Possible uses of electron scattering for the future long-baseline program

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Disclaimer: it’s a **work**shop

Talk is brief with points for feedback on:

- Broader scope: what do we think we need to know about neutrino interactions for long-baseline programs?
- What could be missing from the current proposed program?
- What needs to happen to further develop the connection between electron scattering and neutrino oscillation experiments?
- Content of future workshop on electron scattering program

Why electron scattering?

From LOI#147

$e - A$ scattering provides fundamental input into the modelling of $\nu - A$ interactions. In particular, the vector response in $\nu - A$ interactions is related to $e - A$ scattering via the conserved vector current, and hence the relevant form factors in any $\nu - A$ model are derived from $e - A$ data.

$e - A$ scattering provides a fully analogous process to $\nu - A$ scattering and probes many of the same issues in nuclear modelling (initial state dynamics, multi-nucleon effects, final state interactions, etc.) and thus provides a testing ground for any model of $\nu - A$ interactions.

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Neutrino scattering is comprised of many different processes sandwiched on top of each other.

Electron scattering measurements provide one key piece “in isolation”; otherwise we may misattribute effects in our prediction of neutrino experiment event rates.

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Benefits: fixed kinematics, and precision is generally better than neutrino experiments can achieve

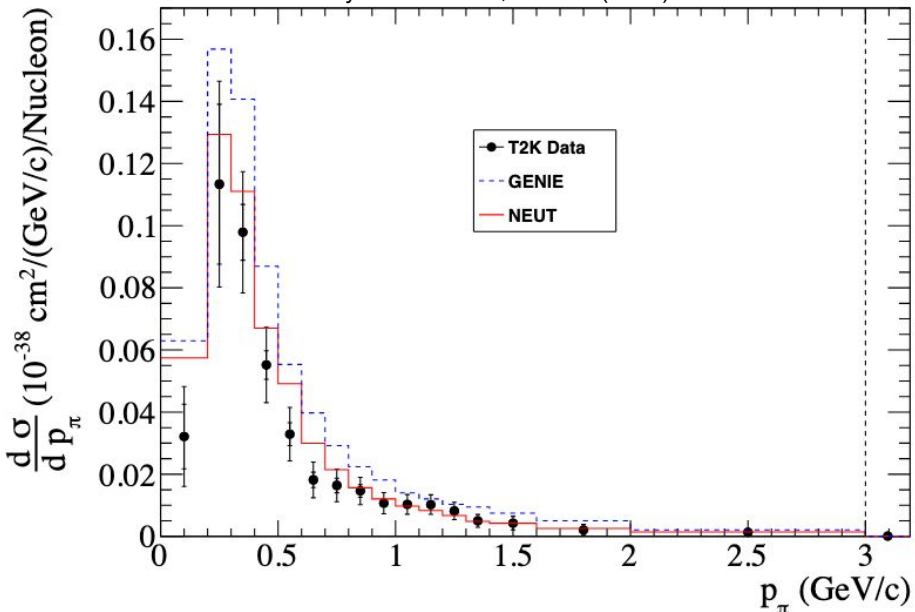
Data can be used as inputs to theoretical models and/or to benchmark neutrino event generators

Needs of experiments - *example T2K*

Next generation of T2K measurements will rely on CC1π+ events

- Disagreements in outgoing pion spectra - *what is the origin?*

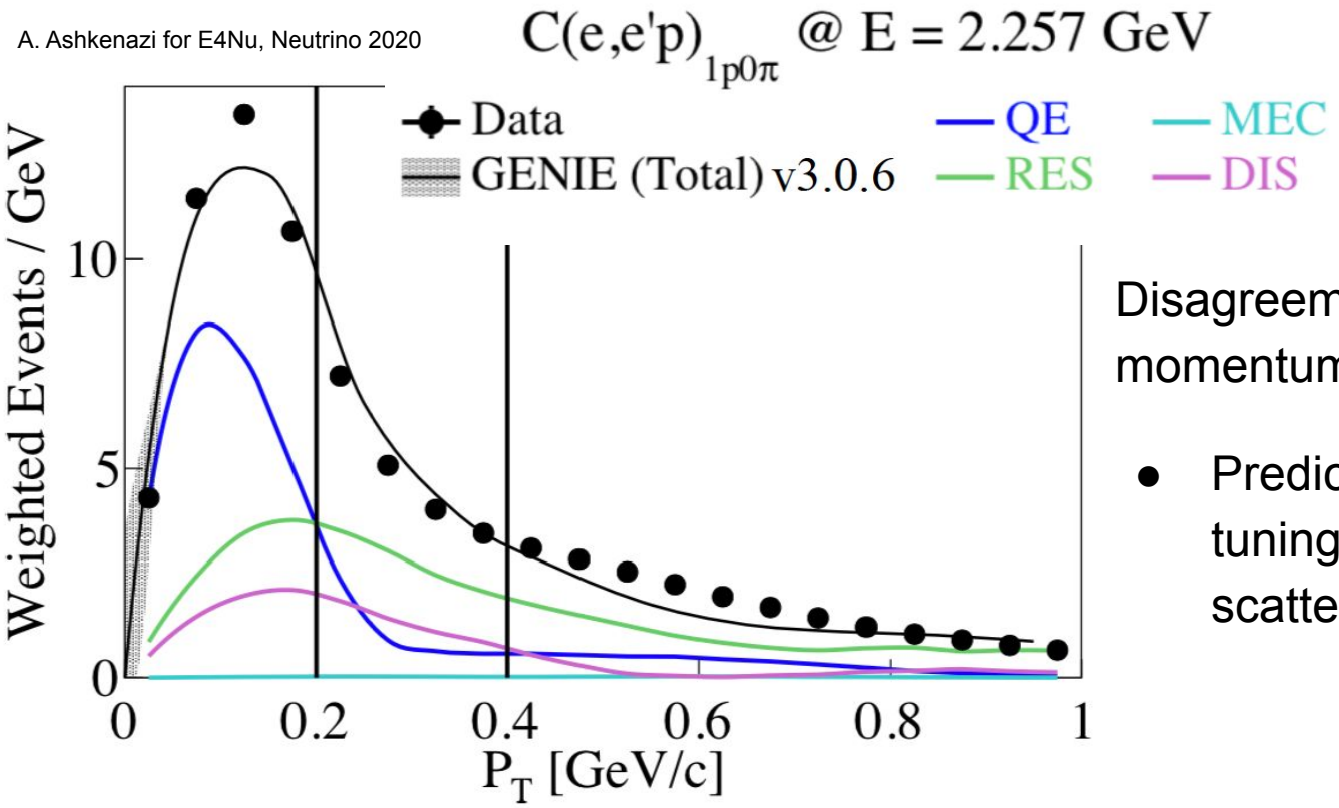
Phys. Rev. D 101, 012007 (2020)



Electron scattering data on a range of targets can help validate FSI modelling.

Benefit of electron scattering data - *example E4Nu*

A. Ashkenazi for E4Nu, Neutrino 2020



Disagreement in transverse momentum distribution

- Prediction already includes tuning to inclusive electron scattering data

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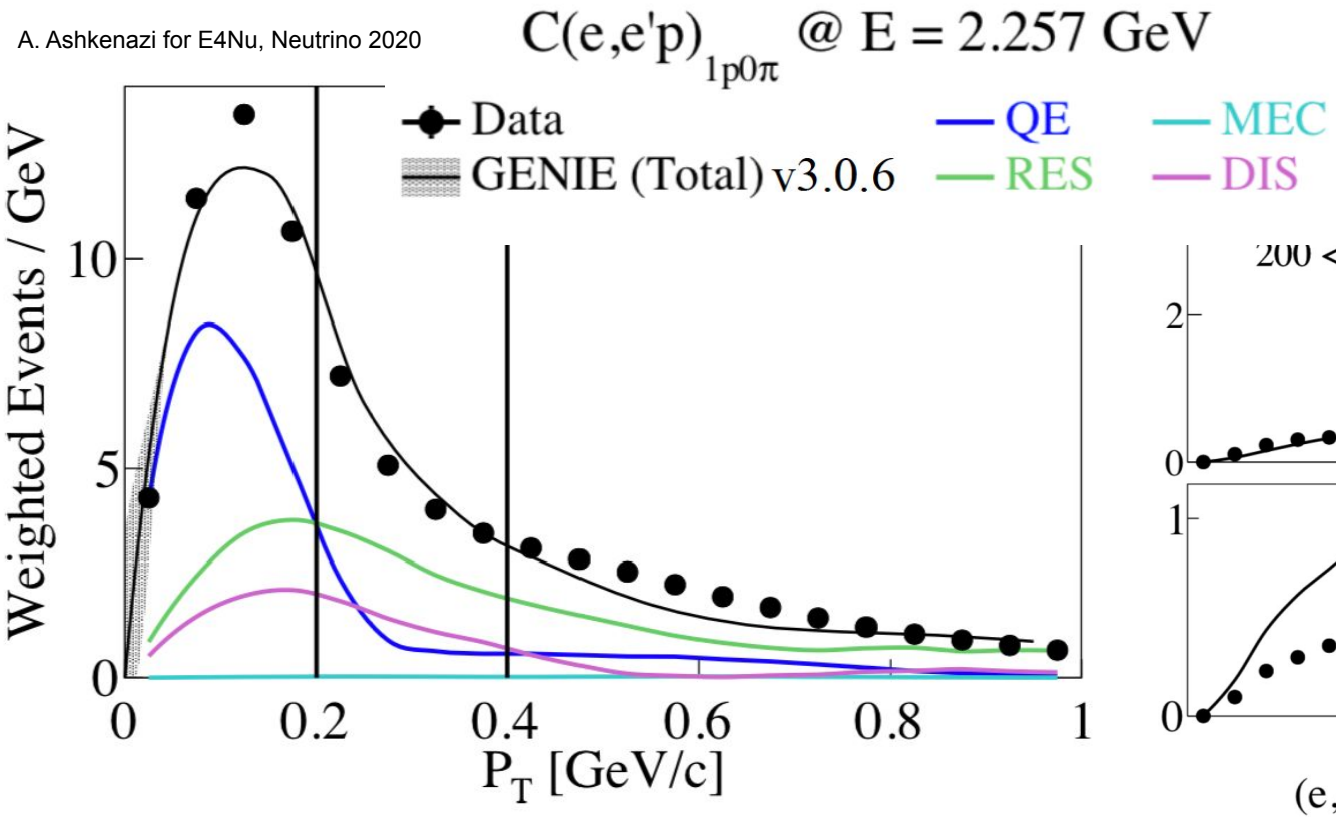
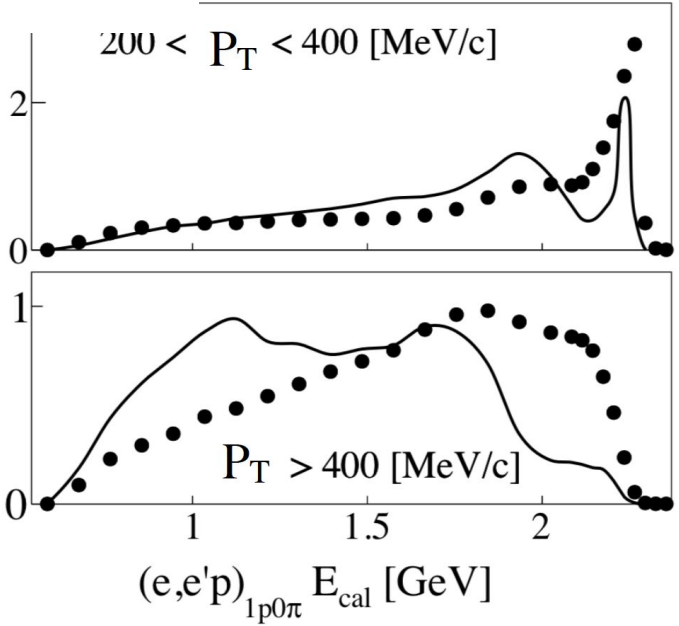
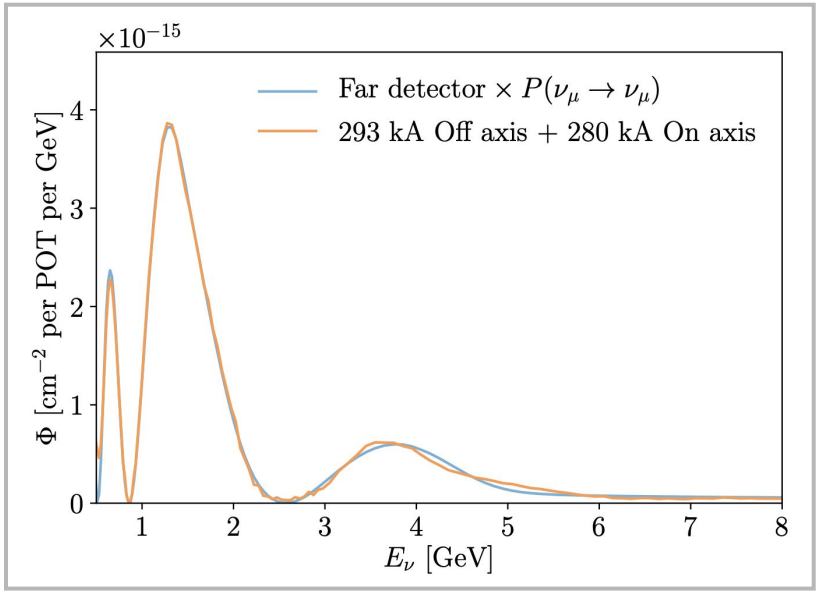


Provides detail in where the missing strength is



Needs of experiments - *example from DUNE*



DUNE PRISM flux matching isn't perfect at higher energies - *will need interaction model for corrections*

This region is also SIS/DIS which is currently not very well understood.

Electron scattering could aid in characterization of hadronic final state kinematics and multiplicity

“Matrix” of needs of experiments - *draft*

Motivation:

- What are the channels of interest? What do we know about them now? And, roughly, what do we want to know?
- Goal is to map this information then to which measurement(s) can be used to characterize the process
- Please add/update with:
  - Which processes are important?
  - What features of the interaction model concern us and why?
  - How do we determine what precision is desired (come back to this at the end)

- Link to draft spreadsheet

“Matrix” of needs of experiments - *draft*

Cross Sections and Neutrino Oscillation

Physics Search	Needed input channel	What features are relevant?	Precision known?	Precision desired?
nue, nuebar appearance [HK, DUNE]	nu, nubar NC1 gamma	rate; photon momentum, angular distribition	T2K: 30%, no experimental measurement	??
signal nue/nuebar appearance, numu/numubar disappearance [DUNE]	2p2h	outgoing muon, proton and pion kinematics. Neutron/proton fraction is known at some level, hadron kinematics not well understood		
signal nue/nuebar appearance, numu/numubar disappearance [DUNE]	CC Resonance production	pi+/pi0 fraction; rate; outgoing muon, proton and pion kinematics. Pion momentum does not seem to be well described		

- Link to draft spreadsheet

Experimental program in electron scattering - *draft*

Electron-Nucleus Scattering: Current and Near-Future Experimental Landscape

Experiments	Kinematics Range	Nuclear Targets	Scattering Type	Detector Characteristics
e-Ar (E12-14-012) at JLab [Data collected in 2017]	E_e = 2.222 GeV Theta_e = 15.5^0, 17.5^0, 20.0^0, 21.5^0 Theta_p = -39.0^0, -44.0^0, -44.5^0 ,-47.0^0, -50.0^0	C, Al, Ar, Ti	Inclusive: e in the final state Exclusive: e, p in the final state	High resolution spectrometers Large acceptance Scintillator counter Drift chambers Cherenkov detector
e4nu at JLab [CLAS12: Planned, LOI#102] [CLAS: data collected]	CLAS12: E_e = 1, 2, 4, 6 GeV CLAS: E_e = 1.2, 2.3, 4.5 GeV	CLAS12: C, O, Ar CLAS: He, C, Fe	CLAS12: Exclusive: e, p, n, pion in the final state CLAS: Exclusive: e, p, pion in the final state	Large acceptance spectrometer Scintillator counter Drift chambers Cherenkov counter Electromagnetic calorimeter
LDMX at SLAC [Planned, LOI#91]	E_e = 4, 8 GeV Theta < 40^0 degrees		Inclusive: e in the final state Exclusive: e, p, n, pion in the final state	Precision tracker Electromagnetic calorimeter Hadronic calorimeter Low-energy threshold

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Are we missing any programs which exist?

- Older data also exists and has been used as well: Link to archive of older data
- LOI#91 and LOI#102

Connection between neutrino and electron programs?

- Challenge: We have a general sense of what's needed, but not necessarily a specific one
- How do we connect the programs - *discuss*
  - Which measurements? Any key design features?
  - Related problem: What do we have already to characterize the axial part of the cross section? Existing program (e.g. MINERvA, T2K, SBN program) and future (near detectors)
  - Related: How do we determine what precision is needed for the processes in question?
- Example: A Snowmass inspired series of mock data challenges?
  - Benefit: would provide concrete examples for experiments to test against
- Your idea here...

Please attend our workshop!

Dec 14th @9am - 12 CT

Agenda:

- **What theory is needed and why to interpret the measurements?** Speaker: Natalie Jachowicz (20 min + 10) + discussion
- **Present “matrix” of needs, advertisements from the LOIs (40 min)** Discussion: Are there gaps in this program which have not been identified? Are there configurations of beam, detector which are absent and needed and why?
- **White paper outline + solicit help (10 min)**

Backup