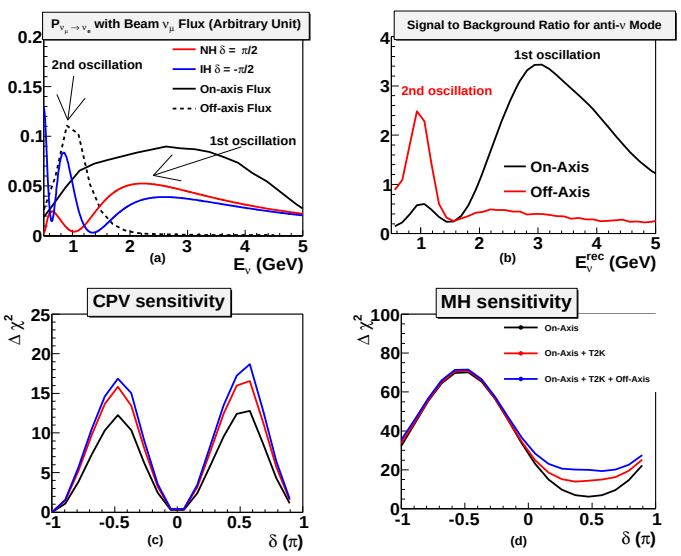
A Second Detector at an Off-axis Location to Enhance the Mass Hierarchy Discovery Potential in LBNE

X. Qian[1], J. J. Ling[2], R.D. McKeown[3], W. Wang[3], E. Worcester[2], C. Zhang[2]
[1]Kellogg Radiation Laboratory, California Institute of Technology, Pasadena, CA
[2]Physics Department, Brookhaven National Laboratory, Upton, NY
[3]Colleage of William and Mary, Williamsburg, VA

The recent discovery of sizable θ_{13} [1-5] opens door to the determination of the neutrino mass hierarchy (MH) and the CP phase δ in the leptonic sector [6]. The Long-Baseline Neutrino Experiment [7] (LBNE) is on its track to access the MH and δ simultaneously with the (anti-)ν_μ to (anti-)ν_e oscillation modes at 1300 km. With a wide band beam, the LBNE on-axis detector (10 kT Liquid Argon detector in phase-I) will cover both the 1st and the 2nd oscillation maxima (Fig. a) with an emphasis on the 1st. Due to the potential cancellation between the matter effect and the effect of δ at the 1st maximum, the discovery potential of MH strongly depends on the true value of δ (Fig. d). In addition, an ambiguity in MH may compromise the mission to determine δ without adequate statistics. While the cancellation happens at the 1st maximum (Fig. a shows the neutrino oscillation probability between normal hierarchy with δ=π/2 and inverted hierarchy with δ=-π/2), the matter effect and the effect of δ will support each other at the 2nd maximum resulting in a distinct feature [8]. We thus propose a second detector at an off-axis location dedicated to the 2nd maximum to enhance the MH discovery potential and the overall performance of the LBNE program.



Due to the 2-body kinematics of the pion decay, the off-axis neutrino flux is narrow in energy [9,10]. Fig. a shows neutrino flux with 2010 beam line design [7] at 27 mr off-axis, which approximately matches the location of the 2nd maximum. The narrow band beam will lead to fewer backgrounds. Fig. b shows the expected signal to background ratio for the anti-ν running (NH and δ=0) with a 10 kT off-axis water Cerenkov (WC) detector (SK2 performance [11] assumed). With sufficient shielding [12], such a detector can work on surface to reduce cost.

The physics sensitivities to MH and δ with the additional 10 kT WC detector (27 mr or 35 km off-axis at a distance of 1300 km) are calculated in GLoBES [13] with the 2010 LBNE flux and the up-to-date neutrino oscillation parameters [14] (Fig. c and Fig. d). The statistical interpretation of MH sensitivity is explained in detail in Ref. [15]. The off-axis detector will considerably improve the combined sensitivity of LBNE phase-I and T2K [16-18] in MH, with slight improvement in δ. In particular, the improvement to MH sensitivity of the second 10 kT off-axis WC detector is equivalent to that of an additional 10 kT on-axis LAr detector at worst possible δ. Such improvement will be further enhanced with optimizations [19]. For example, a narrower off-axis neutrino beam will significantly improve the MH sensitivity without increasing the total flux intensity.

In summary, a second detector at an off-axis location focusing on the 2nd oscillation maximum can enhance the MH discovery potential in LBNE and thus strengthen the measurement of CP phase δ in the leptonic sector.

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