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Status of TACTIC: A detector for nuclear astrophysics

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Abstract

A new detector for nuclear astrophysics studies is being designed and built by TRIUMF and the University of York. The TRIUMF Annular Chamber for Tracking and Identification of Charged particles (TACTIC) is designed to detect low-energy charged particles from inverse kinematics reaction studies performed at the relevant astrophysical energies. TACTIC is a cylindrical ionisation/time-projection chamber with segmented anode strips, which allow the dE/dx of the particle to be determined along with the total energy. Information from drift times allows the particle trajectory to be reconstructed. This in turn identifies the interaction point along the beam axis and hence the centre of mass energy of the reaction. To amplify the expected weak signals, a gas electron multiplier (GEM) will be used in place of the usual Frisch grid. Full digital readout of the charge and timing of each anode strip will be achieved with flash ADC cards allowing pulse shape analysis of the signals.

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1. Introduction

Nuclear astrophysics uses the techniques of nuclear physics to address some of the fundamental questions about the evolution of the universe [1] by endeavouring to understand how and where all the chemical elements were synthesised. Moreover, it attempts to explain the nuclear power sources behind some of the most spectacular astrophysical sites, such as supernovae and X-ray bursters.

Studying the key reactions that influence energy generation or nucleosynthetic pathways requires a variety of techniques and approaches to be exploited. Ideally, these reactions should be probed at the energies occurring in the relevant astrophysical sites. For many cases, this is not possible using current technology due to the extremely low cross sections involved. Where it is feasible, the experimental conditions are still extremely challenging: beam energies in the 0.15–2 MeV/u range; ejected charged particles with energies from a few MeV down to a few tens of keV; radioactive ion beams with low beam intensities but high background from decay of the beam particles; and low cross-sections typically in the μbarn to nbarn range. These conditions highlight the need for high efficiency, large solid angle detectors and it was to address these issues that the TACTIC detector was designed [2].

2. Motivation

One of the current challenges in nuclear astrophysics is to understand where the so-called r-process nuclei are created. These nuclei are neutron rich and thought to be synthesized in an environment with a high neutron flux such as core collapse supernovae. Recent network calculations [3] which have included light nuclei show that, for some models, two reactions chains:

$$\alpha(\alpha n,\gamma)^{9}\mathrm{Be}(n,\gamma)^{10}\mathrm{Be}(\alpha,\gamma)^{14}\mathrm{C}$$

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and

$$\alpha(t,\gamma)^7\mathrm{Li}(n,\gamma)^8\mathrm{Li}(\alpha,n)^{11}\mathrm{B}$$

can significantly influence the final abundances of r-process nuclei. Of these reactions, ^{8}Li(α,n)^{11}B has been the focus of significant experimental effort. This reaction is experimentally challenging for several reasons. Although the cross-section is not particularly low (mbarns), the ^{11}B are ejected with low energy making their detection difficult. Many measurements have been based on the detection of the neutron, but these have suffered from poor efficiency and resolution. Recent measurements [4] have utilised the Multiple Sampling and Tracking Proportional Counter (MSTPC). This active target approach was based on tracking each incident ^{8}Li particle and identifying when a reaction occurred by looking for a change in dE/dx, in coincidence with a neutron event in the plastic scintillator surrounding the MSTPC. However, this technique limits the incident beam intensity to the rate that the MSTPC can handle. Consequently, the TACTIC detector was designed to bypass this restriction on the beam intensity and exploit the higher intensities available at the ISAC radioactive beam facility at TRIUMF.

3. The TACTIC detector

The TRIUMF Annular Chamber for the Tracking and Identification of Charged particles (TACTIC) is a cylindrical ionization/time-projection chamber. Its design criteria are as follows:

- Detect charged particles (protons, alphas, heavy ions) with energies from a few MeV down to 100 keV.
- The target region should be invisible to the active region of the detector.
- Be able to operate without a physical separation (i.e., foil or window) between the target and active regions.
- Have high solid angle coverage.
- Be versatile enough to run at a range of gas pressures and incident beam energies.
- Handle the high background rate associated with running in a radioactive beam environment.
- Be designed to be surrounded by a gamma array without significant attenuation of the gammas.

To achieve these design goals, TACTIC will have cylindrical geometry as shown in Fig. 1. The beam will enter the detector via a window at one end of the cylinder and, depending on the operational mode, may exit at the other end. The beam traverses a central cathode region running along the length of the cylinder, aligned with the optical axis of the beam. This region is about 2 cm in diameter and is bounded either by cathode wires running parallel to the beam axis or a foil window, depending on the reaction under investigation. The wires/window are held at a negative voltage with respect to the rest of the detector.

The active region of the detector is also cylindrical, concentric to the cathode region, with a diameter of about 10 cm. This region is bounded by a gas electron multiplier (GEM) [5,6], which serves two purposes. Firstly, it acts as a Frisch grid and secondly, it allows the signals to be amplified in a controllable way. The voltage across the GEM can be varied allowing the amount of amplification to be adjusted according to the demands of the experiment. In cases where the particles' energy is high enough not to require amplification, the GEM voltage can be reduced, thus reducing the electron multiplication and maintaining the maximum energy resolution possible; alternatively when detecting very low energy particles, the voltage can be increased to maximise the signal.

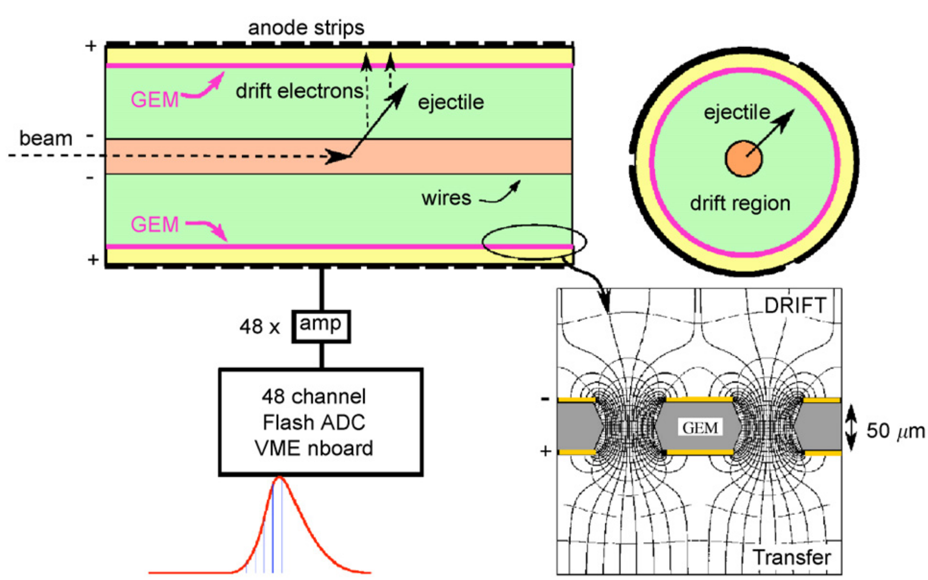

Fig. 1. Schematic view of TACTIC. The inset of the GEM field lines taken from ⟨http://gdd.web.cern.ch/GDD⟩.