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Sealed drift tube cosmic ray veto counters

R. Rios [a,*], E. Tatar [a], J.D. Bacon [b], T.J. Bowles [b], R. Hill [b], J.A. Green [b], G.E. Hogan [b], T.M. Ito [b], M. Makela [b], C.L. Morris [b], R. Mortenson [b], F.E. Pasukanics [b], J. Ramsey [b], A. Saunders [b], S.J. Seestrom [b], W.E. Sondheim [b], W. Teasdale [b], M. Saltus [c], H.O. Back [d], C.R. Cottrell [d], A.T. Holley [d], R.W. Pattie Jr. [d], A.R. Young [d], L.J. Broussard [e], B.W. Filippone [f], K.P. Hickerson [f], J. Liu [f], M.P. Mendenhall [f], B. Plaster [g], R.R. Mammei [h], M.L. Pitt [h], R.B. Vogelaar [h], J.W. Martin [i]

[a] *Idaho State University, Pocatello, ID 83209, USA*
[b] *Los Alamos National Laboratory, Los Alamos, NM 87544, USA*
[c] *Sloan Enterprises, NC, USA*
[d] *North Carolina State University, Raleigh, NC 27695, USA*
[e] *Duke University, Durham, NC 27708, USA*
[f] *California Institute of Technology, Pasadena, CA 91125, USA*
[g] *University of Kentucky, Lexington, KY 40506, USA*
[h] *Virginia Polytechnic Institute and State University, Blacksburg, VA 24061, USA*
[i] *University of Winnipeg, Winnipeg, Canada MB R3B 2E9*

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ABSTRACT

We describe a simple drift tube counter that has been used as a cosmic ray veto for the UCNA experiment, a first-ever measurement of the neutron beta-asymmetry using ultra-cold neutrons. These detectors provide an inexpensive alternative to more conventional scintillation detectors for large area cosmic ray anticoincidence detectors.

1. Introduction

At sea level, cosmic ray muons are detected on an average of 1 muon $\mathrm{cm}^{-2}\,\mathrm{min}^{-1}$ [1]. For precision measurements, this can be problematic. The muons contribute directly to the background and also generate secondary electrons that saturate and distort the lower region of the measured energy spectrum. Furthermore the muon flux varies throughout the day and from day to day. Therefore, for extended measurements, corrections based on short background runs cannot restore the true energy spectrum. Protection against cosmic ray muons requires massive amounts of shielding. Typically this is done by placing the experiment deep underground and even then the cosmic ray muons rate is only suppressed, not eliminated [1]. Due to these reasons, anticoincidence cosmic ray veto detector systems are standard components of low signal rate experiments. The most common muon veto systems utilize liquid or plastic scintillators. These veto counters must cover the entire fiducial volume of the primary detector and must have efficiencies close to 100%. As the size of the primary detector region increases so does the cost and complexity of the muon veto system.

Efforts have been made to reduce the cost of large area muon veto systems [2,3]. Small permanently sealed multiwire proportional chambers for X-ray applications were built to reduce the cost and maintenance of gas handling systems [4]. Large 7.6 m drift tube counter modules made of 8 cells with rectangular cross sections were used to measure cosmic rays. During tests, gas to the cells was sealed off. Two overlaid modules are reported to achieve a muon detection efficiency of essentially 100% [5]. The sealed veto tubes in this work were prototyped for the detectors proposed for muon tomography [6].

Gas filled detectors provide practical and cost effective solution with wide range applications. They have the advantage of simple construction, decent energy resolution, and good position resolution. Disadvantages include limited timing resolution, low counting rate, and often cumbersome gas handling system.

* Correspondingauthor.
E-mail address: rrios@lanl.gov (R. Rios).

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In this paper we describe the construction and performance of inexpensive and sealed drift tube proportional detectors that have been used as large area veto detectors for the UCNA experiment at LANSCE.

The UCNA experiment [7,8,9] is designed to measure the β-asymmetry in neutron beta decay using ultra-cold neutrons (UCN). With sufficient statistics and careful understanding of systematics, this measurement will place important constraints on standard model parameters. The experiment stores polarized UCN in a decay trap surrounded by a solinoidal superconducting spectrometer with holding field of 1 T. The β-asymmetry is measured by detectors located at the ends of the spectrometer. This experimental setup requires a large muon veto system with a total sensitive area larger than 7 m^2. In addition, the muon veto system has to be located in the fringe field of the spectrometer. Therefore it has to function in magnetic fields exceeding 100 G.

2. Drift tube construction

The tubes are made of 5.08 cm diameter aluminum tubing with a wall thickness of 0.089 cm and a length of 3.65 m (Fig. 1). The tubes are cleaned with alcohol before welding on the end caps. The end caps hold a feedthrough that centers an anode wire (25 μm gold plated tungsten) in the tube. The construction of the feed-throughs begins with 0.16 cm diameter brass tubes being placed inside 0.32 cm diameter PEEK tubes. Then these are sealed in commercial 0.32 Swagelok male tapered pie thread compression fittings. The Swagelok fittings are threaded into the tube ends and sealed with epoxy.

The wire stringing and assembly are done in a normal lab space, without the use of a clean room. The wires are strung in the tubes by mounting the tubes vertically. First, the wire is threaded through the top fittings. Then the short piece of 0.16 brass tubing is crimped on the 20 μm thick wire, and the wire is fished through the opening at the lower end of the tube. A 50 g weight is used to tension the wire before a final crimp is made.

The tubes are pumped to less than 2 mbar with oil free roughing pumps that are backfilled with argon and pumped again. They are leak checked and filled with a 50/50 mixture of argon and ethane gas at 800 mbar (approximately the ambient atmospheric pressure in Los Alamos). Filling is done through a Swagelok tee fitting at one end of the drift tube. Finally, the filling tube is mechanically crimped to seal the gas in the tube.

After optimizing the technique the average assembly time for a tube dropped to about 15 min. At this time the dominant cost in building these detectors was the cost of materials.

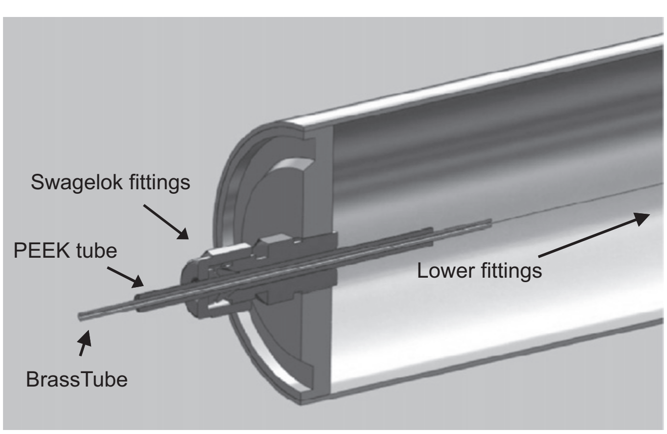

Fig. 1. Cut-away view of one end of a drift tube muon detector.

3. Cosmic ray veto

The neutrons used in the UCNA experiment are produced by a 4 μA 800 MeV proton beam from the LANSCE accelerator at the Los Alamos National Laboratory. Neutrons are moderated and cooled in a solid deuterium source before being transported to the polarizing magnets and the decay trap through roughly 12 m of guides [10].

The transport and storage time of the ultra-cold neutrons is approximately 50 s, which allows the counting of the neutron decay products to be performed when the proton beam is off.

During this period, the largest sources of background arise from cosmic rays and background gammas. Using the proportional drift tubes described above we have developed an inexpensive and reliable muon veto counter that improves the signal to noise ratio in the experiment [7].

The beta detectors are mounted in a vacuum system inside the warm bore at the edge of the magnetic field [8]. This constrains the space available for the cosmic ray veto counter. Since the detector operates in a high magnetic field region, special restrictions are placed on detector configurations and technology. Unlike photo-multipliers, the proportional tubes have added advantage of not requiring magnetic shielding. The muon veto system sits outside the spectrometer cryostat.

The tubes are glued together into 8-tube modules. Five such modules were configured to surround one of the detectors in the UCNA experiment. Additional drift tubes were added to cover the areas where the modules joined. The tubes are wired in series with high voltage coaxial cables and SHV connectors. The eight tubes in a module are wired together with a soldered copper wire that is terminated at both ends with an SHV connector. Modules are connected with shield coaxial cables. The high voltage cable transports the signals 5 m to the NIM electronics.

High voltage is provided through a 30 MΩ resister to the tubes. The signal is decoupled from the high voltage using a 10 nF capacitor. The signals are amplified with a timing filter amplifier with a 500 ns integration time and zero differentiation time, and are converted to logic signals with a leading edge discriminator.

4. Performance

Fig. 2 shows the muon veto system installed around the spectrometer. Amplified signals are ~100 mV for cosmic rays. The thresholds are set at 30 mV with the noise levels around ~10 mV. Over the four years of operation, no degradation in signal amplitude or increase in noise has been observed. Neutron drift

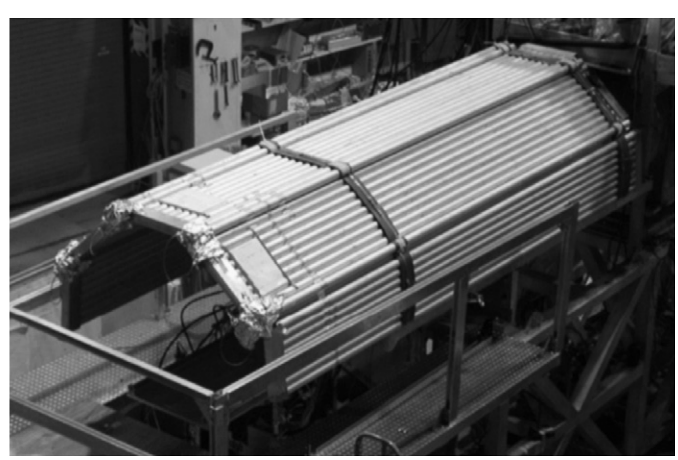

Fig. 2. Photograph of the muon veto detector covering one side of the UCNA experiment.

tube detectors made of the same design were determined to have a lifetime of above 40 years through a combination of tests that included gas leakage, outgassing of impurities from the wall into the tube, and polymerization of the gas species in the detector [11]. The muon detectors have been operating for 3 years with no apparent reduction of efficiency.

The singles rate for the muon veto system is $\sim$250 events s^{-1} m^{-2}. The singles rates in the tubes are attributed to cosmic rays and environmental gamma radiation. Through the course of the experiment, we monitored the singles rates in the veto system. Although these were generally stable and constant, we saw large excursions over the course of a week of running when the room ventilation system was turned off. We tracked this to radioactive argon, produced through neutron capture, building up in the room.

Despite being large, the muon drift tube structure is light compared to other detectors of similar dimensions, $\sim$4 m in length. The drift tubes can be tilted up quickly to gain access to the beta detectors and the bore of the magnet. To reduce the overall space, the drift tubes can also be rearranged around the measurement apparatus as seen in Fig. 2.

The muon veto detector is designed to reduce the cosmic ray background in the electron detector system of the UCNA. A detailed description of the system can be found in Refs. [7–9]. It has three major components: a low-pressure multiwire proportional chamber (MWPC), a 3.5 mm thick, 15 cm diameter plastic scintillator ("β-detector"), and another 25 mm thick plastic scintillator with the same diameter located behind the first one. The second scintillator, or "backing veto", is used to reject horizontally projected cosmic rays that do not cross the muon drift tubes but can still trigger an event in the β-detector.

The readout of the cosmic ray veto is shown schematically in Fig. 3. The signal from the main beta trigger acts as the START of a time-to-analog-converter (TAC). The TAC is used to allow flexible time range for observing the coincidence peak. The analog pulse from the drift tubes is discriminated and produces a timing signal, which stops the TAC after passing through a 640 ns delay. The output of the TAC (a voltage level) goes into a peak sensing ADC (PADC), which is read after each main trigger.

The cosmic ray veto counter signal, digitized via the above prescription, is shown in Fig. 4. Muon events are identified and vetoed through a triple coincidence between the muon drift tubes, plastic scintillator, and MWPC. Random coincidence events are seen as flat background outside the coincidence peak. Those events are due to the events in which the signals from the cosmic ray veto and the main trigger were not causally related but were accidental. The number of events per channel to the left of the peak is slightly higher than that to the right side of the peak due to accidental stops.

The coincidence window was 320 ns long. Coincidental to accidental coincidence ratio was 25:1. The coincidence rate between the beta detector and the drift tubes before background subtraction was 1.54 counts/s. The accidental coincidence rate at which a real beta event is registered as a muon was 0.06 counts/s. With an average beta decay for each side at 7 Hz, the beta decays falsely tagged as muons occur at a rate of one out of every 160 events.

The energy spectrum in the main beta scintillator is shown in Fig. 5. The raw spectrum without the drift tube cut is the outermost histogram. The solid gray (hatch) histogram is a subset of those in coincidence (anticoincidence) with the cosmic ray veto. The higher energy end of the vetoed events (gray histogram) reaches beyond the neutron beta spectrum end point, corresponding to the cosmic muons impinging on the beta scintillator. The cosmic ray veto drift tubes also have some sensitivity to the environmental gamma rays.

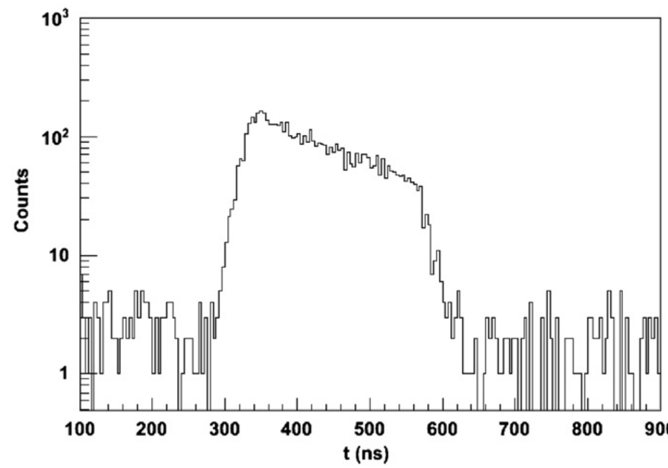

Fig. 4. Coincidence events among the beta detector, MWPC, and muon drift tubes over typical 1 h run.

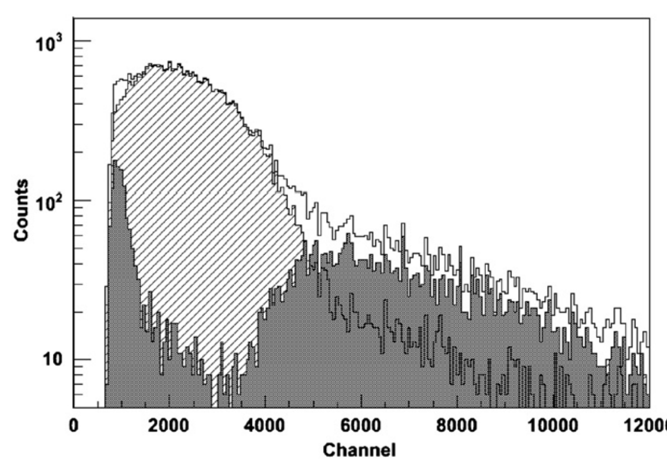

Fig. 5. Neutron beta decay energy spectrum with cosmic ray veto counter cuts. The white histogram is the raw data, the hatched histogram is the data after muon veto cuts, and the gray region contains the vetoed events.

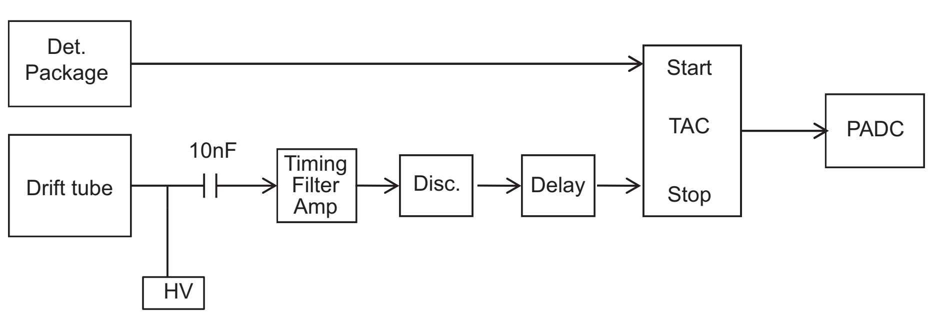

Fig. 3. Cosmic ray veto readout.

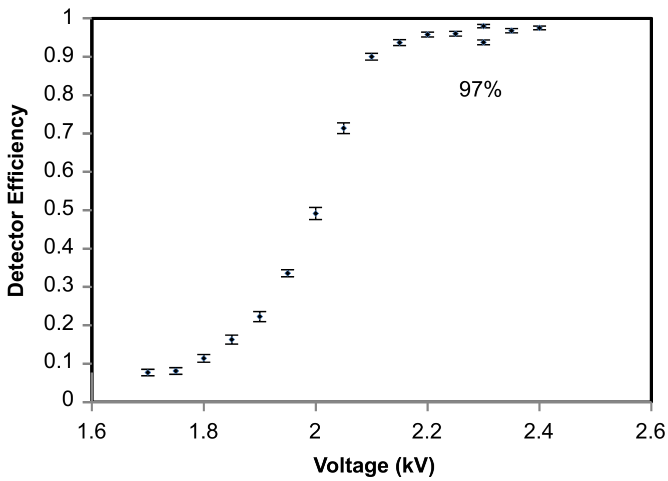

Fig. 6. Muon detection efficiency in a $\sim$100 G field.

The lower end of the same spectrum corresponds to secondary electrons generated by muon interaction with the experimental apparatus.

The detector efficiency was measured with two sets of drift tube arrays and in double coincidence with the beta decay scintillator detectors. The value was compared to that of a triple coincidence between the drift tubes and the beta detectors. The coincidence rate was 1–2 muons s^{-1}. The efficiency plateaus at 97%. With a high voltage of 2.1 keV the 3% inefficiency can be explained by passage of muons between cylindrical muon drift tubes (Fig. 6).

The efficiency can be improved by adding another array of drift tubes offset from the original array. This reduces the number of muons that pass between the drift tubes. Based on the background rate in the UCNA experiment, a 97% efficient muon veto detector is sufficient for the precision we wanted to achieve.

5. Summary

We have described a sealed drift tube cosmic ray veto detector that is being used in the UCNA experiment at Los Alamos National Laboratory. The veto system has been in operation for three years, demonstrating simple and reliable large area veto shielding system, working in high magnetic field environment.

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