Quasielastic fixes for Generator R-3_00_04

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GENIE User Forum

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Changes to CCQE event generation in GENIE v3

- **QELEventGenerator**

  - New default in v3, used for Nieves CCQE in v2
  - Old generation chain sampled nucleon kinematics, then lepton kinematics independently
  - QELEventGenerator accounts for correlations by throwing both sets of variables simultaneously

- **Differential cross section**

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

  - Not simply dQ^2 phase space anymore
  - Square root factor comes from solving energy-conserving delta function
  - Similar to NuWro, NEUT implementation
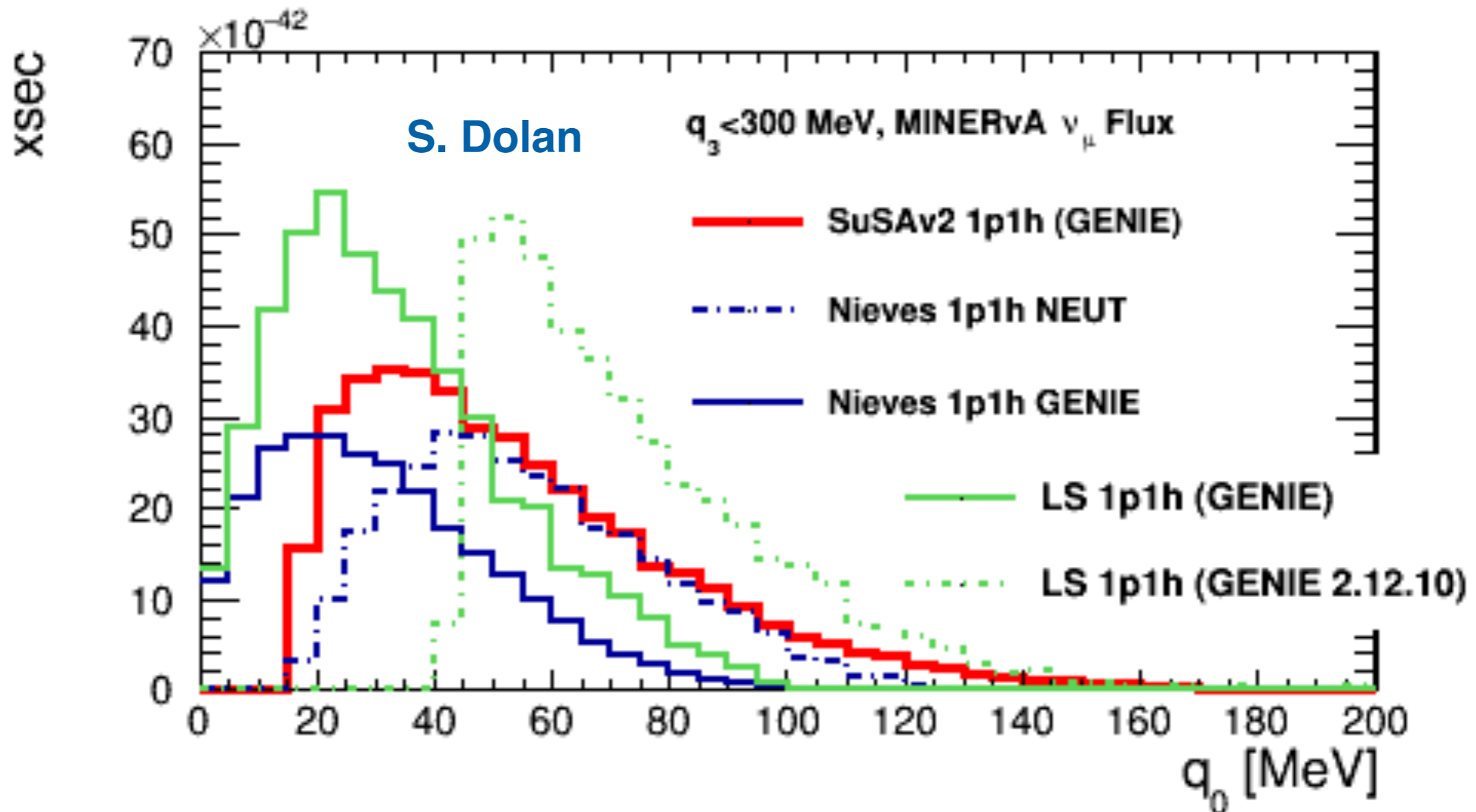
Discovery of issues with the new generator

- **Stephen Dolan and a group of MicroBooNE analyzers independently discovered strange behavior in several kinematic variables**
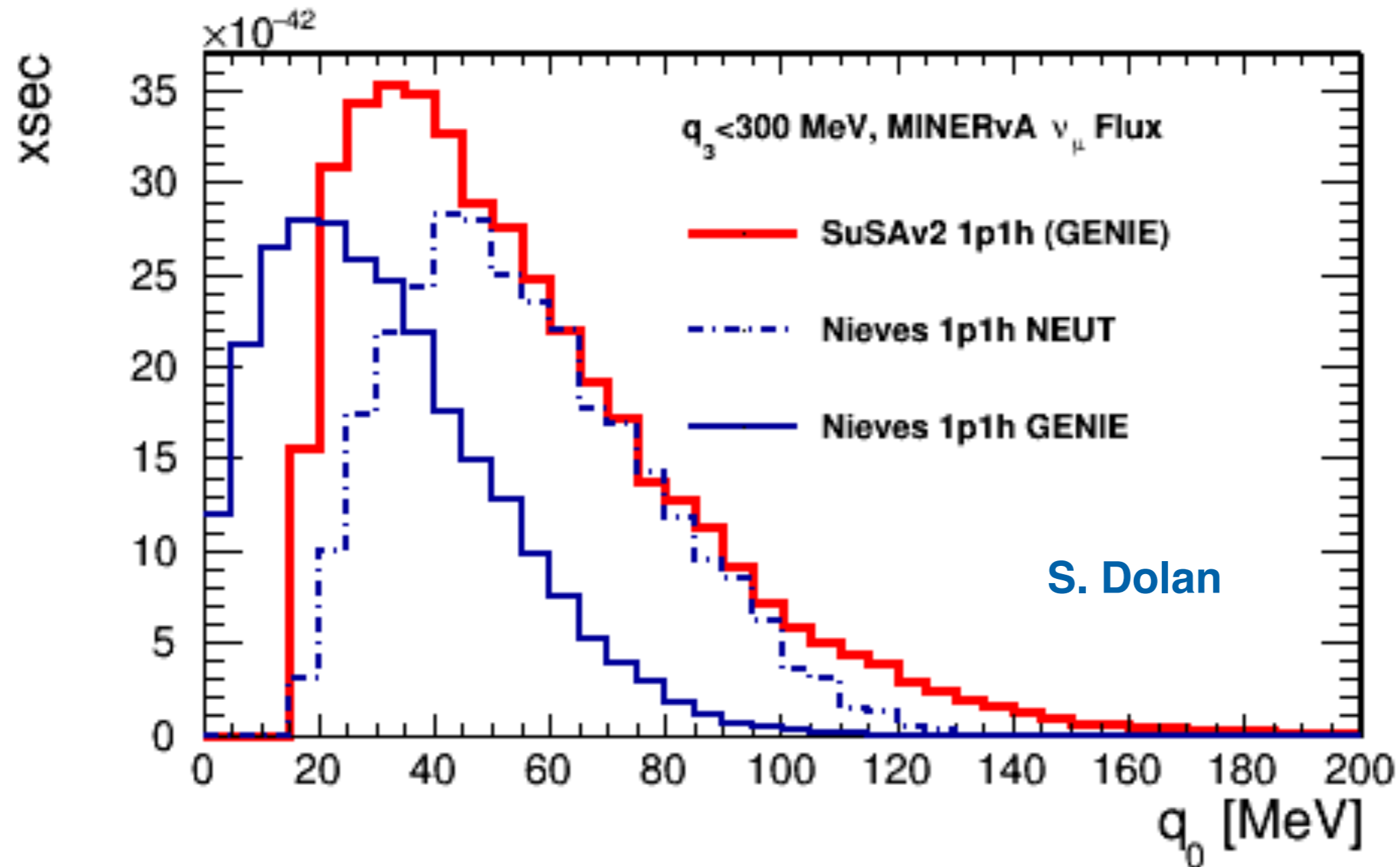
Energy transfer systematically lower in GENIE versus NEUT

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Discovery of issues with the new generator

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Issue is related to new event generator.

Shift in q0 seen between GENIE versions.

Discovery of issues with the new generator

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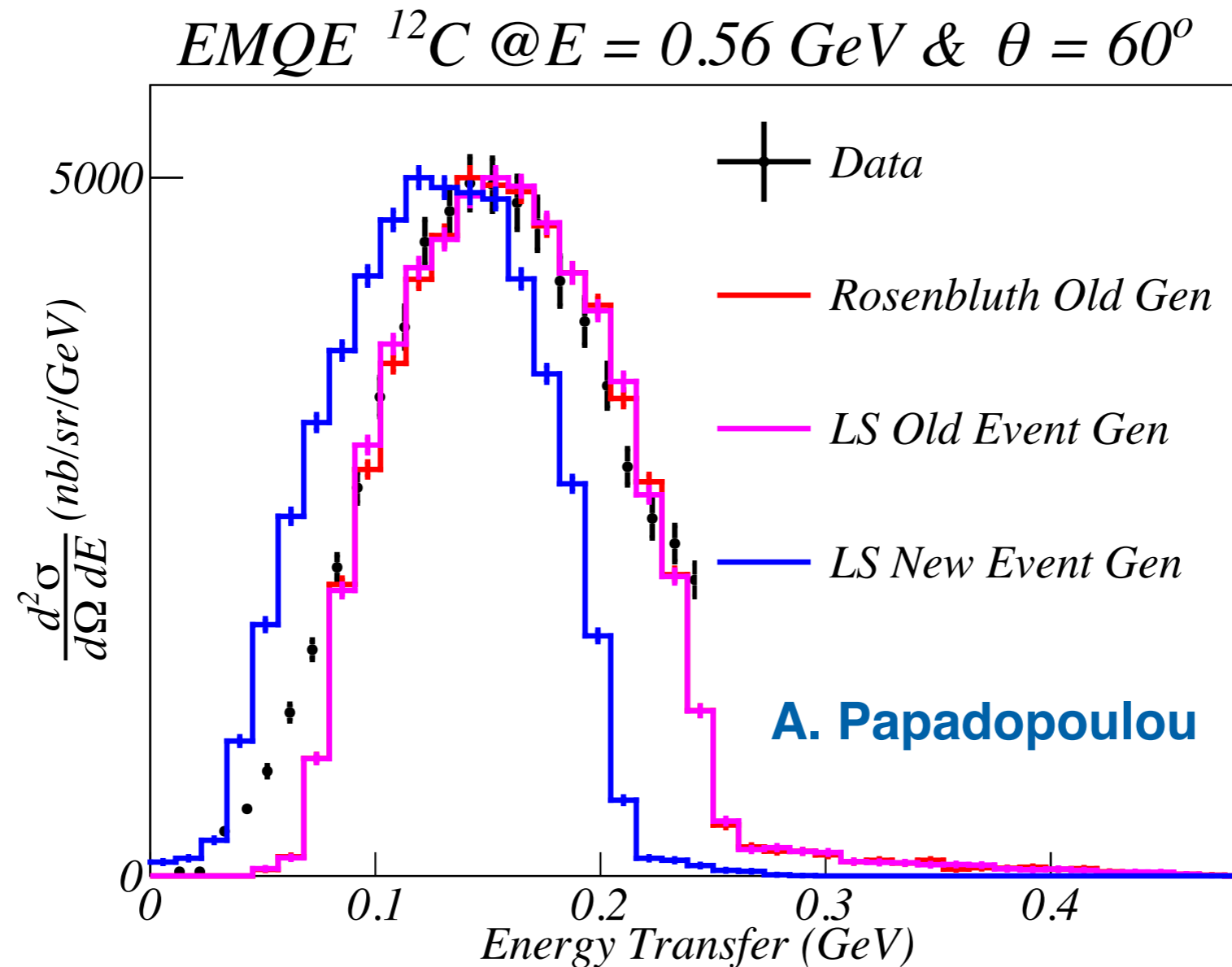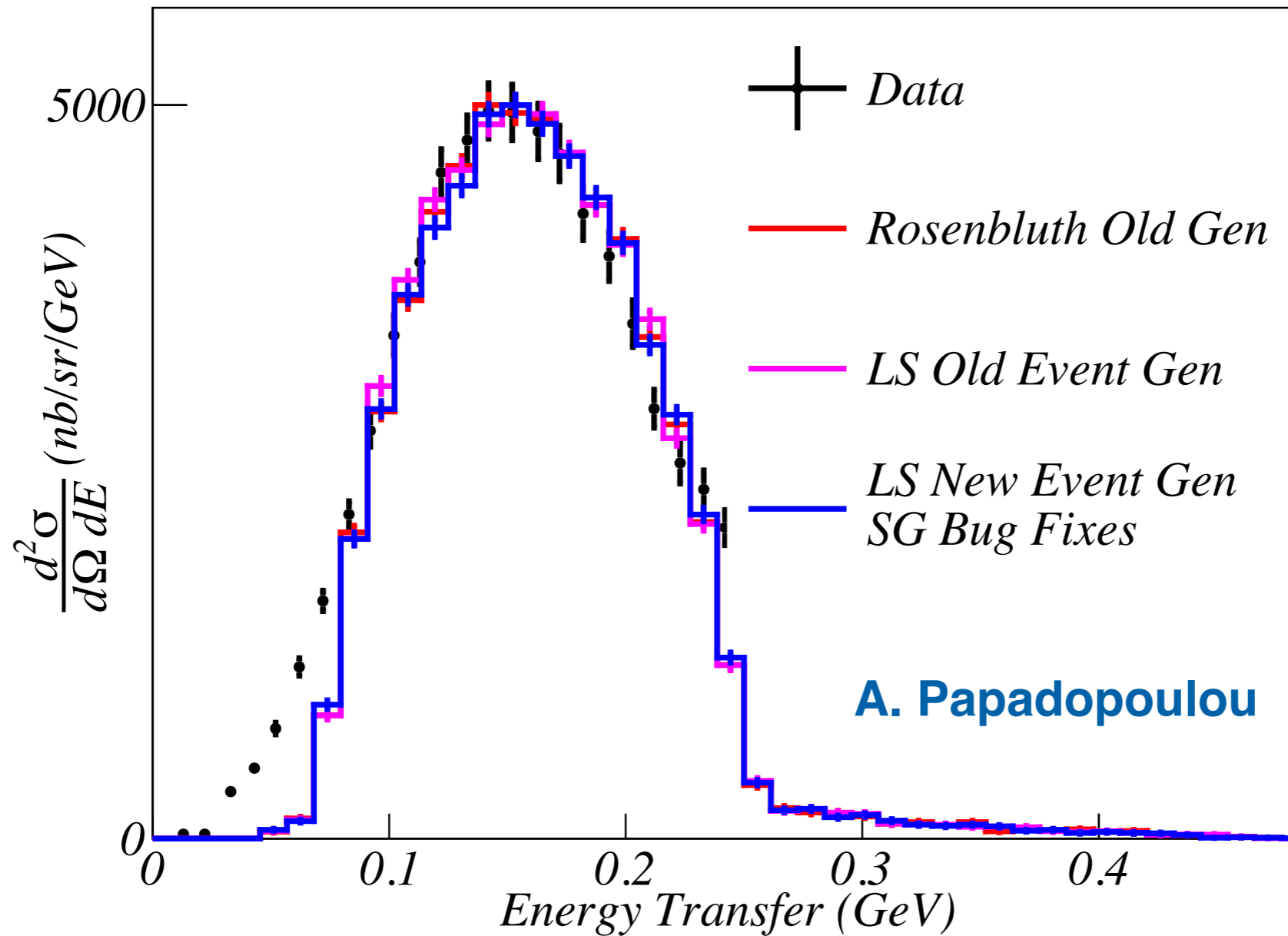
$$EMQE \; {}^{12}C \; @E = 0.56 \; GeV \; \& \; \theta = 60^{o}$$

Legend:
- Data
- Rosenbluth Old Gen
- LS Old Event Gen
- LS New Event Gen

A. Papadopoulou

Y-axis: $\frac{d^2\sigma}{d\Omega \, dE} \; (nb/sr/GeV)$, X-axis: Energy Transfer (GeV)

Old behavior for q0 agrees with electron scattering data

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Fixes for v3.0.4

- An internal GENIE investigation tracked down the underlying cause of this issue and identified a few other more minor problems

- **Nucleon binding energy neglected in QELEventGenerator**
  - Unlike the default generation chain for v2, QELEventGenerator currently puts the struck nucleon on-shell
  - This effectively ignores the binding energy and leads to overestimates of Mandelstam s and the lepton kinetic energy. This in turn leads to a bias in q0, Bjorken x, etc.

  - **v3.0.4 corrections fix the treatment of the binding energy in a consistent way**
    - Initial nucleon energy is off-shell
    - Corrected momentum transfer used in tensor contraction ("de Forest prescription") $L_{\mu\nu} \, \tilde{A}^{\mu\nu}$
    - BindingEnergyAggregator removed from chain to avoid double-counting

  - Treatment now closer to recent recommendations by A. Bodek (arXiv:1801.07975)

# Electron data/GENIE comparison improves after BE fixes

EMQE ^{12}C @ $E = 0.56$ GeV & $\theta = 60^o$

Data

Rosenbluth Old Gen

LS Old Event Gen

LS New Event Gen
SG Bug Fixes

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$\frac{d^2\sigma}{d\Omega\,dE}$ (nb/sr/GeV)

Energy Transfer (GeV)

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Other CCQE fixes for v3.0.4

- Pauli blocking removed for Charm-CCQE channel
- Corrected angle definitions used in new QELEventGenerator phase space
- New spline integrator: same cross section used for splines and generation
- **Llewellyn-Smith energy conservation fix:**
  - $q0 > 0$ cut needed in cross section
  - Previous absence led to an unphysical high-KE tail for outgoing lepton

CCQE events for 560 MeV muon neutrinos on 40Ar, G18_02a_00_000 (LS model)

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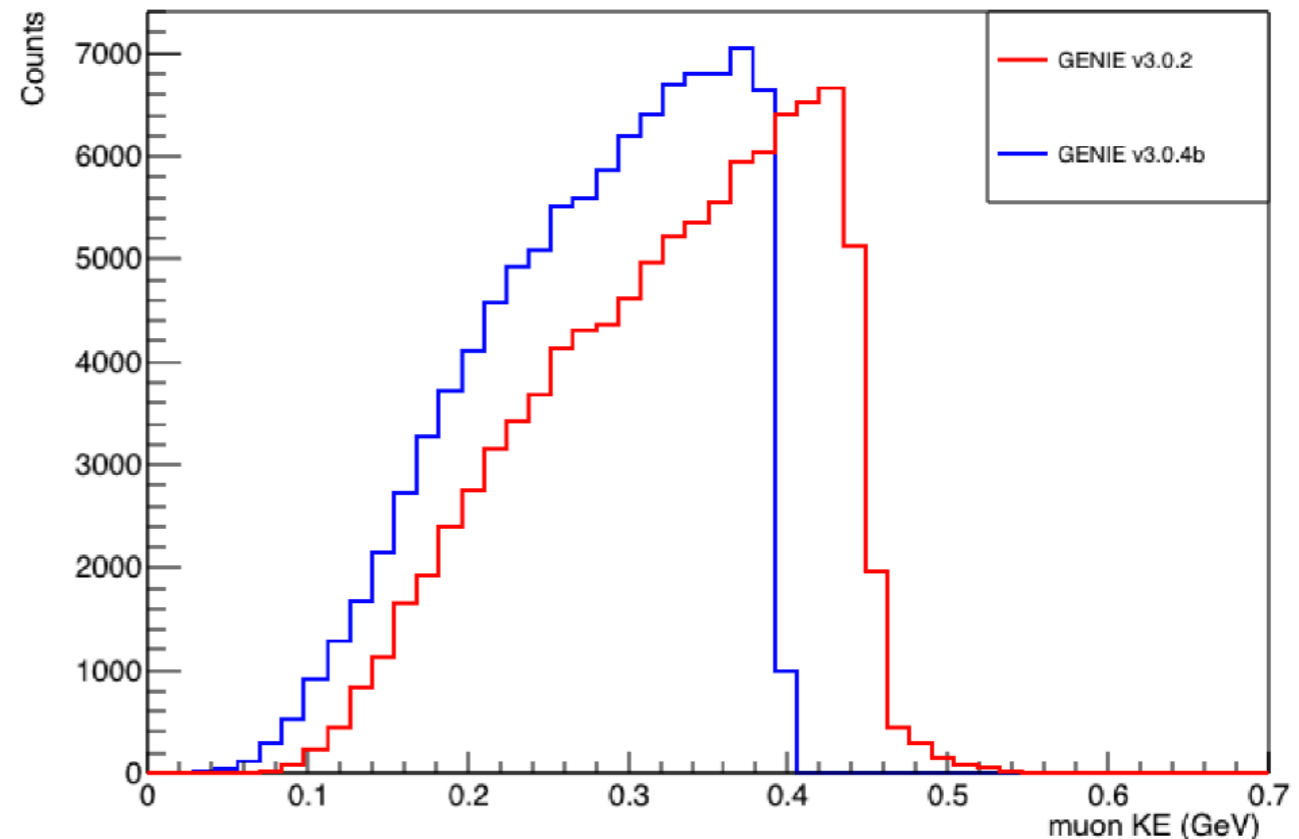
Other CCQE fixes for v3.0.4

- **Nieves CCQE fixes:**

  - Finish incomplete implementation of Coulomb effects (added correction to 3-momentum transfer)

  - Tensor contraction $L_{\mu\nu}\,\tilde{A}^{\mu\nu}$ evaluated in lab frame (assumed by Nieves in derivation of RPA-corrected expressions for tensor elements)

  - **Frame problem in calculation of Mandelstam s while integrating v3.0.2 splines**

CCQE for ν_μ on ^{40}Ar, G18_10a_00_000

- v3.0.2
- v3.0.2, s fix
- v3.0.4, on-shell
- v3.0.4

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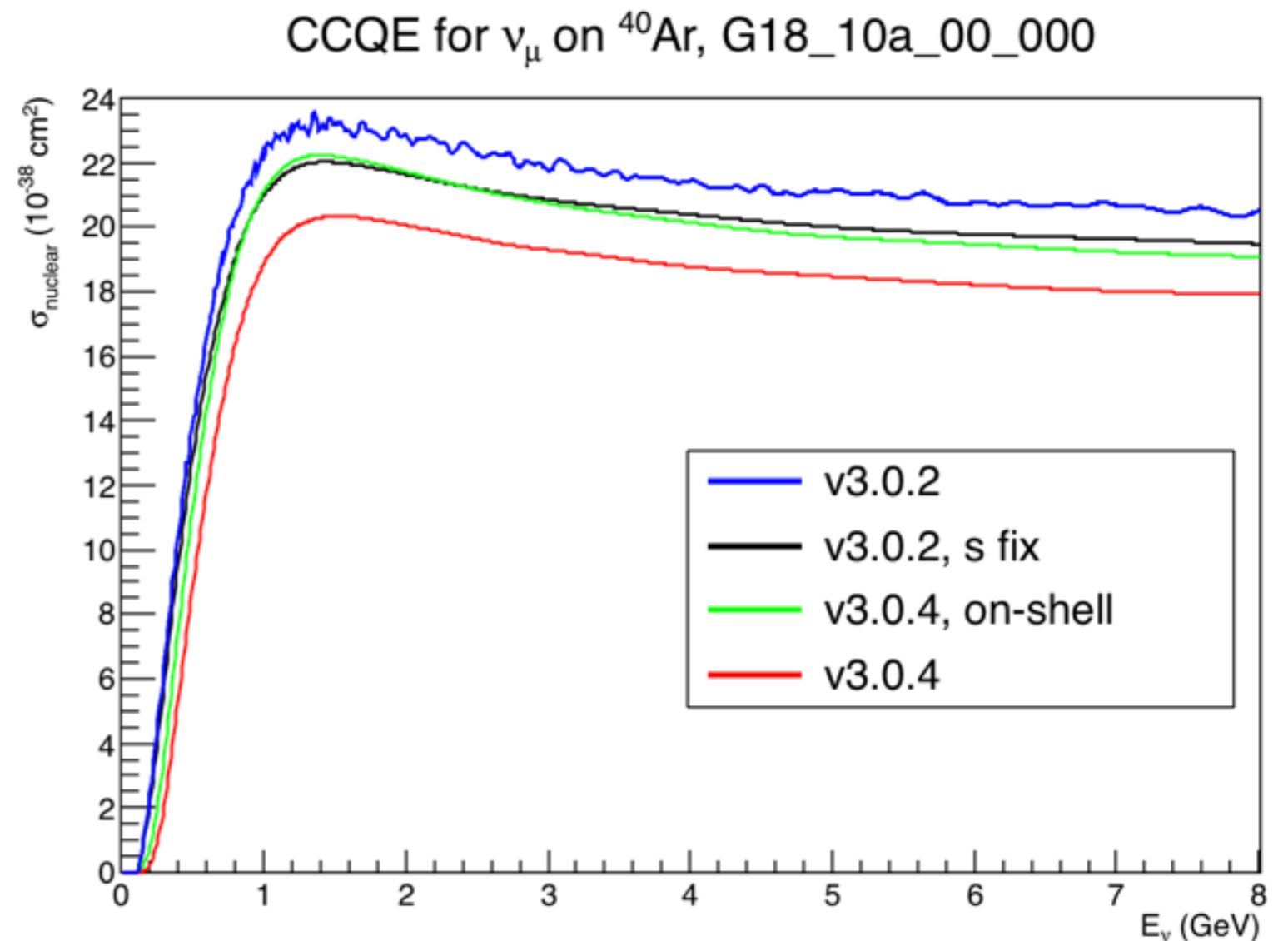
Current status

- **Release candidate for v3.0.4 has been created**
  - Incorporates all fixes mentioned so far for CCQE, several others for other channels

  - Will be used by MicroBooNE for testing of their GENIE v3-based workflow for their new MC production ("MCC9")

- **Work continues within GENIE to finalize v3.0.4 release**

  - Slow CCQE event generation performance
    - Some optimizations rendered invalid with inclusion of binding energy

  - Issues unique to events just above threshold under study
    - Pauli blocking (allowed phase space can be very small)
    - Numerical stability of Coulomb & RPA corrections in Nieves CCQE model

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