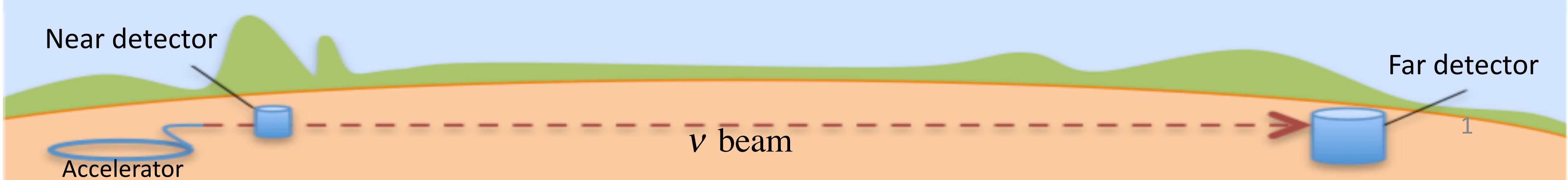
Update: Studies of neutrino energy reconstruction using electron scattering data

Mariana Khachatryan - ODU



Outline

1. Introduction.
2. March 2019 status:

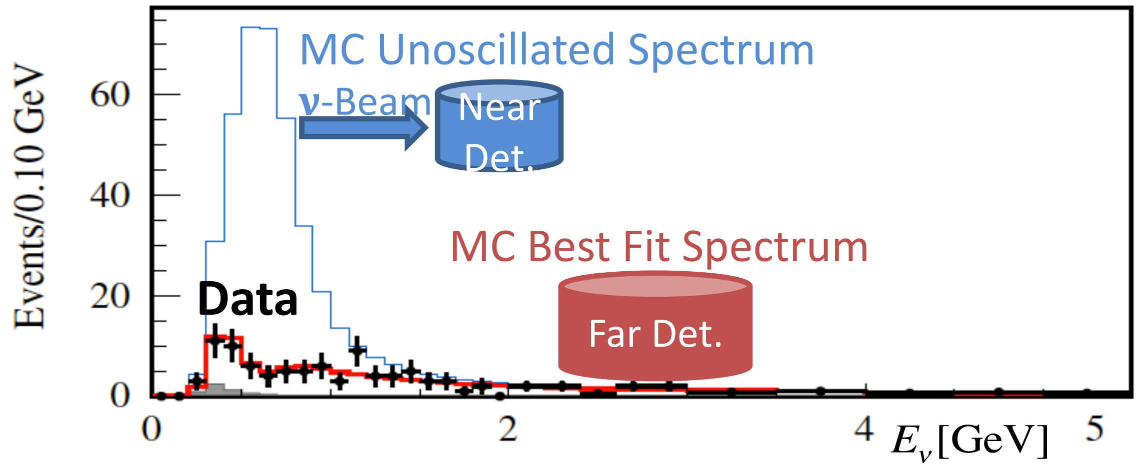
   - Analysis review ongoing.
   - Looked at (e,e'), (e,e'p) events with zero detected pions and photons.
   - Reconstructed energies E_{Cal}, E_{QE}.
   - Subtraction for undetected π^+, π^- and extra p complete.
   - Started subtraction for undetected γ.

3. Status today:

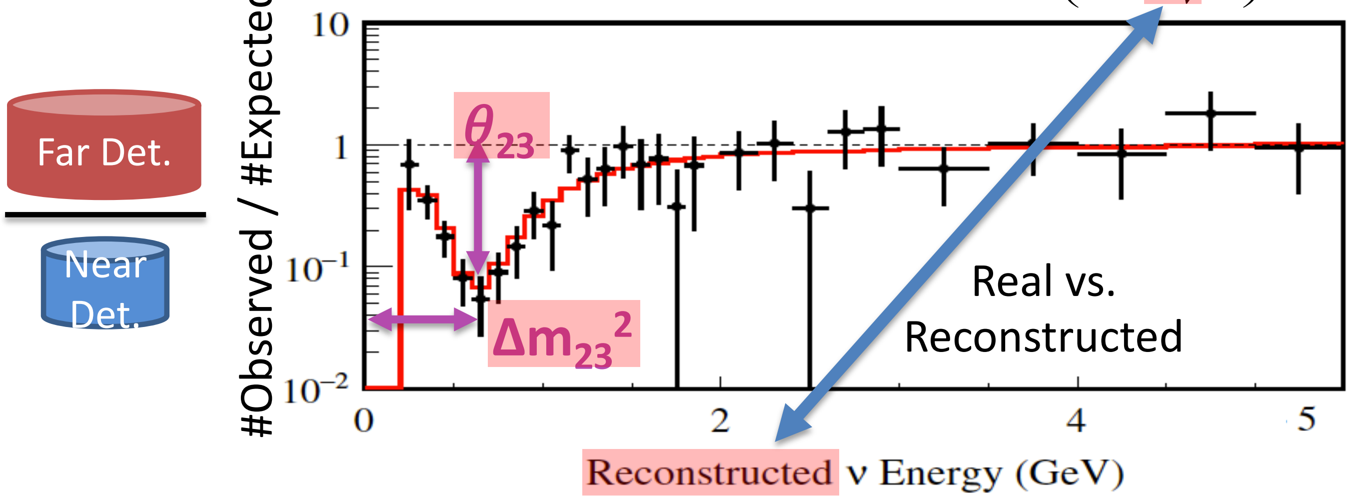
   - Completed subtraction for undetected π^+, π^-, γ and extra p.
   - Modified e^- momentum correction.
   - Analyzed the 1.1 GeV e2a data.
   - Determined binding energy values for E_{Rec} calculations.

(Long Baseline) Oscillation Challenge

T2K experiment L=295km



$$P(\nu_\mu \to \nu_\mu) = \sin^2(2\theta_{23}) \times \sin^2\left(\frac{\Delta m_{32}{}^2 L}{4E_\nu}\right)$$



T2K, Phys. Rev. D 91, 072010 (2015)

Energy Reconstruction for QE reactions

(1) Cherenkov detectors:
- Detect: leptons & pions
- Miss: protons and neutrons

(2) Tracking detectors:
- Detect: Charged particles + π^0
- Miss: Neutrons and charged particles below threshold.

Use Lepton kinematics
Assuming QE interaction

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

ε-single nucleon separation energy
M- nucleon mass
m_l – outgoing lepton mass
k_l, E_l -lepton three momentum, energy
θ_l-lepton scattering angle

Use Final-State Calorimetry
Assuming low residual excitations

$$E_{Cal} = E_l + \sum T_p + \varepsilon + \sum E_\pi$$

T_p-kinetic energy of knock out proton
E_π-energy of produced meson

E2a experiment

Targets:

<u>CLAS: ^{3}He , ^{4}He, ^{12}C, ^{56}Fe</u>

T2K: CH, H_2O

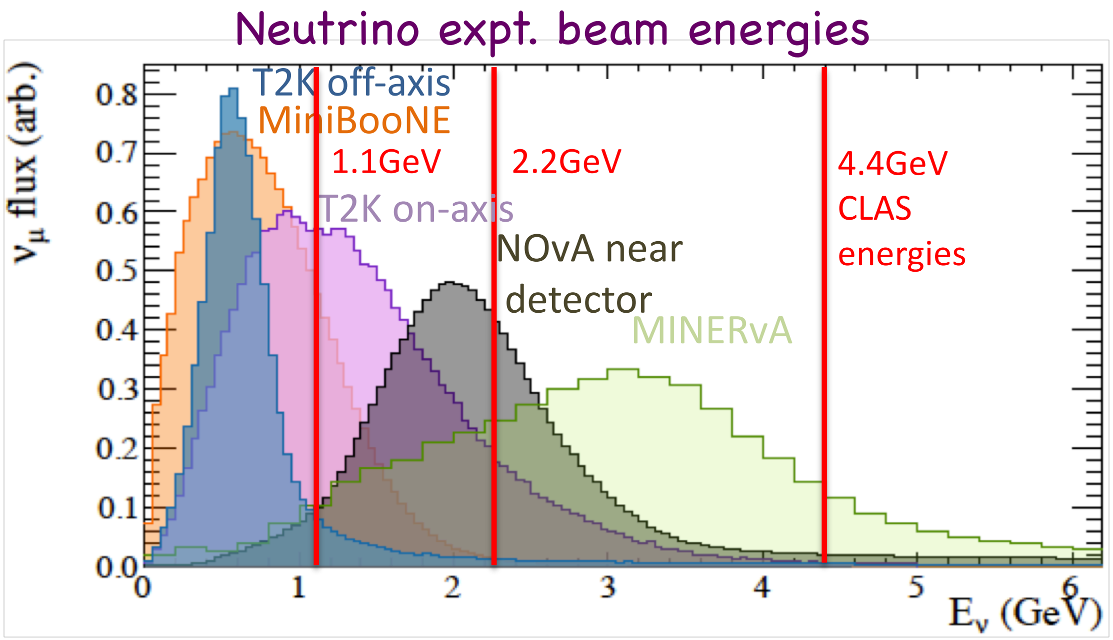
Minerva: ^{3}He, ^{4}He, C, Fe, H_2O

Microboone: Ar

Miniboone: mineral oil (C, H, O)

Nova: $C_6H_3(CH_3)_3$

DUNE: Ar



QE Event Selection

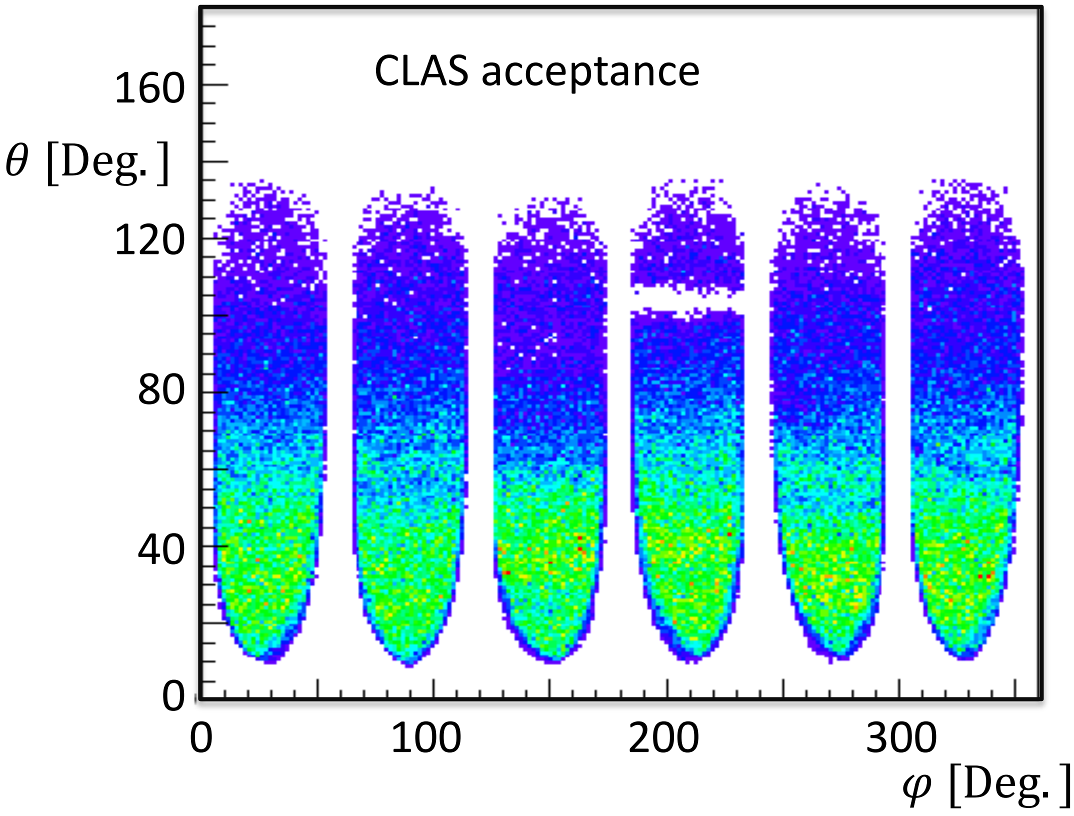
As close to QE as one can get:

- Scattered electron,
- Knockout proton,
- Zero pion,
- Zero gammas in the EC.

Scale the e^- scattering data with $1/\sigma_{\text{Mott}}$ to have 'neutrino like' data!

Background Subtraction

Want 0π (e,e’) and (e,e’p) events.
Need to account for undetected π, γ and extra protons.

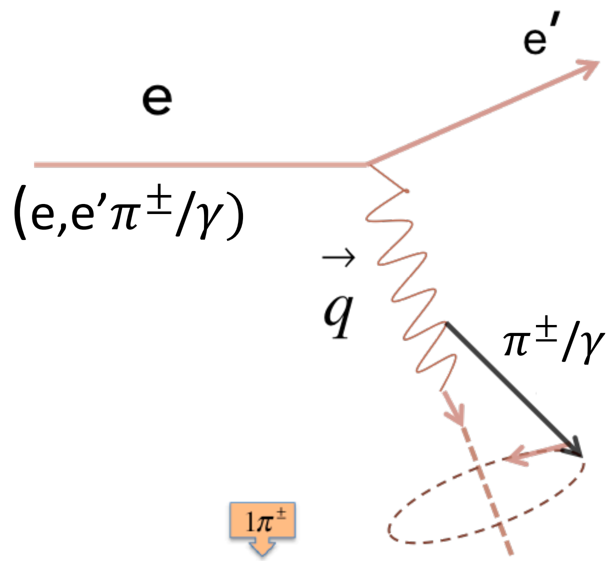


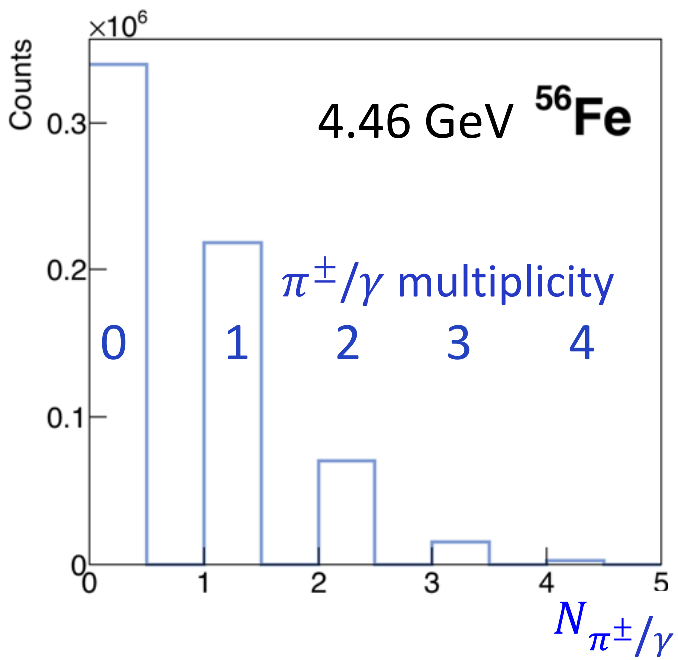
Background Subtraction in (e,e') analysis

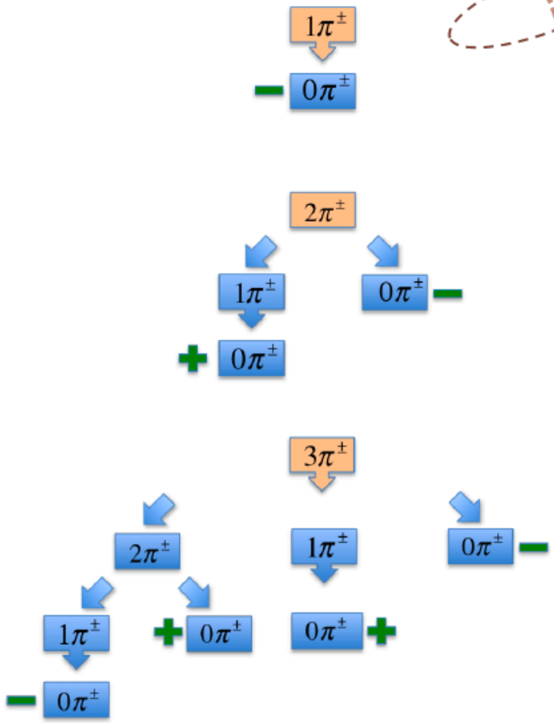
Subtract for $\pi^{\pm}$ and γ:

Data Driven Correction:

1. Use measured (e,e'$\pi^{\pm}/\gamma$) events,
2. Rotate π around q to determine its acceptance,
3. Subtract (e,e') $\pi^{\pm}/\gamma$ contributions,
4. Repeat for 2 $\pi^{\pm}/\gamma$, 3 $\pi^{\pm}/\gamma$.

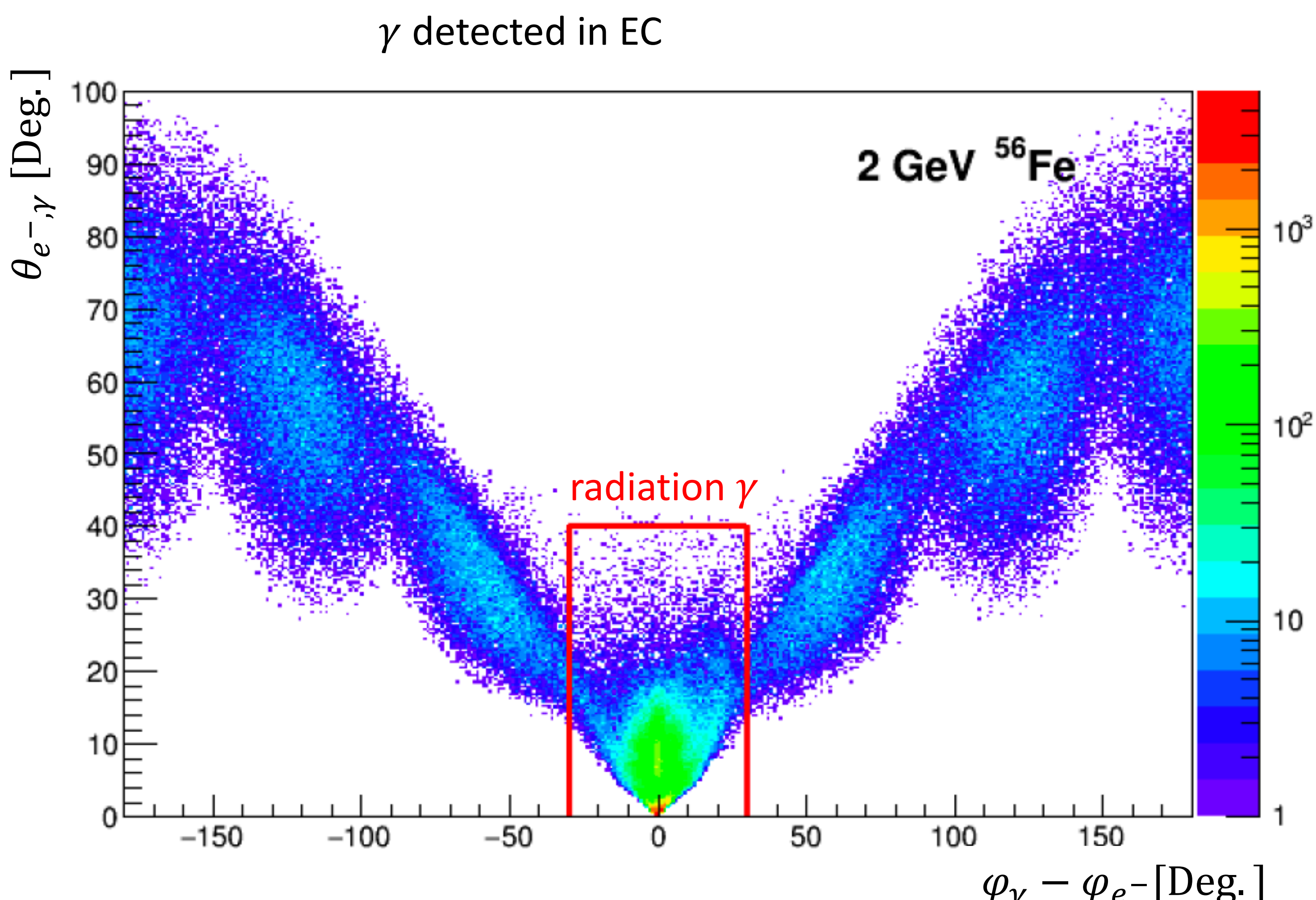






Background Subtraction

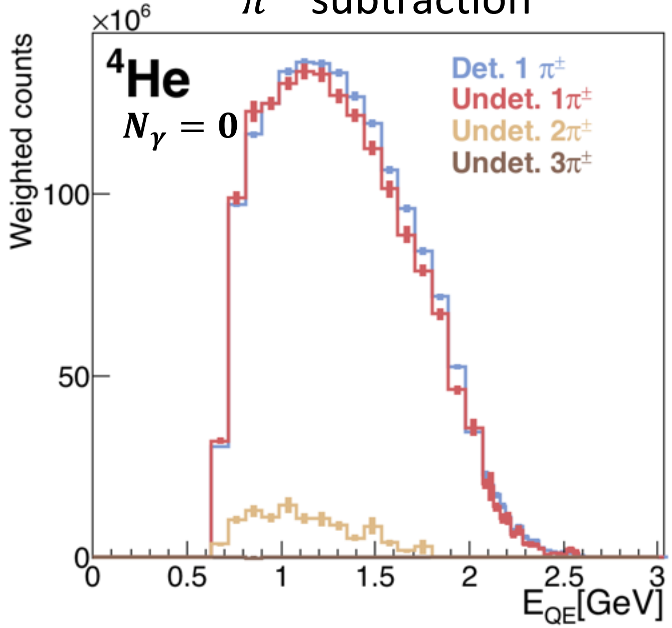
Selecting non-radiation γ.



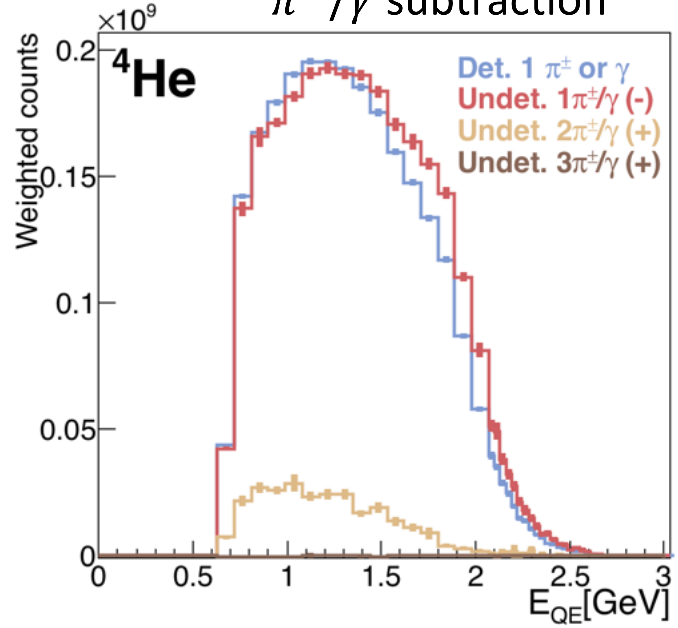
(e,e') $\pi^{\pm}/\gamma$ subtraction

2.26 GeV

$\pi^{\pm}$ subtraction

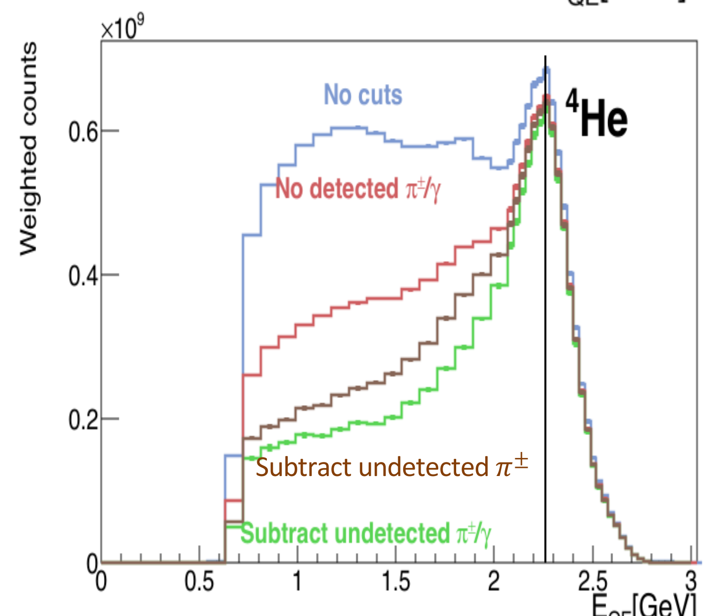


$\pi^{\pm}/\gamma$ subtraction



π detected in TOF+DC

γ detected in EC

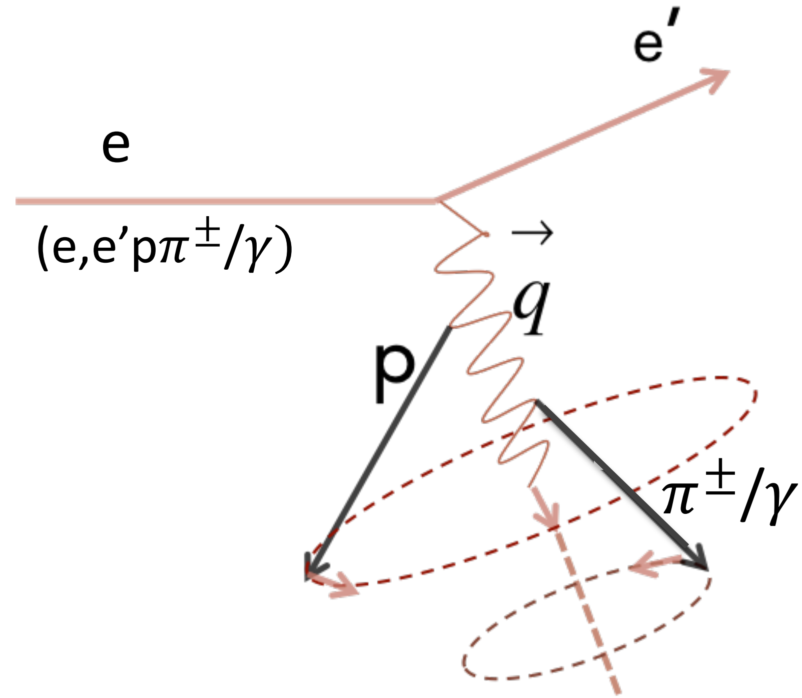


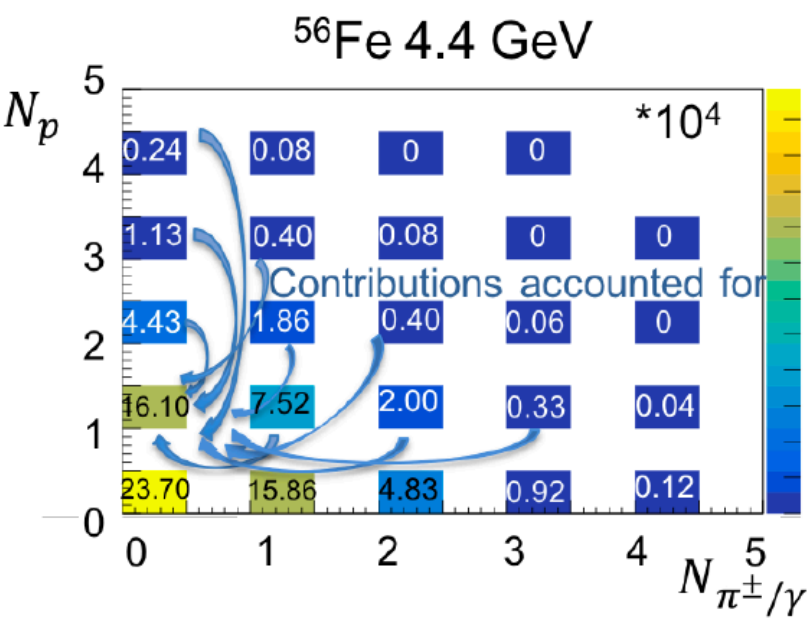
Background Subtraction in (e,e’p) analysis

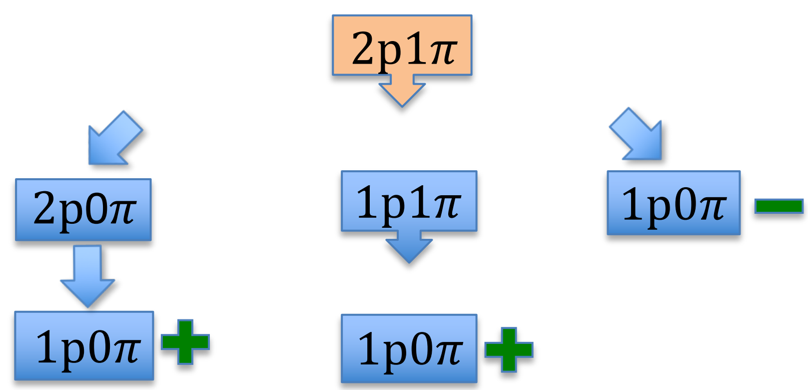
Subtract for undetected $\pi^{\pm}, \gamma$ and multiple p.

Data Driven Correction:

1. Use measured (e,e’p$\pi^{\pm}/\gamma$) events,
2. Rotate π around q to determine their acceptance,
3. Subtract (e,e’p)$\pi^{\pm}/\gamma$ contributions
4. Do the same for 2p, 3p, 2p+$\pi^{\pm}/\gamma$ etc





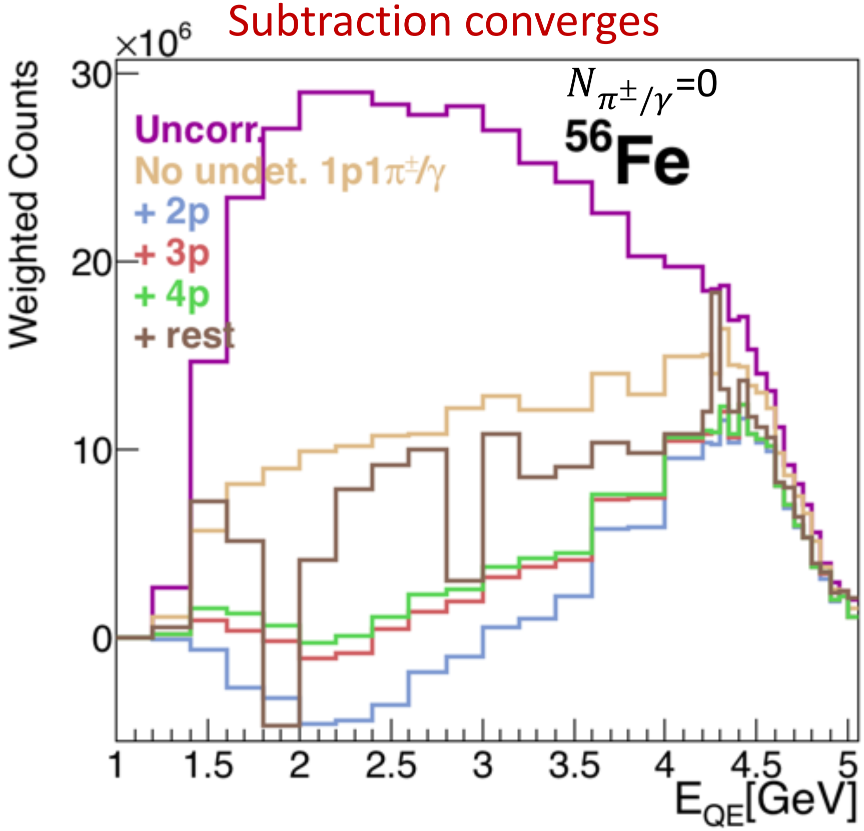


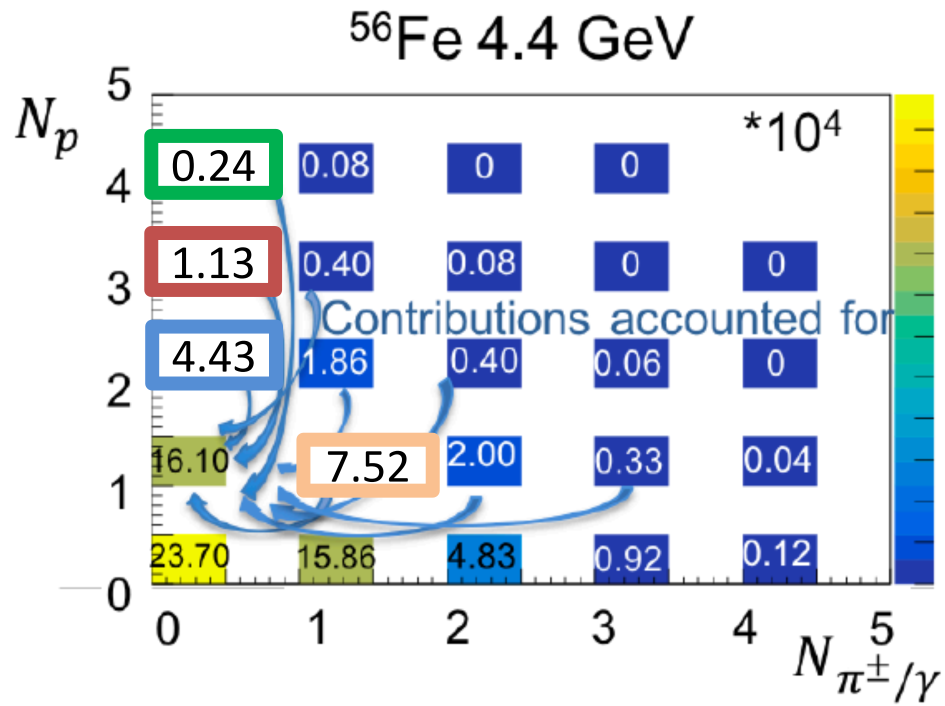
^{56}Fe (e,e'p)

4.46 GeV

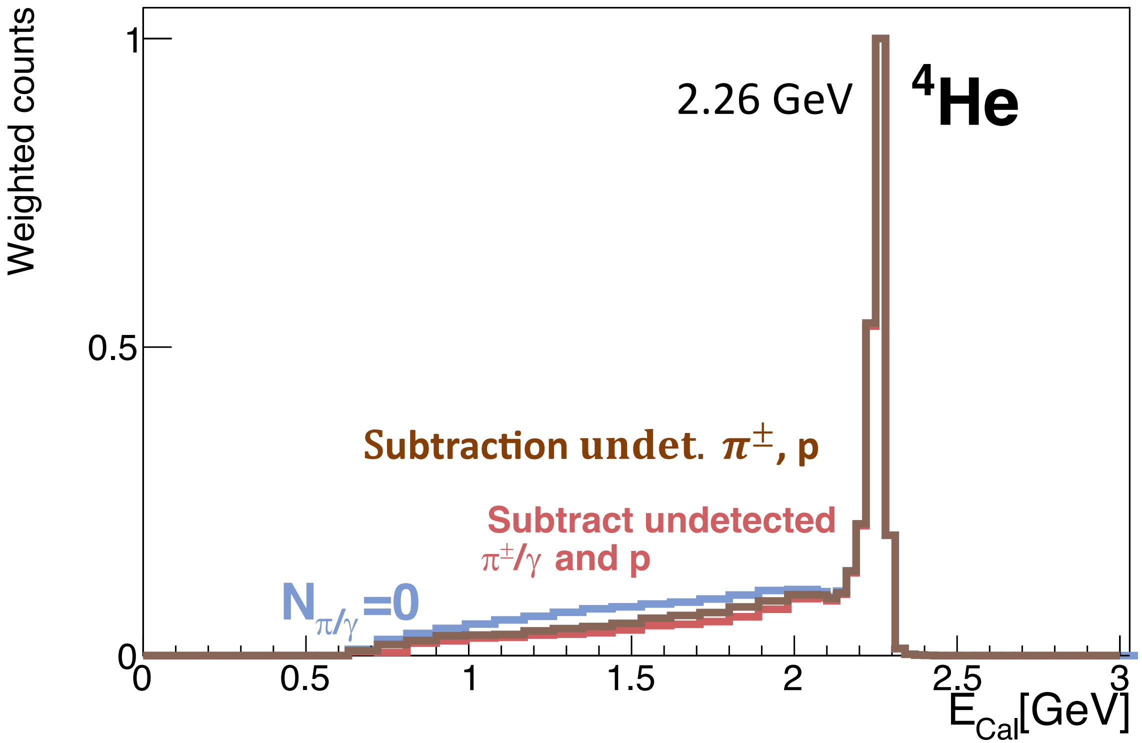
Proton subtarction

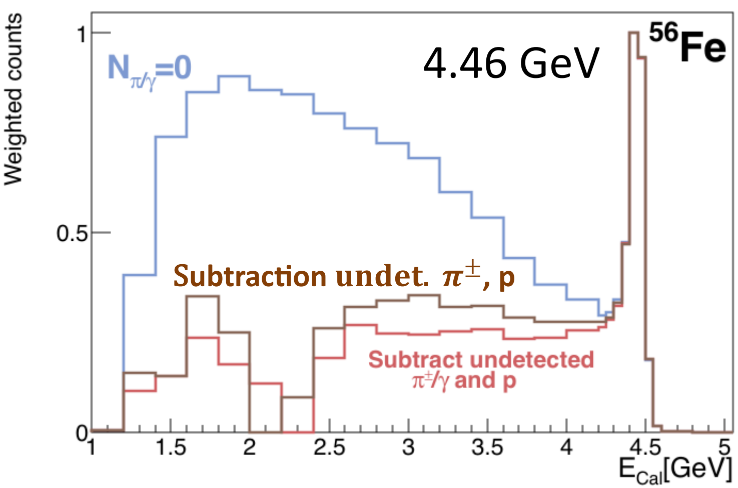
Subtraction converges





Proton subtarction



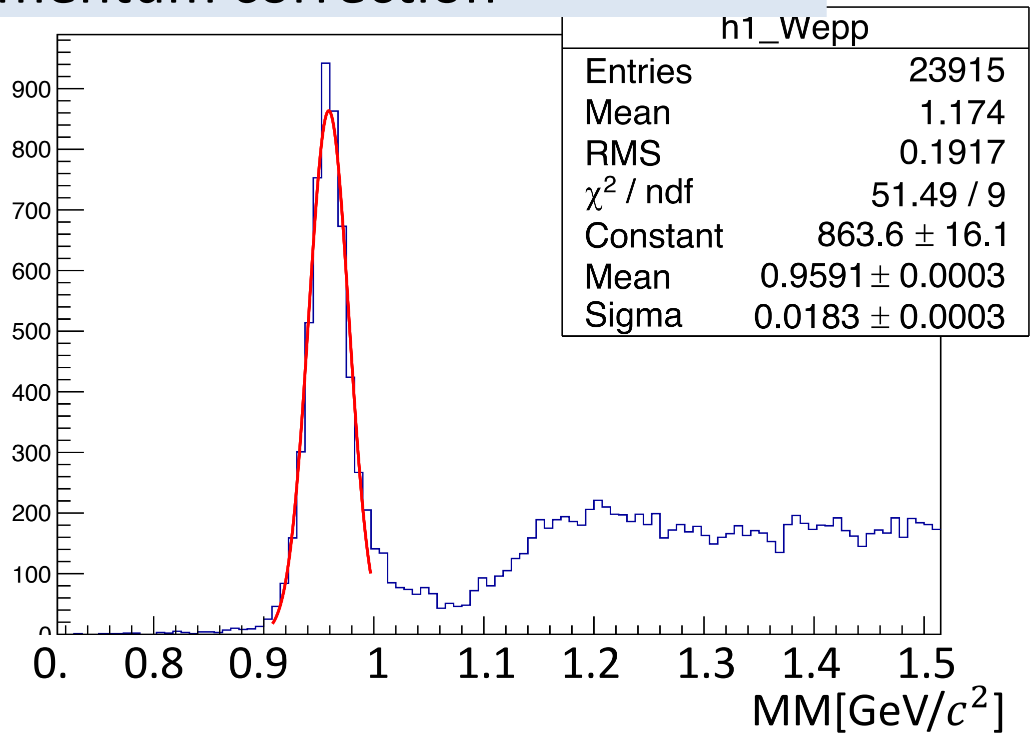


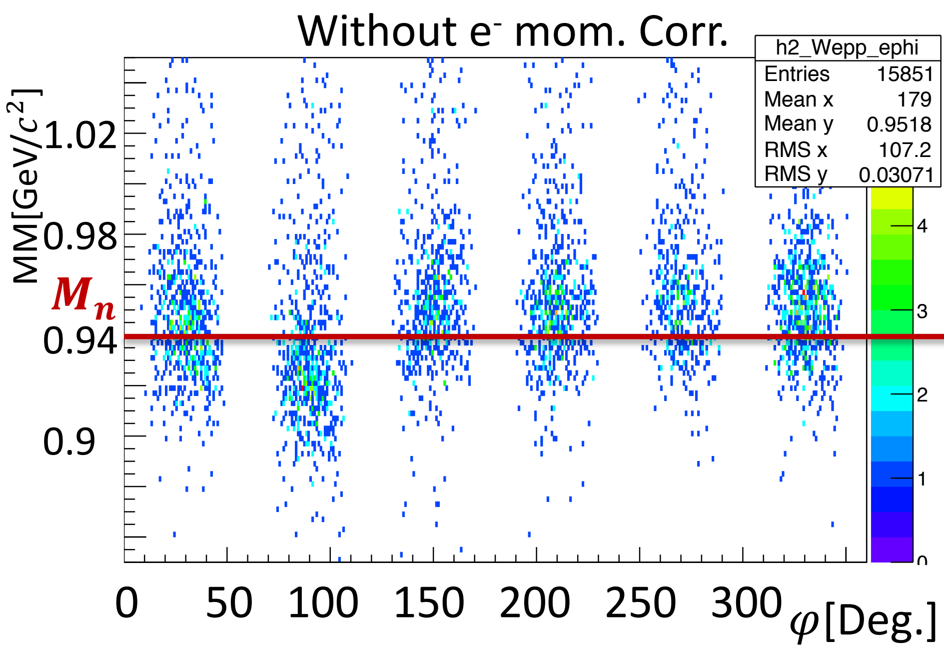
e^- momentum correction

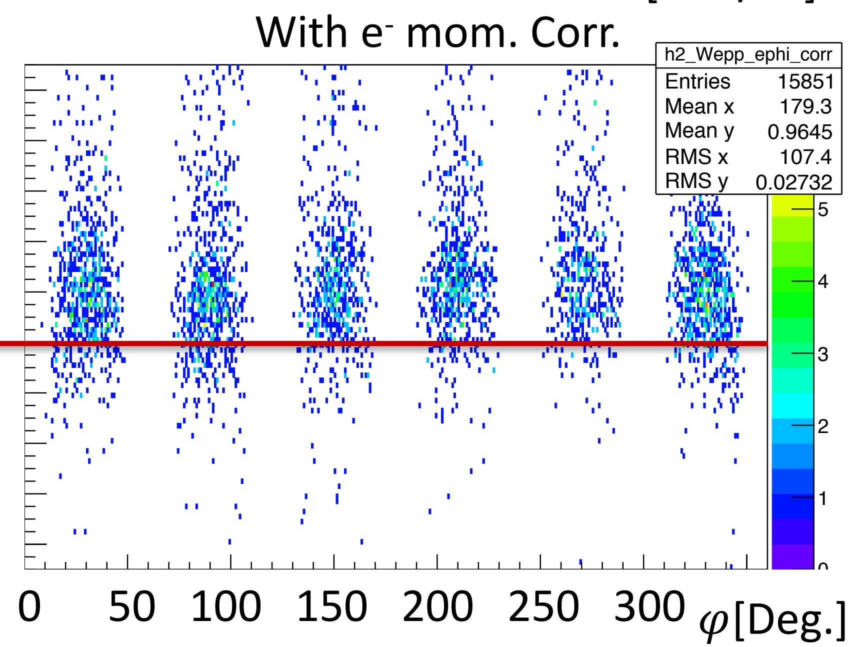
2 GeV

^{3}He (e,e'pp)n

Problem: neutron peak in wrong location







2 GeV

^{3}He (e,e'pp)n

e^- momentum correction

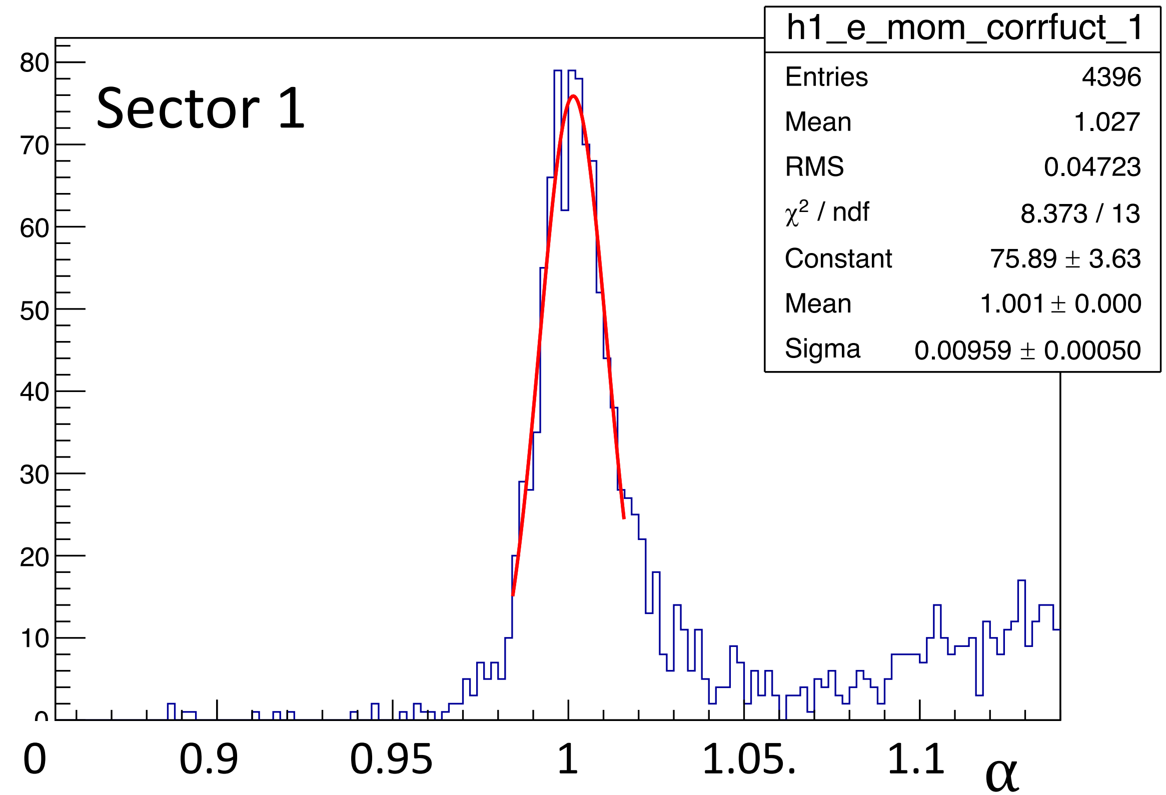
Solution: multiply e^- momentum by a different factor α in each sector

$MM^2 = (P - P_e)^2 = M_n^2$

$P_e(\alpha p_e, \alpha\overrightarrow{p_e})$

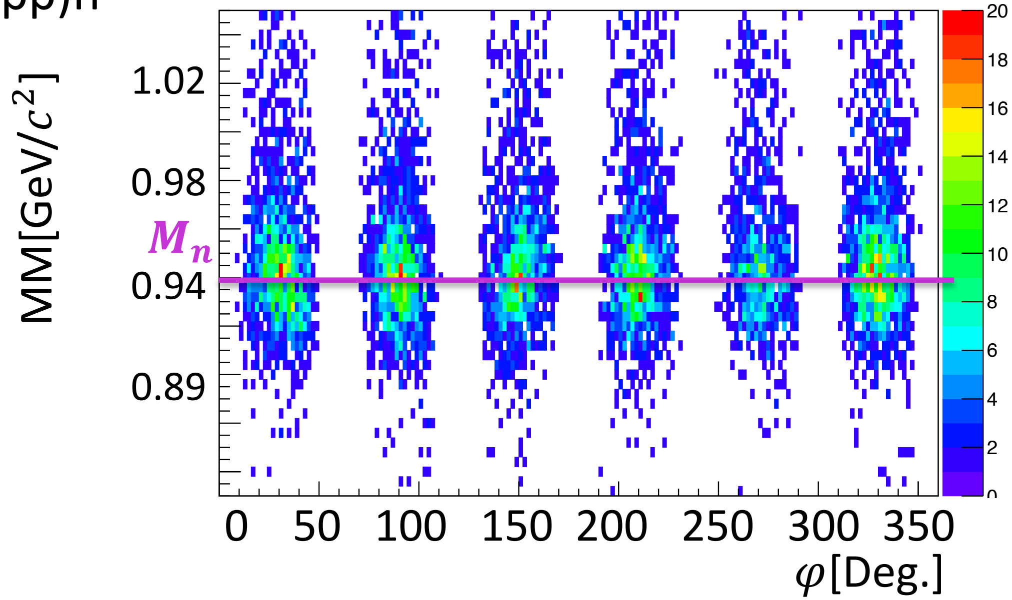
$P(\mathrm{E}, \vec{P}) = P_{^3\mathrm{He}} + P_{\mathrm{Beam}} - P_{p_1} - P_{p_2}$

$$\alpha = \frac{-0.5(M_n^2 - P^2)}{E p_e - \vec{P}\overrightarrow{p_e}}$$

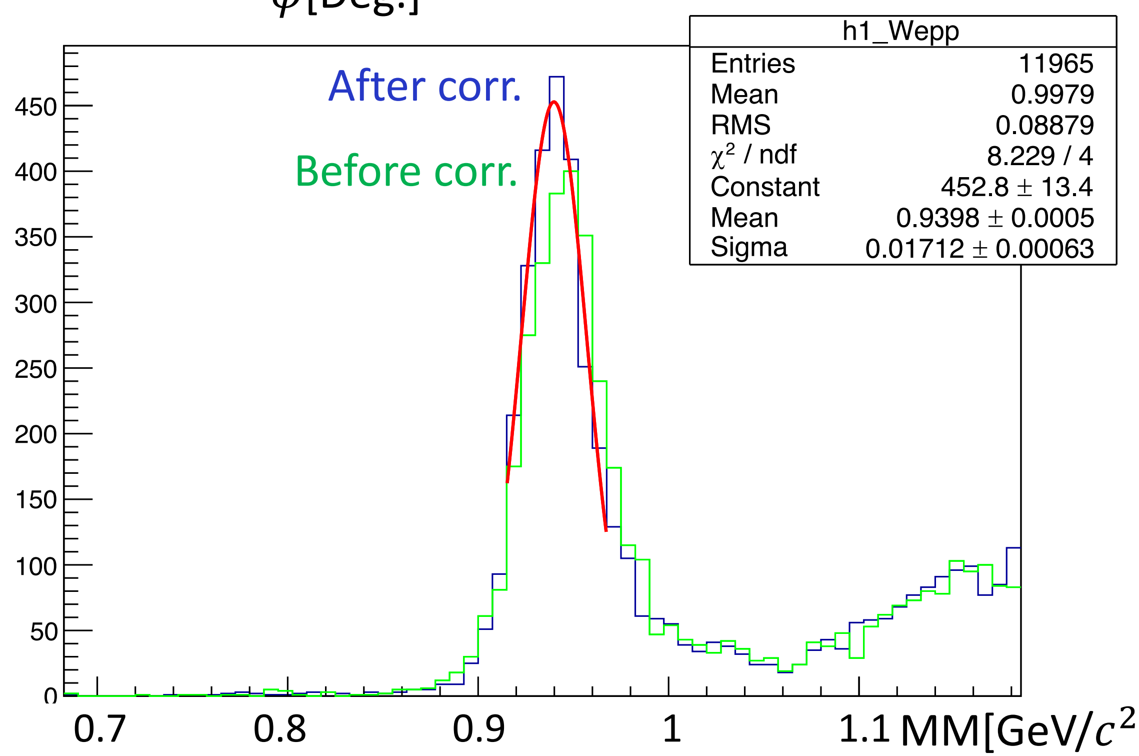


2 GeV
^{3}He (e,e'pp)n

e^{-} momentum correction



Same set of α factors at 2 and 4 GeV (Same magnetic filed)



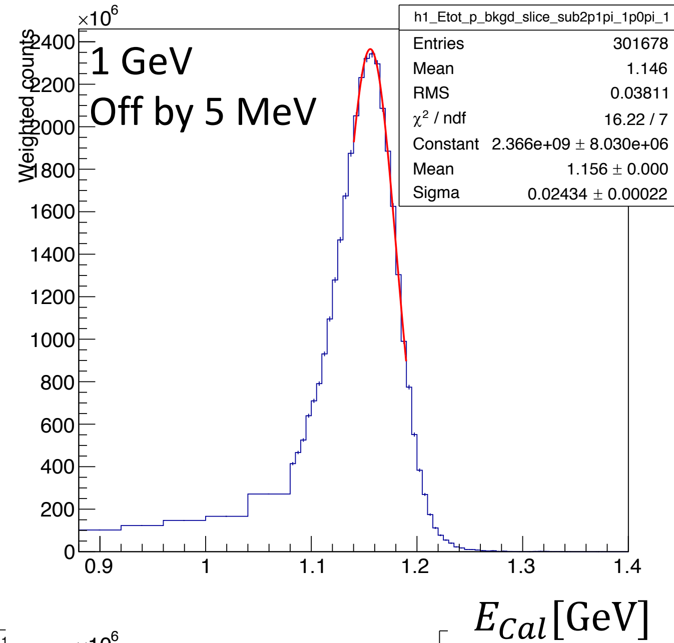
Correcting for binding energy

$$E_{Cal} = E_l + T_p + \varepsilon$$

$$\varepsilon = E^{A}_{Bind} - E^{A-1}_{Bind}$$

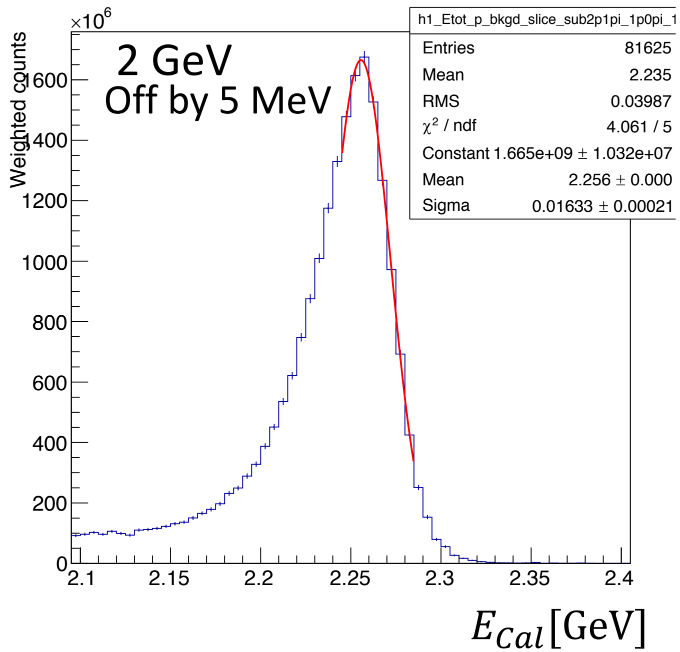
$\varepsilon(^{3}\mathrm{He})$=5 MeV
$\varepsilon(^{4}\mathrm{He})$=20 MeV
$\varepsilon(^{12}\mathrm{C})$=16 MeV
$\varepsilon(^{56}\mathrm{Fe})$=10 MeV

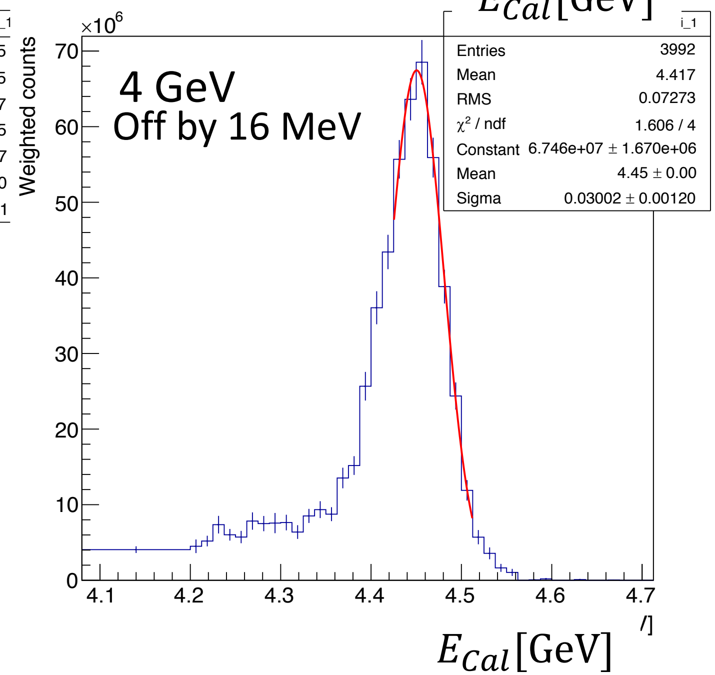
^{12}C



Use these offsets to correct the binding energy used in E_{Cal} and E_{QE}

Target	E_{Cal} offset [2GeV]
^{3}He	4 MeV
^{4}He	5 MeV
^{12}C	5 MeV
^{56}Fe	11 MeV



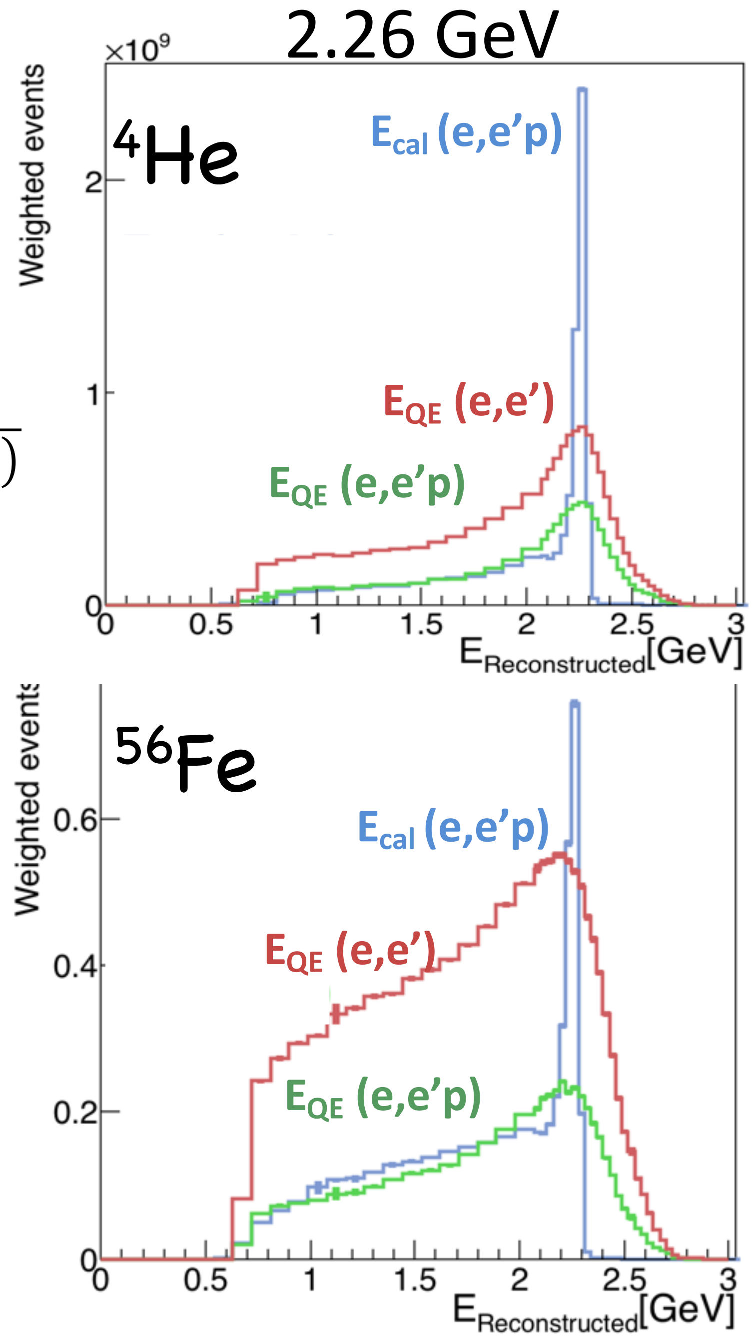


Results

Large A dependence

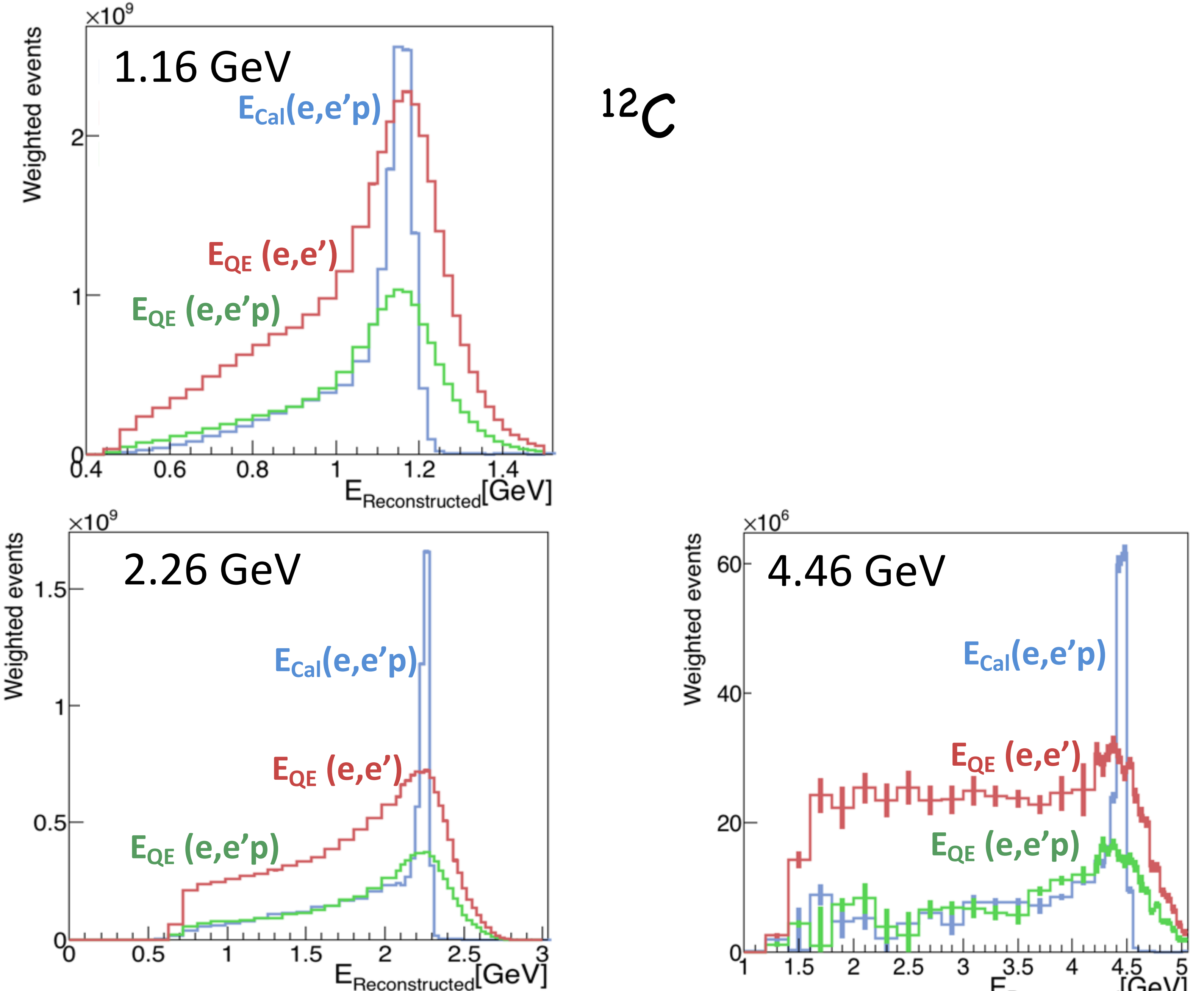
$$E_{Cal} = E_l + T_p + \varepsilon$$

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



1. E_{QE} has worse peak resolution than $E_{Cal.}$
2. Same tail for E_{QE}+$E_{Cal.}$
3. ^{56}Fe is predominantly tail.
4. ^{56}Fe is much worse than ^{4}He.

Large E dependence

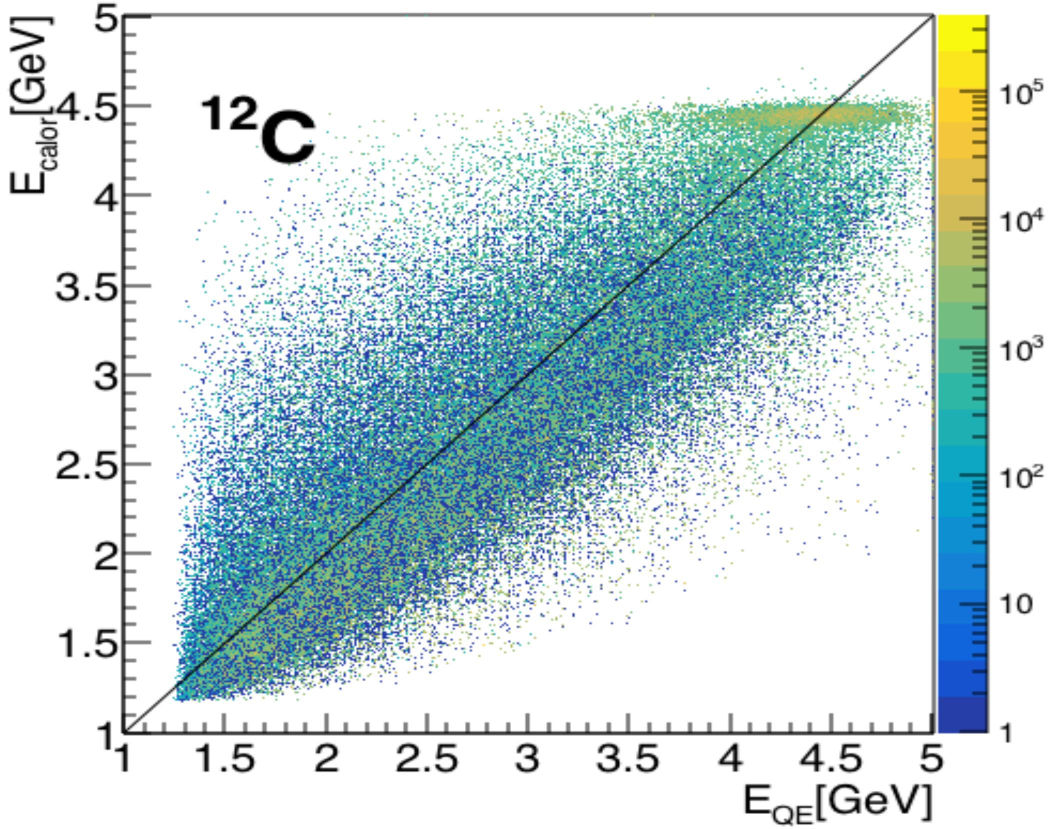


Better reconstruction at lower energies.

E_{QE} vs E_{Cal}

Agreement between to methods doesn't imply correct energy reconstruction.

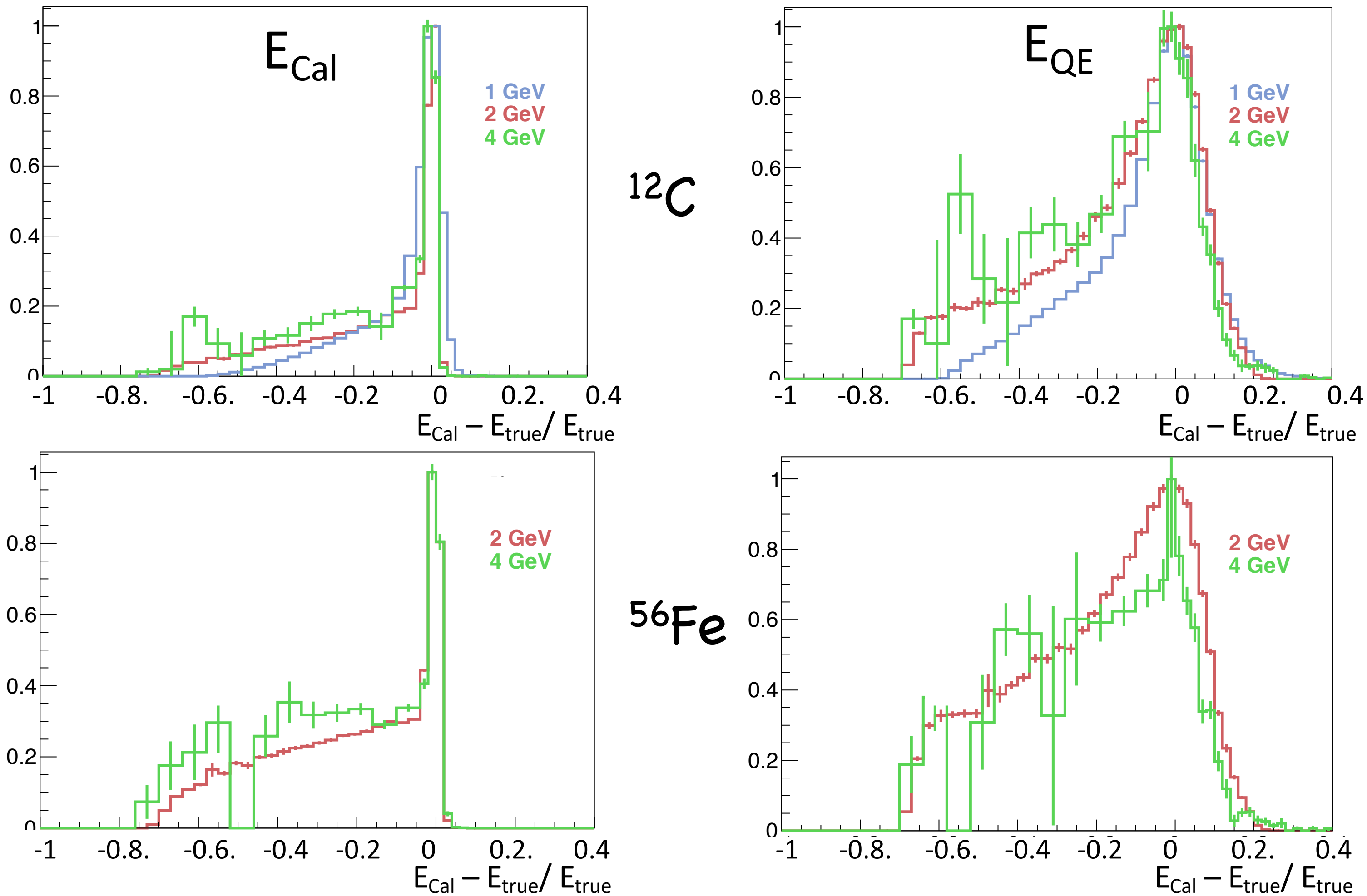
4.46 GeV



Fractional energy feed down

(e,e’p)

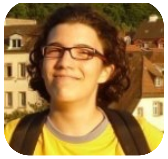
The fractional energy feed down is bigger at higher energies.



Summary

1. The first use of electron data to test neutrino energy reconstruction algorithms
   - select zero-pion events to enhance quasi-elastic signal
     - ✧ Subtract for undetected π and extra p.
   - just using scattered lepton (E_{QE})
     - ✧ used in Cherenkov-type neutrino detectors
   - total energy of electron plus proton (E_{Cal})
     - ✧ used in calorimetric neutrino detectors
2. Only 0.1-0.66 of events reconstruct to within 5% of the beam energy
   - better for lighter nuclei
   - improved by a transverse momentum cut
3. Added 1GeV analysis.
4. Analysis complete.
5. Update note for committee.
6. Anticipate paper submission soon.

Chris Marshal
(LBL)



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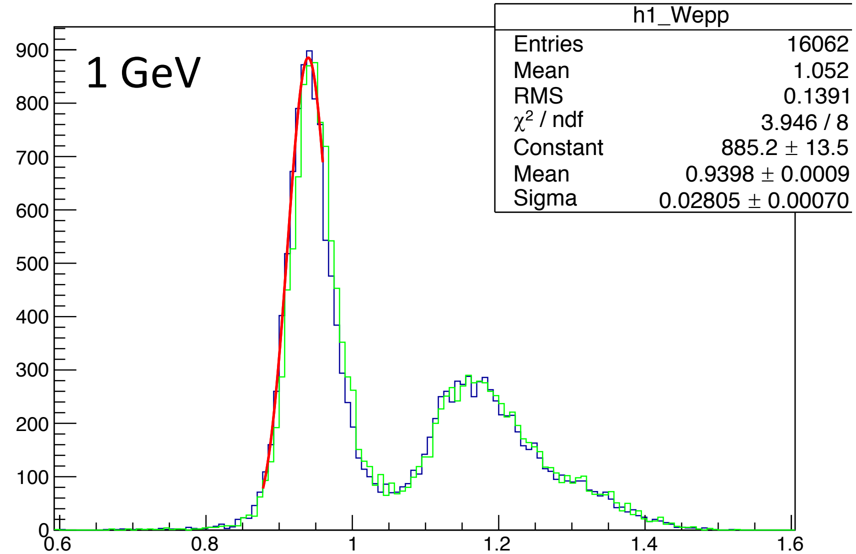
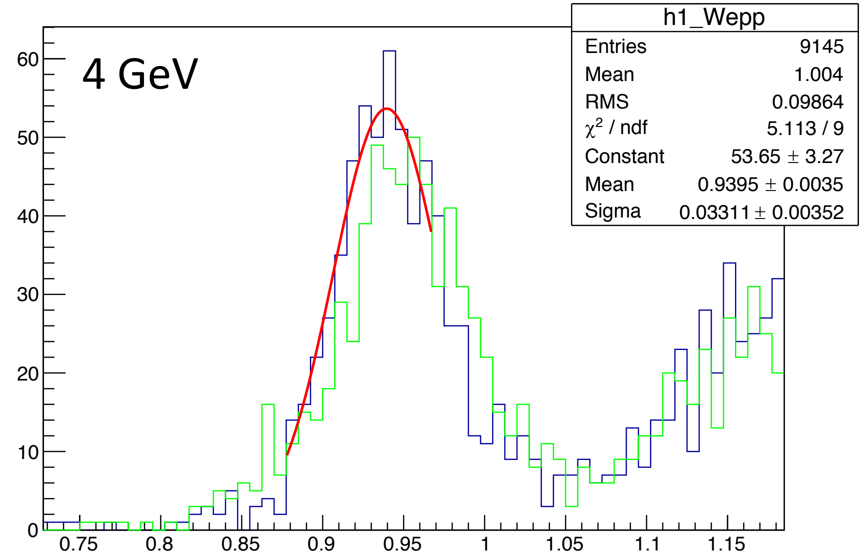
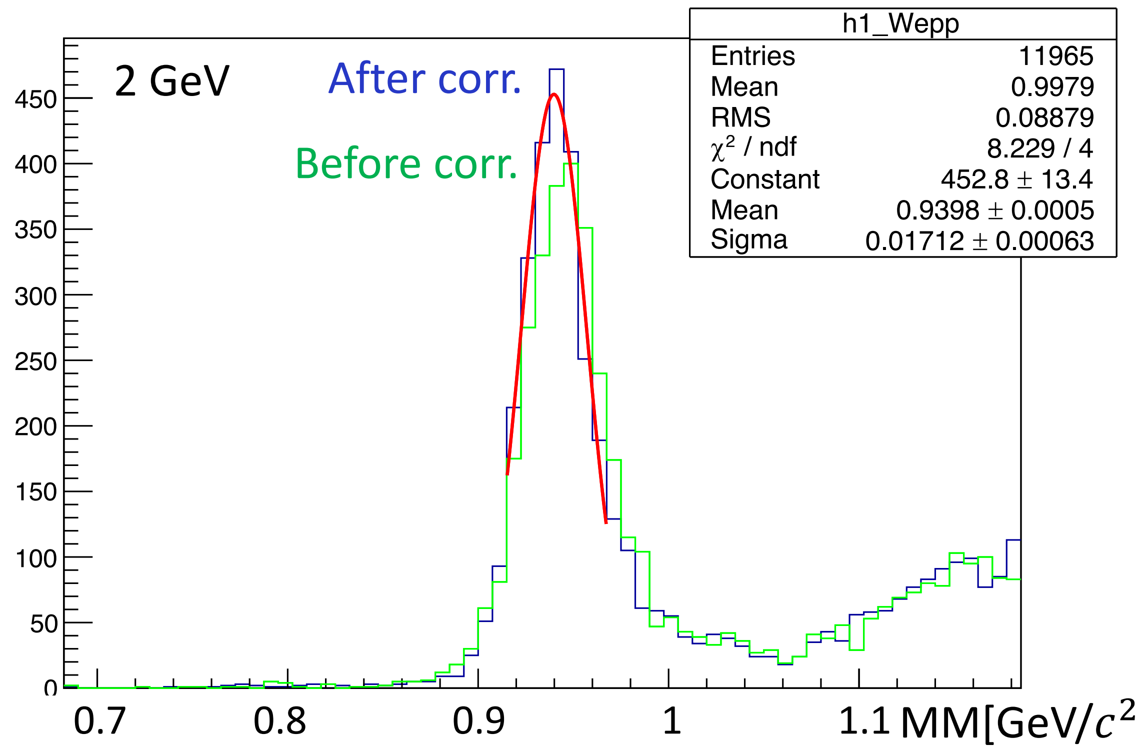
^{3}He (e,e'pp)n — e^- momentum correction



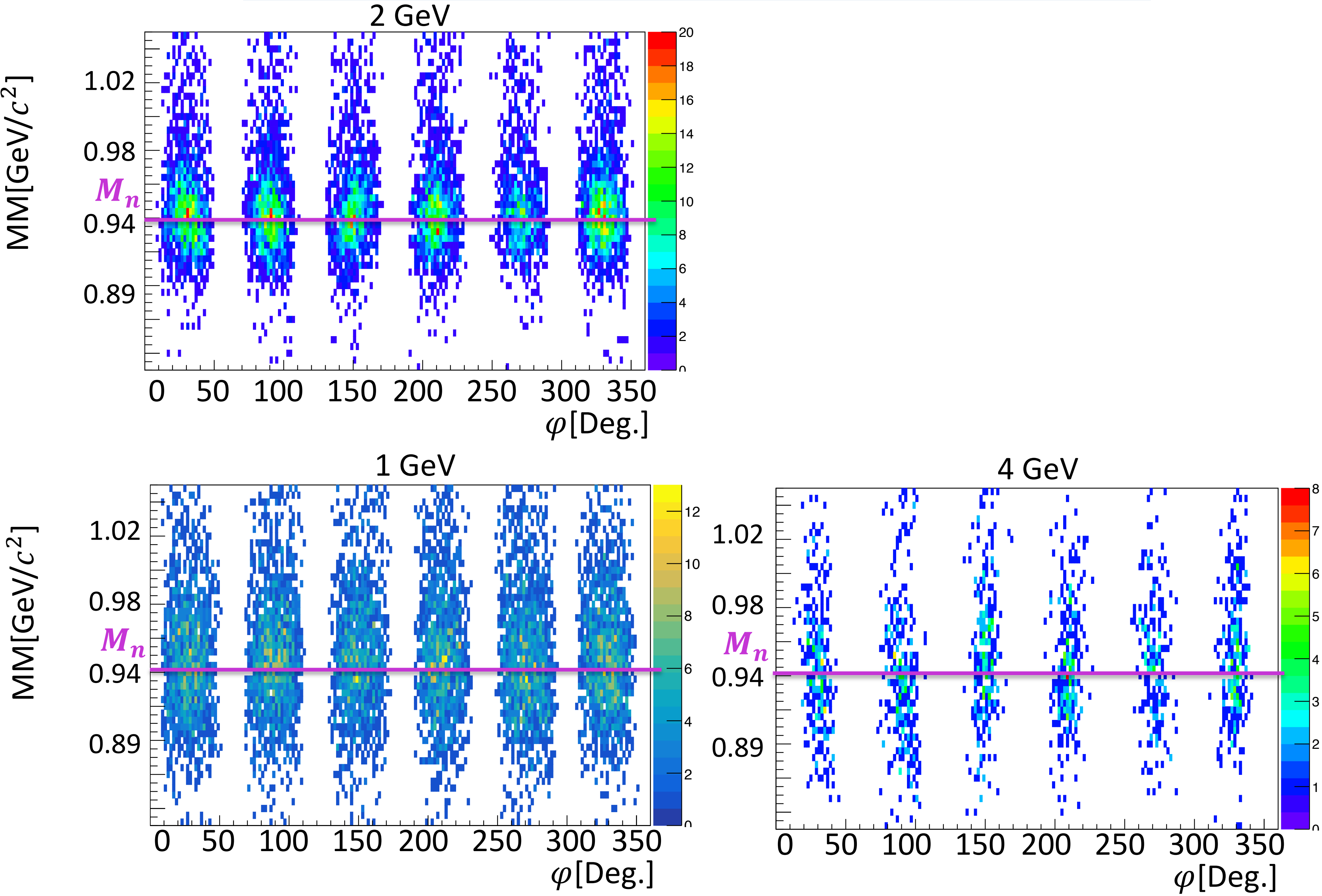




Same set of α factors at 2 and 4 GeV (Same magnetic filed)

^{3}He (e,e'pp)n

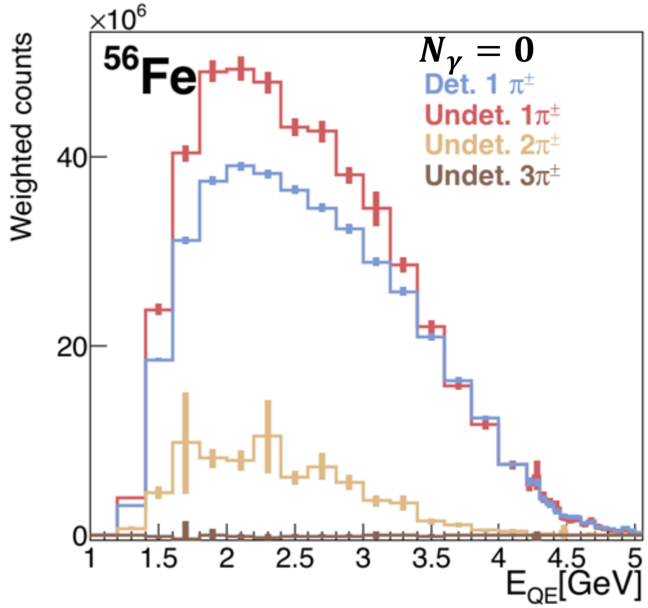
e^{-} momentum correction



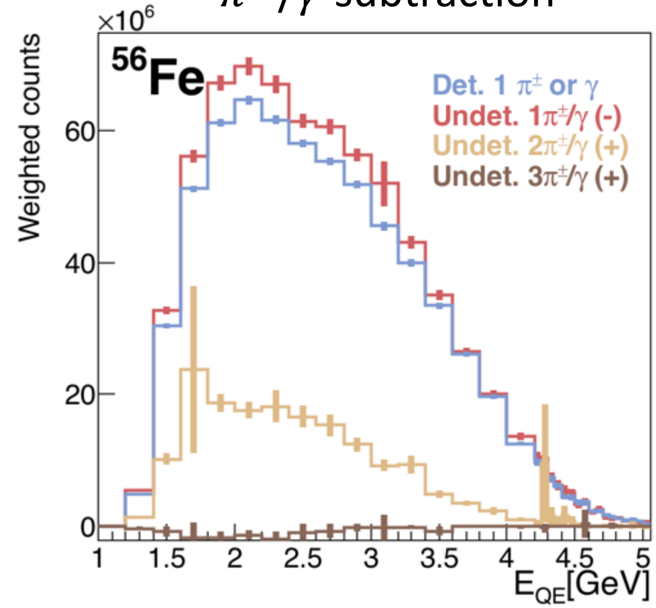
(e,e') $\pi^{\pm}/\gamma$ subtraction

^{56}Fe 4.46 GeV

$\pi^{\pm}$ subtraction

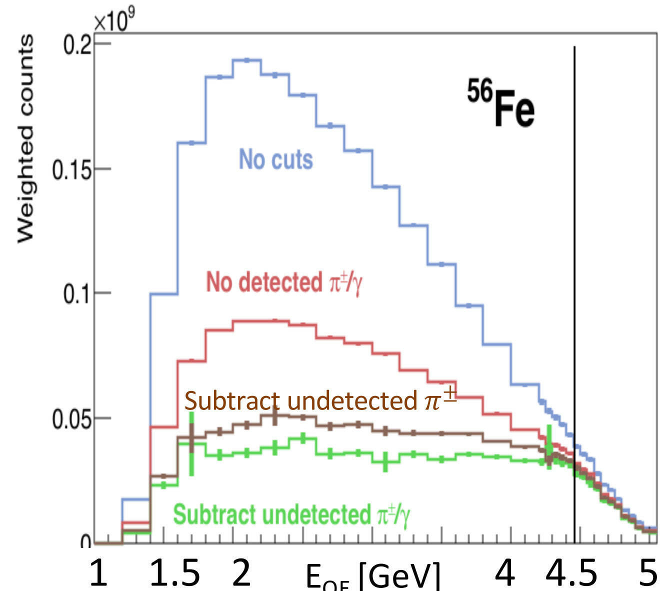


$\pi^{\pm}/\gamma$ subtraction



π detected in TOF+DC

γ detected in EC



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^{56}Fe (e,e'p)
4.46 GeV

Proton subtarction