Constraining Neutrino Interaction Generator: GiBUU

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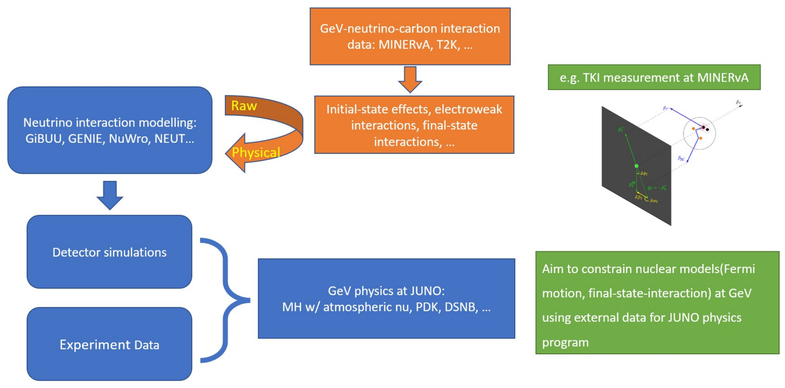
1. Introduction

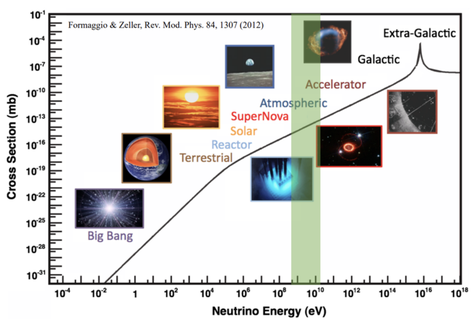
- One way to study the GeV physics at JUNO is, use the Neutrino interaction modeling tools like GiBUU, GENIE, NuWro or NEUT, to help do the detector simulations, then combine the simulation data with the JUNO experiment Data, to study the GeV physics at JUNO, like Mass Hierarchy with atmospheric neutrino, proton decay, DSNB and so on.

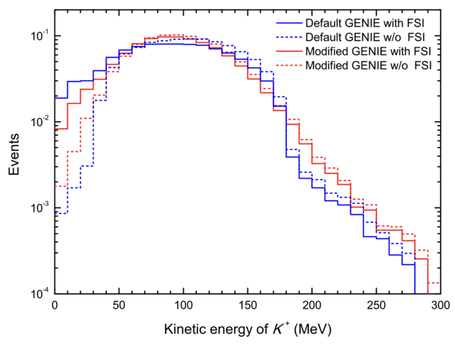


- Since we havent got the JUNO experiment data, and the neutrino interaction model constraining of GeV region is insufficient, we can use the GeV-neutrino-carbon interaction data from other experiment, like MINERvA, T2K, to help constrain the neutrino interaction model, like Initial-state effects, electroweak interactions, final-state interactions, and so on.
- Tihs poster aims to use the MINERvA TKI measurement data to constrain the Fermi motion and final-state interactions (FSI) model in GiBUU.

2. Motivation

- For the study of JUNO, it is necessary to deeply understand the neutrino-nucleon interaction process of GeV. Studies of DSNB, reactor neutrino (Neutral current background), proton decay, etc. also rely on this energy region. [1]
- The model constraining of this energy region is insufficient, and needs neutrino generator to help understand it.
- Can indirectly constrain the model in the Neutrino Generator we care about through other experimental data.

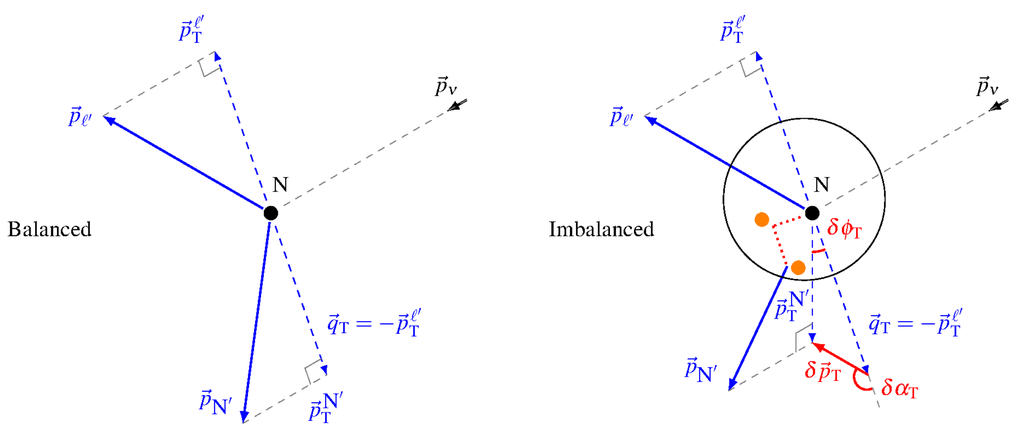




- For Proton Decay $p \to \bar{\nu}K^+$ in JUNO, The energy spectrum of K^+ is directly affected by the **Fermi Motion** and **Final-State Interactions (FSI)** in the nucleus.
- The Kaon phase space overlap with GeV-neutrino interaction product → background for rare searches. [2]

3. Constraining neutrino interactions

GeV ν-A interactions are complicated. Hadron production below the DIS regime and nuclear medium effects such as Fermi motion, final-state interactions (FSIs), 2-particle-2hole (2p2h) excitation, contribute significantly to the systematic errors in measuring the neutrino energy and flux. Accelerator neutrino experiments have provided valuable data to constrain the details of neutrino interactions.
Among various cross-section observables, the **Transverse Kinematic Imbalance (TKI)** [3, 4] can precisely identify intranuclear dynamics, or the absence thereof, in neutrino-nucleus interactions—an analogue of the missing energy technique used in collider experiments.



1. As the 3D extension of the missing p_{T} (δp_{T}), the **Furmanski-Sobczyk *emulated nucleon momentum*** $p_{\mathbf{n}}$ [5, 6] describes the Fermi motion of the struck nucleon.
2. The ***transverse boosting angle*** $\delta\alpha_{\mathbf{T}}$ [4] describes the direction of δp_{T}.

References

[1] X.-G. Lu. FNAL Neutrino Seminar, 1 April 2021
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[6] X.-G. Lu and J. T. Sobczyk, Phys. Rev. C **99**, 055504 (2019).
[7] X.-G. Lu *et al.* [MINERvA], Eur. Phys. J. ST **230**, 4243 (2021).
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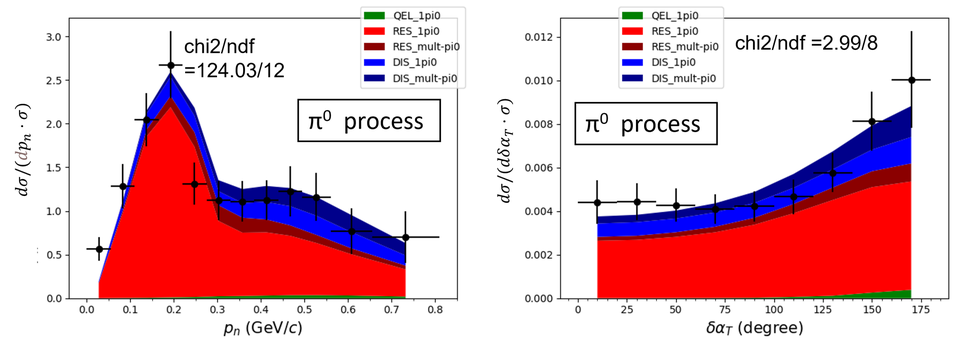
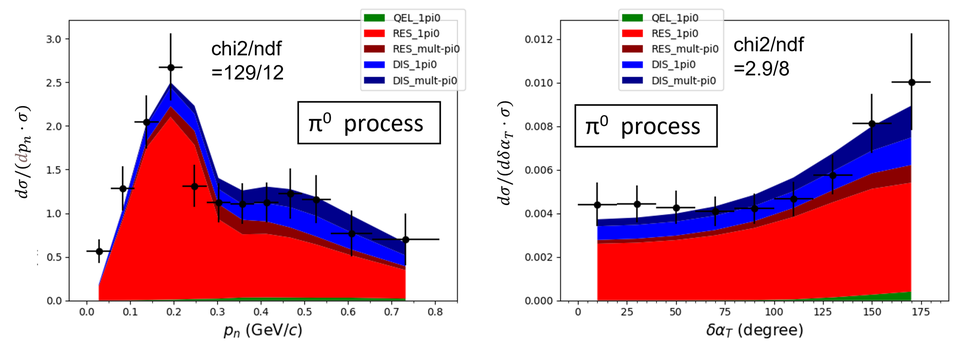
4. GiBUU TKI result with different model

Predictions of TKI by various event generators are compared to the **MINERvA** [7] π^0 measurement where the final state contains one μ^- ($1.5 \leq p_{\mu^-} \leq 20$ GeV/c, $\theta_{\mu^-} < 25$ °), at least one π^0, and at least one proton ($p_p \geq 0.45$ GeV/c). The TKI is formed by combining the π^0 and proton kinematics against the muon [8].

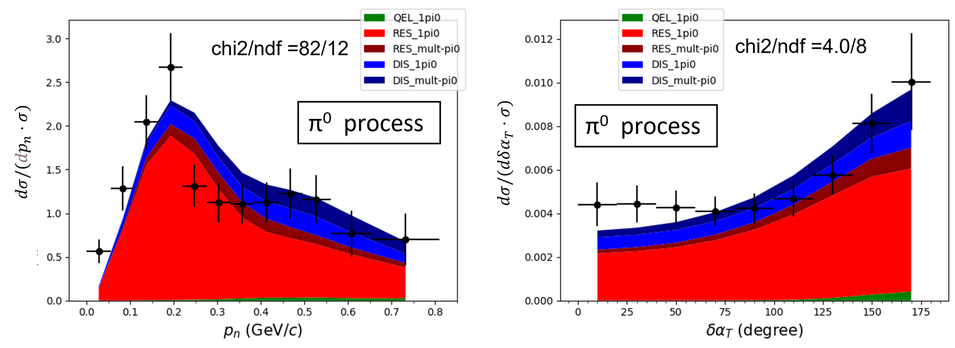
1. **Soft momentum-dependent potential model**



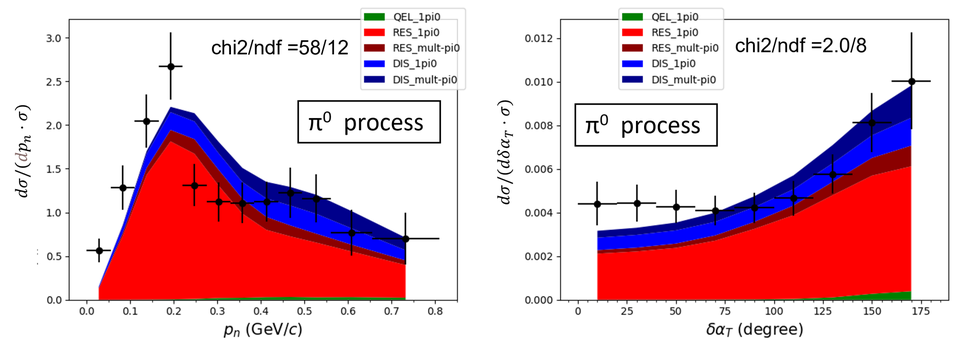
2. **Hard momentum-dependent potential model**



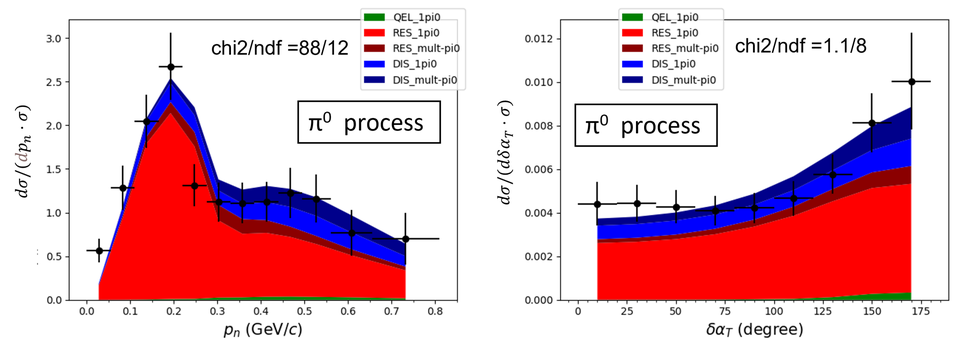
3. **Soft non-momentum-dependent potential model**



4. **Hard non-momentum-dependent potential model**



5. **Medium momentum-dependent potential model (GiBUU Default)**



GiBUU provides reasonable description to MINERvA TKI data.

5. Summary

- Using TKI data measurement by MINERvA, to understand and constrain GiBUU.

chi2/ndf	0 π		π^0	
	Pn	dalphat	Pn	dalphat
Soft momentum-dependent potential	357.99/23	16.90/11	124.03/12	2.99/8
Hard momentum-dependent potential	223.82/23	14.07/11	128.72/12	2.88/8
Soft non-momentum-dependent potential	91.30/23	25.34/11	82.09/12	3.97/8
Hard non-momentum-dependent potential	48.57/23	27.07/11	76.02/12	4.05/8
Medium momentum-dependent potential (jobCard Defult)	306.59/23	17.08/11	126.73/12	2.95/8

- In GiBUU, the hard-momentum-dependent model and hard-non-momentum-dependent model showed a better fit to the MINERvA TKI data.

Model constraint work is still in progress, in collaboration with Ulrich Mosel.