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Probing the neutrino reactor anomaly with the T2K near detector

Davide Sgalaberna[*] **for the T2K Collaboration**
ETH Zurich, Switzerland
E-mail: davide.sgalaberna@cern.ch

Hints of possible electron neutrino disappearance that might be explained with the presence of additional sterile neutrinos (ν_s) have been observed in the so-called reactor and Gallium anomalies. This can be tested with the near detector (ND280) at the T2K experiment, a long baseline neutrino oscillation experiment designed to precisely measure the PMNS matrix by looking for the appearance of ν_e in a ν_μ beam. Thanks to its short baseline ND280 can be used to study sterile neutrino oscillations. Furthermore a very good ν_μ-ν_e separation can be performed and the large part of ν_μ background can be rejected. A full sensitivity study of $\nu_e \rightarrow \nu_s$ disappearance in the 3+1 neutrino mixing model is presented and compared with the other experimental results.

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[*] Speaker.

1. Sterile neutrinos

Sterile neutrinos are right-handed and do not undergo weak interaction. Their existence can be studied through the mixing with the active neutrinos. The 3+1 model is the minimal extension of the standard three neutrino mixing with the addition of one sterile neutrino field ν_s to the standard three active neutrino fields (ν_e, ν_μ and ν_τ).
In this model the ν_e to ν_s mixing is described by the survival probability

$$P_{\nu_e \to \nu_e} = 1 - \sin^2 2\theta_{ee} \cdot \sin^2 \left(\frac{1.27 \Delta m^2_{41} L_\nu}{E} \frac{[GeV]}{[eV]^2 [km]} \right) \tag{1.1}$$

where L_ν and E are the neutrino flight path and energy and $\sin^2 2\theta_{ee}$ and Δm^2_{41} are respectively the $\nu_e \to \nu_s$ transition amplitude and the mass square difference between the sterile and the standard neutrinos. Two indications of $\nu_e \to \nu_s$ disappearance come from the so-called "reactor neutrino anomaly" [2] and "Gallium anomaly" [3], [4], that can be explained assuming $\sin^2 2\theta_{ee} \sim 0.2$-$0.5$ and $\Delta m^2_{41} \sim 1\text{eV}^2$. Δm^2_{41} is much larger than the other two standard mass differences and is responsible for the short baseline oscillations.

2. Sensitivity to sterile ν_e disappearance with the near detector at T2K

The T2K (Tokai-to-Kamioka) experiment is a long baseline neutrino oscillation experiment that aims to precisely measure the PMNS matrix through the observation of $\nu_\mu \to \nu_e$ appearance. The neutrino beam is generated by a high intensity 31 GeV/c proton beam interacting on a carbon target and is detected by a near detector (ND280), 280 m from the target, and a far detector located 295 km away (Super Kamiokande). The neutrino beam is composed of about 99% of ν_μ and the remaining 1% of ν_e [1]. Since ND280 is close to the neutrino production target, it can be sensitive to an indirect detection of non standard neutrino oscillations.

The 3+1 model is used for the sensitivity study at ND280 to $\nu_e \to \nu_s$ where $U_{\mu 4}$ is assumed to be 0 in order to investigate the Gallium and reactor anomalies.

A clean ν_e sample with a purity of 67% is selected thanks to a very good μ-e separation: the magnetic field allows the separation of opposite charged particles and thanks to the good performance of the TPC and using informations of the Electronic Calorimeter (ECal) the 99.8% of μ is rejected. Then binned templates are built using the MC reconstructed energy distribution in the CCQE hypothesis (figure 1).

The dependency on the oscillation parameters ($\sin^2 2\theta_{ee}$, Δm^2_{41}) is introduced by weighting the ν_e component with the oscillation probability (equation 1.1). Neutrino flux, cross section, final state interaction and detector systematic uncertainties are taken into account introducing 50 nuisance parameters in the fit.

The MC sensitivity study at 90% C.L. is performed in the non oscillation hypothesis using a likelihood-ratio technique and the standard 2 d.o.f. confidence level method. The study is done with the data statistics until summer 2013 (6×10^{20} p.o.t.) taking into account all the systematic uncertainties and with all the statistics that T2K should collect during the next years (8×10^{21} p.o.t.), considering only statistical uncertainties. As shown in figure 2, with the current statistics part of the "Gallium anomaly" can be investigated. In the future, considering also that flux systematic

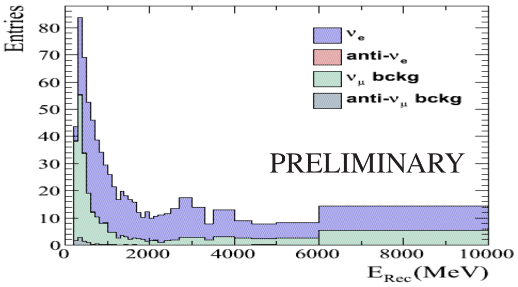

Figure 1: MC Reconstructed energy distribution at ND280 obtained after applying the ν_e selection. It corresponds to an exposure of 6×10^{20} p.o.t.

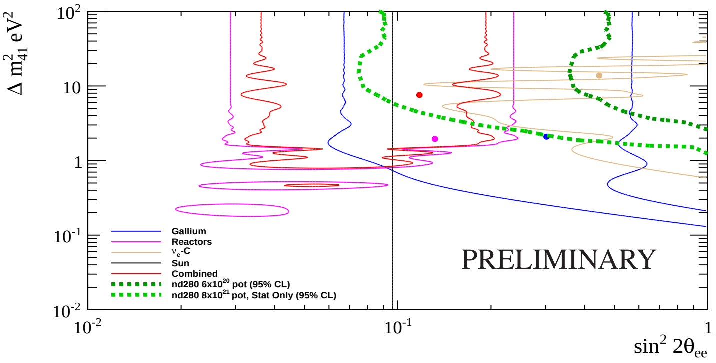

Figure 2: Comparison of the ND280 sensitivity with allowed region of $\nu_e \rightarrow \nu_s$ disappearance measured by other experiments [6]: Gallium experiments (blue), reactor anomaly (pink), solar experiments (black), $\nu_e C$ scattering data from LSND and KARMEN experiments (yellow) and the combined result (red). The dots correspond to the fitted minima of each different exclusion region. The ND280 sensitivity is shown taking into account all the systematic uncertainties with 6×10^{20} p.o.t. and only statistical uncertainties with 8×10^{21} p.o.t.

uncertainties will decrease thanks to the hadron production measurements of the NA61 experiment [5], also part of the allowed region of the reactor anomaly will be studied.

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