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Validation of neutrino energy estimation using electron scattering data

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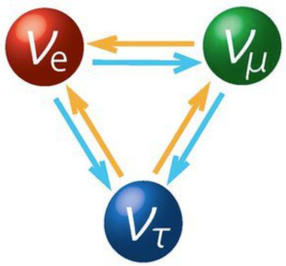
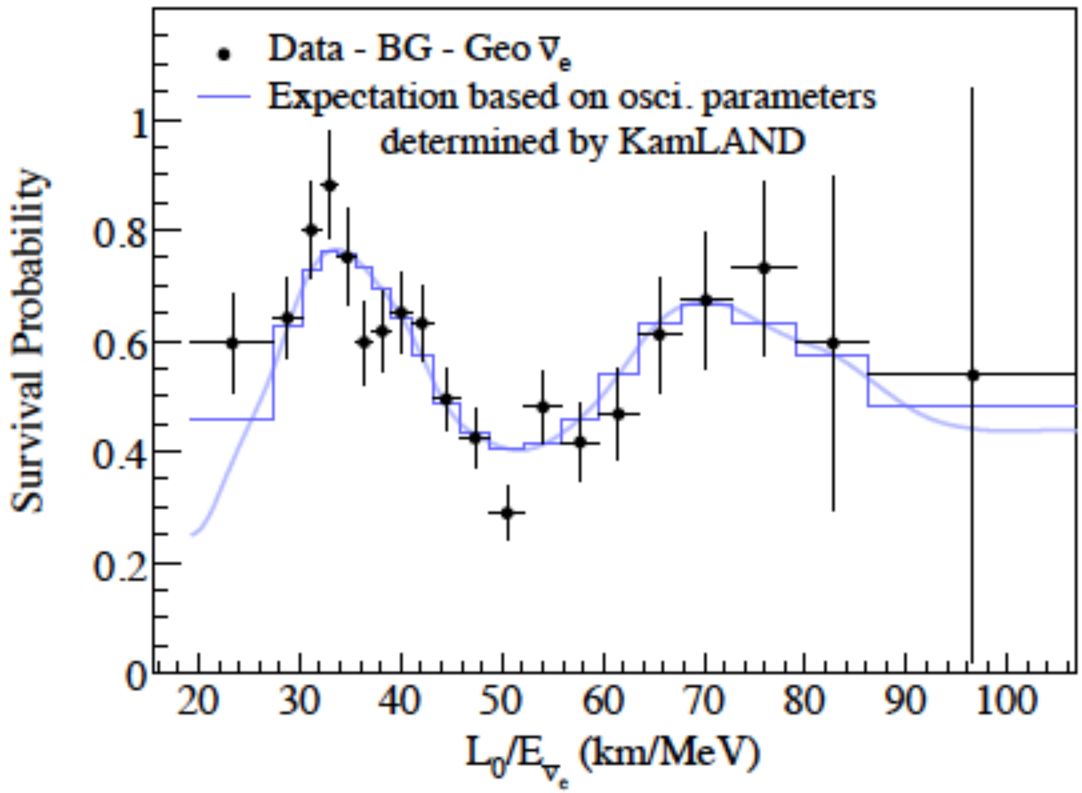
Outline

- The importance of energy reconstruction in neutrino oscillation experiments
- Neutrino-nucleon Charged Current interactions
- Different neutrino experiment detectors
- Testing neutrino beam energy reconstruction methods with electron scattering CLAS e2a experiment data

Neutrino oscillations



$$P(\nu_\mu \to \nu_x) = \sin^2(2\theta) \times \sin^2\left(\frac{\Delta m^2 L}{4E_\nu}\right)$$



KamLAND, PRL 100, 221803 (2008)

CC quasi-elastic scattering

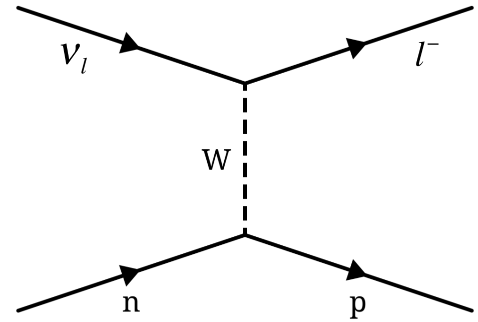
Charged Current (CC) Weak interaction

mediated by $W^{\pm}$ bosons

$$j_{\mu}^{\pm} = \bar{u}\frac{-ig_W}{2\sqrt{2}}(\gamma^{\mu} - \gamma^{\mu}\gamma^{5})u$$

g_W – coupling strength

CC QE



$$\nu_l + n \rightarrow l^- + p$$

$$\bar{\nu}_l + p \rightarrow l^+ + n$$

Lepton scattering

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

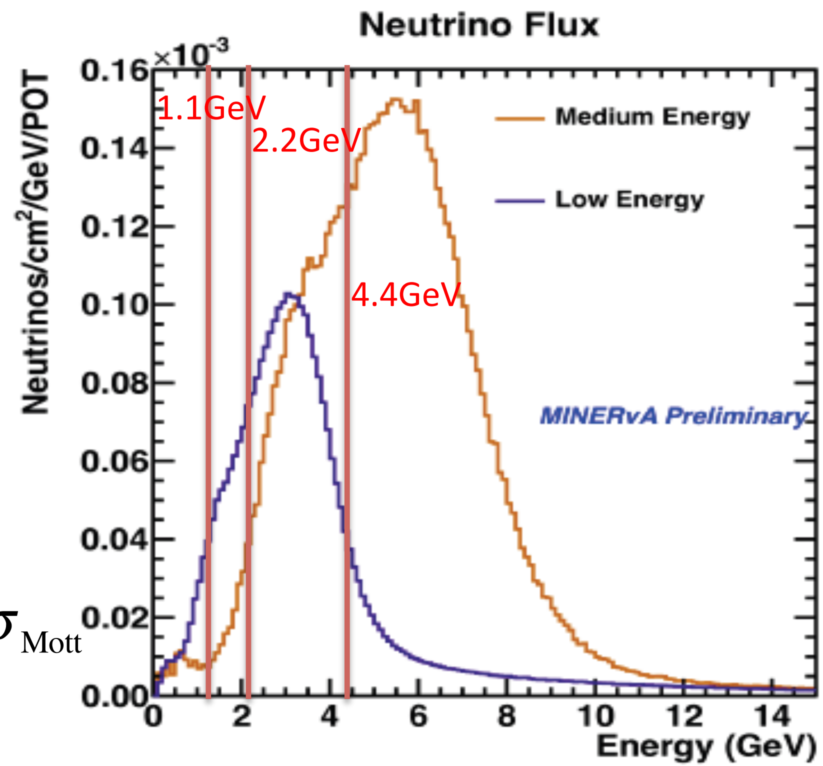
$\varepsilon \approx 20$ MeV binding energy

M-nucleon mass

$m_l = 0$ outgoing lepton mass

k_l – lepton three momentum

θ – lepton scattering angle



Scale the electron scattering data with $1/\sigma_{\mathrm{Mott}}$ to have 'neutrino like' data!

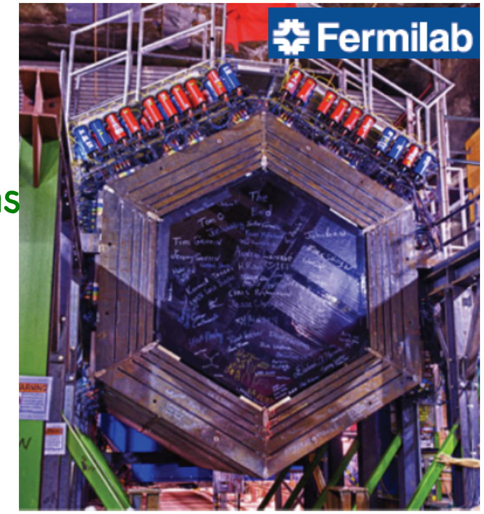
MINERvA | MicroBoone

3D view

Scintilation based detector

Study:

- ❑ Neutrino oscilations
- ❑ nuclear effects
- ❑ nuclear structure functions.



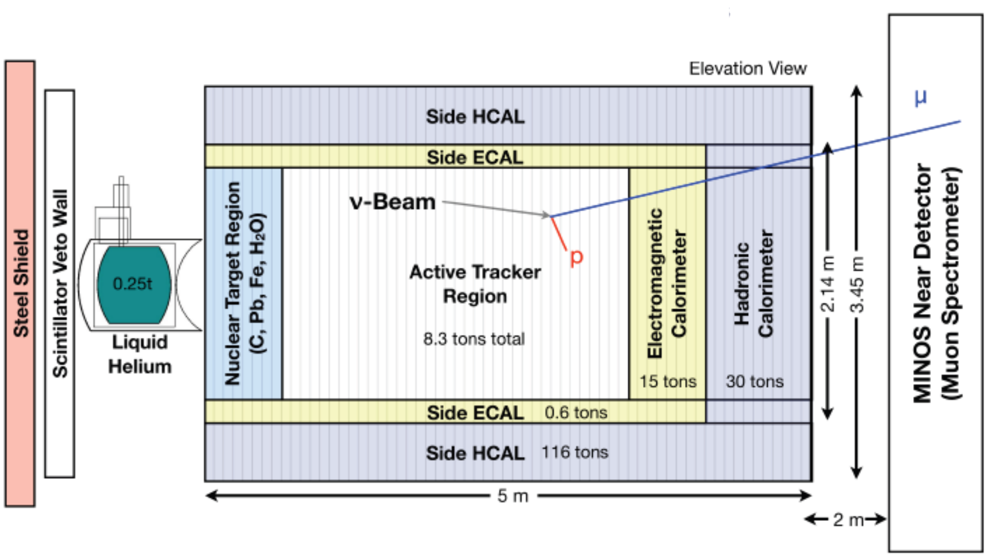
3D view

Liquid Argon Time Projection Chamber.

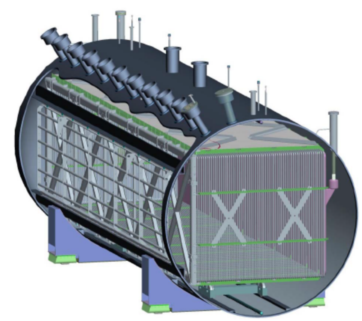
Measure:

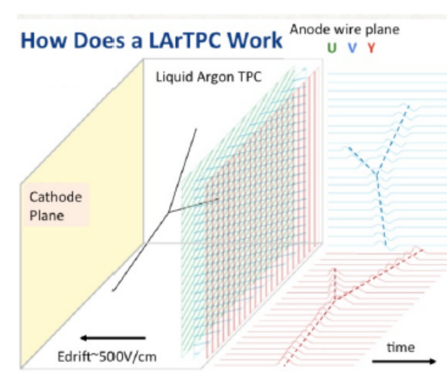
- ✧ Low energy neutrino cross sections

Schematic view of MINERvA



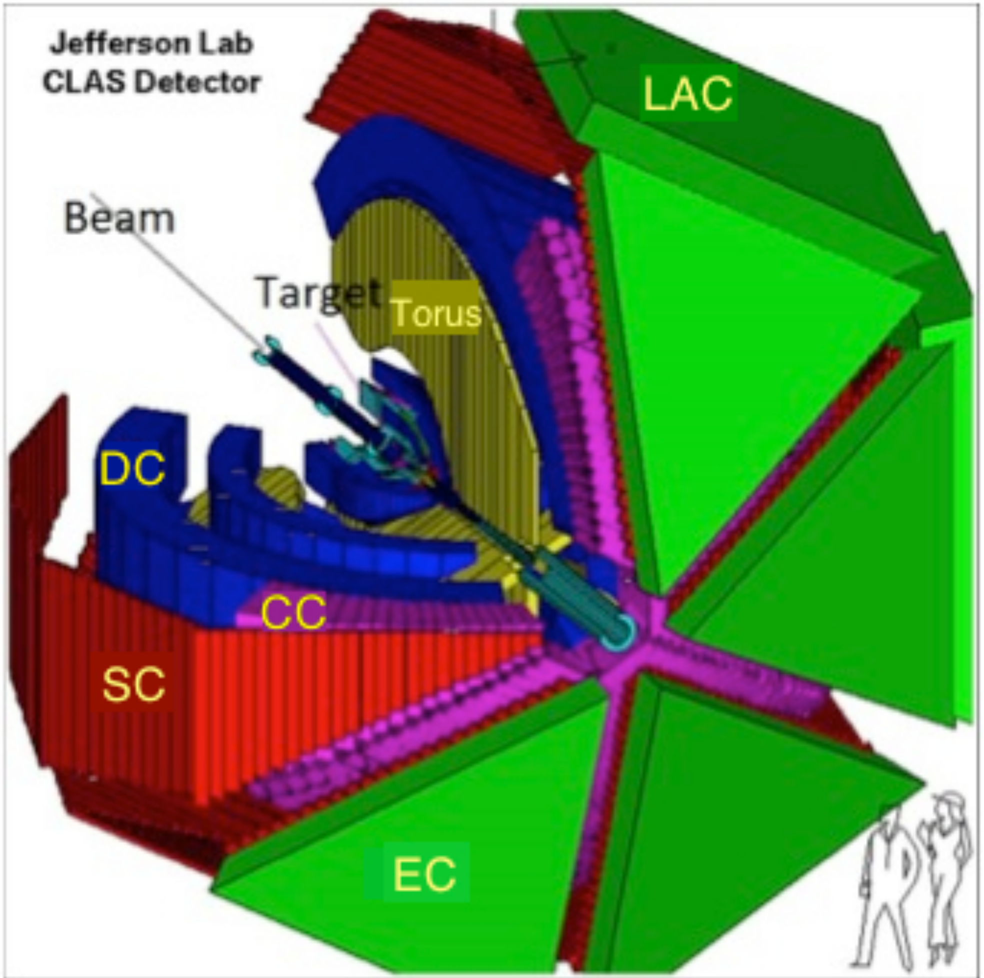
Schematic view of MicroBoNE



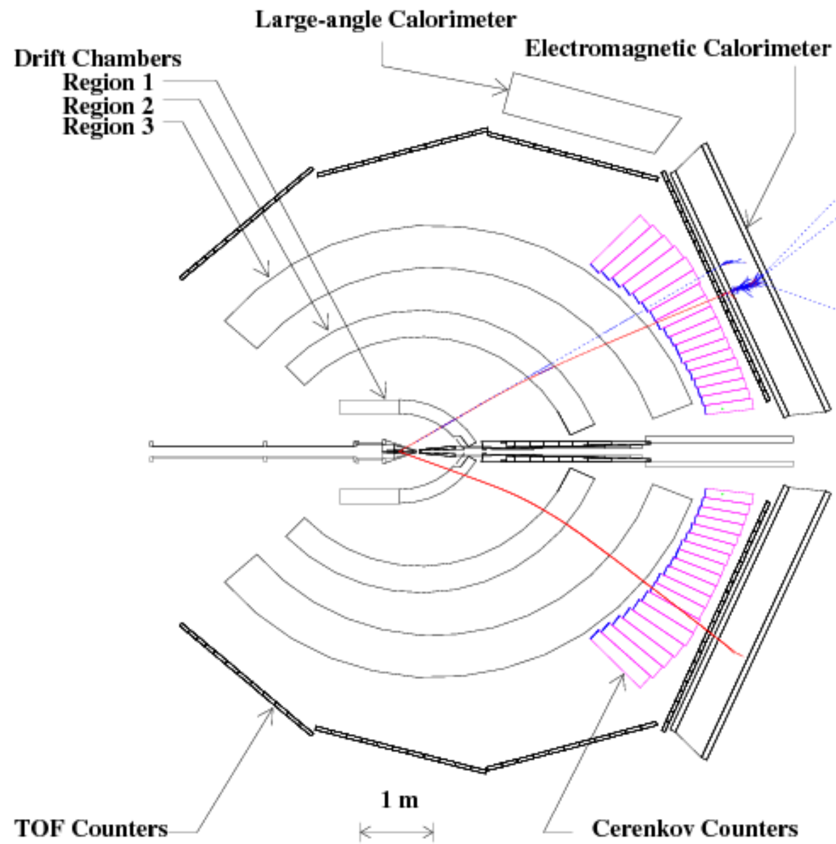


CLAS detector package

3D view



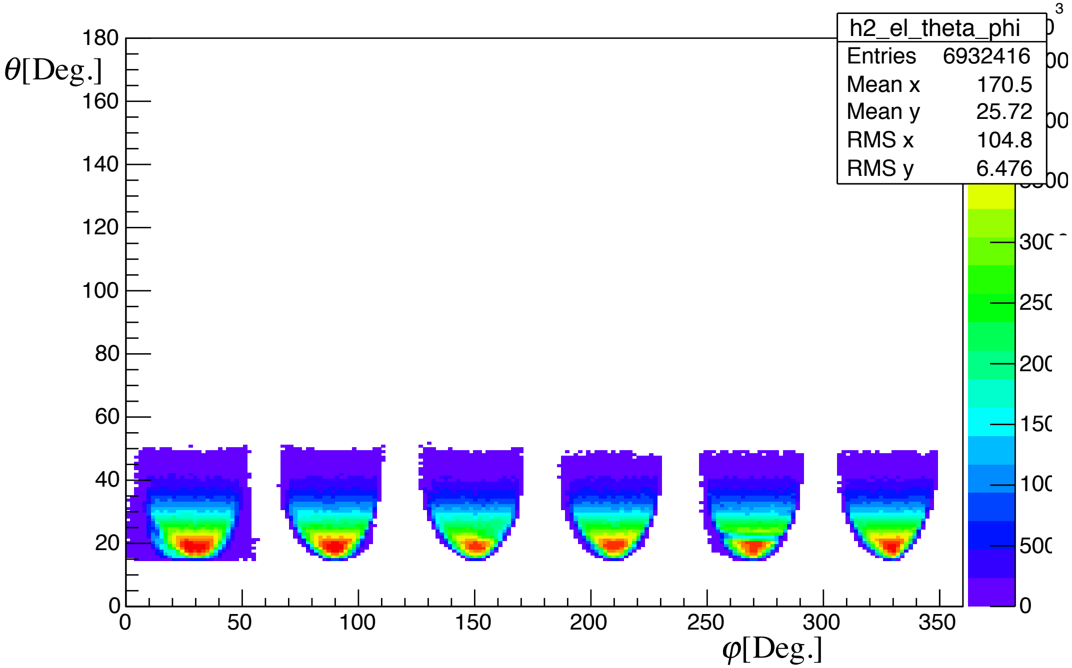
Slice view



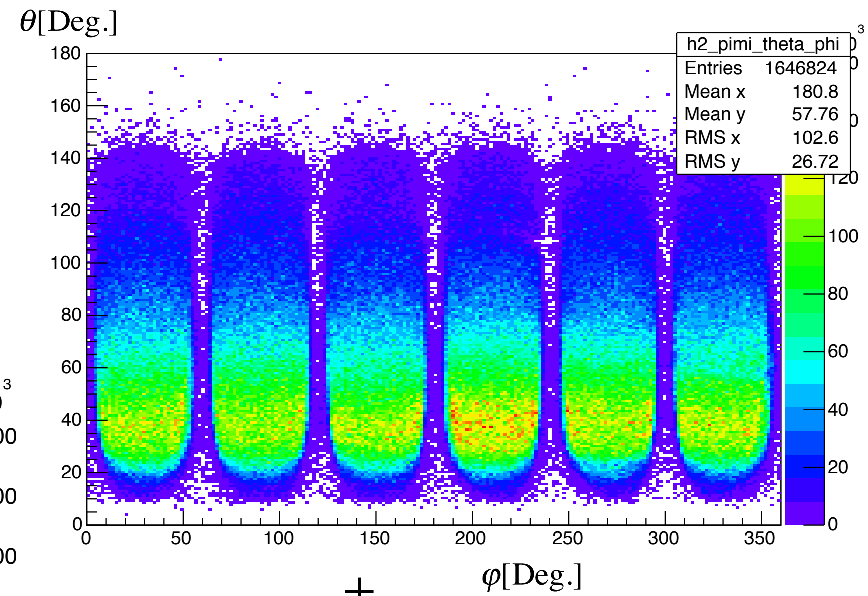
θ and φ distributions

E2a ^{4}He 4.461 GeV (e,e′p) skim

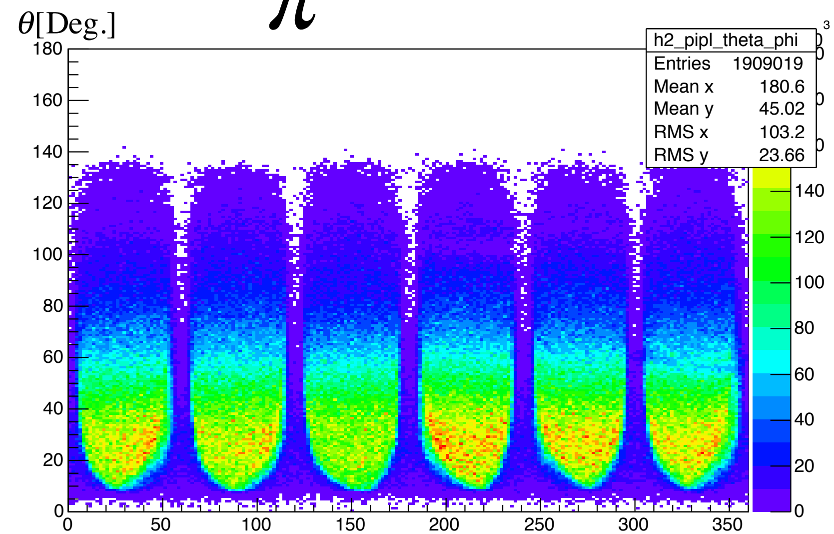
e^{-}



π^{-}



π^{+}



Electron scattering data

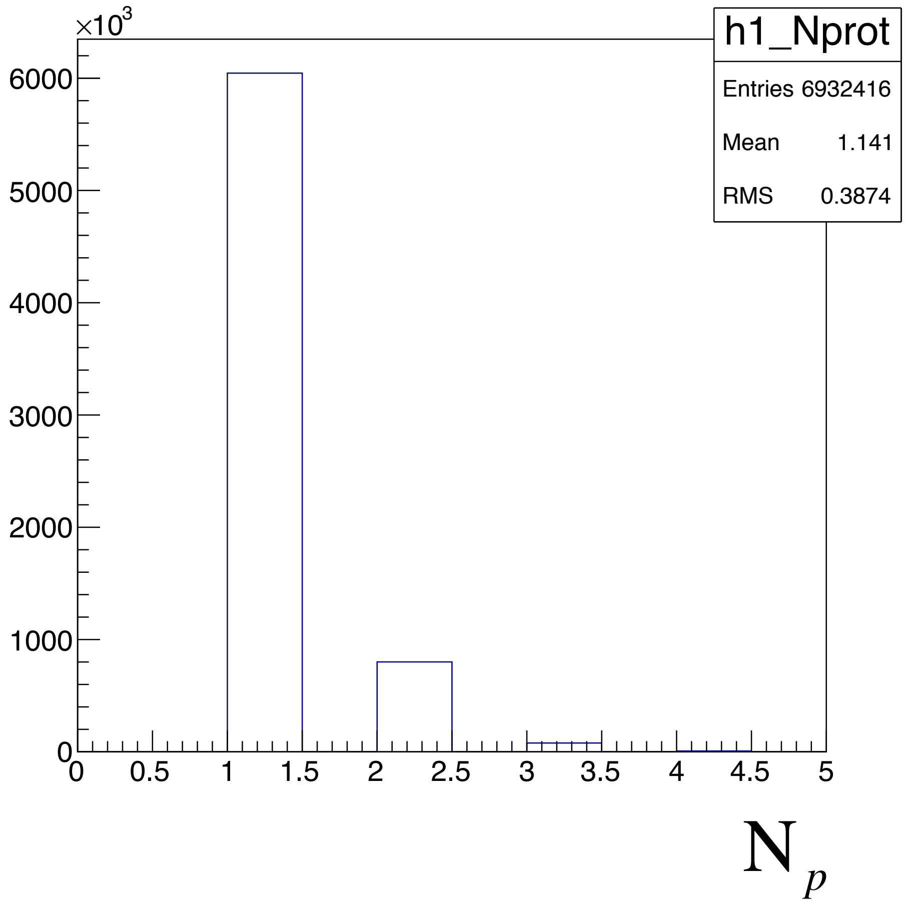
^{4}He(e,e'p), ^{12}C, ^{3}He 4.461 GeV e2a experiment data

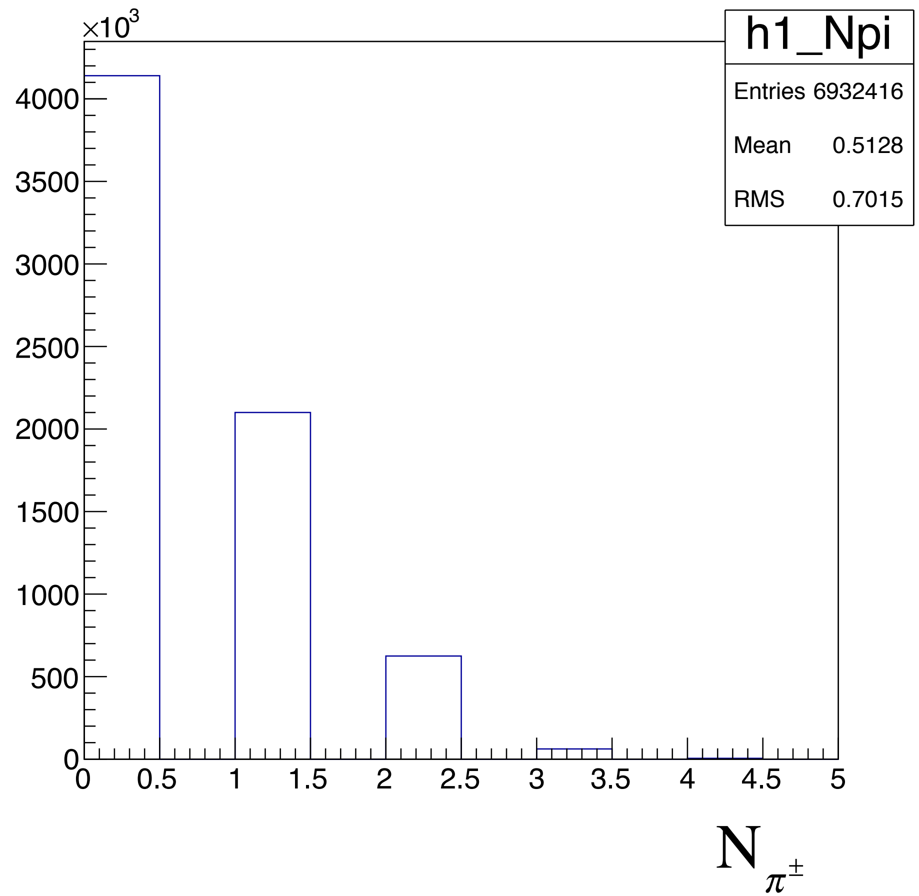
Other data available : ^{3}He, ^{4}He, 2.2+4.4 GeV (e,e'p) skim
^{3}He, ^{4}He, C, Fe 1.1, 2.2 and 4.4 GeV

	Beam energy			
Target	1.161 GeV	2.261 GeV	4.461 GeV	Total triggers
^{3}He	141	217	186	544
^{4}He	-	333	445	778
^{12}C	62	238	310	610
^{56}Fe	-	23	30	53
CH2	10	35	21	66
Empty cell	19	69	33	121

Number of events with pions and protons

E2a ^{4}He 4.461 GeV (e,e′p) skim



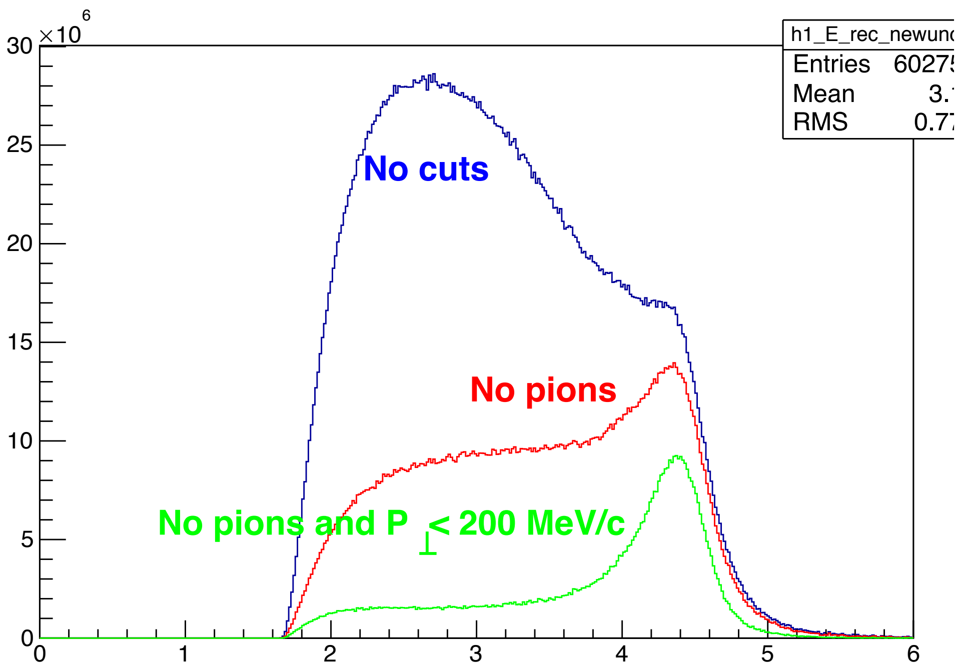


Reconstructed (e,e') energy

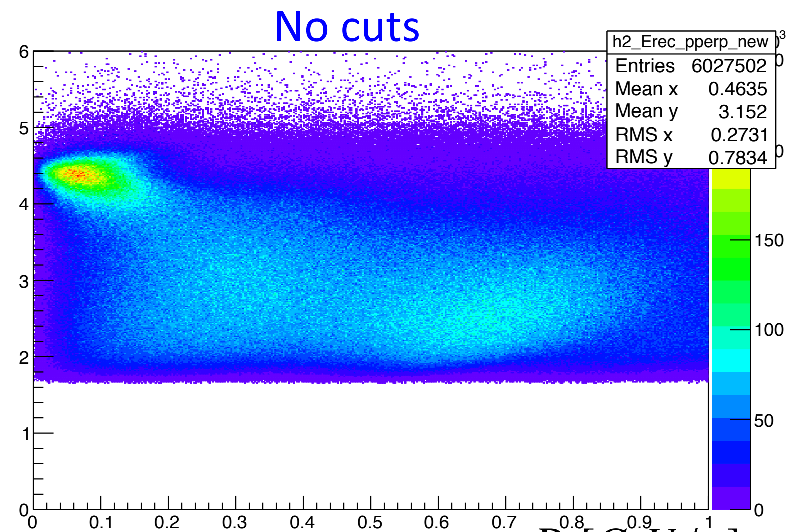
E2a ^{4}He 4.461 GeV

e$^-$ only

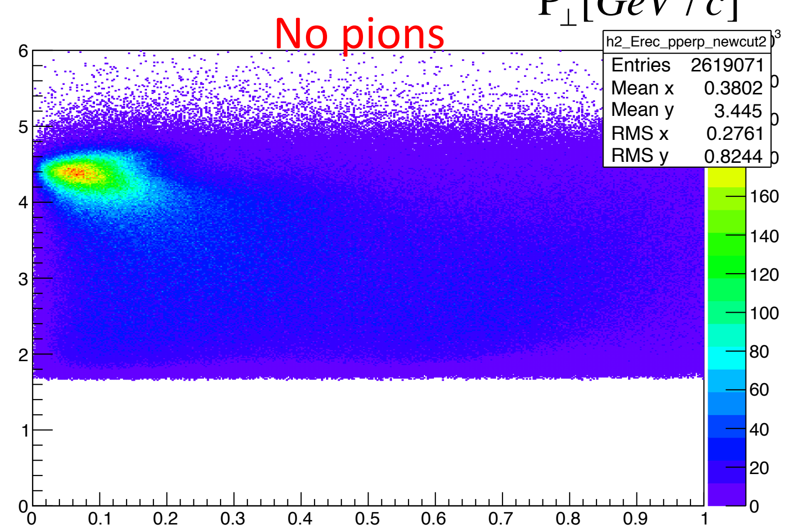
$E_{rec}[GeV]$



$E_{rec}[GeV]$



$P_\perp[GeV/c]$



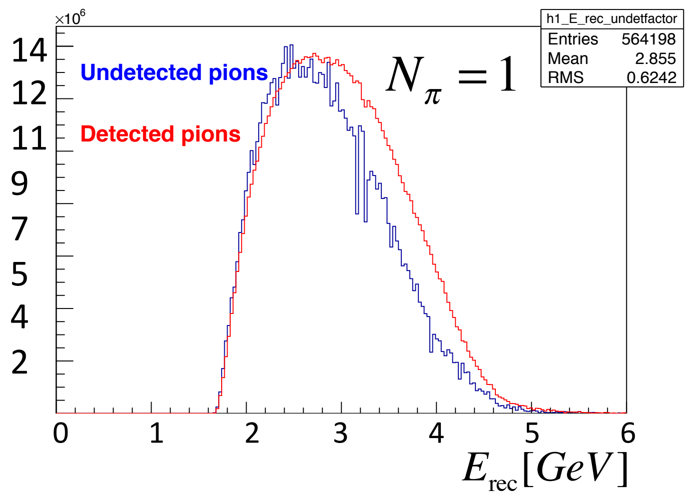
$P_\perp[GeV/c]$

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

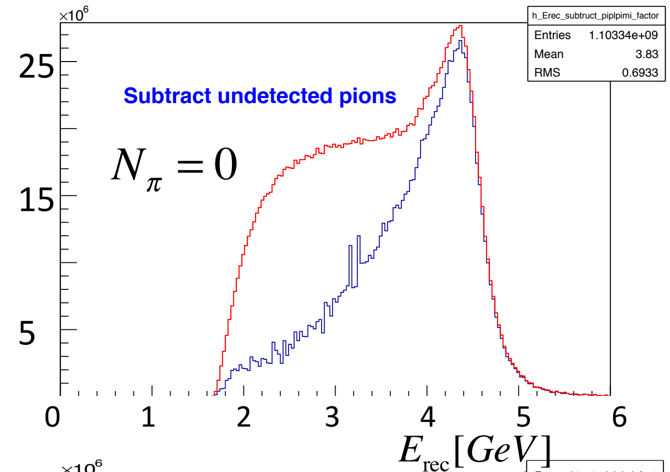
Subtracting undetected pions

Cuts

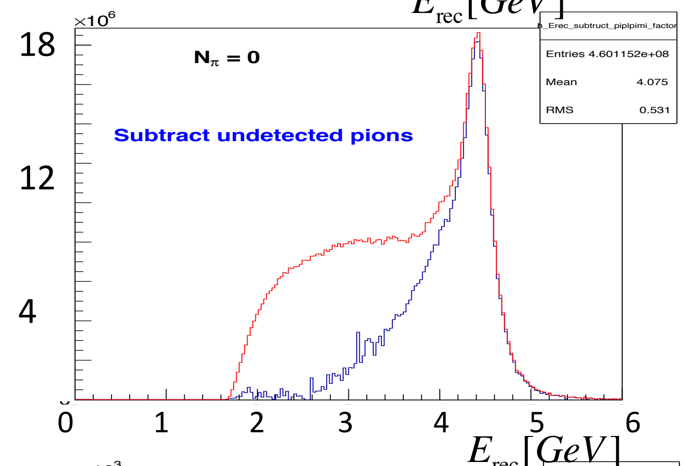
No π_+ , $\pi_$and no photons coming from π_0 decay



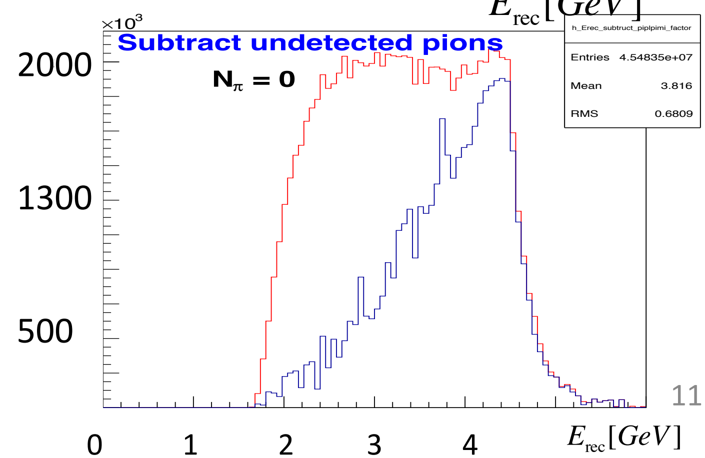
^{4}He



^{3}He



^{12}C



(e,e'p) E_{tot}

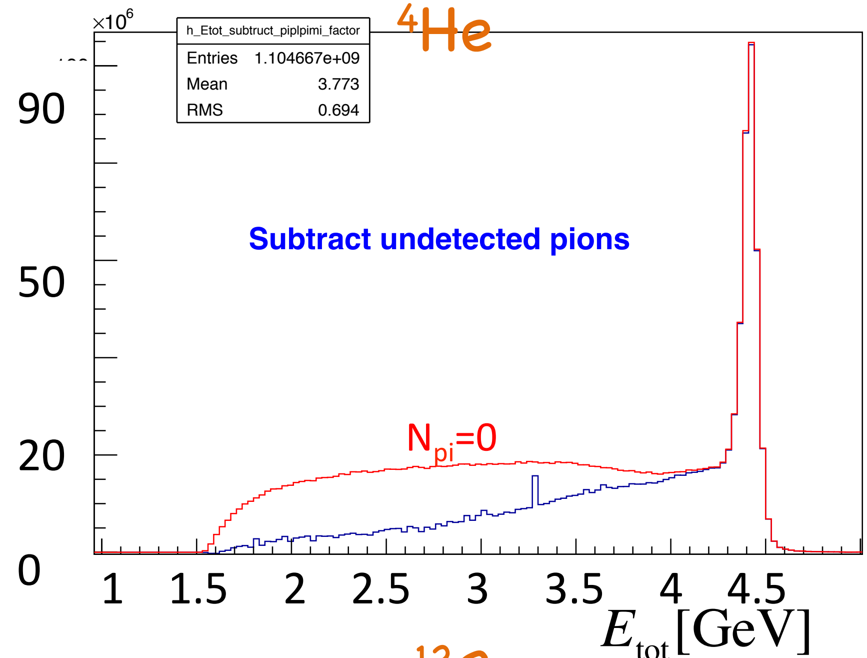
$E_{tot}=E_{e'}+T_p+E_{Binding}$

$E_{e'}$-energy of scattered electron

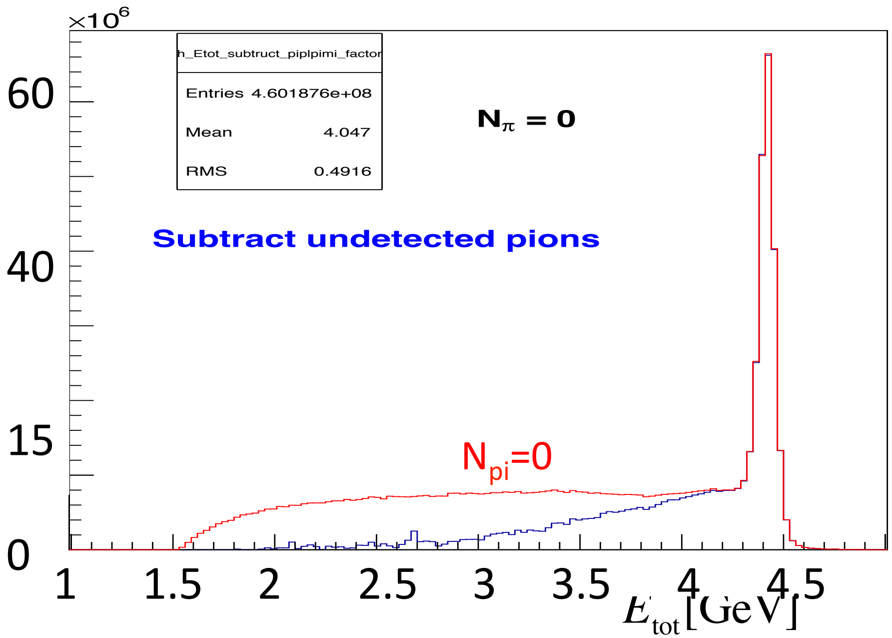
T_p-kinetic energy of knock-out proton

$E_{binding}$-Difference between binding energies of A and A-1 nuclei

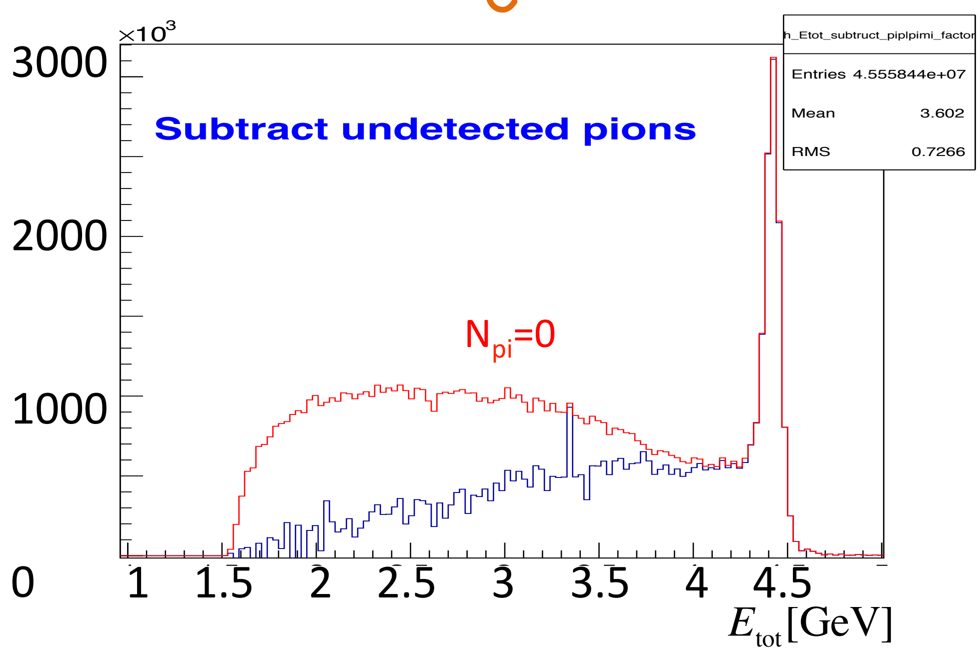
^{4}He



^{3}He



^{12}C



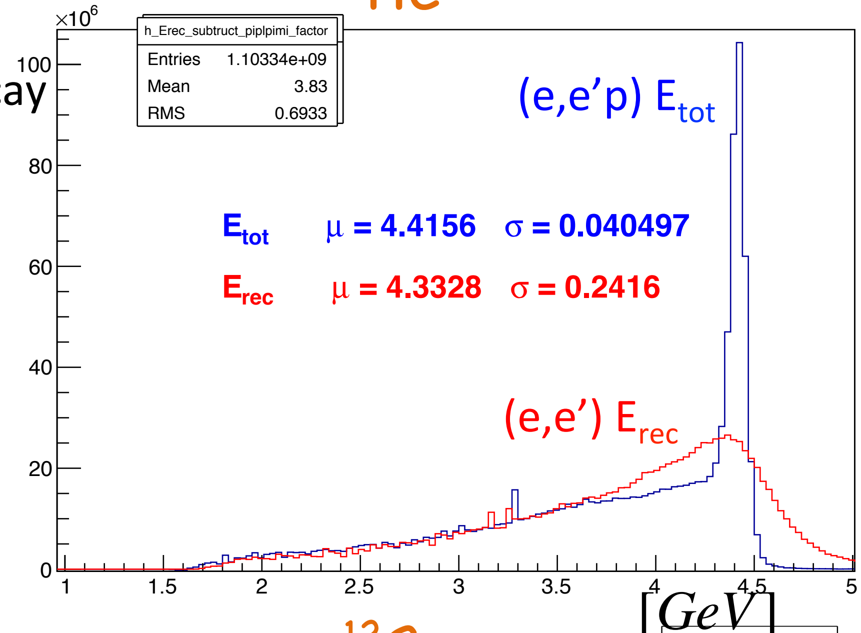
(e,e’p) E_{tot} vs (e,e’) E_{rec}

Cuts

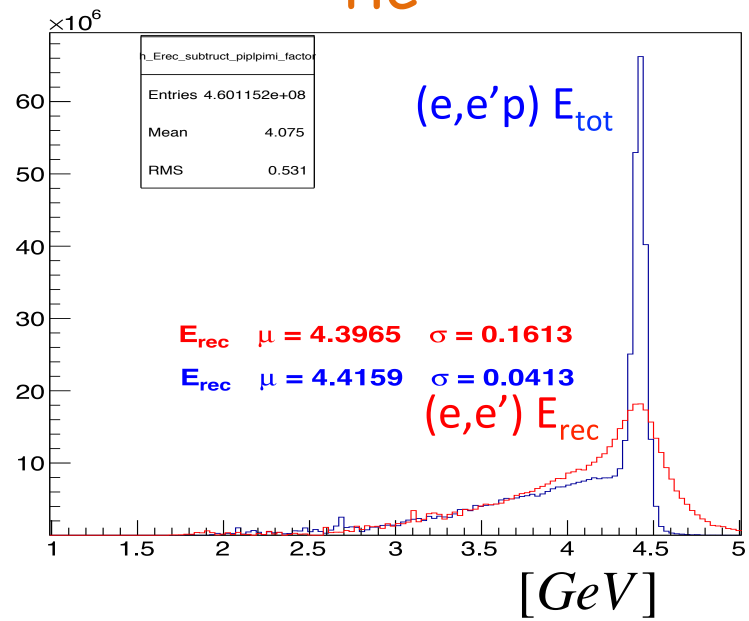
No π_+, π_- and no photons coming from π_0 decay

$$E_{\text{tot}} = E_{e'} + T_p + E_{\text{Binding}}$$

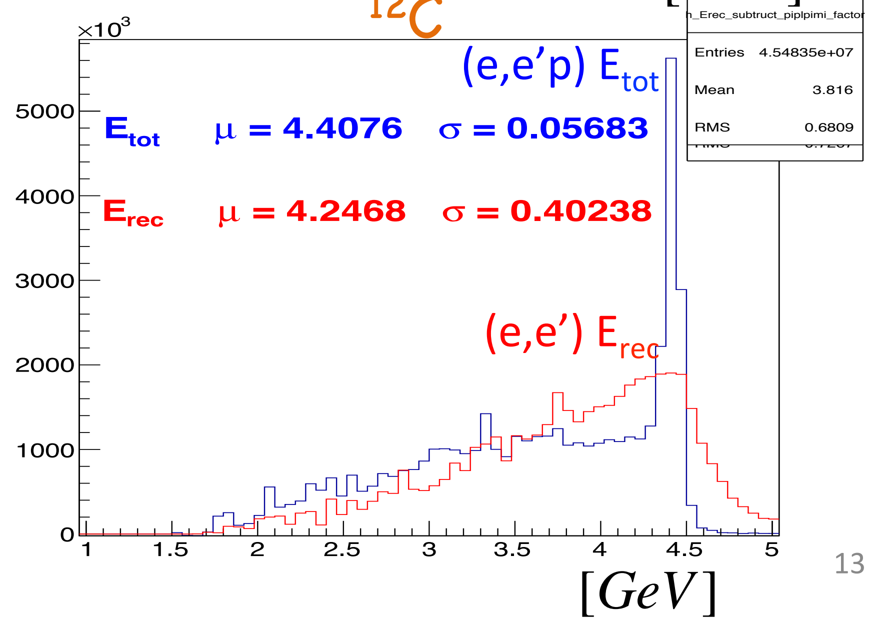
^{4}He



^{3}He



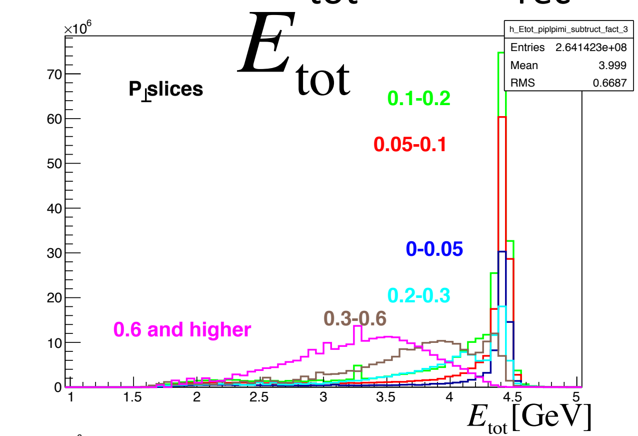
^{12}C



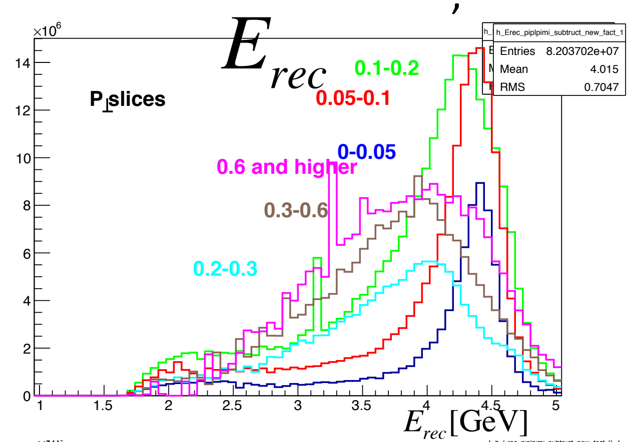
Six $P_\perp$ regions

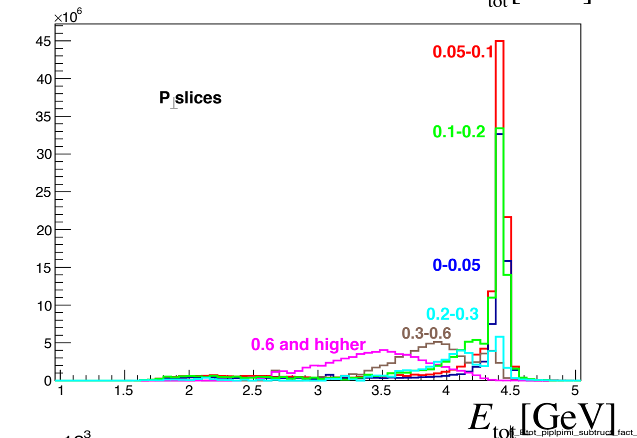
0 GeV/c – 0.05 GeV/c
0.05 GeV/c – 0.1 GeV/c
0.1 GeV/c – 0.2 GeV/c
0.2 GeV/c – 0.3 GeV/c
0.3 GeV/c – 0.6 GeV/c
0.6 GeV/c and higher

E_{tot} and E_{rec} for ^{3}He, ^{12}C and ^{4}He at 4.461 GeV

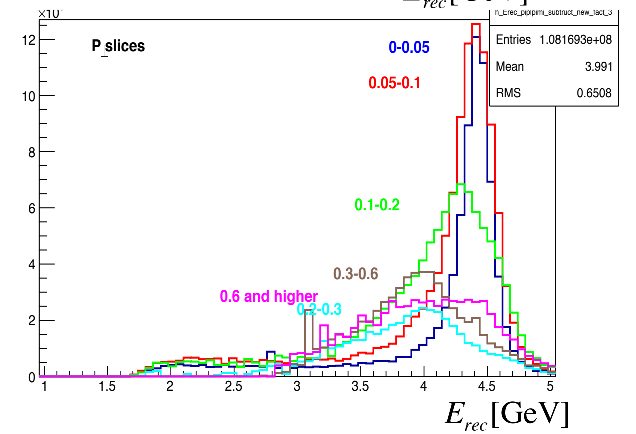


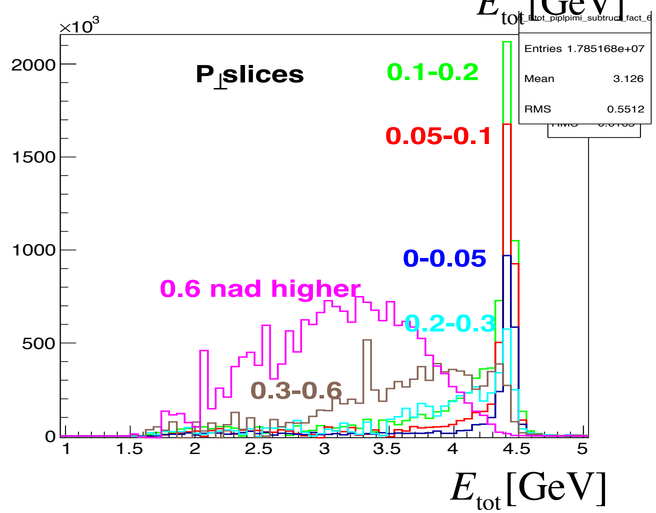
^{4}He



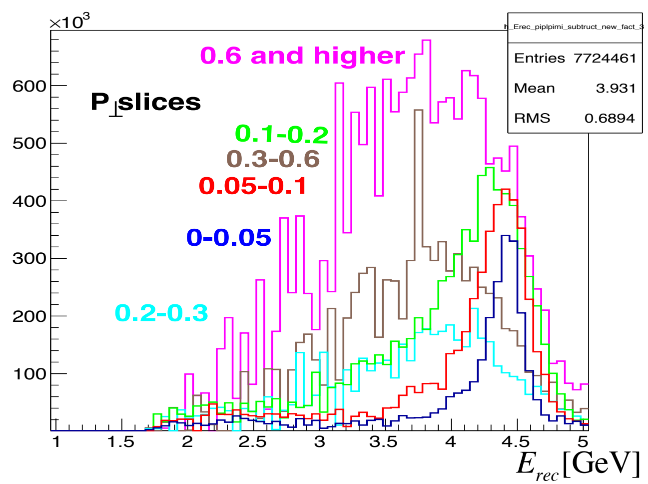


^{3}He





^{12}C

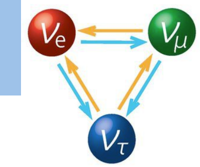


Conclusion

- Have obtained the beam energy using (e,e′) and using (e,e′p).
- Erec obtained using (e,e′) isn't accurate as not all the events are quasi-elastic at these energies
- E_{beam} is better reconstructed using (e,e′p)
- The reconstruction can be further improved with a transverse momentum cut
- It works better for light nuclei

Backup slides

Neutrino oscilations

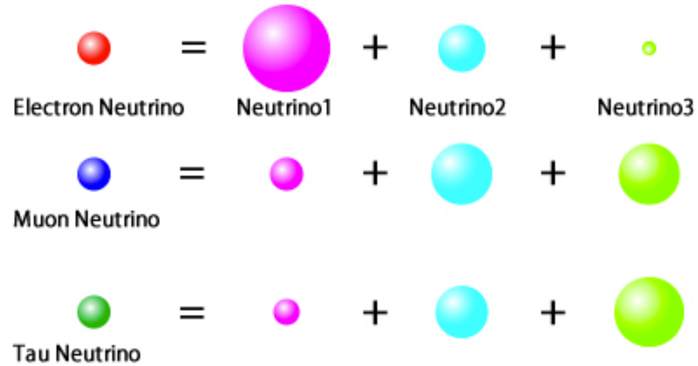


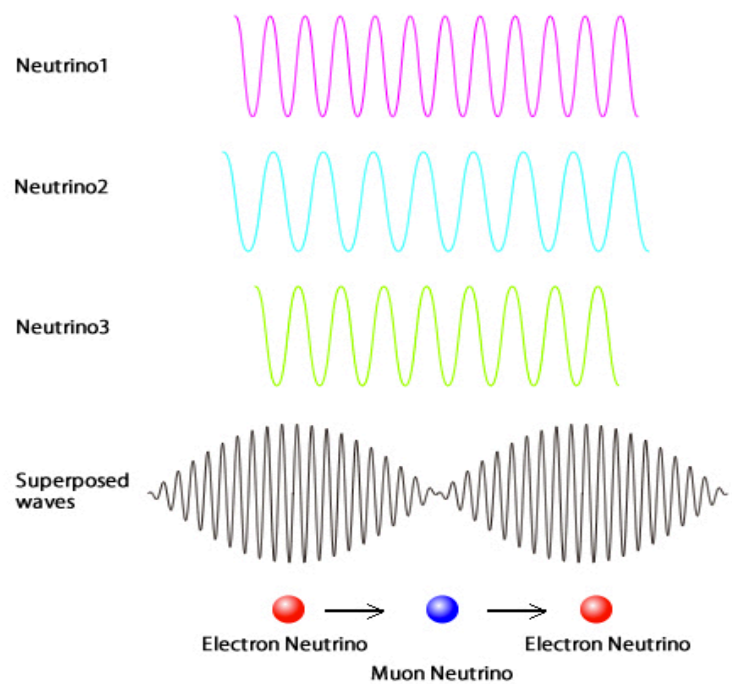
Neutrinos are classified in terms of:

"Pontecorvo-Maki-Nakagawa-Sakata" matrix

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \overbrace{\begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix}}^{\text{"Pontecorvo-Maki-Nakagawa-Sakata" matrix}} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Flavor states are superpositions of mass states and vice versa.





Q^2 vs ν

Q2 - four momentum transfer
Nu - energy transfer