Plan for $\bar{\nu}_\mu$ CC inclusive cross section measurement

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This document outlines the steps towards a $\bar{\nu}_\mu$ CC inclusive measurement and gives an estimate of the time needed.

1. Overview

This analysis will be done with the CAFAna framework, with the possibility of resorting to art, if the current information included in CAF does not suffice for studying neutrons, which are crucial for estimating the neutrino energy for RHC.

2. Outline

2.1. Determine the Data and MC Samples to Use

(i) The data used for this analysis is without question to be the sort RHC datasets taken right before the 2016 summer shutdown.
The SAM definition is `prod_caf_S16-08-04_nd_numi_rhc_epoch4a_v1_goodruns`.

(ii) Real condition MC will be used. There are two production MC datasets available as of now.
   (a) `prod_caf_R16-03-03-prod2reco.h_nd_genie_nonswap_genierw_rhc_nova_v08_epoch4a_v1`
   (b) `prod_caf_R16-03-03-prod2reco.h_nd_genie_nonswap_genierw_rhc_nova_v08_epoch4a_v1_neutron-hp-fix`

   The difference between the two is that the second dataset uses the Geant4 high precision neutron model. At this moment the high precision one is used.

2.2. Event Selection

The standard quality cut `kNumuQuality` and containment cut `kNumuContainND` perform well and will be retained. The standard PID `remid.pid>0.75` was optimized for oscillation analyses and will be replaced by `remid.pid>0.29`, an optimal value for cross section measurements.

2.3. Background Estimation

- Relative proportions of background channels coming from ν_μ, ν_e, $\bar{\nu}_e$, and NC are obtained with MC.
- The overall normalization factor will be estimated by the sideband method.

2.4. Flux Predictions

The nominal Dk2Nu flux files are used, and a comparison with the PPFX flux files will be made.

2.5. Unfolding

The unfolding procedure is very actively developed for ν_μ CC inclusive measurement. Once the machinery is done, it should be able to apply directly to the $\bar{\nu}_\mu$ case.

2.6. Systematic Uncertainties

Each of the following items has a systematic uncertainty associated with it.

- event selection efficiency
- background
- flux
- unfolding
- GENIE

2.7. Constraint on Wrong Sign Contamination

The wrong sign component could be constrained by looking for distributions which have different shapes for ν_μ and $\bar{\nu}_\mu$ and fitting the data distribution to the two templates.

Two distributions are found to have different shapes, namely the CCQE muon angle and the distance between the reco neutrino interaction vertex and the starting point of the subleading reco Kalman track of 2 track CCQE events.

3. Timeline

Determining datasets to use and event selection only need some fine-tuning and therefore not much more time is needed for these two items. As for background estimation, flux predictions, unfolding and systematic uncertainties, although for $\bar{\nu}_\mu$ CC numbers will be different from those for ν_μ CC, the machineries leading to the numbers are very much the same. If all the machineries are developed, the time needed will be that for generating customized Monte Carlo samples and rerun the scripts. Given the size of MC samples I had generated before for nuclear model study, 4 weeks is my current estimate. Lastly, the only item that does not exist in the ν_μ CC measurement is the wrong sign constraint. Four weeks is my estimate for this item.
In summary,

items	time needed
determining datasets, event selection	2 weeks if needed
background estimation, flux predictions, unfolding, systematic uncertainties	follow ν_μ CC, 4 weeks
wrong sign constraint	4 weeks