MicroBooNE

Late Light Analysis and TPC Crate Performance Tests

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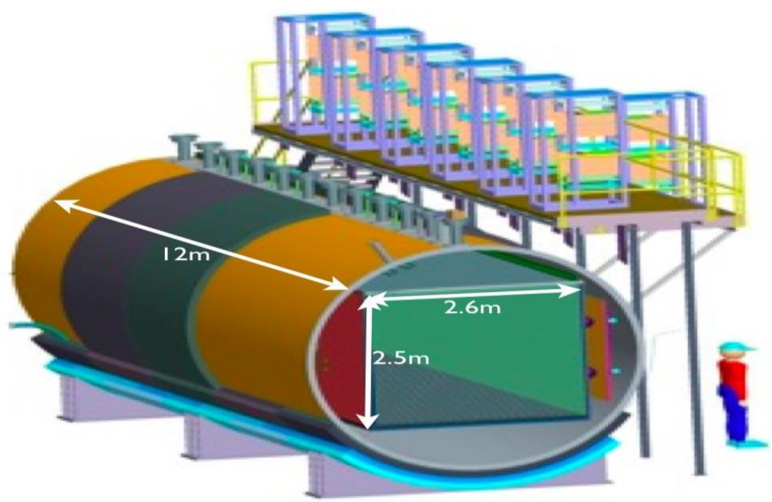
MicroBooNE's New Detector Technology

- MicroBooNE is a Liquid Argon Time Projection Chamber, abbreviated LArTPC, that uses about 170 tons of liquid argon to track interactions due to Neutrinos.



MicroBooNE Depiction

- 32 to 40 8-inch photomultiplier tubes (PMTs)
- Searching for $\nu_e/\bar{\nu}_e$ appearance

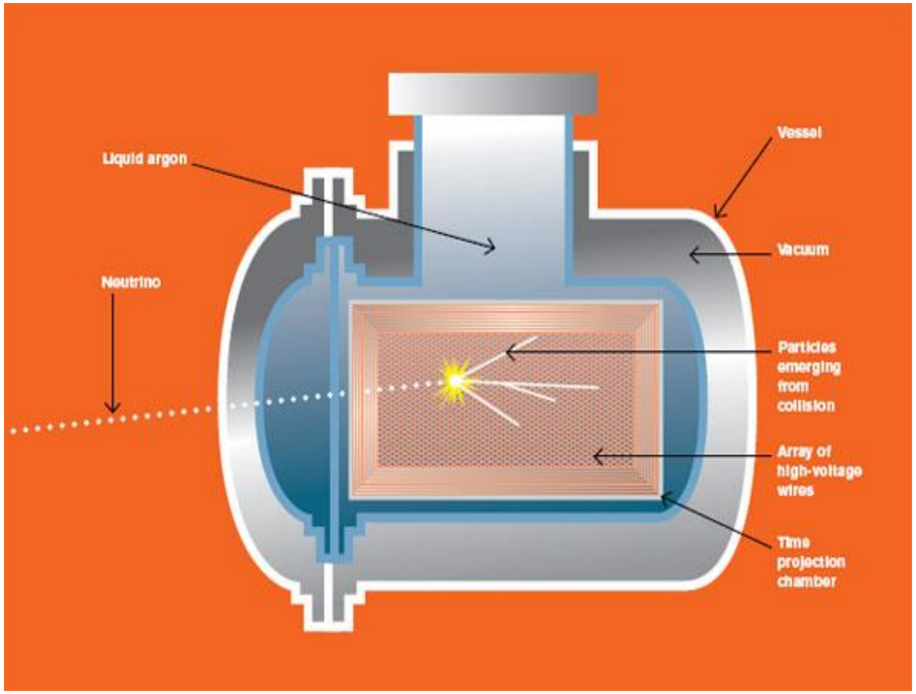
Potential of LArTPC

- Design allows numerous possibilities to expand off of its predecessor, MiniBooNE.
  - - Higher Precision (about twice that of MiniBooNE)
  - - Can tell the difference between a photon and an electron-positron pair by measuring dE/dx
  - - Can investigate the low energy excess witnessed at MiniBooNE
  - - Acts as a precedent for future liquid argon detector experiments
  - - Designed to detect neutrinos that arrive very quickly from supernovae

Cryostat During Delivery

Liquid Argon

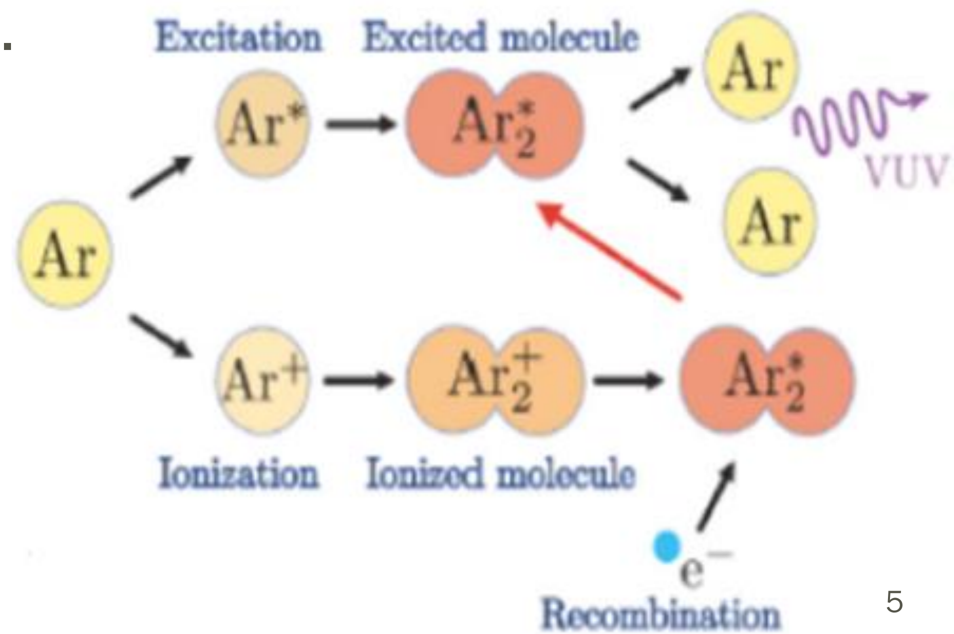
- Liquid argon (LAr) is chosen to detect neutrinos because of its high density, which means more probability for neutrino-Argon interactions (neutrino cross sections), non-reactive and inert so electrons can pass freely through it, and, compared to other noble elements, cheap.
- Fermilab's LAr purity demonstrator (LARPD) created a filtration system maintain LAr purity, which is important for electron drift. It can maintain LAr purities of 100 ppt (parts per trillion) of oxygen, perfect for the experiment.



Depiction of LArTPC-neutrino interaction
(not MicroBooNE)

Scintillation Light

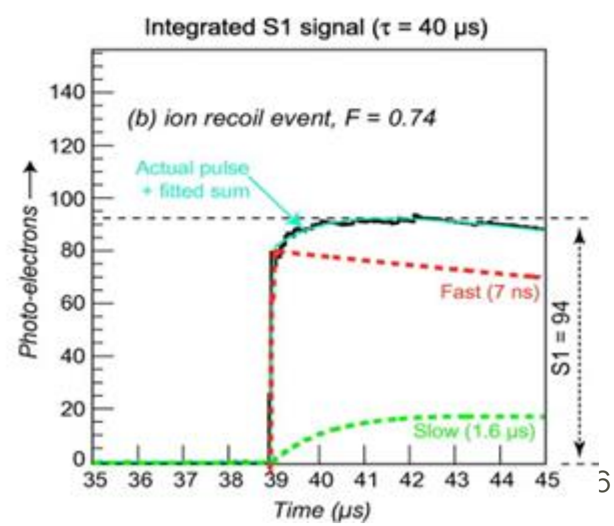
- When Argon becomes ionized, electrons drift through the LAr towards the photomultiplier tubes.
- An excited or ionized argon atom combines with an argon atom in its ground state, producing an excimer.
- The excimers decay back into ground state argon, releasing light in the form of UV light.



Argon Interactions

Late Light

- For better or for worse, there is a secondary product of the interactions that produces additional light called "late light."
- Excited or ionized argon can enter a singlet or triplet energy state, each of which has its own decay constant.
- The decay constant of the singlet state is 6 nanoseconds and is termed "prompt light"
- The decay constant of the triplet state is 1.6 microseconds (much larger) and is termed "late light"



Fast (prompt) light versus slow (late) light

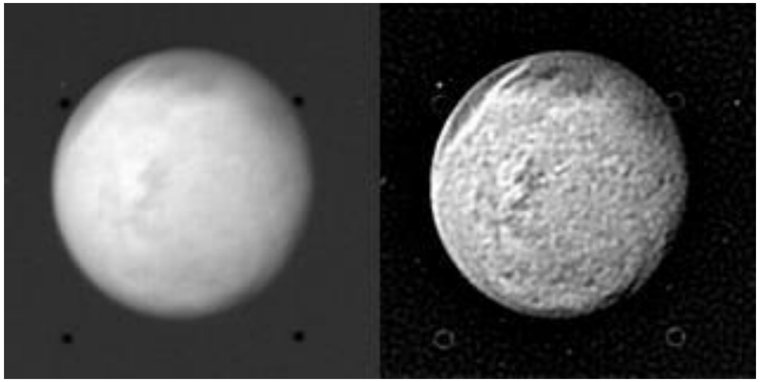
Acquiring the Convoluted Data

- Need to differentiate between prompt and late light for accurate data acquisition and determination of light sources.
- Given data acquired at Bo using a similar setup, the real-time arrival of the neutrino event is recorded.
- The pulse heights are given from the readout in ADC units in an aesthetically appealing shape, granted by convolution with a shaper pulse that comes out of a shaper module.
- The actual data is a near-instantaneous pulse of light, but, through convolution, a time-dependent weighted average is acquired.

$$(f * g)(t) \stackrel{\text{def}}{=} \int_{-\infty}^{\infty} f(\tau)\, g(t-\tau)\, d\tau$$

Deconvolution

- Deconvolution is, essentially, the inverse of convolution. Given the pulse provided by the readout and the shaper pulse that constructed it, deconvolution can extract the shaper from the readout pulse to retrieve delta functions (tall spikes) that resemble the instantaneous arrival of light.
- Many algorithms exist to perform deconvolution, the chosen one, for its sensitivity and ease of use, was Gold's algorithm.



Example of the Effects of Deconvolution in Image Processing

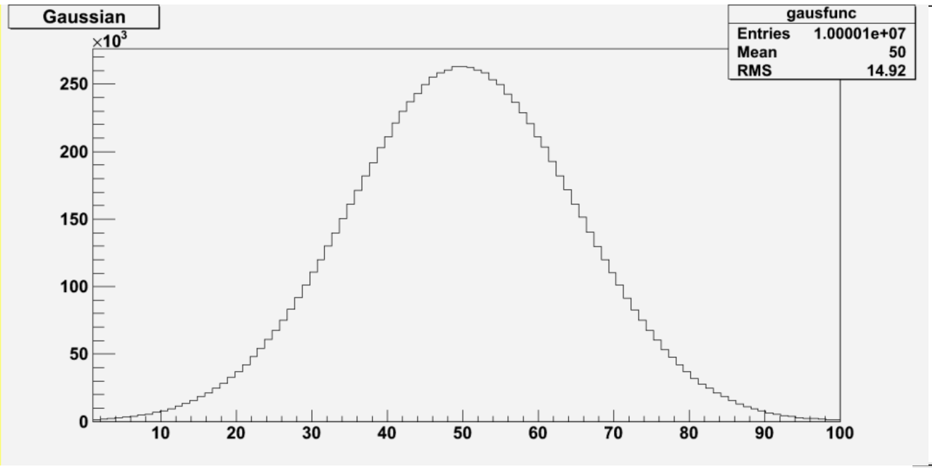
Preliminary: Analysis Code

- Moving from interpretive code to compileable code
- Data input and output in the form of root files, text files, and graphical images in .ps format.
- Boolean options to allow the user to choose what to process and what not to process (time/memory allocation can be reduced)
- Ensuring that the pulses were properly stored in memory and passed designated thresholds
- Taking advantage of the trigger and discriminator to ensure accurate, full readout
- Assured correct baseline was used throughout

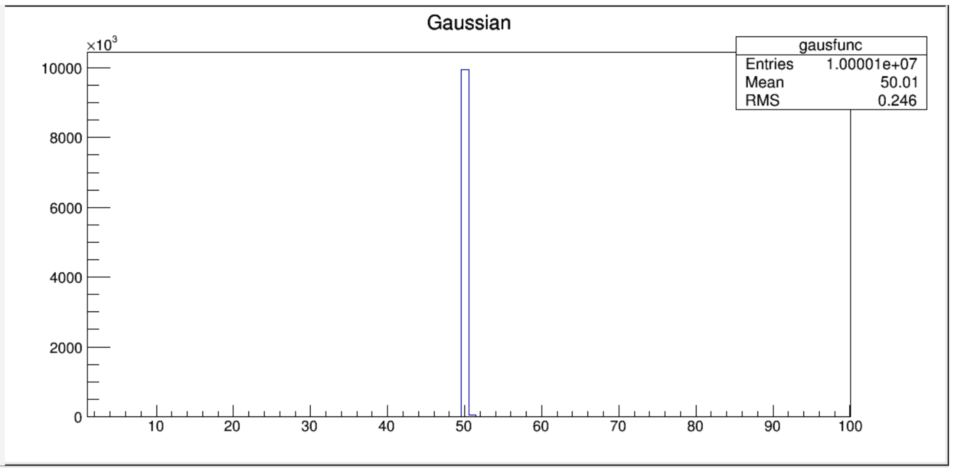
Testing the Method

- A property of deconvolutions is that a function deconvoluted with itself should be a single spike.
- To ensure that the deconvolution method worked in the anticipated manner, a simple Gaussian was constructed and deconvoluted with itself.

Original Gaussian



Deconvoluted Gaussian



- This result is as expected, so the method is reliable.

Finding a Shaper Pulse

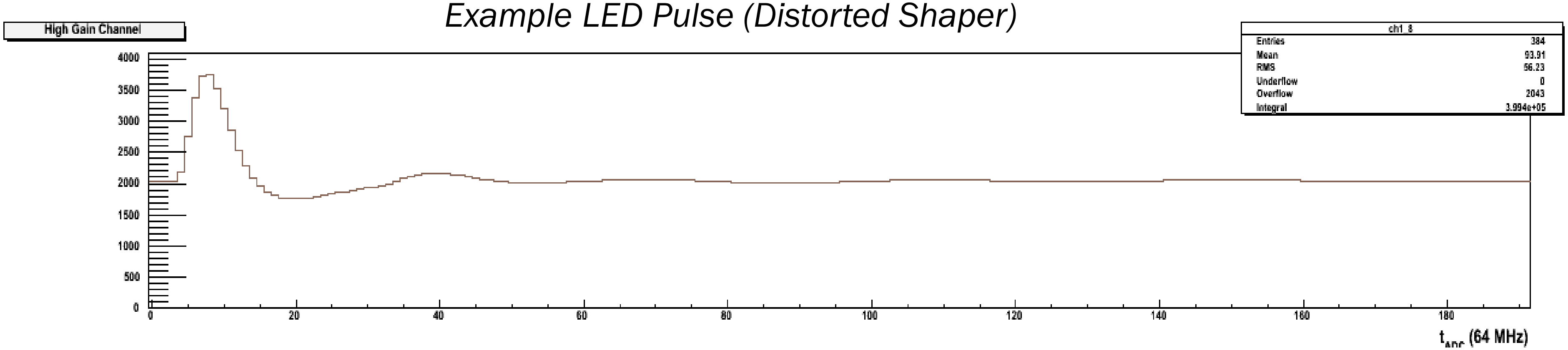
- To perform the deconvolution on the Bo data, an appropriate shaper pulse is required.
- The shaper unit used produces a simple, unipolar shaper pulse, but the splitter for the electronics causes voltage differences that result it a distorted shape, with a dip that goes below baseline and a second crest.

Ideal Unipolar Shaper Pulse

A New Shaper

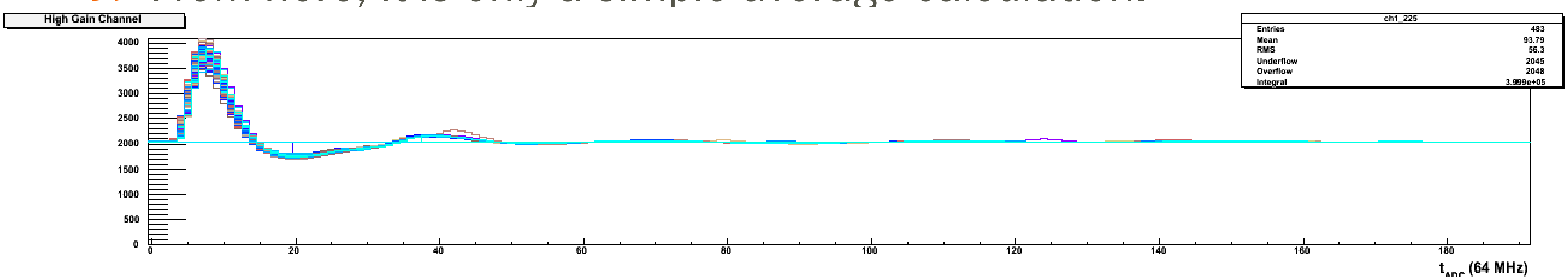
- In order to perform the deconvolution studies in the presence of this deformed shaper pulse, Bo Data taken with an LED pulse can be used.
- The idea is that, since convolution and deconvolution are inverses, the shaper that was already convoluted into the data should be able to be deconvoluted with the pulse and give the same result as if the shaper pulse were clean.
- To eliminate noise, the average was taken over about 1,000 LED events.

Example LED Pulse (Distorted Shaper)



The Average Pulse

- Simply adding all the pulses and dividing by the number you added would be ideal, but the pulses happen at slightly different times within the window the data is preserved, , sometimes with more than one pulse in a frame.
- Trick: the time difference between the trigger and the LED pulse is constant, so, given the recorded time of arrival of the trigger, the LED pulses can all be shifted so that they match peaks, troughs, etc. accordingly.
- From here, it is only a simple average calculation.

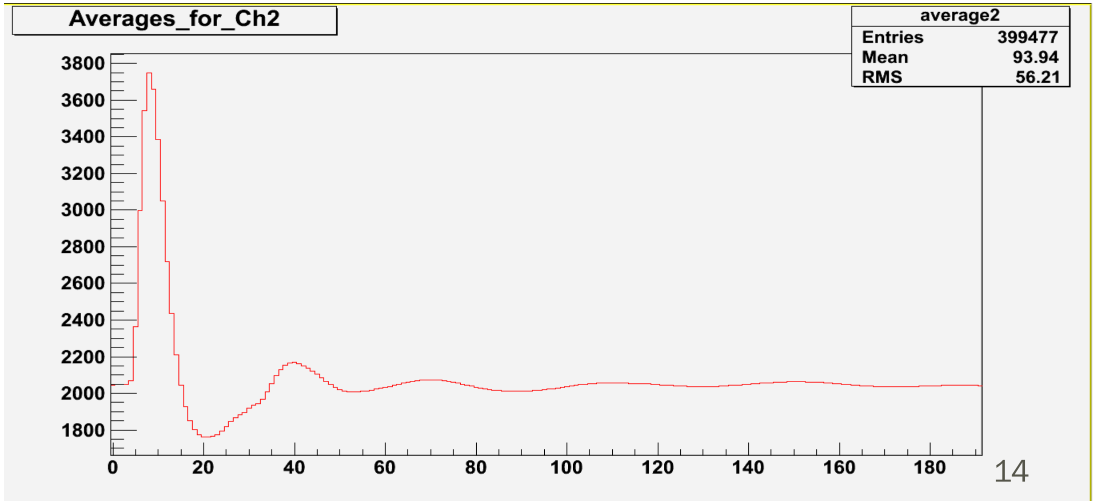


200 Overlayed LED Pulses

Results: an Acceptable Average

- The average over about 1,000 LED pulses was taken and produced a reasonable average pulse that was used in deconvolution studies.
- Two separate channels for data readout, high gain and low gain. High gain takes 10/11 of the data, low gain takes 1/11 of the data. Different energies need different proportions of the data to avoid saturation and provide resolution.
- Focus will be on LED at 1650 Volts in the High Gain Channel for aesthetics.

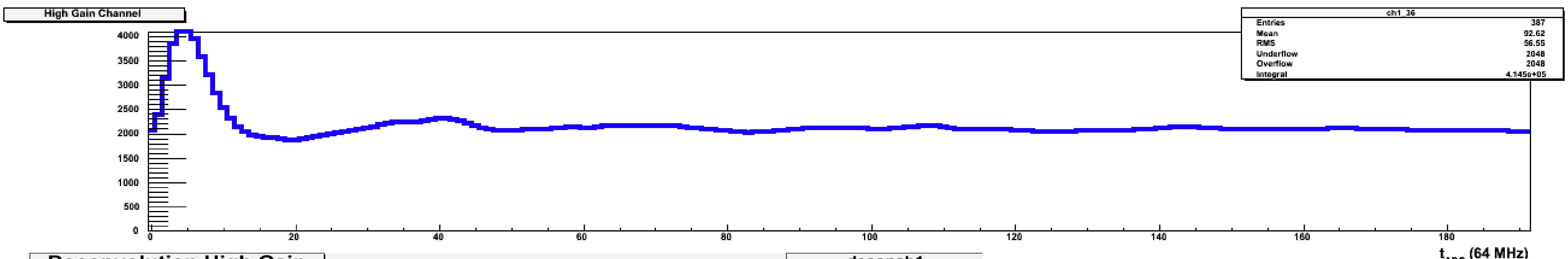
Average High Gain LED Pulse at 1650 Volts

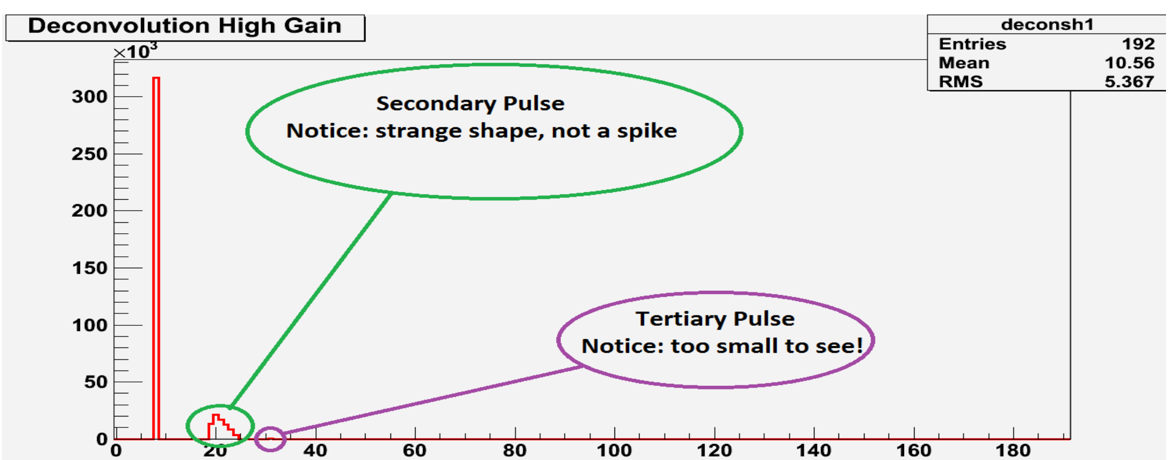


Deconvolutions with Cosmic Pulses

- Deconvolutions of cosmic pulses collected at Bo and the average LED shape led to, in all cases, the large initial spike (very large in comparison to original pulses) and various secondary, or even tertiary in some cases, smaller pulses with various shapes and heights.

Typical Cosmic Pulse



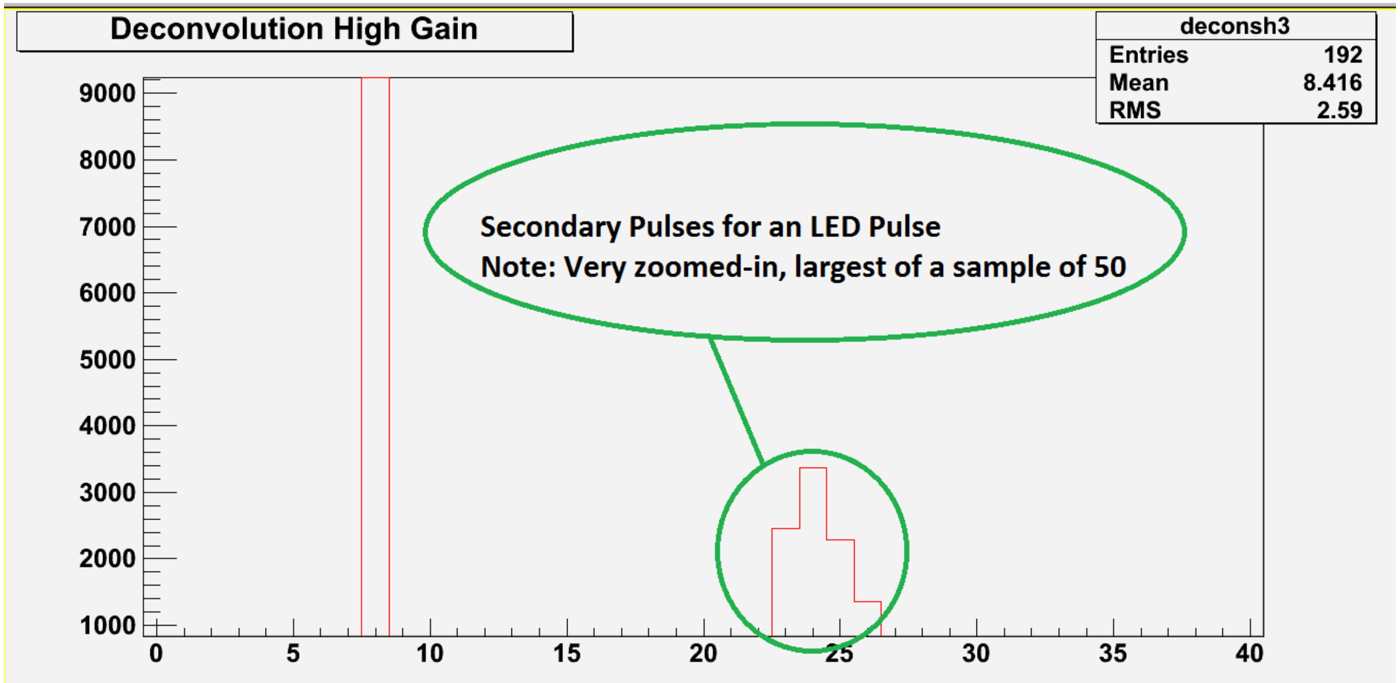


Typical Cosmic's Deconvolution

Check: Deconvolution of LED Pulses

- Have to make sure it's only a single spike like the Gaussian
- There is a large spike with a value of about 400,000.
- There is a strange, small, elongated secondary pulse.

Zoomed-in Example of LED Deconvolution



Looking for Answers

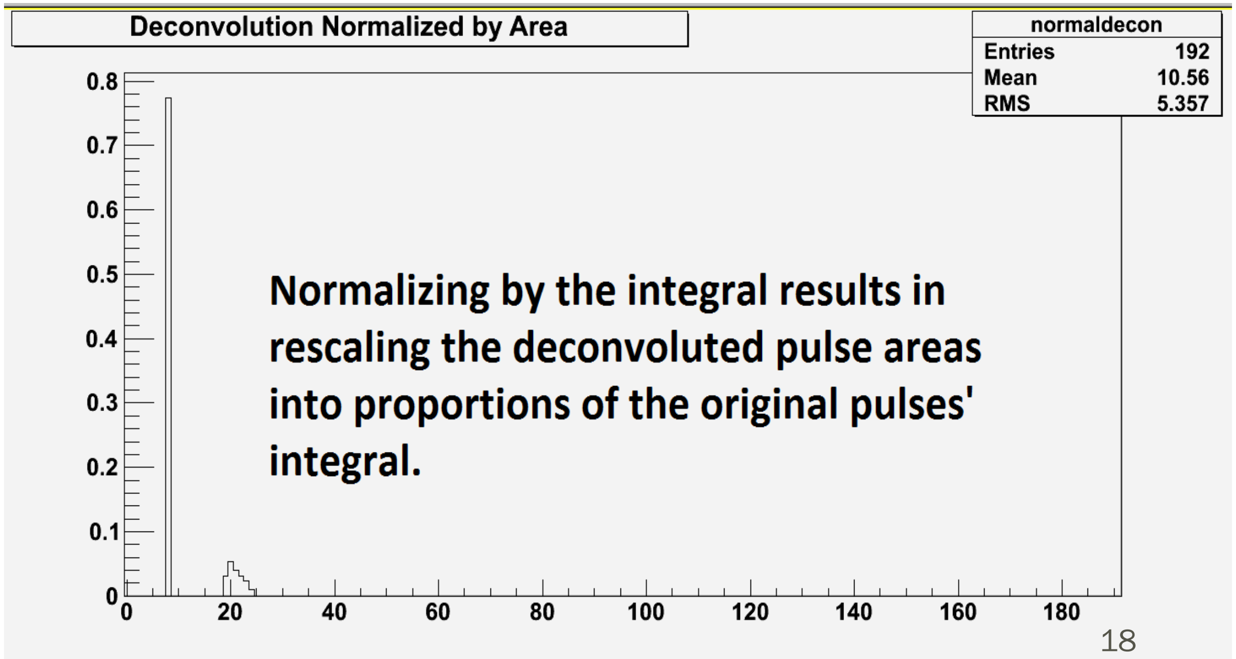
- Two main goals:
  - 1. Eliminate Secondary Pulses in LED Pulses
  - 2. Identify Secondary Pulses in Cosmic Pulses

- Ideas:
  - - Normalization
  - - Checking secondary pulse bin numbers
  - - Watching ranges of secondary pulses' peak heights
  - - Tertiary Pulses

Normalization

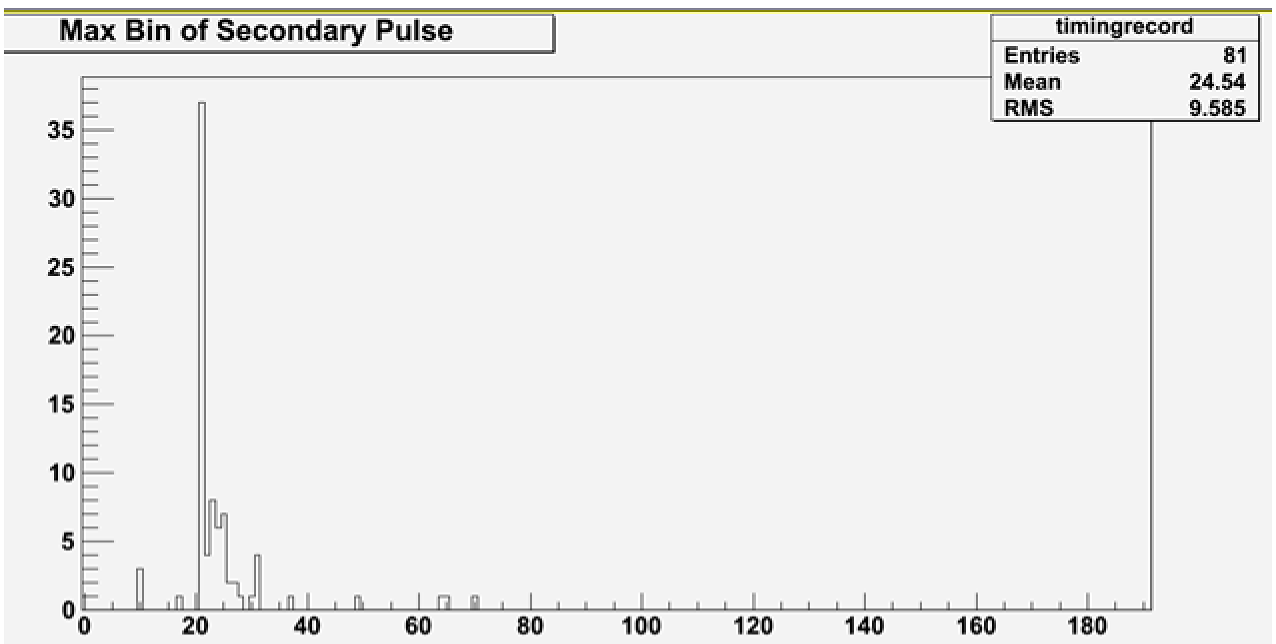
- The units from the deconvolution become complicated, so normalizing with respect to the area under the original, convoluted pulse might shed some light on the matter.
- It is clear that the deconvolution pulses are proportional to the integral of the shaper pulse.

Deconvolution Normalized by Shaper's Integral



Secondary Pulse Times/Bins

- The beginning of the secondary pulse was recorded over 156 high gain cosmic pulses.
- There was a small variety, but there was a strong preference for the 20th bin. The arrival of late light would be expected to occur within a short range of time.

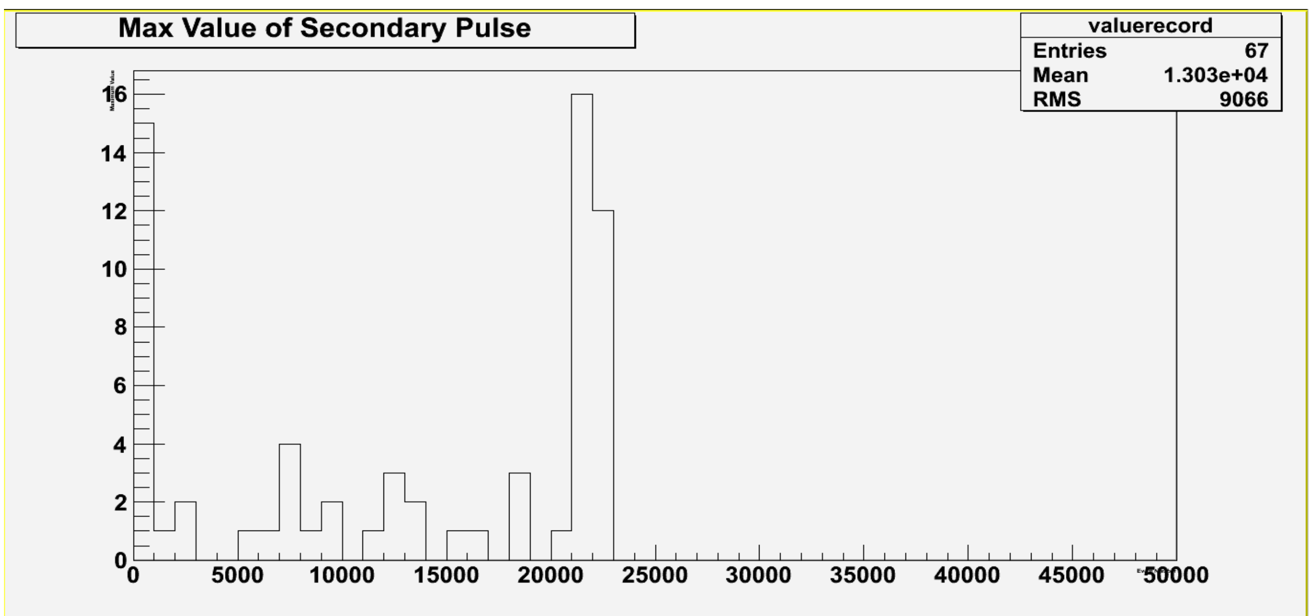


Arrival Bin (Time Tick) for Secondary Pulse

Preferred Secondary Peak Heights

- The secondary pulse peaks were recorded over 156 cosmic pulses.
- Late light is expected to have a value of 1 PE, so the value recorded for secondary peaks should be indicative of whether or not the secondary pulse is late light.

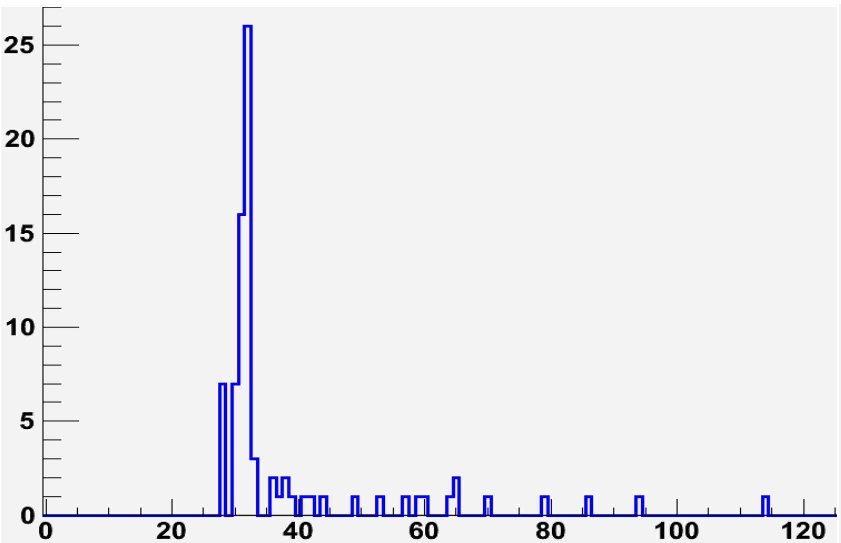
Number of Each Secondary Pulse Height



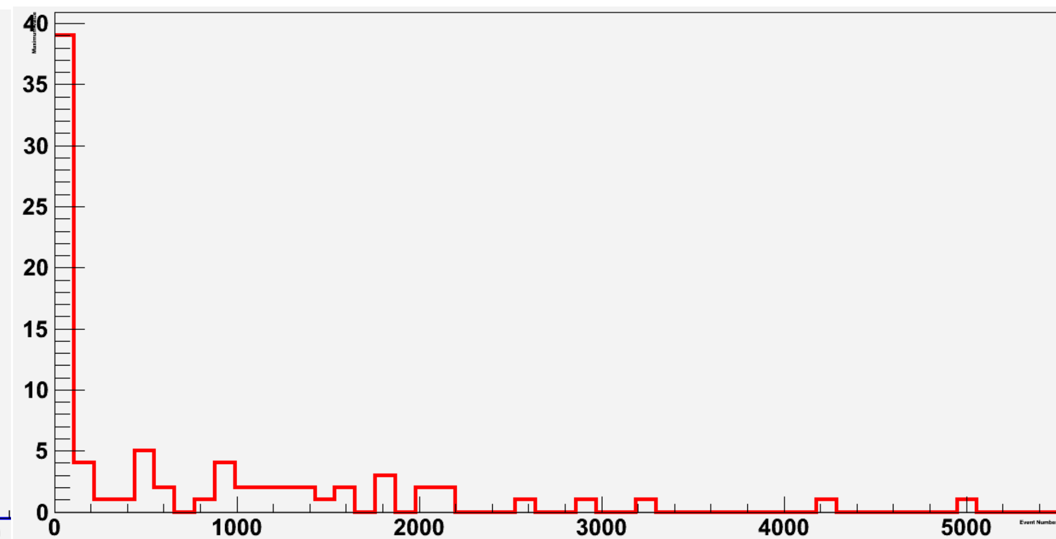
Tertiary Pulses

- The previous two investigations were repeated for tertiary pulses.

Tertiary First Bin (Time Tick)



Tertiary Peak Heights



- Bin 31 was clearly the favored time tick
- The peak heights had a large spread, especially because fewer events had tertiary pulses. 1,000 to 2,000 still seems favored.

Insights

- The favored time bins for each of the peak heights were 9, 20, and 31, respectively. Each of these is 11 ticks apart.
- Spread of peak height and arrival time increases with pulse number.
- The shape of the secondary pulse is very different from both the primary and the tertiary pulses.
- The primary pulse has a height of about 320,000 to 460,000. The secondary pulse has a height of about 21,000 to 23,000. The tertiary pulse has a height of about 1,000 to 2,000.
  - 320,000 /21,000 = 15.2 21,000/15.2 = 1,382
  - 420,000/23,000 = 18.3 23,000/18.3 = 1,257
  - Point: The ratio between the primary and secondary peak heights is about equal to that between the secondary and tertiary peak heights

Conclusions

- The consecutive deconvoluted pulses seem to occur at periodic intervals (11 ticks per period) with peak heights about 1/15 of the previous peak.
  - Could be reflections of the pulse that are inflated by deconvolution
  - Data is being taken at Fermilab with different cable lengths to see if the peaks shift accordingly
- None of the deconvoluted pulses show the large decay constant expected of late light.
- The peaks occur at almost the same time as the local maximums and minimums of the pulses.
- Ultimately, it seems like the only way to tell is to perform the analysis on the cleaned, unipolar shaper that is being used at Bo now to ensure there are no lingering effects of the ringing from the splitter.

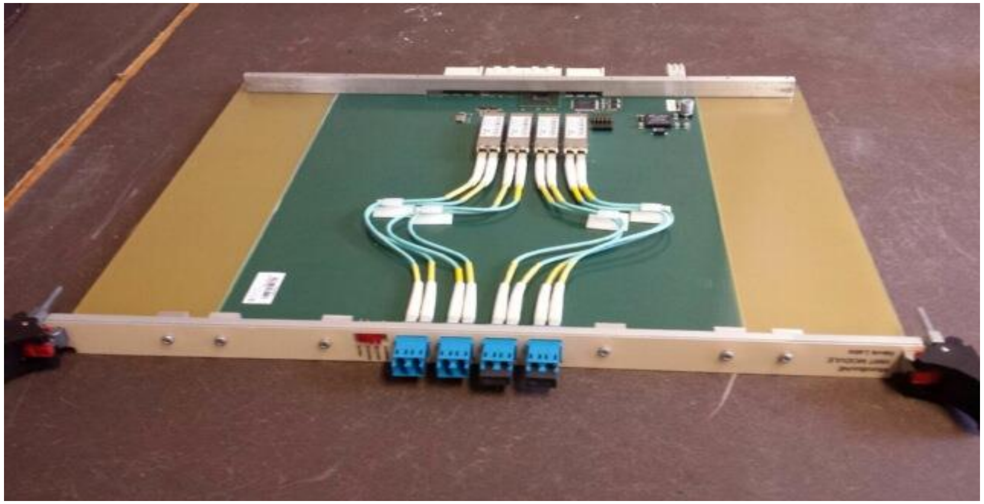
TPC Crates

- TPC Crates hold 16 FEMs (front-end modules), an XMIT (transmit) module, and a control module. They allow the data to be readout from the TPC.
- There are 9 crates total, each with their own set of FEMs, XMIT, and control module.
- Each system must be checked in three different performance tests to ensure compatibility and the elimination of timeout errors witnessed earlier this summer.

Fully Installed Crate

Finalizing the Crates

- All crates, backplanes, clocks modules, FEMs, Control modules, and XMITs were given labels with corresponding serial numbers which were recorded and checked.
- All XMIT and control modules were constructed and tested to ensure compatibility with their crate.



Constructed XMIT Module

- The crates are on their way to Fermilab!

Acknowledgements

- Thanks to the following people for making this program a great experience!
  - Mike Shaevitz
  - Georgia Karagiorgi
  - Leslie Camilleri
  - Kazuhiro Terao
  - Nancy Bishop
  - David Kaleko
  - MicroBooNE partners
  - Amazing REU group
  - John Parsons
  - Everyone at Nevis

Nancy Bishop Packing the Crates for Fermilab

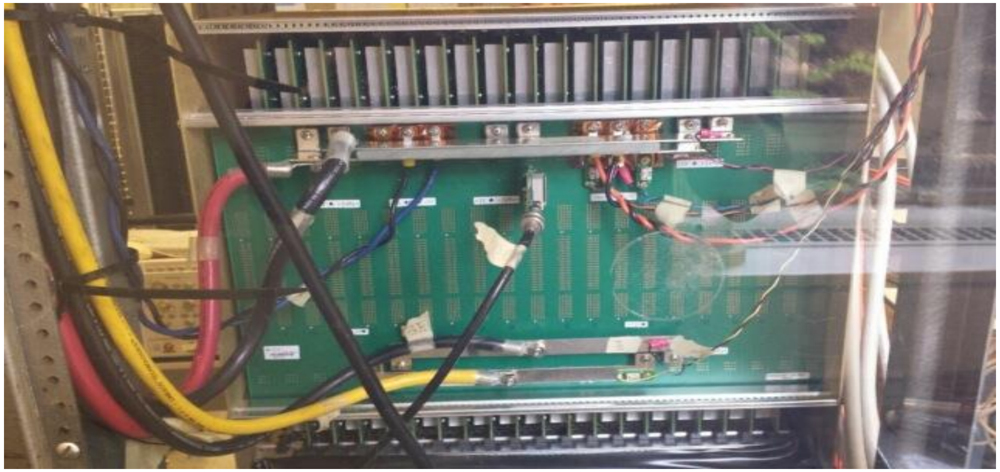
Backup Slides

DMA Timeouts

- Early this summer, the TPC system installed at Nevis repeatedly had "DMA timeout" errors.
- DMA timeouts are errors that halt the analysis program and essentially make a data collection run useless.
- These errors seemed to occur on specific TPC Crate slots and perhaps on specific event numbers.
- The analysis was edited to try to fix the issue.
- Crate testing resumed in late June.

Testing

- There are three types of tests the crates needed to pass: beam event backplane tests, supernova backplane tests, and ASIC event tests.
- The first two simply test that the crate works properly in all parts for testing.
- ASIC testing is the final configuration and the actual testing.



Installed Crate Backplane

- After extensive testing, all crates passed all three tests.

DMA Diagnosis

- During testing the crates would experience DMA timeout errors when the power of a local fan system was turned off.
- This process was repeated and the same result occurred each time. The timeout still happened on the same slots that had previously experienced them.
- Tests on the oscilloscope have shown that drop in voltage occurs as the fan is turned off and the DMA timeout occurs.
- Further studies are being prepared to isolate what voltage enters the trigger board.

ASIC Unit