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Neutrino energy reconstruction in disappearance experiments with calorimetric and kinematic methods

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Summary. — Modern experiments aimed at measuring neutrino oscillation parameters have entered the age of precision. The determination of these parameters strongly depends on the ability to reconstruct the energy of the neutrinos. We compare two different energy reconstruction techniques: the reconstruction based on the kinematics of the outgoing lepton and the one based the calorimetric method.

1. – Neutrino energy reconstruction

Consider charged current neutrino scattering on a nucleus: $\nu_\ell(k) + A \rightarrow \ell^-(k') + X$, where X denotes a final state of n nucleons knocked out from the nucleus and m mesons produced in the process. The neutrino energy can be reconstructed using the kinematic of the outgoing lepton, *i.e.* assuming that the invariant hadronic mass W^2 is known. In this case, applying energy and momentum conservation, the neutrino energy is given by

$$E_\nu^{kin} = \frac{2(nM - \epsilon_n)E' + W^2 - (nM - \epsilon_n)^2 - m_\ell^2}{2(nM - \epsilon_n - E' + |\vec{k'}| \cos\theta')}, \tag{1}$$

where E' is the energy of the outgoing lepton, $\vec{k'}$ its momentum and θ' its angle with respect to the direction of the incoming beam. ϵ_n represents the separation energy and W^2 is set to the squared nucleon mass M^2 for meson-less events, and to M_Δ^2 otherwise (with $M_\Delta = 1.232\,\text{GeV}$). The knowledge of the particles in the final state, and of their

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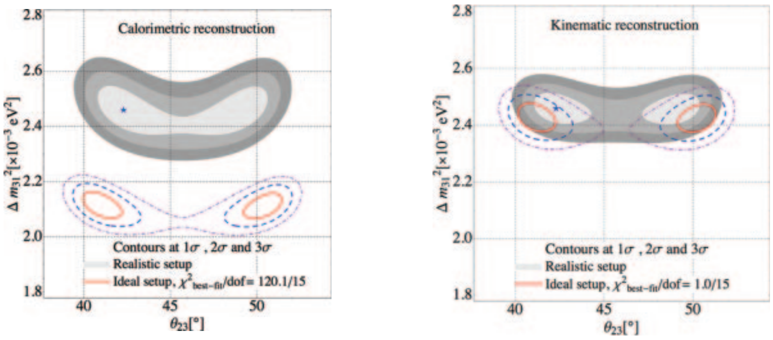

Fig. 1. – (Color online) Confidence regions at $1, 2$ and 3σ for calorimetric (left panel) and kinematic (right panel) reconstruction. The shaded areas are obtained when the true and fitted rate are computed with the same set of migration matrices (from realistic setup). The lines are obtained when the fit is performed using the event distribution derived from ideal migration matrices. The star represents the true input values $(\theta_{23}, \Delta m^2_{31}) = (42.30°, 2.46 \times 10^{-3}\,\mathrm{eV}^2)$.

deposited kinetic energies, can be used to reconstruct the neutrino energy using the so-called calorimetric method

$$E_\nu^{cal} = E' + \epsilon_n + \sum_i^n (E_{\mathbf{p}'_i} - M) + \sum_j^m E_{\mathbf{h}'_j}, \tag{2}$$

where $E_{\mathbf{p}'_i}$ and $E_{\mathbf{h}'_j}$ denote the energies of the i-th knocked-out nucleon and of the j-th produced meson, respectively. These two reconstruction schemes were employed to analyze the events generated with GENIE [1]. We produced the migration matrices, $\mathcal{M}_{ij}$, that define the probability for an event with true energy in the j-th bin to be reconstructed in the i-th energy bin.

2. – Results

The analysis for the oscillation parameters has been done using the software GLoBES [2, 3], in the oscillation channel $\nu_\mu \to \nu_\mu$. We compare the results, for the two reconstruction methods in eqs. (1), (2), obtained in a long-baseline experiment ($L = 295\,\mathrm{km}$), with a narrow band off-axis beam peaked at $\sim 600\,\mathrm{MeV}$. The *true* event rates are computed with the oscillation parameters reported in ref. [4], and using migration matrices generated accounting for detector effects such as detection efficiencies and energy resolution for outgoing particles, with the aim of reproducing a "realistic" experimental setup. The study of the oscillation parameters is performed comparing the results for the fit, when we use "ideal" migration matrices, *i.e.* all the particles in the final state are observed and their measured energies are equal to the true ones. The results, in the $(\theta_{23}, \Delta m^2_{31})$ plane, are shown in fig. 1. The confidence regions are obtained requiring $\Delta\chi^2(\theta_{23}, \Delta m^2_{31}) < 2.30, 6.18, 11.83$ (details in refs. [5] and [6]). The calorimetric reconstruction, compared to the kinematic one, even if it includes a deeper knowledge of the final state, suffers most from the experimental uncertainties linked to its reconstruction.

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