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POSSuMUS-Detector

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We present the novel developed Position Sensitive Scintillating Muon SiPM - Detector (POSSUMUS). This modular designed scintillation detector is capable to determine particle positions in two-dimensions with resolution of a few mm for minimum ionizing particles. POSSUMUS is usable for large area trigger applications with relatively few readout channels. Position resolution in the transverse direction is achieved by combining two trapezoidal shaped plastic scintillators to form one rectangular shaped scintillator module. Each trapezoid is optically insulated against the other. The amount of light produced by incoming particles is proportional to their path length in the trapezoid and thus position dependent. The longitudinal position resolution, along the scintillator rod, is determined by propagation time of light. In both trapezoids the scintillation light is collected by wavelength shifting fibers (WLS fibers) and guided to Silicon-Photomultipliers (SiPMs) to measure the position dependent light yield. The SiPMs are located at opposite sides of an WLS fiber, an automatic voltage adjustment allows for a stable gain of the detected light signals. Because of its modularity, the POSSUMUS-detector can be used for large sized trigger applications of different sizes. By combining several scintillator rods, position sensitive areas from 100 cm^2 to few m^2 are achievable. In this paper we present a fully operating prototype of POSSUMUS, the multi-channel gain stabilization system for SiPMs and results for transverse and longitudinal position resolution.

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[*] Speaker.

[†] A footnote may follow.

1. Detector Concept

We are developing a large area scintillation detector with the capability to get a position information in two spatial dimensions. The **Po**sition **S**ensitive **S**cintillating **Mu**on **S**iPM Detector (POSSuMUS) is based on a modular concept to reach large detector areas of up to several m^2 with few readout channels.

To reach areas of square meters, we are combining several modules of rectangular scintillator modules. Each module consists of two trapezoidal shaped scintillators with a maximal length of 2 m and a planned cross section area of 0.18 m^2 for each module. This is displayed in a schematic diagram in figure 1. POSSuMUS provides a fast trigger information, which is feasible by the scintillation process. Besides the trigger information, POSSuMUS provides position information in two spatial dimensions, whereby the envisaged spatial resolution for the longitudinal-coordinate (x) is about 5 cm and for the transverse-coordinate (y) about 5 mm.

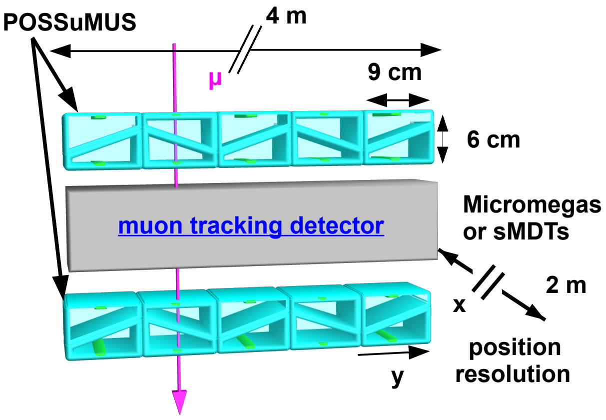

Figure 1: Modular concept of POSSuMUS is realized by combining several scintillator modules to form cross section areas in the order of m^2. POSSuMUS provides a fast trigger information and a two-dimensional position information.

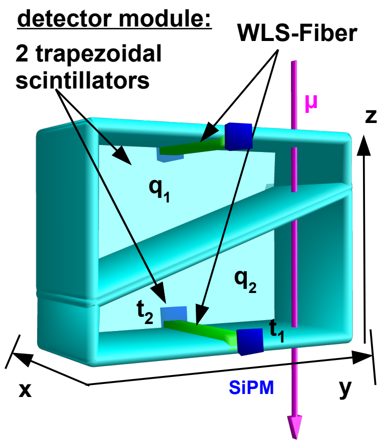

Figure 2: One module of POSSuMUS consists of two trapezoidal shaped scintillators. Trapezoids are optically insulated. Position information is achieved by path-length dependent light yield.

In figure 2, one module of POSSuMUS is shown. Each module consists of two trapezoidal shaped scintillators (type *BC* 400 [1]), which are forming a rectangular unit. The trapezoids are optically insulated from each other.

To collect the scintillation light created by traversing ionizing particles, we are using **W**ave-**L**ength-**S**hifting Fibers (type *BCF* 98). At least one WLS fiber is glued into each trapezoid and guides the collected light to Silicon-Photomultipliers (SiPMs), which are used for photon detection.

The idea of this detector concept is to determine the position of ionizing particles in one direction by the amount of scintillation light created in both trapezoids. Due to the geometry, the amount of light is path-length dependent.

$$\text{transverse direction}: \ y \propto \frac{q_1}{q_1+q_2}, \quad (1)$$

Therefore the light yield ratio in formula 1 determines the position sensitivity in y, with q_1 and q_2 being the detected amount of light in in trapezoid one and two. Assuming : $\frac{dq}{dz} = \text{const.}$ along the path length z a spatial resolution of few mm is expected.

To determine the position of traversing particles in the longitudinal direction (x), the propagation time of light within the scintillator is used. Since SiPMs detect incoming photons at both ends of each WLS-fiber, one can calculate the time difference of the arrived light at both ends. From this information we achieve a position sensitivity with a spatial resolution of few cm via the following relation.

$$\text{longitudinal direction}: \ x \propto t_1 - t_2 \ (3)$$

Results for the longitudinal direction (x) are not in explicitly shown here, see [2].

2. Silicon Photomultiplier and Gain Stabilization

The detection of path-length dependent light yield is realized with SiPMs. We are working with SiPMs of Hamamatsu with an active area of $(3\ \text{mm})^2$ and a pixel size of $(100\ \mu\text{m})^2$ [3].

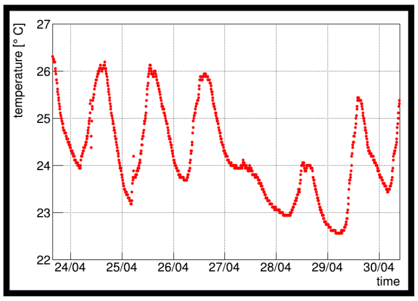

Figure 3: Temperature variation over a period of one week in the laboratory.

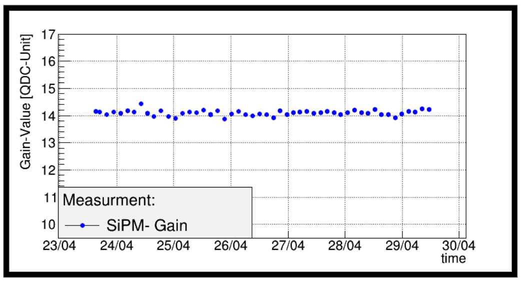

Figure 4: Stable gain condition for one SiPMs, using an automatic gain stabilization system for one week. The variation in gain without stabilization would be about 35 %

One essential point to interpret the detected signal height correctly, is the determination of the gain for each SiPM and the stability of this factor over a long period of time. The gain is determined by the voltage U_{over}, which corresponds to the difference between applied voltage, U_{bias}, and the temperature dependent breakdown voltage, $U_{bd}(T)$.

$$U_{over} = U_{bias} - U_{bd}(T) \ \ (4)$$

For all SiPMs, which are used for POSSuMUS, $U_{bd}(T)$ was measured at the same temperature and a correction factor for the temperature dependence of $U_{bd}(T)$ was determined. This correction factor is 60.8 mV/ K [4], and globally valid for all Hamamatsu devices used. As rule of thumb the signal height of a SiPM-device is changing by 10 % / K [3].
To spare the effort of cooling the whole detector, we developed a serial voltage divider, which

is capable to adjust automatically the applied voltage according to the temperature variations of the environment. The temperature is directly measured at the SiPMs, with a sensor in thermal contact. We equipped the serial voltage divider with digital potentiometers, which are capable to adjust 64 voltage channels separately. The steering of the potentiometers is realized via an I^2C-communication [4].

In figure 3, the temperature variation with a maximum change of 3.5 °C in the laboratory is shown for a period of one week. In figure 4 the gain of one SiPM is shown over the same period of time. The gain is determined by recording dark rate events of the SiPM. The corresponding signal height spectrum shows a peak spectrum, where each peak corresponds to the number of firing SiPM pixels. The gain value is determined out of the difference of neighboring peaks and monitored in parallel with the cosmic muon measurement. Despite the temperature variation in the laboratory, the gain stays constant over the whole period, with an accuracy of about 2 %.

3. POSSuMUS Prototype

3.1 Prototype Detector

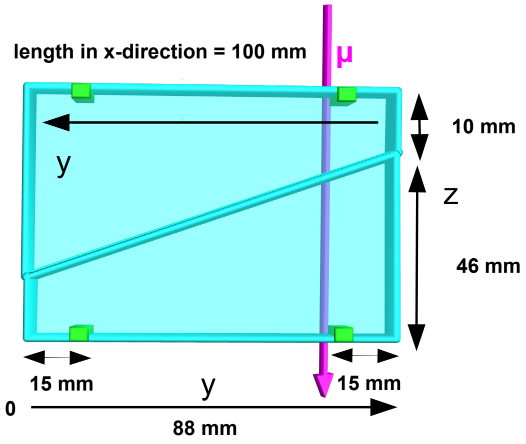

Figure 5: New prototype detector, whereby each trapezoid is equipped with two WLS fibers.

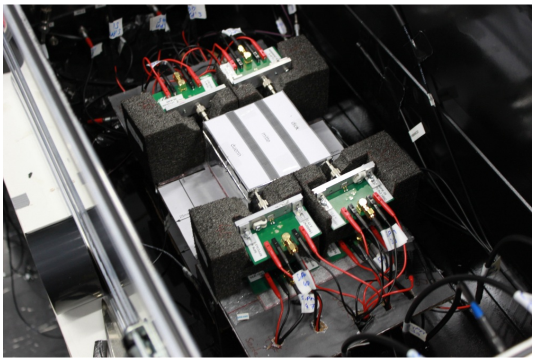

Figure 6: POSSuMUS is equipped with 8 SiPMs for a double sided readout. FC-connectors coupling visible in silver.

The proof of principle of our detector concept was shown in [5], we present now results for an improved prototype of POSSuMUS.

As indicated in figure 5, each trapezoid has a width of 88 mm and a height of 46 mm at the thick side and 10 mm at the thin side. The length of the scintillator for this prototype is 100 mm. Both scintillators are wrapped in three layers of diffusely reflecting Tyvek material [6] and one layer of aluminum foil, for avoiding light leaks.

Each trapezoid is equipped with two WLS fibers, with a diameter of 1.5 mm. They are located at a distance of 15 mm from the edges of the scintillator and glued in grooves with a depth of 3.5 mm, respectively. At both ends of each fiber one SIPM is mounted. All eight SiPMs are operated with

stabilized gain, see section 2. The fibers are air coupled to the SiPMs via FC-connectors, as visible in figure 6. No optical grease is inserted between SiPM and fiber.
Data acquisition is realized by a combined TDC-QDC VME-readout [7], [8] for signal-height and timing information. We are triggering on cosmic muons with two 3-fold-segmented trigger scintillators, located on top of and below the detector. In figure 6, the position of the trigger scintillators are indicated by the white rectangular areas.

3.2 Signal Height spectra

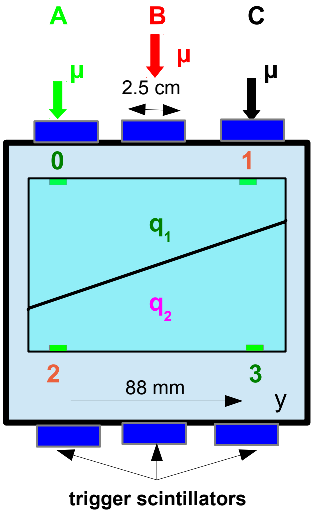

Figure 7: POSSUMUS is seen form one readout side with a 3-fold-segmented trigger, investigating vertical tracks.

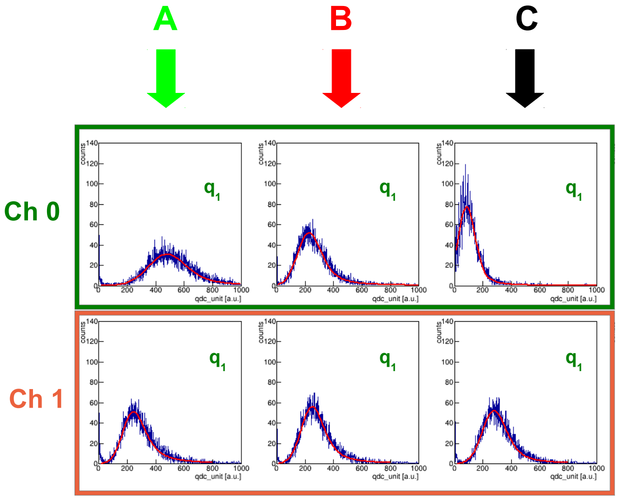

Figure 8: Signal height spectra for three vertical trigger positions for two channels 0 and 1 in trapezoid q_1.

In figure 7, a sketch of the detector is displayed with four readout channels 0, 1, 2, 3 sitting at the same side. Only vertical tracks are considered, discriminated by the 3-fold-segmented trigger scintillators, indicated by A, B and C.
Firstly we focus on channel 0, which is located at the thick side of trapezoid q_1. The light response is shown in the first row of figure 8, these spectra correspond to three different vertical trigger positions. Each of the spectra is fitted by a convoluted Landau-Gaussian-function. The most probable value (MPV) of the fit is extracted for further analysis. This function is chosen, since minimal ionizing particles have a landau like energy loss within the scintillator and the response of a SiPM is Gaussian like for large photon numbers.
If one compares the light spectra for channel 0 for case A, B and C, one recognizes a clear decrease of the signal height (MPV) from left to right as expected from the change of the path-length for cosmic muons in trapezoid q_1.
For *channel* 1, which is located at the thin side of *trapezoid* q_1, the signal height spectra are displayed in the second row of figure 8. This channel shows no variation in the signal height due to

different path lengths of cosmic muons in the scintillator.

The signal height spectra of channel 2 and 3 in trapezoid q_2 show the same results, channel 3 shows a path length dependent variation of the light yield, channel 2 does not.

3.3 Position Sensitivity for Vertical Tracks

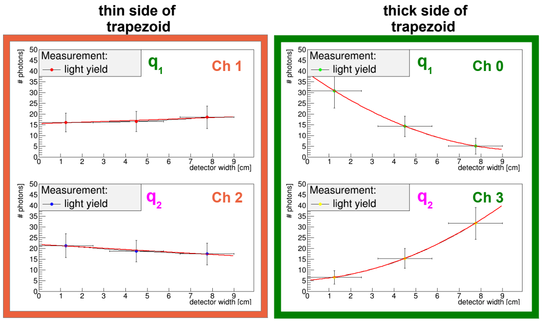

Figure 9: The detected light yield is shown for channel 0, 1, 2, 3 of POSSuMUS as a function of the trigger position. Channels at the thick side, namely 0 and 3 show position dependent light yield, channels at the thin side, namely channel 1 and 2 do not.

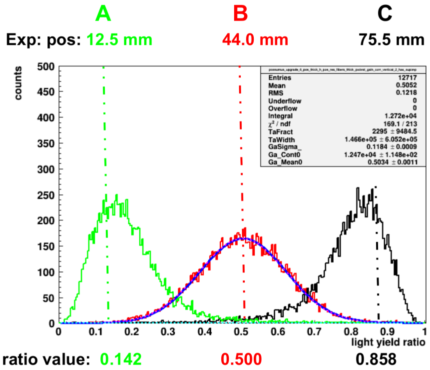

Figure 10: Light yield ratios corresponding to different vertical trigger positions. Position sensitivity is clearly visible, spatial resolution is 15 mm. The vertical lines correspond to the expected positions of the respective MPVs

The number of detected photons for each SiPM is calculated from the division of the MPV of the signal height spectra, see Figure 8, by the gain of the corresponding SiPM, see figure 4. The variation of the detected light yield with respect to the vertical trigger combinations is shown for four channels of POSSuMUS in figure 9.

The first column corresponds to the detected light yield for channels located at the thin side of each trapezoid. The first plot of the first column depicts the light yield of the fiber located at the thin side of the trapezoid q_1. One recognizes an insignificant increase of the number of photons, from 15 to 18 photons with decreasing path length in the scintillator. The amount of light is not path length dependent. One observes the same behavior in trapezoid q_2, represented by plot two of column one.

The second column shows the position sensitivity of channels 0 and 3, located at the thick side of both trapezoids. As expected from the geometry, the number of detected photons is decreasing with shorter path length in the scintillator. The measured light yield varies between 5 to 30 photons, depending on the trigger positions. The second plot in column two reveals the same position sensitive behavior for trapezoid q_2.

The results for trapezoids q_1 and q_2 on the opposite readout side are identical.

For the following we are using *only* the position sensitive channels located at the thick side of each trapezoid to demonstrate position sensitivity of the detector and determine the spatial resolution of the detector.

We calculate the light yield ratio using equation 1 and plot the result in figure 10.

One recognizes three clearly separable peaks, which correspond to vertical tracks related to trigger

conditions A, B, C. For case B, the light yield ratio leads to a mean-value of 0.5, as expected, since the path length is the same in both scintillators and therefore the detected light yield is the same in both trapezoids. The standard deviation of the spatial resolution is about 15 mm.
The deviations, from the expected values for cases A and C, arise from the non linear light yield behavior, see figure 9. This effect has not yet been corrected for in the analysis. The limitation of the spatial resolution originates from the width of the trigger scintillators of 25 mm and from the photon statistics.

3.4 Position Sensitivity for Inclined Tracks

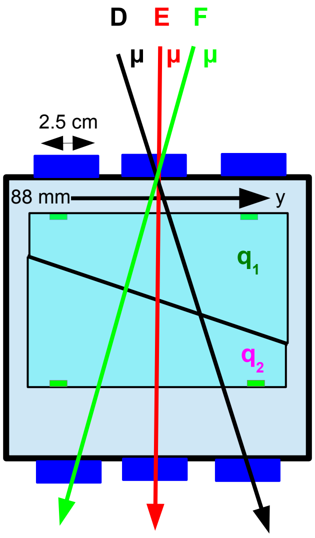

Figure 11: Schematic for the investigation of inclined tracks: Cosmic muons traverse the center trigger module on top of the detector and one of the trigger modules below the detector.

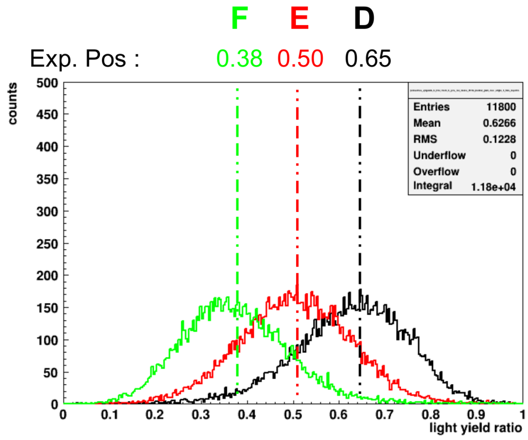

Figure 12: Light yield ratios correspond to two inclined tracks, case D and F, and one vertical track, case E, position sensitivity is clearly visible. The mean values of the three curves coincide largely with the expected position given by the vertical lines.

After proving the detector concept for vertical tracks, we show now, that the detector principle is also applicable for inclined tracks.
In figure 11, one case for inclined tracks with the existing trigger system is chosen, where all incoming muons hit the mid-upper trigger scintillator. In D, E and F, three possible cases for two inclined tracks and one vertical tracks are described.
For determining the position sensitivity of inclined tracks, we use again only the position sensitive channels, which are located at the thick side of the trapezoidal scintillator rods.
In figure 12, the distributions of case D , E and F are clearly separable. The spatial resolution for inclined tracks is similar to the resolution of vertical tracks.
The spatial resolution is still limited by the convolution with the trigger width of 25 mm and by the photon statistics.

4. Summary

We have presented a new concept for a large area scintillation detector with relatively few readout channels. POSSuMUS is capable to provide a fast trigger information and a position sensitivity in the y direction with a spatial resolution of few mm. This is realized by combining two trapezoidal shaped scintillator to form a rectangular scintillator module.

We presented a fully working stabilization system for the gain of the SiPMs. This system allows for constant gain at the SiPM over a long period in time.

We have shown with an improved prototype detector, that the position sensitivity due to the geometric shape is good and the spatial resolution of the detector is about 15 mm for vertical tracks. The detection efficiency is about 97 %.

Spatial resolution in the 2^{nd} position coordinate, due to the propagation time of light in the scintillator is about 10 cm. Results can be found in [2].

References

[1] Saint-Cobain: *Saint-Gobain, plastic scintillators*, www.detectors.saint-gobain.com/

[2] Müller, R. : *Development of a Position Sensitive Scintillating Detector,* Master Th. LMU (2013)

[3] Hamamatsu: *S12572-100CMPPC*, www.hamamatsu.com/

[4] Grossmann, J. : *Optimization studies for an SiPM based scintillation detector, Master Th. in preparations LMU 2014* Master Th. LMU

[5] Ruschke, A. : *Spatial resolving SiPM-detector for cosmic muons, PoS(EPS-HEP 2013)045*

[6] Tyvek : *wrapping material*, www2.dupont.com/Tyvek/

[7] CAEN V775: *TDC Data Sheet*, www.caen.it/

[8] CAEN V792: *QDC Data Sheet*, www.caen.it/