Design and testing of YAP:Ce array for DAPPER

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An array of cerium-doped yttrium aluminum perovskite (YAP:Ce) scintillators has been designed and tested for use in DAPPER (the **D**etector **A**rray for **P**hotons, **P**rotons, and **E**xotic **R**esidues) for the purpose of obtaining a TOF measurement to distinguish fusion events from interesting (d,p) products. DAPPER will measure photons emitted from excited ^{58}Fe nuclei from a ^{57}Fe(d,pγ)^{58}Fe reaction in inverse kinematics with future plans to measure the ^{59}Fe(d,pγ)^{60}Fe reaction. The target is CD_2 and fusion is possible with the carbon. The YAP:Ce array is positioned approximately 80 cm from the target position which would give a 3 ns separation in the flight time between the fusion and (d,p) centroids. YAP:Ce is a radiation hard, fast timing detector that has been shown to take up to 2.5E9 pps of ^{63}Cu for 10 minutes without a noticeable reduction in the rise time of the signals. The rise time is typically around 2-3 ns when coupled to a Hamamatsu 1924A photomultiplier tube (PMT). New active bases were constructed in order to improve the saturation rate for these detectors.

In a previous test run [1], the saturation rate of a YAP:Ce detector was tested using a beam of ^{84}Kr at 7.5 MeV/u. When placed at 0 degrees and using various bases coupled to a Hamamatsu 1355 PMT, the maximum rate achieved on the detector was 1.7E6 pps. This was achieved using the lowest resistance base and with the lowest operating voltage (-800 V). In order to improve performance, new bases were built using a template for active bases [2]. High (HR), mid (MR), and low (LR) resistance bases were constructed for the 1924A PMTs to be tested with a beam of ^{63}Cu at 7.5 MeV/u accelerated down the K150 SEE line. A temperature sensor made contact with the active base during the run in order to monitor the performance of the detector as temperatures increased.

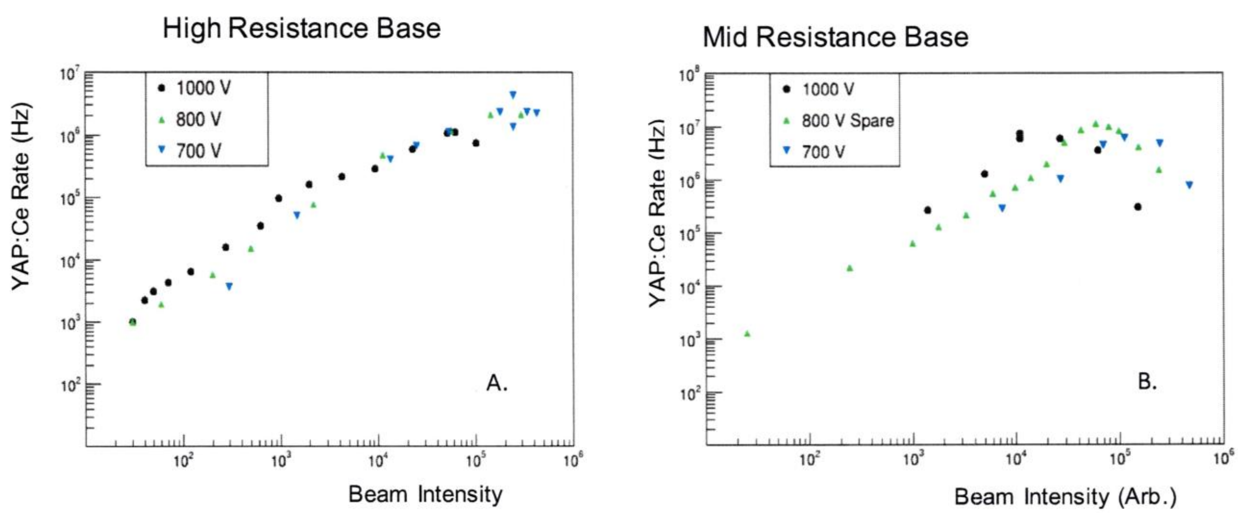

Fig. 1. The resulting YAP:Ce saturation rate as a function of the beam rate measured by a plastic scintillator for both the high (A) and mid (B) resistance bases at various voltages. The HR base achieved a maximum 1.2E6 pps at 700 V while the MR base achieves 1.0E7 pps around 800 V.

Fig. 1 shows the improved saturation rate achieved by the MR base compared to the HR. The LR base saturated around the same rate as the MR but generated more heat during the run. This higher heat can damage the circuit and render the base unusable so the MR base was chosen for the array. During this test, the full beam of ^{63}Cu (2.5E9 pps) was delivered to the YAP:Ce detector for 10 minutes after which some damage was indicated by a shift in the integrated charge of the signals. However, within the resolution of the electronics, the rise time of the waveforms was unaffected indicating that the timing resolution was maintained.

The geometry of the array was determined given its collection efficiency for the beams. The ^{57}Fe beam is stable and the beam is quite symmetric when delivered through MARS. The radioactive ^{59}Fe beam has an asymmetric beam divergence which affects the spread of the reaction products. A simple toy model was built to look at the spread of the products for both the stable and radioactive beams and the resulting collection efficiency of the array for various geometries.

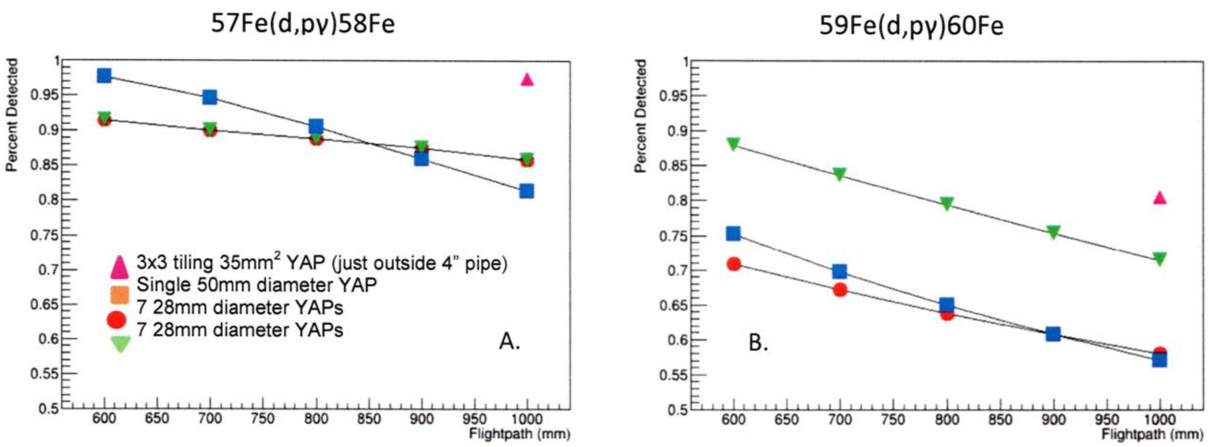

Fig. 2. Percent of residues collected given the geometry of the YAP:Ce array for the stable beam (A) and the radioactive beam (B) as a function of the distance of the array from the target position.

The geometry ultimately chosen (Fig. 3) gives flexibility in the distance from the target position as it can fit within the 4" beam pipe and can be oriented in such a way that improves the collection efficiency for the future radioactive beam experiment while not sacrificing efficiency for the stable beam.

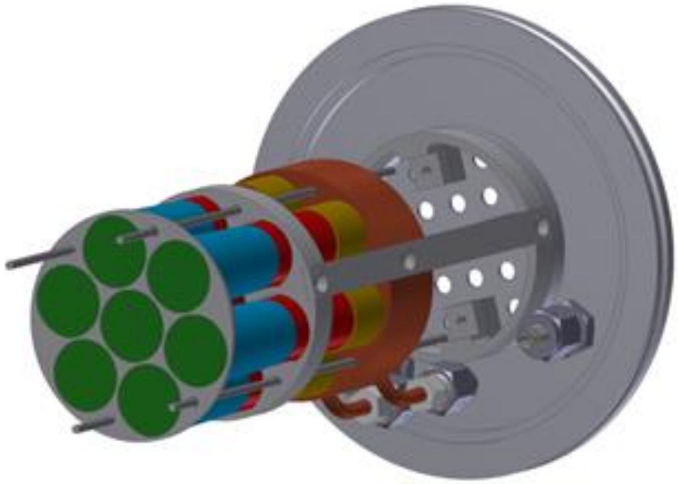

Fig. 3. CAD drawing of the YAP:Ce array. The green circles represent the YAP:Ce crystals, the blue cylinders are UVT light guides, the red cylinders are the 1924A Hamamatsu PMTs, and the gold pieces are the active bases. The bases are then slotted into an actively-cooled copper block (bronze).

[1] A.B. McIntosh and A. Abbott., *Progress in Research*, Cyclotron Institute, Texas A&M University (2019-2020), p. IV-72.

[2] P. Ren *et al*., Nucl. Sci. Tech. **28**, 145 (2017).