GEM TN-93-417

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O. Kiselev, O. Prokofiev, A. Vorobyov

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Abstract

Electron drift velocities and Lorentz angles have been measured in various fast gas mixtures: Ar - CH_4, Ar - C_2H_6, CO_2 - CF_4, Ar - CO_2 - CF_4, and also in pure CH_4, C_2H_6, CF_4, and CO_2. The measurements were carried out in crossed magnetic and electric fields using a new experimental method based on detection of α-decay recoils in coincidence with α-particles. The magnitude of B and E fields could be varied up to B = 1.4 T and E = 6.5 kV/cm. As the result of these studies, a triple Ar - CO_2 - CF_4 mixture was recommended for the GEM Muon System.

Introduction

The goal of the studies was to find a chamber gas for Cathode Strip Chambers (CSC) in the GEM Muon System. The gas mixture should meet a number of requirements:

1. The drift velocities (W) should be fast: W$\geq$ 80mm/μs .
2. The Lorentz angles (α) should be as small as possible: $\alpha \leq 8°$ at B = 0.8 T .
3. Diffusion of the electrons should be low .
4. The gas amplification factor should be up to 10^5 .
5. The gas mixture should be nonflammable, non-aggressive chemically .
6. The CSC aging effects should be small .

On the other hand, there is no strong requirement for high stability of drift velocity. So the operational electric field can be chosen not on the plateau of the W(E) dependence.

Method and Experimental Setup

The measurements of electron drift velocities and Lorentz angles were carried out using a new method based on detection of α-decay recoils [1]. This method provides a possibility to produce ionization in a well localized volume (due to the short range of the recoils) at a precisely determined time (by detection of α-particles). The advantage of the method is high precision in the drift time measurements which is achieved with quite simple technique.

To study the electron drifts in magnetic fields, a special CSC combined with a drift cell was designed (Fig.1). The anode plane is made of 15 μm diam. W/Au wires with 2mm wire spacing. The grid G (25 μm diam.; 0.5 mm wire spacing) separates the drift cell from the CSC. The main drift space (distance between the cathode C1 and G) is

$$L_d = 9.45 \pm 0.02 mm.$$

The anode plane is at equal distances from G and from the cathode C2 (2.18$\pm$0.02mm). Both cathodes are made of the Cu-clad G10 boards. C2 has etched strips on its surface (1.7 mm wide, 2 mm spacing) oriented perpendicular to the direction of the anode wires. All strips are connected to a delay line (5 ns/mm). C2 and G are at zero potential. The HV at C1 was variable while the HV at the anode plane was constant during the measurements. An opening of 0.7 mm in diam. was drilled in C1 opposite to the central anode wire. A similar opening was drilled in C2, but it was shifted along the wire by 5.7mm. These openings were glued with 3 μm Cu foils. Two very thin ^{208}Po α-sources were deposited on the surfaces of these foils. The 5.11 MeV α-particles can penetrate through the foils and are detected with two Si-detectors D1 and D2. The 100KeV recoils are emitted inside the chamber volume. The range of the recoils being very small ($\leq$50μm) [2], they all are stopped in the vicinity of the cathodes.

The electron charge produced by the recoils is collected on the anode. The chamber was placed inside a magnet so that the magnetic field was perpendicular to the electric field

and the drifted charges were deflected along the anode wires in the opposite directions for the left and right drift cells of the CSC. Such two-sided configuration of the drift chamber allows to take into account the drift time and the deflection of the electron charge in the gap between the grid and the anode plane. In the measurements, the start signals were produced by D1 or D2, and the stop signals came from the anode. Fig.2a shows one of the measured time spectra.The distance between the two peaks in Fig.2a is the drift time T_D between C1 and G. The electron drift velocity projected on the electric field direction is determined as

$$W_{\|} = T_D/L_D \ .$$

This measurement of the drift velocity has absolute precision of $\pm$ 1% and relative precision of $\pm$ 0.1%. The position of the avalanche at the anode wire is measured by the delay time of the signals induced on the C2 strips. Fig 2.b demonstrates the measured position spectrum with two peaks corresponding to two α - sources. Let $\Delta\ S_D$ be the displacement of the peak corresponding to the C1 recoils when the magnetic field is changed from B=0 to B. Also let $\Delta\ S_{pc}$ be a similar displacement of the peak corresponding to the C2 recoils. Then the Lorentz angle is

$$\alpha = \mathrm{arctg}\ (\Delta\ S_D - \Delta\ S_{pc})/\ L_D \ .$$

The accuracy of the absolute measurements of α is $\pm$ 0.5°. The amplitude of the anode signals can also be measured.The amplitude spectrum in coincidence with D1/D2 is shown in Fig.3.

The purity of the gases used for the measurements was as follows: Ar(99.99%), CH_4(99.9%), C_2H_6(99.9%), CO_2(99.9%) and CF_4(99.95%). The gases were mixed by a method of partial pressures with accuracy of 1%. During the measurements the gas flow rate was a few chamber volume per hour. The chamber was operated at normal conditions(20°C and 1atm.).

Results

1. Comparison with other high precision measurements.

For comparison with other measurements, we have chosen gas mixtures where the most precise data on electron drift velocities and Lorentz angles are available from experiments with laser beams [3, 4]:

90% Ar + 10% CH_4, 50% Ar + 50% C_2H_6, 100% CH_4, 100% C_2H_6.

Our results are presented in Figs.4 to 9 and in Table 1-4. One can see from the figures that our data agrees well with the data from other precise experiments, wherever such comparison is possible [5, 6, 7, 8].

2. Study of new gas mixtures.

With the goal to find the optimal gas mixture for the CSCs, we have studied the following gases:

100% CO_2, 100% CF_4,

30% CO2 + 70% CF4, 50% CO_2 + 50% CF_4, 70% CO_2 + 30% CF_4,

50% CO_2 + 30% CF_4 + 20% Ar, 50% CO_2 + 20% CF_4 + 30% Ar.

The results are presented in Figs. 10 to 14 and in Table 5-11. The data from other experiments [9, 10, 11] for zero magnetic field in pure CO_2 and CF_4 are also shown. Our results with magnetic field can be compared only with measurements [12] for CO_2 + 50%CF_4.

3. Possible choice of gas mixture for GEM Muon Chambers.

Unfortunately, the requirements of high drift velocity and small Lorentz angle are contradictory : the an increase of W (at fixed E) leads to increase of α. However, the ratio of W to α can be enlarged with the increase of the electric field. This one can see from our data. In most of the gases studied, the ratio W(mm/μs)/α(deg) is around 8 at E = 4 kV/cm, and it is increased to about 12 at E = 6 kV/cm. Practically that means that at E = 4 kV/cm none of these mixtures can simultaneously satisfy the requirements: W $\geq$80 mm/μs and α $\leq$8°. On the other hand, at 6 kV/cm we have a choice between 100% CO_2, 70% CO_2 + 30% CF_4, 50% CO_2 + 20% CF_4 + 30% Ar. All these mixtures meet the above requirements.

The further criteria is the gas amplification factor. From that point of view the triple mixture has some advantage as it provides the highest gas amplification at this value of the electric field. Also this gas mixture proved to be stable enough against electrical break downs. There is an additional advantage of this mixture when it is used in the End Cap CSCs. In this case the deflection of the collected charge by the magnetic field occurs when this charge drifts quite close to the wire ($\leq$1mm) where the electric field is considerably higher than 6 kV/cm. However, one can see from Fig 14 that the Lorentz angle decreases at high electric fields in this gas mixture .This should reduce the effect of the magnetic field on the space resolution of the CSCs. It is important also that α remains small even at low E as some part of the ionization charge may be collected from the space between the anode wires where the electric field is relatively low. All these arguments allowed us to recommend the CO_2/Ar/CF_4 mixture for the GEM Muon System.

In future studies we plan to extend the measurements to higher electric fields and to optimize the components in the mixture.

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Table 1: **Argon-ethane (50/50)**

	B = 0	B = 0.5 T		B = 1.0 T		B = 1.4 T	
E [kV/cm]	W [mm/μs]	W [mm/μs]	α [degree]	W [mm/μs]	α [degree]	W [mm/μs]	α [degree]
0.11	22.7						
0.21	36.8						
0.32	43.8						
0.42	47.6						
0.53	49.8						
0.63	51.2	44.0	30.6	24.8	57.5		
0.74	52.0						
0.85	52.4	48.1	23.9	32.7	50.3		
0.95	52.6						
1.06	52.7	50.0	19.5	38.4	43.6	25.9	59.2
1.16	52.6						
1.27	52.4	50.7	15.8	42.4	37.3	31.5	53.5
1.38	52.1						
1.48	51.9						
1.59	51.6	50.7	12.3	45.7	29.2	37.9	44.5
1.69	51.3						
1.90		50.1	9.9	47.1	22.9	41.7	36.8
1.93	50.7						
2.12	50.1	49.7	8.9	47.4	19.6	43.4	32.4
2.33	49.5	49.2	7.8	47.5	17.5	44.3	28.6
2.54	49.1						
2.65		48.6	7.0	47.4	14.6	45.2	23.8
2.75	48.7						
2.96	48.3	48.0	6.3	47.2	12.5	45.6	20.2
3.17	48.1	47.7	6.0	47.0	11.4	45.7	18.3
3.39	47.8	47.4	5.8	46.9	10.2	45.8	16.2
3.70	47.5	47.1	5.1	46.7	9.4	45.8	14.2
3.81	47.3						
4.02	47.1	47.0	4.7	46.4	8.1	45.8	12.5
4.23	46.9	46.5	4.4	46.3	8.0	45.8	11.6

Table 2: **Argon-methane (90/10)**

	B = 0	B = 0.4 T		B = 0.83 T	
E [kV/cm]	W [mm/μs]	W [mm/μs]	α [degree]	W [mm/μs]	α [degree]
0.07	37.6				
0.13	53.9				
0.17	52.0				
0.22	48.9	17.7	67.2		
0.33		25.7	59.3		
0.43	37.7	29.5	48.8		
0.54		29.9	38.9		69.3
0.64	31.6				63.6
0.85	28.5	27.3	20.1		48.6
1.06	26.6	25.9	14.2		36.5
1.27		25.0	10.6		
1.59	24.6	24.2	7.8		20.0
1.90		23.9	6.0		
2.12		23.8	5.3		
2.64		23.8	3.9		
3.17		23.8	3.1		

Table 3: Methane (100%)

	B = 0	B = 0.5 T		B = 1.0 T	
E [kV/cm]	W [mm/μs]	W [mm/μs]	α [degree]	W [mm/μs]	α [degree]
0.11	23.7	12.0	41.9		
0.21	50.0	21.9	46.6		61.8
0.26		27.0	47.8		
0.32	72.7	32.0	48.9	13.0	63.9
0.37		37.3	49.5		
0.42	87.4	42.4	49.2	16.2	65.5
0.53	98.1	52.9	48.2	19.4	66.5
0.63	102.8			22.7	67.0
0.74	106.5	71.4	44.0	26.2	67.1
0.85	106.8	78.3	41.2	30.1	66.7
0.95	105.1	83.5	38.4	34.3	66.0
1.06	103.6	86.7	35.6	38.9	64.7
1.17				33.0	63.2
1.27	99.7	89.3	30.5	48.4	61.3
1.37					59.5
1.48					57.1
1.59	92.5	87.2	24.3	60.6	54.4
1.90	85.9	83.0	19.7	67.2	46.1
2.12	82.0	79.9	17.5	69.0	41.8
2.33	78.5	77.0	16.0	69.3	37.5
2.64	74.2	73.1	14.1	68.6	32.3
2.96	70.7	69.9	12.3	66.9	27.6
3.17	68.8	68.2	11.1	65.7	25.2
3.38	67.0	66.4	10.4	64.5	23.1
3.70	64.5	64.3	8.9	62.5	20.2
4.02	62.8	62.4	8.1	61.0	17.7
4.23	61.7	61.3	7.7	60.0	16.6

Table 4: **Ethane (100%)**

	B = 0	B = 0.5 T		B = 1.0 T	
E [kV/cm]	W [mm/μs]	W [mm/μs]	α [degree]	W [mm/μs]	α [degree]
0.11	16.3				
0.21	28.2	19.3	29.5		
0.42	41.4	33.2	26.5		
0.63	47.2	41.4	23.1	28.6	43.9
0.85	50.2	46.4	19.4	35.4	38.9
1.06	52.0	49.3	16.3	40.5	34.8
1.27	53.1	51.2	14.0	44.3	30.2
1.48	53.9	52.6	12.4	47.1	27.3
1.69	54.3	53.5	10.7	49.1	24.4
1.91	54.5	53.9	9.6	50.4	21.4
2.12	54.5	54.1	8.9	51.4	18.6
2.33	54.6	54.4	8.0	52.2	16.7
2.54	54.5				
2.65		54.2	7.2	52.8	14.5
2.75	54.4				
2.96	54.2				
3.18	54.1	54.2	5.8	53.0	11.8
3.38	54.0				
3.60	53.9				
3.70		53.8	5.3	53.0	9.8
3.81	53.7				
4.02	53.6				
4.23	53.4	52.5	4.5	52.9	8.6

Table 5: CO_2 (100%)

	B = 0	B = 0.5 T		B = 1.0 T		B = 1.4 T	
E [kV/cm]	W [mm/μs]	W [mm/μs]	α [degree]	W [mm/μs]	α [degree]	W [mm/μs]	α [degree]
1.59	12.3						
1.90	15.0						
2.12	17.0	16.6	2.8	16.5	5.0	16.4	6.7
2.65	22.5	22.2	3.0	22.0	5.7	21.8	7.7
2.96	26.6						
3.17	29.5	29.0	3.5	28.6	6.5	28.3	8.6
3.70	37.9	37.4	3.9	36.8	7.7	36.3	9.9
4.02	44.1						
4.23	47.6	47.0	4.2	46.0	8.0	45.3	10.6
4.76	57.3	56.8	4.1	55.6	8.0	54.6	11.1
5.29	66.1	65.9	4.6	64.3	8.8	63.1	11.6
5.82	73.5	73.4	4.1	71.7	8.5	70.7	12.1
6.35	79.8	79.5	4.1	77.6	8.5	76.7	11.4

Table 6: CF_4 (100%)

	B = 0	B = 0.8 T	
E [kV/cm]	W [mm/μs]	W [mm/μs]	α [degree]
0.23	48.3	14.5	48.3
0.54	77.0	33.1	45.7
0.85	92.2	51.0	40.3
1.06	99.4	62.2	36.2
1.27	104.6	72.2	32.8
1.59	111.7	84.0	27.5
1.90	117.2		
2.12	120.7	99.5	22.8
2.64	127.6	110.3	19.8
3.17	134.1	118.5	17.4
3.70	138.3	126.0	15.5
4.23	140.1	131.1	13.8
4.76	142.1	134.6	12.6
5.29	141.8	136.3	11.7
5.82	139.6	136.3	11.0
6.34	136.0	134.5	10.2
6.45	135.3	134.5	9.8

Table 7: **CO_2-CF_4 (30/70)**

	B = 0	B = 0.8 T	
E [kV/cm]	W [mm/μs]	W [mm/μs]	α [degree]
0.85	17.0	16.5	9.4
1.06	21.0	20.3	9.5
1.27	25.0	23.9	9.3
1.59	30.9	30.0	9.3
1.90	36.8	35.4	9.2
2.12	40.6	39.5	9.3
2.64	50.4	48.8	9.0
3.17	60.2	58.3	9.1
3.70	69.7	67.6	8.9
4.23	79.0	76.7	9.3
4.76	87.3	85.2	8.7
5.29	94.6	92.3	8.6
5.82	100.3	98.2	8.6
6.34	104.4	102.4	8.5
6.45	105.1		

Table 8: **CO_2-CF_4 (50/50)**

	B = 0	B = 0.8 T	
E [kV/cm]	W [mm/μs]	W [mm/μs]	α [degree]
1.06	14.2	14.1	5.9
1.27	16.8	16.6	6.0
1.59	21.4	21.0	6.0
1.90		25.1	6.1
2.12	28.7	28.3	6.2
2.64	36.6	35.6	6.6
3.17	44.9	43.7	6.5
3.70	53.7	52.0	6.7
4.23	63.0	60.9	6.9
4.76	72.0	69.5	7.2
5.29	80.7	77.6	7.4
5.82	87.9	85.0	7.5
6.34		90.2	7.1
6.45	94.4	91.3	7.1

Table 9: **CO_2-CF_4 (70/30)**

	B = 0	B = 0.8 T	
E [kV/cm]	W [mm/μs]	W [mm/μs]	α [degree]
1.27	12.7		
1.59	15.9	15.8	4.2
1.90	19.4		
2.12	21.8	21.6	4.4
2.64	28.1	27.8	4.5
3.17	35.3	34.8	4.8
3.70	43.5	42.7	5.3
4.23	52.4	51.3	5.7
4.76	61.8	60.4	5.9
5.29	70.7	69.1	6.2
5.82	78.6	76.7	6.3
6.34	84.8	83.1	6.3
6.45	86.2	84.1	6.1

Table 10: **CO_2-CF_4-Ar (50/20/30)**

	B = 0	B = 0.8 T	
E [kV/cm]	W [mm/μs]	W [mm/μs]	α [degree]
0.85			6.0
1.06	13.6	13.5	6.1
1.27		16.3	6.2
1.59	20.9	20.8	6.4
1.90		25.6	6.6
2.12	29.7	29.0	6.8
2.64	39.5	38.8	7.5
3.17	51.4	50.1	8.0
3.70	63.0	61.4	8.8
4.23	73.4	71.5	8.9
4.76	81.2	79.4	8.7
5.29	87.0	85.0	8.5
5.82	91.4	89.3	8.2
6.34	94.4	92.5	8.0
6.45	94.8	93.6	7.8

Table 11: **CO_2-CF_4-Ar (50/30/20)**

	B = 0	B = 0.8 T	
E [kV/cm]	W [mm/μs]	W [mm/μs]	α [degree]
0.85			6.2
1.06	13.7	13.5	6.3
1.27	16.5	16.2	6.7
1.59	20.9	20.6	6.8
1.90		25.1	7.0
2.12	28.9	28.4	7.1
2.64	37.4	37.0	7.2
3.17	48.1	46.6	8.0
3.70	59.0	57.2	8.4
4.23	69.8	67.6	8.6
4.76	79.3	76.7	8.7
5.29	86.2	83.9	8.6
5.82	91.7	89.2	8.5
6.34	94.0	91.6	8.3

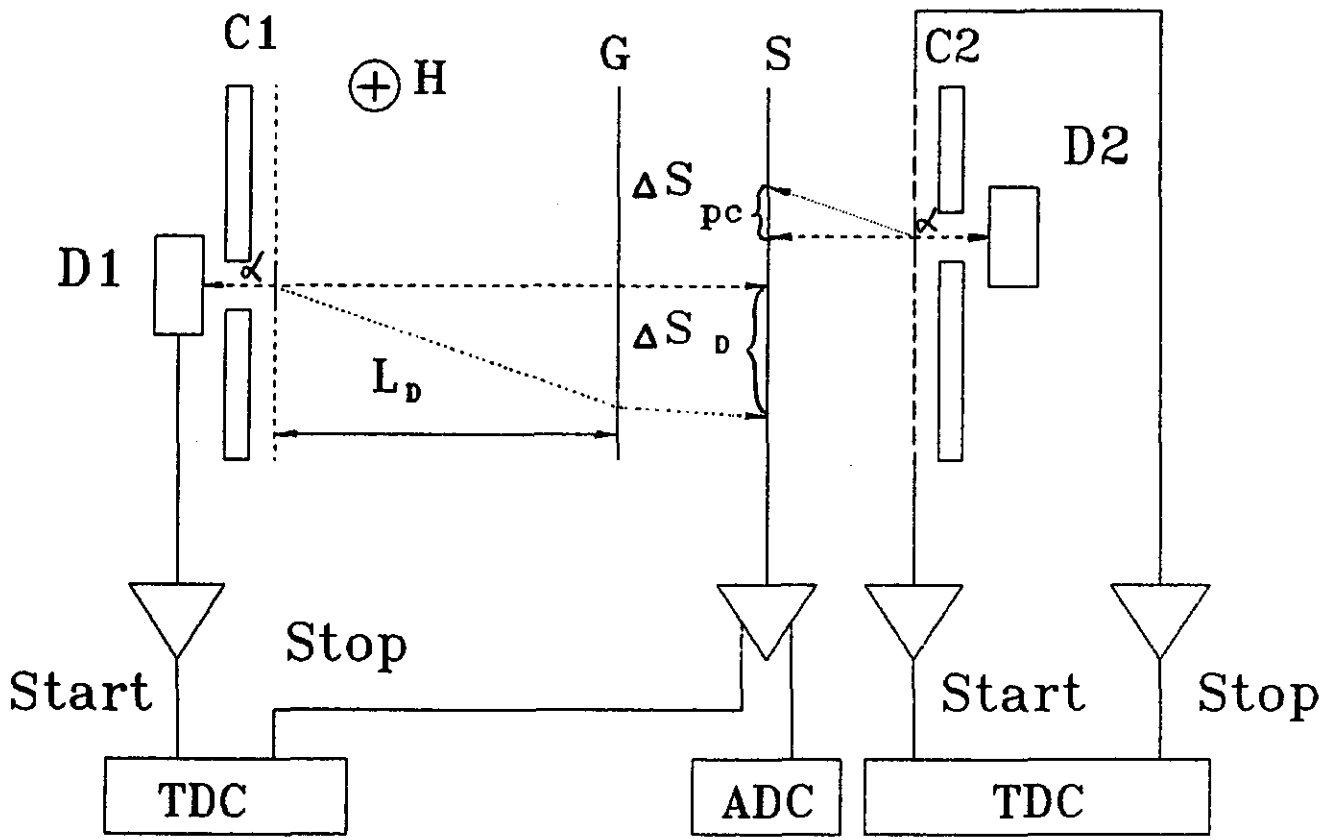
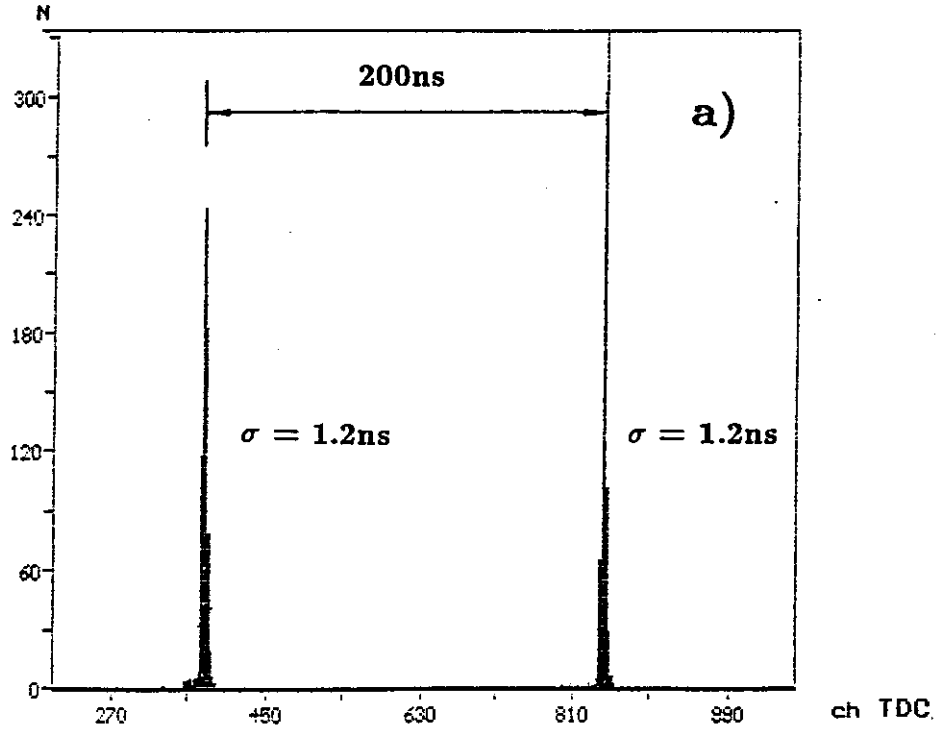


Fig.1 Schematic view of the experimental set-up.

C1,C2 - cathodes, S - anode plane, G - grid, D1,D2 -Si-detectors.
The dash curves are a drift path of electrons without the magnetic field,
the dot curves with the magnetic field.
ΔS_D and ΔS_{pc} are displacements of the peaks corresponding to the C1 and C2 recoils when the magnetic field is changed from B=0 to B.



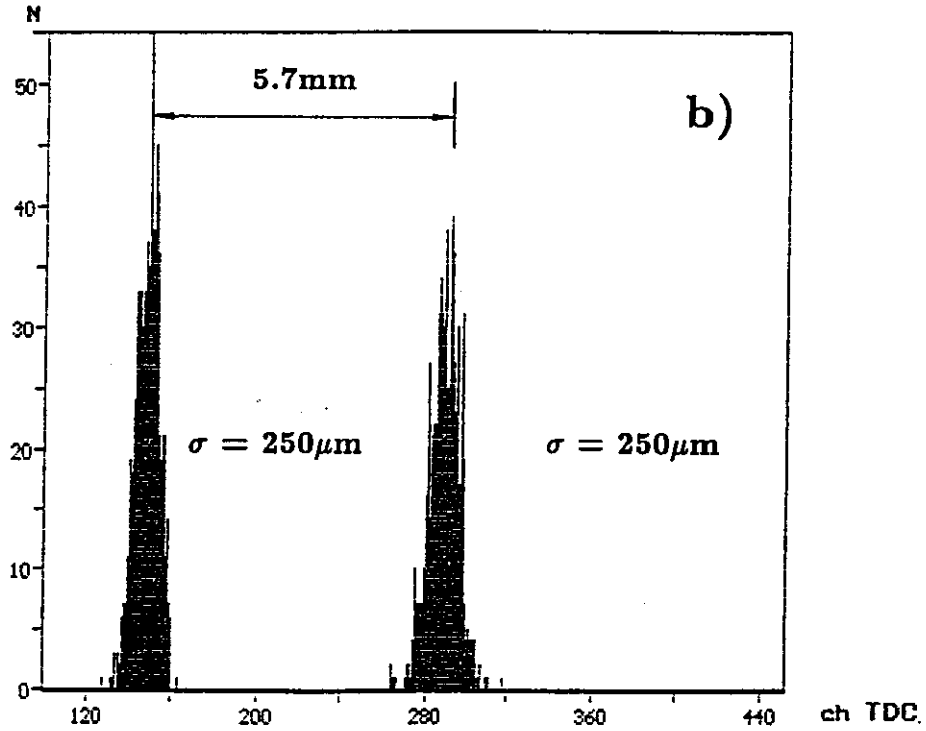


Fig.2 Typical time distribution of:

(a) the anode signals with respect to the signals from Si-detectors.

(b) the cathode signals from the C2-strips in coincidence with α-particles.

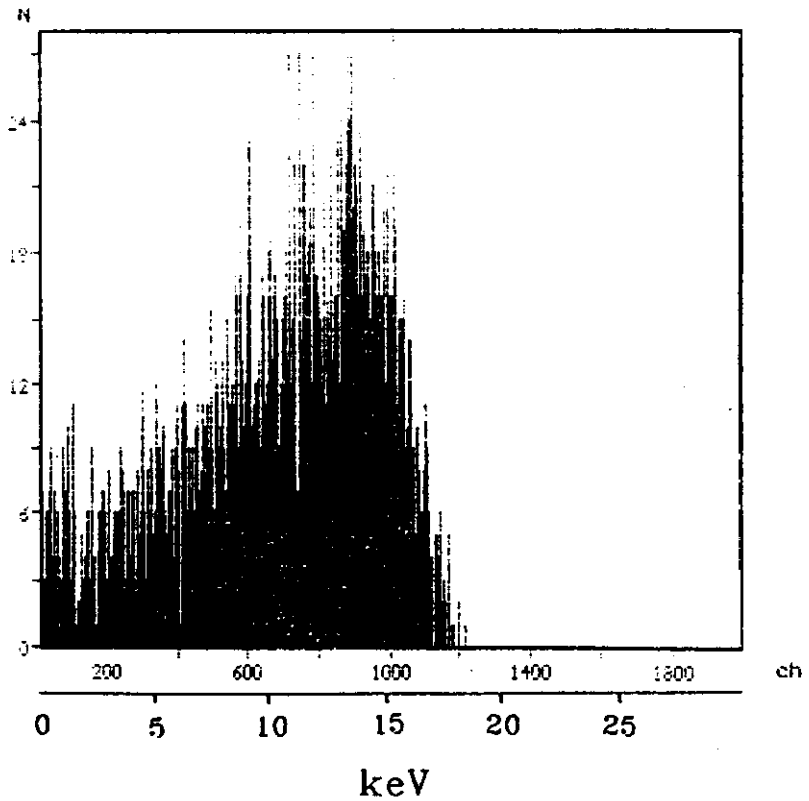


Fig.3 The amplitude spectrum of the anode signals from α-recoils obtained in coincidence with α-particles.

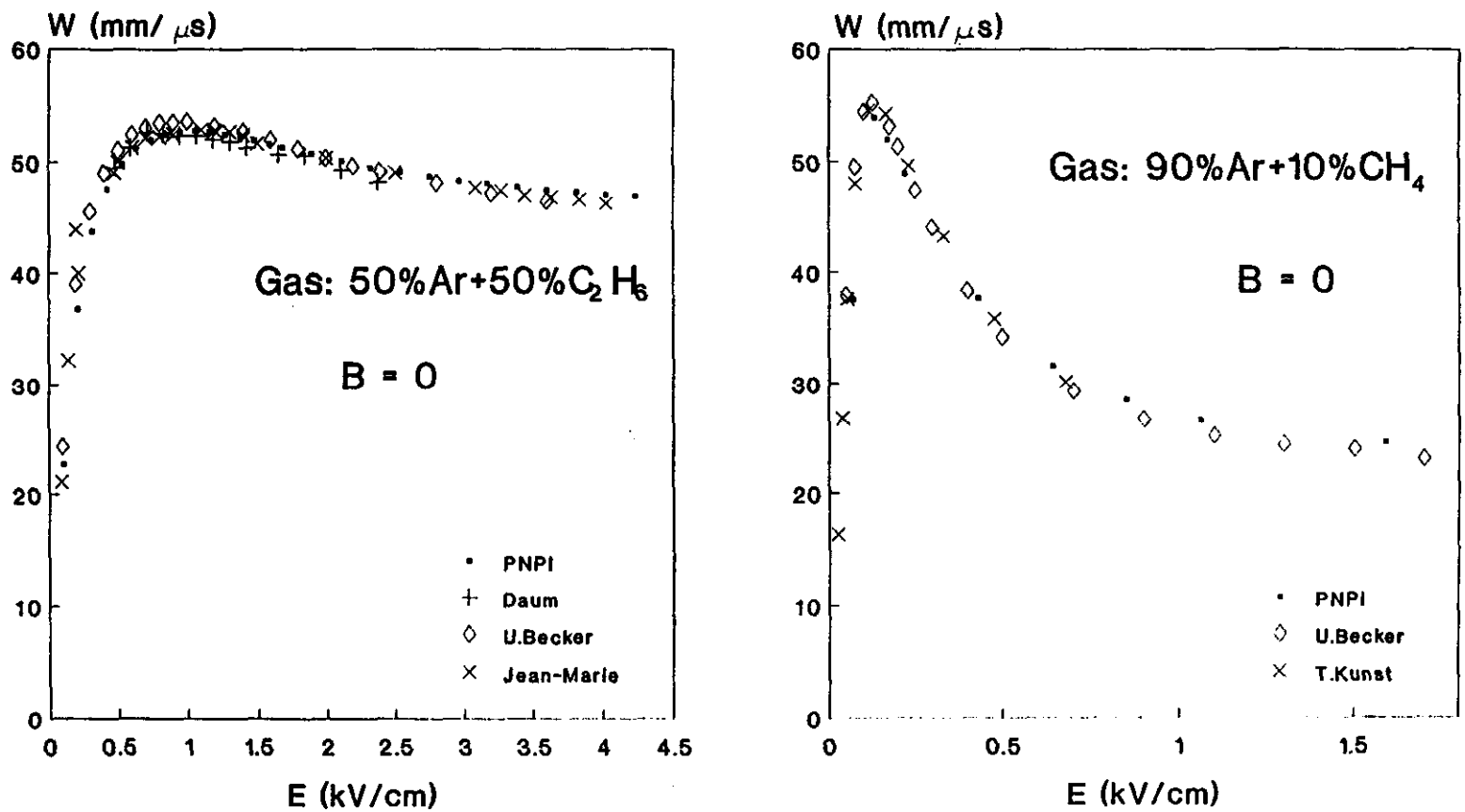


Fig.4 Comparison of our measurements electron drift velocity in 50%Ar + 50%C_2H_6 and 90%Ar +10%CH_4 with other data.

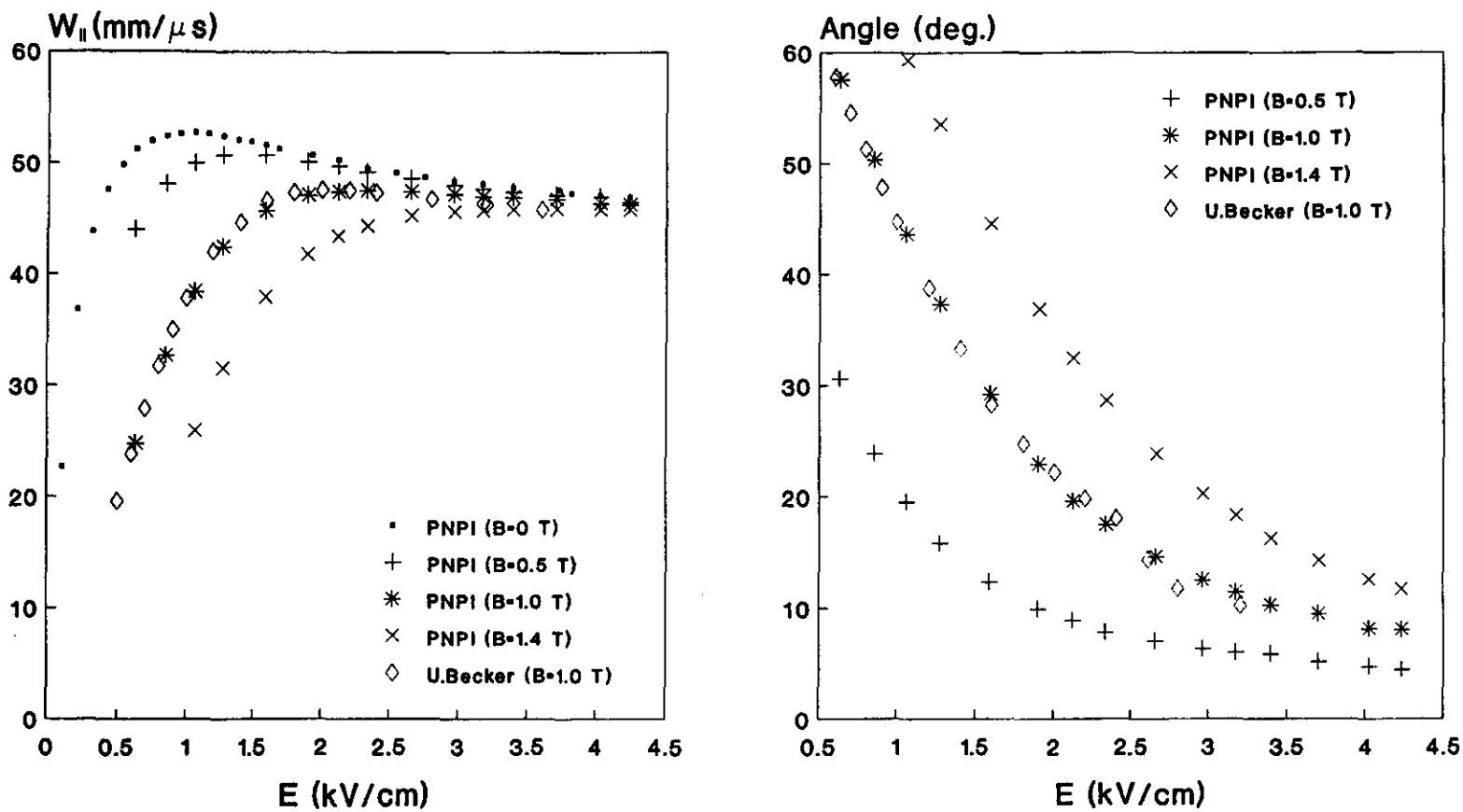


Fig.5 Our measurements of parallel electron drift velocity and Lorentz angle in 50%Ar+50%C_2H_6 for B = 0, B = 0.5, B = 1.0 and B = 1.4 T. For B = 1.0 T comparison to the data of U.Becker [3].

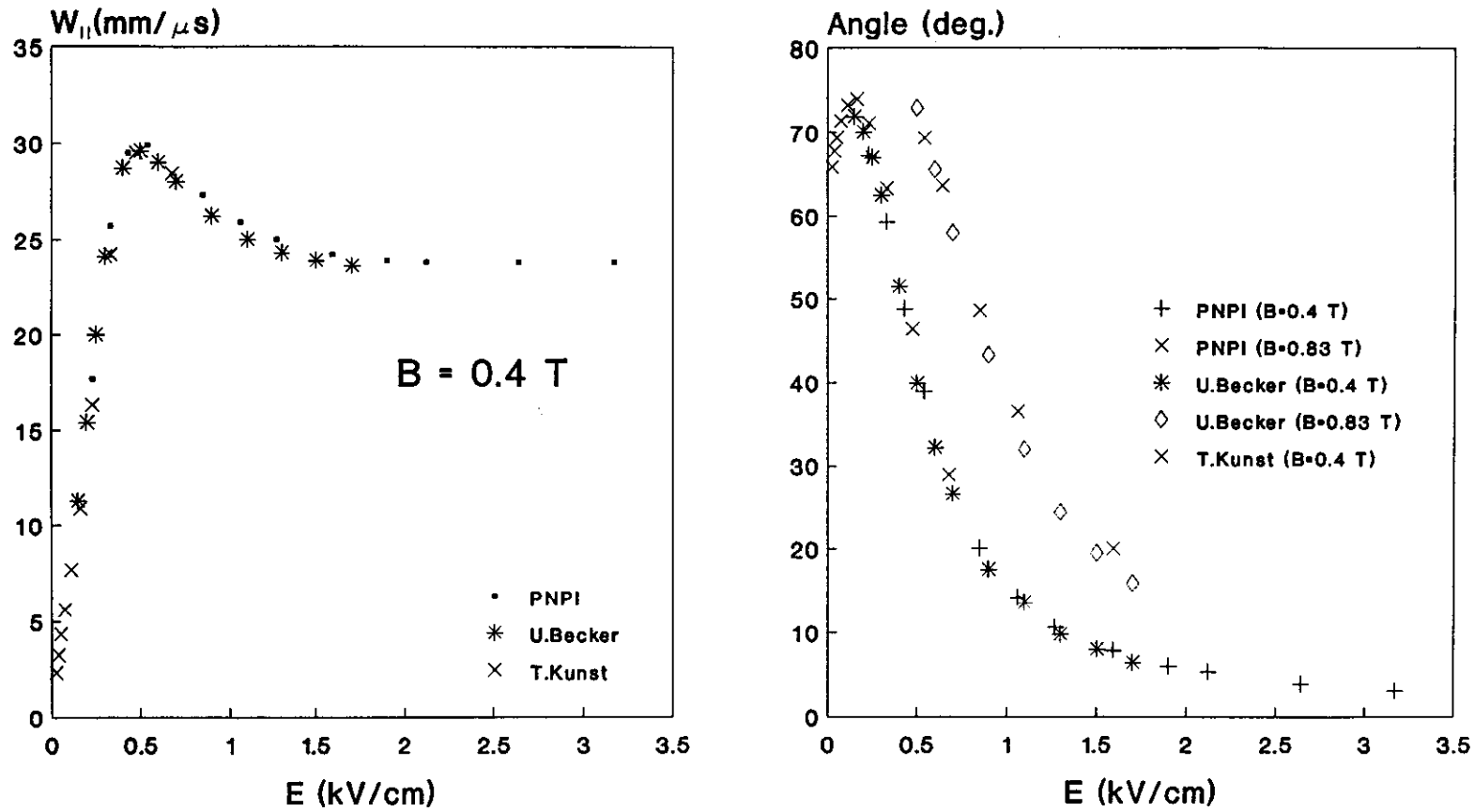


Fig.6 Comparison of our measurements parallel electron drift velocity and Lorentz angle in 90%Ar + 10%CH_4 with other data.

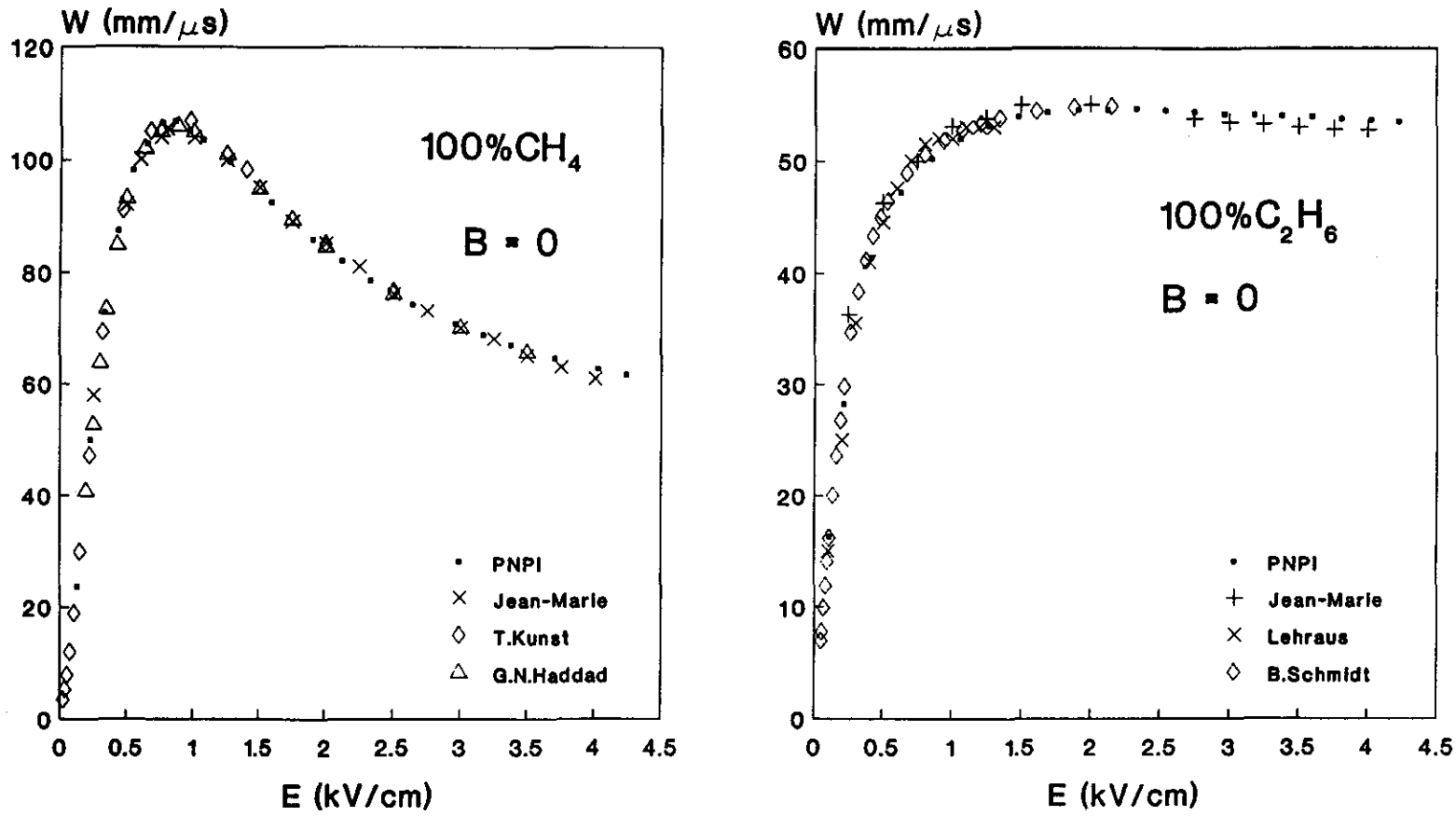


Fig.7 Our measurements of electron drift velocity in pure CH_4 and C_2H_6
For comparison other data of ref. [4,5,7,8] also shown.

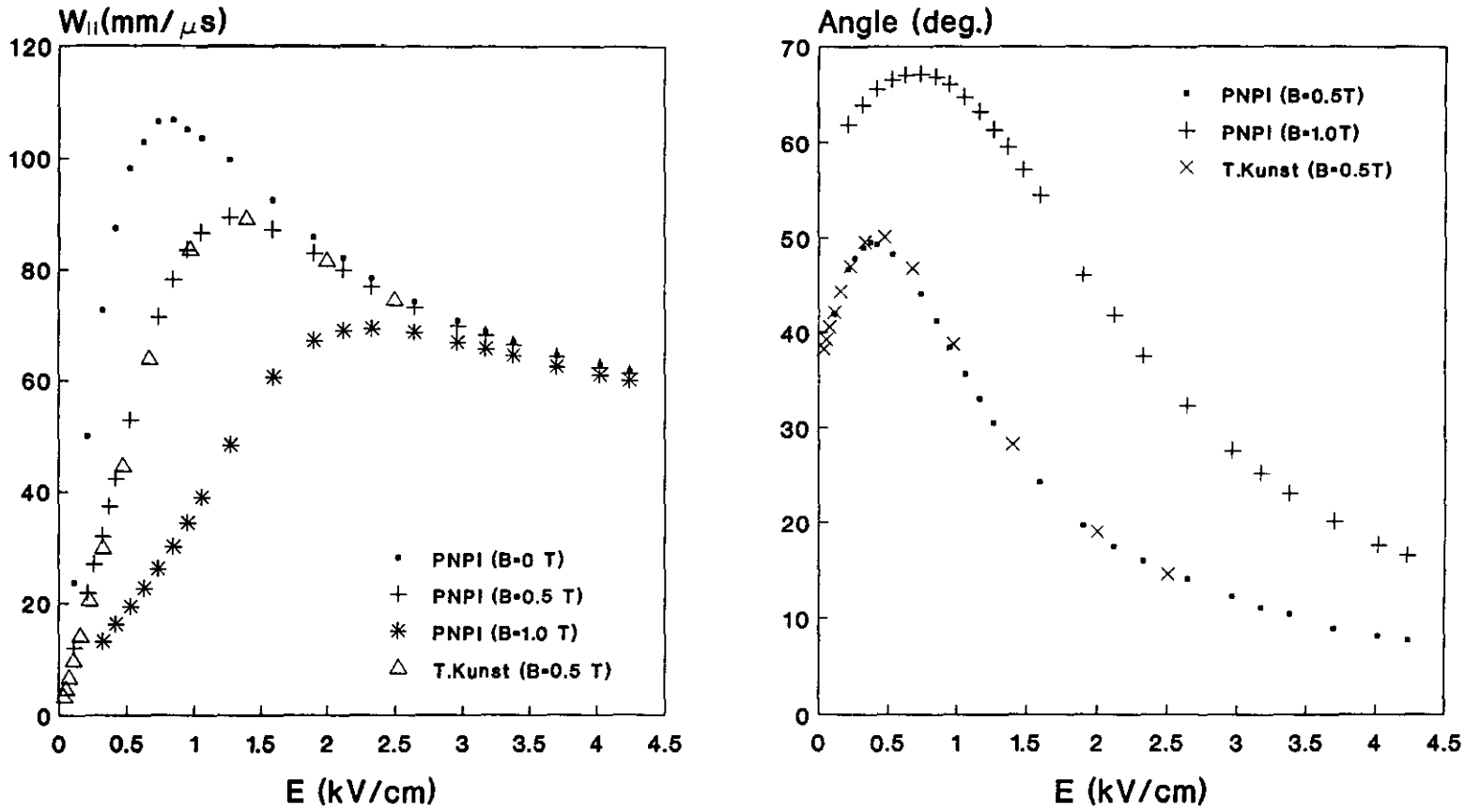


Fig.8 Our measurements of parallel electron drift velocity and Lorentz angle in pure CH_4 for B = 0, B = 0.5 and B = 1.0 T. For B = 0.5 T comparison to the data of T.Kunst [4].

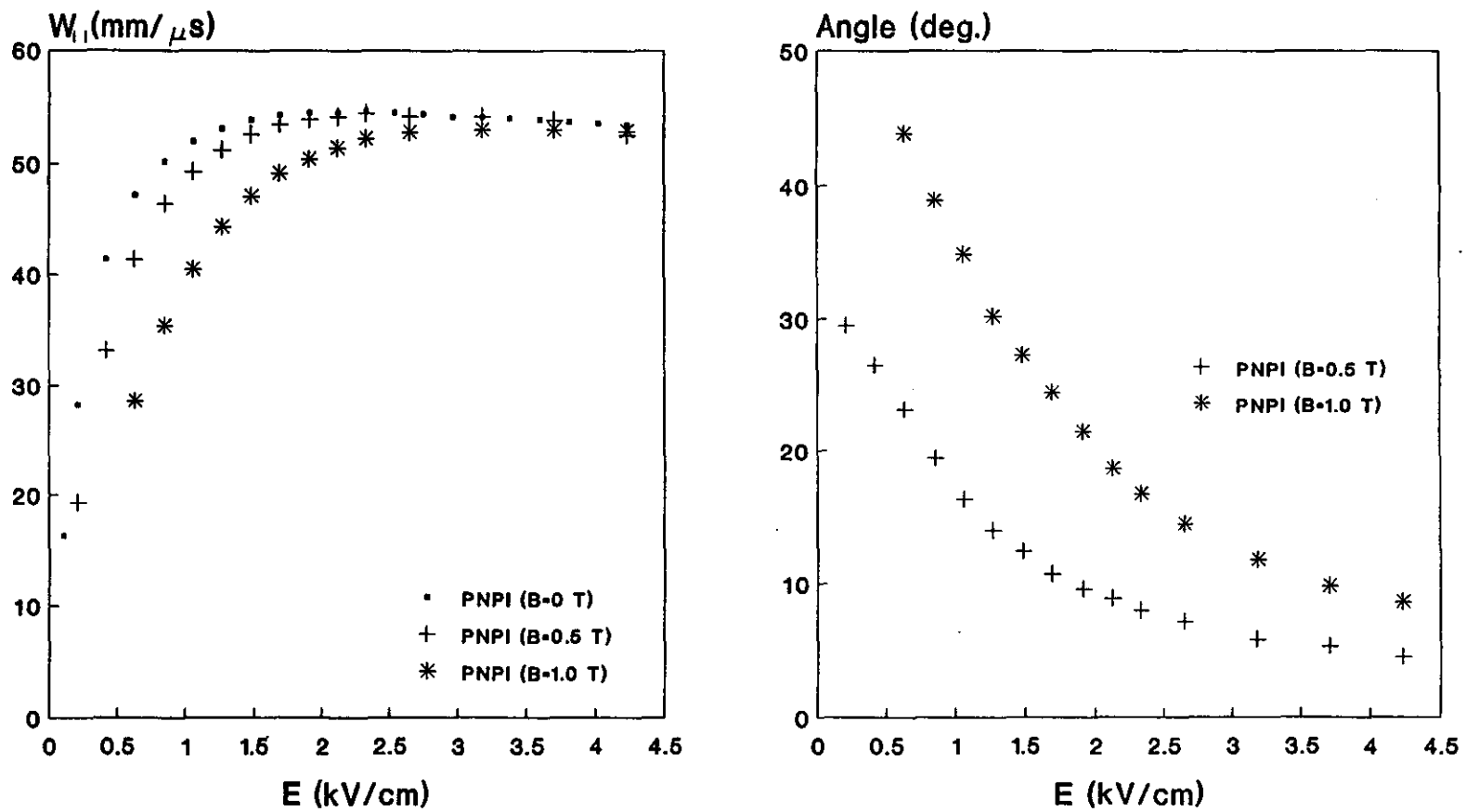


Fig.9 Our measurements of parallel electron drift velocity and Lorentz angle in pure C_2H_6 for B = 0, B = 0.5 and B = 1.0 T.

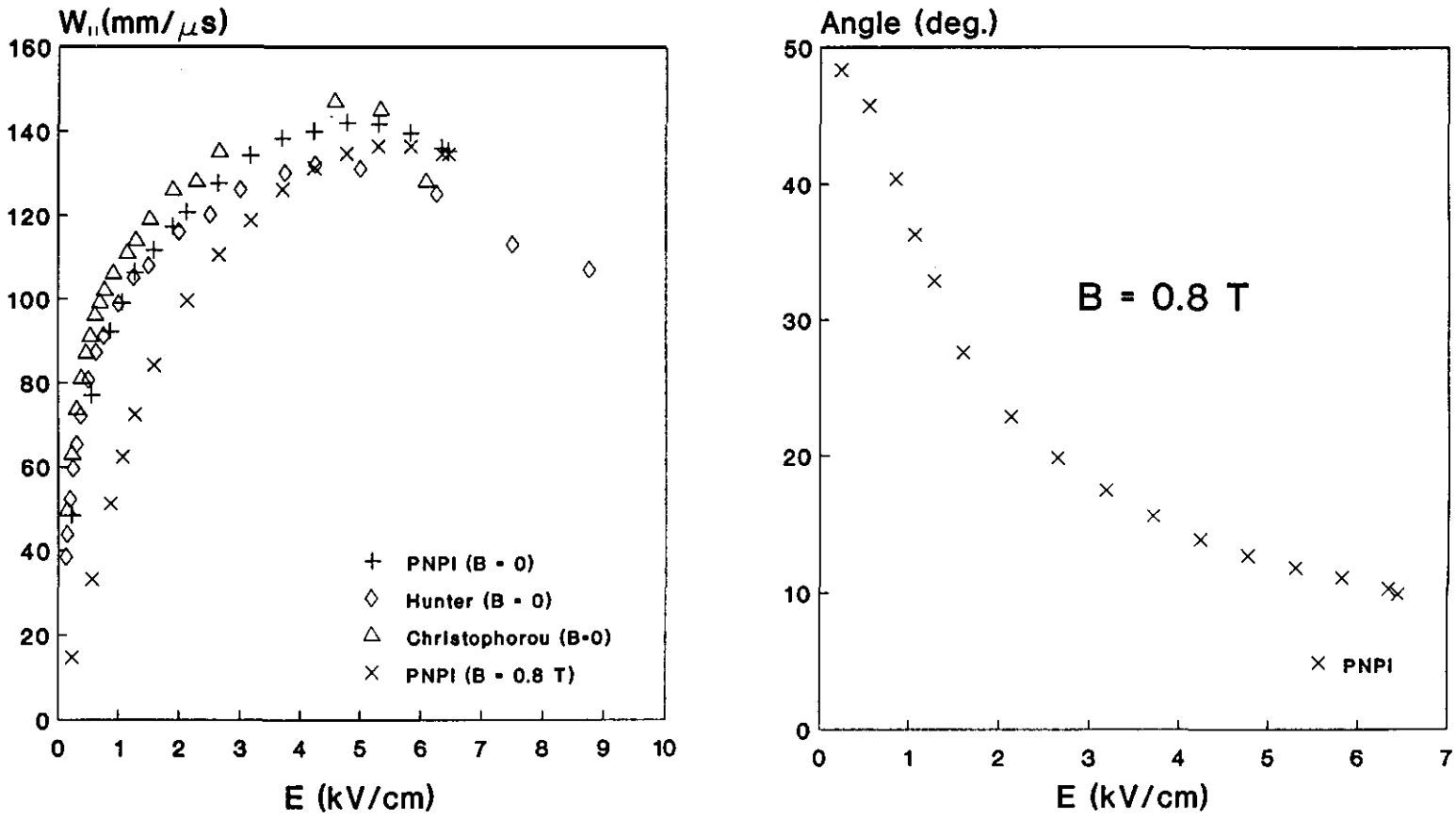


Fig.10 Our measurements of parallel electron drift velocity and Lorentz angle in pure CF_4 for B = 0, B = 0.8 T.
For B = 0 T comparison to the data of ref. [10,11].

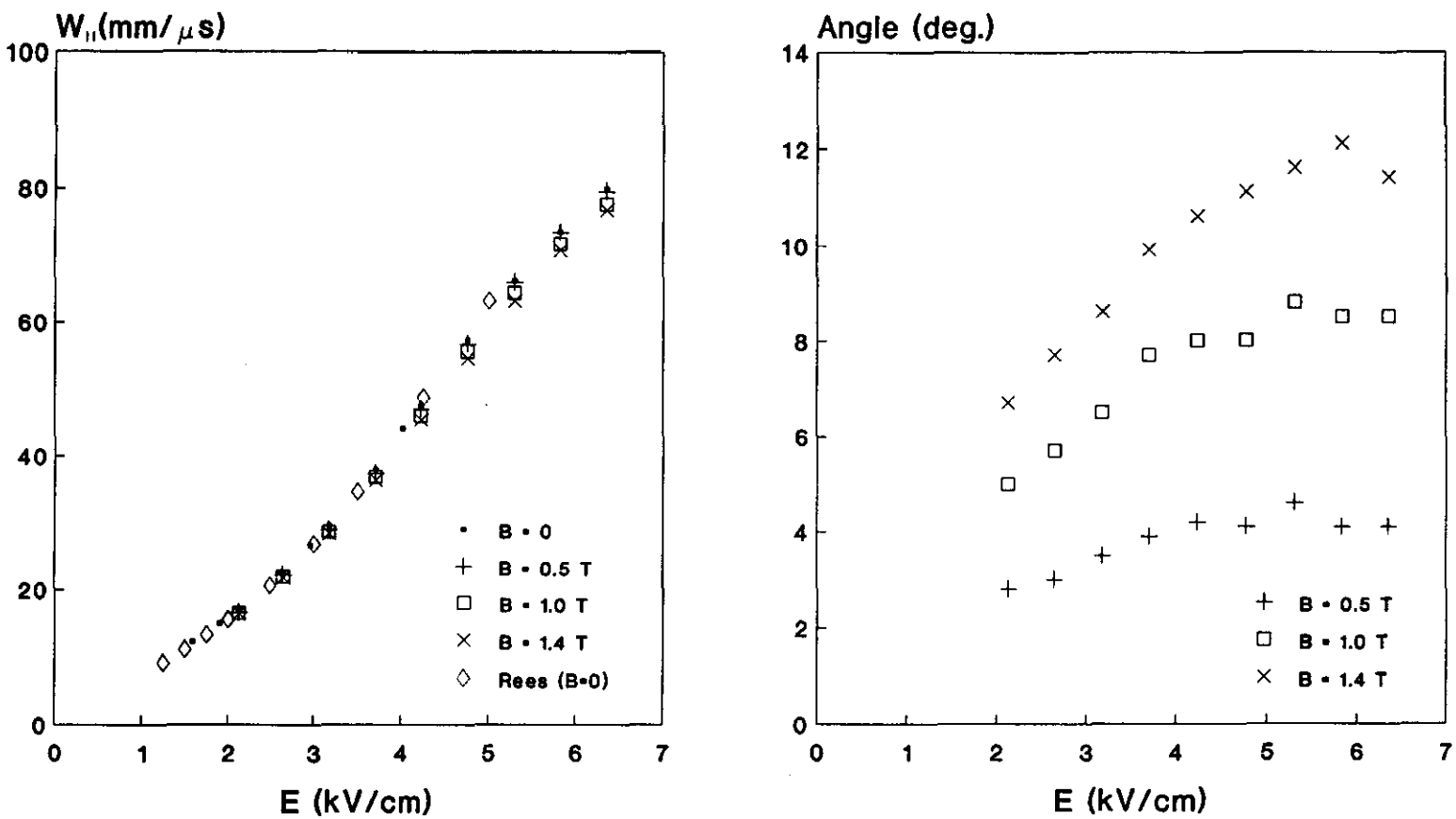


Fig.11 Our measurements of parallel electron drift velocity and Lorentz angle in pure CO_2 for B = 0, B = 0.5, B = 1.0 and B = 1.4 T. For B = 0 T comparison to the data of J.Rees [9].

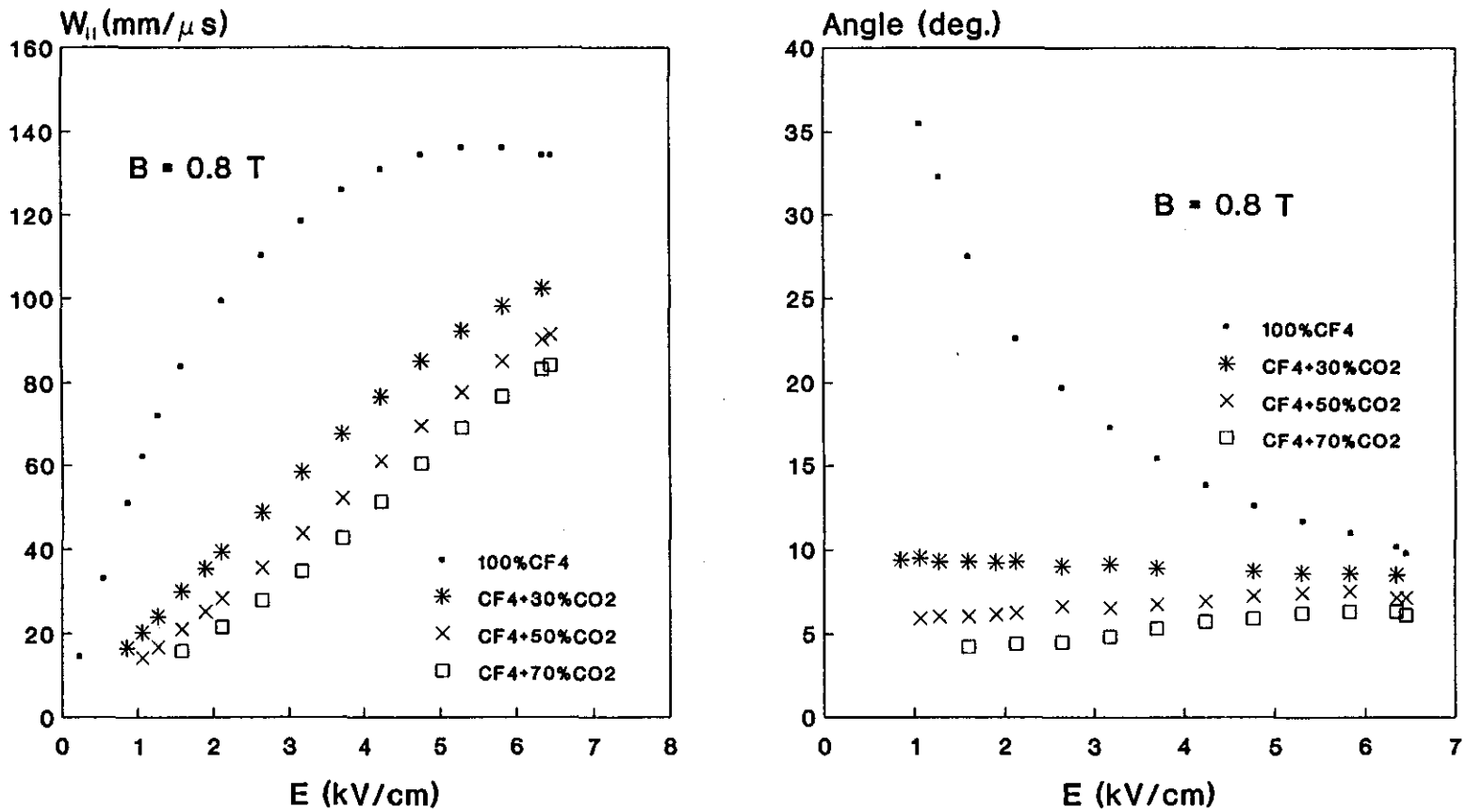


Fig.12 Our measurements of parallel electron drift velocity and Lorentz angle in CO_2 - CF_4 gas mixtures for B = 0.8 T.

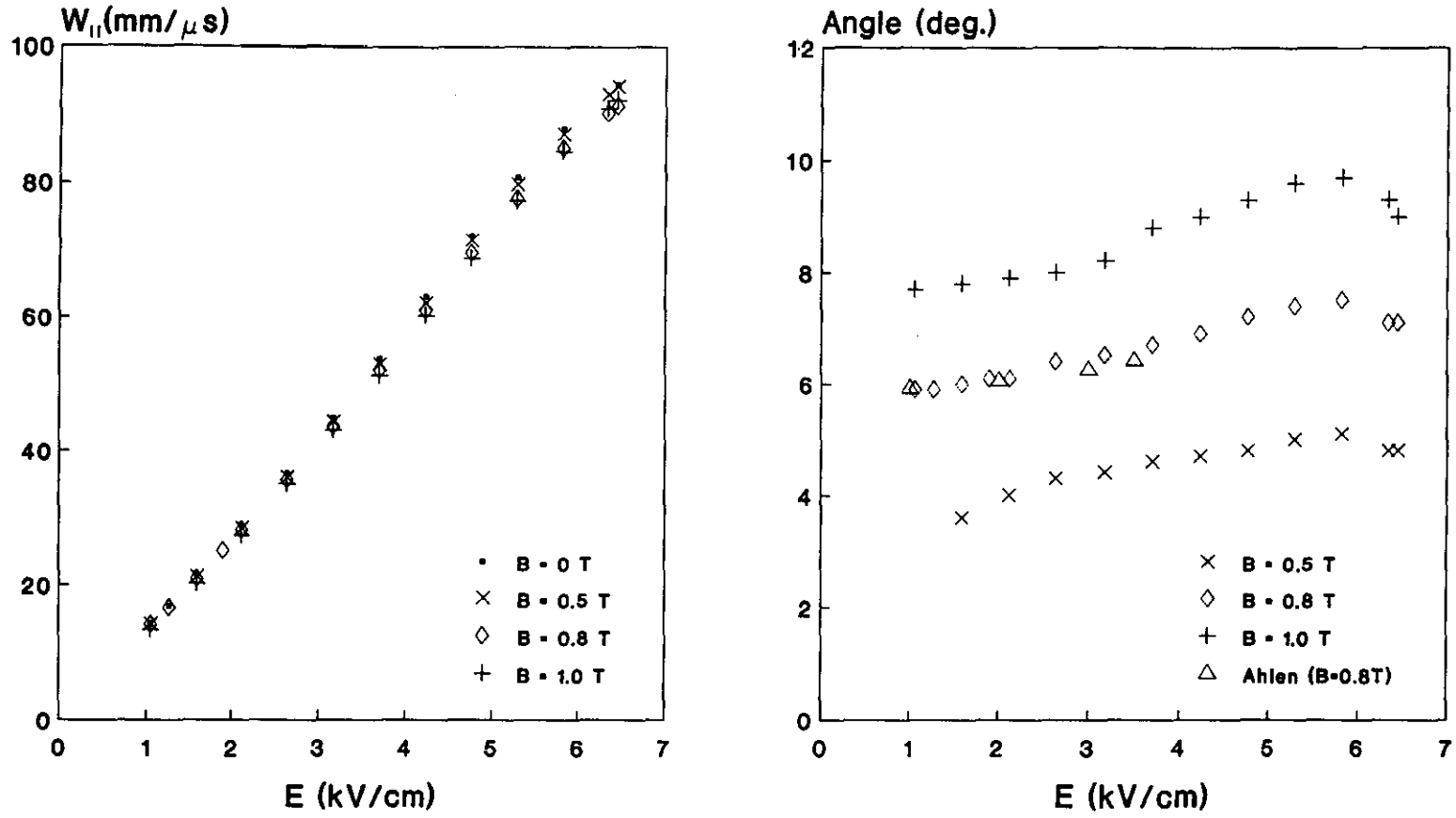


Fig.13 Our measurements of parallel electron drift velocity and Lorentz angle in 50%CO_2 + 50%CF_4 for B = 0, B = 0.5, B = 0.8 and B = 1.0 T. For B = 0.8 T comparison to the data of S.Ahlen [12].

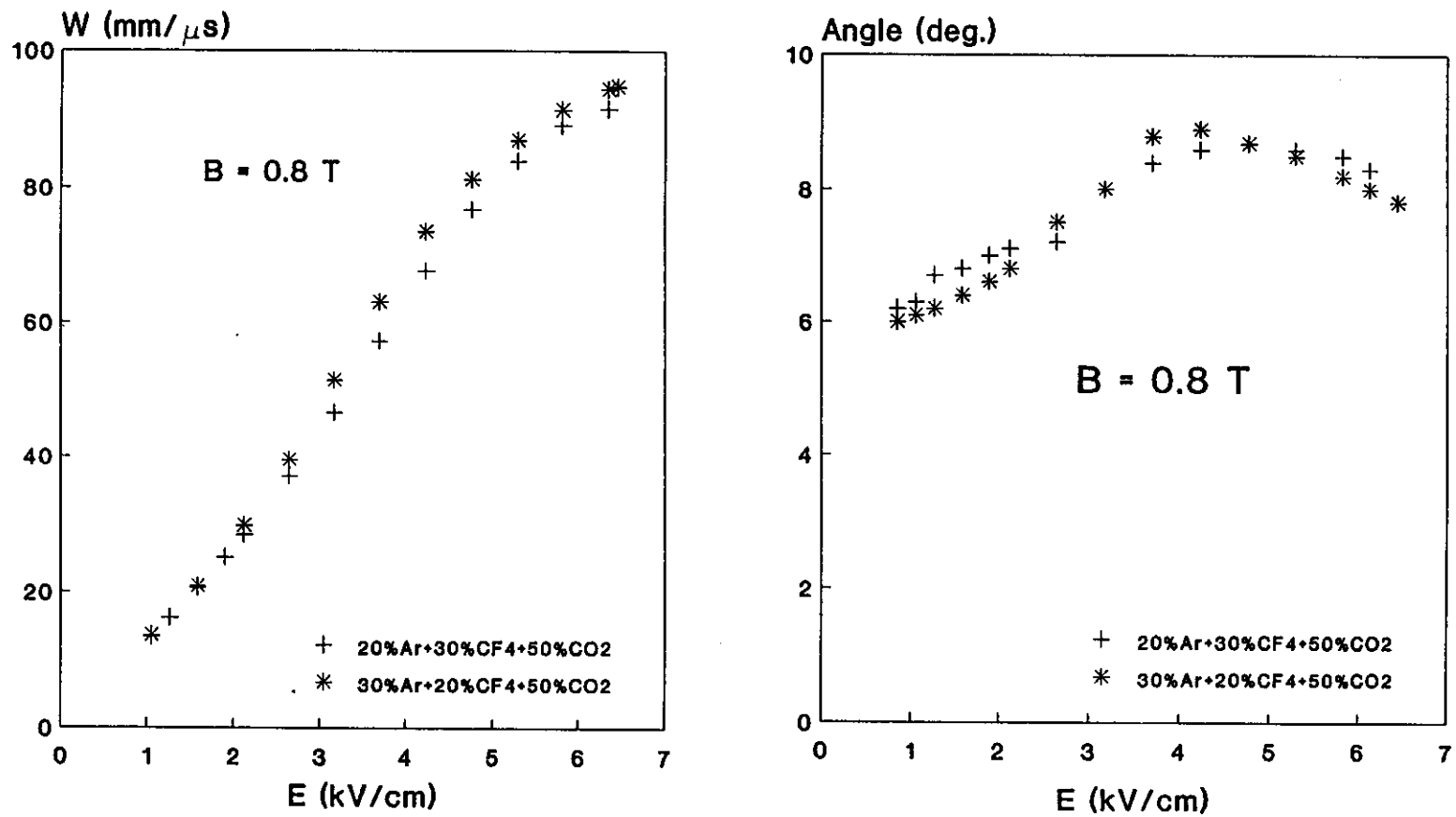


Fig.14 Our measurements of parallel electron drift velocity and Lorentz angle in $50\%CO_2 + 30\%CF_4 + 20\%$ Ar and $50\%CO_2 + 20\%CF_4 + 20\%$Ar for B = 0.8 T.