EXPERIMENTAL SET-UP FOR HIGH-ENERGY γ-RAY STUDIES AT THE WARSAW CYCLOTRON AND FIRST EXPERIMENTS*,**

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A multidetector set-up has been developed for the detection of photons between 5 and 40 MeV. It consists of 10 cm x 10 cm *BGO* cylinder shielded with active and passive shields against the cosmic-rays and the γ-ray background and of a multiplicity filter consisting of 28 detectors (BaF_2 and NaI(Tl)). The neutrons are discriminated with TOF. The system is installed at the new Warsaw Cyclotron. It is intended for studies of giant dipole resonances in hot nuclei and of bremsstrahlung at low beam energies. The first experiments and the plans for further development of the set-up are described.

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1. Introduction

High-energy γ-rays from nuclear collisions have been studied with great interest in recent years. These studies concern gamma rays from the decay of giant dipole resonance (GDR) built on highly excited states of compound nuclei produced in heavy-ion fusion reactions [1–4] as well as bremsstrahlung photons emitted in collisions between individual projectile and target nucleons [5–7]. The former have provided new information on the nuclear properties at high temperature and high spin. The latter carry information about the reaction mechanism and the phase space distribution of nucleons in the colliding nuclei. The experimental set-up JANOSIK (Joint Array for giaNt resOnance Studies wIth K = 160 Warsaw Cyclotron), described in the present work, is intended for studies of the giant resonances as well as of the bremsstrahlung at low bombarding energies.

2. JANOSIK set-up

The set-up consists of high-energy γ-ray spectrometer and a multiplicity filter. It allows to measure high-energy γ-ray spectra in coincidence with low-energy γ-rays in order to discriminate against non-fusion processes and to estimate the angular momentum of the decaying compound nucleus. The high-energy γ-ray spectrometer consists of 10 cm $\times$ 10 cm cylindrical bismuth germanate scintillator [8], an active plastic scintillator anticoincidence shield made ot two 17 cm $\times$ 35 cm $\times$ 1 cm plates placed above and below the crystal and a passive lead shield, 10 cm thick, surrounding the crystal on the sides, top and bottom, with a lead collimator in the front.

The multiplicity filter consists of 28 cylindrical detectors: 10 BaF_2 (each of 5 cm $\times$ 5 cm scintillator) and 18 NaI(Tl)'s (8 scintillators of 3" $\times$ 3" and 10 scintillators of 2" $\times$ 2.5"). All detectors are mounted on a special stand which allows for various configurations of the filter. Since large cooled target chamber has been used all detectors have been mounted at a distance of 16 cm from the center of the target looking at the target center. The efficiency calibration for 1.17 MeV γ-rays performed by a standard method [9] using ^{60}Co source allowed to estimate the total filter efficiency for a given configuration to be 10%.

A schematic layout of the electronics used in first experiments is shown in Fig. 1. Five parameters have been recorded by 5 ADCs, *i.e.* the energy signal of BGO, the time between (BaF_2 + NaI) multiplicity filter and BGO detector, the BaF_2 and NaI folds, and the bit pattern indicating presence or absence of the beam and the signal from the plastic anti-coincidence shield. The last one was used to discriminate against cosmic-ray background. The beam current was collected by a Faraday cup and measured by an integrator.

Deadtime outputs from ADCs were OR-ed together and connected to the gate input of current integrator, thus correcting for system deadtime losses. Data have been recorded in an event by event mode.

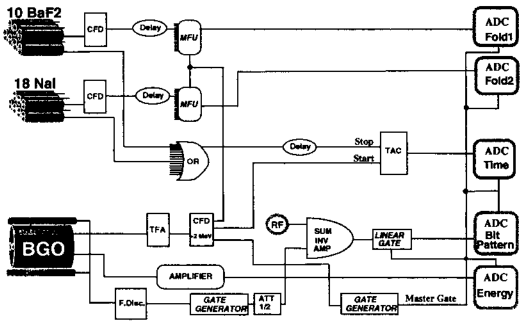

Fig. 1. Schematic layout of the electronics used in the measurement of the ^{12}C + ^{27}Al reaction.

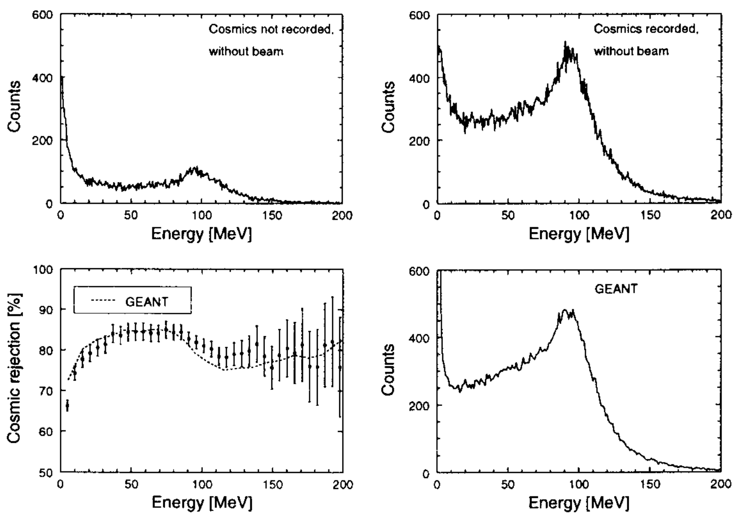

Fig. 2. Background off-beam spectra measured using the *BGO* spectrometer with the lowered gain in order to record the full energy deposited by cosmic rays.

Detailed studies of the off-beam background have been performed. The spectra recorded in an anticoincidence (left top) as well as in a coincidence (right top) with a signal from the plastic shield are shown in Fig. 2. For the purpose of this test the gain of the BGO spectrometer was lowered to record the full energy deposited by cosmic rays. Cosmic ray peak measured at $E_\gamma =$ 100 MeV is in agreement with the GEANT calculations for the 10 cm $\times$ 10 cm cylindrical BGO surrounded by plastic and lead shields. Cosmic-ray rejection efficiency for the simple plastic shield used in the present set-up obtained from the two upper spectra of Fig. 2 and calculated with GEANT is shown as a function of energy in Fig. 2. In the energy range of interest for GDR studies the efficiency was about 80%. Discrimination against the cosmics in the in-beam experiment was further improved by the coincidence with the RF of the cyclotron.

The high-energy spectra recorded on-line with coincidence requirements on the presence of the beam and plastic scintillator signal are shown in Fig. 3. In the spectra measured in anticoincidence with the signal from the plastic shield, with and without beam, individual lines are clearly visible which may be used for energy calibration and in-beam check of the gain stability of the spectrometer, as mentioned already in [8].

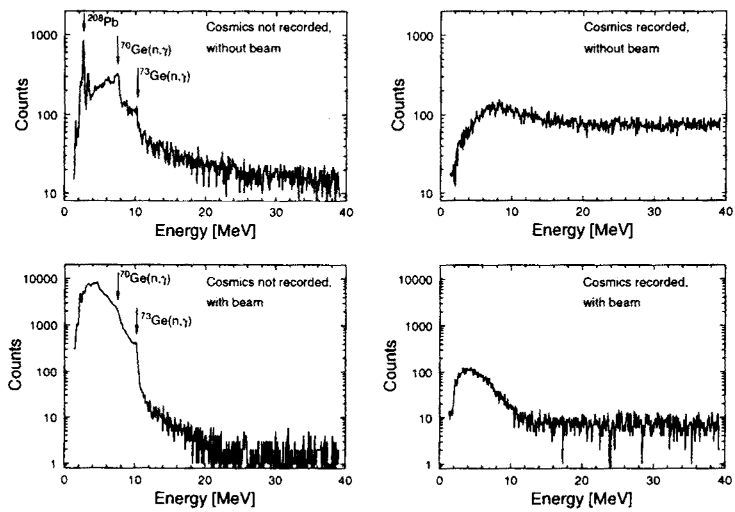

Fig. 3. Measured high-energy spectra for the ^{12}C + ^{27}Al reaction at $E_{\rm lab}$ = 34.2 MeV and θ_γ =90^0 with coincidence requirements on the presence of the beam and plastic scintillator signal.

The time-of-flight technique was used to separate prompt γ-rays produced in the target from the neutron-induced events. The START input of TAC was provided by the BGO signal, the STOP- by the multiplicity filter signal. The target-BGO detector distance was 68 cm which was a compromise between the necessity of having a reasonable solid angle of detection and of having good n-γ discrimination. The time resolution of the detection system determined during the test run with ^{12}C beam of 38 MeV from the Warsaw Cyclotron was 8.5 ns, giving a reasonable n-γ discrimination (see Fig. 4).

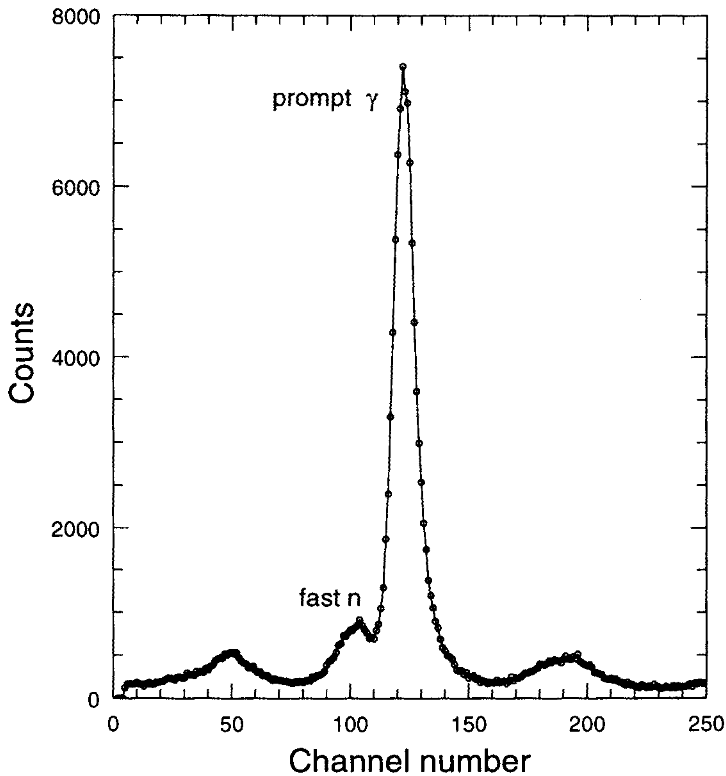

Fig. 4. Total time-of-flight spectrum for the ^{12}C + ^{27}Al reaction at $E_{\rm lab}$ = 34.2 MeV and θ_γ =90^0.

3. Results of the test experiment

The test experiment has been performed with the ^{12}C beam at 38 MeV from the Warsaw Cyclotron and the ^{27}Al target of 2.7 mg/cm^2. Beam energy averaged over the target thickness was 34.2 MeV. The compound nuclei of ^{39}K were populated at excitation energy of 40.3 MeV. Similar reaction has earlier been studied at the University of Washington in Seattle [10].

The high-energy spectrum of prompt γ-rays from ^{12}C + ^{27}Al reaction measured with the JANOSIK set-up is shown in Fig. 5. The spectrum was obtained from the measured data sorted with the condition for beam presence and the anticoincidence with the plastic scintillator signal, after gating by the time-of-flight. In order to transform raw spectra into cross section the knowledge of target thickness, total accumulated charge, solid angle and the estimate for γ-ray detection efficiency of BGO detector was used. Total cross sections were obtained assuming an isotropic angular distribution.

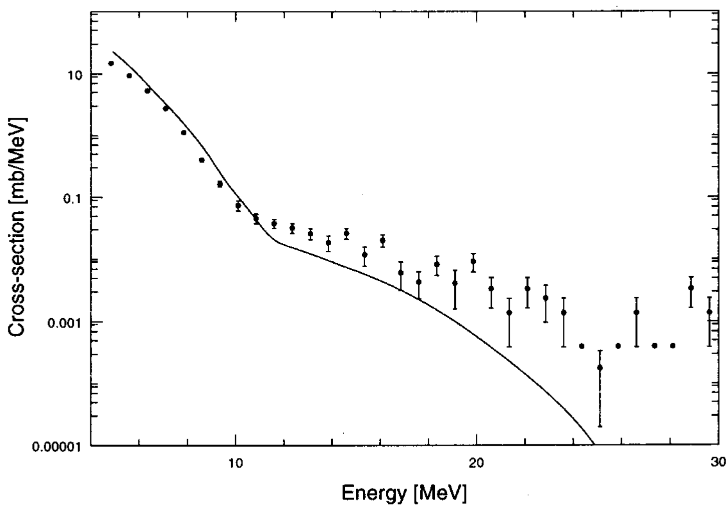

Fig. 5. Measured high-energy γ-ray spectrum for the ^{12}C + ^{27}Al reaction at E_{lab} = 34.2 MeV. Solid line: statistical model CASCADE calculations folded with the *BGO* detector response function.

Statistical model CASCADE calculations performed for the measured reaction with the level density in the Reisdorf approach [11] and the GDR parameters $S = 0.85$, $E_{\text{GDR}} = 16.6$ MeV, $\Gamma_{\text{GDR}} = 11$ MeV (see Ref. [10]) folded with the BGO spectrometer response function are shown in Fig. 5 as a solid line. The excess of the count rate observed at high energies can be attributed to the yet imperfect cosmic ray background rejection.

4. Conclusions and outlook

The experimental set-up JANOSIK for high-energy γ-ray studies at the Warsaw Cyclotron is described. The set-up consists of the high-energy γ-

ray BGO spectrometer and the multiplicity filter. The in-beam test was performed for the ^{12}C + ^{27}Al reaction with 38 MeV ^{12}C ions.

As a further development, the set-up will be equipped with another high-energy detector, a 25 cm × 29 cm NaI(Tl) cylinder with a plastic scintillator anticoincidence shield (BICRON) and a lead shield. A rotating table to measure angular distributions is under construction. The experiments on ^{12}C + ^{27}Al and ^{12}C + $^{\mathrm{nat}}$Si reactions will be continued.

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