Electronics Testing, LArSoft Analysis, and Data Acquisition for MicroBooNE

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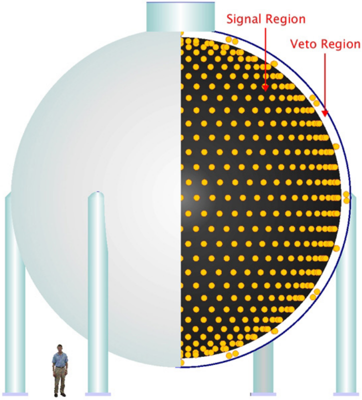
Outline

1. Mini & Micro - BooNE
2. Low Energy Excess
3. LArSoft Analysis
4. PMT Gain Study
5. Splitter Reflection
6. PMT Data Acquisition

MiniBooNE

MiniBooNE Detector



Studied:

$\nu_\mu \rightarrow \nu_e$ oscillations, both modes

With:

- Cerenkov detector, 950,000 liters of mineral oil, 1520 phototubes in 12-meter diameter sphere

Found:

- Observed data above 475 MeV are consistent with expected background
- A low energy excess below this energy

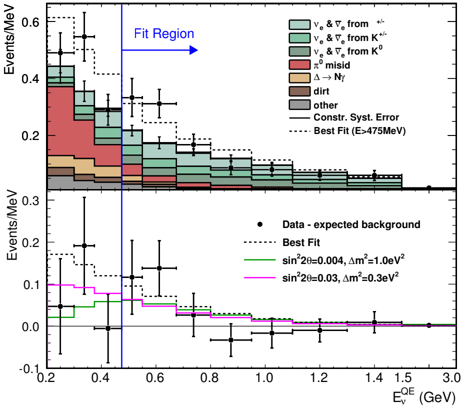
Excess events in 200 - 475 MeV neutrino energy region found by MiniBooNE.

Variety of interpretations by many beyond the Standard Model physics including...

- 3+N Sterile Neutrinos

...*but* could be misidentified ν_μ $\rightarrow$ can not distinguish e^- and γ signal

MicroBooNE detector proposed to study even lower ν energy



A. A. Aguilar-Arevalo et al. (MiniBooNE Collaboration), "Event Excess in the MiniBooNE Search for $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ Oscillations", Phys. Rev. Lett. 105, 181801 (2010)

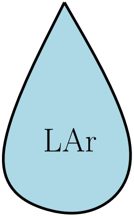
MicroBooNE - Detector

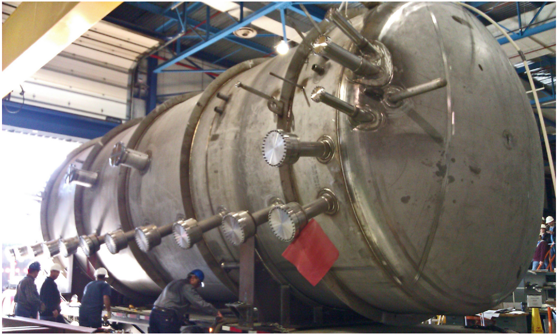
Specifications

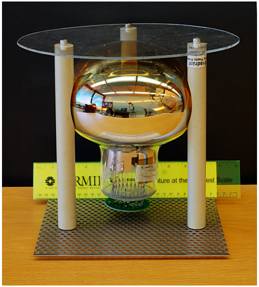
- 170 ton liquid argon cryostat
- Time Projection Chamber (TPC) with 3 wireplanes
- 32-40, 8-inch photomultiplier tubes

Will study

- $\nu_e/\bar{\nu}_e$ appearance





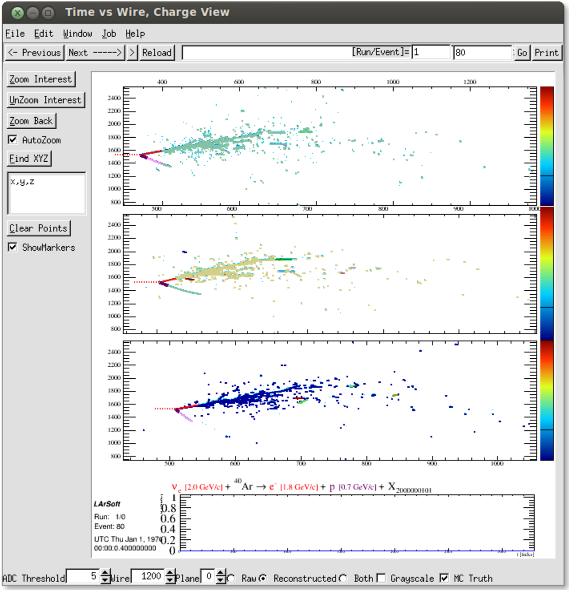


LArSoft - Detector Simulation

LArSoft is a complete set of simulation, reconstruction, and analysis tools for liquid argon detectors

- Whole detector simulated by GEANT4 (LArG4)
- Neutrino beams simulated by GENIE, all other particles possible
- Reconstruction chain developed

Event display for three wireplane, can investigate reconstructed parameters against truth... →



LArSoft - Event Reconstruction

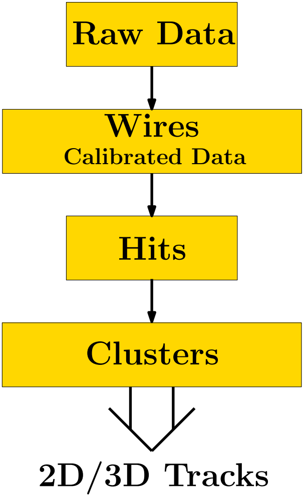
Reconstructing neutrino interactions inside MicroBooNE

Clustering

- **Hits** are signal vs time information from a calibrated Wire object and looks for peaks that indicate real energy deposition occurred
- **Clustering** algorithms identify reconstructed wire hits which are correlated both spatially and temporally
- **DBSCAN** and **Fuzzy Clustering** are two such algorithms

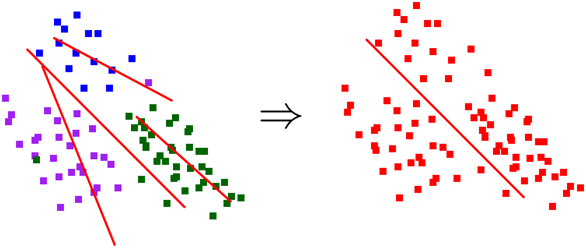
Energy

- Total visible energy deposited on TPC from e^- showers



LArSoft - Cluster Studies

1. Generate ν_e events filter for $1e^- + 1p$ final states, simple event topology
2. I wrote a LArSoft module, MCHitter, to calculate *purity* and *efficiency* of reconstructed clusters
3. Compare DBSCAN, FuzzyCluster



Purity

Efficiency

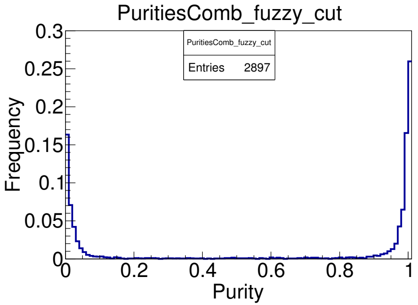
Measures

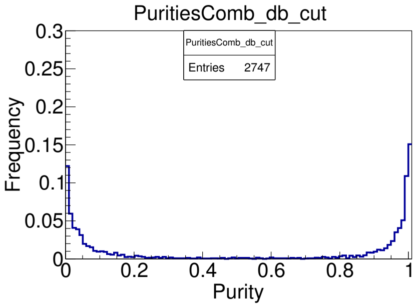
- How much of a cluster is composed of a each true particle
- If less than 1: clustering algorithm could not distinguish true particle hits from one another

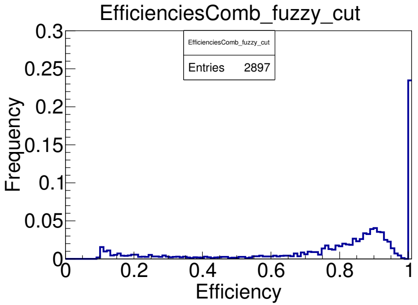
Measures

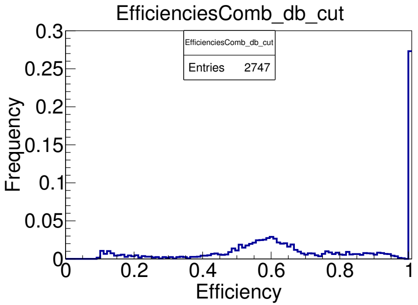
- How many of all hits the particle generated are in a specific cluster
- If less than 1: algorithm failed to group the hits created by the particle into a single cluster

LArSoft - Cluster Studies - $1e^{-} + 1p$

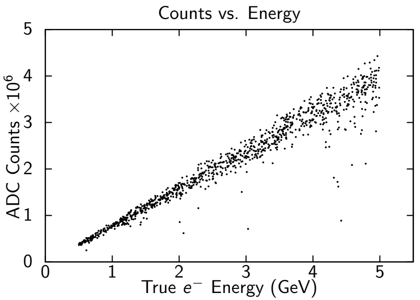


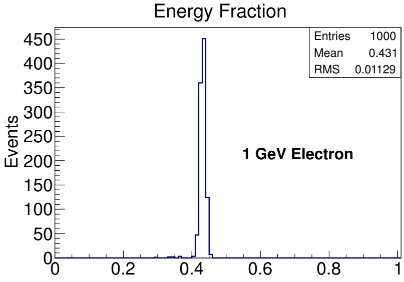


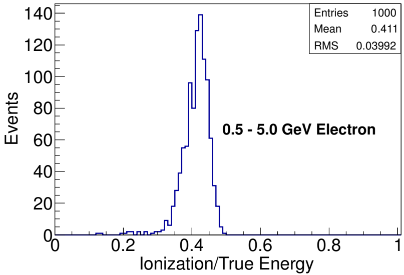




LArSoft - Energy Studies





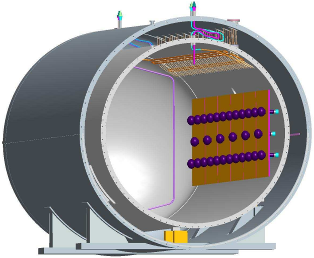


- Visible energy fraction $\sim$ 45%
- Reconstructed ADC counts from hits scaled linearly with true e^- energy
- Important for detector calibration

MicroBooNE Optical System

Phototube array

- 32-40, 8-inch photomultiplier array located behind TPC wireplanes will collect Argon scintillation
- The primary importance of the optical systems is for **triggering** on events
- Optical information can also contribute to event reconstruction



- I tested a R5912 8-inch PMT, similar to the ones used in MicroBooNE minus the wavelength shifting coating and single coaxial input. Will be used to study read out electronics

PMT - Gain

Definition

Phototube gain is the ratio of secondary electrons collected on the anode to primary electrons ejected from cathode → *amplification* factor

Procedure

1. Pulse PMT with blue LED @ 100 Hz
2. Record mean (μ_v) peak height and standard deviation (σ_v) of output voltages, and $\int Vdt$ over 6000 triggers
3. Repeat for different input voltages

$$G \equiv \frac{N_s}{N_p}$$

$$\mu_v = CGN_p$$

$$\sigma_v = CG\sqrt{N_p}$$

$$\Rightarrow N_p = (\mu_v/\sigma_v)^2$$

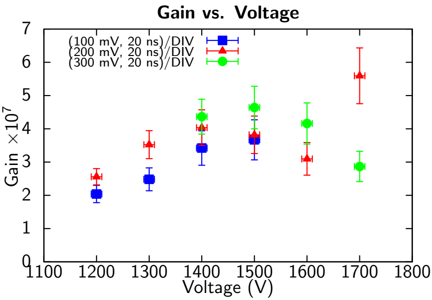
and

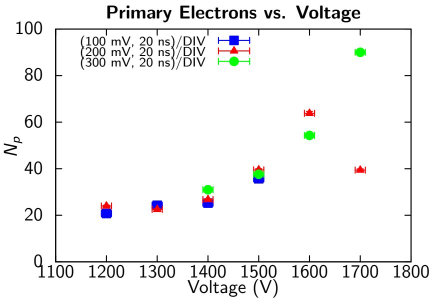
$$N_s = \frac{\int Vdt}{eR}$$

$$\Rightarrow G = \frac{\int Vdt}{eR}\left(\frac{\sigma_v}{\mu_v}\right)^2$$

G: Gain
N_s: Number of secondary electrons
N_p: Number of primary electrons

PMT - Gain - Results I

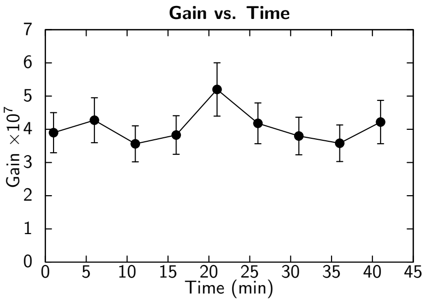


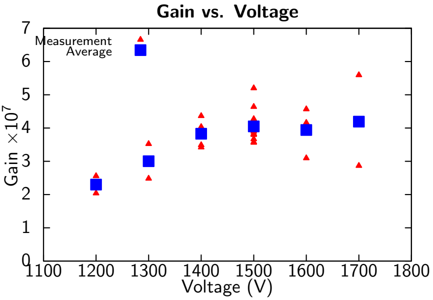


- Took data at different oscilloscope precisions (window size)
- Spec. sheets reports gains at 10^7
- Optimal operating voltage is 1500 V
- Interesting gain response at high voltages

- Number of primary electrons deviates as function of input voltage
- Should remain constant
- Photocathode electrons non-poissonian?

PMT - Gain - Results II





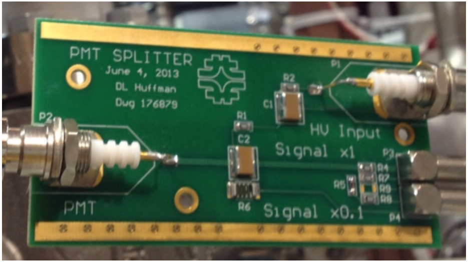
- Variation in gain at constant 1500 V over 40 minutes
- Spread is about $\pm$ one unit around 4×10^7

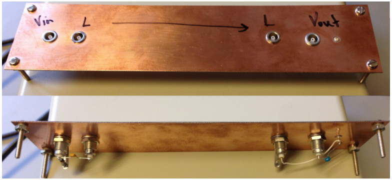
- Every measurement over 1.5 week period plotted in red, blue square is the average as estimate of systematic uncertainty
- Largest source of systematic uncertainty is the oscilloscope precision

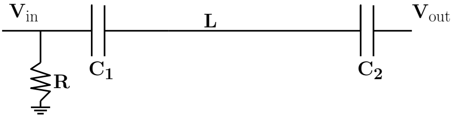
PMT Splitter - Ringing - Setup

A current test of MicroBooNE's optical system is called Bo. Bo is a liquid argon test chamber for MicroBooNE photomultipliers, cold electronics, high voltage system and much more.

An issue arose during electronics testing with the splitter used to split the HV input from the PMT signal, signal reflection observed in shaper







A simple circuit was used to study the PMT signal reflection between the splitting capacitor C_2 and the PMT base

PMT Splitter - Ringing - Reflection

Why is there reflection?

- Impedance differentials along the length of the circuit reflect EM signals
- Splitting circuit, and 50 Ω cable are at different impendances.

Toy Circuit

- Varying L controls the timescale of reflection
- Varying C_2 controls amplitude

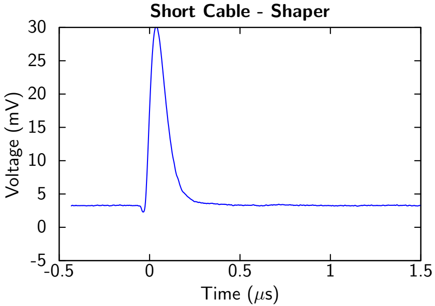
No ringing is observed when:

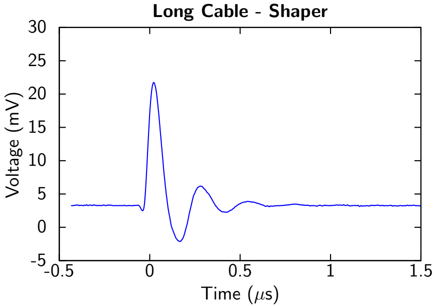
$$\tau_{circuit} = R_{\mathrm{cable}} C_2 \gg \tau_{travel} = \frac{\mathrm{L}}{v_{\mathrm{signal}}}$$

**Much greater $\sim$ 3-5 times

$$v_{\mathrm{signal}} = 1 \text{ foot}/1.5 \text{ ns}$$
$$\mathrm{L} = 4 \rightarrow 20 \text{ meters}$$
$$C_2 = 1 \text{ nF} \rightarrow 10 \text{ nF}$$

PMT Splitter - Ringing - Tests





$$\tau_{\text{circuit}} = 50\ \Omega \cdot 1\ \text{nF} = 50\ \text{ns}$$

Short cable L = 4 m

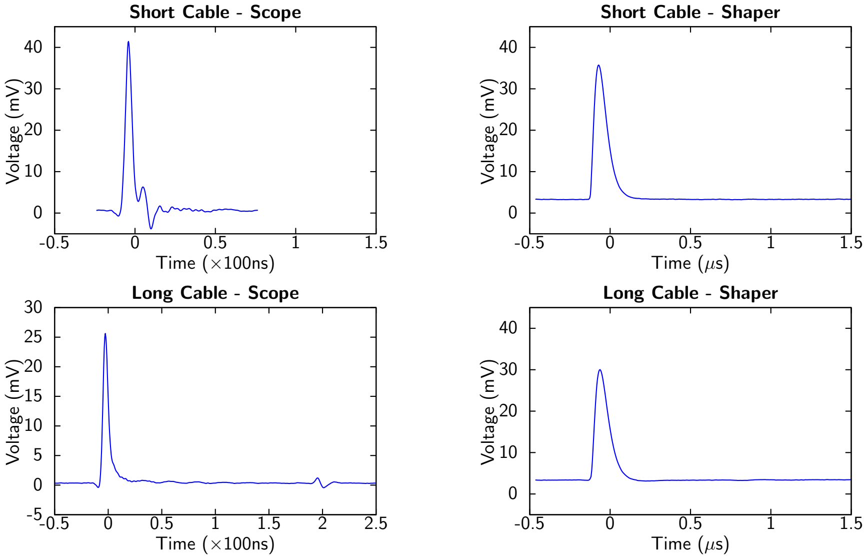
- $\tau_{\text{circuit}} > \tau_{travel} = 4\ \text{m} \cdot 1.5\ \text{ns/foot} \sim 20\ \text{ns} \rightarrow$ *no* ringing

Long cable L = 20 m

- $\tau_{\text{circuit}} \ngtr \tau_{\text{travel}} = 10\ \text{m} \cdot 1.5\ \text{ns/foot} \sim 100\ \text{ns} \rightarrow$ *yes* ringing

PMT Splitter - Ringing - Tests II

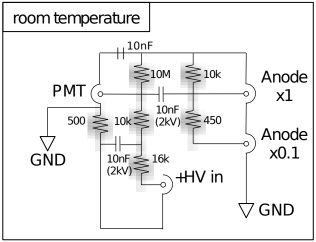
Increase τ_{circuit} by $C_2 \rightarrow 10$ nF



PMT Splitter - Ringing - Results

Results

- Bo circuit sees ringing in the shaper output when it shouldn't, with same parameters are test circuit
- Bo circuit has another capacitor in series with the splitting capacitance *reducing* effective capacitance
- Bo circuit has high voltage across the splitting capacitance further *reducing* capacitance



Capacitance in MicroBooNE splitter circuit used with Bo is being increased!

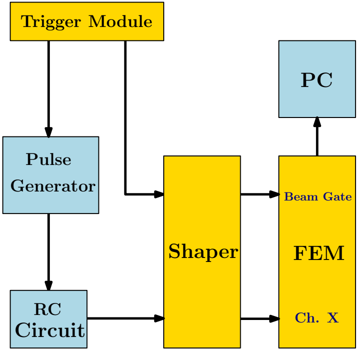
PMT - Data Acquisition - Setup

Procedure

- Use the controller module to trigger a pulse generator
- Feed the pulse to the RC circuit built for the ringing tests. This generates a narrow (few nanosecond) PMT-like pulse of variable charge depending on the pulse amplitude.
- Feed into the shaper and read out through the FEM

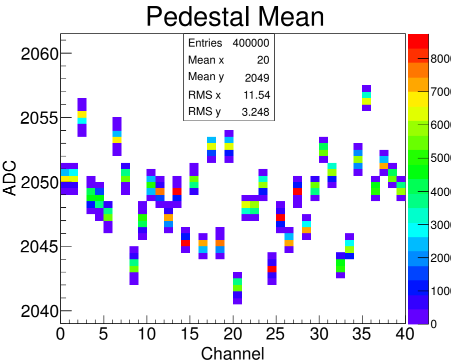
Decoder & Analysis Module

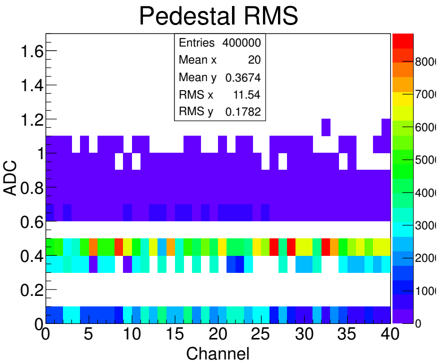
- `pmtbaseline`
  - written with Kazu's framework
- Pedestal calculation and subtraction per shaper channel
- Calculate signal peak and area for pulse recon.



PMT - Data Acquisition - Results

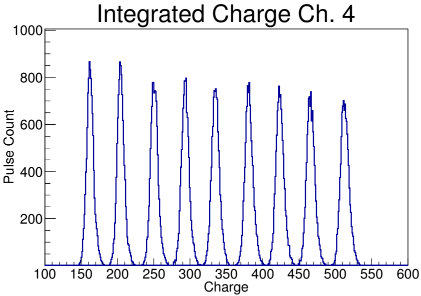
Pedestal mean and standard deviation calculated from the first 5 points of the beam gate sample. Mean, RMS plotted versus FEM channel number



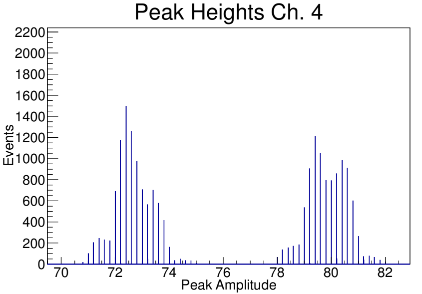


- Pedestal mean $\sim$ 2049, pedestal varies over 10 ADC counts
- Pedestal RMS $\sim$ 0.37

PMT - Data Acquisition - Results II

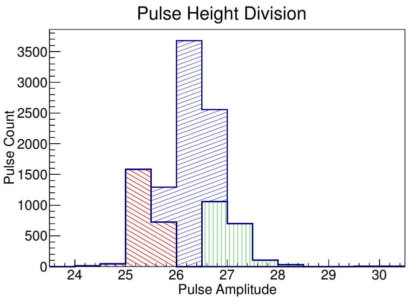


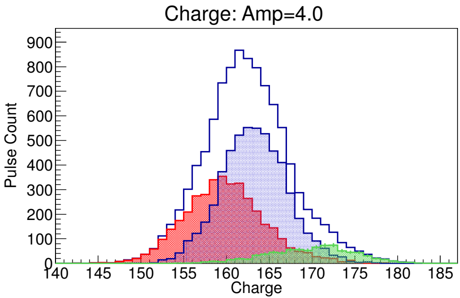
- Distribution of integrated charge. Increasing in amplitude to the right by 500 mV input. High energy tail on each distribution $\rightarrow$ not gaussian



- 2/9 distribution of peak heights, another estimator of pulse energy. Would expect peak heights to be gaussian as well but because of a digitization effect there are 3 distributions

PMT - Data Acquisition - Results III

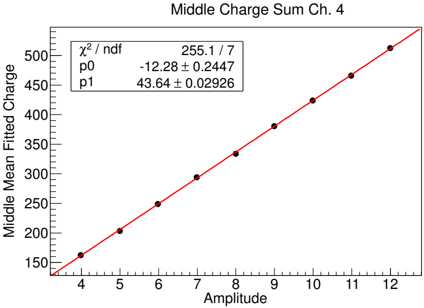


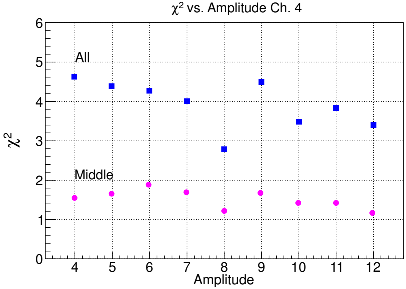


- Make 3 cuts on pulse amplitude distribution
- Find max bin, look ± 0.5 as estimate of digitization effect

- Charge distribution split by peak cuts

PMT - Data Acquisition - Results IV



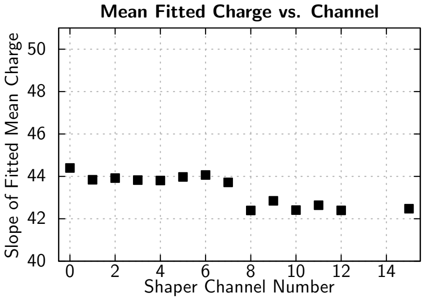


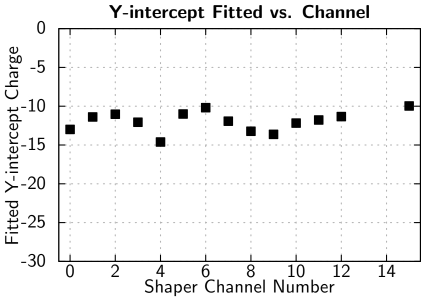
- For each input A, plot mean
- Linear as function of input A

- Magenta: middle peak fits
  Blue: fits without cuts
- For each input A, plot χ^2 goodness of fit parameter
- Cuts are indication better selection of sample selection

PMT - Data Acquisition - Results V

Repeat over all shaper channels





- Slope of fitted mean plotted over channel number

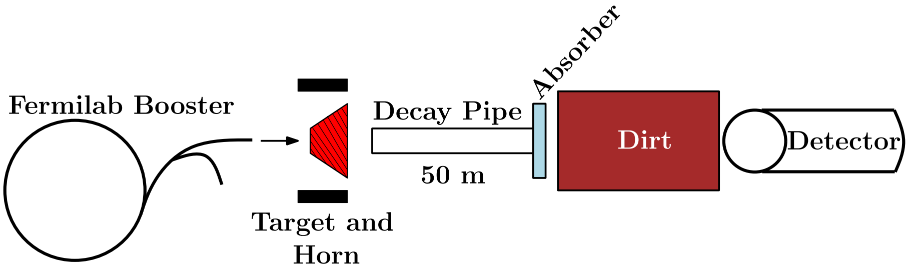
- Y-intercept of fitted mean plotted over channel number
- Shows non linearity at low energy ($A < 4$)

Thanks To:

- *David Caratelli* for being a great lab partner
- *Kazu* for teaching me PyROOT
- *Mike Shaveitz* for the opportunity to work on MicroBooNE
- *John Parsons* for adminstrating the REU
- *Georgia* for getting me started with LArSoft
- *REU Students* for being great friends

BACKUP

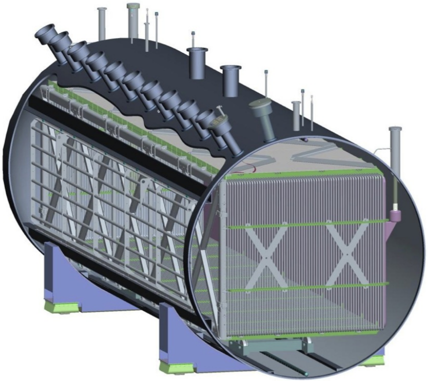
Producing Neutrinos - Fermilab Booster

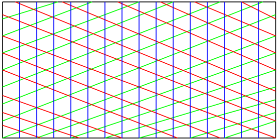


1. 8 GeV protons produced in booster
2. Impinge on Beryllium target, magnetic horn focusses $\pi^{\pm}$ & $K^{\pm}$ depending on neutrino mode
3. Mesons decay via $\rightarrow \mu^{\pm} + \bar{\nu}_{\mu}/\nu_{\mu}$ channel, some $\mu^{\pm} \rightarrow e^{\pm} + \bar{\nu}_{\mu}/\nu_{\mu} + \nu_e/\bar{\nu}_e$
4. Absorber filters charged leptons

MicroBooNE - Advantages

- Liquid argon TPCs have a low energy resolution at a few MeV, far below the hundreds of MeV threshold on MiniBooNE, and will be able to resolve the size of the signal at lower energies.
- MiniBooNE could not differentiate between electrons and photons, a TPC can "see" the difference $\rightarrow e^-$ connected to a primary vertex which is singly ionizing, γ are doubly ionizing and have a gap between vertex
- Detector R&D for larger TPC experiments to search for CP violation in neutrino sector

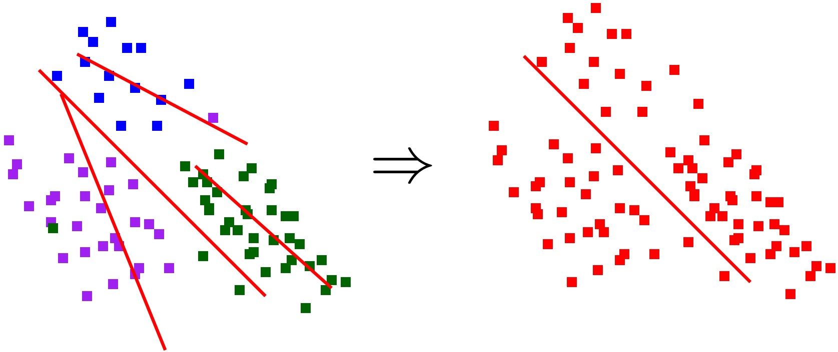




TPC wireplanes: red and green "induction" planes $\pm 60^\circ$ to vertical, Blue parallel "collection" plane

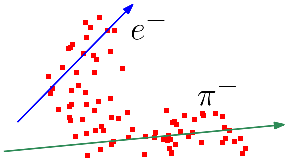
LArSoft - Cluster Studies

1. Generate single electron, muon and uniform flux CC ν_e events with singles.fcl and GENIE. Filter for $1e^- + 1p$ final states
2. Reconstruct clusters with modified uboone offline .fcl script
3. Feed to a module I wrote, MCHitter, to calculate purity and efficiency of reconstructed clusters
4. Compare DBSCAN, FuzzyCluster



LArSoft - Cluster Studies - Purity & Efficiency

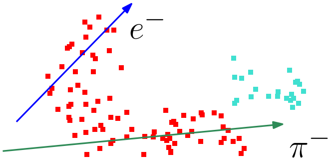
$$\textbf{Purity} = \frac{\text{\# of hits from trackID in cluster}}{\text{total \# of hits in cluster}}$$



Measures

- How much of a cluster is composed of a each true particle
- If less than 1: clustering algorithm could not distinguish true particle hits from one another

$$\textbf{Efficiency} = \frac{\text{\# of hits from trackID in cluster}}{\text{total \# of hits for that trackID}}$$



Measures

- How many of all hits the particle generated are in a specific cluster
- If less than 1: algorithm failed to group the hits created by the particle into a single cluster