Recent updates to NEUT

Andy Furmanski

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NEUT – a history

- FORTRAN based neutrino interaction generator

- Originally written for simulation of neutrino interactions in the kamiokande detector

- Use continued for Super-kamiokande

- K2K and now T2K both used NEUT as their primary generator

- Ongoing updates added primarily by SK/T2K collaborators
    - T2K required additional targets, geometries
    - Reweighting for systematics based on GENIE

- Most of the recent updates are for CCQE, or CCQE-like interactions
    - Motivated by requirements from T2K

- Last 18 months have seen significant additions

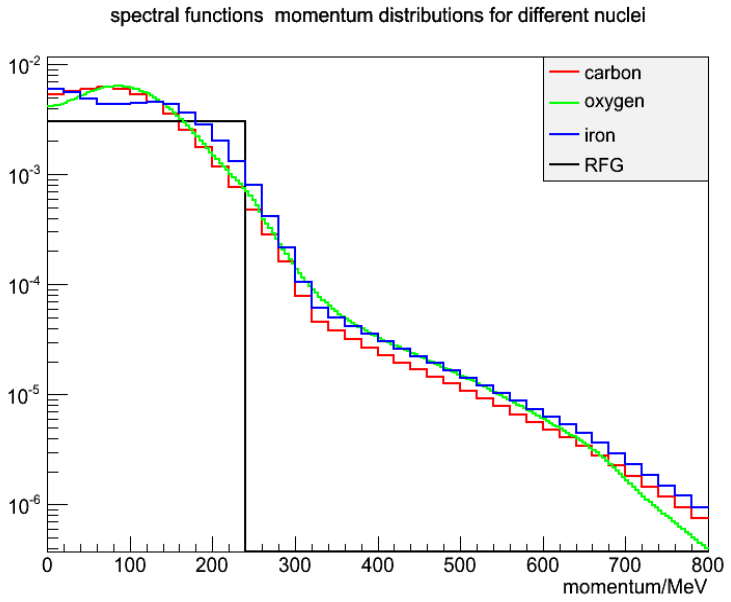
Spectral function

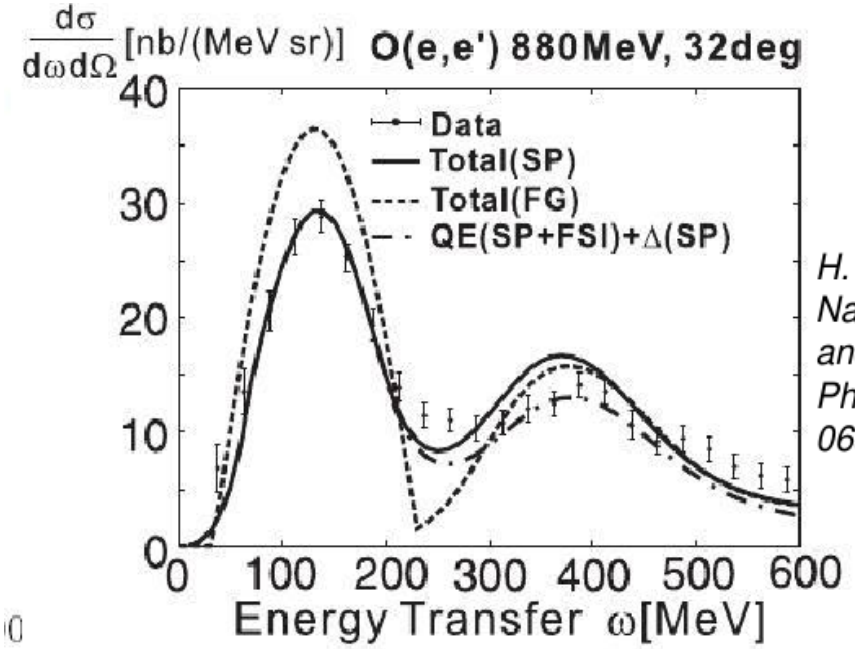
- Previously CCQE model used RFG model

- More realistic model – spectral function, developed by O.Benhar et al

- Better agreement found with electron scattering data

- Implementation in NEUT based on NuWro





H. Nakamura, T. Nasu, M. Sakuda and Omar Benhar, Phys. Rev. C 76, 065208 (2007)

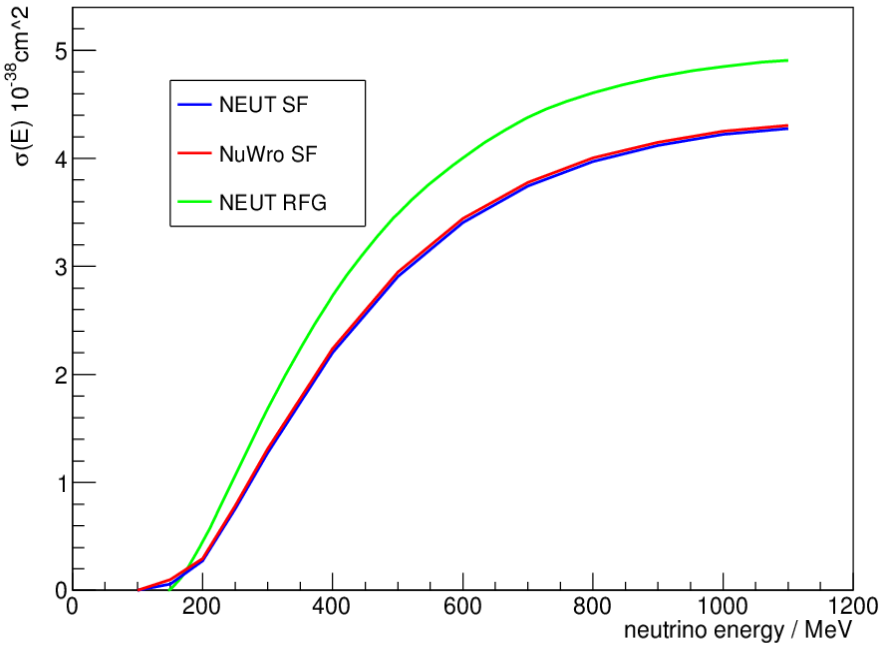
Spectral function (2)

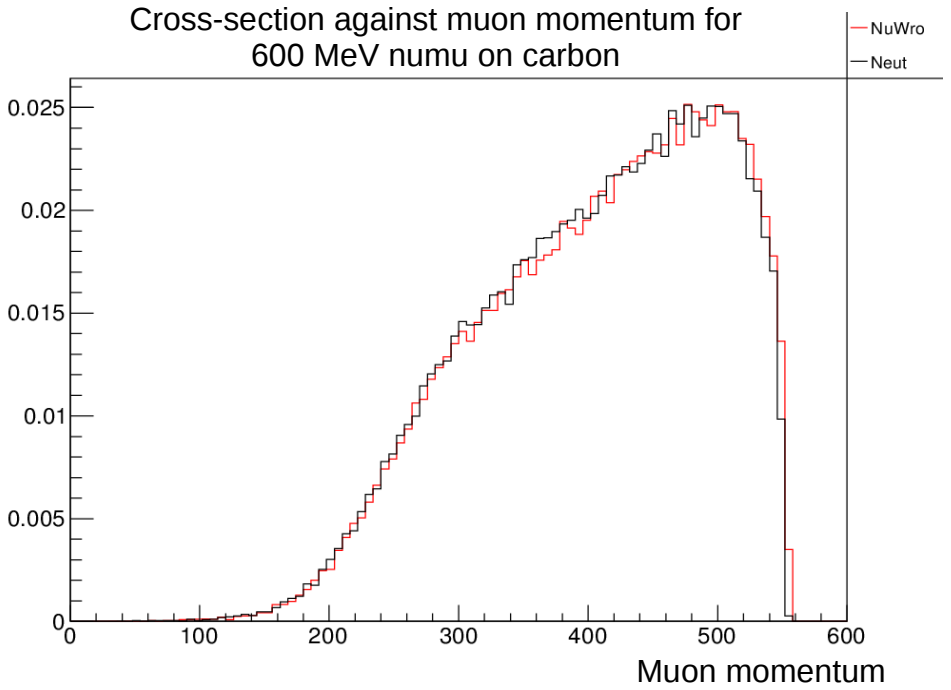
- Standard Impulse approximation used

- Available for carbon, oxygen, and iron (other nuclei fall back to RFG)

- Also applied to NCEL interactions

- Pauli-blocking implemented with a hard cut-off





Spectral function (3)

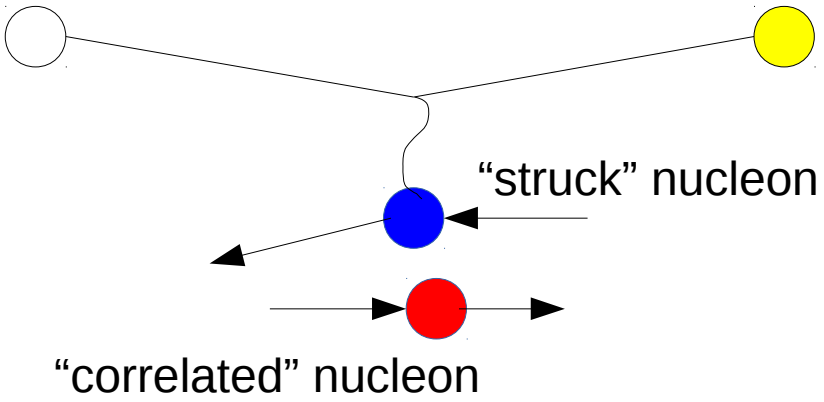
- Spectral function model also predicts multi-nucleon ejection

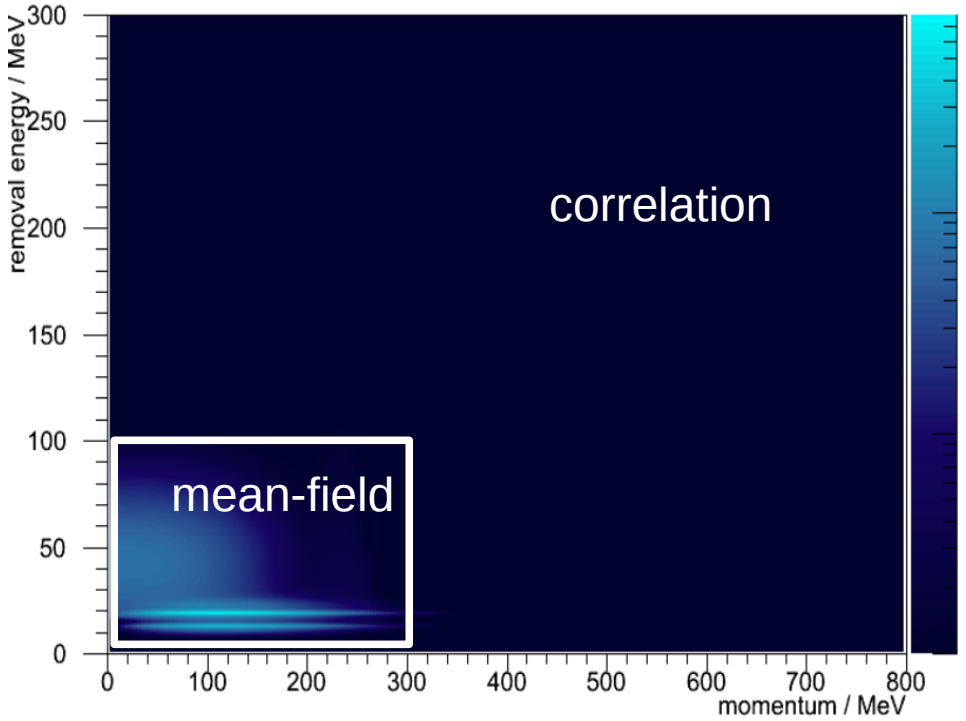
- “Correlation” term comes from correlated pairs of nucleons
  - high momentum, high binding energy
  - relative momentum high (to preserve a stationary nucleus)
  - treated as back-to-back equal momenta

- Interaction proceeds with one nucleon

- Observer, correlated partner ejected with no momentum change

Note: this is a recent addition – not included in T2K near-future results





Meson exchange currents

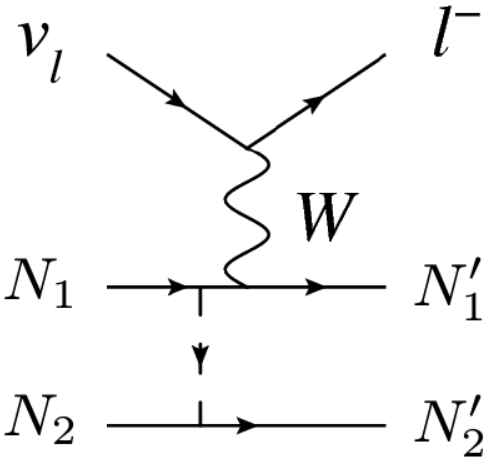
- MEC models enhance the CCQE-like cross-section significantly around 1GeV
    - Combats the MiniBooNE Ma = 1.35

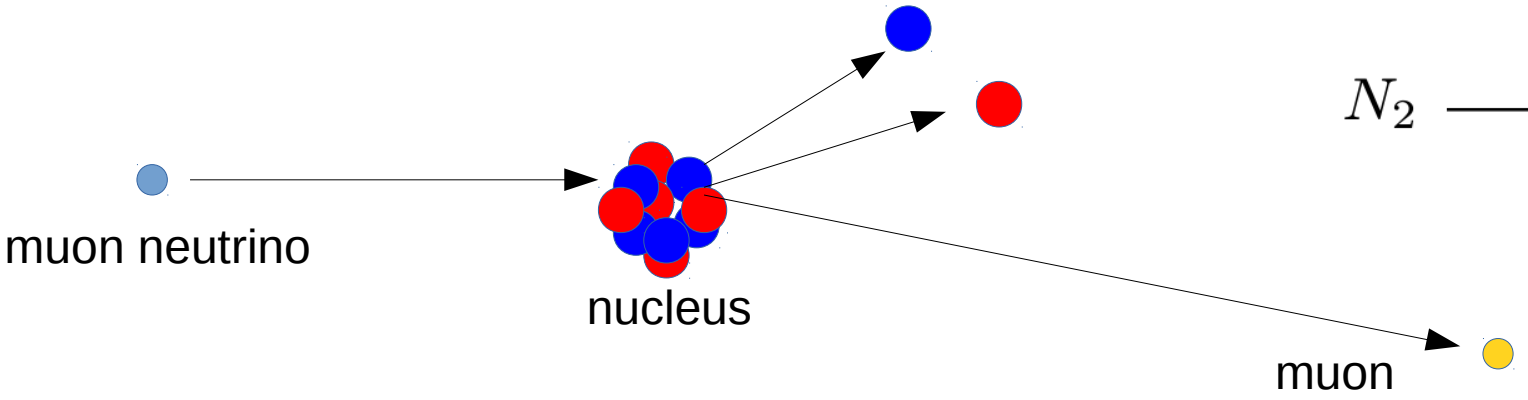
- Interaction with a pair of nucleons

- Nieves' MEC model available

- Calculation of 49 different diagrams

- Code made available to NEUT developers





Meson exchange currents (2)

- Nieves' code too slow to incorporate directly into NEUT

- Look-up tables pre-calculated

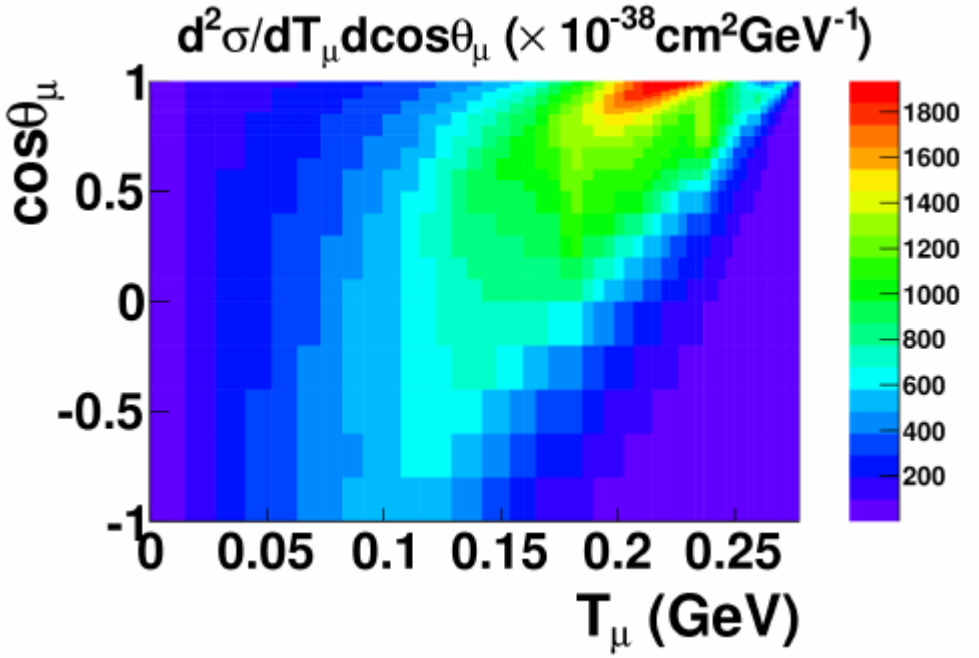
- Provide cross-section as a function of (E_ν, T_μ, cos θ_μ)

- Only lepton kinematics predicted

- For hadron kinematics, use Sobzcyk model
  - Developed by NuWro collaborators

- High energy extension to model
  - based on q3 cut

- For more details, see talk by P.Sinclair



RPA corrections

- RPA (random phase approximation)
  - Accounts for propagation of p-h hole through medium

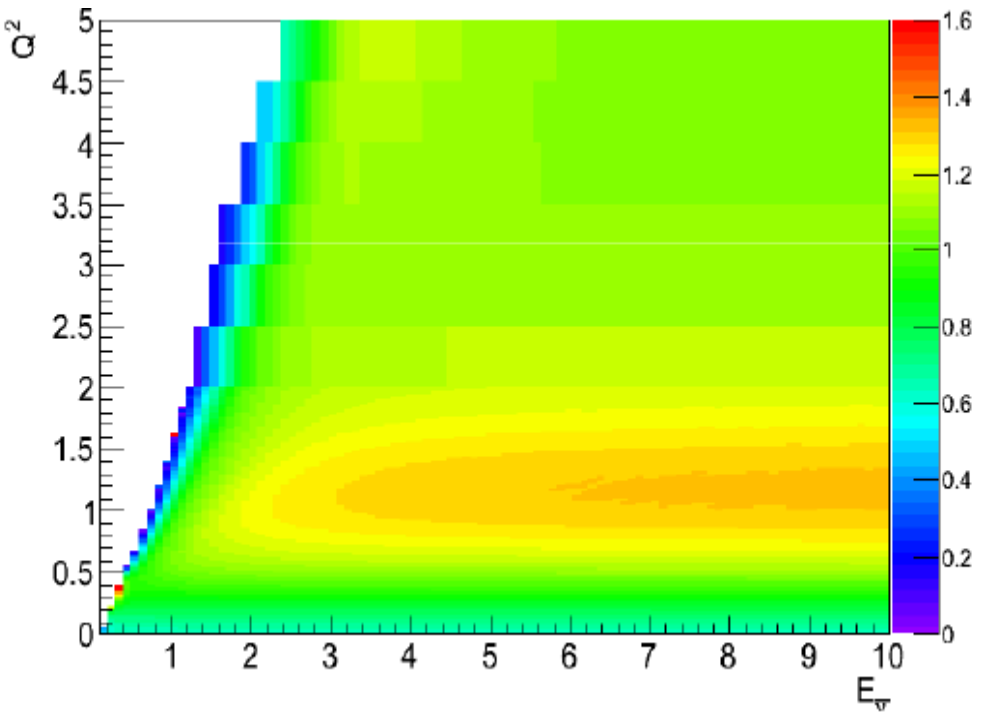
- Low Q^2 suppression

- Also use Nieves' calculation

- Provided with tables of CCQE RPA/non-RPA

- Some E_ν dependence
  - Mainly affects anti-nu

- Calculation assumes LFG model
  - Still valid for RFG
  - Approx. for SF

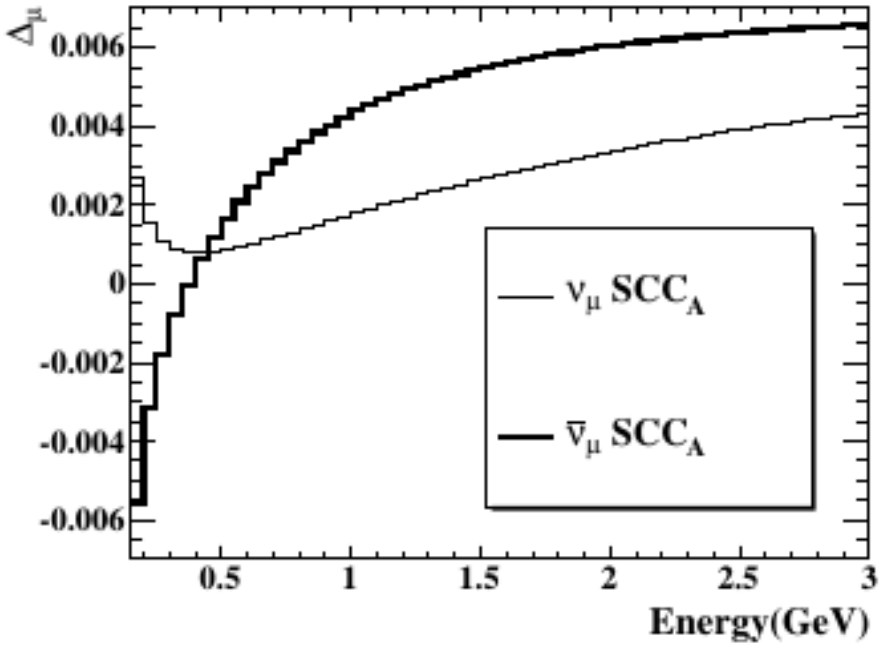


CCQE form factors

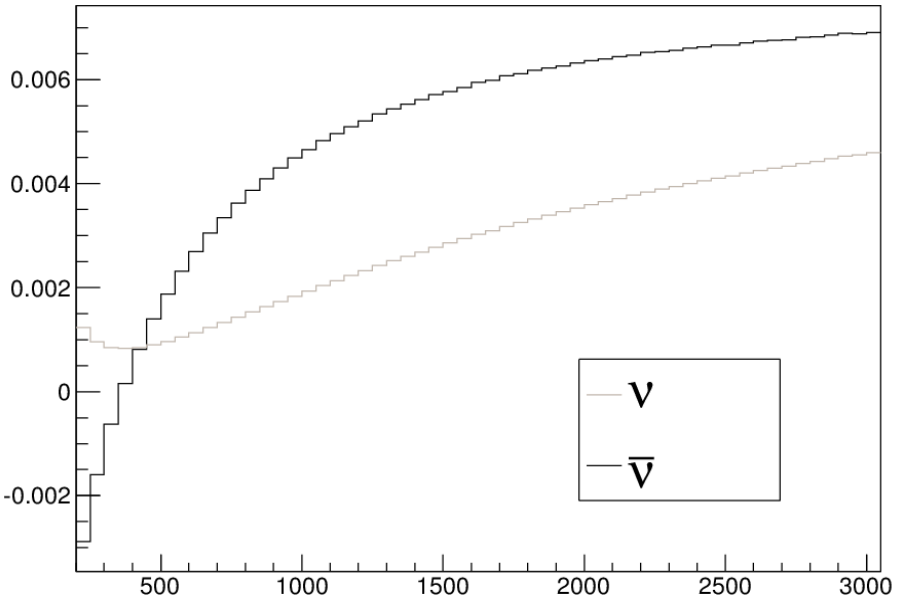
- Previously only used Dipole form factors
  - Now also available BBBA05, BBBA07

- Second class currents also added as an option
  - based on paper by M.Day and K.McFarland (Arxiv:1206.6745)

Arxiv:1206.6745



NEUT



Pion form factors

- Previously Rein-Sehgal form factors were used

- Replaced with more realistic form factors

- Provided by Graczyk & Sobzcyk

- For more details, see talk by Y.Hayato

Future plans

- **Improvements**
  - nn/np/pp fractions for 2p2h models
    - Theory/data for guidance?

  - SF model
    - FSI affecting lepton (see talk / poster by A.Ankowski)
    - Pauli-blocking models (hard cut-off is a poor approximation)

- **Additional Models**
  - Effective spectral function model based on superscaling
    - Bodek and Coopersmith

  - Local fermi gas for CCQE
    - Better to incorporate RPA

  - Update Bodek-yang correction

  - Alternative MEC models (Martini)?

  - Radiative CCQE

Summary

- Much work has been put into updating NEUT over the last 18 months

- Many updates to the CCQE, or CCQE-like model
    - Spectral function
    - MEC
    - RPA
    - Form factors

- Also updates to the single pion form factors

- Already being used in studies at T2K and Hyper-K

- More updates planned for the future

Thank you