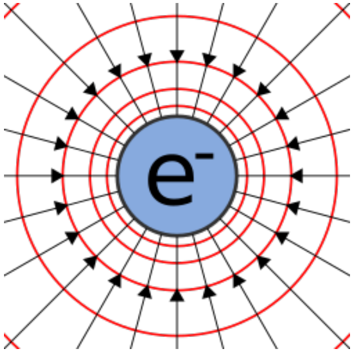
Neutrino Energy Reconstruction Methods Using Electron Scattering Data

Hen Lab

Laboratory for Nuclear Science @ MIT



Afroditi Papadopoulou

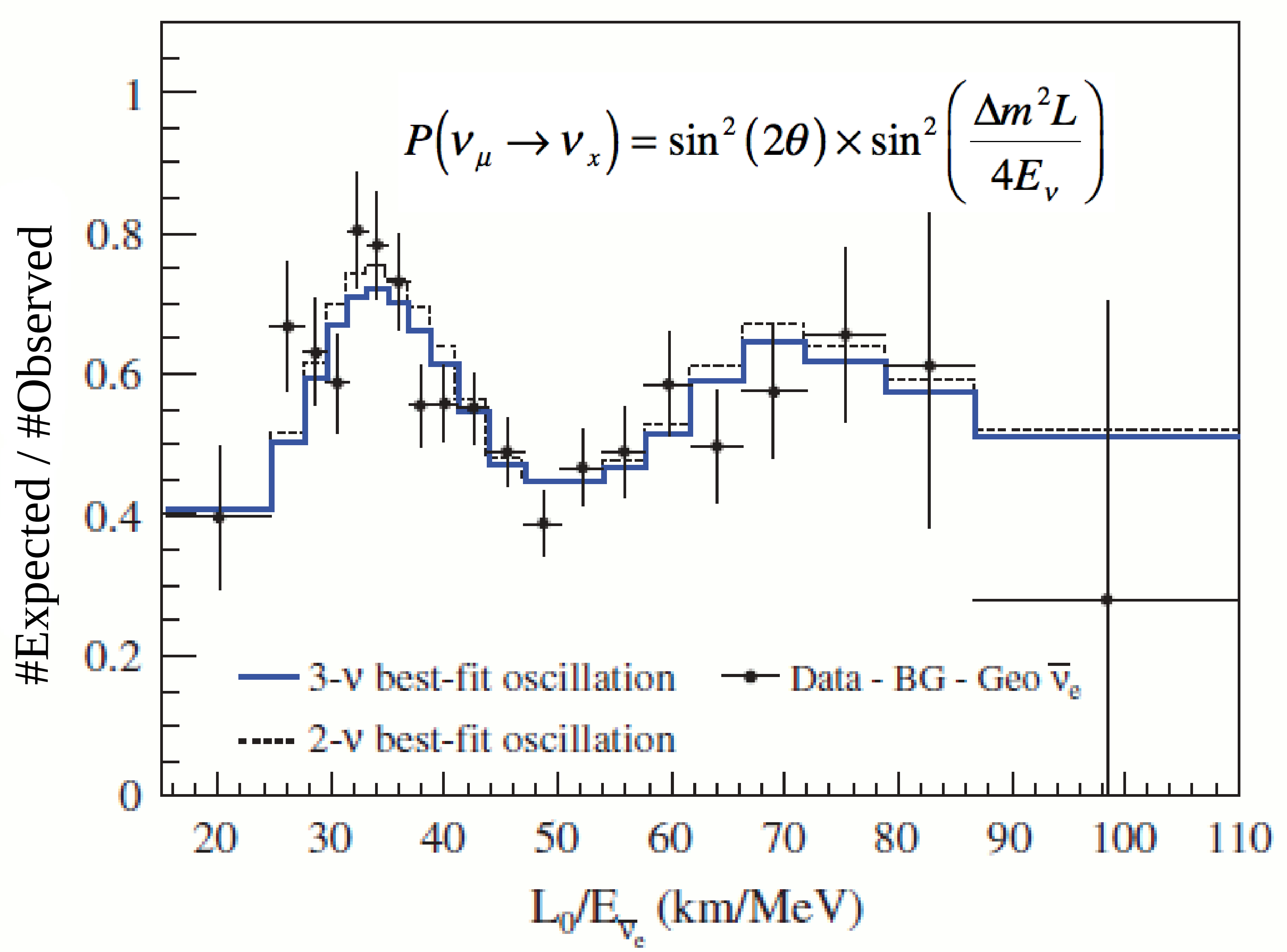
Pre-conference, EINN 2017

10/29/17

Outline

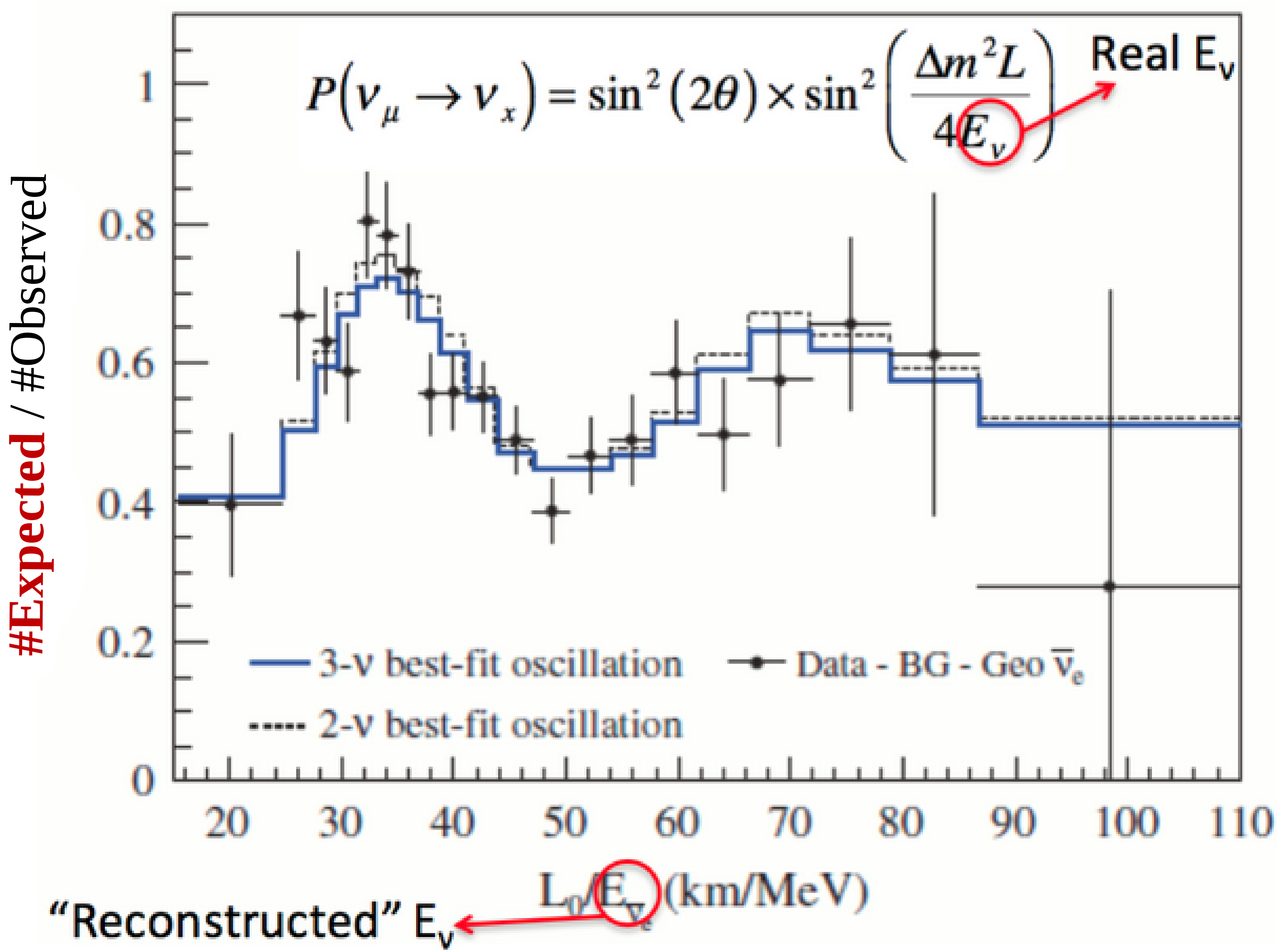
- Nuclear Physics and Neutrino Oscillations.
- Outstanding Challenges for
  Next Generation Oscillation Experiments.
- Electrons for Neutrinos!
- Future plans.

Importance of
Neutrino Energy Reconstruction
in Oscillation Experiments



KamLAND, PRL 100, 221803 (2008)

Neutrino Oscillations



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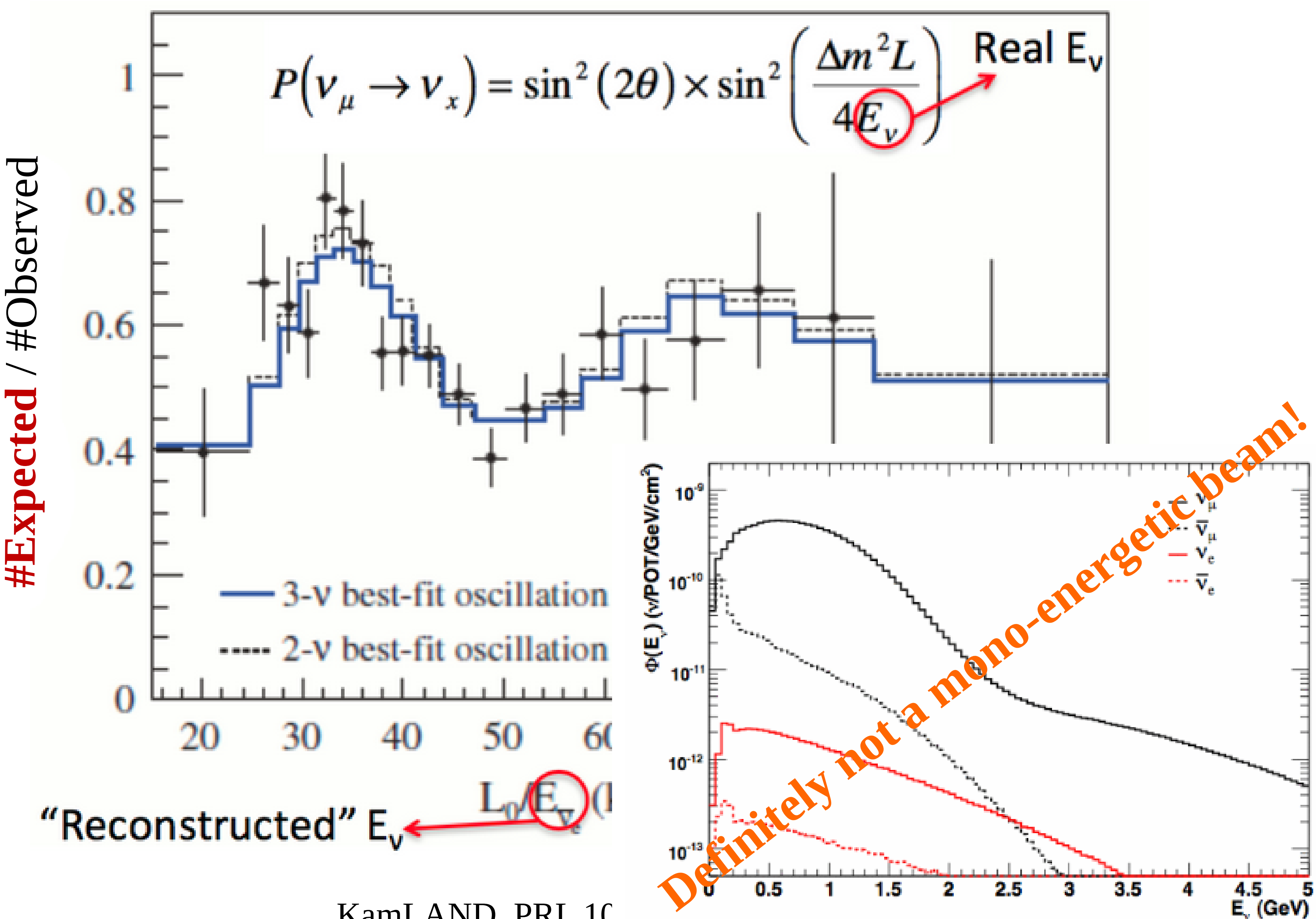


KamLAND, PRL 1(

Energy Reconstruction Methods in Neutrino Experiments

Energy Reconstruction Methods

Leptonic Reconstruction

(only scattered lepton)

$$E_\nu^{\text{kin}} = \frac{2M\varepsilon + 2ME_l - m_l^2}{2(M - E_l + |k_l|\cos\theta)}$$

$\varepsilon \approx 20$ MeV binding energy

M-nucleon mass

$m_l = 0$ outgoing lepton mass

k_l – lepton three momentum

θ – lepton scattering angle

Example

T2K

Calorimetric Reconstruction

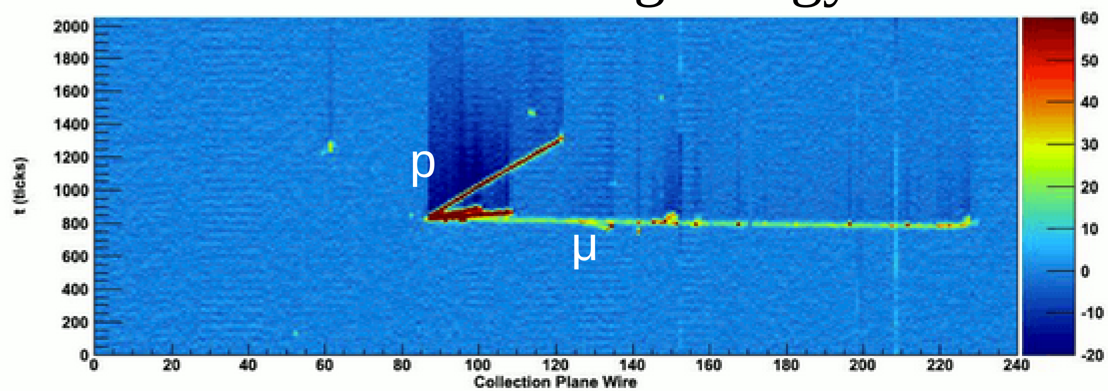
(sum over all particles)

$E_\nu^{cal} = T_h + E_l + BE$

T_h – hadron kinetic energy

E_l – lepton energy

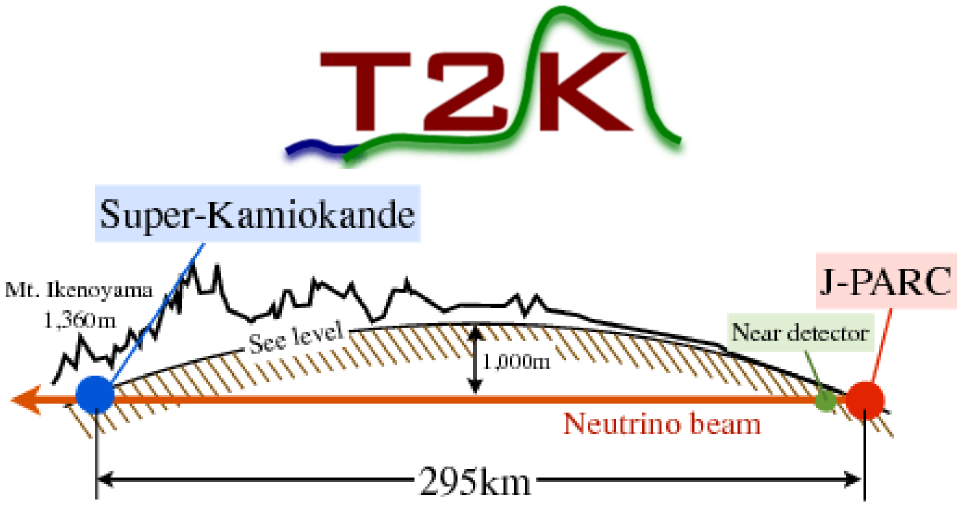
BE – binding energy

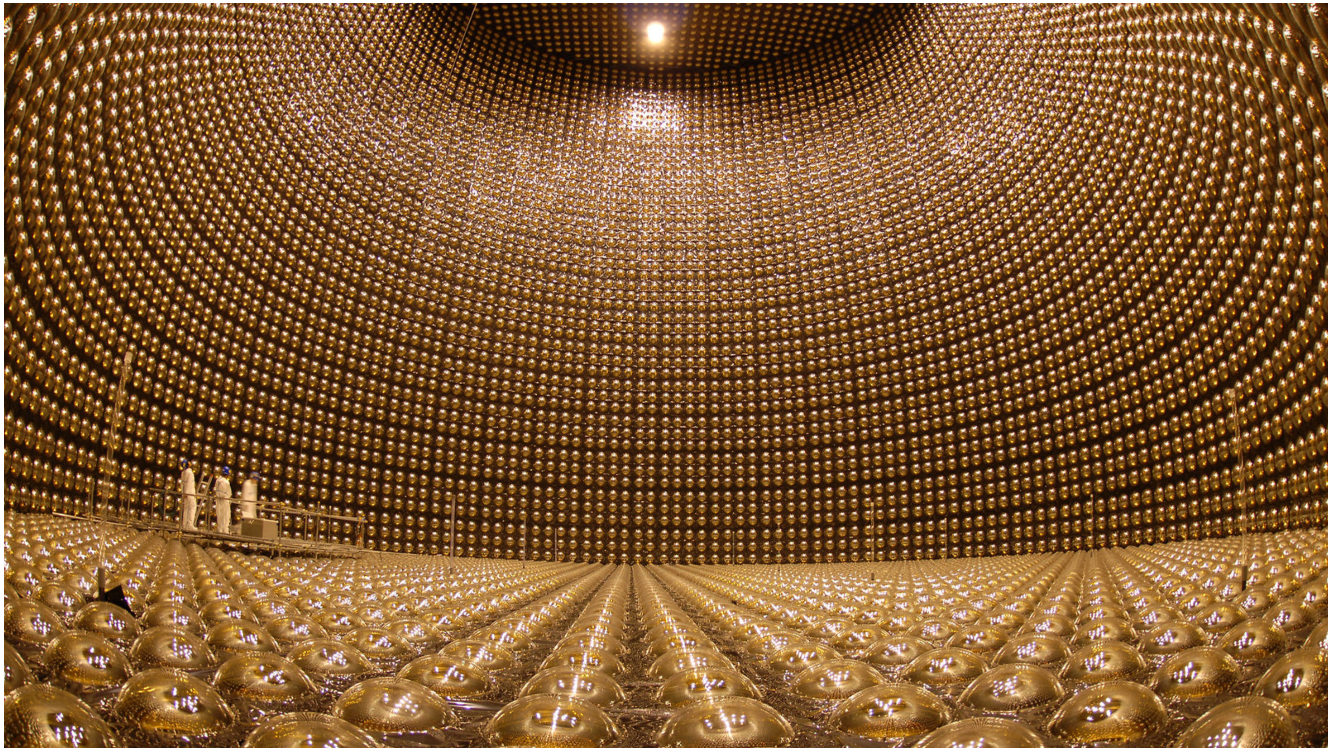


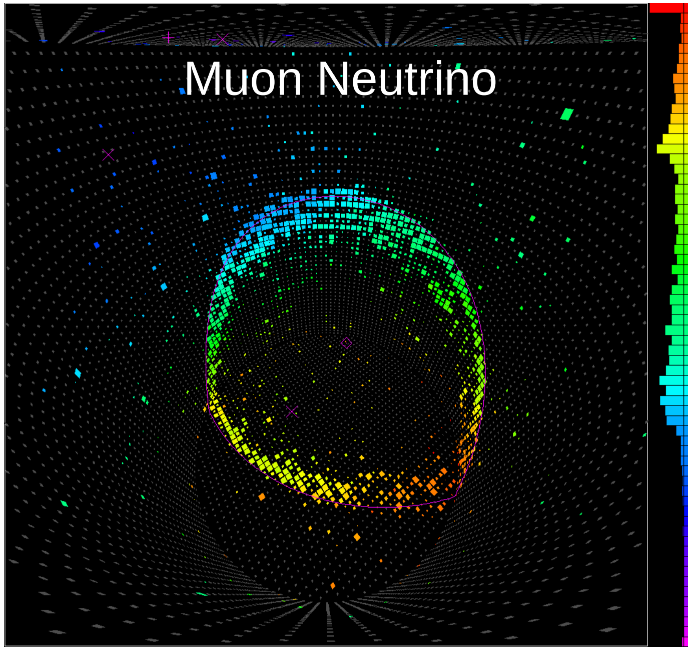
Example

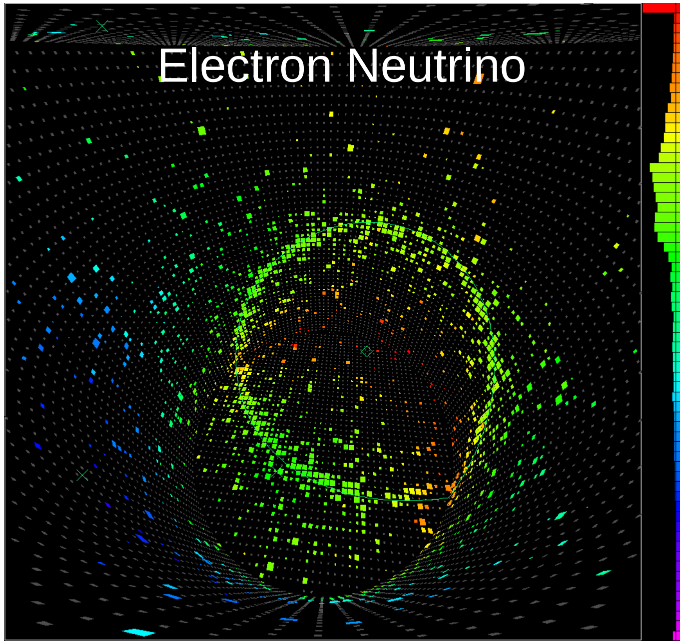
μBooNE

Example: Leptonic Reconstruction



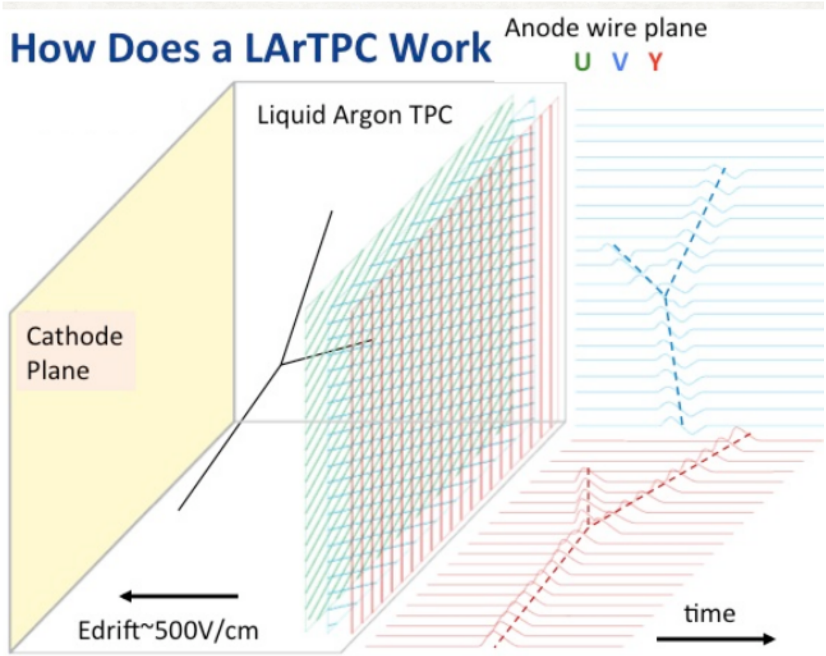


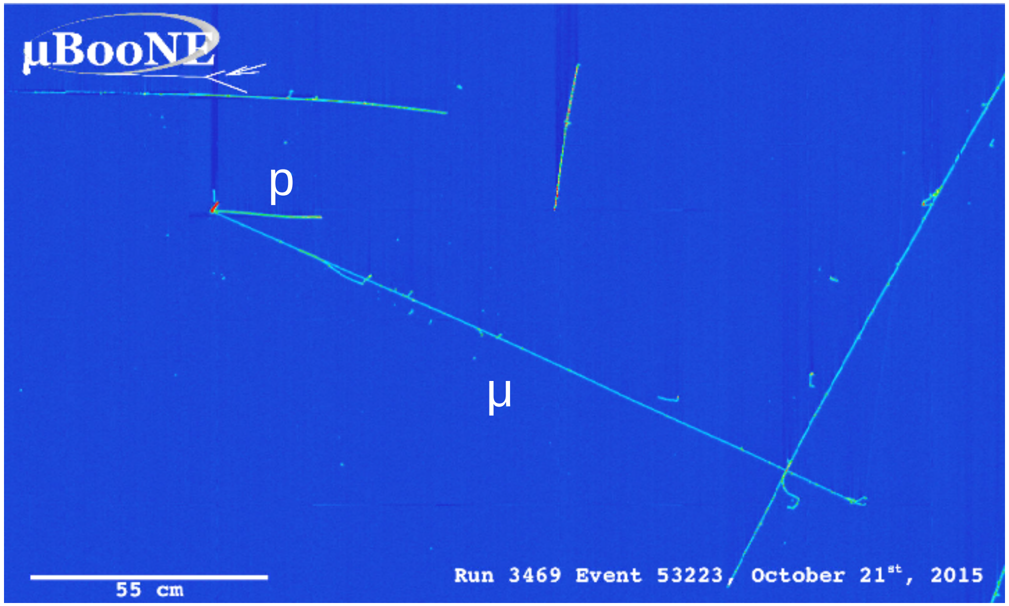




Example: Calorimetric Reconstruction

- Large liquid argon target for neutrino interactions.
- Charged particles produced in the interaction ionize the argon.
- Ionization electrons drift to anode wire plane due to electric field.
- Signal from electrons on wires is read out.
- Reconstruct images of events.

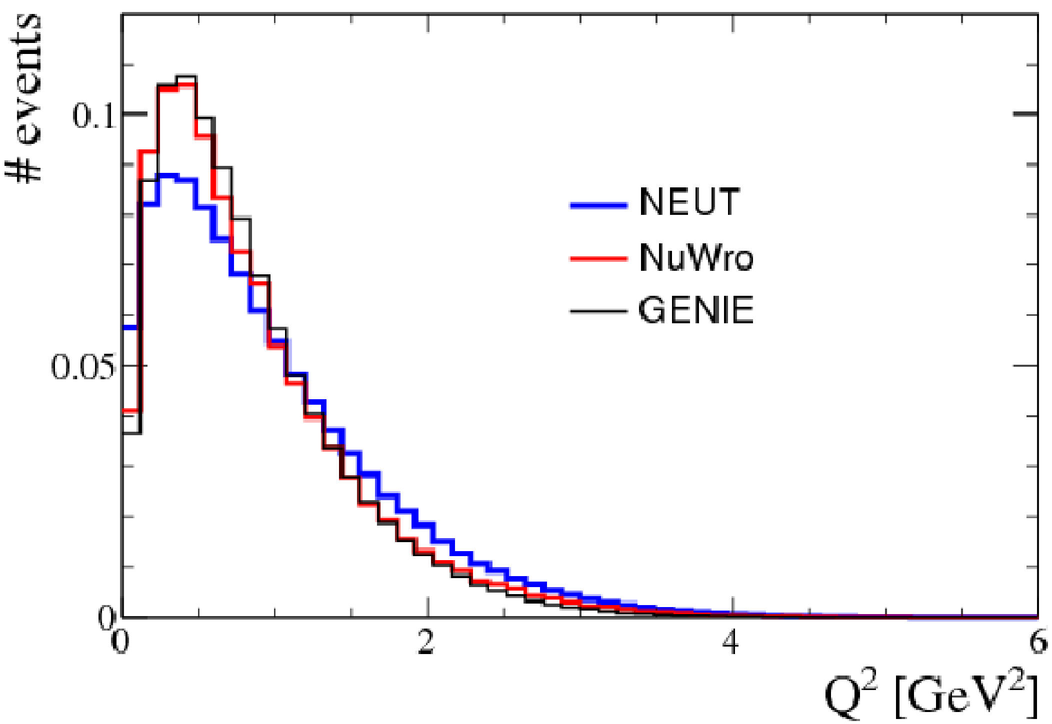


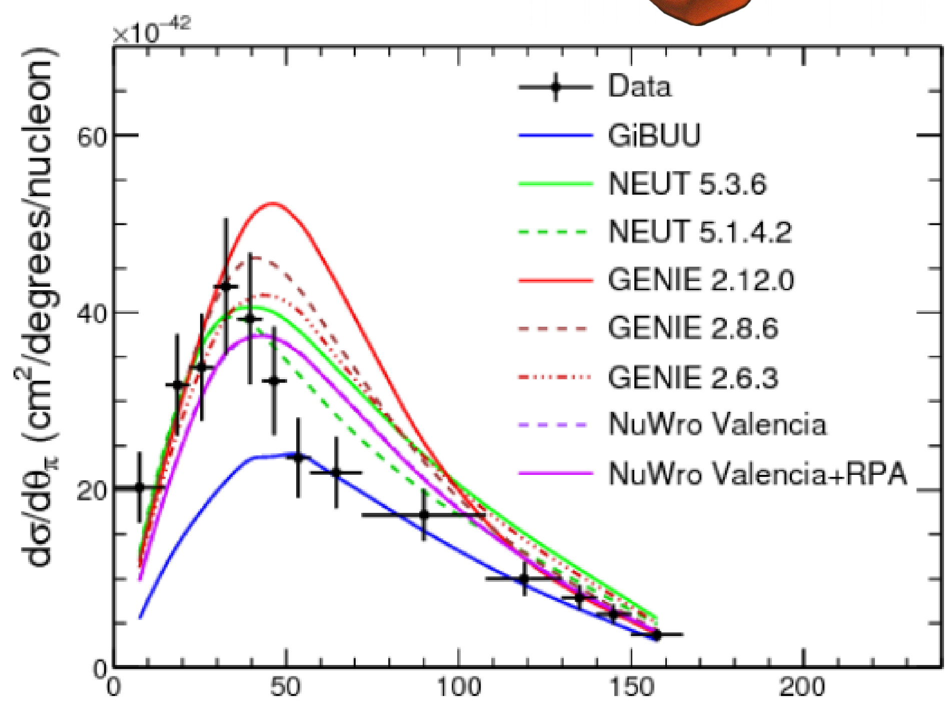


Issues with Neutrino Event Generators

Issues with Neutrino Event Generators

- Significant disagreement between different generators.
- None of the Nuclear Models is capable of explaining the data.





B.G. Tice, et al. (MINERvA Collaboration)
Phys. Rev. Lett. 112 (2014) 231801

New Strategy

New Strategy

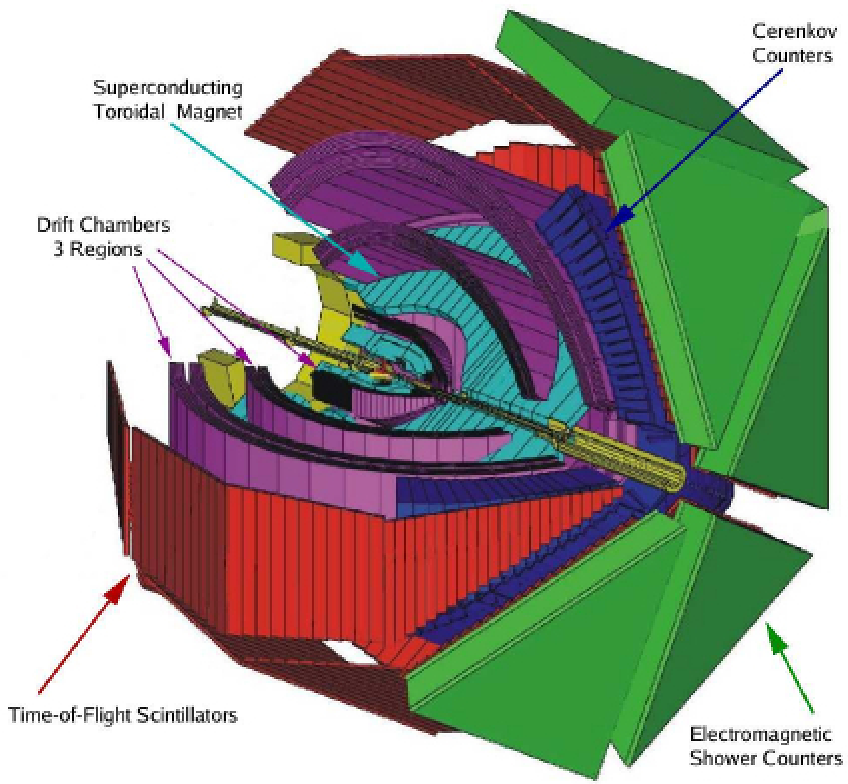
Electrons for Neutrinos!

- Use e-scattering data to constraint ν-data.

Why ?

- e and ν share many common aspects of the interaction.
- Beam energy and EM interaction well known → good test of nuclear responses (FSI, multi-nucleon effects etc.)
- CLAS@JLab has a large number of e-scattering data in a wide phase-space.

Beam energy (# triggers)			
Target	1.161 GeV	2.261 GeV	4.461 GeV
^{3}He	141	217	186
^{4}He	-	333	445
^{12}C	62	238	310
^{56}Fe	-	23	30
CH2	10	35	21
Empty cell	19	69	33



- Use data recorded by CLAS to study E_{beam} reconstruction and cross-sections.
- Select (e,e'p) events (requiring no pions, 2^{nd} protons, ...).
- Analyze them as “neutrino data” (assuming unknown beam energy).
- Compare to GENIE Neutrino Event Generator predictions.
- Identify parts in phase-space where energy reconstruction and GENIE predictions agree well.

Simulating (e,e’p) events using the GENIE Neutrino Event Generator

Analysis on ^{12}C @ E = 4.461 GeV

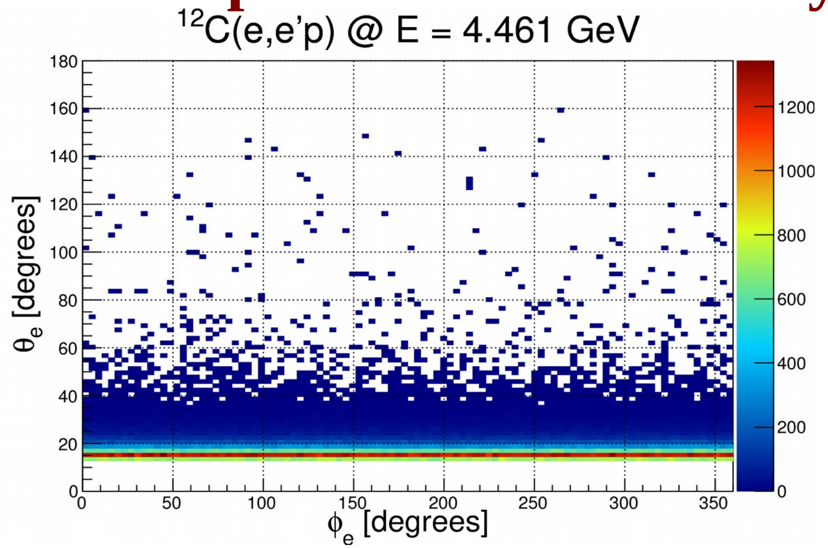
- Only 1 proton above threshold (300 MeV/c)
- No other charged particles above threshold
- N neutral particles
- $Q^2 \geq 1$ GeV^2/c^2
- W < 2 GeV/c^2
- $|x_B - 1| < 0.2$

Simple kinematics

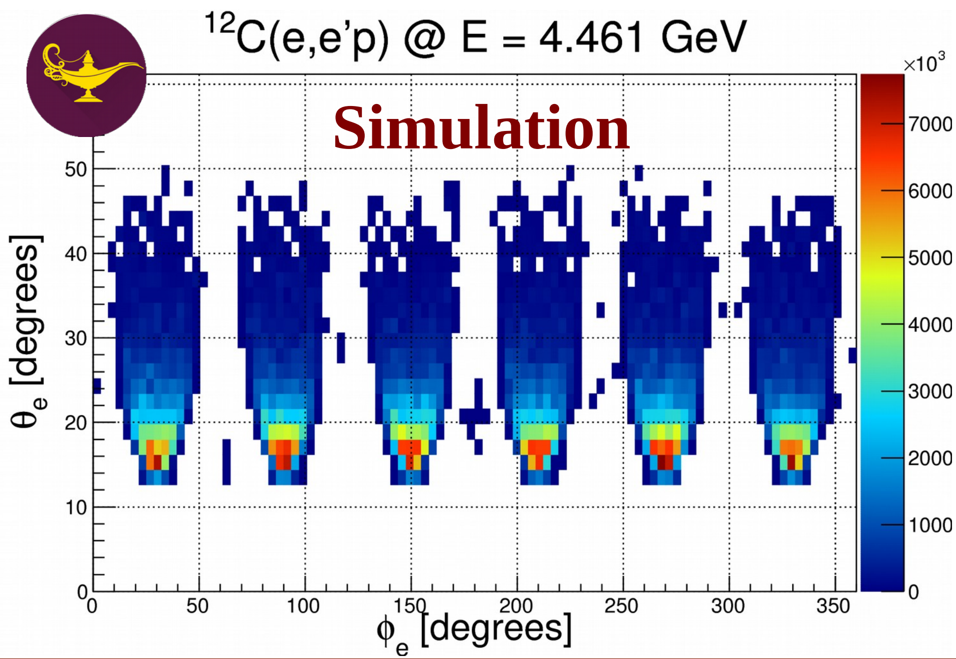
Simulation

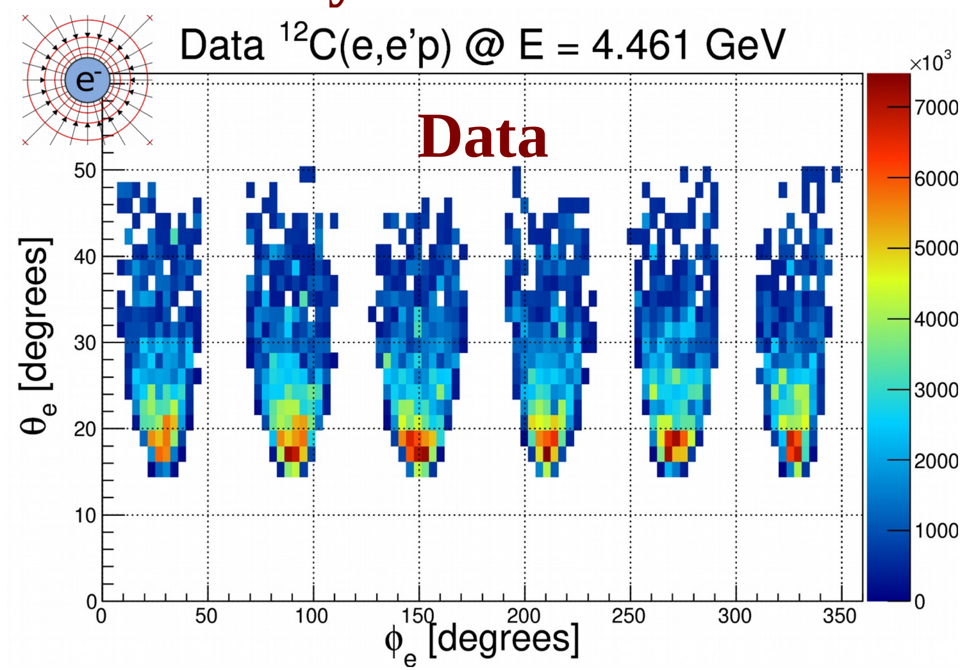
- Only EM QE & MEC events
- PLOTS AFTER DIVISION WITH MOTT XSECTION!
- PLOTS AFTER INCLUDING CLAS ACCEPTANCE!

Before application of acceptance and division by Mott xsection

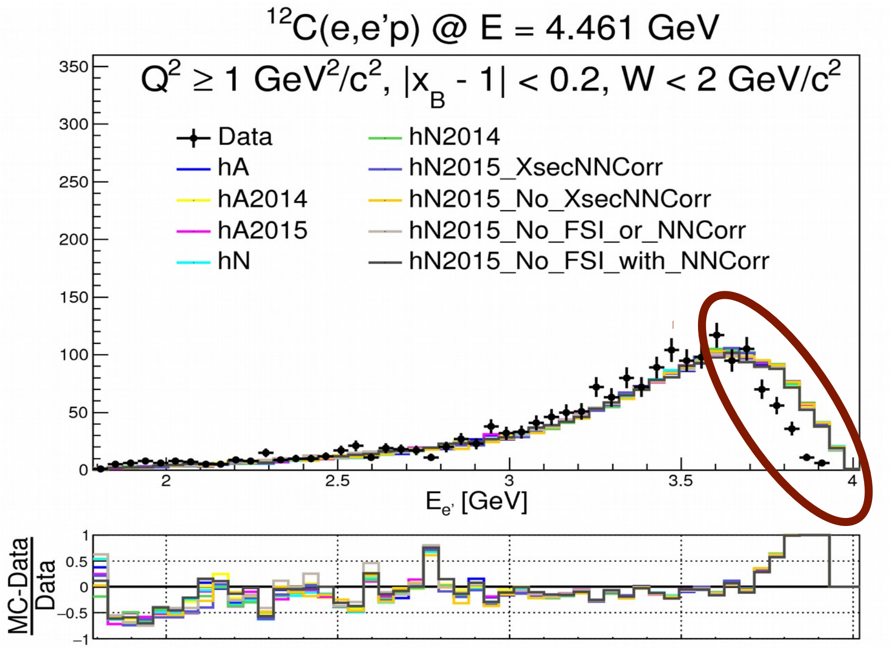


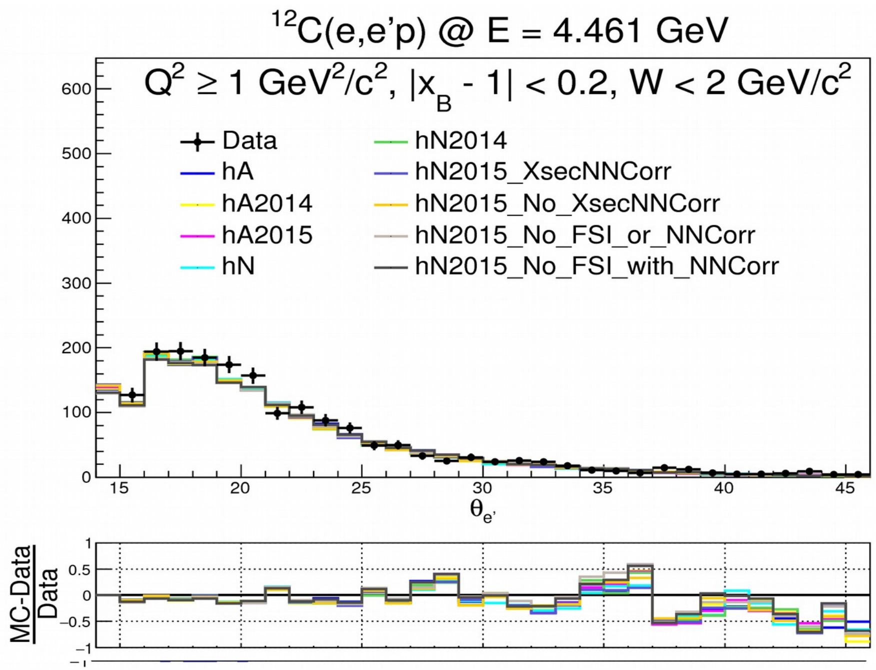
After application of acceptance and division by Mott xsection

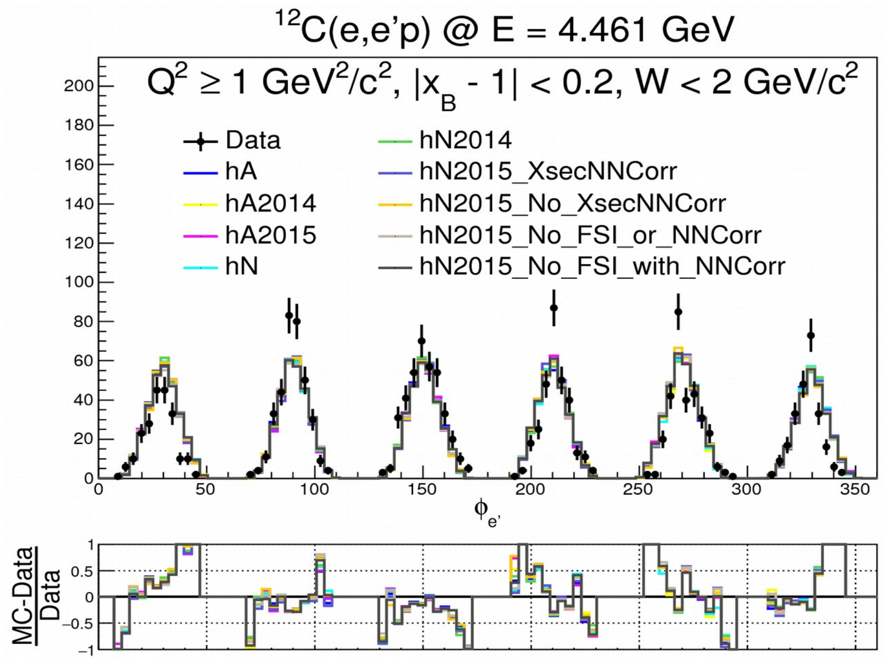




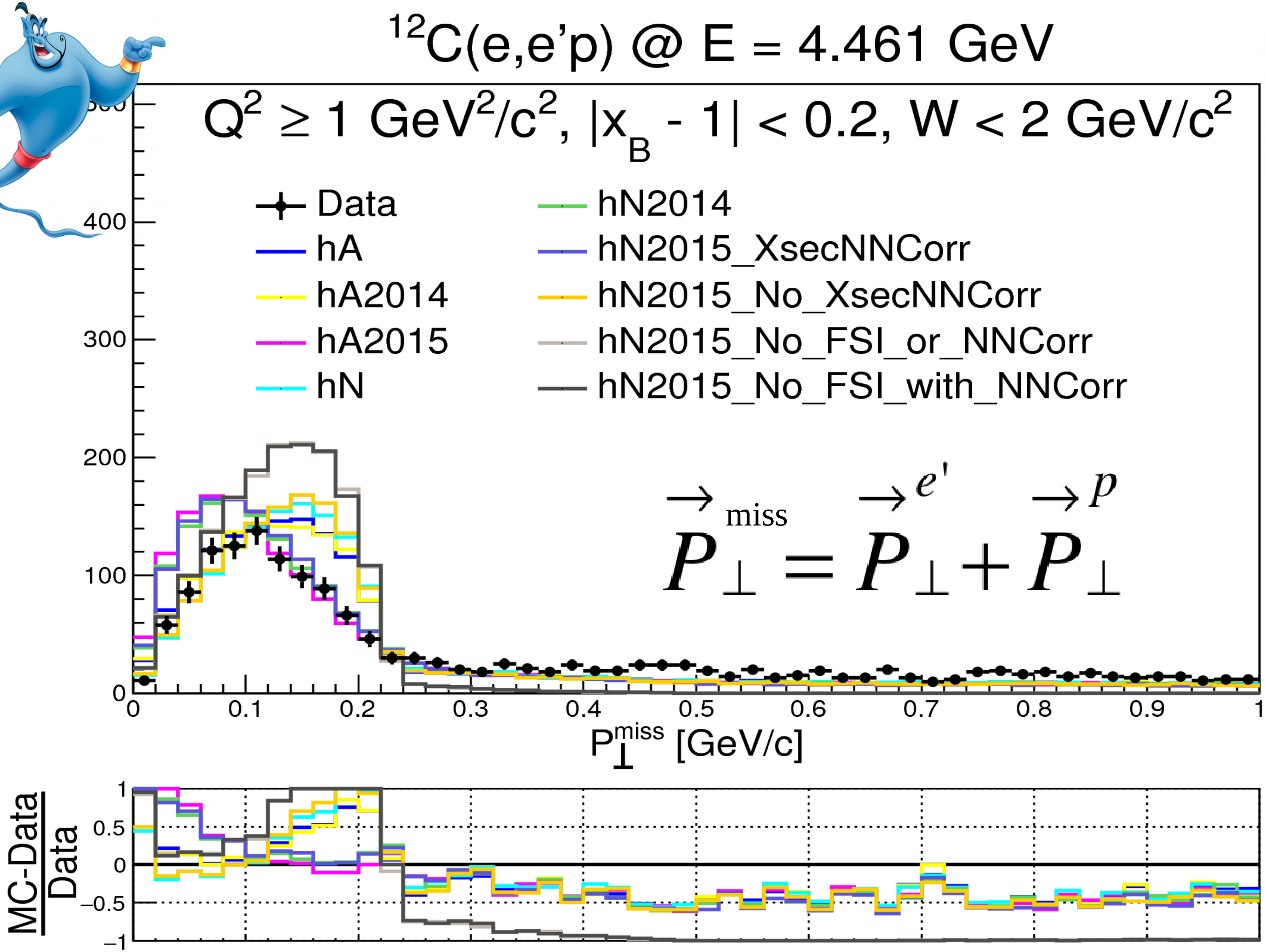
Electron Phase-Space







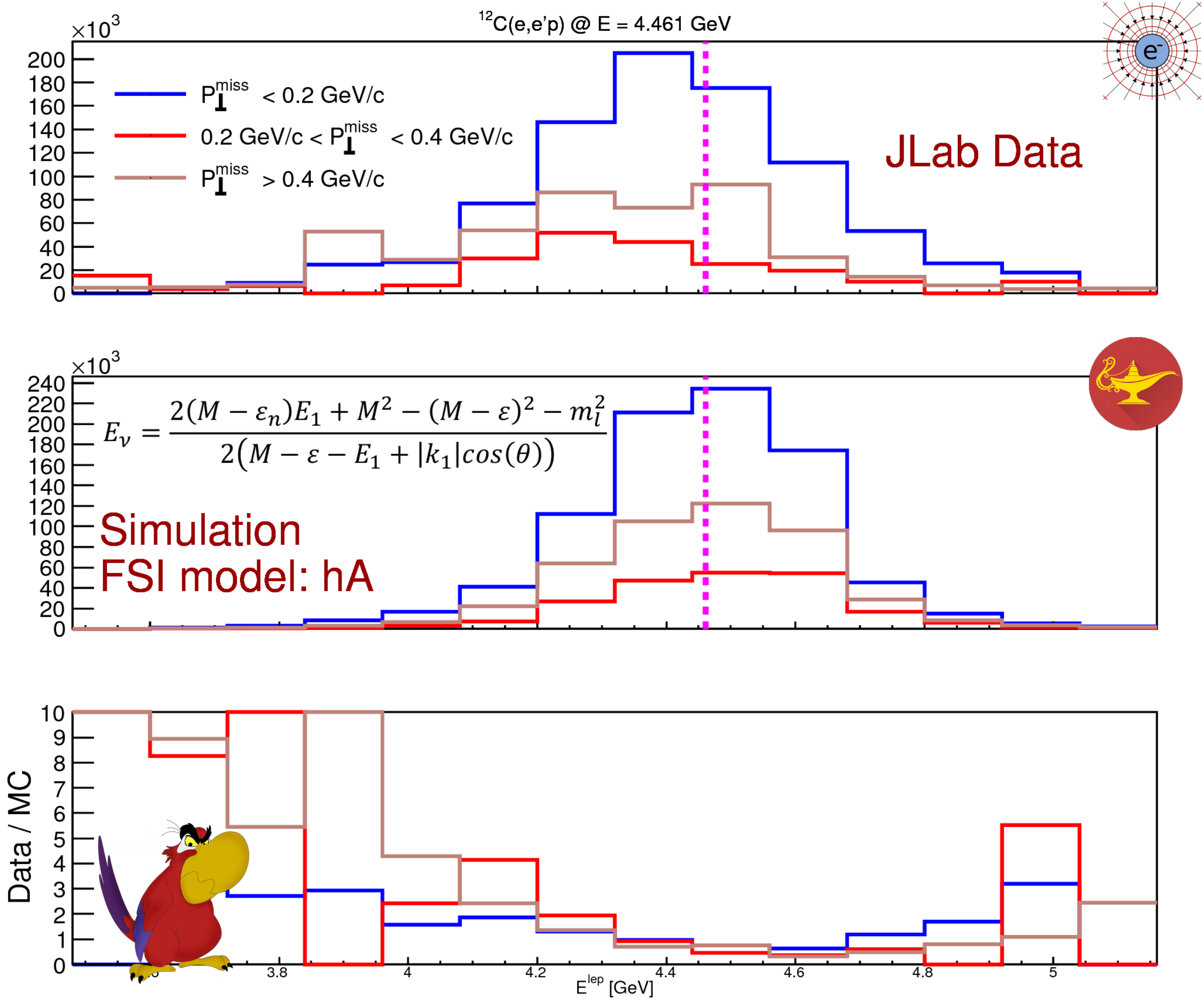
Transverse Missing Momentum



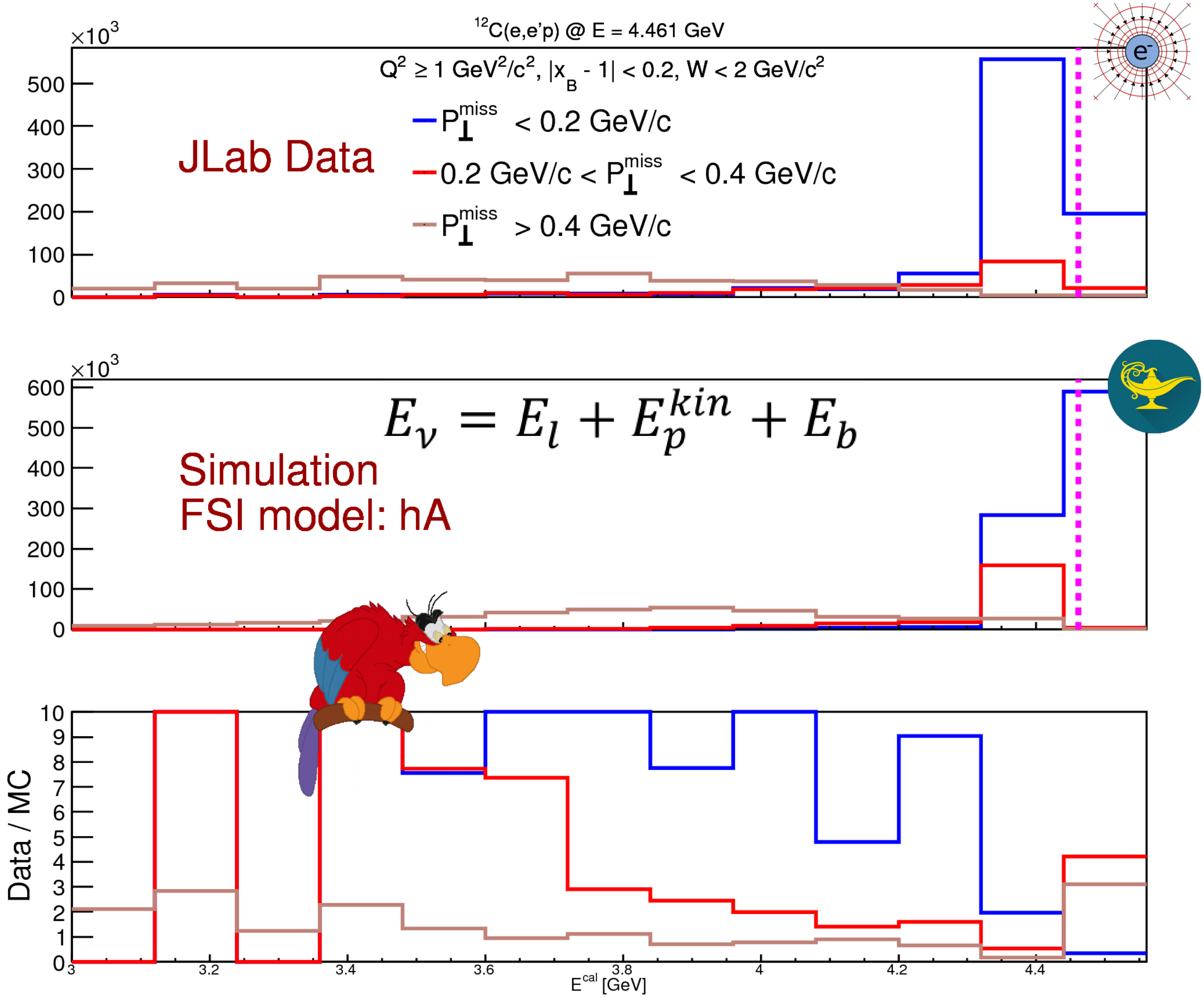
Testing the Neutrino Beam Energy Reconstruction Methods in $P^{miss}_{\perp}$ Slices

$$\vec{P}^{\,miss}_{\perp} = \vec{P}^{\,e'}_{\perp} + \vec{P}^{\,p}_{\perp}$$

Leptonic Energy Reconstruction in $P^{miss}_{\perp}$ Slices



Calorimetric Energy Reconstruction in $P^{miss}_{\perp}$ Slices



Future Plans

Future Plans

Benchmarking the GENIE Neutrino Event Generator Against Electron Scattering Data

- Study the (e,e'p) phase-space to identify regions with good and bad energy reconstruction & GENIE modeling.
- Expand to other generators / reactions / nuclei / energies.
- Study impact on bias in oscillation analyses.

Thank you !

Backup Slides

GENIE: Event Selection

Analysis on ^{12}C @ E = 4.461 GeV

- 1M events (to be increased)
- Only EM QE & MEC events
- PLOTS AFTER DIVISION WITH MOTT XSECTION!
- PLOTS AFTER INCLUDING CLAS ACCEPTANCE!
- eg2 map (e2a map on its way)

- Only 1 proton above threshold (300 MeV/c)
- No other charged particles above threshold
- N neutral particles
- $Q^2 \geq 1$ GeV^2/c^2
- W < 2 GeV/c^2
- $|x_B-1| < 0.2$

- GENIE version: trunk
- Nuclear Model: Relativistic Fermi Gas Model

Data: Event Selection

Analysis on ^{12}C @ E = 4.461 GeV

- Only 1 proton above threshold (300 MeV/c)
- No other charged particles above threshold
- N neutral particles
- $Q^2 \geq 1$ GeV^2/c^2
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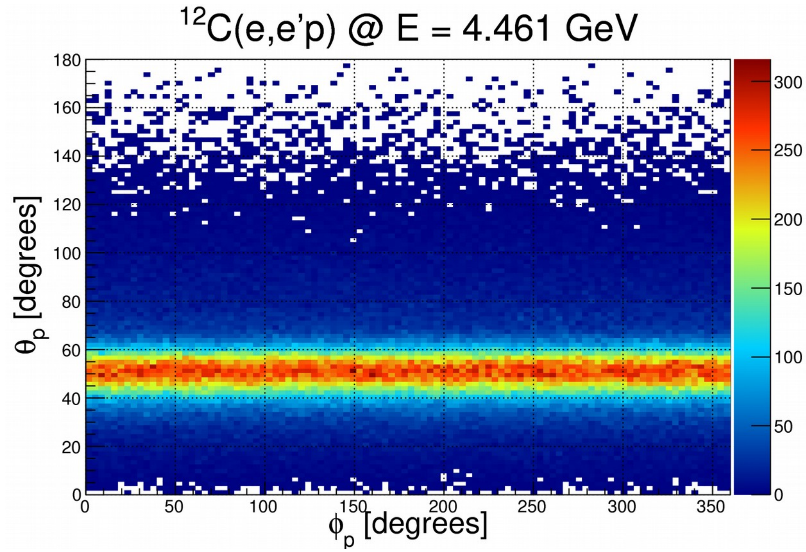
- $|x_B - 1| < 0.2$

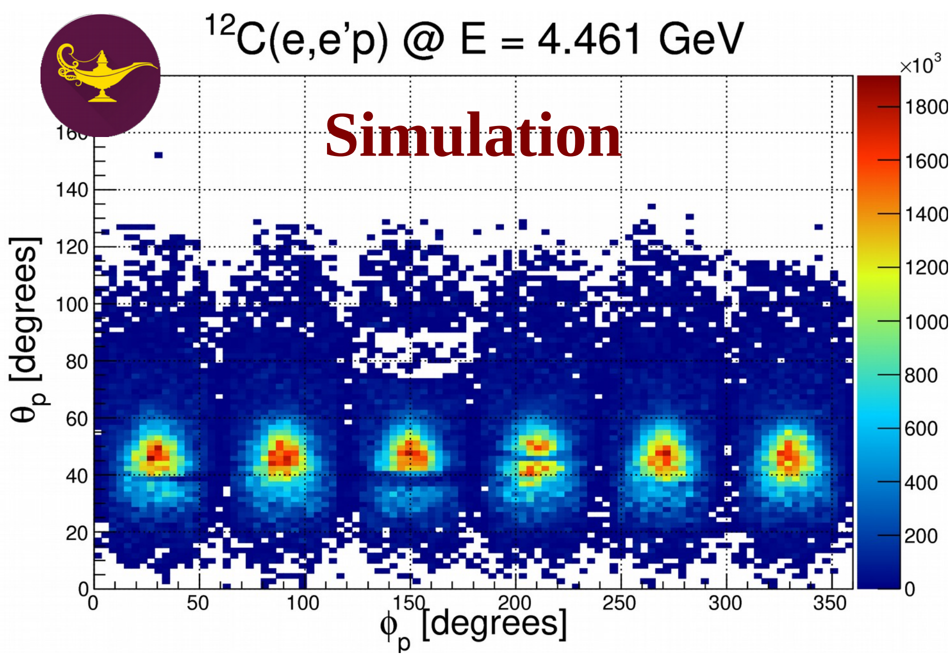
- e, p PID, fiducial and vertex cuts
- Fiducial cuts on charged pions
- No photons coming from π^0 decay
- Subtraction for undetected pions
- Subtraction for undetected two proton events that contribute to one proton events

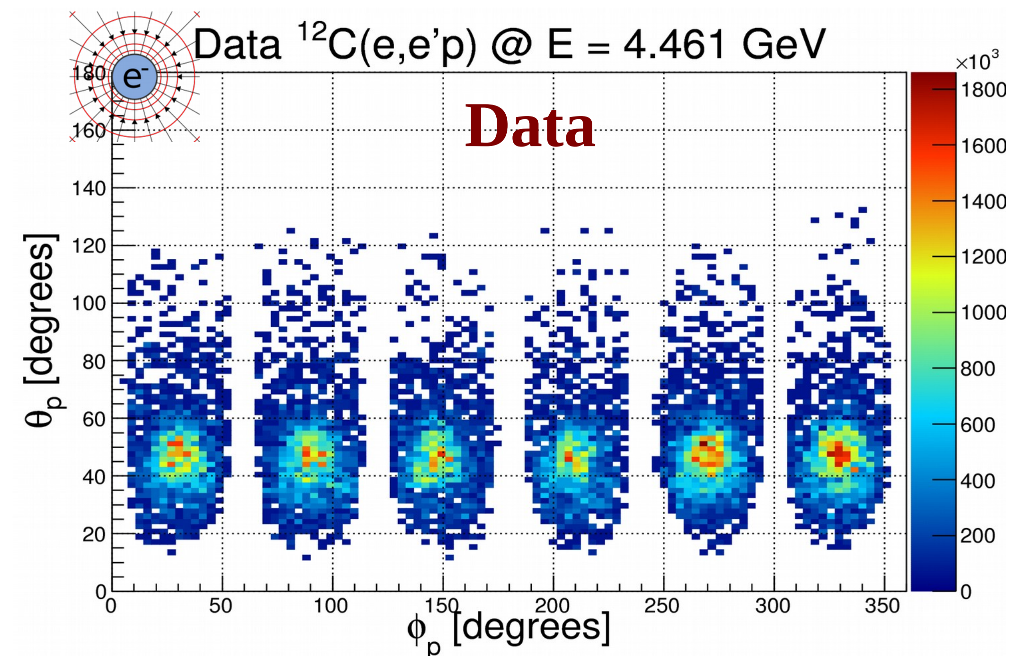
Proton θ_p vs φ_p Plots

Before acceptance correction and division by Mott xsection



After acceptance correction and division by Mott xsection





Proton Plots