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The Partial Truncated Icosahedron Phoswich Detector Array: a Light Charged Particle Array for Pionic Fusion Measurements

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Abstract

The Partial Truncated Icosahedron (ParTI) phoswich detector array has been designed to detect charged pions and other light charged particles in pionic fusion reactions. The array has been constructed and characterized in a series of beam experiments. It is composed of 15 plastic/thalium-doped cesium iodide (CsI(Tl)) phoswich detector units arranged on the faces of a truncated icosahedron geometry which covers approximately 20% of the solid angle. The phoswich detectors have been shown to be capable of isotopic identification of Z = 1 and Z = 2 particles and elemental identification of at least up to Z = 3 using fast vs. slow pulse shape discrimination (PSD). Some advantages of employing digital electronics are discussed including identification of charged pions independent of PSD using their characteristic waveform response and selective event triggering using a muon decay trigger. A calibration method for the array is also described.

Keywords: Phoswich; Pion Detection, PionicFusion.

1. Introduction

The Partial Truncated Icosahedron (ParTI) phoswich array has been constructed in order to detect pions and light charged particles created in pionic fusion experiments. Pionic fusion is the process by which two nuclei fuse during a

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collision and then deexcite exclusively by the emission of a pion (Braun-Munzinger 1987). The final state of the system is composed of the fusion residue with the same total number of nucleons as the colliding system and a pion. The species of the fusion residue and the charge of the emitted pion satisfy charge conservation. Pionic fusion has been observed in multiple reacting systems (some examples can be found in Horn 1996, Joulaeizadeh 2011, Le Bournec 1981) with reported cross sections ranging from approximately 100 nb to approximately 250 pb. The cross section is generally observed to decrease with increasing size of the reacting system.

The pionic fusion process represents the most extreme example of subthreshold pion production. Typically, the term "subthreshold" is applied to pion production when the average center of mass energy of a nucleon-nucleon collision is below 140 MeV – the approximate rest mass of the charged pion (Braun-Munzinger 1987). This corresponds to reactions in which projectiles have kinetic energies of 280 MeV/nucleon. This threshold is useful because pion production in nuclear reactions is understood as proceeding through nucleon-nucleon processes like Δ and N^* resonances. In pionic fusion reactions, by comparison, the total available center of mass energy in the colliding system is just above the mass energy of the pion such that the average available energy in the nucleon-nucleon frame can be as low as 11 MeV (Horn 1996).

The fact that these extreme subthreshold processes have been observed would seem to indicate that pion production may be possible through mechanisms beyond the single nucleon-nucleon collision models. Indeed, as pion production reactions reach deeper into the subthreshold regime, single nucleon-nucleon collision models increasingly under predict the production cross sections (Shyam and Knoll 1984). Responding to this issue, various collective models for pion production have been proposed including statistical emission from an excited source (Aichelin 1984), pionic Bremsstrahlung (Vasak 1980), Hartree-Fock mean field theory approaches (Tohyama 1984), and various clustering models (Toshitaka Kajino 1987, Joulaeizadeh 2011). Each of these, however, has had limited or no success providing a general description of deep subthreshold pion production.

Using the ParTI array and the Momentum Achromat Recoil Spectrometer (MARS) (Tribble 1989) located at the Texas A&M University Cyclotron Institute, an experiment was designed to provide the first coincident measurement of a fusion residue and charged pion resulting from the pionic fusion reaction $^4\mathrm{He} + {}^{12}\mathrm{C} \rightarrow {}^{16}\mathrm{N} + \pi^+$. That experiment was performed using a ^{4}He beam at 55 MeV/nucleon delivered by the K500 Superconducting Cyclotron and analysis is currently underway. In this manuscript the details of the ParTI array, a characterization of its particle identification abilities, the calibration method, and some advantages of pairing the array with digital electronics are presented.

2. The ParTI Phoswich Detector Array

The ParTI phoswich array was designed for use in the pionic fusion experiment for the purpose of identifying charged pions. It is comprised of 15 plastic/CsI(Tl) phoswiches arranged on the faces of a truncated icosahedron geometry. It covers approximately 20% of the solid angle. The target is positioned in the center of the truncated icosahedron shape and the distance from the center to the face of the phoswich detectors is 4.75" for pentagonal phoswich geometries and 4.63" for hexagonal phoswich geometries (phoswich geometries will be discussed more in the following section). Each face of the array is an individual aluminum frame which holds a single phoswich detector. The frames are held together using aluminum tabs machined with the appropriate angles to create the truncated icosahedron geometry. A photograph of the populated detector array is shown in Fig. 1.

2.1. The Phoswich detectors

The term "phoswich" is an abbreviation of "phosphor sandwich" and describes a detector which is made up of two scintillating components with different characteristic scintillation times which are optically coupled together and to a single photo-sensitive unit. There are 3 different geometries of phoswiches within the ParTI array. Twelve of the fifteen total detectors have the geometries of regular pentagons or hexagons corresponding to the faces of the truncated icosahedron shape. Each side of every polygon is 1.5". The other 3 units populate a single hexagonal face of the truncated icosahedron and are modified such that there is a hole in the center of the face for the beam to pass through.