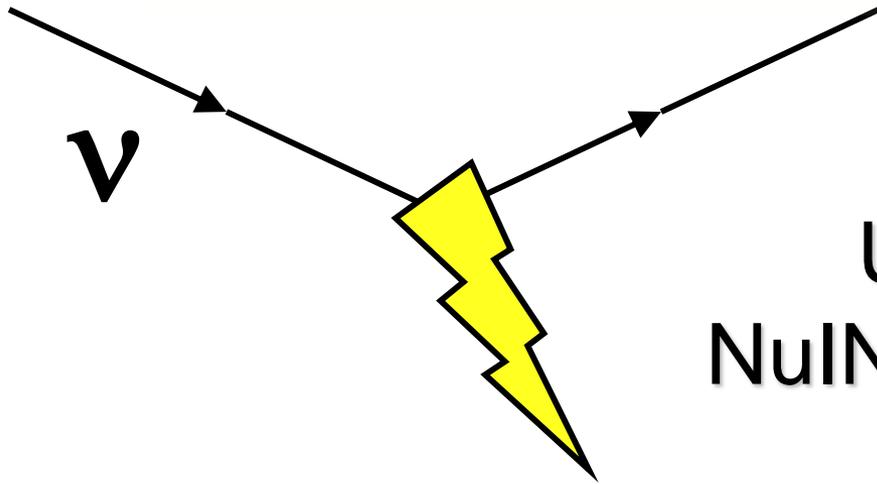
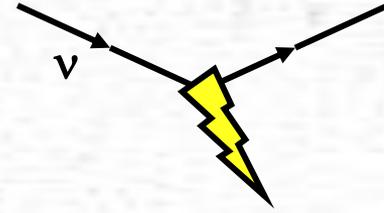


The Path Forward: An Experimentalist's View



Kevin McFarland
University of Rochester
NuINT 2012 Rio de Janeiro
27 October 2012

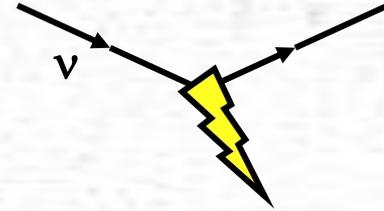
Path Forward?



Paths can be dangerous,
especially when you are
part of them.

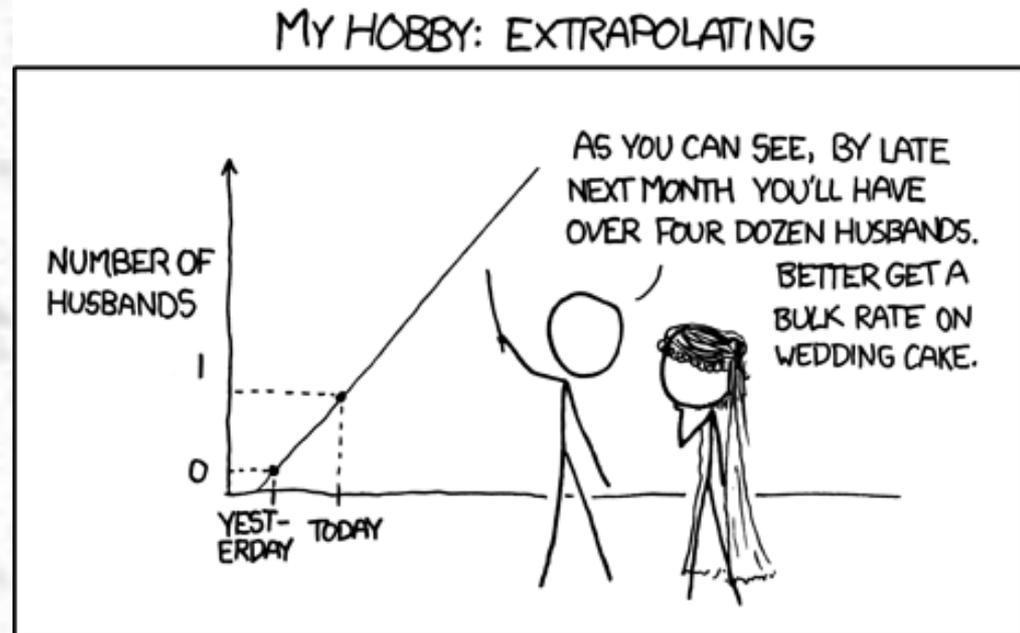


Path Forward?

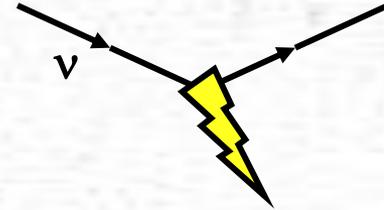


Paths can be dangerous, especially when you are part of them.

Predicting the future? Experimentalists should avoid extrapolations.



Revisiting our Past



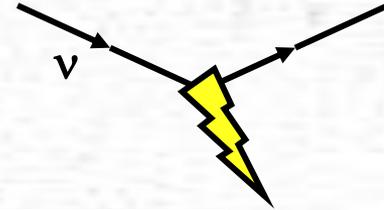
I have fond recollections of NuINT01...

- Where the neutrino community had its first encounter with multi-nucleon correlations, spectral functions (Much to the amusement of our nuclear physics colleagues)



- *Where I had my first encounter on the receiving end of Tony Thomas.*

Revisiting our Past



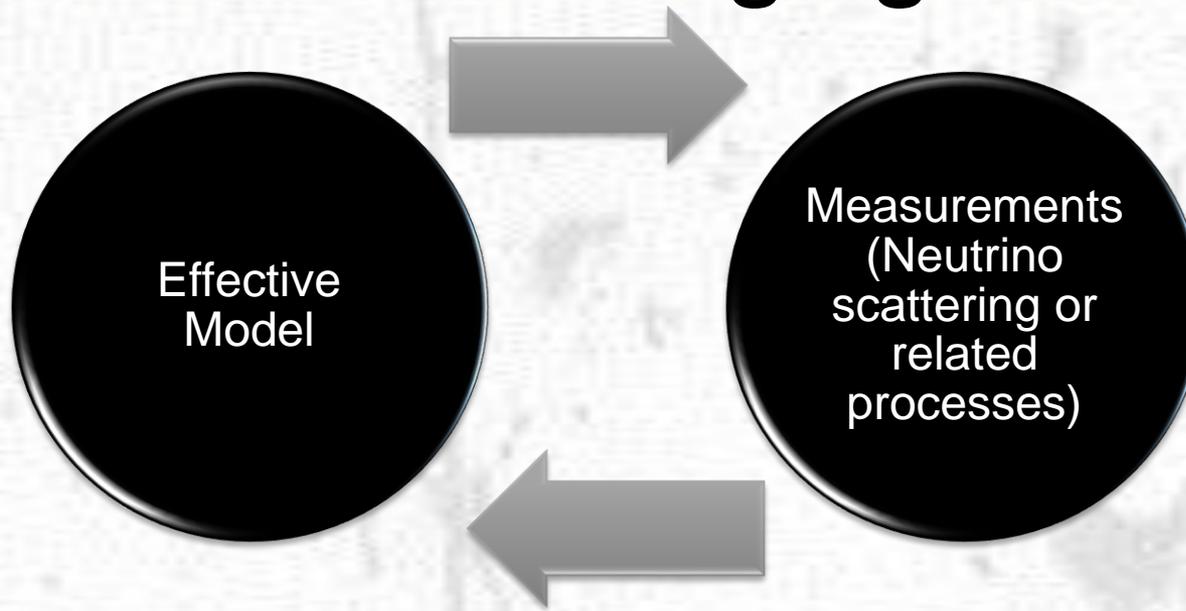
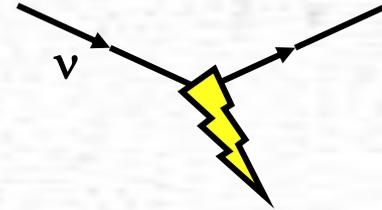
I have fond recollections of NuINT01...

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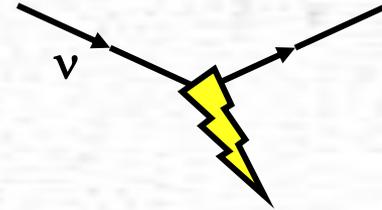
- *Where I had my first encounter on the receiving end of Tony Thomas.*
- *And responded by finishing my glass of wine...*

Why Tony and I were ~~shouting~~ at each other exchanging ideas



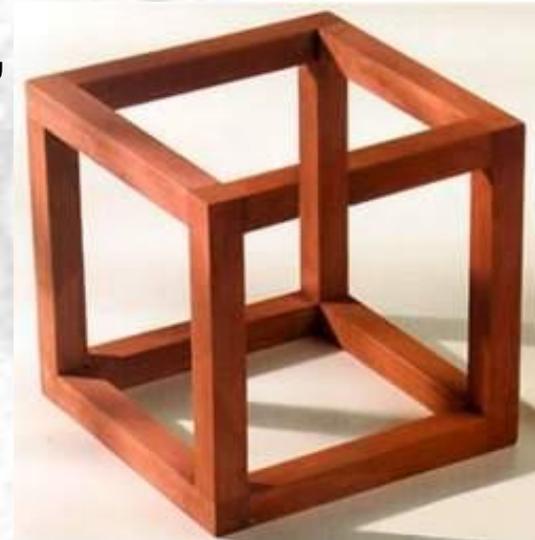
- Our iterative process uses data to improve models
- Our models are effective theories, ranging from pure parameterizations of data to microphysical models with simplifying assumptions.
 - “Effective” has both positive and negative meanings, but in particular here I mean that these are not first-principles calculations from QCD.

The Mosel Paradox

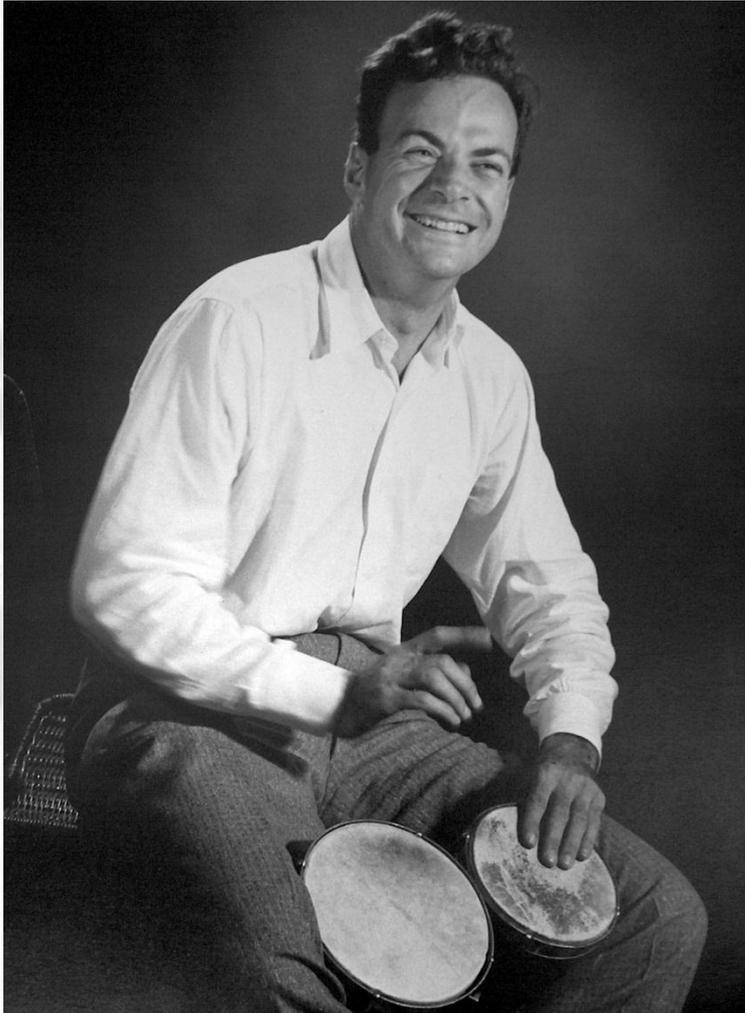
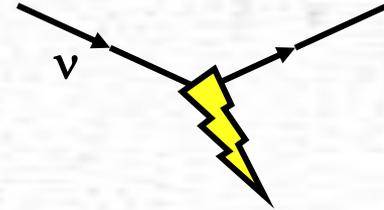


Theorist's paradigm: "A good generator does not have to fit the data, provided [its model] is right"

Experimentalist's paradigm: "A good generator does not have to be right, provided it fits the data"



Great Samba Musicians Weigh In...



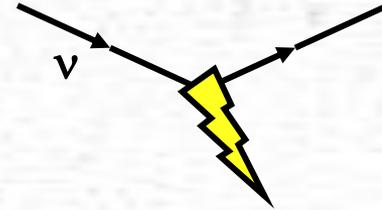
“It doesn't matter how beautiful your theory is; it doesn't matter how smart you are.

If it doesn't agree with experiment, it's wrong.”

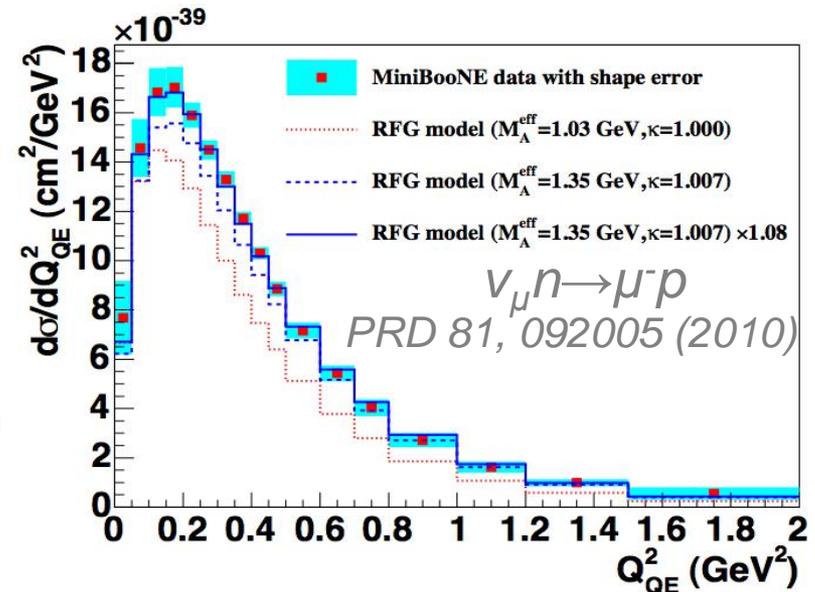
— Richard Feynman

This is surely true, but invalidating one side of an argument doesn't make the other side correct!

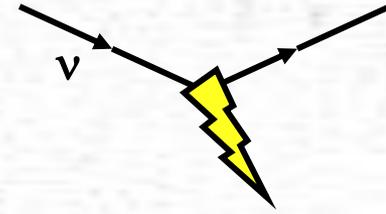
Counter Argument



- *Experimentalists can do (and have done, and will do) shameful things when confronted with data and model disagreements!*
- MiniBooNE oscillation analysis approach:
 - Modify the dipole axial mass and Pauli blocking until model fits data.
 - But there is nothing fundamental backing this approach. It's a mechanical convenience to parameterize the data for the oscillation analysis.



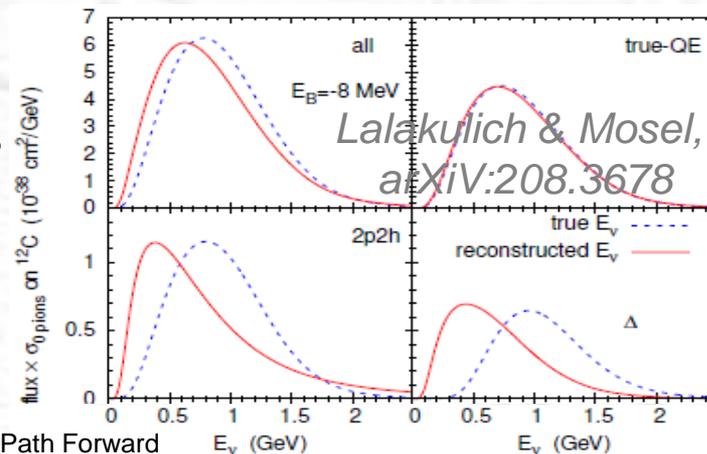
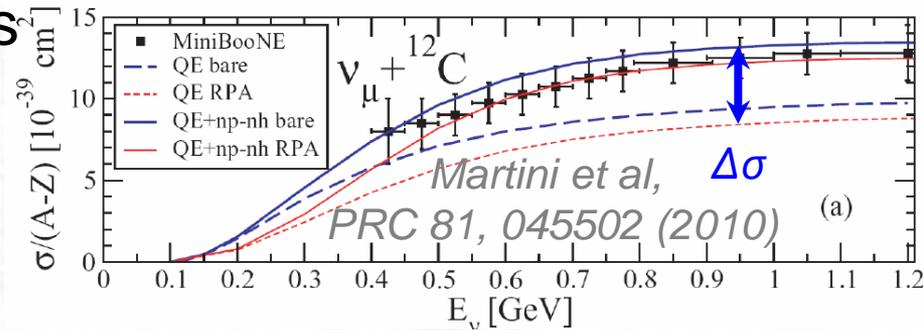
Counter Argument (cont'd)



- What we now know believe about the MiniBooNE oscillation analysis approach:

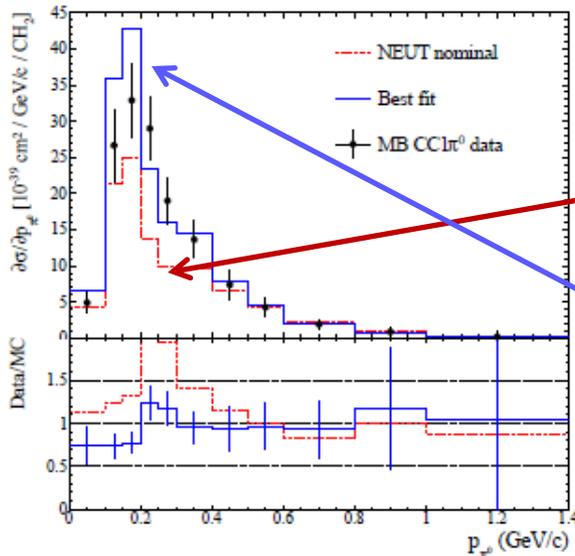
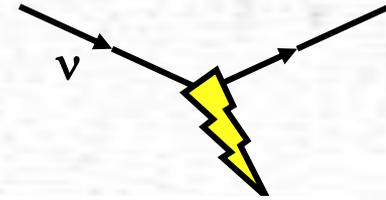
- In a simplistic view, there are neglected contributions from multi-nucleon pairs.
- Those pairs alter the kinematics.
- MiniBooNE got its energy reconstruction wrong by picking the wrong physics to modify.
- OK within uncertainties? If so, only by luck.

$$\nu_{\mu} n \rightarrow \mu^{-} p + \nu_{\mu} (np)_{\text{corr.}} \rightarrow \mu^{-} pp$$



Also demonstrated by Nieves, Ankowski here at NuINT12

Counter Argument (cont'd)

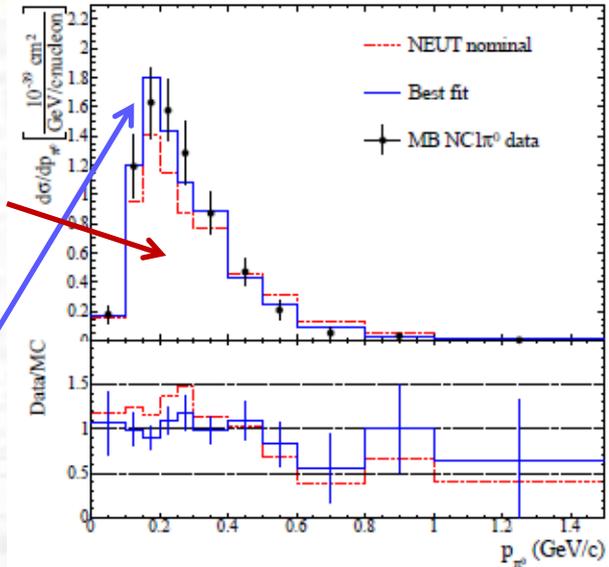


(a) $CC1\pi^0 |p_{\pi^0}|$

P. Rodrigues, NuFact 2012
and NuINT12

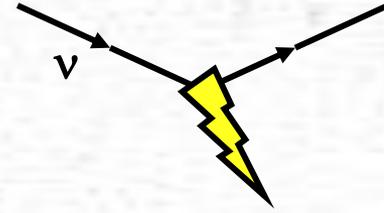
Rein-Sehgal
[Ann. Phys. 133, 79-153 (1981)]
implementation in NEUT

“Tuned” Rein-Sehgal
to modify Q^2 distribution,
pion spectrum, rate



(c) $NC1\pi^0 |p_{\pi^0}|$

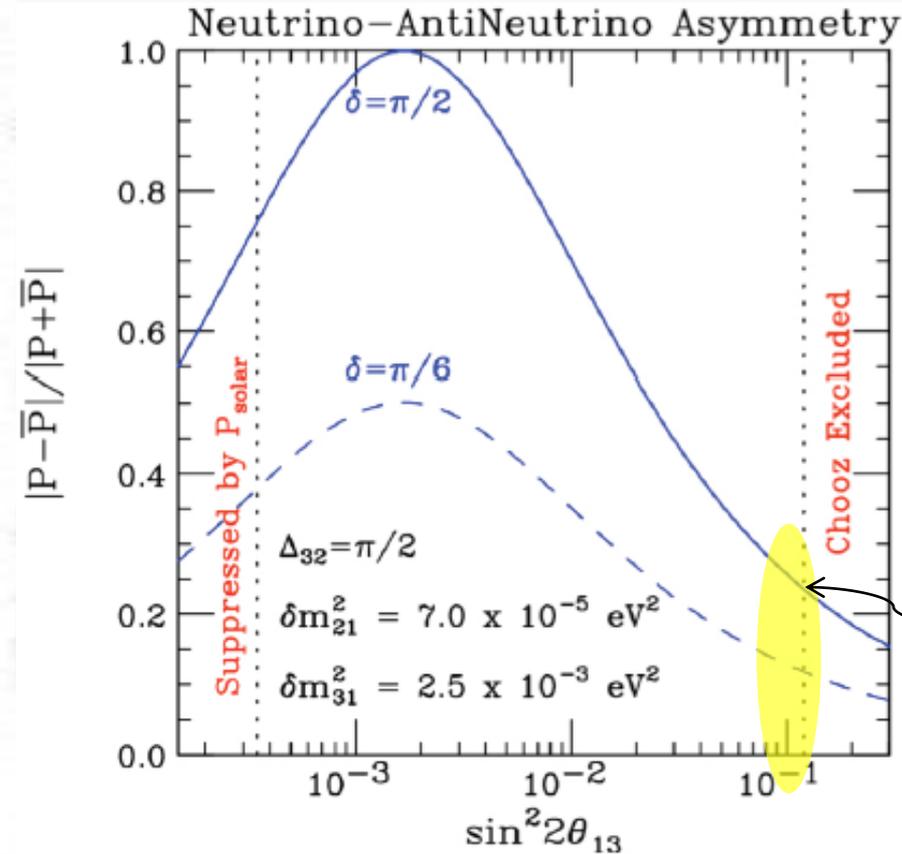
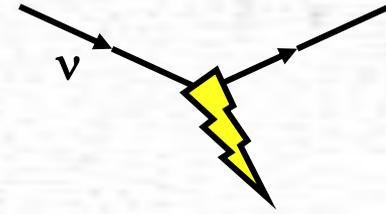
- *But what else can experimentalists do? Mea culpa.*
- T2K finds poor agreement between Rein-Sehgal and MiniBooNE $\nu_\mu N \rightarrow \mu^- \pi^{(+)\ 0} N^{(\prime)}$ and $\nu_\mu N \rightarrow \nu_\mu \pi^0 N$ data.
- *Ad hoc* tuning “breaks” assumptions of underlying model, e.g. CC-NC universality of process and relation among resonances, to force good agreement.



Are we ready for current and future oscillation experiments?

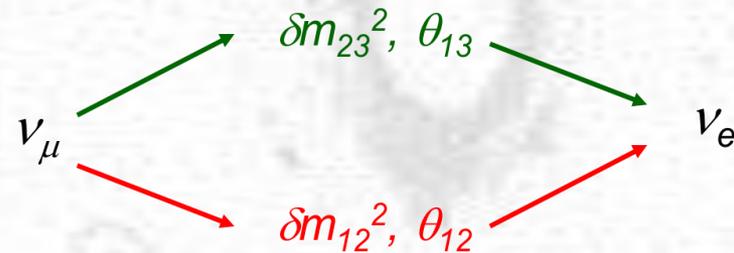


Oscillations: Large θ_{13}



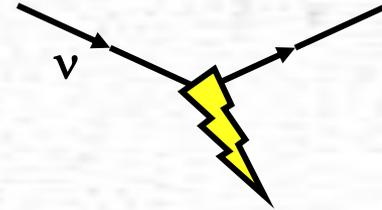
(Parke 2003, arXiv:0710.554)

- Large θ_{13} means high rate of $\nu_{\mu} \rightarrow \nu_e \dots$
 - But fractional CP asymmetry decreases as θ_{13} increases

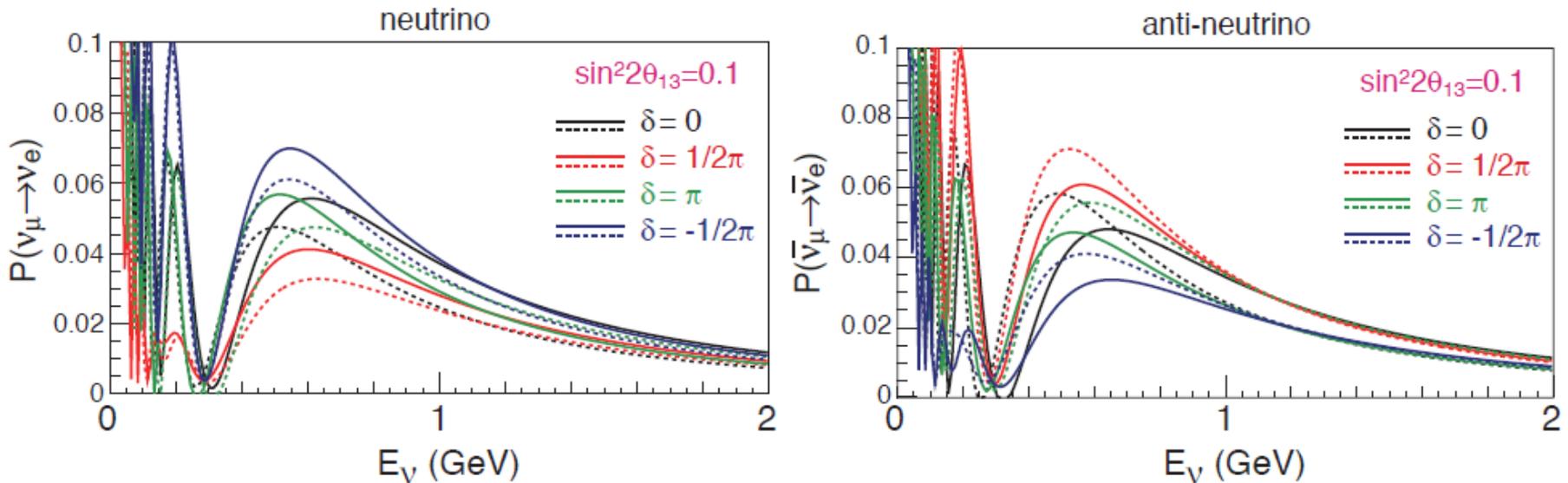


- Nature put us here
- As we all know, that puts us in the position of having good statistics, but systematics become more important.

Oscillation Needs

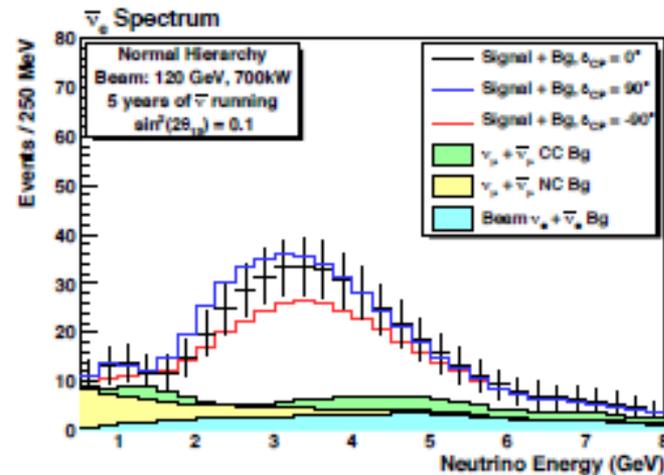
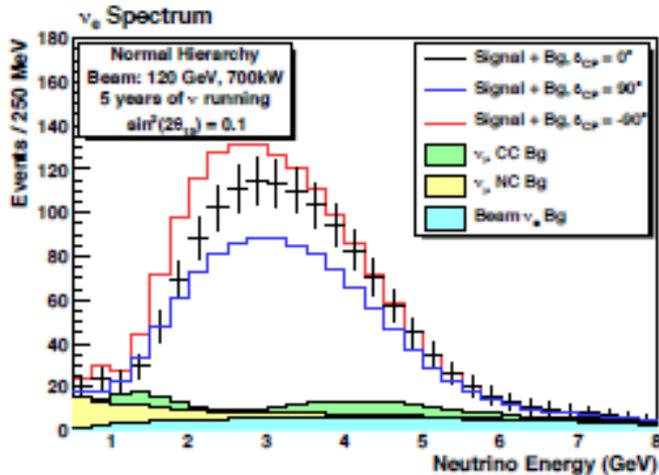
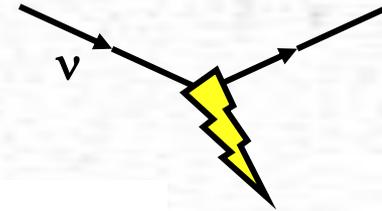


- Discovery of CP violation in neutrino oscillations requires seeing distortions of $P(\nu_\mu \rightarrow \nu_e)$ as a function of neutrino and anti-neutrino energy.



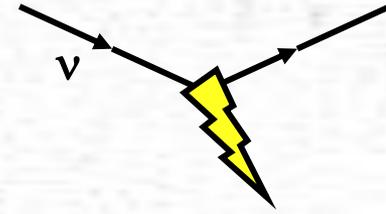
Oscillation Probabilities for $L=295$ km,
Hyper-K LOI

Oscillation Needs



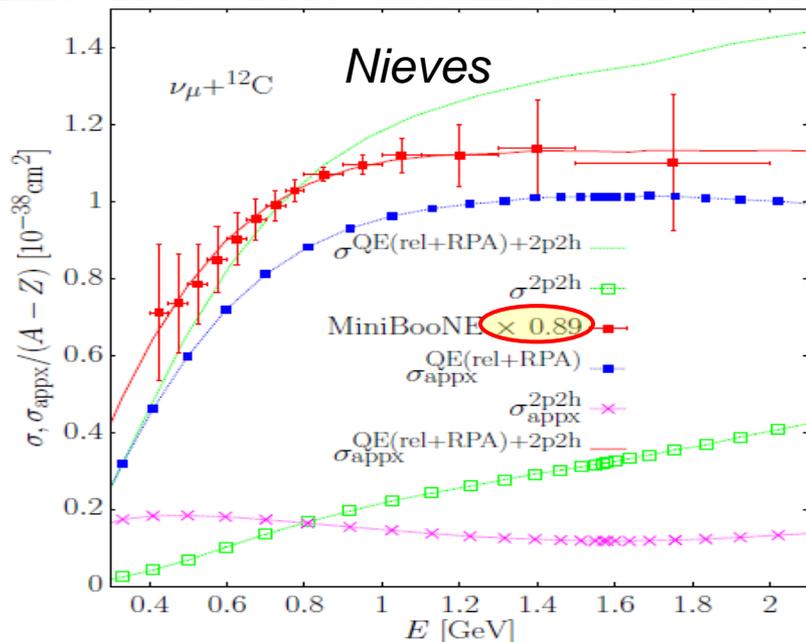
- Maximum CP effect is range of red-blue curve
- Backgrounds are significant, vary with energy and are different between neutrino and anti-neutrino beams
 - Pileup of backgrounds at lower energy makes 2nd maximum only marginally useful in optimized design
- Spectral information plays a role
 - CP effect may show up primarily as a rate decrease in one beam and a spectral shift in the other

Are we ready?



Where we are now

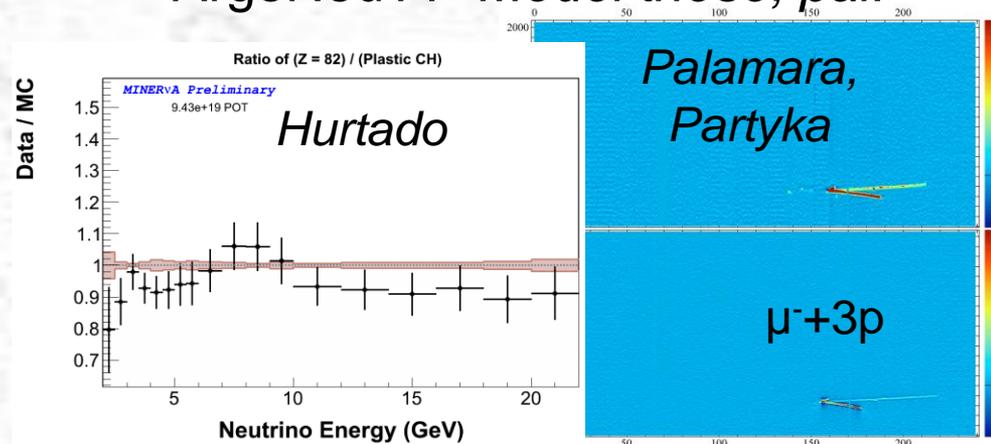
- We are still working out the best models for MiniBooNE's simplest reaction near the inelastic threshold

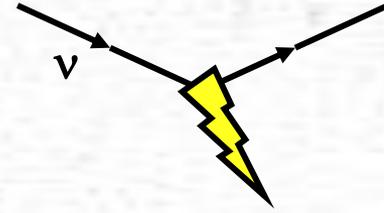


Where we need to be

for T2K, NOvA, HyperK/LBNE/ LAGUNA and new xsect data

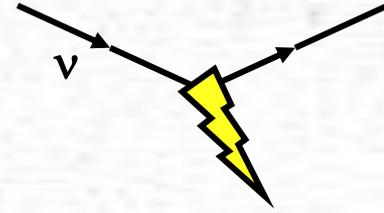
- High precision predictions for energy reconstruction and backgrounds for oscillations.
- Energies up to 5-8 GeV
- Are we ready for MINERvA, ArgoNeuT? *Model these, pal!*





Some homework for NuINT14



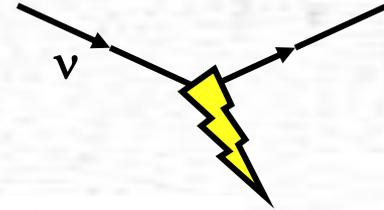


Some homework for NuINT14

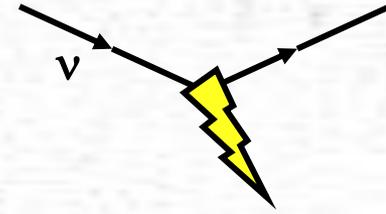


Getting Best Models into Generators

- Our generators lag the best theory
- This is not because we lack a flexible generator framework or because we are lazy.
- Why is it hard?
 - Calculations aren't always "complete" in specifying final state, covering all kinematics, etc.
 - Difficult or impossible to put in a complete calculation for a single exclusive or semi-inclusive final state.
 - *Even if that complete calculation is better, it may not be clear how to factorize from the ensemble of reactions and effects in the generator.*



Getting Best Models into Generators (cont'd)

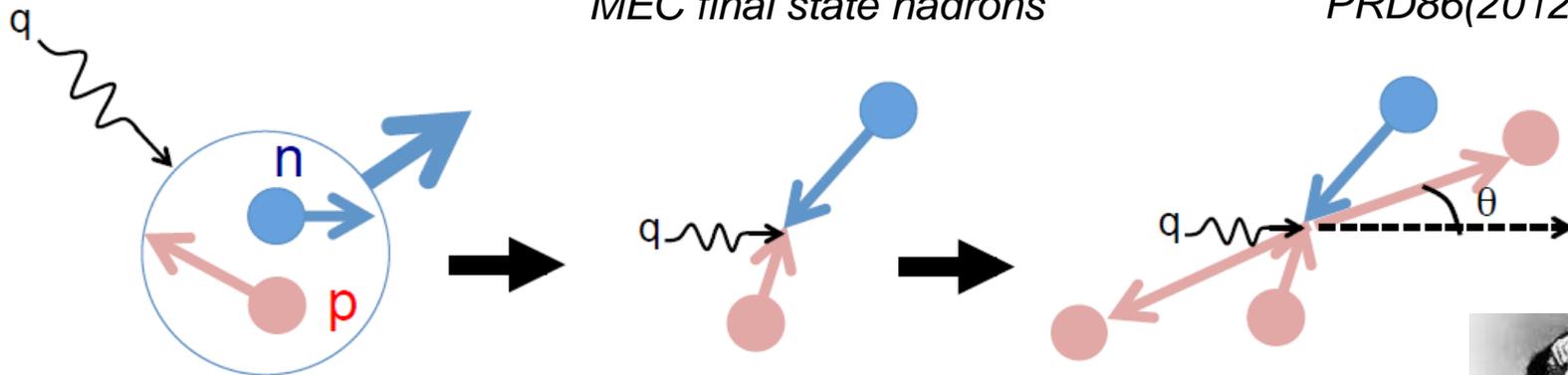


In GENIE, Neutrino interaction is simulated in several steps

- (1) specify leptonic model
- (2) specify hadronic model
- (3) specify FSI model

*Katori and Dytman
Hadronic Cluster model for
MEC final state hadrons*

*Work also addressing this by:
Lalakulich, Gallmeister,
Mosel PRC86(2012)014614
and by Sobczyk
PRD86(2012)015504*

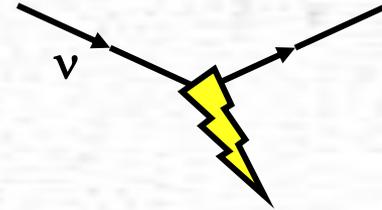


- Generator requires description of the final state.
- But MEC models calculate lepton kinematics.
- Have to “sew on” a model for the hadronic final state to implement in a generator.



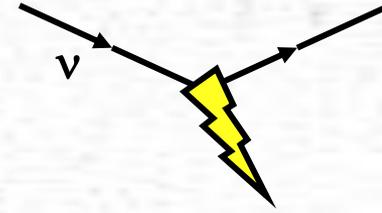
Frankenstein's Model?

Getting Best Models into Generators (cont'd)

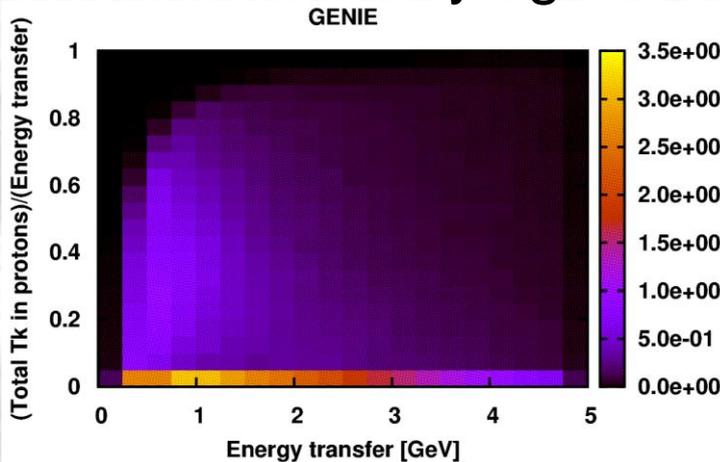


- It may be hard, but there is an urgent short list of needed improvements
 - Spectral functions replacing Fermi gas model at least for (quasi)elastic processes
 - RPA and MEC effects for CCQE
 - Improved nucleon-level models for pion production. At a minimum, improving Rein-Sehgal tunes is urgent.
 - Coherent pion updates and single kaon production as well
 - Addressing any weaknesses at multi-GeV energies
 - And can we get to more realistic (GiBUU? Sato-Lee?) cascade models for FSI? More later on FSI...
 - eA modes for generators for comparisons

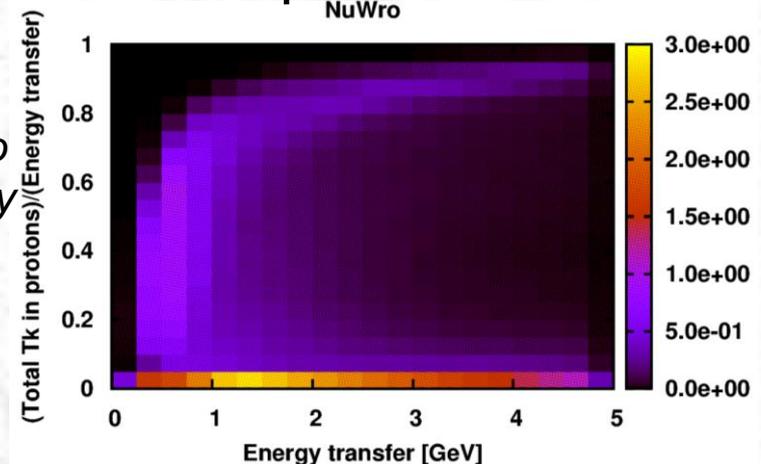
Value of Generator Comparisons



- A great recent NuINT tradition.
 - Valuable for judging which observables are reliable and for identifying weaknesses in generator implementation.

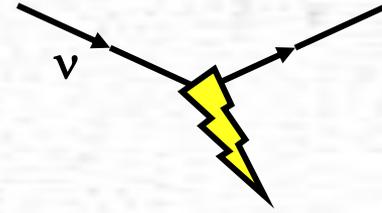


T. Golan, Single Pion Production: GENIE vs NuWro Fraction of Energy Transfer seen in Protons



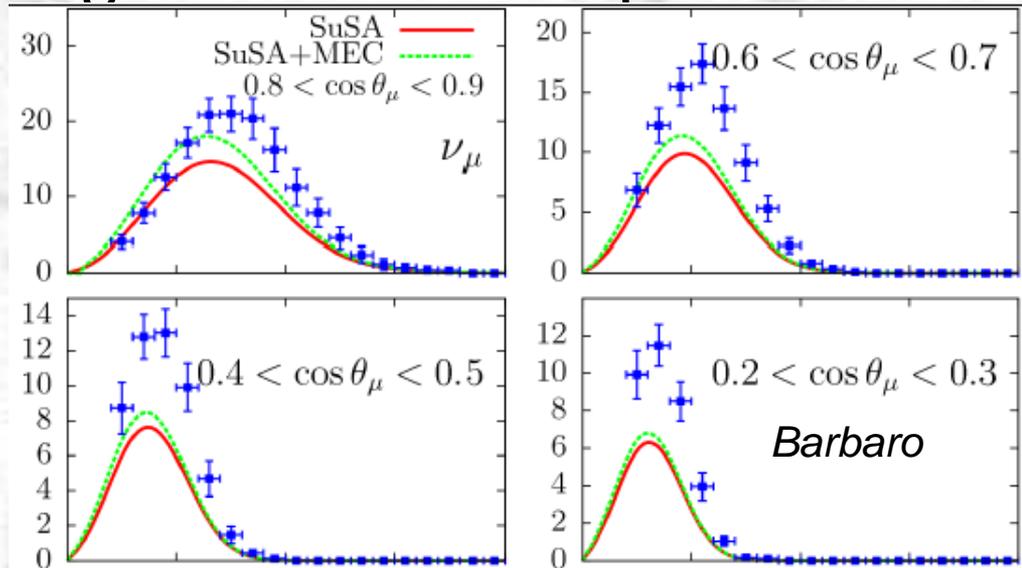
- We need to do this systematically & frequently.
 - Like breathing, it should not only be a hobby.
 - Priority work: merging non-interaction parts of generators. Using GENIE driver would be sensible?

Limitations of our best “Model Independent” Data

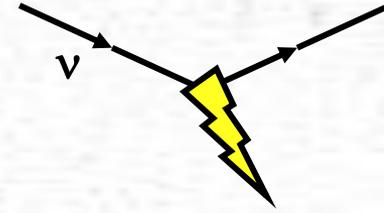


- The best of model independent approaches:
 - *Every experimental result* at this conference was expressed in terms of the final state outside of nucleus
 - Backgrounds were often constrained by data
- The limits of striving for model independence:

- Best illustrated by MiniBooNE CCQE p - θ
- Very valuable for the field & right thing to do
- But...



Limitations of our best “Model Independent” Data

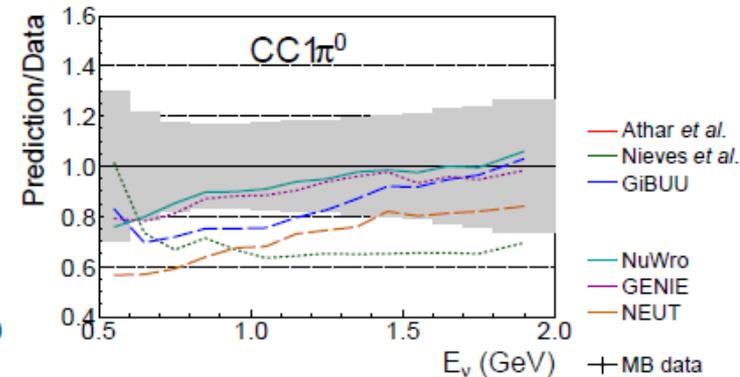
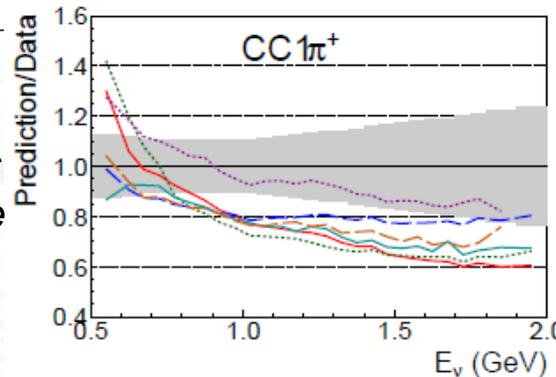


- Getting the correlations in uncertainties right is important for model testing!

Model	Scale	M_A (GeV)	$\frac{\chi^2}{\#\text{bins}}$
LFG	0.96 ± 0.03	1.32 ± 0.03	35/137
Full	0.92 ± 0.03	1.08 ± 0.03	50/137
Full $ q > 0.4^\dagger$ GeV	0.83 ± 0.04	1.01 ± 0.03	30/123

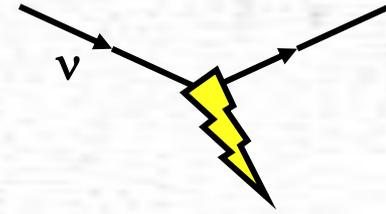
Nieves model fits. Too good χ^2 means correlations aren't correctly accounted for

Rodrigues argued that best power to test pion data comes from multiple channels, but we lack correlations among these datasets.

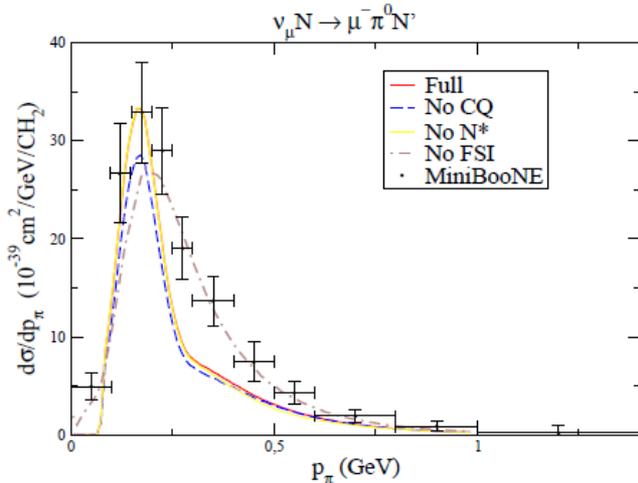


- Binning data in general kinematics is hard to scale to more complicated final states.

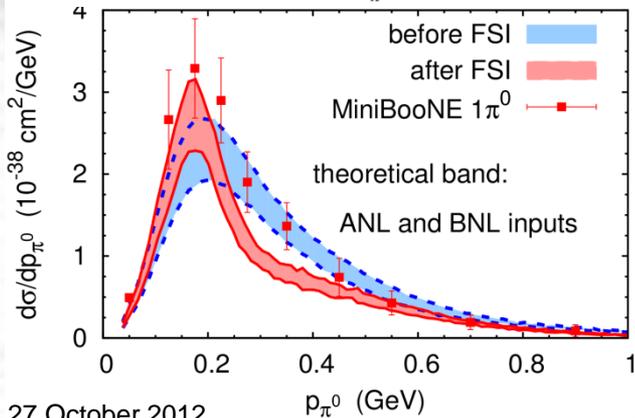
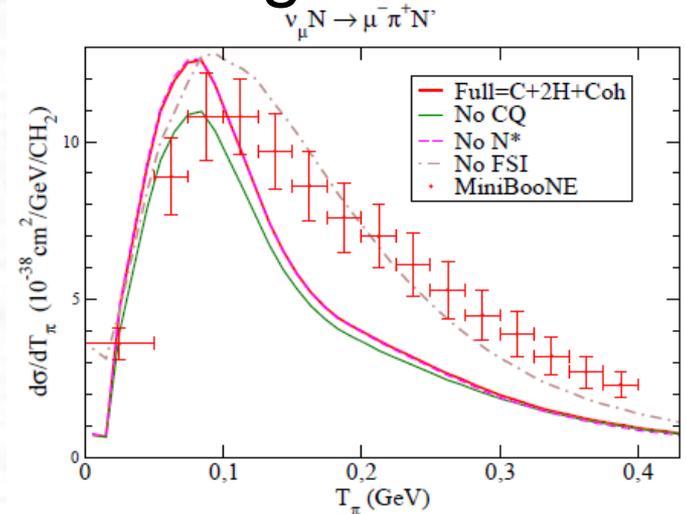
Cascading Failure?



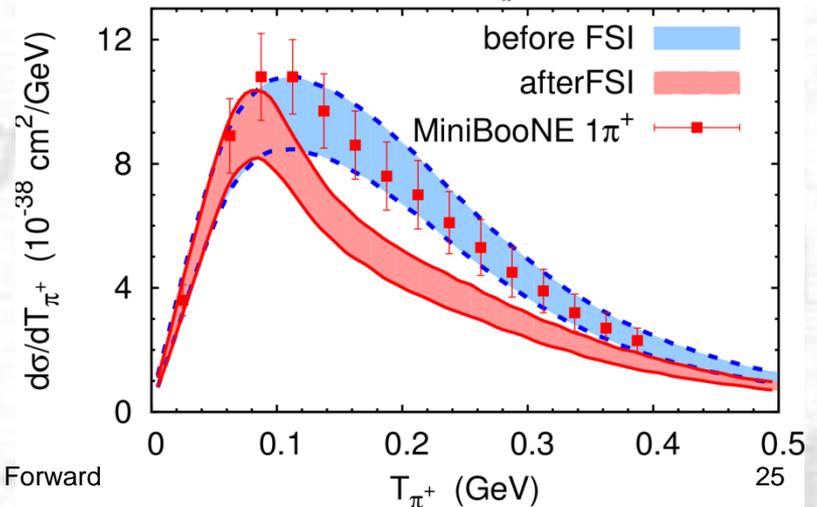
- Pion spectrum in MiniBooNE is baffling.
 - Appears to prefer no FSI



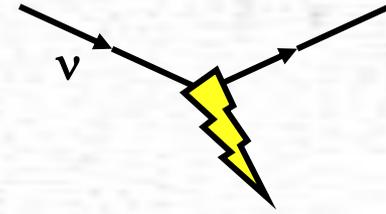
Hernandez model. All channels fit better with no FSI.



Lalakulich shows a similar result with GiBUU.

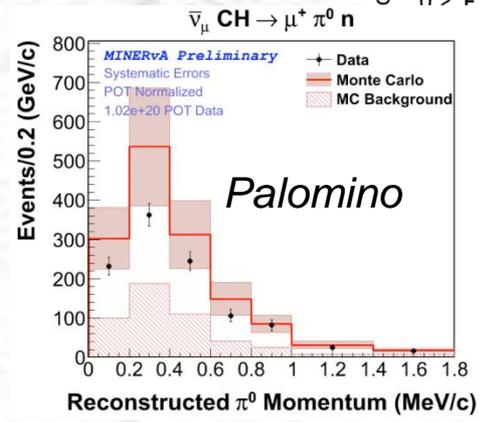
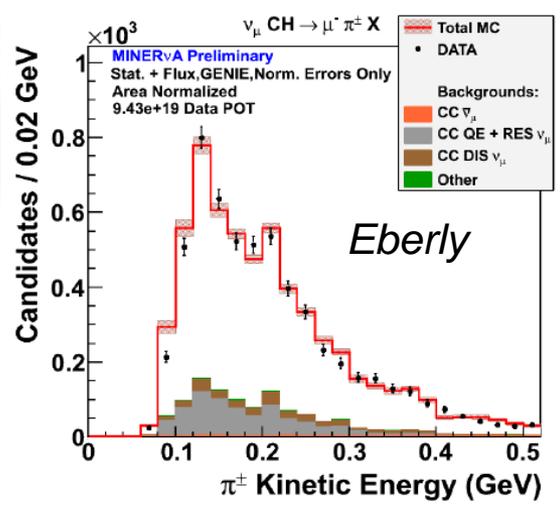
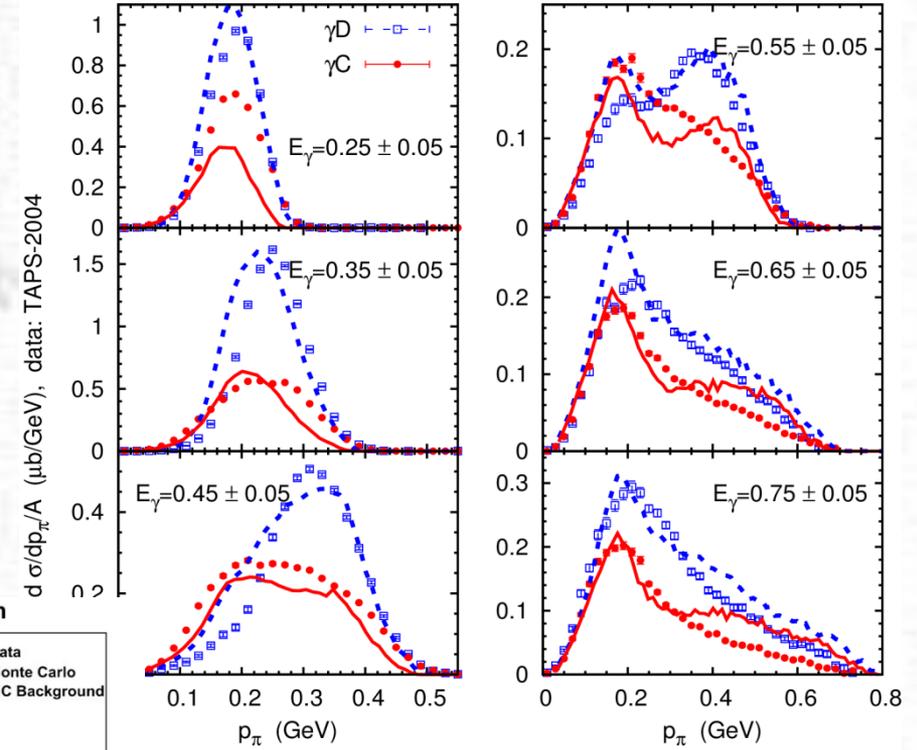


Cascading Failure?



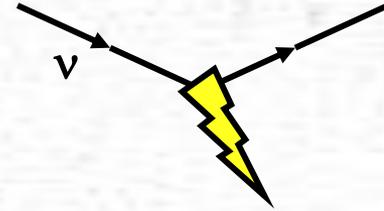
- But that's crazy!
FSI can't be absent.
 - For example, GiBUU pion photoproduction on D_2 and C.
- Also, look at MINERvA

Lalakulich (GiBUU)



MINERvA is still in a very early stage, but tendency is for shape of pion spectrum to be correct. It will be interesting if this holds up.

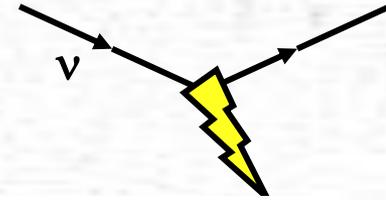
Formation Zombies



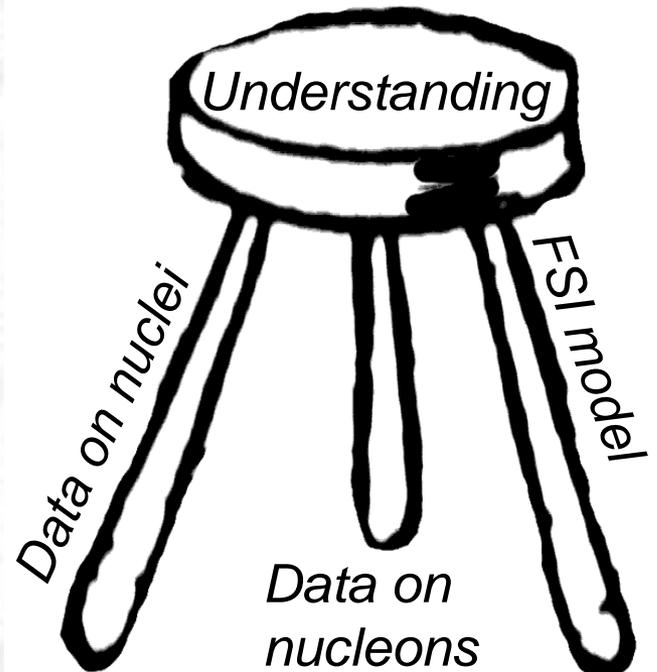
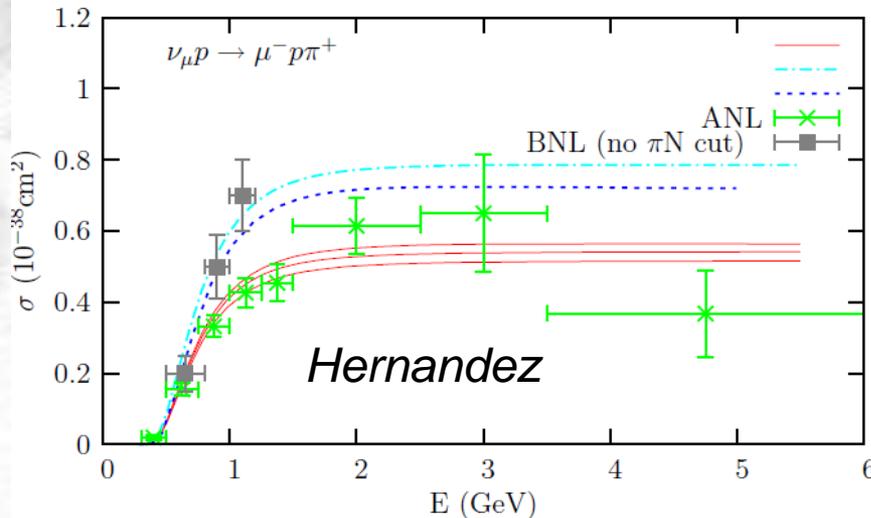
I don't believe the Δ really is a zombie in the nucleus. You don't either.

- I found the discussion about “formation zones” in the resonance region worrying.
 - NuWro, NEUT and GENIE all make different choices to account for propagation of the baryon resonance in the nucleus.
 - Golan speculated this was the source of some odd generator disagreements.
- Can we use results from GiBUU, which has the most complete cascade model, to motivate choices in other generators?
- What else can we do soon to address this for current and near future exp'ts?

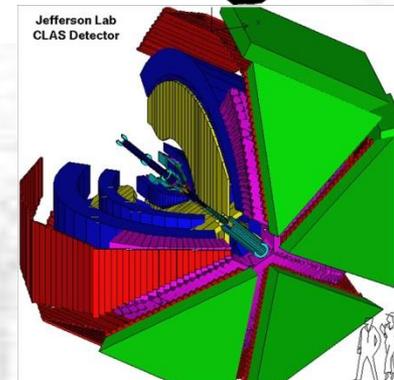
D_2 : Disappointing Data?



- Ideally to resolve our pion conundrum, we would go to *reliable* nucleon level data
 - Unfortunately, we don't have it.

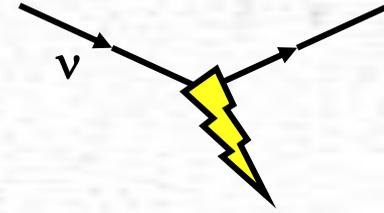


- eN vs. eA data: our only hope for exclusive states? (MINERvA is proposing a D_2 target, but for DIS.)

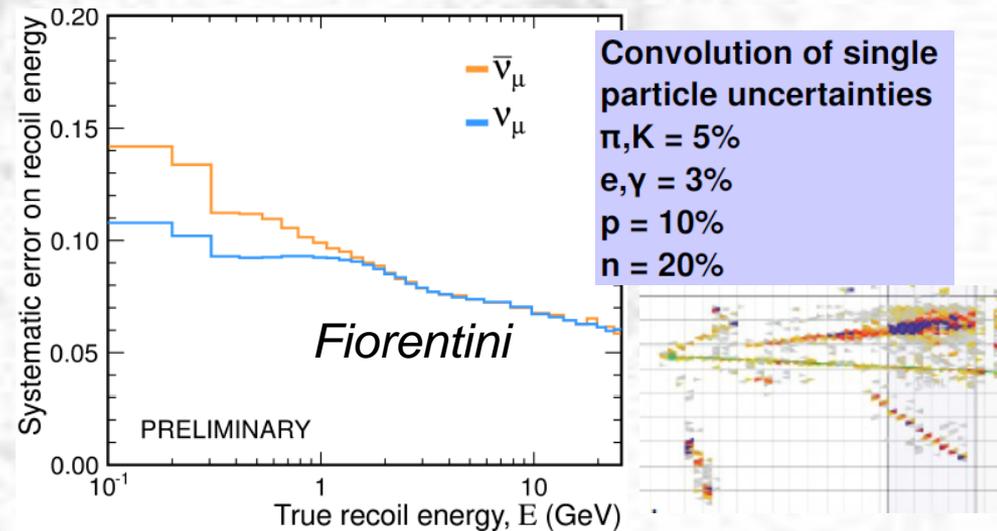
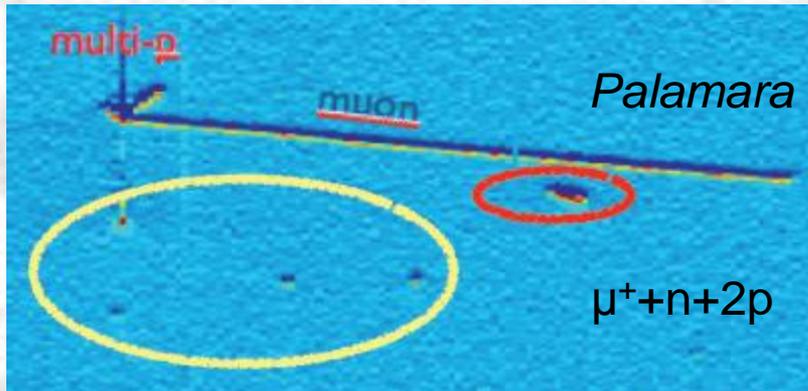


Experimentalists Unite!?

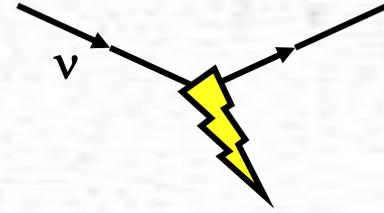
Secondary Interactions



- We saw many examples of reliance on details of models of hadron interactions *in detectors*.

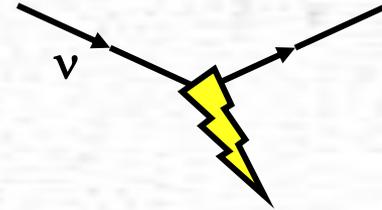


- There is a clear path forward: check models against data, testbeam.
- Much commonality in this work. Could we all benefit from a community working group?



Conclusions

Path Forward



- It's true; extrapolation is dangerous.
 - But it is also true that we have a long “to do” list from lessons we have (or should have) already learned.
- There are common needs for interaction and oscillation experiments that experimentalists, as a community should do more to address:
 - Generator tests & tuning, secondary interactions, ...
- Theory faces an enormous challenge with new data and new needs for oscillation exp'ts.
 - Higher energies, need details of complicated final states, less tolerance of uncertainties.

