

# THE COMETA SPECTROMETER FOR STUDY OF THE MULTI-BODY DECAYS OF HEAVY NUCLEI

D.V. Kamanin<sup>1</sup>, Yu.V. Pyatkov<sup>1,2</sup>, V.E. Zhuchko<sup>1</sup>, N.A. Kondtayev<sup>1</sup>, A.A. Alexandrov<sup>1</sup>,  
I.A. Alexandrova<sup>1</sup>, N. Jacobs<sup>3</sup>, E.A. Kuznetsova<sup>1</sup>, V. Malaza<sup>3</sup>, S.I. Mulgin<sup>4</sup>,  
A.O. Strekalovsky<sup>1</sup>, O.V. Strekalovsky<sup>1</sup>

<sup>1</sup>Joint Institute for Nuclear Research, Dubna, Russia

<sup>2</sup>National Nuclear Research University “MEPHI”, Moscow, Russia

<sup>3</sup>University of Stellenbosch, Faculty of Military Science, Military Academy, Saldanha 7395, South Africa

<sup>4</sup>Institute of Nuclear Physics, National Nuclear Centre, Almaty, Kazakhstan

## INTRODUCTION

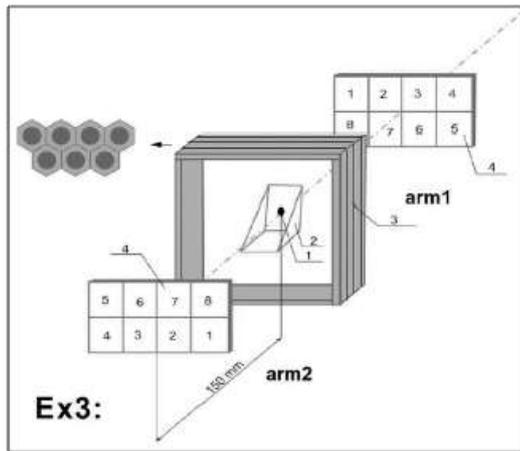
In our previous experiments [1–4] we have observed multiple manifestations of new ternary decay of low and middle excited heavy nuclei called “collinear cluster tri-partition” (CCT) due to the features of the process observed. The main results were obtained at the modified FOBOS and mini-FOBOS setups based on the gas filled detectors of the FOBOS spectrometer [5] in the frame of the “missing mass” method. It means that only two fragments were actually detected in each fission event (in opposite detectors, at  $180^\circ$ ) and their total mass  $M_s$  was served as a sign of a multi-body decay, if it is significantly smaller than the mass of the initial system. In order to increase reliability of selecting of the CCT events by means of direct detection of all the CCT partners new COMETA spectrometer was put into operation in the Flerov Laboratory of the JINR. A simpler prototype of this spectrometer we have successfully used earlier for searching for the CCT channel in the reaction  $^{232}\text{Th} + d$  (10 MeV) [6].

Peculiarity of the experiment consists in measuring of the heavy ions masses in the frame of the TOF-E method in the wide range of masses and energies.

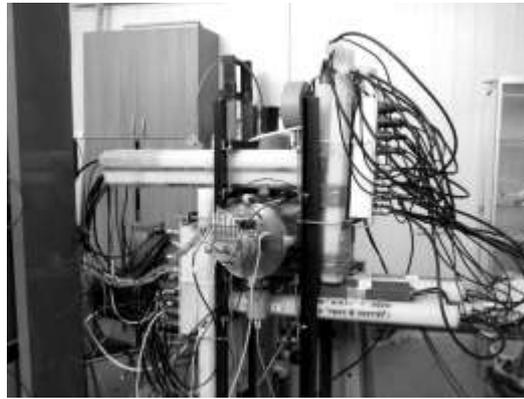
## DETECTORS

COMETA is the double arm time-of-flight spectrometer (fig. 1, 2) which includes micro-channel plate (MCP) based “start” detector with the  $^{252}\text{Cf}$  source inside, two mosaics of eight PIN diodes each and a “neutron belt” comprises 28  $^3\text{He}$  filled neutron counters. Each PIN diode (the surface area of  $2 \times 2 \text{ cm}^2$ ) provides both energy and timing signals. The neutron belt is located in the plane perpendicular to the symmetry axis of the setup. Different ways to arrange the neutron counters in the belt were examined applying the MCNP code [7]. The configuration shown in fig. 1 was chosen. According to modeling and previous experiments, the detection efficiency is estimated to be ~5% and ~12% for the neutrons emitted in binary fission and from an isotropic source, respectively.

Thus the geometry of the neutron belt provides preferential detection of the neutrons emitted isotropically.



**FIGURE 1.** Scheme of the COMETA setup which consists of two mosaics of eight PIN diodes each (4), MCP based start detector (2) with the  $^{252}\text{Cf}$  source inside (1) and a “neutron belt” (3) consisting of 28  $^3\text{He}$ -filled neutron counters in a moderator. The cross section of the belt is marked by the arrow.



a

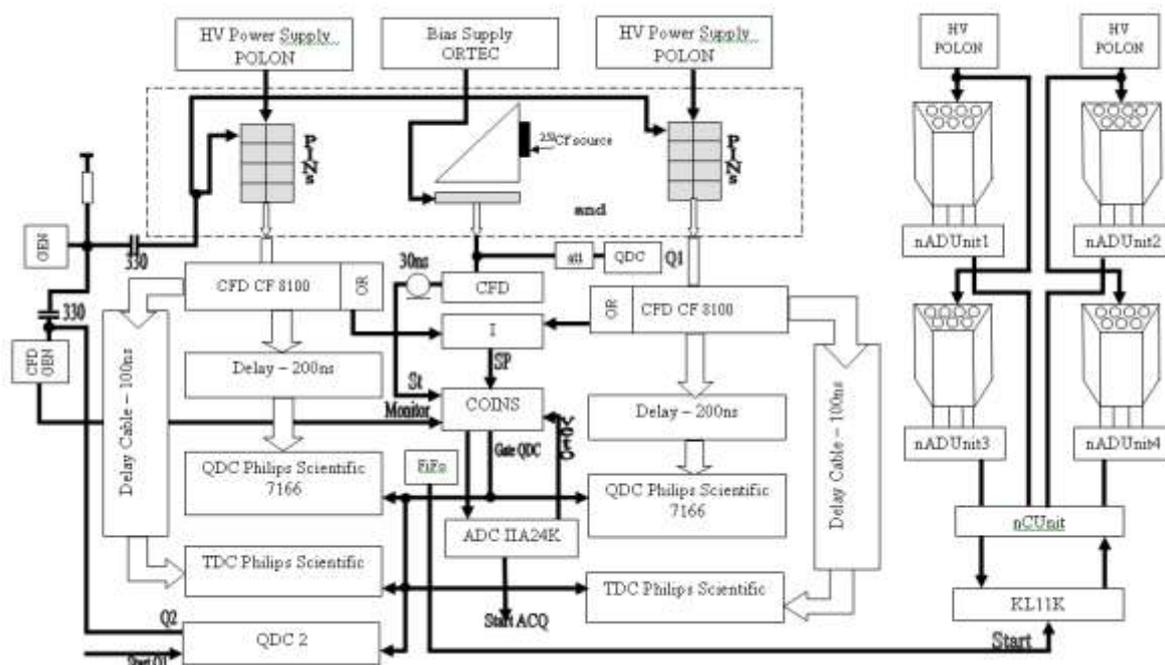


b

**FIGURE 2.** Overall view of the COMETA spectrometer (a), start detector and PIN diodes mosaic in one of the spectrometer arms (b).

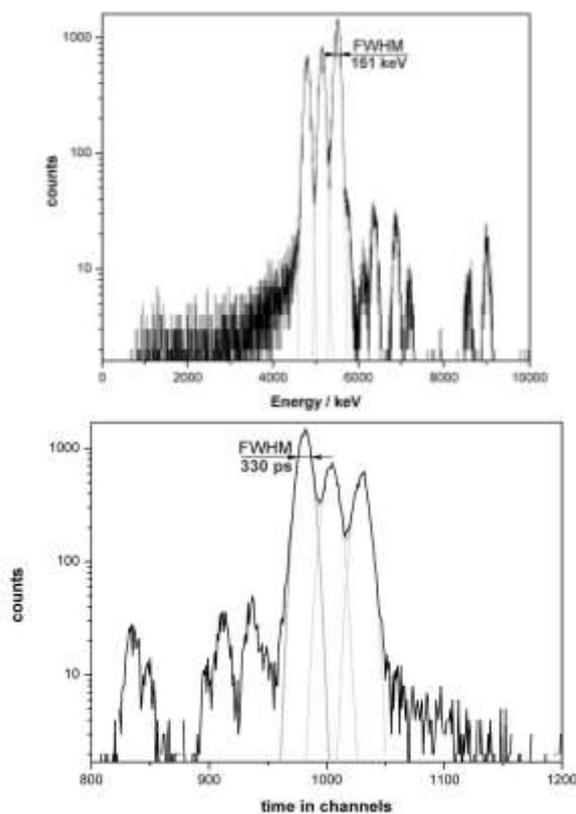
## ELECTRONICS

The scheme of the electronics used is shown in fig. 3. Energy and time resolution obtained with  $\alpha$ -particles are shown in fig. 4 and fig. 5, respectively. Fig. 6 demonstrates mass resolution achieved for the Ni isotopes. In particular the mass resolution estimated by the line  $M2 = \text{const} = 68$  amu does not exceed 1.5 amu (fwhm).



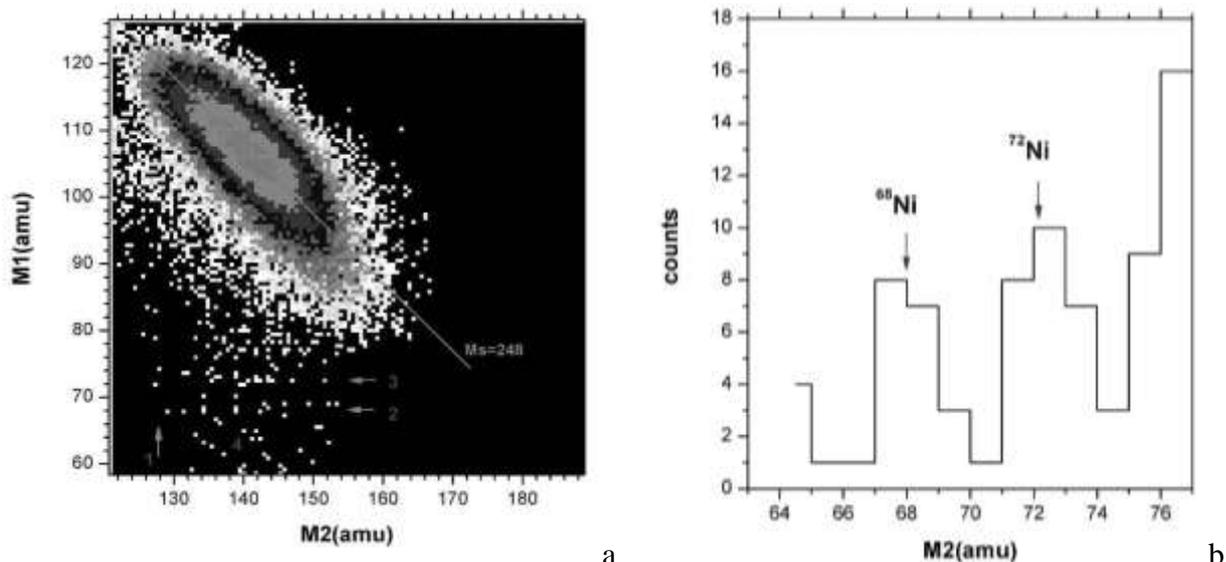
**FIGURE 3.** Schematic diagram of the electronics used.

The peculiarity of the electronics used (i.e. TDCs for measuring the FF time-of-flight (TOF) and QDCs for measuring the FF energy ( $E$ )) resulted in a relatively low price of the TOF/ $E$  channel at acceptable spectrometric parameters.



**FIGURE 4.** Energy resolution of the PIN diode used in the spectrometer for  $\alpha$ -particles from the mixture of  $^{233}\text{U}$ ,  $^{238}\text{Pu}$ ,  $^{239}\text{Pu}$ . The most intensive lines: 4824 keV, 5499keV, 5155keV.

**FIGURE 5.** Time resolution for “start-stop” pair: MCP based timing detector / PIN diode.



**FIGURE 6.** (a) The region of the mass distribution for the FFs from  $^{252}\text{Cf}$  (sf) around the locus of a conventional binary fission. No additional gates for the selecting the events presented were used. The arrows 1–3 show the positions of the magic nuclei of  $^{128}\text{Sn}$ ,  $^{68}\text{Ni}$  and  $^{72}\text{Ni}$  on the axes. Two tilted lines  $M_s = M_1 + M_2 = 196$  amu and  $M_s = 202$  amu (marked by number 4) start from the “magic” partitions 68/128 and 68/134, respectively. (b) Projection of the bottom part of the plot (a) onto the  $M_1$  axis.

## DATA ACQUISITION SYSTEM

The data acquisition system (DACS) for the COMETA is based on those used earlier at FOBOS spectrometer. The entire system is organized on the basis of several PCs with the x86 processors under the operational systems family Win32 (beginning from the Windows XP up to Windows 7). Using of these OS and x86 family gave us very simple possibility to scale up the computational power of the DACS. The main features of our DACS are the possibilities of the online accumulation of the experimental data while they are stored, the presorting and visualization of the data proceeds without reduction of the speed of data acquisition and also we have the possibility to analyze offline the data from our experiment.

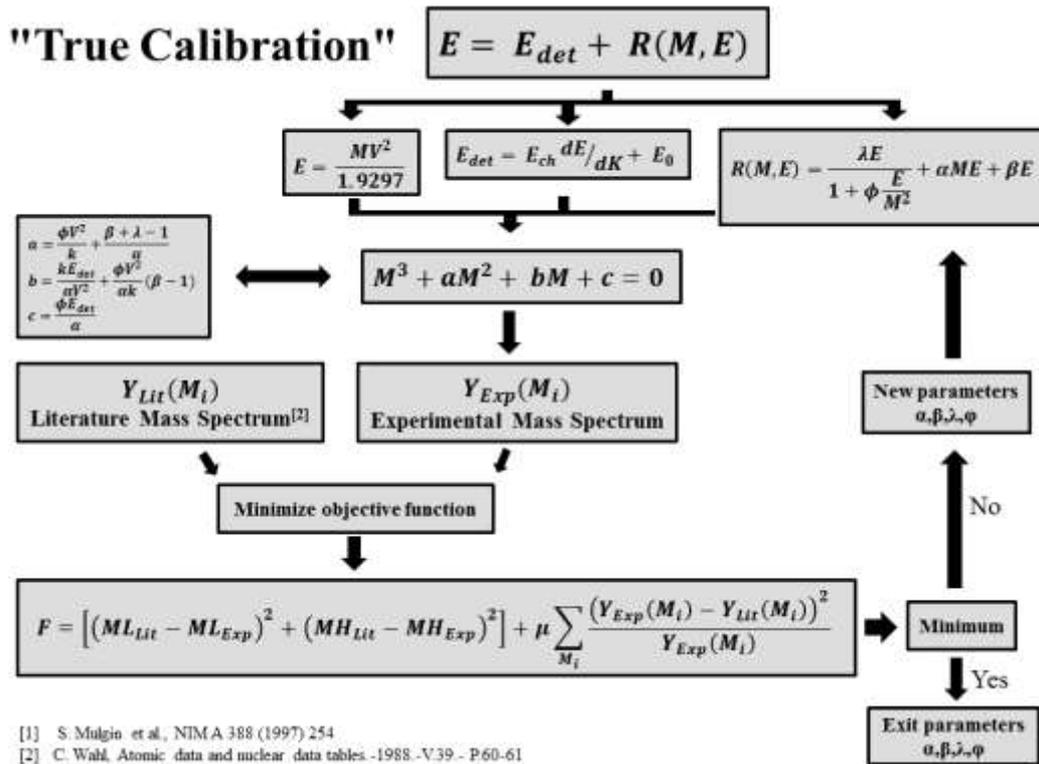
## CALIBRATION OF E & T CHANNELS, CALCULATION OF THE TOF-E FF MASSES

The use of the Si-semiconductor detectors in TOF- $E$  spectrometry of heavy ions (or FFs) is known to have delicate methodological problems due to the “amplitude (pulse-height) defect” and “plasma delay” effects in the  $E$  and TOF channels, respectively. The first effect involves nonlinearity in the dependence of the “deposited energy versus electrical charge measured”, while the latter distorts the TOF used in the calculation of the heavy ion masses. Correct accounting for both effects needs rather complicated procedure of the FF mass reconstruction.

Actually we use three-step approach in the reconstruction of the TOF- $E$  FF masses. At the first stage a simplified approach is used as follows. Two coefficients of the linear time calibration are calculated using the velocity spectrum of the known FFs from the literature. The energy calibration dependence is presented as a parabolic curve passing via three points, namely through the known centers of the energy peaks for the light and heavy fragments, and 4

the energy of the alphas of natural radioactivity of  $^{252}\text{Cf}$  nucleus. Such approach gives quite satisfactory results for there reconstruction of the FF masses, at least, in the vicinity of the loci of binary FFs, as can be inferred, for instance, from fig. 6. In the frame of this simple approach we have a possibility for the on-line estimation of the current status of the experiment. At the same time both specific distorting effects mentioned above are taken into account rather roughly.

At the second step much more complicated procedure based on the parameterization of the pulse-height defect (PHD) proposed by S. Mulgin and coauthors (“true calibration”, fig. 7) is used. It lets to reconstruct the FF kinetic energy and mass taking into account PHD as a function of these parameters in the frame of certain iterative procedure.



**FIGURE 7.** Calibration procedure, algorithm for “true calibration”.

At the last step TOF is corrected for plasma delay while PHD is also taken into account. Preparation of the corresponding program is in progress.

We use the following approach for taking into account the plasma delay:

$$t_{true}[\text{ns}] = T_{exp}[\text{ch}] * a[\text{ns/ch}] + b[\text{ns}] - \Delta t_p[\text{ns}],$$

where  $T_{exp}$  is an experimental time-of-flight [ch],

$t_{true}$  – the “true” time-of-flight [ns],

$\Delta t_p$  – the plasma delay [ns]

$a$  – the channel width [ns/ch] known from the time-calibrator,

$b[\text{ns}]$  – the time const, defined by  $\alpha$ -particles from  $^{252}\text{Cf}$  (sf) at already fixed  $a$ .

According to the parameterization proposed in ref. [8] the plasma  $\Delta t_p$  is expressed as follows:

$$\Delta t_p = 1.33 \frac{M^{1/6} E^{1/2}}{E_{NAPR}} \text{ that is } \Delta t_p = \gamma M^{1/6} E^{1/2}$$

Here  $E_{NAPR}$  a field strength in the PIN diode. The values for mass  $M$  and  $E$  obtained in the frame of the “first approximation” approach were used. The full vector of the parameters  $\{\alpha, \beta, \lambda, \varphi, \gamma\}$  is obtained by the minimization of the following function:

$$F = [ \langle ML_T \rangle - \langle ML \rangle^2 + \langle MH_T \rangle - \langle MH \rangle^2 ] + \mu \sum_{M_{TE}} \frac{Y M_{TE} - Y_T M_{TE}^2}{Y M_{TE}} + \omega \sum \frac{(V(M_{TE}) - V_T(M_{TE}))^2}{V(M_{TE})} \quad (1)$$

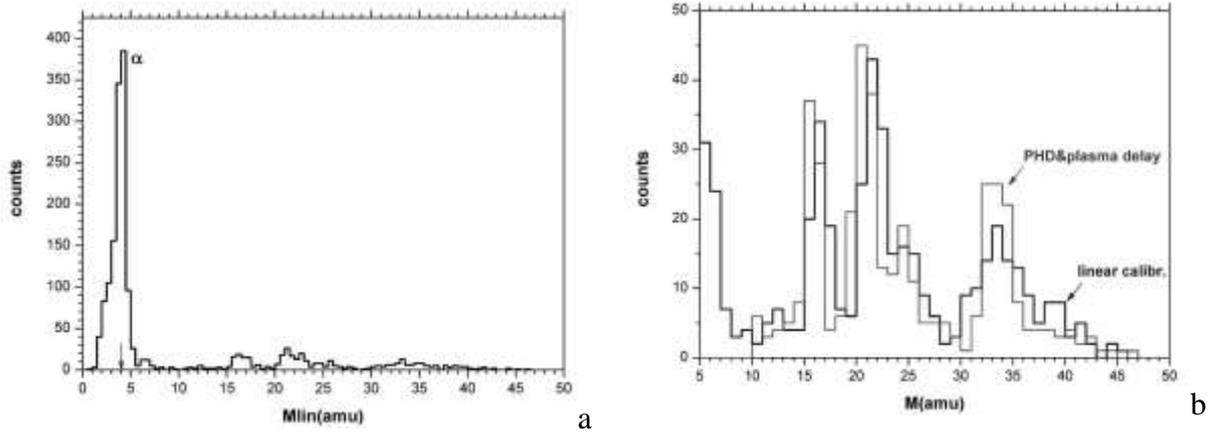
Where  $Y(M_{tE})$  and  $V(M_{tE})$  are respectively the spectra of quasi-masses and velocities calculated at the current values of the parameters, while  $Y_T(M_{tE})$  and  $V_T(M_{tE})$  are the spectra known from the literature. The parameters  $\mu$  and  $\omega$  define a relative weight of the corresponding terms in Eq. (1).

Fig. 8 compares two different approaches for calculation of the mass spectra of light ions from the CCT process.

In the linear calibration approach both TOF and  $E$  channels were calibrated using corresponding generators and known position of the alpha-peak for the  $^{252}\text{Cf}$  (sf). As can be inferred from fig. 8 good agreement is observed between both approaches. It could be stressed that one of them namely the one accounting for PHD and plasma delay can be used in all the range of the detected fragments from light ions up to the FFs from binary fission.

Thus three-step approach for the reconstruction of the TOF– $E$  FF masses was put forward:

- taking into account of the pulse-height defect and plasma delay effect on the average;
- correct accounting for the pulse-height defect;
- final approach with correct accounting for both distorting effects.



**FIGURE 8.** Mass spectrum of light ions obtained in the frame of linear both TOF and  $E$  calibrations (a); comparison of linear approach with this when both pulse-height defect (PHD) and plasma delay are taken into account (b).

## CONCLUSIONS

The COMETA setup presented here proved to be an adequate instrument for study of the very specific multi-body decay channel of heavy nuclei called collinear cluster tri-partition (CCT). Forthcoming upgrade of the spectrometer involves essential increase of its aperture for fragments from multi-body decays.

## REFERENCES

1. Yu.V. Pyatkov et al., Eur. Phys. J. A. 2010. V. 45. P. 29–37.
2. Yu.V. Pyatkov et al., Physics of Atomic Nuclei. 2010. V. 73. P. 1309–1316.
3. Yu.V. Pyatkov et al., Bulletin of the Russian Academy of Sciences. Physics. 2011. V. 75. P. 949–952.
4. Yu.V. Pyatkov et al., Eur. Phys. J. A. 2012. V. 48. P. 94–109.
5. Y.-G. Ortlepp et al., NIM A. 1998. V. 403. P. 65–97.
6. D.V. Kamanin et al., Physics of Particles and Nuclei Letters. 2010. V. 7. P. 121–126.
7. MCNP – “Monte Carlo N-Particle code”. <http://mcnp-green.lanl.gov>
8. H.O. Neidel, H. Henschel, NIM. 1980. V. 178. P. 137–148.