12 GeV Upgrade: FY06 R&D

Full-scale prototypes of the Hall D Forward and Central Drift Chambers

Report September 29, 2006

Purpose

This report describes the Hall D R&D on the forward (FDCs) and central drift chambers (CDCs) which will be used to measure particle trajectories in the detector. The primary goal is to address all issues that need to be addressed prior to the design of the final chambers. In particular, these studies are directed at understanding the trade-offs between many competing requirements for the chambers including placement of sense and field wires, optimal spacing of cathode and ground planes, and layout of on-chamber electronics, while at the same time minimizing material in the active volume and maintaining a robust design.

Risk Reduction

The particles from interactions in the experimental target travel through the drift chambers as their trajectories are being determined. Therefore very close attention needs to be paid to the amount of material in the chambers themselves to insure that the effects of multiple scattering and energy loss do not degrade the measurements of interest. In addition to the geometric placement, the number and the accuracy of each position measurement needs to be considered globally to achieve the momentum resolution goals of the experiment. The risk of cost and schedule overruns will be minimized by careful evaluation of materials and methods of chamber construction prior to detailed design.

Background

The prototyping effort for the Central Drift Chambers (CDCs) is being carried out at Carnegie Mellon University under the supervision of Curtis Meyer. The Forward Drift Chambers (FDCs) are being prototyped under the supervision of Daniel Carman from Ohio University. The FDC prototyping activity is being conducted at Jefferson Lab by his research associate Simon Taylor and supported by the JLab detector and electronic groups. This interim report describes work performed in FY06. The project builds on previous R&D which was reported last year, and continues next year before beginning the design phase. Additional details of the effort summarized in this report can be found in several internal GlueX technical notes, most recently GlueX-doc-604 and GlueX-doc-681.

Central DC Report

The CDC is a straw-tube chamber surrounding the experimental target with approximately 3200 channels. The straw-tube design has been chosen to minimize the support material needed in the down-stream end-plate of the chamber. This is crucial because many of the charged particles pass through this end-plate before entering the

forward tracking region of the detector. The CDC will be readout using Flash ADCs (FADC), allowing both a time and energy measurement for each hit in the chamber. While the final chamber will have custom FADCs, prototype work is being carried out with a 200 MHz commercial unit.

Prototype Construction

The Carnegie Mellon group has designed and built a full-scale, one-quarter model of the final CDC. This model has about 70 straw tubes with wires, and fully maps out all radii and the straight and 6 degree-stereo wires of the final chamber. In the construction of this chamber, use was made of both aluminized mylar and aluminized kapton straw tubes. **Based on the better mechanical robustness of the kapton tubes relative to the mylar tubes, the CMU team has decided that the final chamber should be built using kapton tubes.** This decision was based on several factors. First and foremost was the rejection rate for tubes. Approximately 90-95% of the mylar tubes had to be rejected for mechanical defects, while under 5% of the kapton tubes had to be rejected. While the initial cost of an individual mylar tube is cheaper than a kapton tube, when the rejection rates and the time involved in identifying good tubes are factored in, the costs are very similar. In addition, the mylar tubes are quite susceptible to damage in both handling and during constructions, while the kapton tubes are much more forgiving.

The initial CDC design called for a 2 m long chamber. However, since the detector review of October 2004, most of the original design parameters have been re optimized. **Based on work with the prototype, Monte Carlo studies of detector performance, and some background rate estimates in the chamber, we have decided that the final chamber will be 175 cm long, rather than 200 cm.** This has no impact on the electronics channels, but does slightly reduce some material and makes construction a bit easier. It also appears to improve the estimated tracking resolution slightly.

We have also found that shifting the nominal location of the stereo and straight layers, as well as the addition of a couple of additional inner layers, can significantly improve the vertex resolution of the chamber. A final decision on this is awaiting Monte Carlo calculations on the background rates in the chamber.

High Voltage Distribution

During late 2005, an early version of a high-voltage distribution board was built for the CDC. This board allows one to put high voltage (about +2000 V) on the wires in the straw tubes, and then capacitively couples these to the read-out electronics. The first version was highly susceptible to both noise and cross talk, and may best be described as a learning experience.

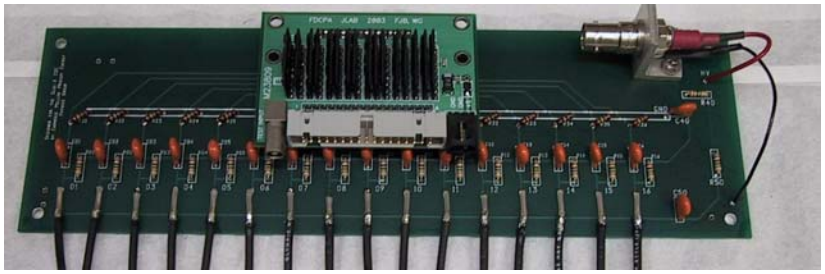

Figure 1 The prototype high-voltage distribution board with a CLAS preamplifier card mounted directly on the board.

Based on these early lessons, and subsequent discussions with people from the CLEO collaboration, we developed a new design for this board. In close consultation with Gerard Visser of Indiana, we refined this design on a CAD system and eventually had several boards produced. These boards were designed to have the electronic layout of the final boards. However, the exact shape, size, and connector types for the final boards await the design of the chamber preamplifiers. The cross-talk has been significantly reduced with a preamplifier plugged directly into the distribution boards, and the signal-to-noise ratio appears to be at a very reasonable level in the lab. Figure 1 shows the current version of the high-voltage board with a CLAS preamplifier mounted on it.

Tests with Cosmic Rays

The CMU group has a VME crate, computers, and local network infrastructure to facilitate the installation of a data acquisition (DAQ) system. We have obtained from Jefferson Lab an in-crate computer system, an F1 TDC module and recently a pair of SIS3200 200 MHz FADCs. These latter modules are similar to the ultimate readout electronics to be used on the chamber.

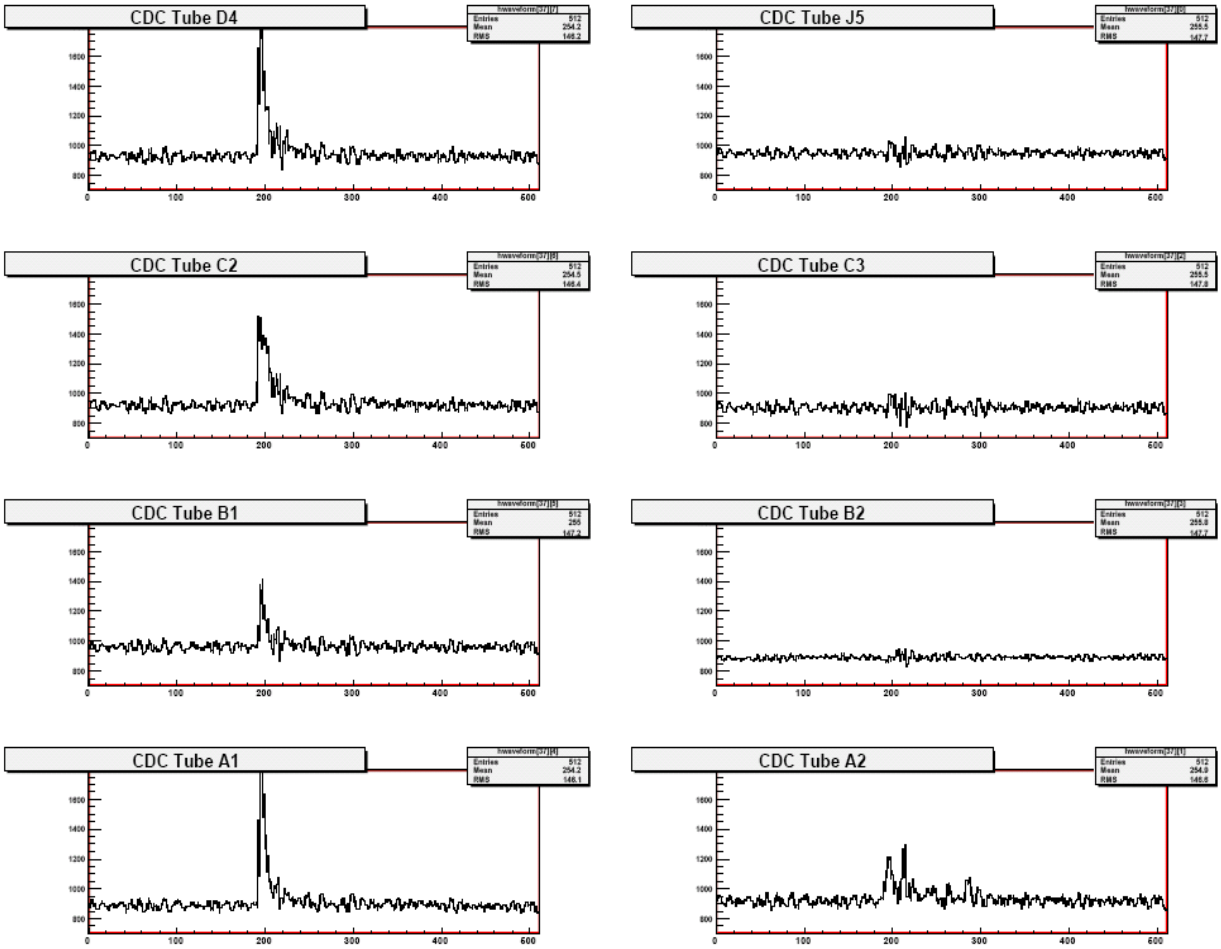

Figure 2 A cosmic ray going through four tubes in the CDC prototype and recorded with Flash ADCs

Currently a pair of very small area scintillators are set up above and below the instrumented tubes of the prototype chamber and used to select cosmic-rays. The DAQ system has been setup to read the response of the prototype and pass the events to a simple analysis program which extracts data from the FADC, filters them and then graphically displays the detector signals. Figure 2 shows a 4-tube coincidence from one event demonstrating that the entire system is functional and delivering sensible data. Because of the small area of the straw tubes, the data rate is about 1 event per minute, so runs of several days are required to obtain sufficient good events for study. We are currently in the process of collecting several large samples for analysis.

Forward DC Report

We have constructed a cosmic-ray test stand to be used to study resolution characteristics of the FDC cathode strip prototypes. The setup is shown in Figure 3.

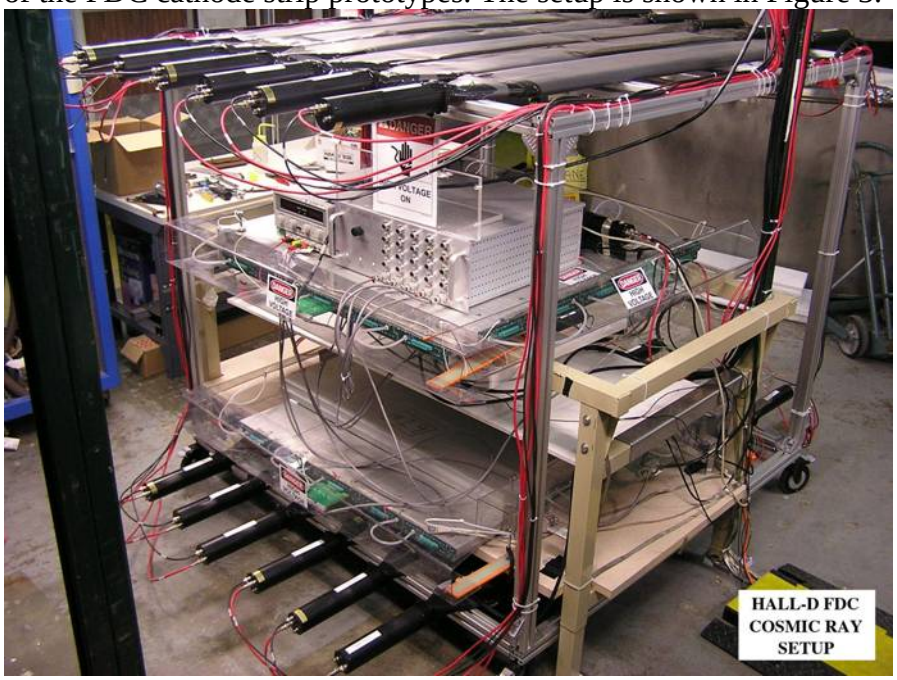

Figure 3 The cosmic-ray stand for study of the resolution characteristics in the FDC prototype.

Small-scale FDC prototype chamber

The FDC prototype cathode chamber has been designed primarily to provide us experience with cathode strip chambers. Through detailed study of this prototype we have been able to make design decisions on which electrode structure and layout will fulfill the design requirements for the final FDC chambers. The prototype has also provided important insights into the mechanical design, tolerances, construction and assembly techniques, noise immunity, and calibrations that will be important for the final FDC detector design.

A schematic of the FDC prototype chamber is shown in an exploded view in Figure 4. The basic chamber layout consists of two cathode planes with strips oriented at 45 degrees sandwiching a single wire plane. The gas volume is defined by two outer aluminum frames that each includes an aluminized mylar window. The active area of the prototype chamber is roughly 20cm x 20cm, and the chamber is about 8cm thick.

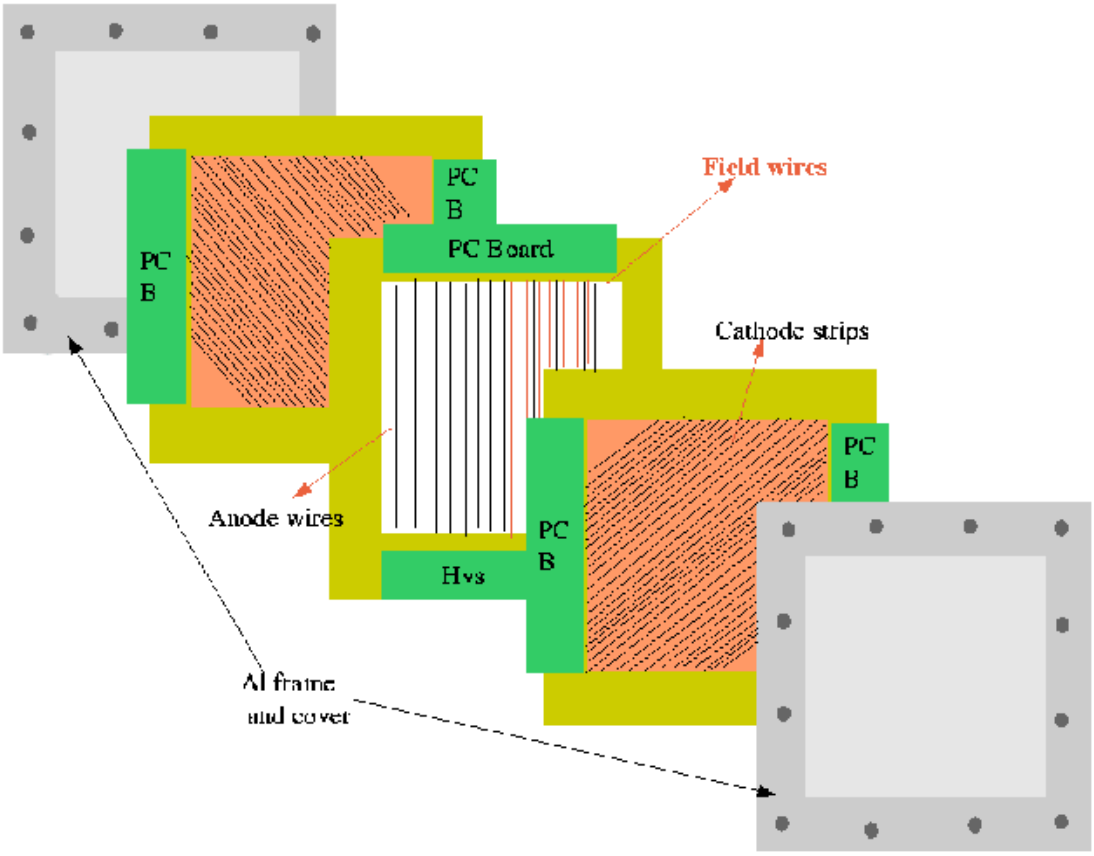

Figure 4 Schematic representation of the FDC prototype chamber in an exploded view showing the wire plane, two cathode planes, and the two aluminum window frames.

One of the central questions that we have been investigating through our R&D program for the FDC system regards the optimal electrode structure in our cathode chambers. The test chamber has purposefully been designed to act as a test bed for any number of electrode configurations. So far we have tested wire planes consisting of anode wires only and planes consisting of alternating anode and field-shaping wires. **The results from our prototype studies indicate that we can meet the design specifications for resolution in cathode coordinates with the inclusion of the field wires. This is a novel aspect of our chamber design.**

Anode-Cathode Separation

The gain of the FDC chambers depends critically on the separation between the cathode planes and the wire plane (referred to as the ``half-gap''). Our early cathode plane samples suffered from noticeable folds and wrinkles that lead to local variations in the half-gap and hence the gain. In our small-scale prototype we did not attempt to

pretension the cathode planes before they were attached to their frames to remove the defects. We have been in contact with the circuit board manufacturers regarding the defects and they will able to work with us to eliminate these problems. For the full-scale cathode planes our nominal flatness specifications for the cathodes are 50 μm.

Beyond local distortions in the cathode due to folds and wrinkles, there is another important distortion effect that must be considered in the design of the full-scale cathodes. When high voltage is applied to the wires, the grounded cathode planes are deflected toward the wires dues to electrostatic pressure. This distortion is largest at the center of the cathodes and uniformly decreases to zero at the perimeter. Kapton by itself offers little resistance to this deflection. In the small-scale prototype, given its small size, this deflection does not present a serious problem. We are currently investigating two techniques to mitigate this electrostatic distortion to optimize the chamber resolution. The first approach is to pretension the cathode planes and to attach the pretensioned planes to a support frame. The second approach is to laminate the cathode plane to a rigid backing. Both approaches, which are described further below, have advantages and disadvantages.

Cathode Plane Tensioning

Our first approach to keep the cathode plane flatness within our specifications is to pretension the cathode planes. This method has the advantage of reducing the amount of material within the detector, but suffers from the lateral distortions it induces on the cathode planes. Brian Kross of the JLab Detector Group has designed a tensioning mechanism for the cathode planes of the small-scale prototype which has been used to tension a set of cathode planes. The tensioning was performed at a level to reduce the size of the folds and wrinkles to our predetermined flatness specifications. However the lateral distortions of the cathode strips in the tensioned planes were deemed unacceptable for the final detector design. In spite of this, we installed a set of these tensioned planes in the small-scale prototype to evaluate their performance. The final resolution results showed little difference between the wrinkled planes and the pretensioned planes.

Brian Kross has made adjustments to the design of the tensioning system given our experiences with the small-scale prototype cathode planes. The design of the tensioning system for the full-size 1.2 m planes is complete and the parts have been ordered. We expect that a combination of improved quality of the cathode planes from the manufacturer, coupled with improvements to the tensioning system, will allow for a final decision to be made on this approach.

Cathode Plane Backing

Our second approach for establishing and maintaining the flatness of the 1.2 m cathode planes is to attach the Kapton planes to backing material made out of Rohacell, a low-density foam (density of 0.032 g/cm^3). This approach is attractive in that the flatness tolerance for our cathodes can more easily be met without any worries of cathode plane lateral distortion. The drawback is the increased material thickness and the worsened momentum resolution. In this scheme we are working to include the backing while striving to minimize the overall material thickness.

To date we have obtained samples of the Rohacell foam and are studying its properties. Several groups at JLab have extensive experience with this material. It is used in Hall B to provide a backing for the mirrors in the Cerenkov counters being designed for the CLAS12 detector. The material is fully machinable and its surface can be polished to flatness well beneath that required for the FDC. Pieces of Rohacell that can be used for our 1.2 m cathode planes are now on order and a design has been completed to construct a cathode-Rohacell-ground plane-Rohacell-cathode ``sandwich'' using minimal epoxy layers. This will enable us to finalize our construction procedure for the full-scale prototype detector. We are also devising a scheme to quantify the flatness of the ``sandwich''. Based on these experiences, we will converge on a final design and a final set of quality control techniques.

We are also aggressively working to complete full GEANT Monte Carlo simulations of the FDC system to make final choices on the allowable material budget in order to achieve the design coordinate resolution values for the FDC. Our initial studies from a fast parametric Monte Carlo (HDFast) have indicated that our nominal sandwich design should allow us to achieve the design resolution for this system. We continue to hone the design to minimize the overall material thickness.

Chamber Resolution Studies

This report presents the first results for the field+sense wire configuration of the anode plane. We have measured the efficiency curves for our current gas mixture of 90% argon - 10% CO_2 for various combinations of the sense and field wire high voltage. A good compromise between gain and noise was achieved when the sense wires are at +1650 V and the field wires are at -300 V. The reconstructed positions from the cathode data are shown in Figure 5. The average position resolution under these conditions was 158$\pm$3 μm. This improves upon the typical resolution of about 180 μm obtained with the sense wire only configuration and show that the structure of our nominal design can achieve the required resolution for the tracking system.

The cathode resolution as a function of position on the detector is shown in Figure 6 to verify uniformity. Even with the relatively poor statistics in this study (acquired in a week--long run with incident cosmic ray muons), there is no indication of any strong dependence of cathode resolution on strip length. More detailed studies of the small-scale prototype are underway to better quantify the cathode resolution as a function of cathode strip length. In the full-scale chamber, the lengths of the cathode strips will vary from 10 to 120 cm and therefore the variation of the chamber resolution with strip length must be minimized.

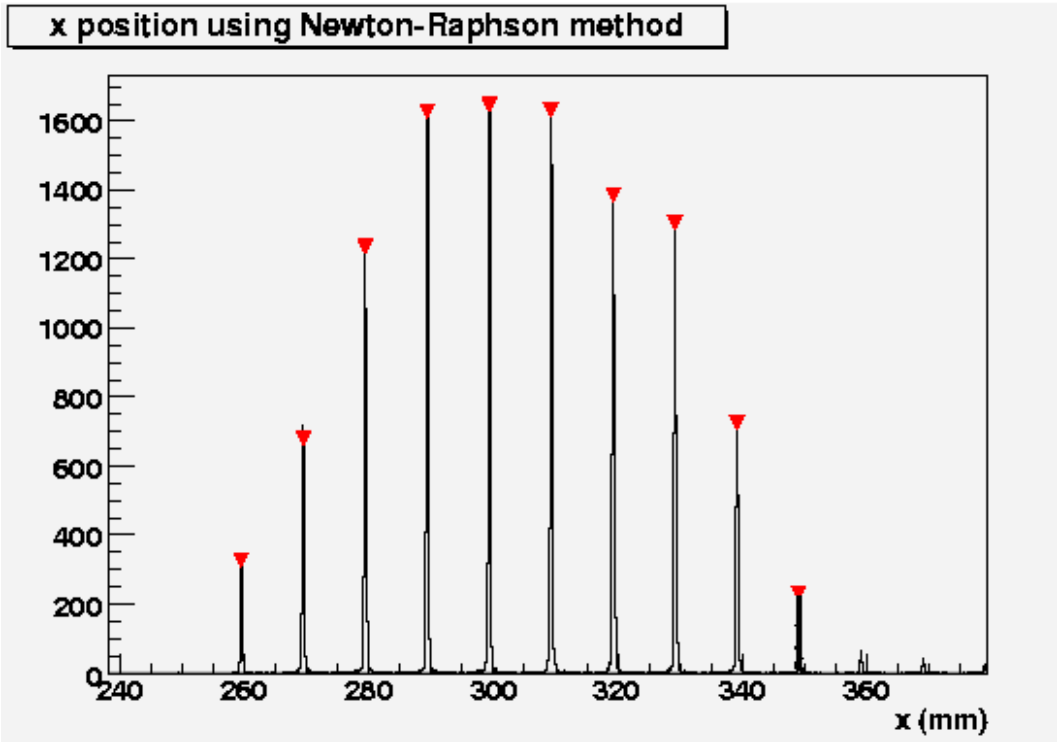

Figure 5 Wire position from cathode data for sense HV=1650 V and field HV=300 V. The average cathode coordinate resolution from these data is 158±3 μm.

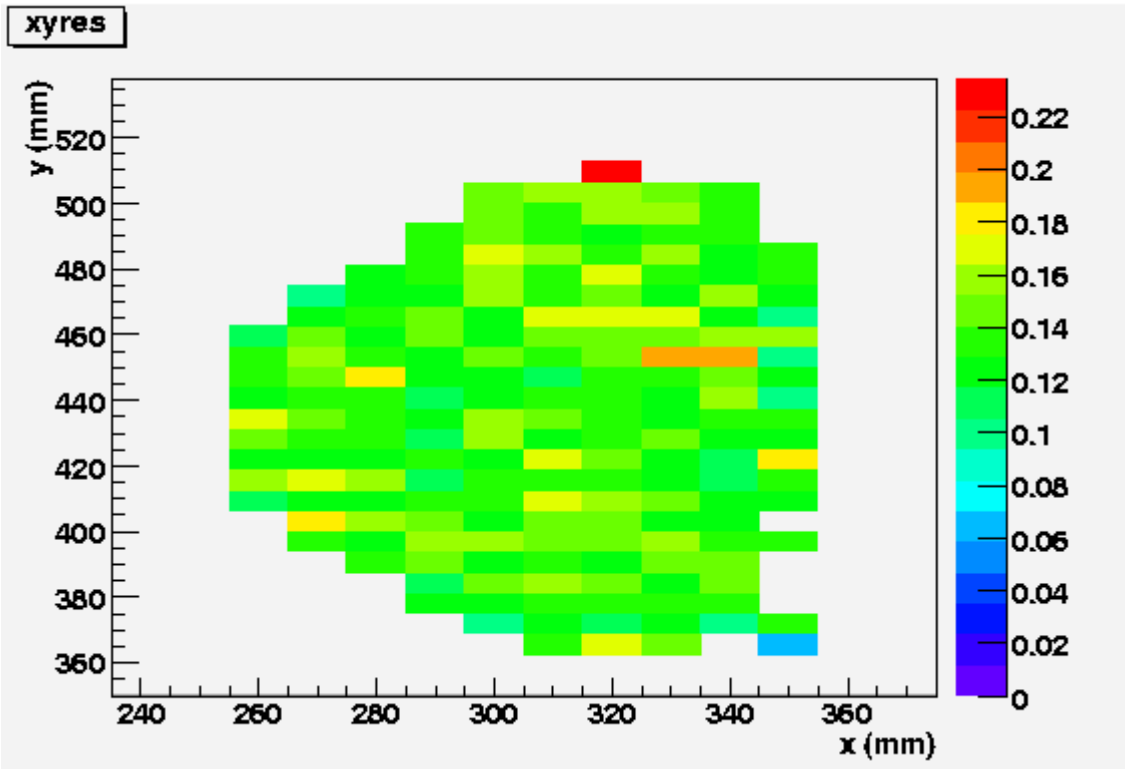

Figure 6 Position resolution as a function of position on the chamber for sense HV=1650 V and field HV=300 V.

Summary and Conclusions

Both the central and forward drift chamber systems are on track to make final decisions on the basic design for these chambers before the end of next year. The procedures for assembly of the CDC are in place and a working full-length prototype is being used to study performance with cosmic rays. The setup will provide a test bed for checking on-board electronics and analysis of pulses from passing particles. The FDC has a working prototype which has been used to measure the resolution and has shown that design goals can be achieved. The procedures for building full-scale chambers are currently under study and options are being evaluated against the goals of the experiment.