AIDA 2020

Gain Stabilization of SiPMs

Task 14.2.2

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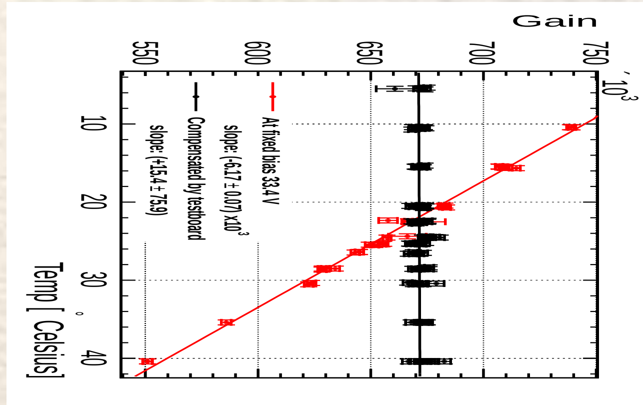
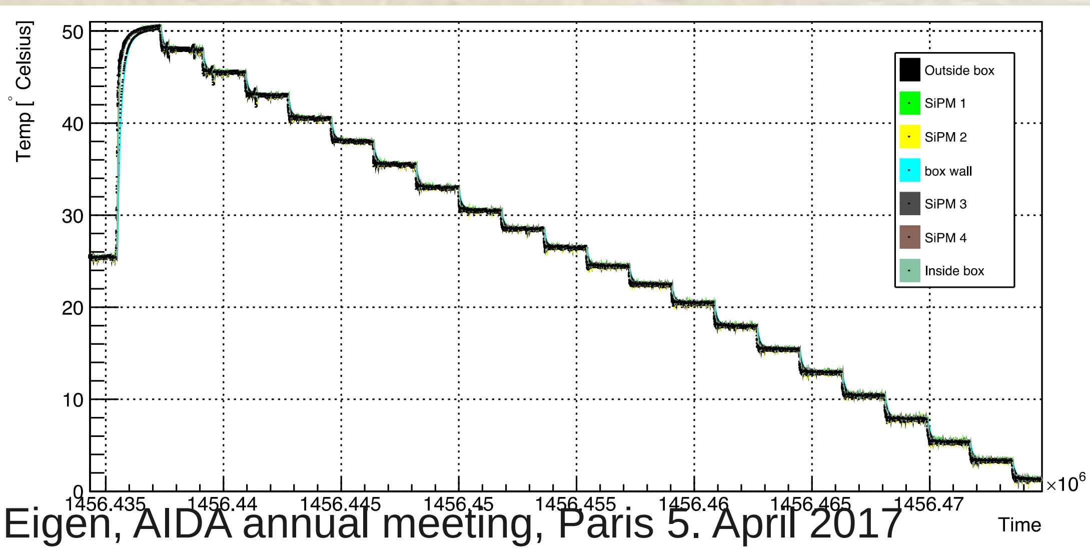
Introduction

- 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
- 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

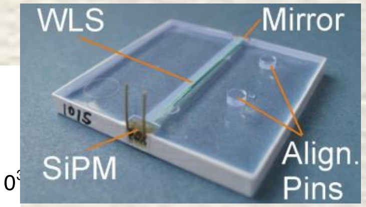


- We tested gain stabilization for **30** SiPMs from Hamamatsu, KETEK and CPTA stabilizing 4 SiPMs simultaneously with one *dV/dT* setting ➔goal: **achieve stable gain: ΔG/G <±0.5% in 20°-30°C range**

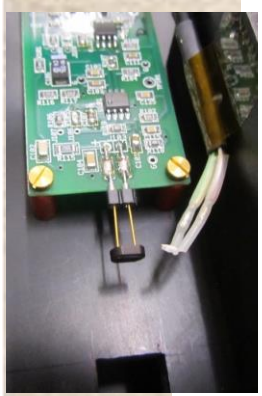


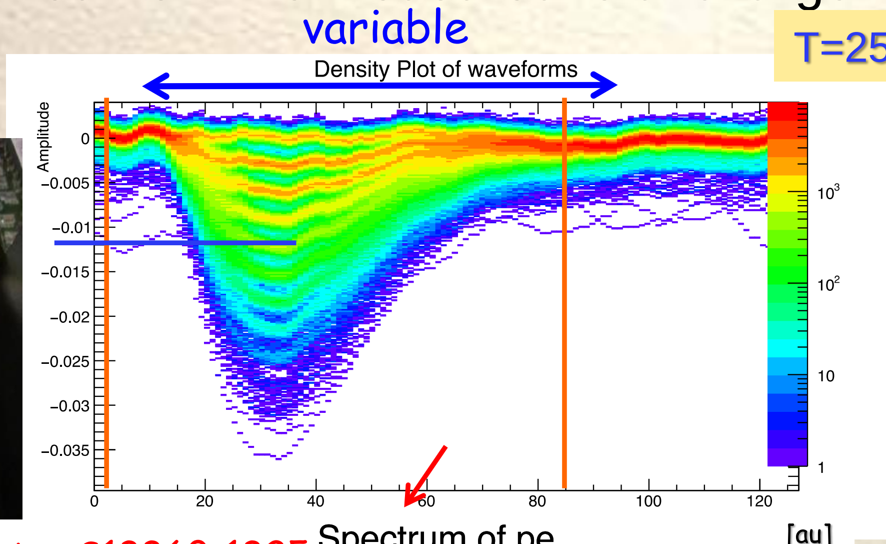
Extraction of Photoelectron Spectra

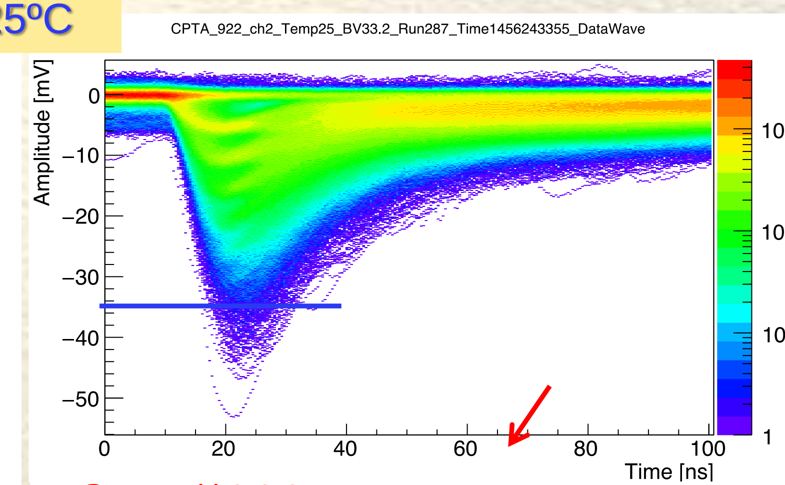
- For 18 Hamamatsu MPPCs, we integrate each waveform over time window waveform stays below the baseline ➔ pe spectra are obtained from the measured total charge
- For 8 KETEK and 4 CPTA SiPMs, we determine the waveform minimum for each pulse from which we extract the pe spectra

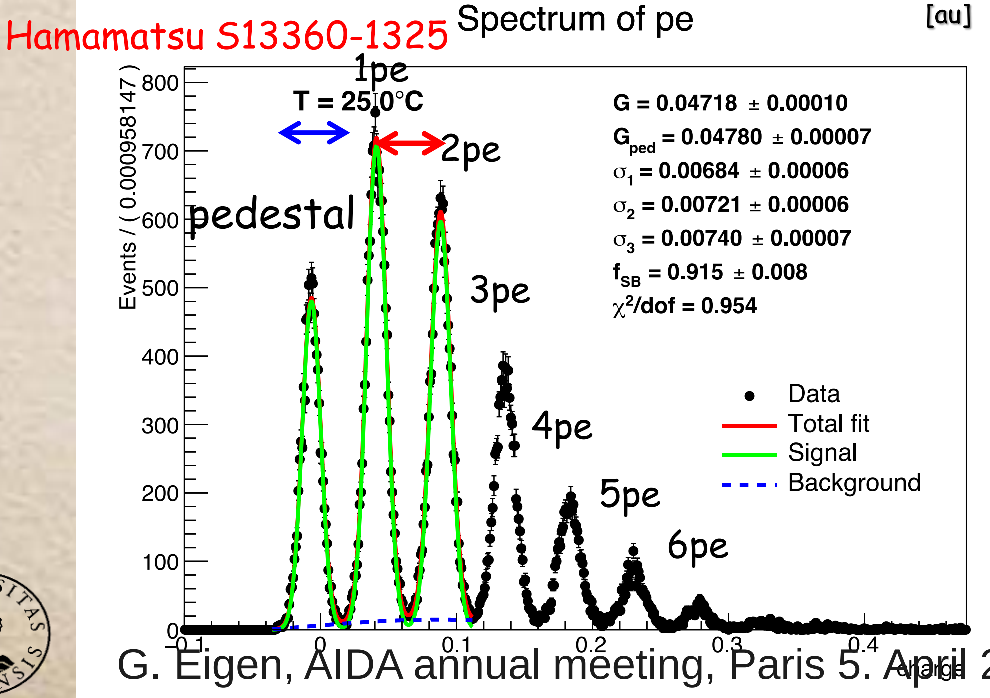


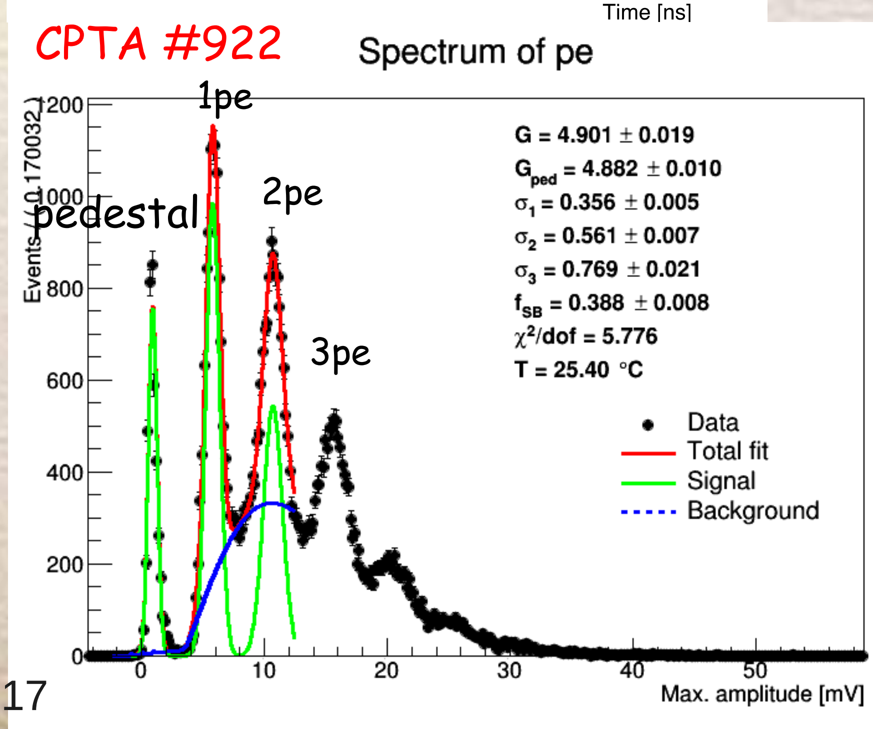
With trenches











Gain Determination

- We define the gain as the distance between the first and the second pe peaks
- In the standard fit, we fit the pedestal, first pe peak and second pe peak each with a Gaussian G_i and fractions f_{ped}, f_1

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

- Besides the signal peaks, we include a background F_{bkg} that is determined by a sensitive nonlinear iterative peak-clipping algorithm (SNIP)
- Thus, the likelihood function is

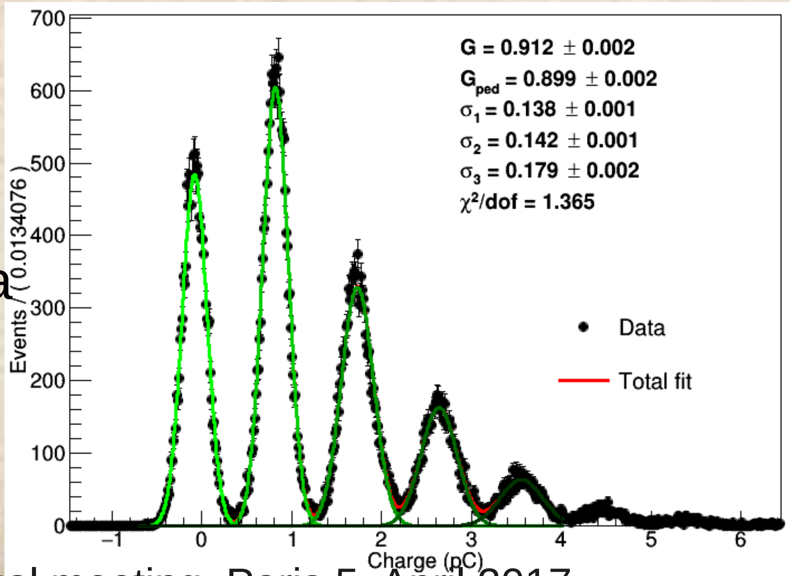
$$L = \prod_{i=1}^{50000} \left[f_s F_{sig}\left(w^i\right) + \left(1 - f_s\right) F_{bkg}\left(w^i\right) \right]$$

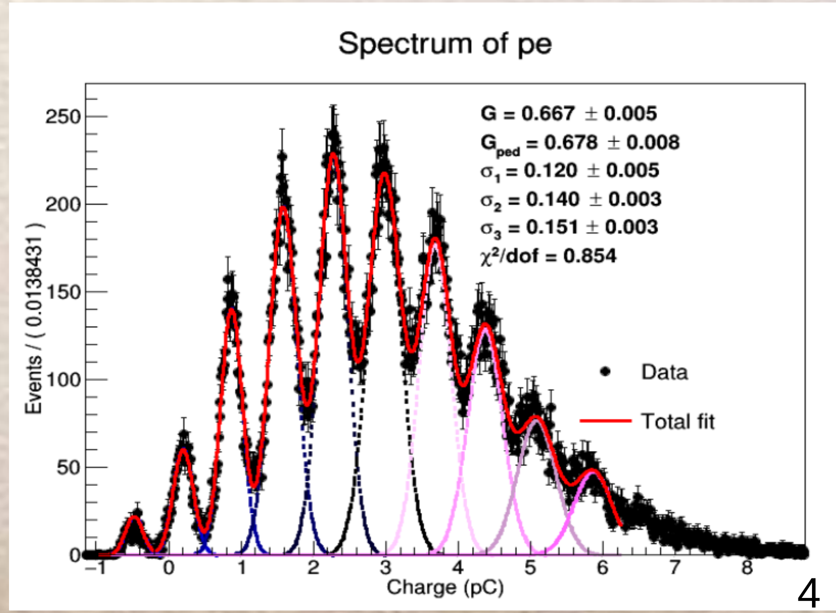
f_s: signal fraction

- In the new fitting methodology, we fit the pedestal and all visible peaks with Gaussians G_{ped} and G_i, where all widths are free parameter but the distance between pe peaks is fixed, except for the distance between pedestal and first pe peak

- No background polynomial yet

- We perform binned fits of the pe spectra extracted from 50000 wave forms

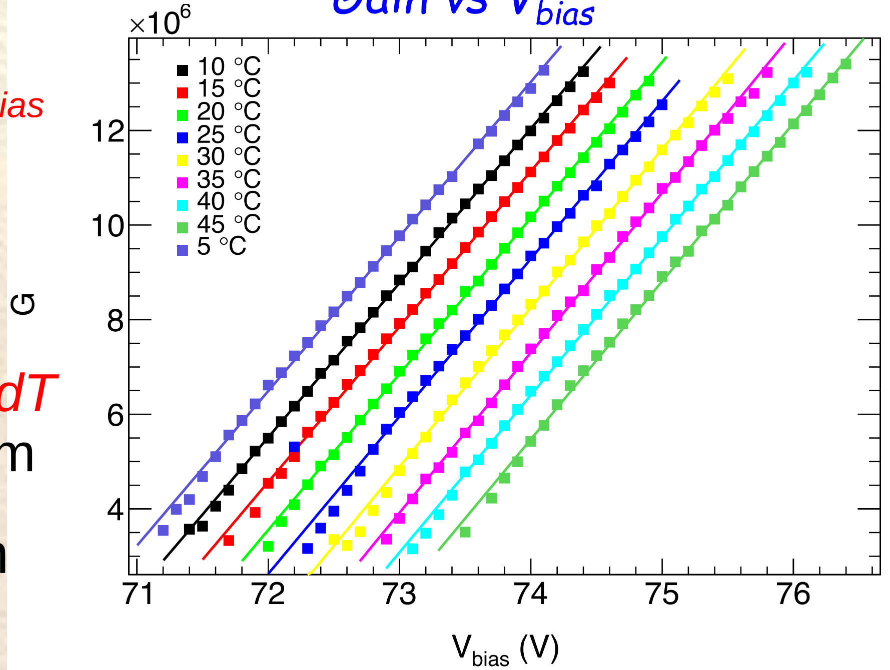




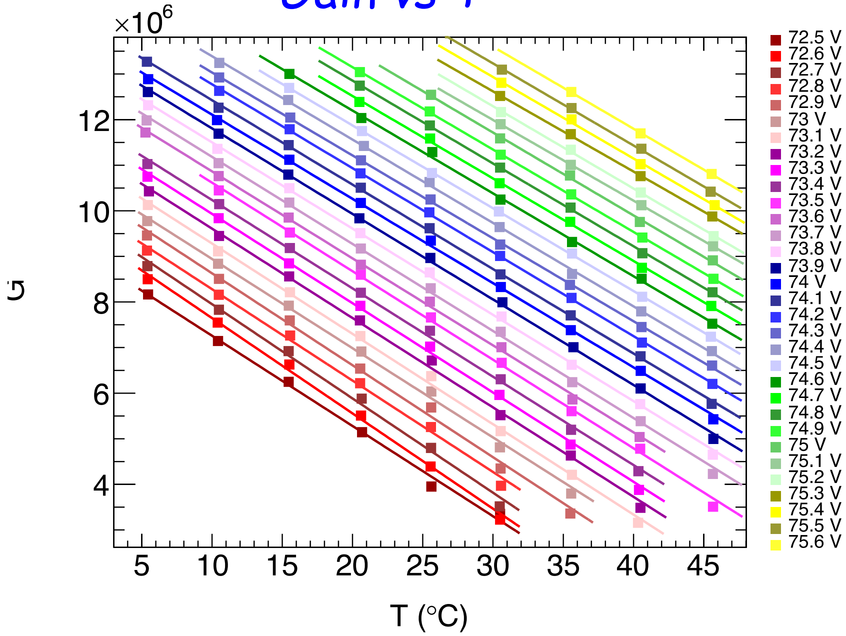
dG/dV, dG/dT & dV/dT Measurements (new fits)

- 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

Gain vs V_{bias}

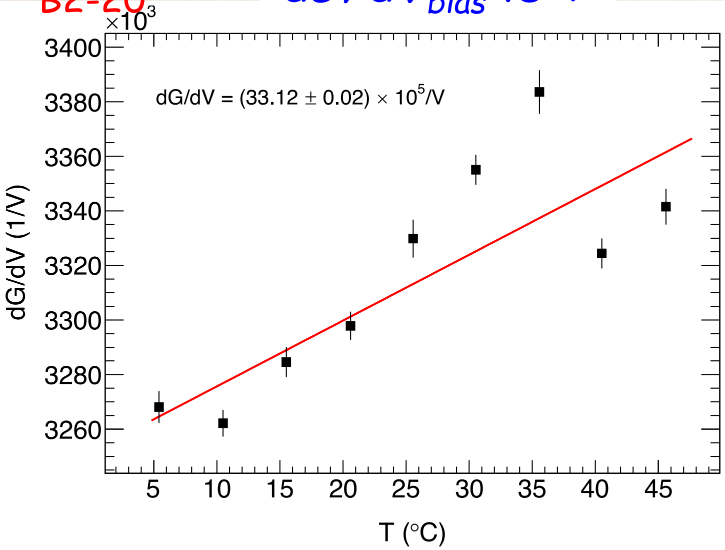


Gain vs T

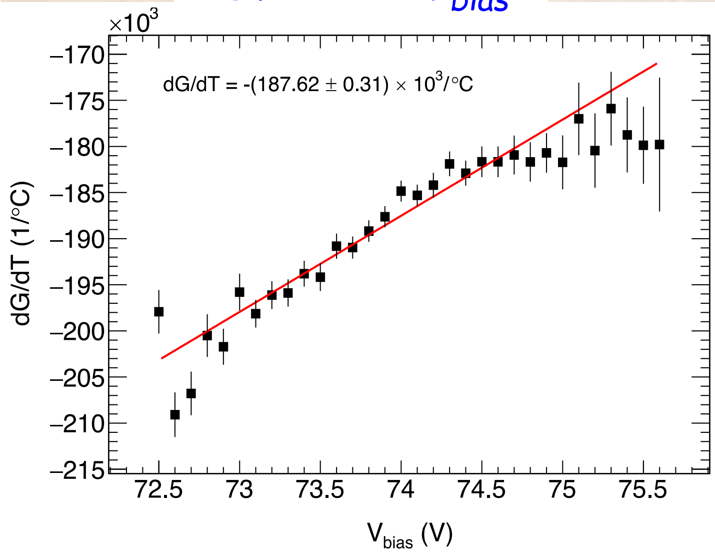


Hamamatsu B2-20

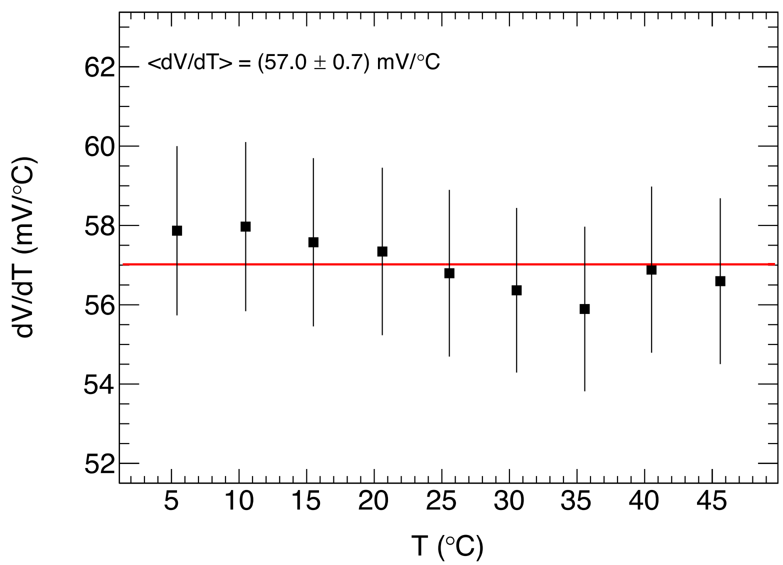
dG/dV_{bias} vs T



dG/dT vs V_{bias}



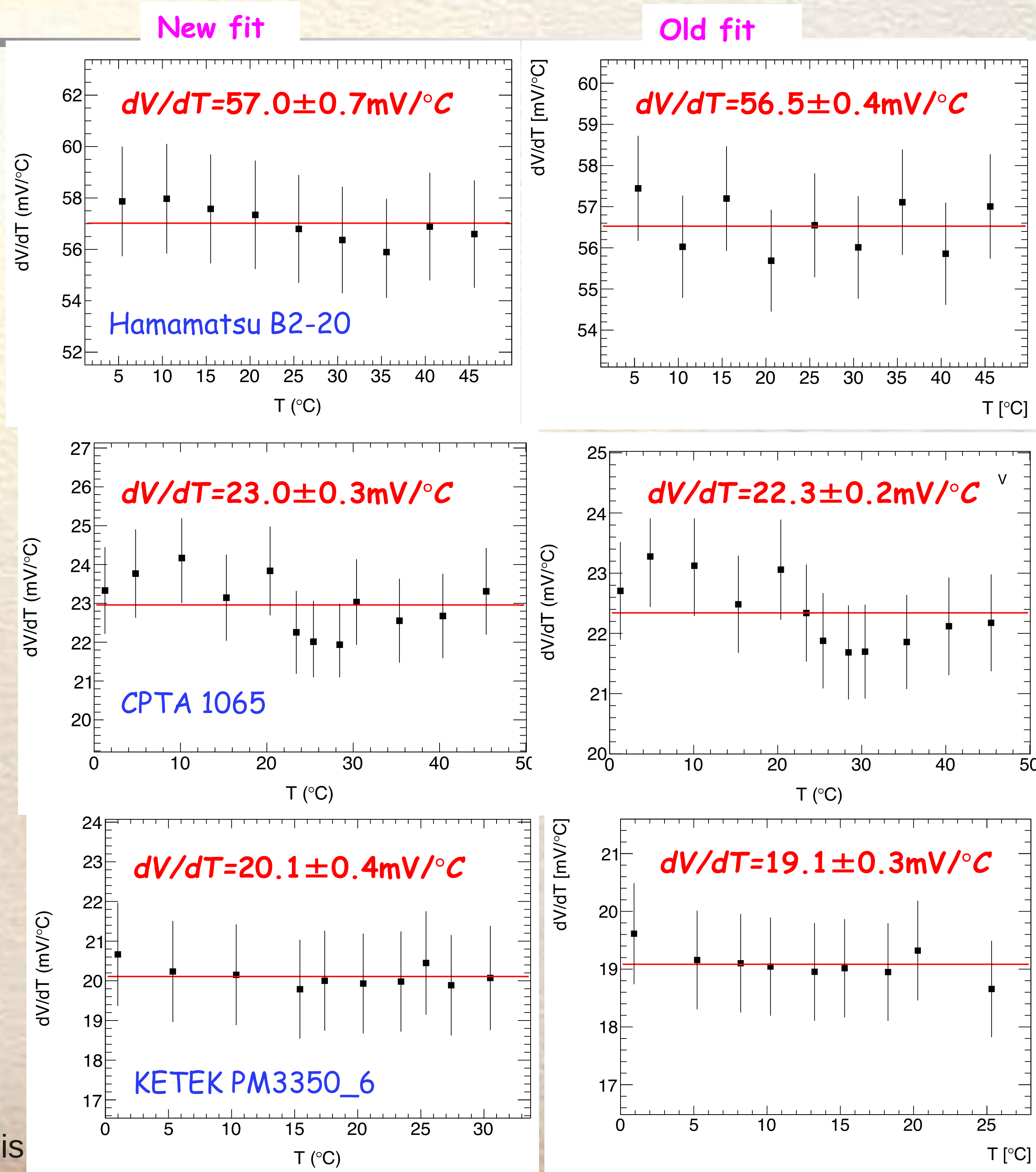
dV_{bias}/dT vs T



- **$dG/dV = (33.12 \pm 0.02_{stat}) \times 10^6/V$**
- **$dG/dT = -(1.8762 \pm 0.0031) \times 10^5/°C$**
- **$dV/dT = (57.0 \pm 0.1_{sys})$ mV/°C**

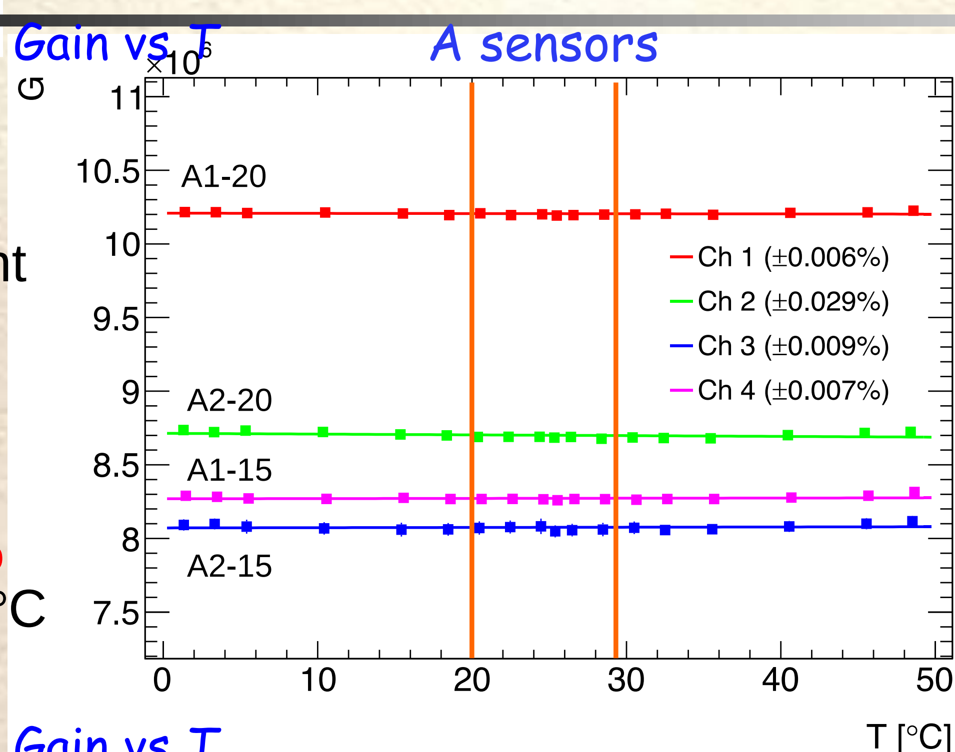
Compare 2 Fitting Strategies

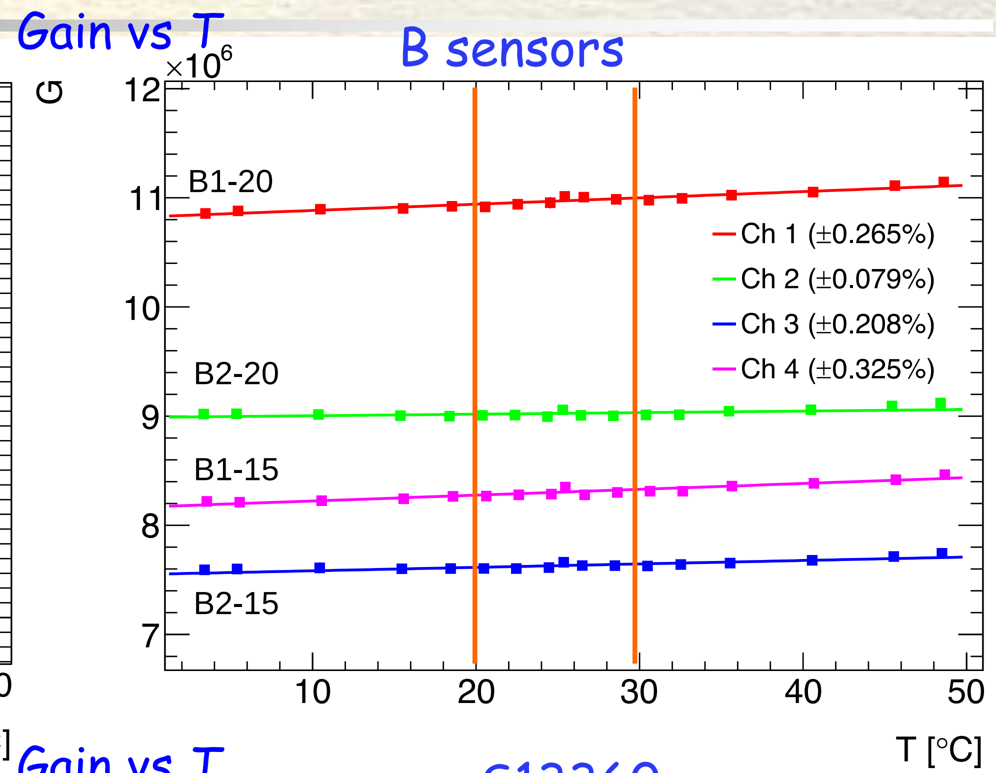
- We obtain the same dV/dT for Hamamatsu A, B & S12571 MPPCs within errors for both fitting strategies
- For KETEK and CPTA SIPMs we have tested the new fitting methodology on one channel so far
- For these two SiPMs, dV/dT values agree within two agree within 2 standard deviations
- We will do the remaining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

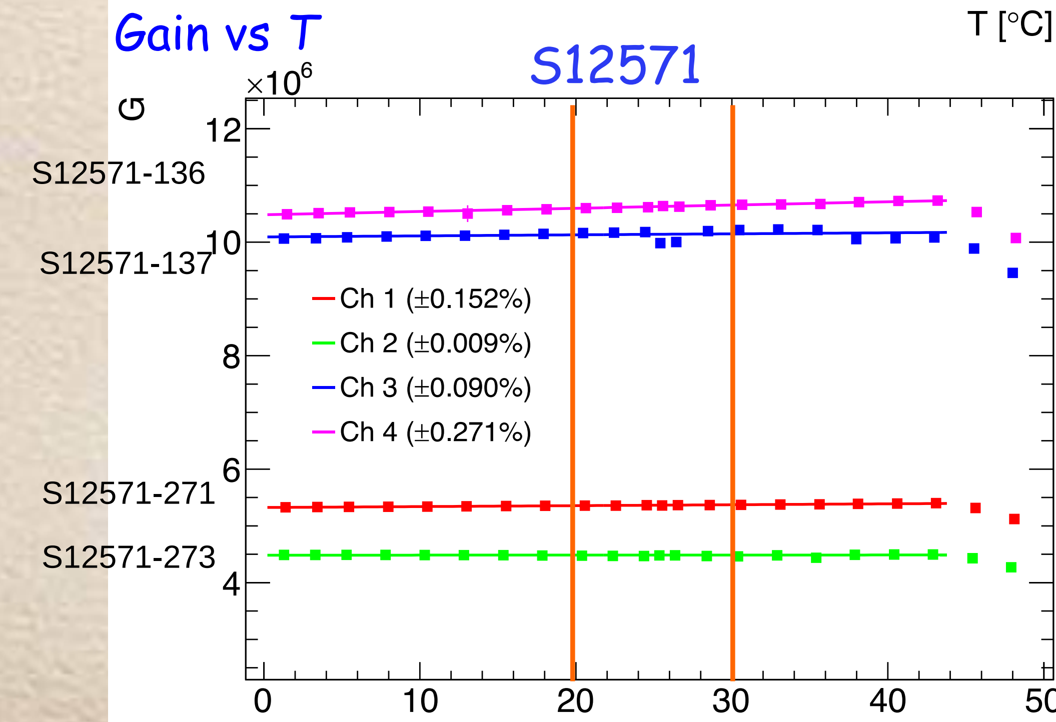


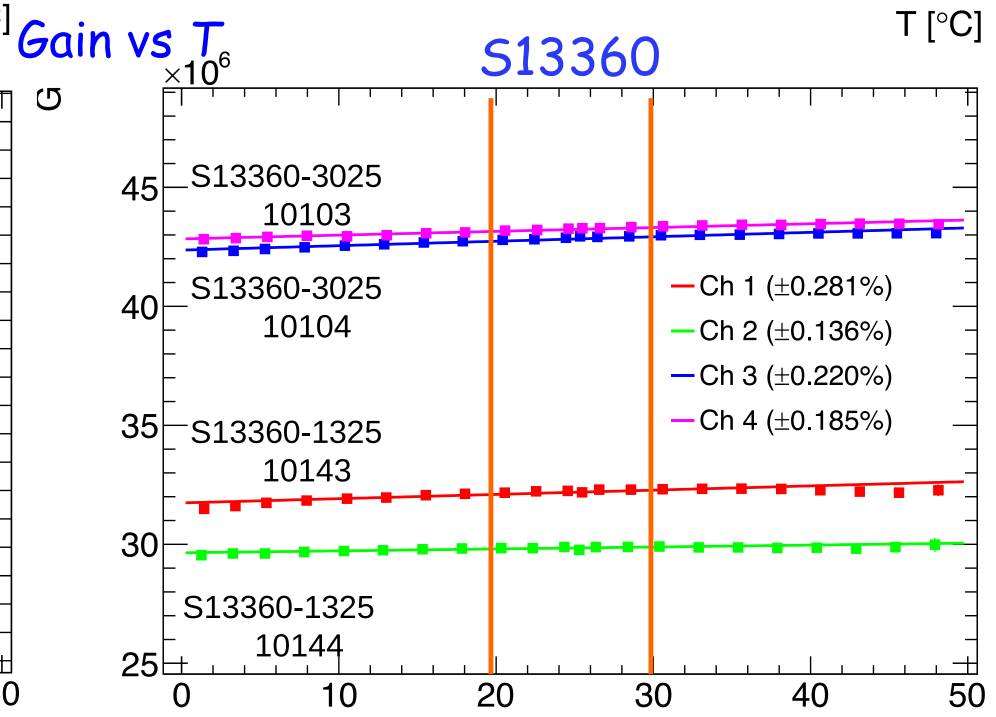
Gain Stabilization for Hamamatsu MPPCs (old fits)

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



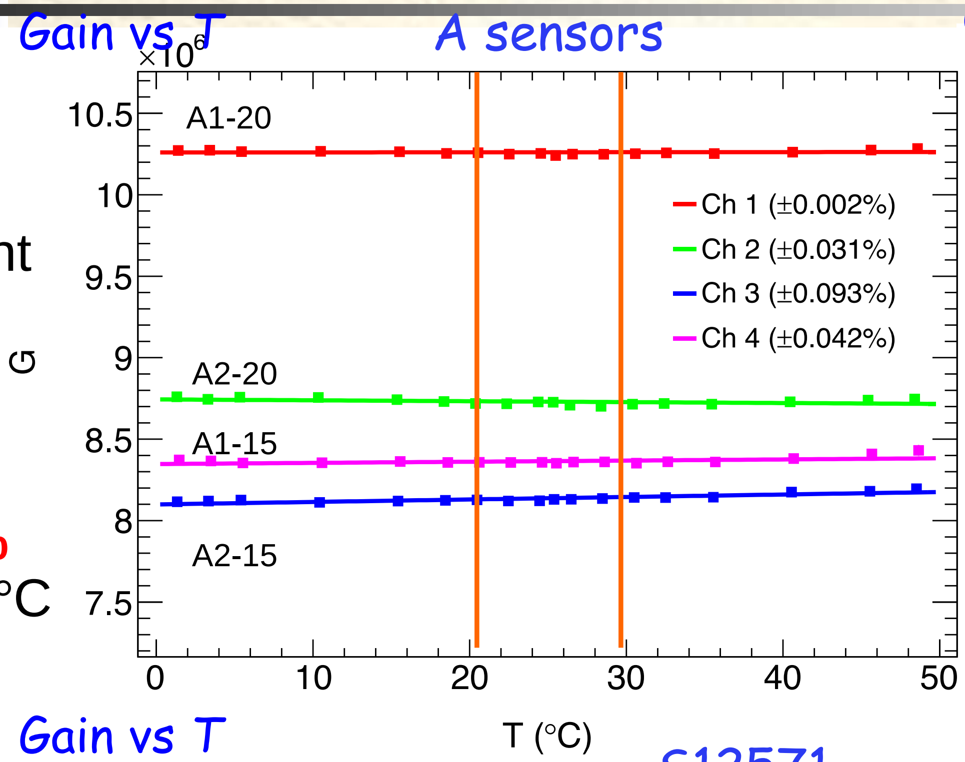


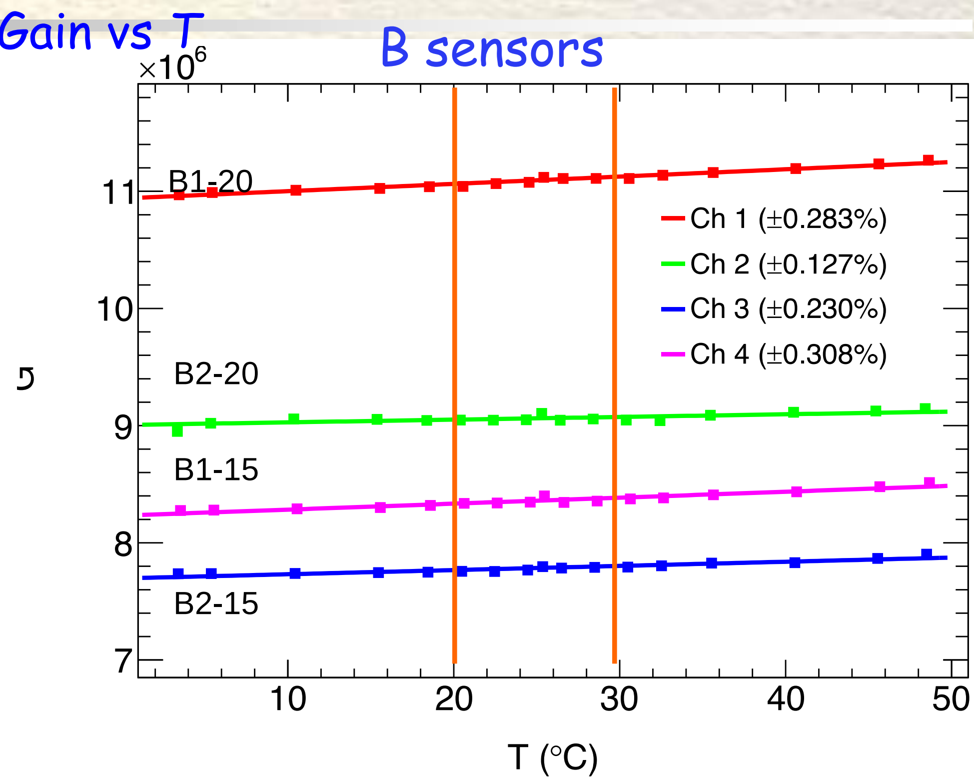


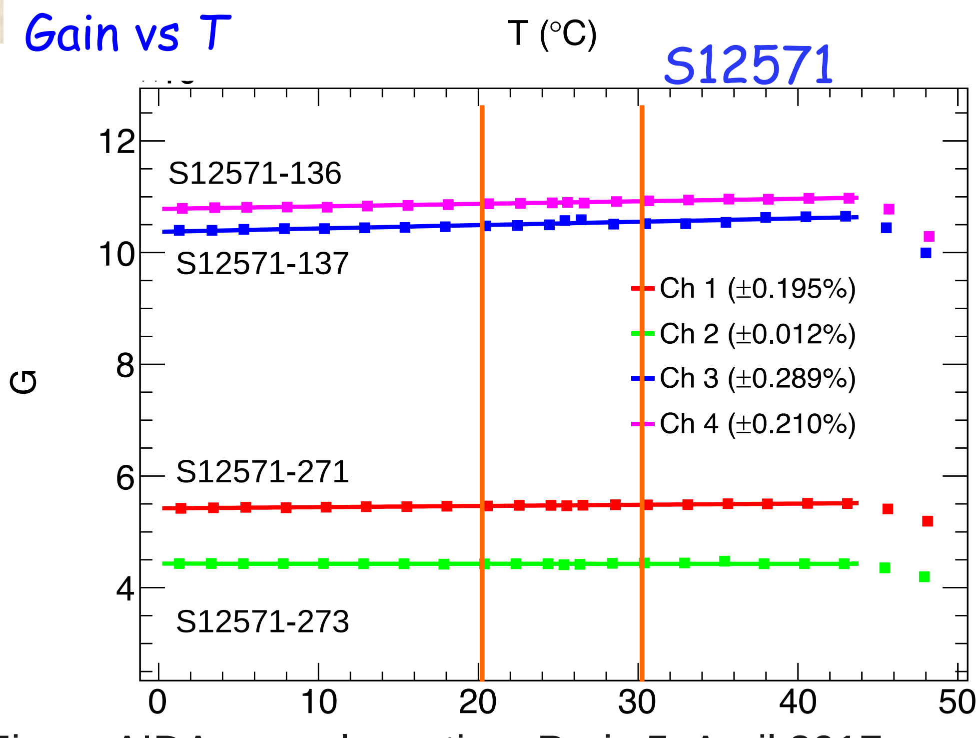


Gain Stabilization for Hamamatsu MPPCs (new fits)

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

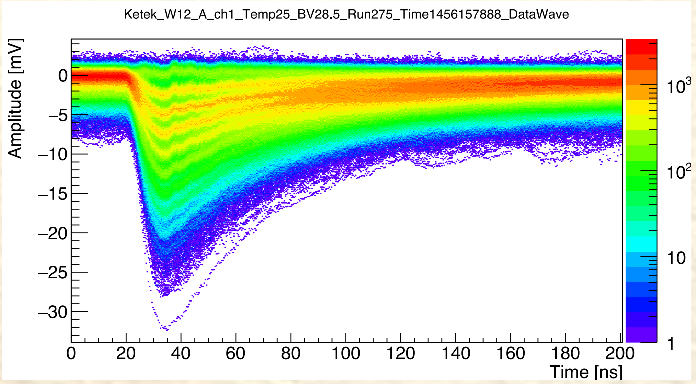


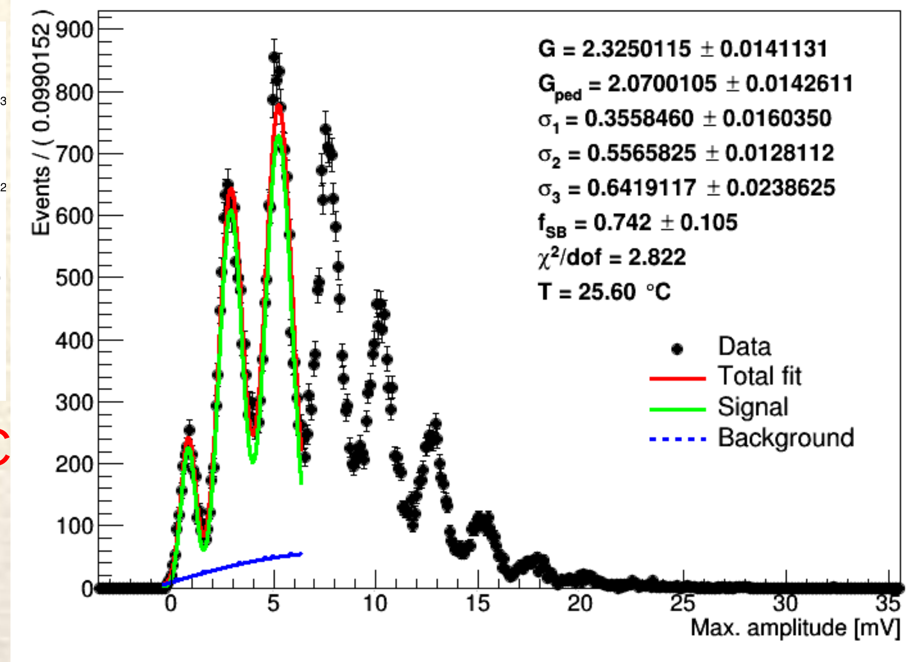




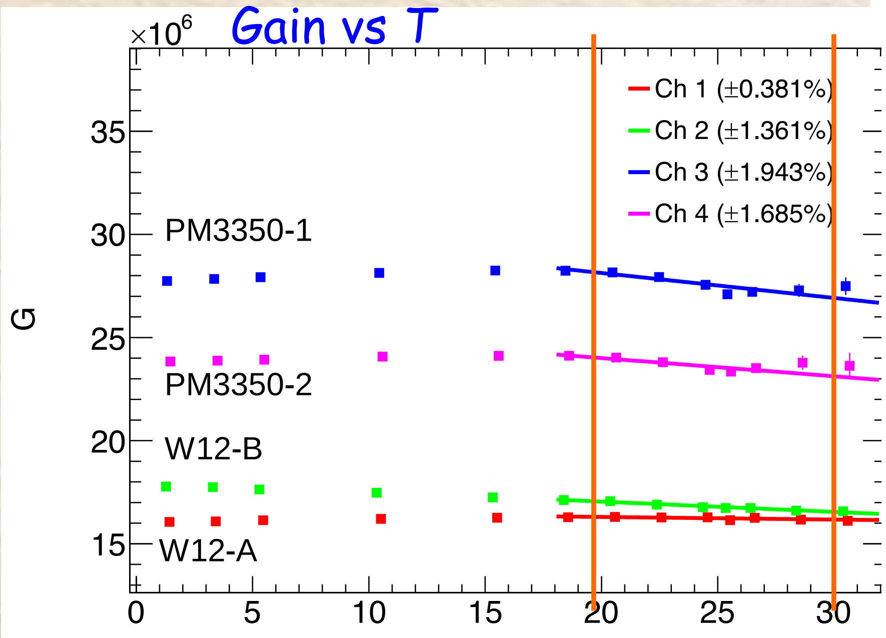
Gain Stabilization of KETEK SiPMs

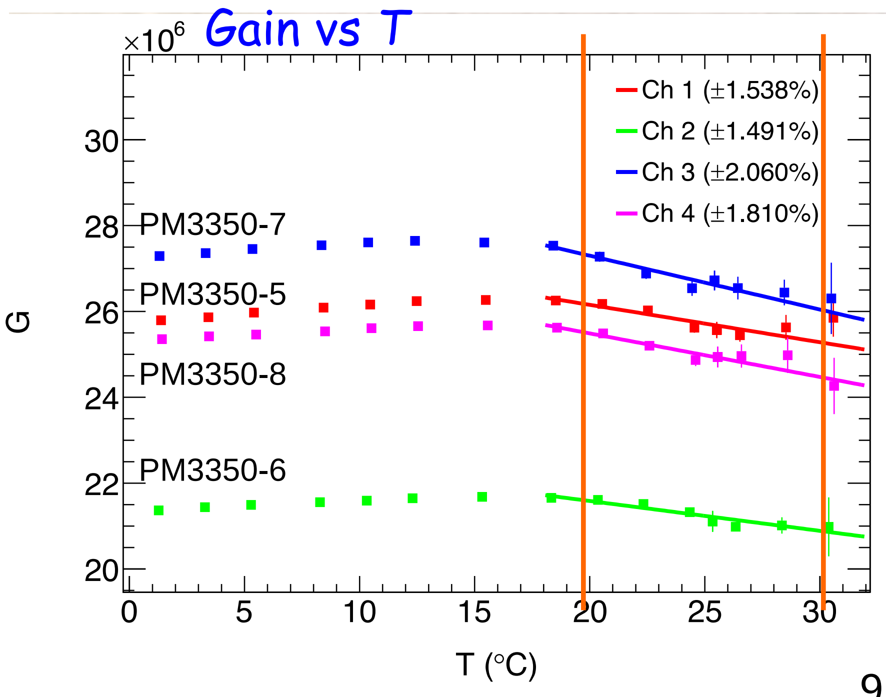
- Decay time of KETEK SiPMs is much longer than that of other SiPMs ➔waveforms typically do not return to baseline within 200 ns wide integration window





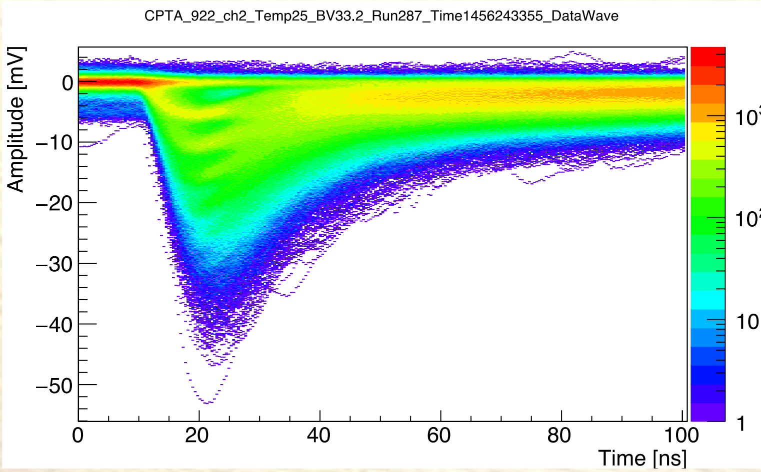
- Simultaneous gain stabilization for 4 KETEK SiPMs in two batches: *dV/dT*=18.2 mV/°C
- KETEK sensors show more complicated V(T) behavior ➔linear correction is not sufficient
- 1°C -18°C: G rises
- 18°C -22°C: G is uniform
- 22°C-30°C G falls off
- Only 1 SiPM satisfies **<±0.5%** requirement

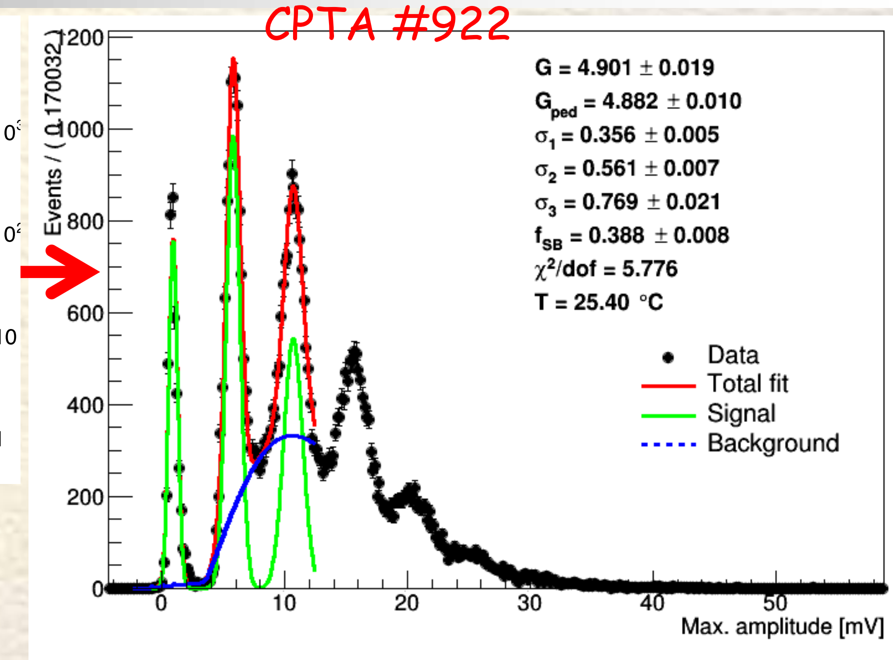


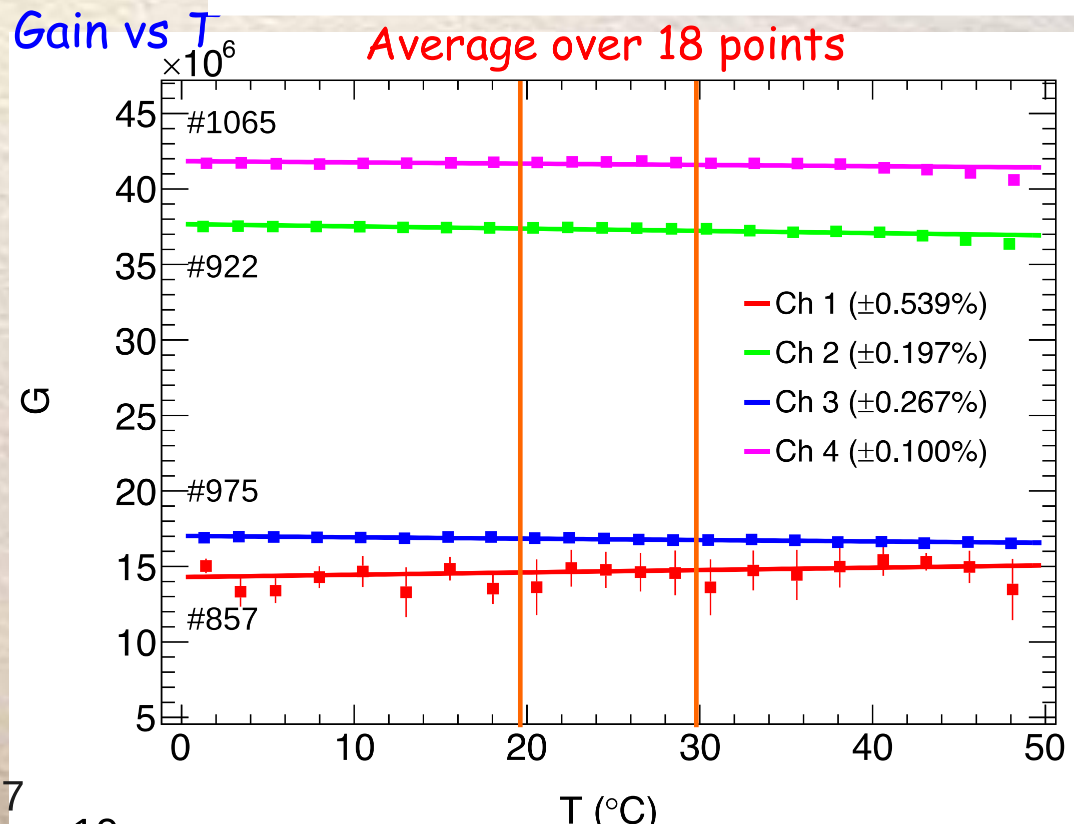


Gain Stabilization of CPTA SiPMs

- 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 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

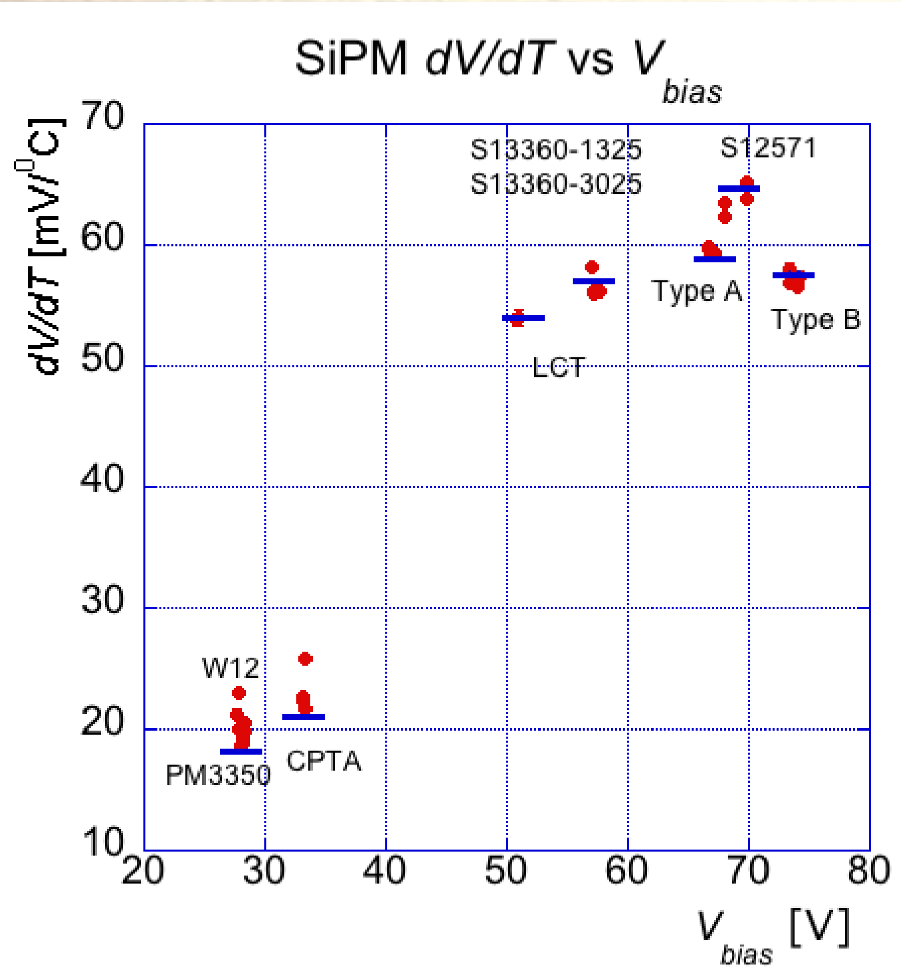






Measured *dV/dT* Values vs V_{bias} (old fits)

- 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

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: **ΔG/G < ±0.5%** in the 20°C-30°C *T* range ➔ most MPPCs satisfy **ΔG/G < ±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 1°C-30°C *T* range
- Gain stabilization of CPTA SiPMs works fine
  ➔ for 3 SiPMs, **ΔG/G < ±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
- We are checking KETEK and CPTA gain stabilization with new fit model
- Paper draft is progressing

Questions

1. **Infrastructure**: To what extend is your work an infrastructure or part of an infrastructure that can be used in the European (and beyond) Research Area?
   ➔ This work is relevant for the AHCAL and other large arrays of SiPMs

2. **Network:** Does your work belong to a bigger network on similar research topics (this is similar but not exactly the same as 1))?
   ➔ Large calorimeter systems such as those used in medical applications (PET, etc)

3. **Synergies**: Do you create synergies beyond your actual field of working?
   ➔ We think of extending measurements to temperatures below 0°C, which are of interest for neutrino experiments such as DUNE

4. **Industrial partners:** Are you in contact or will you in the near future establish sustained contacts with industrial partners (of any size)?
   ➔We have not contacted any company yet, this may be useful for applications

Acknowledgment

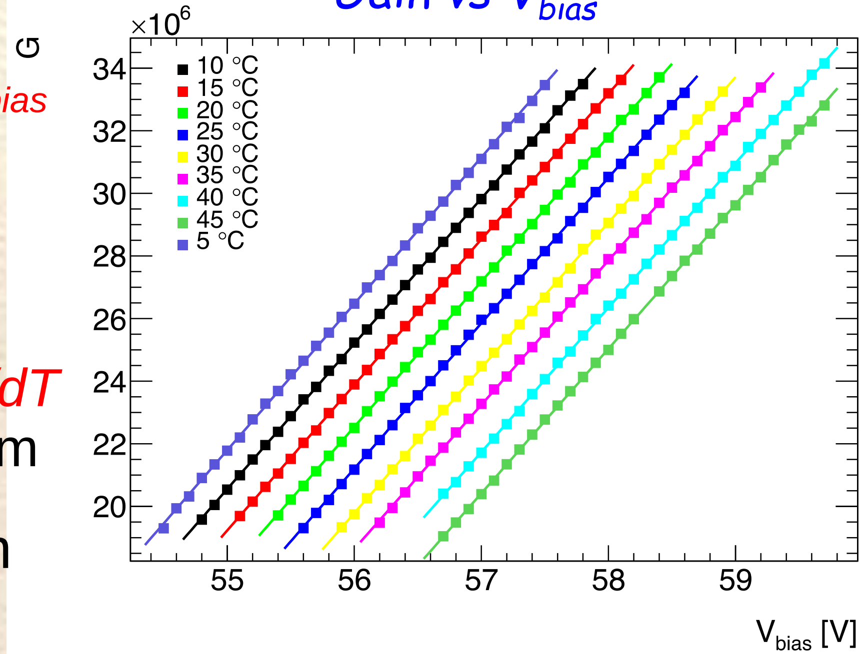
- We would like to thank L. Linssen, Ch. Joram, W. Klempt, and D. Dannheim for using the E-lab and for supplying electronic equipment

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

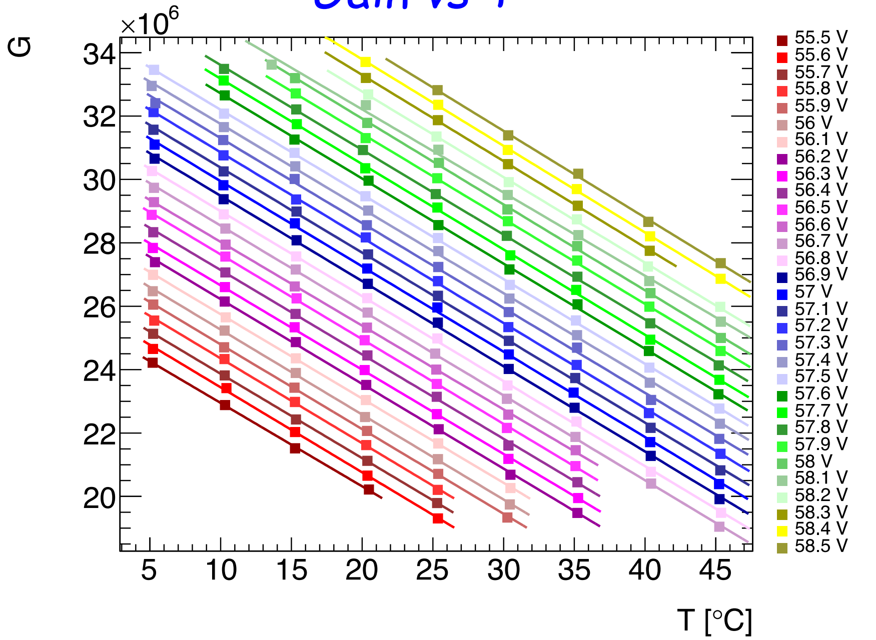
dG/dV, dG/dT & dV/dT Measurements

- 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

Gain vs V_{bias}

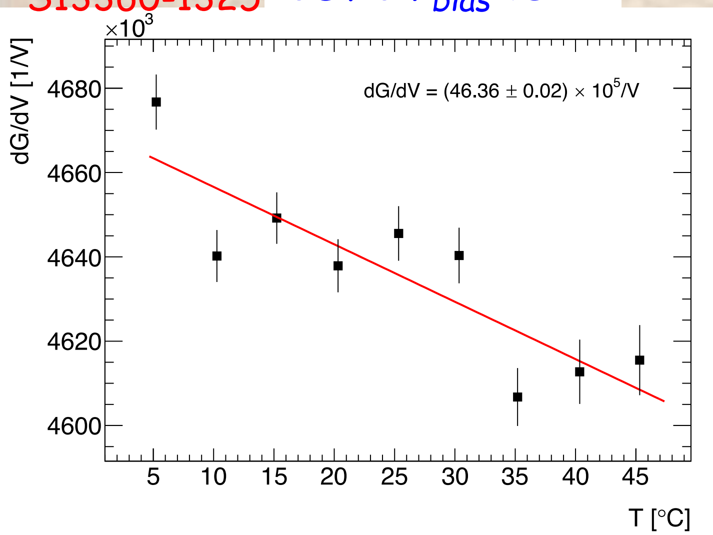


Gain vs T

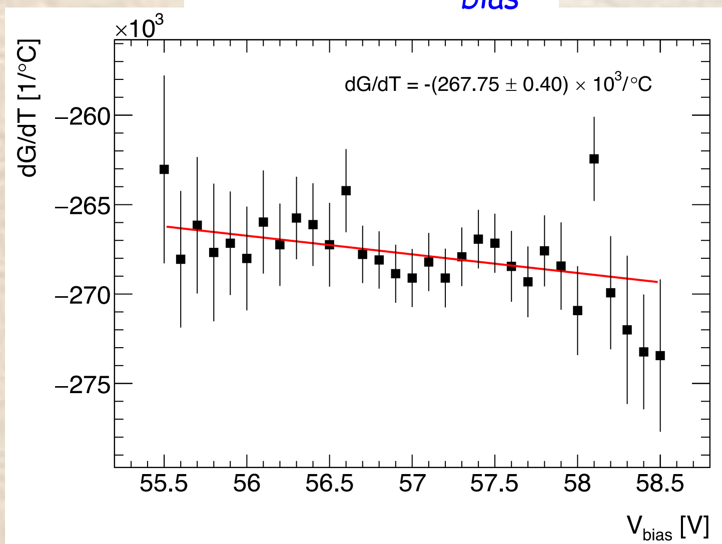


Hamamatsu S13360-1325

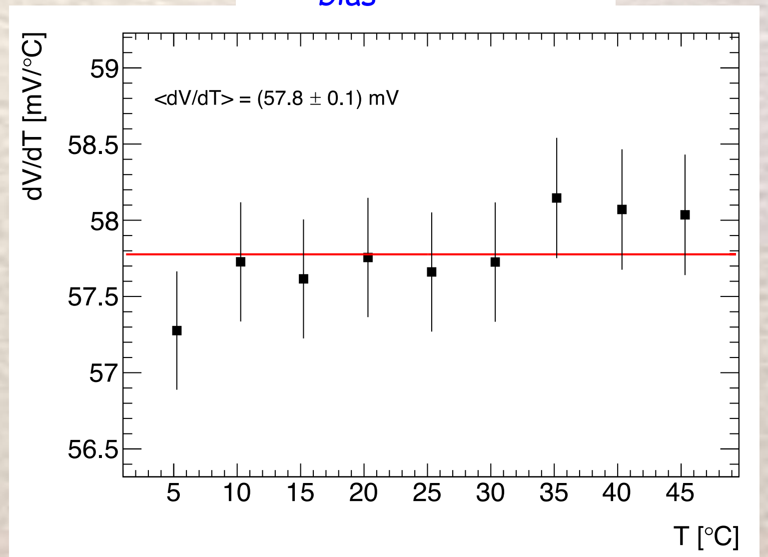
dG/dV_{bias} vs T



dG/dT vs V_{bias}



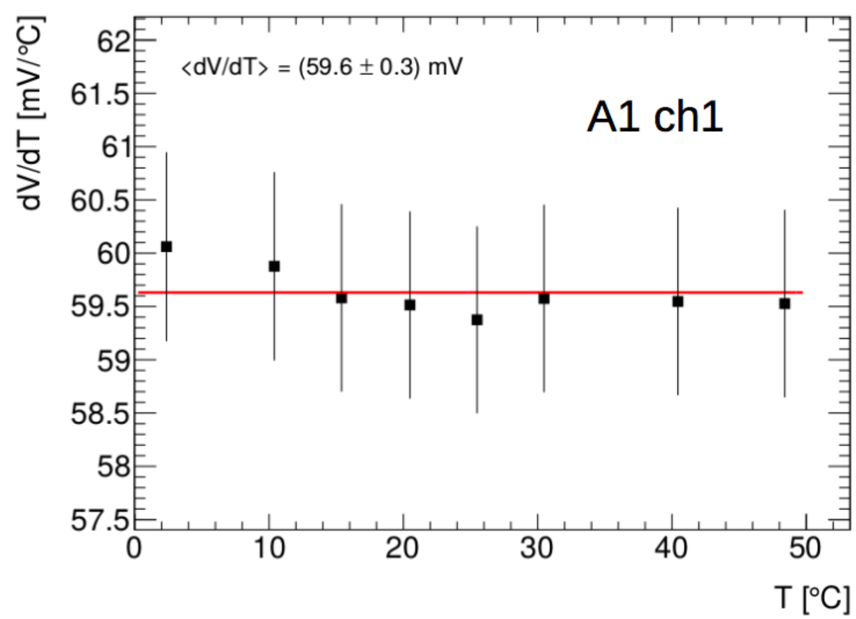
dV_{bias}/dT vs T

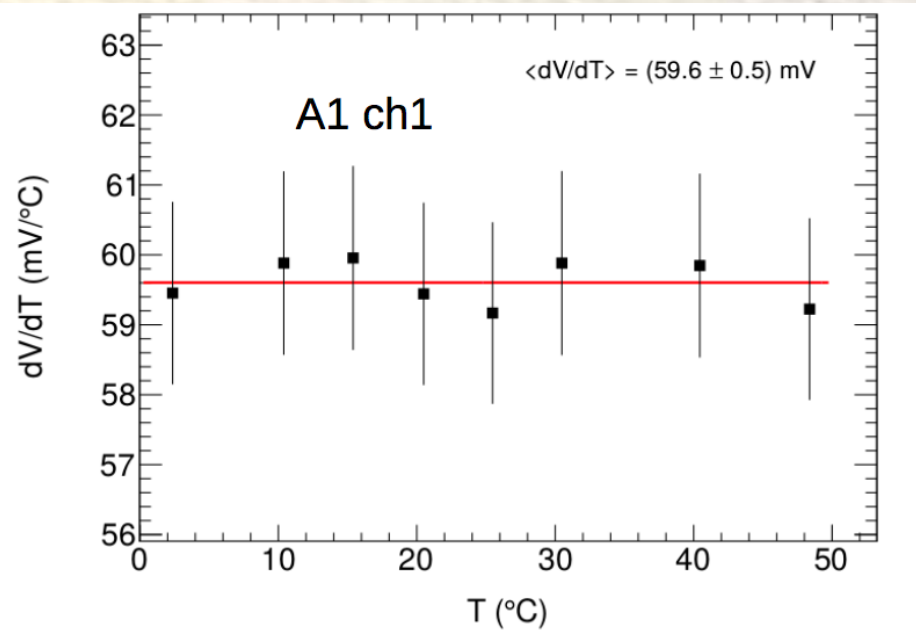


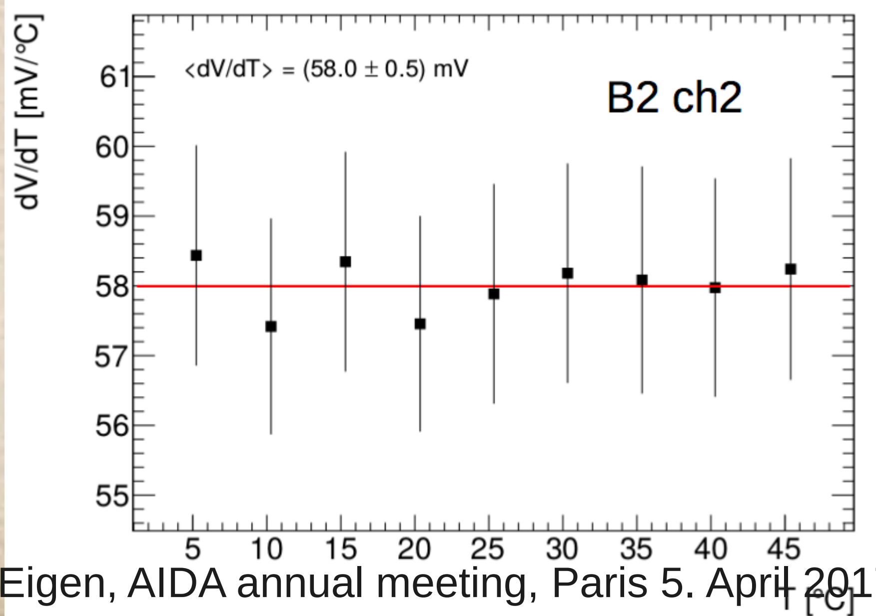
- $dG/dV=(4.636 \pm 0.002_{stat}) \times 10^6/V$
- $dG/dT=(2.6775 \pm 0.004) \times 10^5/°C$
- $dV/dT=(57.8 \pm 0.1_{sys})$ mV/°C

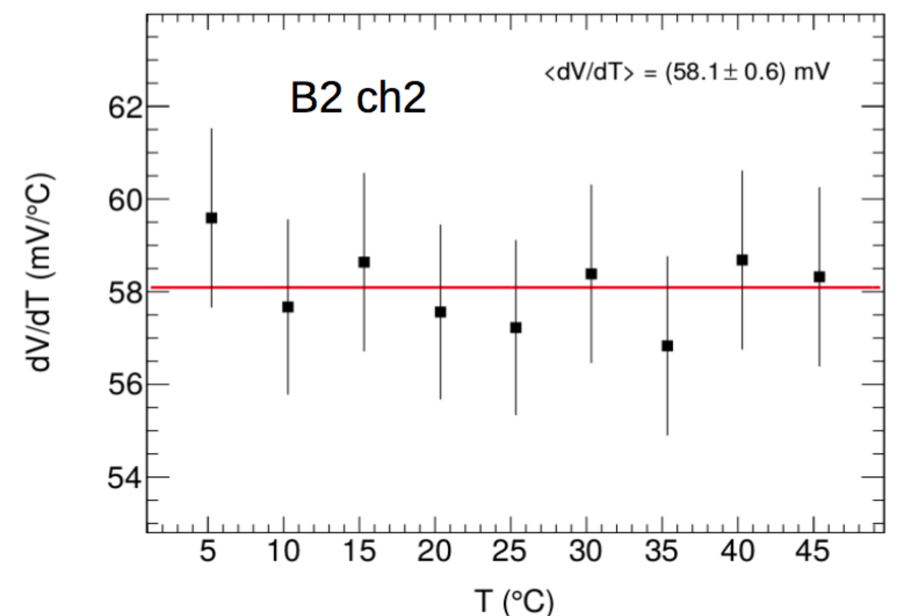
Compare 2 Fitting Strategies for A & B SiPMs

- 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