Status of Near Detector Data-driven Geometric Efficiency Correction

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Wei Shi
From Ciaran’s talk at last CM

- Analysis cuts include **hadronic energy veto** and **lepton selection** at the ND and FD
- A standard efficiency correction using the Monte Carlo would introduce cross section model dependence (more next slide)
- Instead, we are working to develop a data-driven geometric efficiency correction to remove this model dependence
Correct for efficiency
• Efficiency used as normalization for each true $E_{\text{vis}}$ bin during data unfolding & smearing
• Current efficiency obtained from MC simulated samples
  • Many neutrino-nucleus interaction modeling uncertainties affect this correction

Systematic impact on FD prediction
• Efficiency correction mostly impacted by cross section systematics (e.g., multi-pion production, MaCCQE, MvCCRES)
• Smaller impact from flux systematics
• Detector systematics impact negligible
• Impact on ND side often stronger than FD side

More plots available in my talk at last CM
The Geometric Efficiency Correction

Want to minimize impact from systematics at ND geometric efficiency correction

- One way is to use a data-driven approach to obtain the ND geometric efficiency (instead of relying on MC)
  - Use symmetries of neutrino CC interactions in ND LAr
    - Rotation symmetry with respect to the neutrino beam axis
    - Translation symmetry in the ND LAr volume
  - For a given selected ND event, randomly rotate and translate the reconstructed hadronic energy deposits, muon position, and momentum vectors \( N \) times (currently used \( N \approx 5000 \))
    - Hadronic energy
      - Among \( N \) trials, the fraction of those that passed the hadronic containment cut is the hadronic part geometric efficiency
    - Lepton selection
      - Use a neural network trained on particle gun MC to estimate the lepton (now focus on muon) selection efficiency in each trial
  - Combine both to get event-level efficiency

\[
\eta = \frac{0 \times 0.8 + 1 \times 0.3 + 0 \times 0.7 + 1 \times 0.4 + 1 \times 0.95}{5} = 33\%
\]
Geometric Efficiency for Hadronic Energy Containment

- Hadronic energy containment
  - Energy deposited in the outer 30 cm of the active volume less than 30MeV
  - Cris showed result before (pasted below)
Geometric Efficiency for Muon Selection

- A neural network outputs probability for the muon fully contained in ND LAr, sampled in the tracker, or not selected.

From Cris’ talk
Geometric Efficiency for Muon Selection

• A neural network outputs probability for the muon fully contained in ND LAr, sampled in the tracker, or not selected.
Events never selected at ND

• Previous slide also shows it’s impossible to have perfect correction
  • **Some events will never be selected at ND but could be selected at FD**
  • ND data lose prediction power for such FD events so we need to identify them and predict differently

• One way to identify such events is to put each FD event in the ND and calculate its geometric efficiency in ND (i.e., hadron E veto and muon selection with neural network)
  • Classify FD events with very low ND geometric efficiency as never selected
FD Event Analyzer

- Built an event analyzer to interface with the FD simulation sample in LArSoft and produce a flat ROOT tree for convenient data analysis
  - Currently mostly running analyzer interactively (SBU/FNAL dunegpvm machines)
  - Soon will test running jobs on more FD MC files on FNAL machines to get larger stats
    - An earlier test job running on a single FD MC file is successful
If don't do coordinate transform for FD event, the coordinate will be representing this in ND.

Not physical at ND
Event Topology Rotation for Off-axis ND Positions

- Need to rotate the FD event again if we want to evaluate its geometric efficiency in an off-axis ND
  - Neutrino beam direction is different for off-axis ND positions
  - Neutrino production distance from the target also depends on the off-axis position (right plot)

- After this, randomly translate and rotate the FD event to get its efficiency (similar to an ND event)
Summary

• The data-driven ND geometric efficiency correction is critical for minimizing impact from cross section systematics

• Students at SBU are working on this and making steady progress
  • Geometric efficiency of ND events
    • Baron Wu (SBU undergraduate), Cris Vilela (CERN)

  • Geometric efficiency of FD events in ND
    • Flynn Guo (SBU graduate), Wei Shi (SBU postdoc)

• Next steps and timeline
  • Plan to set a ND efficiency threshold, and only include ND and FD events that are above this threshold in the main analysis
  • FD events below this threshold will be treated separately, since they cannot be directly constrained by ND events
  • Aim for a first version of the geometric efficiency correction for the next collaboration meeting
Back up
Muon fully contained in NDLAr
Muon tracker matched
Muon detected (fully contained + tracker matched)
Muon undetected