The Central Drift Chamber Detector for GlueX

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Abstract

The central drift chamber is a straw-tube wire chamber of cylindrical structure located around the target inside the bore of the GlueX spectrometer solenoid. Its purpose is to detect and track charged particles with momenta as low as 0.25 GeV/c as well as identify protons at low momenta. The construction of the detector is described and operation and calibration are discussed in detail. The design goal of 150 μm in position resolution alog the radius of the chamber has been reached.

Keywords: 29.40.Gx, 29.40.Cs

1. Introduction

The GlueX Central Drift Chamber (CDC) is part of the GlueX experiment in Hall D at Jefferson Lab (Newport News, VA). This experiment [1] aims to elucidate confinement in Quantum Chromo Dynamics (QCD), by searching for hybrid mesons with gluonic degrees of freedom and exotic quantum numbers [2] [3]. In case of GlueX the 12 GeV electron beam from the CEBAF accelerator is used to generate a high energy polarized photon beam through coherent bremsstrahlung off a thin diamond crystal. The highly collimated photon beam will impinge on a liquid hydrogen target to produce various hadronic states that will immediately decay into long lived neutral and charged particles. Various detector systems including the CDC are used in concert to reconstruct the initial hadronic state based on the measurements of the decay particles.

The CDC is a cylindrical straw-tube drift chamber situated within the up-stream end of the GlueX spectrometer magnet (a solenoid). It surrounds an extended liquid hydrogen target and a start counter detector and it is designed to fully track charged particles by providing timing and energy loss measurements. The required average position resolution of each straw measurement must be about 150 μm to guarantee a momentum determination of the charged particles with a resolution of 2% or better.

Prior to construction of the CDC, the proposed materials were evaluated and used to build two prototype chambers of shorter straw tubes and a sector with full length straw tubes. These prototypes were then used to study chamber characteristics and performance, including radiation resistance, choice of gas mix and energy loss (dE/dx) together with simulations that are reported here [4].

2. Construction

2.1. Overview

The CDC contains 3522 straw tubes of diameter 1.6 cm arranged in 28 layers, located in a cylindrical volume with an inner radius of 10 cm and outer radius 56 cm, measured from the beamline.

Each straw tube contains an anode wire of 20 μm diameter gold-plated tungsten. A layer of aluminum on the inside wall of the tube forms the cathode. The straws contribute structural rigidity to the assembly, support the tension of the wires, provide a uniform electric field and also prevent the wires from making contact with their neighbors, which would cause massive electrical shorts in the event that one should break.

The tracking volume is enclosed by an inner shell of G-10, an outer shell of aluminum, a carbon fiber endplate at the downstream (forward) end and an aluminum endplate at the upstream end. The endplates are linked by 12 aluminum support rods which were bolted into place to maintain the relative location of the endplates after alignment. Fig. 1 shows the endplates, inner shell, and support rods before the straws were installed. The holes in the endplates were milled precisely to position the ends of the straws correctly.

There is a cylindrical gas plenum outside each endplate. The upstream plenum has polycarbonate sidewalls and a polycarbonate endplate, while the downstream plenum has Rohacell sidewalls and a thin endwall of mylar film,

Figure 1: CDC frame prior to the installation of the straw tubes.

aluminized on both sides. The inner and outer shells are sealed along their seams and where they meet the endplates, forming another plenum around the straws. The dimensions of the CDC are given in Table 1.

Active volume inner radius:	9.92 cm
Active volume outer radius:	55.54 cm
Active length:	150.0 cm
Chamber assembly inner radius:	8.75 cm
Chamber assembly outer radius:	59.74 cm
Upstream gas plenum length :	3.18 cm
Downstream gas plenum length :	2.54 cm

Table 1: Geometry of the CDC's active volume and gas plenums

The materials used for construction were chosen to minimize the amount of material in the tracking volume, especially at the downstream end. They are listed in Appendix A.

The electronics are mounted on standoffs on the polycarbonate endplate. Signal wires pass through the gas plenum to the crimp pins via threaded holes in the polycarbonate endplate which are sealed with an O-ring and a threaded bushing.

2.2. Straws

The straw tubes were manufactured by Lamina Dielectrics[1] from four layers of mylar tape wound into a tube. The innermost layer of tape has 100 nm of aluminum vapor-deposited onto the side that faces inwards. The total wall thickness of the tube is 114 μm and the inner diameter is 15.55 mm. The electrical resistance of each straw, from one end to the other, is between 75 Ω and 100 Ω. During manufacture of the straws the mandrel was covered with a 50 μm layer of mylar to protect the the thin aluminum layer on the inside of the straws.

The straws are arranged in 28 radial layers surrounding the inner shell. 12 of the layers are axial (parallel to the beam axis) and the remaining 16 are placed at stereo angles of $\pm 6^\circ$. These are ordered such that the innermost 4 layers are axial, followed by (at increasing radius) 4 layers at $+6^\circ$, 4 layers at -6°, 4 axial layers, 4 layers at -6°, 4 layers at $+6^\circ$ and 4 axial layers. This is shown in Fig. 2.

The layers are paired and located so that the first layer of each pair contains the largest number of straws possible for its radius, and the straws in the second layer are close-packed against those in the first. This is illustrated in Fig. 3. The number of straws in each layer is listed in Appendix B, together with the radial distance of each wire from the beamline at the center of the chamber and at the inside face of the two endplates.

A non-conductive epoxy is used to glue each straw tube to its neighbors within the same layer at three points evenly distributed along its length. In the first layer of each pair, every sixth straw is also glued to the straw behind it. In the second layer of each pair, every straw is glued to the straw behind it. Fig. 4 shows straws in opposing stereo layers 8 and 9 and Fig. 5 shows the outermost row of straws, with the outer shell partly installed.

[1]www.lamina.uk.com

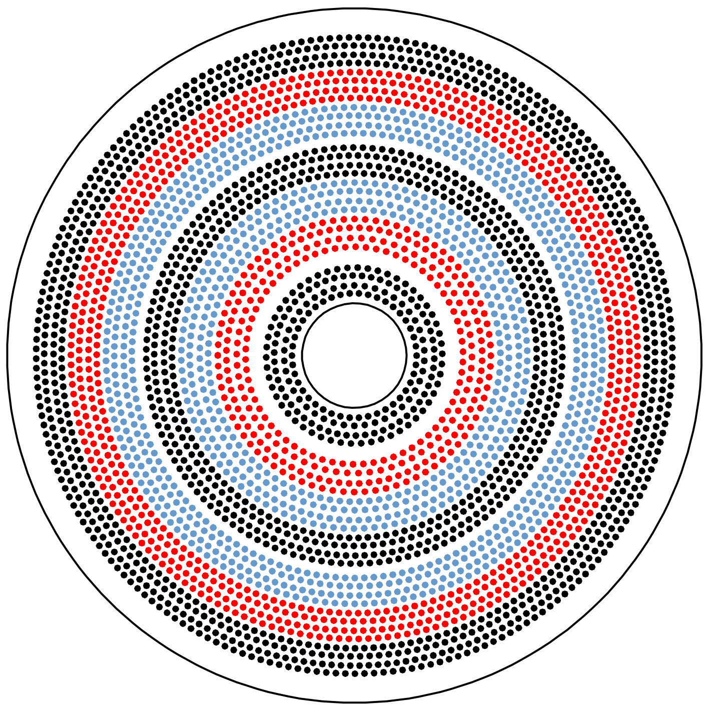

Figure 2: Diagram showing the position of the straws at the upstream endplate. The axial straws are shown in black, the $+6°$ stereo layers are shown in red and the $-6°$ stereo layers are shown in blue.

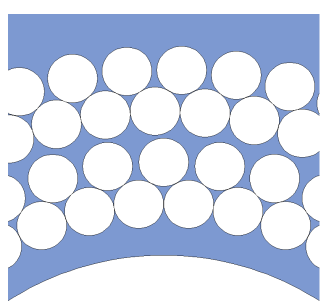

Figure 3: Diagram showing close-packing of the straws in a small section of rows 1 to 4.

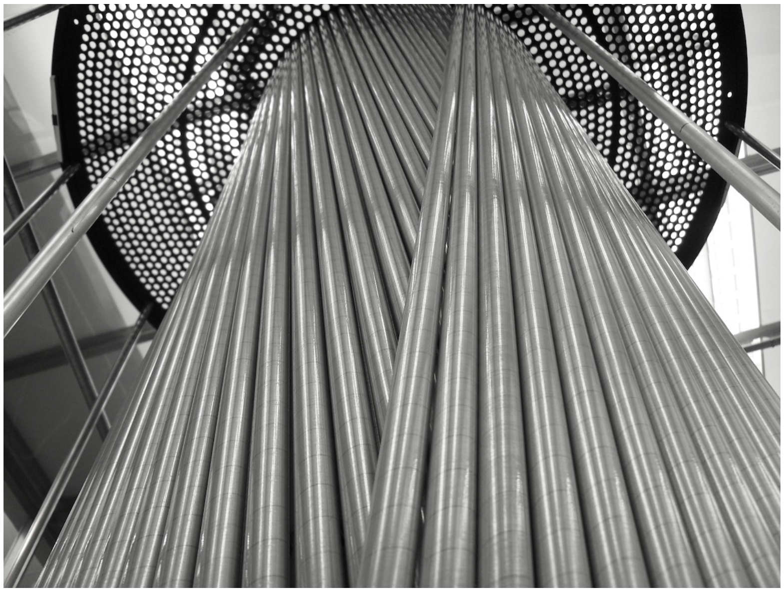

Figure 4: Straw tubes in stereo layers 8 and 9.

Figure 5: Straw tubes in layer 28, with one half of the outer shell in place.

2.3. Straw and wire assembly

The straw assembly components are shown in Fig. 6. A 'donut' ring is glued inside each end of the straw. A 'feedthrough' tube is glued through the endplate into the donut, to hold the straw in position. Two types of donuts, feedthroughs, and epoxy are used: Noryl plastic donuts and feedthroughs are glued into the carbon fiber endplate with non-conductive epoxy, and aluminum donuts and feedthroughs are glued into the aluminum endplate with silver conductive epoxy. The conductive epoxy ensures that the electrical grounding of the aluminum endplate is shared with the aluminum feedthroughs, donuts, and the aluminum layer on the inside of the straw. Sufficient epoxy is used to make each joint gas-tight.

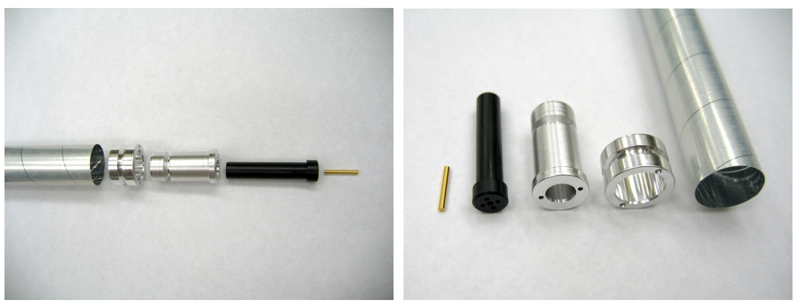

Figure 6: Straw, donut, feedthrough, pinholder and crimp pin.

The donuts and feedthroughs have a recess in their exterior surface which is accessed by 2 narrow holes bored lengthwise into the component wall. The holes act as glue ports, permitting epoxy to be injected into the recess (glue trough) through one hole while air exits through the other. This enables the epoxy to create a strong joint by filling the trough completely. The dimensions of these components are given in Appendix C.

The anode wires are held in place by gold-plated copper crimp pins inside Noryl plastic tubes, 'pinholders', which were inserted into the feedthroughs. The inner diameter of the pinholder is 1.47 mm at the top, making a very close fit with the crimp pin, then after 6 mm of length the diameter is reduced to 1.27 mm for a further length of 1.63 mm to hold the crimp pin in place, before opening out to a diameter of 5.08 mm for the rest of the length.

The pins were crimped when the wire was under tension, applied by suspending a 30 g weight from the wire, with the chamber orientated so that the wire was hanging vertically. The anode wire is 20 μm diameter tungsten with a flash coating of gold, supplied by Luma-Metall[2]. Each pinholder has 4 additional holes surrounding the crimp pin which permit gas to flow in and out of the straw.

2.4. Wire tension measurements

The tension on each wire was measured a few weeks after stringing, and again some time later, using two Helmholz coils and a control device which alternated between applying a sinusoidal voltage to the wire and measuring the induced current on the wire. The wire tension was calculated from the frequency of the applied voltage when the system reached resonance. This technique is described elsewhere [5]. The chamber is shown with the Helmholz coils in place in Fig. 7.

A delay in the straw supply during construction led to the innermost 6 axial rows being strung when 19 of the 28 rows of straws had been installed. The tension measurements were interleaved with the stringing work and after all 28 rows of straws had been installed and strung, the 5th and 6th axial rows were found to have low tension. All the straws in these two rows, any other straws with very low tension and the few straws with broken wires were restrung and remeasured. Most of the wire breakages occurred close to the crimp pin and within a few weeks of stringing. After that time there were no more breakages for the following year. When stringing was complete, the tension on each wire was between 0.265 N and 0.294 N.

[2]www.luma-metall.se

Figure 7: Wire tension measurement

2.5. Gas flow

Six aluminum tubes of inner diameter 6.35 mm run the length of the CDC, close to the inside wall of the outer cylindrical shell, taking the gas supply from outside the upstream end through the polycarbonate plate and both endplates into the downstream plenum, where the gas enters the straw tubes through the holes in the pinholders. The gas passes through the straw tubes into the upstream plenum and then through ten holes in the lower half of the aluminum endplate into the void between the straws and the outer shell of the CDC. Six holes near the top of the aluminum endplate permit the gas to leave the void through exhaust tubes. Five thermocouples within each plenum enable the temperature of the gas to be monitored. The gas used is a mixture of 50 % CO_2 and 50 % Ar at atmospheric pressure.

2.6. Electrical shielding

Electrical shielding is required to minimize the amount of electromagnetic noise picked up by the signal wires. The aluminum endplate is the common ground for the straw tubes and also the outer shell, which provides electrical shielding around the tubes. Each half of the outer shell is glued to the aluminum endplate and G-10 outer hub with non-conductive epoxy. In order to ensure a good electrical connection, tabs of aluminum are glued over the joint between the outer shell and the endplate with conductive epoxy at twenty points around the outer radius.

The long straight edges of the two halves of the outer shell were covered with non-conductive glass-cloth electrical tape and then joined together with a strip of 25 mm wide copper tape with a non-conductive backing. The copper tape is grounded to the endplate by a tab of copper attached with conductive epoxy. This arrangement ensures that the sidewalls of the cylindrical outer shell have a good connection to the grounded aluminum endplate, while the discontinuity between the two halves of the shell prevents eddy currents from spiraling around the CDC in the event of a magnet quench. For additional reinforcement, a 114 mm wide strip of 0.13 mm thick kapton film was glued onto the shell, covering the copper tape along the seam. The kapton was glued onto the shell on either side of the tape with DP190 epoxy.

The upstream outer gas plenum sidewall is covered with 0.13 mm thick copper tape. A copper braid is soldered to the tape at intervals and glued to the aluminum endplate with conductive epoxy. The downstream plenum endwall material is mylar, aluminized on both sides. Rectangular tabs extend outwards from the endwall around its radius. These are glued to the sidewall and outer shell with conductive epoxy.

Grounded shielded extension cables are used for the downstream thermocouples along the length of the CDC, and for all the thermocouples from the upstream end to the electronics racks, in order to minimize any electrical pickup.

3. Electronics

The hookup wires, which pass through the polycarbonate endplate and onto the crimp pins inside the upstream gas plenum, were made from RG-316 wire as follows: at one end of the wire, the inner conductor was exposed for approximately 5 mm and the teflon dielectric was exposed for a further 5 mm. The end of the shielding braid was sealed with epoxy to prevent gas from migrating along the cable inside the braid. A silver bead was soldered onto the end of the center conductor and then covered with a narrow tube of conductive rubber, approximately 15 mm long, which fits tightly over the bead. Heat-shrink was then used to seal over the region from the end of the outer covering and braid to the end of the conductive rubber tube. An O-ring and threaded bushing were fed onto the hookup wire before its other end was finished by stripping back the braid 10 mm and then soldering a ferrule to the braid, then stripping the dielectric 5 mm from the end of the wire. Two hookup wires, one complete and one partly assembled, are shown in Fig. 8. The length of wire used for each connection was between 9.3 cm and 12.5 cm; this was chosen to be as short as possible, without causing excessive strain on the solder joints.

The polycarbonate endplate was polished to transparency so that the crimp pins would be clearly visible through it. Each hookup wire was installed by inserting it through a threaded hole in the polycarbonate endplate and sliding the conductive rubber over the corresponding crimp pin until it made a snug fit as the silver bead made contact with the end of the pin. The O-ring and threaded bushing were then fitted into the hole in the endplate, and the ferrule and center conductor at the other end of the hookup wire were soldered onto pads of a transition board. The transition boards are mounted onto standoffs located on the polycarbonate endplate - one standoff mounts directly to the polycarbonate endplate while the other (grounding) standoff threads onto another standoff which is mounted onto the Al endplate

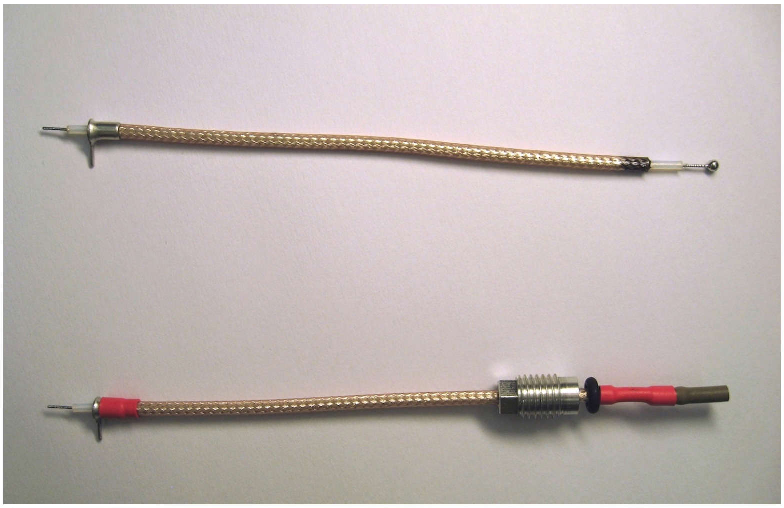

Figure 8: Two hookup wires, the upper wire is part-assembled and the silver bead is visible.

and protrudes through a hole in the polycarbonate endplate, sealed with an O-ring.

There are 149 transition boards, each of these is soldered to 20 to 24 hookup wires which are connected to straws from 3 to 4 neighboring rows. Some of the transition boards and standoffs are shown in Fig. 9. Each transition board houses a 30-pin connector for installation of a high voltage board (HVB) that provides approximately 2 kV for up to 24 wires, 2 connections of approximately 2 kV for the shielding braids, 2 ground connections to the grounding standoffs and 2 unused connections which are located between the HV and ground connections. The HVBs also house the preamplifier cards.

The preamplifiers have 24 channels per board, are charge-sensitive, and capacitatively coupled to the CDC. The preamplifiers are connected to 125 MHz 12-bit flash analog to digital converters (fADC), with three preamplifiers to each fADC.

4. fADC readout and timing

The fADCs sample the signal data from the detector using a 8 ns period. Following a trigger, if a pulse is found, the readout data contain the pulse time, pulse amplitude, pulse integral, pedestal before the start of the pulse, a quality code for the time measurement and the number of overflow samples

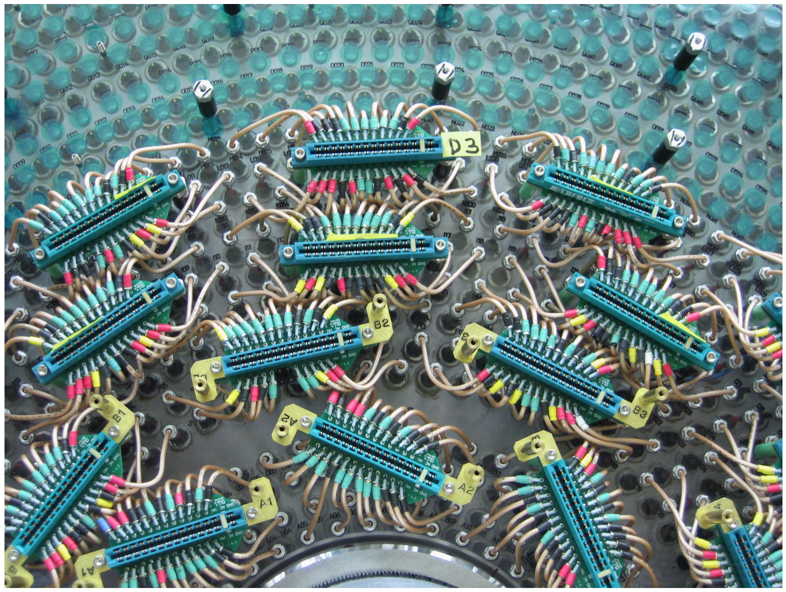

Figure 9: Hookup wires and transition boards.

within the integral period, fitted into two 32-bit words. The fADCs can also output the data in a much longer diagnostic format, which appends the raw sample data to its usual compact output, and in some other output formats which are designed for use with the GlueX Forward Drift Chambers.

Configuration parameters allow the user to specify the start of the pulse data window relative to the trigger arrival time, the length of the window, the number of samples used for the pedestal calculation, the number of samples by which the local pedestal calculation precedes the pulse threshold crossing signal and the factors by which the pulse amplitude, integral and pedestal are scaled down before output by right-shifting, and the thresholds which are used for pulse identification and timing.

The trigger signal prompts the firmware to search through the data window for a pulse, which is found if two or more consecutive samples exceed the pedestal at the start of the data window by the hit threshold value or more. If a pulse is found, the local pedestal is calculated a few samples (configurable) before the hit threshold crossing sample. The samples immediately after this are searched again to find the start of the pulse, first by searching forward to find the first sample value which exceeds the local pedestal by a high timing threshold or more, and then back from this point to find where the signal value exceeds the local pedestal by low timing threshold or less. Looking for the larger threshold crossing and backtracking to find the lower threshold crossing ensures that the edge of the pulse has been found and not a smaller fluctuation. The first sample whiuch is at or above the low timing threshold crossing is upsampled by a factor of 5 and then interpolated to find the threshold crossing point in units of sample/10. Various quality checks are made throughout the pulse analysis and if any are failed then the quality code bit is set. In certain cases, such as sample values of zero, or pedestal values above a set limit, then the firmware does not look for the time threshold crossings but returns a time value of the hit threshold crossing time minus a constant to indicate the error condition. Similarly, if any problems are encountered during upsampling (for example, unrealistic steps in signal value which could be caused by faulty connectors) then the time value returned contains the low time threshold sample and a code indicating the error condition.

Signal integration starts with the low timing threshold crossing sample and ends at the end of the pulse data window. If any overflow samples are found during the integration then the overflow count is incremented, up to a maximum of 7. If the pulse height, integral or pedestal values are too large to fit into their allocated space in the output words, their output has all bits set.

The pulse time quantity returned by the algorithm is converted to a time in offline software by multiplying by 0.8 ns, which is one tenth of the sample period. It includes a constant offset, corresponding to the earliest possible drift time (when a track passes through a wire). This offset is determined during offline analysis and subtracted from the drift time returned by the algorithm to give the net drift time.

5. Tracking and Particle Identification

The tracking chambers are designed to reconstruct the momenta of the charged particles emerging from the target. The transverse momentum, $p_\perp$ and the dip–angle, λ, ($\lambda = \frac{\pi}{2} - \theta$) are measured from the curvature of the tracks in the solenoidal field and their initial direction. The total momentum and the longitudinal momentum are then obtained from these as $p_{total} = p_\perp \sec\lambda$ and $p_\parallel = p_\perp \tan\lambda$. The accuracy of the $p_\perp$ measuremen depends on the $r - \phi$ resolution of the tracking chambers, while the λ measurement relies on an accurate measurement of both z and the distance traveled. The tracking system in the GlueX detector must cover as close to a 4π solid angle as possible over a wide range of particle momenta and must have sufficient momentum resolution to be able to identify missing particles. To achieve these goals, the LASS detector [8] design was used as our starting point. This device used several different tracking elements each optimized for a particular region in the detector. All tracking devices are located inside the barrel calorimeter, which is in turn inside the 2.08 T solenoid. Surrounding the target is a cylindrical straw-tube drift chamber (CDC) which provides very good $r - \phi$ and good z resolution. In addition, this detector provides some dE/dx information to aid in the separation of π's, K's and p's up to momenta of about 0.45 GeV/c – a regime where dE/dx measurements work extremely well. In the forward region, round planar drift chambers (FDC) are arranged in four identical tracking packages. These packages allow tracking particles down to about one degree with respect to the beam line. A summary of the tracking chamber parameters are given in Table 2.

System	*Radius*		*Length*		*Resolution*	
	$r_{\min}$ (cm)	$r_{\max}$ (cm)	z_{min} (cm)	$z_{\max}$ (cm)	$\sigma_{r-\phi}$ (μm)	σ_z (mm)
CDC	9.9	55.5	17	167	150	1.5
FDC	$3.0^{\dagger}$, $3.9^{\ddagger}$	48.5	176	364	150	fixed

Table 2: A summary of the tracking chamber parameters. The z values under *Length* indicate the smallest and largest z of the combined system. The z origin is at the upstream end of the magnet. The z resolution for the CDC comes from $\pm 6°$ stereo layers. The z resolution of the planar chambers is assumed to be given by their position in space. †FDC packages 1 and 2, ‡FDC packages 3 and 4.

Pattern recognition is an important part of track reconstruction. This process requires finding local clusters of hits and associating them into small track segments that can be combined into larger tracks. In order for this procedure to work well, it is desirable to have sufficient hits in close proximity such that they will be easily associated. In the forward direction cathodes and anodes in each layer of the FDC are arranged such that together they provided a 3-dimensional point. Each package consists of six closely spaced planes. Such packages allow local identification of track segments with a reasonable measure of curvature. This has then been repeated four times to provide sufficient segments for high efficiency track-segment linking. In the CDC, the pattern recognition issue is dealt with by creating three sections containing several adjacent straight tubes. These are then interleaved with two sets of crossed stereo layers.

6. Alignment Parameters

7. Efficiency and Resolution

8. Overall Performance

9. Acknowledgements

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics under contract DE-AC05-06OR23177.

10. Appendices

Appendix A. Construction materials

Appendix B. Location of the wires

Appendix C. Dimensions of the straw assembly components

Appendix D. CDC properties

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Upstream endplate:	0.9525 cm Al (3/8” plate)
Downstream endplate:	0.6 cm Carbon Fiber
Support rods (12):	Al
Upstream inner hub	Al
Downstream inner hub	G-10
Thickness of inner shell (mm):	0.5 mm G-10
Upstream outer hub	G-10
Downstream outer hub	G-10
Thickness of outer shell (mm):	1.6 mm Aluminum 6061
Outer shell joints:	Scotch 27 glass cloth electrical tape
	2.54 cm wide 0.127 mm thick Cu tape
	11.43 cm wide 0.127 mm thick Kapton film
Outer shell connections to endplate (21) :	3 cm x 2.54 cm x 0.05 mm Al tabs
Outer shell connections to endplate (2) :	3 cm x 2.54 cm x 0.05 mm Cu tabs
Straw tube (inner diameter):	1.555 cm
Straw tube (material):	Aluminized Mylar
Straw tube (thickness):	114(0.1) μm Mylar(Al)
Upstream donuts and feedthroughs (3522):	Al
Downstream donuts and feedthroughs (3522):	Noryl plastic
Pinholders (7044):	Noryl plastic
Crimp pins (7044):	Au plated Cu
Anode wires (3522):	20 μm gold-plated W
Upstream plenum sidewall:	3 mm Polycarbonate
	0.127 mm Cu tape
Upstream plenum endwall:	1.58 cm Polycarbonate
Downstream plenum sidewall:	2.54 cm Rohacell
Downstream plenum endwall:	50 μm Aluminized Mylar
Gas pipes (6):	Al, inner diameter 6.35 mm
Gas line widgets (6):	plastic
Gas line widgets (6):	Al
Hose barbs (6):	stainless steel
Thermocouples (10)	Constantan Cu-Ni, Kapton coating
Conductive epoxy:	920-H
Non-conductive epoxy:	DP-190 (straw assembly, Kapton film)
Non-conductive epoxy:	DP-460NS (outer shell and hubs)

Layer	Straws	Radius (cm) (center)	Radius (cm) (endplate)	Stereo (radians)
1	42	10.7219	10.7219	0.00000
2	42	12.0797	12.0797	0.00000
3	54	13.7802	13.7802	0.00000
4	54	15.1447	15.1447	0.00000
5	66	16.9321	18.6765	0.10470
6	66	18.3084	20.1945	0.11314
7	80	20.5213	21.9827	0.10470
8	80	21.9009	23.4606	0.11168
9	93	23.8544	25.1226	−0.10470
10	93	25.2362	26.5780	−0.11072
11	106	27.1877	28.3070	−0.10470
12	106	28.5712	29.7475	−0.10999
13	123	31.3799	31.3799	0.00000
14	123	32.7577	32.7577	0.00000
15	135	34.4343	34.4343	0.00000
16	135	35.8128	35.8128	0.00000
17	146	37.4446	38.2650	−0.10470
18	146	38.8314	39.6822	−0.10855
19	158	40.5369	41.2959	−0.10470
20	158	41.9248	42.7099	−0.10826
21	170	43.6152	44.3216	0.10470
22	170	45.0038	45.7326	0.10801
23	182	46.6849	47.3455	0.10470
24	182	48.0737	48.7539	0.10779
25	197	50.3747	50.3747	0.00000
26	197	51.7597	51.7597	0.00000
27	209	53.3631	53.3631	0.00000
28	209	54.7464	54.7464	0.00000

Table B.3: The number of straws in each layer of the CDC. The radius at the center is the wire location half-way between the two endplates. The radius at the endplates is where the wire passes through the endplate. For axial layers, both radii are the same. For the stereo layers, the radius at the endplate is larger than it is at the center. There are some small differences between the non-zero stereo angles imposed by the close-packing of the rows of straws.

Component	Inner diameter	Outer diameter	Length
Straw (straight)	1.552 cm	1.575 cm	149.809 cm
Straw (stereo)	1.552 cm	1.575 cm	150.571 cm
Donut (top)	1.111 cm	1.575 cm	0.063 cm
Donut (rest)	1.111 cm	1.552 cm	0.889 cm
Al feedthrough (top)	0.635 cm	1.270 cm	0.254 cm
Al feedthrough (rest)	0.635 cm	1.111 cm	2.159 cm
Noryl feedthrough (top)	0.635 cm	1.270 cm	0.254 cm
Noryl feedthrough (rest)	0.635 cm	1.111 cm	1.803 cm
Pinholder (top)	0.147 cm	0.787 cm	0.396 cm
Pinholder (rest)	0.508 cm	0.635 cm	2.906 cm
Crimp pin	0.0203 cm	0.147 cm	1.206 cm

Straw Length	150 cm
Straw ID	15.55 mm
Wall thickness	109 μm
Aluminum layer	100 nm
Thickness (28 layers)	
Mylar	2.22% Rad.Length
Gas	0.34% Rad.Length
Thickness (End Plate)	2.14% Rad.Length
Gas	50% Ar / 50% CO_2
Gas Flow	$\sim 3\ \ell$/min
Preamps (GASS-2)	149 cards
fADC125-MHz, 72 ch	50 modules
HV CAEN A1550P	+2110V
LV, MPOD MPV8008	$<$ 8V, 0.47A/card
Drift position σ	$\sim 150\ \mu m$