Proposal to join the CLAS12 Collaboration through limited membership

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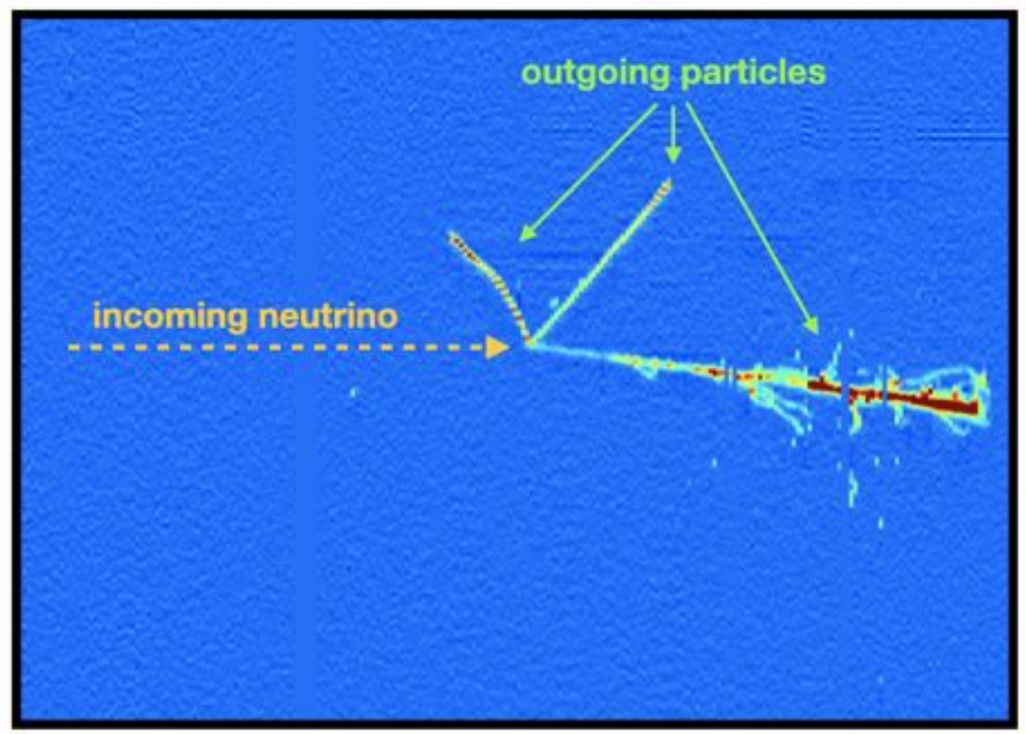
PAC Meeting

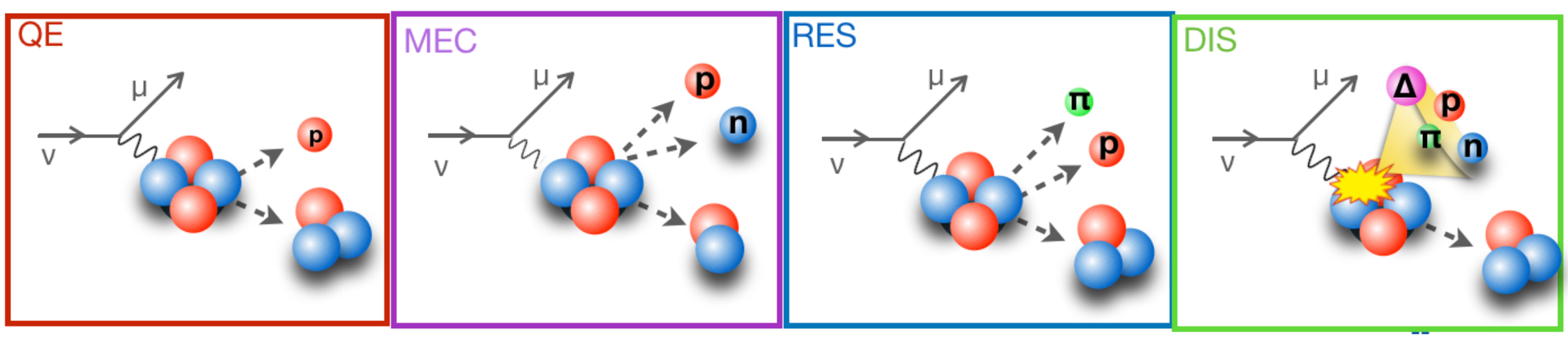
09 December 2020

Neutrino Scattering is complicated

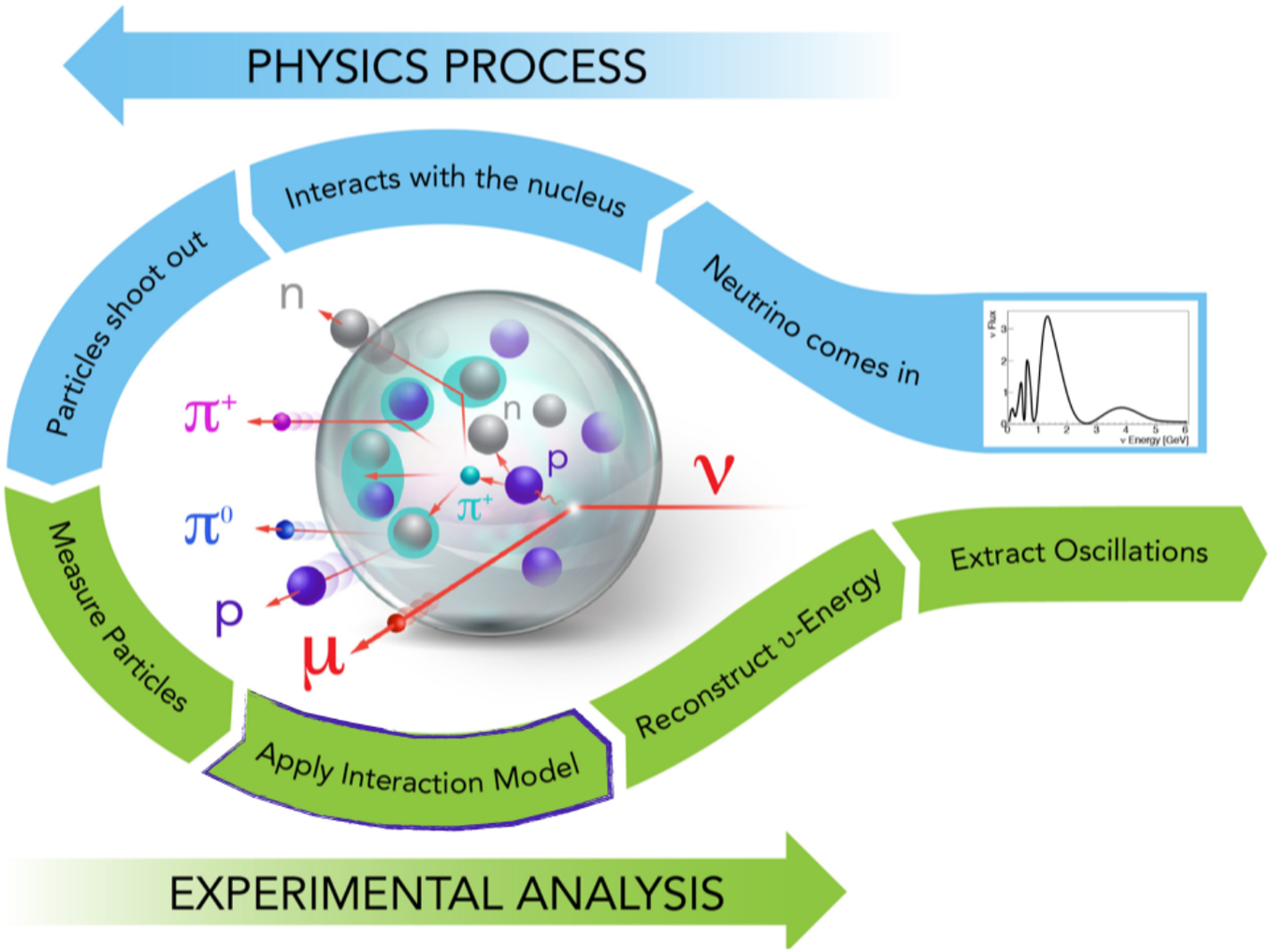
Initial nuclear state
- Nucleon motion
- Long range correlations
- Short range correlations
- Nucleon removal energies
- Form factors



Final state interactions
- Reinteractions of outgoing particles
- Knockout of new particles



How to Extract Neutrino Physics



$$N_e(E_{rec},L) \propto \Sigma_i \int \Phi(E,L)\sigma_i(E) f_{\sigma_i}(E,E_{rec})dE$$

Understanding neutrino-nucleus interactions is required to extract the oscillation signal from detector data

Current oscillation experiments report significant systematic uncertainties associated with the assumptions made in the neutrino-nucleus interaction models

Attacking the Monster From All Sides

The flux is different at the near compared to the far detector due to geometry and oscillation, the convolution of flux, cross section, and nuclear effects are different

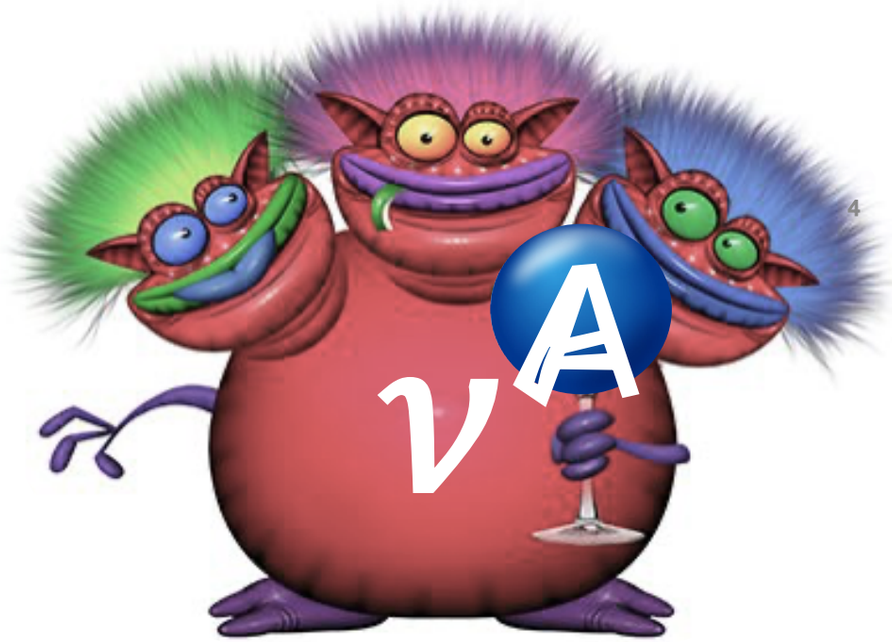
Event-Generators

Must reproduce e^- & ν data to extract oscillation parameters.

e-scattering

Monochromatic e^-:

- Vector currents
- Same initial nucleus
- Similar interactions
- Same final state interactions
- …



ν-scattering

ν near-detector:

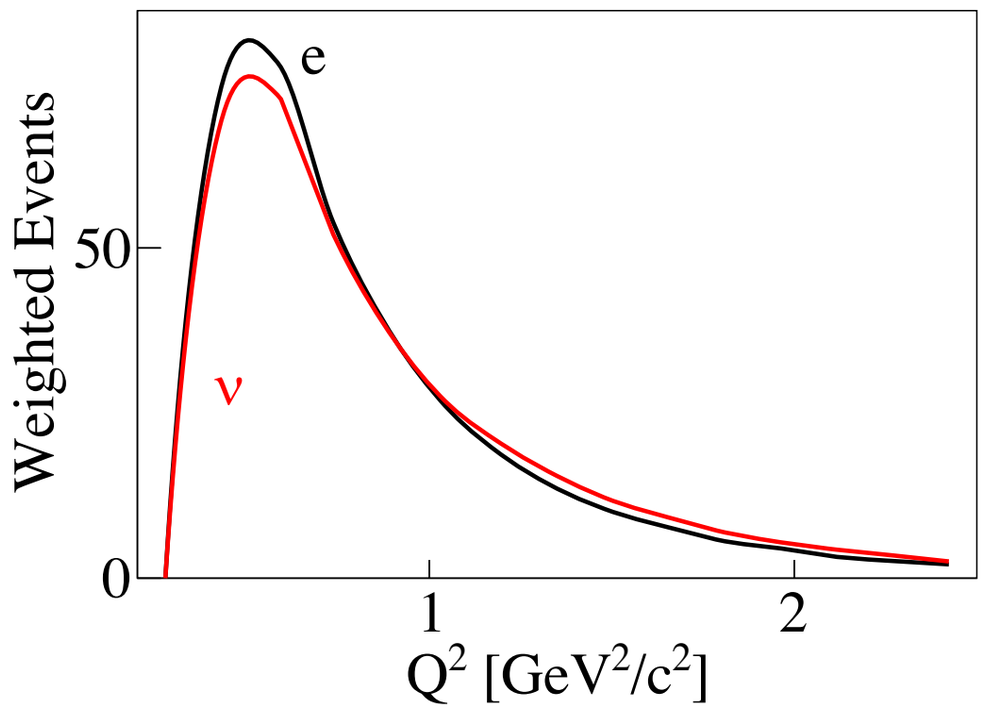
- Axial & Vector-Axial currents
- Ultra-low Q^2
- …

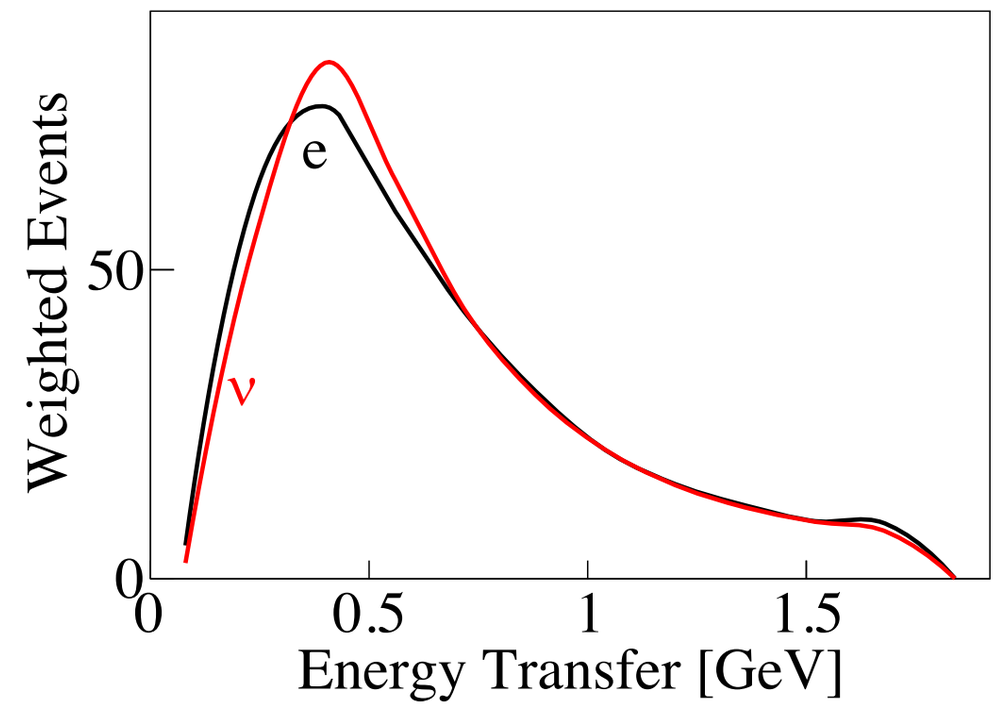
Why Electron Scattering?

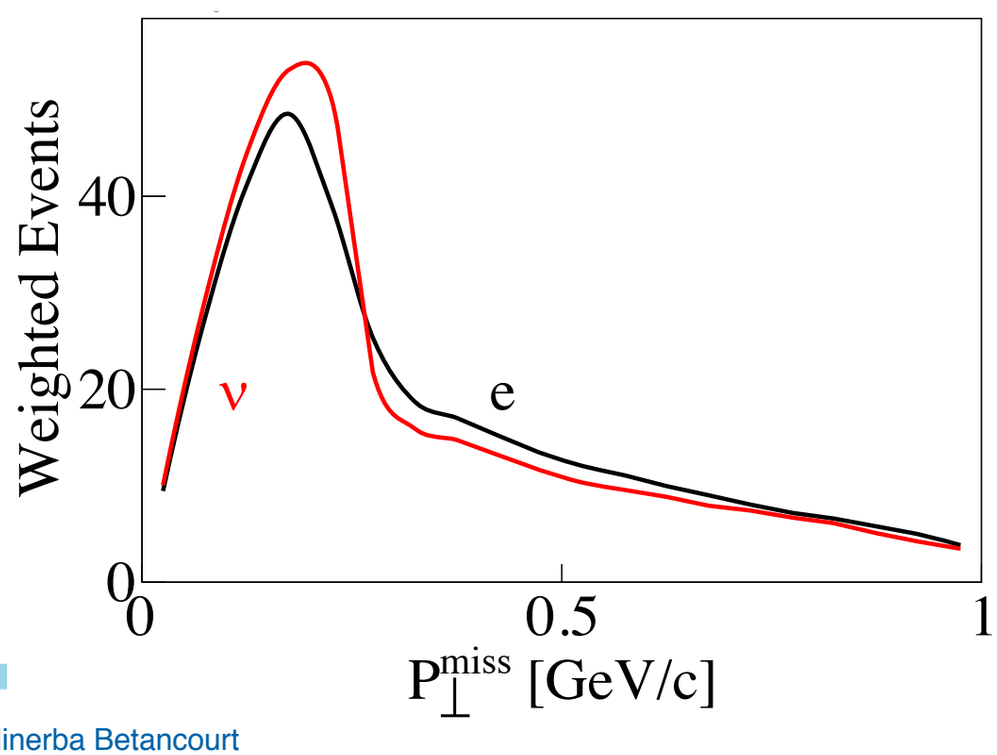
- e & ν interact similarly
- Many nuclear effects identical
  - (FSI, multi-N effects, …).
- e beam energy is known
- → can test energy reconstruction
- Constrain ν event generators (GENIE)
  - Updated e-GENIE to be as similar as possible to ν-GENIE

- Electrons for Neutrinos (e4ν)
  - Use monochromatic electron beams and large acceptance detectors
  - Measure exclusive final states in the Jefferson Lab CLAS and CLAS12 detectors
  - In order to
    - constrain nuclear effects (ground state, final state interactions)
    - constrain vector part of interaction

ν & e^- are very similar!



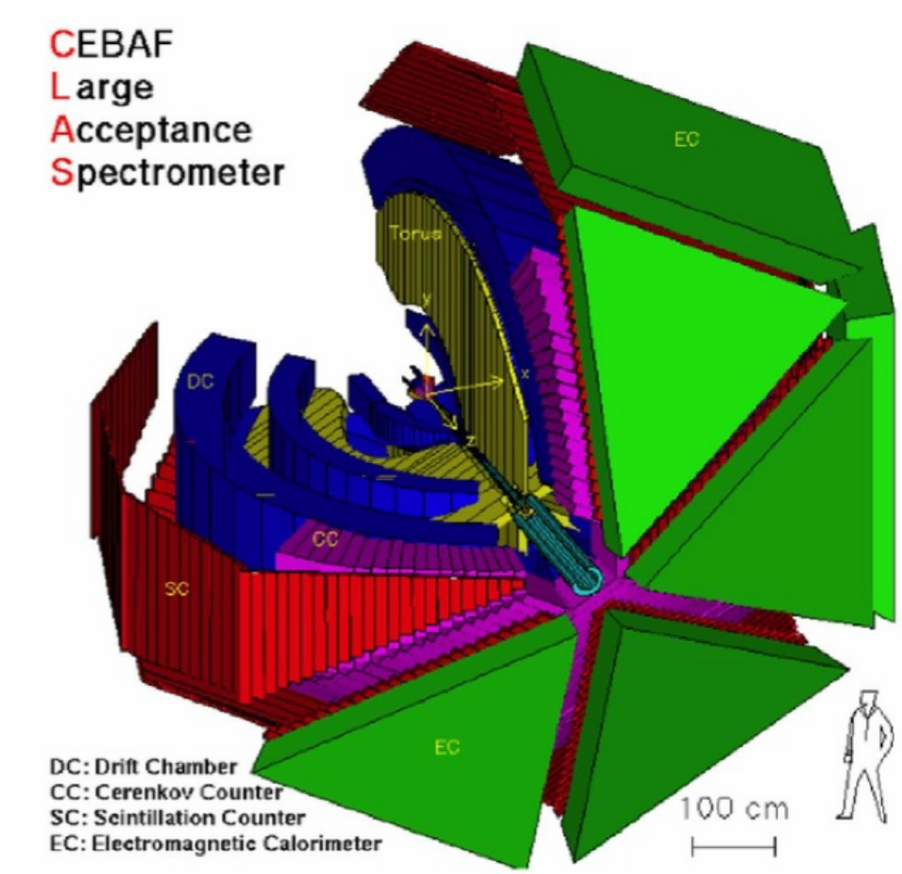


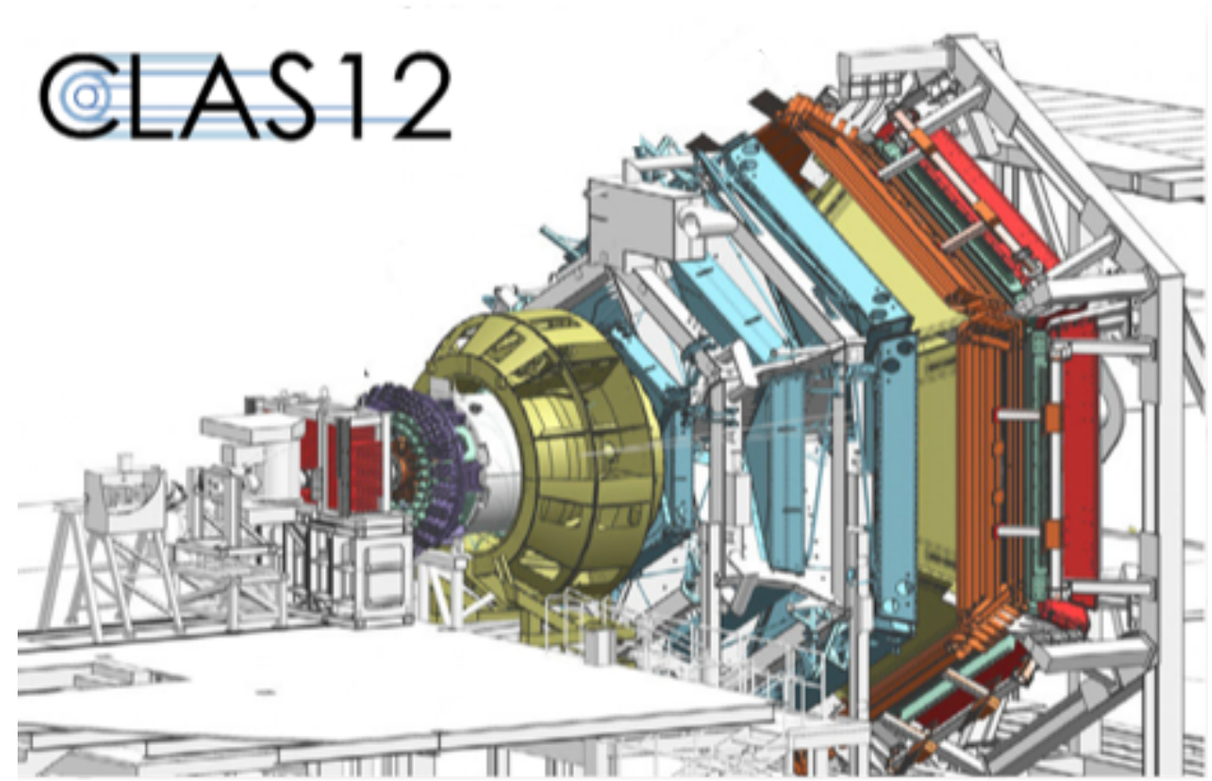


2.26 GeV on ^{12}C

$1p0\pi$ events,
$\theta_{lepton} > 15°$.
Area normalized

Electron Scattering with CLAS and CLAS12 at JLab





- 1999 and 2003 Data:
  - ^{3}He, ^{4}He, C, Fe
  - 1.1, 2.2, 4.4 GeV
  - moderate detector thresholds
  - $\theta_e > 15 - 20^o$

First data taking: summer 2021

- C, Ar
- 2, 4, 6 GeV
- moderate detector thresholds
- $\theta_e > 5 - 10^o$

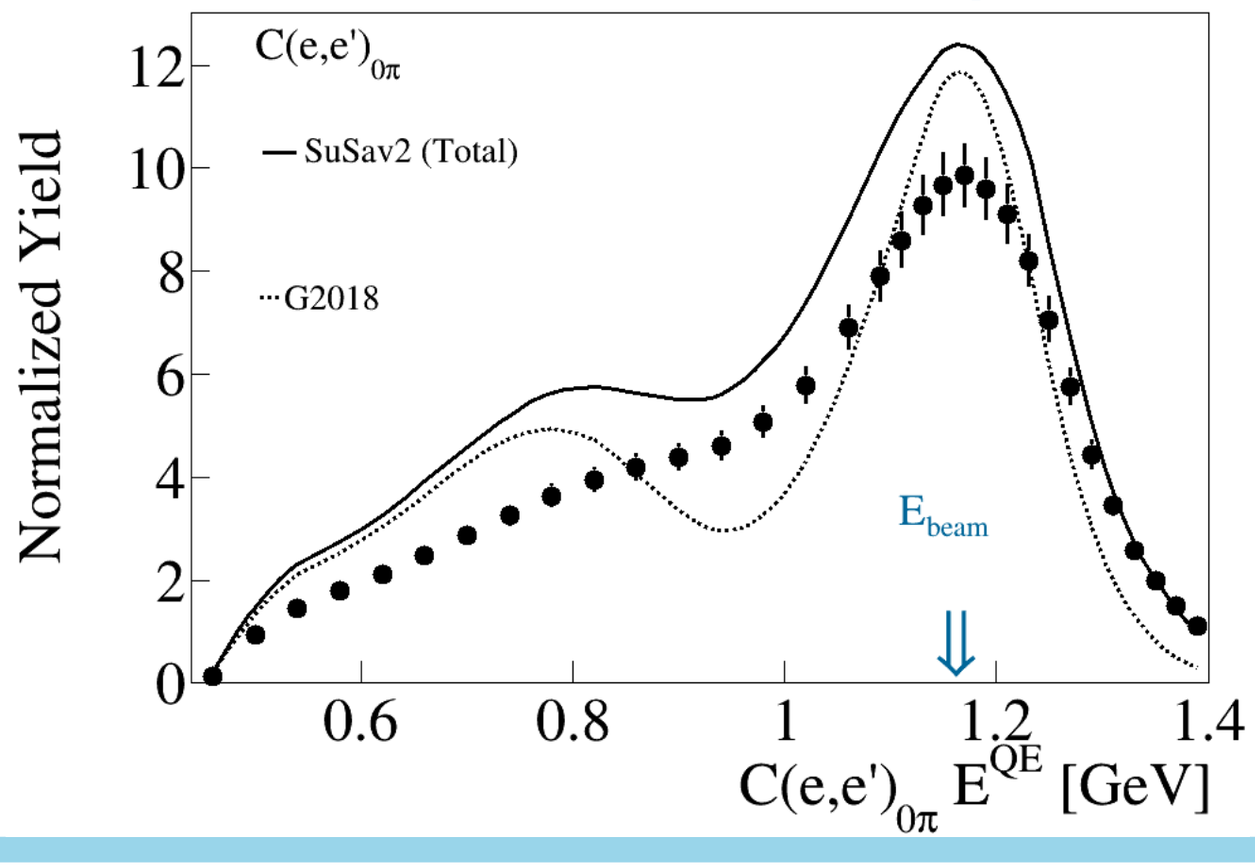
Later runs on ^{16}O at 1 and 2 GeV

First Analysis recently submitted for publication

- Analyze electron data as neutrino data
  - Starting with $1p0\pi$
  - Select lepton or lepton+proton final state (0π or $1p0\pi$)
    - Correct for events with undetected other particles
  - Scale by Q^4 to probe relevant phase space
  - Reconstruct incoming lepton energy
  - Compare to event generators

1.161 GeV

Inclusive 0pi Events



E_{QE} reconstructed from lepton only

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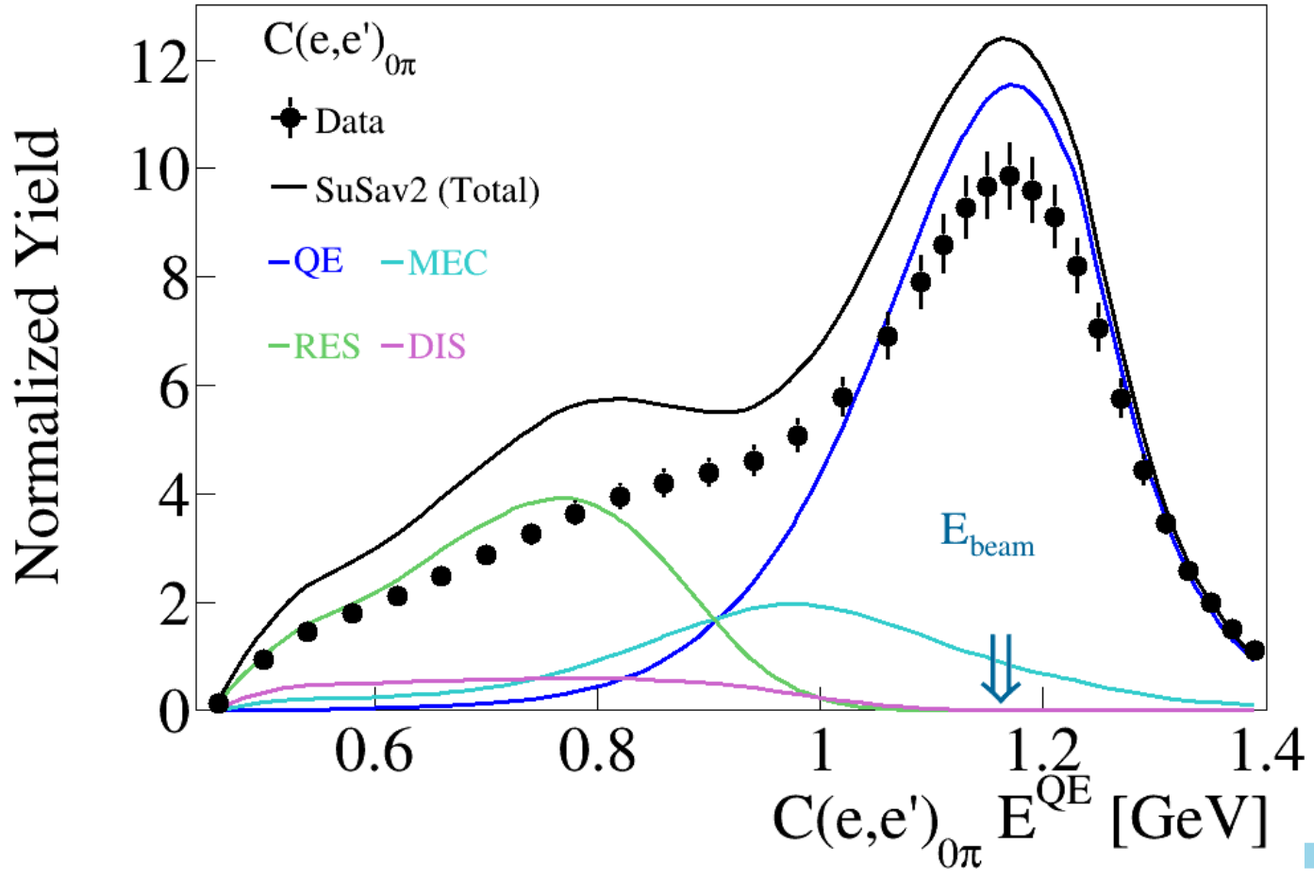
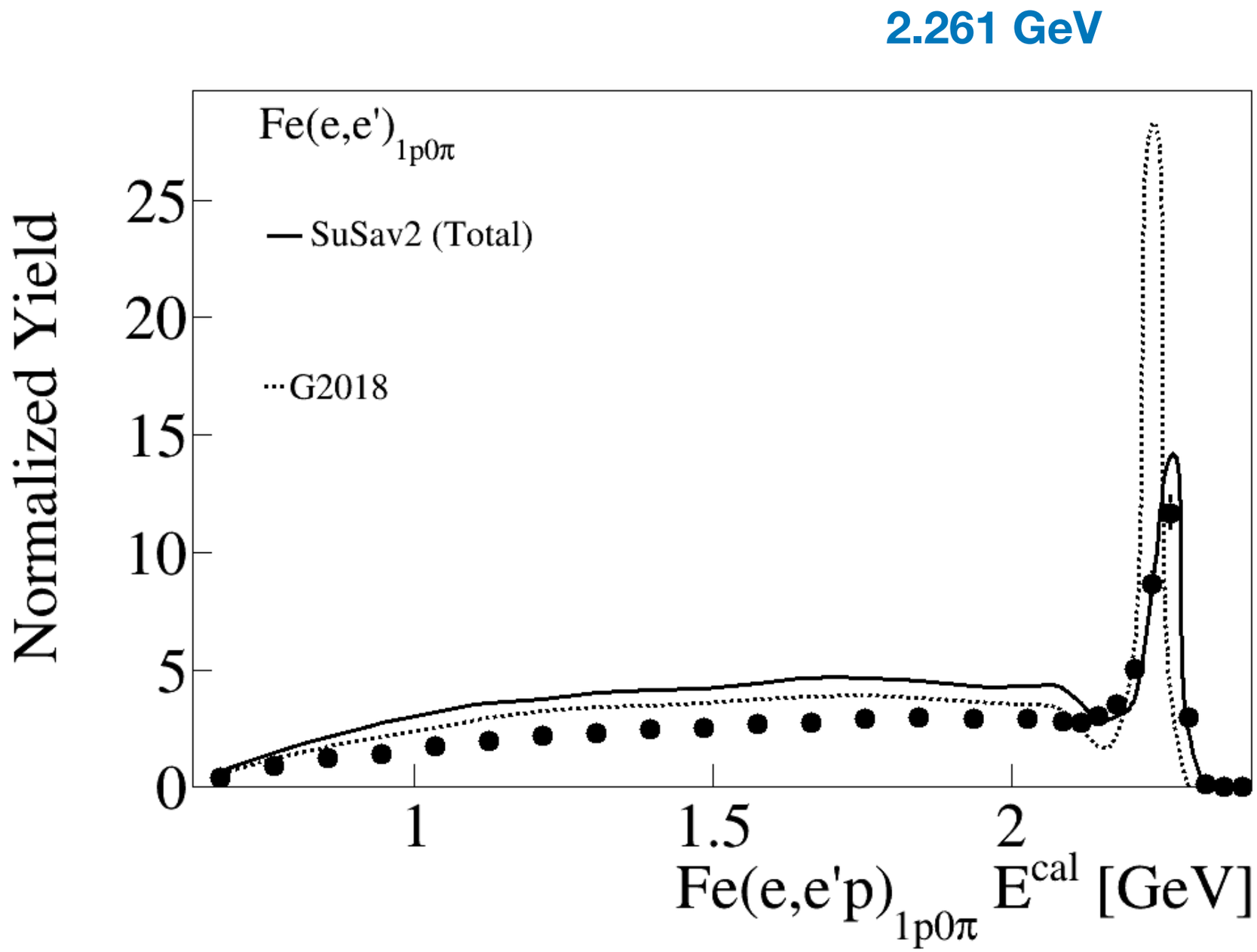


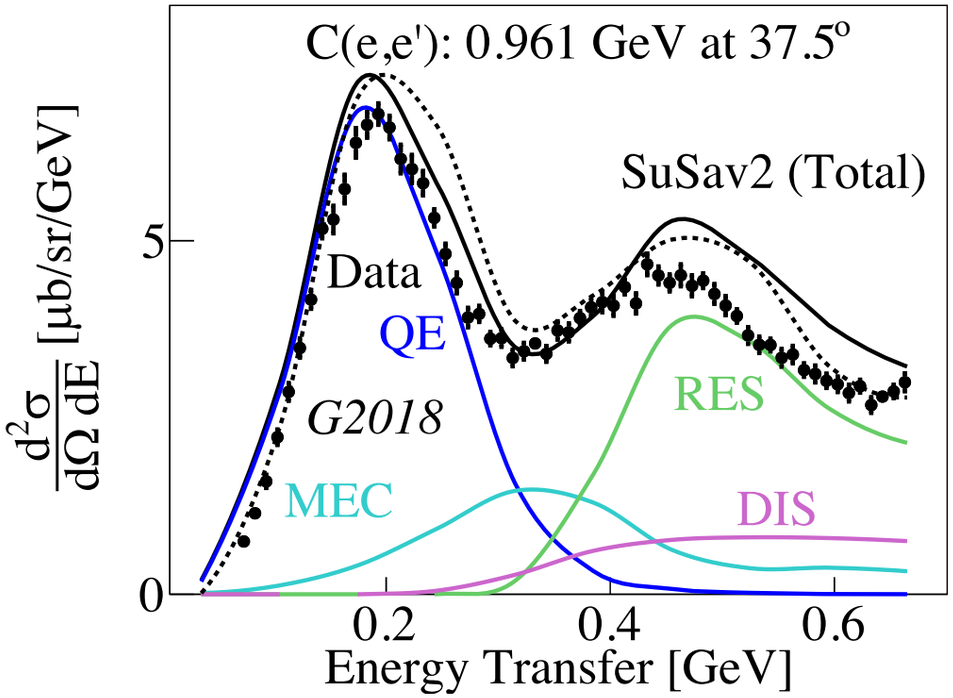
E_{QE} reconstructed from lepton only

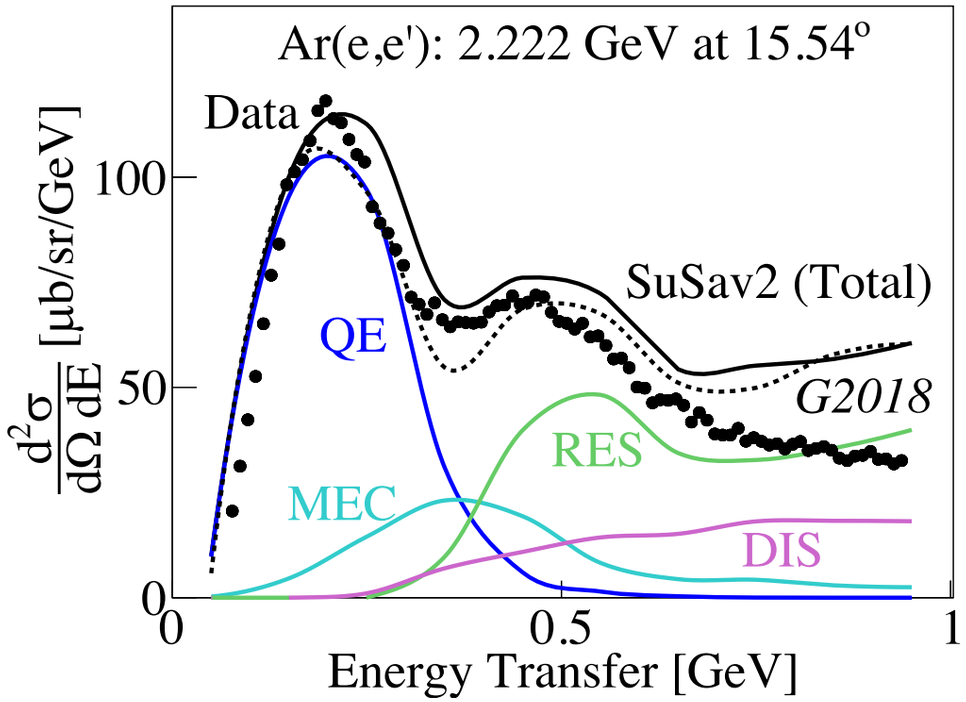
Exclusive 1p0pi Ecal Reconstruction

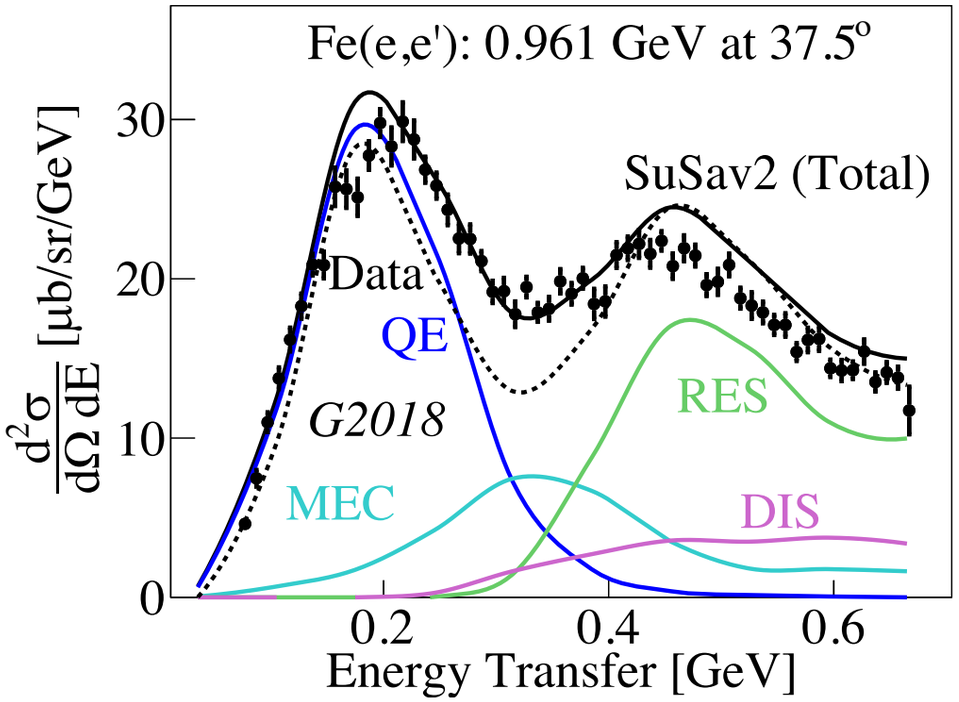
$$E_{cal} = E'_e + T_p + E_{bind}$$



Inclusive electron scattering







Reasonable data-model agreement

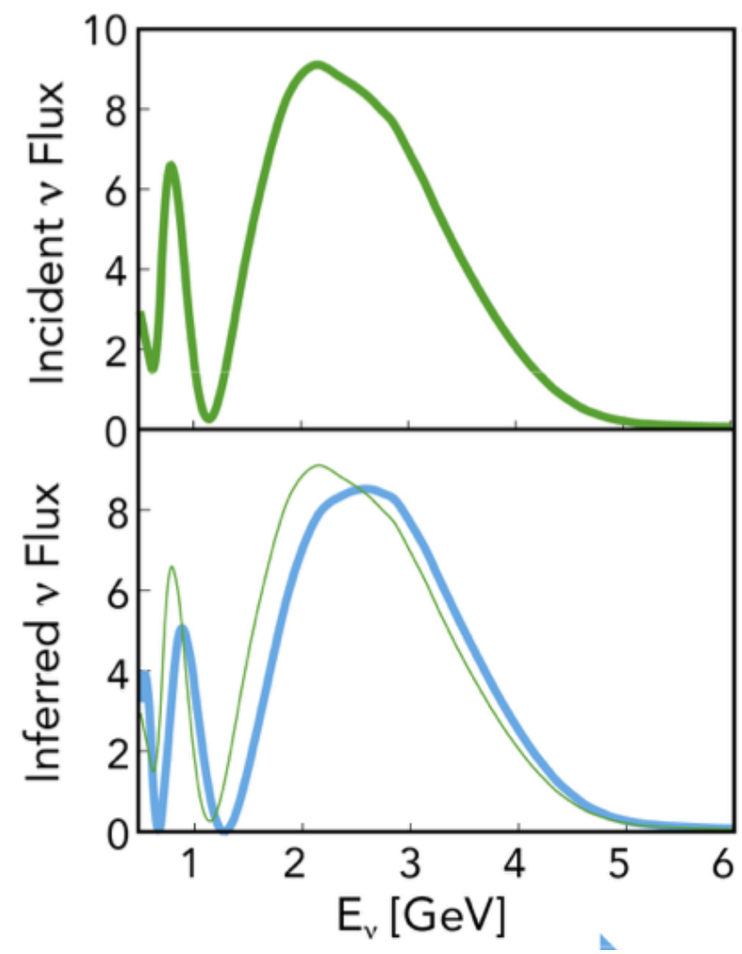
Electron-GENIE paper submitted to PRD: arXiv:2009.07228

Effect on reconstructed beam energy

$$N_e(E_{rec},L) \propto \Sigma_i \int \Phi(E,L)\sigma_i(E) f_{\sigma_i}(E,E_{rec})dE$$

1. Take typical oscillated incident energy spectrum
2. Smear with GENIE-derived feed-down matrix
3. Reconstruct with data-derived feed-down matrix

Big differences!



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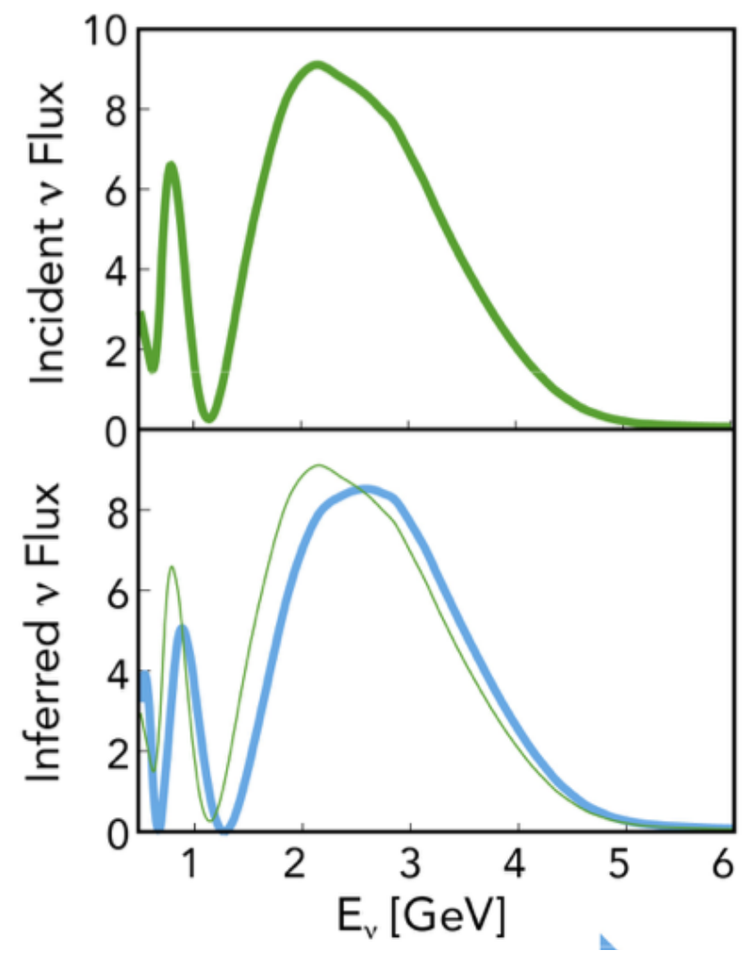


Big differences!

Next step: use the new data to improve event generators!

e4v Collaboration

- Old Dominion University
- MIT
- Jefferson Lab
- Tel Aviv U
- Michigan State
- Fermilab
- U Pittsburgh
- York University, UK

- New collaborators from:
  - UCL,
  - College of William & Mary,
  - U of Texas,
  - Arlington,
  - Rutgers U,
  - U of Maine
  - LBL

Join us!

e4v Collaboration

All are welcome to join e4v

a new collaboration with members from the neutrino and electron scattering communities

Effort needed:

- Analyze data
- Upgrade models and parameters in event generators
- Understand the implications for neutrino physics

Working groups:

- Data analysis (require to join CLAS as limited member)
- Modeling development
- Implication on neutrino studies
- Tuning

Proposal to join the CLAS Collaboration through limited membership

- Benefits of "limited membership"
  - No need to take shifts
  - can participate in data analysis
    - **We need neutrino experts to help guide the data analysis**
  - Authorship on papers
  - Can present preliminary data in talks
- Duties of limited membership
  - None!
- Restrictions of "limited membership"
  - Require CLAS approval of all public results, both preliminary and final
    - Typically managed by CLAS Full members
  - Require CLAS approval of all talk abstracts and conference proceedings
  - Require CLAS approval of all papers
    - Typically managed by CLAS Full members
  - Notify CLAS of all talk requests

Summary

- e4ν collaboration
  - Many institutions
  - Analyzing exclusive electron scattering data
  - Improving GENIE
  - Determining implications for neutrino scattering
  - First papers submitted
- Jefferson Lab CLAS Collaboration
  - Lots of existing data under analysis
  - Lots more new data to come in 2021
  - **Join the CLAS Collaboration** to participate in and help guide the data analysis
    - Lots of benefits
    - No extra duties
    - Typical collaboration restrictions on presentations and publishing
- Excellent opportunity for Fermilab to contribute to this effort

Backup Slides

Fermilab Involvement

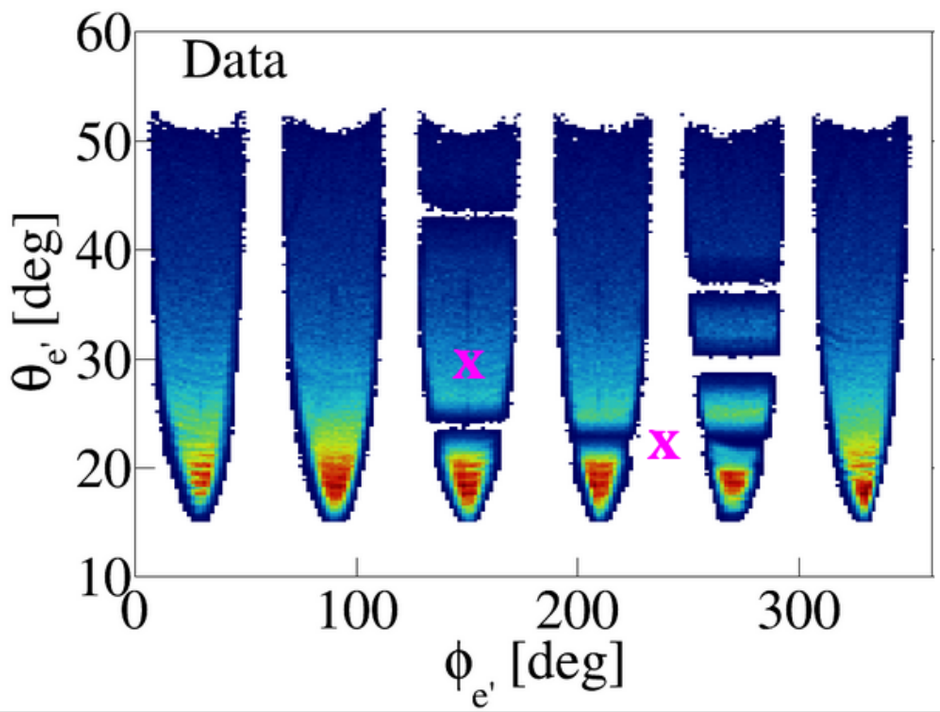
- Minerba Betancourt (Associate Scientist): Data analysis and implications on neutrino physics
- Steven Gardiner (Research Associate): GENIE event generator
- Kirsty Duffy (Lederman Fellow): Data analysis and implications on neutrino physics

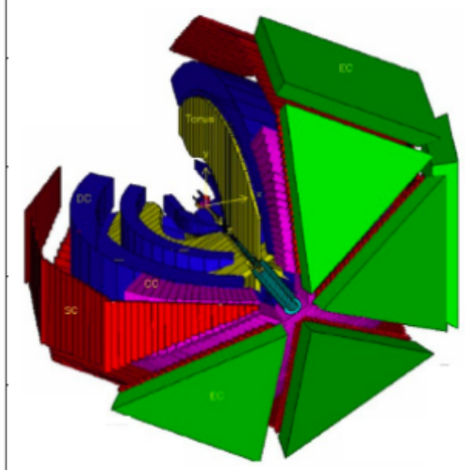
10-20% level of involvement from each

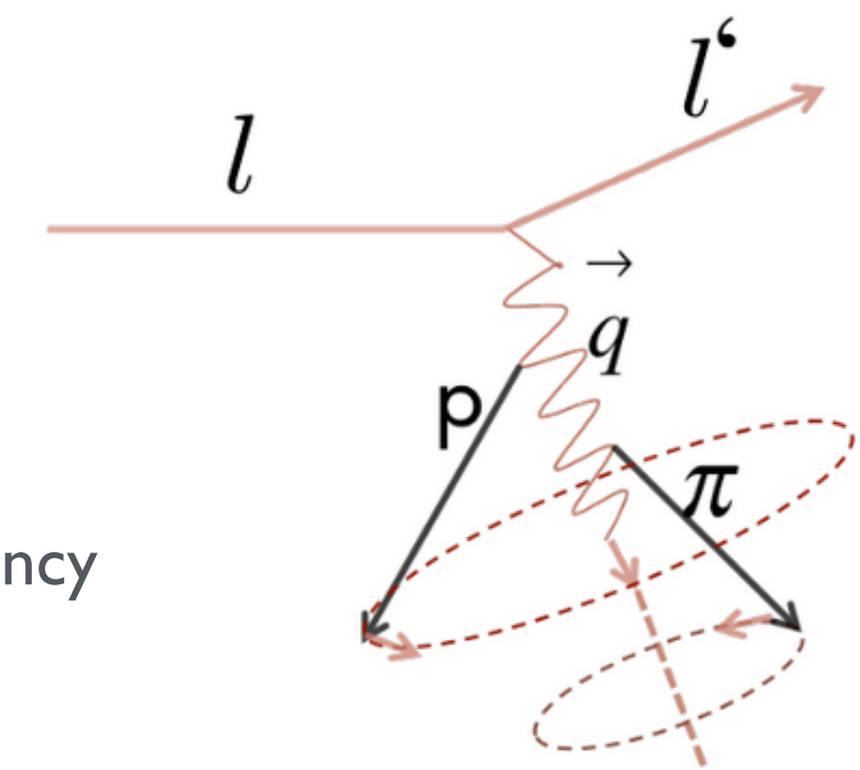
Working with theorists: Noemi Rocco (Fermilab) and Saori Pastori (Washington U)

Data Driven Correction

- Non-QE interactions lead to multi-hadron final states
- Gaps make them look like QE-like events







- Use measure (e,e'pπ) events
- Rotate p, π around q to determine π detection efficiency
- Subtract undetected (e,e'pπ)
- Repeat for higher hadron multiplicities