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Testbeam Results of Endcap RPC's

Ijaz Ahmed, M. Irfan Asghar, Hafeez Hoorani[a)]

National Centre for Physics, Islamabad, Pakistan

Zia Aftab, J.A. Jan, M.Shariq Khan, Tariq Solaija

Pakistan Atomic Energy Commision, Islamabad, Pakistan

Abstract

In this paper, results are presented from the beamtest in 2002 of the full-scale RE-2/2 prototype RPC chamber assembled in Pakistan. The results are mainly related with the efficiency, time resolution, and rate capability of this non-oiled RPC. The CMS collaboration has imposed strict criteria on the performance parameters for RPC's. These results show that prototype RPC's meet with all the CMS criteria and are suitable for installation in CMS detector.

a) Corresponding Author, email: Hafeez.Hoorani@cern.ch

1 Introduction

The Pakistani group is responsible for the RPC's which are being installed in the Compact Muon Solenoid (CMS) detector endcap regions, specifically RE2/2, RE2/3, RE3/2, RE3/3 on both forward and backward directions. For this purpose several prototypes were made from 1999-2003 and they were tested at the European Centre for Nuclear Research (CERN) using X5 beam [1]. The present results are obtained from data which were taken at CERN during the testbeam performed in 2002. The shape of the RPC is trapezoidal and it covers 10^o in ϕ. The endcap RPC's are double gap chambers with the readout strips running perpendicular to the beam line (in ϕ). An RPC consists of two parallel plates made out of bakelite with a bulk resistivity of the order of 10^{10} Ω *cm*, separated by a gas gap of 2 *mm*. The bakelite used in making of RE2/2 prototype RPC has resistivity 3×10^{10} Ω *cm*. The whole structure is made gas tight. The outer surfaces of resistive material are coated with conductive graphite paint to form the high voltage and ground electrodes. The readout is performed by means of 96 copper strips separated from the graphite coating by an insulating Polyethylene (PET) film.

Resistive Plate Chambers (RPC's) are detectors with an excellent time resolution [2] which is crucial at the Large Hadron Collider (LHC) due to the beam crossing time of 25 *ns*. These are the dedicated chambers used for the first level muon trigger. The good performance of RPC's is crucial in assigning the muon to the right bunch crossing. The event rate at LHC is expected to be extremely high due to the large total pp cross-section at centre-of-mass enegy of 14 *TeV* [3]. There will be on average of 20 inelastic collisions every bunch crossing and the level 1 trigger reduces this high input rate by a factor 10^4. This rate is further reduced by the HLT to 100 *Hz* before the information is written to tape.

The RPC in streamer mode fulfill the CMS specification of rate capability 100 Hz/cm^2. However in the high η region the rate could be as large as 1 KHz/cm^2. A reasonably safe estimate of 1 kHz/cm^2 gives therefore the highest rate at which RPC's are expected to work. The RPC operated in avalanche mode could sustain this high rate. The hit rate associated with the neutron and gamma background is 20 Hz/cm^2 in the barrel and reaches a maximum of 250 Hz/cm^2 in the forward region at $\eta = 2.1$.

2 Experimental Setup

Fig.1 shows the schematic diagram of the muon test facility at CERN. The prototype RPC was tested using the Gamma Irradiation Facility (GIF) at the X5 testbeam. The muon beam was delivered by SPS (Super Proton Synchrotron) accelerator, with an average momentum of 200 GeV/c. This background flux in the forward and backward regions due to low energy photons (up to 100 *MeV*) may reach upto a level of $10^5 cm^{-2} s^{-1}$.

The data acquisition system was triggered by a set of scintillators. Two Beam Chambers (BC) with a spacial resolution better than 200 μm were used to track the muons. The RPC was placed vertically between beam chambers and scintillators at a distance 3200 mm and 5100 mm from BC1 and BC2 respectively. The distance between the RPC and source was 1300 *mm*. The height of the beam with respect to the ground was 1260 *mm*.

The rate capability of the RPC was tested with the help of a gamma source in GIF, an intense ^{137}Cs source used to induce a background rate similar to that expected at LHC. To mimick the background conditions we used a gamma source of 740 *GBq* having energy of the order of 661 *keV*. There was a system of moveable lead filters which could reduce the flux of photons by a factor of 10^4. Tests were performed with absorption 1 (ABS 1, i.e. no filters), absorption 2, 5 and 10 (ABS 2, ABS 5 and ABS 10 i.e absorption factors 2, 5, and 10 with respect to ABS 1). The width of the gas gap was 2 *mm*. The strips were trapezoidal in shape and there were 32 strips per η segment. The average strip length was 548 *mm* and strip pitch was 18.7 *mm* - 21.7 *mm*. The gas mixture used was 96% $C_2H_2F_4$ and 3.5% iso-C_4H_{10} and 0.5% SF_6 as quenching gas. This mixture of gas will be used in the real experiment in 2007. The signals from the strips were preamplified. The charge sensitivity of the preamplifier was 2 *mV/fC* and the nominal discrimination threshold was set to 87.5 *fC* (*175 mV*). The signal from the readout eletronics were fed into multihit TDC with a 64 μs gate and sensitivity upto 1 *ns*. The TDC was set in common stop mode. The time of the RPC was measured with respect to the trigger.

The effective counting rate of the chamber was determined from the distribution of the time difference between two consecutive clusters [6]. The time of an RPC signal is always recorded with respect to the trigger signal.

3 Experimental Results

To estimate the most important parameters of the RPC, some basic plots related to Beam Chambers and RPC are shown in Fig 2. In this figure, top left plot shows the number of strips fired by the incident inonizing particles in a selected time window, top right plot demonstrates the hit occupancy on the strips, bottom left plot represents time distribution relevant to the Beam chambers, while bottom right plot shows the time distribution on the 32nd strip in a selected time window.

3.1 Dark Current

The detector draws some amount of current even when the source is off, this current is known as dark current. For the efficient performance of the chamber, the value of the dark current should be minimal. Fig. 3 shows the variation of the average dark current for three gaps i.e top small gap, top large gap and full gap. Under the highest gamma radiation background (656 Hz/cm^2), the dark current reaches about 200 $\mu A/m^2$, 240 $\mu A/m^2$, 280 $\mu A/m^2$ for top small, large gap and full gap respectively at high voltage value of 10.5 KV. The highest power consumption for full gap can then be calculated as, $10.5\ kV \times 280\ \mu A/1.1694\ m^2 = 2.5\ W/m^2$, which satisfies the CMS requirement of less than 3 W/m^2 for an RPC.

3.2 Efficiency

At each HV point, the efficiency of the chamber was determined as the ratio of the number of correct chamber responses to the number of correct triggers. The correct chamber response is defined as at least one hit read by the RPC strips within the expected time window for triggered events. A correct trigger is an event with a beam track that goes through the active area of the RPC. This is computed using the beam chambers information and the geometrical parameters shown in Fig. 1. The efficiency of the RPC in a given time window is defined according to [7],

$$\epsilon = \frac{[(\mathrm{N_{ob}}/\mathrm{N_t}) - \mathrm{P_s}]}{1 - \mathrm{P_s}} \tag{1}$$

where $\mathrm{N_{ob}}$ is the number of observed events, $\mathrm{N_t}$ is the number of total events and $\mathrm{P_s}$ is the probability of the spurious hits. The probability of the spurious hits is determined by counting the hits in a time window dalayed by 100 *ns* after the trigger. Fig. 4 shows the typical efficiencies of the detector for different intensities of the source. The efficiencies were computed for a 25 *ns* time window centered at the mean arrival time of the fastest strip. The efficiency is maximal when the source is off.

The efficiency is plotted at threshold of 200 *mV*. The value of the efficiency is approximately 98.3% at operating voltage (voltage at which the efficiency becomes maximum and is independent of applied voltage). The efficiency plateau starts at 9.5 *kV* and ends at 10.5 *kV* except at ABS 1. For good performance of the RPC [8] its efficiency plateau should lie in the range of 300 V. It is clear from the Fig. 4 that efficiency plateau of the RPC used is more than 300 V. The study performed in [9] shows that the maximum efficiency and length of plateau are dependent on gas mixture.

3.3 Time Resolution

Time resolution is defined as the RMS width of a gaussian function fit to the signal time distribution, which is one of the most important parameters for a fast muon trigger system. The CMS specification for RPC's time resolution is better than 3 *ns*. The time resolution has been calculated and plotted in Fig. 5 and Fig. 6. Its value is independent on the intensity of the source: it is 1.26 *ns* when the source is on and 1.24 *ns* when the source is off, which is well below the consecutive bunch crossing time difference 25 nsec at LHC.

The main resolution figure is determined by a Gaussian fit to the time distribution of the most likely strip within 25 nsec, and the timing tails are characterized as the fraction of events whose distance to the mean value exceeds due the gaussian profile of muon bunch. Good efficiency and timing properties will be crucial for the performance of the trigger algorithm, the latter in particular will play a very delicate role, since individual hits have to be assigned to the right bunch crossing. In the study performed in [9], it is clear that in CMS trigger efficiency is about 99% with an RPC of time resolution less than 3 ns.

3.4 Cluster Size

A hit is defined as signal recorded on a single readout strip. A cluster is defined by grouping adjacent strips with hits inside a time window of $\Delta t = 20$ *ns* centered around the fastest strip. The cluster size should be small in order to achieve the required momentum resolution and to minimize the number of possible ghost-hit associations. For good performance of the RPC, the mean cluster size should not be greater than three. It is clear from Fig. 7 that in the region of operating plateau (9.5 - 10.5 KV), the cluster size is below 3. At higher values of applied voltage, due to high rate and increase in electronic noise, the strips on which signal induce are increased. For more details about the cluster and cluster counting see [10].

3.5 Rate Capability

Rate capability is defined as how many particles a detector can handle in unit time. Mathematically the rate R is defined as

$$R = \left[\frac{(\mathrm{N_{cl}})}{\mathrm{N_{events} A \Delta t}} \right] \tag{2}$$

where A is the area of chamber, N_{cl} number of cluster found in time interval Δt and N_{events} is the number of triggers. The chamber counting rate is estimated by using the clusters. Time difference between random events are well described by an exponential distribution characterized by a probability density function,

$$f(t) = a \exp(-at) \tag{3}$$

where *'t'* is the time and *'a'* represents the average rate at which events are occuring. In Fig. 8 the time difference between two consecutive clusters over 32 strips with ABS1 is shown. The slope of the curve gives directly the overall counting rate. We compute a rate of 800 Hz/cm^2 averaged over 32 strips area under the maximum flux from the gamma source (ABS1) with applied voltage of 10 kV. The rate capability is plotted by counting the clusters and is shown in Fig. 10. The rate is very low when the source is off and its value goes upto 1.1 kHz/cm^2.

4 Conclusions

The performance of 2 *mm* wide double gap RPC, with bulk resistivity of 3×10^{10} Ωcm, has been studied with a full-scale prototype of the CMS endcap chamber. The main characteristics such as efficiency, time resolution, rate capability and cluster size have been studied and compared with the CMS requirements. On the basis of results obtained it can be concluded that the prototype RPC has performed well and the current design is suitable for mass production of RPCs.

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References

[1] Test beam Results of the forward RPC Prototype Chamber for CMS Muon Detector, CMS NOTE 2001/014

[2] CMS Technical Proposal, CERN/LHCC 94-38 LHCC/P1 15 December 1994, page 126

[3] LHC White Book, CERN/AC/93-03; 'LHC Conceptual Design Report', CERN/AC/95-05

[4] An RPC based Technical Trigger for the CMS Experiment, CMS CR-2006/088

[5] Technical Design Report, The Muon Project, CERN/LHCC 97-32, Page 252, (Table:5.1.1)

[6] M. Abbrescia et al., Study of long-term performance of CMS RPC under irradiation at the CERN GIF, Nucl. Instr. and Meth. A 533 (2004) 102-106

[7] R. Santonico, R. Cardarelli, Nucl. Instr. and Meth. A 187 (1981) 377.

[8] Zia Aftab, et al., Test beam Results of the Forward RPC Prototype Chamber for CMS Muon Detector, CMS NOTE 2001/014

[9] Technical Design Report, The Muon Project, CERN/LHCC 97-32, Page 251, (Fig:5.1.2.)

[10] M.Abbrescia et al., Recent results and developments on double-gap RPCs for CMS, Nucl. Instr. and Meth. A 409 (1998) 43-45

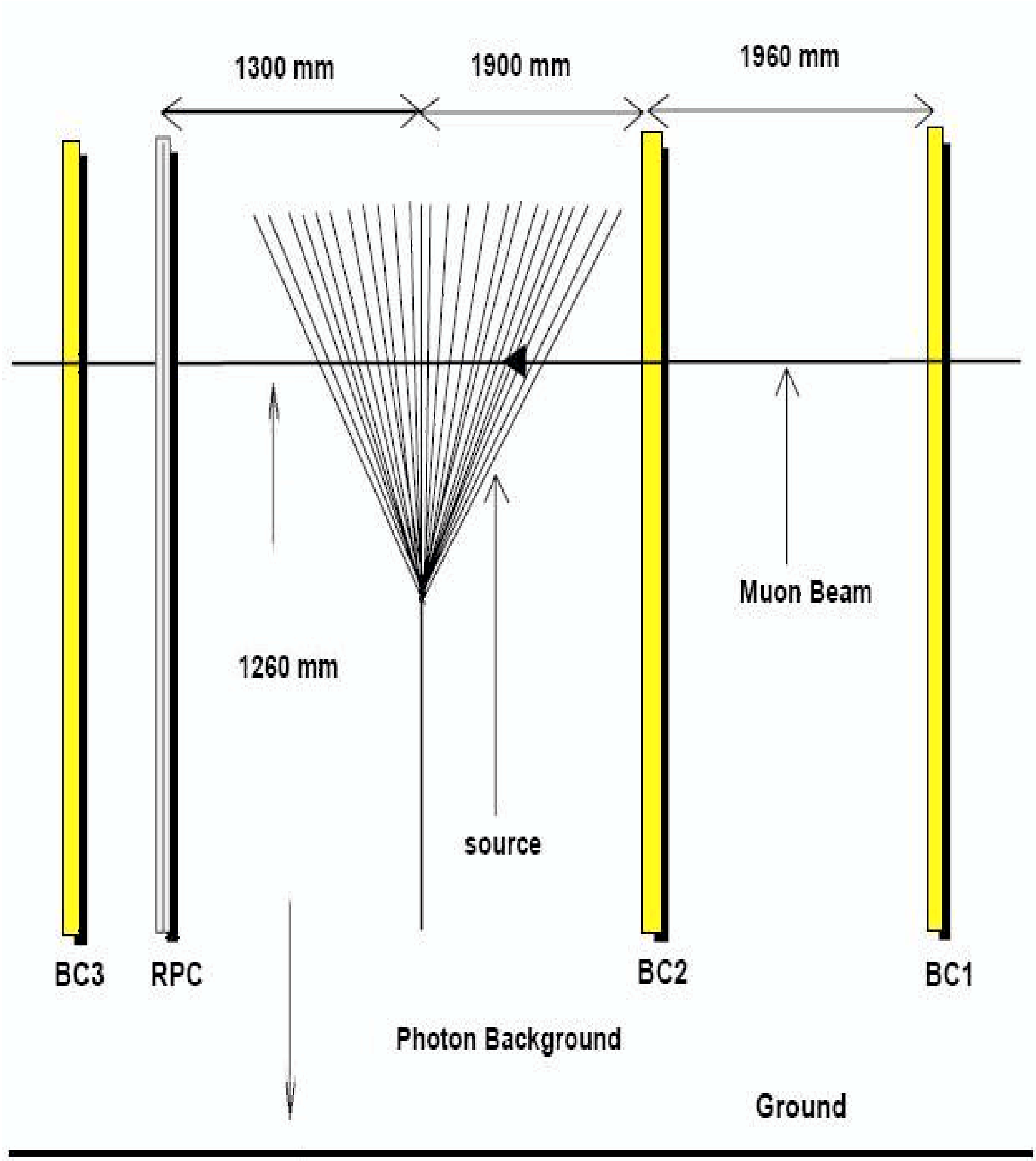

Figure 1: Schematic diagram of experimental setup used for testing full-scale RE2/2 prototype in the GIF area at CERN.

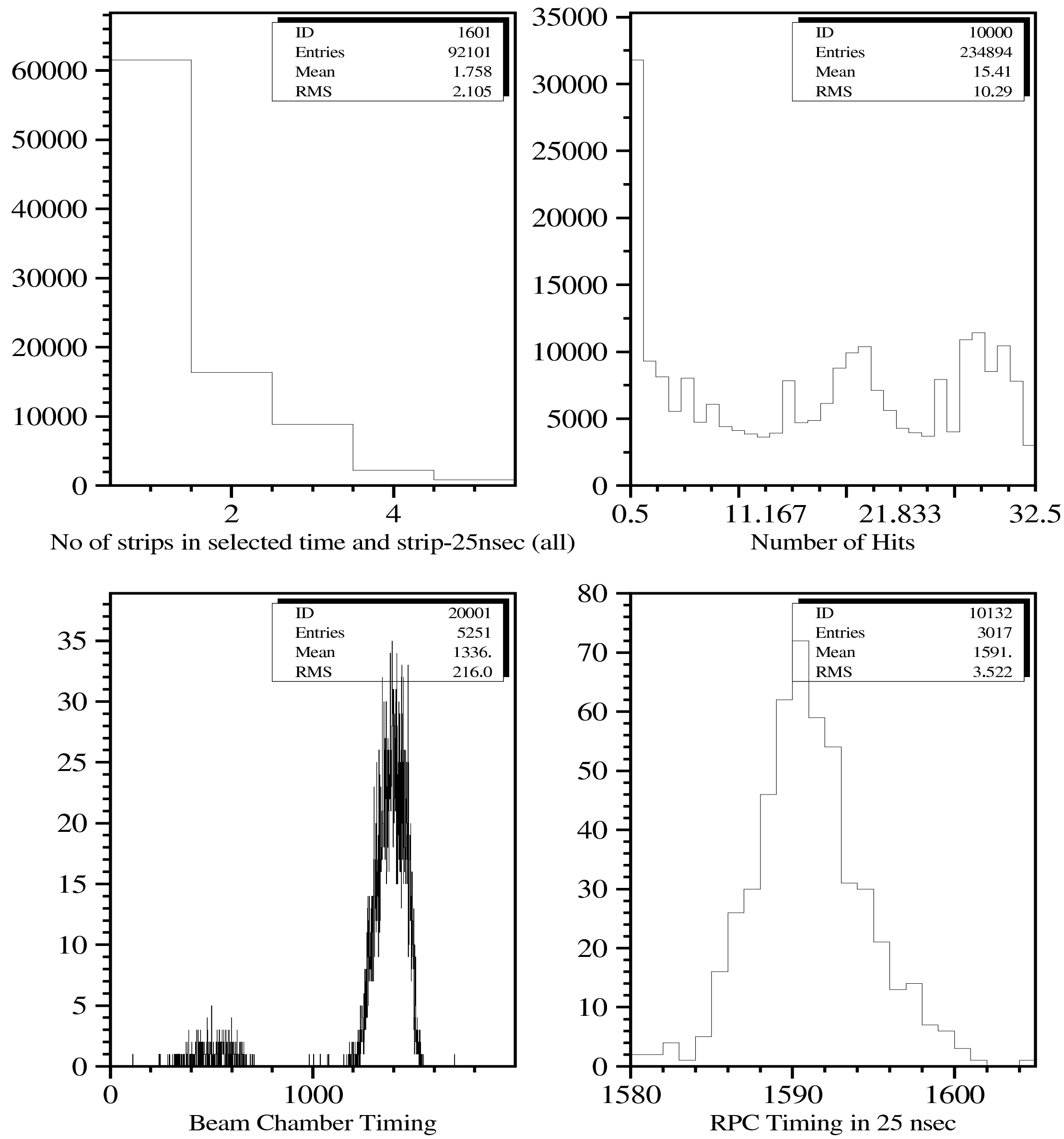

Figure 2: Top left plot shows the total number of strips fired by the through to going particle within 25 nsec time window. Top right plot shows the number of hits produced on each strip of RPC within triggered window of 25 nsec. Bottom left plot represents the Beam Chambers timing, the earlier peak in time forms by the electronic noise of the detector, while second peak shows the arrival time of the muon beam. Bottom right figure shows the hit profile on 32nd strip of the PRC inside the time window set by the Beam Chambers

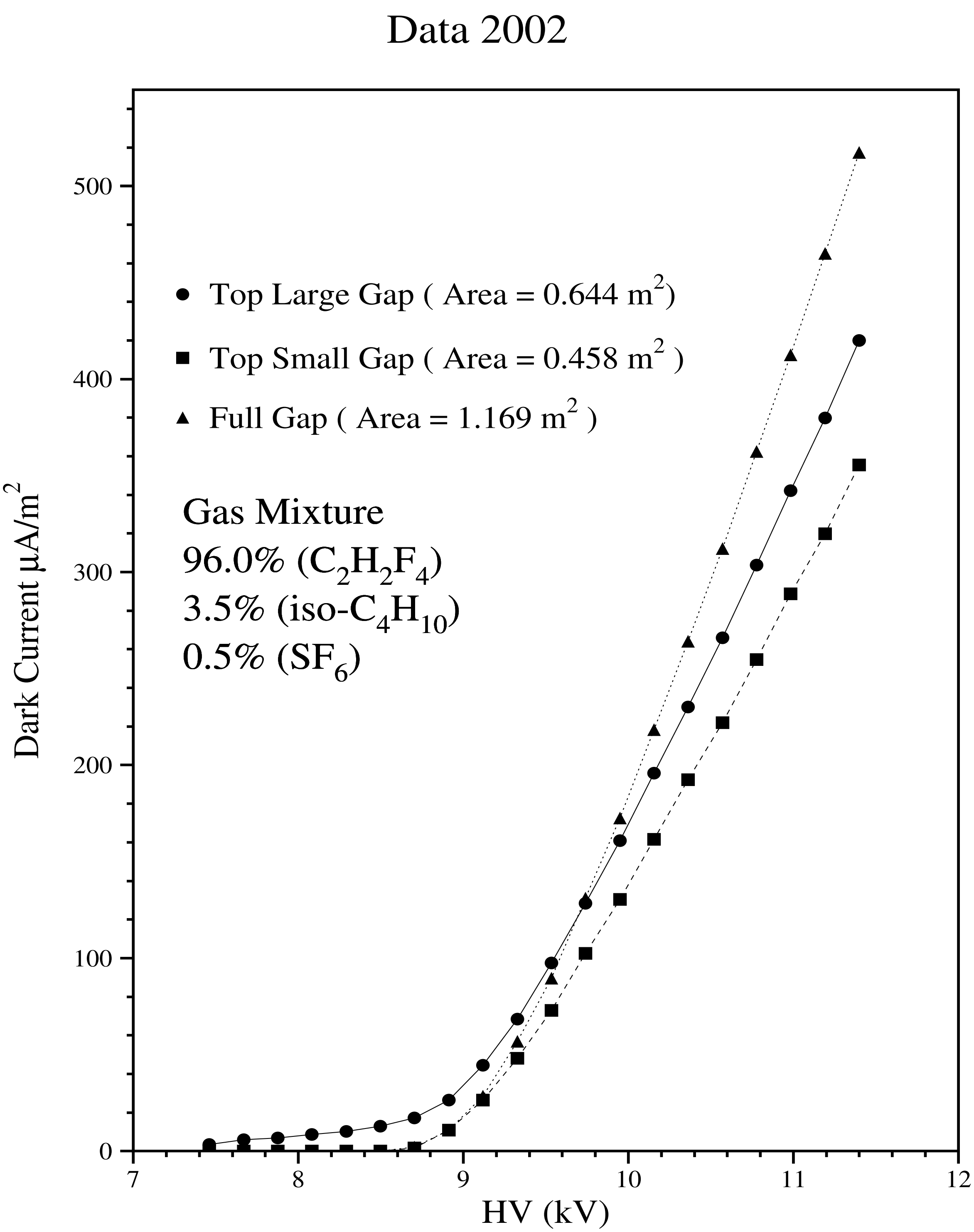

Figure 3: The amount of dark current per square meter vs high voltage shown for three gaps used in the construction of the chamber.

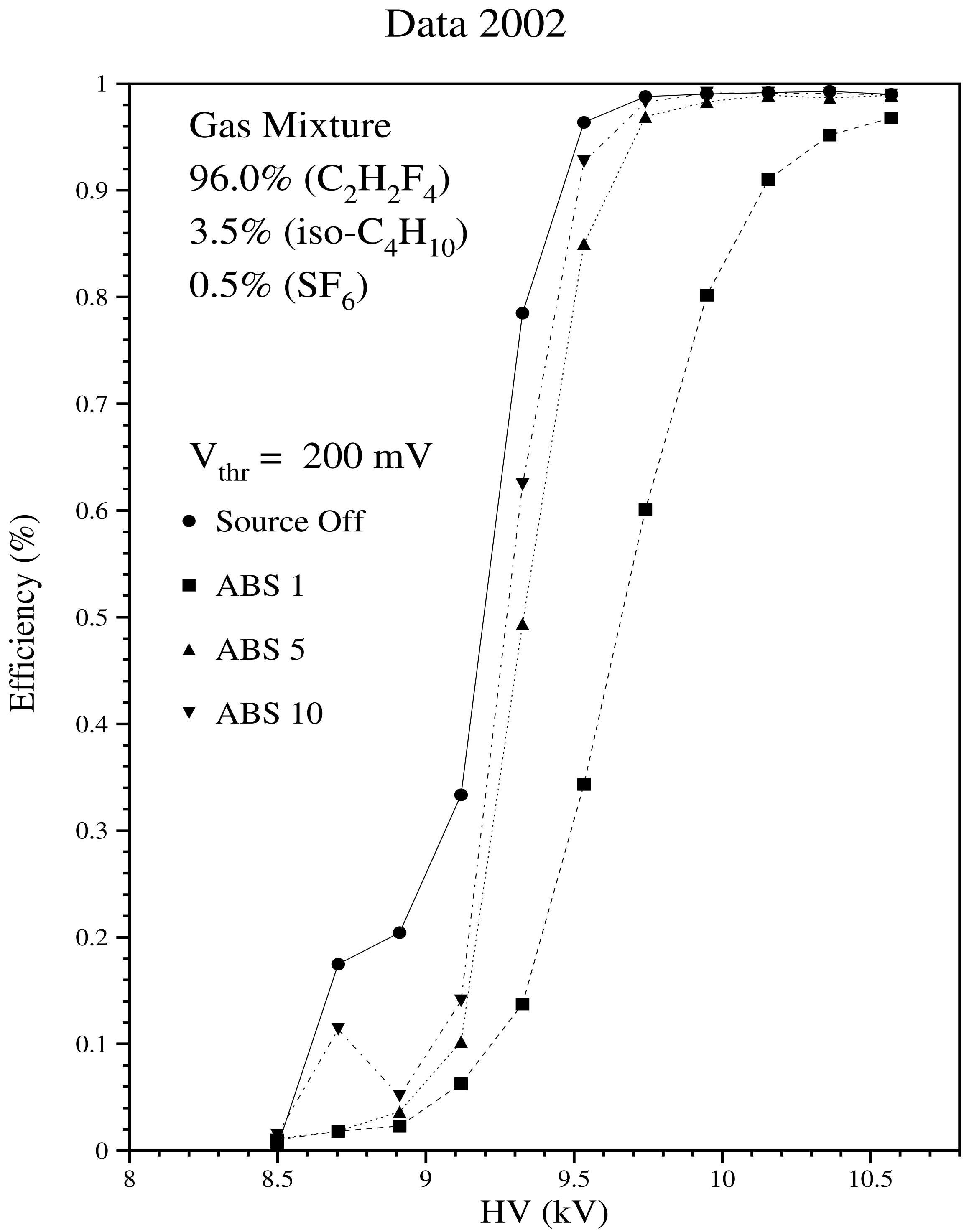

Figure 4: The efficiency of the chamber vs applied high voltage is shown for various source conditions at given signal threshold of 200 mV.

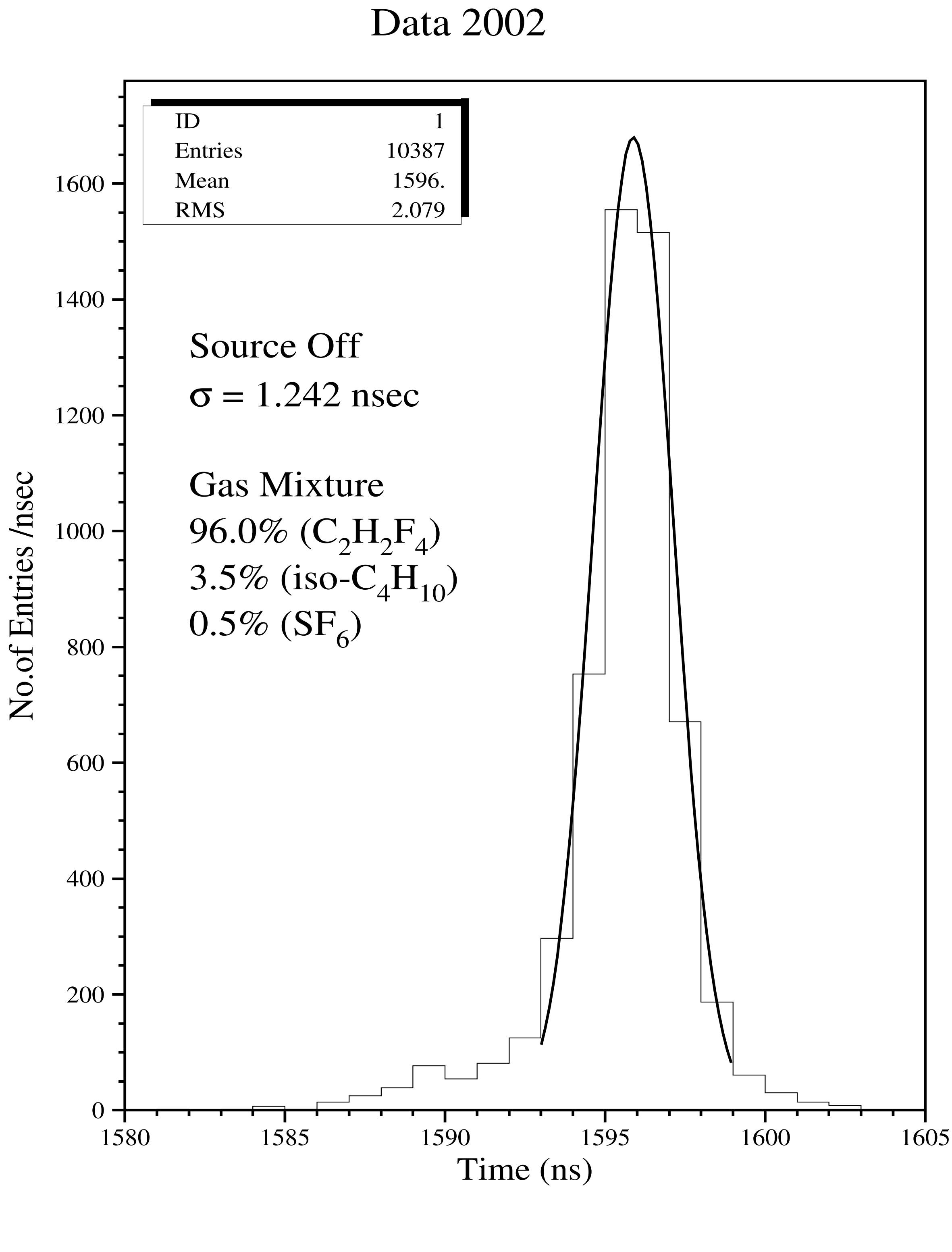

Figure 5: The time resolution of the chamber with source off is shown, which is obtained by using a Gaussian fit to the distribution of mean arrival time of a strip.

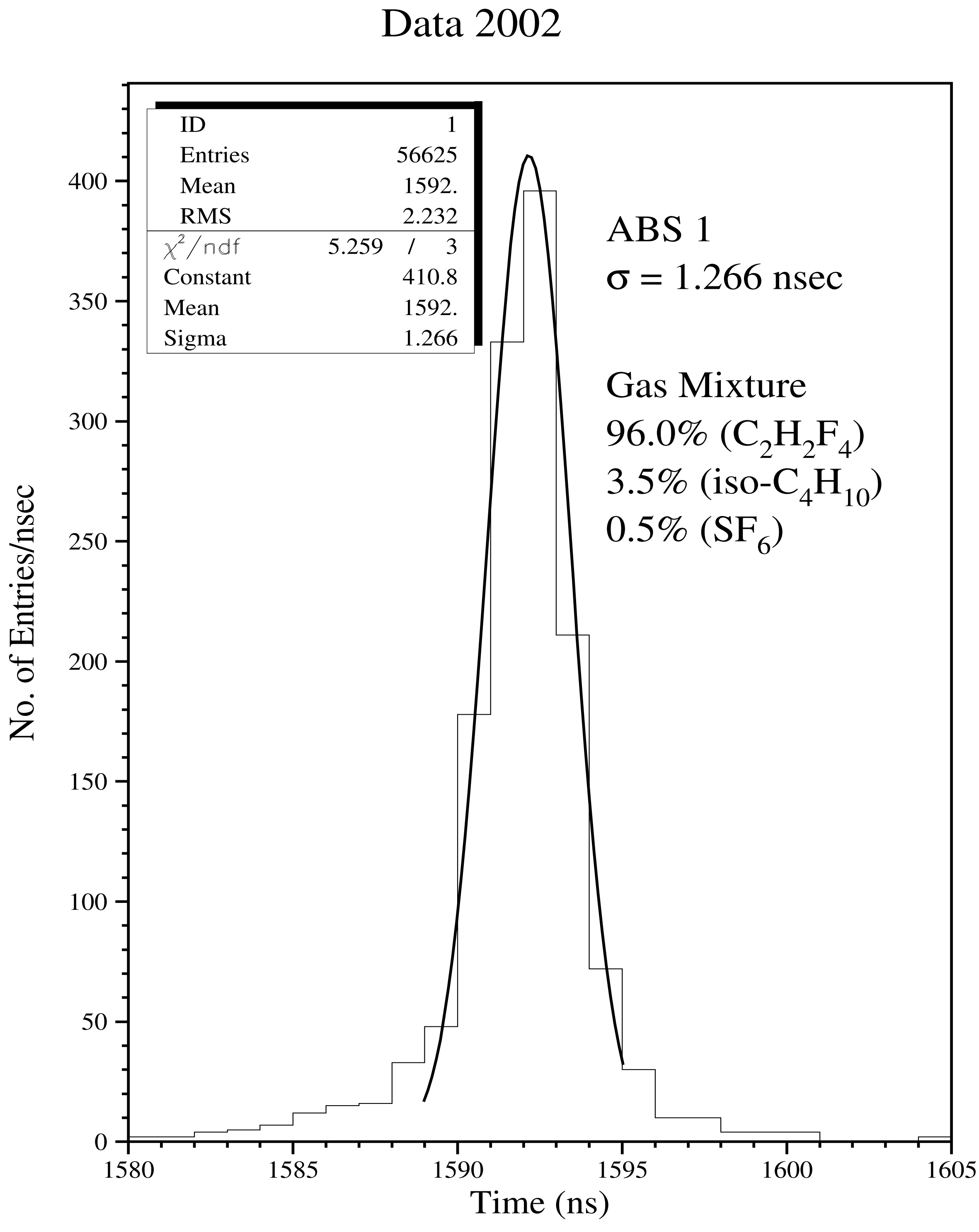

Figure 6: The time resolution of the chamber with source on is shown, which is obtained by using a Gaussian fit to the distribution of mean arrival time of a strip.

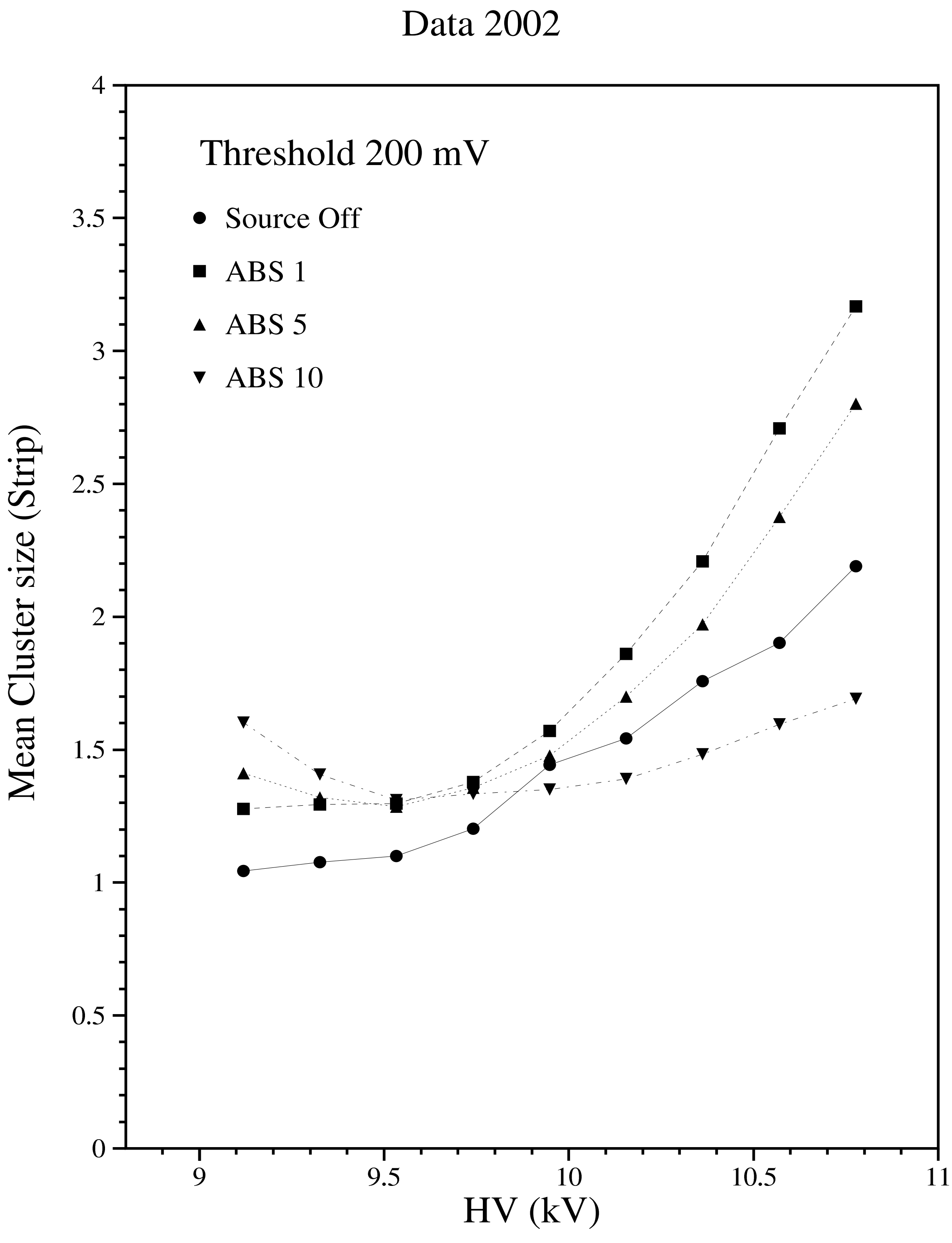

Figure 7: The mean cluster size distribution as a function of high voltage is shown.

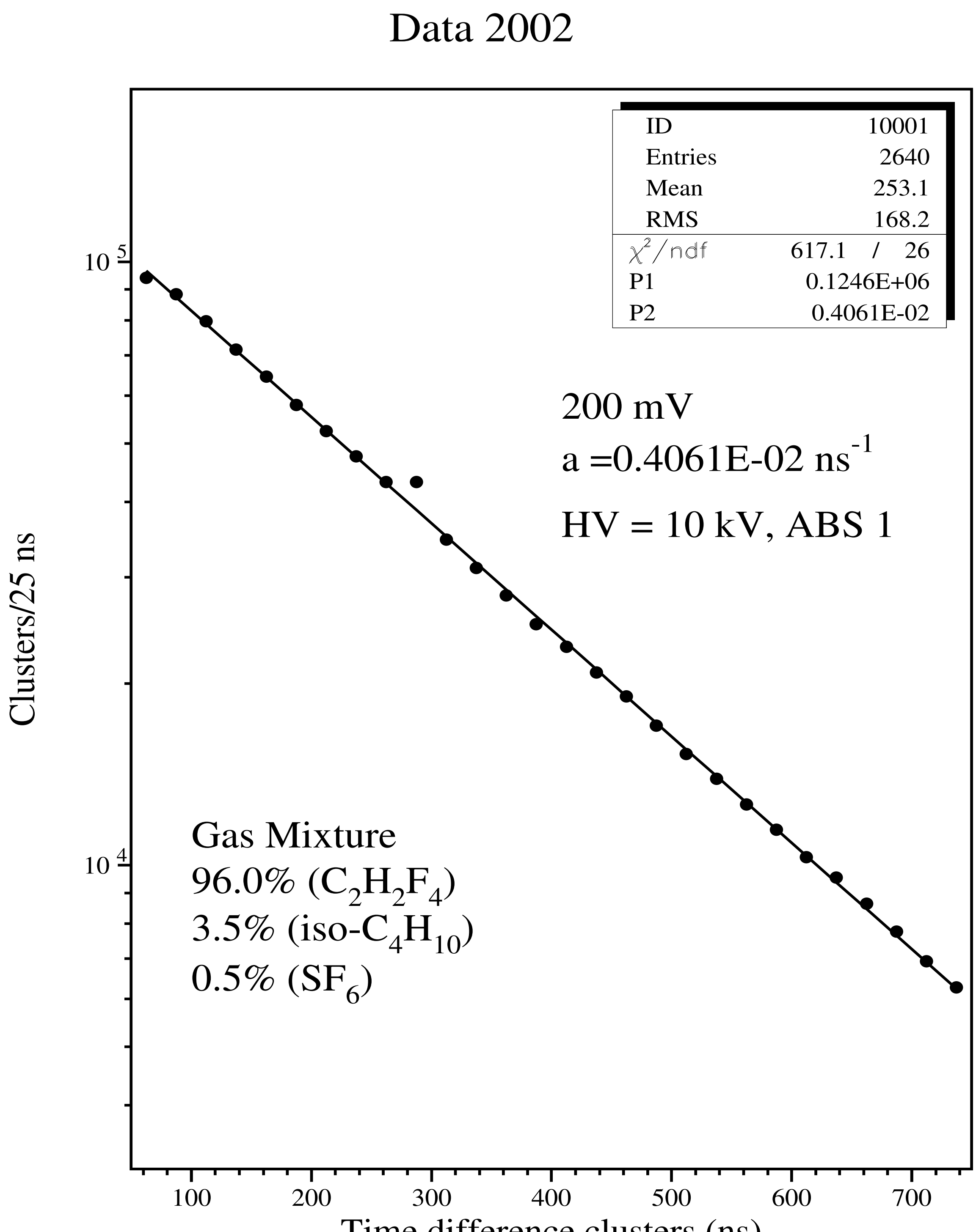

Figure 8: Time difference between two consecutive clusters. The straight line fit gives the slope of the curve which corresponds to the parameter a, which is defined in the text.

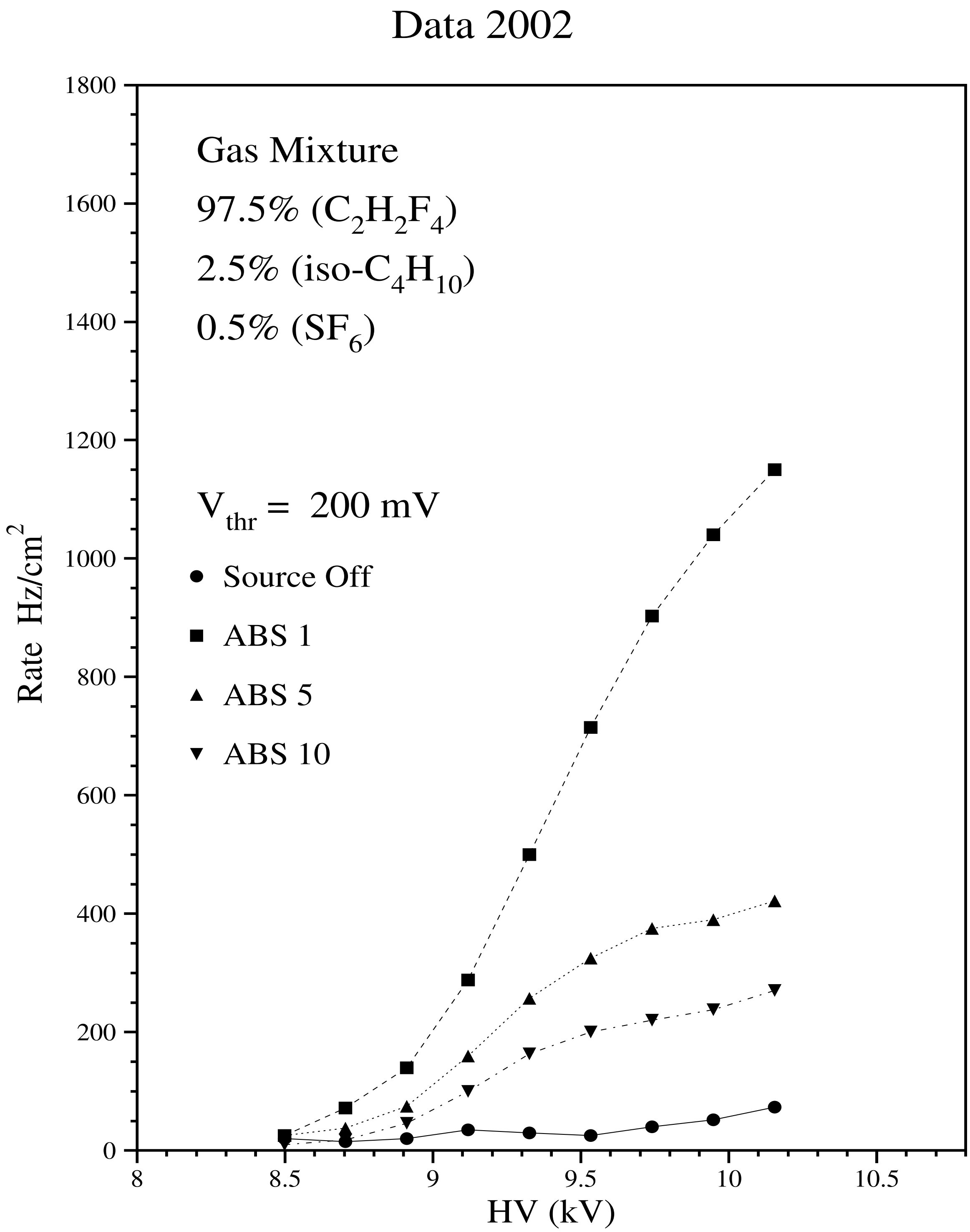

Figure 9: The chamber counting rate is shown for different gamma source conditions at different applied voltages