Characterization of the gain temperature dependence in SiPM

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Introduction

Goal:

- Adaptive power supply for the SiPM bias voltage, regulating V_{bias} with varying temperature as to keep the gain constant ($< 1\%$) for the AHCAL.

To develop this, we need:

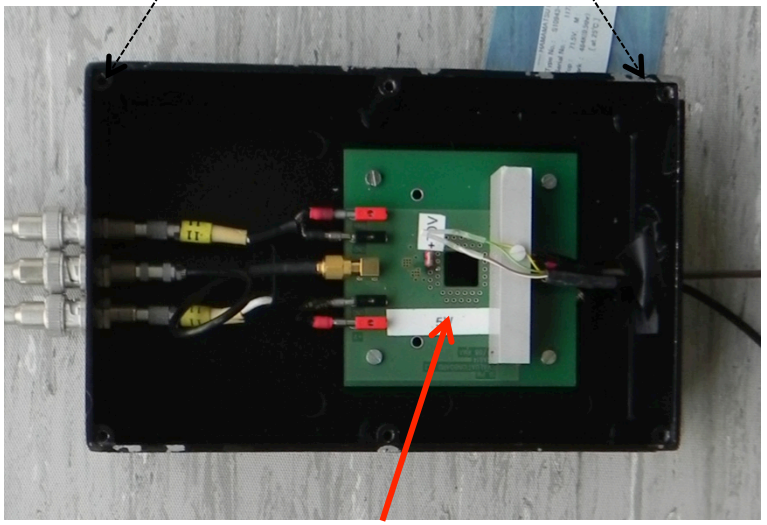
- To characterize SiPM gain as function of temperature.
  - Define voltage function (dV/dT) to obtain constant gain.

This talk:

- Describe setup
- Characterization of new sensors obtained from:
  - Hamamatsu
  - KETEK

(CPTA SiPM & previous sensors were shown at ECFA LC2013)

Setup

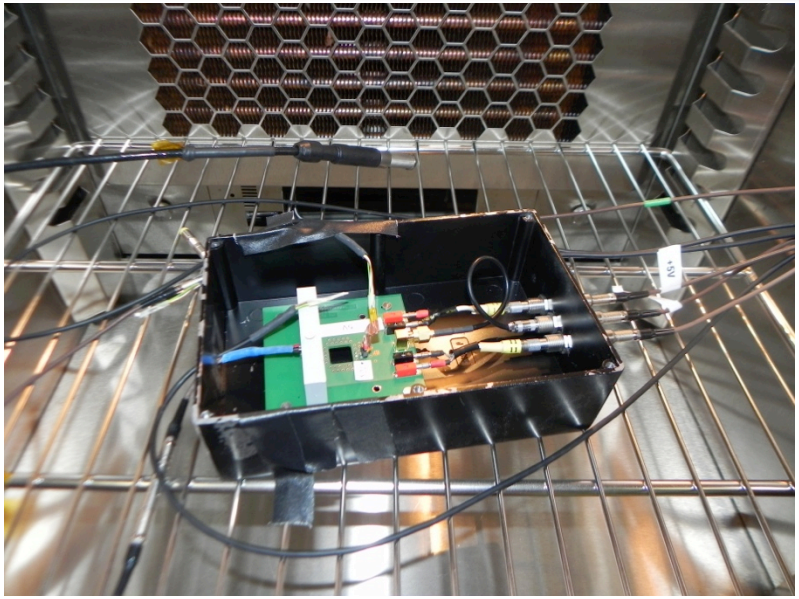


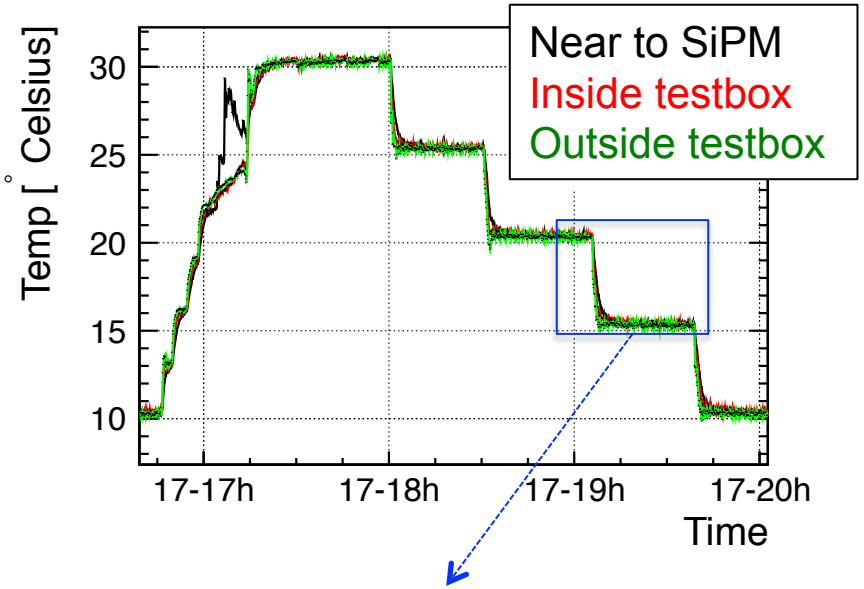
SiPM + preamp + T-sensor + LED

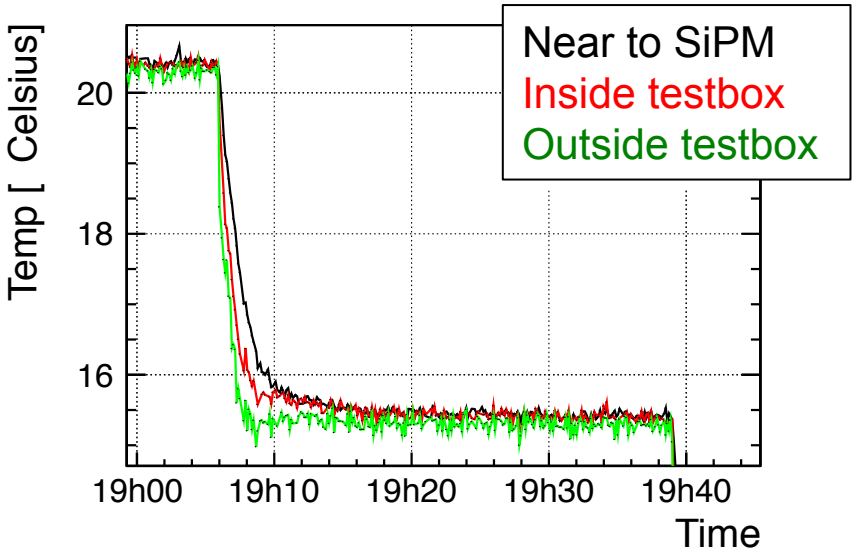
- 'Climate Chamber'
  (Used for stress tests in CERN bondinglab)
  - Accurate to 0.1C.

- Digital oscilloscope readout by laptop
- LV and bias voltage supply
- Pulse generator for LED

Temperature measurement







- 3 Pt1000 sensors:
  1. Nearby SiPM
  2. Inside black testbox
  3. Outside black testbox

- T set to 10, 15, 20, 25 & 30C.
  - $T_{SiPM} \sim T_{SET} + 0.4C$
  - Offset consistent over full range.

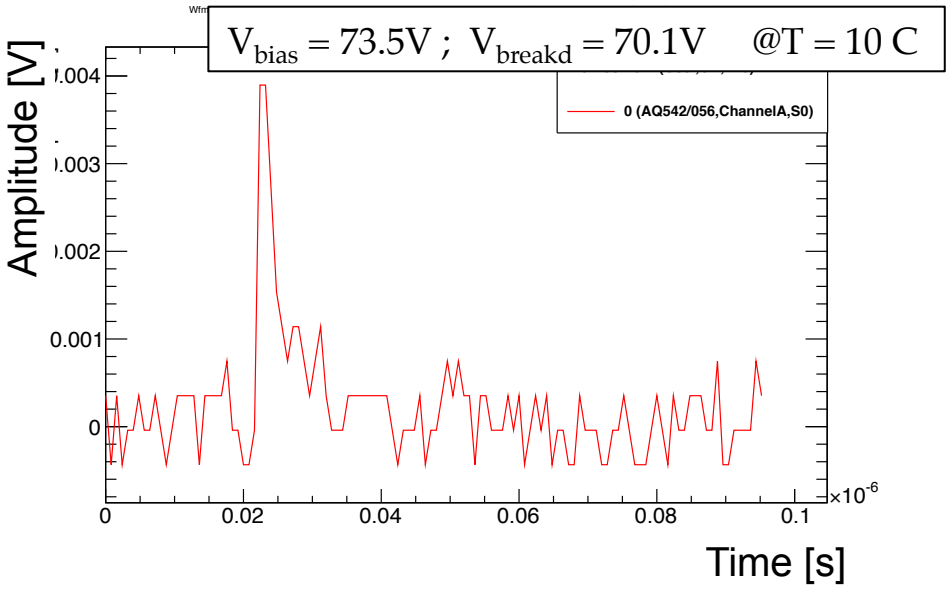
Photon spectrum – Hamatsu MPPC (20 um, sample B, #1)

Digital oscilloscope (picoscope):

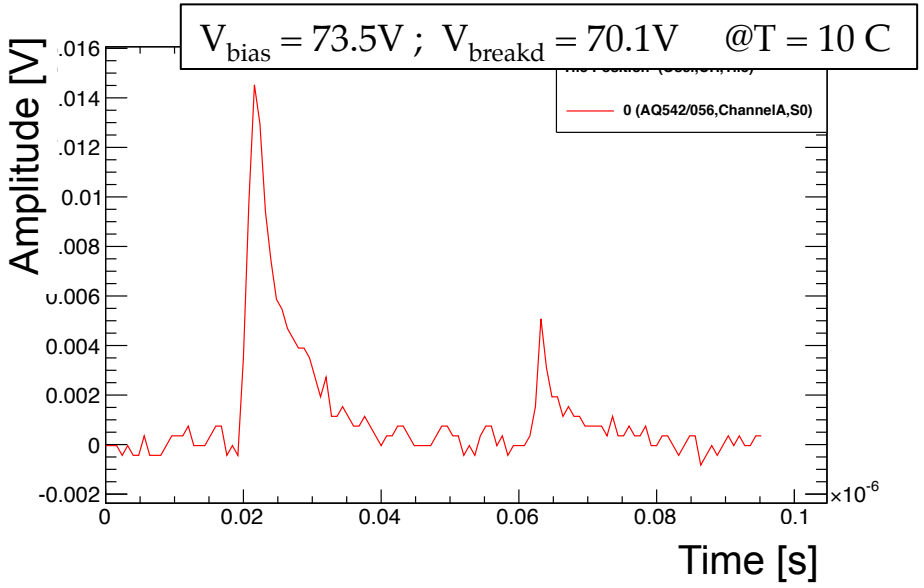
- 8bit ADC
- Sampling / 800ps
- Trigger on LED signal

With T3B DAQ:

- Example of 1-p.e. waveform →



- Example of multiple p.e. →



Using T3B analysis framework, integrate waveform.

- After a pedestal subtraction, waveforms are identified by rising edge at 1.5 mV and falling edge at 0.4 mV.

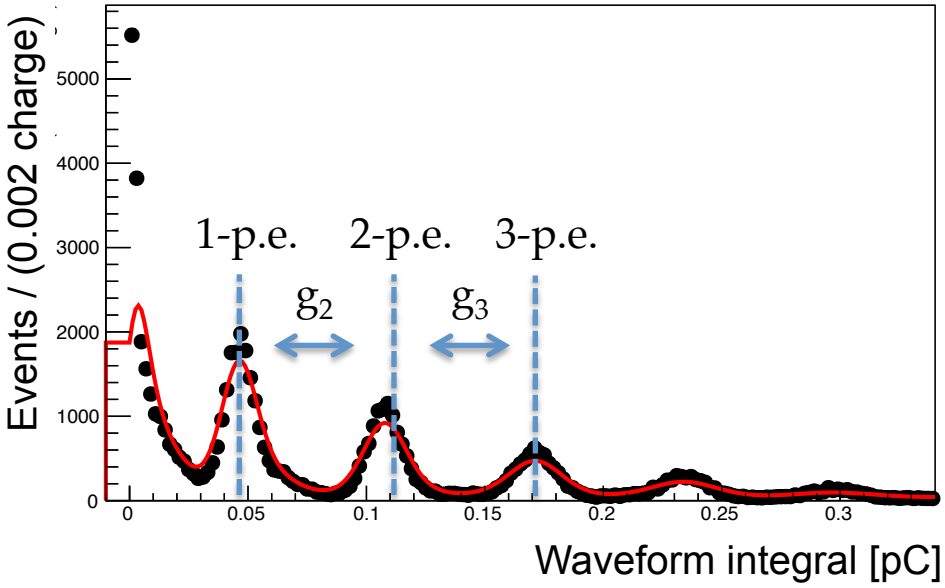
Photon spectrum – Hamatsu MPPC (20 um, sample B, #1)

From 50k triggers, waveforms are integrated:

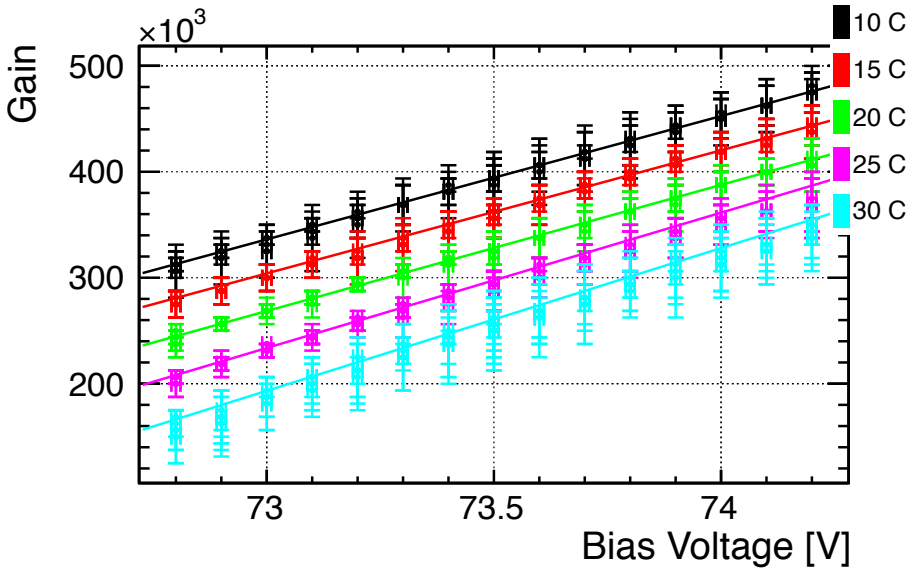
→ Extract the gain by measuring the distance from 1-p.e. peak to 2-p.e. peak.

→ Use RooFit p.d.f.: models the distribution as a superposition of gaussians.

- Only include measurements which result in at least 3 peaks.
- Define uncertainty on gain to be difference between g_2 and g_3.



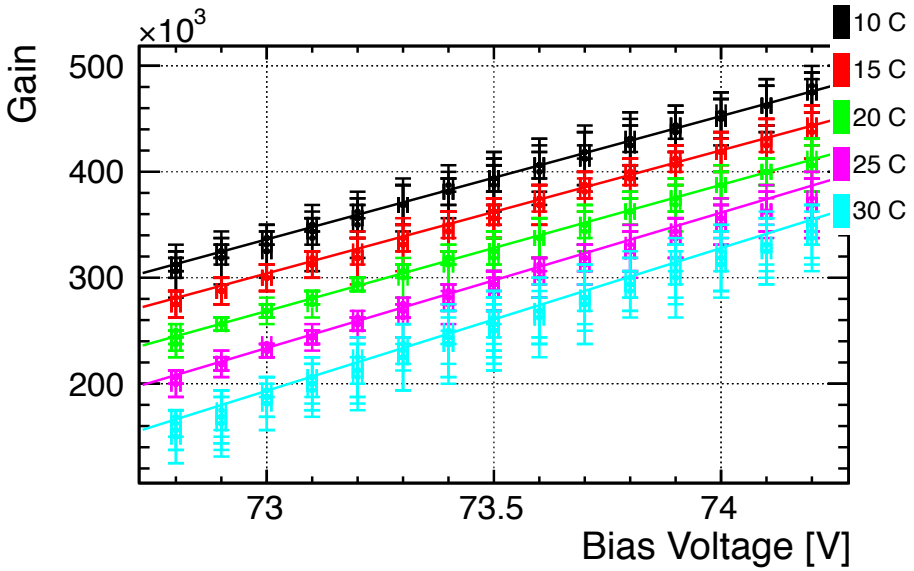
Gain vs voltage for different temperatures - MPPC (#B1)



- Measured at 5 different temperatures:
  - 10-30C, in steps of 5C.
- At each temperature, varied bias voltage in steps of 0.1V:
  - Took at least 5 measurements at each temperature and V point.

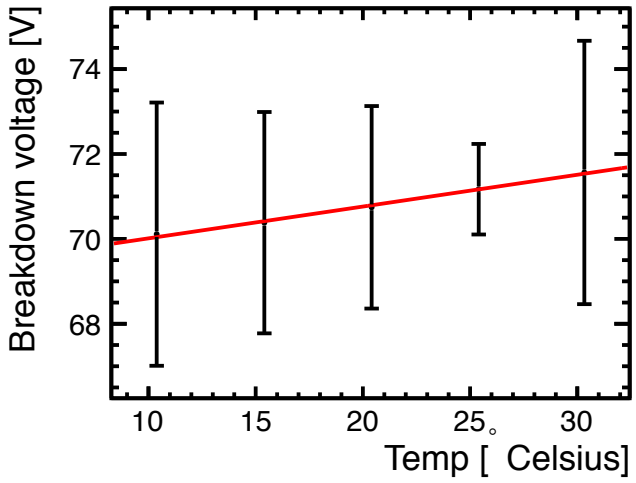
- Each entry is the gain extracted from 50k waveforms
- For comparison: the gain as measured by Hamamatsu at 25C with nominal Voltage of 73.33 V is 2.3×10^5 for this MPPC.

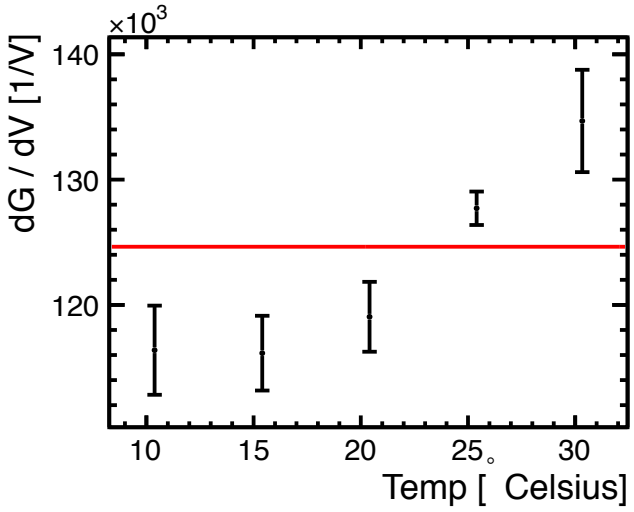
Gain vs voltage for different temperatures - MPPC (#B1)



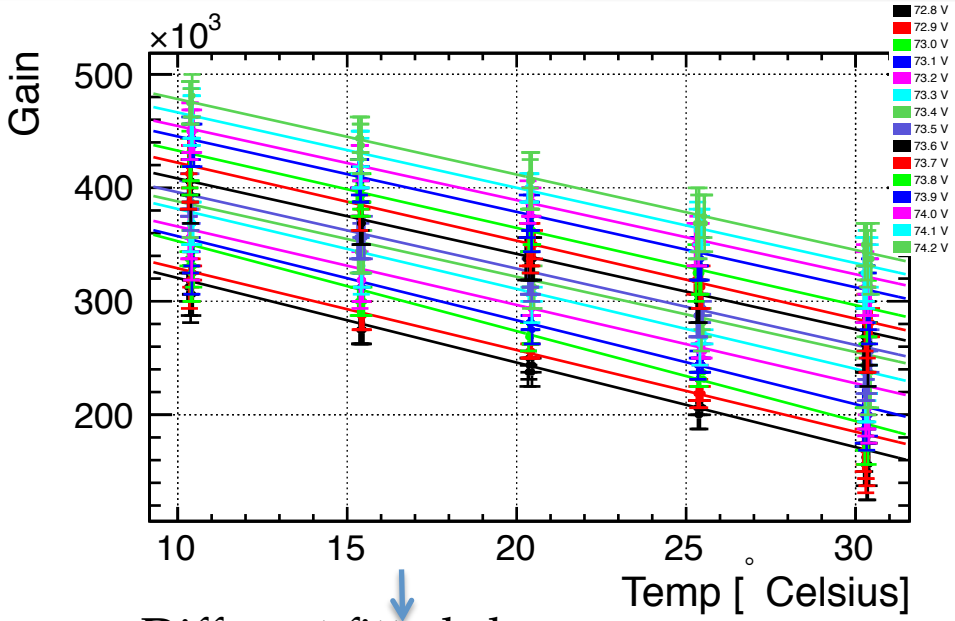
Assuming a linear dependency for Gain on V:

- Breakdown voltage increases linearly with temperature, as expected.
- Capacitance (=dG/dV) should be independent of temperature: systematic effect is visible.



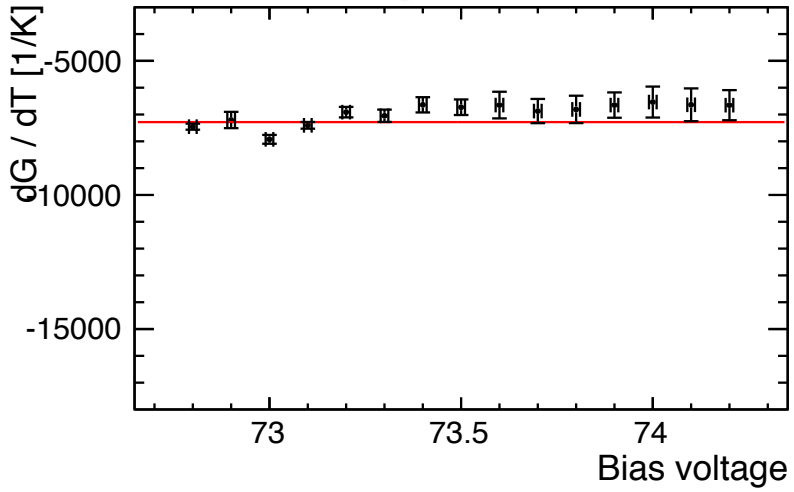


Gain vs temperature for different V - MPPC (#B1)



← Same data as previous slide.

Different fitted slopes



For a constant gain, dV / dT:

- Averaging the fitted slopes, and assuming as uncertainty the spread of slopes:
- dV/dT = - av (dG/dT) / av(dG/dV)

  = 54.6 +- 6.4 mV / K

Hamamatsu MPPC Overview

At 25C	#11759	#A1	#A2	#B1	#B2
Pitch [um]	50	20	15	20	15
Measured Gain [x 10^5]	9.6 +- 0.1 (V_{bias} = 71.7V)	2.7 +- 0.2 (V_{bias} = 66.7V)	2.2 +- 0.1 (V_{bias} = 67.2V)	2.7 +- 0.2 (V_{bias} =73.3 V)	2.3 +- 0.2 (V_{bias} = 74.0V)
$V_{breakdown}$ [V]	70.5 +- 0.6	64.9 +- 2.1	64.4 +- 4.0	71.2 +- 1.2	71.4 +- 2.5
dV / dT [mV/K]	54.2 +- 2.0	59.8 +- 4.8	62.3 +- 7.1	54.6 +- 6.4	56.8 +- 5.3

5 different types of MMPC

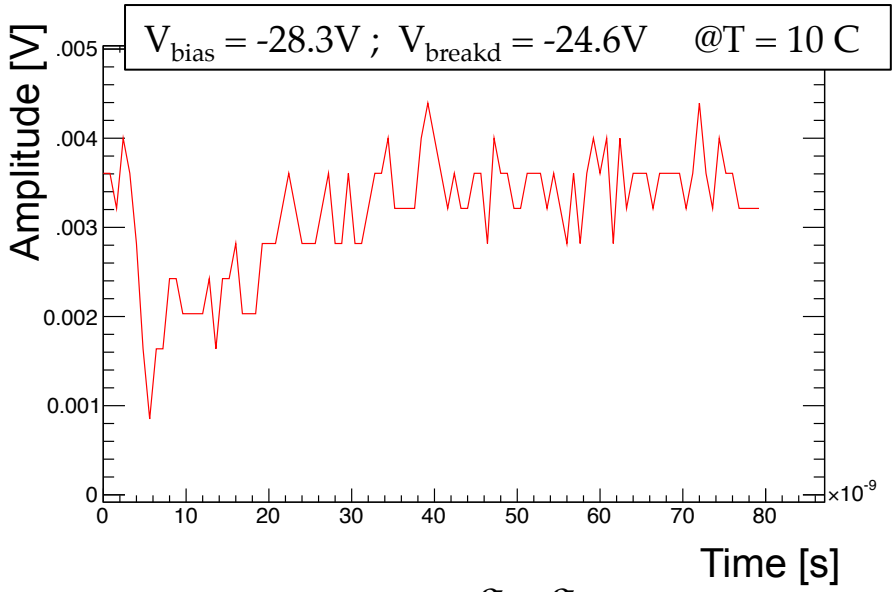
- Gains are given for an overvoltage of ~2V
  - Differences due to pixel sizes

- #11759 is the 'older' batch of 50 um pitch.
- Sample A and B are new sensors, Hamamatsu did not specify the difference.
  - Differ in breakdown voltage; sample B resembles more the older batch.
  - No significant difference in temperature dependence.

Photon spectrum – KETEK (MP15 V6-W8)

Size: 1.2x2.4mm^2 (15 um pitch)

- Example of 1γ waveform →
- Signal from KETEKs is positive.
  - T3B analysis inverts waveforms

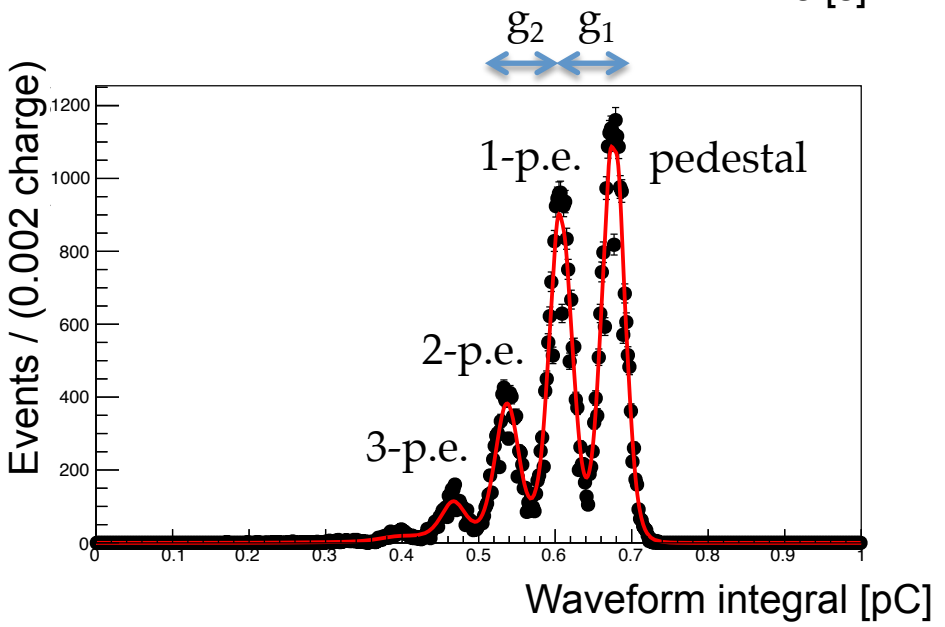


From 50k triggers, waveforms are integrated over full 80ns window:

→ Extract the gain by measuring the distance from pedestal to 1-p.e. peak.

→ Uncertainty on gain is defined as difference between g_1 and g_2.

→ Only consider measurements with gain uncertainty < 4%.



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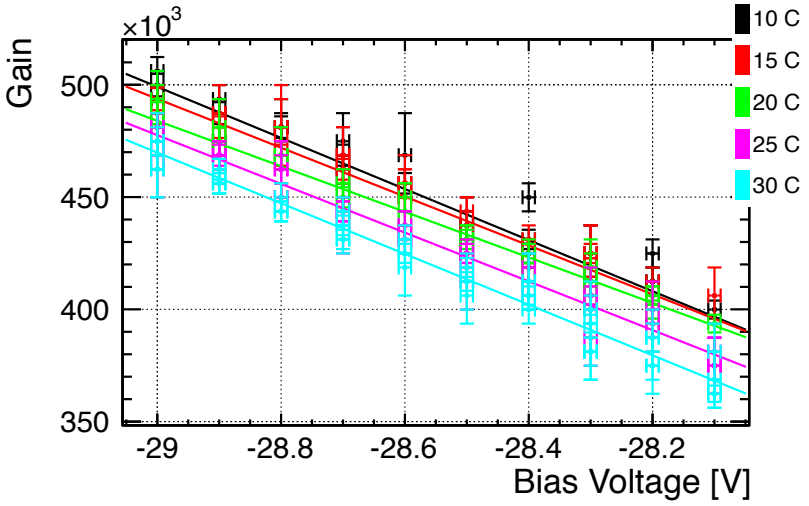
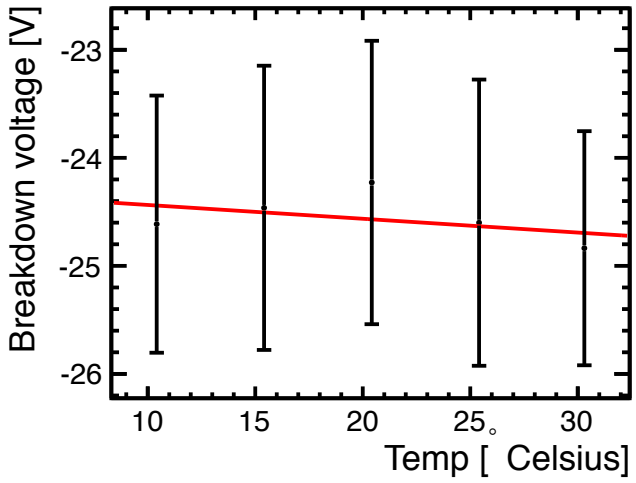
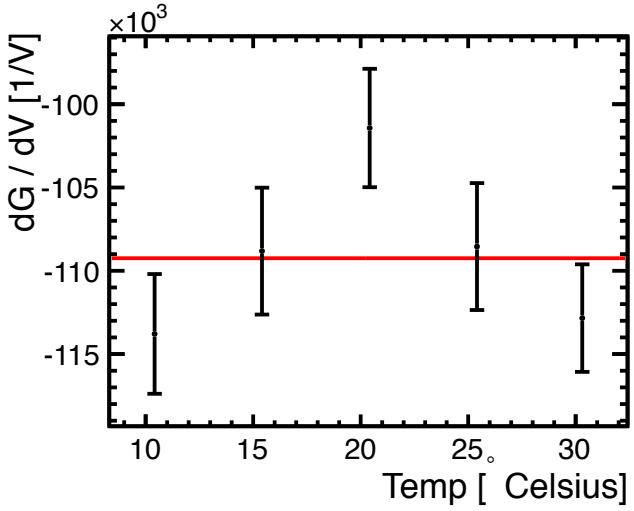


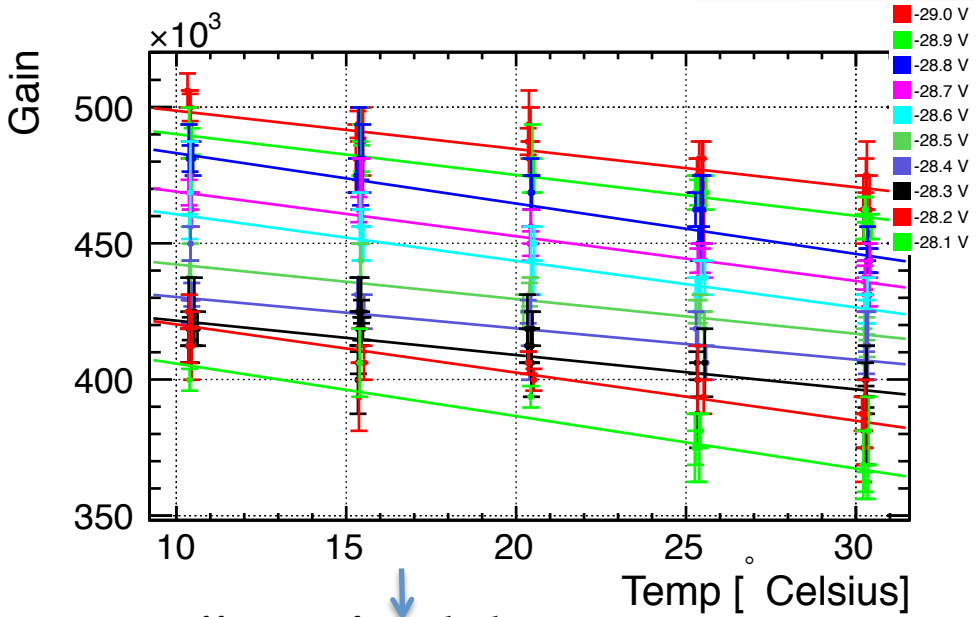
Assuming linear dependency Gain on V:

- Breakdown voltage increases linearly with temperature, as expected.
- Capacitance (=dG/dV) should be independent of temperature

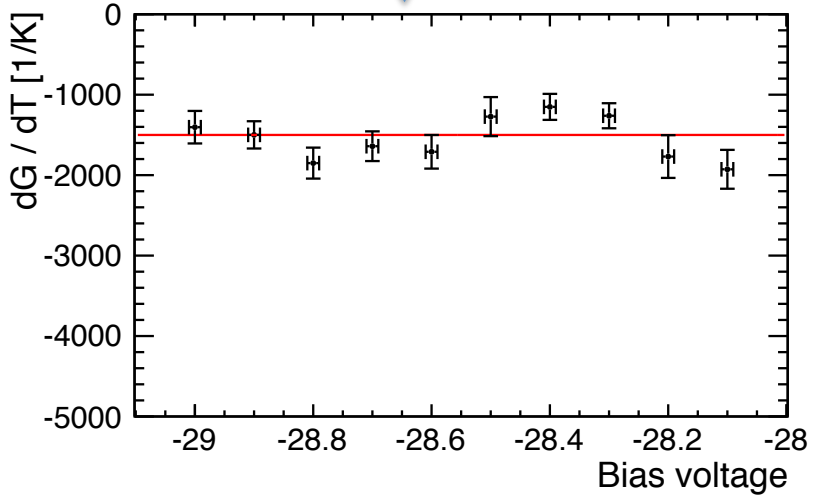




Gain vs temperature for different V – KETEK



Different fitted slopes



← Same data as previous slide.

For a constant gain, dV / dT:

- Averaging the fitted slopes, and assuming as uncertainty the spread of slopes:
- dV/dT = - av (dG/dT) / av(dG/dV)

  = -14.4 +- 3.7 mV / K

KETEK SiPM

At 25C	KETEK MP15 V6	KETEK MP20 V4		CPTA SiPM #857
Pitch [um]	15	20		40
Measured Gain [x 10^5]	3.7 +- 0.2 (V_{bias} = -28.0 V)	5.6 +- 0.3 (V_{bias} = -28.0 V)		7.7 +- 0.2 (V_{bias} = 33.4)
$V_{breakdown}$ [V]	-24.6 +- 1.3	-24.9 +- 0.6		31.9 +- 0.7
(dG / dT) / G [%]	0.4 +- 0.1	0.7 +- 0.1		0.9 +- 0.1
dV / dT [mV/K]	-14.4 +- 3.7	-20.3 +- 0.8		14.9 +- 1.5

Obtained 2 new sensors from KETEK:

- Sizes: 1.2x2.4mm^2 (15 um pitch) and 3.0x3.0mm^2 (20 um pitch)
- Operate at relative large overvoltage of ~3-4 V.

For comparison, one CPTA SiPM (2nd generation AHCAL tile) is listed:

- KETEK achieves similar dV/dT as CPTA
- KETEK have relative smaller dG/dT, as they operate at higher overvoltage

Gain stability

From the uncertainty on the determined dV/dT, calculate the gain stability with changing temperature of ±5C :

	Hamamatsu	CPTA	KETEK
dV / dT [mV/K]	55 – 60	12 – 18	14 – 20
Gain stability [%]	0.8 – 1.5	0.2 – 1.0	0.1 – 0.5

- Except for the small pitch Hamamatsu, all sensors have stability <1%
- Assuming that the dV/dT uncertainty is largest contribution to inaccuracy of adaptive power supply, the goal of 1% stable gain seems doable.

Summary

Built a test station to measure the temperature dependence of SiPM

- Based on the components and DAQ of T3B tests

Showed results for several SiPMs

- Most of the sensors show results as expected
  - Systematic behaviour observed for dG/dV as function of temperature.
- Except for the smallest pitch Hamamatsu, all sensors can be characterized with enough precision for a gain stability of $< 1\%$.
- Note underway.

Backup

Hamamatsu MPPC Overview

At 25C	#11759	#A1	#A2	#B1	#B2
Pitch [um]	50	20	15	20	15
Measured Gain [x 10^3]	959 +-10 (V_{bias} = 71.7V)	269 +- 16 (V_{bias} = 66.7V)	223 +- 14 (V_{bias} = 67.2V)	269 +- 15 (V_{bias} =73.3 V)	225 +- 15 (V_{bias} = 74.0V)
$V_{breakdown}$ [V]	70.5 +- 0.6	64.9 +- 2.1	64.4 +- 4.0	71.2 +- 1.2	71.4 +- 2.5
dG / dV [10^3/V]	767 +- 0.16	138 +- 4	81 +- 2	127 +- 0.08	84 +- 5
dG/dV / G	0.80	0.51	0.36	0.47	0.37
dG / dT [10^3/K]	-41.6 +- 1.2	-8.2 +- 0.6	-5.0 +- 0.6	-6.9 +- 0.7	-4.7 +- 0.3
dG/dT / G [%]	4.3 +- 0.1	3.0 +- 0.3	2.2 +- 0.3	2.6 +- 0.3	2.1 +- 0.2
dV / dT [mV/K]	54.2 +- 2.0	59.8 +- 4.8	62.3 +- 7.1	54.6 +- 6.4	56.8 +- 5.3
Gain stability[%]	0.8	1.2	1.3	1.5	1.0

The dG/dT/G varies, but this could be due to the differences in overvoltage!

CPTA SiPM Overview

At 25C	857	922	975	1065	1677
Pitch [um]	40	40	40	40	40
Measured Gain [x 10^5]	7.7 +- 0.2 (V_{bias} = 33.4)	6.4 +- 0.2 (V_{bias} = 33.1)	5.8 +- 0.2 (V_{bias} = 33.3)	6.3 +- 0.2 (V_{bias} = 33.1)	13.1 +- 0.2 (V_{bias} = 33.3)
$V_{breakdown}$ [V]	31.9 +- 0.7	31.8 +- 0.5	32.0 +- 0.9	31.8 +- 1.1	31.7 +- 0.8
dG / dV [10^5/V]	4.5 +- 0.1	4.8 +- 0.1	4.7 +- 0.2	5.0 +- 0.1	8.0 +- 0.1
dG / dT [10^3/K]	-6.8 +- 0.7	-6.0 +- 1.2	-6.0 +- 1.0	-7.2 +- 1.3	-14.4 +- 0.5
dG/dT / G [%]	0.88 +- 0.09				
dV / dT [mV/K]	14.9 +- 1.5	12.5 +- 2.5	12.8 +- 2.1	14.4 +- 2.6	18.1 +- 0.7
Gain stability[%]	0.4	0.9	0.9	1.0	0.2

KETEK SiPM Overview

At 25C	MP15 V6 - W8	MP20 V4 – W12
Pitch [um]	15	20
Measured Gain [x 10^3]	370 +- 20 (V_{bias} = -28.0 V)	564 +- 27 (V_{bias} = -28.0 V)
$V_{breakdown}$ [V]	-24.6 +- 1.3	-24.9 +- 0.6
dG / dV [10^3/V]	-108 +- 6	-186 +- 1
dG / dT [10^3/K]	-1.5 +- 0.4	-3.8 +- 0.2
dG/dT / G [%]	0.4 +- 0.1	0.67 +- 0.05
dV / dT [mV/K]	-14.4 +- 3.7	-20.3 +- 0.8
Gain stability [%]	0.5	0.1

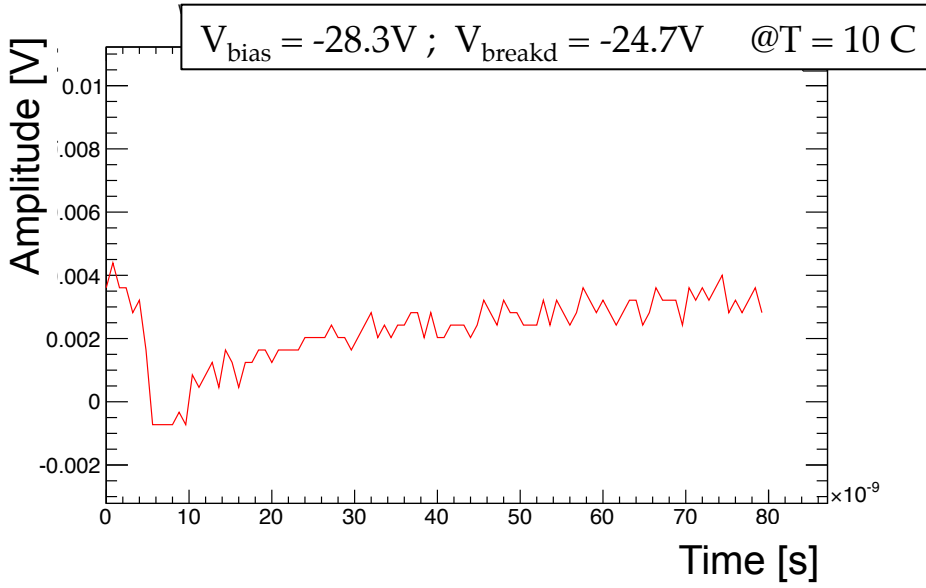
Results for KETEK:
MP20 V4 – W12

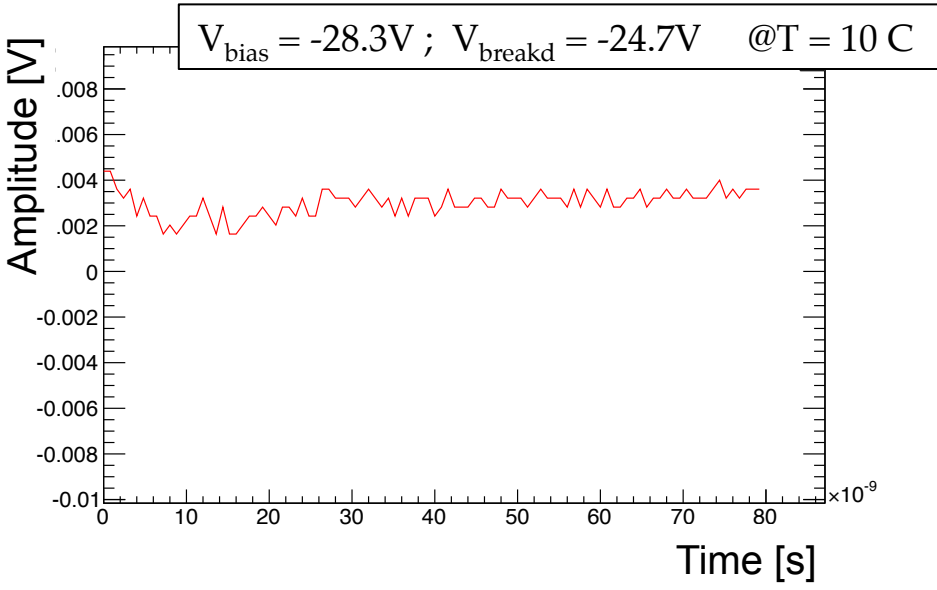
Photon spectrum – KETEK (MP20 V4 – W12)

- 8bit ADC
- Sampling / 800ps
- Trigger on LED signal

- Example of 2photon waveform→
- Due to using the T3B DAQ, which inverts the signals, the positive signals generated by the KETEK SiPM are displayed inverse.

- Example of 1 photon →





Photon spectrum –KETEK (#W12)

From 50k triggers, waveforms are integrated over the full width of the 80 ns triggered window.

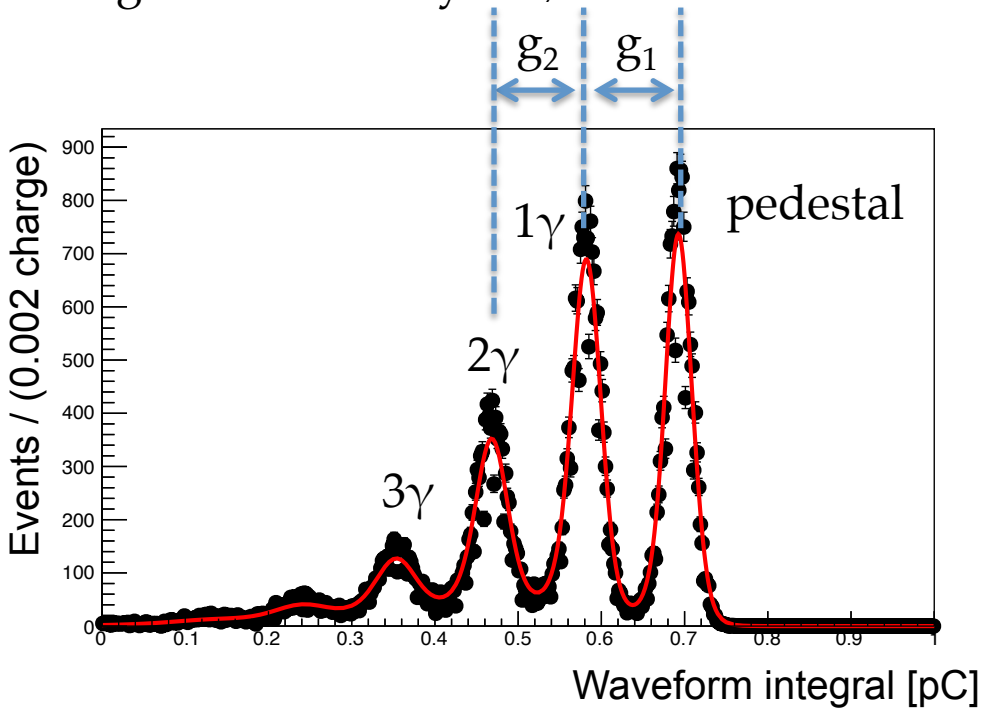
→ Extract the gain by measuring the distance from pedestal peak to 1γ peak.

→ Use RooFit p.d.f.: models the distribution as a superposition of gaussians.

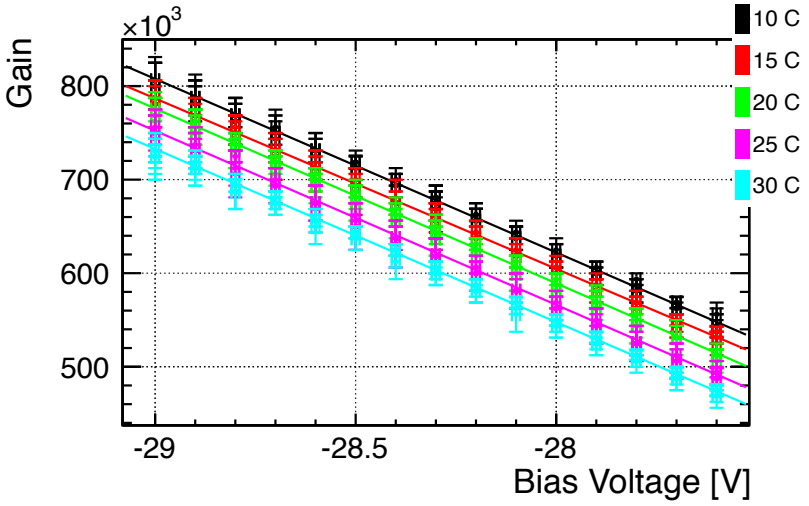
- Only include measurements which result in at least 3 peaks.
- Define uncertainty on gain to be difference between g_1 and g_2.
- Only include measurements with gain uncertainty < 4%.

The pedestal peak is at the (random) value of 0.7pC:

- Shift has been implemented simply to have the spectrum fall within window expected by the T3B analysis framework.



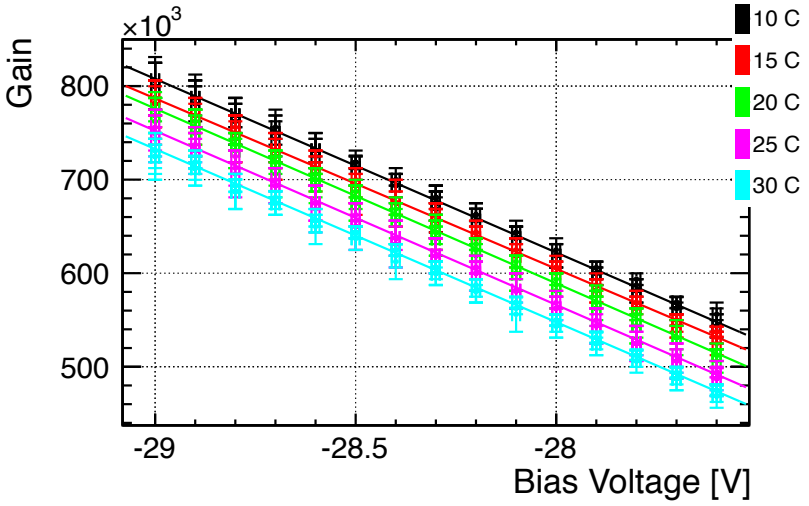
Gain vs voltage for different temperatures - KETEK (#W12)



- Each entry is the gain extracted from 50k waveforms
- Uncertainty on gain is from the difference between g_1 and g_2 . (see previous slide)

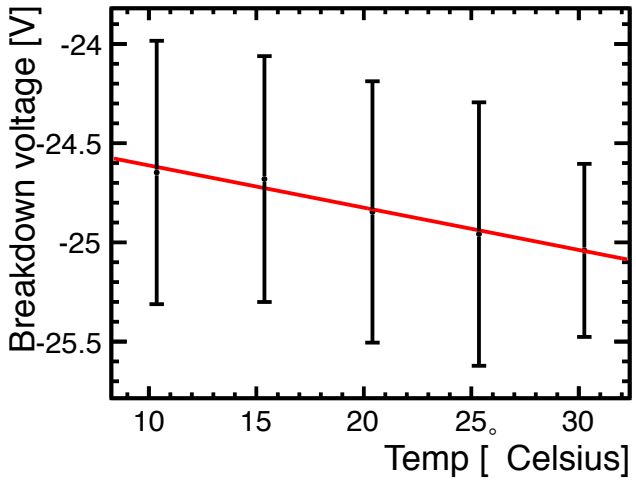
- Measured at 5 different temperatures:
  - 10-30C, in steps of 5C.
- At each temperature, varied bias voltage in steps of 0.1V:
- Took at least 5 measurements at each temperature and V point.

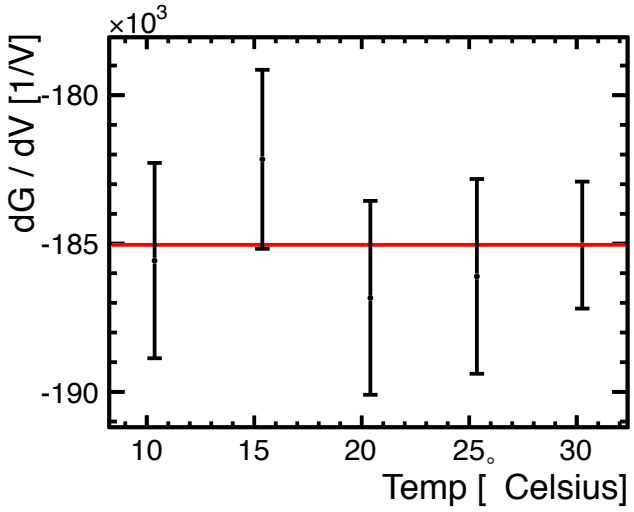
Gain vs voltage for different temperatures - KETEK (#W12)



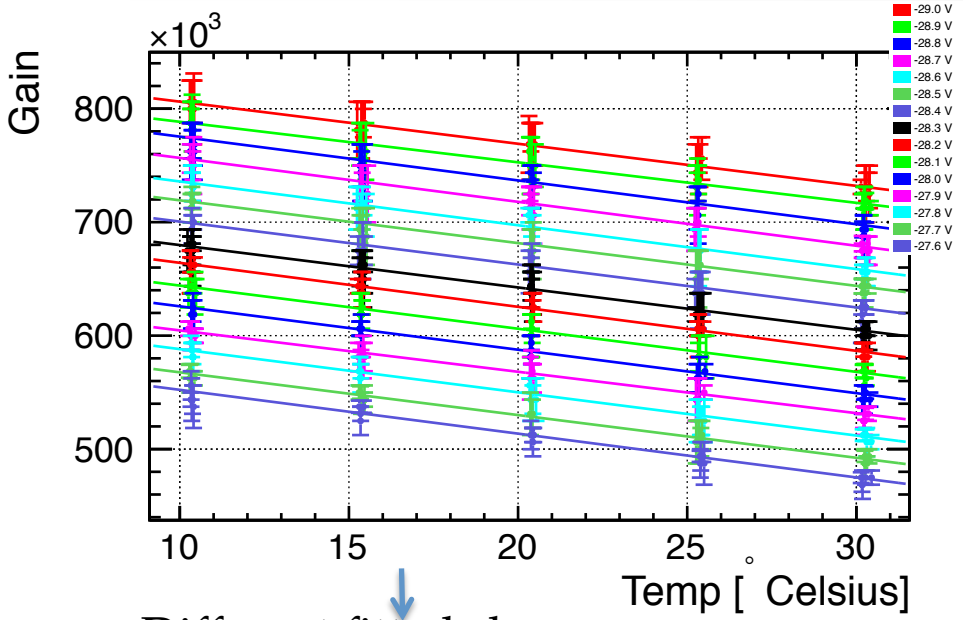
Assuming a linear dependency for Gain on V:

- Breakdown voltage increases linearly with temperature, as expected.
- Capacitance (=dG/dV) should be independent of temperature.

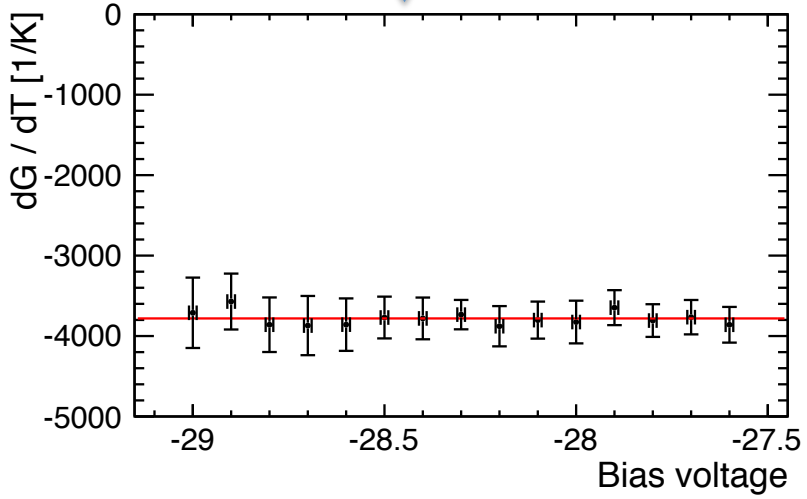




Gain vs temperature for different V - KETEK(#W12)



Different fitted slopes



← Same data as previous slide.

For a constant gain, dV / dT:

- Averaging the fitted slopes, and assuming as uncertainty the spread of slopes:
- dV/dT = - av (dG/dT) / av(dG/dV)

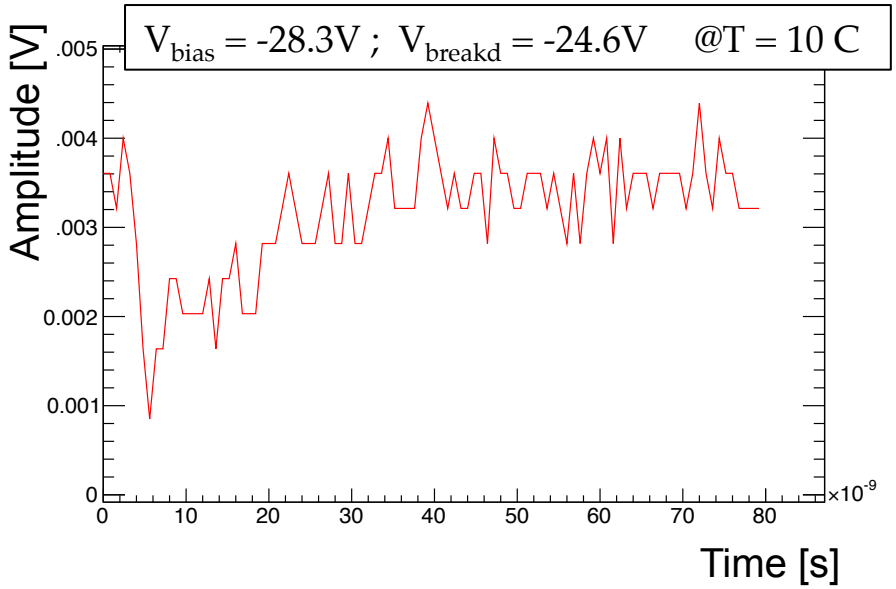
  = -20.3 +- 0.8 mV / K

Results for KETEK: MP15 V6-W8

Photon spectrum – KETEK (MP15 V6-W8)

- 8bit ADC
- Sampling / 800ps
- Trigger on LED signal

- Example of 1γ waveform →

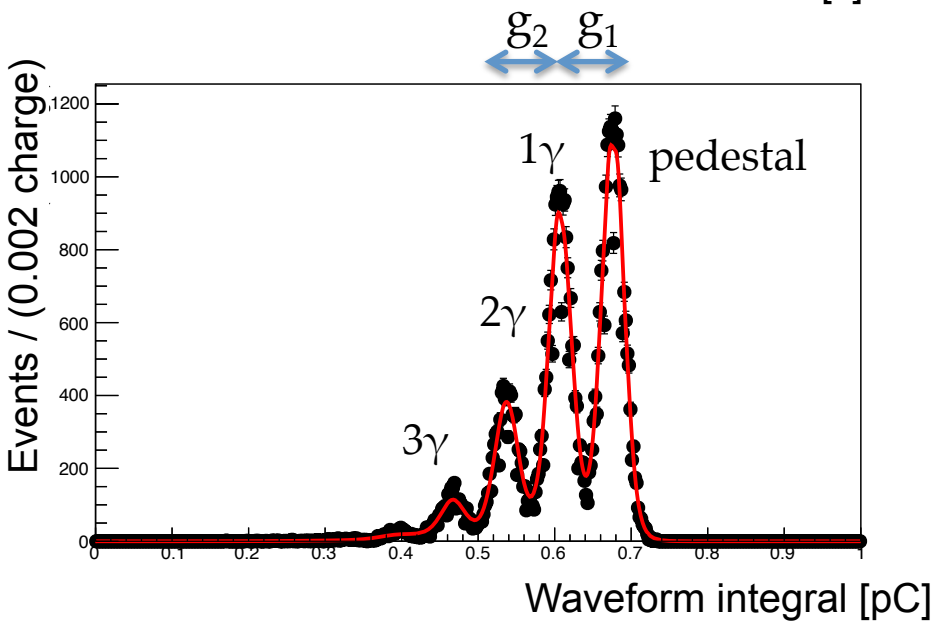


From 50k triggers, waveforms are integrated over full 80ns window:

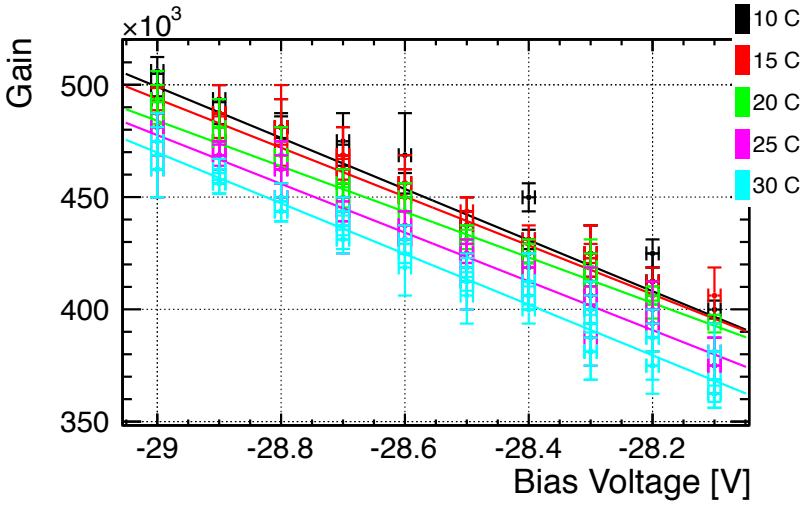
→ Extract the gain by measuring the distance from pedestal to 1γ peak.

→ Uncertainty on gain is defined as difference between g_1 and g_2.

→ Only consider measurements with gain uncertainty < 4%.

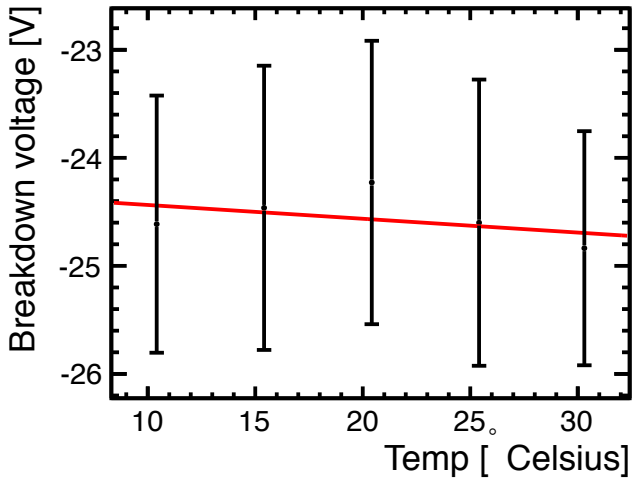


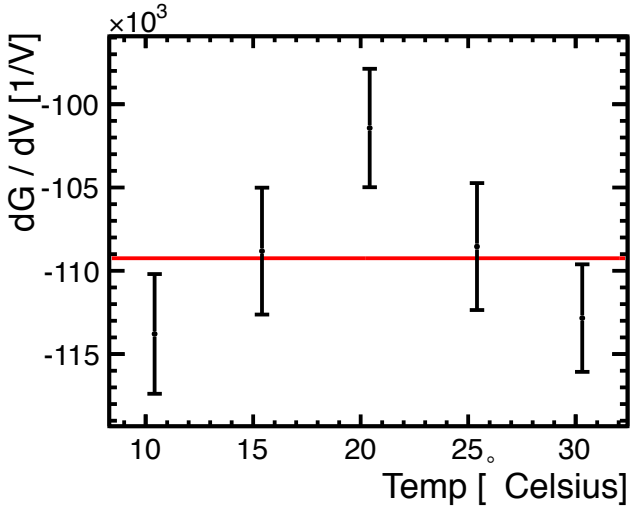
Gain vs voltage for different temperatures – KETEK (W8)



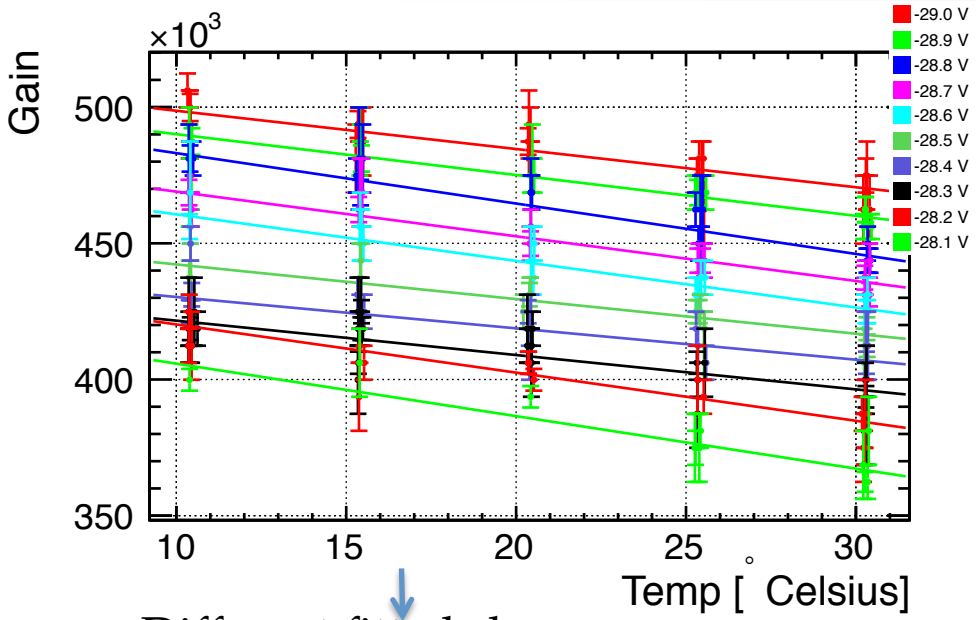
Assuming a linear dependency for Gain on V:

- Breakdown voltage increases linearly with temperature, as expected.
- Capacitance (=dG/dV) should be independent of temperature: systematic effect is visible.



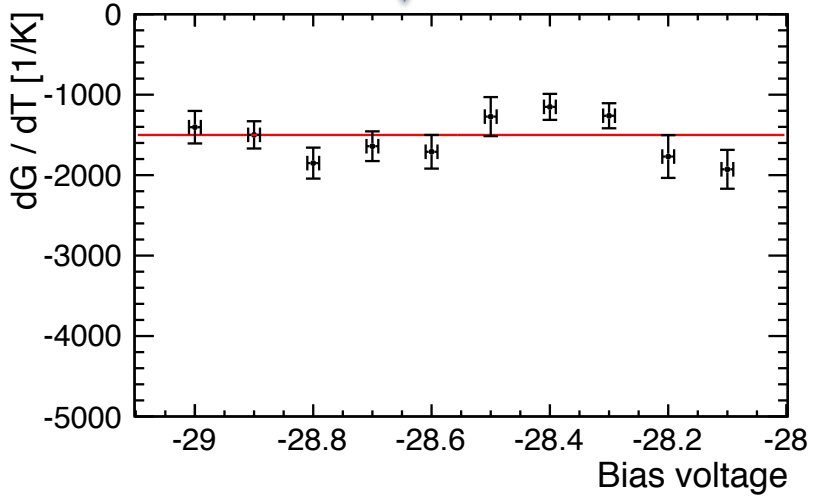


Gain vs temperature for different V – KETEK (W8)



← Same data as previous slide.

Different fitted slopes



For a constant gain, dV / dT:

- Averaging the fitted slopes, and assuming as uncertainty the spread of slopes:
- dV/dT = - av (dG/dT) / av(dG/dV)

  = -14.4 +- 3.7 mV / K

Results for Hamamatsu MPPC: 20 um pitch, sample B, #1

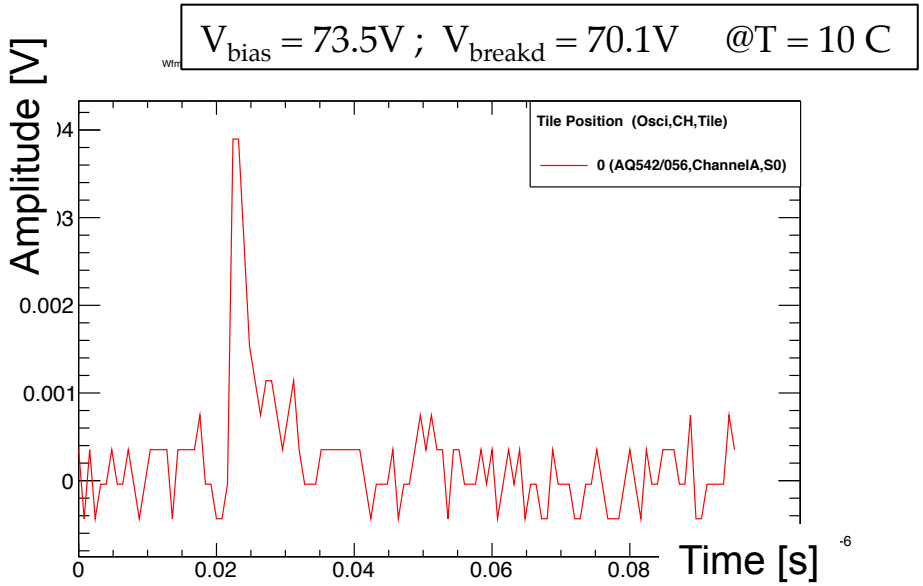
Photon spectrum – Hamatsu MPPC (20 um, sample B, #1)

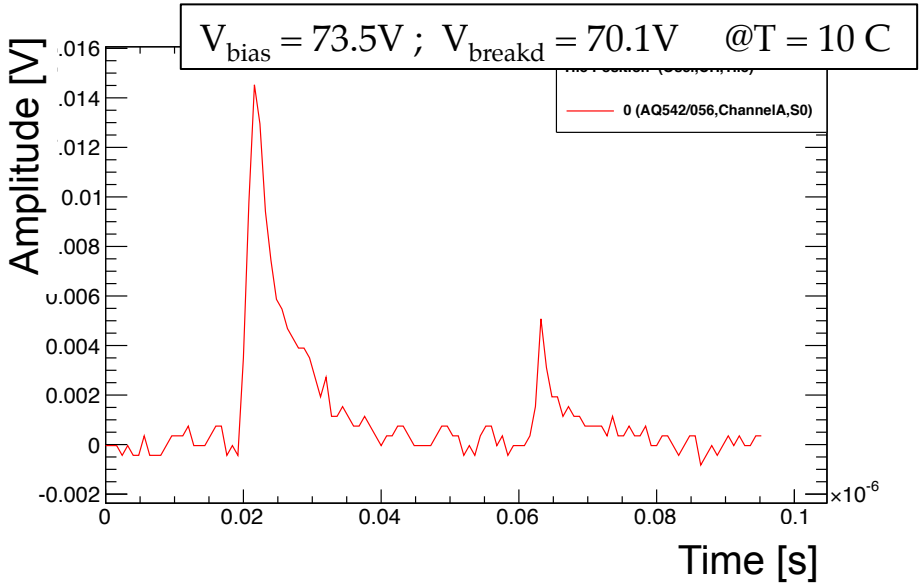
- 8bit ADC
- Sampling / 800ps
- Trigger on LED signal

- Using T3B analysis framework, integrate waveform.
- Example of 1photon waveform→

- Example of multiple photons →

- After a pedestal subtraction, waveforms are identified by rising edge at 1.5 mV and falling edge at 0.4 mV.





Photon spectrum – Hamatsu MPPC (20 um, sample B, #1)

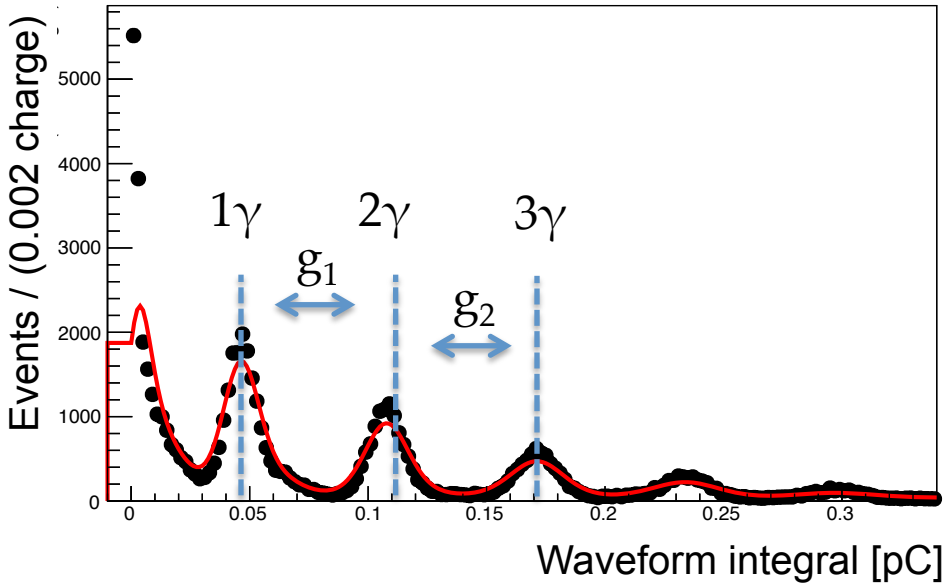
From 50k triggers, waveforms are integrated:

- wf identified by rising edge at 1.5 mV and falling edge at 0.4 mV.

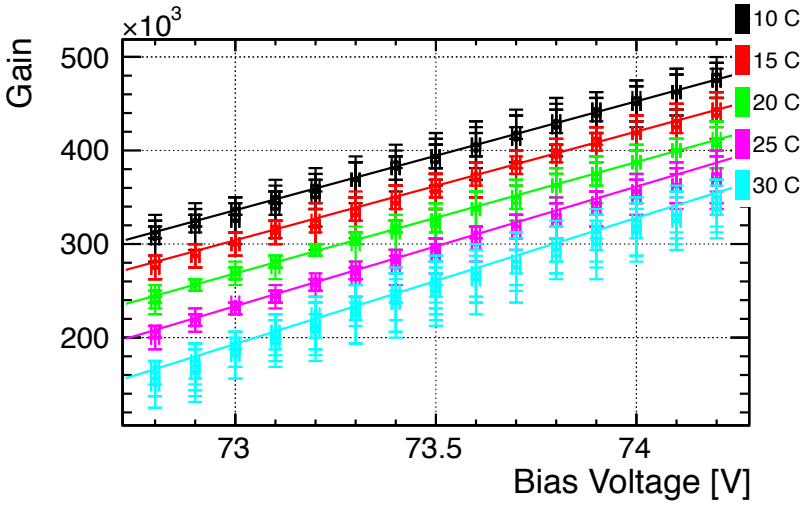
→ Extract the gain by measuring the distance from 1γ peak to 2γ peak.

→ Use RooFit p.d.f.: models the distribution as a superposition of gaussians.

  - Only include measurements which result in at least 3 peaks.
  - Define uncertainty on gain to be difference between g_1 and g_2.



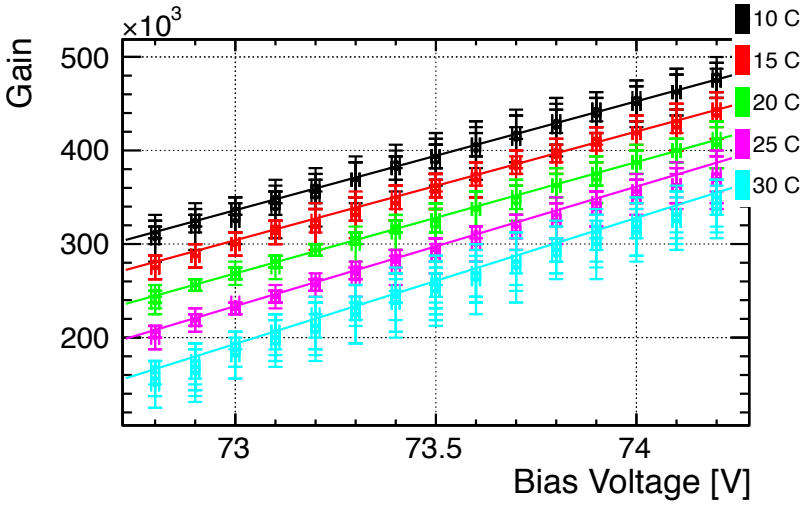
Gain vs voltage for different temperatures - MPPC (#B1)



- Each entry is the gain extracted from 50k waveforms
- Uncertainty on gain is from the difference between g_1 and g_2 . (see previous slide)

- Measured at 5 different temperatures:
  - 10-30C, in steps of 5C.
- At each temperature, varied bias voltage in steps of 0.1V:
- Took at least 5 measurements at each temperature and V point.

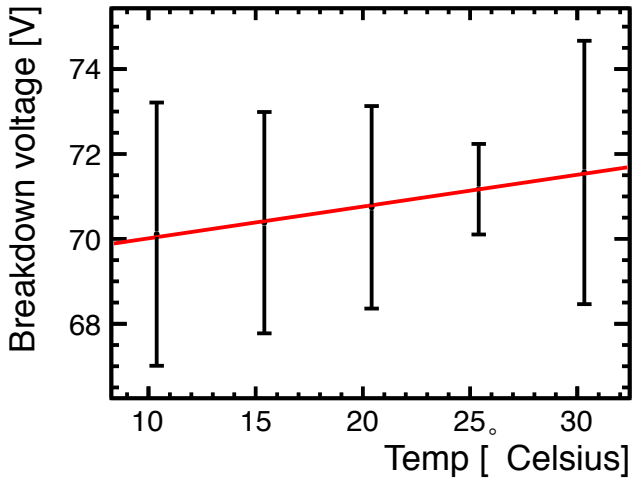
Gain vs voltage for different temperatures - MPPC (#B1)

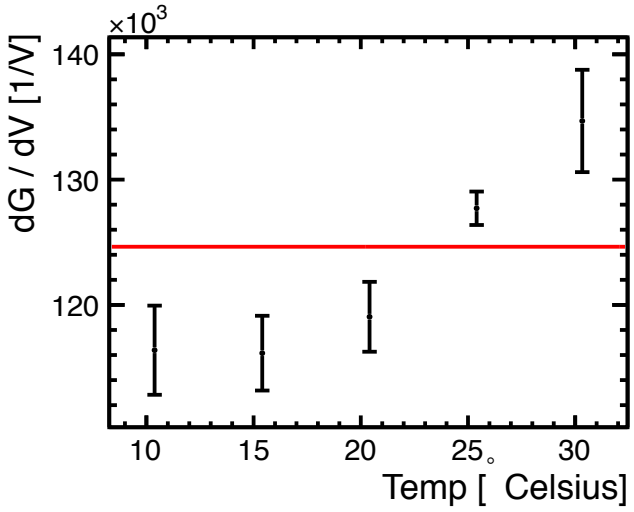


For comparison: the gain as measured by Hamamatsu at 25C with nominal Voltage of 73.33 V is 2.3×10^5 for this MPPC.

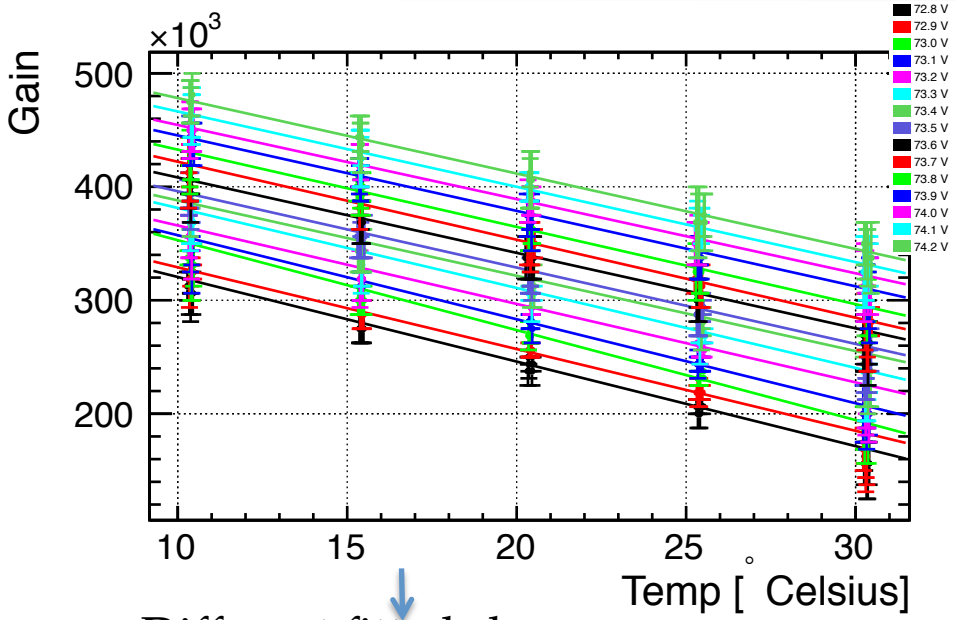
Assuming a linear dependency for Gain on V:

- Breakdown voltage increases linearly with temperature, as expected.
- Capacitance (=dG/dV) should be independent of temperature: small systematic effect is visible.



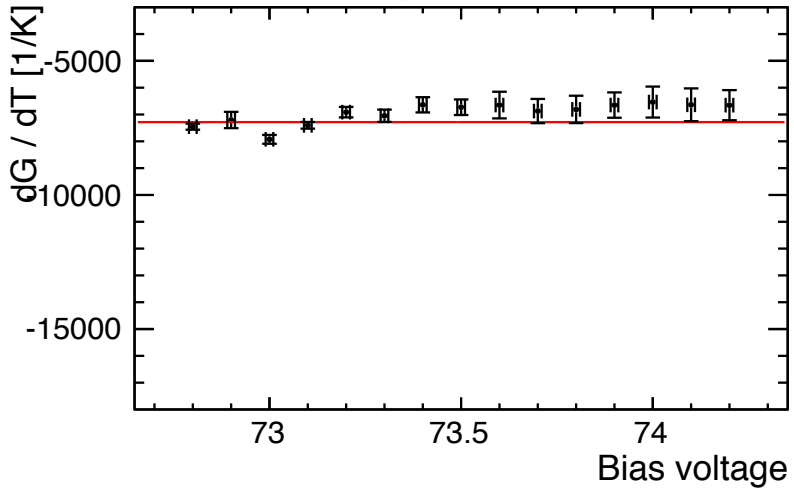


Gain vs temperature for different V - MPPC (#B1)



← Same data as previous slide.

Different fitted slopes



For a constant gain, dV / dT:

- Averaging the fitted slopes, and assuming as uncertainty the spread of slopes:
- dV/dT = - av (dG/dT) / av(dG/dV)

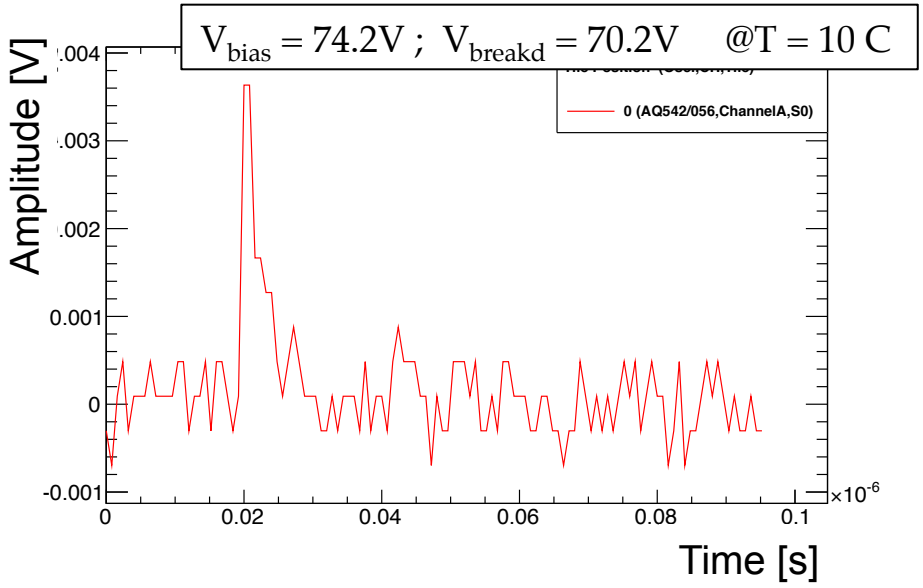
  = 54.6 +- 6.4 mV / K

Results for Hamamatsu MPPC: 15 um pitch, sample B, #2

Photon spectrum – Hamatsu MPPC (15 um, sample B, #2)

- 8bit ADC
- Sampling / 800ps
- Trigger on LED signal

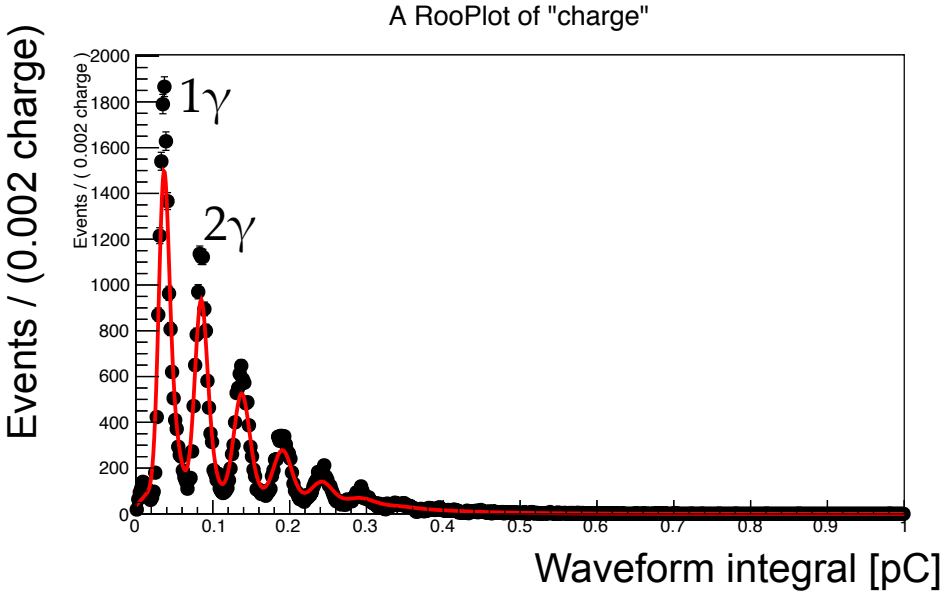
- Example of 1γ waveform →



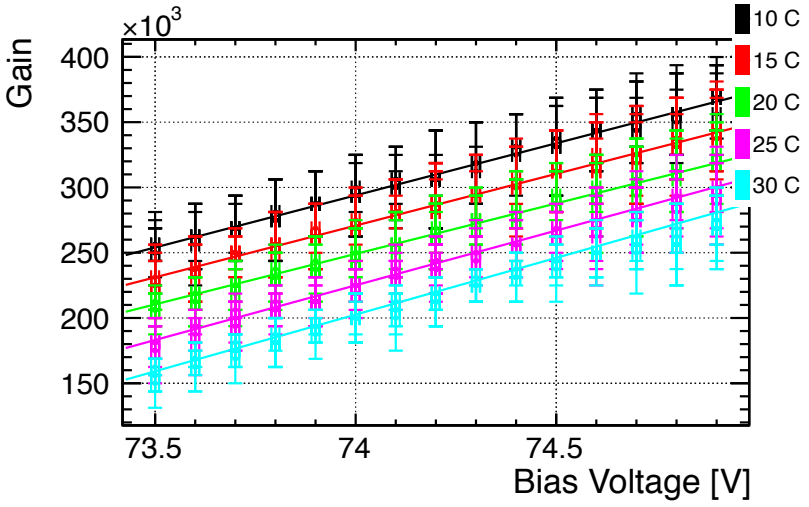
From 50k triggers, waveforms are integrated:

- wf identified by rising edge at 1.5 mV and falling edge at 0.4 mV.

→ Extract the gain by measuring the distance from 1γ peak to 2γ peak.



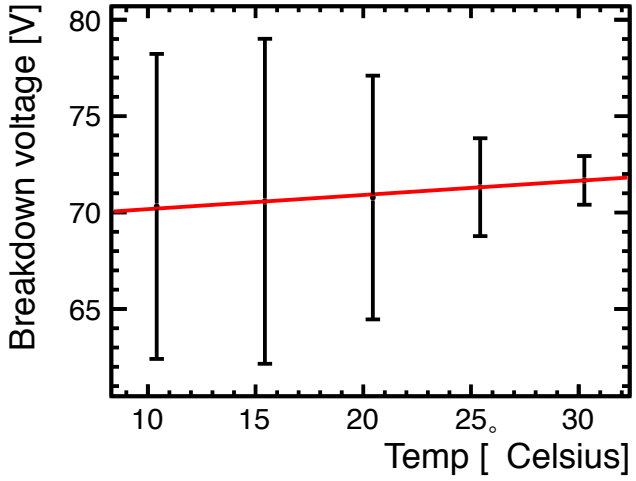
Gain vs voltage for different temperatures - MPPC (#B2)

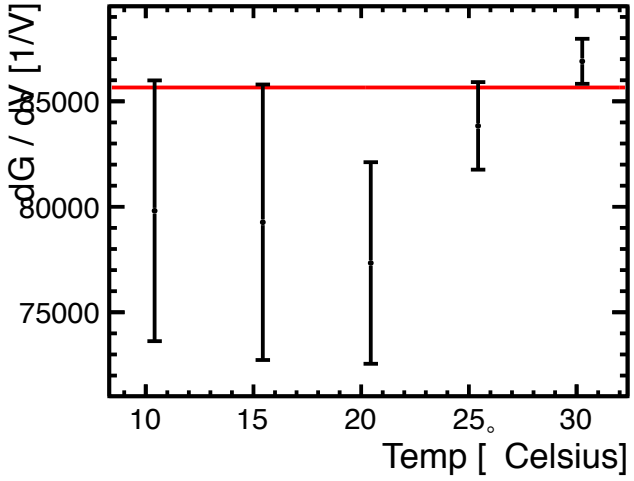


For comparison: the gain as measured by Hamamatsu at 25C with nominal Voltage of 73.99 V is 2.0×10^5.

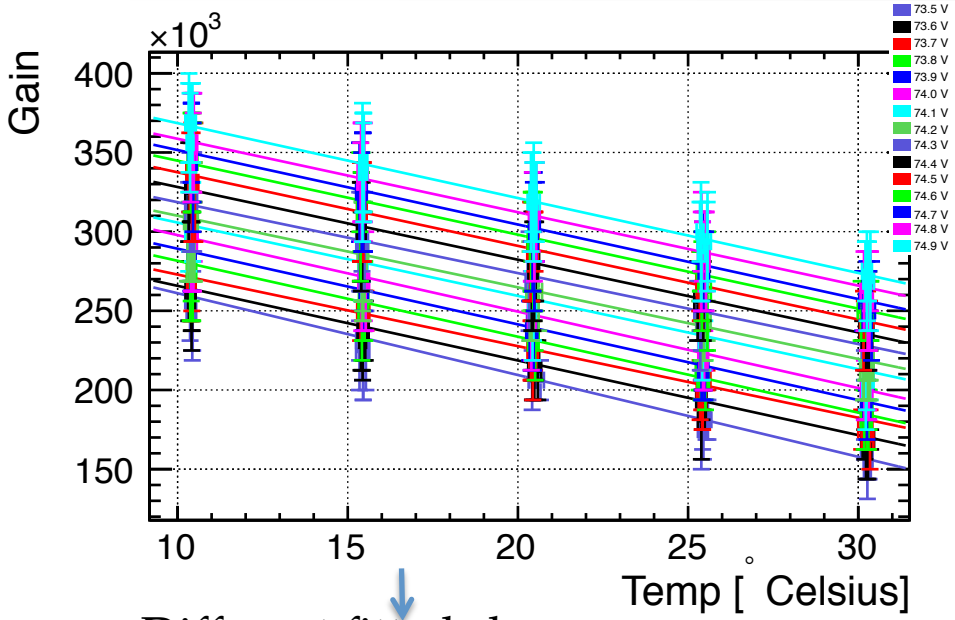
Assuming a linear dependency for Gain on V:

- Breakdown voltage increases linearly with temperature, as expected.
- Capacitance (=dG/dV) should be independent of temperature.



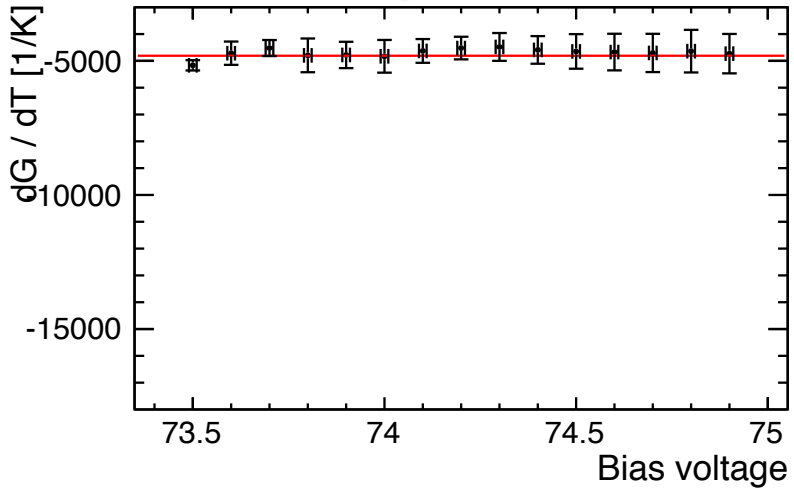


Gain vs temperature for different V - MPPC (#B2)



← Same data as previous slide.

Different fitted slopes



For a constant gain, dV / dT:

- Averaging the fitted slopes, and assuming as uncertainty the spread of slopes:

- dV/dT = - av (dG/dT) / av(dG/dV)

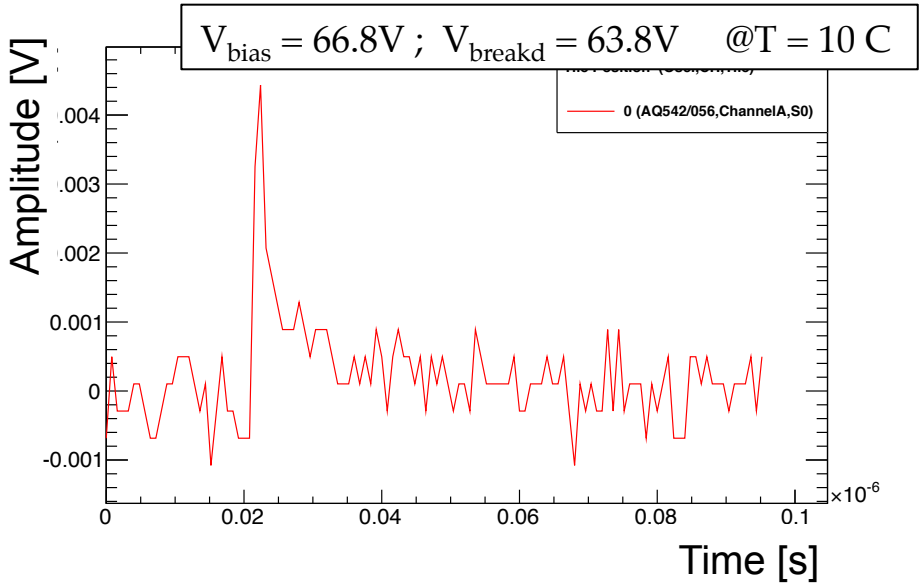
  = 56.8 +- 5.3 mV / K

Results for Hamamatsu MPPC: 20 um pitch, sample A, #1

Photon spectrum – Hamatsu MPPC (20 um, sample A, #1)

- 8bit ADC
- Sampling / 800ps
- Trigger on LED signal

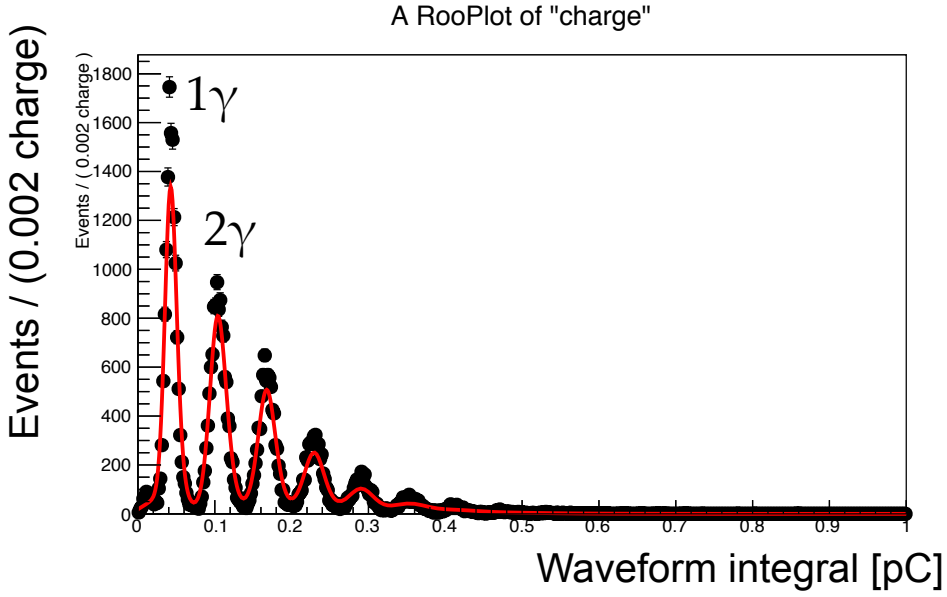
- Example of 1γ waveform →



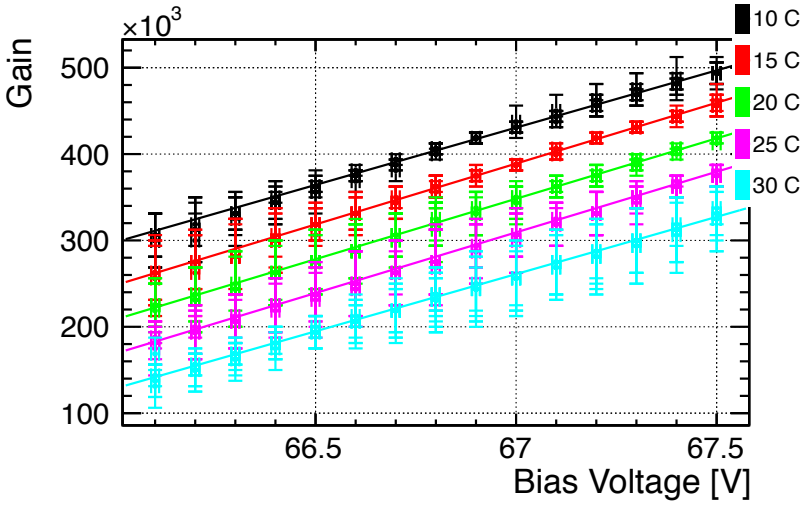
From 50k triggers, waveforms are integrated:

- wf identified by rising edge at 1.5 mV and falling edge at 0.4 mV.

→ Extract the gain by measuring the distance from 1γ peak to 2γ peak.



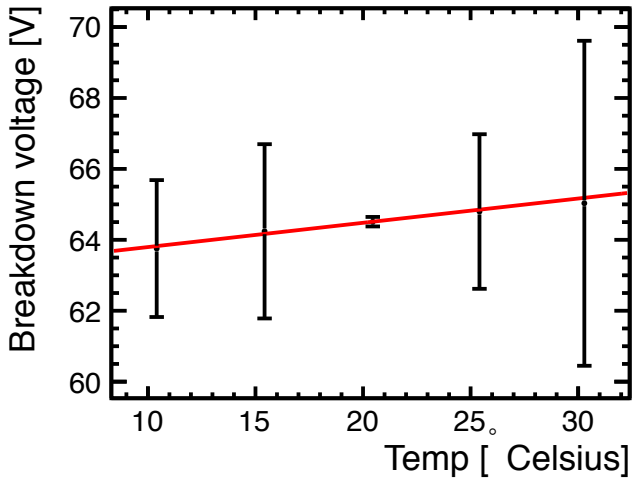
Gain vs voltage for different temperatures - MPPC (#A1)

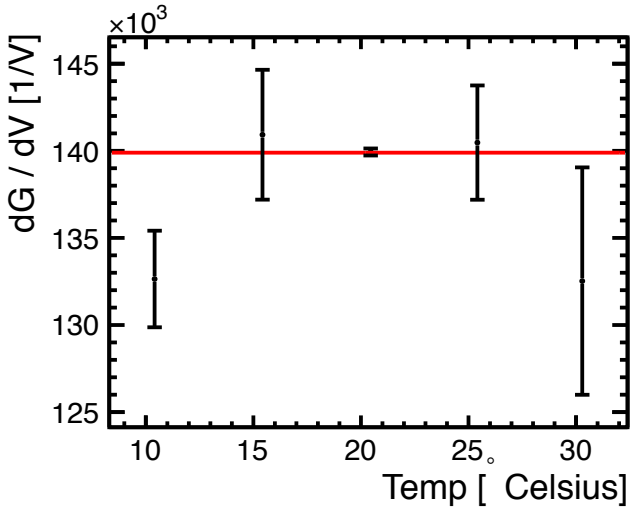


For comparison: the gain as measured by Hamamatsu at 25C with nominal Voltage of 66.73 V is 2.3×10^5.

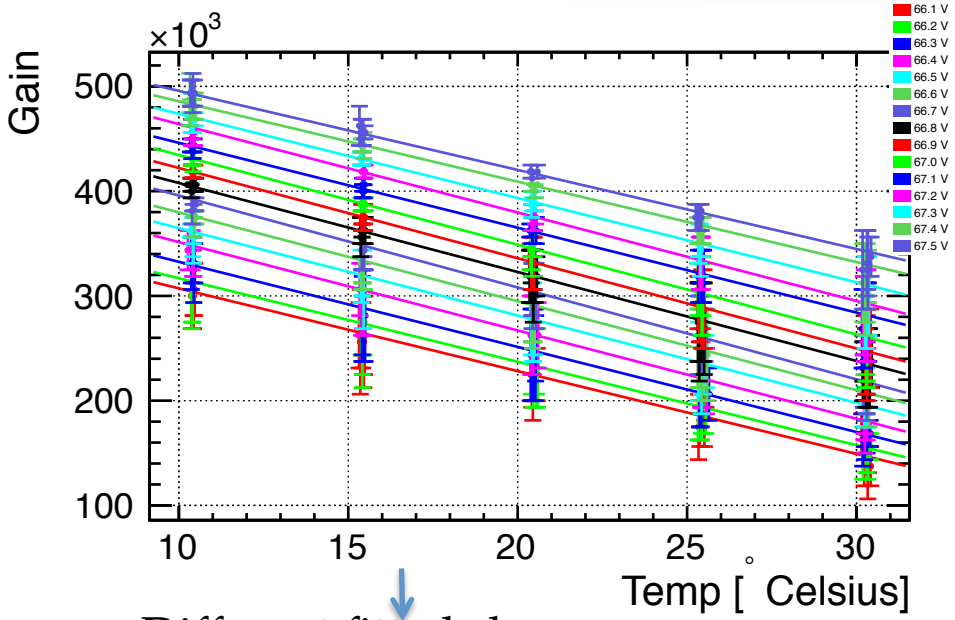
Assuming a linear dependency for Gain on V:

- Breakdown voltage increases linearly with temperature, as expected.
- Capacitance (=dG/dV) should be independent of temperature.

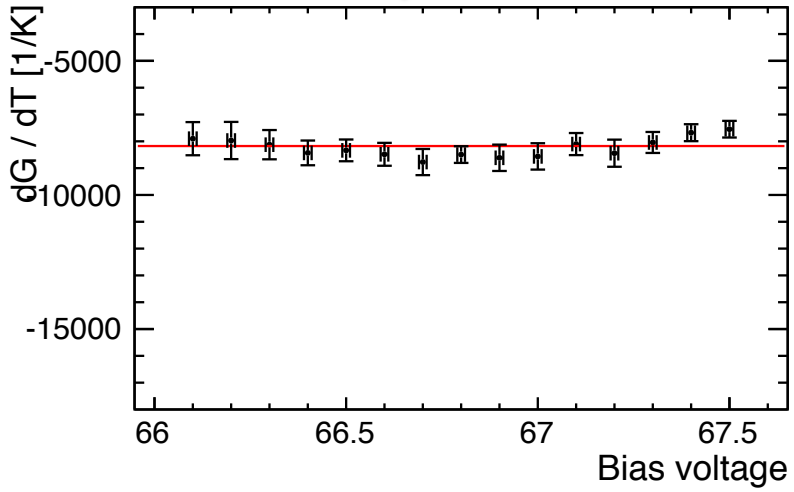




Gain vs temperature for different V - MPPC (#A1)



Different fitted slopes



← Same data as previous slide.

For a constant gain, dV / dT:

- Averaging the fitted slopes, and assuming as uncertainty the spread of slopes:

- dV/dT = - av (dG/dT) / av(dG/dV)

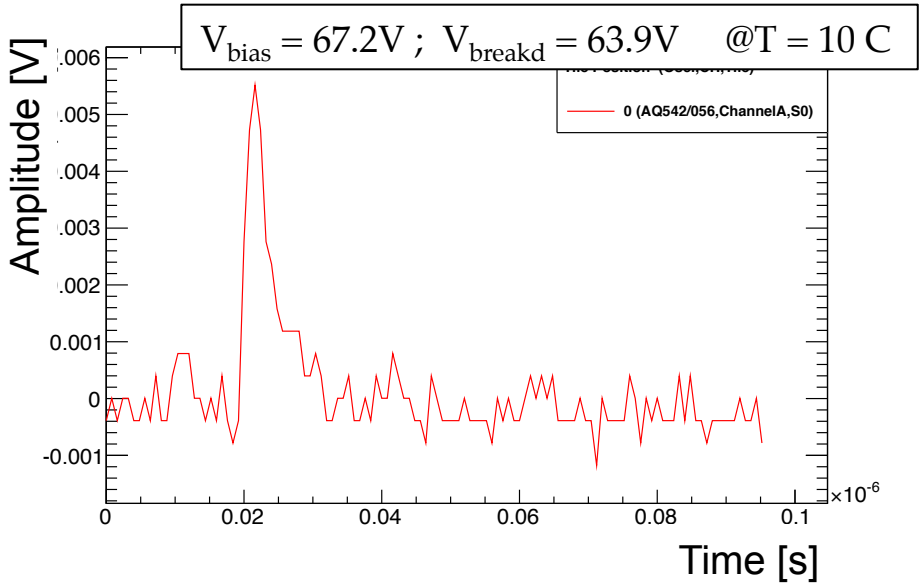
  = 59.8 +- 4.8 mV / K

Results for Hamamatsu MPPC: 15 um pitch, sample A, #2

Photon spectrum – Hamatsu MPPC (20 um, sample A, #2)

- 8bit ADC
- Sampling / 800ps
- Trigger on LED signal

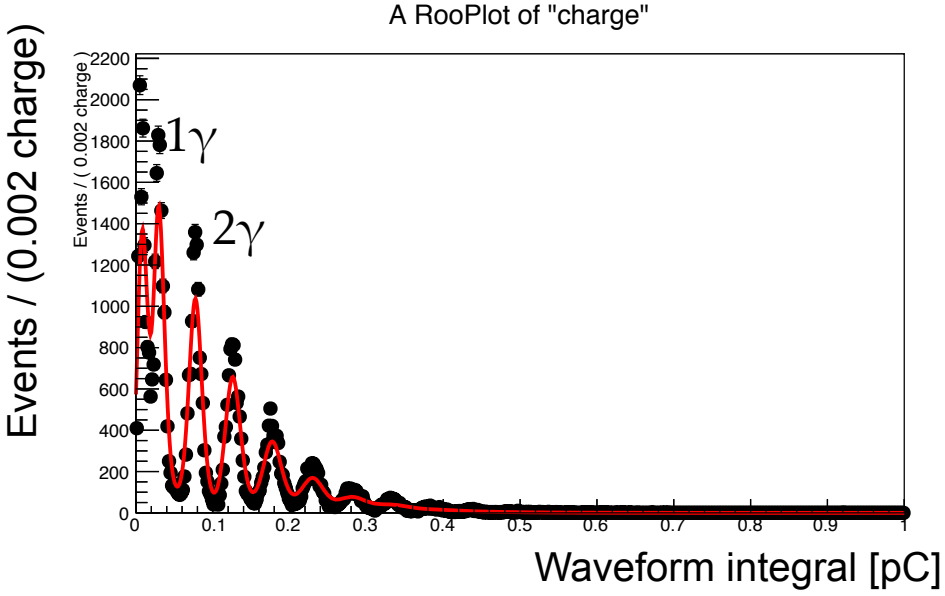
- Example of 1γ waveform →



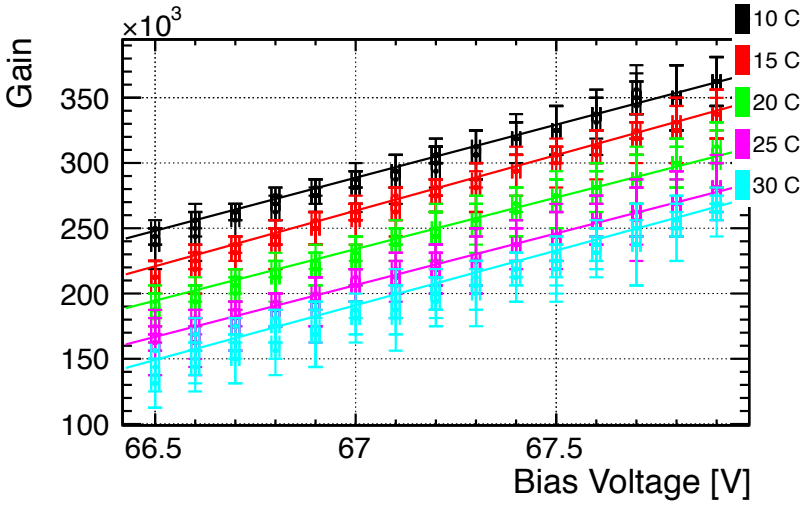
From 50k triggers, waveforms are integrated:

- wf identified by rising edge at 1.5 mV and falling edge at 0.4 mV.

→ Extract the gain by measuring the distance from 1γ peak to 2γ peak.



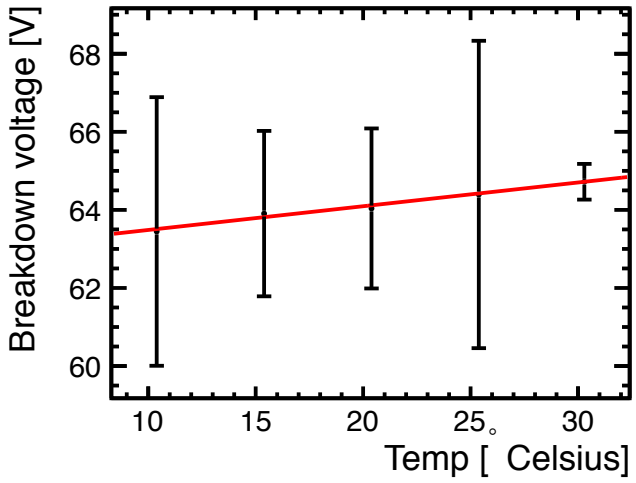
Gain vs voltage for different temperatures - MPPC (#A2)

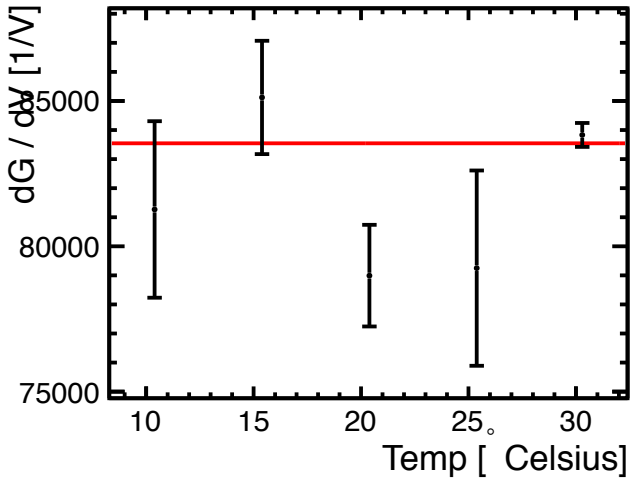


For comparison: the gain as measured by Hamamatsu at 25C with nominal Voltage of 67.15 V is 2.0×10^5.

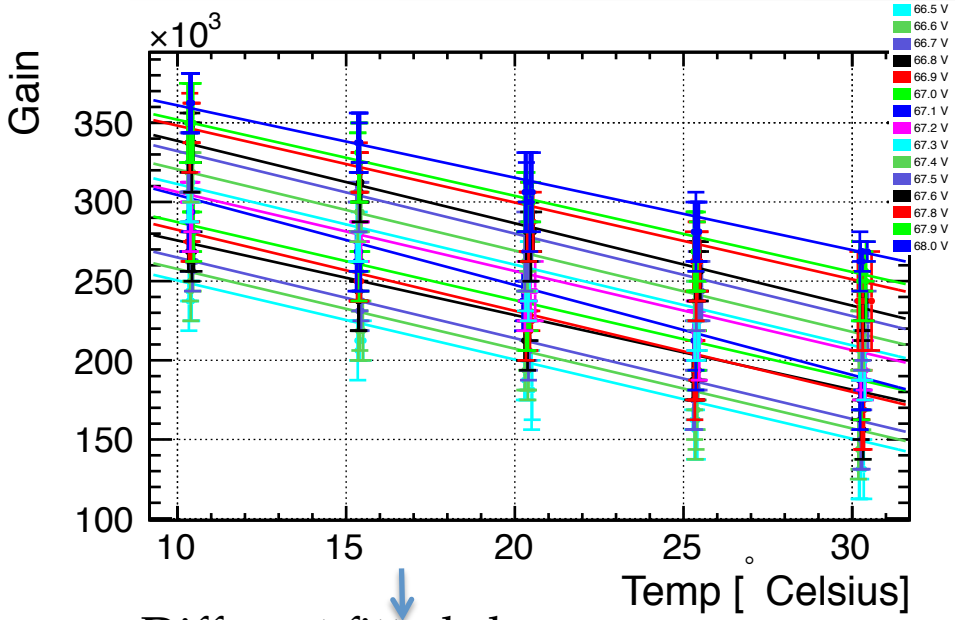
Assuming a linear dependency for Gain on V:

- Breakdown voltage increases linearly with temperature, as expected.
- Capacitance (=dG/dV) should be independent of temperature

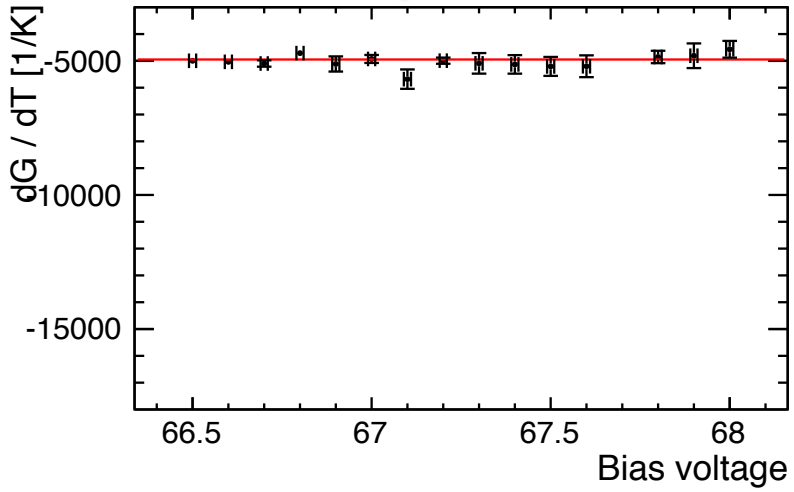




Gain vs temperature for different V - MPPC (#A2)



Different fitted slopes



← Same data as previous slide.

For a constant gain, dV / dT:

- Averaging the fitted slopes, and assuming as uncertainty the spread of slopes:

- dV/dT = - av (dG/dT) / av(dG/dV)

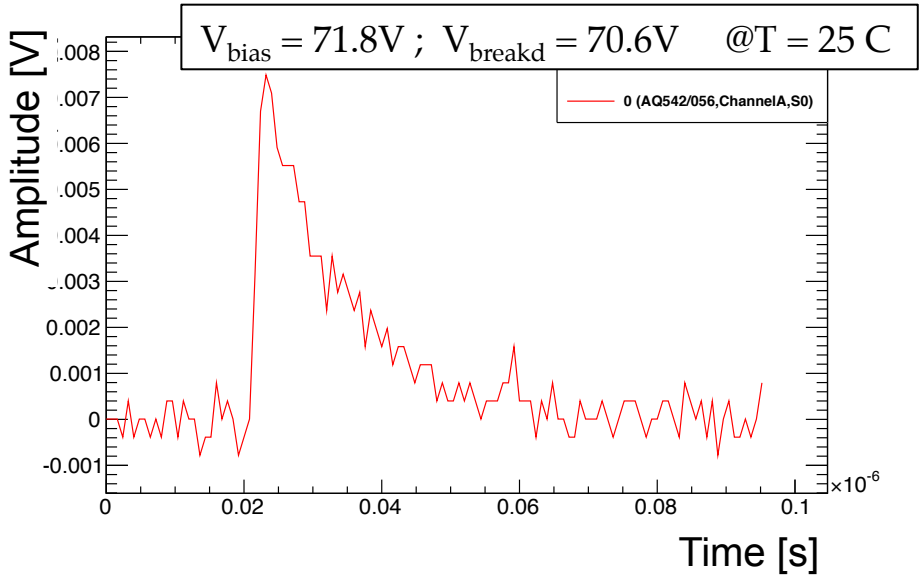
  = 62.3 +- 7.1 mV / K

Results for Hamamatsu MPPC: 50 um pitch

Obtaining photon spectrum – Hamatsu MPPC (50 um pitch)

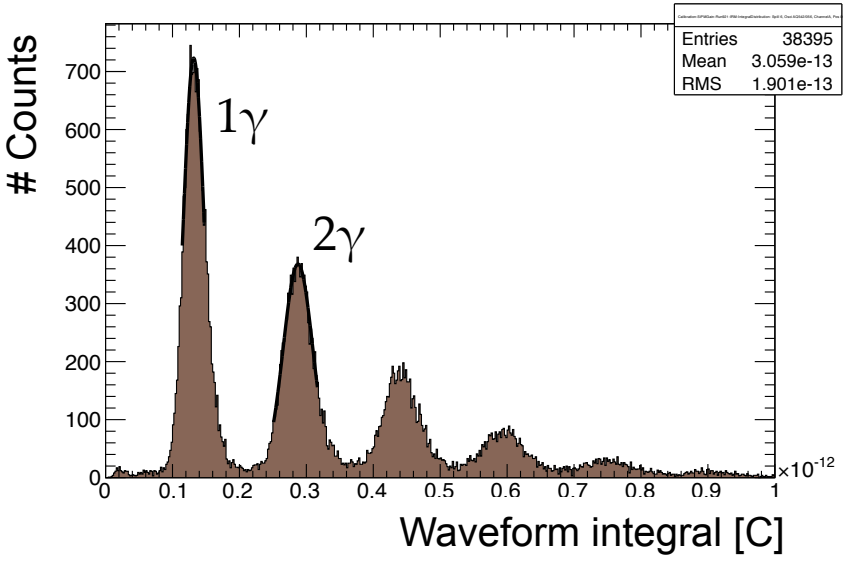
- 8bit ADC
- Sampling / 800ps
- Trigger on LED signal

- Using T3B analysis framework, integrate waveform

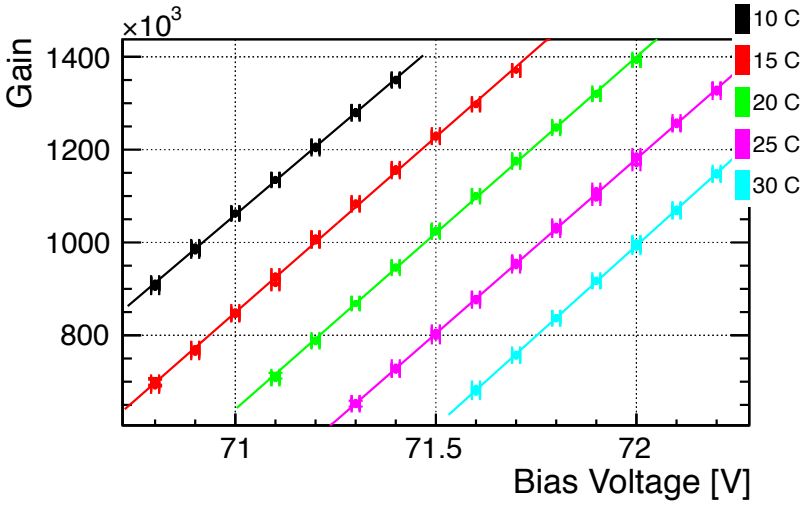


From 50k triggers:

- Waveforms integrated
  → wf identified by rising edge at 2.5 mV and falling edge at 0.4 mV.
- Fit each peak with gaussian dist.
- Extract gain from 2γ - 1γ peak to ~1% accuracy.
  (Pedestal is subtracted in analysis)



Gain vs voltage for different temperatures - MPPC (#11759)

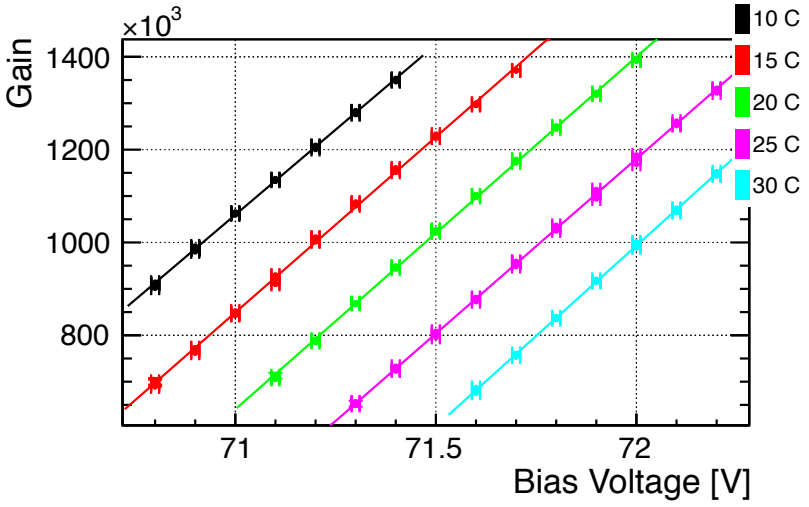


- Each entry is the gain extracted from 50k waveforms
- Uncertainty on gain calculation is from the uncertainty on the gauss' means.

- Measured at 5 different temperatures:
  - 10-30C, in steps of 5C.
- At each temperature, varied bias voltage in steps of 0.1V:
  - range varied, assuming dV/dT ~50 mV/K (for constant gain)

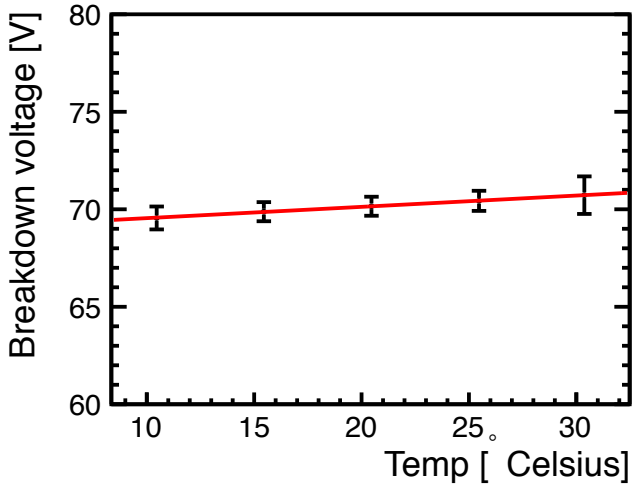
- Took at least 5 measurements at each temperature and V point.

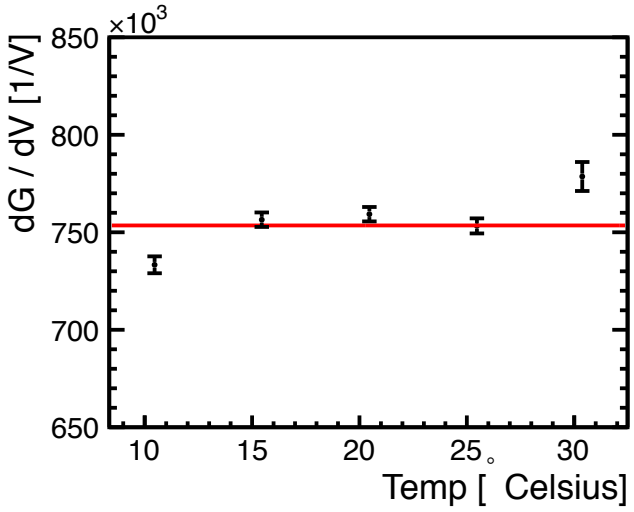
Gain vs voltage for different temperatures - MPPC (#11759)



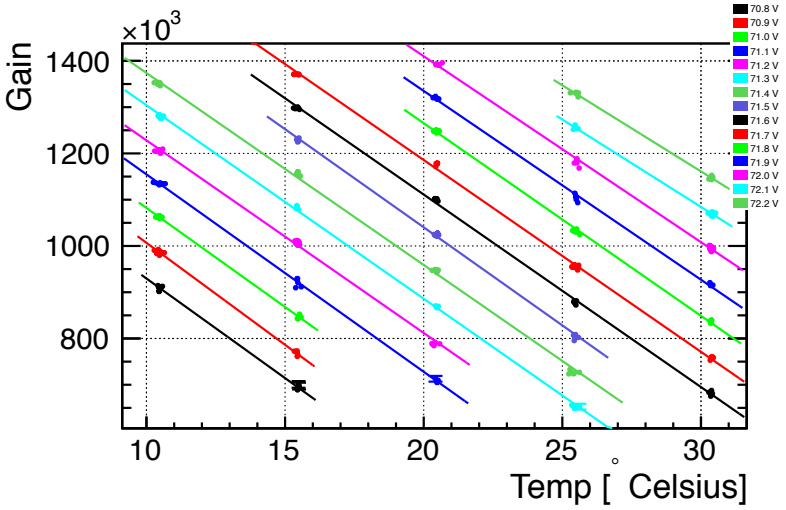
Assuming a linear dependency for Gain on V:

- Breakdown voltage increases linearly with temperature, as expected.
- Capacitance (=dG/dV) should be independent of temperature: systematic effect is visible.





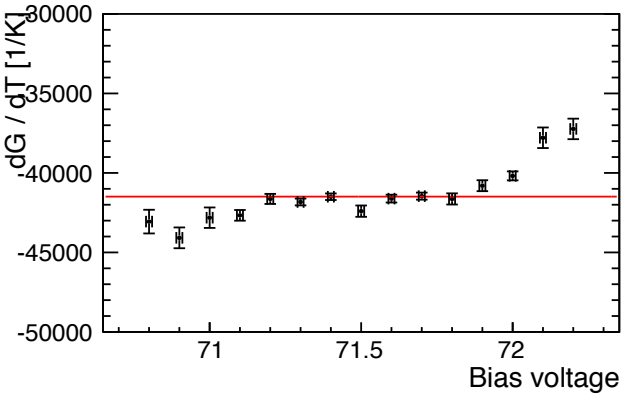
Gain vs temperature for different V - MPPC (#11759)



← Same data as previous slide

- For highest and lowest V_{bias}, accuracy of slopes decreases.

Different fitted slopes



For a constant gain, need dV / dT:

- Averaging the fitted slopes, and assuming as uncertainty the spread of slopes:
- dV/dT = - av (dG/dT) / av(dG/dV)

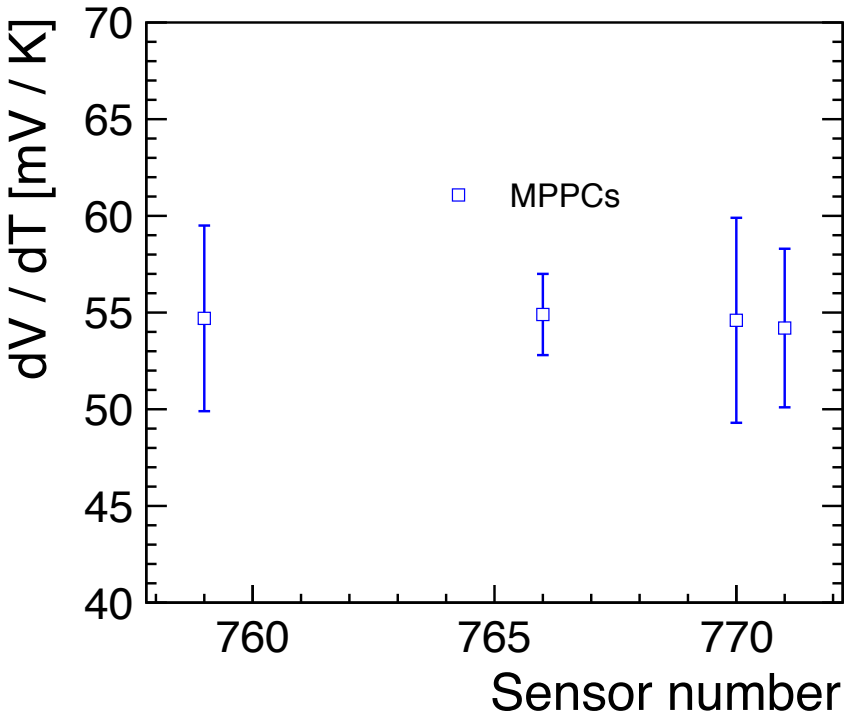
  = 54.2 +- 2.0 mV / K

Results for several Hamamatsu MPPCs

Tested 4 MPPCs

- Determine for each
  - average dG/dT
  - average dG/dV
    (See backup slides)

- Calculate the voltage-temperature dependency for a constant gain →

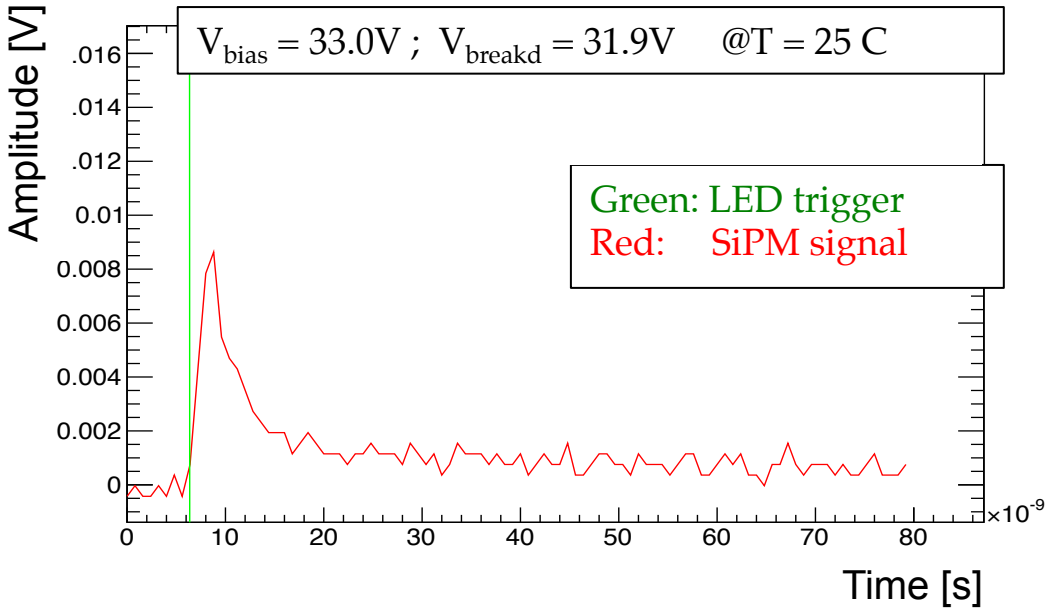


- Results for all 4 sensors vary less than 1%.
  - Individual uncertainties are large as I have simply taken the spread in slopes as uncertainty.

Results for CPTA SiPM

Photon spectrum for CPTA SiPM

- The same setup, now with CPTA SiPM
  - These come attached to tile
    (same sensor+tile as used in 2nd generation CALICE AHCAL prototype)
  - Wrapped in aluminum foil, LED shines at small hole in foil near SiPM



Signal is different than Hamamatsu MPPC

- Longer tail
- Decomposition into single photon waveforms does not work.

→ Integrate over full 80ns.

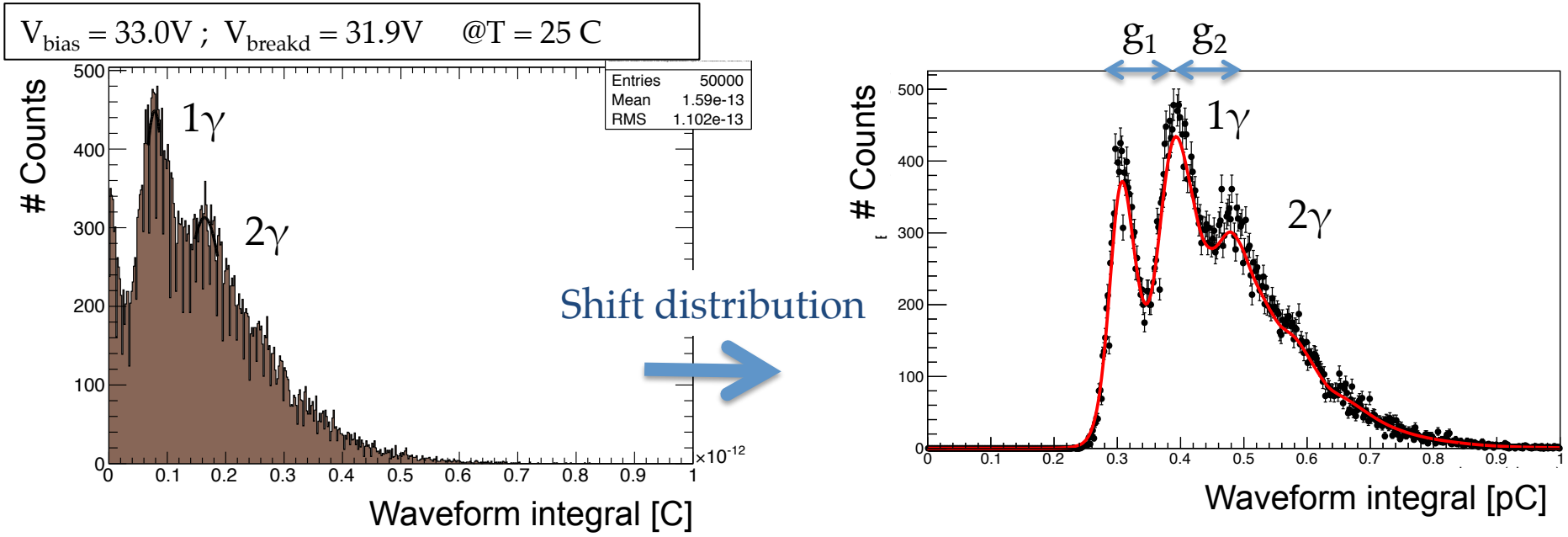
Fitting p.d.f. to spectrum

Unfortunately the 2γ peak is not always clear.

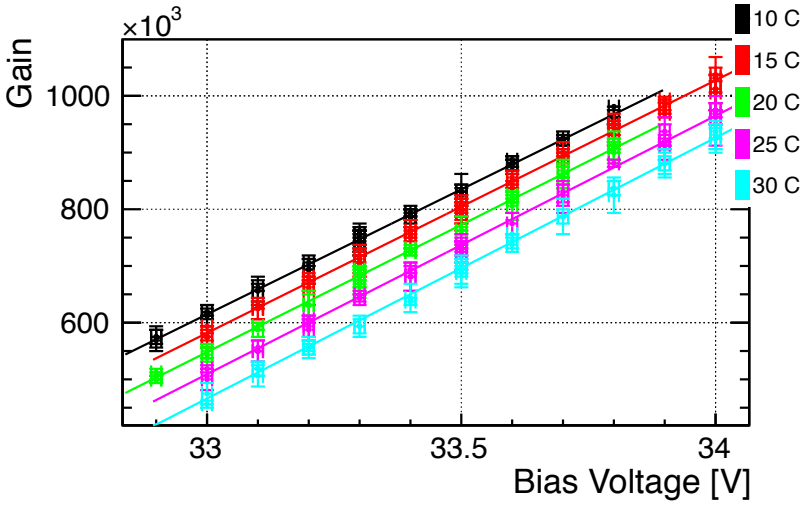
→ Extract the gain by measuring the distance from pedestal peak to 1γ peak.

→ Use RooFit p.d.f.: models the distribution as a superposition of gaussians.

- Only include measurements which result in at least 3 peaks.
- Define uncertainty on gain to be difference between g_1 and g_2.
- Only include measurements with gain uncertainty < 4%.

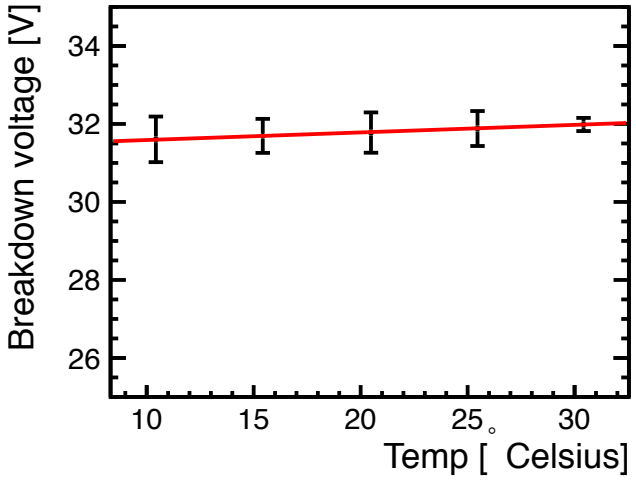


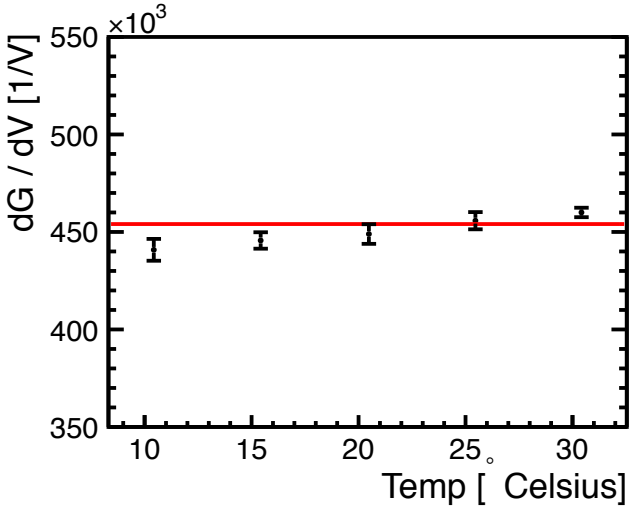
Gain distribution – CPTA SiPM (#857)



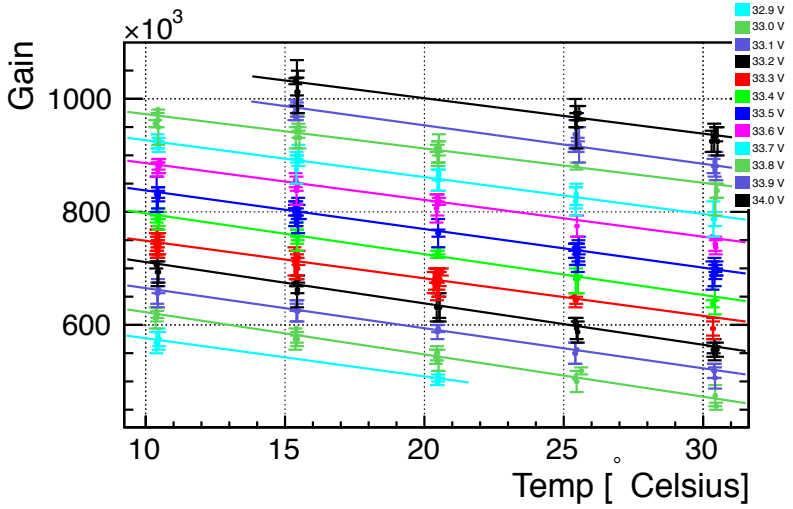
- Each entry is the gain extracted from 50k waveforms
- At 5 different temperatures, with varying bias V in steps of 0.1V
  - At least 5 measurements at each temperature and V point.

→ Systematic effect of dG/dV with temperature again visible



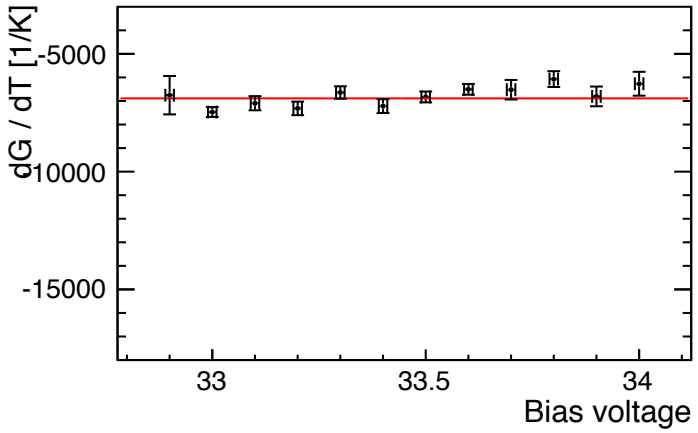


Gain distribution – CPTA SiPM (#857)



← Same data, plotted as Gain vs T, for the different bias voltages set.

Different fitted slopes



For a constant gain, need dV / dT:

- Averaging the fitted slopes, and assuming as uncertainty the spread of slopes:
- dV/dT = - av (dG/dT) / av(dG/dV)

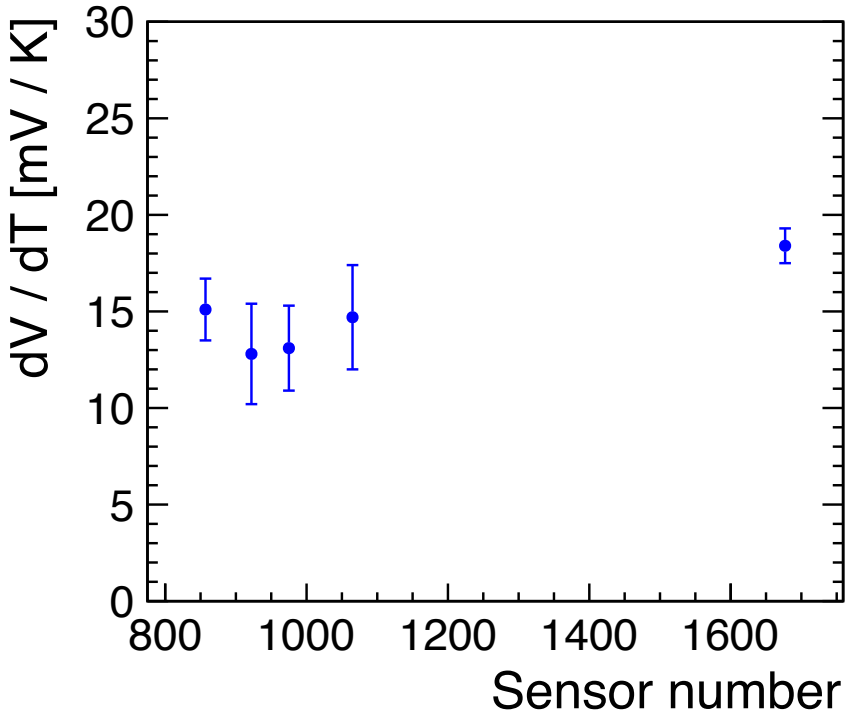
  = 14.9 +- 1.5 mV / K

Results for several CPTA SiPMs

- Repeated the measurements on 5 different SiPM+tile
  - 4 are similar in gain
  - 1 (#1677) is different and has ~ 2x higher gain.
  - See backup slides for individual measurements.

- Variation between 4 similar SiPM is ~10%

- #1677 is easier to characterize, thanks to its higher gain.



Results for several CPTA SiPMs

Results are in agreement with what can be expected.

- From Evgueny Tarkovsky: