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STUDIES OF HELIUM BASED DRIFT CHAMBER GASES FOR HIGH-LUMINOSITY LOW ENERGY MACHINES*

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Abstract

Future high luminosity low energy machines will need low mass tracking chambers in order to minimize multiple scattering of the relatively low momentum tracks produced at these facilities. A drift chamber using a helium based gas rather than a conventional argon based gas would greatly reduce the amount of multiple scattering. This paper summarizes measurements of the drift velocity and position resolution for gas mixtures of helium with CO_2 and isobutane and helium with DME. Good spatial resolutions are obtained. A design of a drift chamber with only 0.12% of a radiation length (gas plus wire) over a 60 cm tracking distance is presented.

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◇Presented talk.

1. Introduction

At future B factories, Tau/Charm factories, or Phi factories, the availability of large samples of events will provide measurements with small statistical errors. It will be desirable to reduce the systematic errors also. One of the limitations on the momentum resolution of tracks at these energies, which are predominantly at low momenta (< 1.0 GeV/c), is the error due to multiple scattering in the tracking chambers. Another source of error at high luminosity electron-positron machines is the synchrotron photons that can cause high singles rates in the tracking chambers, causing confusion in the track finding and fitting. Both of these problems can be minimized by reducing the amount of scattering material in the tracking chambers with the use of a gas with low atomic number, such as helium, and wire material with low mass. This paper describes measurements of drift chamber properties with helium based gases, and also presents a design of a drift chamber with a helium based gas for use at a B factory.

Typical large drift chambers using an argon gas can achieve spatial resolutions of about 140 μm and momentum resolutions of about (0.5 to 1.0)p%, where p is the transverse momentum of the track in GeV/c. Multiple scattering in the chamber adds about 0.7% in quadrature to the momentum resolution. For track momenta less than 0.5 GeV/c, the momentum resolution is dominated by multiple scattering. Since the radiation length of helium is much longer than that of argon, a helium based gas mixture could reduce the multiple scattering term considerably. Helium alone is not a stable gas for drift chambers and must be mixed with a quencher. The first large drift chamber to use helium measured a resolution of 260 μm [1] with a mixture of helium and 6% propane. Measurements in a MarkII prototype chamber with a helium:CO_2:isobutane(78:15:7%) mixture indicated a resolution equal to that with an argon based gas [2]. Recent measurements

with varying amounts of CO_2 and isobutane in helium have been reported by our group [3] and by Playfer et al. [4], showing that good spatial resolution is attainable. Mixtures of helium-DME have been used by Cindro et al. [5] and Playfer [4], showing that even better resolutions are provided by these mixtures.

1.1 Gas Properties

Properties of individual gases and gas mixtures are shown in Table 1 [6,7], giving the radiation length X_0 and the primary and total ion-pair production in the gas at 1 atm and 20°C from a minimum ionizing particle. The ion-pair values given for mixtures are simply the sum of the fractional components in the mixture. Several mixtures of helium are shown, as well as an example of an argon based gas for comparison. From the table we see, for example, that the Helium:CO_2:isobutane(83:10:7%) mixture, hereafter denoted as HCI107, has a radiation length 7.7 times larger than the argon mixture Ar:CO_2:CH_4(89:10:1%), and so would greatly reduce multiple scattering. On the other hand, HCI107 produces only 39% as many primary ion pairs as the argon mixture, so we would expect a poorer spatial resolution from the helium mixture. However, the measurements show that the spatial resolution of the helium mixture is in fact comparable to the argon based gas.

One interesting property of helium mixtures is the possibility of increased ionization due to the Penning effect. Helium has a metastable state at 19.8 eV, which is higher than the ionization levels of other components (13.7 eV for CO_2, 10.6 eV for isobutane) used in the mixtures in Table 1. Helium atoms that are excited to metastable states by the passage of a particle in the gas or in the avalanche process near the sense wire, are able to transfer energy by collision to other atoms, which in turn ionize and so increase the total number of primary ions.

In pure helium, the metastable states can only de-excite by photon emission, and not by ionization. Some studies of Penning mixtures have been made on Ne-Ar mixtures [8,9], but no calculations have been found for the mixtures considered here.

2. Spatial Resolution

Our measurements in He-CO_2-isobutane [3] were made in a jet cell having a maximum drift distance X of 33 mm, a sense wire diameter of 30 μm, and six sense wires spaced 8.33 mm apart. Figure 1 shows the spatial resolution from approximately 1000 cosmic ray tracks in the cell for each gas mixture operating at a charge density of about 14 nC/m on the sense wire (for a chamber voltage of 4600 V), and an electric field of 900 V/cm in the uniform field region. For the HCI107 mixture, the resolution is very similar to that of the Argon mixture. Figure 2 shows resolutions, averaged over the range $X < 8$ mm and $X < 24$ mm, for various mixtures of gas as a function of the high voltage on the chamber. The HCI107 mixture appears to be the best overall choice for providing the longest radiation length, the best resolution, and the largest operating region in chamber voltage.

Another gas mixture of interest is He:DME. The radiation length of DME is relatively large, it provides a large number of ion-pairs, and is a good quencher. Measurements in He:DME(70:30%) mixtures by Cindro et al. [5] in a small cell geometry, and by Playfer et al. [4] in a jet cell geometry are shown by the dashed lines in fig. 1. The resolution near the wire is comparable to that for the He:CO_2:isobutane mixture, but has a considerably better resolution of about 80 μm at a few millimeters from the sense wire.

3. Drift Velocity

Drift velocities in helium mixtures tend to be relatively slow, as shown in fig. 3. At E/p values of 600 V/cm at 1 atm, the drift velocity for the HCI107 gas is about 18 μm/ns, and for the mixture with 30% DME it is about 6 μm/ns. Whether such a low drift velocity is desirable or not depends on the experiment.

4. Cell Design Considerations For Helium Mixtures

Having greatly reduced the amount of material in the gas by using a helium mixture, the wire material becomes significant and its mass must also be reduced. One would like to choose a cell design with the least amount of wire volume in the chamber, and a wire material with the least amount of radiation lengths.

In a B factory workshop at SLAC [2], we made detailed comparisons between a small cell and a jet cell drift chamber for use at a B factory. In both cases we considered 40 layers of sense wires, grouped into eight or ten superlayers, with the superlayers alternating between axial (wires along the cylindrical axis) and stereo (wires at about 3° to the axis) directions; the inner and outer radii of the chamber were 18 and 80 cm, respectively. The (half) cell sizes used were 7.5 mm for the small cell and 25 mm for the jet cell. Sense wires were spaced 10 mm apart in the jet cell. The most obvious difference between the two cases is the fewer number of sense and field wires in the jet cell, by about a factor of two, and the linear electric field in the jet cell. The jet cell has the advantage of fewer electronic channels, and a simpler time-to-distance relation, but the small cell also has its advantages.

We studied the amount of wire material, averaged over all cells, for the two designs and found that even though the small cell has more wires, the total amount of wire material is less in the small cell case by about 16%. This is primarily due to

the additional (thicker) wires necessary in the jet cell at the ends of the cell, where the fields on the wires are large due to boundary effects between superlayers.

There are other advantages in the small cell design. The spatial resolution is better because diffusion is not a factor at small drift distances. The aging lifetime should be better by a factor of two, because the ionic volume swept by a sense wire is half as large. The pipeline electronics can be shorter because the maximum drift time is smaller by a factor of three. Particle identification by dE/dX is slightly better, since all the gas is sampled (jet cells have dead space between superlayers). Finally, the critical tension needed on the sense wires for electrostatic stability is about five times less [2] for the small cell than for the jet cell. This means that sense wire tensions, and also field wire tensions, can be reduced in the small cell design, thereby reducing the thickness of the end plates. This also allows lighter materials (such as aluminum, which tends to creep at higher tensions) to be used safely for the field wires at a lower tension.

We have chosen a small cell for our B factory R&D, and considered both a square cell as well as a hexagonal design. The helium based gases all have drift velocities that are almost linear with electric field at low electric field values, so any cell with a low field region will suffer with long collection times. The corner regions of the square cell have such undesirable low fields. A hexagonal design has much less of a corner, and would be a better choice, except for the matching difficulty at superlayer boundaries. A possible solution is to place additional wires at the mid radius of the zigzag pattern of field wires at a layer boundary, producing a layer of wires at a constant radius which now allows azimuthal dislocation of cells across superlayer boundaries, as shown in fig. 4. In effect, the hexagonal cells become square at the superlayer boundary. Figure 5 shows isochrones [10] for a cell within a superlayer as well as for a boundary layer. The collection time from hexagonal

corners is good, while cells at superlayer boundaries behave like half square and half hexagonal.

With the above cell structure, we can calculate the total radiation lengths in a B factory chamber and the expected resolution. Table 2 shows the amount of radiation lengths in a chamber with 40 cylindrical layers of hexagonal cells extending in radius from 19 cm to 80 cm with 6800 cells total. The total material seen by a track traversing at 90° to the chamber axis is 0.0012 radiation lengths for the HCI107 gas/aluminum wire compared with 0.0066 for the argon mixture/copper wire. Figure 6 shows the momentum resolutions for these cases, calculated by a computer program by W. Innes [11] which uses the method of Billoir [12] to treat the correlated errors from multiple scattering from layer to layer. Three layers of silicon strip detectors at a radius of 2.7 cm from the interaction point have also been included. The magnetic field is 1.0 Tesla. Average spatial resolutions of 140, 140, and 110 μm were used for the Argon, He-CO_2-isobutane, and He-DME mixtures, respectively. The helium mixtures are seen to have a resolution about half that of the argon mixture at momenta from 0.1 to 0.5 GeV/c. Below 0.12 GeV/c, the tracks spiral in the drift chamber, making fewer hits and therefore resulting in poorer resolution as the momentum decreases. The difference between the He-CO_2-isobutane and He-DME mixtures is slight. The He-DME mixture shows its improved resolution above 1 GeV/c, and a slightly poorer resolution below 0.4 GeV/c.

Conclusion

Drift chambers using helium-CO_2-isobutane or helium-DME mixtures are well suited for use at future low energy machines. Momentum resolutions about half that of argon-based chambers can be expected in the low momentum range of interest. The drift velocity of these mixtures is relatively low, especially in the DME mixture, which may require the use of electronics with longer pipeline storage in a high trigger environment. Aging properties of these mixtures has yet to be measured.

REFERENCES

[1] W. Zimmermann, V. Hepp, R. Kellogg, M. Schmitt, A. Skuja, A. Backer, C. Grupen, H. Suhr, G. Zech, N. Magnussen, H. Meyer, Nucl. Instrum. Methods A243 (1986) 86.

[2] A. Boyarski, P.Burchat, M. King, A. Weinstein, in Proc. Workshop on Physics and Detector Issues for a B Factory, 1990; SLAC–373 (1991). A. Seiden first suggested the use of this mixture.

[3] P. Burchat, J. Hiser, A. Boyarski, D. Briggs, SLAC–PUB–5626 (1991).

[4] S.M. Playfer, R. Bernet, R.A. Eichler, B. Stampfli, ETHZ–IMP–PR–91–3 (1991).

[5] V. Cindro, H. Kolanoski, A. Lange, D. Lauterjung, F. Muller, T. Siegmund, W. Soder, H. Thurn, NIM A309 (1991) 411–421.

[6] Review of Particle Properties, Phys. Lett. B239 (1990).

[7] F. Sauli, CERN Report 77–09 (1977). DME values from F. Sauli, private communication.

[8] H. Sipila, IEEE Trans. Nucl. Sci. NS–26 (1979) 181.

[9] J.P. Sephton, M.J.L. Turner, J.W. Leake, Nucl. Instrum. and Methods 219 (1984) 534.

[10] The isochrone plots were provided by E. Soderstrom, SLAC.

[11] W. Innes, TKFTMN, A program for calculating tracking errors, SLAC, 1991.

[12] P. Billoir, Nucl. Instrum. and Methods 225 (1984) 352.

Table 1

Radiation length X_o, [6] and the primary and total ion-pair production [7] from a minimum ionizing particle traversing a gas at atmospheric pressure and 20°C. Individual gas components and mixtures used in this study are shown..

Gas Mixture	Ratio	X_o (m)	Primary Ions/cm	Total Ions/cm
Helium (He)	–	5690	5.9	7.8
Argon (Ar)	–	118	29.4	94
Methane (CH_4)	–	696	16	53
Carbon Dioxide (CO_2)	–	196	34	91
Isobutane (C_4H_{10})	–	182	46	195
DME (C_2H_6O)	–	238	55	160
HRS gas (Ar:CO_2:CH_4)	89:10:1	24	29.7	93.3
He:CO_2 :isobutane	73:20:7	652	14.3	37.5
	78:15:7	777	12.9	33.4
	83:10:7	960	11.5	29.2
	88:5:7	1258	10.1	25.1
	82:15:3	931	11.3	25.9
	80:10:10	833	12.7	34.8
He:DME	70:30	723	20.6	53.5
	80:20	1020	15.7	38.2

Table 2

Radiation length inside a drift chamber having 40 layers of hexagonal cells and (A) an Ar-CO_2-methane mixture and copper field wires, or (B) a He-CO_2-isobutane HCI107 mixture with aluminum field wires. The gas is at atmospheric pressure at 20° C. The tracking length is 60 cm.

	Number of Radiation Lengths	
	Case A	Case B
6,800 sense wires tungsten (20 μm)	0.00020	0.00020
36,680 field wires (55 μm)	0.00195 (Cu)	0.00031 (Al)
Gold plating on field wires (5 μinch)	0.00008	0.00008
Gas (mixture)	0.0043 (Ar)	0.00061 (He)
TOTAL	0.0066	0.0012

Figure Captions

1. Resolution as a function of drift distance for HRS gas and He-CO_2-isobutane mixtures. The dashed curves for He-DME are from Ref [5] for $X < 6$ mm and from Ref [4] for $X > 4$ mm.

2. Resolution as a function of chamber voltage for Ar-CO_2-methane and various He-CO_2-isobutane mixtures (4600 volts gives 14 nC/m on the 30 μm sense wire).

3. Drift velocity as a function of the electric field at atmospheric pressure for Ar-CO_2-methane, He-CO_2-isobutane, and He-DME [5] mixtures.

4. A drift chamber design based on hexagonal cells arranged in superlayers. The cell size is approximately 1 cm per side. A layer of field wires is placed midway between superlayers to allow cells to change size and relative position across a superlayer boundary.

5. Isochrones for hexagonal cells, for a He-CO_2-isobutane(83:10:7) mixture in a 1 T magnetic field. The circular contour lines are shown every 100 nsec, and the radial lines show the trajectories of drifting electrons.

6. Momentum resolutions expected in a B factory chamber having 40 cylindrical layers from 19 to 80 cm in radius and 3 layers of silicon strips at 2.7 cm, in a 1 Tesla field for the gas mixtures indicated. The helium mixtures have a better resolution by a factor of 2 compared to the argon mixture for momenta from 0.1 to about 0.5 GeV/c.

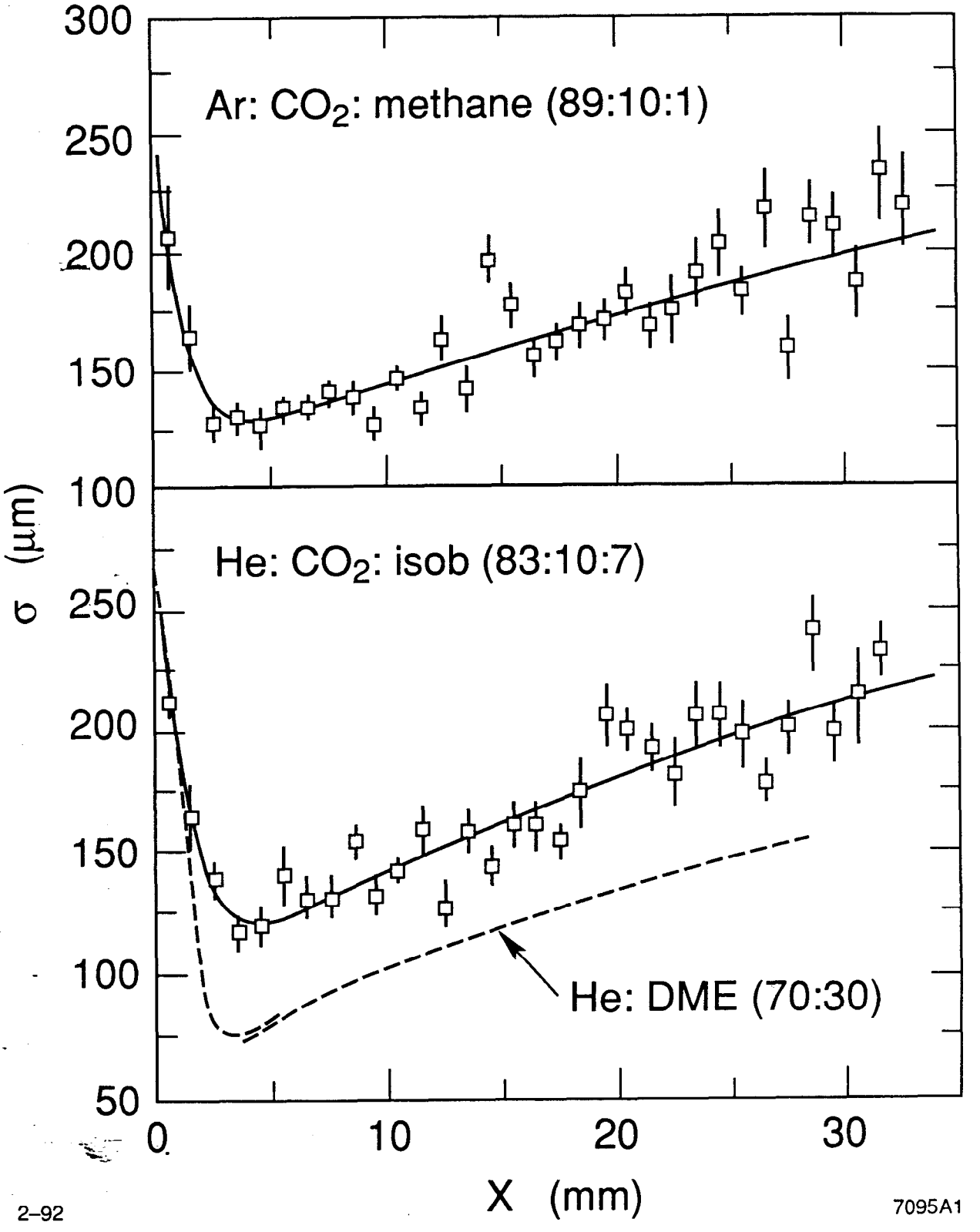

Ar: CO_2: methane (89:10:1)
He: CO_2: isob (83:10:7)
He: DME (70:30)
σ (μm)
X (mm)
300
250
200
150
100
250
200
150
100
50
0
10
20
30
2–92
7095A1

Fig. 1

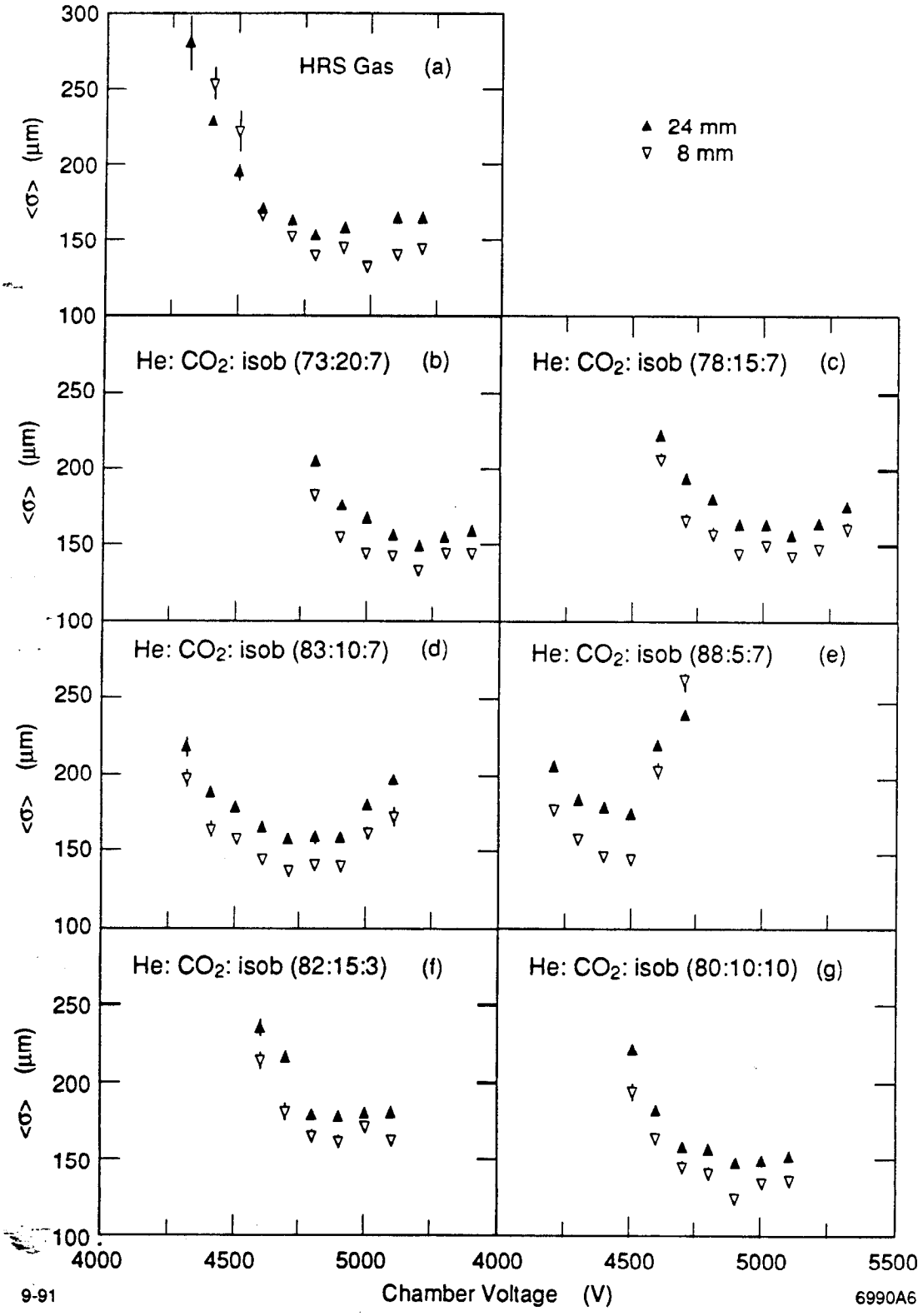
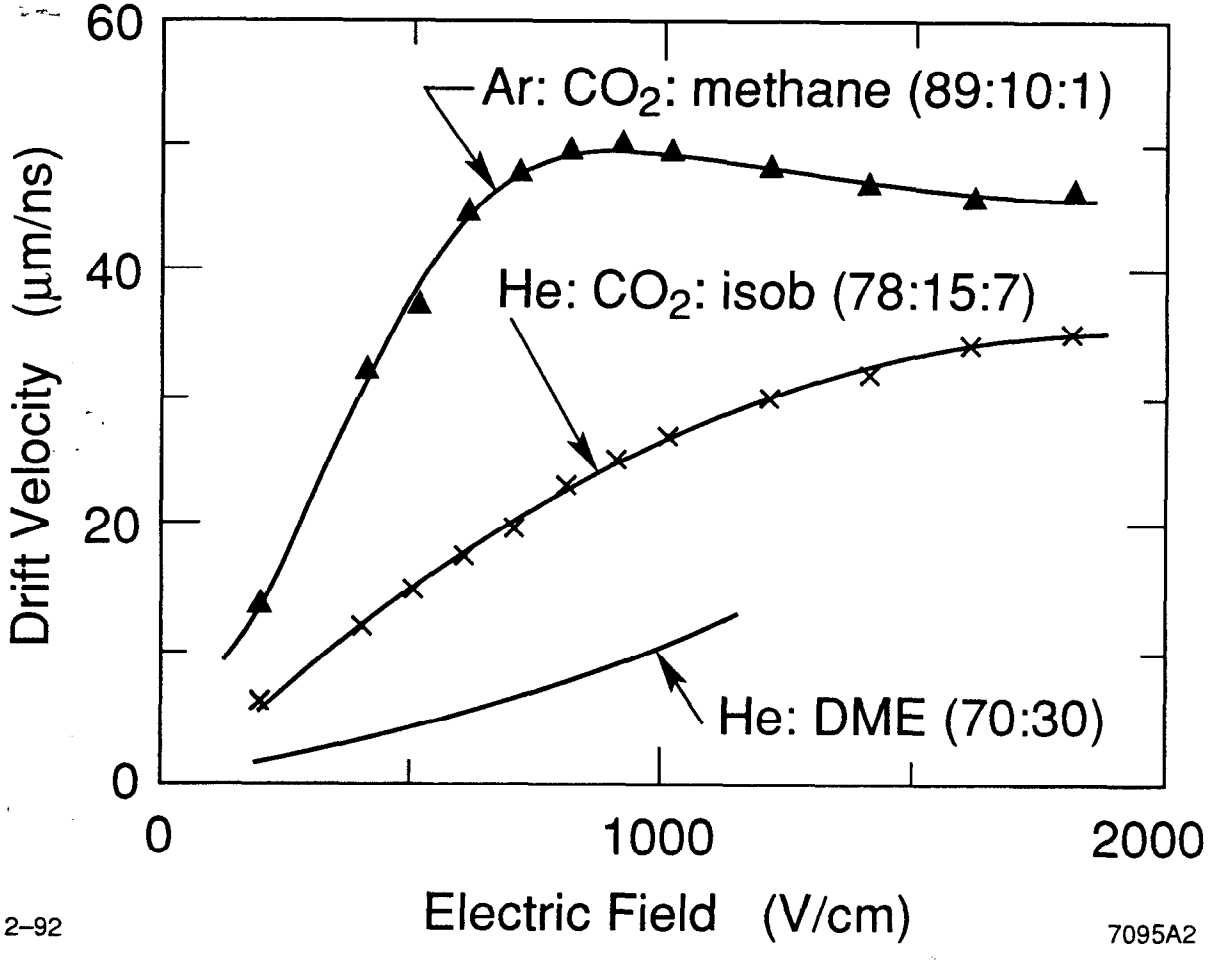

HRS Gas (a)
▲ 24 mm
▽ 8 mm
He: CO2: isob (73:20:7) (b)
He: CO2: isob (78:15:7) (c)
He: CO2: isob (83:10:7) (d)
He: CO2: isob (88:5:7) (e)
He: CO2: isob (82:15:3) (f)
He: CO2: isob (80:10:10) (g)
<σ> (μm)
300
250
200
150
100
4000
4500
5000
5500
Chamber Voltage (V)
9-91
6990A6

Fig. 2



2-92

7095A2

Fig. 3

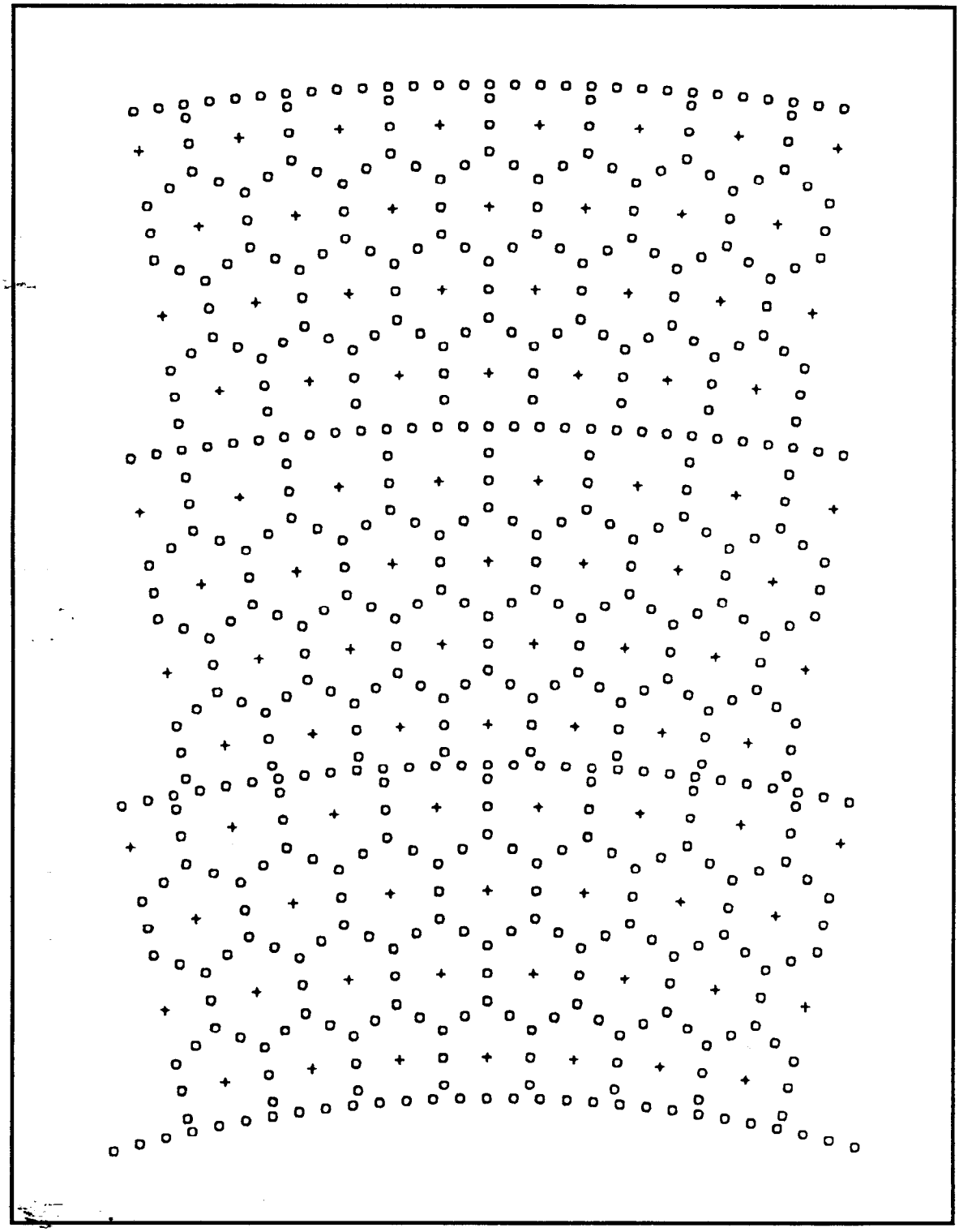
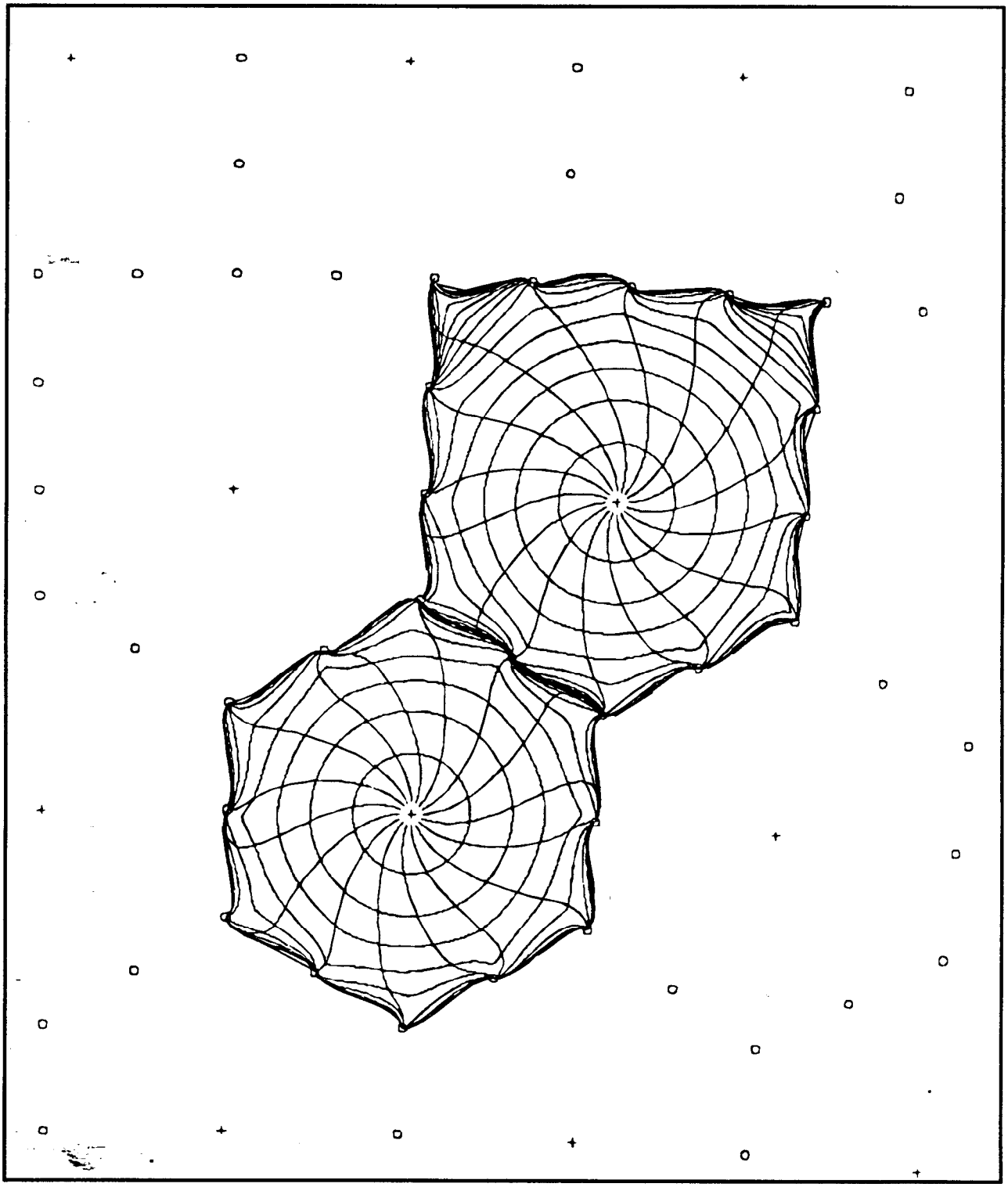


Fig. 4



2–92

7095A5

Fig. 5

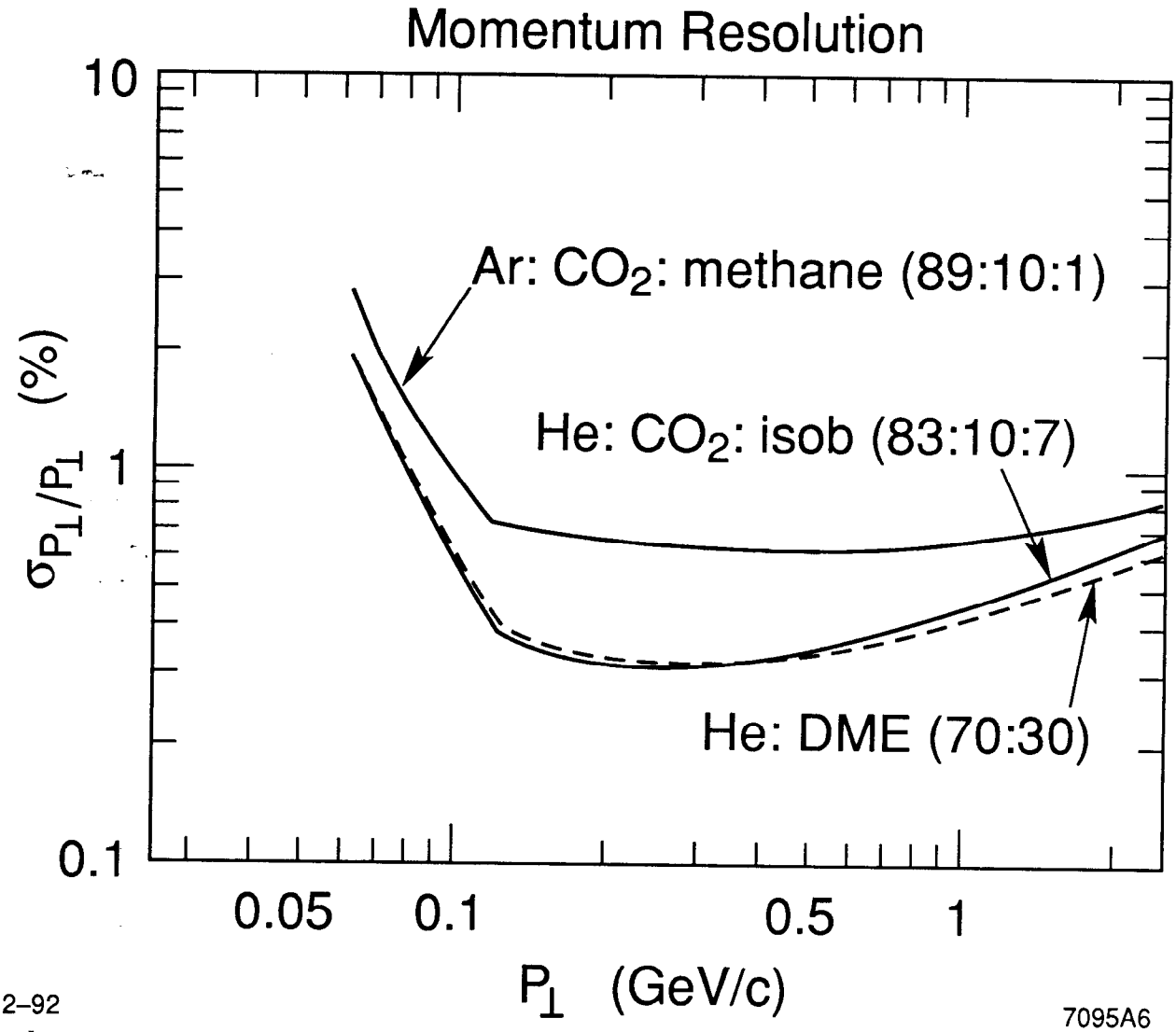

Momentum Resolution
10
1
0.1
$\sigma_{P_\perp}/P_\perp$ (%)
Ar: CO_2: methane (89:10:1)
He: CO_2: isob (83:10:7)
He: DME (70:30)
0.05
0.1
0.5
1
$P_\perp$ (GeV/c)
2–92
7095A6

Fig. 6