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Beam test results for MSGC's with thick metal strips.

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Abstract

Micro Strip Gas Counters with robust gold strips have been developed at IMEC, the Interuniversity Microelectronics Center at Leuven, in Belgium. The electroless plating technology was used, allowing to achieve a strip thickness of up to 1.6 μm on 10x10 cm^2 substrates. Results on signal to noise ratio, spark rate, resulting damages and detector occupancy are presented for counters exposed to various intensities of heavily ionizing particles.

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1 Introduction.

Micro Strip Gas Counters (MSGC's) are foreseen to equip the outermost part of the CMS tracker [1]. It was shown by Monte Carlo simulations that the physics goals of the experiment can be achieved with a counter detection efficiency of 98% for Minimum Ionizing Particles (MIP's). This requires to operate the counters above a minimum signal to noise ratio, the value of which will be discussed later.

On the other hand, the MSGC's will be exposed to high fluxes of charged and neutral particles during LHC running. Most of these particles are hadrons, which may generate heavily ionizing particles (HIP's) by nuclear interactions in the counter material. Due to the high charge density in the avalanche of a HIP, some of them develop into a streamer. If one of these streamers propagates up to a cathode strip, the group of 16 cathodes connected together to the high voltage supply, discharges, leading to a spark of energy that may be sufficient to damage the strip. This is particularly true for MSGC's with gold strips that are currently produced in industry, by the lift-off technique. The thickness of the strips is limited to $0.6\ \mu$m with this method. As the melting temperature of gold is low, this leads to a very fast destruction of these strips in the presence of sparks [2]. As a consequence, the gain has to be limited to avoid sparks in the presence of HIP's. Still it is possible to produce MSGC's with gold strips that can be operated spark free, up to a signal to noise ratio about twice the one required for efficient detection of MIP's in the CMS tracker, in the presence of a flux of HIP's similar to the one expected at LHC, at 70 cm from the beam pipe [1].

Nevertheless, attempts were made to develop MSGC substrates with thicker gold strips in order to produce counters that can withstand an occasional spark. Chromium is a candidate for the strip material, but in the CMS tracker the strips are up to 25 cm long, and therefore this metal is ruled out because of its too high resistivity. Only gold remains as it has been proven to avoid the ageing of the counters. This paper reports on the development of MSGC's with thick gold strips at IMEC, the Interuniversity Microelectronics Center at Leuven in Belgium [1)] and their subsequent tests in high intensity hadron beams.

2 MSGC substrate production at IMEC.

The technology to produce MSGC substrates at IMEC is the following: an adhesion layer of 300 $\AA$ of titanium is first sputtered on a plate of AF45 or D263 borosilicate glass, 0.3 mm thick. Over this, a copper layer of $0.8\ \mu$m is sputtered and then etched to produce the electrode pattern. For that, a photolitographic step using a mask is applied, followed by the removal of the unwanted copper and titanium via wet and plasma etching. The substrate is then immersed in a palladium solution. This element deposits only on the copper strips and it serves as a catalyst for a redox reaction that will grow a layer of $0.8\ \mu$m of nickel on the copper. This step is called electroless plating. Via a subsequent substitution reaction, a layer of about $0.2\ \mu$m of nickel is then replaced by gold. This procedure has some advantages. First, due to their increased thickness ($1.6\ \mu$m) and the use of less fragile metals than gold, the strips are more robust and have a twice lower resistance ($25\Omega/$cm) than those of substrates made with the lift-off technique. Secondly, the electroless plating process rounds off the edges of the strips as can be observed on figure 1. This was expected to lower the probability of discharges. The mask used for the production has parallel strips with an anode pitch of 200 μm. The anode width is 9 μm, which becomes 8 μm on the substrate, after the plating. The anode cathode distance is 51 μm and the overall size of the mask is 10x10 cm^2.

To avoid charging of the substrates with ions at high rates, it was decided to coat the glass support of the CMS MSGC's with a thin semiconductive layer of either aluminium nitride, polydiamond, or Pestov glass (S8900). For the production tested here, a layer of aluminium nitride is applied on the glass, before printing the metal strips. It has a resistivity of $\sim 5\ 10^{16}\ \Omega/\Box$ and should ease the removal of ions, leading to a more uniform and constant gain. It also slows down the ageing [3]. The risk of discharges is further reduced by the passivation of the cathode edges with a polymer strip, using a second mask. The polymer used is benzocyclobuthene (BCB).

Different kinds of MSGC's have been produced at IMEC, not only coated (C) and passivated (AP) substrates but also substrates with no coating and for some of them, also no passivation. The different types of IMEC MSGC's tested here are presented in Table 1.

Three batches of the above substrates were produced at IMEC, labelled successively 1, 2 and 3. The defects on the substrates after production were evaluated by visual inspection. Main defects were islands and residuals on the substrate. An anode strip was marked as bad and left floating if an island or an excess of metal exceeded one half of the interstrip distance ($\geq 20\mu$m). In our last production, this problem could be reduced from about 5% of the strips to 2%. The best quality pattern was obtained on bare glass, but the quality of patterning still needs to be further

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Table 1: Specifications of the tested IMEC MSGC's.

Detector type	Coating	Passivation
NON	no	no
UAP	no	BCB
CAP	Al_2 $NO_3 \geq 5\ 10^{16}\Omega/\square$	BCB

improved.

The IMEC MSGC counters were assembled in a way allowing easy interventions, called the "open design", described in reference [4]. For the counters assembled with substrates of the two first batches, the drift planes were made of AF45 glass with a 20 nm thick gold cladding. In order to improve the drift high voltage behaviour, for the last batch, the drift planes were goldplated Ferrozell plates, 0.5 mm thick, fixed on a special frame glued on the substrate. After the high voltage test in a nitrogen atmosphere, at -520 V on the cathode strips, some anode strips were disconnected to achieve a stable operation without overcurrents ($\geq 1\ \mu$A).

To allow the comparison of the IMEC substrates with the standard "Performance prototypes" substrates foreseen by the CMS collaboration [1], such a substrate, with S8900 coating and advanced passivation, was purchased from the Italian company ALENIA [2)]. Produced using the same mask design, the lift-off lithography process used, yielded gold strips with a thickness of only 0.6 μm. This substrate was mounted in CERN in a barrel MSGC prototype designed by the INFN-Pisa.

3 Beams description.

3.1 CERN T9 pion beam.

The IMEC counters were first tested in the 8 Gev/c pion beam T9, at CERN. This secondary PS beam is bunched with a duty cycle of 5%. It was tuned to its maximum intensity of $\sim$ 10 kHz/mm^2. The HIP's rate is calculated to be more than 1% of the full intensity and the energy deposited by these HIP's is approximately 10 times higher than that of MIP's. This reproduces approximately the charged particles irradiation at the LHC [5], but only during the short duration of the bunch. The area irradiated by the beam is about 2x4 cm^2 and the counters were exposed during two weeks.

3.2 PSI πM1 pion beam.

Simulation studies have shown that the charge particle energy deposition in the counters, expected during LHC operation, is best approached by 300 Mev/c pions [5]. The continuity of irradiation may have also an influence on the discharge occurence in MSGC's. Therefore, the counters were also tested in the πM1 beam at the Paul Scherrer Institute (PSI) cyclotron in Villingen, Switzerland. This 300 MeV/c pion beam is bunched at a frequency of 50 MHz leading to an approximately continous beam. The average beam intensity could be varied between 10-20 Hz/mm^2, called low intensity (LI), and 5 kHz/mm^2, called high intensity (HI). In the centre of the beam, at high intensity, the particle rate can reach 9 kHz/mm^2. The PSI high intensity beam reproduces approximately the charged particles irradiation at the LHC [5]. At PSI, the irradiated area exceeds the detector size, allowing to expose the detector edges. Counters were tested during two periods of two weeks.

3.3 LLN neutron beam.

The ionization losses of neutron induced HIP's are still several times higher than those induced by pions. In order to study the behaviour of the IMEC counters in presence of neutrons, some of them were also exposed to an intense neutron beam, at the cyclotron of Louvain-la-Neuve (LLN), in Belgium. The energy spectrum of that beam has an average of 20 MeV. It is also a continuous beam and the neutron intensity could be varied between $\sim$ 100 kHz/mm^2 (LI) and $\sim$ 2500 kHz/mm^2 (HI). Already at low intensity, this neutron rate is about 30 times higher than the one expected at LHC. Spark rates observed at the LLN beam are thus not a concern for the operation of MSGC's in CMS. The accumulated fluence during the 9 hours of the exposure is about $5.7\ 10^{10}$ neutrons/mm^2, slightly more than during one half LHC year. The HIP's production yield is estimated to be $2\ 10^{-5}$ HIP's per neutron [6]. The irradiation area also exceeds the detector size.

[2)] ALENIA, Roma, Italy

4 Experimental setup.

The detectors were flushed with a Ne/DME (1/2) gas mixture and read out with PreMux128 chips via an MF1 service board [7]. The single strip noise agrees to the one measured for preceding MSGC protypes with the same electronics (7-8 ADC channels, corresponding to 1500-1600 e^-) [7].

The high voltage, provided by CAEN power supplies, was connected to each group of 16 cathode strips via a 5 MΩ resistor. In this way, the ∼100 pF capacitance of the cathode group was isolated from the rest of the high voltage supply system, with a time constant of 0.5 ms. As a consequence, the total charge available for a spark was limited to 53 nC at a typical cathode strip voltage of -530 V. The current drawn by the the high voltage power supply had a trip level set at 1 μA , 1 μA and 10 μA during the high intensity tests at T9, PSI and LLN respectively. The drift plane was decoupled from the high voltage system by a 1 MΩ resistor. Since the drift plane capacitance is lower, 30 pF, but the drift voltage is higher, ∼3000V, one finds a factor of two higher in stored charge, namely 100 nC .

The spark detection was done by monitoring the current of the cathode strips and of the drift planes from the high voltage power supplies. Two types of floating picoamperemeters were used: a fast one with a response time smaller than 100 μs and an integrating one with a time constant of 30 ms. The resolution of the picoamperemeters depends on its range (0.1, 1 or 10 μA) and was better than 5% of the full scale. The sampling period was 2 ms at PSI, and 20 ms at LLN. In the PSI beam, at high rate, the maximum irradiation currents drawn by the counters were about 100 nA and 200 nA for the cathode strips and the drift planes respectively. In LLN, these currents were up to about 8 μA and 4 μA respectively. At LLN, the drift current is smaller than the anode current. This is caused by a lower drift voltage. The currents were analysed off line. A spark was defined as an overcurrent exceeding a threshold of 3 standard deviations above the average irradiation current. Figure 2 shows typical sparks as observed at the PSI high intensity beam. It should be noted that the current spikes observed are due to the recharging of the discharged electrodes, with a time constant fixed by the picoampermeter and not by the detector characteristics.

5 Gas gain and signal to noise ratio at low intensity.

The signal to noise ratio, SNR, is defined as the most probable cluster charge divided by the cluster noise. For the gas mixture used here and MSGC's with an anode pitch of 200 μm, the cluster size has been measured to be about N_{cl}=2.3 strips which means that the cluster noise will be of the order of 2400e^- [7]. With this definition of the SNR, the minimum SNR needed to obtain a detection efficiency of 98% for MIP's, with detectors equipped with the PreMux electronics, was measured to be ∼9. In CMS with the final APV electronics operating in a deconvolution mode, a factor 2.2 has to be applied bringing this minimum to ∼19 [1].

In figure 3, the SNR is shown as a function of the cathode voltage, for different substrates, in the low intensity beam of PSI. The drift voltage was V_d ∼-3.6 kV. Although the same mask was used for all detectors important gain differences are observed. They are due to the different types of detectors. In the case of UAP2 and UAP3, supposed to be of the same type, the large difference observed is to be attributed to the artwork quality, the electroless plating process being not yet under control during the first batches. In the low intensity beam, the highest measured SNR's are 53 for the UAP3, at V_c∼-570 V, and 54 for the ALENIA detector, at V_c∼-590 V. This corresponds to 3 times the minimum SNR needed for full efficiency detection of MIP's in CMS. Note that these values may not be the ultimate ones because the measurements usually stop when the sparking rate starts to increase, at a rate of about 1 Hz. The dashed lines correspond to a logarithmic extrapolation of the data up to the maximum attainable cathode voltage without irradiation. This shows that even at low intensity, the presence of HIP's reduces the length of the efficiency plateau. However, at low intensity of HIP's, all detectors demonstrate a sufficient margin of at least a factor 2 in SNR.

6 Performances in the presence of HIP's, at high intensity.

The exposure of the various detectors to the high intensity beams described in section 3 is summarized in table 2. For LLN, the low intensity runs are also quoted as their intensity is already higher than the one expected at LHC.

Not all the detectors were operational during the entire exposure time, either because of space limitations or because the detector developed a problem during the exposure. This was the case for NON2 that went into a short after 4 hours at high intensity at PSI. After an intervention in the experimental area, the ALENIA detector developed a small gas leak of about 2 ml/min. From then onwards, fast ageing of this counter was observed, loosing a factor 4 in SNR. Similar observations of fast ageing with DME in combination with moisture were reported by HERA-B [8].

The main danger for an MSGC is a short circuit on the substrate which disables at least one cathode group. The

Table 2: MSGC exposures in the high intensity beams.

Beam	Period	Detector	Exposure time
T9	October 98	NON1,CAP2	150h
PSI	November 98	UAP2, NON2, CAP2	205h
PSI	April 99	UAP3, ALENIA	155h
LLN	December 98	UAP2, CAP2	6h(HI), 3h(LI)

short circuit normally develops after a number of damaging discharges. We do not know neither the exact amplitude of such sparks nor the average number of sparks required to produce a short for an IMEC MSGC. We assume that HIP's can produce avalanches which are able to grow into a discharge preferably near a defect. Thus the strips should be robust enough to sustain a limited number of sparks during irradiation. The end of the efficiency plateau will be determined by the maximum acceptable sparking rate. Obviously to achieve a long efficiency plateau, the number of defects on the substrate should be minimized to reduce the source of sparks.

6.1 Spark amplitude

There are different kinds of sparks. First those on the substrate which involve one or more cathode groups. Figure 4 shows the charge distribution for the cathode strips discharges observed in the PSI high intensity beam for the ALENIA(a) and UAP3(b) detectors. The drift voltage was set at -3.4 kV and the cathode voltage, at about -530 V. The most significant peak, at about 40 nC, corresponds to the discharge of one cathode group. The value observed here is 25% lower that the estimated stored charge (see section 4). This might be explained either by the fact that the charge displayed in figure 4 is obtained by integration of the current versus time curve and that the absolute calibration of the picoamperemeters is imprecise or by an incomplete discharge of the cathode group. Discharges of two or more groups are also observed. The overcurrents with a charge less than 2 nC are considered as quenched streamers. The peak at 10 nC might be due to the discharge of a cathode group partially damaged, with disconnected strips. The normal avalanches from MIP's, with a typical charge of 10^{-5} nC, are not displayed on figure 4.

The second type of sparks is related to the drift plane. These drift sparks are usually correlated with sparks on the cathodes unless they occur outside the active detector area. The UAP2 and CAP2 detectors badly suffered from drift sparks at PSI in november 98. At high intensity, the drift voltages had to be reduced from 3.6 kV to 2.7 kV, loosing a factor 1.7 in SNR. In the april 99 test at PSI, the drift plane material had been changed from glass to Ferrozell and the detector edges were protected by a frame. Then the drift sparks had almost disappeared: we found in total, 7 correlated sparks for the UAP3 detector and 3 sparks in the ALENIA MSGC, all of charge less than 20 nC, showing that they are not discharges of the full drift plane but rather parallel plate quenched streamers.

6.2 Sparking rate.

The sparking rate depends on the voltages, the gas mixture, the irradiation rate and the exposure time. Table 3 shows the number of sparks registered during different exposures to the PSI high intensity beam, as well as the corresponding exposure time, the SNR at the working point and the number of lost channels, for the different detectors exposed there. These lost channels were identified using the RMS noise distribution for the anode signals, as well as from the response to calibration pulses injected into the PreMux electronics inputs, either directly or via the cathode groups. The statistics quoted for the ALENIA counter concern the period before the gas leak and include no high voltage scan as it is the case for the UAP3 detector, for example. If the whole exposure time of 255h is taken into account, the ALENIA counter underwent 60 sparks leading to 12 lost channels.

Table 3: Sparks statistics in the high intensity beam at PSI.

Detector	Time at high intensity	SNR	Number of sparks	Number of lost channels
CAP2	205h	13	2800	1
UAP2	135h	14	5000	3
NON2	4h	12	220	8
UAP3	137h	20	737	3
ALENIA	24h	19	6	2

Comparison of same type substrates from different production batches, UAP2 and UAP3, clearly indicates the reduced sparking rate for the substrate with a better quality artwork , UAP3. The ALENIA MSGC, produced via the lift-off process, according to the CMS performance prototype specifications, exhibits an even better behaviour. The thin metallisation, 0.6 μm, allows an improved strip definition leading to far less sparks. On the other hand, the robustness of the thick multimetal strips of the IMEC MSGC substrates is demonstrated by the modest channel losses at rather high sparking rates. For the UAP3 detector, all 3 lost channels show a PreMux electronics failure indicating that the preamplifier inputs are damaged by the sparks rather than the strips themselves. The opposite is the case for the thin gold strips of the ALENIA substrates. This subdivision is not available for the other IMEC counters. Table 3 also indicates that without advanced passivation, the channel loss is far more severe (NON2).

Figures 5 and 6 compile the sparking rate measured at PSI, versus the cathode voltages, for the CAP2, UAP2, UAP3 and ALENIA MSGC substrates, without beam (NB), with the low intensity beam (LI) and with the high intensity beam (HI). That the tendency of increased sparking rate with increasing HIP intensity continues also beyond the LHC conditions, represented by the ”PSI HI”, is illustrated by the behaviour in the high intensity neutron beam at the LLN cyclotron (LLN), also shown on figure 5.

As long as the spark rate was kept below $\sim$0.03 Hz per counter, a stable operation could be maintained, which means: no trip during at least one hour. Figure 7 shows the maximal attainable SNR at this maximum allowable sparking rate of 0.03 Hz per counter, for different MSGC substrates in different exposures. Without beam, the differences between substrates reflect the artwork quality. However, a reduction of the maximum attainable SNR with increasing HIP intensity is seen for all detectors in rather similar proportions. This clearly indicates that HIP's are responsible for the observed sparks. Up to the high HIP intensity in the LLN neutron beam, which corresponds to several hundred times the expected rate at the LHC, no saturation seems to set in.

The question of substrate hardening has also been addressed. The sparking rate can change with time since some artwork defects can be burned away and others may appear due to damaging sparks. As an example, after irradiation at LLN, the CAP2 detector developed a leakage current and finally went into short. On the contrary, the UAP2 detector improved substantially, as shown in figure 8 where the spark rate versus the cathode voltage is shown before and after irradiation with HIP's, at LLN.

6.3 Detector occupancy due to sparks.

To estimate the detector occupancy induced by sparks, the behaviour of the readout channels was studied both during and after the occurence of sparks. To see how sparks affect the readout of the whole detector, data have been taken in the LLN high intensity beam, using as a trigger, the spark signal itself. Figure 9 shows the ADC count as a function of the channel number. The first two cathode groups and the last eight groups are not connected. The real signals are negative and saturate at $\sim$ 200 ADC counts. Between channels 260 and 325, several bunches of saturated signals due to a distributed spark, are observed. Most of the rest of the detector shows a positive saturated signal of $\sim$ 540 ADC counts. This is attributed to the direct capacitive coupling of all strips. Indeed, the current driven from the various cathode groups to restore the charge on the discharged group, flows to a circuit with a time constant of 0.5 ms (see section 4). The corresponding frequency should be low enough to leave the PreMux outputs unaffected.

To study the recovery time of the readout after a spark, a laboratory test was performed using a spark gap (Siemens 230), connected to the central cathode group. It produces a stable discharge of the full group powered at 280 V, with a period of $\sim$ 5 ms. Figure 10 shows the channel outputs as a function of the channel number, for different delays of the readout with respect to the spark trigger, ranging from 30 ns to 4 ms. Calibration pulses were injected in every fourth channel of the PreMux at times correlated to the readout. Due to direct capacitive coupling of all strips, the discharge signal spreads over the whole substrate in the first few nanoseconds, saturating the PreMux chips. As a consequence, the calibration pulses are no longer seen. This particular behaviour of the readout might be explained by a saturation effect of the first amplification stage of the PreMux. In the first stage the signal is limited to the level of 5-6 MIP's (300000e-). Because of the AC coupling to the next stage we can see the positive and negative differentiated signals with a time constant of $\sim$200 ns. It is only after 10 μs that the calibration pulses are fully restored on all channels except on the about hundred channels surrounding the sparking cathode group. They require almost 4 ms to restore. These dead times of 10 μs for 80% of the detector and 4 ms for the other 20% of it, lead to a negligible detector occupancy, even at the maximum allowable sparking rate of 0.03 Hz per detector.

7 Conclusions.

In collaboration with IMEC we have successfully developed MSGC substrates with 1.6 μm thick strips, made of layers of copper, nickel and gold on top. The process used is standard for multichip modules assembly and it can be developed into a technique suitable for mass production. The quality of the artwork is not yet equal to the one obtained in industry by the lift-off technique leading to gold strips of 0.6 μm thickness. However tests in high intensity beams have shown encouraging results. The strips are robust to the point that the detectors can sustain thousands of sparks without strip breakage.

At low radiation levels, in the bunched CERN beam, one has seen signal to noise ratios in excess of 100. The presence of a high intensity beam of heavily ionizing particles diminishes the maximum attainable signal by a factor of the order of 2 to 3 for all the substrates tested, including also an industry prototype (ALENIA).

Two out of the four IMEC substrates have shown to work well in the PSI high intensity beam (UAP3 and CAP2). Stable operation was obtained during 135 hours, at high intensity, at a SNR$\sim$20. This ratio is above the minimum that will be required to obtain full MIP detection efficiency when the counters will be equipped with the CMS front-end electronics. The counters were operated up to SNR$\sim$30 with a spark rate of 0.03 Hz. This spark rate corresponds to a negligible channel occupancy. This maximum signal to noise ratio corresponds to a plateau length of about 40V. To ensure really spark free operation of these IMEC substrates at high intensity, one would have to use preamplifiers at least as sensitive as the PreMux chips used in these tests.

8 Acknowledgements

We gratefully acknowledge the cooperation of the personnel from the MAP/MCM division at IMEC, whose infrastructure and support permitted the production of the substrates. Special thanks also to R. Pins, from the IIHE-ULB, for her collaboration during the production and the quality control of the substrates. We are also indebted to our funding agencies which made this work possible, namely: the Fonds National de la Recherche Scientifique (FNRS), the Fonds voor Wetenschappelijk Onderzoek-Vlaanderen (FWO-V) and the flemisch government via a ”Geconcerteerde Onderzoeksactie” of the University of Antwerp.

References

[1] CMS collaboration, Technical Design Report Tracker, CERN/LHCC 98-6,CMS TDR 5,1998.

[2] B.Schmidt, NIM A419 (1998) 230-238.

[3] R. Bouclier et al., NIM A367 (1995) 168-172.

[4] O. Bouhali et al., Technical Design Report: A Possible Approach for the Construction of the CMS Forward-Backward MSGC Tacker, CMS NOTE-1997/081.

[5] M. Huhtinen, Factors to scale highly ionizing particle rates in MSGC irradiation tests to the LHC radiation environment, CMS NOTE-1997/073.

[6] W. Beaumont et al., MSGC test with fast neutrons, CMS NOTE-1998/014.

[7] O. Bouhali et al., CMS Forward-Backward MSGC milestone, CMS NOTE-1998/095.

[8] private communication

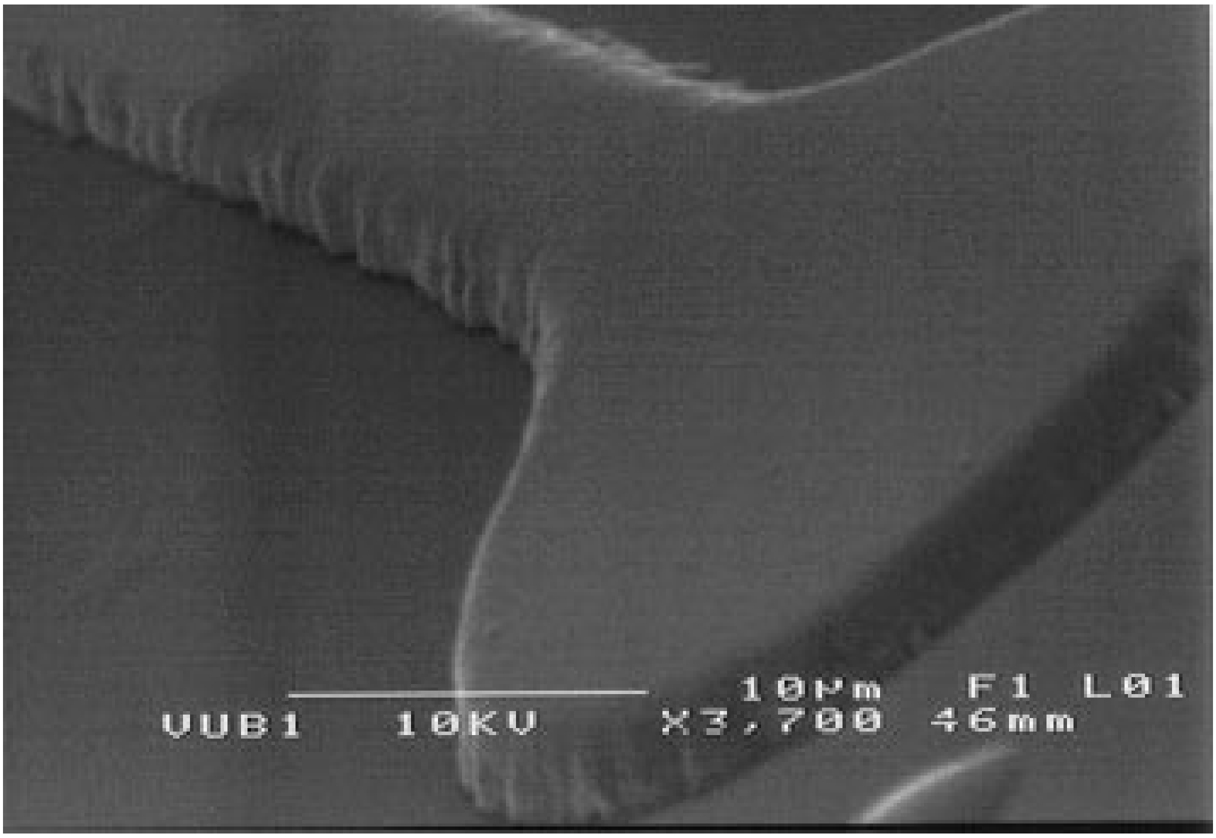

Figure 1: The anode strip edge obtained in IMEC. The strip width is $\sim 8\mu$m.

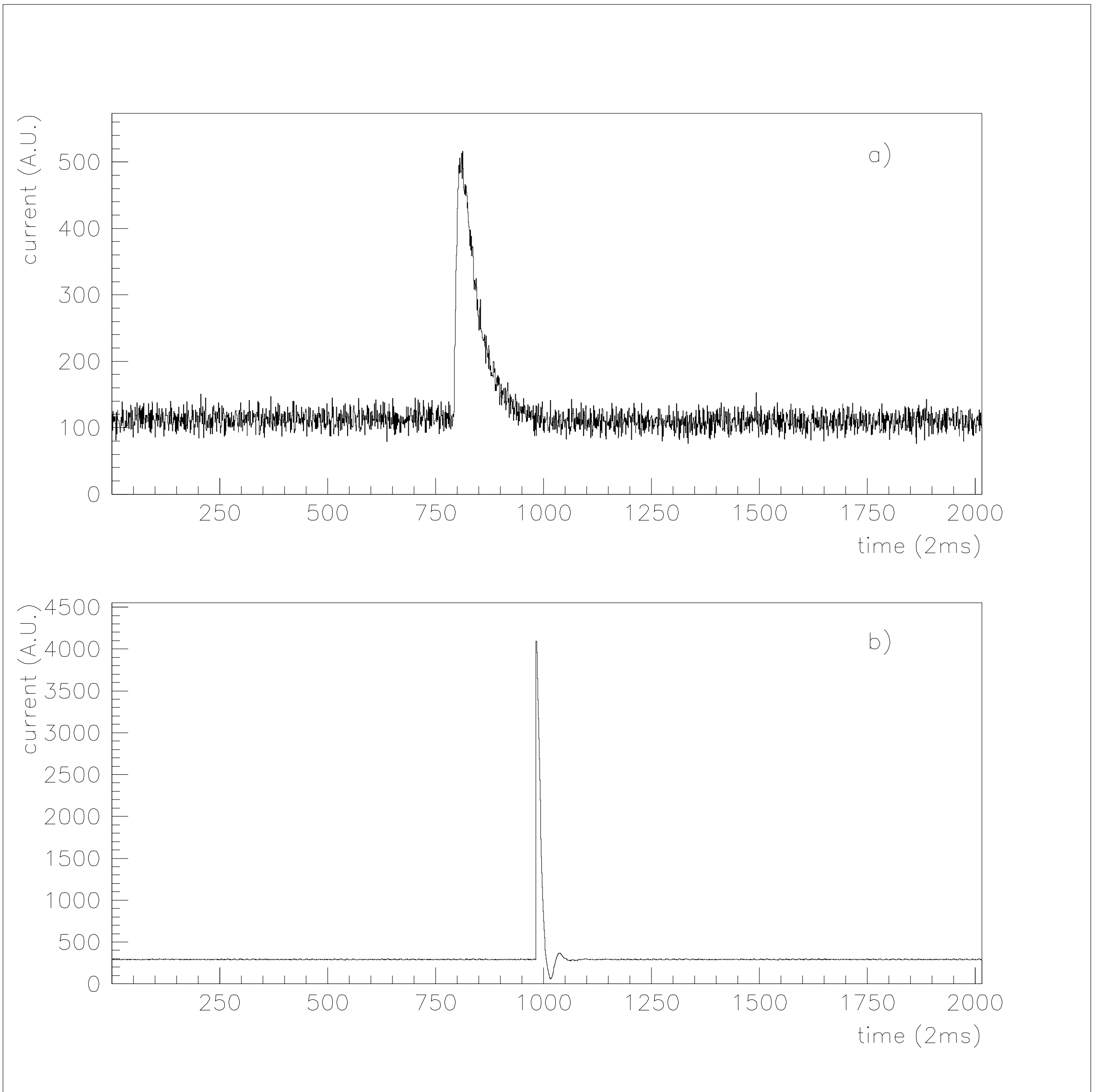

Figure 2: Cathode (a) and drift (b) currents as a function of time, when a spark occurs in the high intensity beam in PSI. The two events displayed here are not correlated.

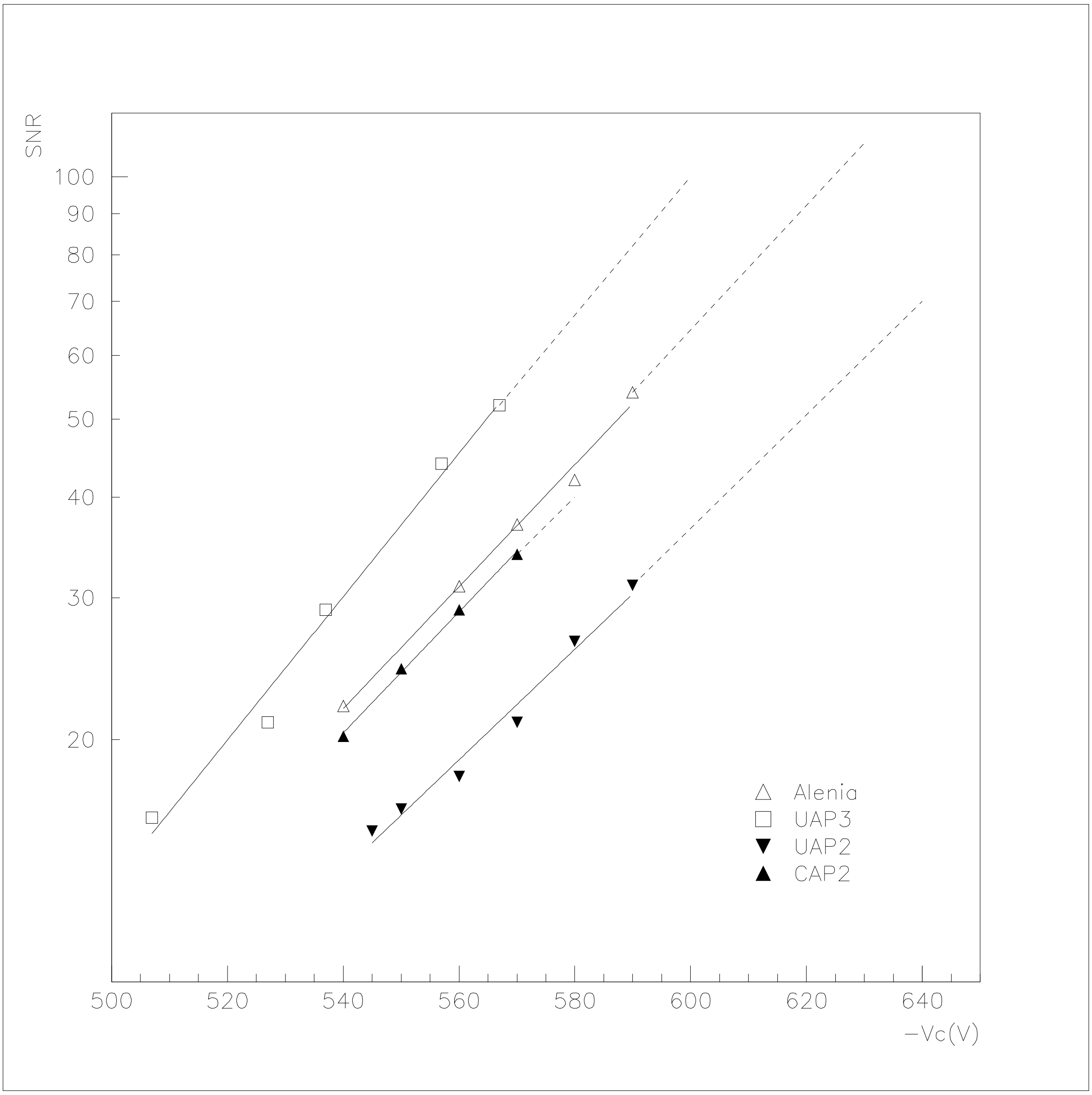

Figure 3: SNR as a function of the cathode voltage, for different substrates, in the low intensity beam of PSI. The drift voltage was V_d ∼-3.6 kV. The dashed lines correspond to a logarithmic extrapolation of the data up to the maximum attainable cathode voltage without irradiation.

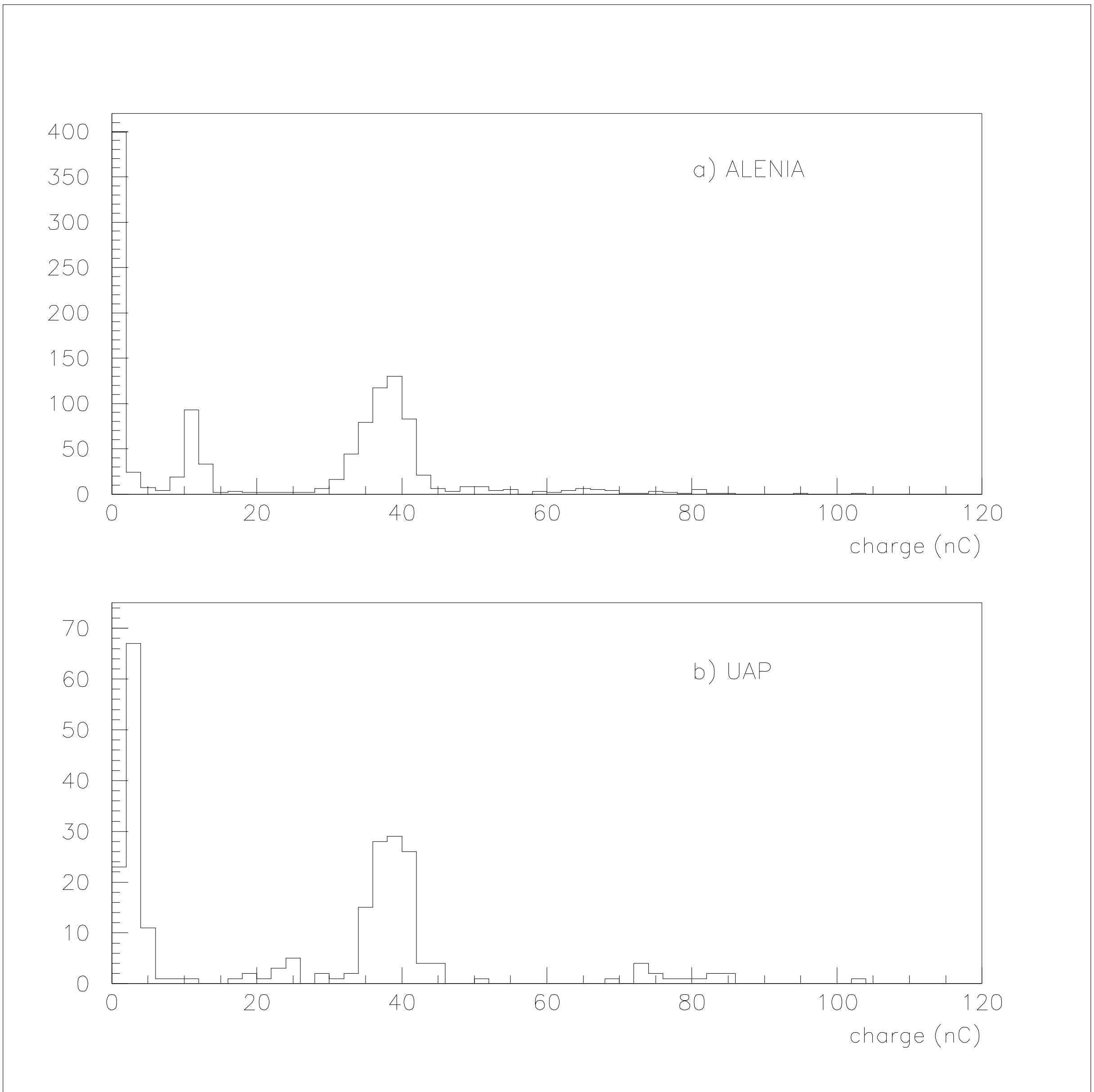

Figure 4: Charge distribution of cathode strips discharges observed for ALENIA(a) and UAP3(b) MSGC's in the PSI high intensity beam. The counters are operated at a drift voltage of about -3.4 kV and a cathode strip voltage of about -530 V.

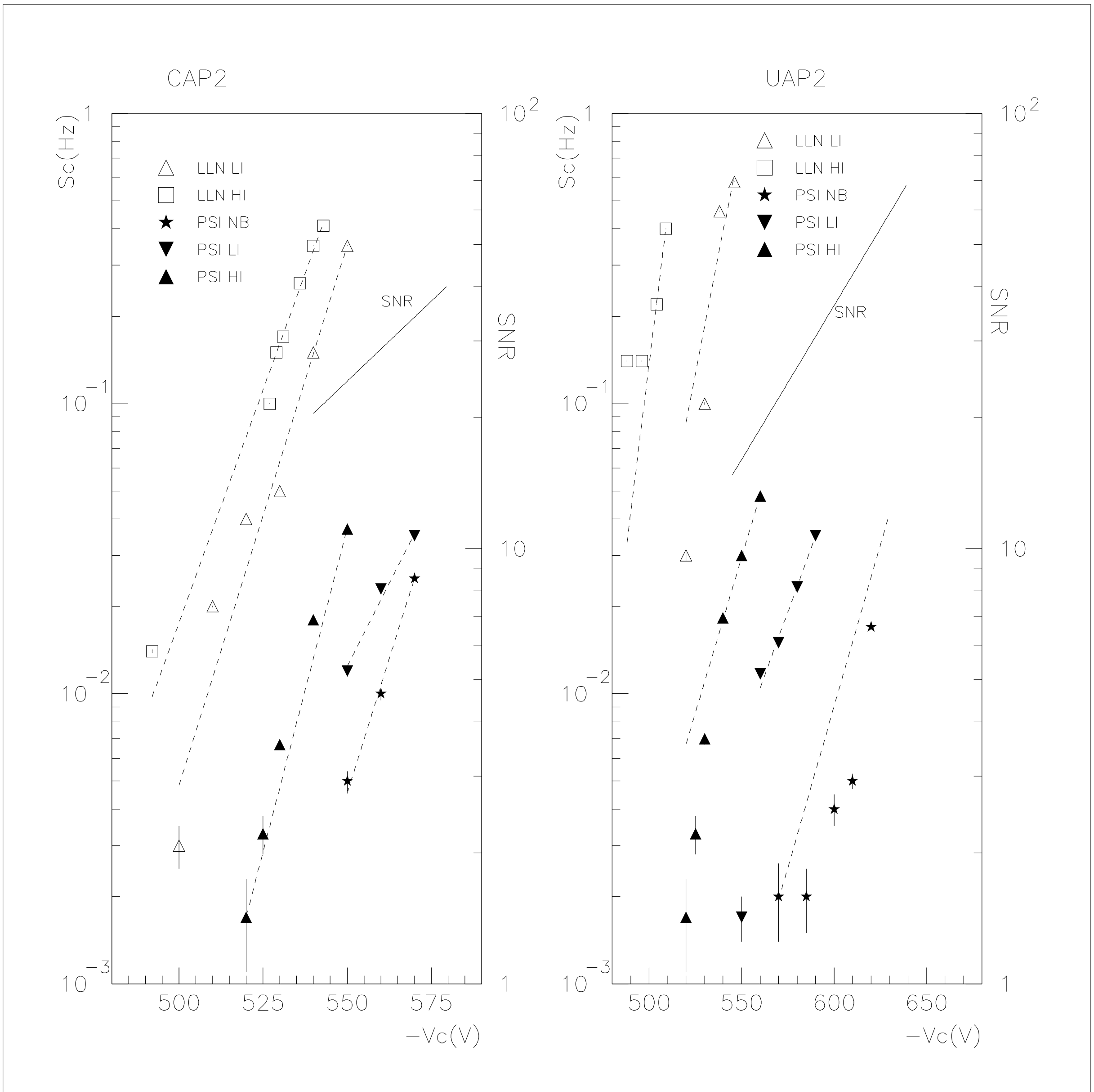

Figure 5: Sparking rate as a function of the cathode voltage for the CAP2(left) and UAP2(right) substrates, at PSI and LLN. Data have been taken with various beam conditions, without beam (NB), with the low intensity beam (LI) and with the high intensity beam (HI). The straight line shows the corresponding SNR.

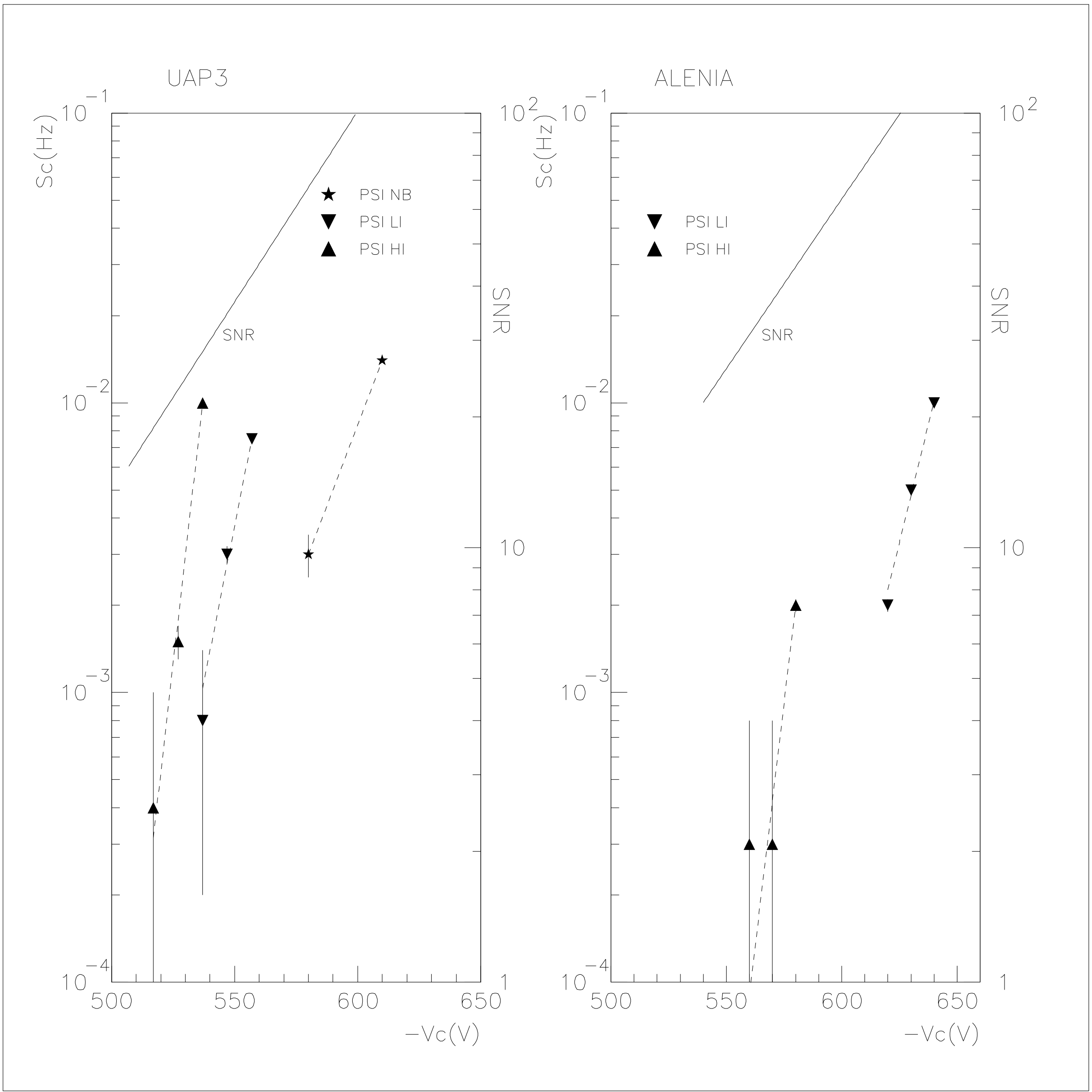

Figure 6: Sparking rate as a function of the cathode voltage for UAP3(left) and ALENIA(right) at PSI, with various beam conditions. The straight line shows the corresponding SNR.

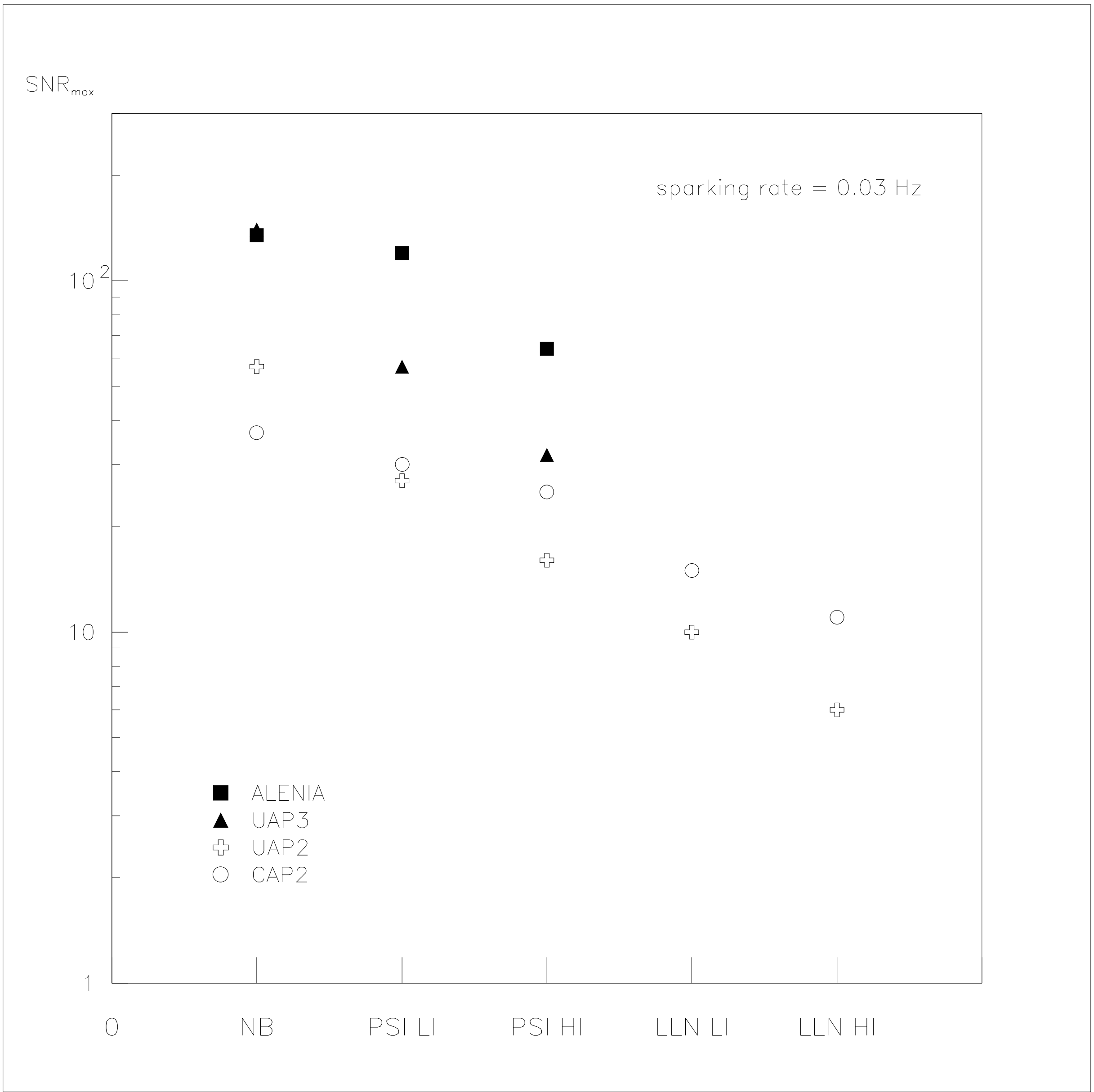

Figure 7: Maximum SNR achieved for various detectors in different beam conditions, when limiting the sparking rate to 0.03 Hz.

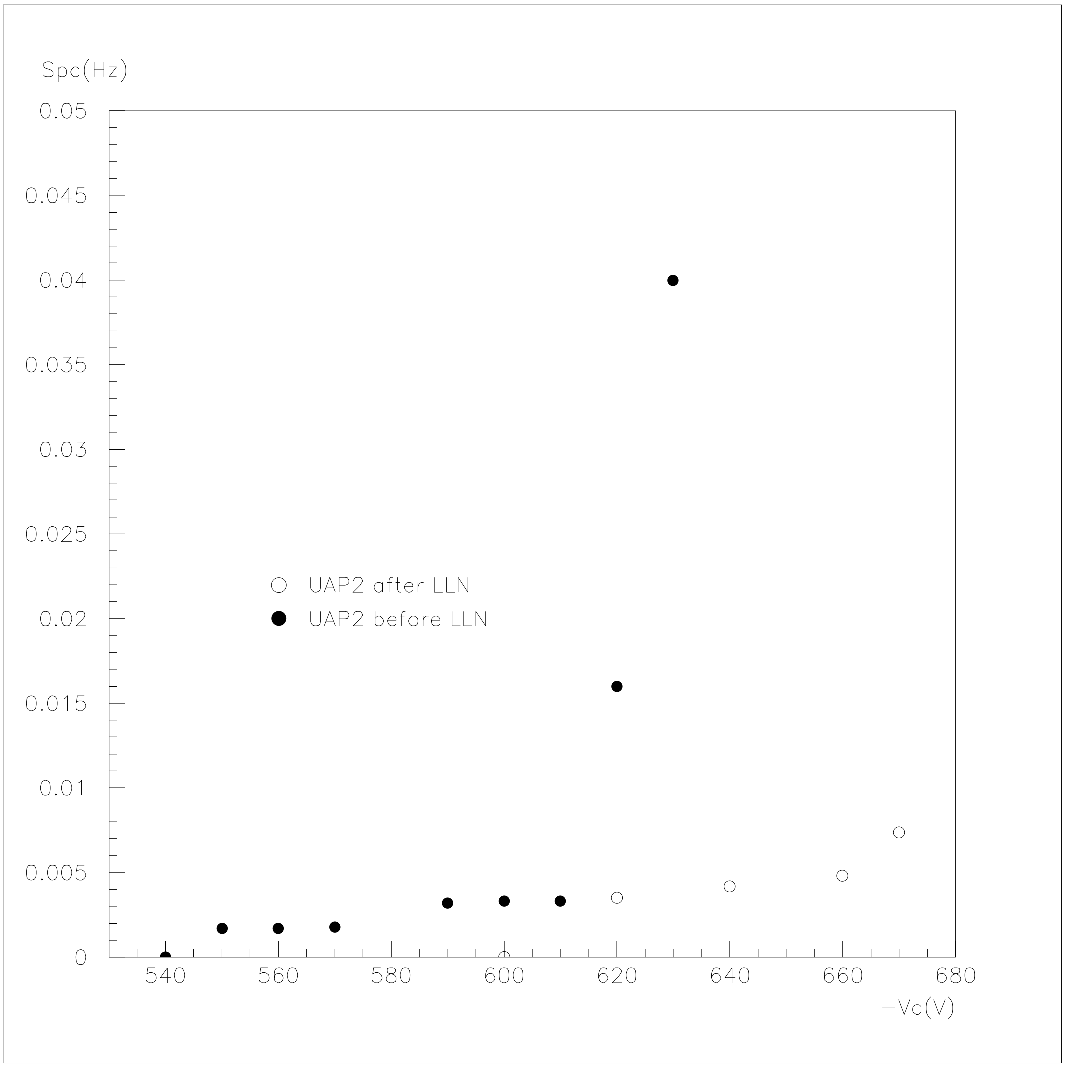

Figure 8: Sparking rate as a function of the cathode voltage for the UAP2 detector exposed to the high intensity beam at PSI, before and after the LLN tests at high intensity.

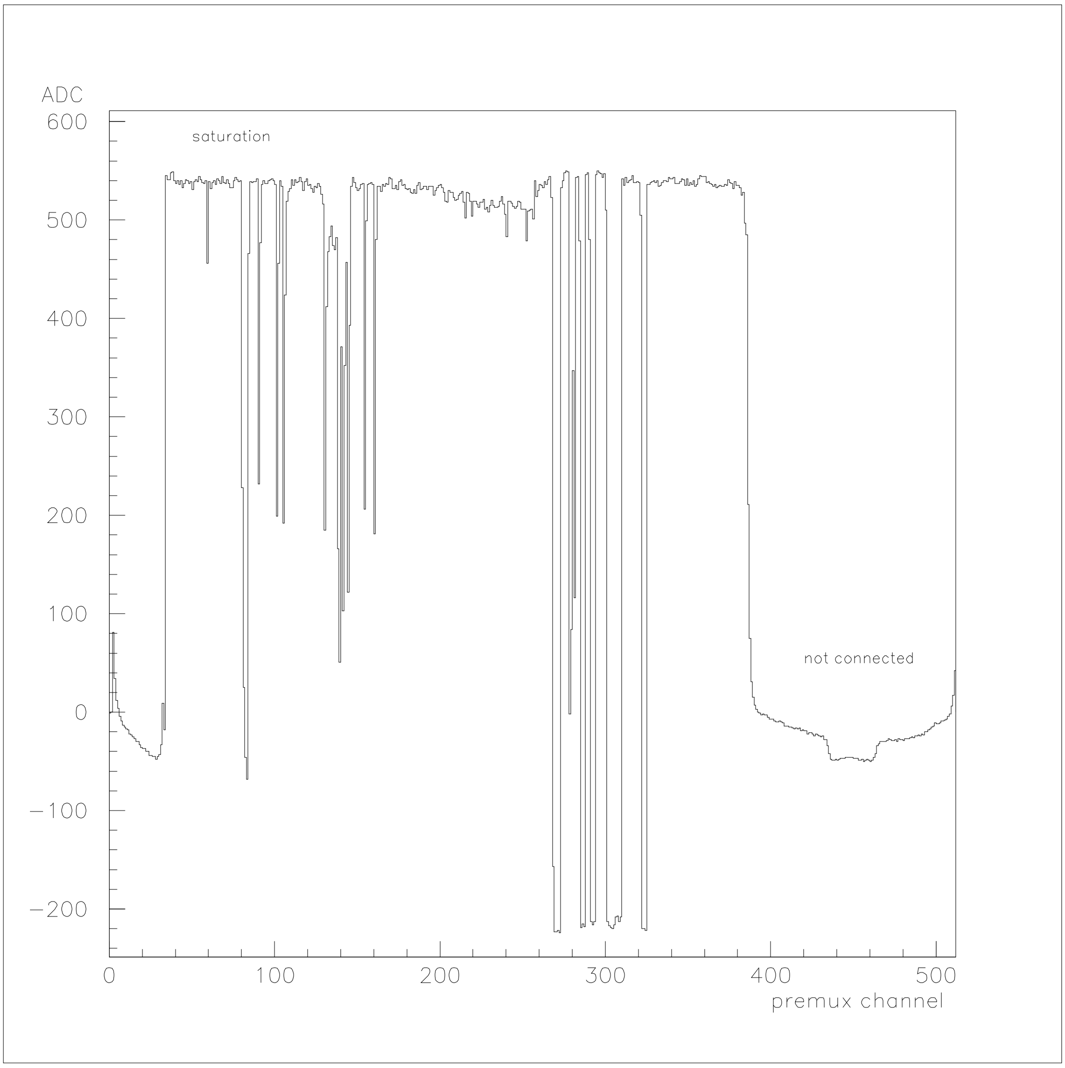

Figure 9: The PreMux signals read out for the CAP3 detector, as a function of the channel number, in the LLN high intensity neutron beam, with a trigger from sparks. The first 2 cathode groups and the last 8 groups are not connected.

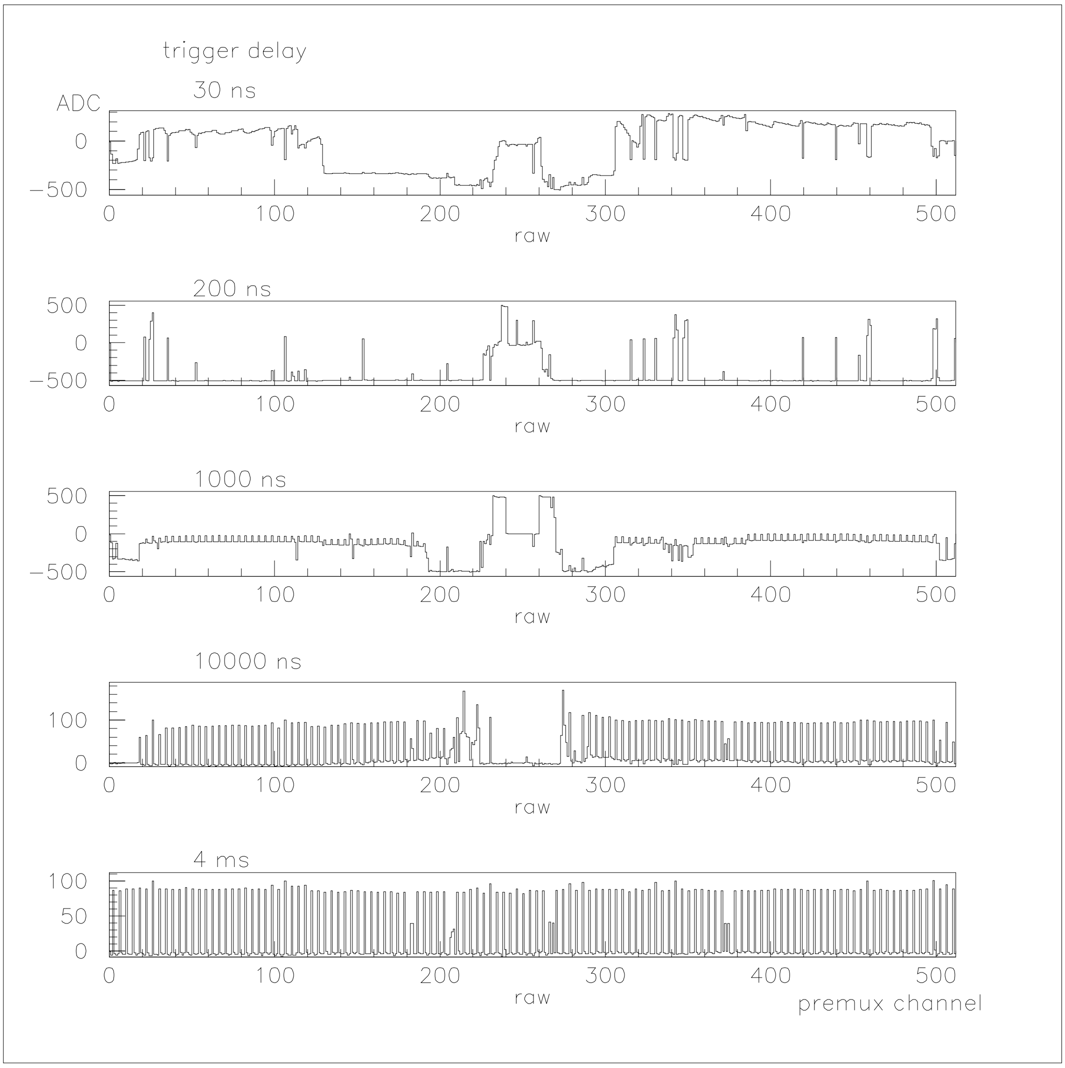

Figure 10: The PreMux signals read out for the ALENIA MSGC, as a function of the channel number, when discharges are produced on the central cathode group by means of a spark gap, for various delays of the readout with respect to the spark trigger. Calibration pulses are injected on every fourth channel at a time correlated to the delayed readout.