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A NEW BEAM DIAGNOSTIC SYSTEM FOR THE MASHA SETUP

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A new beam diagnostic system based on the PXI standard was developed, tested, and used in the MASHA setup experiment. The beam energy and beam current measurements were carried out using several methods. The online time-of-flight energy measurements were carried out using three pick-up detectors. We used two electronic systems to measure the time between the pick-ups. The first system was based on fast Agilent digitizers (2-channel, 4-GHz sampling rate), and the second one was based on a constant fraction discriminator (CFD) connected to a time-to-digital converter (TDC, 5-ps resolution). A new graphical interface to monitor the electronic devices and to perform the online calculations of energy was developed using MFC C++. The second system based on microchannel plate (time-of-flight) and silicon detectors for the determination of beam energy and the type of accelerated particles was also used. The beam current measurements were carried out with two different sensors. The first sensor is a rotating Faraday cup placed in front of the target, and the second one is an emission detector installed at the rear of the target. This system is now used in experiments for the synthesis of superheavy elements at the U400M cyclotron of the Flerov Laboratory of Nuclear Reactions (FLNR).

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INTRODUCTION

One of the significant changes over the past years in the MASHA mass spectrometer setup was an upgrade of the beam diagnostic system. MASHA stands for the Mass Analyzer of SuperHeavy Atoms. The spectrometer was developed at the Flerov Laboratory of Nuclear Reactions to carry out precise measurements of atomic masses and spectroscopic studies of superheavy atoms [1]. The precise measurements of beam parameters are important for nuclear reactions. To synthesize superheavy elements, it is useful to carefully measure the beam energy and beam intensity. For the MASHA setup, we had to improve the measurements of the two previous beam parameters. The results of the development and the general information on the beam diagnostic system are presented in this paper.

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1. ONLINE BEAM ENERGY MEASUREMENT

The online time-of-flight beam energy measurement [2] is based on pick-up detectors. A simple cylindrical detector embedded in an ion guide and connected to a coaxial cable is used (Fig. 1).

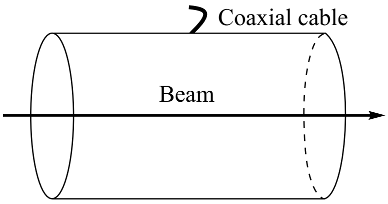

Fig. 1. Schematic drawing of a pick-up detector

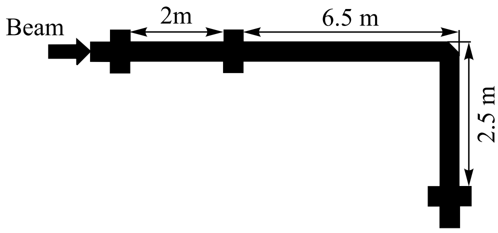

Fig. 2. Pick-up detectors arrangement

The capacity between the ion guide and the pick-up detector decreases signal intensity. The capacity can be minimized by increasing the pipe diameter of the ion guide. A preamplifier is connected to the pick-up detector at the minimum distance. By connecting the pick-up detector to the preamplifier, the capacity and resistivity were added to the feedback, which caused high frequency on the preamplifier. The preamplifier served as a generator. It was therefore necessary to adjust one preamplifier strictly to one detector. We adjusted precisely the feedback of the preamplifier and the resistivity between the first and the second preamplifier stages. Three detectors were used to improve the reliability and accuracy of the measurement (Fig. 2).

Such a setup allows one to carry out two independent energy measurements. The distance between the first pair of the detectors is 2 m and that between the second pair is 11 m. The accuracy is low when the distance between the detectors is short. However, when the distance is longer, we have to look for a second or another peak in the row [3]. Using new electronic devices, like digitizers, it is possible to check the second or another peak in the row and improve the accuracy. In general, we measured the time between the pick-up detectors. To calculate the energy from the time Δt, we used a relativistic equation

$$E = m_a \left(\frac{1}{\sqrt{1 - \left(\frac{l}{\Delta t c}\right)^2}} - 1 \right), \tag{1}$$

where l is the distance between the pick-up detectors, c is speed of light, and m_a is the isotopic weight. We measured the time Δt by using the Agilent 9210 digitizer (2-channel, 4-GHz sampling rate) and the Agilent TC842 TDC (12-channel, 5-ps resolution). Both devices were connected in parallel with the pick-up detectors (Fig. 3). CFD in the figure stands for a constant fraction discriminator, and HPF is a high-pass filter.

In the energy measurement setup, we used a Phillips scientific 715 constant fraction discriminator (CFD) and a Phillips scientific 744 splitter. The CFD was connected in tandem with the TDC to eliminate the impact of signal amplitude changes on the measurement and to achieve higher accuracy. TDC worked with NIM standard pulses produced by the CFD. We achieved good measurement accuracy by collecting many Δt's and calculating an average

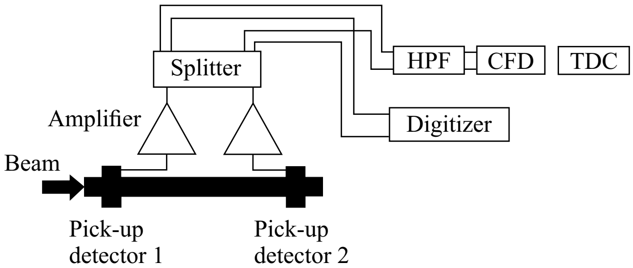

Fig. 3. Schematic view of pick-up detectors connected to the digitizer and TDC

Δt because the beam bunch frequency was about 14 MHz. In front of the CFD, a HPF was embedded to eliminate low-frequency noise. In the second system, digitizers were used for signal evaluation. The system allowed online signal processing (Fig. 4).

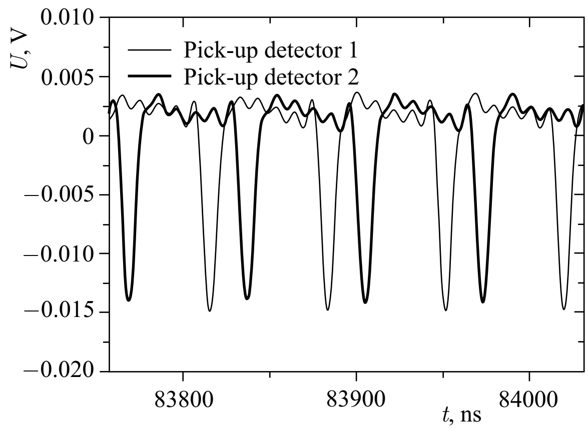

Fig. 4. Signal from the pick-up detectors measured by the digitizer

The noise was filtered with the fast Fourier transformation, and the energy resolution was improved with the numerical constant fraction. A peak position was determined with the linear and quadratic least square regression and many other methods. In Figs. 5 and 6, the measured energy evaluated with the quadratic and linear least square regression is shown.

The observed energy fluctuation can be real or sometimes caused by signal noise in the pick-up detectors. The electronic devices were assembled together with a short distance between them to reduce signal noise.

With this setup, we achieved an energy measurement accuracy of about 1% at a 2-m distance between the detectors and 0.25% at an 11-m distance between the detectors. The greatest advantage of digitizers is their versatility [6]. It is possible to improve the accuracy by using numerous mathematical algorithms developed for signal processing. Cyclotron diagnostics is also possible by analyzing signal shape with digitizers. Time calibration was done by comparing the time delay between the first and second branches of the energy measurement system (Fig. 7).

The pick-up detectors were replaced by a generator. In front of the splitter, we added a coaxial cable to increase the delay in one branch. This was done since a very small time delay was impossible to measure with the used electronic devices. The coaxial cable was also

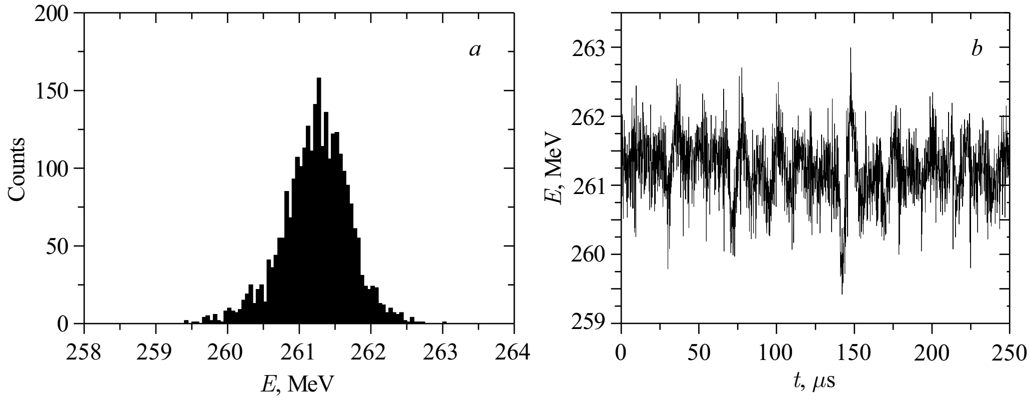

Fig. 5. Spectrum and energy dependence on time for the quadratic least square method

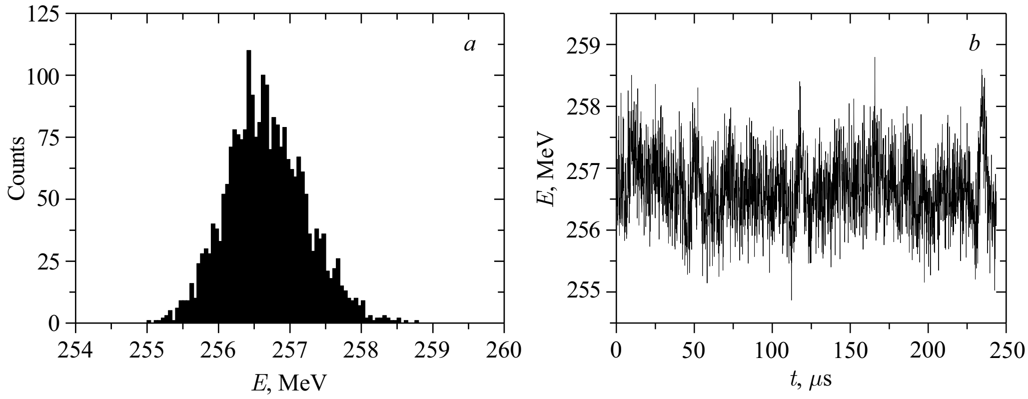

Fig. 6. Spectrum and energy dependence on time for the linear least square method

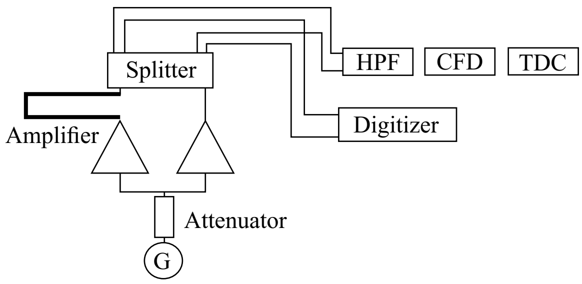

Fig. 7. Scheme of time calibration connection

kept in the physical experiment. Under this approach, we expect that both pick-up detectors possess the same properties.

2. OFF-LINE BEAM ENERGY MEASUREMENT

The second energy measurement system combined the time-of-flight energy measurement and a semiconductor detector [7] (Fig. 8).

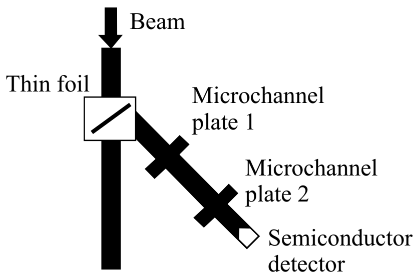

Fig. 8. Microchannel plates and semiconductor detector arrangement

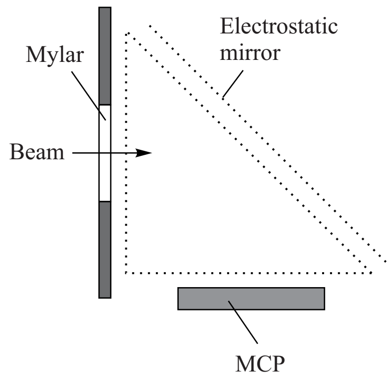

Fig. 9. Microchannel plate layout

The time-of-flight measurement was based on microchannel plates (MCPs). This system had a worse energetic resolution, but the time-of-flight detectors in combination with the semiconductor detectors allowed beam particle mass determination. According to Eq. (1), if we know the time Δt and the energy E, it is possible to determine the beam isotopic weight m_a. The time-of-flight setup detected the electrons emitted by a beam from the Mylar and bounced by the electrostatic mirror directly to the MCPs (Fig. 9).

A signal from the detectors was processed by a CFD, a time-to-analog converter (TAC), an analog-to-digital converter (ADC), a gate generator (GG), and a logical element AND (Fig. 10).

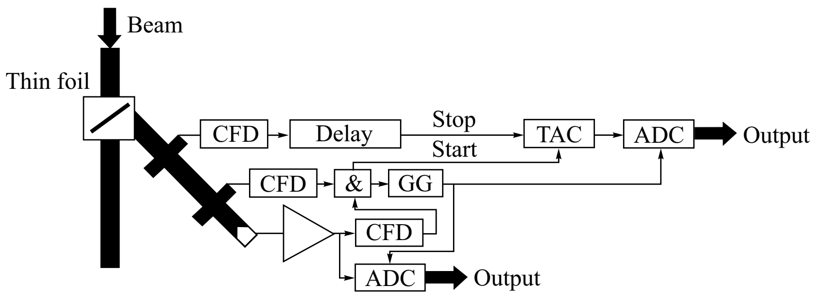

Fig. 10. Electronic scheme of signal processing from MCPs and the semiconductor detector

A source of alpha particles with three different energies was used in the calibration measurement (Fig. 11).

3. BEAM CURRENT

The beam current measurement was based on the Faraday cup [4] placed before the target. The online beam intensity measurement collected electrons [5] by an electrode assembled close to the target (Fig. 12).

The electrons were emitted by a beam from the target. The electrode was connected to highly precise 50-μA-range power suppliers made at JINR. A high potential of about 100 V was applied to the electrode to support the collection of the emitted electrons.

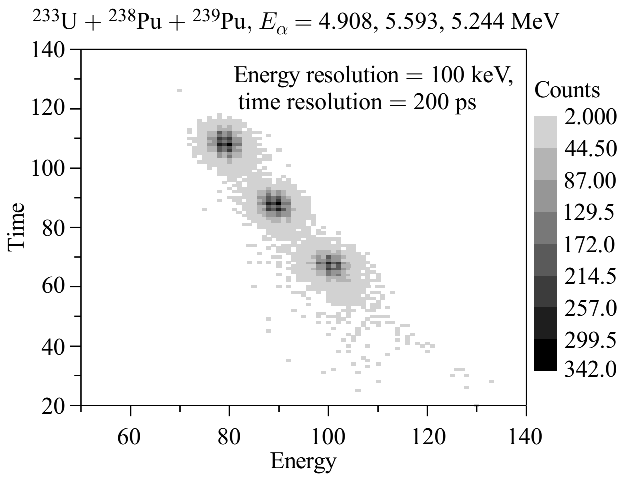

Fig. 11. The data measured with the time-of-flight and semiconductor detector

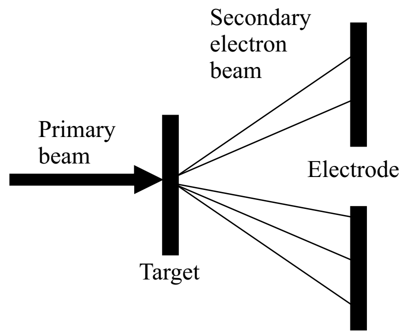

Fig. 12. Online beam intensity measurement

CONCLUSIONS

The new beam diagnostic system improves the capabilities of the MASHA setup and allows determination of the properties of atoms. The precise beam energy measurements increase the probability of the synthesis of superheavy atoms. The accuracy of the time-of-flight energy measurement increased proportionally to the distance between the two pick-up detectors. The second system based on the microchannel plate and silicon detector for the determination of the type of accelerated particles was also used. The accuracy of measurements based on the pick-up detectors was about 0.25%, and that of the measurements based on the silicon detector was approximately 2%. From the signal saved by the digitizers, a beam shape can be determined, which allows operators to diagnose the accelerator. The online beam current measurement was performed by the emission detector and calibrated by the Faraday cup. All the devices were monitored by a computer using the LabVIEW and C++ MFC programs. The graphical interface for the beam diagnostic and measurement systems was developed in C++ MFC.

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