T2KLAr: Tools & Detector Performance

Anselmo Meregaglia , André Rubbia (ETH Zürich)

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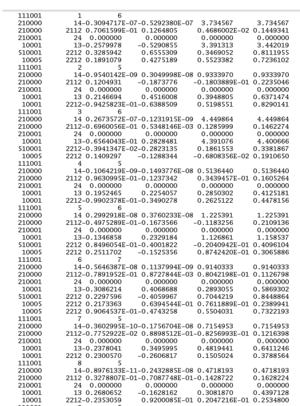
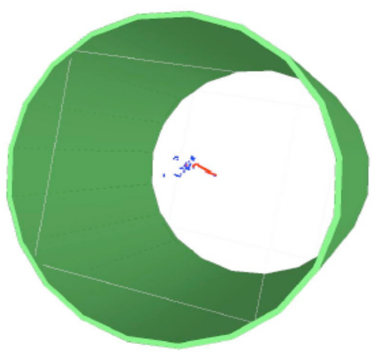
Tools

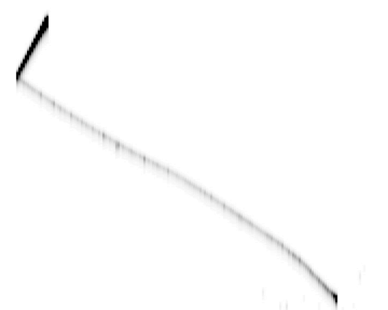
- T2KLAr software is made up of:
    1. Geant4.
    2. Fullreco.
- Our G4 simulation was developed as a “stand alone” one, but it is being integrated with the T2K2km full simulation (T.J.Corona).
- The full chain to produce and process a neutrino MC event is the following:



Input File.txt from NUX/NEG/NUANCE neutrino generator



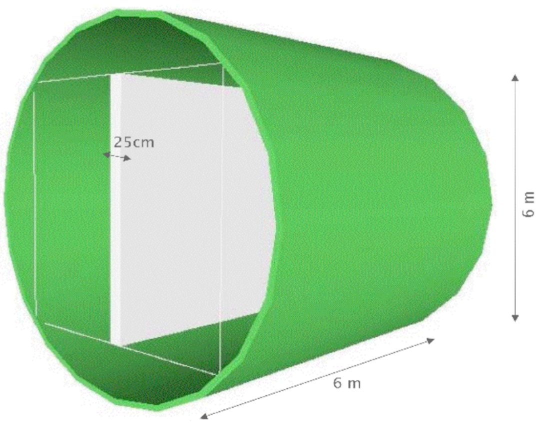
Geant4 simulation of the event with a .g4root output file

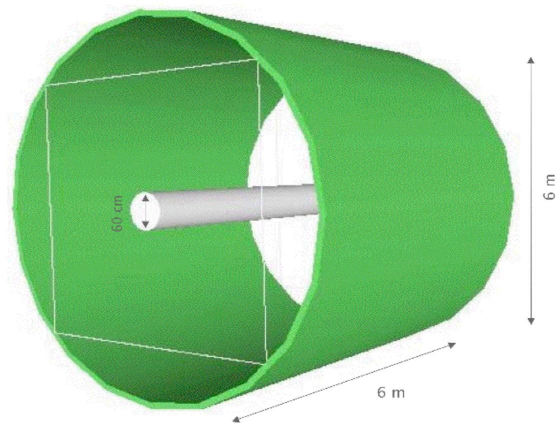


Reconstruction of the event using Fullreco from the .g4root file

Geant4 Geometry

- We have implemented our LAr detector in Geant4 including the possibility of selecting a water inner target.



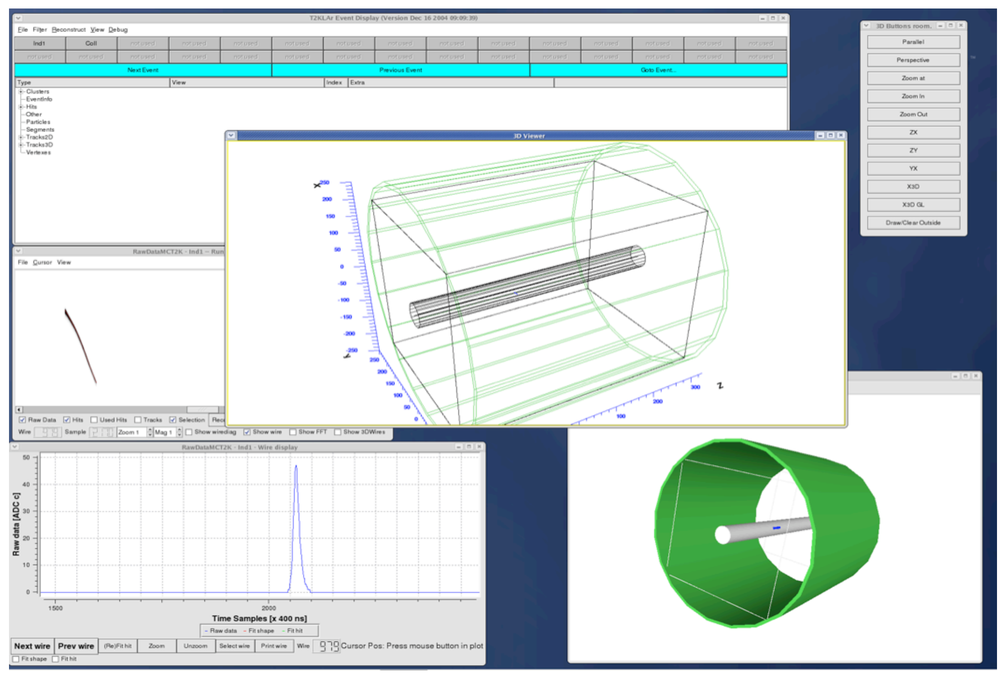


- This volume will not be “active” so studies are being carried out, taking into account real engineering problems, to choose the target which will allow for a better performance.

Fullreco

- Fullreco is the reconstruction package.
- It contains all the functions that allow, starting from ADC counts on a defined wire and sample, to build hits, clusters and tracks, and to perform a PID.
- It also contains functions that build a 3D image starting from the two different 2D views (wire planes).
- Fullreco can be used in two ways:
  1. Batch mode: to process many events without looking at them.
  2. Interactive mode: a GUI interface named Qscan has been developed to look at the events.
- In Qscan it is possible to use all the analysis tools and functions of Fullreco.

NOTE: All the packages we use can be downloaded from : http://neutrino.ethz.ch/T2KLAr/



Production Status

- NUX generator:
  1. 90000 events have been produced.
  2. Full cross section has been used to produce QE and inelastic interaction in an inclusive way.
  3. Fermi motion has been taken into account.
  4. No reinteraction has been included.

- NEG generator:
  1. 90000 events have been produces.
  2. Exclusive production of QE and RES events.
  3. Fermi motion has been taken into account.
  4. Reinteraction on Ar has been included in 60000 events.
  5. Pauli blocking effect has been taken into account.

- NUANCE generator: in progress.
- These events have been used for the following analysis and are available on line.

Detector Performance

- Two main issues concerning our detector performance are currently under study:
    1. The resolution of the reconstructed ν energy.
    2. The sensitivity on the QE/non-QE measurement.
- The results on our detector performance are obtained taking into account the presence of a WC detector (i.e. for the muon reconstruction).

Hypothesis

- All the events are produced at the centre of our detector.
- Most of the muons are not fully contained. Considering a dE/dX of ~ 2MeV per cm, only muons with energy lower than ~ 600 MeV are fully contained. Nevertheless we assume that the combined use of LAr and WC will allow for a precise energy reconstruction of the muon and we focus on the hadronic energy.
- To reconstruct the neutrino momentum we assume a "perfect" particle ID, which is used to convert the deposited kinetic energy to total momentum. This PID comes from MC but relies also on "match MC hits" which is a function in the reconstruction so it has an intrinsic error.
- We also assume a perfect angular reconstruction and rescale the momentum components according to the ratio: $|P|_{reconstructed} / |P|_{MC}$.
- We use a cut-off on momentum: 310 MeV/c for protons (kinetic energy of 50 MeV) and 53.8 MeV/c for charged pions (kinetic energy of 10 MeV).

ν_μ CC Energy Reconstruction

- We compare two possible ways to reconstruct the energy of the neutrino:
  1. Measuring only the muon.
  2. Measuring the muon and the hadronic energy.
- The first method is effective for QE events by assuming a fixed kinematics (i.e. ignoring Fermi motion), and the neutrino energy can be calculated as:

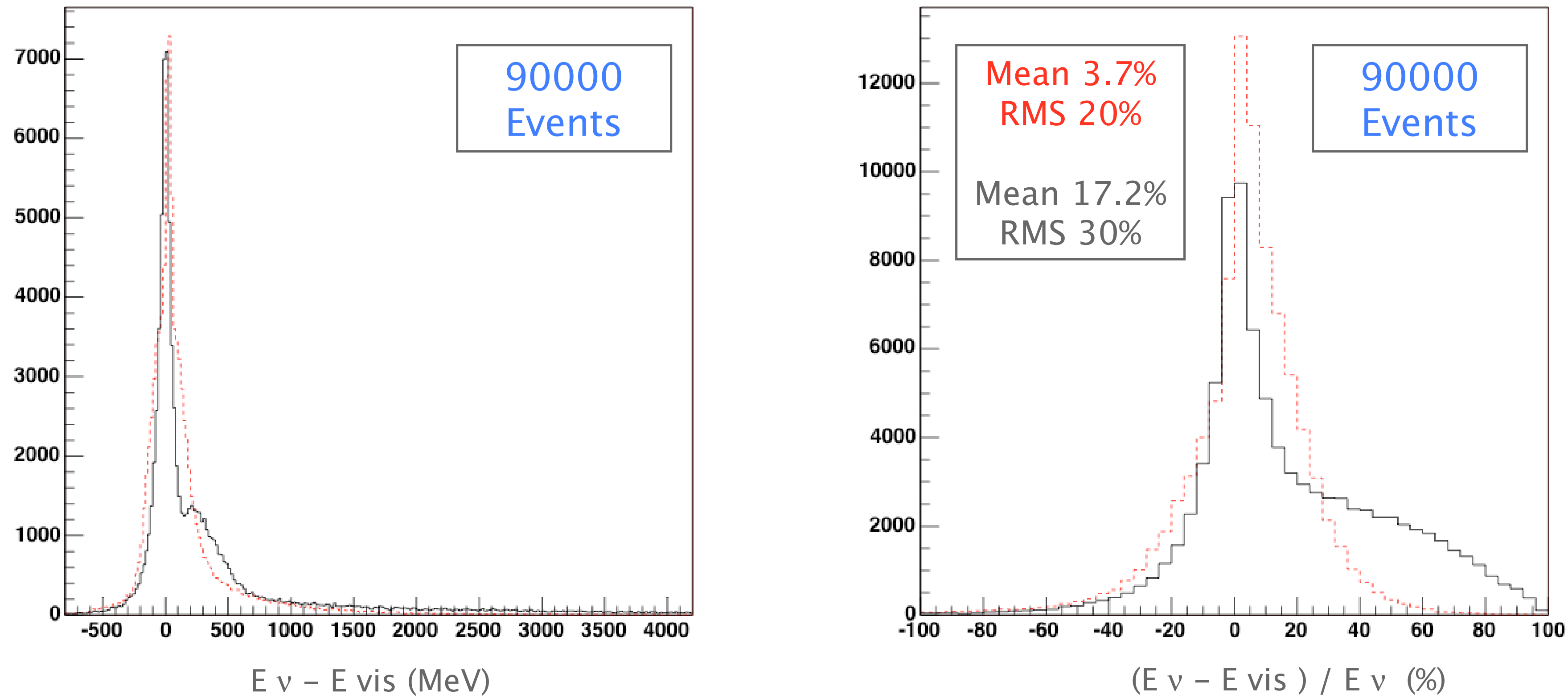
$$E_\nu^{rec} = \frac{m_N E_\nu - m_\mu^2/2}{m_N - E_\mu + p_\mu \cos\theta_\mu}$$

- Having reconstructed the momenta of individual particles (see previous slide), the second method relies on the conservation of momentum:

$$E_\nu^{rec} = |p|_\nu^{rec} = \sqrt{\left(\sum p_x\right)^2 + \left(\sum p_y\right)^2 + \left(\sum p_z\right)^2}$$

- The analysis has been carried out using 90000 complete events from NUX generator. No reinteraction has been included and only Fermi motion has been taken into account.

All Events: Full Reconstruction Vs μ Stand Alone Measurement

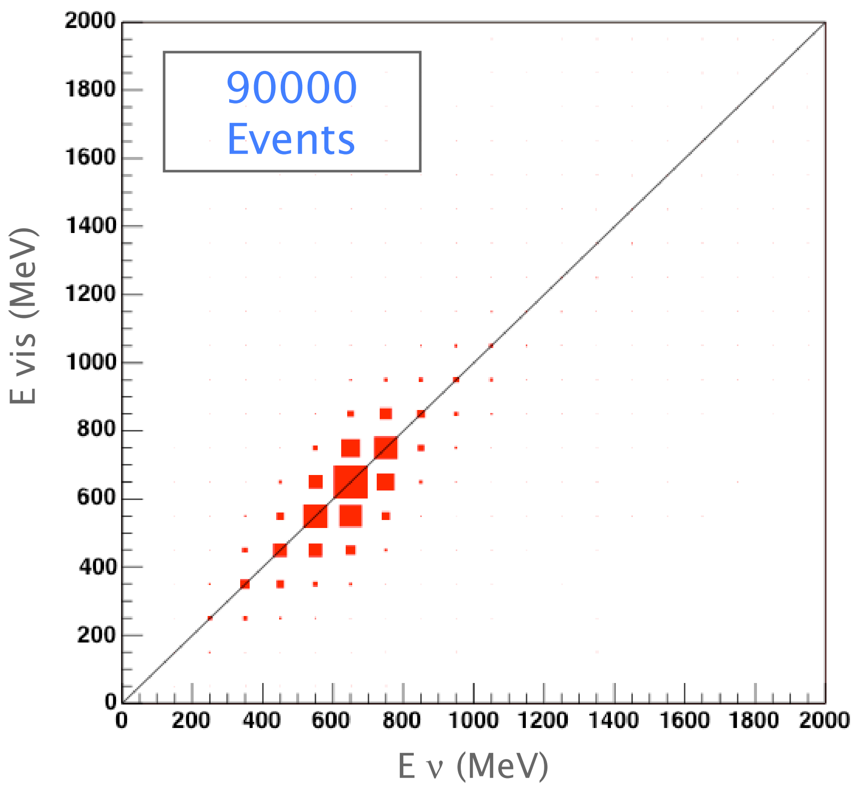


complete reconstruction

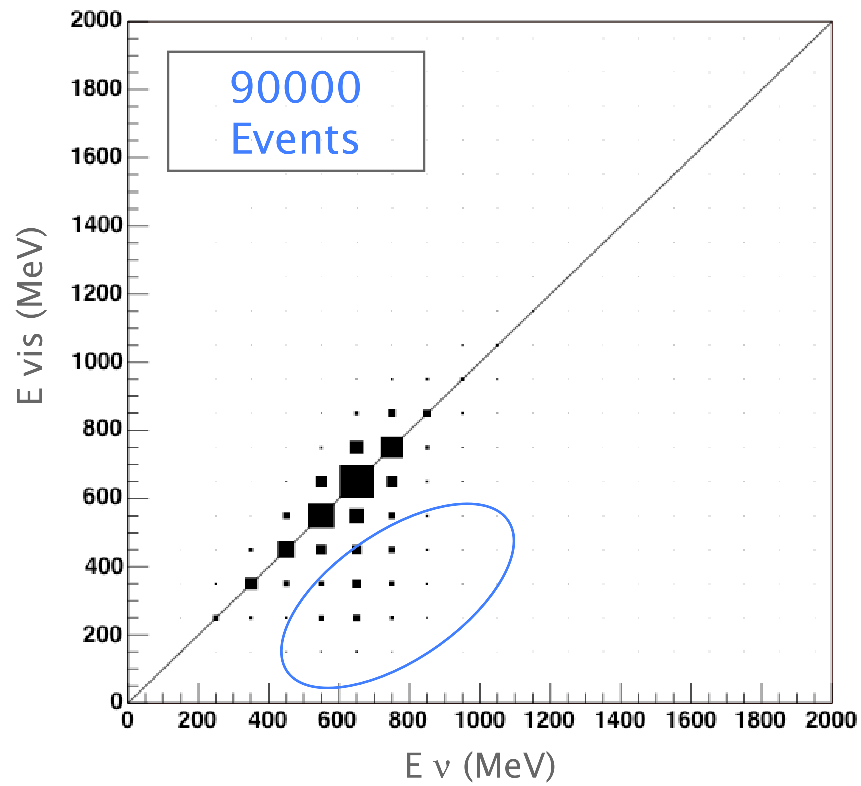
μ stand alone reconstruction

All Events: Full Reconstruction Vs μ Stand Alone Measurement

Full Reconstruction

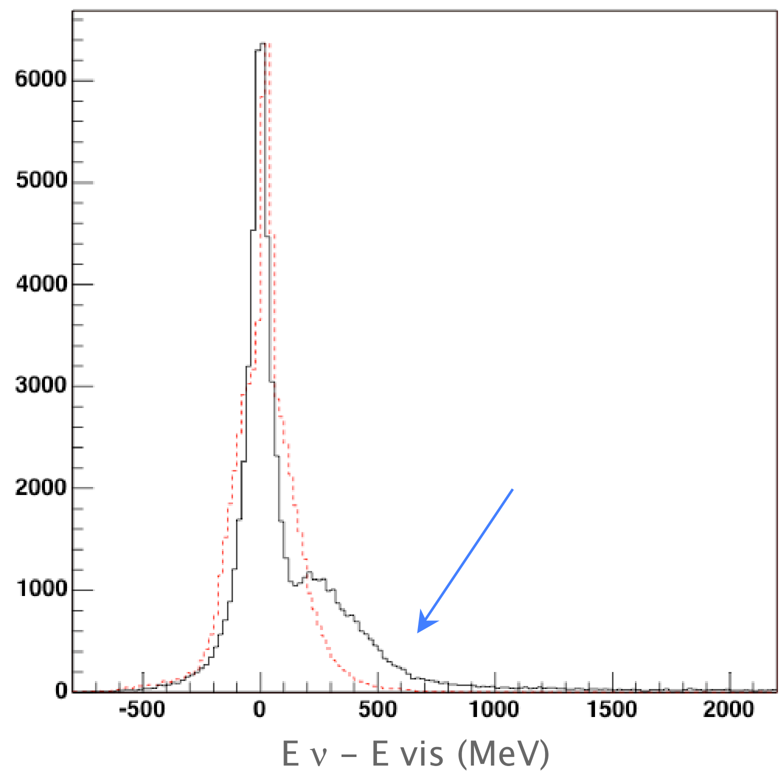


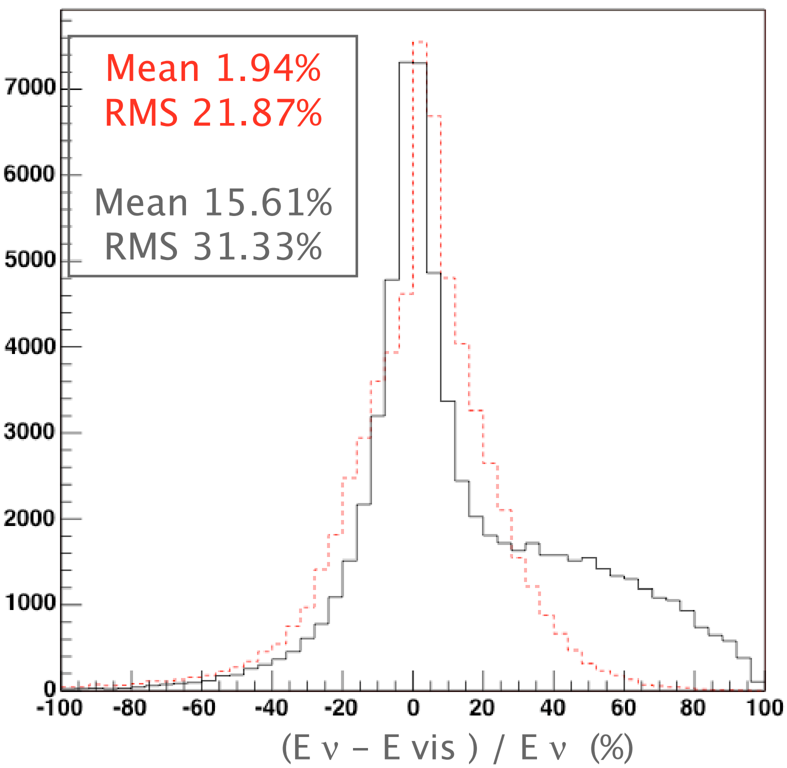
μ only



All Events: Full Reconstruction Vs μ Stand Alone Measurement

Cut on E_{vis} < 1250 MeV





- - - - - complete reconstruction

——— μ stand alone reconstruction

Comments

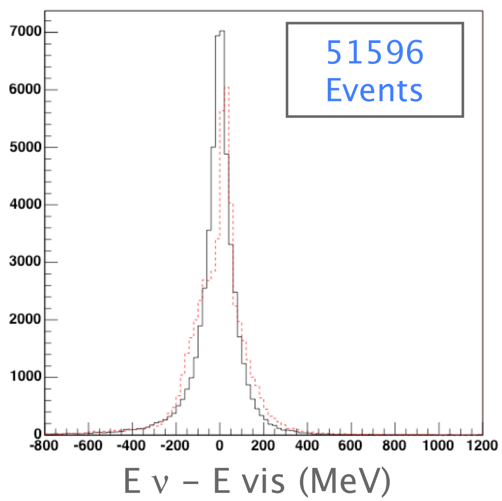
- The measurement of the hadronic energy improves the resolution on the reconstructed neutrino energy by ~ 10%.
- The measurement of the hadronic energy allows to have a gaussian resolution.

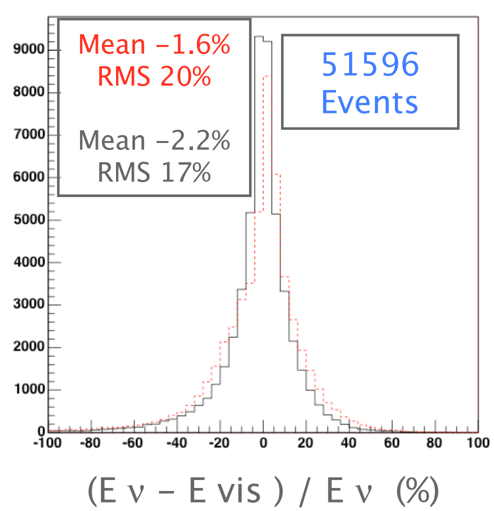
Nuclear Reinteraction

- We studied how nuclear reinteraction affects our resolution on the reconstructed neutrino energy.
- NEG generated events (D.Autiero) have been used for this purpose:
  - 30000 QE interactions on Ar.
  - 25000 non-QE interactions on Ar.

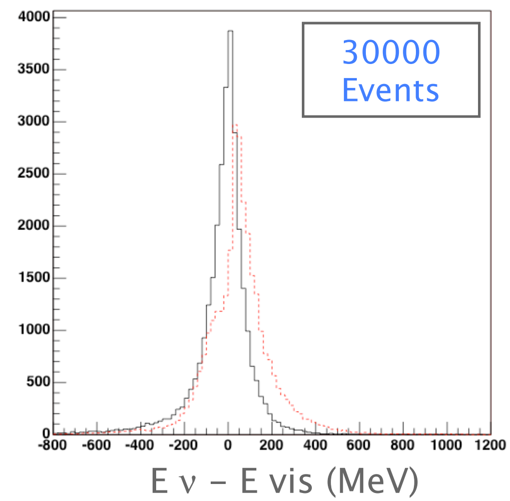
QE Interactions

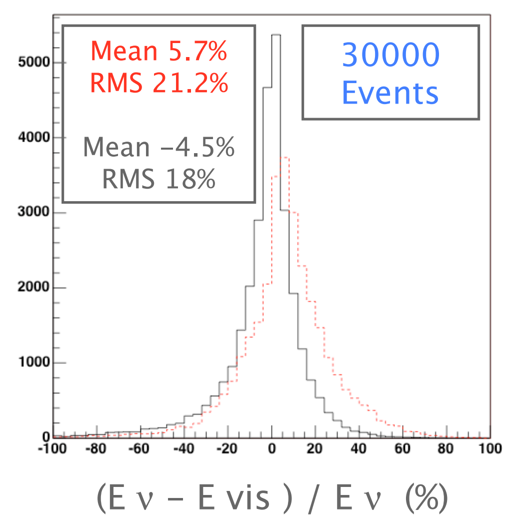
NUX NR





NEG Ar





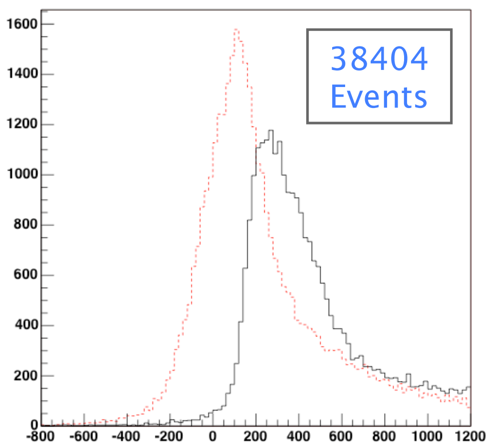
complete reconstruction

μ stand alone reconstruction

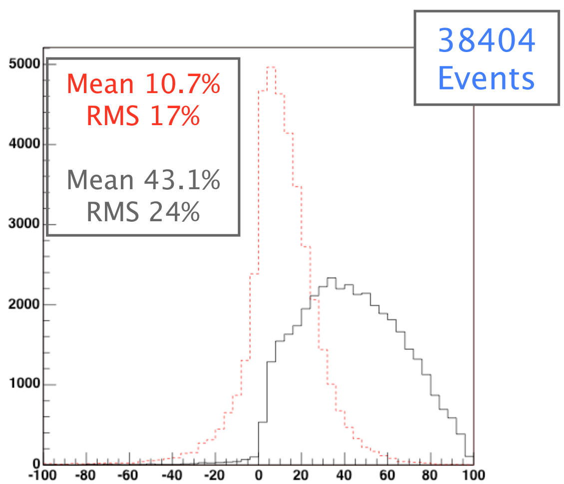
non–QE Interactions

Work in progress

NUX NR (Full)

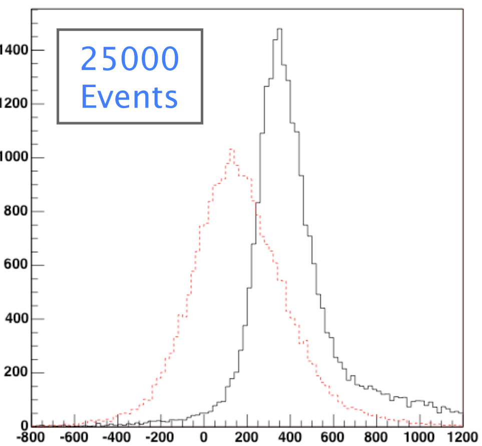


E ν – E vis (MeV)

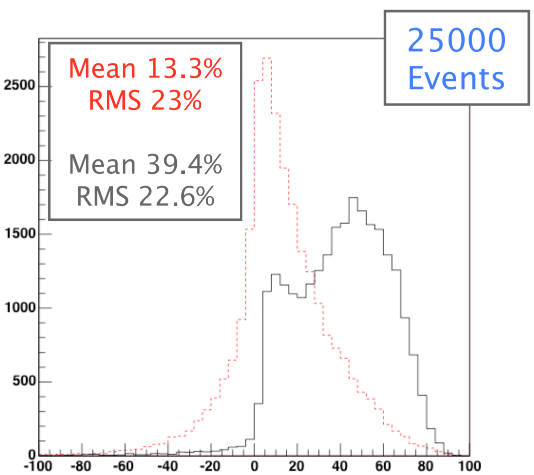


(E ν – E vis) / E ν (%)

NEG Ar (Res)



E ν – E vis (MeV)



(E ν – E vis) / E ν (%)

complete reconstruction

μ stand alone reconstruction

QE/non-QE Measurement

- The measurement of the ratio QE/non-QE is our final goal. To achieve it we analyse the distribution of 2 variables that could be eventually used to discriminate the two types of events:

  1. 4-momentum transferred Q^2.
  2. Invariant mass of the hadronic system W.

$$Q^2 = 4E_\nu E_\mu \sin^2 \theta/2$$

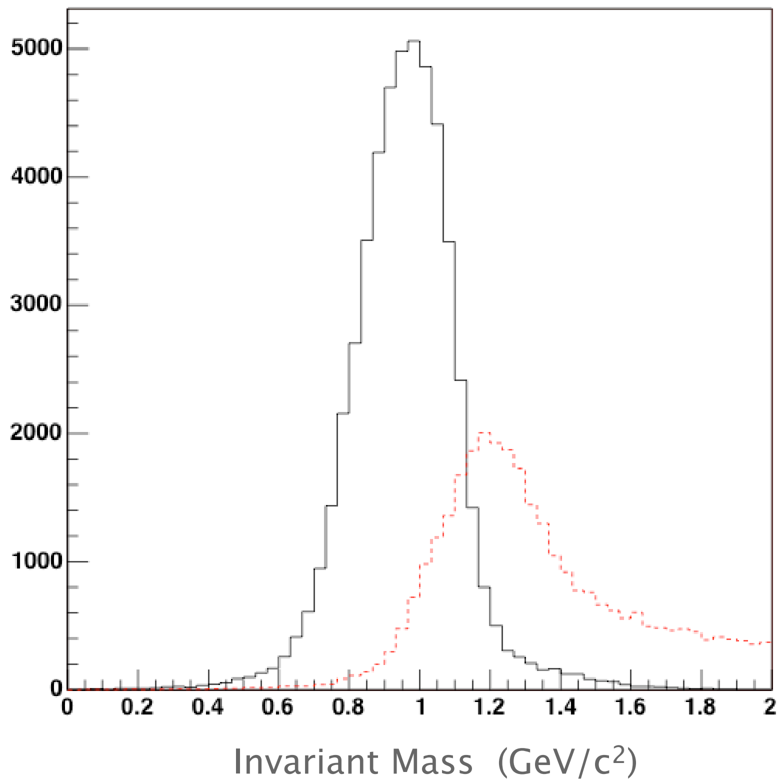
$$W^2 + Q^2 = 2M\nu + M^2$$

$$\nu = E_{had} - M = E_\nu - E_\mu$$

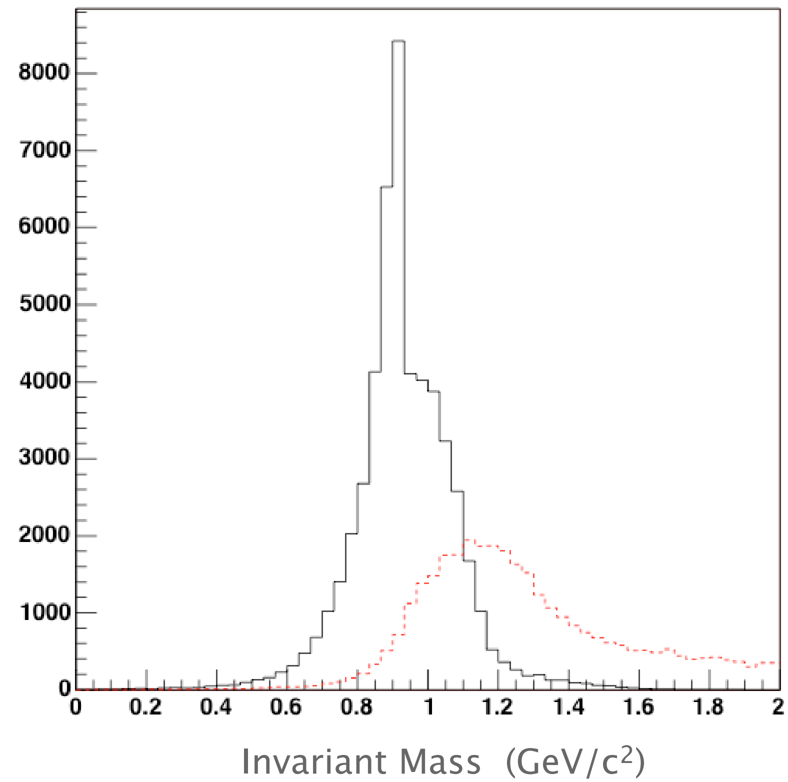
- The analysis has been carried out using 90000 complete events from NUX generator. No reinteraction has been included and only Fermi motion has been taken into account.

W Reconstruction

MC information (generator level)



Fullreco

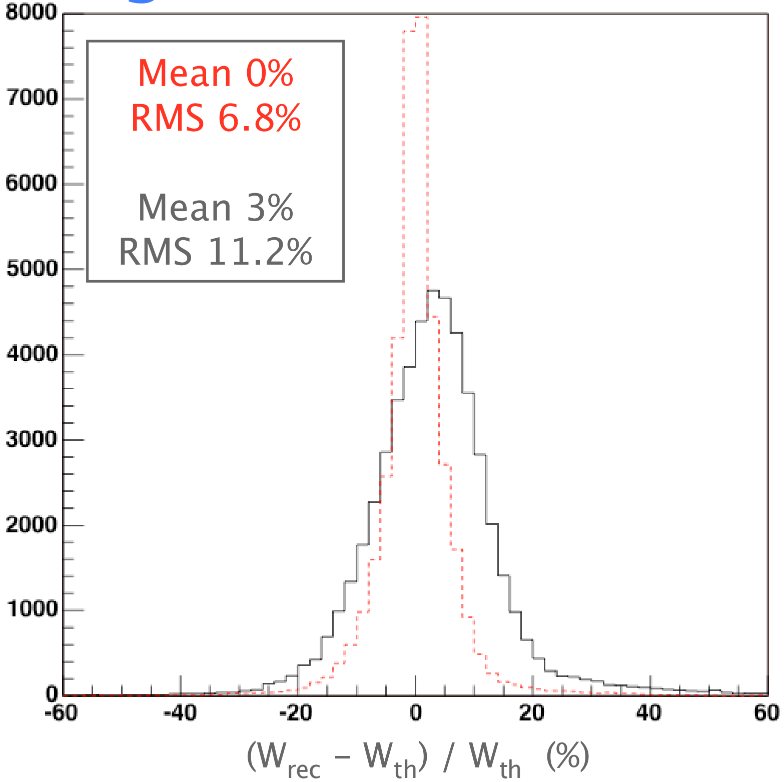


QE interactions (51596 Events)

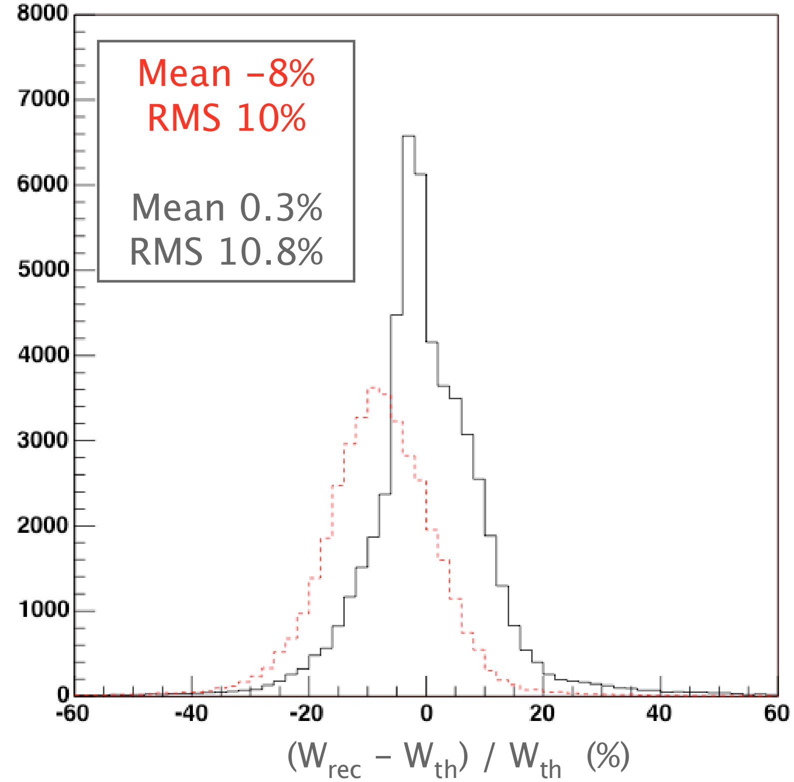
non-QE interactions (38404 Events)

W Resolution

MC information (generator level)



Fullreco

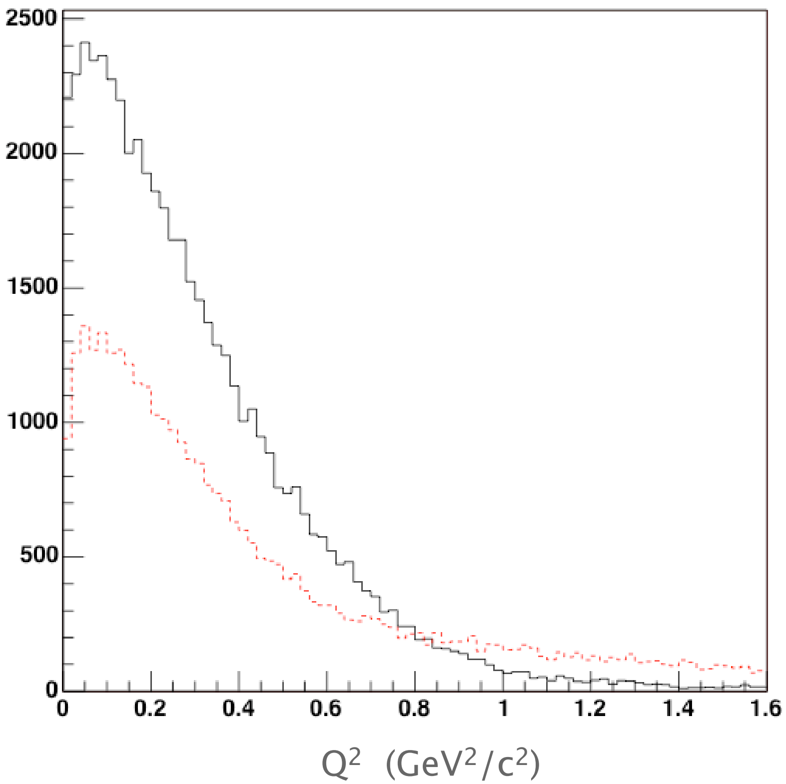


QE interactions (51596 Events)

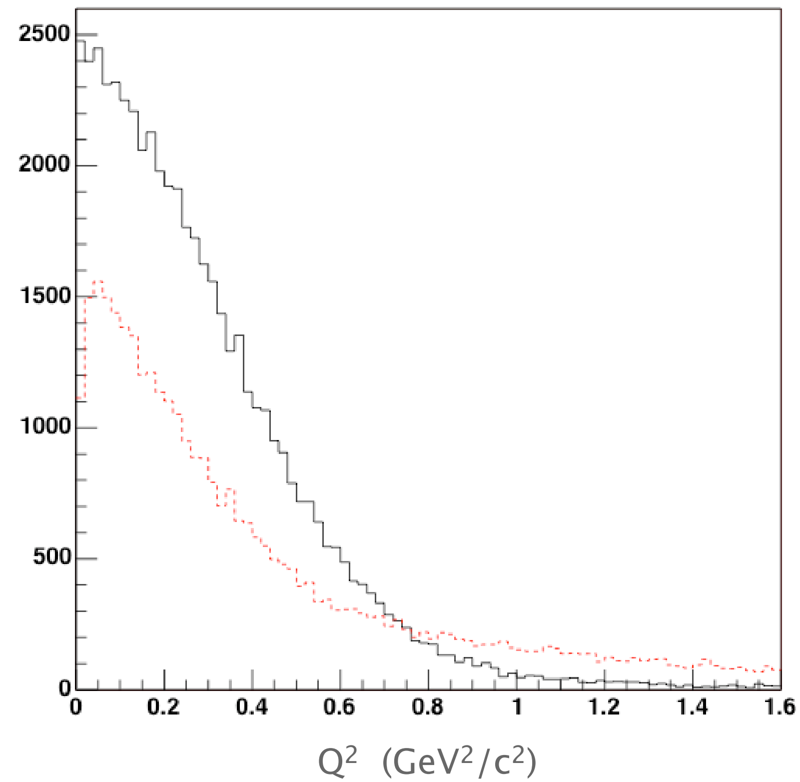
non−QE interactions (38404 Events)

Q^2 Reconstruction

MC information (generator level)



Fullreco

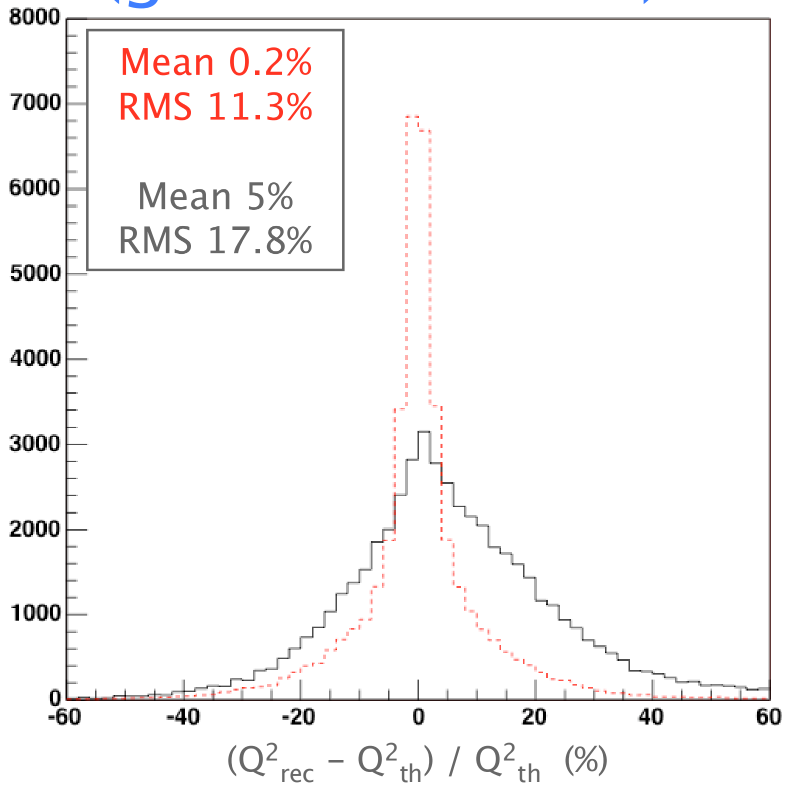


QE interactions (51596 Events)

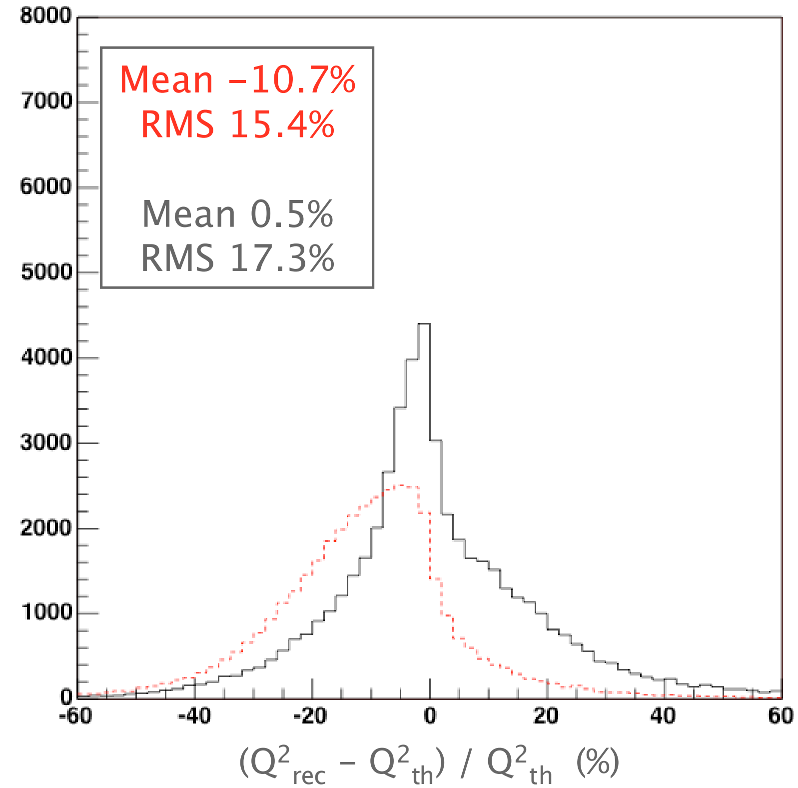
non-QE interactions (38404 Events)

Q^2 Resolution

MC information (generator level)



Fullreco



QE interactions (51596 Events)

non-QE interactions (38404 Events)

Nuclear Reinteraction

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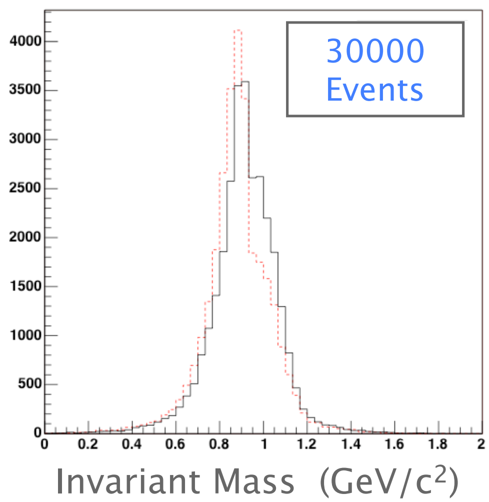
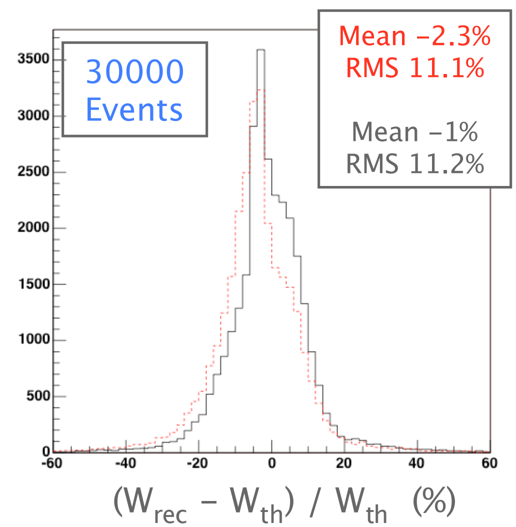
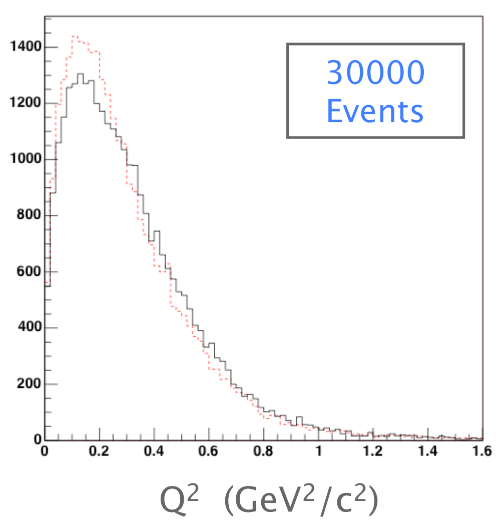
QE Interactions

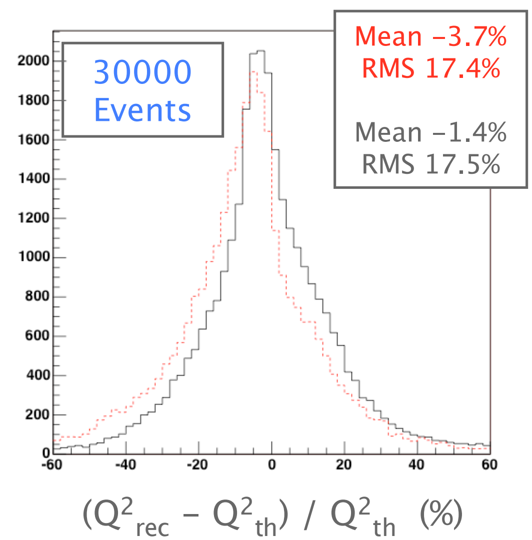
W





Q^2





Nuclear effects (Ar) NEG

No nuclear effects (NR) NEG

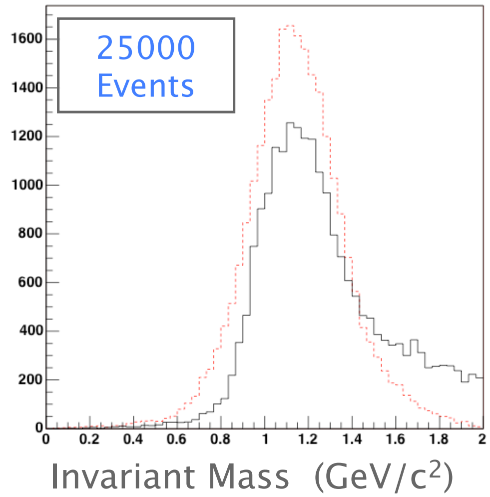
non–QE Interactions

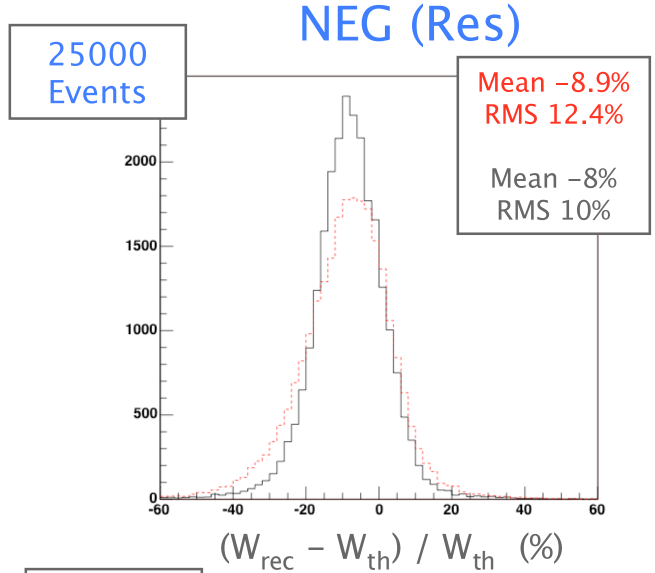
Work in progress

NUX (Full)

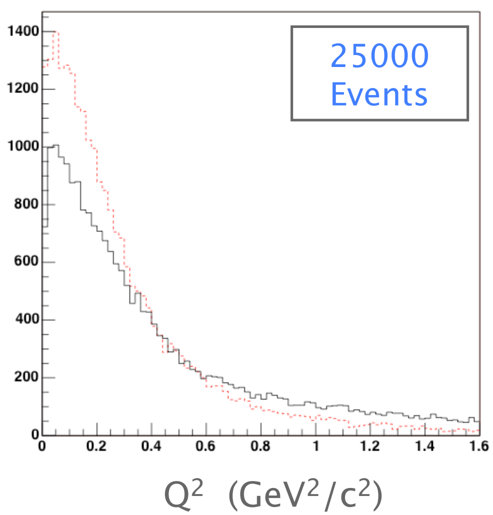
NEG (Res)

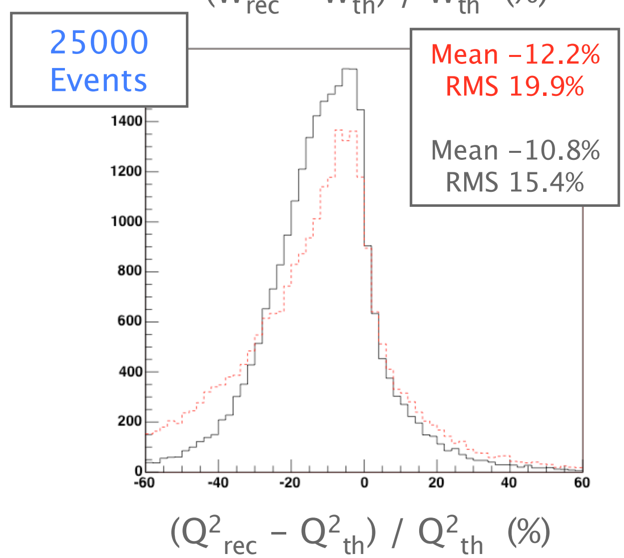
W





Q^2





Nuclear effects (Ar) NEG

No nuclear effects (NR) NUX

Preliminary Comments

- Discrimination on the type of event based on these 2 variables has not yet been done, but given our resolution, this seems quite promising.
- Nuclear effects do not degrade our resolution on Q^2 and W.
- The reconstructed spectra of W and Q^2 change because of the difference between NEG and NUX events, but the resolution is not affected too much.
- To discriminate between QE and non-QE interactions, in addition to the study of Q^2 and W, we can apply a topological criteria. This should enhance our capability to distinguish between the two types of events.

QE/non-QE Measurement Based On Topology

- We can distinguish between QE and non-QE events, using topological classes:
    1) CLASS0 : only a muon.
    2) CLASS1 : a muon and a proton above reconstruction cuts.
    3) CLASS2 : a muon,(a proton) and other particles above reconstruction cuts.
- In case of no reinteraction (NR) the separation is almost perfect:
    - 100% of QE events are in CLASS0 (10.86%) or CLASS1 (89.14%)
    - 99.98% of non-QE events are in CLASS2
- Taking into account nuclear effects (Ar) the results are:
    - 96.73% of QE events are in CLASS0 (30.58%) or CLASS1 (66.15%)
    - 95.17% of non-QE events are in CLASS2

QE/non-QE Measurement Based On Topology

- Using NUX events instead of NEG events changes ratio between events in CLASS0 and events in CLASS1 because of Pauli blocking effect.
- NUX QE events:
  - CLASS0 (18.54%) or CLASS1 (81.46%)
- NEG QE events:
  - CLASS0 (10.86%) or CLASS1 (89.14%)
- The difference is appreciable and will give us important information on nuclear effects and neutrino interaction cross section at low energy.

The End

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