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A critical appraisal of the LSND anomaly

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The so-called ‘LSND anomaly’, a 3.8σ excess of $\bar{\nu}_{\mathrm{e}}$ events interpreted as originating from $\bar{\nu}_\mu \rightarrow \bar{\nu}_{\mathrm{e}}$ oscillation, gave rise to many theoretical speculations. The MiniBooNE Collaboration reported inconsistency of this interpretation with the findings from their search for $\nu_\mu \rightarrow \nu_{\mathrm{e}}$ oscillations. Yet the origin of the LSND anomaly was never clarified. A critical issue is the prediction of the background $\bar{\nu}_{\mathrm{e}}$ flux that was used in the analysis of the LSND experiment. For this, decisive input comes from pion spectra measured with the HARP large-angle spectrometer under conditions that closely resemble the LSND situation: a proton beam with 800 MeV kinetic energy hitting a water target.

1. INTRODUCTION

The LSND experiment at Los Alamos studied the $\bar{\nu}_{\mathrm{e}}$ flux originating from protons with 800 MeV kinetic energy hitting a beam dump consisting of water to a good fraction. They reported a 3.8σ excess of $\bar{\nu}_{\mathrm{e}}$ events over background [1]. The excess was interpreted as originating from $\bar{\nu}_\mu \rightarrow \bar{\nu}_{\mathrm{e}}$ oscillation, which gave rise to many theoretical speculations as to the existence of sterile neutrinos.

The MiniBooNE Collaboration reported inconsistency of this interpretation with the findings from their search at FNAL for $\nu_\mu \rightarrow \nu_{\mathrm{e}}$ oscillations [2].

A critical issue in the LSND analysis is the background level of $\bar{\nu}_{\mathrm{e}}$ events that originates from the decay chain $\pi^- \rightarrow \mu^- \rightarrow \bar{\nu}_{\mathrm{e}}$. An underestimate of π^- production which was quite uncertain at the time of the LSND experiment, would reduce the anomalous excess of $\bar{\nu}_{\mathrm{e}}$ events. The relevant input is a precise measurement of the ratio of secondary π^- to π^+ production by 800 MeV protons.

With a view to clarifying this issue, the HARP detector at the CERN PS that took data in 2001 and 2002 with proton and pion beams with momentum from 1.5 to 15 GeV/c, also recorded data from the exposure of a water target to protons with 800 MeV kinetic energy (1.5 GeV/c momentum).

This paper reports ratios π^-/π^+ from this exposure and compares them with the ratios that were used in the LSND analysis.

2. DETECTOR CHARACTERISTICS AND PERFORMANCE

The HARP detector combined a forward spectrometer with a large-angle spectrometer. The latter comprised a cylindrical Time Projection Chamber (TPC) around the target and an array of Resistive Plate Chambers (RPCs) that surrounded the TPC. The purpose of the TPC was track reconstruction and particle identification by $\mathrm{d}E/\mathrm{d}x$. The purpose of the RPCs was to complement the particle identification by time of flight. For the work reported here, only the HARP large-angle spectrometer was used [3, 4]. Its salient technical characteristics are stated in Table I. The good particle identification capability stemming from $\mathrm{d}E/\mathrm{d}x$ in the TPC and from time of flight in the RPC’s is demonstrated in Fig. 1. Correct particle identification is of crucial importance as 800 MeV protons produce many more secondary protons than π^+’s. This is highlighted in Fig. 2 which demonstrates that the decomposition of the observed secondary particle spectrum into particle species is well understood.

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Table I: Technical characteristics of the HARP large-angle spectrometer

TPC	**RPCs**
$\sigma(1/p_{\mathrm{T}}) \sim 0.20 - 0.25\ (\mathrm{GeV}/c)^{-1}$	Intrinsic efficiency $\sim 98\%$
$\sigma(\theta) \sim 9$ mrad	$\sigma(\mathrm{TOF}) \sim 175$ ps
$\sigma(\mathrm{d}E/\mathrm{d}x)/\mathrm{d}E\mathrm{d}x \sim 0.16$	

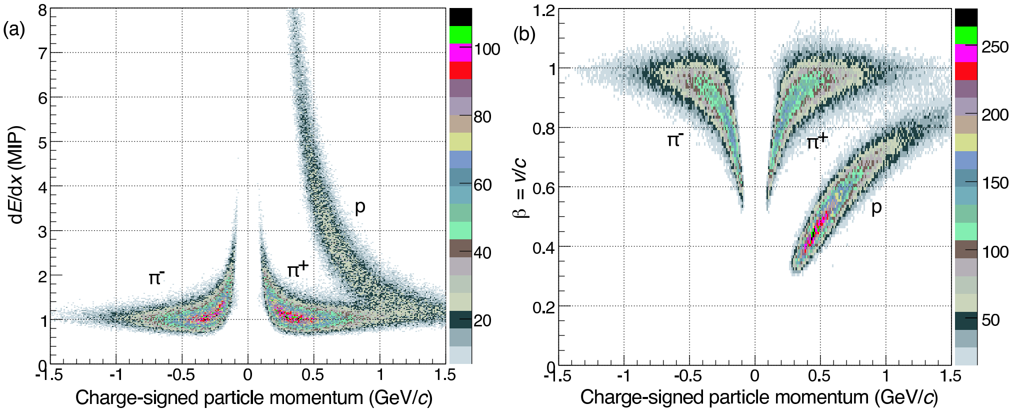

Figure 1: Specific ionization $\mathrm{d}E/\mathrm{d}x$ (left panel) and velocity β (right panel) versus the charge-signed momentum of positive and negative tracks in $+8.9$ GeV/c data.

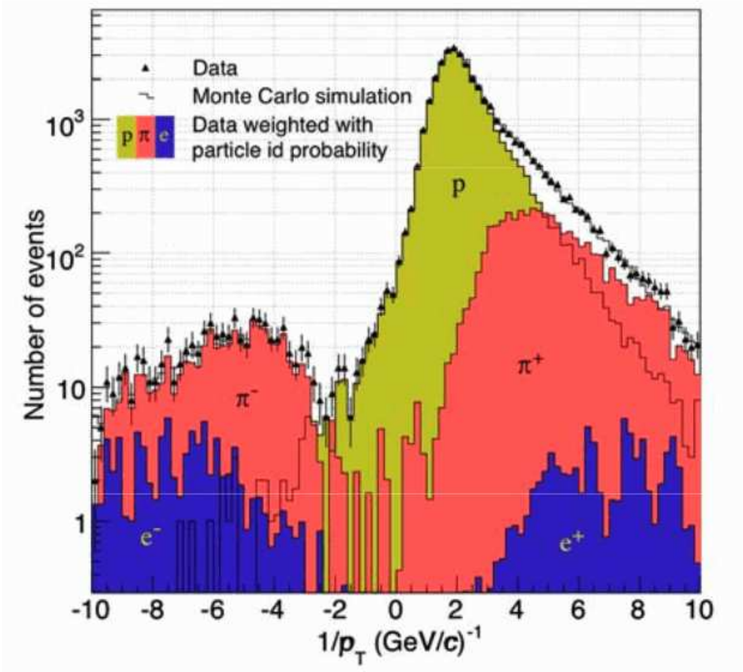

Figure 2: Decomposition, on a logarithmic scale, of the observed spectrum of secondaries from the interaction of 800 MeV protons in water into particle species, as a function of the charge-signed $1/p_{\mathrm{T}}$.

3. HARP–CDP MEASUREMENTS VERSUS LSND MONTE CARLO SIMULATIONS

Most positive pions from the interaction of the 800 MeV protons in the beam dump are slowed down and decay at rest, while a few per cent decay at flight. The positive muons from the decay also slow down and mostly decay at rest, with only a very small fraction decaying in flight. The neutrino flux resulting from positive pions consists of ν_μ, ν_e, and $\bar{\nu}_\mu$. For negative pions the decay chain is the same except for charge conjugation, yet negative pions that come to rest disappear 100% by strong interaction, and likewise negative muons at the 90% level by weak interaction. The neutrino flux resulting from negative pions can only come from pions decaying in flight, and muons decaying in orbit after capture. The neutrino flux consists of $\bar{\nu}_\mu$, $\bar{\nu}_\mathrm{e}$, and ν_μ. Overall, the $\bar{\nu}_\mathrm{e}$ which is of interest is reduced by a factor of order 10^{-4}. In more detail, the reduction depends on the level of π^- production, the probability of π^- decay in flight (related to the momentum spectrum and the beam dump geometry), and of the probability of a stopped μ^- to decay in orbit.

Our measurement addresses the first of these three issues. Figure 3 shows preliminary results of the measured ratio of π^- to π^+ production in four bins of polar angle θ with respect to the incoming proton direction. Also shown is the parametrization of this ratio that was used in the LSND analysis [5]. The measured ratio is smaller than the parametrization. Thus, if by the time of the LSND analysis our data had been known, the reported anomalous excess of $\bar{\nu}_\mathrm{e}$ events would have been even larger. Further work on this interesting result is in progress.

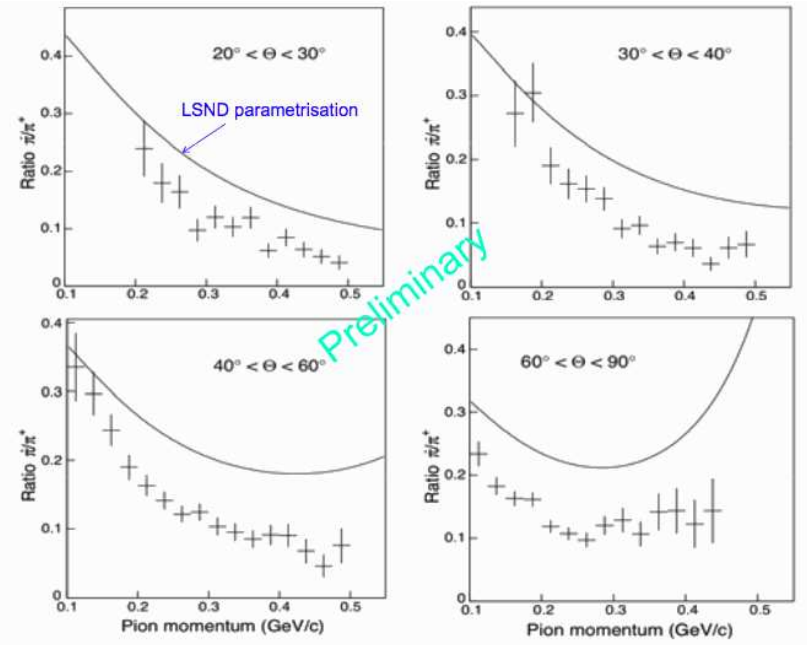

Figure 3: Ratios π^-/π^+ in four bins of polar angle θ with respect to the incoming proton direction, as a function of pion momentum; the crosses denote data, the lines represent the parametrization that was used by LSND.

References

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[4] V. Ammosov *et al.*, Nucl. Instrum. Methods Phys. Res. **A578** (2007) 119
[5] We thank Myungkee Sung for providing the LSND parametrization; the program code is available at *http://hep.phys.lsu.edu/sung/lsnd/beammc/index.html*