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AIDA-2020

Advanced European Infrastructures for Detectors at Accelerators

Presentation

Gain stabilization of SiPMs and afterpulsing

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Gain Stabilization of SiPMs and Afterpulsing

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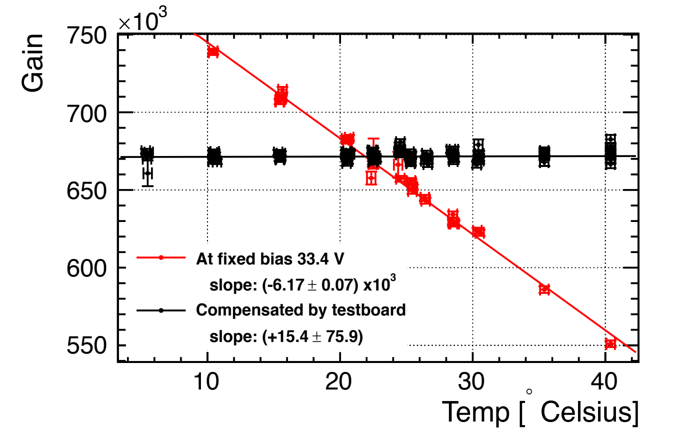
Outline

- Introduction
- Measurement methodology
- Determination of dV_b/dT
- Gain stabilization of Hamamatsu MPPCs
- Gain stabilization of KETEK SiPMs
- Gain stabilization of CPTA SiPMs
- Studies of afterpulsing
- Conclusions and outlook

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 readjusted to compensate for T changes
- This requires the knowledge of ***dV/dT***, which is obtained from measurements of G vs V_b for different T to extract *dG/dV* and *dG/dT* and in turn ***dV/dT***



- Gain stability is important for large detector arrays such as an analog hadron calorimeter for ILC detector
- We tested this procedure in a climate chamber at CERN
  - 1.) For each of 30 SiPMs we measured G vs V_b for different T to extract dV_b/dT
  - 2.) We performed gain stabilization of **30** SiPMs from Hamamatsu, KETEK & CPTA stabilizing 4 SiPMs simultaneously with one ***dV/dT*** compensation value

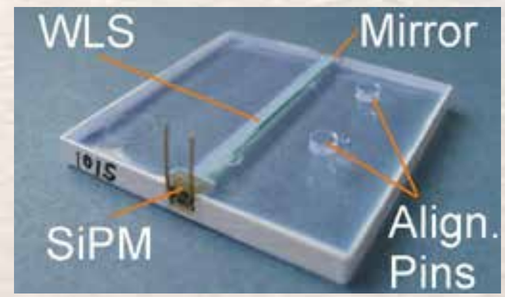
    ➔ perform automatic compensation with adaptive power supply

- Goal: **achieve stable gain if *ΔG/G* <±0.5% in 20°-30°C range**

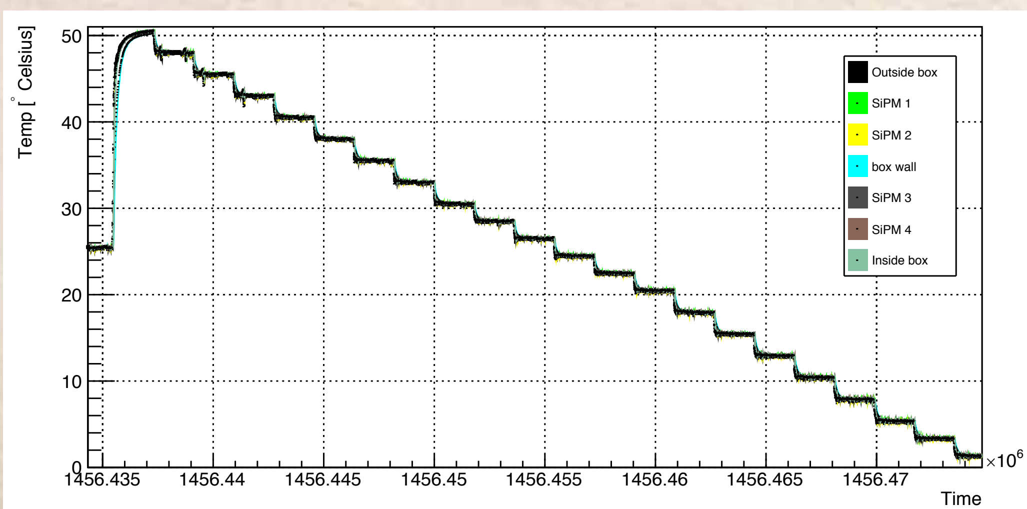
Temperature Measurements

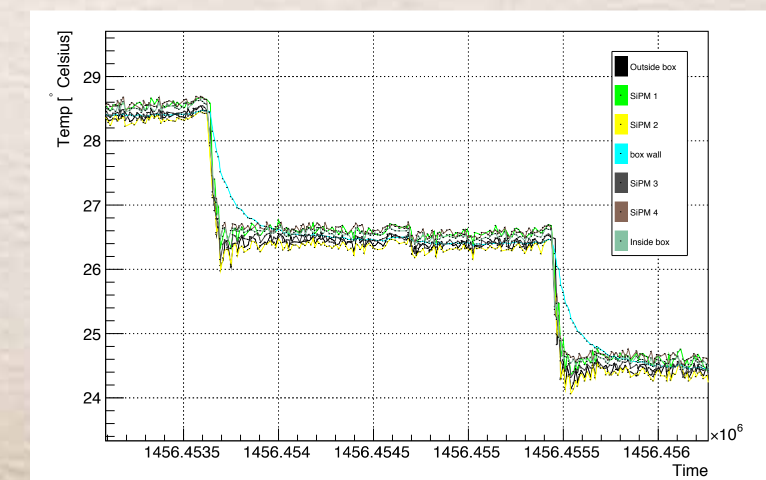
- We shine blue LED light via optical fibers on each SiPM
- At a rate of 10kHz, the light is pulsed using sinusoidal pulse above a fixed threshold; signal is 3.4 ns wide
- Each signal of the 4 SiPMs is recorded with a 12 bit digital scope after amplification by a 2-stage preamp
- Hamamatsu & KETEK SiPMs are illuminated directly

- CPTA sensors are glued to a WLS fiber placed in a groove in a scintillator tile
  ➔ light has to pass through the tile and WLS fiber



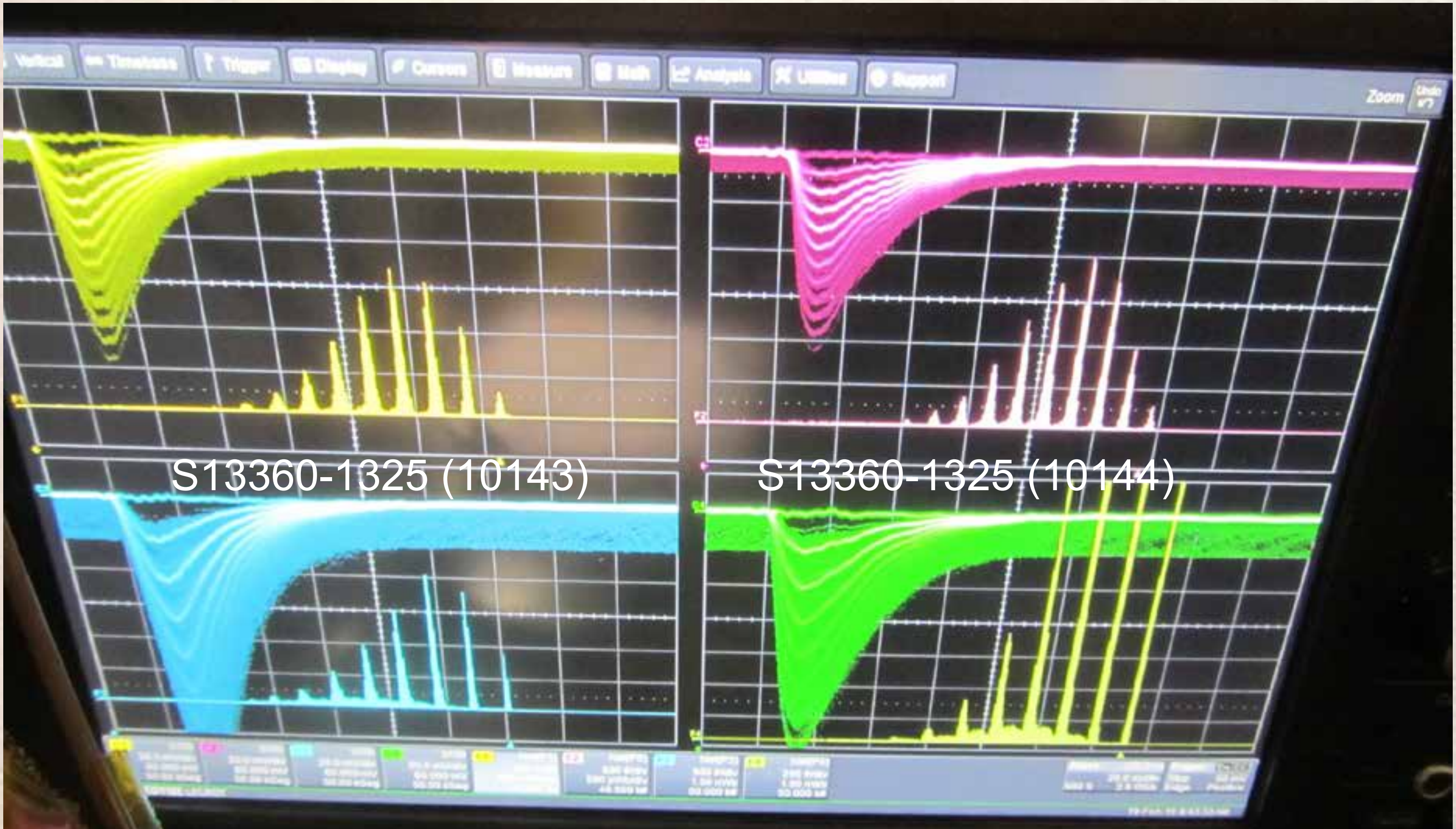
- Vary *T* from 48°-2°C (20°-30°C) in 2.5°C (2°C) steps
  - $T_{SiPM}=T_{set}$ ±0.5°C (ramp up/down); accuracy ~±0.2°C





Study of Hamamatsu MPPCs with Trenches

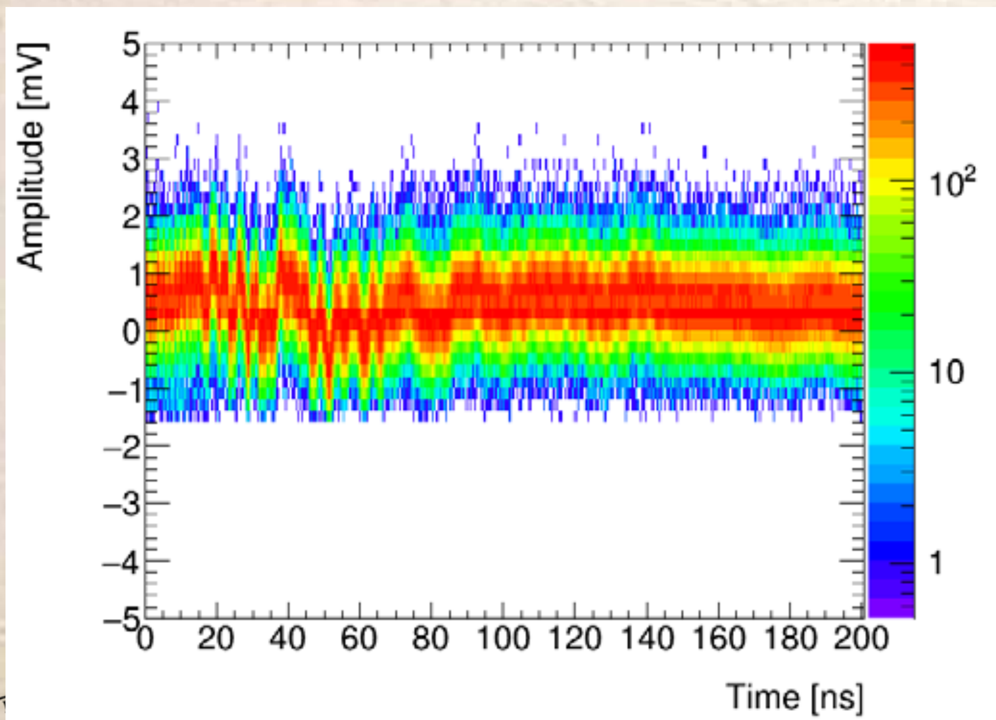
- Waveform and pe spectra of 4 S13360 MPPCs (trenches)
- S13360-3025 (10103) S13360-3025 (10104)

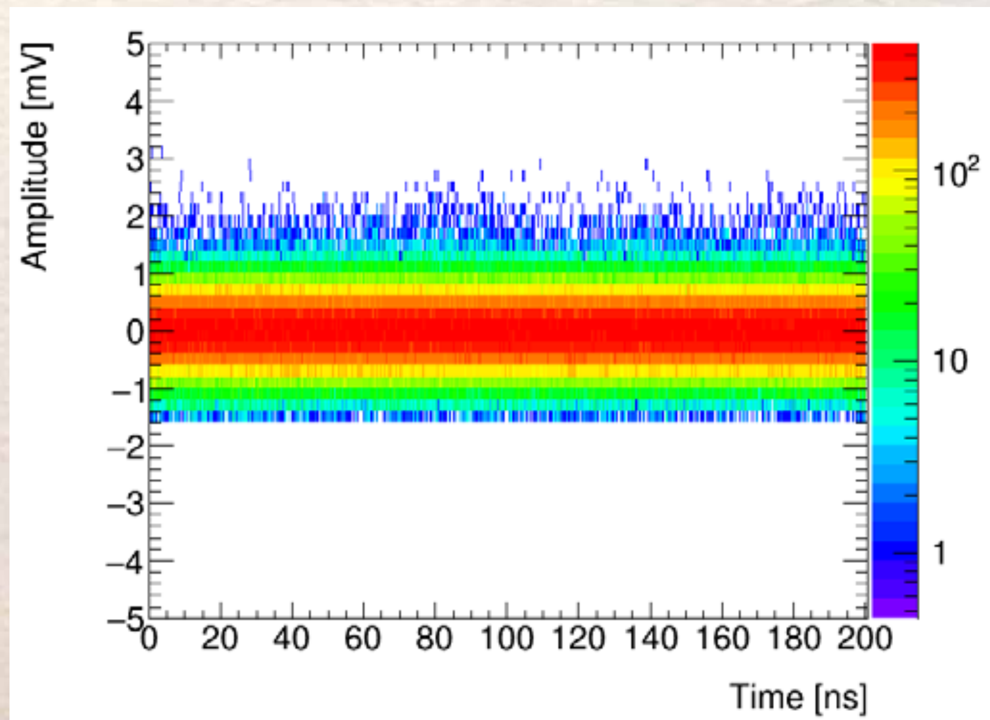


- S13360-1325 (10143) S13360-1325 (10144)

Removal of Parasitic Noise Signal

- We remove a parasitic noise signal caused by a defective light pulse cable
- First, we sample 21 points before the signal waveform starts (8.4 ns)
- We fit the distribution with a Gaussian function and define a threshold by $\mu-3\sigma$
- We select all pedestal distributions that lie above the threshold
- We determine the average and subtract it from all waveforms

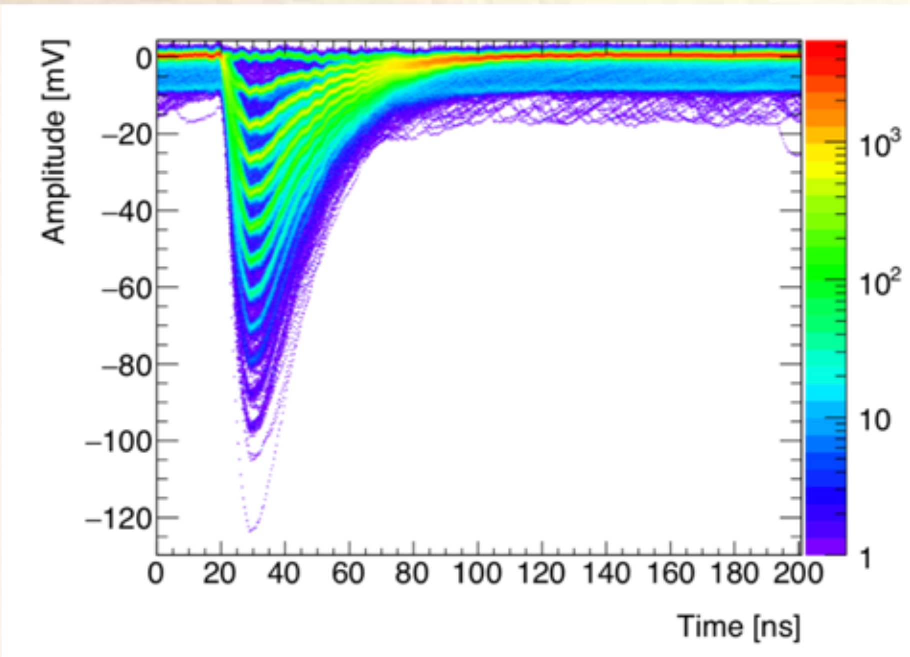




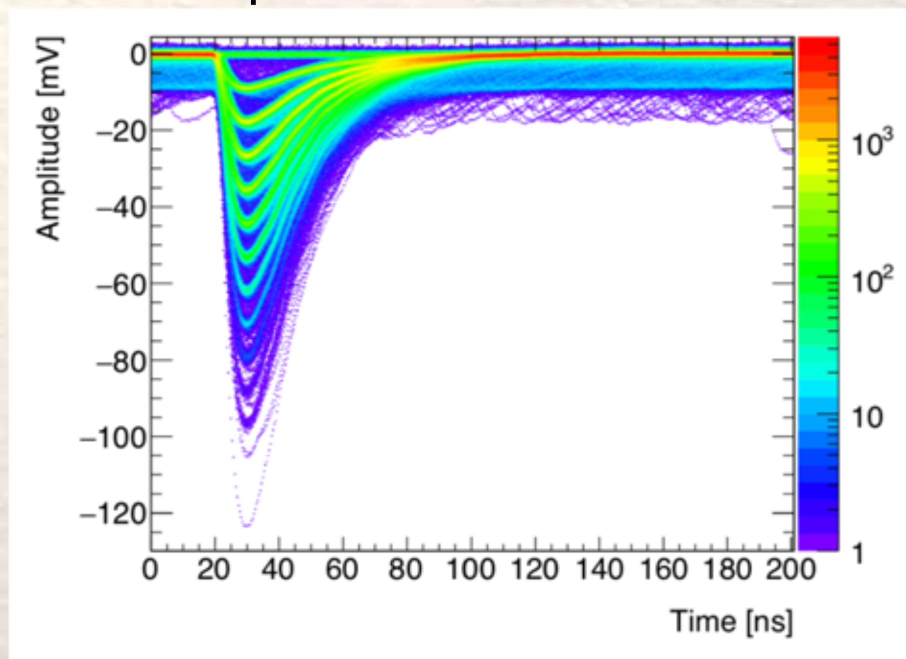
Removal of Parasitic Noise Signal

- Removing the parasitic noise signal improves the shape of the waveforms
- This, in turn, improves the determination of the peak positions

Before parasitic noise removal



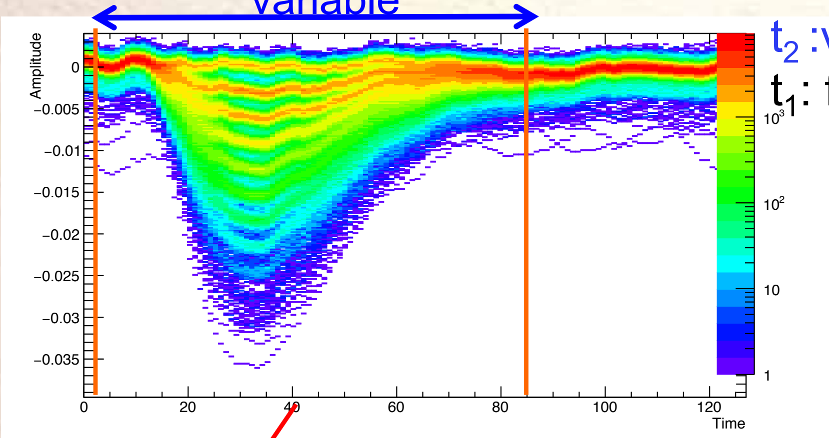
After parasitic noise removal

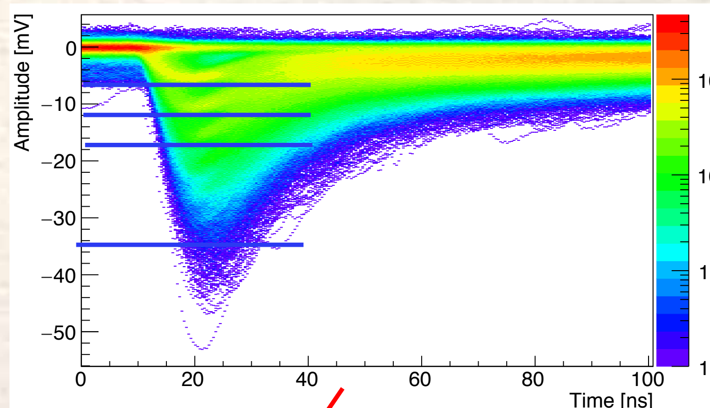


- We then extract photoelectron spectra using 2 methods
  - Integrate waveform
  - Determine minimum of the waveform

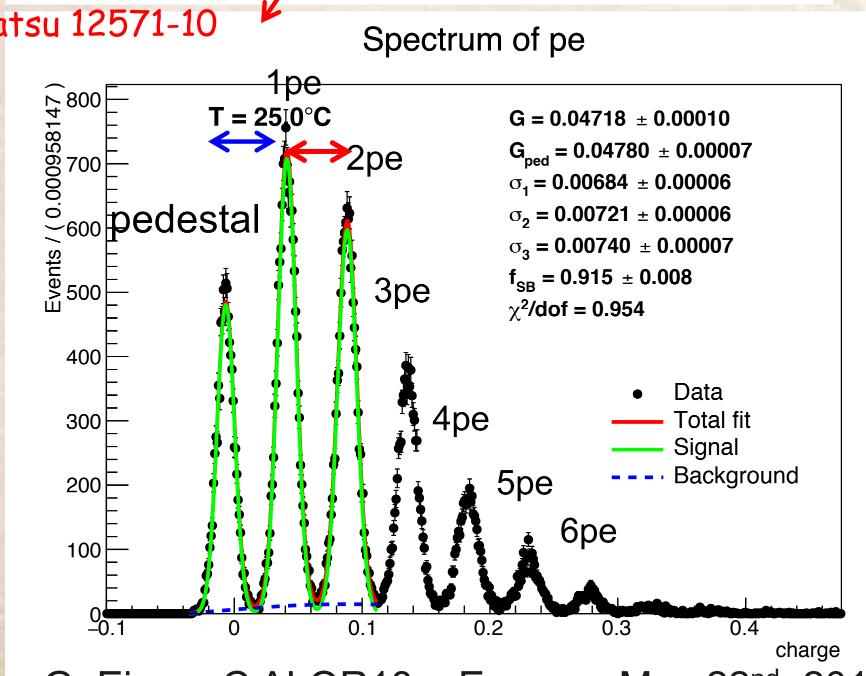
Two Methods to Extract Photoelectron Spectra

- We take 50000 waveforms at each V_b and T point and store them for offline analysis
- Integrate each waveform over t_2-$t_1$window
  ➔ total charge, integer # of pe
- Determine minimum of waveform amplitude
  ➔ A_{peak}, typically integer # of pe

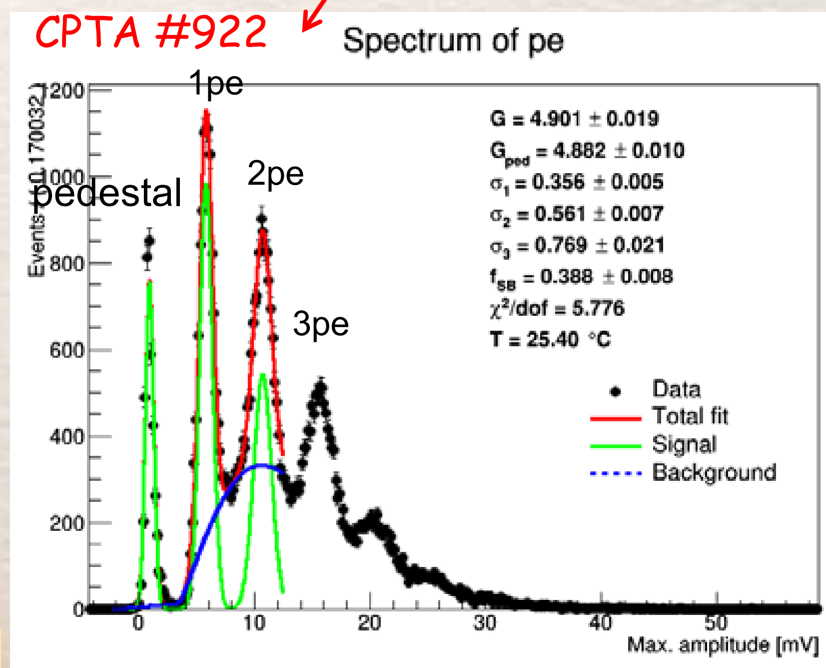




Hamamatsu 12571-10



CPTA #922



T=25°C

Gain Determination

- **Gain: distance between two adjacent photoelectron peaks**
- We choose distance between first and second photoelectron peaks
- Distance between pedestal and first photoelectron peak yields the same gain
- We fit the photoelectron spectra extracted from 500000 waveforms with a likelihood function

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

f_s: signal fraction

- We use two different fit models

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

  - First model:
    separate Gaussian G_i for pedestal, first p.e. & second pe peaks and fractions f_{ped}, f_1; include background F_{bkg} determined by a sensitive nonlinear iterative peak-clipping algorithm (SNIP) available in ROOT
  - Second model:

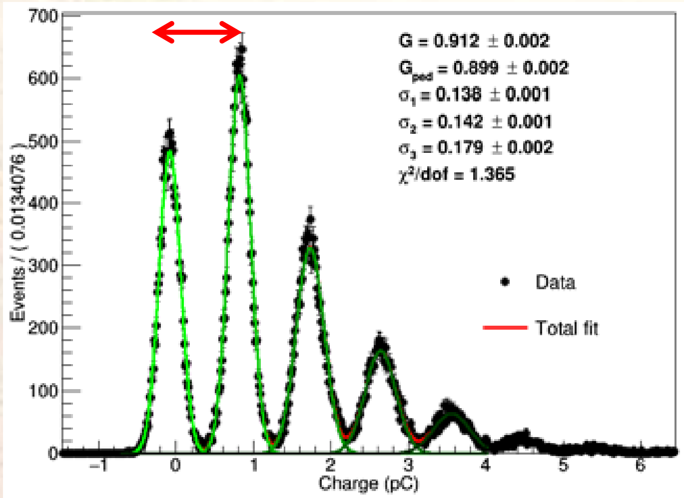
$$F_{sig} = f_{ped} G_{ped} + \sum_{i=1}^{n-1} f_i G_i + \left(1 - f_{ped} - \sum_{i=1}^{n-1} f_i\right) G_n$$

➔ fit pedestal and all visible peaks with Gaussians G_{ped} and G_i, where all widths and fit fractions are kept as free parameters, use no background pdf

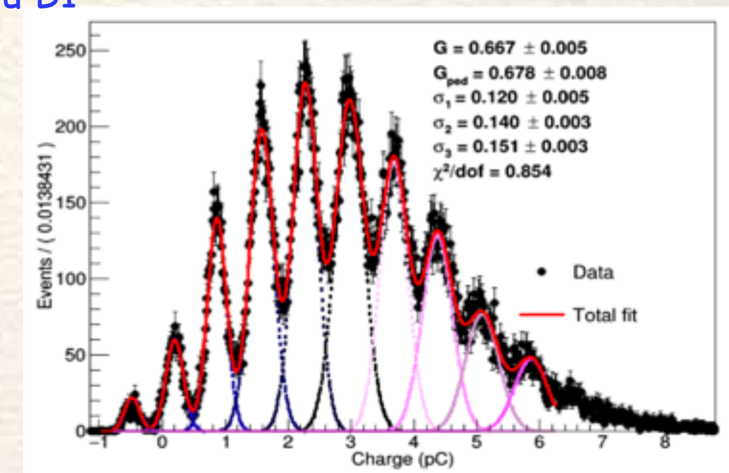
Two Fit Models

- First fit model | Second fit model

Hamamatsu S12571

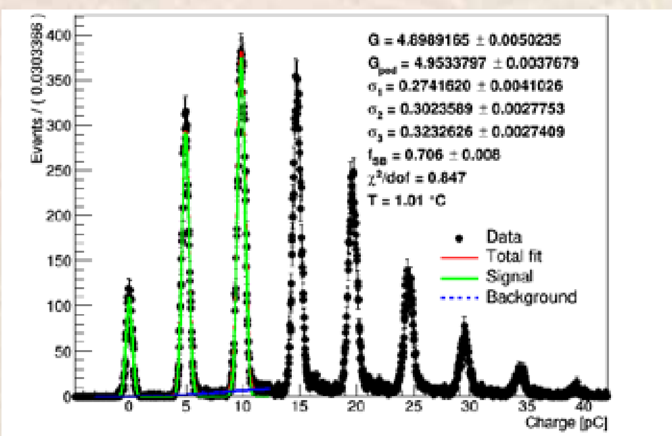


Hamamatsu B1



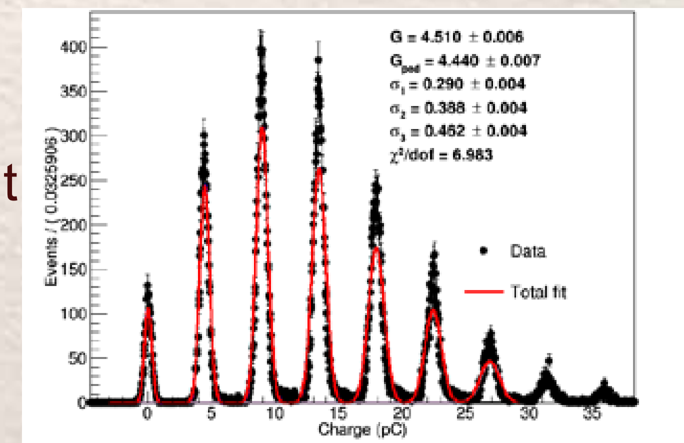
- Use first fit model for bias voltage scans of all SiPMs and gain stability tests of Hamamatsu MPPCs with trenches

Hamamatsu S13360 with fit model 1



Second fit model yields poor fits without modeling of tails on right-hand side

Hamamatsu S13360 with fit model 2

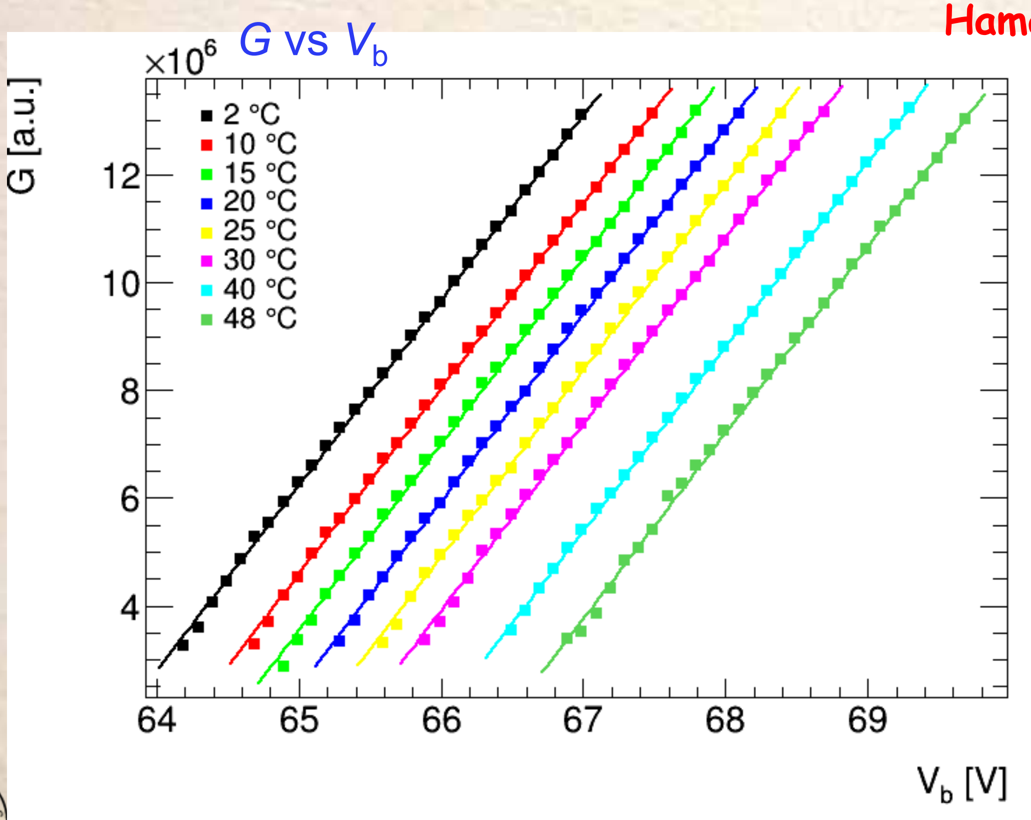


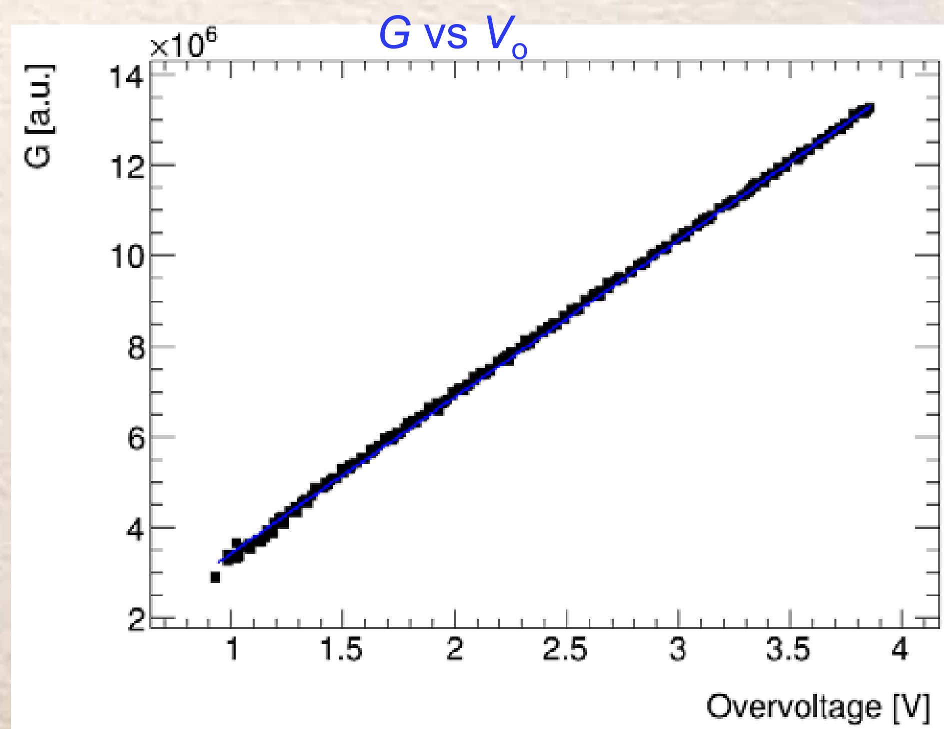
- Use second fit model for gain stability tests of all Hamamatsu MPPCs without trenches, all KETEK and CPTA SiPMs, for bias voltage scans of some MPPCs without trenches

Determination of dG/dV_b with Fit Model 2

- Typically, we explore the 2°C-48°C temperature range
- At fixed temperature, we measure ***G*** vs ***V_b*** ➔ at each point we take 50k waveforms
- The ***G*** vs ***V_b*** dependence is linear for all *T*, with similar slopes
- Except for low overvoltages V_o, all gains show linear dependence on V_o independent of *T*

Hamamatsu A1-20

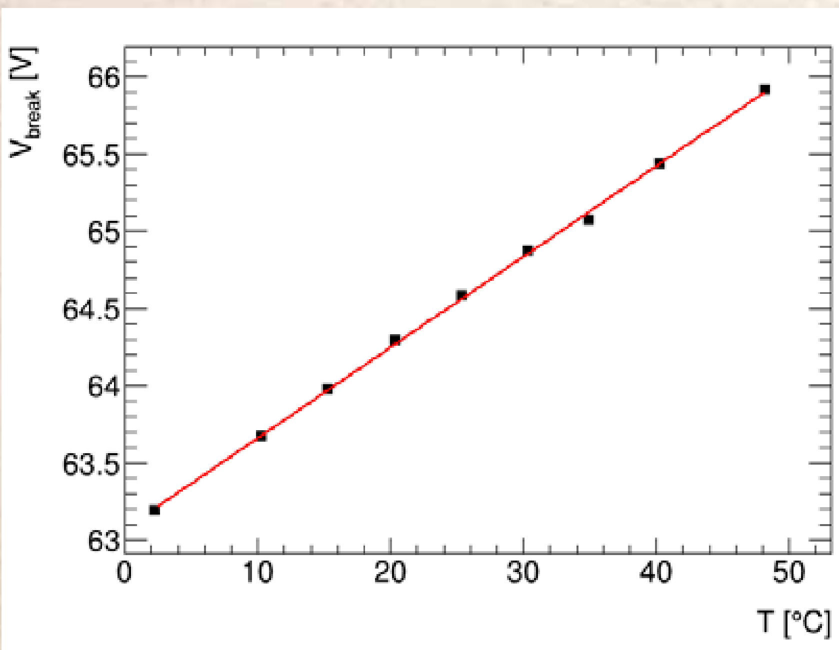


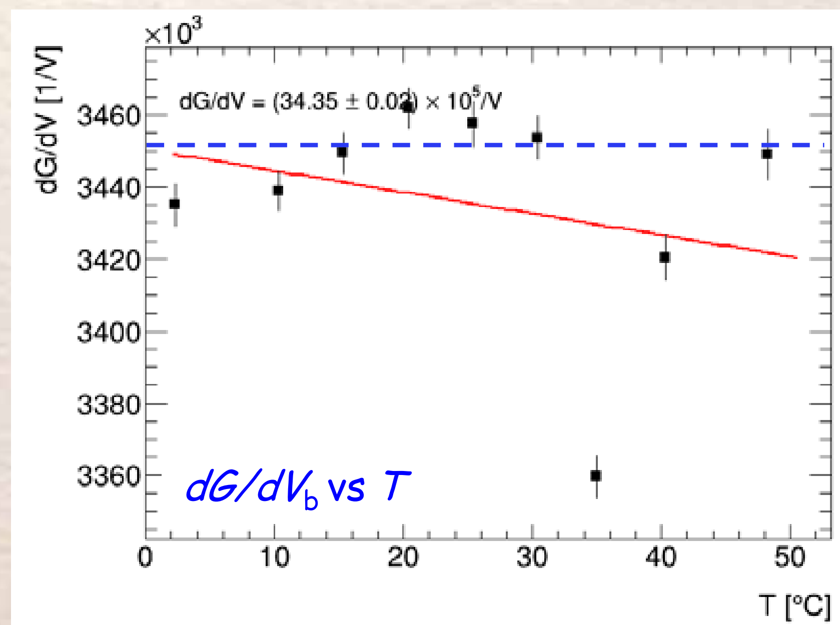


Determination of dG/dV_b with Fit Model 2

- For each temperature point, we perform a linear fit for G vs V_b to extract
  - breakdown voltage
  - dG/dV
- Breakdown voltage increases linearly with T ➔ dV_b/dT
- ***dG/dV*~C**, for some SIPMS it shows a clear linear T dependence
- Fit dG/dV_b vs T with linear functions but only use constant term
  ➔ variation from constant is <3%

Hamamatsu A1-20





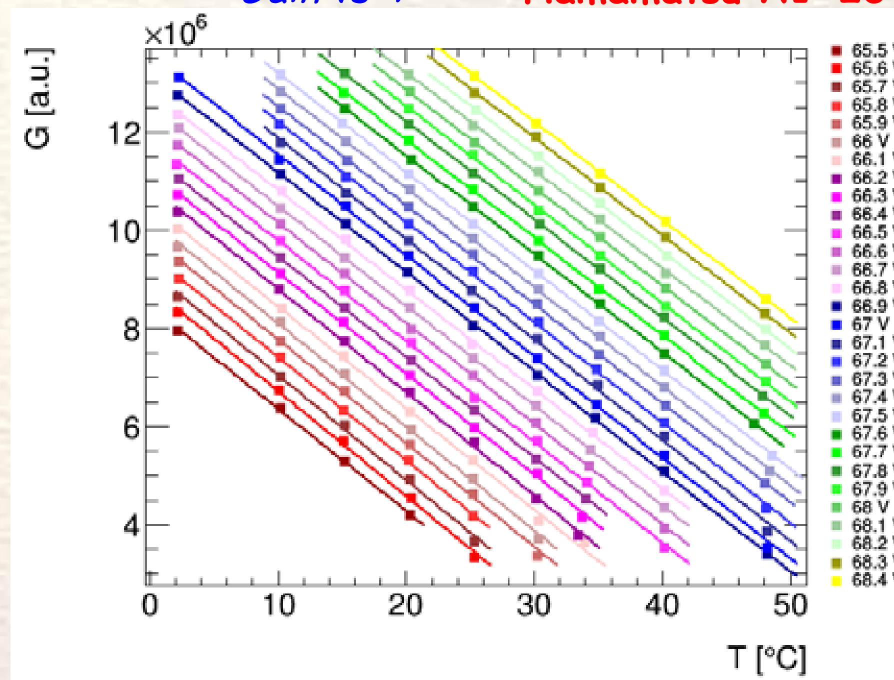
- **$dG/dV = (34.5 \pm 0.1) \times 10^5/V$**

Determination of *dG/dT* & *dV_b/dT* with Fit Model 2

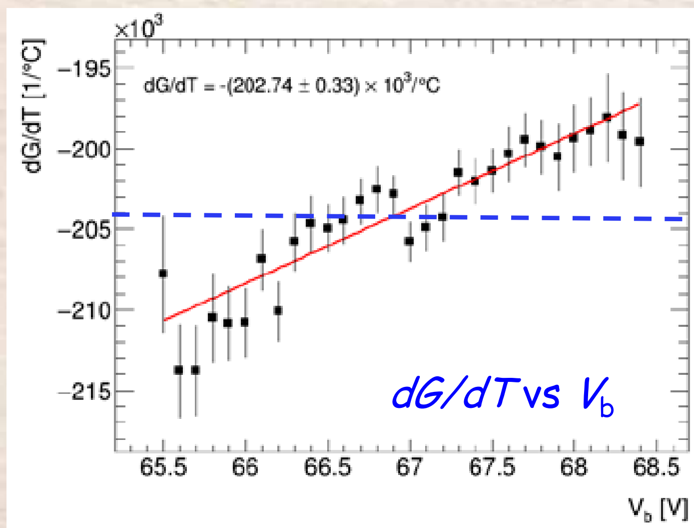
- For fixed V_b, we plot *G* vs *T* ➔ ***dG/dT***
- Fit ***dG/dT*** vs V_b with linear functions, use only constant term
  ➔ variation from constant is <3%
- We extract ***dV/dT*** from simultaneous fit of the gain to V_b and ***T***

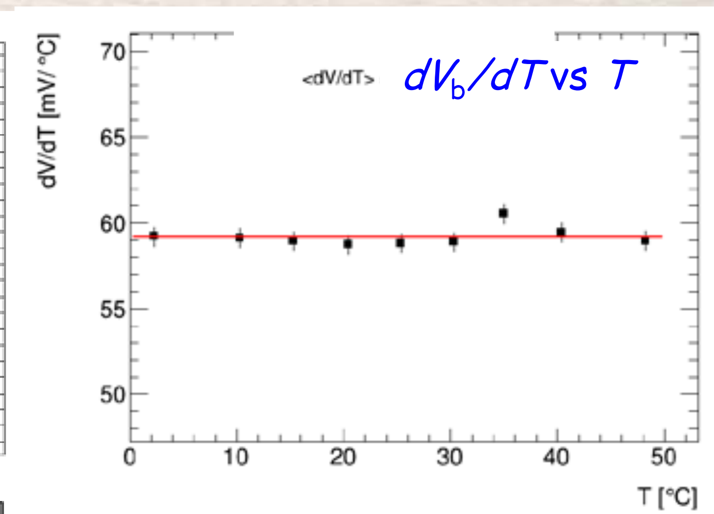
$$V_0 = V_{nom}(T_0) + \frac{dV_b}{dT}(T - T_0) \quad \& \quad G = G(V_0, T_0) + \frac{dG}{dV_b}(V - V_0)$$

- Fit yields: ***dV/dT*=(59.1±0.1) mV/°C**



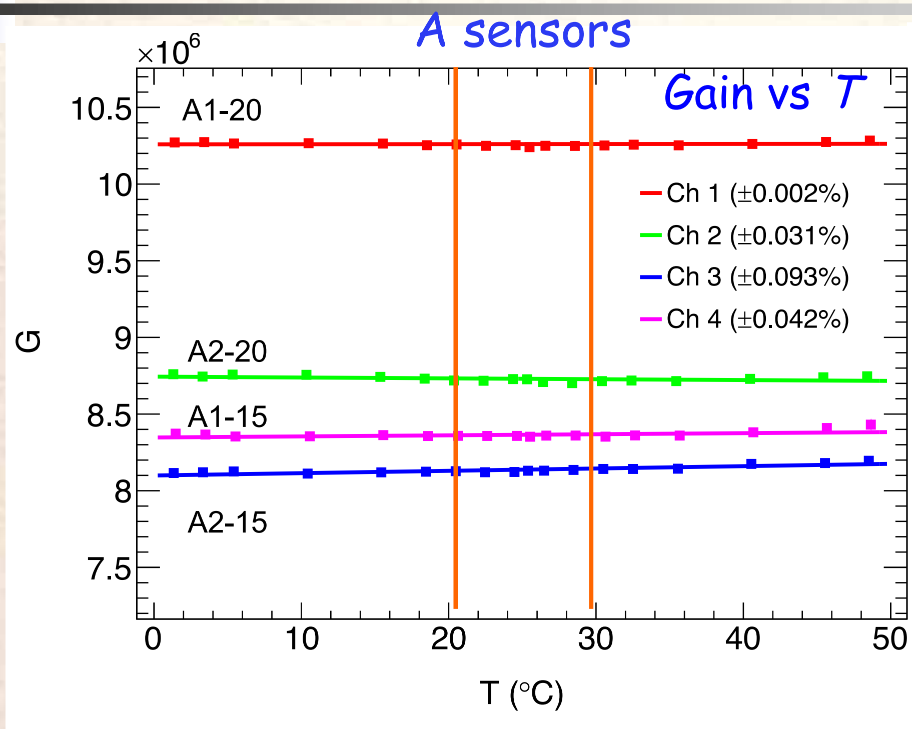
- From the breakdown voltage V_{break} vs *T* we extract
  ***dV/dT*=58.7±0.3 mV/°C**
- For stabilization of Hamamtsu type A MPPCs we used
  ***dV/dT*=59.0 mV/°C**

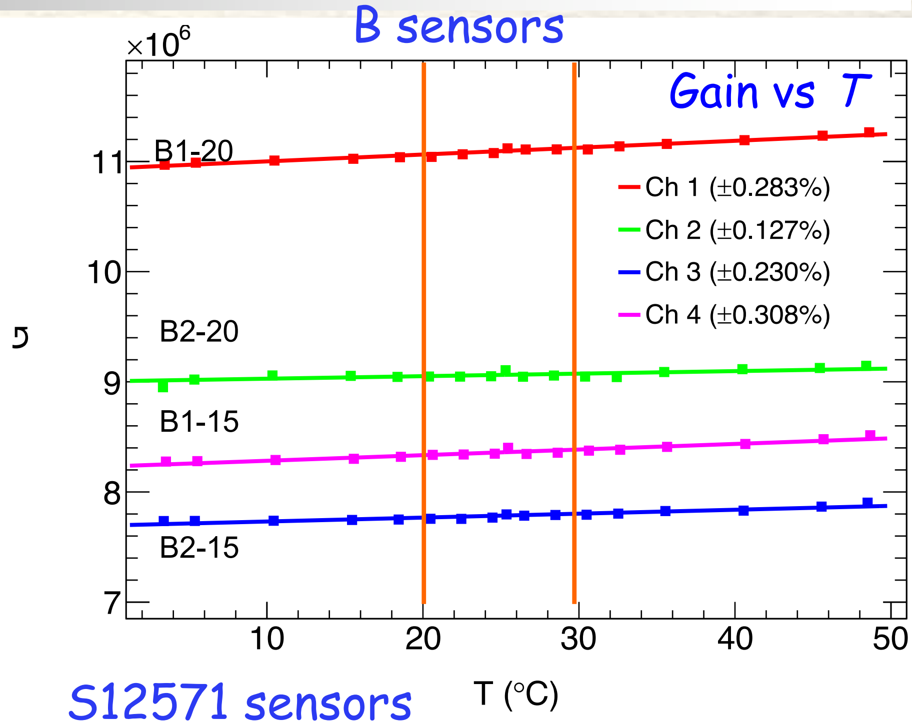


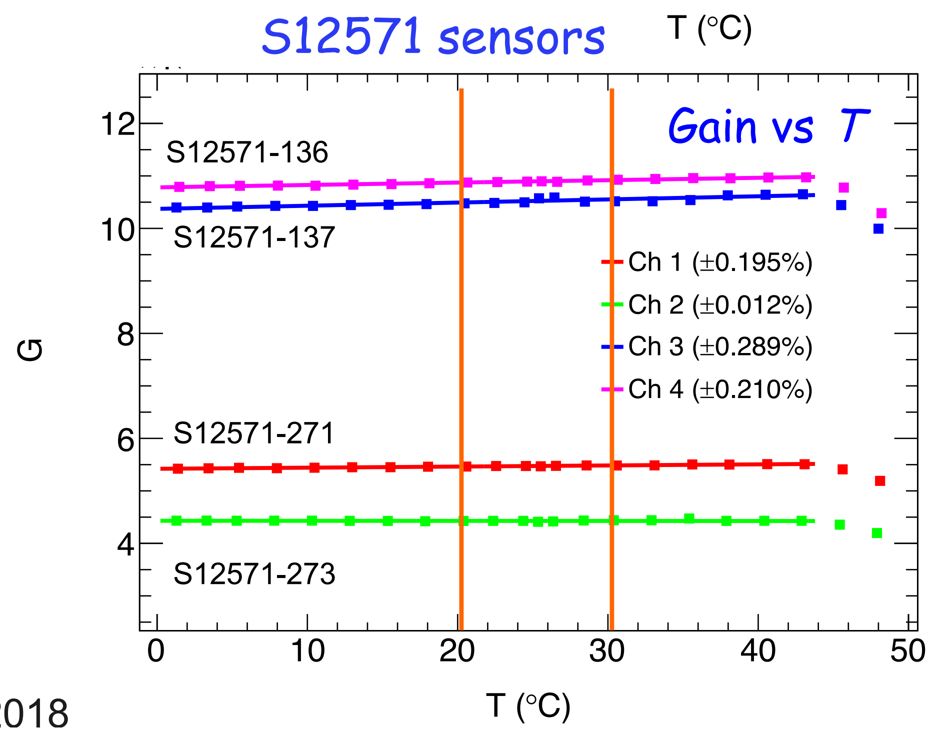


- ***dG/dT*=-(2.0274±0.0033)×10⁵/°C**

Gain Stabilization: Hamamatsu MPPCs w/o Trenches



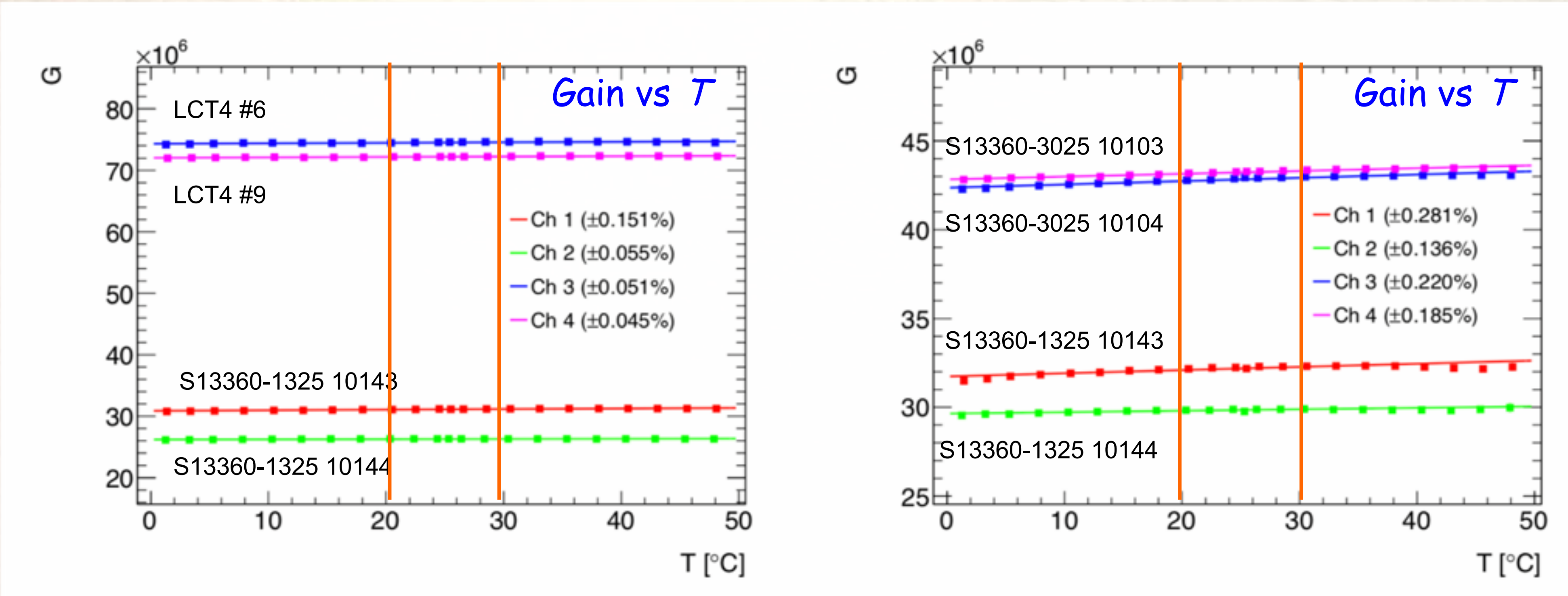




- Fit p.e. spectra of all MPPCs without trenches with **fit model 2**
- All 12 MPPCs satisfy our requirement of ***ΔG/G <±0.5%*** in 20° –30°C *T* range
- Some MPPCs satisfy this requirement In the entire *T* range 2° – 48°C

Gain Stabilization: Hamamatsu MPPCs w Trenches

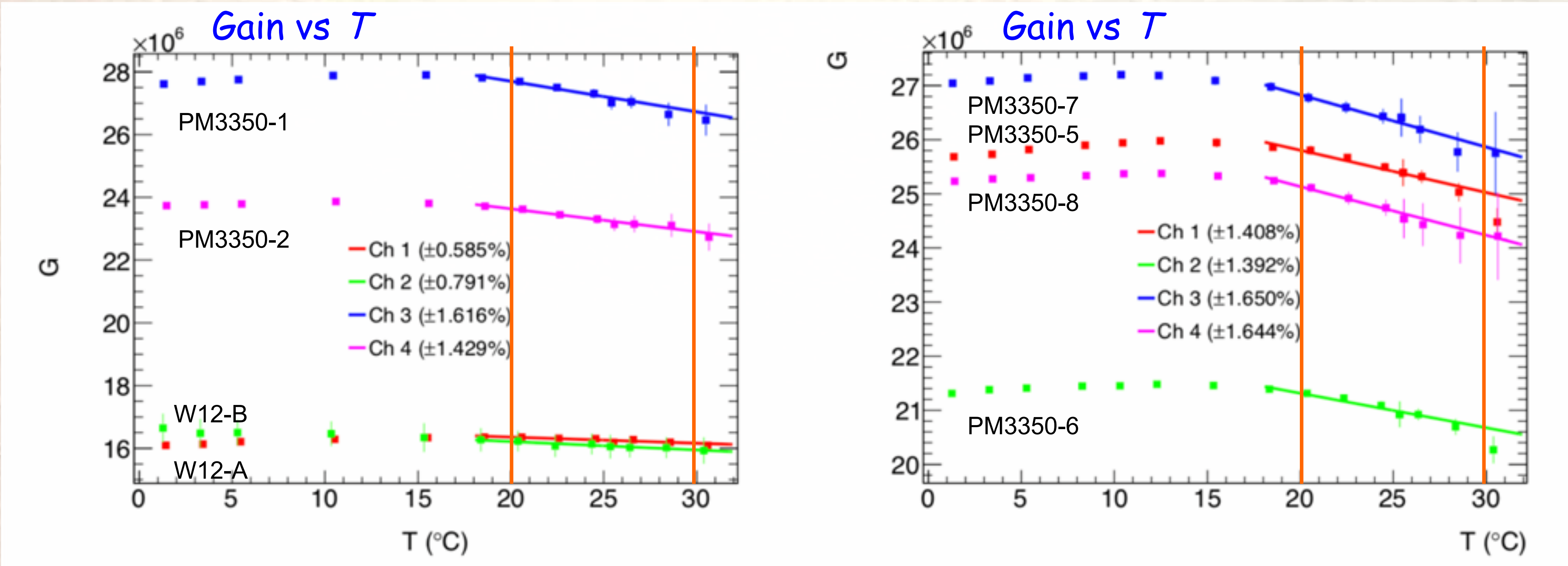
S13360-1325 & LCT4 sensors | All S13360 sensors



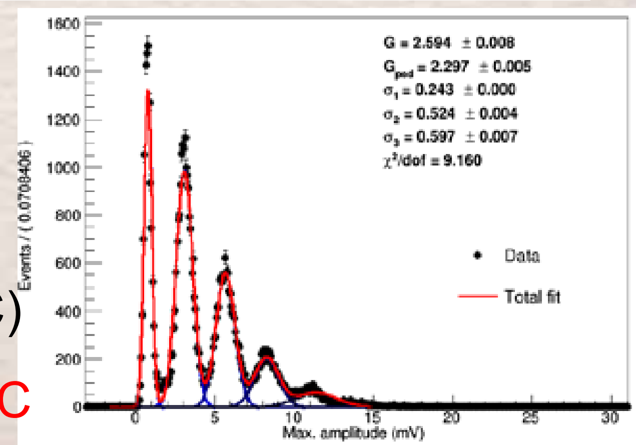
- Fit photoelectron spectra of all MPPCs with trenches with **fit model 1**
- All 6 MPPCs satisfy our requirement of ***ΔG/G < ±0.5%*** in 20° – 30°C *T* range
- All LCT4 and some S13360 sensors show stabilization in 2° – 48°C *T* range

Gain Stabilization of KETEK SiPMs

- Simultaneous gain stabilization for 4 KETEK SiPMs in two batches: ***dV/dT*=18.2 mV/°C**



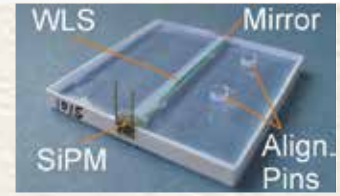
- Fit all photoelectron spectra with fit model 2



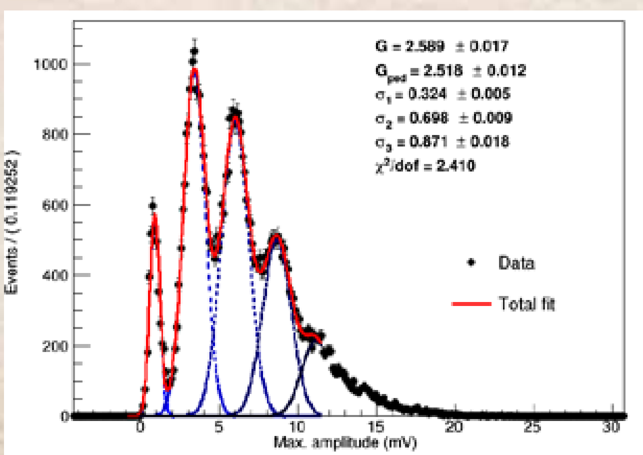
- KETEK SiPMs show more complicated V(T) behavior
  ➔linear correction is not sufficient
  ➔ sensors do not function above 30°C
  ➔*G* rises (1-18°C); uniform *G* (18-22°C); *G* falls off (22-30°C)

- No SiPM satisfies the **<±0.5%** requirement for *T*=20° –30°C

Gain Stabilization of CPTA SiPMs

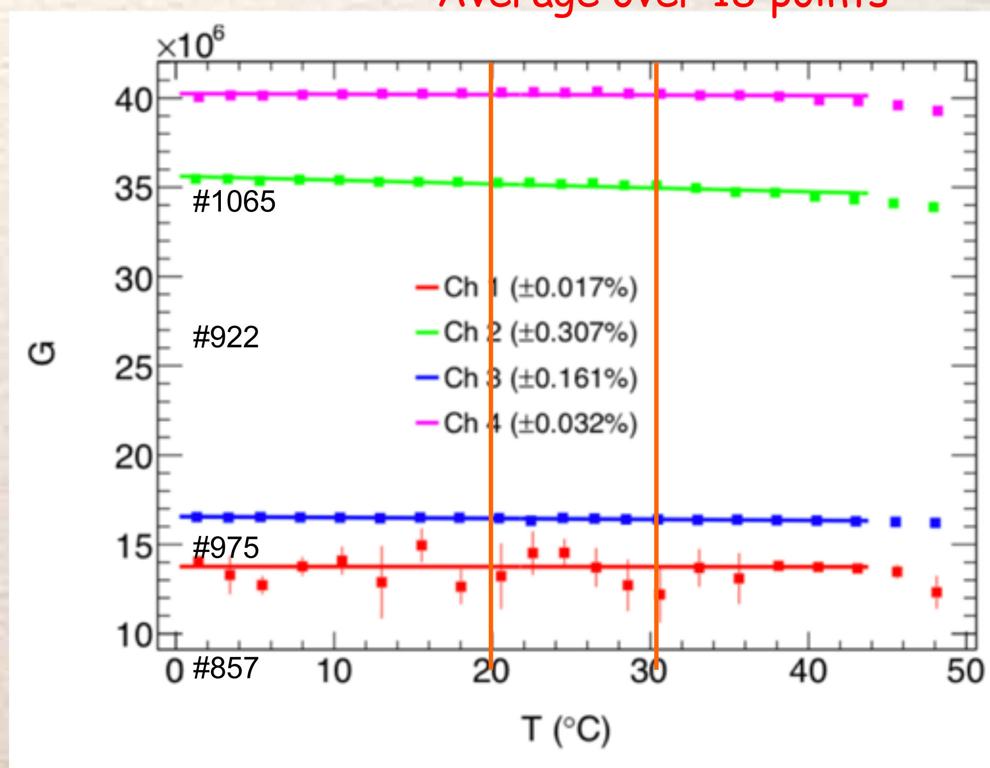


- CPTA SiPMs are illuminated via scintillator tile
- We adjust V_b with regulator board using *dV/dT*=21.2 mV/°C to stabilize 4 CPTA SiPMs simultaneously
- We test gain stability within *T*=2°- 48°C taking ≥ 18 samples of 50k waveform samples at each *T*
- The gain is nearly uniform up to 30°C
- SiPMs in ch#2 and ch#4 look fine; ch#1 is noisy, ch#3 changed gain at T=45°C but looks ok
- All 4 SiPMs satisfy our requirement of **>±0.5%** within 20°C -30°C *T* range



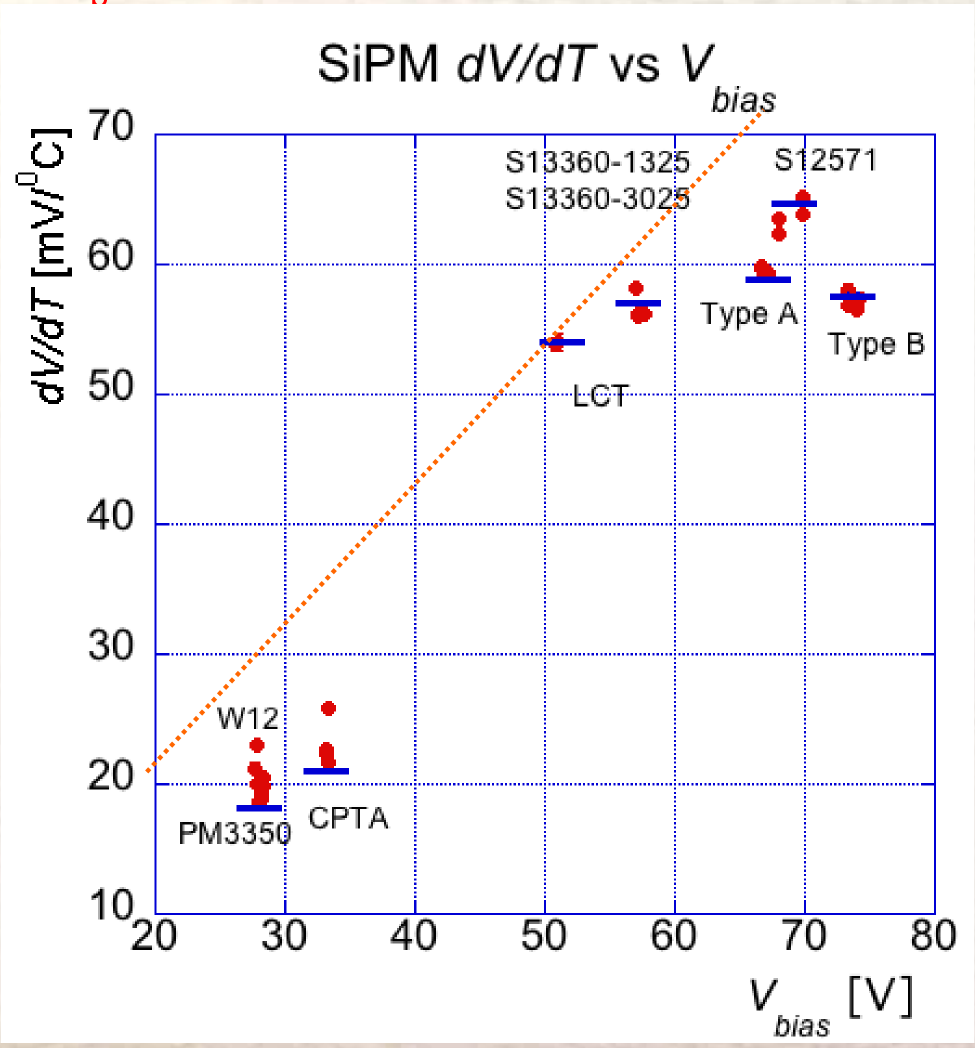
Gain vs *T*

Average over 18 points



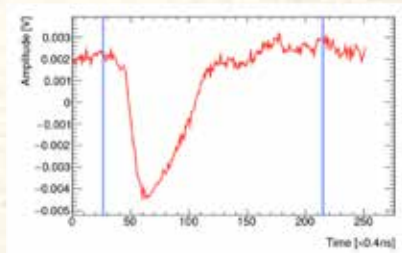
Measured *dV/dT* Values vs V_{bias}

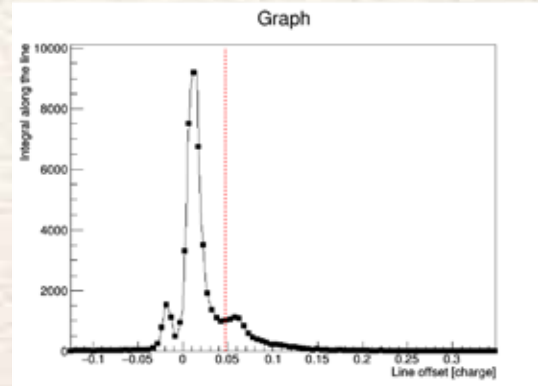
- Look for correlations between operating voltage and measured *dV/dT* for all SiPMs
- For most SiPMs *dV/dT* increases linearly with V_b
- Exceptions:
  - Hamamatsu B type MPPCs
  - Hamamatsu MPPCs with trenches
  - ➔ They have lower V_b for similar ***dV/dT***
- KETEK & CPTA SiPMs have larger ***dV/dT*** spread than Hamamasu MPPCs without trenches



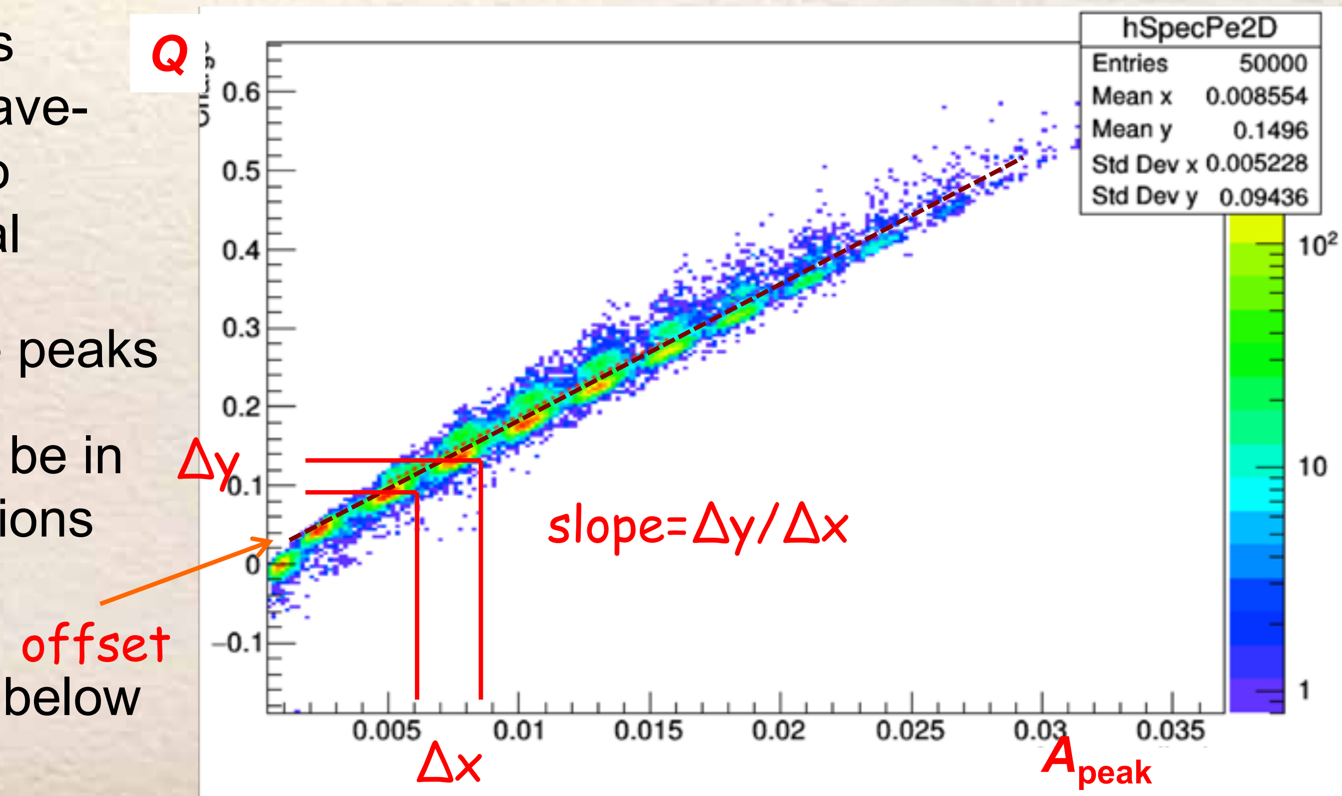
Does Afterpulsing affect Gain Stabilization?

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





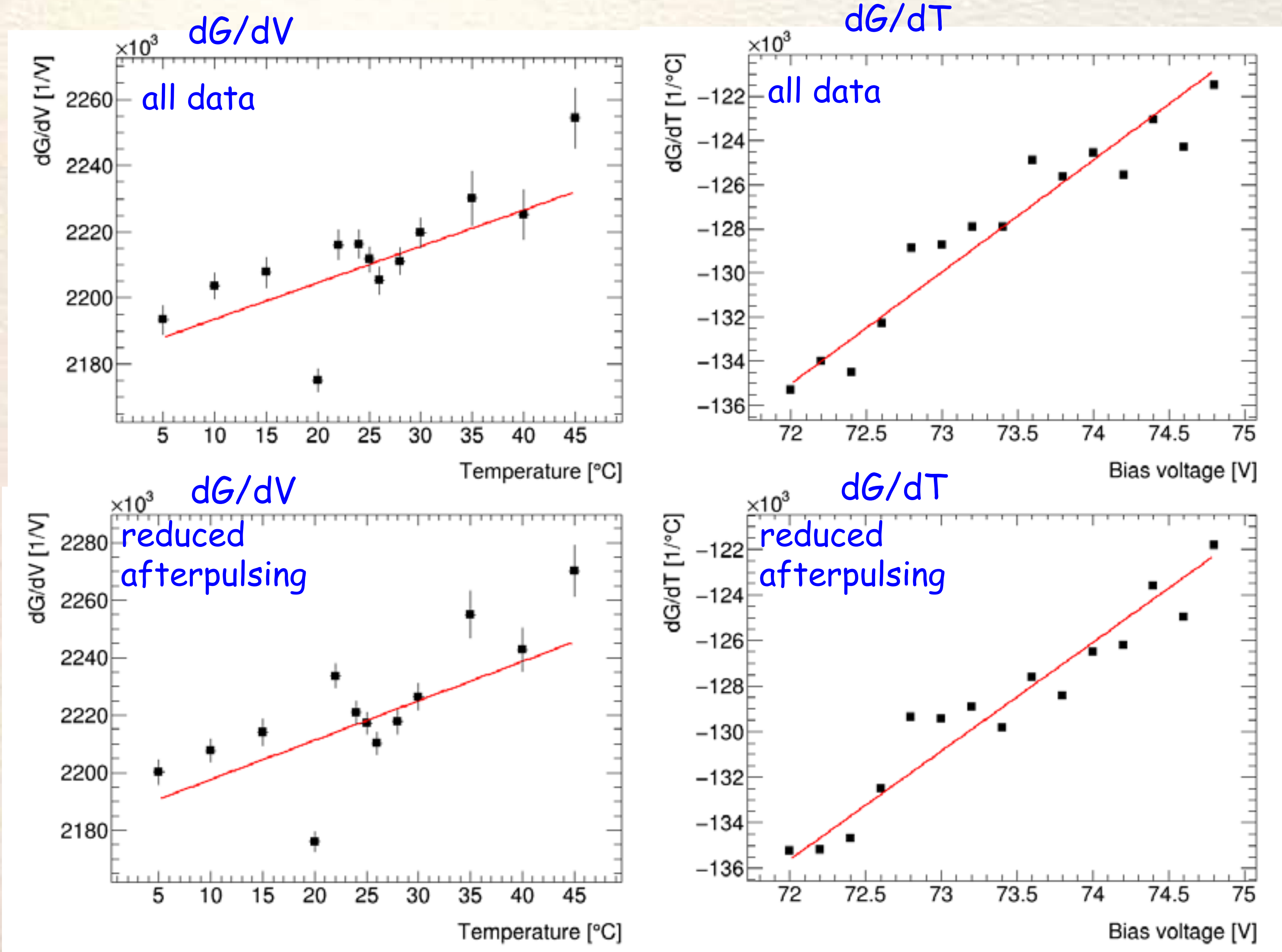
- We analyze the scatter plot of ***Q*** versus A_{peak}
- Signal without afterpulsing lies on the diagonal
- Signal with afterpulsing is shifted upwards since wave-form is broadened due to delayed secondary signal
- Set slope with 2pe & 3pe peaks
- Dashed line is chosen to be in valley between the 2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



dG/dV & *dG/dT* for Reduced Afterpulsing

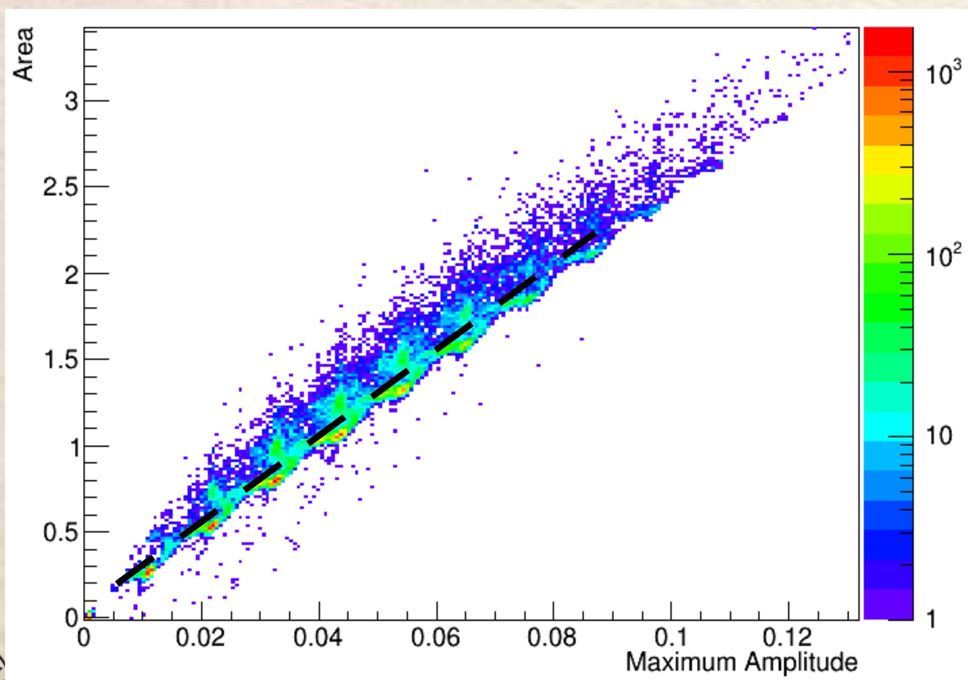
- The *dG/dV* & *dG/dT* distributions for sample with reduced afterpulsing look look similar as those for all data

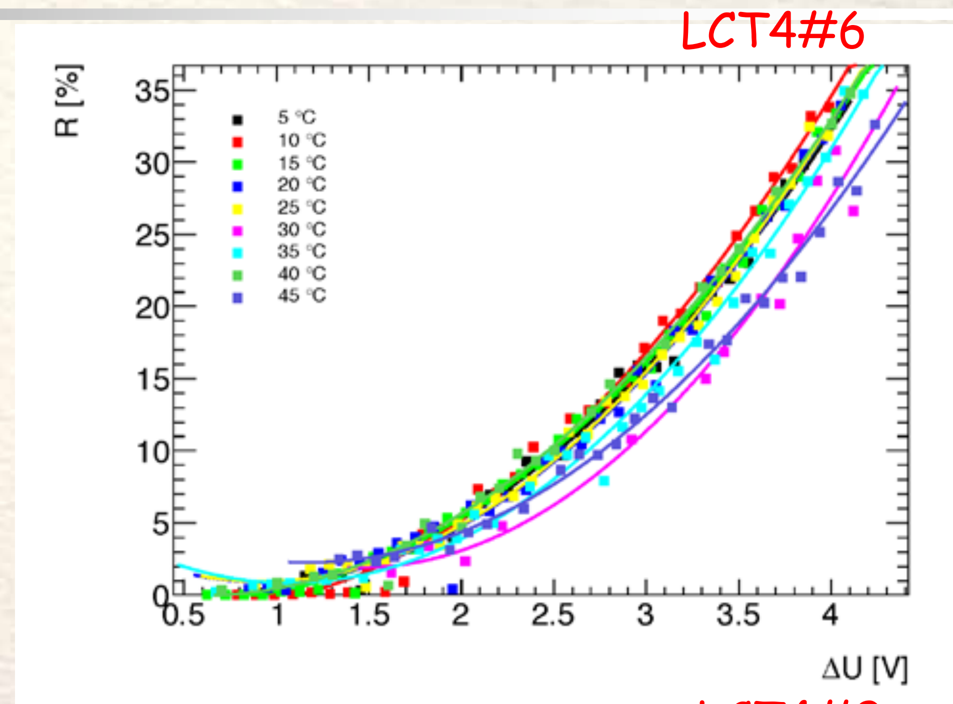
- Within errors get the same fit results
  ➔ visually slopes of red lines are the same

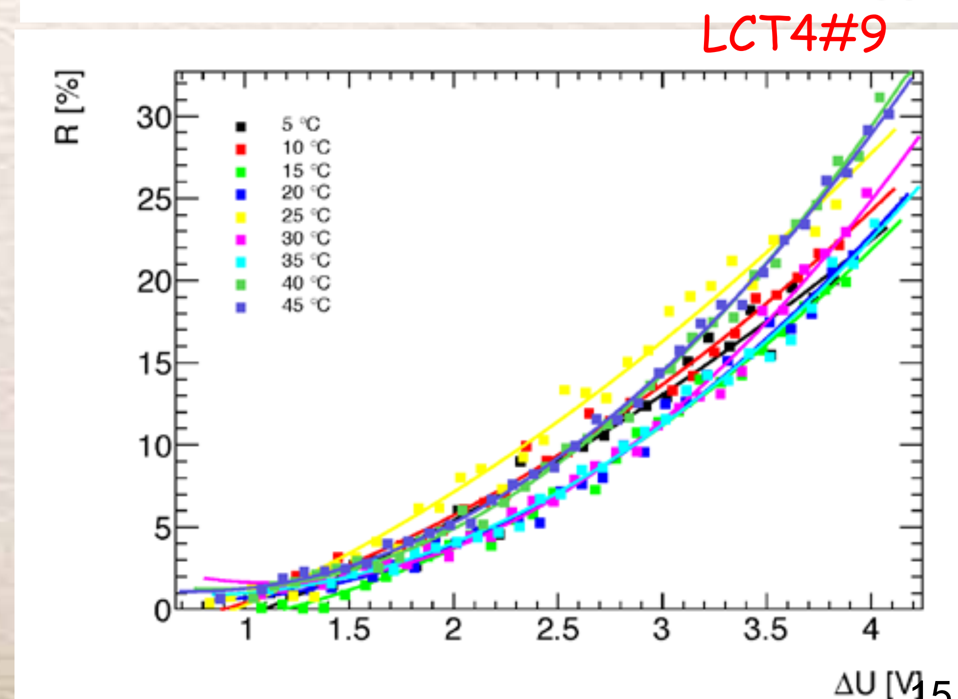


Afterpulsing of LCT4 MPPCs

- 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







Conclusions and Outlook

- We successfully completed gain stabilization tests for 30 SiPMs and demonstrated that batches of similar SiPMs can be stabilized with **one** dV_b/dT compensation value
- All 18 Hamamatsu MPPCs satisfy the stabilization goal: $\Delta G/G < \pm 0.5\%$ for T=20°C-30°C
  ➔ most MPPCs satisfy $\Delta G/G < \pm 0.5\%$ in the extended *T* range 2°C-48°C
- Gain stabilization of KETEK SiPMs is more complicated
  - Range of stabilization is limited to 2°C-30°C *T* range
  - No SiPM satisfies our requirement ➔need individual ***dV/dT*** values
- Gain stabilization of CPTA SiPMs works fine
  ➔ for all 4 SiPMs, $\Delta G/G < \pm 0.5\%$ is satisfied in 20°C-30°C range
- Afterpulsing does not affect gain stabilization results
- Afterpulsing strongly depends on overvoltage not temperature
- Results will be published in JINST
- In the analog HCAL, V_b adjustment can be implemented on the electronics board
  ➔need array of temperature sensors to monitor T adequately in entire AHCAL

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

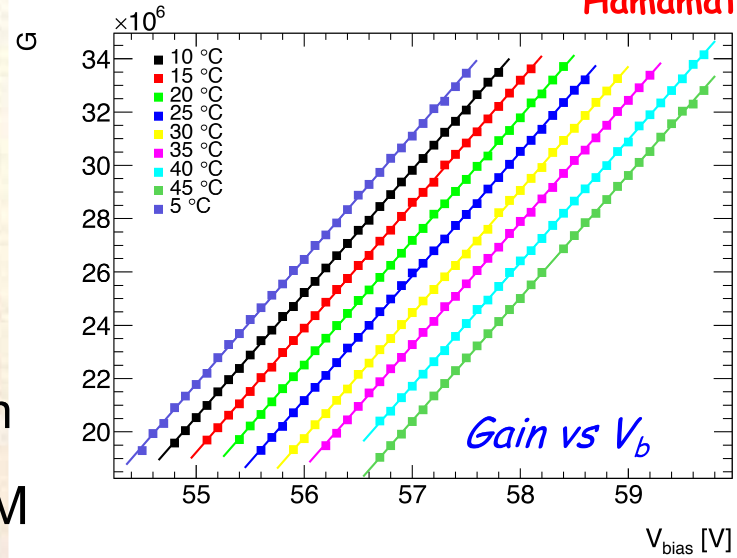
Backup

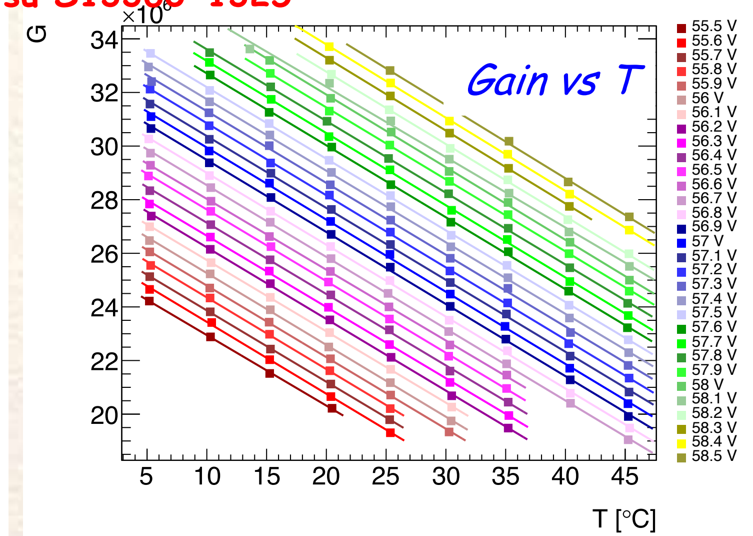
Slides

dG/dV_b, dG/dT & dV_b/dT Results with Fit Model 1

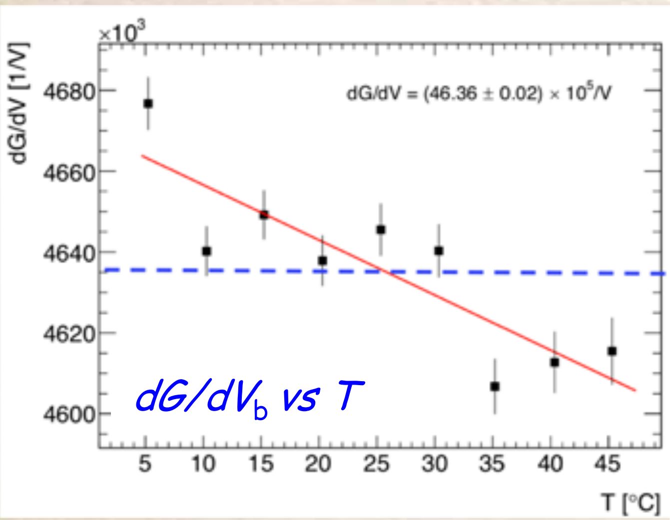
- For fixed T, measure G vs V_b ➔ dG/dV_b
- For fixed V_b plot G vs T ➔ dG/dT
- Extract all dV_b/dT for fixed T& average them
- Do this for each SiPM

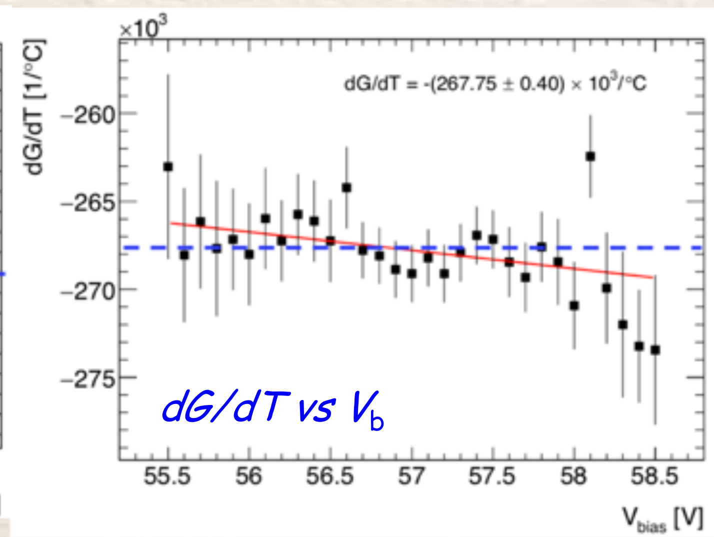
Hamamatsu S13360-1325

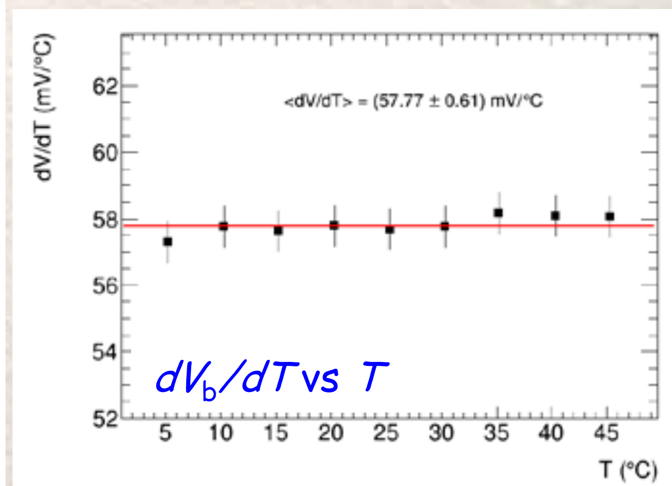




- Fit dG/dV_b and dG/dT with linear functions, use only constant (slope are small <1%)



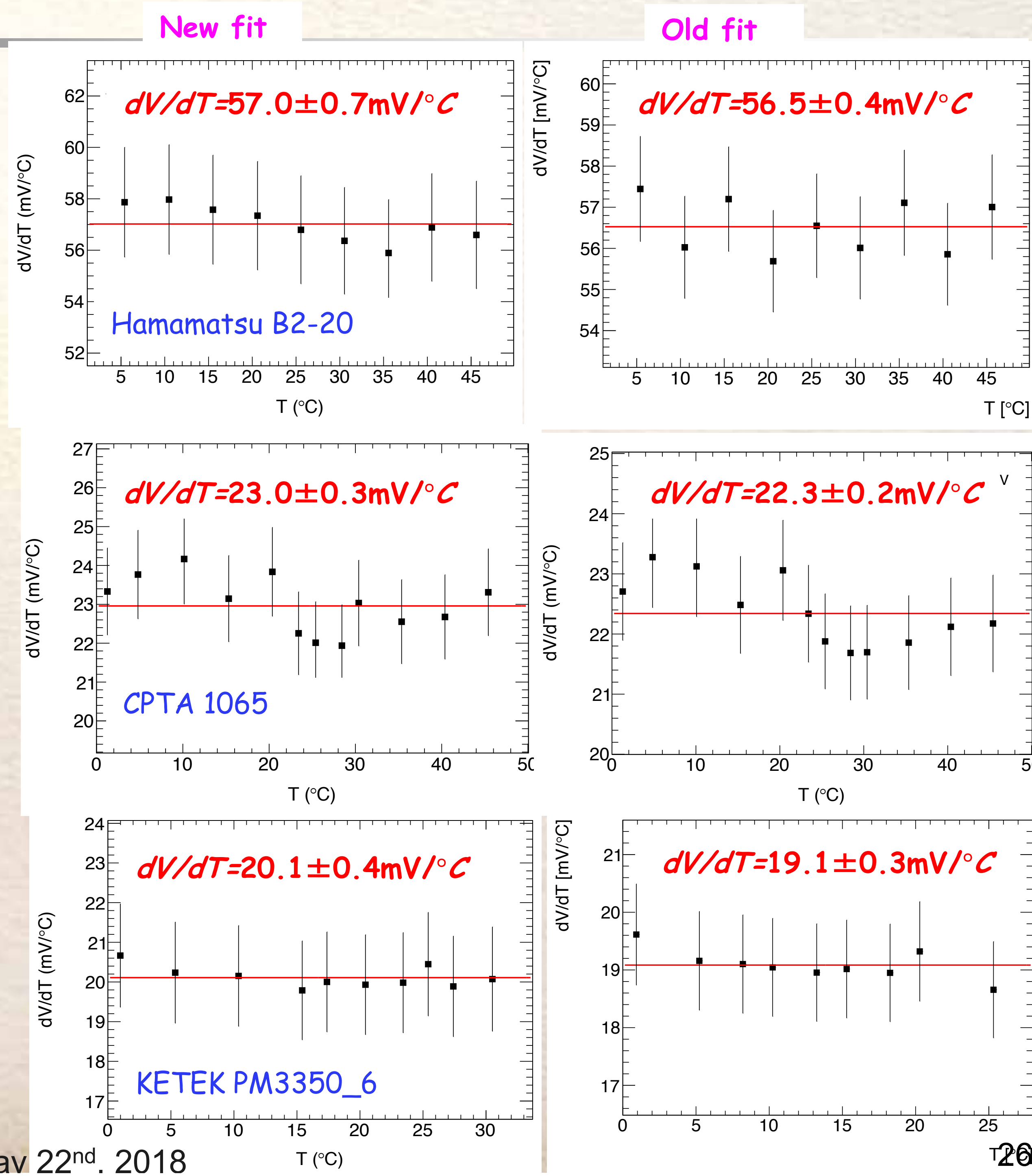




- $dG/dV=(46.36\pm0.02_{stat})\times10^5$/V
- $dG/dT=(2.6775\pm0.004)\times10^5$/°C
- $dV/dT=(57.8\pm0.1_{sys})$ mV/°C

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



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