MicroBooNE TPC Calibrations

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Outline

1. **MicroBooNE Experiment**
   - MiniBooNE
   - Detector

2. **Electronics**

3. **Calibrations**
   - Gain/Linearity Tests
   - Cross Talk
   - Peak Timing Test

4. **Silicon Photomultipliers**
Goals of MicroBooNE Experiment

1. Explore low energy neutrino interactions, where MiniBoone saw an unexplained excess
2. Further measure neutrino interaction cross sections
3. Test liquid argon detector
LSND, MiniBoone excess of $\nu_e$

Different $\Delta m$ suggests 4th mass eigenstate $\rightarrow$ sterile neutrino

MicroBooNE created to explore 0.1-1GeV area of neutrino interactions

MiniBooNE cannot discern $\gamma$ from electrons
MicroBooNE Detector

- Liquid Argon acts as ionization medium as well as scintillator
- 170 ton cryostat
- 3 wire planes offset by 60 degrees, 2 induction, one collection
  - Charged particles drift toward wires and are collected
  - 8256 total wires
- Photons are collected by PMTs behind wire planes
Figure: Cross section of MicroBooNE detector

Figure: Example LArTPC, not actual MicroBooNE detector
Single Vessel Cryostat with 8-10% Ullage Foam Insulation

Decoupling and CMOS Analog Wire Bias
Front End ASIC in LAr @ ~90K

"Cold"-Twisted Pair Cables [2.5-3.5m]

Warm Flange
2x8 + 2x7 rows pin carriers
32 readout channels/row

"Warm"-Shielded Twisted Pair Cables [~20-30m]

Intermediate Amplifier Line Driver

Faraday Cage Extension

DAQ in Detector Hall

TPC Readout Board
Digitizing Section

Data Handling Section
On Board Memory

FPGA
D-SER

Optical Transmitter

To DAQ PCs

To DAQ PCs
Path of electronic signal

1. **Wires (or capacitor in parallel)** - Inside detector
2. **ASIC** - Preamplifier, shapes pulse with an optimal time of 1µs
3. **ADC** - digitizes symbol with 12 bit range, at a frequency of 2 MHz
4. **FPGA** - processes and reduces data to reasonable amount and stores it temporarily
5. **DAQ PC (Data Acquisition)** - stores data for future analysis
Electronics

![Diagram of electronic components]

- ADCs
- FEM Board
- FPGA

MicroBooNE TPC Calibrations

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Calibrations

- Test electronics readout each time the detector is moved or changed in any way
- Write code modules to do analysis of the output data for when the detector starts taking data

Figure: Example pulsed channel

Pulsed Channel

- Entries: 97
- Mean: 47.93
- RMS: 27.69
Generation of Signal

1. Input voltage on capacitor induces charge on the wire
2. Signal goes through ASIC, with specific gain and shaping

There are 8256 waveforms created, one for each channel. For gain tests, the maximum ADC count is extracted from each channel’s waveform.
Gain/Linearity Tests

- For each channel, fit the data to a line–get the gain from the slope
- 16 channels per asic
- 4 asics per FEM, 12 FEMs per feedthrough

Gain Calculations

\[ C \times V_{ASIC} = Q_{in} \times G_{ASIC} \times G_{int} \times G_{ADC} \]

Slope = \( G_{ASIC} \times G_{int} \times G_{ADC} / C \)
Linearity

Figure: Overlaid Linearity Curves for 768 channels

- 4 gain settings, lower gain has lower slope
- Saturation of ASIC
- Induction wires have baseline of 2000 ADCs
- Collection wires baseline 450 ADCs
- One visible bad channel
Gain for Each Channel

**Figure**: One channel is probably bad, see extra large gain
Cross Talk Analysis

For each subrun in the cross talk analysis:

- Pulsed some channels, but not all
- Look for pulses on unpulsed channels
Cross Talk

Looking at the Maximum ADC count for each channel shows that 1 channel per ASIC was pulsed.
Cross Talk–Within ASIC

Cross Talk Formula

Cross Talk = \frac{\text{MaxADC-Baseline for unpulsed channel}}{\text{MaxADC-Baseline for pulsed channel}}

Figure: Empty Event: Cross talk levels around 1%

Figure: Cross talk levels elevated for induction channels
Cross Talk

RMS Noise

\[ RMS = \sqrt{\frac{\sum (ADC - Baseline)^2}{N}} \]

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Cross Talk

Empty Event

Cross Talk Event

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Cross Talk

Average Cross Talk over 100 events

Cross Talk in ASIC

<table>
<thead>
<tr>
<th></th>
<th>Entries</th>
<th>Mean x</th>
<th>Mean y</th>
<th>RMS x</th>
<th>RMS y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross Talk in ASIC</td>
<td>731</td>
<td>30.48</td>
<td>6.03</td>
<td>18.23</td>
<td>3.421</td>
</tr>
</tbody>
</table>

Channel

FEM
In a previous calibrations run, we pulsed a total of 192 channels instead of 48. We saw the cross talk on induction channels increase linearly.

**Figure: Pre-Move**

**Figure: Post-Move**
Cross Talk Conclusions

- In the 2 data sets available (pre- and post-move), the change in cross talk % is linearly related to the number of channels pulsed.
  - went from 0.6% cross talk to 2.5% cross talk when pulsing 4x the number of channels
- Would eventually like to pulse 2, 3, 4, etc channels per ASIC to get more complete data
- Lack of map of channel number to actual wire proximity → no way to test cross talk vs proximity to wire
- Most importantly, no new broken channels
Peak Timing Test

The trigger is delayed, and we want to look at the effects upon the pulse. For a single channel, took the average waveform over the entire subrun (100 events).

![Waveform diagram](image)

**WF_Ch_1_ev_11001-11100**

- Entries: 97
- Mean: 48.17
- RMS: 27.86
The maximum ADC count for each subrun-delayed in 50ns increments
Then calculated the integral over the pulse area for each subrun and compared them based on the trigger delay.
Silicon Photomultipliers (SiPMs)

- SiPMs are much smaller than PMTs
- Lower gain than PMTs, but lower voltage required
- Not sensitive to magnetic fields
SiPM Setup

1. Pulser sends trigger to LED
2. LED sends photons at SiPM
3. SiPM photons cause avalanche, amplification of signal
4. Signal goes to amplifier
5. View signal on oscilloscope
SiPMs

Looked at bias voltage of SiPM vs output

\begin{center}
\begin{figure}
\centering
\begin{tikzpicture}
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height=\textwidth,
axis lines=left,
axis line style={-},
axis x line=middle,
axis y line=middle,
xtick={25,25.2,25.4,25.6,25.8},
xticklabels={25,25.2,25.4,25.6,25.8},
ytick={0,50,100,150,200},
yticklabels={0,50,100,150,200},
xmin=25,
xmax=26.8,
ymin=0,
ymax=200,
]

\addplot[domain=25:25.8,samples=100,red,thick] {0.2*x + 637.3};
\addplot[only marks] table [x=bias, y=output] {data.csv};

\end{axis}
\end{tikzpicture}
\caption{SiPM Output vs Bias Voltage}
\end{figure}
\end{center}

$\chi^2 / \text{ndf} = 26.14 / 6$

\begin{align*}
p_0 &= -637.3 \pm 157.1 \\
p_1 &= 254.3 \pm 6.172
\end{align*}
SiPMs

Looking to see single photon on oscilloscope. Noise levels at room temp may be too high
A hearty thank you to everyone who helped to make this possible.

- Mike Shaevitz
- Leslie Camilleri
- David Caratelli
- Georgia Karagiorgi
- David Kaleko
- John Parsons
- the NSF
- the rest of the REU students
Backup Slides
Each run is organized in a particular fashion:

- Each run contains 125 subruns, each of which contains 100 events
- Each subrun is different and is used to test the electronics for different gain and shaping settings
  - There are 20 subruns for peak timing tests, 15 for cross talk, etc
- Each event is 100 time ticks at 50 Hz trigger rate
- There is also a second run of long events where the noise is tested
Overlay of fit residuals for one feedthrough (64 channels). Some pattern suggests underlying nonlinearity.
Cross Talk

Empty Event

Cross Talk Event

Cross_Talk_event_6800

Entries 779
Mean x 31.97
Mean y 5.985
RMS x 18.71
RMS y 3.45

Cross_Talk_event_9000

Entries 731
Mean x 30.68
Mean y 5.997
RMS x 18.24
RMS y 3.419

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Cross Talk RMS Noise

**Figure:** Pre-Move RMS Noise Distribution

**Figure:** Post-move RMS Noise Distribution