Calibration of the Extended Quadrihedral NaI(Tl) Spectrometer by Cosmic Muons

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Abstract—The results of cosmic muon calibration of the extended quadrihedral NaI(Tl) spectrometer are presented. The signal amplitude and energy resolution of the spectrometer in the direction transverse to the spectrometer axis have complex dependences on the photomultiplier voltage and particle entrance point to the spectrometer. At a photomultiplier divider voltage $U = 1150 \pm 10$ V, the region of uniform signals is observed over ~90% of the spectrometer length, the relative energy resolution is $\delta \approx 7\%$.

Keywords: calibration, NaI(Tl) spectrometer, energy resolution, cosmic muons

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The near-threshold neutral pion photoproduction on the neutron ($\gamma + n \rightarrow \pi^0 + n$) has not yet been experimentally studied in detail.

It is planned to study this process on a special setup using an extracted electron beam and a system for tagging photons at C-25P “Pakhra” accelerator of the Lebedev Physical institute [1, 2].

Within the present problem, it is planned to study the behavior of the total cross section of the neutral pion photoproduction on the neutron using a setup consisting of extended quadrihedral NaI(Tl) spectrometers (Fig. 1) [3]. The destination of these spectrometers is to measure $\gamma$-rays from decay of $\pi^0$ mesons emitted from a carbon target positioned at the assembly center and to determine their energy. At such a setup configuration, electromagnetic $\gamma$-ray-induced showers should develop in the direction transverse to the spectrometer axis. In this case, a problem arises, associated with the nonuniformity of signals coming from various $\gamma$-ray entrance points to each spectrometer with respect to the photomultiplier (PM) placed at one end face of the spectrometer. To study the dependence of the signal amplitude and the amplitude resolution on the $\gamma$-ray entrance point to the spectrometer in the transverse direction, preliminary calibration by cosmic muons was performed. At the existing configuration of extended NaI(Tl) spectrometers used in this setup, there is only one parameter which can be varied to achieve the best signal uniformity in the transverse direction of the spectrometer; this is the PM divider voltage.

Each of four setup spectrometers $12 \times 12 \times 45$ cm$^3$ in size consists of three NaI(Tl) scintillator units $12 \times 12 \times 15$ cm$^3$ in size glued with each other. The radiation length in the transverse and longitudinal direction is $4.8X_0$ and $18X_0$, respectively ($X_0 = 2.5$ cm is the NaI(Tl) radiation length ($\rho = 3.67$ g/cm$^3$)). The spectrometer is viewed from the end face by one photomultiplier FEU-52 with standard voltage divider.

The calibration scheme of one of the NaI(Tl) spectrometers is shown in Fig. 2. The spectrometer was arranged between two trigger counters $S_1$ and $S_2$ $4 \times 4 \times 0.5$ cm$^3$ in size, placed at a distance of 15 cm from each other. Before calibration, using a $^{60}$Co radiation source, the effective operating voltages at $S_1$ and $S_2$ were determined, time delays were set between $S_1$ and $S_2$ and between $S_1$ and $S_2$ and the NaI(Tl) spectrometer.

Signals from a cosmic muon passage through $S_1$ and $S_2$ were fed to shapers Sh$_1$ and Sh$_2$ (the shaping threshold of both shapers was $U_{thr} = 30$ mV, the signal durations were $T_{Sh1} = T_{Sh2} = 20$ ns) and then, through delay units $D_1$ and $D_2$, to the coincidence circuit CC. The signal the coincidence circuit CC of

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duration $T_{cc} = 100$ ns was fed to the long signal shaping LSS unit which formed signal $T$ 1000 ns long. Signal $T$ was a trigger signal ($T = Sh \cdot S$) “Start” for triggering unit 4 of the input charge-to-digital converter (CDC) using which the signal from the NaI(Tl) spectrometer was “written” to the computer memory through a crate controller of the CAMAC system.

Figure 3 shows the dependences of the average signal amplitude from the NaI(Tl) spectrometer on the longitudinal coordinate and PM voltage. We can see that the average signal amplitude come to the PM from the far spectrometer end face (the inset in Fig. 3) at all voltages is about twice lower than the average amplitude in the case of particle passages near the PM. The amplitude nonuniformity along the spectrometer length exists almost for all studied PM divider voltages. However, at voltage $U = 1100$ V, the amplitude is almost constant over ~90% of the spectrometer length.
It can be assumed that the spectrometer size has an effect on the signal nonuniformity at a significant spectrometer depth. The light collection in an extended and relatively “narrow” spectrometer volume is much worse, than in a spectrometer of the same length, but with a larger aperture. In the case at hand, the size cannot be changed, but its effect can be reduced by decreasing the PM sensitivity, i.e., by lowering the divider voltage ($U \leq 1180$ V) (dependence $1$ in Fig. 3).

The dependence of the relative energy resolution of the NaI(Tl) spectrometer on the FEU-52 PM divider voltage and the cosmic muon entrance point $x$ to the spectrometer (the inset in Fig. 3): ($1$) 4 cm, ($2$) 22 cm, ($3$) 38 cm, ($4$) 40 cm, and ($5$) 44 cm.

We can see that $\delta$ varies from 4 to 10% depending on the divider voltage and the point of muon passage through the spectrometer. The resolution degrades as the point of muon passage through the spectrometer recedes from the PM and the divider voltage increases. It can be assumed that there are significant fluctuations associated with light collection in a dense material in spectrometer volume regions far from the PM. However, Fig. 4 shows that there is a small voltage range $U = 1150 \pm 10$ V at which the energy resolution of the NaI(Tl) spectrometer is almost constant over the entire spectrometer length and is $\delta \approx 7\%$.
For given spectrometer sizes and used PM type, the voltage \( U = 1150 \pm 10 \text{ V} \) is optimum.

When calibrating three remained NaI(Tl) spectrometers by cosmic muons, the dependences similar to those in Figs. 3 and 4 were obtained. Numerical values of the obtained dependences differ from the presented ones no more than by \( \sim 20\% \).

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