Nuclear Inst. and Methods in Physics Research, A 898 (2018) 90–97

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

A radial time projection chamber for α detection in CLAS at JLab

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ARTICLE INFO

Keywords:
Time projection chamber
Gas electron multipliers
Alpha particles
DVCS
Nuclear physics

ABSTRACT

A new Radial Time Projection Chamber (RTPC) was developed at the Jefferson Laboratory to track low-energy nuclear recoils to measure exclusive nuclear reactions, such as coherent deeply virtual Compton scattering and coherent meson production off ^{4}He. In 2009, we carried out these measurements using the CEBAF Large Acceptance Spectrometer (CLAS) supplemented by the RTPC positioned directly around a gaseous ^{4}He target, allowing a detection threshold as low as 12 MeV for ^{4}He. This article discusses the design, principle of operation, calibration methods and performances of this RTPC.

1. Introduction

Until recently, the Thomas Jefferson National Accelerator Facility, in Newport News, Virginia, USA, has provided high power electron beams of up to 6 GeV energy and 100% duty factor to three experimental Halls (A, B, C) simultaneously. The CEBAF Large Acceptance Spectrometer (CLAS) [1], located in Hall-B, was based on a superconducting toroidal magnet and composed of several sub-detectors. Fig. 1 shows a three dimensional representation of the baseline CLAS spectrometer:

- Three regions of Drift Chambers (DC) for the tracking of charged particles [2].
- Superconducting toroidal magnet to bend the trajectories of charged particles, thus allowing momentum measurement with the DC tracking information.
- Threshold Cherenkov Counters (CC) for electron identification at momenta < 2.7 GeV/c [3].
- Scintillation Counters (SC) to identify charged hadrons by measuring their time of flight [4].
- Electromagnetic Calorimeters (EC) for identification of electrons, photons and neutrons [5].

For certain experiments the base CLAS system was complemented with ancillary detectors. For example, the measurement of the Deeply Virtual Compton Scattering (DVCS) process ($eH \rightarrow e'H'\gamma$, where H is a nucleon or nucleus) necessitates an upgrade of the photon detection system. Indeed, with a 6 GeV electron beam, the majority of DVCS photons are produced at very forward angles, where the acceptance of the EC was poor. To extend the detection range, an inner calorimeter (IC) was built for the E01-113 experiment in 2005 [6]. The IC was constructed from 424 lead-tungstate ($PbWO_4$) crystals, covering polar angles between 5°and 15°[7]. To protect the CLAS detector and the IC from the large flux of the low energy Møller electrons, a 5 T solenoid magnet was placed around the target to shield the detectors. To detect recoiling α particles from the coherent DVCS on Helium, a new radial time projection chamber (RTPC) was developed to track low energy nuclear fragments. The solenoid field was used to bend tracks

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https://doi.org/10.1016/j.nima.2018.04.052
Received 12 July 2017; Received in revised form 25 April 2018; Accepted 25 April 2018
Available online 7 May 2018
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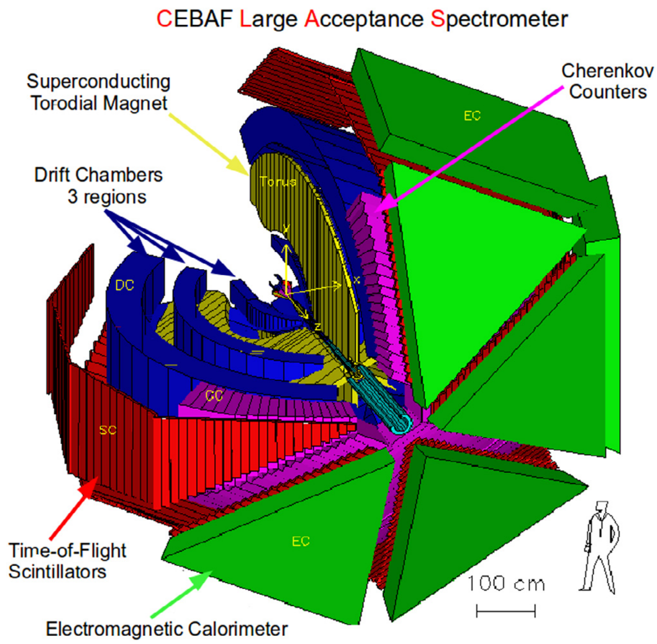

Fig. 1. A three dimensional representation of the baseline CLAS setup. The full description is given in the text.

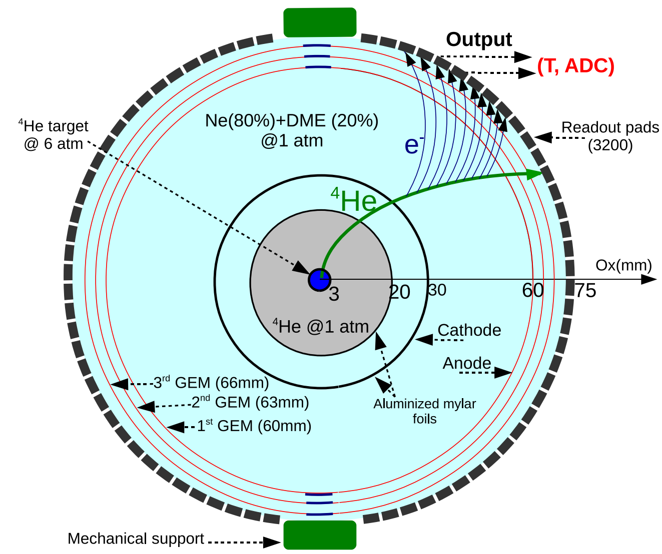

Fig. 2. Schematic drawing of the CLAS RTPC in a plane perpendicular to the beam direction. See text for description of the elements.

and measure momentum of particles in the RTPC. The CLAS detector supplemented with both IC and RTPC was used in 2009 during a three months experimental run [8,9] with a longitudinally polarized, 130 nA and 6.064 GeV electron beam incident on a gaseous ^{4}He target.

The original design of the RTPC was developed for the BoNuS experiment at Jefferson Lab which took data with CLAS in 2005 [10]. Significant improvements were made to the RTPC mechanical structure and fabrication technique that both increased the acceptance and reduced the amount of material in the path of the outgoing particles. Moreover, the data acquisition electronic was improved to increase the event readout rate. The enhanced design, used in the 2009 DVCS experiment, is described in Section 2 of this article. The data acquisition system is described in Section 3, the calibration methods in Section 4 and the tracking algorithm in Section 5. Finally, the overall performances of the RTPC are described in Section 6.

2. RTPC design

With a 6 GeV incident electron energy, the recoiling ^{4}He nuclei from coherent DVCS have an average momentum around 300 MeV/c (12 MeV kinetic energy). Such low energy α particles are stopped very rapidly, so the RTPC was designed to be as close as possible to the target and fit inside the 230 mm diameter shell and cryostat wall of the solenoid magnet bore of CLAS.

The new CLAS RTPC is a 250 mm long cylinder of 158 mm diameter, leaving just enough room to fit pre-amplifiers between the RTPC outer shell and the solenoid. The electric field is directed perpendicularly to the beam direction, such that drifting electrons are pushed away from the beam line. These electrons are amplified by three layers of semi-cylindrical gas electron multipliers (GEM) [11] and detected by the readout system on the external shell of the detector as illustrated in Fig. 2. The RTPC is segmented into two halves with independent GEM amplification systems that cover about 80% of the azimuthal angle.

We detail here the different regions shown in Fig. 2 starting from the beam line towards larger radius:

- The 6 atm ^{4}He target extends along the beamline forming the detector central axis. It is a 6 mm diameter Kapton straw with a 27 μm wall of 292 mm length such that its entrance and exit 15 μm aluminum windows are placed outside of the detector volume. The detector and the target are placed in the center of the solenoid, 64 cm upstream of the CLAS center.
- The first gas gap covers the radial range from 3 mm to 20 mm. It is filled with ^{4}He gas at 1 atm to minimize secondary interactions from Møller electrons scattered by the beam. This region is surrounded by a 4 μm thick window made of grounded aluminized Mylar.
- The second gas gap region extends between 20 mm and 30 mm and is filled with the gas mixture of 80% neon (Ne) and 20% dimethyl ether (DME). This region is surrounded by a 4 μm thick window made of aluminized Mylar set at −4260 V to serve as the cathode.
- The drift region is filled with the same Ne-DME gas mixture and extends from the cathode to the first GEM, 60 mm away from the beam axis. The electric field in this region is perpendicular to the beam and averages around 550 V/cm.
- The electron amplification system is composed of three GEMs located at radii of 60, 63 and 66 mm. The first GEM layer is set to $\Delta V = 1620$ V relative to the cathode foil and then each subsequent layer is set to a lower voltage relative to the previous to obtain a strong (∼1600 V/cm) electric field between the GEM foils. A 275 V bias is applied across each GEM for amplification.
- The readout board has an internal radius of 69 mm and collects charges after they have been multiplied by the GEMs. Pre-amplifiers are plugged directly on its outer side and transmit the signal to the data acquisition electronics.

The GEM technology has been chosen for the flexibility of the GEM foils, which can be easily used to produce a curved amplification surface. Also, GEMs are known to have relatively low spark rate [12], which is important when trying to detect highly ionizing slow nuclei that deposit large amount of energy. The GEMs for this RTPC are made from a Kapton insulator layer, 50 μm thick, sandwiched between two 5 μm copper layers.[1] The mesh of each GEM layer is chemically etched with 50 μm diameter holes with double-conical shapes as illustrated in Fig. 3. The

[1] The GEM foils were produced by Tech-Etch, Inc.