Mechanics of Factorizing Hadron Reinteraction from Hard Scattering

Kevin McFarland

9 January 2020

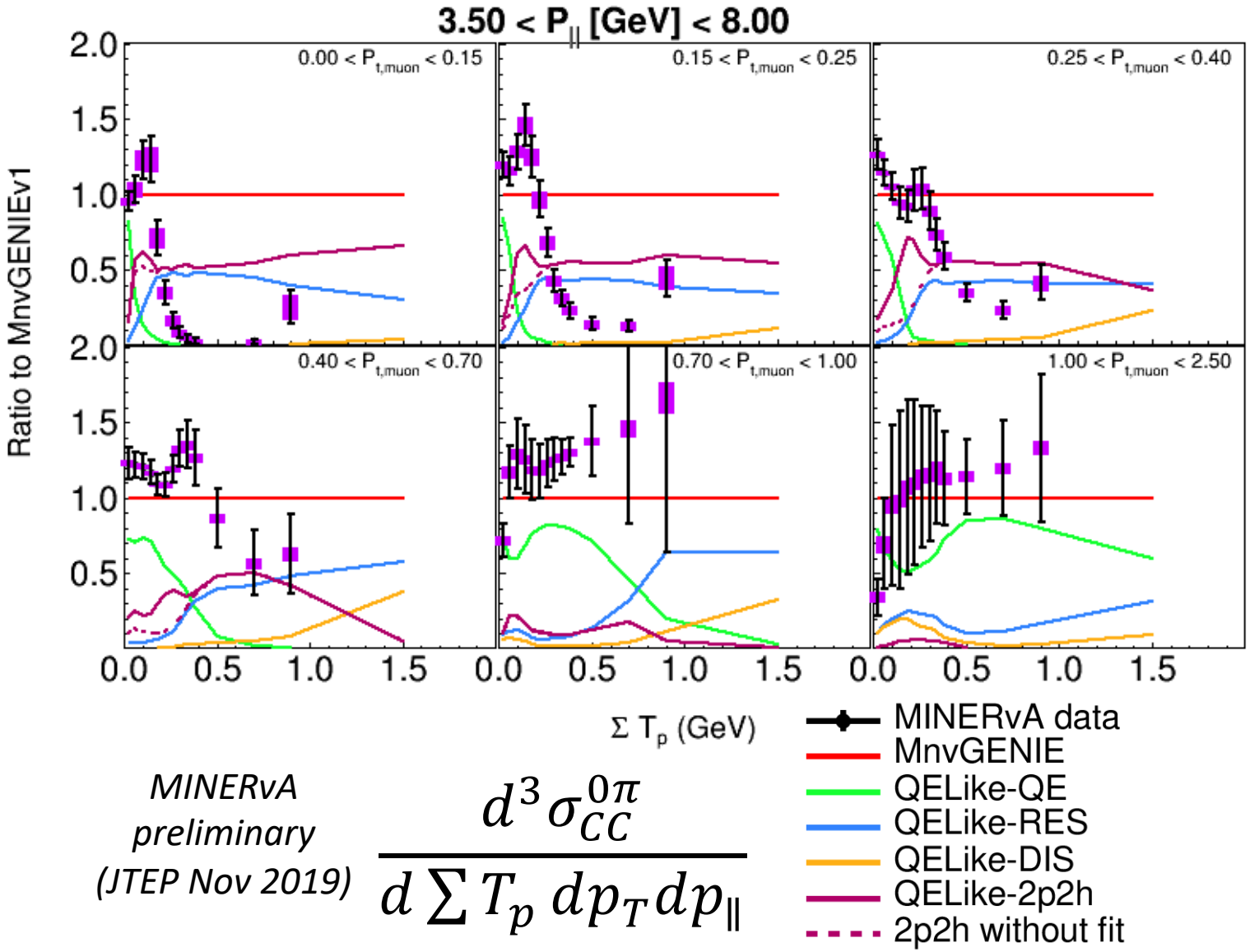
Why would we want to do this?

- Provides a mechanism for a “lightweight” generator for a model to add a hadron rescattering prediction without fully implementing into the generator that has that prediction.
- Allows for more straightforward comparison of both hard scattering and hadron rescattering predictions of different models against data without conflating the two effects.

I’m going to be careful (mostly?) to write “hadron rescattering” instead of “final state interactions” (FSI) since the latter also includes nuclear potential effects, like Coulomb effects and “binding” from the potential well, etc.

Why do this?

- Here's a timely example of such a need.
- Above the QE and 2p2h peak regions in CCQE-like (no meson) events with low p_T muons, MINERvA sees none of the pion absorption events that models predict.
- Is mismodeling in primary production or reinteraction?



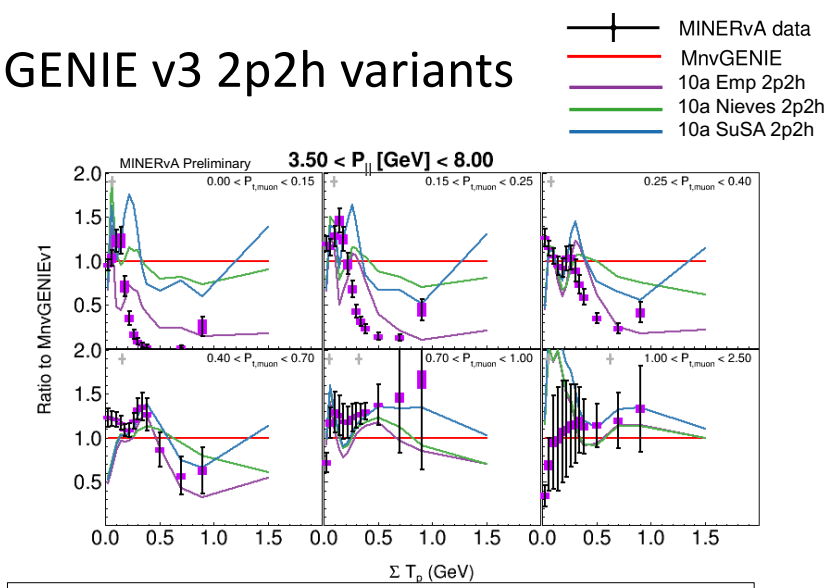
MINERvA preliminary (JTEP Nov 2019)

$$\frac{d^3\sigma_{CC}^{0\pi}}{d\sum T_p\, dp_T dp_\parallel}$$

Why?

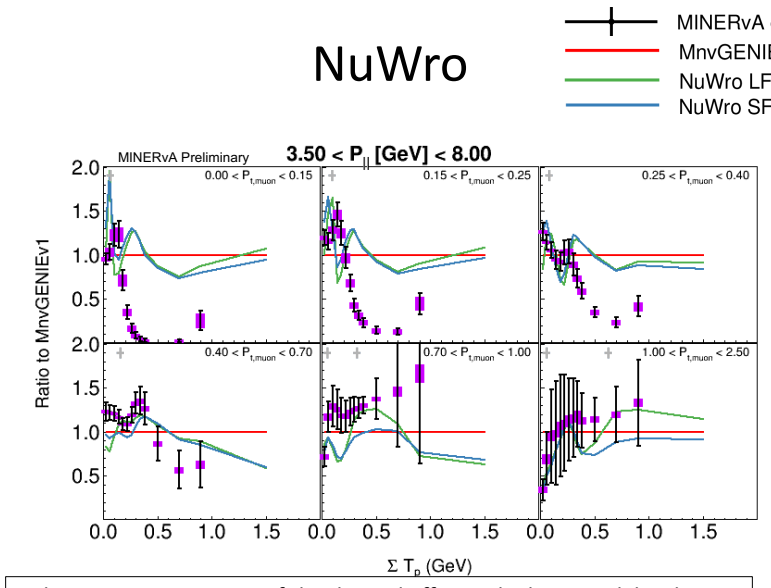
- Each model has different pion absorption (including different final state).
- Each model has different pion production (and possibly 2p2h).
- Easier to make conclusions if one of these could be varied at a time.

GENIE v3 2p2h variants



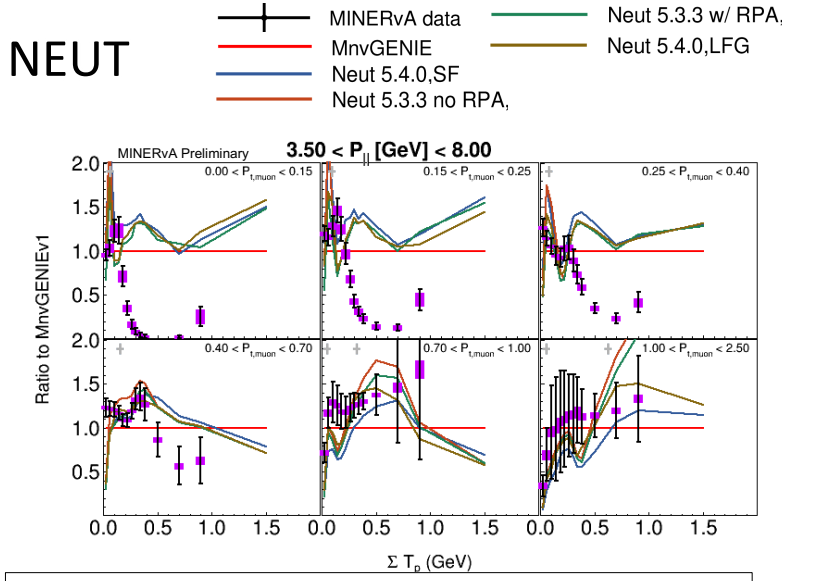
Observation: Empirical 2p2h much better at high recoil. All models bad at low recoil.

NuWro



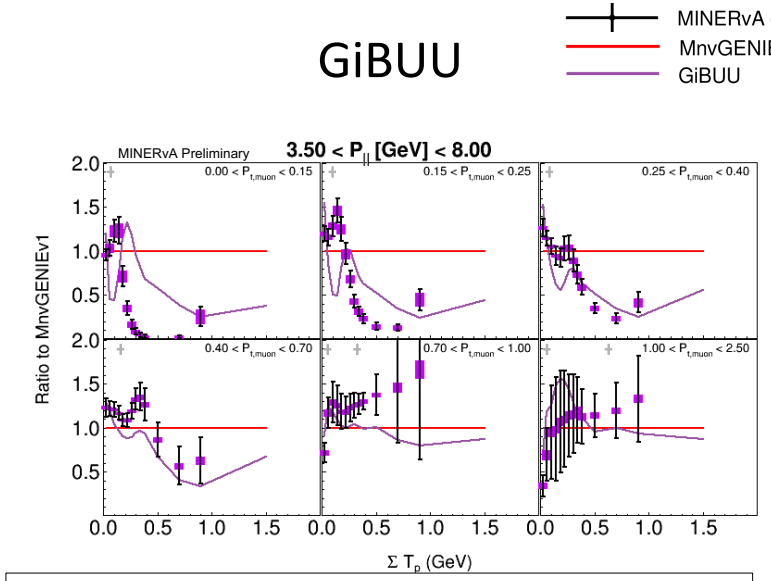
Observation: Has some of the desired effect at higher recoil, but lower recoil is shifted

NEUT



Observation: Higher $P_{t,\mu}$ is much better than low $P_{t,\mu}$ over predicts more in the higher recoil regions

GiBUU



Observation: Has the more of the desired shape in the higher recoil and moderate to high P_t, but the low recoil is poorly modeled

What goes wrong with this?

- I see three primary problems.
- Cannot correctly factorize the hard scattering from hadron reinteraction.
  - *Nevertheless, all of our models, except* maybe *GiBUU's, do this incorrect thin. Doesn't makes sense to let aspirational future goals restrict our current tools.*
- Inconsistency between nuclear model assumed in hard scattering and nuclear model assumed in hadron reinteraction.
  - *But our standard generator models are littered with this problem because we use predictions (Nieves 2p2h, Rein-Sehgal, DIS models) where we either have integrated hard scattering with a particular model, or we ignore or oversimplify nuclear effects in hard scattering.*
- We would not transmit sufficient information to connect the hard scattering event with the hadronic reinteraction simulation.
  - *We should design a solution that doesn't do that.*

Simple (too naïve?) approach

- Each generator has "hard interaction" produced particles in output record.
  - (Different identification, but either a uniform format, or translation can fix this.)
  - Hard interaction in all generators (except GiBUU?) handles nuclear potential effects, including Coulomb effects.
- Remove rescattered hadrons.
- Second generator process only resimulates hadronic rescattering.
  - Takes result of flux, geometry, hard scattering, from the event record only.

Y. Hayato slide (NEUT) from yesterday

$\nu_\mu + p \rightarrow \mu^- + p + \pi^+$

$\pi^+ + n \rightarrow \pi^0 + p$

$p + N \rightarrow p + p$

This particle is not simulated.

Index	Particle	Status	Parent particle ID	Status (detail)
#1	Incident ν_μ	0	0	-1
#2	Incident Proton	0	0	-1
#3	Outgoing μ^-	1	1	0
#4	Outgoing Proton	0	2	7 (produced particles)
#5	Outgoing π^+	0	2	4 (charge exchange)
#6	Re-scattered π^0	1	5	0
#7	Re-scattered proton	1	4	0
#8	Re-scattered proton	1	4	0
#9	De-excitation gamma	1	2	0

- Probably need to add some information to do this (next slide).

What additional information is needed?

- In a “local” model, where the nuclear effects vary with position in the nucleus, there is a correlation between the hard interaction and the hadron reinteraction probabilities.
  - Need to at least encode this “local” position, as a radius, or perhaps a 3D position in the same coordinates/frame as hard interaction produced particles.
  - (The latter approach would remove some statistical jitter in throwing the position of the interaction within the nucleus, but maybe that isn’t important.)
- If we want consistency among nuclear models, then we need to encode information about the nuclear model.
  - We should think about this, but it’s not obvious that this is possible for all models.
  - Ulrich provided us information about how this is done for GiBUU.
- What else did I miss?
- Discussion.