Optimal Design of Plastic Scintillator Counter with Multiple SiPM Readouts for Best Time Resolution

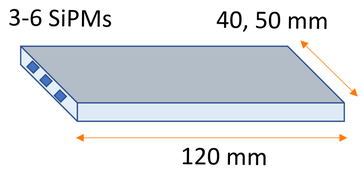
東京大学
素粒子物理国際研究センター
International Center for Elementary Particle Physics
The University of Tokyo

Rina Onda, onda@icepp.s.u-tokyo.ac.jp
K. Ieki, T. Iwamoto, S. Kobayashi, N. Matsuzawa, T. Mori, M. Nakao, M. Nishimura, S. Ogawa, W. Ootani, Y. Uchiyama

0. Abstract

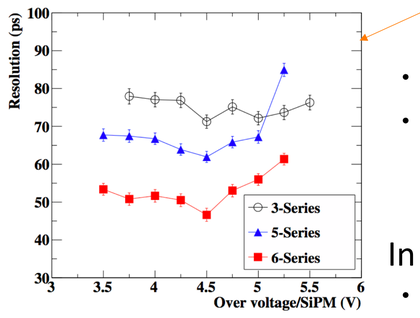
This study aimed to make a timing counter of best time resolution with an about 10 cm square plastic scintillator read out by multiple SiPMs. To achieve this, SiPM connection scheme, counter geometry and plastic scintillator were investigated. As a result of these optimization, time resolution of a counter whose readout scheme of SiPMs was 4 series 4 readouts on each side and scintillator size was 80 × 175 × 5 mm^3 was 28 ps, which was time resolution with small position dependence.

1. Timing Counter with SiPM Readouts



From the previous study about a timing counter
Plastic scintillator : BC422, Saint-Gobain
40, 50 × 120 × 5 [mm^3]
Risetime 0.35 [ns] Ref. 1
SiPM : 3-6 SiPMs × 2 sides

Time Resolution of Series Connected SiPM Readout

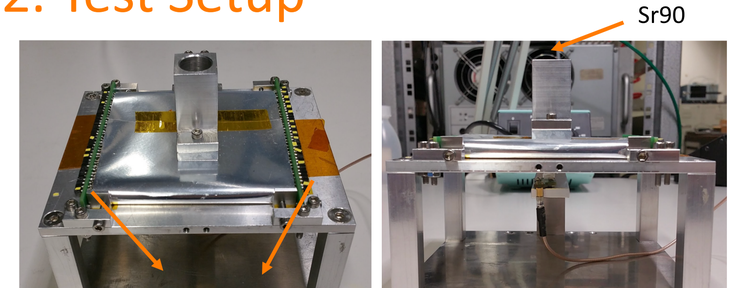


Ref. 2

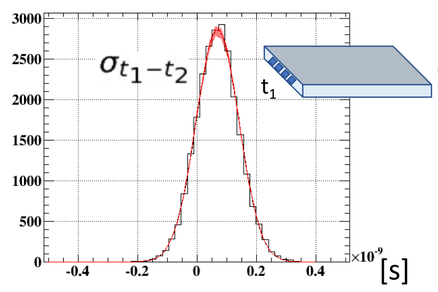
Time resolution becomes better as light yields get larger
→ **Use more SiPMs**
- **But too many readout channels are not desirable**
- Compared series and parallel connection
  Smaller capacitance makes risetime faster
  → **Series connection is better**

In this study, to make a larger timing counter
- Optimize SiPM connection scheme
- Optimize counter geometry
- Optimize plastic scintillator

2. Test Setup



Change the number of SiPMs used or the method of connections



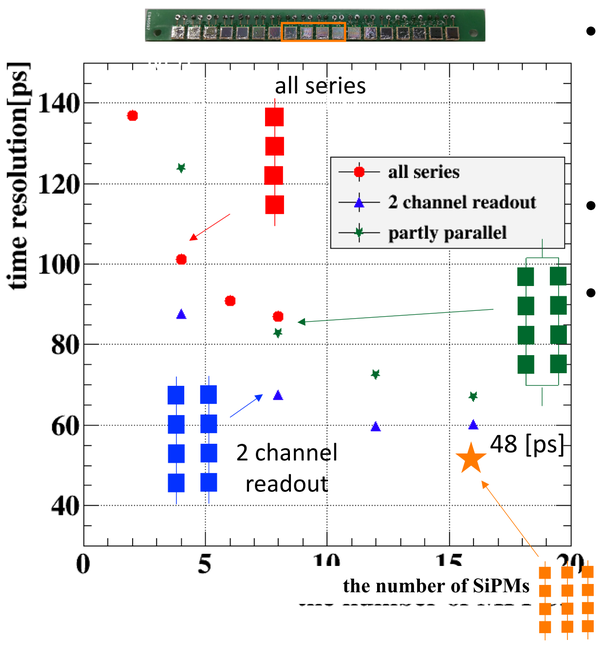
Readout Scheme
Pole zero cancellation
SiPMs — Amp — Waveform digitizer

Plastic scintillator : BC-420, Saint-Gobain, 92 × 92 × 5[mm^3]
Risetime 0.5 [ns]
Attenuation length 140 [cm]
SiPM: MPPC S13360-3050PE, Hamamatsu Photonics
3 × 3 [mm^2] photosensitive area, V_{br} ~ 52 [V]
18 SiPMs × 2 sides
Reflector : ESR2 (Polyester)
Optical grease : 6262A, OHYO KOKEN KOGYO CO.

Resolution was calculated by subtracting the time of one side t_1 from the other side t_2

$$\sigma_{counter} = \frac{\sigma_{t_1-t_2}}{2}$$

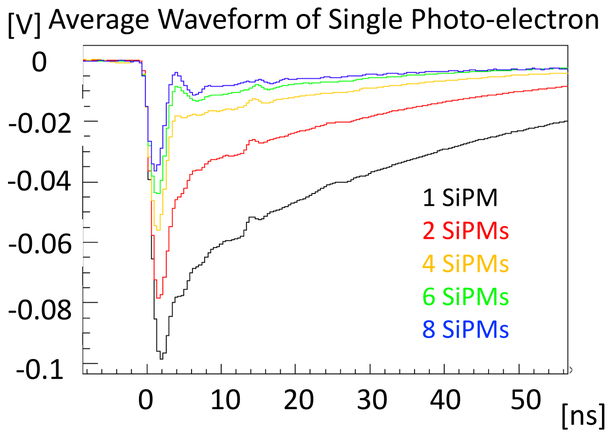
3. Optimization of SiPM Connection Scheme



- Tested three types of connections
  - all series : capacitance C
  - 2 channel readout : capacitance 2C
  - partly parallel : capacitance 4C
- Time resolution gets better as more SiPMs are used as expected
- Measurements show improvement of time resolution starts to saturate when about 4 SiPMs are connected in series
  →2 channel readout and partially parallel connection are better when the number of SiPMs is more than 8

The best time resolution with the optimized connection, 4 series × 4 readouts, for the scintillator (92 × 92 × 5 [mm^3])

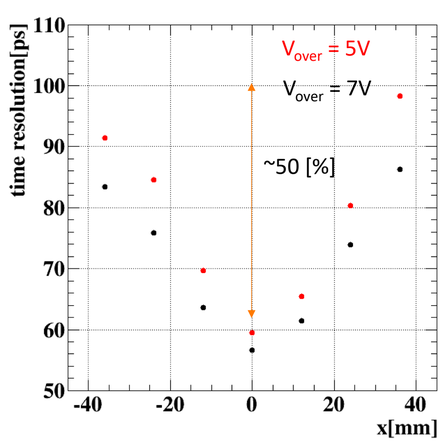
[V] Average Waveform of Single Photo-electron



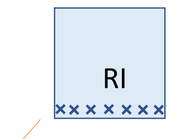
As more SiPMs are connected in series, capacitance gets smaller
- Width becomes narrower
  → Faster risetime
- **Pulse height becomes lower**
  → **S/N is not good when there are too many SiPMs connected in series**

Saturation of time resolution improvement

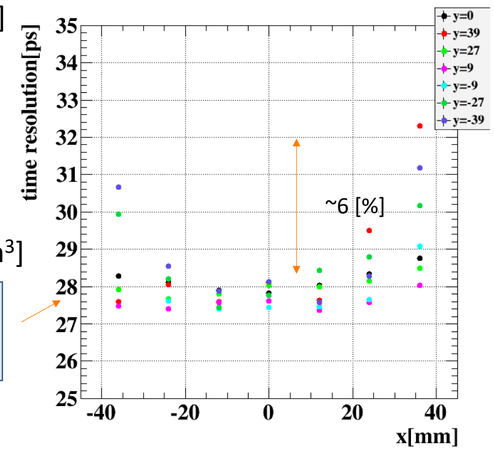
4. Optimization of Counter Geometry



92 × 92 × 5 [mm^3]



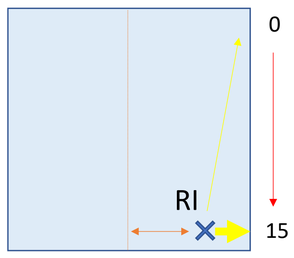
80 × 175 × 5 [mm^3]

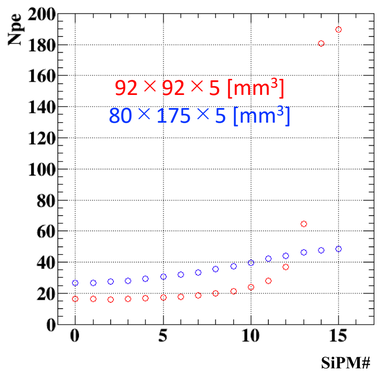


- Measurement of position dependence of time resolution using the scintillator (92 × 92 × 5 [mm^3], BC-420)
  - Large position dependence of time resolution was observed
  - When RI is near to the side SiPMs attached to, light yields of some SiPMs are too small depending on their positions
    →less statistics & worse S/N
- From simulations below, if the distance from the irradiated position to SiPMs is longer, the light yield difference between SiPMs is less
- Measurement using a longer scintillator (80 × 175 × 5 [mm^3] , EJ-230)
  - **Smaller position dependence of time resolution in the same acceptance**
    50 [%] → 6 [%]
    ←**smaller position dependence of light yields**

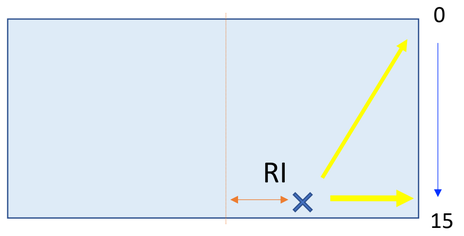
Light yield simulation

92 × 92 × 5 [mm^3]





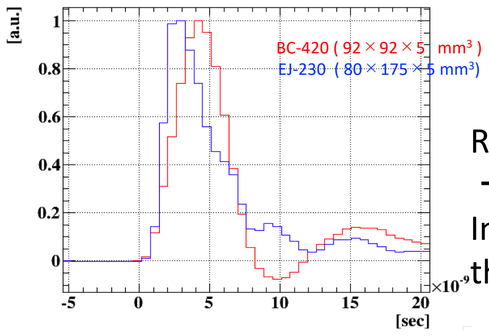
80 × 175 × 5 [mm^3]



the same distance from the center, but not from SiPMs

5. Optimization of Plastic Scintillator

Average Waveform



Scintillator	Risetime [ns]
BC-420 (92 × 92 × 5 mm³)	2.017
EJ-230 (80 × 175 × 5 mm³)	1.055

1 /2

Risetime of EJ-230 is **twice faster** than that of BC-420
→ time resolution is supposed to be better
Indeed, time resolution of EJ-230 was much better than that of BC-420
42 [ps] → 28 [ps] @ the center (V_{over} = 7 [V])

6. Conclusion

- More SiPMs improve time resolution
- Series connection has trade-off effects
  - Faster risetime → better time resolution
  - Pulse height reduction → worse time resolution
- For uniformity of time resolution, it is effective to place SiPMs far from its acceptance
- Achieved 28 [ps] time resolution at the center with small position dependence (< 5 [ps]) using the optimized configuration as follows.
  - Plastic scintillator : 80 × 175 × 5 [mm^3] , Risetime 1 [ns]
  - SiPMs connection : 4 series × 4 readouts × 2 sides

References

1. https://www.crystals.saint-gobain.com/sites/imdf.crystals.com/files/documents/sgc-bc418-420-422-data-sheet_69699.pdf
2. M. Nishimura et al., Pixelated positron timing counter with SiPM- readout scintillator for MEG II experiment. In *Proceedings 4th Int. Conf. on New Photo-Detectors*, PoS(PhotoDet 2015)011, Mo- scow, Russia, (2016)