QE/nQE measurement

Status Report

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Objective

We want to measure the ratio QE/nQE using a statistical separation.

We compare two different methods: one is based on a fit of the W (invariant mass) distribution whereas the other one is based on a 2D fit of muon momentum and angle.

We use 90000 NUX events as our MC events and 44000 NEUT events as “real data”.

To obtain an upper limit on the systematics NUX has not been tuned in any way: neither reinteraction nor Pauli blocking has been included.

Muon 2D fit

Muon 2D fit

Given MC 2D distributions of P_μ Vs θ_μ for QE and nQE we use them to fit a full 2D distribution minimizing the χ^2:

$$\chi^2 = \frac{\sum_i \left[x_i - N(\alpha QE_i + (1-\alpha) nQE_i) \right]^2}{x_i}$$

Where α is the parameter, i is the "cell" index (a cell is 20 degrees $\times$ 250 MeV/c and the range is 0-180 for the angle and 0-12 GeV/c for the momentum) and N is the normalization constant given by:

$$N = \frac{X_{tot}}{\alpha QE_{tot} + (1-\alpha) nQE_{tot}}$$

Only cells with more than 0 entries are considered in the χ^2 minimization.

Self consistency test

At first, a test of self consistency has been carried out: the sample distributions have been obtained from 80000 events and used to fit the remaining 10000 events.

This test allows for a measurement of the statistical error since no systematics is present.

$\alpha = 0.498 \pm 0.011$

$\chi^2 = 108.8/95$

$QE/nQE = 1.33 \pm 0.04$

$QE/nQE_{\text{expected}} = 1.36$

$\sigma_{stat} = 3\%$

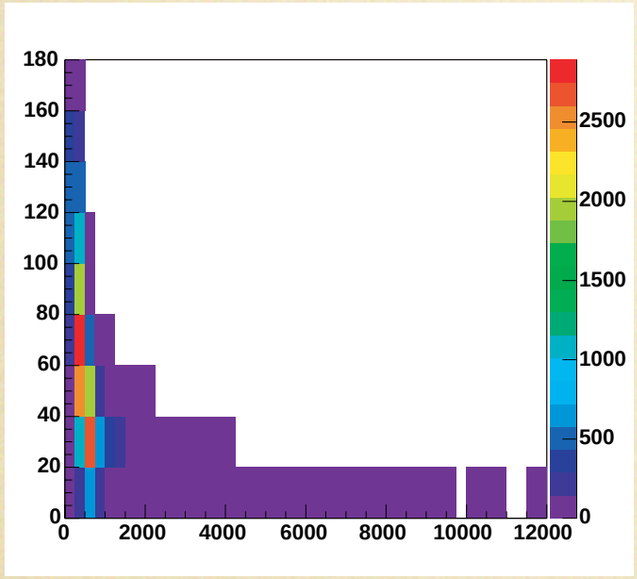
...1 year...(190k events)

$\Downarrow$

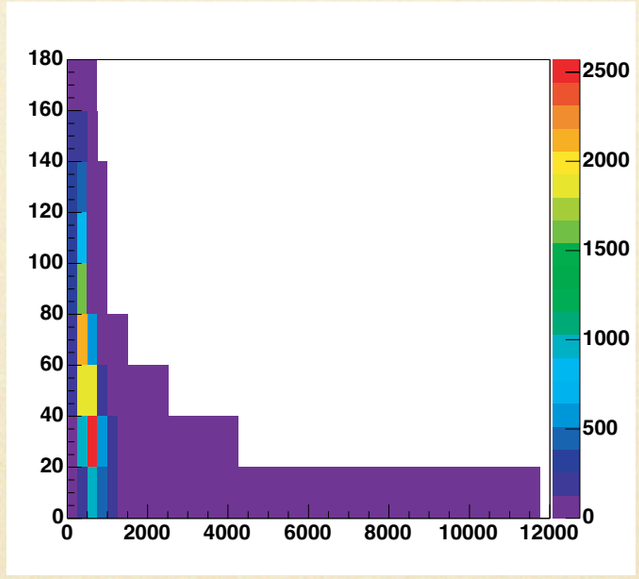
$\sigma_{stat} = 0.7\%$

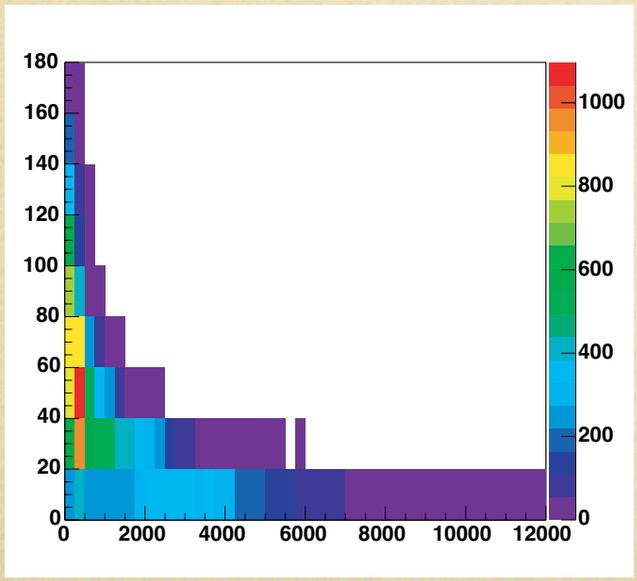
Fit on NEUT events

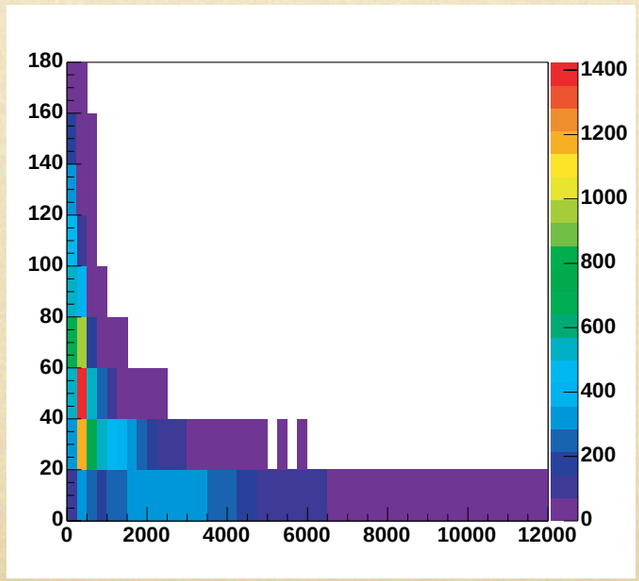
NEUT



NUX (normalized to NEUT)







$\alpha = 0.372 \pm 0.004$

$\chi^2 = 1082/100$

$QE/nQE = 0.797 \pm 0.011$

$QE/nQE_{\text{expected}} = 1.092$

$\sigma = 1.2\%$

discrepancy 27%

Comments

The statistical error is negligible compared to the systematic error.

The discrepancy is due to the different 2D distribution in NUX and NEUT cases. Although nuclear reinteraction should not affect the muon, Fermi motion and Pauli blocking do. (see slides on NUX - NEUT comparison)

Need to tune MC on real data....

A conservative estimate of the systematics is given by the discrepancy between the predicted and the expected value of QE/nQE (27%). This value is expected to decrease when a Pauli blocking is introduced in our MC and Fermi motion is better implemented.

Test using cuts

Fit on NEUT: cut on Fermi momentum

A preliminary test to check if the discrepancy decreases changing the Fermi momentum distribution was made excluding events with momentum higher than 300 MeV/c.

Although there is a small improvement, it seems that the high Fermi momentum was not the main cause of the discrepancy.

$\alpha = 0.374 \pm 0.003$

$\chi^2 = 1096/100$

$QE/nQE = 0.817 \pm 0.012$

$QE/nQE_{\text{expected}} = 1.092$

$\sigma = 1.5\%$

discrepancy 25%

Fit on NEUT: Pauli blocking

A preliminary test to check if the discrepancy decreases including Pauli blocking was carried out. Pauli blocking has been introduced in a very coarse way imposing a sharp cut on the momentum of the nucleon at 220 MeV/c.

Although the discrepancy decreases considerably, the result is not reliable since the fit is not good as it is evident from the value of χ^2.

$\alpha = 0.378 \pm 0.001$

$\chi^2 = 5545/100$

$QE/nQE = 0.901 \pm 0.013$

$QE/nQE_{\text{expected}} = 1.092$

$\sigma = 1.4\%$

discrepancy 17.5%

Fit on NEUT: cut on Fermi momentum and Pauli blocking

Both the cut on the Fermi momentum and the Pauli blocking have been introduced in the MC.

Once again the discrepancy decreases considerably, but the result is not reliable since the fit is not good as it is evident from the value of χ^2.

$\alpha = 0.380 \pm 0.004$

$\chi^2 = 5529/100$

$QE/nQE = 0.930 \pm 0.013$

$QE/nQE_{\text{expected}} = 1.092$

$\sigma = 1.4\%$

discrepancy 15%

Comments

It seems that the differences between NUX and NEUT are not simply due to Fermi motion and Pauli blocking.

Do they have a different cross section for neutrino interaction?

(Axial mass in NUX = 1.03 GeV , axial mass in NEUT = 1.1 GeV)

W distribution fit

W distribution

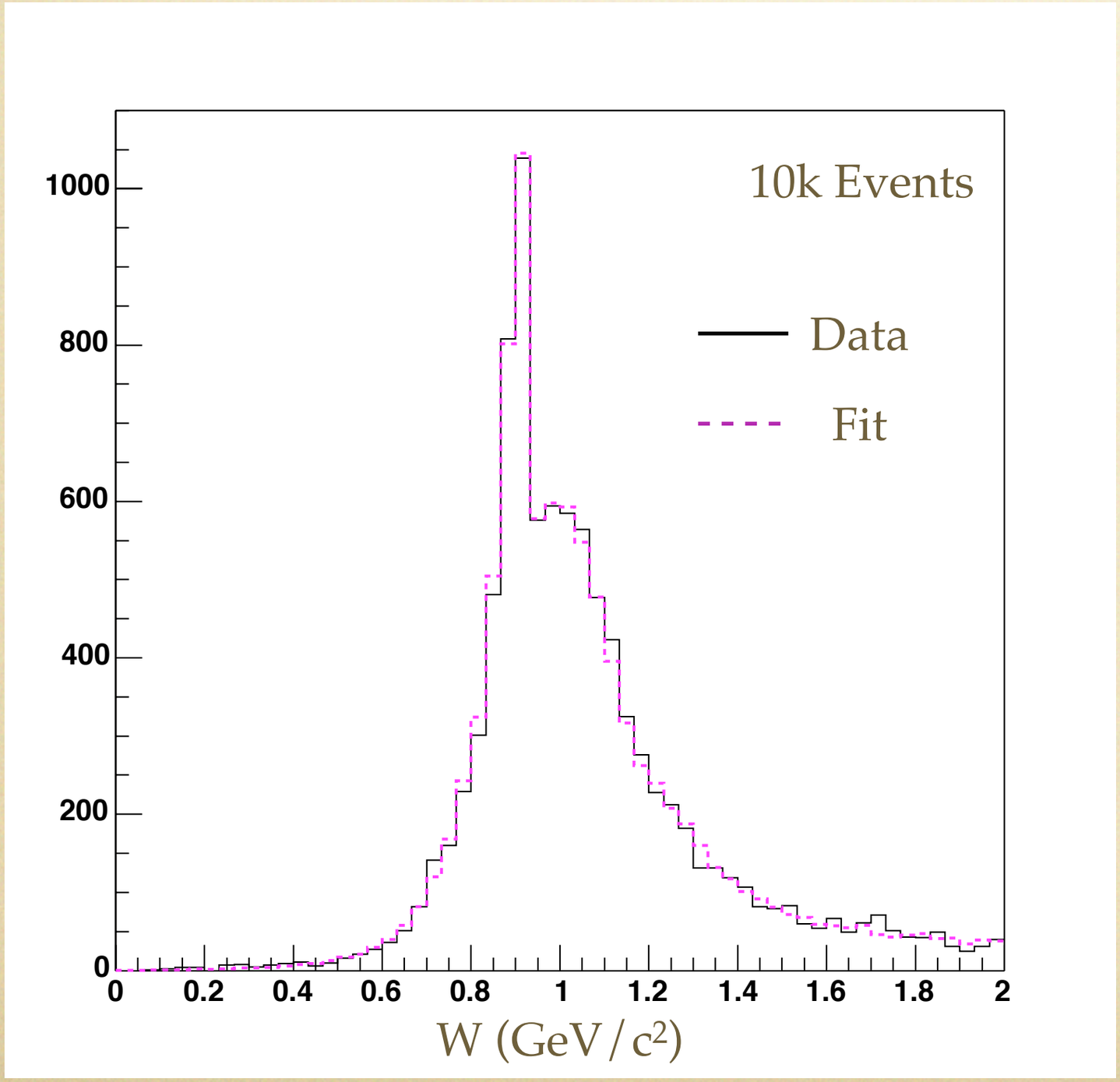
Given MC distributions of W for QE and nQE we use them to fit a full distribution of W minimizing the χ^2:

$$\chi^2 = \frac{\sum_i \left[x_i - N(\alpha(QE_i^{CL\neq 0} + \beta QE_i^{CL=0}) + (1-\alpha) nQE_i) \right]^2}{x_i}$$

Where α,β are the parameters, *CL=0* stands for events where only the muon is seen, *i* is the bin index (60 bins from 0 to 2 GeV/c^2) and *N* is the normalization constant given by:

$$N = \frac{X_{tot}}{\alpha(QE_{tot}^{CL\neq 0} + \beta QE_{tot}^{CL=0} - nQE_{tot}) + nQE_{tot}}$$

Self consistency test



$\alpha = 0.502 \pm 0.009$

$\beta = 1.027 \pm 0.07$

$\chi^2 = 65.2/58$

$QE/nQE = 1.37 \pm 0.03$

$QE/nQE_{\text{expected}} = 1.36$

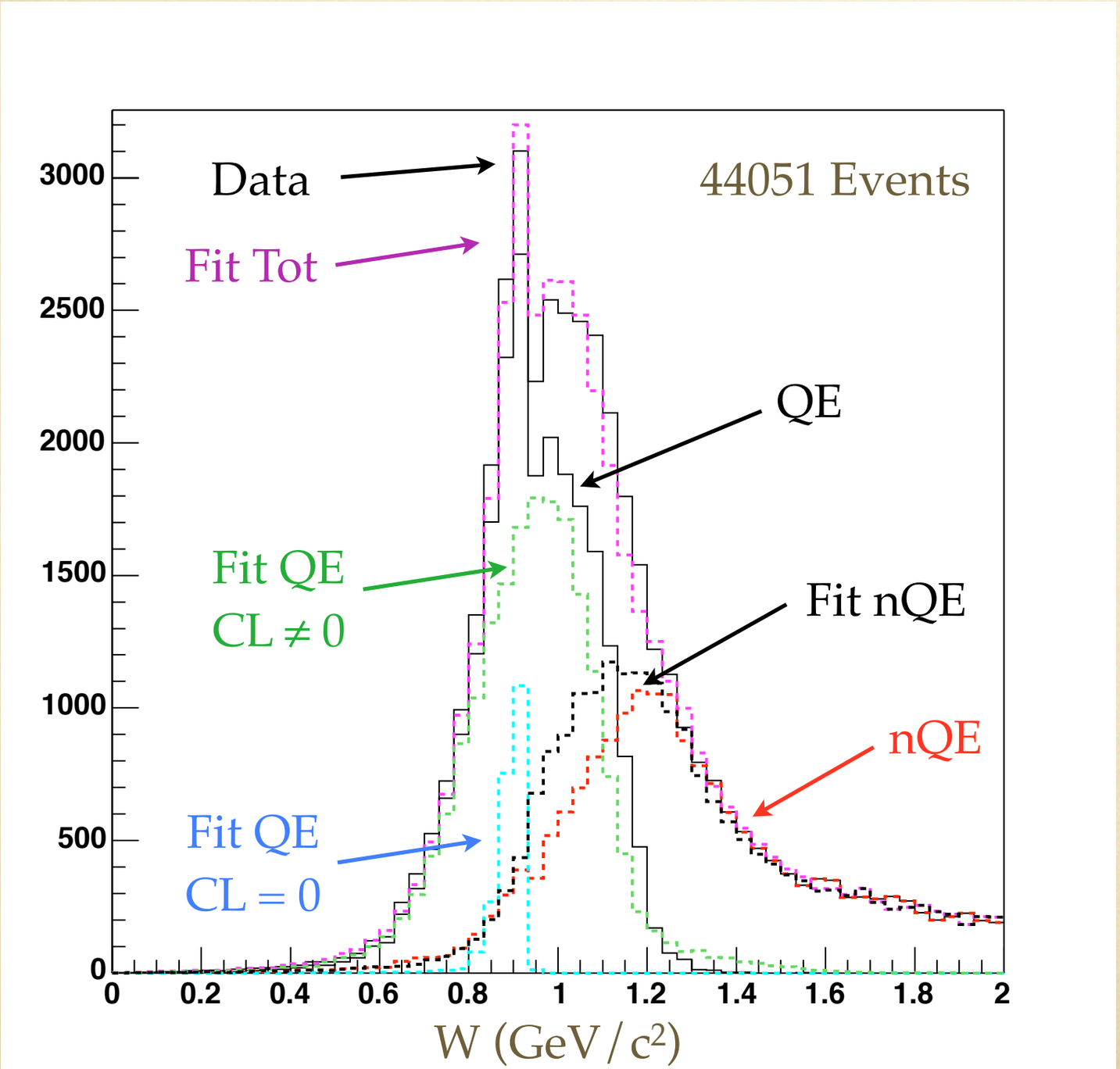
$\sigma_{stat} = 2.4\%$

...1 year...(190k events)

$\Downarrow$

$\sigma_{stat} = 0.6\%$

Fit on NEUT events



$\alpha = 0.422 \pm 0.004$

$\beta = 0.53 \pm 0.03$

$\chi^2 = 239.1/58$

$QE/nQE = 0.897 \pm 0.02$

$QE/nQE_{\text{expected}} = 1.092$

$\sigma = 2.2\%$

discrepancy = 18%

Comments

The statistical error is negligible: ~0.6% after 1 year.

The discrepancy is due to the different shapes of the W spectra. The real shape is unknown and influenced by nuclear effects (nuclear reinteraction, Fermi motion, ...).

Need to tune MC on real data....

A conservative estimate of the systematics is given by the discrepancy between the predicted and the expected value of QE/nQE (18%). This value is expected to decrease when a nuclear reinteraction model is implemented in our MC.

Test using cuts

Fit on NEUT: cut on Fermi momentum

$\alpha = 0.399 \pm 0.004$

$\beta = 0.47 \pm 0.03$

$\chi^2 = 438.9/58$

$QE/nQE = 0.813 \pm 0.02$

$QE/nQE_{\text{expected}} = 1.092$

$\sigma = 2.6\%$

discrepancy = 25%

Fit on NEUT: Pauli blocking

$\alpha = 0.392 \pm 0.004$

$\beta = 0.50 \pm 0.03$

$\chi^2 = 466.9/58$

$QE/nQE = 0.867 \pm 0.02$

$QE/nQE_{\text{expected}} = 1.092$

$\sigma = 2.4\%$

discrepancy = 21%

Fit on NEUT: cut on Fermi motion and Pauli blocking

$\alpha = 0.373 \pm 0.004$

$\beta = 0.43 \pm 0.03$

$\chi^2 = 653.6/58$

$QE/nQE = 0.801 \pm 0.02$

$QE/nQE_{\text{expected}} = 1.092$

$\sigma = 2.8\%$

discrepancy = 26.6%

Comments

Imposing cuts on Fermi momentum and introducing Pauli blocking does not reduce the systematic errors.

The values of the χ^2 increase and the results obtained are not reliable.

As it was already clear when performing a 2D fit based on muon momentum and angle, at this stage NUX data is too different from NEUT to fit it well.

Final remarks

Final Remarks

For both the methods the statistical error is negligible compared to the systematic ones.

Both methods require a tuning of the MC to reduce the systematic errors.

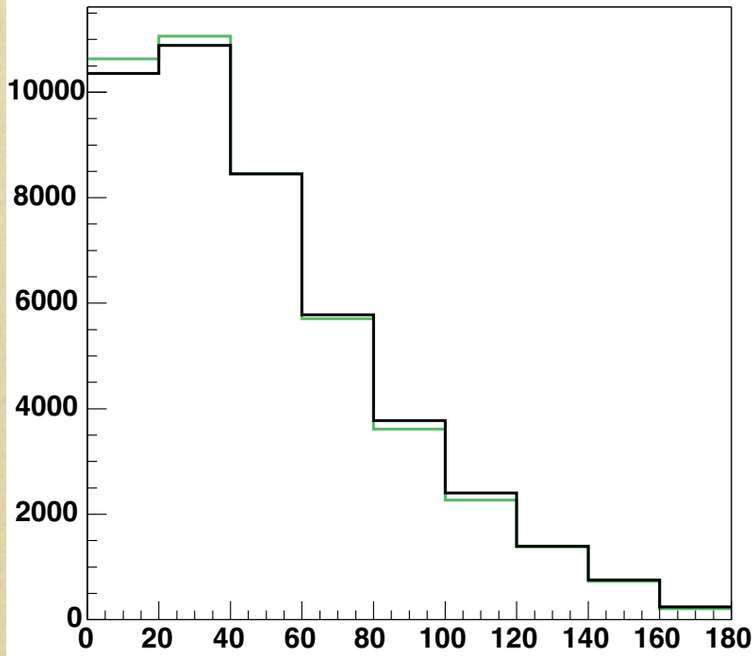
At this stage, the measurement of the hadronic energy (fit on W) seems to provide smaller errors compared to the measurement of the muon alone:

	fit on W	fit on μ
Statistics	2.5%	3.0%
Statistics 1 year	0.6%	0.7%
Systematics	18%	27%

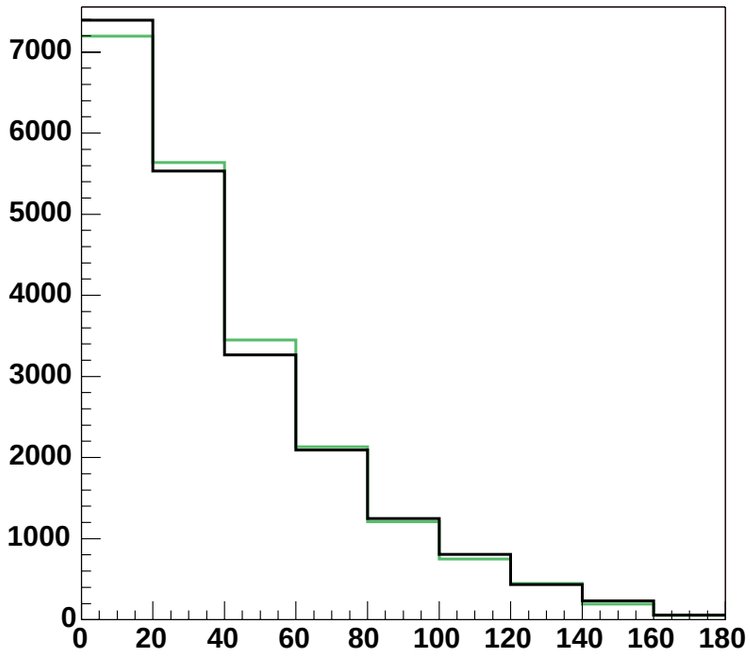
NUX - NEUT
comparison

θ_μ comparison

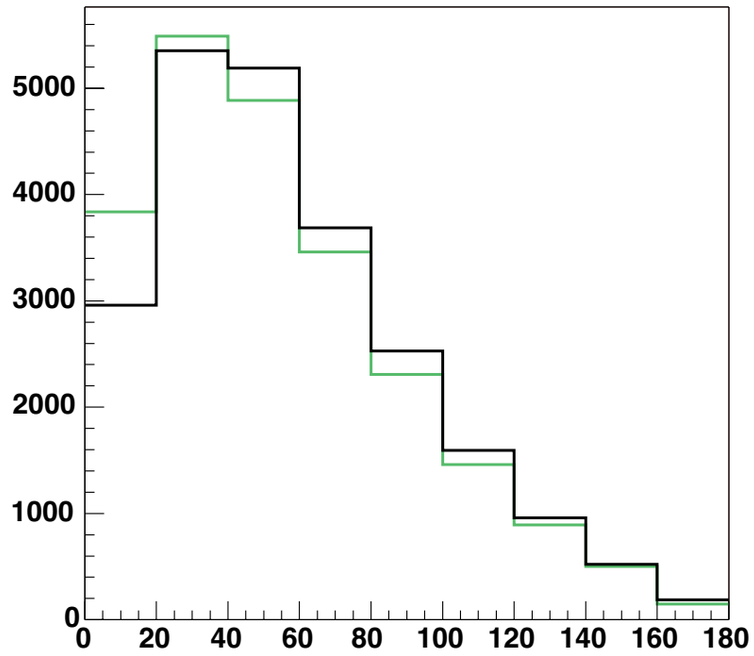
TOT



nQE



QE



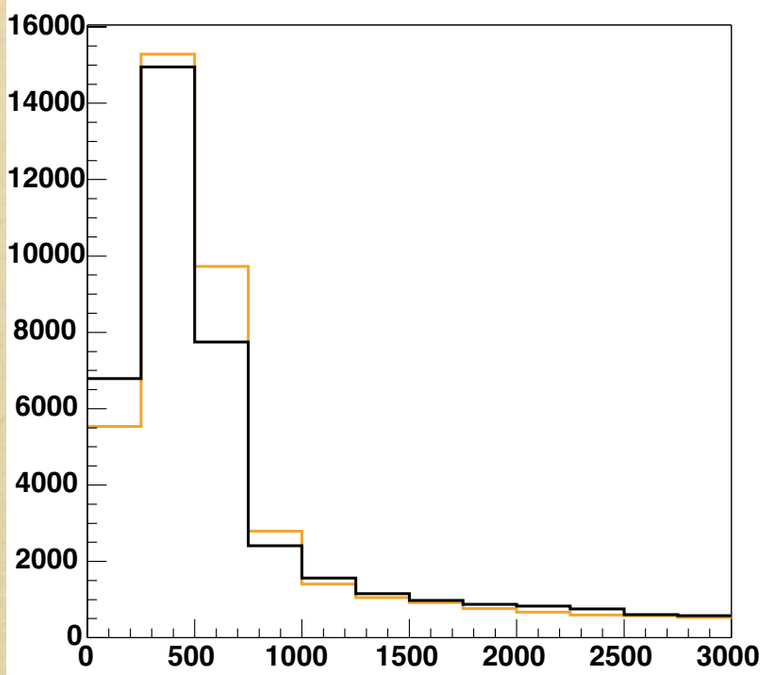
Muon Angle (degrees)

NUX

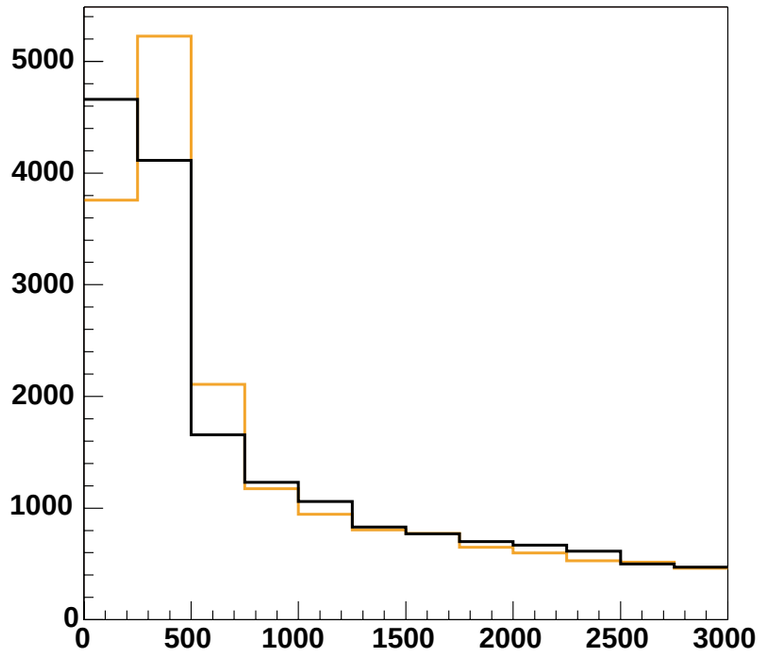
NEUT

P_μ comparison

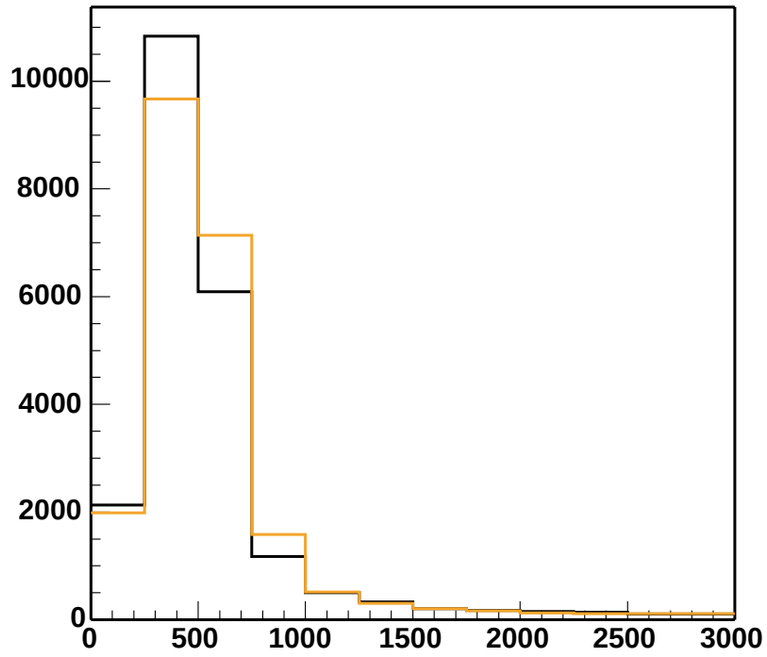
TOT



nQE



QE



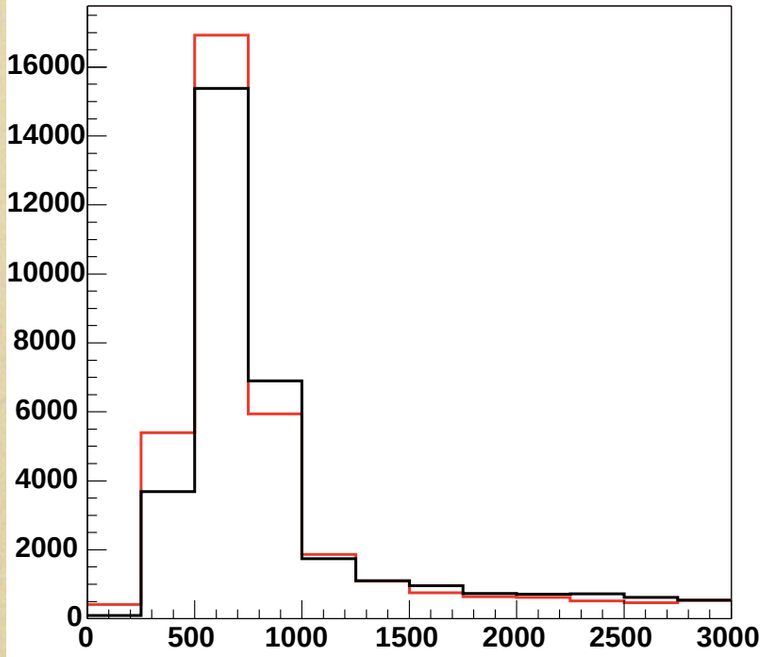
Muon Momentum (MeV/c)

NUX

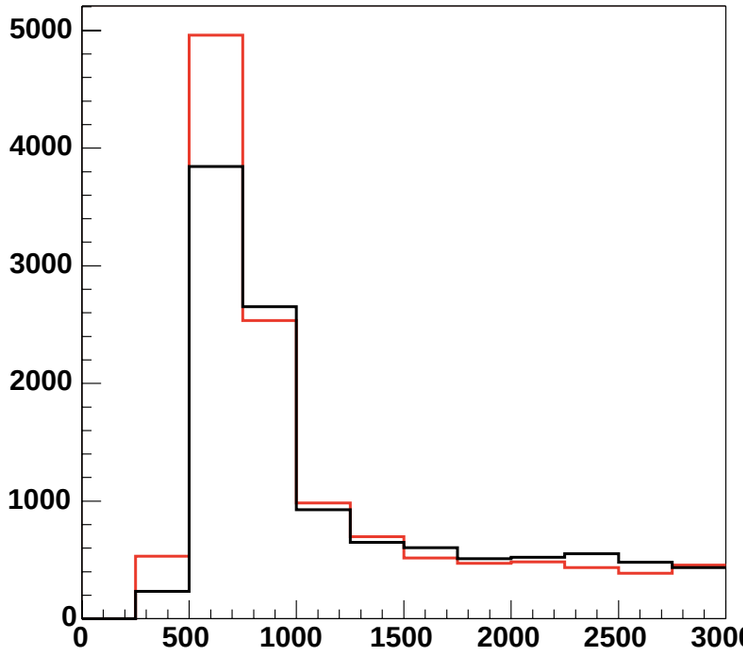
NEUT

E_ν comparison

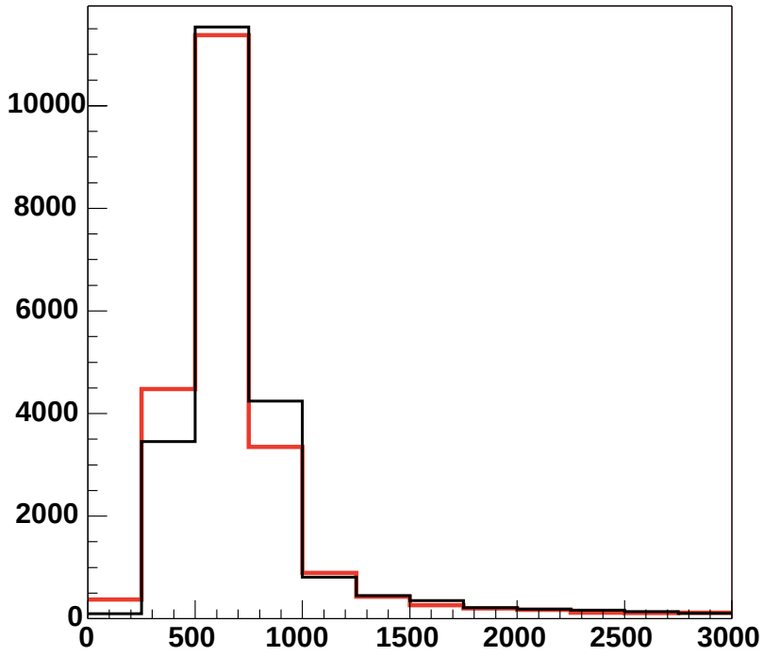
TOT



nQE



QE

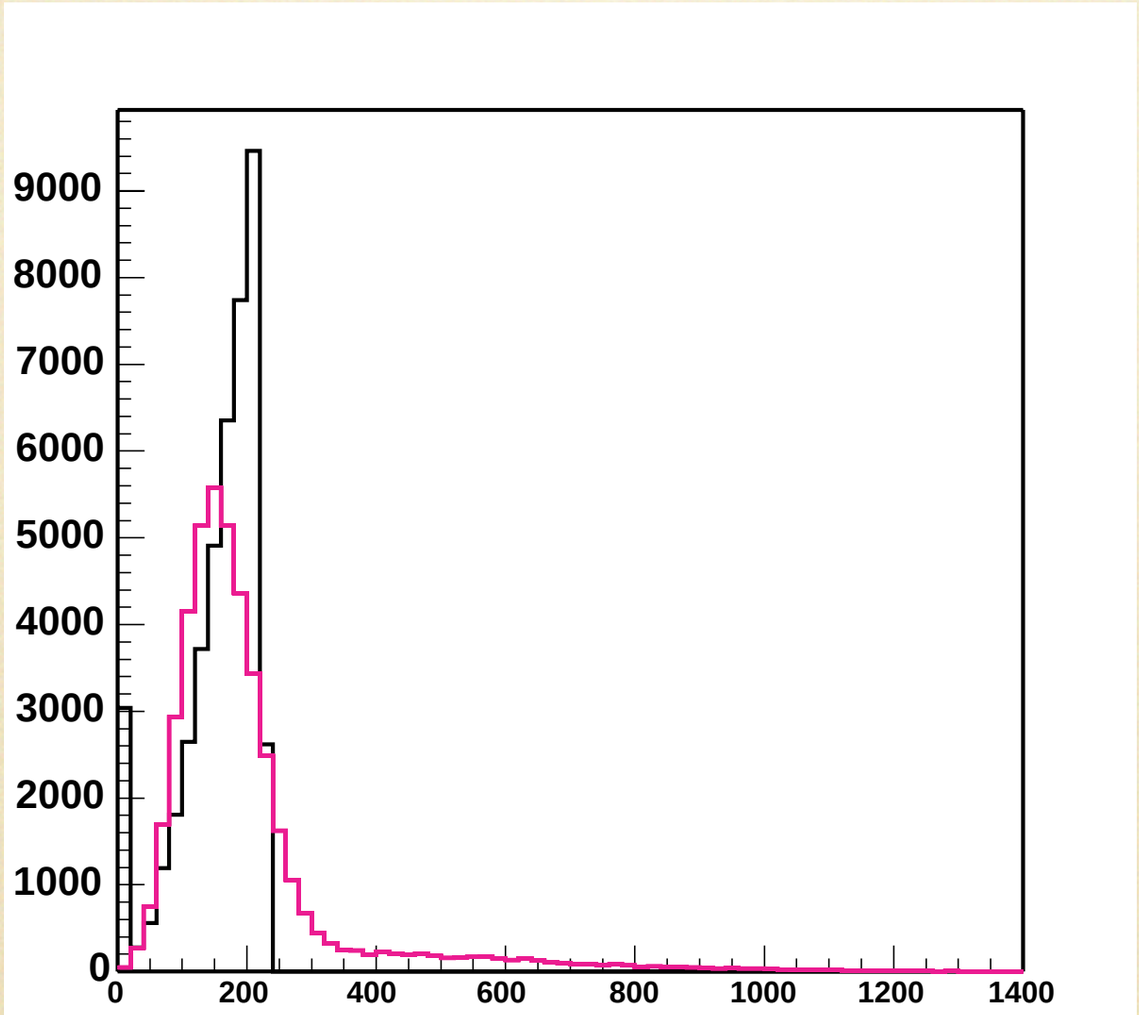


Muon Momentum (MeV/c)

NUX

NEUT

Fermi Motion



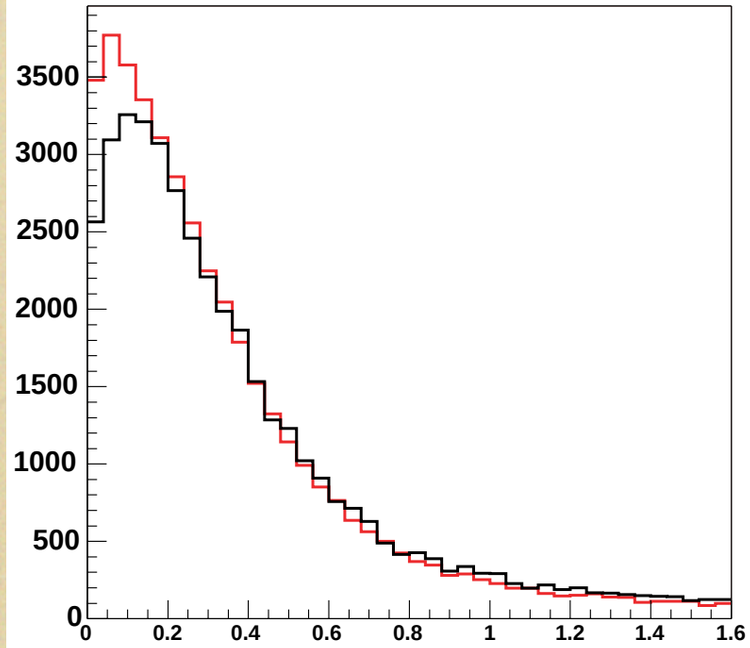
Fermi Momentum (MeV / c)

NUX

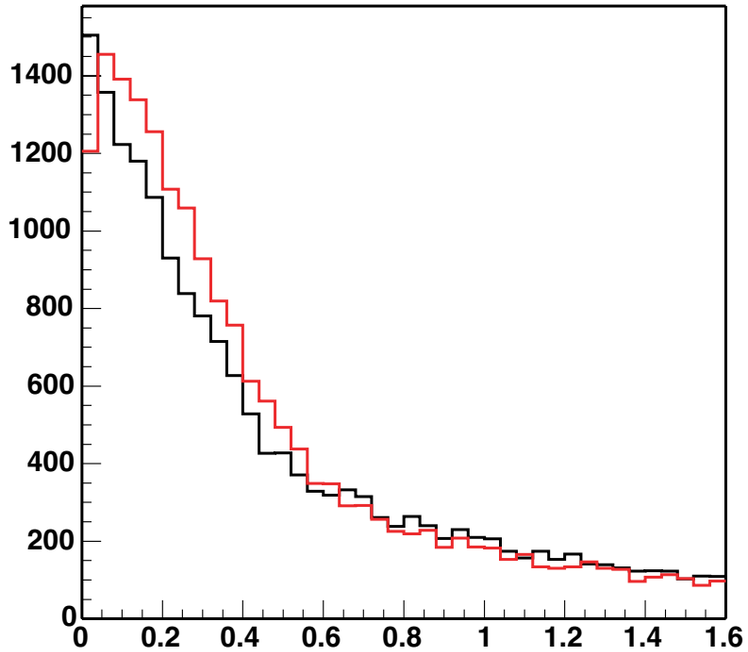
NEUT

Q^2 comparison

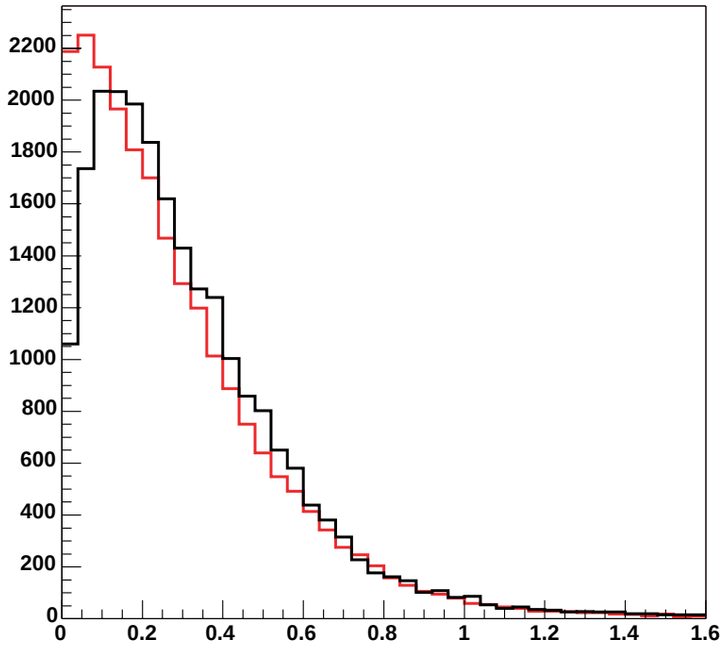
TOT



nQE



QE



Q^2 (GeV^2/c^2)

NUX

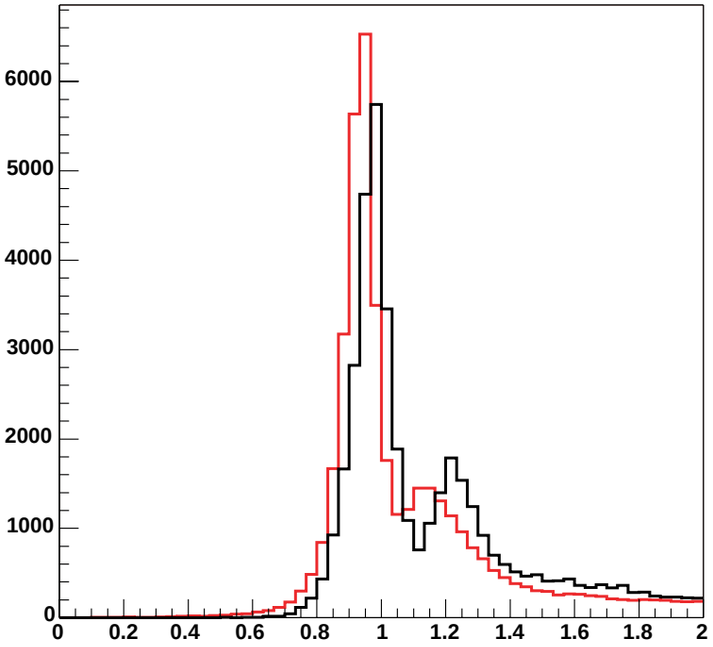
NEUT

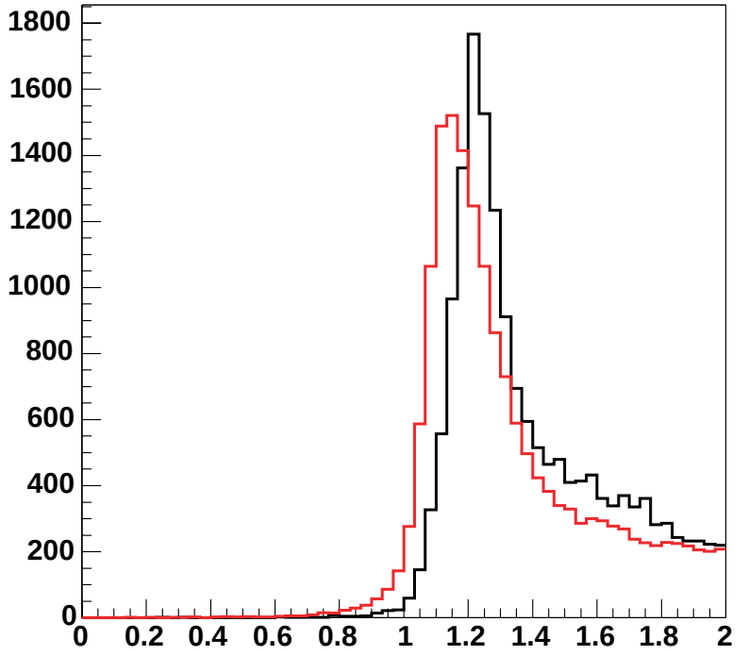
W comparison

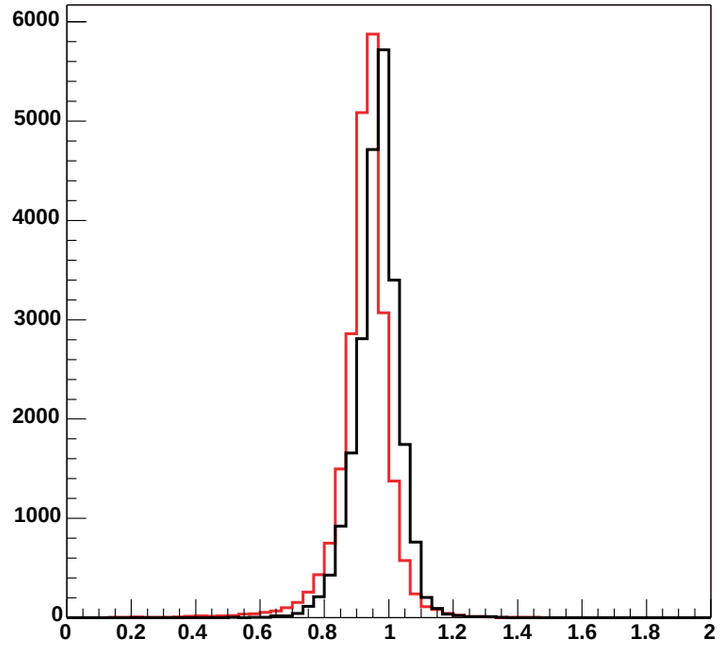
TOT

nQE

QE







W (GeV / c^2)

NUX

NEUT

The End

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