GENIE Base Model efforts

The new NIUWG group is making systematic uncertainty knobs on neutrino interaction cross sections (among other activities)

These knobs will be relatively tightly coupled to the base model.

Technical & physics details will likely be visible to some end users.
Thats what this outreach is about.

Thanks for the logo Asher!
Not a moment too soon.

GENIE Base Model efforts

Not long ago, DUNE used GENIE 2.12.x with hA FSI

LArSoft has been using GENIE 3.00.06 for a little while
don't know what comprehensive model was chosen

LArSoft test release v09_58_02_01 uses GENIE 3.02

NIUWG (the new group) plans a GENIE 3.02 with custom patches

Different audiences (you!) will have different interests:
Technical changes AND/OR physics changes in the event record

GENIE event record enums

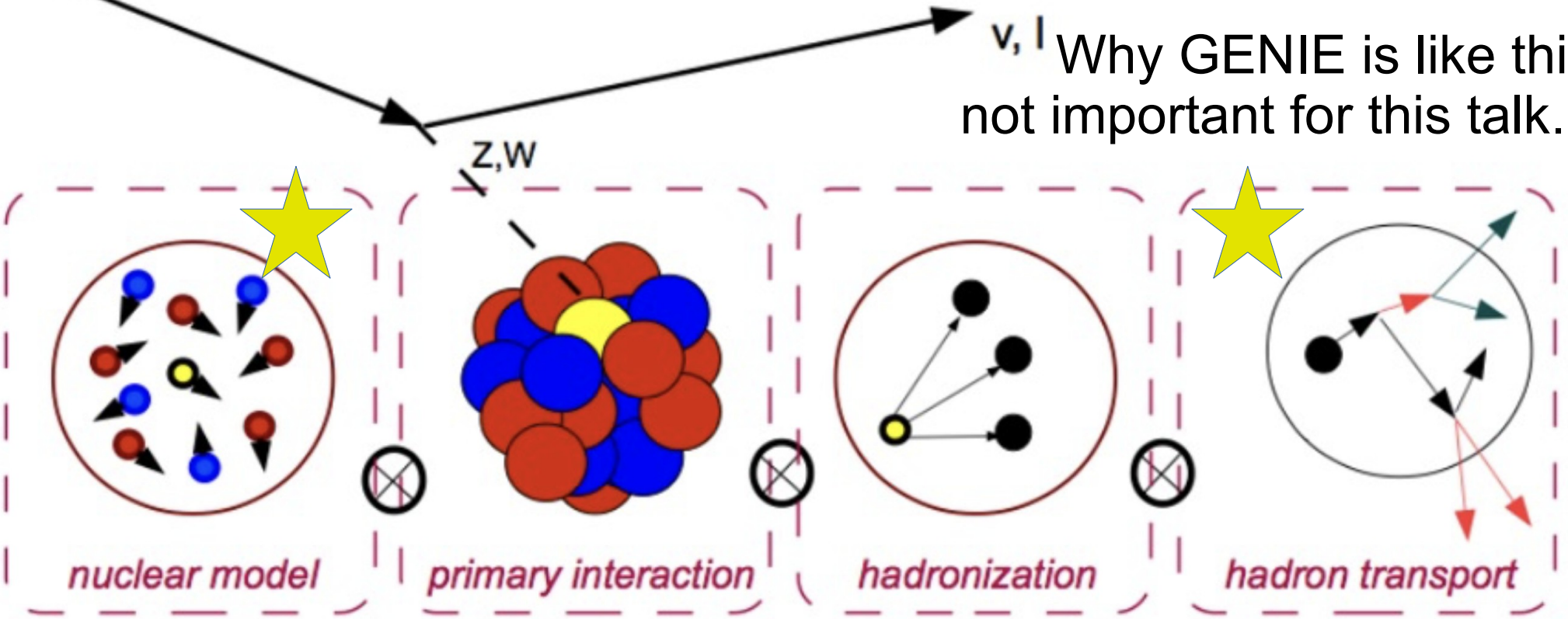
Widely used enums in GENIE have changed from Genie2

Interaction type
QE or RES or 2p2h or Coherent etc...

And the Fate of a hadron during the FSI process
nucleon knockout, absorption, charge exchange, inelastic pi prod

Places that hard code what integer is 2p2h or coherent or IMD
e.g. some analysis code, probably needs to watch.

Abbreviated reminder of the factorization concept



Why GENIE is like this
not important for this talk...

Choices in each step are saved in the GENIE event record
We are changing at least two in ways that could surprise users

Hadron transport = hAIntranuke2018

Smaller MFP than Genie2, more re-interactions in Ar
Gives a reasonable description of MINERvA C, Fe, Pb π+ data

Because of its simplicity, one step instead of multi-steps
Every hadron has exactly one fate, including no FSI.
Simplifies systematics calculators, gives us some for free

The simplified cascade is in the GENIE record
in the short term saves a lot of special case accounting

In the long term (data era) expect we will use INCL++
please avoid writing custom code that expects hA

First Fix to hAIntranuke2018

The process pion absorption on two nucleons
Was intended to pick pn pairs like 95% of the time

The fix restores that intended behavior
and matches the documentation and citations

If you had experience with GENIE2 hA
The fixed version will produce more pp final states
in our zero pion samples (plan LAr sample in osc. analysis)

Plan a systematic knob to change this fraction.

Second Fix to hAIntranuke2018

Code that handled an off-shell two-body collision in hA
caused crazy predictions for GENIE2 users.

The worst outcomes were turned off in GENIE3
by disabling a fate even though the bug remained for other fates

We've implemented one stage of the MINERvA fix.
Do not plan to implement the second stage.

Will document the mild effects on remaining fates.
Should be unnoticeable to downstream processing.

hAIntranuke2018 jargon

Many experiments have switched to hNIntranuke
We are keeping hA for ease of reweighting.
Public Service Announcement, the jargon is different in enum code.

hA “Elastic” might better be called diffractive, small angle scatter
It is disabled, and this fate now literally maps to noFSI.
Of mild/negligible interest to bring it back with MINERvA code.

hA “Inelastic” = hN “Elastic” means one additional nucleon knockout
hA “pi production” = hN “Inelastic” means pion production

Charge Exchange is the same name, probably identical code.
Absorption (e.g. πNN to NN) is the same except for the fixes

[Skip] What about that elastic process?

hA “Elastic” might better be called diffractive, small angle scatter
It is disabled, and this fate now literally maps to noFSI.
Of mild/negligible interest to bring it back with MINERvA code.

Imagine external pi+ scattering off argon measures,
like in intro optics, a black-disk diffraction pattern
where the only effect is a slight change in angle
The old model in GENIE would barely be seen in MINERvA data.

Does it happen when the pi+ comes from inside the nucleus?
Black disk diffraction. Maybe not. Unclear.
Ok. Should there be some angle smearing ? Probably.

New topic: de-excitation photons

GENIE has long had 6 MeV deexcitation photons for oxygen

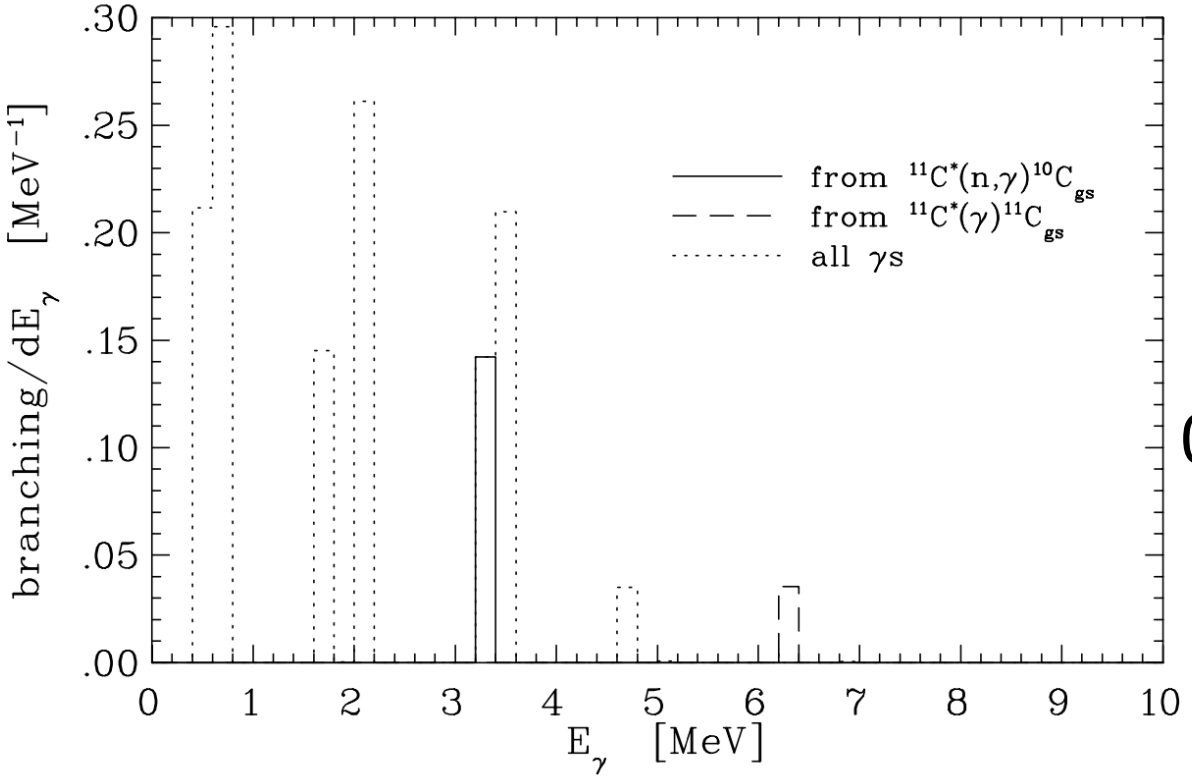
On MINERvA, undergraduate Brandon Reed and I had been using a paper by Kamyshkov as a base for Carbon deexcitation

The paper covers neutron-hole, and nn-hole in C and O and touches on (updates) the original O paper used in GENIE.

Took one night to add it to existing GENIE code, plus bugfixes

Proposal, make Argon use the same spectrum.
Even if its wrong, at least we have something in the sim to reweight.

de-excitation photons, neutron-hole Carbon



pectra of γs from de-excitations of $s_{1/2}$ hole of neutron disappearance in ^{12}C. The dotted line is for all γs.

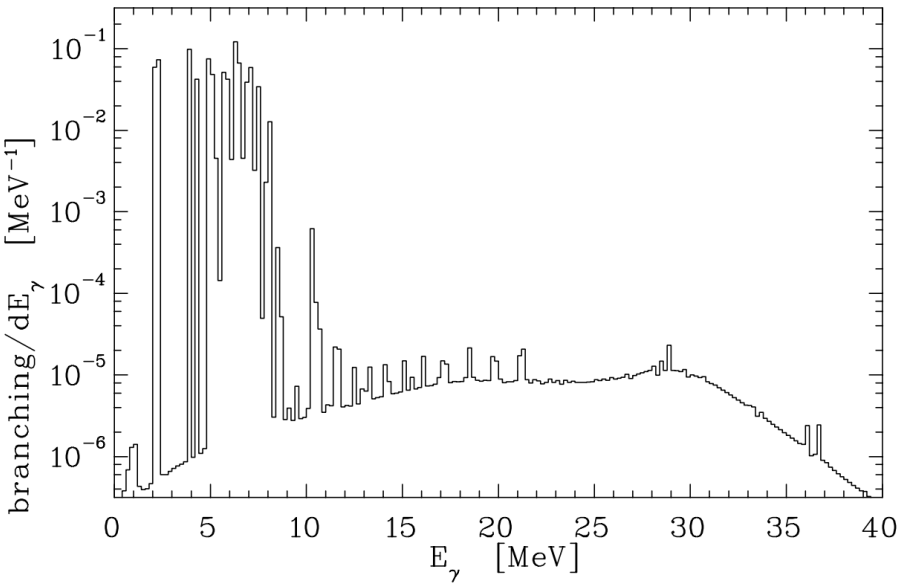
2/6 of the time, select from the S1/2 on the left

4/6 of the time, select from the P states, producing 0.2 MeV photon 20% of time

Result, a photon in 22% of QE interactions.

Ignore the nucleon-ejection component of the prediction

Can Skip de-excitation photons, neutron-hole Oxygen



Spectrum of γs from de-excitation of a $s_{1/2}$ hole resulting from neutron disappearance in ^{16}O. The energy bin
[eV.

DUNE doesn't need oxygen
WC proton decay legacy

The Kamyshkov calculation is different than whats in Genie for neutron-hole S1/2

This prediction has photons at 2, 4, 4.4, and 5-7 MeV

GENIE has 22% gives 7 MeV

SuperK and HyperK folks have made measurements too.

de-excitation photons for Argon

The most visible effect will be a MeV photon in the final state

In several experiments and in Nuisance
custom code at various stages would query the event record
and assign an effective sub-sample topology like
"CC zero pion = lepton, any nucleons, zero mesons, nothing else"
We expect such a thing to be used in the next oscillation analysis

The problem for legacy code is the "nothing else" part.
Any instances of such a selection must be modified to
allow one or more MeV-scale photons in the final state.

Later, when we switch to INCL++ or Geant4, there may be more.

Skip this inner bremsstrahlung

I’ve wanted for a while to add photons from inner bremsstrahlung

Major addition, not enough time.
Few percent of events will have them.

Will be visible especially to detectors
In a magnetic field.

Intermediate and Final State Particles

behavior for tau, neutral pions, other short-lived mesons

decay taus within GENIE using better model

Robert Hatcher will turn this on.

Will be using the interface to Pythia8
but maybe I misunderstood which decayer he meant.

The GENIE record will have the decay products
(leptonic or pions) then pass them to the detector.

The decay products will be available
within the GENIE record

NOT decay of pizeros but yes eta, eta-prime, rho

The former is an interesting choice

it means you can NOT do electromagnetic shower counting
(and em shower energy and angle distributions)
from the GENIE record alone. Need info from Geant4 stage.
Is that ok ? Or is that a problem for some workflow ?

Some experiments used to decay pizeros (LBNE FastMC)
and both versions decay eta and eta prime and rho (omega, phi)
whose decay modes are primarily pions and photons

potential consequences

The GENIE event record will
always record the particle before decay

If we don't already, we will expand our
signal topology selections
to have a method that crawls the
GENIE event record and say
"yes pizero" or "yes eta"
or "yes tau"

I presume that at least ML training needs such things

What nucleon did we select in the initial state

The most important parts of this will be coded into NuSystematics and the user won't worry about them (or the user will add to NuSystematics)

These changes give us a path to evolve our physics reach into the ND hadronic energy distributions and further oscillated Enu spectra

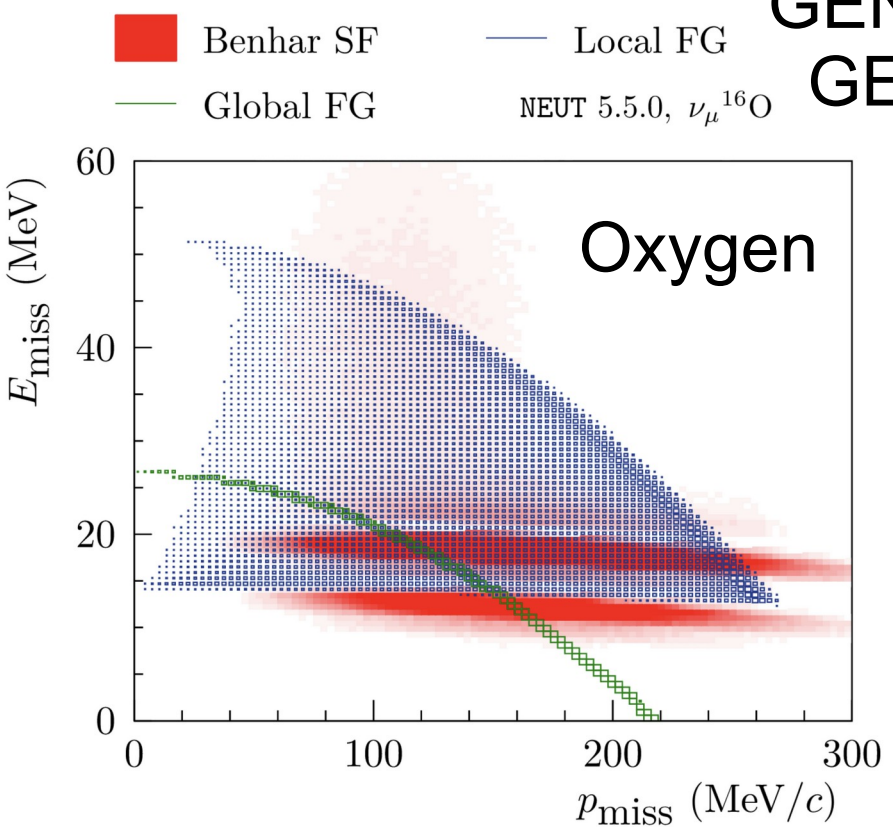
...even while waiting for proper spectral function models in GENIE

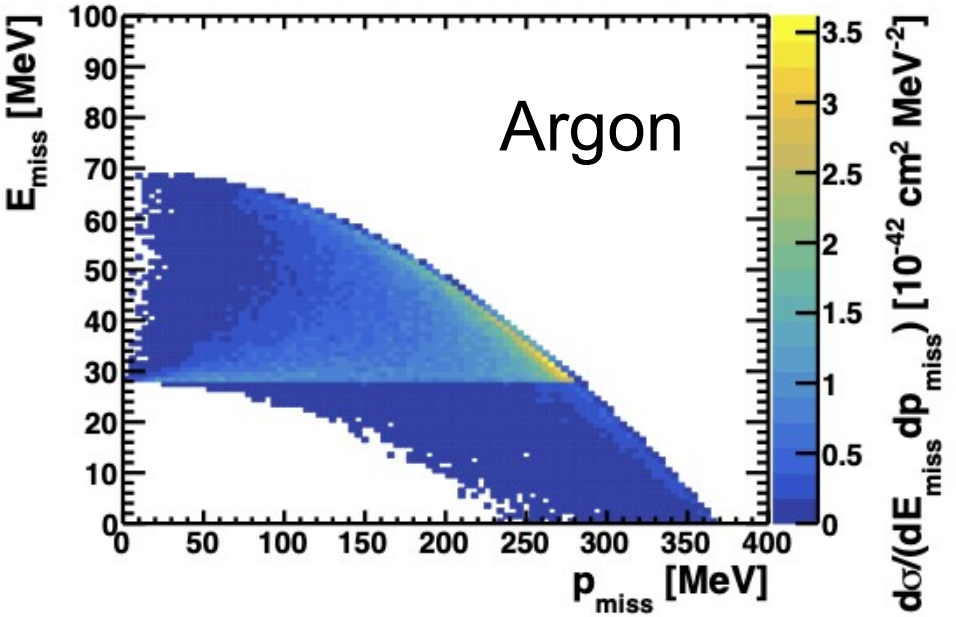
Let 1000 correlated nucleons bloom!

Red on left is few years away; today will get the right

Eur.Phys.J.ST 230 (2021) 24, 4469-4481

GENIE2 a flat line at 40 up to p=500 MeV
GENIE3 a flat line at 29 up to 280 MeV



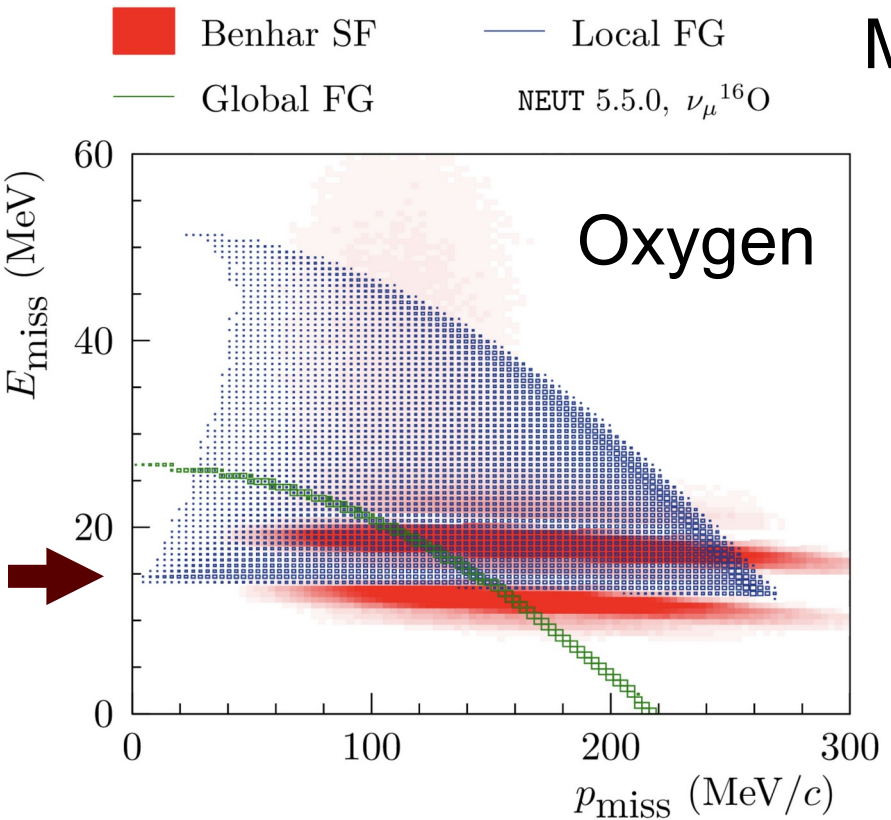


$$E_{miss} = \omega - T_p^{pre-FSI} - \Delta m_{n\to p} - T_{rem}$$
$$\vec{p}_{miss} = \vec{p}_\nu - \vec{p}_\mu - \vec{p}_p$$

User won't notice unless your sample is sensitive to ~10 MeV effects. Some ND fitting will be.

DANGER: seriously considering to insert a shift here

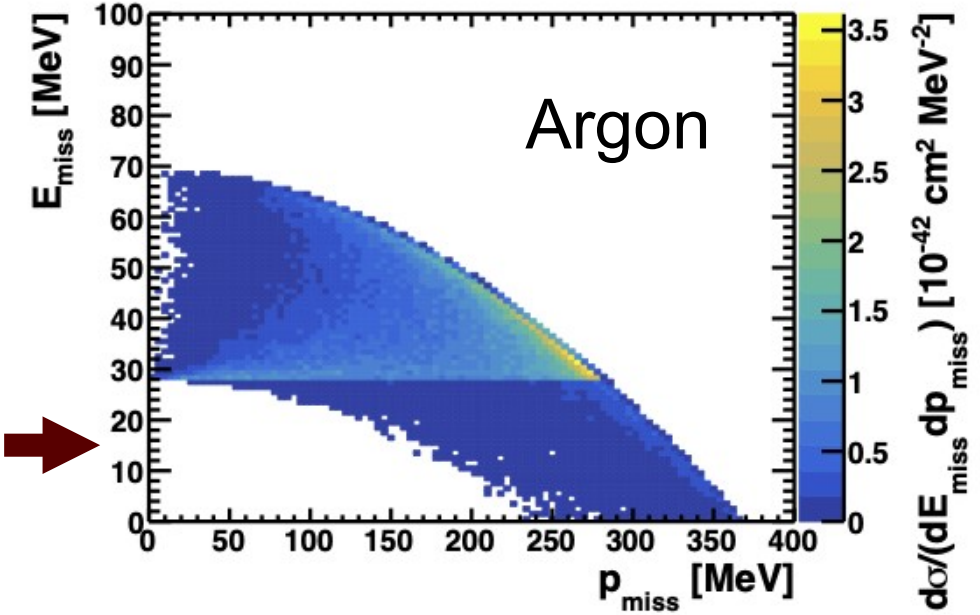
Eur.Phys.J.ST 230 (2021) 24, 4469-4481



$$E_{miss} = \omega - T_p^{pre-FSI} - \Delta m_{n\to p} - T_{rem}$$

$$\vec{p}_{miss} = \vec{p}_\nu - \vec{p}_\mu - \vec{p}_p$$

GENIE distribution starts at 28 MeV
Maybe it should start closer to 10 MeV



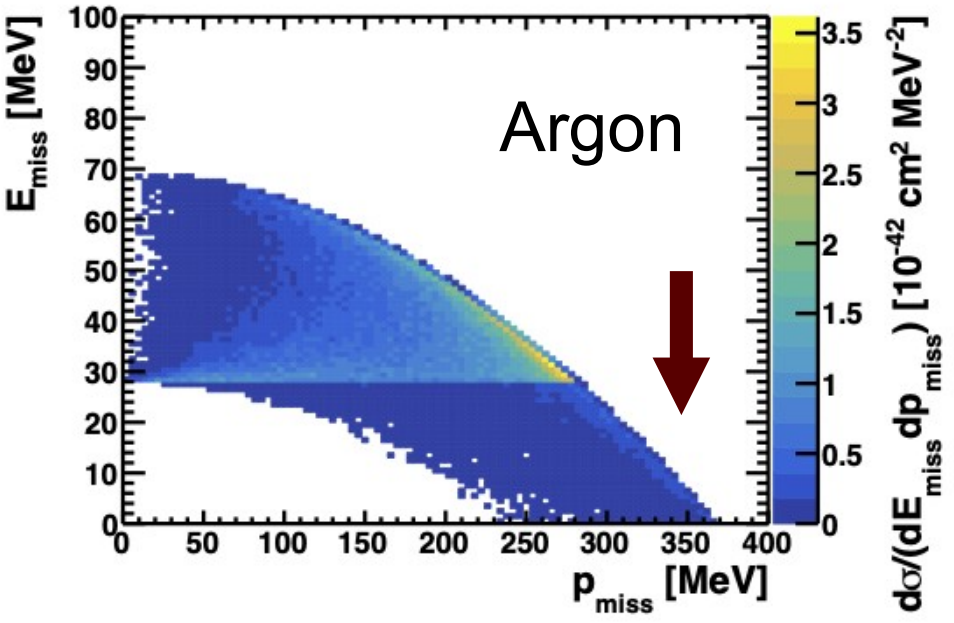
Not sure what the effect is on user.
Required to turn on a base reweight to get default physics behavior?

High-side tail to the initial nucleon distribution

In GENIE2 this was the “Bodek-Ritchie” tail. MINERvA recently tested enhancing this population.

Most GENIE3 LFG users did not have these events this is a new feature.

Empirical spectral function models always have this But we can’t match the structure



It is on and reweightable enhancing it will be a knob No change the event record

2p2h base model is SuSA (Megias et al.)

SuSA model covers more kinematics

Can reweight to Valencia 2p2h
(or even to the Empirical MEC)

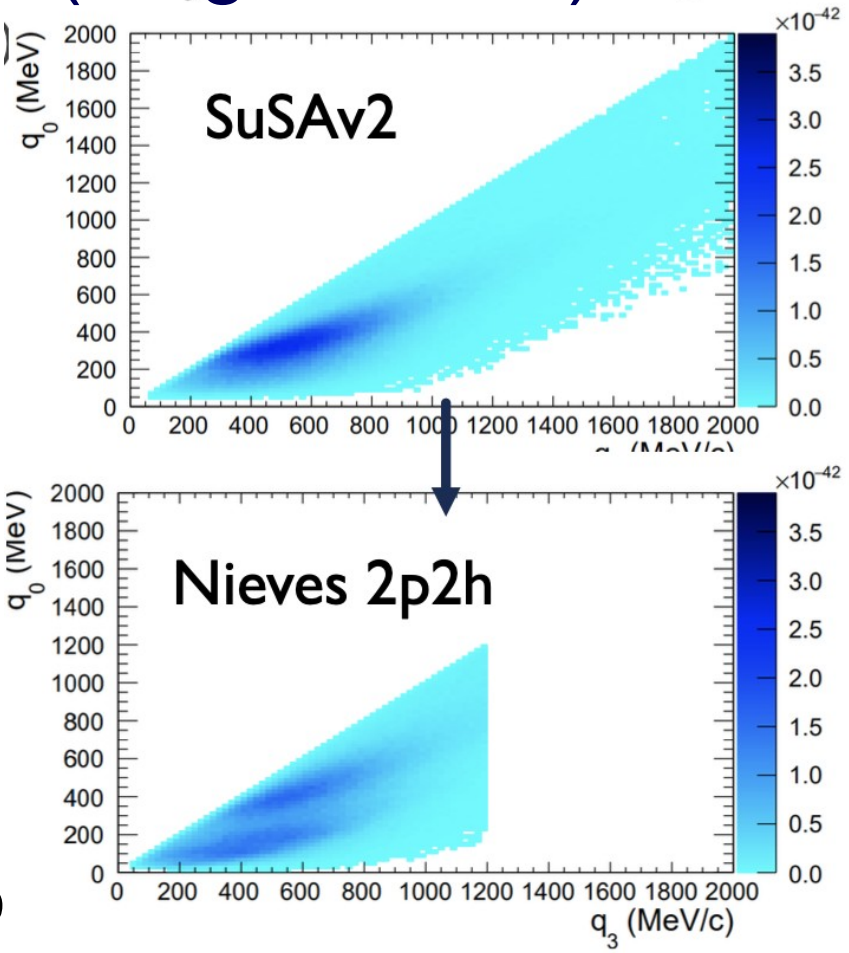
Or any future model delivered using the same hadron tensor scheme

Should be transparent to the user

Except will lose the Δ component tag

the only event record changes

NuSystematics will have new knobs to dial around internal physics features



Phys. Rev. D 101, 033003 (2020)

SRC correlated pair spectator nucleon

There is code in GENIE to eject a spectator nucleon from a short-range correlated pair in the nucleus (for example, CLAS / JLAB HallA, Nature v609 p41 2022)

The code is not ready for prime time. Oh well.

If it was, it would look like another nucleon came out but not due to the nucleon knockout FSI process

In fact, that second nucleon might itself experience FSI

Eventually need a method to crawl the event record for this

The recoil nucleus is not passed to the simulation

This is a guess, actually. Not sure if this is LArSoft behavior.

GENIE usually does not create a recoil nucleus at all.
Leaves the residual Ar, Cl, S nucleus as a hadron blob.

Oh, except for interactions on hydrogen and deuterium.
For hydrogen, there is no recoil nucleus. Ok. Thats safe.

For deuterium, sometimes Genie3 makes a spectator
but sometimes it does not. Meh.
Anybody using LArSoft to simulate a bubble chamber?

Conclusions

The proposed version of Genie3 for next production run

Will create an event record that has the same structure
but has different physics features
than previous versions used by DUNE.

NuSystematics will be tightly coupled to this version of Genie3

Could break downstream efforts to
hard-code topology from the event record
And longer future features will break them again.

Backups

Want a new slide with concepts for the BSM group

Jae had a talk last meeting and pointed out especially
That BSM signatures will be sensitive to SM tails.
What do things look like in the tail of the distribution
And to what extent will the DIRT2 era NuSystematics
Actually do something with those tails ?
Get the slide from Jae and pick something that speaks to them.

More detail on deexcitation

The paper I am using for carbon deexcitation isn't quite right
But may be close enough for typical neutrino ND work.

It is for neutron and double-neutron disappearance
But not proton, double-proton, or neutron+proton

Use the neutron spectrum for both neutron and photon knockout
If we are sensitive to it, add a weight knob to make them different

Double nucleon knockout next slide ...

More detail on deexcitation

The neutron disappearance C12→C11 spectrum is given
With a statements that double neutron is under half that at most.
The reason is that the resulting excited state is so energetic
That shedding another nucleon or alpha is preferred
Which carries off all the KE and does not result in a photon.

So non-QE reactions and high FSI reactions
should produce fewer photons.

We could get more information from Fluka and INCL++