

# Position resolution from time difference in scintillator strips for the muon system

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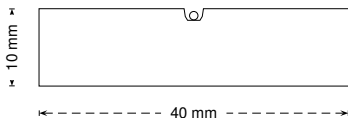
# Motivation

- Few tests so far of possible muon-system sensors for future colliders
- Instrumented area very large and difficult to reach for maintenance – a reliable and economical solution would be of great advantage
- Long scintillator strips (up to  $\sim 3$  m) with SiPM readout interesting for reliability, reasonable construction and operation costs and relatively low number of readout channels
- Measurement of hit position along the strip offers a possibility to resolve multiple hits and limit position uncertainty

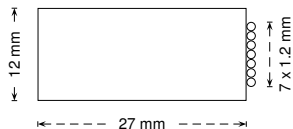
## Section 2

### Tests

# Tested strip configurations



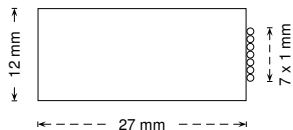
a)



b)



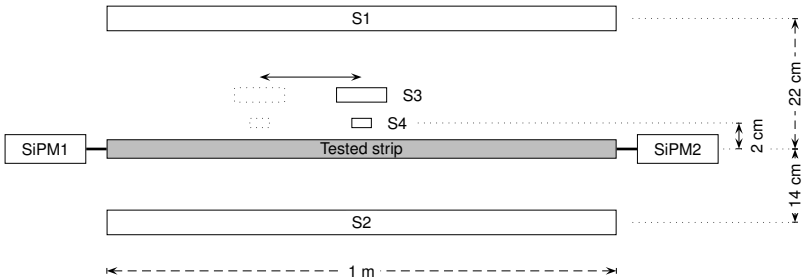
c)



d)

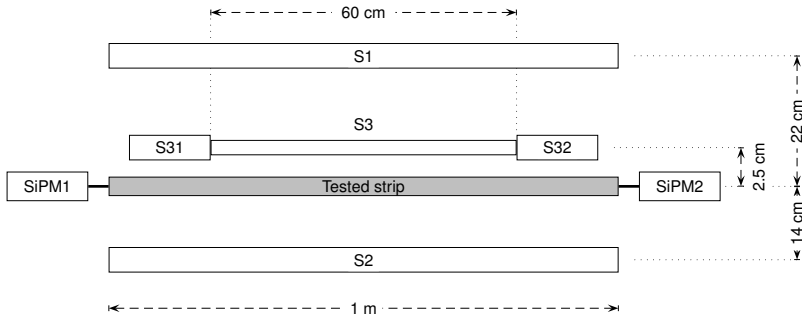
- a) MINOS strip with one Kuraray Y-11 WLS fiber
- b) Bicron 404A strip with 7 Kuraray Y-11 WLS fibers
- c) MINOS strip with 4 Bicron BCF-92 WLS fibers
- d) Bicron 404A strip with 7 Bicron BCF-92 WLS fibers

# Test setup 1



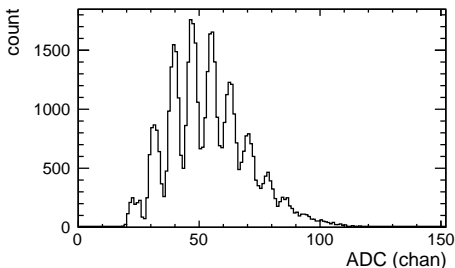
- S1 and S2 are scintillation counters with vacuum PMT.
- S3 and S4 are small-area counters with vacuum PMT, movable along the tested strip. Width of S4 is 2.7 cm.
- SiPM1 and SiPM2 are **Hamamatsu S10931-050P** photodetectors.
- Trigger:  $S1 \cap S2 \cap S3$
- Offline selection: Presence of signal in SiPM1, SiPM2 and S4;  
 $E_{S4} > E_{min, Landau}$

# Test setup 2



- S1 and S2, SiPM1 and SiPM2 are the same as in setup 1.
- S3 is the *reference* strip with vacuum PMT S31 i S32.
- Trigger:  $S1 \cap S2 \cap S31$
- Offline selection: Presence of signal in SiPM1, SiPM2 and S32;  
 $E_{S31} + E_{S32} > E_{min, Landau}$

# Calibration – amplitude



- SiPM illuminated with LED pulses  
Driver pulses for LED:
  - Triangular pulse shape,
  - Minimum amplitude to see photons in SiPM  $A_{min} = 1.1 \text{ V}$ ,
  - Pulse length above 1 V level:  $t_{pulse} \approx 2.5 \text{ ns}$
- Cross talk calibration using inefficiency (pedestal peak relative area)
- SiPM bias voltage chosen for measurements:  $U_{bias} = 71.8 \text{ V}$   
resulting in cross talk factor  $X = 1.35$



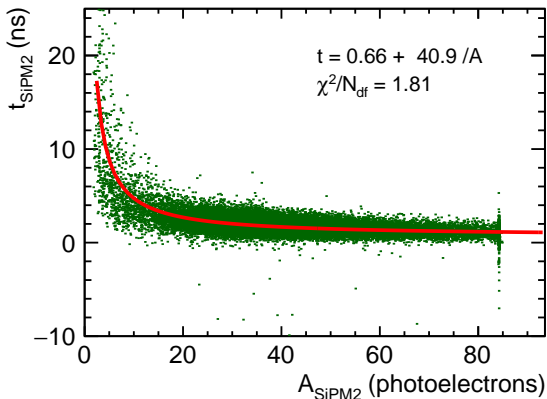
# Photon yield

Photon yield per muon per SiPM, using selection cuts for muon events (coincidence,  $E > E_{min, Landau}$ )

Configuration	Photon yield per muon (photoelectrons)
<i>A</i>	10
<i>B</i>	19
<i>C</i>	20
<i>D</i>	>30

Configurations *C* and *D* were selected for time- and position resolution tests.

# Correction of the amplitude effect

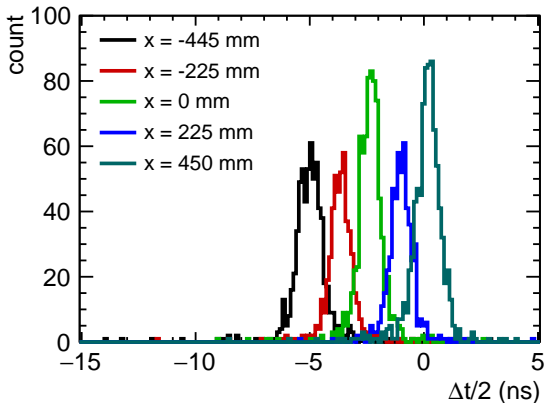


- Correction for SiPM by fitting the function  $\Delta t = C + a/A$  to data.
- Counters with vacuum PMT less affected due to fast signals, lower thresholds and the  $E > E_{\text{min,Landau}}$  cut

## Section 3

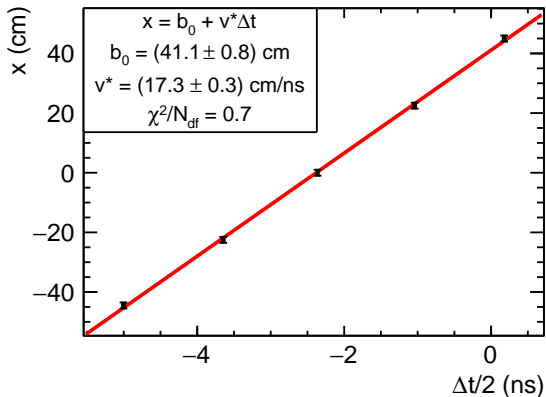
### Results (Configuration $D$ )

# Sensitivity of $\Delta t/2$ to the muon location



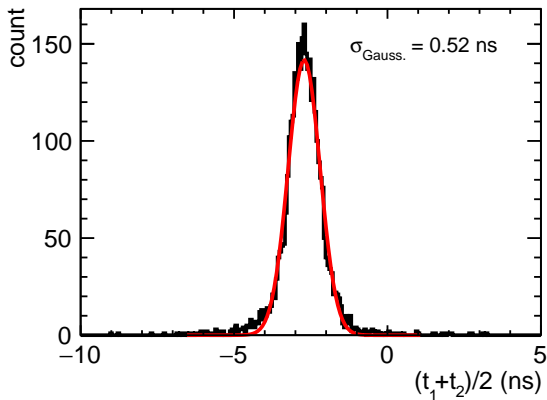
- Measurement in 5 different positions  $x$  of S3 and S4
- 7 to 12 hours per position – 500 to 1000 events per position after selection

# Calibration of location, signal propagation speed



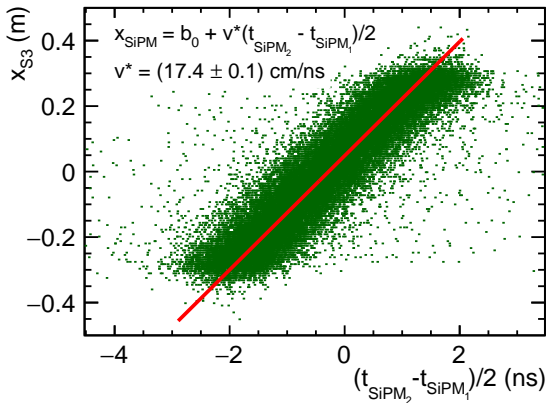
- 5 different positions  $x$  of S3 and S4
- Straight-line fit  $x$  vs.  $\Delta t/2$
- Speed of signal propagation from the slope  $v^* = 17.3 \text{ cm/ns}$
- Position resolution  $\sigma_x = v^* \sigma_{\Delta t/2} = 7.7 \text{ cm}$

# Time resolution per strip



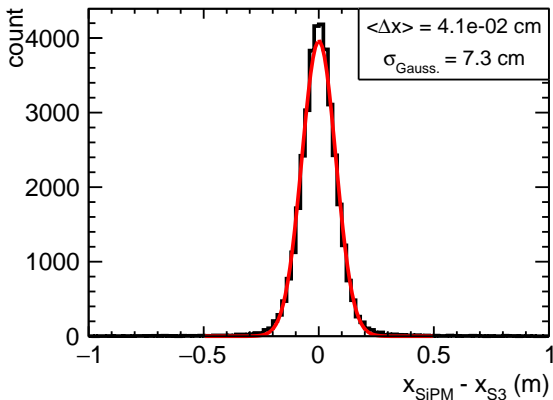
- $(t_1 + t_2)/2$  collected in all 5 positions x of S3 and S4
- Gaussian width  $\sigma_t = 0.52$  ns

# Position calibration, signal propagation speed in setup 2



- Straight line fit  $x$  vs.  $\Delta t/2$
- Speed of signal propagation  $v^* = 17.4 \text{ cm/ns}$

# Position resolution in setup 2



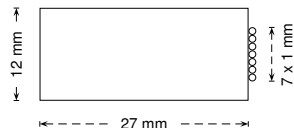
- Position deviation between the tested and the reference strips in configuration  $D$
- Fitted Gaussian width  $\sigma = 7.3 \text{ cm}$



# Tabular results (configurations *C* and *D*)



Configuration *C*



Configuration *D*

Conf.	side #	Yield per $\mu$ (photoel.)	$\sigma_x$ (setup 1) (cm)	$\sigma_x$ (setup 2) (cm)	$\sigma_t$ (ns)	$v^*$ (cm/ns)
<i>C</i>	1	21	14.8	14.8	0.91	18.1
	2	20				
<i>D</i>	1	31	7.7	7.3	0.52	17.2
	2	36				

## Section 4

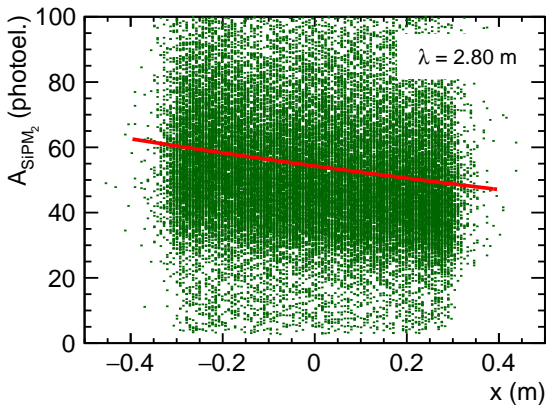
### Summary

# Summary

- Several scintillator+WLS strip configurations tested for photon yield, position and time resolution in 2 setups.
- Light yield up to 36 photoelectrons per muon per SiPM
- Position resolution  $\sim 7$  cm
- Time resolution 0.5 ns per strip
- Non-negligible uncertainties due to the setup
  - Results are conservative
  - Beam tests needed
- More details can be found in [arXiv:1510.03030](https://arxiv.org/abs/1510.03030)

# Backup slides

# Signal attenuation in scintillator+WLS



- Attenuation length  $\lambda = 2.8 \text{ m}$
- Large relative spread of signal intensity (Poissonian)