Forward Drift Cahmber for the GlueX experiment at the 12 GeV CEBAF machine

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Abstract. The GlueX experiment will search for exotic mesons produced by 9 GeV linearly polarized photons from the upgraded CEBAF machine. It is critical to detect and measure the four-momenta of all the charged particles and photons resulting from the decays of the mesons. The solenoid-based detector system includes tracking detectors and calorimeters. The Forward Drift Chamber, FDC, consists of 24 circular planar drift chambers of 1m diameter. Additional cathode readout is required to achieve efficient pattern recognition. The detection of photons by the electromagnetic calorimeters imposes constraints on the amount of material used in the FDC. The specific features of the detector and the readout electronics will be described. Results from the tests of the full scale prototype will be presented, as well.

Keywords: hybrid mesons, drift chambers

INTRODUCTION

The quark model of the mesons as bound states of a quark and an antiquark is based on the success in explaining the meson spectroscopy using the quantum numbers of the two quarks only. Quantum Chromodynamics (QCD) gives a richer picture of the mesons as strongly interacting quarks and gluons. The inclusion of gluonic degrees of freedom results in predictions for mesons in which the gluons are excited and contribute to the quantum numbers of these so called hybrid mesons. Some of the hybrid mesons have exotic quantum numbers not allowed by the quark-antiquark model. The existence of hybrid mesons is supported by Lattice QCD calculations [1] that made significant progress during the last years. Despite of the extensive experimental search, the results are controversial; still there is evidence [2] for a few isovector exotic states. The GlueX experiment [3] will search for such hybrid mesons with masses up to 2.8 GeV.

The identification of the hybrid mesons with exotic quantum numbers requires measurements of the four-momenta of all the charged particles and photons from the decay of the mesons. This necessitates a hermetic detector with a flat acceptance with respect to the meson decay products. The GlueX detector presently under construction will be installed in the newly built Hall D of the upgraded CEBAF machine at Jefferson Lab. The experiment will use 9 GeV linearly polarized photons produced from the 12 GeV electron beam. The polarization as an additional degree of freedom is critical for identifying the quantum numbers of the produced mesons.

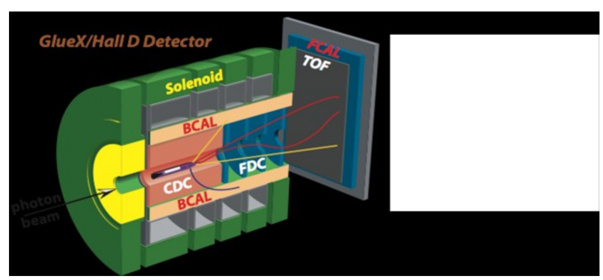

FIGURE 1. GlueX detector: Solenoid, Central Drift Chamber, Forward Drift Chamber, Barrel Calorimeter, Forward Calorimeter, Time of Flight.

The GlueX detector (Fig.1) consists of a tracking system that includes the Central Drift Chamber (CDC) and the Forward Drift Chamber (FDC), and two electromagnetic calorimeters, the Barrel Calorimeter (BCAL) and the Forward Calorimeter (FCAL). All the detectors, except FCAL, are placed inside the bore of a solenoid with a longitudinal magnetic field of 2T. The FDC tracks the charged particle in the forward direction. The CDC employs 1.6cm diameter straw tubes used for tracking at large angles and for low energy charged particle identification. The BCAL is a scintillation-fiber/lead calorimeter, the FCAL is a lead-glass calorimeter, both with high energy (~6%/√E) and position (~6mm/√E) resolution, aiming to register the photons in the full 4π acceptance. The Time of Flight scintillator wall will be used for particle identification and timing.

FORWARD DRIFT CHAMBER DESIGN

The FDC will consist of four cylindrical packages, each having 6 drift chamber layers. Each layer (Fig.2) consists of two cathode strip planes on both sides of the wire plane. Each wire plane has alternating sense and field wires 5mm apart. The main design parameters are summarized in Table 1.

TABLE 1. Main drift chamber parameters.

Parameter	Value	C
Sense wire diameter	20 μ	
Field wire diameter	80 μ	
Cell size	10x10 mm^2	
Cathode strip pitch	5mm	
Active area diameter	1m	
Strip to wire angle	75°	
Gas mixture	Ar/CO_2	
Gas gain	2 - 8 10^4	
Total number of drift layers	24	
Total thickness of active area	1.3% R.L.	

The most critical requirement in the FDC design is to minimize the amount of the material not only in the active area of the chamber but also at the periphery: the frames, supporting systems and cables. At the same time the mechanical structure must be robust enough to minimize the deformations and to allow for good gas tightness. In an early design the chamber frame was made out of solid G10 material. Monte Carlo simulations showed a significant fraction of the photons from meson decays being converted by the frames and not properly reconstructed in the BCAL or FCAL due to the strong magnetic field. This required a design change in which the frames are composite: an outer thin G10 skin with an inner part made out of Rohacell material, reducing the total frame thickness by a factor of two. However, a full scale prototype built in this manner showed problems with gas tightness and robustness of the whole construction. This was mitigated in the final design, where a small fraction of the frame around the gas spacers is kept solid G10.

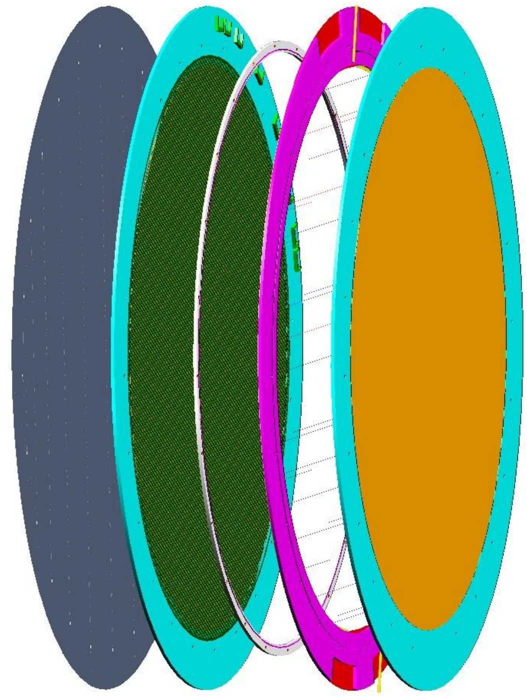

FIGURE 2. One drift chamber layer, from right to left: cathode strip plane, wire plane, spacer ring, second cathode strip plane, ground

The high particle densities - especially in the forward direction - require good pattern recognition. To achieve this, each drift layer has cathode strips on both sides of the wire plane. For a standard drift chamber, using the drift time from one wire plane only would give two lines parallel to the wire as possible hit positions. The cathode information allows to reconstruct the position of the gas avalanche along the wires. Thus, apart from the left/right ambiguity, each chamber layer provides a spatial point that contributes greatly to the identification of the charged tracks in the presence of a high magnetic field and to the reconstruction of the particle momenta. A resolution of 200μm is required for both wire and strip coordinates in order to achieve the physical goals of the experiment.

A gas mixture of Ar/CO_2 is our preference, as both gases are non-flammable and neutral. The exact percentage of the components will be determined experimentally based on the stability of operation and the optimum wire and strip resolutions. High argon percentage results in a weaker dependence of the drift velocity on the electric field and better resolution. However, in the presence of a magnetic field one would prefer lower drift velocities and therefore higher CO_2 concentration, to minimize the Lorentz force effects. Detailed simulations and experimental investigations are underway to quantify the magnetic field effects and study the stability of operation in the case of low CO_2 admixture.

The readout of the full FDC detector will require 2300 wire channels and 10,300 cathode strip channels. It is critical for both, wire and strip resolutions, to have a low noise-to-signal ratio even with a large detector capacitance (up to 100pF for the strips). For that purpose, an eight-channel preamplifier employing a novel ASIC was designed [4], providing good readout density at reasonable cost. The preamplifier has a peaking time of 11ns. Noise of about 2000e+20e/pF has been measured at a gain of 3mV/fC. The ASIC also includes a discriminator that will be used for the wire readout, connected to 64-channel TDC. In case of the strip readout, the differential outputs of the preamplifier are fed into a 72-channel flash ADC [5] with 8ns sampling time.

STUDIES WITH FULL-SCALE PROTOTYPE

Three full-scale drift chamber layers have been built to investigate the chamber performance. The results presented here were done with 40/60% Ar/CO_2 mixture using cosmic tracks, although other studies were done with radioactive sources and other gas mixtures.

The use of flash ADCs provides the opportunity to implement powerful methods to reduce the noise. The noise in adjacent channels with similar strip lengths has similar time structure and magnitude. This allows subtraction of the common noise from the signal using the channels not affected by the hit. By reading the flash ADC samples and applying such a procedure off-line, we were able to achieve a position resolution from the strips as good as 100μ m (Fig.3). Since the avalanches are created near the sense wires, the strips can be used to reconstruct the wire positions. That allows the estimation of the strip resolution. The strips are oriented at 75^{o} with respect to the wires and a geometrical factor was taken into account to estimate the resolution in reconstructing the position along the wires. The position is reconstructed by calculating the center-of-gravity of the signals above a certain threshold induced on at least five adjacent strips. Thus the resolution is dominated by the signal-to-noise ratio. One can see from Fig.3 that the resolution improves by increasing the signal amplitudes (via high voltage), which means that the signal-to-noise ratio increases at the same time.

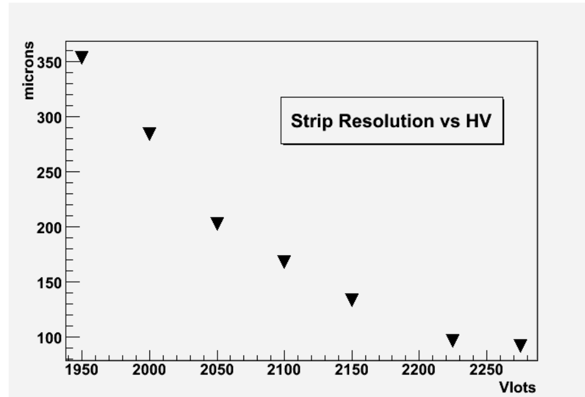

FIGURE 3. Preliminary result for the cathode strip resolution in reconstructing the position along the wires, for different sense wire voltages using cosmics (Ar/CO_2 40/60%, plateau starts at 2000V, field wire at -500V).

To estimate the wire resolution, two chamber layers were placed one on the top of the other, with wires oriented in the same direction. The difference between positions reconstructed from the two chambers was compared with the same difference calculated from the angle of the cosmic track reconstructed with an external tracking system. Because of the small distance between the chambers as compared to the base of the external system, the resolution of the latter does not contribute to the presented results. The estimated wire resolution is plotted at Fig.4 as a function of the distance to the wire in one of the chambers, averaged over the same distance in the other chamber. The measured resolution reaches the design value. However, an additional contribution is expected from the magnetic field effects. Possible improvements of the time-to-distance relation and of the gas mixture are studied using Garfield code [6] and tested experimentally.

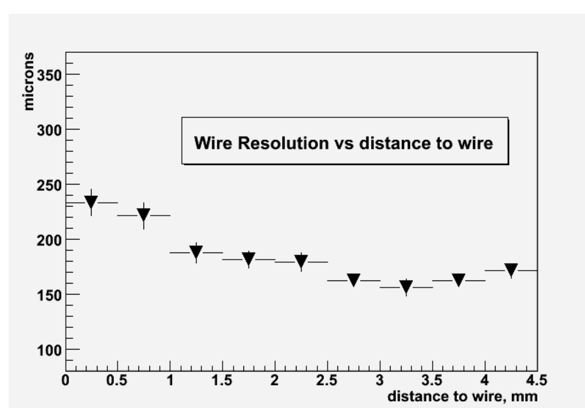

FIGURE 4. Preliminary result for the wire resolution using cosmics (Ar/CO_2 40/60%, 2225/-500V sense/field wire voltage).

We found that the chamber required higher than expected (from previous studies) high voltage to achieve maximum efficiency. Further investigations showed that the plateau starts earlier for hits with smaller drift times. This is illustrated at Fig.5 where the mean wire charge is plotted against the drift time. The wire charge was calculated from the maximum wire amplitude, as recorded with the flash ADC, taking into account the preamplifier gain. Thus, it represents the charge integrated over the peaking time of the circuit, rather than the total charge. The drop of the charge with increasing drift time indicates that the electrons recombine while drifting to the anode wire. Garfield simulations including only a 0.1% oxygen contamination (Fig.5) can explain the above behavior. Indeed, the above percentage was confirmed by measuring the oxygen contamination of the gas in the chamber. The contamination is a result of poor gas tightness due to the fragile G10/Rohacell frames. A mechanical prototype with a solid G10 ring at the position of the gas spacers was constructed. This increased the frame thickness by only a small fraction but at the same time guaranteed the gas tightness of the chamber.

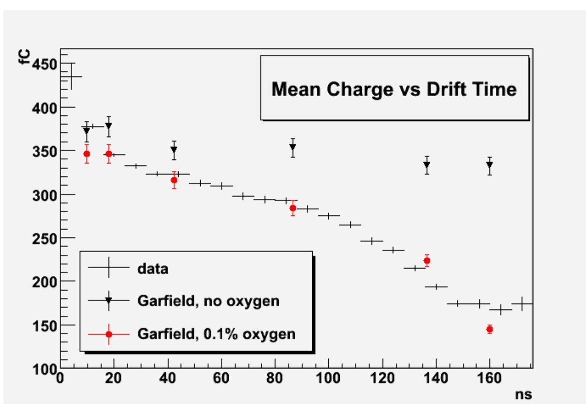

FIGURE 5. Preliminary results: Mean charge, as obtained from the flash ADC maximum amplitude, versus drift time, compared to Garfield [6] simulations without and with 0.1% oxygen contamination (2225/-500V sense/field wire voltage, Ar/CO_2 40/60%).

SUMMARY AND CONCLUSIONS

The GlueX experiment will search for hybrid mesons with exotic quantum numbers not allowed by the quark-antiquark meson model. The Forward Drift Chamber was designed to track charged particles with high resolution needed to identify the decay products of the hybrid mesons. The information from both, the wires and the two cathode strip planes, allows reconstruction of a spatial point within one chamber layer, improving the pattern recognition. The mechanical design reflects the delicate balance between robustness and low detector thickness minimizing the loss of detected photons in the e.m.-calorimeters due to conversions. Low noise to signal ratio was achieved by using novel ASIC preamplifiers and flash ADCs. Studies with a full-scale prototype demonstrated that the design strip and wire resolutions can be achieved. It was found that the oxygen contamination of the gas was responsible for the poorer signals at larger drift distances. The investigations with the prototype helped to improve significantly the FDC mechanical and electrical design. The FDC production will start at the end of 2010.

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