Notes on neutrino energy reconstruction

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1 Kinematics of $\nu e^- \to l\nu$ interaction

There is a well-known kinematic relation for the two-body interaction $\nu e^- \to l\nu$

$$E_\nu = \frac{2E_l m_e - m_l^2 - m_e^2}{2(m_e - E_l + p_l \cos\theta_l')}, \tag{1}$$

where E_ν is the incoming neutrino energy, E_l (p_l) is the outgoing lepton energy (momentum), θ_l' is the outgoing lepton angle with respect to the incoming neutrino and m_e (m_l) is the electron (outgoing lepton) mass. A near detector measures the angle of the outgoing lepton with the z axis - θ_l, rather than the angle θ_l'. Let the coordinate system be as shown in Figure 1. The azimuth angle of the neutrino can be determined by the position of the vertex in the detector. Let's assume it is zero for simplicity. Then, the relation between θ_l' and θ_l is given by

$$\cos\theta_l' = \cos\theta_\nu \cos\theta_l + \sin\theta_\nu \sin\theta_l \cos\varphi_l, \tag{2}$$

where θ_ν is the neutrino angle with respect to the z axis and φ_l is the azimuth angle of the lepton (in xyz frame).

2 Naive neutrino energy reconstruction.

Let's use Equation 1 with the assumption $\theta_l' = \theta_l$ to reconstruct the neutrino energy. The lepton's energy and angle with respect to z axis are taken from MC truth (no detector resolution is involved!). The resolution matrix and the relative difference $(E_\nu^{rec} - E_\nu^{true})/E_\nu^{true}$ for the event sample at hand are shown on Figure 2. The reconstructed neutrino energy significantly deviates from the true one.

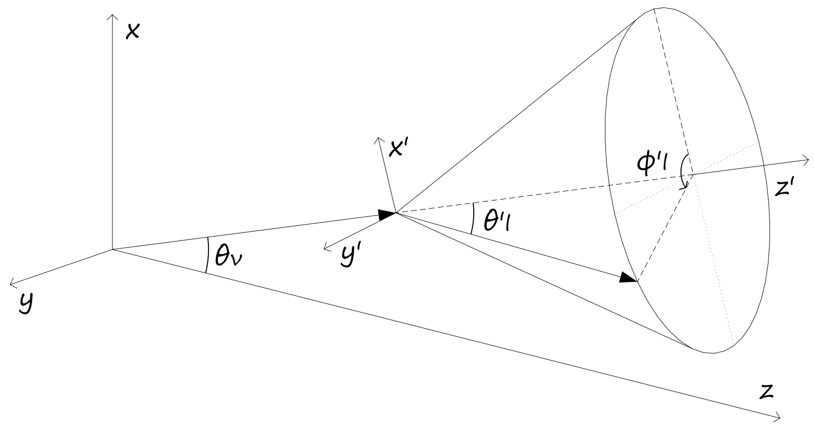

Figure 1:

3 Improved neutrino energy reconstruction.

The unknown angle θ_ν can be constrained from the radial position of the vertex, the possible muon decay positions and the $E_\nu < E_{beam}$ limit. Then one can average on the possible θ_ν angles and estimate θ'_l by using Equation 2. Again, the lepton's kinematic variables (E_l, θ_l, φ_l) are taken from MC truth. The resolution matrix and the relative difference $(E_\nu^{rec} - E_\nu^{true})/E_\nu^{true}$ for the event sample at hand are shown on Figure 3. One can see a significant improvement over the naive method. However, the ambiguity coming from the unknown neutrino angle (or muon decay position) cannot be eliminated on event-by-event basis.

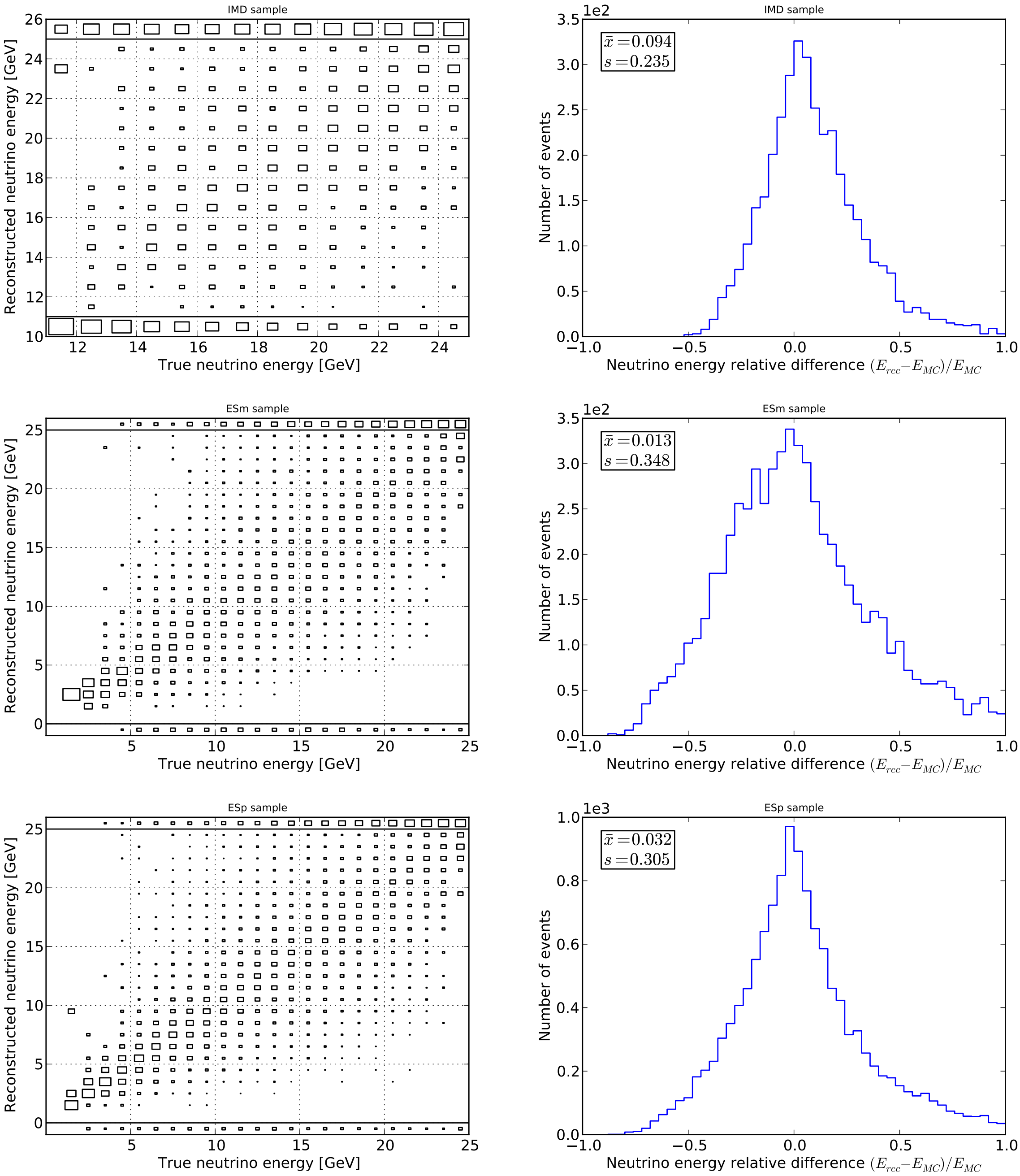

Figure 2: Naive reconstruction. Left - resolution matrix (sum over each column is normalized to unity). Overflow and underflow bins are separated with horizontal lines. Right - relative difference $(E_\nu^{rec} - E_\nu^{true})/E_\nu^{true}$ for the leptonic event sample (background excluded). Top - IMD sample, middle - ES$^-$ sample, bottom - ES$^+$ sample.

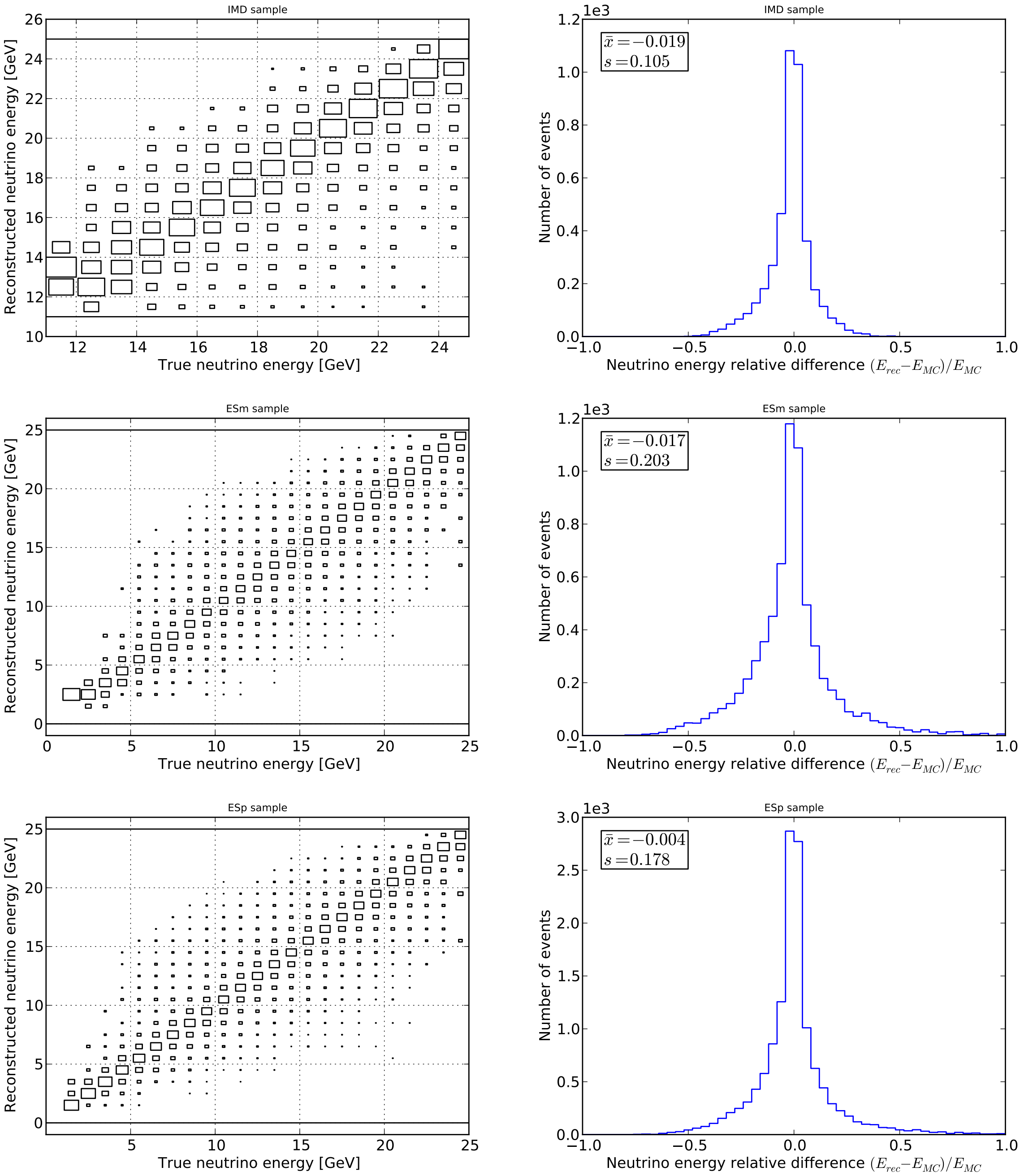

Figure 3: Improved reconstruction. Left - resolution matrix (sum over each column is normalized to unity). Overflow and underflow bins are separated with horizontal lines. Right - relative difference $(E_\nu^{rec} - E_\nu^{true})/E_\nu^{true}$ for the leptonic event sample (background excluded). Top - IMD sample, middle - ES$^-$ sample, bottom - ES$^+$ sample.