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Gain Stabilization of SiPMs

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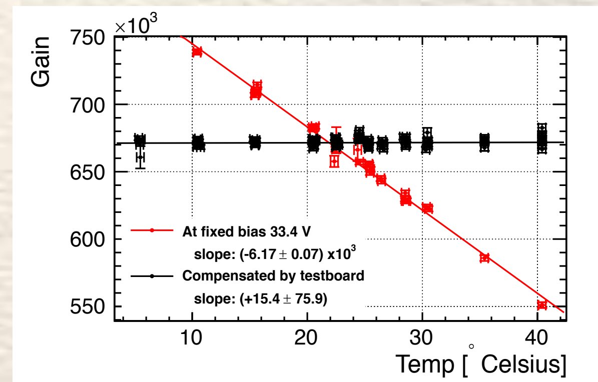
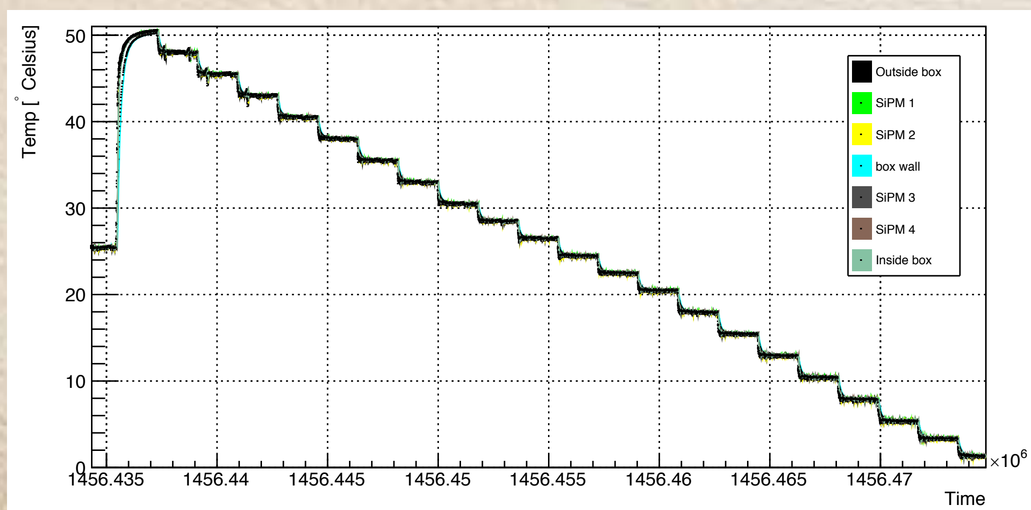
Introduction

- The gain of SiPMs increases with bias voltage V_{bias} and decreases with temperature T
- To operate SiPMs at stable gain, V_{bias} can be adjusted to compensate for T changes
  ➔ important for operation of large detector system like analog hadron calorimeter
- This requires the knowledge of *dV/dT*, which is obtained from measurements of *dG/dV* and *dG/dT*
- We tested this procedure in a climate chamber at CERN in February 2016 using a linear approximation for *dV/dT* performing automatic *dV/dT* adjustments with an adaptive power supply



- We tested gain stabilization for **30** SiPMs from Hamamatsu, KETEK and CPTA stabilizing 4 SiPMs simultaneously with one ***dV/dT*** setting ➔goal: **achieve stable gain if ΔG/G <±0.5% in 20°-30°C range**



Study of Hamamatsu MPPCs with Trenches

- Waveform and pe spectra of 4 S13360 MPPCs
- S13360-3025 (10103) S13360-3025 (10104)

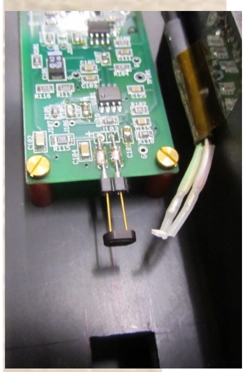
- S13360-1325 (10143) S13360-1325 (10144)

Extraction of Photoelectron Spectra

- For 18 Hamamatsu MPPCs, we integrate each waveform over time window waveform stays below the baseline ➔ pe spectra are obtained from the measured total charge

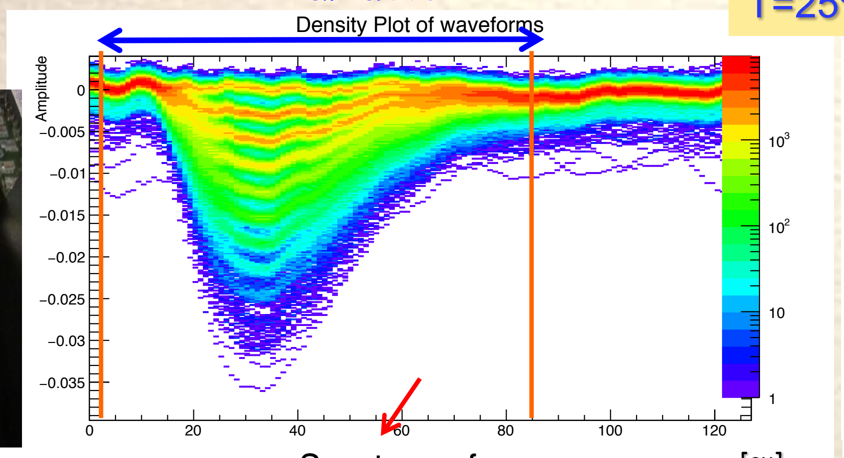
- For 8 KETEK and 4 CPTA SiPMs, we determine the waveform minimum for each pulse from which we extract the pe spectra

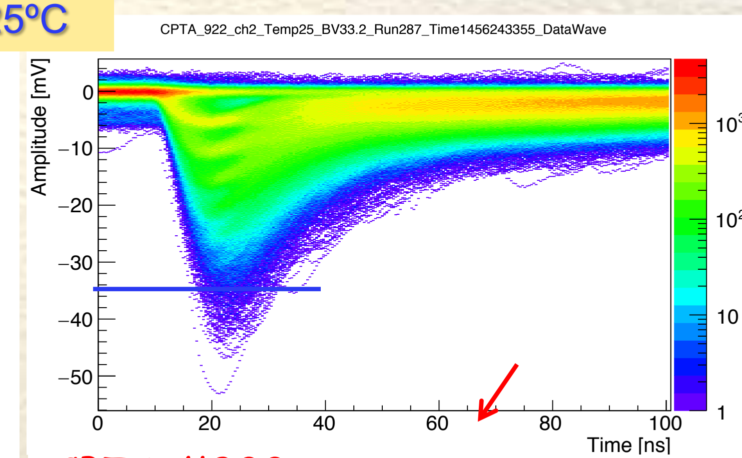
With trenches

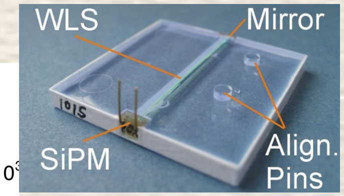


variable

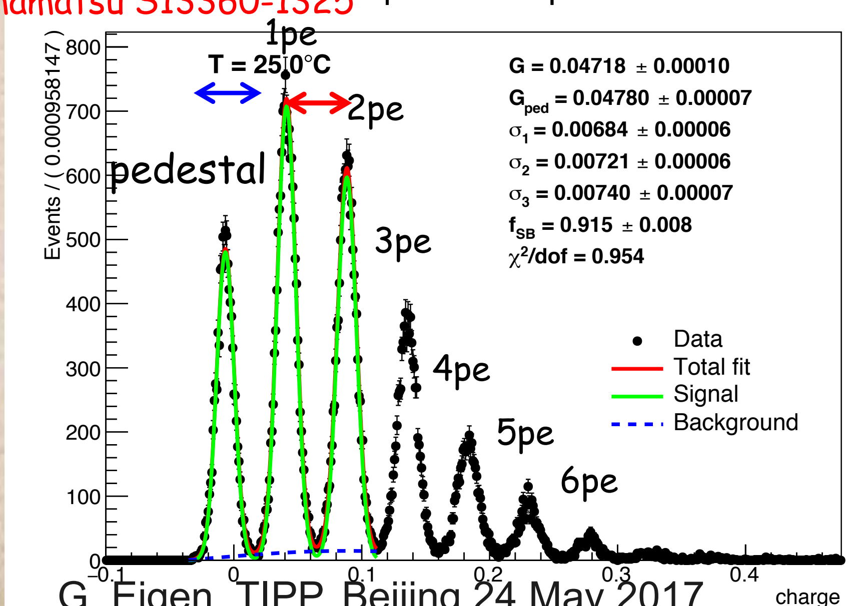
T=25°C



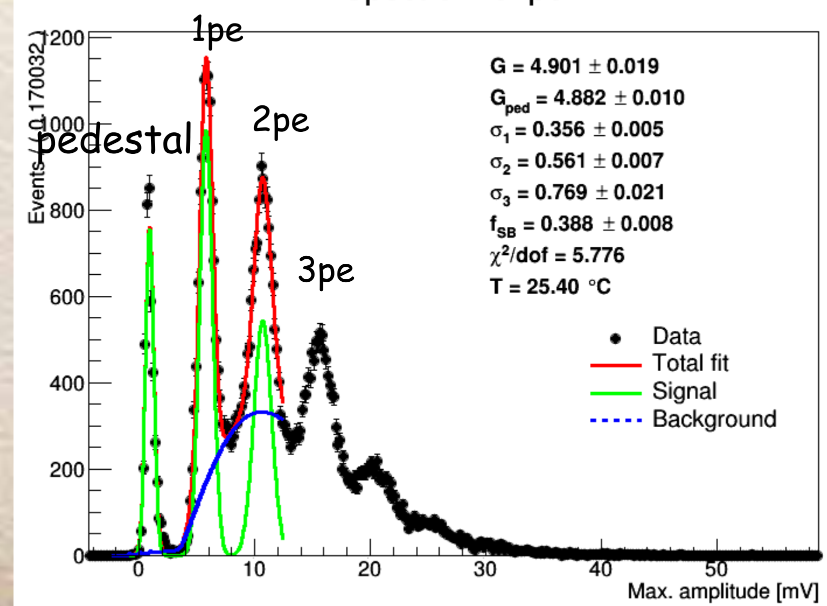




Hamamatsu S13360-1325 Spectrum of pe



CPTA #922 Spectrum of pe



Gain Determination

- **Gain: distance between the first and the second pe peaks**
- Standard fit: separate Gaussian G_i for pedestal, 1. pe peak & 2. pe peak and fractions f_{ped}, f_1

$$F_{sig} = f_{ped} G_{ped} + f_1 G_1 + \left(1 - f_{ped} - f_1\right) G_2$$

- Include background F_{bkg} determined by a sensitive nonlinear iterative peak-clipping algorithm (SNIP) available in ROOT
- Thus, the likelihood function is

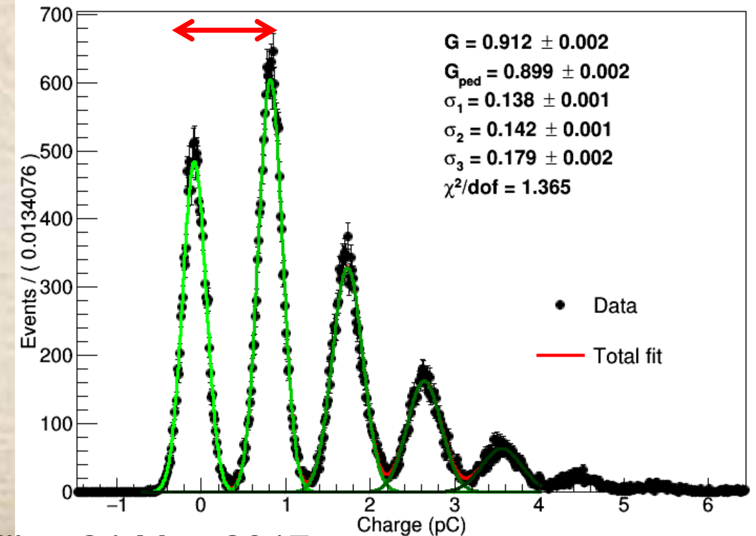
$$L = \prod_{i=1}^{50000} \left[f_s F_{sig}\left(w^i\right) + \left(1 - f_s\right) F_{bkg}\left(w^i\right) \right]$$

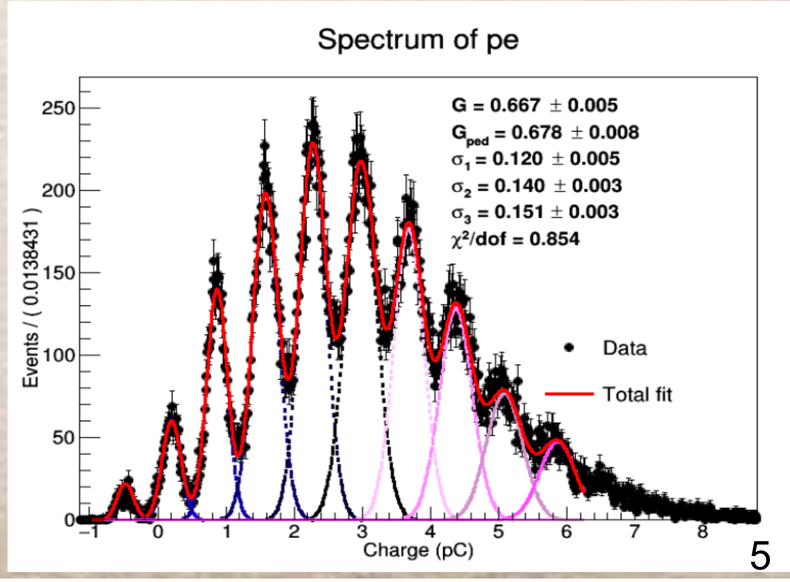
f_s: signal fraction

- New fitting methodology: fit pedestal and all visible peaks with Gaussians G_{ped} and G_i, where all widths are free parameters but distance between pe peaks is fixed, except for distance between pedestal and first pe peak

$$F_{sig} = f_{ped} G_{ped} + \sum_{i=1}^{n-1} f_i G_i + \left(1 - f_{ped} - \sum_{i=1}^{n-1} f_i\right) G_n$$

- No background polynomial yet
- Perform binned fits of pe spectra extracted from 50000 wave forms



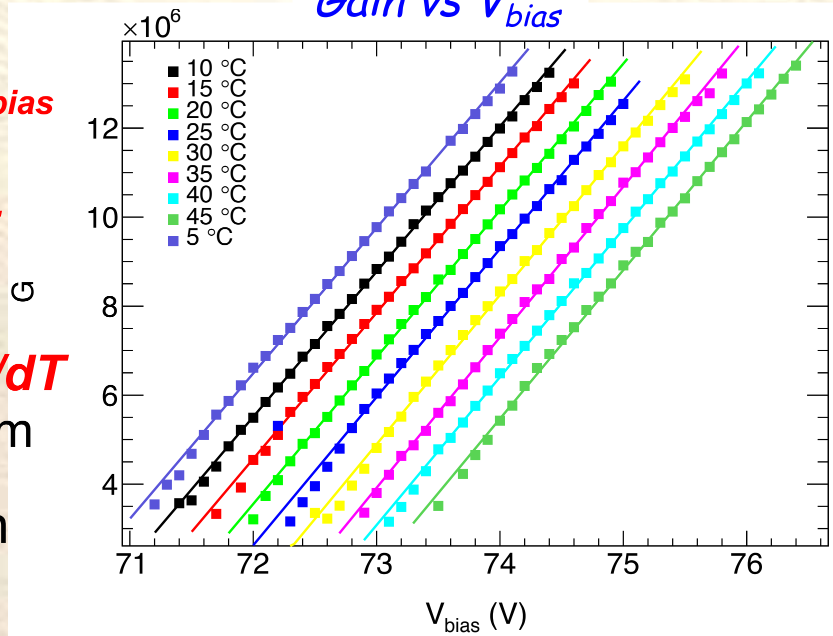


dG/dT, dG/dV & dV/dT Measurements (new fits)

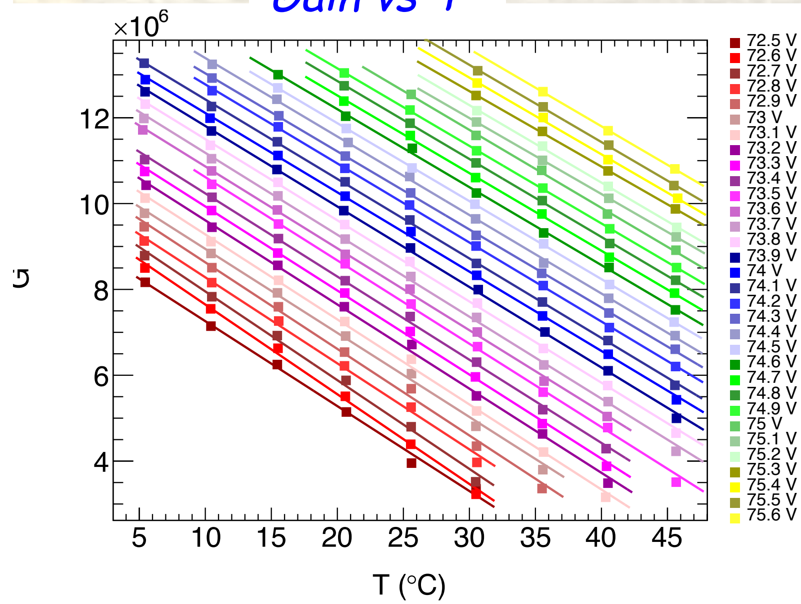
- For fixed T measure ***dG/dV_bias***
- For fixed V_{bias} measure ***dG/dT***
- For fixed T extract all ***dV_bias/dT*** and average them
- Do this for each SiPM

Hamamatsu B2-20

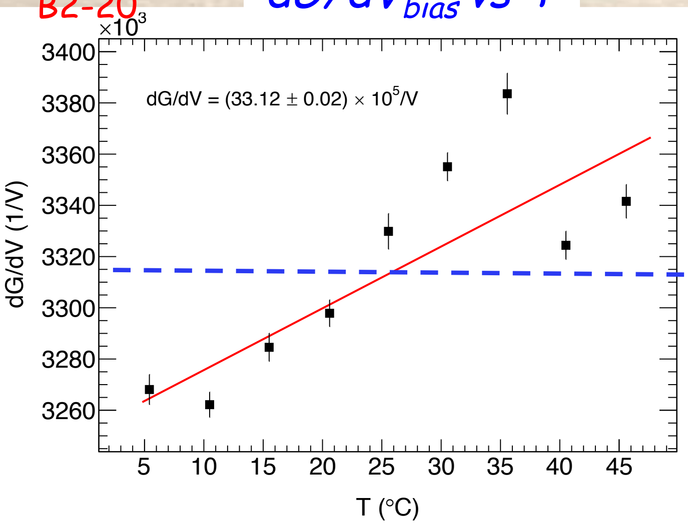
Gain vs V_{bias}



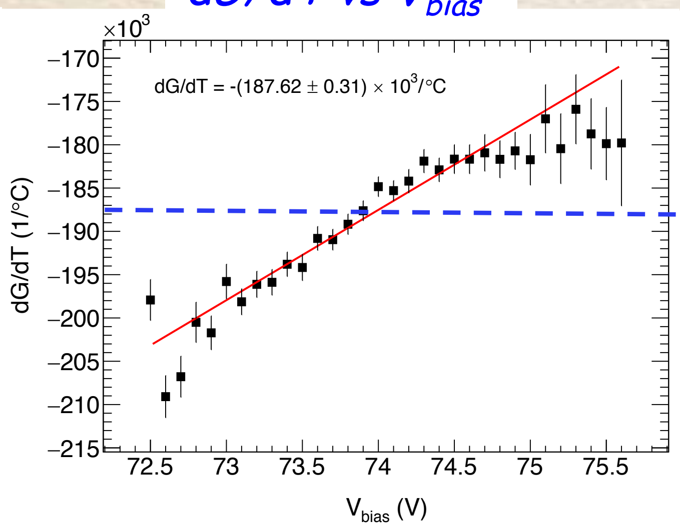
Gain vs T



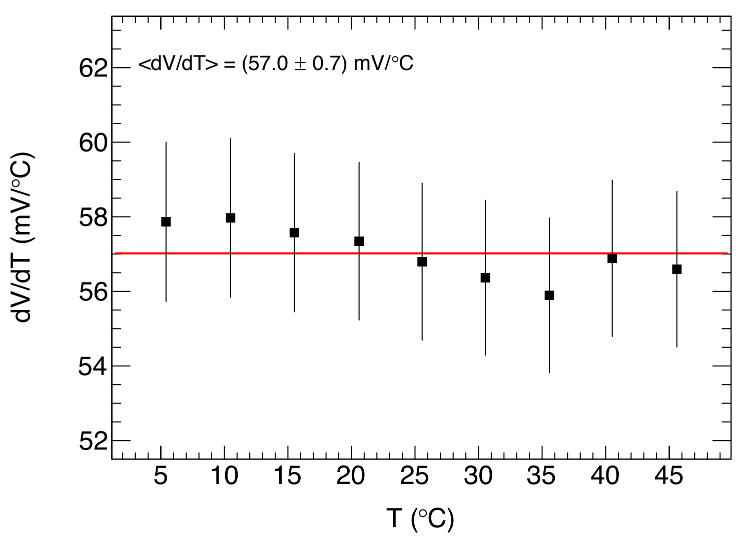
dG/dV_{bias} vs T



dG/dT vs V_{bias}



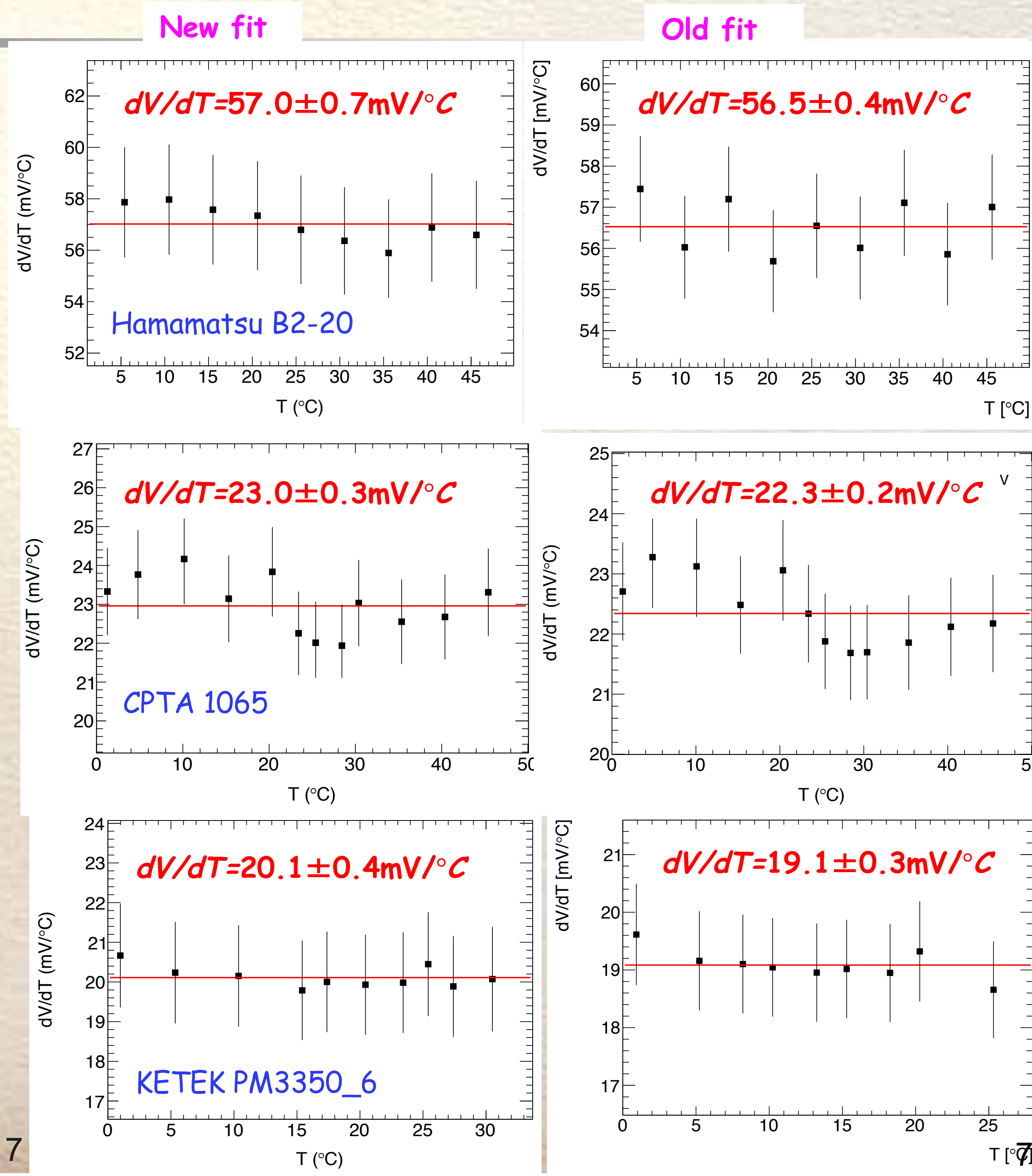
dV_{bias}/dT vs T



- ***dG/dV***=**(33.12±0.02$_{stat}$)×10⁶/V**
- ***dG/dT***=**-(1.8762±0.0031)×10⁵/°C**
- ***dV/dT***=**(57.0±0.1$_{sys}$) mV/°C**

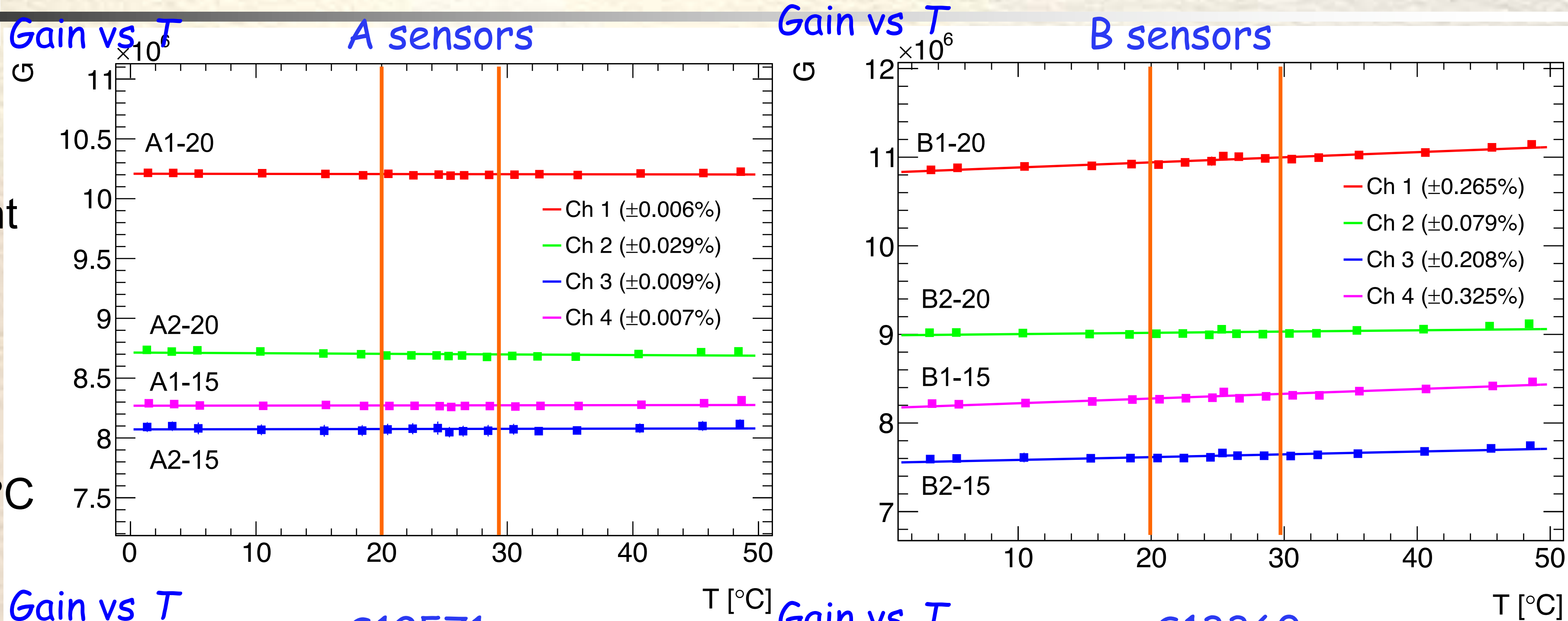
Compare 2 Fitting Strategies

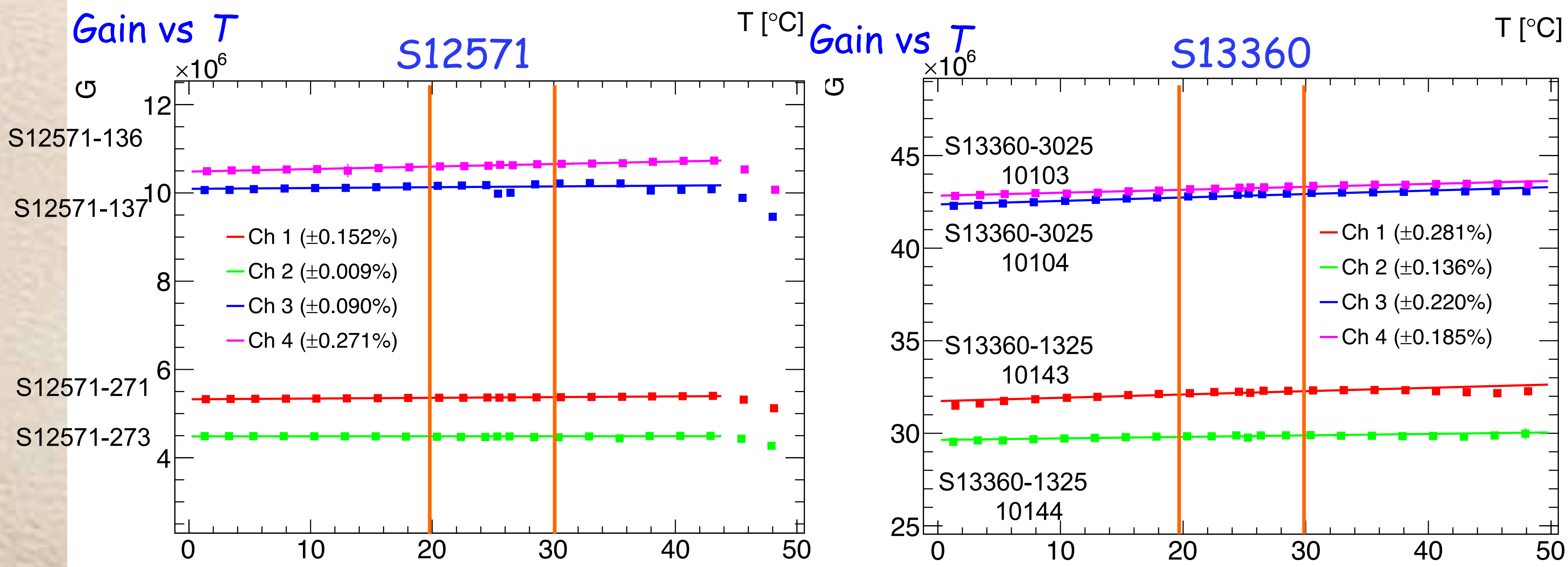
- We obtain the **same** dV/dT for Hamamatsu A, B & S12571 MPPCs within errors for both fitting strategies
- For KETEK and CPTA SIPMs we have tested the new fitting methodology on one channel so far
- For these two SiPMs, dV/dT values agree within two agree within 2 standard deviations
- We will do the remaining KETEK and CPTA SiPMs soon



Gain Stabilization for Hamamatsu MPPCs (old fits)

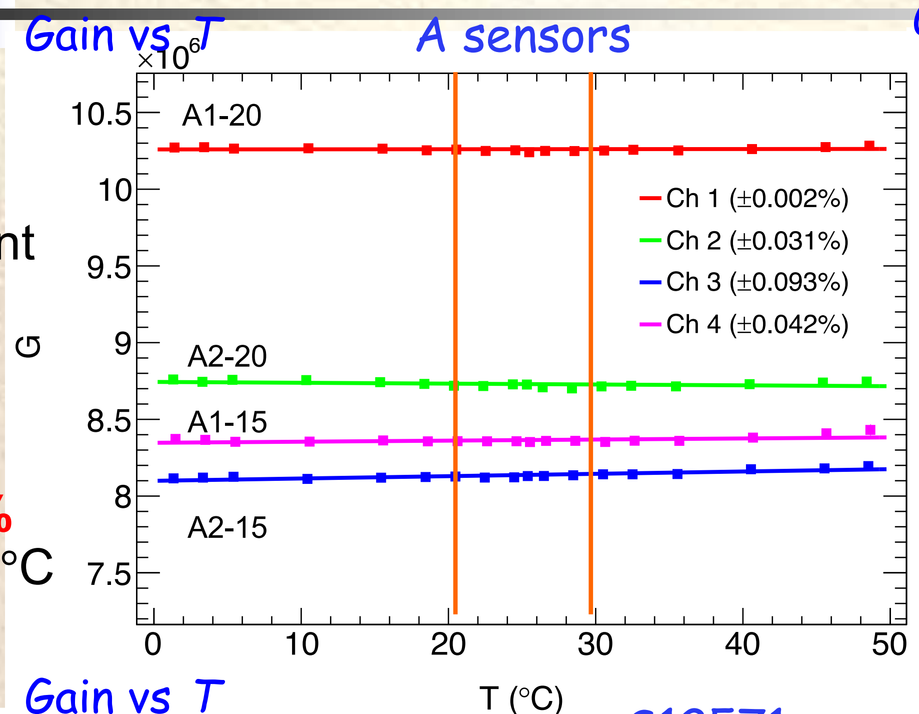
- All 16 MPPCs satisfy requirement that deviation from stability Is **<±0.5%** in 20° –30°C *T* range

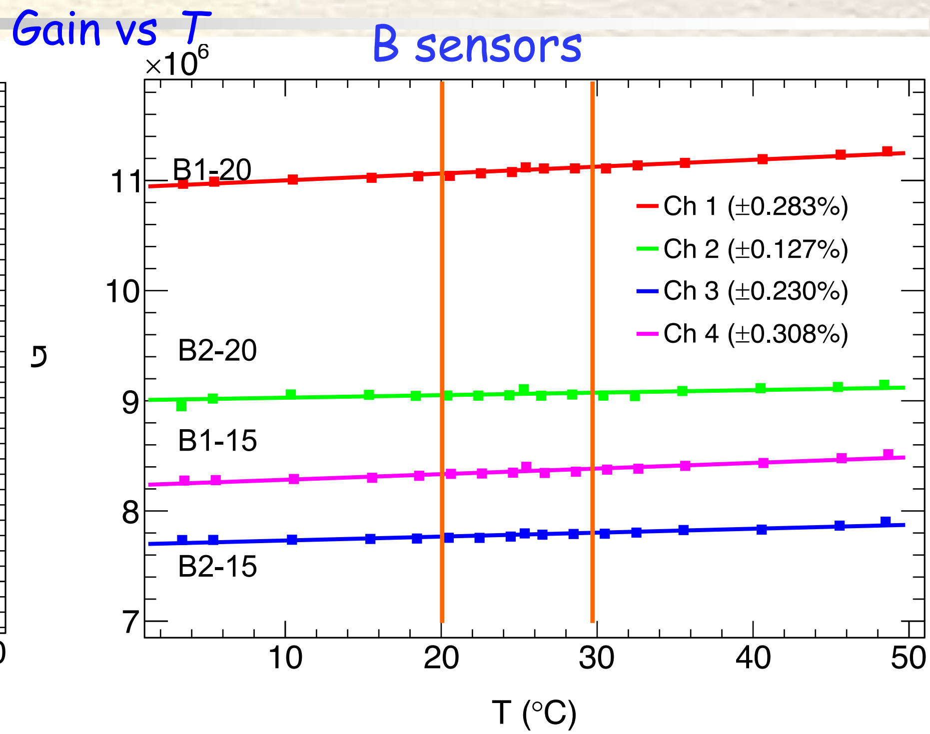


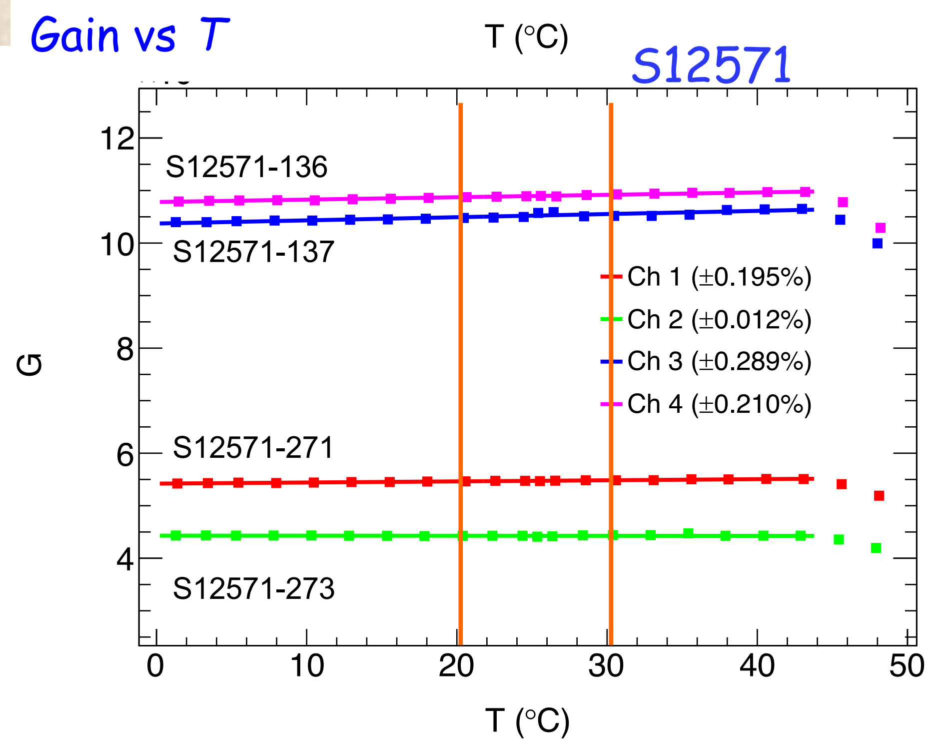


Gain Stabilization for Hamamatsu MPPCs (new fits)

- All 12 MPPCs satisfy requirement that deviation from stability Is **<±0.5%** in 20° –30°C *T* range

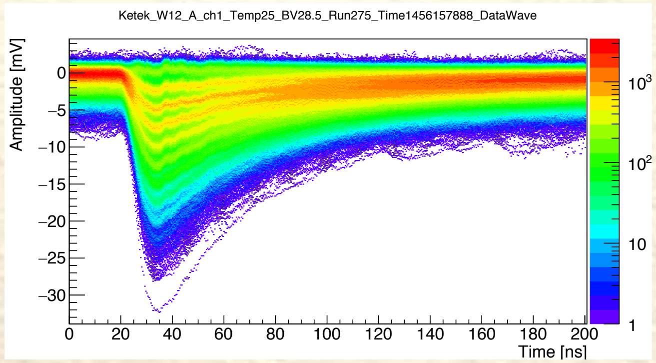


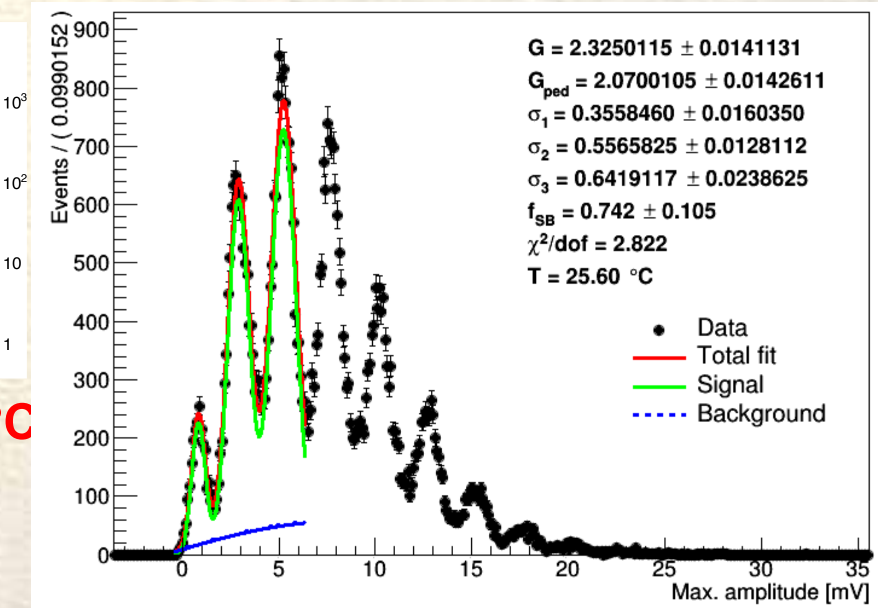




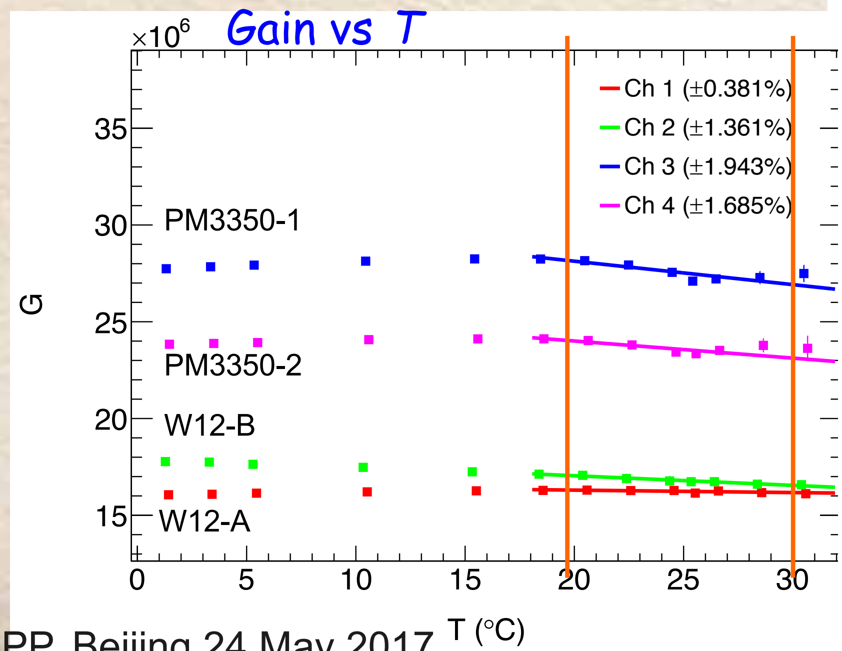
Gain Stabilization of KETEK SiPMs

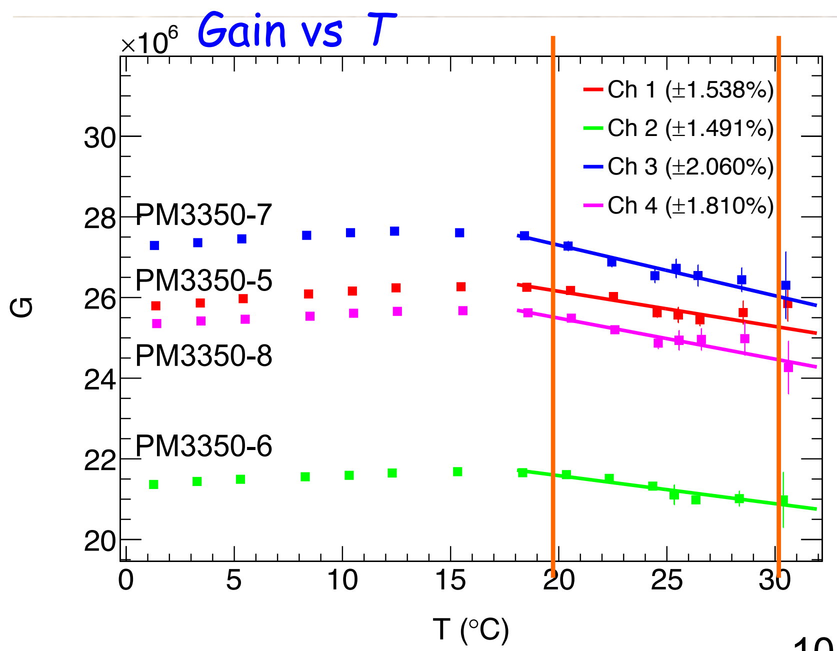
- Decay time of KETEK SiPMs is much longer than that of other SiPMs ➔waveforms typically do not return to baseline within 200 ns wide integration window





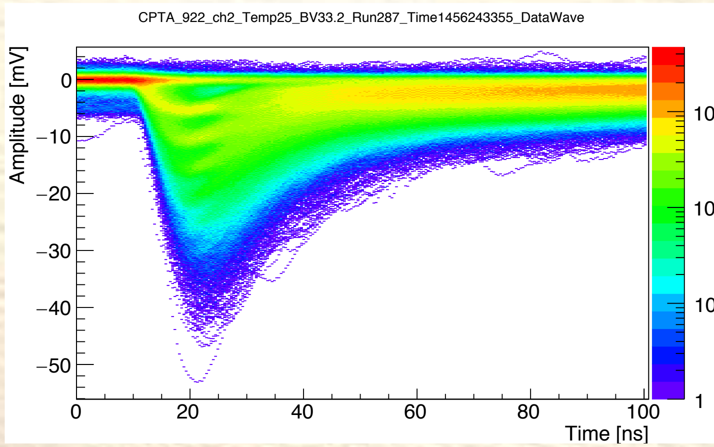
- Simultaneous gain stabilization for 4 KETEK SiPMs in two batches: ***dV/dT*=18.2 mV/°C**
- KETEK sensors show more complicated V(T) behavior ➔linear correction is not sufficient
- 1°C -18°C: G rises
- 18°C -22°C: G is uniform
- 22°C-30°C G falls off
- Only 1 SiPM satisfies **<±0.5%** requirement

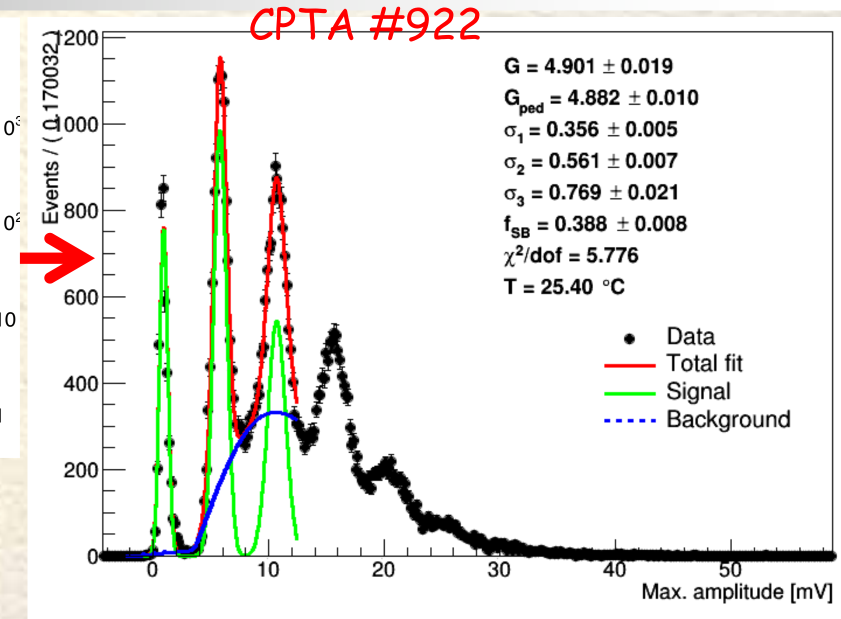




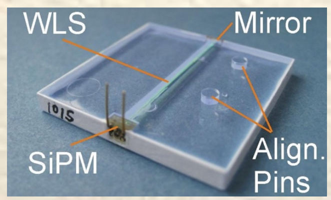
Gain Stabilization of CPTA SiPMs

- CPTA SiPMs are illuminated via scintillator tile

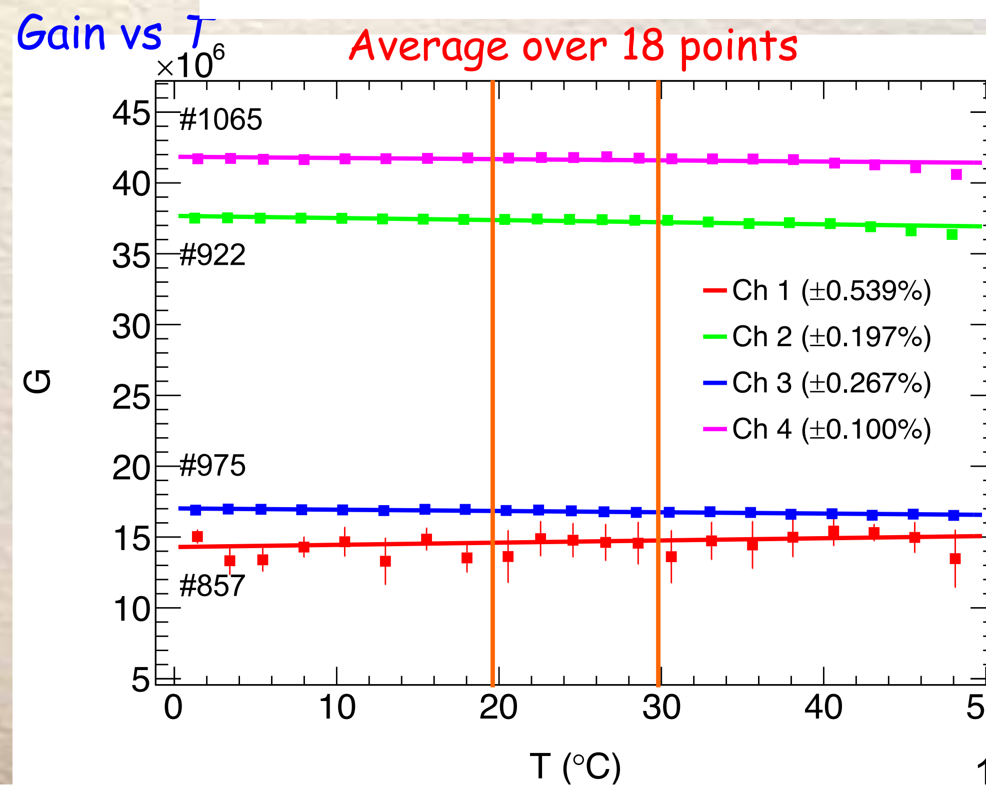




- We adjust V_{bias} with regulator board using dV/dT=21.2 mV/°C to stabilize 4 CPTA SiPMs simultaneously

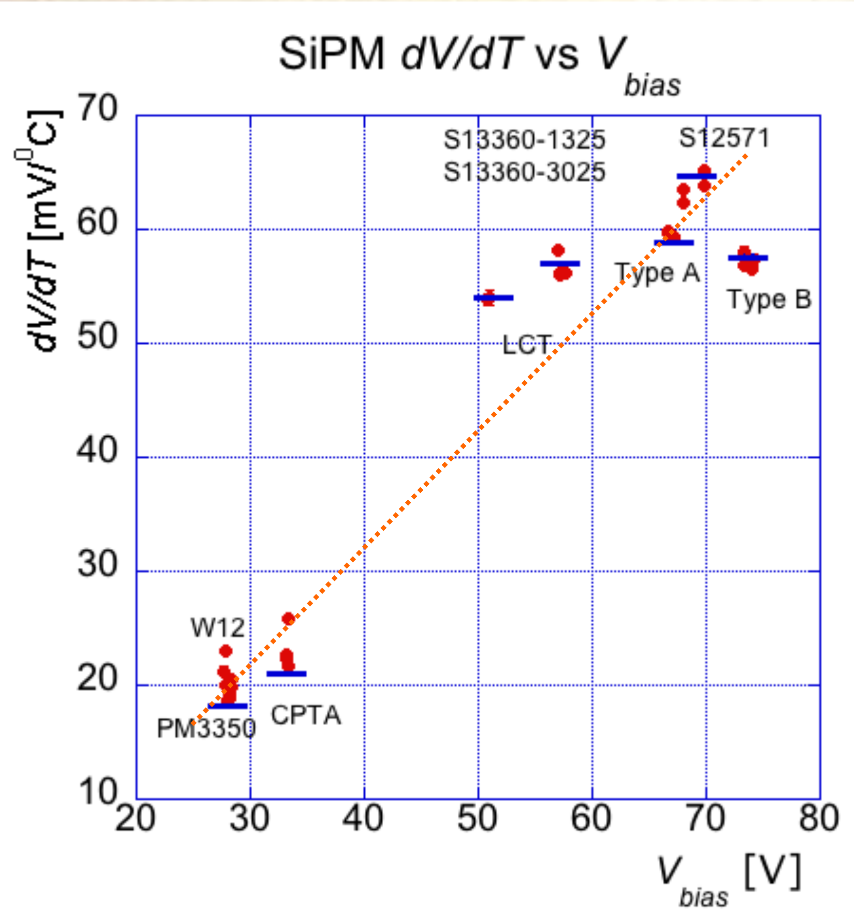


- We test gain stability within T=1°- 48°C taking ≥ 18 samples of 50k waveform samples at each T
- The gain is nearly uniform up to 30°C,
- SiPMs in ch# 2 and ch#4 look fine; ch#1 is noisy, ch#3 changed gain but looks ok
- Three SiPMs satisfy our requirement of **>±0.5%** within 20°C -30°C T range



Measured *dV/dT* Values vs V_{bias} (old fits)

- Look for correlations between operating voltage and measured *dV/dT* for all SiPMs



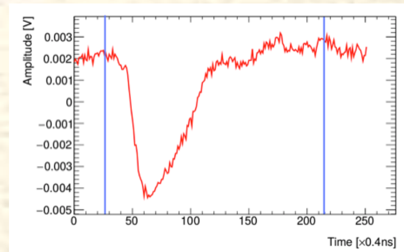
MPPC	dV/dT [mV/°C]
A1-15	59.2±0.4
A2-15	59.3±0.3
A1-20	59.6±0.4
A2-20	59.8±0.3
B1-15	57.3±0.5
B2-15	56.5±0.3
B1-20	56.9±0.4
B2-20	58.0±0.5
S12571-271	63.9±0.2
S12571-273	65.2±0.2
S12571-136	63.5±0.3
S12571-137	62.3±0.3
LCT4#6	53.9±0.5
LCT4#9	54.0±0.7
S13360-10143	56.2.±0.3
S13360-10144	58,1±0.3
S13360-10103	56.0±0.2
S13360-10104	56.1±0.1

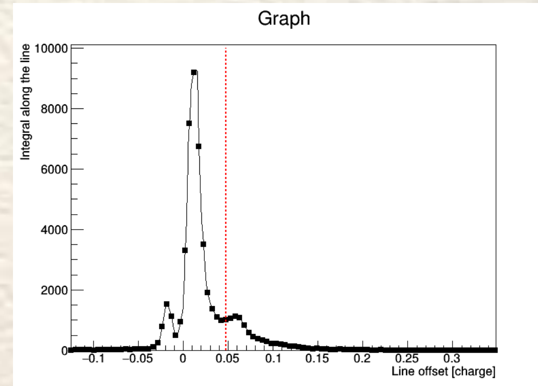
SiPM	dV/dT [mV/°C]
W12A	21.2±0.4
W12B	23.0±0.2
PM3350	20.0±0.3
PM3350	18.7±0.4
PM3350	18.8±0.2
PM3350	19.1±0.3
PM3350	20.5±0.2
PM3350	19.8±0.4
#857	21.6±0.4
#922	22.6±0.2
#875	25.9±0.3
#1065	22.3±0.2

- *dV/dT* increases with V_{bias}
- KETEK & CPTA SiPMs have larger *dV/dT* spread than Hamamasu MPPCs of same type
- Hamamatsu MPPC with trenches have lower bias voltage for similar dV/dT

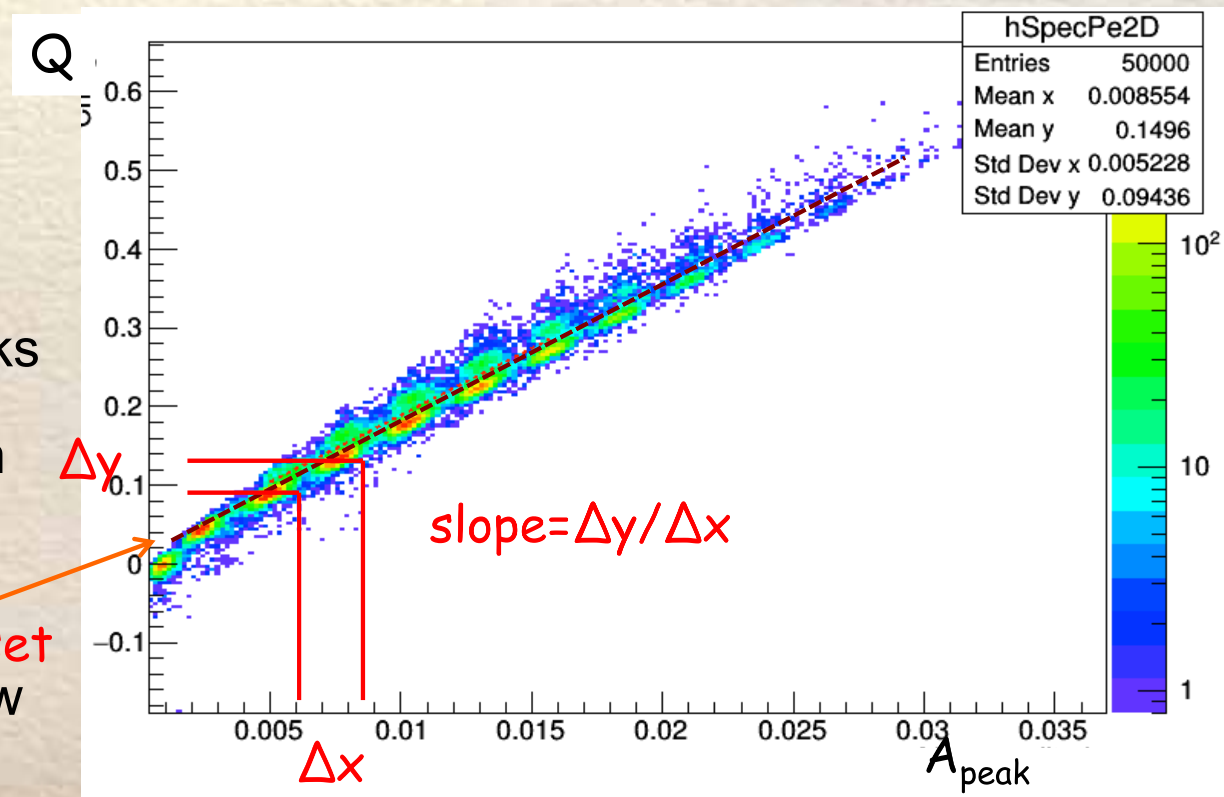
Does Afterpulsing affect Gain Stabilization?

- We determine the pe spectra from the waveforms in 2 ways
  - integrated charge Q
  - magnitude of the peak A_{peak}





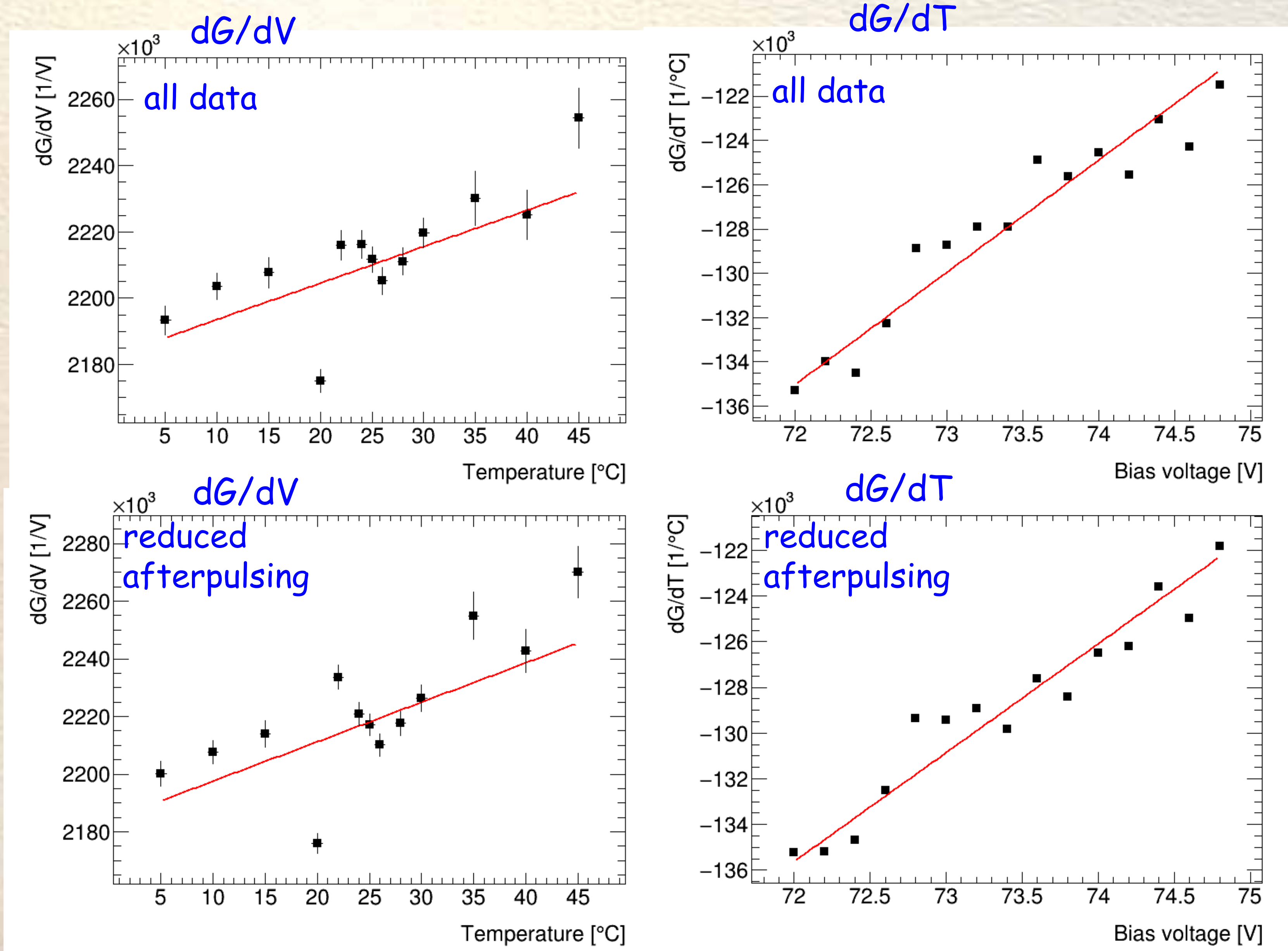
- We analyze the scatter plot of Q versus A_{peak}
- Signal without afterpulsing lies on the diagonal
- Signal with afterpulsing is shifted upwards since waveform is broadened due to delayed secondary signal
- Set slope with 2pe & 3pe peaks
- Dashed line is chosen to be in valley between the 2 regions ➔ best separation
- Redo analysis for region below dashed line



dG/dV & dG/dT for Reduced Afterpulsing

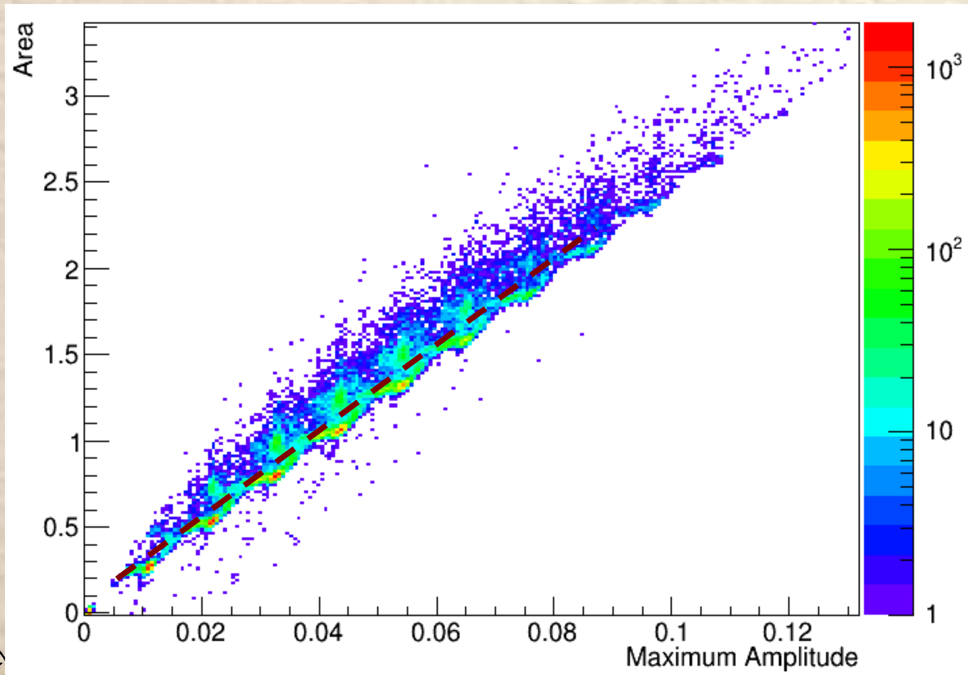
- The dG/dV & dG/dT distributions for sample with reduced afterpulsing look look similar as those for all data

- Within errors get the same fit results
  ➔ visually slopes of red lines are the same

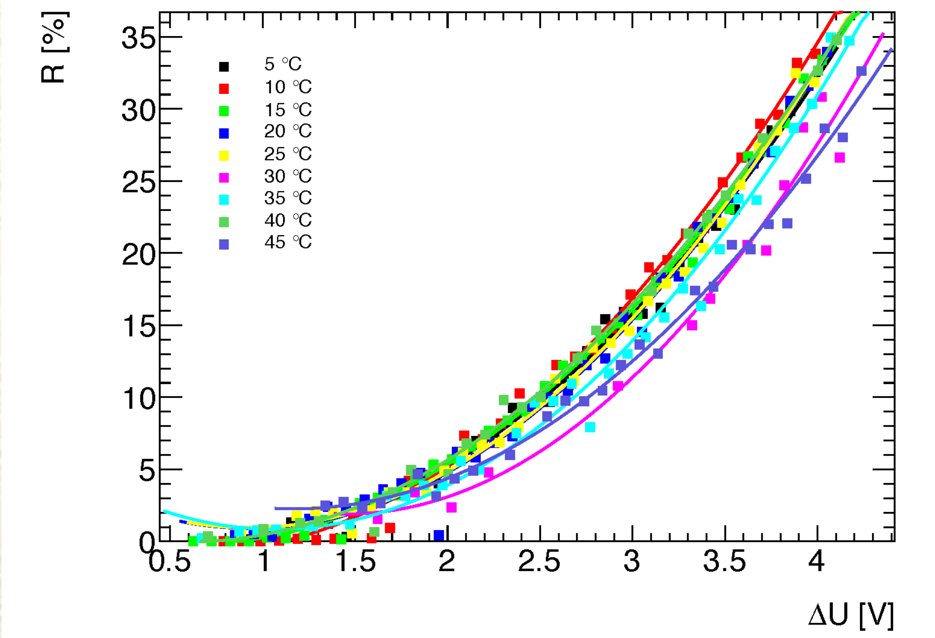


Afterpulsing of LCT4 MPPCs

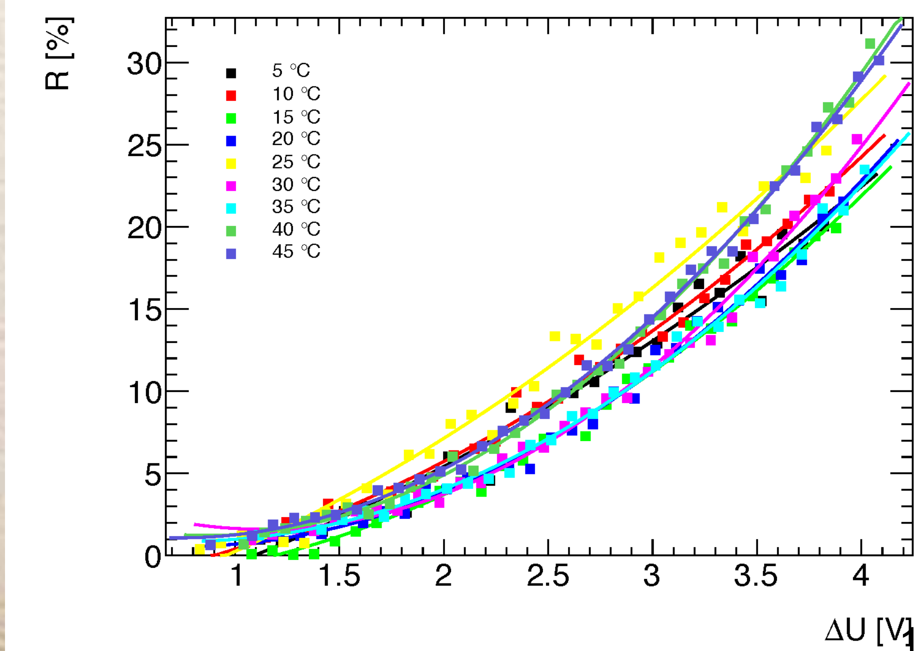
- Define afterpulsing
  R=events above dashed line/all events
- Study R as a function of V_{bias} for each T
- R shows rapid increase with V_{bias}
- R shows no explicit T dependence
  ➔ Spread indicates systemematic effects of procedure



LCT4#6



LCT4#9



Conclusions and Outlook

- We successfully completed gain stabilization tests for 30 SiPMs and demonstrated that batches of SiPMs can be stabilized with **one** ***dV/dT*** correction
- All 18 Hamamatsu MPPCs, 6 with trenches and 12 without trenches, satisfy the goal: **$\Delta G/G < \pm 0.5\%$** in the 20°C-30°C *T* range ➔ most MPPCs satisfy **$\Delta G/G < \pm 0.5\%$** in the extended *T* range 1°C-50°C
- Gain stabilization of KETEK SiPMs is more complicated,
  - Signals are rather long and are affected by afterpulsing
  - range of stabilization is limited to 1°C-30°C *T* range where SiPMs have more complex V(T) behavior ➔need individual ***dV/dT*** values to stabilize gain of 4 SiPMs in 20°C-30°C *T* range
- Gain stabilization of CPTA SiPMs works fine
  ➔ for 3 SiPMs, **$\Delta G/G < \pm 0.5\%$** is satisfied in 20°C-30°C range
  ➔ procedure works with scintillator and wavelength shifter attached
- We checked all Hamamatsu MPPCs without trenches with new fit model and get the same results; for MPPCs with trenches we need 2 Gaussians per peak
- In the analog HCAL for ILC, V_{bias} adjustment will be implemented on electronics board
- Afterpulsing does not affect gain stabilization results
- Afterpulsing strongly depends on overvoltage not temperature

Acknowledgment

- We would like to thank L. Linssen, Ch. Joram, W. Klempt, and D. Dannheim for using the E-lab and for supplying electronic equipment

- We further would like to thank the team of the climate chamber at CERN for their support

SiPM Properties

- Test 18 Hamamatsu MPPCs (6 w trenches), 8 KETEK SiPMs and 4 CPTA SiPMs

SiPM	Serial#	Size [mm^2]	Pitch [μm]	#pixels	V_{bias} [V]	Gain [10^6]	SiPM	Serial#	Size [mm^2]	Pitch [μm]	#pixels	V_{bias} [V]	Gain [10^6]
Type A	A1	1×1	15	4440	67.22	0.2	W12	1	3×3	20	12100	28	0.54
Type A	A2	1×1	15	4440	67.15	0.2	W12	2	3×3	20	12100	28	0.54
Type A	A1	1×1	20	2500	66.73	0.23	PM33	1	3×3	50	3600	28	8
Type A	A2	1×1	20	2500	67.7	0.23	PM33	2	3×3	50	3600	28	8
Type B	B1	1×1	15	4440	74.16	0.2	PM33	5	3×3	50	3600	28	8
Type B	B2	1×1	15	4440	73.99	0.2	PM33	6	3×3	50	3600	28	8
Type B	B1	1×1	20	2500	73.33	0.23	PM33	7	3×3	50	3600	28	8
Type B	B2	1×1	20	2500	73.39	0.23	PM33	8	3×3	50	3600	28	8
S12571	271	1×1	10	10000	69.83	1.35	CPTA	857	1×1	40	625	33.4	0.71
S12571	273	1×1	10	10000	69.87	1.35	CPTA	922	1×1	40	625	33.1	0.63
S12571	136	1×1	15	4440	68.08	2.29	CPTA	975	1×1	40	625	33.3	0.63
S12571	137	1×1	15	4440	68.03	2.30	CPTA	1065	1×1	40	625	33.1	0.70
LCT4	6	1×1	50	400	53.81	1.6							
LCT4	9	1×1	50	400	53.98	1.6							
S13360	10143	1.3×1.3	25	2668	57.18	0.7							
S13360	10144	1.3×1.3	25	2668	57.11	0.7							
S13360	10103	3×3	25	14400	57.6	1.7							
S13360	10104	3×3	25	14400	56.97	1.7							

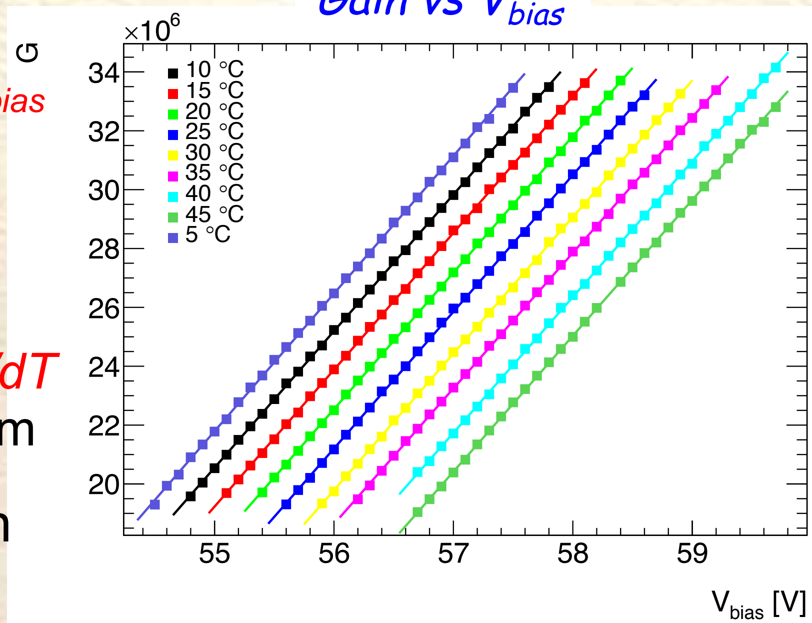
- Use 3 types of MPPCs with trenches
  - Two experimental samples (LCT4)
  - Two 1.3 × 1.3 mm^2 sensors
  - Two 3 × 3 mm^2 sensors

dG/dV, *dG/dT* & *dV/dT* Measurements

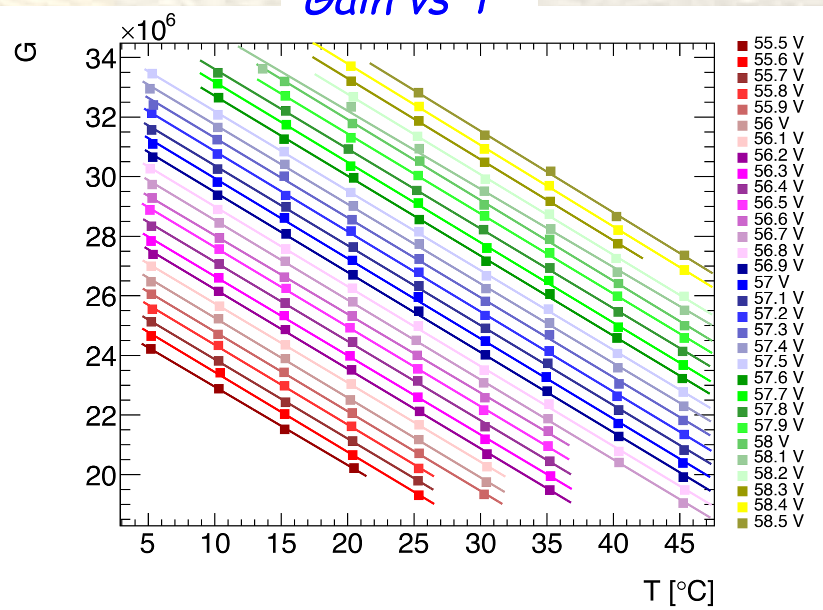
- For fixed T measure dG/dV_{bias}
- For fixed V_{bias} measure dG/dT
- For fixed T extract all dV_{bias}/dT and average them
- Do this for each SiPM

Hamamatsu S13360-1325

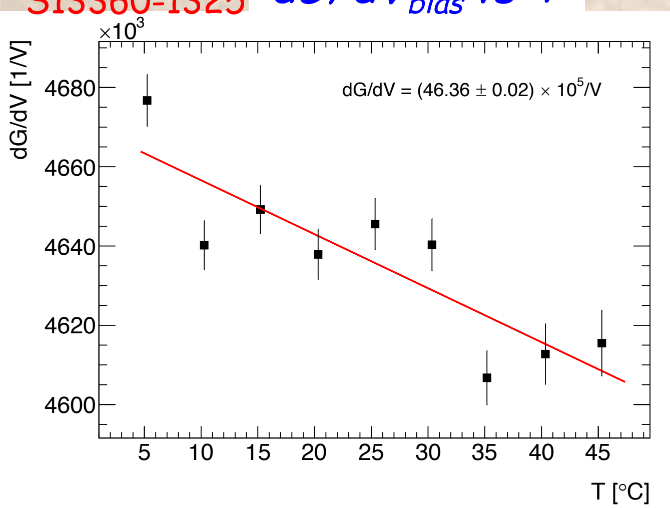
Gain vs V_{bias}



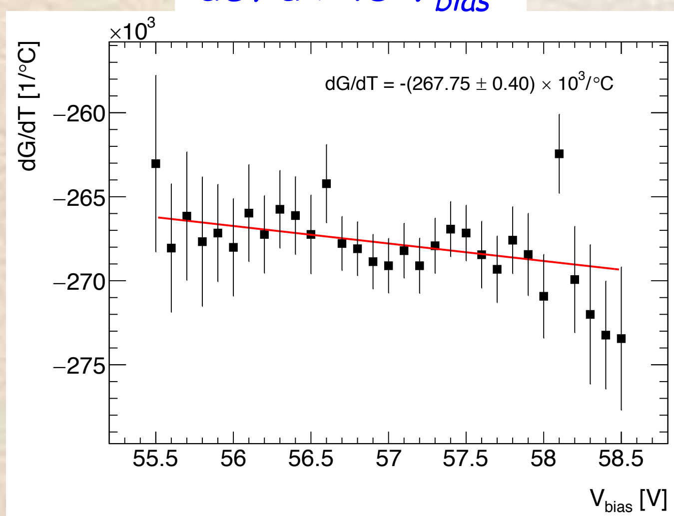
Gain vs T



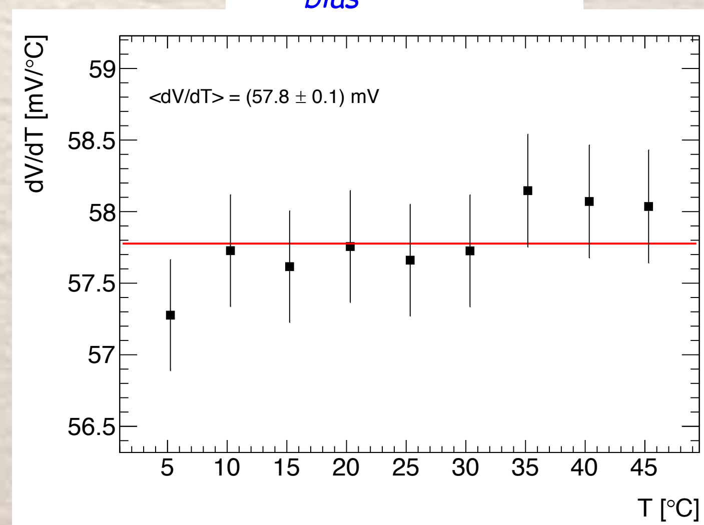
dG/dV_{bias} vs T



dG/dT vs V_{bias}



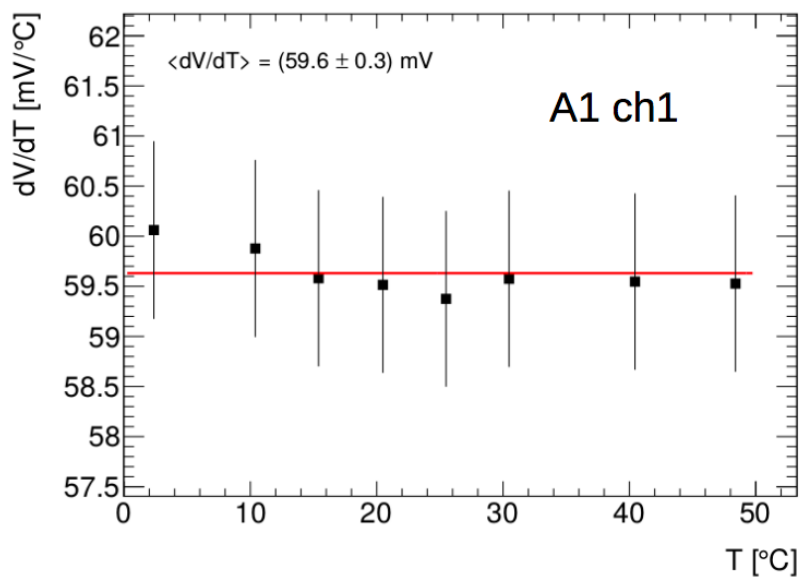
dV_{bias}/dT vs T

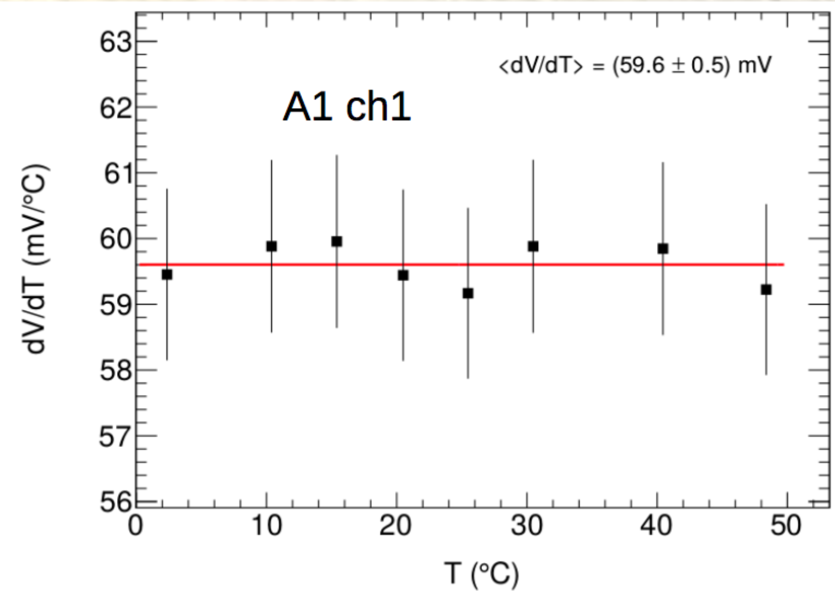


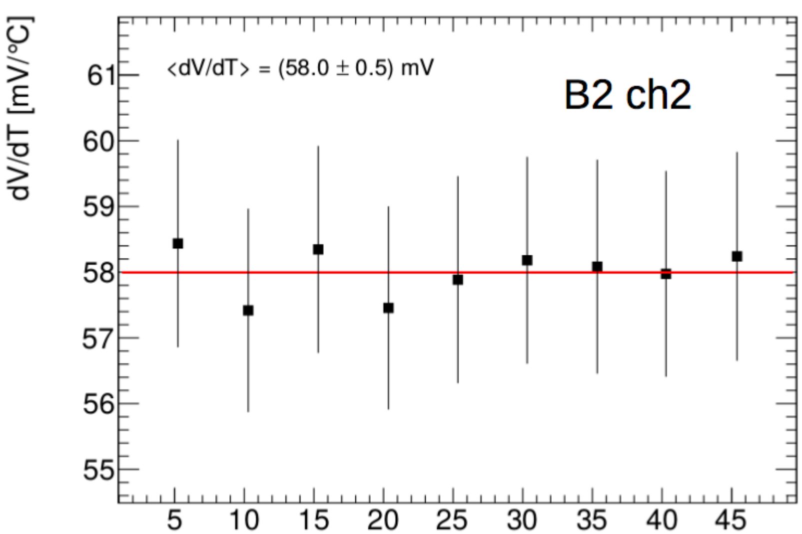
- $dG/dV = (4.636 \pm 0.002_{stat}) \times 10^6/V$
- $dG/dT = (2.6775 \pm 0.004) \times 10^5/°C$
- $dV/dT = (57.8 \pm 0.1_{sys})\ mV/°C$

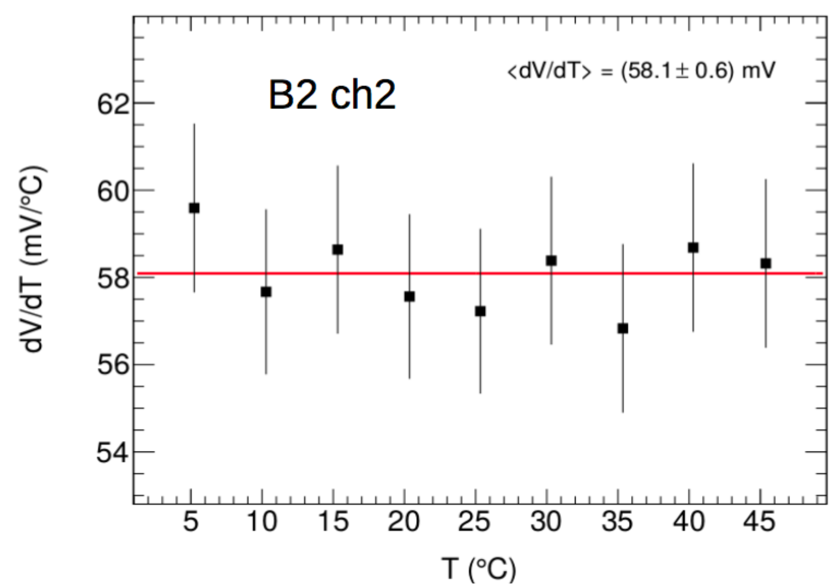
Compare 2 Fitting Strategies for A & B SiPMs

- We obtain same dV/dT for Hamamatsu A and B SiPMs for both fitting strategies









Compare Fitting Strategies for S12571 & S13360 SiPMs

- We obtain same dV/dT for Hamamatsu S12571 and S13369 SiPMs for both fitting strategies