R&D FOR A 4.6 METERS LONG DRIFT CHAMBER AS A POSSIBLE MAIN TRACKER AT JLC

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Measurements of wire tensions, gravitational and electrostatic sags for a 4.6m test chamber are described. A method to calculate the wire sags knowing the initial position of and tension and high voltage on each wire is developed. There is a good agreement between measurement and calculation.

1 Introduction

One of the most important goals of the JLC experiment is to discover and study the Higgs boson. In order to make full use of the physics potential of JLC, desirable is a high resolution central tracker with $\sigma_{p_T}/p_T \sim 10^{-4} \times p_T(\mathrm{GeV})$[1]. Even if we assume a spatial resolution of 100μm per wire, a magnetic field of 2T, the number of sampling points of 100, the tracking chamber becomes as large as 2.3m in radius and 4.6m in length. Due to substantial gravitational and electrostatic sags, achieving a spatial resolution of 100μm/wire for a 4.6m long chamber is quite non-trivial. We need to be able to predict wire positions very precisely under the influence of gravitational and electrostatic forces.

We have been developing a software program to predict wire displacement, knowing the cell structure, wire tension, and high voltage on each wire. The validity of the prediction has to be proved experimentally. For this purpose, we have developed a wire tension and position measurement system. We have measured wire tensions, gravitational and electrostatic sags for a 4.6m long test chamber in order to compare them with the prediction.

Figure 1: 4.6 m CDC test chamber

2 Test Chamber Parameters

Our test chamber is 4.6m long and has endplates of $70 \times 70\text{cm}^2$, providing 7 identical small jet-cells of $7 \times 10\text{cm}^2$. The structure of a single cell is shown in Fig.2 together with high voltages on wires. The figure also specifies the wire naming convention to be used hereafter. The sense wires have a potential of 2.5kV and are surrounded by ground wires and grid wires with -0.5kV which are placed 5mm away from the sense wire plane. The dummy sense wires have 2.15kV. The potentials of the field wires F1-F10 change linearly in this order from -0.5kV to -4.6kV. Left and right edge field wires are at -4.6kV. The high voltages on the field wires were chosen so as to get as uniform a drift field as possible. The equipotential and drift lines were calculated using GARFIELD [2] and are shown in Fig.3. The maximum drift length is 5cm.

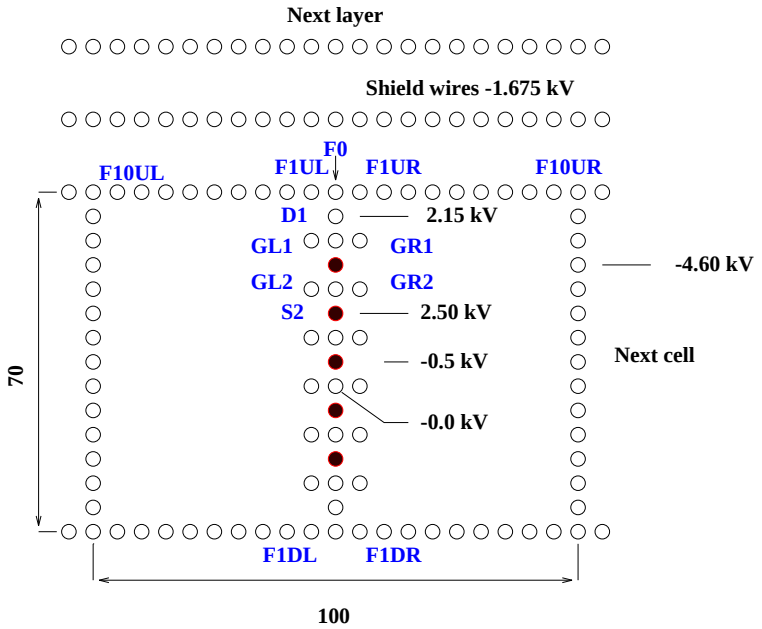

Figure 2: Single cell structure

The sense wires are 30μm diameter gold-plated tungsten and were strung with 10mm spacing. All the other wires are 130μm diameter gold-plated aluminum wires. The reason for this choice of Al as the wire material is to minimize the total wire tension so as to reduce the thickness of chamber endplates. As a chamber gas the mixture of 90%CO_2 and 10% Isobutane is used.

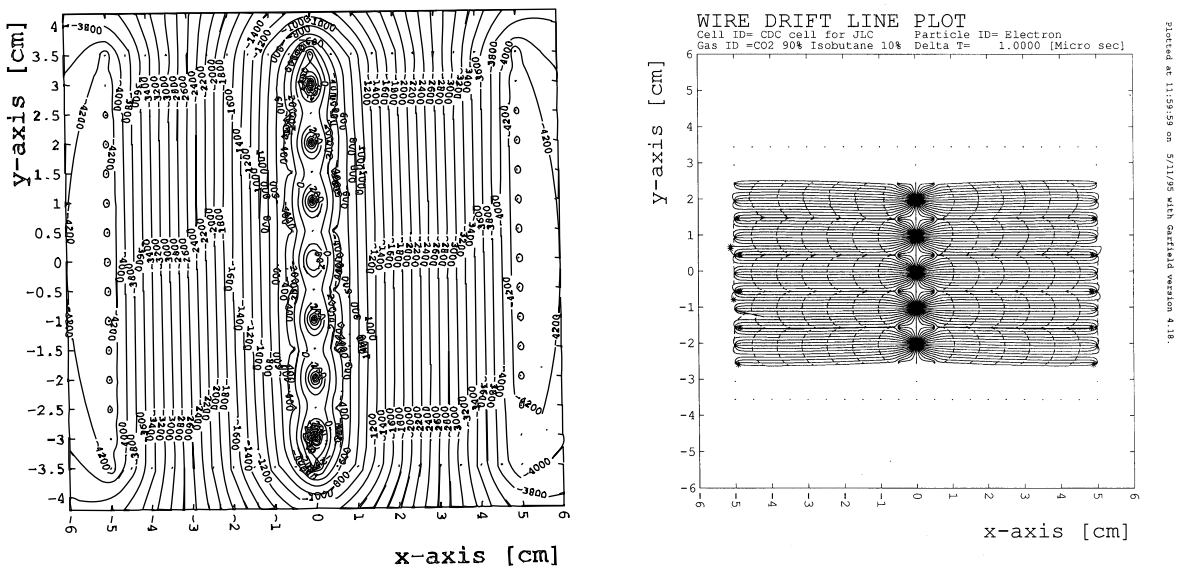

Figure 3: The equipotential (left) and drift (right) lines in a single cell

3 Wire Tension Measurements

Almost all methods of wire tension measurements are based on the same basic principle, by exciting oscillations of a wire at its resonant frequency, and then determining the tension by using the relation

$$T = 4\rho \cdot l^2 \cdot f^2 \tag{1}$$

where T is the wire tension, ρ is the mass of the wire per unit length, l is the wire length, f is the fundamental resonance frequency. The block diagram of our wire tension measurement system is shown in Fig.4. As shown in Fig.4, the tension measurement is accomplished by passing a sinusoidal current through a chamber wire, which is placed in a magnetic field (B $\simeq$30Gauss) perpendicular to the wire. The Lorentz force acting on the wire produces a mechanical oscillation. This induces an electromotive force across the wire due to Faraday's law of electromagnetic induction and modulates the current. By detecting this modulation while sweeping frequency, we can thus determine the resonance frequency.

We repeatedly measured the wire tensions for the central cell during 2 years. A typical lineshape for an aluminum field wire is shown in fig.4 as a function of frequency. Each thread corresponds to a resonance frequency. The resonance frequency was measured and the corresponding tension was calculated using Eq. 1. The results are shown in Figs.4 a) and b) for field and

sense wires, respectively. There is still a tension drop of about 10%/year for gold-plated Al field wires unlike gold-plated W sense wires which now reach a tension plateau.

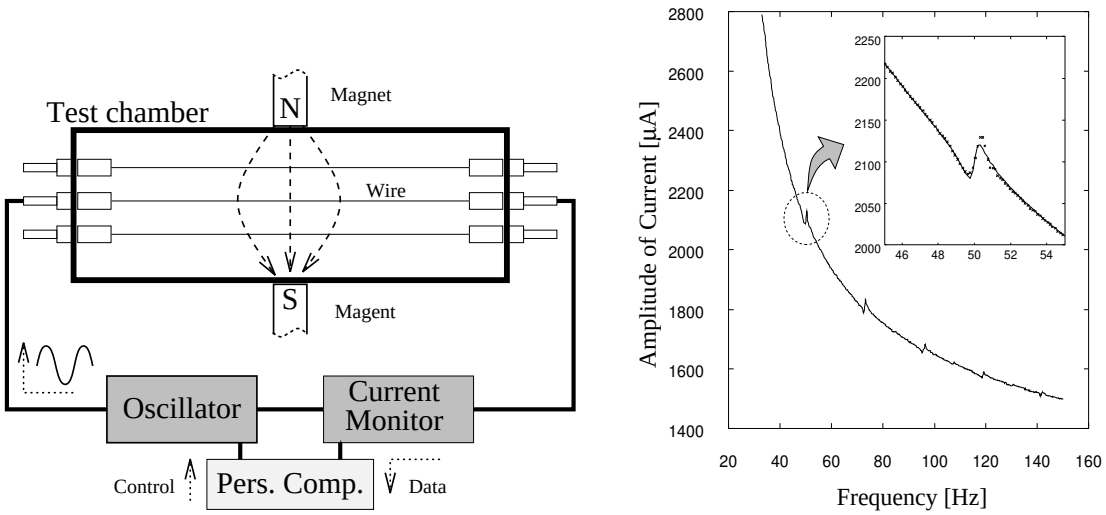

Figure 4: Block diagram of tension measurement system (left) and frequency distribution of a typical wire (right)

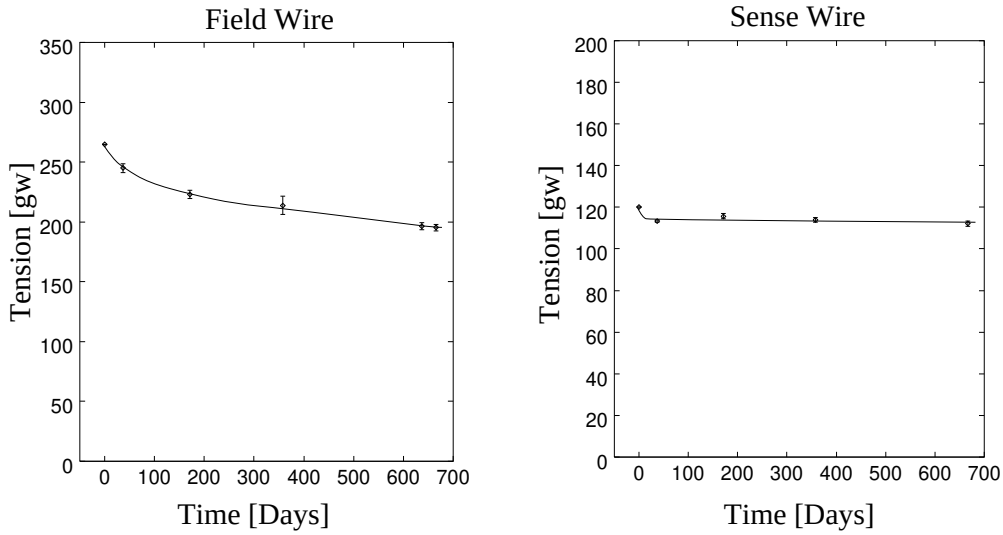

Figure 5: Tension versus time for field (left) and sense (right) wires

4 Gravitational Sag

4.1 Measurements

For measurements of the gravitational sag we used 2 CCD cameras one for horizontal and the other for vertical position measurements. Each of these 2 cameras has an area of sight of 1mm $\times$ 1mm and a focal depth of $\simeq$ 1mm. Fig.6 is a schematic view of our gravitational sag measurement system. The measurement procedure is as follows. Using the vertical camera fiducial marks on the chamber windows and a wire position are measured (pos.1 in Fig.6). Then we rotate the test chamber by 90° and measure the wire deflection due to gravitational sag relative to the line connecting the fiducial marks using the horizontal camera (pos.2 in Fig.6). The camera positions are computer-controlled with a step size of 0.5μm/pulse and are monitored by linear scales of 5μm resolution. Since the area of sight and the focal depth are so small, getting a target wire in sight is not easy. In order to help us find a wire to be measured, a laser beam spotter of 2mm diameter is mounted on each camera body so as to illuminate the focal point. Typical pictures of field and sense wire images from the CCD cameras are shown in Fig.7. The image size is 1 $\times$ 1mm^2. The results of the gravitational sag measurements are given in table 1. The average gravitational sags for field and sense wires are 600μm and 300μm, respectively.

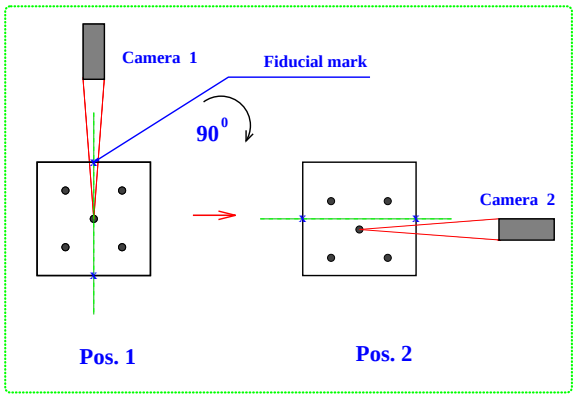

Figure 6: Principle of gravitational sag measurements

5 Calculations of the Wire Displacement due to Gravitational and Electrostatic Forces

The wires in a drift chamber are subject to gravitational and electrostatic forces that tend to displace them. The equation for the equilibrium position of a wire is given by

$$T \cdot \frac{d^2\vec{\delta}}{dz^2} = \left(\vec{F}_e + \vec{F}_g\right), \qquad (2)$$

where T is the wire tension, $\vec{\delta}(z) = \vec{\delta}_g + \vec{\delta}_e$ is the displacement perpendicular to the wire and z is the coordinate along the wire direction. $\vec{F}_e$ and $\vec{F}_g$ are the

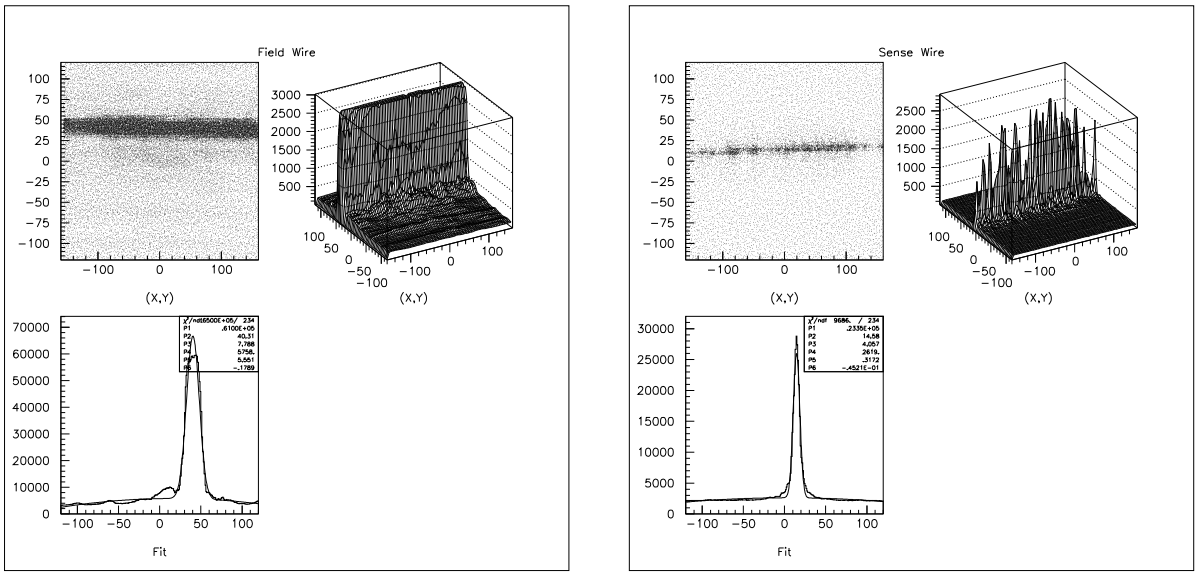

Figure 7: Typical wire images for a 130 μm field wire (left) and a 30 μm tungsten sense wire (right)

electrostatic and gravitational forces acting on the wire, respectively. Due to the linearity of the equation we can separate the gravitational and electrostatic parts and treat them independently.

5.1 Calculation of the Gravitational Sag

The gravitational sag is governed by

$$T \cdot \frac{d^2\vec{\delta_g}}{dz^2} = \vec{F_g} = \rho \cdot \vec{g}, \tag{3}$$

where ρ is the linear density of the wire, g is the acceleration of gravity. The solution for this equation is

$$\vec{\delta_g}(z) = \frac{1}{2} \cdot \frac{\rho \cdot \vec{g}}{T} \cdot z\,(z - L)\,,$$

where L is the wire length (L=4.6m). The sagitta of the wire is therefore

$$Y \equiv |\vec{\delta_g}(L/2)| = \frac{L^2}{8} \cdot \left(\frac{\rho \cdot g}{T}\right). \tag{4}$$

The results of the gravitational sag measurements and calculations are compared in table 1, showing good agreement.

Table 1: Results of the gravitational sag measurements and calculations

Wire name	Y(meas) (μm)	Y(calc) (μm)
S1	362	304
S2	334	312
S4	353	320
S5	363	310
G1	603	518
G2	607	562
G3	588	561
G5	621	560
G6	613	562
GR1	639	540
GR2	635	552
GR3	612	546
GR4	597	531
GL1	538	552
GL2	521	555
GL3	587	563
GL4	704	552
GL5	567	564

6 Electrostatic Sag

6.1 Measurements

For electrostatic sag measurements we used the same wire position measuring system as in the gravitational sag measurements. Measuring scheme is sketched in Fig.8. We first get a wire in sight on both the horizontal and vertical cameras with the high voltages off. Then we measure the horizontal (ΔX) and vertical (ΔY) displacements in the camera screens after turning on the high voltages. The wire stability in the electrostatic field has been checked by turning on and off the high voltages several times. We found no instability. The results of our electrostatic sag measurements are summarized in table 2 for sense wires and surrounding Al wires.

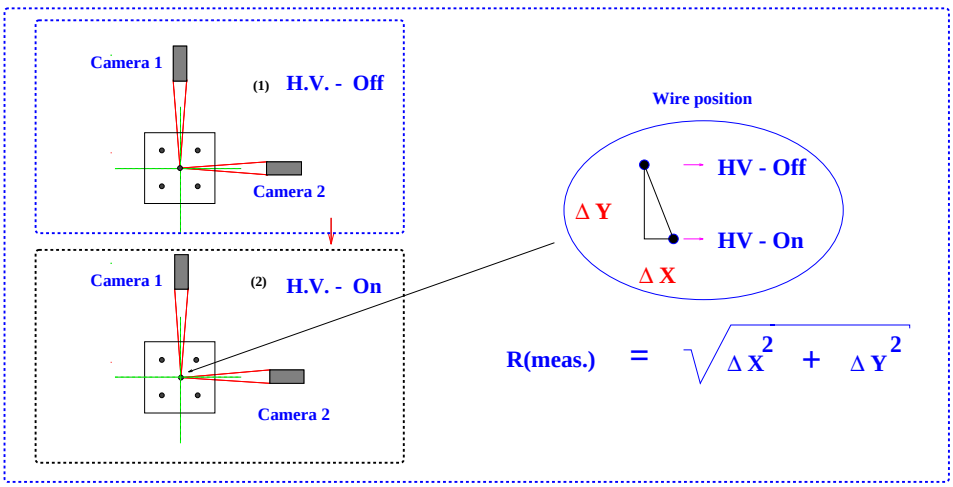

Figure 8: Schematic view of the electrostatic sag measurements.

Table 2: Results of the electrostatic sag measurements and predictions

	Measurement			Calculation					
				1-st iteration			2-nd iteration		
Wire name	ΔX (μm)	ΔY (μm)	R (μm)	ΔX (μm)	ΔY (μm)	R (μm)	ΔX (μm)	ΔY (μm)	R (μm)
S1	-117	49	128	1	-1	1	3	50	50
S2	61	111	127	2	85	85	0	160	160
S3	36	96	102	-1	76	76	1	147	147
S4	-10	80	81	-1	66	66	-4	132	132
S5	-110	37	116	0	43	43	0	80	80
GL1	593	-43	594	536	-10	536	596	-13	596
GL2	552	-18	552	519	-12	519	586	-16	586
GL3	556	-26	557	511	-11	511	567	-15	567
GL4	546	-33	547	521	-9	521	579	-14	580
GL5	561	-36	562	508	-6	508	563	-9	563
GL6	522	18	523	494	1	494	543	-0.3	543
GR1	-558	-1	558	-546	-11	546	-608	-14	608
GR2	-562	-36	563	-517	-12	517	-583	-16	583
GR3	-564	-21	565	-491	-10	491	-542	-13	542
GR4	-542	-23	543	-505	-9	505	-559	-12	559
GR5	-531	-10	531	-505	-6	505	-559	-9	559
GR6	-515	-14	515	-483	1	483	-529	0.2	529
F1UL	127	-14	128	54	-10	25	85	-55	101
F1UR	-146	-51	154	-27	-23	36	-84	-54	100
F1DL	113	76	136	25	92	25	83	53	98
F1DR	-129	91	158	-30	25	39	-83	53	98

6.2 Calculation of the Electrostatic Sag

The equation for the electrostatic sag is

$$T \cdot \frac{d^2\vec{\delta_e}}{dz^2} = \vec{F_e}, \tag{5}$$

where $\vec{F_e} = q\vec{E}$ is the electrostatic force acting on the wire, q is the charge per unit length and $\vec{E}$ is the electric field acting on the wire which is generated by the other wires. Ignoring the z-dependence of $\vec{E}$, the solution is given approximately by

$$\begin{pmatrix} \Delta X \\ \Delta Y \end{pmatrix} = \vec{\delta_e}(L/2) = \frac{L^2}{8} \cdot \left(\frac{q \cdot \vec{E}}{T} \right) \tag{6}$$

If the displacement is so large that the field variation from the original position to the one after the displacement is substantial, we need to iterate this procedure to calculate the displacement from the electrostatic field.

We have developed a software program to do this and predict the wire displacement, knowing the cell structure, wire tension and high voltage on each wire.

Fig.10 is an illustration of the wire deflection in our 4.6m test chamber due to gravitational and electrostatic forces. The original position ($\bigtriangledown$) is the initial position of a wire on endplates. The gravitational sag ($\Box$) is the position of the wire under the gravitational force and the point ($\star$) is the measured wire position after applying high voltages. Called first iteration ($\circ$) is the calculated value of the wire deflection in the electrostatic field when other wires are at the positions after the gravitational sags, which were calculated by Eq. 6. The input parameters for the second iteration are the new wire positions from iteration 1 ($\bullet$).

Results of the predictions and measurements for sense wires S1 and S2 are shown in Fig.9. There is a small left-right asymmetry with respect to the original sense wire plane in measurements, which could not be reproduced by the calculation. Probably the source of such an asymmetry can be attributed to the influence of the other cells.

In Fig.10 we compare the measurement and prediction for a few field wires which are on the left and right sides of the sense wire plane. There is a good agreement not only in the magnitude of deflection but also in its direction. It is clear that the prediction from the second iteration is better.

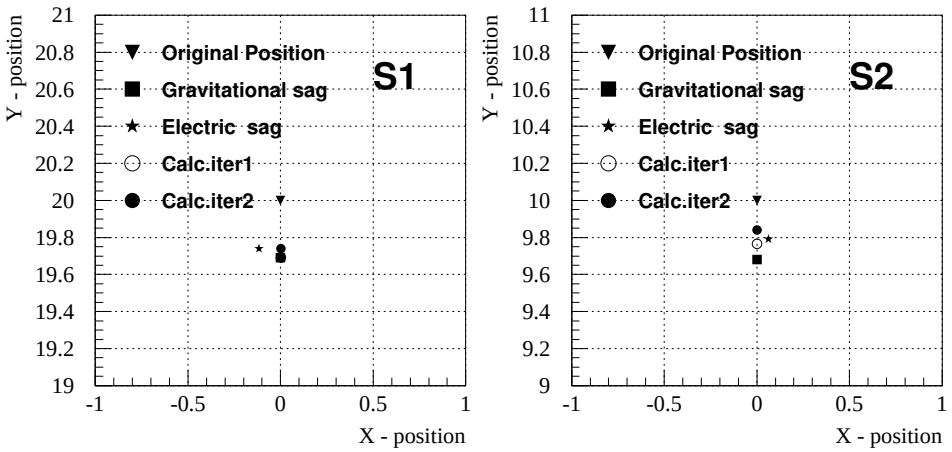

Figure 9: Positions of sense wires

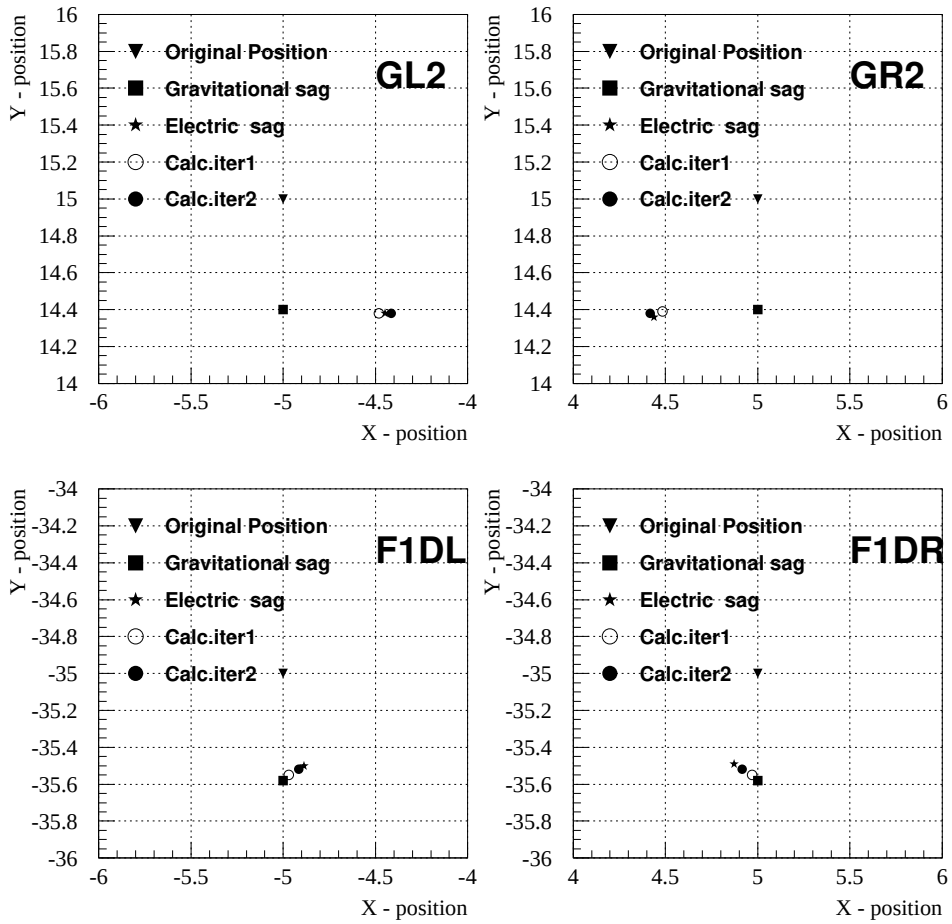

Figure 10: Positions of the field wires

7 Conclusions

We have measured the time-dependence of tensions on Al field wires and tungsten sense wires. We found a uniform tension drop of about 10%/year for Al wires even after 2 years. We need more detailed studies for field wire material choice. We have developed a wire position measurement system. Using this we measured the gravitational and electrostatic sags. The average gravitational sags for field and sense wires are 600μm and 353μm, which are in good agreement with predictions 553μm and 312μm, respectively.

We have developed a software program to calculate wire displacements in electrostatic fields, knowing the cell structure, wire tension and high voltage on each wire. There is a good agreement with measurements for field wires surrounding sense wires.

In the case of sense wires, there is some left-right asymmetry in measurement, which could not be reproduced. Probably, the source of this asymmetry is the influence of the other cells. Preliminary results from our measurements seem promising, but there are still a lot of things to do before we can conclude that we perfectly understand the wire behavior in an electrostatic field.

In principle, we can software-align wires using particle tracks, provided that x-t relations are known. The x-t relations depend, however, on the wire positions, since they affect the electrostatic fields. In order to make such a software alignment practicable, initial wire alignments given by the wire deflection calculations should be accurate enough. The question is how accurate they should be. We are planning to do cosmic ray tests to answer this question and to study feasibility of the software alignment technique in combination with the wire deflection predictions.

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2. Veen Hove, A Drift Chamber simulation program GARFIELD, 1994.