

LNF-11/05 (P)  
7 April 2011

## MEASUREMENT OF THE ABSOLUTE GAS GAIN AND THE GAIN VARIATIONS STUDY IN STRAW-TUBE DETECTORS

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### Abstract

We present results the absolute gas gain measurement of a straw drift-tube detector filled with the binary gaseous mixture ArCO<sub>2</sub>(10%) at 2 bars gas pressure. The measurement was performed using intensive 1.3 GBq <sup>137</sup>Cs-source in order to be able to measure the primary ionization current corresponding to the unity gas gain. The results of gas gain measurement vs. voltage at fixed gas pressure and temperature were fitted and parameterized by Diethorn's formula for further studies of the gas gain variations.

PACS: 29.40.Cs

*Submitted Nuclear Instruments and Methods A*

*Published by  
Servizio Informazione e Documentazione Scientifica dei LNF  
Ufficio Biblioteca e Pubblicazioni*

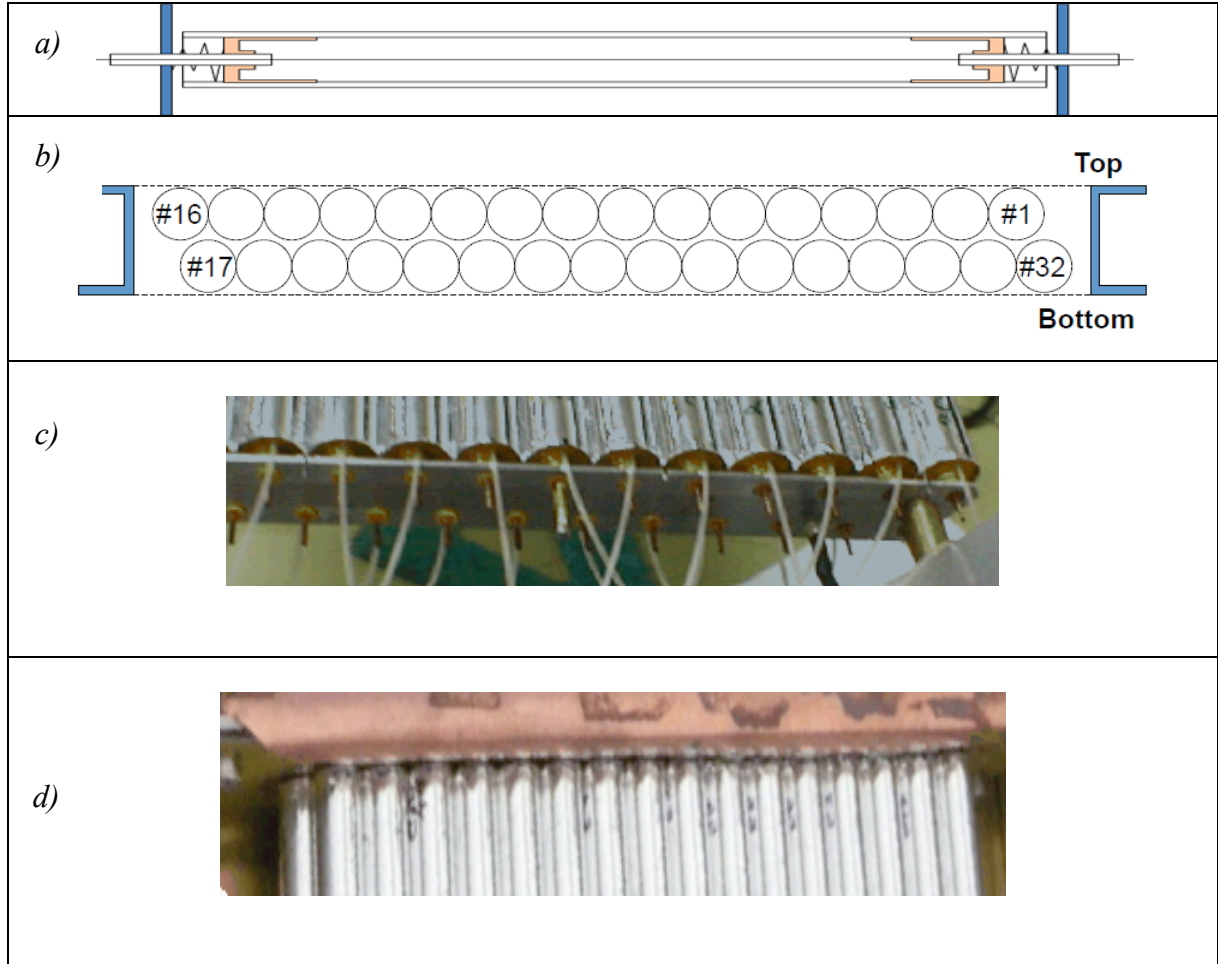
## 1 Introduction

Straw trackers of various configurations have been built for the large scale experiments, which are successfully taking data at present and are showing high efficiency with good spatial resolution, proving that the straw drift-tubes are rather reliable and attractive tracking devices, see [1-3].

In order to optimize the design of the tracker it is necessary to know the dependence of the gas gain as a function of applied voltage and gas pressure for a given gas mixture. Many operating characteristics of the straw drift-tubes can be found in literature for various gas mixtures at atmospheric gas pressure [4], but no data exist above 1 bar gas overpressure, especially of binary mixture of our interest ArCO<sub>2</sub>(10%). High contamination of Argon in the gas mixture is taken for reduction of the electron drift velocity. In addition, increasing of the gas pressure further reduces the electron drift velocity. The gas gain versus voltage at fixed pressure and temperature has been measured in a dynamic range of 10<sup>5</sup> starting from the unity gain. Measured data were fitted by Diethorn's formula [5] for further studies of the gas gain variations. In the present article we report of a systematic study of gas gain variations versus the applied voltage, gas pressure (over-pressure) and wire diameter in order to optimize the design and performance of the straw tracker.

## 2 Experimental setup

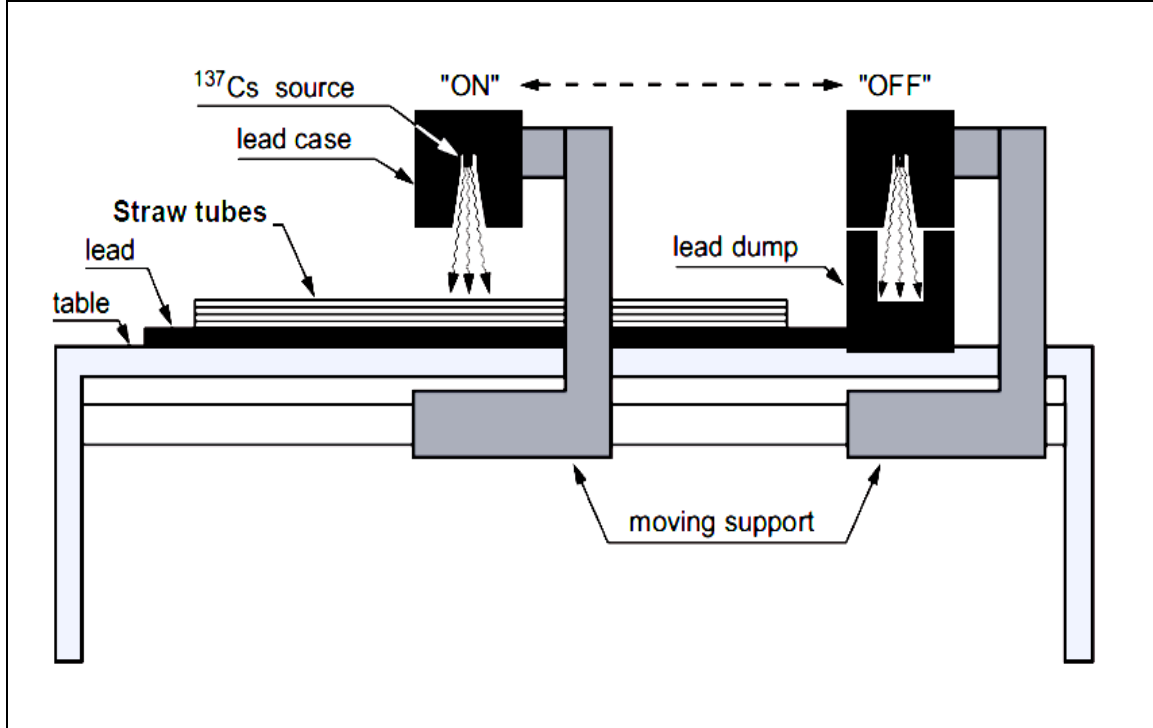
The module of the straw tracker prototype constructed with 32 straw drift-tubes for measurements is shown in Fig.1. The module consists of 0.75 m long Mylar tubes with a wall thickness of 30  $\mu$ m and a straw tube of 10 mm diameter aluminized on both the inner and outer surfaces (see Fig.1a). The Mylar used here is the preferred compared to the Kapton material because of its well suited mechanical properties like a high Young's modulus and tensile strength [4, 5]. The tungsten (*W+3%Re*) wires of 20 microns diameter were pre-stretched by using a weight of 40 g at the nominal gas over-pressure of 1 bar inside the each straw drift-tube. The proposed technique with over-pressure of 1 bar inside the straw tube (2 bar absolute gas pressure) has some advantages. It provides self-supporting the required wire tension and stretches tube by the gas over-pressure inside the each single straw of the module. For further rigidity the straw tubes in the module were glued together in a stretched state along straws with staggered one layer with respect to another one by 10 mm, see Fig.1b and Fig.1c.



**FIG.1:** Schematic view of a single straw drift-tube in cross-section (a); 32-straw detector module (b); far-end is fully floating as shown in (c); on the near-end, where the electronics is located, the cathodes has been grounded via Copper foil as presented in (d).

An absolute gas gain measurement in the straw drift-tube is based on measuring of the primary ionization current corresponding to the unity gas gain observed along an ionization plateau at low voltages. In order to measure very small current of an order of pico-Amper at low voltage, the intensive  $1.3 \text{ GBq } ^{137}\text{Cs}$ -source was used. The setup is shown in Fig.2. It was constructed for gas gain measurements in the Multi-wire Proportional Chambers and consists of a table which supports the detector under test and an intensive  $1.3 \text{ GBq } ^{137}\text{Cs}$ -source carefully screened and collimated by a lead case, see ref. [6]. The source can be moved over the whole surface of the table. The auto-ranging Keithley-485 pico-ammeter with sensitivity of  $0.1 \text{ pA}$  was connected between the cathode and the ground in measurements for operation at the ground potential. As shown in [6], the ionization plateau has to have the same level at low positive and negative voltages, already starting from  $10 \text{ V}$  and extending at least to  $500 \text{ V}$ . In order to simplify measurements we used two blocks of batteries of  $50 \text{ V}$  and  $100 \text{ V}$

assuming that both voltage values are well within the detector ionization plateau. The battery is an ideal floating power supply preventing a parasitic loop in ground, allows accurate measurements of very small currents.



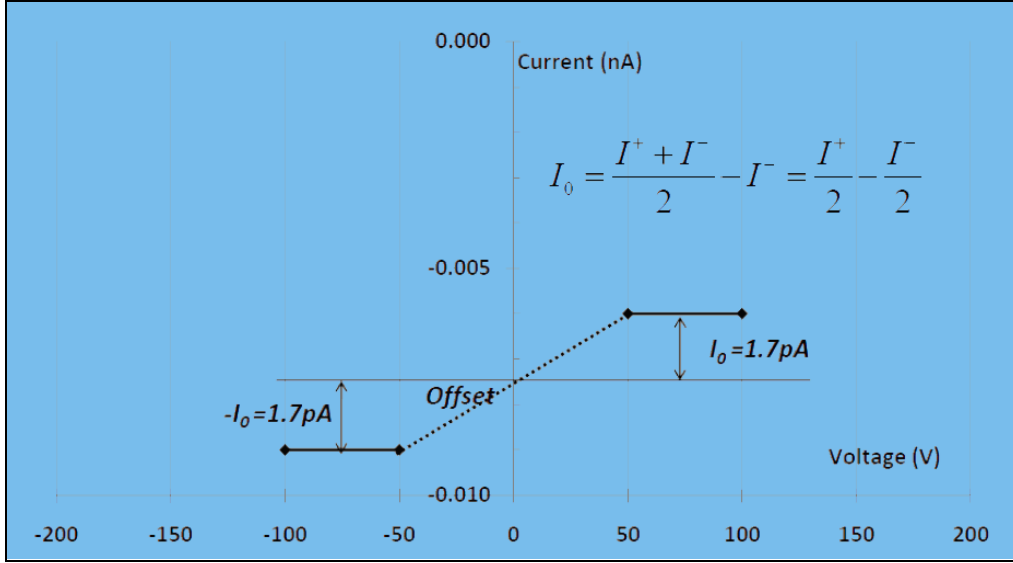
**FIG.2:** Experimental setup for gas gain measurements with the intensive  $1.3 \text{ GBq } ^{137}\text{Cs}$ -source for illumination the straw detector module.

### 3 Results of measurements

#### 3.1 Measurement of the ionization current

Results of measurements of the ionization current were averaged over 4 points, 2 points at  $\pm 50 \text{ V}$  and 2 at  $\pm 100 \text{ V}$ . Two currents ( $I^+$  and  $I^-$ ) from each single straw drift-tube were recorded one at positive and one at negative voltage by switching polarity of the battery connected to the wire via the resistor of  $10 \text{ MOhm}$ . Due to offset of the Keithley-485 the measured currents did not change polarity, when the polarity of batteries was changed, however the switching polarity technique gives double value of the ionization current ranged from  $I^+$  to  $I^-$  at source position ON, as shown in Fig.3. The dark current was measured at source position OFF, i.e. located out of the active area. The contribution of the dark current to the ionization current was negligibly small for both batteries. Values of the ionization current found at  $\pm 50 \text{ V}$  and  $\pm 100 \text{ V}$  were very close within r.m.s., as was expected:  $I_0 = 1.70 \pm 0.21 \text{ pA}$ . Similar results within r.m.s. were obtained for different straws of the 32-straw detector module.

The gas pressure and temperature had been constant during measurement of the ionization current.



**FIG.3:** Illustration for finding the ionization current: the switching polarity technique used here gives double effect in the current difference at source ON when the polarity of batteries was changed, however, measured currents  $I^+$  and  $I^-$  did not change polarity due to offset.

### 3.2 Measurement and parameterization of the gas gain

Once the ionization current  $I_0$  has been found, then the gas gain at any voltage  $V$  is the ratio of currents  $I/I_0$ , where  $I$  is the current corresponds to  $V$ . The voltage  $V$  was set in the range of  $1000-1900$  V at which the gas gain was ranged from  $10^2$  to  $10^5$ .

Let us consider some formulas which will be used below for gas gain parameterization and further study. The multiplication of ionization in gas is described by the 1-st Townsend coefficient  $\alpha$ , which is defined as the mean number of secondary electrons produced by free electron per centimeter of its drift path in the electric field [5]:

$$dN = \alpha N_0 dr \quad (1)$$

For an axial detector, like the straw drift-tube detector, the integration of this equation between the point  $r=r_{min}$ , where the electric field  $E_{min}$  becomes sufficient to start an avalanche and  $r=a$ , i.e. wire surface at field  $E_a$ , one can write for the gain amplification factor:

$$G = \frac{N}{N_0} = \exp \int_{r_{min}}^a \alpha(r) dr = \exp \int_{E_{min}}^{E_a} \alpha(E) \frac{dr}{dE} dE = \exp \int_{E_{min}}^{E_a} \frac{\alpha(E)}{E^2} \frac{V}{\ln(b/a)} dE \quad (2)$$

Here  $N$  is the final number of electrons in the avalanche developed in vicinity of the anode wire,  $N_0$  is the initial (primary) number of electrons created in the gas at  $r=r_{min}$  and  $\alpha(E)$  is the first Townsend coefficient. The derivative  $dr/dE$ , can be obtained from  $E=V/[r \cdot \ln(b/a)]$ .

Assuming that  $\alpha(E)$  is proportional to  $E$ ,  $\alpha(E)=kE$ , and substituting it and derivative  $dr/dE$  to (2) this equation can be re-written in the log-scale as:

$$\ln G = \frac{V}{\ln(b/a)} \int_{E_{\min}}^{E_a} \frac{k}{E} dE = k \frac{V}{\ln(b/a)} (\ln E_a - \ln E_{\min}) = k \frac{V}{\ln(b/a)} \ln \left( \frac{E_a}{E_{\min}} \right), \quad (3a)$$

in the linear scale as a function of voltage it will be:

$$G = \left( \frac{V}{a \ln(b/a)} \frac{1}{E_{\min}} \right)^{k \frac{V}{\ln(b/a)}}, \quad (3b)$$

where  $E_{\min}$  is the electric field at critical radius  $r=r_{\min}$  beyond which the field is still too low to support charge multiplication at normal gas density  $\rho_0$ . This parameter depends on the gas density  $\rho$ . The gas density at normal conditions is the following:  $\rho_0=R(p_0/T_0)$  where  $R$  is the constant, the gas pressure  $p_0$  and temperature  $T_0$  are the atmospheric pressure of  $1 \text{ bar}$  and room temperature of  $293 \text{ K}$ , respectively.

Diethorn [9] has parameterized  $\alpha(E)=kE$  at  $k=\ln 2/\Delta V$  and (3) is the Diethorn's formula. Here  $k$  means the following: free electron at energy  $q\Delta V$  ( $q$  is the charge of the electron) drifting on a potential difference between two points  $r=r_{\min}$  and  $r=a$  is able to create  $2^Z$  generations of new electrons and  $Z$  is the factor normalized this potential difference to  $\Delta V$ , i.e. describes the avalanche multiplication process.

The gas gain according to the Diethorn's formula is a function of the voltage, gas pressure and temperature, but also shows dependence on the detector geometry (radii of the anode wire and cathode tube):

$$G = \left( \frac{V}{A} \right)^{\frac{B}{\ln 2}}, \quad (4)$$

where coefficients  $A$  and  $B$  are the following:

$$A(p, T) = a \ln(b/a) E_{\min} \frac{p}{T} \frac{T_0}{p_0}, \quad (5)$$

$$B = \frac{\Delta V \ln(b/a)}{\ln 2}. \quad (6)$$

The Diethorn's formula, see Eq.(4)÷Eq.(6), will be used here for parameterization of measured data. The ratio of the number of electrons  $N/N_0$  is replaced by current ratio  $I/I_0$  for gas gain finding, where  $I$  is the current measured at a given voltage  $V$  applied to the wire while  $I_0$  is the primary ionization current corresponding to unity gas gain.

### 3.2.1 Gas gain dependence on the voltage

The gas gain measured as a function of voltage is presented in Fig.3 for a single straw drift-tube. Similar relations are found for other straw tubes in the module. The Diethorn's parameters  $E_{min}$  and  $\Delta V$  were extracted directly from plot using *Slope* and *Intercept* of the simple linear fit:

$$\frac{\ln G}{aE_a} = \frac{\ln 2}{\Delta V} \left( \ln \frac{E_a}{\rho / \rho_0} - \ln \frac{1}{E_{min}} \right) \Rightarrow y = \frac{\ln 2}{\Delta V} \left( x - \ln \frac{1}{E_{min}} \right), \quad (7)$$

where

$$\Delta V = \frac{\ln 2}{Slope} [V], \quad (8)$$

$$E_{min} = \exp\left(\frac{Intercept}{Slope}\right) / 1000 [kV/cm]. \quad (9)$$

In specific coordinates,  $\ln(G)/aE_a$  as a function of  $\ln E_a/(\rho/\rho_0)$ , the dependence becomes linear according to (7). According to (8) and (9) the Diethorn's parameters  $\Delta V=27.4 V$  and  $E_{min}=32.0 kV/cm$  were obtained at  $Slope=0.0253$  and  $Intercept=0.2623$  at low electric fields, while  $\Delta V=29.0 V$  and  $E_{min}=30.4 kV/cm$  at  $Slope=0.0239$  and  $Intercept=0.2466$  at high fields, respectively. The first region is expanded to the gas gain  $2.2 \times 10^4$ , while the second one up to  $10^5$ . Reduction of the gas gain seen in Fig.3 at high fields is explained by space charge effects: the gas gain as a current ratio becomes more sensitive to the space charge, which reduces effective field near the anode wire.

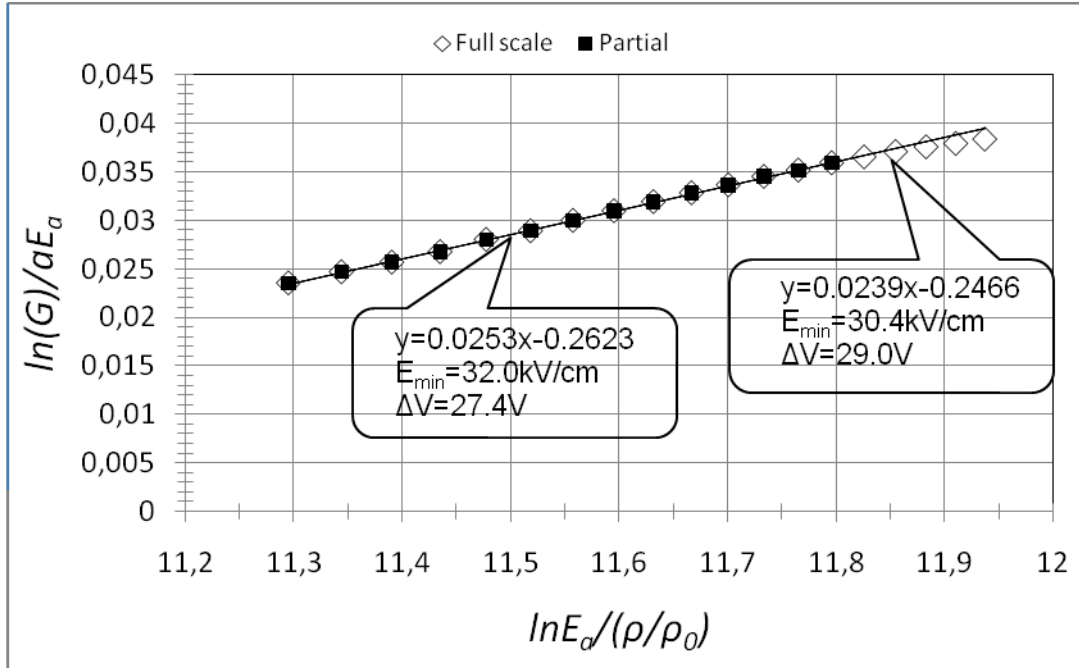
### 3.2.2 Gas gain dependence on the gas over-pressure

We measure below also a dependence of the gas gain from gas pressure variations:

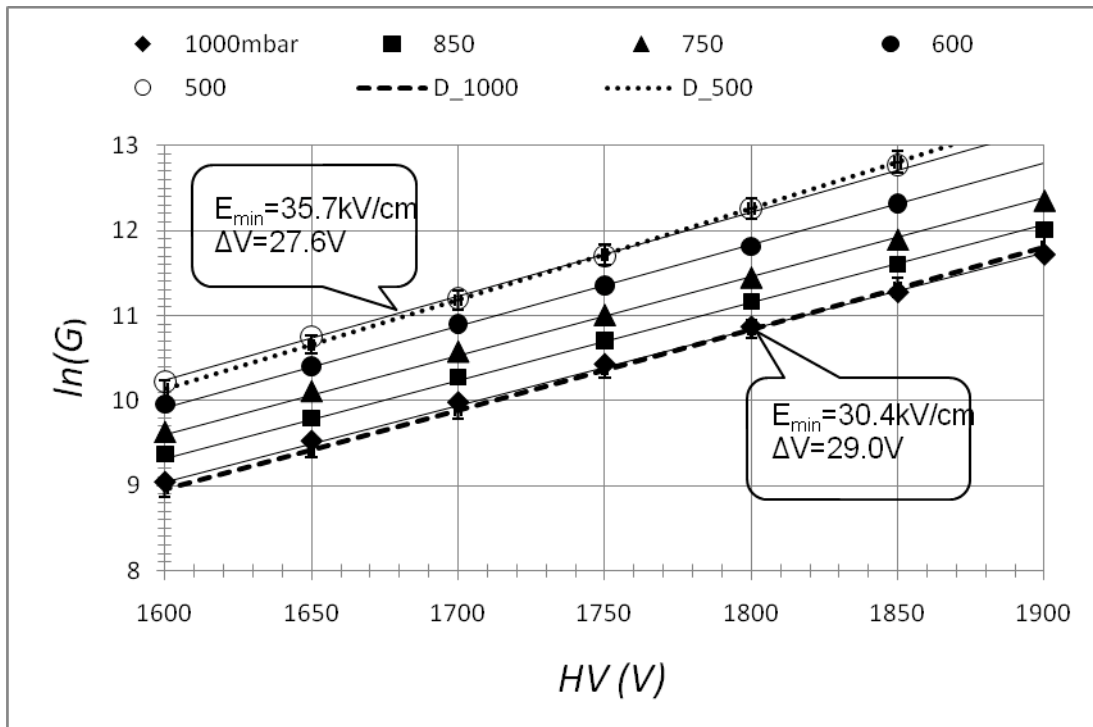
$$\frac{\Delta G}{G} = \frac{V}{B} \frac{\Delta \rho}{\rho} = \frac{V}{B} \left( \frac{\Delta T}{T} - \frac{\Delta p}{p} \right), \quad (10)$$

where B is the constant defined by the Diethorn's parameter  $\Delta V$  which does not depend on pressure, see equation (6).

The first our goal is to specify further increasing of the gas gain by reduction the over-pressure. Fig.4 shows in log-scale the gas gain versus voltage for over-pressure variations in range of 500-1000 mbar at fixed temperature. As is shown, the reduction of over-pressure is able to increase the gas gain even more than  $10^5$ , if needed, still keeping the tube stretched.



**FIG.3:** Diethorn's parameters  $E_{min}$  and  $\Delta V$  according to Eq.(8) and Eq.(9) at various ranges of electric fields.



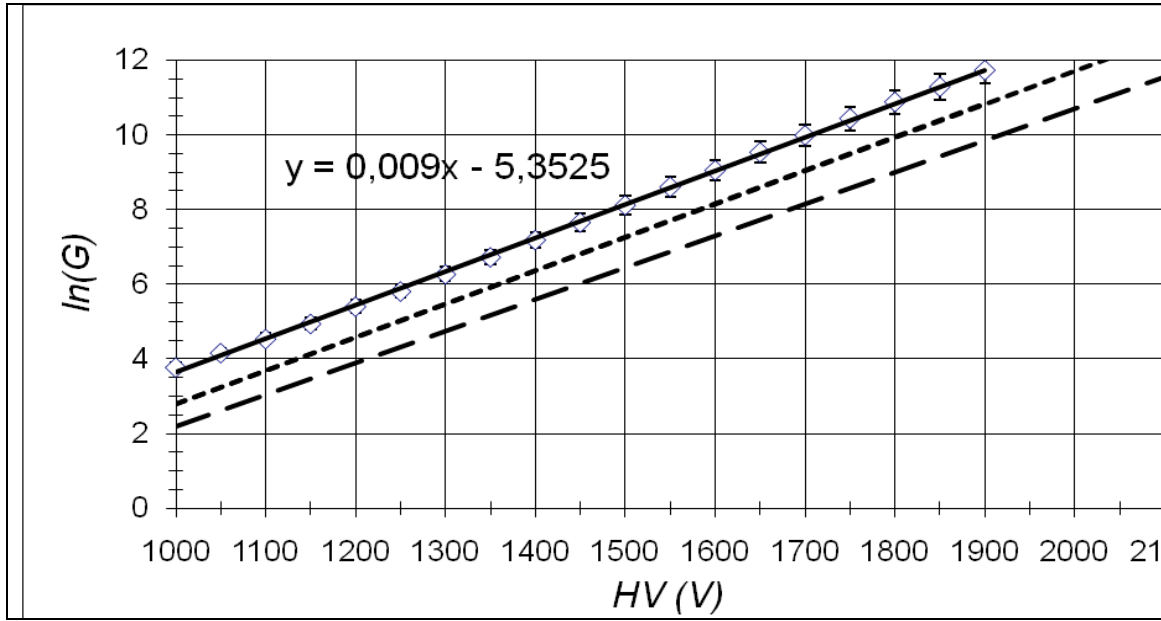
**FIG.4:** Gas gain measurements (points), fit (solid lines) and calculations with Diethorn's formula (dash and dot lines) vs. voltage at gas over-pressure in range of 500-1000 mbar.

### 3.2.3 Gas gain variation as a function of wire diameter

The sense wire resistance is a key parameter in straw-tube performance. The dominant source of noise is not in the pre-amplifier but is due to the wire resistance, and the noise r.m.s. depends on  $\sqrt{R_{wire}}$ . The nominal wire diameter used here is  $20 \mu m$ . The resistance of



$W+3\%Re$  wire according to Luma datasheet [7] is  $R_{wire}=293 \Omega/m$ . The gold coating reduces the resistance slightly, but the 3% rhenium increases the resistance significantly (the resistivity of rhenium is about four times that tungsten according to handbook). If one takes 30- $\mu m$  of wire diameter the resistance would be  $R_{wire}=293 \times (20/30)^2=130 \Omega/m$ . We conclude that in case of 30- $\mu m$  of wire diameter the resistance is reduced approximately by factor of 2 and the noise r.m.s. by  $\sqrt{2}$ . The straw-tube spatial resolution will vary when the signal-to-noise ratio small. It is the main reason for increasing the gas gain and reducing the noise r.m.s. for getting high spatial resolution. An influence of the wire diameter to the gas gain was investigated for wire diameters of 20, 25 and 30 microns using the Diethorn's formula with known  $E_{min}$  and  $\Delta V$  for a given gas. As is shown in Fig.5, a shift to higher voltage by 100 V (at wire diameter 25  $\mu m$ ) and 200 V (at wire diameter 30  $\mu m$ ) for the same gas gain value is observed. This shift in voltage for getting the same signal amplitude is well acceptable for the straw-tube detector under development.



**FIG.5:** Gas gain measurements (points) with best linear fit for 20  $\mu m$  (solid line) and for 25  $\mu m$  and 30  $\mu m$  (dash lines) at Diethorn's parameterization  $E_{min}=32.0 \text{ kV/cm}$  and  $\Delta V=27.4 \text{ V}$ .

The linear fit presented in Fig.5 helps to specify a derivative which is in the log-scale equal to 0.009 and in the scale corresponds to:

$$\Delta G = \frac{\partial G}{\partial V} \Delta V \approx e^{0.009 \Delta V} \Rightarrow \Delta G \approx 2.5 \text{ per } \Delta V = 100V. \quad (10)$$

This parameter is useful in practice for tuning the gas gain by incrementing the applied voltage.

## 4 Conclusion

Measurements of the absolute gas gain in the straw-tubes filled with binary gas mixture ArCO<sub>2</sub>(10%) at 2 bar gas pressure, Diethorn's parameterization of the gas gain and further study of gain variations have been performed. Our goal was to study the ways on optimization of the design characteristics and performance of the large straw tracker which is under development and has to have the spatial resolution better than 150 microns (r.m.s.). The conclusion of this work is the following: the wire diameter can be increased from 20 to 25 or even 30 microns which allows reduce the resistance and the noise r.m.s. in electronics, while the gas gain  $10^5$  has to be used for getting the signal-to-noise ratio as high as possible. According to measurements, at such gas gain we do not see yet serious limitations due to space charge effects and streamers, the straw-tubes operate stable.

## 5 Acknowledgements

Authors would like to thank the LHCb group at LNF for using both their <sup>137</sup>Cs-source and setup.

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