Study of the A(e,e'n) reaction

A data-mining project using CLAS EG2 data

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February 25, 2016

CLAS collaboration meeting

A(e,e'n) analysis (Part I)

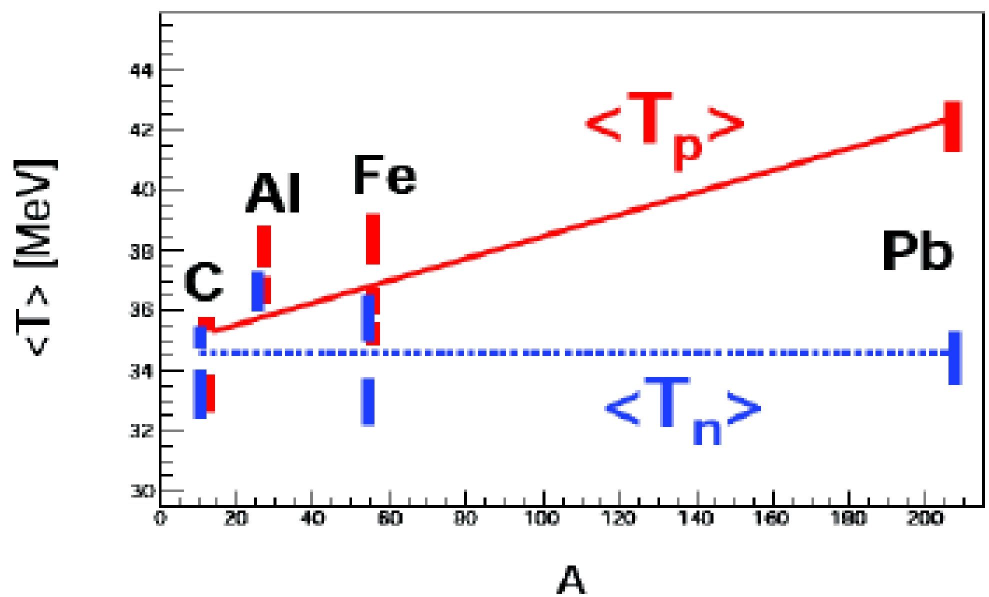
* Motivation
* Particle Identification
* Extracting A(e,e'p)/A(e,e'n) QE ratios
* Future plans (parts II & III)

np-dominance in asymmetric neutron rich nuclei

Pauli principle → $\langle T_n \rangle > \langle T_p \rangle$

SRC → $\langle T_p \rangle \overset{?}{>} \langle T_n \rangle$

<u>Prediction:</u>



$$n_p(k) = \begin{cases} \eta \cdot n_p^{M.F.}(k) & k < k_0 \\ \frac{A}{2Z} \cdot a_2(A/d) \cdot n_d(k) & k > k_0 \end{cases}$$

(And the same for neutrons)

O. Hen et al., Science 346, 614 (2014)

How to check this hypothesis experimentally?

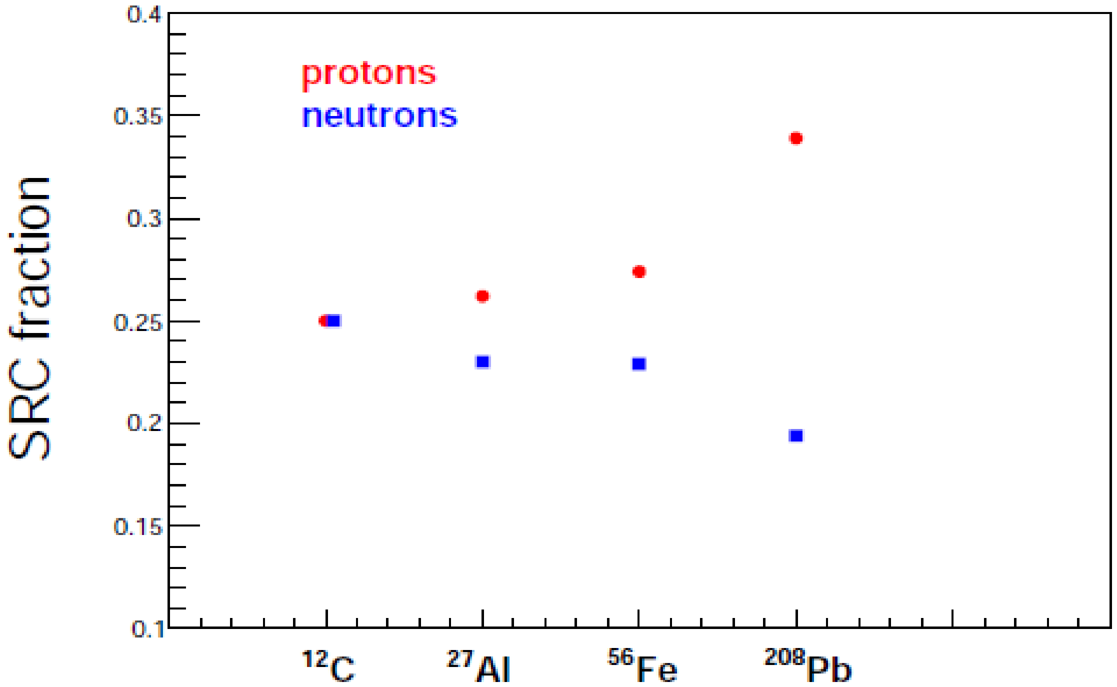
$$^{208}Pb: \quad N=126 \quad P=82$$

$$R_p = \frac{protons_{k>k_F}}{protons_{k<k_F}} \approx \frac{20}{82-20} = 0.32$$

$$R_n = \frac{neutrons_{k>k_F}}{neutrons_{k<k_F}} \approx \frac{20}{126-20} = 0.19$$

$$For\ ^{208}Pb:$$

$$\frac{R_p}{R_n} = 1.7$$



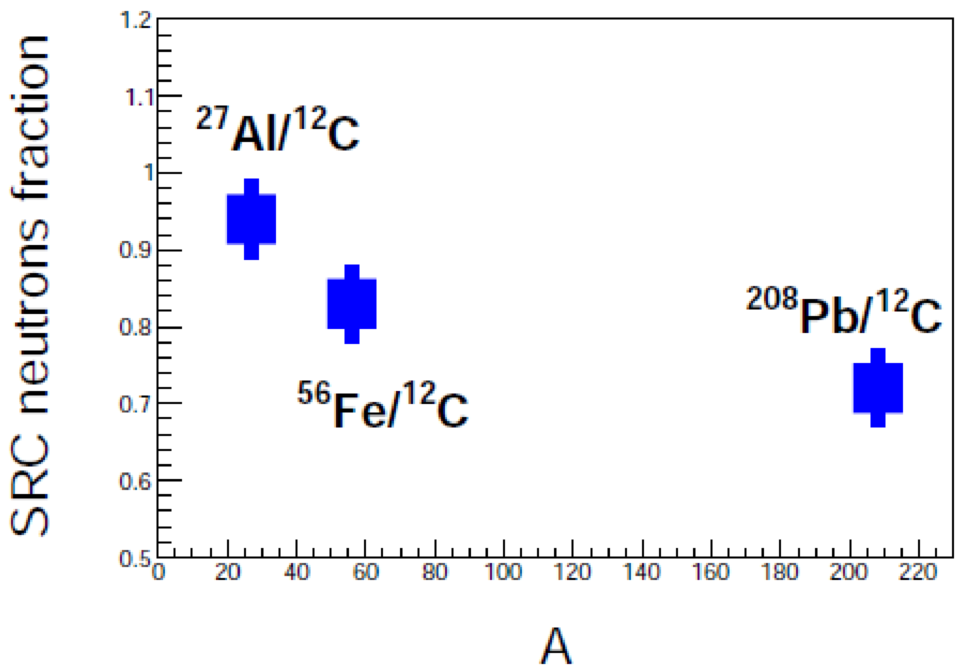
Calculation based on the np-dominance model

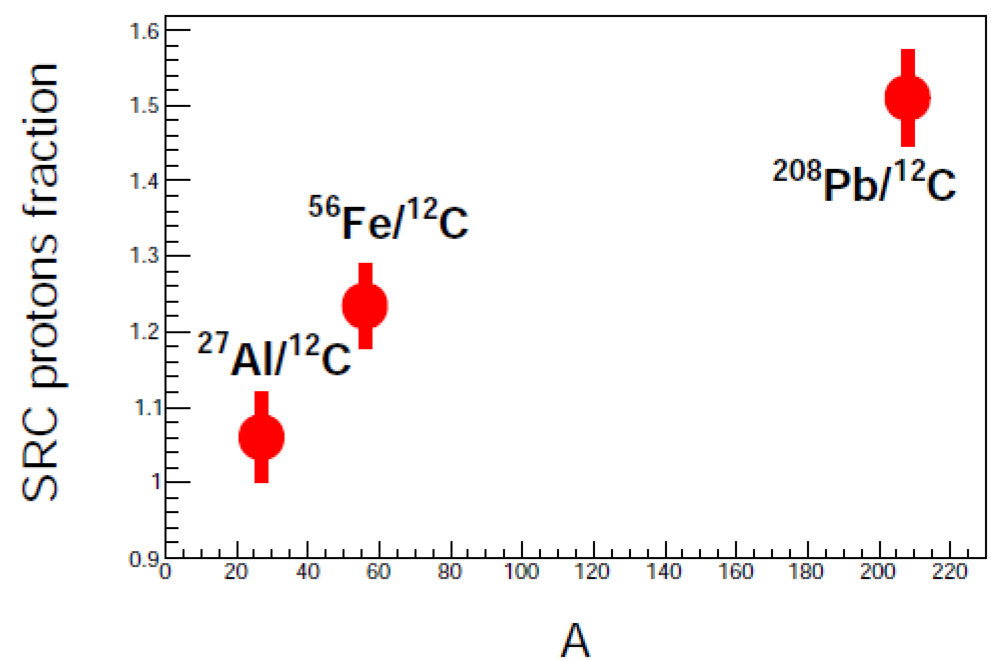
$$A(e,e'N)_{k<k_F} = \int_0^{k_0} n^{M.F.}(k)\,k\,dk$$

$$A(e,e'N)_{k>k_F} = \int_{k_0}^{\infty} n^{SRC}(k)\,k^2\,dk$$

$$\frac{A(e,e'n)/^{12}C(e,e'n)_{k>k_F}}{A(e,e'n)/^{12}C(e,e'n)_{k<k_F}}$$

$$\frac{A(e,e'p)/^{12}C(e,e'p)_{k>k_F}}{A(e,e'p)/^{12}C(e,e'p)_{k<k_F}}$$





Particle Identification

 Electrons (Approved CLAS analysis note, O. Hen, 2012)

 Protons (Approved CLAS analysis note, O. Hen, 2012)

 Neutrons (M. Braverman TAU thesis, 2014)

Pions (For calibration. Approved Hall-B thesis, R. Dupre, 2011)

Extracting A(e,e'p)/A(e,e'n) QE events ratio

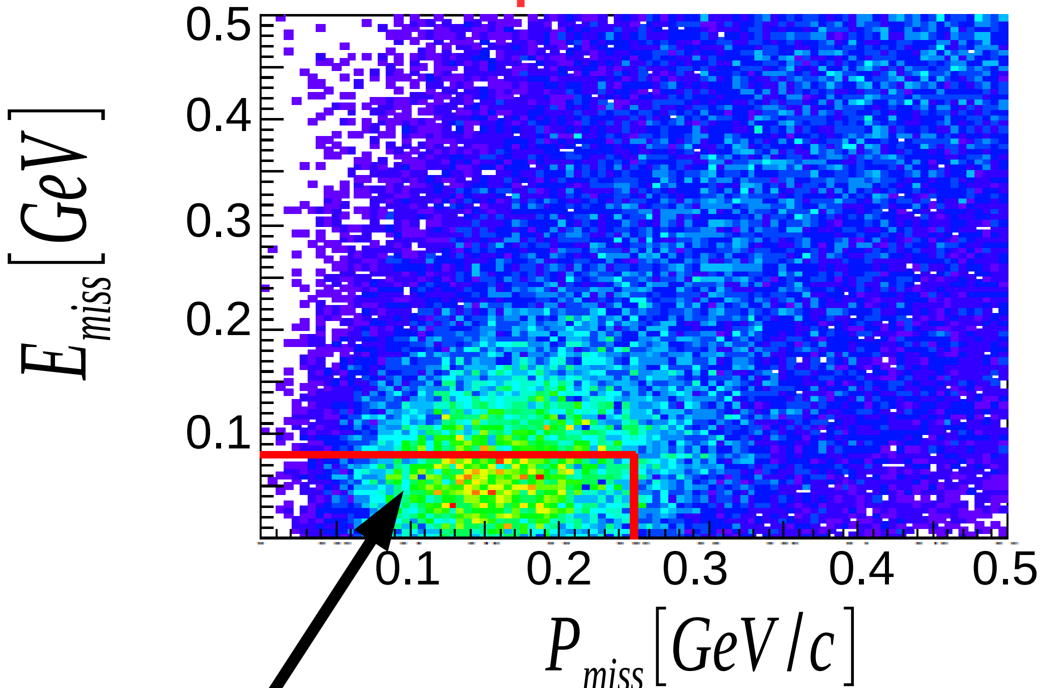
EG2 data: $d,\ {}^{12}C,\ {}^{27}Al,\ {}^{56}Fe,\ {}^{208}Pb$

* Select (e,e'p) sample
* Identify (e,e'n) & (e,e'p) QE events
* Check the events selection
* Apply corrections
* Extracting the ratios

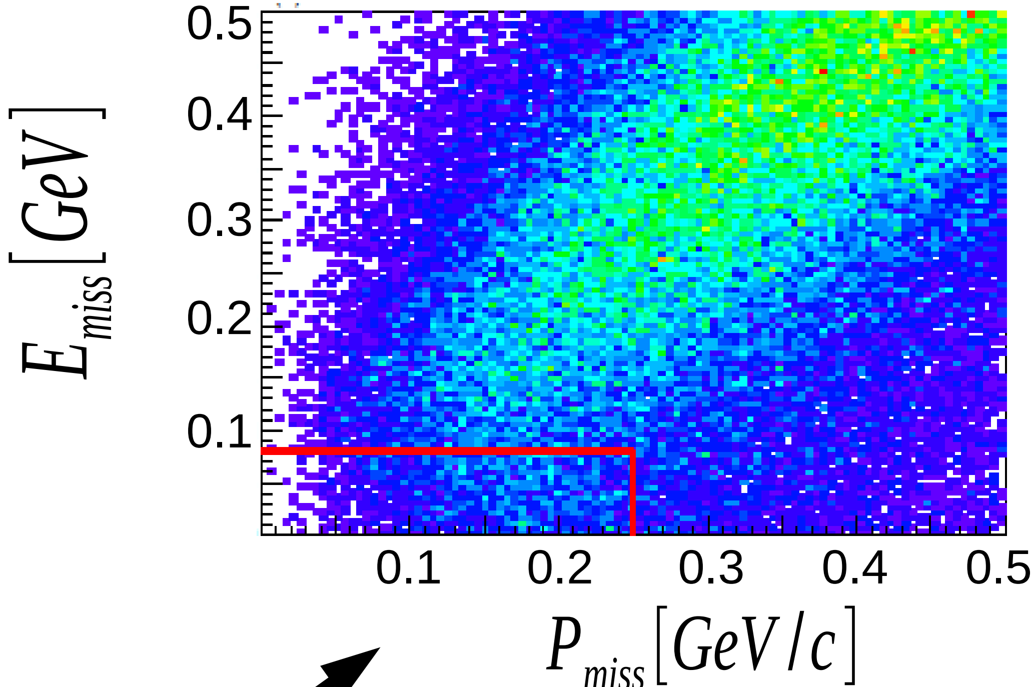
Selecting Quasi-Elastic events

Mean-Field QE events: low initial momentum ($k<k_F$) and separation energy of the knockout nucleon.

protons



neutrons



QE peak:

$P_{miss}<0.25$ GeV/c

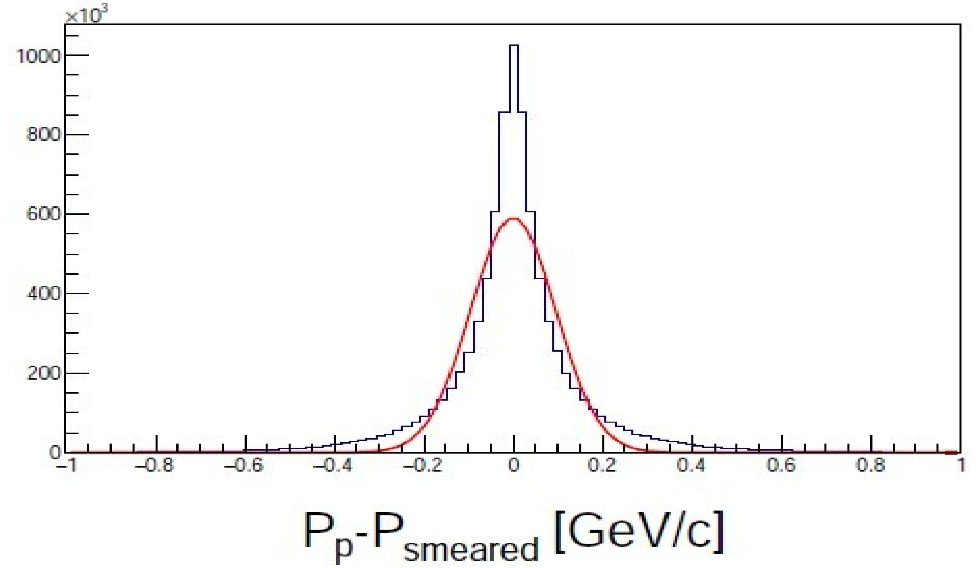
$E_{miss}<0.08$ GeV

Problem: Poor resolution in the EC $\Delta P \approx 0.2 GeV/c$

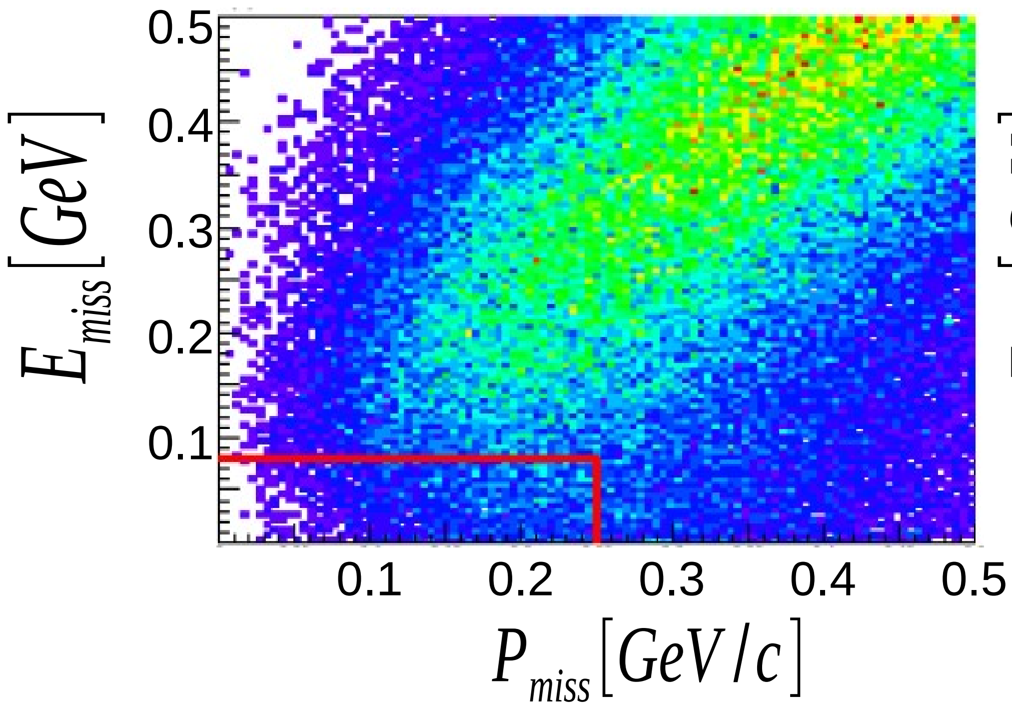
Solution 1: Using smeared protons

Neutrons energy deposit in the EC:

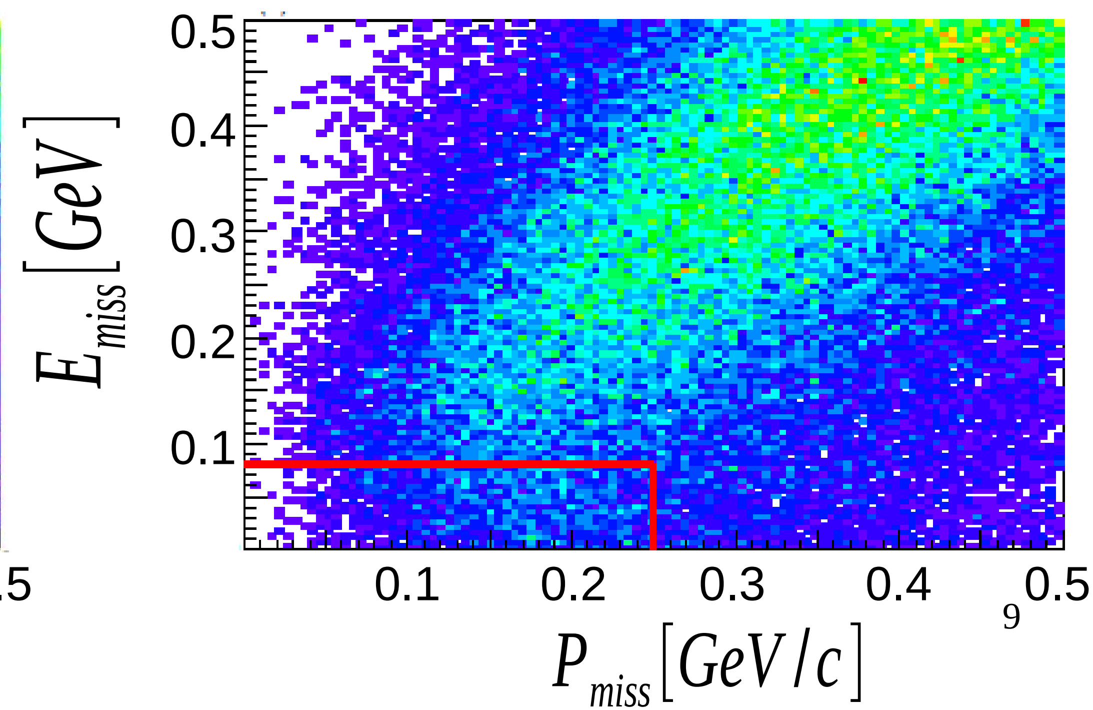
32% - inner layers
47% - outer layers
20% - both layers



smeared protons



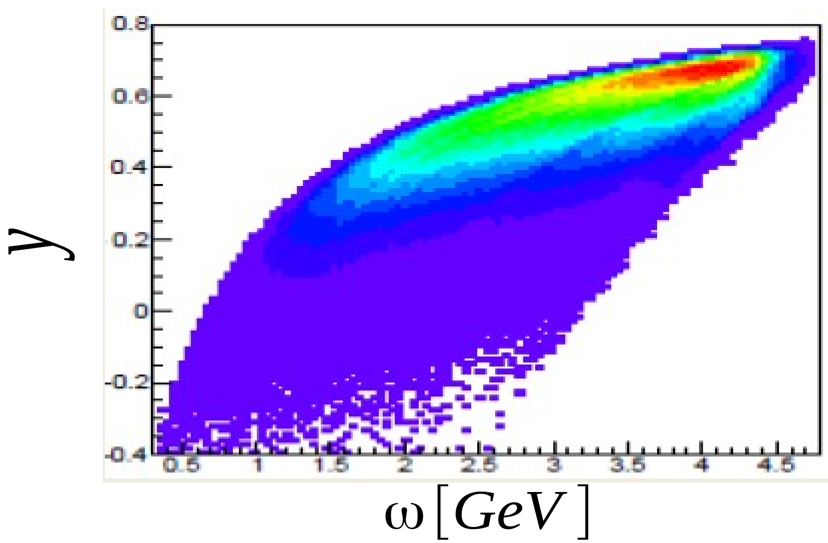
neutrons

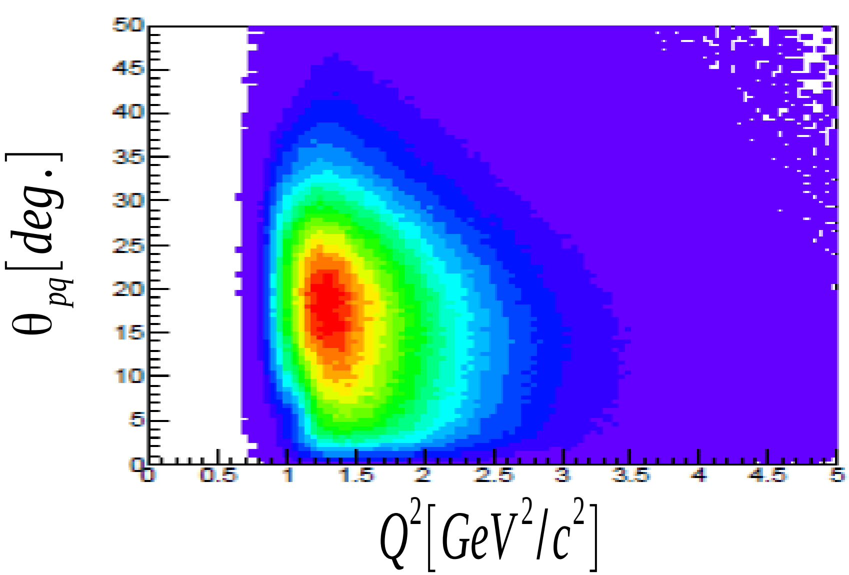


Solution 2: Using electron quantities and scattering angle of the nucleon

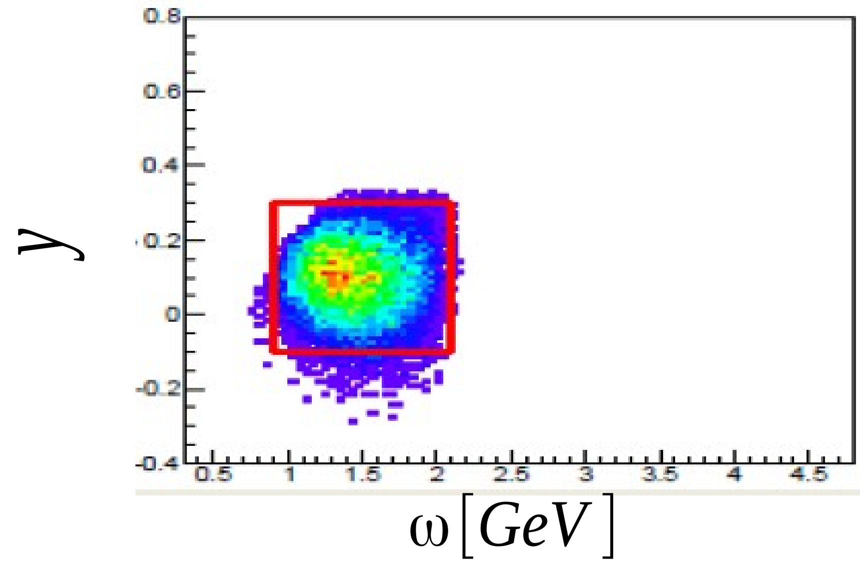
un-smeared protons

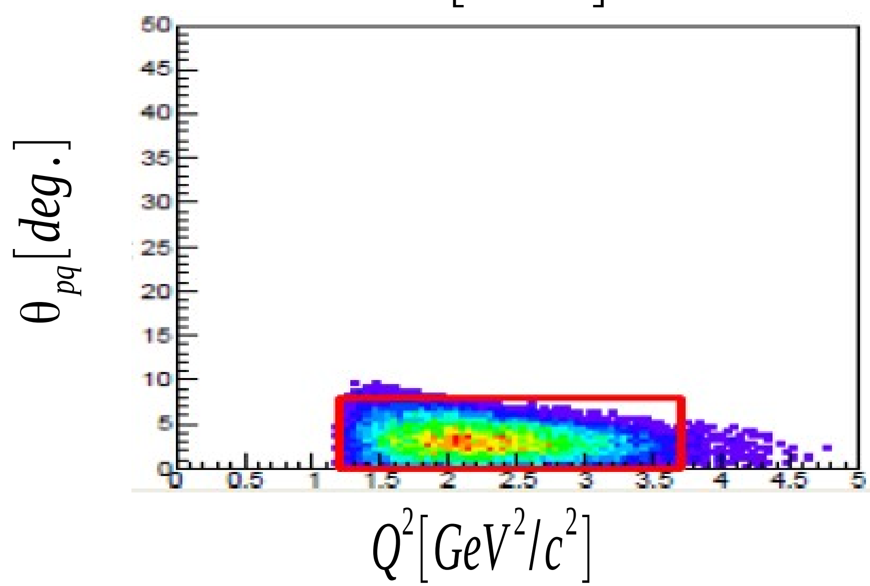
Before the QE cuts





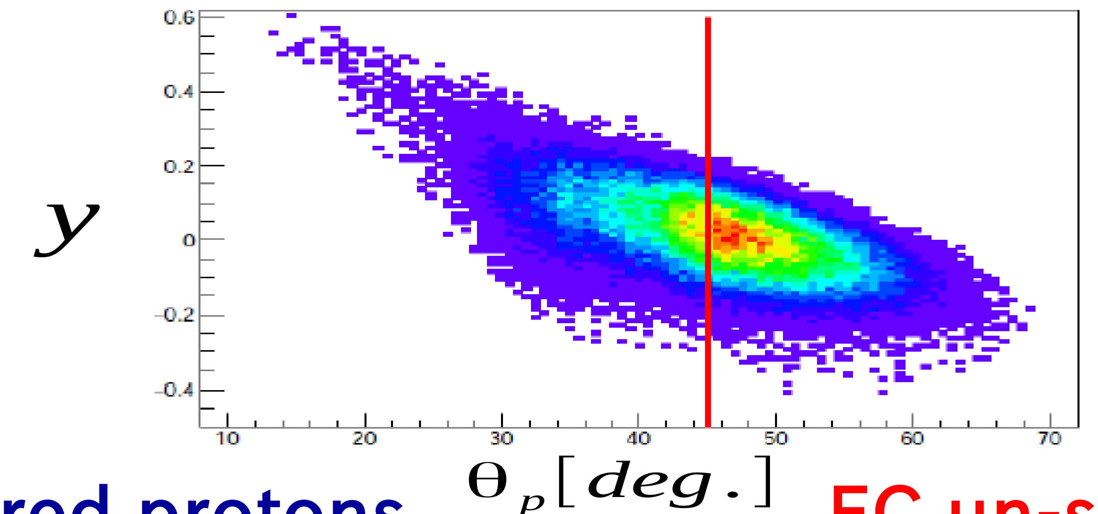
After the QE cuts





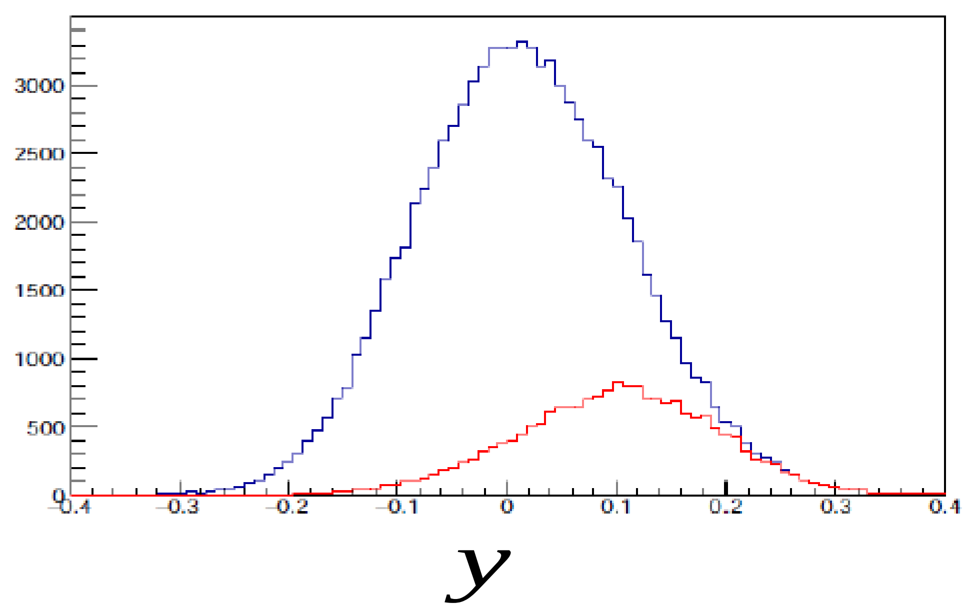
Comparing un-smeared protons

QE cuts: $P_{miss} < 0.25\,GeV/c$ $\quad E_{miss} < 0.08\,GeV$

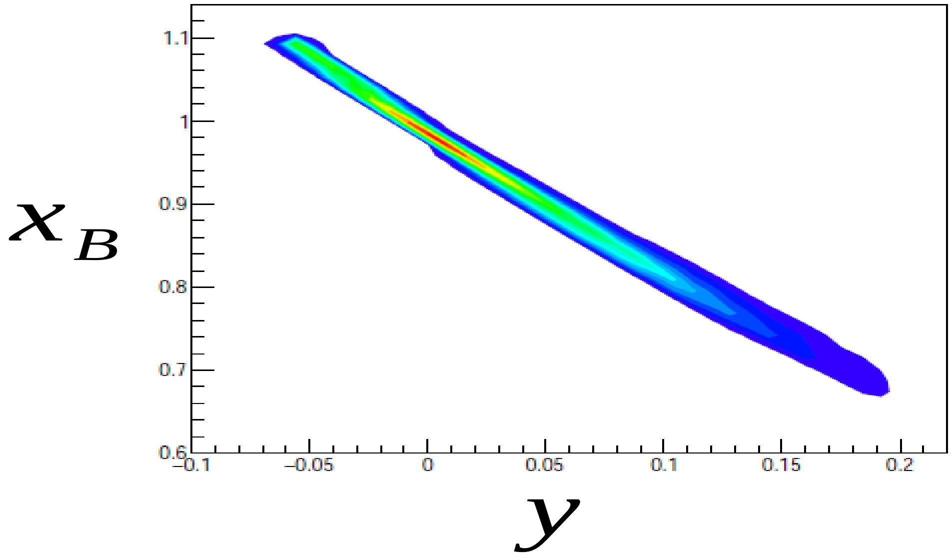


All un-smeared protons

EC un-smeared protons

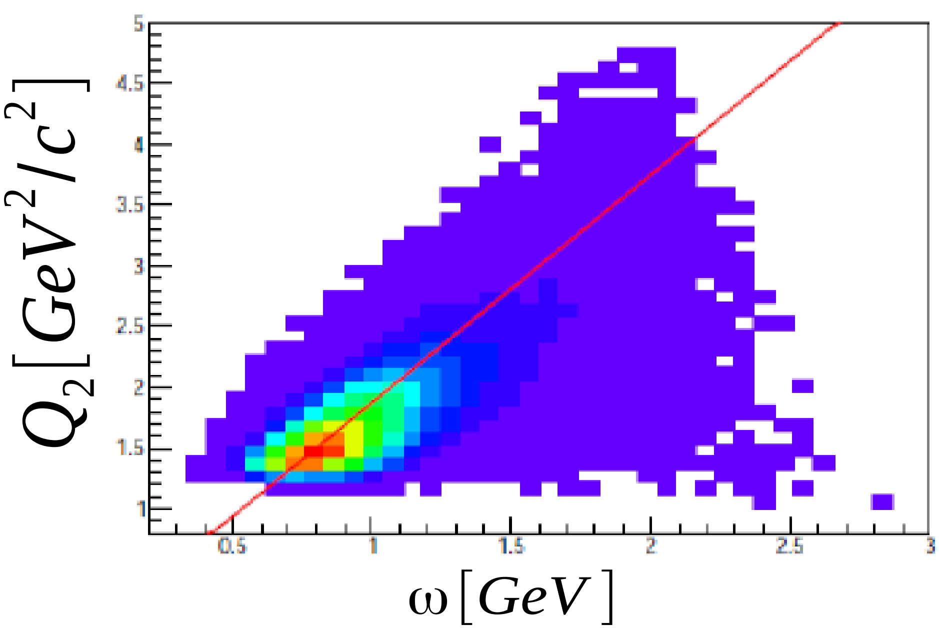


Comparing un-smeared protons

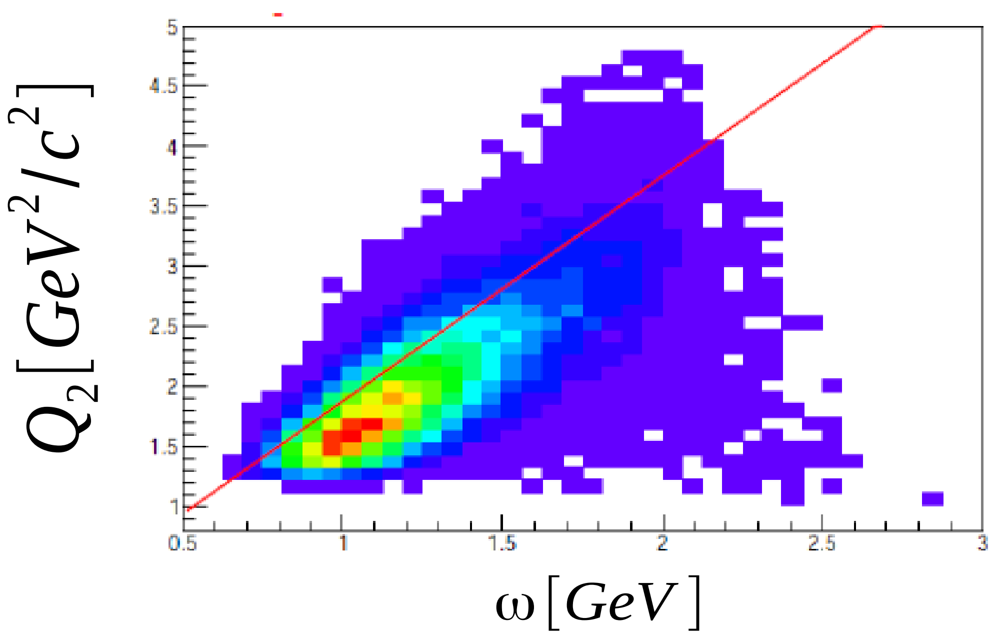


QE events → $x_b \approx 1$

All un-smeared protons



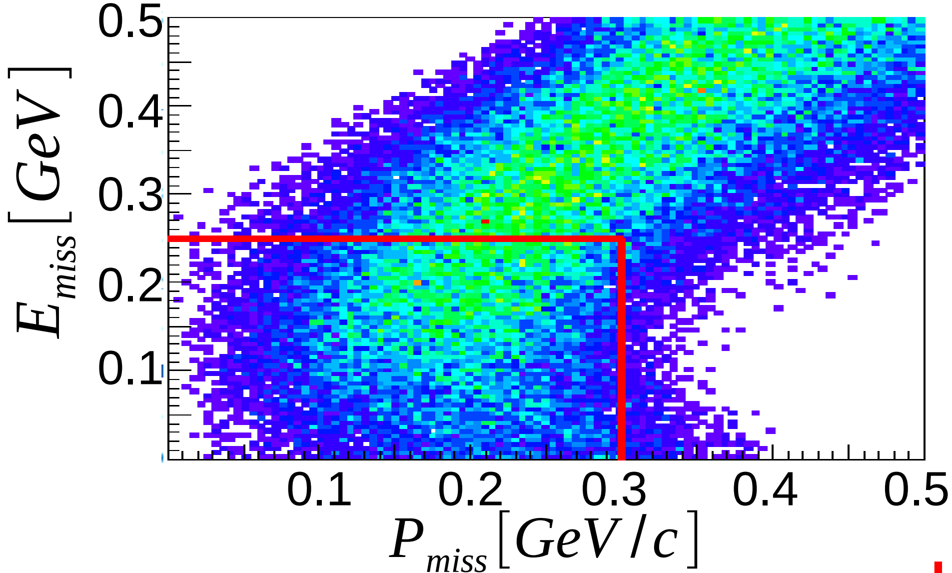
EC un-smeared protons



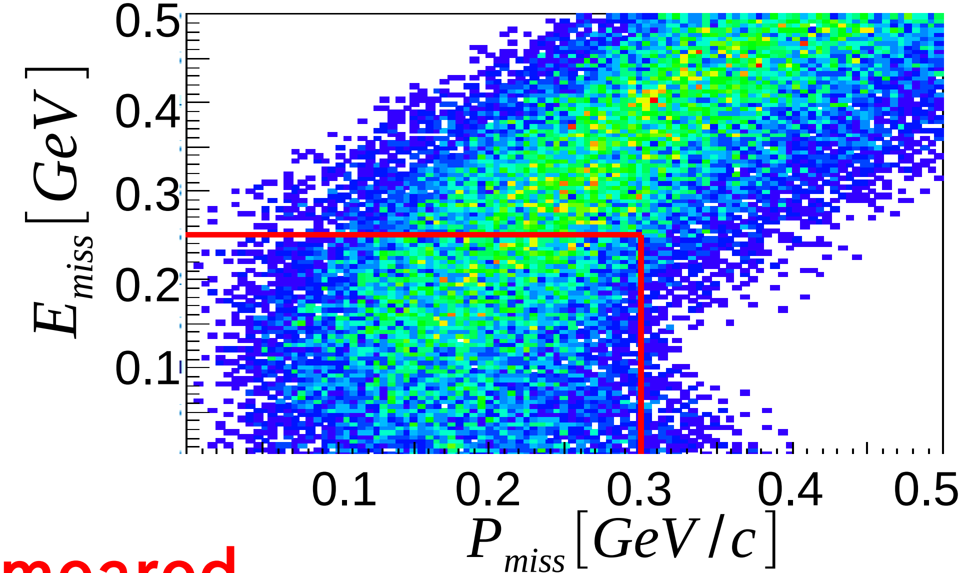
Back to the cuts:

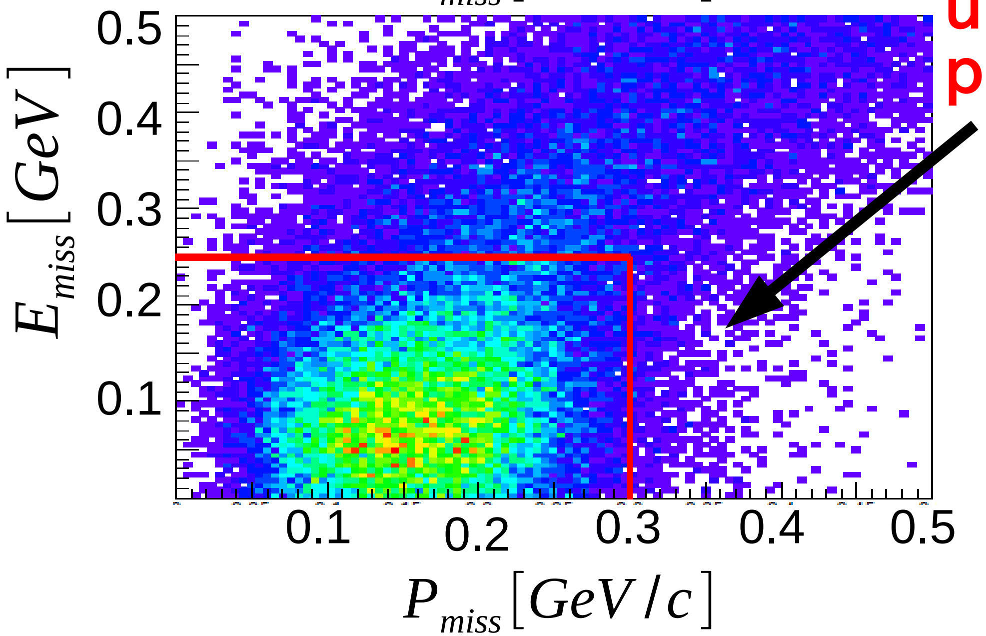
$-0.1 < y < 0.3$ $0.9 < \omega < 2.1\,GeV$ $\theta_{pq} < 8^o$ $1.2 < Q^2 < 3.7\,GeV^2/c^2$

smeared protons



neutrons





un-smeared protons

The selected cuts:

$P_{miss} < 0.3\,GeV/c$

$E_{miss} < 0.25\,GeV$

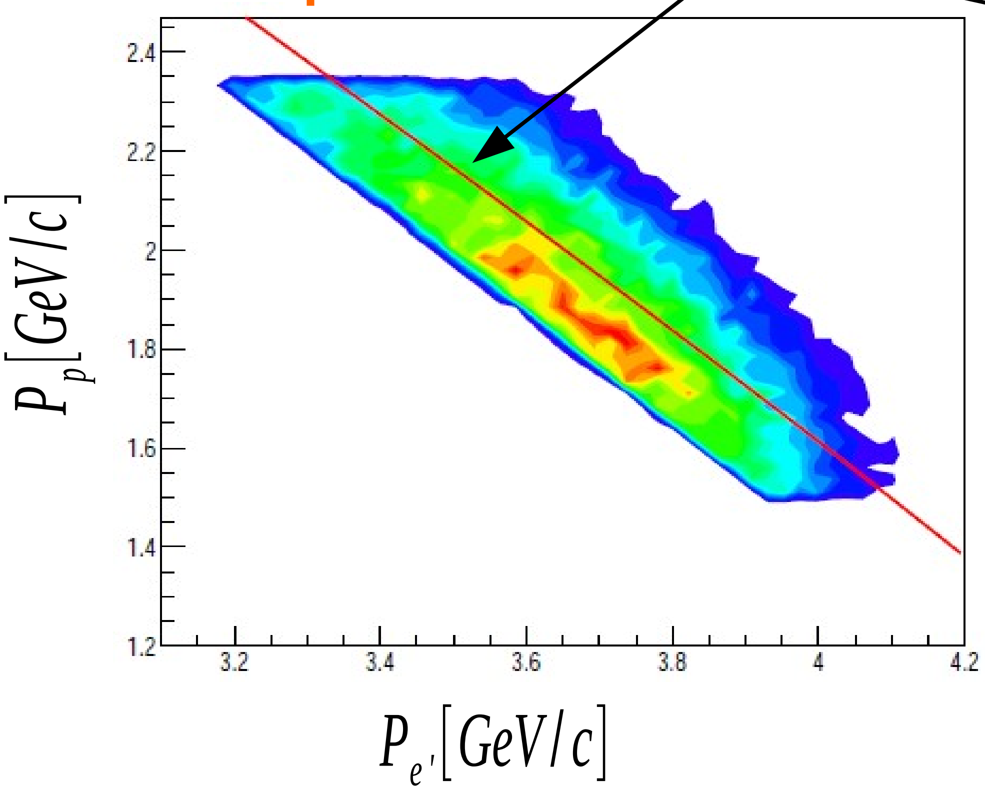
Checking the event selection

Energy momentum conservation:

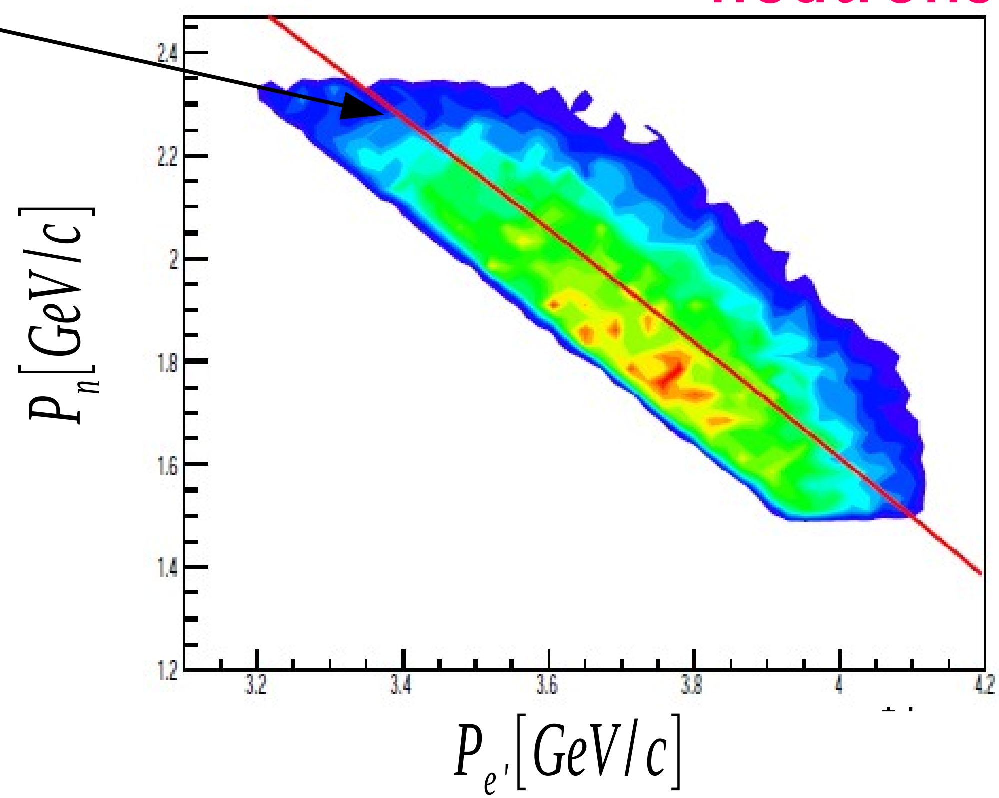
$$\left(E_{beam},\left(0,0,E_{beam}\right)\right)+\left(M_N,\vec{0}\right)=\left(E',\vec{P}_{e'}\right)+\left(E_N,\vec{P}_N\right)$$

$$|\vec{P}_N|=\sqrt{\left(E+M_N-|\vec{P}_{e'}|\right)^2-M_N^2}$$

smeared protons



neutrons

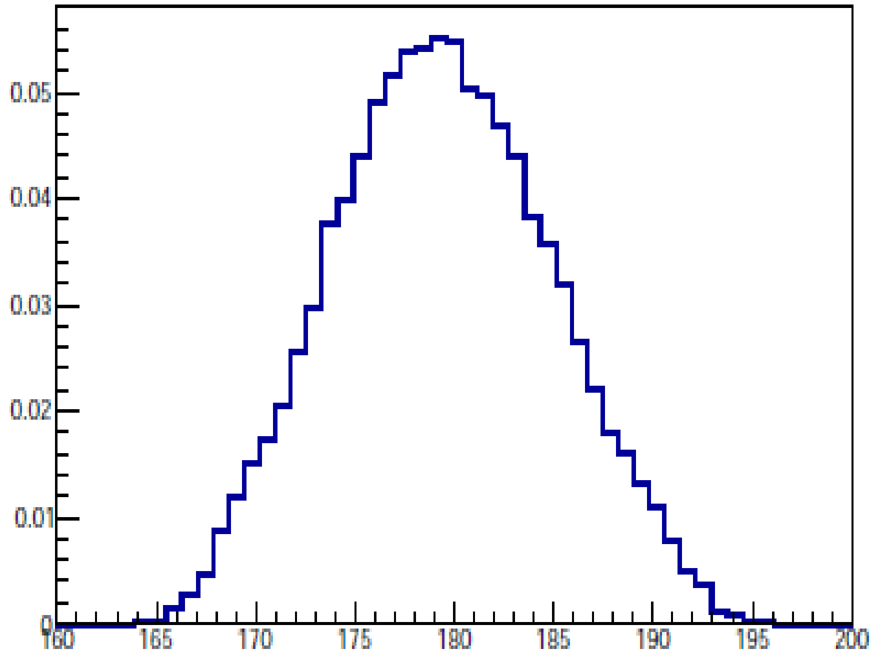


Checking the event selection

From energy momentum conservation:

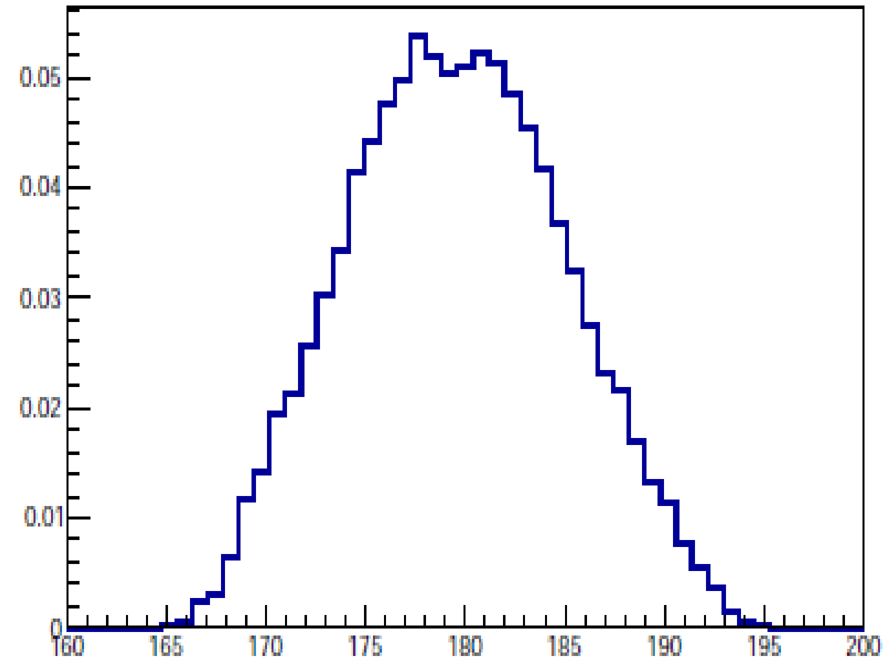
$$|\varphi_N - \varphi_{e'}| = 180^o$$

smeared protons



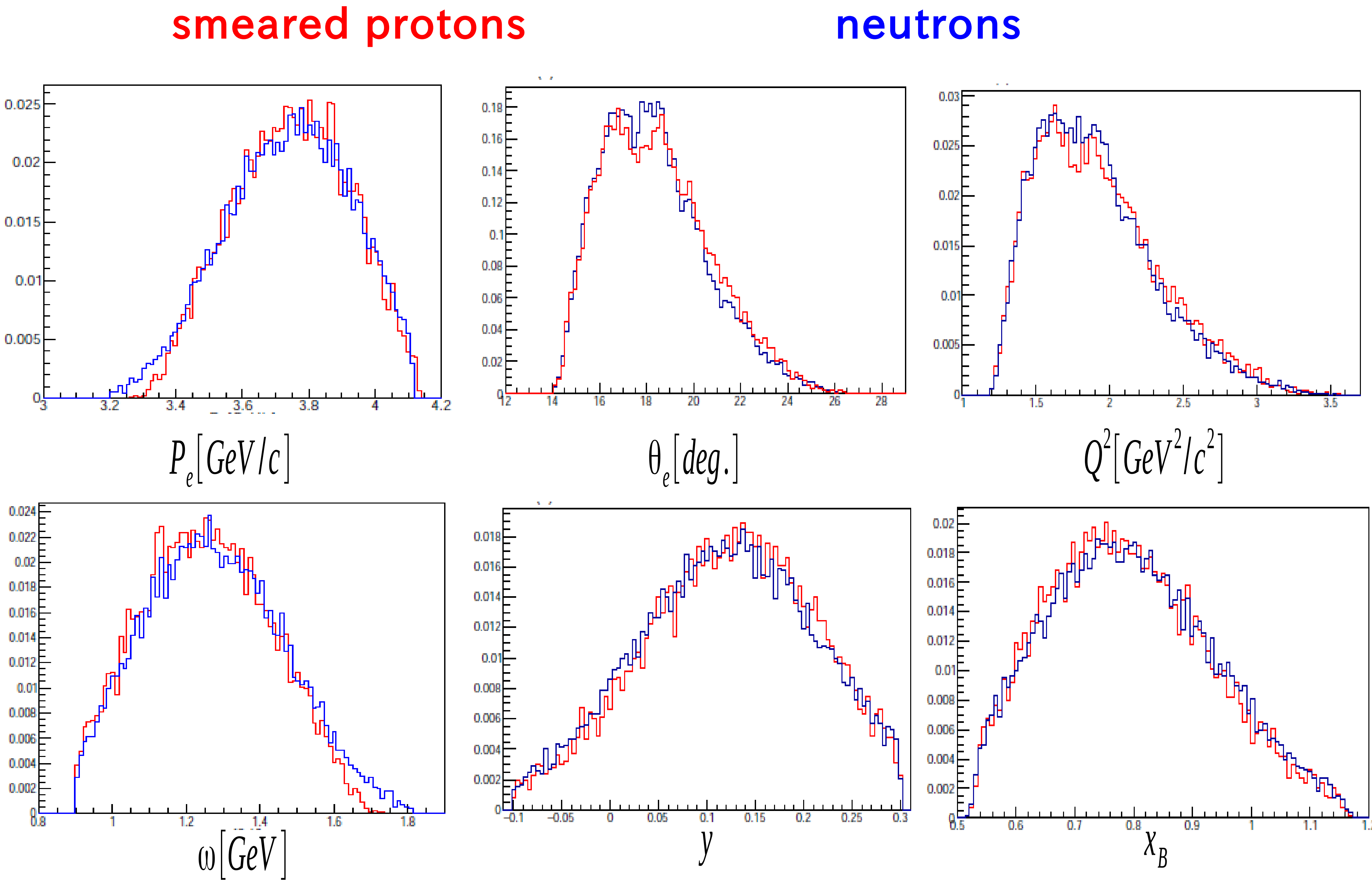
$|\varphi_p - \varphi_{e'}|[deg.]$

neutrons



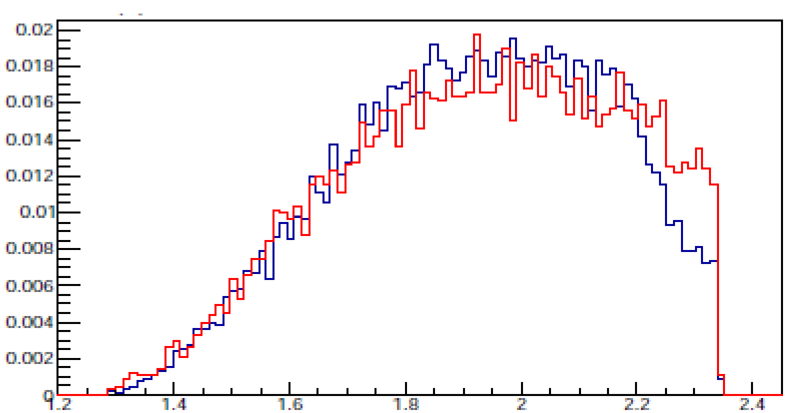
$|\varphi_n - \varphi_{e'}|[deg.]$

Comparing the smeared protons and neutrons

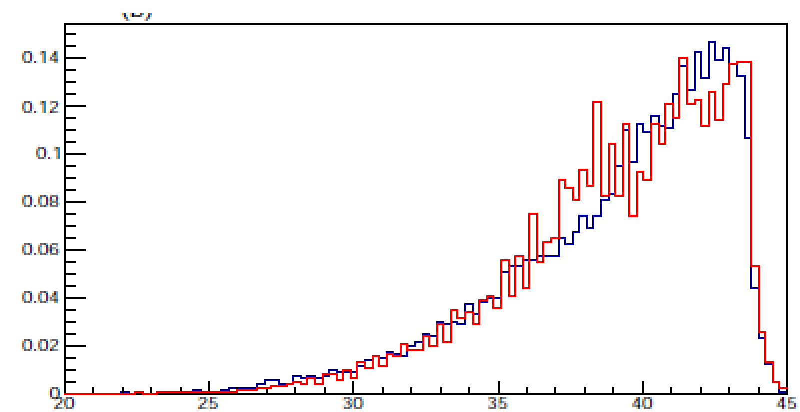


Comparing the smeared protons and neutrons

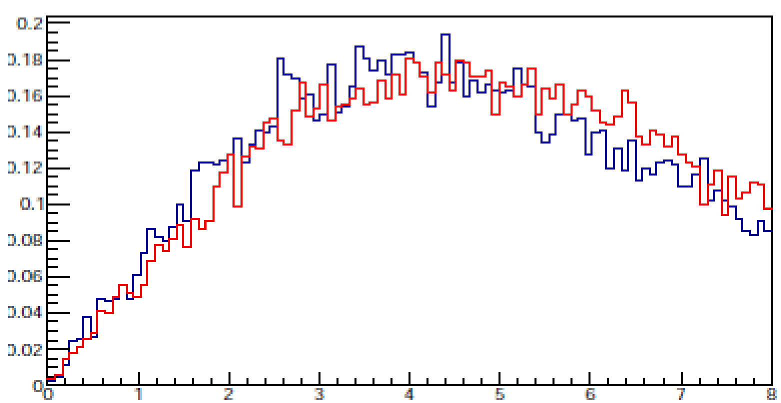
smeared protons   neutrons



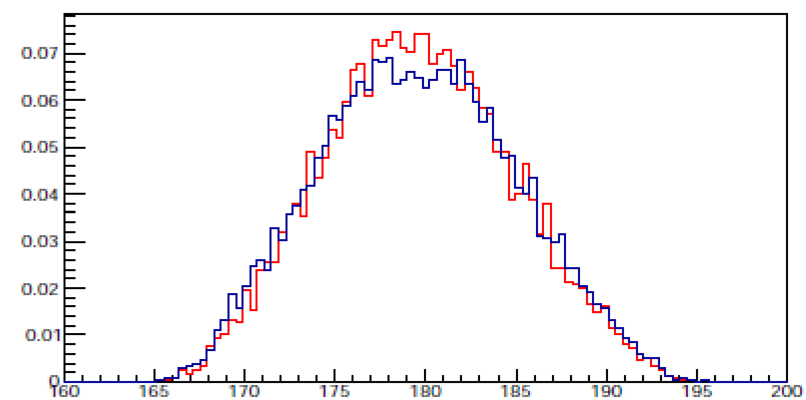
$P_{p/n}[GeV/c]$



$\theta_{p/n}[deg.]$



$\theta_{pq/nq}[deg.]$



$|\varphi_{p/n} - \varphi_e|[deg.]$

Applying corrections

protons

* Coulomb correction
* Detection efficiency
* Acceptance correction

neutrons

* Detection efficiency
* Acceptance correction
* EC fiducial cut

Protons simulation

* 10,000 electrons from the data.

* Proton momentum & scattering angle uniformly distributed.

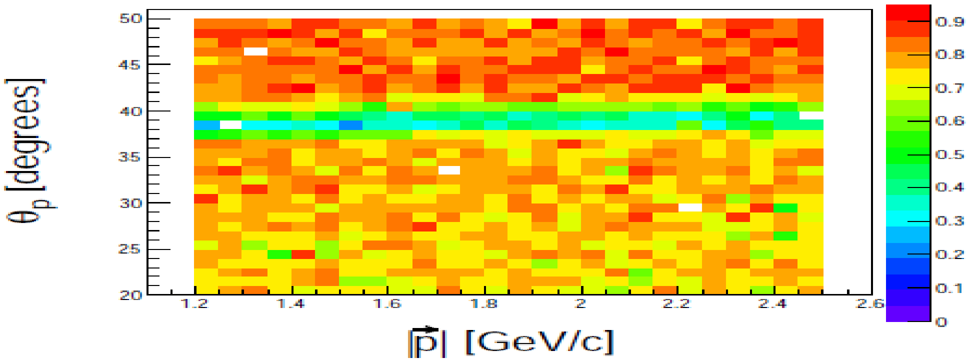
* 100xphi angle uniformly distributed.

* Running through CLAS MC simulation.

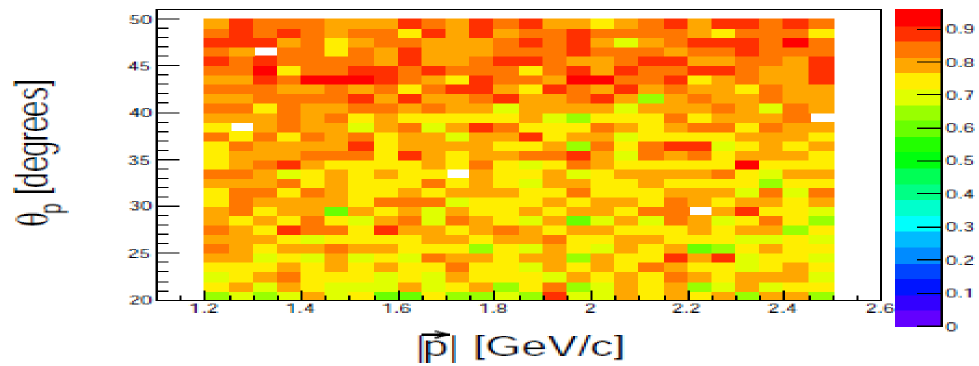
* Dividing event by event by the ratio of reconstructed/generated.

Protons simulation - results

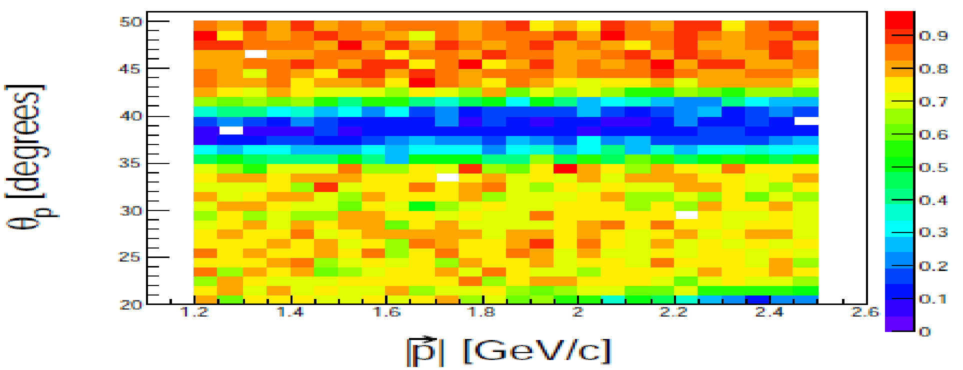
Sector #1



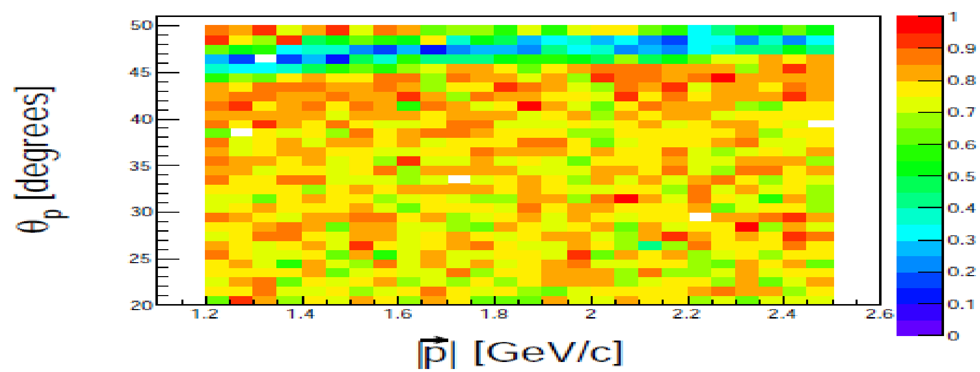
Sector #2



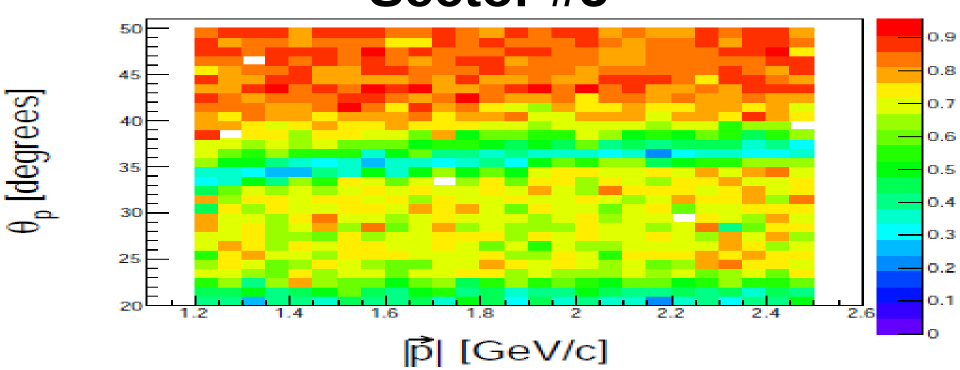
Sector #3



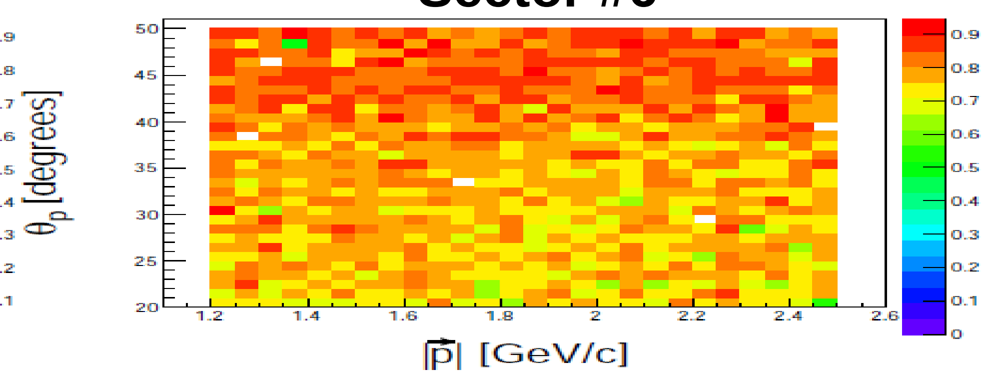
Sector #4



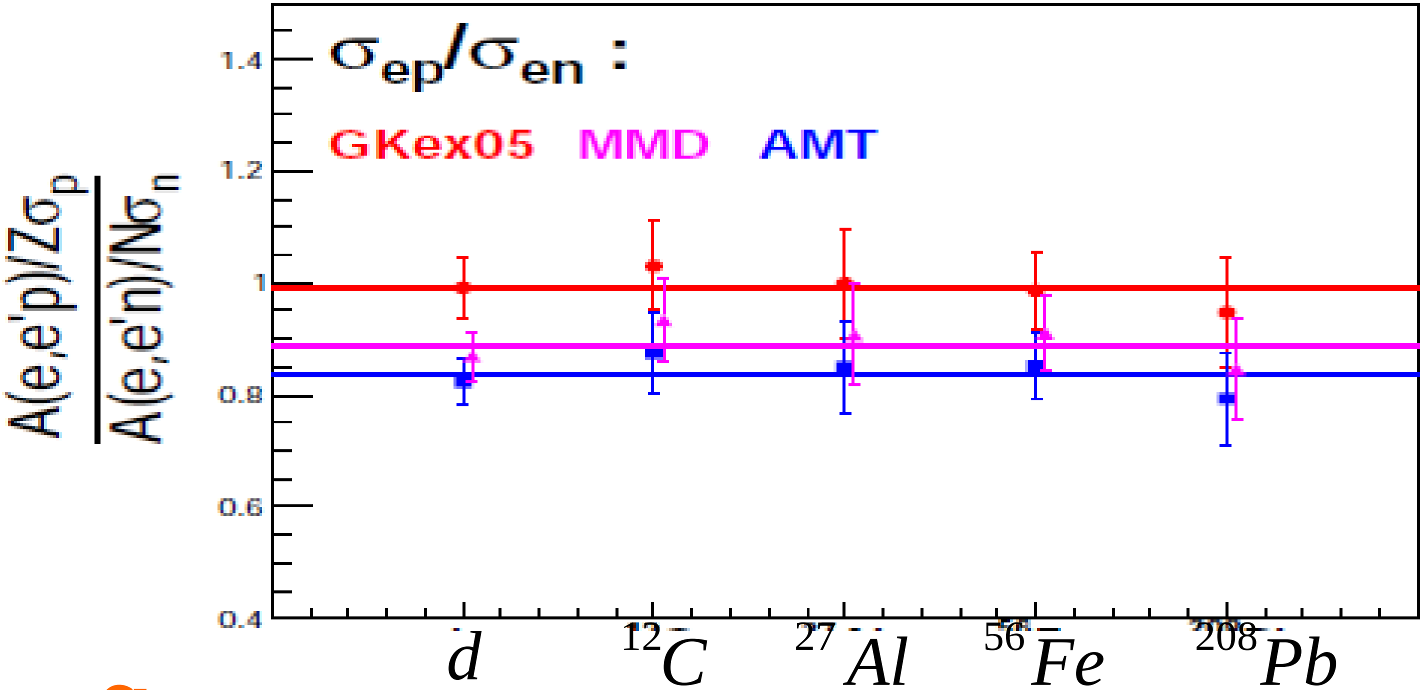
Sector #5



Sector #6



Extracting A(e,e'p)/A(e,e'n) QE ratios



Constant fits:

0.99 ± 0.04

0.88 ± 0.03

0.83 ± 0.03

W. P. Ford, S. Jeschonnek & J. W. Van Orden, arXiv:1411.3306v1 [nucl-th] (2014)

Part II: Carbon

Extracting the ratios of:

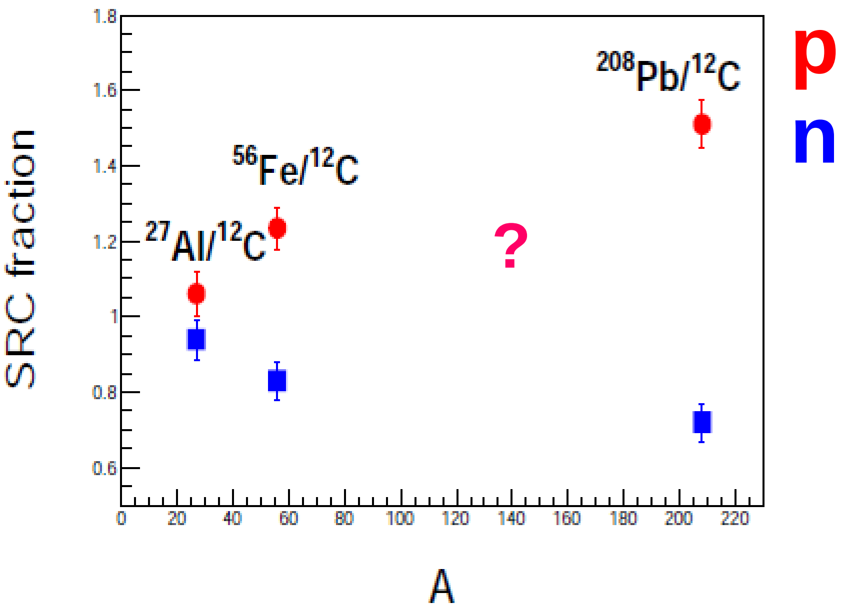
$$\frac{{}^{12}C(e,e'n)\,high}{{}^{12}C(e,e'n)\,low} \stackrel{?}{=} \frac{{}^{12}C(e,e'p)\,high}{{}^{12}C(e,e'p)\,low}$$

Part III: 'Blind analysis'

Estimate relative number of high momentum nucleons:

$$\frac{A(e,e'n)/{}^{12}C(e,e'n)\,high}{A(e,e'n)/{}^{12}C(e,e'n)\,low}$$

$$\frac{A(e,e'p)/{}^{12}C(e,e'p)\,high}{A(e,e'p)/{}^{12}C(e,e'p)\,low}$$



Study of 2N-SRC via the A(e,e'np) reaction

A data-mining project using CLAS EG2 data

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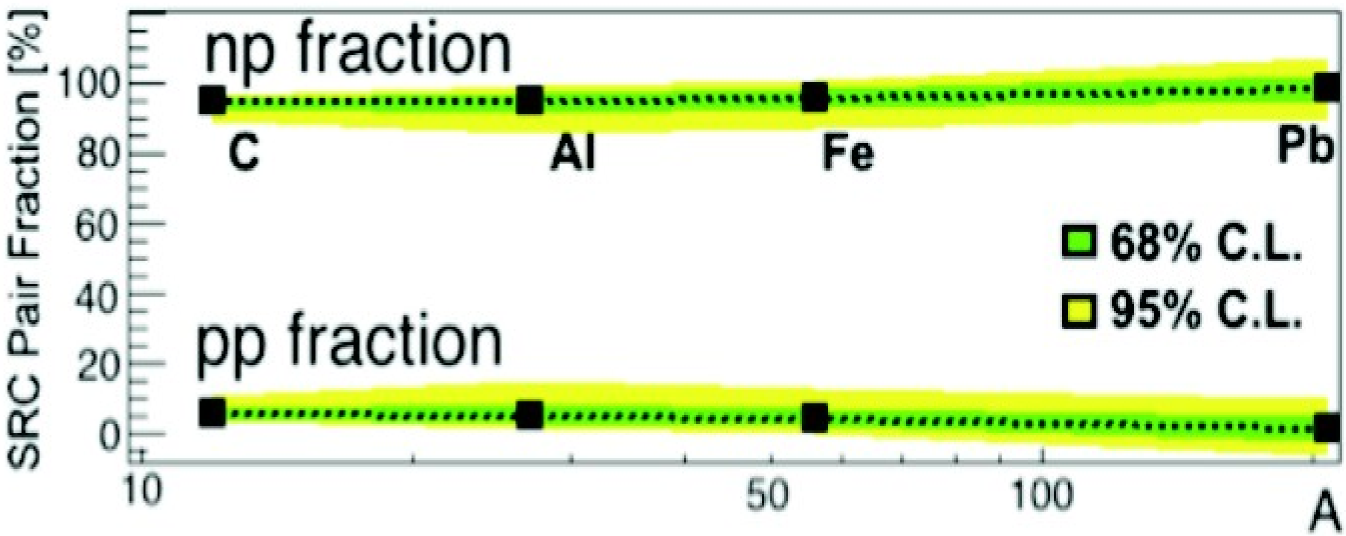
np – Dominance

using EG2 data



Based on measurements of (e,e'p) and (e,e'pp) 2N-SRC events

$$\frac{A(e,e'pn)}{A(e,e'pp)} \sim 20$$

O. Hen et al., Science 346, 614 (2014)

The (e,e'np)/(e,e'pp) ratio

Expected ratio:

* np-dominance (#np/#pp˜20)
* Leading n vs. leading p (2)
* Proton and neutron cross-sections ratio (˜3)
* Neutron detection efficiency in the EC (˜1/3)

$$\frac{A(e,e'np)}{A(e,e'pp)} \sim 1$$

Following approved CLAS analysis notes (O. Hen 2012) to identify 2N-SRC (e,e'p) events:

* $x_B > 1.2$
* $0.3 \leq P_{miss} \leq 1\, GeV/c$
* $\theta_{pq} \leq 25^o$
* $0.62 \leq |\vec{P}_{lead}|/|\vec{q}| \leq 0.96$
* $M_{miss} \leq 1.1\, GeV/c^2$

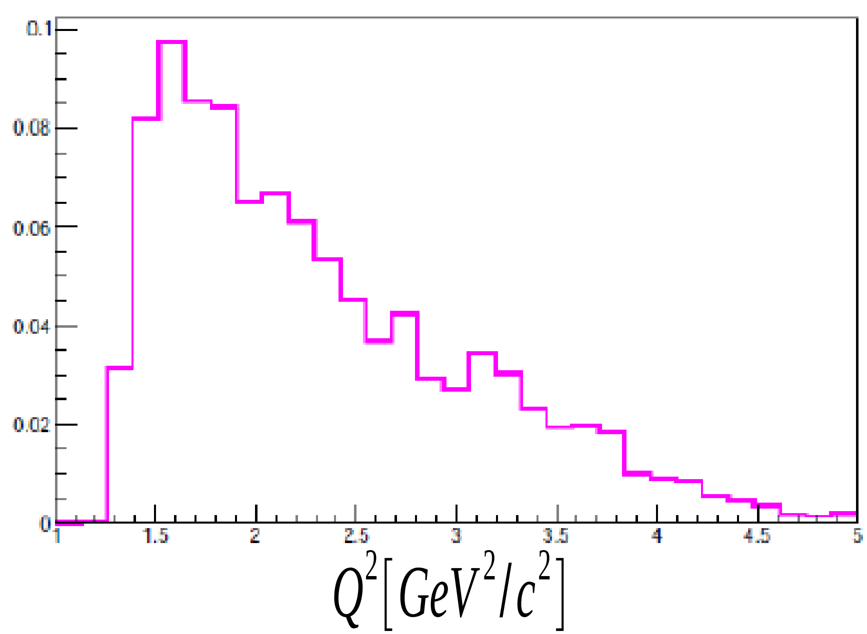
Modifying the cuts

to select (e,e'n) events

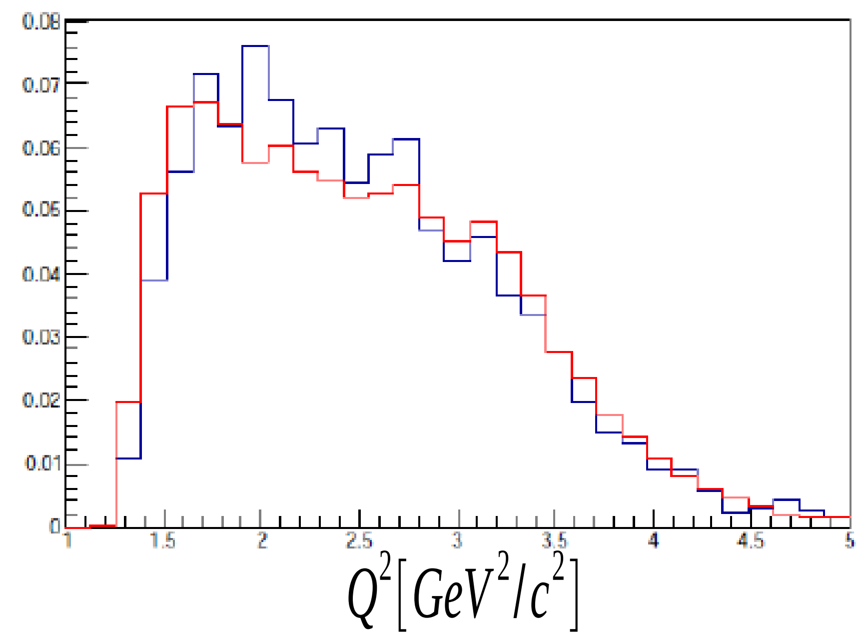
* Low statistics ⟶ $x_B > 1.1$
* Poor resolution:

$$0.3 \le P_{miss} \le 1 GeV/c \longrightarrow 0.1 \le P_{miss} \le 1.2 GeV/c$$

un-smeared protons



smeared protons neutrons

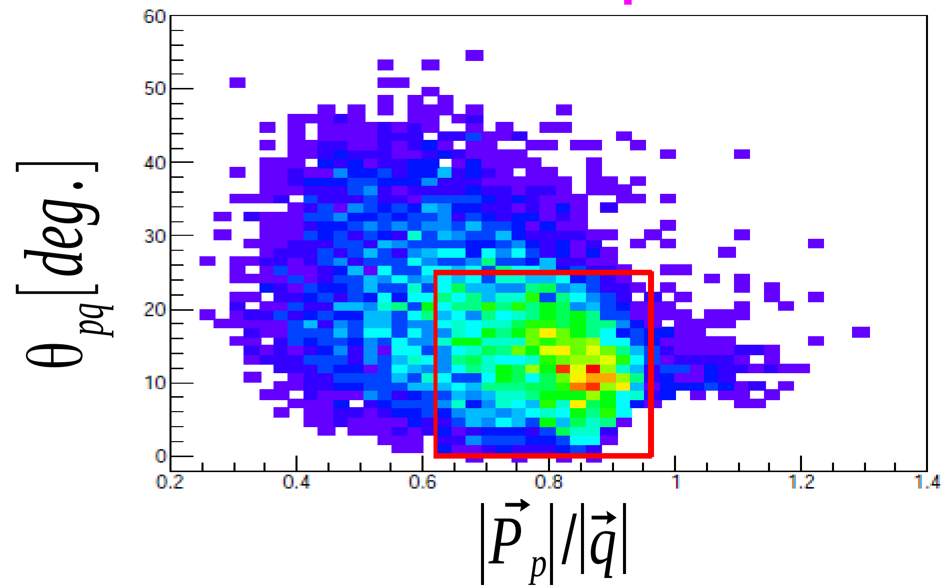


Modifying the cuts

* $0.62 \leq \frac{|\vec{P}_p|}{|\vec{q}|} \leq 0.96$

* $\theta_{pq} \leq 25^o$

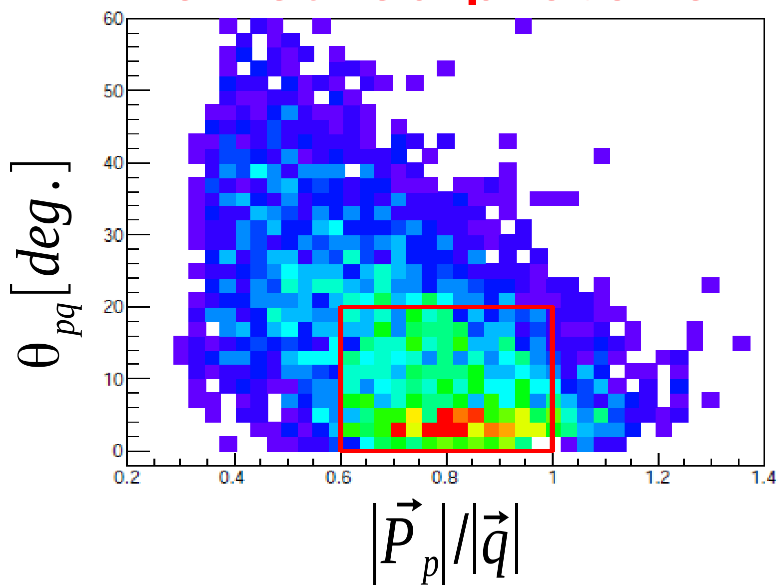
un-smeared protons



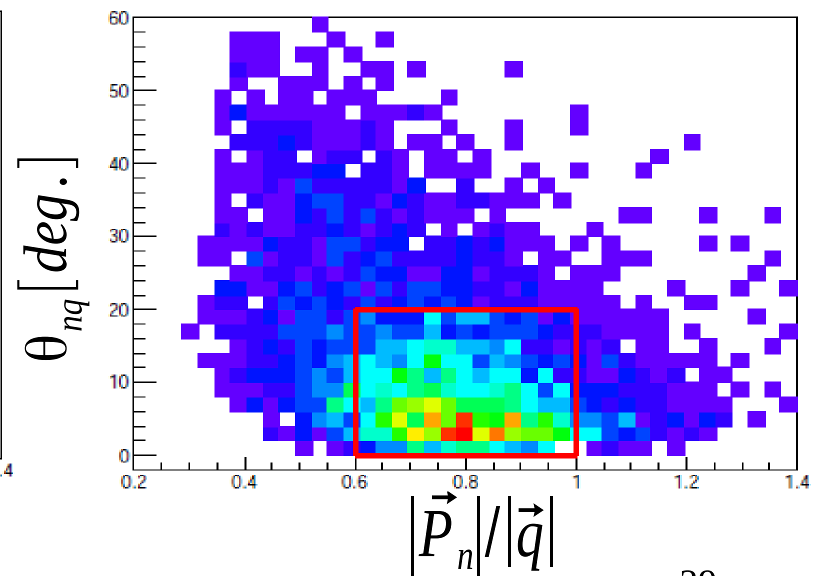
$$0.6 \leq \frac{|\vec{P}_N|}{|\vec{q}|} \leq 1$$

$$\theta_{pq} \leq 20^o$$

smeared protons

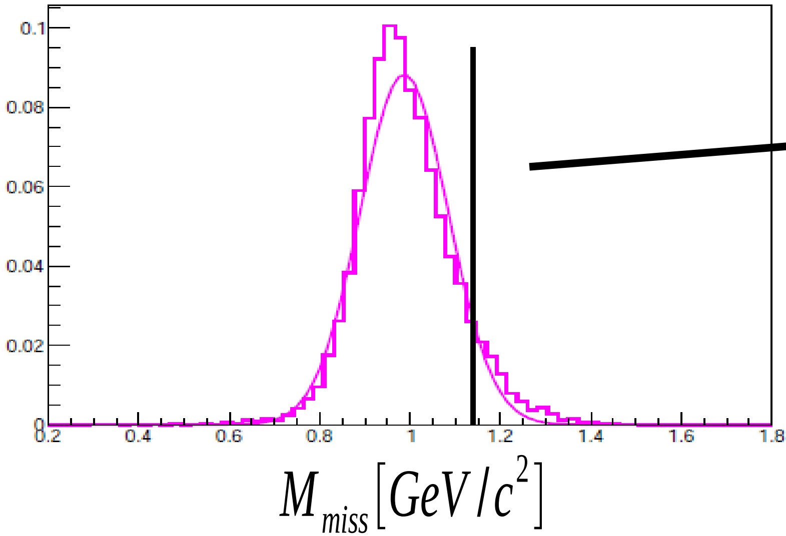


neutrons



Modifying the cuts: Missing mass

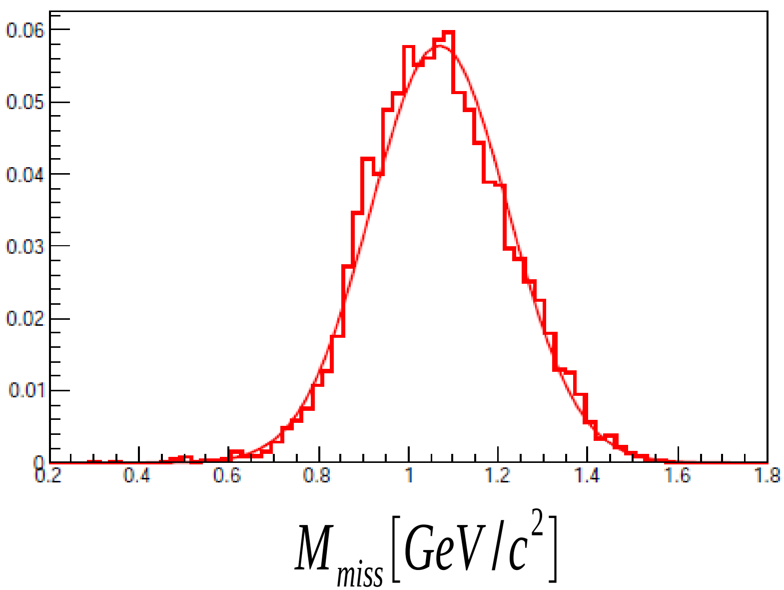
un-smeared protons



$M_{miss} \leq mean + m_\pi = 1.14 GeV/c^2$

$mean = 1.0$
$\sigma = 0.11$

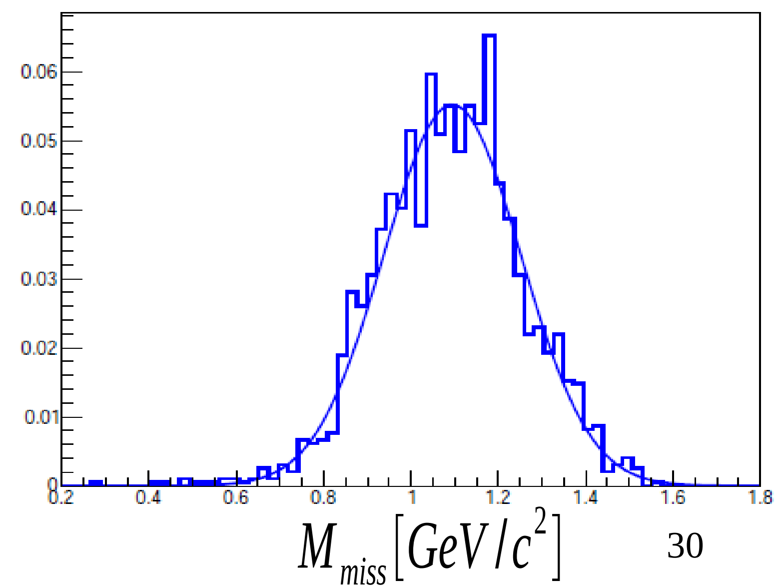
smeared protons

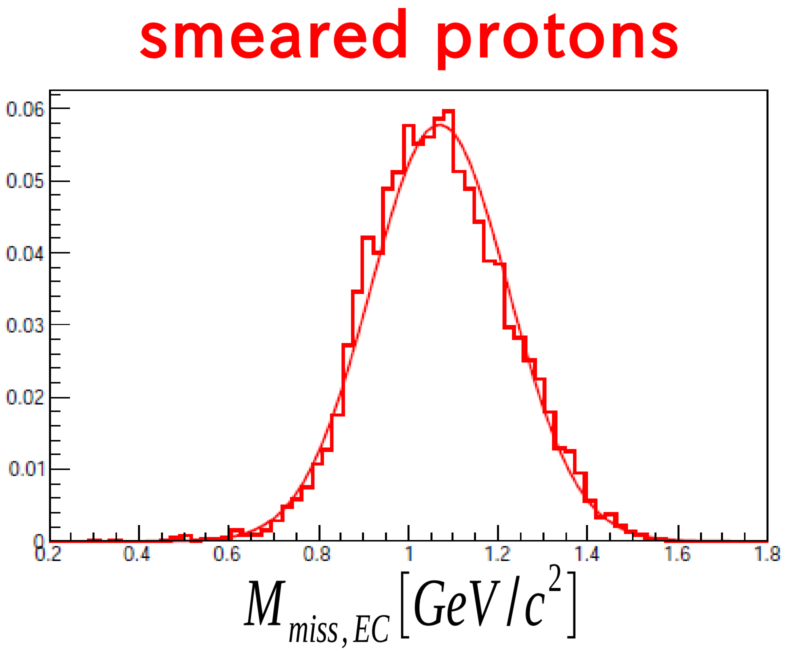


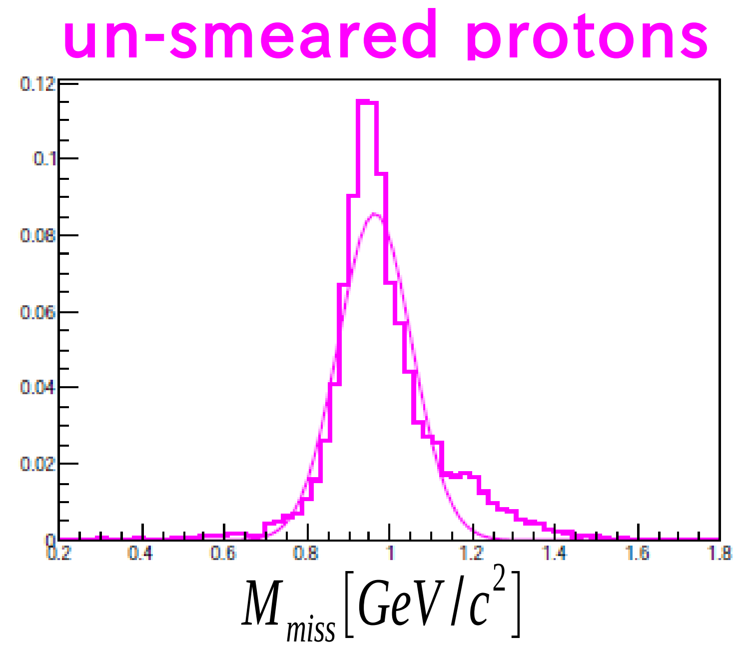
$mean = 1.06$
$\sigma = 0.15$

neutrons

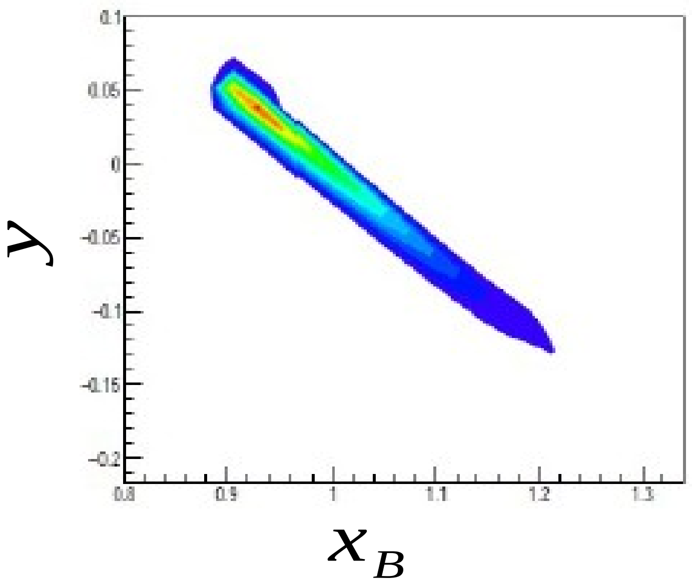
$mean = 1.09$
$\sigma = 0.16$







The y variable



$$x_B > 1.1 \Leftrightarrow y < -0.05$$

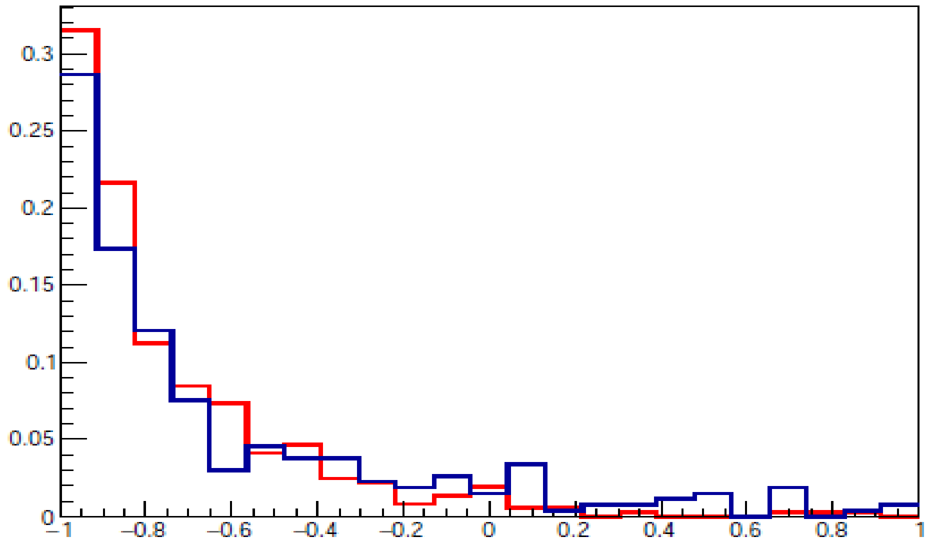
Adding a recoil proton: $|\vec{P}_{recoil}| > 0.3\,GeV/c$

The selected (e,e'np) & (e,e'pp) events:

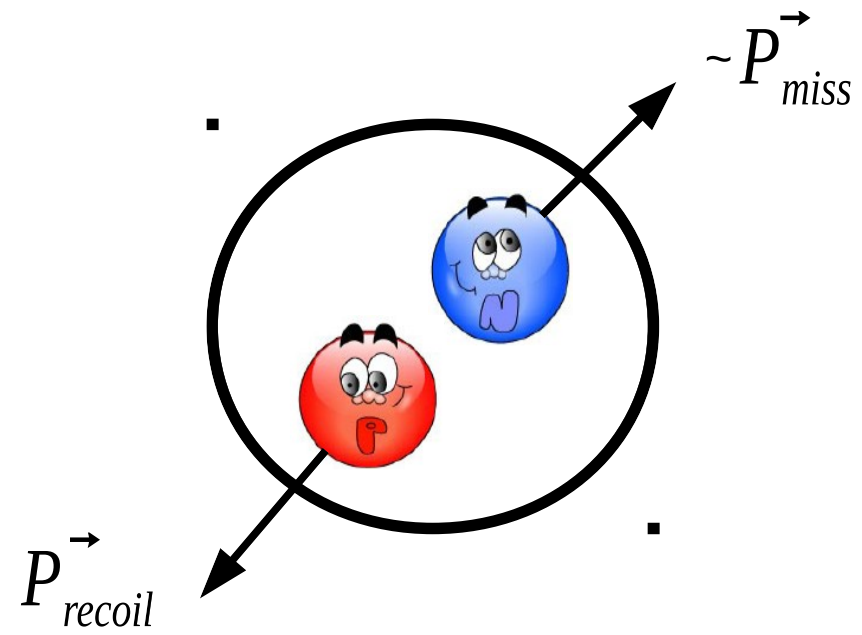
- $x_B > 1.1$
- $0.1 \leq P_{miss} \leq 1.2\,GeV/c$
- $\theta_{pq} \leq 20^o$
- $0.6 \leq |\vec{P}_{lead}| / |\vec{q}| \leq 1$
- $|\vec{P}_{recoil}| > 0.3\,GeV/c$

Opening angle distribution

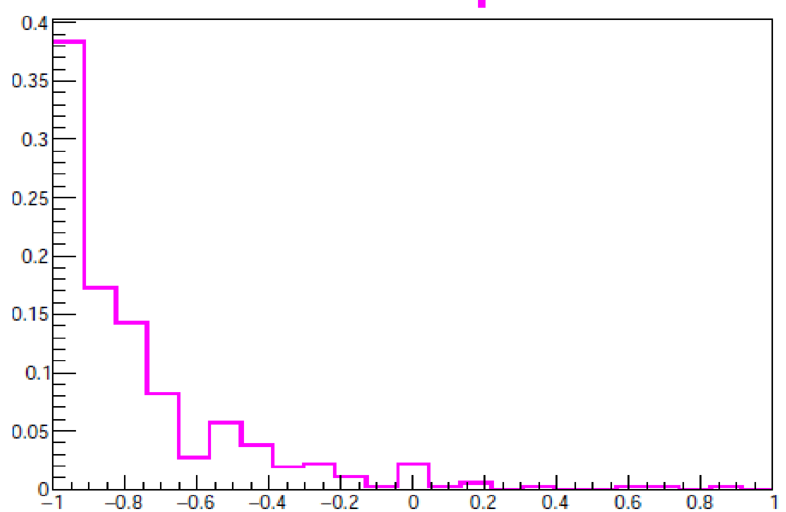
smeared protons neutrons



$\cos\left(\theta_{\vec{P}_{miss},\vec{P}_{recoil}}\right)$



un-smeared protons



$\cos\left(\theta_{\vec{P}_{miss},\vec{P}_{recoil}}\right)$

Preliminary result

#(e,e'np) = 293

#(e,e'pp) = 365

Next step:

* Correct for cross sections ratio event-by-event
* Correct for neutron efficiency event-by-event
* Apply other corrections

Backup Slides

$$A(e,e'N)_{k<k_F} = \int_0^{k_0} n^{M.F.}(k)\,k\,dk$$

$$A(e,e'N)_{k>k_F} = \int_{k_0}^{\infty} n^{SRC}(k)\,k^2\,dk$$

Considered 3 models for $n_{M.F.}$

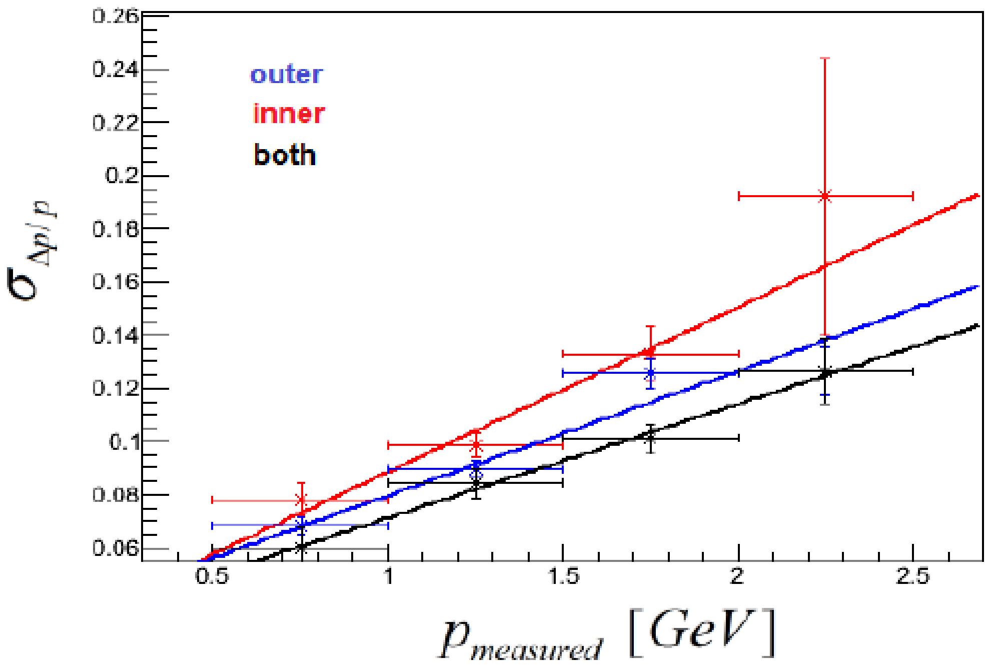
* Wood-Saxon
* Serot-Walecka
* Ciofi & Simula

Considered 2 values of K_0:

* 300 MeV/c
* k_F

Uncertainty was taken as the difference between the different results.

Neutron momentum resolution for the different layers

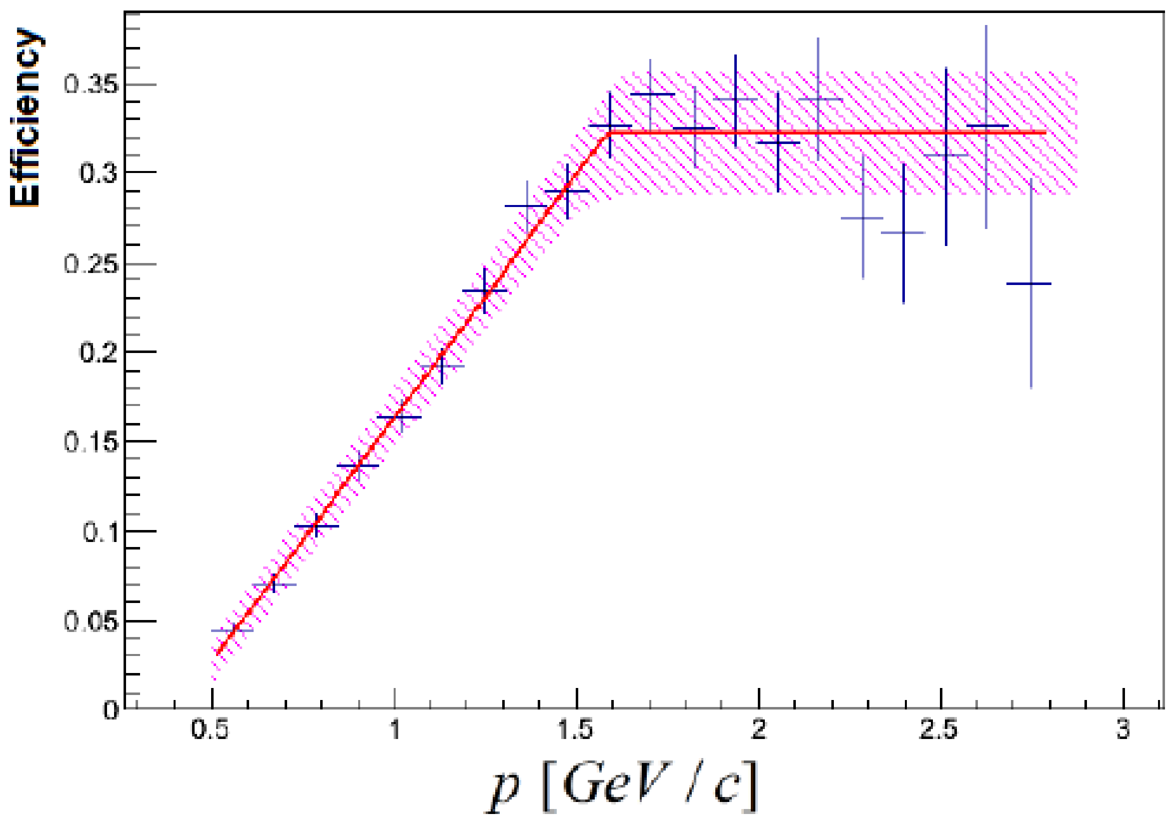


$$\sigma(\Delta p/p) = a + b \cdot p$$

	Inner	Outer	Both
a [%]	3 ± 3	3 ± 2	3 ± 2
b [%]	6 ± 3	5 ± 1	4 ± 1
χ^2/NDF	0.70	0.66	0.66

Neutron detection efficiency

$$\epsilon = \frac{\#d(e, e'p\pi^+\pi^- n)}{\#d(e, e'\pi^+\pi^-)n}$$



Parameterizations for the proton and neutron cross-sections