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MicroBooNE's Search for a Photon-Like Low Energy Excess

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MicroBooNE is a liquid argon time projection chamber (LArTPC) detector that took data from 2015-2021. One of its primary goals is to investigate the unexplained excess of electromagnetic events in the lowest energy ranges observed in the same neutrino beamline in the MiniBooNE experiment. While one leading interpretation of this anomaly is electron neutrino appearance due to sterile neutrino oscillations, a viable Standard Model explanation is neutrino-induced single photon events. The MicroBooNE single photon analysis looks to test this interpretation by measuring the rate of neutrino-induced resonant neutral current (NC) delta baryon production and subsequent delta radiative decay with a single photon in the final state, NC $\Delta \rightarrow N\gamma$. This search for a process that has never been observed before in neutrino scattering is projected to improve upon the current experimental limit from T2K by greater than a factor of thirty. This talk will present the status of the MicroBooNE single photon analysis and the outlook for subsequent measurements.

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[*] Speaker

1. Introduction

This talk presents the first MicroBooNE single photon search for NC Δ radiative decay as an interpretation of the MiniBooNE low-energy excess (LEE) [1–3]. This anomaly has been interpreted as evidence for new types of neutrinos or other physics beyond the Standard Model. A key question that has persisted about the LEE is the fact MiniBooNE could not differentiate neutrino interactions producing an electron (such as from ν_e appearance due to light sterile neutrinos) from those with a single photon in the final state. Thus, both types of interactions must be examined independently as a source.

Here we outline the photon-like and electron-like interpretations of MiniBooNE, the NC Δ radiative decay hypothesis, and the blind analysis developed to search for this process in MicroBooNE. Sensitivities are given for the expected MicroBooNE first result on Runs 1-3 and for the full data set on Runs 1-5. The conclusion discusses the unblinded results which were subsequently released for the first MicroBooNE single photon measurement with an exposure of 6.80×10^{20} protons on target (POT).

2. The MicroBooNE Experiment

MicroBooNE is an 85 metric ton active volume LArTPC situated at a similar baseline as MiniBooNE in the Fermilab Booster Neutrino Beam (BNB) [4]. The BNB is a ν_μ pure beam with $\langle E_\nu \rangle = 0.8$ GeV. LArTPC technology allows MicroBooNE to discriminate between electromagnetic showers originating from electrons and photons using both calorimetric and geometric information. The two key metrics are the ionization energy deposition (dE/dx) at the start of the shower and the photon conversion distance.

3. The NC Delta Radiative Decay Hypothesis

Neutrino-induced neutral current (NC) production of the $\Delta(1232)$ baryon resonance with subsequent Δ radiative decay is predicted to be the dominant source of single photons in neutrino-argon scattering in the BNB energy range [5]. Although Δ radiative decay is predicted in the Standard Model, it has never been directly observed in neutrino scattering. The leading limit in the neutrino sector in the energy range < 1 GeV was performed by T2K, for which the 90% confidence level limit is ~ 100 times the theoretically predicted rate of NC Δ radiative decay [6].

In a fit to the radial distribution of the MiniBooNE data with statistical errors only, an enhancement of the Monte Carlo prediction for NC $\Delta \rightarrow N\gamma$ by a normalization factor of $x_{\text{MB}} = 3.18$ gave the best fit for the observed LEE [3]. In MicroBooNE, we take this factor of 3.18 enhancement to the predicted NC $\Delta \rightarrow N\gamma$ rate as the signal definition for the single photon search. The T2K limit and the enhanced model are shown in Fig. 1.

4. The MicroBooNE Single Photon Search

The MicroBooNE NC $\Delta \rightarrow N\gamma$ search exclusively targets events with a single, photon-like electromagnetic shower and either no tracks or one proton-like track. These are referred to as

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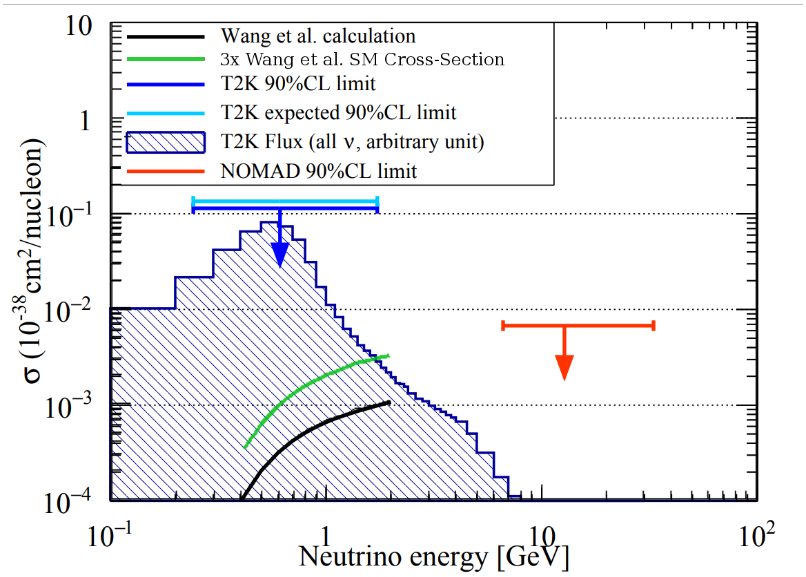

Figure 1: The 90% CL bound on NC Δ radiative cross-section at O(1GeV) energy by T2K [6]. Shown also in green is the Wang et al. Standard Model cross-section scaled up by a factor of ~3, the enhancement needed to fully explain the MiniBooNE excess.

$1\gamma 0p$ and $1\gamma 1p$ topologies respectively and primarily probe $\Delta \to n\gamma$ and $\Delta \to p\gamma$ decays. Both selections were developed using a small unblinded data set for data and Monte Carlo comparisons. High-statistics samples of NC π^0 data events were also used to minimize the systematic effects on this key background to the single photon selections. The final selections for the two single photon topologies are fit for the NC Δ radiative rate with a constraint from the *in situ* NC π^0 measurements.

The first selection step for both topologies is a set of pre-selection cuts targeting obvious backgrounds and misconstructions. Events that pass the cuts are then input to a set of boosted decision trees (BDTs), each of which is designed to reject a distinct background and select NC $\Delta \to N\gamma$ events. These include specifically cosmic, ν_e, and NC π^0 events in addition to the other neutrino backgrounds. The BDTs for the $1\gamma 1p$ and $1\gamma 0p$ selections are trained and optimized for each selection independently. The optimized BDT classifier score cuts correspond to the highest statistical significance of the NC $\Delta \to N\gamma$ signal over background in each sample. The Monte Carlo prediction for the final selections of the $1\gamma 1p$ and $1\gamma 0p$ topologies is shown in Fig. 2.

5. Projected Sensitivity

The expected 90% confidence level limits for a first result on Runs 1-3 and a second result on Runs 1-5 are shown in Fig. 3. Here we see that we expect the MicroBooNE measurement to be able to probe into region of 3.18× enhancement to NC $\Delta \to N\gamma$, the MiniBooNE single photon hypothesis, with the full data set. Moreover, the expected MicroBooNE limit is upwards of a factor of thirty improvement over the prior limit from T2K.

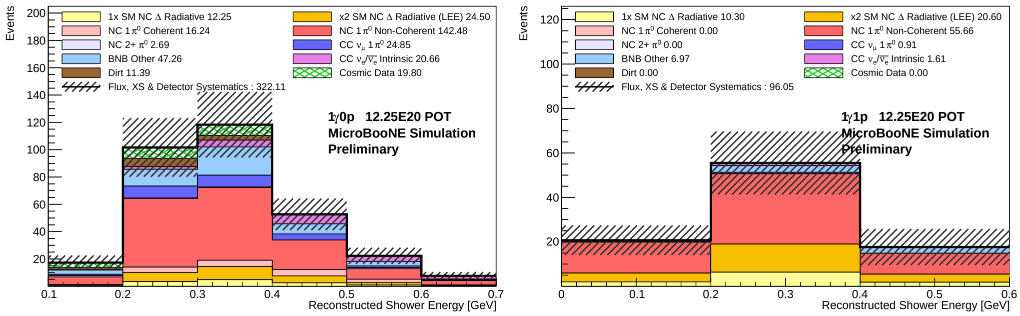

Figure 2: Final selection distributions for the $1\gamma 0p$ (left) and $1\gamma 1p$ (right) topologies. The distributions show predictions scaled to 12.25×10^{20} POT, which corresponds to the total POT for Runs 1-5.

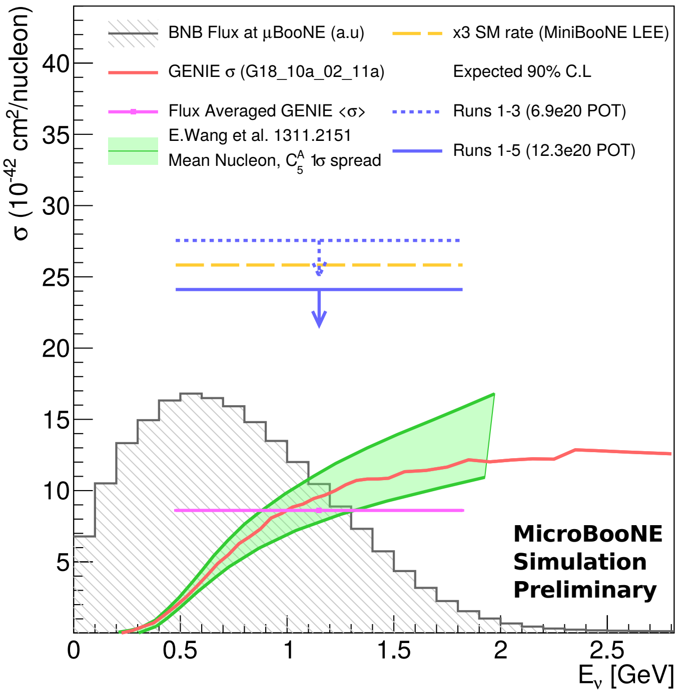

Figure 3: The expected classical 90% confidence intervals assuming observation of data consistent the unenchanced rate of NC Δ radiative decay. The GENIE v3 cross-section prediction is shown in red, alongside a leading theoretical calculation of the full single photon emission rate on argon in green [5], showing agreement with GENIE. The BNB neutrino flux is shown as the hashed gray histogram, as well as the total flux averaged GENIE cross section as the single point in magenta. The width of the horizontal errors bars represents 68% of the flux-times-cross-section distribution. Highlighted in yellow is the 3× the flux-averaged GENIE cross-section that represents the approximate enhancement to the Δ radiative decay rate in order for it to be the sole explanation of the MiniBooNE LEE.

6. Conclusion

As of October 2021 the unblinded result is available in [7]. No significant data excess was observed and the data disfavors a candidate photon interpretation of the MiniBooNE low-energy excess as a factor of 3.18 times the nominal NC Δ radiative decay rate at the 94.8% CL in favor of the nominal prediction. As expected, this measurement is the world-leading constraint neutrino-induced NC $\Delta \to N\gamma$ and provides a first direct test of the MiniBooNE anomalous excess under the photon-like hypothesis. In conjunction with the set of first CC ν_e measurements from MicroBooNE to test the electron-like hypothesis [8], which also show no significant excess, we can conclude that the true source of the MiniBooNE anomaly remains elusive.

With this first single photon search, MicroBooNE is demonstrating how LArTPC detector technology can be used to search for rare neutrino interactions with a photon in the final state. Subsequent results from MicroBooNE will include data from the full run period (1-5), corresponding to 12.25×10^{20} POT or nearly double the statistics of the first result presented here. This will also be expanded to include searches coherent photon production and more exotic photon-like processes in the near future.

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