Performance of PHENIX Muon CSCs with Different Chamber Gases

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1 Introduction

The performance of a prototype PHENIX muon cathode strip chamber (CSC) with different chamber gases has been studied. Since the muon tracking chambers will reside inside a magnet during operation, it is preferable to have a chamber gas which has a small Lorentz angle to minimize the resolution degradation caused by the Lorentz angle. A search of the literature was performed to see what gases would give us our desired small Lorentz angle [1]. Several recommendations were given for CF_4 mixtures which would give a relatively small Lorentz angle in our magnetic fields. To understand the performance of our chambers with these gas mixtures, the resolution, efficiency, and charge distributions were studied for gas mixtures of CF_4:isobutane (50:50), CF_4:isobutane (20:80), CF_4:CO_2:isobutane (20:60:20), CO_2:CF_4 (50:50) and Ar:isobutane (70:30) bubbled through isopropyl alcohol. The last gas was used as a reference gas that has been well studied, to which we could compare the faster gas mixtures.

2 The Prototype Cathode Strip Chamber and Readout System

The chamber that was used for the gas studies was a full-size Station 2 prototype cathode strip chamber that contained one gap. A full description of the chamber can be found in [2]. The chamber half-gap was 0.32 cm, the anode wire spacing was 1 cm, and the cathode strip spacing was 0.5 cm, with 1 cm readout.

Sixteen cathode strips were instrumented with NMS preamplifiers (ref), which went to an 11-bit FERA ADC and was read out using a CODA [3] data acquisition system. The NMS amplifiers are not the amplifiers that will be used in the final PHENIX system, and are known to be noisier than the specifications that have been given for the PHENIX electronics. A calibration of the amplifier-ADC system found that the noise in the system is approximately 14600 electrons/channel or 2.3 fC. Because of this large noise (our PHENIX noise specification is 3000 electrons/channel), our resolution is limited by noise and can be expected to meet our 100 μm specification only at the highest gains of the chamber.

3 Cosmic-Ray Test Stand and Analysis Methods

3.1 Test-Stand

A cosmic-ray test stand was assembled to test the CSC (see Figure 1). The test stand consisted of two scintillators for triggering on cosmic rays and four drift chambers for tracking the cosmic rays to the prototype chamber. Each drift chamber had two x planes and two y planes, giving a total of eight x and eight y planes for tracking.

The acceptance of the cosmic ray test stand covered approximately (0,11) degrees with respect to a track that would be normal to the anode wires, and the angular distribution was centered around approximately 5 degrees because of the alignment of the chambers, the instrumented area of the CSC, and the position of the scintillators.

The resolution of each drift chamber plane was approximately 100 μm, giving a pointing resolution of approximately 80 μm if a chi-square cut of 1.0 was placed on a fit to straight tracks passing through the chambers. The resolutions that were measured were therefore a quadrature sum of an 80 μm projection error plus the intrinsic resolution of the CSC. Cosmic rays were used to align the drift chambers and CSC, and the error in the alignment is somewhat uncertain but is expected to be small compared to the 80 μm projection error.

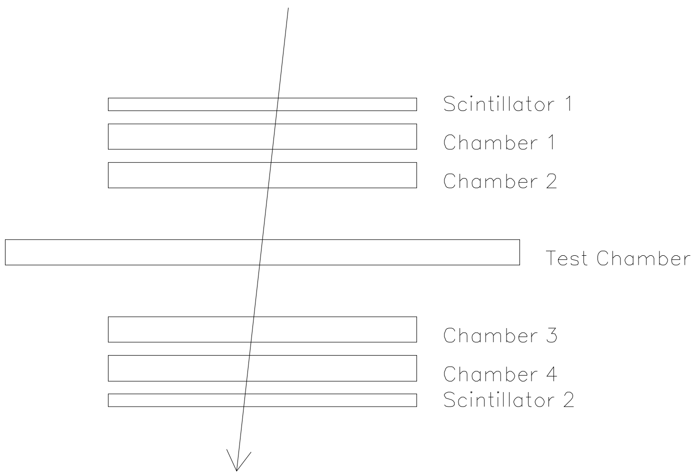

Figure 1: A schematic of the cosmic-ray test stand that was used to study the performance of the prototype CSC.

3.2 Calibrations

The sixteen cathode strip electronics channels were calibrated by putting a square pulse of known duration and voltage through a resistor pack into the preamplifier. This gave us a known charge that went through the amplifier into the charge-integrating ADC, allowing us to calculate the number of channels/fC in the amplifier-ADC chain. The resistors were matched to about 1%, and no correction was made for the difference in resistor values, so some calibration error may also be contributing to our resolutions.

The position of a track in the CSC was extracted from the pulse- height distribution measured on the cathode strips. The position was extracted from Q_m/Q_{tot} where Q_m is the charge measured on the peak strip and Q_{tot} is the sum of charges measured on all strips in a cluster. A cluster is defined to be a contiguous set of strips which are above a threshold cut.

The calibration of hit position versus Q_m/Q_{tot} was determined using cosmic rays which are assumed to uniformly populate the instrumented area of the chamber. If the distribution is uniform then one can write:

$$\frac{dN}{dx} = \frac{dN}{dq}\frac{dq}{dx} = c \tag{1}$$

where q = Q_m/Q_{tot} and x is the position on the strip Q_m. If you invert $\frac{dq}{dx}$ and integrate:

$$\int \frac{dN}{dq} dq = c \int \frac{dx}{dq} dq \tag{2}$$

$$x \propto \int \frac{dN}{dq} dq \tag{3}$$

showing that x is proportional to the integral $\int \frac{dN}{dq} dq$ integrated up to q. A table of $\int \frac{dN}{dq} dq$ is taken from the uniformly distributed cosmic ray data and is normalized by requiring that the integral from 0 to infinity is equal to the distance between readout strips. This provides a look-up table for converting Q_m/Q_{tot} into x.

3.3 Efficiency Calculations

Efficiencies were measured by selecting tracks from the drift chambers which pointed to the instrumented area of the CSC and requiring that the CSC:

- Have one cluster in the active area of the chamber.
- Have at least two cathode strips in the cluster above threshold so that it is possible to fit the position of the track.
- The resulting fit position must be within 0.5 cm of the projected position of the drift chambers.

If more than two clusters were found in the instrumented section then the CSC was recorded as being inefficient, so it is quite possible that the efficiencies that will be listed below are somewhat smaller than they will be when more sophisticated tracking software is used.

4 Performance of CSC with Different Gases

As stated in the introduction, the resolution, efficiency, and charge distributions were studied for each gas mixture. Results will be given for Ar:isobutane (70:30), CF_4:isobutane (50:50), CF_4:isobutane (20:80), and CF_4:CO_2:isobutane (20:60:20). A mixture of CO_2:CF_4 was also tried, but we were unable to get stable performance from the chamber except over a very limited voltage range at low gain. It is uncertain whether this was because of the gas mixture or a problem with our gas system, so it will be studied some more in the future.

4.1 Charge Distributions

For each of the gas mixtures, data were taken from the cosmic-ray test stand chambers and the CSC at several voltages of the CSC covering the efficiency plateau. For each of these voltages, cathode strip clusters were found and the voltage of the peak strip in the cluster was recorded. The mean value of this peak strip versus chamber voltage for the four gas mixtures is shown in Figure 2. As can be seen in the figure, the CF_4 mixtures tend to require higher operating voltages to reach the efficiency plateau, but they also tend to produce larger signals on the cathode strips across the plateau. This latter feature may be an advantage since it should be easier to meet our signal-to-noise requirements if we have larger signals in the chamber. However, we must also make sure that our ADC gives us the needed range to cover the expected cathode strip pulse heights if we are to use a CF_4 mixture.

4.2 Efficiency Plateaus

For each gas mixture, the efficiency of the CSC was measured for several voltages. The efficiency was determined in the way that was described in the Analysis Methods section and the voltages were selected to try to cover the efficiency plateau from the low efficiencies up to break-down voltage. For some of the mixtures, the data points do not go all the way down to the low efficiency region, but are close. The data are shown in Figure 3.

All gas mixtures showed a reasonably broad plateau with the CF_4:isobutane (20:80) giving the largest plateau of approximately 500 V.

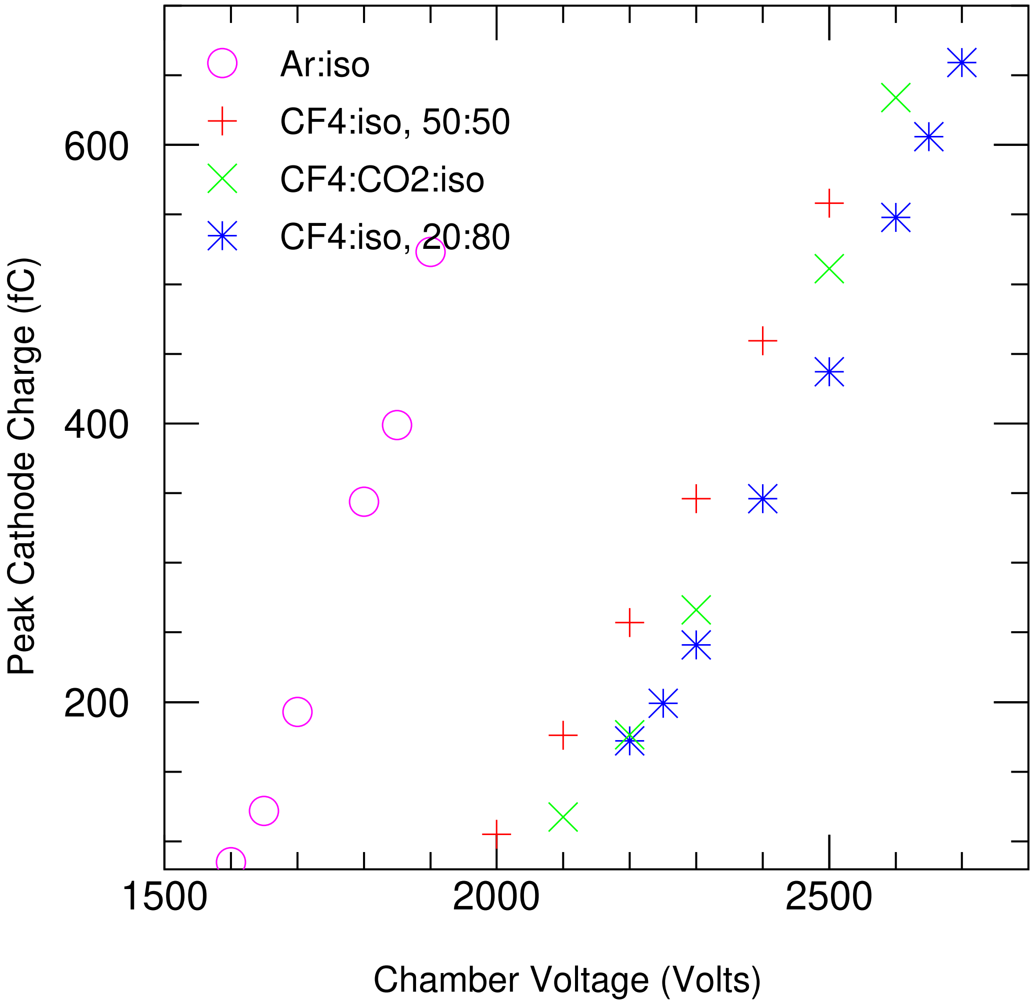

Figure 2: The average charge of the peak cathode strip (converted into fC) versus chamber voltage for the four gas mixtures studied.

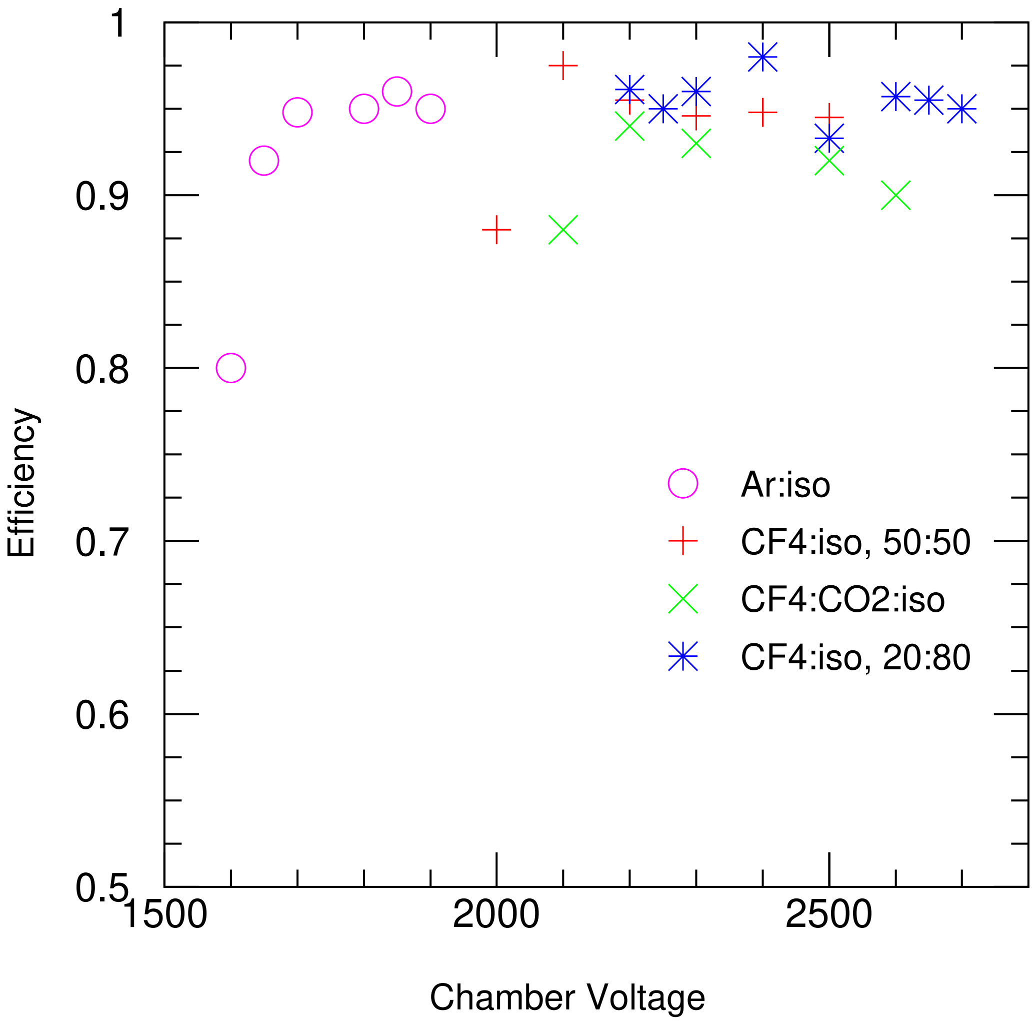

Figure 3: The efficiency of the CSC versus chamber voltage for the four gas mixtures studied.

4.3 Chamber Resolution

All gas mixtures achieved a resolution of approximately 100 μm at the high end of the efficiency plateaus, where the signal-to-noise ratio should have been close to what we hope to achieve with the PHENIX electronics. An example resolution distribution, averaged over all accepted tracks, pulse-heights, etc. is shown in Figure 4 for the CF_4:isobutane (20:80) mixture, at 2650 volts.

If the expected projection error of 80 μm is subtracted from the residual, we obtain a resolution of approximately 85 μm for the chamber with this gas and voltage setting.

5 Conclusions

All the gas mixtures studied in this paper will give good chamber resolutions and have a broad operating plateau. However, the CF_4 mixtures have significantly smaller Lorentz angles, and they also appear to provide a better possibility for maintaining good signal:noise ratios because they give larger pulse-heights on the cathode strips across the plateau. The CF_4:isobutane, (20:80) mixture appears to be the best of the CF_4 mixtures because it has the largest operating plateau, larger cathode signals, and according to the literature has one of the smallest Lorentz angles (approximately 8.5 degrees at 1 Tesla).

References

[1] B. V. Dinesh, "Lorentz Angle Effect in Gas Mixtures," http://phnxmu.lanl.gov/Files/muon/notes/phenix-muon-95-22/dinesh.html.

[2] D. M. Lee, et al, "Large CSC Chamber for the PHENIX Muon Detector with Ultra Thin Cathode Foils," 1996 IEEE Nuclear Science Symposium Conference Record, Vol. 1, 274.

[3] CEBAF On Line Data Acquisition, http://alcor.cebaf.gov/coda/.

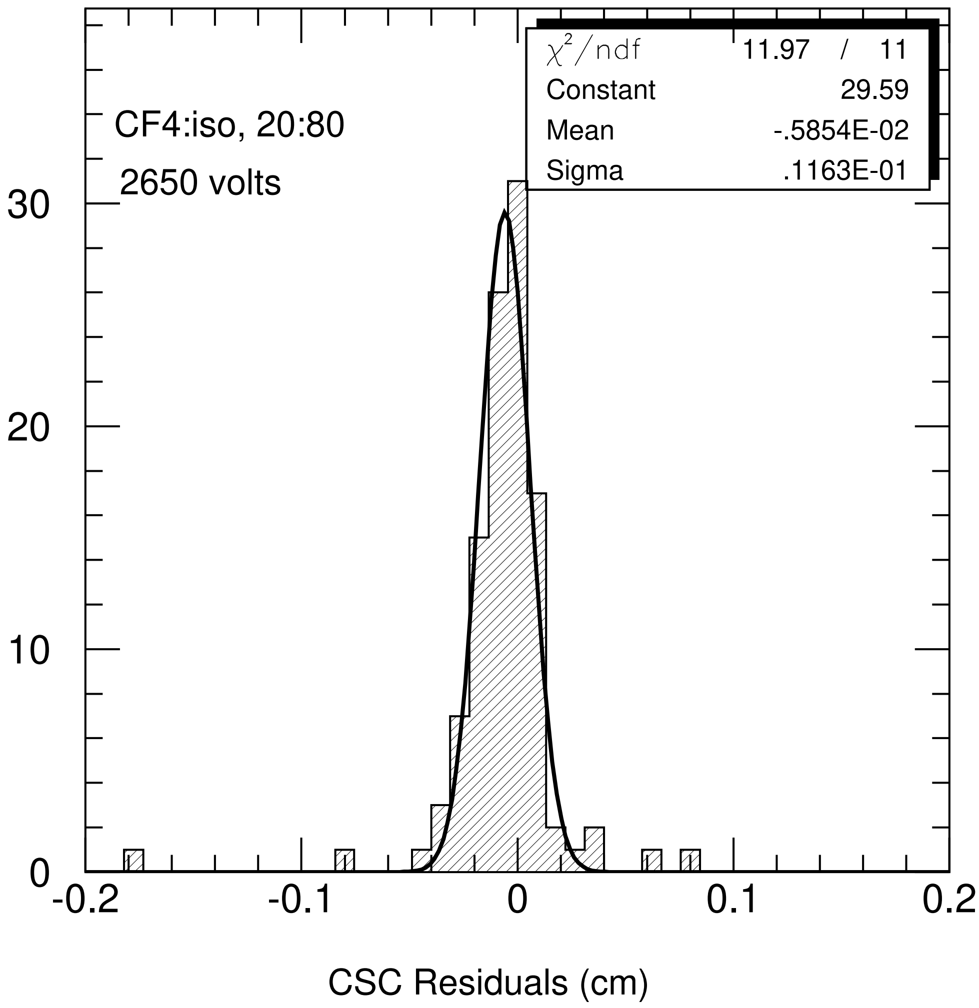

Figure 4: The residuals of the projection of the cosmic ray test-stand fitted track minus the fitted position in the CSC. The residuals include all tracks in the active area that pass a chi-square cut in the drift-chamber fit of less than 1.0.