Anode Response Summary

11.08.2017, protoDUNE-DP integration meeting

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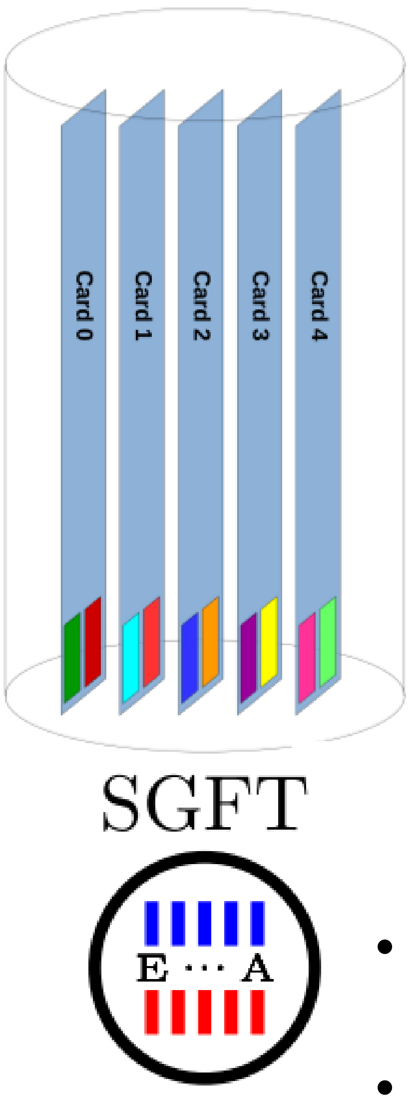
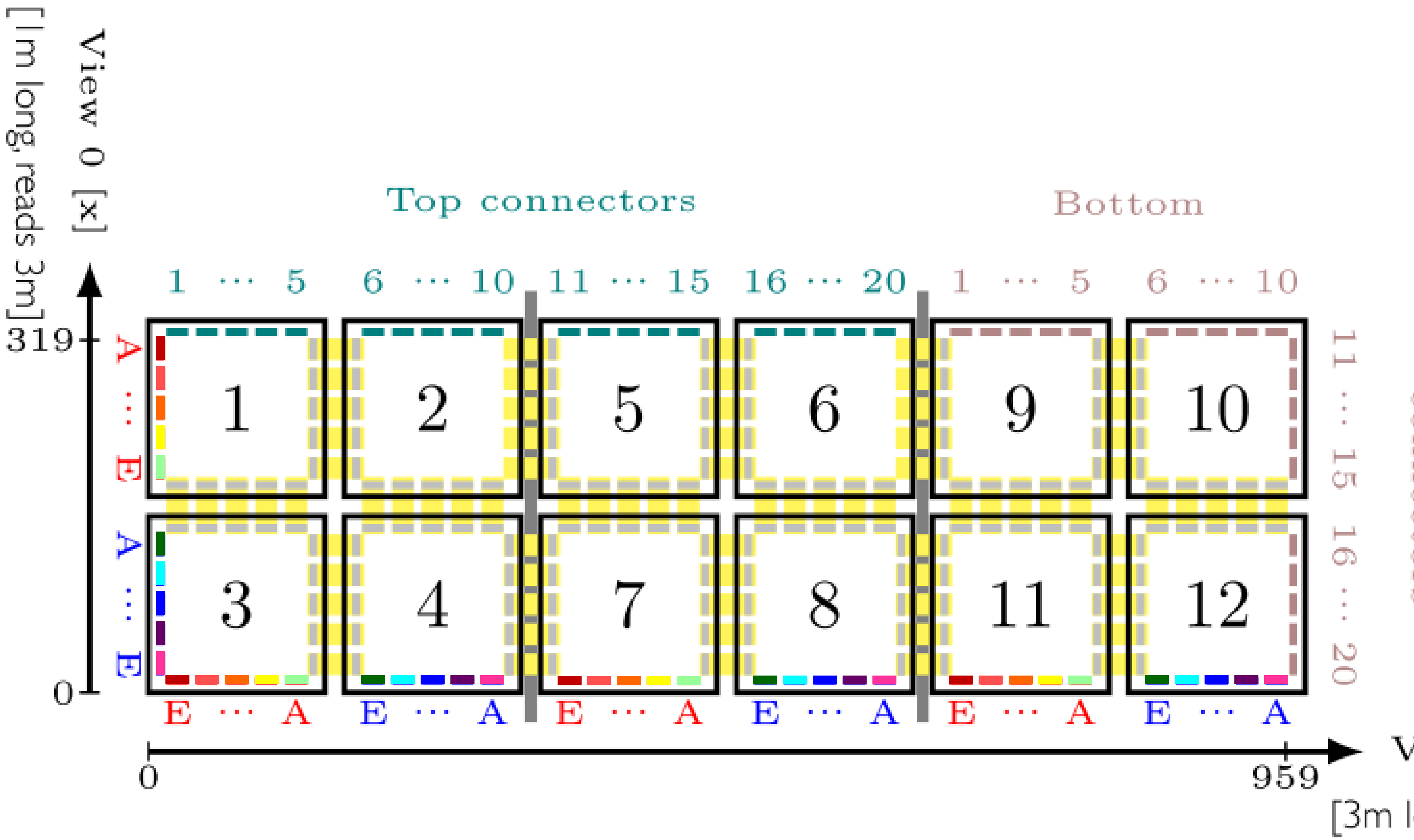
Summary

- Description of pulsing system
  - Mapping of channels
  - Old system
  - New system
  - Pulsing measurements taken
- Pulse waveform and noise contamination
  - Analysis of waveforms
- Comparison between the two views
- Evaluation of crosstalk and analysis
  - Capacitive vs. inductive crosstalk
  - Pulsing of single anode module
  - Equivalent circuit model and capacitance measurements
- Conclusions
- Next steps

Description of pulsing system





- Top and bottom connectors on calibration flange on SCFT2 lead to all channels
  - Each connector connects to 20 groups of 32 channels
- Each SGFT chimney holds 5 cards with 2 connectors of 32 channels
  - Each connector on card reads from a different anode module

Old pulsing system

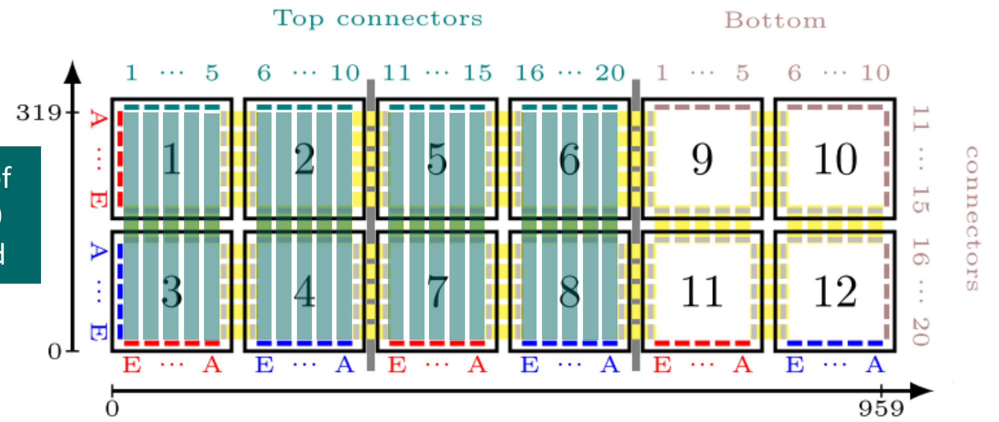
- Cable from pulser was directly connected to calibration flange on SCFT2 chimney
- Pulser synchronized with trigger of DAQ
  - Pulse always arrives at the same tdc
- 2 modes
  - 1. 20 connectors with 640 channels pulsed simultaneously
  - 2. 1 connector with 32 channels pulsed simultaneously
    - Pulser had to be manually connected to individual connector
- Each channel is pulsed through a 1 pF capacitor: injected charge Q = C V

Pulser

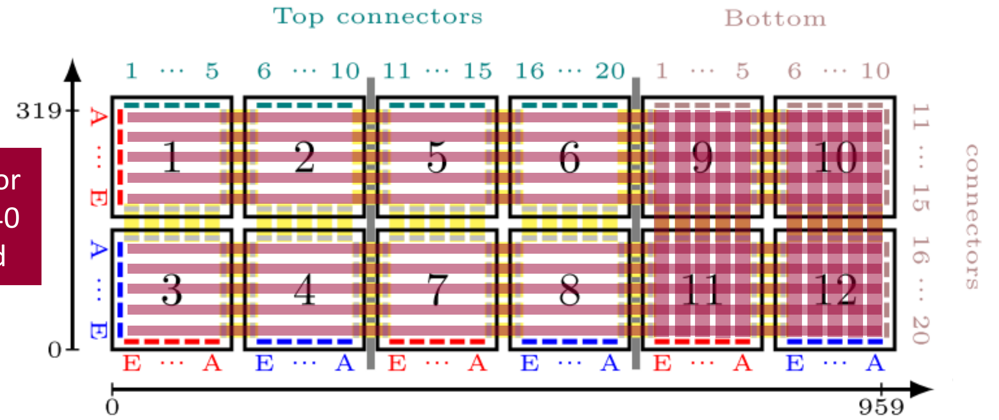
DAQ trigger sync

Shielded cable

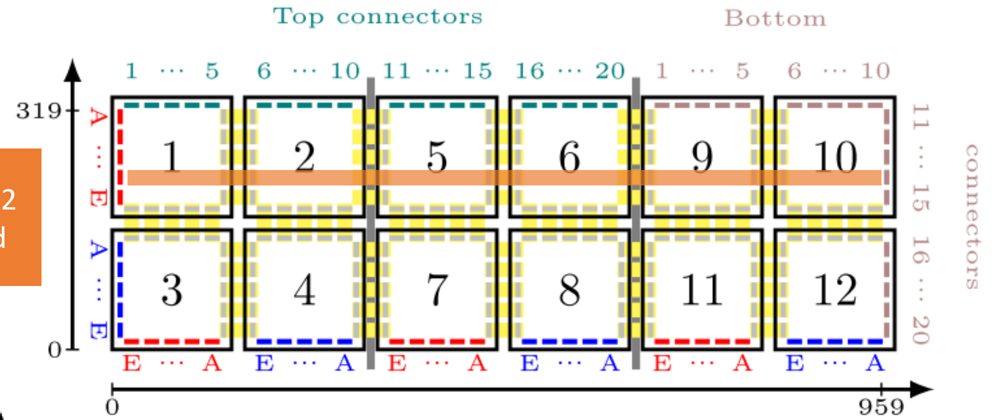
Top connector of flange with 640 channels pulsed



Bottom connector of flange with 640 channels pulsed



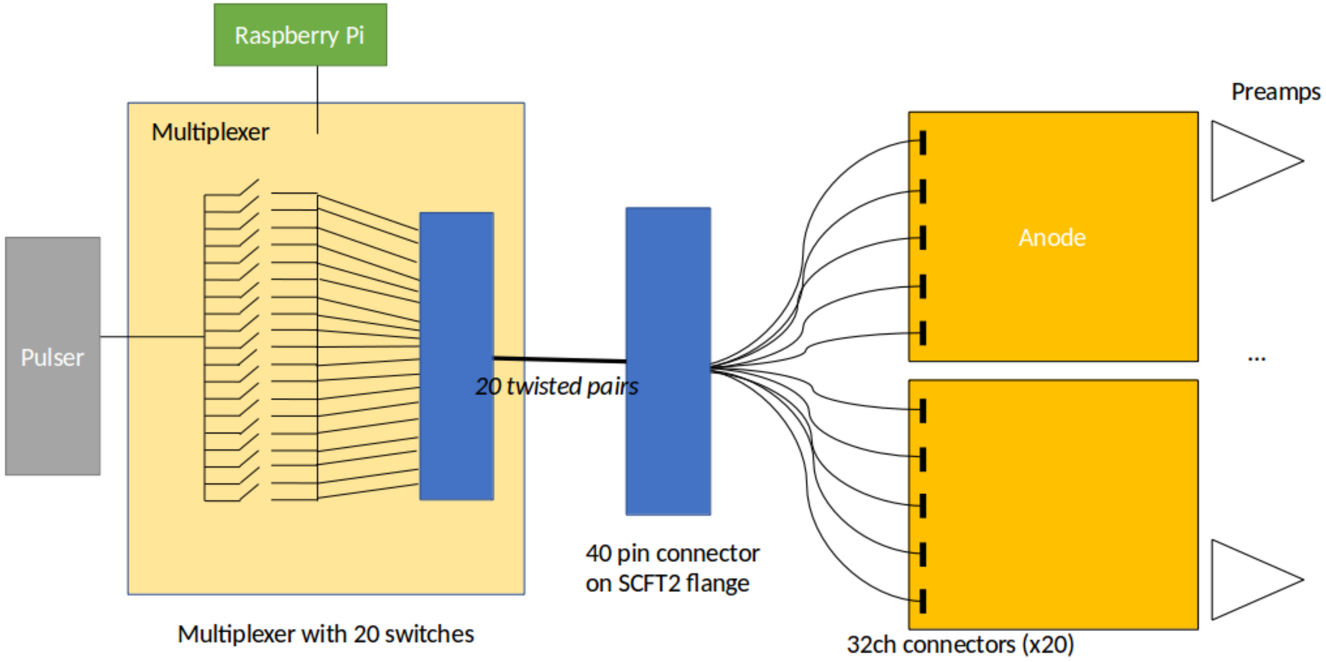
1 connector of 32 channels pulsed

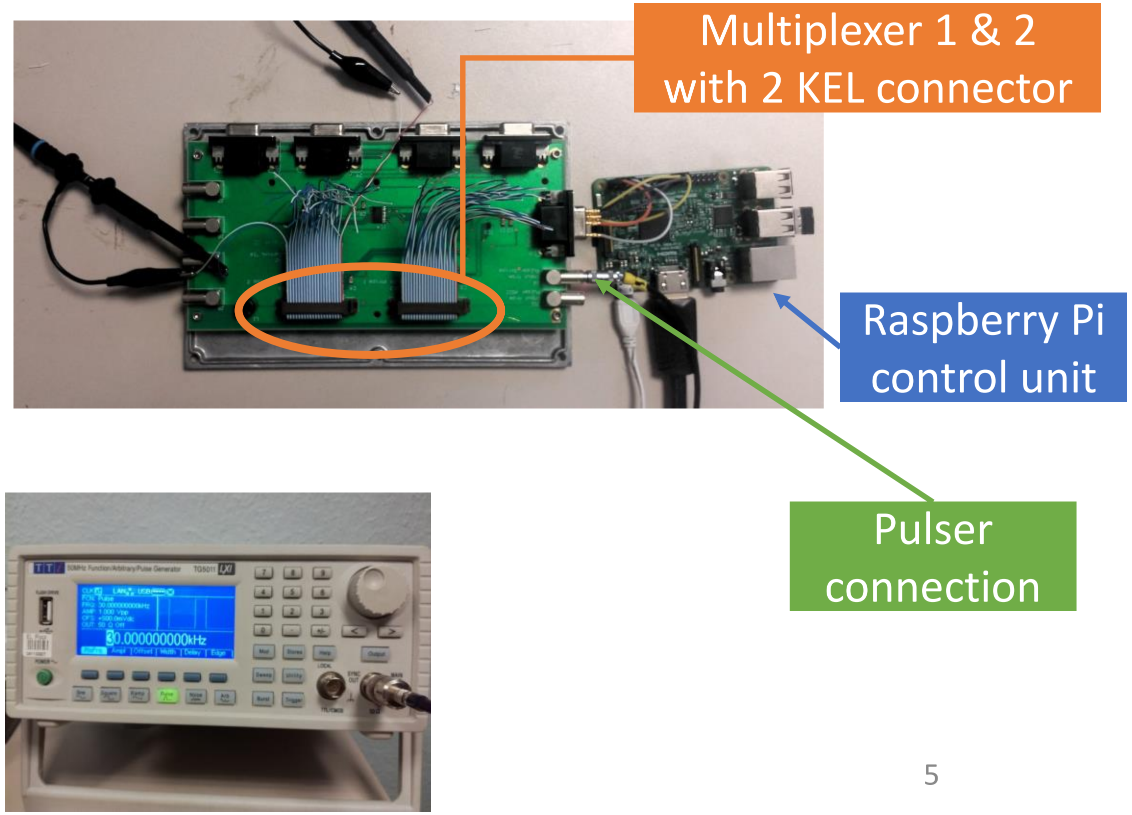


Calibration Flange on SCFT2 chimney

New pulsing system

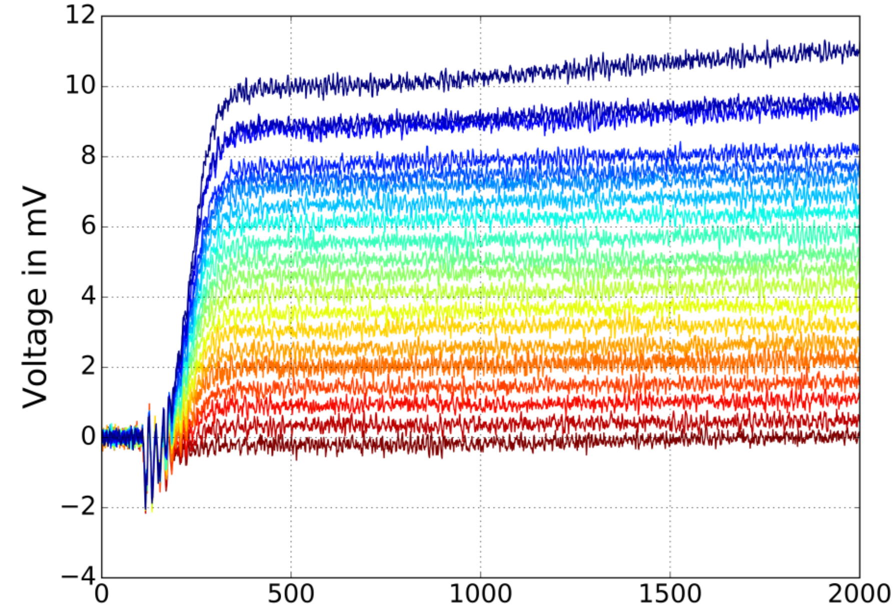
- Developed by Cosimo Cantini and Kevin Fusshoeller
- Employs 2 Multiplexers with 20 switches for 20 connectors (connected to 32 channels each)
  - Multiplexer connected to pulser
  - Raspberry Pi control unit with GUI controls position of switches and which connecter is pulsed
  - Pulsed channels can be selected remotely



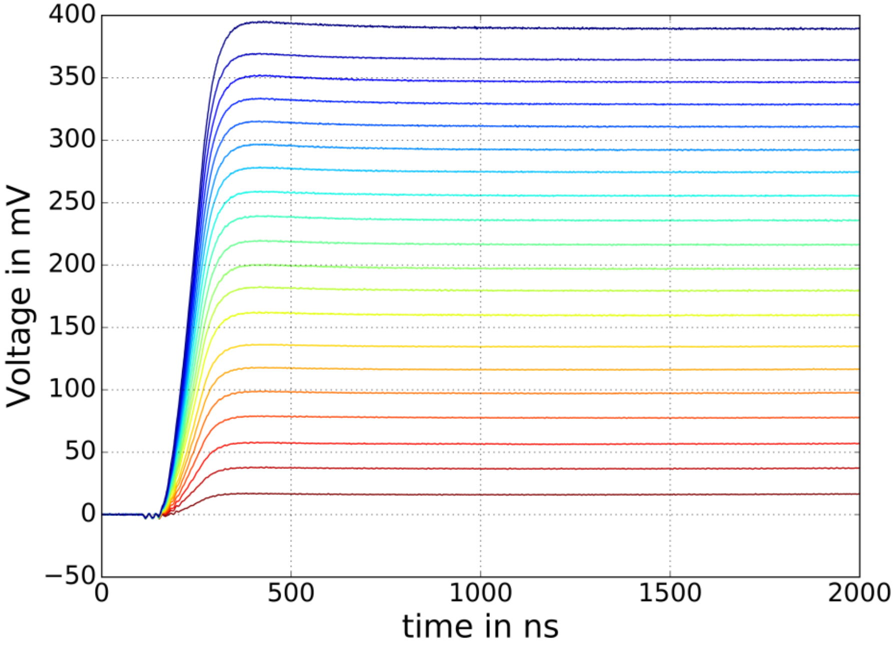


New pulsing system: measured response

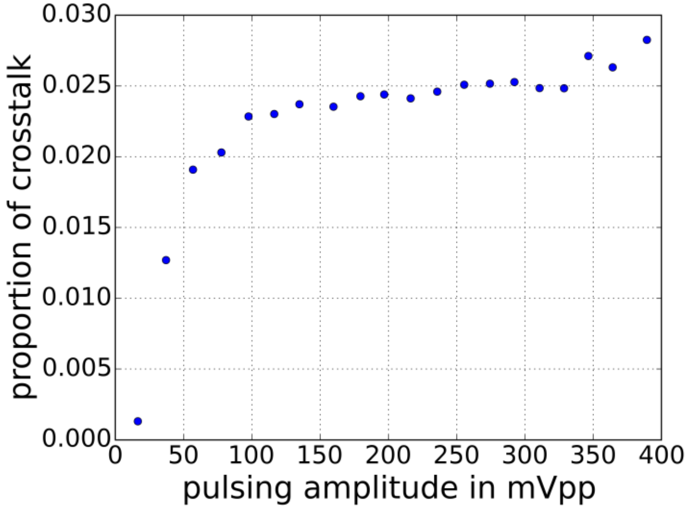
- One switch of multiplexer closed → Signal
- All other switches open → Crosstalk
  - Crosstalk response not linear with pulsing amplitude
  - Up to 3% crosstalk for amplitudes of 400 mVpp at level of multiplexer
  - Not suitable for pulsing amplitudes above 5 Vpp

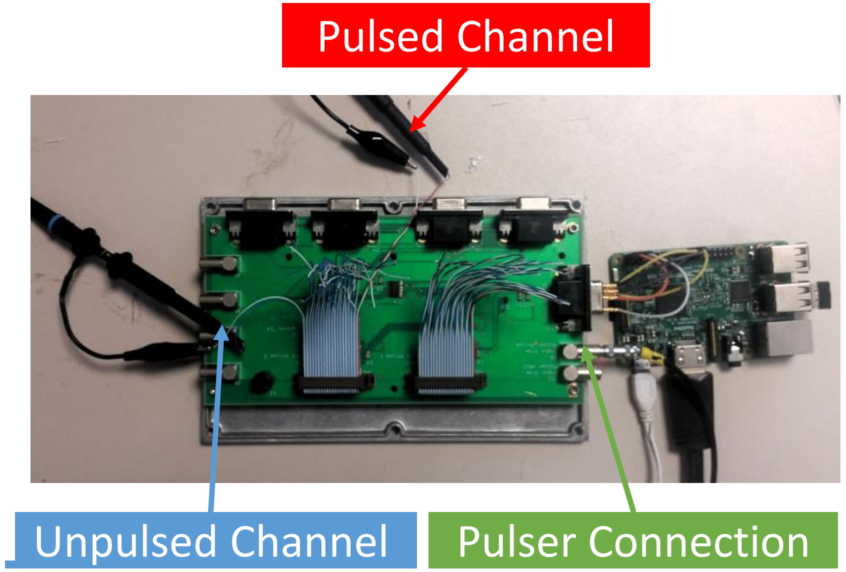


Response unpulsed channel



Response pulsed channel





Pulsing measurements performed

- Pulsing measurements were taken in
  - December of 2016: using the old pulsing system where pulser had to be connected manually to each connector of 32 channels
    - Purpose:
      - Check for dead channels
      - Examine if we see crosstalk
  - July/August 2017: using the new pulsing system where the pulsed connector could be selected through the multiplexer and old pulsing system
    - Purpose:
      - Check new pulsing system for scalability to 6x6x6 ProtoDune
      - Compare the two pulsing systems
      - Analyze differences between the 2 views
  - August 2017: extraction grid was pulsed directly through the pulser
    - Purpose:
      - Check for broken wires in the extraction grid
      - Analyze differences between the 2 views

Pulsing measurements performed in 2016

Run	Pair	Crate	Card	Card Channels			DAQ Channels			View Channels		
BOTTOM CONNECTORS												
288	20	0	0	31	to	0	0	to	31	288	to	319
289	19	0	1	31	to	0	64	to	95	256	to	287
290	18	0	2	31	to	0	128	to	159	224	to	255
291	17	0	3	31	to	0	192	to	223	192	to	223
292	16	0	4	31	to	0	256	to	287	160	to	191
293	15	0	0	63	to	32	32	to	63	128	to	159
294	14	0	1	63	to	32	96	to	127	96	to	127
295	13	0	2	63	to	32	160	to	191	64	to	95
296	12	0	3	63	to	32	224	to	255	32	to	63
297	12	0	3	63	to	32	224	to	255	32	to	63
298	11	0	4	63	to	32	288	to	319	0	to	31
299	9	3	3	0	to	31	1152	to	1183	896	to	927
300	8	3	2	0	to	31	1088	to	1119	864	to	895
301	7	3	1	0	to	31	1024	to	1055	832	to	863
302	6	3	0	0	to	31	960	to	991	800	to	831
303	5	3	4	32	to	63	1248	to	1279	768	to	799
304	4	3	3	32	to	63	1184	to	1215	736	to	767
305	3	3	2	32	to	63	1120	to	1151	704	to	735
306	2	3	1	32	to	63	1056	to	1087	672	to	703
307	1	3	0	32	to	63	992	to	1023	640	to	671

Rawdata available on EOS:
/eos/experiment/wa105/data/311/calibrations

- bottom pair 10 seems to be missing
- **blue runs** have no or partly pulses in the data

Pulsing measurements performed in 2016

Run	Pair	Crate	Card	Card Channels			DAQ Channels			View Channels		
TOP CONNECTORS												
308	1	1	0	32	to	63	352	to	383	0	to	31
309	2	1	1	32	to	63	416	to	447	32	to	63
310	5	1	4	32	to	63	608	to	639	128	to	159
311	3	1	2	32	to	63	480	to	511	64	to	95
312	4	1	3	32	to	63	544	to	575	96	to	127
313	6	1	0	0	to	31	320	to	351	160	to	191
314	7	1	1	0	to	31	384	to	415	192	to	223
315	9	1	3	0	to	31	512	to	543	256	to	287
316	8	1	2	0	to	31	448	to	479	224	to	255
317	11	2	0	32	to	63	672	to	703	320	to	351
318	10	1	4	0	to	31	576	to	607	288	to	319
319	12	2	1	32	to	63	736	to	767	352	to	383
320	13	2	2	32	to	63	800	to	831	384	to	415
321	14	2	3	32	to	63	864	to	895	416	to	447
322	15	2	4	32	to	63	928	to	959	448	to	479
323	16	2	0	0	to	31	640	to	671	480	to	511
324	17	2	1	0	to	31	704	to	735	512	to	543
325	18	2	2	0	to	31	768	to	799	544	to	575
326	19	2	3	0	to	31	832	to	863	576	to	607
327	20	2	4	0	to	31	896	to	927	608	to	639

Rawdata available on EOS:
/eos/experiment/wa105/data/311/calibrations

- **red runs** had pairs swapped [now fixed by Cosimo]

Pulsing measurements performed in 2017

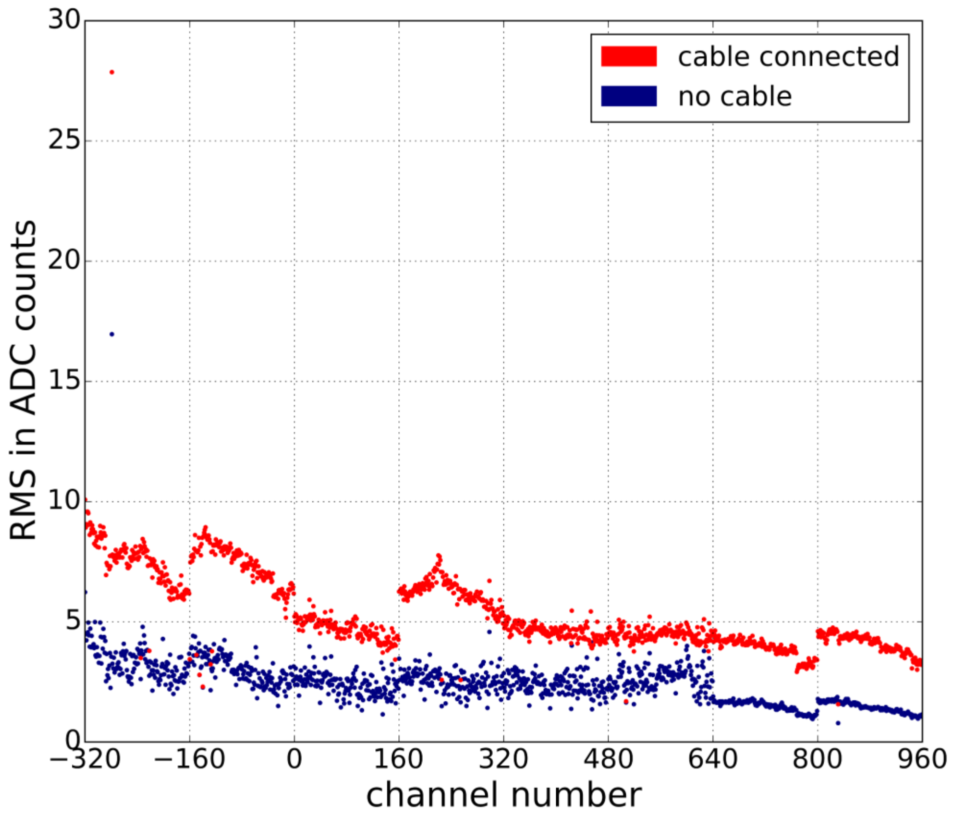
	A	B	C	D	E	F	G	H	I	J	K
1	Run	Frequency	Amplitude	Rise/Fall time	Load	Duty cycle	Delay	Connector on the flange	Offset	ChannelInPS	Events
2	862	3 Hz	25 mV p2p	500 ns	110 ohm	50%	200us	top	0V	1	356
3	863	3 Hz	25 mV p2p	500 ns	110 ohm	50%	200us	bottom	0V	29	369
4	864	3 Hz	25 mV p2p	100 ns	110 ohm	50%	200us	bottom	0V	29	314
5	865	3 Hz	25 mV p2p	100 ns	110 ohm	50%	200us	top	0V	1	363
6											
7											
8	Tests 3.08.2017										
9	866	noise run	no cable connected, PMTs off							1	151
10	867	noise run	pulser cable connected							29	177
11	868	3 Hz	150 mV p2p	100 ns	110 Ohm	50%	300 us	bottom	0V	29	261
12	869	3 Hz	150 mV p2p	100 ns	110 Ohm	50%	300 us	top	0V	1	251
13	870	3 Hz	14 mV p2p	100 ns	110 Ohm	50%	300 us	top	0V	1	261
14	871	3 Hz	20 mV p2p	100 ns	110 Ohm	50%	300 us	top	0V	1	265
15	872	3 Hz	50 mV p2p	100 ns	110 Ohm	50%	300 us	top	0V	1	259
16	873	3 Hz	75 mV p2p	100 ns	110 Ohm	50%	300 us	top	0V	1	287
17	874	3Hz	100 mV p2p	100 ns	110 Ohm	50%	300 us	top	0V	1	328
18	875	3Hz	125 mV p2p	100 ns	110 Ohm	50%	300 us	top	0V	1	270
19											
20	876	3 Hz	125 mV p2p	100 ns	110 Ohm	50%	300 us	bottom	0V	29	263
21	877	3 Hz	100 mV p2p	100 ns	110 Ohm	50%	300 us	bottom	0V	29	257
22	878	3 Hz	75 mV p2p	100 ns	110 Ohm	50%	300 us	bottom	0V	29	437

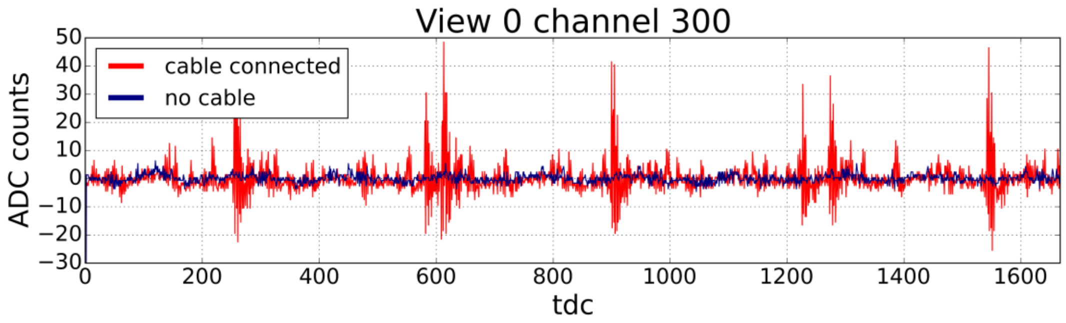
Rawdata available on EOS:
/eos/experiment/wa105/data/311/calibrations

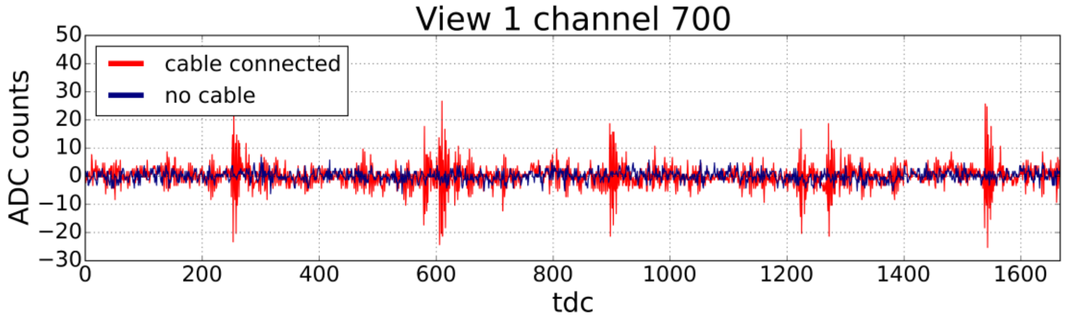
For details and pulser settings for all pulsing runs in 2017, see:
https://docs.google.com/spreadsheets/d/1cQZMX3LaPUulXwOv80rHwujI3NdsgMhE5oJlxmWMee0/edit?ts=5981f191#gid=0

Level of noise

- Dedicated noise runs are taken before each set of pulsing measurements
  - One before shielded cable is connected to the flange, one after with pulser off
  - Shielded Cable introduces a lot of incoherent high frequency noise





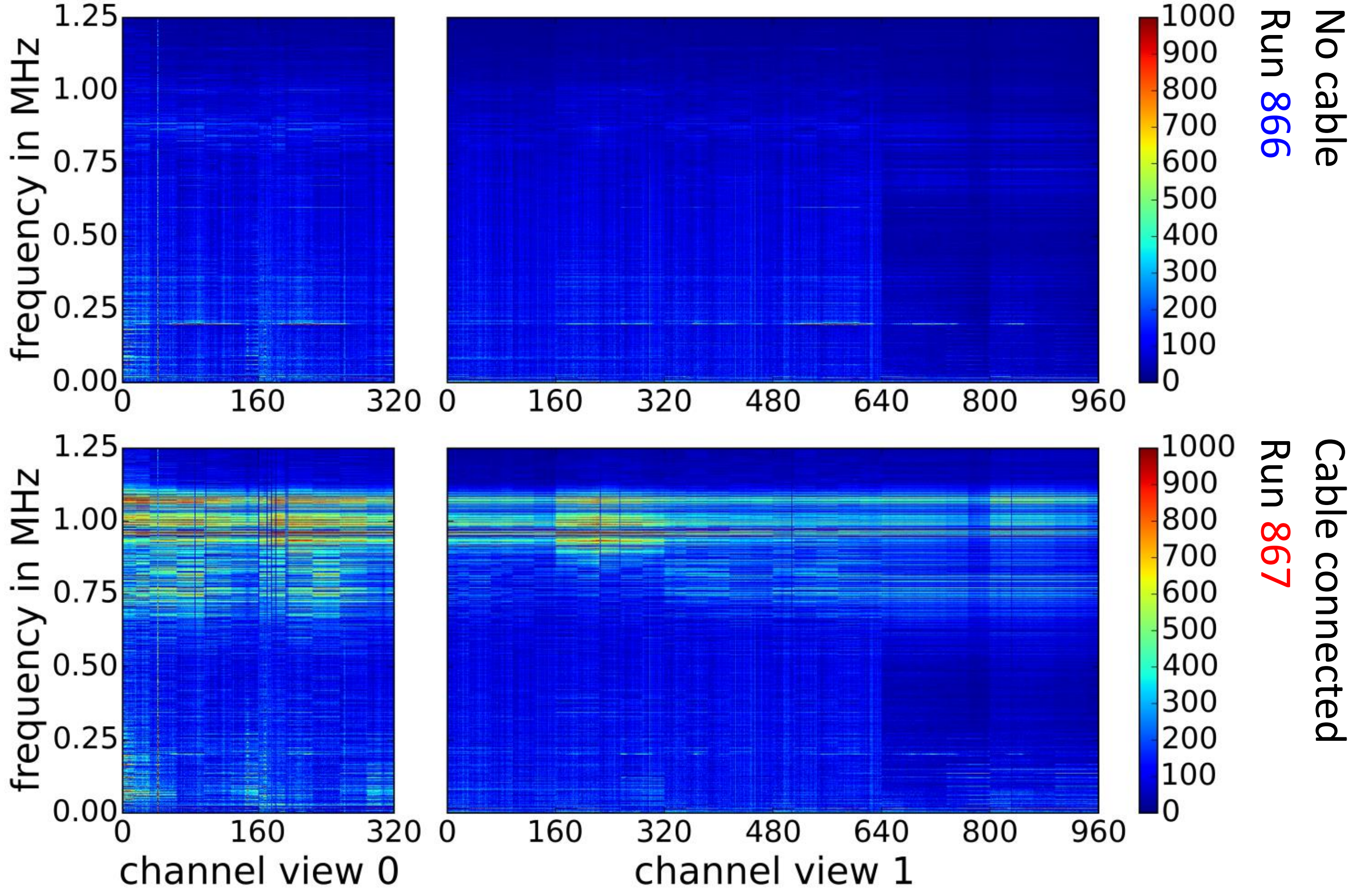


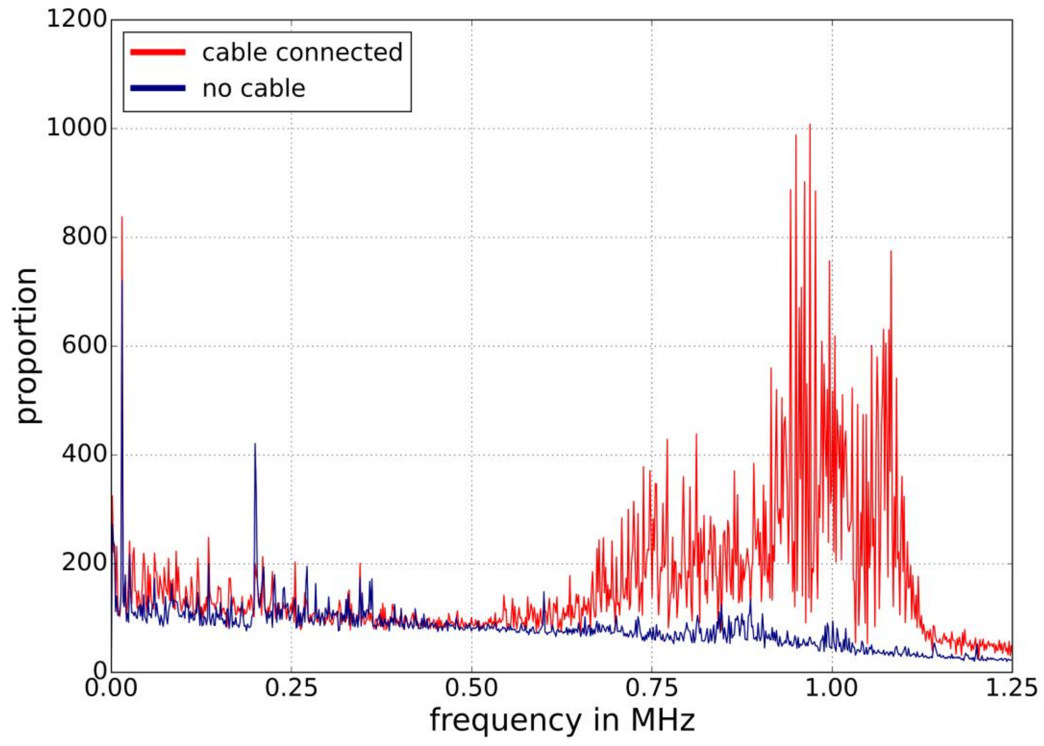
Runs 866 & 867

	No cable connected	Cable connected
Average RMS view 0	3.21 ADC	7.41 ADC
Average RMS view 1	2.15 ADC	4.65 ADC
Average RMS combined	2.41 ADC	5.34 ADC

Frequency map of noise

- Dedicated noise runs are taken before each set of pulsing measurements
  - Frequency map shows that high level of high frequency noise above 0.5 MHz is introduced by shielded cable

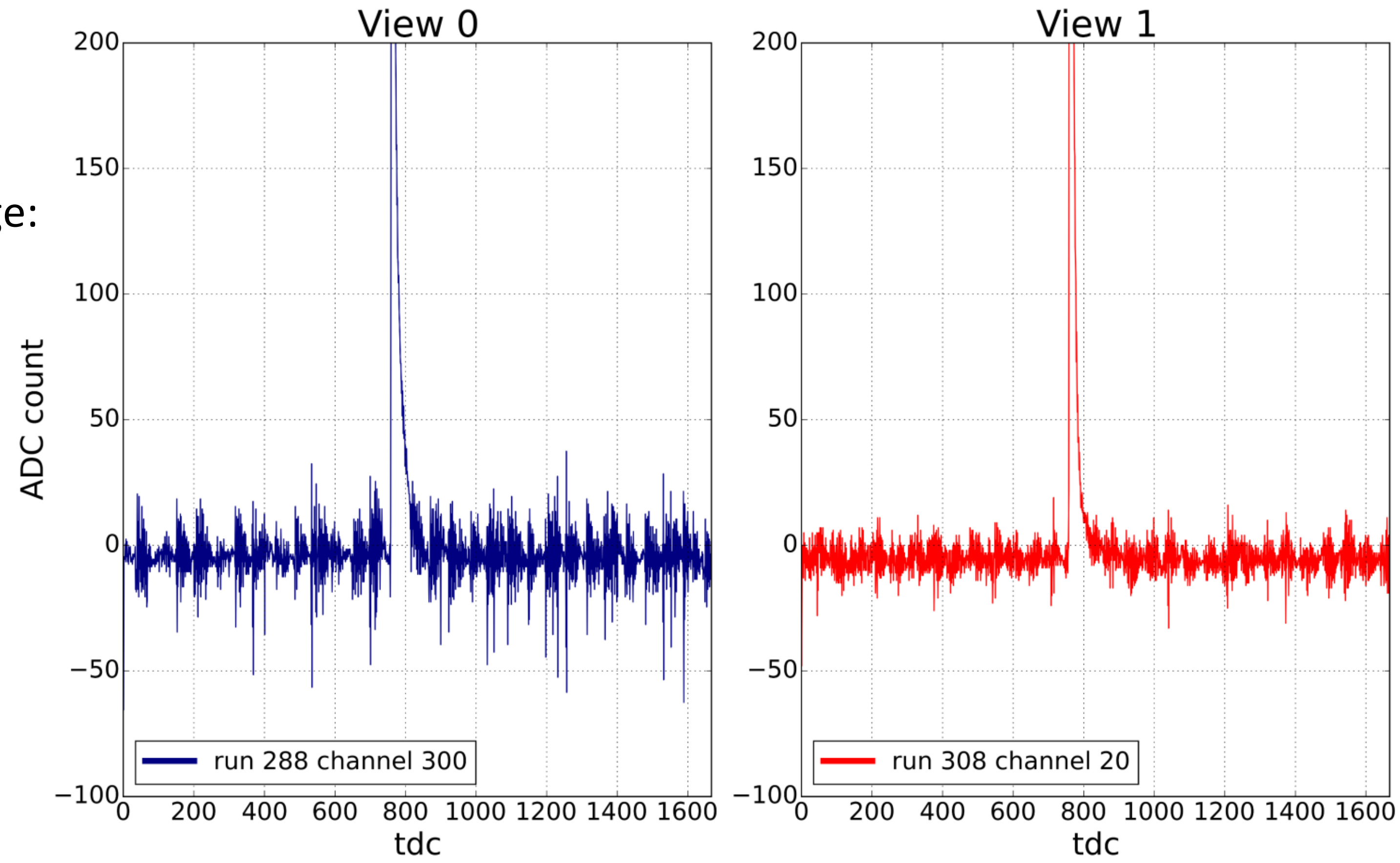




Noise reduction

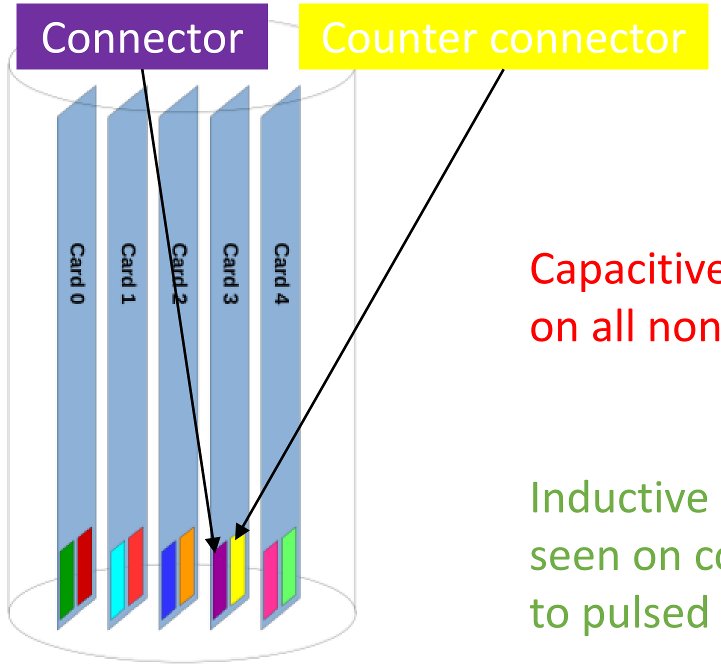
- Two approaches can be used to reduce the noise:
  1. Fourier transform is taken and high frequency components of signal are cut
  2. Average of several hundred events is taken to “smooth out” the waveform
     - Pulser is synchronized with DAQ such that pulse always arrives at the same time

Noise introduced by shielded cable at the flange:



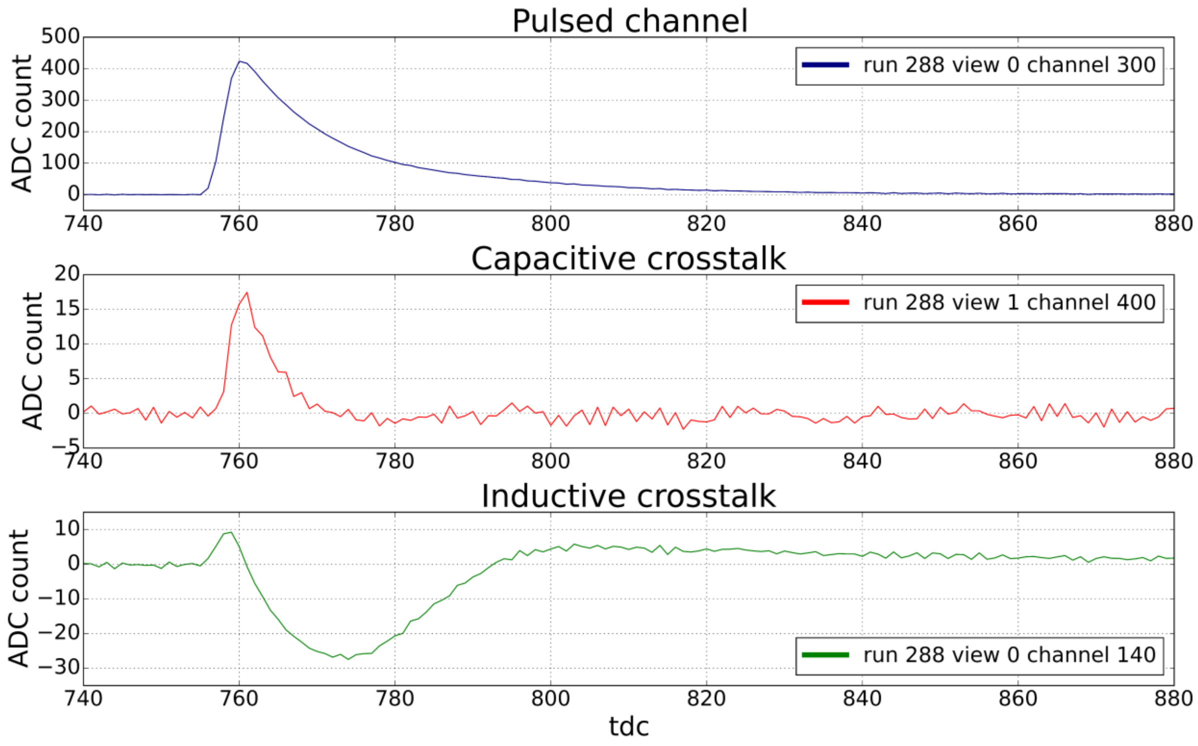
Analysis of waveforms

- Pulse finding method:
  1. Define a time window where the pulse should be (740 to 880 tdc for 100 ns rise/fall times)
  2. Subtract pedestal, defined as average of all ADC counts outside of time window for each channel
  3. Define an ADC threshold to consider a pulse
  4. Find maximum ADC count within that time window
  5. Pulse height is given if max ADC > ADC threshold
  6. Pulse integral is given if max ADC > ADC threshold and is sum of all ADC values within time window
- The same procedure is used to find maximum and integral for crosstalk signals seen on nonpulsed channels
- Also used for inductive crosstalk channels on counter connector to pulsed connector. In addition the minimum within the time window is given.



Capacitive crosstalk is seen on all nonpulsed channels

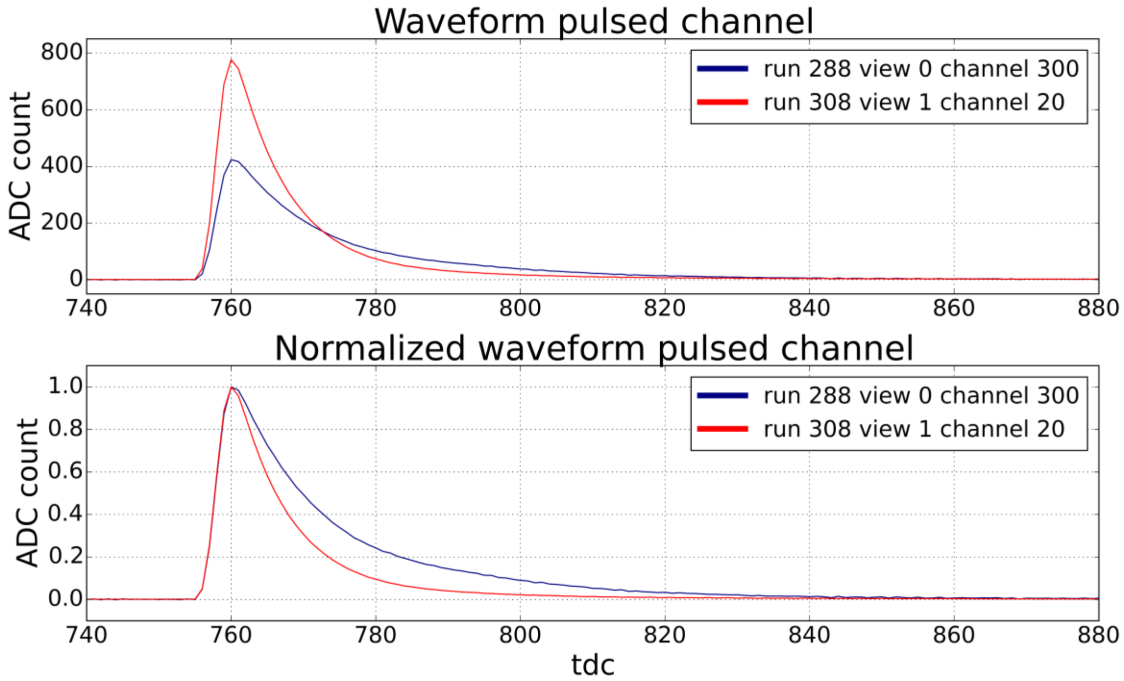
Inductive crosstalk is only seen on counter connector to pulsed connector

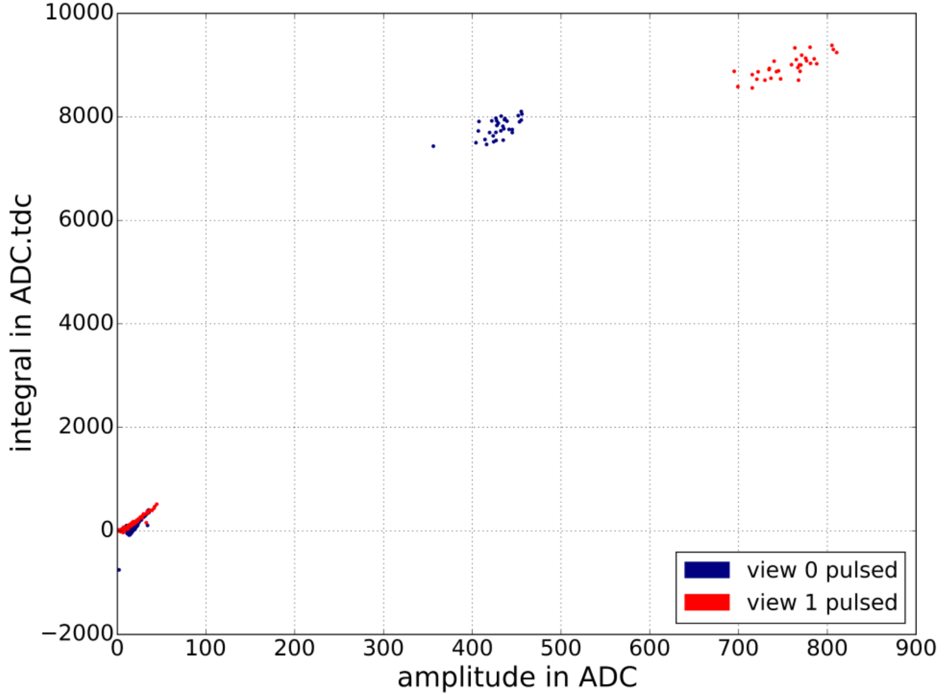


Comparison between the two views

- Capacitance to ground of 3m long strips in view 0 is 3 times that of 1m strips in view 1
  - Thus more charge is lost in view 0 due to attenuation caused by capacitive crosstalk
  - All strips have high impedance resistor to ground
    - Different capacitances for strips in both views change RC constant, thus modifying the signal shape
    - Integral should be used for analyzing data

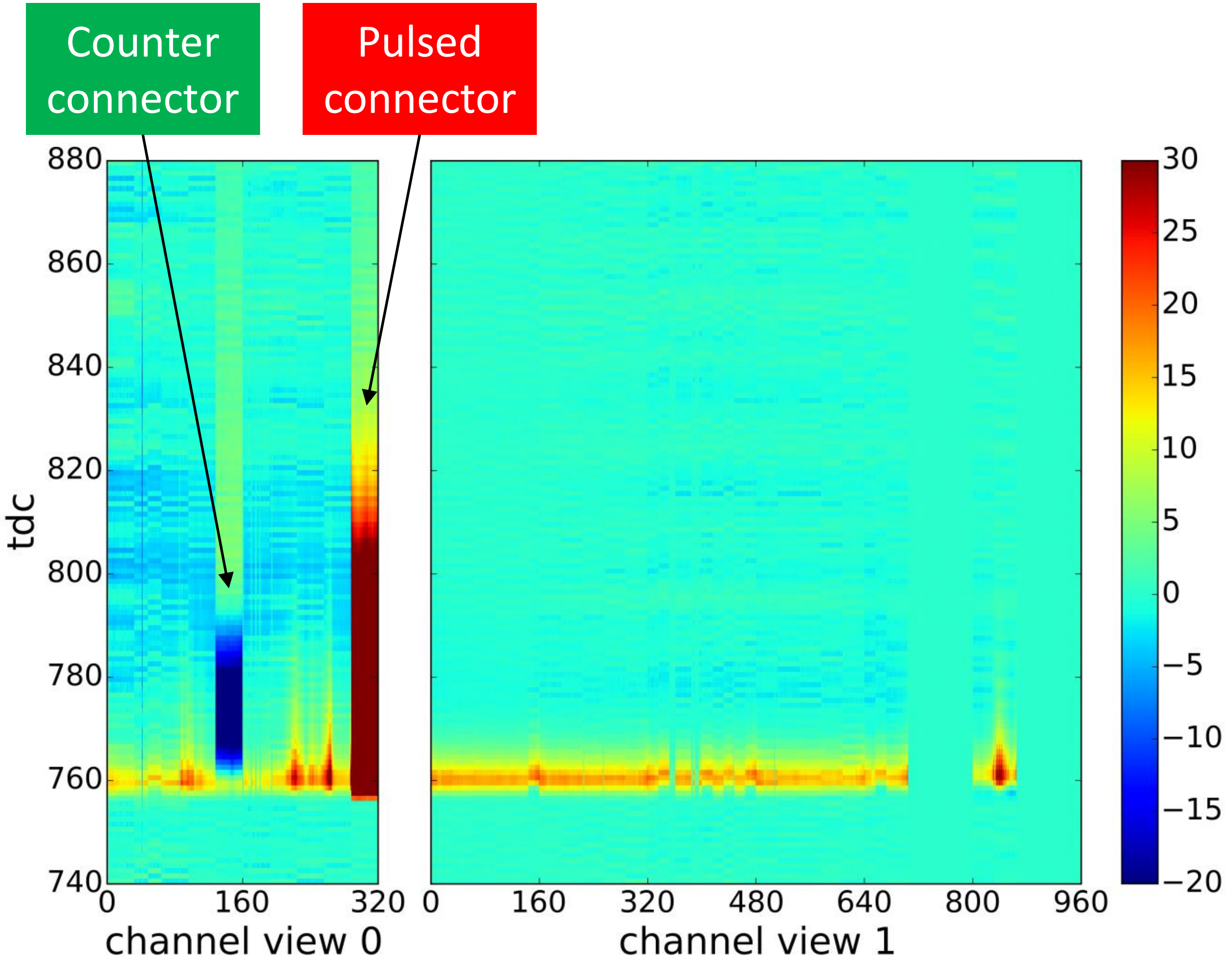
Amplitude view 0	429 ADC
Amplitude view 1	757 ADC
Amplitude ratio	**1.76**
Integral view 0	7786 ADC.tdc
Integral view 1	8974 ADC.tdc
Integral ratio	**1.15**

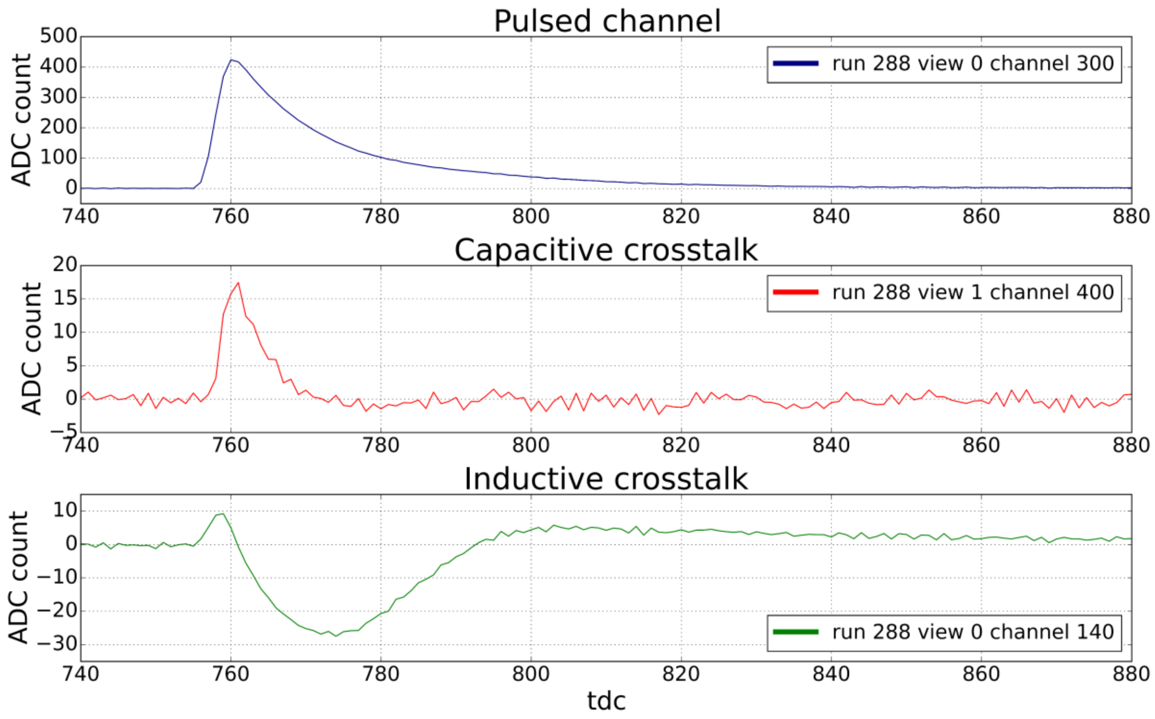




Analysis of crosstalk

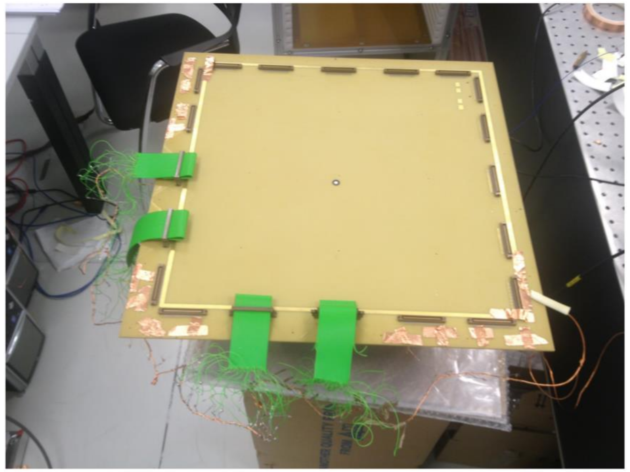
- Crosstalk is observed:
  - At the level of the anode → capacitive crosstalk of a few %
  - At the level of the preamps on the counter connector → inductive crosstalk

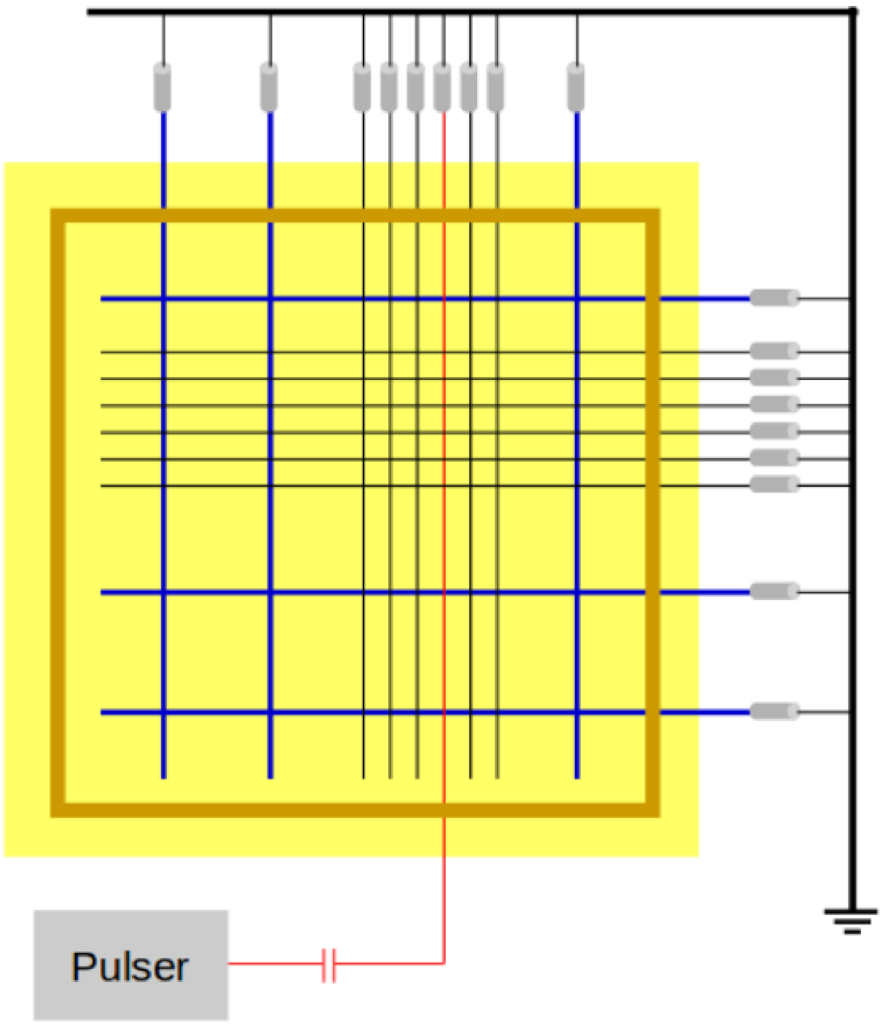




Pulsing of single anode module

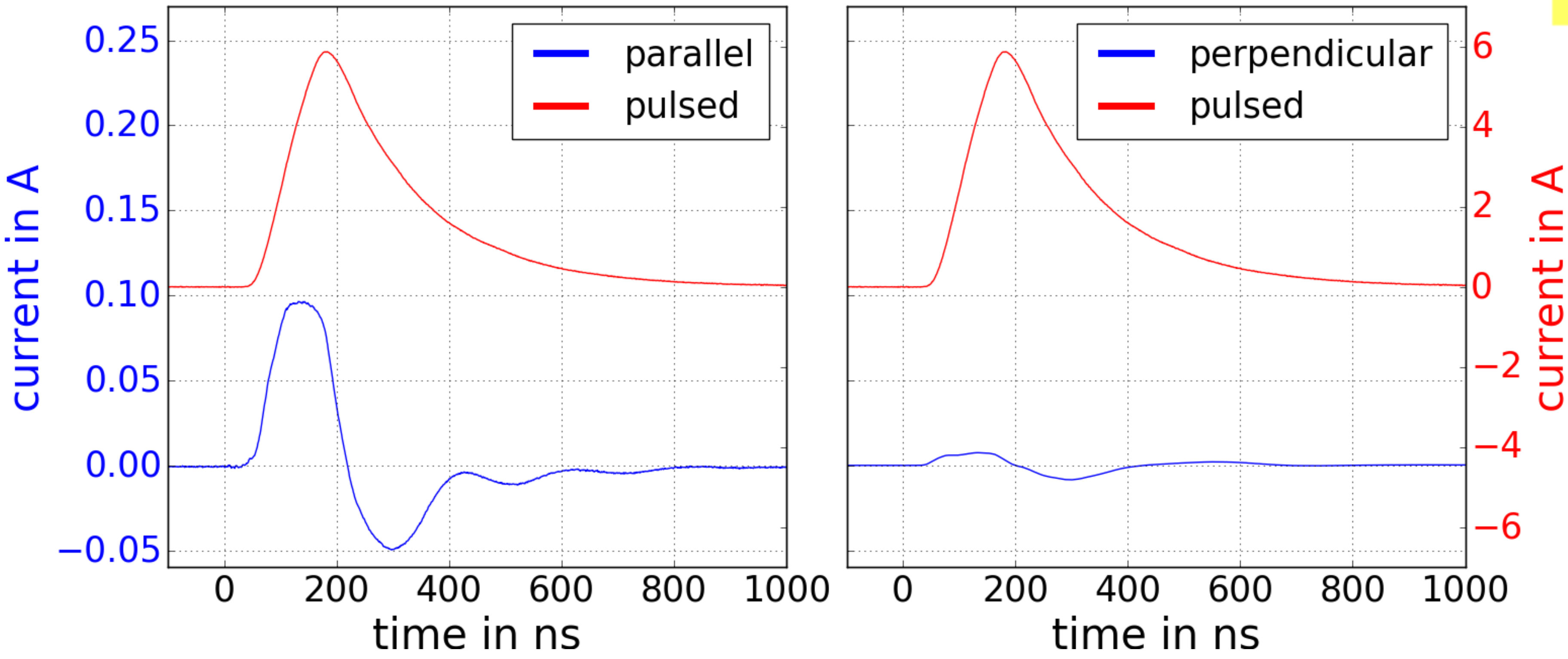
- To better understand the capacitive crosstalk at the level of the anode, a single strip on a 0.5x0.5 m2 anode module was pulsed
- All nonpulsed strips were connected to ground through 150 Ω resistors
  - 128 strips connected individually
  - All other strips connected in groups of 16
- Response measured by placing high impedance oscilloscope probes across resistors

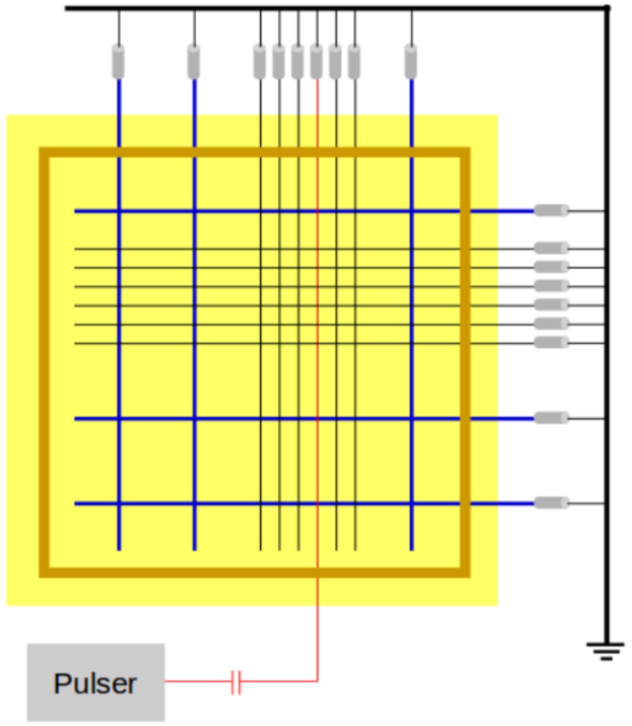




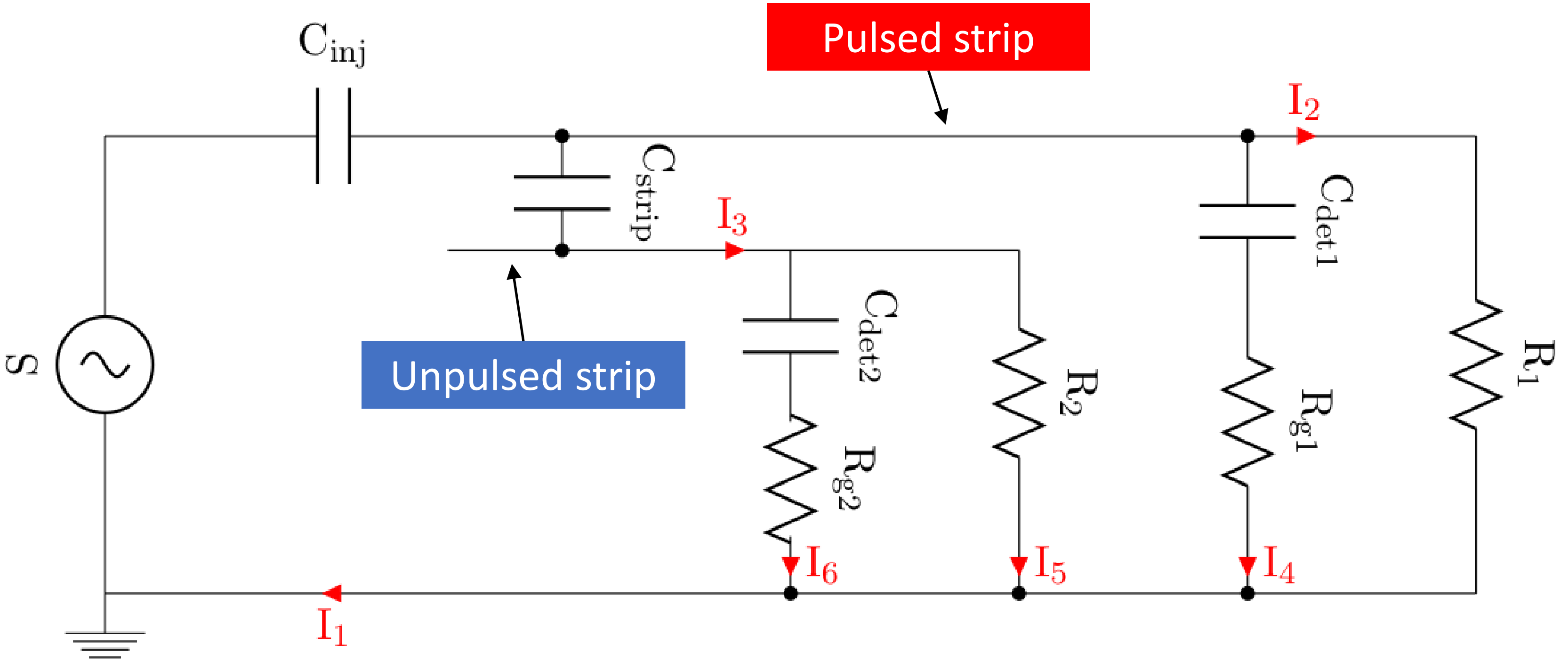
Pulsing of single anode module

- Red: response of pulsed strip, measured across 150 Ω resistor
- Blue: response of closest parallel strip and group of 16 perpendicular strips divided by 16





Equivalent circuit model



Set of differential equations obtained from Kirchhoff laws:

$$I_1 = I_2 + I_3 + I_4$$

$$I_3 = I_5 + I_6$$

$$\frac{d}{dt}V_S - \frac{1}{C_{inj}}I_1 - \frac{1}{C_{strip}}I_3 - \frac{1}{C_{det2}}I_6 - R_{g2}\frac{d}{dt}I_6 = 0$$

$$-\frac{1}{C_{det1}}I_4 - R_{g1}\frac{d}{dt}I_4 + R_2\frac{d}{dt}I_5 + \frac{1}{C_{strip}}I_3 = 0$$

$$-R_2\frac{d}{dt}I_5 + R_{g2}\frac{d}{dt}I_6 + \frac{1}{C_{det2}}I_6 = 0$$

$$-R_1\frac{d}{dt}I_2 + R_{g1}\frac{d}{dt}I_4 + \frac{1}{C_{det1}}I_4 = 0$$

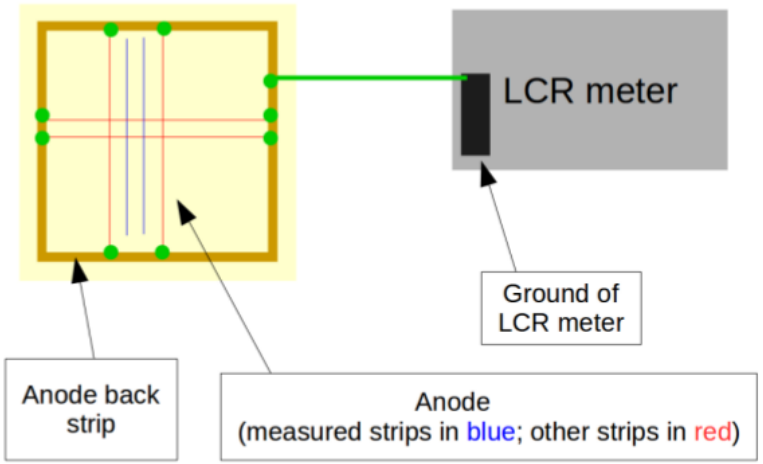
- Each strip is terminated by the preamp, modeled as a low impedance resistor R_i
- Each strip has a capacitance to all other strips C_{det}, which are also terminated by the preamp

Capacitance measurements

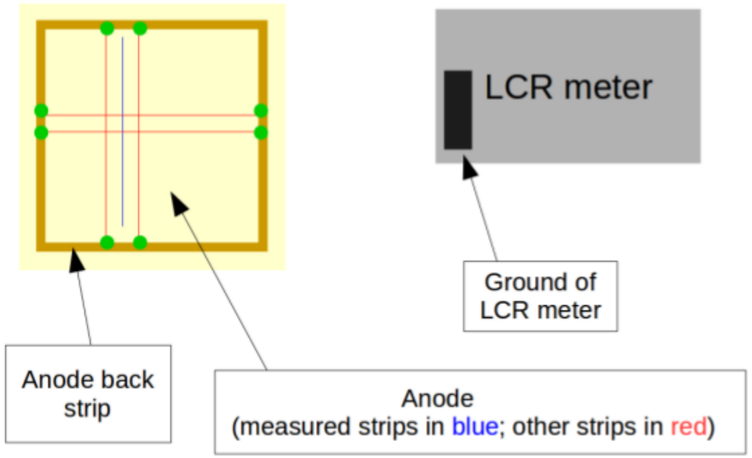
- Capacitance was measured between:
  - 2 parallel strips for varying distances
  - 1 strip and all other strips which were connected together
  - 1 strip and anode metal back strip
- These capacitances were used for the equivalent circuit model

	Measured	COMSOL simulations
Capacitance 1 strip to all others	78 pF	36.14 pF
Capacitance 1 strip to anode back strip	1.7 pF	
Capacitance closest parallel strips	7.6 pF	1.3 pF
Capacitance 2nd closest parallel strips	1.2 pF	
Capacitance 3rd closest parallel strips	0.5 pF	
Capacitance after 4th closest parallel strips	≤ 0.4 pF	
Capacitance perpendicular strips	0.4 – 0.5 pF	0.15 pF

Setup for measuring capacitances between 2 individual strips:

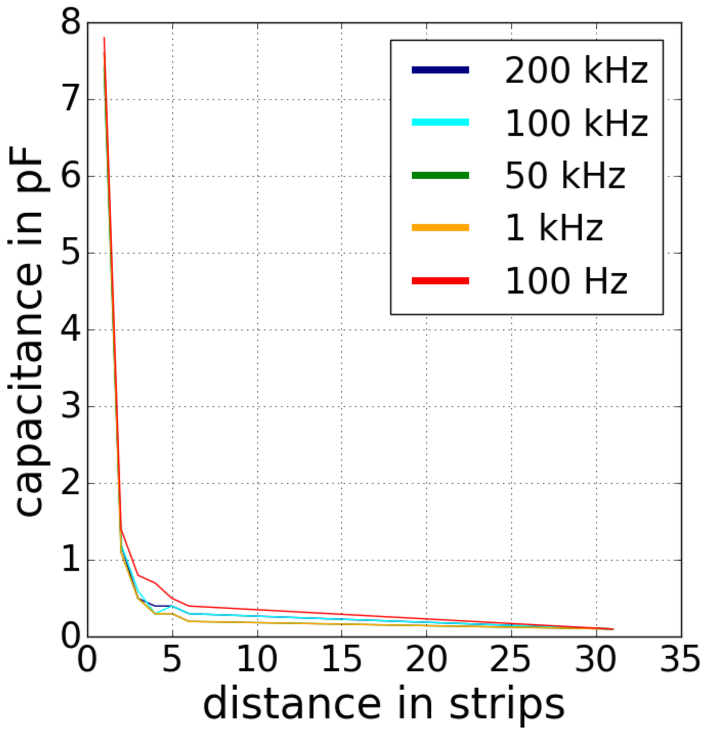


Setup for measuring capacitances between 1 strip and all other strips:



Capacitance measurements

Capacitance between parallel strips:



	Measured	COMSOL simulations
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Capacitance 1 strip to anode back strip	1.7 pF	
Capacitance closest parallel strips	7.6 pF	1.3 pF
Capacitance 2nd closest parallel strips	1.2 pF	
Capacitance 3rd closest parallel strips	0.5 pF	
Capacitance after 4th closest parallel strips	≤ 0.4 pF	
Capacitance perpendicular strips	0.4 – 0.5 pF	0.15 pF

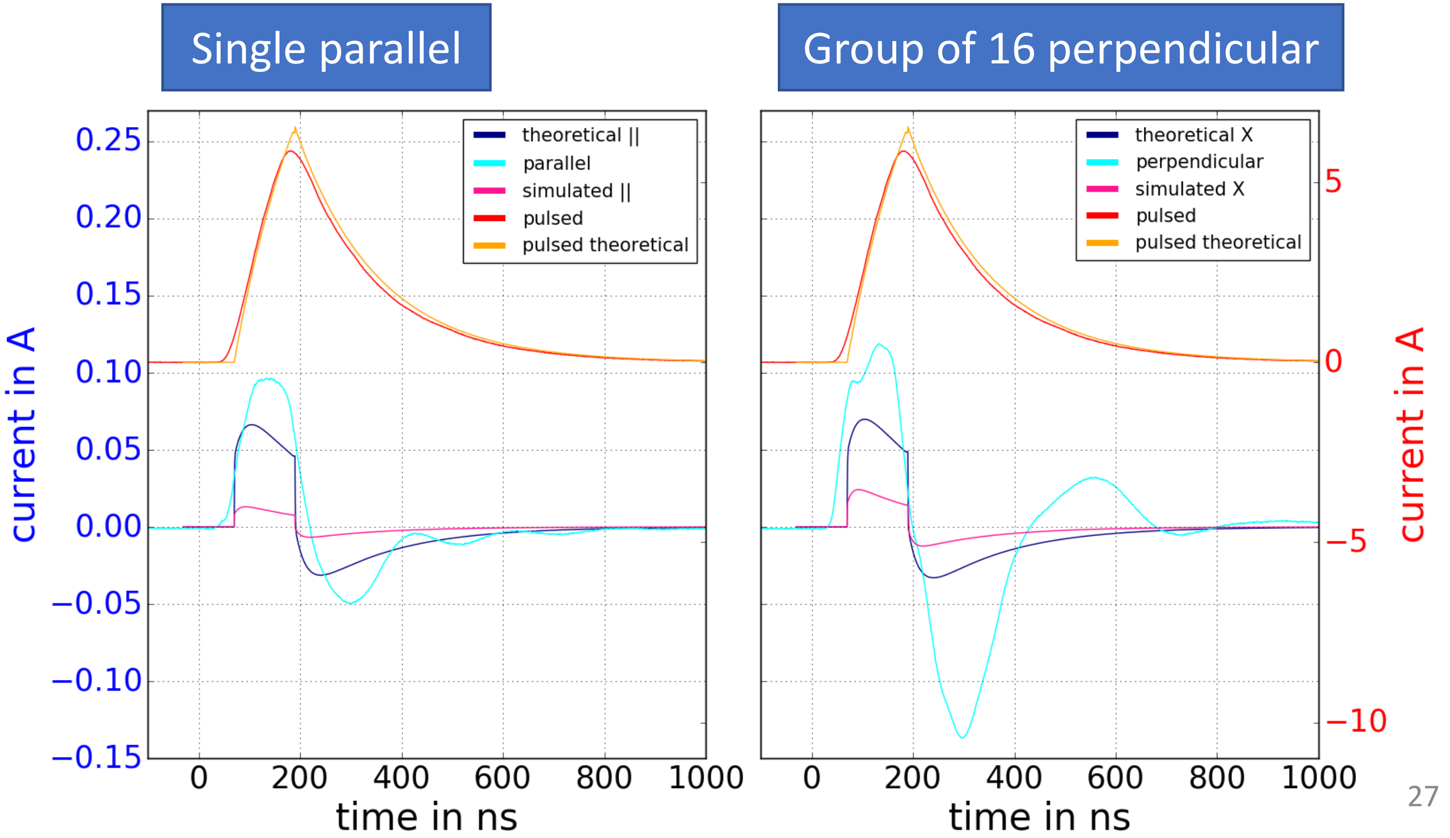
- Capacitance to anode back strip is negligible
- Capacitance of 1 strip and all others really is the sum of all capacitances between the strip and all other strips:

$$78\ \text{pF} \approx 160 \times 0.4\ \text{pF} + 2 \times (7.6 + 1.2 + 0.5 + \ldots)\ \text{pF}$$

Numerical solution to equivalent circuit model

- Using the measured capacitances, a solution to equivalent circuit model was computed numerically
- This numerical solution is compared to the pulsing measurements on 1 anode model
- Pulse shape: square wave with frequency: 100 Hz, rise/fall times: 100 ns, amplitude: 10 Vpp

Shown is the response of the pulsed strip (axis on the right), the measured response of a nonpulsed strip, the theoretical response form the equivalent circuit model and the simulated response according to the COMSOL simulations.



Numerical solution to equivalent circuit model

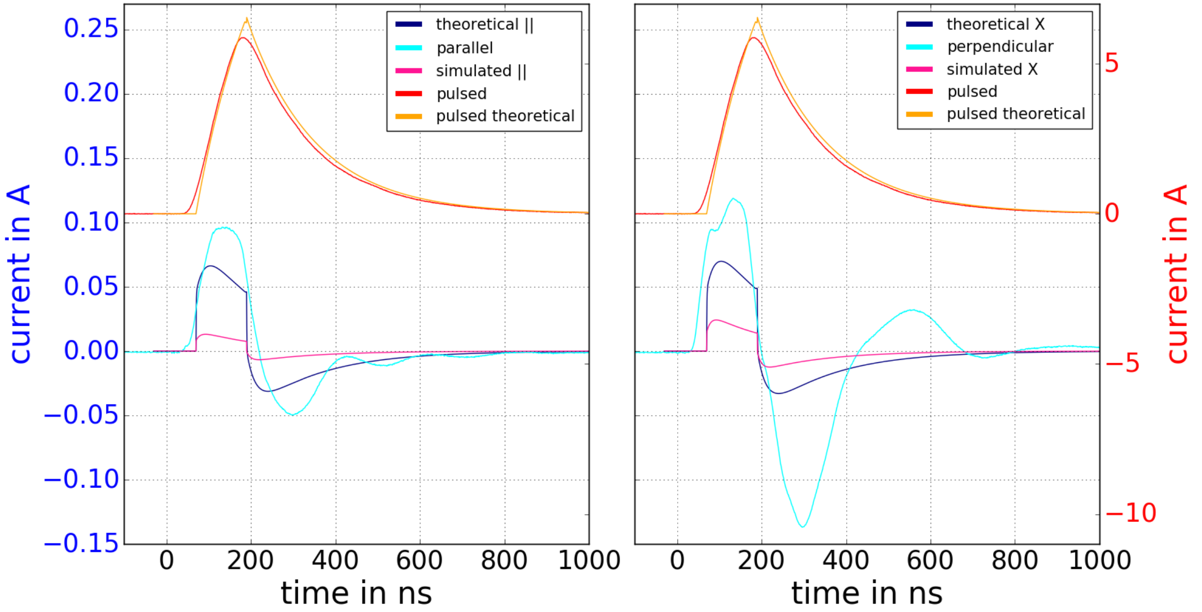
- Proportion of signal heights between pulsed strip and perpendicular strip: 0.114 %
- With 32 strips pulsed, we get a proportion of 32 x 0.114 % = 3.64 % between the signal heights, thus explaining the observed crosstalk on perpendicular strips
- For parallel strips, higher order capacitive couplings leads to the observed crosstalk:
  - Each strip in view 1 couples to 320 strips in view 0
  - Thus a signal with a proportion of 320 x 0.114 % x 3.63 % = 1.32 % is obtained through second order coupling alone

Shown is the response of the pulsed strip (axis on the right), the measured response of a nonpulsed strip, the theoretical response form the equivalent circuit model and the simulated response according to the COMSOL simulations.

For more details, see: http://cds.cern.ch/record/2268416

Single parallel

Group of 16 perpendicular



Charge sharing analysis

- From Cosimo Cantini's anode model and the capacitance simulations, the fraction of charge seen at the preamp with respect to the injected can be modeled as follows:

$$\frac{Q_{amp}}{Q_{inj}} = \frac{1}{1 + \frac{C_{det}}{C_{dec}}}$$

where $C_{det} = 78\,pF$ from capacitance measurements

- Therefor the fraction of charge seen in the two views is:

$$\frac{Q_{1m}}{Q_{3m}} = \frac{C_{dec} + C_{\mathrm{det}[3m]}}{C_{dec} + C_{\mathrm{det}[1m]}} = \frac{2200\,pF + 6 \times 78\,pF}{2200\,pF + 2 \times 78\,pF} = 1.132$$

- To be compared with the measured ratio for the integral of 1.152

Conclusions

- New pulsing system has potential to simplify pulsing measurements to obtain full calibration curves for all channels but needs to be improved
- The different capacitive couplings in view 0 and 1 cause different attenuations and signal shapes
  - Measured ratio between integrals: 1.15
  - Theoretical ratio between integrals: 1.13
  - For data analysis the integral (i.e total amount of charge) is the relevant quantity be used
- Uniform crosstalk at the level of the anode is understood from pulsing measurements
- Inductive crosstalk needs to be investigated further

Next steps

- Improve new pulsing system and pulse the anode for various amplitudes and rise times to see integral vs. amplitude behavior
- Improve equivalent circuit simulations to account for different RC constant in both views
- Grid and LEM pulsing measurements are to be taken and compared anode pulsing measurements
- Check the data for the different attenuations observed in pulsing measurements