Benchmarking State-of-the-Art Theory and Empirical Models of Pionless Neutrino-Argon Scattering in GENIE

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Based on arXiv:2605.14196

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Simulation of neutrino-nucleus interactions

- Next-generation long baseline neutrino oscillation experiments need improved simulation of neutrino-nucleus interactions.
- Physics ingredients
  - Nuclear ground states
  - Form factors
  - Primary neutrino-nucleon vertex
  - Final state interactions
  - Nuclear de-excitation

Primary Interaction

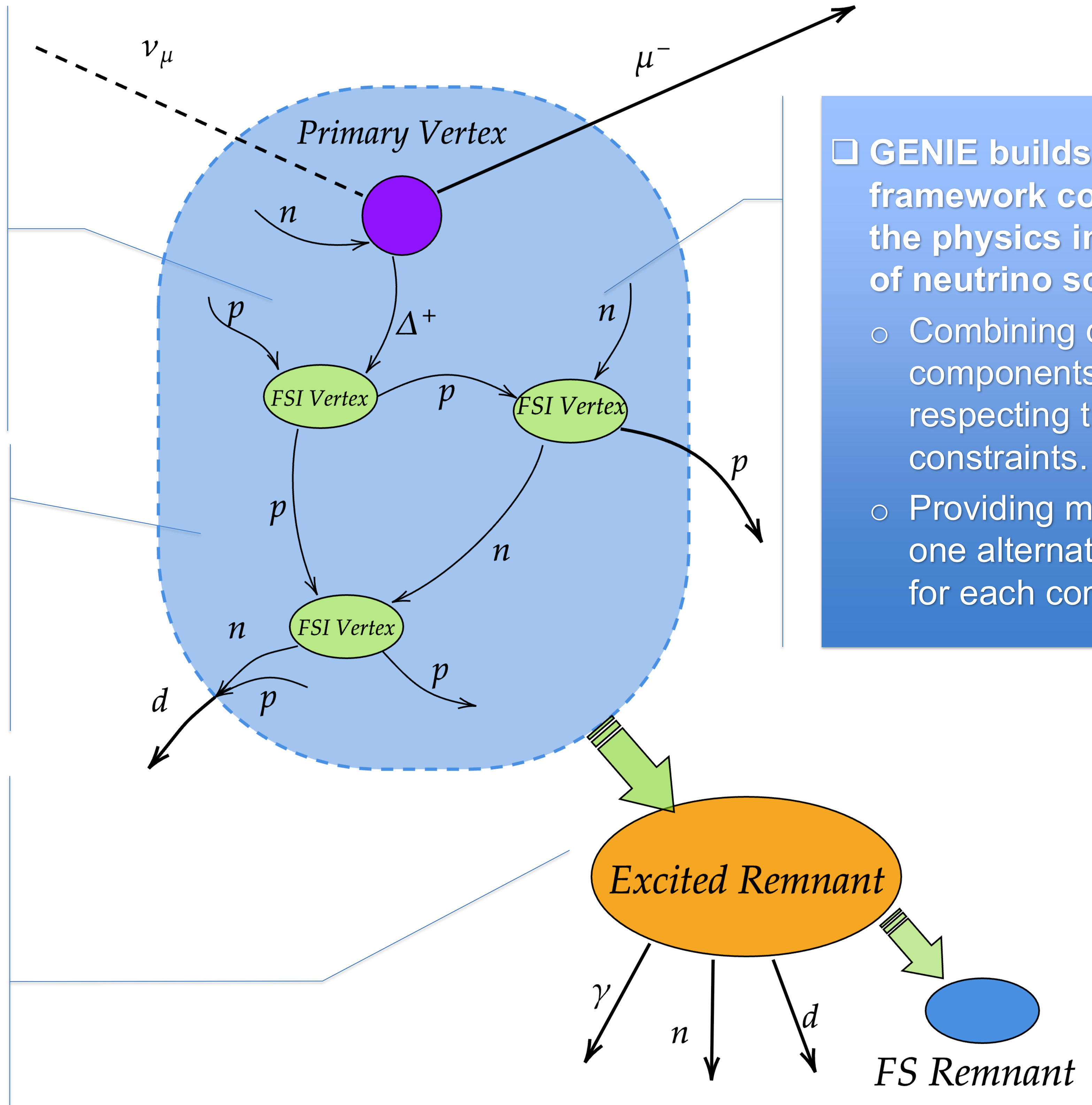
- Neutrinos interact with nucleons (protons/neutrons) inside a nucleus.
- Nuclear ground states: local Fermi Gas (LFG) v.s. spectral function (SF).
- Axial form factor: deuterium v.s. lattice QCD.
- QEL, RES, MEC, DIS …

Final State Interactions (FSI)

- Hadrons coming from neutrino primary vertex can re-scatter with other nucleons inside a nucleus.
- hA2018 model v.s. INCL++.

De-excitation of the remnant nucleus

- New feature comes with the implementation of GENIE-INCL++.
- Photons, nucleons & clusters.
- Abla, GEMINI …



GENIE builds a framework connecting the physics ingredients of neutrino scattering

- Combining different components while respecting the physics constraints.
- Providing more than one alternative model for each component.

Conclusions

- GENIE's especially flexible code structure allows straightforward interchange of model components in comparisons with data.
- The MicroBooNE data reveal a preference for the LQCD axial form factor over deuterium fit.
- GENIE's native hA2018 model achieves a better fit than the INCL++ model.
- MicroBooNE data in this study cannot discriminate between LFG and SF.

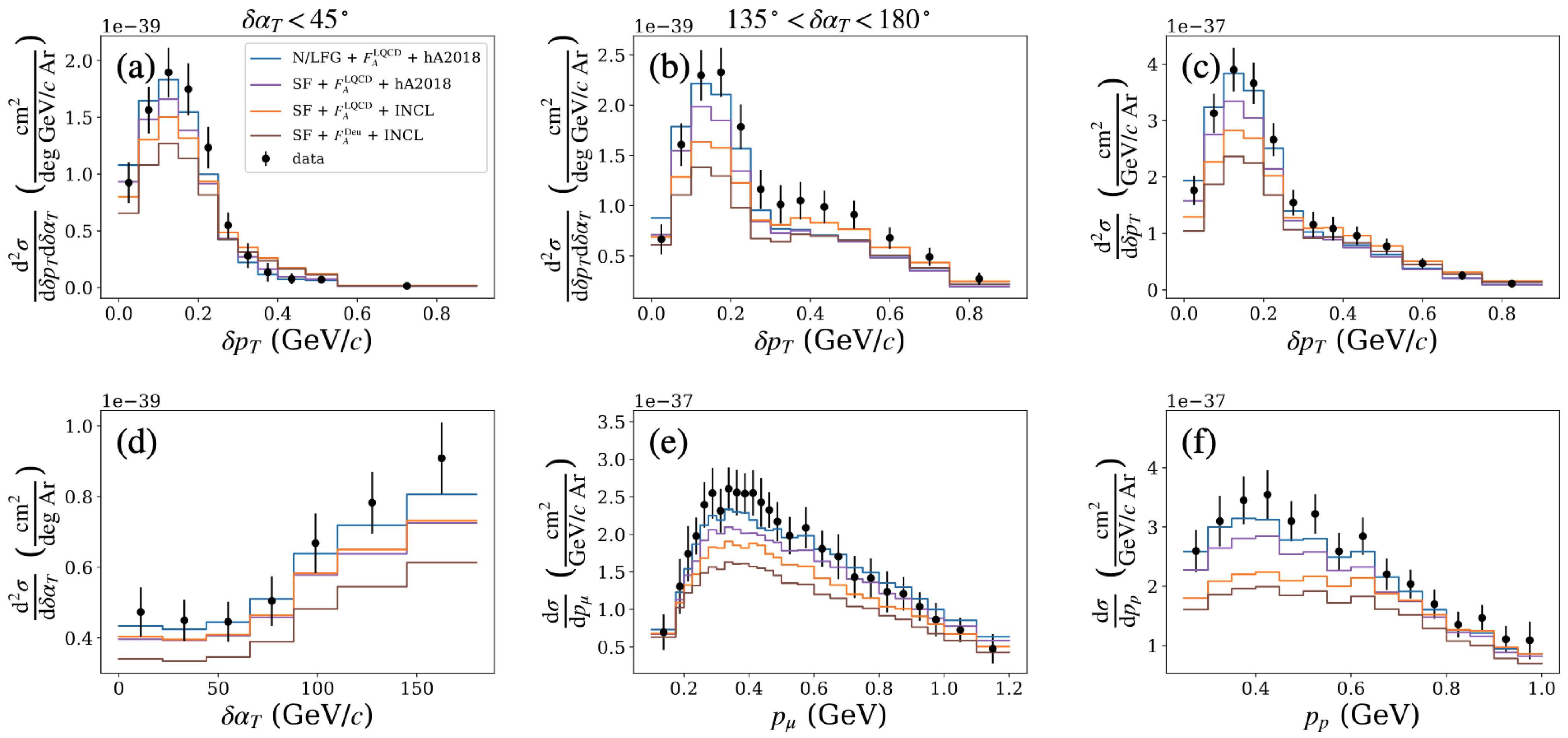


Table 1: χ^2/ndf (p-value) of MC and reference simulations relative to MicroBooNE data.

Configuration	δp_T vs. $\delta\alpha_T$[a]	δp_T	$\delta\alpha_T$	p_μ	p_p
N/LFG + F_A^{LQCD} + hA2018[b]	35.98/49 (0.92)	6.78/13 (0.91)	3.47/7 (0.84)	16.29/26 (0.93)	16.05/15 (0.38)
SF + F_A^{LQCD} + hA2018	34.25/49 (0.95)	6.36/13 (0.93)	5.19/7 (0.64)	18.82/26 (0.84)	15.59/15 (0.41)
N/LFG + F_A^{Deu} + hA2018	44.21/49 (0.67)	9.59/13 (0.73)	10.19/7 (0.18)	20.89/26 (0.75)	19.95/15 (0.17)
N/LFG + F_A^{LQCD} + INCL	56.01/49 (0.23)	9.09/13 (0.77)	5.75/7 (0.57)	17.66/26 (0.89)	26.94/15 (0.03)
SF + F_A^{Deu} + hA2018	43.52/49 (0.69)	11.91/13 (0.54)	11.12/7 (0.13)	30.98/26 (0.23)	24.93/15 (0.05)
SF + F_A^{LQCD} + INCL[c]	66.61/49 (0.05)	15.72/13 (0.26)	5.47/7 (0.60)	23.91/26 (0.58)	32.25/15 (0.01)
N/LFG + F_A^{Deu} + INCL	68.42/49 (0.03)	16.33/13 (0.23)	8.73/7 (0.27)	27.98/26 (0.36)	31.56/15 (0.01)
SF + F_A^{Deu} + INCL	81.91/49 (0.00)	23.94/13 (0.03)	10.01/7 (0.19)	35.08/26 (0.11)	38.83/15 (0.00)
MicroBooNE Tune	42.61/49 (0.73)	7.31/13 (0.89)	3.96/7 (0.78)	24.59/26 (0.54)	17.38/15 (0.30)
AR23	38.05/49 (0.87)	10.63/13 (0.64)	7.56/7 (0.37)	28.96/26 (0.31)	24.07/15 (0.06)

[a] The χ^2/ndf (p-value) in this column include contributions from intermediate $\delta\alpha_T$ bins not shown in Fig. 1.
[b] Best empirical tune.
[c] Most theoretical tune.

arXiv:2605.14196   Github dev branch

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