

# Gas gain on single wire chambers filled with pure isobutane at low pressure

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## Abstract

The gas gain of single-wire chambers filled with isobutane, with cell cross-section 12x12 mm and wire diameters of 15, 25, 50 and 100  $\mu\text{m}$ , has been measured at pressures ranging 12-92 Torr. Contrary to the experience at atmospheric pressure, at very low pressures the gas gain on thick wires is higher than that on thin wires at the same applied high voltage as was shown in [1]. Bigger wire diameters should be used in wire chambers operating at very low pressure if multiple scattering on wires is not an issue.

*Key words:* first Townsend coefficient, low pressure, gas gain, isobutane

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## 1 Introduction

Electric field in the cylindrical wire chamber is defined as

$$E = \frac{V}{r \ln(b/a)} \quad (1)$$

where  $a$  and  $b$  are the wire and cathode radii, and  $r$  is the distance from the wire center. Electric field drops very fast with distance from the wire surface and at normal conditions most gas amplification takes place within 3-5 wire radii. At atmospheric pressure small diameter wire requires much lower applied high voltage in order to reach the same gas gain as on larger diameter wire. This is the reason why small diameter wires are used in wire chambers. The

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situation changes when gas pressure decreases to the level of a few tens of Torr. As was recently shown [1], in chambers with the same geometry the gas gain becomes higher on a thick wire compared to that on a thin wire at the same applied high voltages.

The present work was done to verify the gas gain on single wire chambers as a function of wire diameters and gas pressure.

## 2 Experimental setup

Tests were carried out with single-wire chambers. The chambers have a cell cross section 12x12 mm and a wire length of about 20 cm. Chambers are made of aluminum alloy with double sided aluminized mylar on two sides serving as cathodes. Chambers with wire diameters 15, 25, 50 and 100  $\mu\text{m}$  have been tested. The chambers were placed in an aluminum vacuum box. The box was pumped out and filled with pure *iso* -  $C_4H_{10}$  a few times, and finally it was pumped out to the required pressure for the test measurements. The measurements have been done at pressures of 92, 52, 32 and 12 Torr. The pressure was monitored with a pressure gauge with a precision of  $\pm 1$  Torr. Chambers were irradiated with an  $^{55}\text{Fe}$  x-ray source collimated with a 1.6 mm thick G10 plate with 3 mm hole. This plate was placed directly over the mylar cathode with the hole close to the cell edge. Signals from the chambers were self triggered and fed into a LeCroy 2249W ADC, with a gate width of 1  $\mu\text{s}$  for all tests.

## 3 Results and discussion

$^{55}\text{Fe}$  x-ray photons have energy 5.9  $keV$  (80%) and 6.49  $keV$  (20%). The x-rays undergo only photoabsorption in pure *iso* -  $C_4H_{10}$  at these energies. The released electrons have a range of about 700-750 $\mu\text{m}$  in pure *iso* -  $C_4H_{10}$  at atmospheric pressure. At 92 Torr the range becomes about 6 mm, while it is about 11 mm, 17 mm and 45 mm at 52, 32 and 12 Torr respectively. At low pressure, there is a high probability that electrons will leave the 12x12 mm cell before they lose all their energy. Some of the electrons lose all their energy within the cell, but do not give a full avalanche if the ionization electrons originate close to the wire surface. As a result, the measured charge spectrum has a continuous distribution with a full photoabsorption peak at the high energy end from the electrons which stop inside of the cell and give a full avalanche.

The total x-ray photoabsorption results in 5.9  $keV$  energy loss inside of a cell. The average energy required to produce an ion-electron pair in pure *iso* -  $C_4H_{10}$  is 23  $eV$  [2]. Thus, the photoabsorption of 5.9  $keV$  x-ray photons

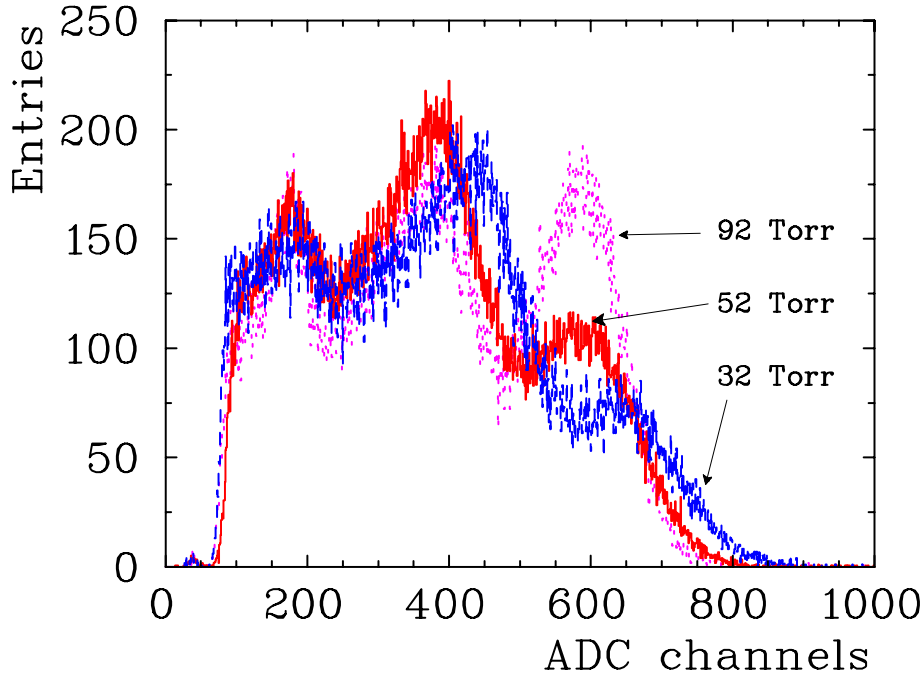


Fig. 1. Charge spectra on the single-wire chamber, with a  $25 \mu\text{m}$  diameter wire, filled with pure *iso* -  $C_4H_{10}$  at pressure 92, 52 and 32 Torr. Applied voltages are 1150 V, 1000 V and 950 V respectively. Chamber irradiated with  $^{55}\text{Fe}$  x-rays. Gas gains are in the range 9000-13500. The total absorption peak resolution degrades with decreasing gas pressure.

results in about 256 electrons in pure *iso* -  $C_4H_{10}$ . This number will be used to calculate the gas gain in the test chambers.

Figure 1 presents charge distributions measured on the  $25 \mu\text{m}$  wire at pressures of 92, 52 and 32 Torr. Spectra were taken at applied high voltages of 1150 V, 1000 V and 950 V respectively. Gas gains at these applied voltages are in the range 9000-13500. As mentioned earlier the spectra have continuous distributions with full photoabsorption peaks at the end. The fraction of events in the photoabsorption peak, and its resolution, drop with decreasing pressure. All charge distributions were fit with an exponential function to describe the tail of continuous charge distribution combined with a gaussian for the photoabsorption peak. The gaussian function gives the photoabsorption peak center and its sigma. The results of the gaussian fit were used to calculate the gas gain.

Figure 2 shows the gas gain as a function of applied voltage on all four tested wires at a gas pressure of 92 Torr. Here and on the next two figures the straight lines are exponential fits of experimental points. One can see that at 92 Torr the thinner wires have higher gas gain at the same applied high voltage. Resolution is much poorer on the thin wires, which resulted in fewer points on the  $15 \mu\text{m}$  and  $25 \mu\text{m}$  wires.

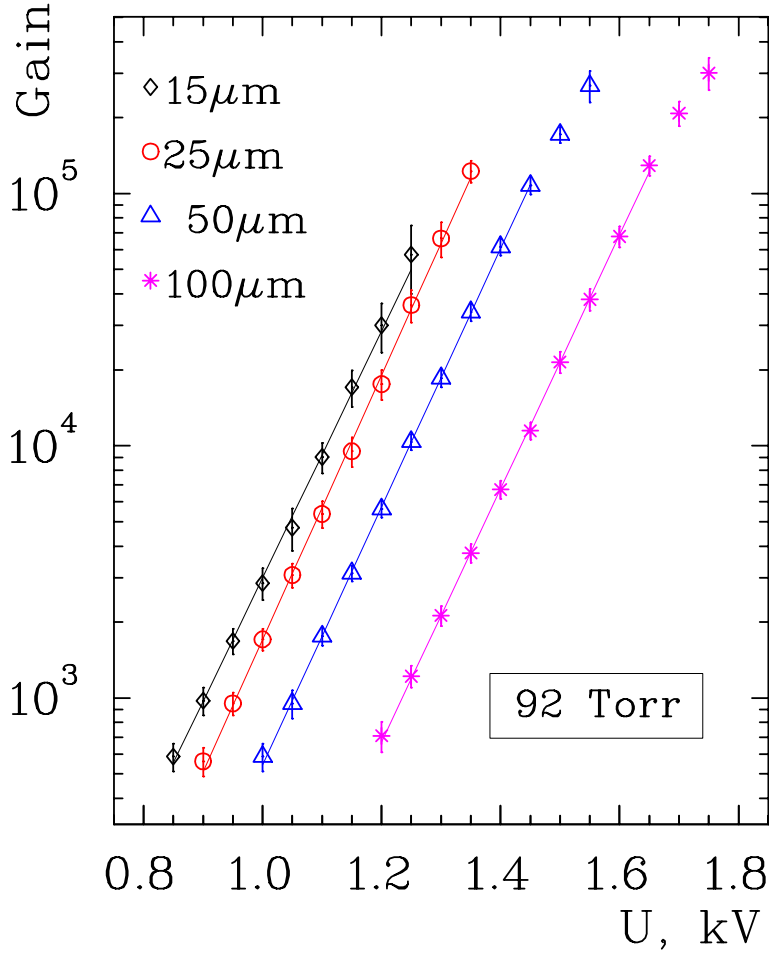


Fig. 2. Gas gain versus high voltage of single-wire chambers with 15, 25, 50 and 100  $\mu\text{m}$  diameter anode wires. Chambers are filled with pure *iso* -  $C_4H_{10}$  at 92 Torr and irradiated with  $^{55}\text{Fe}$  x-rays. The straight lines represent exponential fits of experimental points.

At a pressure of 52 Torr (fig. 3) there are visible changes compared with 92 Torr. The smaller the wire diameter the smaller the slope of gas gain versus high voltage dependence. At lower voltages, the gain is higher on the 15  $\mu\text{m}$  wire compared with that on the 25  $\mu\text{m}$  wire. Above 1000 V, gain on the 15  $\mu\text{m}$  becomes equal or even lower than on the 25  $\mu\text{m}$  wire and even approaches that on the 50  $\mu\text{m}$  wire.

Figure 4 depicts gas gains on the tested wires at a pressure of 32 Torr. Resolution becomes very poor here, especially for the 15 and 25  $\mu\text{m}$  wires. As in the two previous cases, the gas gain is higher on thinner wires at low voltages, but that changes very quickly. At 900 V gains on the 15, 25 and 50  $\mu\text{m}$  are already equal and eventually reverse the order compared with higher pressure. Above 1050 V the gain on the 100  $\mu\text{m}$  wire almost reaches that on the 15  $\mu\text{m}$  wire.

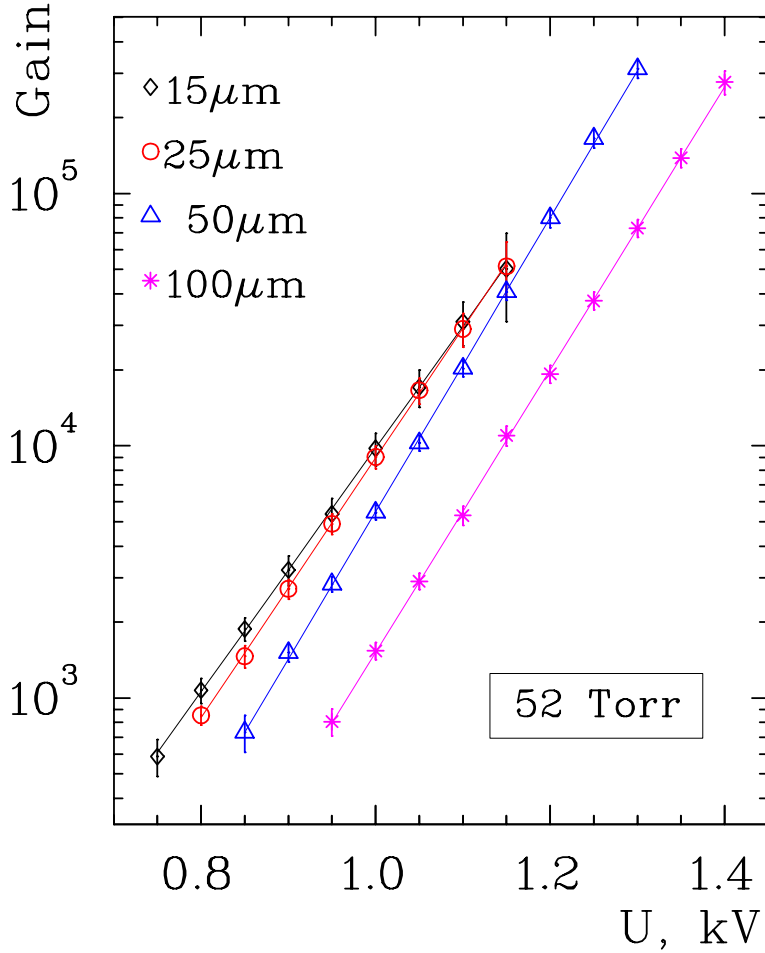


Fig. 3. Gas gain versus high voltage of the same chambers as in fig.2 at 52 Torr pressure. Note that gas gain of 15  $\mu\text{m}$  wire is nearly the same as for 25  $\mu\text{m}$  wire at 1050 V.

Further lowering of pressure results in very poor resolution and the full absorption peak disappears. At 12 Torr, charge spectra have been taken on all four wires with 800 V applied voltage. Spectra were presented in [1] and are shown here in fig.5. There are no indications of full absorption peaks on any wires. The edges of the charge distributions do indicate gas gain on each wire. One can see that at 12 Torr and 800 V the gas gains are higher on the bigger diameter wires.

Data taken at low pressure showed that for a given wire diameter, the resolution of the photoabsorption peak degrades with increasing high voltage and decreasing gas pressure. Thin wire has worse resolution at the same pressure and applied high voltage compared to thick wire.

In [1] an electric field  $E_m$  was introduced where electrons gain enough energy to ionize atoms over the mean free path  $\lambda_m$ , i.e.  $eE_m\lambda_m = I_0$ , where  $\lambda_m = 1/n\sigma$  [3]. Here  $I_0$  is the gas ionization potential,  $\sigma$  is the total cross

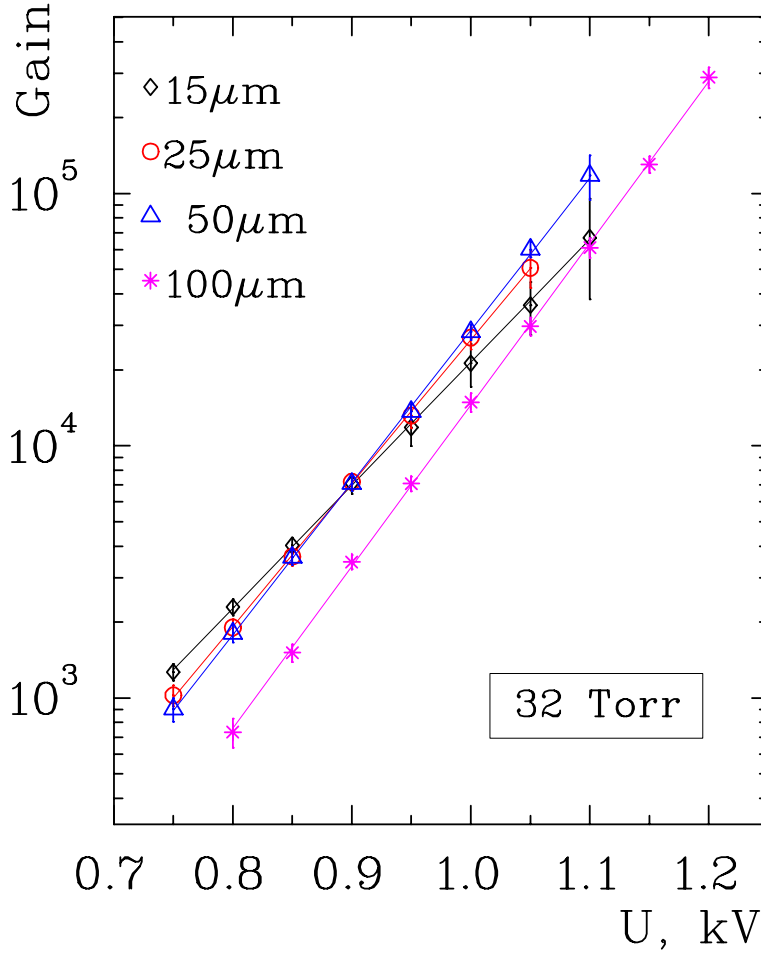


Fig. 4. Gas gain versus high voltage of the same chambers as in fig.2 at 32 Torr pressure. At lower voltages the gas gain is higher on the thinner wires at the same applied high voltage. Eventually the order reverses for the three thinnest wires.

section for electron collision with atoms,  $n$  is the density of gas atoms,  $e$  is the electron charge. Above this electric field strength the first Townsend coefficient has very weak dependence on electric field and is defined mainly by the electron's mean free path.

One can understand the gas gain behaviour, shown in fig.5, by looking at the reduced electric field strength distributions near the wires and taking into account the behaviour of the first Townsend coefficient at high electric field, proposed in [1]. Figure 6 shows the reduced electric fields of all four tested wires as a function of distance from the wire surfaces. Pressure is 12 Torr and 800 V is applied to each chamber. The critical reduced electric field for pure *iso*- $C_4H_{10}$ , where the avalanche starts, has been estimated using data from [4] and found to be  $S_c \simeq 86 \text{ V/cm} \cdot \text{Torr}$ . Electric field  $E_m$  for pure *iso*- $C_4H_{10}$  at 12 Torr with  $n = 4.3 \cdot 10^{17} \text{ cm}^{-3}$ , total cross section  $\sigma \simeq 10^{-15} \text{ cm}^2$  [5]

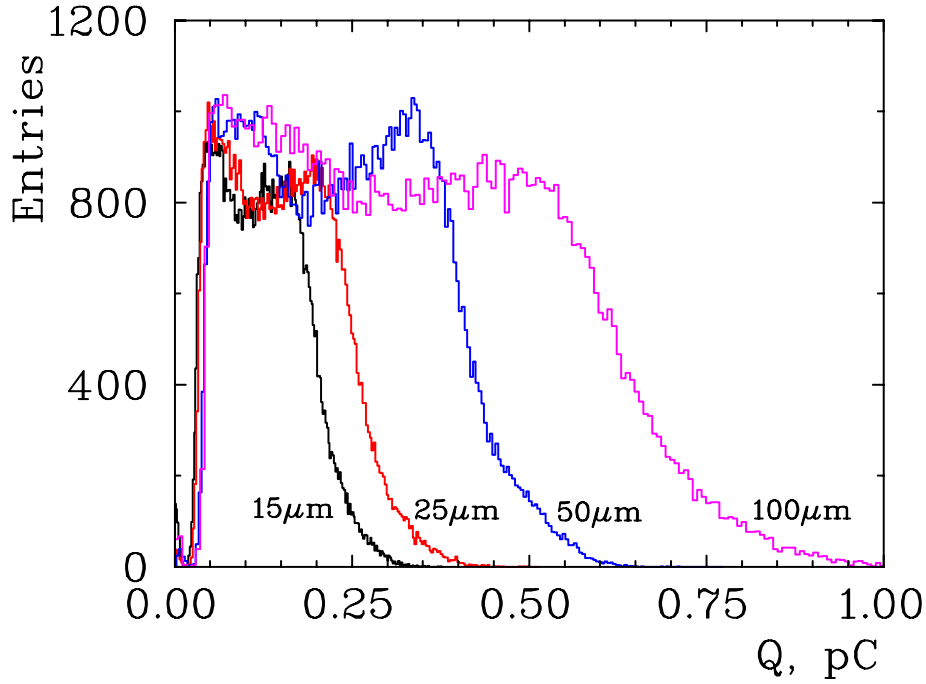


Fig. 5. Measured charge spectra on single wire chambers with 15, 25, 50 and 100  $\mu\text{m}$  diameter anode wires filled with pure iso- $\text{C}_4\text{H}_{10}$  at 12 Torr. All chambers are at 800 V and irradiated with  $^{55}\text{Fe}$  x-rays. The bigger the wire diameter, the higher the gas gain.

and 10.8 eV an ionization potential [2], is estimated to be  $E_m \approx 4.65 \text{ kV/cm}$ . These values of  $S_c$  and the reduced field  $S_m = E_m/P \approx 390 \text{ V/cm} \cdot \text{Torr}$  are shown as well. The avalanches start farther from the surfaces of thick wires. Everywhere at field  $S < S_m$  thicker wires have higher reduced electric field that results in a higher first Townsend coefficient. Beyond reduced field  $S_m$  the first Townsend coefficient has very weak dependence on electric field and stays practically the same for all wires even though the thinner wires have much higher electric field there. Such a behaviour results in higher total gas gain on thicker wires.

The poor energy resolution in our measurements was primarily caused by the small cell size (12x12 mm cross section) of the single wire chambers which were used in the test measurements. One would need to use chambers with bigger cell size to improve resolution.

It is interesting to notice from the comparison of fig.2-4 that saturation is visible only on 50 and 100  $\mu\text{m}$  wires at pressure 92 Torr. The highest gain there is about  $3 \cdot 10^5$  which corresponds to a collected charge of about 12 pC. The reason for this is that photoelectrons released by  $^{55}\text{Fe}$  x-rays have much longer range at low pressure and many avalanches are distributed along the wire. Recall, that at atmospheric pressure, saturation starts when the total charge in the avalanche exceeds  $\approx 1 \text{ pC}$ .

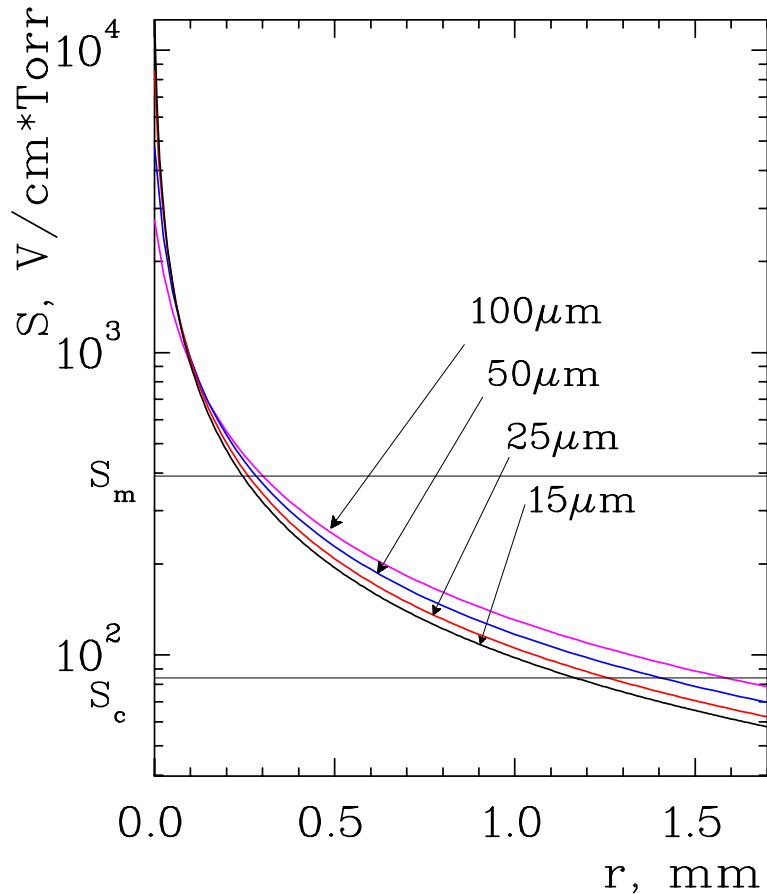


Fig. 6. Reduced electric field  $S$  on single wire chambers with 15, 25, 50 and 100  $\mu\text{m}$  diameter anode wires as a function of distance from the wire surfaces. All chambers are at 800 V and pressure 12 Torr.

#### 4 Conclusion

We have measured gas gain on 15, 25, 50 and 100  $\mu\text{m}$  diameter wires in single-wire chambers filled with pure *iso* -  $C_4H_{10}$  at pressures in the range 12-92 Torr. Our results clearly demonstrate that at low pressures, gas gain becomes higher on thick wires than on thinner wires, in wire chambers having the same geometry and applied high voltage. The gas gain versus high voltage dependence slopes are smaller on the smaller diameter wires at low pressure. This is a consequence of the fact that at high electric field strength the first Townsend coefficient is limited by the electron's mean free path.

Bigger wire diameters should be used in wire chambers operating at very low gas pressures where scattering on the wires is not an issue. Specific recommendations should be addressed for each gas and chamber geometry. Operating voltage (i.e. gas gain) should be taken into account as well because the



gas gain versus high voltage curves on different diameter wires have different slopes.

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