Precise gain measurement of the LHCb muon chambers

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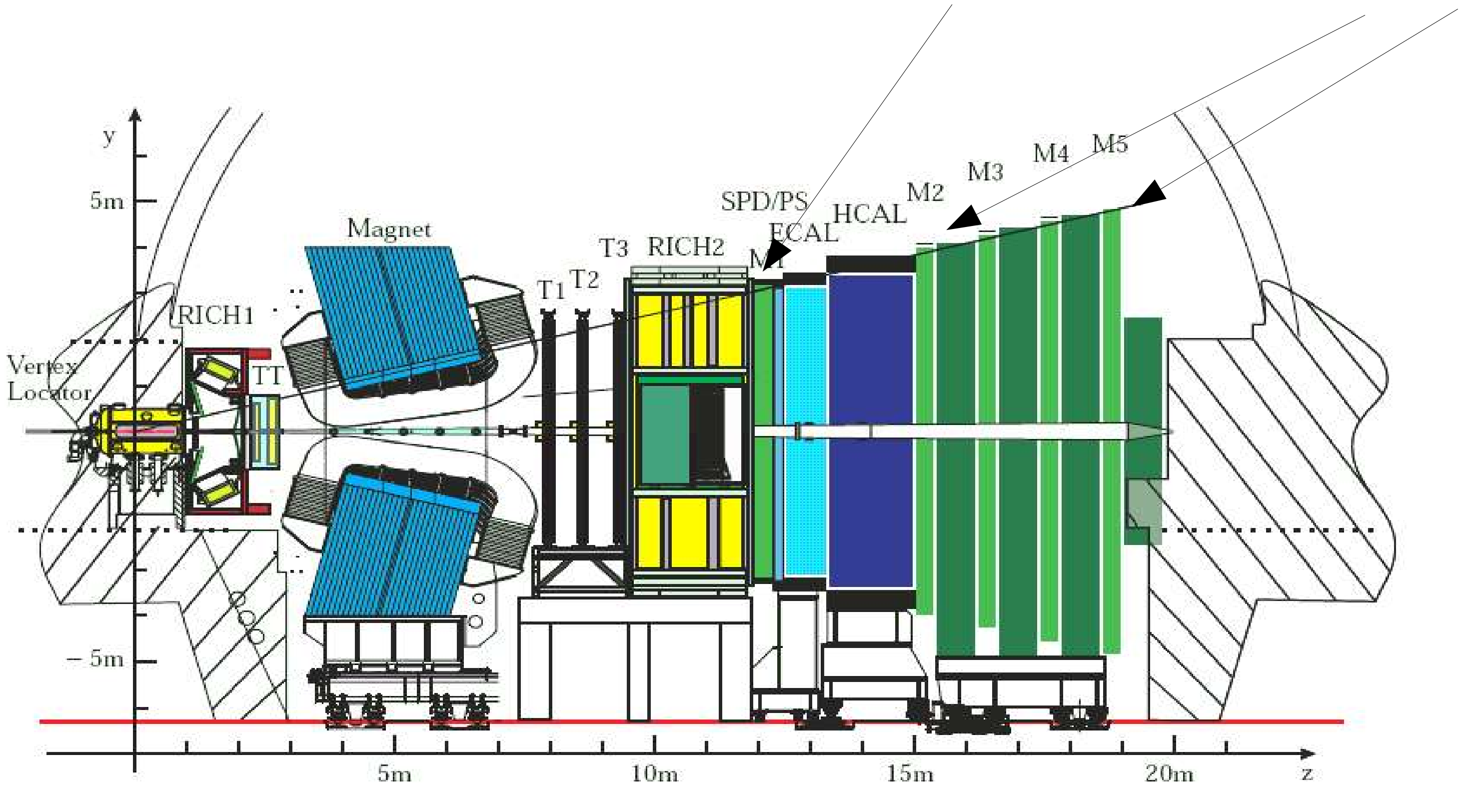
The LHCb Muon System

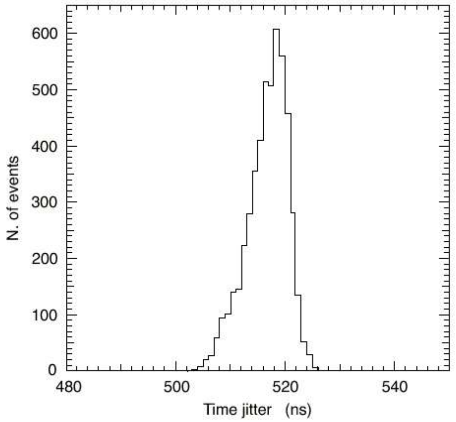
- Five tracking stations placed along the beam axis: M1 upstream and M2-M5 downstream the Calorimeters;

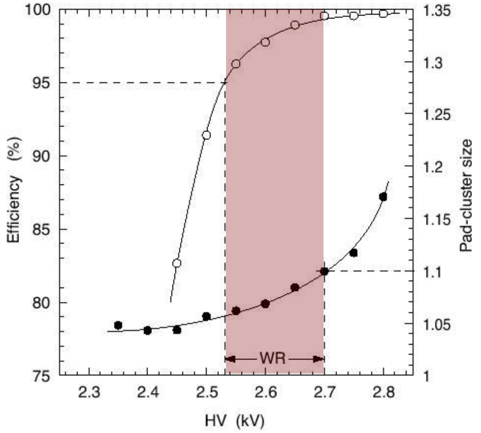


- 1368 MWPC and 24 Triple-GEM detectors, for a total area of 435 m^2;
- System provides information for the Level 0 trigger and muon-identification;

The LHCb Muon MWPC

- MWPC are made of 2 (M1) or 4 (M2-M5) identical gaps:
  - 5 mm height;
  - 30 µm diameter gold-plated tungsten wires placed at the center;
  - Pitch of 2 mm;
  - An $Ar/CO_2/CF_4$ (40/55/5) gas mixture;
  - Readout on wires and/or segmented cathode

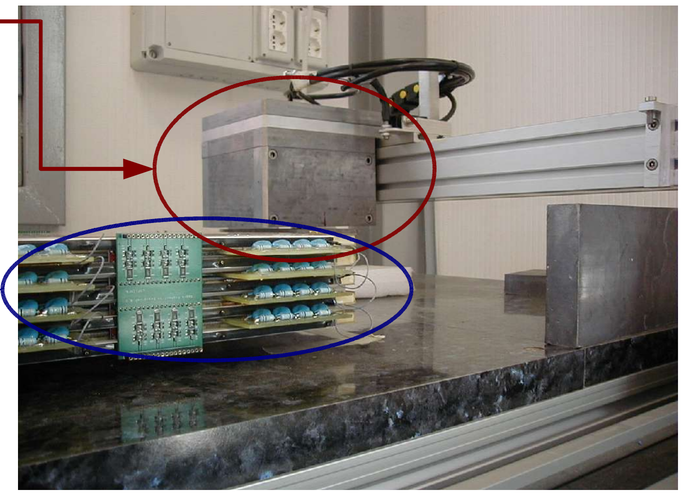




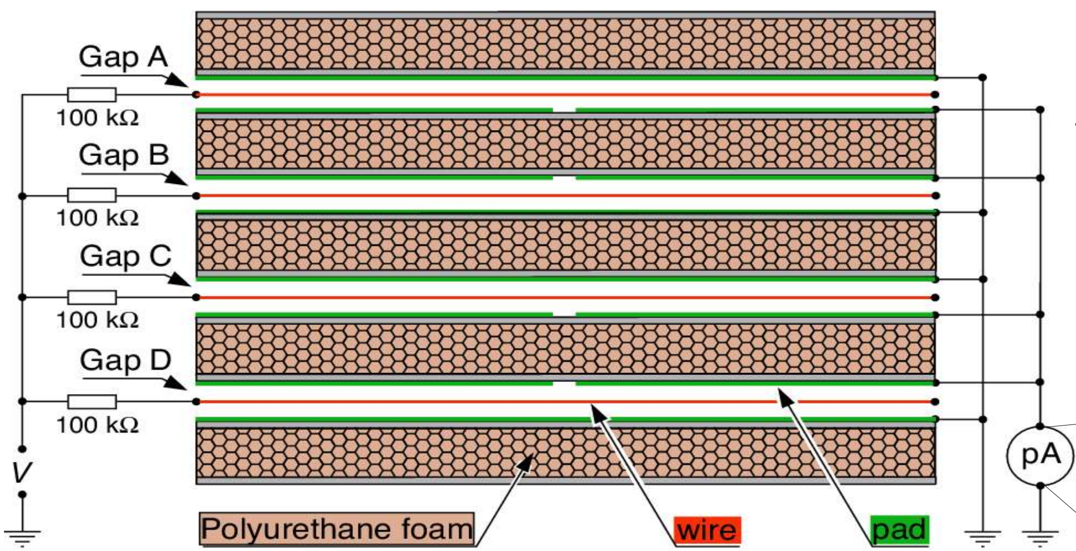
- The level-0 trigger requires a fast and highly efficient measurement of muon Pt;
- Requirements for a double-gap:
  - 95% of efficiency in bunch crossing identification;
  - average number of hits per track lower than 1.1;

Experimental set-up

- A four-gap chamber, gas flushed (50 cm^3/min) was exposed to the 662 keV photons of a 1.3 GBq ^{137}Cs radioactive source;



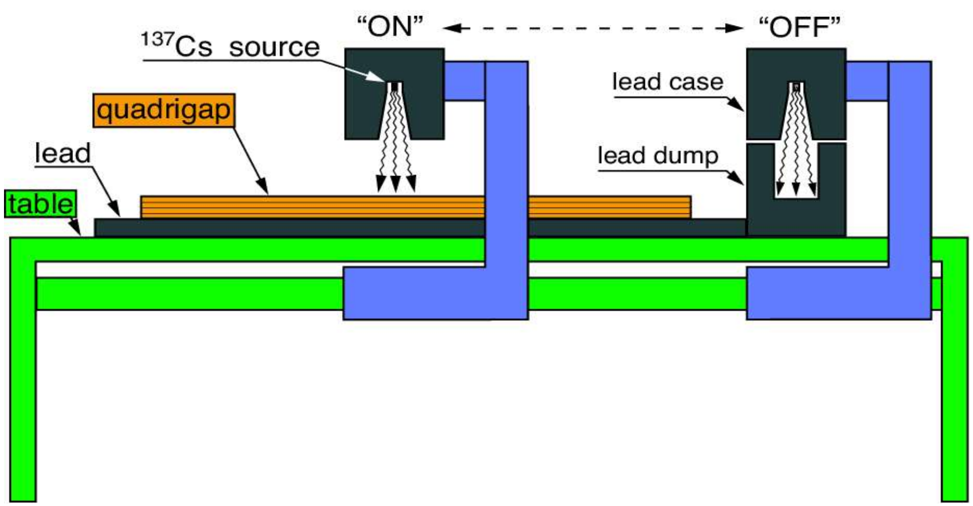
- The wire plane was supplied at a voltage *V* by means of a high voltage system (CAEN SY2527) or commercial batteries for $|V| < 500$ V;

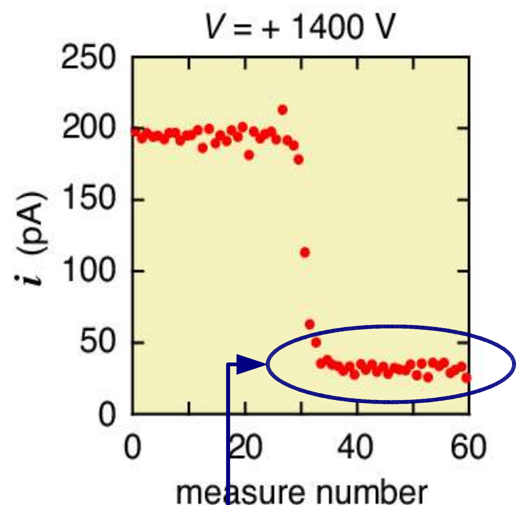


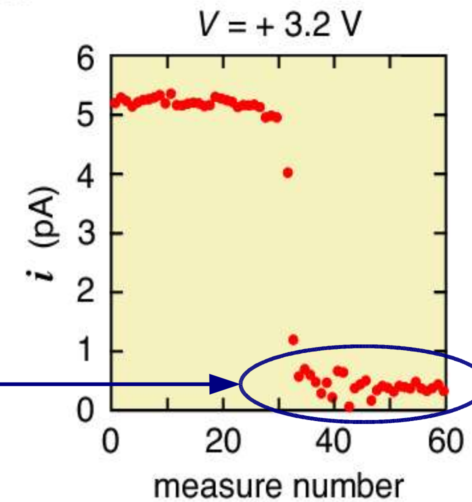
- The current drawn by the chamber *i* was measured on the ground return by means of an electrometer (Keithley 6845A) providing an accuracy as high as 10 fA;

The measurements

- In each measurement we recorded several values of the current flowing into the electrometer with the radioactive source in “ON” and “OFF” position:



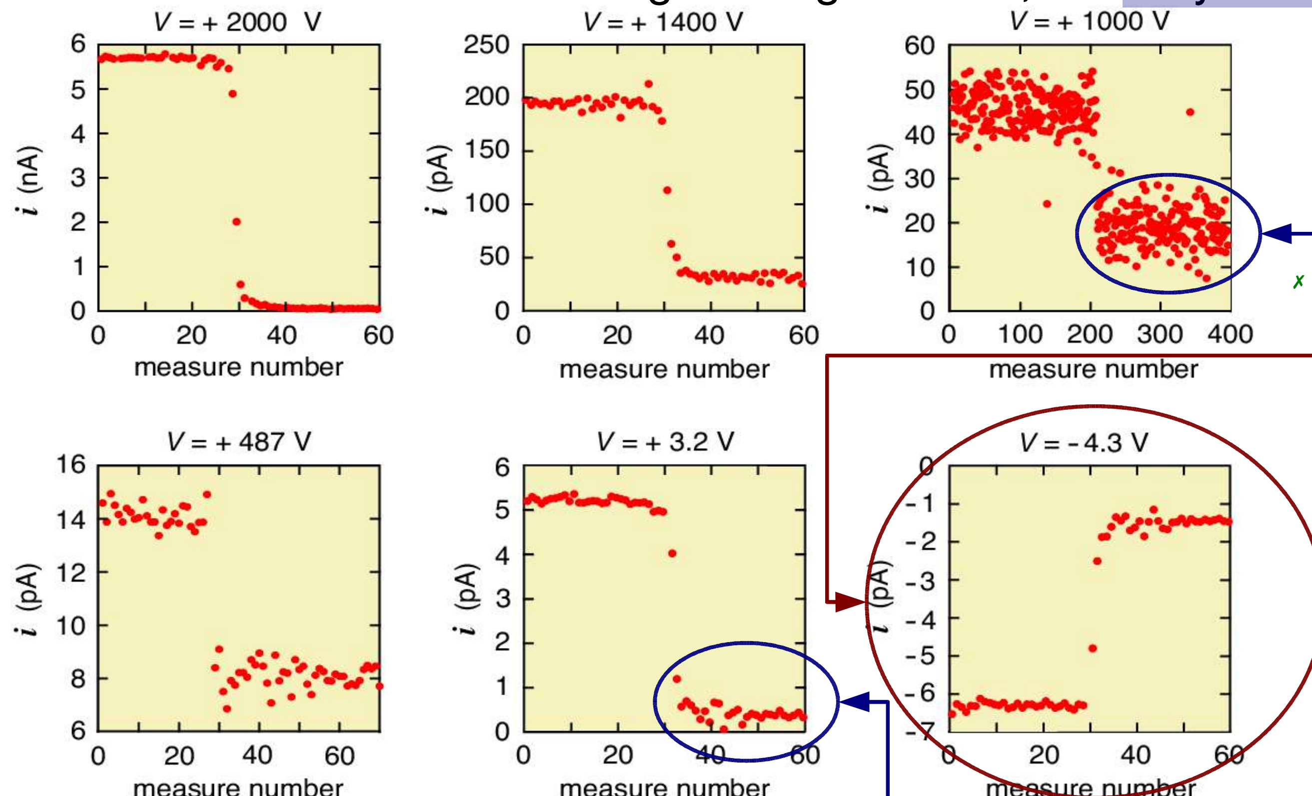




- It was possible to evaluate the an offset in the current drawn for each value of the voltage supply *V;*
- The difference ΔI between the average values of the currents ON and OFF was taken as the results of the measurement;

The high voltage supplies

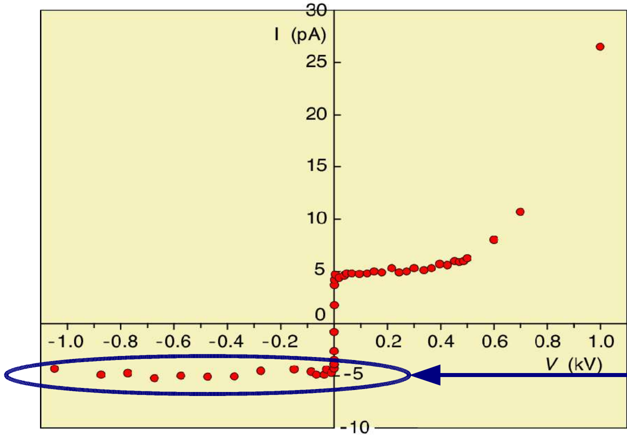
- We used two different voltage supply systems:
  1. CAEN SY2527: able to reach high voltage values, but very noisy;



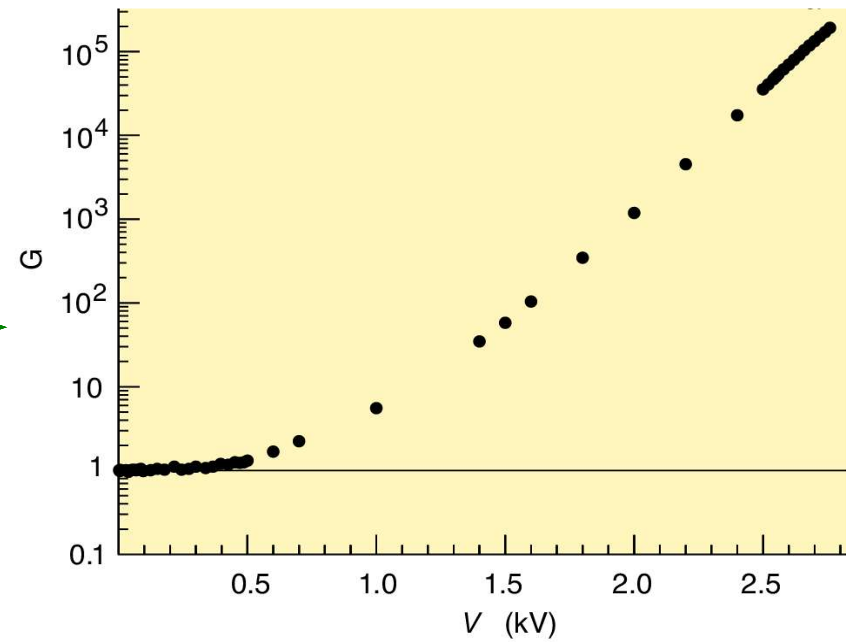
- We also provided a negative voltage to the wires in order to turn off the gas gain and get a better evaluation of the ionization current (I*);

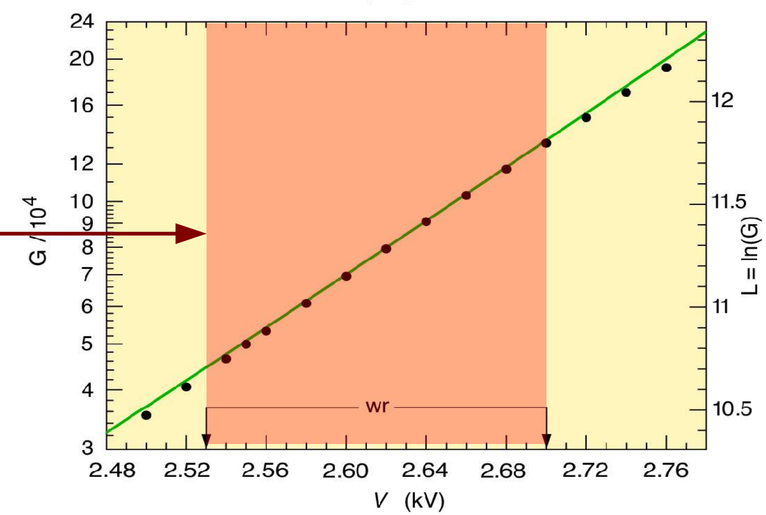
  2. Commercial batteries in series or voltage values below 500 V, extremely stable;

The gain as a function of HV



- From very precise measurements at low values of the voltage applied to the wires the primary ionization current was evaluated to be
  $$I^* = 4.76 \pm 0.20 \text{ pA};$$
- Confirmed by the negative voltage data;
- The gas gain, evaluated by means of I*, in the LHCb working region ranges from 4.4×10^4 to 1.5×10^5;





Dependence on the gas density

- From ideal gas equation: $$\frac{\Delta\rho}{\rho_0} = \frac{\Delta P}{P_0} - \frac{\Delta T}{T_0}$$
- The gas gain G dependence on the gas density at first order can be linearized:

$$\frac{\Delta G}{G_0} = \alpha\,\frac{\Delta\rho}{\rho_0} = \alpha\,(\frac{\Delta P}{P_0} - \frac{\Delta T}{T_0})$$ for T = const. → $$\frac{\Delta G}{G_0} = \alpha\,\frac{\Delta P}{P_0}$$

- The ionization current I* is function of the gas density too. The energy released by an ionizing particle grows linearly with P:

$$\frac{\Delta I^*}{I_0^*} = \beta\,\frac{\Delta P}{P_0}$$

with $\beta \leq 1$. β being equal to 1 only for particle crossing the full gas gap;

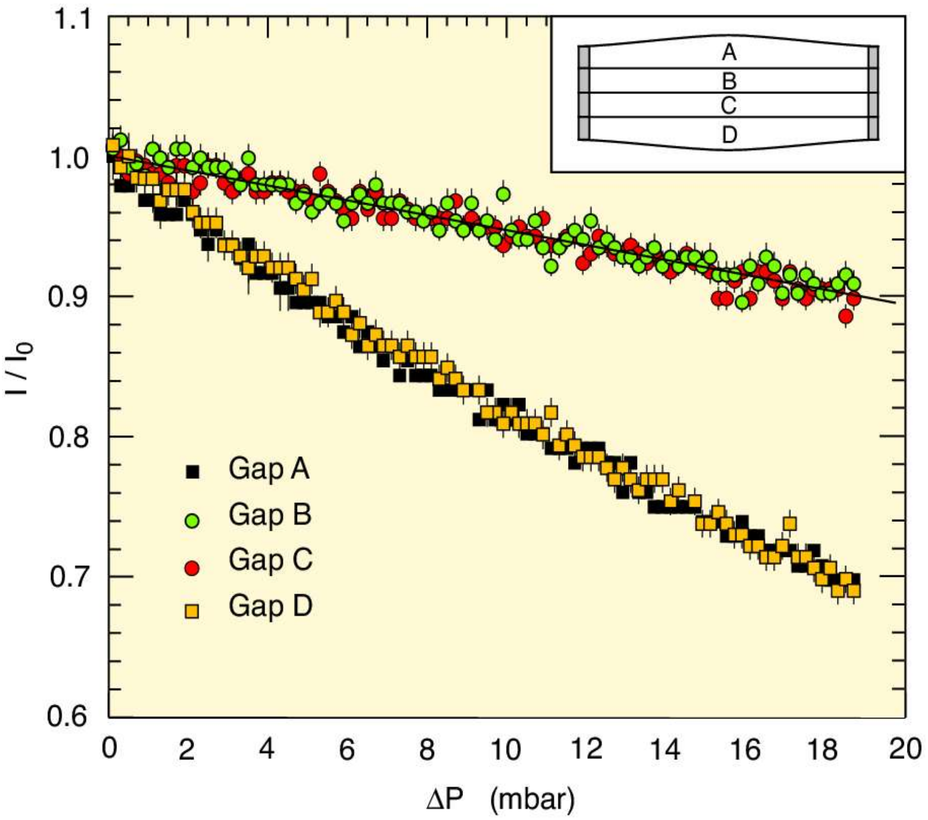
- Therefore the dependence of the current drawn (I = G x I*) by the chamber on the gas pressure is given by:

$$\frac{\Delta I}{I_0} = (\alpha + \beta)\,\frac{\Delta P}{P_0}$$

The drawn current as a function of the gas ρ

- The dependence of the current drawn was studied as a function of the gas pressure in order to evaluate the behavior of the gain as a function of the gas density.
- The gas pressure inside the chamber was increased up to about 20 mbar;
- The external gaps experienced a slight mechanical deformation that enhanced the gain decrease;
- In the HV range 2400V-2750V the slope (for gaps B and C) from linear fit is:

$$I(P)/I(P_0) = 1 - (5.1 \pm 0.2) \times (\Delta P[bar])$$



I* as a function of the gas pressure

- To study the behavior of the primary ionization current I* as a function of P the current drawn by the chamber was measured for ΔP=20 mbar and ΔP=0 mbar;
- The anode voltage was 47 V;

The difference was evaluated to be:

$$\Delta I^* = 0.078 \pm 0.002 \text{ pA}$$

- $\Delta I^*/I^*$ is 1.64% while $\Delta P/P$ is 2%;
- The value found for β is:

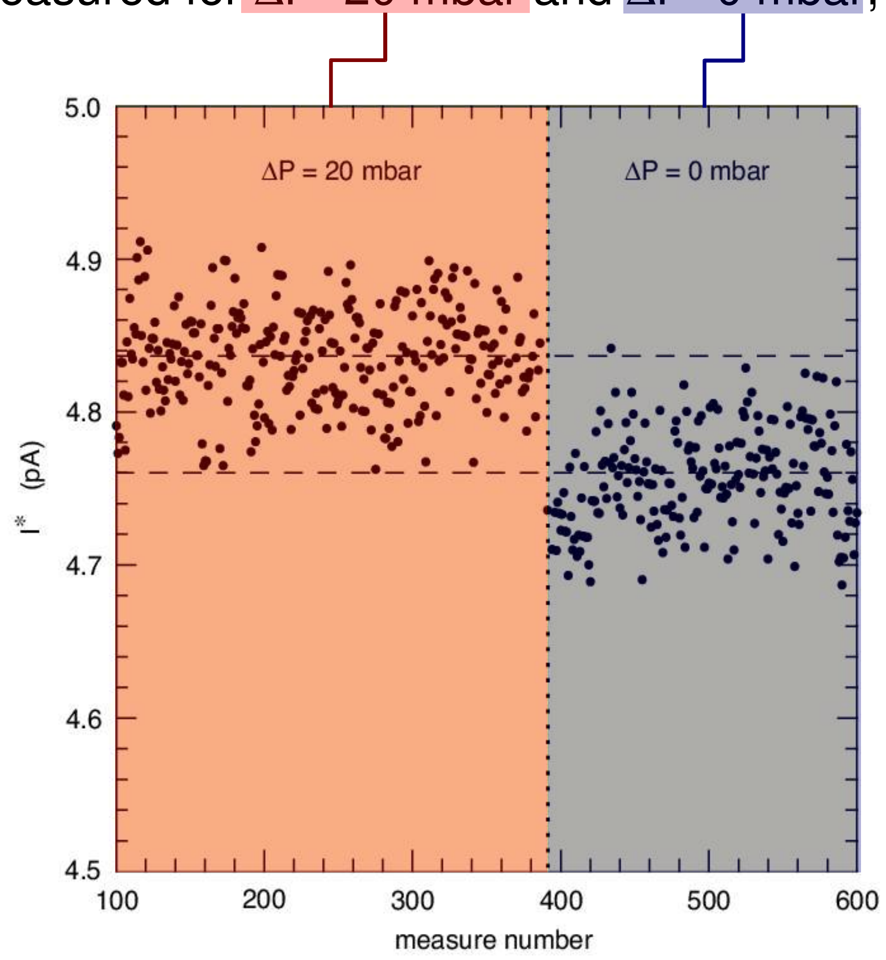
$$\beta = 0.82 \pm 0.06$$

- We can now extract the α parameter:

$$\alpha = -5.9 \pm 0.5$$

valid in the whole working region.

- In LHCb $\beta = 1$ and thus $\alpha+\beta = -4.9$



The Diethorn's formula

- For a wire chamber, the dependence of the gas gain on the anode voltage and geometrical and gas parameters is often described by means of the Diethorn's formula:
- In Diethorn's model the Townsend coefficient is taken as linearly proportional to the electric field: $\alpha_{Town} = kE$;

$$G(V,\rho) = \left(\frac{V}{A(\rho)}\right)^{\left(\frac{V}{B}\right)}$$

V is the anode voltage;

ρ is the gas density;

$$A(\rho) = r_a \ln(r_c/r_a)\, E_{min}\, (\rho/\rho_0)$$

r_c and r_a are the wire and equivalent cathode radii;

E_{min} and ΔV are gas dependent parameters;

$$B = \frac{\ln(r_c/r_a)\, \Delta V}{\ln 2}$$

- E_{min} = minimal field needed for ionization;
- $e\Delta V$ = is the minimum energy required to produce one more electron in the avalanche;

The parameters E_{min} and ΔV (I)

- For each value of V_i, E_{min} and ΔV can be calculated:

(1) From experimental data of the gain as a function of the anode voltage V:

$$E_{min} = \frac{V \exp[L(V)/(L(V) - V D(V))]}{r_a \ln(r_c/r_a)} \qquad \Delta V = \frac{V \ln 2}{(V D(V) - L(V))\ln(r_c/r_a)}$$

where

$$L(V) \equiv \ln[G(V,\rho_0)] = \frac{V}{B}\ln\left(\frac{V}{A(\rho_0)}\right)$$

can be obtained directly from the measured gain values

$$D(V) \equiv \frac{dL}{dV} = \frac{1}{B}\left(1 + \frac{BL(V)}{V}\right)$$

can be calculated from the first derivative of a second order polynomial passing through the considered $L(V_i)$ point and the two neighboring $L(V_{i-1})$ and $L(V_{i+1})$

(2) From experimental data of the gain as a function of the gas pressure:

$$\Delta V = -V \ln 2/\alpha \ln(r_c/r_a)$$

$\alpha = -5.9 \pm 0.5$

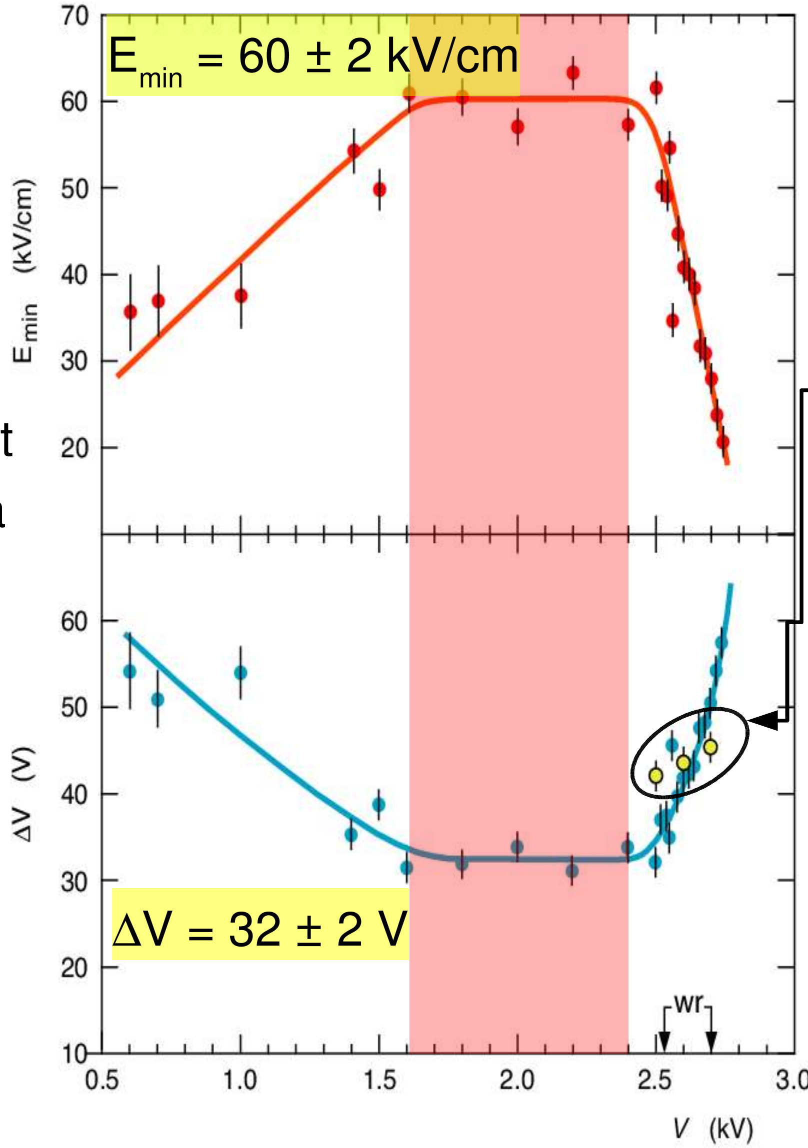
The parameters E_{min} and ΔV (II)

- In the Diethorn's formula E_{min} and ΔV are only dependent on the gas mixtures and do not depend of the anode voltage;

- The experimental results show that the validity of the Diethorn's formula is good in the region:

$$1600\ \mathrm{V} \leq V \leq 2400\ \mathrm{V}$$

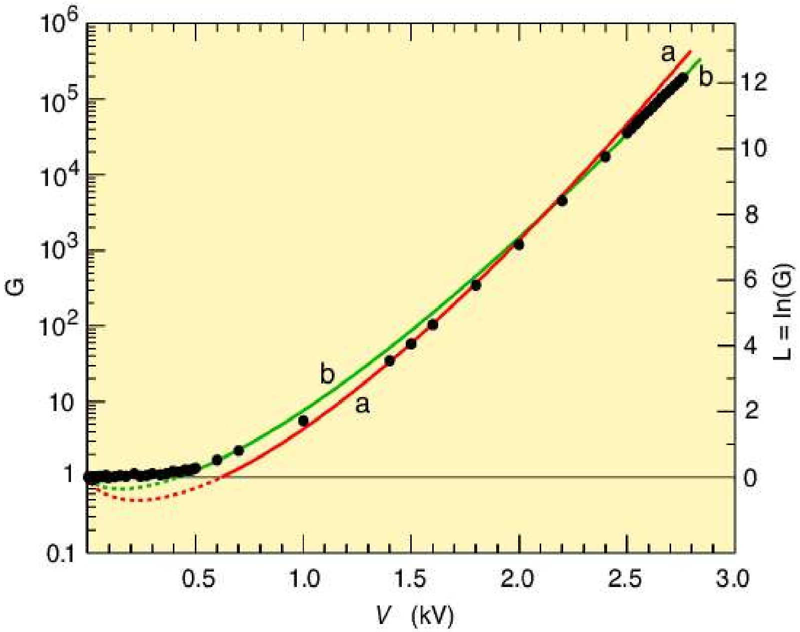
- Outside from this range the approximation $\alpha_{Town} = kE$ is no longer valid;



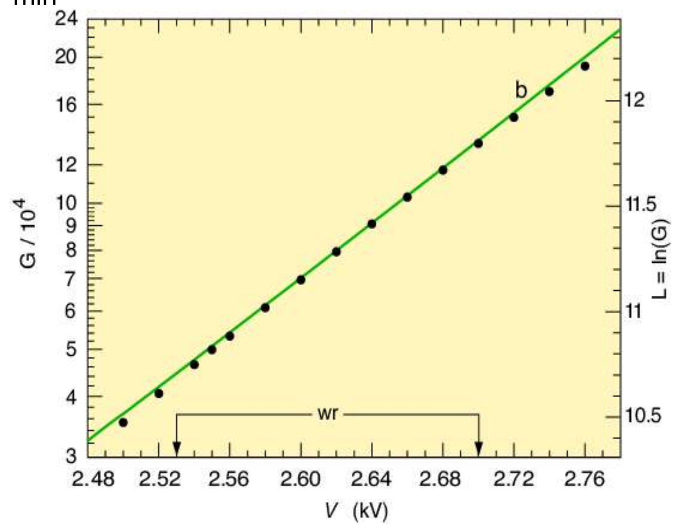
- The values of ΔV evaluated from the measurement of the gain dependence on the gas pressure are in reasonable agreement with the others;

Data fit with Diethorn's function

- We used the Diethorn's formula to fit the experimental behavior of the chamber gain as a function of the voltage applied to the wire;



- The red curve (a) represents G(*V*) calculated assuming E_{min}= 60 kV/cm and ΔV = 32 V;
- As expected the red curve fits well data in the range 1.4 kV ≤ *V* ≤ 2.4 kV;
- Outside from this region the Diethorn's formula can be used to fit data, but E_{min} and ΔV are only fit parameters;



- As an example the green curve (b) represents the best fit obtained in the working region of the chamber;
- E_{min} and ΔV are respectively 42 ± 2 kV/cm and 44 ± 3 V;

Conclusion

- By using a high sensitive electrometer and very stable setup (voltage supplied with commercial batteries) the ionization current generated in a LHCb Muon MWPC by a ^{137}Cs radioactive source was measured;

- This allowed to measure the absolute value of the gain of a typical LHCb Muon MWPC (8.4×10^4 at the working point) and its behavior as a function of the anode voltage and gas density;

- The Diethorn's formula is able to fit well experimental data in the region 1.6 kV $\leq V \leq 2.4$ kV and the gas parameters E_{min} and ΔV are found to be respectively 60 ± 2 kV/cm and 32 ± 1 V;

- The gain variation as a function of the gas pressure has been measured and found to be 0.5%/mbar. A ±15% gain variation can happen in one year. LHCb is thinking on the possibility of correcting by means of the HV.