MPD exclusive channels

Chris Marshall
Lawrence Berkeley National Laboratory
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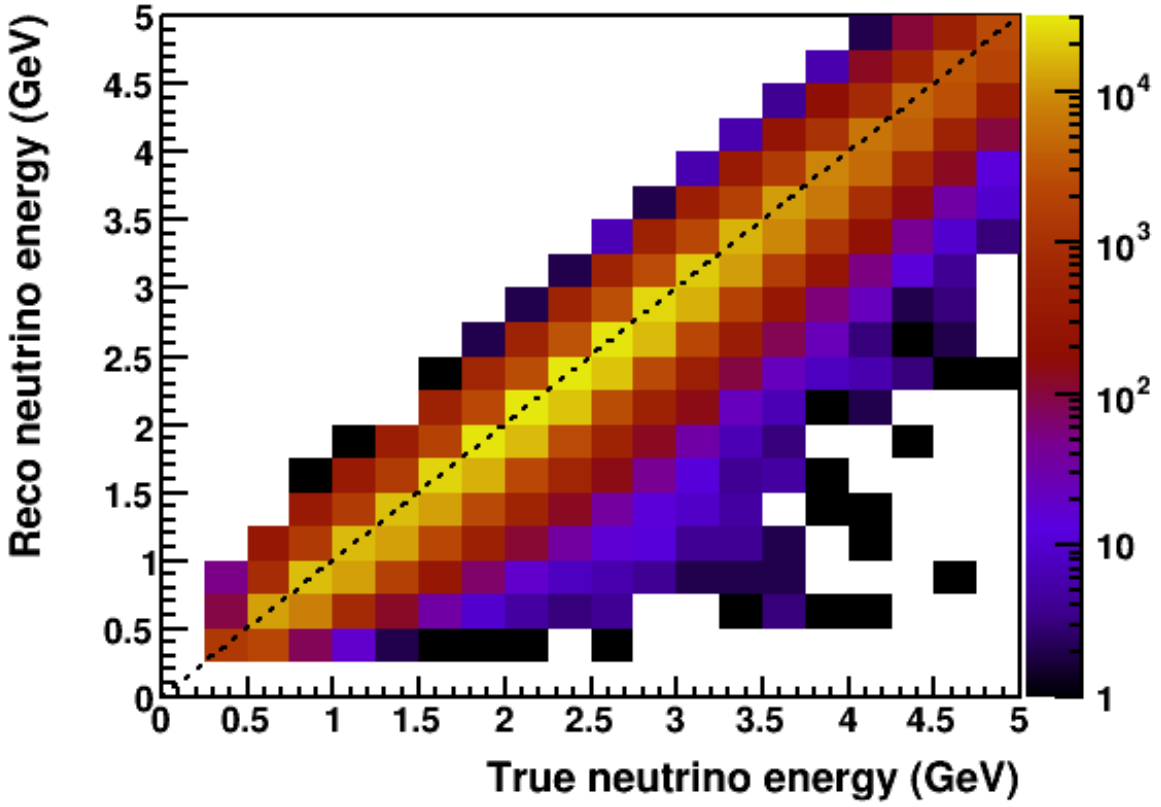
Needs for MPD physics studies

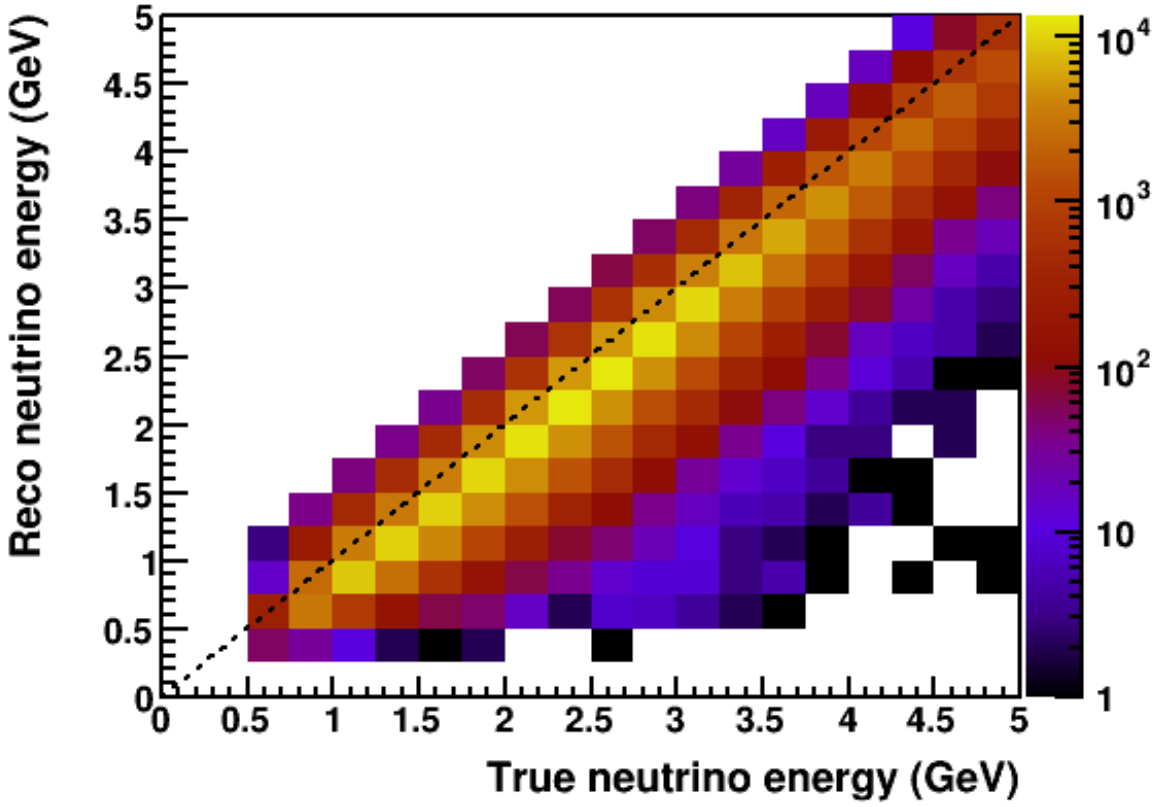
- Why do we need the HPgTPC/MPD and not just a cheap muon spectrometer?
- Demonstrate some physics channel that
  - Impacts LBL oscillation sensitivity/bias
  - Can't be determined by LAr alone
  - Is easily demonstrated with HPgTPC samples
- One idea we have discussed: pion multiplicity

CC0π energy smearing



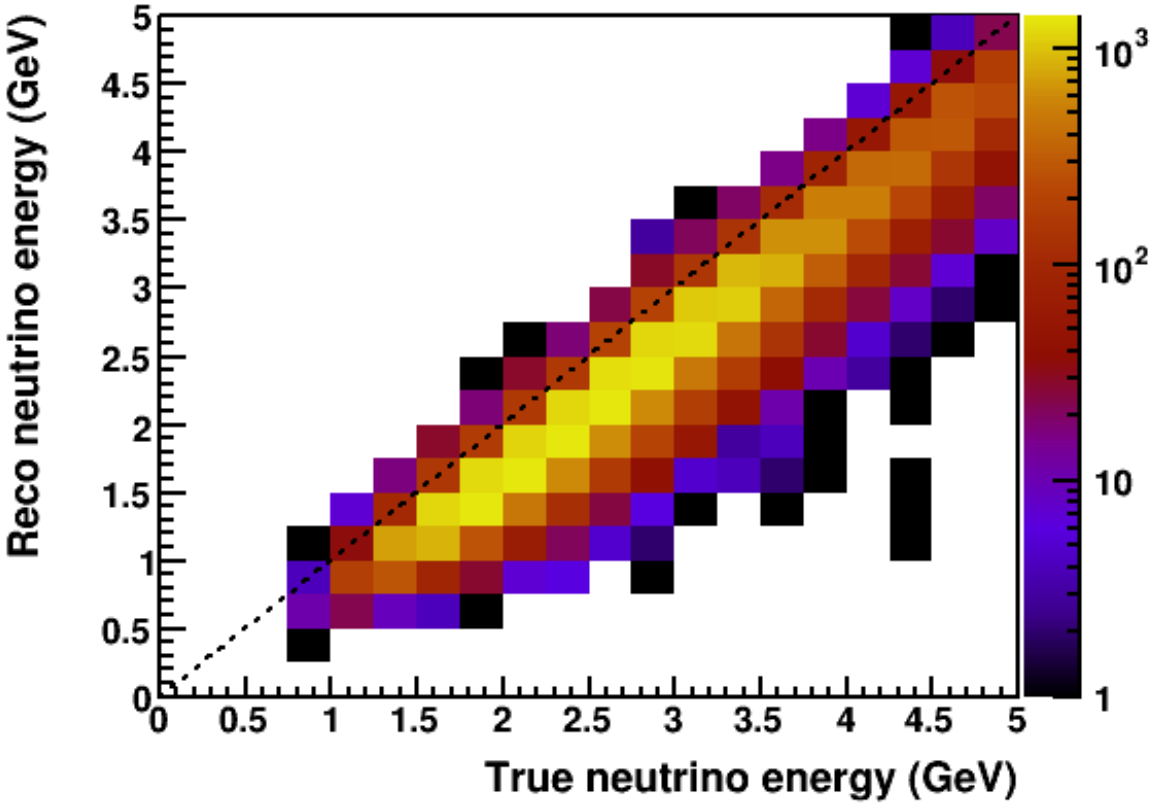
- LAr ND pseudo-reconstructed “FD TDR sample”
- Hadronic energy is determined by summing visible energy
- Cut on energy near the edges ensures reasonable containment

CC1π energy smearing



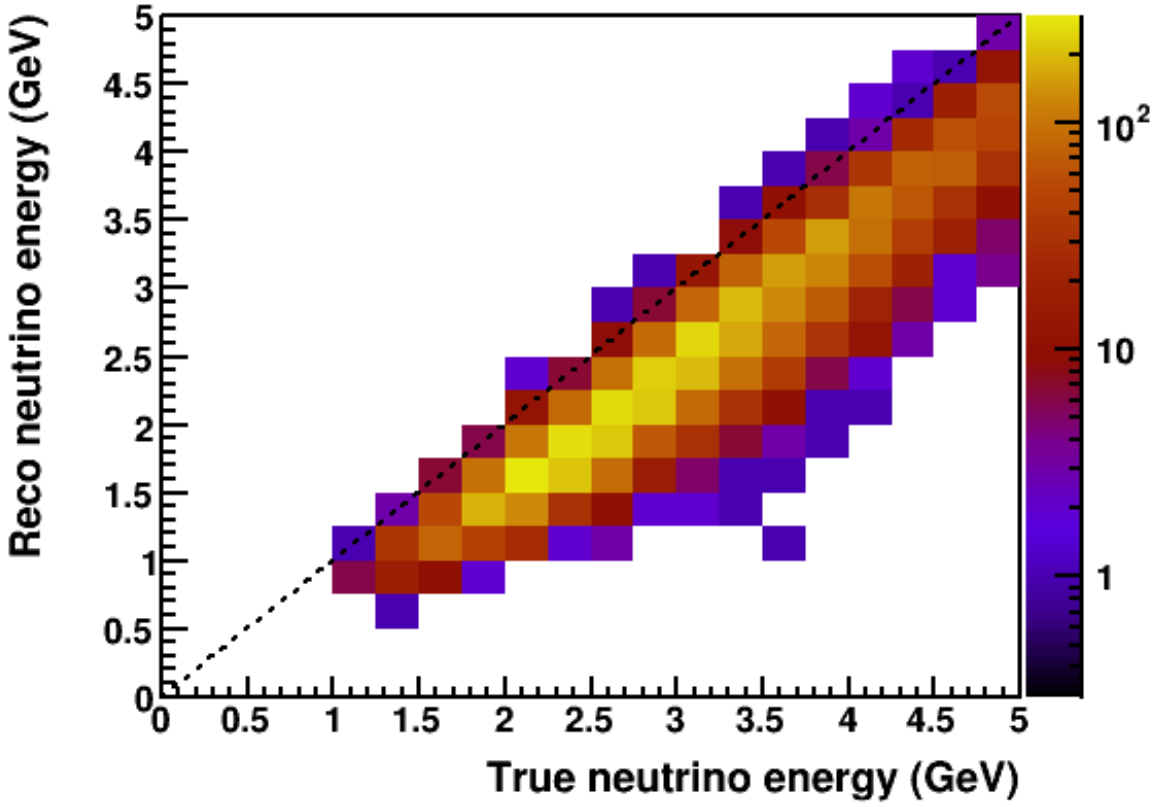
- For events with 1 pion, energy is underestimated on average, by about 1 pion masses

CC2π energy smearing



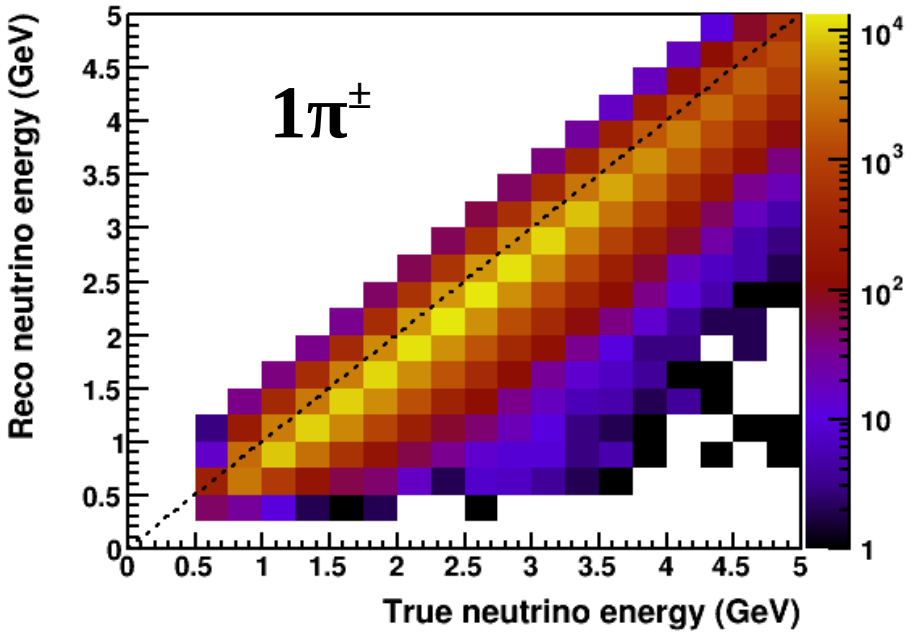
- For events with 2 pion, energy is underestimated on average, by about 2 pion masses

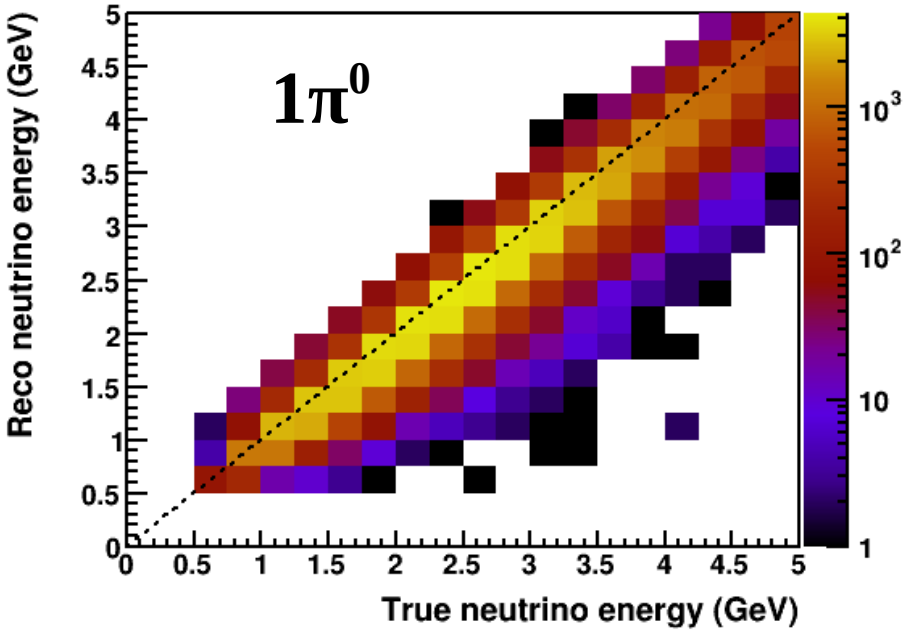
CC3π energy smearing



- For events with 3 pion, energy is underestimated on average, by about 3 pion mass

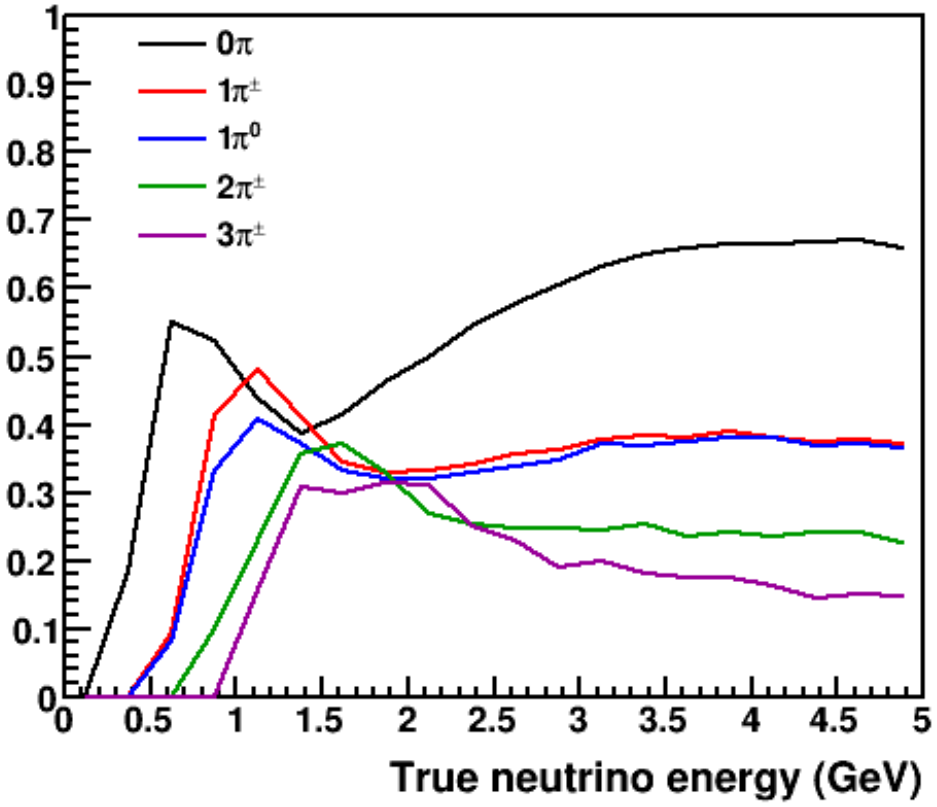
CC1$\pi^{\pm}$ vs. CC1π^{0}





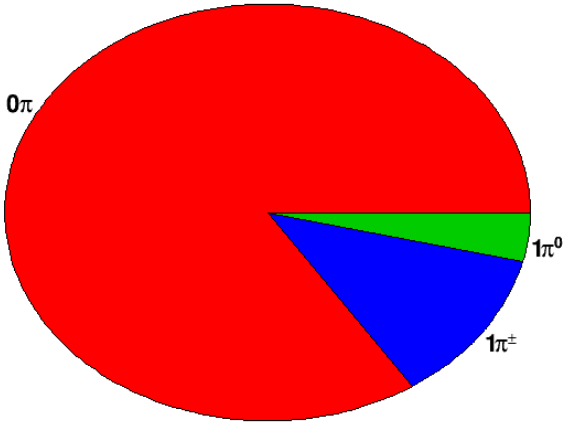
- Charge of the pion has a significant impact on LAr energy reconstruction – we typically see the pion mass when it is neutral

CC acceptance in LAr

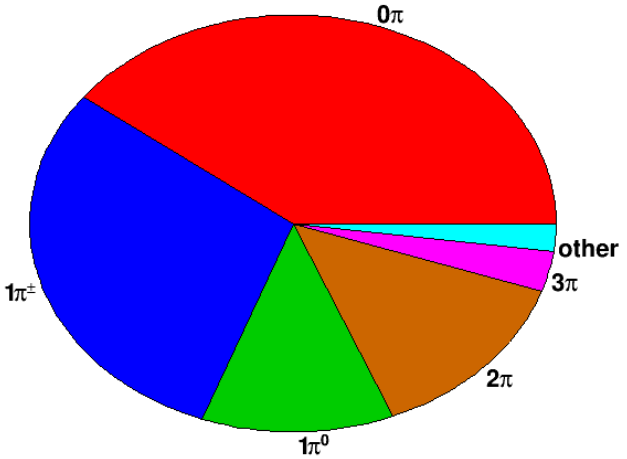


- Muon must be contained or HPgTPC matched, hence the dip
- Hadronic energy must be contained → better efficiency when the same energy is distributed among nucleons instead of mesons

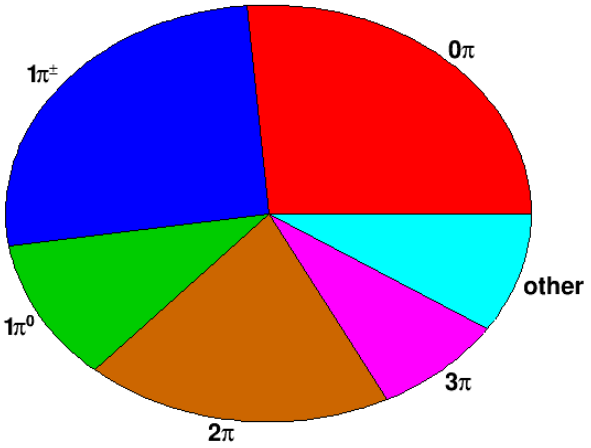
Neutrino energy dependence



$0.4 < E_\nu < 0.8$ GeV



$2.3 < E_\nu < 2.7$ GeV



$4.0 < E_\nu < 4.5$ GeV

- Relative contribution of channels, on Ar, according to one particular model (GENIE 2.12.10 DefaultPlusValenciaMEC)
- Shown for T2K peak energy (left), DUNE peak energy (center), and DUNE falling edge (right)
- CC0π contribution is 85%→35%→25%
- LAr reconstructed distributions will be at least somewhat sensitive to this exact breakdown being correct, but HPgTPC should be able to measure these samples separately in a clean way

Potential for LBL bias

- If the mix of 0π/1π/2π in our model is incorrect, then our model-based energy unsmearing will be wrong, which could lead to biases
  - This could be demonstrated by creating a mock data sample by re-weighting based on pion multiplicity and/or kinematics, and fitting
- If there is any dependence on neutrino energy, then the LAr ND cannot resolve this bias for FD because the fluxes are different
- LAr ND may be able to address this by selecting exclusive final state samples, but this could be challenging due to thresholds, hadronic showers, etc.
- If HPgTPC efficiency is ~flat vs. number of pions, neutrino energy, etc. then these acceptance curves could be directly measured

To do

- Make all these plots for HPgTPC samples
- Demonstrate potential LBL bias by constructing a mock data sample
  - What will probably happen is FD-only will give good fit with wrong oscillation parameters
  - FD + LAr ND will give terrible fit with nuisance parameters pulled all over the place
  - Show that HPgTPC sample allows you to identify *how* the model is wrong, potentially fix it