POSSuMUS:[1]

A **Po**sition **S**ensitive **S**cintillating **Mu**on-**S**iPM Detector

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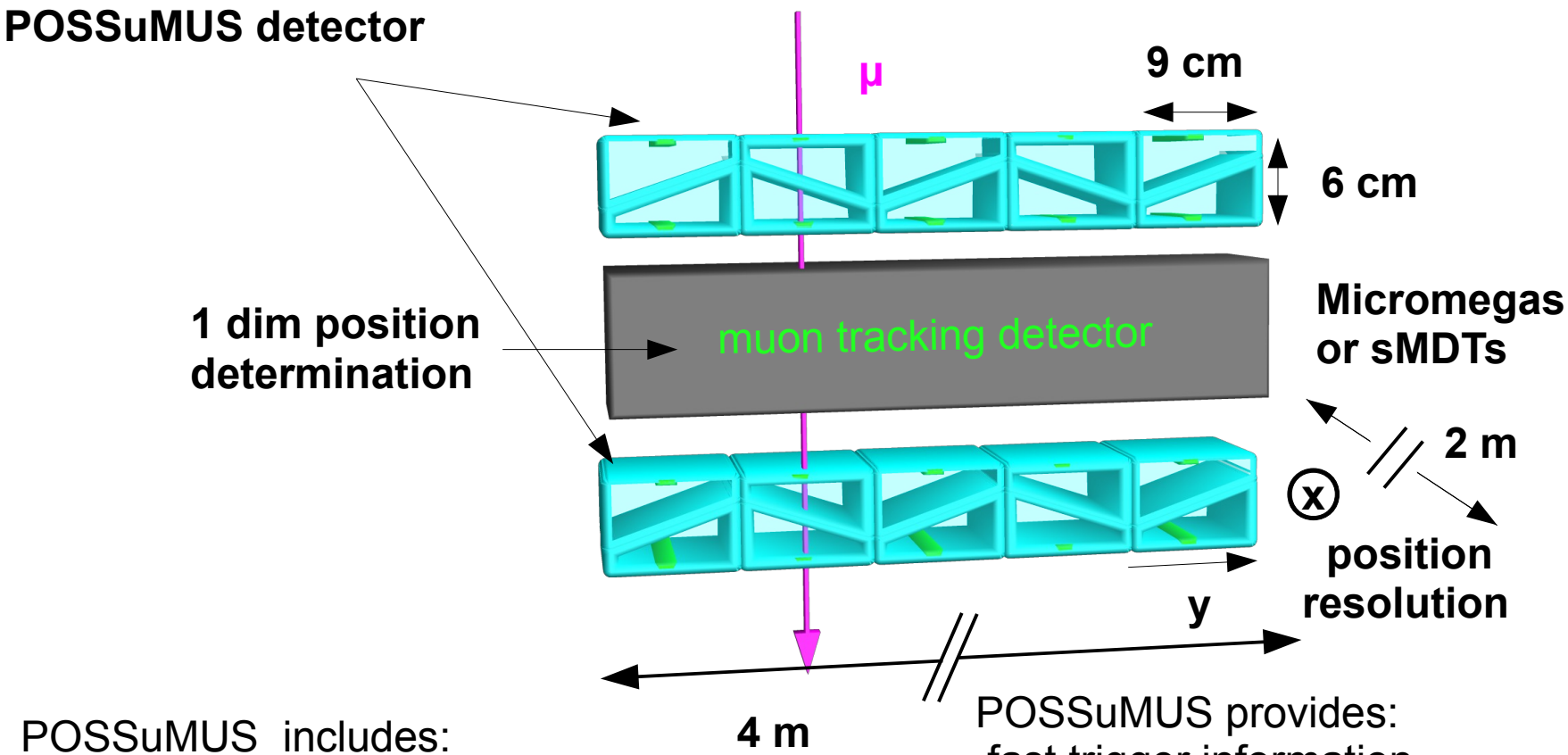
[1]Latin: ” We can “

Outline

1. detector concept of POSSuMUS
2. SiPM & gain stabilization
3. results of a prototype detector
4. summary and outlook

POSSuMUS Detector

Concept of POSSuMUS



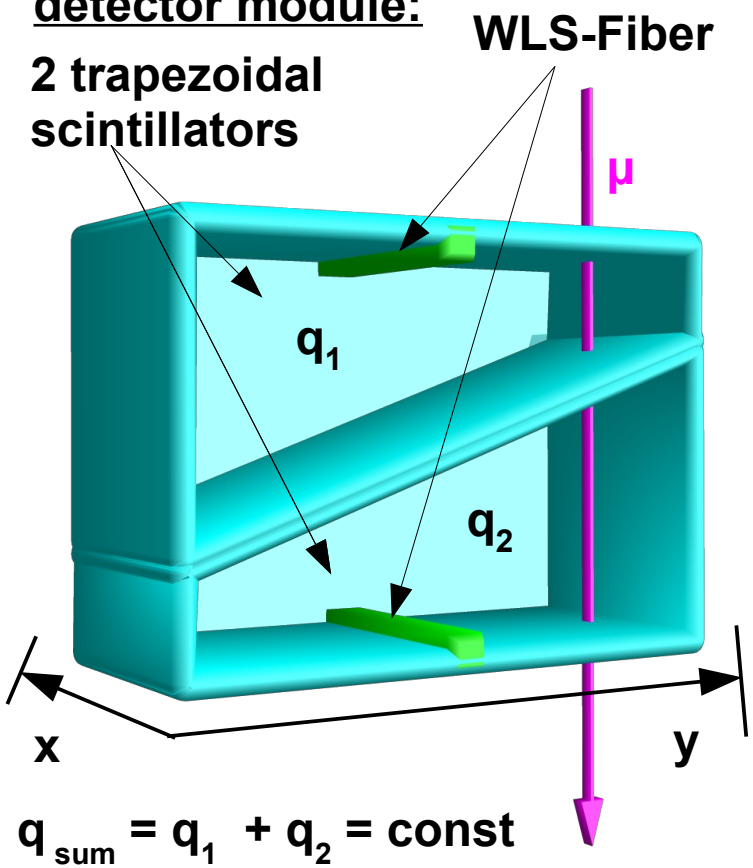
POSSuMUS includes:
- large scale detector O(m^2)
- few readout channels

POSSuMUS provides:
- fast trigger information
- two dimensional position coordinate goal:
  - spatial resolution (in y) of about 5 mm
  - spatial resolution (in x) of about 5 cm

Detector-Concept

detector module:

2 trapezoidal scintillators

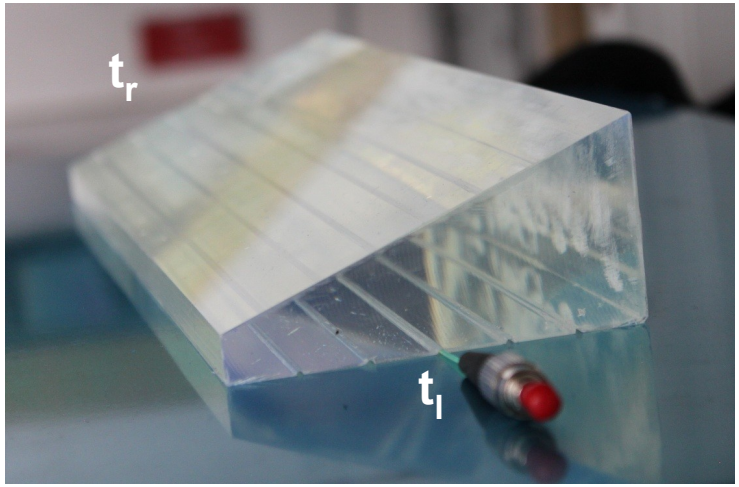


$q_{sum} = q_1 + q_2 = const$

- $q_i \triangleq$ amount of light in scintillator

- trapezoids are optically insulated
- light collection by WLS-Fiber

- light detection with SiPMs



- BC - 400 plastic scintillator
- BCF-92 **W**ave-**L**ength-**S**hifting-Fiber

- position in y → amount of scintillation light is position dependent due to geometric shape

$$y \propto \frac{q_1}{q_1 + q_2} \quad \text{(light yield ratio)}$$

- position in x → by measurement of time difference

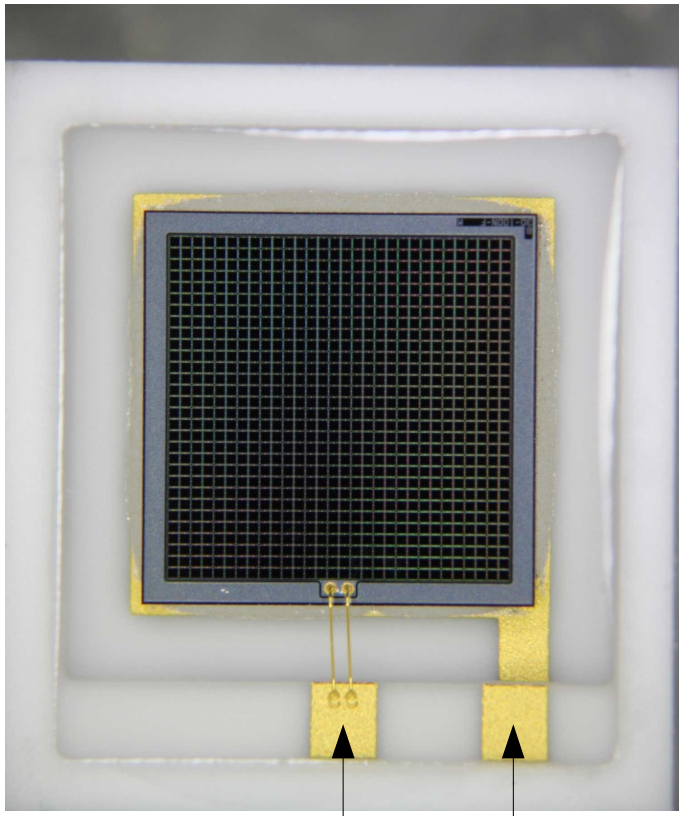
$$x \propto t_l - t_r \quad \text{(propagation time of light)}$$

Silicon Photo-Multiplier (SiPM)

used for light detection

Silicon Photomultiplier (SiPM)

SiPM 100 C
(active area 3x3 $mm^{2)}$



Signal V_{Bias}

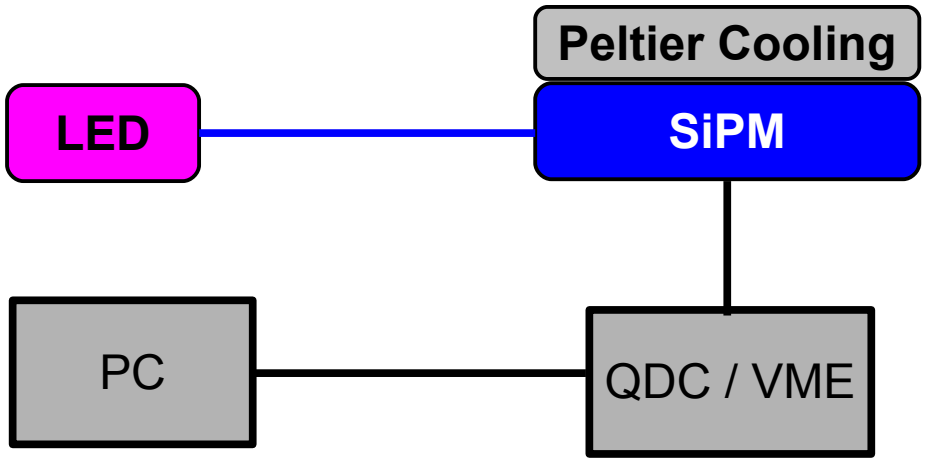
- Hamamatsu SiPM-devices
- active area 3x3 mm^2
- pixel size : $(100\ \mu m)^2$

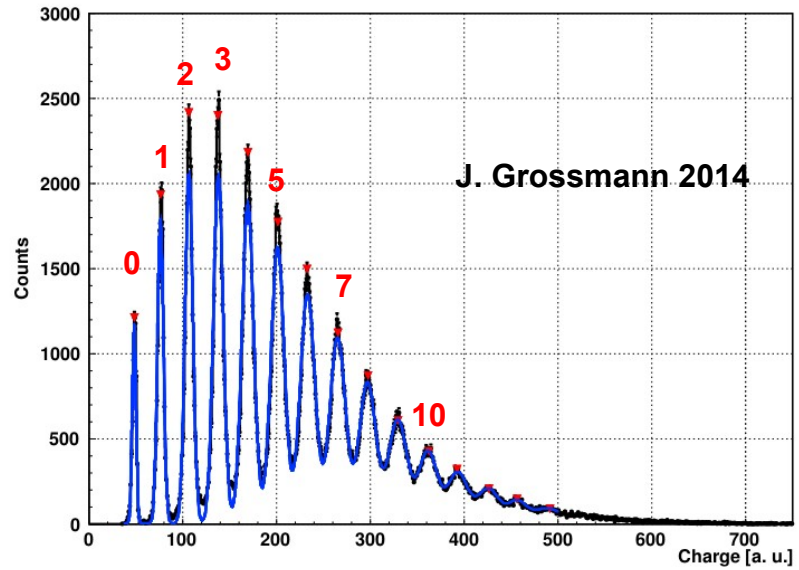
  and pixel numbers: $100 / mm^2$

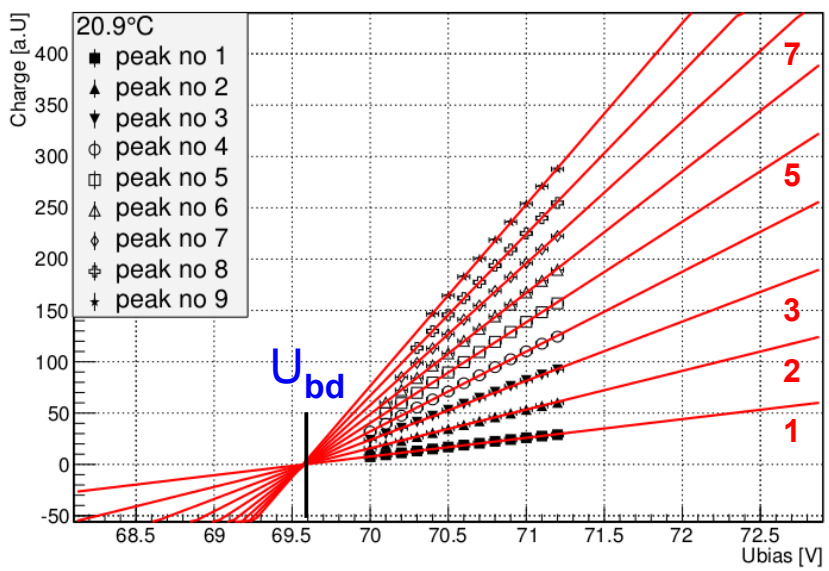
- SiPM: array of **A**valanche **P**hoto **D**iodes
  APD: work in Geiger mode

- advantages:
  - low V_{bias} O (100 V)
  - very fast timing (~100 ps)
  - insensitive to magnetic field
  - photon detection of small light yields (1 – O(100)) photons

Determination of U_{bd}

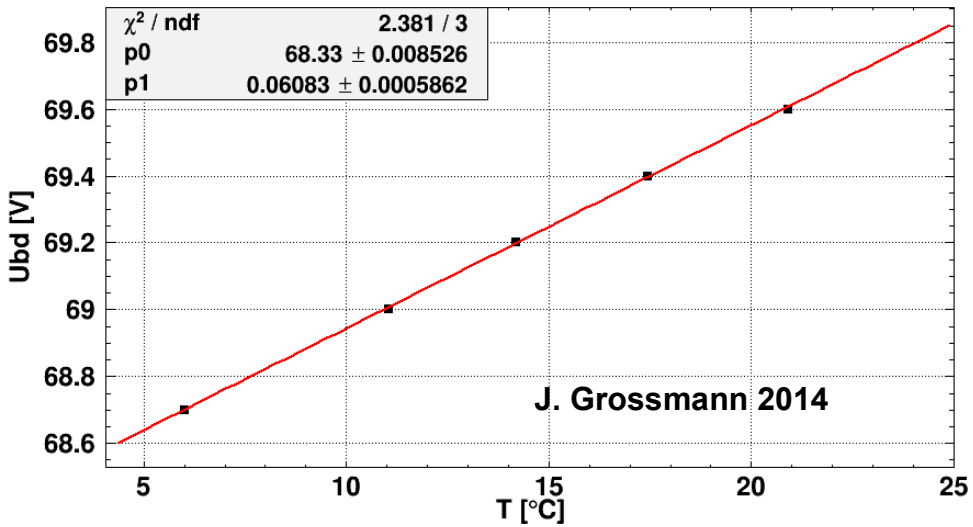






- determination of SiPM - gain, by distance of reference peak (0) to peaks (i) at constant temperature ↔ $\mathbf{U_{over}(T) = U_{bias} - U_{bd}(T)}$
- determination of breakdown voltage U_{bd} : interception point of lines with x-axis
- about 50 SiPMs are characterized
- U_{bd} : **temperature dependent**

Temperature Dependence

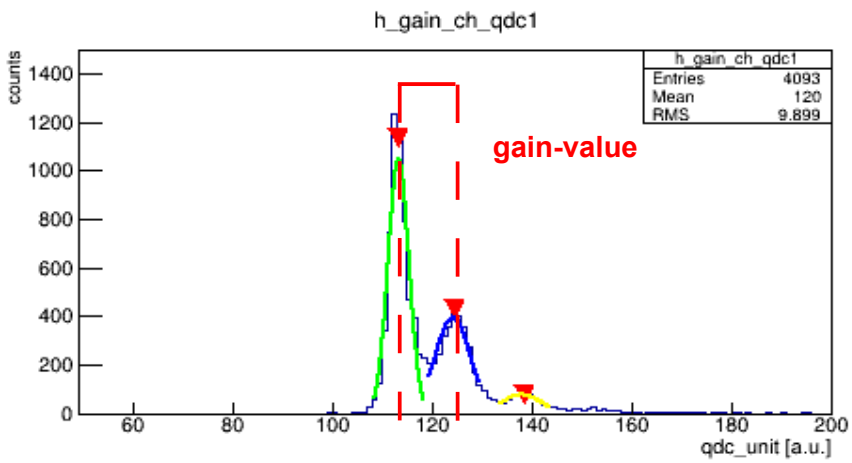


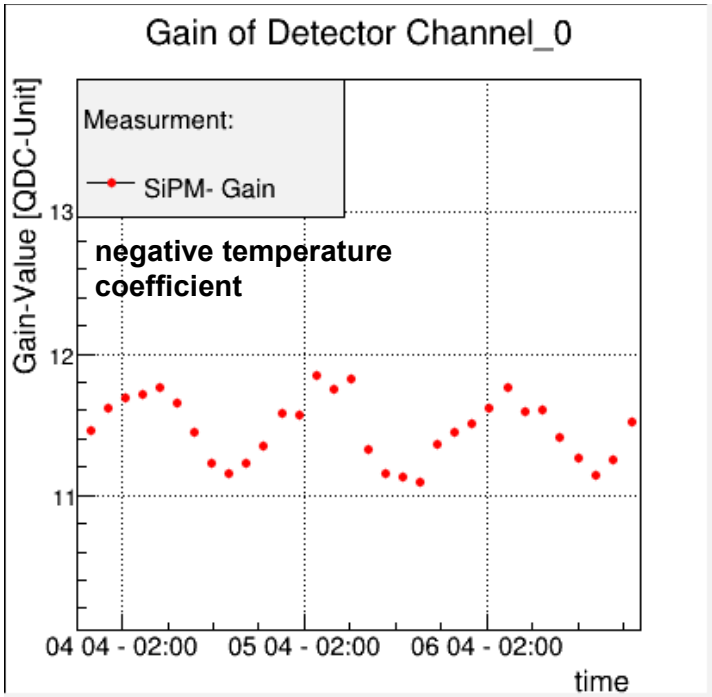
- semiconductor devices are temperature dependent ↔ U_{bd} (T) ↔ gain(T) = $\mathbf{U_{bias} - U_{bd}(T)}$

- determination of U_{bd} for different temperatures → correction factor for stabilization
- measured temperature coefficient for SiPM (3x3 mm² 100 C):

60.8 mV / °K

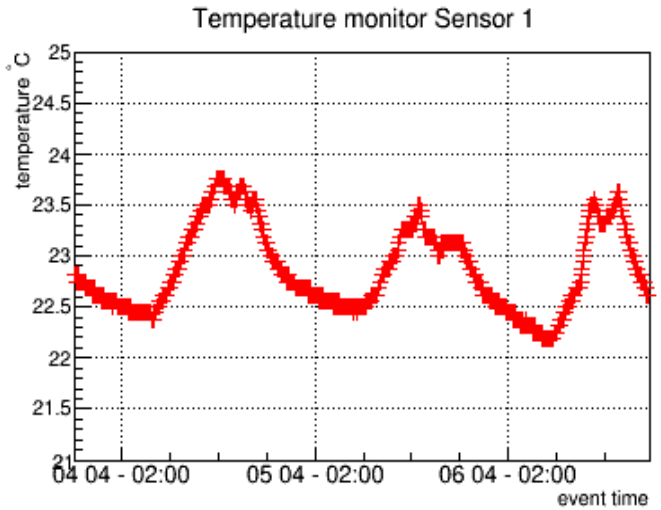
Temperature Dependence



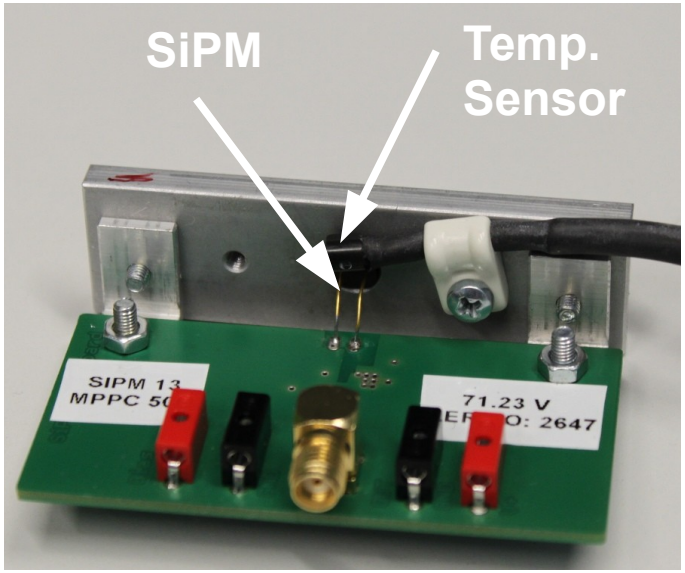


- gain determination (without LED):
  - triggering on dark rate events
  - peak to peak distance proportional to gain
- change of temperature leads to change of gain

→ pulse-height information of SiPM signal is varying with **10% / °K**



Gain-Stabilization for SiPMs



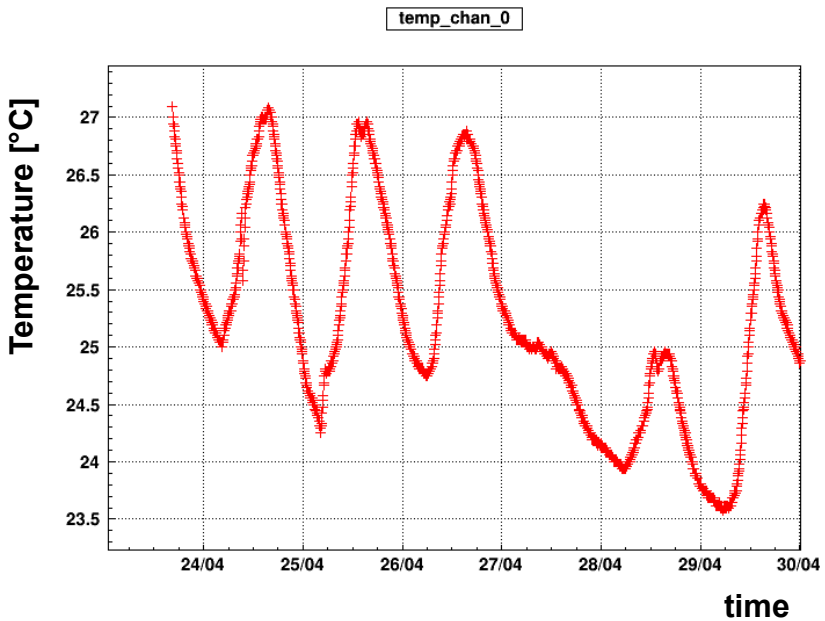
goal : SiPM gain is independent to temperature changes

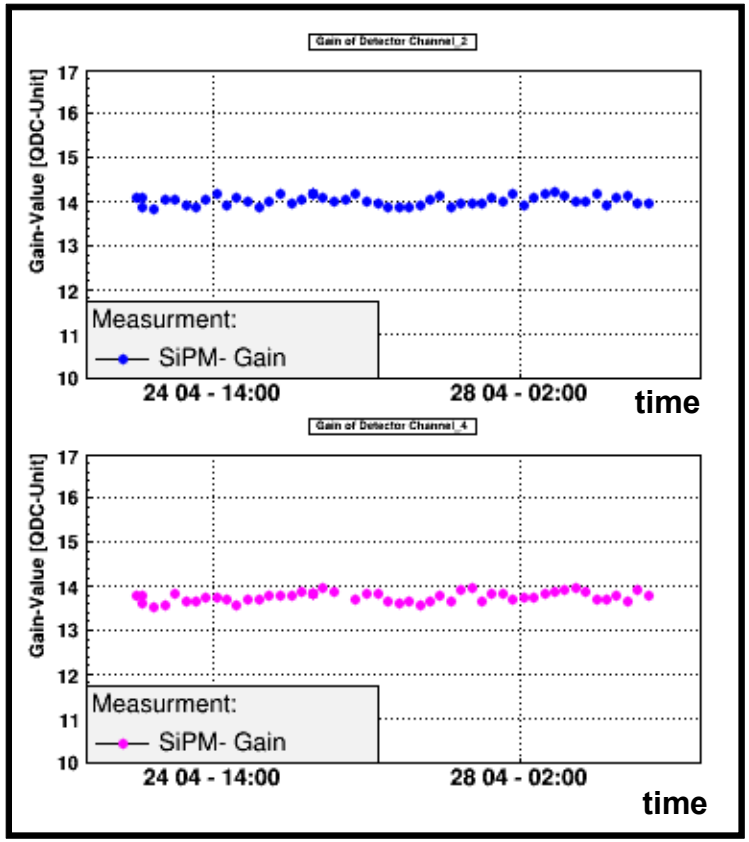
- temperature monitoring directly at SiPM → temperature changes → voltage adjustment → constant gain for light measurement with SiPM

- digital potentiometer is capable to adjust voltages independently (communication via I^2C -Bus)

- 64 channel modular voltage source has been developed for constant gain conditions

Gain Stabilization



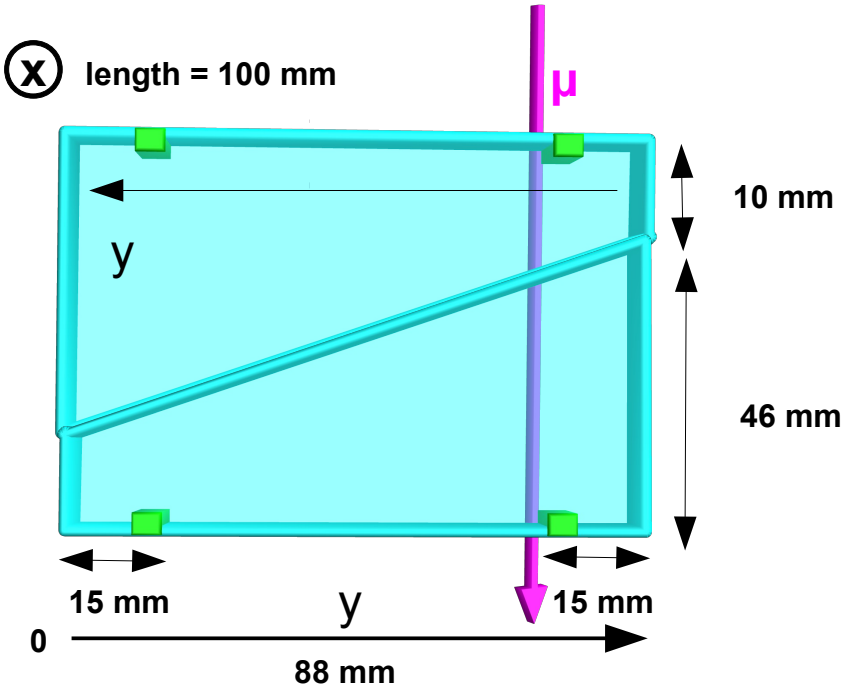


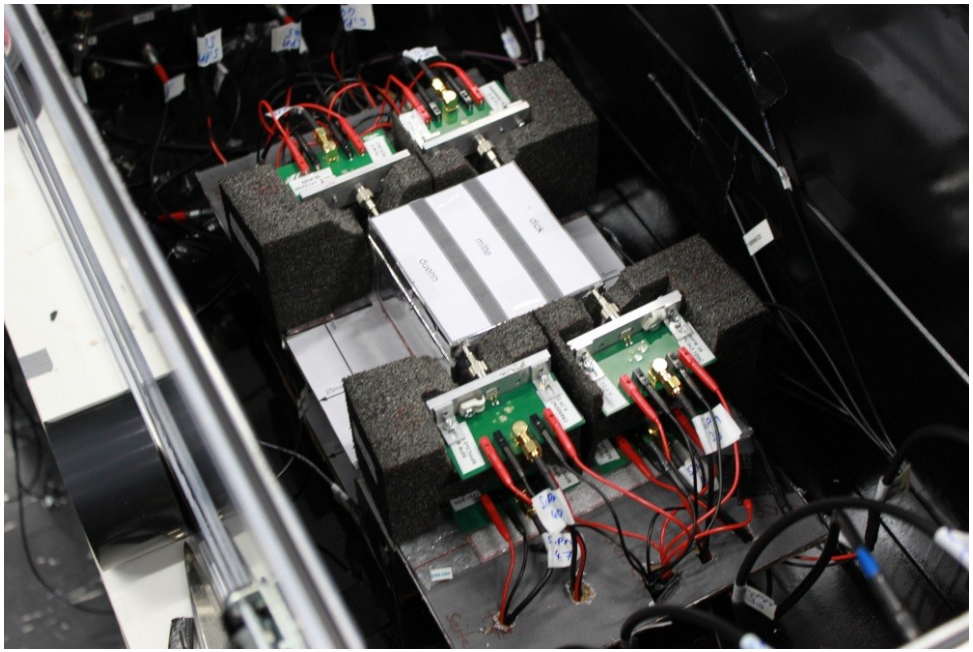
- monitoring every two hours
- automated adjustment of U_{bias} by remotely controllable voltage divider

→ no temperature dependence of SiPM gain
accuracy 2%

Prototype detector

POSSuMUS Prototype





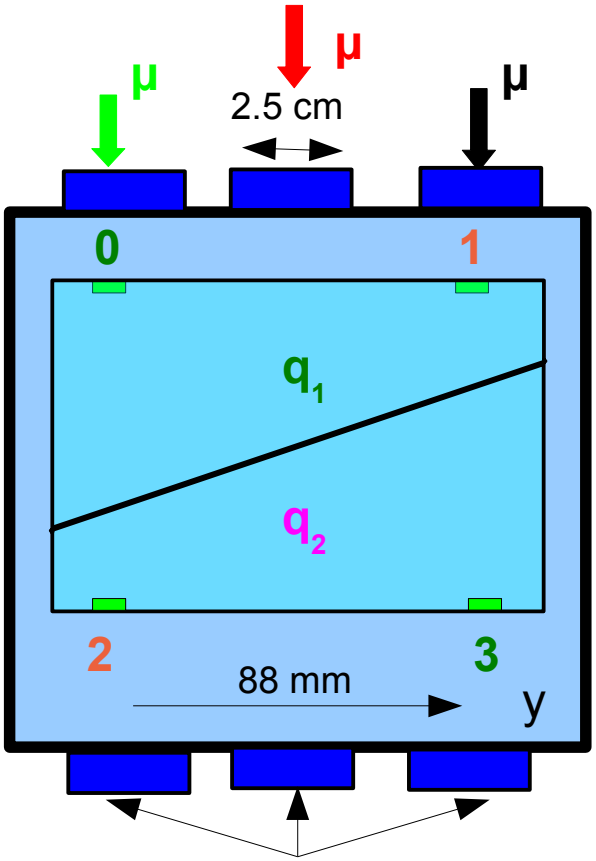
<u>detector characteristics:</u>

- trapezoid wrapped in **diffuse** reflecting Tyvek
- two WLS-fibers of ⌀ 1.5 mm per trapezoid
- two 3x3 mm² SiPMs per fiber
  → 8 SiPMs gain-stabilized

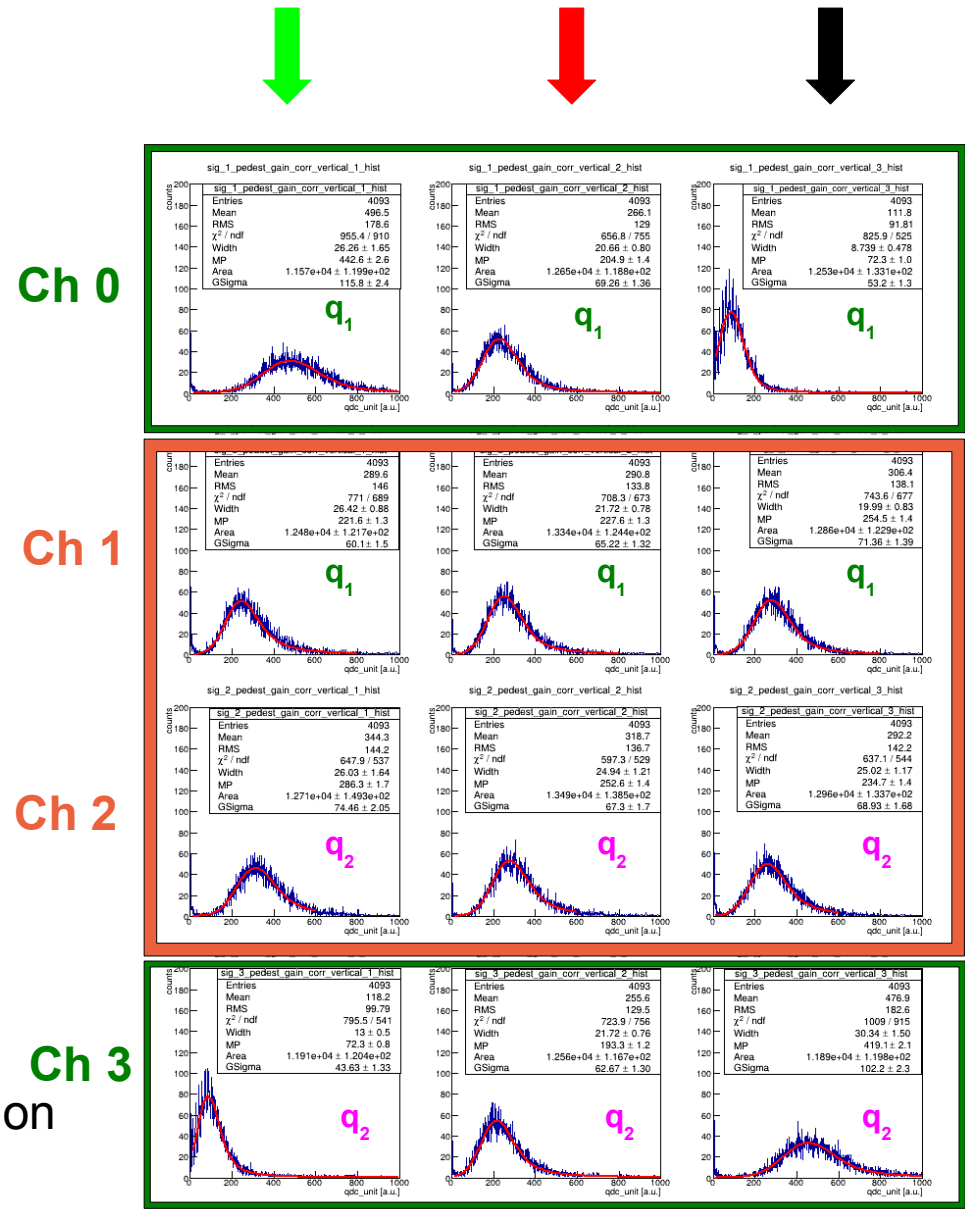
<u>data acquisition:</u>

- triggering on cosmic muons with two 3-fold-segmented trigger scintillators
- TDC-QDC-readout for pulse-height and timing information

Light Spectra

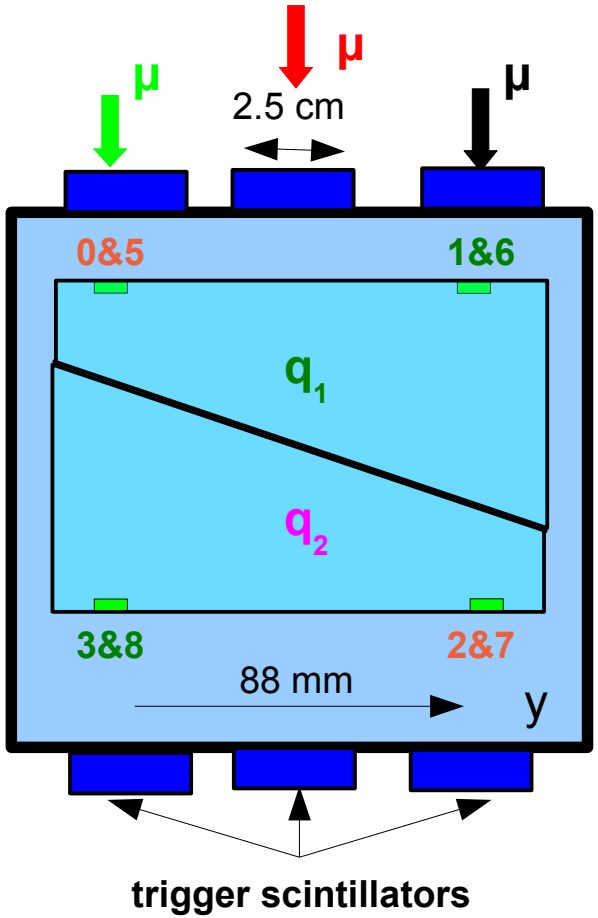


trigger scintillators



- fit of light-spectra with Landau-Gauss function
  - energy loss of muons is landau-like
  - SiPM-response is Gaussian-like
    → convoluted Landau and Gaussian distribution

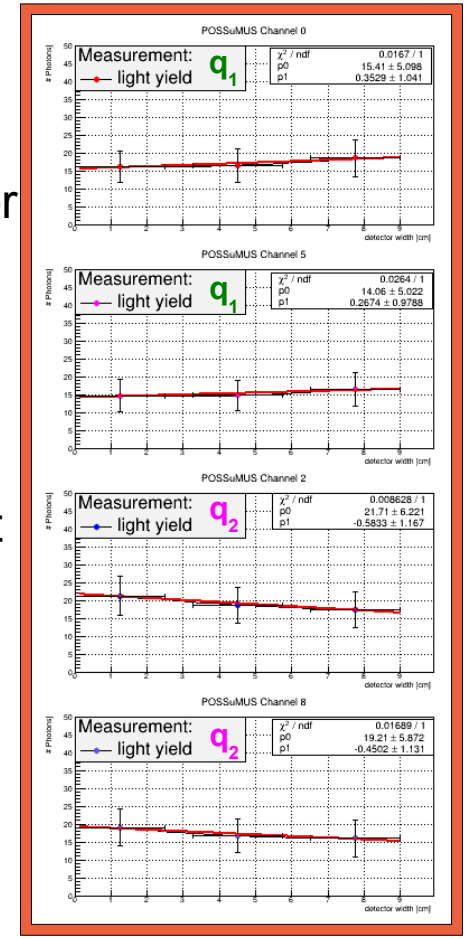
Position Dependence of Light Yield



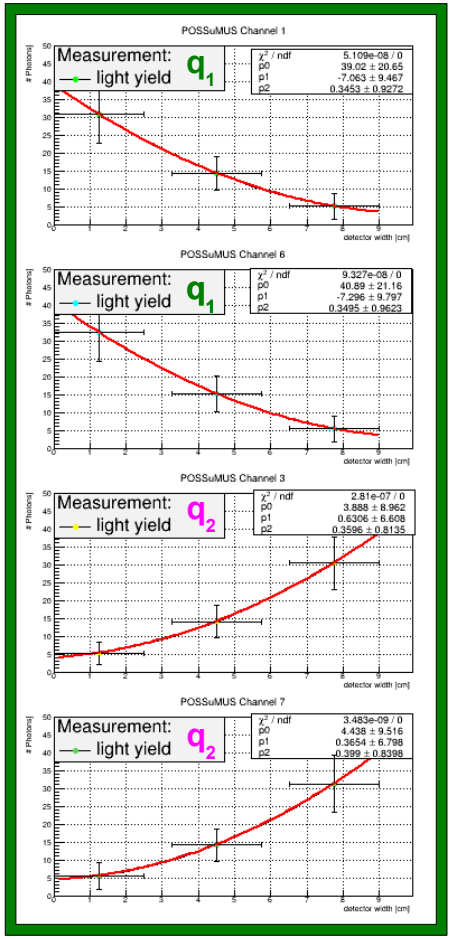
2 · 4 SiPMs
double sided readout

- almost no variation in light yield behavior for thin side fibers (linear fit)
- quadratic fit for light yield behavior for thick side fibers

thin side of trapezoid

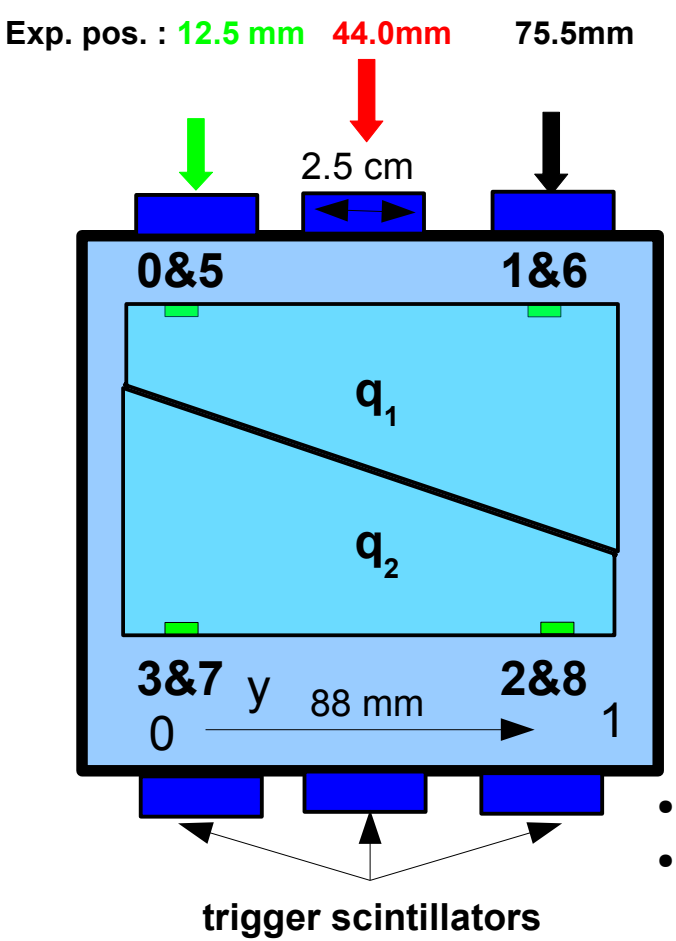


thick side of trapezoid



All channels of POSSuMUS work fine

Position Sensitivity and Spatial Resolution



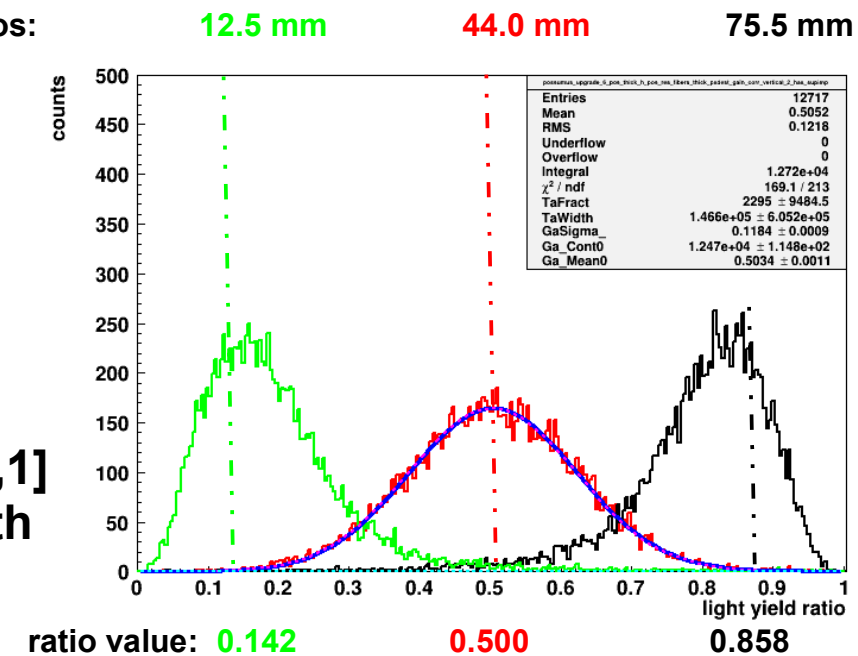
vertical μ-tracks @ trigger width of 2.5 cm :

light yield:

$$q_{sum} = q_1 + q_2 = \text{const}$$

$$y \propto \frac{q_1}{q_1 + q_2}$$

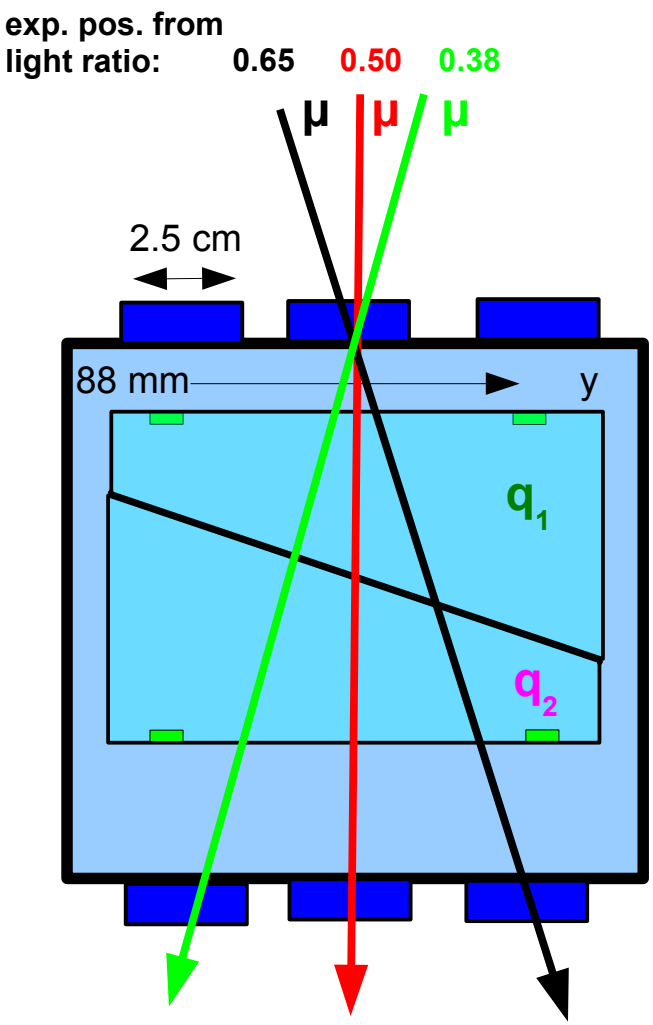
light yield ratio ∈ [0,1] corresponds to width of detector



- detected light yield for middle position: ~ 60 photons
- spatial resolution: 15 mm for middle position

- spatial resolution is limited by trigger width and photon statistics

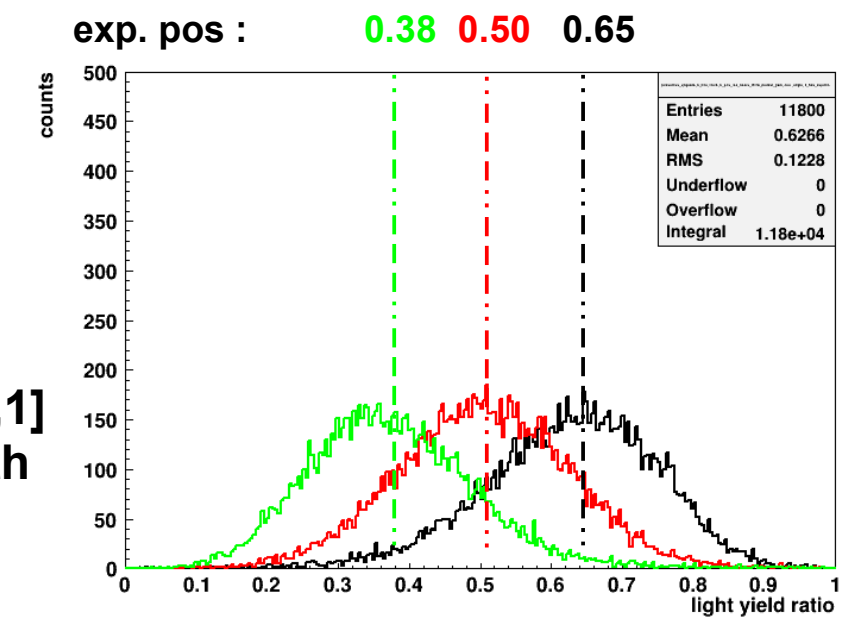
Inclined tracks



- comparison of **vertical** and **inclined** tracks:

$$y \propto \frac{q_1}{q_1 + q_2}$$

light yield ratio ∈ [0,1] corresponds to width of detector



detector principle is applicable for inclined tracks

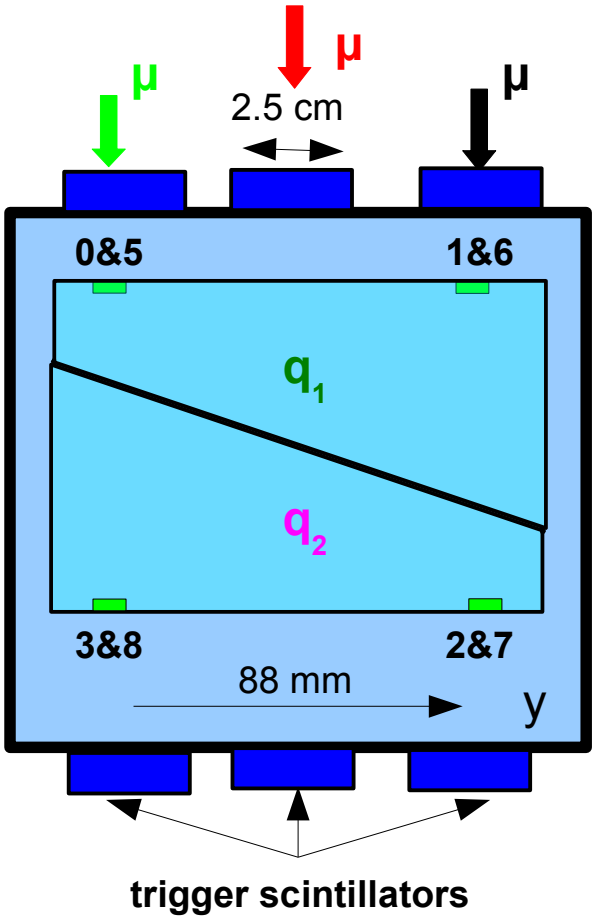
Summary

- POSSuMUS-detector
  - trapezoidal geometry → position sensitivity in y by light yield ratio
  - propagation time of light → position sensitivity in x by time difference
- Silicon Photomultiplier (SiPM)
  - Avalanche Photo Diode , temperature dependent
  - modular voltage source (64 channels) → gain stabilization works
- results for the prototype detector
  - light output 60 photons per muon event
  - spatial resolution in y : due to light yield ratio is 15 mm
  - spatial resolution in x : due to propagation time of light is 10 cm
  - efficiency of detector is 97 %
  - POSSuMUS can be applied to **vertical** and **inclined** tracks

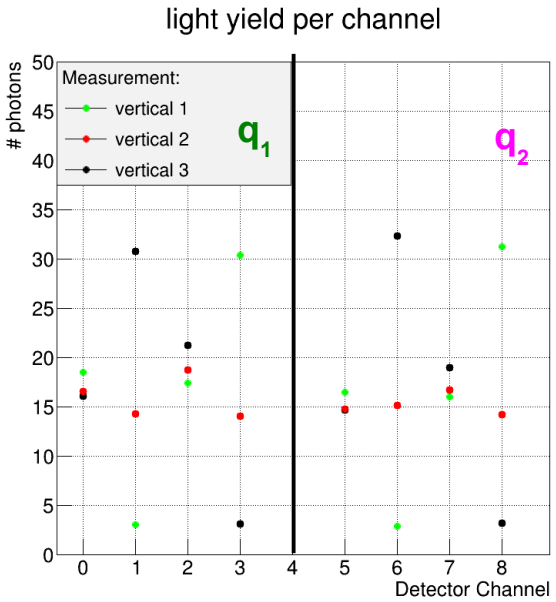
Thank you !

Backup

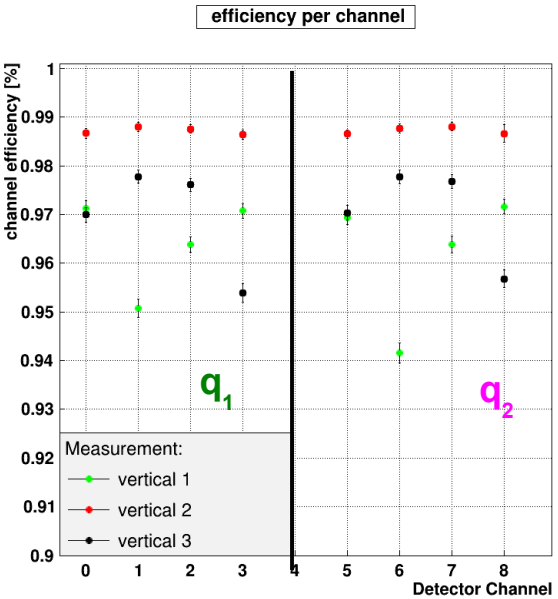
Light yield per channel



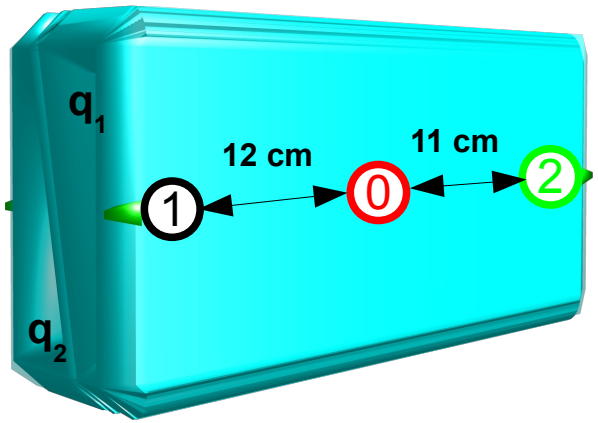
- most probable value of Landau-Gauss- distribution:
  ↔ detected light yield up to
  30 photons per fiber
  for I I I trigger positions
- good position sensitivity for fibers at thick side of each trapezoid
- almost no position sensitivity for channel at thin side

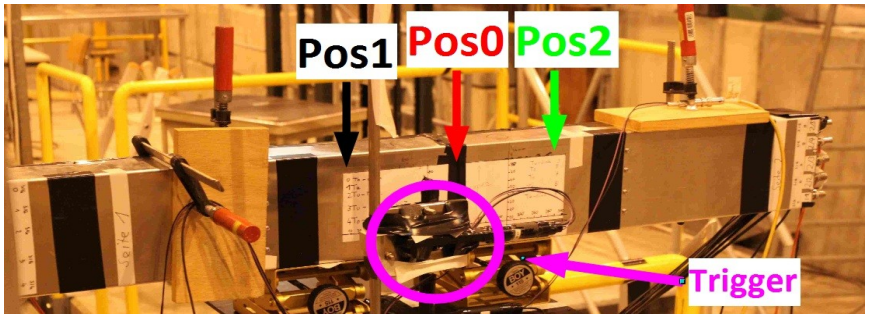


- detector efficiency per channel:
- criterion :
  at least one detected photon
- detector efficiency ~ 97 %
- efficiency drop for fibers at thick site when muon on thin site

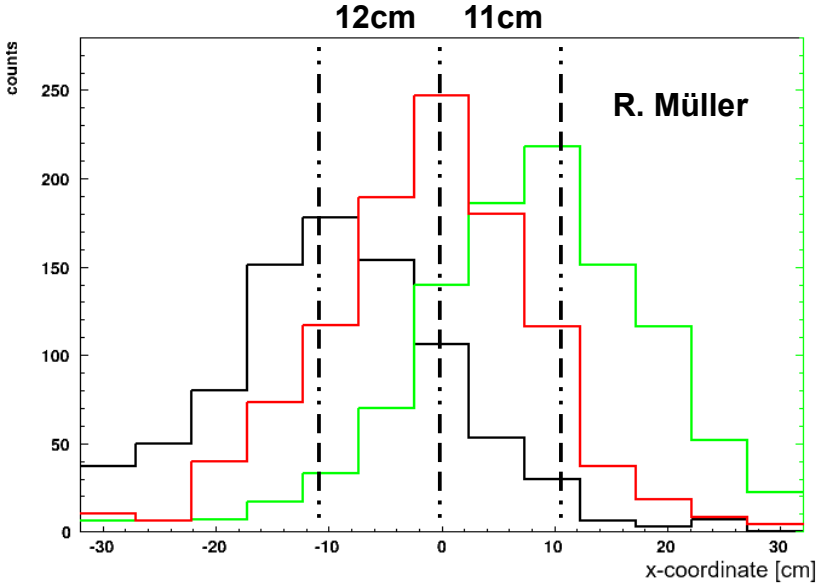


Spatial Resolution in x





- $(10\ \text{mm})^2$ trigger area
- time difference: $t = (x / c) \cdot n_{BC400}$



	expected:
t_{mean} (Pos 1) = (0.03 ± 1.3) ns	0.63 ns
t_{mean} (Pos 0) = (0.69 ± 1.3) ns	
t_{mean} (Pos 2) = (1.10 ± 1.4) ns	0.58 ns

- resolving the x-direction is possible
- resolution is limited by readout electronics (FADC with timing resolution of 0.5 ns)