DUNEreweight

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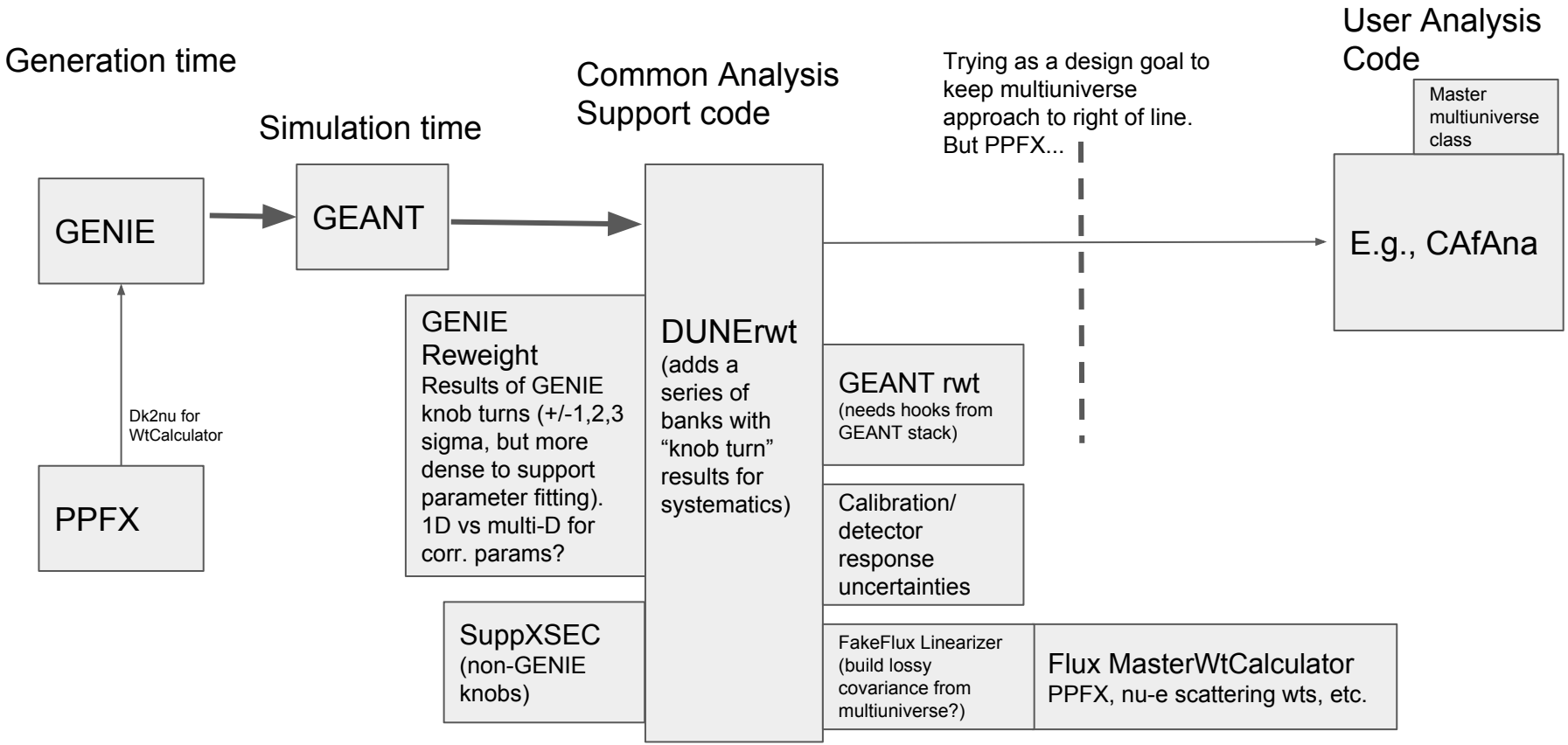
Goals of the effort

- Develop an event reweighting framework that borrows as much hard won knowledge as possible from T2K, NOvA, MINERvA
- Want to encompass many types of systematic uncertainties as possible in one common framework
- Want to pass information about the event in a flexible way to analysis code to support analysis time decisions about how to use the information
- Want to try to keep the framework independent of a specific multiuniverse evaluation technique as possible
- Want to develop a base set of cross-section uncertainties (GENIE knobs + more) as a recommended set for TDR studies
    - Downpayment is a set that is useful for FD only studies now

Relationships to other code and processes

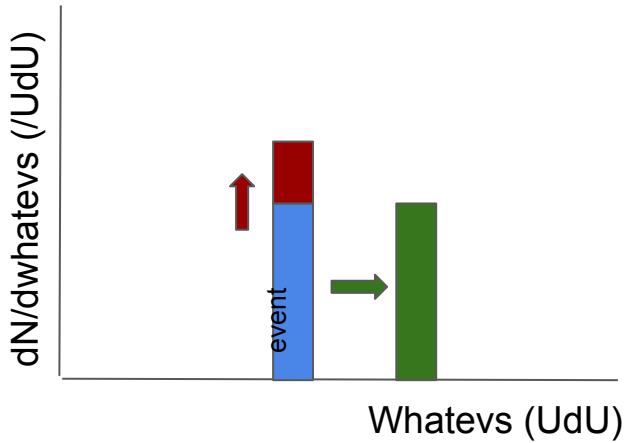


Discussion of Structure

- Parts are very similar to what Matt Bass has ported from larsim's EventReweight and tested.
  - Most concepts can be generalized to the other parts we are interested in.
  - Discussion with Matt 28 March. Conclusion was to try to develop from Matt's initial port as a base.
  - Fine knob turns, needed for some uncertainties, are supported.
- There are some concepts that don't map easily onto this framework
  - Flux (PPFX) uses a multiuniverse technique for evaluating uncertainties.
    - Currently, the flux group linearizes these into covariance matrices for analyzers.
    - Could start from that linearization, or develop/steal code to do it for a new flux version as needed.
  - "Lateral systematics". Explanation on next slide.

“Lateral” vs “Vertical” Systematics

- Forgive the piece of MINERvA jargon. It’s useful and the idea is universal.



Vertical systematics (what we normally think of) reweight events. E.g., most cross-section variations will change the probability of an event occurring.

Lateral systematics will change the value of “whatevs” for a given event. Calibration of energy scale is one example. Some cross-section variations, that invent new phase space, i.e., binding energy, may be best implemented this way also.

- The EventReweight structure only supports vertical systematics.
- Best to eventually have a comprehensive structure for both rather than one-off implementations for lateral systematics.

Interaction uncertainties: nucleon level

- Elastic axial form factor: z expansion with Deuterium constraints (Betancourt, Gran, Hill, Meyer)
  - Flavor dependent cross-section from second class currents from Day-McFarland, implemented as a correction to electron neutrino derived from muon neutrino data.
  - Future: incorporate constraints at high Q^2 from MINERvA
- Resonant pion production… Rein-Sehgal model bandaids
  - Axial form factor and tune of non-resonant from Deuterium (McFarland, Rodrigues, Wilkinson)
  - Known that this non-resonant tune misses essential physics from interference, so either put in shifts of W distribution from data or normalization or both, particularly for processes not driving tune above (antineutrino). Nucleon level pion kinetic energy is a close proxy for W.
- High W is, according to our working notes, a “dumpster fire”.
  - Likely we adopt the NOvA prescription of wide variations of GENIE Rv*2* parameters for now
  - Also, we may opt to place some of the uncertainty, such as fraction of energy in neutrons, in *ad hoc* nuclear corrections in this region.
- Radiative corrections are a big unknown and it is not clear what to do.
  - There is a lepton mass dependence, and therefore flavor dependence, but no useful calculations. T2K has a ~2% uncertainty, correlated between neutrino and antineutrino.

Interaction uncertainties: nuclear level

- Reweighting among initial state models to evaluate uncertainties is complicated or impossible.
  - For this purpose, maybe the best we can do is to borrow T2K techniques for Eb and pF in a GENIE's Fermi gas model. This misses some physics.
    - Note that there is a major mistake in GENIE's Eb implementation (double counting of nuclear mass differences, effectively). See recent Bodek paper.
  - Future: local Fermi gas with a procedure for altering binding and momentum vs. radius? Any way to build in spectral function details?
- Nuclear dependence of FSI is a major concern in our discussions
  - While carbon is relatively well constrained by external data, scaling to argon is not.
  - Make an *ad hoc* procedure to start with carbon appropriate systematics and explicitly scale events based on sensitive quantities, like fractions to neutrons and fraction of hadronic energy in protons/charged pions/neutral pions.
- RPA uncertainties from T2K work (Gran, Sanchez, unfortunately still unpublished AFAIK)

Interaction uncertainties: nuclear level (cont'd)

- Flavor dependence because of thresholds
  - Effects like RPA (screening at low momentum and energy transfer) can affect the flavor ratio prediction due to thresholds
  - Studying explicitly how the energy-momentum transfer space that is affected is sensitive to assumptions about Eb and pF. Will implement as a flavor dependent nuclear systematic.
- Coulomb corrections introduce a (small) neutrino-antineutrino difference.
  - Borrow from T2K. Implementation as a vertical systematic needs work.
  - Maybe we argue this is small enough, ~1 MeV level, to be lower priority.

Interaction uncertainties: other bits

- Neutrino-electron scattering
  - Radiative corrections do contain some unknowns, specifically how precisely radiated photons cluster with electrons. % level effects.
  - Not a priority now since ND neutrino-electron flux studies are already incorporating this.
- Coherent and diffractive processes
  - Coherent on carbon is ~well modeled by Berger-Sehgal in GENIE. Small fudges to pion energy and Q^2 would improve data agreement. Need an C-Ar difference uncertainty which probably is a function of pion energy. Overestimate for now?
  - No need for diffractive except for some ND studies.
- Neutral current processes, beyond what is already in the base models
  - There is likely a background to muon neutrino charged current from fragmentation to hard single pions, and little data to constraint this.
  - Explicitly add a large uncertainty to high z (pion energy/total recoil)?

Short Term Plan

- Developing a plan to code up what we have, starting with EventReweight port
- Continued work on some of the systematic questions
  - Quantify nucleon level uncertainties for single pion production based on data-MC differences and work by Minoo Kabirnezhad on model of resonant-non resonant interference.
  - Initial state nuclear effect flavor dependence with by looking at energy-momentum transfer space for different binding energy and lepton flavor is underway
  - FSI studies to set appropriately conservative uncertainties for scaling to argon.
- Other suggestions or comments?