Neutrino Event Generator: GENIE - tutorials

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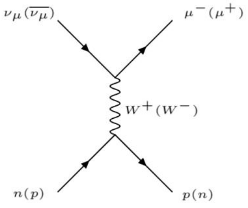
Understanding The Universe Through Neutrinos

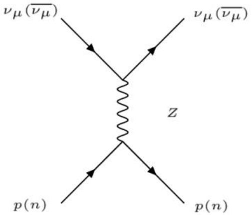
Outlines :

- Can we do better than SAND detector to understand the systematics due to nuclear effect ?
- What is the neutrino energy range that we can detect at ANNIE phase-II and Phase-III ?
- Can we measure Q^2 at 2.5 GeV neutrino beam energy at ANNIE data ?
- Can we understand missing hadrons energy at 2.5 GeV neutrino beam energy with ANNIE phase II or Phase III data ?

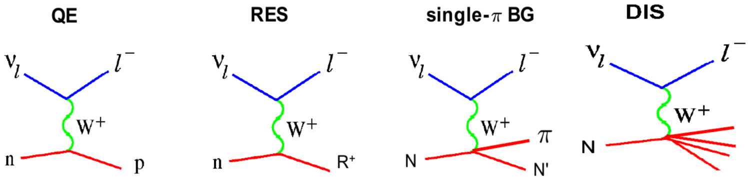
Neutrino-Nucleus Interactions

- A neutrino interacts via charged current and neutral current interactions.



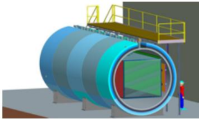


- Various energy dependent neutrino interaction processes

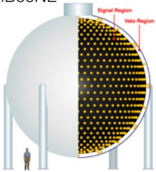


- To increase neutrino interaction rates: experiments use heavy nuclear targets with high atomic mass numbers like Ar(A=40), C(A=6), Ca(A=40).
- Heavy nuclear targets gives a boost to the event statistics in turn reducing the statistical uncertainties but at the same gives rise to the systematic uncertainties which are ultimately required to be tuned.

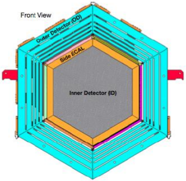
MicroBooNE

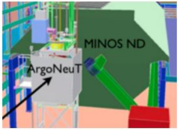


MiniBooNE



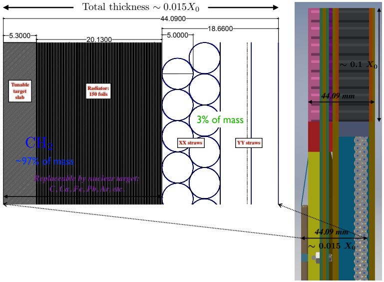
MINERvA





Hydrogen Target

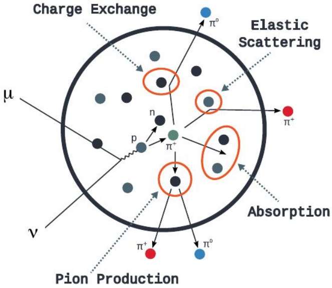
- Control sample free from nuclear effects to calibrate (anti)neutrino energy scale.
- Direct constraints on nuclear effects required to reduce systematics from nuclear targets.
- Straw Tube Tracker designed for a control of ν - target(s), proposed to build at ND hall.
- Separation from excellent vertex, angular and timing resolutions[1].
- Thin targets replaceable during data taking CH_2, C, Ca, Fe, Pb, etc.



[7]R. Petti (South Carolina), (NDNN(nustec2021))

Nuclear Effects

- **Initial State Interactions**
  - Nuclear Binding
  - Fermi motion
  - Pauli blocking
- **Final State Interactions**
  - absorption of outgoing particles
  - rescattering, charge exchange
  - production of new particles
- A model must include realistic description of nuclear effects including both ISI and FSI



Uncertainties in the ν-nucleus cross-section

- Two main reasons:
  - poor knowledge of neutrino flux
  - recent cross section measurements have been performed on nuclear targets
- Neutrino experiments measure a convolution of energy dependent neutrino flux $\bigotimes$ energy dependent cross-section $\bigotimes$ energy dependent nuclear effects.
- Interacting neutrino energy is evaluated based on kinematics of particles in the final state, taking into account detector acceptance.

Calorimetric technique

- Applying the calorimetric approach i.e. summing up all the outgoing particles, E_ν^{Calor} (reconstructed neutrino energy), can be calculated as-

$$E_\nu^{Calor} = E_{lep} + \sum_i T_i^{nuc} + \epsilon_{nuc} + \sum_m E_m \tag{1}$$

- where E_{lep} is the outgoing final state charged lepton's energy, T_i^{nuc} is the kinetic energies of the outgoing nucleons(i.e. the protons and/or neutrons), their corresponding separation energies represented as ϵ_{nuc} and total energy of any other particle produced represented as E_m.
- We can also write Equation(1) as- $E_\nu^{Calor} = E_{lep} + E_{had}$, where,

$$E_{had} = \sum_i T_i^{nuc} + \epsilon_{nuc} + \sum_m E_m \tag{2}$$

- For incoming neutrino with an energy < 1 GeV, CCQE interaction is the dominant interaction mode.
- The two-body kinematics of this interaction offers a simplified calculation of neutrino energy by using the kinematics of the outgoing lepton only i.e. the angle and energy of the outgoing muon.

$$E^{\nu}_{rec} = \frac{2(M - E_b)E_\mu - (E_b^2 - 2ME_b + m_\mu^2 + \Delta M^2)}{2(M - E_b - E_\mu + |\vec{p_\mu}|cos\theta_\mu)} \tag{3}$$

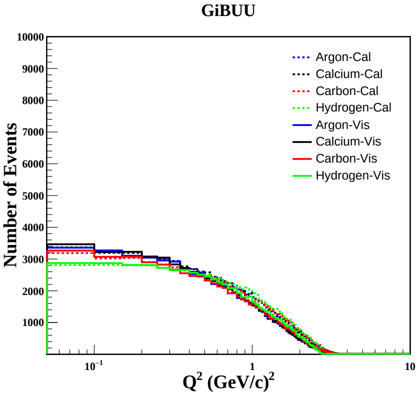
- Here E_μ, m_μ, p_μ is the energy, mass and momentum of the outgoing muon and θ_μ is the angle between the direction of outgoing muon and incoming neutrino. M is the mass and E_b is the binding energy of the struck neutron.
- $\Delta M^2 = M_n^2 - M_p^2$.

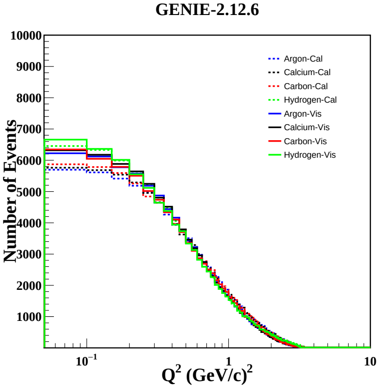
Q^2 Estimation

- Q^2 is calculated as-

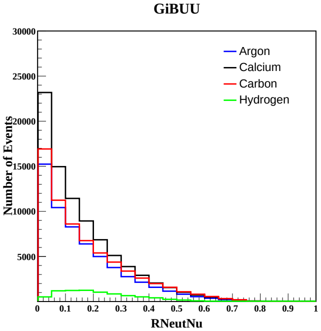
$$Q^2 = 2E^{\nu}_{rec}(E_\mu - p_\mu cos\theta_\mu) - M_\mu^2 \quad (4)$$

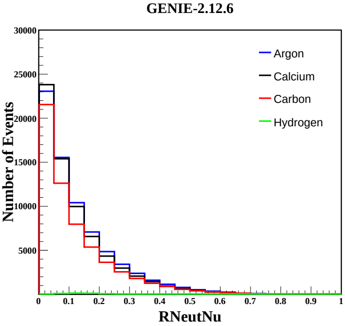
where M_μ, p_μ, E_μ and θ_μ are the mass, momentum, energy and angle of the outgoing muon.

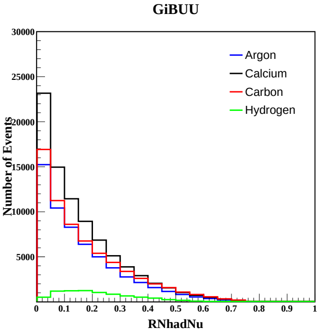


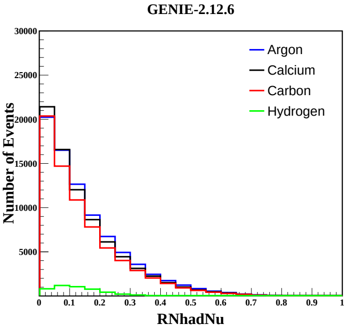


- **RNeutNu** = KE-Neutron/EnuTrue
  This ratio defines the fraction of kinetic energy of neutrons with respect to the true neutrino energy.
- **RNHadNu** = KE-NeutralHadrons/EnuTrue
  This ratio defines kinetic energy of neutral hadrons with respect to the true neutrino energy.






GiBUU
Argon
Calcium
Carbon
Hydrogen
Number of Events
RNhadNu
30000
25000
20000
15000
10000
5000
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


GENIE-2.12.6
Argon
Calcium
Carbon
Hydrogen
Number of Events
RNhadNu
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25000
20000
15000
10000
5000
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1