Cable Length Measurement Using the mu2e Test Stand

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Testing Cables

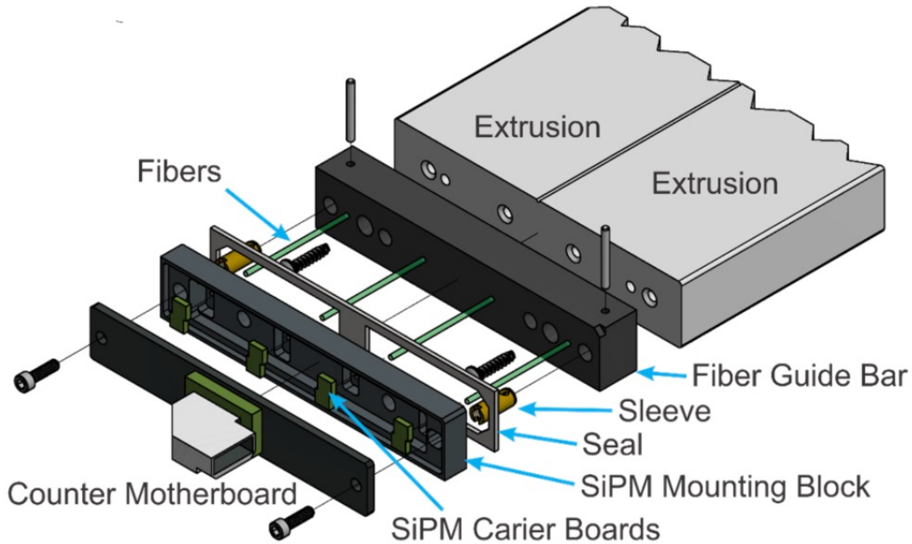
- If we put the digitizing electronics on the outside of TMS, we need to run the analogue signals to the outside of TMS. The length of TMS is 7m = 23’. We purchased cables longer than that.
- mu2e test stand uses HDMI cables so that is what we purchased
- The HDMI cables have 4 twisted pairs, signal and return, with a shield
  - Impedance is 100 +- 15 ohms,
  - The twisted pairs don’t have as accurate impedance as coax, RG58.
- When purchasing HDMI cable AWG, wire size, is not a number the vendors think it is important to tell. They give digital information. So finding the cables with an AWG number was not easy
- Purchased 3 HDMI cables of the following
  - Newegg – 28 gauge, length in feet
    - 3, 6, 10, 10, 20, 25, 30, 35,
  - Cable Wholesale
    - 10 (AWG 28), 25, 35 (AWG 24)

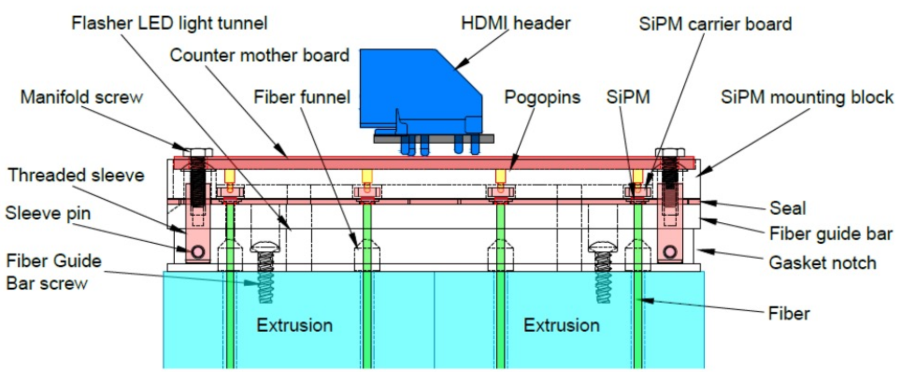
Testing Cables

- Monoprice
  - 10’ (AWG 28) 15’ (AWG 26’)
- Mu2e Monoprice cables tested at the same time
  - 5’ (AWG 32)

- The idea was if the long cables signal was much worse, maybe we could use a thicker cable.
- We discovered the Monoprice cables we purchased did not work with the mu2e setup. We didn’t try to figure it out. The DAQ would not take data with them in.

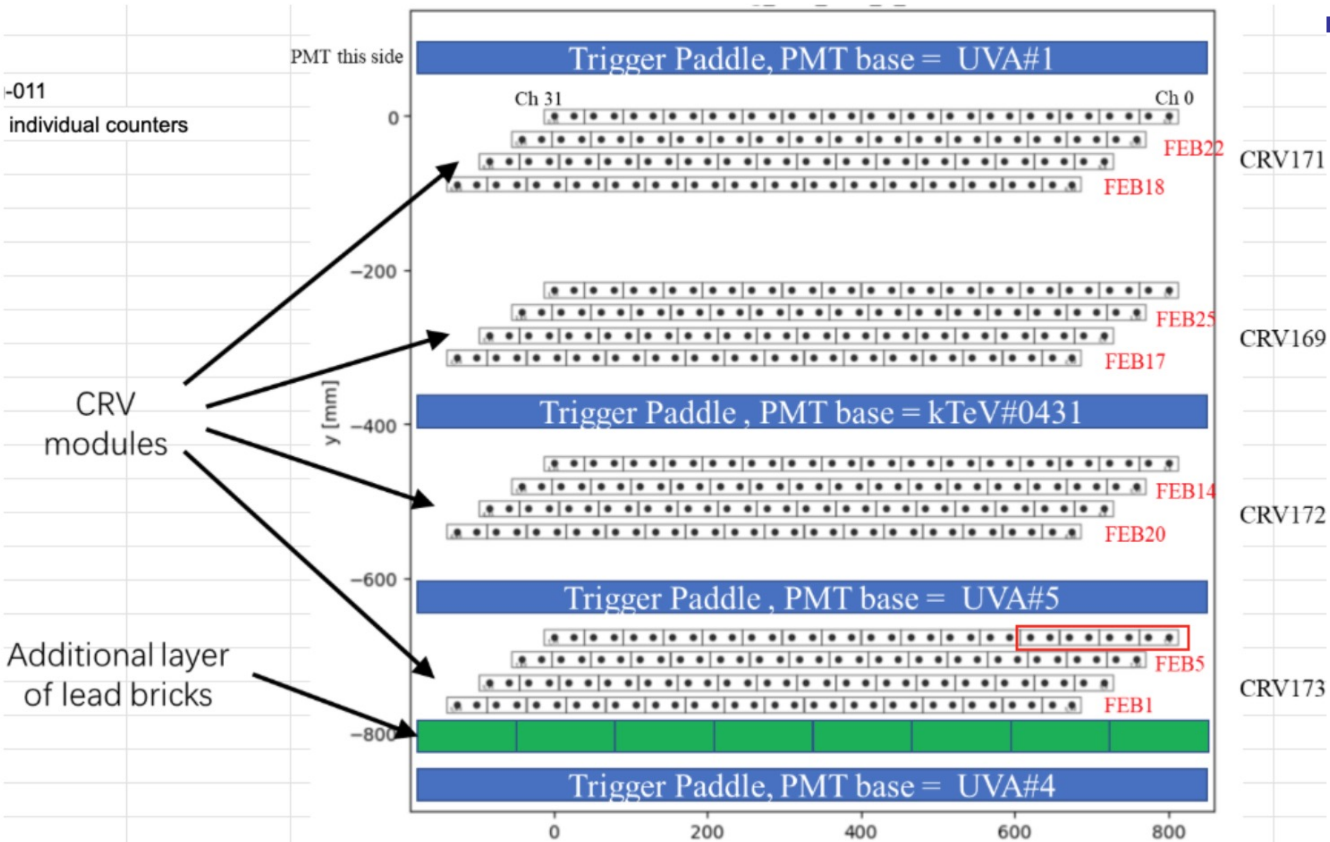
mu2e Setup





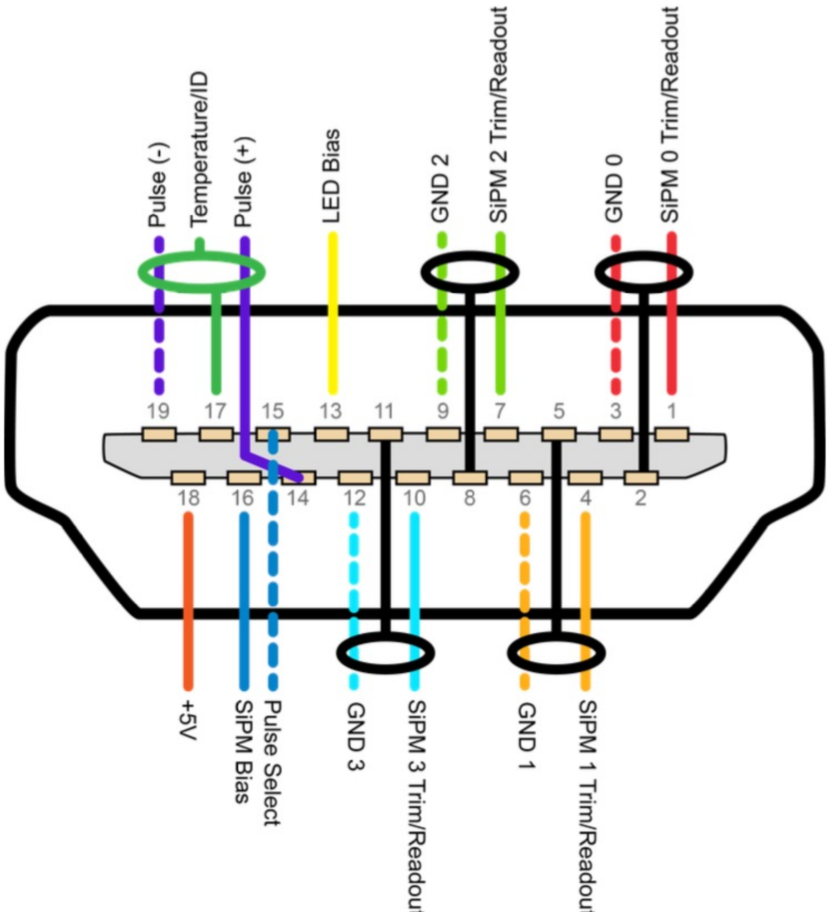
- Scintillator has 2 fibers
- Counter Mother Board has 4 SIPMs to read out 2 scintillator strips.
- HDMI cable with 4 shielded twisted pair bring SIPM signal to readout board (FEB)
- CMP has temperature and bias line to FEB.
- Bias comes to SIPM from both sides of the SIPM. As a result, each SIPM get it own independent bias

Mu2e Setup



- Trigger scintillators on both sides of array, use cosmic rays
- We plug each of the 3 same length cables in a row. Hence, we have 12 SIPMs in a row for the same lengths cable.
  - All the cables are plugged in for the test
- Use 3 FEBs

mu2e HDMI Connector

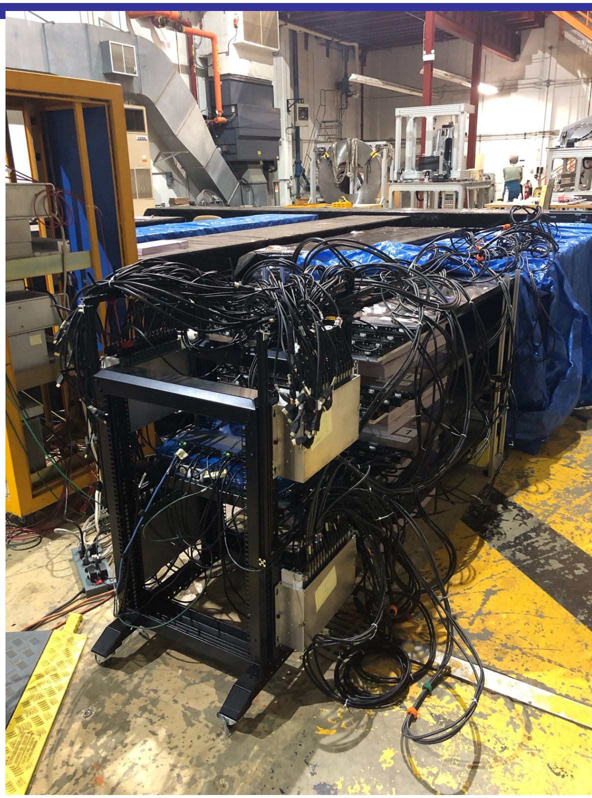


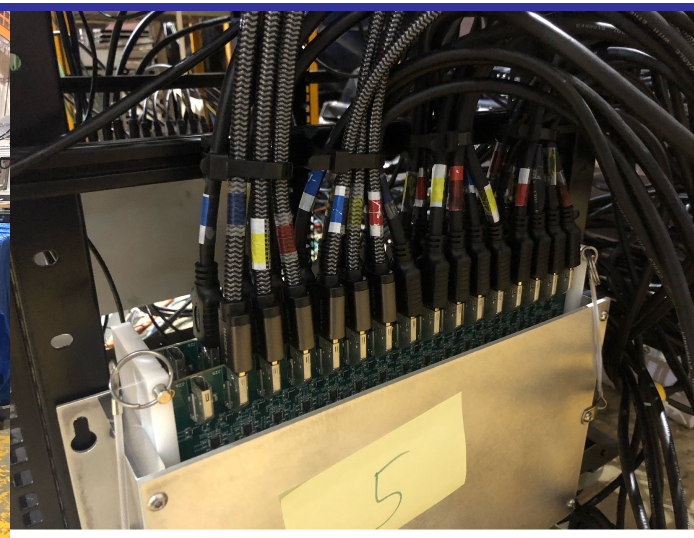
- Shows mu2e HDMI connector
- 4 shielded twisted pairs
  - 100+-15 ohms impedance
- For us to see a signal, the electronics needs to see the bias and the signal cables.
- For the DAQ to run, the DAQ need to see the temp line and probably the 5 volt line.
- Some CMBs had no signals, not sure why.

Pictures

The scintillator bars are 6 m long and the trigger counters are 1 m from the end you see.

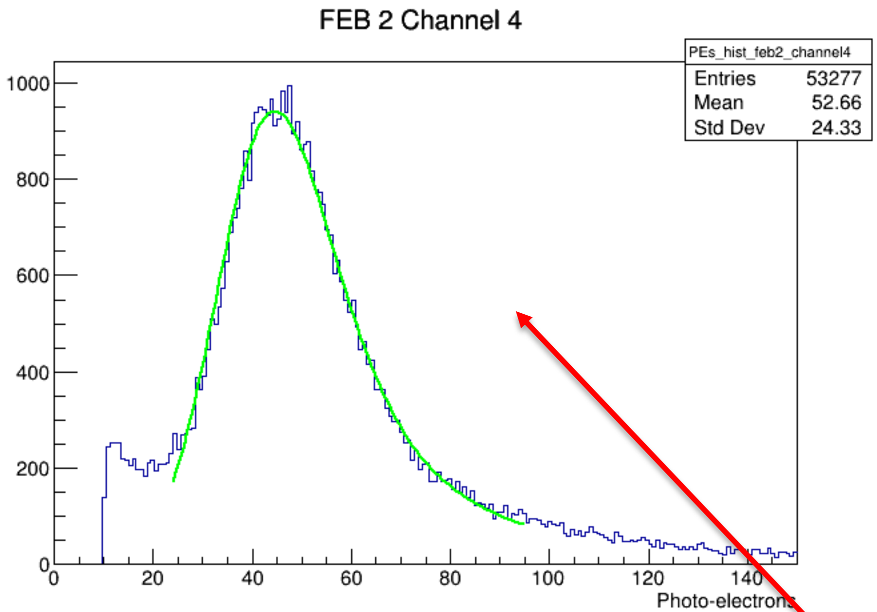
Pictures

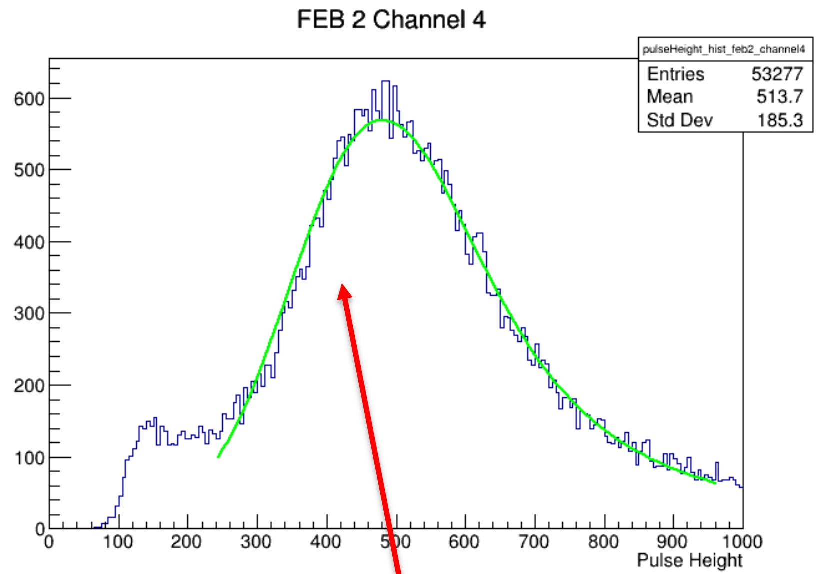




Computer monitor

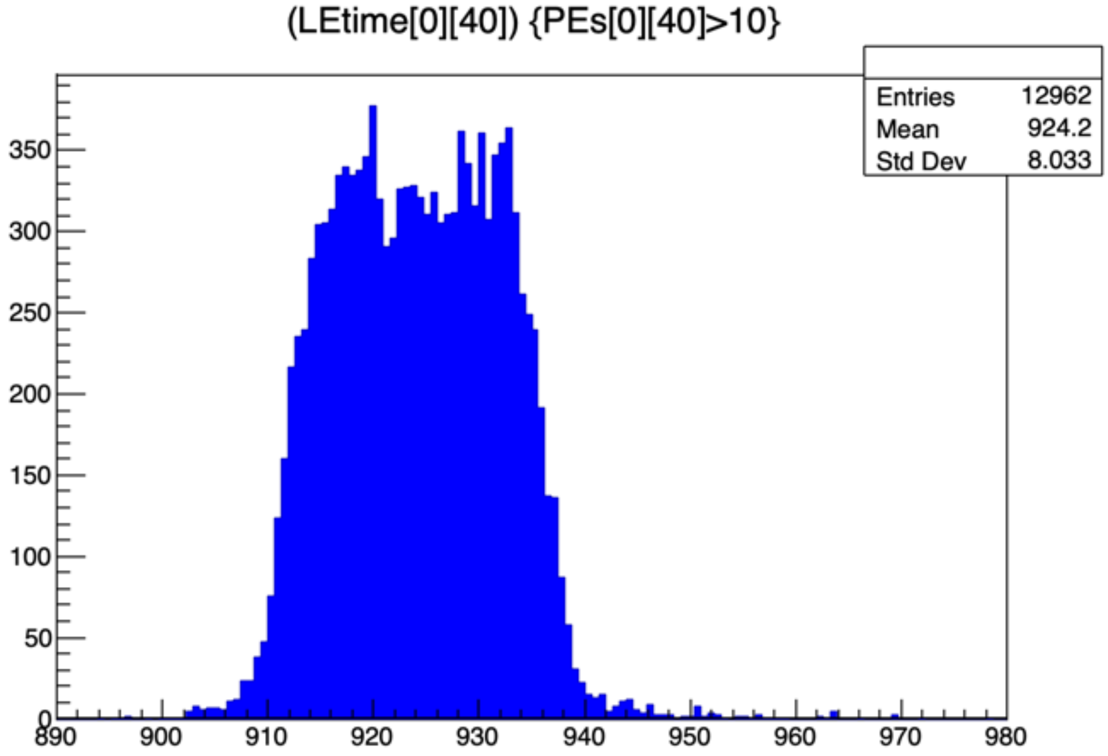
Plot of PE and pulse height





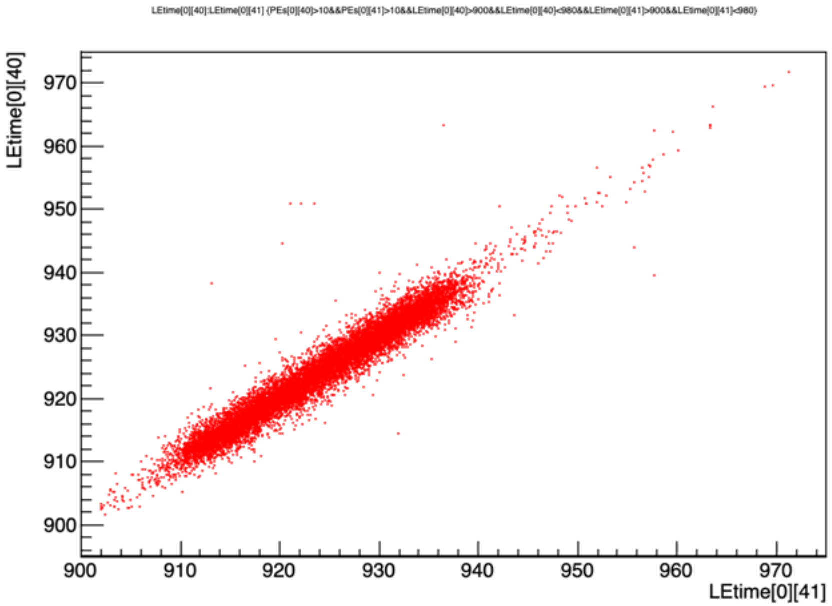
- The 2 variable for charge are photo electrons and pulse height
- PE is calculated from pulse height using calibration constants calculated using SIMPs PE noise.
  - PE is easier to translate to another apparatus so that is what we use

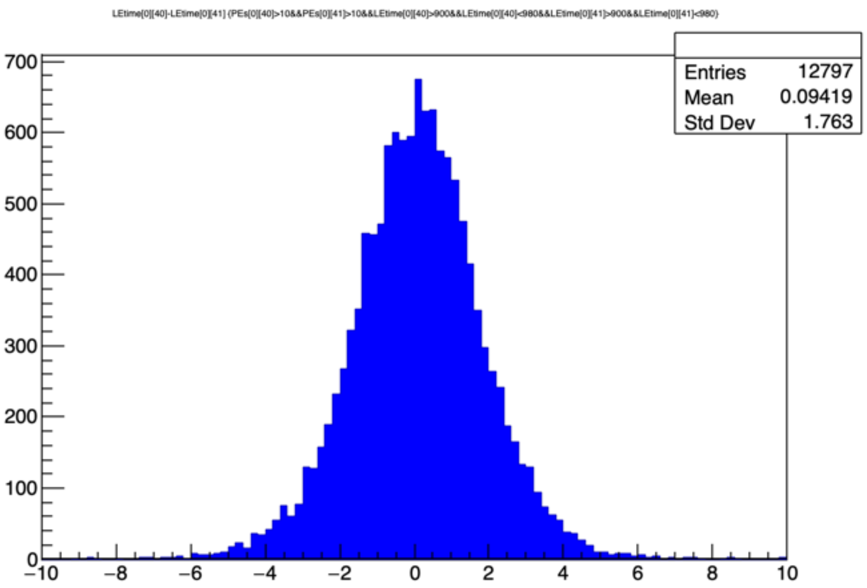
One Scintillator, mu2E cables



- We used variables in mu2e file
- LEtime is the 50% of the fitted pulse height using the Gumbel function.
- There is also a ”time” variable, which is the reconstructed peak time from the Gumbel function
- Units are ns

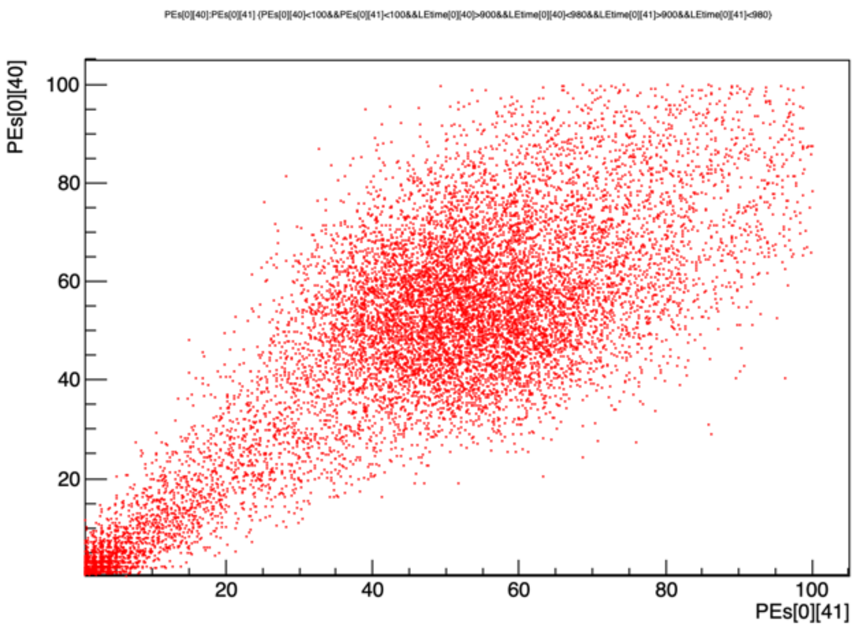
One Scintillator

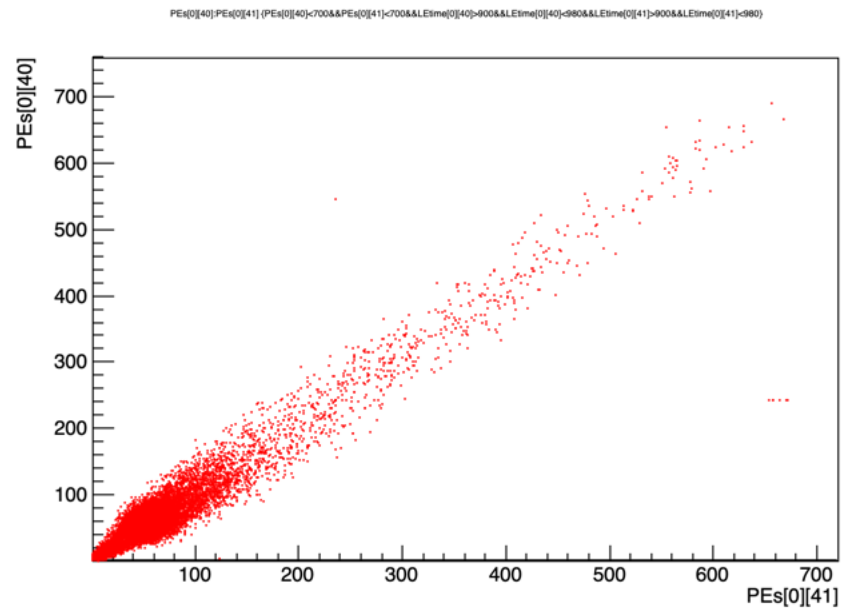




- Left plot is a scatter plot of the timing of the two SIMPs in the same scintillator
- Right plot histograms the difference, I have not divided by sqrt(2)
  - rms/sqrt(2)= 1.25 ns
- For the plots which show the RMS of the difference we divide by sqrt(2) to get the resolution of 1 channel.
- The RMS is calculated for the timing plots using timing cuts of $\pm$ 30 ns about 0.

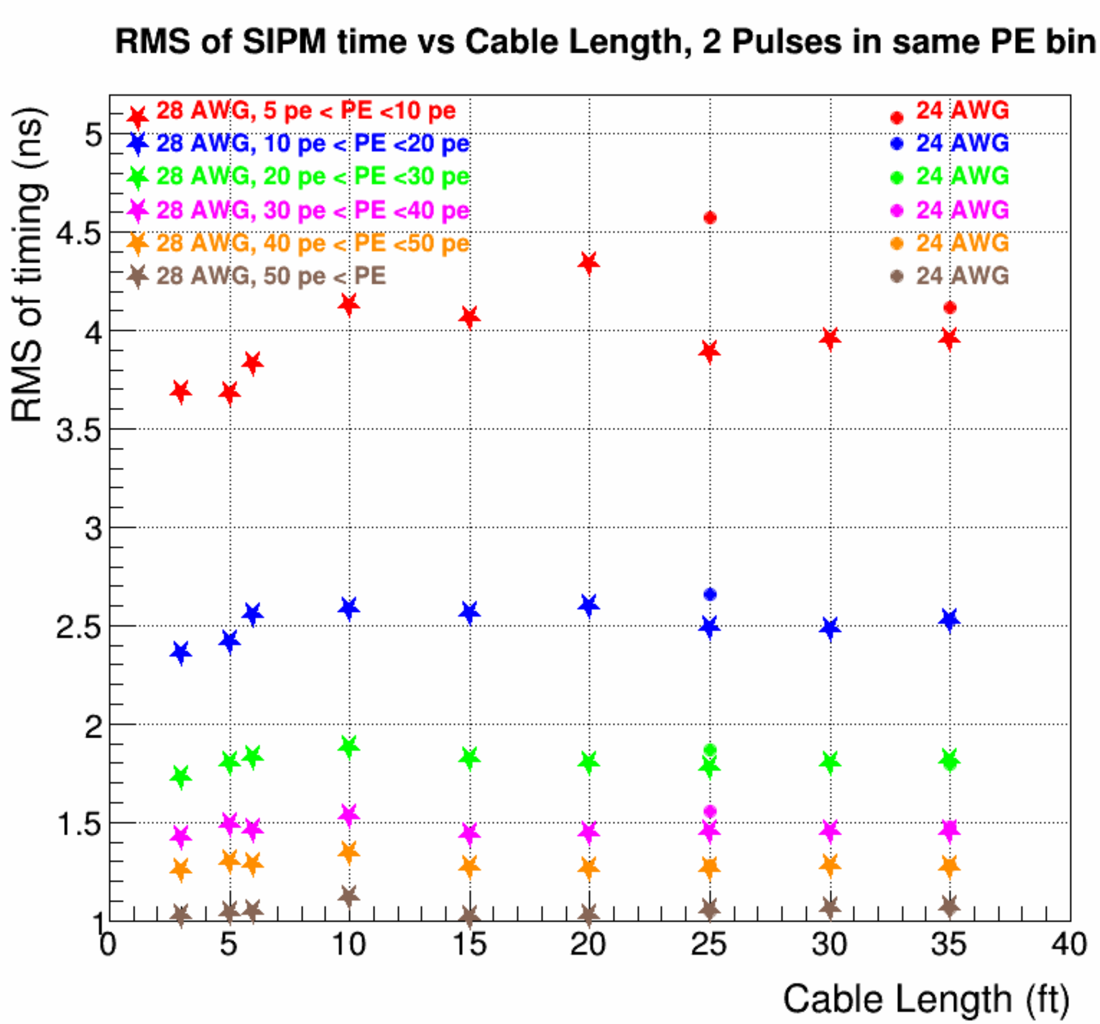
Correlation between PEs





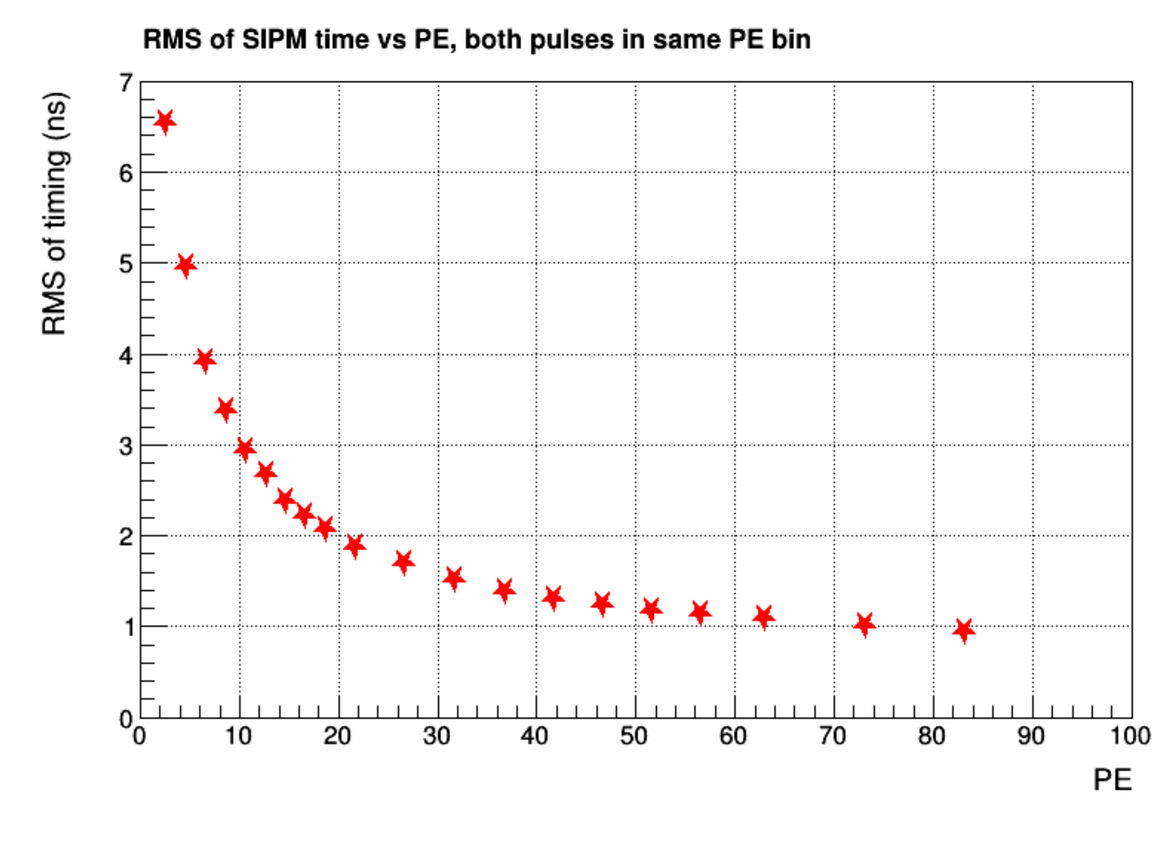
- We are going to look at the LE timing vs pulse height in terms of PEs
- The light to the 2 SIPMs in the same scintillator are obviously correlated.
- The 2 SIPMs are not correlated.

Timing vs length & PE



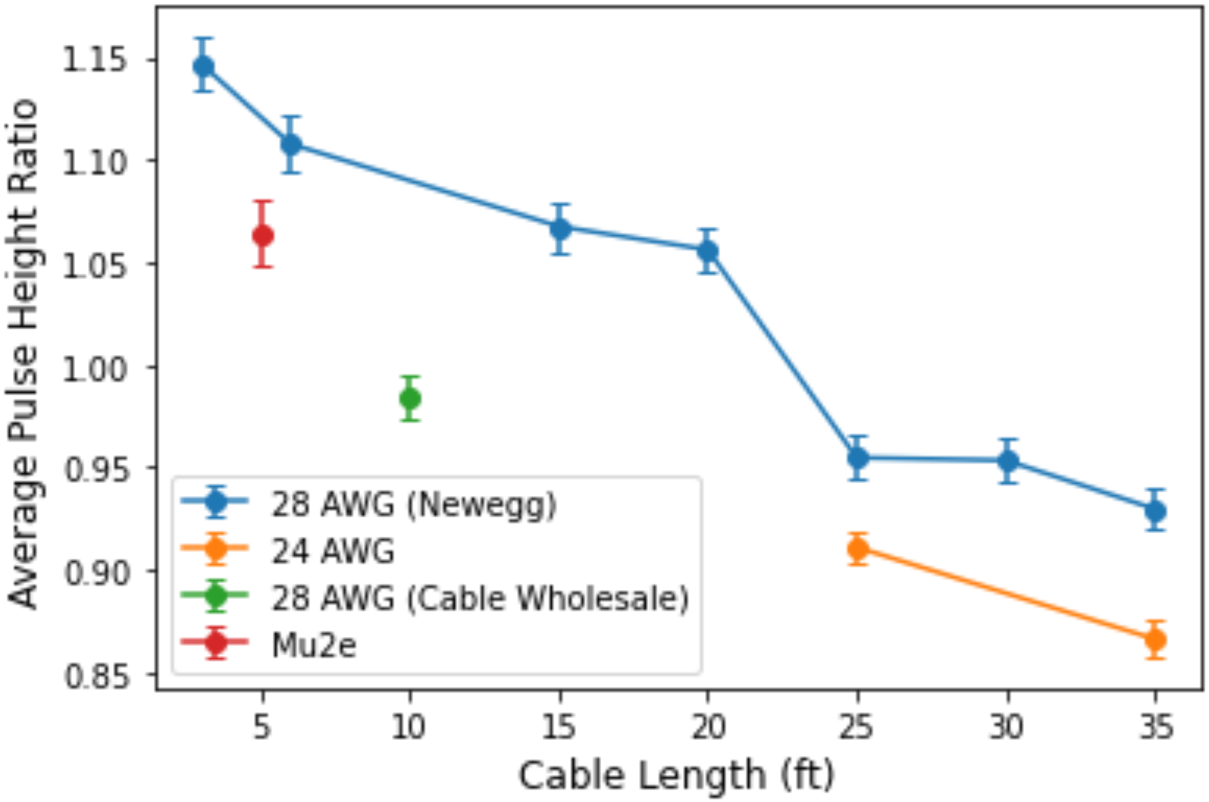
- Some cables dead
  - Monoprice killed the DAQ
  - The 3 10’ 28 AWG Newegg cables were dead, In plot replaced by 10’ 28 AWG Wholesale Cables (WC).
  - The 3’ & 15’ Newegg missing 6/12 SIPMs
  - The 25’ & 35’ WC were missing 4/12 SIPMs
- Not sure why. The temp was read out on all of these.
- The 5’ cable was mu2e so it was 32 AWG
- To 35’ looks like the RMS is fairly independent of Cable length.
- Both pulses in same PE bin
- Resolution falling off at 5 – 10 PE bin

Timing vs PE



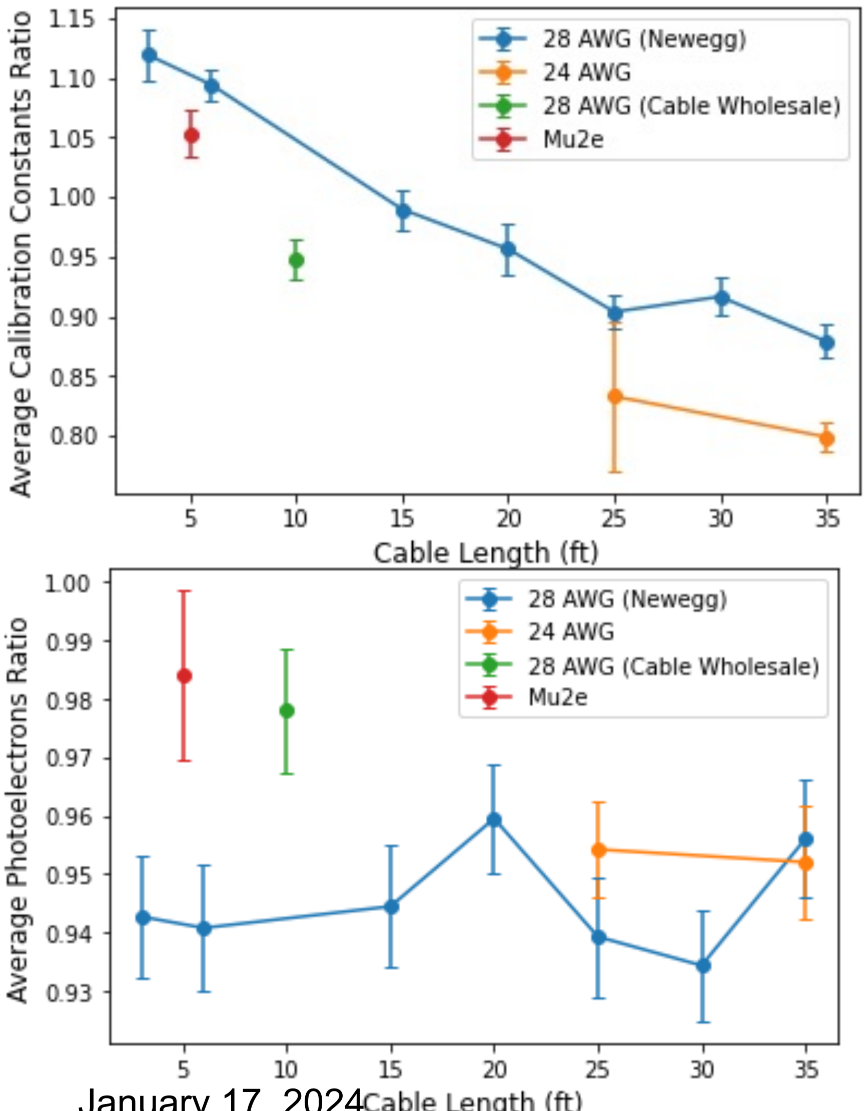
- Timing resolution vs PEs. Both pulses in same PE bin.
- All the data is in the plot.
- Resolution seem a stronger function of PEs than the length of the cables.
- Data higher than 90 PE not shown
- Some of the very low energy pulses might not be a muon, but might be photons coming in from the adjacent strip
  - We don't use tracking

Pulse Height vs length



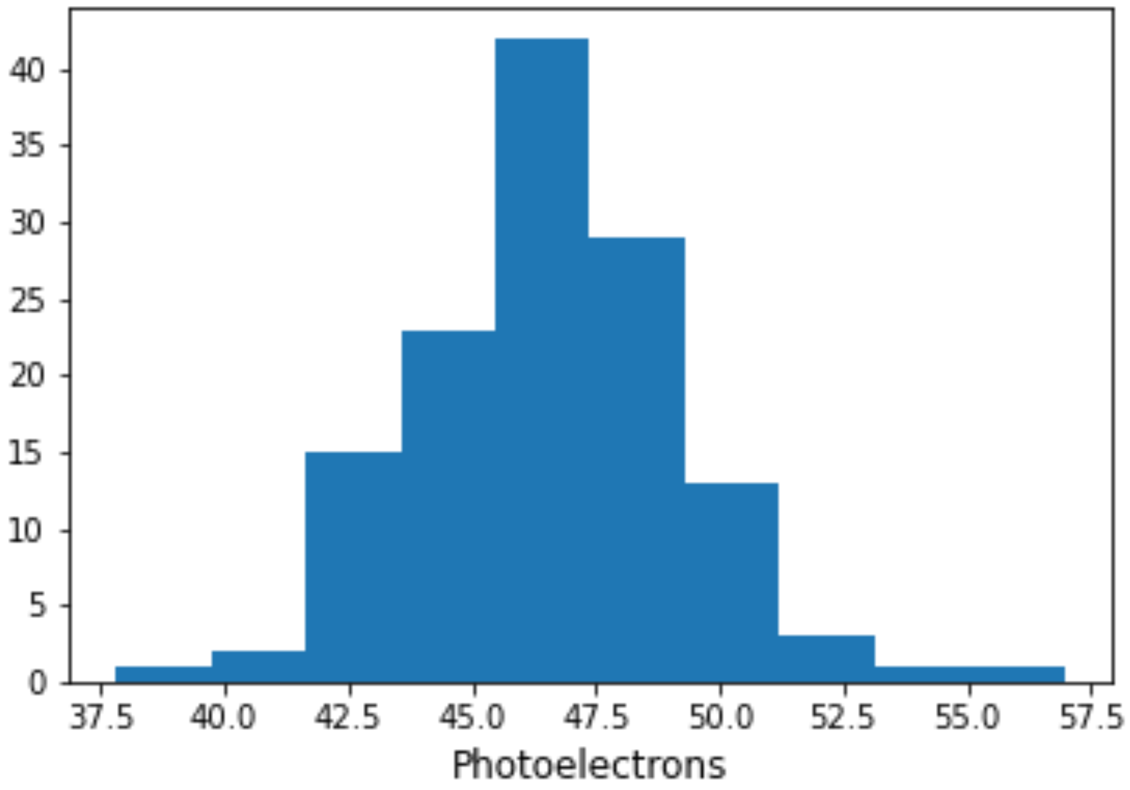
- PH are the ratio of our cables to the mu2e cables in the same SIPM & electronics channel
  - In the slots where we used mu2e cables, They were not the same as previous run with all mu2e cables
- Pulse height falls ~ 22% from 3’ to 35’

PE vs Length



- Normalization done the same way using the previous mu2e run
- The top plot gives the calibration constants getting single PE from SIPM noise.
  - Therefore, the calibration constants have the attenuation of the cable in it.
  - The attenuation is ~ 25% from 3-35’
- Again the 24 AWG look lower than the 28 AWG
- The PEs are relatively flat vs cable length
  - We expect this since that attenuation is removed using the calibration constants.

PE



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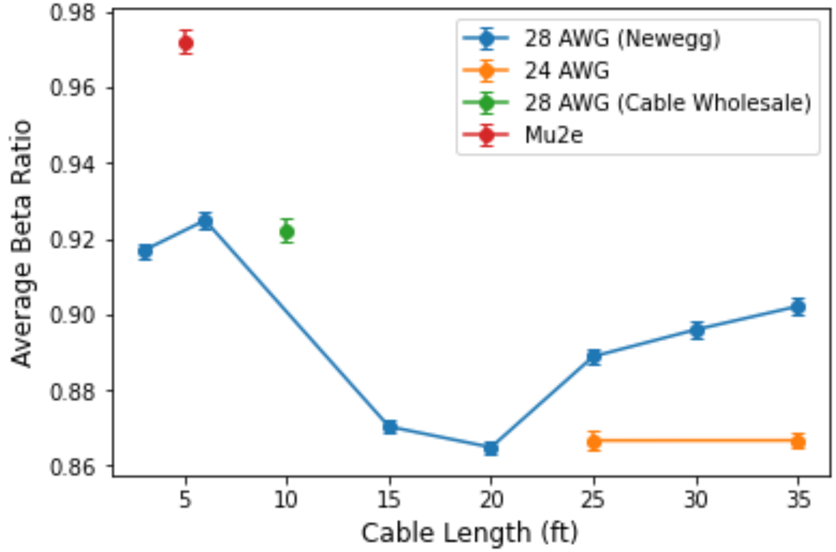
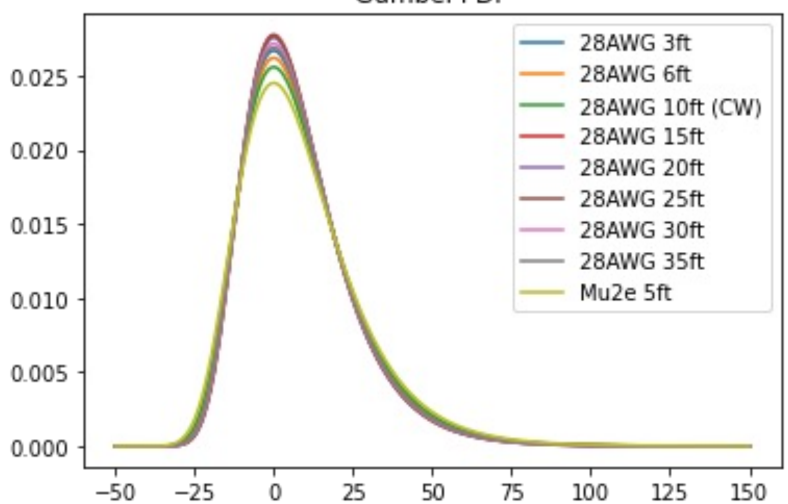
- Histograms the PE for each of the SIPMs in the setup.
- Uses the calibration constant for that run

Pulse fit to Gumbel function

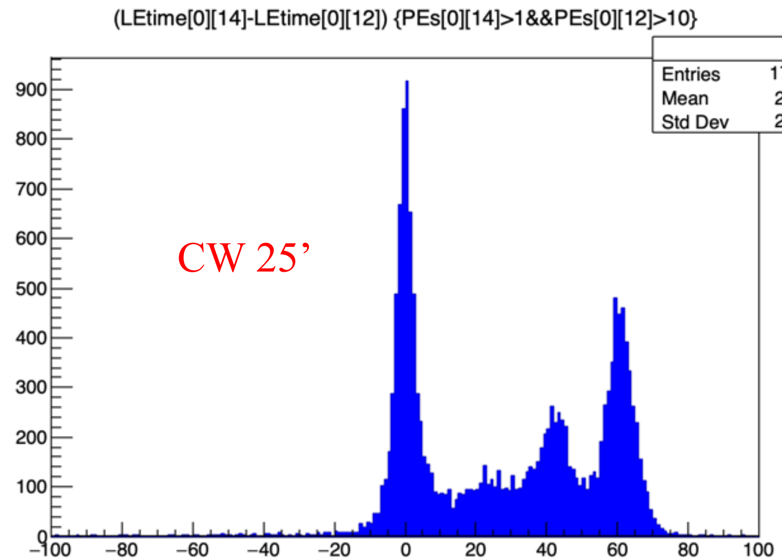


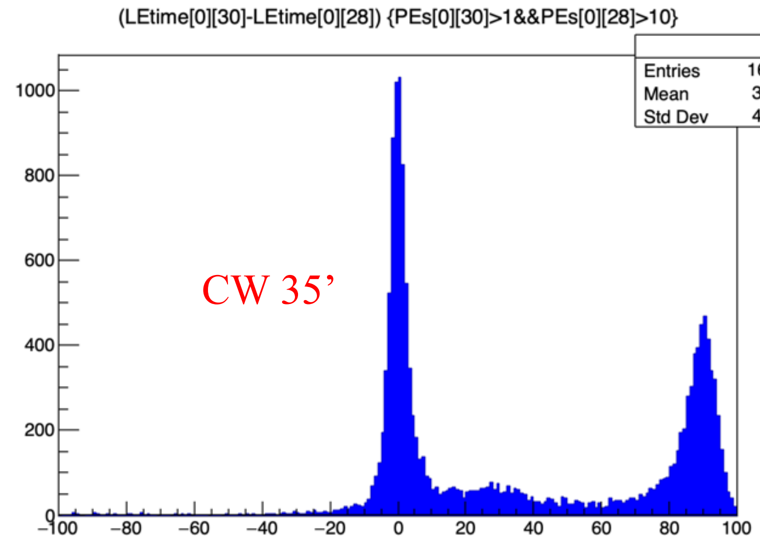


$$F(x;\mu,\beta) = e^{-e^{-(x-\mu)/\beta}}.$$

- The pulse height distribution, beta, is plotted using a Gumbel function. Beta gives the dispersion.
- Lower plot compare shape of the plots
- Not much dispersion vs cable length

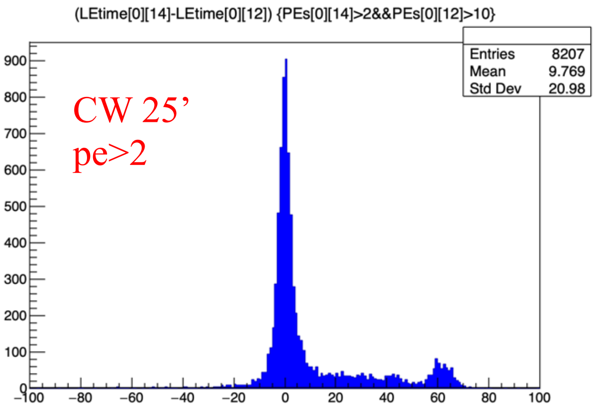
Quality of cables

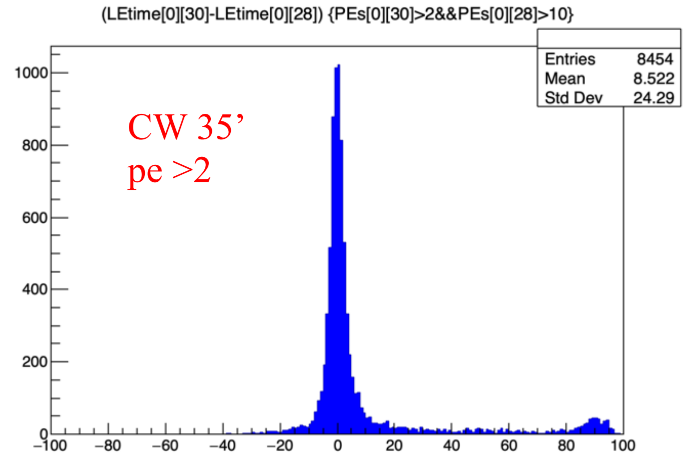


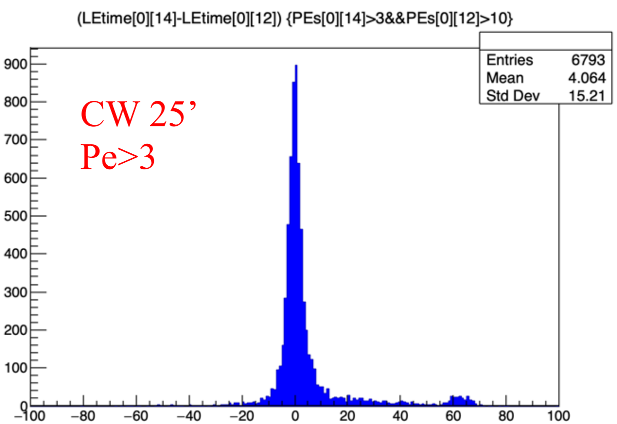


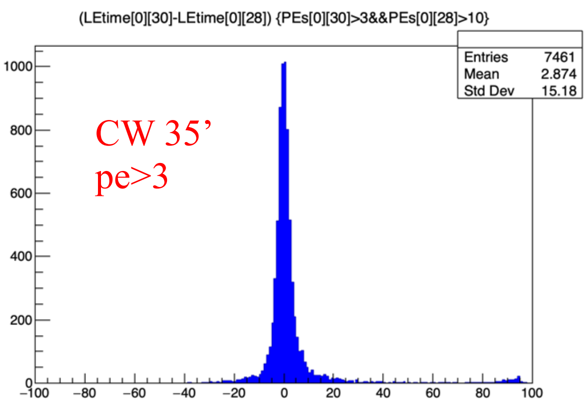
- CW (Cable Wearhouse) cables difference between 2 pulses, different strip, same CMB. One pe>10, to be sure it is a light pulse, one pe > 1, could be noise.
- The peak in center is coincidence of light in adjacent strips
- The right had pulse is the following: part of SIPM signal from light reflects off the FEB, returns to the CMB, cross talk on the CMB transfers this reflected pulse to the output the another SIPM on the CMB and the signal is sent to the FEB
- Not clear what the middle pulse for CW 25, possibly cable cross talk, can't be noise or crosstalk on the CMB as it is 40 ns after the initial pulse
- These reflective pulses are small at the FEB

Reflected signal



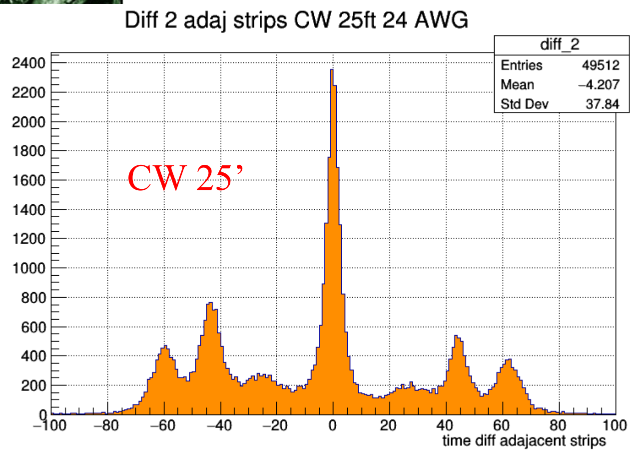


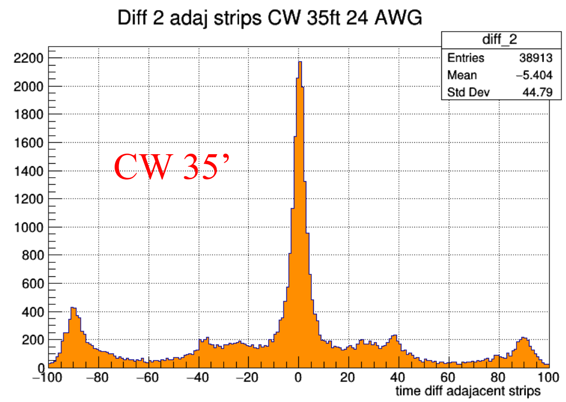


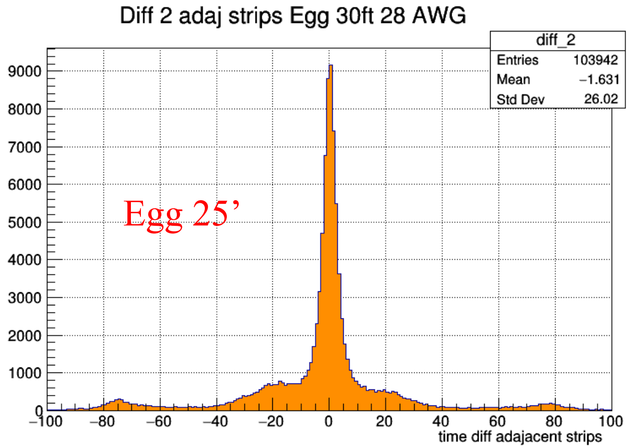


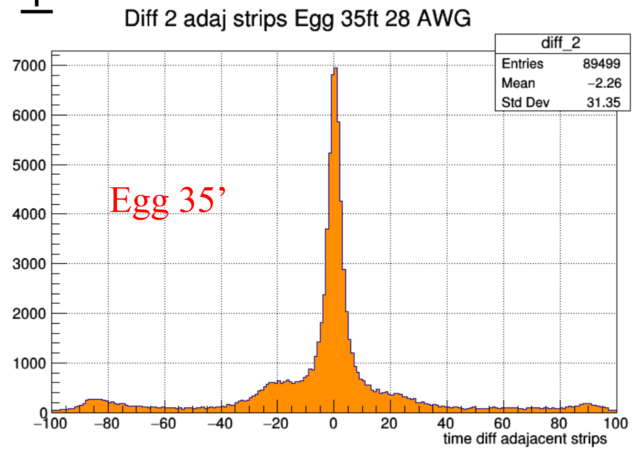
- We are seeing a small reflected pulse for the CW cables
- This is one twisted pair in on HDMI cable. We want

Comparison CW to Egg



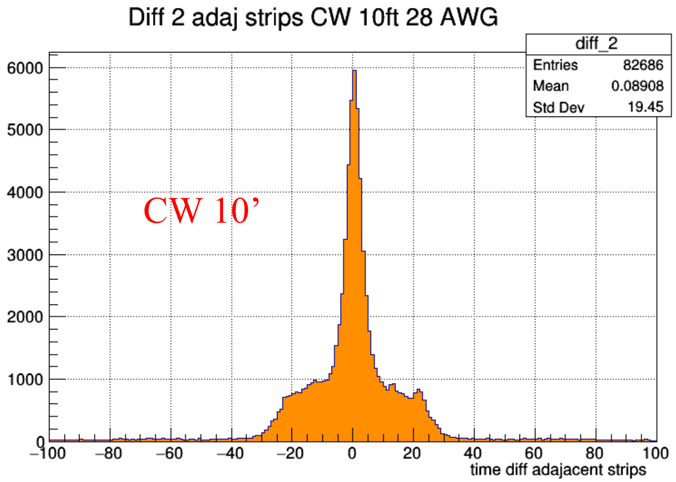


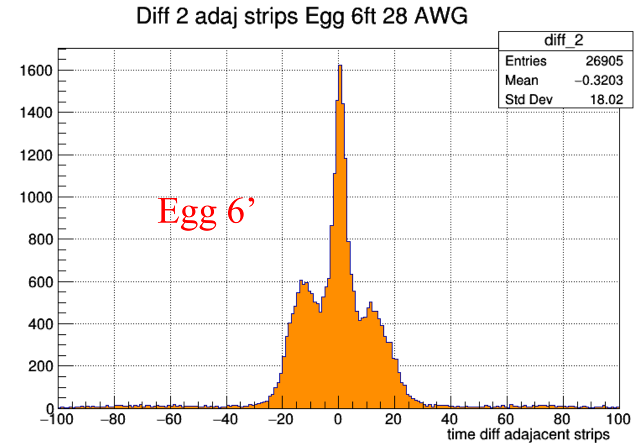


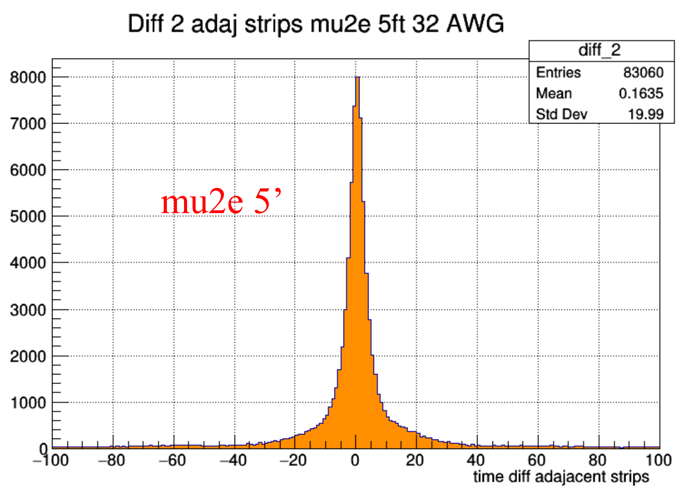


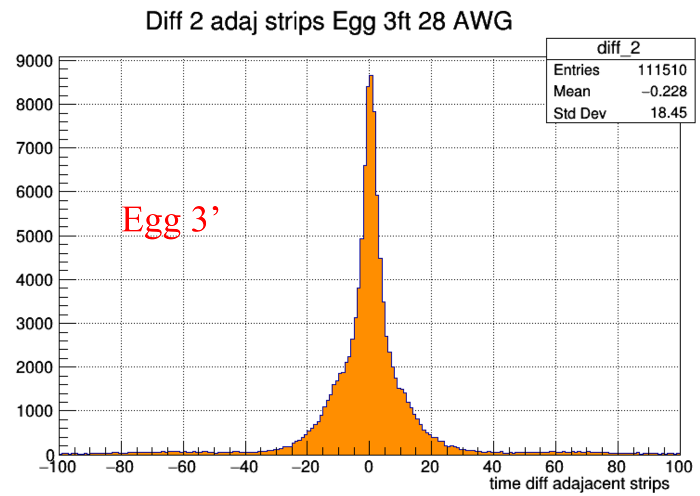
- Center is the pulse with pe>10 & the – and + sides are the reflection, after pulsing or noise.
- Impedance of HDMI cable should be 100 ± 15 Ω, The CW cables don't control their impedance
- This can show up in shorter cables as the signal bounces back and forth on the cable

Not controlling Cable Impedance



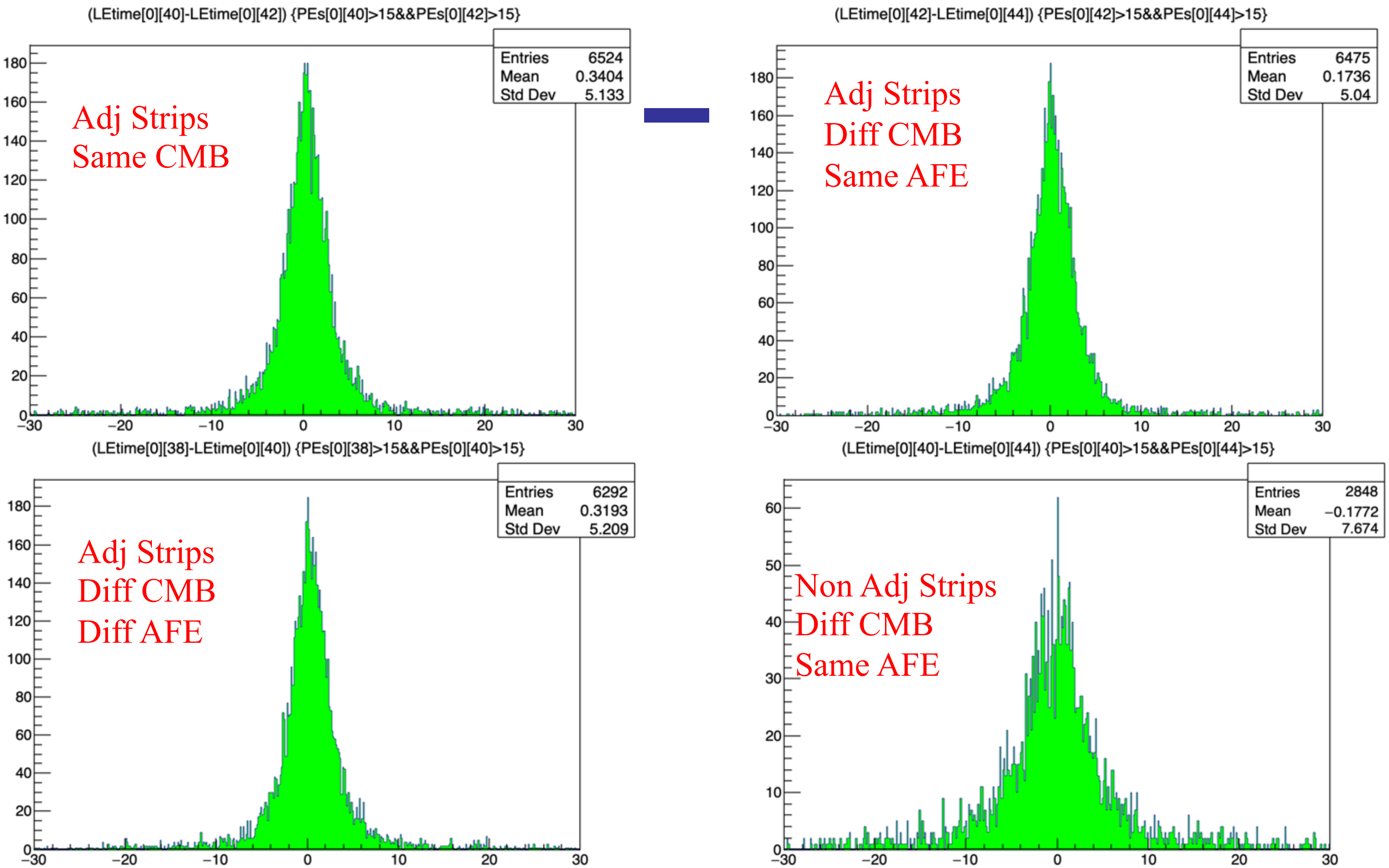






- Egg cables show mismatched impedance, especially 6 '; Mu2e look OK
- Pulsing the cables & looking at reflections with a scope, better than using a sophisticated test stand. But you need to make connection from HDMI to BNC. Breaker boards exist to do this.

Adjacent & Nonadjacent strips



All plots are mu2e 5' Cables

- RMS of adj strips same for all cables, 5ns , whether on same CMD or AFE, AFE = ADC chip
  - Couldn't do this with CW cables, too many CW cables did not read out
- Adj Strips, correlated hits: energy going from one strip to another & air showers from above
- Non adj strips: air showers from above, strips 6 m long is why width ~ 20 – 25 ns, RMS ~ 8 ns
- No evidence that timing using the same scintillator biases the result.

Conclusion

- Light goes down ~23% from 3’ to 35’, so it goes down ~16% from 3’ to 25’
  - Most of the loss appears to be due to attenuation
- The timing resolution appear to be fairly independent of the length at these light level, but does appear to a function of the pulse height.
- The 28 AWB cables & 24 AWG cables were a bit difficult to cable as they were a not as flexible the 32 AWG of the mu2e cables. From these results it is possible that AWG 30 cables could work. However, I could not immediately find long AWG 30 cables online to test.
- The 24 AWB cables seem to be a bit worse than the 28 cables i.e the Cable Wearhouse cables seem worse than the Newegg cables.
  - The cable impedance does not match the FEB for the CW cables as it does for the Newegg cables. Still even for the Newegg cables the impedance does not completely match

Conclusion

- One way of investigating the quality of these cables, or in fact any cables, is to pulse them and look at them with a scope. This would help look at the difference between the Newegg cables and the CW cables. And test what ever cables one buys.
  - This would require building a couple of HDMI <-> BNC converters.
  - Parts exist to do this
  - For Displayport one might have to build a PC board
- We would like to thank the mu2e CRV group especially the following who made this study possible and easy to do.
  - Yuri Oksuzian
  - Yongyi Wu
  - Both from Argonne