PROCEEDINGS OF SCIENCE

Muon scattering tomography with resistive plate chambers

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

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

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

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

S. Quillin
Atomic Weapon Establishment
E-mail: steve.quillin@awe.co.uk

S. Robertson
Atomic Weapon Establishment
E-mail: stacey.robertson@awe.co.uk

C. Steer
Atomic Weapon Establishment
E-mail: chris.steer@awe.co.uk

PoS(RPC2012)079

Resistive Plate Chambers (RPC) are widely used in high energy physics experiments as reliable trigger systems due to their excellent time resolution and rate capability, while generally the track spatial information is obtained by means of different detectors. Studies show that it is possible to produce RPC with good spatial resolution (less than 1 mm) by opportunely choosing the pitch of the readout strips. High resolution RPCs (HRPCs) can be economically produced to cover large areas and represent a valid alternative to more expensive detectors in applications when a spatial resolution of ∼0.5 mm is sufficient. Our group has successfully produced a Muon Scattering Tomography (MST) prototype based on 6 double layers of HRPCs which provide X-Y readout. With that we can obtain 3D tracking of cosmic muons passing in a volume of ∼50 cm x 50 cm x 70 cm. Both the incoming and the outgoing tracks of the muon are reconstructed. The required spatial granularity is achieved by using 330 readout strips per HRPC, with a pitch of 1.5 mm. The detector has been collecting data since June 2011, with the HRPC showing an efficiency above 95% and purity above 98%. The raw spatial resolution on the tracks is 0.8 mm. This is a preliminary measurement and includes the intrinsic detector resolution as well as the extrapolation errors due to multiple scattering in the detectors and separation of the planes.

XI workshop on Resistive Plate Chambers and Related Detectors - RCP2012,
February 5-10, 2012
INFN Laboratori Nazionali di Frascati Italy

*Speaker.

PoS(RPC2012)079

1. Introduction

Resistive plate chambers are currently widely used in high energy physics and astrophysics. Since their introduction in the early '80s [1] they have undergone a constant evolution which led to several families of detectors, each of them characterized by specific features in terms of performance, operational mode and geometric setup of the detectors themselves [2]. Nevertheless, all such families share the same principle of operation [3] and favorable characteristics which contribute to the rapid diffusion and acceptance of RPCs within the scientific community: low cost per unit area, high rate capability, ruggedness, high detection efficiency for minimum ionizing particles and excellent time resolution.

Typically RPCs are used to provide trigger and timing signatures while the spatial information they obtain is complemented by more accurate detectors. However, it has been proven that a spatial resolution better than 1 mm [4, 5] can easily be achieved with specifically designed RPCs. This result suggests that RPCs could be used in a series of applications where the requirements on the particle interaction position are not too strict. An example of such an application is Muon Scattering Tomography (MST), in which cosmic muons are tracked before and after they penetrate a target volume. By studying the distribution of the scattering angles it is possible to create a density map of the materials contained in the volume and probe for the presence of high Z materials, such as special nuclear materials.

The idea of using MST for homeland security has already proven feasible and appealing [6]; several studies are evaluating the use of RPCs for such applications [7]. We are working with the Atomic Weapon Establishment (AWE) to develop a prototype and evaluate its performance. The required spatial resolution for the detector depends on its geometrical size; as a guideline, in order to efficiently detect special nuclear materials and reject medium Z materials, the detector must achieve an angular resolution in the order of a few mrad.

2. Setup

The basic detector unit in our prototype is a 2 mm float-glass RPC: two sheets of glass measuring 58 cm x 58 cm are glued to a 4 cm wide glass frame, so that the gas gap obtained measures 50 cm x 50 cm x 2 mm. The gas mixture used to perform the tests described in this work is composed of Ar (60%), freon gas $R134A$ (30%) and C_4H_{10} (10%).

The external surfaces of the detector are spray painted with Charleswater Statguard to obtain a surface resistivity of 10^5 $\Omega/\Box$. On top of each RPC sits a printed circuit board which hosts the pickup strips. In the current setup each board hosts 330 strips with 1.5 mm pitch. Once all the dead areas on the detector are taken into account, the actual sensitive area remaining measures approximatively 40 cm x 50 cm.

The signal induced on the strips is fed to a hybrid board supporting four HELIX chips. The HELIX is a family of 0.8 μm CMOS readout chips originally designed for the HERA-B experiment [8] and optimized for silicon microstrip detectors and gaseous chambers. Each chip features 128 analog inputs with programmable shaper and amplifiers and a single analog output. When a trigger is received the analog values at the inputs are sampled and multiplexed onto the output. Currently the trigger is provided by two 50 cm x 50 cm scintillators placed at the top and bottom of the pro-

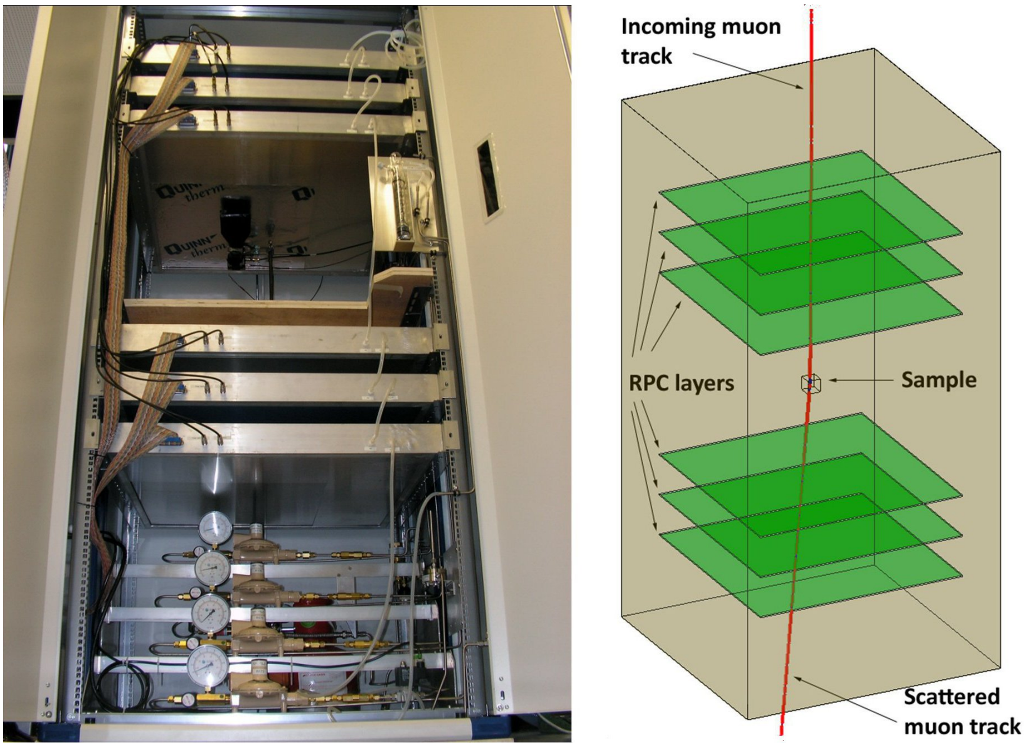

Figure 1: (Left) Picture of the fully assembled system. The six aluminium cassettes contain two RPCs each and provide X-Y readout. The cassettes also provide connections for high voltage, low voltage, data and gas lines. The gas mixing system is visible at the bottom of the cabinet. (Right) GDML sketch of the detector.

totype. An external analog to digital converter is then used to digitize the data; for this we use the commercial CAEN V1724 which also provides clock signals to all the electronics, thus assuring the synchronous operation of the system. Since each hybrid board hosts a daisy chain of 4 HELIX chips, the 330 analog samples from a single RPC can be digitized using a single channel of the V1724.

Our system is comprised of 12 RPCs, hosted in 6 aluminium cassettes to provide X-Y readout. The cassettes slide into a cabinet which provides mechanical support and allows the spacing between detectors to be adjusted; the system is shown in figure 1: it is currently set to allow a central gap of $\sim$70 cm, within which a standard sized suitcase could be inserted.

3. Results

The digitized samples from the RPCs are analyzed by removing the pedestal and applying a simple center of gravity algorithm, which provides the hit position for the muon on each layer. Common mode correction requires particular care: as a consequence of the way in which the strips are routed to the HELIX and the grounding scheme adopted on the front-end boards, the common mode presents some discontinuities which could potentially produce erroneous hit reconstructions (see figure 2). However, this issue and the presence of noisy strips are both taken into account in the hit finding algorithms. The signal to noise ratio for the signals on different layers ranges from

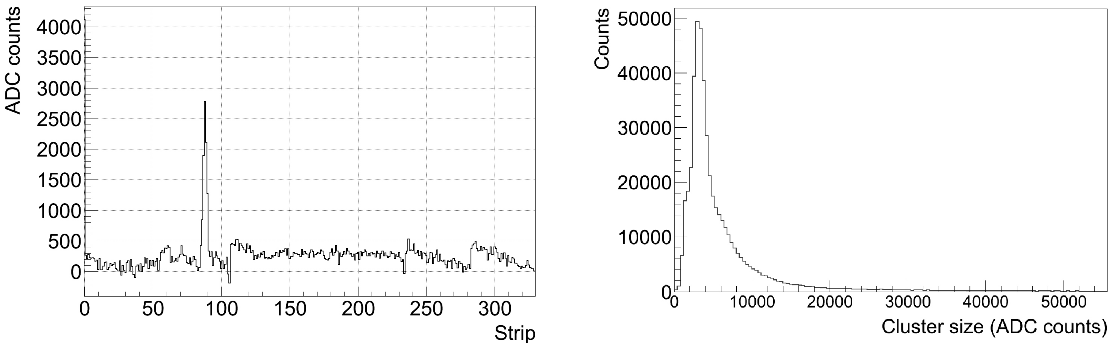

Figure 2: (Left) Signal induced on the strips, once the pedestal has been removed. The peak due to a muon is clearly visible around strip 90. The discontinuous shape of the common mode is taken into account in further steps of the analysis. (Right) Cluster signal distribution for one of the RPC layers. Each ADC count corresponds to a charge of ∼50 pC.

25 to 90: the variation is mainly due to variations in the RPC module noise. Figure 2 (right) shows the cluster signal distribution for one RPC.

Once the hit position on each layer has been determined, the algorithm attempts to fit a straight line across the six layers. A cut on the χ^2 value assures that the track is actually due to a single particle and that there are no false hits or multiple hits. Even with this simple approach we managed to achieve a detection efficiency above 95% and a purity better than 98%.

To test the spatial resolution of the detectors we removed one of them from the linear fit and proceeded to estimate the residual distribution. The result for one layer is shown in figure 3, while the result for all 12 RPCs is shown in figure 4. It is important to note that these represent raw resolutions (σ_{raw}), i.e. they include the error due to multiple scattering within the detector and the error due to the extrapolation of the track. In order to estimate the intrinsic resolution of each layer we are implementing a Geant4 simulation (not covered in this work) representing the materials in our prototype and the geometric arrangement of the layers.

Each muon track is split into its top and bottom components and a Point of Closest Approach (PoCA) algorithm is used to estimate the scattering angle; the detector volume is then divided into voxels and populated according to the number of tracks which scatter within it. Although this is a very simple approach and does not make full use of tomography techniques, it is nevertheless sufficient to prove the correct behavior of the prototype. To test it we placed a block of lead sized 10 cm x 10 cm x 5 cm within the scanner volume and analyzed the data obtained. Figure 5 shows a preliminary analysis of the data: the higher scattering angles are concentrated in the area where we placed the block.

4. Conclusions

RPCs are widely adopted by the high energy physics and astrophysics community but their use outside these very specific fields is still somewhat limited. Muon Scattering Tomography techniques for homeland security could take advantage of this technology and of the knowledge developed by its application in experiments across the world.

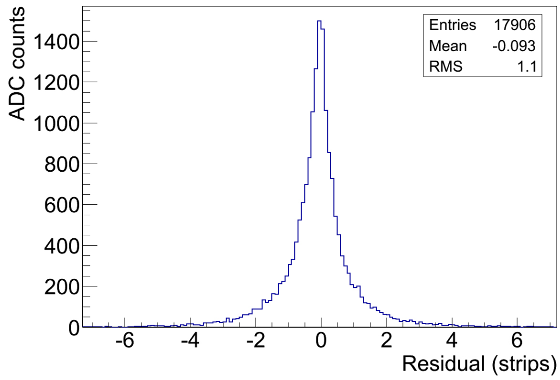

Figure 3: Distribution of the residuals $(X_{estimated} - X_{hit})$ for one of the layers. The x-axis is measured in 1.5 mm strips. The spatial resolution for the detector can be estimated by starting with this distribution and removing the contribution of multiple scattering and linear extrapolation. We are currently working on a Geant4 simulation to estimate such contributions.

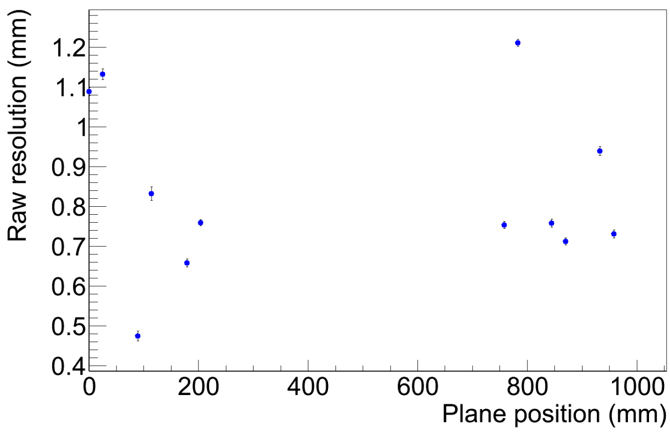

Figure 4: Raw resolution in mm σ_{raw} for the 12 detectors in our system. The effect of a readout problem on layer 3 (located at X= 800 mm) is clearly visible. The fact that the outermost layers have the worst raw resolution is due to the geometrical extrapolation of the tracks and can be corrected by an accurate simulation of the detector geometry.

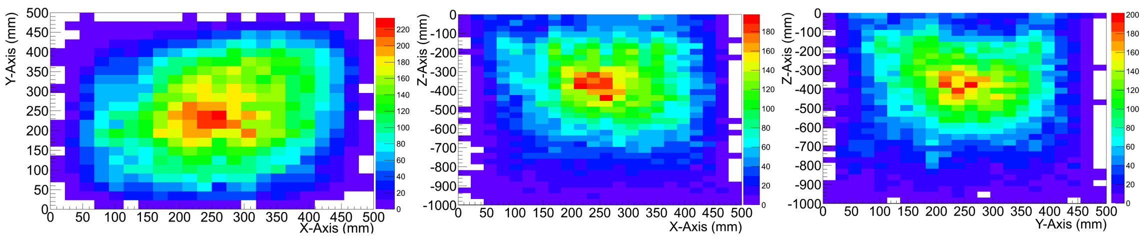

Figure 5: Imaging of a 10 cm x 10 cm x 15 cm lead block placed within the detector. The image is obtained by populating only those voxels where the scattering angle is greater than 30 mrad.

We have built and tested a muon tracking system based on high resolution RPCs. The system is working as expected, allowing us to correctly track cosmic muons. The preliminary results show that the raw spatial resolution is better than 0.8 mm, enough to be successfully used for MST. A simple PoCA analysis of the data collected by the detector shows a block of lead placed within the central gap. This is only the first step of a more complex analysis which requires careful simulation of the detector geometry and the implementation of more advanced tomography algorithms.

References

[1] R. Santonico and R. Cardarelli, *Development of Resistive Plate Counters*, Nuclear Instruments and Methods in Physics Research, vol. 187, pp. 377-380, 1981.

[2] P. Fonte, *Applications and New Developments in Resistive Plate Chambers*, IEEE Transactions on Nuclear Science, vol. 49, pp. 881 - 887, 2002.

[3] W. Riegler and C. Lippmann, *The physics of Resistive Plate Chambers*, Nuclear Instruments and Methods in Physics Research, vol. 518, pp. 86 - 90, 2004.

[4] Y. Jin and C. Jianping and Y. Qian and L. Yuanjing and L. Jin and W. Yucheng and Y. Hao, *Studies on RPC position resolution with different surface resistivity of high voltage provider*, Nuclear Science Symposium Conference Record, pp. 917 - 918, 2008.

[5] E. Ceron Zeballos and I. Crotty and D. Hatzifotiadou and J. Lamas Valverde and M.C.S. Williams and A. Zichichi and P. Fonte and V. Peskov, *Resistive plate chambers with secondary electron emitters and microstrip readout*, Nuclear Instruments and Methods in Physics Research, vol. 392, pp. 150 - 154, 1997.

[6] L.J. Schultz and G.S. Blanpied and K.N. Borozdinand A.M. Fraser and N.W. Hengartner and A.V. Klimenko and C.L. Morris and C. Oram and M.J. Sossong, *Statistical Reconstruction for Cosmic Ray Muon Tomography*, IEEE Transactions on Image Processing, vol. 16, pp. 1985 - 1993, 2007.

[7] L. Cox, P. Adsley, J. O'Malley, S. Quillin, C. Steer and C. Clemett, *Detector Requirements for a Cosmic Ray Muon Scattering Tomography System*, Nuclear Science Symposium Conference Record, pp. 706 - 710, 2008.

[8] ZEUS collaboration, *The design and performance of the ZEUS Micro Vertex detector*, Nuclear Instruments and Methods in Physics Research, vol. 581, pp. 656-686, 2007.

PoS(RPC2012)079