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NUCLEAR PHYSICS DIVISION

Institute of Experimental Physics

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Institute of Experimental Physics

Warsaw University

Edited by: Marek Kirejczyk

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Nuclear Physics Division

Institute of Experimental Physics

Warsaw University

69 Hoża Street, 00–681 Warsaw, Poland

phone: (48 22) 621 67 27
(48 22) 55 32 139

fax: (48 22) 625 14 96

e-mail: sekret@zfja-gate.fuw.edu.pl, sekret@npdaxp.fuw.edu.pl

www: http://zfjavs.fuw.edu.pl

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PREFACE

This Annual Report summarizes the research activities of the Nuclear Physics Division in the year 2001. The scientific reports are grouped in two sections:

- Reaction Mechanisms and Nuclear Structure
- Experimental Methods and Instrumentation.

The current research program of our Division includes "in-house" activities using the beams from the Warsaw Cyclotron of the Heavy Ion Laboratory as well as involvement in research at large accelerator facilities around the world. Most of the work described throughout this report was carried out as joint efforts of various international collaborations.

During the last year we continued our participation in the FOPI, TAPS and WASA-PROMISE international collaborations.

We are strongly involved in the FOPI upgrade project, especially in the construction of the modified TOF detector. The upgrade of the scintillation sub-detector BARREL has been completed and TOF resolution of 110-140 ps for minimum ionising particles was achieved. The analysis of "event-by-event" fluctuations in nuclear collisions has been the subject of our interest for quite some time. Some new results concerning the possible effect of unphysical fluctuations generated by the response function of the FOPI detector as well as by mixing of events of different centrality are presented in this report. A new approach in studying of chemical equilibrium in dense, hot nuclear matter was tested. For this purpose, fluctuations of rare particles (K^+,K^-)produced in ^{58}Ni+^{58}Ni and ^{96}Ru+^{96}Ru nuclear collisions were used. Unfortunately, the number of double-kaon events from these experiments was too small to obtain conclusive results.

The question of mass dependence of sub-threshold neutral pion production in heavy-ion collisions was studied with the TAPS spectrometer. The analysis of experimental data obtained with the Ar beam at 95 AMeV on several targets was completed and neutral pions have been identified through invariant mass analysis.

A new approach to the analysis of fusion exitation functions and fusion-barrier distributions was proposed. About 50 precisely measured fusion excitation functions were perfectly reproduced within the phenomenological model and the systematics of the parameters were obtained allowing to predict not yet measured fusion- or capture excitation functions. This result is important for better planning of future experiments on synthesis of superheavy elements.

During the last year, we continued our study of high-energy γ-ray emission in heavy-ion reactions in the energy range of 5-11 MeV/u. The purpose of this work is to investigate the properties of hot, fast rotating compound nuclei and to extract information on GDR built on excited states – as a function of the nuclear temperature. In our resent experiments with the modified JANOSIK set-up, measurement of high energy γ-rays have been combined with detection of light charged particles. In such a way a more accurate information on the excitation energy and the mass and charge of the decaying nucleus could be obtained.

Using the beam of the Warsaw Cyclotron and the OSIRIS experimental set-up, lifetimes of high spin rotational levels in ^{131}La were measured. The mean lifetimes were extracted with the DSA method and were obtained for six high-spin rotational levels of the yrast band built on the $h_{11/2}$ proton orbital. The exctracted values range from 0.3 ps for the $43/2^-$ state to 1.3 ps for the $23/2^-$ state.

Some interesting results have been obtained for nuclei in the atomic mass region around $A \approx 170$. For example, ^{174}Y was produced in the ^{170}Er(^{7}Li,pxn) reaction and identified with the GASP spectrometer and the charge particle-telescopes system ISIS. A set of four identical γ bands originating from orbitals of different shells was found.

Among contributions concerning experimental methods and instrumentation, I would like to mention the interesting proposal of using the EUROBALL CLUSTER sub-detectors as in-beam polarimeters. Properties of CLUSTER detectors have been studied and compared with the results obtained for CLOVER detectors.

As was already mentioned, most of the work presented in this Annual Report results from close collaboration with our colleagues from many foreign as well as Polish institutes and universities. In this place, I would like to express our deep gratitude to all our friends and collaborators around the world. I would also like to acknowledge the financial support of the Polish State Committee for Scientific Research (KBN).

Krystyna Siwek-Wilczyńska

Research reports

Reaction mechanisms and nuclear structure

Nuclear Physics Division IEP UW
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Neutral pion production in 95A MeV Ar induced reactions

K. Tymińska, K. Piasecki, T. Matulewicz and D. d'Enterria[a]
for the TAPS Collaboration

The production of neutral pions in heavy ion collisions at subthreshold beam energies per nucleon is a process which has been extensively studied for more than a decade. However, a significant part of the available experimental data was obtained in the period when the experimental tools for neutral pion detection evolved from Cherenkov lead-glass counters towards barium fluoride scintillation detectors of superior energy resolution compared to lead-glass spectrometers. In order to solve some problems related to the dependence of neutral pion production on the size of the colliding systems, we have undertaken a systematic study of π^0 production at fixed beam energy and at several targets, ranging from light to heavy ones. Some results obtained from the 60A MeV Ar beam experiment carried out at KVI Groningen have been presented in the previous report [1] and published [2]. Progress in the analysis of the 95A MeV Ar beam experiment carried out at GANIL Caen is presented here.

Neutral pion production was studied in reactions induced by a 95A MeV Ar beam delivered by the GANIL accelerator complex. Targets of C, Al, Ni, Ag and Au were used. This selection allows to uniformly cover the values of impact-parameter-averaged number of participants:

$$A_{part} = \frac{A_P^{2/3} A_T + A_P A_T^{2/3}}{\left(A_P^{1/3} + A_T^{1/3}\right)^2} \tag{1}$$

where A_P (A_T) denotes the mass number of the projectile (target) nucleus. Photons from the dominant (98.9%) neutral pion decay were detected by the TAPS spectrometer [3], arranged in 6 blocks of 8×8 BaF_2 modules each placed at a distance of 56 cm from the target at angles $\pm55°$, $\pm100°$ and $\pm150°$ with respect to beam direction. Each TAPS module was equipped with a thin individual plastic scintillator counter allowing the separation of neutral and charged particles also at the trigger level. The data were recorded with a trigger condition that of least one BaF_2 module in two blocks placed on opposite sides of the beam axis registering a neutral hit with energy exceeding 20 MeV. The beam intensity was adjusted for each target with the condition that most forward modules were operated at a reasonable counting rate, allowing the proper application of pulse-shape analysis.

Data reduction was performed using the FOSTER calibration package [4]. The energy calibration of individual BaF_2 modules (in the wide and narrow QDC integration gate)

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[a] *SUBATECH, Ecole de Mines, Nantes, France*

was based on the position of the QDC pedestal and the position of the cosmic-ray peak (about 38.5 MeV). The energy calibration was finally adjusted by the reproduction of the known mass of the π^0 meson in the invariant mass of two-photon events. This procedure introduced a global correction factor equal to 1.125, which is similar to other TAPS calibrations [5]. The time-of-flight (TOF) spectra were calibrated according to the positions of consecutive beam bunches separated by 74.35 ns (the inverse of the cyclotron RF). Photons are well separated from other particles on the 2-dimensional representation (Fig. 1), where the ratio of the light yields is plotted versus the TOF.

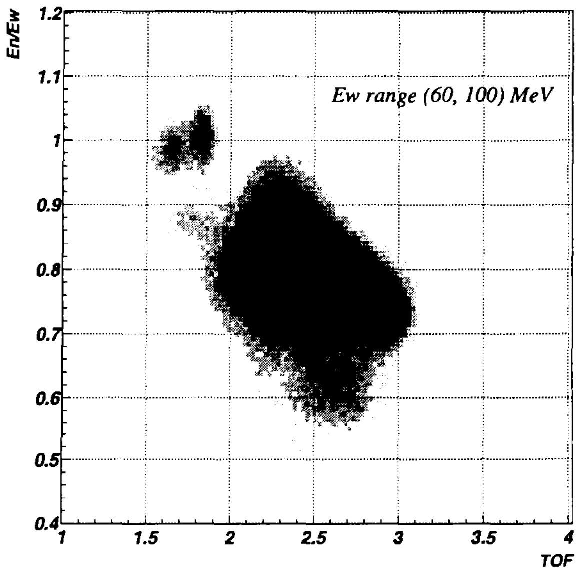

Figure 1: Experimental data presented on a two dimensional plot of ratio of scintillation light in the narrow and wide gate versus the time-of-flight, for the energy window between 60 and 100 MeV. Photons are clearly identified around E_n/E_w=1 and TOF=1.8 ns.

Identified photon events were subsequently subjected to the clusterization algorithm allowing for the reconstruction of initial photon energy (usually spread in several adjacent modules), and the photon impact point. The procedures are described in [6]. Reconstructed photon pairs allowed for the evaluation of the invariant mass according to the formula

$$m_{\gamma\gamma} = \sqrt{2E_{\gamma_1}E_{\gamma_2}\left(1-\cos\vartheta_{\gamma\gamma}\right)} \qquad (2)$$

where E_{γ_i} denote the energy of the i-th photon and $\vartheta_{\gamma\gamma}$ is the opening angle between the photon pair. Invariant mass spectra (Fig. 2) show, for each target, a prominent peak corresponding to neutral pion decay. Several thousand neutral pions were detected for each target. The forthcoming analysis will consist of the following steps:

1. Monte-Carlo simulation of neutral pion efficiency of the TAPS configuration used in this experiment,

2. reconstruction of the kinematic properties of neutral pions within the kinematic fit method [7],

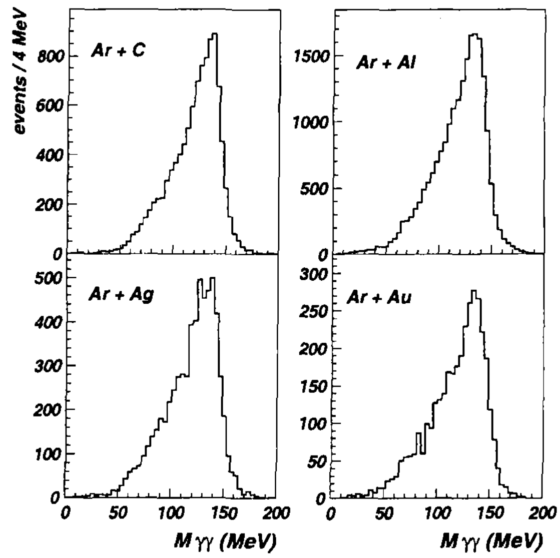

Figure 2: Two-photon invariant mass spectra for 4 targets studied in this experiment.

3. determination of angular distribution of detected neutral pions as well as their energy and momentum spectra.

Acknowledgements: This work was supported by Polish State Committee for Scientific Research (KBN) grant 2P03B 013 14 and by the Collaboration 00-98 of the Convention of IN2P3 France and Poland.

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What we can learn from rare two–kaon events in nuclear collisions

B. Sikora, M. Kirejczyk, K. Siwek–Wilczyńska, K. Wiśniewski

It was recently proposed [1] that fluctuations of rare particles produced in nuclear collisions in elementary processes constrained by U(1) charge conservation can be used to study chemical equilibration. An obvious example is the near-threshold kaon production, which is subject to strangeness conservation. It can be expected that appropriate measurements, though difficult, could for the first time provide direct experimental evidence for chemical equilibration in heavy-ion reactions.

Experiments with the high-acceptance FOPI detector carried out at the highest energies of the SIS accelerator at GSI Darmstadt have so far provided the only set of data that can be used for such studies, which require two–kaon events. The systems studied were ^{58}Ni + ^{58}Ni at 1.93 A GeV and ^{96}Ru + ^{96}Ru/Zr at 1.69 A GeV. The accumulated statistics corresponded to $5 \cdot 10^6$ and $7.7 \cdot 10^6$ central events, respectively.

It was shown in [1], that the distribution of N^0, the primary (freeze-out) kaon multiplicity in a system approaching chemical equilibrium, deviates from the poissonian distribution. Its second factorial moment

$$F_2 = \frac{< N^0(N^0 - 1) >}{< N^0 >^2} \tag{1}$$

reaches in the equilibrium 1/2, i.e. half of the value for poissonian distributions. The symbol <> denotes averaging over the whole set of events.

In the case of rare particles, N^0 would be small, from 0 up to perhaps 3. Therefore, one can rewrite (1) as:

$$F_2 = \frac{\frac{1}{N_{\rm ev}} \sum^{N_{\rm ev}} N^0(N^0 - 1)}{(\frac{1}{N_{\rm ev}} \sum^{N_{\rm ev}} N^0)^2} = \frac{N_{\rm ev}(2N^0_{2K} + 6N^0_{3K} + \ldots)}{(N^0_{1K} + 2N^0_{2K} + \ldots)^2}, \tag{2}$$

where N^0_{nK} denote the numbers of events with n kaons produced. Since approximately $N^0_{1K}/N^0_{2K}/N^0_{3K} \approx 10^4/10^2/1$ in the analysed experiments, formula (2) is practically reduced to

$$F_2 = \frac{2 \cdot N_{\rm ev} \cdot N^0_{2K}}{(N^0_{1K})^2}. \tag{3}$$

In order to express F_2 in terms of the measured numbers N_{nK} of events with n **identified** kaons, one can assume that the there is no correlation in the efficiencies, with which different kaons in an event are detected and identified. Then, $N_{1K} \approx \eta N^0_{1K}$ and

$N_{2K} \approx \eta^2 N^0_{2K}$, where η denotes the efficiency for a single kaon and $N^0_{1K} \gg N^0_{2K}$ is assumed. Substituting this in (3), one obtains

$$F_2 = \frac{2 \cdot N_{\mathrm{ev}} \cdot N_{2K}}{(N_{1K})^2} = F_2^{\mathrm{exp}}. \tag{4}$$

The first scanning of the available data revealed 13 two-kaon events in the Ni+Ni, and 17 in the Ru+Zr experiments, respectively, and no events with higher kaon multiplicity. The resulting F_2^{exp} moments and their statistical uncertainities are 0.77 ± 0.21 and 0.92 ± 0.22 respectively. More elaborate analyses and estimates of possible systematic errors are under way, however one can already conclude that much higher statistics of events are needed to obtain conclusive results. The planned experiments with the upgraded FOPI detector may yield the necessary statistics, increased by one order of magnitude.

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Chemical equilibration of fireball in nucleus–nucleus collisions

I. J. Soliwoda, M. Kirejczyk, B. Sikora, K. Siwek–Wilczyńska, M. M. Smolarkiewicz

The equilibration of nuclear systems produced in heavy ion collisions can be probed by measuring event-by-event (EbE) fluctuations. These fluctuations can be quantified in an analysis of some observables (like perpendicular momentum) averaged eventwise by comparing them with the values of sample averages.

A suitably defined parameter Φ, a measure of EbE fluctuations which approaches zero when the measured system is in the state of thermodynamical equilibrium, has been proposed by Gaździcki and Mrówczyński [1,2].

Continuing our previous studies [3], we investigated the chemical properties of the hadronic matter at freeze-out. The Ru+Ru collisions at 1.69 A GeV beam energy measured in the CDC subsystem of the FOPI detector [4] were analysed. Several selection criteria were applied in order to isolate products originating from the fireball created in these collisions. We concentrated on the EbE fluctuations of the charged pion multiplicity.

The results shown in Fig. 1 demonstrate that the Φ values within the experimental accuracy are the same for peripheral, semicentral and central events and are approximately equal to zero. Thus, EbE fluctuations of pion multiplicity are independent of the centrality of collision and therefore do not depend on the size of the fireball.

The obtained values of the Φ parameter close to zero may support the hypothesis that, even in peripheral collisions, scattering of particles in the fireball is frequent enought and the lifetime of the fireball is sufficiently long to reach states close to chemical equilibrium.

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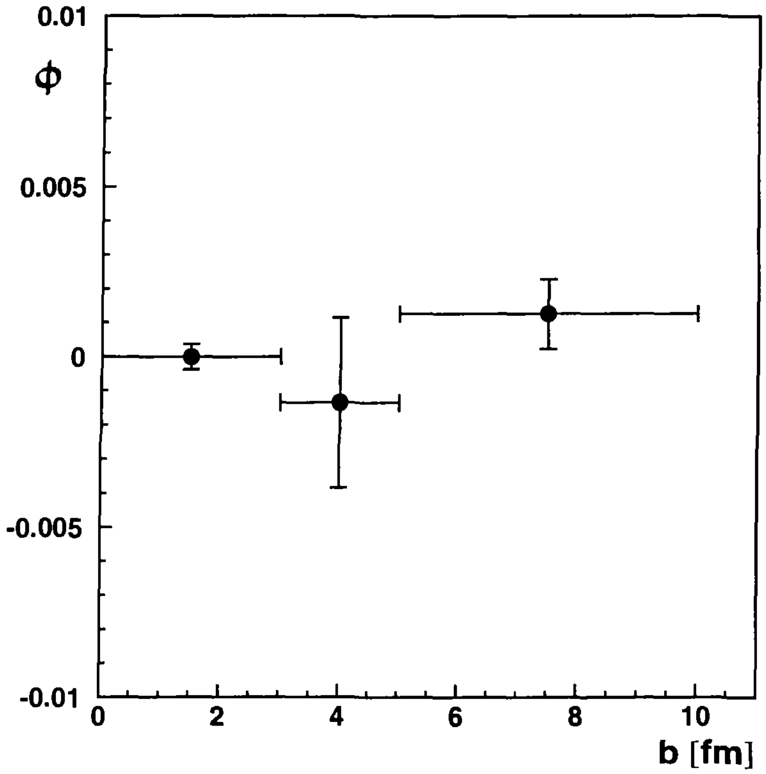

Figure 1: Values of the Φ parameter related to chemical equilibrium for various ranges of the impact parameter.

The influence of IQMD parameters on intermittency

M. M. Smolarkiewicz, M. Kirejczyk, B. Sikora, K. Siwek–Wilczyńska, I. J. Soliwoda

The search for the intermittency signal in heavy ion collisions at beam energies below 1 A GeV has been one of our subjects of interest for some time [1–3]. Data obtained with the FOPI detector [4] at the SIS accelerator in GSI Darmstadt were analysed. The horizontal normalised scaled factorial moments (HNSFMs) method, proposed by Bialas and Peshansky [5] was applied to a search for intermittency.

To compare intermittency parameters with model predictions, two event generators were used: the statistical code WIX [6] and the isospin quantum molecular dynamics code IQMD [7,8], the first, as reference producing no dynamical fluctuations and also suitable for studying the effects of apparatus. Coulomb and hadronic interactions of registered particles with the FOPI detector were estimated with help of the GEANT simulation tool [9].

In the intermittency analyses carried out in a fixed laboratory coordinate system, fluctuations for large $\delta\phi$ bins can be interpreted as an effect of anisotropic ϕ distributions relative to the randomly varying reaction plane. This trivial effect cannot be removed by rotating the experimental events to a common reaction plane, since this would introduce another type of fluctuation due to anisotropy (shadows) in azimuthal acceptance. Therefore, the reaction plane of the simulated IQMD events had to be randomized and, as a result, fairly good agreement with the experiment was obtained for bin sizes $\delta\phi > 45°$. The power-law behaviour of the HNSFMs for $\delta\phi < 45°$ could not however be reproduced in calculations with commonly used model parameters.

In order to study the influence of the IQMD parameters on fluctuations, as a first step, two samples of events were generated. The soft (K = 200 MeV) and the hard (K = 380 MeV) equation of state (EOS) with momentum-dependent interactions were used. Default values of other IQMD parameters, like cross section of nucleon–nucleon interactions, were applied.

In Fig. 1, the deduced values of HNSFMs ($\langle F_i^{\delta\phi}\rangle$) of rank 2 to 5, calculated for the azimuthal angle distribution, are shown. Full circles represent experimental data, open circles — IQMD events generated with hard EOS while squares — IQMD events generated with soft EOS. Values of HNSFMs calculated for hard and soft EOS differ only slightly and both do not reproduce the experimental data.

The influence of other IQMD model parameters on intermittency is under study.

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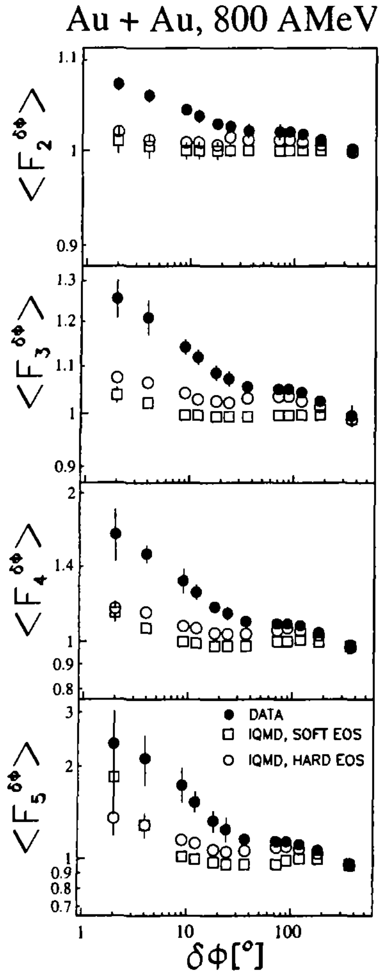

Figure 1: Values of HNSFMs of ranks i = 2, 3, 4, 5, calculated for azimuthal angle distribution, as a function of bin widths $\delta\phi$, for three samples of events: the experimental data (full circles), data generated by IQMD: with hard (open circles) and soft (squares) EOS.

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Study of applicability of the Ma method in intermediate–energy heavy–ion research

M. Kirejczyk

The question whether thermal equilibrium has been reached in a system created in a nuclear collision is an interesting one and has been the subject of research for quite a long time. A direct method for judging if there is an equilibrium or not has been proposed by Białas, Czyż and Wosiek [1], and is called the Ma method, being based on ideas proposed by S. K. Ma. The following arguments are presented more fully in [1] and [2], and here will be only outlined.

In the microcanonical ensemble, one may define thermal equilibrium as the macrostate that consists of the largest number of microstates (or configurations). Within this macrostate, there is an equal probability of finding each of the configurations. Each measured event can be interpreted as a configuration.

If the number of microstates within the macrostate is denoted by Γ, each microstate is equally probable, and p denotes the probability of finding any given microstate (configuration), then $p = 1/\Gamma$. If it is assumed that $p \ll 1$, the probability of finding the same microstate twice is equal to p^2, therefore the probability of finding identical microstates should be

$$P_i = \sum_{\text{all states}} (p^2) = \Gamma \times (p^2) = p = \frac{1}{\Gamma}.$$

So, if N configurations (events) are measured, and N_2 coincidences (pairs of identical events) are found, it may be concluded that

$$\frac{1}{\Gamma} = P_i = \frac{N_2}{\frac{1}{2}N(N-1)}.$$

In order to define "identical" events one may divide the phase-space into a lattice (with each cell having the volume σ), and "quantify" the events. In such a case, if the total phase-space volume occupied by the macrostate is denoted by Ω, one obtains: $\Gamma = \Omega/\sigma$, and therefore

$$\log(\Omega) + \log(1/\sigma) = \log(\frac{1}{2}N(N-1)) + \log(1/N_2).$$

So, if the system is in equilibrium, one may expect a linear dependence of $\log(N_2)$ on $\log(\sigma)$. This dependence is not valid for large σ, where the $p \ll 1$ condition does not hold.

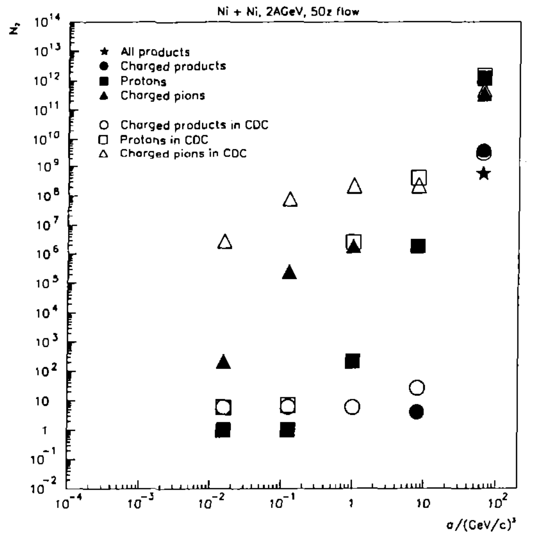
In order to test the applicability of this method, it was used on the data produced by the WIX [3] code, used as an event generator. As WIX uses a statistical model, the events produced do come from an equilibrated source. The lattice was defined in the momentum space and the number of "identical" events was plotted as a function of the cell size. To simulate reality more precisely, in the first attempts about 50% of the available energy was put into the collective degrees of freedom (flow).

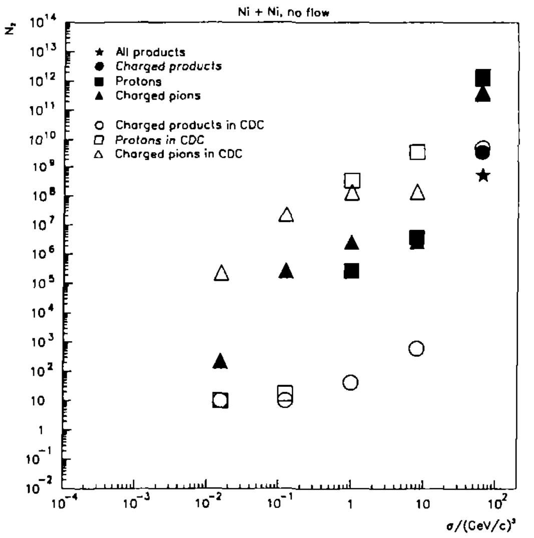
The real detector systems always have limitated detection capability. This means that what is being probed in the experiment is a convolution of the measured microstate with statistical effects. In this study the CDC detector from the FOPI spectrometer was used as an example. CDC is a drift chamber, and has the capability to register and identify all charged particles emitted in the laboratory in polar angles between 30° and 150°.

The first results were reported in [2]. They are not very promising — it was discovered, that there are no coincidences for smaller σ and no linearity test was possible. There was some hint, however, that perhaps including detector-imposed limits may make the method applicable. Several possibilities were proposed as a possible reason for the difficulties: complicated chemical composition, collective flow convoluted with the "equilibrated", statistical emission and, last but not least, deviations from microcanonical character of the "data" imposed by the limited acceptance of detectors.

In order to test whether the collective effects are indeed one of the factors creating problems with the application of Ma method, the WIX code was used to simulate events without any collective effects. The source energy was set to a level, that made the "chaotic" energy (total energy with flow energy subtracted) approximately the same as in the previous study.

The results of applying the Ma method to the "data", where there is significant flow (50% of energy in the collective motion), and to "data" with no collective effects are presented on the figure. Full points depict the full angular range, open points correspond to the CDC angular range. Different shapes signify different product species. There is no visible improvement in the "no flow" case.





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Fusion and capture excitation functions in nuclear collisions

K. Siwek-Wilczyńska, E. Siemaszko, J. Wilczyński[a]

It is well known that fusion excitation functions cannot be satisfactorily explained assuming penetration through a single, well-defined barrier in the total potential energy of a colliding nucleus-nucleus system. In order to reproduce shapes of the fusion excitation functions, especially at low near-threshold energies, it is necessary to assume coexistence of different barriers, a situation that is naturally accounted for in the description of fusion reactions in terms of coupled channel calculations involving coupling to various collective states.

We propose a phenomenological description of the fusion excitation functions and assume the Gaussian shape of the barrier distribution:

$$p(B) = \frac{1}{\sigma_B\sqrt{2\pi}} \exp\left[-\frac{(B-B_0)^2}{2\sigma_B^2}\right], \tag{1}$$

with the mean barrier B_0 and its variance σ_B being free parameters to be determined individually for each reaction by comparing the predicted fusion excitation function with experimental data. By folding the barrier distribution, Eq. (1), with the classical expression for the fusion cross-section for a fixed barrier B,

$$\sigma_{fus} \simeq \pi R_B^2\left(1-\frac{B}{E}\right), \tag{2}$$

one obtains the following formula for the energy dependence of the fusion cross-section [1]:

$$\sigma_{fus} = \pi R_B^2 \frac{\sigma_B}{E\sqrt{2\pi}}\left\{X\sqrt{\pi}(1+\mathrm{erf}X)+\mathrm{e}^{-X^2}\right\}, \tag{3}$$

where $X = (E - B_0)/(\sqrt{2}B_0)$, and erf$X$ is the Gaussian error integral of the argument X. By R_B we denote the distance corresponding to location of the interaction barrier.

We have fitted Eq. (3) to existing data on near-barrier-fusion- and capture excitation functions for about 50 medium and heavy nucleus-nucleus systems. By minimizing χ^2, we have determined individual values of both parameters for each reaction, the mean barrier B_0 and variance σ_B. Fig. 1 shows some examples of this precedure. It is seen from Fig. 1 that experimental fusion excitation functions can be perfectly reproduced with Eq. (3). From the obtained systematics of B_0 and σ_B values combined with predictions

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[a] *Institute for Nuclear Studies, Świerk, Poland*

[4] of the adiabatic fusion barriers, we are able to calculate individual values of both these parameters for any reaction. In such a way, knowing B_0 and σ_B, and using Eq. (3), we can predict fusion- or capture excitation function for systems not yet studied experimentally. The predictions of capture cross-sections are especially important for planning experiments aimed at producing new super-heavy elements.

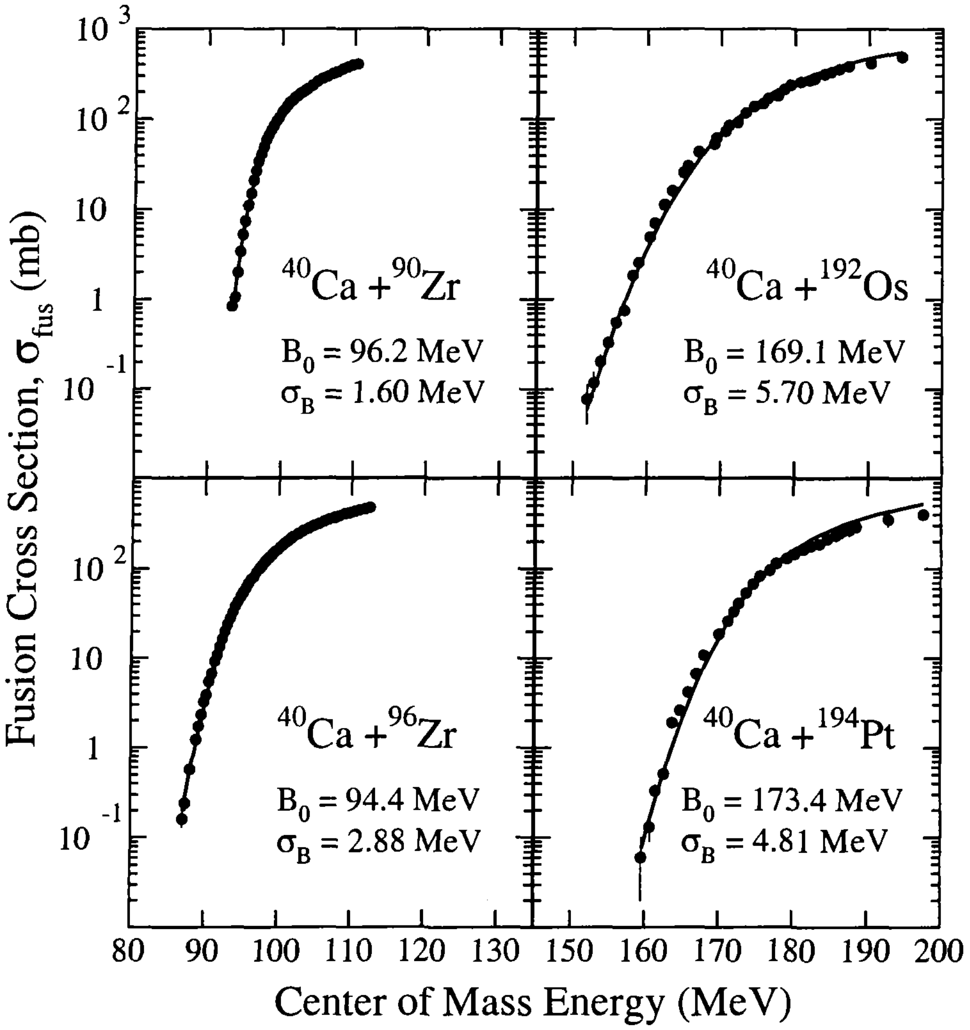

Figure 1: Fusion excitation functions calculated with Eq. (3). Experimental data, taken from Refs. [2] and [3].

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High-energy gamma-ray emission studies with JANOSIK set-up in the ^{20}Ne+^{12}C reaction at 5.2 MeV/u

E. Wójcik, M. Kicińska-Habior, O. Kijewska, M. Kisieliński[a], M. Kowalczyk, J. Choiński[a], W. Czarnacki[b], A. Kordyasz[a], Z. Trznadel[c], K. Piasecki, K. Tymińska, Z. Tymiński, M. Zych

We have begun a project devoted to high-energy γ-ray (E_γ = 5–50 MeV) emission studies in the ^{20}Ne+^{12}C heavy-ion collisions at projectile energies of E_{proj}/A = 5–10 MeV/u. The purpose of this work is to investigate the properties of hot, fast rotating compound nuclei around ^{32}S produced in these reactions and to extract information on Giant Dipole Resonance (GDR) built on excited states in those systems as a function of the effective nuclear temperature.

During the past year, we examined the ^{20}Ne+^{12}C reaction at 5.2 MeV/u beam energy from the Warsaw Cyclotron. It is expected that at this low projectile energy, ^{32}S compound nuclei are formed by complete fusion only and that γ-ray emission is mostly of a statistical character. If so, then the least square fitting of the statistical model calculations to the experimental high-energy γ-ray spectrum should allow extraction of GDR parameters via the CASCADE code. The angular distribution coefficient, $a_1(E_\gamma)$, calculated in the compound nucleus center-of-mass frame from the measured data using Legendre polynomial parameterization should be consistent with zero for the statistical emission. The $a_2(E_\gamma)$ coefficient carries information about the deformation of the nuclei in which the GDR is built. Thus, the energy spectra and angular distribution of γ-rays emitted in the studied reaction have been measured with the multidetector set-up JANOSIK [1,2]. High-energy γ-rays were separated from neutron-induced events based on the measured time-of-flight. High-energy γ-ray spectra at three angles Θ_{lab} = 60°, 90° and 120° were calibrated with the ^{244}Cm/^{13}C source as well as with monoenergetic lines at 4.44 MeV and 15.1 MeV from the ^{11}B+D reaction at 19.1 MeV ^{11}B beam energy. Spectra at each angle have been normalized to the summed multiplicity (larger than 2) of low-energy γ-rays measured by the multiplicity filter and then transformed to the compound nucleus center-of-mass frame. Final analysis of the measured angular distributions of γ-rays, which should allow a conclusion to be made on the character of their emission, is still in progress.

The γ-ray energy spectrum measured at 90° (see Fig. 1, top) has been fitted with the statistical code CASCADE, assuming the expected, but not yet established, statistical

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[a] *Heavy Ion Laboratory, Warsaw University, Poland*
[b] *Sołtan Institute of Nuclear Studies, Świerk, Poland*
[c] *Warsaw Agricultural University, Warsaw, Poland*

character of the observed high-energy γ-ray emission. The code includes Reisdorf's level density and a spin-dependent moment of inertia. Experimental level densities for nuclei with A = 24-32 [3] have been well reproduced with the Reisdorf's level density parameter r_0= 1.095 fm (see Fig. 2). The isospin also has to be taken into account in the analysis. It is a well known fact that the yield of high-energy γ-rays in the statistical decay of self-conjugate nuclei populated by entrance channels with isospin T=0, as in the case of the ^{20}Ne+^{12}C → ^{32}S reaction, is strongly inhibited in comparison with the yield from the T≠0 entrance channels and in nuclei with N≠Z [4].

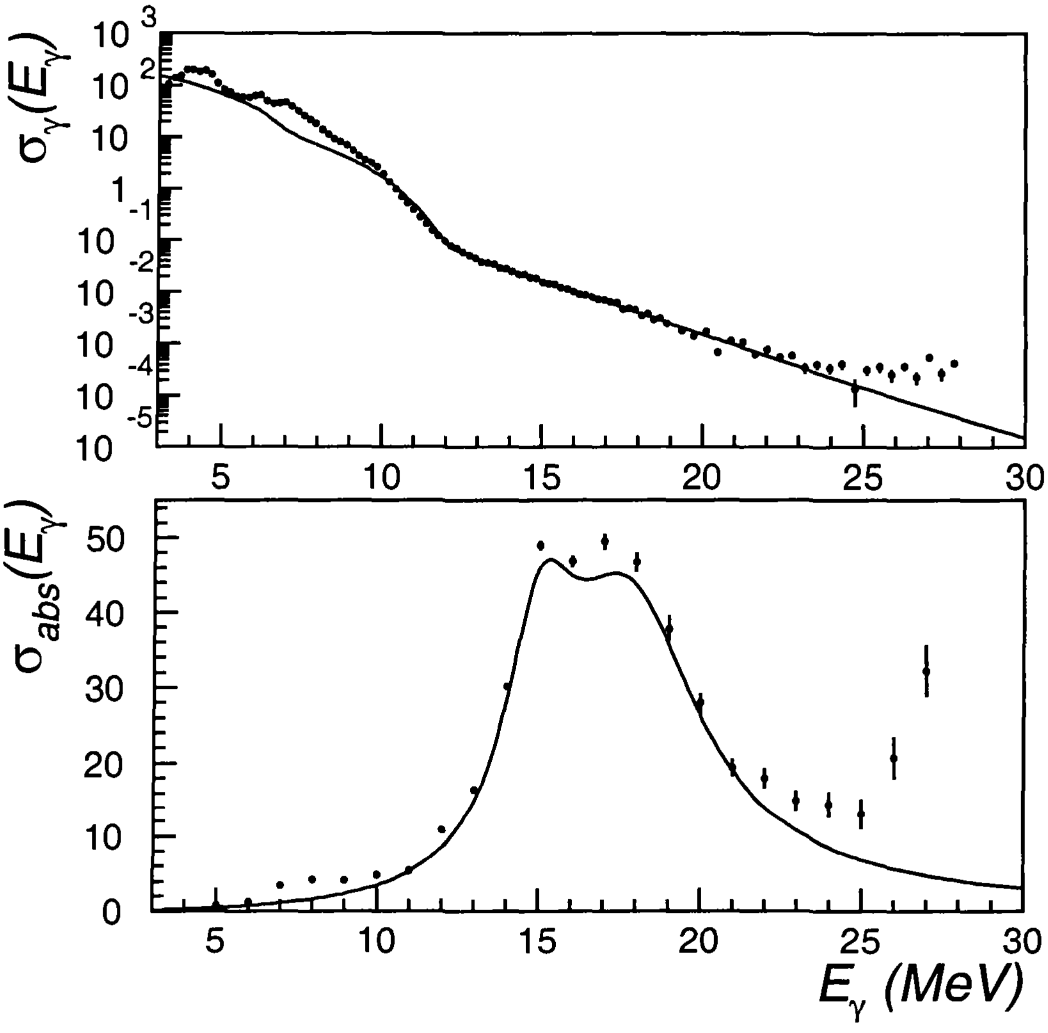

Figure 1: Measured and fitted high-energy γ-ray spectrum (top) and absorption cross-section (bottom) for the ^{20}Ne+^{12}C reaction at 5.2 MeV/u.

This implies good isospin purity in the compound nuclear states at high excitation. In the case of ^{28}Si, for example, weak isospin mixing at excitation energy of about 60 MeV was found and an isospin mixing coefficient $\alpha = 0.032 \pm 0.029$ was derived [5]. We have assumed that the isospin mixing coefficient for ^{32}S at an initial excitation energy of 58.3

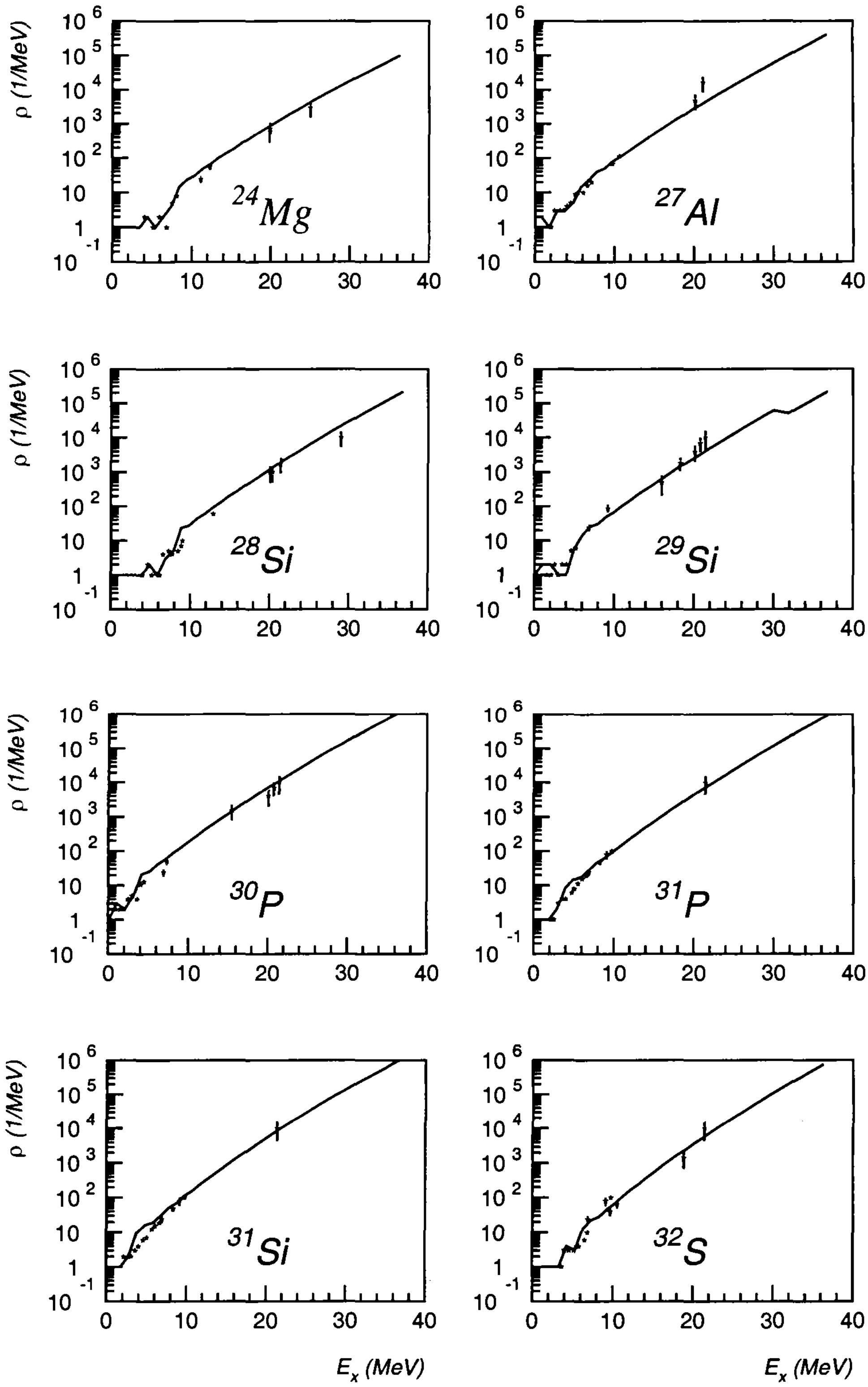

Figure 2: Total level density curves calculated in the Reisdorf approach for some nuclei important in the decay of ^{32}S*, presented together with the experimental data (solid points) from Ref. [3].

MeV also equals $\alpha = 0.032$. With this assumption, we have extracted preliminary values of the parameters for the Giant Dipole Resonance populated in the ^{20}Ne+^{12}C reaction. In the fitting of the statistical γ-ray spectrum calculated with the CASCADE code to the one measured at 90°, the GDR parameters have been treated as free parameters. The quality of the fits with a double Lorentz function representing the GDR strength function (see Fig. 1, bottom) was better than for a single Lorentzian. The preliminary GDR parameters are: $S_{tot} = 0.93 \pm 0.02$, mean $E = 17.0$ MeV, $S_2/S_1 = 2.6 \pm 1.2$, $\Gamma_1 = 2.7 \pm 1.0$ MeV, $\Gamma_2 = 5.4 \pm 0.3$ MeV, and correspond to the average nucleus ^{30}P at average excitation energy of 44.4 MeV, the averaging having been done over compound nucleus decay steps. We plan also to measure the ^{19}F+^{12}C $\rightarrow ^{31}$P reaction populating the nearby compound nucleus at the same excitation energy in order to extract the GDR parameters from the $T \neq 0$ entrance channel.

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Light-charged particle emission studies with JANOSIK set-up in the ^{20}Ne+^{12}C reaction at 5.2 MeV/u

O. Kijewska, M. Zych, M. Kicińska-Habior, E. Wójcik, M. Kisieliński[a], M. Kowalczyk, J. Choiński[a], W. Czarnacki[b], A. Kordyasz[a], Z. Trznadel[c], K. Piasecki, K. Tymińska, Z. Tymiński

Recent results of the analysis of the ^{18}O+^{100}Mo and ^{12}C+^{58,64}Ni reactions [1,2] have shown that in order to extract correct Giant Dipole Resonance parameters from high-energy γ-ray emission studies in heavy-ion collisions at projectile energies above 6 MeV/u, all processes occurring in the collision, i.e. complete and incomplete fusion, preequilibrium nucleon emission and bremsstrahlung γ-ray emission, have to be included. In order to reliably measure the excitation energy, mass and charge of the decaying nucleus produced in the collision, the light emitted particles should be measured and analyzed together with high-energy γ-rays. In accordance with this, we have already started a modification of the multidetector JANOSIK set-up [3,4] which should allow measurement of energy spectra and angular distributions of light charged particles by sixteen Si telescopes placed in the vacuum chamber around the target. Presently, three such telescopes are in operation. Each consists of a 10 µm thick superthin ΔE detector, 130 µm thick ΔE detector and a 11 mm thick E detector.

We plan to use the particle detector system in a new, already started project devoted to γ-ray (E_γ = 5-50 MeV) and light-charged particle ($E_{p,\alpha}$ = 5-50 MeV) emission studies in ^{20}Ne+^{12}C heavy-ion collisions at projectile energies of E_{proj}/A = 5–10 MeV/u. The purpose of this work is to determine the contribution of different processes to the mechanism of the studied reaction at several projectile energies within the discussed range, and to investigate the properties of hot, fast rotating compound nuclei around ^{32}S produced in these reactions, as a function of the effective nuclear temperature.

During the past year, we have examined the ^{20}Ne+^{12}C reaction at 5.2 MeV/u beam energy from the Warsaw Cyclotron. At this low projectile energy, γ-ray and particle emission is expected to be mostly statistical in nature. The γ-ray part of those studies has been presented in [5]. In the first experiment reported here, two prototype Si telescopes consisting of 130 µm thick ΔE and 11 mm thick E detectors have been used. Charged particles: protons, deuterons and alphas were detected at three angles: 50°, 90° and 130° with one silicon telescope, while the second one positioned at 130° was used as a monitor. The two dimensional E–ΔE spectrum with well-distinguishable protons, deuterons and alphas obtained with one telescope positioned at 90° is shown in Fig. 1.

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[a] *Heavy Ion Laboratory, Warsaw University, Poland*
[b] *Sołtan Institute of Nuclear Studies, Świerk, Poland*
[c] *Warsaw Agricultural University, Warsaw, Poland*

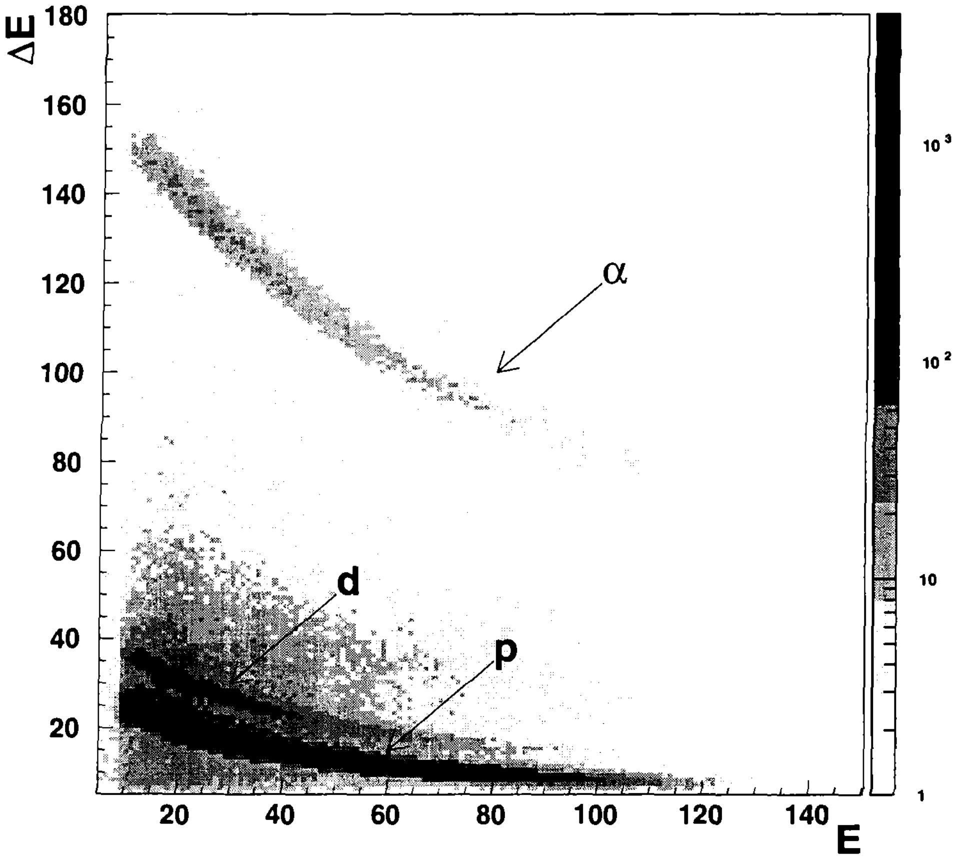

Figure 1: Measured E-ΔE matrix for charged particles obtained with one Si-telescope positioned at 90°, for the ^{20}Ne+^{12}C reaction at 5.2 MeV/n.

The E and ΔE detectors were calibrated with a ^{241,243}Am/^{244}Cm source. In further analyses, charged particles have been identified by using the PID method, which assumes:

$$PID = (E + \Delta E)^b - E^b \propto MZ^2 \tag{1}$$

where:
ΔE — particle energy loss in the ΔE detector,
E — particle energy left in the E detector,
b — a parameter with a value of 1.60–1.75.

The PID is proportional to the product of the particle mass (M) and the square of its charge (Z). Thus, the PID distribution allows for particle discrimination (see Fig. 2). It depends weakly upon the parameter b, since with the increase of b, the peaks corresponding to each particle get wider and tend to be farther from one another. The value $b = 1.67$ was chosen for this experiment.

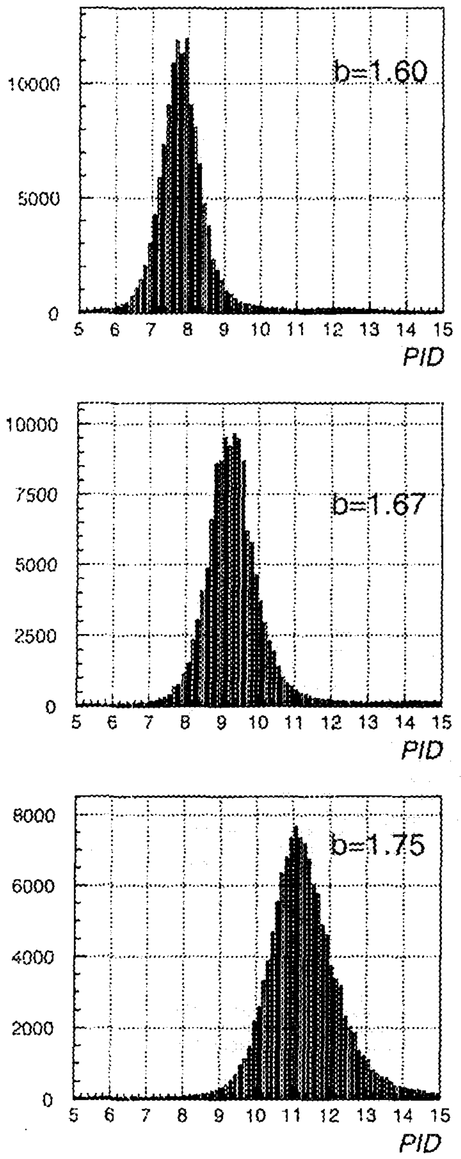

Figure 2: PID distribution for protons from the ^{20}Ne+^{12}C reaction at 5.2 MeV/u with parameter $b = 1.60$–1.75.

The energy spectra for each type of charged particle obtained at 50°, 90° and 130° in the laboratory frame are shown in Fig. 3, together with the statistical model calculations performed with the CASCADE code, in which the same parameters as in the γ-ray analysis were used [5], and transformed from the compound nucleus center-of-mass to the laboratory frame via the Lorentz transformation. Because of the thickness of the ΔE detector, the deuterons and alpha particles at 130° could not be registered by the E detector. Analysis of the data collected during the second experiment with three detector telescopes is in progress.

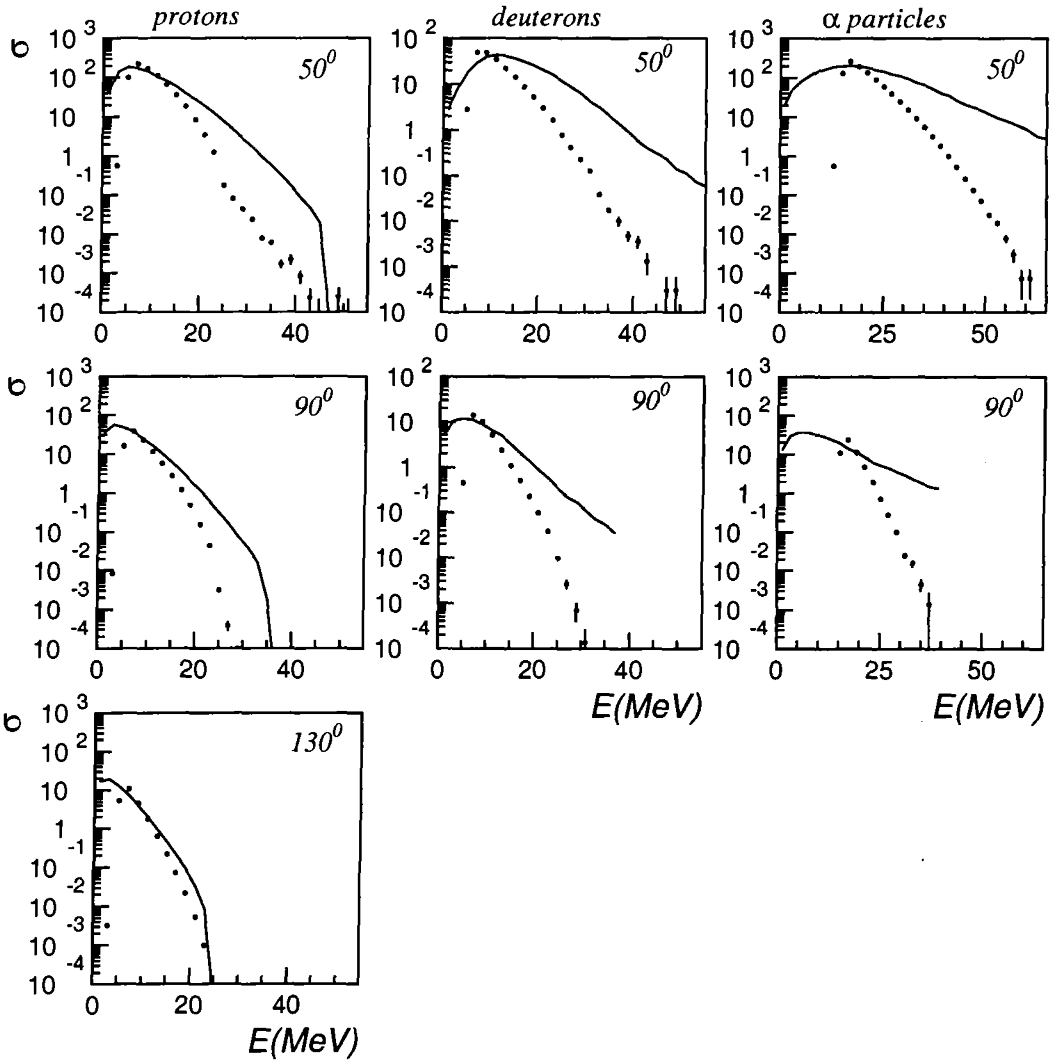

Figure 3: Energy spectra for charged particles emitted in the ^{20}Ne+^{12}C reaction at 5.2 MeV/u measured with one telescope positioned at 50°, 90° and 130° (points), together with CASCADE calculations (lines, preliminary).

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Electric quadrupole transition probability between "yrast" levels of ^{131}La, CQPC and TRS model interpretation of the $h_{11/2}$ band

A. Wasilewski[a], W. Płóciennik[a], E. Grodner, Ch. Droste, T. Morek, J. Srebrny and A. A. Pasternak[b]

Lifetimes of the excited states in ^{131}La have been investigated via the ^{122}Sn(^{14}N,5n)^{131}La reaction using the DSA technique. The ^{14}N beam was provided by the U200P cyclotron of the Heavy Ion Laboratory of Warsaw University. The analysis of the experimental data [1] has given the preliminary lifetime values for the "yrast" levels, with I^{π} from $23/2^-$ to $39/2^-$. Together with the results of RDM experiment [2], we have all E2 transition probabilities for the "yrast" $h_{11/2}$ band from the band head up to the $39/2^-$ level (see Fig. 1). Experimental properties of the $h_{11/2}$ band in ^{131}La have been compared to the CQPC model as well as to Total Routhian Surface calculations.

The CQPC model (see [3],[4] and references given therein) is based on the Q·q interaction of the quadrupole(Q) moment of a core and the quadrupole(q) moment of a quasiparticle. In our case, we have chosen the ^{130}Ba nucleus as both the (A-1) and the (A+1) cores. ^{130}Ba core properties have been described in two extreme versions of the quadrupole nonaxial collective model:

a) the rigid triaxial rotor model of Davydov-Filippov[5]

b) the γ-soft Wilets-Jean model in the extended version presented in [6].

In both cases, the best parameters of these models were chosen to reproduce level energies and B(E2) values for ^{130}Ba experimental data [7].

The main features of both versions of the core model are the following (Lund convention):

a) $E(2_1{}^+) = 324$ keV, $\beta_0 = 0.22$, $\gamma_0 = -23°$, for the Davydov–Filippov model.

b) The main characteristics of the ground state wave function in the γ-soft model are $\beta_{mean} = 0.22$, $\gamma_{mean} = -25°$, the small dispersion in β, the maximal dispersion in γ. β-vibrational mass parameter is about twice as large as the mean value of the rotational and γ-vibrational ones.

Single proton energies for ^{131}La were used according to [4]. The standard value of the χ_{Q-q} coupling constant equal to -9.5 MeV was used. This value agrees with theoretical estimation [9].

As one can see from Fig. 1 (upper panel), the level scheme of ^{131}La is much better reproduced in the framework of the CQPC model with γ-soft core than with the rigid triaxial one. For the B(E2) values, a good agreement between the experiment and the

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[a] *Sołtan Institute of Nuclear Studies, Świerk, Poland*

[b] *A.F.Ioffe Physical Technical Institute RAS, St.-Petersbourg, Russia*

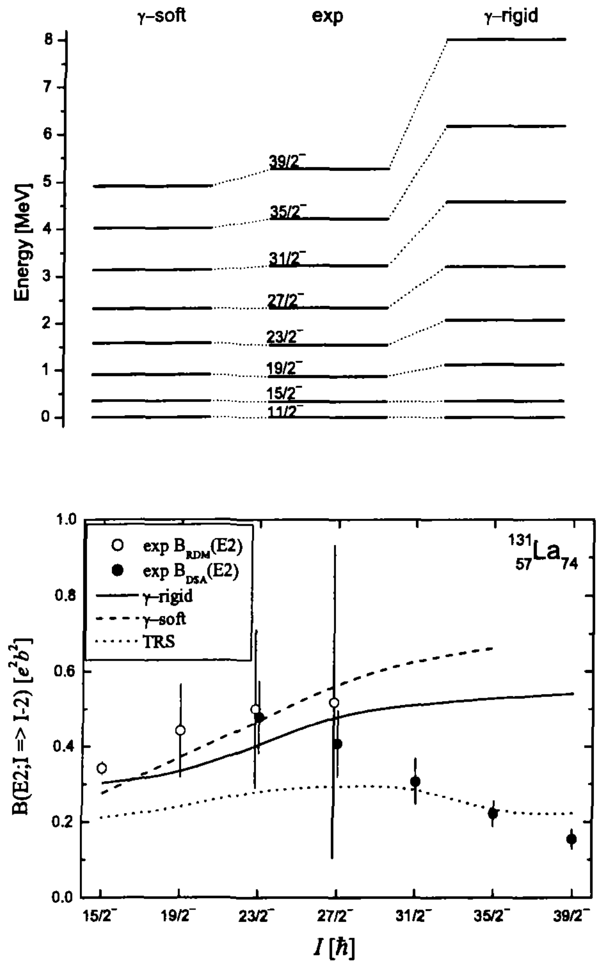

Figure 1: Level energies and B(E2) values in the "yrast" band in ^{131}La measured experimentally and obtained form the CQPC and the TRS model calculations. Experimental B(E2) values are taken from [1]—DSAM and [2]—RDM.

calculation up to the $27/2^-$ level of the "yrast" band was obtained in both versions of the CQPC model. Experimental spin and parity assignment for other negative parity low lying bands (not shown in Fig. 1), as well as the E2/M1 mixing ratio for interband transitions are needed for further experimental verification of both versions of the CQPC model.

For $I \geq 27/2$ a strong drop in collectivity is observed. The experimental B(E2;$39/2^- \rightarrow 35/2^-$) is nearly 3 times smaller than B(E2;$23/2^- \rightarrow 19/2^-$). The collective approach in both versions of CQPC model is unable to properly describe such a drop. For odd nuclei from the $50 \leq Z,N \leq 82$ region the information concerning the B(E2) values for the "yrast" $h_{11/2}$ band is sparse and indicates different behavior. In $^{127}_{57}$La$_{70}$ [9], similarly to ^{131}La, the strong drop in collectivity above $I=27/2$ is observed. In contrast, for $^{119}_{53}$I$_{66}$

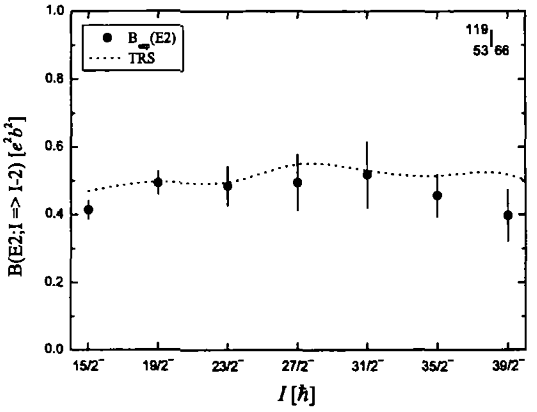

Figure 2: Experimental B(E2) values [3] for the "yrast" band in ^{119}I compared to results of the TRS model calculations.

[3] no drop in collectivity is observed — see Fig. 2. With the aim of understanding the observed experimental data, additional calculations were preformed using the Self-Consistent Total-Routhian-Surface (SC-TRS) model. The routhian was calculated on a grid in the deformation space, which includes the quadrupole deformation (β_2), the quadrupole triaxiality (γ) and the hexadecapole (β_4) degrees of freedom. The ruthian was minimized with respect to shape parameters to obtain equilibrium values. For more detailed description of the TRS model, see Ref. [8]. Transition probabilities B(E2) in the yrast band were estimated from the calculated deformation parameters using the following formula (Lund convention):

$$B(E2; I_i \to I_f) = \frac{5}{16\pi} e^2 Q_t^2 < I_i K 20 | I_f K >^2 \tag{1}$$

were Q_t is given by:

$$Q_t = \frac{cos(\gamma + 30^\circ)}{cos(30^\circ)} \cdot \frac{3}{\sqrt{5\pi}} Z R_0^2 (\beta_2 + \frac{2}{7}\sqrt{\frac{5}{\pi}}\beta_2^2 + \frac{20}{77}\sqrt{\frac{5}{\pi}}\beta_4^2 + \frac{12}{7\sqrt{\pi}}\beta_2\beta_4) \tag{2}$$

The difference between the experimental and theoretical values of B(E2) obtained from the TRS model, observed for $I^\pi \leq \frac{27}{2}^-$ is probably caused by the strong γ-softness of the routhian surfaces at low rotational frequencies. The TRS calculation for ^{131}La suggests that this could be due to a change of the configuration of the $h_{11/2}$ quasiproton from the almost pure K=1/2 to the mixed configuration with K=3/2 and K=5/2, which is related with a decrease of the quadrupole deformation parameter γ from 20° to $\simeq$ 10°. For the better understanding of B(E2) behaviour for high spin levels, more lifetime measurements are needed for the other odd La isotopes as well as for N=74 isotones.

For ^{119}I, when the drop in collectivity is not observed, the TRS model calculations predict stable quadrupole deformation $\beta_2 \simeq 0.29$ and $\gamma \simeq 10^\circ$ without substantial change of the K=1/2 $h_{11/2}$ quasiproton configuration. The results of the TRS model calculation compared to the experimental data are shown in Fig. 2.

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Lifetime Measurements of High-spin States in ^{131}La using the DSA Method

E. Grodner, A. A. Pasternak[a], Ch. Droste, R. Kaczarowski[b], M. Kisieliński[c], A. Kordyasz[c], M. Kowalczyk, J. Kownacki[c], T. Morek, E. Ruchowska[b], J. Srebrny, and M. Wolińska[c]

High-spin excited states in ^{131}La were populated in the ^{122}Sn(^{14}N,5n)^{131}La reaction at a beam energy of 70 MeV. The beam was provided by the Warsaw U200P cyclotron. The ^{122}Sn target was 10 mg/cm^2 thick. $\gamma - \gamma$ coincidences were measured using the OSIRIS array consisting of 10 Compton-suppressed HPGe detectors. The Ge detectors were placed at angles of 25°, 38°, 63°, 90°, 117°, 142° and 155°. The DSA method [1,2] was applied to determine lifetimes of high spin states in ^{131}La.

Data were sorted off-line into several $\gamma - \gamma$ matrices containing events from a specified detector on one axis, and events from all remaining detectors on the second. The matrices were used for lifetime evaluation. Sample spectra from two detectors, placed at forward and backward angles relative to beam direction, are presented in Fig. 1. Lifetimes of several levels were determined from the γ-line shape analysis, taking into account reaction kinematics, the deexcitation process of compound nuclei, the slowing-down process of recoils and geometry of the experimental setup.

The mean lifetime values obtained for six high-spin rotational levels of the yrast band built on the $h_{11/2}$ proton orbital in ^{131}La [3] change from 0.3 ps for the $43/2^-$ state to 1.3 ps for the 23/2- state, which corresponds to B(E2) reduced transition probability values ranging from 50 to 120 W.u.,respectively. The diminishing values of B(E2) suggest the decrease of collectivity with increasing spin value in the $\pi h_{11/2}$ rotational band for spins above $27/2^-$.

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[a] *A. F. Joffe Physical Technical Institute RAS, St Petersbourg, Russia*
[b] *Institute of Nuclear Study, Świerk, Poland*
[c] *Heavy Ion Laboratory, Warsaw University, Warsaw, Poland*

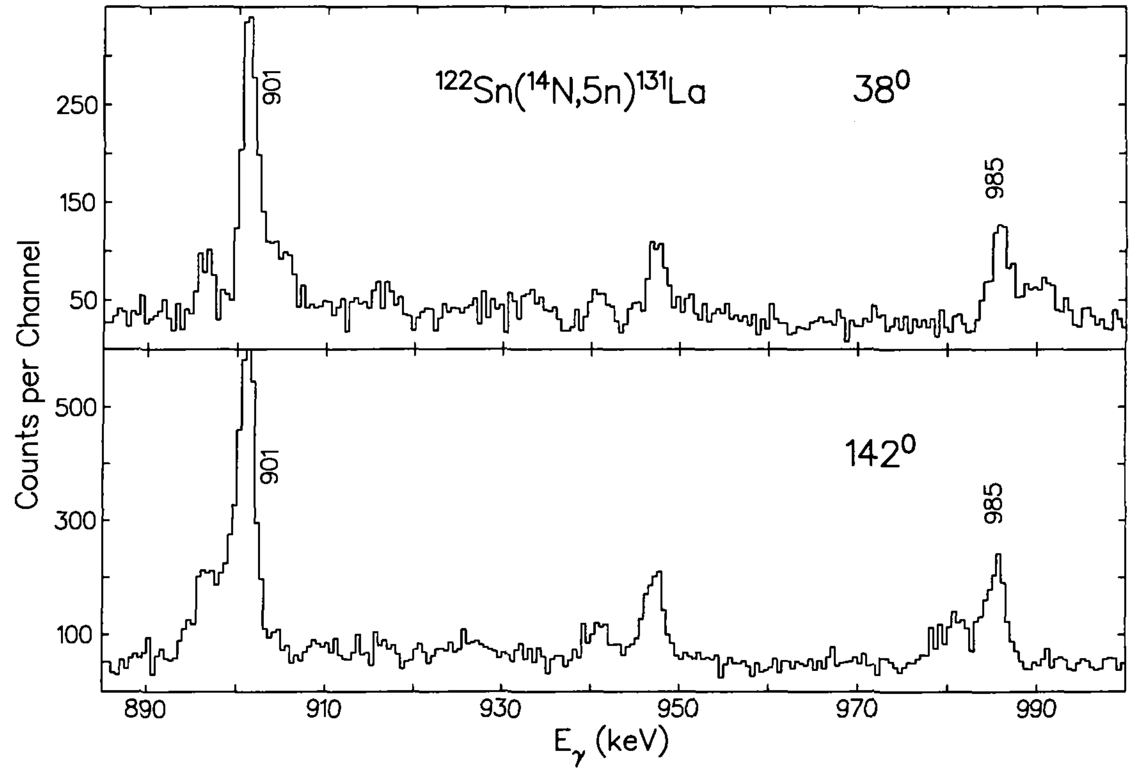

Figure 1: High energy parts of coincident spectra gated on the four lowest transitions from the $\pi h11/2$ yrast band for detectors placed at 38° and 142° relative to the beam direction. The Doppler-broadened line shapes are clearly seen for the 901 and 985 keV transitions. The corresponding lifetimes obtained for these transitions are of the order of 0.4 ps.

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Rotational bands with identical transition energies in nuclei around ^{174}Yb

A. Złomaniec, T. Rząca-Urban, W. Urban[a], W. Gast[b], H. M. Jager[b], L. Mihailescu[b], R. M. Lieder[b], D. Bazzacco[c], S. Lunardi[c], R. Menegazzo[c], C. Rossi Alvarez[c], C. Ur[c], G. de Angelis[d], D. Napoli[d] and T. Venkova[e]

The observation of rotational bands in different nuclei that have identical γ-ray energies had not been expected, as the observed differences are much smaller than the predicted variations caused by mass difference. Such bands (IBs) have been found in several regions of the nuclear chart. In our study, we have concentrated on nuclei around ^{174}Yb. The final nuclei have been produced by the bombardment of ^{170}Er with ^{7}Li at a beam energy of 51 MeV in the incomplete-fusion reaction. The beam was delievered by the Tandem XTU accelerator of the Legnaro National Laboratory. A study has been carried out with the γ-detector array GASP and the charge-particle detector array ISIS. The ^{170}Er target was a self-supporting metallic foil with a thickness of 3.05 mg/cm^2. In this reaction, Lu isotopes (A=171-173) were populated with a maximum cross-section. Neighbouring Yb nuclei were produced with less intensity. Hence, the selectivity of ISIS was needed to extract events related to the emission of protons. The data were sorted off-line into a number of reaction-channel-selected two- and three-dimensional $\gamma\gamma$ matrices and $\gamma\gamma\gamma$, $\gamma\gamma t$ cubes. Previous knowledge on the ground band of ^{174}Yb was derived from Coulomb excitation experiments [1], where the γ-ray energies were found with large uncertainties. The present analysis has allowed the establishment of precise γ- ray energies with much smaller errors. The band shown in Fig. 1 was assigned to ^{174}Yb because its lower γ-transitions are in coincidence with decay transitions already known and newly identified isomers in the ^{174}Yb [2,3] nucleus. In data gated on the proton detected by the charged-particle detector array ISIS, we have identified a second band which has almost identical γ-transition energies with the band in the ^{174}Yb nucleus. The dynamic moments of inertia of both bands are shown in Fig. 2. The second band still has to be assigned to one of the populated Yb isotopes. Discussed bands are very similar to the [541]1/2$^-$ band in ^{171}Lu and the [402]5/2$^+$ band in ^{173}Lu, also observed in the present data. This set of four identical bands is one of the most interesting examples of IBs because bands are based on orbitals originating from different shells. Data analysis is still in progress.

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[a] *Nuclear Spectroscopy Division, Institute of Experimental Physics, Warsaw University, Poland*
[b] *IKP, FZ Juelich, Germany*
[c] *Dipartimento di Fisica and INFN, Podva, Italy*
[d] *INFN, Laboratori Nazionali di Legnaro, Italy*
[e] *INRNE BAS, Sofia, Bugaria*

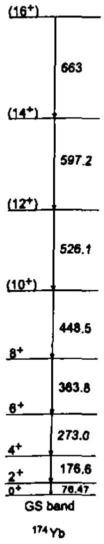

Figure 1: Ground state band in ^{174}Yb observed in presend data.

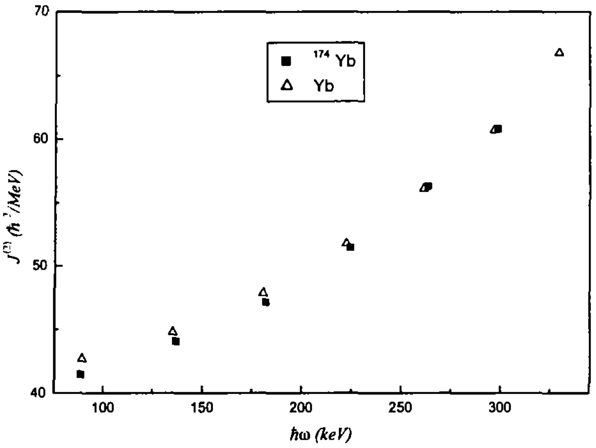

Figure 2: Dynamic moments of inertia versus rotational frequency of the the observed identical bands.

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Research reports

Experimental methods and instrumentation

PL0201657

Nuclear Physics Division IEP UW
ANNUAL REPORT 2001

Tests of the TAPS FOSTER calibration tool on HP-UX and Linux platforms

K. Piasecki

FOSTER [1] is a PAW-based calibration tool designed for the TAPS electromagnetic calorimeter [2]. TAPS is a photon spectrometer composed of 384 BaF_2 scintillation modules arranged in experiment-dependent geometrical configurations. FOSTER creates time and energy HBOOK-type histogams for every module from raw experimental data, allows to perform calibration almost automatically and establishes required triggers and cuts in the energy-TOF phase space.

In December 2001, the Computer Center of IN2P3 in Lyon decided to abandon the HP-UX platform, on which FOSTER functioned. The TAPS collaboration was forced to work on installation of the tool on the Linux platform, which was acomplished. However the compatibility of this code with respect to the version working on the HP-UX platform had to be verified.

Data from Ta+Au collisions obtained at the GANIL facility in Caen, were used for this purpose. The procedures creating HBOOK histograms remained unchanged. The sample covered several sets by 50 runs, with approximate yield of 250000 entries per histogram.

The FOSTER code can be executed either interactively or in batch mode, and it turned out, that in the batch mode the program did not function properly.

In the interactive mode, for a given runset, sums of entries of time-of-flight histograms were compared (see Fig. 1). Relative discrepancies oscillate around 0.1 ‰. Exclusive comparisons of entries suggest that some events in histograms fell into neigbouring channels, which affected underflow and overflow counts. This migration is related to the algorythm of assigning a value from data to the position in a histogram. In order not to produce an artificial structure, the position is automatically smeared by a random number of the range of one histogram channel. The comparison of two histograms created on the same computer platform in unchanged conditions would be a method to check if this algorithm explains discrepancies of the observed magnitude. The tests were positive. It was also checked that the usage of specified triggers does not cause changes in mentioned relative discrepancies.

Much bigger discrepancies appeared between histograms produced by the FOSTER code executed in batch mode on both platforms. In rare cases, they reach the order of about 10%. Since for the Linux platform such a discrepancy between histograms from interactive- and batch-executed FOSTER was not observed, one can conclude that on HP-UX platform, the program functions differently in batch mode compared to other

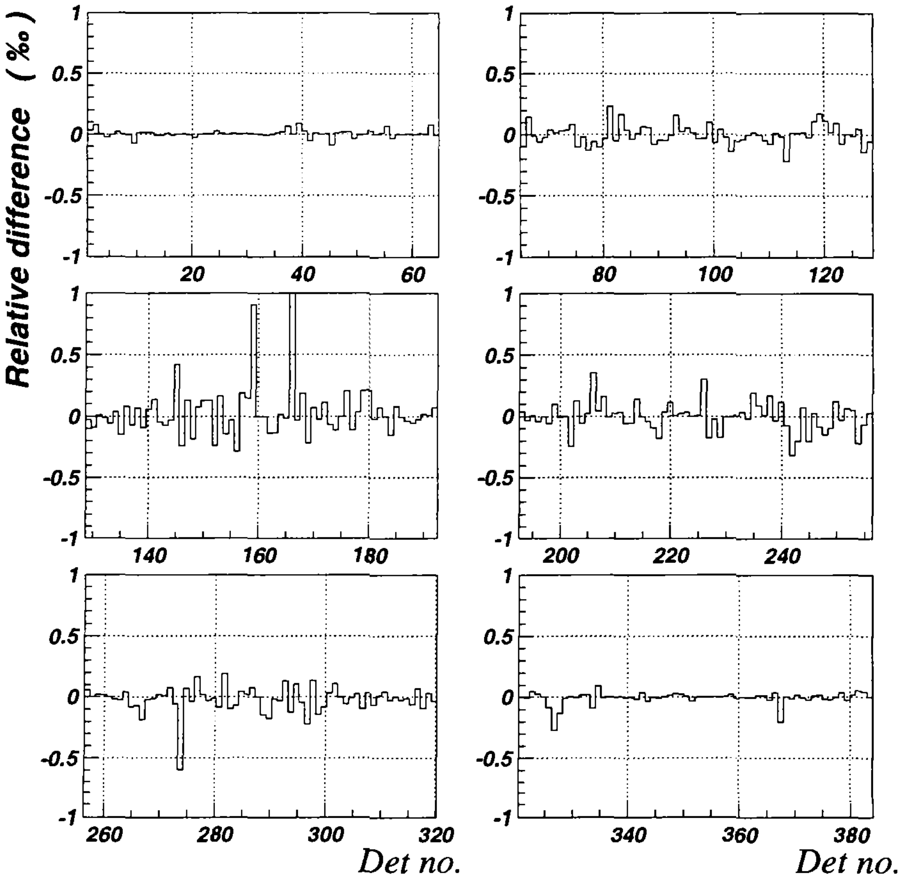

Figure 1: Relative difference of sums of entries in time histograms for each of 384 TAPS modules in exemplary runset between HP-UX and Linux versions

cases. However, during the tests the batch queues on the HP-UX platform had already been shut down and the verification of this conclusion and fixing the error was impossible.

To calibrate the energy of a TAPS module one uses cosmic particles traversing the active material of a detector. The mean energy loss on their path amounts to 38 MeV [2]. The calibration was performed anew on the Linux platform in order to test the constancy of gain coefficients and pedestals with respect to the ones obtained using the HP-UX platform. Gain discrepancies do not exceed the level of 1% and oscillate stochastically (see Fig. 2). It should be mentioned that the accuracy of obtaining the center of the cosmic particle peak is of the same order.

It was checked that the discrepancies of pedestal positions in histograms oscillate by around half a channel, thus one can conclude that no disturbances in the energy calibration appear after transfer of the FOSTER code onto the Linux platform.

The energy and time calibration done by FOSTER installed on the Linux platform does not introduce noticeable disturbances compared to previous results. However, some

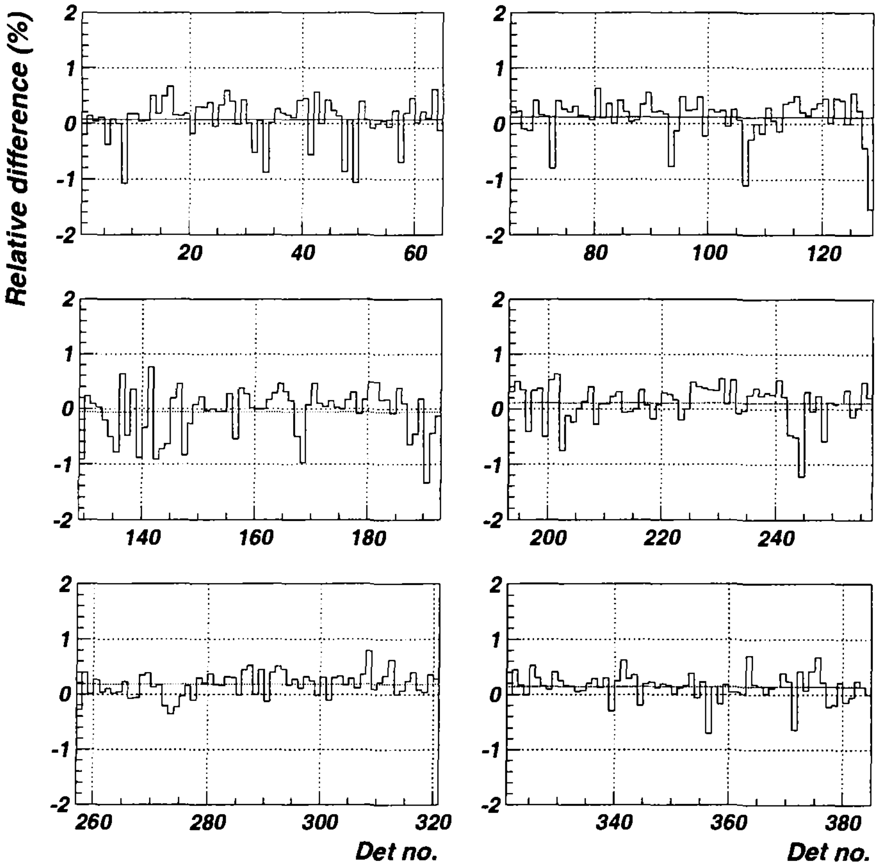

Figure 2: Relative difference of gain coefficients from energy histograms for each of 384 TAPS modules in exemplary runset, between HP-UX and Linux versions. Lines represent the mean difference over a block of 64 modules.

unproper functioning of FOSTER code running on the already closed HP-UX platform in the batch mode was detected.

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CLUSTER detectors as polarimeters in the EUROBALL array

B. Czajkowska, Z. Marcinkowska, Ch. Droste, R. Marcinkowski, T. Morek, G. Rohoziński[a], T. Rząca-Urban, J. Srebrny, W. Urban[b], R. M. Lieder[c], H. Brands[c], W. Gast[c], H. M. Jäger[c], L. Mihailescu [c], D. Bazzacco[d], G. Falconi[d], R. Menegazzo[d], S. Lunardi[d], C. Rossi-Alvarez[d], G. de Angelis[e], E. Farnea[e], A. Gadea[e], D. R. Napoli[e], Z. Podolyak[e]

The EUROBALL array contains segmented detectors (CLOVER and CLUSTER), that enable measurment of the linear polarization of γ-rays. As far as we know, in the EUROBALL array, only the CLOVER detectors have been used for in-beam polarization measurements (see e.g. [1,2]). In this contribution we report the preliminary results concerning properties of the CLUSTER detectors as polarimeters and compare them with those of CLOVER.

In the EUROBALL III array, the CLUSTER detectors are located in 3 rings [3], each containing five CLUSTER detectors. Their detailed position within the rings at angles $\theta = 129.4^\circ$ and 137.4° (with respect to the beam axis) is shown in Fig. 1. In the case of the CLUSTER detector presented in Fig. 1a, incident γ-quanta (coming from the target or another source of γ-rays) are Compton-scattered from one of the segments (for example "a") and absorbed in another segment (for example "g") of the CLUSTER detector. For the pairs a-g, b-c, e-f, g-d (see Fig. 1a), the scattering and absorption occur in adjacent segments located on the emission plane. The corresponding number of coincident events will be denoted as $N(0^\circ)$. Similarly, numbers of events in which scattered γ-quanta connect segment pairs a-b, a-f, b-g, c-d, c-g, d-e, e-g, f-g, will be denoted as $N(60^\circ)$ since the scattering occurs mainly on a plane inclined at $\psi = 60^\circ$ with respect to the emission plane. For the CLUSTER detector presented in Fig. 1b, one gets $N(30^\circ)$ and $N(90^\circ)$. Events in which non-adjacent pairs of segments participate in scattering are not taken into consideration because of small registration efficiency. It follows from our data, that for $E_\gamma = 544$ keV, the coincident efficiency of a non-adjacent pair is about 60 times lower than the corresponding value of an adjacent pair (see also [4]).

From the experiment, one obtains values of $N_{reaction}(\psi)$ and $N_{source}(\psi)$, being the numbers $N(\psi)$ of registered γ-rays emitted from the target and calibration radioactive source, respectively.

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[a] *Institute of Theoretical Physics, Warsaw University, Poland*

[b] *Nuclear Spectroscopy Division, Institute of Experimental Physics, Warsaw University, Poland*

[c] *Forschungszentrum Jülich, D-52425 Jülich, Germany*

[d] *INFN, Sezione di Padova, I-35131 Padova, Italy*

[e] *INFN, Laboratori Nazionali di Legnaro, I-35020 Legnaro, Italy*

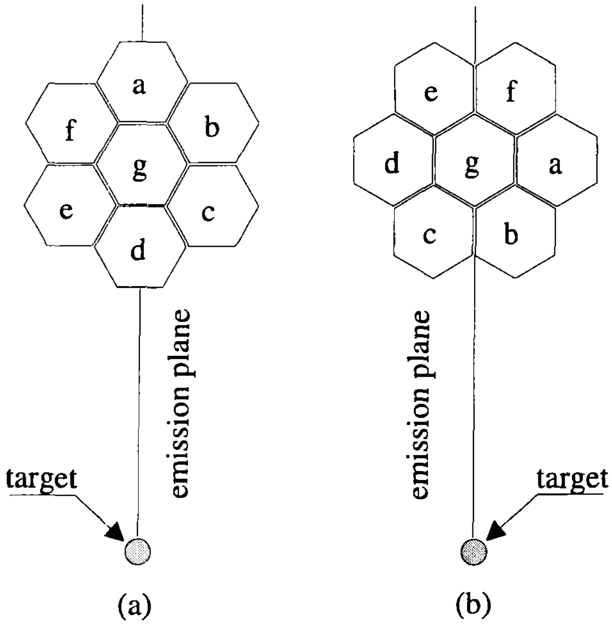

Figure 1: Orientation of the CLUSTER detector with respect to the emission plane spanned on the beam axis (perpendicular to the drawing plane) and vector of γ-quantum momentum. Each CLUSTER detector consists of seven Ge segments. (a) orientation of Ge segments belonging to one of the CLUSTER detectors from the ring at $\theta = 137.4°$. Pairs of adjacent segments are placed at $\psi = 0°$ and $60°$. (b) the same as (a) but for $\theta = 129.4°$. The adjacent segments are located at $\psi = 30°$ and $90°$.

Anisotropy A is defined as:

$$A = \frac{N_{reaction}(\psi')/\epsilon(\psi') - N_{reaction}(\psi)/\epsilon(\psi)}{N_{reaction}(\psi')/\epsilon(\psi') + N_{reaction}(\psi)/\epsilon(\psi)}, \tag{1}$$

where $\epsilon(\psi)$ is coincident efficiency for scattering and registration (in pairs of adjacent segments) of unpolarized γ-quanta. In our case unpolarized radiation was emitted from the ^{152}Eu source placed at target position. Relative efficiency $\epsilon(\psi)/\epsilon(\psi') = N_{source}(\psi)/N_{source}(\psi')$.

For a non-orthogonal polarimeter (like CLUSTER), the following formula connecting asymmetry A with polarization P has been proposed [4]:

$$A = \frac{Q'P}{1 + \alpha Q'P} \tag{2}$$

where Q' is polarization sensitivity of a non-orthogonal polarimeter. The parameter α is defined as

$$\alpha = \frac{sin^2\psi' - cos^2\psi}{cos^2\psi - cos^2\psi'}. \tag{3}$$

In the considered cases, $\psi' = 60°$ and $\psi = 0°$ or $\psi' = 90°$ and $\psi = 30°$ for the CLUSTER positions shown in Fig. 1a or Fig. 1b, respectively.

Table 1: The CLUSTER and CLOVER detectors as polarimeters in EUROBALL III. Energy of γ-rays equal 544 keV

property	CLUSTER	CLOVER
position in the array [a]	θ=129.4°, θ=137.4°	θ=76.4°, θ=103.4°
asymmetry [b]	$A(\theta=129.4°)=0.029(9)$ $A(\theta=137.4°)=0.024(9)$	$A=0.068(8)$
polarization sensitivity [c]	$Q'=0.16(4)$	$Q=0.23(2)$
polarization [d]	$P(\theta=129.4°)=0.184$ $P(\theta=137.4°)=0.142$	$P(\theta=76.4°) =$ $P(\theta=103.4°)=0.294$
accuracy $\Delta P/P$ [e]	≈34%	≈12%

[a] for details, see ref. [3]
[b] see eq. (1)
[c] Q for a CLOVER detector taken from [5]
[d] calculated for σ/I = 0.47 according to [2]
[e] errors of Q values were not taken into account

For ψ'=90° and ψ=0°, one obtains the well-known formula for an orthogonal polarimeter (like CLOVER):

$$A = QP \tag{4}$$

where: Q is polarization sensitivity of orthogonal polarimeter.

In this report, formulae (1)–(3) have been used for the experimental determination of polarization sensitivity of the CLUSTER detectors. The data analysed in this work come from the EUROBALL III experiment, in which ^{142}Gd nuclei were produced via the ^{99}Ru (^{48}Ti, 2p3n) reaction at a beam energy of 240 MeV [2]. The coincident $\gamma - \gamma$ matrices M(0°), M(30°), M(60°), M(90°) were sorted from the target and calibration radioactive source data. The M(ψ) matrix contains the events in which quantum γ_1 hitting a segment is scattered to an adjacent one (at angle ψ with respect to the emission plane), whereas quantum γ_2 (being in coincidence with γ_1) is registered in any of the EUROBALL's Ge detectors. Values of $N_{reaction}(\psi)$ and $N_{source}(\psi)$ were obtained from these matrices. The quality of each pair of segments was checked using a ^{152}Eu source located at target position. Sixteen pairs (from a total of 120) were rejected since their registration efficiencies differ substantialy from the average value. The polarization sensitivity of CLUSTER detectors was measured for the 544 keV E2 ($12^+ \rightarrow 10^+$) transition belonging to band $(+,0)_1$ of ^{142}Gd [2]. To improve statistics, analysed spectra were obtained by summing events from four gates (407 keV, 515 keV, 694 keV, 756 keV) placed on transitions located below the 544 keV one (see level scheme shown in [2]). Polarization of 544 keV γ-rays was calculated (see text below) assuming, following data shown in Fig. 3 of ref. [2], the Gaussian sub-state population distribution σ/I = 0.47.

Table 1 presents the preliminary results concerning the CLUSTER detector used as a polarimeter. They can be easily compared with data from the CLOVER detector [2], since they were deduced from the same EUROBALL experiment.

Polarization $P(\theta)$ given in table 1 was computed for γ-rays emitted towards the CLUSTER or CLOVER detectors located at θ = 129.4° and 137.4° or θ = 76.4° and 103.4°, respectively. The standard formula for the angular distribution of linear polarization of photons emitted from oriented nuclei was used (see e.g. eq. 12 of ref. [6]). This formula can also be applied in our case of two γ-quanta (γ_1 and γ_2) being in coincidence, where polarization of γ_1 (upper transition) is observed, while γ_2 emitted at any direction is registered with the same efficiency at entire solid angle 4π. More realistic calculations done for the CLUSTER detectors belonging to the EUROBALL III array confirmed the validity of this simplification. In this approach, the general formula from ref. [6] and [7] describing the correlation between polarization of γ_1 and emission direction of γ_2 was applied. Total polarization was obtained by summing the contributions from all EUROBALL detectors taking into account their individual positions in the array and efficiencies for registration of γ_2. Both types of calculations mentioned above gave very similar results.

The value of 0.16(4) for the polarization sensitivity of the CLUSTER detectors determined in this work (see table 1) is in reasonable agreement with the calculated one ($Q' \approx 0.175$ for the 40 keV threshold), where a modified version of the GEANT3 simulation code was used [4]. The ratio of polarization sensitivity for a non-othogonal polarimeter to the appropriate value for an orthogonal one is about 0.7. It is worthy of note that the same ratio for point-like Compton polarimeters (with a 90° scattering angle) is 0.75.

The CLUSTER detectors in the EUROBALL III array measure polarization with lower accuracy than the CLOVER detectors for the following reasons:
a) the absolute value of polarization depends on the position of the polarimeter in the array, being the largest for θ = 90°. This means that the position of the CLUSTER rings in the EUROBALL array is not advantageous for polarization measurement,
b) asymmetry A(CLUSTER) lower than A(CLOVER), makes determination of polarization much more difficult in the case of CLUSTER than in the case of CLOVER detectors,
c) although the total intensity registered in pairs of segments in the CLOVER and CLUSTER detectors are similar, for CLUSTER the substantial part of events supplies pairs at ψ = 30° and 60°, which are not so effective for polarization measurements as pairs at ψ = 0° and 90°.

Further analysis is in progress.

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Nuclear Physics Division IEP UW
ANNUAL REPORT 2001

The UWIS isotope separator

A. Wojtasiewicz, R. Béraud[a], W. Białowąs, M. Kisieliński, W. Kurcewicz[b], A. Płochocki[b], B. Roussière[c], S. Sidor

As in previous years, the main activities of the UWIS group in 2001 were concentrated on the development of the IGISOL project at the Heavy Ion Laboratory of Warsaw University [1]. The technical work and on-line experiments were continued with the aim of improving perfomance of the IGISOL device and obtaining radioactive beams of short living isotopes at the set-up collector.

Two new Faraday cups and a grid ion beam scanner were additionally constructed and mounted on the mass separator line to allow better control of ion optics and permit measurement of the partial and the total ionic transmission of the device. The measured total transmission is now of the order of 70%.

The installation of a new corona discharge ion source in the very center of the helium chamber makes it possible to perform mass calibration during on-line experiments. It is also possible with this ion source and with the reference gas leak installed in the helium supply system to evaluate the ionisation efficiency of the ion guide, a very important parameter of the IGISOL. For our facility it has been evaluated to be 10^{-4} to 10^{-6}, depending on helium pressure and purity.

A new high precision magnetometer (Teslameter) was installed which measures the magnetic field of the mass separator and improves the mass calibration, a feature particularly important especially in the case of radioactive beams.

Four short on-line test runs were performed with the IGISOL during 2001. Ni targets and/or Th targets were bombarded with ^{14}N (98 MeV) or ^{20}Ne (80 MeV) heavy ion beams with beam intensities between 15 and 300 nA (electric). The ion guide had worked in the configuration A [2], i.e. there was no separating channel and the primary heavy ion beam passed through the helium chamber.

For the first time weak radioactivity of ^{64}Ga (2.6 min) was collected on the moving tape of the IGISOL collector: the 992 keV γ transition was observed.

To obtain more intense radioactive beams, it seems that it is necessary to increase the intensity of the heavy ion beams on the targets and, at the same time, to decrease the plasma effect in the helium chamber. This will be the aim of the next experiments.

These works were partly performed in the frame of the Warsaw University - IN2P3 (France) collaboration.

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[a] *Institut de Physique Nucléaire, Lyon, France*
[b] *Nuclear Spectroscopy Department, IEP, Warsaw University, Poland*
[c] *Institut de Physique Nucléaire, Orsay, France*

Seminars, personnel and publications

Personnel

Research staff

Krystyna Siwek–Wilczyńska *Head of the Nuclear Physics Division*

Chrystian Droste
Piotr Jaracz
Marta Kicińska–Habior
Olimpia Kijewska*
Marek Kirejczyk
Mirosław Kozłowski
Zuzanna Marcinkowska*
Radosław Marcinkowski*
Tomasz Matulewicz
Tomasz Morek
Krzysztof Piasecki*
Teresa Rząca–Urban
Brunon Sikora
Marcin Smolarkiewicz*
Izabela Soliwoda–Poddany*
Julian Srebrny
Krzysztof Starosta *(untill Mar. 2001)*
Zygmunt Szefliński
Katarzyna Tymińska*†
Zbigniew Tymiński*†
Zdzisław Wilhelmi
Elżbieta Wójcik* *(from Oct. 2001)*

Technical and administrative staff

Wiesław Białowąs
Michał Godlewski
Czesława Gowin
Maciej Kisieliński
Michał Kowalczyk
Magdalena Marcinkowska *(from Feb. 2001)*
Emilia Marczyk *(untill Jan. 2001)*
Sebastian Sidor
Jerzy Tarasiuk
Adam Turowiecki
Andrzej Wojtasiewicz

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* PhD student

† On leave at GSI Darmstadt *(from Sep. 2001)*

Visiting scientists

1.	**Dr. José Bacelar** KVI Groningen, Holland	8. Sep – 12. Sep
2.	**Dr. Ralf Castelijns** KVI Groningen, Holland	8. Sep – 12. Sep
3.	**Prof. José Díaz** IFIC Valence, Spain / SUBATECH, Nantes, France	9. Sep – 13. Sep
4.	**Dr. Alexandr D. Efimov** A.F.Ioffe Physical Technical Institute RAS, St.-Petersbourg, Russia	31. Jan – 26. Feb
5.	**Dr. David d'Enterria** SUBATECH, Nantes, France	22. Nov – 25. Nov
6.	**Prof. Herbert Löhner** KVI Groningen, Holland	5. Sep – 13. Sep
7.	**Dr. Miguel Marques Moreno** LPC, Caen, France	8. Nov – 11. Nov
8.	**Prof. Alexandr A. Pasternak** A.F.Ioffe Physical Technical Institute RAS, St.-Petersbourg, Russia	22. Jan – 26. Feb 28. Mar – 5. Apr 25. Apr – 2. May 17. Jul – 1. Aug 1. Oct – 15. Oct
9.	**Dr. Willibrord Reisdorf** GSI, Darmstadt, Germany	2. Sep – 10. Sep
10.	**Dr. Brigitte Rousierre** Institut de Physique Nucléaire, Orsay, France	22. May – 2. Jun
11.	**Dr. Olaf Scholten** KVI Groningen, Holland	8. Sep – 12. Sep
12.	**Dr. Józef Złomańczuk** Svedberg Laboratory, Uppsala, Sweden	9. Sep – 13. Sep

Seminars held at the NPD in 2001

5.01.2001 **Zygmunt Szefliński** (NPD)
Physics and medicine — report on the "Nuclear Science and Medical Imaging" conference in Lyon

12.01.2001 **Marek Sadowski** (Inst. Nuclear Studies, Świerk)
Progress in the research of controlled nuclear fusion reactions

19.01.2001 **Zbigniew Trznadel** (NPD)
Study of high-energy γ rays from the ^{12}C + ^{58,64}Ni reaction

23.02.2001 **Adam Sobiczewski** (Inst. Nuclear Studies, Warsaw)
Are the nuclei around ^{270}Hs really deformed?

2.03.2001 **Sławomir Wycech** (Inst. Nuclear Studies, Warsaw)
On the pion–hadron coupling constants

9.03.2001 **Krzysztof Piasecki** (NPD)
Sub-threshold π^0 meson production in reactions induced by 60 A MeV ^{36}Ar

16.03.2001 **Andrzej Płochocki** (Inst. Experimental Physics, Warsaw University)
Masses of nuclides far from the stability valley — latest experimental data

23.03.2001 **Paweł Napiorkowski** (Heavy Ion Laboratory, Warsaw University)
Coulomb excitations of K isomers: "old" ideas — "new" physics

30.03.2001 **Teresa Rząca–Urban** (NPD)
Semiclassical description of the magnetic rotation phenomenon in atomic nuclei

6.04.2001 **Marshall Blann** (San Diego, USA)
Monte Carlo treatment of precompound decay in light and heavy ion induced reactions

20.04.2001 **Rainer Lieder** (KFA, Jülich)
On the way to a 4π gamma–ray tracking array

27.04.2001 **Stefan Ćwiok** (Dept. of Physics, Warsaw University of Technology)
Structure of superheavy nuclei

11.05.2001 **Zbigniew Majka** (Physics Inst, Cracow University)
The little Big Bang seen in the BRAHMS experiment

18.05.2001 **Zbigniew Tymiński** (NPD)
Time-of-flight detectors in nuclear physics

25.05.2001 **Tomasz Czosnyka** (Heavy Ion Laboratory, Warsaw University)
Atomic nuclei shapes

1.06.2001 **Maria Kmiecik** (Inst. Nuclear Physics, Cracow)
The measurement of GDR in coincidence with discrete transitions in final nuclei

5.10.2001 **Agnieszka Trzcińska** (Heavy Ion Laboratory, Warsaw University)
Distribution of neutron densities in atomic nuclei obtained from antiprotonic experiments

12.10.2001 **Marian Jaskóła** (Inst. Nuclear Studies, Warsaw)
Nuclear spectroscopy with the help of $(\vec{p}, \alpha)$ reactions on magic and near-magic nuclei

19.10.2001 **Adam Maj** (Inst. Nuclear Physics, Cracow)
Does Nature behave according to the self–organising criticality hypothesis?

26.10.2001 **Jacek Dobaczewski** (Inst. Theoretical Physics, Warsaw University)
News and achievements in nuclear structure theory — on the basis of a lecture delivered at the INPC'01 conference in Berkeley

9.11.2001 **Miguel Marques Moren** (Laboratoire de Physique Corpusculaire, Caen, France)
Correlations in few-neutron systems

16.11.2001 **Helena Białkowska** (Inst. Nuclear Studies, Warsaw)
Why do we study proton–proton collisions if we are interested in nucleus–nucleus collisions?

23.11.2001 **David G. d'Enterria** (SUBATECH, Nantes)
Physics and signatures of the Quark-Gluon-Plasma: First results from the Relativistic Heavy-Ion Collider (RHIC)

30.11.2001 **Zygmunt Patyk** (Inst. Nuclear Studies, Warsaw)
Properties of atomic nuclei in the neighbourhood of lead

7.12.2001 **Piotr Magierski** (Dept. of Physics, Warsaw University of Technology)
Shell effects in neutron stars

Seminars or talks held outside the NPD

14.11.2001, **Marta Kicińska–Habior**
Gigantyczny Rezonans Dipolowy - wyniki otrzymane na wiazce z Warszawskiego Cyklotronu i nie tylko
Talk delivered at the Seminar of the Nuclear Spectroscopy Division, Inst. of Experimental Physics, Warsaw University (Poland)

7.09.2001, **Olimpia Kijewska**
Energetic photons from heavy-ion reactions at 4–12 MeV/u
Talk delivered at the XXVII Mazurian Lakes School of Physics, Krzyże (Poland), 2–12.09.2001

4.09.2001, **Marek Kirejczyk**
Study of thermal equilibrium in heavy ion collisions via Ma coincidence method — test of applicability
Talk delivered at the XXVII Mazurian Lakes School of Physics, Krzyże (Poland), 2–12.09.2001

1.10.2001, **Marek Kirejczyk**
Study of thermal equilibrium in heavy ion collisions via Ma coincidence method — test of applicability
Talk delivered at the FOPI Collaboration meeting, Darmstadt (Germany), 1–2.10.2001

4.09.2001, **Krzysztof Piasecki**
Neutral pions from 60 AMeV Ar + C, Ni, Ag, Au reactions
Talk delivered at the XXVII Mazurian Lakes School of Physics, Krzyże (Poland), 2–12.09.2001

8.02.2001, **Teresa Rząca–Urban**
Search for magnetic rotation in the A=140 region
Invited talk presented at the High Spin Physics 2001 NATO Advanced Research Workshop, Warsaw (Poland), 6–10.02.2001

3.04.2001, **Teresa Rząca–Urban**
Magnetyczna rotacja — nowy typ wzbudzeń jądrowych
Talk delivered at the Seminar of the Nuclear Physics Division, Institute of Physics, Jagiellonian Uniwersity, Kraków (Poland)

1.10.2001, **Brunon Sikora**
Kaon multiplicity fluctuations in FOPI
Talk delivered at the FOPI Collaboration meeting, Darmstadt (Germany), 1–2.10.2001

23.04.2001, **Krystyna Siwek–Wilczyńska**
Statistical decay of heavy nucleus–nucleus systems
Talk delivered at the "Nuclear Physics at borderlines" conference, Lipari (Italy), 21–24.05.2001

3.09.2001, **Krystyna Siwek–Wilczyńska**
Pre- and post-scission neutron evaporation from superheavy systems
Talk delivered at the XXVII Mazurian Lakes School of Physics, Krzyże (Poland), 2–12.09.2001

3.09.2001, **Marcin Mieczysław Smolarkiewicz**
Intermittency analysis in momentum space in Au + Au reactions at 150-800 AMeV
Talk delivered at the XXVII Mazurian Lakes School of Physics, Krzyże (Poland), 2–12.09.2001

9.09.2001, **Katarzyna Tymińska**
Pion reabsorption in nuclear matter: a simple model
Talk delivered at the XXVII Mazurian Lakes School of Physics, Krzyże (Poland), 2–12.09.2001

Degrees granted

BSc (licencjat) theses

Maria Musiak Max
Planck i stulecie teorii kwantów
Planck and the centennial of quantum theory
supervisor: dr hab. Mirosław Kozłowski

Paweł Pęczkowski
Pomiar odległości astronomicznych
The measurement of astronomical distances
supervisor: dr hab. Mirosław Kozłowski

Marta Stambórska
Szachy jako pomoc w rozwijaniu myślenia logicznego u dzieci
Chess as an aid in the development of logical thinking in children
supervisor: dr hab. Mirosław Kozłowski

Agnieszka Stolarczyk
Czesław Białobrzeski — twórca warszawskiej szkoły fizyki teoretycznej
Czesław Białobrzeski — creator of the Warsaw school of theoretical physics
supervisor: dr hab. Mirosław Kozłowski

Iwona Zalewska
Karol Olszewski, Zygmunt Wróblewski i powstanie współczesnej kriogeniki
Karol Olszewski, Zygmunt Wróblewski and the creation of modern criogenics
supervisor: dr hab. Mirosław Kozłowski

MSc (magister) theses

Sławomir Błoński
Energetyczna zdolność rozdzielcza detektorów scyntylacyjnych
Energy resolution of scintillator detectors
supervisor: dr hab. Chrystian Droste and dr Marcin Balcerzyk

Anna Małgorzata Kaczor
Badanie struktury neutrono–nadmiarowych jąder z obszaru zamkniętej powłoki N = 50
Study of neutron–rich nuclei from the region of a closed N = 50 shell
supervisor: dr hab. Teresa Rząca–Urban.

Elżbieta Anna Siemaszko
Systematyka wysokości barier dla reakcji fuzji
The systematics of the barrier heights for fusion reactions
supervisor: dr hab. Krystyna Siwek–Wilczyńska.

Elżbieta Wójcik
Gigantyczny rezonans dipolowy w jądrach A ~ 32
Giant dipole resonance in nuclei with A ~ 32
supervisor: dr hab. Marta Kicińska–Habior.

Katarzyna Kostrzewa
Rozkłady mas poprzecznych mezonów π^+, K^+ oraz protonów w reakcjach S + S, Pb + Pb przy pędzie wiązki ~ 200 A GeV/c
Distribution of transverse masses of π^+ mesons, K^+ mesons and protons in S + S, Pb + Pb reactions at ~ 200 A GeV/c beam momentum
supervisor: dr hab. Mirosław Kozłowski

Anna Utrata
Mezoskopowy model relatywistyczny reakcji ciężkojonowych
Mesoscopic relativistic model of heavy ion reactions
supervisor: dr hab. Mirosław Kozłowski

PhD (doktor) theses

Zbigniew Trznadel
Badanie wysokoenergetycznego promieniowania γ ze zderzeń jonów ^{12}C o energiach 4–12 MeV/u z lekkimi jądrami
The study of high–energy γ–rays emitted from reactions induced by ^{12}C ions at energies 4-12 MeV/u on light nuclei
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Nuclear Physics Division IEP UW
ANNUAL REPORT 2001

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