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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,

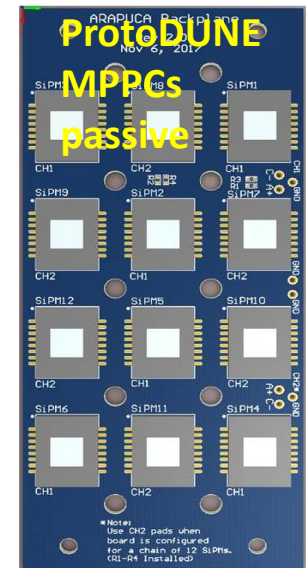
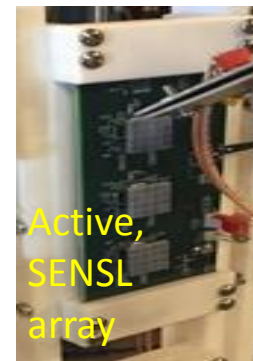
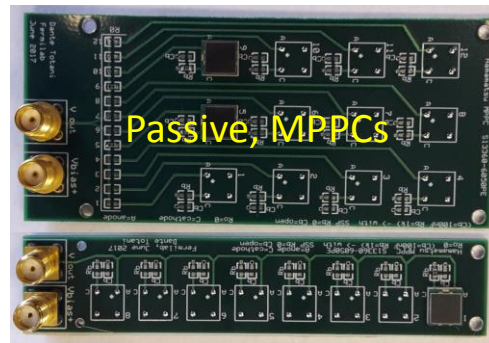
November 12, 2018

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

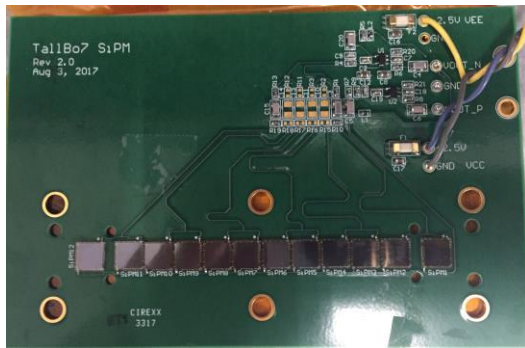
Ch N	Position	Acceptance	Ph	Eff % ? (151KPh)
Ch0	7600	5 e-3	2.95	(0.40)
Ch1	6600	6.7e-3	4.1	(0.41)
Ch3	5800	2.5e-2	11.2	(0.30)
Ch4	4800	2.5e-2	10.1	(0.27)
Ch5	7600	6.9e-3	4.9	(0.5)
Ch6	6600	6.7e-3	4.6	(0.45)
SiPM array	7000	2e-3	21	(7.0)

SiPM array coated with TPB

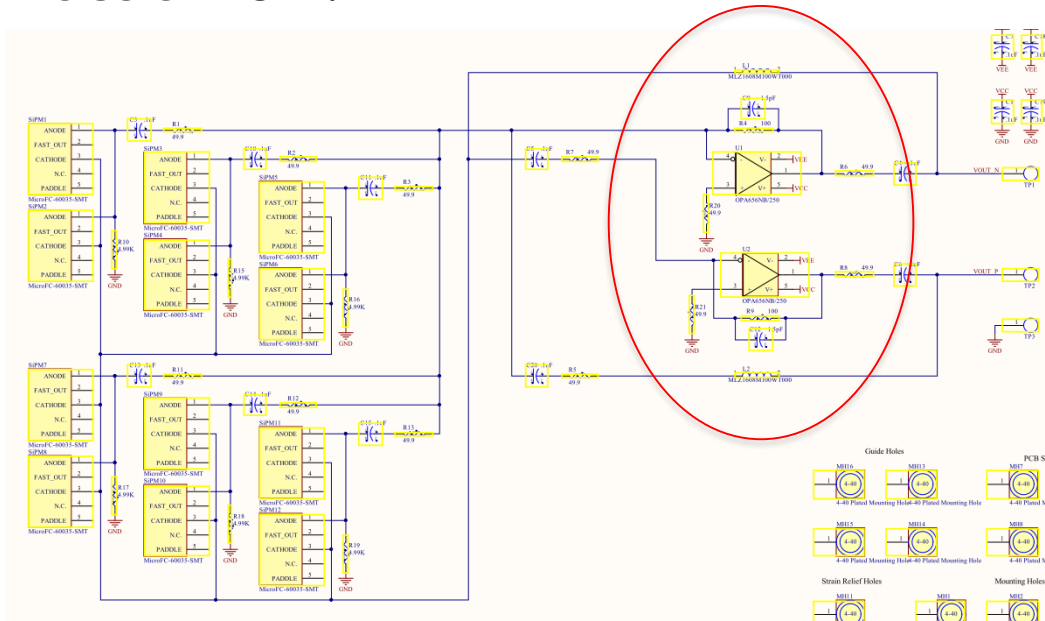
Efficiency > 7%.

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 TalBo run of Oct-Nov 2017



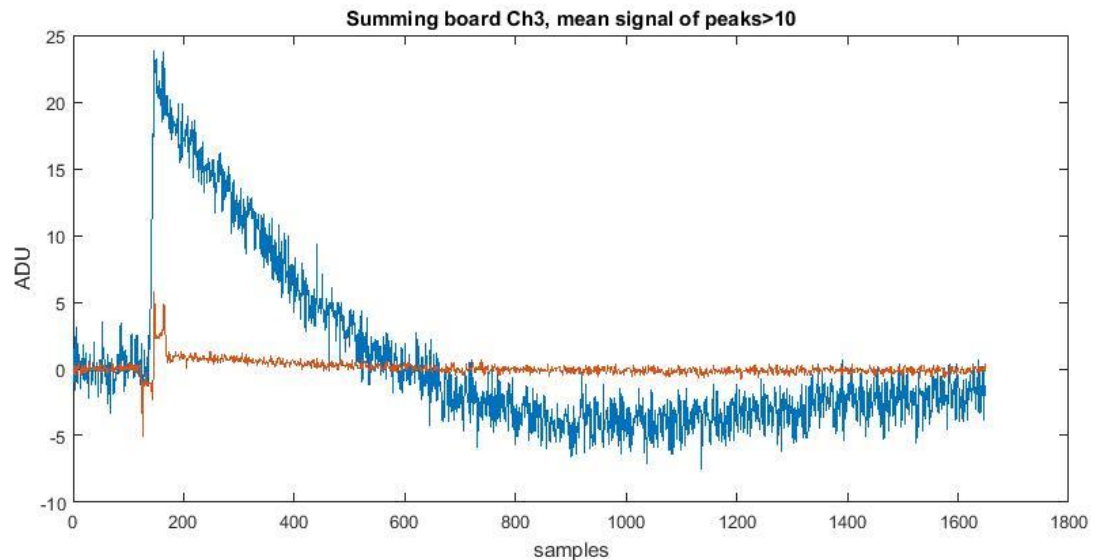
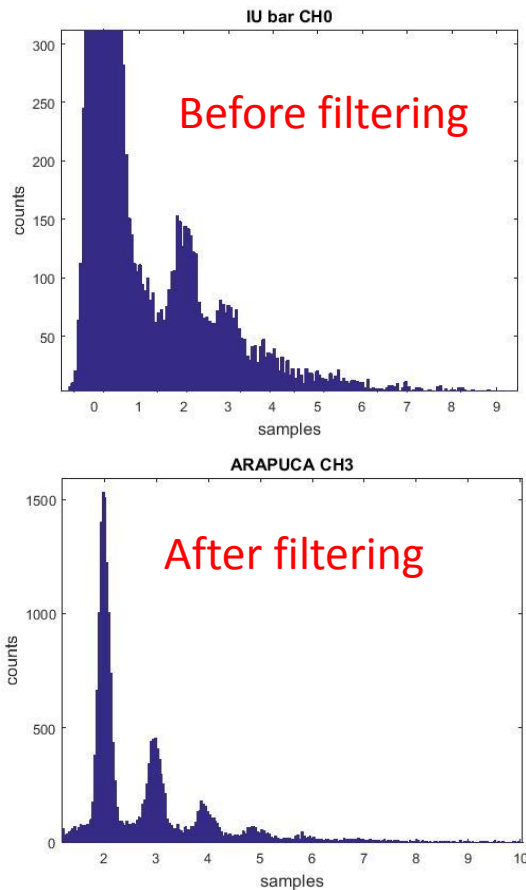
- The design used 2 single ended OP Amps (OPA842) with noise of 2.6nV/√Hz.



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.

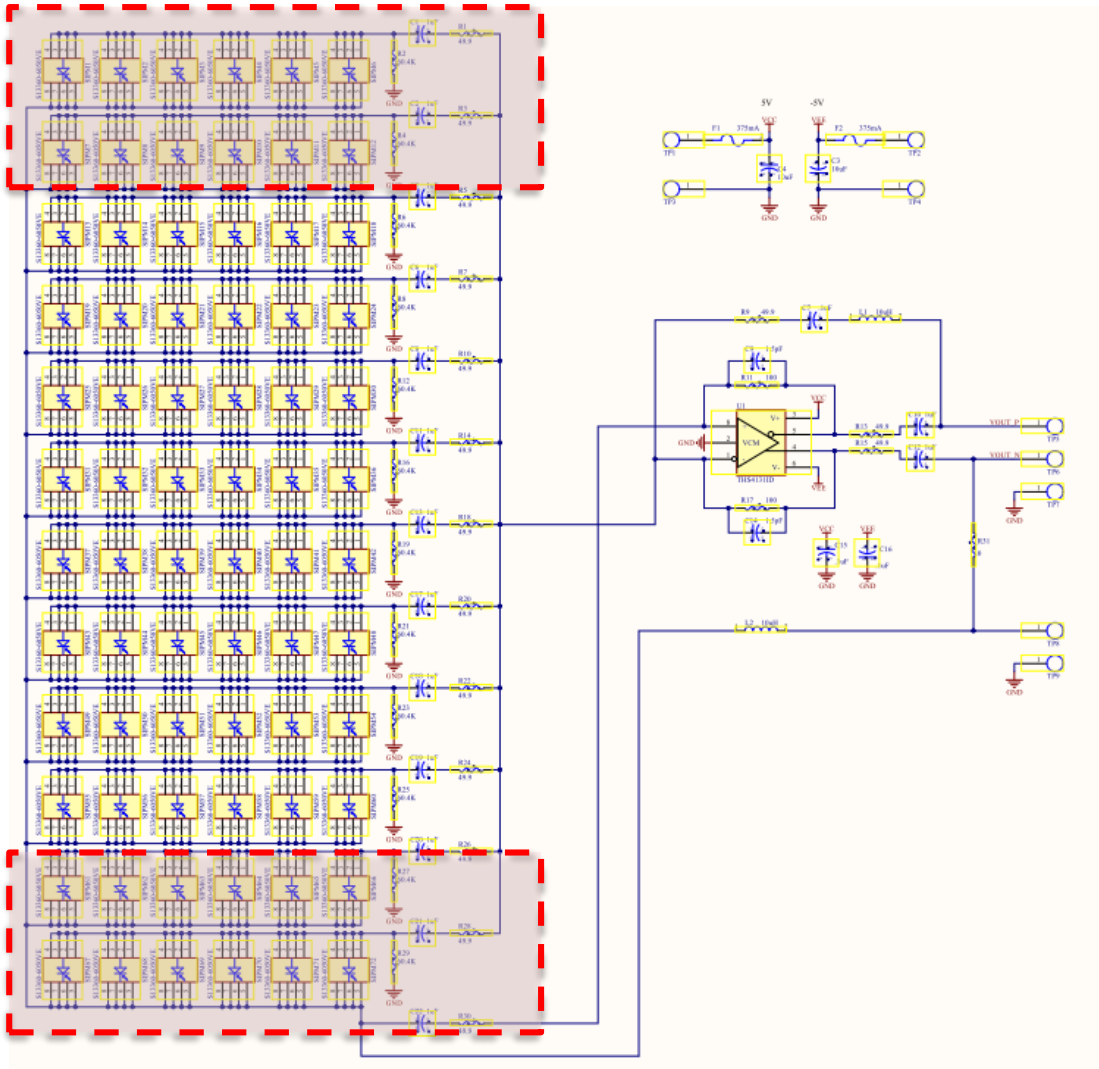
Active ganging of 12 SENSL (6x6 mm C series) summing board for IU light bars, used in the TalBo run of Oct-Nov 2017

- 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.



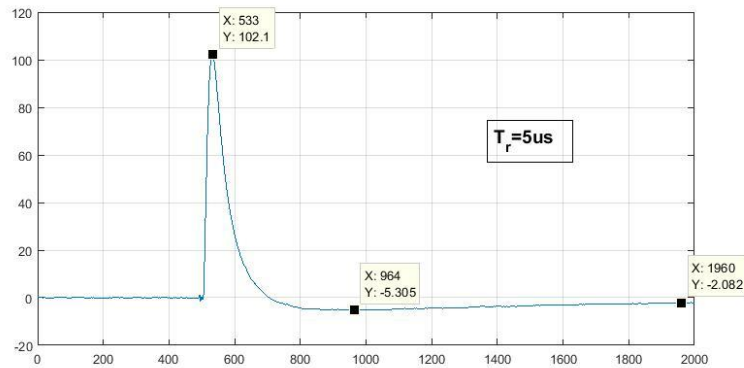
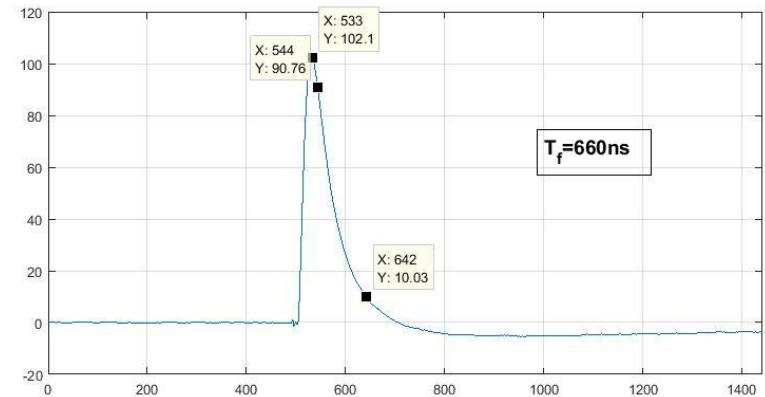
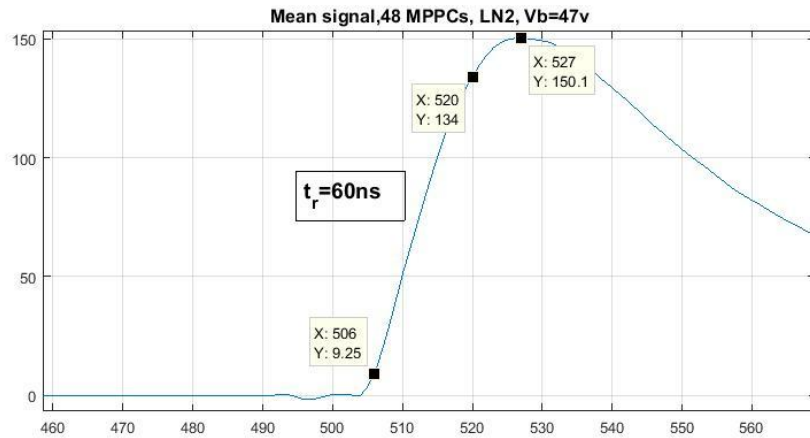
There was also an undershoot in the signal. This is due to AC coupling time constants, not to the summing Op Amp. There was also a “glitch” feature. We believe that is related to the SSP trigger but we are not sure.

72 SiPM active ganging board: 12 x 6 matrix



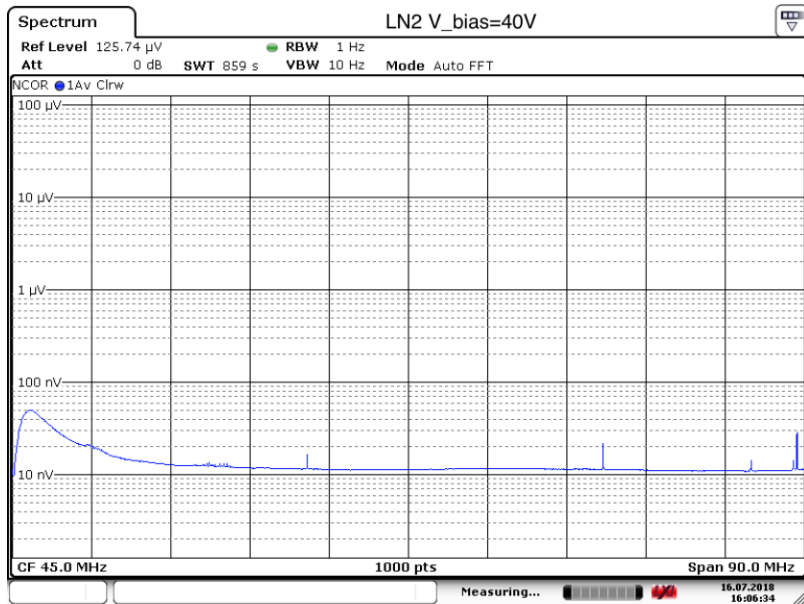
- Each row has 6 MPPCs in parallel.
- We picked 48 for this test.
 - Disconnected 4 rows.
- Tested configuration 8 rows of 6 MPPCs
- 6 parallel MPPCs have a capacitance of ~ 7.8 nF at that V_b .
- Op Amp THS4131

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



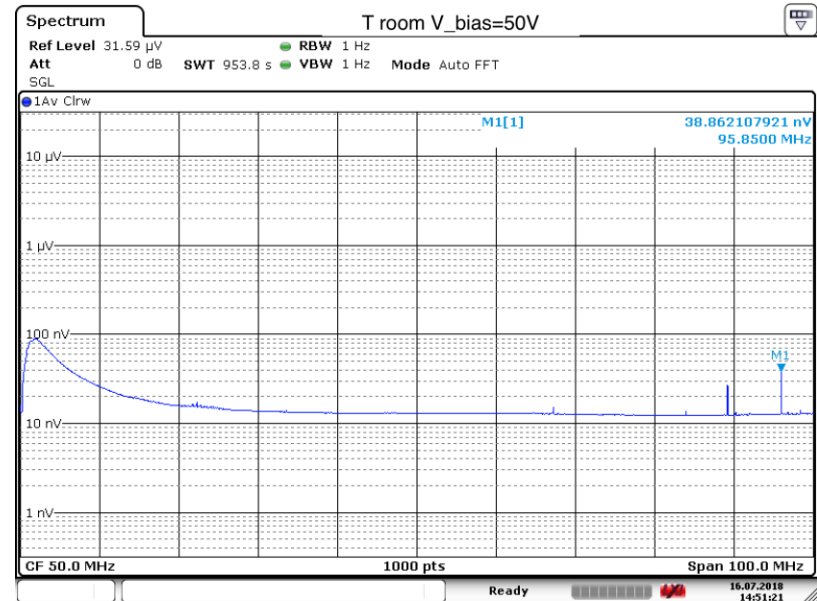
- Rise time 60ns, Fall time 660ns, slow undershoot recovery.
- SSP time constant has not been modified. Some impedance mismatch.

Noise spectrum



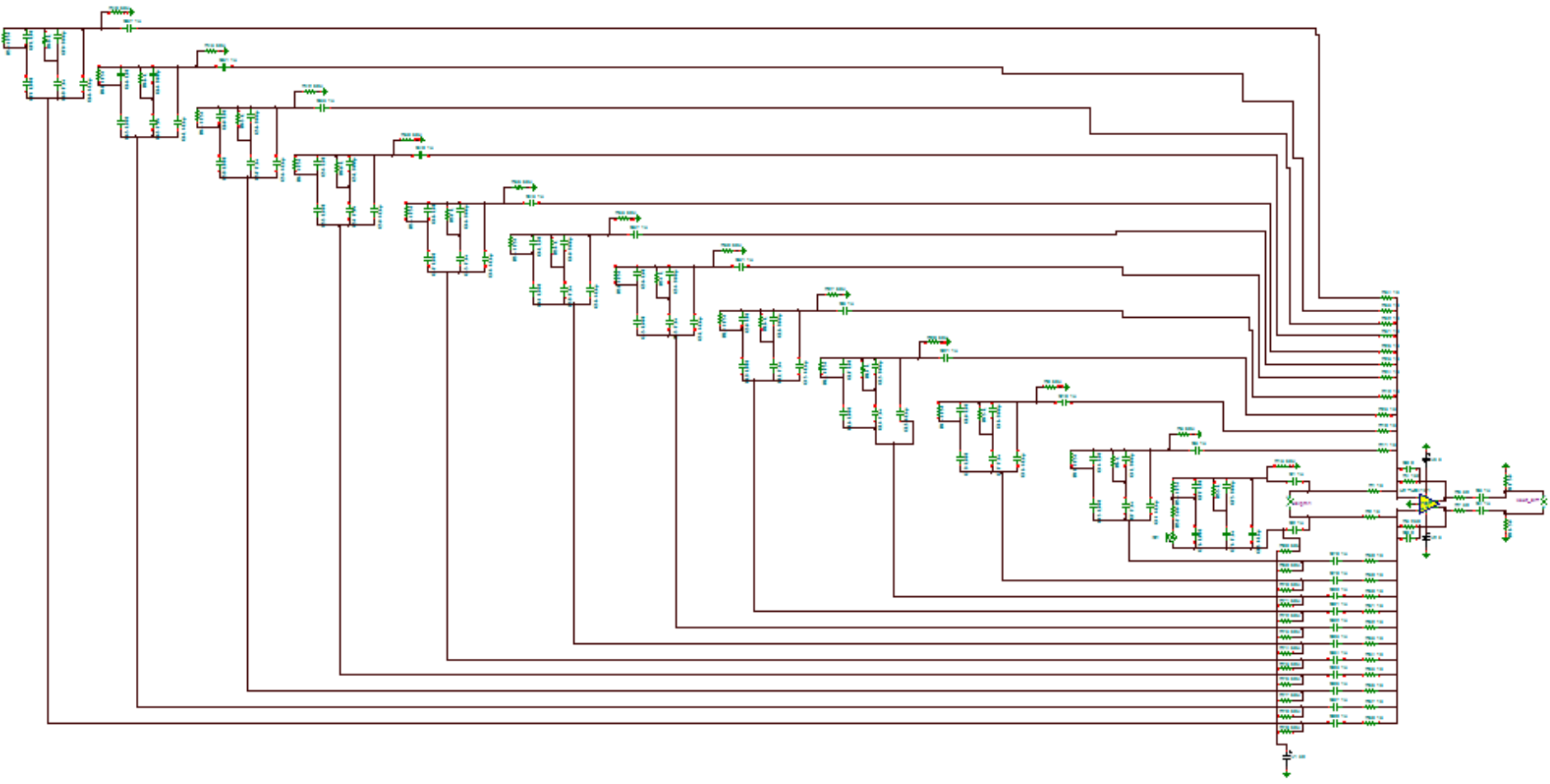
Date: 16.JUL.2018 16:06:34

- Noise is $10\text{nV}/\sqrt{\text{Hz}}$
- $1/f$ at lower frequencies.
- It does not vary much with T and Vb



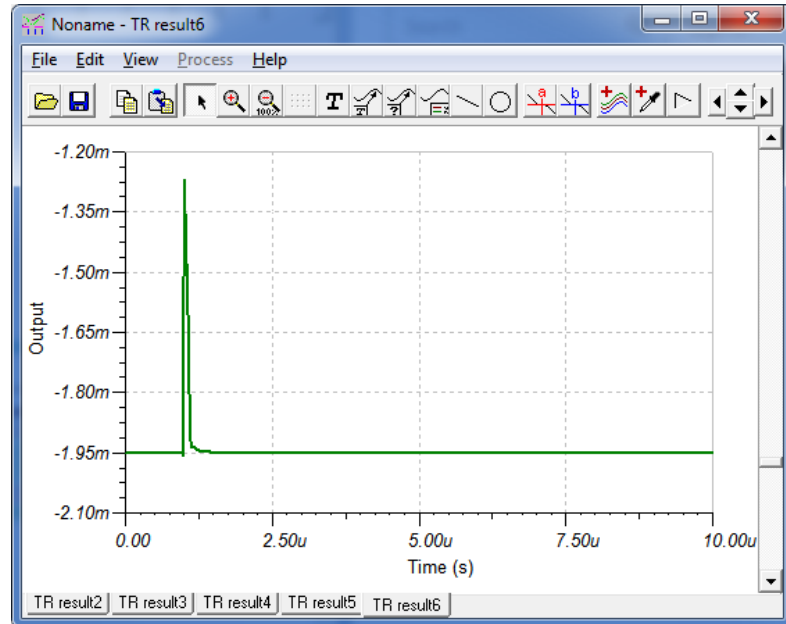
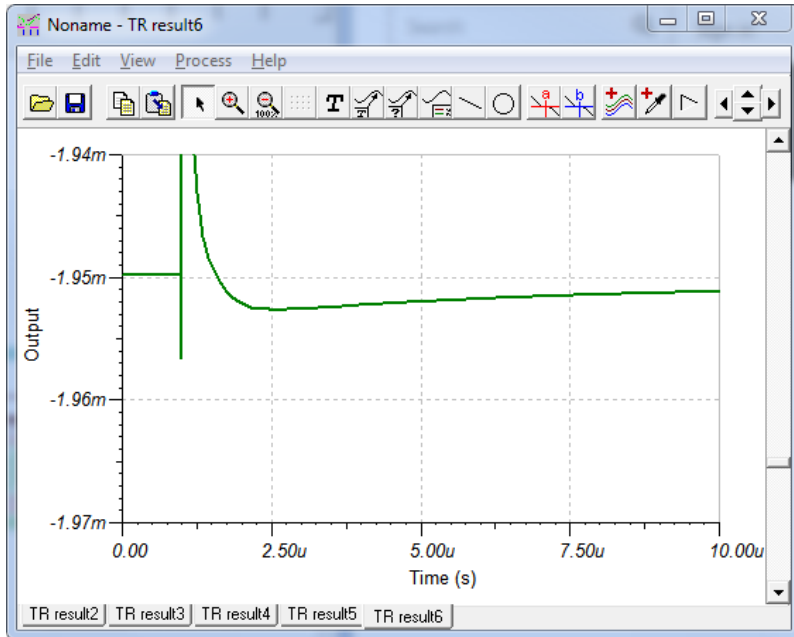
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Simulations



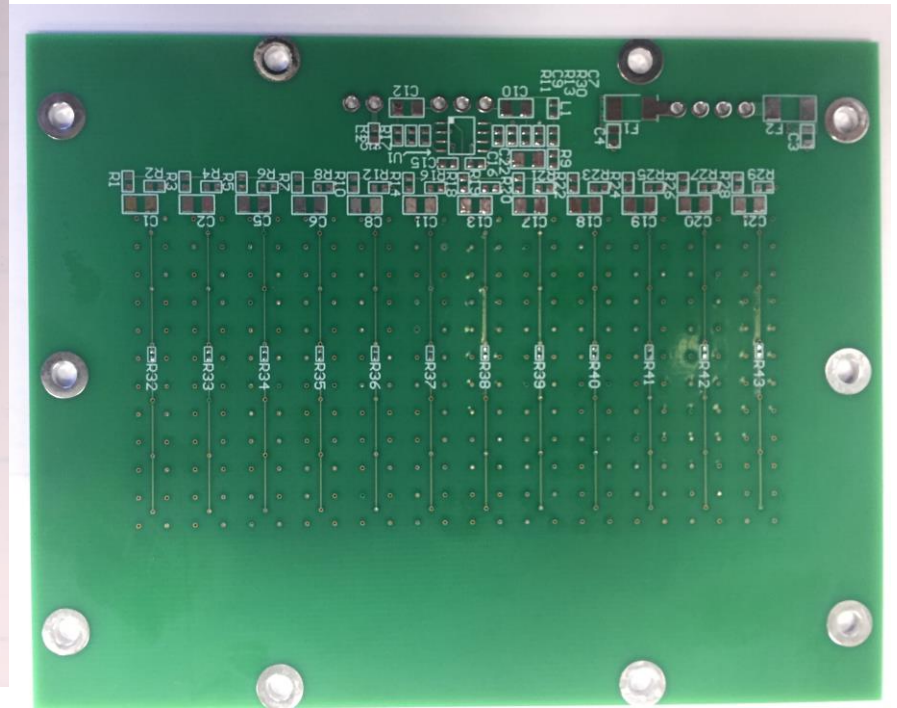
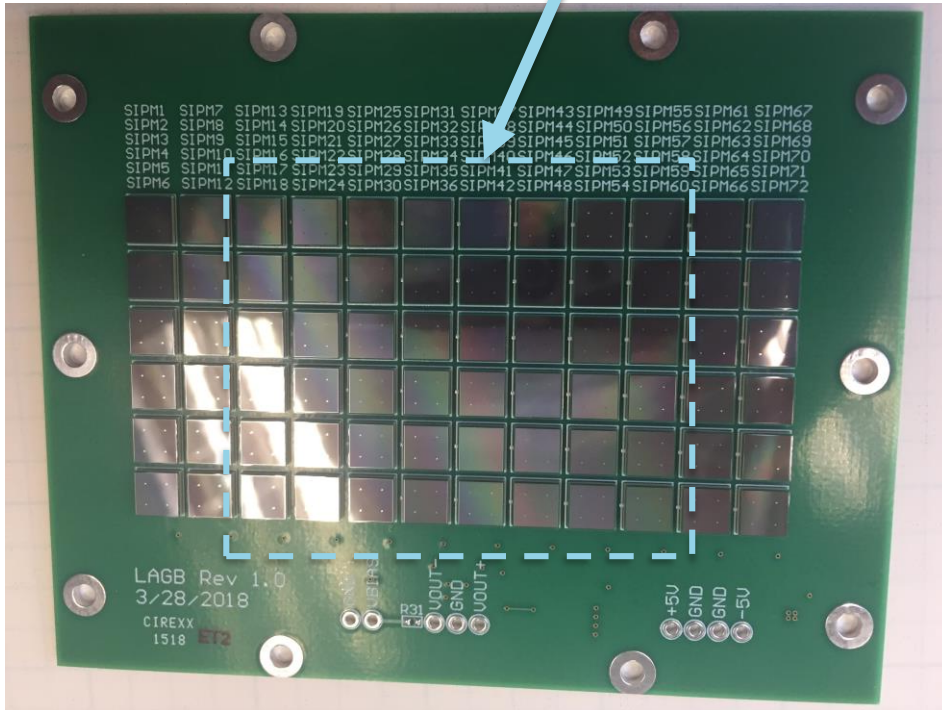
- Simulations are in agreement with results from data.

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.

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

Digitizer
Update Delay [s]: 1.00
AUTO UPDATE ■
Command Busy ● Auto Update Busy ●

XXXXXX P (Predelay Time)

300	I1 (Post Integration Time)	Ch ON	LED Threshold 30	CFD Fraction 0.500
300	I2 (Pre Integration Time)	Ch OFF	LED Threshold 10	CFD Fraction 0.500
200	M1 (Integration Time)	Ch OFF	LED Threshold 16000	CFD Fraction 0.500
10	M2 (Integration Separation Time)	Ch OFF	LED Threshold 300	CFD Fraction 0.500
10	D (CFD Window)	Ch OFF	LED Threshold 0	CFD Fraction 0.500
400	Baseline Start	Ch OFF	LED Threshold 16000	CFD Fraction 0.500
1	Downsample Ratio	Ch OFF	LED Threshold 16000	CFD Fraction 0.500
500	Waveform Pretrigger	Ch OFF	LED Threshold 16000	CFD Fraction 0.500
2000	Waveform Length	Ch OFF	LED Threshold 150	CFD Fraction 0.500
		Ch OFF	LED Threshold 100	CFD Fraction 0.500
		Ch OFF	LED Threshold 100	CFD Fraction 0.500

Positive Disc Edge Select

Disabled Waveform Extension Mode

Internal Trig Mode Timing Mark OFF

Peak Sum Peak Selection CFD Enable OFF

14 Bit Data Width Input Invert OFF

Live Graph ON

Flush Before Read YES File Per Run

Save Header NO Sort Channels

Save Raw NO ASCII Hex

Filename: Test

Number Requested: 10

Number Events: 10

Waiting on Event(s)

 QI Voltage: 0.000

Event # 9

Header: AAAAAAAAAA

Packet Length: 03F4

Trigger Type: 00

Status Flags: 2

Header Type: 0

Trigger ID: 0000

Module ID: 000

Channel ID: 0

Peak Sum: 324409

Peak Time: -10

Prepulse: 466242

Integrated Sum: 483435

Baseline: 4125

Export Event

Sync Count: 00000000

Sync Delay: 3FFE288

Internal Time: 008548B20A8I

Interpreted Time: 0000

CFD Point 0: -574

CFD Point 1: -582

CFD Point 2: -588

CFD Point 3: -584

Waveform Words: 2000

Waveform Min: 1536

Waveform Max: 1669

Pileup

Trigger Polarity: Std. Dev. 22,560

Offset Readout: Std. Dev. All 24,568

CFD Valid

Memory Select

Multi Channel View OFF

Y Axis Mode Linear

Histogram Mode Line

Graph Mode Waveform

Mean: 1568

Min: 1536

Max: 1669

Population: 2000

Scale (Bin Size): 1

Offset: 0

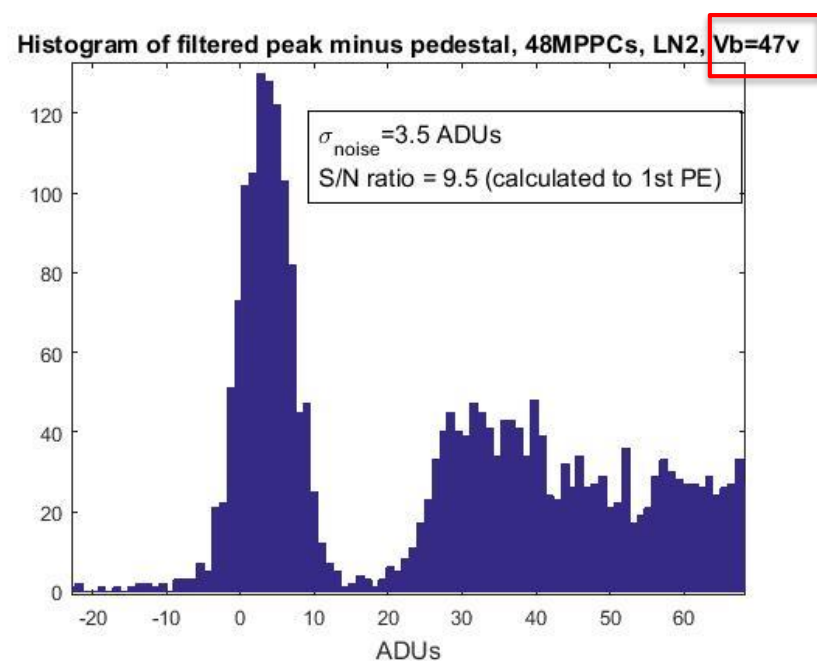
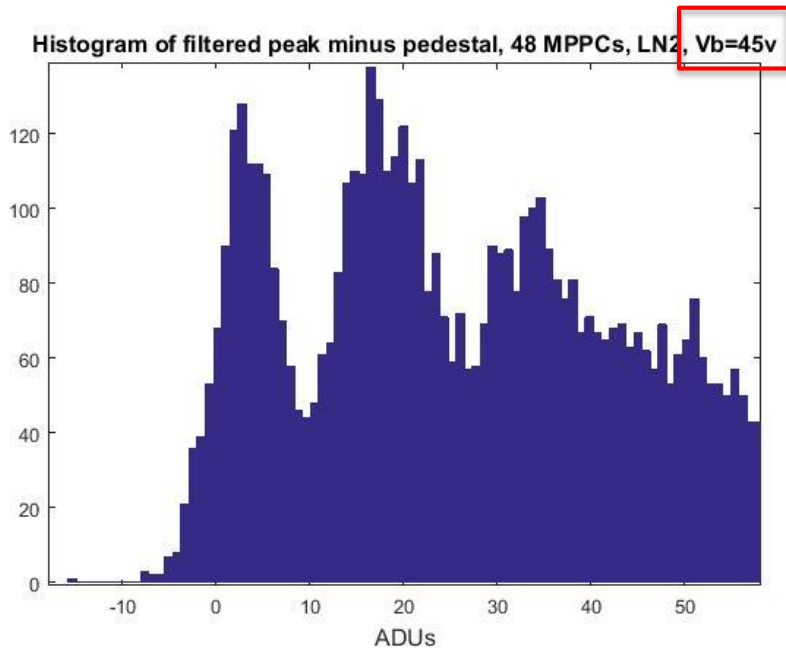
Num Bins: 200

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Presenter | Presentation Title

11/9/2018

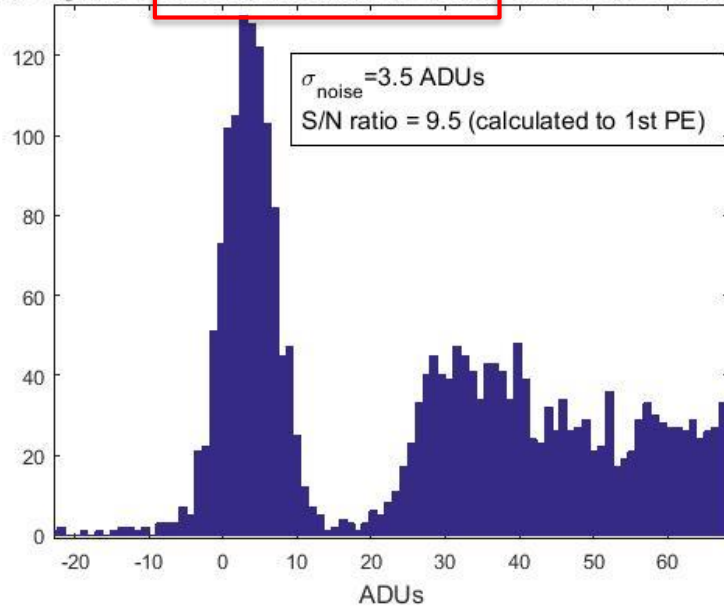
Effect of bias voltage on 48 MPPC



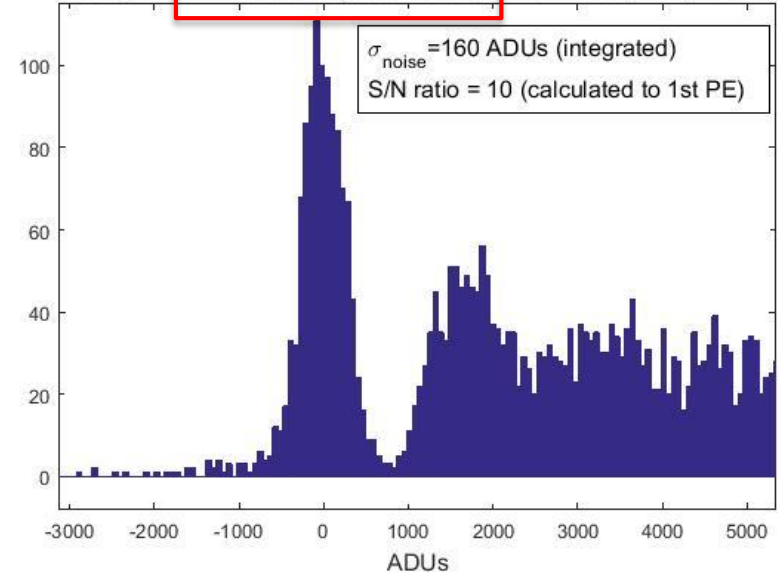
- 48 MPPCs Vb=47v: S/N=10.
- 48 MPPCs Vb=45v: S/N=5.
- S/N measured as the fit of the 1st PE peak to the σ_{noise} .
- For Vb=45v the 1st and 2nd PE histograms are better defined. Probably due an effect of Vb in the relative gains.

Peak minus baseline vs integrated charge (0.6usec)

Histogram of filtered peak minus pedestal. 48MPPCs, LN2, Vb=47v

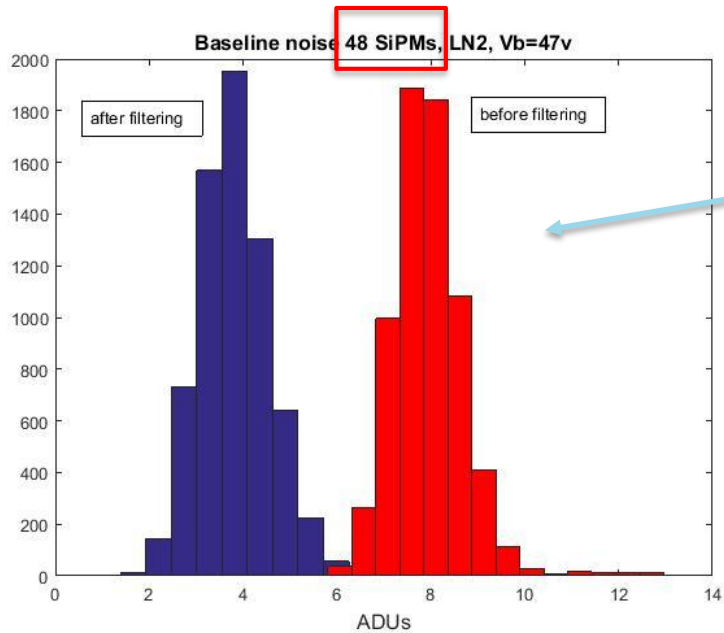


Histogram of filtered integrated charge. 48 MPPCs, LN2, Vb=47v



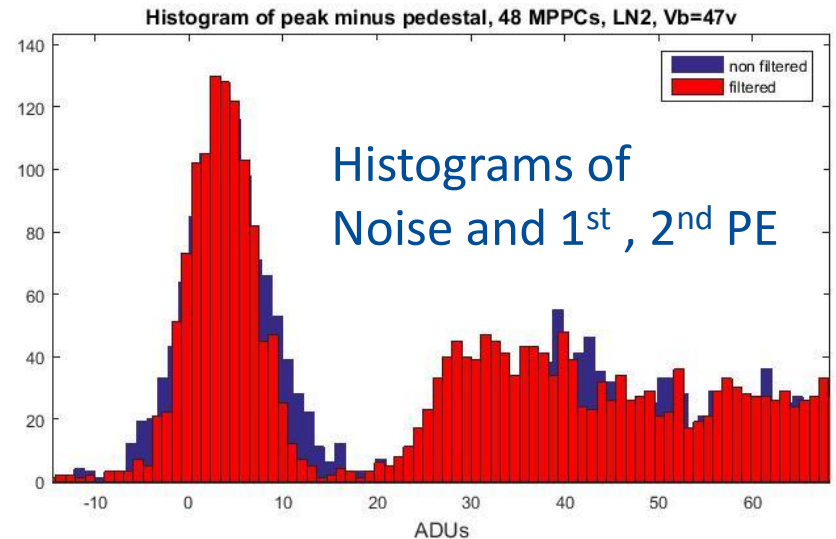
- Very similar S/N.

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



Histograms of

σ_{noise}



Histograms of
Noise and 1st, 2nd PE

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

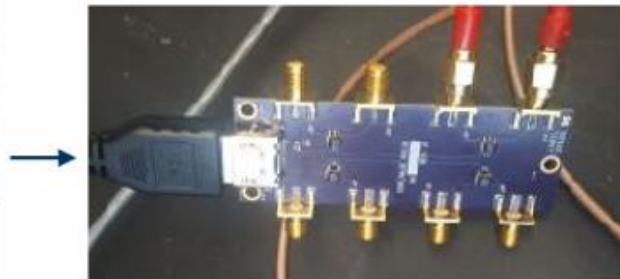
Interfacing the active ganging board to the u2e FEB electronics

72-MPPC active ganging board (left). Each row has six 6x6 mm² 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



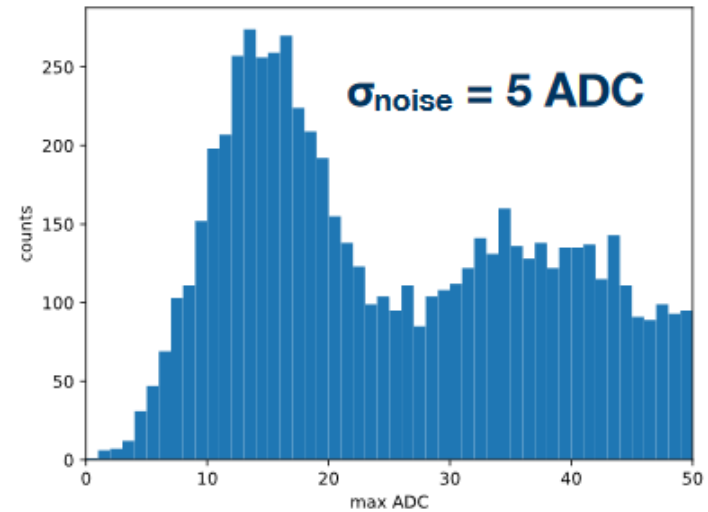
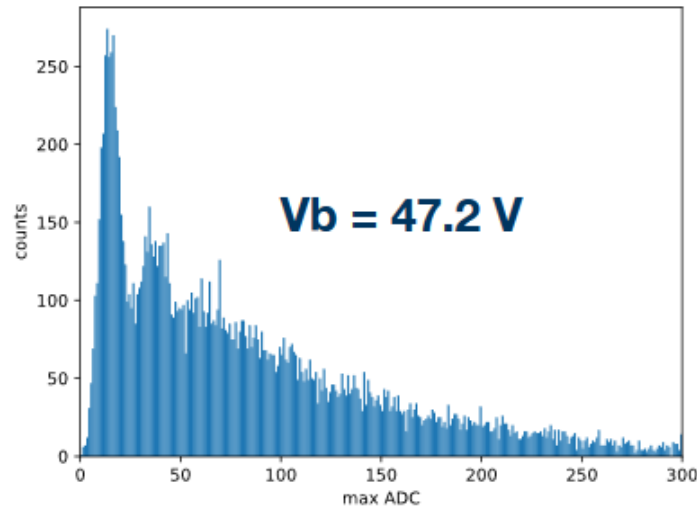
balun from Michigan



FEB

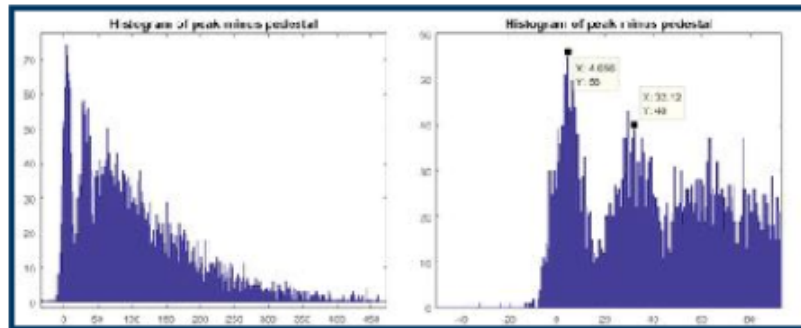
Interfacing the active ganging board to the u2e FEB electronics

Successfully demonstrated single photon resolution!



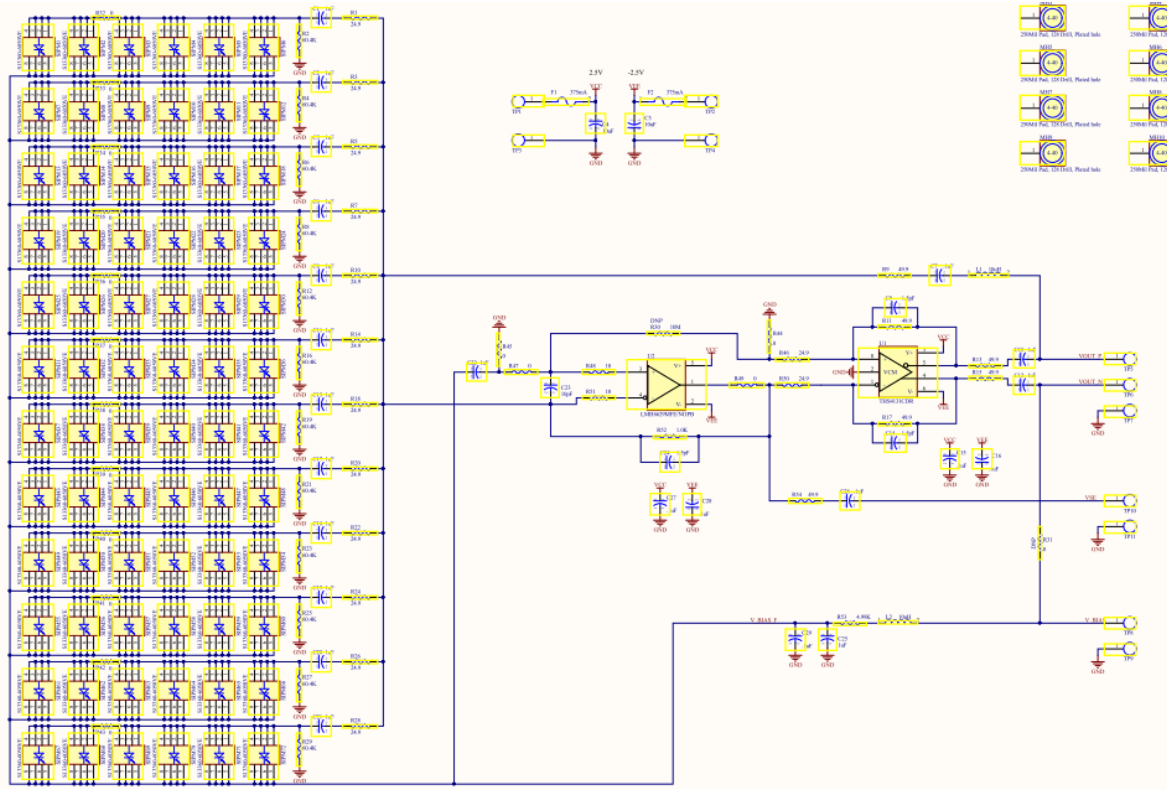
$S/N = 4$ (measured as 1st peak to σ_{noise})

Similar noise without filtering



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

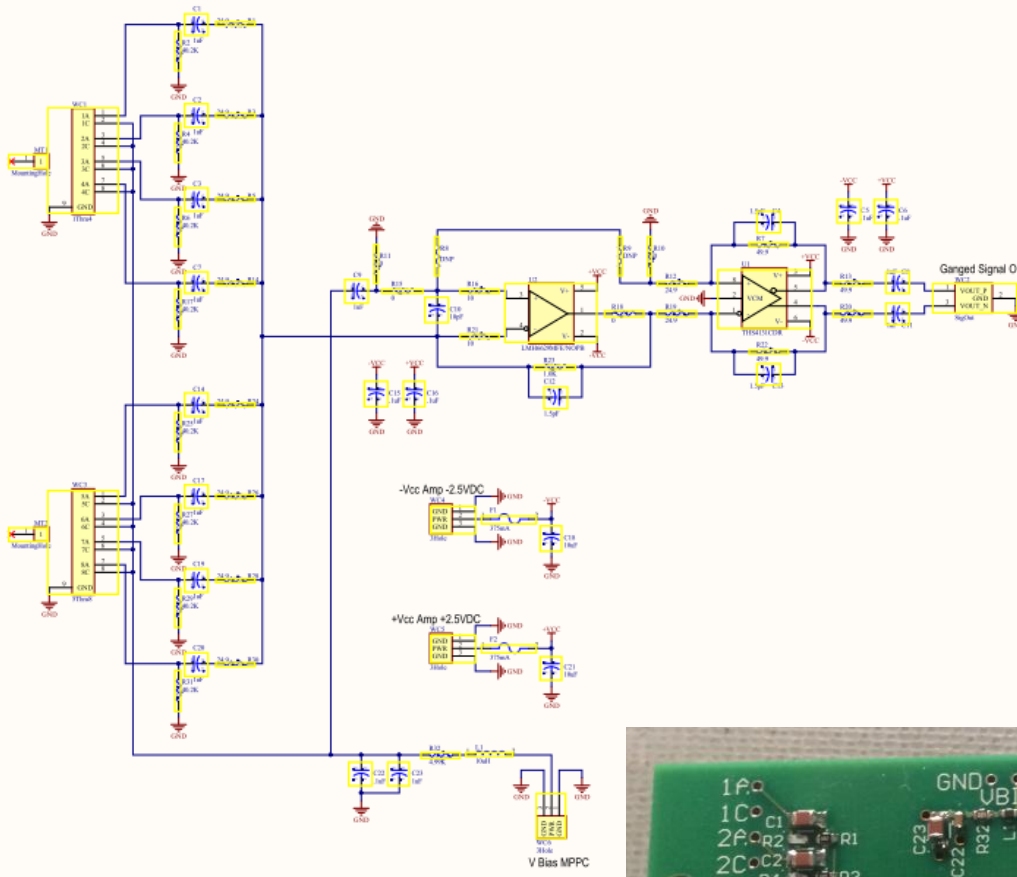
2nd version of the 72 MPPC board



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

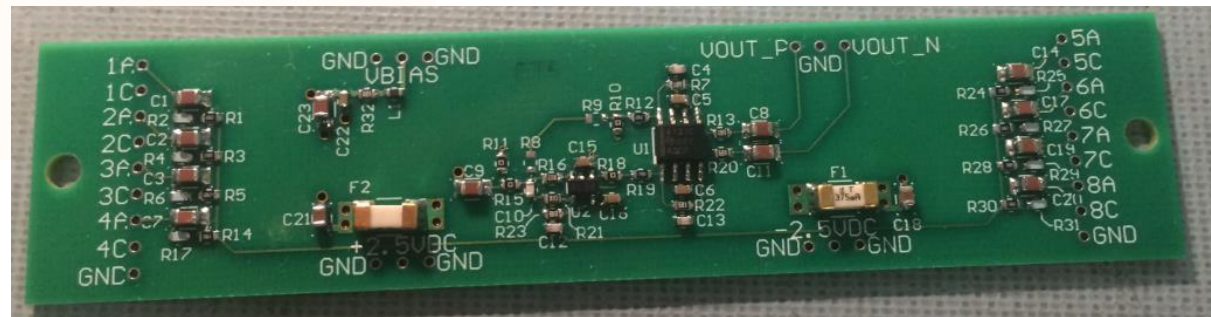


Two stage design, as in the 72 MPPC board.

This board collects signals from a $6 \times 8 = 48$ 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.