Gain Stabilization of SiPMs

Uni Bergen: G. Eigen, E. van der Kraaij, J. Zalieckas
FZU Prague: J. Cvach, J. Kvasnička, I. Polák

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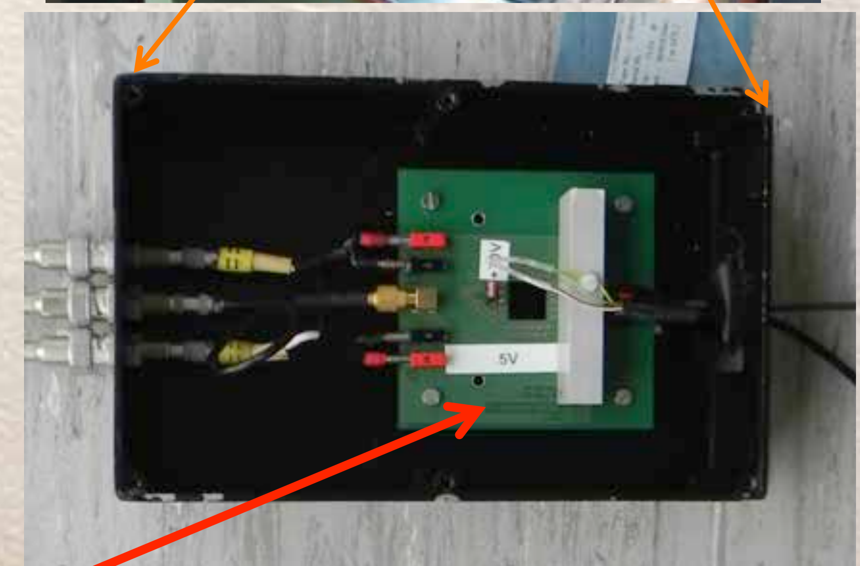
Introduction

- 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 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
  ➔ determine dV/dT to obtain constant gain
  ➔ build V_{bias} regulator prototype to demonstrate proof of principle
- This is work conducted in the framework of the EU project AIDA

SiPM Test Setup

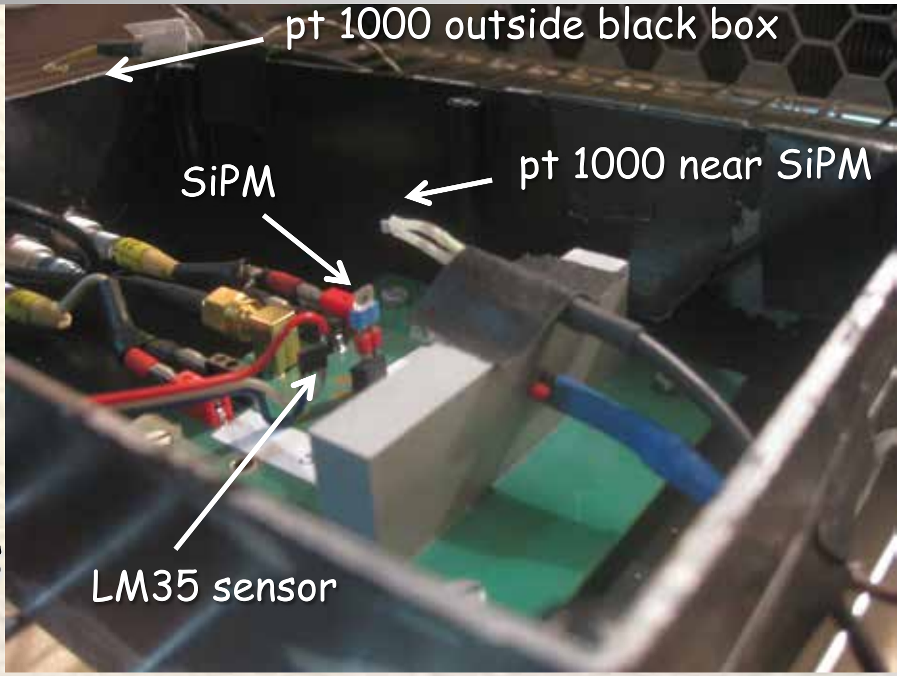
- We work in a climate chamber at CERN that is accurate to 0.1° C
- Use digital oscilloscope read out by PC, low voltage & bias voltage power supplies
- Use pulse generator for LED signal
- Shine blue LED light on detectors

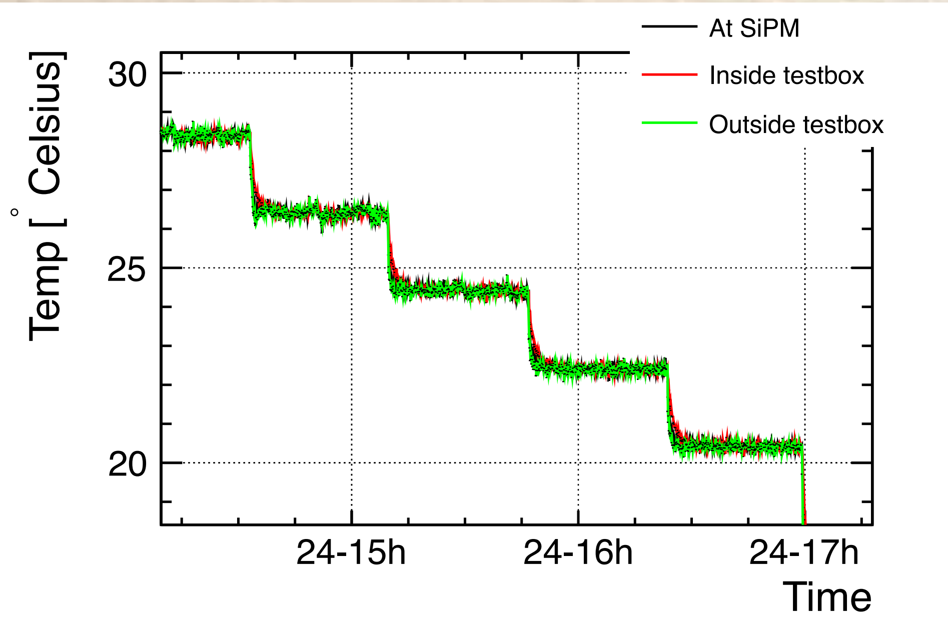


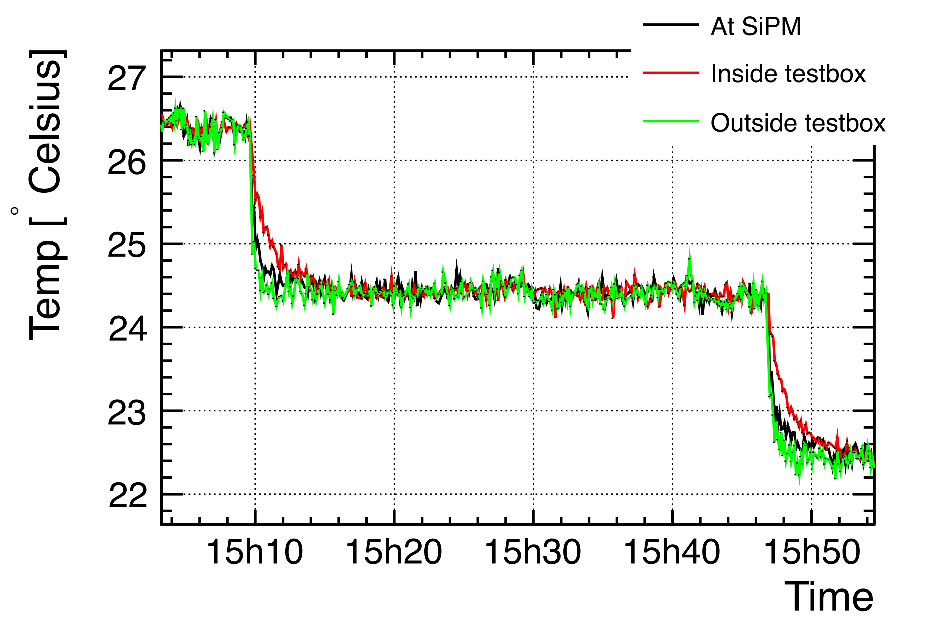
SiPM + preamp +T sensor + LED

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

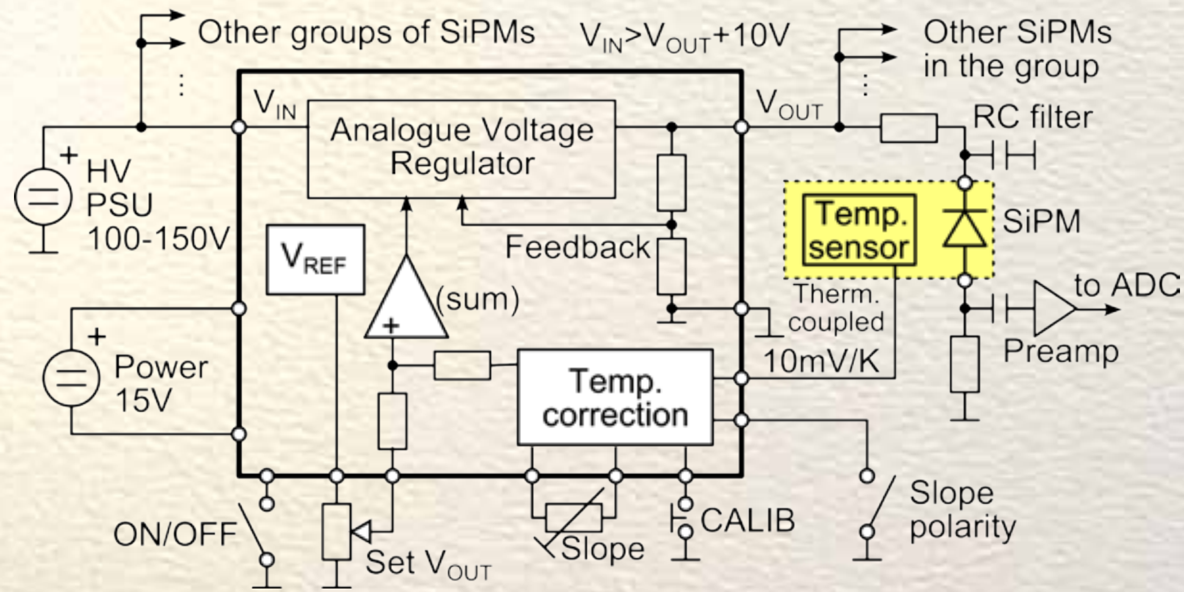
- We measured the dG/dT & dG/dV dependence for 15 SiPMs from 3 manufacturers
- We tested the V_{bias} adjustment on 4 SiPMs:
  - CPTA 857
  - CPTA 1677
  - KETEK W 12
  - Hamamatsu 11759
- Show results for the first 3

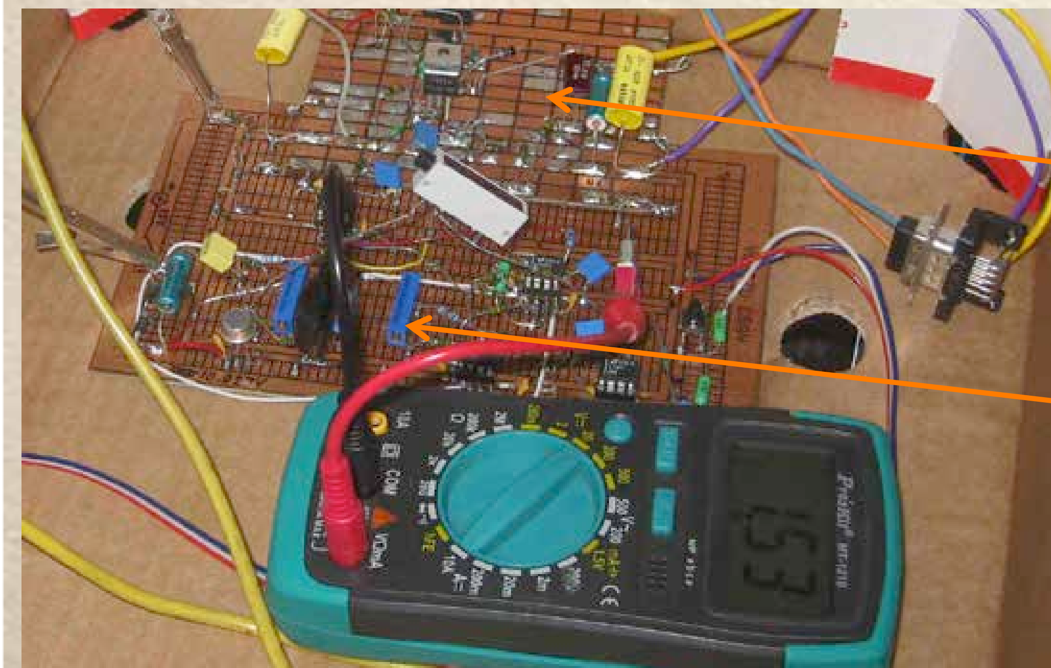
Manufacturer and Type #	Sensitive area $[mm^2]$	Pixel pitch $[\mu m]$	#pixels	Typical V_{bias} [V]	Typical G $[\times 10^5]$	Serial #
Hamamatsu						
→ S10943-8584(X)	1×1	50	400	71.69	7.49	11759
S10943-8584(X)	1×1	50	400	71.57	7.49	11766
S10943-8584(X)	1×1	50	400	71.50	7.48	11770
S10943-8584(X)	1×1	50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

Analogue voltage regulator

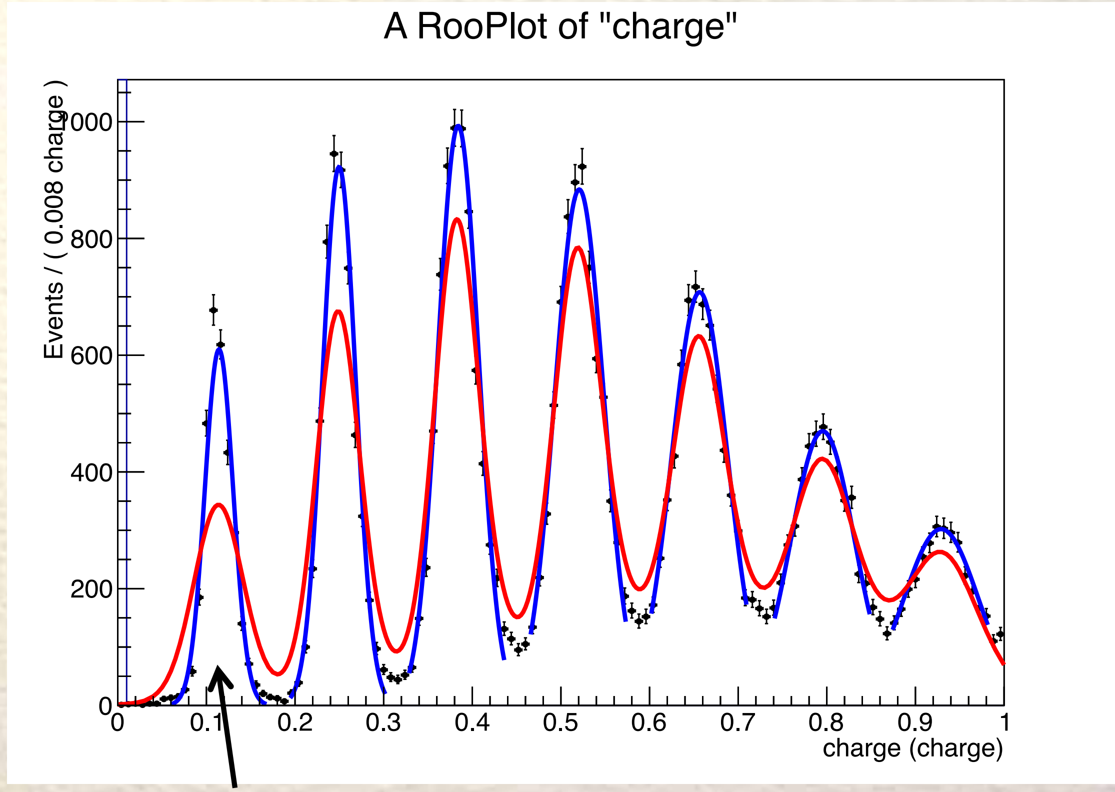
Voltage reference

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)

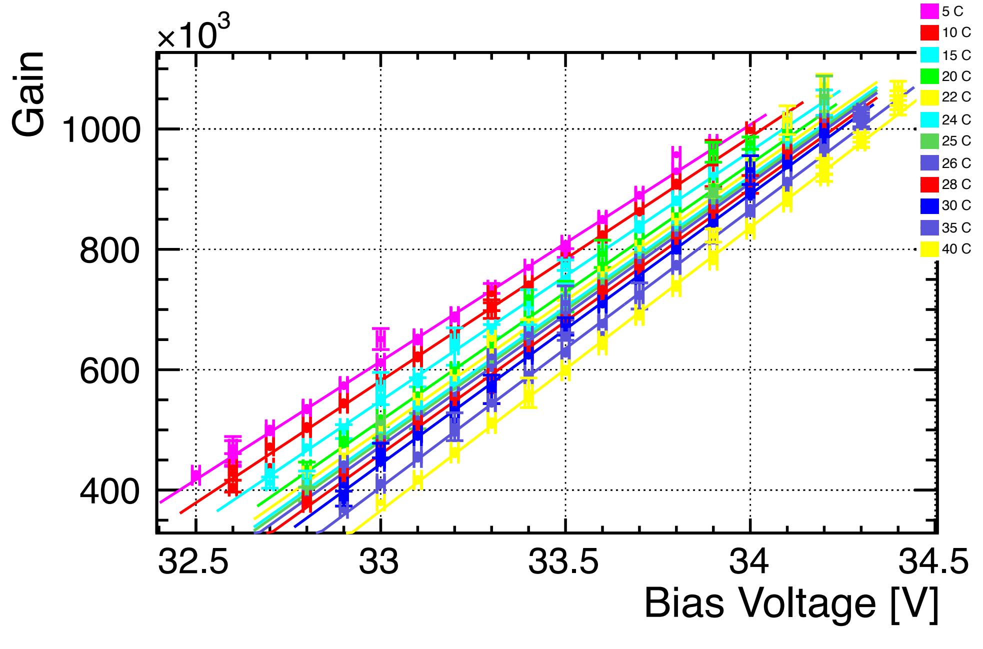
- Define the error on the gain as the errors of the two fitted Gaussian mean values added in quadrature

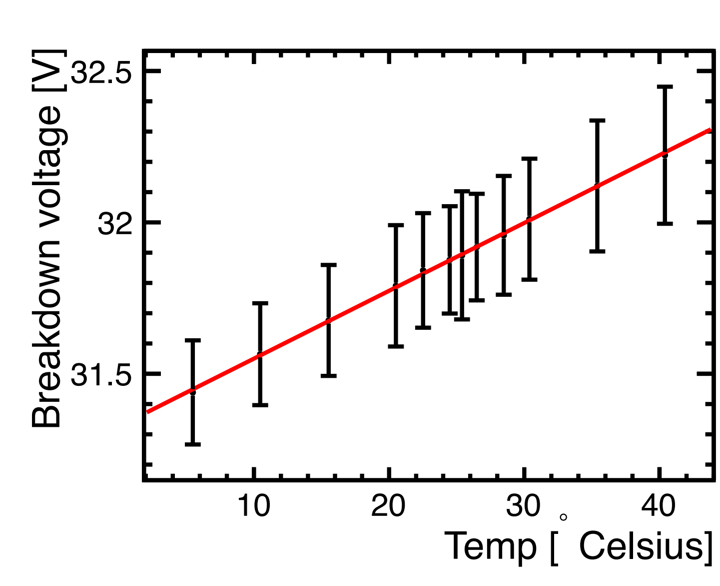


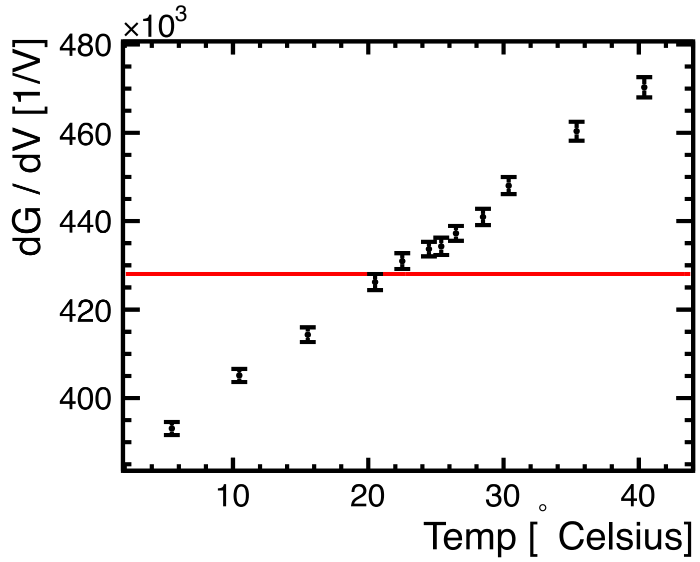
RooFit multikernel function
Individual Gaussian fits

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
  ➔ linear dependence is seen



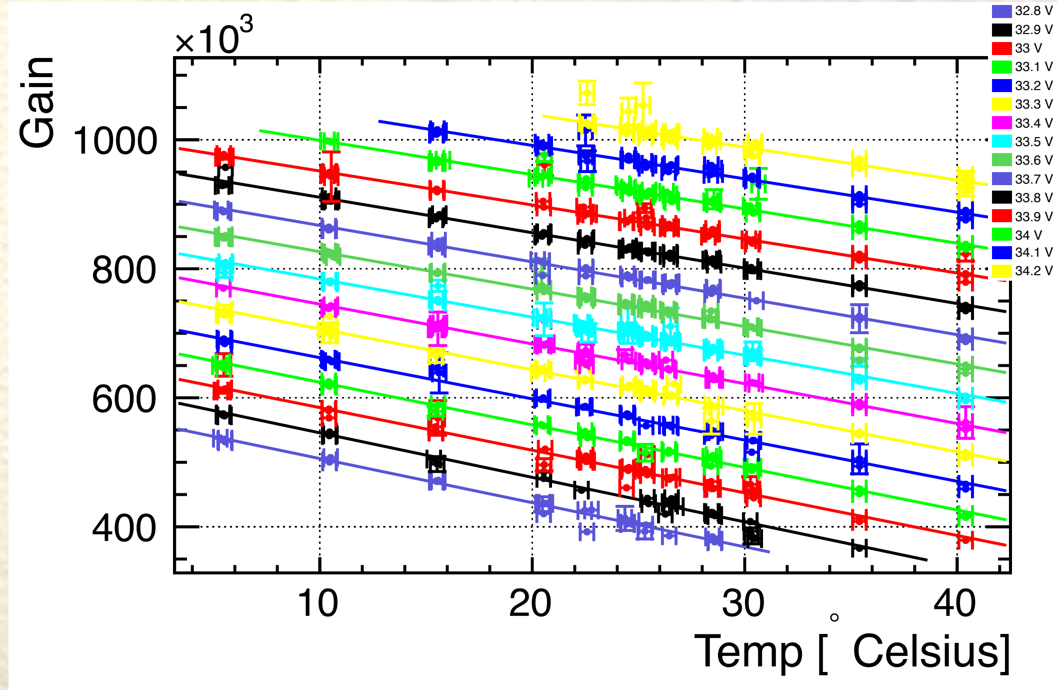


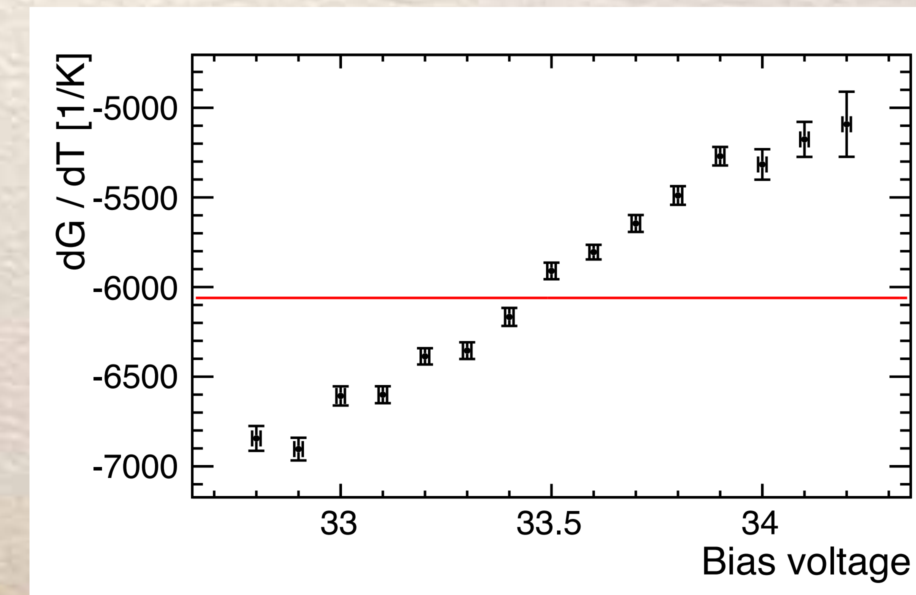


Gain vs Temperature for CPTA 857

- Same data as last slide
- For a constant gain, need to extract dV/dT
- Average fitted slopes and take spread in the slopes as uncertainty:

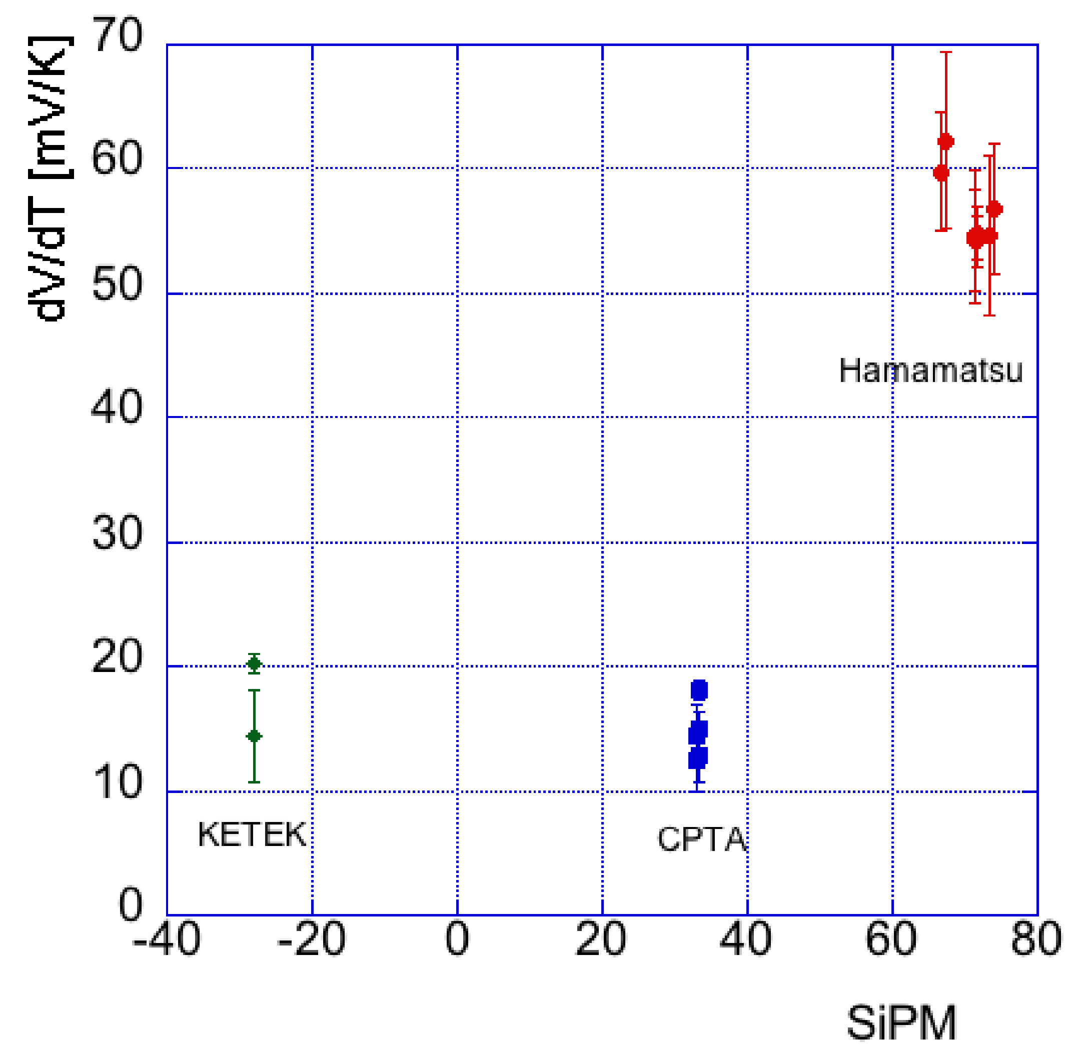
  $dV/dT = \langle dG/dT \rangle / \langle dG/dV \rangle$
  $= 13.7 \pm 2.1$ mV/K





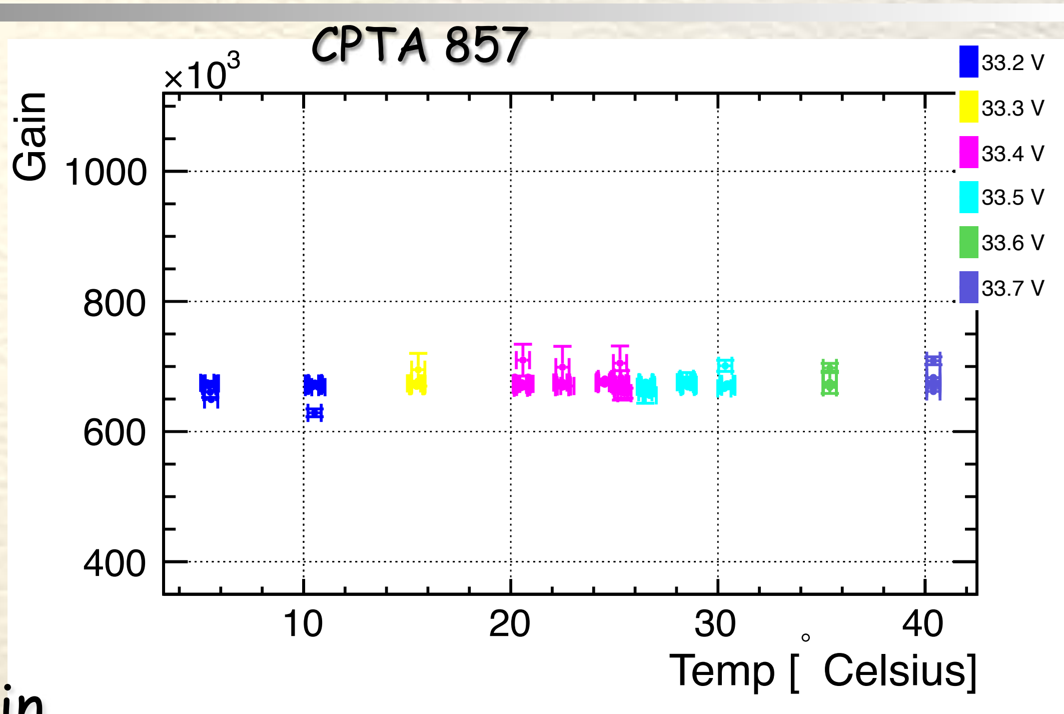
dV/dT Measurements

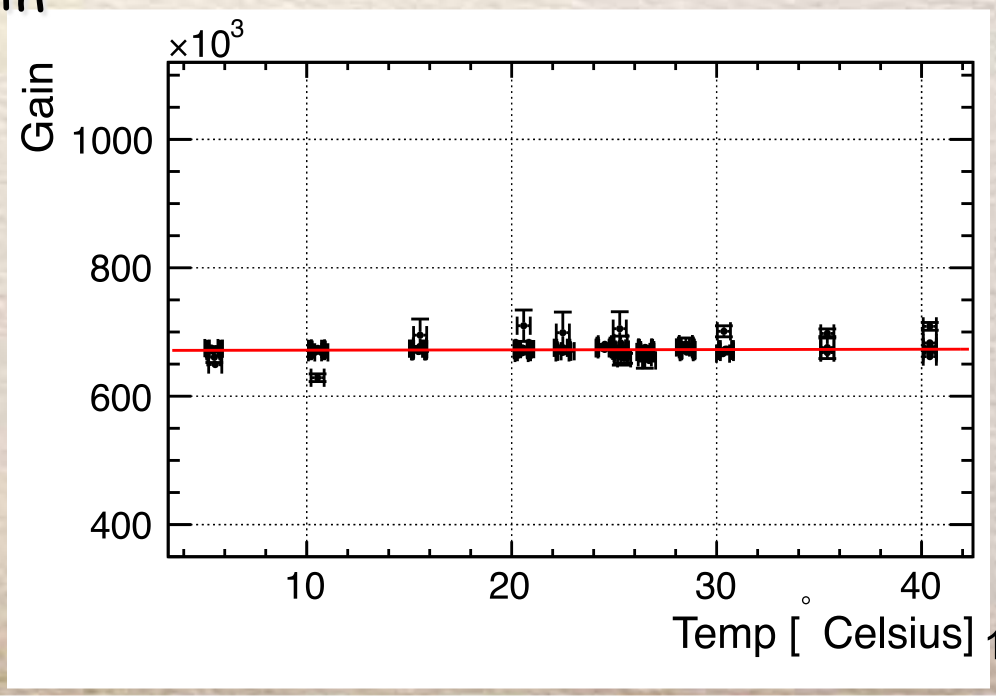
- KETEK SiPMs operate at opposite V_{bias} than CPTA and Hamamatsu SiPMs
- V_{bias} for Hamamatsu is ~70V while V_{bias} for CPTA is ~33V & V_{bias} for KETEK is ~28V
- For KETEK and CPTA, dV/dT is ~15-20 mV/K
  for Hamamatsu, dV/dT is ~55 mV/K



Gain after V_{bias} Adjustment for CPTA 857

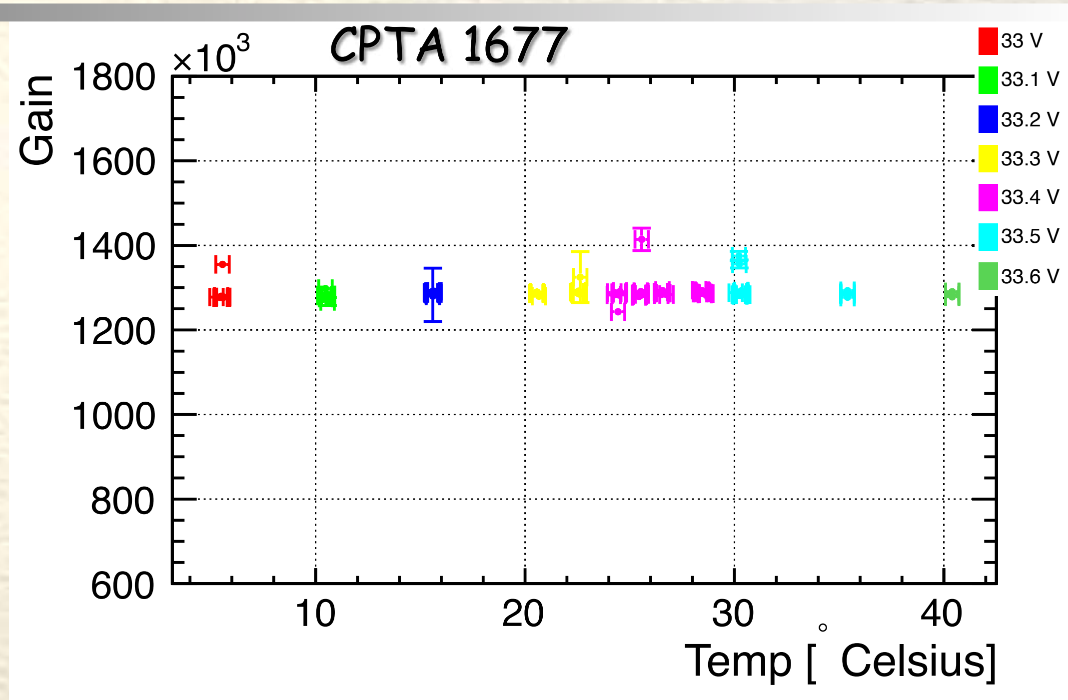
- Adjust voltage continuously using V_{bias} regulator prototype
  Note: color code gives the range of voltage applied
  e.g. magenta: 33.35 <V_{bias}<33.45
- At each T, take 16 samples with 50k waveform each
- See outliers ➔ understand origin
- Linear fit to all data points
  - offset: (6.71±0.0044)x10^5
  - slope: 47.3±19.1
- Gain is uniform in range of interest 5°-40° C ➔ measured non-linearity is < ±0.001

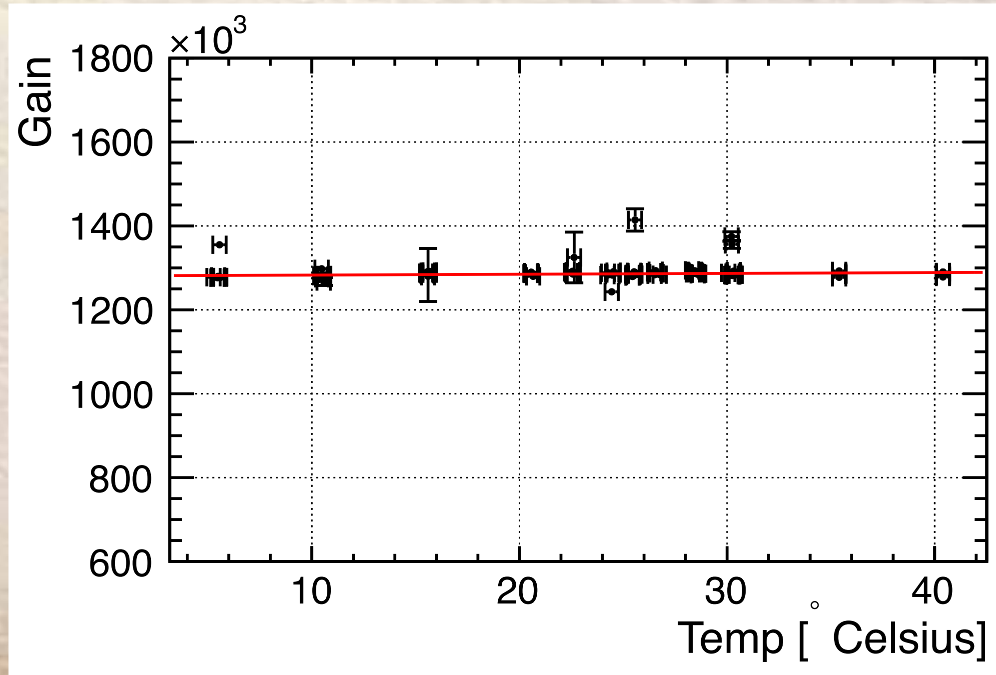




Gain after V_{bias} Adjustment for CPTA 1677

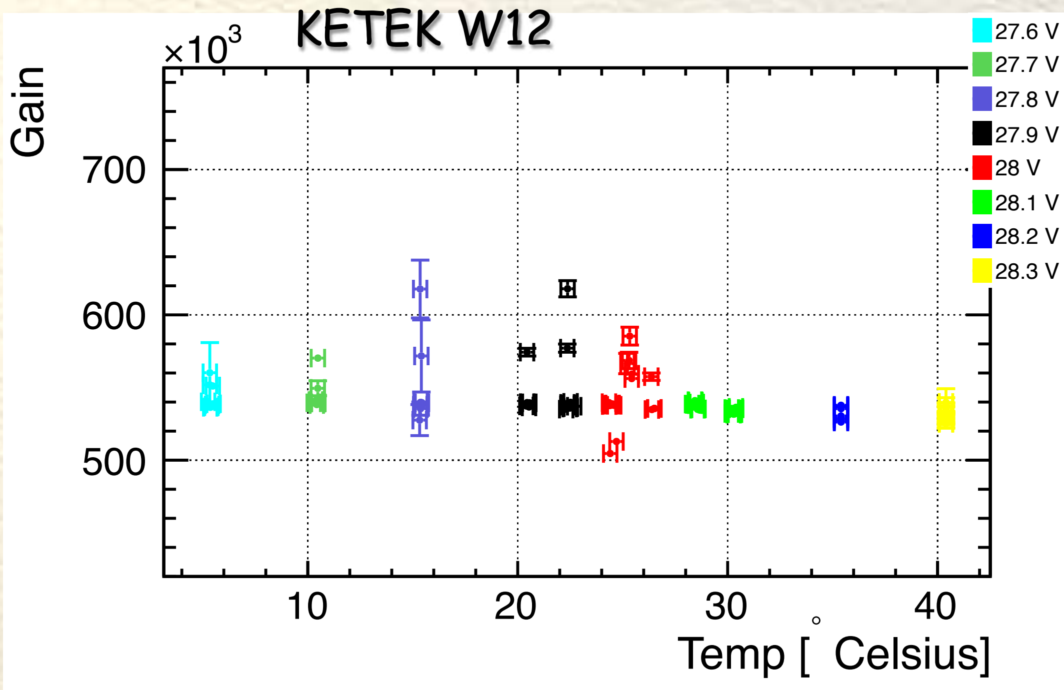
- Measured dV/dT slopes of 18.3±0.6 mV/K for CPTA 1677
- See few outliers
- Linear fit to all data points
  - offset: $(1.28\pm0.00059)\times10^6$
  - slope: 198±24.7
- Gain is basically uniform between 5° C & 40° C
- ➔ non-linearity in measured range is < ±0.002

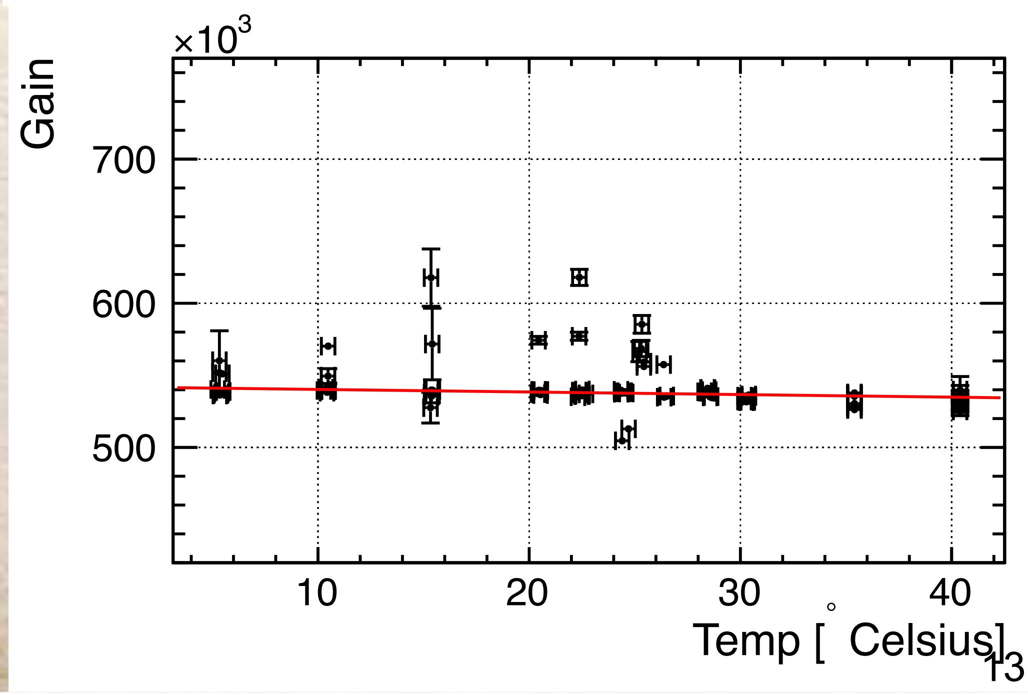




Gain after V_{bias} Adjustment for KETEK W12

- Measured dV/dT slopes of 22.2±1.9 mV/K for KETEK W12
- See more outliers ➔investigate
- Linear fit to all data points
  - offset: $(5.42\pm0.0032)\times10^5$
  - slope: -178±14.5
- Gain still fulfills requirement between 5° C & 40° C
- ➔ non-linearity in measured range is < ±0.0035
- MPPC analysis is still ongoing
- Measured dV/dT slopes of 54.3±3.3 mV/K for MPPC 11759





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 the 3 detectors tested, the maximum voltage adjustments are less than ΔV=0.7 V for range 5°C<T< 40°C
- The gain stabilization with the V_{bias} regulator prototype works well for all three tested SiPMs
  ➔ accuracy is much better than 1% for temperature range 5°C<T< 40°C

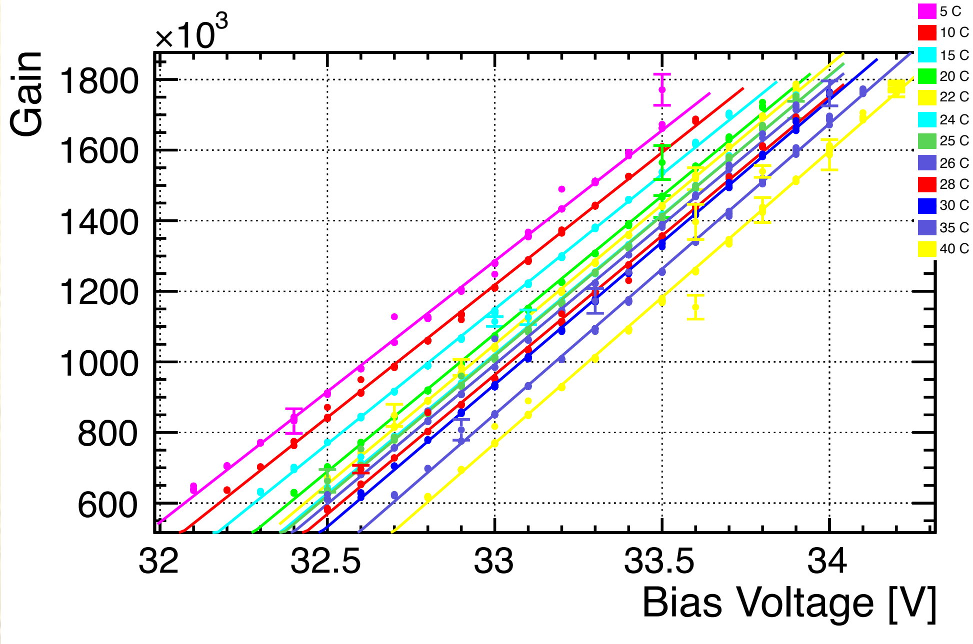
Next Steps

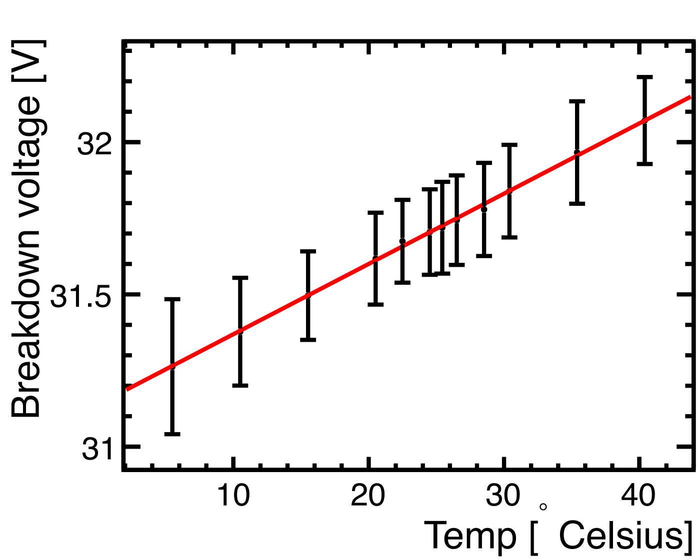
- We need to understand the reason for outliers in the gain vs temperature measurements after V_{bias} adjustment
- Complete the study with the Hamamatsu sensor
- Test the V_{bias} regulator prototype on more SiPMs
- Design V_{bias} regulator PCB and test it on several SiPMs so it is ready for mass production
- Integrate the V_{bias} regulator PCB into the FE readout electronics of the AHCAL

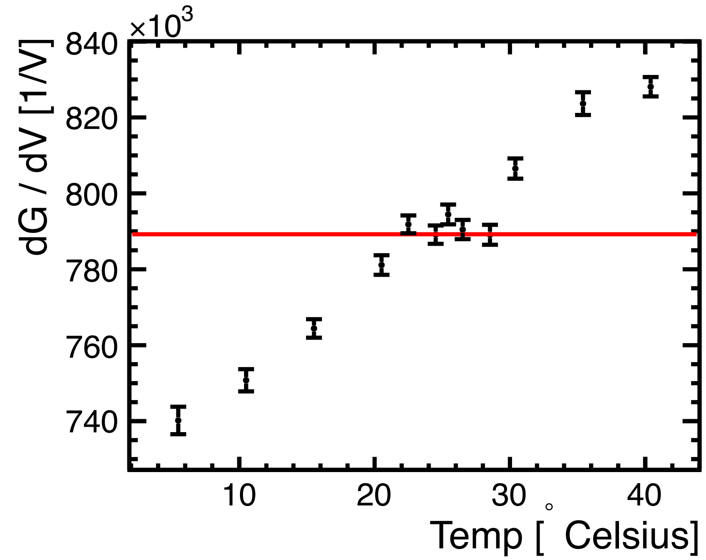
Backup Slides

Gain vs Voltage for CPTA 1677

- Each point is the gain extracted from 50k waveforms
- Linear fit to these distributions yields break-down voltage & dG/dV
- Break-down voltage drops with T
- dG/dV~ capacitance is not constant
  ➔ linear dependence is seen







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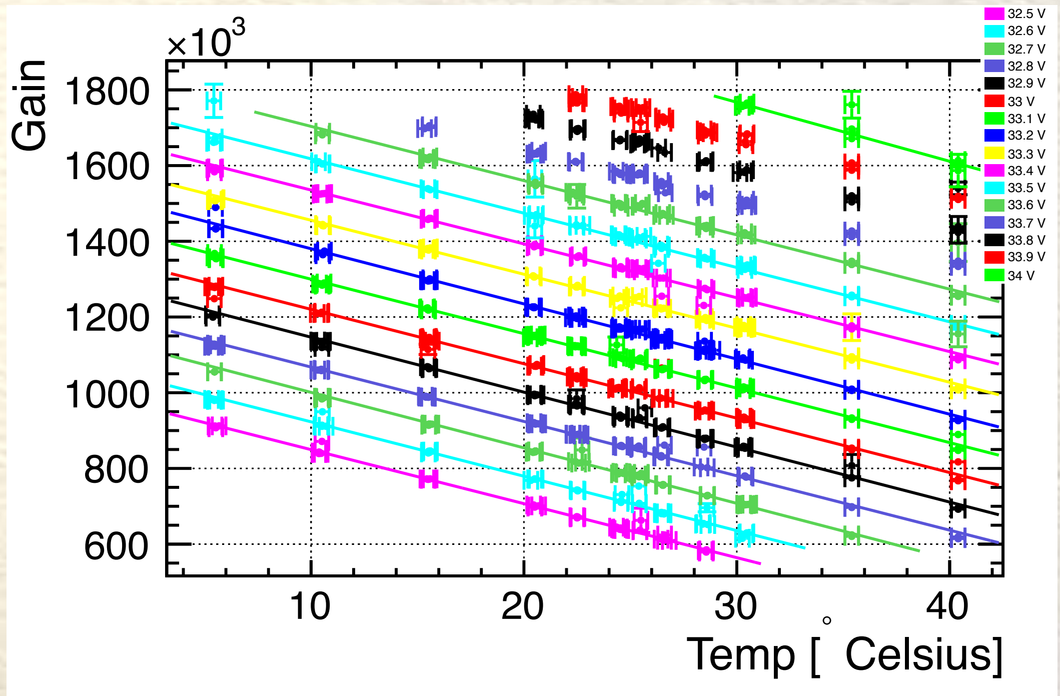
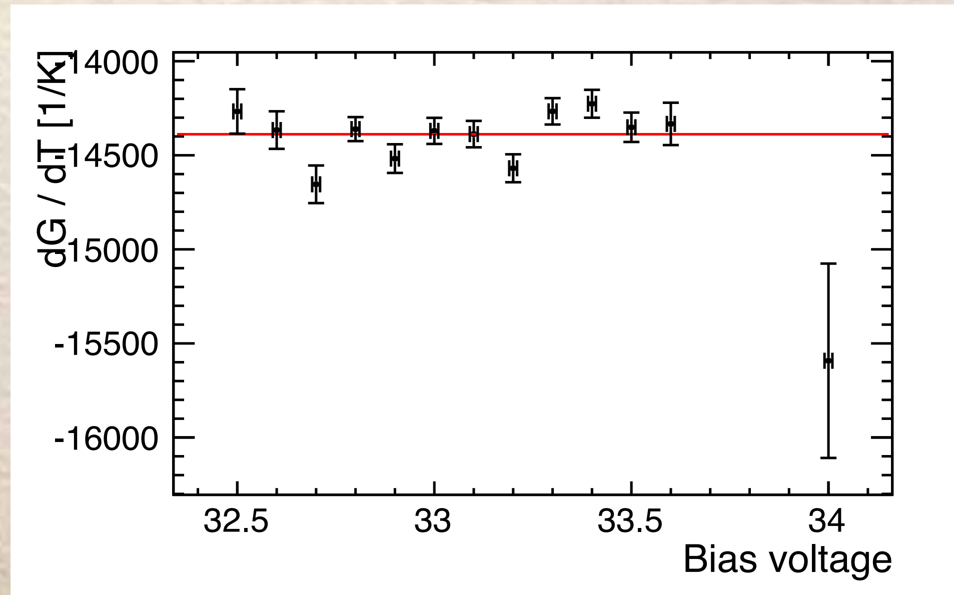
  $= 18.3 \pm 0.6$ mV/K





Gain vs Voltage for KETEK W12

- Each point is the gain extracted from 50k waveforms
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- Break-down voltage drops with T
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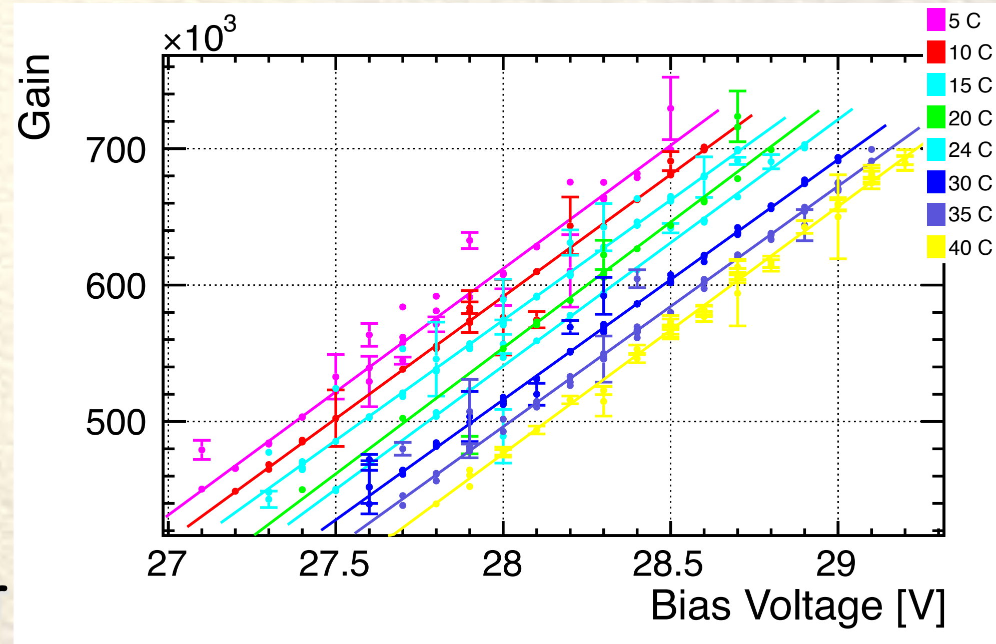

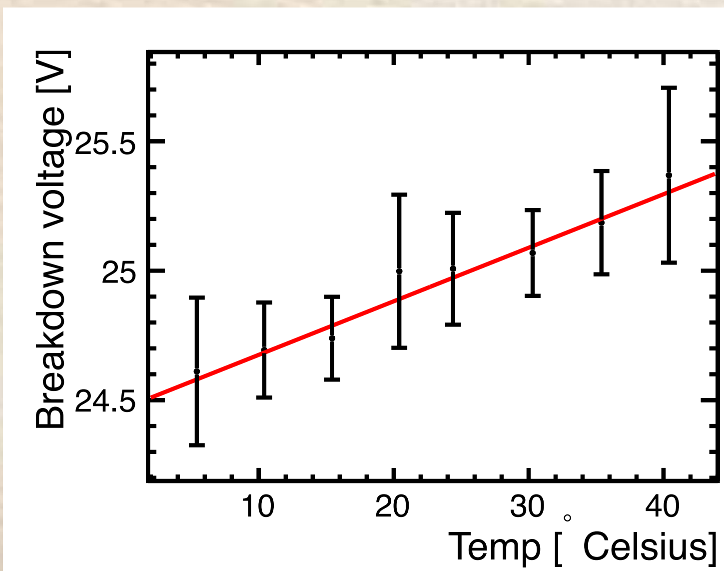

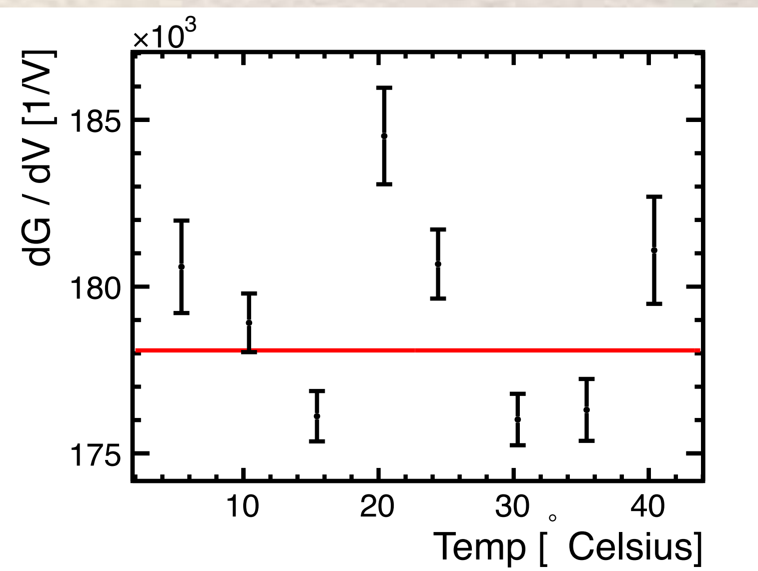

Gain vs Temperature for KETEK W12

- Same data as last slide
- For a constant gain, need to extract dV/dT
- Average fitted slopes and take spread in the slopes as uncertainty:

  dV/dT=<dG/dT>/<dG/dV>
  =22.2±1.9 mV/K