An Expression of Interest to Perform a Search for New Particles Beyond the Standard Model: NewBooNE

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1. Executive Summary

The MiniBooNE experiment recently presented its first neutrino oscillation results [1], where approximately 1000 ν_e candidate events were observed over the entire range of energy ($E_\nu > 200$ MeV) and angle from approximately 5.58×10^{20} protons on target (POT). No significant excess of events was observed at higher energies, but a sizeable excess of events was observed at lower energies. The lack of a significant excess at higher energies allowed MiniBooNE to rule out simple 2-neutrino oscillations as an explanation of the LSND signal; however, the low-energy excess is presently unexplained and is actively being analyzed.

Although MiniBooNE was designed to search for neutrino oscillations, it can be reconfigured to search for new particles beyond the Standard Model with very high sensitivity by replacing the existing target and focusing horn by a beam dump. By having the Booster proton beam interacting directly in a beam dump, the neutrino flux is reduced by a factor of ~ 1000, but the flux of any new weakly interacting particles beyond the Standard Model produced by proton bremsstrahlung in the beam dump is unaffected. Thus, with hardly any background (< 3 events over the entire energy and angular range), new particles produced in the beam dump (or new sources of neutrinos) can be observed with the world's best sensitivity by their electromagnetic decay or scatter in the MiniBooNE detector.

2. Theoretical Motivation

Many proposals for new physics beyond the Standard Model (BSM) predict novel, weakly interacting, light scalar or vector particles. Classical examples of such particles include Majorons, axions, Kaluza- Klein modes in the Randall-Sundrum scenarios with extra dimensions and many others. As discussed over the years, novel light particles could be responsible, among other things, for solving the strong CP problem in QCD, giving neutrino its mass, or even explaining the origin of Dark Energy. Searches for such particles will be extremely difficult at the high energy colliders designed to search for new, high mass particles also associated with ESMs. Even with missing momentum techniques, it will also be exceptionally difficult to define the specific properties associated with such new particles, as well as to place stringent limits on their masses.

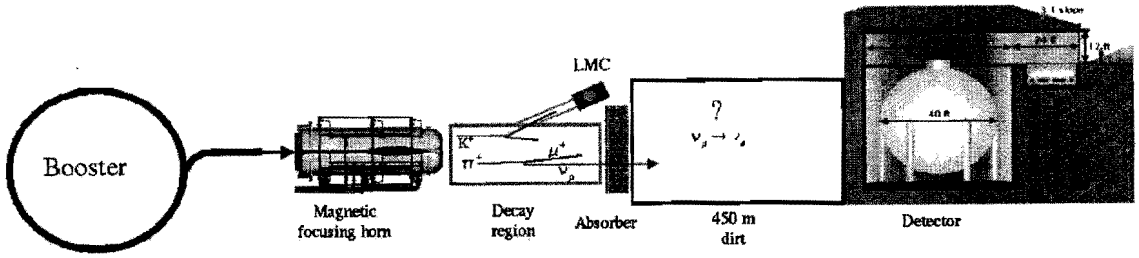

Figure 1: A schematic drawing of the MiniBooNE experiment.

The clean background and high sensitivity of NewBooNE to weakly interacting particles affords an opportunity for ESM discoveries that will be definitive as to both new particle character and mass, at cost levels thousands of times smaller than those associated with high energy colliders. The classic beam dump technique, first employed by Mel Schwartz at SLAC to search for axions, is enhanced by using the high intensity, high energy hadron beam from the FNAL Booster to produce a wide array of particles in great quantities. All conventional (SM) particles, except for neutrinos, are filtered by the beam dump. Thus, there is only a weak interaction background to the search for new weak processes in the MiniBooNE detector induced by scattering or decay of the new neutral particles. Reconstructed rates and angular distributions will be used to distinguish these new particles from neutrino events already well-characterized in the MiniBooNE detector.

3. The MiniBooNE Experiment at Fermilab

A schematic drawing of the MiniBooNE experiment is shown in Fig. 1. The MiniBooNE detector consists of a 12.2 m diameter sphere filled with $\sim$ 800 tons of mineral oil and covered on the inside by 1520 phototubes (PMTs), 1280 of which are detector PMTs and 240 are veto PMTs. The detector is located approximately 541 m downstream from the 71-cm Be target, which is fed by the 8 GeV proton Booster operating at a current of up to 4 μA and with a duty factor of $\sim 10^{-6}$. Protons interacting in the target produce pions and kaons, which are focussed by the magnetic horn and decay in a 50-m long decay pipe. The proton beam points to the center of the tank with an accuracy of $\sim$ 2 m.

Fig. 2 shows the reconstructed neutrino energy distribution of candidate ν_e events from the initial MiniBooNE oscillation result, corresponding to $\sim 5.58 \times 10^{20}$ POT. The points with error bars are the data, while the histogram is the background estimate from a Monte Carlo simulation of the experiment. A total of $\sim$ 1000 data events are observed in the energy region $>$ 200 MeV. (The background from cosmic rays is only about two events.) No significant excess of events is observed in the energy region above 475 MeV; however, a sizeable excess is observed for energies below 475 MeV. This low-energy excess is presently unexplained. Other data sets, including the NuMI, antineutrino, and SciBooNE data, may allow the collaboration to determine

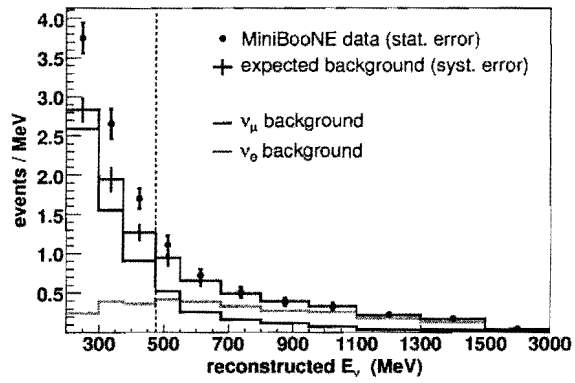

Figure 2: The reconstructed neutrino energy distribution of candidate ν_e events from the initial MiniBooNE oscillation result. The points with error bars are the data, while the histogram is the background estimate from a Monte Carlo simulation of the experiment.

whether the low-energy excess is due to a Standard Model process (e.g. an anomaly mediated radiative gamma process [2]) or to new physics beyond the Standard Model (e.g. a neutrino oscillation model with sterile neutrinos and a new light gauge boson [3]). Results on the low-energy excess and from the new data sets will be forthcoming later this year. After MiniBooNE has completed its data taking in antineutrino mode, then the current target & horn can be removed and the new beam dump installed.

4. NewBooNE

The NewBooNE experiment will make full use of the existing MiniBooNE apparatus. The only change will be to replace the MiniBooNE target and focussing horn by an $\sim$ 2 m long beam dump. Nominally, the beam dump will be made of steel; however, other materials will be considered. With the incident proton beam interacting in the beam dump, secondary pions and kaons will typically interact and come to rest before they have a chance to decay. Therefore, the neutrino flux is estimated to be reduced by a factor of $\sim 10^{-3}$ compared to the MiniBooNE neutrino flux. (The removal of the focussing horn reduces the neutrino flux by one order of magnitude, while the reduced decay-in-flight probability of pions and kaons reduces the neutrino flux by two additional orders of magnitude.) Thus, the total electron-neutrino event rate, over all energies and angles, can be scaled from MiniBooNE to be $\sim$ 1 event per 2×10^{20} POT, corresponding to one year of data taking. For new particles decaying to photons/electrons or scattering in the forward direction ($\cos\theta > 0.99$, where θ is the angle between the incident neutrino and outgoing electron), the expected event rate is < 0.01 events per 2×10^{20} POT. Due to the excellent angular resolution of MiniBooNE ($\delta\theta \sim 3°$), light particle decays should all reconstruct with $\cos\theta > 0.99$. Including systematic errors, NewBooNE will have a sensitivity for new particles that

is an order of magnitude better than MiniBooNE's sensitivity.

5. Estimated Signal Rates

The model of Nelson and Walsh [3] is used to demonstrate the sensitivity of NewBooNE to new light gauge vector bosons. Nelson and Walsh introduce a new light gauge vector boson ("paraphoton") that is consistent with existing experiments. The paraphoton has a mass of ~ 10 keV, a lifetime of ~ 2.5 ns, and a coupling strength of $g^2/e^2 \sim 10^{-9}$. Such a paraphoton would be produced in the beam dump in the forward direction (< 5 mrad) by hadronic bremsstrahlung of the incident proton beam ($\sim 1\% \times 10^{-9}$) followed by the electromagnetic conversion of the paraphoton in the NewBooNE detector (10 radiation lengths times 10^{-9}). Note that the paraphoton would experience hardly any attenuation due to either decay or conversion over the travel distance to the detector. Assuming a reconstruction efficiency of 50%, the number of paraphoton events in the forward direction ($\cos\theta > 0.99$) per 2×10^{20} POT (one year of data taking) is approximately equal to

$$(2 \times 10^{20})(1\%)(10^{-9})(10)(10^{-9})(50\%) = 10.$$

The observation of approximately ten events above an estimated background of 0.01 events would be extremely significant and would imply physics beyond the Standard Model. Therefore, NewBooNE would be able to confirm or rule out the model of Nelson and Walsh. Also, new weakly interacting particles could decay in the NewBooNE detector or contribute to the elastic scattering cross section off electrons. These reactions are also characterized by very forward reconstructed recoil electrons or gammas with $\cos\theta > 0.99$.

6. Cost Estimate

The construction of the beam dump is estimated to cost $\sim$ \$60K. In addition, the shielding in the Booster Neutrino Beam Target Building will have to be removed and then replaced in order to install the beam dump.

7. References

1) A. Aguilar-Arevalo *et al.* [MiniBooNE Collaboration], Phys. Rev. Lett. **98**, 231801 (2007).
2) Jeffrey A. Harvey, Christopher T. Hill, and Richard J. Hill, arXiv:0708.1281.
3) Ann E. Nelson and Jonathan Walsh, arXiv:0711.1363.