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Martin, C. L., Ruprecht, G, Hager, U et al. (5 more authors) (2018) TACTIC : The TRIUMF Annular Chamber for Tracking and Identification of Charged particles. Journal of Physics: Conference Series. 012048. ISSN 1742-6596

https://doi.org/10.1088/1742-6596/940/1/012048

Journal of Physics: Conference Series

PAPER • OPEN ACCESS

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To cite this article: L Martin *et al* 2018 *J. Phys.: Conf. Ser.* **940** 012048

IOP Conf. Series: Journal of Physics: Conf. Series **940** (2018) 012048 doi:10.1088/1742-6596/940/1/012048

TACTIC: the TRIUMF Annular Chamber for Tracking and Identification of Charged particles

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Abstract. An in-depth characterization of the TACTIC detector was performed using data from a ^{148}Gd alpha source and some test runs with a stable ion beam. The detector is an active target time-projection chamber with a blind central region for maximizing beam tolerance and GEM-based electron amplification, equipped with a modern digitizing data acquisition system allowing the recording of full signals. The system was developed to study the reaction $^{8}\mathrm{Li}(\alpha, n)^{11}\mathrm{B}$, which is important for bridging the mass 8 gap in scenarios of low ^{4}He density like Inhomogeneous Big Bang Nucleosynthesis and the production of r-process seeds in supernovae. Both energy resolution and tracking accuracy were found to agree with theoretical predictions and Geant4 simulations. The ^{8}Li beam rate capability of the system is predicted to be of the order of $10^{5}\mathrm{s}^{-1}$, several orders of magnitude higher than most previous measurements of the same reaction, while still maintaining a high detection efficiency of 70 % to 80 %.

1. Motivation

The reaction $^{8}\mathrm{Li}(\alpha, n)^{11}\mathrm{B}$ is considered to be important for bridging the mass 8 gap in scenarios like inhomogeneous Big Bang nucleosynthesis [1] and r-process seed formation in supernovae [2].

While several experiments have measured a cross section for this reaction, there is significant disagreement between the results (see [3] and references therein), and they all suffer from severe rate limitations. To address this, a new time projection chamber (TPC) was built to measure and identify the charged reaction product ^{11}B [4]. The design includes a blind central region to avoid rate saturation due to detected beam particles.

2. Setup

TACTIC is an active target time-projection chamber with radial field geometry [4–6]. A schematic showing the main parts of the detector is given in Figure 1.

In a TPC ion tracks are reconstructed from ionization electrons collected on a segmented anode, one spatial coordinate being calculated from the electron drift time. In TACTIC the anode is segmented into 8 azimuthal sectors of 60 pads each along the beam direction z. A gas electron multiplier (GEM, [7]) amplifies the charge before it enters the amplifier and data acquisition system (DAQ). In order to not overwhelm the DAQ with irrelevant beam-induced

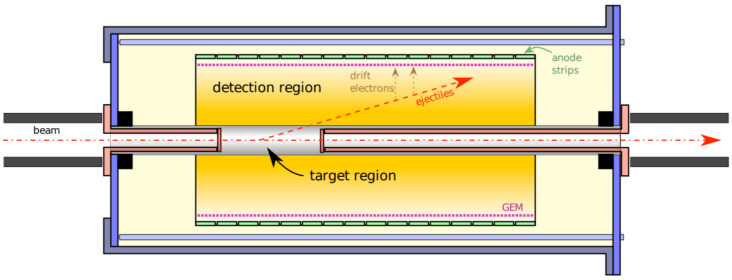

Figure 1. Schematic of basic setup: The beam enters the gas-filled target volume via a mylar window and unscattered beam particles leave the detector again via an additional window downstream. Drift electrons are collected on the segmented anode.

signals, the target region is separated from the detection region by a cathode wire cage. This means only ion tracks at a significant angle to the beam axis produce signals, while the detector remains blind to "unscattered" beam particles.

The DAQ comprises 11 VF48 48-channel sampling ADCs [8], which can record and output the full pulses from each pad or perform some limited on-board data reduction. Tracks affecting more than one VF48 module have to be assembled in the analysis using recorded time stamps.

The main fundamental difficulty of the setup lies in the cylindrical field. While most TPCs use a homogeneous field, leading to a linear relationship between drift time and position, in a radial field the drift velocity is radius-dependent, making an analytical solution impractical. To address this a radius formula was derived by simulation with GARFIELD [9]. Tracking is further complicated by the fact that TACTIC is self-triggering, resulting in the drift times only being known relative to each other. To calculate the radius coordinate the assumption must be made that the last detected pulse originates from a track point just outside the cathode cage.

3. Test results

Several tests were performed with a ^{148}Gd alpha source and stable beam to characterize the tracking capabilities and resolutions as well as efficiency and rate limitations. Any serious problem with the radius calculation would most likely lead to an apparent overall curvature of analyzed tracks. Figure 2 shows the coefficient of a quadratic fit to 1000 tracks as a function of the number of points per track. It is clear that the curvature only strays from zero for tracks with very few points, more consistent with a noise effect than a problem with the radius calculation.

A working tracking algorithm should reproduce the isotropic angular distribution of the alpha source. Figure 3 shows that this is indeed the case for small to medium angles in most sectors, with major discrepancies at large angles, which are explainable due to the small number of measured points and track angle effects on the pulse shape. It is important to keep in mind that large angles are not needed for the detection of ^{11}B in the reaction of interest, however. Fitting the shown expected isotropic angular distribution to the histogram (fit range $20^\circ < \theta < 40^\circ$) for each sector results in a measured source activity of 3278.6(10) Bq, compared with the independently measured activity of 3206(24) Bq. The apparent discrepancy is due to the fact that only the statistical counting error is reported, disregarding other uncertainties.

The cylindrical symmetry gives TACTIC a high geometric efficiency of about 69.5 %, which could be increased to 81.8 % with a relatively simple modification of the cathode wire assembly in the future. The rate capability of TACTIC is limited mainly by the DAQ. Beam tests found the system saturates at an event rate of $2800\,\mathrm{s}^{-1}$ or a data rate of $19\,\mathrm{MB\,s}^{-1}$. Assuming the on-board data reduction can be utilized fully, the data limit should not be reached in normal operation, leaving only the count rate limit. For elastic scattering in typical experimental conditions[1] for $^{8}\mathrm{Li}(\alpha,n)^{11}\mathrm{B}$, Geant simulations show this to be reached at a beam rate of $10^4\mathrm{s}^{-1}$ to $10^5\mathrm{s}^{-1}$, this is compared to other measurements of $^{8}\mathrm{Li}(\alpha,n)$ in Table 1.

[1] e.g. 500 mbar He/CO_2 gas, 10 MeV ^{8}Li beam

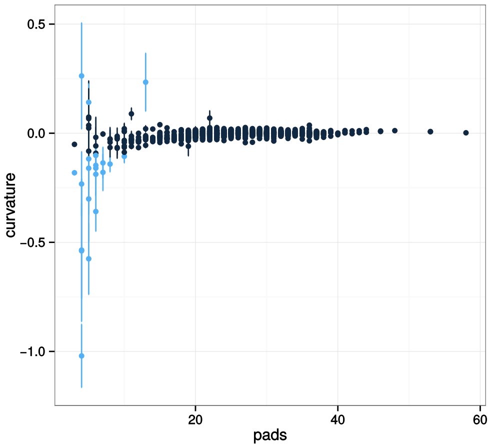

Figure 2. Coefficient of a quadratic fit to 1000 tracks. A significant curvature is only seen for tracks involving very few points.

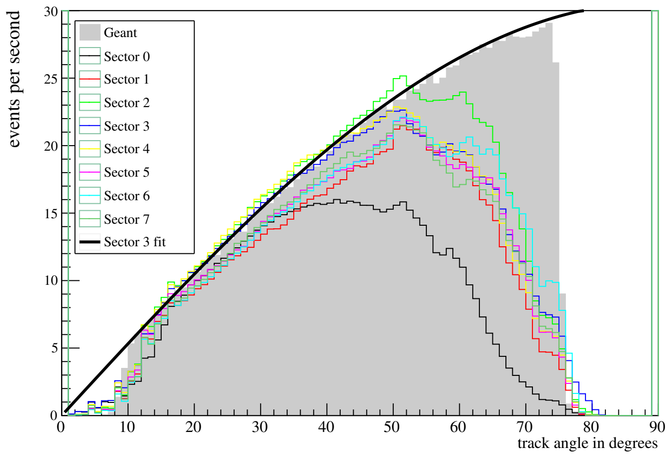

Figure 3. Angular distribution of alpha tracks measured in all 8 sectors compared to Geant4 simulation. Only scaled by measurement time, ignoring differences in geometric efficiency.

Experiment	MUSIC	Polycube	RIKEN [10]	TACTIC
Max. Rate (s^{-1})	23 to 2400	$\approx 10^2$	$\approx 10^5$	10^4 to 10^5
Efficiency (%)	≈ 100	10 to 20	2 to 12.56	70

Table 1. Rate capabilities and efficiency for ^{8}Li$(\alpha, n)^{11}$B measurements (from citations in [3]).

Of course superior rate capabilities are only useful if particle identification can be achieved. While a qualitative understanding of the energy response of the detector exists, GEM effects and pulse-shape-induced angle dependencies of the gain mean energy alone cannot be used for particle identification in TACTIC yet. Geant simulations do however look promising in terms of utilizing the ion stopping length in the gas as an indicator of particle identity.

4. Conclusion

TACTIC is a functioning tracking detector, albeit with a poorly understood energy response. More work is needed to determine to what extent this impedes the particle identification required for the intended reaction ^{8}Li$(\alpha, n)^{11}$B. If particle identification can be achieved to a sufficient accuracy, TACTIC should be capable to improve on previous statistics.

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