INTRODUCTION

The unexplored area of the chart of the nuclides in the region of heavy neutron-rich nuclei is extremely interesting for nuclear structure and nuclear astrophysics investigations. The multinucleon transfer process, at bombarding energies close to the Coulomb barrier, has been suggested as a possible pathway to populate neutron-rich nuclei in the region of the neutron shell closure $N=126$, which is the last “waiting point” in the r-process of astrophysical nucleogenesis.

With this aim, we explored the multinucleon transfer reactions in low-energy collisions of $^{136}$Xe with $^{208}$Pb. The idea is to use the stabilizing effect of the closed neutron shells in both nuclei, $N=82$ and $N=126$, respectively. The proton transfer from lead to xenon might be rather favorable here because the light fragments formed in such a process are well bound (stable nuclei) and the reaction $Q$-values are almost zero.

THE EXPERIMENT

The experiment was carried out at the Laboratori Nazionali di Legnaro. The $^{136}$Xe beam at 870 MeV of bombarding energy was provided by the Tandem-ALPI complex, with an average intensity of 3-5 pmA. The beam impinged on a $^{208}$Pb target, 200 μg/cm$^2$ thick (99.9% enriched) deposited on 20 μg/cm$^2$ carbon backing, and placed at 90° with respect to the beam direction. The PRISMA setup implemented with the second arm, composed by a CORSET microchannelplate (MCP) start detector followed by a position-sensitive parallel plate (PPAC) stop detector and Bragg ionization chamber, was used. The schematic view of the setup is shown in Fig. 1.

Our previous investigations of the reaction $^{136}$Xe + $^{208}$Pb at $E_{lab} = 870$ MeV show that the maximum production cross section for projectile-like fragments (PLF) and target-like fragments (TLF) are at laboratory angle of 45° and 50°, respectively [1]. Consequently, the PRISMA was placed at the laboratory angle $\theta_{lab} = 45°$, while the second arm was positioned at an angle of 52°.

The final mass, energy and charge of PLF were measured using PRISMA. The final mass, energy and charge of TLF were detected with the second arm. Due to the fact that the probability of light particles emission (proton, alpha) is virtually zero for this type of reactions, we can obtain the $Z$ of TLF via $Z$ of PLF. Moreover, the reaction products were studied by two-body kinematics applying double time-of-flight method and the primary mass distributions of the $^{136}$Xe + $^{208}$Pb reaction fragments were obtained.

Masses, velocities, energies and angles of primary reaction products were calculated from measured velocities and angles by using the momentum and energy conservation laws with the assumption that the mass of the composite system is equal to $M_{target} + M_{projectile}$. Extraction of the binary reaction channels with full momentum transfer was
Based on the analysis of the kinematics diagram (see [2, 3] for details).

As a first step, $dT$ (time between PRISMA MCP start detector and PPAC2) andToF2 (time between CORSET MCP start detector and PPAC2) were used to obtain mass and energy distributions of the reaction products. The mass-TKE (total kinetic energy) distribution of binary fragments obtained in the reaction $^{136}$Xe + $^{208}$Pb at a center-of-mass energy $E_{\text{c.m.}}$ of 526 MeV at the angles of 45° ± 7° for PRISMA and 52° ± 3° for the second arm are shown in Figure 2. Only true two-body events are included (no sequential fission). The mass and energy resolutions of the present setup, which define the bin width of the experimental mass and energy yield curves, are taken as the FWHM, respectively, of the mass and energy spectra constructed for the elastic scattering. In this condition, the mass resolution of the spectrometer is 7 u; the energy resolution is 25 MeV. In this case, theToF paths were 25 cm for PRISMA and 82 cm for the second arm. In this condition, the accuracies of fragment velocity measurement are ~3% and ~0.6% for PLF and TLF, respectively.

At the second step, we plan to use PRISMA ToF (time-of-flight between MCP PRISMA and PPAC). This will allow us to improve the accuracy of velocity measurements of PLF up to 0.2% and, consequently, the mass and energy resolution of primary fragments. We estimate that in this case the mass resolution will be about 1%.

From the matrix $\Delta E$ versus $E$ one can select a specific $Z$. Gating on each $Z$, and after reconstruction of trajectories through the spectrometer, one can then obtain the atomic charge state distribution. The charge distribution for fragments with $Z = 54$ (Xe) obtained in present work is shown in Figure 3. Good charge identification for PLF allows us to define the charge of complementary fragment detected by the second arm.

The installation of a second time of flight system on the PRISMA scattering chamber allows to perform high resolution kinematic coincidences. With the additional information provided by the second arm we will be able to associate the mass and nuclear charge distributions of heavy transfer products with each isotope identified in PRISMA. The main purpose of this work is to estimate experimentally the cross section for production of new neutron rich heavy nuclei (including those located along the neutron closed shell $N = 126$). This task will be fulfilled after obtaining the mass distribution using the time of flight between the PRISMA MCP and PPAC within ±1 u resolution. This requires an accurate trajectory reconstruction through the setup and reconstruction of the mass distribution of the PLF which will be used for coincident gates. The analysis is in progress.

This work was supported by the Russian Foundation for Basic Research (Grant No. 13-02-01282-a) and LNL INFN.

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**Fig. 2.** Primary fragments mass-TKE distribution for the second arm, obtained using double ToF measurement. On the right vertical axis the total kinetic energy lost (TKEL = $E_{\text{c.m.}}$ - TKE) scale is reported.

**Fig. 3.** $\rho\beta$ versus $E$ matrix, constructed to select the different atomic charge states of Xe-like ions. The second cut from the right in the matrix corresponds to the most probable charge state $q = 40^+$. The assignment of the other $q$ values is given correspondingly.