# Time Resolution Study of the Range Counter for $K^-$pp Bound State Searches at J-PARC

H. Kumawat[1]*, B. J. Roy[1], Y. Ichikawa[2], H. Ekawa[2], A. Chatterjee[1], S. Kailas[1], H.Fujioka[2], T.Takahashi[3], T.Nagae[2], and E27 COLLABORATION
[1]*Nuclear Physics Division, B.A.R.C., Mumbai - 400085, INDIA and*
[2]*Kyoto university, Kyoto-6068501, Japan,* [3]*KEK, Tsukuba-3050801, Japan*

## The measurement

The E27 collaboration has an ongoing programme on the studies of $\overline{K}$ bound state via the reaction d($\pi^+$, $K^+$)$K^-$pp at J-PARC, Tokai, Japan. The 4-momenta of $K^+$ will be measured by the SKS spectrometer while the decay of $K^-$pp will be registered in the newly constructed Range Counter(RC). The RC consists of several layers of plastic scintillators (BC-420) and will be used for detection & identification of two protons in a coincidence measurement[1]. One of the crucial points is to achieve a very fast timing ($\sim$ 100 ps). In this context, a test measurement has been carried out with this detector using cosmic muons. The geometry used for this test run is as shown in Fig.1. The Scintillator bars were 100 cm long having a thickness of 5, 2, 1 and 2 cm, starting from the top. Two small scintillator tiles, labelled as Trigger 1 and Trigger 2, were placed above and below this set-up and a time coincidence between these two tiles formed the trigger. The position of the trigger detector was moved along the length of the scintillator bars. All scintillator detectors were readout from both ends by PMTs. Cosmic data was collected for sufficient time and a separate run was taken for pedestal correction.

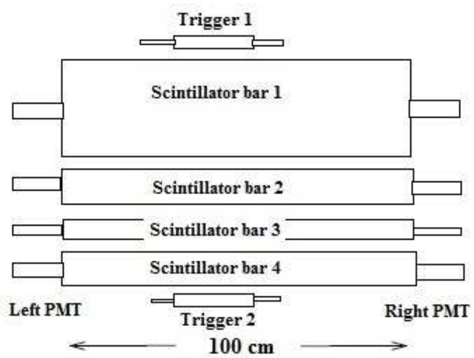


FIG. 1: A schematic diagram of the setup used for timing measurement with cosmic muons for the newly constructed range hodoscope.

## Time Analysis and Results

Timing and energy loss information from all four scintillator bars were collected and time correlation between different scintillator bars were built. For energy, geometric mean of two ADC signals from left and right PMTs of the same bar was taken ($ADC = \sqrt{(}ADC_{Left} \times ADC_{Right})$.

Timing was defined as,

$$TDC_{ij} = (TDC_{iLeft} + TDC_{iRight})/2 - (TDC_{jLeft} + TDC_{jRight})/2,$$

where i, j runs from 1-4(different scintillator bars). In this manner, contribution in the time spread from different sources were minimized.

A typical TDC vs ADC spectrum, so obtained, is shown in Fig.2. A projection on y-axis yields correlated time resolution $\sigma_{ij} = \sqrt{\sigma_i^2 + \sigma_j^2}$. The timing resolution of the individual detectors was then obtained by solving a set of such equations. A time resolution of $\sim$ 300ps was achieved. It was further improved up to 100ps by correcting for slewing effect.

*Email address: harphool@barc.gov.in

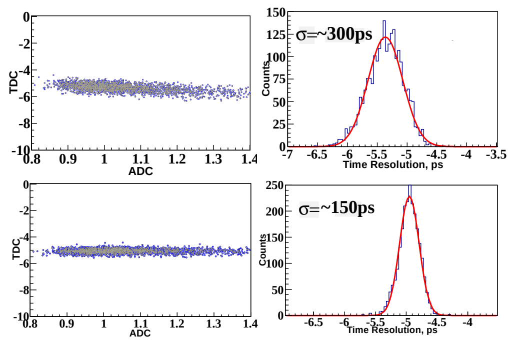


FIG. 2: A typical TDC vs ADC spectrum before(upper left panel) and after(lower left panel) the slewing correction.

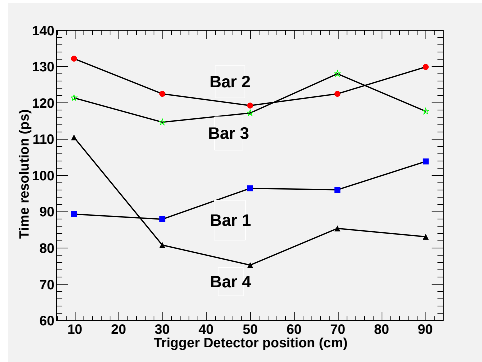


FIG. 3: Time resolution of the four scintillator bars as a function of position along its length.

The slewing effect is, in general, a function of amplitude and rise time of the input pulse. It has the tendency to decrease the propagation delay through the system with increasing input pulse height and/or decreasing input rise time, at a fixed threshold level. The dependence of time spectrum(y) on input signal amplitude(x) was fitted with the following function

$y = \sum_{i=0}^{3} \frac{A_i}{x^{i/2}}$

and the spectrum, after corrected for the slewing effect, is shown in the Fig.2 (lower left part). The improved timing resolution($\sigma$) is shown in the lower right part of Fig.2. In Fig.3 we plot $\sigma$ values for different positions of the trigger detector. A timing resolution in the range of 75-140 ps has been achieved.

## Determination of effective speed of light

The effective speed of light($c_{eff}$) inside the scintillation medium was determined from time difference between the arrival of scintillation photons at the left and right PMTs. The time taken by the scintillation photons to reach the left end ($t_L$) and right end ($t_R$) of the bar is

$t_L = \frac{x}{c_{eff}}$, $t_R = \frac{L-x}{c_{eff}}$,

where x is the position of the trigger detector from the left end of the scintillator bars and L is the length of the bars.

Then the time difference is

$\Delta t = t_L - t_R = \frac{2x-L}{c_{eff}}$.

From the plot of $\Delta$T vs x, effective speed of light was derived. A preliminary analysis yields a value of $c_{eff}$ = 13.3 cm/ns.

In summary, the plastic scintillator based Range Counter, which has been designed and built for the studies of $K^-$pp bound state at the Hadron experimental Hall, J-PARC, has been tested with cosmic muons and time resolution, with time slewing correction, of ∼100 ps has been achieved. The present technique of achieving such a fast timing resolution will be very useful to our other programme on charmonium studies under the PANDA collaboration for the development of a ultra fast timing detector using plastic scintillator with SiPM readout [2].

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## References

[1] T. Nagae *et al.*Experimental Proposal for J-PARC Search for a nuclear $\overline{K}$ bound state $K^-$pp in the d($\pi^+$,$K^+$) reaction,(2011).

[2] B.J.Roy *et al.*, Journal of Phys - Conference Series, 2012 (Submitted)