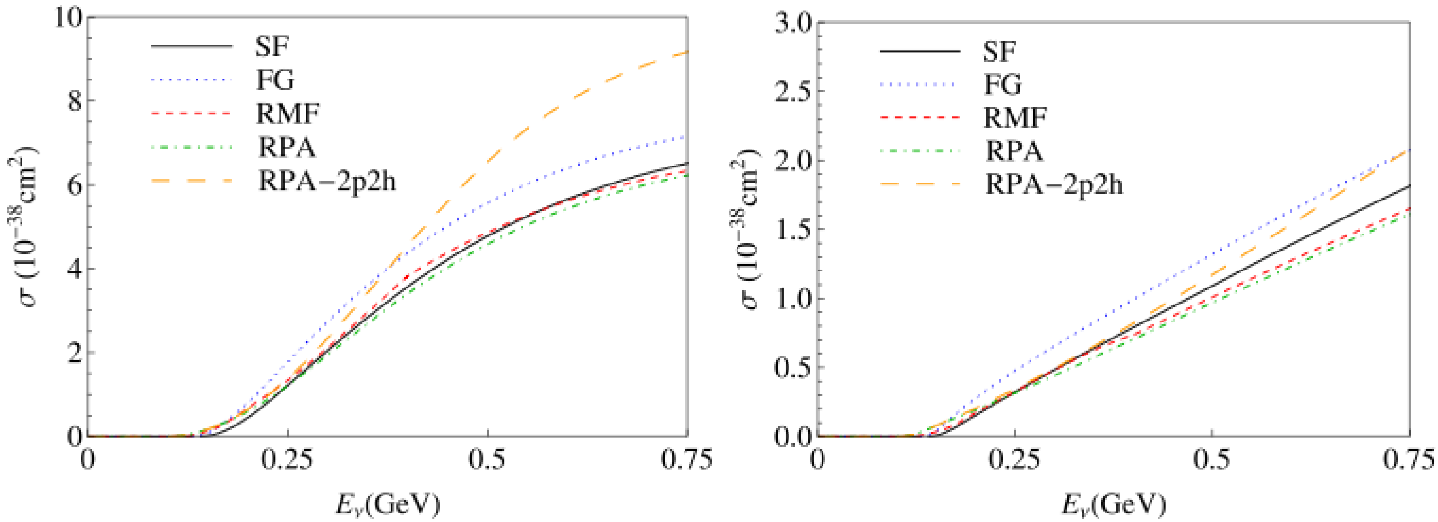
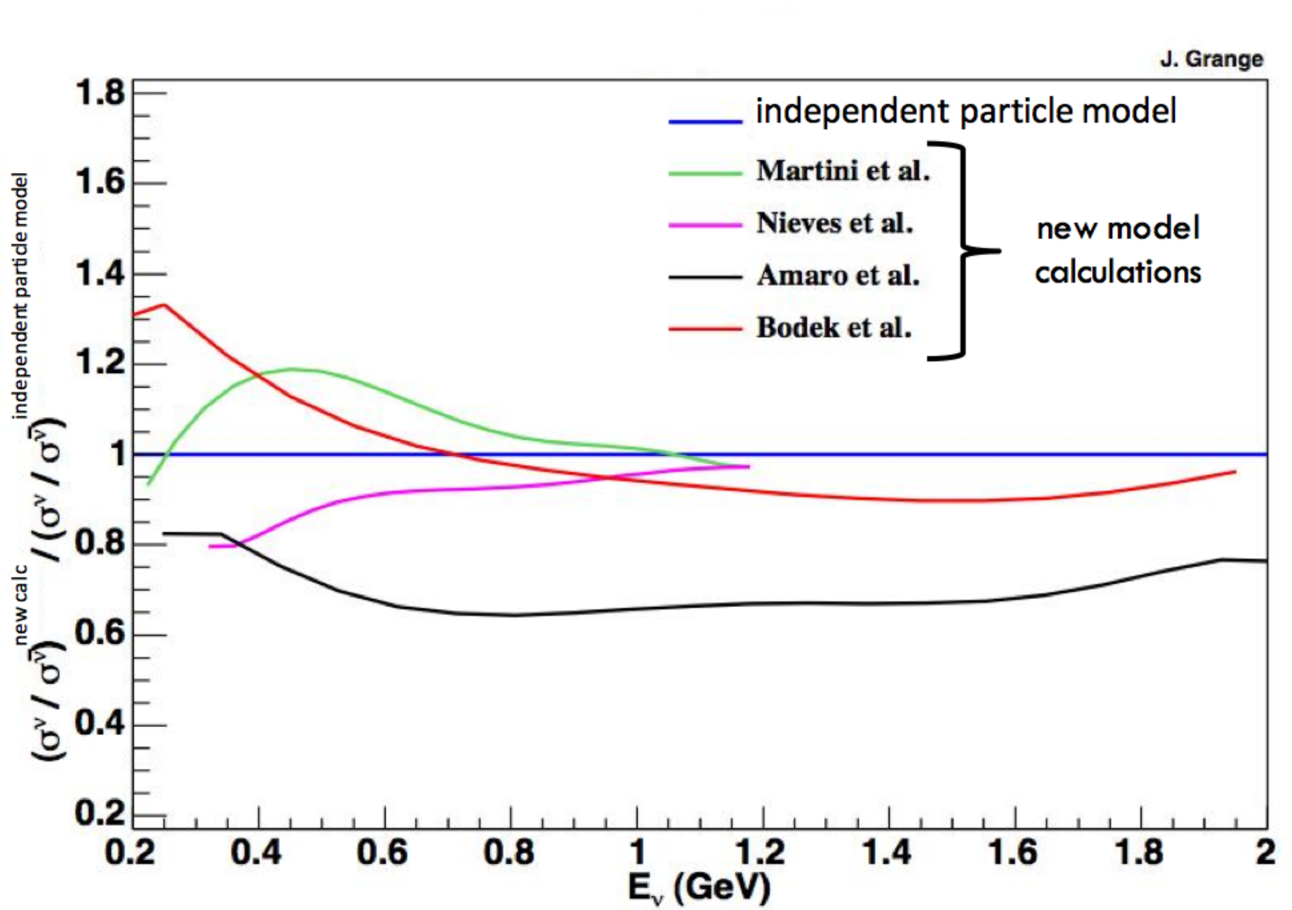


Fig. 1. Total charged current QE cross sections for the $\nu_\mu {}^{16}O \to \mu^- X$ (left panel) and $\bar{\nu}_\mu {}^{16}O \to \mu^+ X$ (right panel) processes in the energy range $E_\nu \sim [0, 0.75]$ GeV.

What about neutrino/antineutrino cross section ratios?

- Different models predict different ratios



And these are ν_{μ} cross section ratios,
Also need this for ν_e

And the theorists are assuming we'll know these ratios (times acceptances) to 1-3% each…

Slide courtesy G. Zeller

Conclusion

- CP phase effect is a small effect, and so flux and cross section errors must be controlled
- For flux, dedicated hadron production measurement indispensable
- For cross section, near detector can do the job, but the current error is ~10% for ν_μ and ~20% for ν_e at T2K
- Serious effects ongoing to reduce the errors of ν flux and ν cross sections

replica target soon!