Neutrino DIS in Nuclear PDF Fits

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Nuclear parton distribution functions (nPDFs) are essential for describing the distributions of quarks and gluons in bound nucleons. Together with QCD factorization theorems, they allow for perturbative predictions of hard-scattering processes involving nuclei. Since the non-perturbative x-dependence of PDFs cannot be calculated from first principles, nuclear PDFs are determined in global analyses by comparing theoretical predictions to a wide range of experimental data.

One particularly important process is deep-inelastic-scattering (DIS) of (anti-)neutrinos off nuclear targets, which provides constraints complementary to charged-lepton DIS and measurements at hadron colliders, particularly at moderate-to-large x and relatively low Q^2. In charged-current DIS, neutrinos interact with quarks through the exchange of a $W^{\pm}$ boson, giving direct sensitivity to different combinations of quark flavours.

The consistent inclusion of neutrino DIS data in global nPDF analyses has been debated for some time. Early studies found indications of large tension between neutrino DIS and charged-lepton DIS/Drell–Yan data, although its significance was shown to depend on the treatment of experimental uncertainties and normalization effects [1, 2, 3]. A dedicated reanalysis within the nCTEQ framework found that the degree of compatibility depends sensitively on the data selection, kinematic cuts and correlated systematic uncertainties, with significant tensions remaining for parts of the neutrino data [4].

Since neutrino DIS probes relatively low Q^2, heavy-quark mass effects can be sizeable and may therefore affect the assessment of these tensions. A consistent description over the full kinematic range requires a treatment retaining the heavy-quark masses m_Q close to the production threshold, while resumming logarithms of (Q^2/m_Q^2) at large scales. General-mass variable-flavour-number schemes, such as the ACOT scheme [5, 6, 7, 8], achieve this by interpolating between the fixed-flavour-number description near threshold and the massless variable-flavour-number description at $Q^2 \gg m_Q^2$, thereby retaining the relevant heavy-quark mass effects while resumming potentially large collinear logarithms.

Massive heavy-quark corrections to charged-current DIS have been developed within general-mass schemes at NNLO [9, 10]. Recently, these results have been implemented in an approximate NNLO ACOT framework suitable for fast PDF analyses [11], showing sizeable mass effects in parts of the kinematic region relevant for neutrino DIS. This provides the basis for a systematic reanalysis of neutrino DIS data in a dedicated nCTEQ fit. The aim of the PhD project is to investigate how the improved treatment of heavy-quark mass effects affects the compatibility of neutrino data with the remaining global nPDF dataset and the resulting flavour-dependent nuclear modifications. Such an analysis represents an important step towards NNLO-accurate global nPDF analyses.

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