Beam Energy Reconstruction in Multi-Hadron Final States in e2a

CLAS Collaboration Meeting

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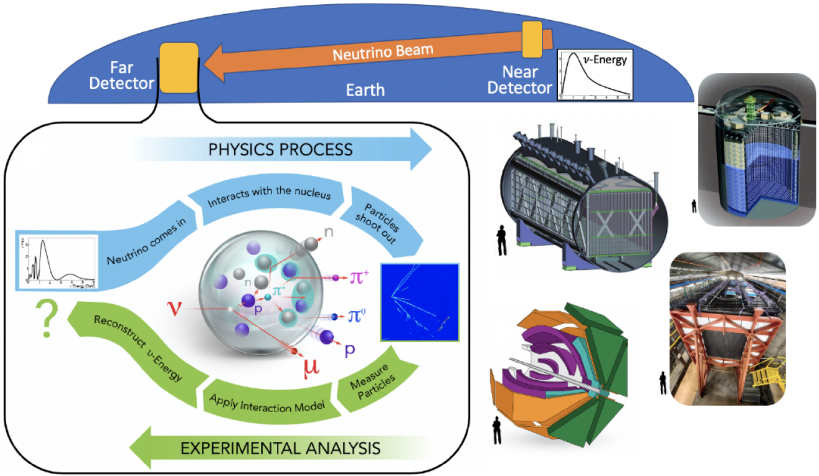
CEBAF Large Acceptance Spectrometer

Electrons for Neutrinos - e4nu

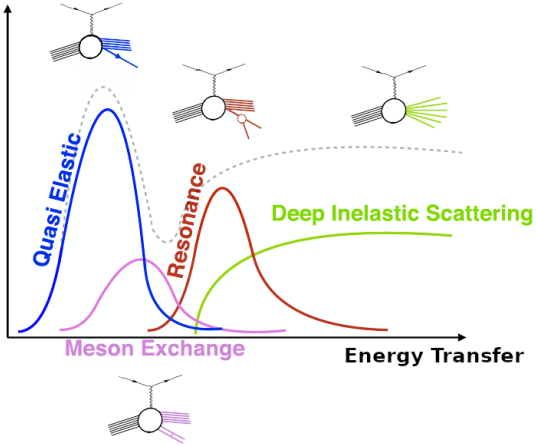


Electrons for Neutrinos - e4nu

- From a CLAS perspective, e4nu uses electron scattering data on nuclear targets
- Seeking to constrain models of lepton-nucleus interations needed to better describe neutrino interactions
- This started with the PhD of Mariana Khachatrtan, supervised by Larry Weinstein[1]
- I've been working with several collaborators to continue this work
- Particular credit goes to Lucas Tracy, Ali Mand, Afro Papadopoulou and Florian Hausenstein

[1] Validation of Neutrino Energy Estimation Using Electron Scattering Data, PhD Thesis, ODU (2019)

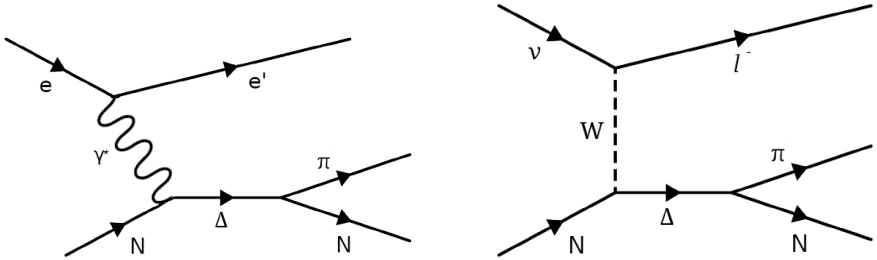
Scattering Processes



- The previous analysis covered "Zero Pion" final states
- Emphisises Quasi-Elastic (QE) process
- This talk: study role of resonance production in single pion channels, A(e,e'pπ)

Resonance Production

- Resonance production from electrons similar to that from neutrinos

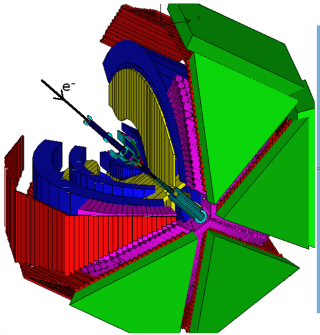


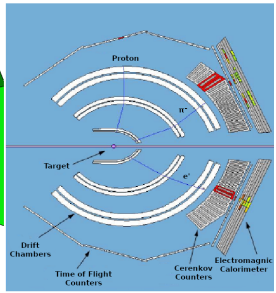
- Study the former to inform models of the latter

e2a Run Period

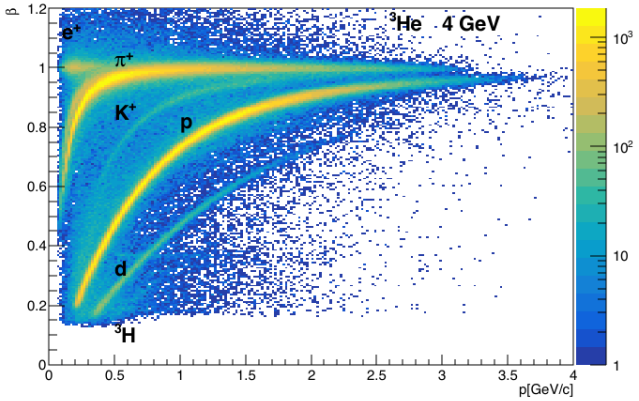
- April/May 1999
- Electron beam experiment
- Various targets

	1.1 GeV	2.2 GeV	4.4 GeV
^{3}He	✓	✓	✓
^{4}He	—	✓	✓
^{12}C	✓	✓	✓
^{56}Fe	—	✓	✓





Particle Identification



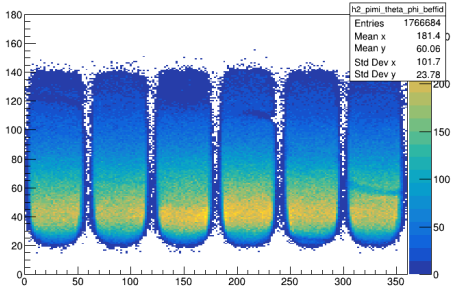
- e2a data previously analysed and published
- Most cuts and corrections common to those analyses
- Select events with electron, proton and charged pion in final state

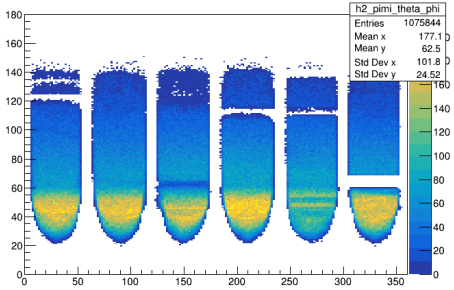
Fiducial Cuts for π^-

For e4nu analyses of e2a, π^- fiducial cuts needed to be defined

- Electron cuts reused for high momentum (>300 MeV) cuts not defined for electron at lower momentum ranges
- New cuts at low momentum - used same procedure as electron and other hadrons

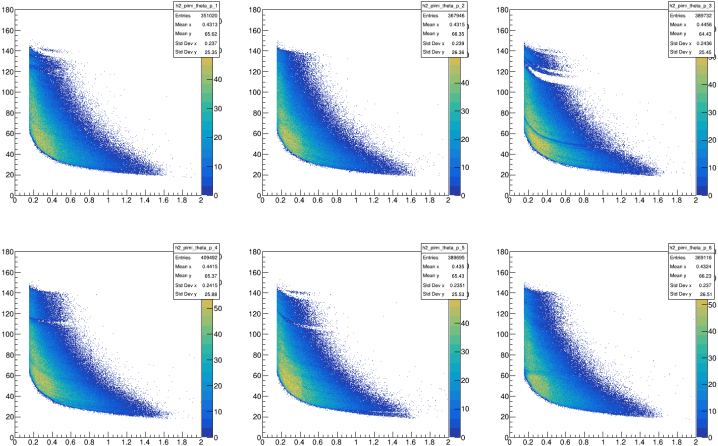
Results look okay at first inspection





Fiducial Cuts for π^-

However, in θ vs momentum, there are clear issues



Fiducial Cuts for π^-

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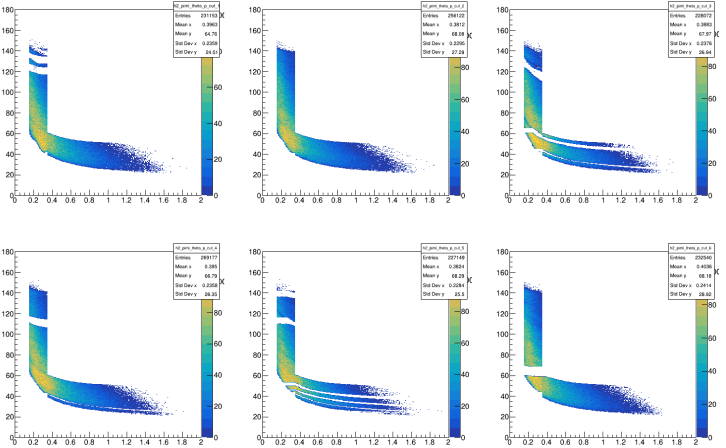
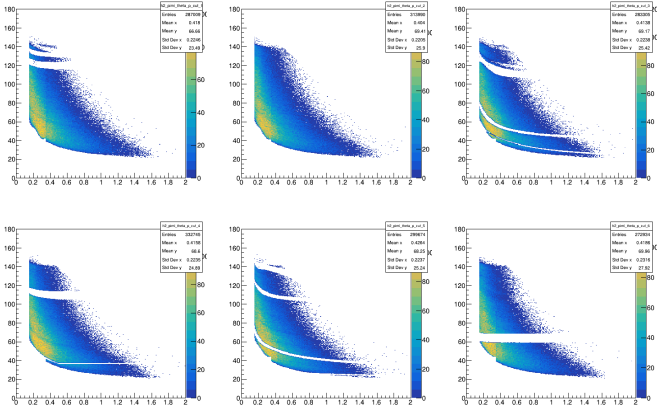


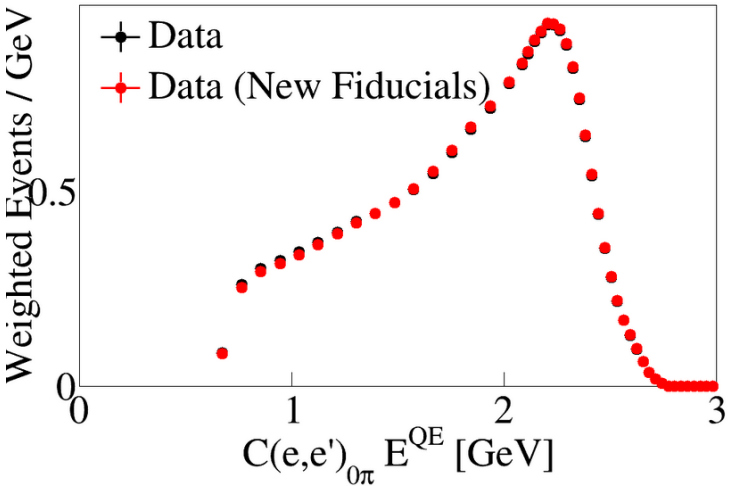
Status



- Finalising updates to π^- fiducial cuts
- Dead channel cuts redefined to low momentum
- Electron cuts replaced to loosen hard upper limit on θ
- Recheck other particles

Status

Effect of π^- fiducial revisions on e4nu analyses is minimal



Energy Reconstruction

- Want to reconstruct beam energy from detected particles
- Two methods, "Calorimetric", using all final state particles

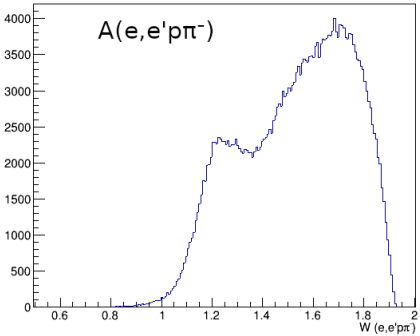
$$E_{cal} = E'_{e^-} + E_p + \epsilon + E_\pi$$

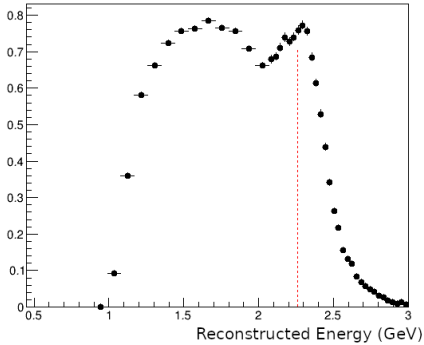
- And "Kinematic", using the scattered electron, assuming Δ production

$$E_{DeI} = \frac{m_\Delta^2 - (m_p - \epsilon)^2 - 2(m_p - \epsilon)E'_{e^-}}{2(m_p - \epsilon - E'_{e^-} + E'_{e^-} cos\theta_{e^-})}$$

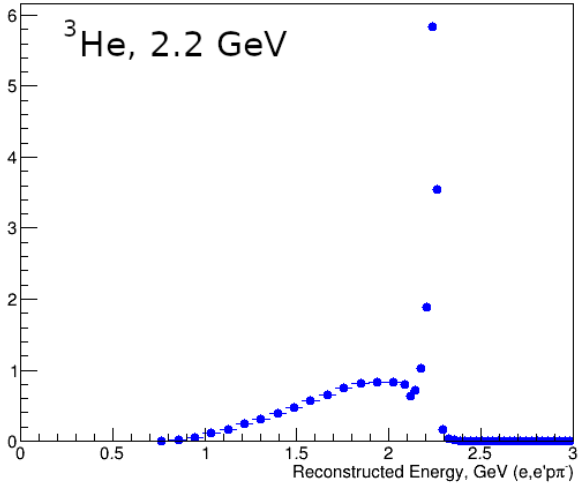
Energy Reconstruction, Kinematic Method

- ^{3}He at 2.2 GeV
- A(e,e'pπ) not Δ dominated, "Kinematic" reconstruction of limited use



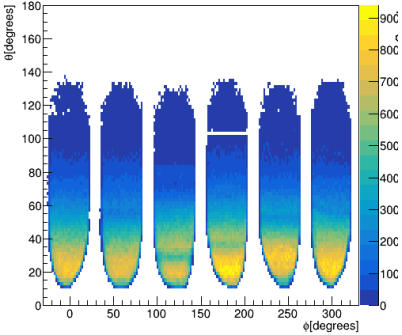


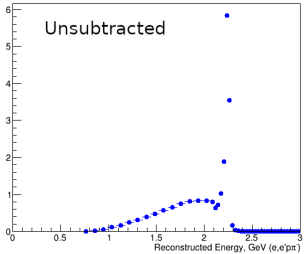
Energy Reconstruction, Calorimetric Method

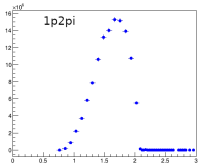


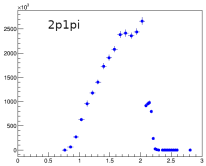
Undetected Particles

- Some particles undetected, fall through CLAS acceptance gaps
- Effect on energy reconstruction



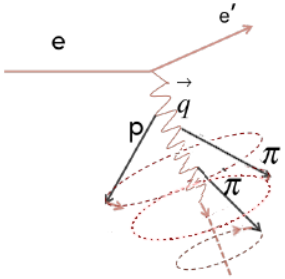






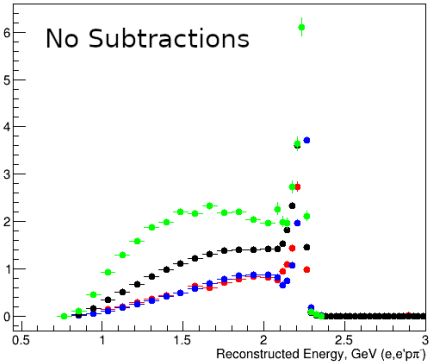
Rotations

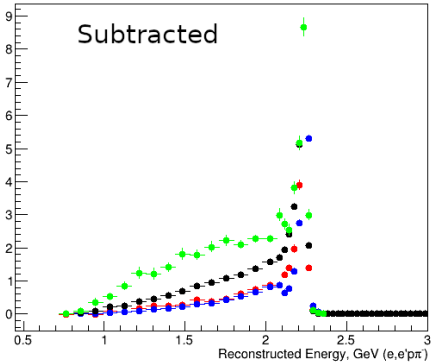
- Select events with multiple hadrons
- Randomly rotate around direction of three momentum transfer
- Some events fall into acceptance gaps
- Proportion of events lost used to estimate undetected ones
- Subtract from energy reconstruction spectra
- Produce "true" 1p1π event samples



Energy Reconstruction, Calorimetric Method, 2.2 GeV

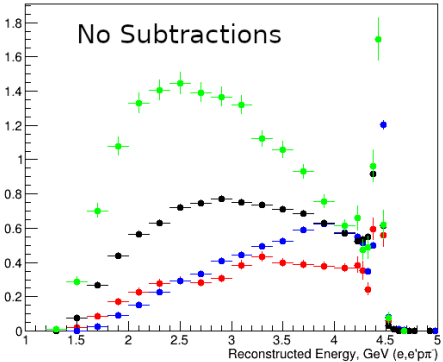
Targets: ^{3}He, ^{4}He, ^{12}C, ^{56}Fe

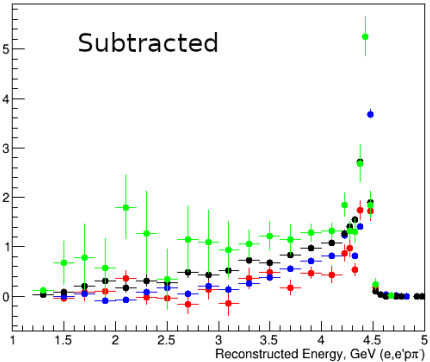




Energy Reconstruction, Calorimetric Method, 4.4 GeV

Targets: ^{3}He, ^{4}He, ^{12}C, ^{56}Fe



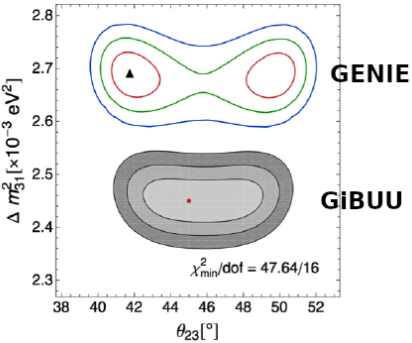


Observations

- Event selection stable
- Kinematic reconstruction poor - not pursuing at this time
- Calorimetric reconstruction produces clear beam energy peak on $p\pi^-$ events
- Larger tails in reconstruction as energy and target mass increase (expected from zero pion analysis)
- Peaks not so clear for $p\pi^+$ (and $p\pi^0$) - not quite ready to drop these yet
- Next steps are to bin in kinematic variables, and compare to neutrino event generators (e.g. GENIE)

(Backup) Event Generators

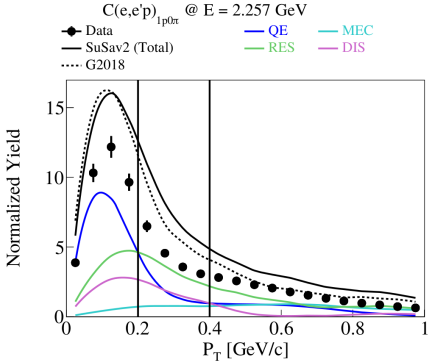
- GENIE (Generates Events for Neutrino Interaction Experiments)
- GiBUU (The Giessen Boltzmann-Uehling-Uhlenbeck Project)



- Each model has different approaches to describing lepton-nucleus interactions
- Different values of neutrino oscillation parameters extracted

(Backup) Event Generators

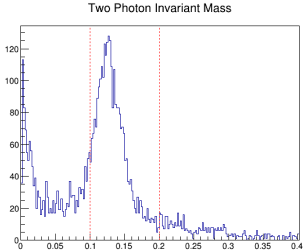
- GENIE is the basis for event generator studies
- Used in predecessor analysis
- Expertise readily available in e4nu

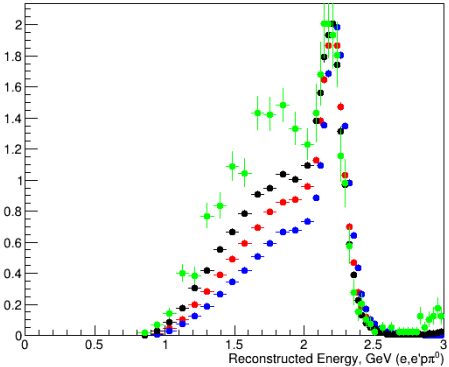


- GiBUU a possible cross-check
- Some experience in York - watch this space

(Backup) Energy Reconstruction, Calorimetric Method, 2.2 GeV

Targets: ^{3}He, ^{4}He, ^{12}C, ^{56}Fe, A(e,e'pπ^0)

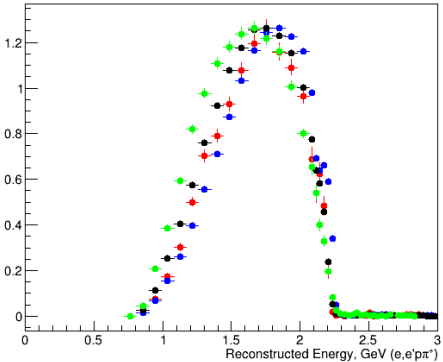


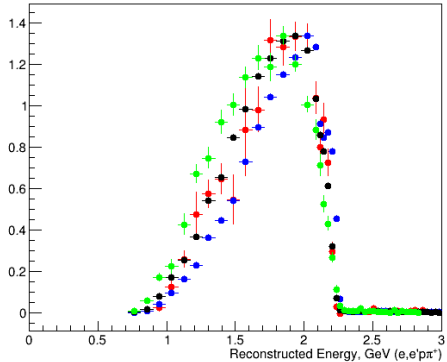


- Very loose π^0 selection from two photon invariant mass
- Beam energy peak visible

(Backup) Energy Reconstruction, $p\pi^+$, 2.2 GeV

Targets: ^{3}He, ^{4}He, ^{12}C, ^{56}Fe





(Backup) Energy Reconstruction, $p\pi^+$, 4.4 GeV

Targets: ^{3}He, ^{4}He, ^{12}C, ^{56}Fe