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Validation of neutrino energy estimation using electron scattering data

Student

Mariana Khachatryan

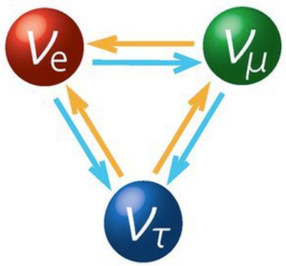
Supervisor

Lawrence Weinstein

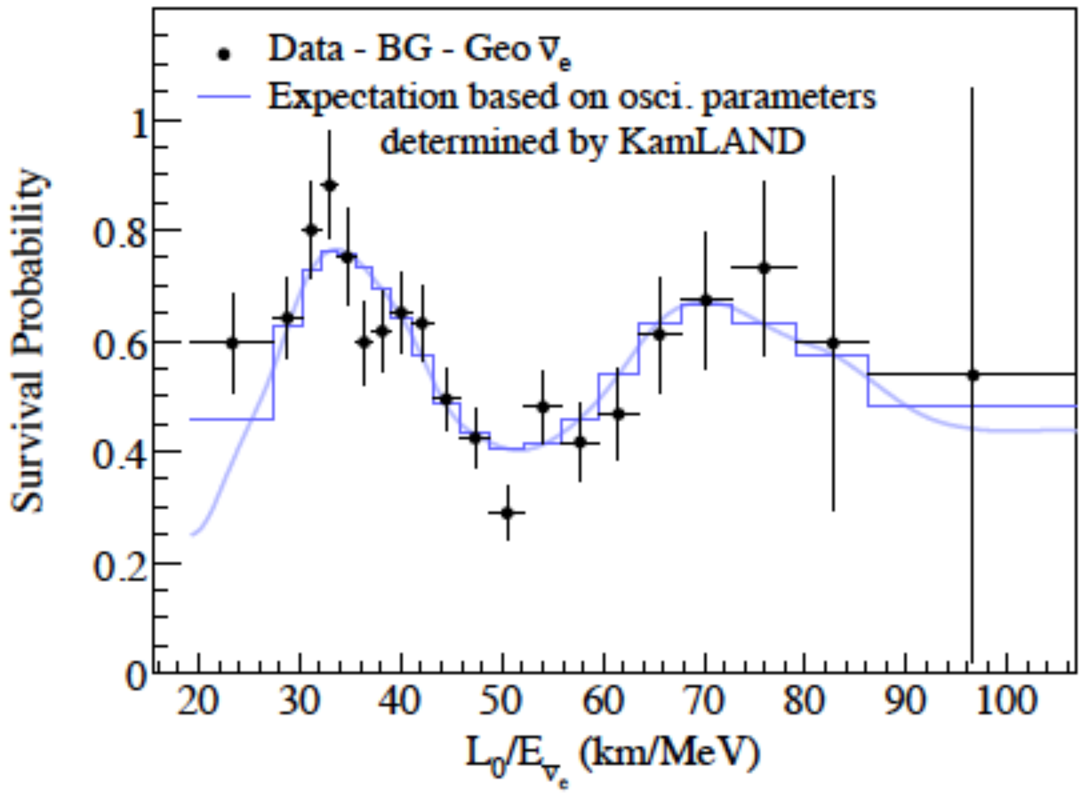
Outline

- 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)

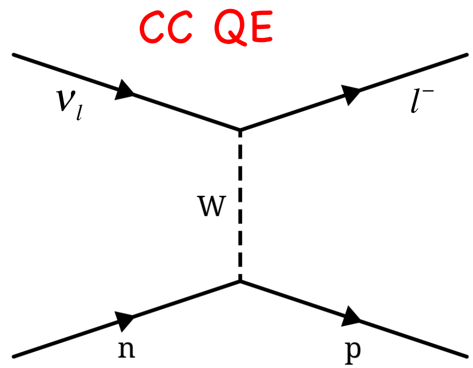
CC quasi-elastic scattering

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



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

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

Electromagnetic current

$$j_{\mu}^{em} = \bar{u}\gamma_{\mu}u$$

Lepton scattering

$$E_{\nu}^{\text{kin}} = \frac{2M\varepsilon + 2ME_1 - m_l^2}{2(M - E_1 + |k_1|\cos\theta)}$$

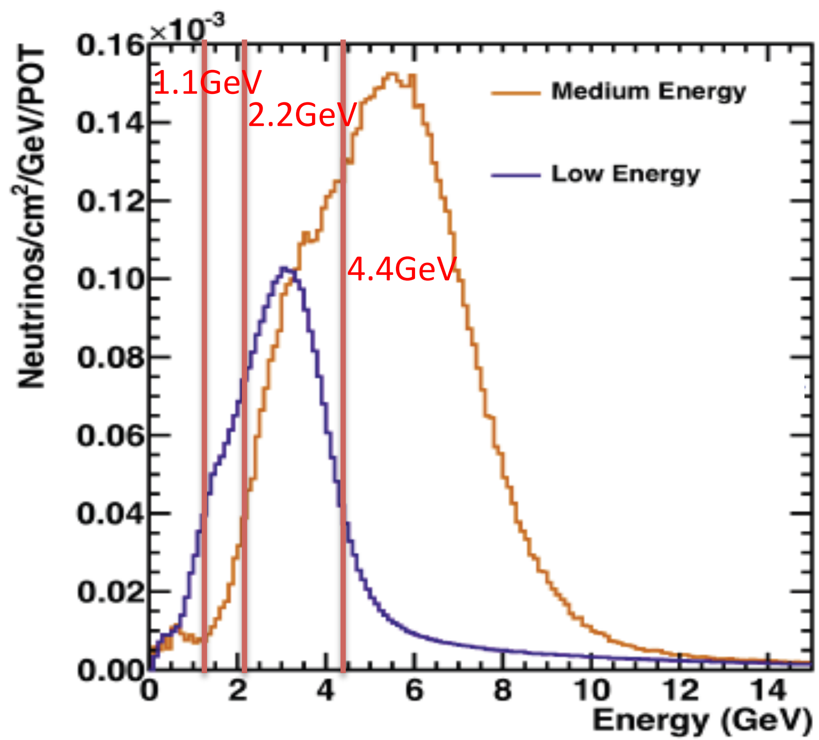
$\varepsilon \approx 20$ MeV binding energy

M-nucleon mass

m_1 outgoing lepton mass

k_1 – lepton three momentum

θ – lepton scattering angle



MINERvA | MicroBoone

3D view

Scintillator based detector

Study:

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

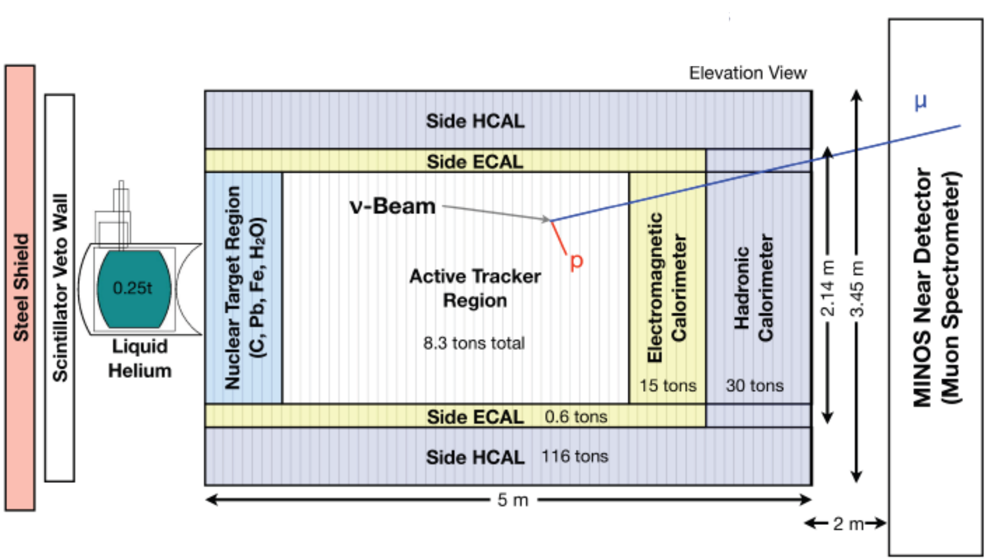
3D view

Liquid Argon Time Projection Chamber.

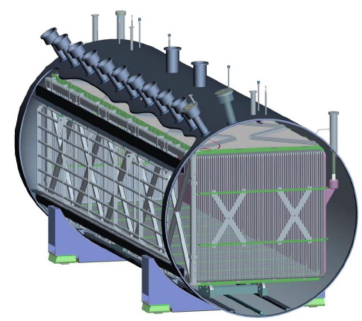
Measure:

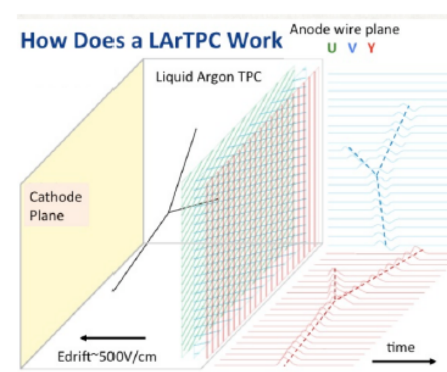
- ✧ Low energy neutrino cross sections

Schematic view of MINERvA



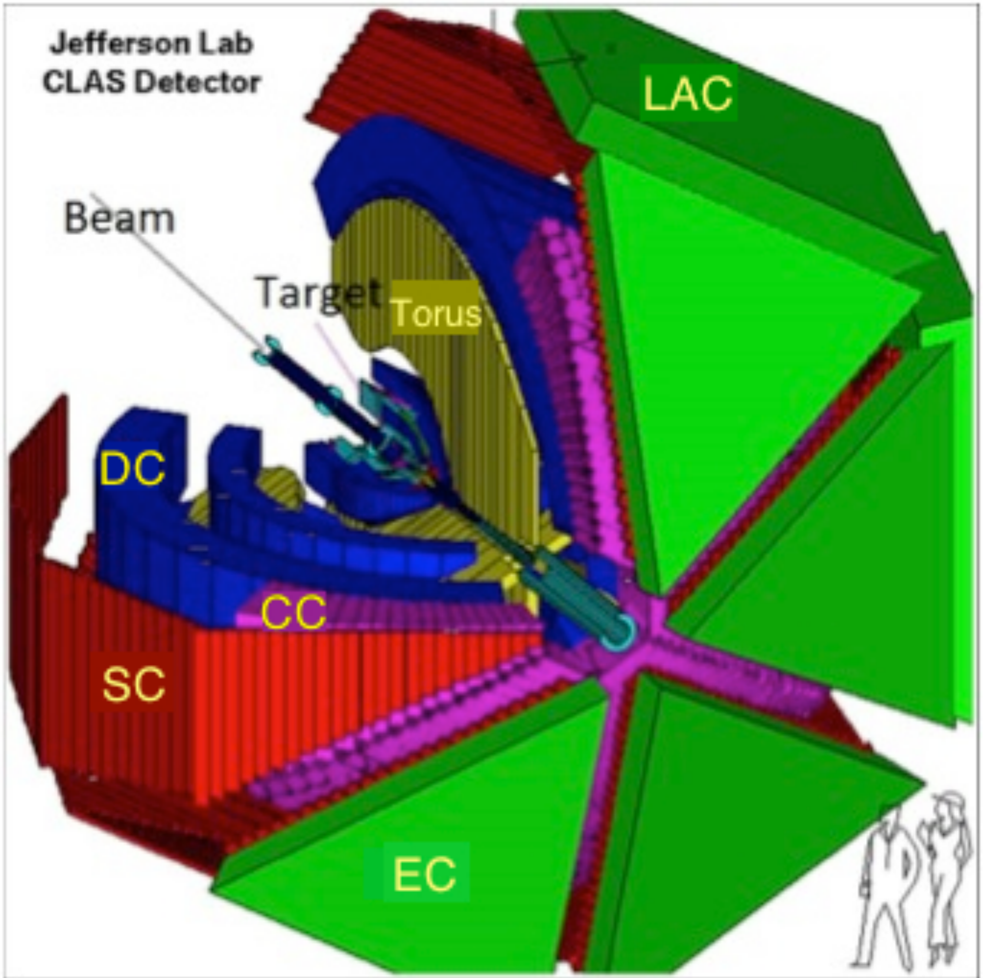
Schematic view of MicroBoNE



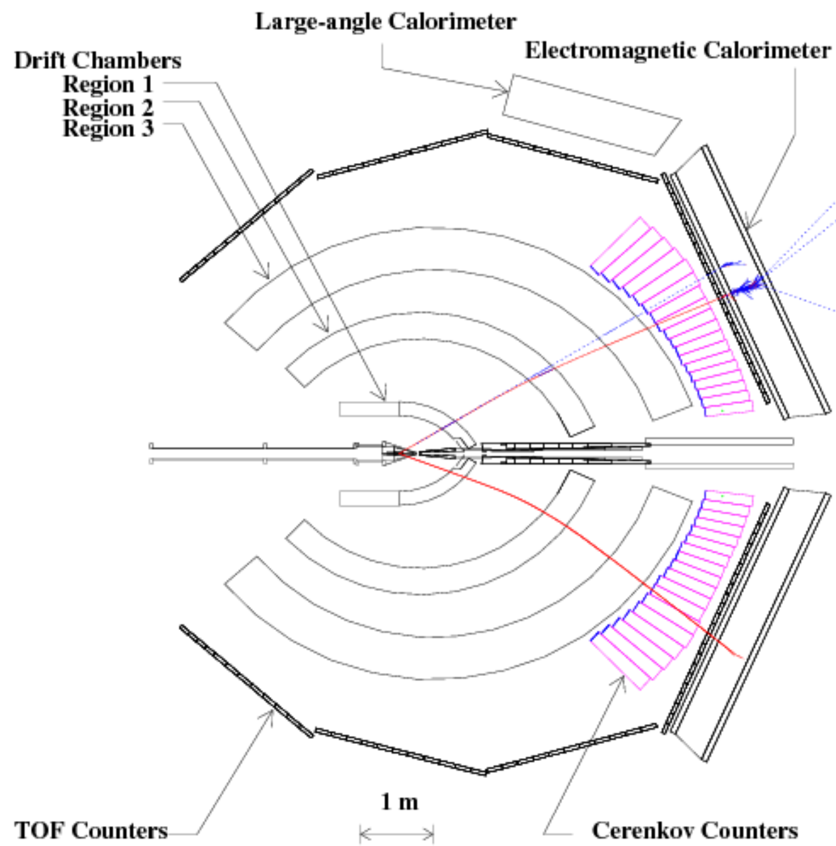


CLAS detector package

3D view



Slice view



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

Electron scattering data

Have analyzed ^{4}He, ^{12}C, ^{3}He , ^{56}Fe 4.461, 2.261 GeV e2a experiment data

Other data available ^{3}He, ^{4}He, C, Fe 1.1 GeV

Good (e,e') and (e,e'p) events with e and p PID, vertex and fiducial cuts and W<2

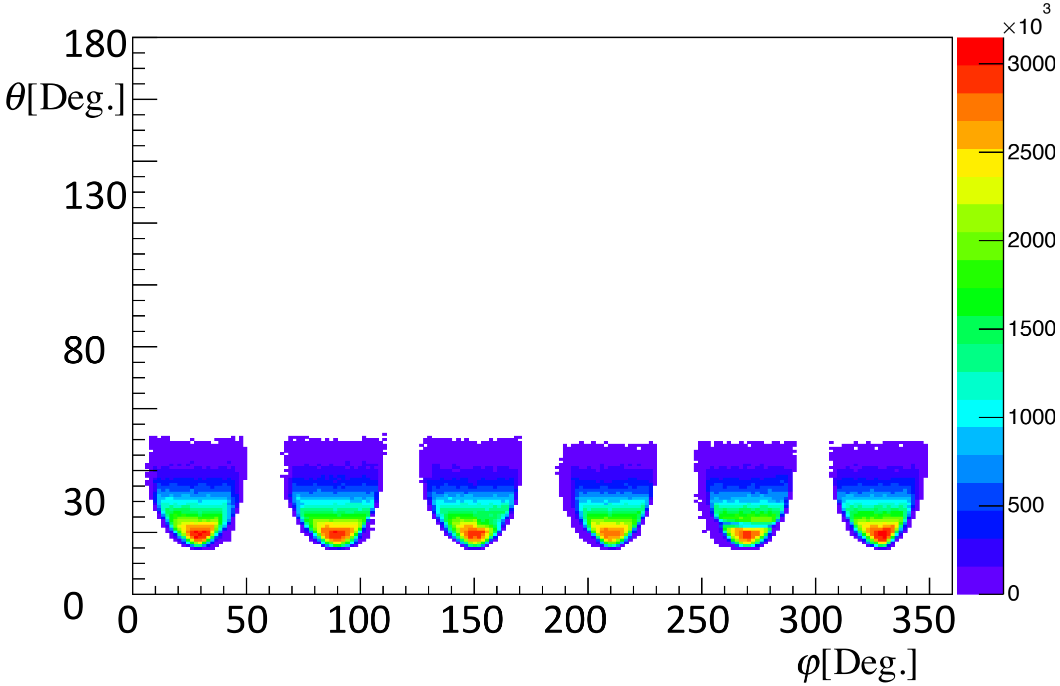
	2.2GeV (e,e')	2.2GeV (e,e'p)	4.4GeV (e,e')	4.4GeV (e,e'p)
3He	28986574	11528930	3906223	1405454
4He	46335555	16671452	7756786	2635998
12C	28964300	10653575	4707597	1494004
56Fe	1488407	523741	393716	121371

4.461 GeV analysis

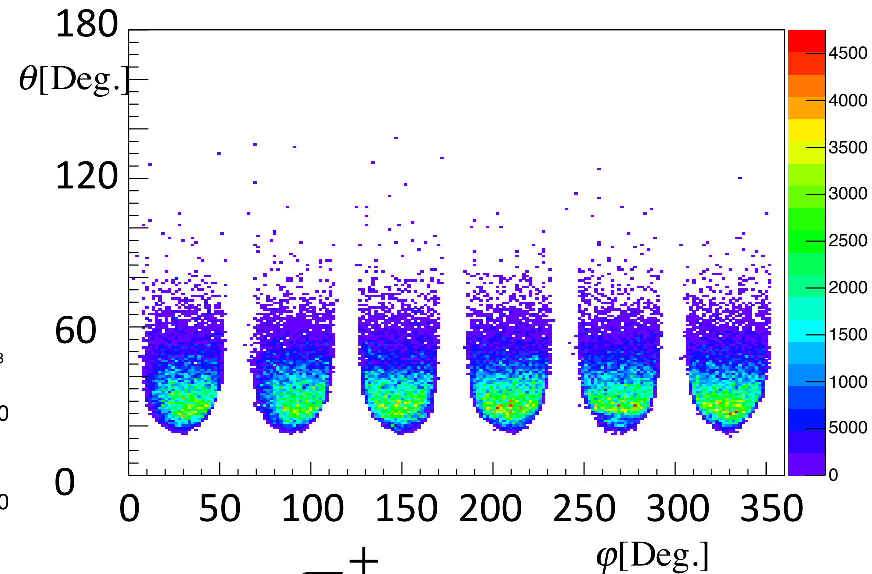
θ and φ distributions

E2a ^{12}C 4.461 GeV

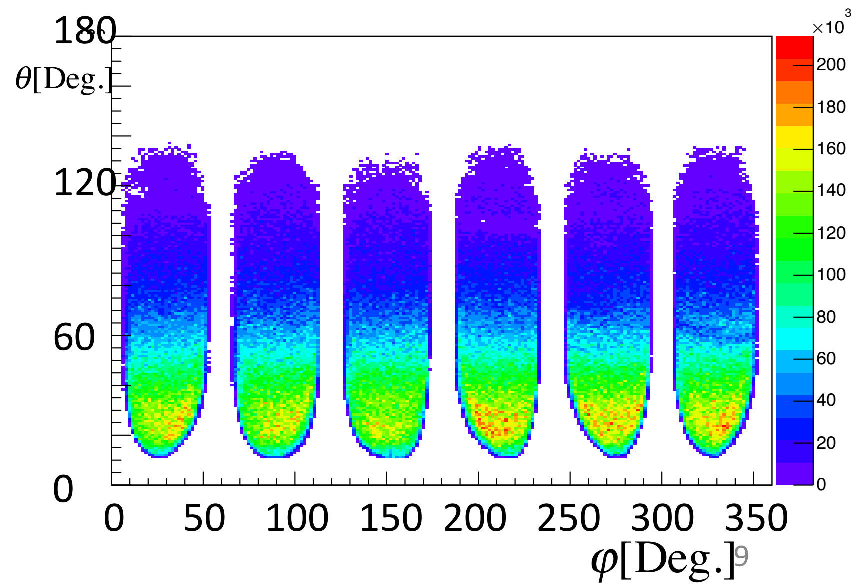
e^-



π^-

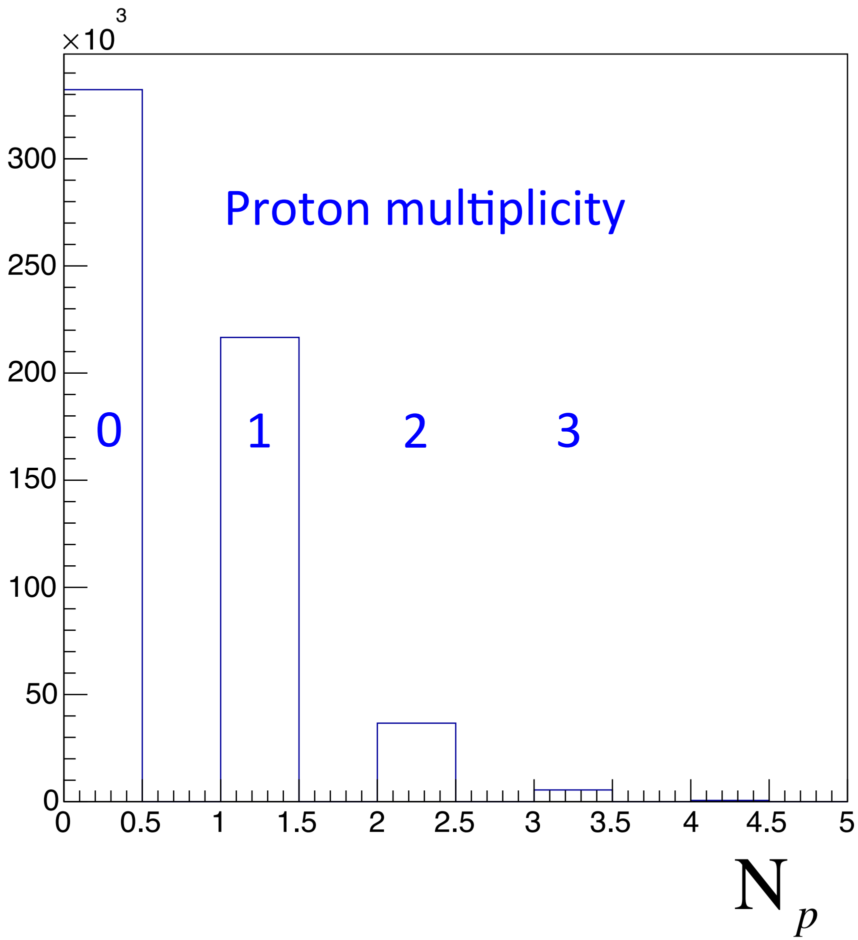


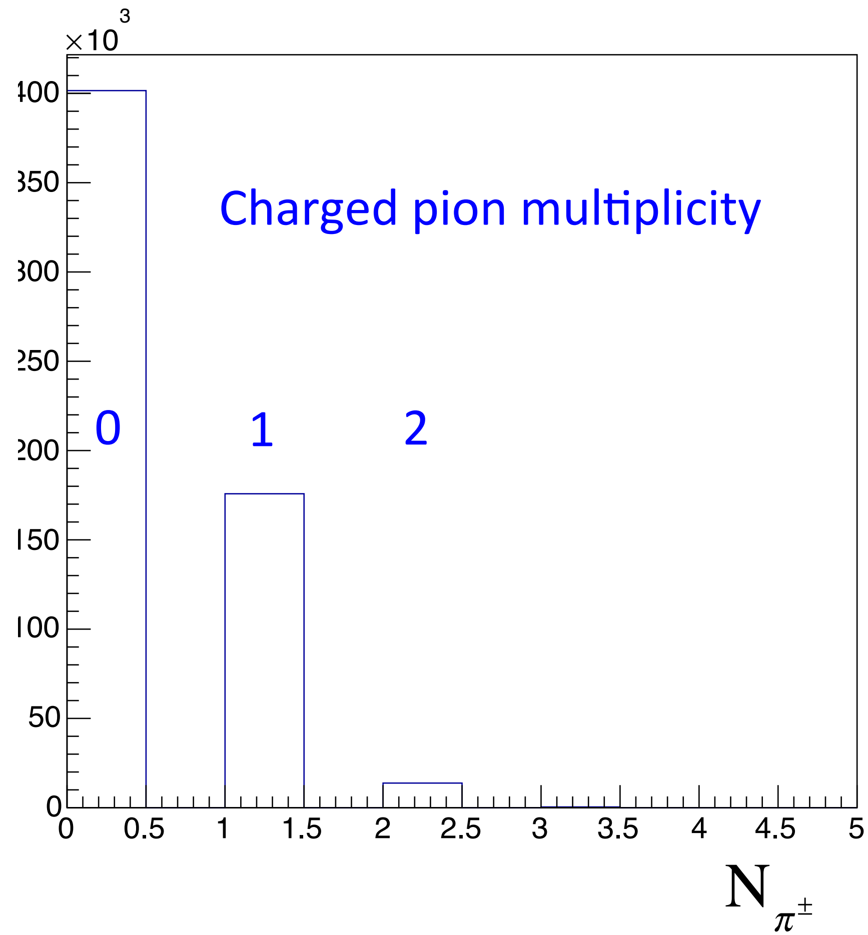
π^+



Number of events with pions and protons

E2a ^{12}C 4.461 GeV

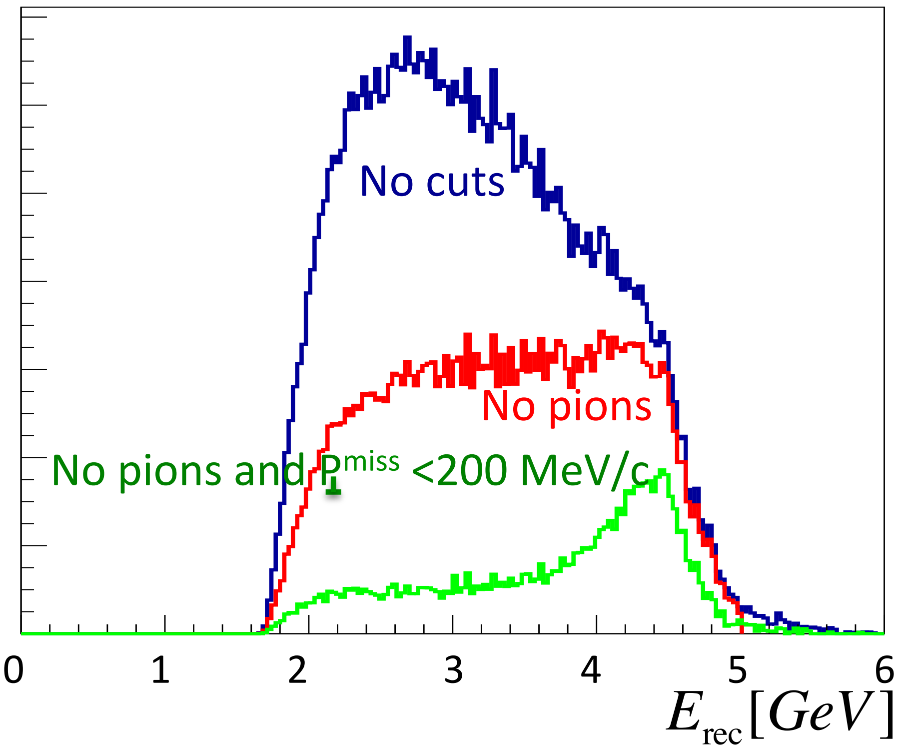


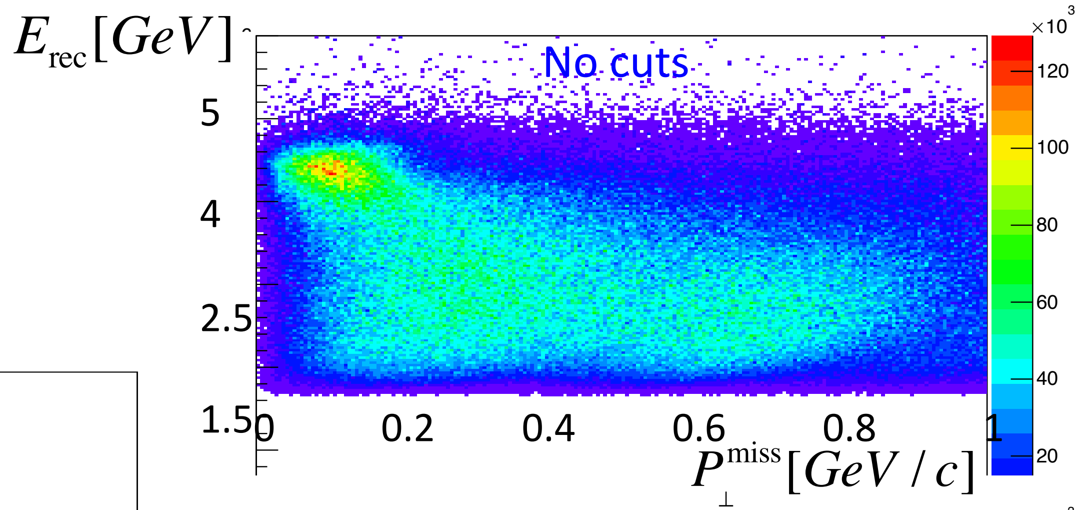


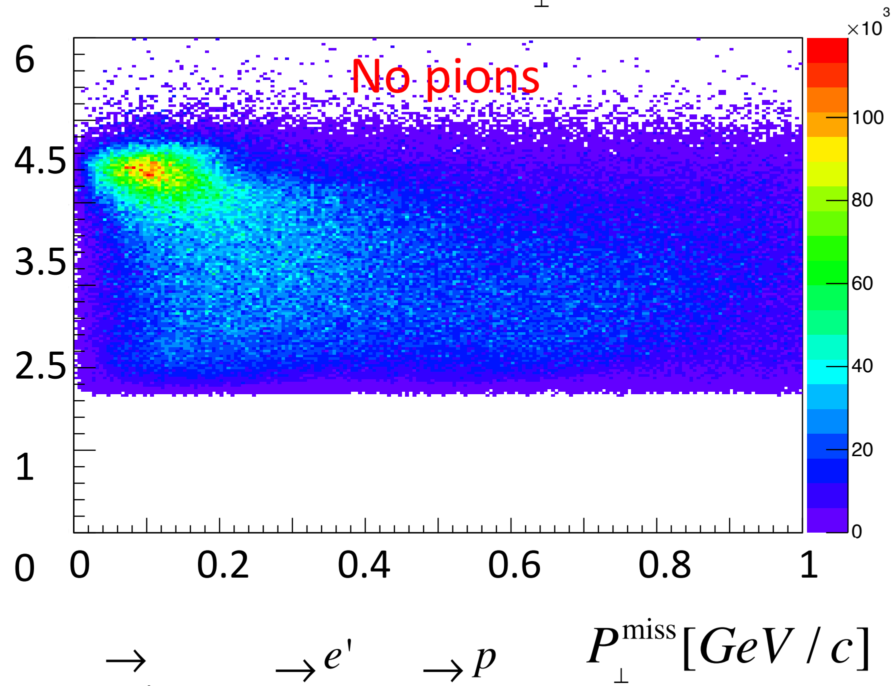
Reconstructed (e,e') energy

E2a ^{12}C 4.461 GeV

e$^-$ only







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

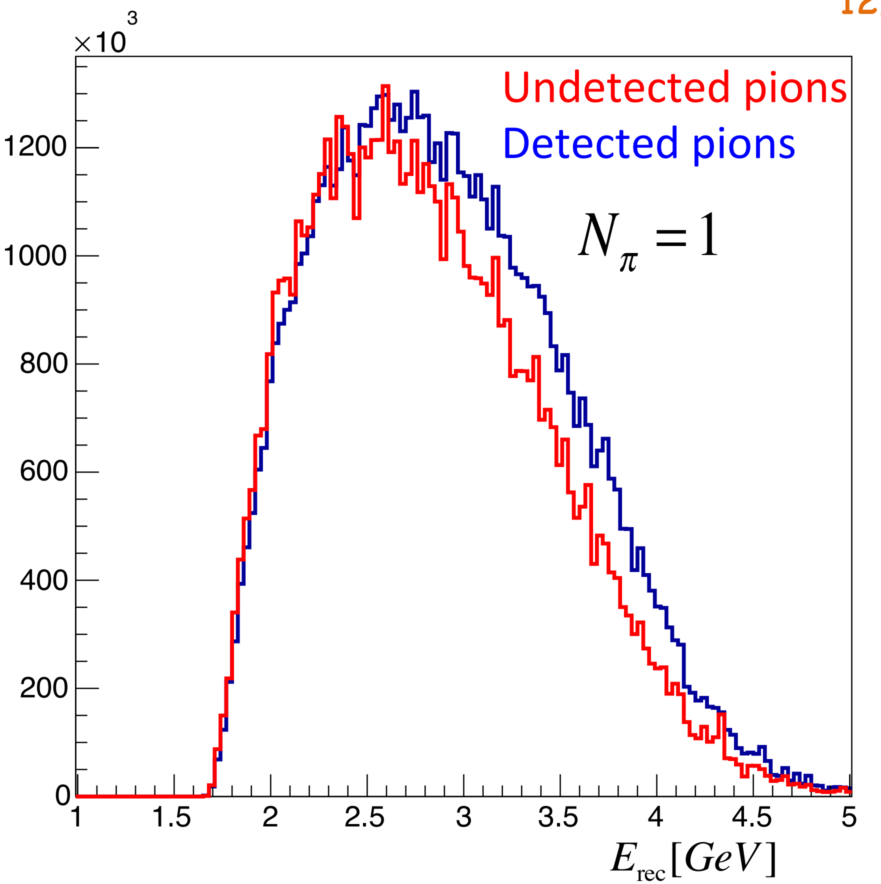
Subtracting undetected pions

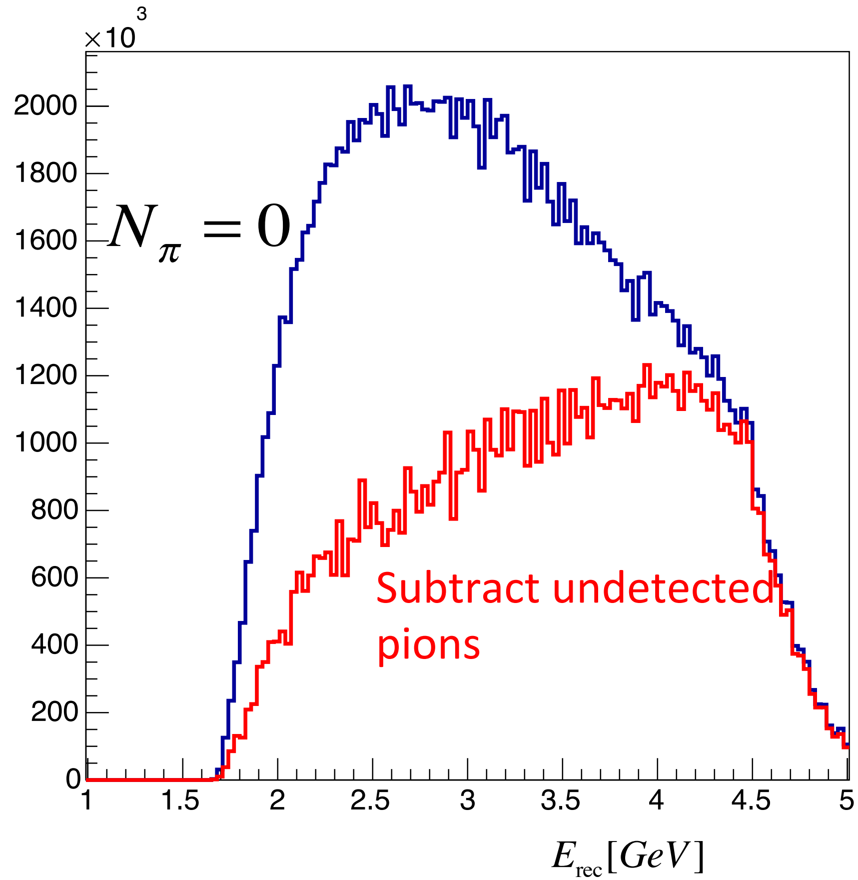
(e,e')

Cuts

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

^{12}C





$E_{\rm rec}[GeV]$

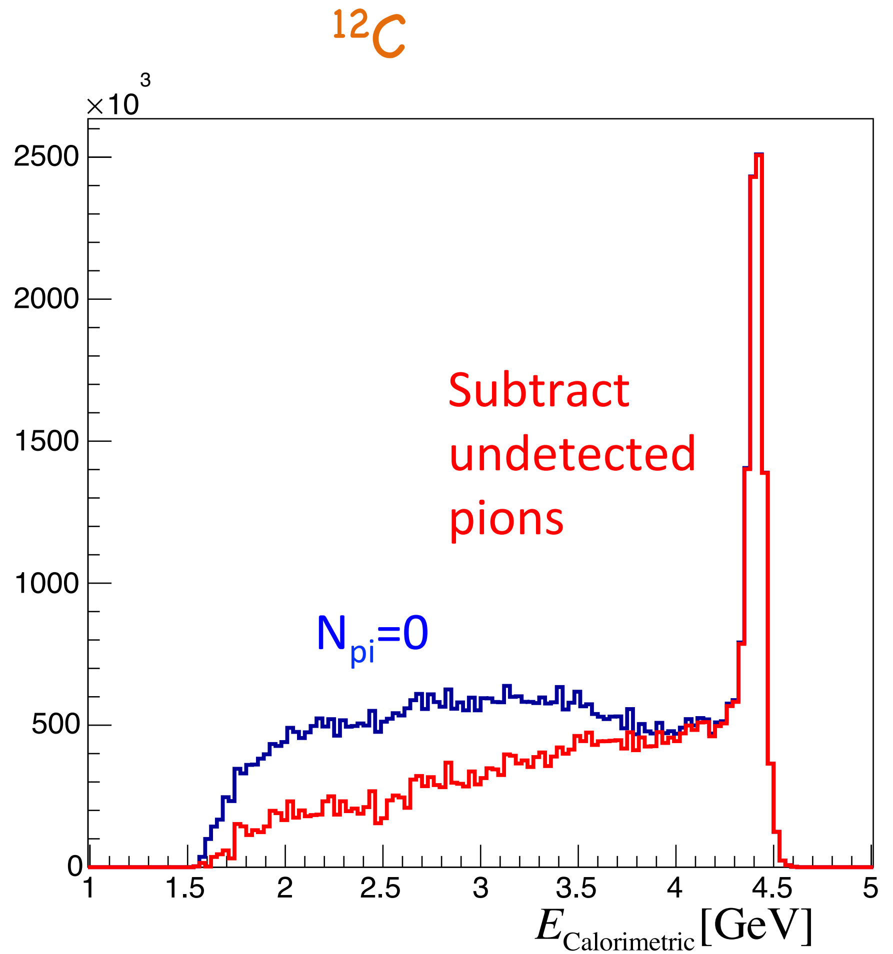
(e,e'p) $E_{Calorimetric}$

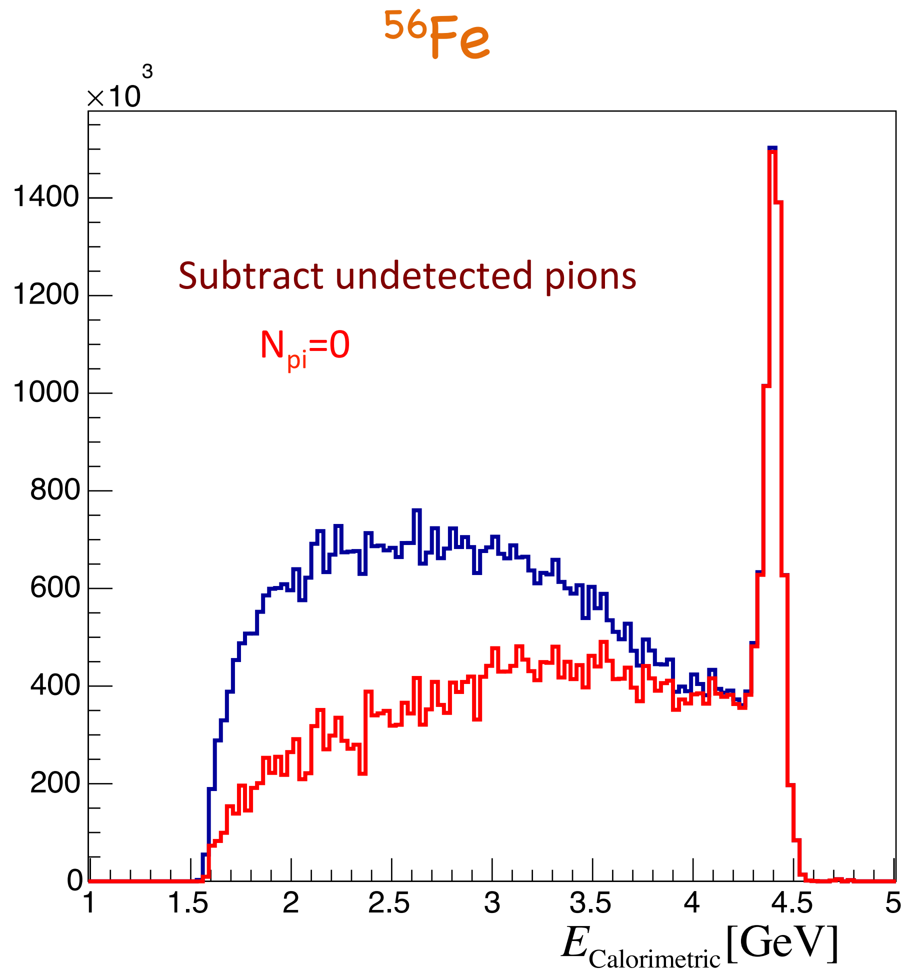
$E_{Calorimetric}=E_{e'}+T_p+E_{Binding}$

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

T_p-kinetic energy of knock-out proton

$E_{binding}$-binding energy difference





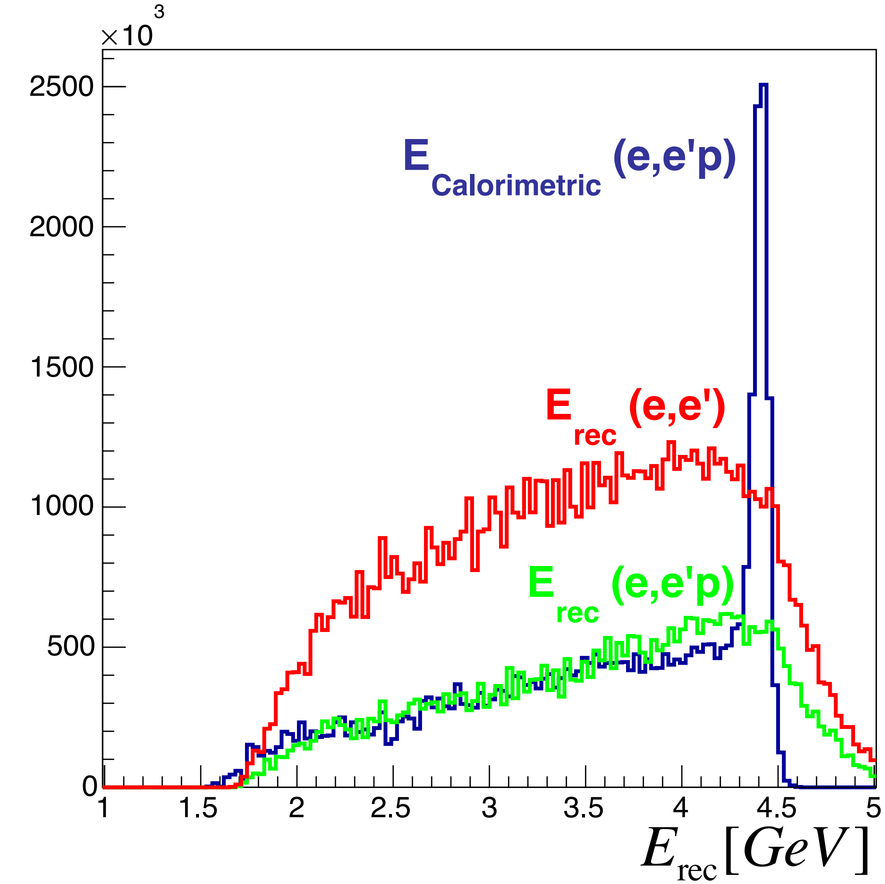
(e,e'p) $E_{calorimetric}$, (e,e') E_{rec} and (e,e'p) E_{rec}

Cuts

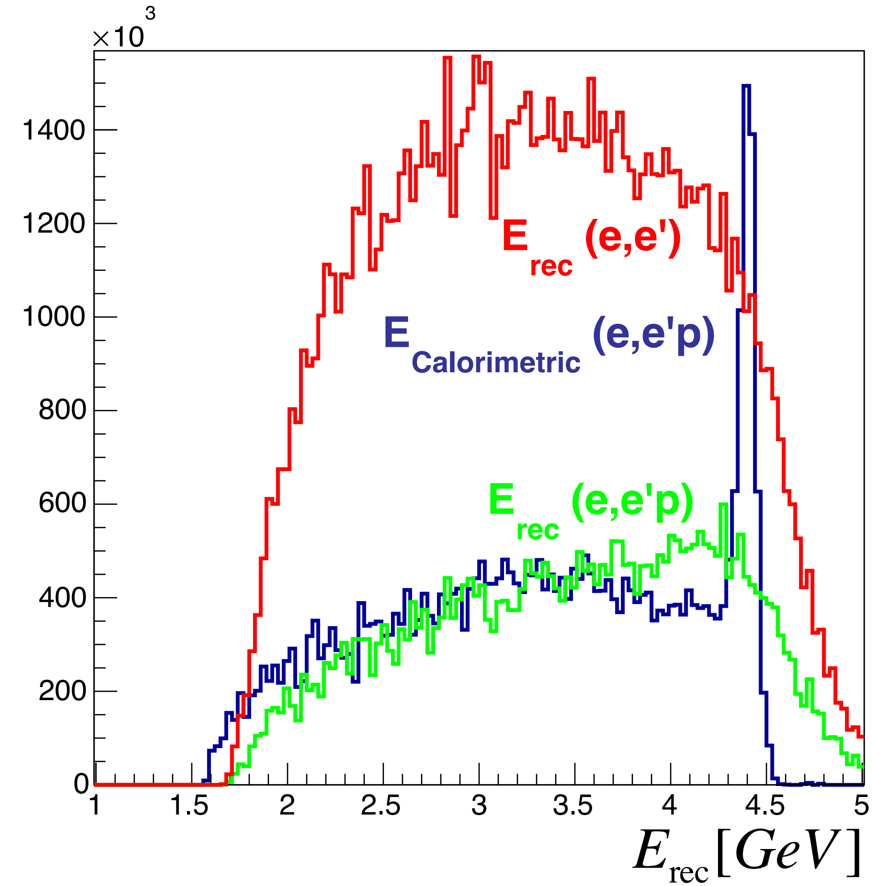
No π_+, π_- and no photons coming from π_0 decay

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

^{12}C



^{56}Fe



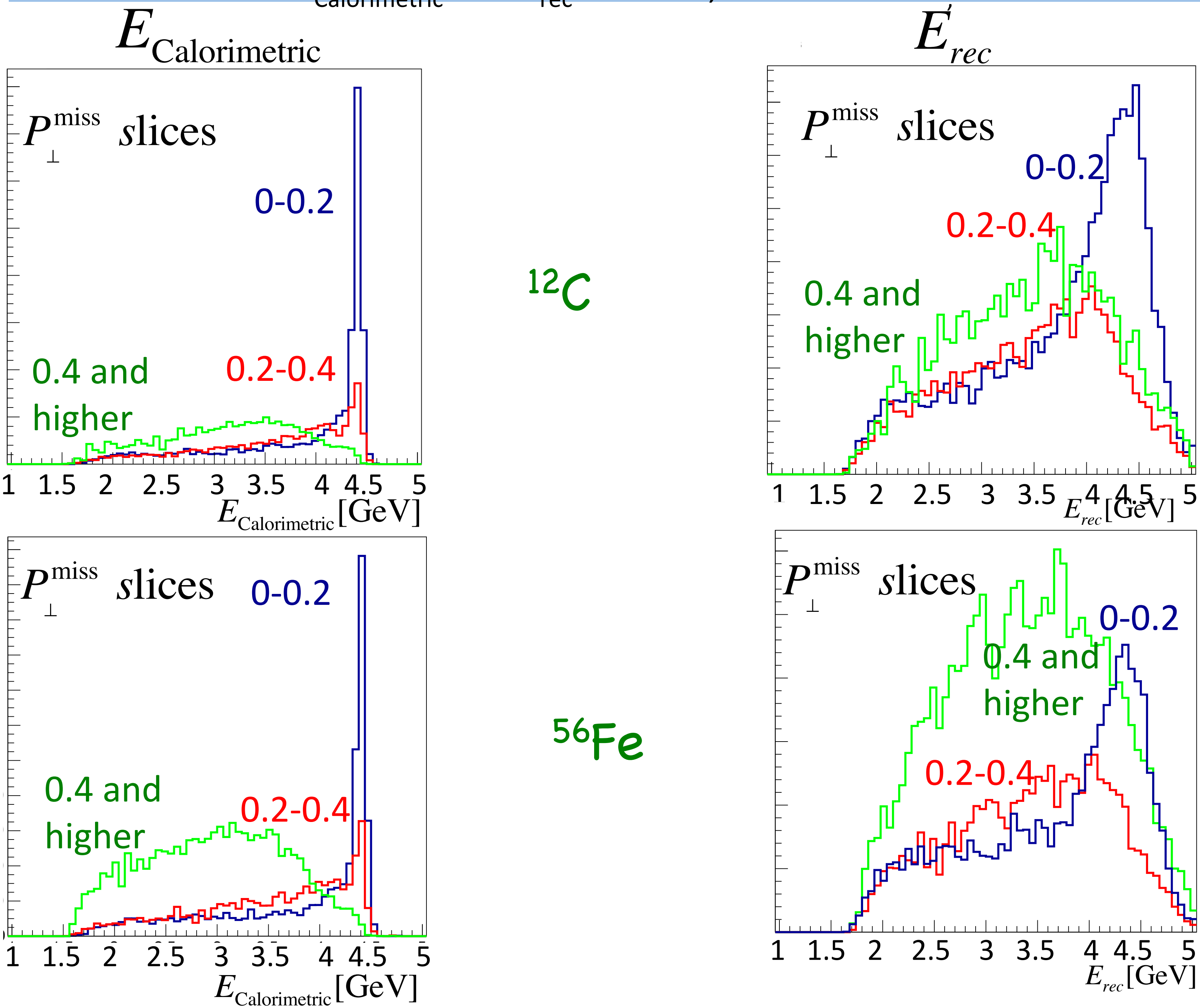
Three $P_{\perp}^{miss}$ regions

0 GeV/c – 0.2 GeV/c

0.2 GeV/c – 0.4 GeV/c

0.4 GeV/c and higher

$E_{Calorimetric}$ and E_{rec} for ^{56}Fe , ^{12}C 4.461 GeV



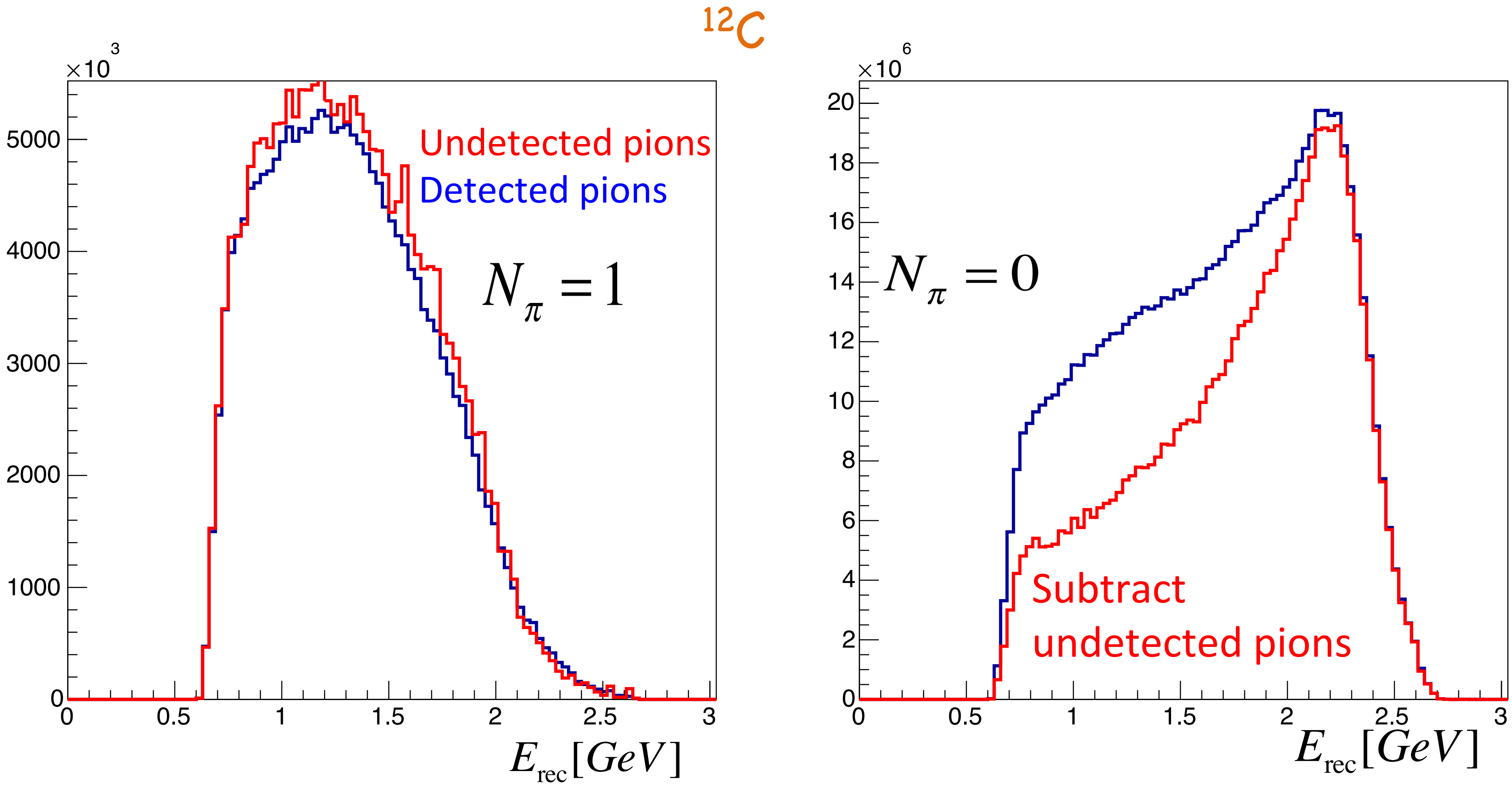
2.261 GeV analysis

Subtracting undetected pions

(e,e')

Cuts

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

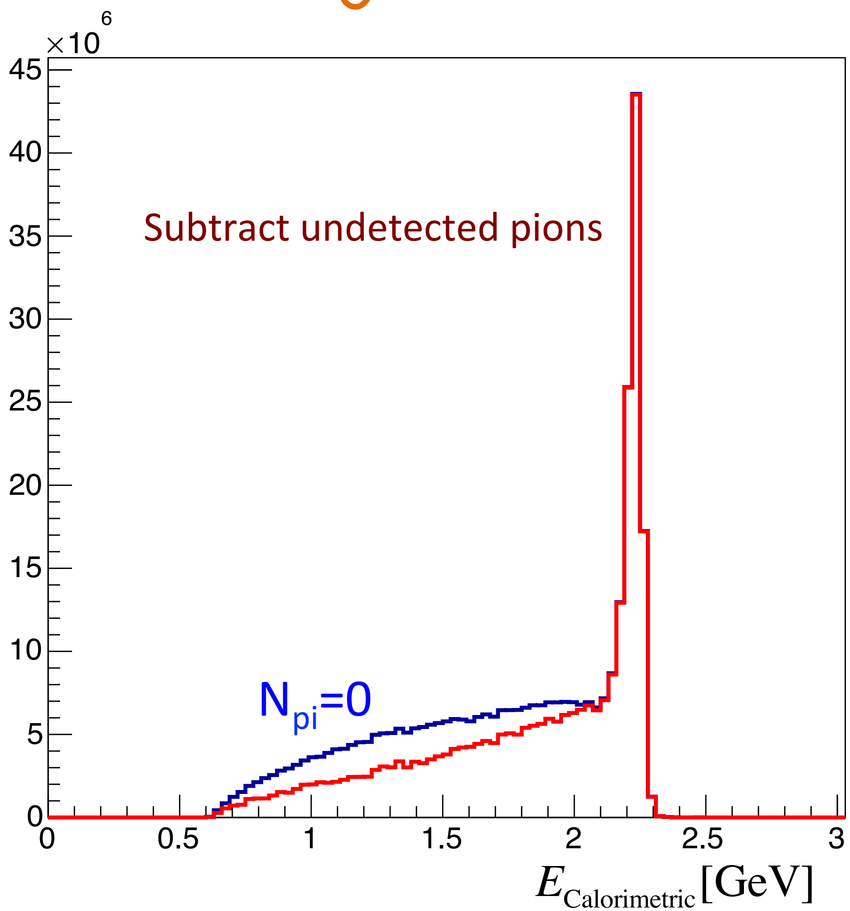


$E_{rec}[GeV]$

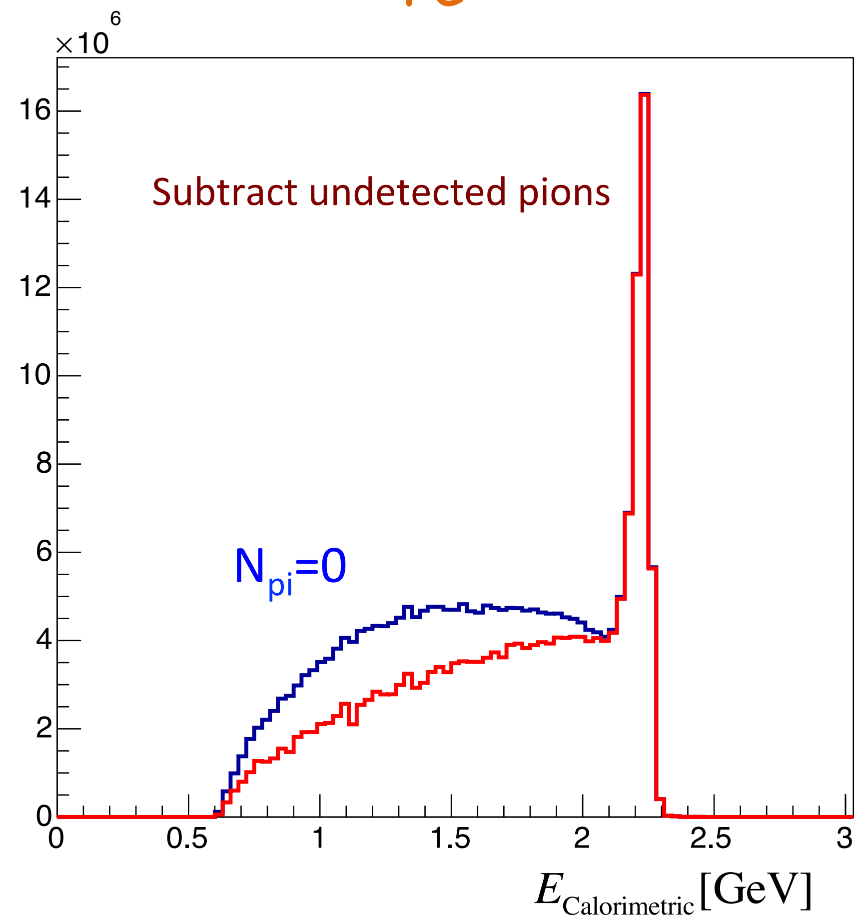
(e,e'p) $E_{Calorimetric}$

$E_{Calorimetric}=E_{e'}+T_p+E_{Binding}$
$E_{e'}$-energy of scattered electron
T_p-kinetic energy of knock-out proton
$E_{binding}$-Difference between binding energies of A and A-1 nuclei

^{12}C



^{56}Fe



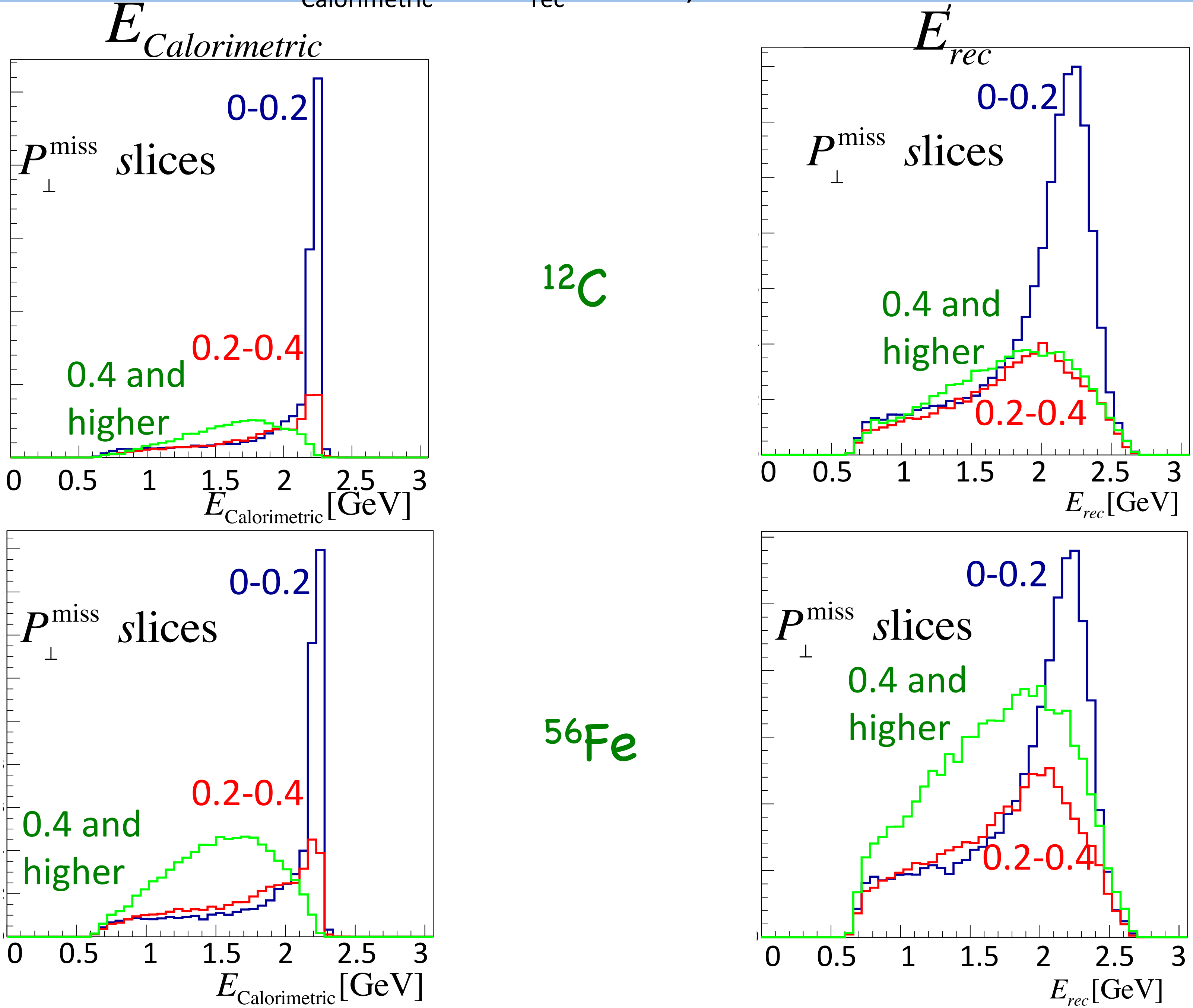
Three $P_{\perp}^{miss}$ regions

0 GeV/c – 0.2 GeV/c

0.2 GeV/c – 0.4 GeV/c

0.4 GeV/c and higher

$E_{Calorimetric}$ and E_{rec} for ^{12}C , ^{56}Fe 4.461 GeV

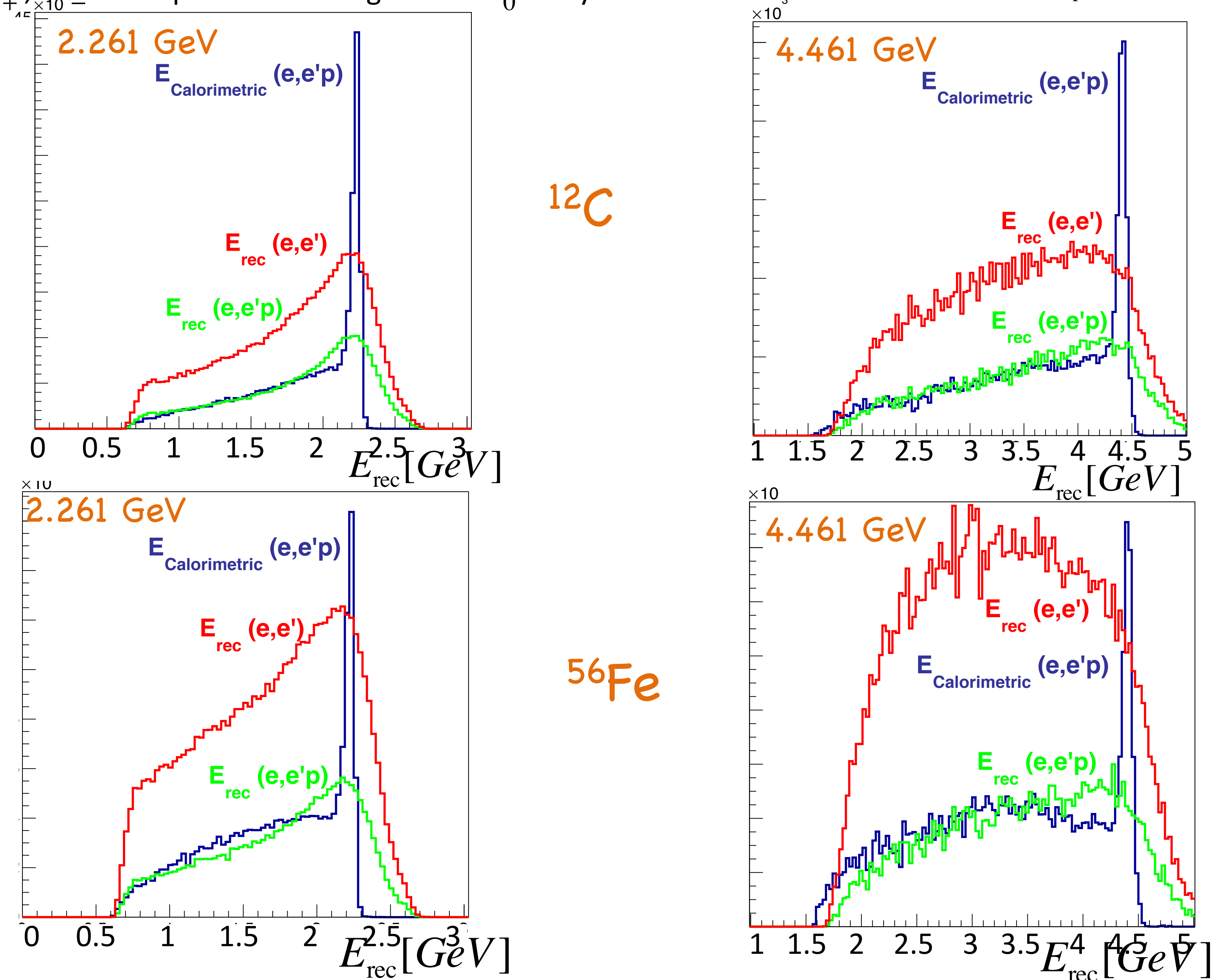


(e,e'p) $E_{calorimetric}$, (e,e') E_{rec} and (e,e'p) E_{rec} for ^{12}C and ^{56}Fe at two energies

Cuts

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

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



Fraction of events reconstructed to within 5% of the beam energy

	2.2 GeV			4.461 GeV		
	E_{rec} (e,e')	E_{rec} (e,e'p)	$E_{calorimetric}$ (e,e'p)	E_{rec} (e,e')	E_{rec} (e,e'p)	$E_{calorimetric}$ (e,e'p)
^{3}He	34%	41%	55%	26%	32%	42%
^{4}He	25%	30%	46%	20%	23%	33%
^{12}C	22%	26%	37%	16%	20%	28%
^{56}Fe	17%	20%	23%	12%	16%	18%

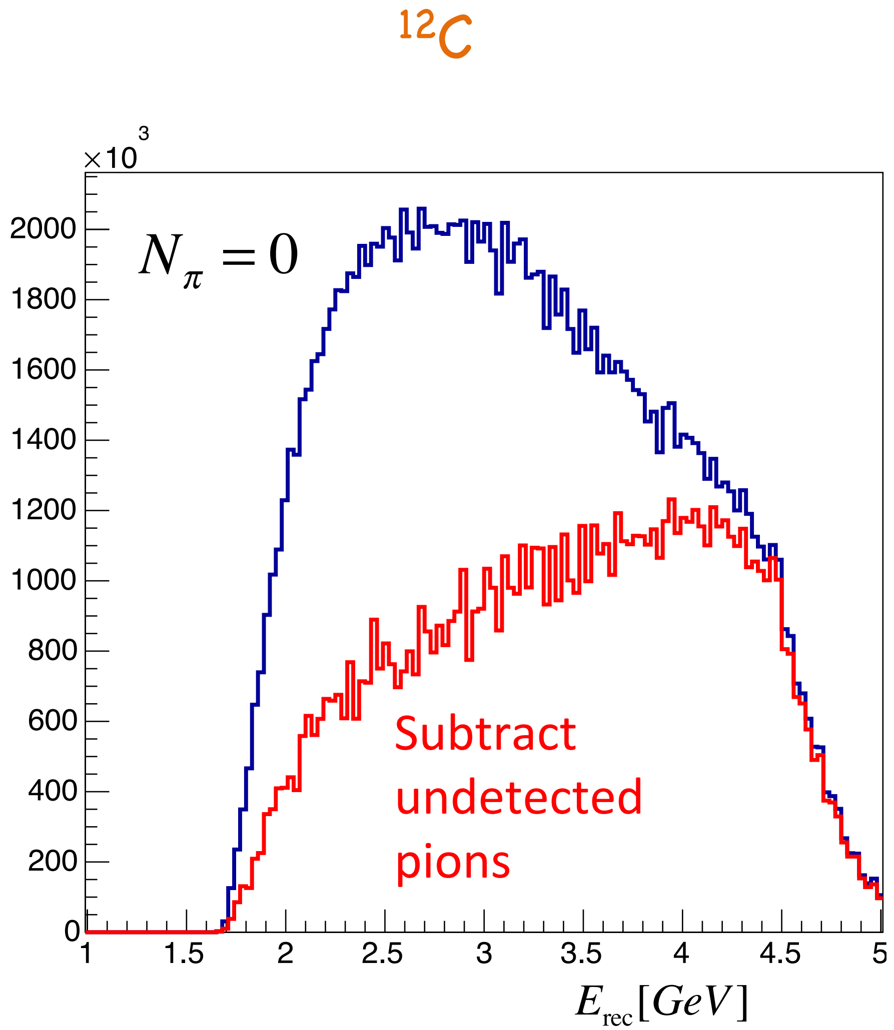
Conclusion

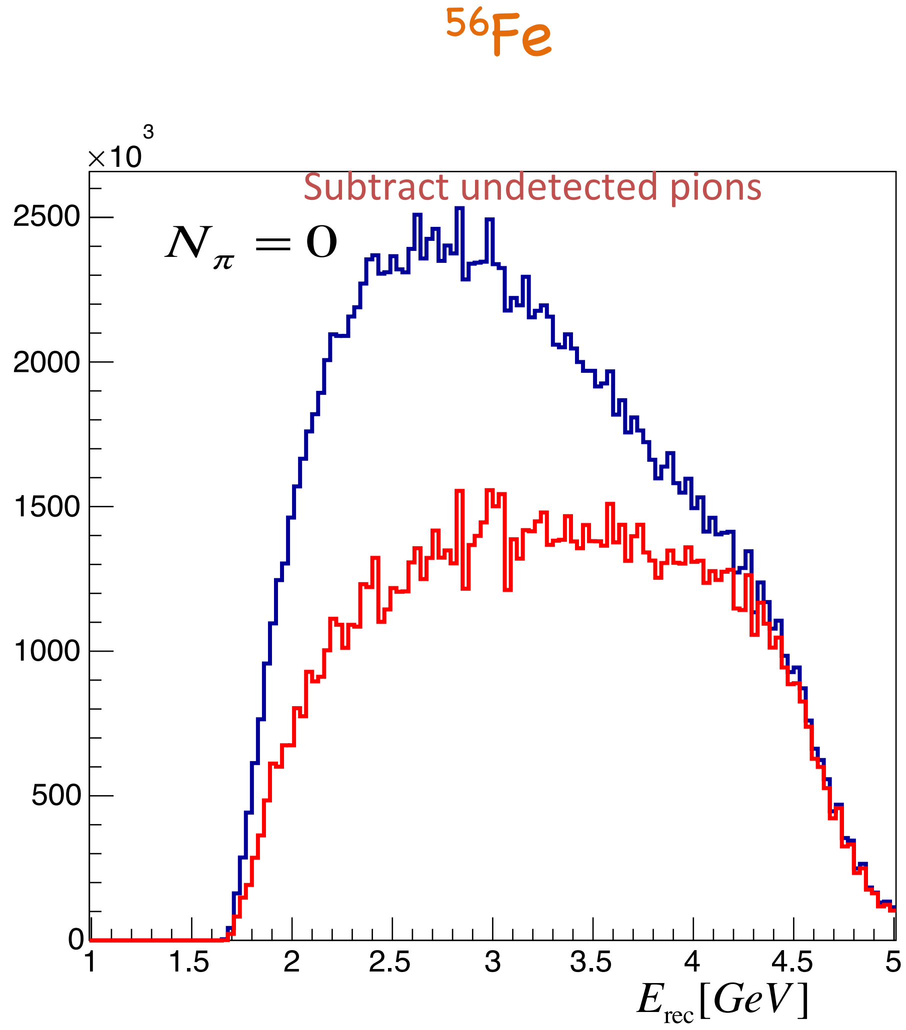
1. First use of electron data to test neutrino energy reconstruction algorithms
   - use zero-pion cuts to enhance quasi-elastic event selection
   - just scattered lepton
     - ✧ used in Cherenkov-type neutrino detectors
   - total energy of electron plus proton
     - ✧ used in calorimetric neutrino detectors
   - improved by a transverse momentum cut to better select QE events
2. Only 12-55% of events reconstruct to within 5% of the beam energy
   - better for lighter nuclei and lower energies
3. Serious implications for neutrino oscillation measurements
4. Tremendous interest in the neutrino community
5. Analysis note in preparation, aiming for PRL
6. Future work:
   - extend analysis to more targets and energies
   - compare to neutrino event generators
   - proposal to PAC 45

(e,e') E_{rec}

Cuts

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



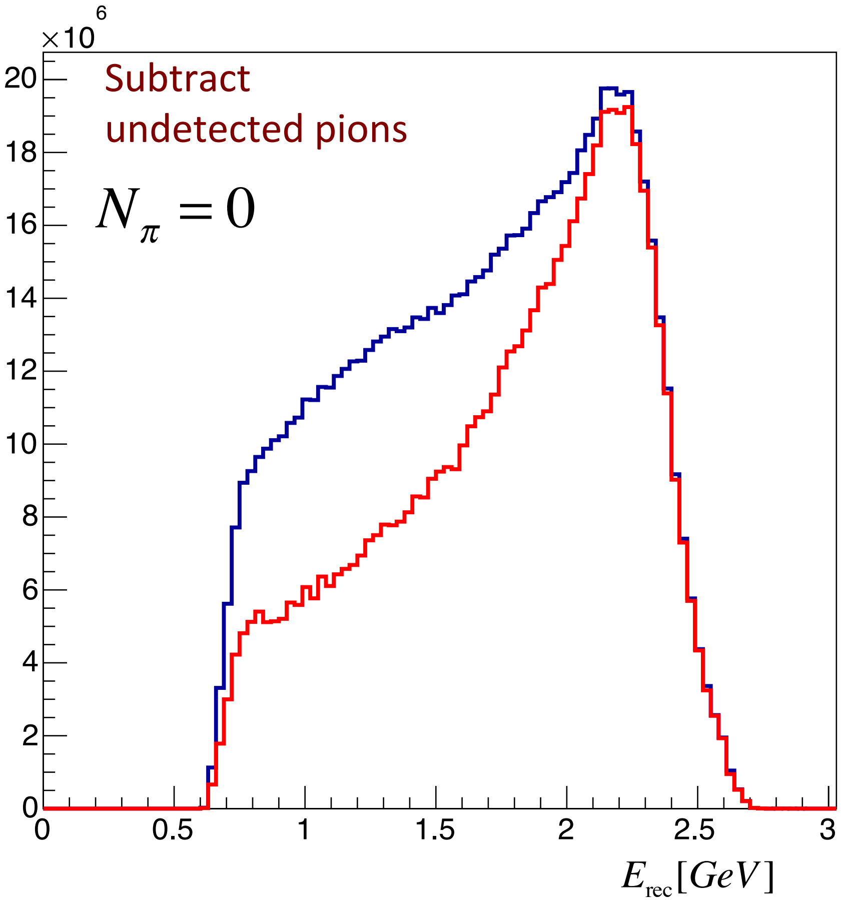


(e,e') E_{rec}

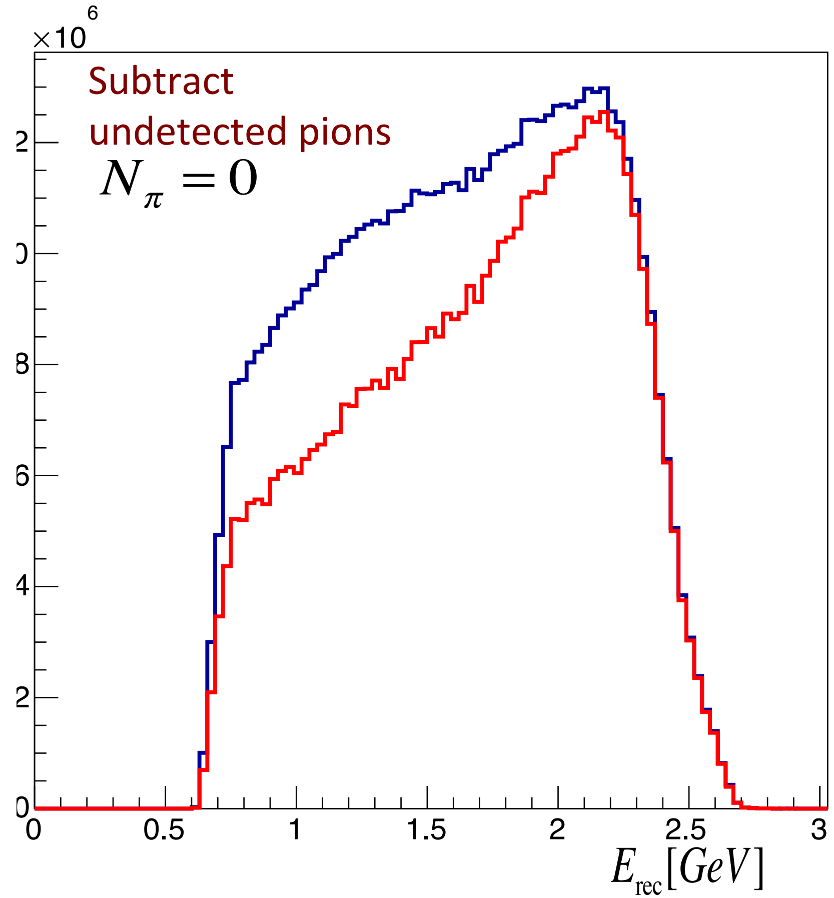
Cuts

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

^{12}C



^{56}Fe



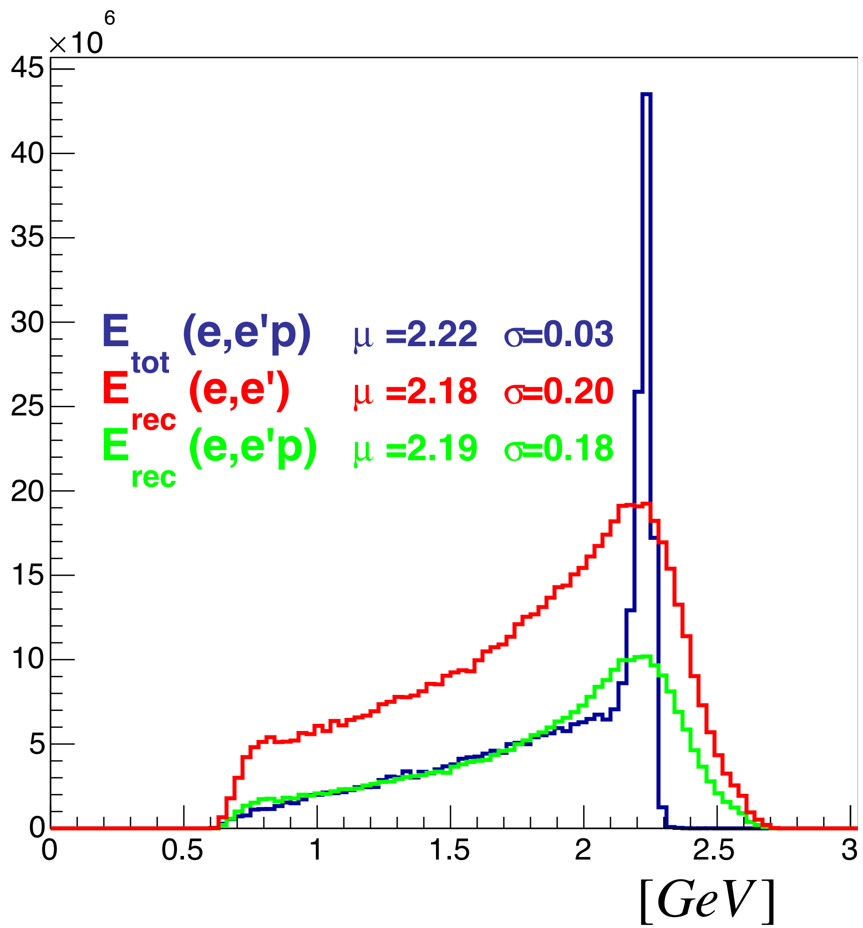
Cuts

(e,e'p) $E_{calorimetric}$, (e,e') E_{rec} and (e,e'p) E_{rec}

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

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

^{12}C



^{56}Fe