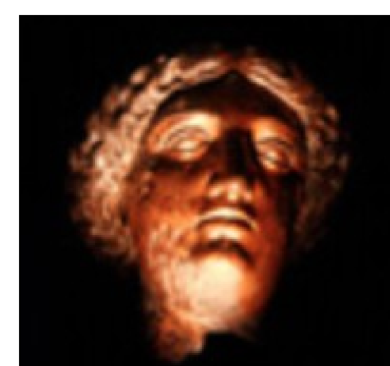
Neutron Hide and Seek

Miranda Elkins
University of Minnesota - Duluth
for the MINERvA Collaboration



Overview

First... Thanks for voting for my poster!

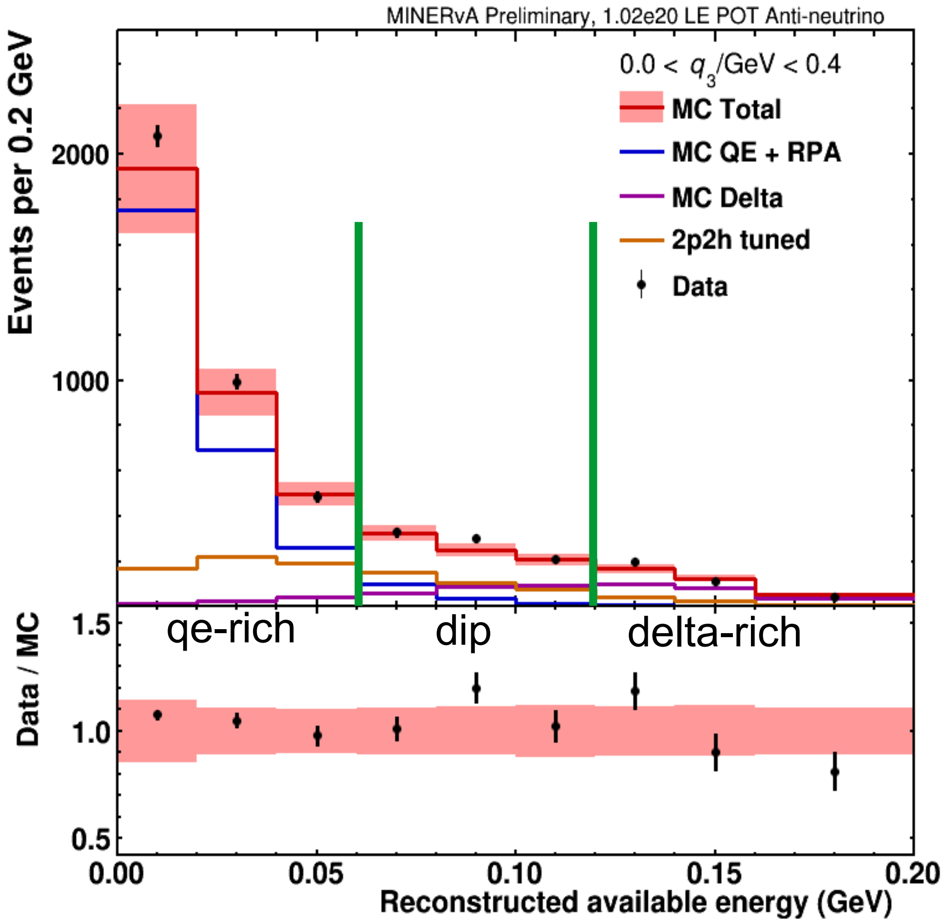
Does the addition of RPA and 2p2h affect nucleon multiplicities and cause agreement between MINERvA simulation and data?

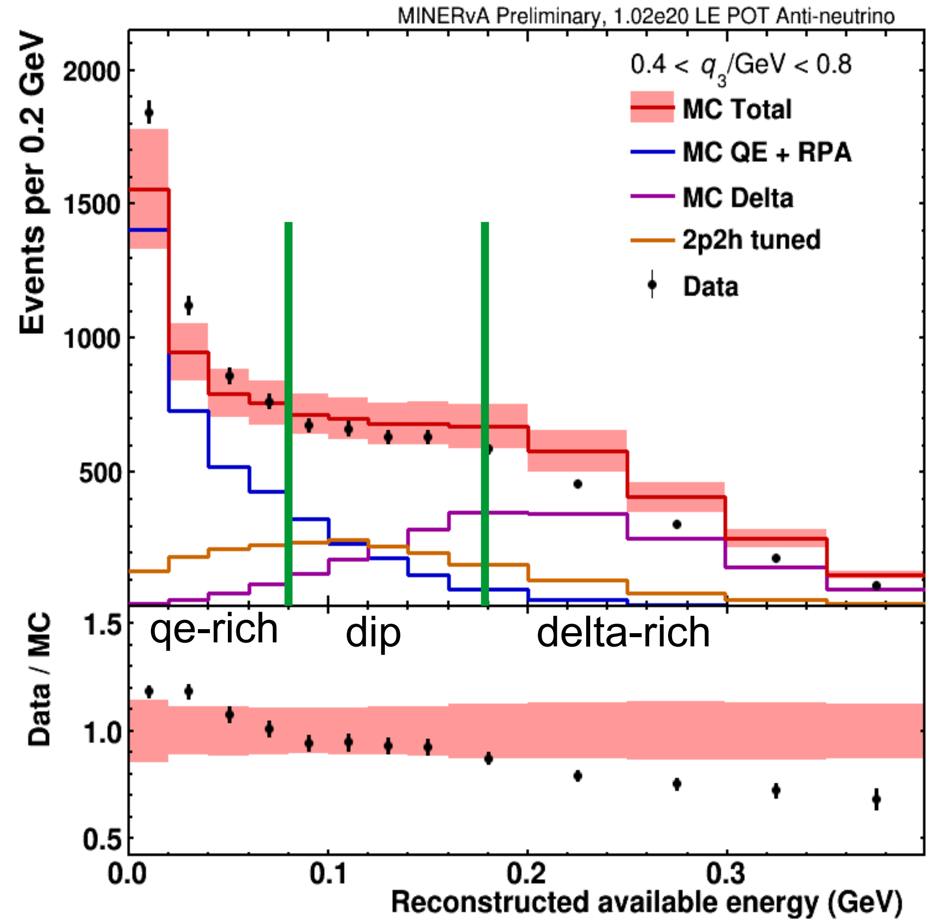
Neutron Counting Algorithm – how does it work?

Neutron Visibility – can we see neutrons and how much of their energy is deposited?

Neutron Multiplicities

Reconstructed Available Energy Plots Agree with Data





Turning on RPA and then the tuned 2p2h causes good agreement between simulation and data
- see R. Gran's talk

Are there other distributions that can be used to check agreement and MINERvA's sensitivity to the addition of these nuclear effects?

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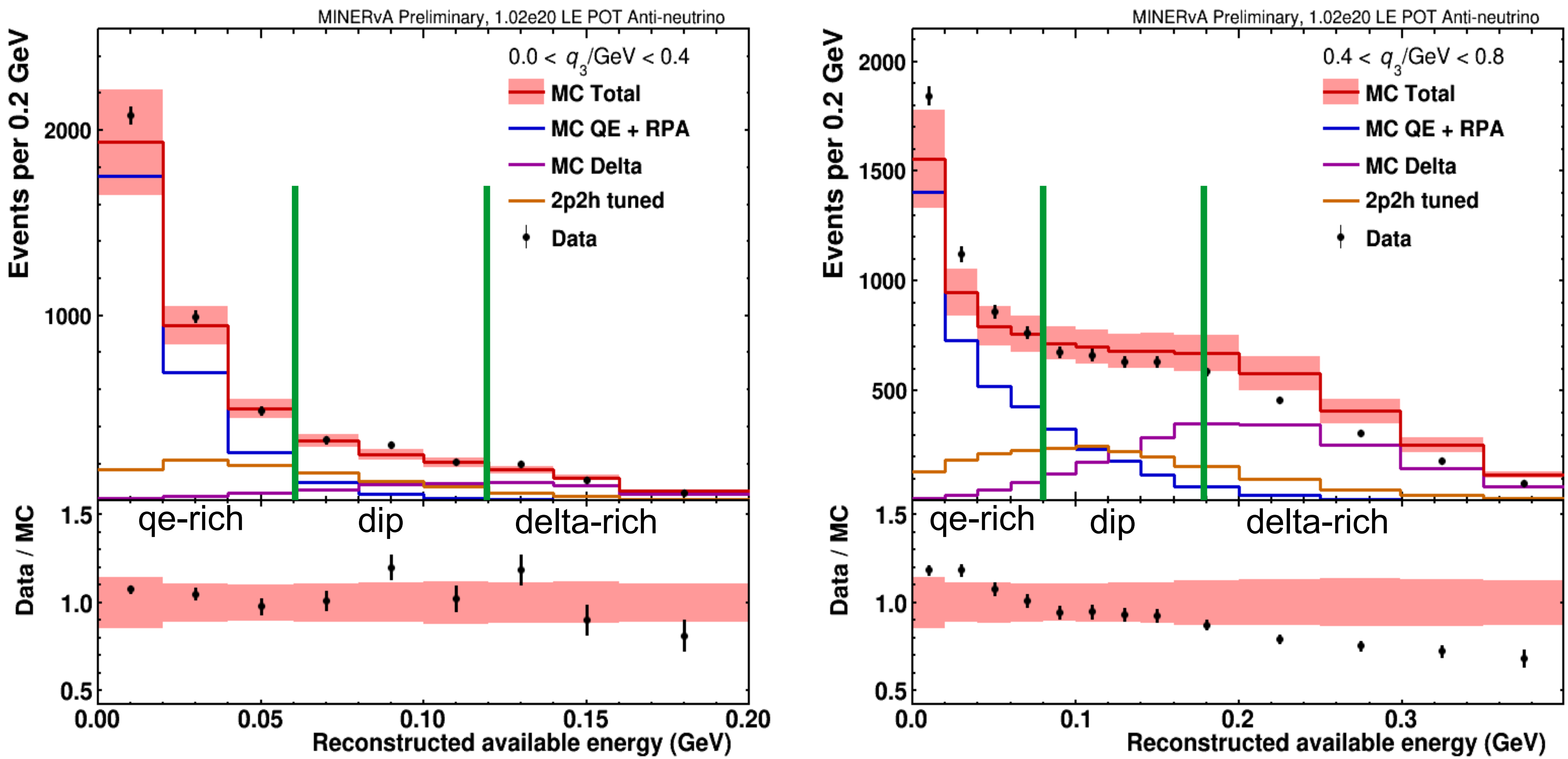

The number of final state nucleons for the events in the three defined hadronic energy regions should be different

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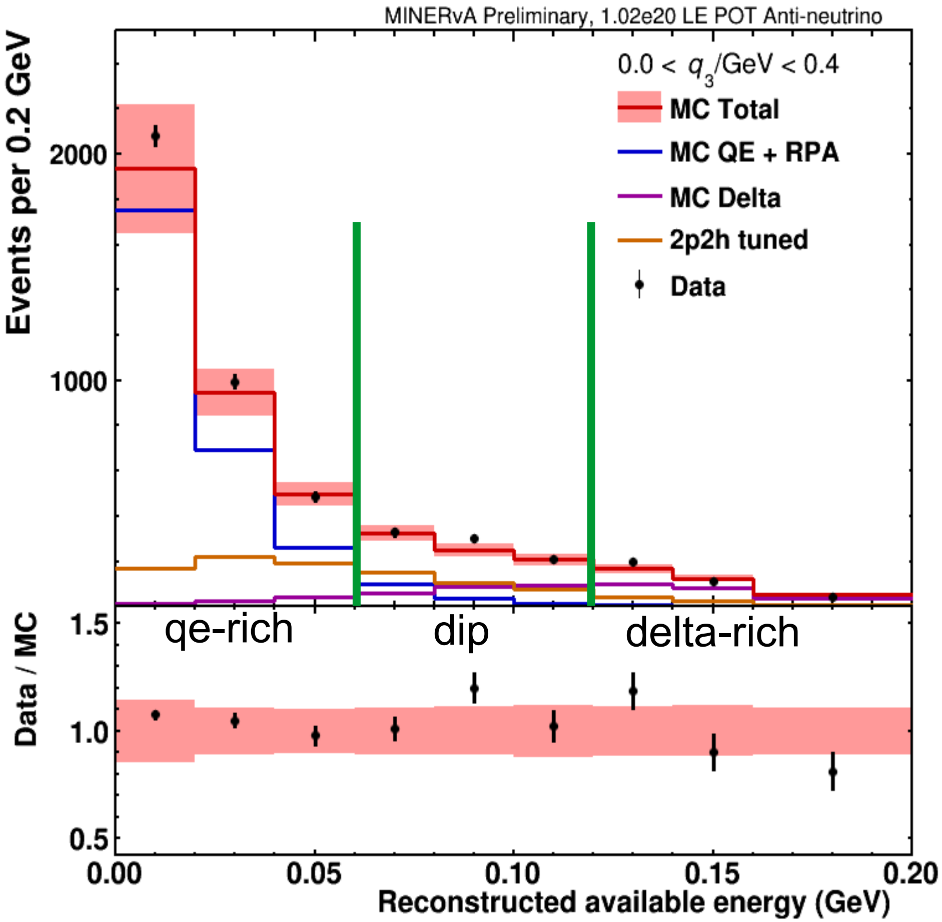

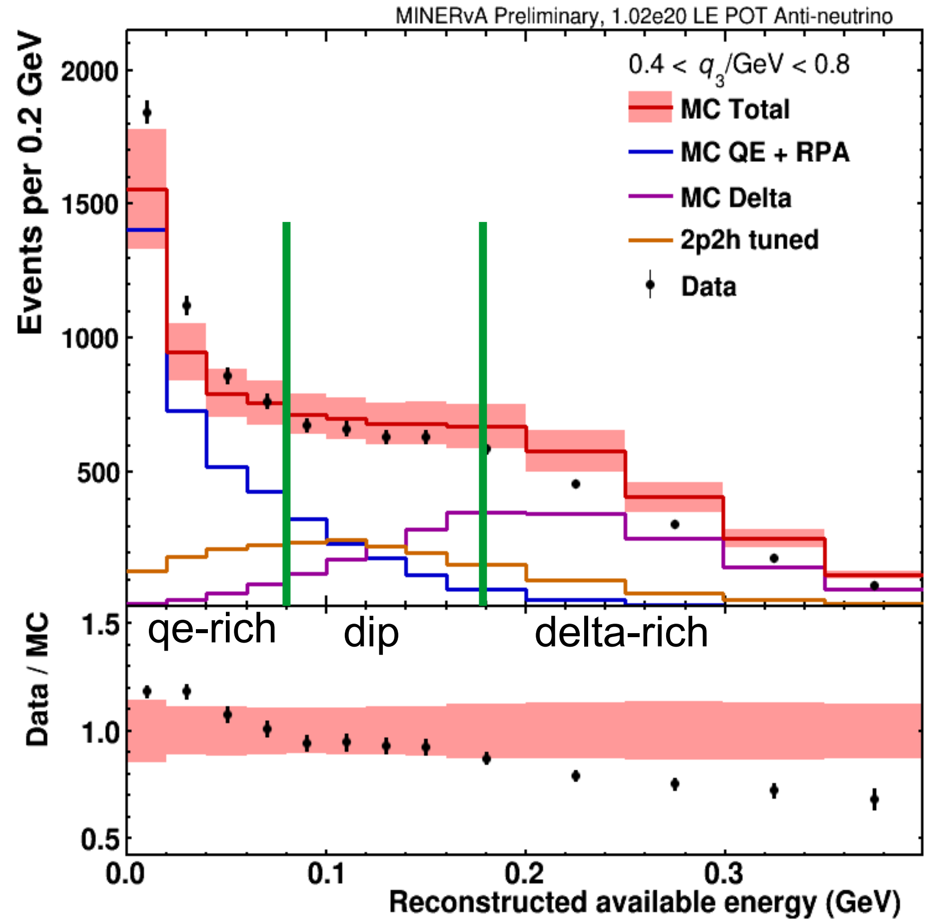

The number of final state nucleons for the events in the three defined hadronic energy regions should be different

So we can count the number of neutrons and protons per event in each of these regions and compare for simulation and data

A Quick Overview of the Neutron Counting Algorithm

Uses spatial information to isolate energy deposits likely from a GENIE neutron:

Ignores deposits near the anti-neutrino's interaction vertex

- Lots of protons and charged pions are here!

Ignores areas near the muon track as well

Combines deposits near one another into a single candidate

The Algorithm Counts Neutrons

The algorithm places **83%** of the energy Geant4 puts in the detector associated with GENIE neutrons into candidates

- Lost energy is near the interaction vertex or too low to meet candidate energy threshold (1.5 MeV)

Simulation Particle Type	0 < reco q3 <0.4 GeV/c	0.4 < reco q3 <0.8 GeV/c
Neutrons	76.60%	59.86%
Protons	00.28%	01.54%
Pi Minus	10.79%	22.31%
Pi Zero	02.70%	10.56%
Muon	06.08%	03.04%
Data Overlay	0.287%	01.97%
Other	00.69%	00.72%

The largest background caused candidates come from GENIE pions!
Background studies show these are irreducible

Neutrons Are Visible but Don't Leave Much Energy

Visibility of neutrons asymptotically approaches 45% as energy increases

Neutron Energy (MeV)	Probability of an Event Having at Least One Candidate
0-10	8%
10-50	31%
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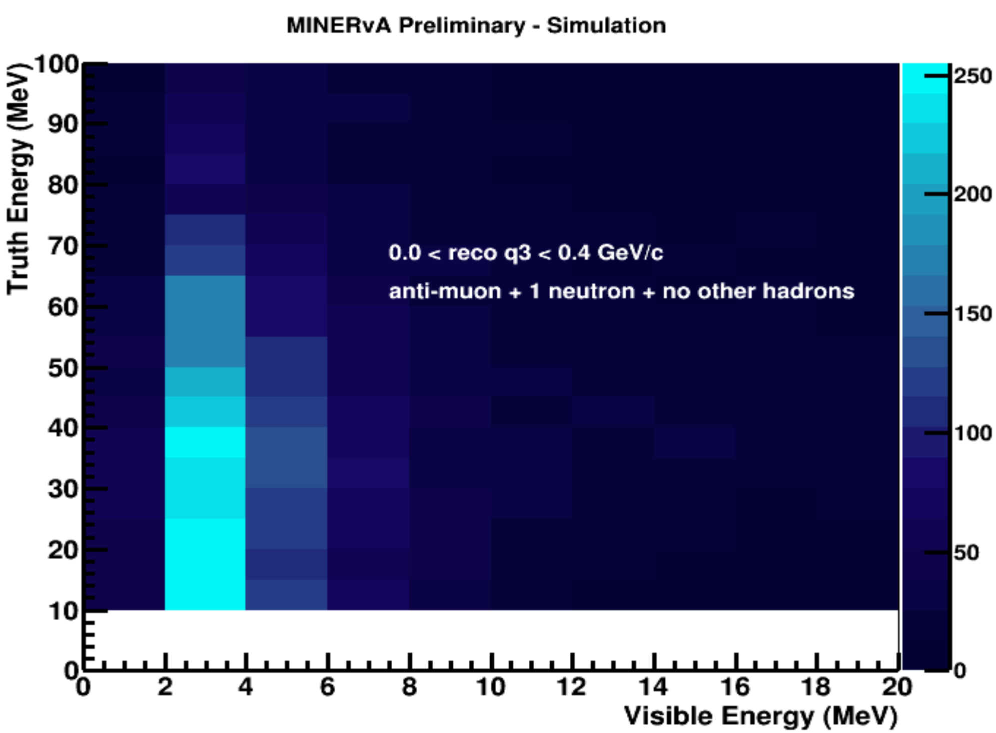
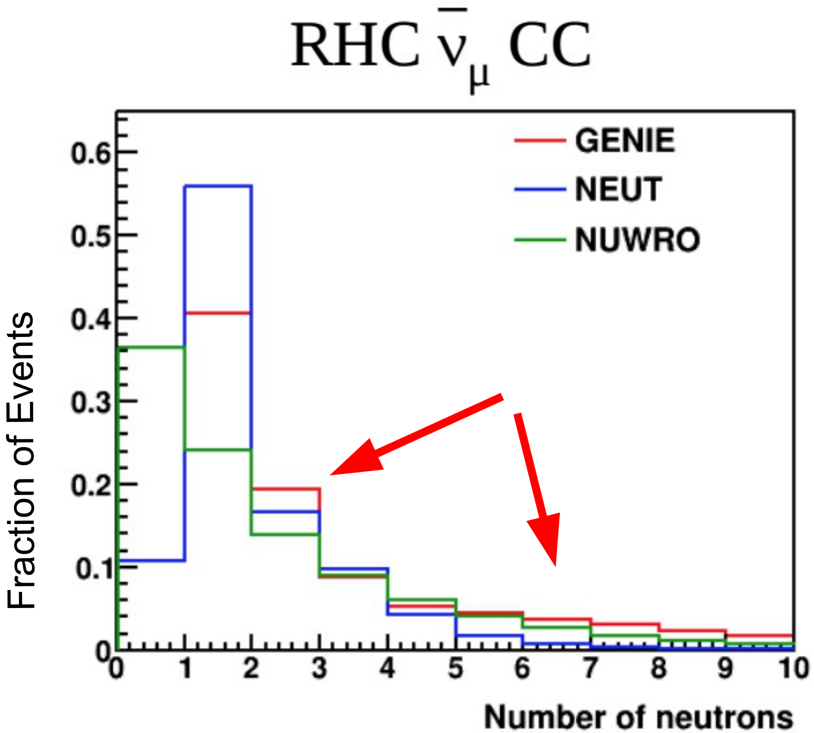
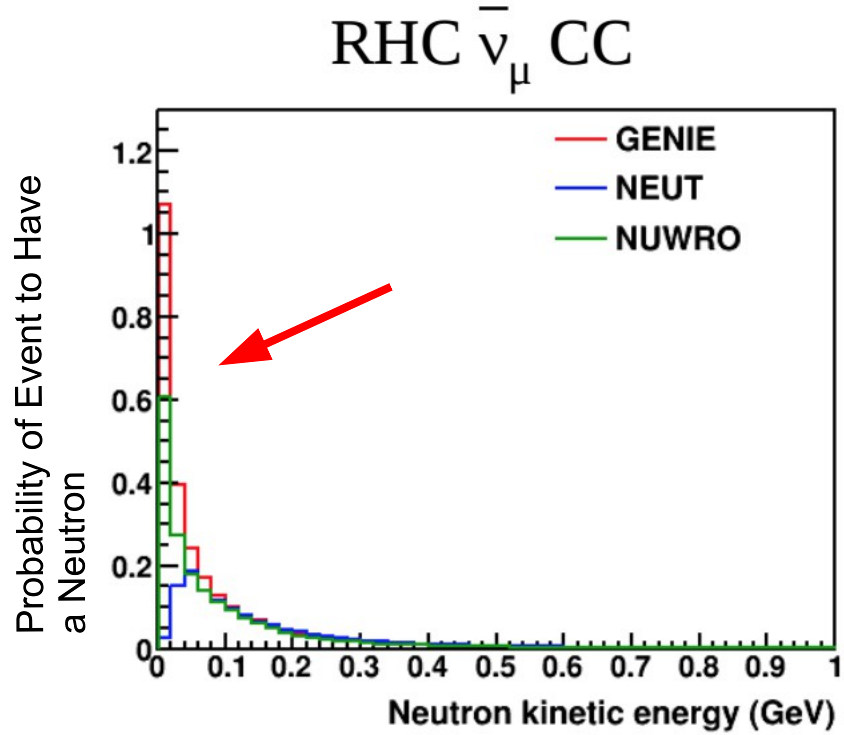


But no matter the truth energy the neutron typically left 10 MeV or less in the detector!

Event Generators Do Not Agree on Neutrons

For DUNE on Argon
Provided by Chris Marshall, Jacob Calcutt, and Kendall Mahn

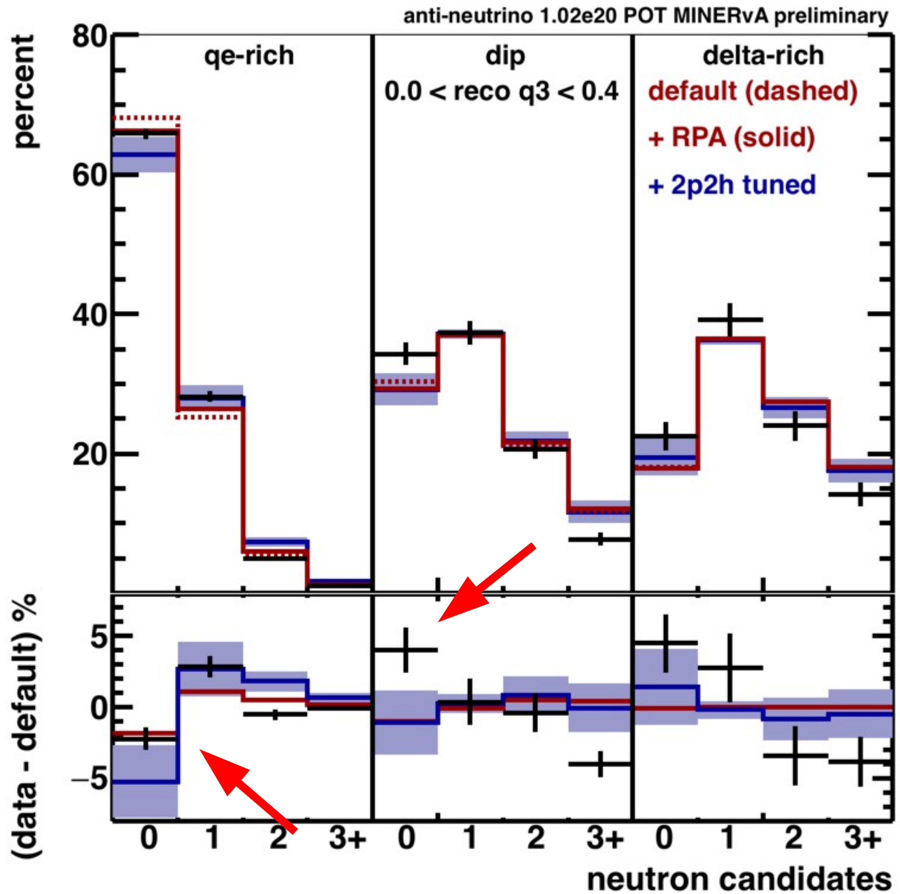


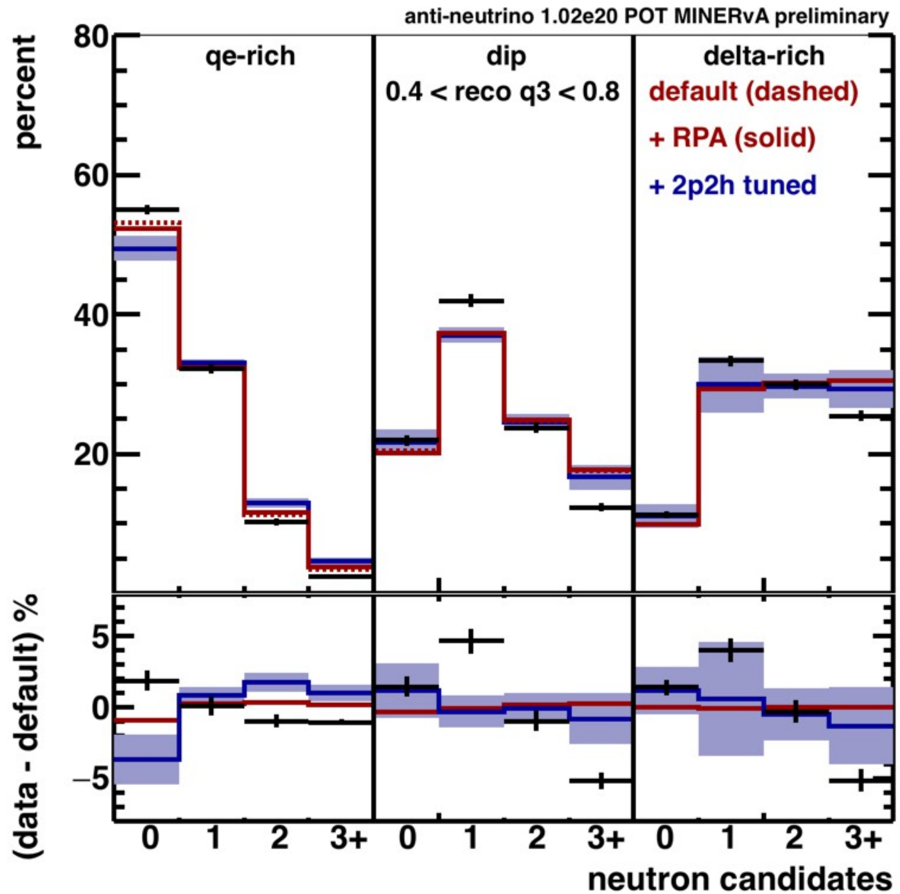


GENIE has the **most** neutrons per event and the most low energy neutrons

The large neutron excess in the first bin in the plot on the right is between 5% and 30% visible. This potential excess is present in GENIE even before 2p2h modifications enhance it further.

There is an Over Simulation of Neutron Candidates





There is an over simulation of candidates in the default simulation - masks RPA and 2p2h sensitivity. Due to GENIE and/or Geant4 making neutrons too visible

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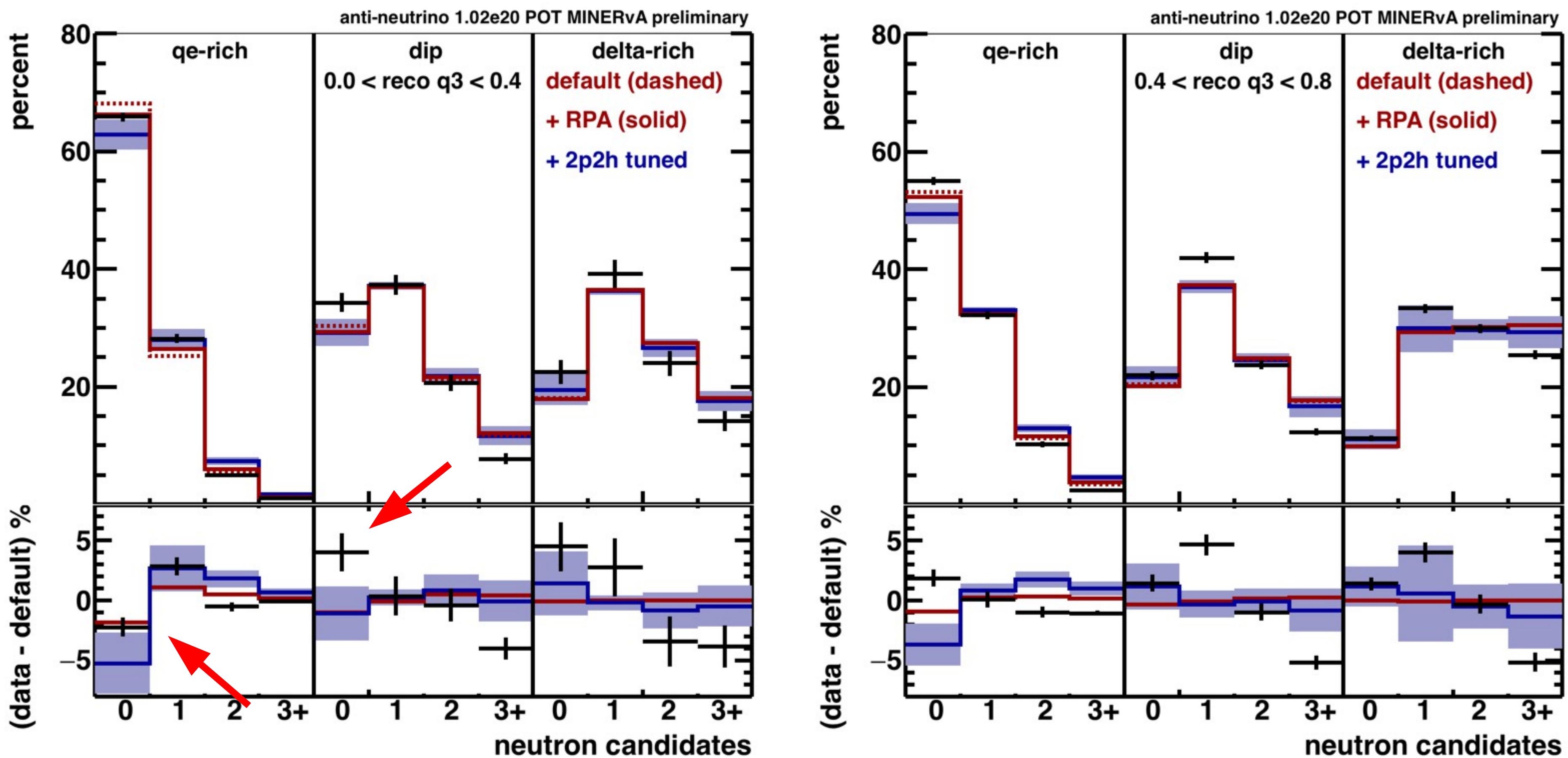

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Turning on RPA effectively increases events with candidates – decreases QE events with less energetic and visible neutrons

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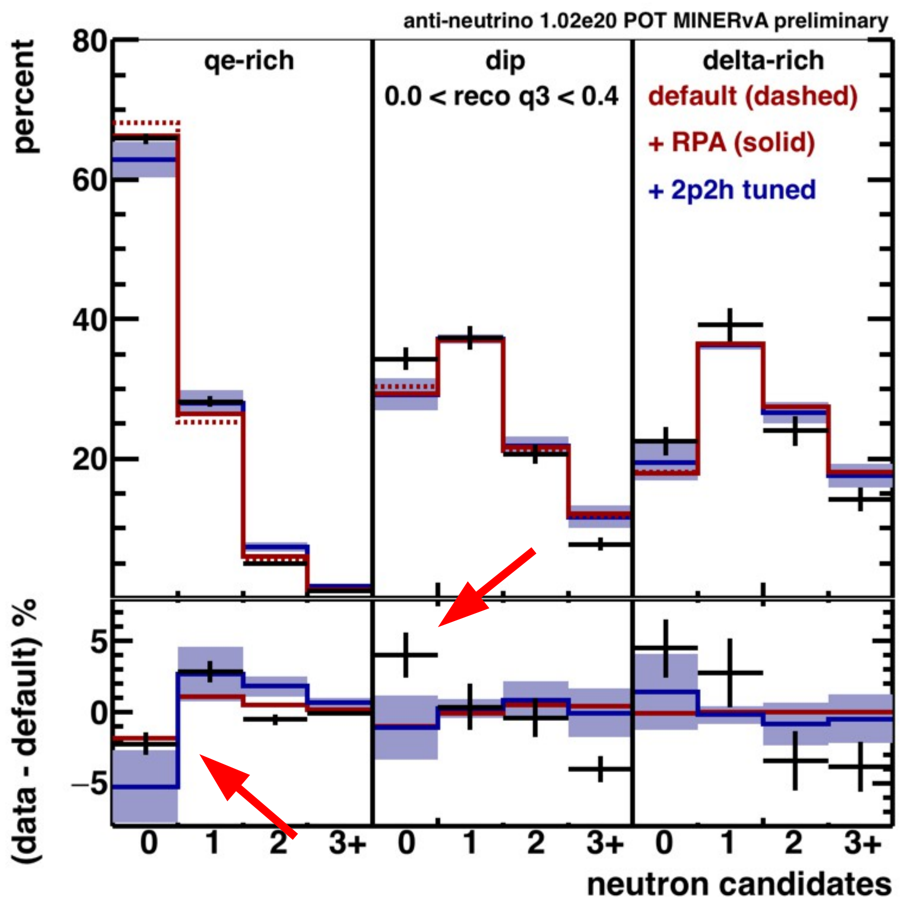
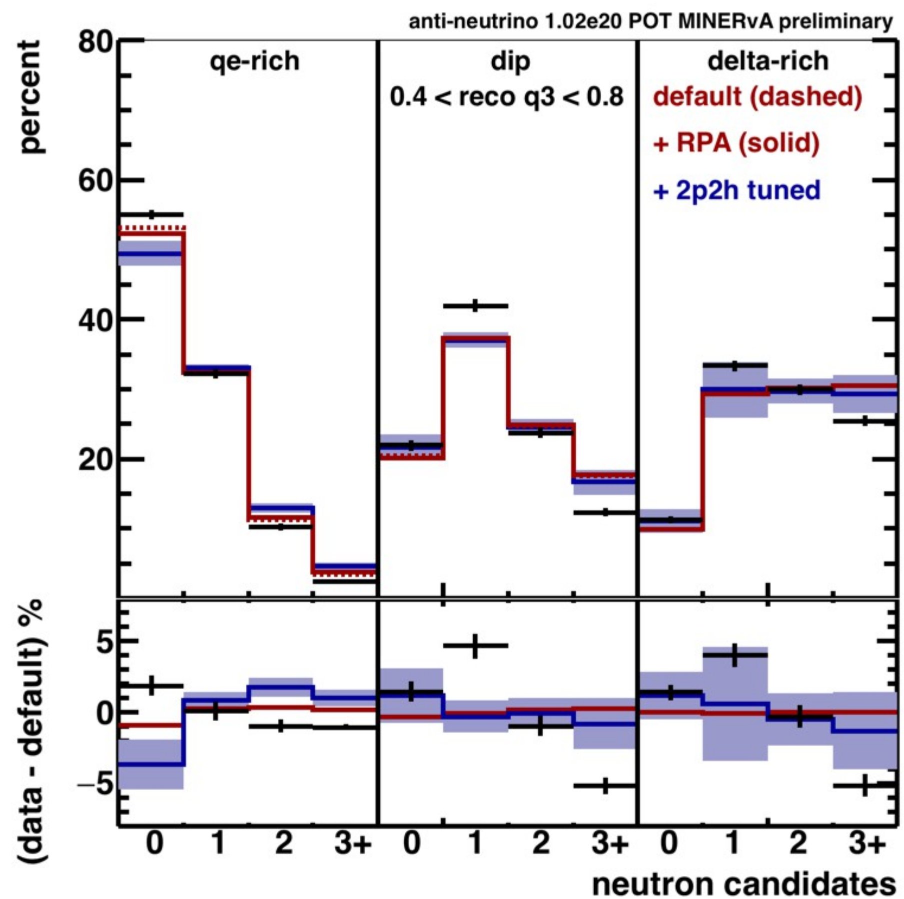




Turning on RPA effectively increases events with candidates – decreases QE events with less energetic and visible neutrons

Turning on 2p2h increases events with candidates – adds in events with more visible neutrons

Review

The first neutron counting algorithm was made and used to study MINERvA anti-neutrino data reactions with nuclei

The algorithm has shown the visibility of neutrons increases with their kinetic energy and peaks around 45%

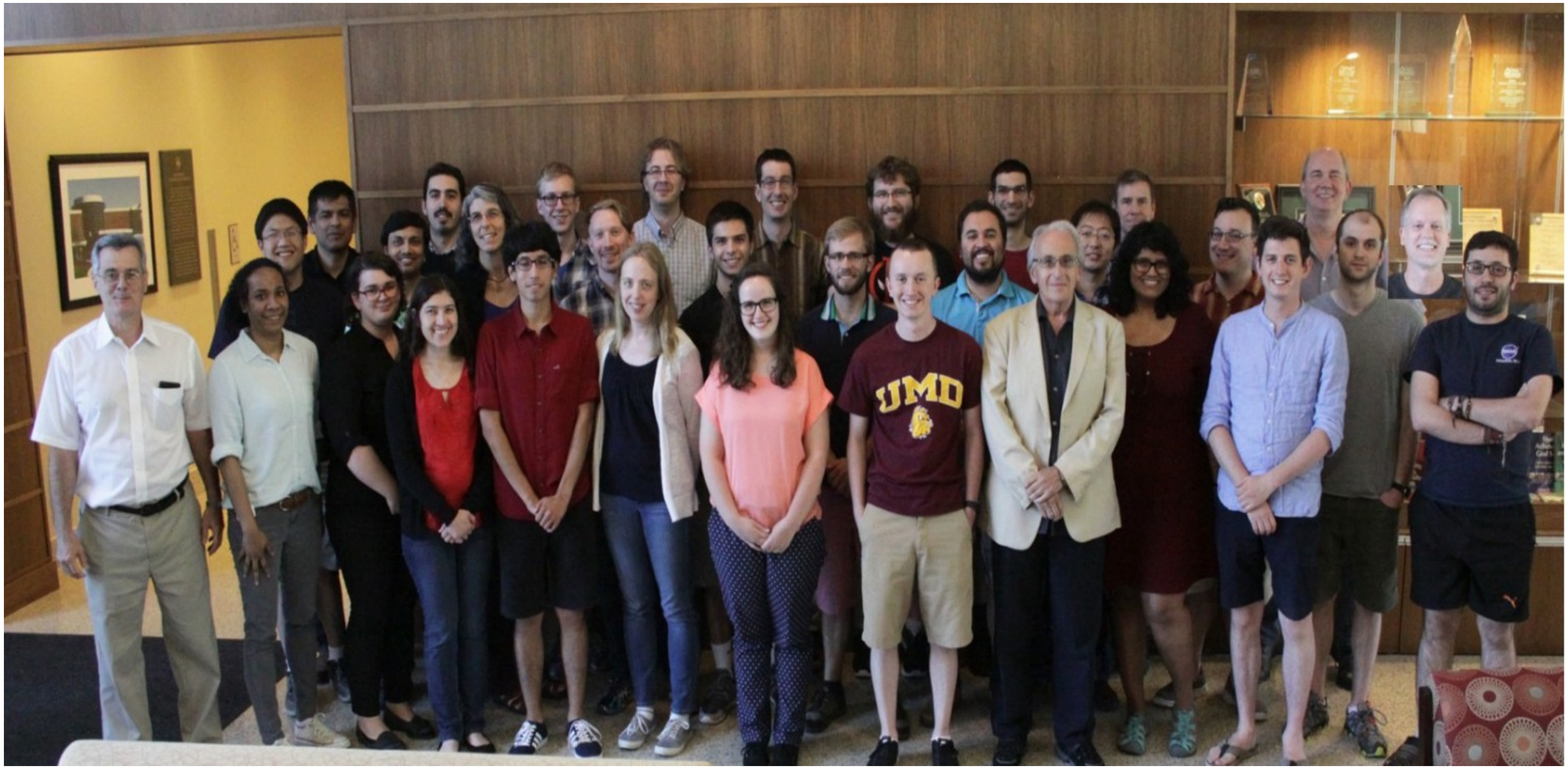
The event generators do not agree on neutrons and GENIE has the most overall and the most low energy neutrons which are visible to MINERvA between 5-30%

Review

The algorithm has shown there is an over simulation of events with candidates and candidates overall

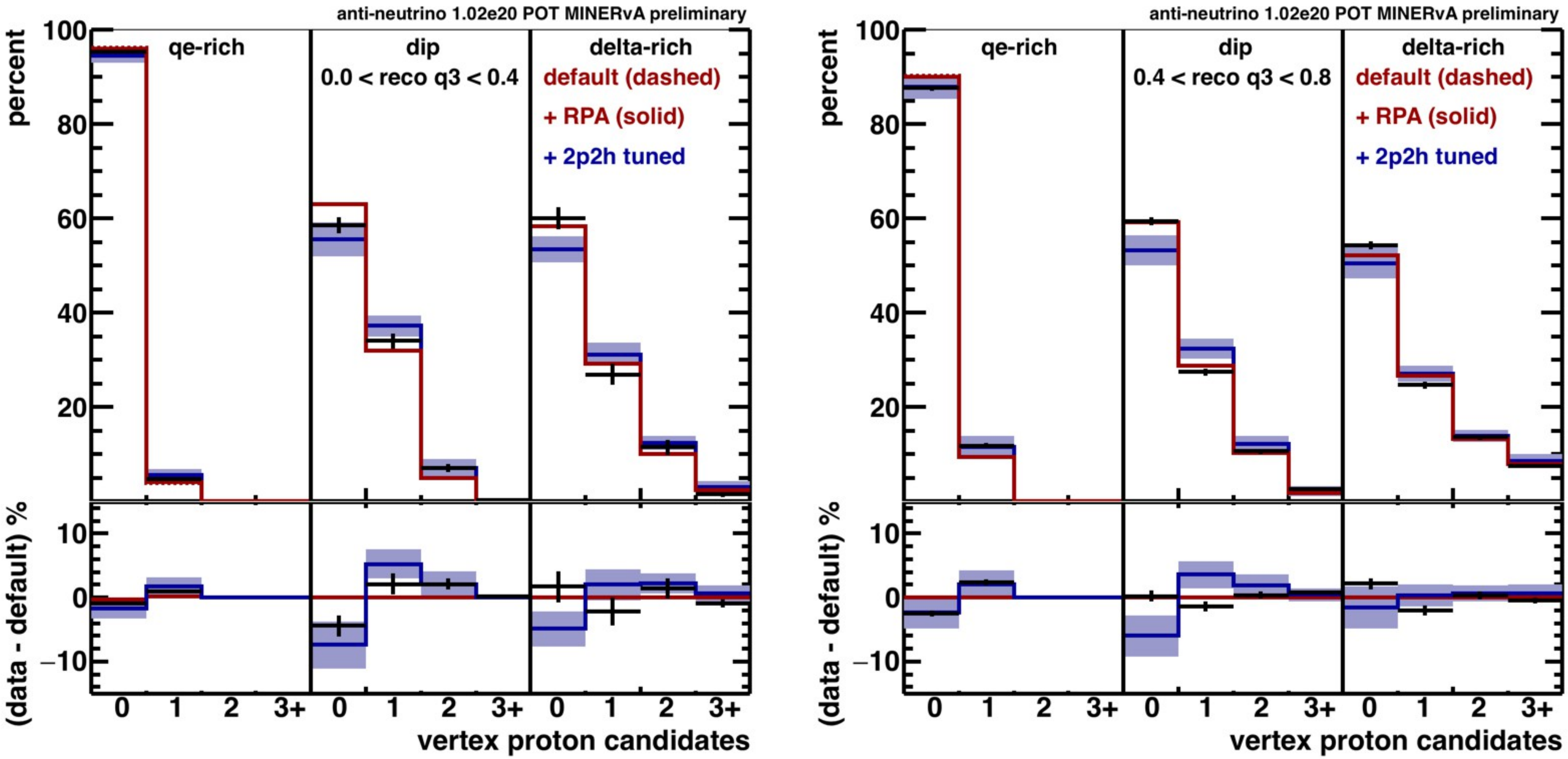
The over simulation masks the sensitivity to the RPA and tuned 2p2h nuclear effects

Thanks!



Backup

Agreement is Better for Proton Counting



Proton counting algorithm comes from neutrino case of this analysis (Rodrigues et al., 2016)

Searches for energy deposits near the interaction vertex of at least 20 MeV. Based on proton's Bragg peak being at its stopping point

Neutron Counting Algorithm Rules

Added a list of clusters that are in the inner detector but outside of vertex region to the AnaTuple

Choose clusters that are isolated but not noise

- The distance of the cluster from the vertex/muon track
- 1.5 MeV <= Cluster Energy
- Not on a track coming from the vertex
- Not part of a filament vertex blob

Created a neutron finder (this is default)

- If a cluster is within a set distance in a view from a previously counted cluster this one is not counted
- If it is in a separate view from a previous cluster but within 3 modules it is considered the same candidate and the energies are summed as a single candidate

Filament Vertex Blobber

Runs in filament mode

Creates a blob with the closest unused cluster then continues to add clusters within range and marks them as used – and then stops!

Made it do 5 iterations to create up to 5 filament blobs near the vertex

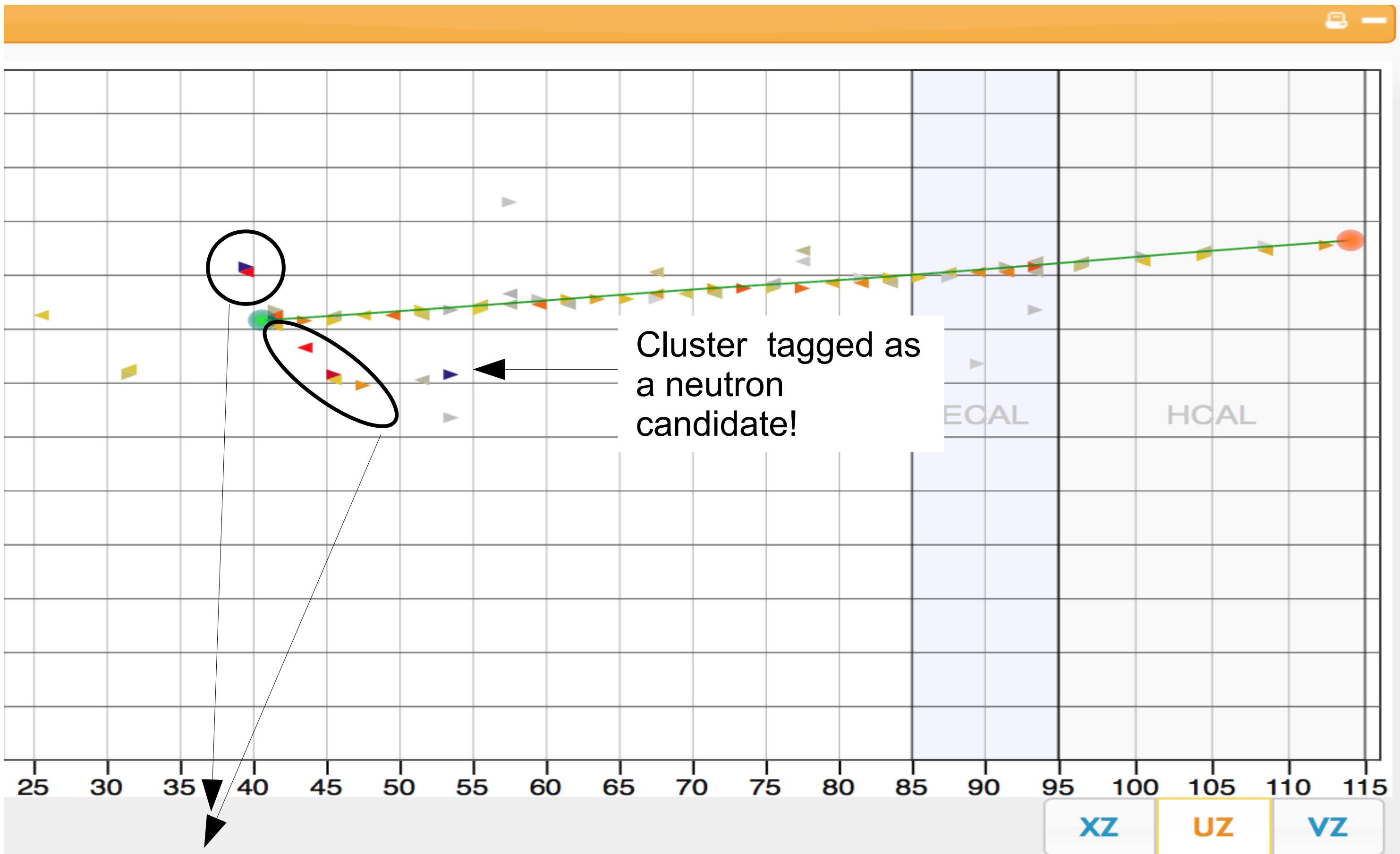
- Always saw 3 or less filament blobs

Searches for clusters within a 2-D distance of 2000mm from the vertex

First cluster must be within 250mm (~5 modules in a single plane) of the vertex

Additional clusters must be within 100mm (~2 modules in a single plane) of closest cluster already added to the blob

Examples of the Filament Vertex Blobber Working



An example of the vertex blobber creating two blobs correctly to help eliminate background

Run-50201 Subrun-152 Gate-1063

The Algorithm Counts Neutrons

Neutron Energy	Low q3	Mid q3
Total (MeV)	236146	1629000
Algorithm Counted (MeV)	194422	1365630
Efficiency	82.33%	83.83%

$$\frac{\text{Neutron energy counted by algorithm}}{\text{Neutron energy left in the detector}} > \frac{\text{Neutron energy counted by algorithm}}{\text{Neutron energy from interaction}}$$

The lost 16-18% is due to low energy neutron clusters and neutron clusters too close to the muon track being ignored, or clusters from a neutron and another cluster from a different particle combined into one candidate

Candidate gets pdg code from largest contributor to the energy

- summed the energy of all of the clusters tagged to be from a GENIE neutron for every event
- summed the energy of all the candidates counted by my algorithm tagged to be from a GENIE neutron for every event

Nucleon Multiplicities

Systematic error bars do not include an uncertainty in Geant4

Still in progress - we are re-evaluating an uncertainty in Geant4 to be more specific to this observable.

The largest systematic uncertainties are

- Neutron counting – Hadronic energy reconstruction, 2p2h, pion absorption
- Proton counting – Birks' suppression, 2p2h, and pion absorption
- Geant4 uncertainty will probably be large

Example of Table with X2

			Components			
		Total X2	qe-rich	dip	qe+dip	delta-rich
Neutron	Pion	24.0016	11.898	7.908	19.807	4.195
Low q3	RPA	18.7624	7.378	8.975	16.352	2.410
12 bins	2p2h	17.442	9.305	8.311	17.615	-0.173
	Phil	18.8275	16.639	3.197	19.835	-1.008
Neutron	Pion	32.4329	-5.041	33.974	28.933	3.500
Mid q3	RPA	29.3127	-4.428	32.562	28.134	1.179
12 bins	2p2h	33.5198	4.071	32.841	36.912	-3.393
	Phil	46.9156	31.658	14.980	46.638	0.277
Proton	Pion	9.73987	0.149	4.813	4.962	4.778
Low q3	RPA	10.0168	-0.584	5.933	5.349	4.668
10 bins	2p2h	10.7576	0.054	1.655	1.708	9.049
	Phil	11.0882	0.528	0.613	1.140	9.948
Proton	Pion	11.3038	4.312	-1.088	3.224	8.080
Mid q3	RPA	11.4164	4.131	-1.040	3.090	8.326
10 bins	2p2h	9.37396	2.289	0.147	2.435	6.939
	Phil	14.9485	0.615	14.485	15.100	-0.151
			(2 bins proton)			

Technical slide: steps to calorimetric reconstruction

We do not start knowing the energy of the neutrino, only the direction.

Measure the energy E_μ and angle θ_μ of the outgoing muon.
Measure the detected energy attributed to hadrons $E_{visible}$.

A. turn $E_{visible}$ into $E_{available}$ using detector MC, discounts neutrons
$E_{available}$ = Proton KE, $\pi^\pm$ KE, π^0, e, γ energy (plus heavier particles)
little neutrino model dependence (some anti-nu model dependence)

B. Use MC and correct to energy transfer q_0 (= E_{had} = ν = ω)
(unbiased, but correction has some dependence on neutrino model)

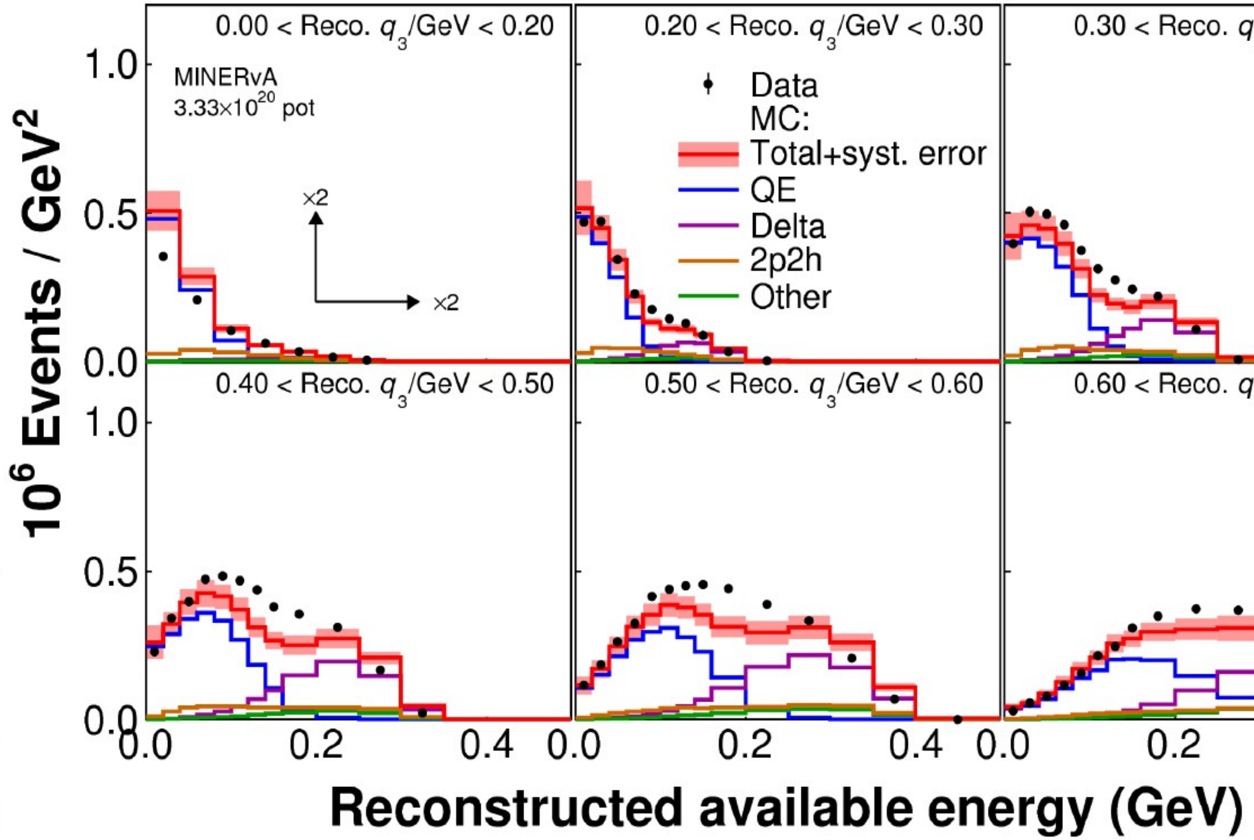
B. Estimated neutrino energy $E_\nu = E_\mu + q_0$

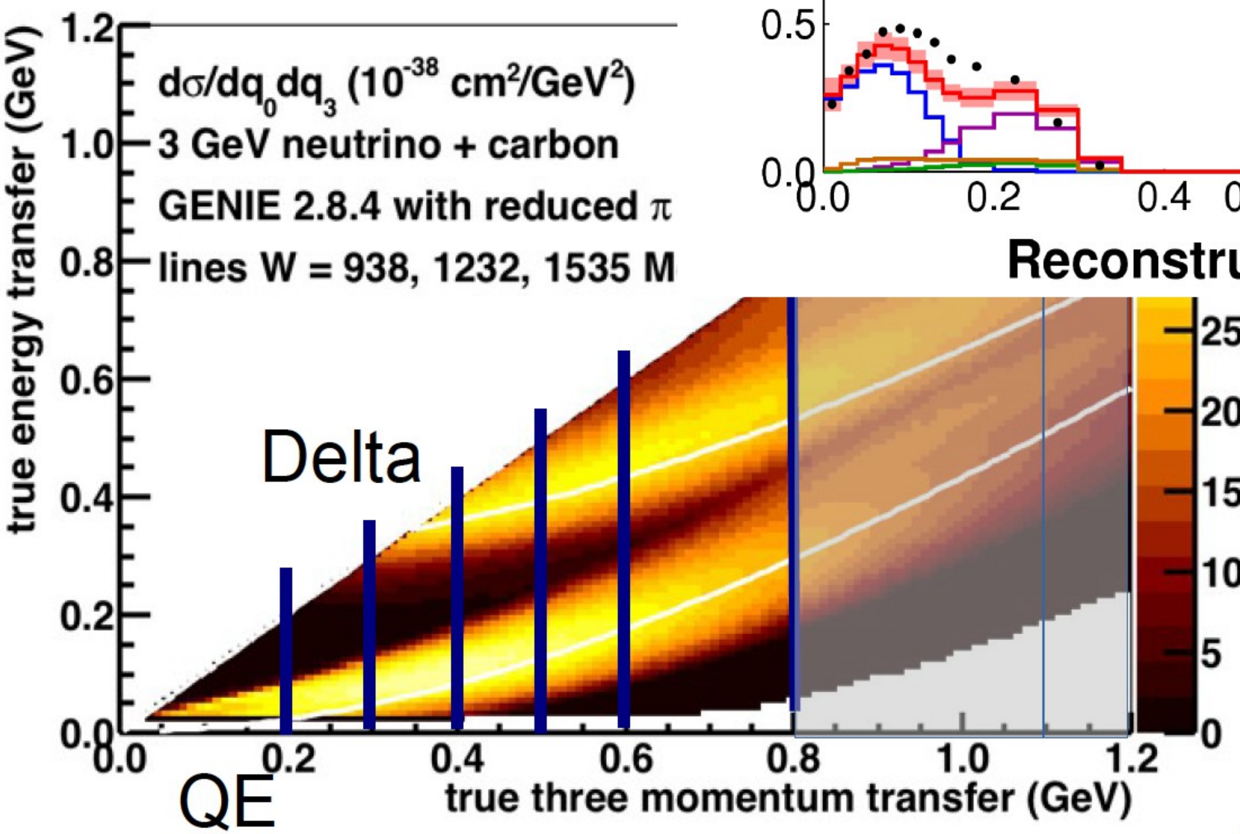
C. Estimated four-momentum $Q^2 = 2 E_\nu (E_\mu - p_\mu \cos\theta_\mu) - M_\mu^2$

D. Estimated momentum transfer $q_3 = \mathrm{Sqrt}(Q^2 + q_0^2)$

Analysis goal: (e,e')-like detail in slices of q3

but use something more observable, detector-centric, less model dependent Eavail instead of true energy transfer





This cross section includes all GENIE nu+C processes, except 2p2h

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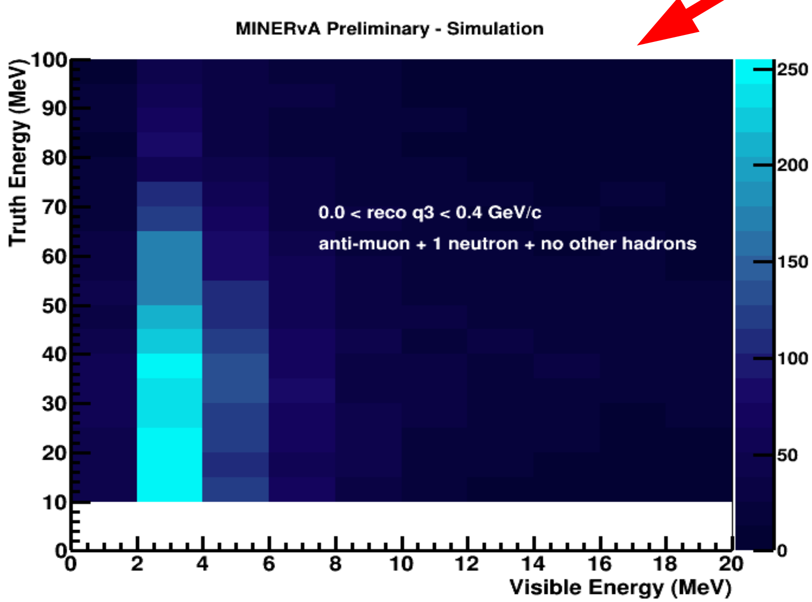

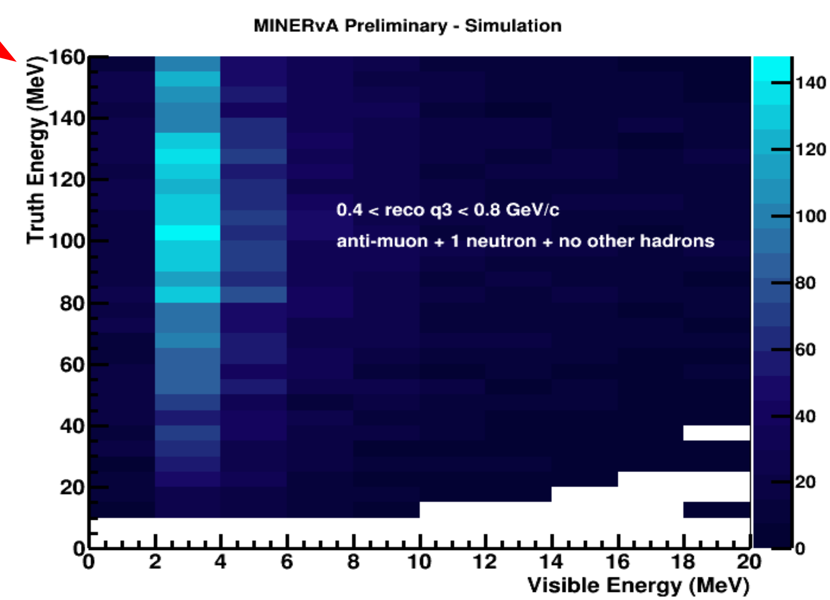

2p2h Model Sensitivity