Nova-NOTE-SIM-40

June 25th 2004

Simulation comparison of a Liquid Scintillator and RPC Detector

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Introduction

We have made a simulations comparison of the proposed liquid scintillator and RPC detectors described in the NOνA proposal, using nearly identical reconstruction and analysis code. Data from a GEANT based simulation of each detector was input into the reconstruction and analysis code developed for each detector. A comparison of the two detector technologies could then be made independent of the reconstruction and analysis techniques.

The comparison was made between a liquid scintillator detector, ignoring the pulse height information, and an RPC detector with one-dimensional readout, i.e. reading out only one coordinate per detector plane. Up to differences in the two defined geometries and readout these two detectors should be the same. The figure of merit (FOM), equal to the signal divided by the square root of the background was used as the comparator.

The only large difference found between the two detectors was that the RPC detector had more hit strips than the scintillator detector, because of the charge spreading between adjacent strips. The two analyses agreed that the scintillator detector gave a FOM, which was approximately two larger than the RPC detector. Addition of the pulse height to the scintillator detector and the second readout coordinate to the RPC detector produced a larger FOM in each case.

Liquid Scintillator Analysis

The liquid scintillator analysis was that described in Off-Axis-Note-Sim-24 and the NOνA proposal, updated slightly to fix problems but similar in all essentials. The pulse height was not used; it was set to 1.0 in all variables. Thus, for example, instead of a cut on total pulse height, the cut was on the number of hit scintillator elements. A cut of 20 on the detected number of photoelectrons was imposed to qualify as a hit element.

The RPC data was supplied as the x/y, z coordinates of hit RPC strips. These were input into the reconstruction as if they were the x/y, z coordinates of the liquid scintillator elements. After this the reconstruction was identical in the two cases.

The main difference noted between the two data sets was that the total number of hits strips in the RPC data was about 25% larger than the number of hit scintillator elements. This was diagnosed as the effect of the charge sharing between adjacent strips in the RPC readout. This has three main effects on the analysis;

1. The containment cut is slightly more severe in the RPC data (65% of events remain after reconstruction and containment against 69% in the scintillator) because a single particle can produce two hits more frequently.
2. The resolution on the total number of hits is slightly worse in the RPC data. Figure 1 shows the total number of hits for electron CC events with an incident neutrino energy between 2.0 and 2.2 GeV for selected events and all events for the scintillator detector. Figure 2 the same for the RPC detector. The RMS/mean for all events is 19.5% for the scintillator and 22.8% for the RPC and 9.7% versus 12.2% for the selected events. Clearly the selected events are strongly biased by the selection procedure.
3. The number of hits/plane in the selected Hough track is larger in the RPC data and the separation between the μ and e CC events is slightly worse. Figure 3 shows this plot for the scintillator and Figure 4 for the RPC data.

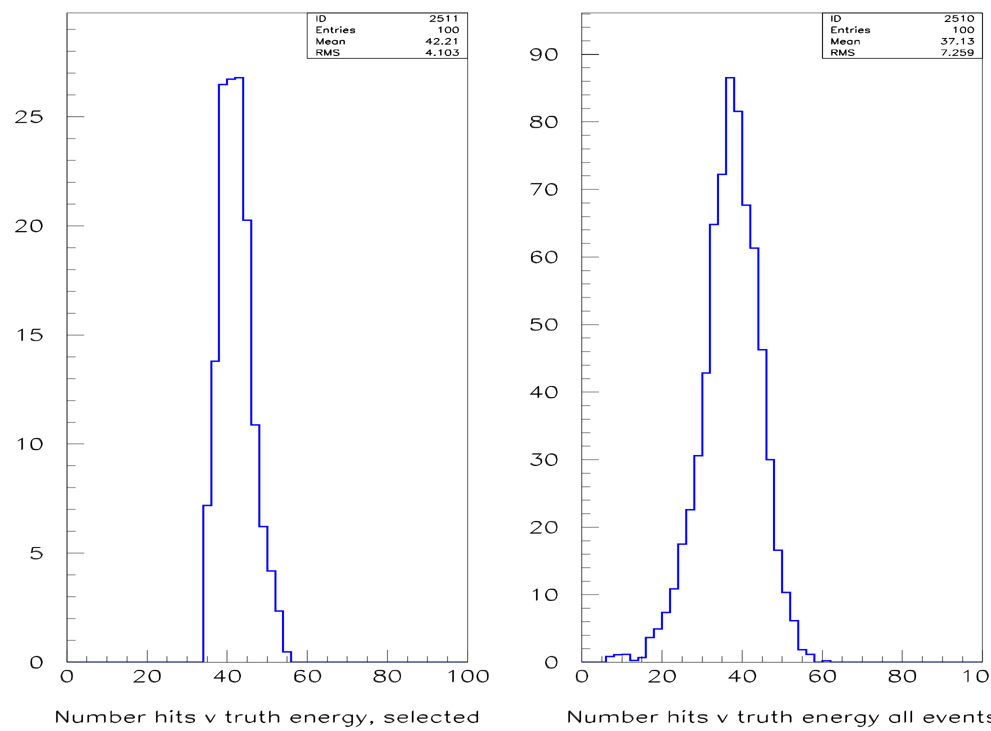

Figure 1: The number of hits in the scintillator detector for e CC events with $2.0<E_\nu<2.2$ GeV. Left; selected events, right; all events

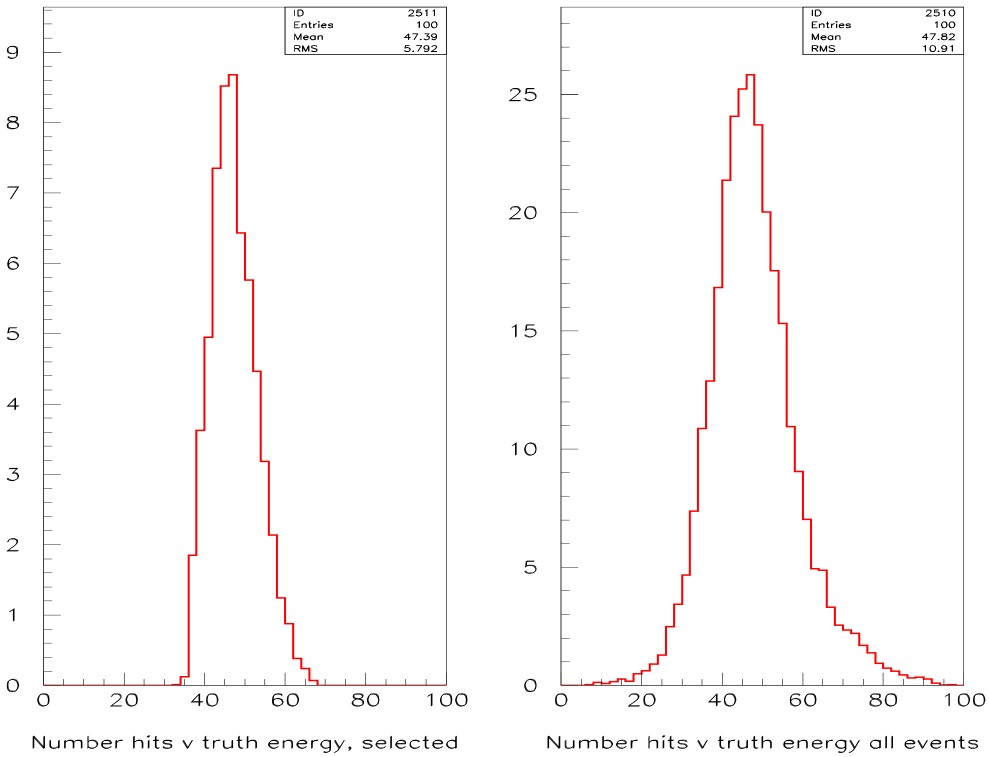

Figure 2: The number of hits in the RPC detector for e CC events with $2.0<E_\nu<2.2$ GeV. Left; selected events, right; all events

Table 1 shows the numbers of background and signal events for a 250kton-year exposure for a site 10km off-axis at 810km from Fermilab and for $\Delta m^2=0.0025$ ev^2 and $\sin^2 2\theta_{13}=0.1$. The numbers are given for this analysis of each data set and for the analysis described in the next section. The numbers for the scintillator option with the pulse height included and the RPC option with two-dimensional readout are also given.

	μCC	NC	e beam	Signal	Background	FOM
Scint. detector, scint program	2.0	12.3	16.3	134.6	30.6	24.3
Scint detector, RPC program	1.6	21.7	11.1	123	34	21
RPC detector, scint program	0.5	11.2	14.5	107.6	26.2	21.0
RPC detector, RPC program	1.1	19.8	13.1	112	34	19.3
Scintillator with pulse height	1.8	11.3	14.7	141.0	27.8	26.8
RPC with 2D readout	1.1	12.7	11.5	123.0	25.3	24.4

Table 1. Numbers of events and FOM for the various combinations of data and programs

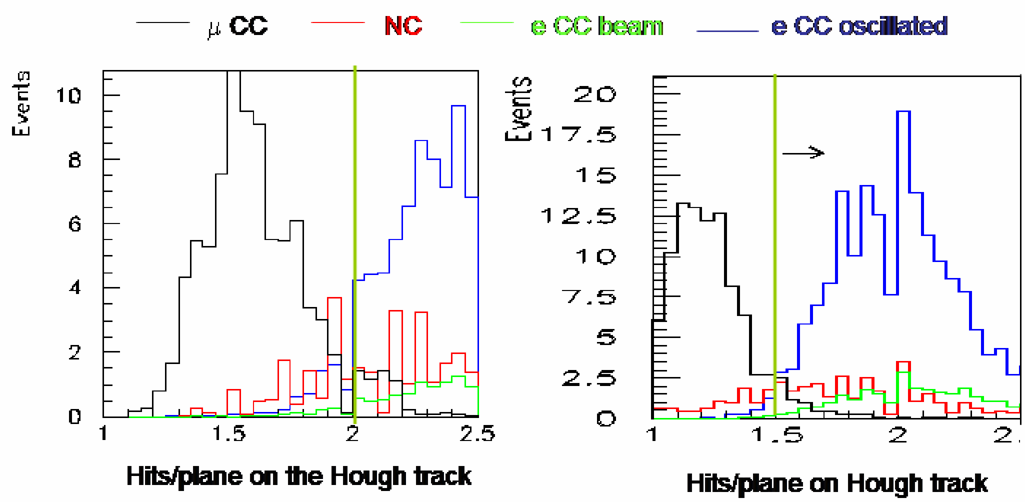

Figure 3: The number of hits per plane on the track found by the Hough transform. The black (left hand) peak is from μ CC events and the blue (right hand) peak from e CC events. The lower histograms are NC events (red) and beam e CC events (green). The right hand plot is for the scintillator detector, the left hand the RPC detector. The vertical line shows the cut imposed in the two cases. Events to the right of the line are accepted as ν_e CC.

RPC Analysis

The RPC analysis will be described in detail in a future note, though it shares many of its essential features with the scintillator analysis. Events are generated using NEUGEN3 with a flat neutrino energy spectrum. In order to represent the event distributions expected at the far detector the events have to be appropriately weighted for an off axis detector 810 km from Fermilab, 10 km off-axis. The event selection proceeded in two stages. In the first stage a set of cuts were applied to distributions where the signal and background were relatively distinct. The second stage of the analysis consists of forming one-dimensional maximum likelihood ratios for the signal and each of the backgrounds.

One unique feature of RPCs is that both x and y coordinate measurements are available at every RPC detector plane, compared to either an x OR y coordinate measurement available from each liquid or solid scintillator plane. Unlike the scintillator-based detectors, however, RPCs provide no pulse height information. For purposes of comparison with the liquid scintillator detector, the RPC data was analyzed using only the x coordinate information for odd numbered RPC planes and only the y coordinate information for the even numbered RPC planes. This results in an alternating x and y readout configuration along the beam direction that is similar to the liquid scintillator detector. Liquid scintillator data in the form of x/y, z coordinates was analyzed using the same RPC reconstruction program, ignoring the pulse height information. The results of this comparison are shown in Table 1.