STUDIES OF MPPC DETECTORS DOWN TO CRYOGENIC TEMPERATURES

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Outline

- Introduction:
  - ✓ The motivation of the present work
- Experimental details
- Main steps of automatic procedure for data analysis:
  - ✓ Baseline restoration
  - ✓ Templates
  - ✓ Peak analysis
- Physics results:
  - ✓ Charge distribution
  - ✓ Gain and Breakdown Voltage
  - ✓ Micro-cell resistance and capacitance
  - ✓ Recovery time
  - ✓ Dark Count Rate
- Summary

MPPC characteristics:

Gain : → the number of charges created in one avalanche in one µcell

Noise :

- dark count → pulses triggered by non-photo-generated carriers (thermal/tunneling generation in the bulk or in the surface depleted region around the junction)
- afterpulse → carriers can be trapped during an avalanche and then released triggering another avalanche
- optical cross-talk → photo-generation during the avalanche discharge. Some of the photons can be absorbed in the adjacent cell possibly triggering new discharges

Signal shape :

- Rise time : $\tau_{rise} \sim R_D \cdot C_D$ (read-out chain should be taken into account)
- Recovery time : $\tau_{recovery} \sim R_q \cdot C_D$ (influence the dead time and dynamic range)

Photon Detection Efficiency, Dynamic Range, Timing resolution

Motivation:

- The temperature and bias voltage represent two parameters affecting the characteristics of the MPPC detectors (breakdown voltage, signal shape, noise, gain etc) and consequently leading to a variation of the final detection characteristics
- Use the properties of MPPC for the understanding of fundamental physics: temperature dependence of thermal generated carriers; life time of afterpulses etc.

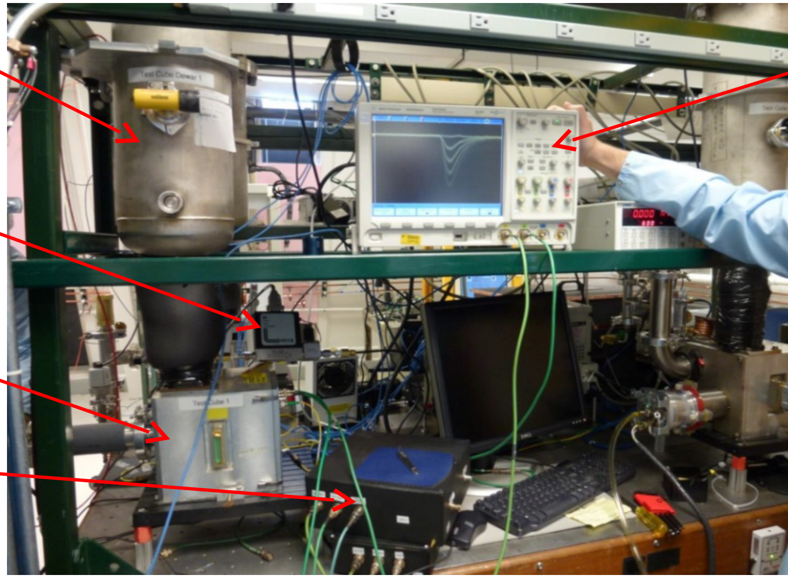
Fermilab set-up for low temperature measurements:

N_2 column

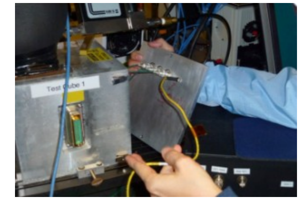
N_2 flow control

Test cube for MPPC

Amplifier



Oscilloscope for data acquisition (20Mhz)



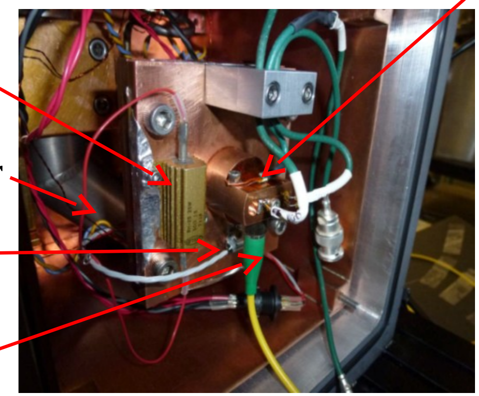
MPPC in front of light

Heater

Cold finger

Pt100

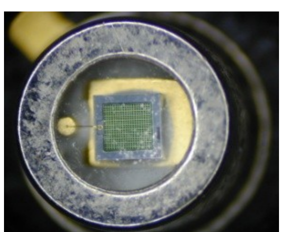
Optical fiber



- T range: from -175°C to 55°C in step of 10°C (24 T values)
- At each T:
  - 12 V_{bias} values for each detector (the same overvoltage independent of T)

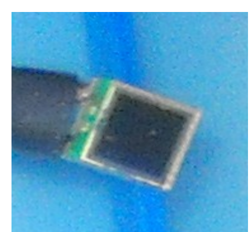
MPPC detectors:

Hamamatsu S10362-11-050U



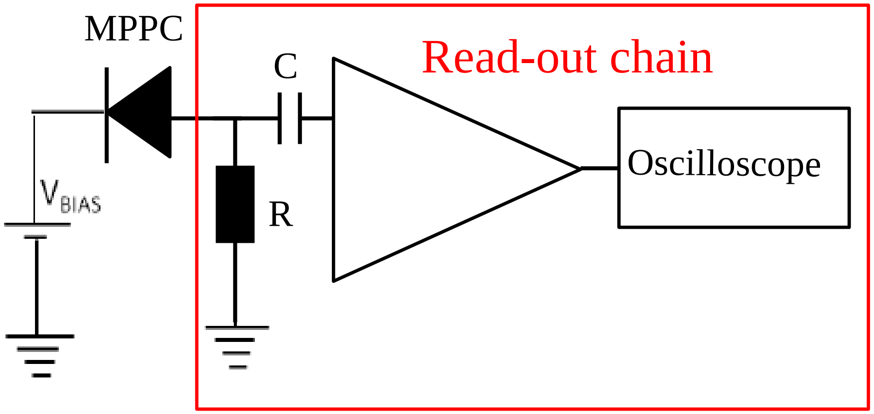
1x1mm^2 total area
50x50µm^2 µcell

Hamamatsu S10931-050P



3x3mm^2 total area
50x50µm^2 µcell

Read out chain:



Read-out chain used for data acquisition

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differentiates the signal with the time constant τ

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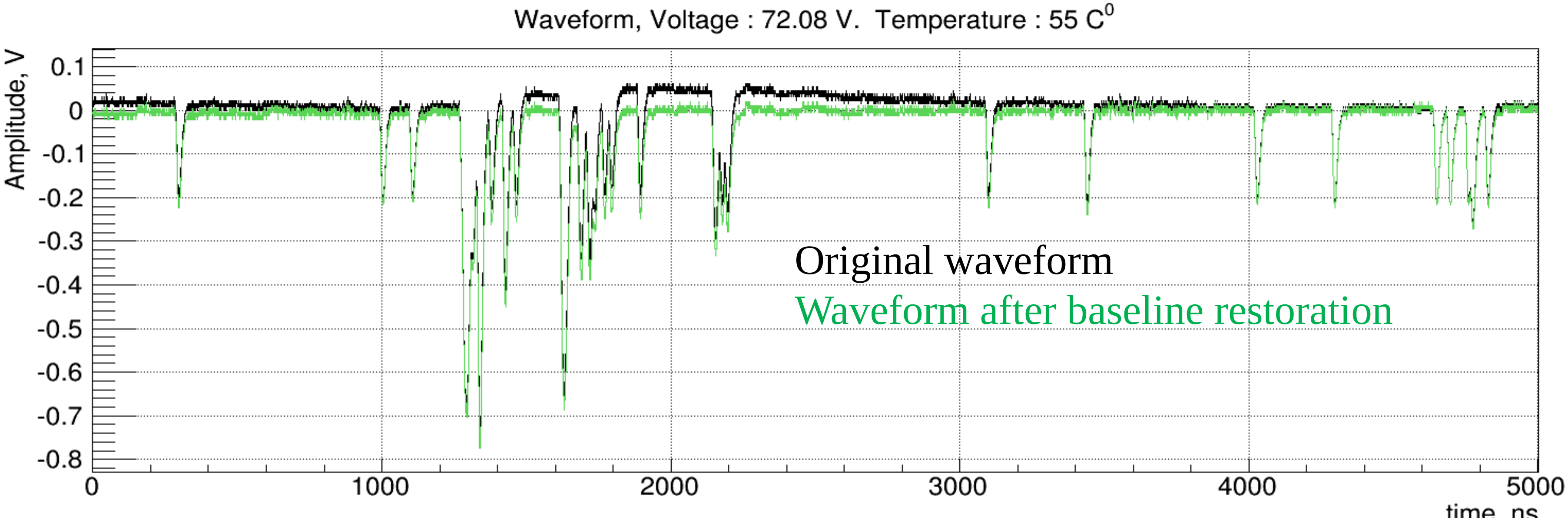
it leads to baseline shift:

- Pulses are siting on shifted baseline
- Pulses shapes are modified (Amplitude, Charge)

Baseline restoration:



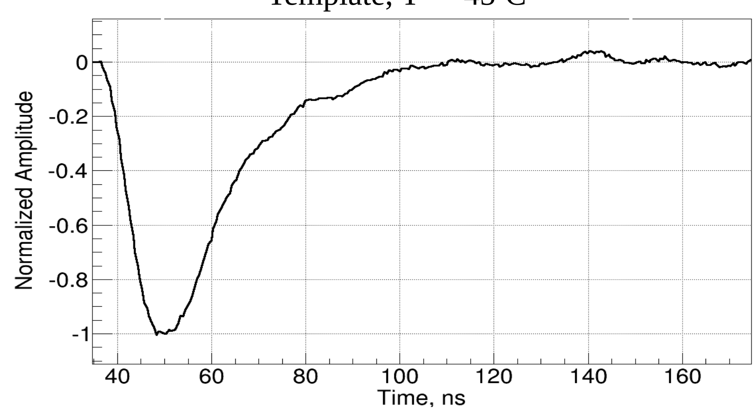
Using such method MPPC charge (Gain) calculation was improved

Automatic procedure:

To analyze experimental data:

- Separate real MPPC pulses from noise
- Calculate MPPC pulse characteristics
- Select single MPPC pulses
- Calculate MPPC detector characteristics

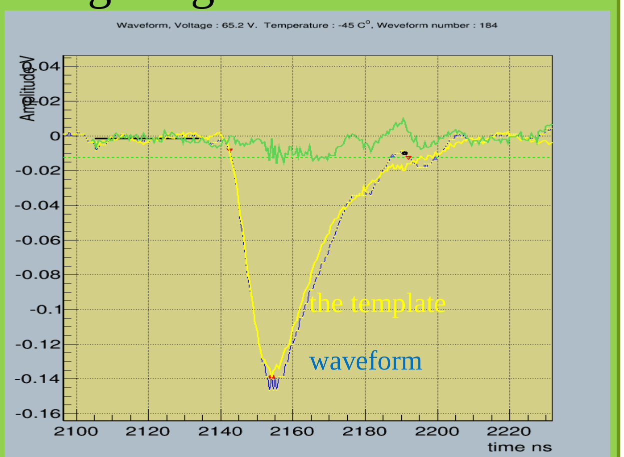
Template: – is the typical MPPC signal shape at a given Temperature



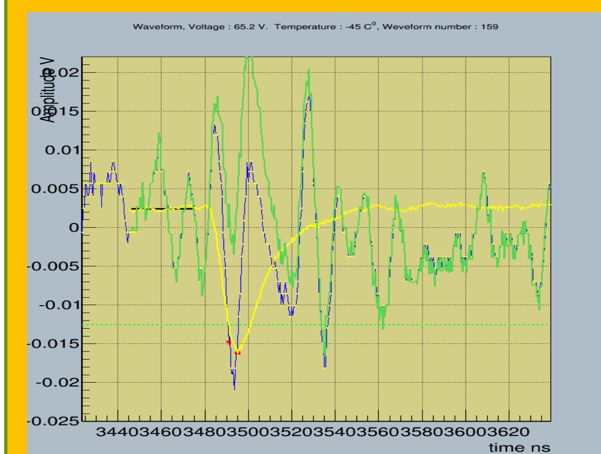
Our aim:

- To compare the template with all pulses and choose for the analysis only the pulses having the same shape as the template (real MPPC shape)

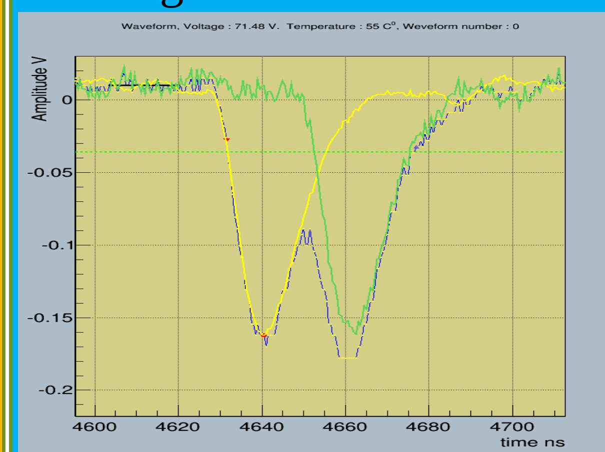
Single signal:



Electronic noise:

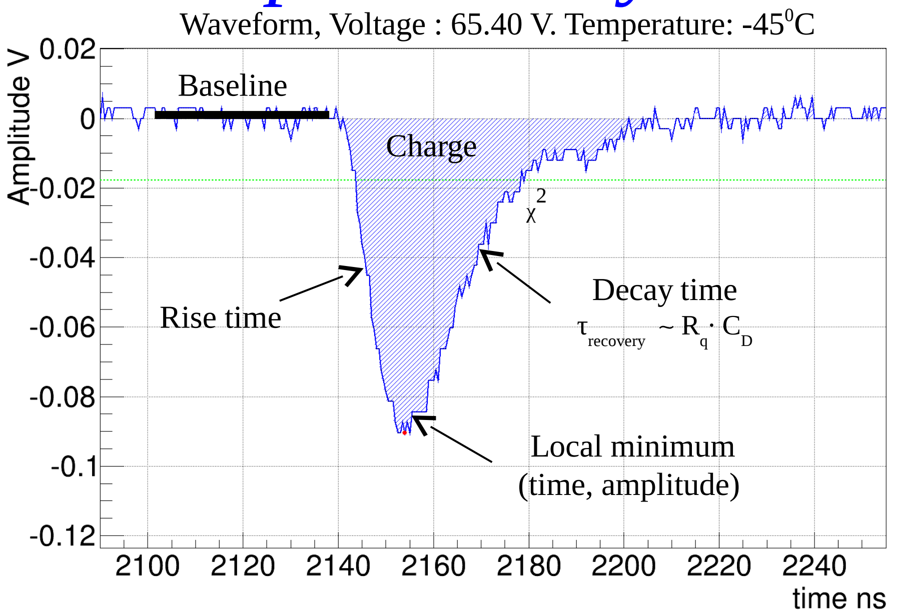


Two signals:

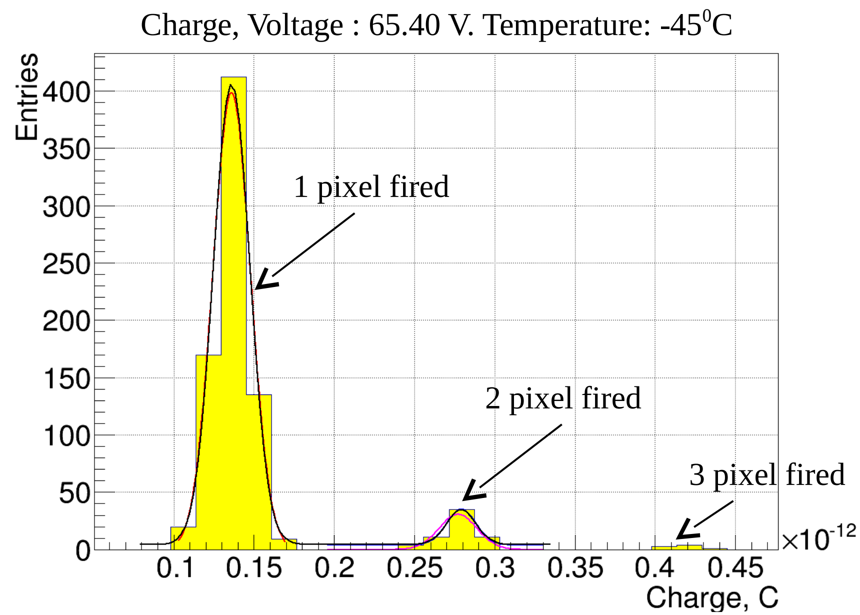


- the real MPPC pulses can be separated from electrical noise
- the sum of few MPPC pulses can be reconstructed

MPPC pulse analysis :



All calculated parameters saved in Ntuple files (one file at a given T and V_{bias})



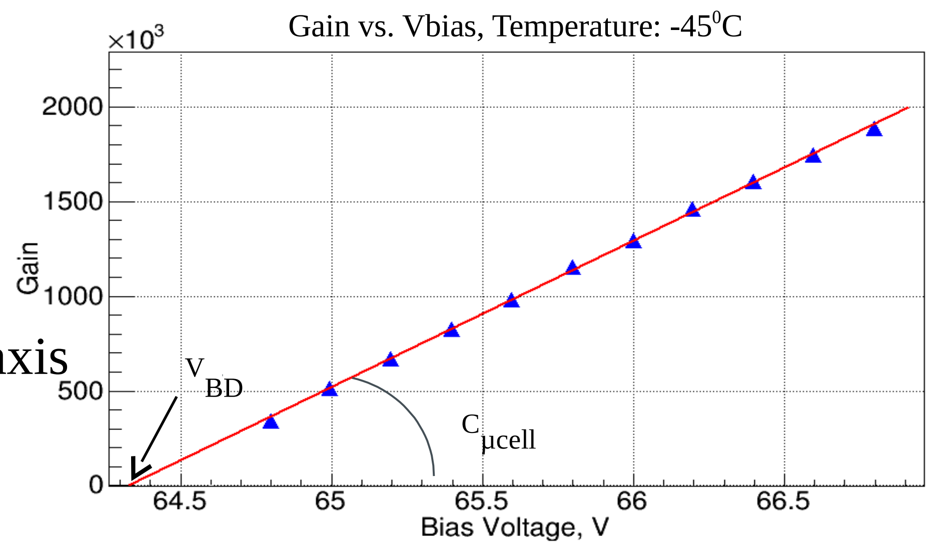
The MPPC charge was determined from Gaussian fit of 1 pixel fired peak

Gain : -the number of charges created one avalanche in one µcell

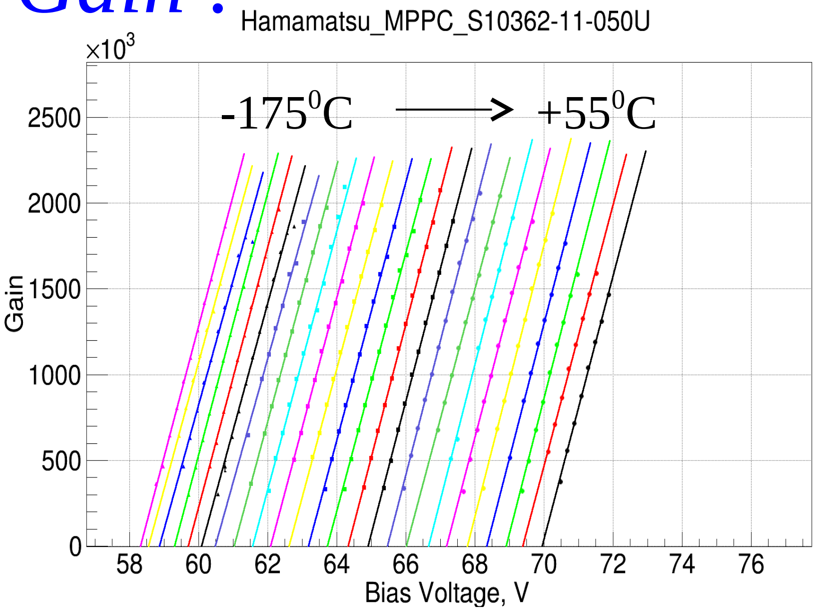
$$Gain = \frac{Q_{cell}}{e} = \frac{C_{cell} \times (V_{bias} - V_{BD})}{e} = \frac{C_{cell} \times \Delta V}{e}$$

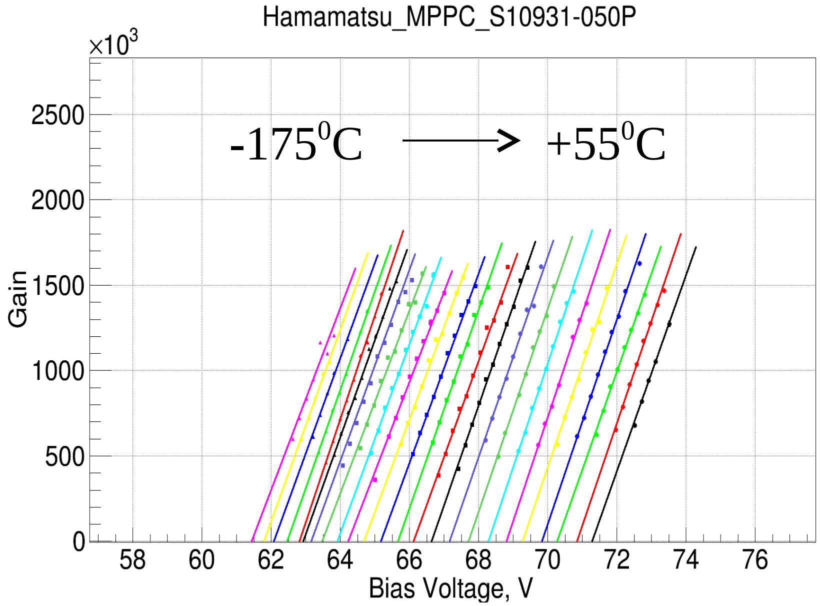
Breakdown voltage : intercept of x axis

$C_{\mu cell}$: *the slope of linear fit*



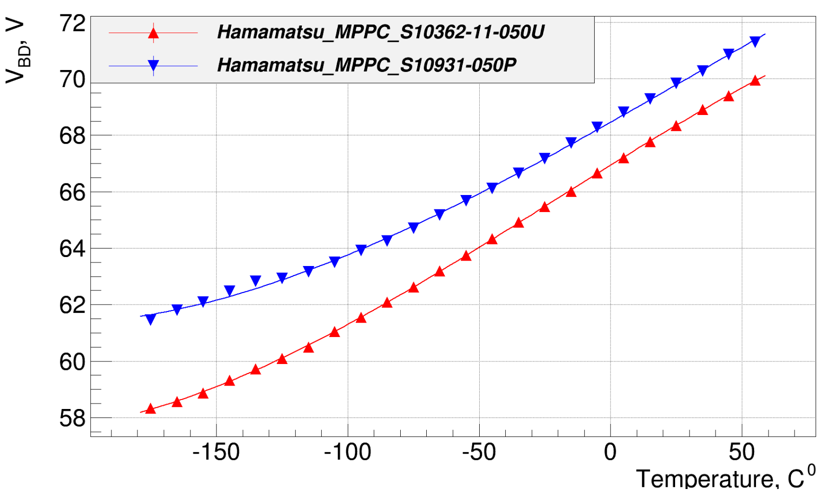
Gain :





@ a given T, G increase linearly with V_{bias}

Breakdown voltage :

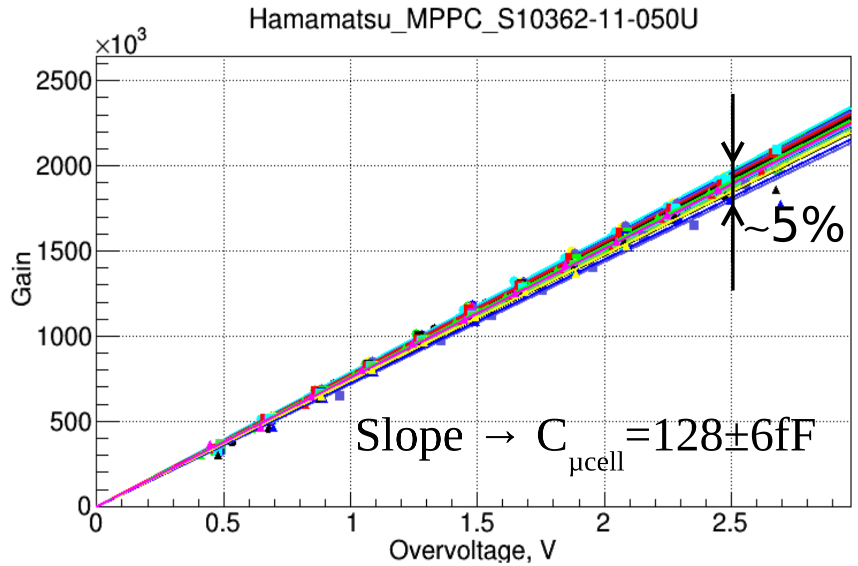


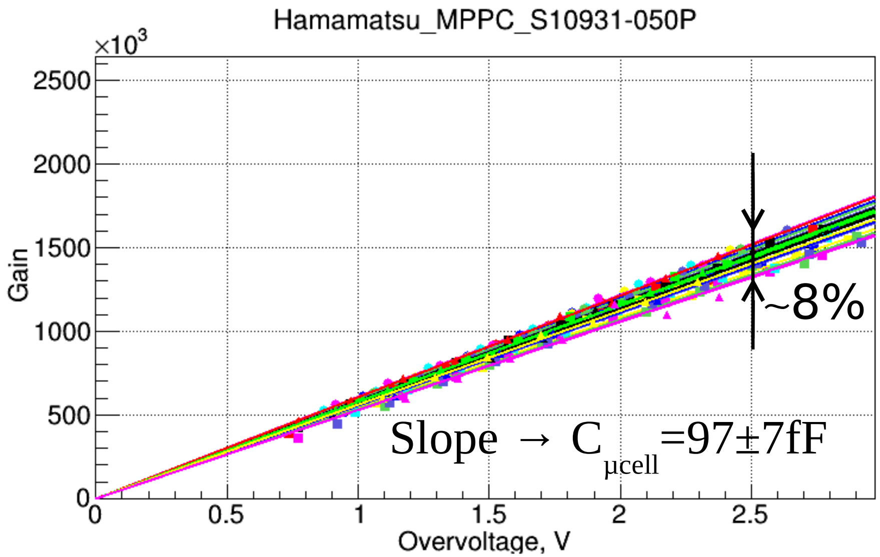
Detectors show different temperature dependence

different structural or technological characteristics

(C.R.Crowell and S.M.Sze "Temperature dependence of avalanche multiplication in semiconductors", Appl. Phys. Letters 9, 6(1966))

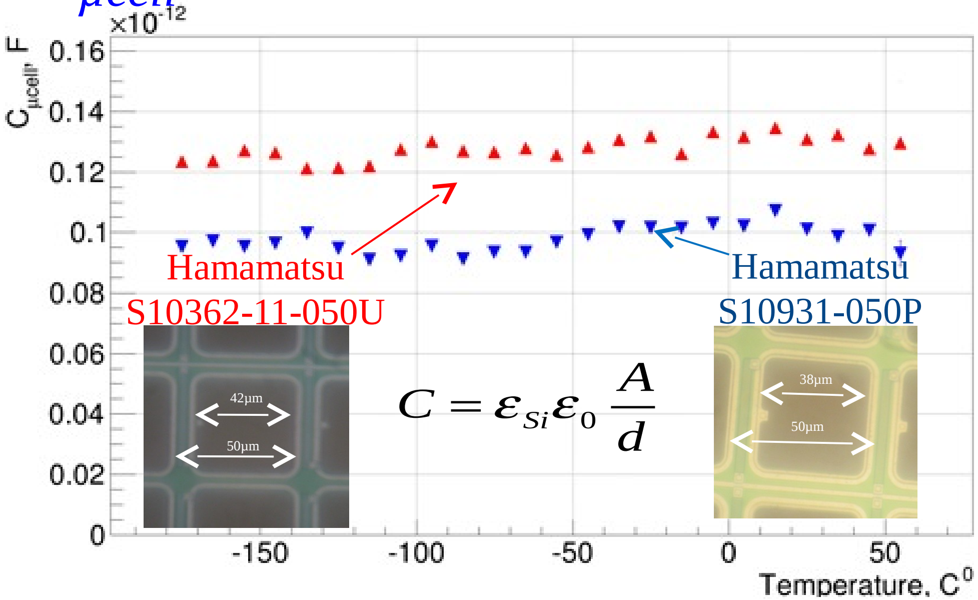
Gain vs Overvoltage:





At a given ΔV the G is constant, independent of T

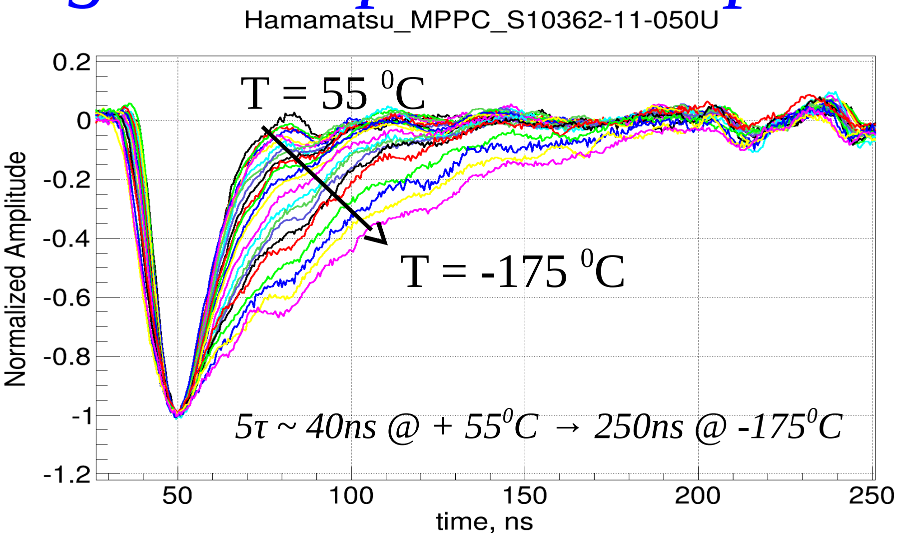
$C_{\mu cell}$ vs Temperature:

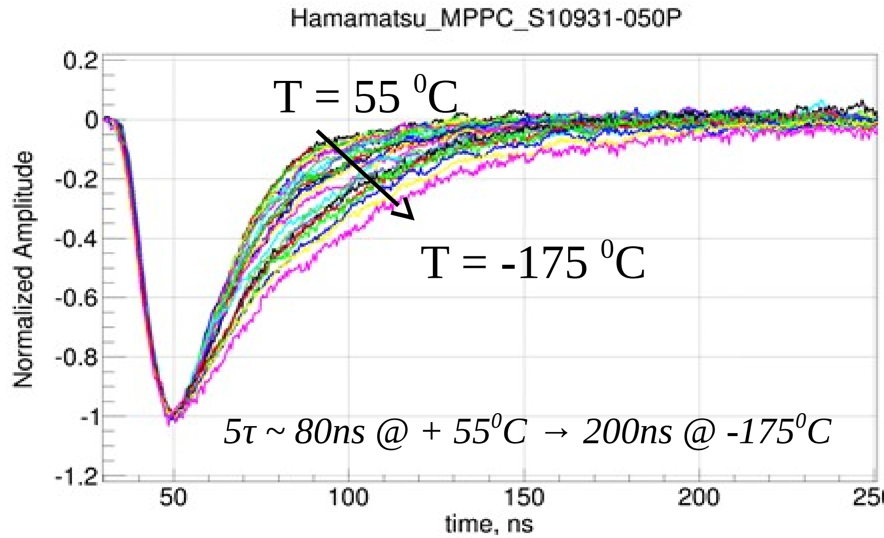


$C_{\mu cell}$ is constant over all T range

~20% of difference between two detectors

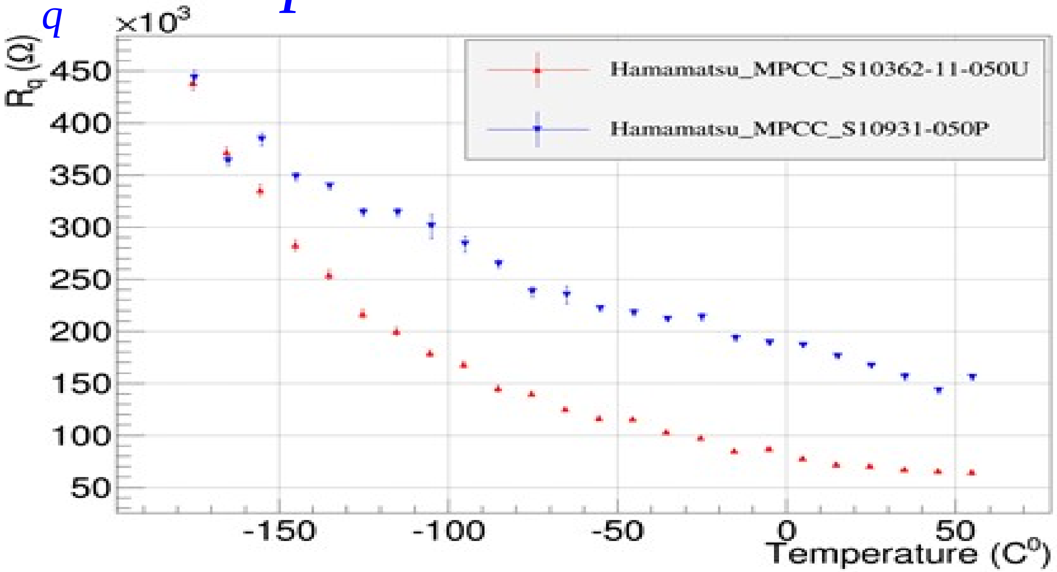
Signal shapes vs Temperature:





Pulse falling edge ($5\tau_{fall} = C_{\mu cell} \cdot R_q$) increase with decreasing T → R_q temperature dependence

R_q vs Temperature:



R_q increase with decreasing T

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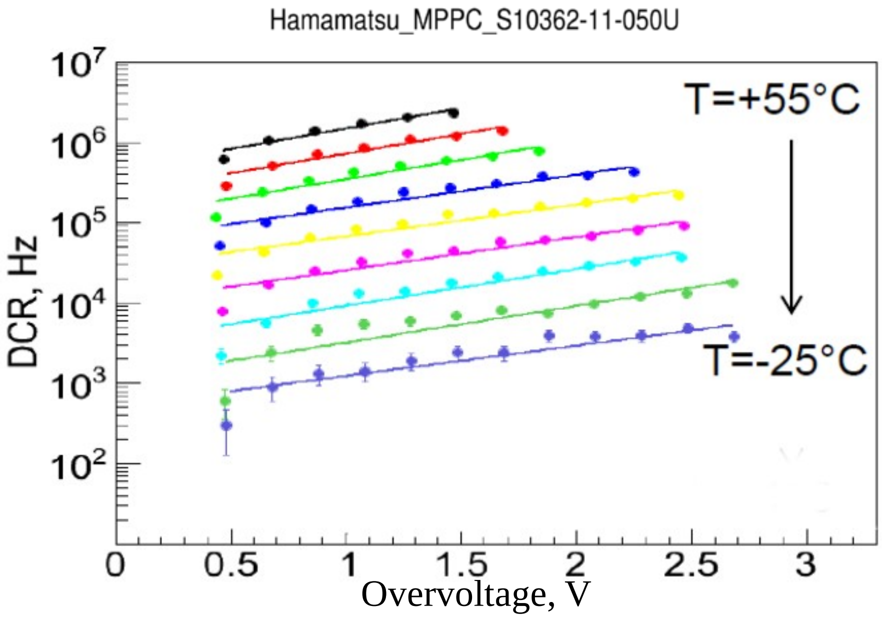
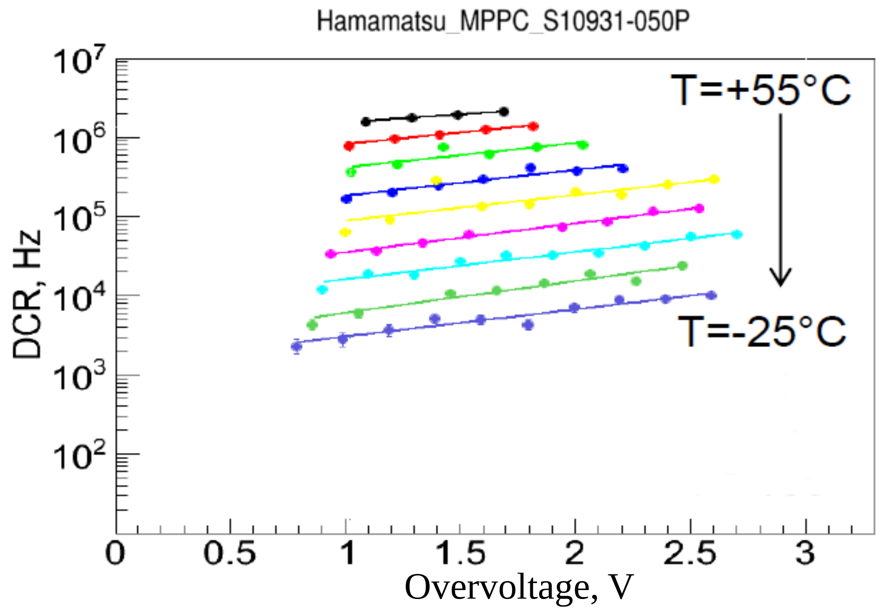
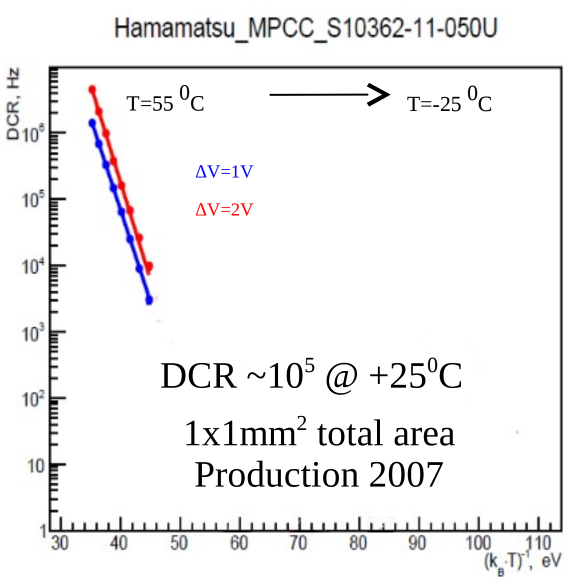
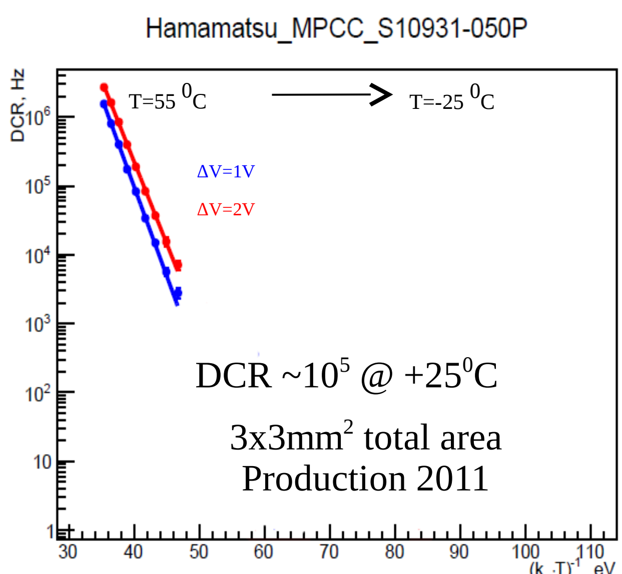
poly-silicon T dependence

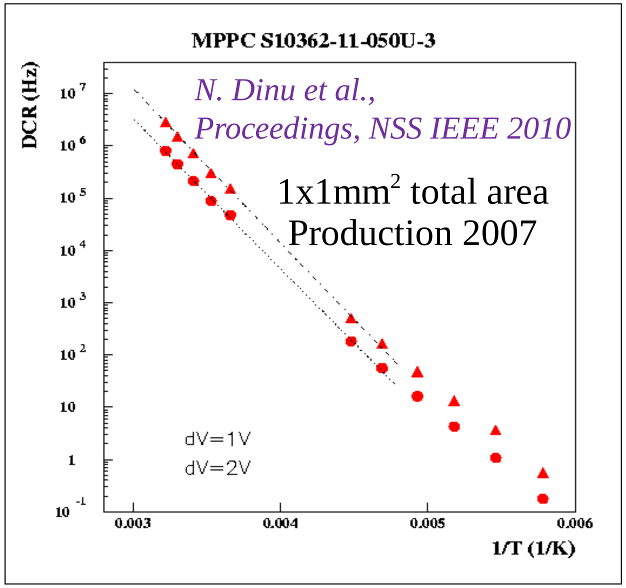
Dark count rate vs Temperature:











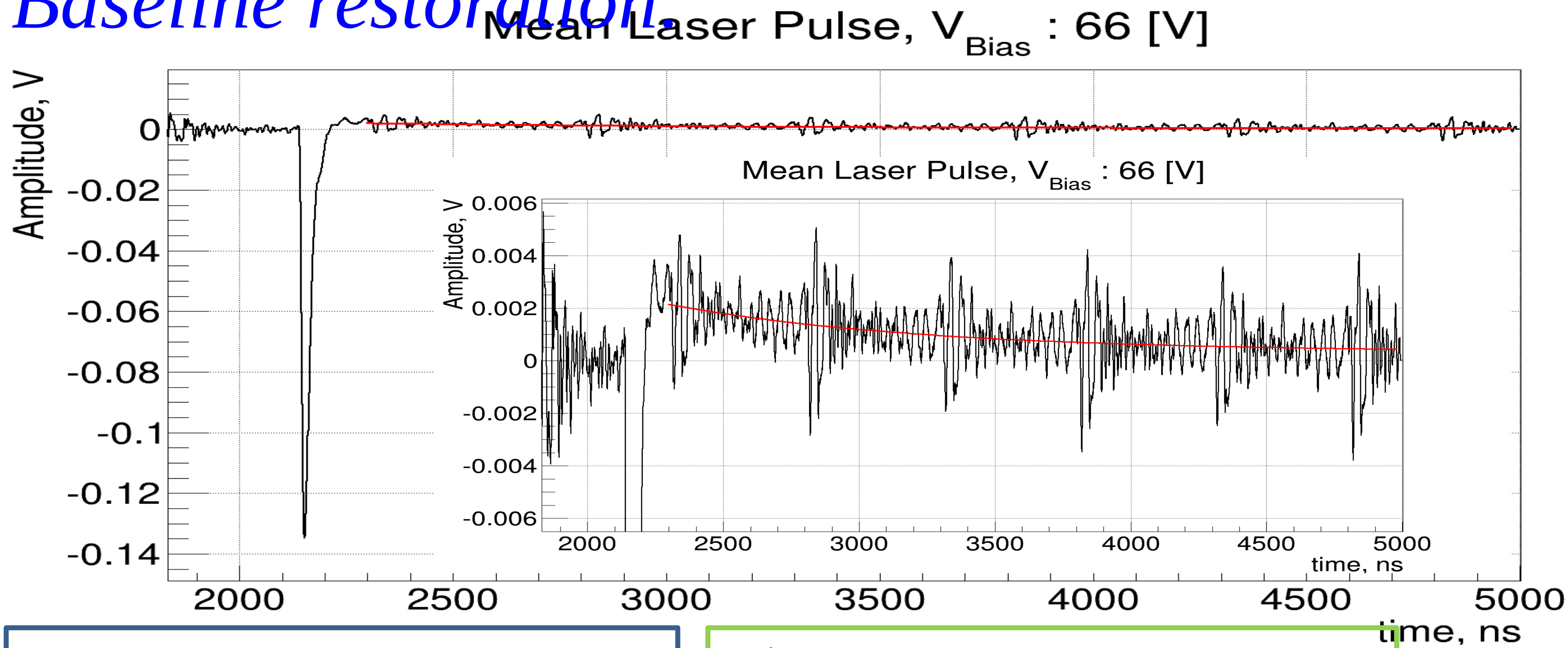
Decreasing T → DCR decreases (thermal generated carriers decrease)

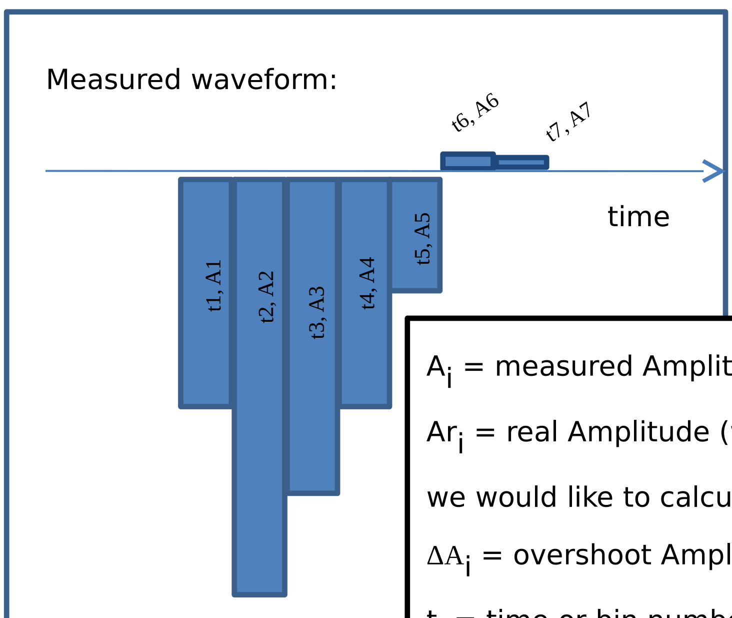
Summary

- MPPC detectors of 1x1 and 3x3 mm^2 50x50µm cell size
  - T range -175°C to +55°C
  - Overvoltage range: 0.5 to 2.5V.
- Automatic procedure for the analysis of the MPPC temperature dependence
  - Baseline restoration
  - Pulse analysis
- Physics analysis: T dependence of MPPC parameters:
  - breakdown voltage
  - gain
  - dark count rate
  - quenching resistance
  - micro-cell capacitance
  - recovery time
- Future work: use this procedure for the understanding of MPPC

Additional Slides

Baseline restoration:



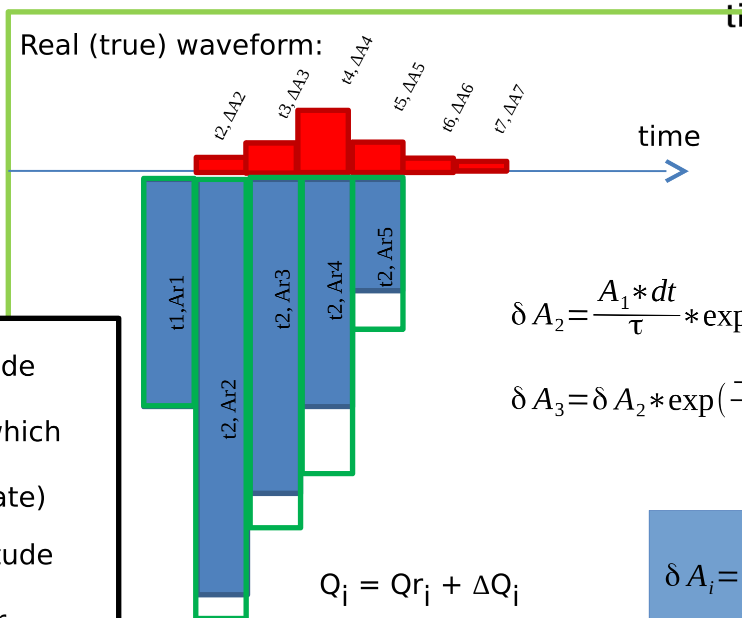


A_i = measured Amplitude

Ar_i = real Amplitude (which we would like to calculate)

ΔA_i = overshoot Amplitude

t_i = time or bin number



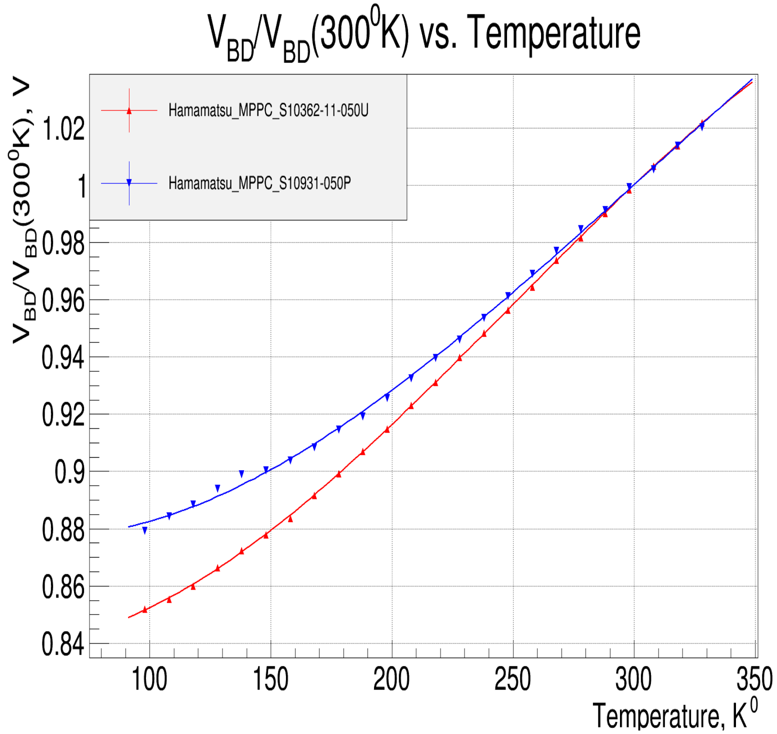
$Q_i = Qr_i + \Delta Q_i$

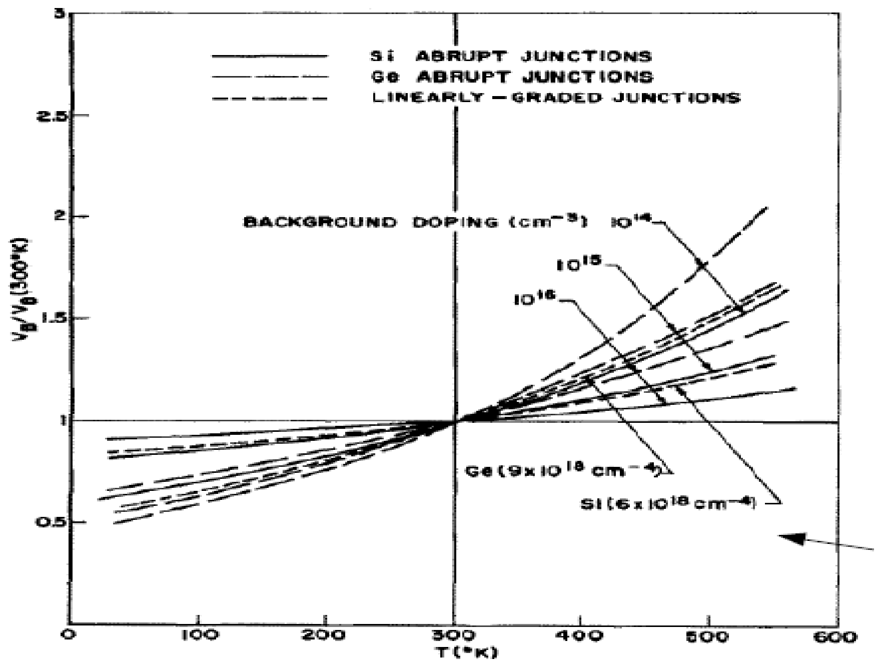
$$\delta A_2 = \frac{A_1 * dt}{\tau} * \exp\left(\frac{-dt}{\tau}\right)$$

$$\delta A_3 = \delta A_2 * \exp\left(\frac{-dt}{\tau}\right) + \frac{A_2 * dt}{\tau} * \exp\left(\frac{-dt}{\tau}\right)$$

$$\delta A_i = \sum_{k=1}^{i-1} \frac{A_k * dt}{\tau} * \exp\left(\frac{-dt}{\tau}\right)^{i-k}$$

Breakdown voltage :





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"Temperature dependence of avalanche multiplication in semiconductors", Appl. Phys. Letters 9, 6(1966)