Yttrium Aluminum Perovskite (YAP) scintillator array as a heavy ion detector for DAPPER

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The detector array for photons, protons, and exotic residues is designed for use with secondary beams to allow measurement of (*d, p*) reactions on unstable nuclei. Such secondary beams typically contain contaminants. The ability to distinguish the contaminants event by event is highly desirable to allow a clean measurement of the photon strength function of a single nuclide. When the secondary beams are already prepared with a selection on rigidity and on velocity, as is the case with MARS, the contaminants can't be distinguished by energy or time-of flight.

To identify heavy ions by Z, the ions can be passed through a degrader and be distinguished by their residual energy. Iron, which is both the beam species of interest, and the reactant of interest in (*d, p*) reactions, will have the highest residual energy after degradation. The cobalt contaminant, and its (*d, p*) residues, will have less residual energy after degradation. Residues arising from fusion evaporation on carbon in the plastic target will have even less energy after degredation.

An array of Yttrium Aluminum Perovskite (YAP) scintillator array has been developed to serve this purpose. It needs to discriminate between iron and cobalt at a rate of at least 3e5 particles per second. Active bases were used for the photomultiplier tubes. Various resistors were used for the active bases. Smaller resistances allow faster recharging of dynodes, which allow higher rate. However, resistors that are much too small draw too much current and are prone to failure of the transistors. Resistors that are somewhat too small do not afford as good energy resolution as larger resistors. A balance must be struck between rate and resolution.

YAP detectors were tested in beam with various bases and at various voltages. The signals from the phototube were sent directly to the input of the SIS3316 flash ADC. Waveforms were recorded, and the timing MAW was used with peak=2 and gap=2 (previously shown to be optimal for measuring 5-9 MeV alpha particles). High and mid resistance bases performed similarly. Adequate resolution can be obtained at high rate. The 7.5 MeV/u copper beam contained chlorine impurity; use of single and double hits of copper and chlorine allowed us to establish that the light output was linear with energy in this energy range. Very high intensity beam was applied to the YAP to simulate 9 days-worth of beam time; the resolution held up sufficiently well.

A secondary beam of ^{57}Fe and ^{57}Co @ 7.5 MeV/u was produced in MARS with roughly equal components of each. This was impinged directly on a YAP and a resolution better than 2% FWHM was obtained. A degrader of aluminum foil of approximately 25µm (heavy duty commercial aluminum foil) was inserted to degrade the beam energy immediately before the YAP. The resolution worsened to around 6%. Rotation of the degrader (to precision of 1 degree) up to 61 degrees allowed increasing the thickness of the degrader to just beyond double the initial thickness. Within this range, the iron and cobalt should have begun to be discernible. However, the peak became broader faster than the two constituents would be expected to separate, and no distinction between iron and cobalt was achieved.

Use of 2 layers of the heavy duty foil performed identically to a rotation of the foil to 60 degrees. Translation of the degrader 14" farther upstream (to a total distance of about 18") to reduce the relative amount of multiple scattering did nothing to improve the situation. The thickness of the foil was measured with a micrometer in multiple places with an accuracy of 0.00005"; 5 measurements reported identical values, one higher by 0.00005" and one lower by 0.00005", indicating the variation of the foil is flat to within the precision of the micrometer, and ruling out gross thickness variations as the primary cause of the lack of Fe/Co resolution; thickness variation might contribute to the problem, but is not the main problem. The energy resolution degrades far faster than a sqrt(E) dependence; photon counting statistics is not the problem. Delta rays are not the problem, as reasonable resolution (6%) was obtained with the degrader at 0 degrees. The iron and cobalt is degraded into the Bragg peak when the degrader is turned to 60 degrees, but the energy is still far above the region where nuclear stopping dominates over electronic stopping. Integrating the waveforms, rather than using the MAW MAX, did not show a significant change in the resolution obtained with the degrader turned near 60 degrees. Changing the degrader from 59 to 60 to 61 degrees produced a very rapidly worsening resolution. At 59 degrees, a poor resolution peak was clearly visible; at 61 degrees the peak was just discernible; at 61 degrees, no peak was observed at all, merely a broad peak at E=0 with a tail extending to higher energy. According to LISE++, energy straggling is too small (<1%) to be the primary cause, though one may question the accuracy of the straggling prediction with this much energy loss.

It is possible that fluctuations in the quenching is the cause of the problem. For highly ionizing particles near the Bragg peak, the excitation and ionization density is very high, and quenching is very large. Since quenching is a stochastic process, some events have more quenching than others. If only the Bragg peak, or just beyond, is in the active volume of the detector, the fluctuations in the quenching must be relatively largest. Perhaps when the signal is nothing but Bragg peak, the fluctuations are so large compared to the amplitude of the signal that the resolution is completely destroyed. It is also possible that there exists a dead layer on the surface of the YAP which is highly non-uniform. It is not clear how either of these possible causes could be dealt with in order to use the YAP to measure very small residual energy.

An experiment could be done with low energy direct beams to verify unambiguously that the thick degrader is playing no role in the destruction of the energy resolution. However, it is not clear what the path forward with YAP for this application would be for any possible result of such a test. An alternate detector technology is likely necessary.