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DEVELOPMENT OF HIGH RESOLUTION TOF DETECTOR FOR RI BEAMS USING CHERENKOV RADIATION*

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We have developed a high time resolution time-of-flight (TOF) detector that detects the Cherenkov light emitted when an RI beam passes through a high refractive index glass. ^{58}Ni and ^{132}Xe beams of energies of 200 A–500 A MeV and secondary beams produced with those beams have been used for the test of the Cherenkov detectors. The time resolution of $\sigma = 5$ ps with the inclusion of system resolution has been achieved with a 420 A MeV ^{132}Xe beam.

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1. Introduction

The production of unstable nuclei in the form of energetic radioactive isotope (RI) beams is an important means to understand features of unstable nuclei through the experimental approach. Sometimes, a high time

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resolution detector is crucial for such experiments. It is not important only to make clear and better identifications of relativistic RI beams with the use of fragment separators; *e.g.* BigRIPS in RIKEN or FRS in GSI, but also to perform modern nuclear physics experiments in which identification and precise measurements of the momentum of isotopes produced through secondary reactions of RI beams are required.

Generally, a plastic scintillation counter has been used as a fast TOF detector. The fast scintillation light of an organic scintillator can be emitted with a decay time of the order of a few ns. On the other hand, the Cherenkov light can be instantly emitted without de-excitation delay. Therefore, it would be advantageous to use the Cherenkov radiation instead of scintillation to measure TOF with high time resolution. Though the number of emitted photons by the Cherenkov radiation in the case of low-Z and low-energy beams is usually very small for an ordinary radiator compared to that of scintillation, this can be overcome for high-energy, high-Z beams by using a high refractive index material as radiator. Employing such a radiator for high-energy beams would also contribute to the increase of collection efficiency of emitted photons satisfying the total reflection condition in the radiator. A schematic drawing of the principle of this detector is shown in Fig. 1.

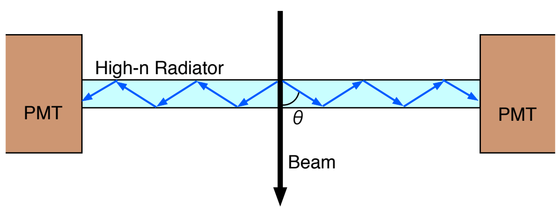

Fig. 1. Schematic drawing of the Cherenkov light emission, propagation, and collection.

2. Experiment

The present Cherenkov TOF detector is basically composed of a thin radiator made out of high refractive-index glass (1 mm thick $\times$ 30 $\times$ 30 mm^2 area) coupled with two photomultiplier tubes on the left- and right-hand sides (2PMT-type; Fig. 2). Then, a 4PMT-type was also constructed which has four photomultipliers contacted on all four side surfaces including up and down sides. The radiator used in the test measurements was S-LAH55V high refractive-index glass manufactured by OHARA Co., Ltd. which has a refractive index of $\sim$ 1.89 at λ = 400 nm. The photomultiplier tubes were HAMAMATSU R11265U, which have a metal-channel-type dynode structure, a transit time spread of 0.27 ns and a quantum efficiency of 43%.

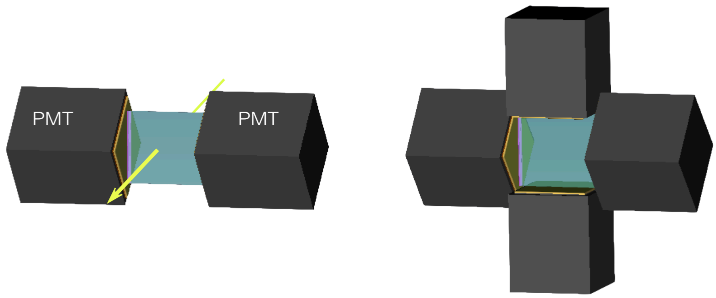

Fig. 2. Schematic drawings of the 2PMT-type (left-hand side) and the 4PMT-type (right-hand side) Cherenkov TOF detectors.

Test measurements were performed at the heavy-ion synchrotron facility HIMAC (Heavy Ion Medical Accelerator in Chiba), the National Institute for Radiological Sciences [1] using the fragment separator beam line [2]. ^{58}Ni and ^{132}Xe beams with energies from 200 A to 500 A MeV have been used for the test of Cherenkov detectors. The digitization of the time interval was done with the combination of a TAC (Time-to-Amplitude Converter) and a high-gain ADC (Analog-to-Digital Converter) to achieve a high resolution for the data acquisition system. A typical setup for the measurement located at the final focus of the beam line F3 is shown in Fig. 3.

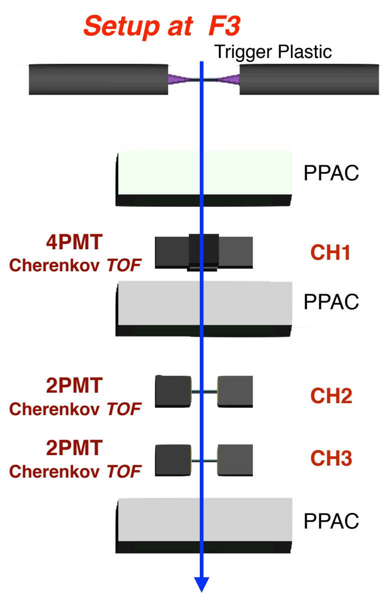

Fig. 3. Schematic drawing of the experimental setup.

3. Results and discussion

A typical time spectrum of the time difference between detectors CH1 and CH2 is shown in Fig. 4. The time information for one detector is obtained by the average of all photomultipliers of the detector. As there are three combination pairs with the three Cherenkov TOF detectors shown in Fig. 3, we can construct three time difference spectra, t(CH1-CH2), t(CH2-CH3), t(CH3-CH1), to obtain time resolution for each pair. The relation

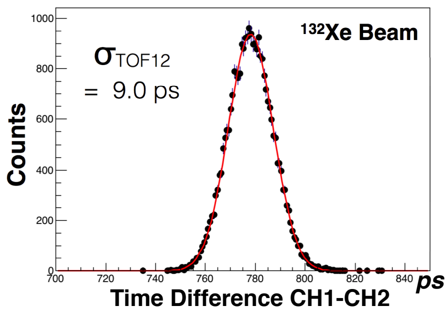

Fig. 4. Typical time difference spectrum between CH1 and CH2 for a ^{132}Xe beam.

between these observed time resolutions and time resolutions of individual detectors is as follows:

$$\begin{cases} \sigma^2_{\mathrm{TOF12}} = \sigma^2_{\mathrm{CH1}} + \sigma^2_{\mathrm{CH2}}\,, \\ \sigma^2_{\mathrm{TOF23}} = \sigma^2_{\mathrm{CH2}} + \sigma^2_{\mathrm{CH3}}\,, \\ \sigma^2_{\mathrm{TOF31}} = \sigma^2_{\mathrm{CH3}} + \sigma^2_{\mathrm{CH1}}\,. \end{cases} \tag{1}$$

Solving these simultaneous equations, time resolutions of individual detectors, $\sigma_{\mathrm{CH1}}, \sigma_{\mathrm{CH2}}$, and σ_{CH3} can be extracted from the observed resolutions.

In order to study the dependence of time resolution on the number of detected photons, we employed different energy beams and also different nuclide beams in the test measurements. The primary beams used were 420 A MeV ^{132}Xe and 500 A MeV ^{58}Ni. Lower energy beams of these primary beams were also obtained by using energy degraders which are thin enough not to cause a degradation of time resolution due to the broadening of beam energies by energy straggling. The time resolution obtained for ^{132}Xe beam plotted against the beam energy is shown in Fig. 5. The time resolution shows better results for higher beam energies, reflecting the larger number of photons emitted by the Cherenkov radiation for higher energies. We could not observe a significant difference between the results of the 4PMT-type and 2PMT-type configurations. The best time resolution of $\sigma = 5$ ps with the inclusion of system resolution has been achieved for both configurations with a 420 A MeV ^{132}Xe beam, where the system resolution is around 3–4 ps.

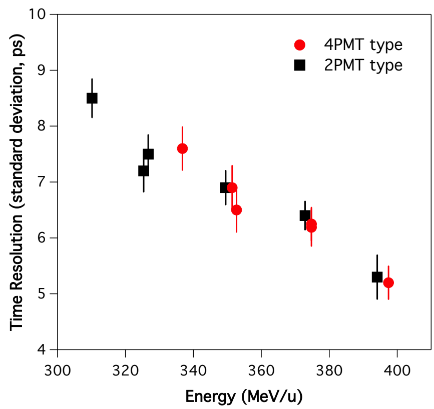

Fig. 5. Time resolution of a detector including system resolution plotted as a function of beam energy for ^{132}Xe beam.

Figure 6 shows the time resolution plotted as a function of the number of detected photons including the data taken with ^{58}Ni beams. The number of detected photons was deduced from a Monte Carlo simulation assuming the almost real conditions of Cherenkov radiation and transit, reflections, escapes, and absorptions of emitted photons, between the beam interaction point and the photocathode window of photomultiplier tube. Because the deduction relies only on the calculation through the simulation and includes conditions close to the real one, the deduced number of detected photons might contain a certain systematic error. However, also in this case, a tendency of a better resolution for a larger number of detected photons is observed when including ^{58}Ni beam data.

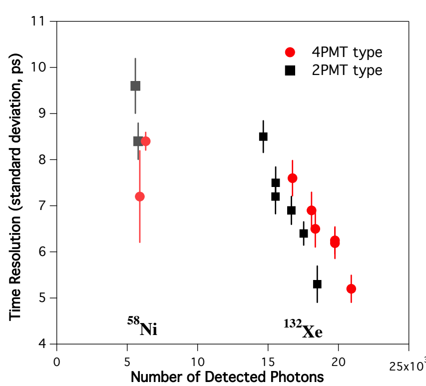

Fig. 6. Time resolution of a detector including system resolution plotted as a function of number of detected photons for the ^{58}Ni and ^{132}Xe beams.

Secondary beams produced from the projectile fragmentation of the ^{132}Xe beam on a Be target of thickness of 2 mm were also used for the test measurements. As an example, the data for ^{120}I are shown in Fig. 7 together with the above data by primary beams as a function of number of detected photons. For the data from the 262 A MeV ^{120}I beam, a larger radiator of size 50×50 mm^2 (1 mm thick) was used. This might cause a somewhat worse time resolution. The 330 A MeV ^{120}I data are comparable to the systematics of other primary beam data although the precision is not so good, and as a whole, they appear to show the tendency of a better resolution for a larger photon number. In order to make the relation between the time resolution and number of detected photons more clear, and to enable a reliable prediction of the time resolution for a certain condition, more systematic analyses of the data including those of secondary beams are now in progress. At the same time, we are going to develop a Cherenkov TOF detector with a larger area.

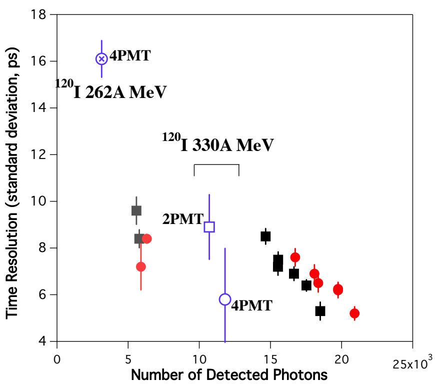

Fig. 7. Time resolution of a detector plotted similarly to Fig. 6 including the data for a ^{120}I secondary beam.

REFERENCES

[1] Y. Hirao *et al.*, *Nucl. Phys. A* **538**, 541 (1992).

[2] M. Kanazawa *et al.*, *Nucl. Phys. A* **746**, 393 (2004).