ν-interaction uncertainties or other measurements

"As these experiments accumulate increasingly large data sets, the contribution of systematic errors will become more significant in the oscillation analysis"

Saint surrounded by three pi mesons
Salvador Dali, 1956

Akihiro Minamino
Kyoto University
Hiroshi Nunokawa
PUC-Rio de Janiero
Rik Gran
University of Minnesota Duluth

NuInt15 summary

ν-interaction uncertainties or other measurements

Saint surrounded by three pi mesons
Salvador Dali, 1956

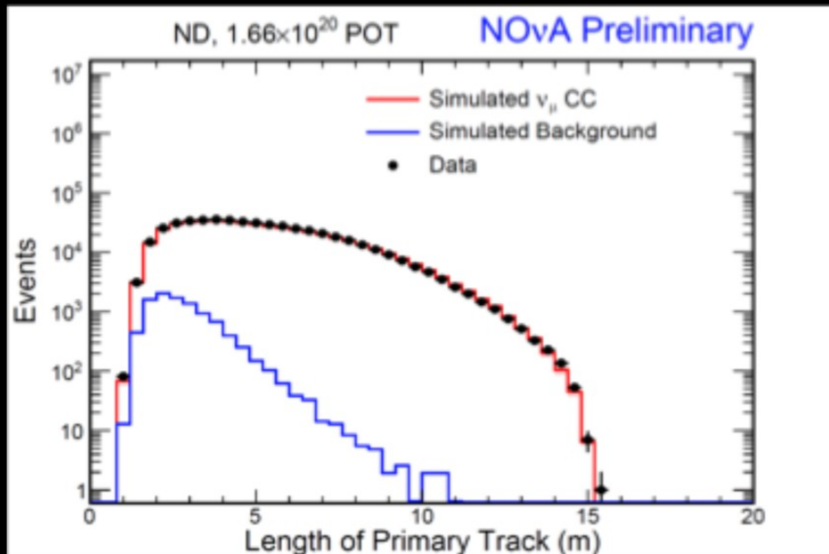
"As these experiments accumulate increasingly large data sets, the contribution of systematic errors will become more significant in the oscillation analysis"

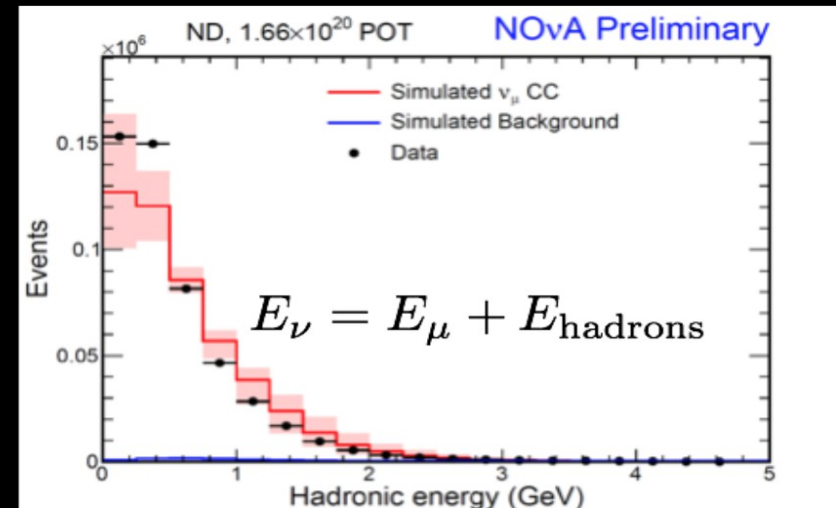
Introduction to NuInt01 proceedings
Morfin, Sakuda, Suzuki

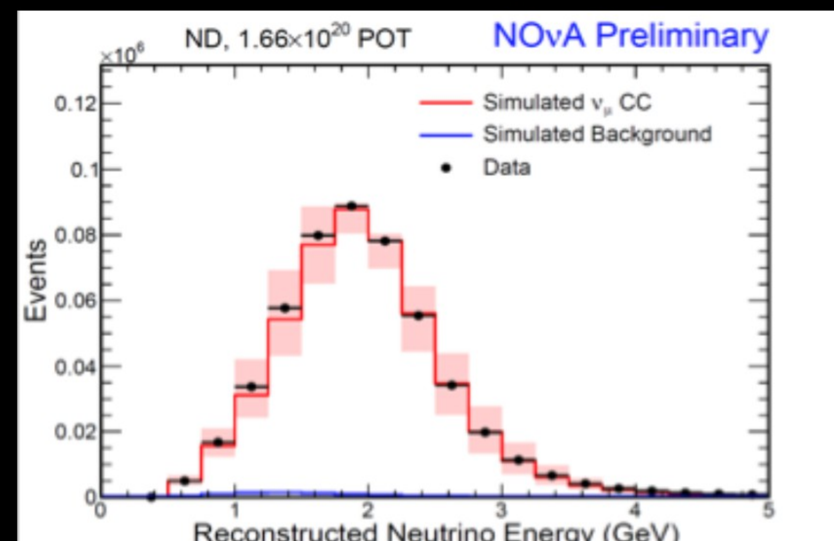
Its a good thing we got an early start

NOvA's largest systematic today

E_{HAD} SYSTEMATIC





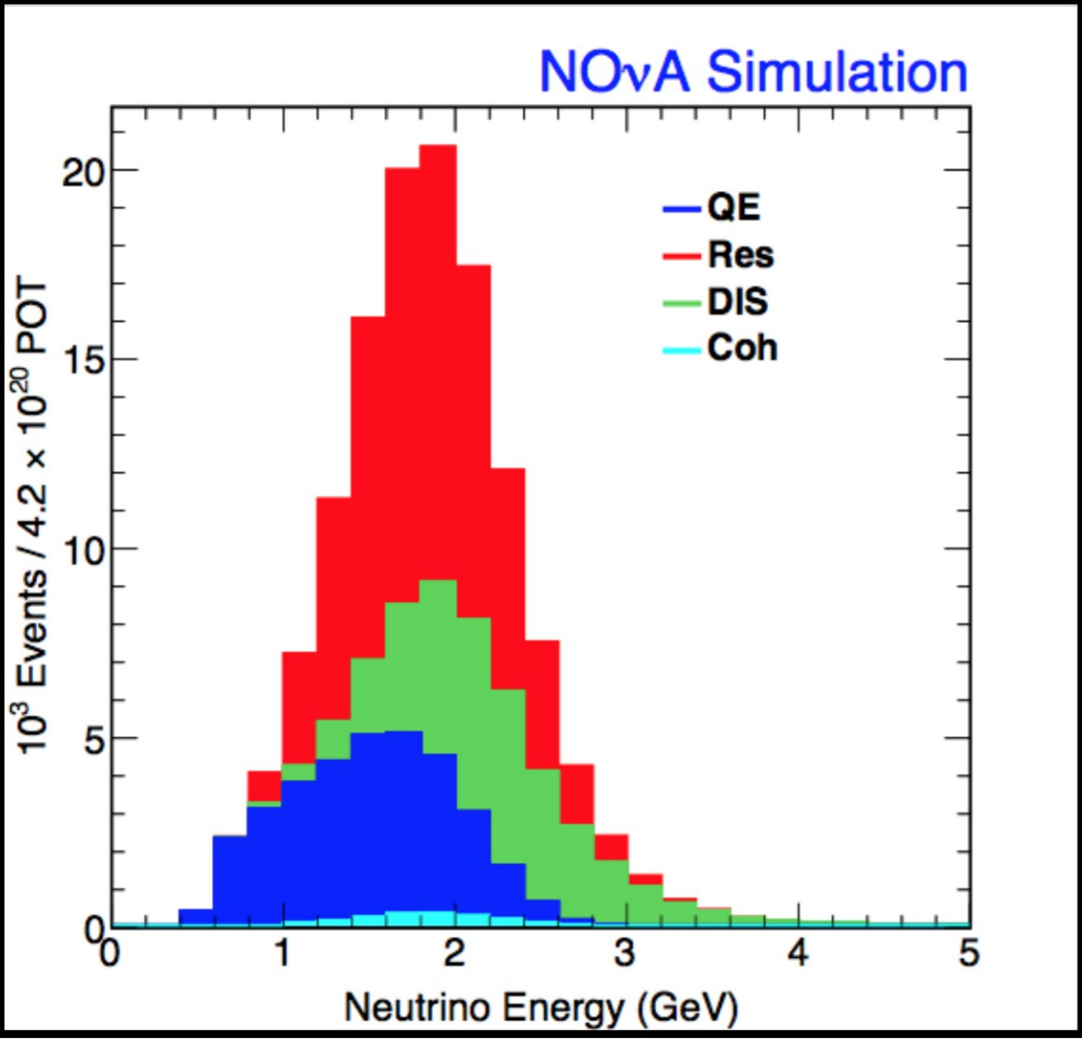


- Muon variables agree well
- Monte Carlo puts 21% more energy into hadron system than seen in data
- Recalibrated the hadronic energy scale to match peaks of the data and MC.
  Correction taken as a systematic on the absolute energy scale
  (6% overall neutrino energy scale uncertainty).

Based on discrepancy between Near Detector data and MC not-yet-known combination of detector, cross section types

Mathew Muether, Wichita State University

ν_μ CC INTERACTIONS



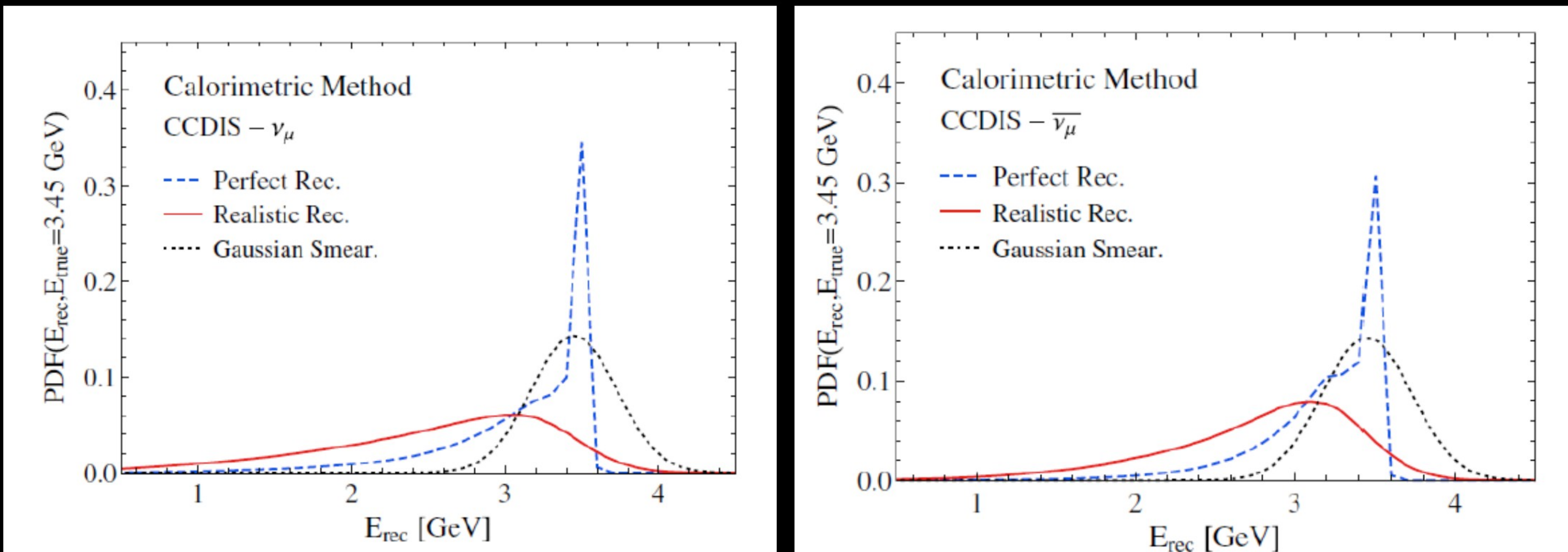
- NOvA has access to all interction types with a narrow-band beam.

Recurring theme, multiple interaction types contribute uncertainties in each are often unique, uncorrelated

Reconstructed-energy distributions

DIS at E=3.5 GeV

C. Mariani



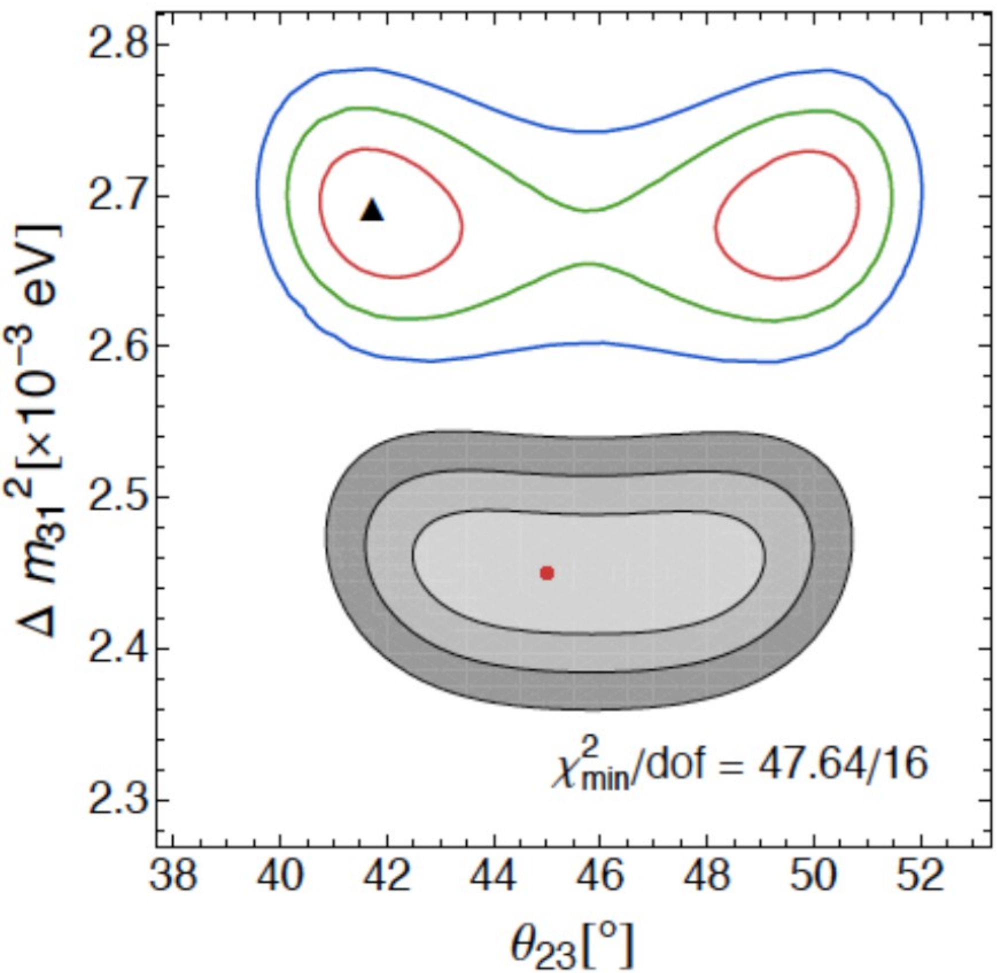
Phys. Rev. D 92, 073014 (2015)
Ankowski,Benhar,Coloma,Huber,Jen,CM, Vagnoni,Meloni

Modeling/tagging neutron final states in DUNE-like experiment
Calorimetric smearing into oscillation max due to DIS

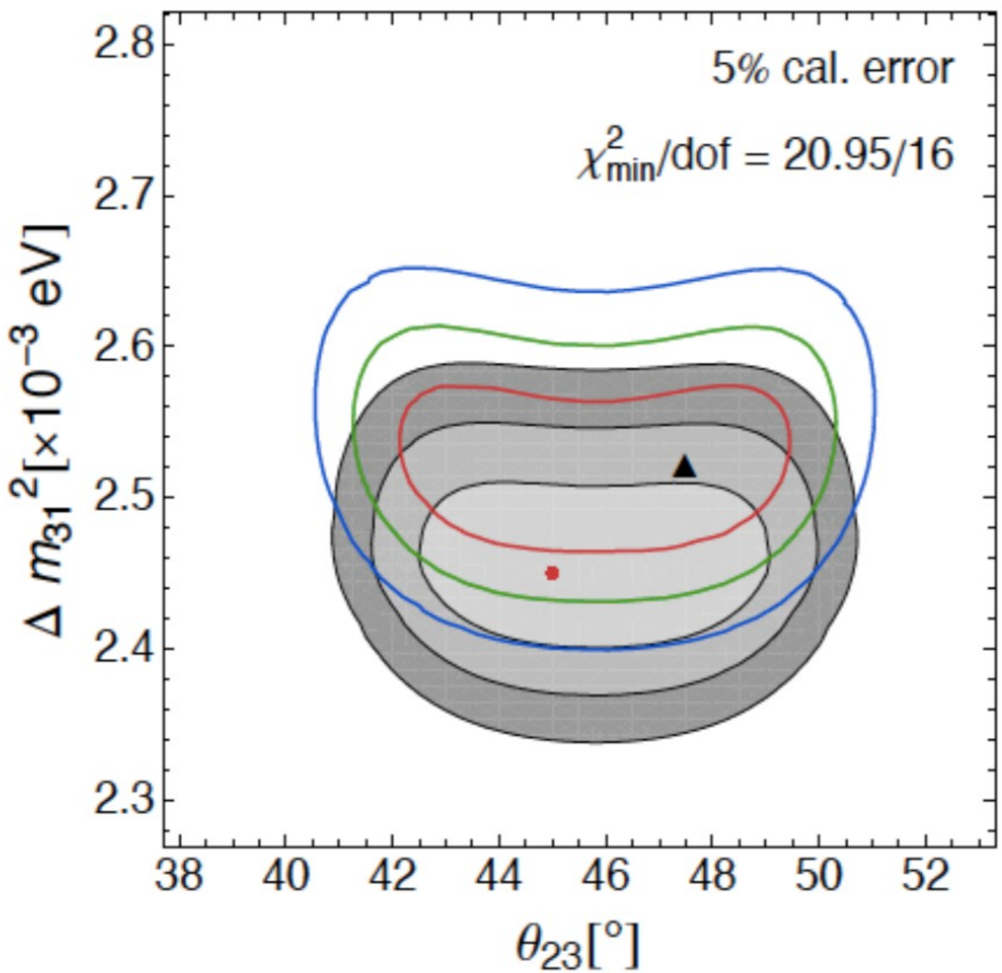
Impact on oscillation T2K/HyperK-like setup

(simulate with one neutrino interaction generator (GENIE) and fit with another generator (GiBUU))

Phys. Rev. D 89, 073015 (2014)
Coloma, Huber, Jen and CM



(a) No calibration error



(b) 5% calibration error

HyperK and DUNE

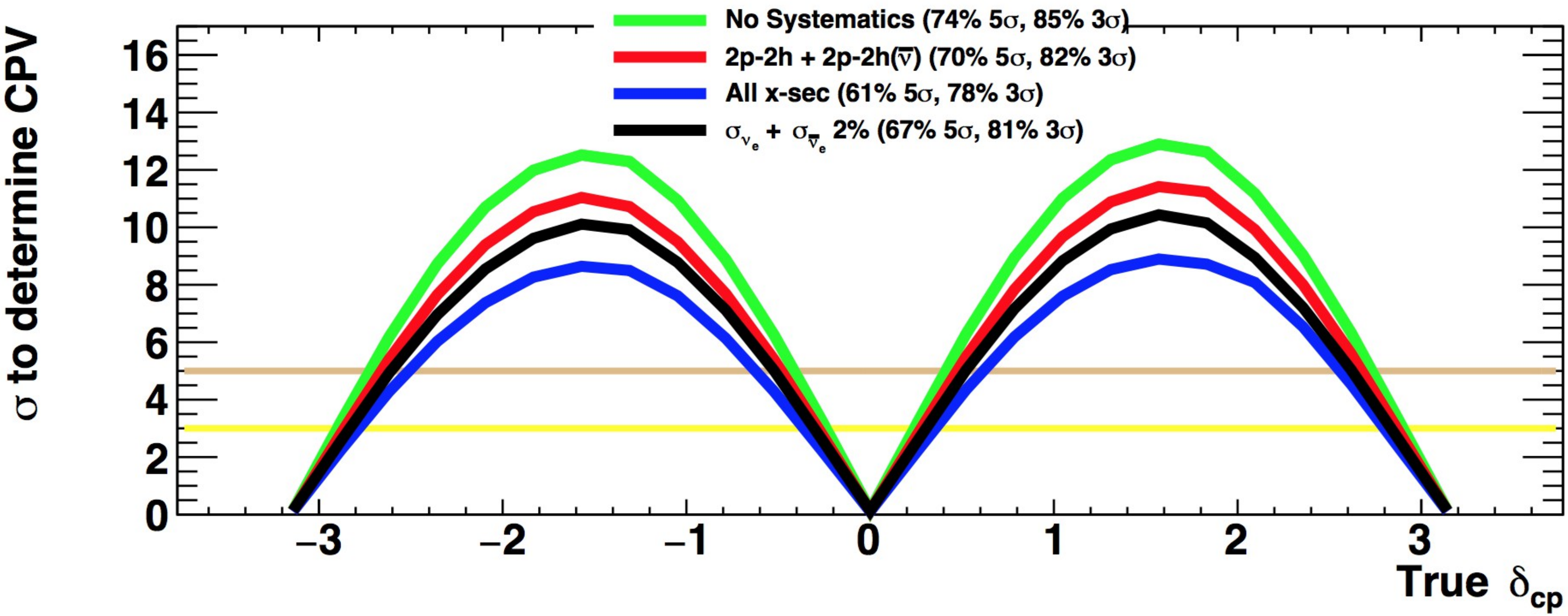
studies WITHOUT a near detector
that show what degrades CP sensitivity

If you have to optimize (make compromises)
in designing a near detector
these inform what is most valuable.

n.b. HyperK (WC) strongly favors kinematic reconstruction
DUNE (Lar) can use calorimetry and kinematics

Raj Shah Study without near detector, degraded sensitivity

ν_e - anti ν_e + 2p-2h



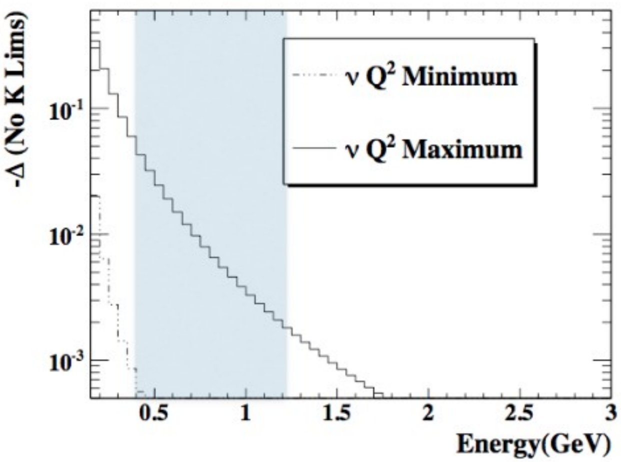
Big contribution from ν_e - anti ν_e norm 2%

$\sigma\nu_e$ not currently constrained by T2K ND280

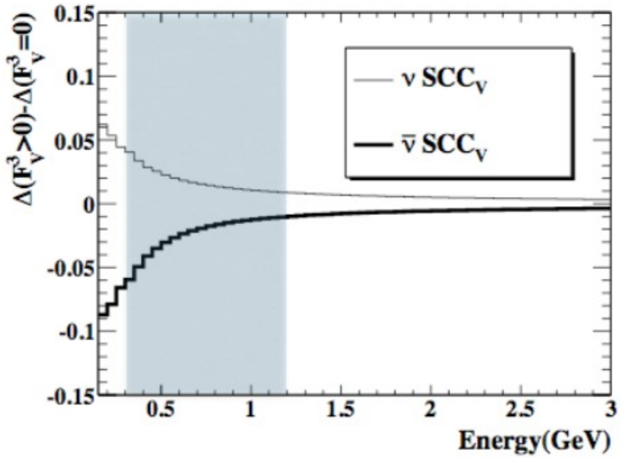
100% unc. 2p-2h parameters next largest

ν_e - anti ν_e Uncertainty

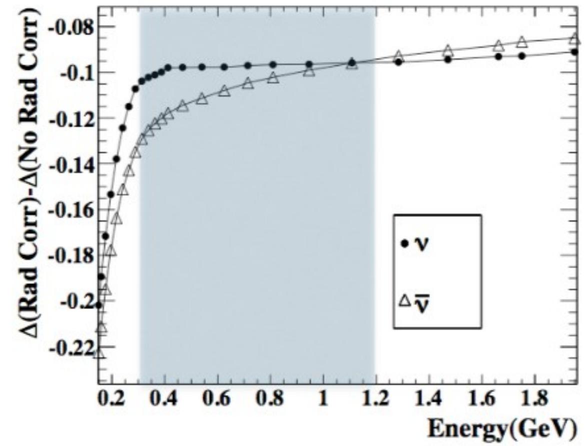
Kinematics



Second Class Currents



Radiative corrections



Day & McFarland (Phys.Rev. D86 (2012) 053003)

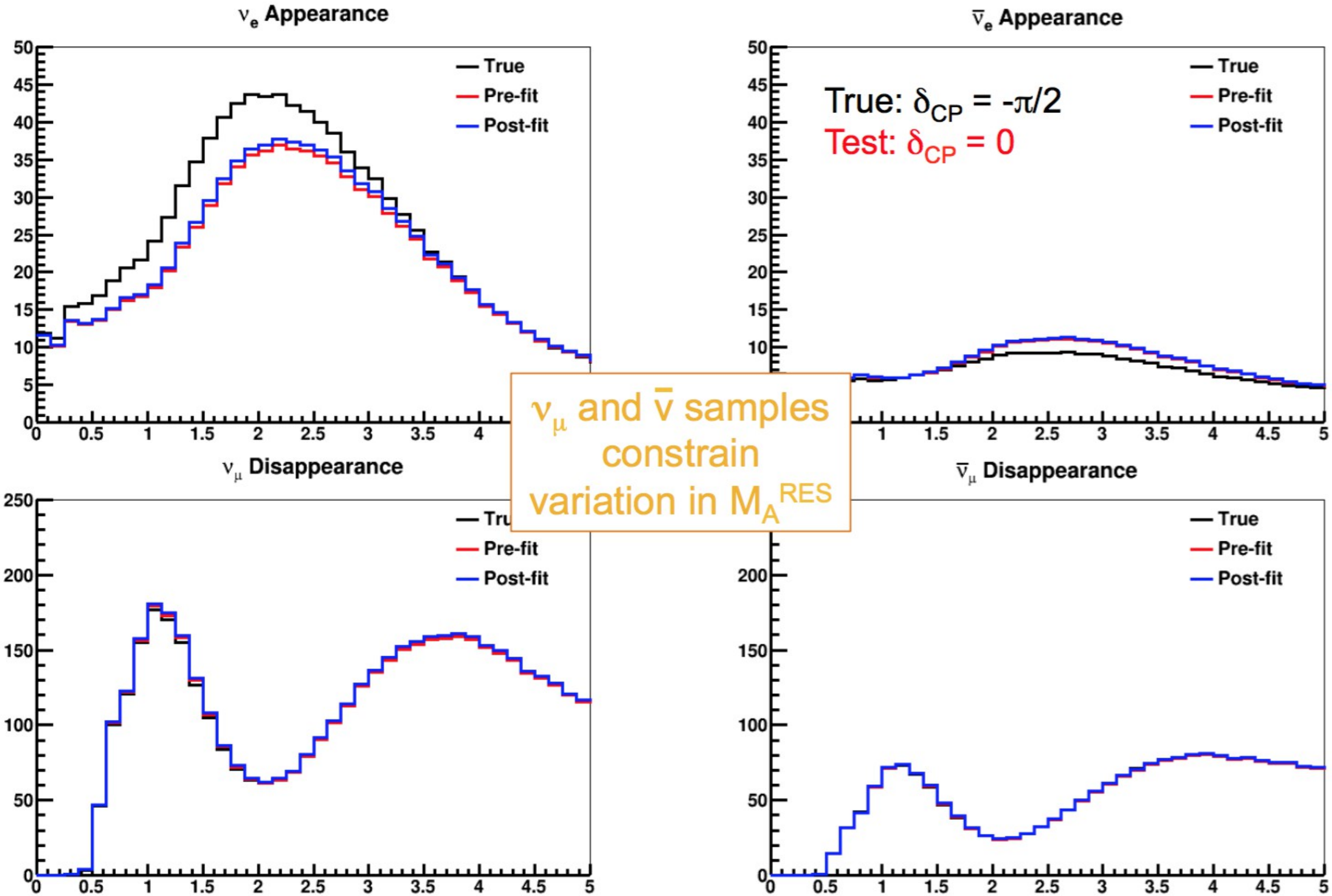
Kinematic allowed region

Second class currents (anti-correlated)

Radiative corrections need to be calculated!

Elizabeth Worcester 4-sample constraint MARes

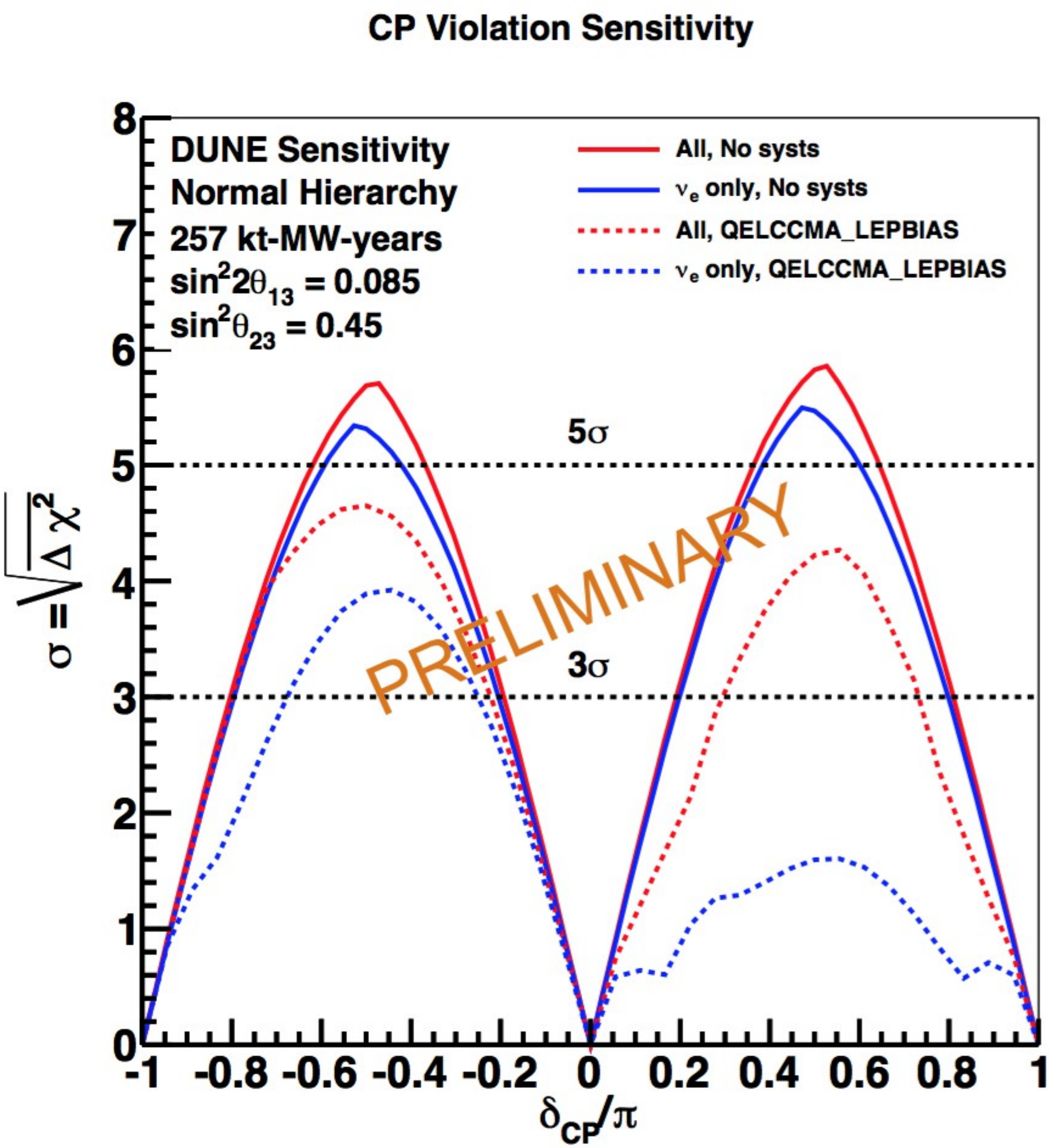
FD Interaction Constraints

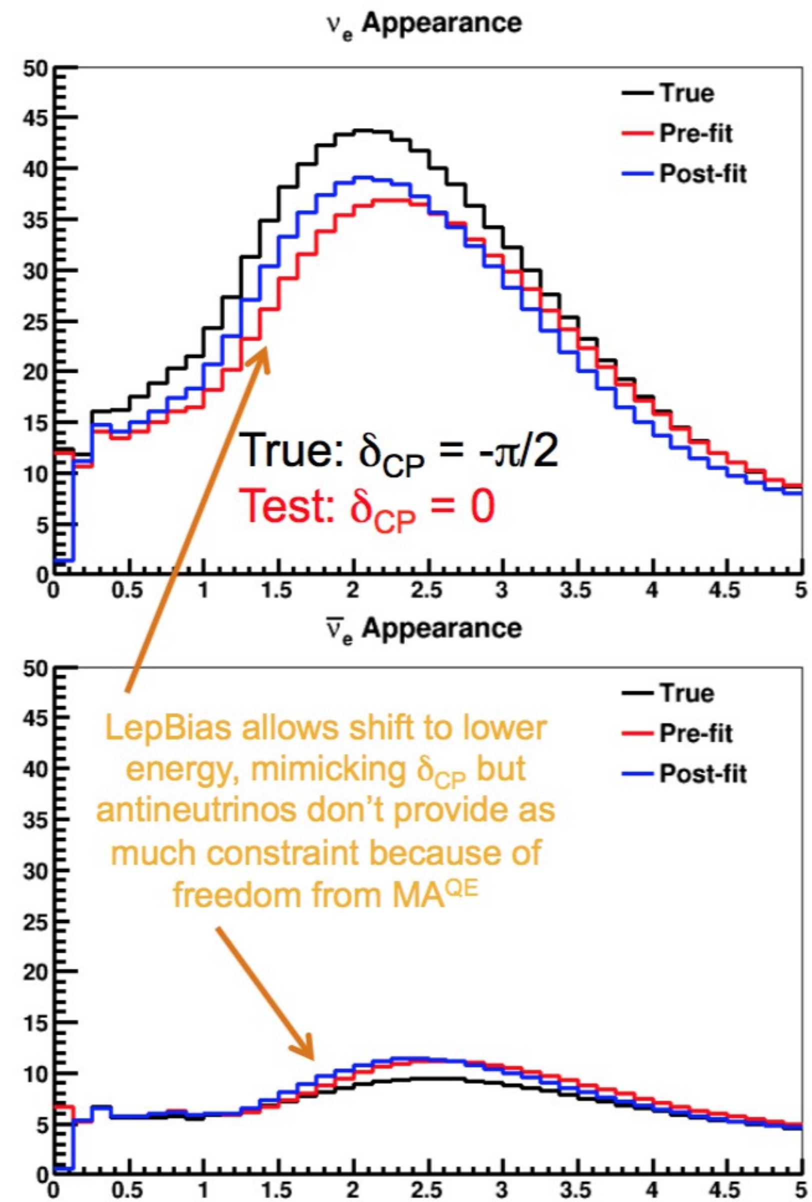


Elizabeth Worcester Effect of multiparameter systematic fitting

Combining Effect of M_A^{QE} & Lepton Energy Bias

DEEP UNDERGROUND NEUTRINO EXPERIMENT





Both HyperK and DUNE slides previous are doing this:

Not assume near detector constraints
informs what near detector must provide
in fact, flux constraint is absolutely vital
(c.f. previous summary talk)

Not assume we learn anything about
neutrino interactions from now

Our community will learn things
these are suggestions for what is important.

Interesting exercise for some of us:
from now to NuInt2020,
how much will the uncertainties shrink?

Neutrino Energy Reconstruction

- LArTPCs enable the use of multiple E_ν definitions
- Each definition of the neutrino energy will be sensitive to different systematics

CCQE-Assumption

$$E_\nu^{QE} = \frac{m_N E_\mu - \frac{m_\mu^2}{2}}{m_N - E_\mu + p_\mu \cos\theta_\mu}$$

Calorimetric Method

$$E_\nu^{calo} = E_\mu + \sum T_p$$

Calorimetric Method with Missing pT

Phys.Rev.D90, (2014)

$$E_\nu^{calo+\not{p}_T} = E_\mu + \sum T_p + E_{sep} + \sqrt{\not{p}_T{}^2 - M_{A-np}^2} - M_{A-np}$$

Unaffected

Slightly Biased

Highly Biased

Nucleon initial momentum

$E_\nu^{calo+\not{p}_T}$ — *Takes into account momentum imbalance*

E_ν^{calo} — *Introduce or reduce energy from the system*

E_ν^{QE} — *Assumes stationary nucleons for QE*

2p2h reactions

$E_\nu^{calo+\not{p}_T}$ — *By correcting for the missing p_T these event will be balanced*

E_ν^{calo} — *The introduction of energy not due to the neutrino will introduce a bias*

E_ν^{QE} — *Assumes scattering of single nucleon*

Qualitative examples

Joseph Zennamo
Fermilab Short Baseline Program

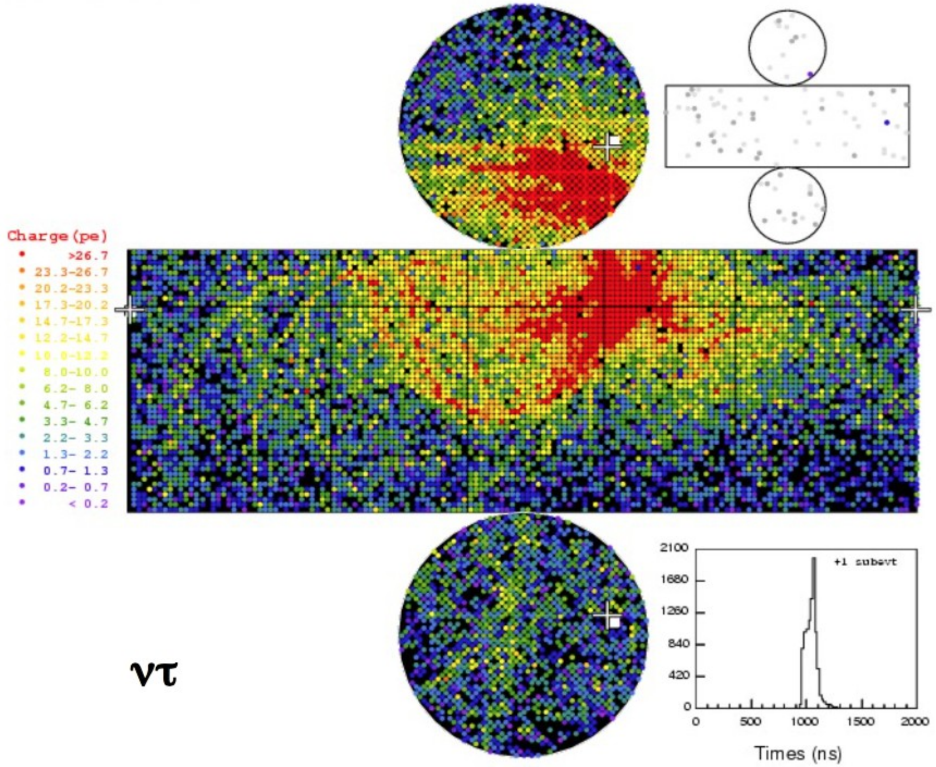
Final State Interactions

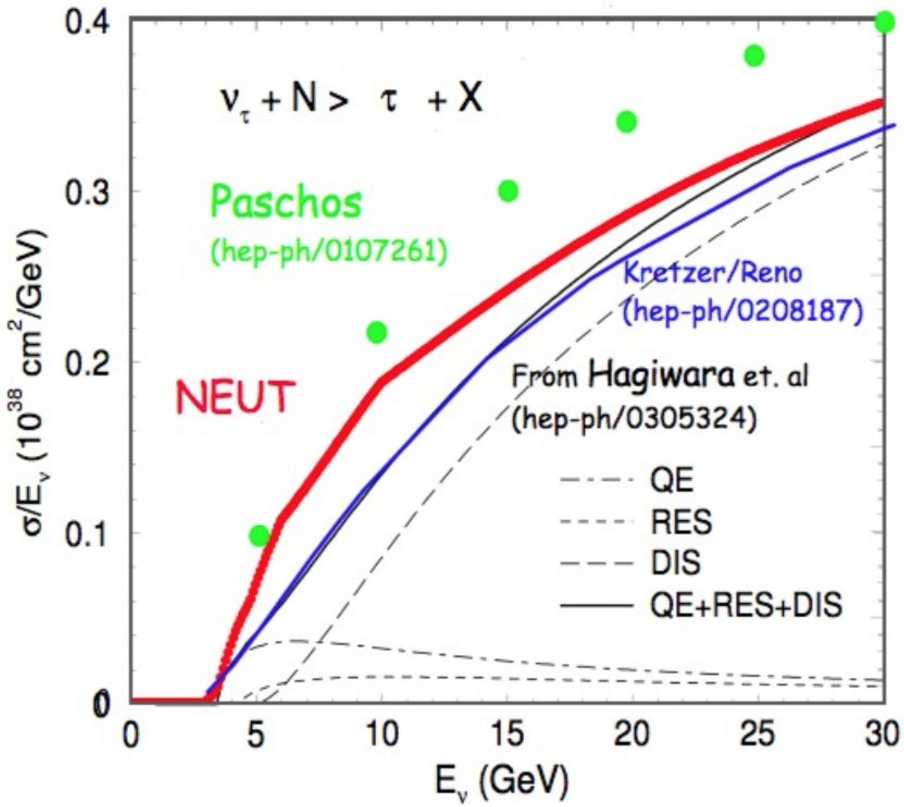
$E_\nu^{calo+\not{p}_T}$ — *Missing energy creates a bias but missing p_T correction reduces impact*

E_ν^{calo} — *No missing p_T correction so full impact on missing energy*

E_ν^{QE} — *If the event is truly CCQE then only the lepton matters but could hide true topology*

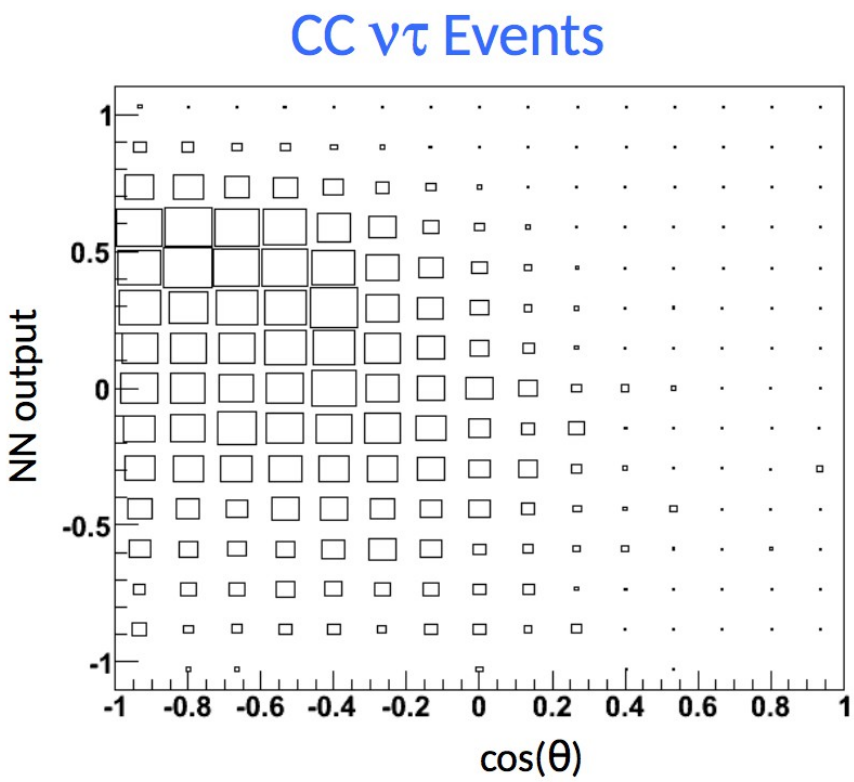
Tau Background For Mass Hierarchy Error

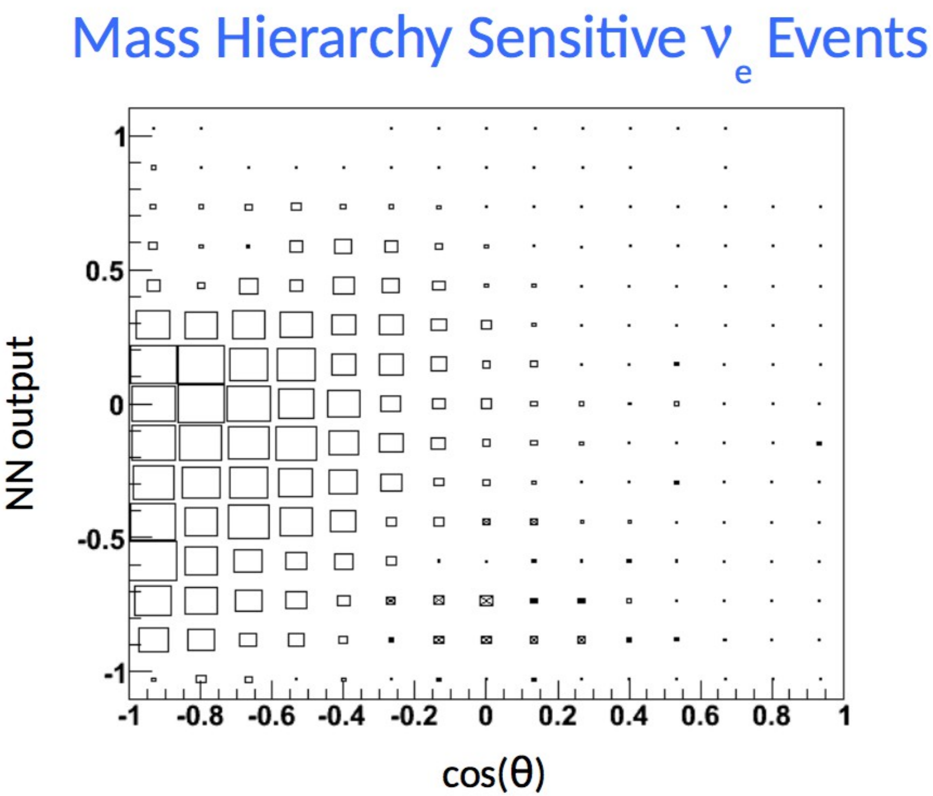




- Many events in the MH energy region are DIS
  - Means many rings
- Hadronic tau decays will produce many visible particles
  - decay is prompt and granularity of the detector is not enough to resolve the tau
  - Many overlapping rings tend to look like electron neutrinos
- Currently the cross section is assigned an uncertainty of 25%, based on model comparisons

Tau Cross Section Error Mitigation





- Currently this error is constrained only somewhat using sidebands in the SK analysis
- However, in a separate analysis CC ντ interactions have been identified in the SK data at 3.8σ
  - Method is based on a neural network which works to identify hadronic τ decays
- This information can be incorporated into the oscillation analysis to further mitigate the effected of these events (work in progress)

MAIN (EFFICIENCY) UNCERTAINT

Jarek
Nowak
Proton Decay

- Nuclear effects – meson (π, η, ω) nuclear effects affect the detection efficiency. The biggest error source

- π nuclear effect – the systematics obtained from comparison between two models (as there is no suitable data). Detection efficiency depends on the probability for the π to escape with out any scattering.

- Fraction of NN-corelated decays -10% of the decays are assumed to come from nucleon correlated to another nucleon (3 body decay). That leads to lower detection efficiency.

- Fermi motion – modeling of the nucleon momenta

Uncertainties for detection efficiency Phys.RevD85,112001

Mode	Meson nuclear effect	Hadron propagation in water	*N*-*N* correlated decay	Fermi momentum	Detector performances	Total
$p \rightarrow e^+ \pi^0$	15%	···	7%	8%	4%	19%
$p \rightarrow \mu^+ \pi^0$	15%	···	7%	8%	4%	19%

BACKGROUND AND EFFICIENCI

Jarek Nowak Proton Decay

	Mode	Super-K Water Ch. Efficiency	Super-K Water Ch. BG Rate (/Mt y)	LAr (generic) Efficiency	LAr (generic) BG Rate (/Mt y)
B-L	$e^+\pi^0$	45%	2	45%	1
B-L	νK^+	16%	7	**97%**	**1**
B-L	$\mu^+ K^0$	10%	5-10	**47%**	**<2**
B+L	$\mu^- \pi^+ K^+$	?	?	**97%**	**1**
B+L	$e^- K^+$	10%	3	**96%**	**<2**
$\Delta B=2$	n nbar	12%	260	**?**	**?**

Rough and unofficial SK efficiency & BG - ETK

A. Bueno et al. hep-ph/0701101

Estimate for water Cherenkov: Kearns (Snowmass, 2013).
For LAr: LBNE Collaboration, arXiv:1307.7335v3 based on Bueno et al. JHEP04 (2007) 041.
Several decay modes with high efficiency and low background in LAr.

Summary

Different measurements
Many different uncertainties