Snowmass2021 - Letter of Interest

Electroweak precision measurements in low energy neutrino experiments.

NF Topical Groups: (check all that apply □/■)

□ (NF1) Neutrino oscillations
□ (NF2) Sterile neutrinos
□ (NF3) Beyond the Standard Model
■ (NF4) Neutrinos from natural sources
■ (NF5) Neutrino properties
□ (NF6) Neutrino cross sections
□ (NF7) Applications
■ (NF9) Artificial neutrino sources
□ (NF10) Neutrino detectors
■ (EF04) EW Physics: EW Precision Physics and constraining new physics

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The specific set of particles and gauge interactions in the Standard Model (SM) predicts univocally the behavior (running) of the weak mixing angle θ_W at different energy scales. Although the running is dependent on the renormalization scheme, the prediction at low energies follows from a measurement of $\sin^2\theta_W$ at high energies [1–3]. Such running has been experimentally confirmed by different experiments observing distinct phenomena. Nevertheless, the only measurement performed with neutrinos precise enough to test the SM prediction, the NuTeV measurement [4], presents a deviation of $\sim 3\sigma$ from the expected standard model value. Several works have raised some concerns on the NuTeV result [5–22], but the final word should come from other experiments. Thus, it is an important endeavour to scrutinize other possible methods to precisely measure the mixing angle with neutrino interactions.

Some of the reasons for the NuTeV discrepancy, as suggested in the literature, are related to the complexities present in neutrino-nucleus interactions [23]. Therefore, processes that do not endure nuclear or non-perturbative effects could shed some light on the NuTeV result. One attractive candidate is the neutrino-electron elastic scattering, a theoretically well known process [24;25]. Nevertheless, measurement of the neutrino-electron scattering presents some experimental difficulties. This process, for instance, is about three orders of magnitude suppressed with respect to neutrino-nucleon charged-current scattering. Thus, achieving competitive measurements would require either large detectors or sources producing a large neutrino flux.

One possible method to measure the neutrino-electron scattering cross section with enough precision consists in considering the near detectors of future experiments, such as the Deep Underground Neutrino Experiment (DUNE) [26] or the Tokai-to-HyperKamiokande (T2HK) [27]. Such near detectors, whose main purpose is to reduce systematic uncertainties for neutrino oscillation measurements, will be impinged by very intense neutrino beams, which will result in unprecedented high statistics of neutrino-electron events. For the specific case of DUNE, the exquisite performance of Liquid Argon TPCs will grant a precise measurement of the recoil electron energy and direction. Nevertheless, the incoming neutrino flux still will have large uncertainties, mainly related to meson production rates.

A viable solution to reduce uncertainties related to the neutrino flux is to consider measurements at different on- and off-axis positions. In DUNE-PRISM [28], a movable near detector in the direction perpendicular to the incoming neutrino beam, the uncertainties will be reduced, thus allowing for a significant improvement on the measurement of the weak mixing angle. It has been shown that DUNE-PRISM could achieve a precision of about $\sim 2\%$ at a momentum transfer of about $\langle Q\rangle \sim 55$ MeV[29].

In addition, another possible way to measure the mixing angle via neutrino-electron scattering is to consider current and future measurements of the solar neutrino flux. As a matter of fact, Borexino has recently presented a measurement of the mixing angle[30]. Although such result is not competitive with the measurement of CHARM[31], it is comparable with the measurement of TEXONO[32], a reactor experiment. In the future, it is expected that solar neutrino measurements could add nontrivial information to the measurement of the weak angle.

Yet a third possibility to measure the weak mixing angle is to exploit the recent measurement of the Coherent Neutrino-Nucleus Scattering (CEνNS). Albeit it is an interaction with the nucleus, the relatively small momentum transfer in the scattering ensures that hadronic uncertainties are of different origins with respect to those impacting NuTeV. In fact, the measurement performed by the COHERENT collaboration[33] has resulted on a measurement of the mixing angle at momentum transfer of $Q \sim 10^{-3}$ GeV[34]. Thus, an independent program of measuring the weak angle can be achieved in experiments intended to measure the CEνNS interaction. Besides COHERENT, of particular interest is the future CEνNS experiment based on Skipper-CCD detectors[35;36], exposed to very intense neutrino sources like nuclear reactors, as the proposed νIOLETA experiment. νIOLETA will have exceptionally low detection thresholds, and relatively high statistics, possibly allowing for a competitive measurement of the mixing angle.

In this letter, we propose to the community to perform a global precision physics analysis of the weak mixing angle with data of current and future neutrino experiments.

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