

Nuclear Aspects of Neutrino Interactions

Using ν & e scattering data to constrain νA modelling



Adi Ashkenazi



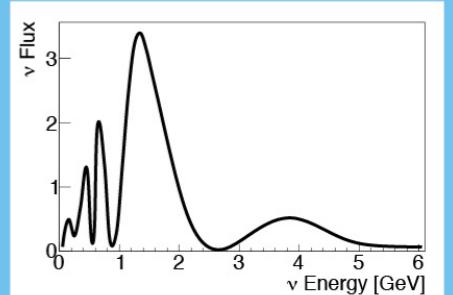
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PHYSICS PROCESS

Particles shoot out

Interacts with nucleus

Neutrino comes in

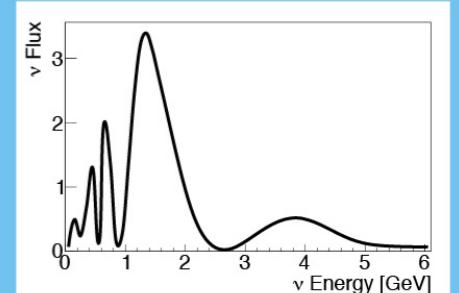


PHYSICS PROCESS

Particles shoot out

Interacts with nucleus

Neutrino comes in



Measure Particles

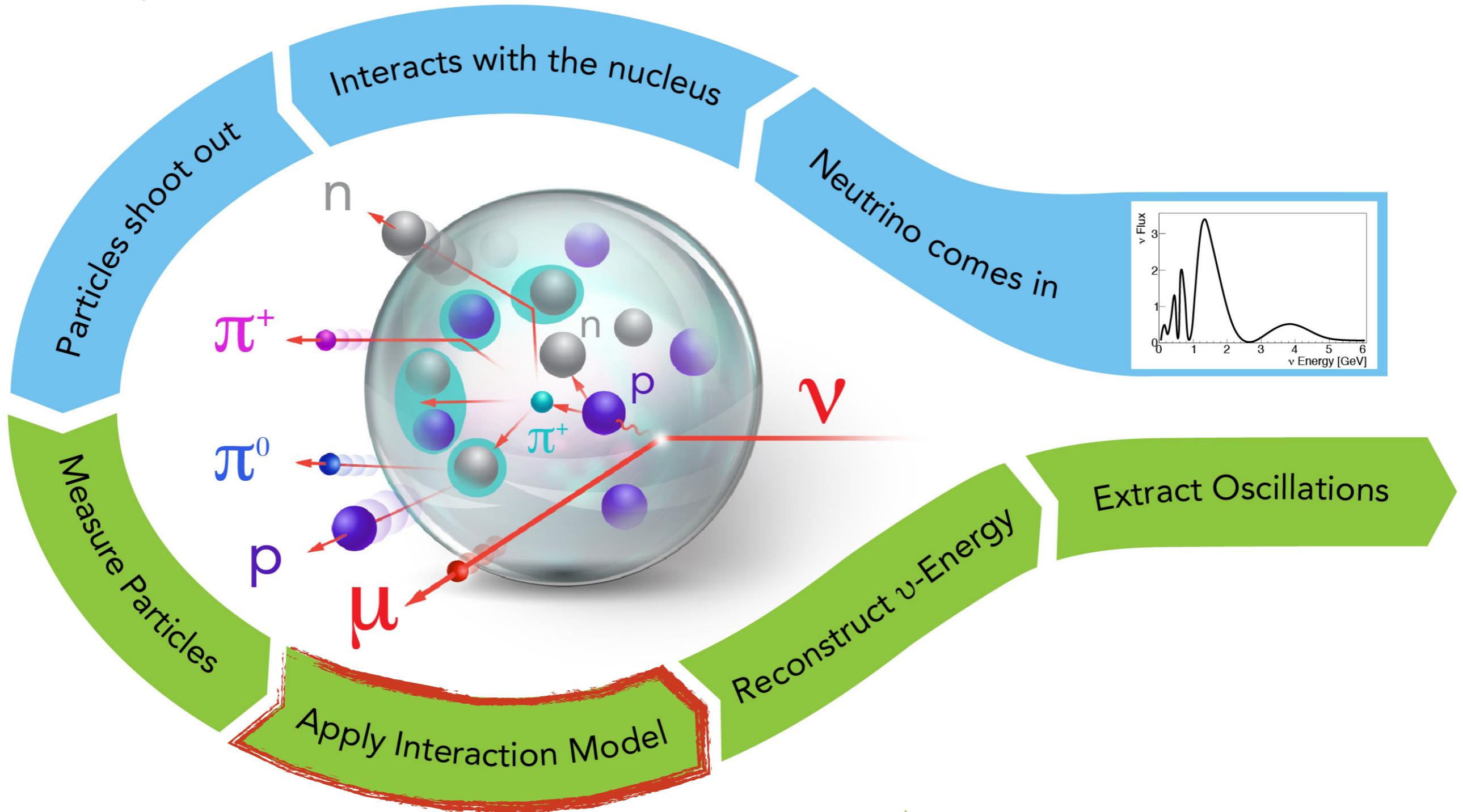
Apply Interaction Model

Reconstruct ν -Energy

Extract Oscillations

EXPERIMENTAL ANALYSIS

PHYSICS PROCESS



EXPERIMENTAL ANALYSIS

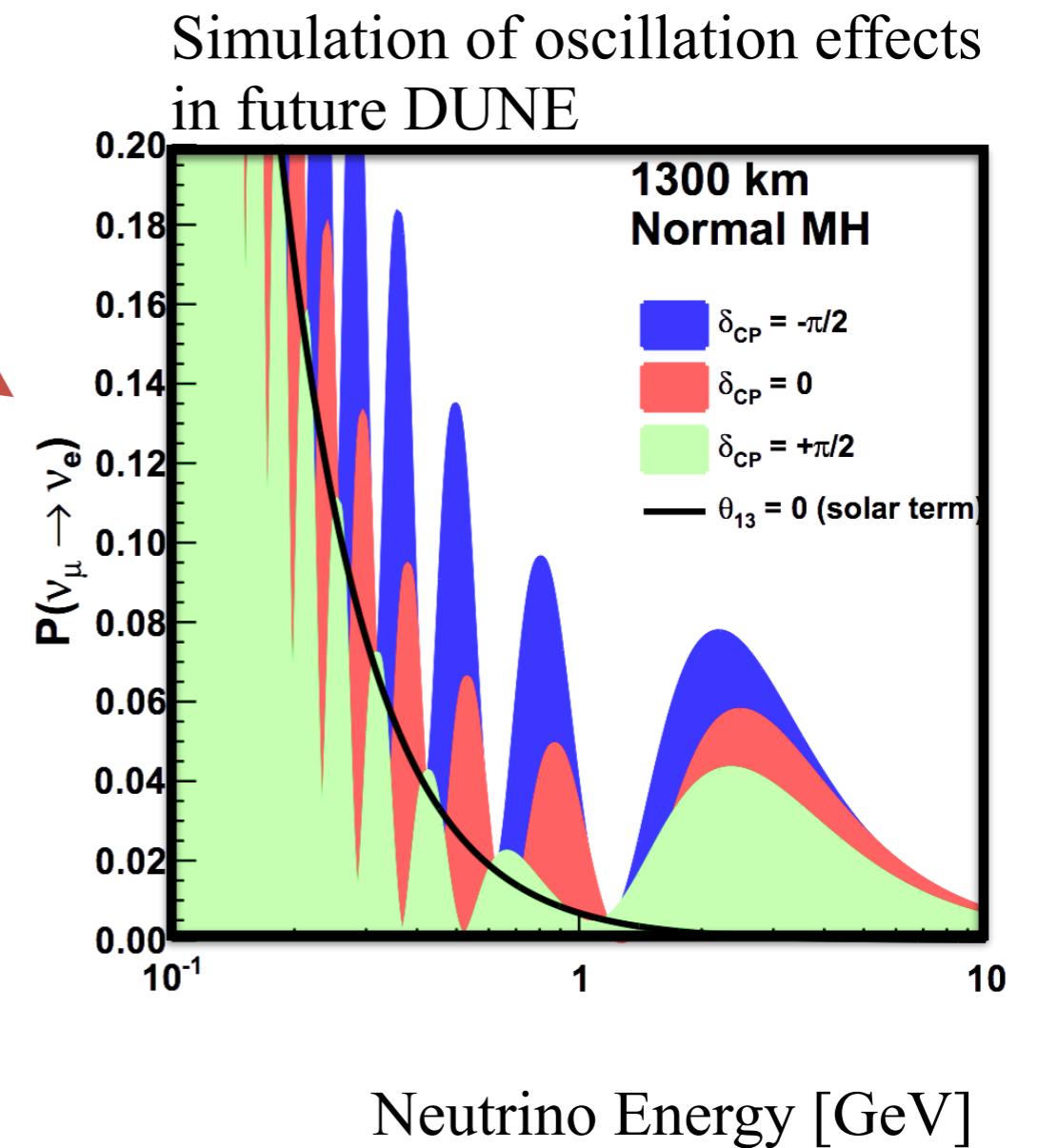
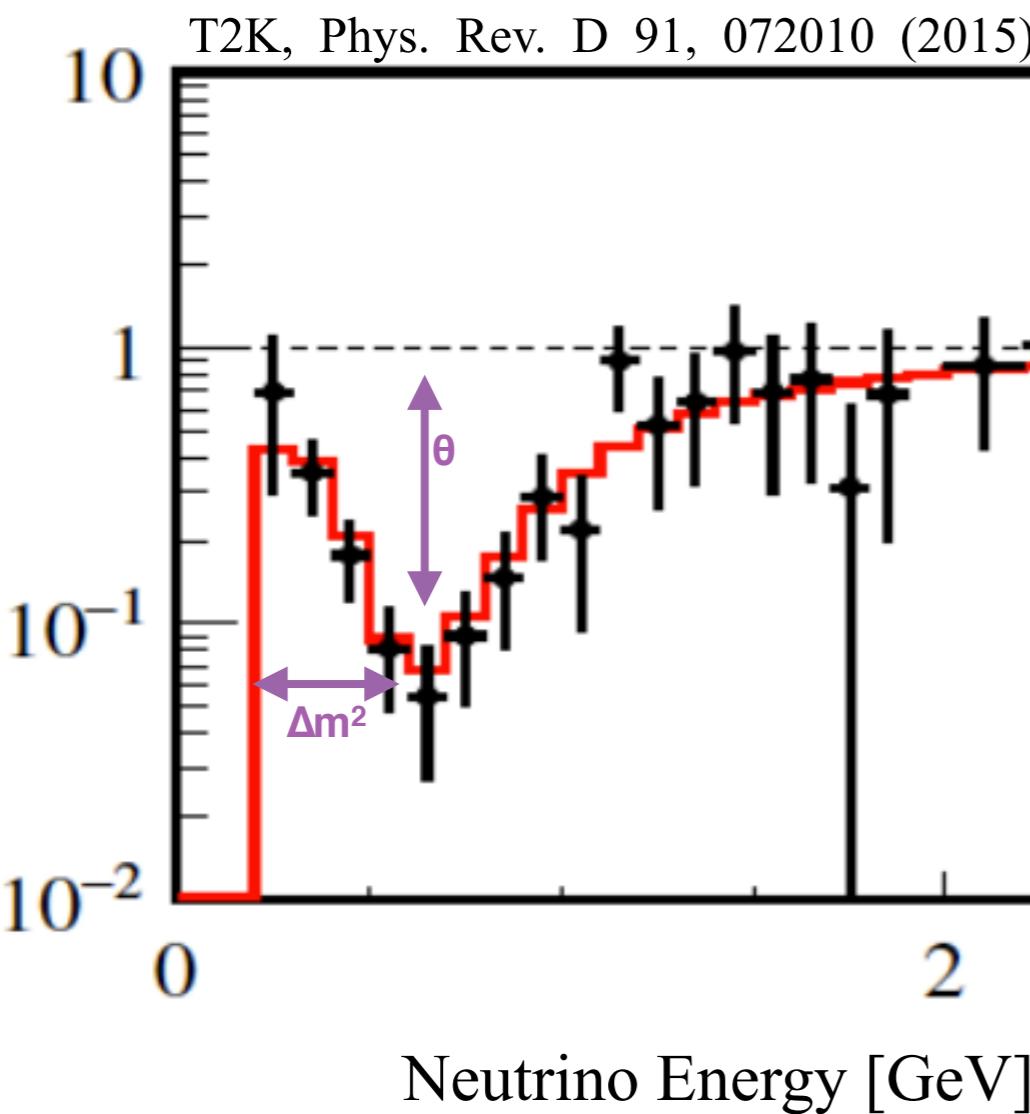
Modelling input is needed for oscillation measurements

$$N(E_{rec}, L) \propto \int \Phi(E, L) \sigma(E) f_\sigma(E, E_{rec}) dE$$

Measurement

Incoming true flux Modelling input

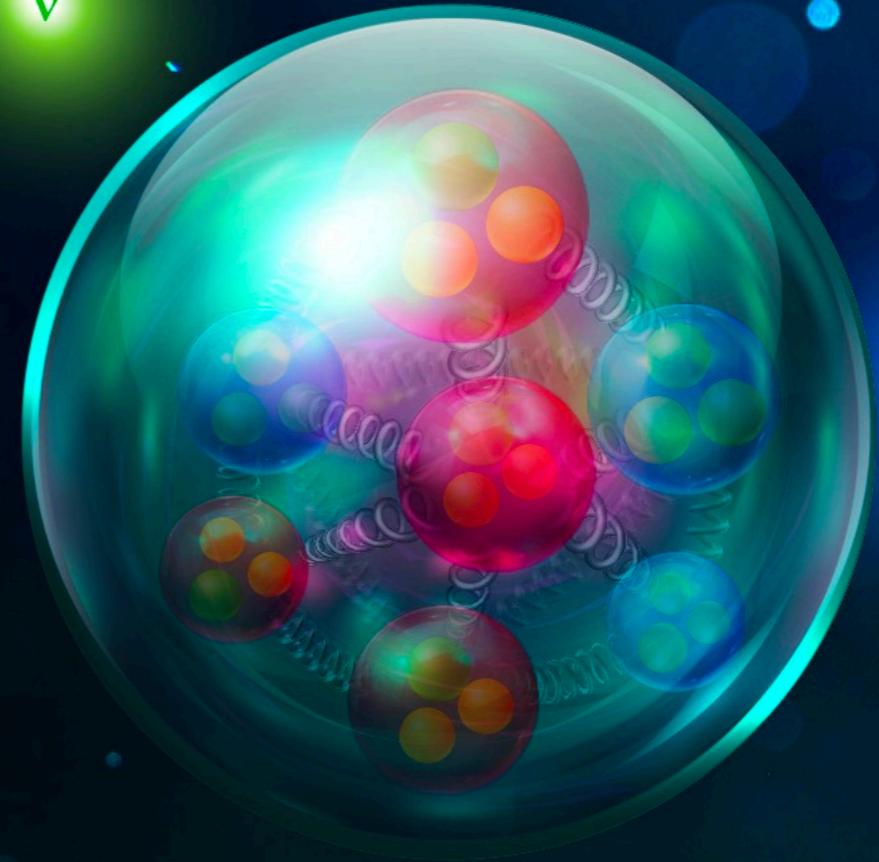
The challenge - next generation high precision



Improving Modelling Input $\sigma(E)f(E,E_{rec})$

Using both electron and neutrino scattering data to:

- Constrain lepton-nucleus interaction models uncertainties
- Test neutrino energy reconstruction





Why electrons?

Electrons and Neutrinos have:

- **Identical initial nuclear state**
- **Same Final State Interactions**
- **Similar interactions**
(vector vs. vector + axial)



Electron beams have known energy

Constraining vA modelling with v & e

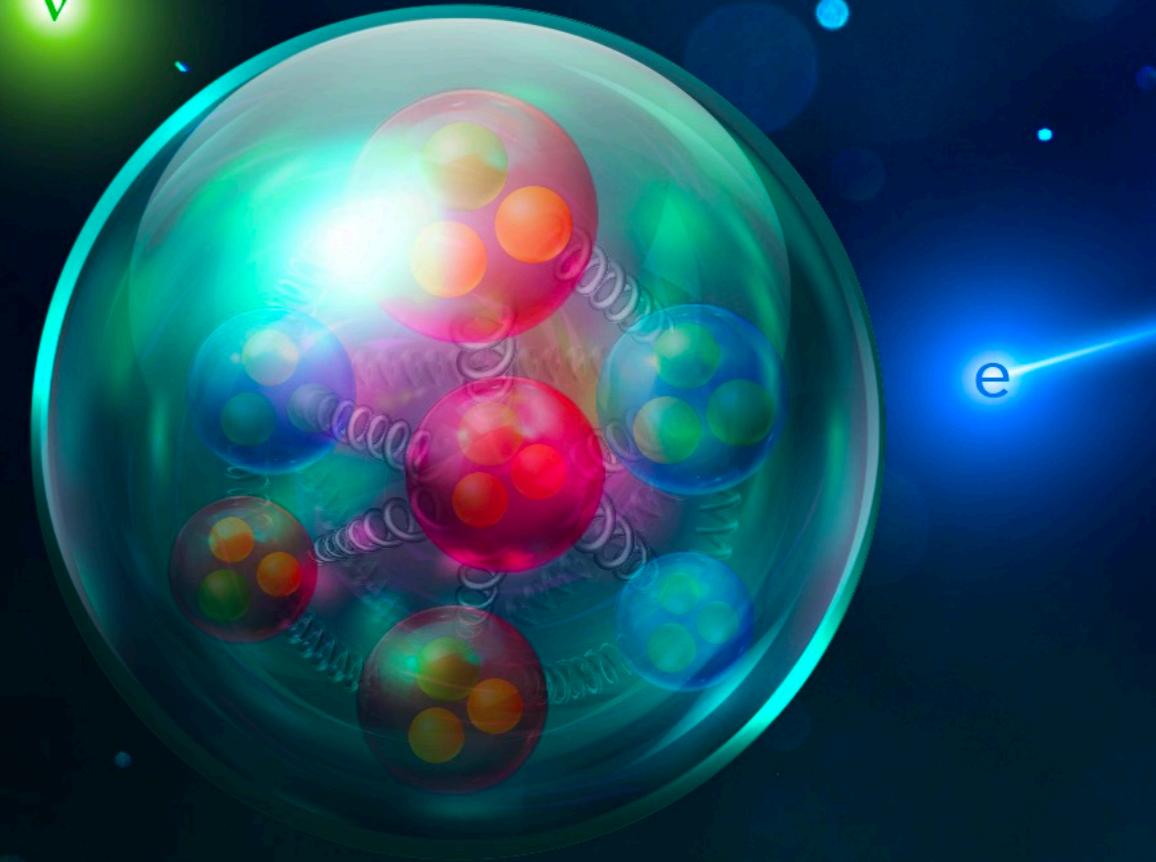
Methodology:

Unify lepton-nucleus models

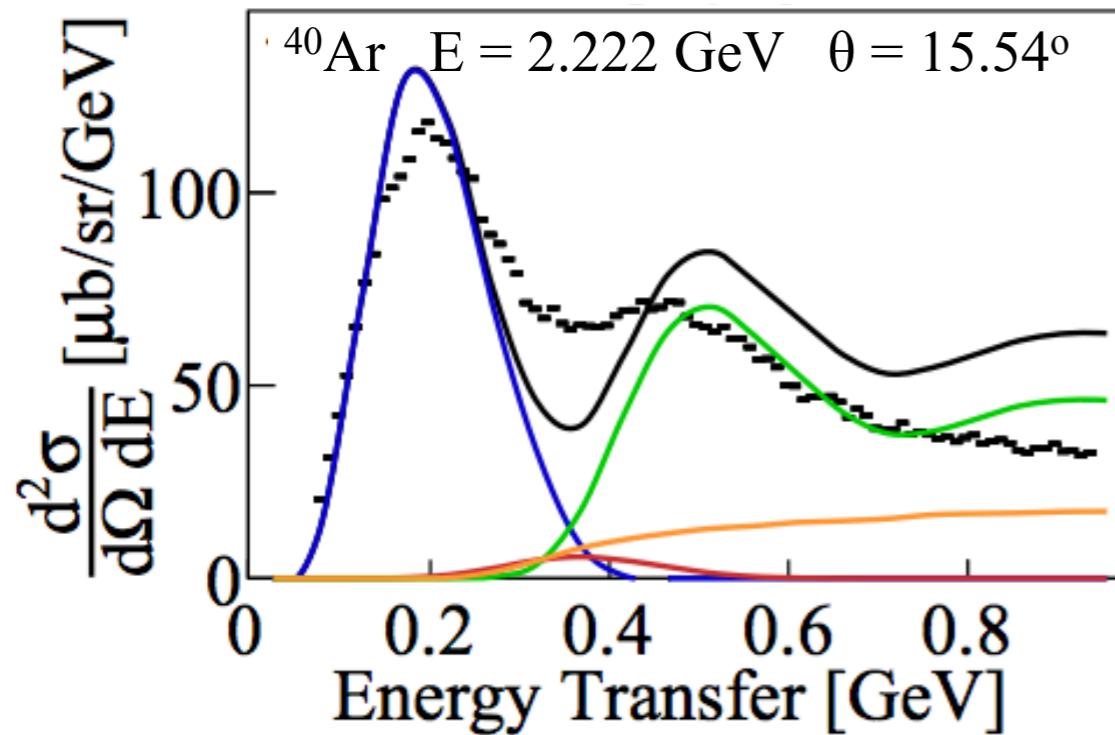
Analyse eA data and vA data

Tune existing models

- First the nuclear and vector part with e
- Then the axial vector part with v

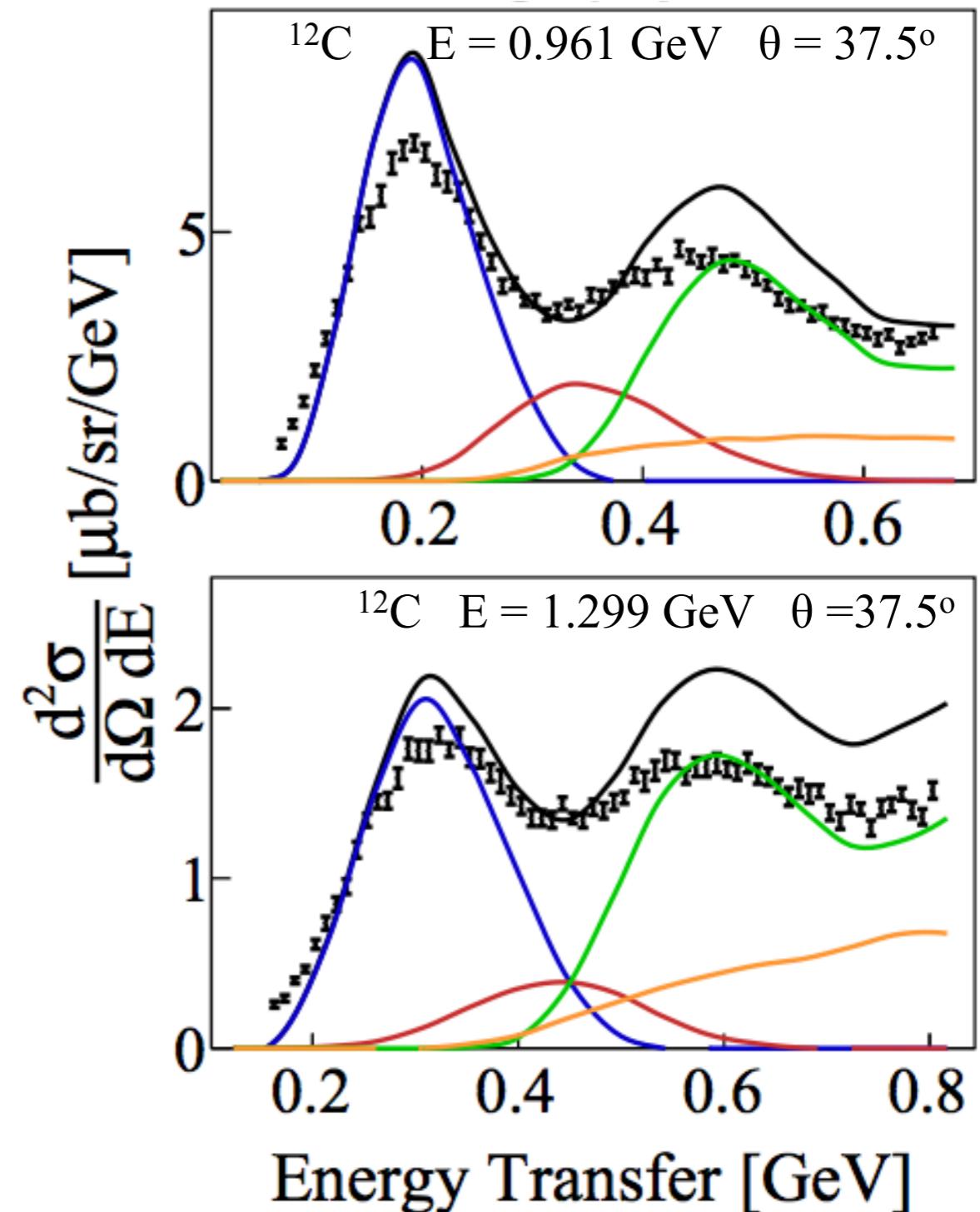


Unifying Models & Testing vs. Inclusive data

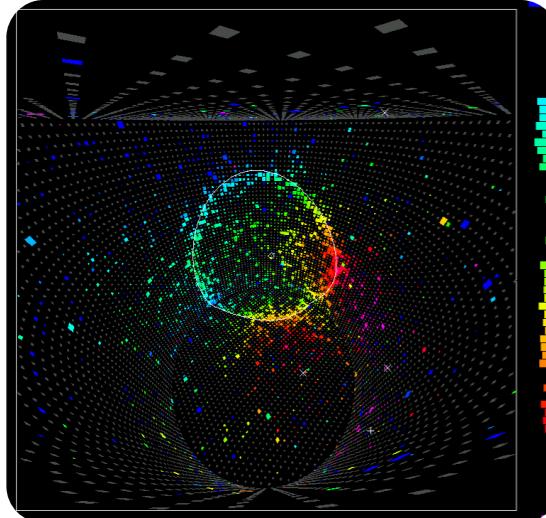


Genie Event Generator
— v3.0.6 tune G18_10a_02_11a

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Incoming Energy Reconstruction



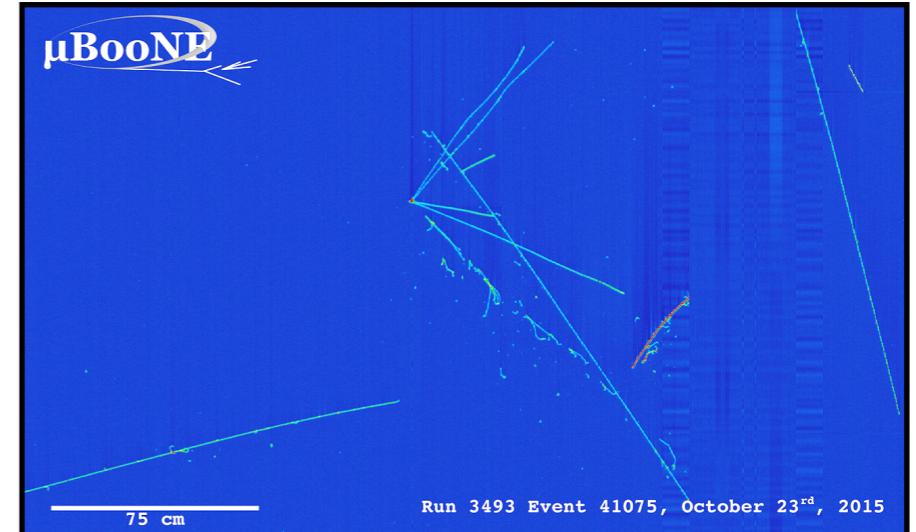
Cherenkov detectors:



Assuming QE interaction

Using lepton only

$$E_{QE} = \frac{2M\epsilon + 2ME_l - m_l^2}{2(M - E_l + |k_l| \cos \theta_l)}$$



Tracking detectors:

Calorimetric sum

Using All detected particles

$$E_{\text{cal}} = E_l + E_p^{\text{kin}} + \epsilon$$

ϵ is the nucleon separation energy ~ 20 MeV

$e4V$ @ the CLAS Detector

Electron beam with energies up to 6 GeV

Large acceptance

Charged particles detection threshold:

300 MeV/c for p

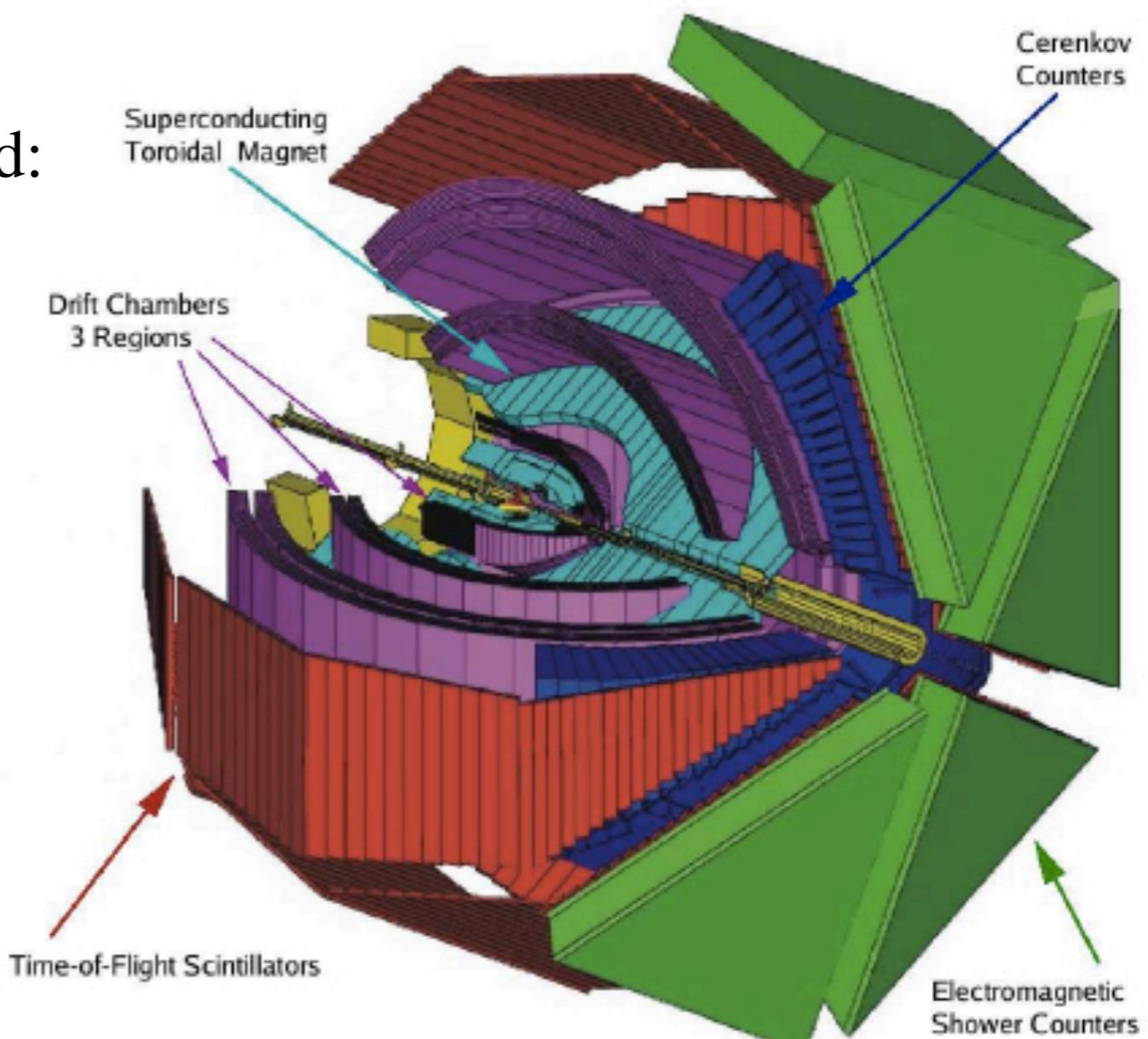
150 MeV/c for $P_{\pi^{+/-}}$

500 MeV/c for P_{π^0}

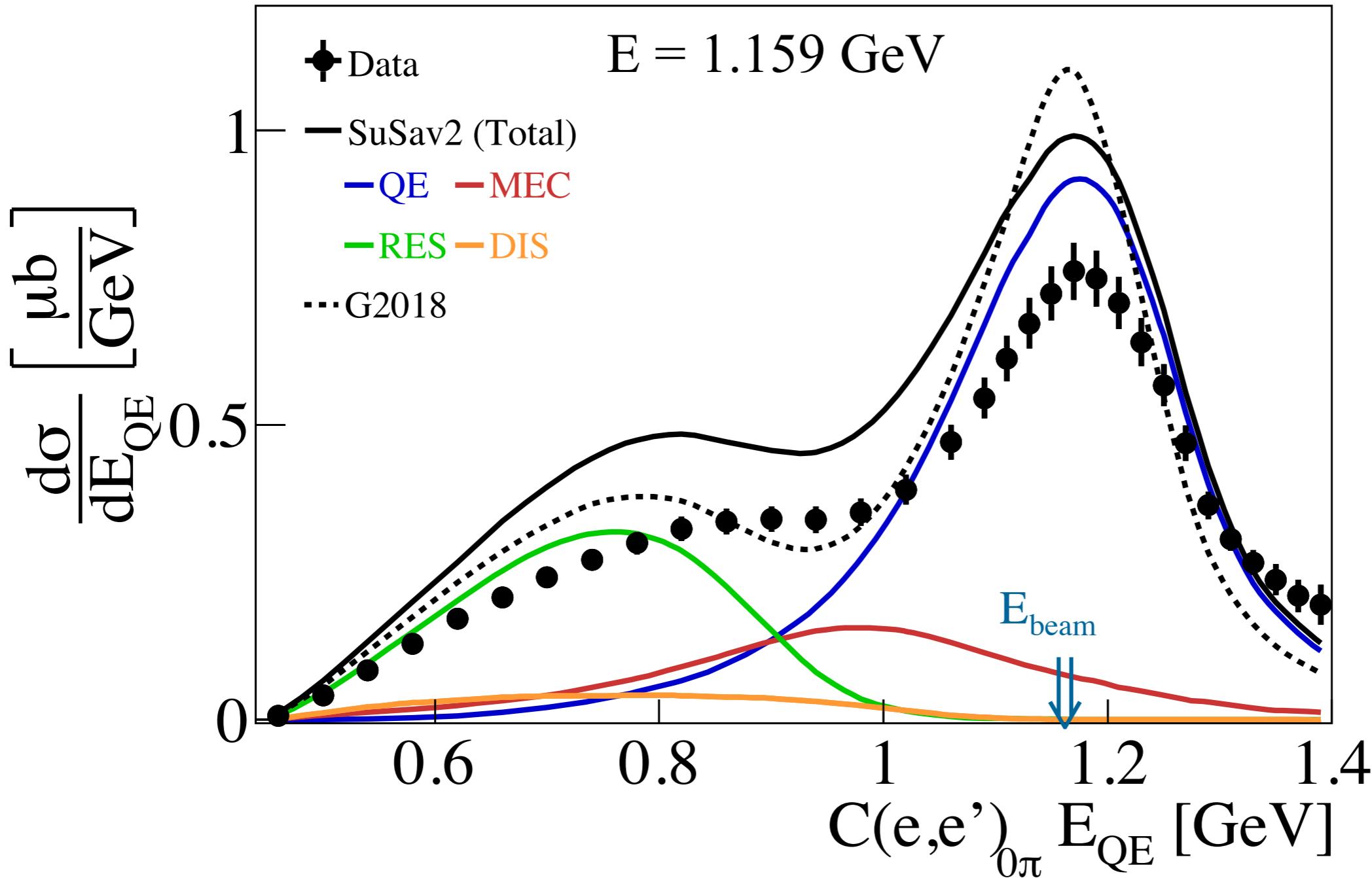
Open Trigger

Targets: ${}^4\text{He}$, ${}^{12}\text{C}$, ${}^{56}\text{Fe}$

Energies: 1.1, 2.2, 4.4 GeV



Inclusive $(e,e')_0\pi$ Energy Reconstruction



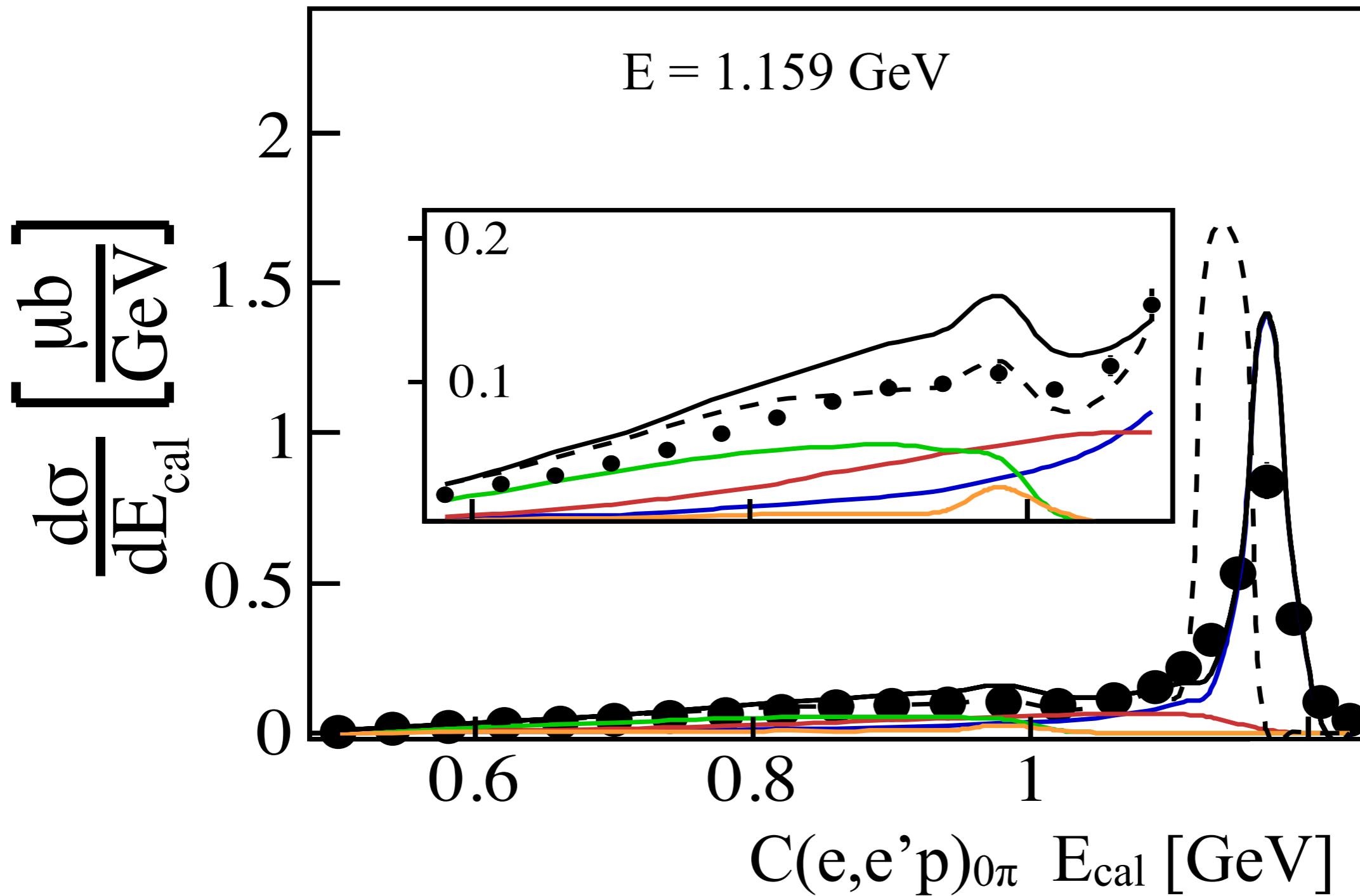
Afroditi
Papadopoulou



Mariana
Khachatryan

$$E_{QE} = \frac{2M\epsilon + 2ME_l - m_l^2}{2(M - E_l + |k_l| \cos \theta_l)}$$

Inclusive $(e,e')_0\pi$ Energy Reconstruction

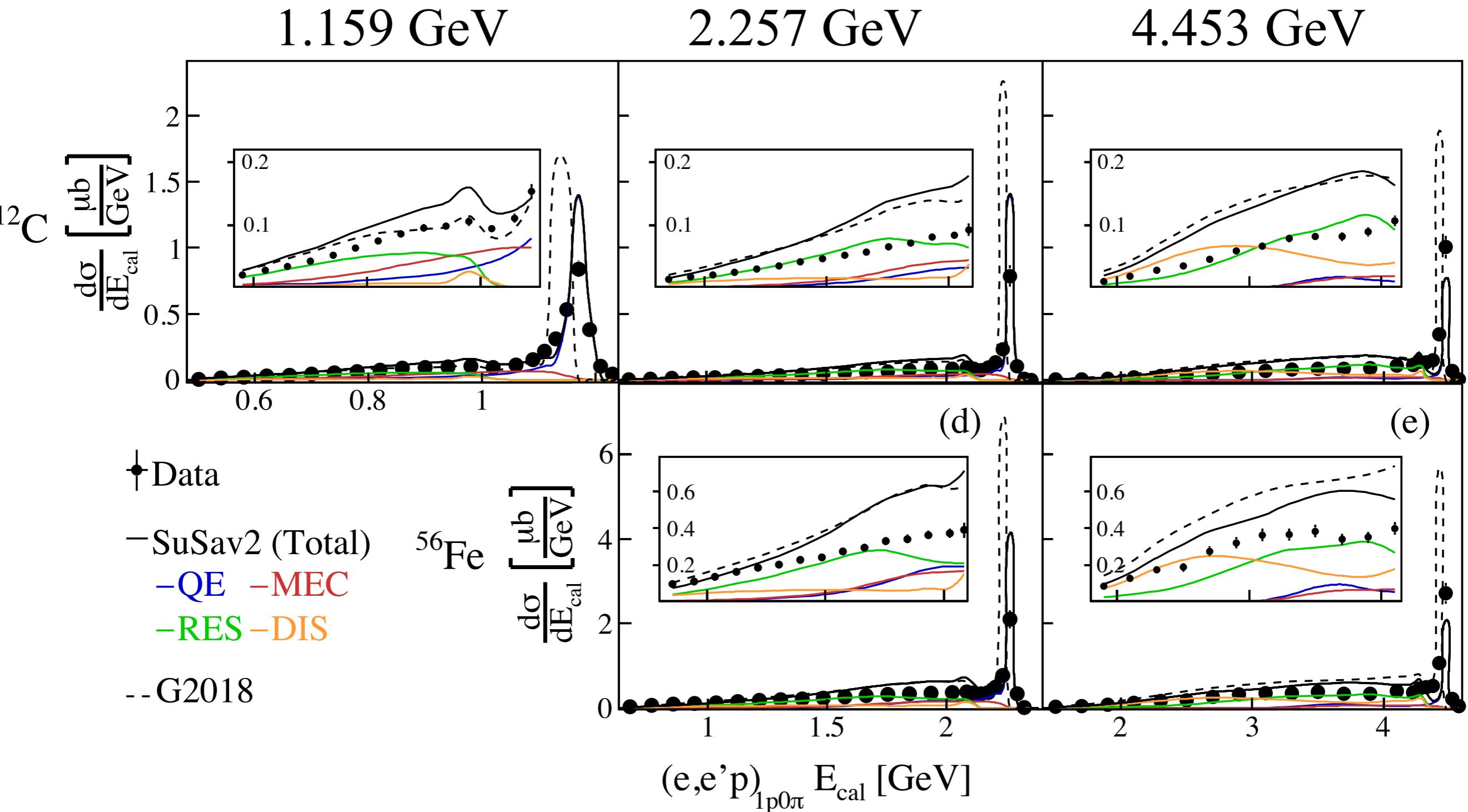


Afroditi
Papadopoulou

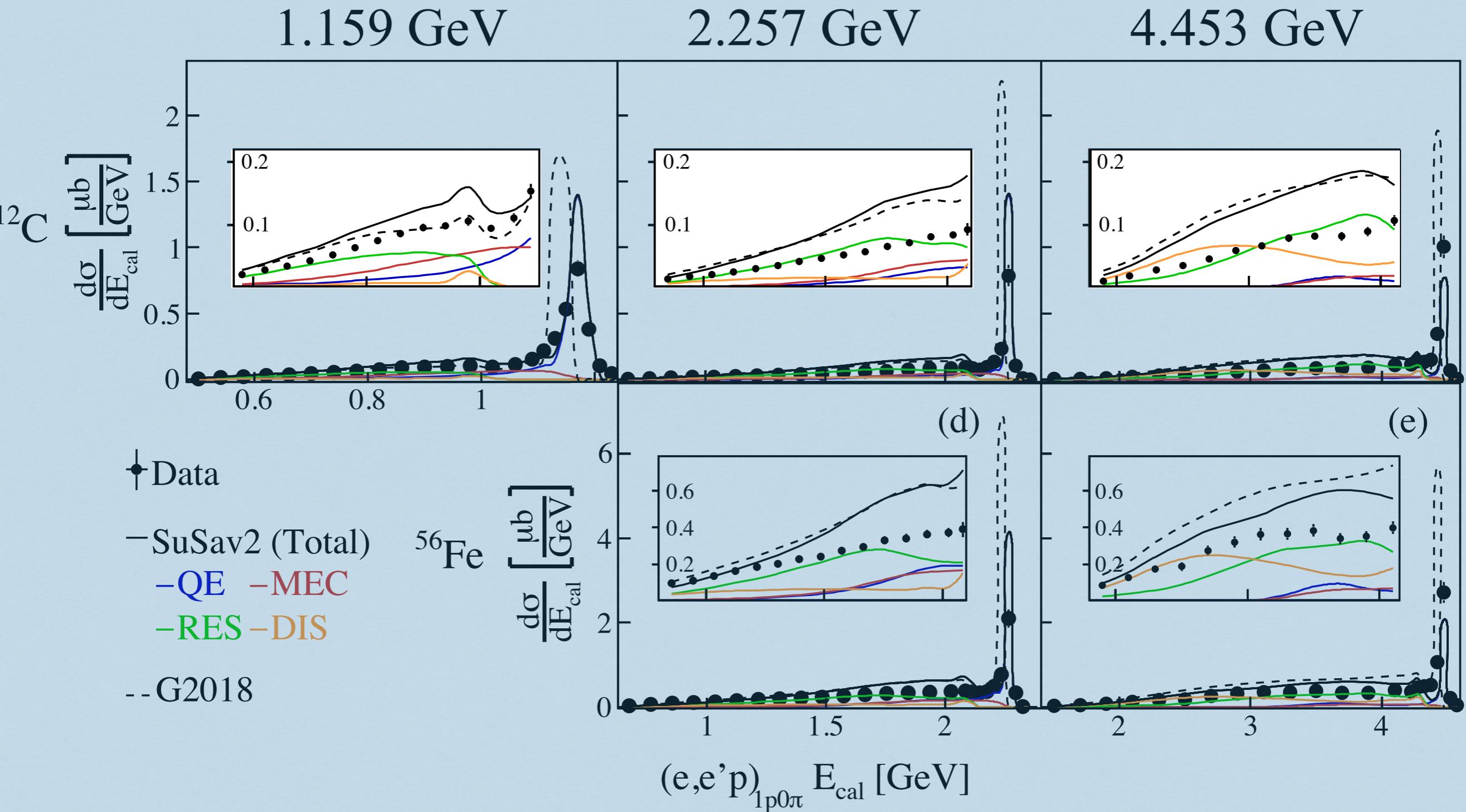


Mariana
Khachatryan

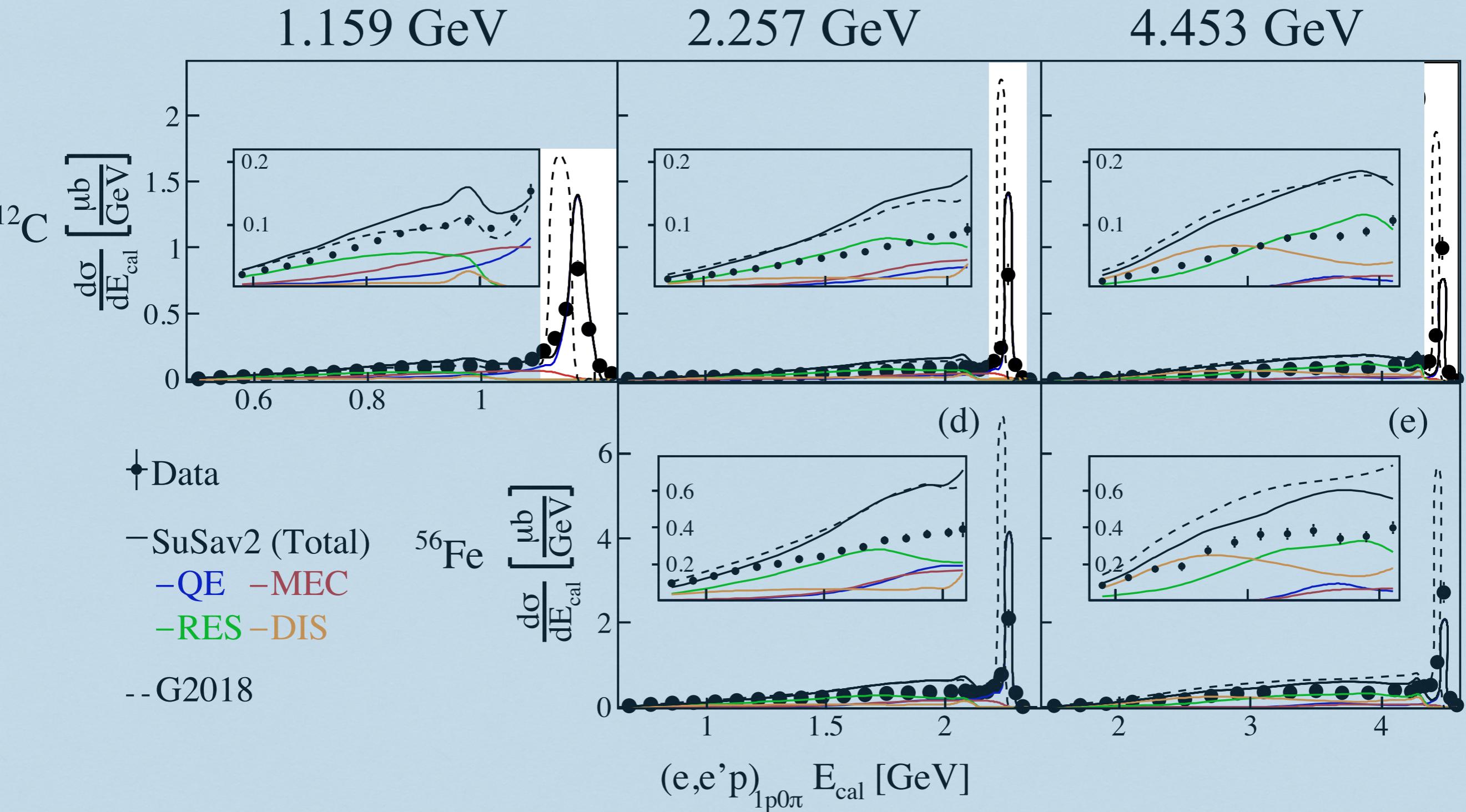
Reconstructed $(e,e'p)_{1p0\pi}$ Calorimetric Energy



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QuasiElastic-like analysis in μ BooNE

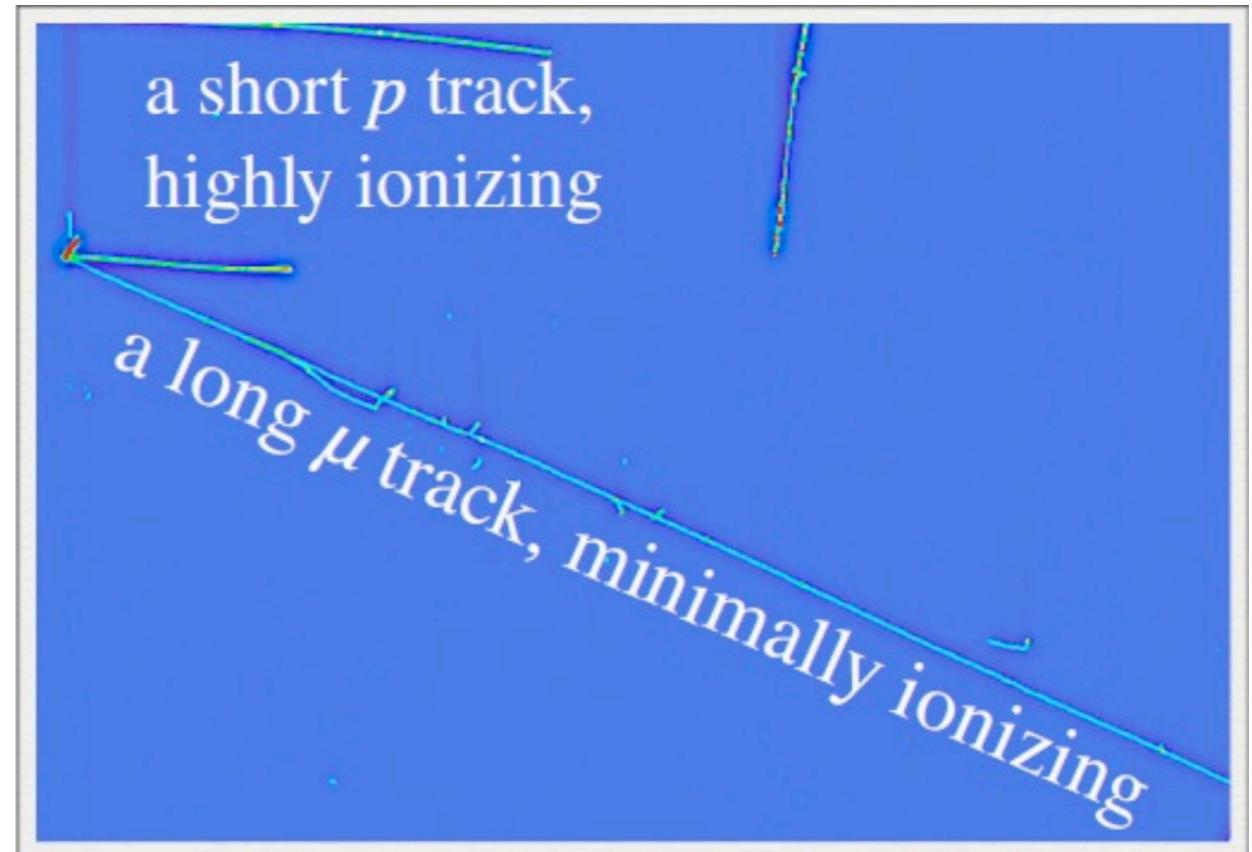
MicroBooNE is a LAr Time Projection Chamber Active mass : 85 tons

Event section:

one muon (**P μ > 100 MeV/c**)

one proton (**P p > 300 MeV/c**)

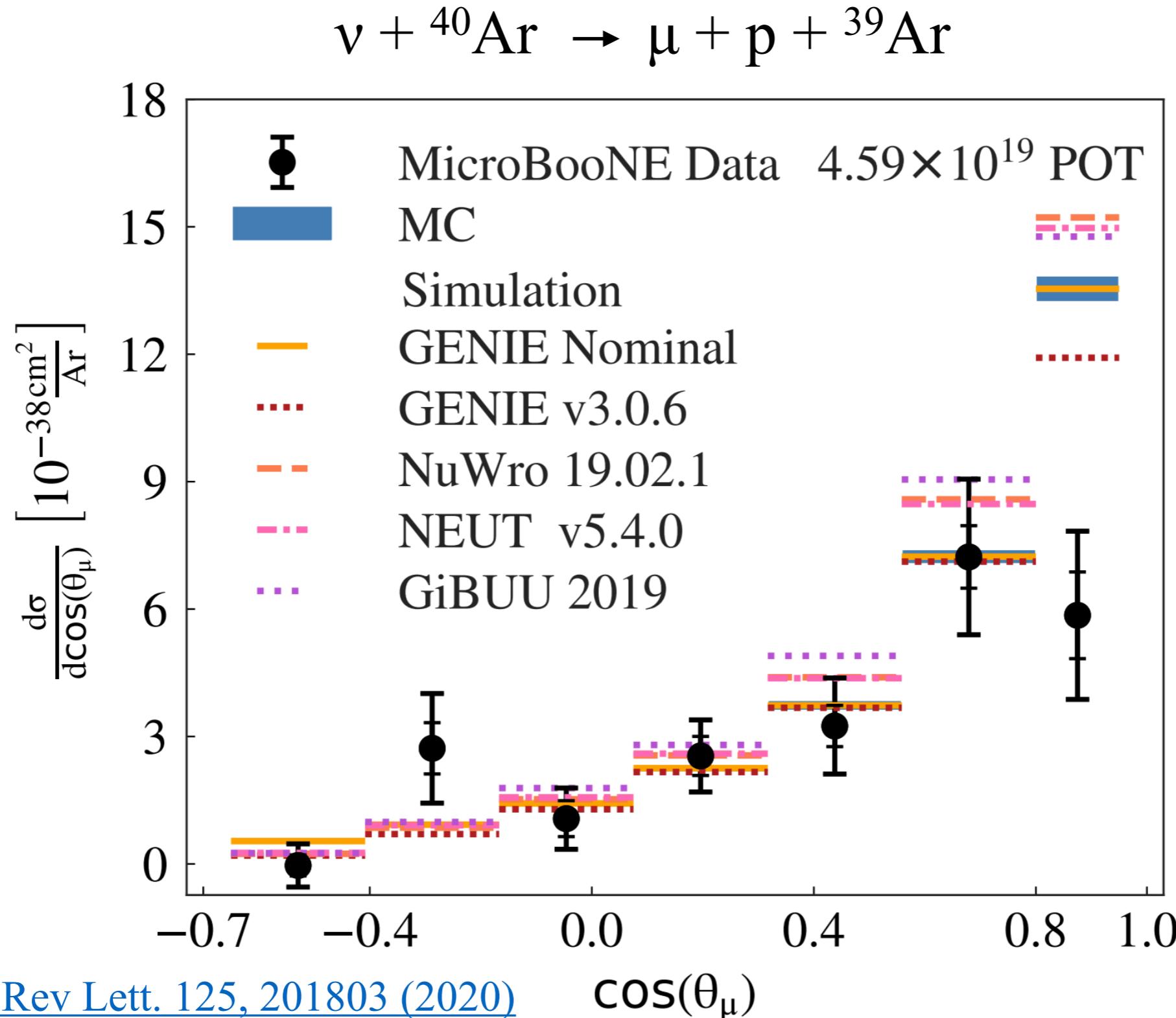
no π^0 , no charged π (≥ 70 MeV/c)



~84% CC1p0 π (~81% CCQE) purity, 20% efficiency

QuasiElastic-like Cross Section

Overall agreement except for forward muon scattering angle

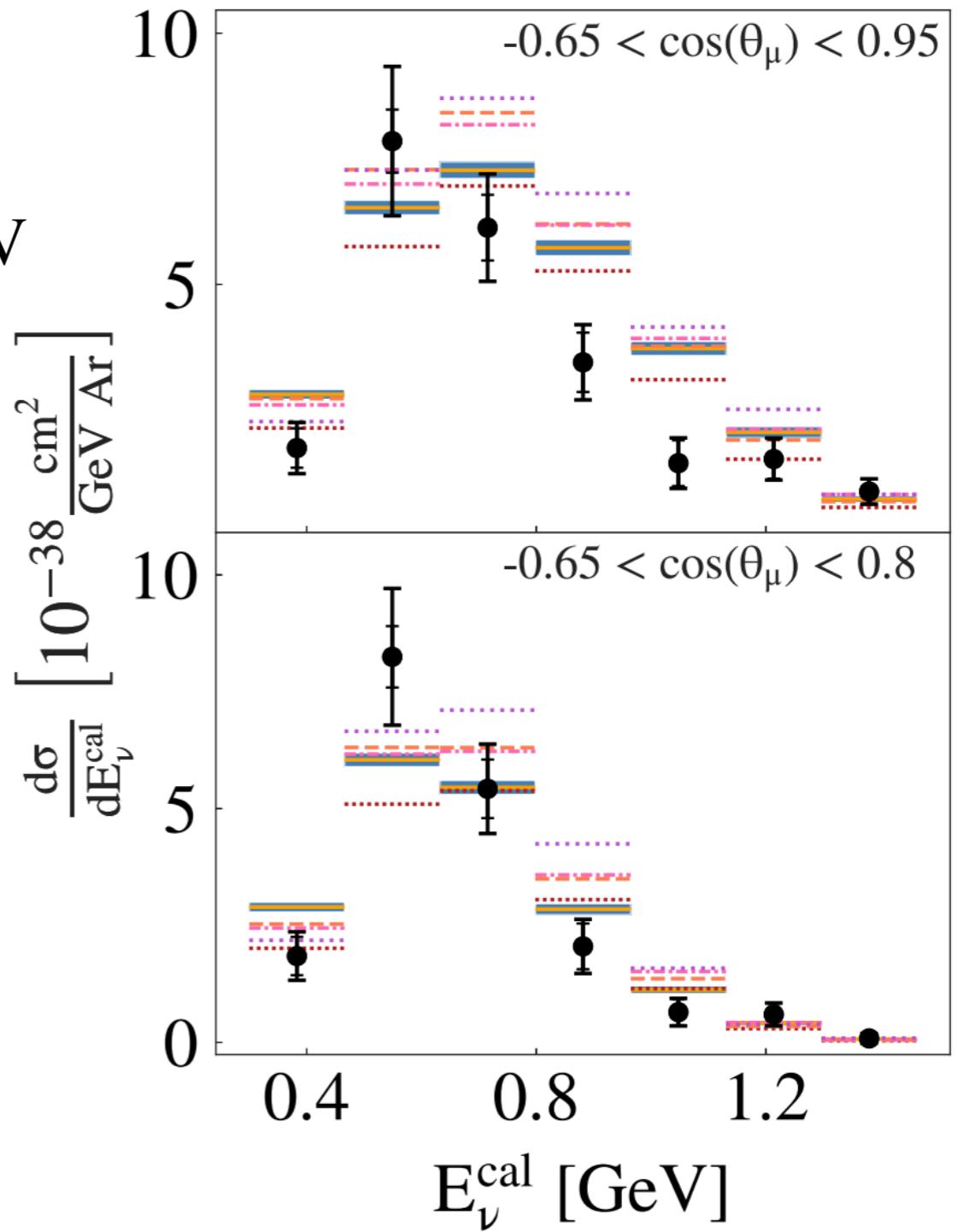


QuasiElastic-like Cross Section

$$E_{\text{cal}} = E_l + E_p^{\text{kin}} + \epsilon$$

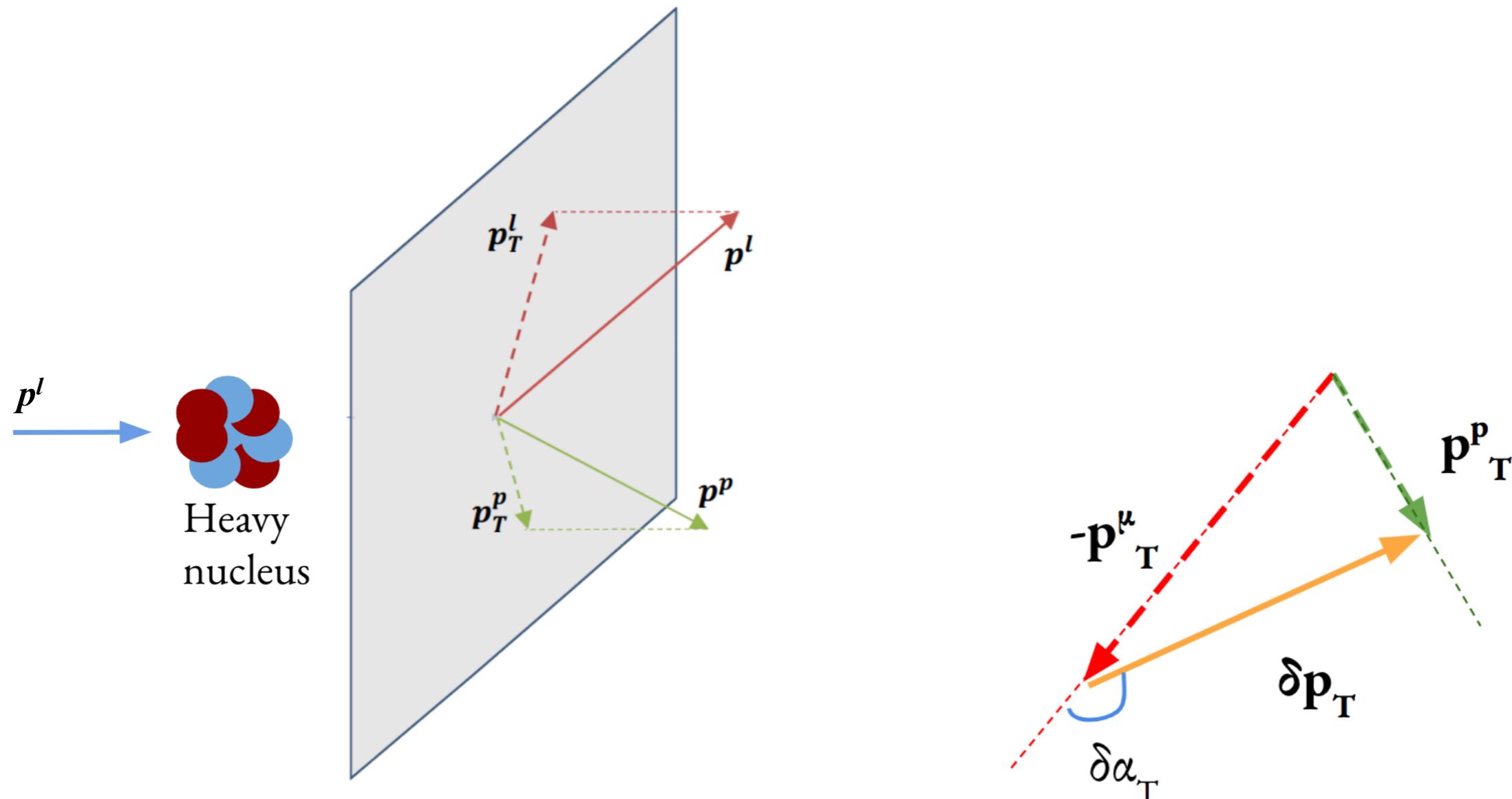
ϵ nucleon separation energy ~ 20 MeV

Better agreement when veto events
with forward scattering lepton



Focusing on different reaction mechanisms

Standard Transverse Variables



$$\vec{P}_T = \vec{P}_T^{e'} + \vec{P}_T^p$$

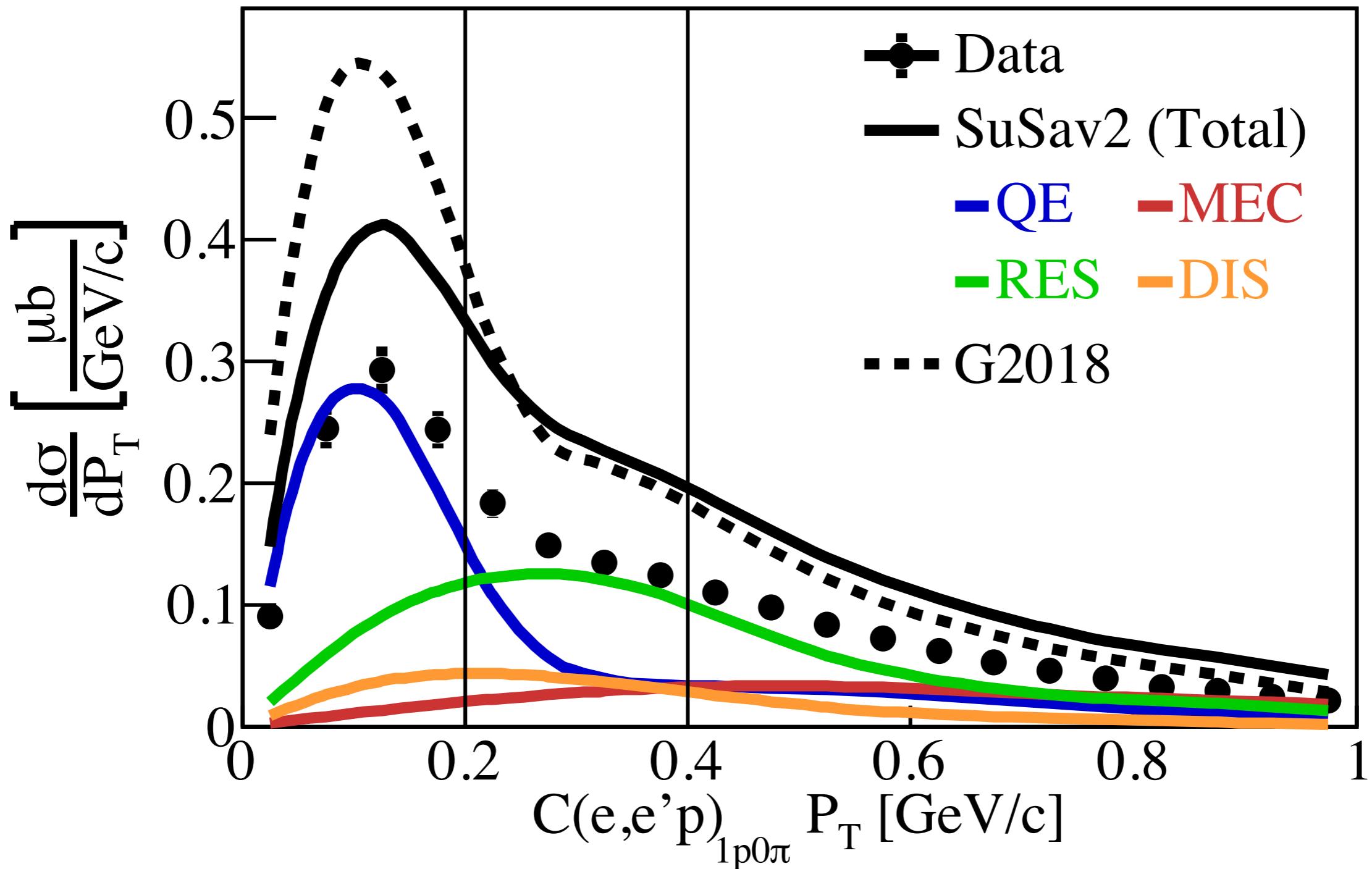
Sensitive to
struck nucleon momentum

$$\delta\alpha_T$$

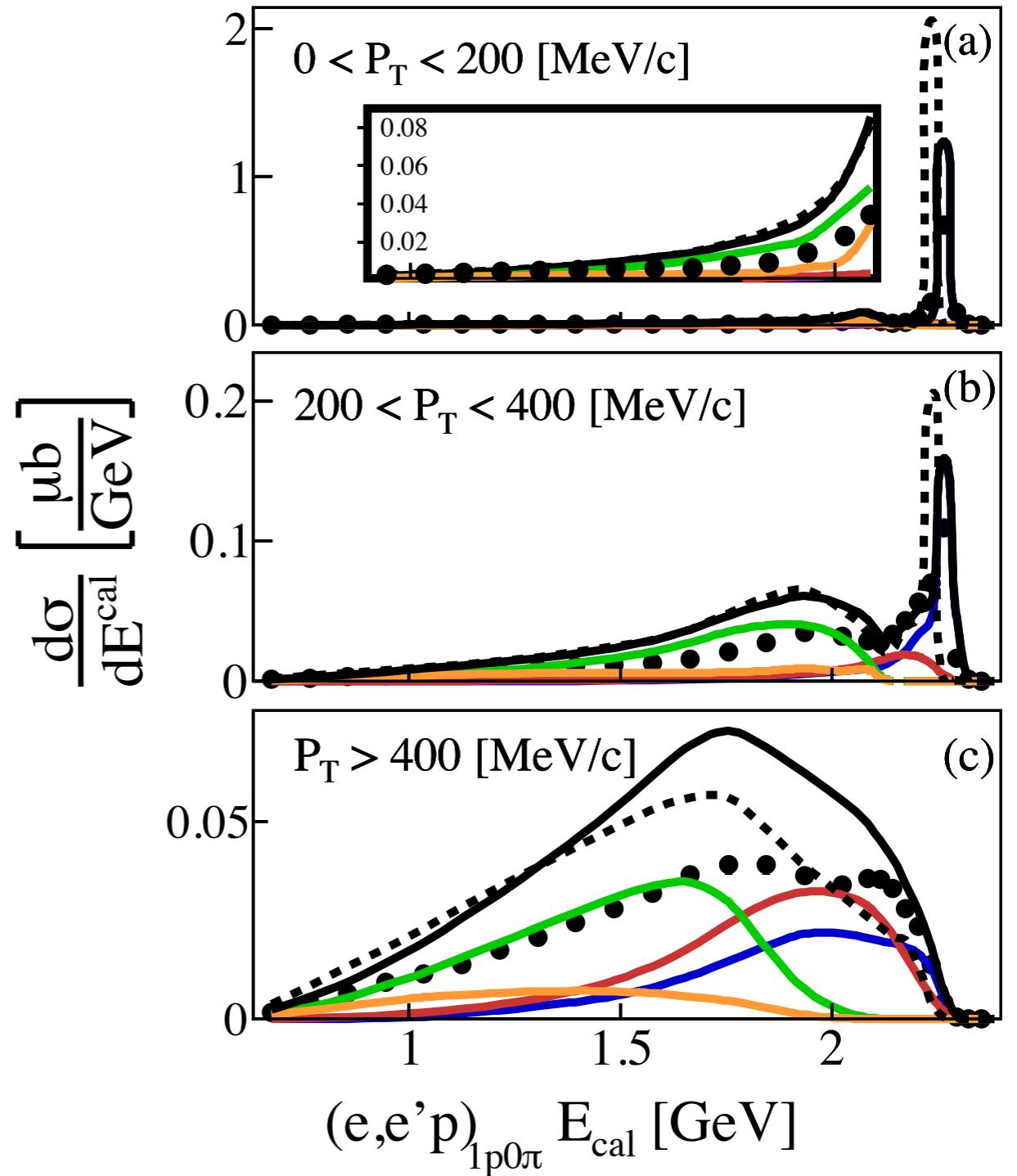
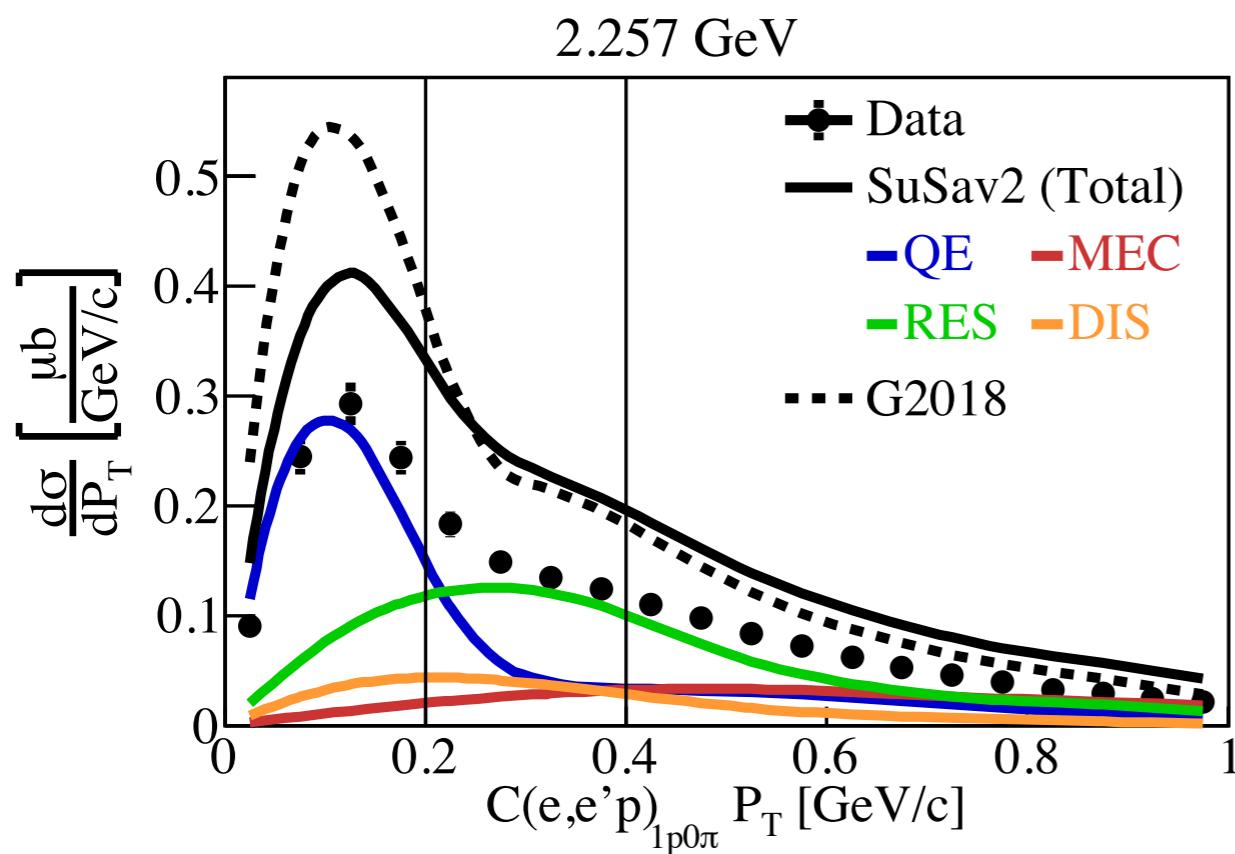
Sensitive to
Final State Interactions, non QE contributions

Transverse missing momentum

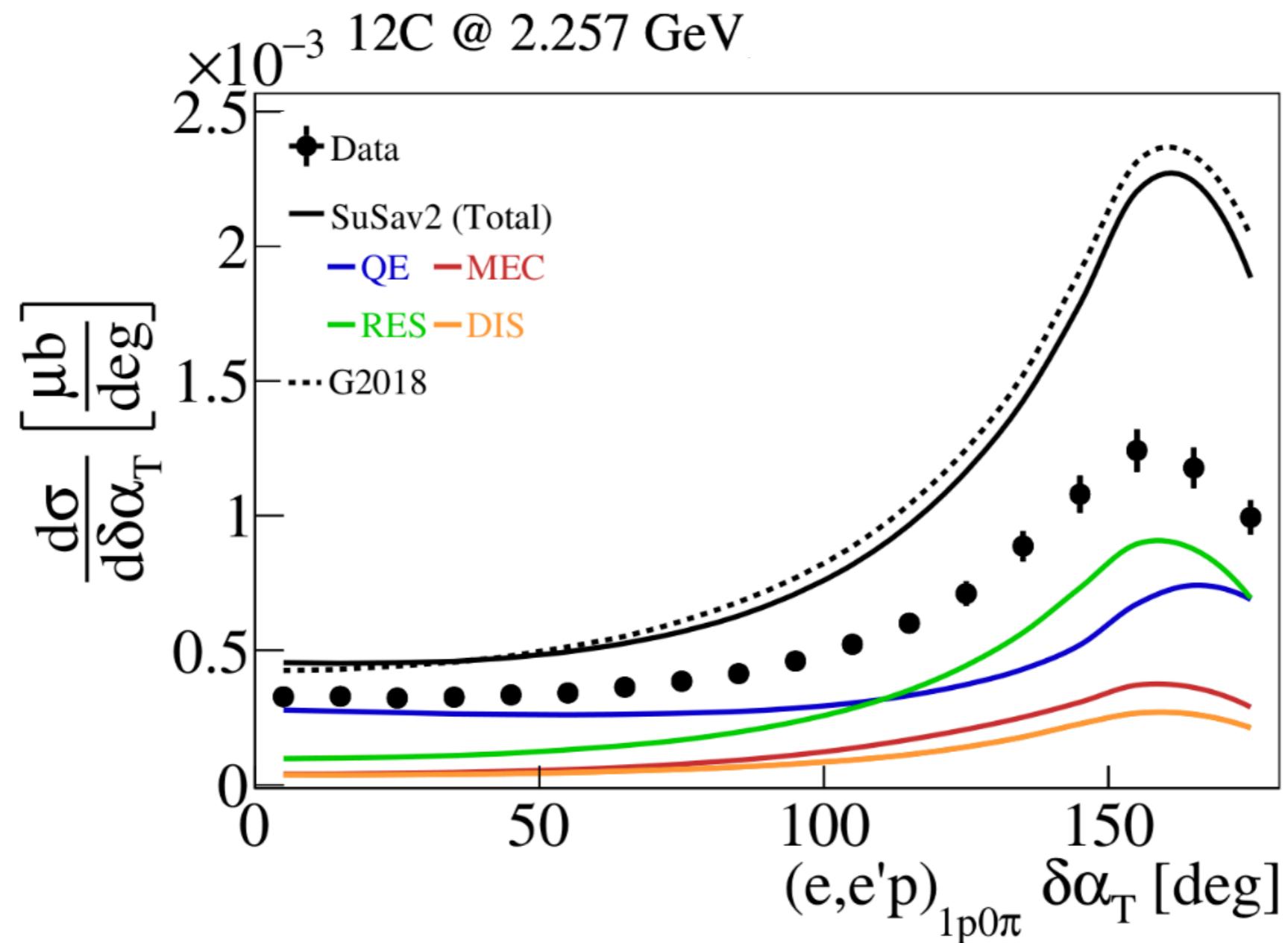
2.257 GeV



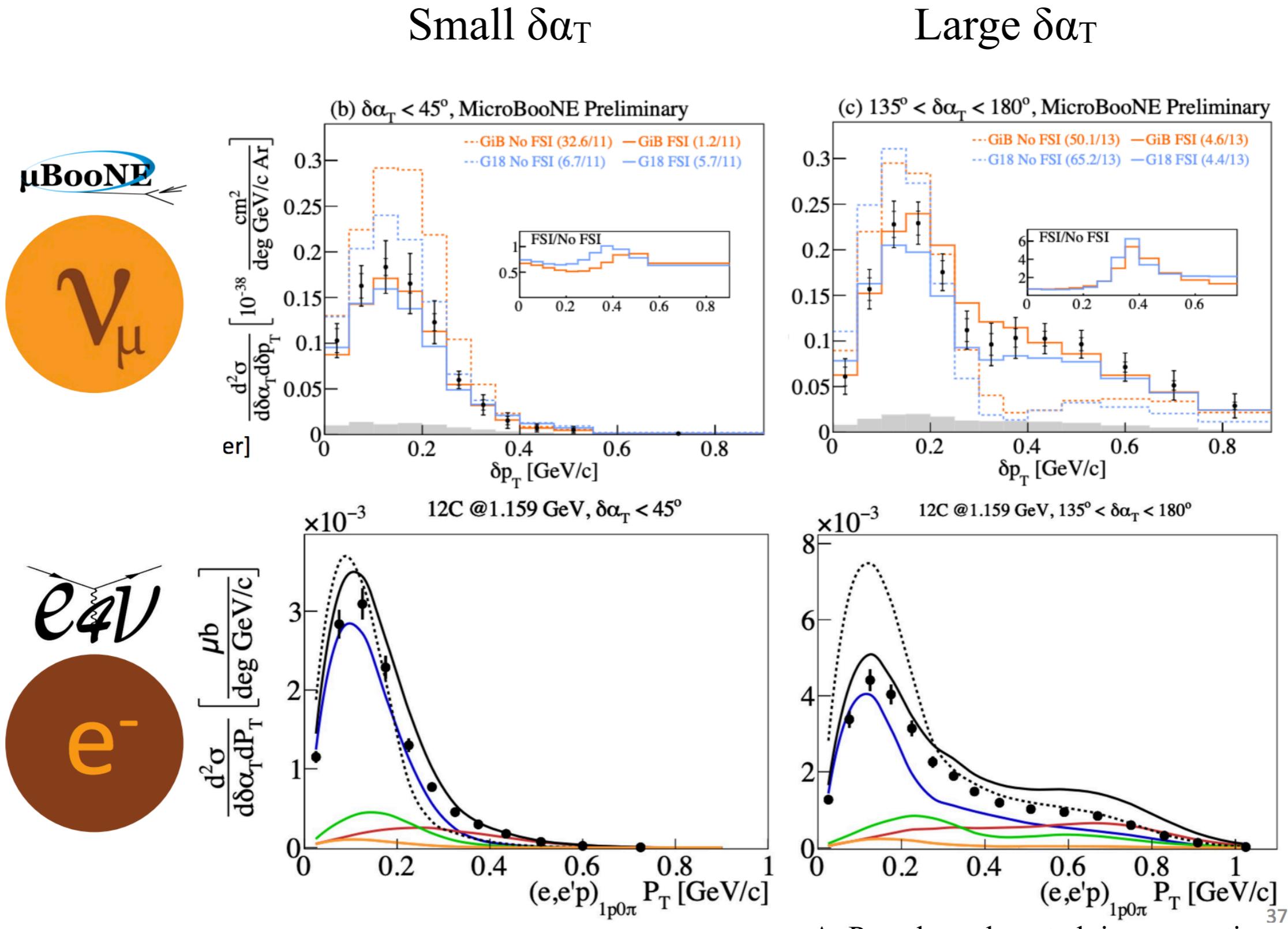
p_T sensitivity to interaction mechanisms



Transverse Kinematic Variables - $\delta\alpha_T$



Similarities between e and ν



New Data from CLAS12

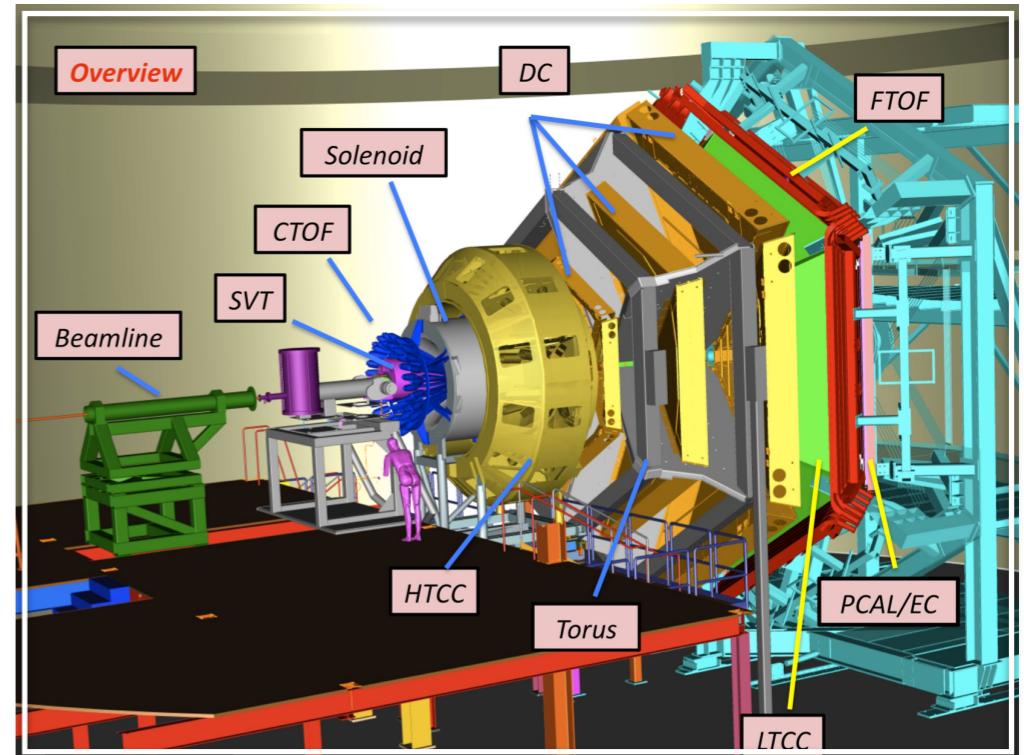
Acceptance down to 5° $Q^2 > 0.04 \text{ GeV}^2$

x10 luminosity [$10^{35} \text{ cm}^{-2}\text{s}^{-1}$]

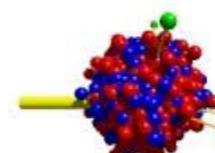
Keep low threshold, better neutron coverage

Targets: ^2D , ^4He , ^{12}C , ^{16}O , ^{40}Ar , ^{40}Ca

(1,) 2, 4, 6 GeV (relevant for DUNE)



Overwhelming support from:



GiBUU
The Giessen Boltzmann-Uehling-Uhlenbeck Project



Justin Estee Joshua Barrow

Summary

νA interaction uncertainties limit oscillation parameters extraction

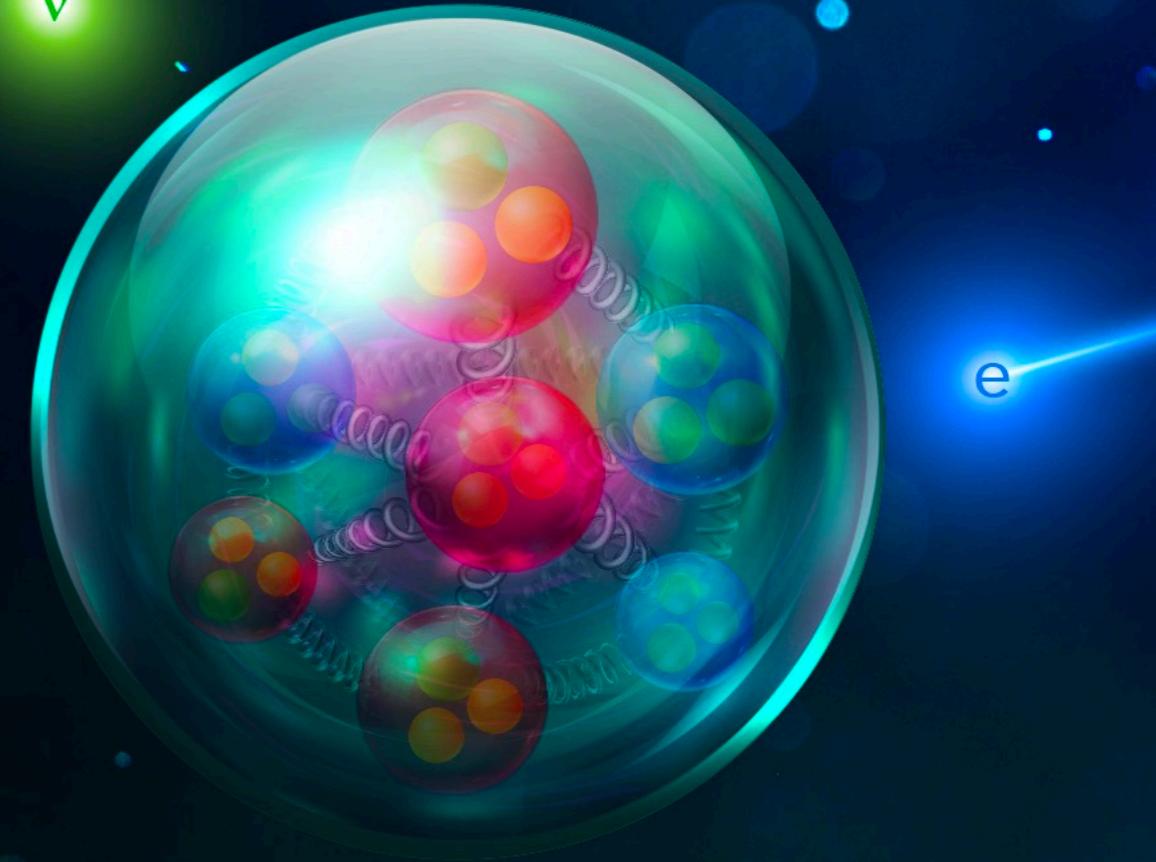
Improving the modelling input in event generators using

e scattering from CLAS

ν scattering data from MicroBooNE

Data/model disagreement even for electron QE-like events especially at high energies, heavy nuclei, and for events with high p_T

New data is on the way



Thank you for your attention

Thank you also to: Or Hen, Larry Weinstein
CLAS, MicroBooNE & e4v Collaborations
The ICHEP2022 organisers
