Gain Stabilization of SiPMs

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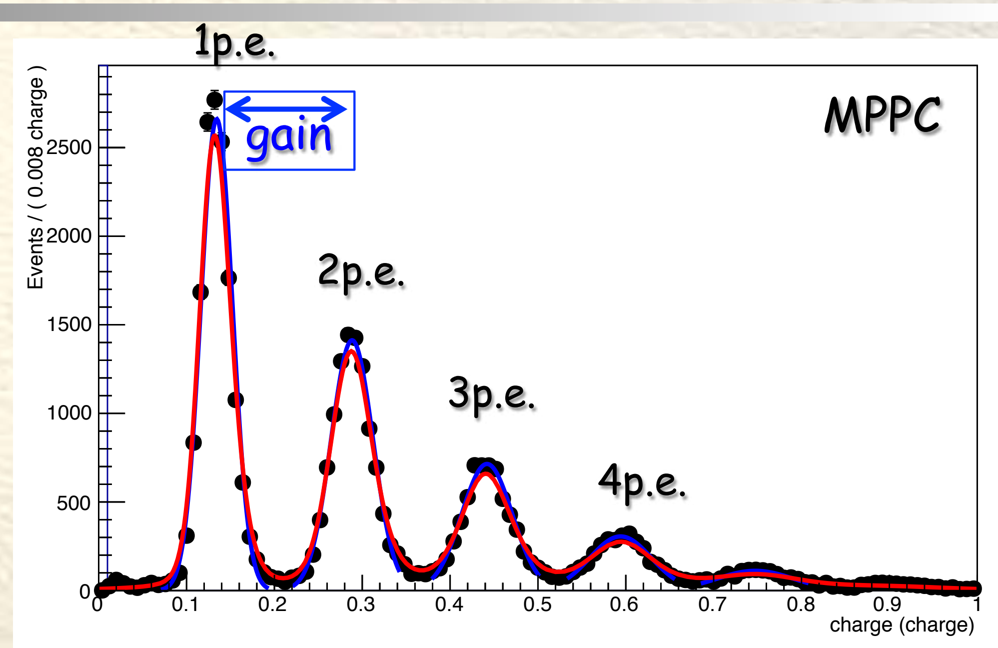
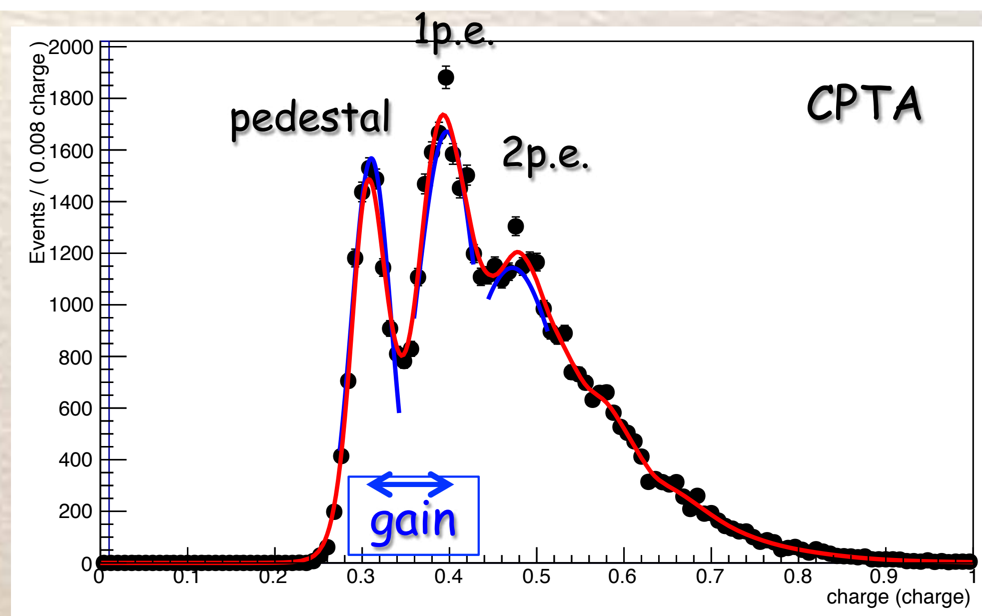
Gain Stabilization of SiPMs

- The gain of SiPMs depends both on bias voltage and on temperature
  - Gain decreases with temperature (T) & increases with bias voltage (V)
- For stable operations, the gain needs to remain constant
  - This can be achieved for example by readjusting V_{bias}
  - ➔ Determine dV/dT from measurements of dG/dV and dG/dT
  - ➔ Build V_{bias} regulator that keeps gain constant (<1%) if T changes
- We measured dG/dV and dG/dT for 15 SiPMs from 3 manufacturers in a climate chamber at CERN (6 of these are not in the catalogue)
- We built V_{bias} regulator test board to show proof of principle on 4 SiPMs
- We used the results to produce the first board in industry and test it
- Work is performed in the framework of AIDA

Gain Determination

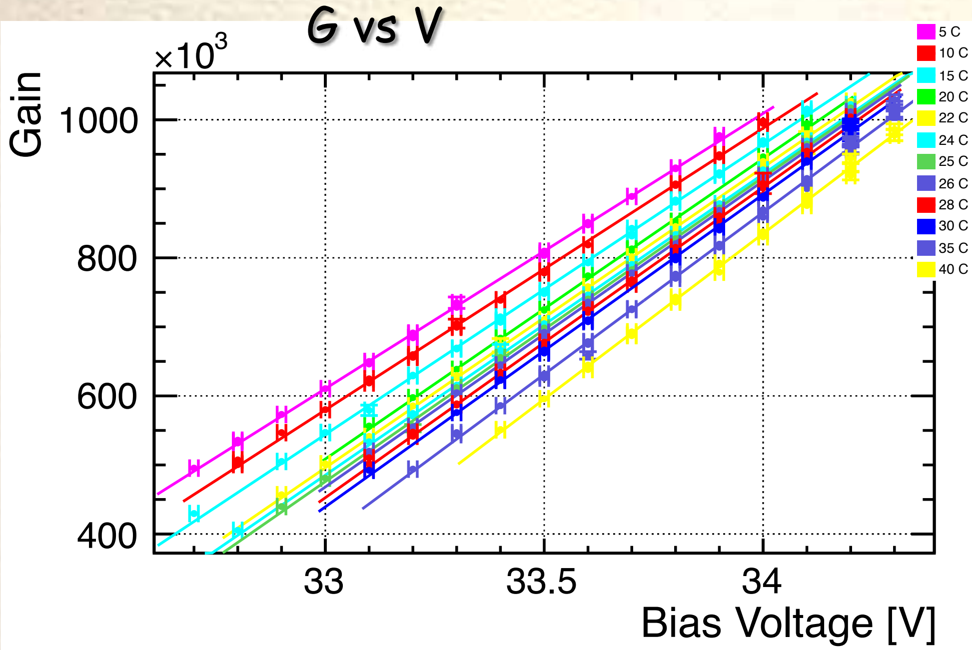
- Determine gain by fitting Gaussian functions to peaks of single pe spectra
- Define gain as
  - Distance between 1 pe & 2 pe peaks (MPPCs)
  - Distance between pedestal 1 pe peak (CPTA, KETEK)
- Define error on the gain as the errors of the two fitted Gaussian mean values added in quadrature

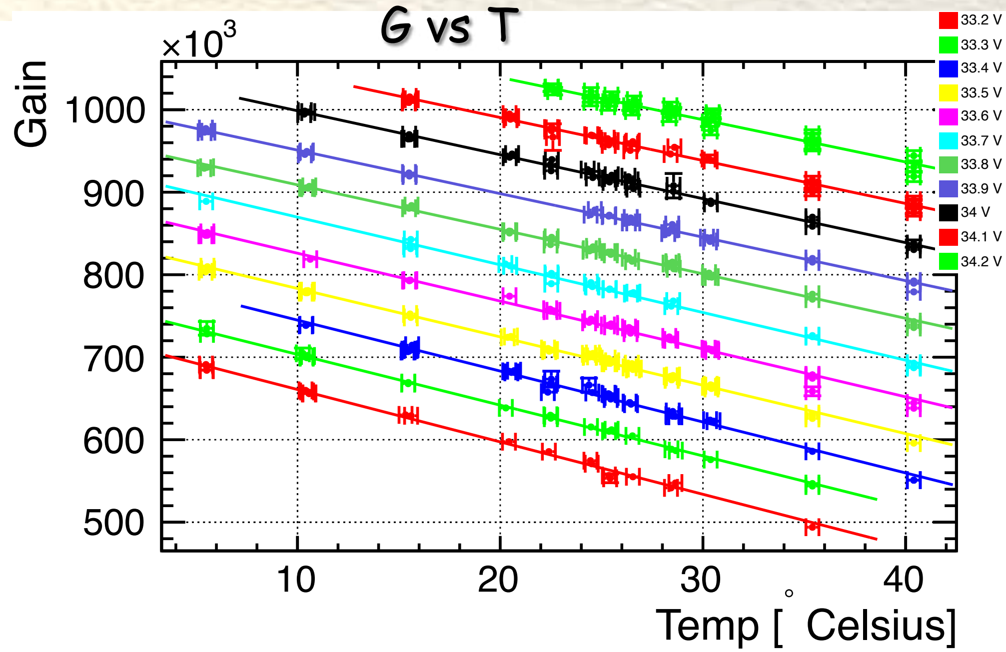


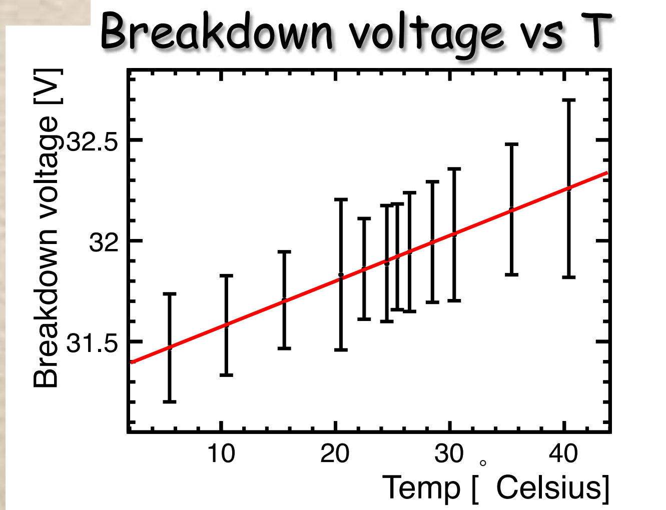


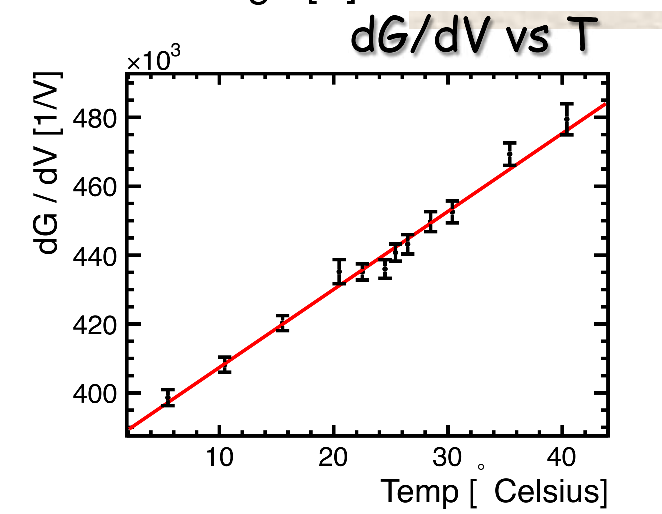
Gain vs Voltage for CPTA 857

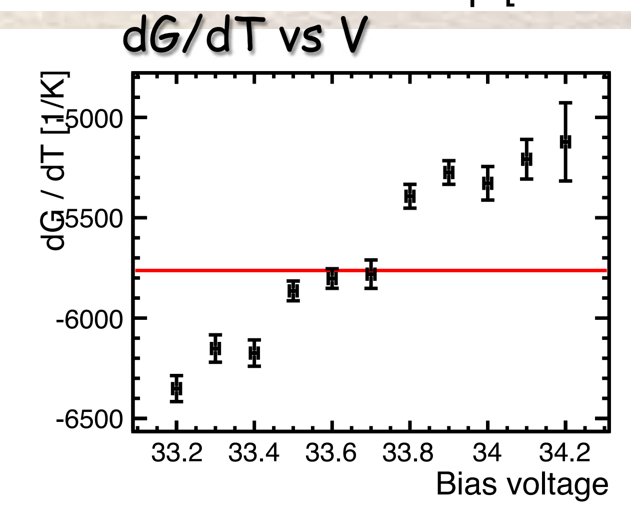
- Take samples of 50k at different T and V values







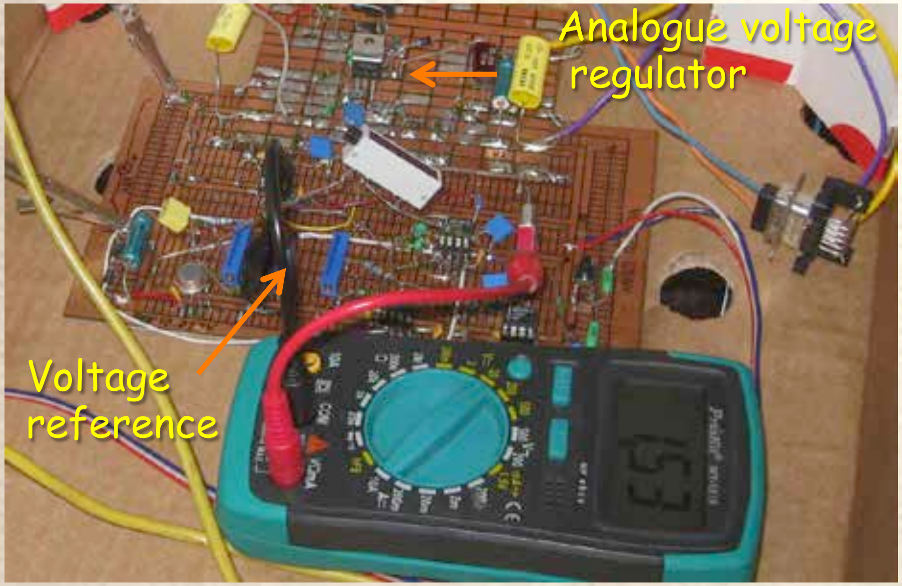




- $dV/dT = \langle dG/dT \rangle / \langle dG/dV \rangle = = -13.33 \pm 0.35$ mV/K

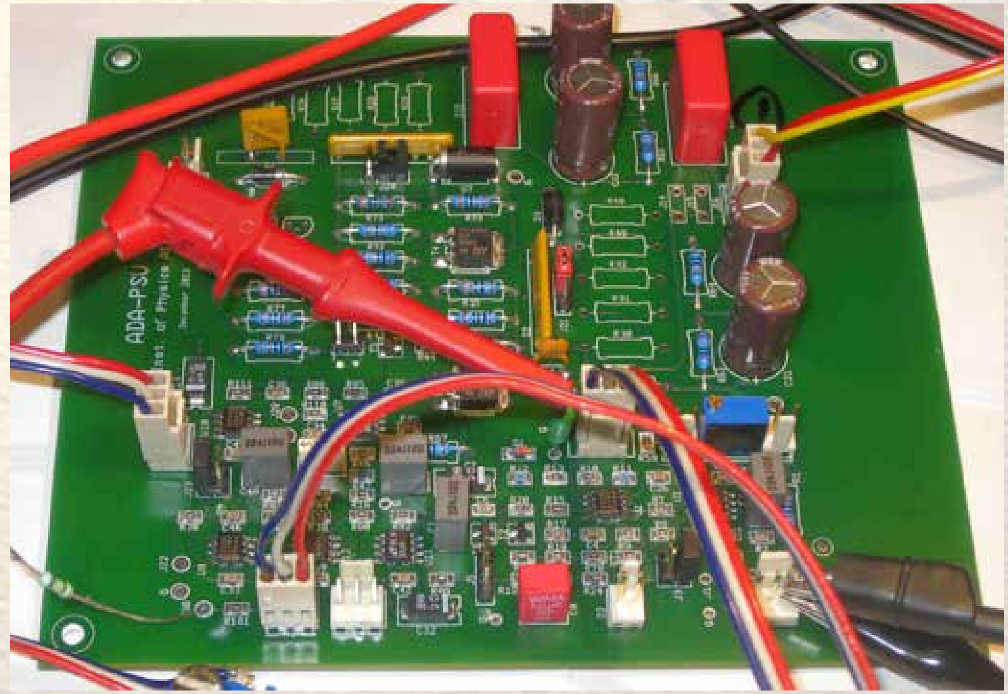
Adaptive Power Regulator

- First test board prototype



- Voltage range: 10 V to 80 V
- Temperature slope:
  <1 to 100 mV/K

- Second industry-made prototype

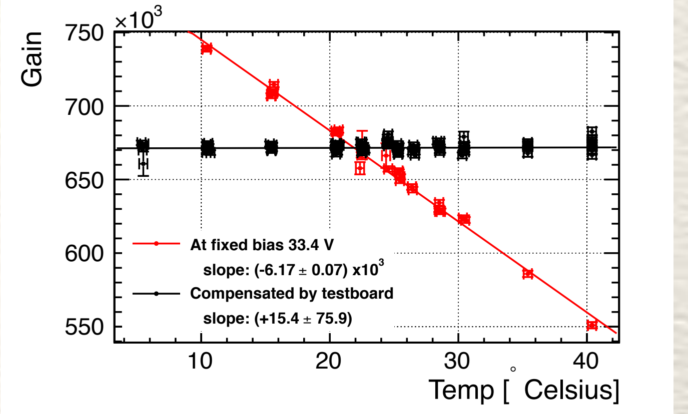


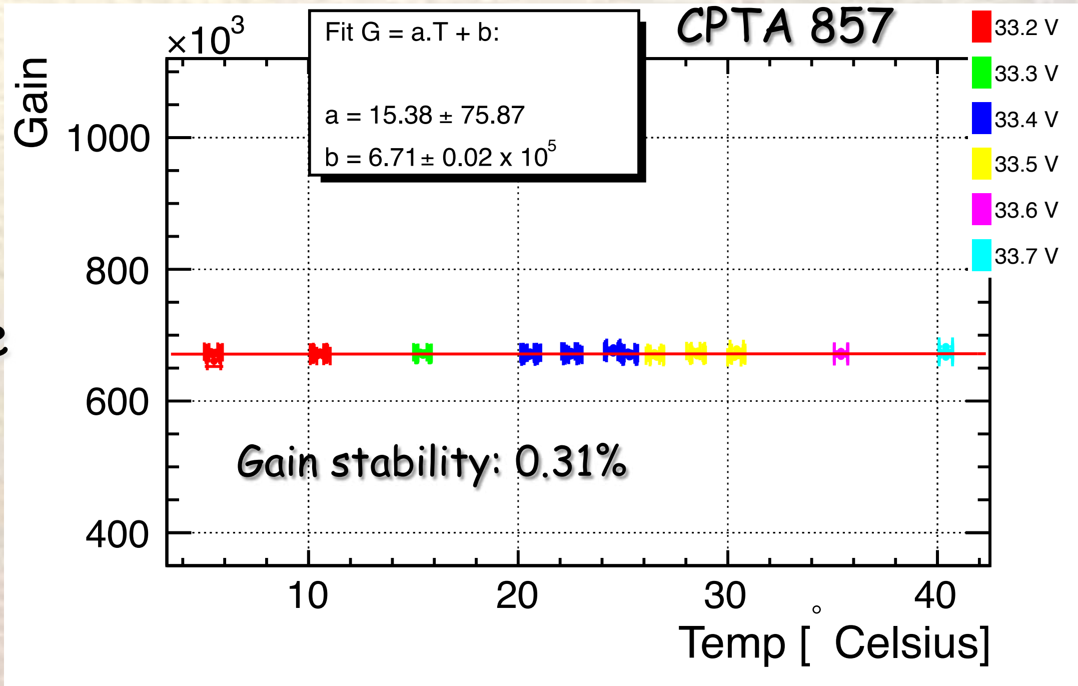
- Voltage range: SiPM: 10 V to 130 V
  APD: 10 V to 450 V
- Delivered to CERN February 2014

Front panel

Gain after V_{bias} Adjustment for CPTA 857

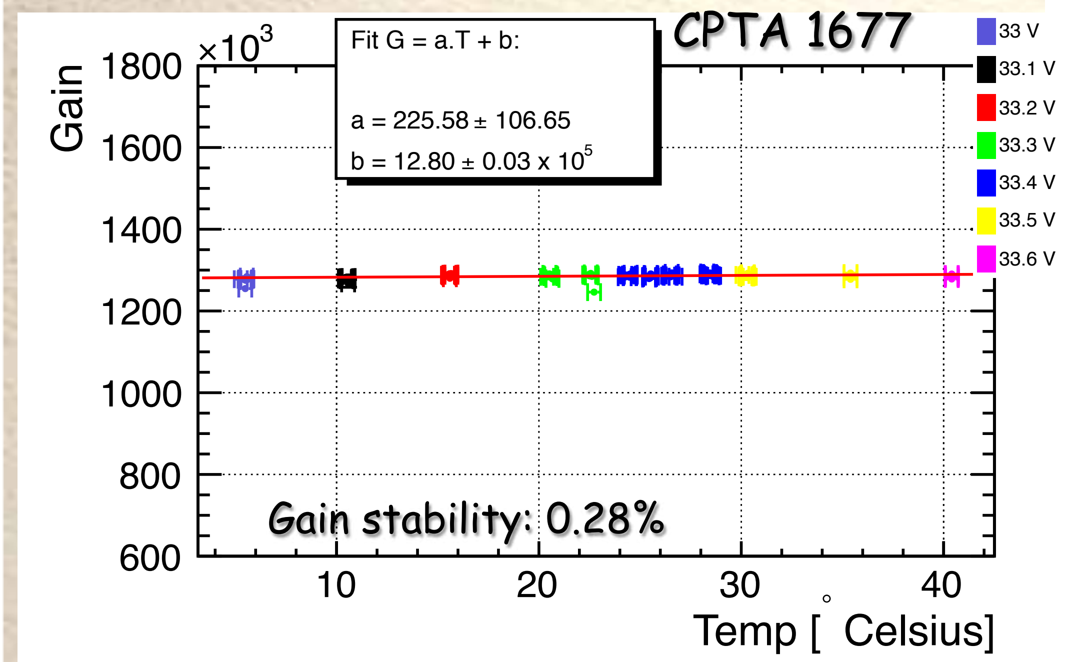
- Adjust voltage continuously using V_{bias} regulator test board
- At each temperature, take 16 samples with 50k events each
- Linear fit to all data points
  - offset: $(6.71\pm0.02)\times10^5$
  - slope: 15 ± 76
- Gain is uniform in 5°-40°C range
  ➔ Deviation is < ±0.04%
- A 43 page AIDA note is completed

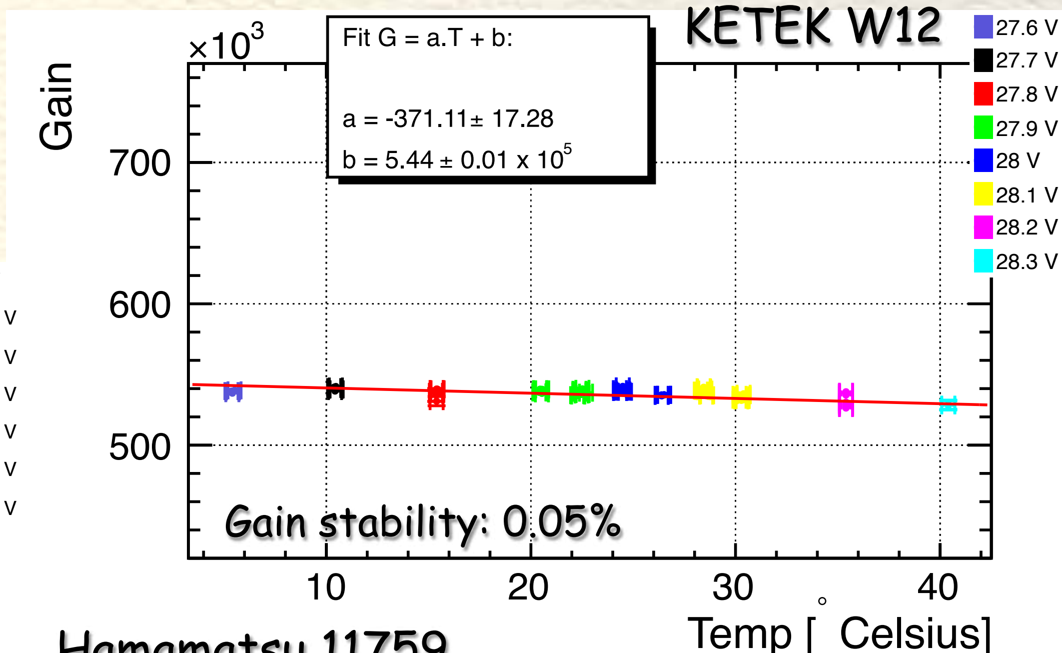


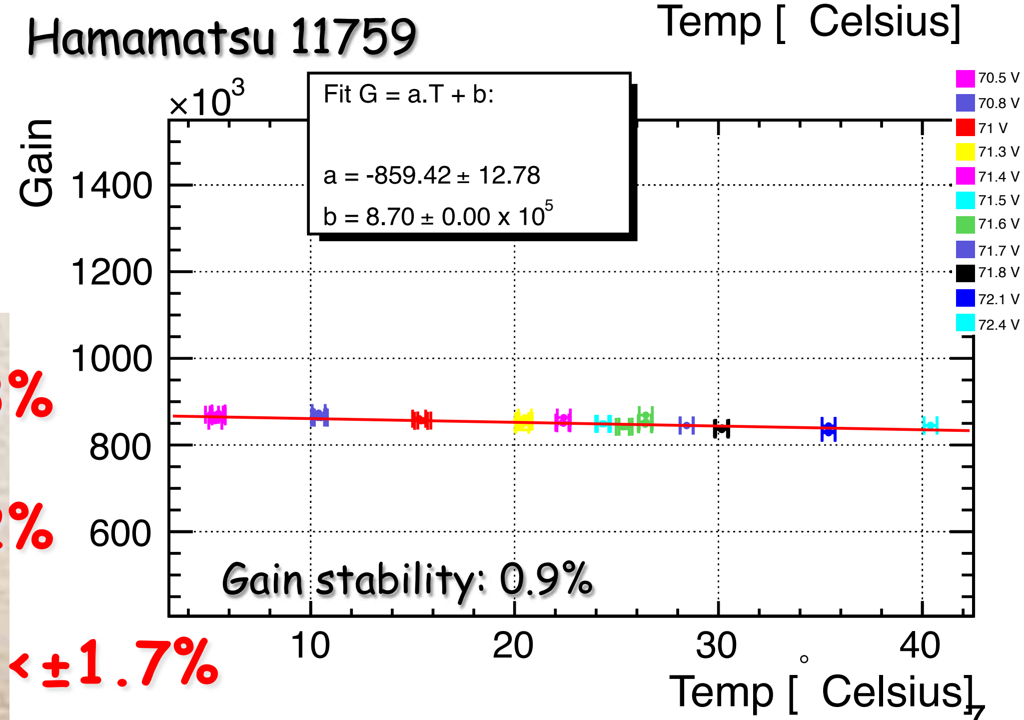


Gain after V_{bias} Adjustment for other SiPMs

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



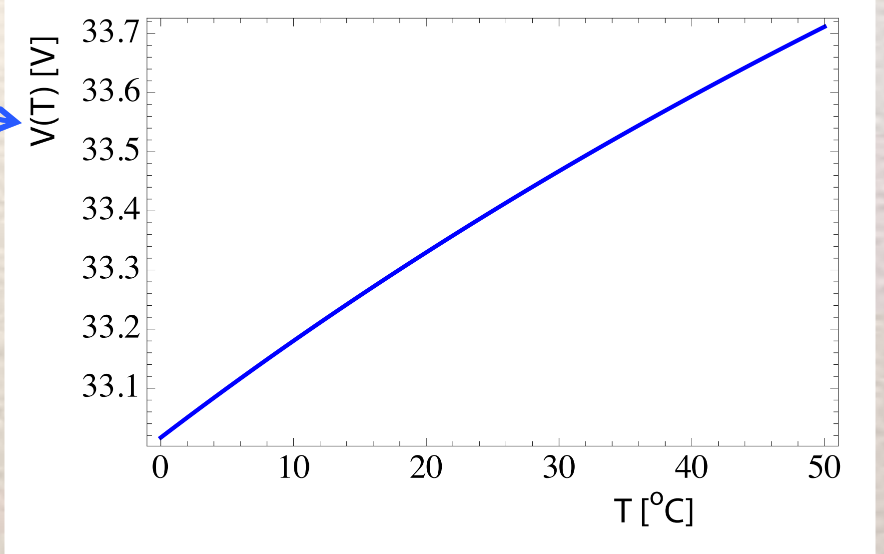




- CPTA 1677: non-uniformity < ± 0.3%
- KETEK W12: non-uniformity < ±1.2%
- Hamamatsu 11759: non-uniformity < ±1.7%

Voltage Temperature Relation

- For stable gain dV/dT is determined by $$\frac{dV}{dT} = -\frac{\partial G(V,T)/\partial T}{\partial G(V,T)/\partial V}$$
- The partial derivatives can be expanded in form of polynomials
  - $dG/dT = a + b*V + \mathcal{O}(V^2)$
  - $dG/dV = c + d*T + \mathcal{O}(T^2)$
- If both partial derivatives are first order polynomials ➔ $$V(T) = \frac{a}{c} + \left(c + d \bullet T\right)^{\frac{b}{d}}$$ (d≠0)
  - For CPTA 857 we obtain

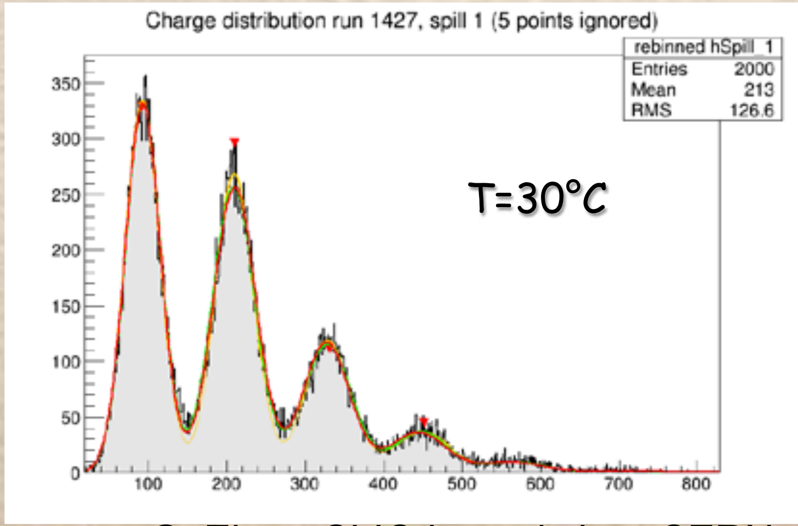


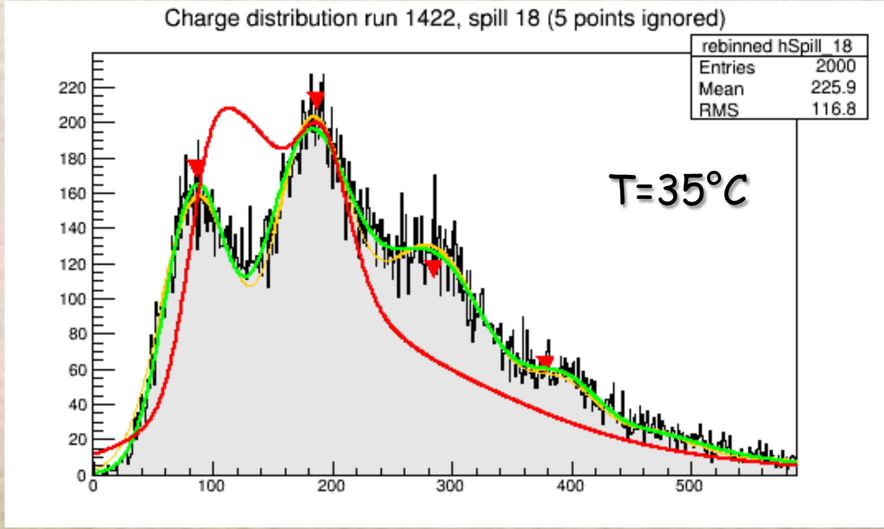
- For d=0 ➔ $$V(T) = \frac{a}{c} + C \cdot e^{\frac{b}{c}T}$$
- If the partial derivatives are constant ➔ V(T) is exactly linear
- For quadratic dependence V(T) has a more complicated solution ~ Tan{f(T)}

In the 20° -30° C range a linear model is a good approximation

Study of KETEK 12 SiPM

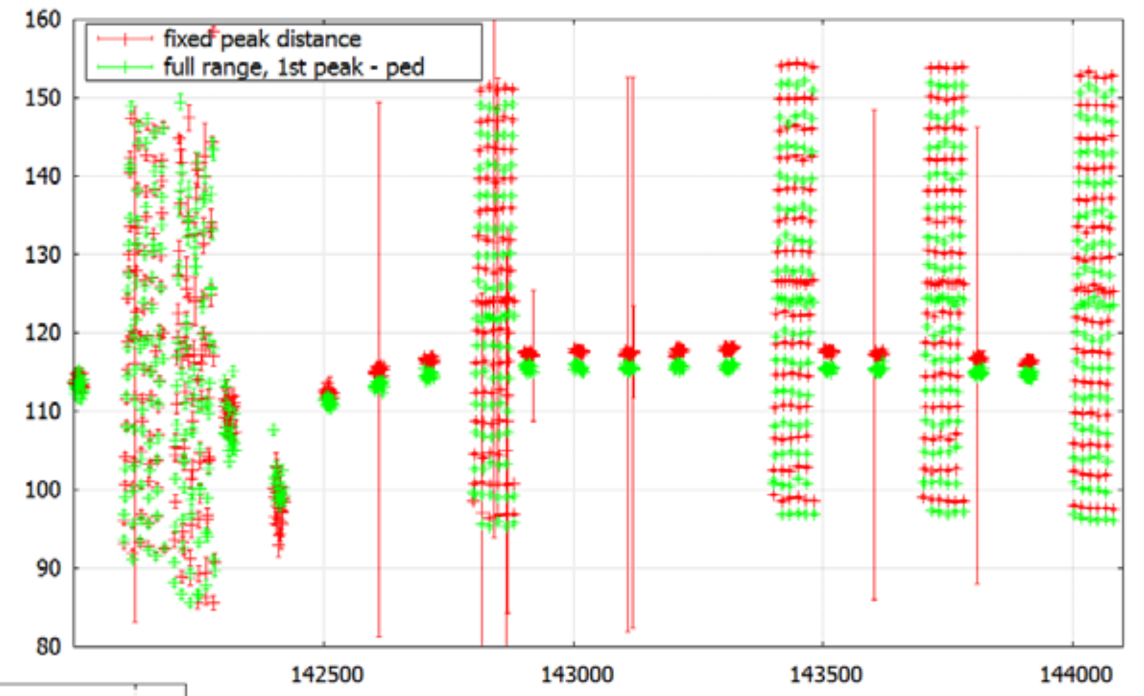
- We started with the analysis of the data taken with the bias voltage regulator prototype board
- We extended the temperature range from 1°C to 50°C
- We try several fitting procedures
  - Fixed-peak Gaussians: sum of Gaussians with fixed distance between peaks
  - Sum of Gaussians with 1.5σ range between 2 p.e & 1. pe. peaks
  - Sum of Gaussians with full range between 2 p.e & 1. pe. peaks
  - Sum of Gaussians with 1.5σ range between 1 p.e peak & pedestal
  - Sum of Gaussians with full range between 1 p.e peak & pedestal

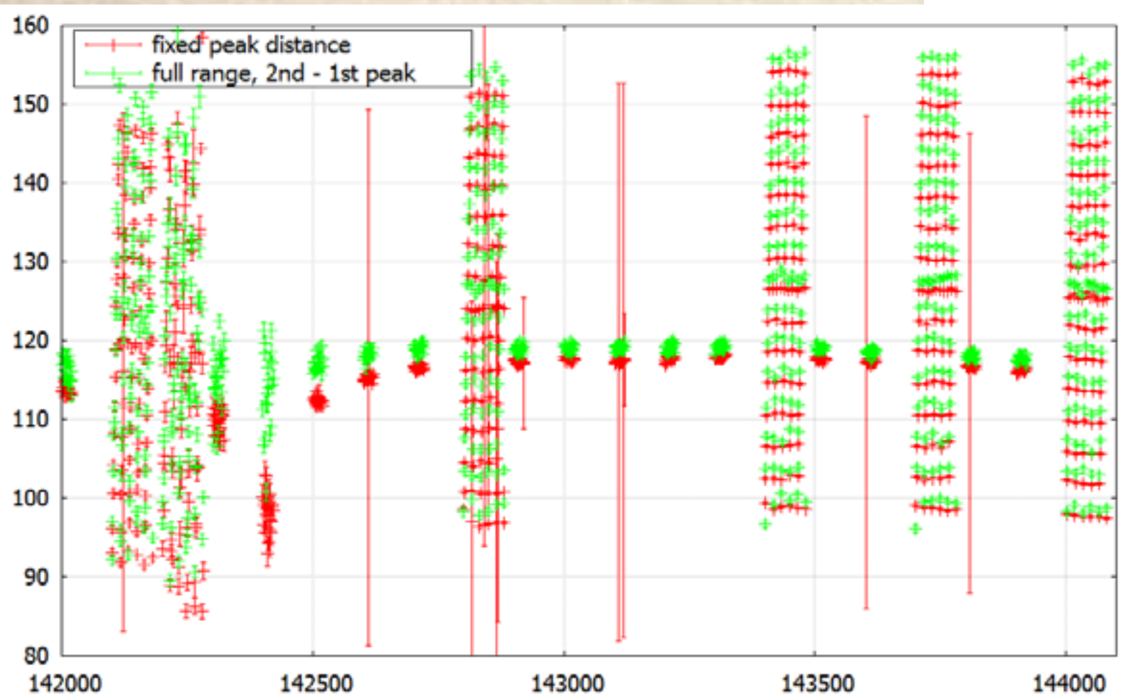




Run Overview

- Compare fixed-distance peaks to full-range fit of 1 p.e. and pedestal
- Fixed-peak fits yield slightly higher gains



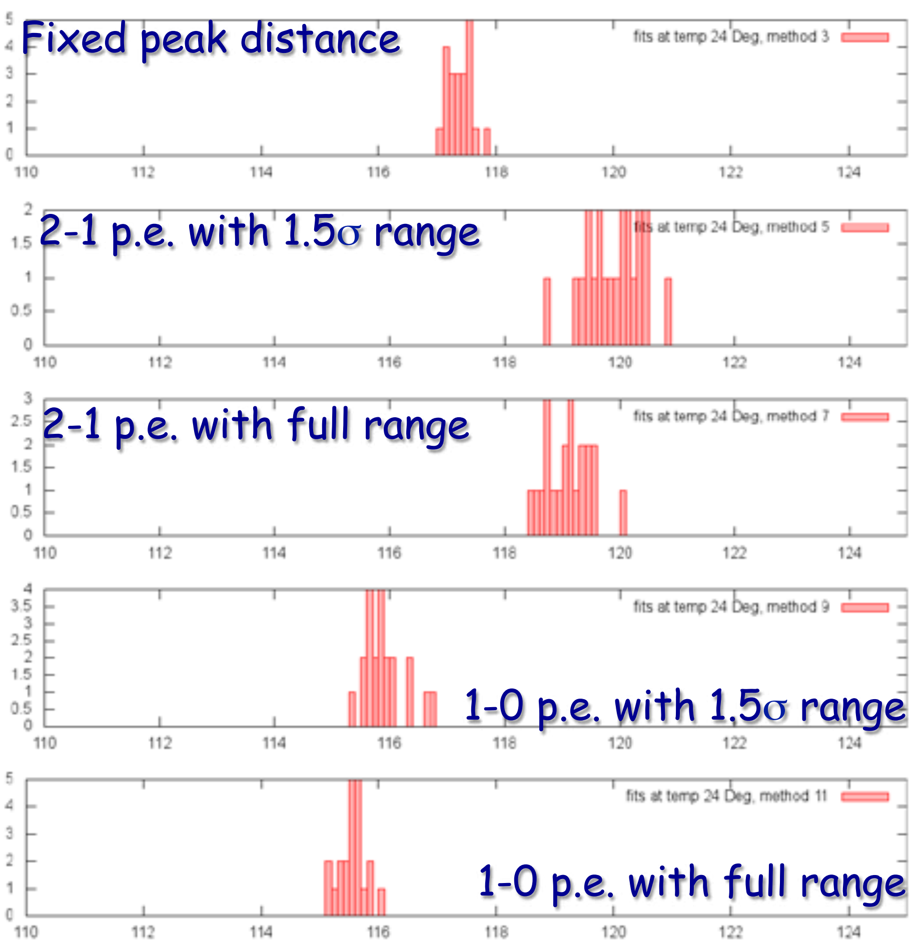


- Compare fixed-distance peaks to full-range fit of 2 p.e. and 1 p.e. peaks
- Fixed-peak fits yield lower gains

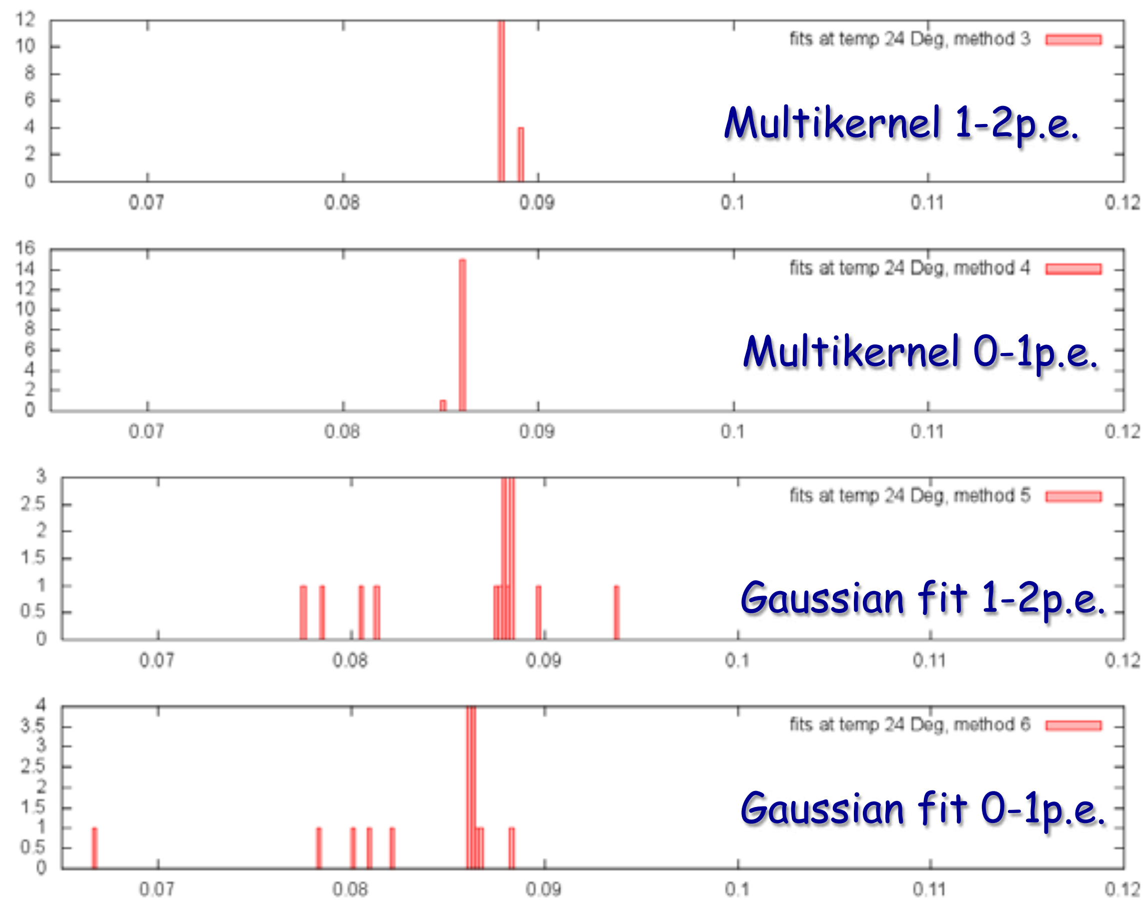
Gain Extracted from Different Fit Methods

- Compare measurements for new board with those for old board
- Fixed-peak distance and multi-kernel fits yield more stable results

New board



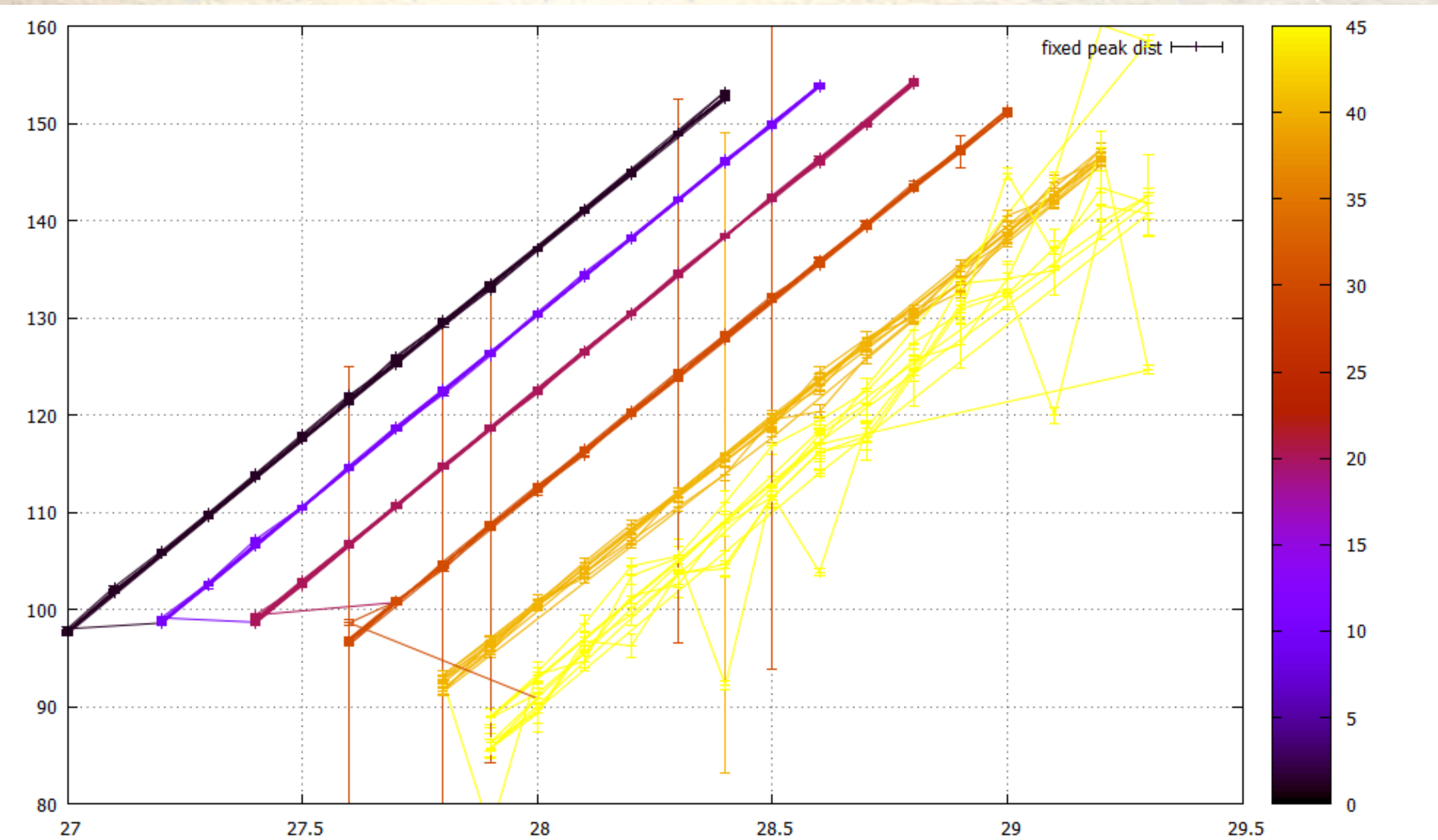
Old board



Gain versus Bias Voltage: Fixed-Peak

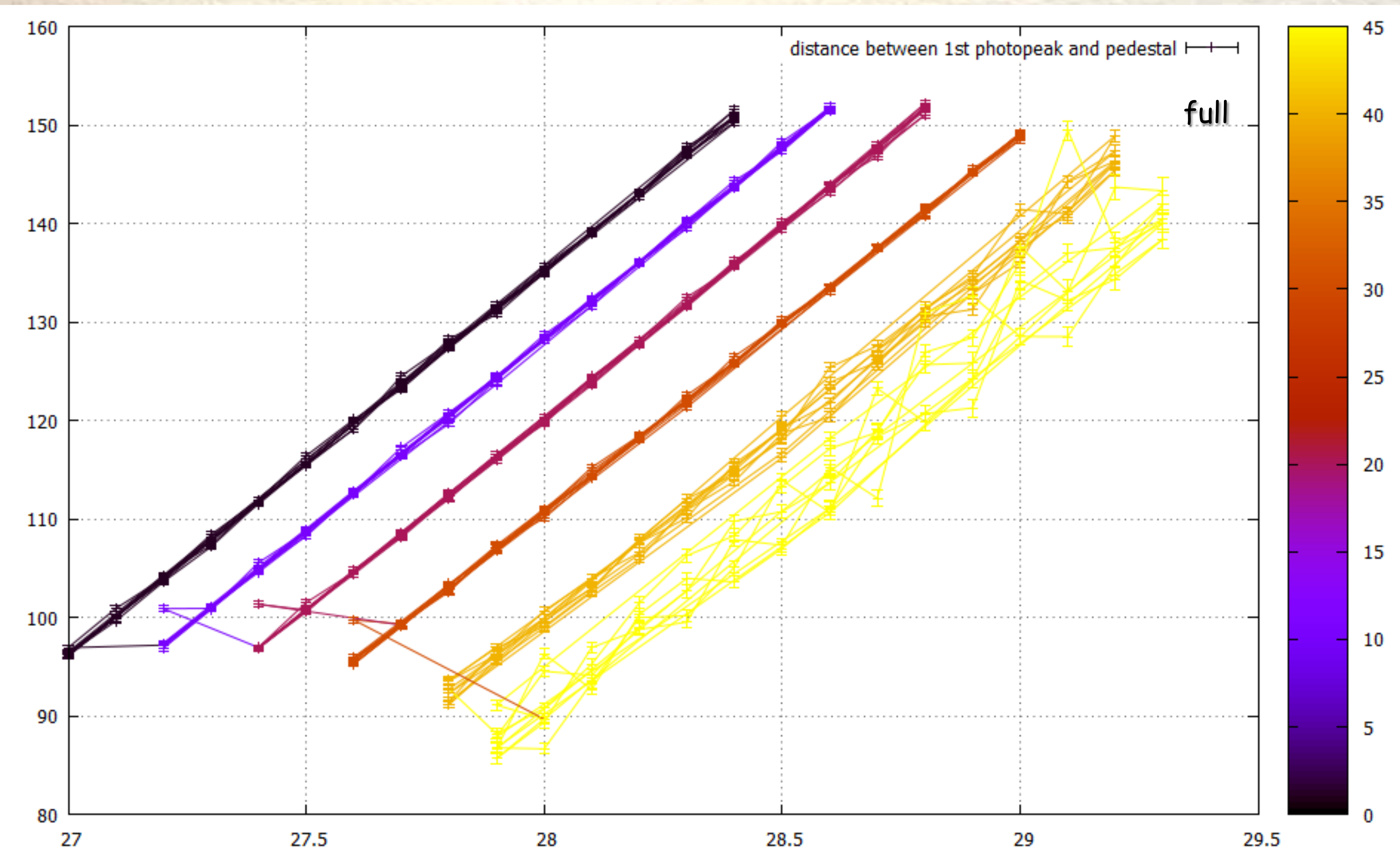
- For low T, slopes are parallel and spread of individual fits is small

➔ For high T, preamplifier probably did not perform properly



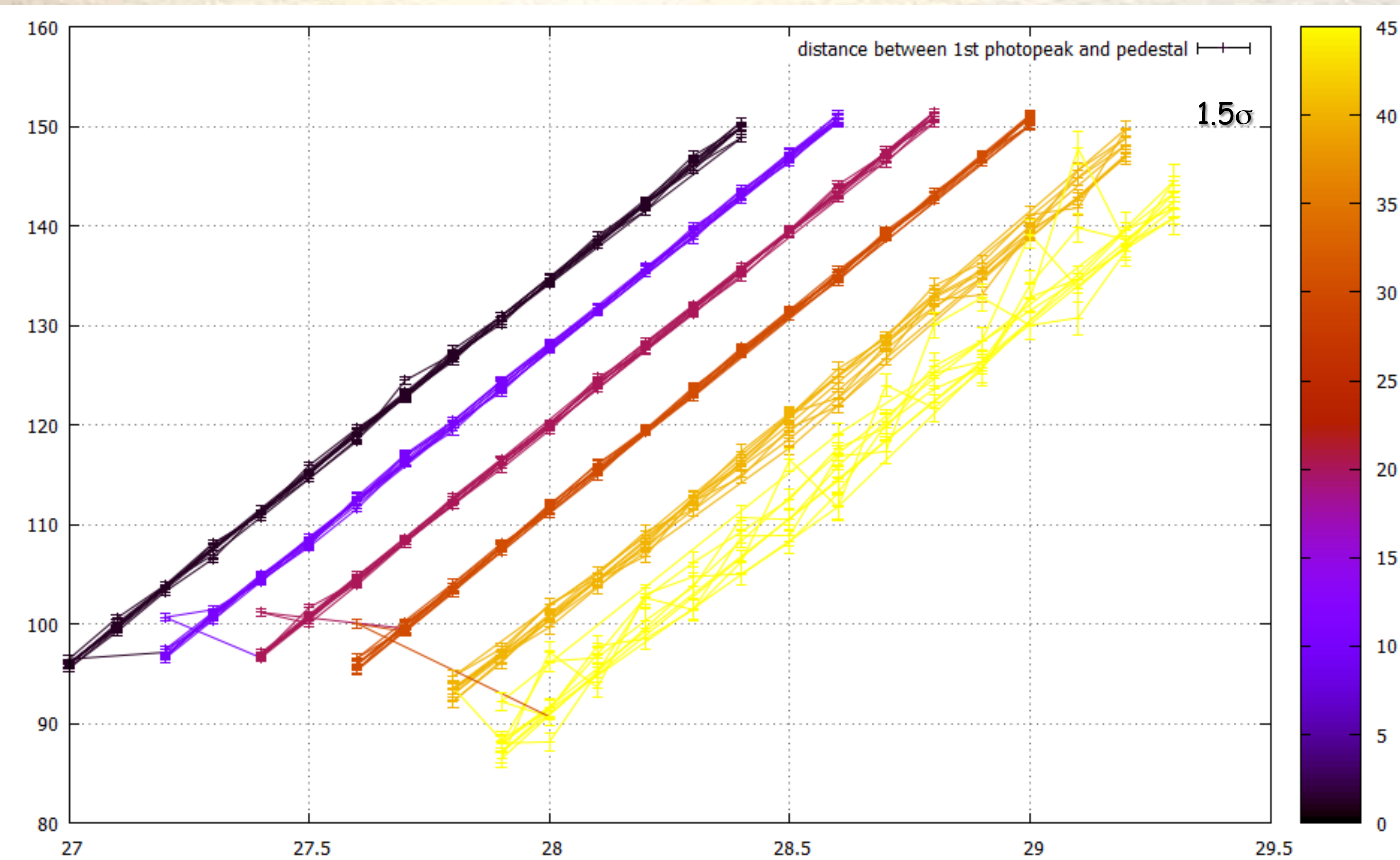
Gain versus Bias Voltage: Full Range 1-0 p.e.

- Slopes are also parallel, but spread of individual fits increases



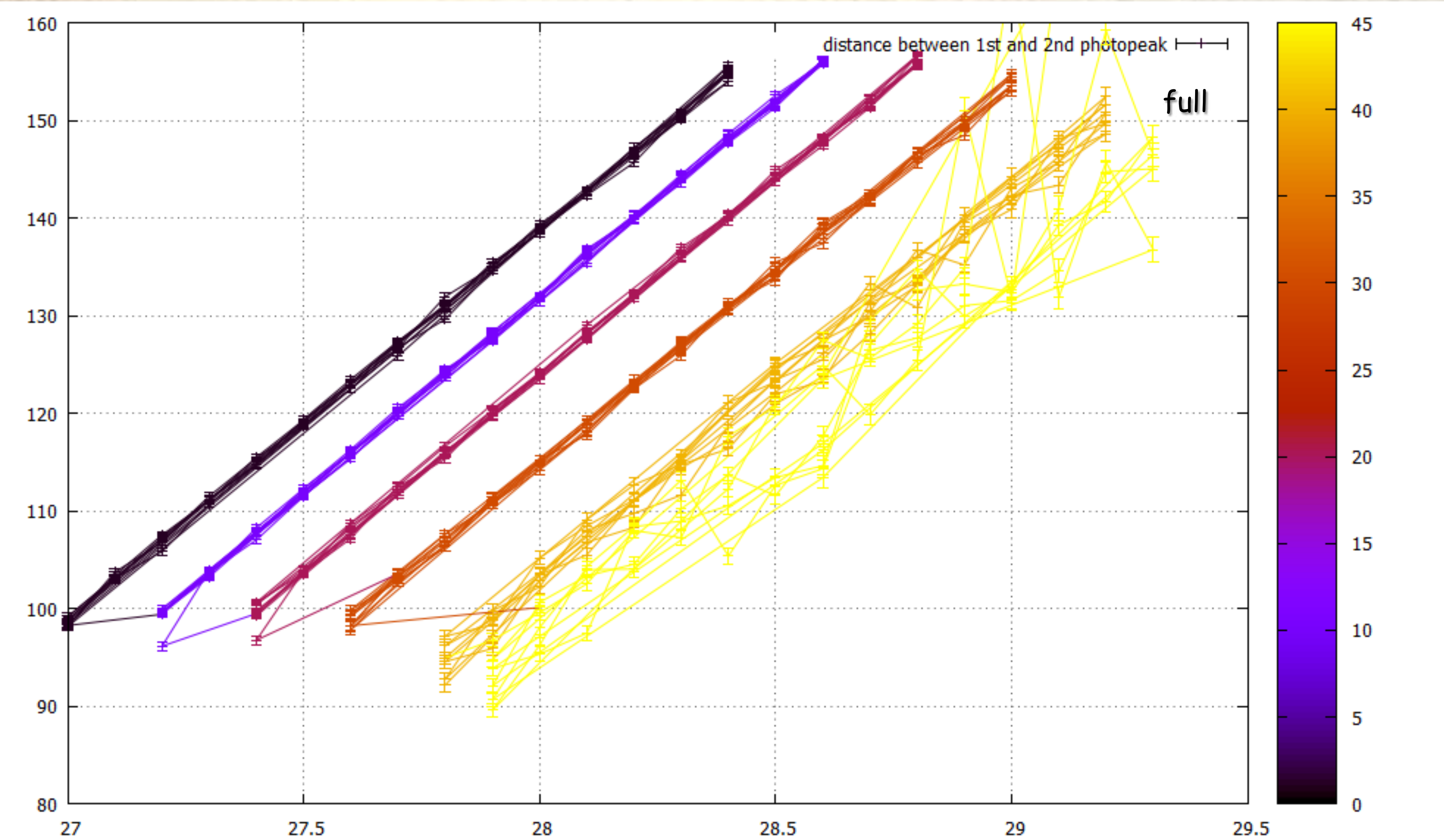
Gain versus Bias Voltage: 1.5σ Range 1-0 p.e.

- For low T, slopes of individual fits are parallel, larger spread



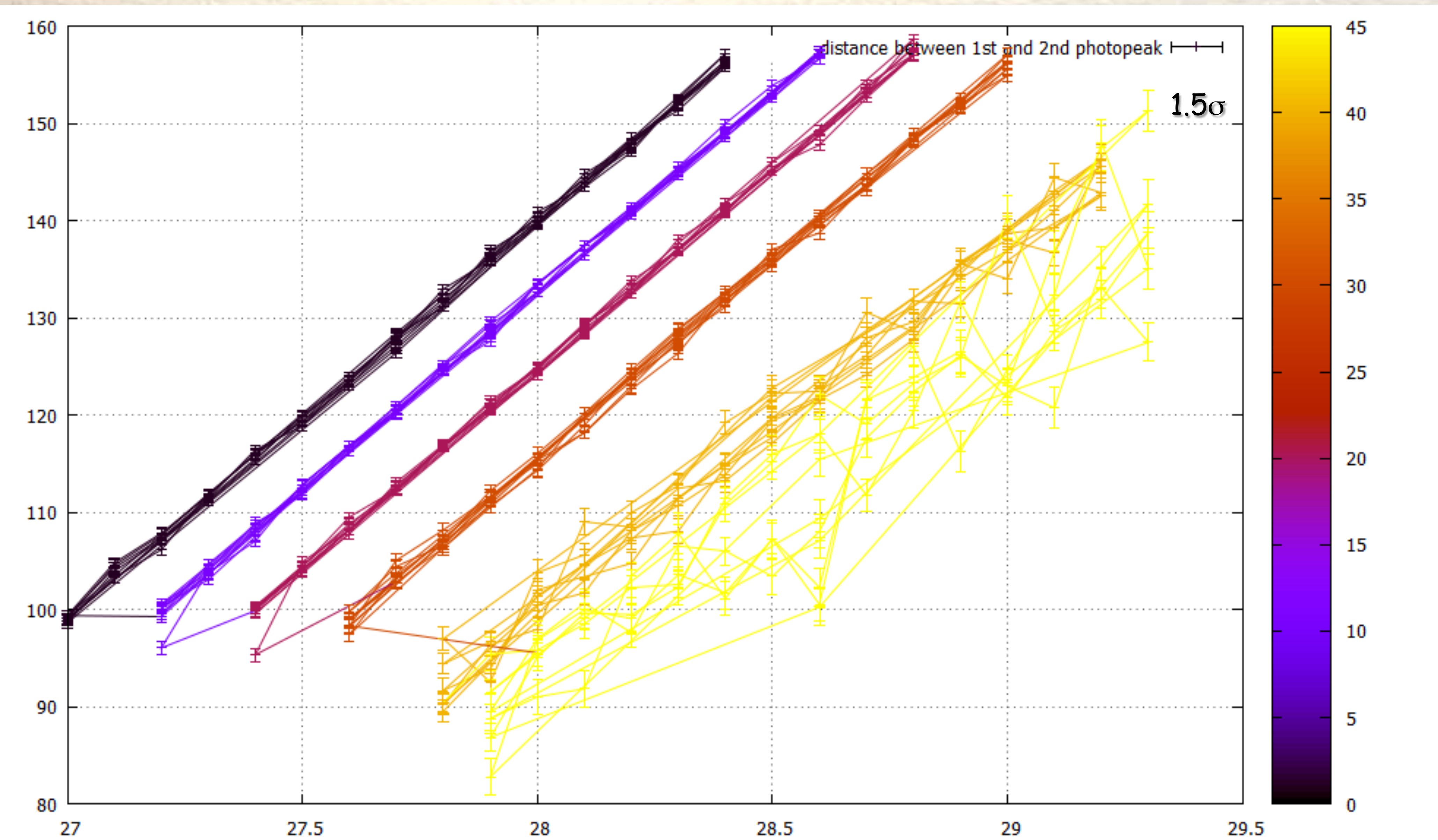
Gain versus Bias Voltage:Full Range 2-1 p.e.

- For low T, slopes are parallel spread of individual fits is larger



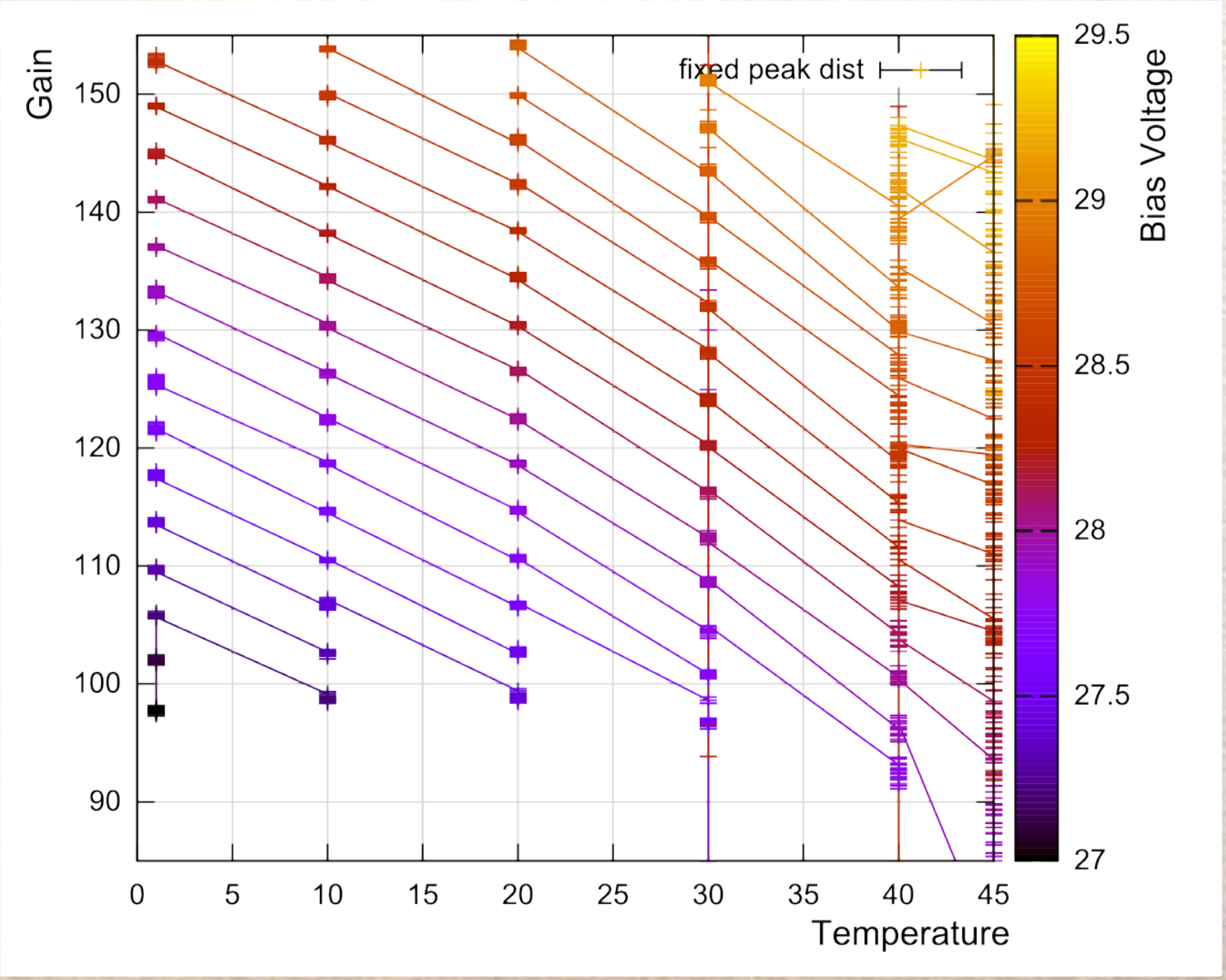
Gain versus Bias Voltage1.5σ Range 2-1 p.e

- For low T, slopes are parallel spread of individual fits is largest



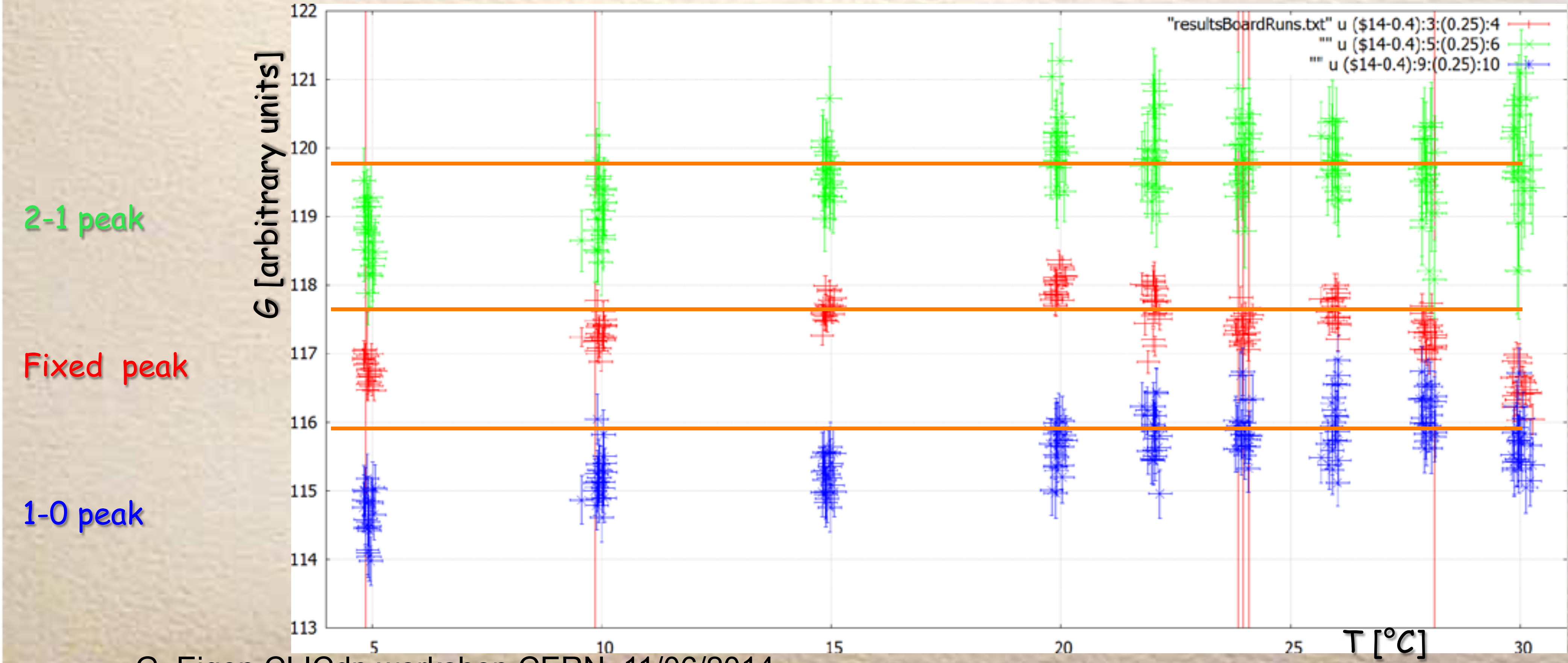
Gain versus Temperature

- Use fixed-peak method to determine temperature dependence



Preliminary Results with New Board

- Gain after bias voltage readjustment for KETEK SiPM 12
- There seems to be a slope up to 20°C? It also drops above 30°C
  ➔ is this real or is it an analysis bias?
- Fixed-peak method is more robust than 1.5σ fits for 1 p.e. – pedestal & 2 p.e. – 1 p.e. peaks



Conclusion

- For studies with the first bias voltage regulator board, the gain stabilization works very well
  → for all four tested SiPMs, gain stability is < 1% as required
- We are analyzing the gain stabilization of 5 SiPMs with the new bias voltage regulator board prototype
  → see problems at higher temperatures >35°C (preamplifier issue?)
  → gain also seems to drop at lower temperature
  (light had to be increased, longer signals, too short integration)
- Fixed-peak fit seem to have smaller variations →more stable?
  Need to understand and fix misfits
- Distance between pedestal 1 p.e. is smaller than that between 2 p.e. & 1 p.e.
- The V(T) dependence has an analytical solution
  → presently a linear dependence is implemented on the board
  → new studies may suggest that a power law may be needed

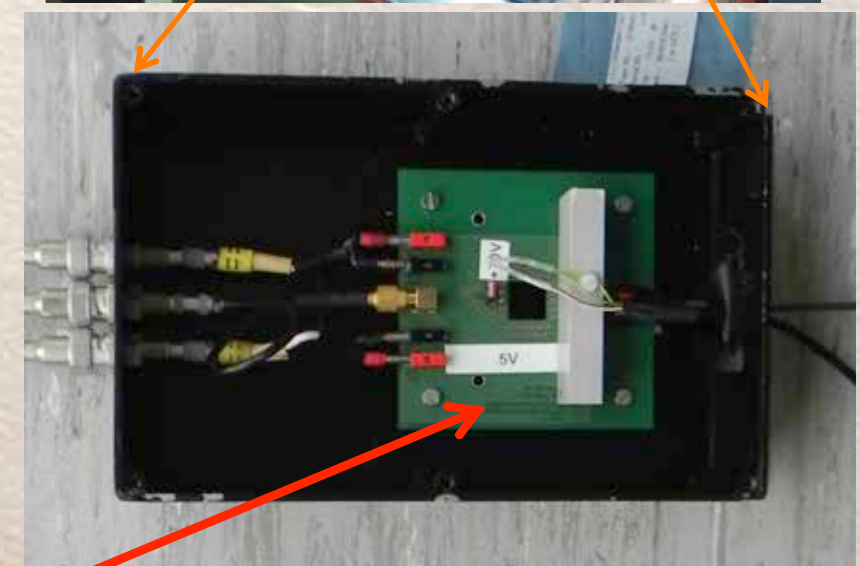
Next Steps

- Complete analysis of our latest runs with 5 SiPMs using the new bias voltage regulator prototype
- Check the preamp performance
- Results may require a modification of the regulator board to allow for power-law corrections
- This may require another test at CERN in climate chamber
- Modify an HBU implemented in the new AHCAL prototype
  ➔ This may proceed in 2 steps (analog and digital separately)

Backup Slides

SiPM Test Setup

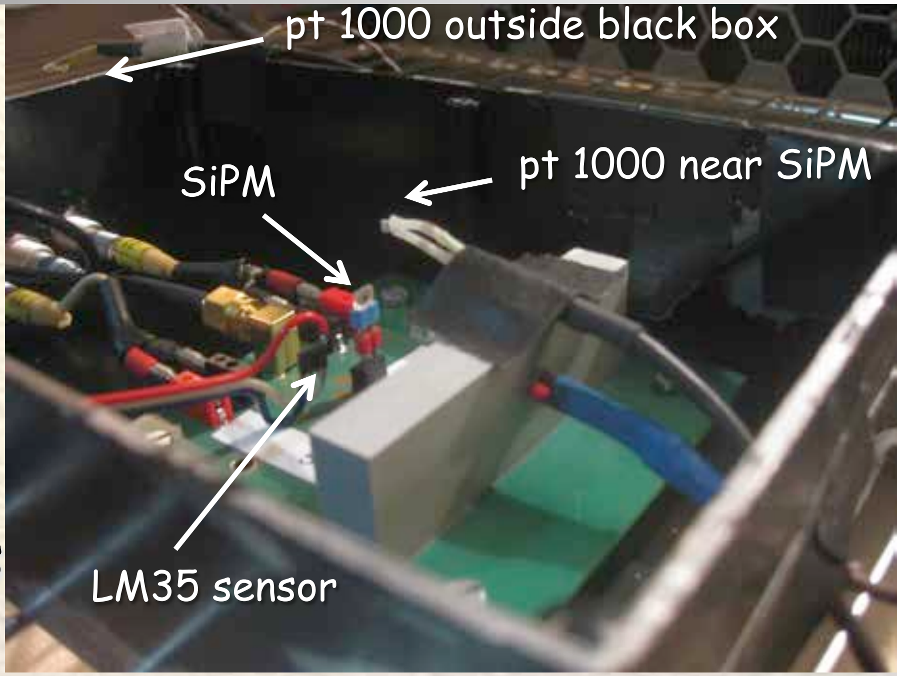
- We work in a climate chamber at CERN that is accurate to 0.2° C
- Use digital oscilloscope read out by PC, low voltage & bias voltage power supplies
- Use pulse generator for LED signal
- Shine blue LED light on detectors

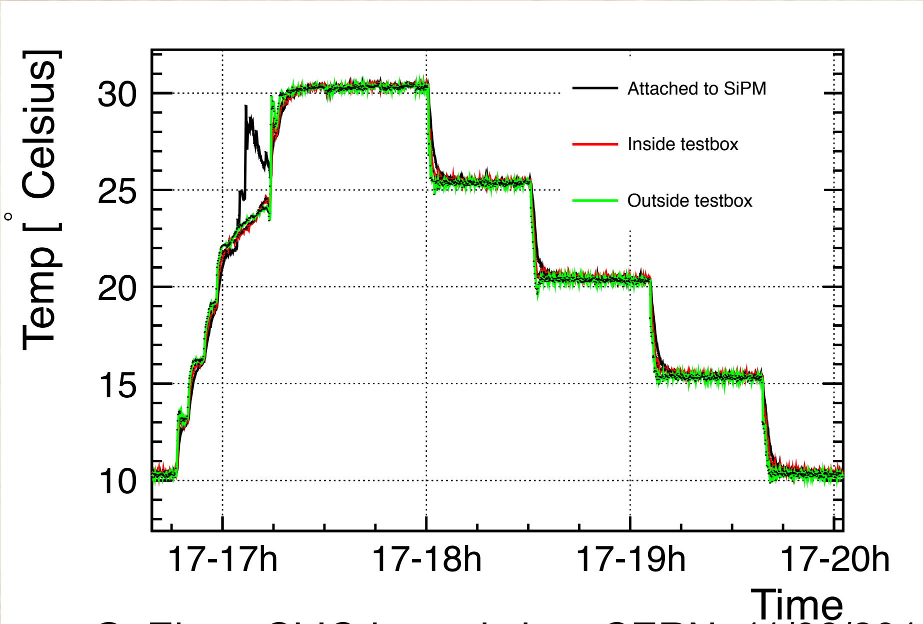


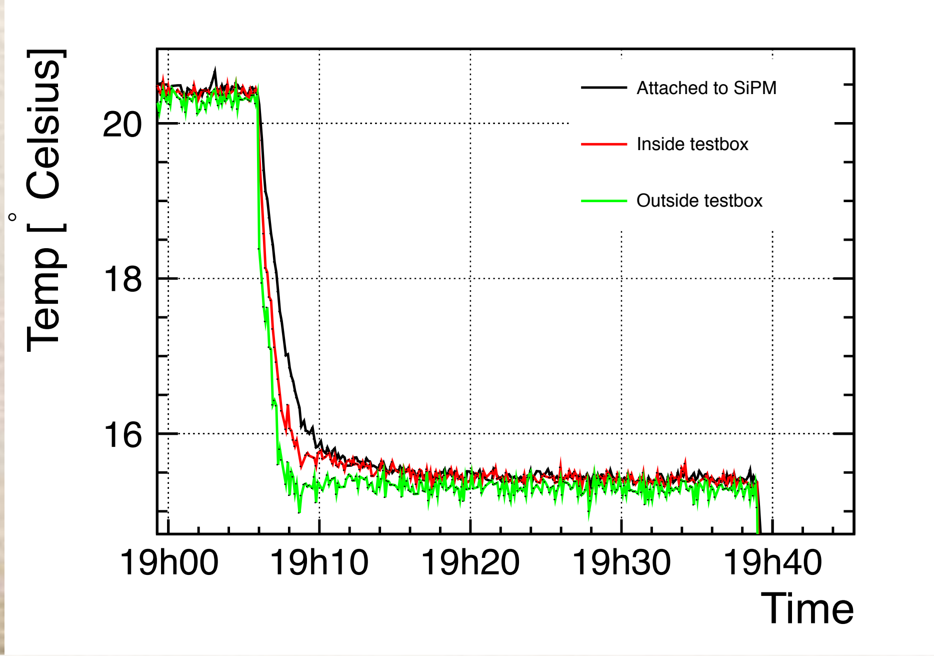
SiPM + preamp +T sensor + LED

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 [μm]	# pixels	Nominal 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	$2\times(1.2\times1.2)$	15	4384	28	3.0	W8
MP20 V4	3×3	20	12100	28	6.0	W12 ←

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

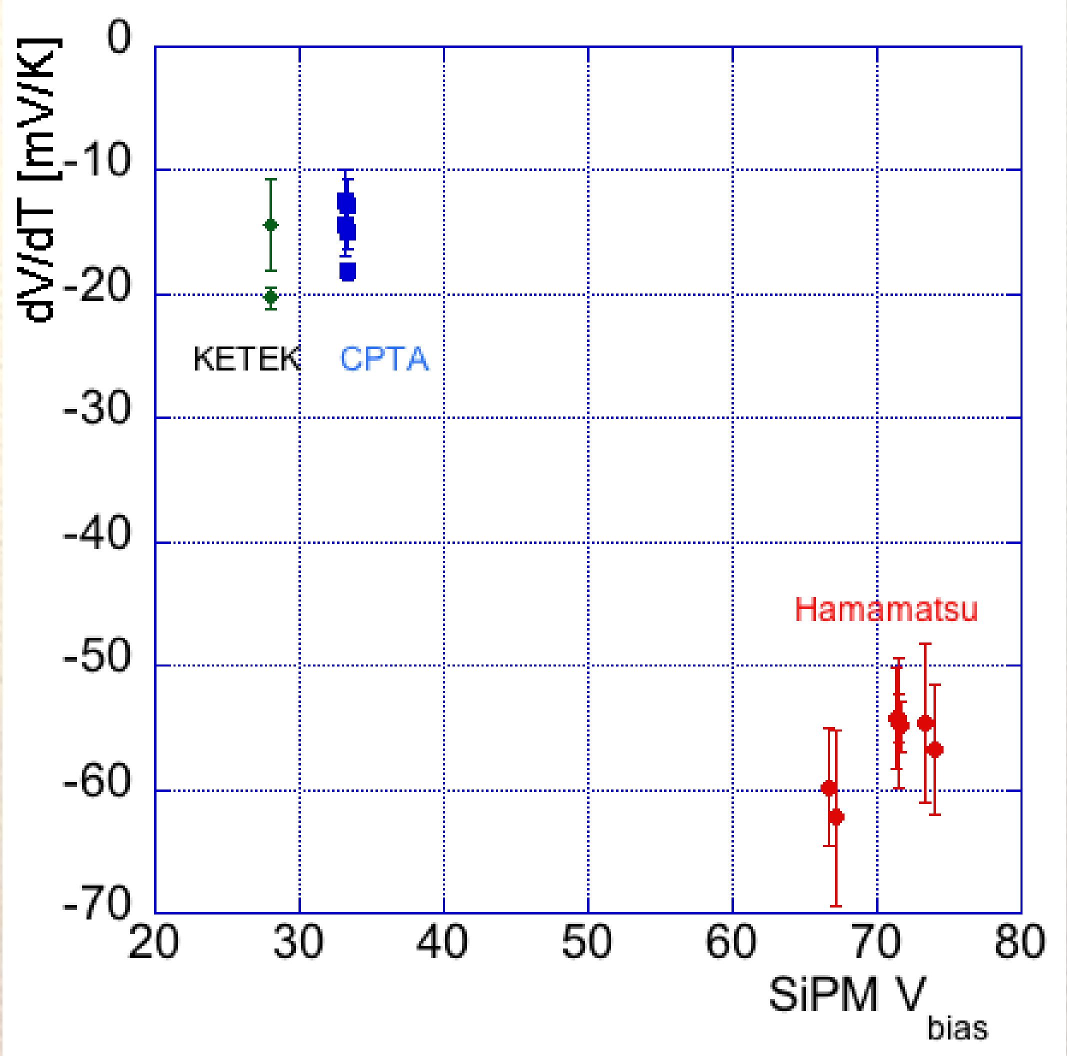
Summary of dV/dT Measurements

- 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



Known Fit Problems

- Wrong Peak-dist calculated
- Misfits mainly at higher temperatures
- Sometimes wrong error determination