Liquid Argon Time Projection Chambers: MicroBooNE and Future Prospects for Neutrino Oscillation Physics

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MOTIVATION: LSND & MiniBooNE

In the 90's, LSND observed an excess of low energy electron anti-neutrino events (Fig 1). 10 years later, MiniBooNE saw an excess in both neutrino and anti-neutrino modes that could be consistent with LSND(Fig 2). This may suggest physics beyond the standard model.

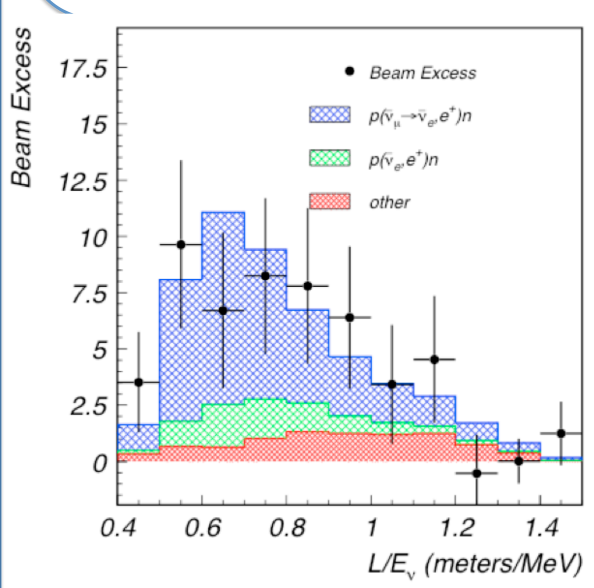


Figure 1: Excess number of $\overline{\upsilon_e}$ in $\overline{\upsilon_\mu}$ beam (LSND collaboration).

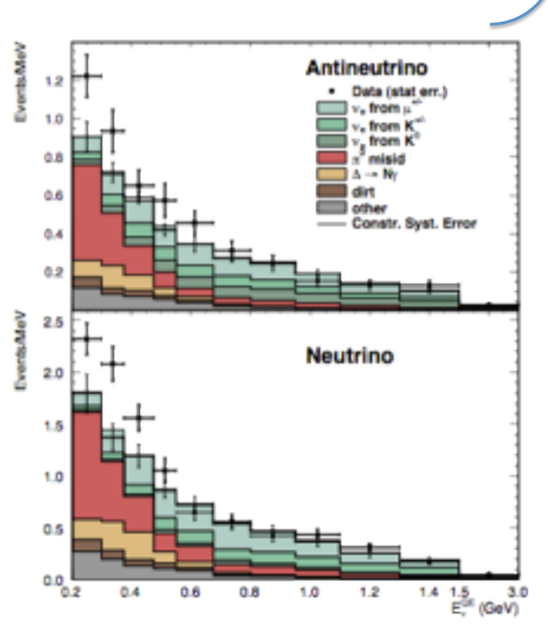


Figure 2: MiniBooNE observed an excess that may be consistent with LSND's results at a similar L/E, the controllable variable in neutrino oscillation experiments (MiniBooNE collaboration).

What is the origin of this excess?

Liquid Argon Time Projection Chambers (LArTPC)

LArTPCs are ideal detectors for neutrino experiments. MicroBooNE—the latest in a series of Booster beam experiments at Fermilab—is a LArTPC that will investigate the excess low energy events seen by MiniBooNE (Fig 2).

Why Argon?

	He	Ne	Ar	Kr	Xe	Water
Boiling Point [K] @ 1atm	4.2	27.1	87.3	120.0	165.0	373
Density [g/cm³]	0.125	1.2	1.4	2.4	3.0	1
Radiation Length [cm]	755.2	24.0	14.0	4.9	2.8	36.1
dE/dx [MeV/cm]	0.24	1.4	2.1	3.0	3.8	1.9
Scintillation [γ/MeV]	19,000	30,000	40,000	25,000	42,000	
Scintillation λ [nm]	80	78	128	150	175	

Figure 3: Properties which make Liquid Argon (LAr) an appealing detector medium.

LArTPC Concept

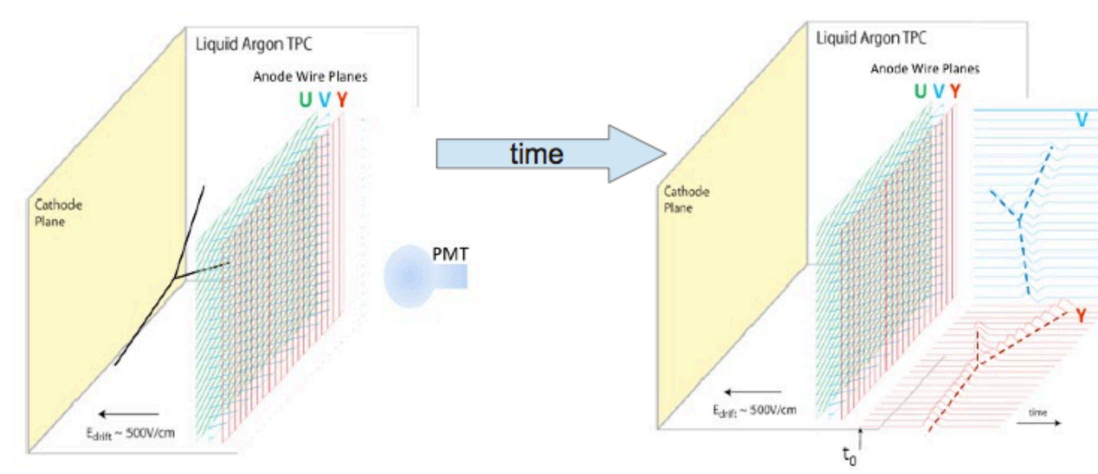


Figure 4: Interaction and drift of an event in a Time Projection Chamber

When an interaction occurs in MicroBooNE's TPC, charged particles ionize Liquid Argon. An applied electric field causes freed electrons to drift towards 3 wire planes (Fig 4). Readout from the planes and 32 8" photomultiplier tubes (PMTs) enables high-precision tracking.

MicroBooNE Detector	
Medium	Liquid Argon
Temperature	87.3 K
Electric Field	500 V/cm
Drift Velocity	1.63 mm/μs
Drift Time	1.63 ms
Light Collection	32 8" PMTs 4 light guide prototypes
Readout	8256 wires 3 planes 3 mm pitch

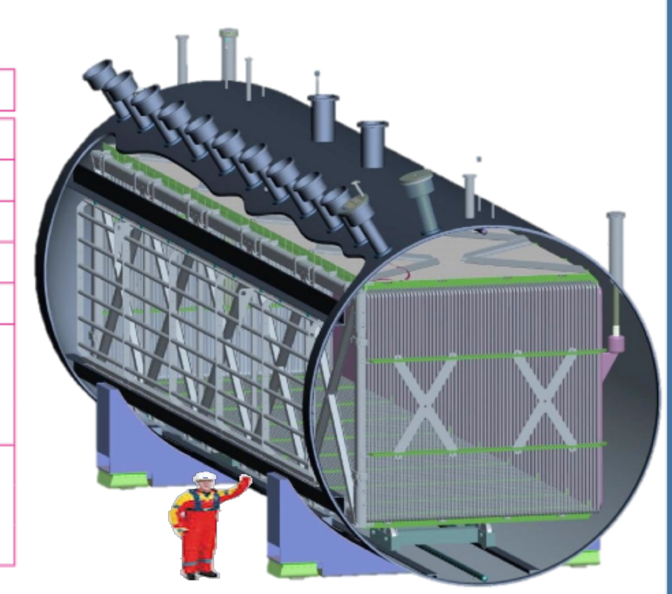


Figure 5a: (Left) MicroBooNE specifics. **Figure 5b**: (Right) MicroBooNE Cryostat and TPC with 6' figure for scale.

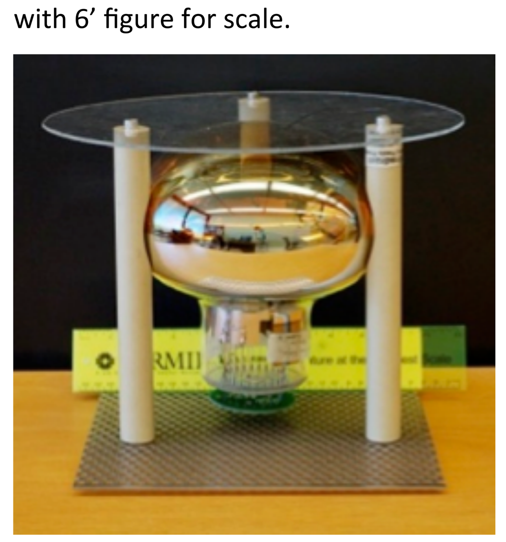


Figure 6: (Left) LAr scintillates outside the visible spectra at 128nm. In order to detect light from events in LAr, MicroBooNE's PMTs sit behind a plate coated in wavelength shifting material (Tetraphenyl Butadiene (TPB)).

LArTPCs provide excellent tracking resolution (Fig 7). Using calorimetric reconstruction and the topology of an interaction, MicroBooNE will be able to distinguish between electrons and photons (Fig 8), MiniBooNE's main background (Fig 2).

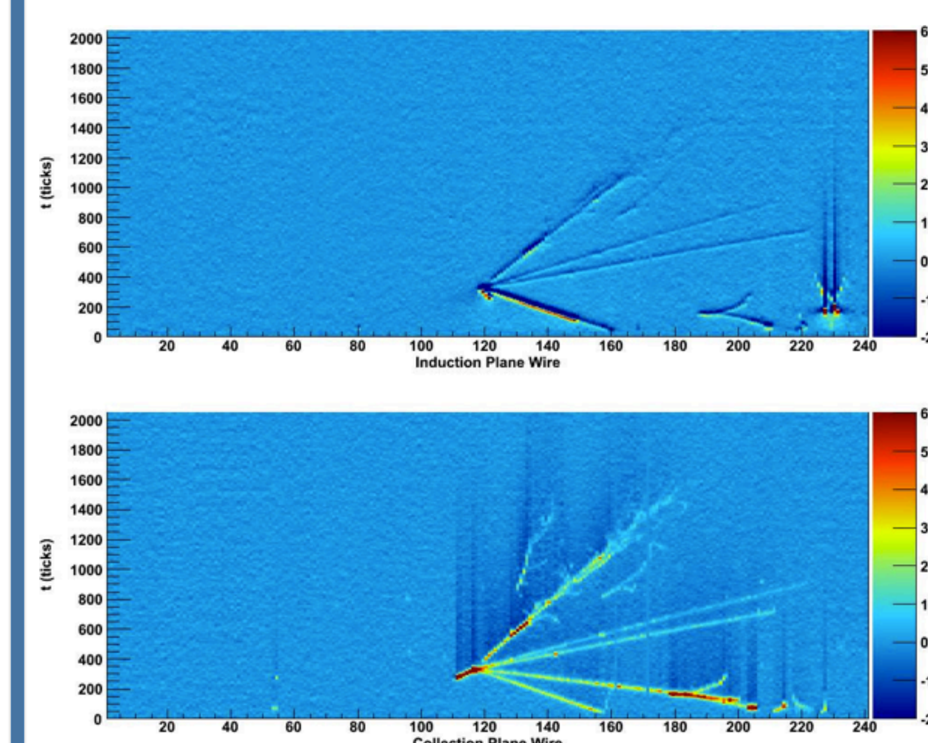


Figure 7: First recorded neutrino interaction in ArgoNeuT, the first LArTPC in a neutrino beam in the US.

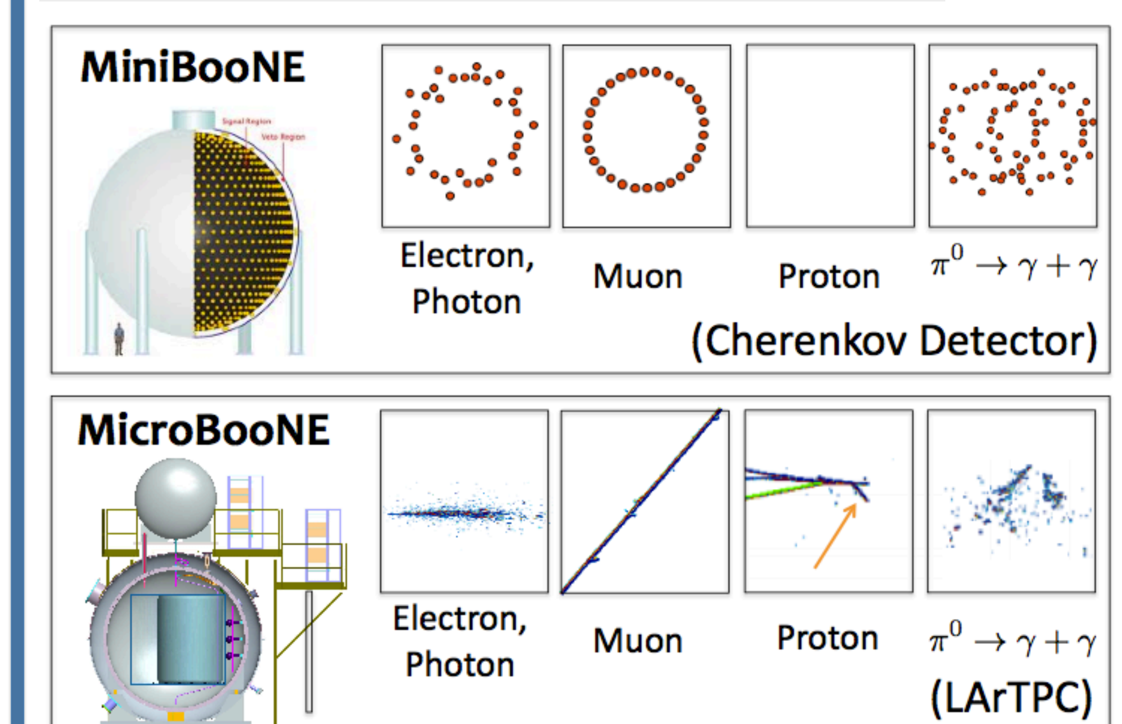
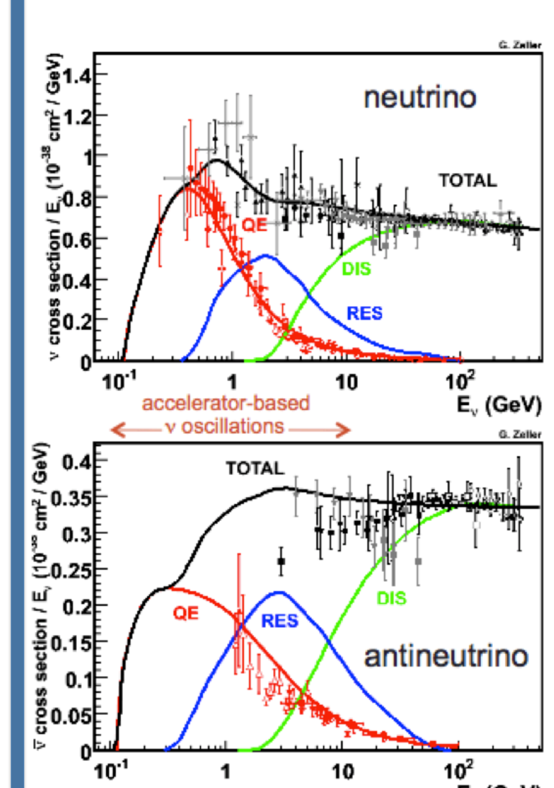


Figure 8: Interactions as seen by the BooNEs.

MicroBooNE will also study neutrino-nucleon interactions around 1GeV. These studies will lead to improved nuclear models and new and refined neutrino cross section measurements.



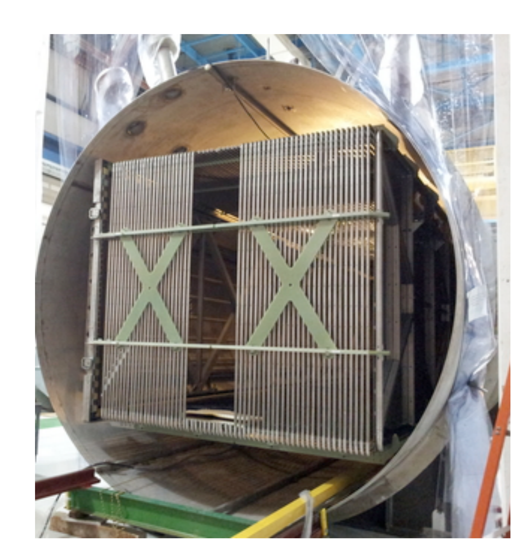


Figure 9a (Left): MiniBooNE-measured cross sections (G. Zeller) for QE events around 1 GeV. The fine-grained resolution of the LArTPC makes nuclear cross sections of high priority interest to the MicroBooNE team. **Figure 9b (Right)**: Construction of MicroBooNE is well underway, with TPC installation taking place last December.

Potential Solutions to MiniBooNE Anomaly

One possibility is that the MiniBooNE excess is due to electron neutrinos. This suggests the existence of "sterile" neutrinos, particles only observable through neutrino oscillations.

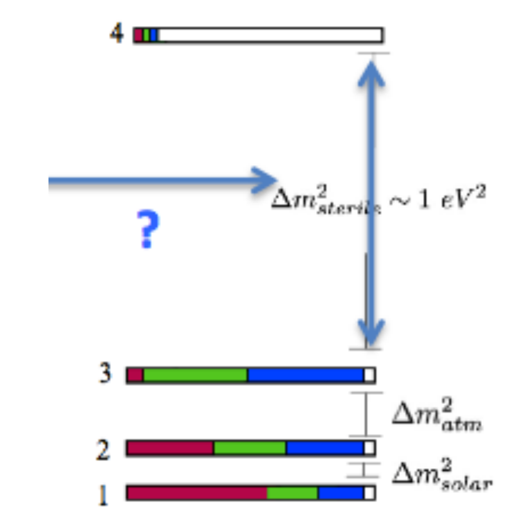


Figure 10: A mass splitting for a 3+1 neutrino model consistent with LSND and MiniBooNE data.

It is also possible that the excess is due to photons. These photons would likely be products of an unknown interaction. In this case, further studies of neutrino cross sections will be necessary.

Future LArTPCs

LArTPCs will continue to play a prominent role in neutrino physics beyond MicroBooNE. There are current plans to do a precision search for sterile neutrinos in the BNB (Fig 11), as well as the long baseline neutrino facility (LBNF) in Lead, South Dakota.

Figure 11: MicroBooNE in the BNB with the proposed LAr1-ND. With multiple detectors, we will be able to completely characterize an oscillation signal.

Lar1-ND will also act as a direct R&D prototype for future, bigger LArTPCs such as LBNF ensuring the continuous development of the LArTPC technology.