Письма в ЭЧАЯ. 2007. Т. 4, № 4(140). С. 608–613

AN EXTENDED REAL-TIME ALGORITHM FOR RADICAL SUPPRESSION OF BACKGROUND PRODUCTS IN HEAVY-ION-INDUCED NUCLEAR REACTIONS

Yu. S. Tsyganov[1]

Joint Institute for Nuclear Research, Dubna

New extended real-time algorithm to extract in a real-time mode correlated recoil-alpha sequences in heavy-ion-induced nuclear reactions has been presented. It operates together with the detection system of the Dubna Gas-Filled Recoil Separator (DGFRS) and provides a radical suppression of background products. The DGFRS detecting module design is presented too.

Представлен новый расширенный алгоритм поиска в режиме реального времени коррелированных пар ядро отдачи — альфа-распад, образующихся в ядерных реакциях с тяжелыми ионами. Алгоритм работает совместно с детектирующей системой газонаполненного сепаратора ядер отдачи (ГНС). Также представлен детектирующий модуль ГНС.

PACS: 25.70.-z; 07.05.-t; 29.85.+c

INTRODUCTION

The Dubna Gas-Filled Recoil Separator is the most efficient facility in use in the field of synthesis of superheavy elements of Flerov Laboratory of Nuclear Reactions of JINR [1]. Their separation characteristics are based on the ion optical properties of the gas-filled magnetic dipole. For the synthesis and study of heavy nuclides, the complete fusion reactions of target nuclei with heavy bombarding projectiles are used. The resulting excited compound nuclei (CN) can de-excite by evaporation of a few neutrons, while retaining the total number of protons. Recoil separators are widely used to transport evaporation residues from the target to the detection system, simultaneously suppressing the background products of other reactions, the incident ion beam, and scattered target nuclei. In this respect, it is very significant that a transport and collection efficiency value have to be high enough to perform experiments with cross sections of the product under investigation of about one picobarn or even part of picobarn. Of course, the detection module should not contribute to the significant decreasing of the mentioned parameter. The detection system of the Dubna Gas-Filled Recoil Separator (DGFRS) consists of silicon 12 strip position sensitive detector to measure recoils energy and their forthcoming alpha (spontaneous fission) decays, and low pressure pentane filled time-of-flight module to detect charged particles incoming from cyclotron. The

[1]E-mail: tyura@sungns.jinr.ru

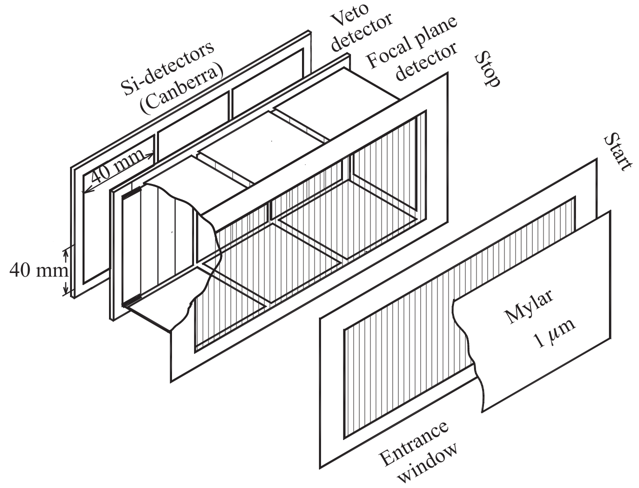

Fig. 1. The detection module of the DGFRS

detection module of the DGFRS is shown in Fig. 1. Silicon «veto» detector, consisting of three separate silicon chips, is placed behind the focal plane one to detect charged long path particles passing through the main position sensitive detector and creating no any signal in the gaseous TOF module [2].

1. REAL-TIME DETECTION MODE FOR RADICAL SUPPRESSION OF THE BACKGROUNDS IN EXPERIMENTS AIMED TO THE SYNTHESIS OF SUPERHEAVY ELEMENTS (SHE)

Usually, to reach high total SHE experiment efficiency, one uses extremely high ($10^{12}n$ to 10^{13} pps, $n > 1$) heavy-ion beam intensities. It means, that not only irradiated target, sometimes (frequently) made on highly radioactive actinide material, should not be destroyed during long-term experiment, but the in-flight recoil separator and its detection system should provide backgrounds suppression in order to extract one–two events from the whole data flow. Typically, the DGFRS provides suppression of the beam-like and target-like backgrounds by the factors of[1] $\sim 10^{15}{-}10^{17}$ and $10^4{-}5 \cdot 10^4$, respectively [3]. Nevertheless, under real circumstances, total counting rate above approximately 1 MeV threshold is about tens to one–three hundreds[2] events per second. Therefore, during, for example, one month of irradiation about $30 \cdot 10^5 \cdot 100 = 3e + 08$ multiparameter events are written to the hard disk during a typical SHE experiment at the DGFRS.

To avoid a scenario that result of the SHE experiment (one–two–three decay chains per month) can be represented as a set of random signals real-time search technique to suppress the probability for detected event to be a random has been designed and successfully applied.

[1]Depending on the reaction asymmetry (projectile to target mass ratio).
[2]Including events having only TOF signal and zero energy (below energy threshold).

Note, that in the reactions with ^{48}Ca as a projectile, the efficiency of SHE recoiling products detection both by silicon and TOF detector is close to 1. Namely, recoil-first (second) correlated alpha-decay signal was used as a triggering signal to switch off the cyclotron beam for a definite (seconds-minutes) and, therefore, detection of forthcoming alpha decays were in fact «background-free». The basic idea to apply such a detection mode is to transform the main data flow to the discrete form [4]. To demonstrate successful application of this technique the spectrum of $^{287}114$ nuclei total α-particle-like energy spectra of events that stopped the beam during $^{242}\mathrm{Pu} + {}^{48}\mathrm{Ca}$ experiment is shown in Fig. 2 [5]. The solid histogram shows the energies of events that switched off the beam that were followed by a beam-off SF event or beam-off α-particles with $E_\alpha = 8.9{-}10$ MeV and a beam-on SF event, with a total elapsed time interval up to 14 min.

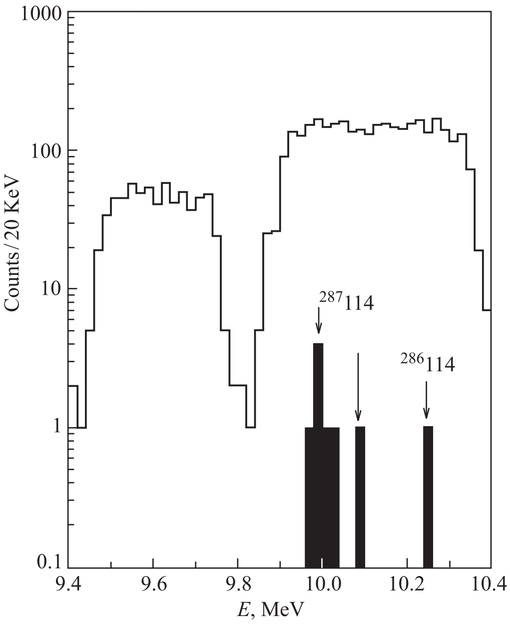

Fig. 2. Spectrum of $Z = 114$ ($A = 287$) detected alpha decays

Note, that background suppression factor estimates as $\sim C_n^m/K$ for the parameter of probability of the whole event to be a random [6, 7]. Here n — the whole number of alpha decays, m — number of alpha decay, which stops the beam and K — suppression factor for single event ($\sim 10^2{-}10^3$). It means, for instance, that in the case of four-alpha-decay chains event, additional suppression factor is about $\sim 10^9$ if first alpha-particle signal provides beam switching [7]. Schematic of the whole process creating a background-free detection of decays is shown in Fig. 3. It takes about 175 μs to provide full beam switching after detection of a correlation recoil-alpha sequence including additional time delay ($\sim$ 60 μs) related to cyclotron operation.

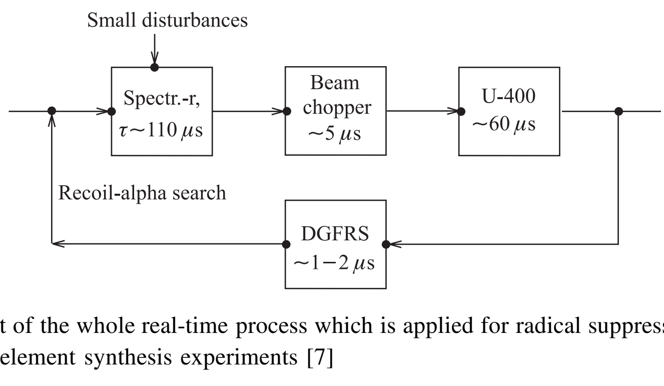

Fig. 3. Flow chart of the whole real-time process which is applied for radical suppression of background products in SHE element synthesis experiments [7]

2. EXTENSION OF REAL-TIME ALGORITHM FOR THE CASE OF NONDEFINITE RECOIL DETECTION EFFICIENCY

Unfortunately, in contrast to relatively high projectile, like ^{40}Ar and ^{48}Ca, when using projectiles from oxygen to magnesium, real threshold of the detection system sometimes does not allow recoil detection with efficiency close to 1 (see Fig. 4).

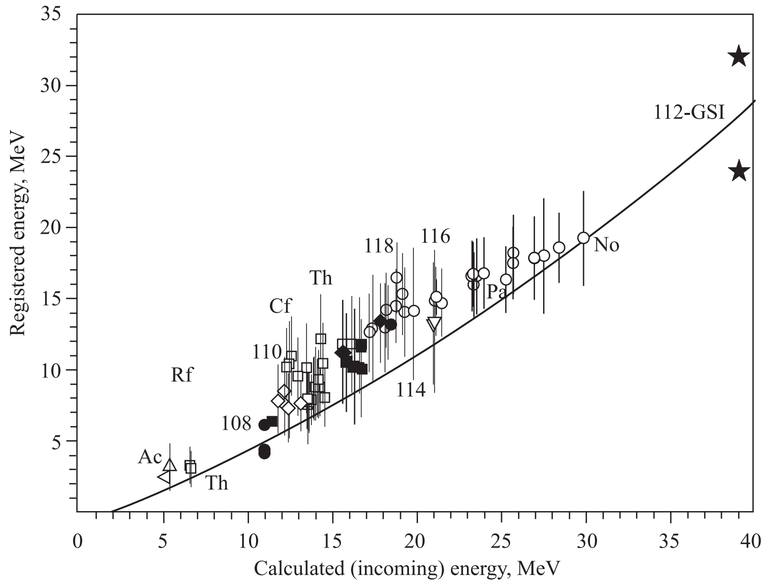

Fig. 4. The dependence of registered heavy-recoil energies against calculated incoming ones for the DGFRS detecting module. The line corresponds to calculations [8] for $^{288}114$ recoil. Two events of $Z = 112$ element synthesized at GSI [9] are shown by stars. Note, that efficiency of Rf recoil detection by silicon detector was not close to ~ 1

It seems more realistic in this case to use both recoil and alpha signals as the first chain of multichain events to provide beam switching. Of course, one assumes, that the above-mentioned value of the recoil detector efficiency is compatible with alpha-particle one. In the second place, this value, in contrast to the first one, corresponding to reactions with ^{48}Ca projectile, may be varied with varying of threshold level during an experiment. The schematic of such an algorithm is represented in Fig. 5.

As reported in [7] loop t_1^+ denotes that in the case of «no success», that is, if no beam stop is generated after recoil-alpha sequence detection, the elapsed time of coming (and detected) alpha particles is written into the appropriate cell of the first («recoil») matrix. Hence, the second alpha-particle in the multichain decay event will provide beam switching if time interval between two alpha decays is less than pre-setting resolved time for first recoil-alpha correlation. In the case if one wants to use separate pre-settings, it is necessary to

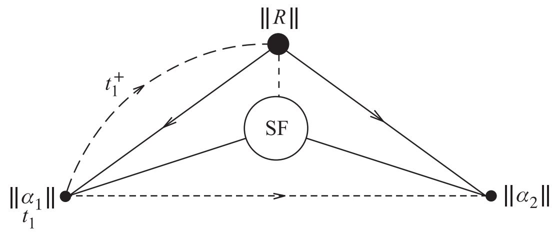

Fig. 5. The schematic of the extended algorithm of real-time search of correlated sequences. In the case if no beam stop is generated by first recoil-alpha sequence the elapsed time of this alpha-particle event is written to the appropriate matrix cell of the «recoil» matrix. In principle, the same operation can also be provided with the second alpha-decay event

use matrix cell in the form of two-dimensional[1] structure, not only to write the elapsed time of the event, but also to use particle identifier. Below, in the form of an example value of probability of pause generation is estimated for the case of $P_r \approx 0.5$ recoil detection efficiency (approximately, it corresponds to $^{20,22}\mathrm{Ne}$ as a projectile, and U, Pu targets at about ~ 1 MeV threshold value): $P_{\mathrm{tot}} = P_r P_\alpha + (1 - P_r P_\alpha)\ P_\alpha = 0.5 \cdot 0.7 + (1 - 0.5 \cdot 0.7)0.7 = 0.805$. In this equation it is assumed, that composite signals, that is the sum of energies both in focal plane and backward detectors and having non-zero position signal in the focal plane one, are taken into account.

CONCLUSION

More universal real-time algorithm has been suggested for the detection system of the Dubna Gas-Filled Recoil Separator. In contrast to the one successfully applied for the nuclear reactions of SHE synthesis at the DGFRS in the last five years, it gives a definite advantage for the reactions with much higher projectile to target mass ratio. It is planned to use the mentioned approach in the nearest future for full fusion reactions with oxygen to magnesium heavy ions at U-400 FLNR, JINR cyclotron. On the other hand, any way to minimize a recoil energy loss when it moves from the target to the point of implantation into the silicon focal plane detector should be under consideration as well together with a reasonable upgrade of the whole DGFRS detection system aimed to reduce the counting rate of signals per one real position cell of PIPS focal plane detector.

Acknowledgements. The author thanks Dr. B. Gikal for his useful specific information on U-400 cyclotron operation. This work is supported in part by grant RFBR N 000. The author is indebted to Dr.'s Polyakov and Sukhov for their help in realization of ideas reported in the present paper and of similar nature.

[1] Or even more than two. From the viewpoint of practical realization the author uses C++ code and one can easily use «structure» or «class» object. To the first approximation, the second component may be as an assuming number of decay chains in a multi-decay event, of course, starting from a recoil signal.

REFERENCES

1. *Subbotic K. et al.* // Nucl. Instr. Meth. A. 2002. V. 481. P. 71–80.
2. *Tsyganov Yu. S. et al.* // Nucl. Instr. Meth. A. 2004. V. 525. P. 213–216.
3. *Lazarev Yu. A. et al.* JINR Sci. Report E7-93-57. Dubna, 1993. P. 205.
4. *Oganessian Yu. Ts. et al.* // Phys. Rev. C. 2004. V. 70. P. 064609.
5. *Tsyganov Yu. S., Polyakov A. N.* // Nucl. Instr. Meth. A. 2006. V. 558. P. 329–332.
6. *Zlokazov V. B.* // Eur. Phys. J. A. 2000. V. 8. P. 81–86.
7. *Tsyganov Yu. S.* JINR Commun. R7-2005-117. Dubna, 2005.
8. *Tsyganov Yu. S.* JINR Commun. E13-2006-77. Dubna, 2006.
9. *Hoffman S. et al.* // Eur. Phys. J. A. 2002. V. 14. P. 147.

Received on July 17, 2006.