# Gain Stabilization of SiPMs

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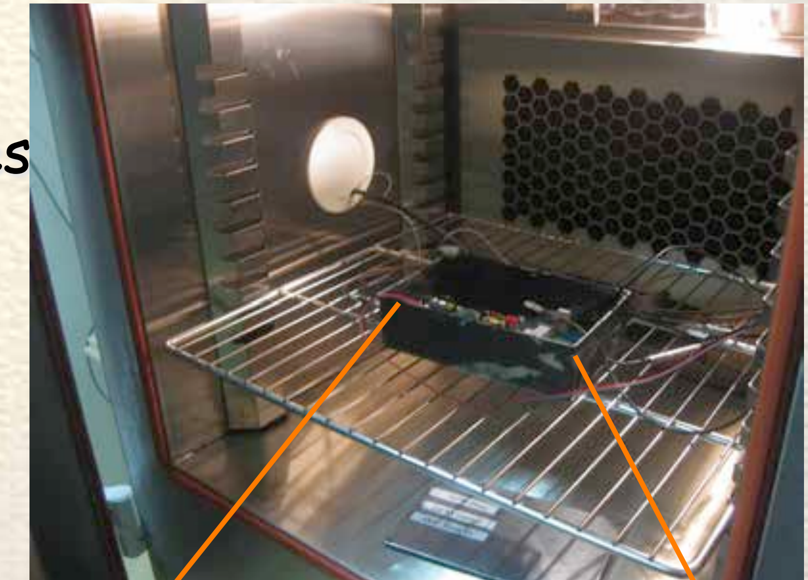
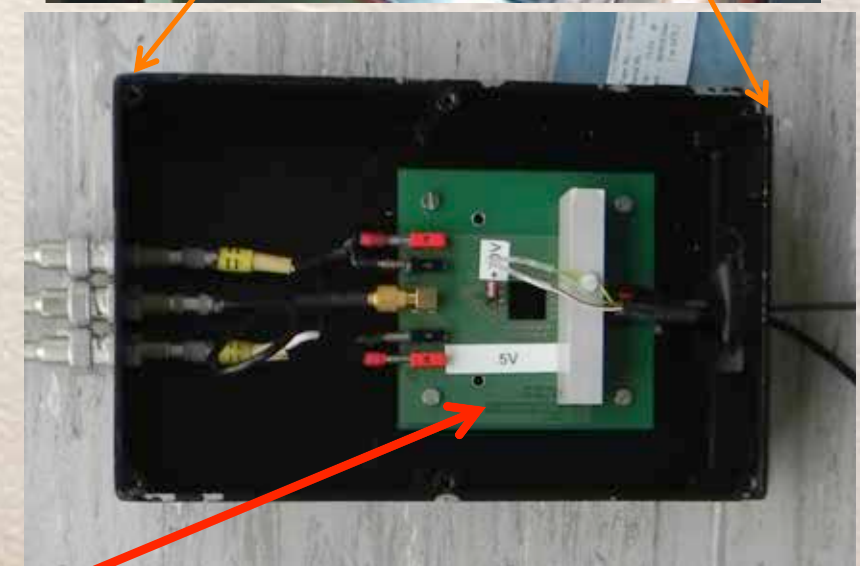
# Introduction

- The gain of SiPMs depends both on bias voltage and on temperature
  - Gain decreases with temperature
  - Gain increases with bias voltage
- For stable operations, we need to keep gain constant
- In an analogue hadron calorimeter with millions of channels, this is a difficult task due to temperature variations
- Thus, it is desirable to adjust $\mathbf{V_{bias}}$ to compensate for **T** changes to keep the gain constant
- Goal: build a $V_{bias}$ regulator to keep gain constant (<1%)
- First, we need to measure SiPM gain vs temperature and $V_{bias}$
  ➔ determine dV/dT to obtain constant gain
  ➔ build $V_{bias}$ regulator test board to demonstrate proof of principle
- This is work conducted in the framework of the EU project AIDA

# SiPM Test Setup

- We work in a climate chamber at CERN that is accurate to 0.1° C
- Use digital oscilloscope read out by PC, low voltage & bias voltage power supplies
- Use pulse generator for LED signal
- Shine blue LED light on detectors

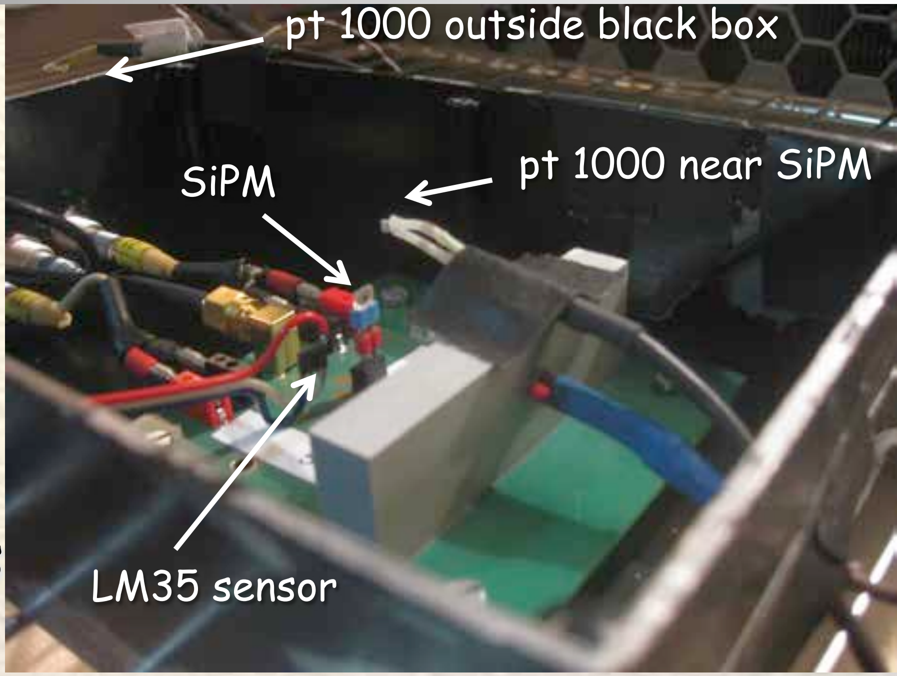



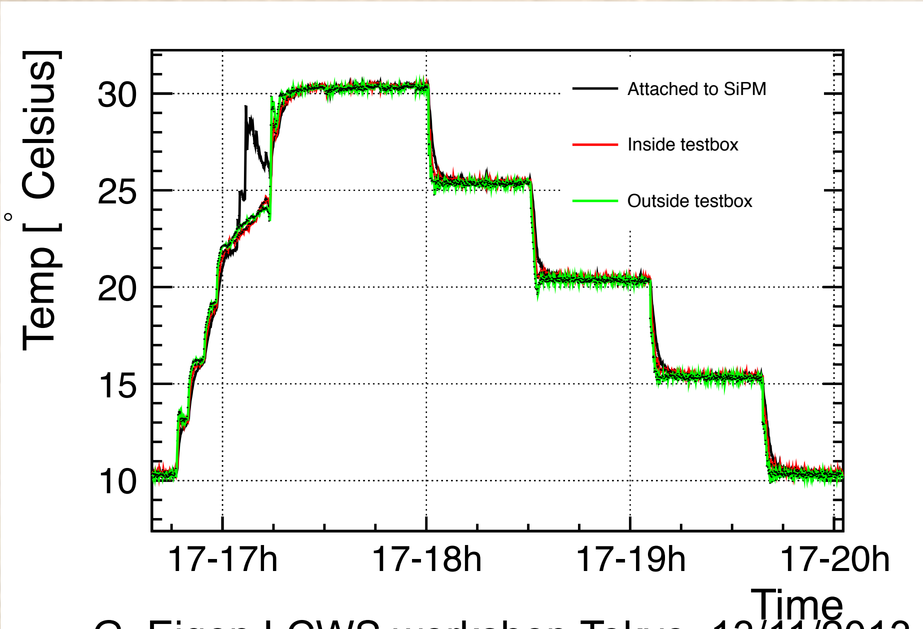


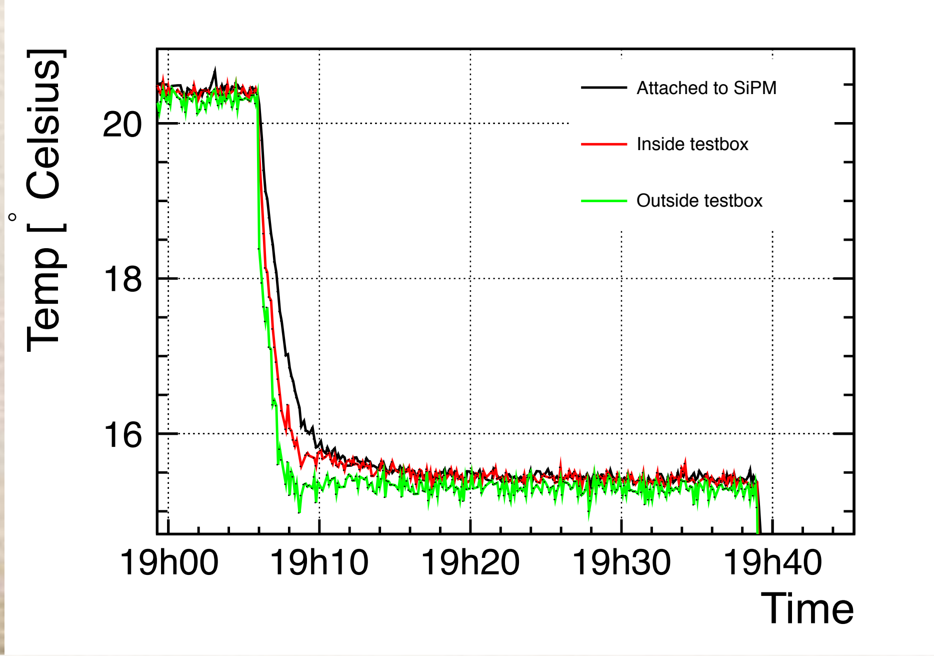

SiPM + preamp +T sensor + LED

# Temperature Measurement

- Use 3 pt 1000 sensors
  - Near SiPM, inside/outside black box
- Use LM35 sensor to measure T to perform gain correction
- Vary T from 5°C to 40°C in 5°C steps except in 20°-30°C range use 2°C steps
  ➔ $T_{SiPM} \sim T_{SET} + 0.4°C$,
  ➔ offset is same over entire range



# SiPM Detectors Tested

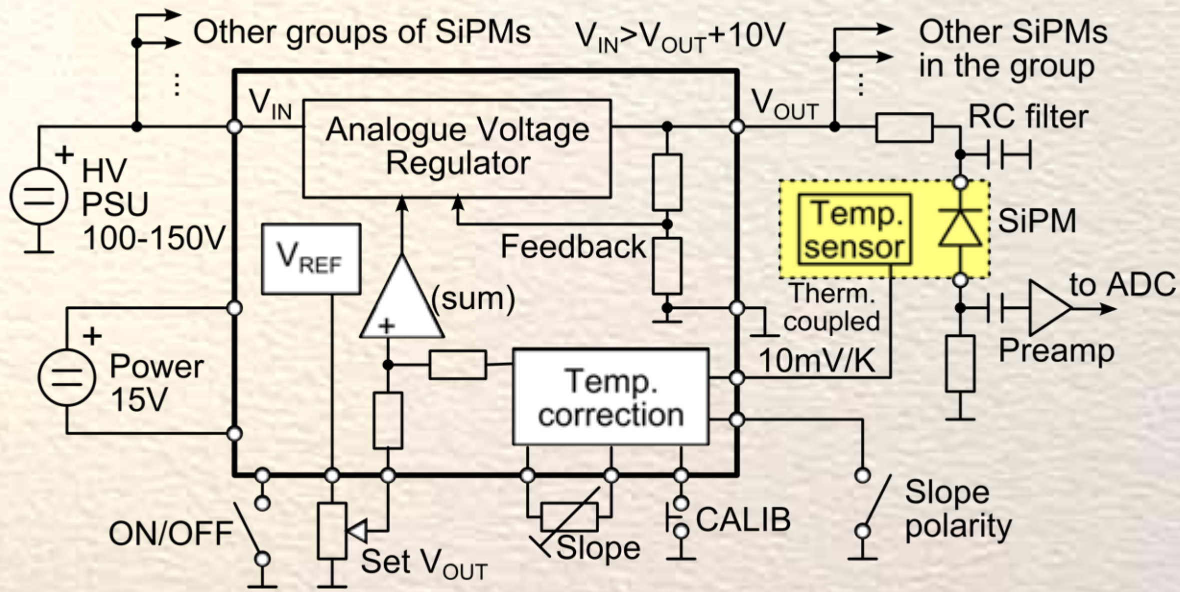
- We measured the dG/dT & dG/dV dependence for 15 SiPMs from 3 manufacturers
- We tested the $V_{bias}$ adjustment on 4 SiPMs:
  - CPTA 857
  - CPTA 1677
  - KETEK W 12
  - Hamamatsu 11759

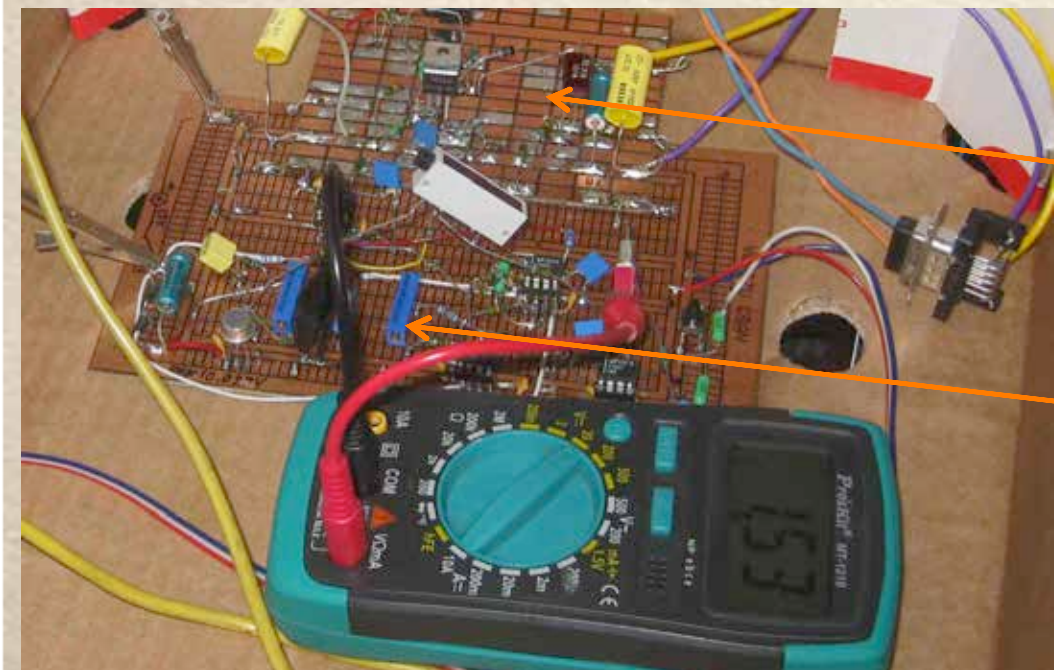
| Manufacturer and Type # | Sensitive area $[mm^2]$ | Pixel pitch $[\mu m]$ | #pixels | Typical $V_{bias}$ [V] | Typical $G$ $[\times 10^5]$ | Serial # |
|---|---|---|---|---|---|---|
| Hamamatsu | | | | | | |
| → S10943-8584(X) | $1 \times 1$ | 50 | 400 | 71.69 | 7.49 | 11759 |
| S10943-8584(X) | $1 \times 1$ | 50 | 400 | 71.57 | 7.49 | 11766 |
| S10943-8584(X) | $1 \times 1$ | 50 | 400 | 71.50 | 7.48 | 11770 |
| S10943-8584(X) | $1 \times 1$ | 50 | 400 | 71.33 | 7.48 | 11771 |
| Sample A | $1 \times 1$ | 20 | 2500 | 66.7 | 2.3 | A1 |
| Sample B | $1 \times 1$ | 20 | 2500 | 73.3 | 2.3 | B1 |
| Sample A | $1 \times 1$ | 15 | 4440 | 67.2 | 2.0 | A2 |
| Sample B | $1 \times 1$ | 15 | 4440 | 74.0 | 2.0 | B2 |
| CPTA | | | | | | |
| → | $1 \times 1$ | 40 | 796 | 33.4 | 7.1 | 857 |
| | $1 \times 1$ | 40 | 796 | 33.1 | 6.3 | 922 |
| | $1 \times 1$ | 40 | 796 | 33.3 | 6.3 | 975 |
| | $1 \times 1$ | 40 | 796 | 33.1 | 7.0 | 1065 |
| → | $1 \times 1$ | 40 | 796 | 33.3 | 14.6 | 1677 |
| KETEK | | | | | | |
| MP15 V6 ? | $2(1.2 \times 1.2)$ | 15? | ? | $-28$ | ? | W8 |
| → MP20 V4 ? | $3 \times 3$ | 20? | ? | $-28$ | ? | W12 |

- Note that CPTA sensors were attached to 3x3 $cm^2$ scintillator tiles while the other sensors were directly illuminated by blue LED

# Layout of the Adaptive Power Regulator

- Design $V_{bias}$ regulator that operates in 10 V to 80 V region plus T correction effects
- Temperature slope: <1 to 100 mV/K, both positive and negative



- First design of test board

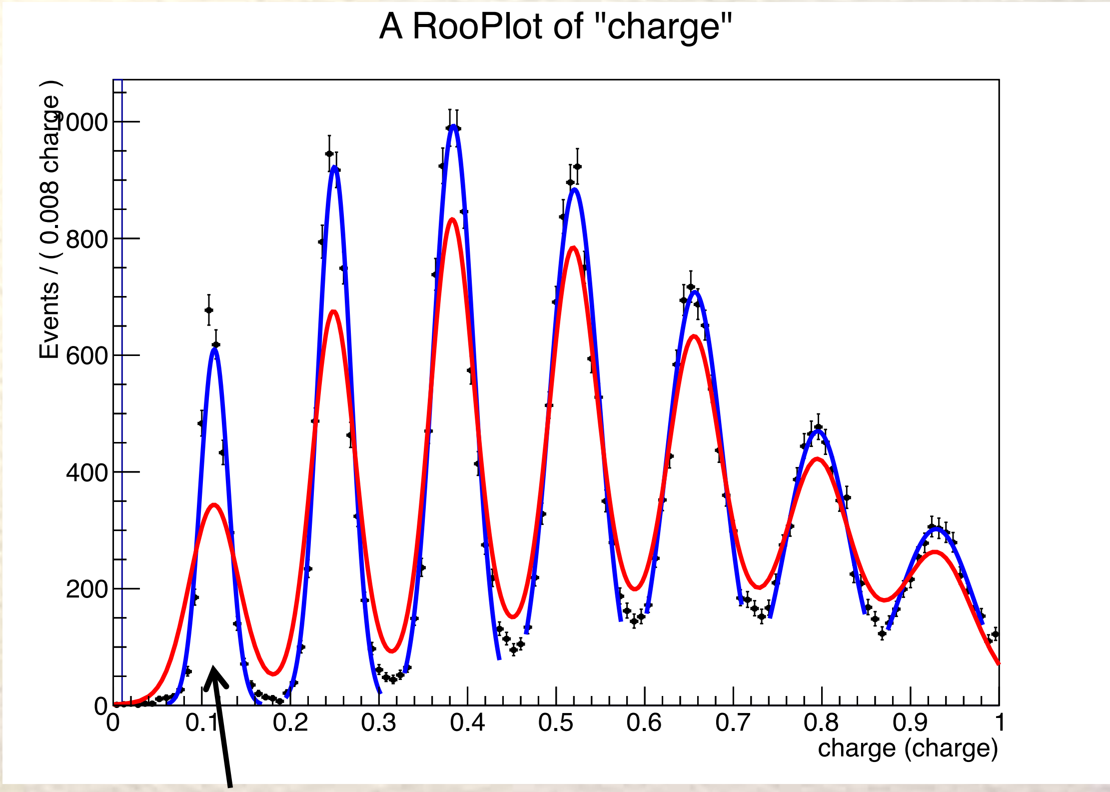
Analogue voltage regulator

Voltage reference

# Gain Determination

- Determine gain by fitting Gaussian functions to peaks of single pe spectra

- Define gain as
  - Distance between 1 pe & 2 pe peaks (MPPCs)
  - Distance between pedestal 1 pe peak (CPTA, KETEK)



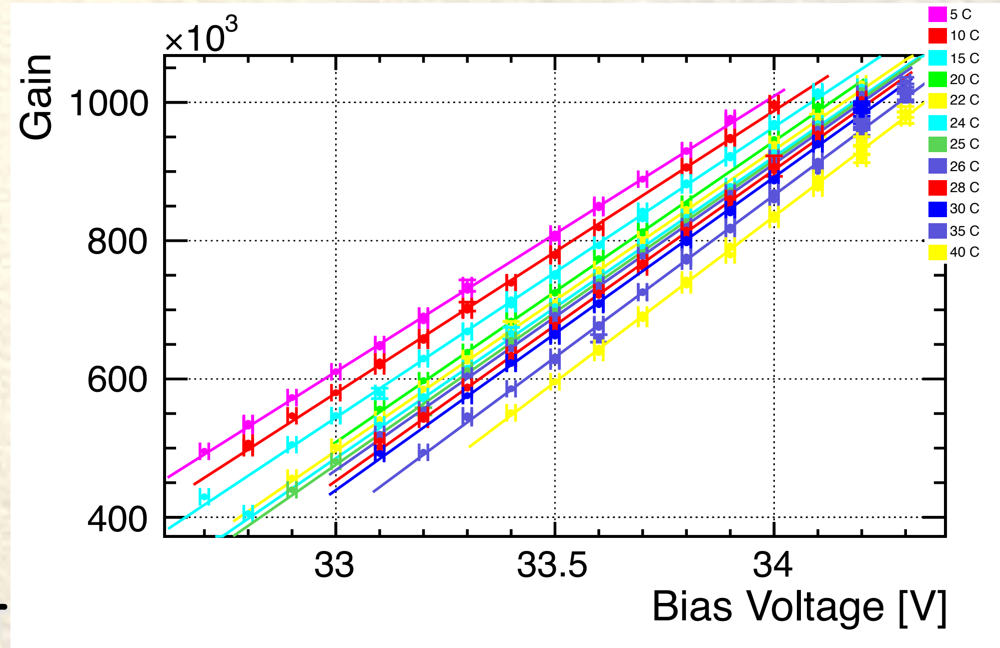

RooFit multikernel function
Individual Gaussian fits

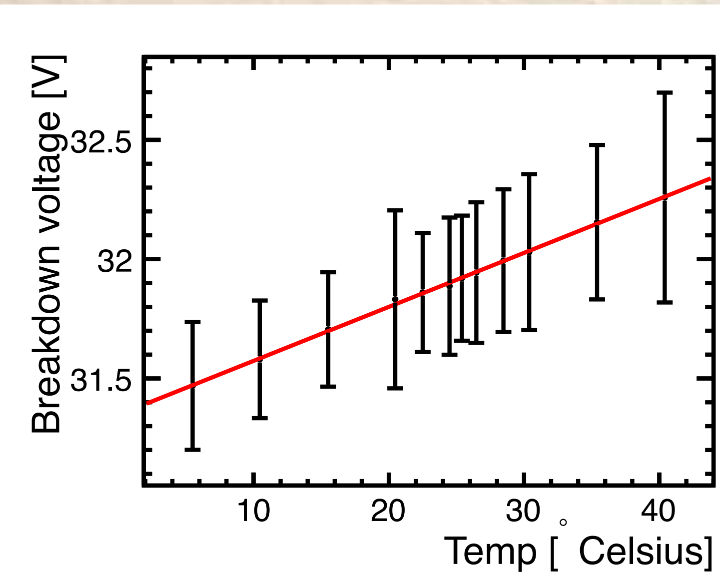
- Define the error on the gain as the errors of the two fitted Gaussian mean values added in quadrature

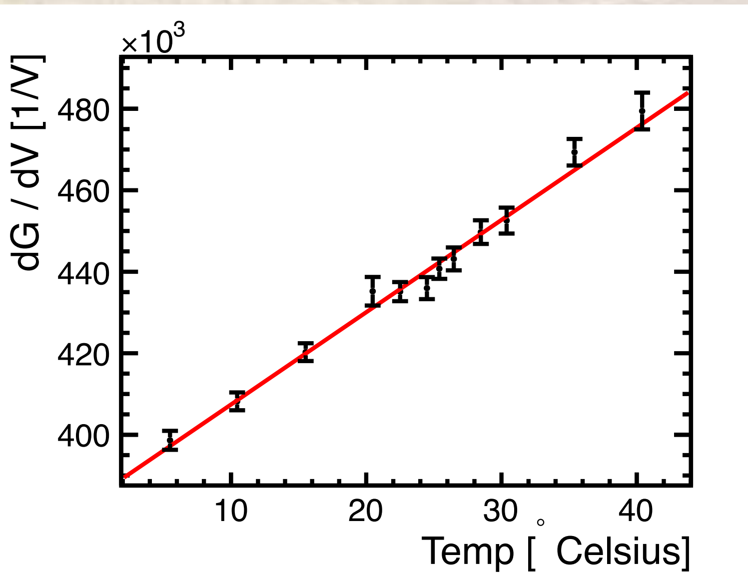
- Require gain extracted from Gaussian peaks and that from multikernel peaks not to differ by more than 20%

# Gain vs Voltage for CPTA 857

- Each point is the gain extracted from 50k waveforms of 80 ns
- Linear fit to these distributions yields break-down voltage & dG/dV
- Break-down voltage drops with T
- dG/dV~ capacitance is not constant
  ➔ it increases linearly with temperature

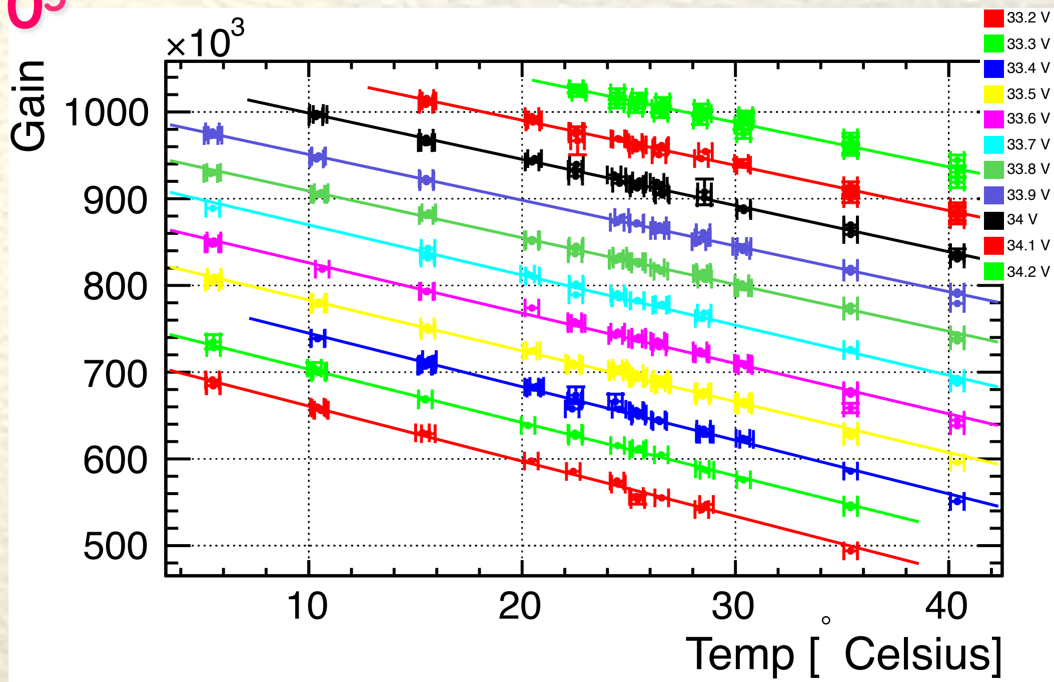


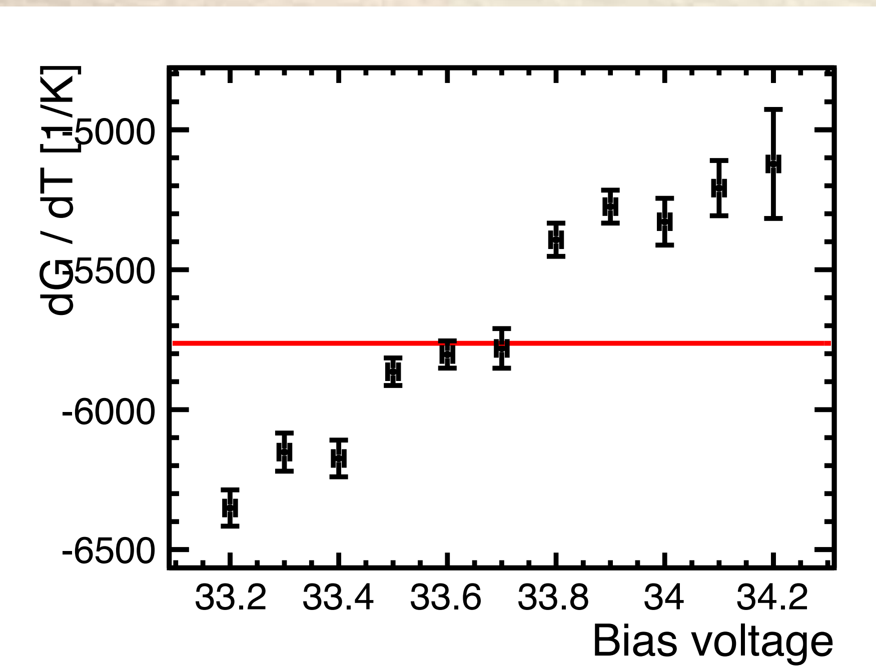



# Gain vs Temperature for CPTA 857

- At $V_{bias}$=33.4 V & T=25°: G=6.4×10⁵
- Extract $V_{breakdown}$=31.9 V
- 0th order polynomial fit yields:
  $dG/dV=(4.32\pm0.01_{stat})\times10^5/K$
- 1st order polynomial fit yields:
  $dG/dV=(4.41\pm0.11_{sys})\times10^5/K$

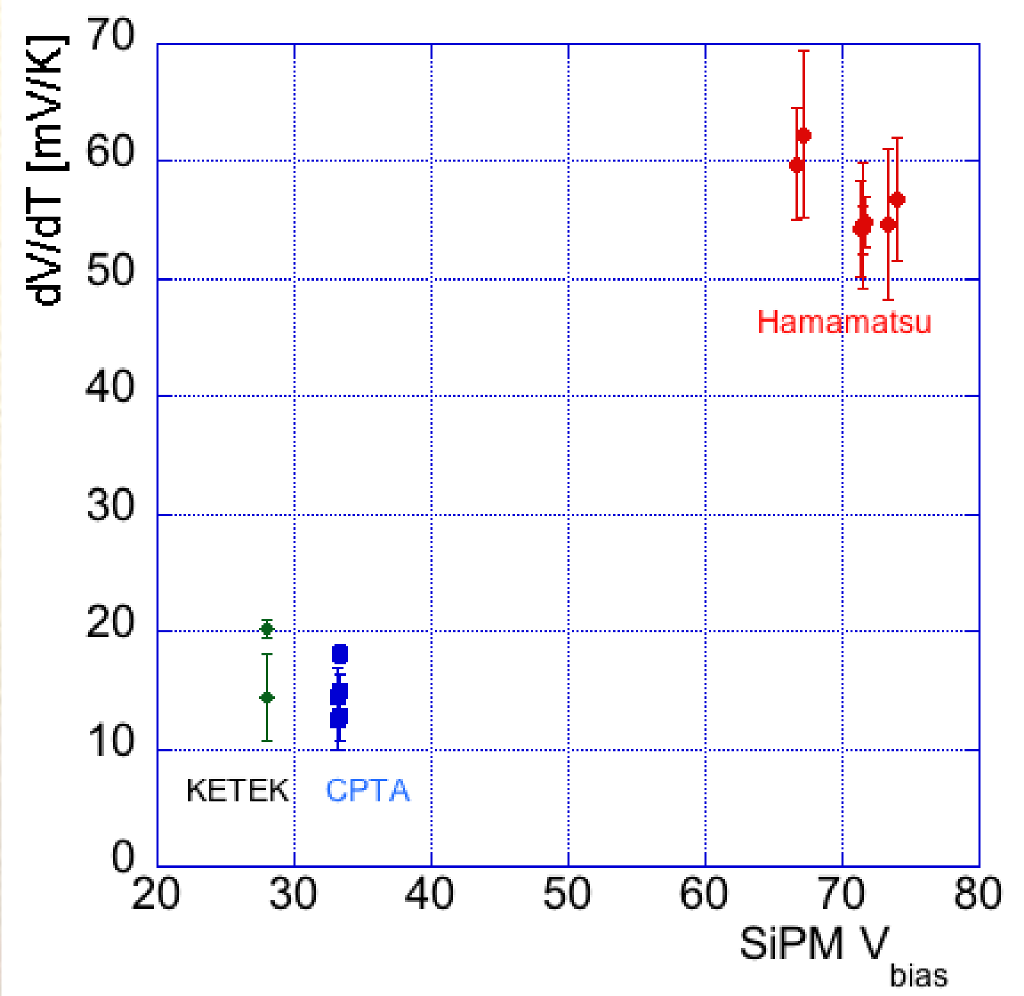



- 0th order polynomial fit yields:
  $dG/dT=(-5.76\pm0.02_{stat})\times10^3/K$
- Determine:
  $dV/dT=\langle dG/dT\rangle/\langle dG/dV\rangle$
  $= 13.33\pm0.35$ mV/K
- Gain stability=$\sigma(dV/dT)/(2G\bullet dG/dV)$
  = 0.12%

# Summary of dV/dT Measurements

- $V_{bias}$ for Hamamatsu is ~70 V while $V_{bias}$ for CPTA is ~33 V & $V_{bias}$ for KETEK is ~28 V
- For KETEK and CPTA, dV/dT is ~15-20 mV/K for Hamamatsu, dV/dT is ~55 mV/K
- Thus, compensation will be simpler for CPTA and KETEK detectors

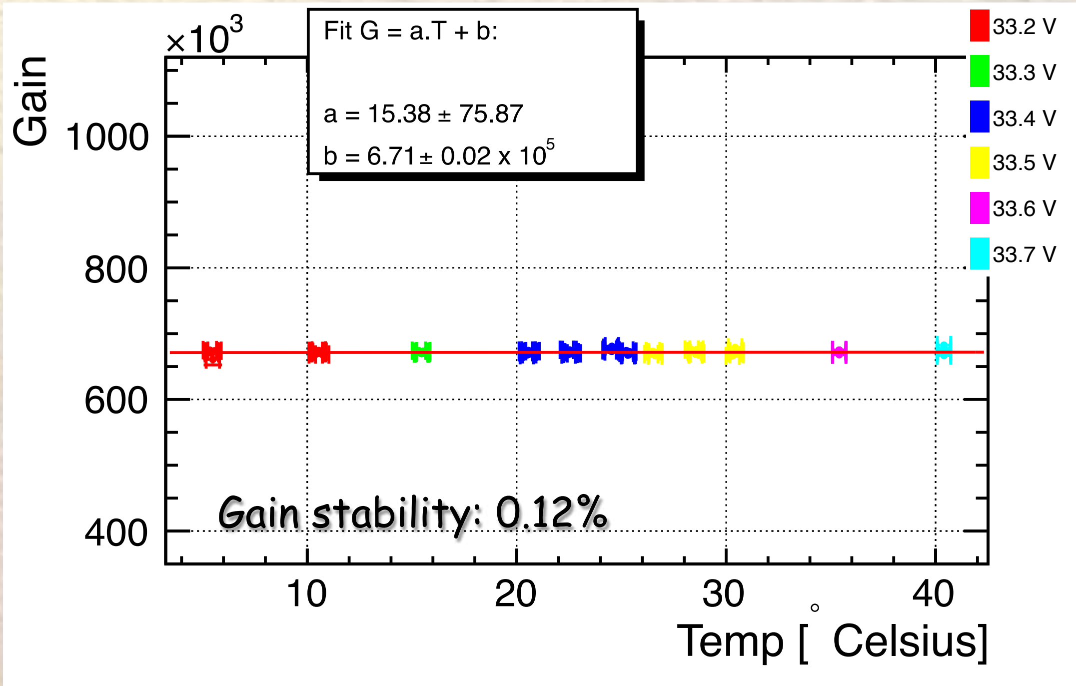



- We tested the compensation on four detectors so far, including samples from all manufacturers

# Gain after $V_{bias}$ Adjustment for CPTA 857

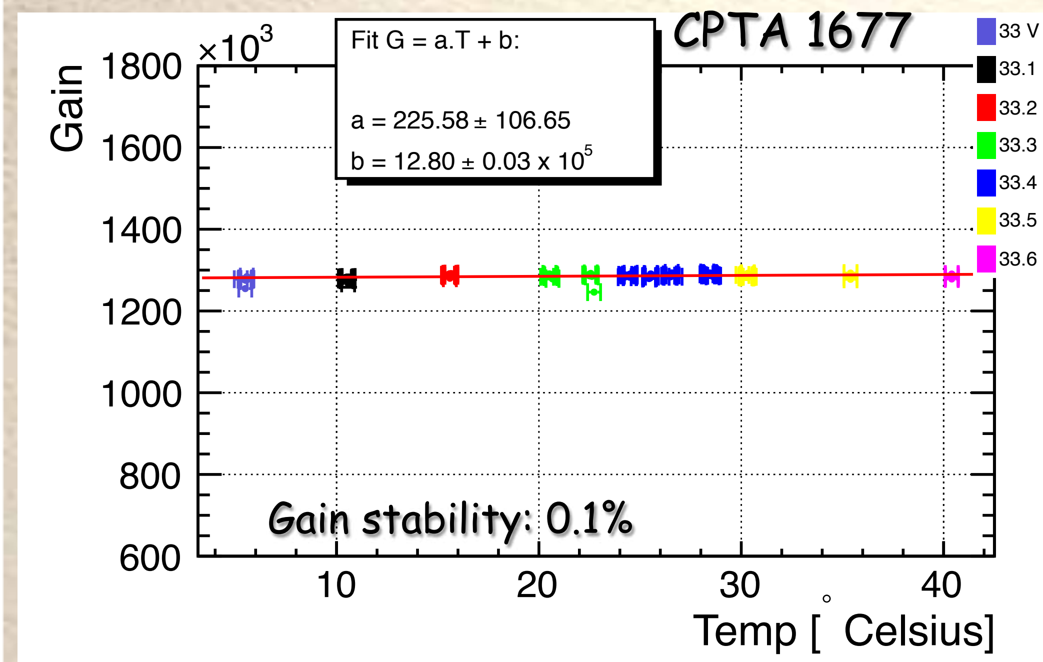
- Adjust voltage continuously using $V_{bias}$ regulator test board
  Note: color code gives the range of voltage applied
  e.g. blue: $33.35 < V_{bias} < 33.45$
- At each temperature, take 16 samples with 50k waveform each
- Linear fit to all data points
  - offset: $(6.71 \pm 0.02) \times 10^5$
  - slope: $15.38 \pm 75.87$
- Gain is uniform in range of interest 5°-40° C
  ➔ measured non-uniformity is < ±0.05%

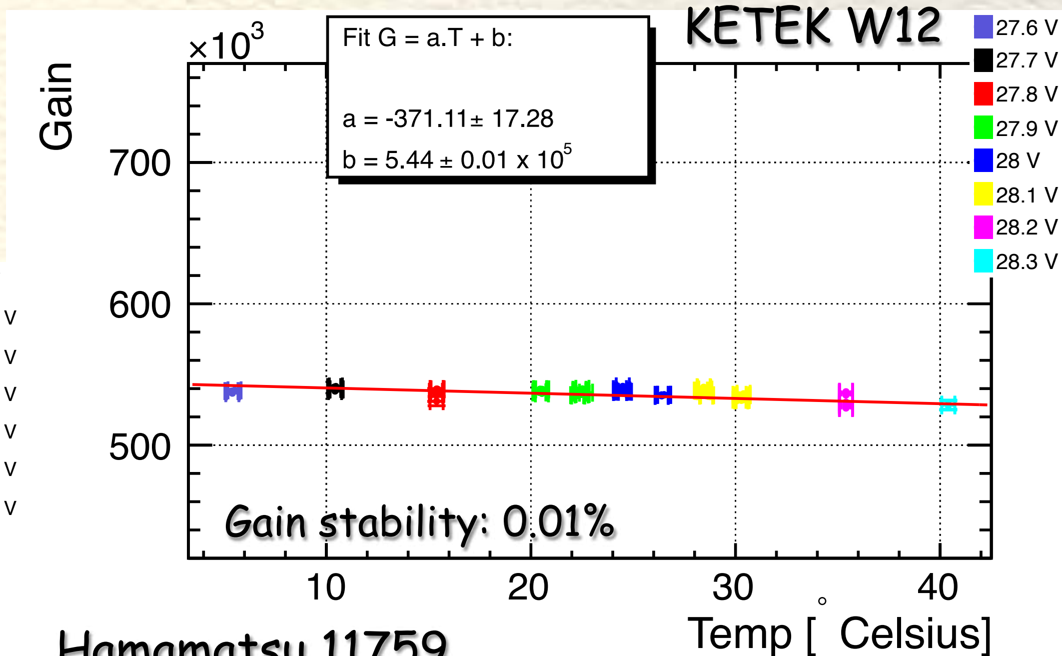
CPTA 857

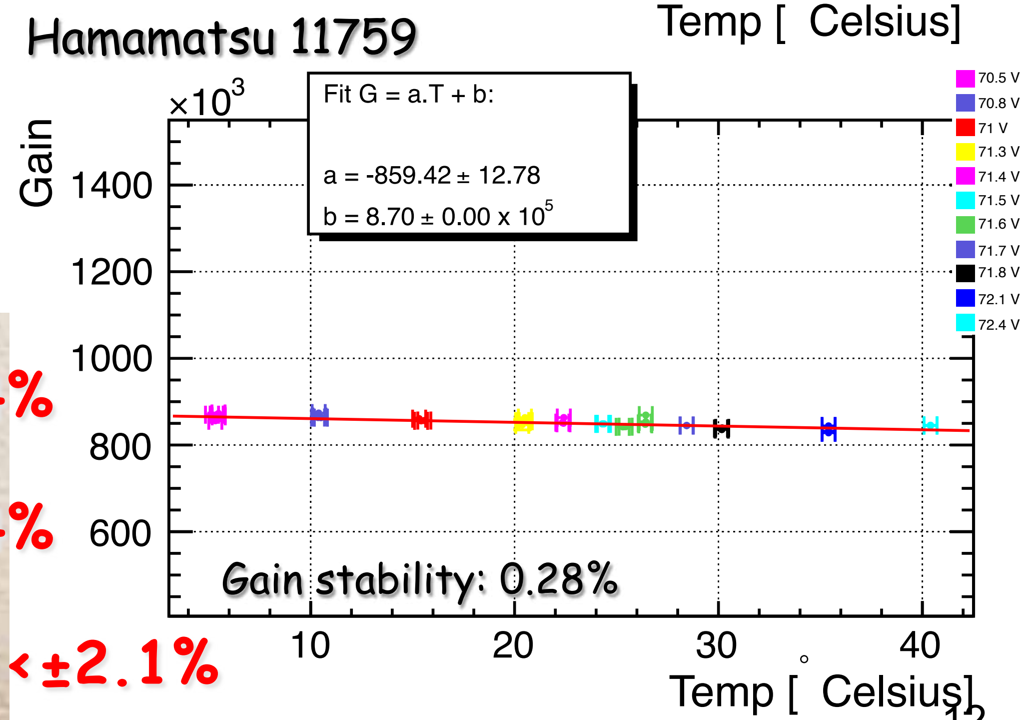


# Gain after $V_{bias}$ Adjustment for other SiPMs

- Perform similar study with 3 other SiPMs from CPTA, KETEK and Hamamatsu




- CPTA 1677: non-uniformity < ± 0.4%
- KETEK W12: non-uniformity < ±1.4%
- Hamamatsu 11759: non-uniformity < ±2.1%

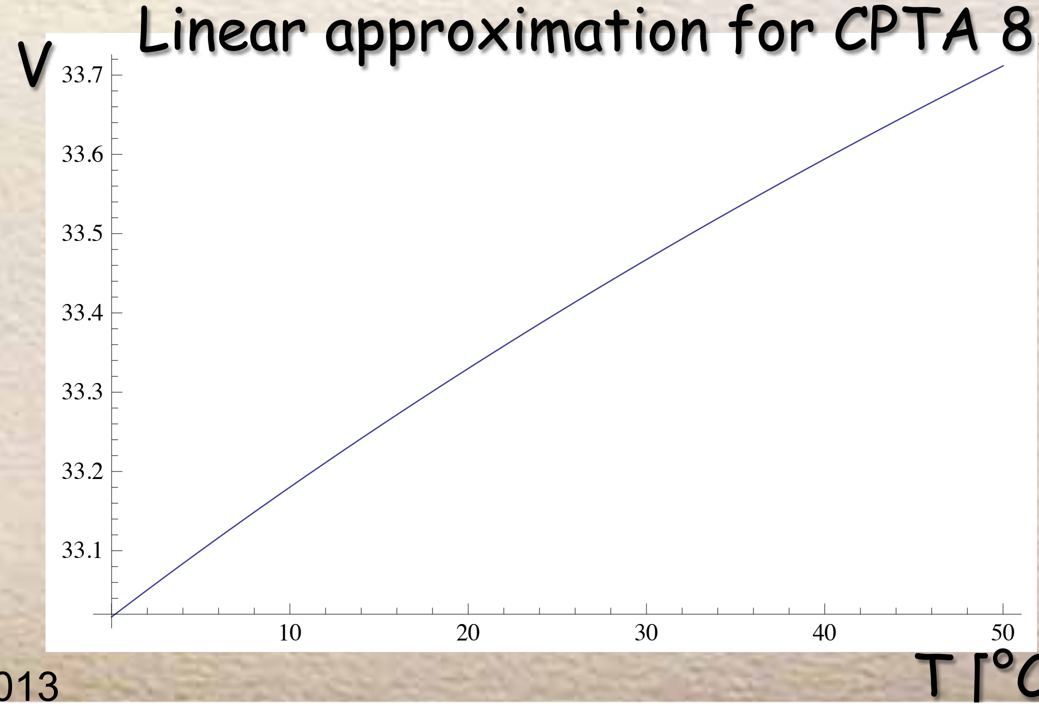
# Voltage Temperature Relation

- dV/dT is obtained from a ratio of 2 first-order differential equations
  - **$dG/dT = a + b*V + \mathcal{O}(V^2)$**
  - **$dG/dV = c + d*T + \mathcal{O}(T^2)$**
- Thus, an analytical solution exists
  - For the above linear case, we get:

$$V[T] = \frac{a}{c} + \left(c + d \bullet T\right)^{\frac{b}{d}} \quad (d \neq 0)$$

  - For quadratic case solution is **~Atan[a'+b'T]**
- For a linear model in dG/dT and dG/dV find following V versus T dependence

Linear approximation for CPTA 857



# Conclusion

- Hamamatsu sensors operate at higher $V_{bias}$ than CPTA/KETEK sensors
- dV/dT is similar for CPTA & KETEK sensors (15-20 mV/K) while Hamamatsu sensors yield larger values ~55 mV/K
- For CPTA & KETEK (Hamamatsu), the maximum voltage adjustments are less than ΔV=0.7 (1.9) V for range 5°C<T< 40°C
- The gain stabilization with the $V_{bias}$ regulator prototype works well
  ➔for all four tested SiPMs, gain stability is **< 1%** as required
- Non-uniformity of gain vs T after compensation is better than
  ➔ **±1%** for CPTA detectors (5°C<T<40°C)
  ➔ **±2.1%** (**±1.4%**) for Hamamatsu (KETEK) detectors (5°C<T<40°C)
  ➔ **±1%** for Hamamatsu and KETEK detectors (20°C<T<30°C)
- V versus T dependence has analytical solution, which for linear dG/dT and linear dG/dV is

$$V[T] = \frac{a}{c} + \left(c + d \cdot T\right)^{\frac{b}{d}}$$

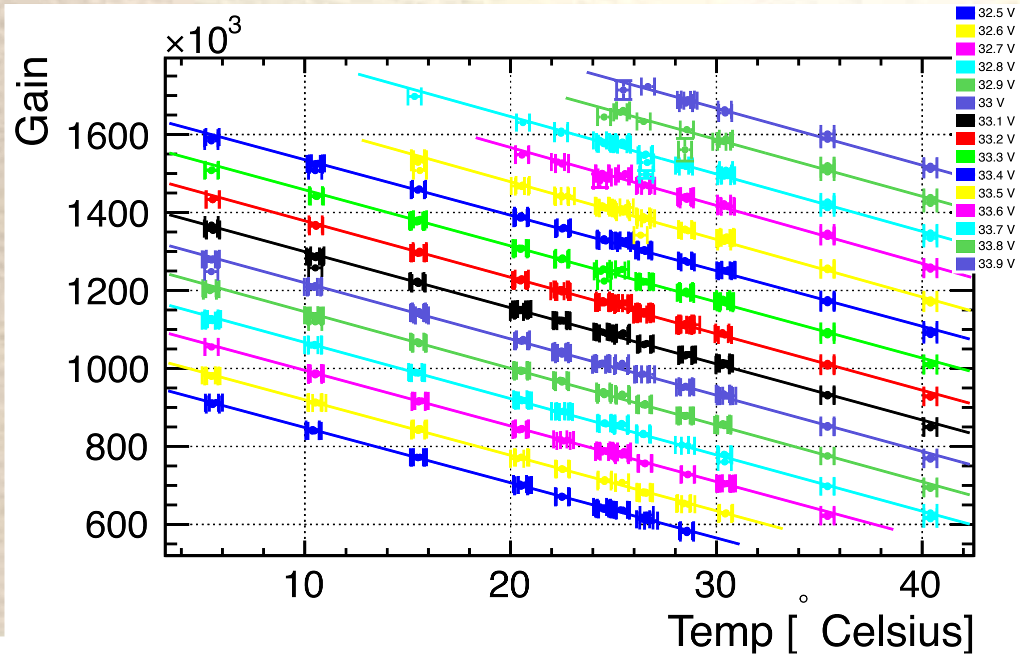
# Next Steps

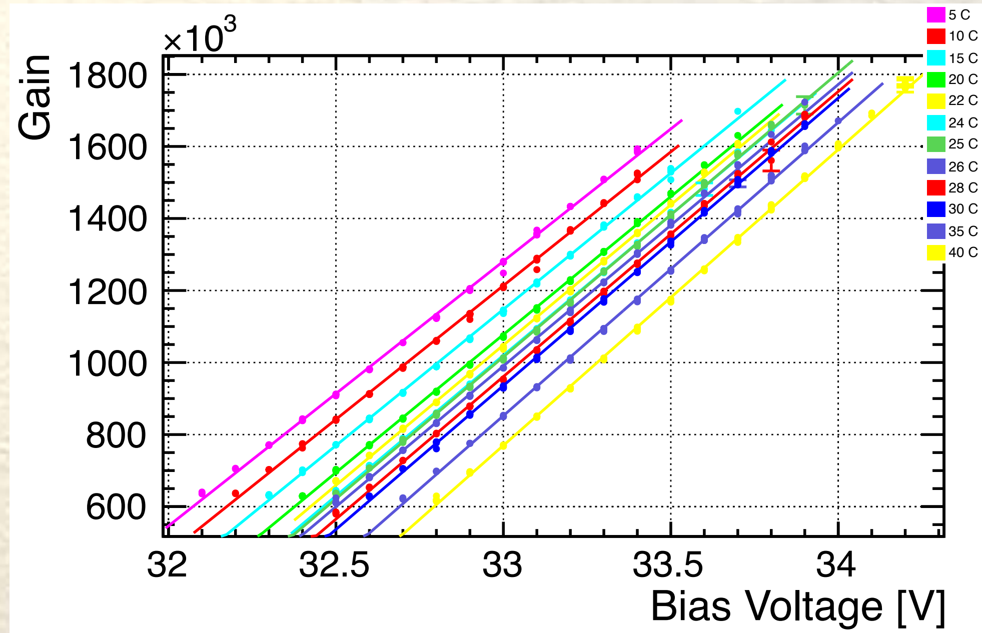
- Test more SiPMs with the $V_{bias}$ test board
- Design $V_{bias}$ regulator PCB ➔ layout is nearly completed
- Produce first $V_{bias}$ regulator PCB prototype ➔ end of 2013
- Test prototype on several SiPMs to come up with the final regulator PCB (ready for mass production) ➔ early 2014
- Integrate the $V_{bias}$ regulator PCB into the FE readout electronics of the AHCAL ➔ summer 2014
- Write final report for AIDA project ➔ fall 2014

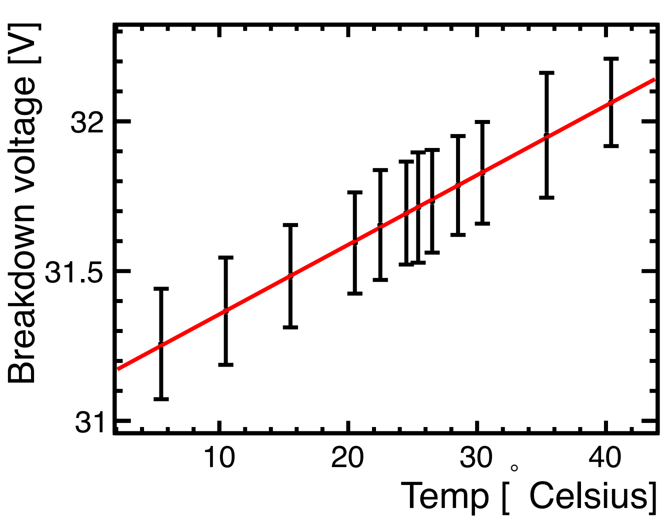
# Backup Slides

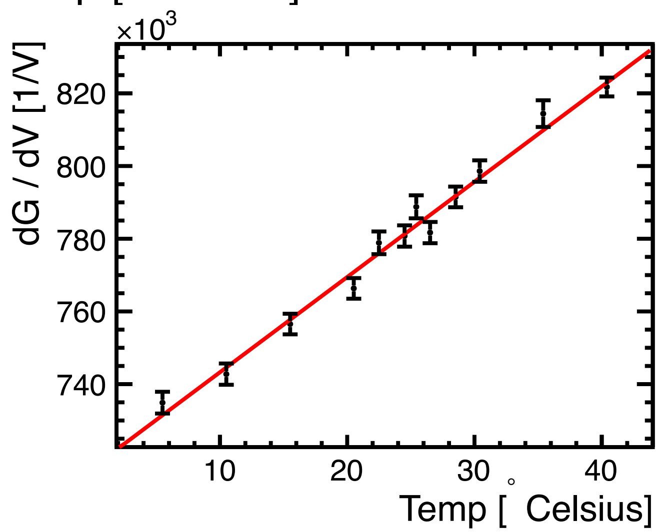
# Results for CPTA 1677

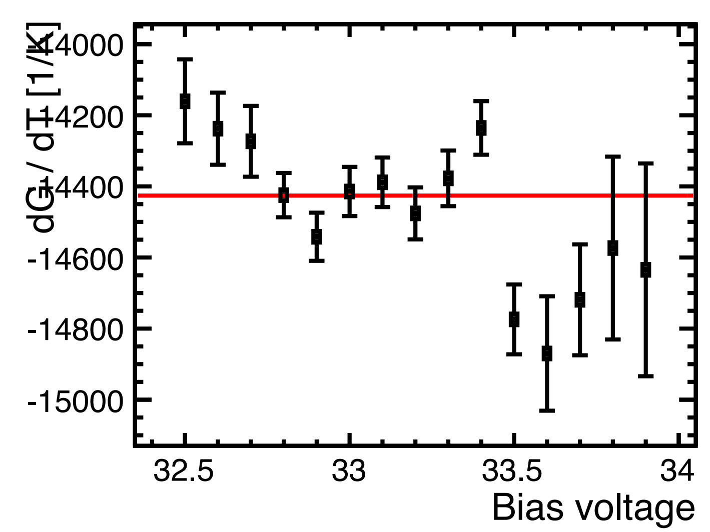
- Extract dV/dT=18.51±0.31 mV/K and gain stability of 0.1%



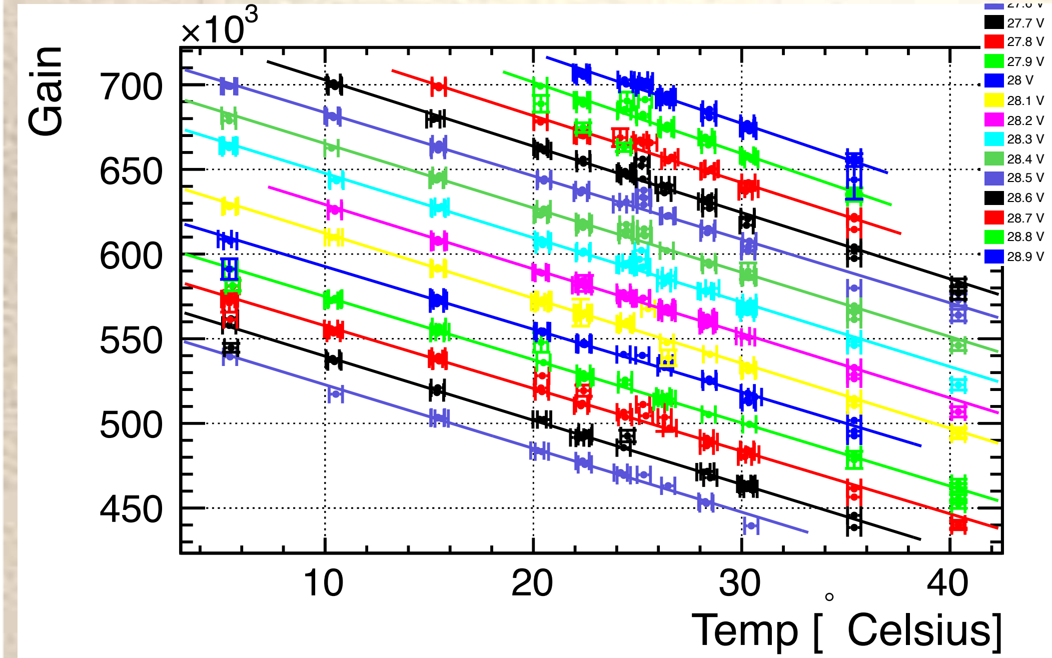



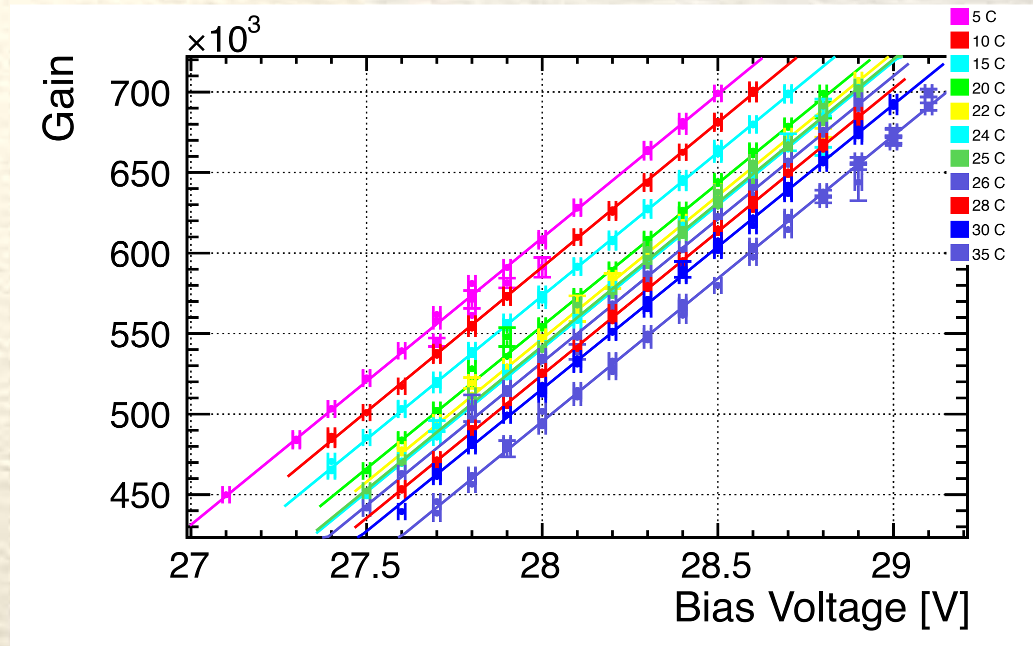



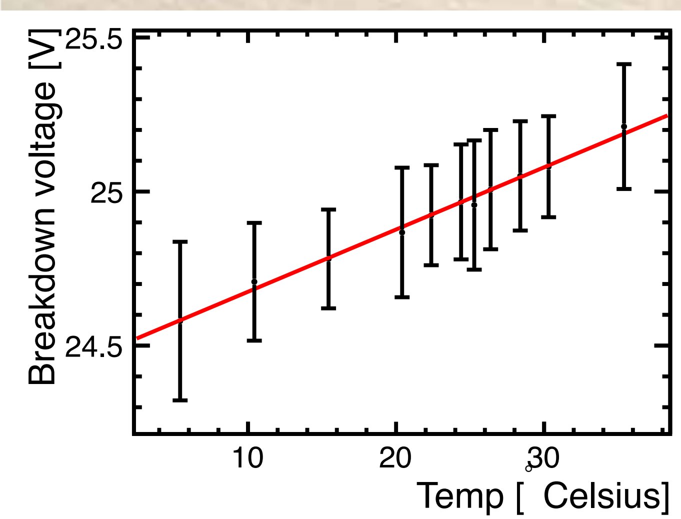



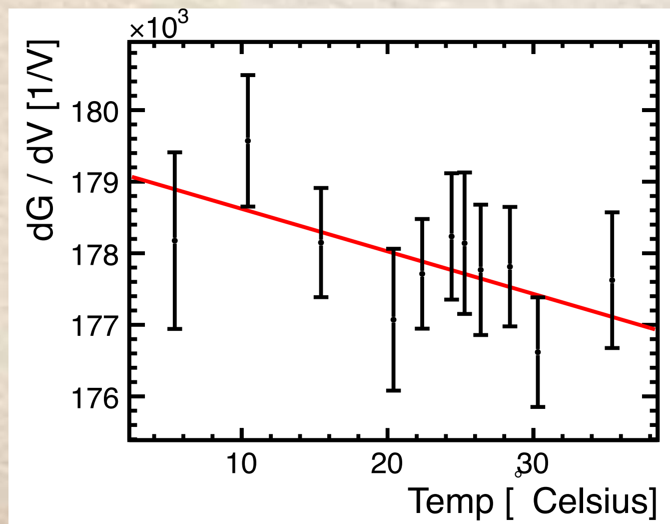
# Results for KETEK W12

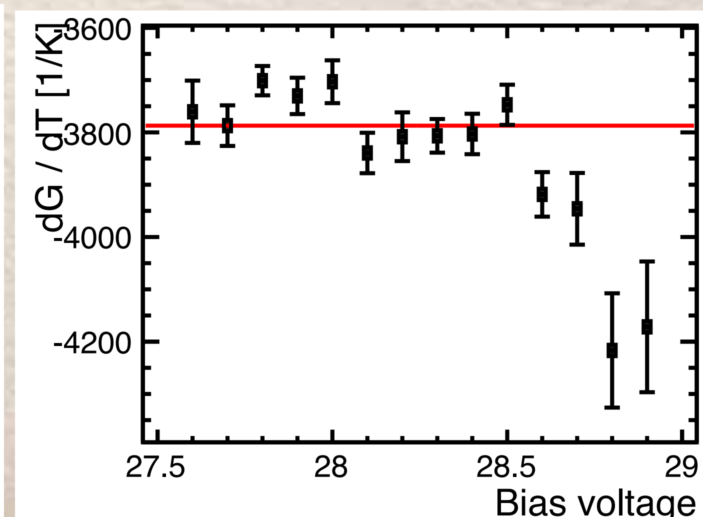
- Extract dV/dT=21.29±0.08 mV/K and gain stability of 0.01%



# Results for Hamamatsu

- Extract dV/dT=54.3±0.75 mV/K and gain stability of 0.28%