ν-Hydrogen Interactions in STT

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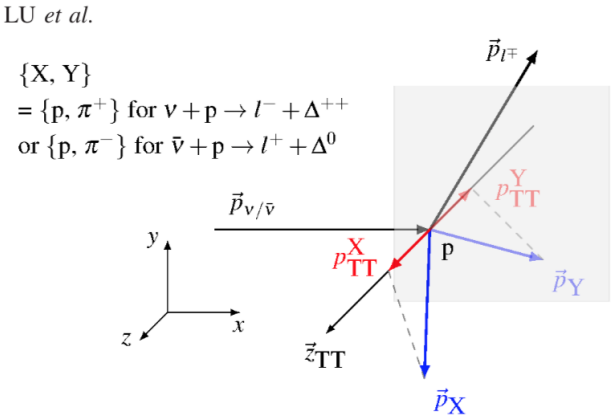
Introduction

- Nuclear effect is important.
- STT (CH2) has abundant hydrogen which is free from nuclear effect.
- Multiple nuclear target including carbon (graphite) target.
- Comparison between H-target and nuclear-target interactions give the best measurement/constraint of nuclear effect.
- Measurement of ν-H interaction is also important to cross-section physics (there has not been any such measurement for 30 years).
- The question is how to isolate the ν-H interaction and statistically subtract the background.

Method of Double-Transverse Kinematics

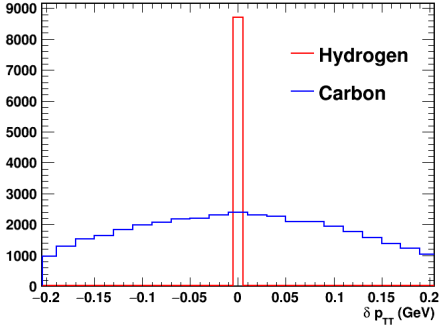


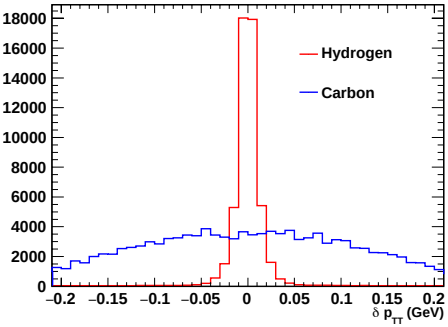
- Method developed by X. Lu *et al.*: Phys. Rev. D **92**, no. 5, 051302 (2015)
- The hadron momentum projection on the axis transverse to both neutrino and muon (double-transverse) should be balanced without nuclear effect.
- Nuclear effect causes imbalance from Fermi motion and final-state interactions.
- The imbalance δp_{TT} gives good separation power between hydrogen and nuclear targets.

STT Study

- STT performance:
  - Momentum resolution: 5%.
  - Angular resolution: 2 mrad.
  - Proton momentum threshold: 200 MeV.
  - π^+ momentum threshold: 70 MeV.
- Statistics:
  - 5 ton CH2, 5 year's running, 80 GeV beam: 3.41 M ν_μ-CC (1.88 M resonance) on hydrogen.
- This talk focus on resonance $\nu_\mu p \to \mu^- p \pi^+$ in neutrino mode (FHC).
  - Use NuWro as generator.
  - 100k CH2 event sample (mockdata).
  - Independent H and C12 samples (using same model as CH2)
  - Perform a test of signal and background normalization.

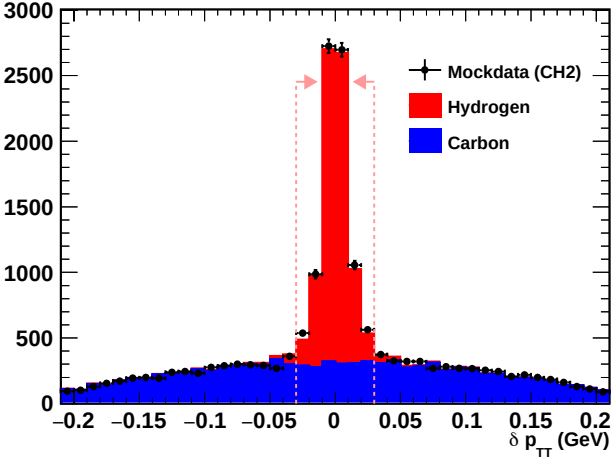
Hydrogen Events Selection





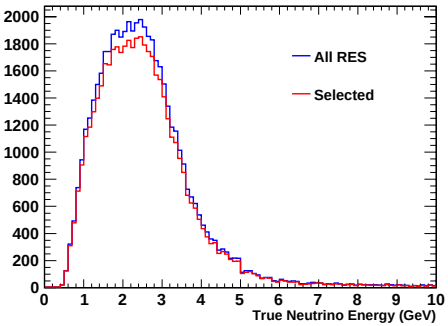
- Left: true δp_{TT}:
  - Hydrogen events peak at exactly zero.
  - The carbon events are smeared out because of Fermi motion and FSI.
- Right: reconstructed δp_{TT} (added threshold and smearing).
  - The reconstructed shape of H events is only detector effect.
  - Good resolution leads to tight cut to reduce background.

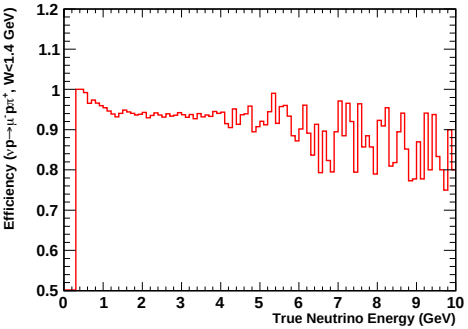
Hydrogen Events Selection and Background Normalization



- Select 3-track ($\mu^- p \pi^+$) events with $W_{rec} < 1.4$ GeV (RES region).
- Signal region: $|\delta p_{TT}| < 0.03$ GeV. Background region: $|\delta p_{TT}| > 0.03$ GeV.
- Normalize signal and background to mockdata.
- Purity is ∼77% in signal region.

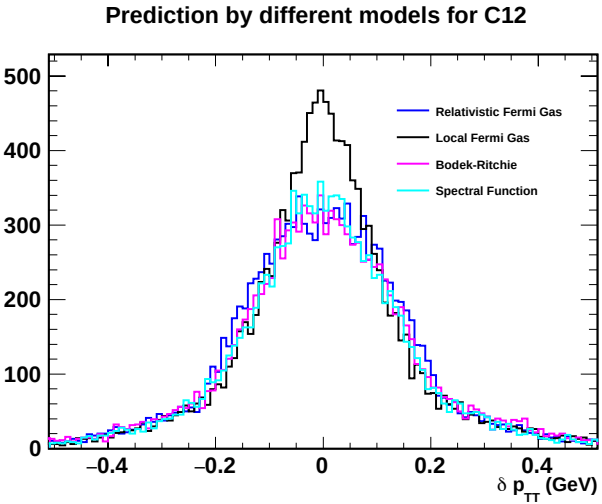
Selection Efficiency





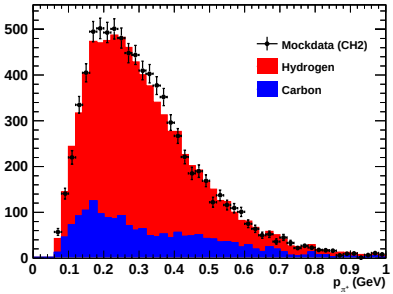
- The efficiency of selecting hydrogen RES events (true $W < 1.4$ GeV) is $\sim$94%, largely independent from incoming neutrino energy.

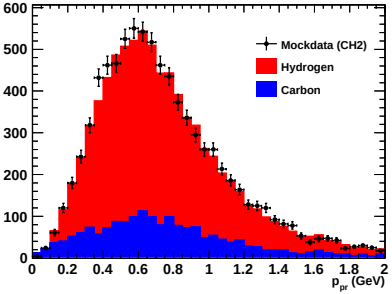
Model dependence of Background Shape

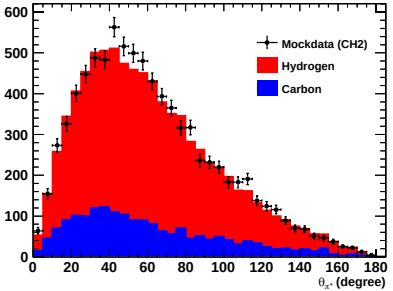


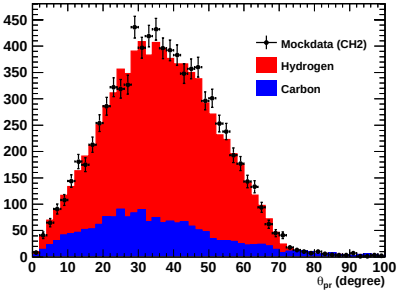
- The shape of carbon background is model-dependent.
- It is important to have dedicated carbon target (graphite) to measure the background shape.
- It also serve as a constraint on nuclear model itself.

Kinematics

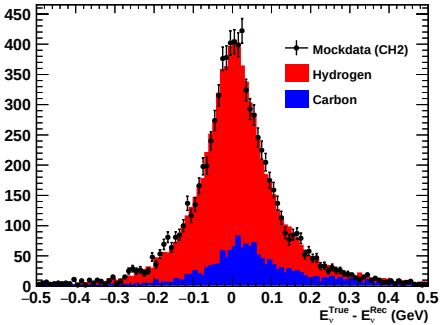

Mockdata (CH2)
Hydrogen
Carbon
p_{π^+} (GeV)

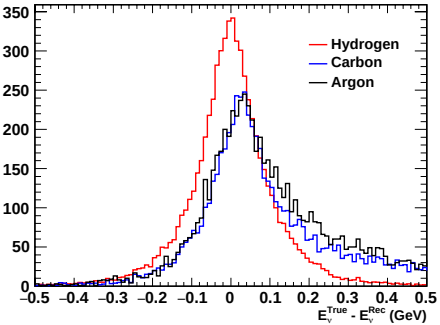

Mockdata (CH2)
Hydrogen
Carbon
p_{pr} (GeV)


Mockdata (CH2)
Hydrogen
Carbon
θ_{π^+} (degree)


Mockdata (CH2)
Hydrogen
Carbon
θ_{pr} (degree)

Neutrino Energy Reconstruction





- The hydrogen sample provide a method of reconstructing E_ν independent from nuclear effect.
- The carbon events show a difference between E_ν^{rec} and E_ν^{true}, which depends on the nuclear model used.
- Nuclear effect for Ar is even larger than carbon.

Summary

- Isolating neutrino-hydrogen interaction provides an nuclear-effect-free sample important for disentangling nuclear effect from other uncertainty sources and getting model-independent measurements in DUNE ND.
- The key features of STT for this study:
  - Abundant hydrogen in CH2 for high statistics.
  - High-resolution, low-threshold measurement of charged particles greatly reduces the carbon background via transverse kinematics cut.
  - Dedicated carbon target constrains the uncertainty from the remaining background.
- Other channels are also possible:
  - $\bar{\nu}_\mu$-RES: $\bar{\nu}_\mu p \to \mu^+ p \pi^-$.
  - Deep-inelastic: similar strategy, use momentums of all final-state particles.
  - $\bar{\nu}_\mu$-QE: if we can measure neutrons (working on this).