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МЕТОДИКА ФИЗИЧЕСКОГО ЭКСПЕРИМЕНТА

PHYSICAL BASIS OF CRITICAL ANALYSIS

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A new approach to provide a fruitful analysis of signal amplitude is proposed. It is this method that has made it possible to eliminate some observed artificial events from the list of candidates for decays of superheavy nuclei. Examples of estimates of measured amplitudes of evaporation residues (EVR) are presented. Some attention is paid to a new «hard» statistical criterion for detecting rare events.

Предложен новый плодотворный подход для амплитудного анализа. Именно этот метод делает возможным устранение ложных событий из списка кандидатов на распад сверхтяжелых элементов. Представлены примеры оценок измеренных амплитуд тяжелых ядер отдачи. Некоторое внимание уделено новому, более «твердому» критерию статистической значимости при детектировании редких событий.

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INTRODUCTION

With the discovery of the «island of stability» of superheavy nuclei by the Dubna Gas-Filled Recoil Separator group [1–3] a few different questions can be considered as an actual matter. One of them is related to establishing of the edges of the «island». Recently, some attempts to start those experiments were performed at Dubna and Darmstadt. Another interesting question of a different matter is: how perfect, fast and reliable should be the detection system for such experiments. Application of digital system on the base of the DSSSD detector together (in parallel) with the modern analog system with a purpose of search for pointer to recoil-alpha correlation in a real-time mode can be considered as a reasonable scenario [4, 5]. Note, that sometimes in analysis of sets of experimental data it is useful to apply not only the knowledge about predicted properties of the nuclides under investigation and values of reaction cross sections, but some knowledge of «non-nuclear» nature related to applications of silicon radiation detectors. In some cases, this analysis can give indication of negative nature, that is, it indicates to a low quality of the given event interpretation.

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1. APPLICATION OF SILICON RADIATION DETECTORS IN THE EXPERIMENTS AIMED AT THE SYNTHESIS OF SHE

In the last years, in the experiments aimed at the synthesis of SHEs at different facilities of FLNR (JINR, Dubna), GSI (Darmstadt, Germany), Riken (Saitama, Japan), LBNL (Berkeley, USA), PSI (Villigen, Switzerland), position-sensitive silicon radiation detectors were the main part of the detection systems. Namely, with these devices it has become possible to establish a genetic link between individual alpha decays of superheavy nuclei. Of course, a strong statistical analysis is required to avoid an interpretation based on a random factor explanation [6, 7]. To this end, namely knowledge about silicon radiation detectors allows experimentalists to reject some events from the list of potential candidates. Below, a few examples of amplitude signal analysis are given.

1.1. Detection of Highly Ionized EVR's Signals of Implanted Heavy Nuclei from Heavy-Ion-Induced Nuclear Reactions. It is a well-known fact that detection of the EVR signal is very important from the viewpoint of general experimental philosophy. Mostly, due to an evident fact that namely from that signal starts a whole multichain event and, therefore, it allows one to estimate half-life value for a product under investigation. Another well-known fact, that under detection with silicon radiation detector the amplitude of the registered signal for strongly ionizing particle can be presented in the form of equation:

$$E_{\text{reg}} = E - \text{PHD}.$$

Here, E_{reg} is a registered energy signal; E — incoming energy value and PHD — Pulse Height Defect value (of course, after a definite calibration procedure with alpha-particle source is performed by the experimentalists).

The PHD value is composed of three components, namely: losses in the entrance window, recombination component and nuclear stopping one [8].

For the DGFRS detection system in [9], an approximate relation $E_{\text{reg}} = E_{\text{reg}}(E)$ has been derived in the form of equation:

$$E_{\text{reg}} \approx -1.7 + 0.74 E_{\text{in}} \quad (10 < E < 40 \text{ MeV}).$$

Additionally, not only empirical relations are useful, but any Monte Carlo calculations too.

In [10], such an approach is performed. With this approach in [11] it was shown that one from three detected events of $Z = 112$ element has an artificial nature (Fig. 1, *a*).

On the other hand, Fig. 1, *b*, *c* demonstrates good agreement for the EVR events detected and for $Z = 118$ events detected at FLNR (JINR), and correction (systematic error) function (plot *b*). In Fig. 2, results for $Z = 112$ EVRs measured at GSI for complete fusion nuclear reaction $^{238}\text{U} + {}^{48}\text{Ca} \rightarrow {}^{283}\text{Cn} + 3n$ are shown.

1.2. Detection of Spontaneous Fission Fragments of Implanted Nuclei. Very often, multichain event contains spontaneous fission signal as a finishing one. As of implantation depth of EVR in silicon is of several microns, some specifics exists in the process of those signals detection. Although the calibration of the SF scale is usually quite a delicate process, definite systematic is applied for experimental result analysis if one uses dimensionless parameters. In [12], parameter $k = E_{\text{esc}}/(E_{\text{foc}} + E_{\text{esc}})$ is proposed to detect any deviations from systematic, where indexes (esc) and (foc) correspond to backward and focal plane detectors, respectively.

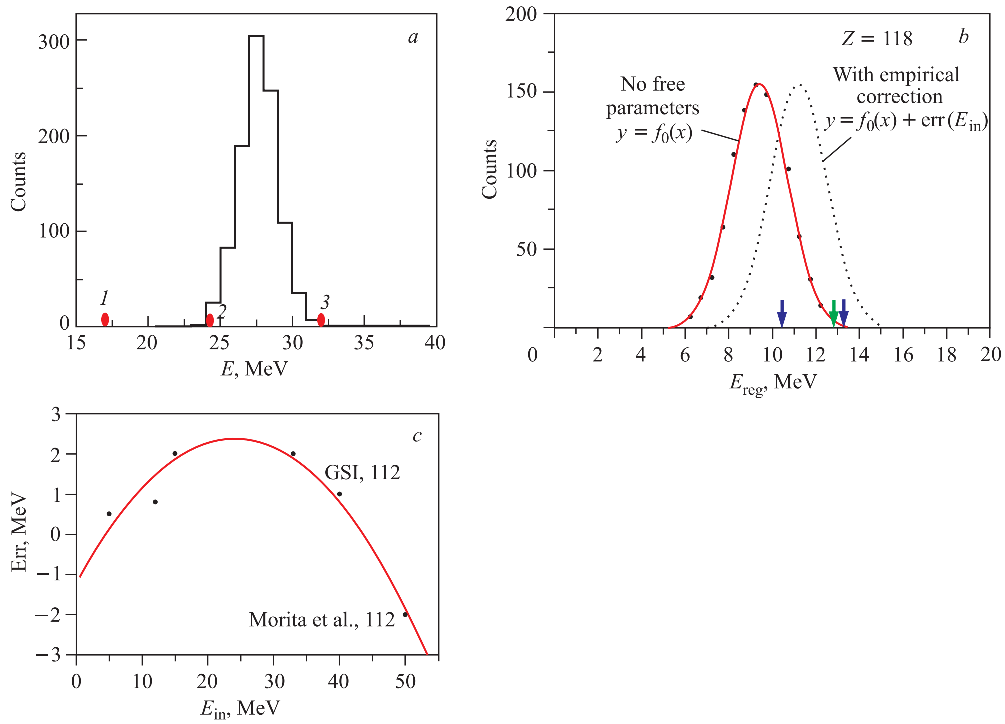

Fig. 1. *a*) Event *1* is considered as having no relation to the effect. It was eliminated from the event list by the authors. *b*) The PC simulations for $Z = 118$ (dotted line — correction to error function). *c*) Dependence of calculation values error against EVR's incoming energy value

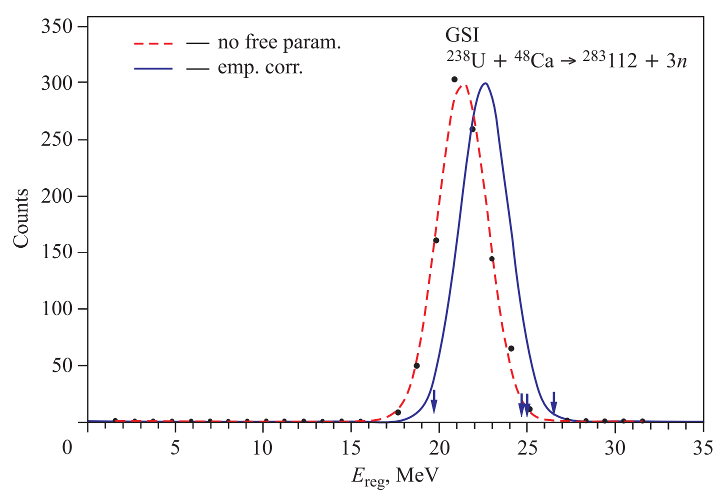

Fig. 2. GSI $Z = 112$ EVR's four events. Dashed line — no free parameters of simulation; solid line — program calibration error function is taken into account

In Fig. 3, those parameters shown for different cases are indicated. It can be easily seen, that energy in the experiment (areas *1*, *2* — data from [13]) was overestimated and, probably, true values of total kinetic energy are slightly smaller.

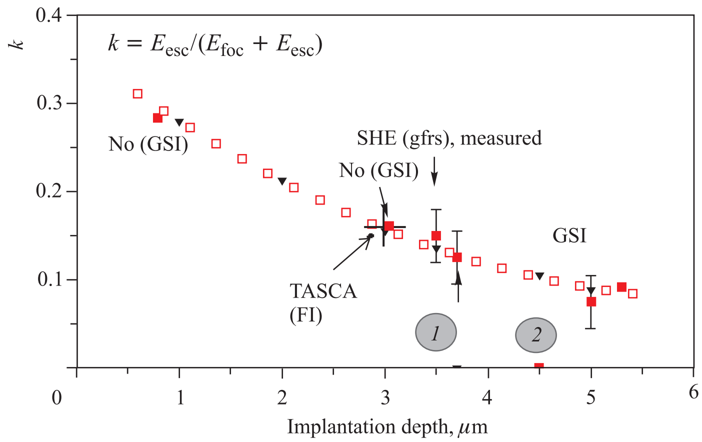

Fig. 3. The dependence of k parameter against implantation depth. Areas *1*, *2* indicate the $Z = 115$ TASCA experiment [13]. Rectangles are calculated values. Area *1* — implantation depth calculated from the EVR energies; *2* — from kinematic calculation starting from the EVR energy in the middle of the target

Additionally, the mean measured value of the EVR energy in the experiment [14] is

$$\langle E_{\rm EVR}\rangle = \\ = \langle 13.4, 13.9, 16.3, 16.1, 16.4, 15.4, 14.1, 12.5, 15.9, 14.5, 16.5, 15.1, 15.3, 14.9, 17.2\rangle \approx \\ \approx 15.2\ \text{MeV}.$$

But, according to the above-mentioned formula (with $E_{\rm in}^{\rm EVR} \approx 33.4$ MeV),

$$\langle E_{\rm calc}\rangle \approx -1.7 + 33.4 \cdot 0.74 = 23\ \text{MeV}.$$

It is probable, that discrepancy is explained by thicker entrance window (more than $\sim 1\ \mu$m Si). The DSSSD detector in [13] with respect to PIPS detectors was used for obtaining the empirical formula.

1.3. A Few Words about Statistics. Sometimes it is useful to calculate probability of missing of several numbers of alpha-particle chains, when one detects event like EVR-α-SF. In Fig. 4, parameter of probability to miss alpha-particle signal for six measured events against the branch to spontaneous fission for mother nuclide is shown. Dotted line indicates the level which was presented in [14].

Another point of view, related to statistics, is the following: calculated (estimated) parameter of expectation for random events N_R is sometimes (if relation of $N_R \ll 1$ is not too valid, i.e., has no excess of several orders of magnitude) useful to apply more strong criteria with normalization the parameter onto the probability of the given chain configuration [15].

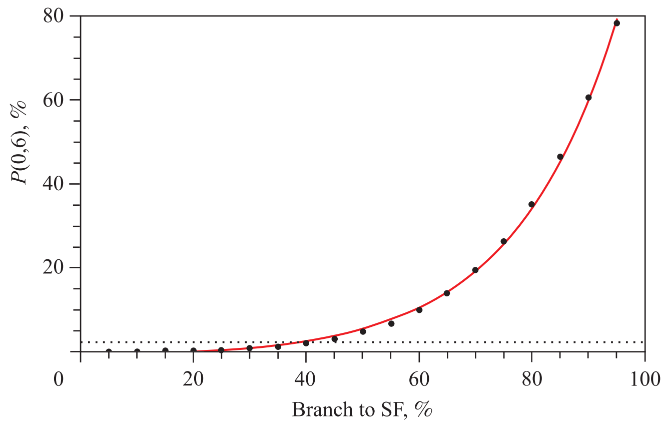

Fig. 4. Probability $P(0, 6)$ for six missed alpha-particle signals against branch to spontaneous fission value

Namely,

$$\tilde{N}_R = N_R / P_{\text{conf}},$$

where P_{conf} is a configuration probability.

In that case a criterion for a true event is $\tilde{N}_R \ll 1$ and for a true background event — $\tilde{N}_R \gg 1$. All other areas of $\tilde{N}_R$ are declared as «*non-clear event*» or «*non-true background*». Namely, this estimate was done for one $Z = 114$ event candidate reported in [16].

2. SPECIFICS IN APPLICATION OF THE DSSSD DETECTOR

When applying the DSSSD detector, one should definitely bear in mind a significant role of an edge effect (charge dividing between neighbor strips), especially for the backside (with respect to beam direction) strips. It is strongly required to take into account that percentage of those effects depends on the source geometry (Fig. 5, *a*, *b*).

That is, when for normally incoming ~ 5 MeV alpha-particle signals, a value for both (neighbor) strip signals may be about 3–4%, whereas for geometry close to 2π, one can achieve up to 20%. Therefore, when one detects a few alpha decays of implanted nuclei, a value close to 20% should be for signals from neighbor strips (for the DGFRS DSSSD detector manufactured by Micron Semiconductor).

3. SUMMARY

In conclusion, typical schematics can be proposed for critical analysis of events ascribed to superheavy nuclei. The principal steps are:

— to simulate the measured EVR energy spectra and to compare with the empirical systematic for nuclei with the closest (Z, A). If necessary, to do recalibration of simulation code;

— to compare the measured events of SHE with both systematics (semi-empirical and/or simulated ones);

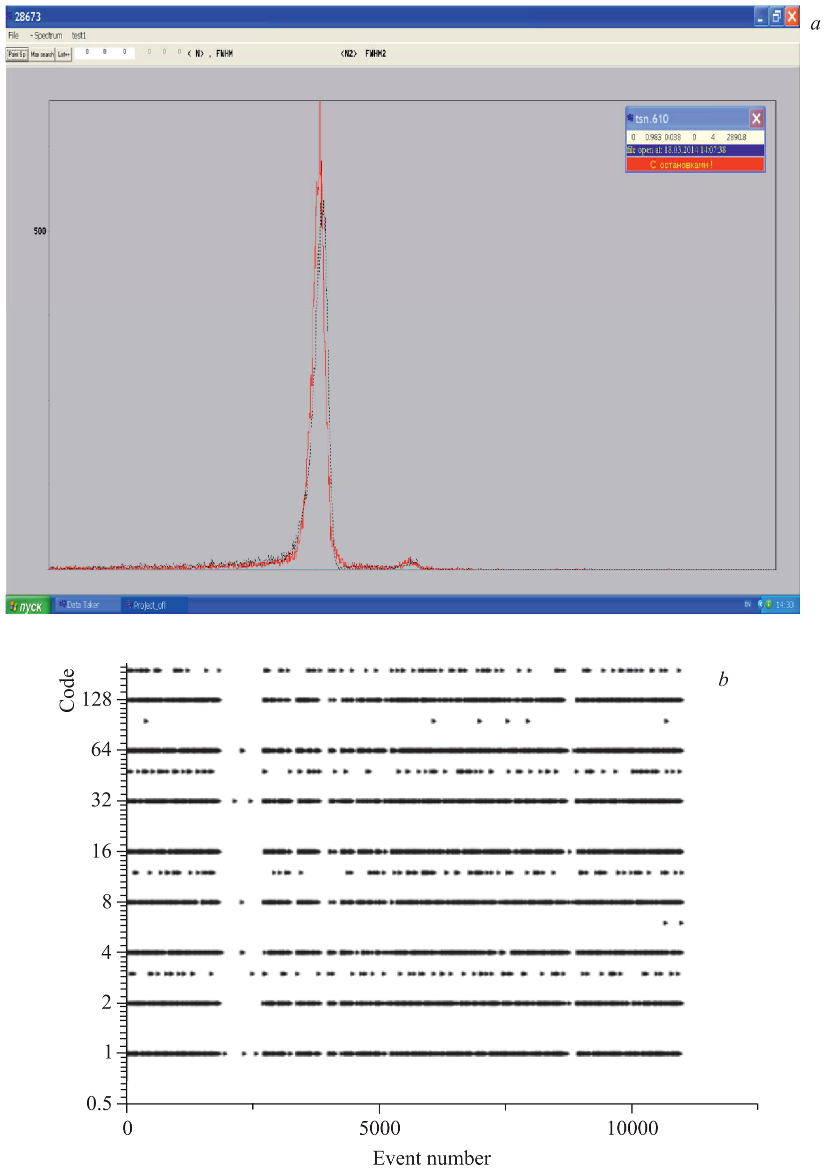

Fig. 5. *a*) Summary alpha spectra measured with front 48 strips (solid line) and back 128 strips (dotted line) of the DSSSD detector. Value of 0.038 (right upper corner) indicates part of signals measured with two neighbor strips (online measurements). *b*) Edge effects for back strips of the DSSSD detector demonstration. Dotted lines — both (neighbor) strips signal sharing. Codes 2^n — single-strip operation

— to compare dimensionless k parameter for the measured SF events with the calculated one;

— if parameter of N_R is not too small, to use more «hard» criterion to eliminate artificial events;

— if one declares losses of some alpha-particle signals, it is necessary to estimate probability of those given of multievent configuration;

— estimation of the relative value of number of signals, which can be explained by strip-to-strip edge effect, is desirable too.

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APPENDIX A

When preparing this manuscript, new paper confirming the DGFRS result on the properties of $^{294}117$ isotope has been published [17]. Two decay chains were reported. These chains start with the ER signals of 6.9 and 9.0 MeV, respectively. Taking into account an extra dead layer of the TASCA DSSSD detector of about 0.5 μm (Si) [18], one can state a good agreement with the spectrum simulated in [12] (see, e.g., Fig. 2 as well).

APPENDIX B

Of course, it is possible to consider recalibration procedure taking into account mass difference between the calibration isotopes and the measured ones (e.g., [19]).

Let us consider an «ideal» calibration case, namely,

$$K = \frac{e_0}{N_0},$$

where k — calibration constant; e_0 — energy yield related to electron-hole pairs generation in silicon; N_0 — channel number.

One should take into account that

$$e_0 = e_0^{\alpha}\left(1 + \eta\frac{m}{M_0}\right),$$

where $M_0 \approx 217 - 4$ (^{217}Th alpha decay from $^{\rm nat}$Yt + ^{48}Ca reaction) and $m = 4$, η — part of energy yield for electron-hole generation.

Therefore, when detecting the SHE alpha decay and under assumption of the same η value mostly explained by the stopping component of PHD (pulse height defect for heavy low energy recoil), one can write:

$$e_{\rm SHE} = e_{\rm SHE}^{\alpha}\left(1 + \eta\frac{m}{M_{\rm SHE}}\right).$$

Additionally, assuming the new channel $N_{\rm SHE}$ is in the close vicinity of N_0, that is $N_1/N_0 \sim 1$.

Finally, it is possible to obtain relation for alpha-particle energy in the form

$$\mu = \frac{e_{\rm SHE}^{\alpha}}{e_0^{\alpha}} \approx \frac{1 + \eta(m/M_0)}{1 + \eta(m/M_{\rm SHE})}.$$

The author considers the above-mentioned formulae as a reasonable scenario to estimate a systematic error of the calibration process.

For $M = 294 - 4$ and $Z = 117$ ($e \approx 11$ MeV) $\eta \approx 0.3$ [19], hence, correction factor μ is approximately equal to

$$\mu = \frac{1 + 0.3 \cdot 4/(217 - 4)}{1 + 0.3 \cdot 4/(294 - 4)} \approx 1.0015.$$

In the vicinity of 11-MeV region, it creates roughly the measured energy shift value as $11000(\mu - 1) \approx 17$ keV.

Note, that for more precise estimation the recombination component of PHD should be taken into account, as well as the difference for η parameter for masses M_0 and $M_{\rm SHE}$.

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