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# R&D on cold electronics and summing board for PD

Gustavo Cancelo (presenter), for the DUNE R&D photon detector collaboration,

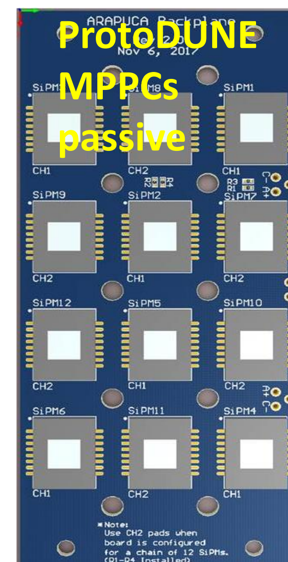
November 12, 2018

# Active ganging and ARAPUCA R&D

- They have been sponsored by Fermilab LDRD grant L2017-028 and DUNE R&D.
- We achieved major milestones for DUNE R&D.
- We had successful runs using the TallBo dewar at PAB in March and November 2017.
  - Results showing ARAPUCA ~1% efficiency and area gains of 4 to 5 were presented in the April 2018 collaboration meeting.
- This talk focuses only on the progress made in active ganging of SIPMs, “cold electronics”.

# 2017 and 2018: passive and active ganging of SiPMs

- We designed a summing board for the SENSL 4x4 array.
- We designed a 12 SENSL (6x6 mm C series) summing board that was used by the IU group in their light bars during the TallBo run of Oct-Nov 2017.
- We have tested Hamamatsu MPPCs (S13360-6050PE) at 25C, -70C and 77K.
- We have designed and used a passive gang of 4 SENSL (6x6 mm C series) for ARAPUCAs during the TallBo run of Oct-Nov 2017.
- We have designed and tested the ARAPUCA back plane with passive gangs of 6 and 12 MPPCs
- We designed 2 versions of actively ganged 48 MPPCs.
- We designed the cold electronics for the new Iceberg.







So, what have we learned?

# TallBo experiment 2017: single channel with 48 SIPMs

- Active ganging: summing board for the SENSL 4x4 array tested at TallBo in March 2017

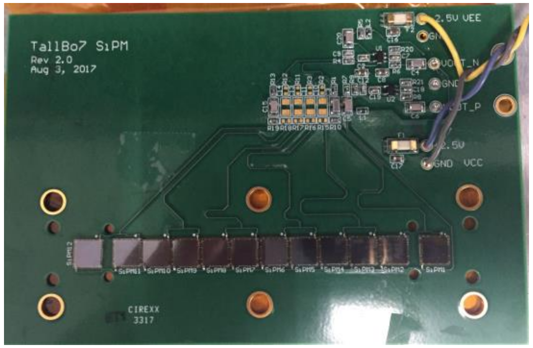
| Ch N | Position | Acceptance | Ph | Eff % ? (151KPh) |
|---|---|---|---|---|
| Ch0 | 7600 | 5 e-3 | 2.95 | (0.40) |
| Ch1 | 6600 | 6.7e-3 | 4.1 | (0.41) |
| Ch3 | 5800 | 2.5e-2 | 11.2 | (0.30) |
| Ch4 | 4800 | 2.5e-2 | 10.1 | (0.27) |
| Ch5 | 7600 | 6.9e-3 | 4.9 | (0.5) |
| Ch6 | 6600 | 6.7e-3 | 4.6 | (0.45) |
| SiPM array | 7000 | 2e-3 | 21 | (7.0) |

SiPM array coated with TPB

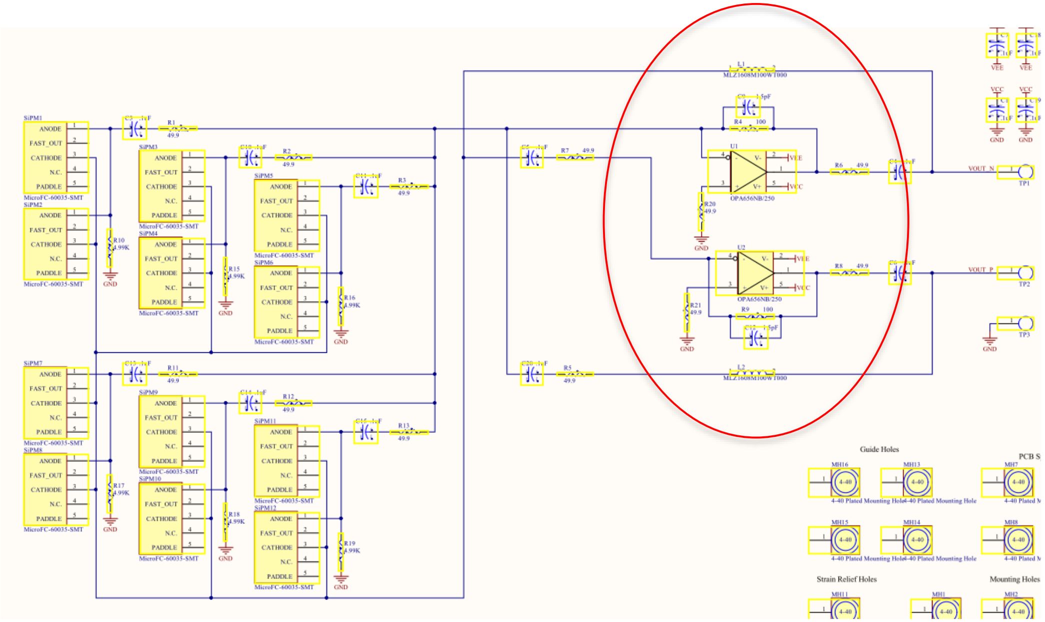
Efficiency > 7%.

Probably higher. We did not have a good characterization of the radioactive source spectrum. Not all photons were coming from alphas.

# Active ganging of 12 SENSL (6x6 mm C series) summing board for IU light bars, used in the TallBo run of Oct-Nov 2017



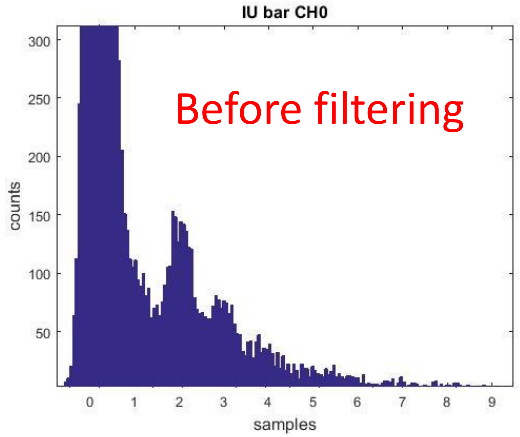

- The design used 2 single ended OP Amps (OPA842) with noise of 2.6nV/√Hz.

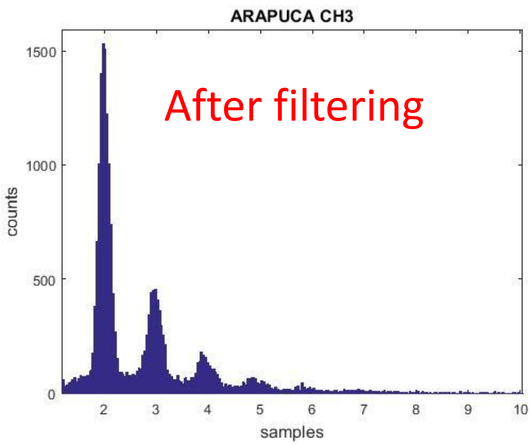


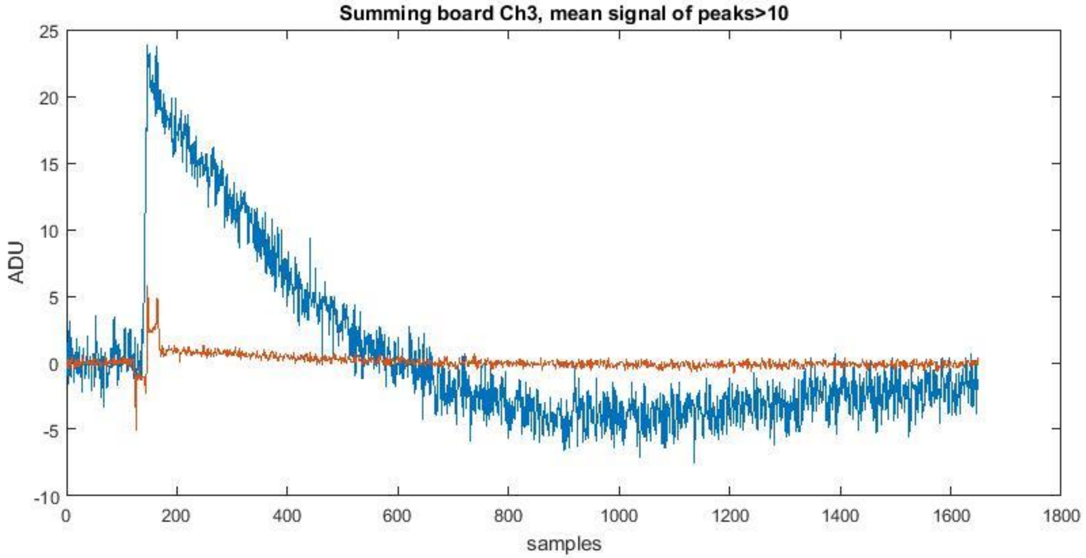
This design was used by Indiana University (S. Mufson et al) during the Oct-Nov 2017 run. We used a 6 x 2 ganging (6 active branches of 2 SiPMs in parallel).
Pseudo differential output to match to the SSP DAQ warm electronics.

# Active ganging of 12 SENSL (6x6 mm C series) summing board for IU light bars, used in the TallBo run of Oct-Nov 2017

- The Op Amp adds noise to the signal.
- It was hard to see single PEs without filtering the data.
- A digital filter (such as a Matched filter) worked well and a good calibration was achieved.

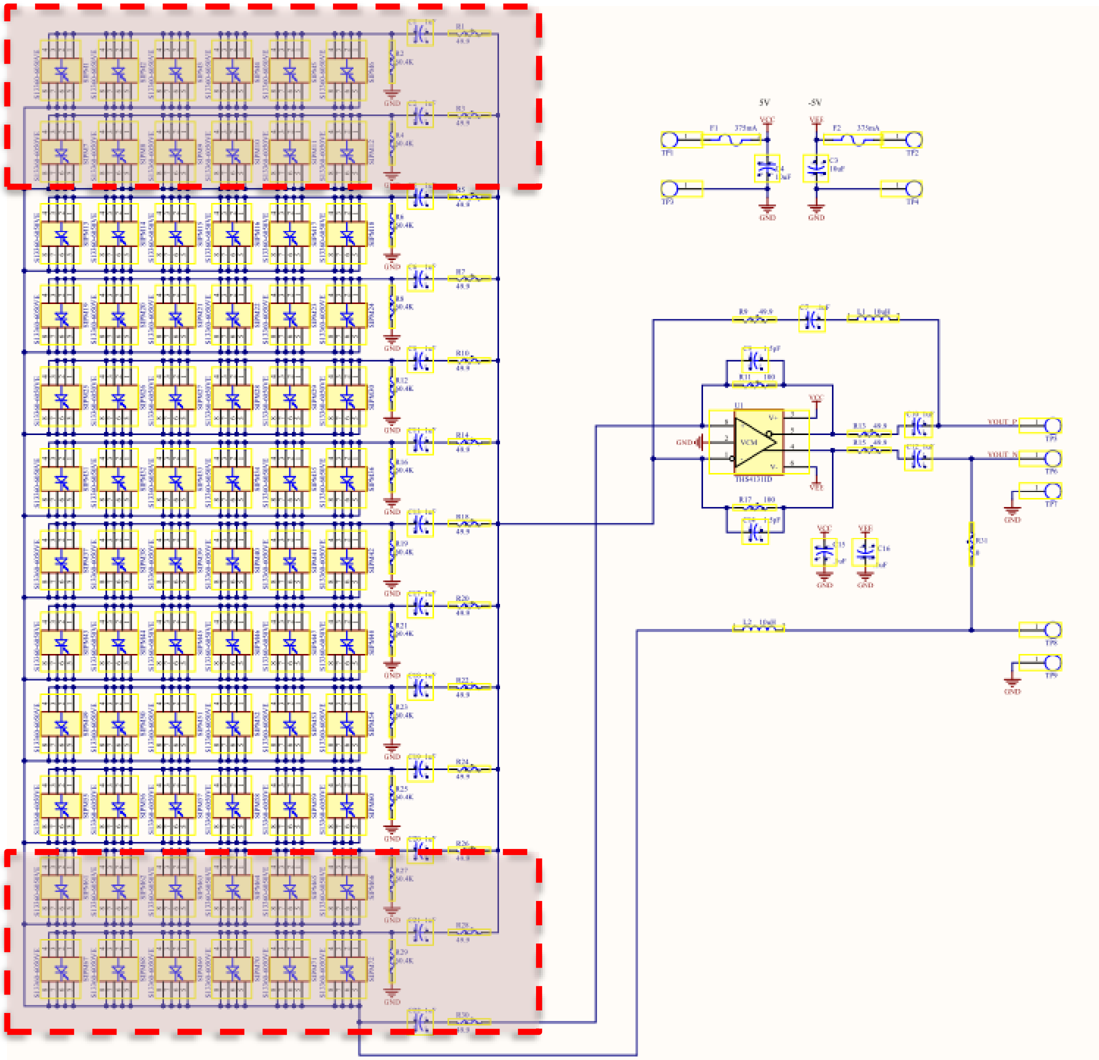


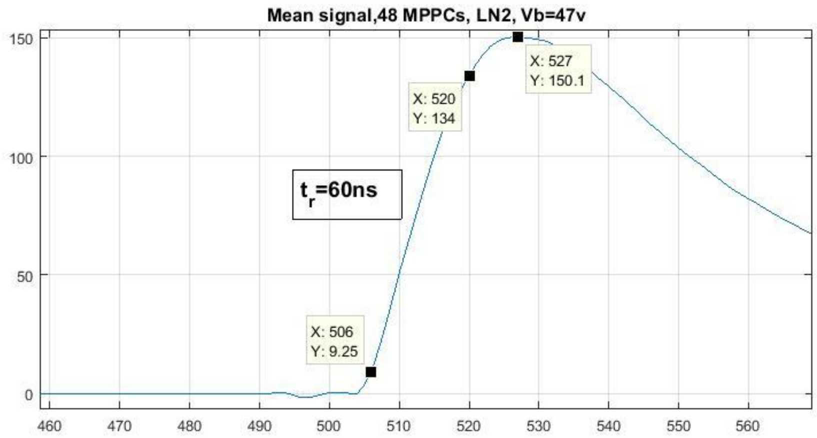

There was also an undershoot in the signal. This is due to AC coupling time constants, not to the summing Op Amp.
There was also a “glitch” feature. We believe that is related to the SSP trigger but we are not sure.

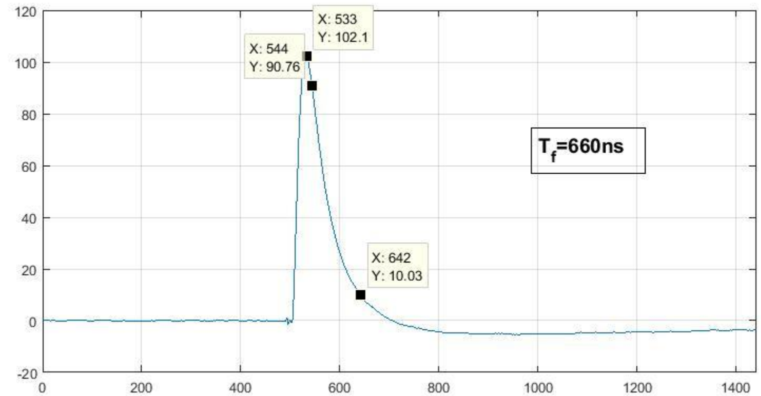
# 72 SiPM active ganging board: 12 x 6 matrix

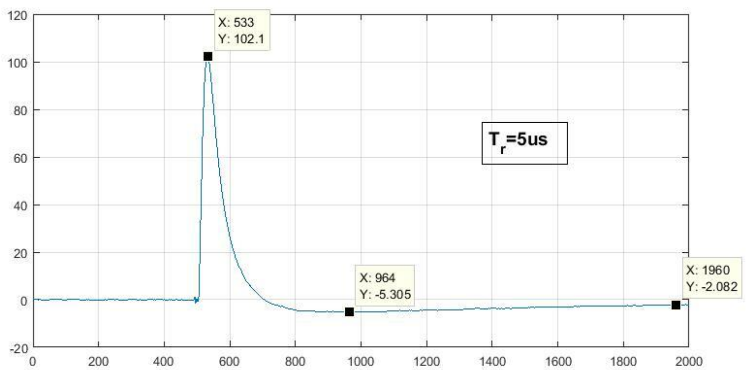


- Each row has 6 MPPCs in parallel.
- We picked 48 for this test.
  - Disconnected 4 rows.
- Tested configuration 8 rows of 6 MPPCs
- 6 parallel MPPCs have a capacitance of ~7.8 nF at that Vb.
- Op Amp THS4131

# Mean signal 48 MPPCs at -70C and Vb=47

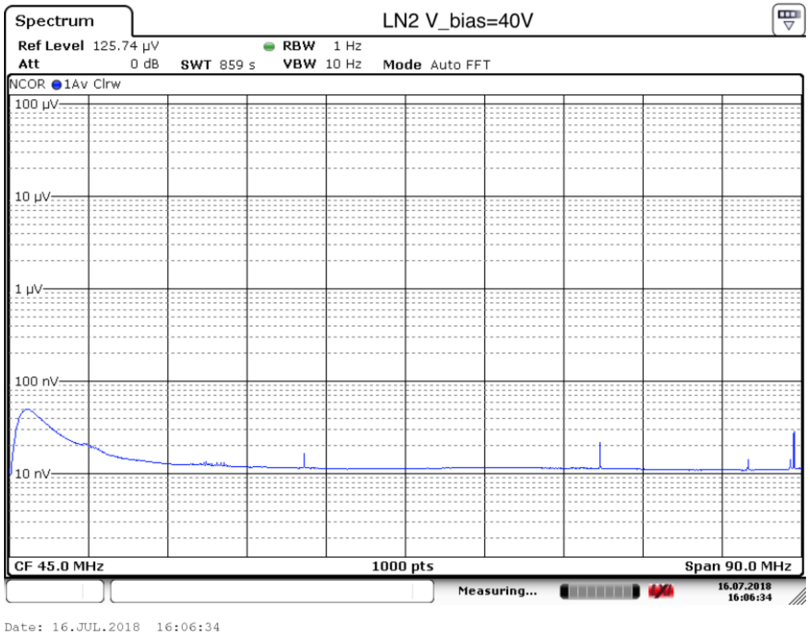


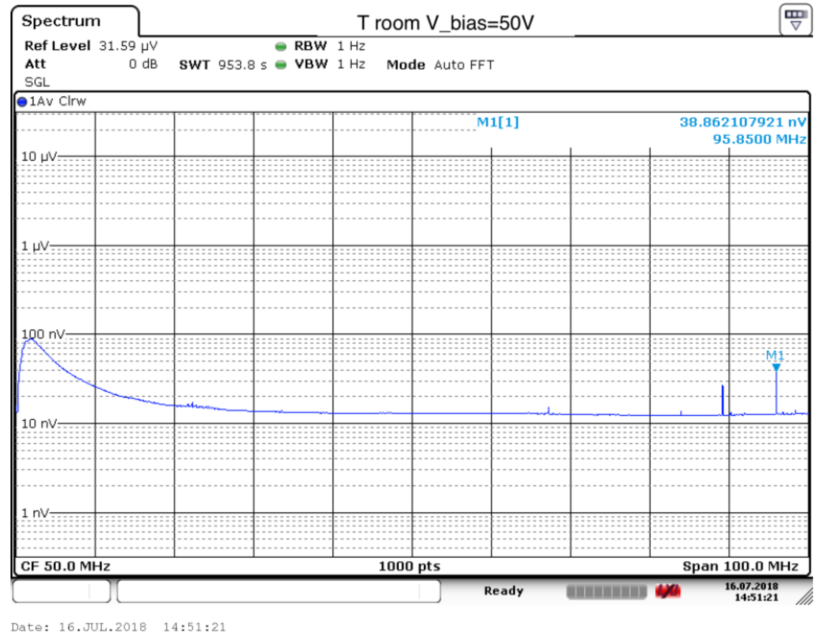




- Rise time 60ns, Fall time 660ns, slow undershoot recovery.
- SSP time constant has not been modified. Some impedance mismatch.

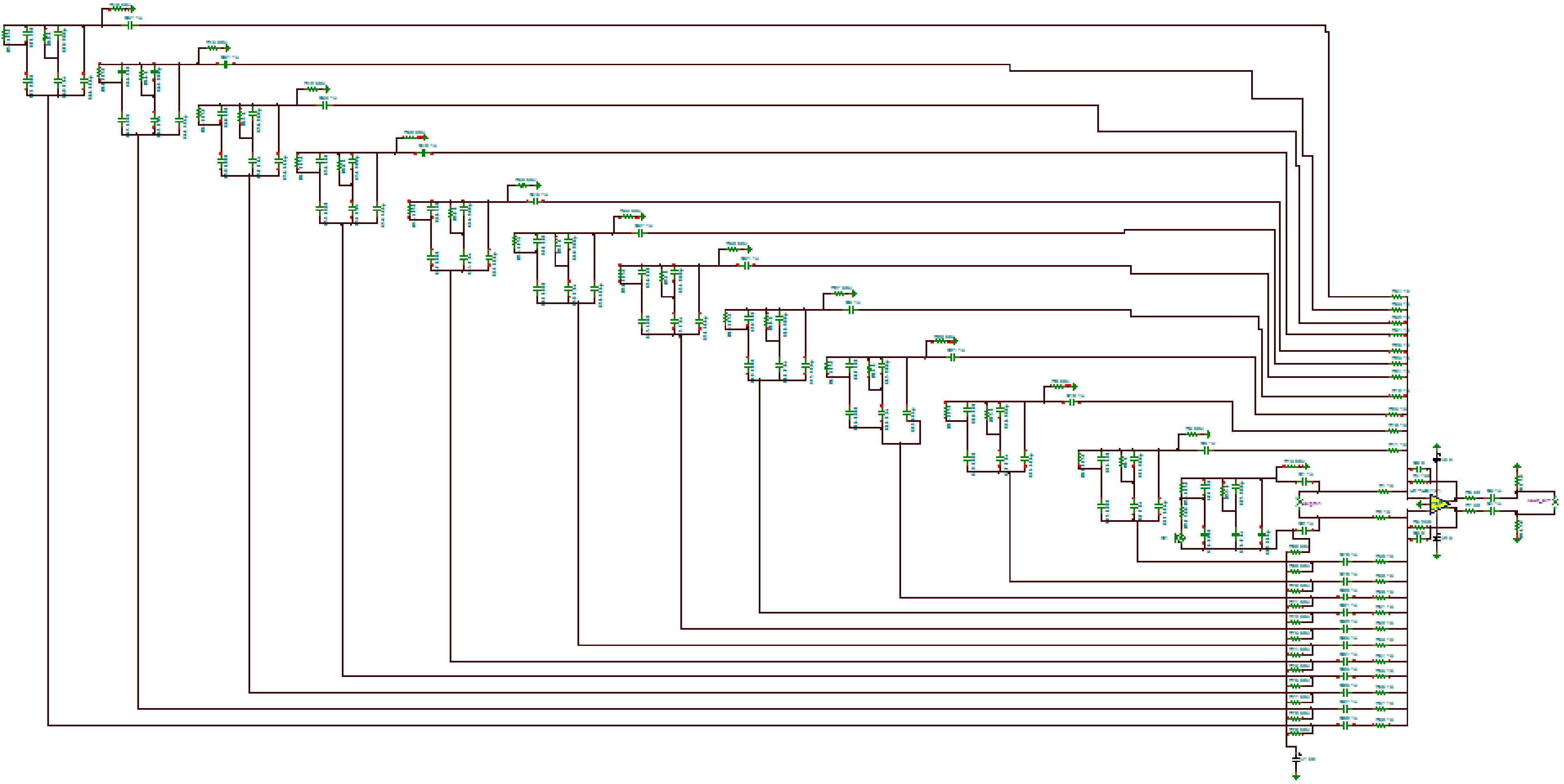
# Noise spectrum



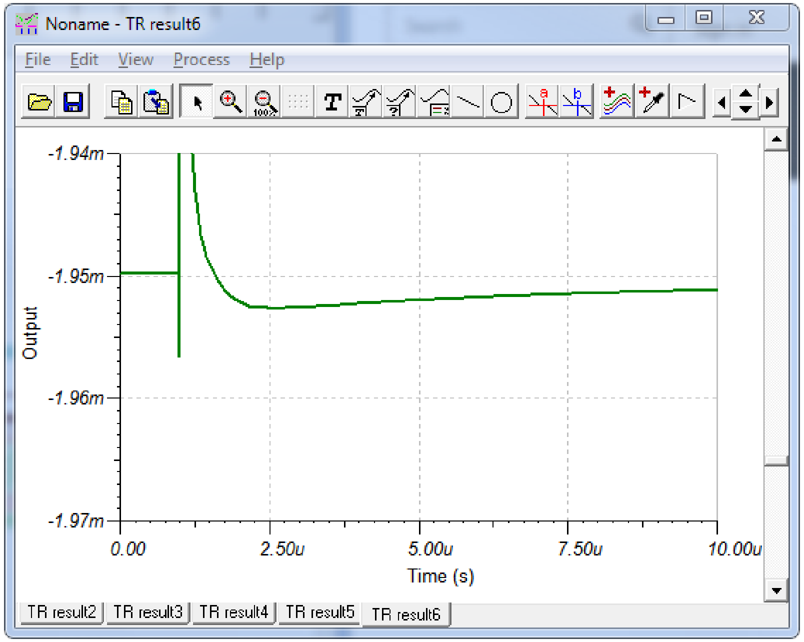

- Noise is 10nV/sqrt(Hz)
- 1/f at lower frequencies.
- It does not vary much with T and Vb

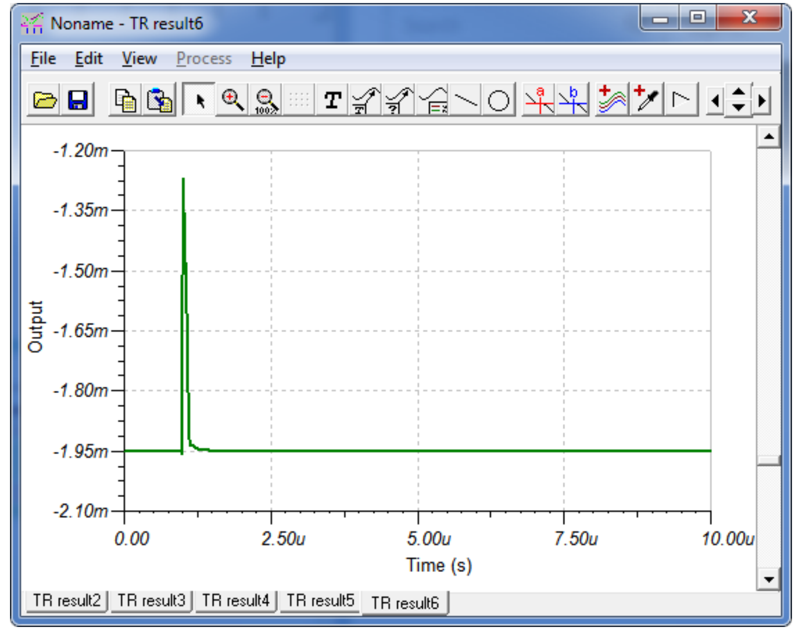
# Simulations



- Simulations are in agreement with results from data.

# passive & active ganging test board: OpAmp simulation




- Simulation of undershoot generated by AC coupling.
- Can be minimized to <0.3% of signal size by adjusting the input pole of the electronics.



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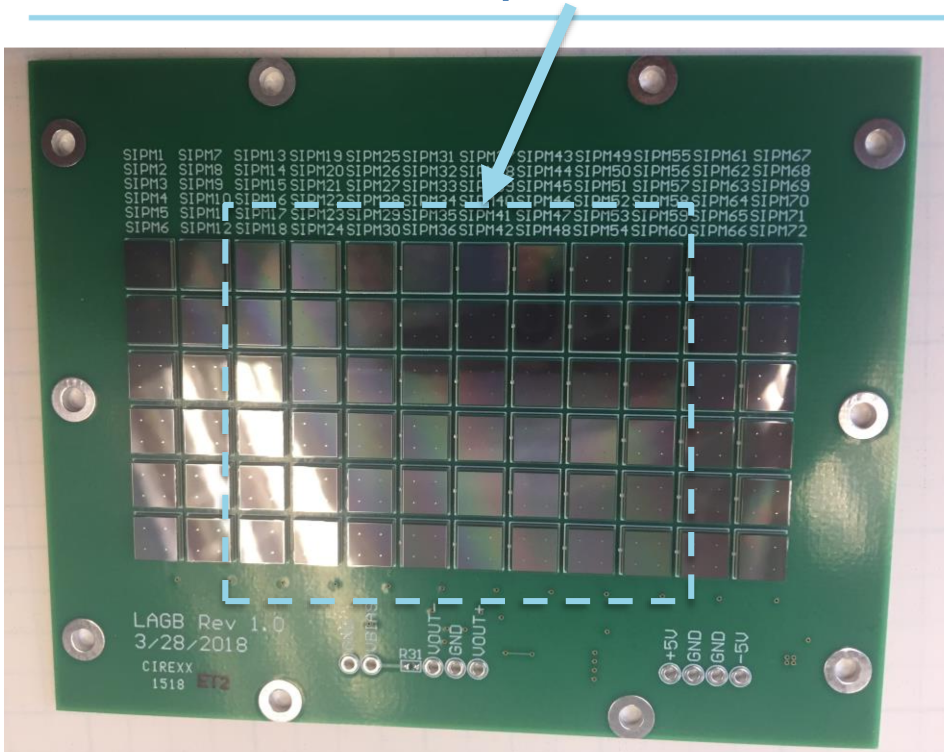
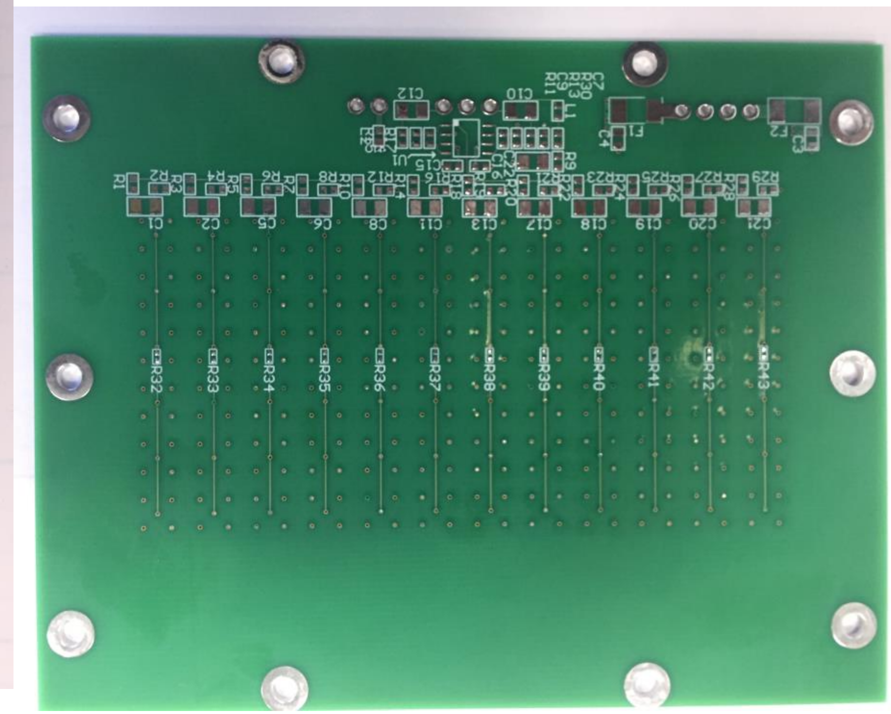
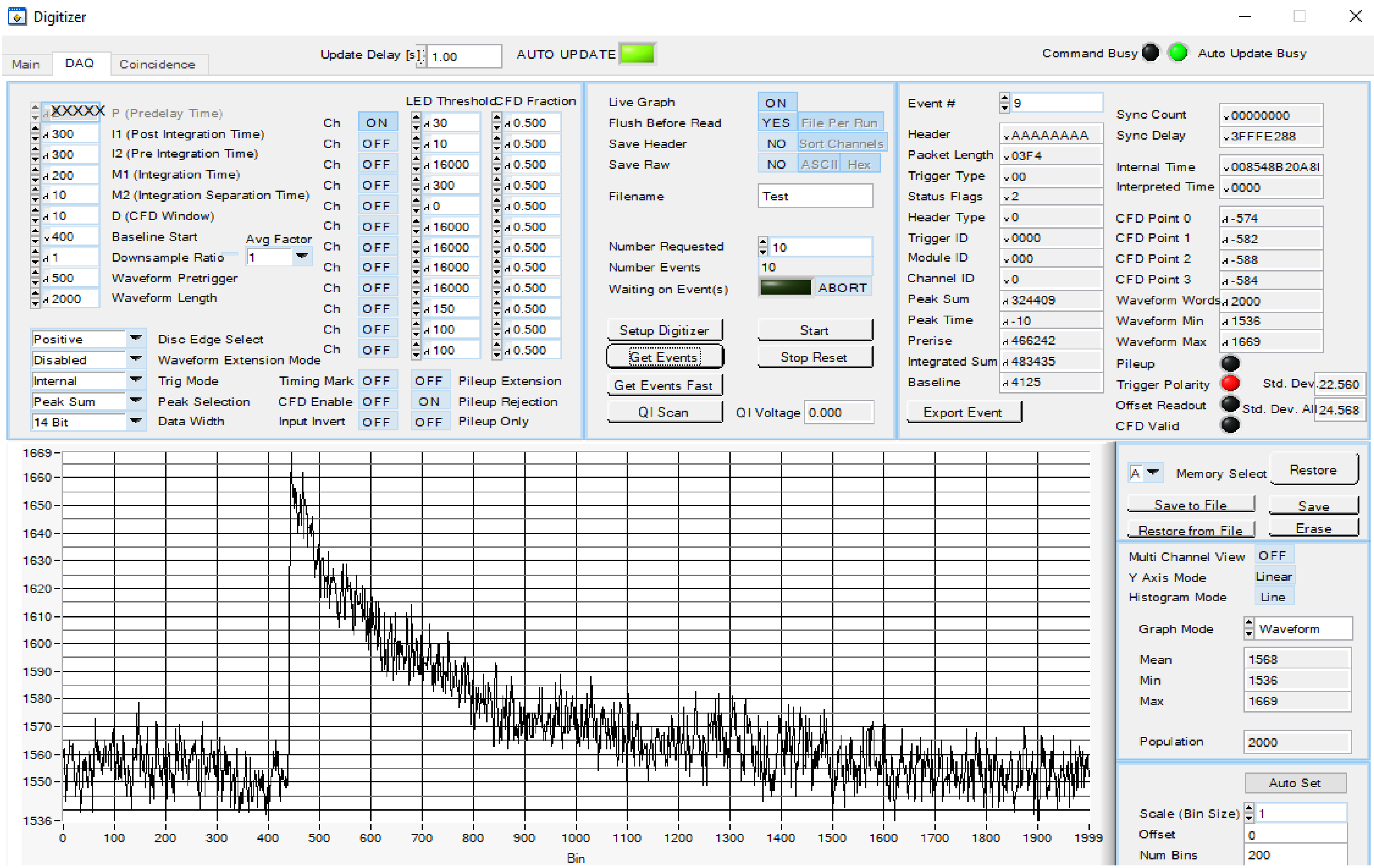
# 72 MPPC board, 48 used for DUNE R&D testing



- Zero ohm resistors allow us to test different configurations.
- Each 6 MPPC branch has a zero ohm resistor that splits it in 3 + 3 MPPC.
- All branches connect to the OpAmp through a resistor that can be removed to remove the entire branch from the test.

# SSP readout



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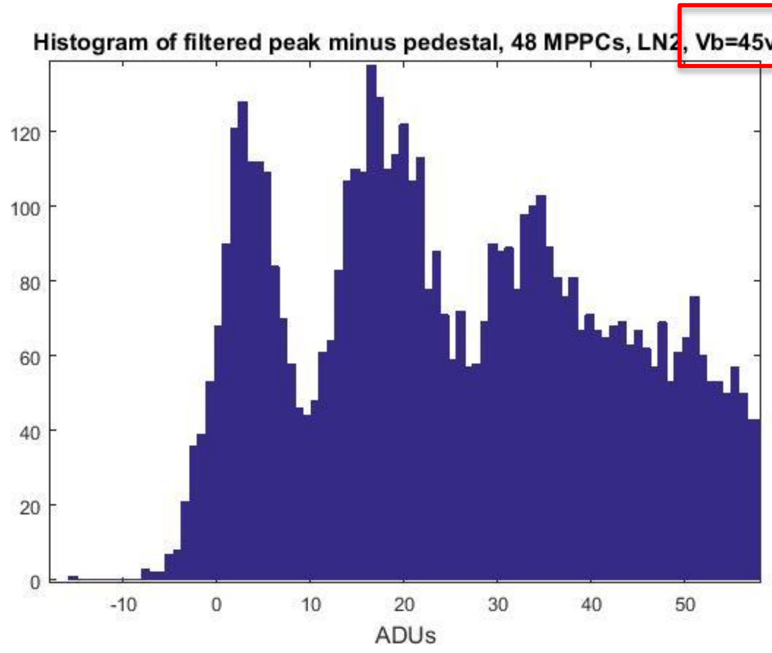
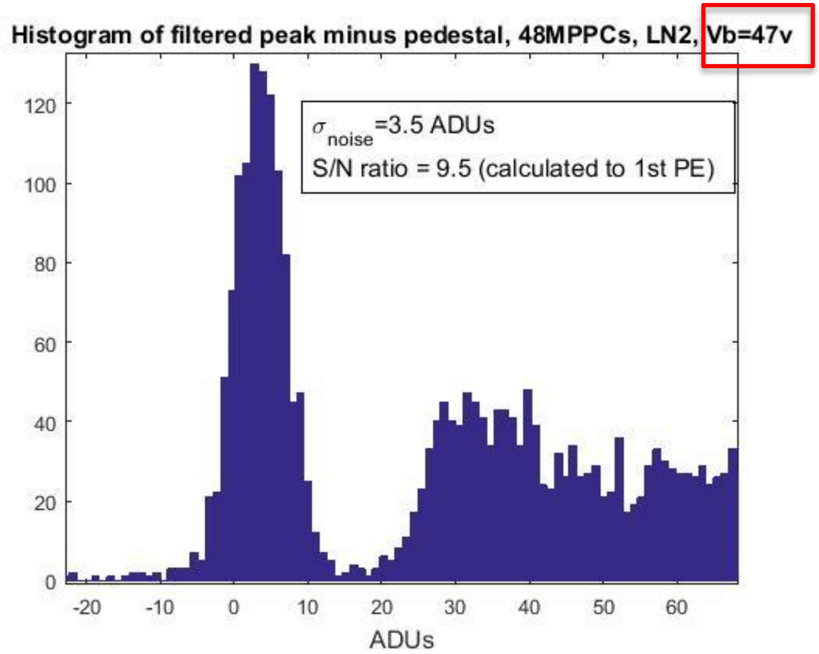
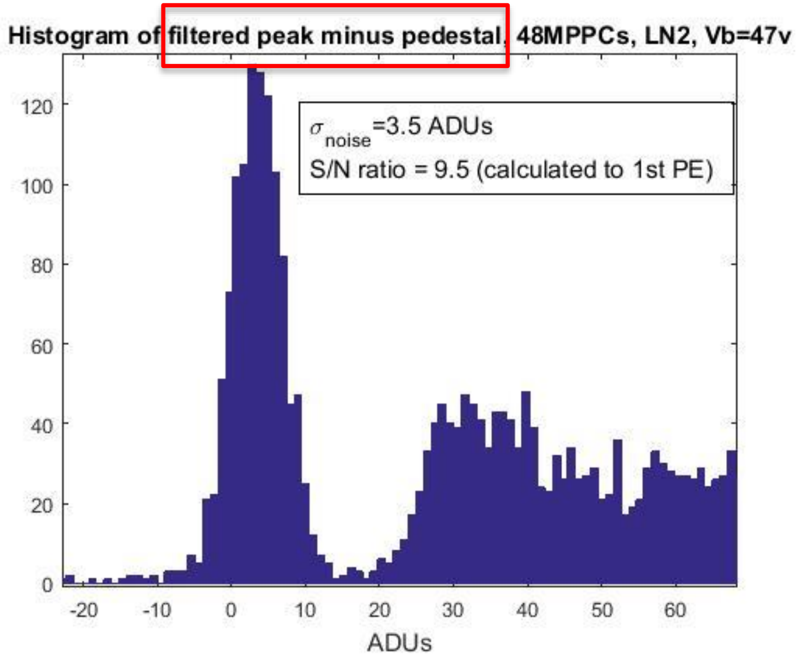
# Effect of bias voltage on 48 MPPC

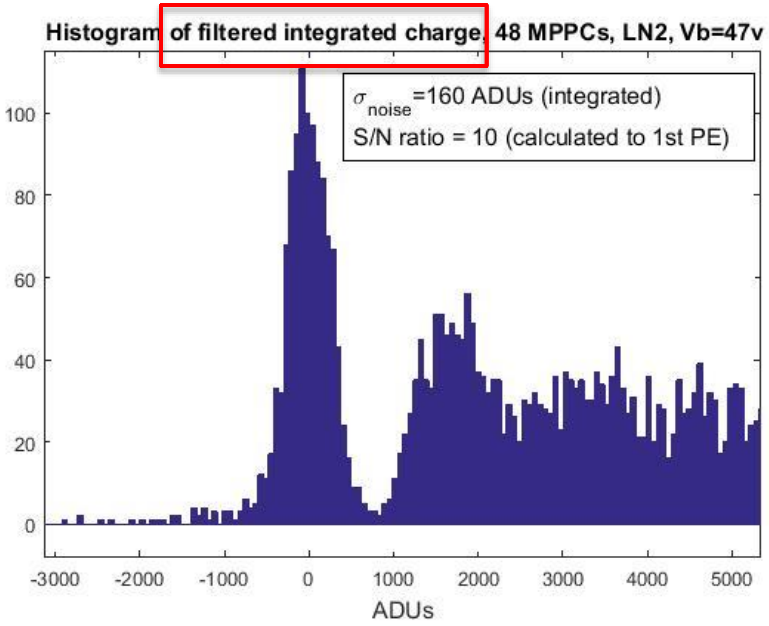



- 48 MPPCs Vb=47v: S/N=10.
- 48 MPPCs Vb=45v: S/N=5.
- S/N measured as the fit of the 1$^{st}$ PE peak to the $\sigma_{noise}$.
- For Vb=45v the 1$^{st}$ and 2$^{nd}$ PE histograms are better defined. Probably due an effect of Vb in the relative gains.

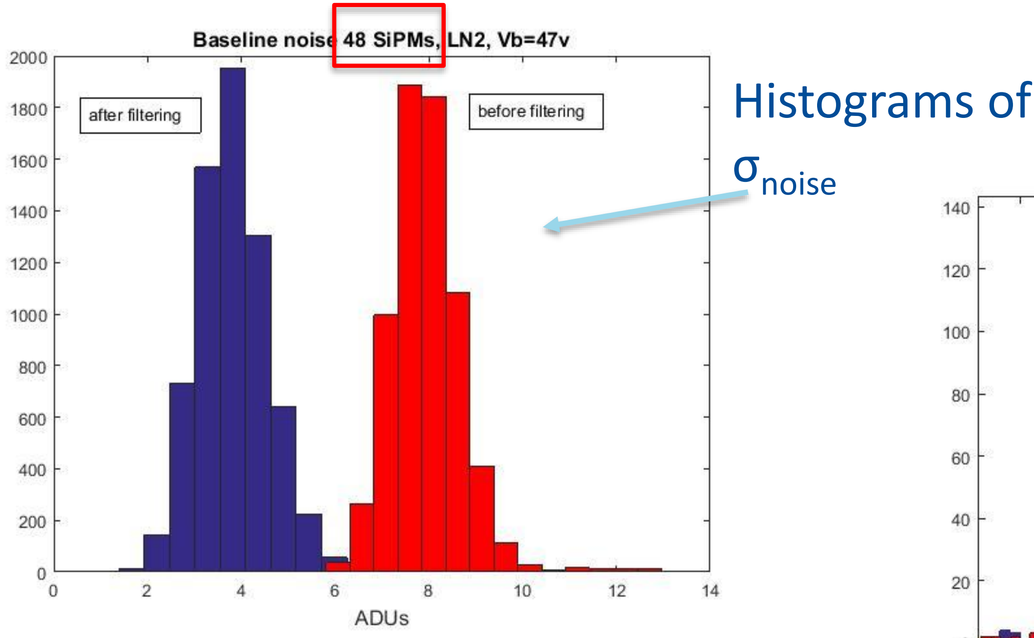
# Peak minus baseline vs integrated charge (0.6usec)

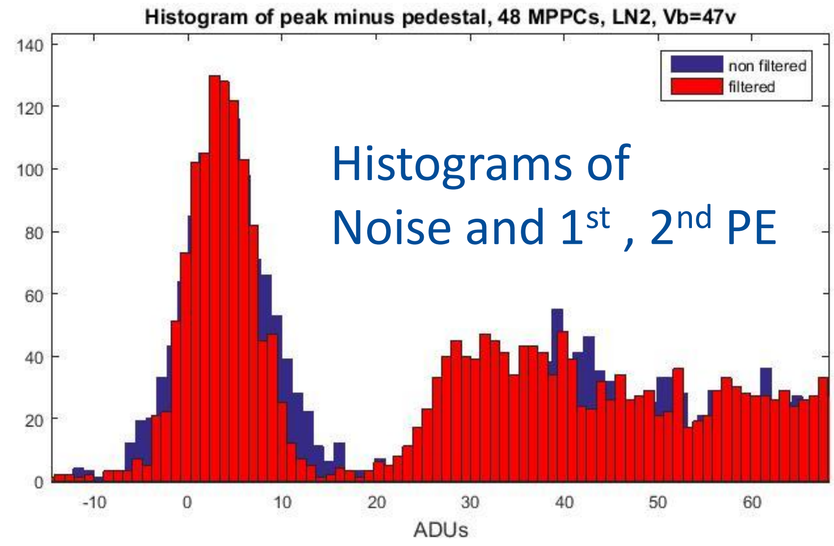



- Very similar S/N.

# Filtering the signal with a matched filter (50 taps long)



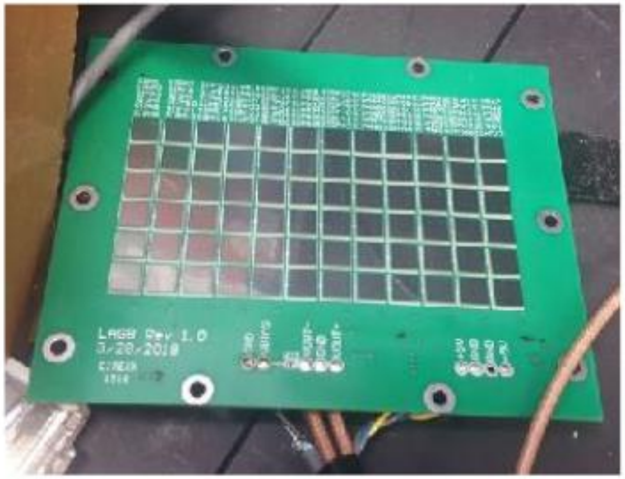




- Good reduction of noise by filtering.
- The 1st, 2nd PE spectrums do not change.

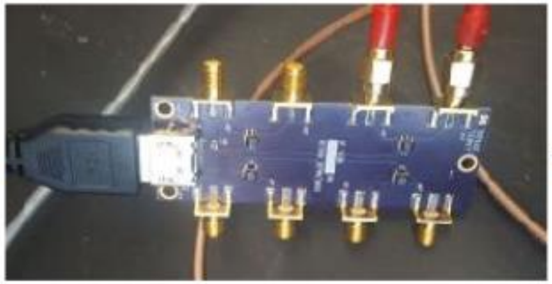
# Interfacing the active ganging board to the u2e FEB electronics

**72-MPPC active ganging board (left). Each row has six 6x6 mm$^2$ Hamamatsu MPPCs in parallel.**

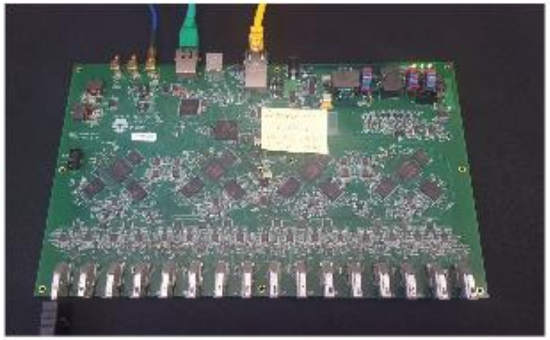
**Balun (middle) to connect the differentiated output from the active ganging board to the front end of the FEB, which is single-ended.**



**Gustavo's board**



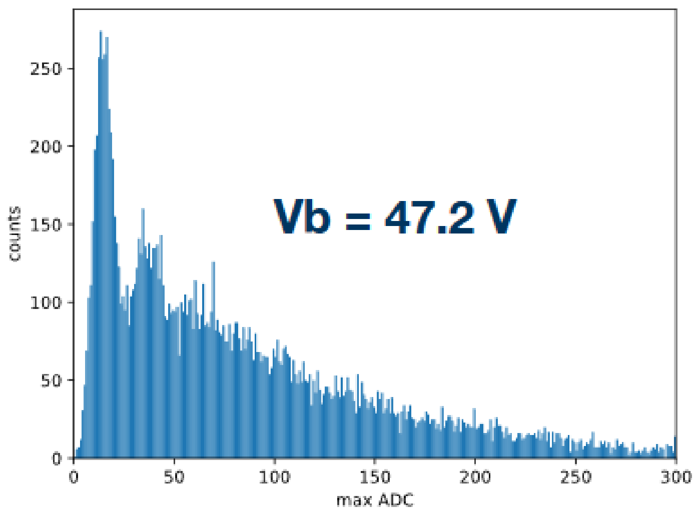
**balun from Michigan**

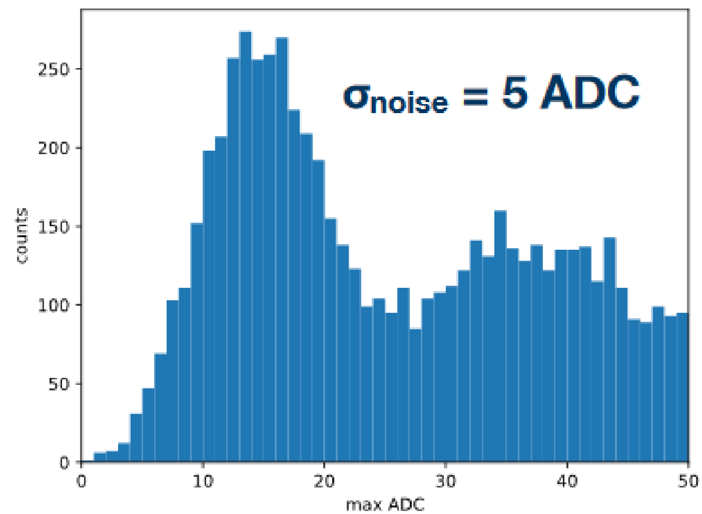


**FEB**

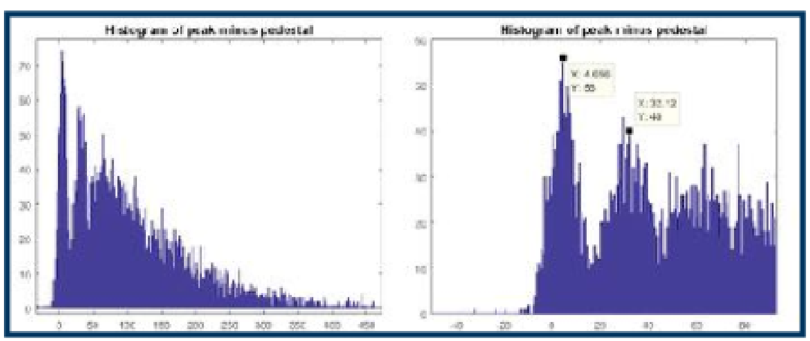
# Interfacing the active ganging board to the u2e FEB electronics

**Successfully demonstrated single photon resolution!**



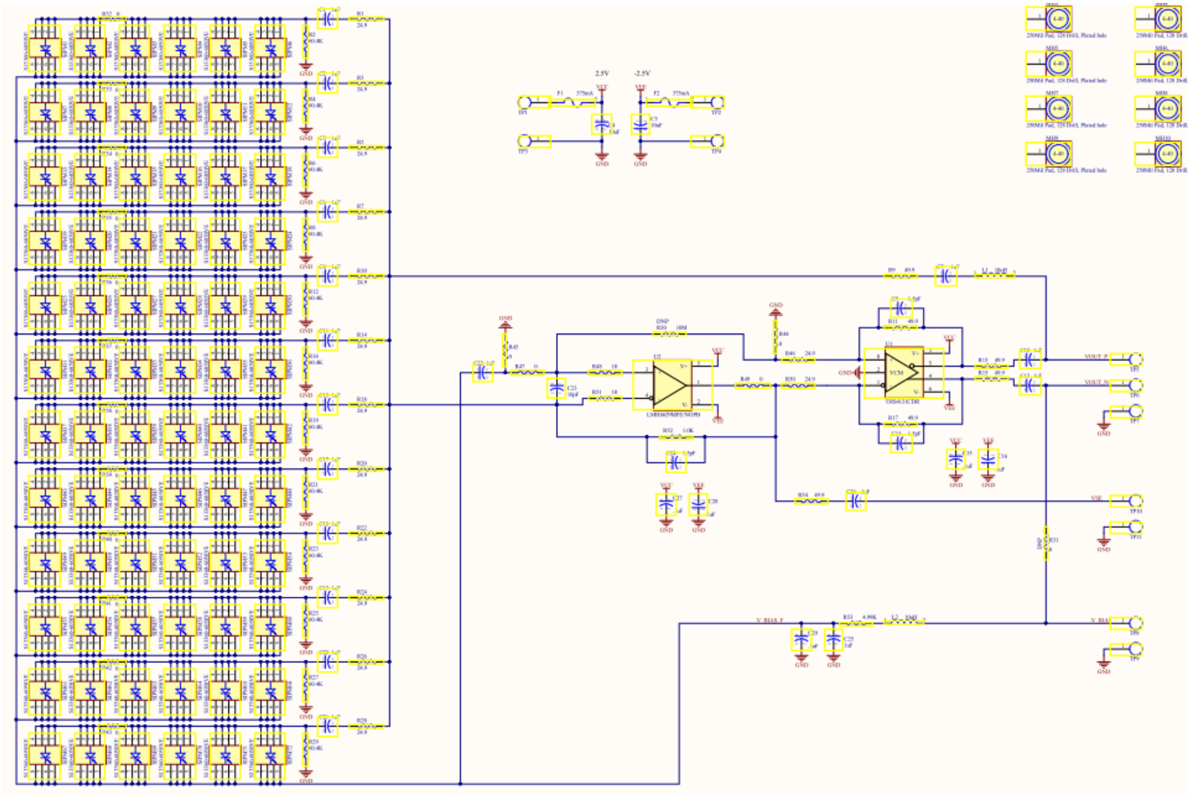

**S/N = 4 (measured as 1st peak to $\sigma_{noise}$)**




Similar noise without filtering

**Results using SSPs (S/N = 5)**
**from Gustavo Cancelo, Dante Totani**

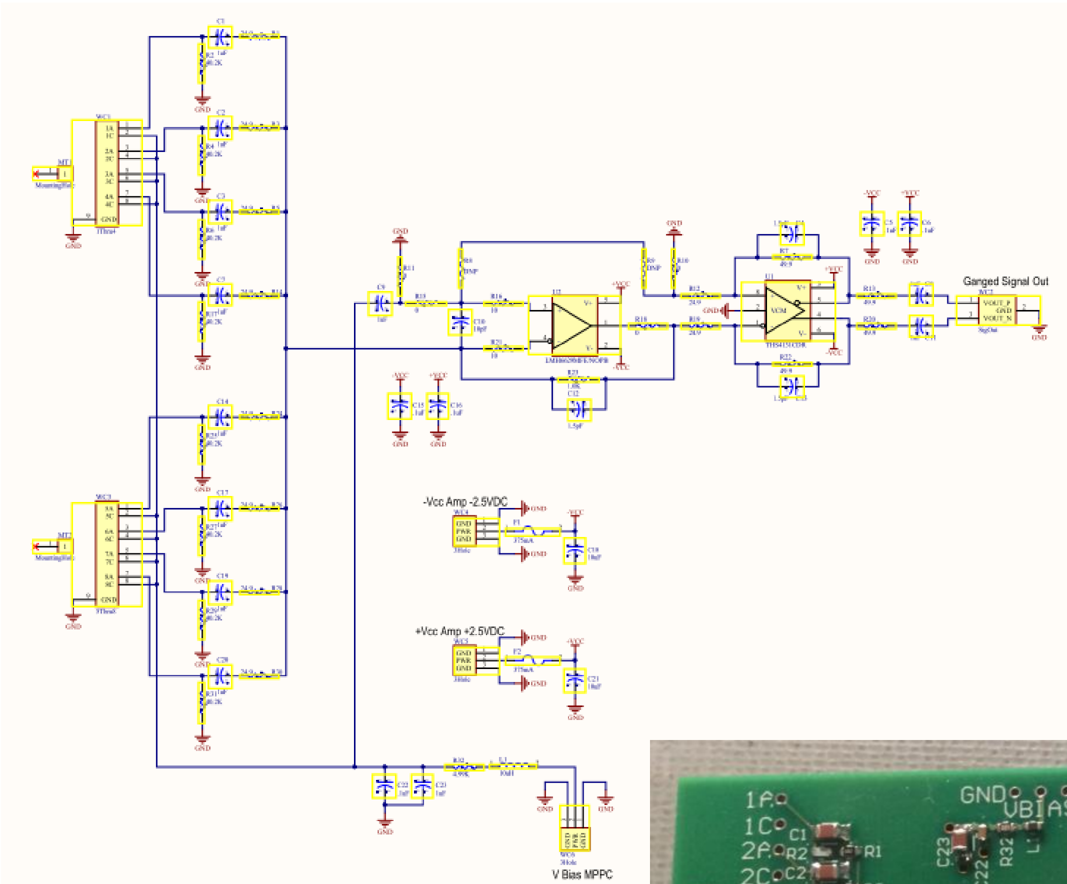
# 2nd version of the 72 MPPC board



The power consumption of the OpAms is below 10 mW at 85K

- This version has a two stage amplifier.
  - 1st stage based on the LMH6629 to achieve better noise.
  - 2nd stage based on THS4131 to keep output differential.
- DUNE can choose between 1st or 2nd version.
  - Characterization of the 2nd version will be done next month.

# Design for Iceberg



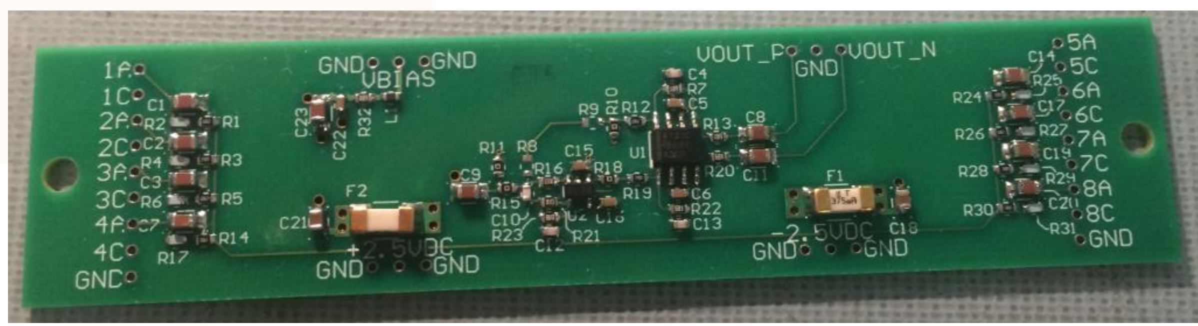

Two stage design, as in the 72 MPPC board.

This board collects signals from a 6 x 8 = 48 MPPC alongside ARAPUCAs.

Vbias and OpAmp bias on separate wires.

In DUNE design we will use only 2 wires for signal and bias combined.

- The 2 wire option has already been tested but due to the short schedule it has not been implemented for Iceberg.



# Summary

- The active ganging of 48 Hamamatsu MPPCs has been successfully demonstrated.
  - Signal to noise ratios, timing and signal shape are very good.
  - A two stage design will improve S/N and keep differential output to minimize external common mode noise.
- Iceberg and ProtoDUNE will give us some more information about external noises from the TPC.
- The interface of the 48-MPPC to the u2e electronics was also successful.
  - That test clears the way to a cost effective design for DUNE.