structed track, the number of event strips reconstructed in the detector's veto regions should be less than four and the total pulse-height in those regions must be less than 2 MIP; and (v) the total number of strips reconstructed in the event must be more than four. Only events that satisfy these criteria are used for further analysis.

D. Far-detector event selection

In contrast to the multiple events per beam spill observed in the near-detector, the rate measured in the far-detector is approximately two events per day within the beam spill times, so the appropriate requirements for event selection are necessarily different. Specifically, the probability that two or more neutrinos produced in the same 10 μs beam spill will interact in the far-detector is negligible. Therefore, if two events are reconstructed in the same spill, the coincidence is due either to a reconstruction failure or else one of the events has a nonbeam origin. Effects of multiple event reconstruction are mitigated by requiring an event to be used in the analysis to contain at least 75% of the total deposited energy during the beam spill.

The main background in the far-detector results from detector noise arising from the electronics and PMTs or from spontaneous light emission from the scintillator and wavelength-shifting fibers [27]. The noise from the electronics and PMTs is removed by setting an energy threshold in the PMTs. The spontaneous light emission is removed by requiring accepted events to include at least nine strips or at least 10 MIP deposited in the detector. Alternatively, events are also accepted if they include more than five strips and deposit more than 5 MIP in the detector.

Muons from cosmic rays are a potential source of background events. Given the 0.2 Hz cosmic-ray muon rate at the far-detector, the number of cosmic-ray-induced-muons that may potentially coincide with beam spills is comparable to the number of beam-induced neutrino interactions observed. Most cosmic-ray-induced muons are well reconstructed and are efficiently removed by the fiducial requirement. However, the reconstruction algorithms are optimized to handle recorded energy flow in the general direction of the beam. Problem cases can thus arise with very steep cosmic muons, which are removed by requiring the absolute value of the muon direction cosine in the longitudinal direction, $|p_z|/E$, to be higher than 0.4. In some cases the events are so steep that they are reconstructed only as showers and may be removed by using selection variables that describe the transverse and longitudinal shower profiles. The transverse variable is defined by calculating the root-mean-square (rms) value of the shower strip positions, whereas the longitudinal variable is defined as the ratio of active strips per plane to the total number of active planes in the event. Only those showers with a transverse rms value lower than 0.5 and (strips/plane)/(event planes) < 1 are accepted for further analysis. Cosmic-ray muons that stop in the detector can mimic beam events if the end of the stopping muon track is interpreted as the vertex and the track is then reconstructed backwards. These events can be identified by performing a linear fit to the timing distribution for strips on a track as a function of the strip longitudinal position. A fit resulting in a negative slope indicates that the event is a downward-going cosmic-ray muon and not a beam neutrino. The sample contamination from cosmic-ray induced muons after these criteria are applied is estimated to be less than 0.1% [28].

Another potential background arises from data recorded while the Light Injection calibration system (LI) is flashing during normal data taking. The light injection events are removed with 99.99% efficiency by using information from a PMT directly connected to the light injection system. By applying additional requirements based on concentrated detector activity, it is estimated that much less than one LI event is accepted in the entire data sample [28]. Furthermore, application of the LI rejection criteria results in no measurable loss of efficiency for beam-neutrino interactions.

IV. EVENT CLASSIFICATION

After the selection criteria described in the previous section are applied, the analysis proceeds by distinguishing charged-current events from neutral-current events. Distinct event classification procedures are employed for each sample, as described below. The reconstructed neutrino energy spectra for both event classes are used in the fits described in Sec. VIII and Sec. IX.

The goal of the event classification is to maximize the efficiency and purity of selected samples of neutral-current and charged-current events. Using Monte Carlo event samples, efficiency is defined as the number of true events of one type which are classified as that type, divided by the total number of true events of that type that pass the criteria described in Sec. III. Purity is defined as the ratio of the number of true events of one type selected to the total number of events selected as that type.

To avoid biases, the methods for identifying neutral-current candidate events and procedures employed in predicting the far-detector spectrum, described in Sec. V, were developed and tested using only the near-detector data and Monte Carlo simulation. All analysis procedures were finalized prior to examining data in the far-detector.

The neutral-current event classification employs several criteria based on reconstruction variables displaying large differences between neutral-current and charged-current events [29]. Charged-current events with short or no apparent tracks and poorly reconstructed events are the two main sources of background. The latter is mitigated by employing the various selections described in Sec. III. The classification variables considered are: *event length*, expressed as the difference between the first