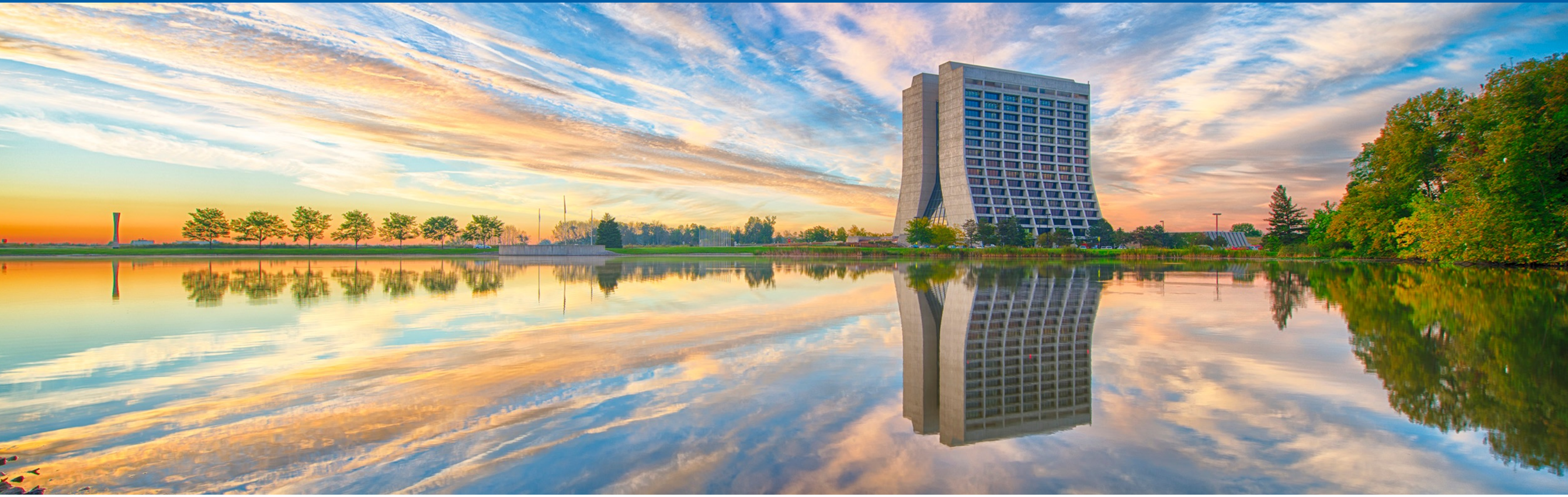

GENIE SF implementation (in progress)

Steven Gardiner

ECT Workshop on Testing and Improving Models of Neutrino Nucleus Interactions in Generators

June 2019

GENIE v2 QE event generation

- Position of primary vertex sampled according to nuclear density
- Nucleon 3-momentum, removal energy sampled from nuclear model (default is a Bodek-Ritchie global Fermi gas)
- Lepton kinematics sampled independently using $d\sigma/dQ^2$
  - If the first attempt is rejected, Q^2 rethrown, but not initial nucleon
- Binding energy handled using an off-shell nucleon 4-momentum
- Pauli blocking handled in a separate step. If blocked, "rewind" to create a new quasielastic event
- CC, NC, and EM all handled similarly, but by separate pieces of code

CCQE event generation in GENIE v3

- New approach developed as part of effort to include Valencia CCQE in v2
  - Became default method for CCQE generation in v3 (old approach preserved for comparisons to historical default model)
  - Vertex position selected as in v2
  - Nucleon kinematics and lepton kinematics now thrown simultaneously using a 6D differential cross section

$$d\sigma = \mathcal{N} \frac{G_F^2 \cos^2\theta_C}{8\,\pi^2 E_{\mathbf{k}} E_{\mathbf{p}} E_{\mathbf{k}'} E_{\mathbf{p}'}} L_{\mu\nu} \tilde{A}^{\mu\nu} P(\mathbf{p}, E) \frac{\sqrt{1 + (1 - \cos^2\theta_0)(\gamma^2 - 1)}}{\left|\mathbf{v}_{\mathbf{k}'} - \mathbf{v}_{\mathbf{p}'}\right|} \left|\mathbf{k}_0'\right|^2 \Theta(|\mathbf{p}'| - k_F)\, d\cos\theta_0\, d\phi_0\, dE\, d^3\mathbf{p}$$

  - Square root factor comes from solving energy-conserving delta function
  - Pauli blocking explicitly handled at differential cross section level
  - Binding energy now handled via de Forest prescription (use on-shell nucleon momentum with an effective energy transfer)

CCQE event generation in GENIE v3

- In the latest GENIE release (v3.0.4), new treatment is limited to CCQE
  - With some changes (couplings, form factors, etc.), the same code could be used for NC, EM
    - I've made a (preliminary) implementation of all 3 in a GENIE development branch
    - Some work needed to make it fully general (how does Valencia RPA change?)
- Note that this approach is compatible with the framework proposed by Luis for model inclusion in generators

$$d\sigma \propto \int d^4p \, H^{\mu\nu} \, A_{\mathsf{fs}}(p+q) \, A_{\mathsf{h}}(p)$$

- In my notation below, $H^{\mu\nu} \leftrightarrow \tilde{A}^{\mu\nu}$, $A_h(p) \leftrightarrow P(\mathbf{p}, E)$, and $A_{\mathsf{fs}}(p) \leftrightarrow \theta(|\mathbf{p}'| - k_F)$
  - SF can be swapped in instead of FG, LFG nuclear models

$$d\sigma = \mathcal{N} \frac{G_F^2 \cos^2\theta_C}{8\,\pi^2 E_{\mathbf{k}} E_{\mathbf{p}} E_{\mathbf{k}'} E_{\mathbf{p}'}} L_{\mu\nu} \tilde{A}^{\mu\nu} P(\mathbf{p}, E) \frac{\sqrt{1 + (1 - \cos^2\theta_0)(\gamma^2 - 1)}}{\left|\mathbf{v}_{\mathbf{k}'} - \mathbf{v}_{\mathbf{p}'}\right|} \left|\mathbf{k}_0'\right|^2 \Theta(|\mathbf{p}'| - k_F) \, d\cos\theta_0 \, d\phi_0 \, dE \, d^3\mathbf{p}$$

Validation status

- Noemi has kindly provided her code for computing EMQE cross sections using the SF formalism
- Different phase space used (differential in outgoing electron energy, angle), so this change is applied in my testing code
    - Energy-conserving delta function solved differently
    - Jacobian
    - Otherwise identical to what is used in event generation
- With form factors, etc., chosen to match hers, I achieve good agreement (see next slide)
- Consistency checks between event generation and differential cross section coming soon
- For MEC contribution, providing an interface to her Fortran calculation could be a good “proof of principle” for a theory API

Validation status