RHC $\bar{\nu}_\mu$ CC samples in LAr ND

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Sign selection of muons from LAr interactions

- Plan to build non-magnetized LAr TPC at near site
- Charge will be reconstructed only for muons that exit LAr TPC and enter a magnetized detector
  - Downstream multi-purpose tracker
  - Magnetized side muon detector?
- Questions:
  - What is the wrong-sign contamination in RHC for contained muons?
  - For side-exiting muons? Must the side muon detector be magnetized?
  - What fraction of the RHC events are contained, side-exiting, etc.?
Flux purity
80GeV 3-horn optimized beam

- FHC and RHC fluxes are of similar purity in the focusing peak, but RHC purity becomes poor above ~6 GeV
- Higher CC cross section makes wrong-sign background less problematic for FHC, and more problematic for RHC
- $\bar{\nu}_\mu$ is ~1% of total FHC CC events for $E_\nu < 5$ GeV – can subtract with MC
RHC muon spectra (log z scale)

- Neutrino/antineutrino cross section is $1/(1-y)^2$, equal at $y \to 0$, which is very forward muons
- At high angles wrong-sign becomes dominant
RHC $\mu^+$ purity (% of all CC)

- Out of the box, purity is $\sim 40\%$ for very high angles, especially backscattered muons.
- Capture rate for $\mu^-$ is $75\%$, so the wrong-sign background can be suppressed by $\sim 4x$, with efficiency loss of Michel tagging.

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RHC contained $\mu^+$ purity and efficiency

- Right plot is fraction of $\mu^+$ in a given bin that are contained
- Left plot is fraction of all contained muons in a given bin that are $\mu^+$
- Purity bad above $\sim$20 degrees muon angle
RHC contained $\mu^+$ purity and efficiency with Michel tag

- Right plot is fraction of $\mu^+$ in a given bin that are contained
- Left plot is fraction of all contained muons in a given bin that are $\mu^+$
- Michel tag improves purity for contained muons to $\sim$70% at high angles, $>90\%$ up to $\sim$60 degrees
In kinematic region where side-exiting muons are critically important, purity is only ~50% (would be ~80% if you had Michel tag but no curvature)

These would be LAr-contained for ~7m wide active region
RHC tracker-matched sample

- Muons above 2 GeV will be sign-selected by curvature in MPT, but below 1.5 GeV the tracker matching is poor
- Sign purity will be ~100% from curvature in magnetic field
**RHC $\mu^+$ purity with regions & percentage of total $\nu_\mu$ CC**

- **All muons**
  - Divide the kinematic space into regions based on how muon is primarily reconstructed:
    - Tracker-matched region, excellent $\mu^+$ purity and momentum resolution – 62.3% of total
    - Good containment, reasonable $\mu^+$ purity, >90% with Michel tag – 11.8% of total
    - Side-exiting region, poor $\mu^+$ purity ~50% out of the box and ~80% with Michel tag – 9.0% of total
    - Good containment, poor $\mu^+$ purity, only ~40% out of the box and ~70% with Michel tag – 1.4% of total
    - Dipole coil region, good $\mu^+$ purity, also tracker-matched for downstream vertices – 15.3% of total

- **Positive Michel tag**
  - wrong-sign scaled by 0.25
True $E_\nu < 4$ GeV only

- Purity overall is much better for flux peak only, percentages for $E_\nu < 4$ GeV:
  - Tracker-matched region, excellent $\mu^+$ purity and momentum resolution – 55.1% of total
  - Good containment, reasonable $\mu^+$ purity, >90% with Michel tag – 14.1% of total
  - Side-exiting region, poor $\mu^+$ purity ~50% out of the box and ~80% with Michel tag – 10.6% of total
  - Good containment, poor $\mu^+$ purity, only ~40% out of the box and ~70% with Michel tag – 1.7% of total
  - Dipole coil region, good $\mu^+$ purity, also tracker-matched for downstream vertices – 18.4% of total
Summary

- ~60% of RHC $\bar{\nu}_\mu$ CC events will be tracker-matched with good sign selection
- ~15% will be contained, 90% of which can be selected with high purity >90% – NC is likely the bigger background
- ~15% are in the “in between” region, a mix of contained, tracker-matched, and coil-death muons
- ~10% are reconstructed only with side detector (same region is 21% for FHC $\nu_\mu$ CC), and would have poor purity without magnetized side detector
Synergy with MPT

- Low-mass tracker sample of RHC $\bar{\nu}_\mu$ CC on Ar, with $4\pi$ sign selection will be a valuable cross-check
Goal: CAFAna study to connect to far detector

- With Seb Jones, Chris Backhouse
- Framework in place to produce CAFAna ND files from edep-sim-based simulation outputs
- Can modify assumptions about sign selection (i.e. assume magnetized side detector), and study effect on FD sensitivity
- But potential limitation is reweightable knobs in cross section model do not cover real cross section uncertainties