Implementing the Martini et al model into the GENIE MC event generator

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NEUTRINO OSCILLATION EXPERIMENTS

- Neutrino oscillation experiments study the **transformation** of neutrinos of flavour α into neutrinos of flavour β
- The **flavour** of the neutrino is **reconstructed** from the **outgoing lepton** in the neutrinos interactions

$$\underbrace{N_{\nu_\beta}(E_\nu^{rec})}_{\text{number of } \nu_\beta \text{ detected events}} \sim \int \underbrace{\Phi_{\nu_\alpha}(E_\nu^{true})}_{\nu_\alpha \text{ flux}} \underbrace{P_{\nu_\alpha \to \nu_\beta}(E_\nu^{true}, L, \Theta)}_{\nu_\alpha \to \nu_\beta \text{ oscillation probability}} \underbrace{\sigma_{\nu_\beta}(E_\nu^{true})}_{\nu_\beta \text{ cross section}} \underbrace{\epsilon_{\text{det}}}_{\text{detector efficiency}} \underbrace{d(E_\nu^{true}, E_\nu^{rec})}_{\text{migration matrix}} dE_\nu$$

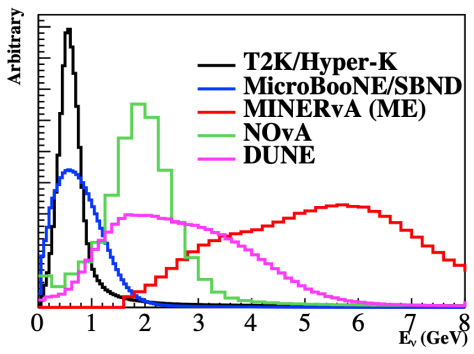
The ν_β **cross section** appears:

- explicitly
- implicitly in the detector efficiency
- implicitly in the migration matrix

⟶ **modelling** the **neutrino - nucleus cross section** is **crucial !**

ENERGY RECONSTRUCTION

- **Neutrino beams** in accelerator based experiments **are not monochromatic**
- The **incoming neutrino energy** is **not known**, so it must be **reconstructed** from observed final state particles
- In T2K, E_ν^{rec} is calculated assuming the **interaction is CCQE** on a stationary nucleon with fixed nuclear binding energy ⟶ used lepton kinematics only



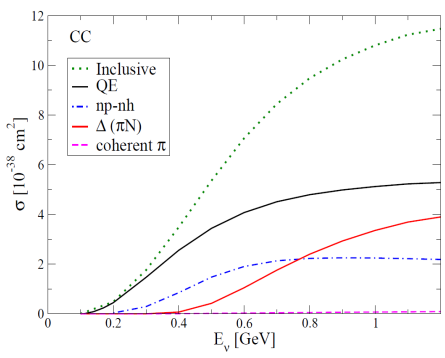
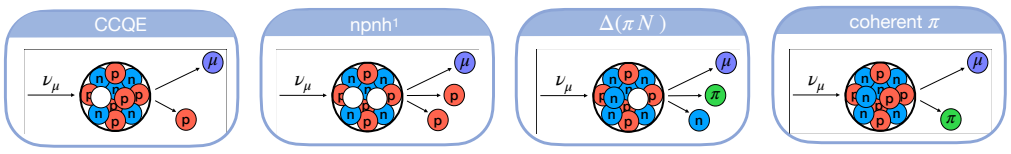
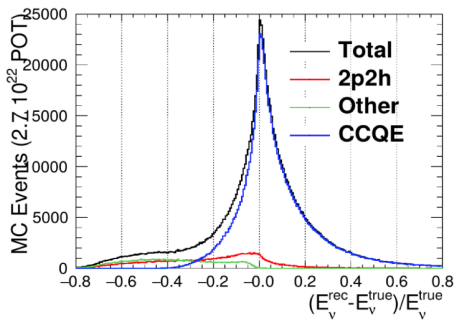


illustration of interaction channels at $E_\nu \sim \mathcal{O}(1\text{GeV})$



- **non-CCQE** interactions lead to a **bias** in E_ν^{rec}
- **npnh interactions** are the **biggest source** of non-CCQE **bias** at T2K and Hyper-K energies



Having a **correct model** that describes the **neutrino - nucleus interaction** is needed to adjust the **mapping** between E_ν^{rec} and E_ν^{true} !

¹npnh represents the case where n > 1 nucleons are knocked out from the nucleus. The 2p2h and 3p3h are both possible. The CCQE is also called 1p1h.

REFERENCES

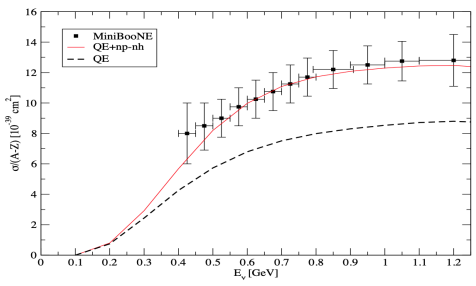
[1] M. Martini, M. Ericson, G. Chanfray, J. Marteau "Unified approach for nucleon knock-out and coherent and incoherent pion production in neutrino interactions with nuclei" In: Physical Review C 80.6 (Dec. 2009)

[2] C. Andreopoulos et al. "The GENIE Neutrino Monte Carlo Generator: Physics and User Manual" arXiv: 1510.5494 [hep-ph] (2015)

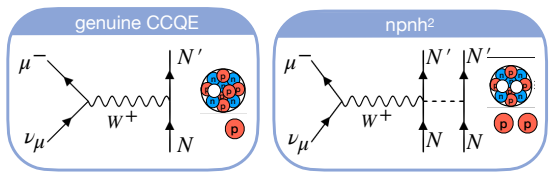
MARTINI et al MODEL

Martini, Ericson, Chanfray and Marteau gave the **explanation** to the **MiniBooNE** CCQE-like **cross section** [1] :

- MiniBooNE studied CCQE-like events **reconstructing** just the l**eptonic part**
- Genuine CCQE and npnh have the **same final states** if one looks at the leptonic part only
- Thanks to the **inclusion of the npnh channel**, the Martini et al cross section predictions matched MiniBooNE data



CCQE-like = genuine CCQE + npnh

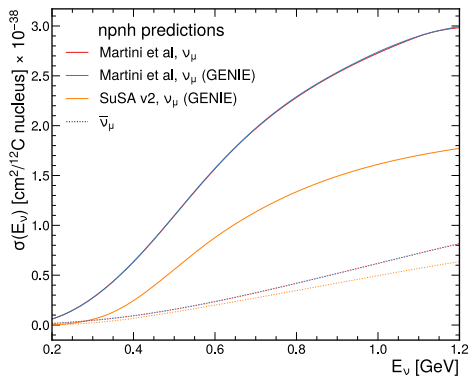


²The picture shows just the 2p2h case, but, as seen in ¹, npnh includes the 3p3h as well.

MARTINI npnh IMPLEMENTATION into GENIE

- **Monte Carlo generators** are needed to **simulate** neutrino - nucleus interactions and to extrapolate the corresponding cross sections
- **GENIE** [2] is one of the main MC event generators
- Aim of this work is to implement the Martini et al model into the GENIE event generator

My **results** of the implementation of the Martini et al npnh cross sections predictions into GENIE are shown below:

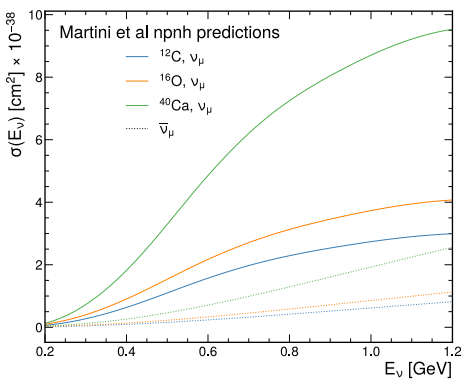


cross section generated in GENIE (blue line) is superimposed to the one generated outside GENIE (red line)

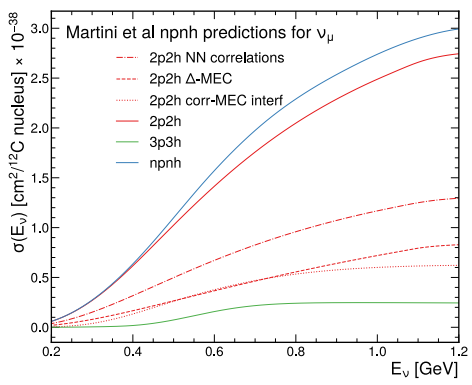
the **npnh Martini** et al model **implementation** into GENIE **is successful** !

The implementation into GENIE is complete and validated for:

- different targets



- 2p2h and 3p3h separation



PERSPECTIVES

- **Finalise** the implementation of npnh channel into GENIE
- **Compare** with available experimental **measurements**
- Use the Martini et al model to help develop **systematic uncertainties** for neutrino oscillation analyses
- Include **other channels** to have the full model implemented

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