

Nuance at MiniBooNE

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Nuance: An Overview

Nuance is a publicly available, open source, neutrino interaction Monte Carlo written by Dave Casper.

- Several models are used to simulate many different types of neutrino interactions.
- Both initial and final state effects are simulated.
- The code was originally designed and written to simulate neutrino events in a water Cherenkov detector.
- Nuance is made up of over 300 subroutines and include files; many 1000s lines of code, much of it not well documented.

The MiniBooNE collaboration has chosen to use Nuance as its neutrino interaction Monte Carlo, but MiniBooNE also realized that Nuance needed to be modified and tested.

FSI Nuance Style

Final state interactions in Nuance are simulated by the subroutine `partnuc.f`.

Any resonant states produced by the neutrino interaction are decayed (or absorbed by $\Delta + N \rightarrow N + N$) prior to partnuc.

These hadrons from the neutrino interaction are then handed to partnuc one at a time to be stepped through the nucleus.

Partnuc has a crude nuclear model of the target based on models of nuclear density and Fermi momentum.

At each step partnuc determines if the hadron interacts with a target nucleon by using the total hadron-nucleon cross section.

If an interaction occurs, then partnuc determines what kind of an interaction and what the kinematics are for the outgoing particles.

Particles produced in final state interactions are also stepped though the nucleus using partnuc.

Modifications to Nuance

With Dave Casper's help and advice we made some minor changes to Nuance.

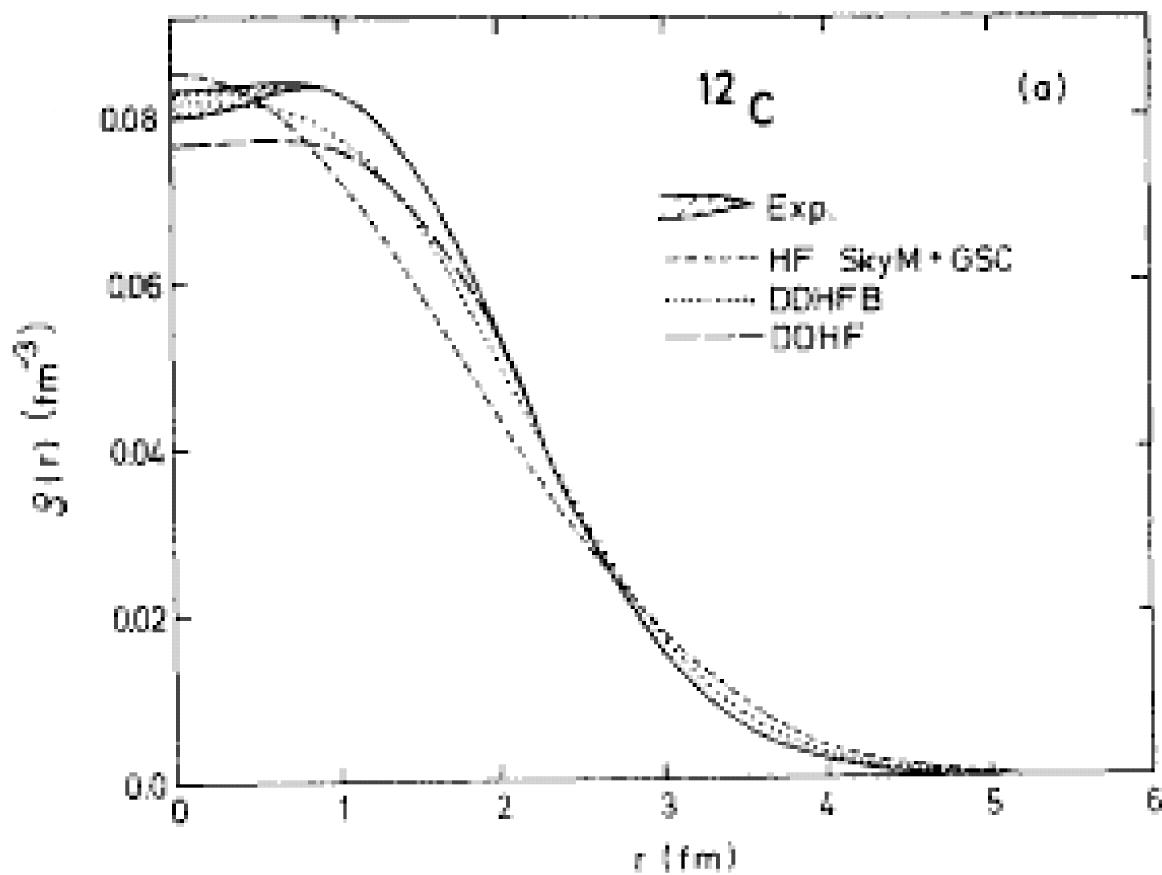
- added a carbon target type to the card file (220 MeV Fermi momentum, 25 MeV binding energy) in order to run with a CH₂ target.
- added a nuclear density model and Fermi momentum distribution model for carbon to partnuc.
- changed a nucleon energy cut in partnuc (from 1380 to 960 MeV)
- particles in partnuc get a 1.0 fm “free” first step
- implemented a nuclear density model that changes as nucleons are scattered out of the target nucleus.

And we made some requests for Dave to make some more complicated additions to Nuance.

- radiative Δ decays ($\Delta_{1232} \rightarrow N + \gamma$)
- non-dipole form factors for the CCQE interaction

Carbon in Partnuc

This is the carbon nuclear density model added to Nuance. W.Rueter *et al.* extracted this model from their electron-carbon scattering data.



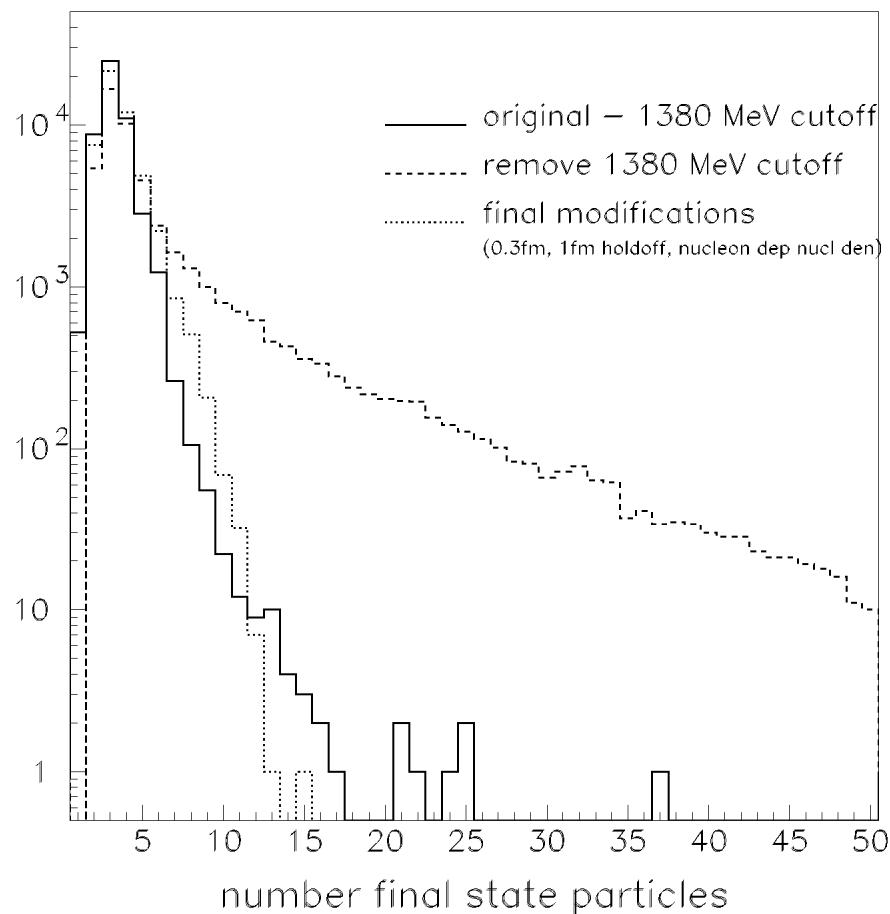
Plot of charge density in carbon from W.Rueter *et al.* Phys Rev C **26** 806 (1982).

1380 MeV Threshold

Originally any target nucleons knocked out of the nucleus during final state interactions were dropped from the event if they had a total energy below 1380 MeV.

Since MiniBooNE is sensitive to nucleons with energy down to about 30 to 40 MeV, we reduced this cut on total energy to 960 MeV.

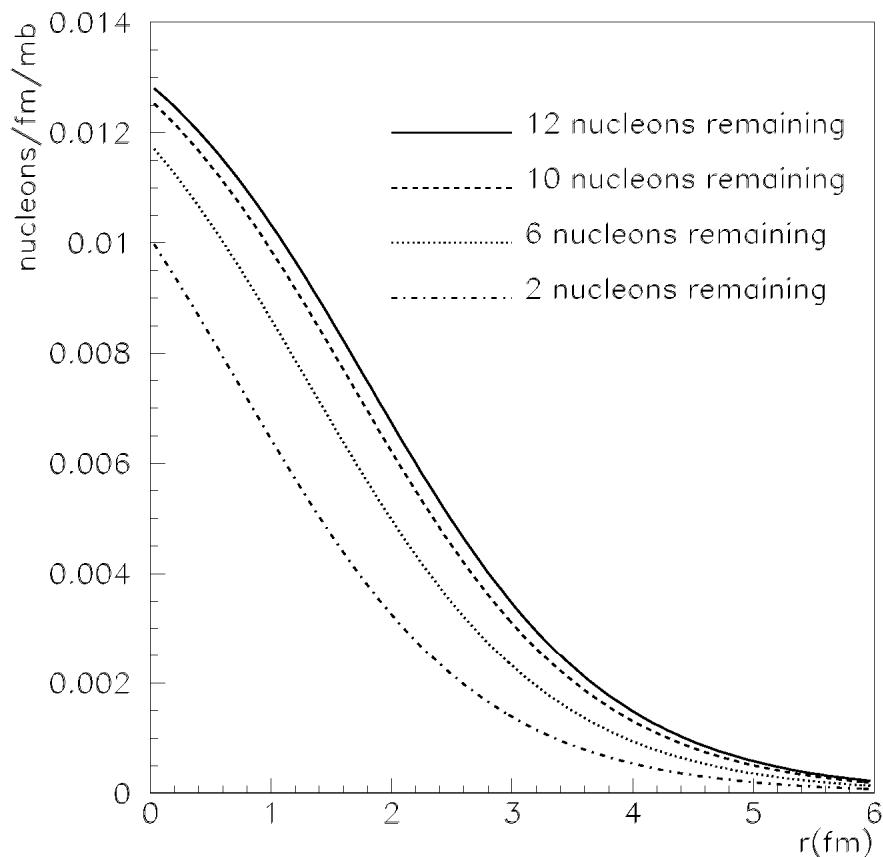
Changing this cut allowed partnuc to produce a large number of lower energy nucleons.



1380 MeV Threshold

Two changes were made to partnuc to fix this problem.

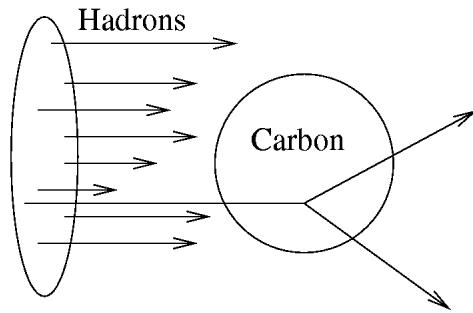
- Particles now get a 1.0 fm first step where interactions can not occur.
- Partnuc now records the number of target nucleons that get knocked out of the nucleus for each initial particle. After two nucleons are knocked out, the nuclear density becomes dependent on the number of remaining nucleons.



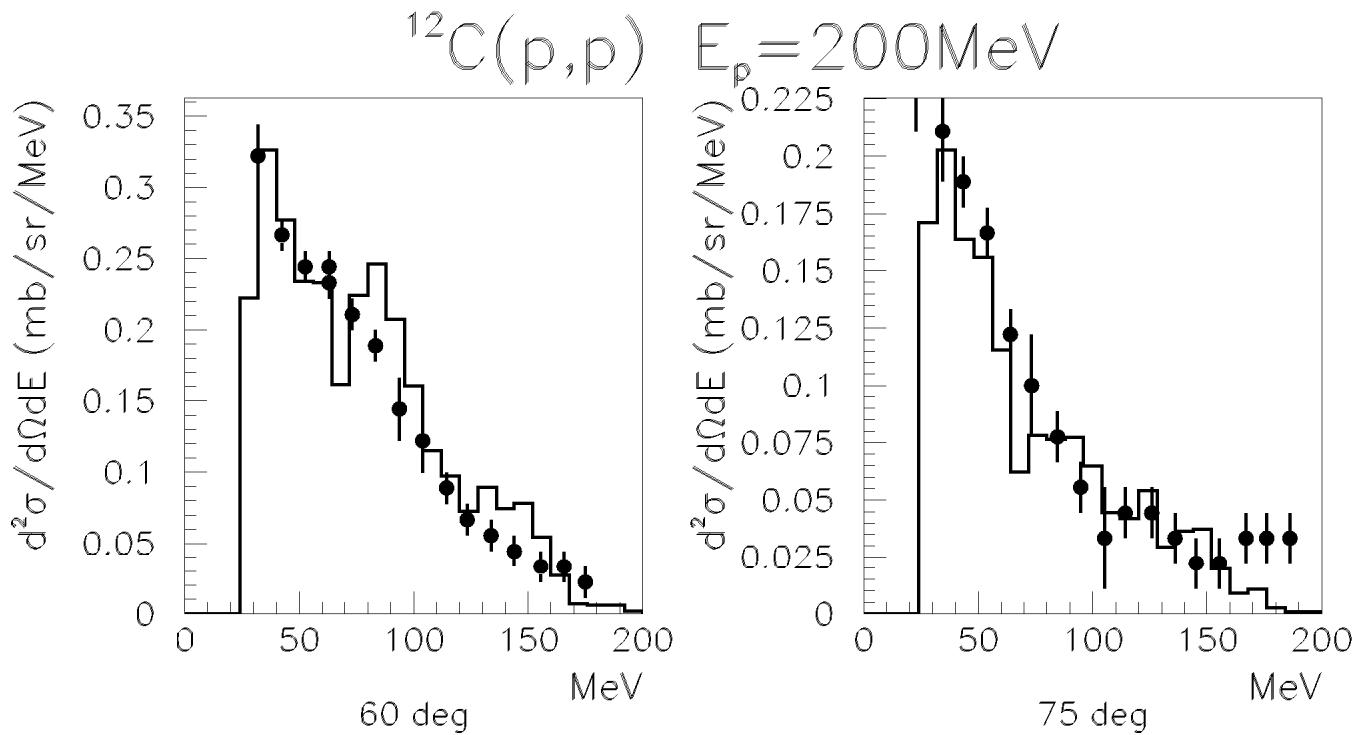
Nuclear density model used in partnuc, parameters are from B.Hahn *et al.* Phys Rev 101 1131 (1956).

Tests of Partnuc

Nuance can be run in “hadron mode” to test the final state interactions simulation in partnuc.



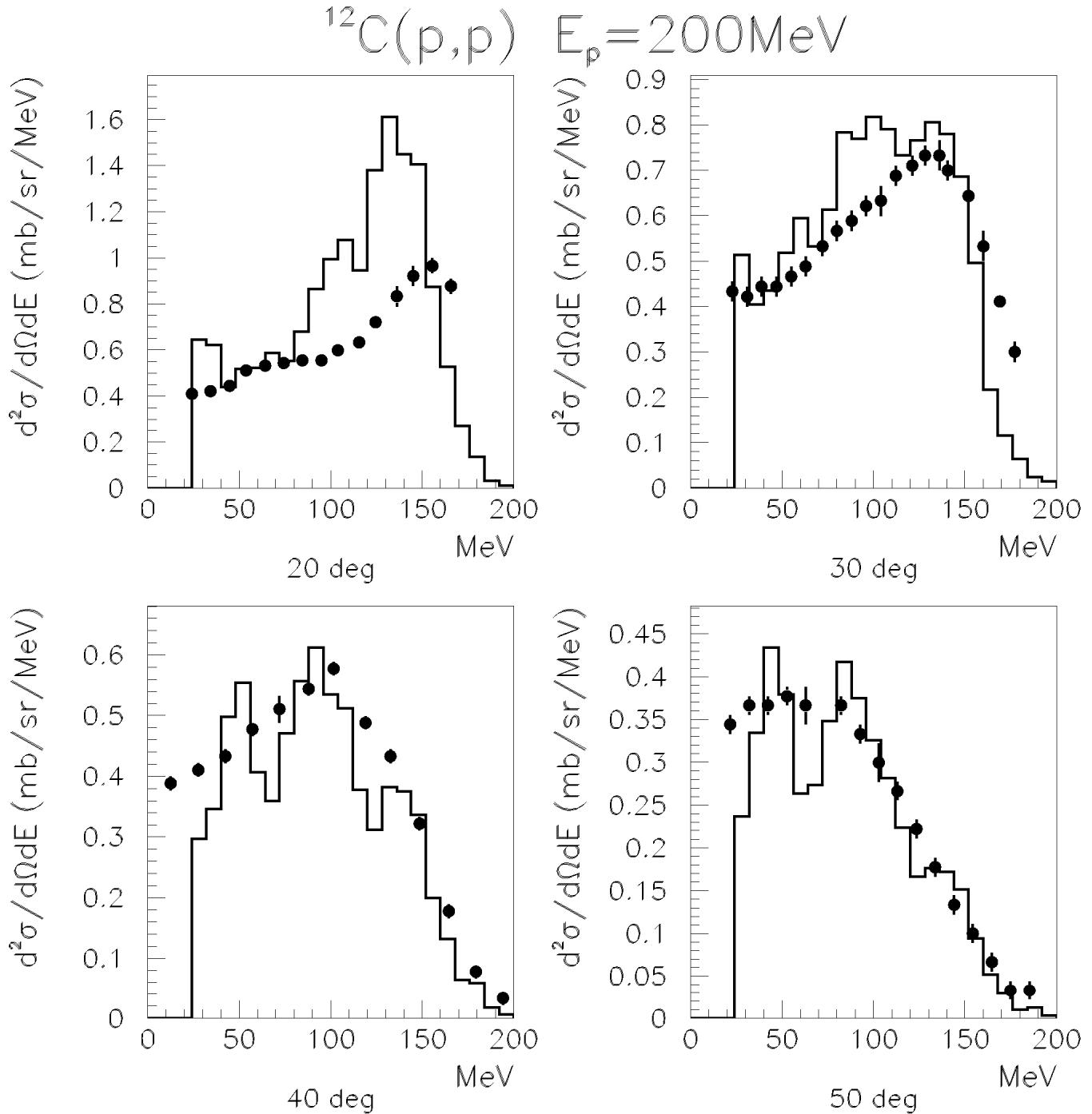
Tests have been done with both protons and pions to compare partnuc to scattering data.



The data points are from S.V.Fortsch *et al.* Nucl. Phys. **A485** 258 (1988).

The solid line is the Nuance prediction.

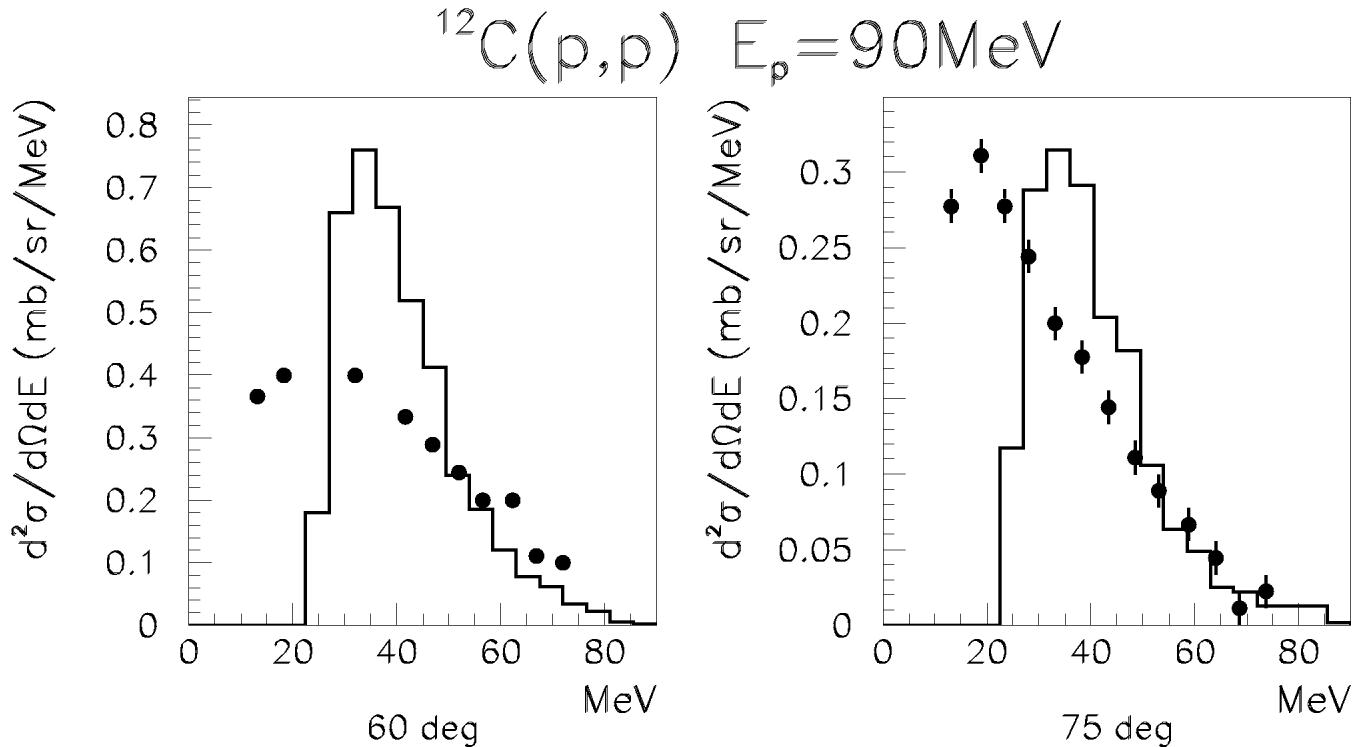
Tests of Partnuc



The data points are from S.V.Fortsch *et al.* Nucl. Phys. **A485** 258 (1988).
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Tests of Partnuc

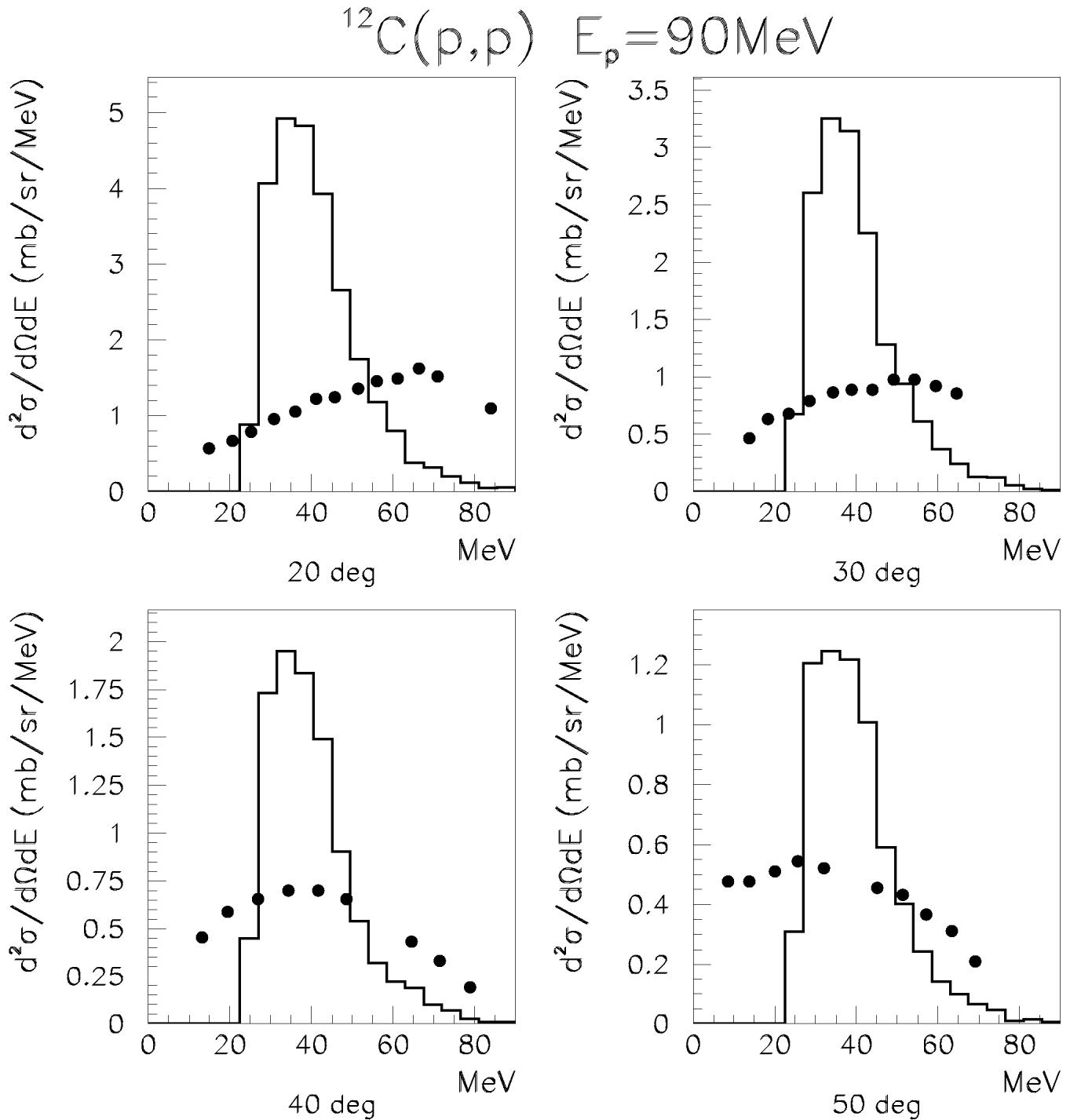
While in general partnuc does a good job reproducing the data at 200 MeV, it does not reproduce the data well at 90 MeV. Note that these plots are all absolutely normalized.



The data points are from S.V.Fortsch *et al.* Nucl. Phys. **A485** 258 (1988).

The solid line is the Nuance prediction.

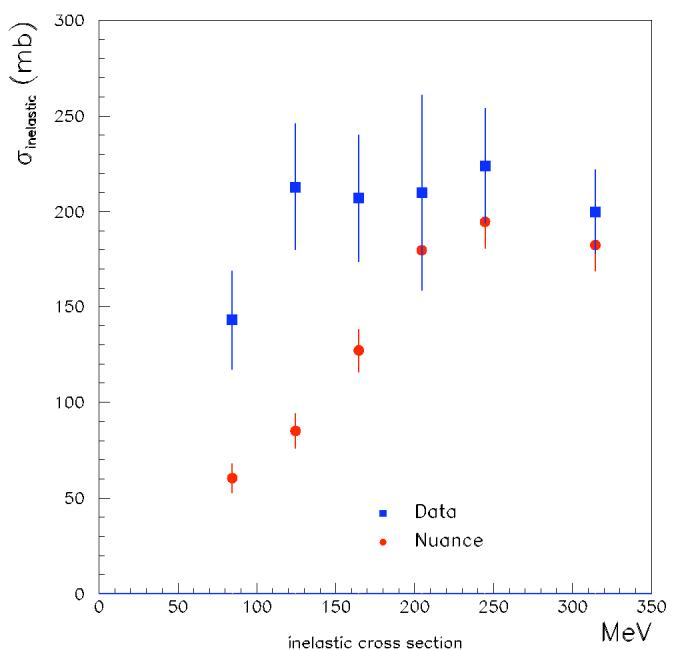
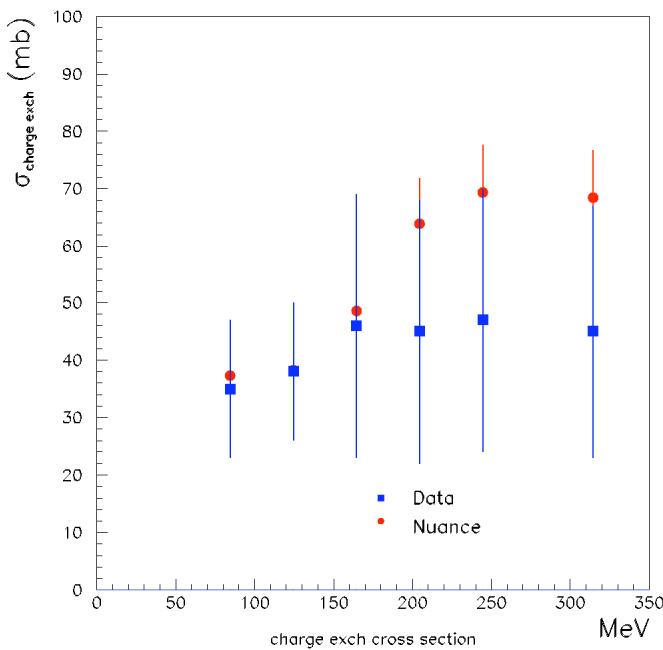
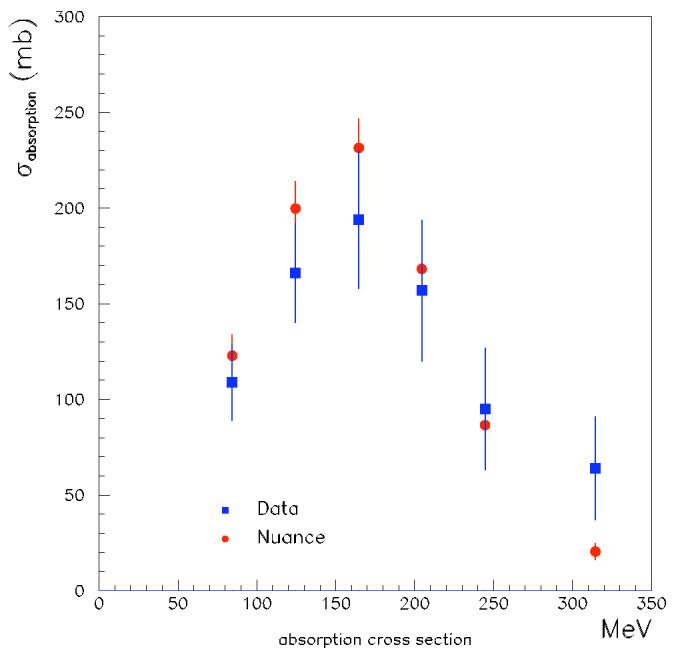
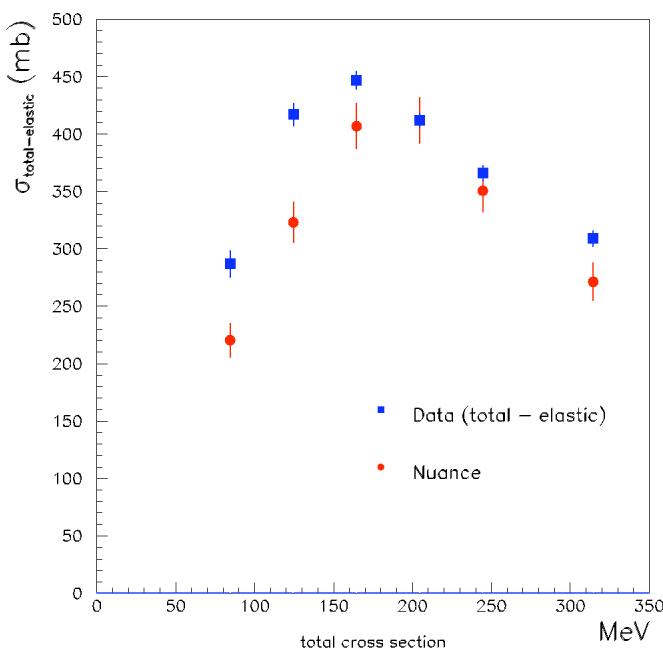
Tests of Partnuc



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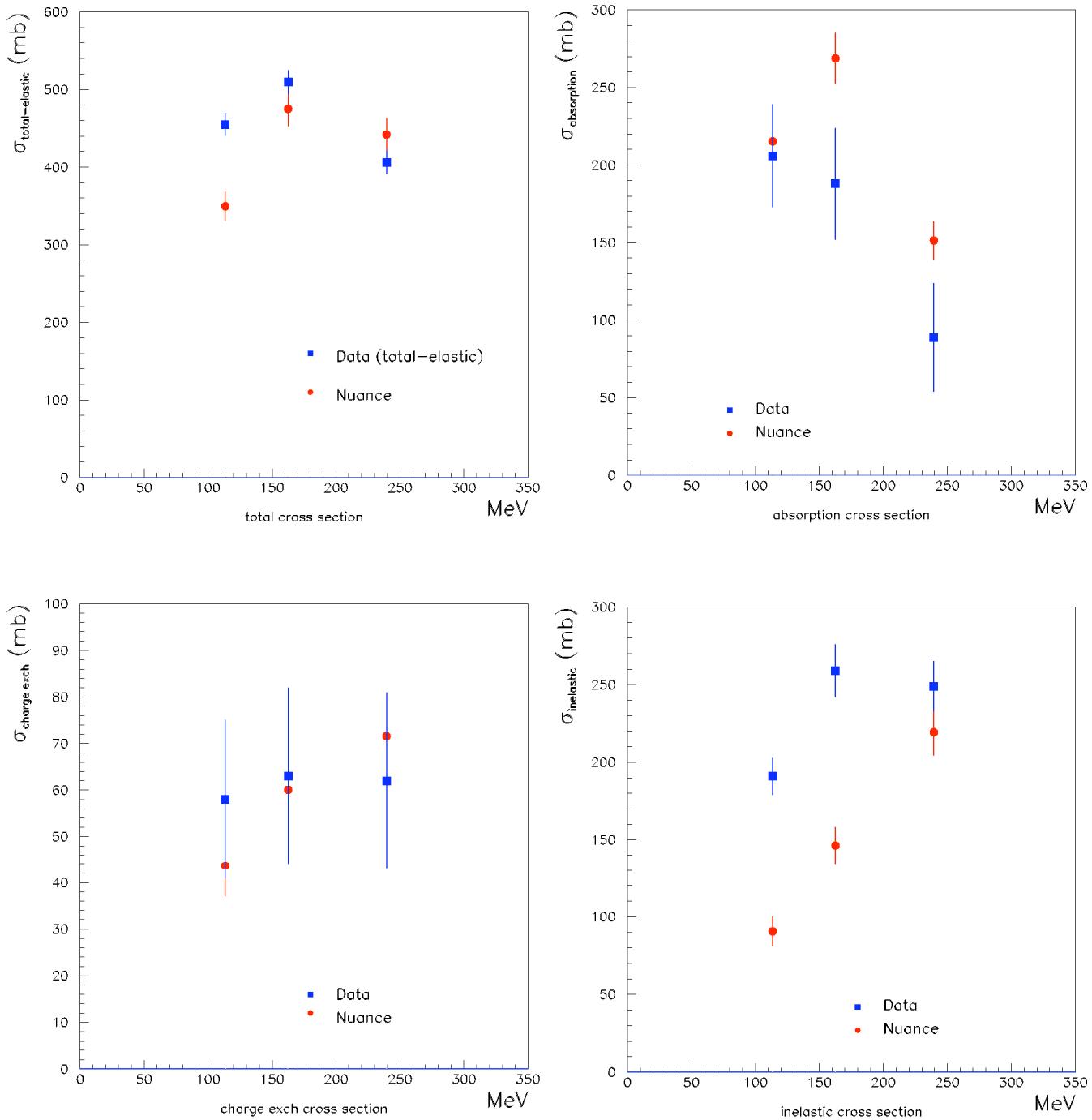
Tests of Partnuc

These plots show partnuc compared to data for π^+ scattering in carbon at a variety of different energies. Since partnuc can not simulate elastic scattering off carbon, that part of the cross section was subtracted from the total cross section.



Tests of Partnuc

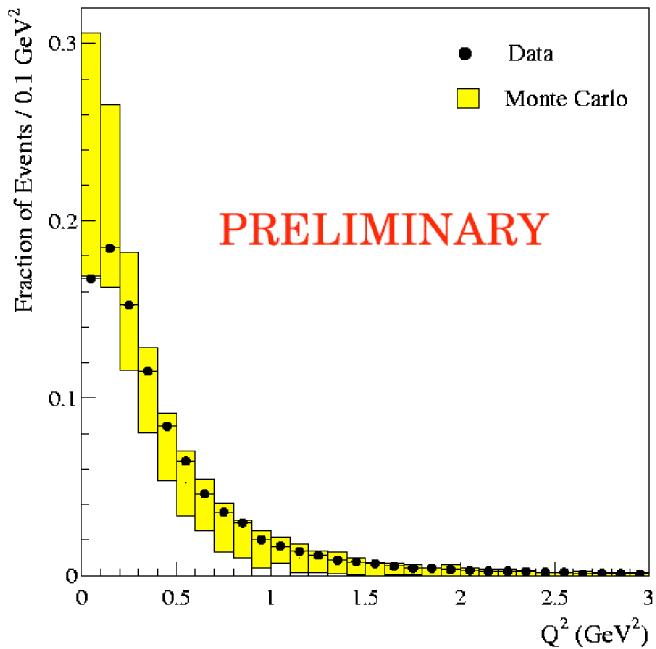
These plots show partnuc compared to data for π^+ scattering in oxygen at different energies. Again the elastic part of the cross section was subtracted from the total cross section.



Data are from C.H.Q.Ingram *et al.* Phys. Rev. C **27** 1578 (1983).

Tests of Quasi-Elastic Scattering in Nuance

MiniBooNE is interested in testing the CCQE model in Nuance, especially the nuclear effects in the model such as Fermi momentum and Pauli blocking.

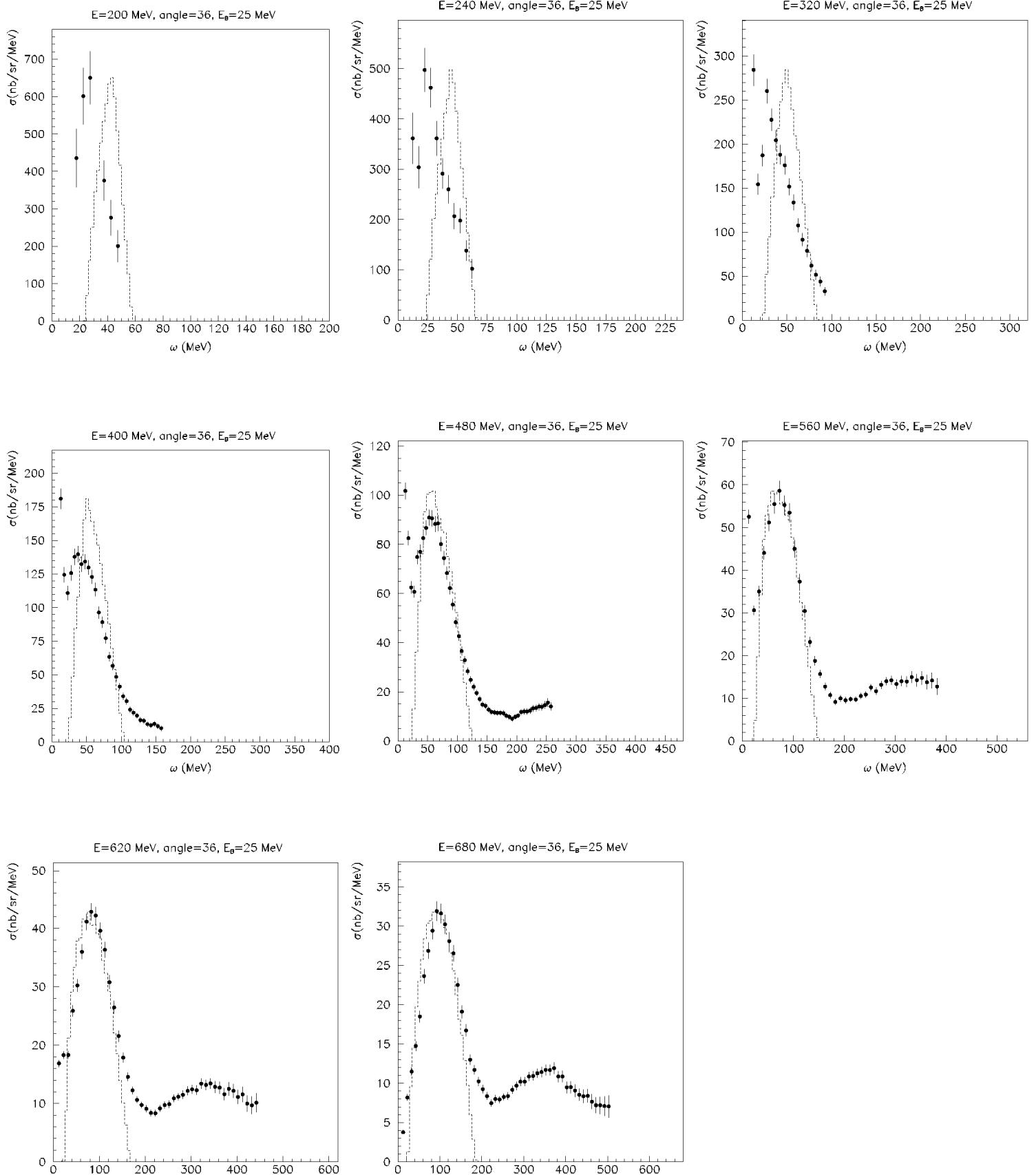


Sam Zeller has modified the Nuance CCQE code to run with electrons instead of neutrinos to test the CCQE model.

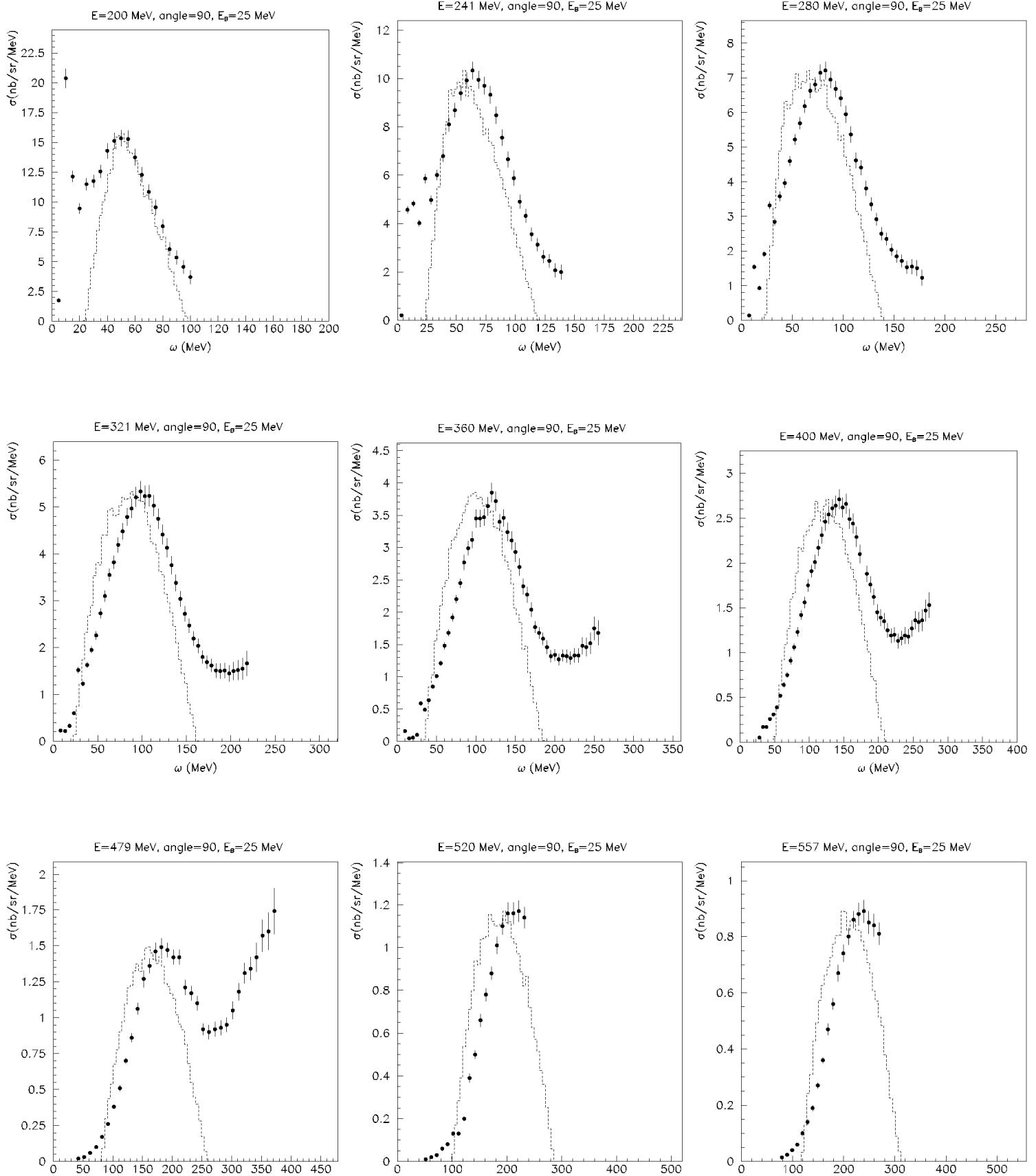
We have compared relatively normalized Nuance predictions to Saclay electron scattering data on carbon (Barreau *et al.*, Nuclear Physics A402 (1983) p.515, and private communications).

While these comparisons are not absolutely normalized, they do show significant shifts with respect to the energy transferred in the event.

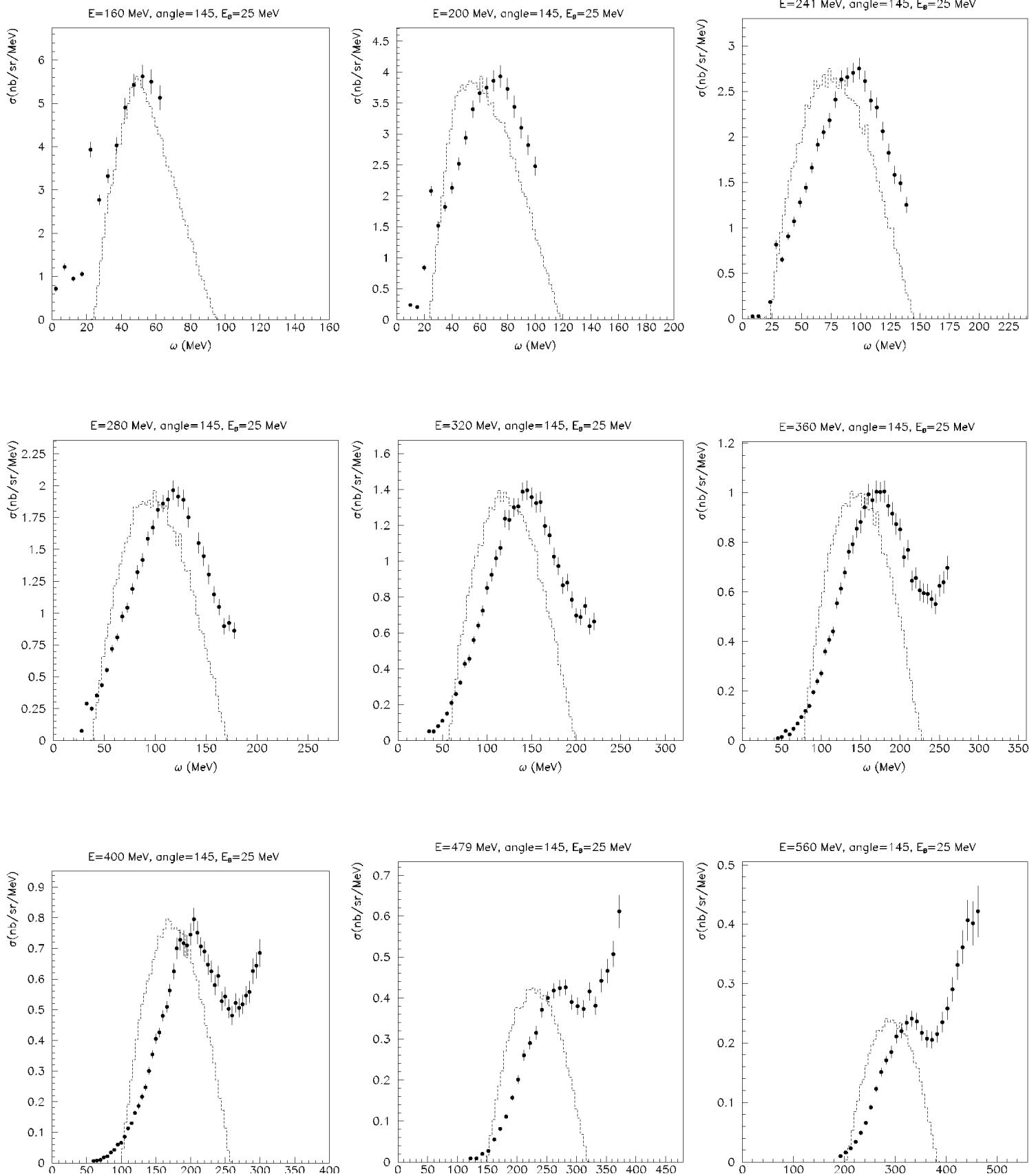
Tests of Quasi-Elastic Scattering in Nuance: 36°



Tests of Quasi-Elastic Scattering in Nuance: 90°



Tests of Quasi-Elastic Scattering in Nuance: 145°



Final Thoughts

- Considering how crude of a model partnuc is, final state interactions appear to generally agree with both pion and nucleon data at most energies.
- While more comparisons to data should be done, Mini-BooNE also needs to determine how sensitive we are to FSI.
- Dave Casper has created the SonOfPartnuc which will someday replace partnuc in Nuance.
- In the near future we hope to have absolutely normalized electron scattering predictions from Nuance for both the quasi-elastic and resonant regions.
- Geoff Mills has been investigating modifications to the Smith+Moniz CCQE model to include effective mass, short range correlations, and other nuclear effects. These corrections will hopefully bring Nuance electron scattering predictions into better agreement with data.