# The performance of GridPix detectors

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***A GridPix detector is a gaseous detector capable of detecting individual single primary electrons from ionizing particles. Such a detector consists of a pixel chip as active anode covered with a thin layer of silicon rich silicon nitride (SiRN) for protection against discharges, an integrated amplification grid (InGrid), applied on top of the chip by wafer post processing techniques, and a cathode plane. The drift region is between the grid and cathode while the gas gain occurs between the chip and the grid.***

***The discharge quenching properties of the SiRN layer have been determined as well as the relation on grid capacitance, grid voltage and gas mixture.***

***Part of the detectors in this report were of the type Gossip, a GridPix detector with a drift gap of ~1 mm. Using such thin drift layer, one may consider this detector as a replacement for a silicon pixel detector. The performance of three Gossip detectors has been investigated by measurements in a test beam at CERN.***

## I. Introduction

The GridPix and Gossip detectors discussed in this report use a TimePix chip as active anode [1],[2]. Since the gas gain occurs directly above the surface of the chip [3], spark protection is required. This is achieved by applying a layer of silicon rich silicon nitride (SiRN) [4] directly on top of the chip. In case of a discharge, the SiRN layer prevents charge to be drained off instantly, but instead causes buildup of a local charge on the layer. The buildup charge locally reduces the discharge current and the electrical field between chip and grid, causing the discharge to quench. On the other hand, regular (proportional) signals are not significantly affected because of capacitive coupling through the SiRN layer. To determine the effectiveness of the SiRN layer, the amount of charge in (quenched) discharges has been measured for different layer thicknesses, different gas mixtures and different grid capacities.

Gossip, ***G***as ***O***n ***S***limmed ***SI***licon ***P***ixels, is a detector optimized for accurate high rate particle detection like at the pixel tracker of Atlas at the sLHC. This is accomplished by applying a very thin (~ 1mm) gas layer in combination with a high granularity pixel chip (50 – 60 µm pitch), thus enabling detection of the individual electrons liberated by the track. Advantage of this approach is the possibility to reconstruct small track segments, thus facilitating tracking in a dense environment. Also the outlook on excellent ageing properties makes the Gossip concept attractive.

Both Gossip [5] and GridPix detectors have been investigated in a test beam at the SPS at CERN for aspects like the single electron efficiency, track efficiency, position resolution and angular resolution.

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## II. Discharge measurements

To operate GridPix detectors reliably for a long time, one needs adequate quenching of the discharges. To determine how detector properties affect the discharge quenching process, discharges have been measured using different gas mixtures and different grid capacities. These tests have been performed on broken or low-grade TimePix chips. The chips were equipped with a 4 µm or 8 µm SiRN layer.

### *A. Measuring proportional signals and discharges simultaneously in an Ar/iC4H10 90/10 mixture*

The discharges were studied by measuring the charge induced on the grid. The samples were irradiated by an $^{55}$Fe source to verify proper detector operation and to provoke discharges. It is obvious that in case of successful discharge quenching, the deposited charge does not significantly depend on the capacitance of the amplification grid. A quenched discharge deposits on the pixel chip only a small fraction of the charge that is stored on the amplification grid, resulting in a minor change in the potential of the grid. This is because the quenching process occurs by locally charging up of the SiRN layer, reducing the electrical field in the gain gap and terminating the discharge. Because of the small capacity of the involved area on the SiRN layer (less than 1 mm$^2$) the potential of the grid is hardly affected.

A set-up has been made that is capable to measure charges of less than 0.1 pC up to more than 10 nC, thus simultaneously covering the range of proportional signals (Fig.1) and discharges (Fig.2). These spectra have been measured with a chip covered with 8 µm SiRN. They show that the proportional charges are of the order 0.2 pC while the discharge signals range between 100 and 1500 pC. The capacitance of the grid and the connected circuitry was approximately 80 pF. So for a grid voltage of -380 V, like used for these measurements, the charge on the grid is 30 nC. Therefore, the total charge on the grid would be hardly affected by a discharge. We observed indeed that increasing the grid capacitance to 1 nF by an external capacitor did not affect the magnitude of the discharge signals.

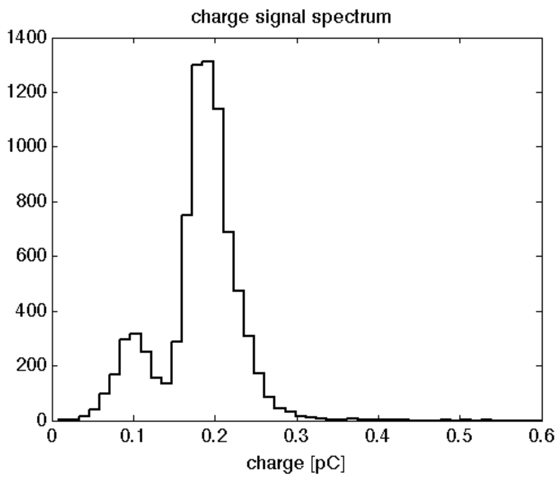


Fig. 1. Proportional charge signal spectrum of $^{55}Fe$ conversions in an $Ar/CH_4$ (90/10) mixture. The grid voltage was -380V, resulting in a gas gain of approximately 5 x $10^3$. At this gain discharges occur occasionally. The conversion rate was approximately 100 $sec^{-1}$ $cm^{-2}$

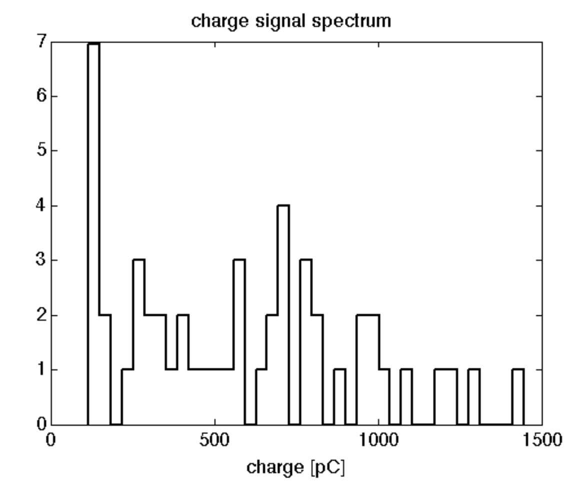


Fig. 2. The same measurement as in Fig. 1 but now in a range up to 1500 pC and the proportional signals cut out. The discharge signals are more than three orders of magnitude larger than the proportional signals. The total number of entries in Fig. 1 and 2 is 8192

### B. *Quenching in different gases with 8 and 4 μm SiRN*

The quenching properties of different gas mixtures have been measured by recording 1000 discharges for each mixture. For the test with a $CO_2$/DME 50/50 mixture the discharges were about one order of magnitude smaller than for a $He/iC_4H_{10}$ mixture running at a 40 V lower grid voltage. Figure 3 and 4 show the result with a 8 μm SiRN layer. We observed no correlation between the magnitude of the discharges and the discharge rate.

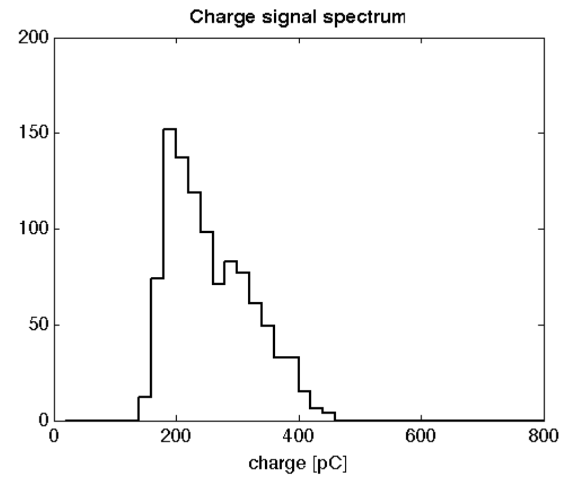


Fig. 3. Charge signal spectrum of quenched discharges in a $CO_2$/DME (50/50) gas mixture. The grid voltage was -580V, the SiRN layer was 8 μm thick.

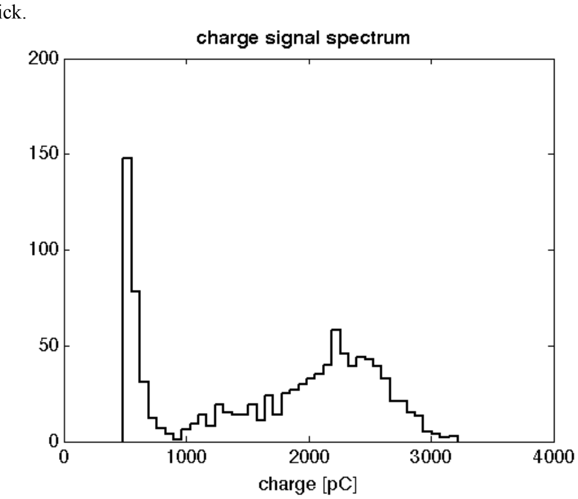


Fig. 4. Charge signal spectrum of quenched discharges in a $He/iC_4H_{10}$ (90/10) gas mixture using the same chip as in figure. 3. The grid voltage was -540V.

For chips with a 4 μm SiRN layer, the average amount of charge was increased by a factor of 1.2 for the $CO_2$/DME 50/50 mixture. Also the width of the distribution is broader (Fig. 5).

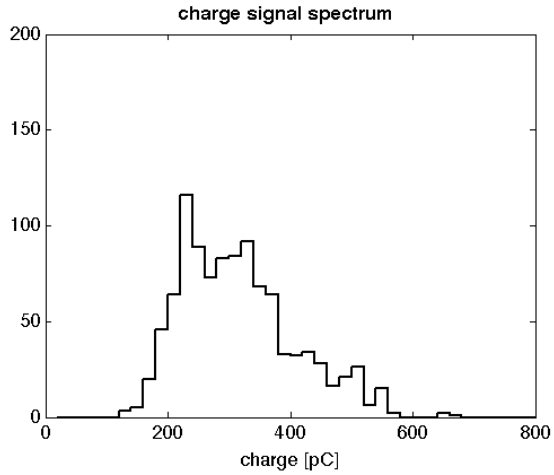


Fig. 5. A discharge measurement in $CO_2$/DME 50/50 using 4 µm SiRN. The average charge signal has hardly increased, but the distribution is broader.

### *C. Defects in the SiRN layer*

In spite of the discharge protection, still some samples showed occasionally much larger discharges during the discharge measurements, using a significant fraction of the charge stored on the grid (more than 6 nC). In case of a large grid capacitance these discharges lead to visible damage like parts of the grid being evaporated and holes being created in the SiRN layer (Fig. 6). But after pacifying these spots (done on samples with 8 µm SiRN) with UV curing resin, these discharges could not be reproduced, even at higher grid voltages. Such behavior only is possible if the SiRN layer as such gives sufficient protection. Therefore, we assume that the occasional breakdowns are due to defects in the SiRN layer. This may explain the occasional detector break downs we observed after a long period of successful operation.

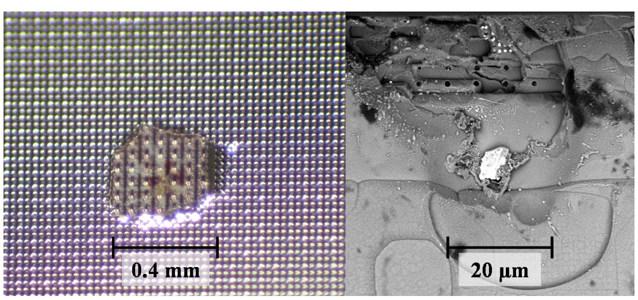


Fig.6. Damage due to a discharge that was not quenched sufficiently. Part of the grid (left) is evaporated and the SiRN layer including chip surface (right) is severely damaged, rendering the chip useless.

## III. THE GOSSIP BEAM TEST AT CERN

### *A. Gossip set-up*

We made a telescope of three Gossip detectors and one GridPix detector (Fig. 7 and 8). The Gossips each had a drift gap of approximately 0.95 mm and the GridPix detector had a drift gap of 19.3 mm. For the analysis, we used the superior position resolution and angular resolution of the GridPix detector to reject triggers from background tracks, tracks outside the fiducial volume and showers. We placed this set-up in the H4 test beam at CERN using 150 GeV/c muons. The test beam first traversed the three Gossip detectors and finally the GridPix. Services like the high voltages, gas flow and the X-Y stage of the telescope were remotely controlled during the experiment. Two scintillators, one in the front and one behind the detectors, defined a 15 mm x 15 mm triggering area.

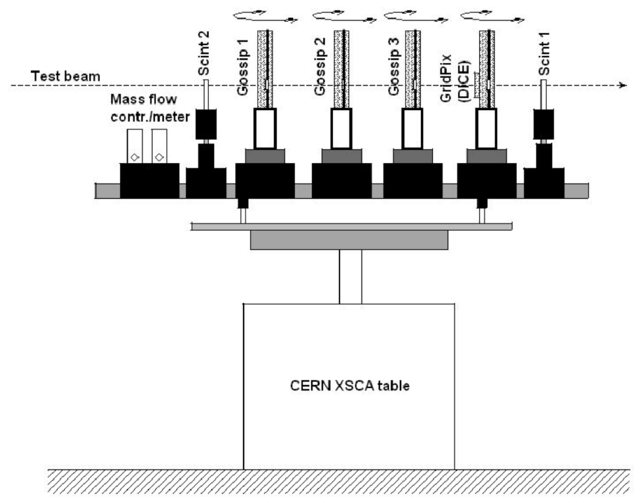


Fig.7 Sketch of the side view of the Gossip telescope mounted on an optical bench.

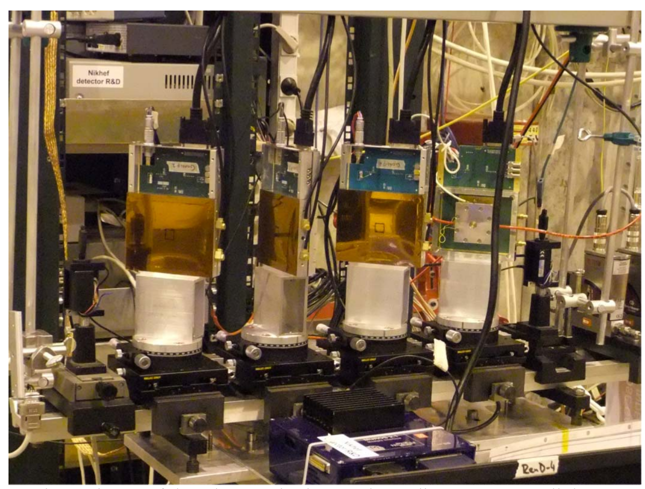

Fig.8. Picture of the telescope in the SPS beam line at CERN. All detectors were placed on rotary stages.

We used a $CO_2$/DME (50/50) mixture for its dense ionization and a low diffusion [6].

### *B. Primary electron detection*

For this test the Gossip detectors were put at an angle of 45° to the beam to reduce the amount of electrons collected by the same pixel (pile up). Tracks were recorded for decreasing negative grid voltage. Using the GridPix detector as a reference, we followed tracks through the three Gossips.

Above a certain grid voltage the gas gain should be sufficiently high such that almost all electrons liberated in the drift gap are detected. Therefore, one would expect a plateau in the curve of the amount of hit pixels as function of grid voltage [7]. However, the result in figure 9 shows that this is not really the case.

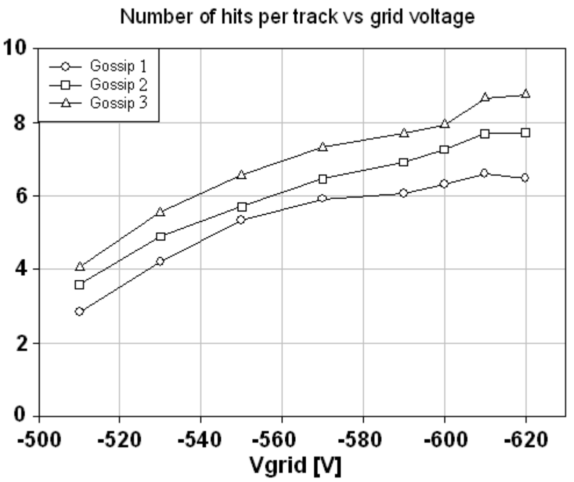


Fig. 9. Hit pixels as function of grid voltage.

According to simulations with Garfield for tracks at 45°, about 8 pixels should be hit on average for a 1 mm drift gap. At a grid voltage of -600V the Gossip detectors perform close to this, except Gossip-1 which suffered from 10% of masked pixels.

For grid voltages less negative than -610V the resolution in the drift direction was seriously deteriorated by time walk. Because of the long rise time of the preamplifier of the cells of the TimePix chip, the moment the discriminator fires depends largely on the magnitude of the charge signal. This effect is aggravated by the fact that a certain amount of charge over threshold has to be collected to let the discriminator fire. Because of the very broad distribution of the gas gain for a single electron, time walk is a big effect, especially for a low gas gain. The effect of this time walk can be seen in the drift time spectrum of the Gossip detectors. Since the ionization should be uniform over the whole drift gap, a square drift time spectrum between about 0 and 90 ns is expected for the applied drift field of 2 kV/cm. But at a less negative grid voltage, i.e. a low gas gain, the drift time spectrum extends to many hundreds of ns beyond the expected drift time domain (Fig. 10). At a more negative grid voltage, the majority of the charge signals cross the discrimination level largely and a reasonable square distribution is seen where most hits are arriving within 110 ns (Fig. 11).

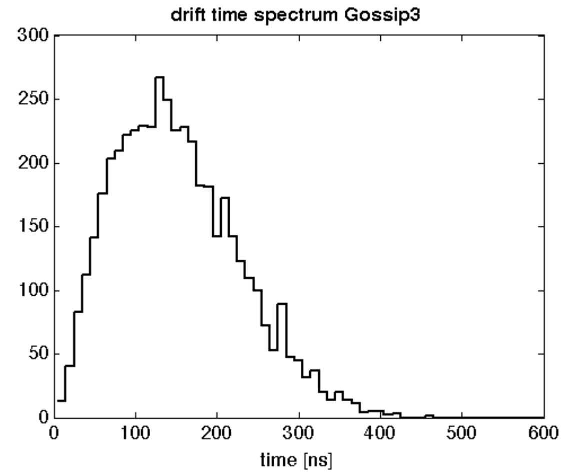


Fig.10. Gossip drift time spectrum for a grid voltage of -530V.

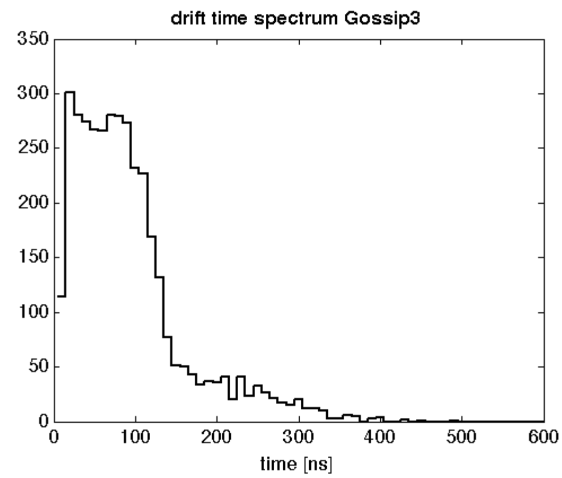


Fig.11. Gossip drift time spectrum for a grid voltage of -620V.

In future the poor timing properties of the present TimePix-1 chip will be greatly improved by the TimePix-2 chip that is presently under development. The improvement will be two-fold. At first a preamplifier with a much higher bandwidth will be used. And secondly the occurring time walk will be corrected by measuring both the moment the charge signal exceeds the threshold (time to threshold) and the width of the charge signal (time over threshold). A prototype chip, Gossipo3 [8] containing the required pixel circuitry already exists and is being tested at present. Simulations based on Gossipo3 specifications have been done to determine the gain in timing accuracy that can be obtained. For low gas gains (<5000) the timing accuracy can be improved from 30 ns to less than 5 ns. These results have to be verified with the measurements on the Gossipo3 chip.

### *C. Track detection efficiency*

To determine how often a track is detected by the Gossip detector, we used the GridPix as a reference. Tracks seen by the GridPix should also been seen by the three Gossips. Figure 12 shows the track efficiency as function of grid voltage.

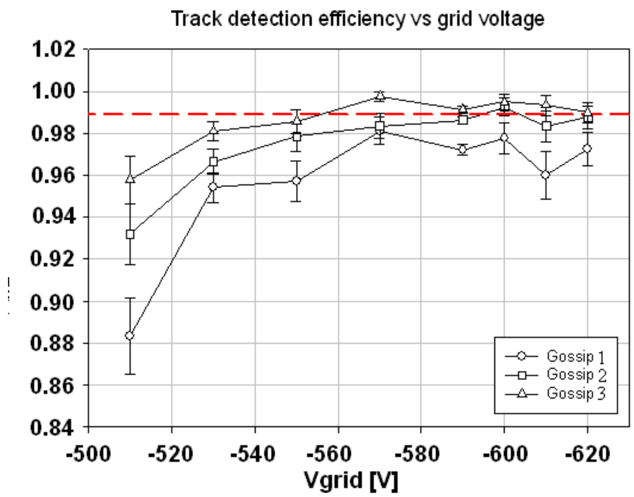


Fig.12. Track detection efficiency as function of grid voltage. The dashed line is the expected maximum efficiency according to simulations with Garfield for a detector with a 1 mm drift gap.

Two Gossip detectors meet the theoretical expectation of 98.9% while Gossip-1 having about 10% masked pixels reaches an efficiency of approximately 97%. Note that from -570 V on, the efficiency curves are really flat, indicating very good single electron efficiency. This is an indication that the permanent rise of the curve number of hit pixels per track (Fig. 9) is not caused by an increase of the single electron efficiency.

### *D. Position resolution*

Measurements to determine the resolution of the Gossip detector have been done for different angles, 0, 0.1, 0.2, 0.4 and 0.78 radians. At the moment only data analysis for the 0 radian has been done. For the analysis, a track has been fitted through Gossip-1, Gossip-3 and through the GridPix detector. Subsequently the residual of the distance between this line and Gossip-2 was determined. The distribution of these residuals is shown in Fig. 13. To reduce the error in the fitted line, Gossip-1 and Gossip-3 are required to have more than 2 pixels hit. The resulting residual is 15 µm. However, since the error in the line fit is still part of this residual, the final position resolution is expected to be slightly better. According simulations the position resolution should be 13 µm.

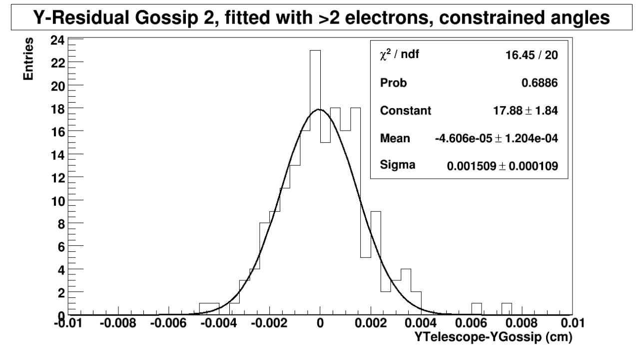


Fig.13. Residual spectrum in Y direction of the second Gossip in row with the track fitted through Gossip-1, Gossip-3 and the GridPix.

## IV. Conclusions

For adequate spark protection, defect-free SiRN layers are required. We found that an 8 µm thick SiRN is usually sufficient. The magnitude of the discharges strongly depends on the gas mixture that is being used. The spectrum of discharges is wide and gets still broader when reducing the thickness of the SiRN layer. The strongly quenching DME/$CO_2$ mixture appears to give the smallest discharges.

The first results from the Gossip test beam experiment at CERN show a good correspondence with the simulations for the efficiency and the position resolution. However, the timing properties of the used TimePix chip partly spoil the resolution in the drift direction by time walk. The presently developed TimePix-2 chip is expected to give a big improvement of this effect by using amplitude information.

## Acknowledgment

We thank J. Rövekamp for the mechanical support that was needed to build several GridPix detectors and P. Jansweijer for the electronic support on the read out of multiple GridPix detectors simultaneously.

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