Carbon Nuclear Deexcitation in MINERνA Data: an Update

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The goal of this project is to find evidence of carbon nuclear deexcitation in MINERνA's neutrino collision data. We know, physically, that such events must take place in the plastic-scintillator detector. Nuclear deexcitation of oxygen is fully simulated, but the MINERνA simulations do not include carbon deexcitation.

By isolating regions of the data expected to have the highest concentration of the deexcitation events, we found strong evidence of carbon deexcitation in the data. The existing simulation of oxygen deexcitation was used to emulate the carbon deexcitation in time. From this, we scaled up the oxygen simulation to estimate the number of carbon deexcita-

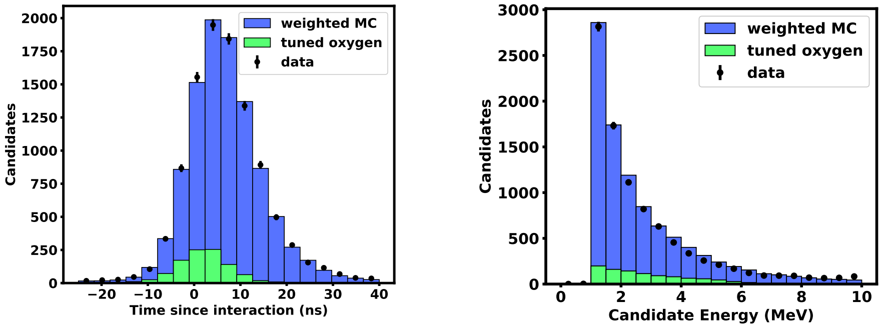

FIG. 1. Oxygen simulation boosted to fill in simulation deficit in time (*left*) and the resulting energy distribution of the candidates (*right*). Subsample corresponds to the nearest (to the original interaction) third of candidates with mid-q3 and low W (standard low-recoil divisions).

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tion events, shown in Fig. 1. The different subsamples yielded a range of inferred carbon deexcitations; this range is likely dependent on the neutron background.

Fig. 1 also shows the spectrum of deposits due to oxygen deexcitation. We know that oxygen deexcitation produces 6 MeV photons, which differs from what would be expected from carbon. We used a different simulation to understand what the neutrino-induced A=11 deexcitation photons should look like in the MINERνA detector. In looking for deexcitation following nucleon knockout, we expect that it should not matter what particle is causing the knockout. Whether it is a neutrino or a neutron, the nucleus should be left in a similar excited state and give the same spectrum. Consequently, to emulate nuclear deexcitation caused by neutrino interactions, we looked at data from a simulation of a neutron beam incident on plastic scintillator. The simulation was made using Geant4 v10r2p02 and two different neutron simulations—one similar to the one used for MINERνA and one "high-precision" (HP) simulation. These tools simulated a neutron beam with 50 MeV of kinetic energy incident on a 15 cm thick rectangular piece of plastic 20 cm × 60 cm in size. We saved only photon-induced Compton-scattered electrons and e^+e^- for the analysis. Neither the photon-producing processes nor the actual photon energies were saved in the data.

Analyzing the simulation data, we see that the two neutron simulations had different energy deposit spectra. The HP neutron simulation has a distinct Compton scattering shape in the event energy spectrum, as seen in Fig. 2. By contrast, the non-HP simulation does not have the characteristic Compton scattering shape. It appears as if the HP simulation events are equivalent to the non-HP events with the Compton spectrum added on top.

We can further explore the event energies by selecting only pair production events. This analysis is shown in Fig. 3, where we can see the HP simulation has discrete energy peaks

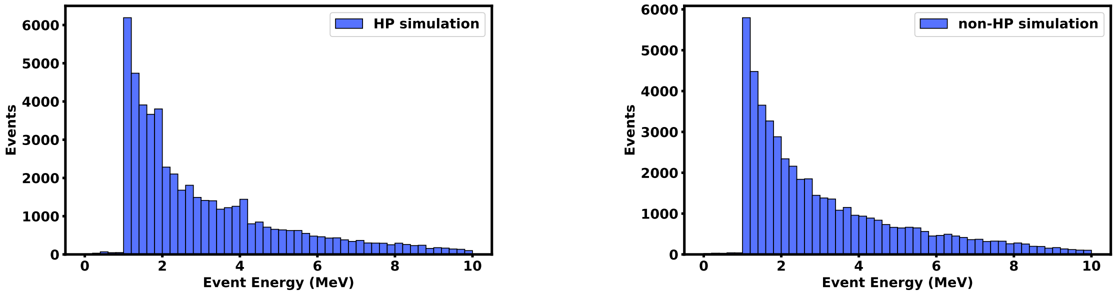

FIG. 2. Histograms of the total energy deposits from the simulated events, both from the HP simulation (*left*) and the non-HP simulation (*right*).

that are not present in the non-HP simulation. Such well-defined peaks would be expected from nuclear deexcitation. The peaks in the HP simulation appear at about 3.5 MeV and 9 MeV. This is surprising since these photon energies do not obviously line up with transitions in either ^{11}B or ^{11}C, shown in Table I.

We think the pair production peaks are lower because the simulated energy deposits are missing one or both photons, with energy equal to an electron mass, from the positron annihilation at rest. So Geant4 appears to be simulating the 2 MeV and the 4 MeV photons.

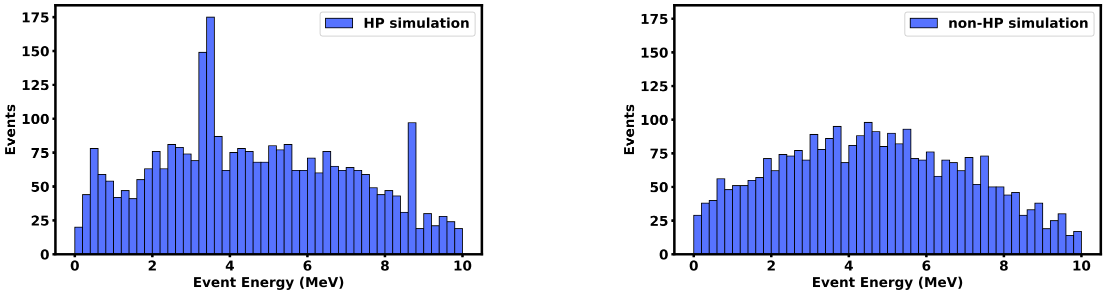

FIG. 3. Energies of the pair production events from the HP simulation (*left*) and the non-HP simulation (*right*).

TABLE I. Nuclear Energy Levels [1, 2].

^{11}C (MeV)	^{11}B (MeV)
2.00	2.12
4.32	4.44
4.80	5.02
6.34	6.74

We do not see the 6 MeV photons in the distribution. There are a number of photons in the 8 to 10 MeV range for the two A=11 nuclei, which accounts for the highest peak in Fig. 3.

From these results, we note that the MINERνA simulation has Geant4 neutron-induced knockout processes which produce a Compton spectrum. The HP configuration of Geant4 adds pair production peaks from 2, 4, and 9 MeV photons to this Compton spectrum. These photons are what we think Geant4 would produce for neutrino-induced knockout processes and differ from the monoenergetic 6 MeV photons produced by GENIE for oxygen.

[1] F. Ajzenberg-Selove, Nucl. Phys. A 490, 1 (1988).

[2] J. H. Kelley *et al.*, Nucl. Phys. A 880, 88 (2012).