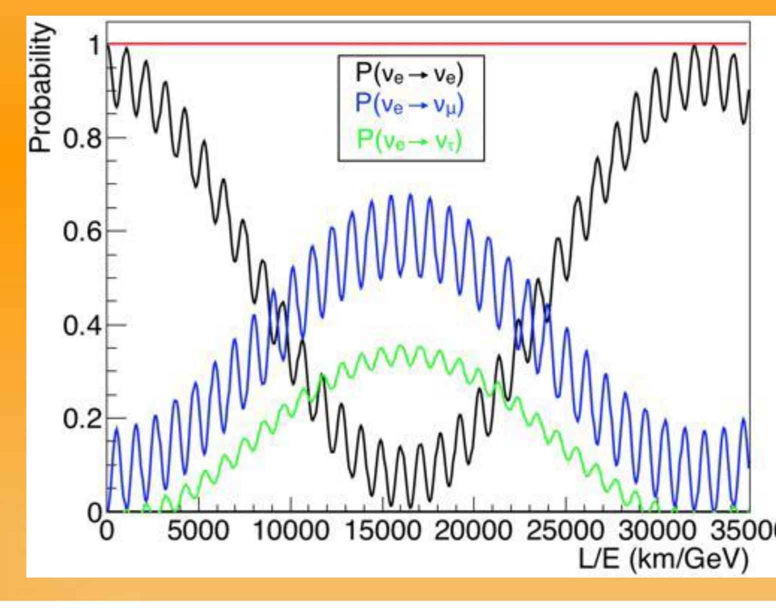
Improving Neutrino Energy Reconstruction in Few-GeV Energy Region with Reconstructed Neutrino Invariant Mass

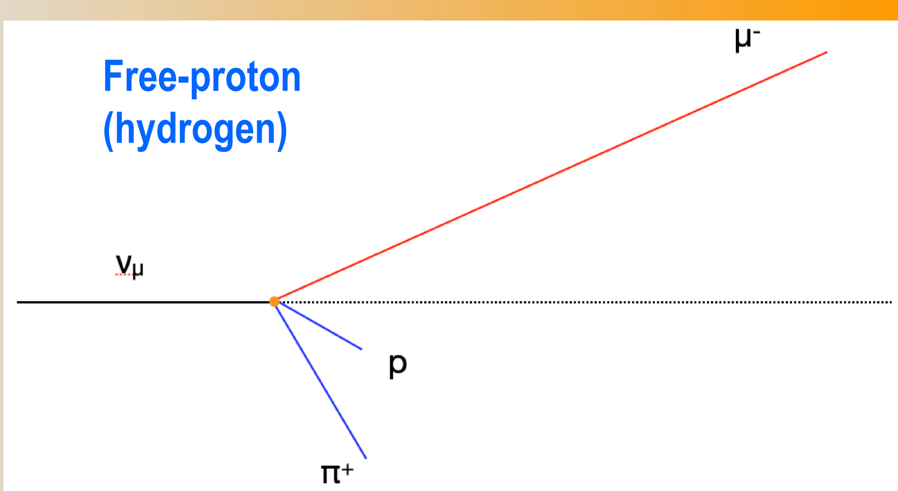
Youjie Lin, Jiajian Tan, Ziyao Wang, Hongyue Duyang

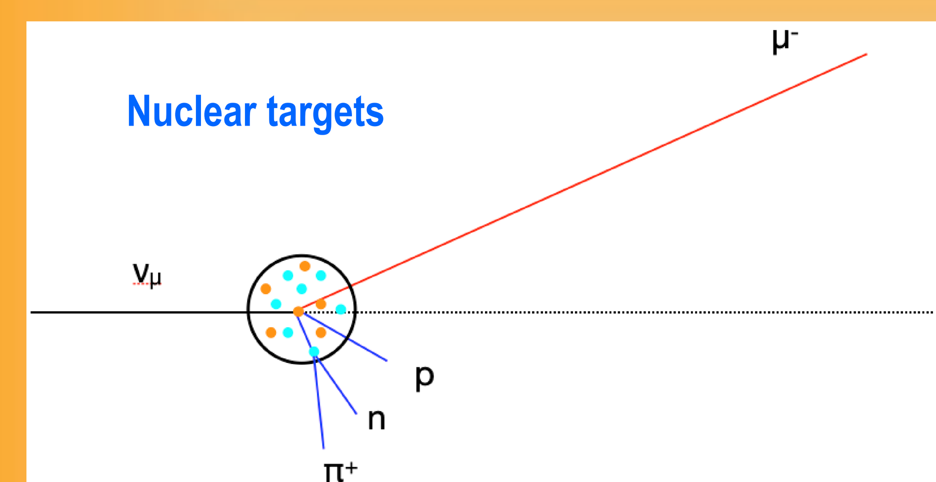
Shandong University

Motivation

- Experiments measure oscillation probabilities as functions of neutrino energy.
  - Accurate knowledge about neutrino energy is crucial!
- Neutrino energy reconstructed are affected by
  - Nuclear effects (Fermi motion, final-state interactions or FSI, nucleon-nucleon correlations, etc.) and
  - Detector effects (threshold, resolution, etc.)
- These effects alter the event topologies seen in detectors, and therefore affect energy reconstruction.





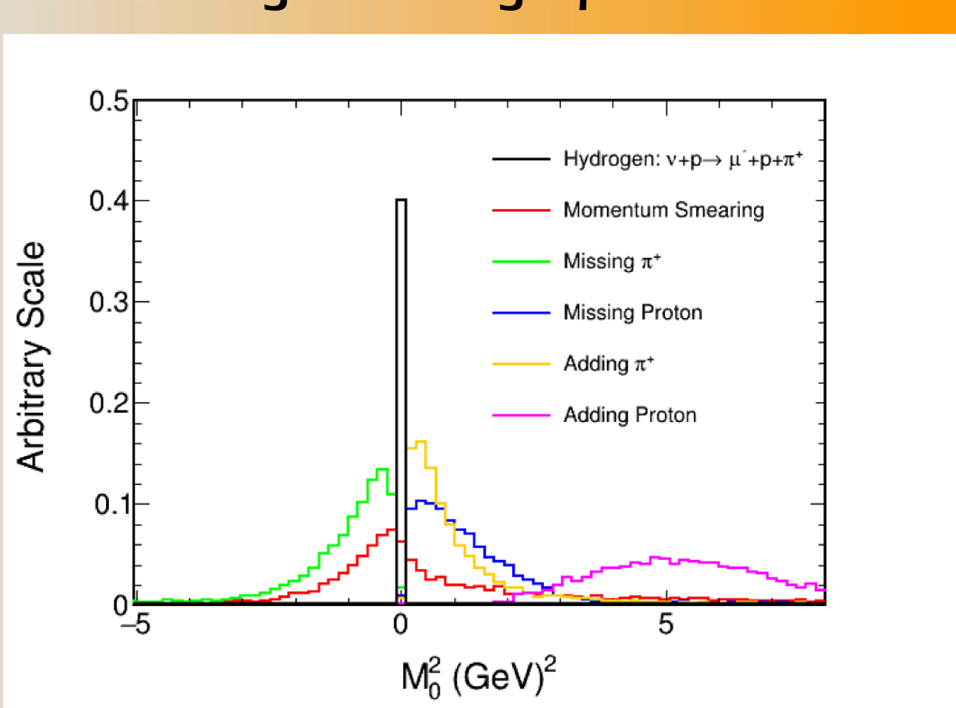


M_0^2 Definition

We define the "reconstructed neutrino mass" M_0^2 as

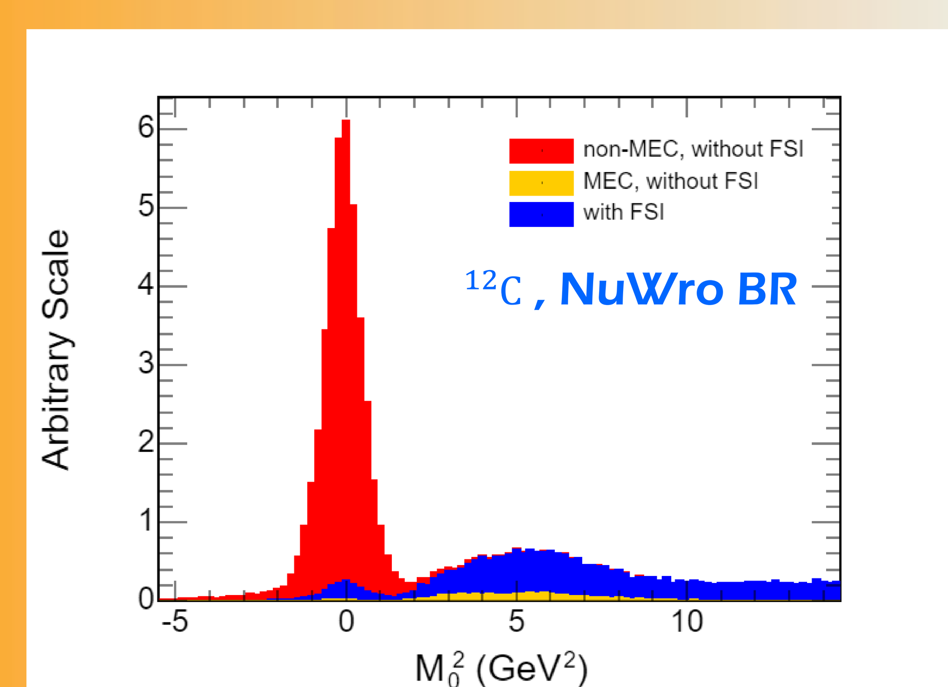
$$M_0^2 = \sum_{\text{final } i} (E_i^2 - \boldsymbol{p}_i^2) - m_p^2$$

where E_i and $\boldsymbol{p}_i$ are the measured energy and 3-momentum of the i^{th} visible final-state particle respectively, and m_p is the rest mass of the proton. The assumption is made that the interaction target is a single proton at rest.

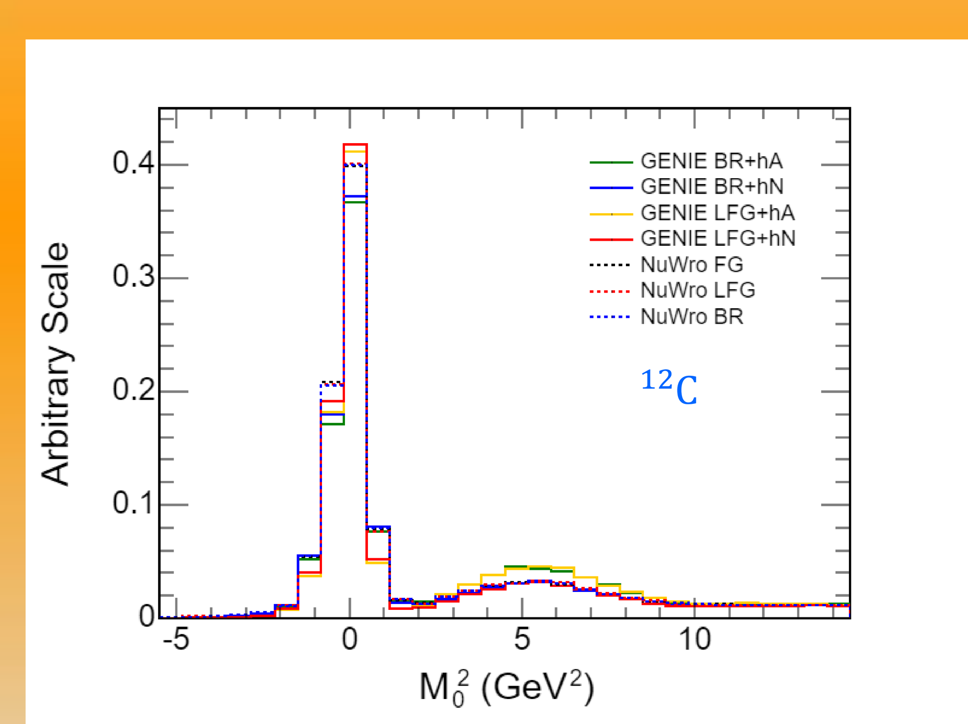


- The final state particles in simulated ${}^1\mathrm{H}(\nu_\mu p \rightarrow \mu^- p \pi^+)$ events are artificially modified, to study the impacts of nuclear effects and detector effects on the distribution on M_0^2.
  - Hydrogen events peaks at zero
  - Missing particle (absorption, thresholds) shift M_0^2 to the left
  - Extra particles (nucleon knock-out, pion production) shift M_0^2 to the right.

Characterizing Nuclear Effects



Nuclear effects can be characterized by M_0^2



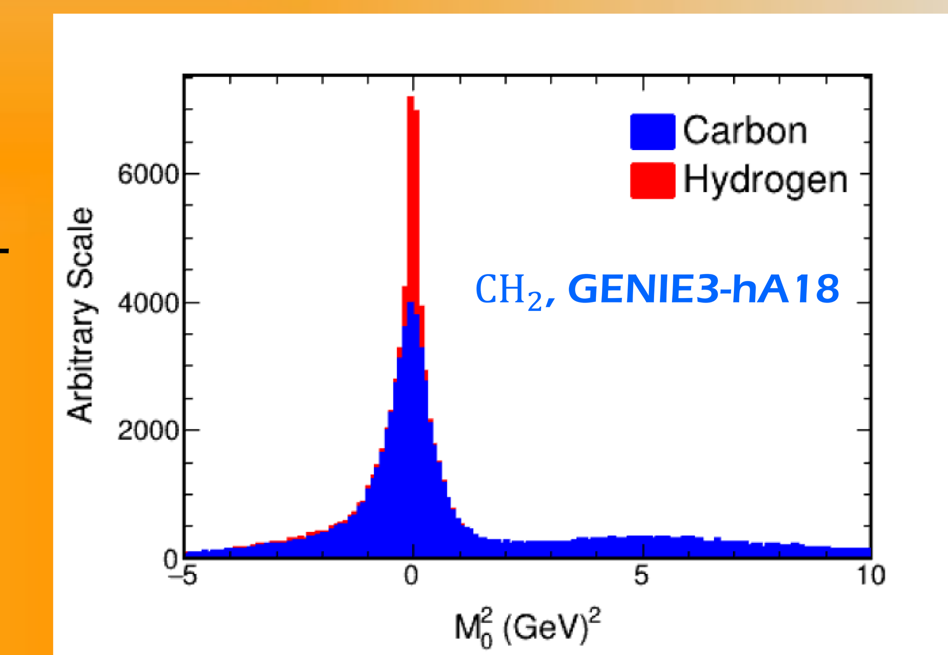
M_0^2 is sensitive to the difference between nuclear models.

Energy Reconstruction

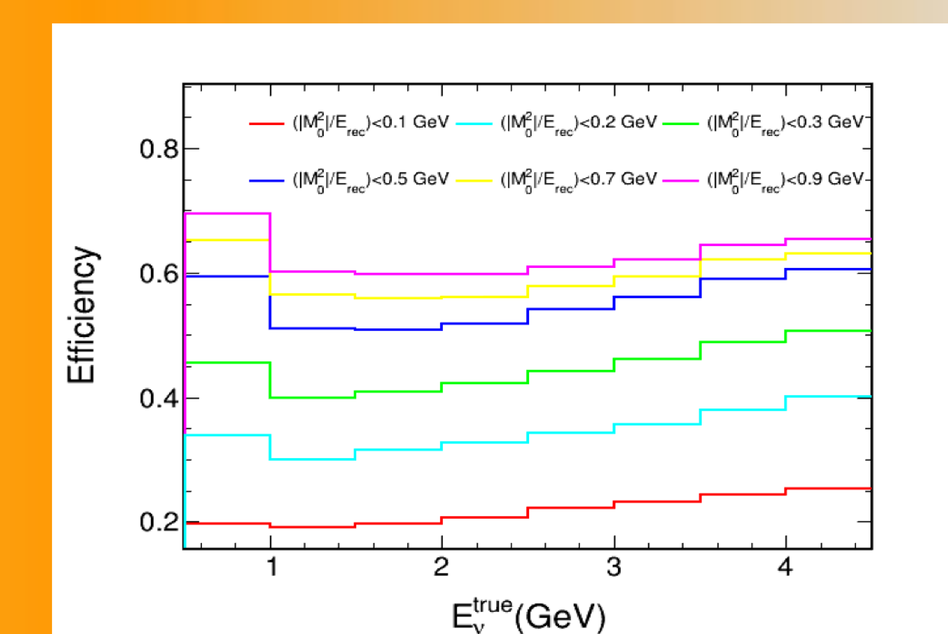
- Neutrino energy is reconstructed as

$$E_\nu^{\text{rec}} = \sum_{\text{final } i} E_i - \sum_{i \text{ is } p/n} m_i$$

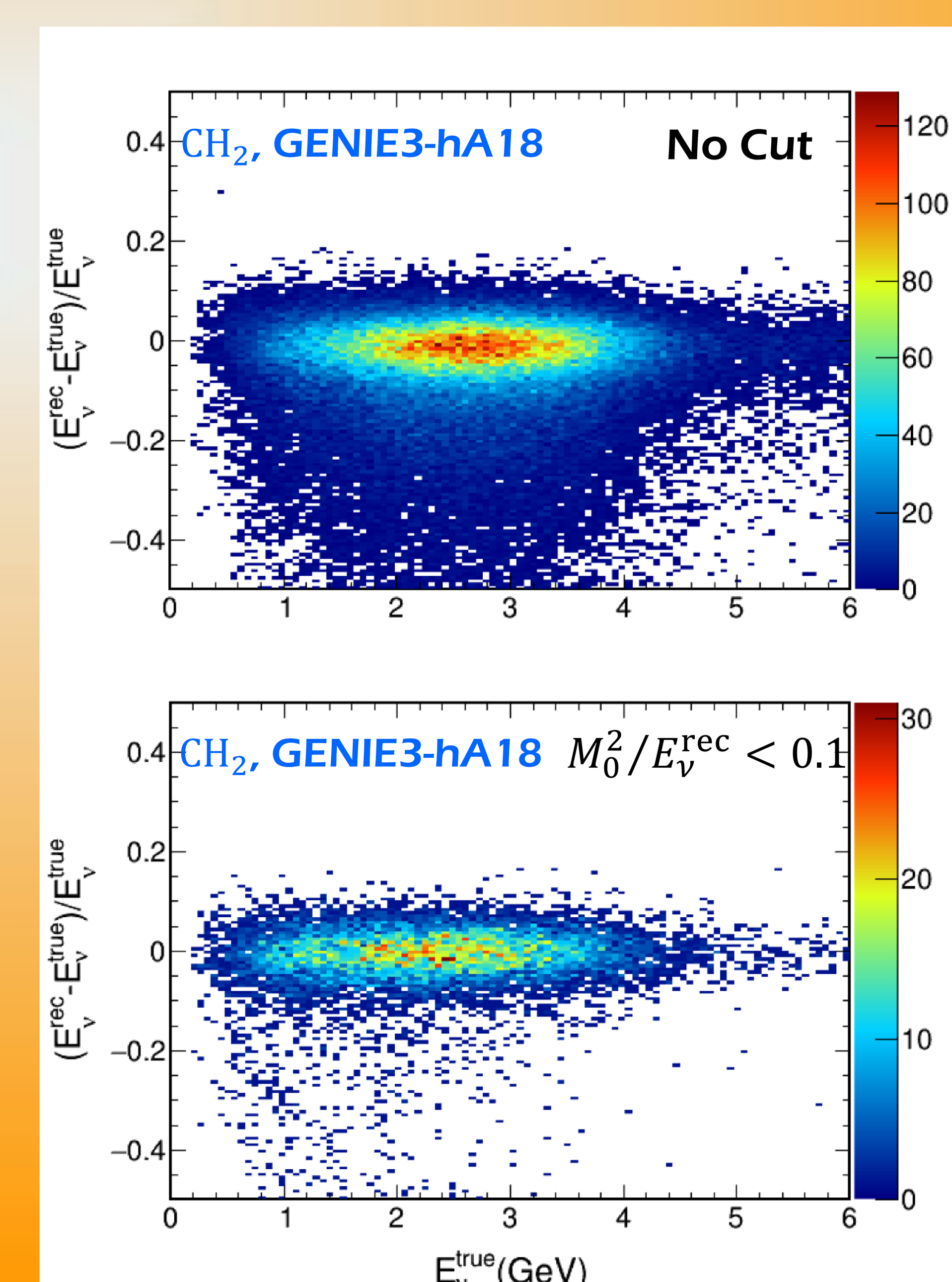
where E_i is the measured energy of the i^{th} visible final-state particle, and m_i is the rest mass.
- Detector assumptions:
  - Neutrons are invisible
  - Proton/π/lepton threshold:0.2/0.05/0.04(GeV)
  - Momentum resolution:
    - Magnitude of momentum: random by Gaussian (true magnitude, 5% * true magnitude)
    - Theta: random by Gaussian(true theta, 0.002(rad))
    - Phi: random by Uniform [0, 2π]
- A cut on M_0^2 selects events less affected by nuclear/detector effects, and also with higher hydrogen contribution (for hydrocarbon targets)
- We choose to cut on M_0^2/E_ν^{rec} which turns out to be less energy-dependent.



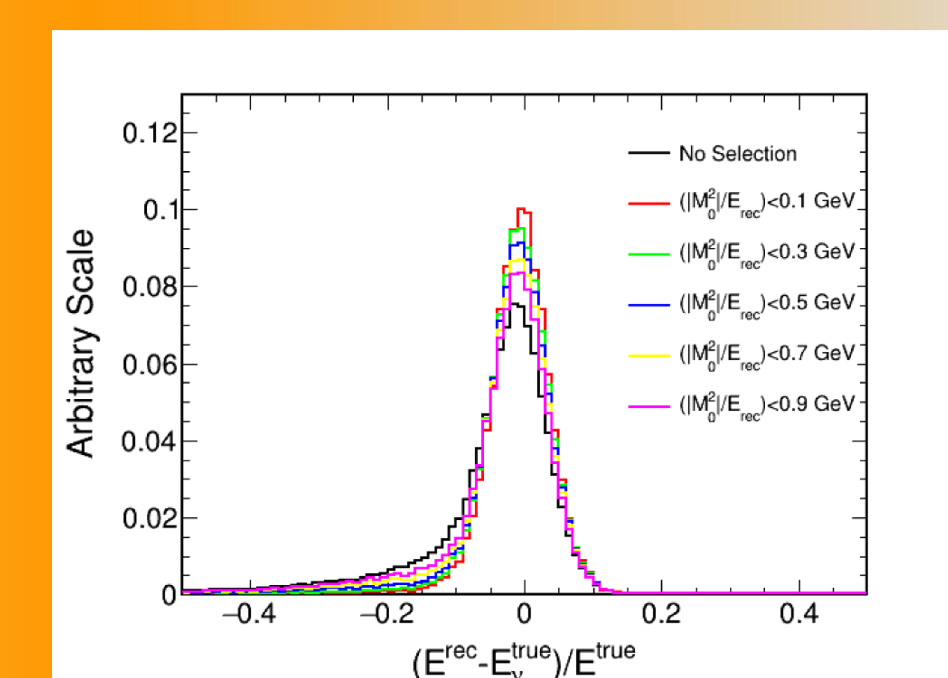
M_0^2 cuts select events with higher hydrogen contribution



Cuts on M_0^2/E_ν^{rec} are less energy-dependent



Events with M_0^2 closer to zero have better reconstructed neutrino energy.



Cut	0.1	0.3	0.5	0.7	0.9	NO CUT
Mean	0.010	0.016	0.023	0.030	0.036	0.047
RMS	0.054	0.063	0.074	0.083	0.089	0.096

Reconstruction bias is significantly reduced.

Conclusion

- The deviation of M_0^2 from zero can be used to describe the extent to which nuclear effects and detector effects affect the reconstruction.
- Simple cuts on M_0^2 can improve neutrino energy resolution in an almost energy-independent way.

Contact Us !

Youjie Lin: 201800180005@mail.sdu.edu.cn

Jiajian Tan: 201900100117@mail.sdu.edu.cn

Ziyao Wang: yktaykketo@mail.sdu.edu.cn

Hongyue Duyang: duyang@sdu.edu.cn