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Use Of The BigSol Time Of Flight Spectrometer In The Study Of Superheavy Element Production

M. Barbui[a], K. Hagel[a], J.B. Natowitz[a], R. Wada[a], P.K. Sahu[a], T. Materna[a], Z. Chen[a], L. Quin[a], G. A. Souliotis[a,g], G. Chubaryan[a], A. Bonasera[a,h], D. Fabris[b], M. Lunardon[b], M. Morando[b], S. Moretto[b], G. Nebbia[b], S. Pesente[b], G. Viesti[b], F. Bocci[c], M. Cinausero[c], V. Rizzi[c], G. Prete[c], S. Kowalski[d], Z. Majka[e], A. Wieloch[e], F.D. Becchetti[f], T.W. O'Donnel[f] and H.Griffin[f]

[a] Cyclotron Institute Texas A&M University, College Station, Texas, 77843
[b] Dipartimento di Fisica dell'Università di Padova and INFN Sezione di Padova, Italy
[c] INFN Laboratori Nazionali di Legnaro, Italy
[d] Institute of Physics, Silesian University, Katowice, Poland
[e] Smoluchowski Institute of Physics, Jagiellonian University, Krakow, Poland
[f] University of Michigan, Ann Arbor, Michigan
[g] Laboratory of Physical Chemistry Department of Chemistry, University of Athens, 15771 Athens, Greece
[h] INFN Laboratori Nazionali del Sud, Catania, Italy

Abstract. A time-of-flight spectrometer with the BigSol superconducting solenoid at Texas A&M was used to investigate the possibility to produce heavy and superheavy nuclei by using two body collisions involving heavy projectiles and targets. The reaction ^{197}Au + ^{232}Th at 7.5 AMeV is studied in this work. Preliminary results for the yields of heavy nuclei are presented.

Keywords: Time of flight, Z identification, heavy elements
PACS: 25.70.Hi 25.70.Jj

INTRODUCTION

The synthesis of superheavy elements (SHE) has been an important topic in both theoretical and experimental nuclear science for many decades. Two standard experimental techniques are currently used to produce SHE: the “cold” and “hot” fusion reactions. “Cold fusion” reactions with Pb or Bi targets [1] produce SHE which are neutron deficient and have short half-lives, whereas “hot fusion” reactions, with actinide targets and ^{48}Ca beams [2], produce SHE with more neutrons, but still very far away from the predicted “island of stability” for SHE.

Two body reactions involving very heavy nuclei can be considered as an alternative method to produce SHE along the “island of stability”. Deep inelastic reactions involving two ^{238}U nuclei at energies around the Coulomb barrier have been studied over the years by several authors from the theoretical [3-5] and the experimental [6-9] point of view. In such experiments the reaction products emitted around the grazing angle were detected. Though the SHE were not detected the results indicate that the observed fragments originate from the binary break up of a rather long living and highly deformed di-nuclear system (DNS). In this work we investigate the reaction ^{197}Au + ^{232}Th at 7.5 AMeV. The experiment was performed using the BigSol time of flight spectrometer of Texas A&M. The energy and the charge distribution of the reaction products were measured. Experimentally, five events with atomic number about Z=100 were detected, however further improvements to the experimental setup are needed in order to increase the detection sensitivity.

EXPERIMENTAL SETUP

The experiment was performed using the BigSol superconducting solenoid time-of-flight spectrometer at the Texas A&M University. A complete description of this device can be found in ref [10]. Fig. 1 shows

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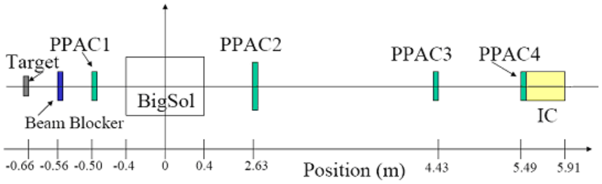

FIGURE 1. Experimental Setup. See the text for details.

the lay-out of the beam line as used in this work. The 7.5 AMeV ^{197}Au beam delivered by the K500 superconducting Cyclotron impinged on a ^{232}Th target of thickness 8.9 mg/cm^2, located near the entrance of the BigSol solenoid. We note that the Coulomb barrier for spherical nuclei in the exit channel is about 680 MeV. Since the ^{232}Th target is very thick the total center of mass energy of the entrance channel drops from 799 MeV to 629 MeV as the beam passes trough the target.

Fragments emitted in the acceptance angle of the solenoid are focused at the focal plane position, approximately 6-meters downstream. A beam blocker and a sixteen-segment annular Parallel Plate Avalanche Counter (PPAC) (PPAC1) placed after the target define the acceptance of the spectrometer in the range 6°-16°. The BigSol magnetic field was tuned in order to optimize the transmission of low energy heavy fragments. The transmission efficiency of the spectrometer for different reaction products was estimated by simulating ion trajectories taking into account the velocity and the average charge state of the ions.

Three position-sensitive PPAC detectors, positioned at 3.3 m (PPAC2), 5.1 m (PPAC3), 6.15 m (PPAC4) from the target, are used to reconstruct fragment trajectories and measure the ions time of flight. The focal plane detector includes PPAC4 and a multi-anode Ionization Chamber (IC), used either as a stopping detector for slow heavy reaction products or as a transmission detector for faster fragments. The IC has an active area of 6.5x6.5 cm^2 and is equipped with 8 parallel anodes, each having a width of 4.65 cm along the beam direction. Several experimental techniques were used in order to eliminate spurious events and pileup. Independent measurements of the time difference between PPAC3 and PPAC4, PPAC2 and PPAC3, PPAC2 and PPAC4 and between PPAC1 and PPAC4 were performed and all time measurements are required to be consistent in order to accept an event. We also implemented a pileup rejection scheme in which we require the measured time between two events in PPAC4 to be more than 8 μs or the event is rejected. Moreover we compared the energy loss in each of the IC anodes measured using both a peak sensing ADC after signal shaping as well as sampling the raw signal using a flash-ADC. These two measurements are also required to agree within 5% in order to accept an event. The analysis of the flash-ADC signals itself also provided a powerful method to reject spurious events.

Time and energy calibrations of the system were obtained by using different heavy ion beams (^{40}Ar, ^{84}Kr, ^{131}Xe, ^{197}Au, ^{238}U) at different energies (7.5 and 15 AMeV) going directly into the detectors with the beam blocker removed. Calibration runs with the direct ^{197}Au beam were repeated at regular time intervals during the measurements. The energy losses in the detectors were calculated using a new effective charge parameterization [11] developed to calculate the stopping powers and the energy loss of the reaction products. This parameterization is based on the existing energy loss data [12, 13] of several heavy ions with $18<Z<92$ in the energy range 0.1-15 AMeV, in the detector materials (mylar and isobutane) and can be used to extrapolate the stopping powers for very heavy elements.

The atomic number identification of the reaction products is obtained with a recursive procedure by iterating over the possible Z from 1 to 130 and comparing the stopping powers measured in each anode as a function of the energy per nucleon with the values predicted by our parameterization. The reconstructed Z is the number that minimizes the average of the absolute values of the differences between the measured stopping power and the predicted one. Fig. 2 shows the Z distribution obtained for the direct ^{197}Au beam at 7.5 AMeV; the resolution $\Delta Z/Z$ is in this case about 3.5% (FWHM).

In a first approximation, a provisional mass of the fragments is assigned simply by requiring that the A/Z ratio of the entrance channel is conserved. For the ions stopped in the IC, the mass is also reconstructed by dividing the total energy measured in the IC and PPAC4 by the energy per nucleon measured from the time of flight between PPAC3 and PPAC4. Due to the large uncertainty in the measurement of the energy

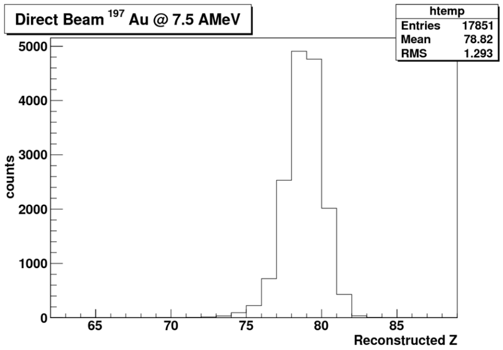

FIGURE 2. Reconstructed Z plot for the direct beam ^{197}Au at 7.5 AMeV.

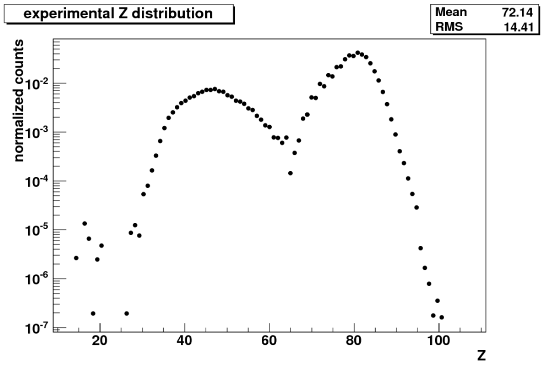

FIGURE 3. Z distribution of the reaction products. The counts are normalized by the total number of events and corrected by the estimated transmission efficiency of the spectrometer.

loss in the PPAC4, the mass resolution ΔA/A is worse than the Z resolution. Therefore in the following analysis we used the reconstructed Z.

The initial energy of the fragments is calculated by correcting the energy measured by the time of flight by the energy losses in the PPACs and in half the target thickness.

EXPERIMENTAL RESULTS

The atomic number distribution of the reaction products emitted in the angular range (6-16°)lab and detected at the BigSol focal plane is shown in Fig.3. By selecting the products emitted in this angular range we intend to filter out relatively central collisions characterized by longer survival time of the DNS and larger energy dissipation compared to peripheral deep inelastic collisions. Different regions in Fig.3 correspond to different reaction mechanisms.

The events with 60<Z<100 result mainly from the break-up of an initial DNS in two fragments. They show a broad peak around the Z=80 corresponding to projectile-like fragments produced in the deep inelastic reaction. The tail of this distribution between Z=60 and Z=70 probably results from charged particle evaporation from the primary excited deep inelastic fragments or from the fission of the very heavy systems. The events with Z<60 are fission fragments from the excited projectile-like or target–like nuclei formed in the deep-inelastic reaction.

A few events (5) with high atomic number 97<Z<102 survived the pileup-rejection filters. The energy loss profile of those events is shown in Fig.4. The energy of those events at the entrance of the IC is about or below 1 AMeV. At this energy the Z

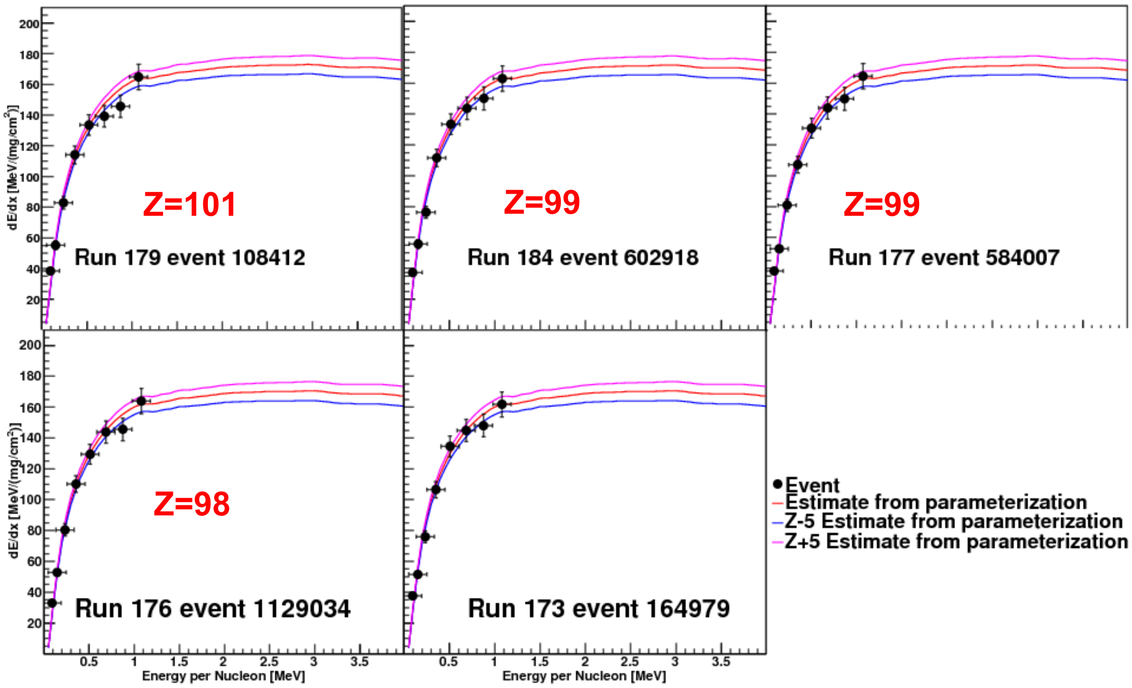

FIGURE 4. Energy loss profile of the five events with Z>97. The red, purple and blue lines show the stopping powers estimated using our parameterization for the identified Z, identified Z+5 and identified Z-5 respectively.

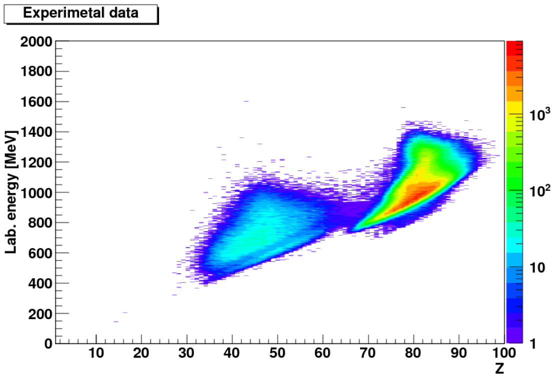

FIGURE 5. Energy of the detected fragment as a function of the atomic number.

resolution of our detector is relatively poor and more accurate measurements are required in order to improve the result. A rough estimate of the reaction cross section for these very heavy elements gives an upper limit of 11 nb/event.

In deep inelastic reactions the kinetic energy of the entrance channel is transformed into internal excitation of different degrees of freedom of the DNS. The analysis of the kinetic energy of the detected fragments as a function of the atomic number can be useful to understand the origin of those events. Unfortunately, with our experimental setup we can detect only one of the reaction products and therefore we cannot obtain a direct measure of the total kinetic energy loss. Fig. 5 shows the energy of the detected fragments as a function of the atomic number. The elastically scattered gold particles are cut by the magnet settings. The low kinetic energy of the products in the range $70<Z<85$ suggests that the detected fragments might originate from relatively long lived systems. The data analysis is still in progress.

CONCLUSIONS

The reaction ^{197}Au+^{232}Th at 7.5 AMeV has been investigated by using the BigSol time of flight spectrometer at Texas A&M. Five nuclei with atomic number larger than 97 were detected during the experiment. The total cross section for those events is about 50 nb. The Z resolution of the system for those events is larger than 5% because their energy is very much degraded before reaching the IC. Therefore a precise identification of the nuclei is not possible. Further improvements of the experimental setup are needed in order to reduce the energy loss of the ions in the detectors. A higher granularity of the IC is also necessary in order to improve the efficiency of the pileup rejection. However the results obtained so far suggest the possibility of producing nuclei with Z about 100.

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