MICROBOONE CALIBRATIONS

Thomas Strauss
For the MicroBooNE experiment
LArTPC

- M.I.P. looses 2.1 MeV/cm
- Ionization
  - Electron-ion pairs
  - Mostly exited molecules
- Excitation
  - Light – see talk Ben Jones
- Ratio is given by
  - Platzman equation*

\[ W_i = E_i + \frac{N_{ex}}{N_i} E_{ex} + E_{se} \]

\[ N_{ex}/N_i = 0.26 \]
\[ W_i = 23.452 \text{ eV} \]

- Measured**
  - 23.6^{+0.5}_{-0.3} \text{ eV}

\[ R_{\text{Statistical}} = \frac{FWHM}{E_0} = \frac{2.35 W_i \sqrt{FN}}{W_i N} = 2.35 \sqrt{\frac{F}{N}} \approx 2.5\% \]

Extract charge

- Recombination (ratio light to charge) depends on applied drift field $E$

$$\frac{Q}{Q_0} = \frac{1}{\xi} \ln(1 + \xi), \quad \xi = \frac{N_0 K_r}{4a^2 u_E}$$

- Electron drift speed depends on applied drift field $E$ and Temperature

$$\bar{v}_d = \mu(E_d, T) \cdot \bar{E}_d$$

Image: MicroBooNE Document Database, #2009

Converting the charge to a signal

- Initial charge cloud disperse: Diffusion*
  \[
  \frac{eD}{\mu} = f \cdot \langle E \rangle \\
  \sigma_{L,T} = \sqrt{2tD_{L,T}}
  \]

- Charge loss due to impurities**
  \[
  N(t) = N_0 e^{-t/\tau_e} \\
  \tau_e[\mu s] = \frac{300}{P_{O_{2\text{equiv}}}[ppb]}
  \]

- Signal on wires
  - Induction
  - Collection

First we need to control: drift field E, purity and temperature T

Only after this electronic readout gets involved

*Journal of Instrumentation, 8(04), 2013.
**Noble Gas Detectors. Wiley, 2006
Cryogenics and purity

- Specification:
  - Oxygen, water < 100ppt
  - Nitrogen level <2ppm
  - Temperature $\Delta T<0.1K$
  - Insulation <15W/m$^2$

- 3 purity monitors for LAr
  - 2 near the TPC volume
  - 1 after the filters

- 1 volume exchange per day

- Gas Purge before fill to remove impurities with 1vol. exch. per 4h

- Temperature probes:
  - GIC THERMODYNAMIC
  - RTD, Platinum 100 $\Omega$,
  - 0.00385 $\Omega/K$
  - $\Delta T<0.1\%$
Purity – Gas analyzer

• Servomex DF-310E (O2 sensor).
  • Range: 0 - 500 ppm.
  • Accuracy: greater of +-0.02% range or +-3% reading.

• Servomex DF-560E (O2 sensor).
  • Range: 0 - 20 ppm.
  • Lowest Detection Level: 75 ppt.

• Tiger Optics Halo+ (H2O sensor)
  • Range: 0 - 20 ppm.
  • Lowest Detection Level: 2 ppb.
  • Sensitivity: +-1 ppb.
  • Accuracy: greater of 4% reading or +-1 ppb.

• LDetek LD8000 (N2 analyzer)
  • 0 – 10 ppm, resolution to .1 ppm
  • Accuracy: better than +-1% full scale.

• Actual physics data will allow to measure purity too much better accuracy, but “blind” to source of impurity
**Temperature**

- Extended ANSYS simulation for technical design review
- Temperature stable <0.1K,
- Heaters on vessel to ensure uniformity
- Spread in drift speed from 0.04-0.002%
Drift field

- Field distortion can lead to ‘bend’ tracks
  - Surface location leads to abundance of ions drifting $10^5$ slower than $e^-$
  - HV chain resistance misalignment

Field inhomogeneity’s

- Track distortion in a controlled way demonstrates the effect of ‘bend’

M. Lüthi, master thesis LHEP Bern
Electric Field – High voltage divider

- Precise study of the resistor chain and its components
- 2 resistor types, one for high, one for low absolute field areas
Space charge - Drift field calibration with an UV laser

- Space charge will be present
- A 266nm UV laser can be used to ionize liquid argon
- Send laser along different paths to map the drift field from both detector ends
UV laser calibration system

- Automatic system, remote control adjustment for position and UV laser energy, provides trigger to the DAQ

UV calibration system

- Ready for installation, one operating for DAQ tests at DAB
Results from the UV laser system

- Automatic position and DAQ readout tested in LHEP Bern
- Modulation of beam intensity depending on mirror position
Cosmic Rays – a tool for calibration

- Many different studies
- Rate
- Energy distribution – Landau shape
- Stopping muons
- Michel electrons

<table>
<thead>
<tr>
<th></th>
<th>Detector Rate (s⁻¹)</th>
<th>Simulation Rate (s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Rate</td>
<td>10.21 ± 0.01</td>
<td>9.63 ± 0.04</td>
</tr>
<tr>
<td>Vertical Rate</td>
<td>2.73 ± 0.01</td>
<td>1.99 ± 0.02</td>
</tr>
<tr>
<td>Diagonal Rate</td>
<td>0.717 ± 0.003</td>
<td>0.87 ± 0.01</td>
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</tbody>
</table>

Errors are statistical only

Cosmic-muon rate from Monte Carlo: 3.72 ± 0.01 kHz (stat. error only)
~6 per 1.6-ms readout frame (~18 muons/event)

MicroBooNE Calibrations, T. Strauss

MicroBooNE Document 2374, 2570, 2805, 2806, 2591, 3130, 3341, 3474, 3413, 3484, *LHEP paper in preparation
Moving to the readout

• Charge arriving on the sensing readout wires creates either an induction or a collection signal
  • 3 planes, 2400 + 2400 induction, 3456 collection
  • 150µm thick copper/gold plated stainless steel
• Wire distances determine resolution:
  • 3mm, <1mm error for 2m drift
Readout Electronics calibrations

- What we want to measure:
  - Baseline
  - Noise
  - Electronics crosstalk
  - Gain and linearity
  - Signal shape/rising time

- Ideally, have these values on full vertical slice of readout
  - Wire → cold electronics → cold cable → feedthrough → warm electronics → digitization
MicroBooNE Cold Electronics Design

Cold Electronics ASIC - Front-End Detail and Calibration Scheme

- $C_{\text{INJ}} \approx 180 \text{ fF}$
  - Integrated injection capacitance (10 x 18 µm²)
  - Measured with high-precision external capacitance

- Charge sensitivity calibration of TPC during assembly, cooling and operation

From H. Chen (BNL) – March 2013, LArTPC workshop
MicroBooNE Cold Electronics Design

Cold Electronics ASIC - Front-End Detail and Calibration Scheme

Wire input path

From H. Chen (BNL)

 Charge sensitivity calibration of TPC during assembly, cooling and operation

\[ C_{\text{INJ}} \approx 180 \, \text{fF} \]

Integrated injection capacitance (10 x 18 µm²)

Measured with high-precision external capacitance

\[ C_{\text{INJ}} \approx \begin{cases} 184 \, \text{fF} & \text{at } 300K \\ 183 \, \text{fF} & \text{at } 77K \end{cases} \]
MicroBooNE Cold Electronics Design

Cold Electronics ASIC - Front-End Detail and Calibration Scheme

Calibration path

\[ C_{\text{INJ}} \approx 180 \text{ fF} \]

Integrated injection capacitance \((10 \times 18 \mu \text{m}^2)\)

Measured with high-precision external capacitance

Charge sensitivity calibration of TPC during assembly, cooling and operation

\[
\begin{align*}
C_{\text{INJ}} & \approx \begin{cases} 
184 \text{ fF at } 300K \\
183 \text{ fF at } 77K 
\end{cases} 
\end{align*}
\]

From H. Chen (BNL)
Can use injected calibration pulse to characterize the cold ASIC behavior, and all downstream readout components!

Signal processing
- Amplification
- Shaping
...and all the way down the readout chain!

From H. Chen (BNL)
Sample pulse

Input: 20 μs square wave (very sharp rise & fall)

Image of a 50 microsecond waveform recorded during a calibration test of the MicroBooNE Time Projection Chamber electronics.

- Beginning of input pulse
- End of input pulse

Sample waveform from an Induction channel recorded with an ASIC gain setting of 4.7 mV/fC
Preliminary results

- One of the ten feedtroughs after detector move to LArTF
- We expect to gain a factor 2-3 in noise reduction by cooling down

32 induction, 32 collection channels, (1\(\mu\)s shaping)

\[
\text{ADC/slope times the test capacitance} = \text{eff. charge}
\]
<table>
<thead>
<tr>
<th>Parameter</th>
<th>LARASIC4 [at 87 K]</th>
<th>Hybrid pre-amp. [at 290 K]</th>
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</thead>
<tbody>
<tr>
<td>Charge gain [mV/fC]</td>
<td>25</td>
<td>2.1</td>
</tr>
<tr>
<td>Transimpedance [mV/nA]</td>
<td>117</td>
<td>13</td>
</tr>
<tr>
<td>Average MIP signal (oscilloscope) [mV]</td>
<td>33.0±7.9</td>
<td>2.8±0.6</td>
</tr>
<tr>
<td>Noise (RMS) [mV]</td>
<td>2.1±0.1</td>
<td>1.1±0.1</td>
</tr>
<tr>
<td>S/N ratio</td>
<td>15.7±3.8</td>
<td>2.6±0.6</td>
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Performance: cold vs. warm

Argon tube Events, LHEP paper in preparation

Preliminary
MicroBooNE Optical System

32 PMTs and 4 light-guide detector installed Aug-Sept 2013.

All units were characterized in warm+cold before installation*

A few units selected for more detailed characterizations in the Bo test stand at Fermilab. (stability, linearity and absolute collection efficiency)

Some techniques for MicroBooNE calibration are explored in liquid argon scintillation R&D papers using the MicroBooNE PMT assembly**:

*JINST 8 (2013) T07005
**JINST 8 (2013) P12015
**JINST 8 (2013) P07011

**Example of late-light SPE calibration**

![Example of late-light SPE calibration](image)
Fiber Calibration System

Each PMT has a calibration fiber coupled to an 450 nm LED outside the cryostat for gain and timing characterizations.

This system will be used for both routine calibrations and commissioning tests.

PMT pre-commissioning run

- Successful run of all PMTs, high voltage, fiber calibration system, MicroBooNE DAQ and offline software with installed PMTs

- Some PMT base problems were found and fixed using the LED calibration system. All PMTs verified working before closing detector.

- First version of automatic gain calibration software used to set nominal HV for each channel

**Instrumented PMT feedthrough**

**Before gain calibration**

**After gain calibration**

Targeted value
Conclusions

• Calibration is not easy

• We know how to do it

• We have great tools that help us to do our job

• Stay tuned for first results