the cross section calculations to correctly account for events that pass all cuts but have a true vertex with $r > 500$ cm. Normalizing to events with true vertex of $r < 500$ cm yields an efficiency of 35%.

C. CC1π^+ background measurement

After the selection of the CCQE and CC1π^+ candidate events (2 and 3 subevent samples, respectively), the CC1π^+ background to the CCQE signal is measured by adjusting the weights of the simulated CC1π^+ events to achieve data-MC agreement in the $Q^2_{\rm QE}$ distribution of the 3 subevent sample. The same weighting, applied to all simulated CC1π^+ events, then provides an estimate of the CC1π^+ background to the CCQE signal. Figure 7 shows the data and MC $Q^2_{\rm QE}$ distributions for the two samples before the reweighting of CC1π^+ MC events. The 3-subevent sample is predicted to be 90% CC1π^+ and shows a large data-MC disagreement in both shape and normalization. The kinematic distribution of muons in CC1π^+ events is similar in both the 2-and 3-subevent samples as can be observed in Fig. 7. This occurs because the majority of CC1π^+ events that are background in the 2-subevent sample are due to muon-capture or pion absorption and the reconstruction of the primary event is, to a good approximation, independent of this. In addition, the μ/e log-likelihood ratio cut (Table II and Fig. 5) is applied for both the 2- and 3-subevent samples, further ensuring that the CC1π^+ events are the same in both samples.

The CC1π^+ reweighting function [Fig. 7(b)] is a 4th-order polynomial in $Q^2_{\rm QE}$ and is determined from the

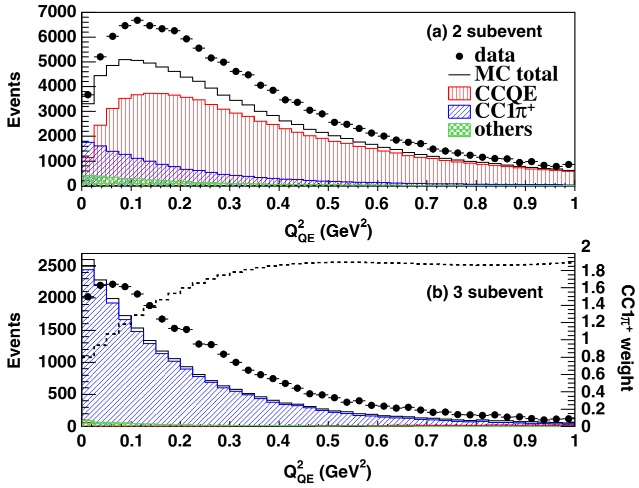

FIG. 7 (color online). Distribution of events in $Q^2_{\rm QE}$ for the (a) 2 and (b) 3 subevent samples *before* the application of the CC1π^+ background correction. Data and MC samples are shown along with the individual MC contributions from CCQE, CC1π^+, and other channels. In (b), the dashed line shows the CC1π^+ reweighting function (with the y-axis scale on the right) as determined from the background fit procedure.

ratio of data to MC in this sample. The 2-subevent sample shows good shape agreement between data and MC. This is because the event model for CCQE was already adjusted to match data in a previous analysis [11] that considered only the shape of the $Q^2_{\rm QE}$ distribution. That analysis did not consider the overall normalization of events.

In practice, this determination of the CC1π^+ reweighting is done iteratively as there is some CCQE background in the 3 subevent sample. An overall normalization factor is calculated for the CCQE sample to achieve data-MC agreement in the 2 subevent sample after subtraction of the CC1π^+ background. This is then applied to determine the CCQE background in the 3 subevent sample. The background from other channels is determined from the simulation and subtracted. This process converges after two iterations.

This method determines a correction to the CC1π^+ rate (as a function $Q^2_{\rm QE}$) using data from the 3-subevent sample rather than relying strictly on simulation. This reweighting is then applied to all simulated CC1π^+ events, in particular, those that are contained in the 2-subevent sample and form most of the background for the CCQE measurement. The error on $M_A^{1\pi}$ within the resonant background model is then set to zero and the resulting error on the CC1π^+ background to the CCQE signal from CC1π^+ production is determined by the coherent π-production errors and the π^+ absorption uncertainty. The statistical errors in this procedure are negligible. Most CC1π^+ events that end up in the 2-subevent (CCQE) sample are due to intranuclear π^+ absorption. This process is modeled in the event simulation as explained in Sec. III D and is assigned a 25% uncertainty. The coherent π-production process is modeled as described in Sec. III C and is assigned a 100% uncertainty.

With the measured CC1π^+ background incorporated, a shape-only fit to the 2-subevent (CCQE) sample is performed to extract values for the CCQE model parameters, $M_A^{\rm eff}$ and κ. This exercise is required to have a consistent description of the MiniBooNE data within the simulation after adjustment of the background. This procedure has no effect on the CCQE cross section results reported here other than very small corrections to the antineutrino background subtraction which uses these parameters. In this fit, all systematic errors and correlations are considered. The CCQE simulated sample is normalized to have the same number of events as data which is the same normalization as determined in the CC1π^+ background determination. The $Q^2_{\rm QE}$ distributions of data from the 2 and 3 subevent samples is shown together with the MC calculation in Fig. 8. The MC calculations include all the adjustments described in this section and agreement with data is good in both samples.

This shape-only fit to the 2-subevent sample yields the adjusted CCQE model parameters, $M_A^{\rm eff}$ and κ,