Experimental Objectives

MicroBooNE Detector and DAQ
TPC
PMT
Readout Process
Readout Equipment

Readout Status Tests
Commissioning of TPC Readout Equipment
Analysis of MicroBooNE Prototype: Bo
Online Monitoring

Summary

μBooNE Summer Research

Readout Process: Hardware, Software, Analysis and Visualization

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Columbia University

August 1, 2013

Outline

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MicroBooNE Objectives

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Summary

- Investigate MiniBooNE 3 σ low energy excess: final state electrons or protons? MiniBooNE Cerenkov detectors can't distinguish between the two ... discovery could lead to new physics (sterile neutrinos?)
- Measure neutrino cross section in liquid argon
- Scale up LArTPC technology for larger scale experiments
- Observation of neutrino artifacts from supernovae
- Measurement of cosmogenic kaon backgrounds to inform proton decay studies (p $\rightarrow K^{+}$... supersymmetry)

MicroBooNE Detector

- 38,000 gallon Cryostat installed on site at Fermi Lab
- Pure liquid argon and TPC and PMT detectors loaded inside
- Stored at about 87 K, with less than 0.1 K temperature gradient

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TPC (Time Projection Chamber)
Theory

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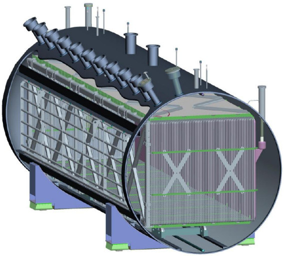
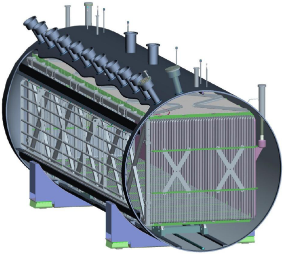


- Cathode on the right side of the TPC frame in the above illustration and set at -128 kV
- Anode and TPC wire planes on left side
- When a minimum ionizing particle interacts in the LAr it acts to ionize the atoms
- E field pushes these electrons with a drift velocity of 1.6 $\frac{mm}{\mu}$s toward the wire planes

TPC



- 2.325 m (vertical) x 2.5604 m (horizontal) x 10.368 m (beam direction)
- Wire orientation: 1 vertical collection plane and two inner induction planes ($\pm$ 60 degrees from vertical)
- Number of channels (wires): 2400 in U and V planes; 3456 in Y plane
- 3 mm wire pitch; 3 mm wire plane separation; 150 micron wire diameter

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PMT (Photomultiplier Tube)

Theory

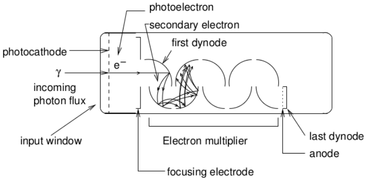
Photoelectric Effect

Process in which electrons in the valence band are excited by a photon enough to overcome the energy gap and enter the conduction band.

Secondary Electron Emission

Process in which primary electrons interact with a surface and induce the emission of secondary electrons.

PMT



- PMT is a vacuum tube with a photo-sensitive cathode (photocathode) and anode on either end, with a series of electron multipliers (dynodes) arranged in between
- Photocathode is a semiconductor and when struck by light, it emits electrons through the photoelectric effect
- Electrons are guided by electric field lines to the nearest dynode
- Dynodes are arranged in increasing electric potential and act to produce secondary electron emission

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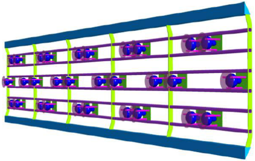
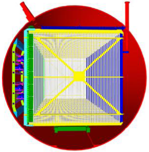
PMT





- Up to 40 8" PMTs lining the beam-right side of the TPC frame. PMTs arranged outside the induction plane (Y Plane)
- Bi-alkali, 14 dynode Hamamatus PMTs with gains up to 10^9
- Due to geometry, about 2 photoelectros expected per 1 MeV energy loss in LAr by a minimum-ionizing particle
- Prompt light occurs within 6 ns of interaction (used for triggering) while late light occurs up to 1.6 μs later

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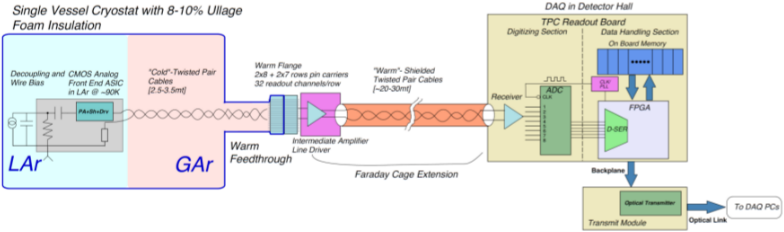
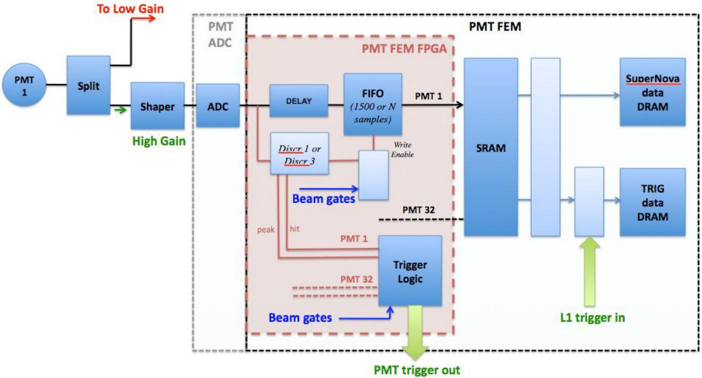
Readout Process
Single Channel TPC Readout



Readout Process
Single Channel PMT Readout



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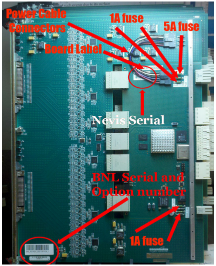
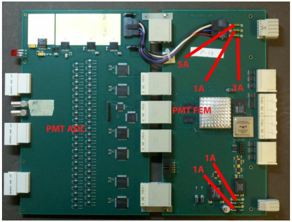
Readout Equipment

TPC and PMT FEMs/ADCs





- 130 TPC FEMs+ADCs with 64 channels a piece to readout 8,256 wires
- 2 PMT FEMs+ADCs to readout 32-40 PMTs. PMT signal split between high gain and low gain boards. Each board receives its signal from corresponding shapers and digitizes the signal at 64 MHz. The high gain FEM is responsible for triggers, while both FEMs condense and store data for DAQ packaging

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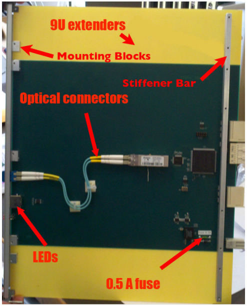
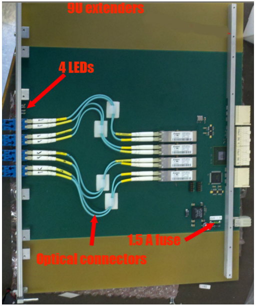
Readout Equipment

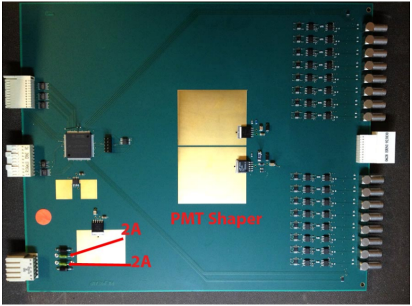
Controller and XMIT





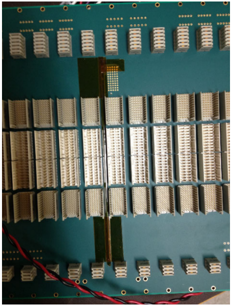
- Crate control board responsible for configuration at run startup and status and timing readback
- XMIT board responsible for high/low gain FEM data to DAQ machines in either the trigger stream or continuous supernova stream

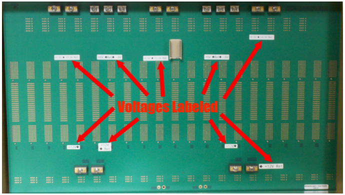
Readout Equipment
Shaper and Clock



- High and low gain shapers turn raw analog signals from the PMTs into a unipolar shape and pass signal to ADCs
- Each crate has a clock module responsible for providing common timing information for all boards. Each crate clock receives its signal from a global clock fanout that keeps all crates synchronized.

Readout Equipment
Backplane Front/Back





- 22 slots connecting FEMs/ADCs to controller and XMIT in the TPC crates and FEMs/ADCs to controller, shaper, trigger and XMIT in the PMT crate
- HV set at + 5.5 V, -5.5 V, + 3.3 V and + 12 V

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Crate Tests

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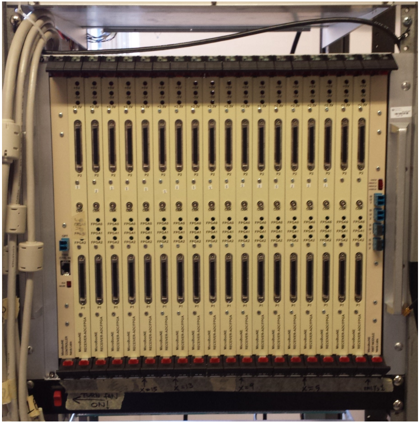

- Fully loaded crate with controller on the far left, XMIT on the far right and 18 ADC/FEM boards in between.

Crate Tests

Prior to the summer: Individual Board Tests

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- All FEMs, FEM/ADC pairs, controllers, and XMITs were tested and clearedm
- Proper booting was verified and data was successfully read out through all modes: controller readout, XMIT neutrino readout and XMIT supernova readout
- Problems with 1 or 2 bit data mismatches observed but fixed by installing heat sinks on the FPGAs of all boards.
- Problem with bad header data fixed by repairing the eprong on the boards
- DMA timeout errors were observed but it was assumed that changes made to the FPGA firware had addressed this issue.

Crate Tests

Backplane Test: Neutrino (Beam) Mode

- Motivation: Ensure all backplane links are functional and memory integrity and token passing is properly maintained in a fully loaded backplane
- Fully populated crate with 18 FEM/ADC boards loaded, with the crate controller in the second slot from the left and the XMIT to the immediate right of the FEM/ADCs
- Fake data generated in the Stratix III FPGA and loaded onto each FEM.
- At least 50,000 events read out through the trigger path and before/after data checking undergone
- Results: All FEMs booted properly and DRAM integrity generally maintained
- Problem: Occasional clock problems (result: DMA timeout errors)

Crate Tests
DMA Timeout Errors

- Direct Memory Access: System memory accessed independently of the CPU. In transferring large batches of data, it greatly reduces overhead.
- DMA Timeout: Previous data failed writing to the DAQ machine and never sends signal to FEM for next batch of data.
- When did it occur: On a random event (typically after 10k-20k events) during data checking. It would not happen with every board or even every crate, but only certain boards in certain crates in particular slot positions.

Crate Tests
DMA Timeout Errors Continued

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- Solution: Run the fanout clock's power supply through a surge protector (funny story for how this was discovered – if time)
- Further tests: Voltage spikes already observed on scope when connected to the fanout. Want to observe the signal as it's entering the crate before drawing conclusions.
- Potential cause: Thresholds for particular boards set too low?

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Crate Tests

Backplane Test: Supernova Mode

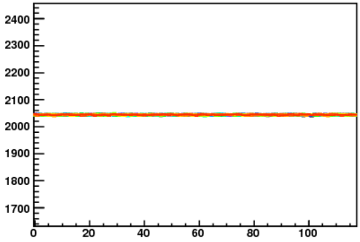
- Motivation: Test backplane connections, FEM booting procedure and data integrity under continuous supernova readout
- Similar to the neutrino test with fake data generated in the Stratix III FPGA and loaded onto each FEM.
- 400,000 events read out through the SN path and before/after data checking undergone
- In order to keep data rates low, test performed with four ADC+FEM boards at a time
- Results: Booting procedure correct and no DMA timeout problems observed

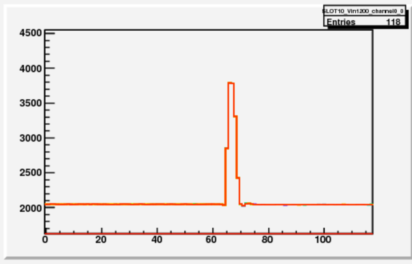
Crate Tests

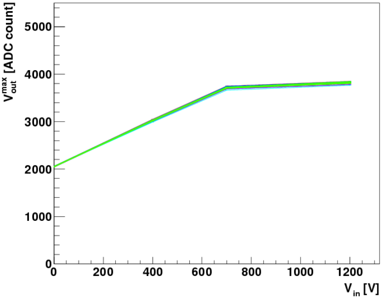
Final Assembly Test: Controller Readout

- Each crate loaded in its final, experimental configuration. Between 11-15 ADC/FEMs per crate, with a controller and XMIT. A trigger board was used, as well, to simulate the role played by the PMT crate. "Real" data simulated by injecting a signal from a function generator
- Why: Final form of the readout crates and this offers one last check on any unexpected surprises
- Results: Everything checked out $\rightarrow$ See next slide

Crate Tests
Final Assembly: Results







Crate Tests

Final Assembly: XMIT Readout

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- Same configuration as the previous test but this time readout is set through the XMIT neutrino stream. Function generator again used to simulate real event readout.
- Why: Similar to Controller test but XMIT readout is more efficient and the version of the readout used in μBooNE
- Results: Same as the Controller tests. Readout linear across all channels at all different input voltages

First Crates Shipped

- Done testing. All TPC boards/crates cleared (except for one)
- One exception is a crate loaded with boards that had DMA timeout errors. The problem seems to be under control, but it is being held for further diagnostic tests

- First four crates being shipped this week to FNAL for installation. More to follow ... hopefully!

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Analysis of MicroBooNE Prototype: Bo
Different Npe calculations for scope and ADC data

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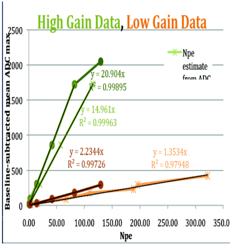

- What: Different energy LED pulses used for calibration purposes as triggers in MicroBooNE prototype (Bo).
- Why is this a problem: The calculations for the number of photoelectrons present at the photocathode should be the same before and after the data enters the ADC.
- Original suspicion: ADC hexadecimal data being read out incorrectly or noise biasing the calculations

Analysis of MicroBooNE Prototype: Bo
First Attempt: Rewrite readout program

- Limited amount of data but all data now read and processed $\rightarrow$ up to 3x as many pulses being read from some files
- Bad events (about 1/7 of the total events) now skipped $\rightarrow$ less noise
- Timing cuts enacted so pulses that are asynchroneous with the trigger are cut $\rightarrow$ further reduction in noise
- Calculated individual baselines for each event (rather than assuming all were 2048) $\rightarrow$ more accurate mean for each distribution

Analysis of MicroBooNE Prototype: Bo

Result: Only slight improvements

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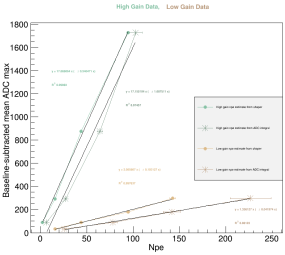

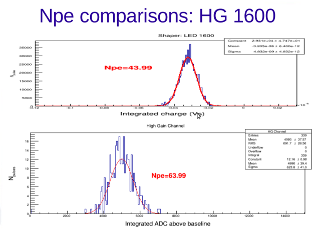

- Distribution expected to be Poisson at low Npe but approximated by Gaussian at high Npe
- ADC biased by binning choice ... low stastics
- There also may be a problem with the way the integrated charge was calculated on the scope ... Due to a faulty splitter, the first data from Bo contained ringing around the pulse. This may have biased the calculated baseline value.

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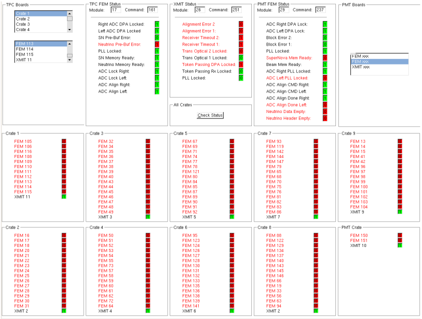
First Version of Readout Status GUI



- Designed for shifters and experts
- Designed to be intuitive and informative
- Future versions: increase its scalability so it can be easily implemented in large scale μBooNE online monitoring framework

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- Eight crates commissioned and one being held for further diagnostic testing.
- Npe discrepancy still troubling but may be an innocuous cause.
- Online monitoring environment being actively developed
- Outlook
  - Experiment on target to begin taking data in late spring 2014.

Acknowledgements I

- Thank you to everyone who helped me this summer ... everyone in MicroBooNE and at Nevis ... all the students who were a part of the program ... and everyone at the NSF for sponsering the REU