Gain and Breakdown Voltage Measurements

CLICdp: ECAL Lab Meeting (CERN)

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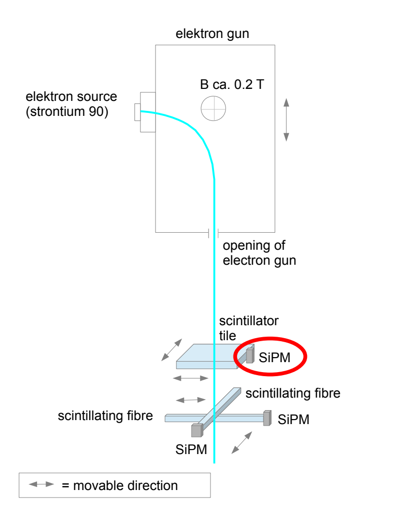
Setup for study of Scintillator tiles with SiPM Readout

○ Setup in cooled dark room (temperature about $20\,^{\circ}\mathrm{C}$):



Electron source strontium $^{90}\mathrm{Sr}$:

- $\mathrm{Sr} \rightarrow \mathrm{Y}\,(e_2^- + \overline{\nu}_e) + e_1^- + \overline{\nu}_e$
  ↪ Selectable electron energy ↩
- Opening:
  $(\Delta X, \Delta Y) = (1.2\,\mathrm{mm}, 1.2\,\mathrm{mm})$

Scintillators covered by reflecting foil:

- Trigger fibres:
  1 mm x 1 mm x 20 mm
- Scintillator tile:
  15 mm x 15 mm x 1 mm

SiPMs from Hamamatsu:

- area of $1\,\mathrm{mm}$, 400 pixel $(50\,\mu m)$
- direct coupling to the scintillator

↪ **This talk:**

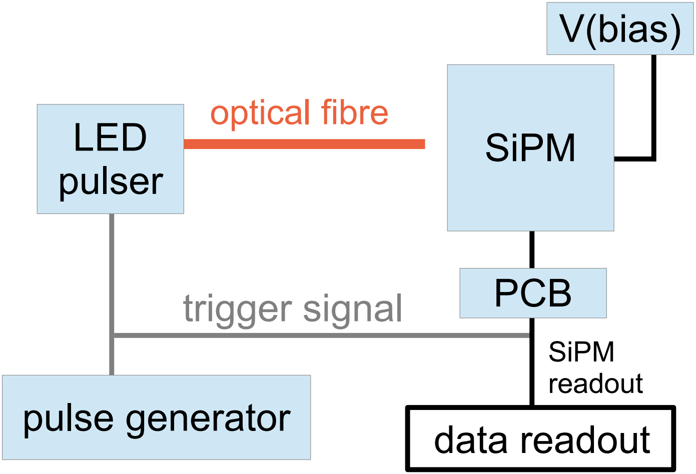
About characterization of the SiPM which is used to readout signal in scintillator tile

Setup for Characterization of SiPM

Same setup, but:

- Replace scintillator tile by optical fibre, connected to LED pulser
- Do not use trigger and electron gun

Simplified schematic of the setup for the characterization of the SiPM:



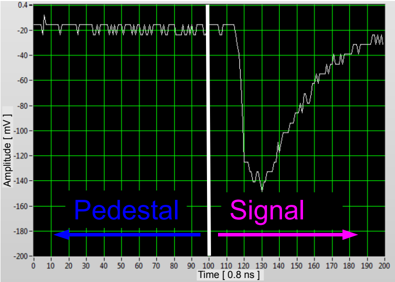
Observable to Measure Signal in SiPM

Observable to measure signal in SiPM = charge in SiPM:

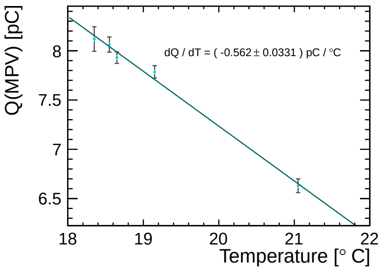
$$Q = \frac{\int \text{pulses}\,dt}{F_{\text{amplification}} \cdot R_{\text{picoscope}}}$$

$(R_{\text{picoscope}} = 50\,\Omega,\ F_{amplification} = 9)$

Pedestal correction:



Temperature correction:

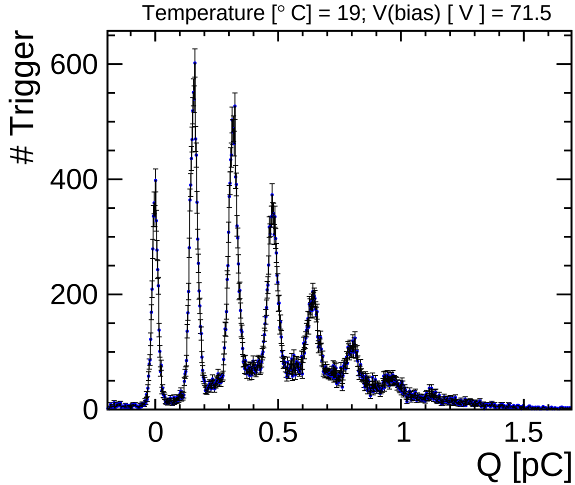


$\Rightarrow$ **Pedestal and temperature correction of the charge:**

$$Q^{\text{corrected}} = \left(Q^{\text{signal}} - \frac{N^{\text{signal}}}{N^{\text{pedestal}}} \cdot Q^{\text{pedestal}}\right) \cdot \frac{1}{1 + \alpha_r \cdot (T_0 - T)}$$

$$\alpha_r = \frac{dQ}{dT} \cdot \frac{1}{Q(T_0)}$$

Measured Charge Spectrum

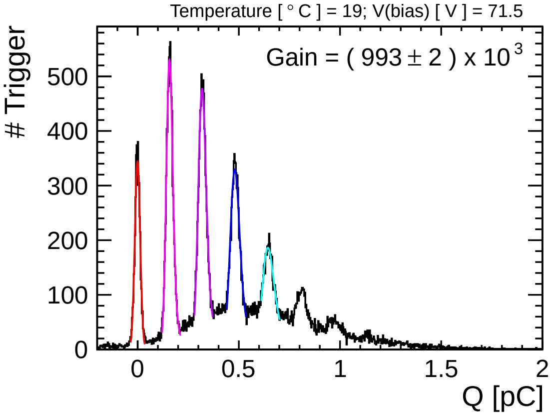


(Pedestal & temperature corrections applied)

↪ Peaks from different number of photoelectrons clearly visibly

↪ Underlying noise spectrum from afterpulses ?

Gain Calculation



- First peak corresponds to pedestal
- **Fit Gauss function to pedestal peak** $\Rightarrow \mathrm{Q}(\mu)$

- Other peaks correspond to signal of ≥ 1 photoelectron
- **Fit Landau $\otimes$ Gauss functions to each other peak** $\Rightarrow \mathrm{Q}(\mathrm{MPV})$

$\Rightarrow$ **Gain calculation:**

$$\mathrm{g_{i,j}} = |\mathrm{Q_i} - \mathrm{Q_j}|/\mathrm{e}$$

$\{\mathrm{i,j}\}$ = peaks in charge distribution with $|\mathrm{i} - \mathrm{j}| = 1$

e = elementary charge

$\Downarrow \Downarrow \Downarrow$

weighted mean:

$$\mathrm{Gain} = \sum_{\mathrm{i,j}} \frac{\mathrm{w_{i,j}} \cdot \mathrm{g_{i,j}}}{\mathrm{W}}$$

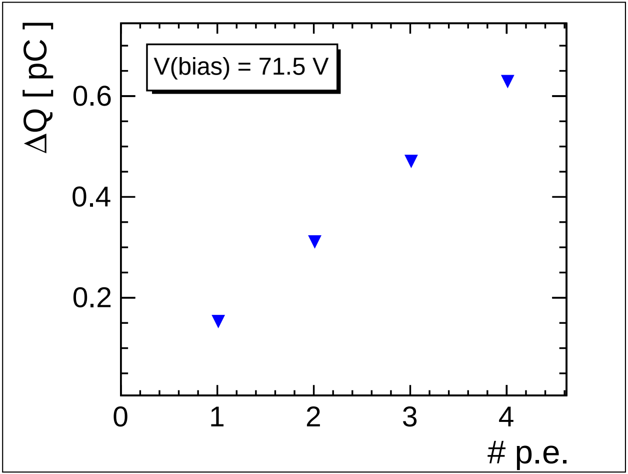
weights of uncertainties:

$$\mathrm{w_{i,j}} = \frac{1}{\sigma^2_{\mathrm{g_{i,j}}}}, \ \mathrm{W} = \textstyle\sum_{\mathrm{i,j}} \mathrm{w_{i,j}}$$

$\hookrightarrow$ Check linear dependence of $\mathrm{Q(MPV)} - \mathrm{Q}(\mu)$ for different photoelectron peaks to validate calibration of charge to number of photoelectrons

Cross Check of the Gain Calculation

- Identify peaks in charge spectrum with different numbers of photoelectrons # p.e.
  - Calculate for each # p.e. difference in charge to pedestal peak ΔQ



$\hookrightarrow$ Can calibrate measured charge to # p.e. with the measured gain:

$$\boxed{\#\,\mathrm{p.e.} = \mathrm{Q}/(\mathrm{Gain}\cdot\mathrm{e})}$$ (e = electron charge)

Uncertainties of the Gain Calculation

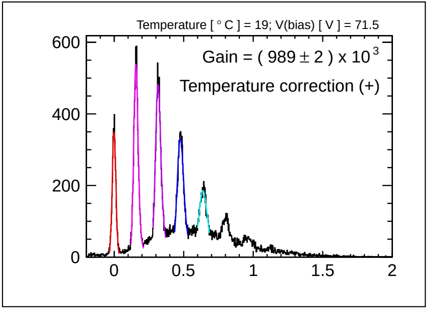
Motivation:

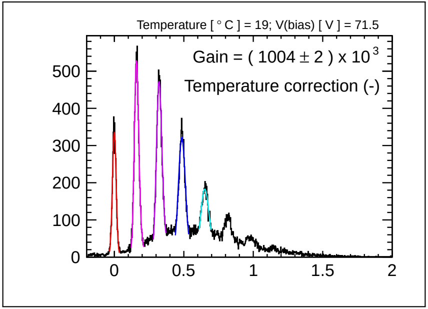
Breakdown voltage calculation by linear fit of gain values for different bias voltages

Composition of uncertainties in gain measurement:

1.) Propagate uncertainties of $\mathrm{Q(MPV)}$ and $\mathrm{Q}(\mu)$ (in the order of $1\,\%$)

2.) Uncertainties from the temperature correction:





$\hookrightarrow$ Additional uncertainty of $0.75\,\%$ from the temperature correction $\hookleftarrow$

Breakdown Voltage Calculation

Motivation:

- Currently used bias voltage of $V(\text{bias}) = 71.5\,V$ is optimal value for $T = 25°C$
- Temperature in the dark room is in the range of $T = (18 - 22)°C$

↪ Calculate breakdown voltage to check if $V(\text{bias}) = 71.5\,V$ is optimal

Measurement of breakdown voltage corrected to $T = 19\,°C$:

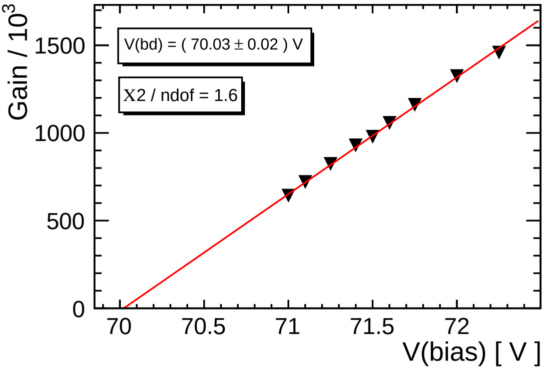
- Repeat gain calculation for different bias voltages

$$\text{Gain} \propto (V(\text{bias}) - V(\text{bd}))$$

$(V_{bd} = \text{breakdown voltage})$

↪ Linear fit of Gain vs. bias voltage

↪ Determine V_{bd} from intersect of linear fit function with x-axis



Temperature Dependence of the Breakdown Voltage

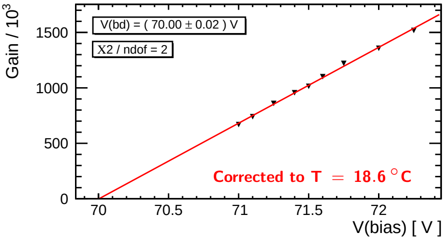
Expectations:

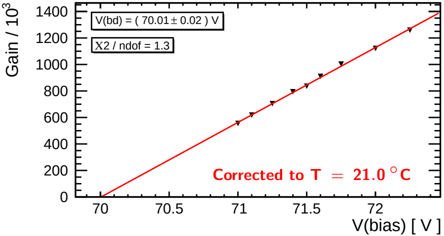
Higher temperature leads to higher thermal vibrations of silicon lattice

↪ Smaller path length of the electron

↪ Higher breakdown voltage

Correct measurement of breakdown voltage for different temperatures:





↪ Value of breakdown voltage is stable ↩

in considered temperature range of the measurements

⇓ ⇓ ⇓ ⇓

Is V(bias) = 71.5 V the optimal value of the bias voltage ?

Breakdown Voltage / Interpretation of Results

Is V(bias) = 71.5 V the optimal value of the bias voltage ? :

◦ Bias voltage should be safely above breakdown voltage

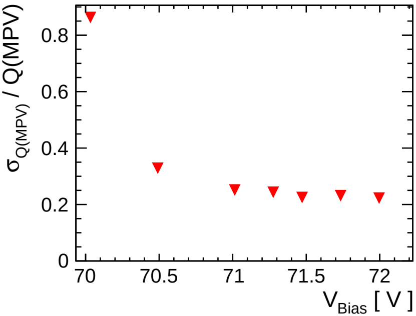
◦ But the signal to noise ratio might get worse with higher bias voltage

⇓ ⇓ ⇓

Measure signal in scintillator tile for different bias voltages:

◦ Use the "initial" setup (see page 2)

◦ Measure charge in center of the scintillator tile for different bias voltages of the SiPM at the scintillator tile



↪ Used bias voltage of $V(\mathrm{bias}) = 71.5\,\mathrm{V}$ seems to be in a good range

Summary and Outlook

- **Measurement of gain:**

  ⟶ Conversion of charge into number of photoelectrons

  ⟶ Comparison to other studies

- **Measurement of breakdown voltage:**

  ⟶ Confirmation that used bias voltage is in a good range

- **To do:**

  ⟶ Characterisation of new SiPMs

  ⟶ Application of new SiPMs for uniformity studies