Nuclear Instruments and Methods in Physics Research A330 (1993) 121–124
North-Holland

NUCLEAR
INSTRUMENTS
& METHODS
IN PHYSICS
RESEARCH
Section A

"The Tube": a simple 4π detector for enhancing channels in γ-ray spectroscopy experiments

P.-F. Hua, D.G. Sarantites, L.G. Sobotka, J.L. Barreto [1] and A. Kirov
Department of Chemistry, Washington University, St. Louis, Missouri, 63130, USA

Received 13 November 1992

A simple 4π charged-particle sensitive detector useful for γ-ray spectroscopy is described. The detector is a plastic scintillator tube, which surrounds the target. The tube is segmented into four optically isolated cylindrical arcs. The tube is an efficient charged particle hit detector with a very small photon interaction probability.

1. Introduction

In recent years, heavy ion induced reactions have enriched our understanding of nuclear properties at high spin and excitation. Discrete γ-ray spectroscopic investigations have employed a variety of multidetector arrays to study exotic nuclear behaviour. These have led recently to the observation of many superdeformed band structures [1,2]. Heavy ion induced reactions generally produce neutron deficient compound nuclei with substantial charged particle and fission decay widths. In such cases, a large number of exit channels are populated and this makes it difficult to select a particular channel for study. Spectroscopic studies of rare earth nuclei often employ γ-ray multiplicity gating techniques to select a specific xn channel. For medium or lighter A nuclei, large cross sections for charged particle emission lead to many channels with similar γ-ray multiplicities which cannot be selected by γ-ray multiplicity gating. In such cases charged particle identification in a 4π arrangement can come to the rescue and greatly enhance the selection of the desired channel [3,4]. Furthermore, for heavy neutron deficient systems, fission limits the population of high spin states in the residues and leads to similar γ-ray multiplicity distributions from evaporation residues and fission. In this case, charged particle gating becomes very important for selecting the desired channels and for removing the large γ-ray background from fission.

When 4π counting of charged particles is employed, one usually faces the problem of absorption and scattering of the γ-rays through rather massive particle detector arrays, which can cause deterioration of the response of the Compton suppressed Ge spectra by decreasing the peak-to-total ratio for γ-detection. While a device capable of particle identification and possibly good energy resolution is required to investigate the interplay between statistical charged particle emission and the feeding of discrete bands [5], these capabilities are not necessary for discrete line spectroscopic experiments. For example, for xn channel selection, charged particles only need to be detected (not identified) thereby allowing for event rejection.

In evaluating what is the best particle detector for a specific task, it is important also to keep in mind the counting rate capabilities of the various possible devices. In spectroscopy experiments, γ-ray energy resolution, statistics and the quality of the Compton suppression are of paramount importance. Thus, for example, we have found that for spectroscopic studies, the advantages of particle identification and energy information provided by the CsI(Tl) detectors of the Dwarf Ball [3] are offset to some extent by (a) the substantial increase of background due to scattering of photons in the rather massive Dwarf Ball, and (b) by the counting rate limitations (< 5000 counts/s) in each element. Clearly, the scattering problem can be substantially reduced by minimizing the mass and atomic number of the charged particle detectors.

In this communication a simple 4π device is described, which was constructed with the above issues in mind. It has the following features: (a) high counting rate capability (b) minimal low Z mass with very low trigger efficiency for γ-rays, so as not to effect the quality of the Ge Compton suppressed spectra, (c) high solid angle coverage ($\sim 97\%$ of 4π), and (d) responds with high efficiency to charged particles and is capable

---

[1] On leave from Instituto de Física da UFRJ-21945 RJ, Brazil.

of tagging one, two or three charged-particle channels. In section 2 a detailed description of the device is given, and in section 3 its performance in a recent spectroscopic investigation is presented, and its potential uses and limitations are discussed.

2. Description of the device

The present device, termed "the Tube", was constructed from fast plastic scintillator material [6]. The device is shown in fig. 1. It consists of four optically isolated arc shaped paddles arranged together to form a cylinder. Each paddle has a cylindrical section and a tapered section which adiabatically, i.e., with approximately constant cross section, leads to a circular end to match a photomultiplier tube. The entire device, including the adiabatic light guiding section, was cut from a solid block of scintillator material.

With a target placed at the center of the cylindrical section of the detector on a minimal mass frame, a geometric coverage $\simeq 97\%$ of 4π is obtained. The thickness of the scintillator at the cylindrical section is 3 mm. At this thickness 17 MeV protons and 68 MeV α-particles are stopped, if they enter perpendicularly to the scintillator surface (90° to the beam direction). For particles entering at any other angle, higher energy particles are stopped. The paddles were optically isolated by covering them with aluminized mylar of minimal thickness (180 $\mu g/cm^2$). The light is collected from one end of each paddle by an end-on photomultiplier tube [7].

The adiabaticity of the scintillator cross section, results in a uniform pulse-height response along the length of the detector. This response was measured with a collimated monoenergetic α-source and found to vary only by 20% between the two ends of each of the scintillator paddles.

Each sector can easily be operated at rates near 150 kHz as was done in an actual in beam experiment.

3. Performance of the device and discussion

This device cannot distinguish between protons or α-particles and provides only crude particle energy information. On the other hand, it can efficiently count light charged particles and, with a limited efficiency, fission fragments at high rates. Its small mass and low Z provides minimal absorption and scattering of reaction γ-rays that pass through it.

Initially it was hoped that this device, in addition to detection of light charged particles, would respond efficiently to fission fragments and thus be used to veto fission, which for neutron deficient compound nuclei is a major contributor to the γ-background. A pulse height spectrum taken with a ^{252}Cf source (decaying 97% by α-emission and 3% by fission) showed fission fragment pulses extending beyond the α-peak, but a considerable fraction of them had low pulse height due to the large quenching of the light emission in the plastic. As discussed below, other experimental constraints limit severely its capability to count directly fission fragments from an actual experimental situation.

The Tube was calibrated for response to γ-rays using an ^{88}Y source placed at its center. A Ge detector was used to gate on the 898 and 1836 keV γ-rays and record the fraction of triggers above 100 keV in the Tube. It was found that the triggering efficiencies for 898 and 1836 keV γ-rays were, 0.030 ± 0.001 and 0.023 ± 0.001, respectively. These results are in reasonable

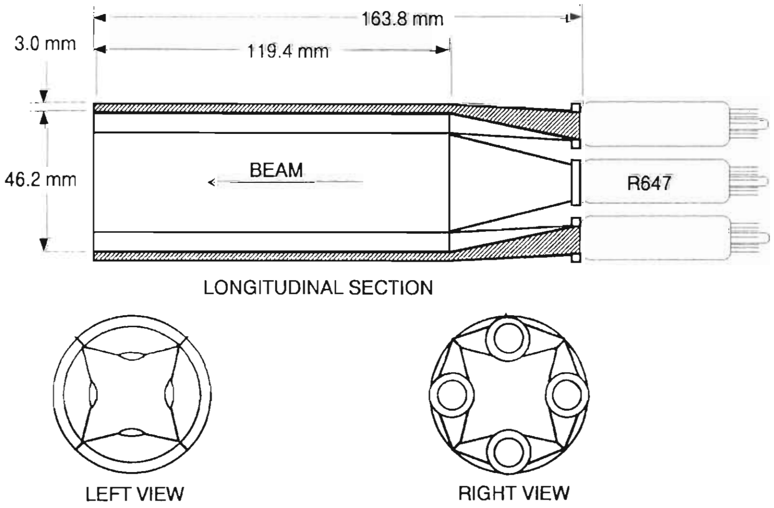

Fig. 1. Cross sectional views of the channel selecting detector. The length of the photomultipliers is not shown to scale.

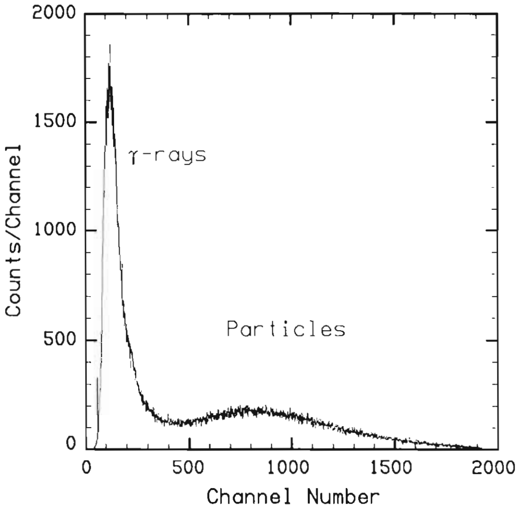

Fig. 2. Pulse-height spectrum of the detector from the reaction of $^{32}S + ^{154}Gd$. The lower energy peak is associated mainly with γ rays from the reaction. The upper, broader peak is associated with the detection of light-charged particles. The two peaks are reasonably well separated at the minimum.

agreement with a simulation by the Monte Carlo code GEANT [8], which gives 0.025 and 0.019 at 900 and 1800 keV, respectively.

The response to α-particles of 5.8 MeV was measured with an ^{249}Cf source and found to be close to the geometric coverage.

The Tube was recently used in a spectroscopy experiment by bombarding a ^{154}Gd target with a 165 MeV ^{32}S beam from the Holifield Heavy-Ion Facility for the purpose of studying the 4n, p3n, and 2p2n exit channels. In this experiment sufficient Ta absorber was inserted with varying thicknesses, in 3 rings, at angles below 80° (the laboratory grazing angle is 88°) to stop the elastically scattered beam particles. In that arrangement 16 Compton suppressed Ge detectors were used to record the γ-ray spectra at high resolution and 4 BaF_2 scintillation detectors inserted in 4 NaI(Tl) anticompton shields were used as an 8-detector multiplicity filter.

In this experiment the pulse heights and times from each of the four paddles were stored in coincidence with two or more Compton suppressed Ge detectors using two charge integrating ADCs (LeCroy FERA, and a time-to-FERA converter with a FERA ADC [9] for time). Fig. 2 shows a pulse height spectrum taken with one of the paddles of the Tube in the above reaction. The lower peak, labelled "γ-rays" has an intensity consistent with the γ-triggering efficiencies and the γ-ray multiplicities from this reaction. Its intensity is comparable to that of the broader peak labelled "particles", which includes detection of protons and α-particles from all angles. The pulse height of these particles should have similar distributions due to the larger quenching of light in the plastic from α-particles compared to protons. The broadening of the evaporative spectra due to the reaction kinematics is to a large extent responsible for widening of the particle spectra.

The direct response of the Tube to fission fragments themselves is reduced substantially due to the Ta absorber foils at forward angles. Beyond 80° the kinetic energy of the fission fragments drops rapidly and this together with the very large quenching of the light places the pulse height of most of the directly detected fission fragments under the γ-peak. However, for neutron deficient compound systems such as the $^{186}Hg^*$ some of the fission fragments are proton rich, so that one might expect some proton emission from the excited fragments. We have made estimates of these probabilities and of the prefission proton emission by Monte Carlo simulations with the evaporation code GEMINI [10]. The average proton multiplicity from fission was estimated to be <0.1 per fission event. This clearly indicates that the Tube will not respond significantly to fission. Thus, most of the fission background will remain with the (HI, xn) channels, whereas the particle tagged channels will have very little fission background.

The effectiveness of the Tube in selecting channels is addressed next. The first issue is the efficiency of the Tube in tagging channels. From fig. 2 it is seen that part of the particle peak is lying underneath the γ-peak indicating an identifiable charged-particle detection efficiency of ~ 70%.

In the offline analysis Ge $E_\gamma \times E_\gamma$ matrices were constructed by requiring that a total recorded γ-ray multiplicity $M_\gamma \geq 4$ be present. The γ-ray multiplicity included the sum of triggers from the Ge, BaF_2, NaI(Tl) detectors, and Tube paddles that fired in the γ-peak. These $E_\gamma \times E_\gamma$ matrices where gated by none, one, or two paddles of the Tube that fired which corresponds to no particle, one or two particles detected. Based on observed discrete γ-lines, the 0-particle matrix was found to contain 30% of the 1-particle tagged matrix and a small fraction of the 2-particle tagged matrix. These results are consistent with an average particle selecting efficiency of 0.7 for these reactions. A pure (HI, xn) $E_\gamma \times E_\gamma$ matrix can be produced by subtracting the appropriate fractions of the 1-particle and 2-particle matrices, respectively, from the 0-particle matrix. Similarly, a pure 1-particle matrix can be obtained by subtracting an appropriate fraction of the 2-particle matrix from the 1-particle matrix.

The selective power of the Tube is illustrated in fig. 3, where Ge energy spectra are shown for 0-, 1-, and 2-particles detected in the Tube. These were constructed as the total projections from the correspond-

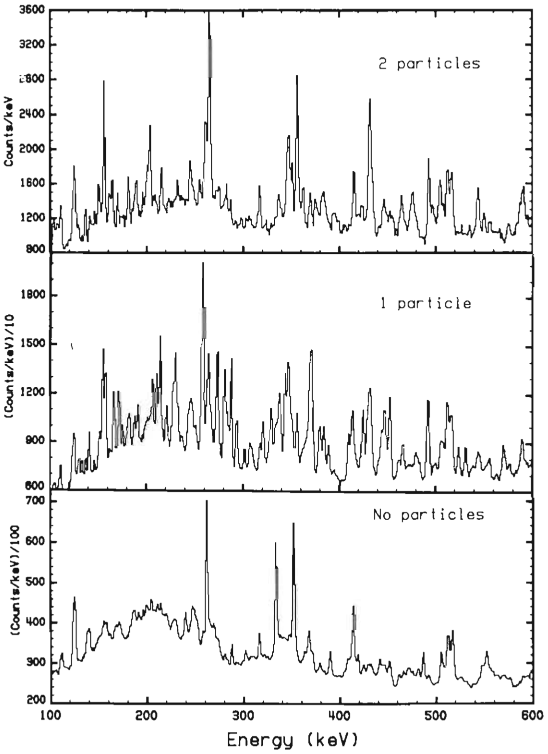

Fig. 3. Energy spectra of γ-rays from the reaction $^{32}S+{}^{154}Gd$ tagged according to the number of paddles that fired. The no-particle and 1-particle spectra contain mainly γ-rays from ^{182}Hg and ^{182}Au nuclei respectively, while the 2-particles spectrum clearly shows γ-rays from ^{182}Pt. The particle tagged spectra show no contribution from the xn channels. The no-particle spectrum shows small contribution from the particles channels which can be subtracted out.

ing $E_\gamma \times E_\gamma$ matrices. The 0-particle spectrum has a small contribution from the particle channels that can be subtracted as described above. It is seen that the three spectra have almost no peaks in common and the particle tagged spectra are free from the xn channel (0-particle) spectra and from fission. The 0-particle spectrum is dominated by ^{182}Hg γ-rays, while those of 1-, and 2-particles contain mainly ^{182}Au, and ^{182}Pt, respectively. Based on the estimates of the fission tagging for this experiment, it is fair to say that the bulk of the fission events were suppressed from the xn channels by the high M_γ requirement. Since the compound nucleus in this reaction had high Z, emission of α-particles was small compared to protons, as expected from statistical model calculations and supported by the γ-ray spectra in fig. 3.

The usefulness of the Tube as a tool for enhancing spectroscopic studies is at its best in neutron deficient high Z compound systems. For normal kinematics reactions, as the Z of the compound nucleus is decreased, the energy of the evaporative spectra decreases due to the reduction of the Coulomb barrier. This will shift a larger fraction of the particle pulse-height spectrum under the γ-peak, thus decreasing the particle tagging efficiency. However, the simplicity of this device suggests that the geometry of the Tube should be optimized for each class of experiments with similar experimental conditions. Thus, the length and/or the thickness of the scintillator may be judiciously chosen to minimize the response to γ-rays while maximizing the efficiency of tagging charged particles. Such an optimization can easily be done with the code GEANT [8].

Acknowledgements

This work was supported in part by the U.S. Department of Energy under Grant Numbers DE-FG02-88ER-40406 and DE-FG02-87ER-40316. We would like to thank Dr. R.J. Charity for helpful discussions and for running the GEMINI calculations.

References

[1] P.J. Nolan and P.J. Twin, Ann. Rev. Nucl. Part. Sci. 38 (1988) 533.
[2] R.V.F. Janssens and T.L. Khoo, Ann. Rev. Nucl. Part. Sci. 41 (1991) 321.
[3] D.W. Stracener et al., Nucl. Instr. and Meth. A294 (1990) 485.
[4] C. Baktash et al., Phys. Lett. B255 (1991) 174.
[5] D.G. Sarantites et al., Phys. Rev. Lett. 18 (1990) 2129.
[6] Plastic scintillator BC-400, Bicron Corp. Newbury, Ohio, USA.
[7] Hamamatsu Corp., Model R647 (12-mm diameter 10-stage photomultiplier tubes).
[8] R. Brun et al., GEANT3 Users Guide (Data Handling Division EE/84-1 CERN, 1986).
[9] FERA ADC, LeCroy Corp. Model No. 4300B.
[10] R.J. Charity et al., Nucl. Phys. A483 (1988) 371.