In-beam tests of a new ToF wall for the R^{3}B setup*

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Introduction

An important part of the R^{3}B setup will be the tracking system which allows the identification of mass and atomic number of the incoming beams as well as of the outgoing beam-like fragments and the emitted protons. Also, precise information on the momentum of the detected particles is required. The main design goals of the tracking system are: Measurement of the nuclear charge and mass with a resolution allowing separation of neighboring nuclei up to the Pb region; Total momentum measurement with a relative resolution of $\Delta P/P < 2\text{x}10^{-3}$ (σ); Operation in a high-rate mode (up to 1 MHz) and in a multi-hit mode with large acceptance; Detection efficiency of the combined system should exceed 85%. These goals will be accomplished by using a series of detectors, see [1], placed before and after the large acceptance dipole magnet GLAD. Silicon detectors for energy-loss and position measurement, thin plastic scintillator fiber detectors for position measurements, fast scintillator detectors for timing and energy-loss measurements (ToF wall), and large-area straw-tube gas detectors for evaporated protons flying at forward angles through the spectrometer into the proton arm. Several prototypes of the tracking detectors have been tested during the S438 experiment in 2014 using stable beams of ^{58}Ni and ^{48}Ca at 500 AMeV. Especially valuable was also the SOFIA experiment with FRS settings for ^{187}Tl and ^{194}Bi at $\sim$ 700 AMeV which could be used in a parasitic manner and allowed us to test the detector properties for heavy nuclei.

In this report the main results of the Time-of-Flight (ToF) wall will be presented. A prototype of the new ToF wall was positioned about 13 m downstream of the target, behind the large-acceptance dipole magnet ALADIN. The ToF wall is based on a fast plastic scintillator material and the active part will cover an area of 120x80 cm^2 in the final stage. It will consist of 4 planes, each containing 44 vertical scintillator paddles with a thickness of 5 mm. The scintillators are read out by photomultipliers on both far ends. The prototype which was used for the tests was equipped with only 6 paddles per plane. In all experiments we have been able not only to measure incoming beams but also their residues created in reactions of incoming particles at different materials situated in front of the detector prototype. Beside the time-of-flight, this detector gives also information on the nuclear charge of the outgoing particles.

In [4] we have reported on LED tests of the ToF wall prototype. Here, we will discuss results obtained with heavy-ion beams in the above-mentioned beam times.

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Results

During the beam tests two different read-out systems have been tested: A prototype of a new multichannel electronic card TAMEX [2] combined with the LAND front-end [3] and a general purpose Pre-Amplifier-Discriminator PADI [5] combined with a VFTX module [6]. The PADI system measures the time-over-threshold of the photomultiplier signals whereas the TAMEX electronics utilizes in addition a charge-to-time converter in order to determine the charge of the signal. Both systems have been developed by the GSI EE group.

Furthermore, the influence of different wrapping materials on the light transport in the scintillators were tested.

Time resolution

As discussed in Refs. [4, 7] in order to match the momentum resolution of other parts of the tracking system the relative time-of-flight resolution of the ToF wall should be around $2 \cdot 10^{-4}$ for nuclei in the lead region which translates into a time precision of better than 16 ps (σ) for the ^{197}Bi beam measured here. For lighter nuclei of course the requirements on the ToF resolution are not that strong; e.g. for the ^{58}Ni beam measured in this experiment a ToF resolution of 37 ps is sufficient.

Beam	σ_t **/ ps**	σ_t^{det} **/ ps**
^{48}Ca	52	18
^{58}Ni	41	14
^{194}Bi	22	8

Table 1: Time resolution measured with the ToF wall prototype (PADI electronics) between individual paddles (middle column) and the expected time resolution for the full detector (last column) for different incoming projectiles.

In the present experiments, the intrinsic time resolution of the detector was determined by the measurement of the time difference between two successive scintillator paddles which were hit by the same beam particle. Table 1 contains an overview of the measured time resolution and, based on these values, the expected performance for the full detector with 4 planes. It can be seen that the expected time resolution in all cases is well below the values needed to separate neighboring masses even for nuclei in the lead region.

During the ^{58}Ni beam time the properties of the ToF wall could be monitored for varying beam rates. Time and nuclear-charge resolution have been measured at 5 different rates ranging from 5 kHz to 1 MHz. It could be demon-

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strated that the excellent performance can be maintained even at very high beam rates up to 1 MHz (see Table 2).

Rate / kHz	σ_t / ps	σ_t^{det} / ps
5	41	14
59	41	14
375	45	16
1000	64	23

Table 2: Time resolution measured with the ToF wall prototype (PADI electronics) between individual paddles (second column) and the expected time resolution for the full detector (last column) for different counting rates in the experiment with ^{58}Ni beam.

Nuclear-charge resolution

In the present experiments, the time-over-threshold measurement of the photomultiplier signals was used to determine the nuclear charge of the ions by energy-loss measurements in the scintillator. In order to separate charge Z from $Z-1$ even for the most challenging heavy beams (e.g. Pb) a nuclear-charge resolution of $\sigma_Z/Z{<}1\%$ is necessary. Table 3 shows the measured Z-resolution for the test beams and Fig. 1 shows a measured charge spectrum for a ^{194}Bi beam.

Beam	σ_Z	σ_Z/Z / %
^{48}Ca	0.15	0.75
^{58}Ni	0.19	0.68
^{194}Bi	0.34	0.41

Table 3: Nuclear-charge resolution measured with the ToF wall prototype (PADI electronics) for different projectiles.

One can see that even for ^{194}Bi the resolution is good enough to resolve neighboring charges.

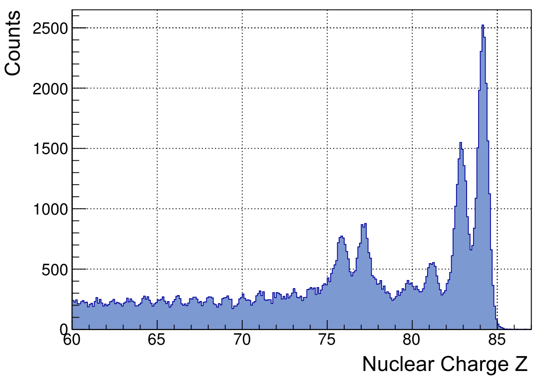

Figure 1: Nuclear-charge spectrum obtained from energy-loss measurements of two scintillator paddles for a FRS setting around ^{194}Bi. The main peak at Z=83 is suppressed by cuts in order to see neighboring charges better.

The performance of the detector was also checked at different beam rates with ^{58}Ni ions and an excellent Z-resolution around 0.2 Z-units (σ) could be achieved for rates up to 1 MHz.

Rate / kHz	σ_Z	σ_Z/Z / %
5	0.19	0.68
59	0.19	0.68
375	0.23	0.82
1000	0.23	0.82

Table 4: Nuclear-charge resolution measured with the ToF wall prototype at different counting rates using ^{58}Ni beam.

Furthermore, we have tested the stability of the nuclear-charge measurements at different rates. In experiments where beam rates can change drastically it is mandatory that the relative shift in the nuclear-charge measurements remains below 1% in order to avoid dependencies of the peak position in the energy spectrum on the counting rate. By choosing a photomultiplier voltage around 400 V, corresponding to signal amplitudes of about 60 mV, we have, during the ^{58}Ni experiment, reached very stable nuclear-charge measurements with relative shifts in Z remaining below 1% also for the highest rates of 1 MHz. This was only possible by using the new electronics read-out developed by the GSI EE group.

Conclusions

We have tested the properties of a prototype of the new ToF wall detector using several beams. We have shown that even in case of nuclei in the lead region we can fulfill the design goals concerning time-of-flight and nuclear-charge resolution even at the highest counting rates of 1 MHz.

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