Electrons for neutrinos

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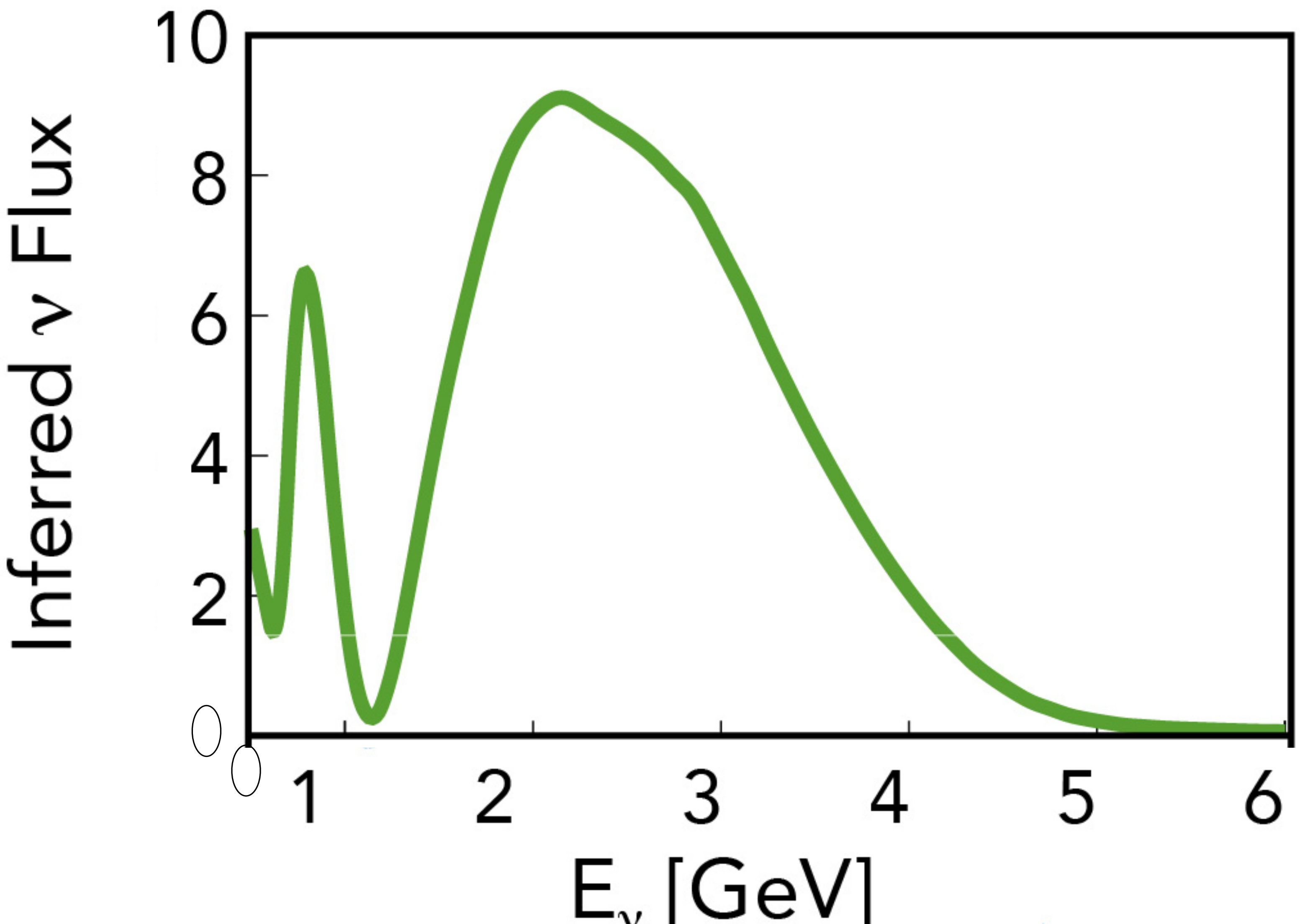
12/10/2020 NuSTEC Board Meeting

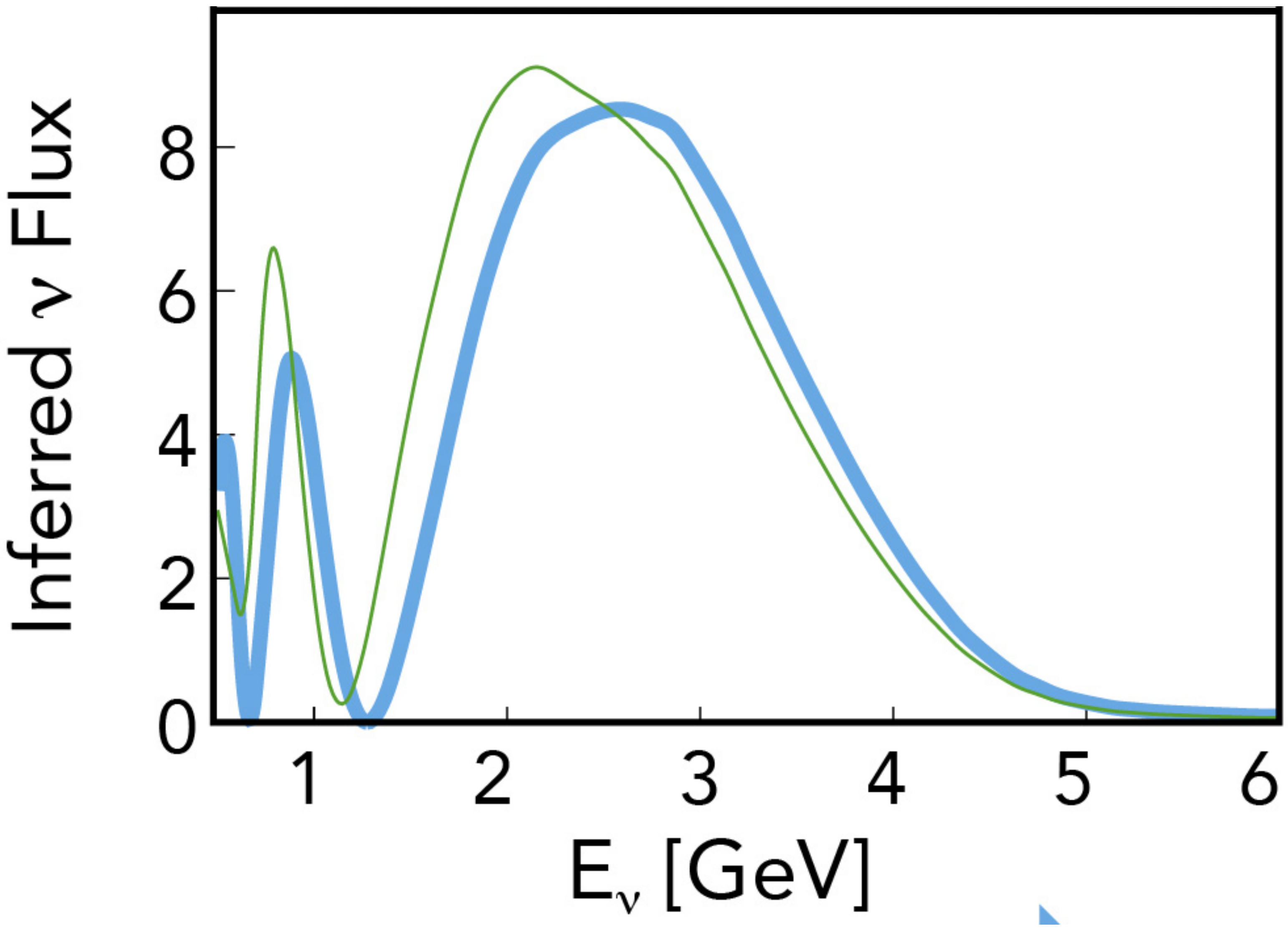
The Challenge - Extract the incoming ν flux



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

Measurement Incoming true flux Modelling input

The Challenge - Modelling dependency



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

Measurement Incoming true flux Modelling input

How to improve modelling?

Improve theory

$$\sigma(E) f_\sigma(E, E_{rec})$$

Modelling input

How to improve modelling?

Improve theory

$$\sigma(E) f_\sigma(E, E_{rec})$$

Modelling input

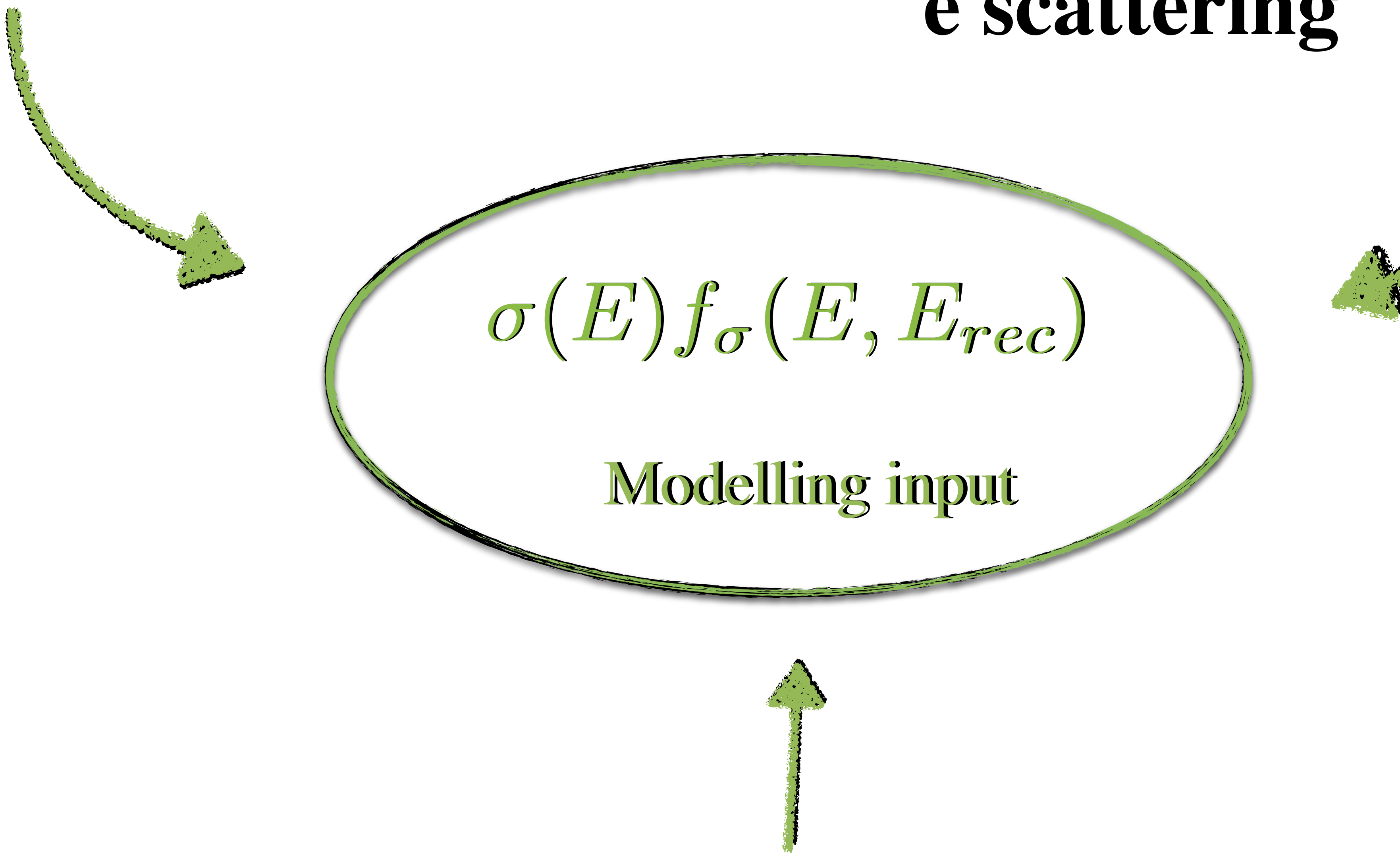
Use near detector

How to improve modelling?

Improve theory

Use external constraints

e scattering

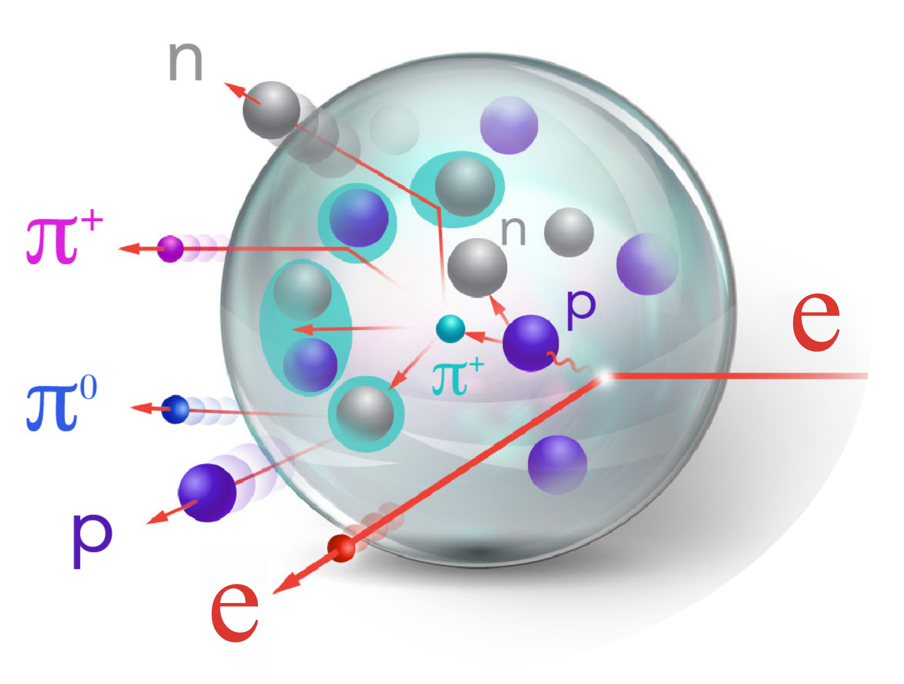


Use near detector

Why Electrons?

- Electrons and Neutrinos have:
  - Similar interactions
    - Vector vs. Vector + Axial Vector
  - Many identical nuclear effects
    - Ground state (spectral function)
    - Final state interactions

Electron beams have known energy



Objectives

Leverage wide phase space exclusive electron scattering data for the benefit of neutrino experiments

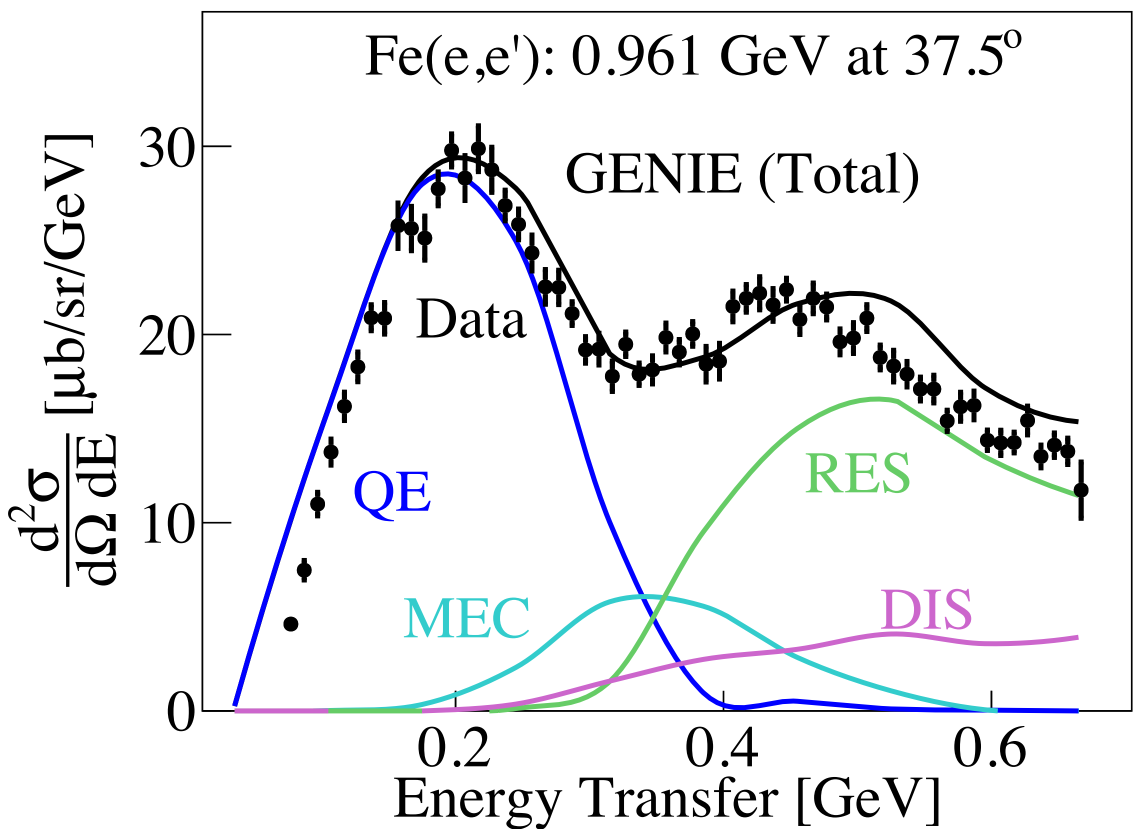
- Benchmark neutrino event generators
- Constrain modelling systematic uncertainties
- By analysing as many channel as possible
- Testing incoming energy and A dependencies
- Showing implication on neutrino physics
- Improve modelling and offer dedicated tunes

Event Generator

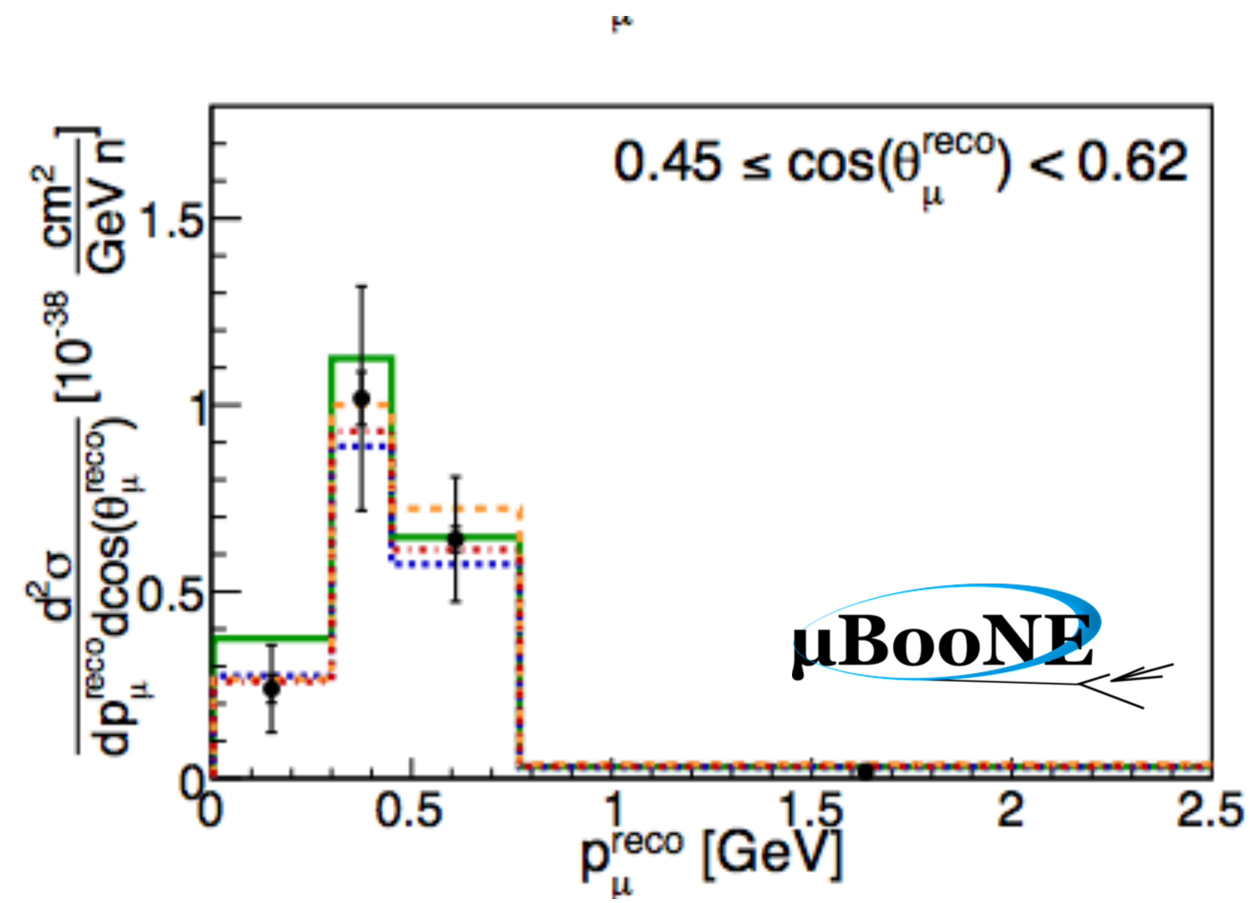
Genie widely in use by the US neutrino community

Latest version v3.0.6 tune G18_10a_02_11a

Nicely reproducing inclusive results



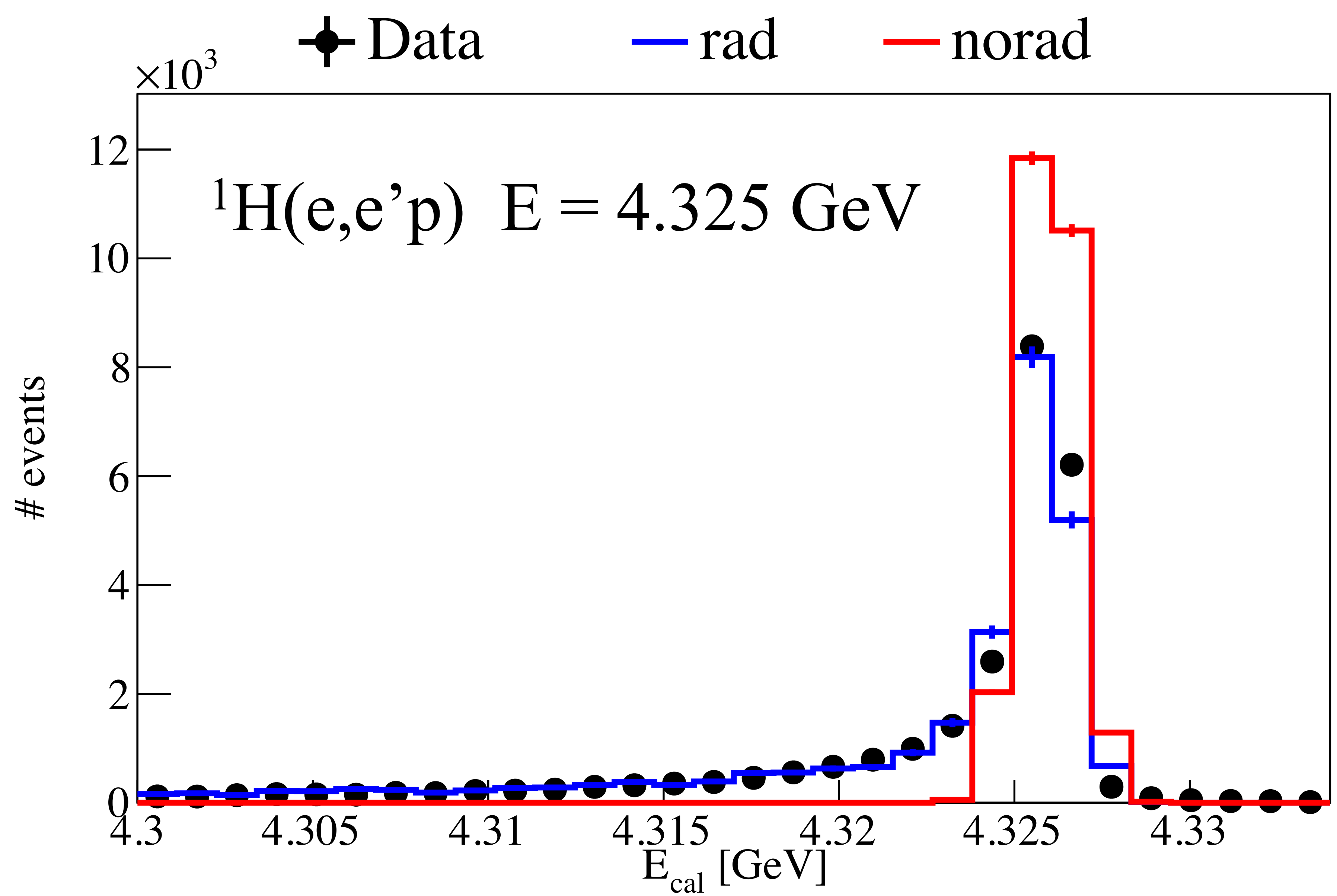
arXiv:2009.07228 [nucl-th]



Phys. Rev. Lett. 123, 131801 (2019)

Genie Event Generator

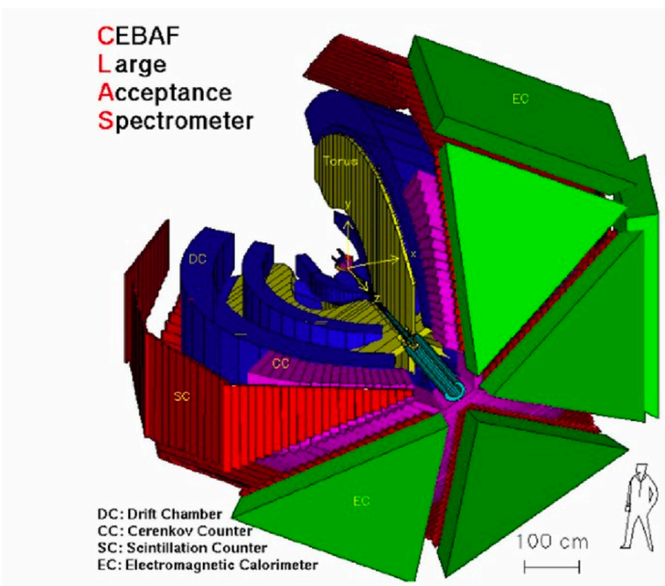
Adding radiative effects



v3.0.6 tune G18_10a_02_11a [Mo and Tsai]

Possible electron facilities

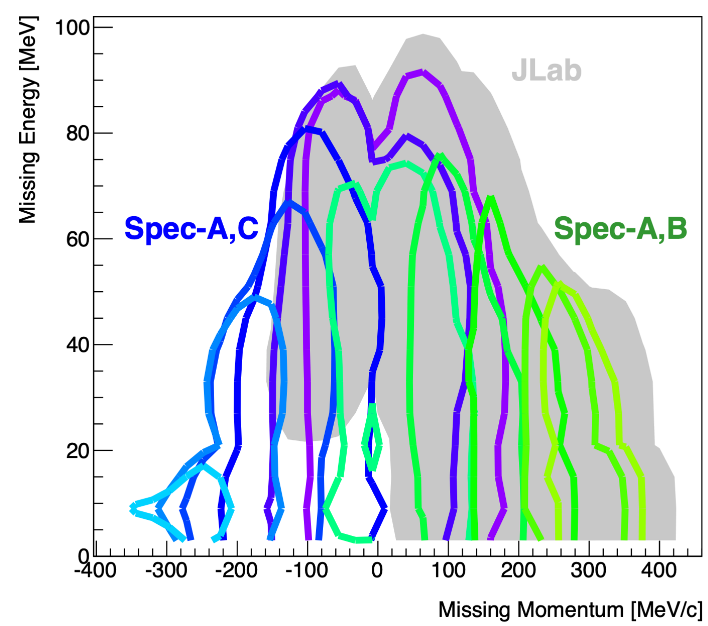
e4ν



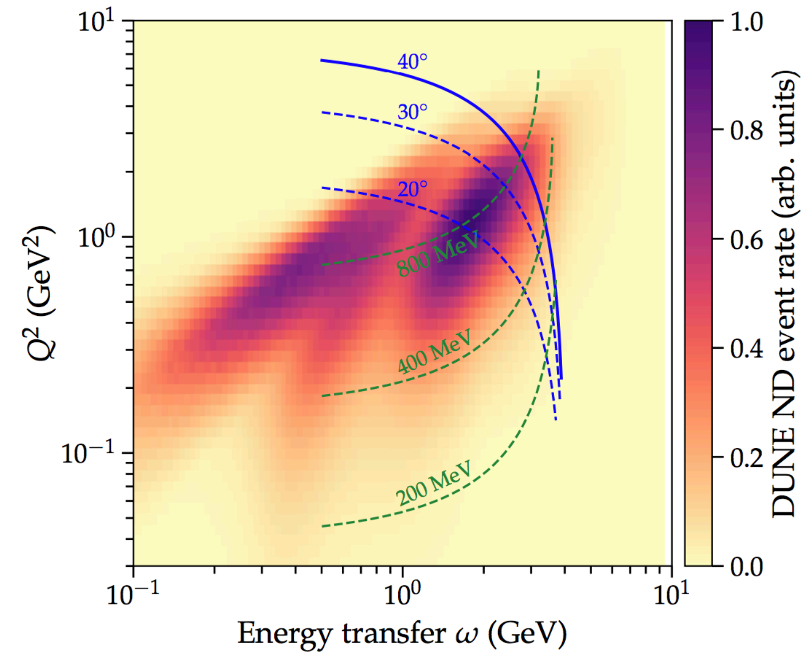
Jefferson Lab

LOI 102

Mainz MAMI accelerator testing their sensitivity



Lepton-Nucleus σ Measurements with LDMX



PRD 101, 053004 (2020)

SLAC

LOI 91

General LOI 147

CLAS Detector

Large acceptance, Open Trigger

Charged particle detection thresholds:

$\theta_e > 15^o$

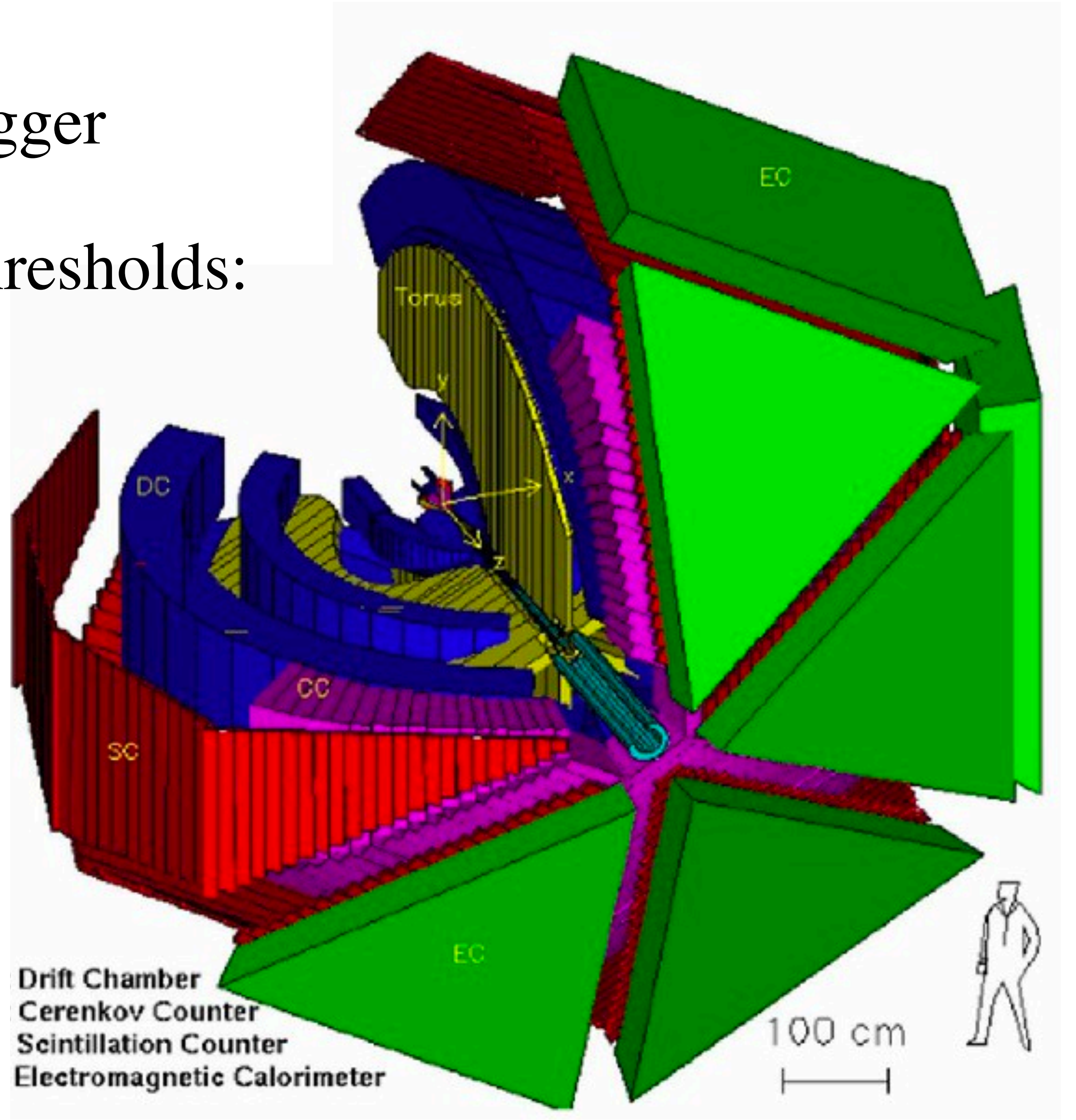
$P_p > 300$ MeV/c

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

$P_{\pi 0} > 500$ MeV/c

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

Energies: 1.1 , 2.2, 4.4 GeV



e4ν 1p0π Event Selection

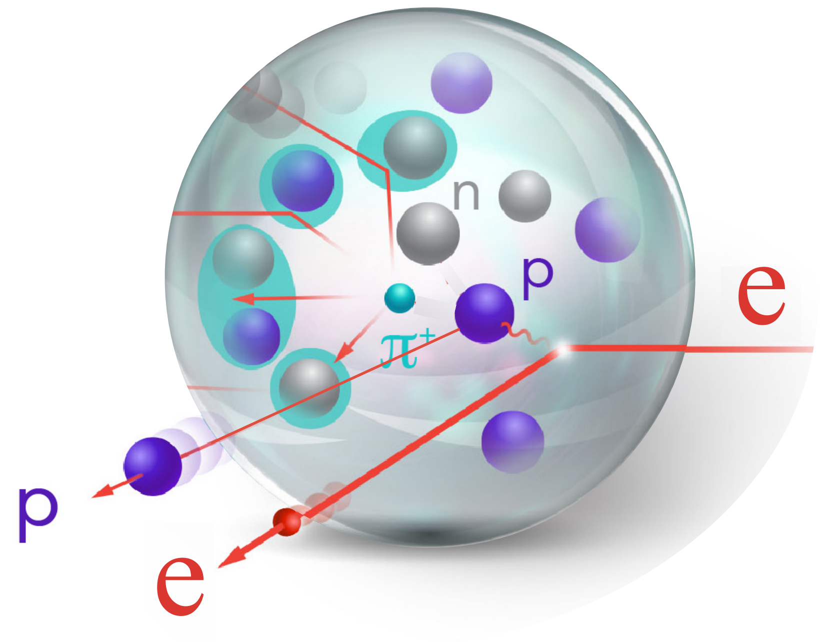
Focus on Quasi Elastic events:

1 proton above 300 MeV/c

no additional hadrons above threshold:

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

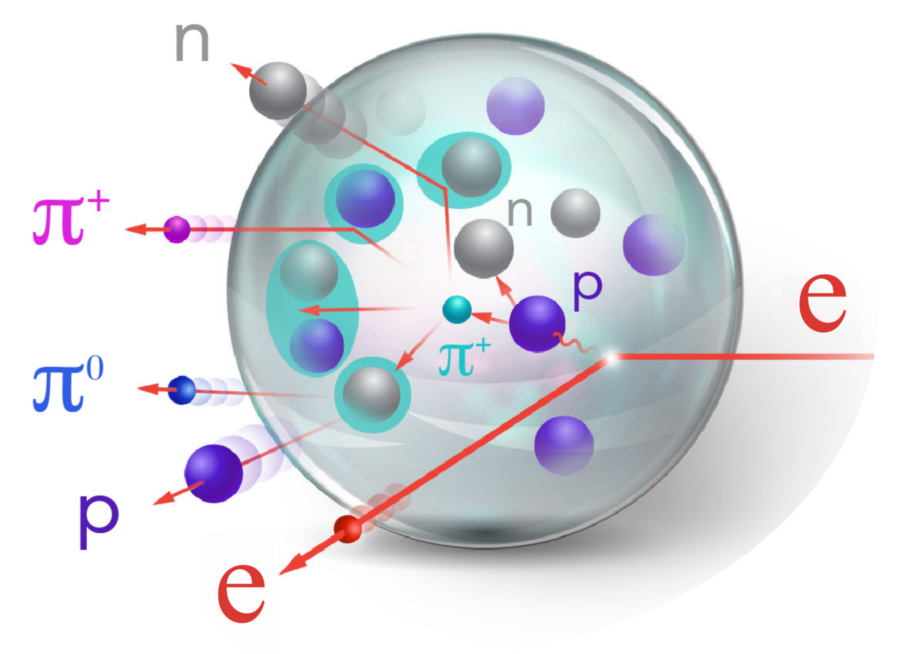
$P_{\pi}^{0} > 500$ MeV/c



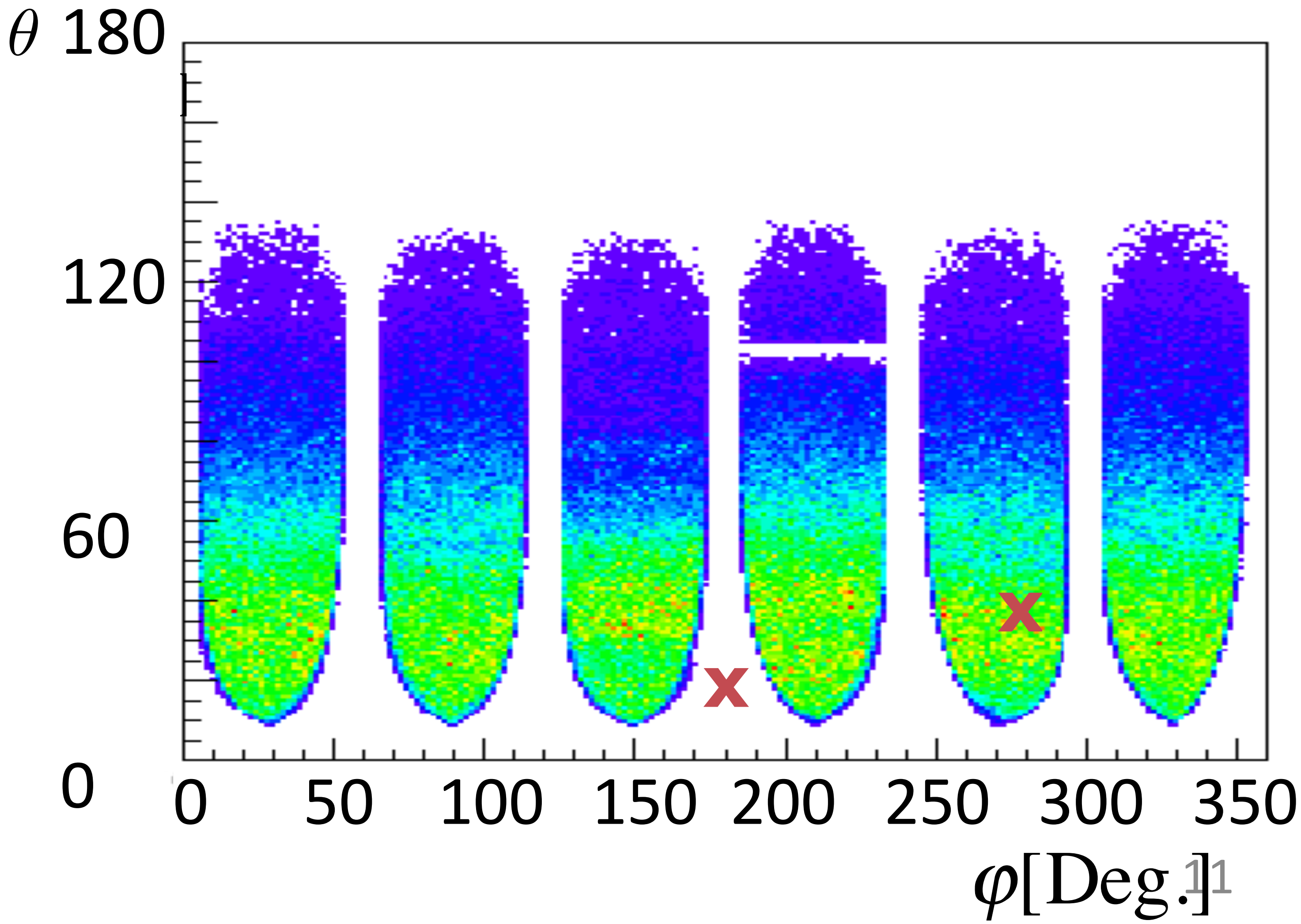
e4ν: Playing the Neutrino game

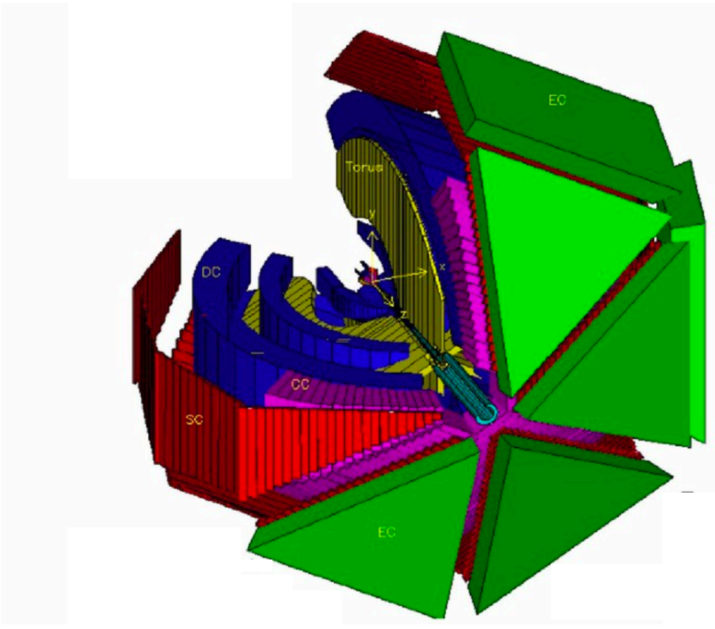
Analyse electron data as neutrino data

- Select lepton + proton final state (1p0π)
- Scale by $\sigma_{\nu N}/\sigma_{eN} \propto 1/Q^4$
- Reconstruct incoming lepton energy
- Benchmark neutrino event generators



Subtract for events w/ undetected hadrons





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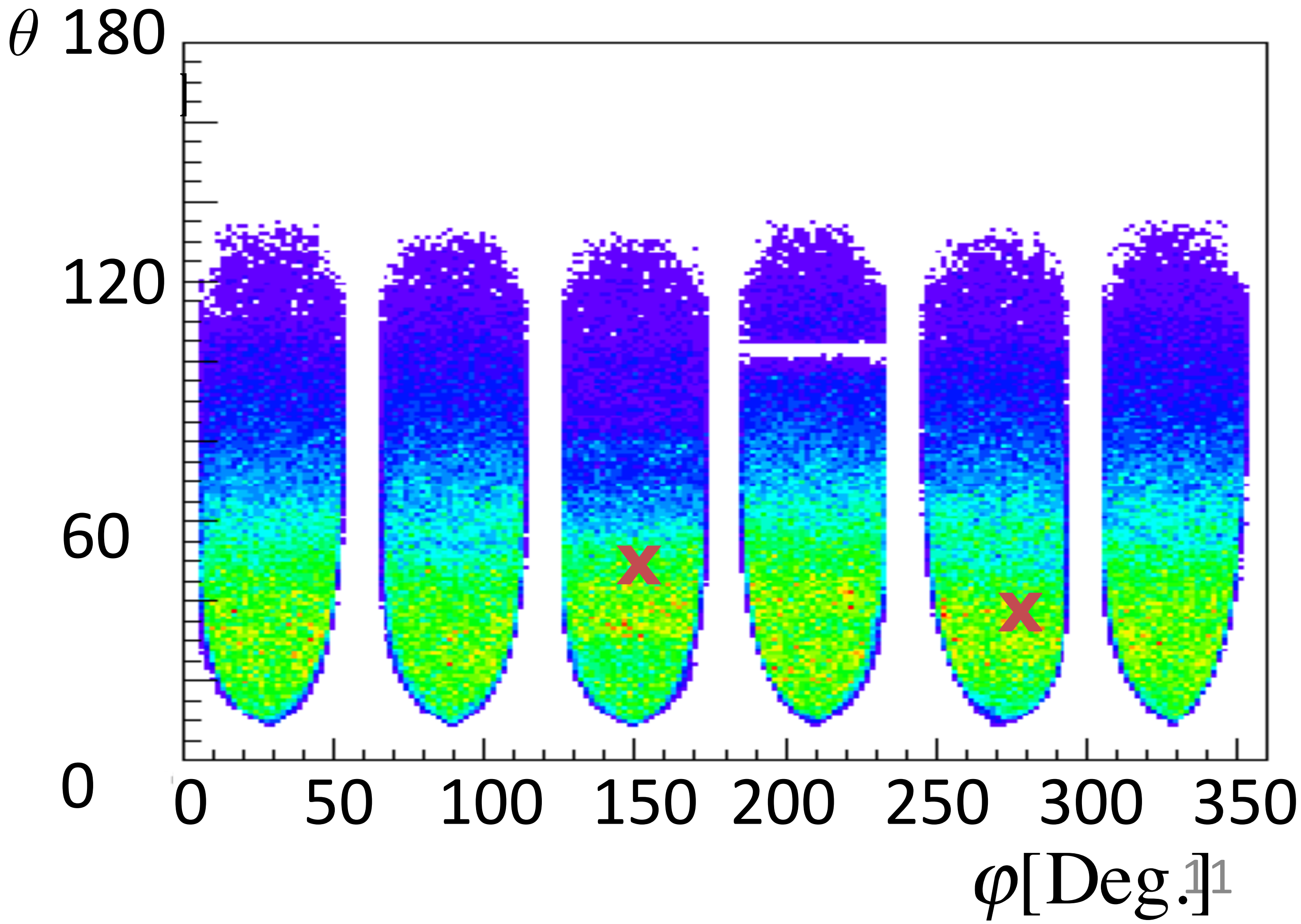
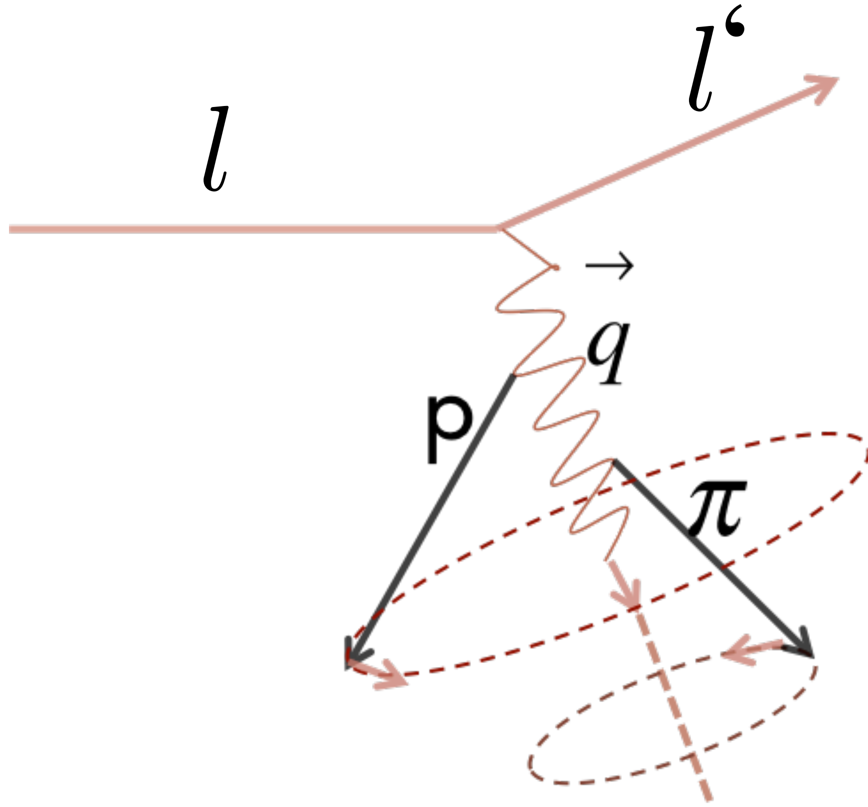




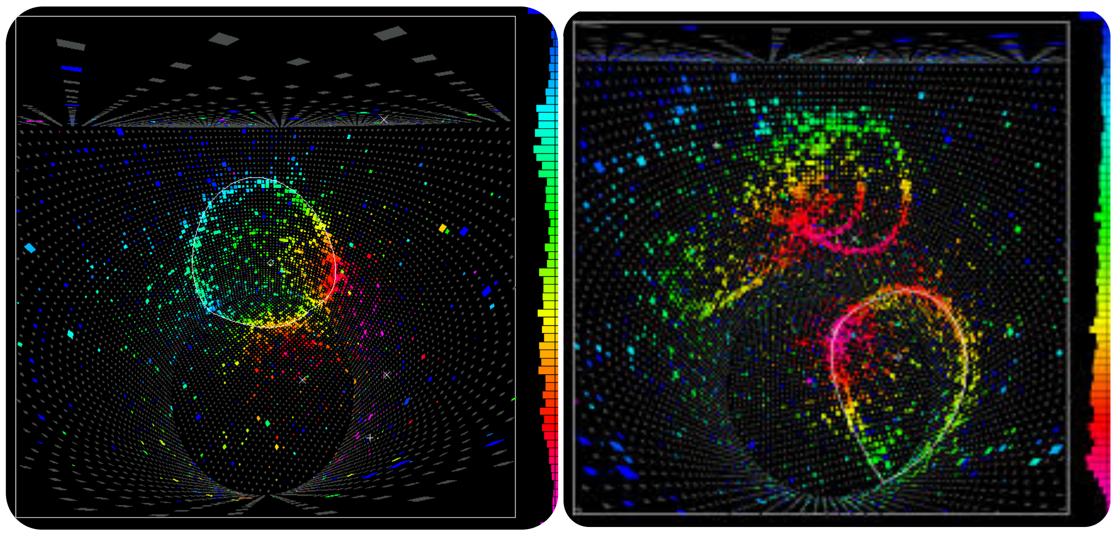
Using two hadron events:

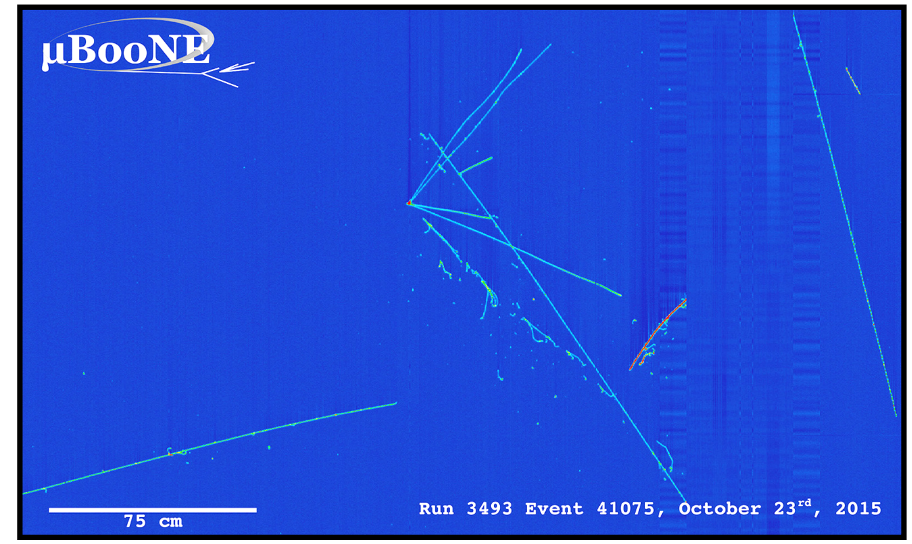
Rotating the two hadrons around q, to determine detection efficiency

Same for final states with more than 2 hadrons

Subtracting QE like background

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

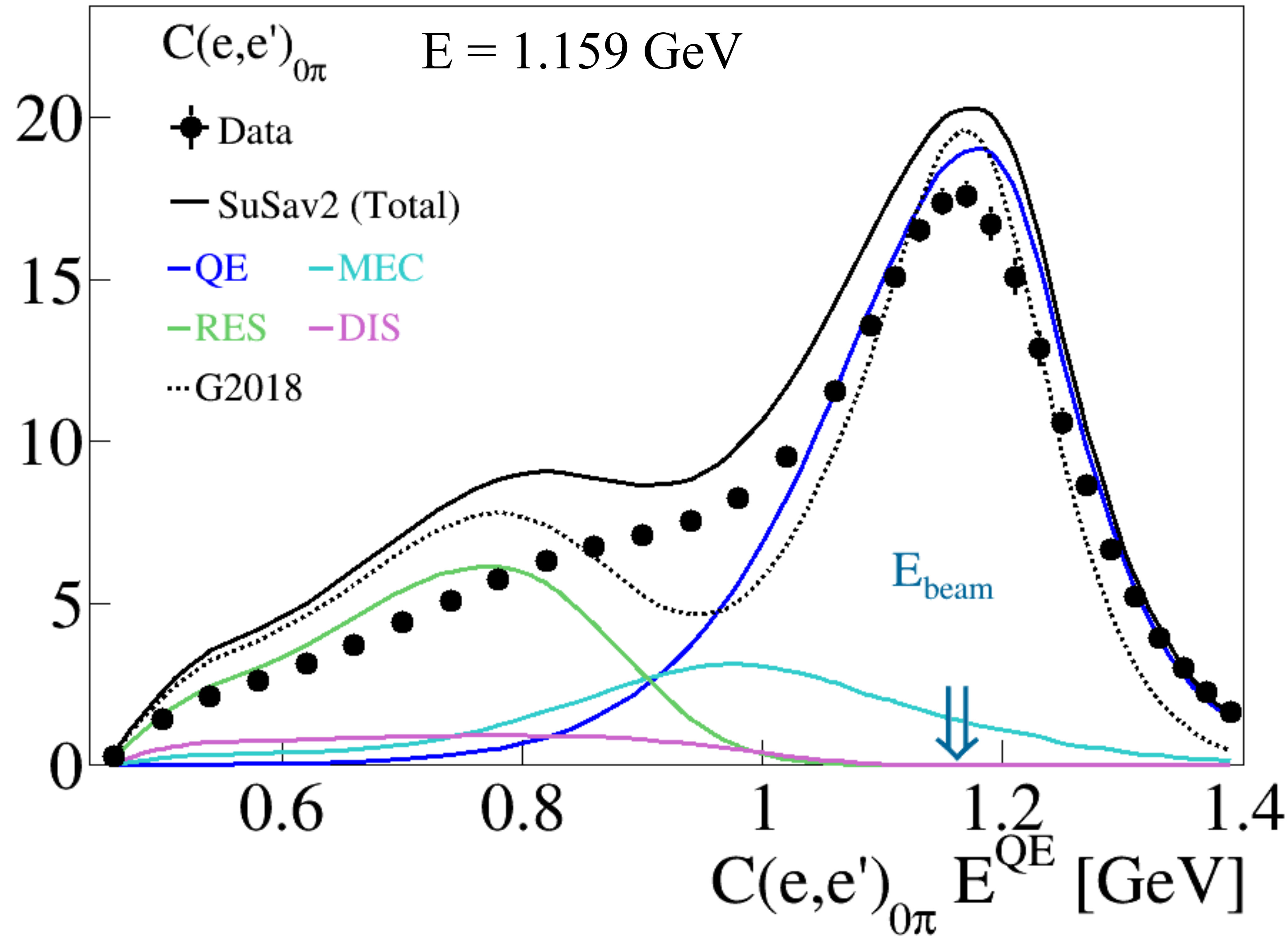
Using All detected particles

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

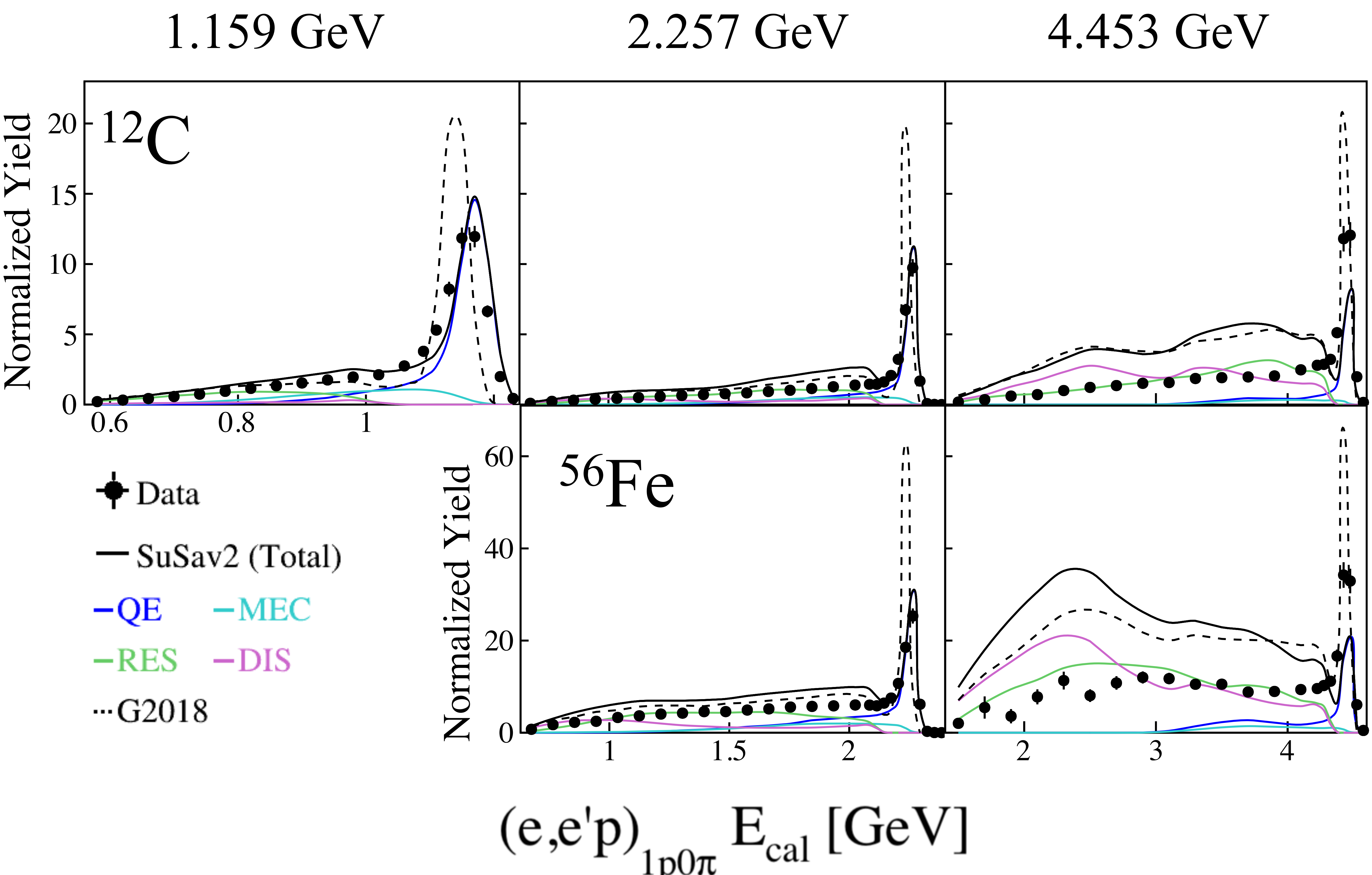
[1p0π]

ϵ is the nucleon separation energy ~ 20 MeV

Disagreements between Data and MC

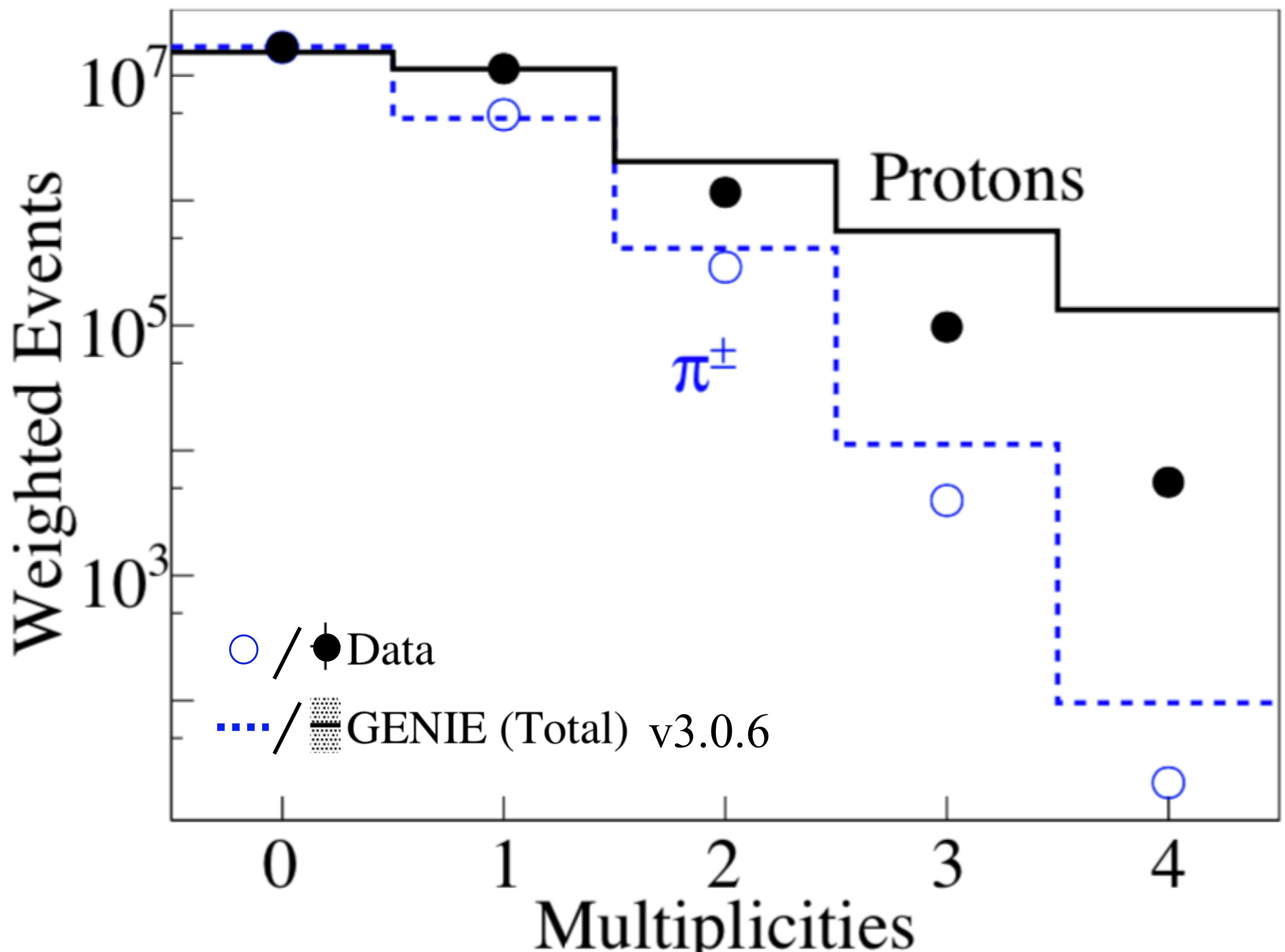


Disagreements between Data and MC

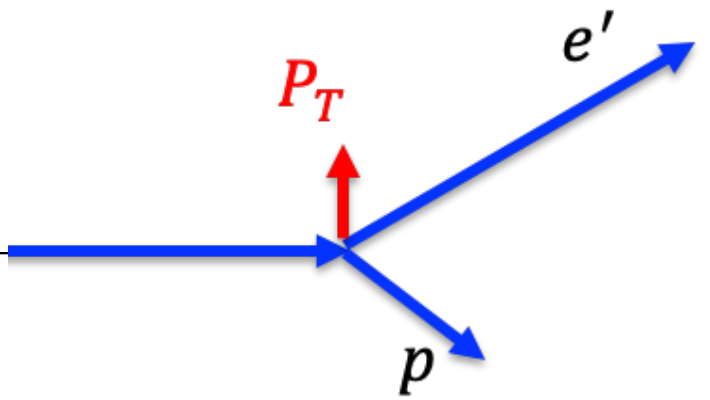


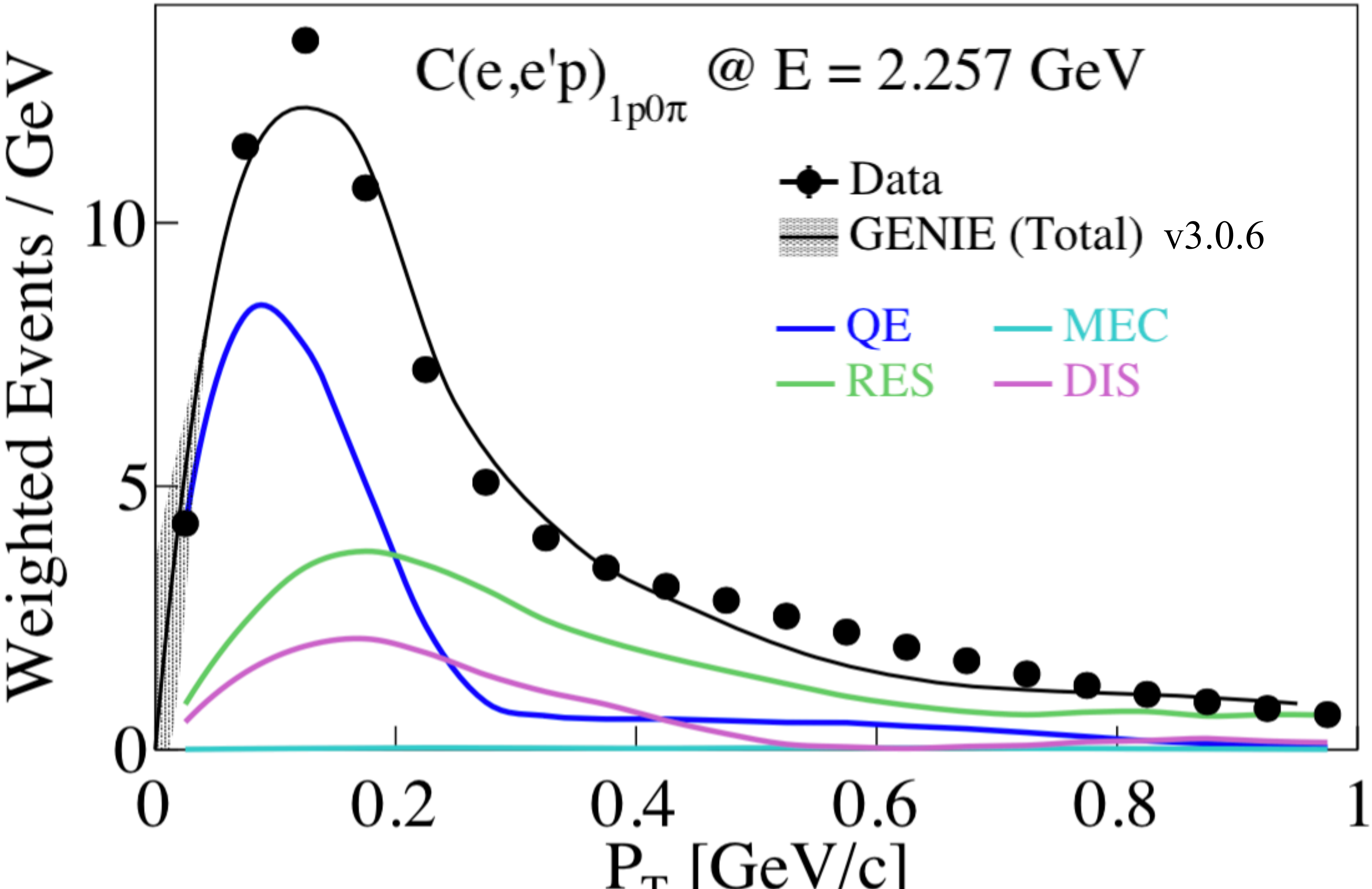
Multiplicities

$E = 2.257$ GeV $\quad {}^{12}C$

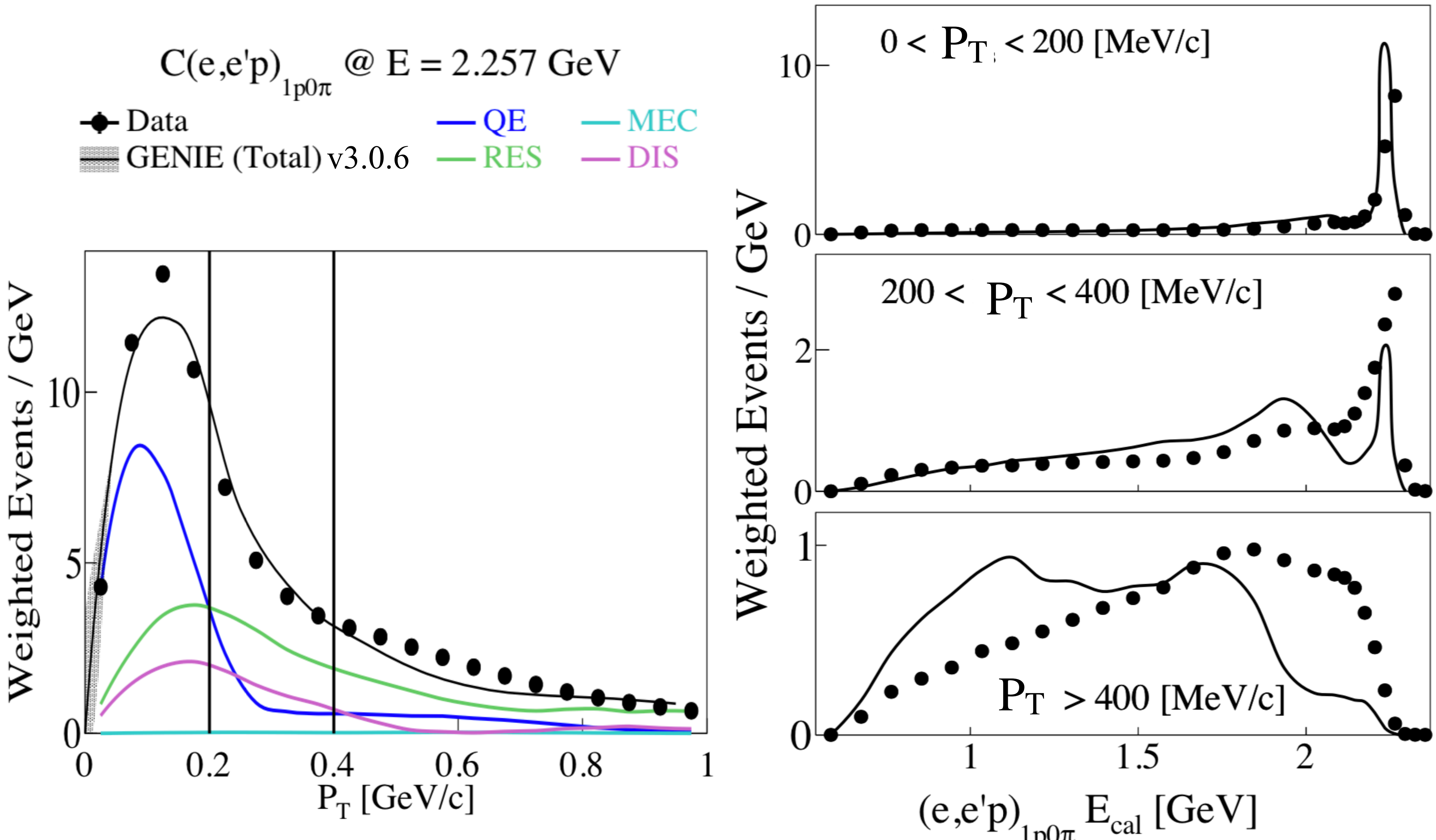


MC vs. (e,e'p) Data: $\vec{P}_T = \vec{P}_T^{e'} + \vec{P}_T^{p}$





MC vs. (e,e'p) Data: $\vec{P_T} = \vec{P_T^{e'}} + \vec{P_T^{p}}$



Future Plans -Approved run for CLAS12

Acceptance down to 5^{o} $Q^2 > 0.04$ GeV^2

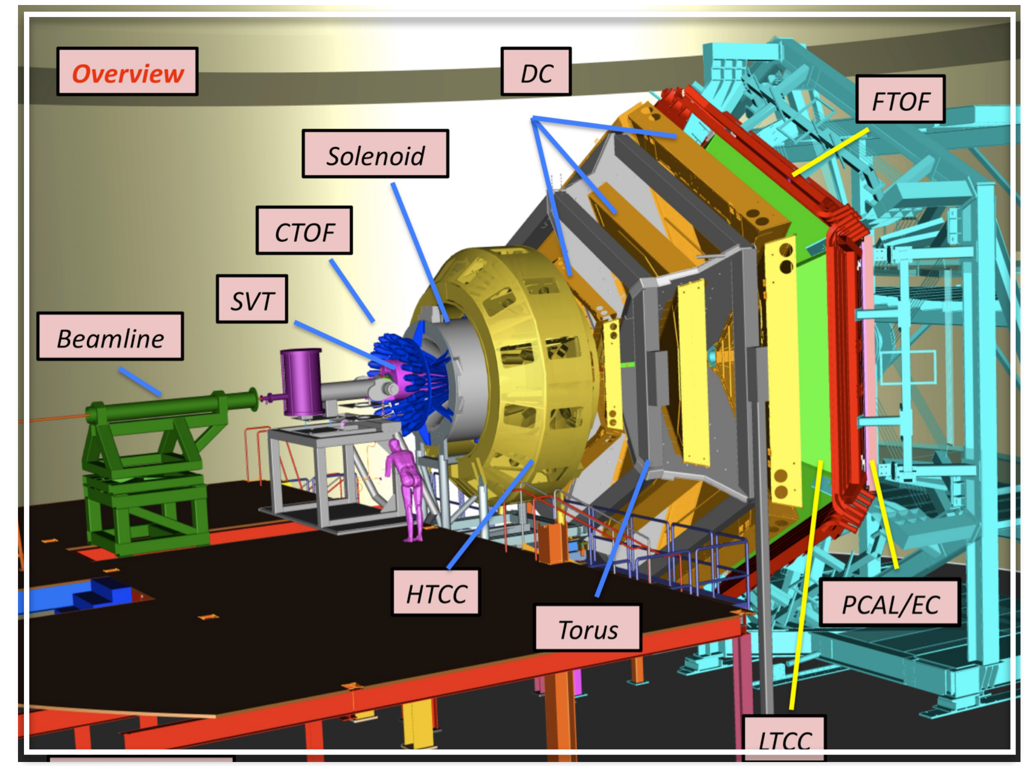
x10 luminosity [10^{35} cm^{-2}s^{-1}]

Keep low thresholds

Targets: ^{2}D, ^{4}He, ^{12}C, ^{16}O, **^{40}Ar**, ^{120}Sn

1 - 7 GeV (relevant for DUNE)

Running planned for 2021

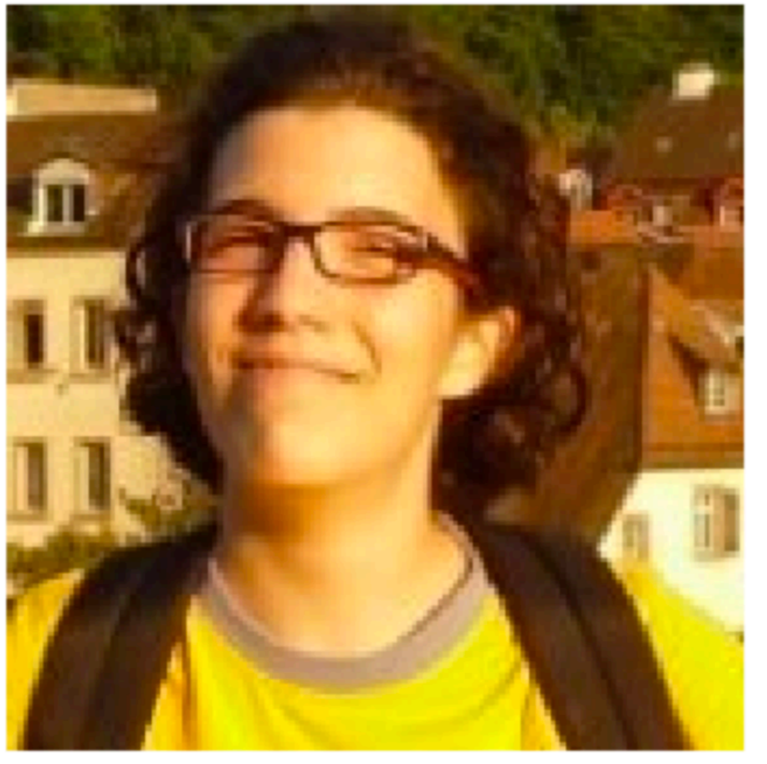


Overwhelming support from:

DUNE ICECUBE SOUTH POLE NEUTRINO OBSERVATORY Hyper-Kamiokande T2K NOvA MINERvA

Fermilab GiBUU The Giessen Boltzmann-Uehling-Uhlenbeck Project Genie μBooNE

e4v The team



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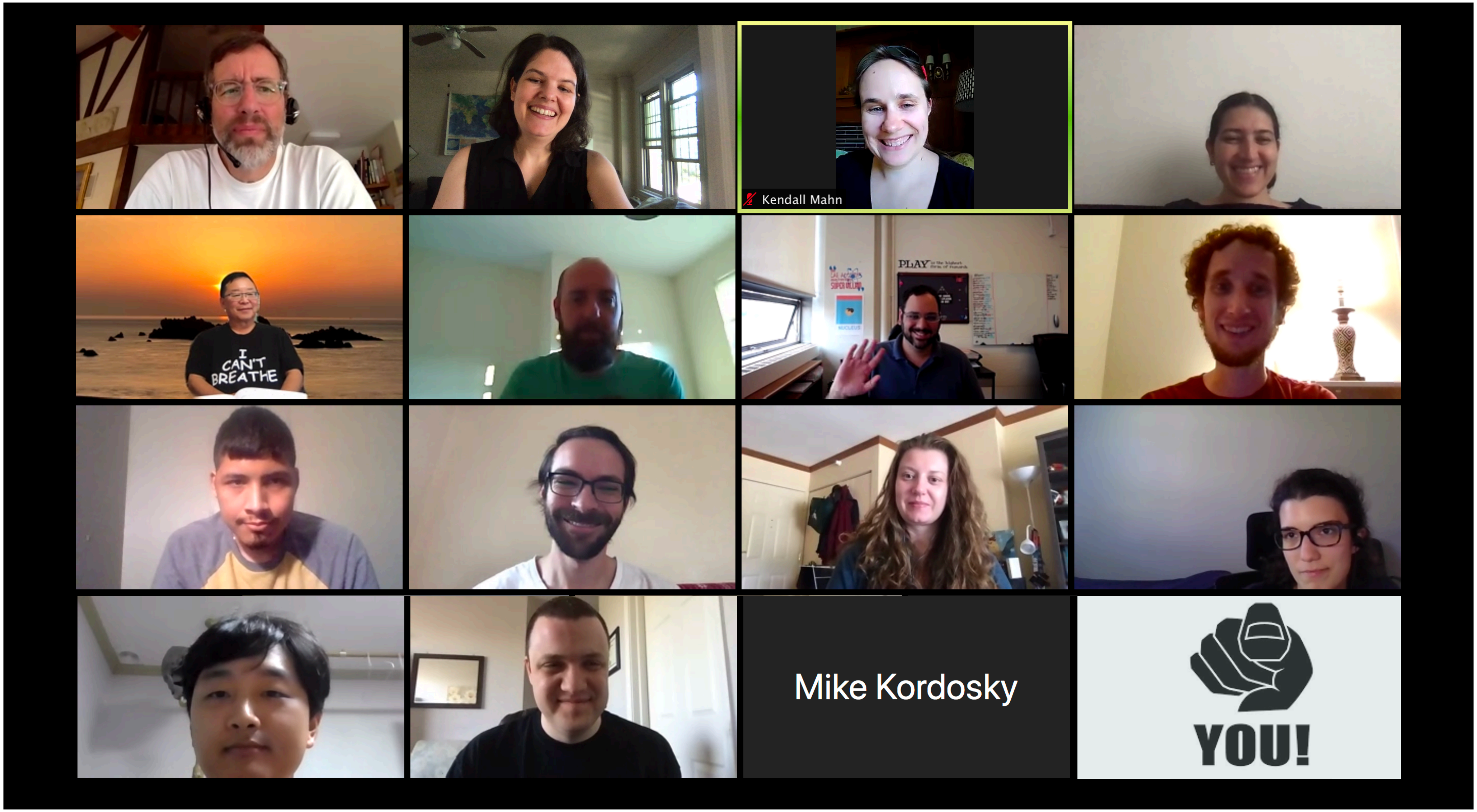
CSIC
Consejo Superior de Investigaciones Científicas

e4ν The team



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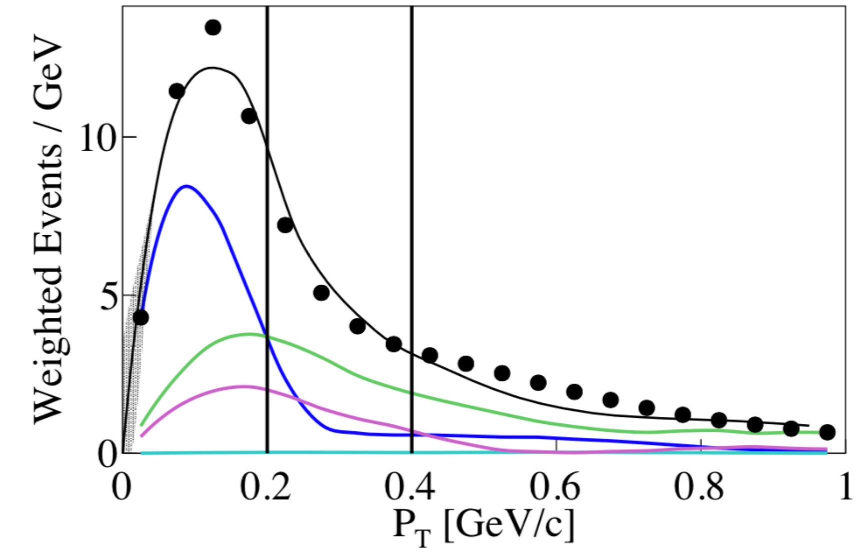
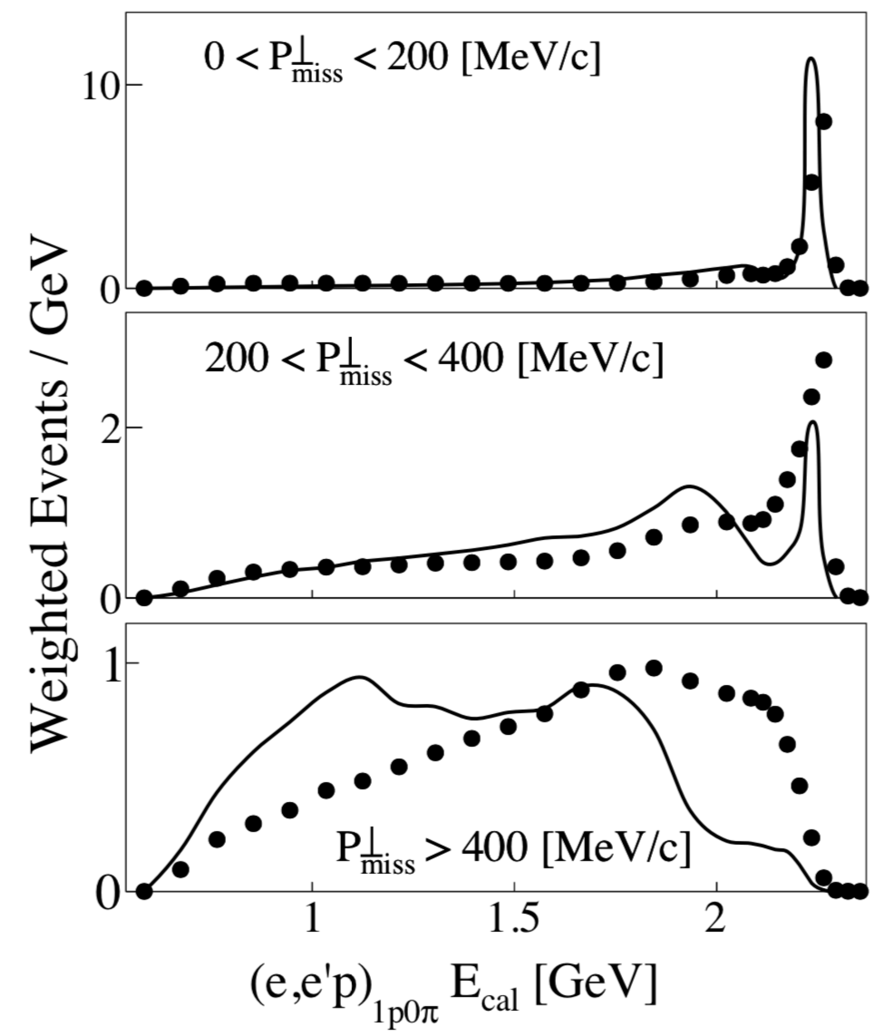
Summary

- Testing νA Models with wide phase-space eA data.
- Data-MC disagreements for QE-like events
  - Especially for high transverse momentum.
  - Large potential impact on DUNE
- More data coming very soon
- Looking forward to keep improving models, offering tunes and and to collaborate with all electron scattering project. (see Snowmass NF06 meeting next week)

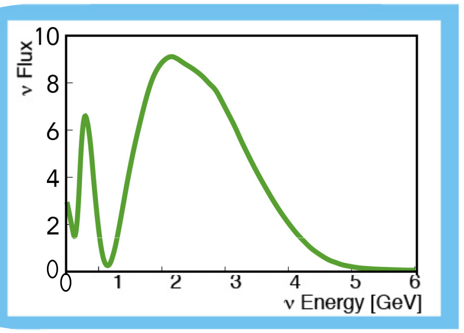




Thank you for your attention

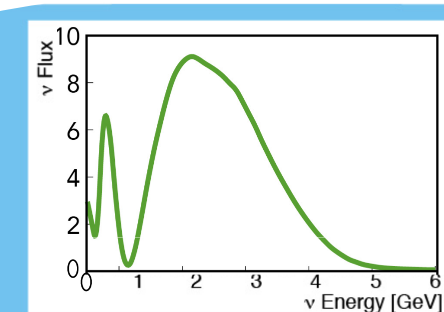
PHYSICS PROCESS

Particles shoot out ← Interacts with nucleus ← Neutrino comes in



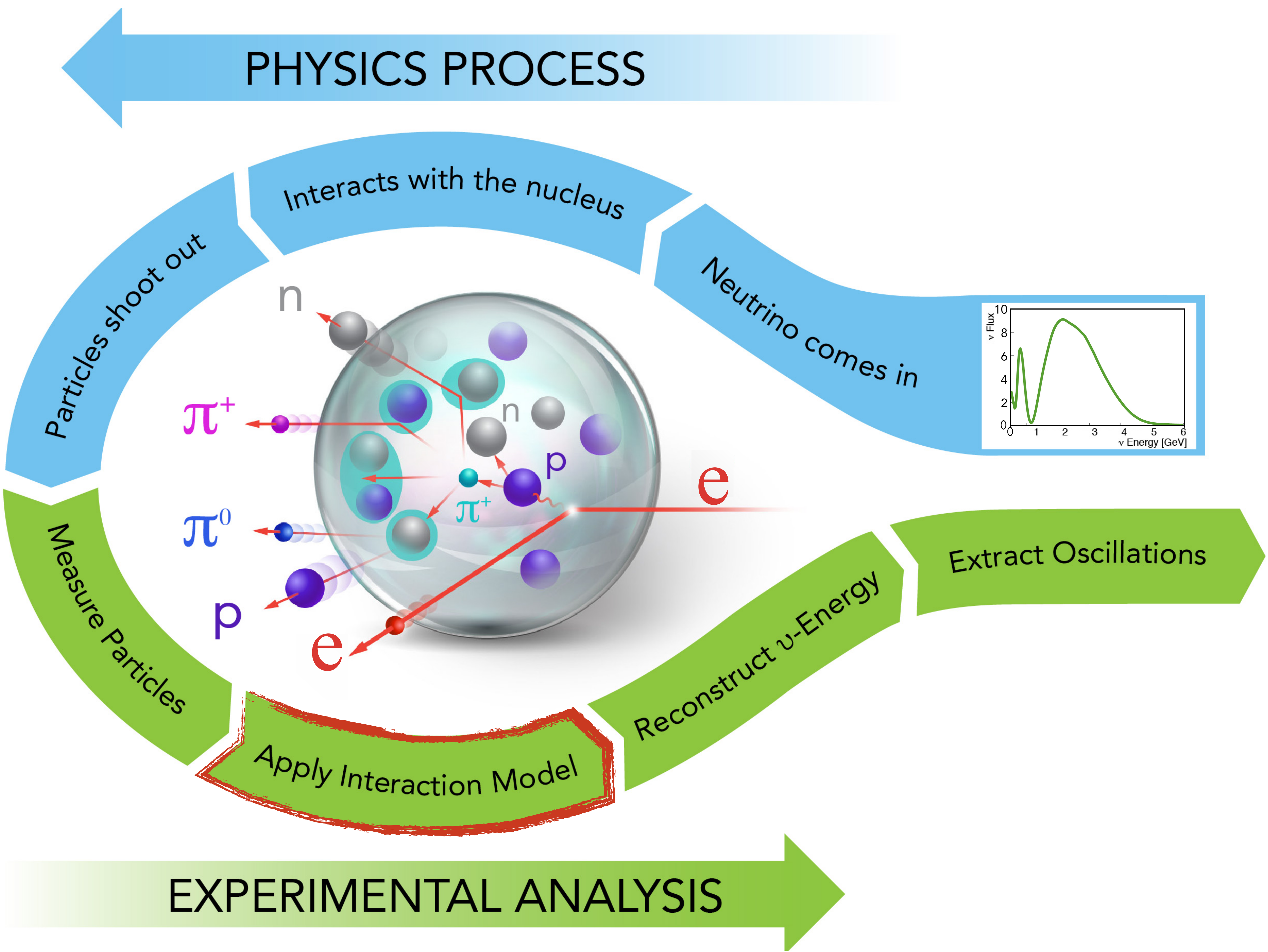
PHYSICS PROCESS

Particles shoot out ← Interacts with nucleus ← Neutrino comes in



Measure Particles → Apply Interaction Model → Reconstruct ν-Energy → Extract Oscillations

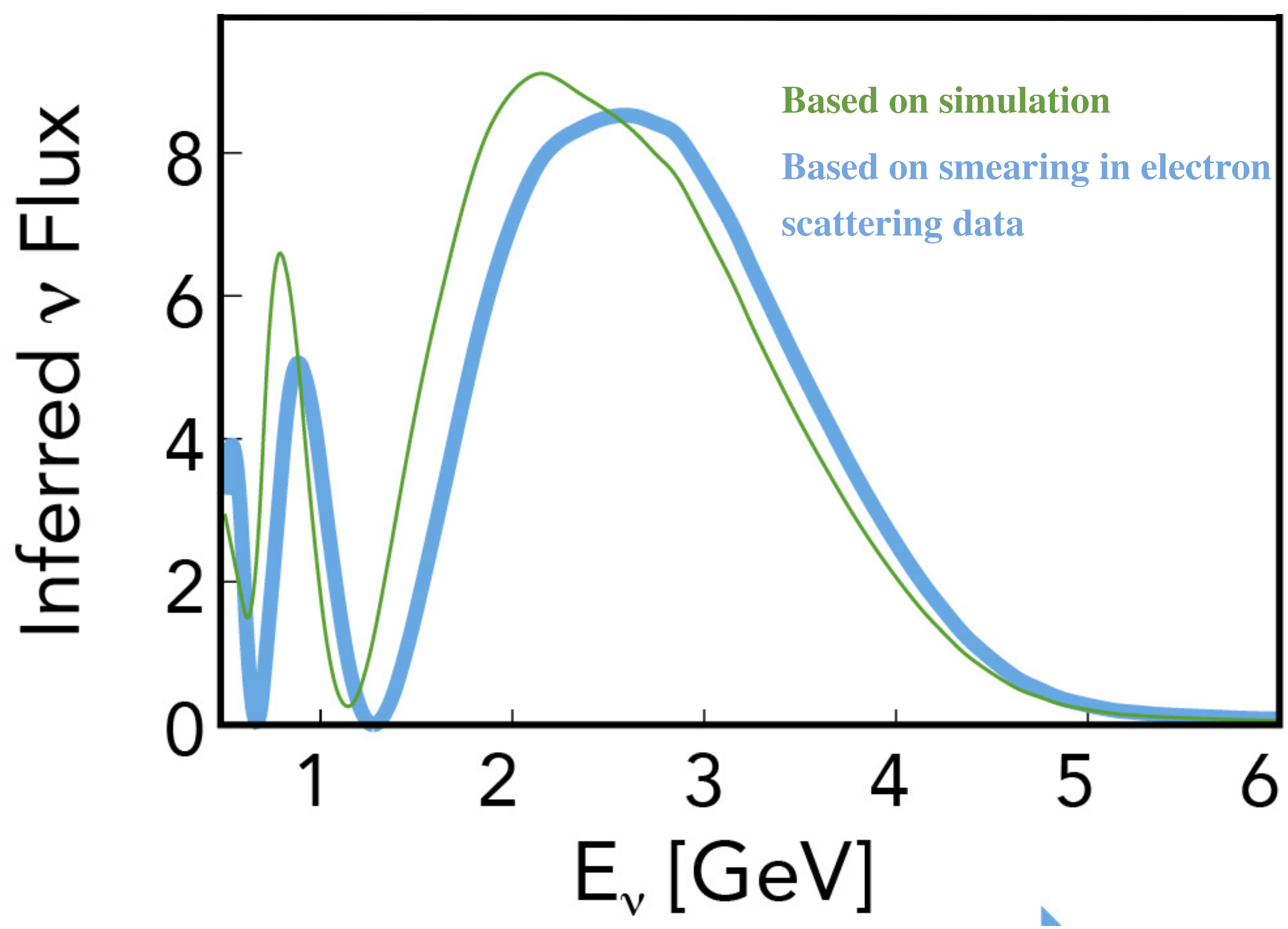
EXPERIMENTAL ANALYSIS



PHYSICS PROCESS
Interacts with the nucleus
Particles shoot out
Neutrino comes in
ν Flux
ν Energy [GeV]
n
π+
π0
p
e
Measure Particles
Apply Interaction Model
Reconstruct υ-Energy
Extract Oscillations
EXPERIMENTAL ANALYSIS

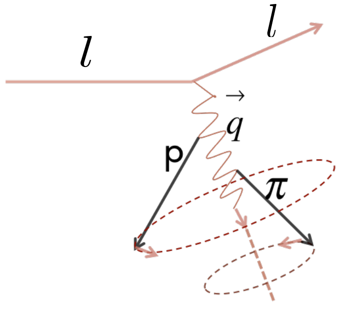
Miss-modelling might impact mixing parameters

Extract Oscillations

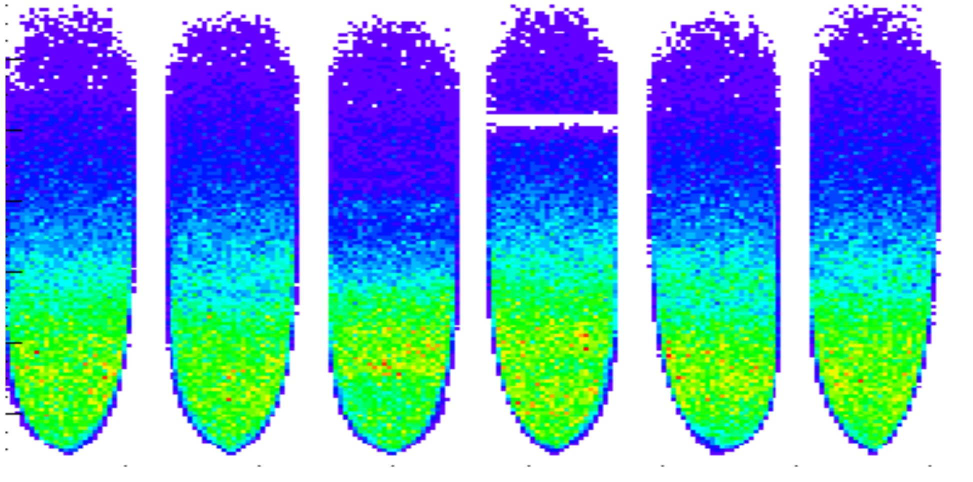


Systematic Uncertainties

$\phi_{q\pi}$ independence of the pion-production cross section for background subtraction



Varying CLAS π acceptance

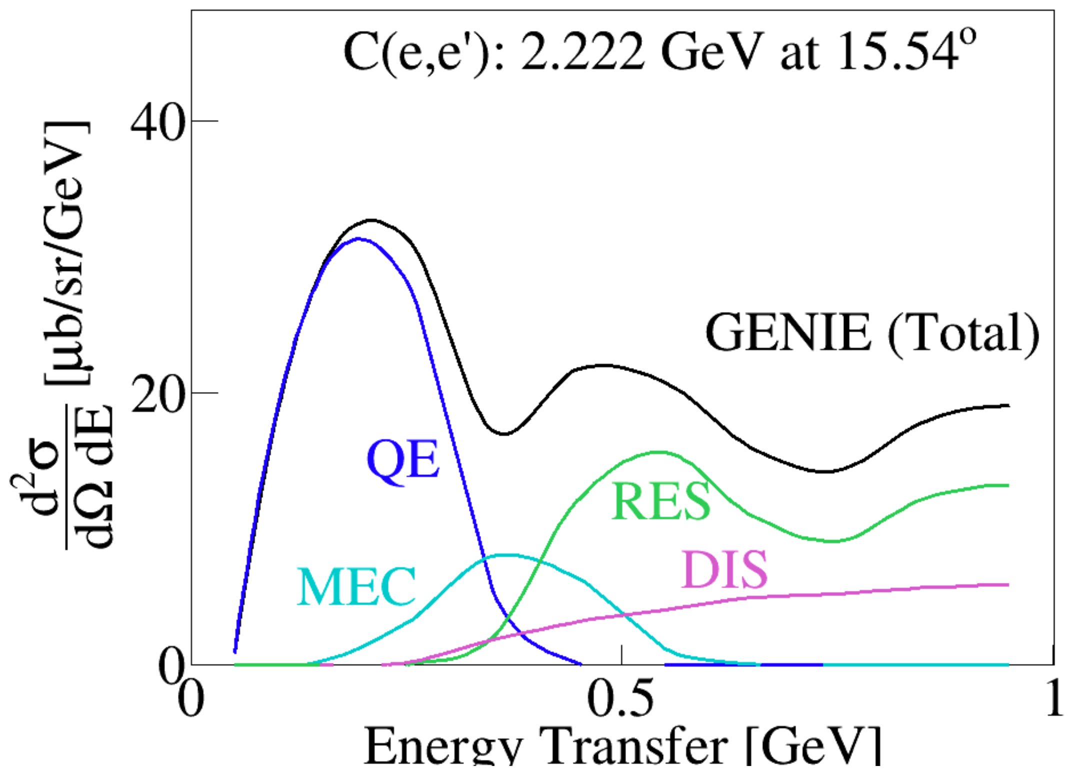


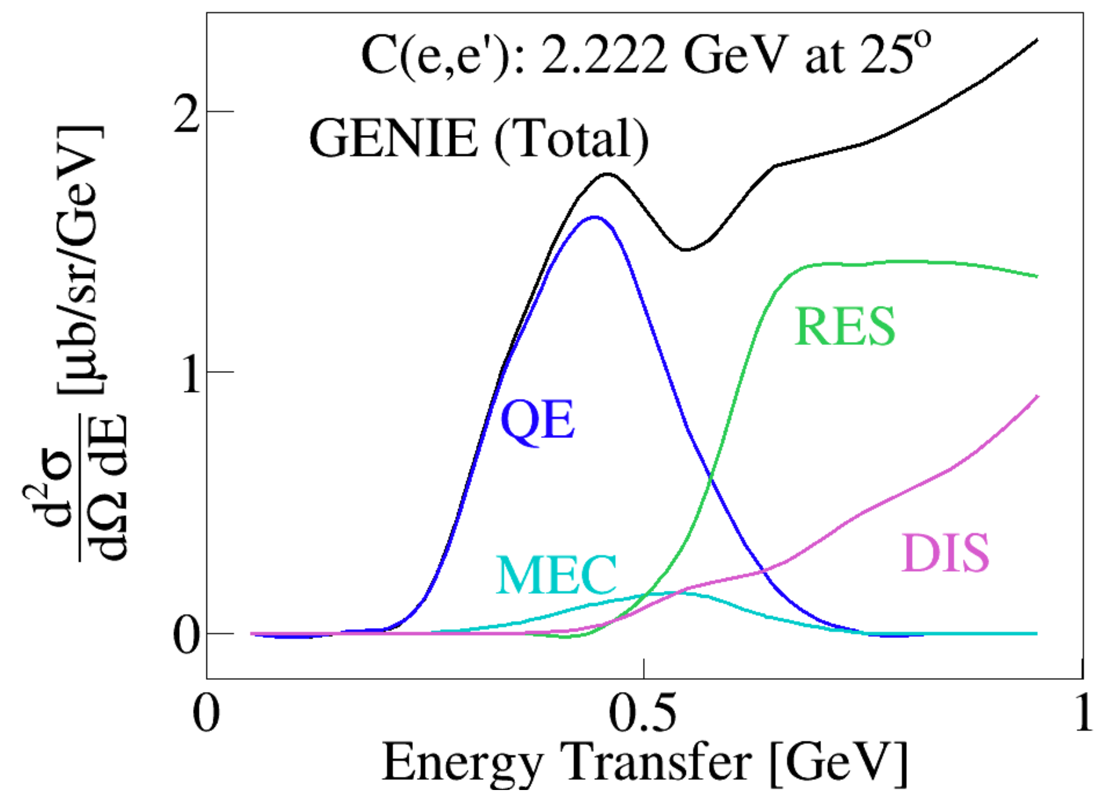
Varying the photon identification cuts

Estimate systematic uncertainties by comparing independent measurement in each sector.

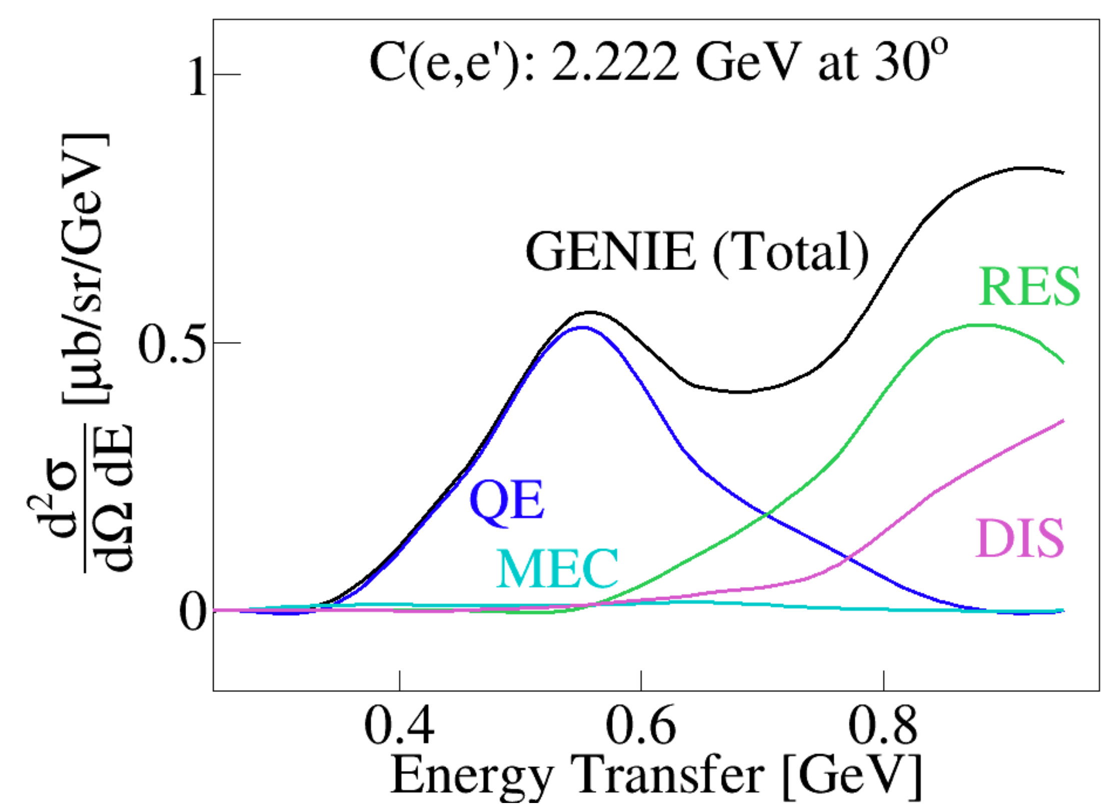
Use Hydrogen elastic scattering for absolute rate measurement.

Where did the MEC go?





CLAS6: 15° < θ_e < 45°



GENIE Simulation

Genie v3.0.6 tune G18_10a_02_11a

	electrons	neutrinos
Nuclear model	Local fermi gas model	
QE	Rosenbluth CS	Nieves model
MEC	Empirical model	Nieves model
Resonances	Berger Sehgal	
DIS	AGKY	
FSI	hA2018	
Others	Adding radiative correction	

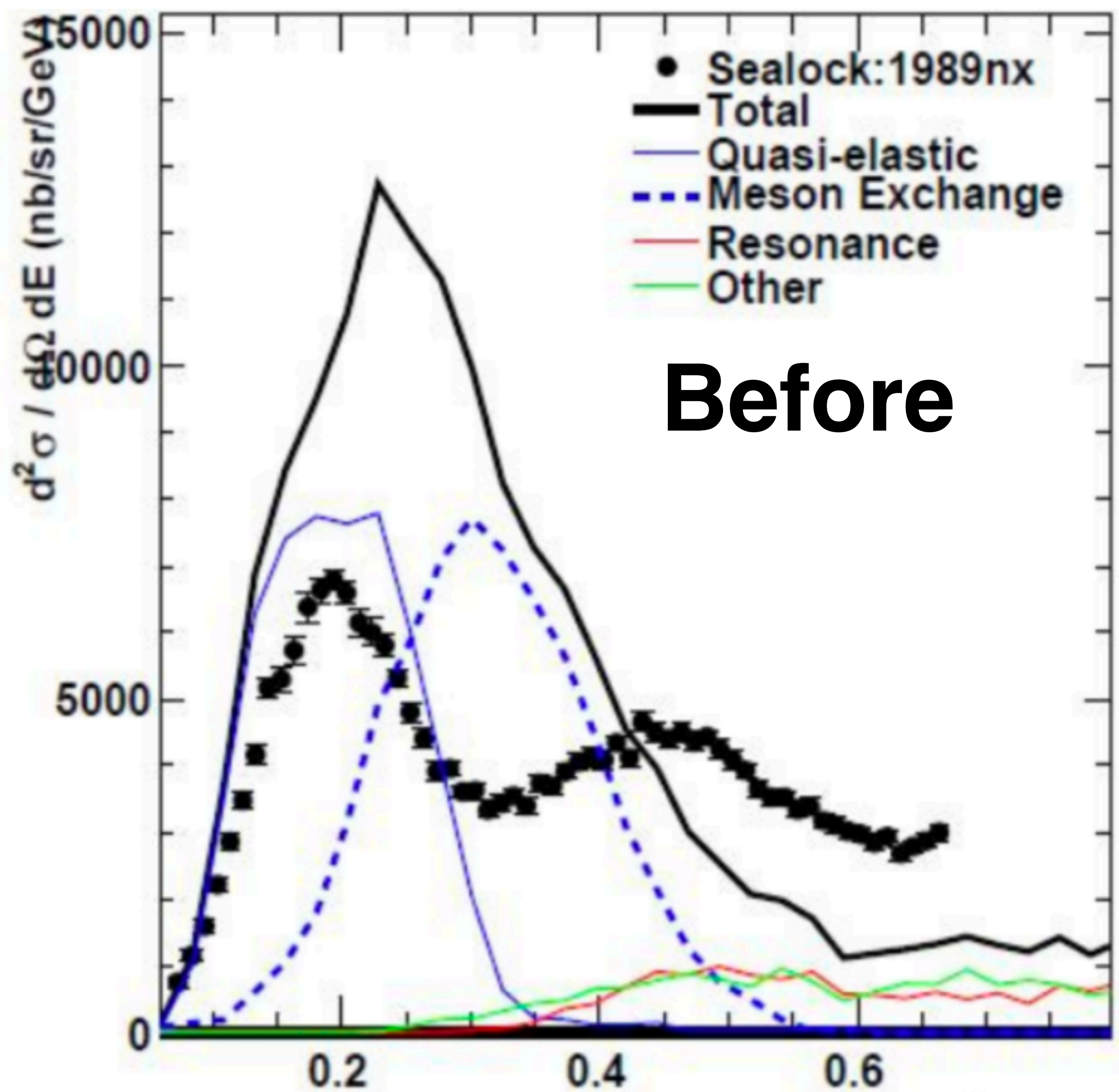
GENIE Simulation

Genie v3.0.6 SuSA

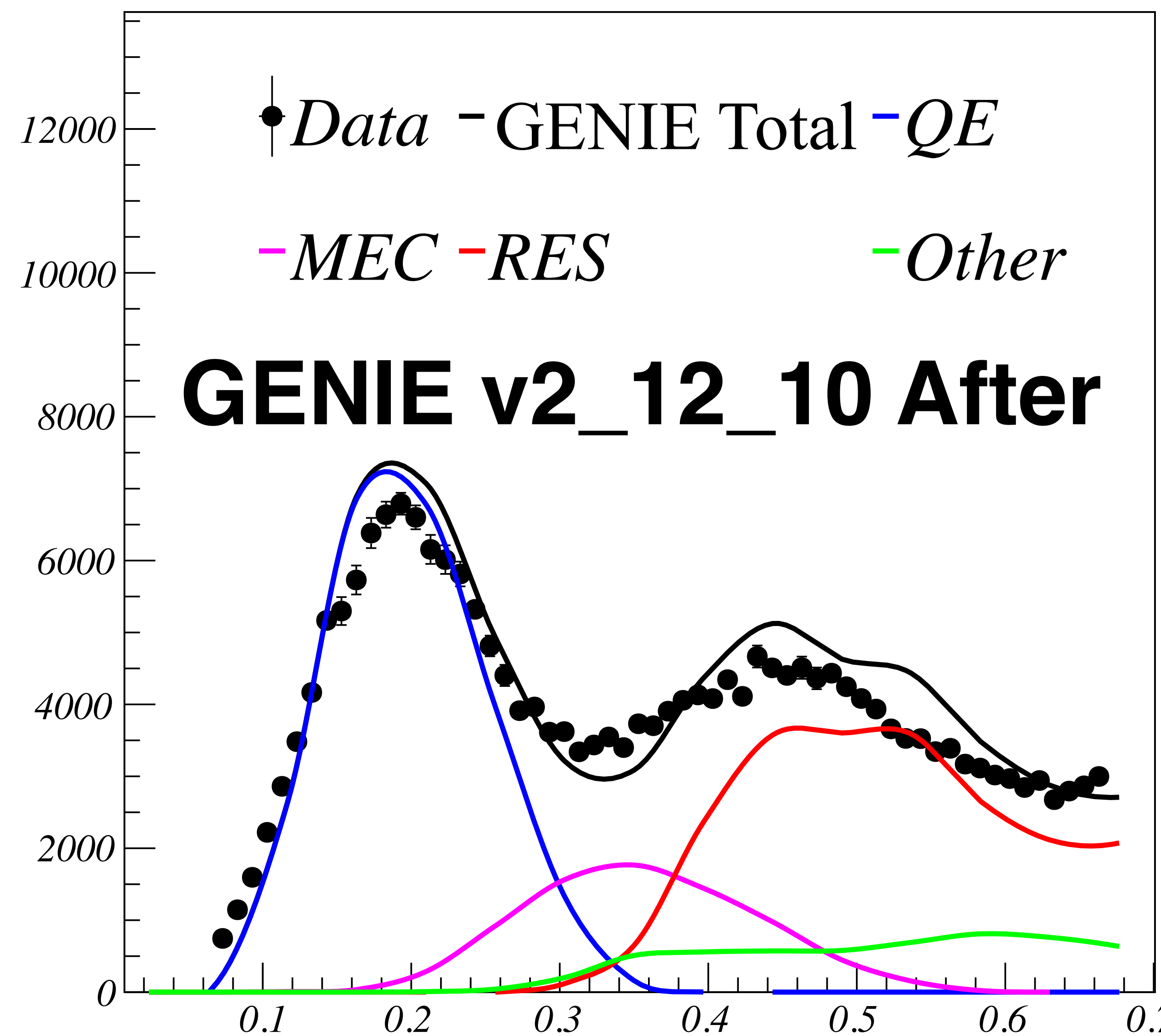
	electrons	neutrinos
Nuclear model	Local fermi gas model	
QE	Rosenbluth CS	Nieves model
MEC	SuSAv2	SuSAv2
Resonances	Berger Sehgal	
DIS	AGKY	
FSI	hA2018	
Others	Adding radiative correction	

Testing neutrino generators with inclusive electron scattering data

12C(e,e') E = 0.961 GeV $\theta = 37.5^\circ$

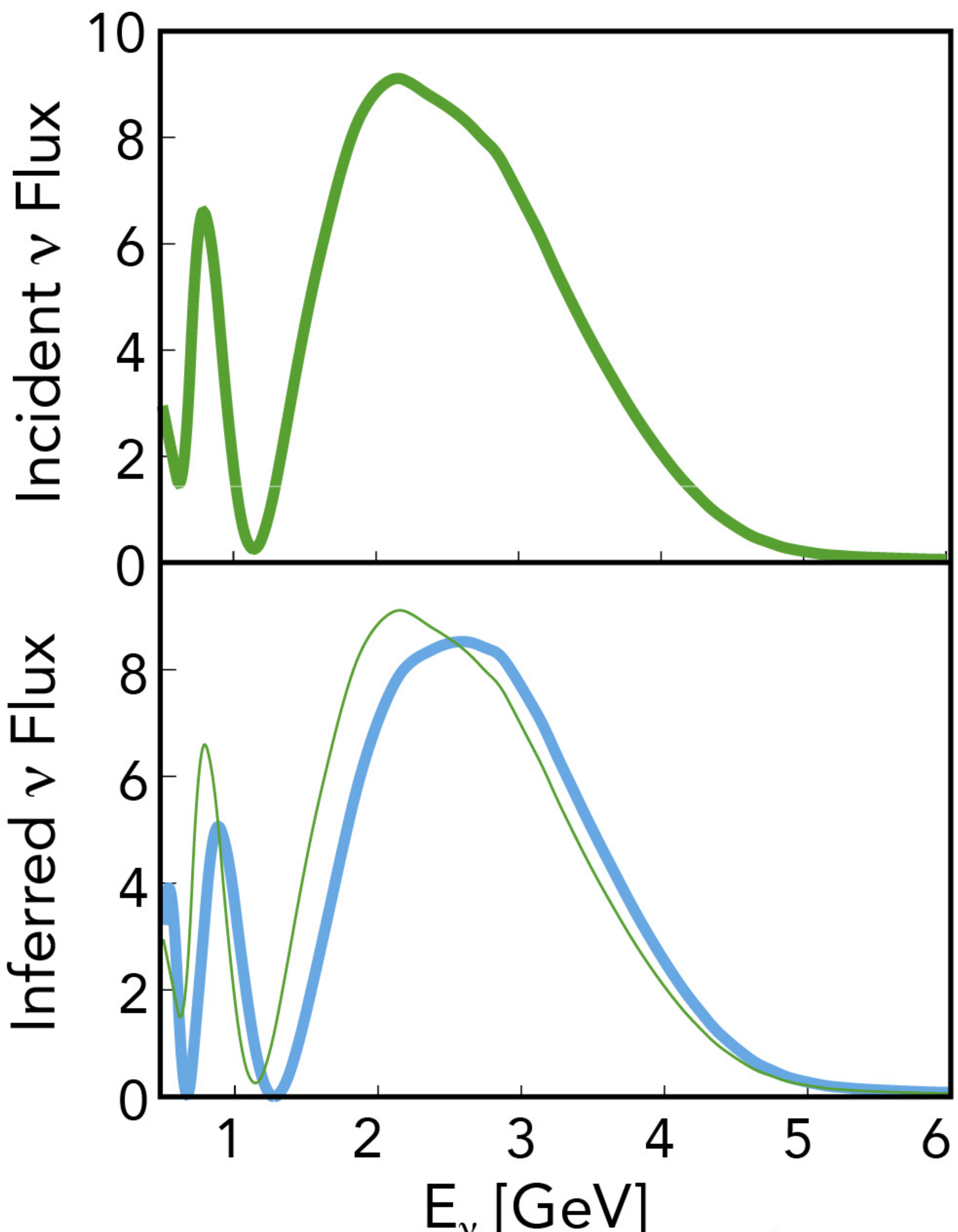


$E^l - E^{l'}$ [GeV]



$E^l - E^{l'}$ [GeV]

Potential implication on DUNE analysis



- ν_e appearance channel (all inclusive)
- Using existing parameter constraints from reactors + others experiments
- Smearing energy based on events with:

1e1p selection

$\theta_e > 15^o$

$P_p > 300$ MeV/c

No $P_{\pi+/-} > 150$ MeV/c

Reconstructed based on simulation

Reconstructed based on smearing in electron scattering data