PROCEEDINGS of CHEF 2013

High resolution muon tracking with resistive plate chambers for detection of special nuclear material

P. Baesso[*]
University of Bristol
E-mail: paolo.baesso@bris.ac.uk

D. Cussans
University of Bristol
E-mail: david.cussans@bris.ac.uk

C. Thomay
University of Bristol
E-mail: christian.thomay@bris.ac.uk

J. Velthuis
University of Bristol
E-mail: jaap.velthuis@bris.ac.uk

J. Burns
AWE
E-mail: jon.burns@awe.co.uk

S. Quillin
AWE
E-mail: steve.quillin@awe.co.uk

C. Steer
AWE
E-mail: chris.steer@awe.co.uk

M. Stapleton
AWE
E-mail: matt.stapleton@awe.co.uk

A muon tracker based on resistive plate chambers is described, with particular emphasis on the hardware and the read-out electronic. The tracker is used to measure the angular scattering of cosmic muons as they traverse a suitcase-sized volume. The solution adopted, based on pick-up strips and independent read-out channels, allowed us to achieve a spatial resolution of 500 μm, which is sufficient to discriminate between high-Z and low-Z materials.

Calorimetry for High Energy Frontiers - CHEF 2013,
April 22-25, 2013
Paris, France

[*]Speaker.

1. Introduction

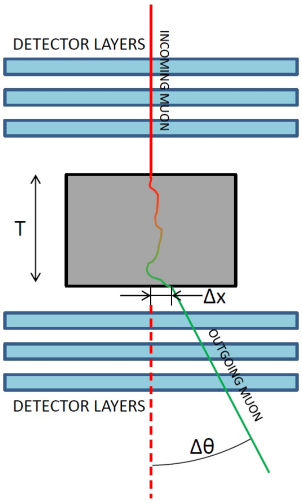
Resistive plate chambers (RPC) are widely used in high energy physics experiments thanks to their excellent performance in terms of detection efficiency, time resolution, reliability and ease of operation [1] as well as for their low cost per unit area.
The typical use of RPCs consists in exploiting their timing resolution, which can easily be in the nanosecond region, to provide a reliable trigger source, while the spatial granularity is often of the order of 1 cm. However, it has been shown that RPCs can reach sub-millimeter spatial resolution when coupled with an opportune read-out [2, 3, 4]. This makes RPCs excellent candidates in applications where large detection areas are required to track charged particles with a resolution of the order of 500 μm. Simulation studies [5] suggest that this resolution would be adequate for Muon Scattering Tomography (MST), in which cosmic muons are tracked before and after they penetrate a target volume, as shown in figure 1a. RPCs can also be successfully adopted as detector to perform muon radiography of large volumes such as silos containers, and very large geological targets such as volcanos. By recording the flux of muons which transverse the volume and comparing it to the muon flux from the incidence direction (which can be obtained from simulation or measured on-site), an estimate of the target's density can be derived from the muon flux attenuation [6, 7].
The idea of using MST for homeland security has already proven feasible and appealing [8] and we have started a collaboration with the Atomic Weapon Establishment to build a prototype scanner based on glass RPCs. The detector is shown in figure 1b. We have presented some of the results in a previous work [9], showing that the detector is performing as expected and that an intrinsic spatial resolution of 310 μm is achievable. In this work we will describe the detector hardware and the operation parameters in detail.

2. Detector setup

The prototype is based on six detection planes, with each plane being comprised of two glass RPCs. The RPCs constitute the basic detection layer and have a surface of 58 cm $\times$ 58 cm. The chambers are made of three sheets of 2 mm float glass; the central sheet is flow cut to produce a square frame with an internal size of 50 cm $\times$ 50 cm so that when glued together[1] the three sheets form a 2 mm chamber. Four extra glass disks (ϕ 20 mm) are glued in the middle of the chamber to increase the mechanical rigidity. Two gas inlets are used to flush the chambers with gas. Currently the system runs with a mixture of 95 % freon (R-134a) and 5 % iso-butane flowing at 25 ml/min with a pressure of 500 Pa (2 inches of water) above the atmospheric pressure.
The external surfaces of the chamber are painted with a resistive coating[2] which acts as distribution plane for the high voltage. The typical resistivity value for the paint ranges between 500 k$\Omega/\square$ and 1 M$\Omega/\square$. Adhesive copper tape is place at the edge of the painted area to provide an electrical contact point to solder the high voltage lead. The chambers are mainly operated in avalanche mode, using a voltage of 10000 V. Until recently we could not tune the high voltage individually for each chamber. This means that some RPCs operated in a sub-optimal configuration.

[1] Silicon glue Verifix 2K-P/2K, manufactured by Bohle.

[2] Statguard conductive acrylic paint.

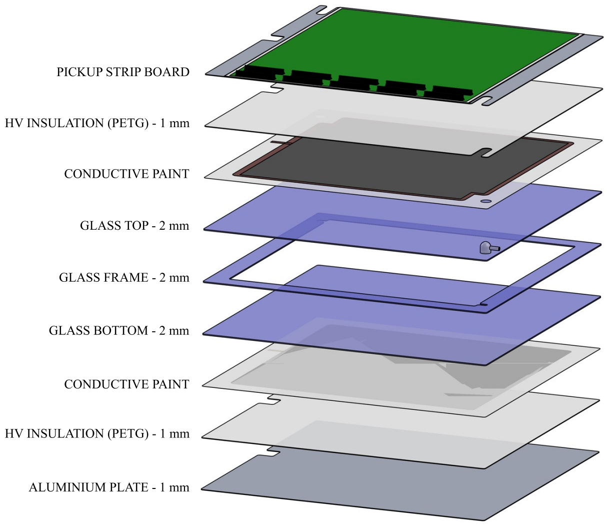


(a)

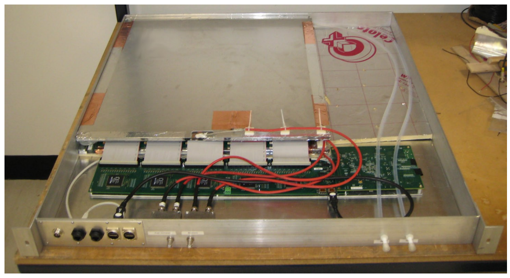
(b)

Figure 1: (a) Muon scattering tomography principle. The muon passes through the upper detectors, scatters in the target, and leaves via the lower detectors. By studying the distribution of the scattering angles θ it is possible to create a density map of the materials contained in the volume and probe for the presence of high-Z materials. (b) View of our prototype: the six detection planes are separated by a gap where test samples are introduced.

A PCB with 320 strips is used to pick up the electric signal produced by particles traversing the chamber. The strips have a pitch of 1.5 mm and run across the full length of a chamber. An insulating layer of 1 mm PETG is interposed between the strip board and the high voltage plane. Figure 2a shows an exploded view of a detection layer. The two RPCs in a plane are oriented at 90 degrees with respect to each other to obtain X-Y hit position information. The chambers are hosted in an aluminium cassette which also includes the front-end electronics.
The current front end is an evolution from our previous setup [4] and is based on the MAROC3 [10] front end chip. The 320 pickup strips of each RPC are readout by a custom made front end board designed at the University of Bristol. The board, visible in figure 2b, hosts five MAROC chips which are configured and read out through signals generated by a field programmable gate array (FPGA) board. All the front end boards in the system work with a synchronous clock of 32 MHz. The analog inputs of a MAROC chip are connected to built-in shapers and analog-to-digital converters (ADC) so that, upon receiving a trigger, the chip produces 64 digital samples of 12-bit and transmits them to the FPGA. The FPGA collects the ADC samples from the five chips on the readout board and stores them, together with a time stamp and trigger number, on a local buffer which can be polled by the data acquisition PC. All the communication between FPGA and PC is performed over an Ethernet link implemented using the IP-bus protocol [11]. A more detailed description of the readout system can be found in [12].



(a)



(b)

Figure 2: (a) Exploded diagram of one RPC. (b) One of the cassettes with two RPCs and one of the front end boards installed.

3. Summary of the performance and conclusions

Data collected so far show that the detector is working as expected: all the chambers have an efficiency above 95 % and an intrinsic spatial resolution between 300 μm and 900 μm. The signal purity, defined as the probability that a cluster actually belongs to a traversing particle and is not due to noise or fake events, is also above 95 % for all the RPCs. Some of the layers are affected by streamers, which degrade their performance. This can be explained by non uniformity in the construction process, the use of the same high voltage for all of the layers and the lack of corrections for changes in pressure and temperature of the gas mixture. We are correcting these issues by replacing the HV power supply with a multi-channel one and implementing a feed-back loop in the gas system to compensate for variations in temperature and pressure.

The read-out boards have a very low noise (about 3-5 ADC counts) which translates in a S/N ratio better than 300 for all the detection layers. Exploiting this fact, we are now performing tests to increase the length of the pick-up strips and to reduce the number of read-out channels. Preliminary data show that we could maintain a sub millimeter spatial resolution while substantially reducing the required number of channels, thus lowering the unit cost per detection area.

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