SiPM and scintillator characterization for highly granular calorimeters

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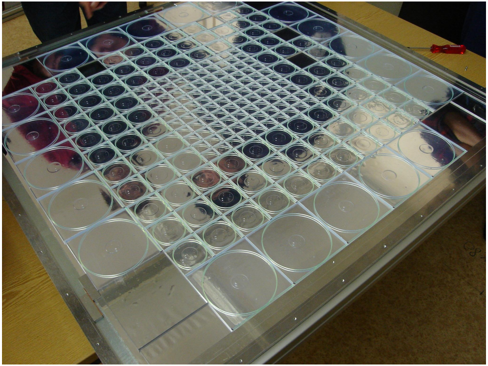
CALICE AHCAL Main Meeting

Motivation

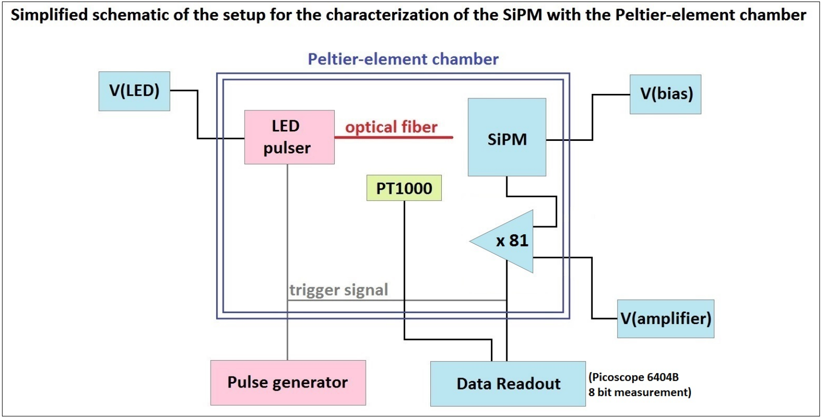
- Improve understanding of scintillators and SiPMs and related systematic effects in HCAL and ECAL applications
- Characterize impact of scintillator wrappings and tile size on measured light yield



Sensitive layer of the CALICE AHCAL

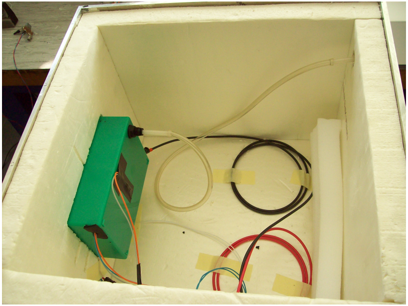
Calibration of the SiPM: Gain vs. Temperature

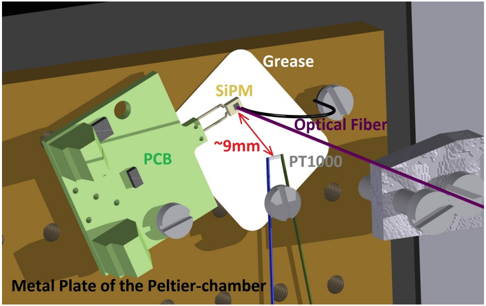
Schematic of the Gain vs. Temperature measurement



- Optical fiber in front of the SiPM connected to an LED pulser
- Measure SIPM signal from individual photons for gain calibration
- Temperature regulation is done by a thermally isolated Peltier-element chamber with temperature range covering well region of interest [15°C - 30°C]

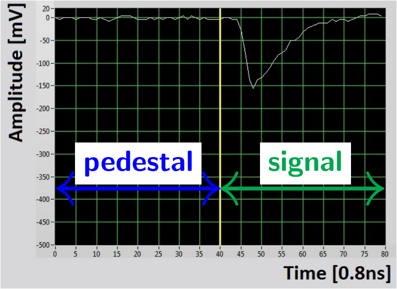
The interior of the Peltier-element chamber



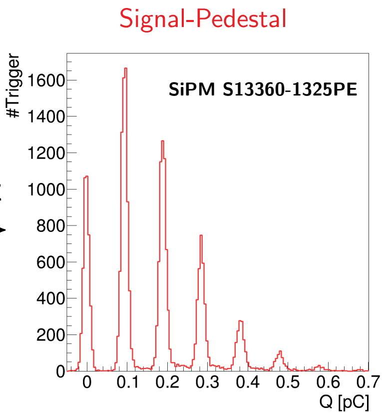


- The temperature of the metal plate inside is adjustable
- Ensure good heat flow between metal plate, SiPM and thermometer (PT1000) by using thermally conductive grease
- The temperature of the SiPM is measured with the PT1000 thermometer
- Temperature of metal plate is measured directly on metal plate

The method of the charge measurement



$\int dt$
$\Longrightarrow$



- Two time windows for pedestal and signal measurement
- Convert signal and pedestal response to charge by time integration
- Subtract pedestal from signal event-by-event

The fitting procedure

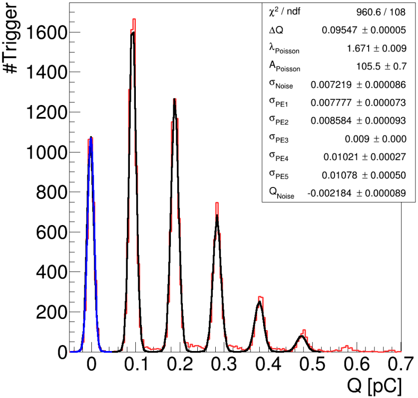
- Measure the charge of single photons
- Measure T simultaneously

- Fit as many peaks as possible using separate Gaussian functions with correlated parameters:

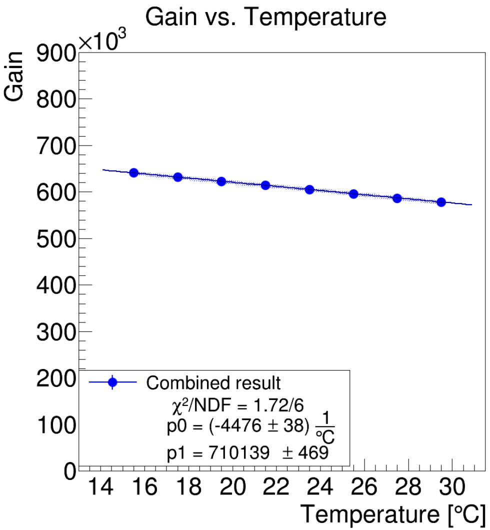
  $A_{Poiss} \cdot \mathbf{Poisson}(n_{peak}; \lambda) \cdot \mathbf{Gauss}(x; Q_{PE1} + i \cdot d; \sigma_i)$
- d = distance between the peaks
  $\Rightarrow$ Gain (=G)

- Repeat the method for every T value

  $\Rightarrow$ G – T dependence



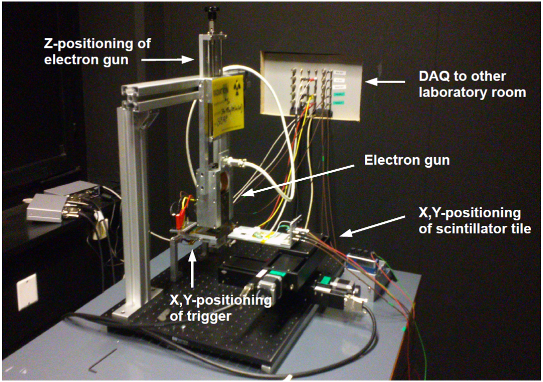
G - T calibration results

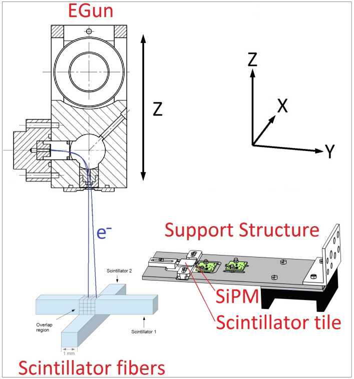


- Scanned a temperature range [15.5 ℃- 29.5 ℃] two times (↑ and ↓) with 2 ℃ steps
- Combine the ↑ and ↓ measurements
- Fit G − T with linear function: $G(T) = p_0 \cdot T + p_1$
  $\Rightarrow$ 0.76 $\left[\frac{\%}{℃}\right]$ dependency
- Stable results within $< 1\%$ when changing N_{bins}, N_{peaks}, LED settings

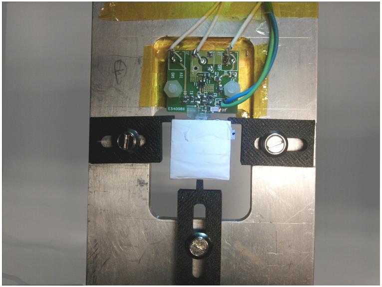
Results of the scintillator tile scans

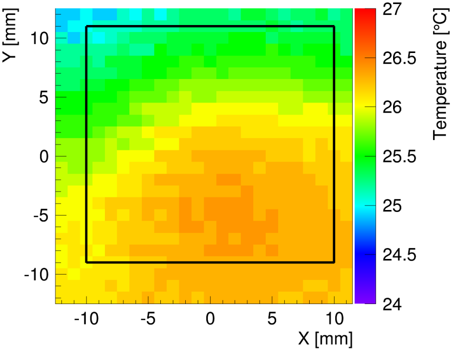
The experimental layout for tile-measurements at CERN





Immediate environment of the scintillator tile

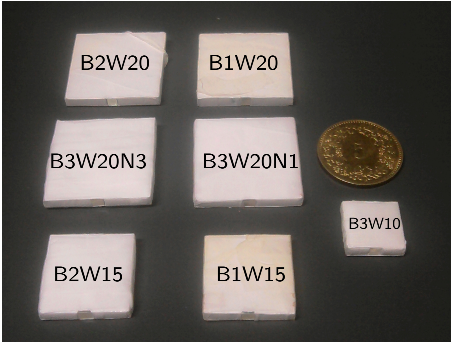




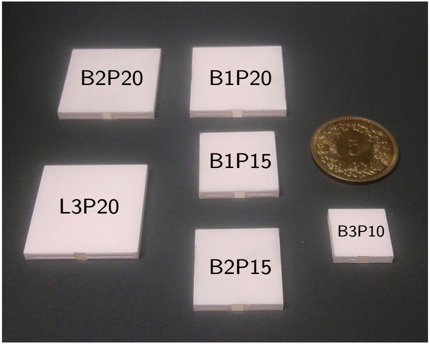
- Use tile support structure with low material close to the tile to avoid signal from stray electrons in the support structure in the tile
- 1 mm step size, 100 s measurement time for each step
- Temperature variation during the measurement ~ 2 ℃
  - ⇒ influence on the SiPM gain $\sim 1.5\%$
  - ⇒ correct the temperature to $T_{ref} = 25$ ℃

Scanned tile set

Wrapped tiles



Painted tiles

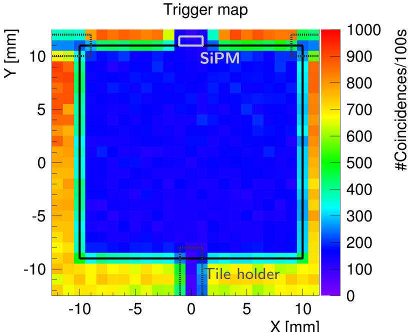


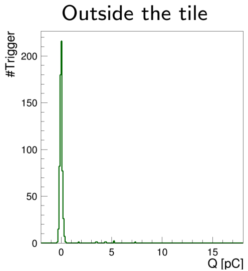
- coating:
  - ⇒ wrapping (3M foil)
  - ⇒ reflective paint
- size:
  - ⇒ □20x2 mm^3
  - ⇒ □15x2 mm^3
  - ⇒ □10x2 mm^3

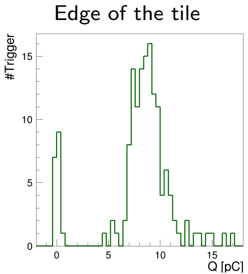
Regions of a tile scan

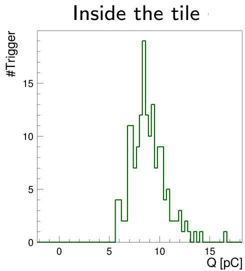
e^- beam is $\sim 1\text{mm}^2$
$\Rightarrow$ 3 regions depending on the beam position:

- e^- beam outside of the tile
- e^- beam on the tile edge
- e^- beam inside of the tile









Regions of a tile scan

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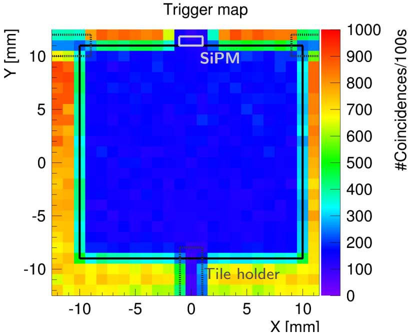
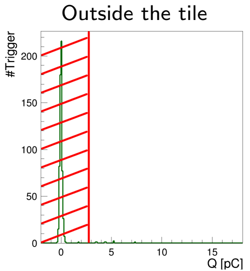
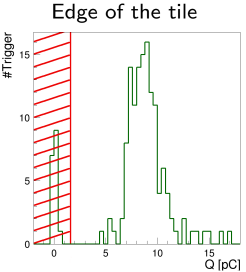
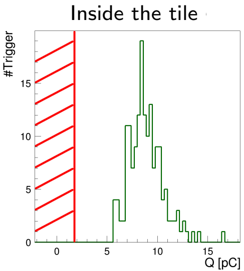
Remove events with charge similar to $Q_{\text{ped. subwindow}}$

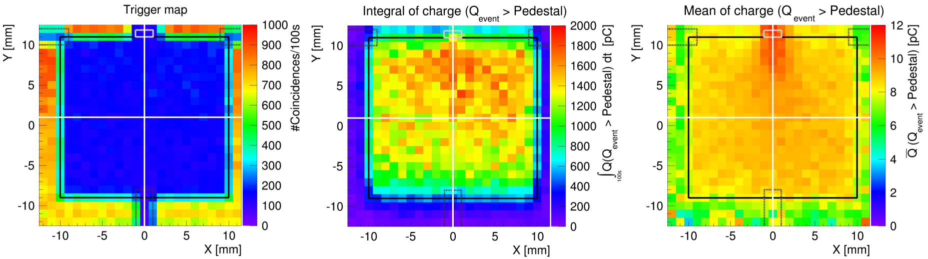






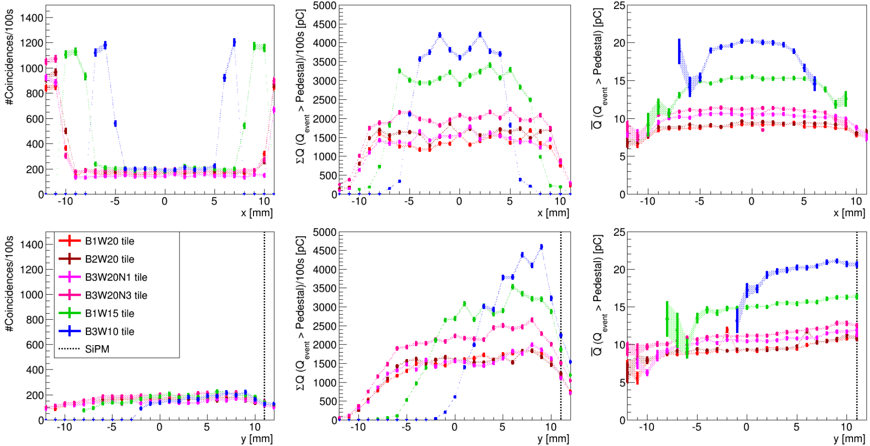


Evaluation of the tile scans



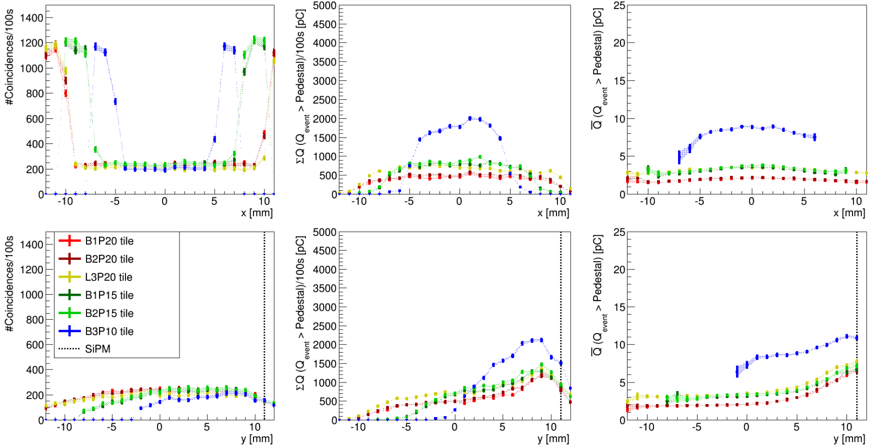
- 3 types of map from the scanned area:
  - ⇒ Trigger map: verify position of the tile edges
  - ⇒ Integral of the charge map: Investigate the edge effects and the uniformity
  - ⇒ Mean of the charge map: Compare the light yield of the tiles
- Study observables for two slices in x and y direction

Slices of all wrapped tiles



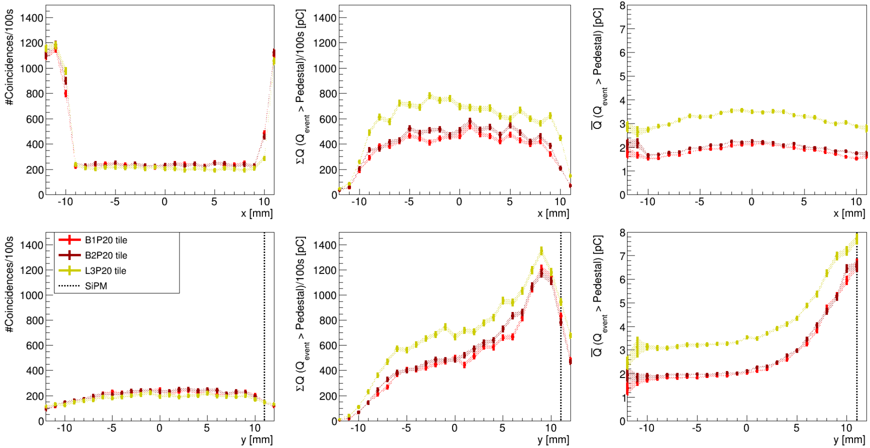
- The light yield scales with the sizes of the tile (∼ SiPM area to tile front area)
- The light yields of the wrapped tiles of same size differ to each other by 20%

Slices of all painted tiles



- The light yield of the painted tiles is $\sim 4-5$ times lower than for wrapped tiles
- The light yield is more similar for painted tiles of same size (within 7%) than for wrapped tiles (20%)

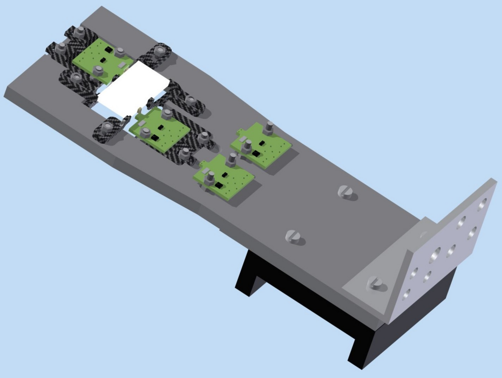
Slices of □20x2 mm^3 painted tiles

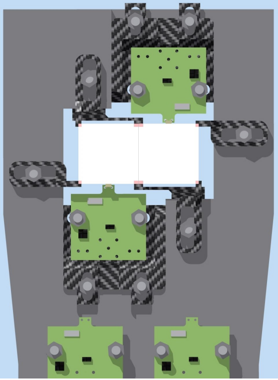


- The light yield of the painted tiles can be increased by using thicker painting:
  - ⇒ 2 layers of painting
  - ⇒ 3 layers of painting (50% more light yield)

2 tile setup

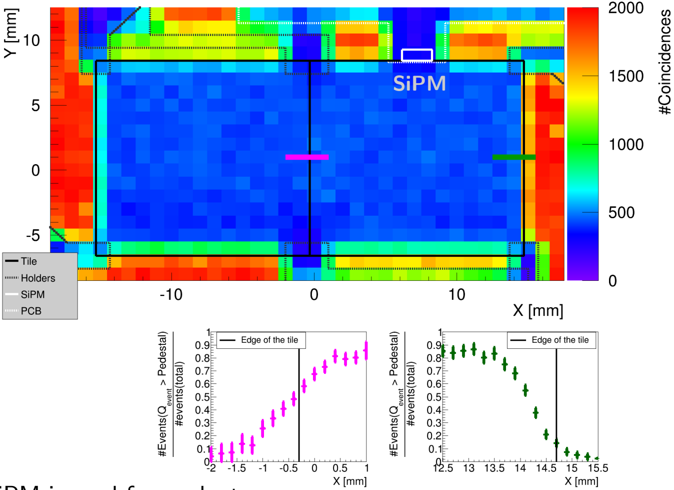
Layout of the 2 tile measurement





- Multi-tile setup for investigation of edge effects
- Setup allows for investigation of different tile sizes ($20x20\,mm^2$, $15x15\,mm^2$, $10x10\,mm^2$)

First results



- One SiPM is used for readout
- On the trigger map the position of the tiles, the holders, the SiPM are visible
- Higher ratio of events above pedestal at the common edge can come from light leakage or stray e^- in the neighboring scintillator tile

Summary and Outlook

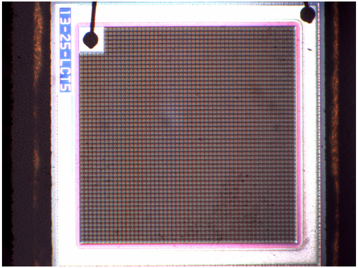
- Gain-temperature calibration
  - ⇒ Controlled temperature with Peltier-element chamber [15.5℃- 29.5℃]
  - ⇒ Ensured good heat flow between all components using thermal grease
  - ⇒ Calibrated gain as a function of temperature and studied systematic uncertainties
- Tile scans
  - ⇒ The light yield of the wrapped tile is $\sim 4-5$ times higher than for the painted tile independent of the size
  - ⇒ The light yield scales with the sizes of the tile ($\sim$ SiPM area to tile front area)
  - ⇒ The light yield is more similar for painted tiles of same size (within 7%) than for wrapped tiles (20%)
  - ⇒ The light yield of the wrapped tiles is more homogeneous than the painted tiles
  - ⇒ The light yield of the painted tiles can be increased using thicker painting
  - ⇒ 2 tile setup: Higher ratio of events above pedestal at the common edge
- Outlook
  - ⇒ Connection between T dependence of gain and tile scan measurements
  - ⇒ Further investigations with the multi-tile setup with 2 or 4 tiles of different sizes
  - ⇒ Comparison of different SiPMs (pitch, type)

Thank you for your attention!

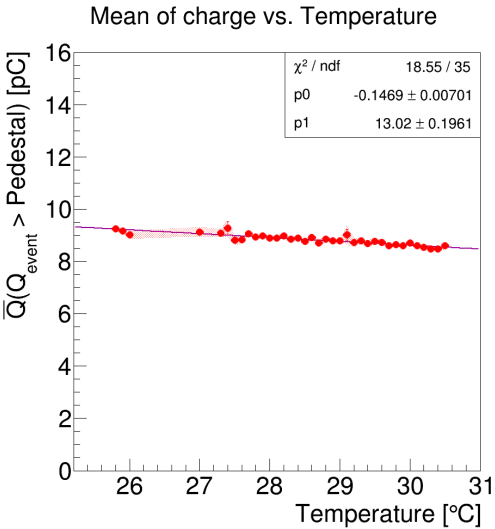
Reminder: The SiPM

- Silicon Photomultipliers (SiPMs) are photon sensitive devices built from an avalanche photodiode array on common Si substrate
- The gain (G) of a SiPM depends on the temperature (T)
- For a correct signal reconstruction, the temperature dependence needs to be known → Gain-Temperature calibration
- Gain can be estimated using well-defined signal from single photons

- Hamamatsu MPPC:
  1.3x1.3 mm^2 effective photonsensitive area
  2668 pixels, 25 µm pixel size
  Type No.: S13360-1325PE
  Serial No.: 10036

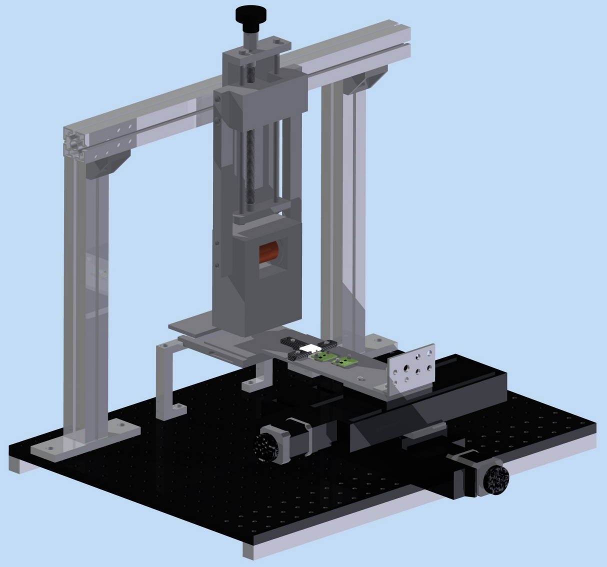


Q - T calibration results



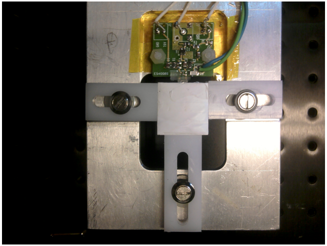
- Measure over long period in central region of tile
- Combine the data of same temperature
- Fit the dataset with linear function:
  $Q(T) = p_0 \cdot T + p_1$
  $\Rightarrow$ 1.57 $\left[\frac{\%}{°C}\right]$ dependency
- Reminder: for the G - T
  $\Rightarrow$ 0.76 $\left[\frac{\%}{°C}\right]$ dependency
- Stable results within $< 1\%$

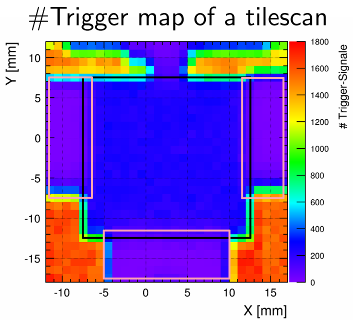
Rendered setup at September 2015

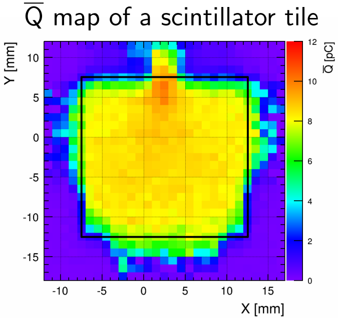


Setup at November 2014

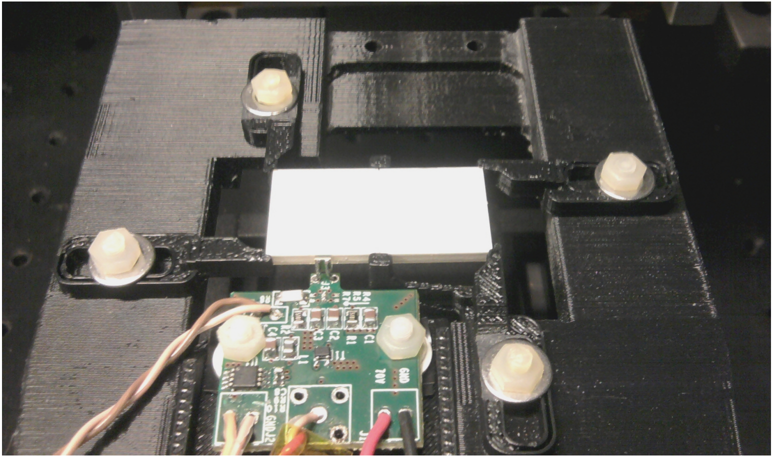
- At the beginning:
  use "high-material" tile holders to hold the scintillator in place
- The #Trigger map shows the transparency of the support structure
- Even if the electron beam does not hit the scintillator, stray particles produced in the tile holders leak into scintillator resulting in a measurable signal







2 tile setup



Inside of the Peltier-element chamber