HADRONIC EXCITATION OF THE GIANT DIPOLE RESONANCE IN ^{208}Pb AND ^{40}Ca AT $E_{\vec{p}} = 200$ MeV

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The isovector giant dipole resonance is one of the best examples of collective vibrational motion in nuclei. It has been known and studied for almost fifty years, but it is still a prolific source of information about nuclear structure, effective interactions among nucleons, and even the dynamics of nuclear reactions. The GDR has been intensively studied by electromagnetic interactions, however quantitative exploration of the hadronic excitation of the GDR has been difficult, since the GDR is generally much less strongly excited by hadronic probes than is nearby isoscalar strength. This experiment is intended to cast light on the isovector GDR excited by the proton-nucleon strong interaction and determine the shape of the GDR transition potential.

Our understanding of the nuclear multipole response is based largely on the study of inelastic scattering. The giant resonance region is composed of many broad, overlapping resonances which require careful decomposition. The validity of assumptions made in carrying out such a decomposition in the analysis of experimental data is often not clear. The extraction of the weakly excited GDR (in hadronic scattering) is nearly impossible in a singles experiment, but it can be isolated cleanly, even from other strongly excited multipole states, by gamma-coincidence techniques. This is because almost all of the ground-state E1 strength is carried by the GDR while the ground-state electromagnetic widths of higher multipoles are intrinsically much smaller. A 14-MeV 1^- state in ^{208}Pb exhausting 100% of the isovector GDR sum rule strength has a ground-state γ-decay width 100 times stronger than that of a 2^+ state fully exhausting the E2 sum rule at the same excitation energy.

By requiring a γ-decay to the ground-state, it is possible to enhance the GDR signal by a factor of approximately 1000.[3,4] This extremely effective filter enables us to isolate the GDR cleanly and to measure the differential cross section and analyzing power as well as cast light on the strength of the isovector optical potential.

Beam time for this experiment, IUCF-E360, to study the reactions $^{208}\mathrm{Pb}(\vec{p}, p'\gamma_0)$ and $^{40}\mathrm{Ca}(\vec{p}, p'\gamma_0)$ was scheduled as two allotments in April, 1993 and in September, 1993. Because of significant manpower and equipment overlap, this experiment was performed in close association with IUCF-E354.[5]

Inelastically scattered protons were detected in the IUCF K600 magnetic spectrometer with its standard instrumentation operated in the septum magnet mode.[6] The septum magnet allows for spectrometer angles less than 6° and simultaneous deposition of unscattered beam in a well-shielded beam dump downstream, thus helping to reduce the intense background radiation. Radiation emitted from the target was detected in the Oak Ridge National Laboratory BaF_2 array. The detector array consists of 76 BaF_2 crystals of hexagonal cross section with an inscribed diameter of 6.5 cm and a length of 20 cm. The crystals were arranged in four close packed units consisting of 19 crystals each. Three BaF_2 packs were positioned on beam right approximately 50 cm from the target at 54°, 94°, and 135°. A single pack was suspended at the same distance above the 0.25″ thick aluminum thin-walled scattering chamber. The beam polarization was normal to the scattering plane.

This experiment was the first attempt at using this scintillator array with a proton beam and several difficulties were immediately apparent. The background of protons and neutrons scattered into the detectors posed one of the greatest technical challenges. These particles were largely produced by beam scattering in the beam line, target, and beam dump. Four inch thick Pb walls were built to shield the in-plane detectors from upstream scattered protons and downstream backscattered protons. A significant rate of protons in the detectors remained after these actions were taken which clearly indicates that the protons resulted from target interactions. This rate was large enough, especially since it consisted almost entirely of high energy (large current) pulses, to cause significant problems for the performance of our photomultiplier and base assemblies. Consequently further measures were taken to shield the BaF_2 array from scattered protons. Aluminum plates of varying thickness (thickest for the most forward detectors) were placed in front of each of the packs to stop or reduce the energy of the bulk of the protons. In spite of these efforts, a significant influx of energetic protons from (p, 2p) scattering remained the beam-current limiting feature of the experiment, restricting us to beam intensities a factor of 2 to 3 less than our original experimental design plans.

The basic goal of the experiment is to measure coincidences between inelastically scattered protons in the K600 spectrometer and γ-rays in the BaF_2 detectors. From these, those coincidences corresponding to direct γ-ray de-excitation from the inelastically excited target to the ground state are identified from the γ-ray energy determination and the excitation energy measurement provided by the K600. The technical problems which must be overcome in the analysis are the identification of the pulses in the BaF_2 produced by γ-rays from those produced by protons and neutrons, and the identification of real $p-\gamma$ coincidences.

The excellent timing and pulse shape characteristics provide our primary tools for these identifications. Figure 1 shows a typical TDC spectrum started by a proton on the focal plane and stopped by a BaF_2 pulse. The prompt peak is surrounded by an accidental peak on each side. The broad bump to the right of the prompt peak results from massive particles (p and n) which have a longer time of flight to the detector than γ-rays. While the intrinsic timing of the BaF_2 detectors is somewhat better than the 4 ns resolution we have achieved, we are easily able to discriminate between γ-rays and other particles traversing the 50 cm flight path from the target. A major difficulty though is the relatively large uncorrelated background under these peaks.

A feature of the BaF_2 helpful in identifying high energy neutrons and quasi-elastically scattered protons is their light yield characteristics. Charged particles and high energy

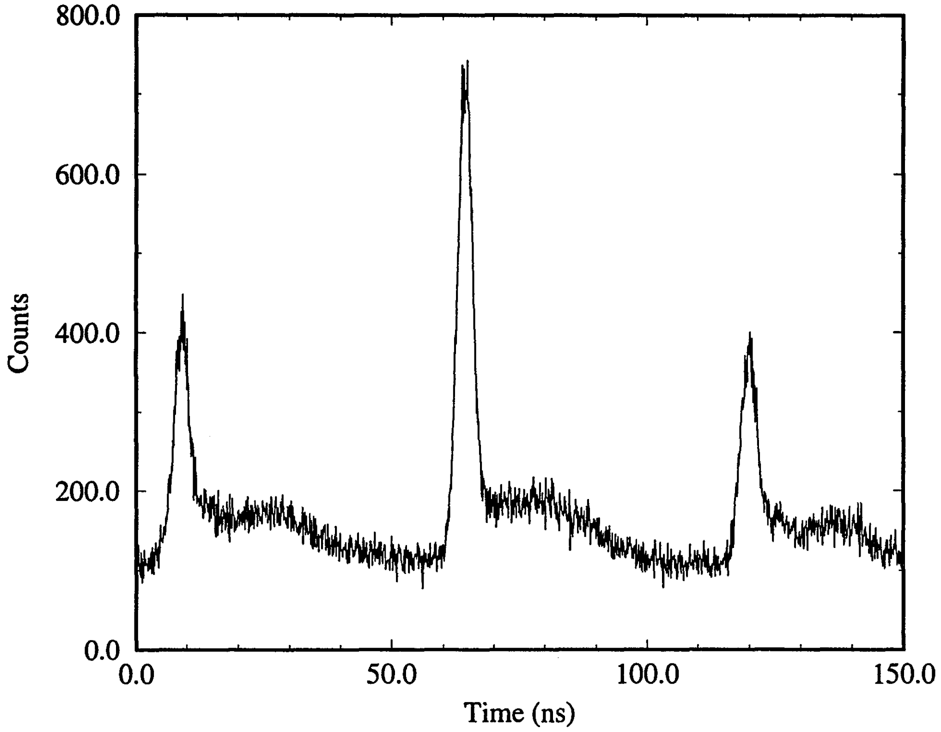

Figure 1. Typical TDC spectra started by a proton on the K600 focal plane and stopped by the coincident signal in a BaF_2 detector.

neutrons ($E_n \geq 10$ MeV) produce less intense fast light output in the crystals than γ's. Exploiting this fact by using two gates, a short 50 ns time gate to integrate the fast component and a long 1.5 μs gate to integrate the slow component, provides good pulse shape discrimination. Figure 2 shows a typical fast light vs. slow light correlation used for particle rejection.

The majority of the primary data analysis has been completed, however dealing quantitatively and rigorously with the large backgrounds encountered remains problematic. The ^{208}Pb data provides an excellent test case for these aspects of the analysis since we have extensive data on the excitation and decay of ^{208}Pb from earlier heavy-ion experiments.[3,4] If our current efforts to understand the ^{208}Pb data involving extensive BaF_2 detector response and Monte Carlo simulations produce results consistent with existing data, results for absolute differential cross sections and analyzing powers for both ^{208}Pb and ^{40}Ca will follow within a short time.

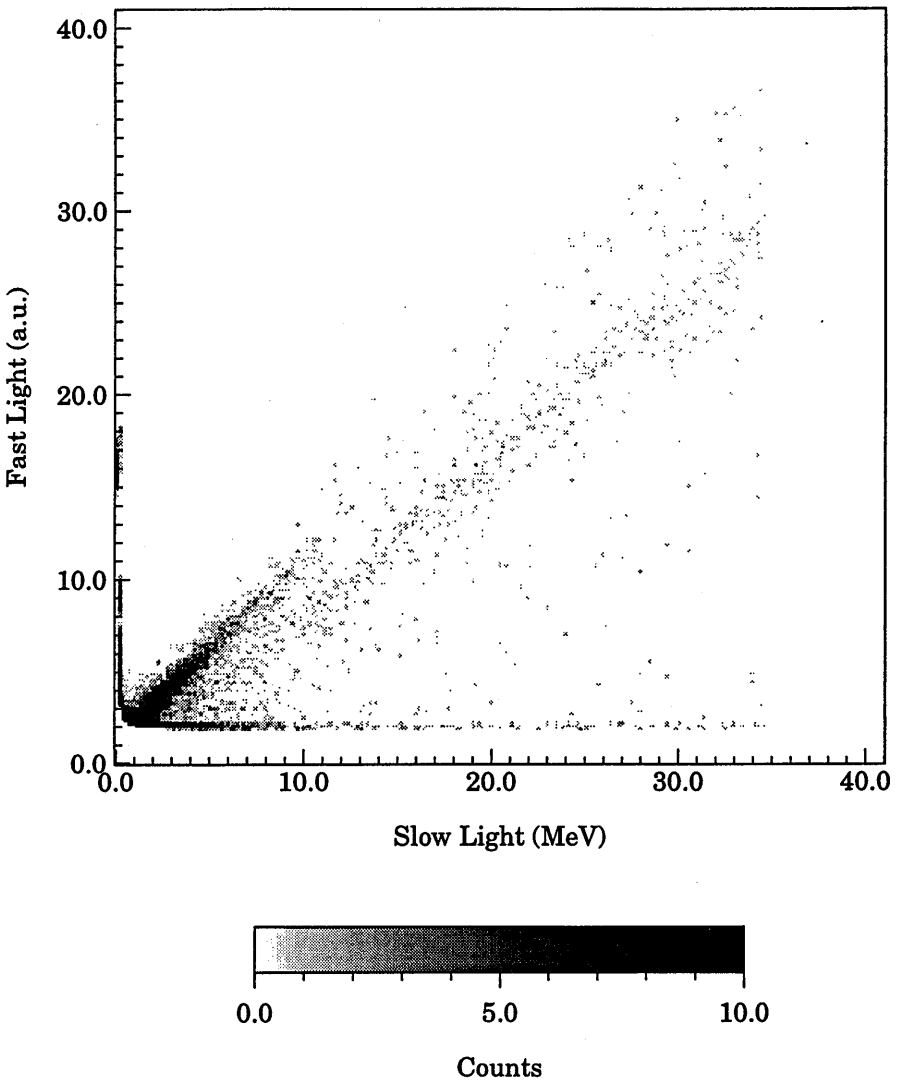

Figure 2. BaF_2 fast ultraviolet response vs. total light output. The fast light scale is adjusted such that gamma rays lie along the diagonal. High energy neutrons and charged particles produce a smaller fast/slow ratio.

1. Partial support provided by Vanderbilt University and Oak Ridge Associated Universities under the Laboratory Graduate Research Program.
2. Managed by Martin Marietta Energy Systems, Inc. under contract DE-AC05-84OR21400 with the United States Department of Energy.
3. J. R. Beene, *et al.*, Phys. Rev. C **39** 1307 (1989).
4. J. R. Beene, *et al.*, Phys. Rev. C **41** 920 (1990); J. R. Beene, *et al.*, Phys. Rev. C **41** R1332 (1990).
5. S. P. Wells, *et al.*, IUCF Sci. and Tech. Rep. May 1993-April 1994, p. 19.
6. G.P.A. Berg, *et al.*, IUCF Sci. and Tech. Rep. May 1993-April 1994, p. 220.