Development of a total-kinetic-energy counter for high-rate experiments at ZeroDegree spectrometer

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A total-kinetic-energy (TKE) counter for particle identification at the ZeroDegree (ZD) spectrometer was tested in 2014. The detector is aimed at the discrimination of not fully stripped ions for the mass region $A \gtrsim 100$. For example in the case of $^{136}$Sn (RIBF31), the mass-to-charge ratio $(A/Q)$ is sufficiently close (50%–60%) to that of $^{70}$Sn for a good resolution in the TOF–$B\rho$–$\Delta E$ method. The mass resolution was not as good as 1% (FWHM). Silicon-glass scintillator was tested. The feasibility of charge-state identification using this scintillator was tested. The TKE counter is required to have a resolution of 1% (FWHM) in order to separate the fully stripped ions from the neighboring charge-state contaminants. In order to separate the fully stripped ions from the neighboring charge-state contaminants, the TKE counter is required to have a mass resolution of 1% (FWHM).

Considering the beams with high counting rate (~100 kepc), the counter should have a short decay time and radiation resistance. For this purpose, a $\alpha$3$''$ LaBr$_3$(Ce) scintillator with a 0.5-mm$^2$ aluminium housing is prepared. It is mounted downstream of the F11 multiple sampling ionization chamber (MUSIC). In previous studies, the feasibility of charge-state identification using this scintillator was tested. The mass resolution was not as good as 1% (FWHM). Simultaneously, a quenching phenomenon was observed, namely, the light yield per energy deposition of the incident beam decreases as a function of $Z$. To obtain higher resolution, the degree of the quenching phenomenon should be known for the optimization of the amplification factor of the light readout.

In 2014, two types of light readouts were tested. For the first case, five PIN-photodiodes (S3204-08, HPK) were aligned on the downstream surface of the scintillator. A second setting (tested in the experiments RIBF61, RIBF51R1 and RIBF56R1), the readout consists of a $\alpha$3$''$ PMT (R6909IA, HPK) and a tapered-type divider (E5859, HPK) coupled with the scintillator. In this report, the result of the second setting is discussed.

During three experiments, the amplitudes of the signal of the PMT were measured using an oscilloscope with several high-voltage (HV) settings. The ZD spectrometer was set for $^{132}$Sn (20.8 GeV), $^{70}$Ni (15.2 GeV), and $^{22}$O (5.21 GeV), for the respective

Fig. 1. Amplitude of the PMT output with several HVs for each ZD spectrometer settings.

Table 1. Signal amplitudes per unit energy.

<table>
<thead>
<tr>
<th>Particle</th>
<th>Amplitude (mV/GeV)</th>
<th>Quenching factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{132}$Sn</td>
<td>124</td>
<td>1</td>
</tr>
<tr>
<td>$^{22}$O</td>
<td>40</td>
<td>0.32</td>
</tr>
<tr>
<td>$^{70}$Ni</td>
<td>19</td>
<td>0.16</td>
</tr>
<tr>
<td>$^{132}$Sn</td>
<td>15</td>
<td>0.13</td>
</tr>
</tbody>
</table>

experiments. Figure 1 shows the signal amplitudes as a function of applied HV for different isolopes. For reference, data of the $\gamma$-ray calibration before and after the experiments with $^{22}$Na, $^{60}$Co and $^{137}$Cs sources are also plotted. They are normalized by the energy of the $\gamma$-ray, namely, the amplitudes per 1 MeV.

For the $^{132}$Sn and $^{22}$O settings, owing to the frequent implantation rate (~40-100 kepc) and high light yield, the PMT output was saturated with overcurrent of the divider circuit when the HV value was above 700 V. On the other hand, the slopes below 700 V are similar to the one of $\gamma$-ray. This ensures that the PMT has linearity even for the lower operation voltage.

By extrapolating the $\gamma$-ray results to the lower-voltage region, the light yield of the scintillator is compared with heavy ions. The values in the center column of Table 1 are the signal amplitudes per the kinetic energies when the HV is set at 650 V. The quenching phenomena of the light yield are observed obviously. According to this result, optimum gain of the PMT can be discussed. A new divider circuit designed from this result will be tested in 2015.

References
4) He Wang et al., in print.

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∥6 The kinetic energies of heavy ions are deduced from the $B\rho$ values of the last dipole of ZD spectrometer.
∥7 The ratio of the signal amplitudes per energies of heavy ions to that of $\gamma$-ray.

- 210 -