

## DETECTOR DEVELOPMENT AND CALIBRATION

### FEASIBILITY STUDY FOR INVESTIGATIONS OF $(\vec{p}, p'\gamma)$ REACTIONS WITH THE K600 SPECTROMETER

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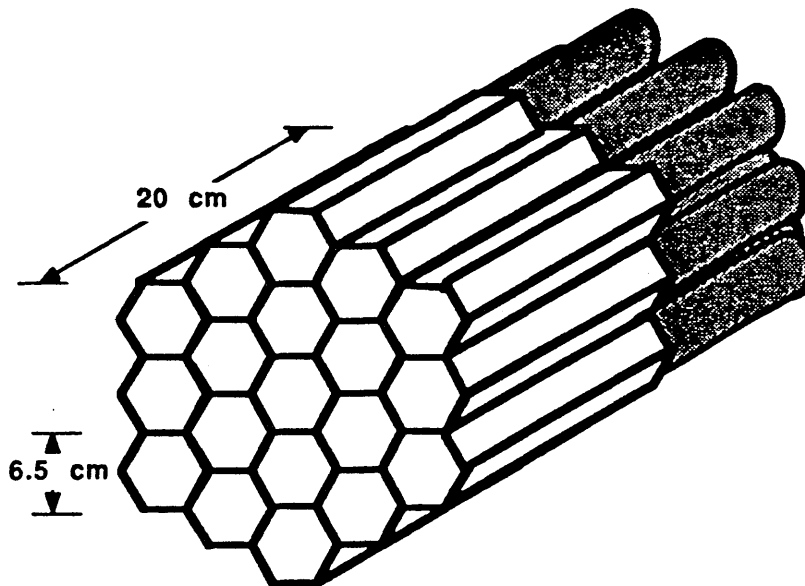
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Several experiments designed to measure spin observables for the  $(\vec{p}, \vec{p}')$  reaction have been successfully performed using the K600 spectrometer and its associated focal plane polarimeter (FPP).<sup>1</sup> A "complete" set of spin observables for discrete states, however, provides at most eight independent quantities, whereas for a transition of the form  $0^+ \rightarrow J^\pi$ ,  $(8J+3)$  independent quantities are required for a complete determination of the scattering amplitude. For transitions in which the spin  $J$  of the excited state is non-zero, additional information can be obtained by studying the polarization of the recoil nucleus. This information can be obtained through measurements of the angular correlation between the scattered proton and the particle emitted in the nuclear deexcitation. In fact, for transitions with the simple spin sequence  $0^+ \rightarrow 1^+$ , measurements of the type  $(\vec{p}, p'\gamma)$ , in which the polarizations of the outgoing proton and photon are not detected, when combined with the complete sets of  $(\vec{p}, \vec{p}')$  observables discussed earlier, will provide sufficient information to completely specify the scattering amplitude.<sup>2</sup> It is therefore natural to extend the K600 and FPP system to include the capability for coincident photon detection. A proposal to use this system for the  $(\vec{p}, p'\gamma)$  reaction on the two dominant  $1^+$  states in  $^{12}\text{C}$  ( $T = 1$  at 15.11 MeV,  $T = 0$  at 12.71 MeV) has been approved by the PAC (E354) and granted the necessary beam-time to measure all of the coincident observables.

For  $(\vec{p}, p'\gamma)$  investigations to be practical, the  $\gamma$ -ray detection system used must be compatible with the environment in which the measurements are to be performed. The results of various shielding tests<sup>3</sup> indicate that the experimental cave in which the K600 spectrometer is housed has a large, time-uncorrelated  $\gamma$  component in its room background profile. This is present to some extent even when the unscattered beam is deposited in an external shielded beam dump. In addition, there has typically been a "low-momentum halo" in the incident beam, which generates prompt  $\gamma$ -rays in the room as it strikes beam-line elements along its path to the K600 target. Through recent work by

the K600 small-angle and beam dynamics groups, a procedure for delivering "halo-free" beam to the K600 has been established.<sup>4</sup> While these developments significantly improve the background situation in the K600 cave, the  $\gamma$  detection scheme must be capable, through hardware and software requirements, of unambiguously identifying those  $\gamma$ -rays emitted from the excited target nuclei.

Of the many types of  $\gamma$  detectors available, we feel the best choice for coincident  $\gamma$  detection in the K600 cave environment is  $\text{BaF}_2$ . These crystals have the dual advantage of both excellent timing characteristics (due to a fast response component, with  $\lambda \sim 220$  nm) and the ability to maintain energy resolution (this from a slow component, with  $\lambda \sim 310$  nm) comparable to more conventional  $\gamma$  detectors such as NaI, which have much poorer timing characteristics. Shown in Fig. 1 is one of four close-packed 19-detector bundles, or 19-packs, of  $\text{BaF}_2$  (supplied by the ORNL collaborators) which we plan to use as our photon detection system in the K600 cave.<sup>5</sup> Each of the 19  $\text{BaF}_2$  crystals in each pack is hexagonal in shape, 6.5 cm across and 20 cm long, which is sufficiently thick to stop a 200 MeV  $\gamma$ -ray with a conversion efficiency of nearly 100%. Associated with these crystals are individually-matched photomultiplier tubes with quartz photocathodes and highly stabilized bases. The detector hardware and signal-processing electronics has been designed for optimum time and energy resolution, while the logic and event readout schemes have been tailored for maximum efficiency in identifying and processing potential events.



*Figure 1.* A close-packed 19-detector bundle of  $\text{BaF}_2$  detectors, showing the dimensions of the individual crystals. The shaded cylinders represent phototube and base assemblies.

In September 1990, we were given 9 shifts of dedicated discretionary beam-time (preceded by 3 shifts of split-beam running) which we used to test the feasibility of using this photon detection system in conjunction with the K600, and to determine the limitations of this combined system due to detector properties, electronics capabilities, and computer speed and efficiency. The ORNL collaborators brought one of the four 19-packs to IUCF for this test. The goals of this run were to: i) set up the  $\text{BaF}_2$  array as an independent working system in the K600 cave; ii) measure the raw rates and response characteristics in the  $\text{BaF}_2$ 's when in this environment; iii) obtain information needed in order to deduce off-line the room background profile; iv) integrate the  $\text{BaF}_2$  system with the "standard" K600 system; and v) observe real proton- $\gamma$  coincidences.

Shown in Fig. 2 is a schematic diagram of the configuration we used for this run. The  $\text{BaF}_2$  array was positioned such that the center detector was in the reaction plane on beam right at  $\theta_{\gamma ab} = 90^\circ$  with respect to the incident beam direction and approximately 45 cm from the  $6.5 \text{ mg/cm}^2$   $^{12}\text{C}$  target. Walls of lead were stacked both upstream and downstream

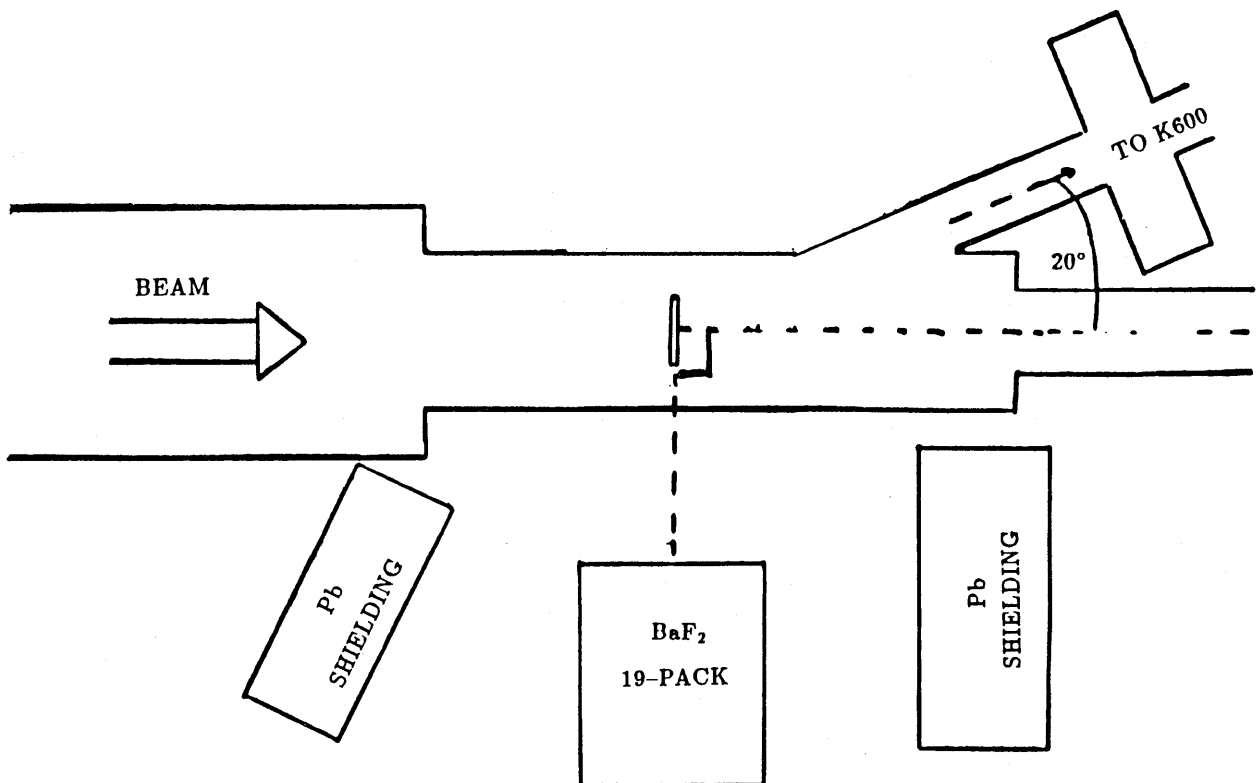


Figure 2. Experimental configuration used during the  $(p, p'\gamma)$  test run. The  $\text{BaF}_2$  detectors were placed 45 cm from the target at  $90^\circ$  beam right with respect to the incident beam direction. The upstream and downstream Pb walls were used to shield the  $\text{BaF}_2$  detectors from prompt  $\gamma$ -rays generated in beam-line elements and the external beam dump, respectively.

downstream of the BaF<sub>2</sub> detectors to shield them from  $\gamma$ -rays emitted from beam-line elements and the external beam dump, respectively. For this test run, we were limited to a single proton scattering angle ( $\theta_{lab} = 20^\circ$ ) due to restrictions imposed by our use of an existing thin-walled scattering chamber compatible with the K600 beamline (a thin-walled chamber is required so that the emitted  $\gamma$ -ray flux is not attenuated too severely). At this angle, the cross section for the 4.44 MeV  $2^+$  state in  $^{12}\text{C}$  is near its maximum (4.5 mb/sr), while the cross section for the 15.11 MeV  $1^+$  state (the state of primary interest for experiment E354) is at a minimum (0.01 mb/sr).<sup>6</sup> We therefore decided to focus our analysis on the lower energy transition.

In this run four signals were read out by CAMAC for each detector that fired a low threshold discriminator: fast timing information, relative to the K600 focal plane scintillators; a low-gain/wide-gate pulse height, for high resolution over a large photon energy range; a high-gain/wide-gate pulse height, for higher resolution over the energy range of primary interest; and a high-gain/short-gate pulse height, whose amplitude is dominated by the fast (ultraviolet) component of the scintillator response. This information was used to provide tight time correlation with the beam burst arrival at the K600 target, moderately tight correlation with proton arrival time at the K600 focal plane scintillator, and pulse-shape discrimination against both charged particles and neutrons. These requirements, combined with subtraction of "accidental" events, as determined by recording photon coincidences with protons of the adjacent beam burst, lead to very clean particle-gamma energy correlations.

Two separate electronic signals that incorporated BaF<sub>2</sub> detector information were used as event triggers: a prescaled ( $\div 18,000$ ) signal generated by a logical OR of the 19 BaF<sub>2</sub> high-gain/wide-gate anode signals which pass the low-threshold discriminator (200 mV, corresponding approximately to a 2 MeV  $\gamma$ -ray), and another generated by a logical AND (with a 200 ns overlap width) between the signal just described (before prescaling) and a valid K600 focal plane signal. The BaF<sub>2</sub> singles events provide valuable information about the K600 room background profile, which will aid us in the design of shielding configurations for future runs. These events also allow us to determine the raw singles rate in the BaF<sub>2</sub> detectors while in the K600 cave. With  $\sim 3$  nA of 185 MeV protons incident on our 6.5 mg/cm<sup>2</sup>  $^{12}\text{C}$  target, we observed a rate of  $\sim 250\text{K}$  events/sec in the entire 19-pack. For the coincident events, we were able to observe the 4.44 MeV photons, emitted from the excited  $2^+$  state in  $^{12}\text{C}$ , on top of an exponential background after only a few hours of running, prior to applying any software conditions. Adding a loose time cut (approximately 5 ns wide) between the photon detector and the focal plane scintillator revealed a clear peak between 4 and 5 MeV. If a comparable cut was also placed on the "accidental" peak in the time spectrum, which corresponded to coincidences between particles from different beam bursts, and this was used to subtract events from those that fell within the "true" time cut, then an essentially background-free peak emerged, of sufficient resolution that escape peaks might be visible (Fig. 3). Our estimated energy resolution was approximately 1 MeV.

The results of this test run are very encouraging for future experiments using the ( $\vec{p}, p'\gamma$ ) reaction with the K600 spectrometer and a BaF<sub>2</sub>-based photon detection system. In particular, we can now proceed with remaining hardware development for experiment

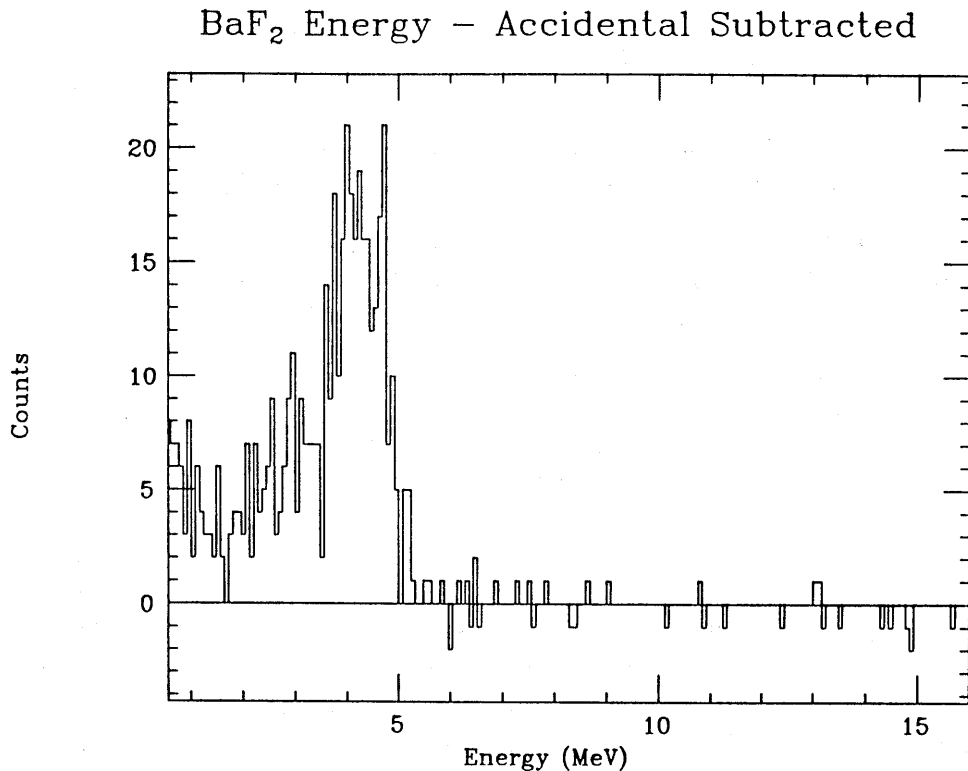


Figure 3. A single BaF<sub>2</sub> detector pulse height spectrum, gated on the relative time-of-flight between the proton arrival at the K600 focal plane and the time signal of this detector, and "accidental" events (as described in the text) subtracted.

E354. Future plans regarding this experiment involve the completion of the K600 septum magnet,<sup>7</sup> the development of a new thin-walled scattering chamber compatible with the septum magnet mode and the K600 beamline, and the installation of a VME-based electronics and readout system for faster and more efficient event processing.

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