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Wire instability for STAR-TPC readout

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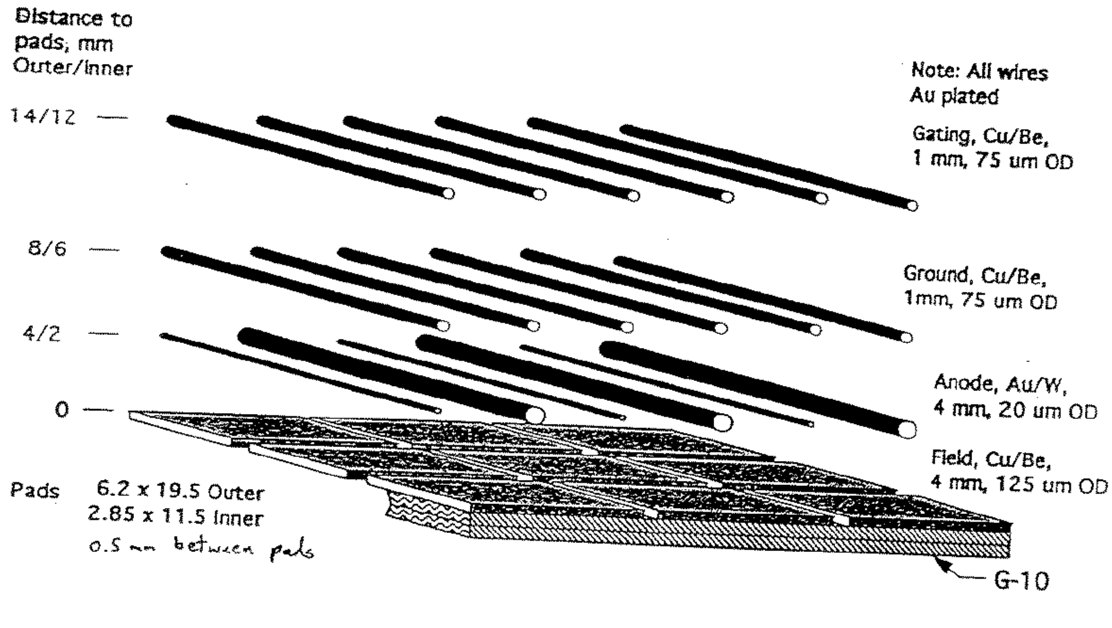
1 Introduction

This note is to consider the stability of a sense wire in the MWPC. In particular, the effect is estimated in the MWPC readout for the STAR-TPC where the field wires may be left out for the ease of cost and construction. The MWPC geometries are shown as below for both outer and inner sectors. At given bias voltages, charges on various wires are calculated by using a program called Garfield[1]. The electrostatic forces exerted on the sense wire are then evaluated among various wires. Stable condition can be obtained for the sense wire if its tension force is larger enough to balance the electrostatic force.

The operation voltages are 1200V on sense wire, 0V on both Field wires and Ground wires. When field wires are absent, A. Sobel *et. al.* observed that the anode voltage had to be raised from 1200V to about 1400V in order to get comparable pulse height on the pad readout. In the following, we consider two cases: (1) V_a = 1200V with Field wire, (2) V_a = 1400V without Field wire for each sector. Furthermore, we explore the optimum gap between the Ground plane and the Sense/Field wire plane in terms of electrostatic stability.



2 Formulae for the forces

Let q_s, q_F, q_G and q_P be the linear charge density on the sense, Field, Ground wires and Pad plane (assuming $50\mu m$ wide strips), respectively. They were calculated via surface electric fields using the Garfield program. s (=2mm) is the spacing between sense and Field wires. η is a small displacement of the sense wire ($\eta << s$). (1) The in-plane force between the displaced sense wire and other sense and Field wires is:

$$F_s^{in} = \frac{q_s}{2\pi\epsilon_0}\left[\sum_{n=1}^{\infty}\left(\frac{q_F}{(2n-1)s-\eta} - \frac{q_F}{(2n-1)s+\eta}\right) + \sum_{n=1}^{\infty}\left(\frac{q_s}{(2n)s-\eta} - \frac{q_s}{(2n)s+\eta}\right)\right]$$
$$\approx \frac{\pi q_s(q_F+q_s/3)\eta}{8\epsilon_0}\frac{\eta}{s^2}$$

(2) The out-plane force between the displaced sense wire and other sense and Field wires is:

$$F_s^{out} = \frac{q_s}{2\pi\epsilon_0}\left[\sum_{n=1}^{\infty}\frac{q_F\cdot 2\eta}{((2n-1)s)^2+\eta^2} + \sum_{n=1}^{\infty}\frac{q_s\cdot 2\eta}{(2ns)^2+\eta^2}\right] \approx \frac{\pi q_s(q_F+q_s/3)}{8\epsilon_0}\frac{\eta}{s^2}$$

(3) The out-plane force on a sense wire from the Ground plane is:

$$F_{sG} = \frac{q_s}{2\pi\epsilon_0}q_G\left[\frac{1}{t} + \sum_{n=1}^{\infty}\frac{2t}{t^2+(nu)^2}\right] \approx \frac{q_s q_G}{2\pi\epsilon_0}\frac{12.56304}{t}$$

where the Ground-wire spacing u=mm, the gap between the sense wire and the Ground plane t=4mm. The relative strength between F_s^{out} and F_{sG} is:

$$\frac{F_s^{out}}{F_{sG}} = \frac{\pi^2}{4\cdot 12.56304}\left|\frac{q_F+q_s/3}{q_G}\right|\frac{\eta t}{s^2}$$

(4) The out-plane force on a sense wire from the Pad plane is:

$$F_{sP} = \frac{q_s}{2\pi\epsilon_0}q_P\left[\frac{1}{h} + \sum_{n=1}^{\infty}\frac{2h}{h^2+(n\nu)^2}\right] \approx \frac{q_s q_P}{2\pi\epsilon_0}\cdot\left\{\begin{array}{l} 47.65\times 10^3(outer-sector) \\ 50.05\times 10^3(inner-sector) \end{array}\right\}$$

where the Pad-wire spacing $\nu = 50\mu m$, the gap between the sense wire and the Pad plane $h = 4$ or 2mm.

(5) The restoring force due to wire tension[2]:

$$F_R = \frac{8\eta T}{L^2}$$

where T is the wire tension in gram and is typically about 50g, L is the wire length.

3 Limit on the sense-wire length

To estimate the maximum length of the sense-wire, we consider the balance between the wire tension force and the electrostatic force due to sense and field wires only. To be stable, $F_s \leq F_R$. Since $F_s = \sqrt{(F_s^{in})^2 + F_s^{out})^2} = \frac{\pi q_s|q_f+q_s/3|}{8\epsilon_0}\frac{\sqrt{2\eta}}{s^2}$, and $F_R = \frac{8\sqrt{2}\eta T}{L^2}$, $L_{max} = s\sqrt{\frac{64\epsilon_0 T}{\pi q_s|q_F+q_s/3|}}$. (Note: For the case w/o field wire, $q_F = 0$.)

Another formula is from the Particle Properties Data Booklet (June l992, page 136) concerning the proportional chamber wire instability :

$$L \leq 59\sqrt{T}\left[\frac{t}{V} + \frac{s}{\pi V} ln\left(\frac{s}{\pi d}\right)\right]$$

where V is in kV, and T is in grams-weight equivalent. $L_{max} \approx 3.2m$ (at V=1.2kV) and 2.7m (at V=1.4 kV) using t=4mm, s=4mm, d=0.02mm. These two formula are consistent with each other.

4 Displacement of the sense wire

Once we consider the force on the sense wire due to the Ground plane and the Pad plane, there exist equilibrium conditions which provide estimates on the sense-wire displacement.

$$\begin{aligned} F_{sP} + F_{sG} + F_s^{out} + F_R &= 0, \\ \frac{q_s q_G}{2\pi\epsilon_0} 3.14 \times 10^3 \left(1 - \frac{F_{sP}}{F_{sG}}\right) &= \frac{8T}{L^2}\eta - \frac{\pi q_s(q_F + q_s/3)}{8\epsilon_0 s^2}\eta. \end{aligned}$$

Since the wire tension force is inverse proportional to L^2 the shorter the wire, the stronger the restoring force. Using L=1m, we can get an upper-limit estimate of the sense-wire displacement. The corresponding values are listed in the following tables.

The gain variation due to the sense-wire displacement is calculated by[4]

$$\frac{\Delta G}{G} = \frac{\Delta E}{E} lnG$$

assuming $lnG \approx 10$. The electric field variation is estimated by displacing the sense wire by η.

Outer Sector	w. Field	w/o Field	w. Field	w/o Field	w.Field	w/ Field
s-G gap	5mm		4mm		3mm	
V_s(V)	1200	1400	1200	1400	1200	1400
E_s(V/cm)	190109	181712	192950	189896	197271	201481
$q_s/(2\pi\epsilon_0)$	190	182	193	190	197	201
E_F(V/cm)	14788	/	14056	/	12946	/
$q_F/(2\pi\epsilon_0)$	-92.4	/	-87.9	/	-80.9	/
E_G(V/cm)	2208	4556	2774	5433	3633	6672
$q_G/(2\pi\epsilon_0)$	-8.2	-17.0	-10.3	-20.3	-13.5	-24.9
E_P(V/cm)	860	1610	843	1530	806	1410
$q_P/(2\pi\epsilon_0)$	-0.68	-1.28	-0.67	-1.22	-0.64	-1.12
L_{max}(m)	4.6	3.3	5.0	3.2	6.2	3.0
$\eta(\mu$ m)(1m)	-30.3	-52.3	1.1	17.0	70.9	164.6
F_s^{out}/F_{sG}	2.6e-2	4.6e-2	5.0e-2	1.0e-2	1.2e-2	6.5e-2
F_s^{out}/F_R	4.8e-2	9.7e-2	4.0e-2	0.11	2.6e-2	0.12
F_{sP}/F_{sG}	1.57	1.43	0.98	0.91	0.54	0.51
$\Delta G/G(\%)$	0.6	1.5	1.2e-3	9.7e-2	1.3	5.7

Inner Sector	w. Field	w/o Field	w. Field	w/o Field	w.Field	w/o Field
s-G gap	2mm		3mm		4mm	
V_s(V)	1200	1400	1200	1400	1200	1400
E_s(V/cm)	215613	241455	209756	230070	206869	222958
$q_s/(2\pi\epsilon_0)$	216	241	210	230	207	223
E_F(V/cm)	8309	/	9790	/	10540	/
$q_F/(2\pi\epsilon_0)$	-51.9	/	-61.2	/	-65.9	/
E_G(V/cm)	4476	6844	3154	5165	2366	4102
$q_G/(2\pi\epsilon_0)$	-16.7	-25.5	-11.7	-19.3	-8.8	-15.4
E_P(V/cm)	1314	1960	1402	2197	1452	2385
$q_P/(2\pi\epsilon_0)$	-1.05	-1.56	-1.12	-1.75	-1.16	-1.90
L_{max}(m)	5.1	2.5	7.8	2.6	13.3	2.7
$\eta(\mu$ m)(1m)	167	338	-21	- 26	-89	-172
F_s^{out}/F_{sG}	2.0e-2	0.10	2.4e-3	1.5e-2	6.2e-3	0.16
F_s^{out}/F_R	3.8e-2	0.17	1.6e-2	0.15	5.6e-3	0.15
F_{sP}/F_{sG}	0.50	0.49	1.14	1.08	2.10	1.96
$\Delta G/G(\%)$	0.8	3.3	1.1	1.9	4.4	19

5 Conclusion

This study concludes that removing Field wires will decrease the electrostatic stability of MWPC readout. However, careful choices of the wire plane geometries can alleviate the instability. Optimum geometries seem to exist. For the inner sector, the Ground plane should lie 3mm above and the Pad plane 2mm below the sense/Field wire plane. For the outer sector, the Ground plane should lie 4mm above and the Pad plane 4mm below the sense-Field wire plane.

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References

[1] Rob Veenhof, "Garfield, a drift-chamber simulation program (V4.10)", CERN Program Library entry W5050, 1992.

[2] H.J. Hilke, "Electrostatic forces and capacitances in the TPC", TPC-LBL-78-50, Aug. 23, 1978.

[3] F. Ragusa, L. Rolandi, "Gain stability in ALEPH TPC", ALEPH-LEP Note# 89, Feb. 1, 1983.

[4] F. Sauli, "Principles of Operation of Multiwire Proportional and Drift Chambers", CERN 77-09, May 3, 1977.