Abstract

This note gives an overview of the current research activities for the micropattern GridPix and Gossip detectors. As such it is intended as a technical backup document for the ATLAS R&D Proposal (ATL-P-MN-0016) on GridPix/Gossip. In addition we present the new ideas we are developing or intend to develop.

The main advantages of GridPix/Gossip are treated: outlook for extremely high radiation tolerance and a very low material budget.

In addition we mention a number of applications for this technology: the ATLAS b-layer at the sLHC, an L1 trigger and TRT, a preshower tracker and a hadron calorimeter tracker.

We also treat the various technological steps that have to be taken: mechanical construction of the stave, services (powering, optical links).

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Disclaimer

This note is intended to serve as a technical backup document for the ATLAS R&D Proposal (ATL-P-MN-0016) on GridPix/Gossip [1]. It gives an overview of the results obtained until now on the current R&D activities on the gaseous pixel detectors GridPix and Gossip. In addition we present the new ideas we are developing or intend to develop.

As such this note is not intended as a detailed technical description of a possible GridPix or Gossip based system in ATLAS.
1 The principle of the gaseous pixel detectors GridPix

1.1 Introduction
GridPix is a gaseous pixel detector where the readout pixel chip is part of the process of particle detection. The functioning of GridPix is illustrated in fig. 1. In the gas filled drift volume above the Micromegas grid, electron-ion pairs are created along the track of a traversing particle. Due to the electric field, the electrons drift towards the Micromegas grid and are subsequently focused into the holes of the grid. The grid is put at -400 V with respect to the (grounded) readout pixel chip, creating a strong field in the 50 µm high avalanche gap. As a result, each single electron entering a hole of the grid causes an electron avalanche of sufficient magnitude to be detected by the pixel circuitry. By recording the arrival time of the avalanche charge signal, the original position in Z of the primary electron can be deduced: GridPix is a single-electron sensitive Time Projection Chamber (TPC). By combining the data of all participating electrons, a track segment can be reconstructed in space.

Fig. 1. Principle of GridPix/Gossip

The functioning of GridPix is illustrated in fig. 2 by a measurement of two low-energetic electrons in a GridPix detector using a TimePix chip [2] with a 30 mm high drift space. A fiducial readout surface of 14*14 mm² was populated with a matrix of 256*256 pixels having a square pixel pitch of 55 µm. The detector was placed in a magnetic field of 0.2 T with the field lines running parallel to the drift direction and filled with a He/isobutane mixture. In future we intend to apply mixtures with higher ionization and lower diffusion for MIP detection.

Fig. 2. Image from a GridPix detector: the electrons due to ionization by two β tracks from a 90Sr source

Two innovations have been essential for the technical realisation of GridPix: the protection
layer SiNProt to make the pixel chip discharge proof, and InGrid, the Integrated Micromegas and pixel chip, by means of MEMS technology, on top of pixel chips. Several applications for GridPix in ATLAS are treated in this report. Apart from that, GridPix could also be used in preshower detectors and particle-flow calorimetry at ILC/CLIC.

1.2 SiNProt

SiNProt is a high resistivity layer that is deposited on the surface of the pixel chip as a protection against spark discharges. This protection is essential since the operation of gas avalanche detectors is generally accompanied by micro discharges leading to a) evaporation of the surface structure of the chip due to the hot plasma of the discharge and b) a too large input charge damaging the pixel circuitry. Both risks can be eliminated by covering the pixel chip with a high-resistivity layer. At a spark discharge immediately a significant potential difference is created leading to a reduction of the electric (avalanche) field, thus quenching the discharge in an earlier stage. Note that this principle is already applied to quench the discharges in Resistive Plate Chambers (RPCs).

Initially we applied a 20 µm thick layer of amorphous silicon as a spark protection. Chips covered with this layer have operated flawlessly for weeks. Presently we apply silicon nitride (Si₃N₄) that has been made slightly conductive with a silicon dope. In this way the resistivity can be tuned between 10⁸ to 10¹⁵ Ω.cm. Due to its lower relative permittivity εᵣ (11, 5 respectively), a layer as thin as 7 µm has proven to be adequate. Unlike amorphous silicon, depositing Si₃N₄ is a common practise in thin film processing industry and research.

Note that in case the electronic input circuit is provided with an input protection where the excess charge is dumped into an input resistor, the thickness of the Si₃N₄ layer may be further reduced. This is the case for the designed Medipix-3 chip where a thickness of only 2 µm is expected to be sufficient.

Examples of recorded discharges are shown in fig. 3 and fig. 4. In fig. 3 the discharges were induced by particles from radon decay. Pixels in the discharge funnel are over-exposed, affecting the neighbouring cells by cross talk to the columns.

In case of fig. 4 the grid capacity had been reduced from 100 to 25 nF by applying a smaller decoupling capacitor. As a result, the discharge amplitude is reduced as well and the pixel circuitry is no longer over-exposed.
A cross section of a deposited Si$_3$N$_4$ layer is shown in fig. 5. In order to limit the chip temperature during deposition, the layer is applied in 5 steps of 2.4 μm. In the future it may be possible to reduce the layer thickness to 2.4 μm by including an input protection in the pixel frontend.

1.3 InGrid

InGrid is a Micromegas grid that is created on top of a substrate (usually a pixel chip) by means of photolithographic wafer post processing. With this technology the pillars can be made sufficiently narrow such that they do not create insensitive spots. In addition, this method provides a better control of the height of the amplification gap and enables low-cost mass production.

Equipped with SiNProt and InGrid, the pixel anode chip forms the monolithic active readout anode of the gas-filled drift volume.
As an additional protection against damage by discharges, we study the replacement of the aluminium InGrid by a high-resistive Si$_3$N$_4$ layer. Such a grid may actually make the SiNProt layer superfluous. We also consider the replacement of the present pillar material (SU8) by an insulating ceramic. This would result in an all-ceramic monolithic device that is capable to withstand high temperatures. An additional advantage would be the absence of outgassing, reducing the risk on (rapid) ageing (Ch 11.3).

1.4 TwinGrid

The duration of the (charge) signal in GridPix may be pretty long (20–50 ns) since it is given by the ionic drift from the (SiNProt) anode to the grid (see ch 10.2). To obtain a faster charge collection, we consider adding a second InGrid structure on top of the first one. Between both grids the potential difference is such that the avalanche develops itself mainly here and not above the anode. Most of the avalanche electrons will still be attracted by the holes in the bottom grid and subsequently reach the anode in a few ns. Because of the absence of ions directly above the anode, the duration of the charge signal is expected to be very short. First TwinGrids have been made (see fig. 7), their operation is under study.

![Fig. 7. Example of TwinGrid](image)

1.5 GOSSIP

Gossip (Gas On Slimmed Silicon Pixels) is a speciality of GridPix where the height of the drift gap has been minimized to enable extremely high rate applications. To achieve still a hit efficiency for MIPS of ~
99%, the gap height should be 1 – 1.2 mm, depending on the applied chamber gas. The drift time is limited to 25 ns, well suited to LHC pixel readout schemes. Because of this geometry, Gossip is functionally comparable to planar silicon pixel or strip track position detectors (fig. 8). In Gossip a pixel is virtually formed by the assembly of a short gas column in the drift gap, the associated hole in the Micromegas, and the input pad and preamp circuit of the pixel chip. With memory-per-pixel included, each pixel unit is a stand-alone detector, pushing the granularity of the detector to the maximum.

A functional prototype of Gossip is shown in fig. 9 using the CMS PSI-46 pixel chip. For this prototype a Micromegas foil was placed on top of the chip that was spark-protected by a layer of amorphous silicon. The unit was covered by a cap sealing the gas volume, and acting as drift cathode.

The functioning of three Gossips equipped with TimePix chips and a 1.0 mm high drift gap, is illustrated (fig. 10) by an event from a recent test beam experiment (CERN H8, 15 GeV π, 26 June 2009). The beam hit the Gossips at about 10º to the normal. A mixture of Ar/isobutane 80/20 was applied. After the three Gossips also a GridPix detector with a 20 mm high drift gap was placed under the same angle.

A preliminary analysis of this event shows that the detectors are operating quite well. Under the operating conditions on average 3.5 clusters are expected in the Gossips which is in agreement with the number of hit pixels. A few pixels show excessive drift times, possibly caused by large time slewing. By counting the number of hit pixels in the GridPix plot, one may deduce that the single electron efficiency for this event is better than 50%.
2 Comparing GridPix/Gossip to planar silicon detectors

Basically, the detecting medium of GridPix detectors is gas. Compared to solid-state detectors, gas has the advantage of a negligible mass of the detecting medium, but the disadvantage of too low primary ionization for direct detection. Therefore, the charge signal has to be enhanced by an avalanche process. Compared to solid state detectors, these properties result for GridPix/Gossip in the following advantages and disadvantages:

2.1 Advantages of GridPix/Gossip

- Gas is permanently exchanged or refreshed: therefore there is no radiation damage of sensor material; comparing the collected charge per unit of surface with ageing results for wire chambers, there is an outlook for extremely high radiation tolerance, exceeding the possibilities of solid state sensors [3];
- The magnitude of the (charge) signal is tuned by the grid voltage and may have the same magnitude of that of silicon or more;
- There is no bias or dark current through the detection medium;
- In gas $\varepsilon_r = 1$: therefore, and for geometrical reasons, the signal source capacity is as low as ~10 fF, allowing fast, low power and low noise preamps;
- Gossip measures in three dimensions the positions of all single electrons induced by a passing fast charged particle. A track segment is thus measured instead of hit point, and dE/dX information is obtained;
- The probability to generate confusing δ-rays is much smaller. In addition, δ-rays may be recognized, distinguished from primary track ionization, and rejected;
- Gossip has a low probability to detect (background) neutrons and X-rays;
- The technology to produce GridPix detectors is cheap. The detector consists of a CMOS chip on which SiNProt and InGrid are made using standard MEMS technology (no bump bonding). This results in a competitive price per cm$^2$;
- Gossip can operate in a wide temperature range from -100 to + 50 °C;
- The low electronic power dissipation, the absence of bias current, and the wide operational temperature range greatly reduce the demands on the cooling system. As a result the mass of the cooling system may be significantly diminished compared to a silicon tracker for high luminosity application, and integration of cooling and (stave) support is well possible.

2.2 Disadvantages & limitations of GridPix/Gossip:

- Discharges are possible between grid and pixel chip that may damage or destroy the pixel chip. This problem has been solved using an adequate protection layer;
- Risk of ageing by the deposition of polymer on the anode, leading to a (rate dependent) decrease of the gas gain. On the other hand, intrinsically the radiation tolerance of Gossip is much better than can be achieved with any of the presently known solid-state detector technologies. The subject of ageing is discussed in Ch 11;
- The track position resolution is limited by the minor amount of primary ionization, by diffusion of the drifting electrons, and by the pixel/strixxel size. Most tracks generate only a few primary electrons, consequently limiting the track position resolution;
• The data volume per track is a factor ~3 larger than for solid state detectors since 3D info of many individual electrons is registered;
• More services: two high voltage lines (grid + drift cathode) are needed instead of one, as well as two (thin) gas lines;
• The regulation of the grid voltage is critical.
• The charge collection time may be long, given by the sum of the maximum drift time and the duration of the charge signal itself. It will probably exceed one LHC bunch period.
3 Applications of GridPix/Gossip in ATLAS Upgrade

3.1 GridPix: active gas volumes: general concepts
For the ATLAS Upgrade, the GridPix technology can be applied at the following subdetectors:

- Pixel Vertex Tracker and B-layer: Gossip (GridPix with a short drift gap)
- Silicon strip tracker: Gossip as Strixel detector (see Ch 3.3)
- Outer Tracker/L1 trigger detector in the Inner Detector (see Ch 12.4)
- Transition Radiation Tracker using GridPix (see Ch 12.3)
- Pre-shower detector
- Hadron Calorimeter

The essence of GridPix is the registration in space of a track segment of a charged particle by measuring the individual ionization electrons. In principle the resolution of the measurement is only limited by the diffusion of the drifting electrons, the finite number of primary electrons and the inaccuracy in the drift time measurement due to the electronics slew rate. Of these, the inaccuracy of the drift time measurement is dominant. Therefore, the best results are obtained if the influence of the Z measurement on the final track position is small.

We may achieve this by orienting the detectors such that the drift path is almost parallel to high momentum tracks from the interaction point. For the ATLAS barrel we should tilt the detectors by the Lorentz angle (5–10º), enabling an overlapping geometry. For the ATLAS ID endcaps we have instead the advantage that the (solenoidal) magnetic field runs parallel to the drift path, reducing the transverse diffusion.

The thickness of the gas layer (which corresponds to the maximum drift length) is constrained by the allowed arrival time of the charge signal, the pixel occupancy, and the diffusion which worsening the spatial and time resolution.

3.2 Gossip for the Pixel Vertex Tracker and B-layer
Here we apply the minimal drift length of 1–1.2 mm and tilt the detectors to the Lorentz angle. For the gas mixture of the present working point (Ch 4.2) this amounts 9º. From this number and adding a second layer to enhance the position resolution and to improve the mechanical stability, we derive the configuration shown in fig. 11. For the R-φ plane the electrons in this ‘small turbine’ geometry drift about parallel to the direction of stiff radial tracks, leading to a minimal projected track length and thus to the best position resolution. For the pixel pitch we take 50*165 µm², a value that has been derived from the achievements of the Gossipo-2 prototype chip (analogue part, Ch 6.1) and the design of the digital part of the FE-I4 chip for silicon detectors.

Consequently, even non-time resolved pixel chips like FE-I4 [4] can be applied, providing a reasonable spatial resolution (see Ch 5.2).

Because of the minor power dissipation in the (gaseous) sensor (≤ 10 mW/cm² for the B-layer at the sLHC), the low power dissipation that is anticipated for the pixel chip (~ 0.2 W/cm²)
and the fact that Gossip can also function in room temperature, the CO$_2$ cooling can be integrated in the support stave. The temperature increase during bake-out of the beam tube causes probably the most severe boundary condition of the stave design.

Engineering studies where mainly carbon fibre composites and TPG construction materials (see Ch 7.1), CO$_2$ cooling, serial powering, optical communication (Iflink, see Ch 8.1) are included, result in a total radiation length of 1.25% $X_0$ for the configuration in fig. 11.

A simulation of the position resolution of Gossip at 55 µm square pixel pitch and 1.8 ns time resolution (Ch 5.5) gives a value of 13 µm (ignoring time slewing effects) which improves to 11 µm for a track fitted through several layers. Gossip is expected to cope with the maximum particle rate in the ATLAS sLHC B-layer (Ch 10.3).

3.3 **Gossip as short strip detector in the upgraded Atlas ID**

The Gossip technology may also be applied for larger pad sizes like at the proposed ATLAS detector for short strips where it will have comparable performance. The basic element of this detector is a large CMOS chip of 25*25 mm$^2$, containing 512 rows of strips that are n-fold subdivided. As a result we end up with a matrix of elements (“strixels”) of dimension 0.115*(25/n) mm$^2$. The support of the strixel detectors could follow the B-layer stave concept (Ch 7.1).

3.4 **GridPix tracker/L1 trigger and Transition Radiation Tracker**

![Fig. 12. Measured pion tracks (left) and electron tracks (right). The colour indicates the magnitude of the charge signal.](image)

At radii around 1000 mm, the GridPix detector with a drift gap of ~17 mm may provide fast L1 triggering data from the ATLAS Inner Detector by reconstructing short tracks in a few µs. In addition, by placing a radiator in front of GridPix, particle identification is possible by analysing the ionization clusters from γ quanta (see Ch 12).
An example of a measured pion and electron track in a test beam experiment are seen in fig. 12. The 5 GeV/c particles enter the GridPix detector under an angle of $25^\circ$. The detector is filled with a Xe/CO$_2$ mixture. A TR radiator was placed in front of the detector. At the electron tracks the three superimposed $\gamma$ quanta are clearly visible, enabling particle identification.

The GridPix tracker for L1 trigger and TRT is explained in detail in Ch 12.
4 Gossip working point

4.1 Overview
Determining the optimal working point for Gossip will be an extended process of optimization of the operational parameters that unfortunately are not independent of each other. But for the present experiments and simulations we have decided to use the following specifications:

1. Chamber gas: DME/CO₂ 50/50 at atmospheric pressure
2. Gas gain: 5,000 to 10,000
3. Drift velocity: 50 µm/ns
4. Geometric parameters
   a. height of the drift gap: 1.0 mm. This gives the following values for the selected gas:
      i. => average number of clusters in the gas gap: 4.5 (perpendicular incidence)
      ii. => average number of primary electrons in the gas gap: 12.5 (perpendicular incidence)
   b. height of the avalanche gap: 50 µm
   c. thickness of the protective SiN layer: 7 µm
5. Pixel chip parameters: using the characteristics of the Gossipo-2 prototype pixel chip. This involves amongst others:
   a. dimensions of the pixel cell: 50*165 µm²
   b. dimensions of the anode pad: 22*22 µm² (based on the Gossipo-4 design values)
   c. shaping time of the preamp: 25 ns
   d. input noise: 70 e⁻
   e. TDC least count: 1.73 ns

4.2 Chamber gas
Being the detecting medium, the choice of the chamber gas may be the most thorough. We want to have a gas that has the lowest diffusion, high drift velocity but a low Lorentz angle, high cluster density, stable HV operation, not being prone to rapid ageing (formation of polymers in the avalanche). And still the quenching properties should not be that extreme, preventing normal operation. As an example, using pure isobutane gives the highest cluster density (84/cm), permitting the shortest drift gap, but it is probably impossible to operate with an acceptable gas gain.

Based on previous experience with MSGCs we have chosen for the moment the DME/CO₂ 50/50 mixture at atmospheric pressure. This is called a very cool mixture having one of the lowest possible mobilities i.e. even for high drift fields the electron energy is still thermal. As a consequence, such mixture has a very low diffusion (~100 µm/√cm, both transversal and longitudinal). Since the mobility is practically constant even for high fields, an acceptable drift velocity (50 µm/ns) is still possible, but at a much higher field than normal (3 kV/cm). Also the grid voltage has to be set higher than usual to get an acceptable gain: around -600 V which requires better discharge protection.

The cluster density of this mixture is pretty high (45 clusters/cm), enabling a relatively thin drift gap. Note that the detection efficiency of a gaseous detector is not determined by the Poisson statistics on the total primary ionization but by the limited number of ionization clusters.
4.3 Gas gain

Two performance parameters are directly affected by the gas gain: efficiency and drift time resolution due to slewing. Since the charge signal spectrum of the avalanche from a single electron has a broad distribution starting at zero (Ch 10), we will always lose certain fraction of the single electron events. For a high signal over threshold value, i.e. a high gain, this loss will be minimal. Note also that most events are not single electron events. Slewing becomes dominant for charge signals that do not exceed much the threshold. But the slewing error can be reduced by a correction based on the measured time-over-threshold (ToT) or a second discriminator threshold. For the expected noise level of 70 e⁻ (Ch 6.1) we may set the threshold as low as 350 e⁻. Using a gas gain between 5,000 and 10,000 would reduce the fraction of lost events to practically zero while also slewing would be limited to a few ns. But it is possible that operational stability and ageing effects will put constraints on this number.

4.4 Drift velocity

To keep the charge collection time from the drift gap within one bunch crossing, we assume presently a drift velocity of 50 µm/ns. This brings us to a maximum charge collection from the drift gap of 20 ns. To get the total charge collection time, also the ionic drift time has to be added (Ch 10.2). It is desirable to increase the drift velocity, but this may be hard to achieve.

4.5 Geometric parameters

4.5.1 Height of the gas gap

For the gas mixture in 4.2 we would have at a gap height of 1.0 mm an ionization efficiency of 98.9%, so we believe that this height is an acceptable compromise between detector efficiency and charge collection time.

4.5.2 Height of the avalanche gap

Following the outcome of a study [5] on the optimal avalanche gap, we keep the gap height on the presently used value of 50 µm.

4.6 Pixel chip parameters

Here we base ourselves on the existing Gossipo-2 pixel chip in 130 nm technology. With this chip the following parameter values have been realized (see Ch 6.1):

4.6.1 Dimensions of the pixel cell

50 x 165 µm². Based on the dimensions of the analogue part of the Gossipo-2 pixels and the design of the digital part of the FE-I4 chip for silicon pixel detectors.

4.6.2 Frontend shaping time

25 ns, a compromise between the demand for a response within one bunch crossing and a low noise level.

4.6.3 Input noise

70 e⁻, a value realized for the Gossipo-2 chip. Note that there is practical no influence of the detecting medium to the input noise (no bias current, no additional input capacity).

4.6.4 TDC least count

1.73 ns, a reasonable compromise between a practical number of TDC counter bits (4) and the required TDC range (one bunch crossing of 25 ns), see Ch 5.5.
5 Simulation Gossip position resolution

5.1 Introduction
Using the available software tools, the functioning of a Gossip detector was simulated for the Gossip working point (see Ch 4) and the following, partly derived, parameter values. The simulation was done in GARFIELD using the values for the cluster density and the total ionization from HEED and MAGBOLTZ to calculate the drift velocity and diffusion. The electrical field was calculated in GARFIELD for the following potentials:

- Drift voltage -700 V
- Grid voltage -400 V
- Pixel chip voltage 0 V

These values led for the applied CO₂/DME 50/50 mixture to the following numbers from MAGBOLTZ:

- Diffusion 98.5 µm/√cm (longitudinal), 114.5 µm/√cm (transversal)
- Drift velocity 55.6 µm/ns

For the simulation three parameters were varied to determine their influence on the position resolution:

- Pixel dimensions
- Resolution of the drift time measurement
- Angle φ of the track to the normal to the pixel chip.

For each parameter set the simulation in GARFIELD was done for 1000 muon tracks of 10 GeV/c. For Gossip we took a drift gap of 1 mm high. Fig. 13 shows the definition of the used nate system.

To calculate the ionization along the track, certain probability was assumed for the traversing particle to liberate an electron from a gas molecule. We indicate these primary electrons as clusters. A small fraction of them have sufficient energy to liberate additional (secondary) electrons, sometimes they even can induce a short and dense track (δ electron). For the present simulation we did include off-track effects due to the photon interaction between charged particles. But at this stage we omitted ionization by fluorescence and Auger effects. Time slewing was discarded as such, but its ef-

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Fig. 13. Coordinate system and nomenclature of track parameters. The X-Y coordinate \((X_0, Y_0)\) is given by the crossing point of the fitted track with the reference plane.
fect can be estimated from simulations using different least counts for the time measurement. Events ing only one ionization electron (~5%) were discarded since they do not allow a track fit in a single Gossip detector. However, they can still be used for track fitting through multiple Gossip layers.

Note that track reconstruction using a single crossing is a special feature of the Gossip concept that is not present for other high rate detector technologies.

5.2 Calculating spatial resolution

To calculate the spatial resolution, we follow all electrons, primary and secondary, that are liberated by a muon track generated by GARFIELD. Ideally, electron $e_i$ would arrive, after its drift time $T_i$, in point $(X_i, Y_i)$ (see fig. 13). However, this 3D coordinate is deteriorated by transversal and longitudinal diffusion and by the development of the avalanche. In addition the finite digitization of the electronics adds to this inaccuracy. As a result the 3D position of electron $e_i$ is reconstructed as $T_{ni}, X_{ni}, Y_{ni}$.

Subsequently, in an analysis routine a straight line was fitted through these space points. The fitted line is parameterized by the crossing point with the X-Y plane and the angles $\phi$ and $\theta$. For the fit the weight of points $T_{ni}, X_{ni}, Y_{ni}$ is inversely proportional to the square of the assumed residuals of the measured space points. These residuals are build up by contributions from diffusion of the electrons in the gas, the finite pixel size, the scattering of the initial electron-ion pairs from the track and the least count of the time measurements.

To calculate the XY position resolution we use the crossing point $(X_0, Y_0)$ of the fitted line with a reference plane above the pixel chip. The fitted line traverses the reference plane under angle $\phi_0$ to the normal; the projection of the track on the reference plane has an angle $\theta_0$ to the X-axis (fig. 13). The position resolution is derived from the crossing point with the reference plane to minimize the contribution of the angular error of the track fit (lever arm effect). Naively one would expect the optimal reference plane to be halfway between the pixel chip and the cathode plane, i.e. 500 µm above the pixel chip. But it is a bit closer to the pixel chip because of two effects: 1.) the lesser weight of hits with a big drift distance and 2.) the occupation of pixel cells by an earlier hit form the same track (see Ch 5.4).

Fig. 14 shows that the optimal height of the reference plane is 300 µm for perpendicular incidence where the shielding effect is biggest, while for 45° the optimal height is close to 500 µm. The last result indicates that the weight factor does not play an important role for a time accuracy of 2.0 ns. But other simulations show that for a smaller time least count the weight factor becomes more significant, causing the height of the reference plane to approach 300 µm.

For the simulations in this chapter we kept the height of the reference plane to 300 µm.
5.3 Simulation results
An example of the residuals of the measured crossing points with the reference plane is shown in fig. 15. For these plots, tracks were generated with a random crossing point (X,Y) with the reference plane but with a fixed angle of incidence $\phi_0 = 0.79$ rad ($45^\circ$) and $\theta_0 = 0$. To trace a possible asymmetry and to get an impression of the physical limits imposed by diffusion and the small number of ionization electrons, we took for the pixel chip ideal but unrealistic parameters like 1 $\mu$m pixel pitch and 0.1 ns time resolution. The distributions are symmetric around zero, indicating that possible systematic effects are small. At the tails the distributions exceed the fitted Gaussians because of $\delta$ tracks. For a tracker with at least three Gossip layers these tails may be eliminated in off-line analysis.

Fig. 15. Simulated residual histograms of X-X$\phi_0$ and Y-Y$\phi_0$ respectively for tracks tilted in X direction ($\phi_0 = 45^\circ$ and $\theta_0 = 0$) and a pixel pitch of 1 $\mu$m. Gossip was operated at the standard working point (see Ch 4). The width of the Gaussian fit through the residuals is 6.8 $\mu$m in X and 4.4 $\mu$m in Y.

5.4 Spatial resolution as a function of $\phi$
While for the simulation results in fig. 15 a non-realistic pixel pitch had been used, the study was repeated for bigger pitches as well. Fig. 16 shows the angular dependence of the spatial resolution in X for various square pitches until 55 $\mu$m. Note that the value of 55 $\mu$m has been actually realized with the Gossipo-2 chip.

The outcome of the simulation in fig. 16 shows that for a realistic pixel pitch a resolution of 13 $\mu$m can be obtained. The plotted numbers for the resolution are obtained from a Gaussian fit through the residual distribution, discarding the non-Gaussian tails. For the simulation the time resolution was set at the (non-realistic) value of 0.1 ns.

Fig. 16. The spatial resolution $X - X_\phi$ vs angle of incidence $\phi$ for different (square) pixel pitches, assuming a perfect time measurement.
If more than one electron is collected almost simultaneously by the same pixel, only the first one will be detected. Therefore, for skewed tracks where more electrons are hit, the statistics of the fit are improved and thus the resolution. This effect is shown in fig. 17 where the detection probability of an individual ionization electron is plotted versus the angle of incidence for different pixel dimensions. The figure shows that for a 55 µm pixel pitch and a perpendicular angle of incidence, only one third of the ionization electrons is actually registered. For 45º this number is doubled, explaining the improvement of the position resolution for angles bigger than 0.4 rad (fig. 16).

5.5 **Spatial resolution as a function of the least count for time registration**

Instead of the negligible time least count of 0.1 ns, we also investigated more realistic values. Fig. 18 shows that for small angles the position resolution of a Gossip with 55 µm pixels is independent on the bin width while there is a limited effect for angles larger than 20º. Note that in practice the accuracy of the time measurement will never be better than a few ns because of time slewing or other electronic effects.

![Fig. 17. The probability p for an individual primary electron to give the first hit to a pixel](image)

![Fig. 18. Position resolution vs angle of incidence φ for different time measuring least counts.](image)
5.6 Position resolution for fitted tracks in a Gossip multilayer tracker

The position resolution of Gossip is slightly improved after track fitting through multiple Gossip layers. Since now the angle of incidence is well constrained, redoing the fit for a given track angle eliminates the effect from the angular error. The results in fig. 19 for a pitch of 55 µm are about 2 µm better than the results of the non-constrained fit in fig. 16. Note that this procedure is generally followed by other high rate detector technologies where track fit cannot be made from a single detector crossing.

![Fig. 19. Position resolution X – X₀ vs angle of incidence φ. For the fit the angle of incidence is fixed in φ and θ.](image1)

5.7 Using pixel chip FE-I4 (no time information)

We also investigated the special case where the pixel chip does not provide any time information like the planned FE-I4 [4]. This chip, exclusively developed for planar silicon detectors, has larger pixel pads (50 µm in X, 250 µm in Y). The only time information is given by the 40 MHz bunch crossings. Since in this case no track fit can be done on a single detector crossing, the angles of incidence φ and θ were fixed during the fitting procedure.

![Fig. 20. The spatial resolution vs the angle of incidence φ using the FE-I4 chip.](image2)

Fig. 20 shows that for φ not exceeding 0.1 rad a position accuracy of 16 - 18 µm can be obtained. So for small angles a Gossip B-layer detector could be made using pixel chips designed for a silicon sensor like the FE-I4 chip, where literally the Si layer is replaced by a gas layer.
6 Electronics: pixel chip developments

6.1 The Gossipo-2 chip

The requirements for a pixel chip for Gossip differ from those for pixel chips for silicon sensors in a high luminosity environment. This applies for the maximum input current that is only given by the charge signal (0.5 nA per pixel for the sLHC B-layer), eliminating the need for an input current compensating circuit. In addition the source capacity seen at the pixel input pad is only 10 fF. These characteristics enable a low noise and low power preamp with a small pixel surface as has been demonstrated by the Gossipo-1 chip.

To measure the Z coordinate of a primary electron a TDC is required to measure the arrival time of the charge signal. This feature was implemented first at the TimePix chip [2] that has been based on the Medipix-2 chip. Here the TDC is made by counting clock pulses instead of X-ray induced pulses. The counter is started by a charge signal on a counting rate of up to 100 MHz until a shutter cycle generates a common stop for all pixels.

Fig. 21. The Gossipo-2 chip: functional diagram and layout drawing

In the design of the Gossipo-2 chip (fig. 21), the counting rate has been brought to the desired level of 640 MHz. Using a 4-bit counter, the phase of the charge signal relative to the LHC bunch period is registered. A second 4-bit counter registers the number of LHC bunch periods to the readout. Implemented in 130 nm technology, the pixel cell of the Gossipo-2 could be made as small as 55*55 µm. The pad surface is 22*22 µm². Differences between the threshold settings of the different pixels can be corrected for by a 4 bit DAC that is incorporated at each pixel.

Gossipo-2 has been realized in a multi project wafer run. During testing the following performance has been measured:
- Power consumption per pixel 1.5 µW
- Rise time ~15 ns
- Fall time (adjustable) 50-3000 ns
- Charge gain 85 mV/ke
- Parasitic input capacity 30 fF
- Input noise 70 ENC
- Minimal threshold 350 e−
- Intended least count of threshold ADC 80 e−
- Frequency internal oscillator 640 MHz

We observed problems with the threshold setting for a fraction (10–15%) of the pixel cells. A too large offset of the threshold prevented proper operation of these cells.

6.2 **Gossipo-2 tracker**

Since the Gossipo-2 chip basically has the intended performance for a Gossip detector, in spite of the minor sensitive area (0.88 x 0.88 mm²), we started constructing a Gossip detector based on this chip. With four of these detectors a tracker will be made for a test beam experiment to measure the position resolution of Gossip.

![Cross section of the Gossipo-2 detector in development using the Gossipo-2 chip](image)

*Fig. 22. Cross section of the Gossipo-2 detector in development using the Gossipo-2 chip*

*Fig. 22* shows the designed Gossipo-2 detector where the chip that is mounted on a chip package, is provided with a SiNProt layer and an InGrid. 1.2 mm above the chip a cathode foil is added that is supported by a frame with gas inlet and outlet. Since the drift distance is larger than the dimensions of the sensitive area, the drift field would fan out from the chip on. Therefore, a field shaping foil (red) has been added to provide a homogeneous and linear drift field.

6.3 **Overcharge protection**

To make the pixel chip more robust, we will possibly equip the frontend with a dissipation circuit for dumping the superfluous electric energy in case of a spark discharge. Such a circuit has already been designed for the MediPix-3 chip. According to a thermal finite-element simulation of the p-n junction, that circuit should survive input charges of up to 10 pC. If the Gossipo chip were equipped with such a protec-
tion, the thickness of the SiNProt (see 1.2) layer could be made thinner, reducing the cross talk between the pixels.

6.4 **Gossipo-3 and 4 development**

We are developing Gossipo-3 as a small MPW chip to test a new version of the preamp. Thereafter, Gossipo-4, an enlarged version of Gossipo-2 will be produced having a 32*32 pixel matrix. Compared to the Gossipo-2, major improvements will be implemented:

- 32*32 pixel matrix, size 60 µm square, total dimension 1.92 mm square
- Time measurement by fast counter (4-bit) and by latency counter (12 bit), giving a total time span of 102 µs with 1.73 ns resolution
- Also operation possible in 24 bit counting mode
- Common fine tuning of fast oscillator using a 4 bit DAC
- Charge amplitude measurement by time over threshold (ToT) with 200 e⁻ resolution over a range of 28,000 e⁻
- Monitor output for InGrid charge signal and analogue pixel signal
- Improved frontend feedback, avoiding out-of-range pixels

The design is expected to be finished (tape-out) by the end of 2009.

In addition, on a longer term the TimePix-2 chip is being developed by the CERN/MediPix collaboration [2].

![Fig. 23. Block diagram of a pixel of Gossipo-4](image)

6.5 **Possible future chip developments**

MC simulations (see Ch 5.6) have shown that at present the position resolution of Gossip is for a big deal limited by the finite pixel dimensions and time accuracy. For ideal frontend electronics, i.e. an negligible pixel size and a sub ns time resolution, simulation gives an accuracy of 10 µm (fig. 16) while for the realistic values of 55 µm pixel size in Y direction and 2 ns time accuracy, the resolution is more than doubled to 20 – 25 µm (fig. 18). These numbers indicate that it is worthwhile to reduce the pixel size in future and to improve the time accuracy. Note that especially slewing may heavily contribute to the time resolution. At the test beam example (fig. 10) the drift time of a number of pixels was hundreds of ns off, probably
from slewing at small charge signals. Increasing the gas gain will reduce the fraction of these badly timed hits, but only using a double threshold may bring this error back to an acceptable value.

Another problem is the increased data volume of Gossip/GridPix compared to solid state detectors since many electrons give individual hits. For Gossip having a limited number of hit pixels per track (~5) one has two options: 1) adding intelligence on frontend level using hits from neighbouring pixels at the cost of an increased pixel size (50*~165 µm²) or 2) accepting a greatly increased datastream at the benefit of reduced pixel dimensions and thus an improved position resolution. Note that for a pixel chip with a lot of local intelligence the digital power dominates at the sLHC B-layer.

In case of using GridPix as a L1 trigger, a completely different pixel chip has to be designed. This chip should have local intelligence based on challenging inter-neighbour pixel communication for rapid track fitting, using data from clusters of ~50 hit pixels across many bunch crossings.
7 Stave engineering, services, cooling and detector mass

7.1 Stave engineering
The special properties of Gossip/GridPix bring, compared to planar silicon sensors, a lot of advantages in engineering the support and services like operating in a large temperature range including room temperature while the preamp power is very low. Using the new technology of CO₂ cooling, serial powering and optical data connections, a double Gossip stave would have a relative radiation length of 1.25% as will be set out below.

The elementary mechanical model of Gossip is shown in fig. 24. A Gas/Cathode ‘GasCat’ frame that defines the gas volume and supports the cathode foil is mounted on top of the slimmed pixel chip. The cathode foil is not drawn. The wire bonding pads are located in the external part of the pixel chip (left). The gas holes are made in two oppositional (mould injected) edges of the cathode frame. On the stave the gas connections are serialized from one Gossip to another. Since the gas volume of a single Gossip is very small (~ 0.25 ml), thin (0.8 mm outer diameter) gas tubing may be used.

The actual configuration of a barrel from Gossip staves depends on the accuracy time resolution that can be achieved. For a pixel chip that does not provide proper time information, the best position resolution is obtained if the ionization electrons drift parallel to the track, i.e. the angle of incidence of the track should be about the Lorentz angle. This configuration is shown in fig. 25 (left). But in case there is time information available with an accuracy of 2 ns or better (see Ch 5.5), we basically have the freedom to alter the angle of incidence and configurations like fig. 25 (right) become possible where a track passes several Gossips.

Fig. 24. Mechanical model of Gossip consisting of the Si pixel chip slimmed to 50 µm thickness and the GasCat cathode frame with the gas connections.

Fig. 25. Left: a layer of Gossip detectors with the angle of incidence equal (+/-0.1 rad) to the Lorentz angle for stiff tracks. Right: in case of sufficient time resolution, the spatial (4D!) resolution of Gossip is independent of the incident track angle, allowing a larger range (+/-0.8 rad) of the angle of incidence.
To improve the mechanical stiffness with a minimum amount of material, the stave may be better constructed as a dual-row stave from two layers of Gossip like is shown in fig. 26.

Fig. 26. Cross section of a ‘dual-detector row’ stave. The fibres of the PG are oriented from the cooling pipe to the detector plane for best heat conductivity.

Here we presume a stave length of 800 mm, covered with two rows of 48 Gossips (fiducial surface 2 cm²). If we further assume a heat dissipation of 0.1 W/cm² per chip, then the total heat-load of the stave would be 20 W, omitting the heat load from the power regulation and the optical link. To get rid of this heat, the chips are directly glued onto a 100 µm thick layer Thermal Pyrolitic Graphite (TPG). The heat from this layer is transferred through a block of Pyrolitic Graphite (PG) to a 1 mm diameter Pyrex tube connected to the CO₂ cooling system. Note that the silicon chips also contribute to the stiffness. The sag depends on the angular orientation but is 0.3 mm at most. Because of the symmetric heat load there is in principle no additional sag during operation.

18 of these dual-row staves may form the barrel of the ATLAS B-layer at the sLHC (see fig. 27).

Fig. 27. Assembling the dual-row staves to a B-layer barrel (R = 37 mm) for the ATLAS sLHC

Thermally, the temperature differences on the chip are limited to 2 ºC, while the difference between the CO₂ temperature and the temperature of the core surface in the PG does not exceed 0.5 ºC.
Evaluation of the mechanical composition of the dual-row stave leads to the following numbers for the relative radiation length $X/X_0$.

<table>
<thead>
<tr>
<th>Element</th>
<th>Number of elements in a stave</th>
<th>$X/X_0$ per element (%)</th>
<th>$X/X_0$ total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 µm thick pixel chips</td>
<td>2</td>
<td>0.053</td>
<td>0.106</td>
</tr>
<tr>
<td>Cathode frame</td>
<td>2</td>
<td>0.083</td>
<td>0.166</td>
</tr>
<tr>
<td>TPG layer</td>
<td>2</td>
<td>0.048</td>
<td>0.096</td>
</tr>
<tr>
<td>PG body</td>
<td>1</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Glass cooling tube</td>
<td>1</td>
<td>0.83</td>
<td>0.083</td>
</tr>
<tr>
<td>Carbon fibre composite</td>
<td>3</td>
<td>0.1</td>
<td>0.3</td>
</tr>
<tr>
<td><strong>Total $X/X_0$ for dual-row stave</strong></td>
<td></td>
<td></td>
<td>1.251</td>
</tr>
</tbody>
</table>

*Fig. 28. Simplified 3D view of the B-layer barrel from dual-row staves.*

Because of the low material budget, the Gossip concept can also be applied at larger radii for strixels. In this case one could widen the dual-row stave by spokes that keep the rows at larger distance. The result is a stiff tracker at two different radii (*fig. 29*).
Fig. 29. Dual-stave concept at a larger radius (strixel region). The spokes connecting the staves greatly enhance the stiffness of the assembly.
8 Services

8.1 Optical links: IfLink
The presently used system based on a VCSEL-silicon photodiode link cannot be used for ATLAS B-layer because of the limited radiation tolerance [6]. However, the material needed for data transmission by a Kapton-copper or a Kapton-aluminium bus to the optical transmitters and receivers at patch panel PP0 would be dominant in the total mass of the detector. Therefore we are studying optical data transmission based on thermally graded quartz fibre that is intrinsically rad-hard.

In IfLink [7], the optical communication is done using the Pockels effect. Here the permittivity $\varepsilon_r$ of the medium is changed by an electric field perpendicular to the direction of the traversing light. In the low radiation level service area a monochromatic light source is placed that is coupled to a (single mode) optical fibre.

In the hot radiation area of the Gossip tracker the light passes a small Pockels modulator that is driven by the data steam, and returned to a Mach-Zehnder interferometer (MZI) comparing it with the incoming light. A feedback system keeps the MZI at a dark fringe. The outcoming modulated light signal is transferred to a photo-diode. The same fibre can be used by placing a mirror near the modulator for the return light as shown in fig. 30.

Note that basically the frequency of the (laser) light source must be very stable: the permitted variation is inversely proportional to the transmission length. This constraint can be avoided by using a “twisted pair” of fibres with opposite modulation from one to another. Since the dark-fringe feedback system at the MZI keep the light paths constant, the phase difference is now independent of the frequency of the light source. As a modulator Lithium Niobate crystals may be used [8] as well as a thermally poled electro optic active fibre.

8.2 Powering

8.2.1 Powering concepts
For Gossip using 130 nm or lower electronics technology, the supply voltage is low (~1.2V) while the supply current is relatively high (5A at both ends of a stave). For conventional powering this involves conductor cross sections running from almost zero in the stave centre to 10 mm$^2$ at both ends of the stave, increasing X/Xo by 0.6% for a dual-stave assembly. This drawback makes a system of many Gossips unattractive for direct power supply from a remote (~100 m) unit. Therefore, either serial powering or parallel powering using DC-DC converters is considered. Serial powering could be included in a connection for ‘Data In’ and ‘40 MHz Sync’, in the form of a kapton-copper flex structure. The contribution to the detector mass would be negligible.
8.2.2 Light Powering

The metal power conductors can be completely eliminated if the electrical power is optically administered. This would be possible by powering via optical fibres, avoiding drawbacks of not having a common ground (serial powering) or switching noise (DC-DC converters). Presently solar panels from micro-diodes achieve 50% energy efficiency, so a luminous power of 0.5 W would be sufficient to power a single Gossip pixel chip (0.2 W @ 1.2V). The limiting requirement, being the allowed temperature of the micro-diodes, could be fulfilled by immersion into the nearby present liquid CO₂. But the problem of radiation hardness of such a device has not yet been solved.

8.3 µHV

Further reduction of the amount of external electrical wires to the Gossip detector would be achieved by using a local miniaturized HV supply for the grid voltage (-500 V @ 10 µA) and the cathode voltage (-1000 V @ < 1 µA). Because of the limited electrical power (5 mW), the dimensions of such device may be pretty small. Commercially available supplies are not sufficient rad hard, apply mostly a lot of material and often cannot operate in a magnetic field. In addition they can deliver much more current, making them bulky while the trip level isn’t sensitive enough.

Presently Nikhef is developing a micro HV supply for use on a Gossip stave aiming for the following specifications:

- dimensions ≤ 2 cm² PCB surface
- maximum output power 5 mW
- small idle power (few mW)
- ranging from -200 to -1000 V
- radiation hardness until 10⁷ Gy (1000 Mrad)
- minimal noise emittance
- stabilized output voltage, low ripple
- high resolution current measurement in the output HV line (≤ 1 nA least count)
- resolution trip level setting in the few nA region
- external communication via CAN, JTAG, USB, ......

To generate the HV, we plan to make use of the Cockroft-Walton principle from 50V supply voltage (fig. 31).

In the first phase of the project we intend to use communication via a PCI bus. The dimensions of the prototype will be about 4*5 cm². The current in the HV line is measured as the voltage drop across a resistor, digitized and coupled to ground level by inductive DC-DC converters. Note that the power supplies from this phase are already very interesting for application in the laboratory for prototype testing. More information is seen at [9].

![Fig. 31. Intended Cockroft-Walton circuit](image-url)
9 Integrated dose and particle rates at the sLHC

9.1 Dose and rate requirements for the ATLAS B-layer at the sLHC
To calculate the total radioactive dose that is deposited in a detector in the ATLAS B-layer [10], we assume a total p-p cross section of 79 mb. Assuming an integrated luminosity of 3000 fb⁻¹, a safety factor of 2, and 6.3 tracks/η per interaction, we end up with a fluence of 3*10^{17} tracks/η which is dominated by pions. At R = 37 mm this results into a MIP dose of 3.4*10^{16}/cm². For 1 MeV neutrons this translates into 2.0*10^{16} n_{eq}/cm², assuming a pion damage factor of 0.6. For silicon this corresponds to a dose of 9.5 *10^6 Gy.

The same consideration brings us to an assumed MIP rate of 0.9 GHz/cm².

9.2 Required performance for Gossip at the ATLAS B-layer at the sLHC
To convert the dose and rate values of the B-layer to the operating demands of Gossip, we use the present Gossip working point in this report (Ch 4) using a DME/CO₂ 50/50 mixture:

• Ionization density 126 electron/ion pairs/cm track
• Cluster density 45 /cm
• Size of metal pixel pickup pad 20*20 µm
• Gas gain: 5000

From these assumptions and using the values for the rate and the radiation dose in Ch 9.1 we may derive other operating parameters of Gossip at the B-layer at the sLHC:

• Theoretical maximum of the efficiency: 98.9% (detected tracks per layer)
• Ionization for perpendicular angle of incidence: 12.6 electron/ion pairs
• Rate per pixel: 27 kHz
• Occupancy for 50 ns dead time: 2.7 % (assuming all primary electrons give an individual hit and that multi-hit electronics is used)
• Averaged charge signal current density: 9.0 µA/cm²
• Sensor induced heat: 5.4 mW/cm² (exclusively from the signal current)
• Averaged charge signal current per pixel: 274 pA
• Accumulated charge: 243 C/cm²

9.3 SiNProt resistivity

• Resistivity of the SiNProt layer. We use the density of the charge signal current and a layer thickness of 7 µm. We further permit a voltage drop of 10 V across the SiNProt layer. These assumptions lead us to a maximum permissible bulk resistivity of 1.6*10^9 Ω.cm.

• Pixel-to-pixel resistance. From the bulk resistivity of the SiNProt layer and using the pixel dimensions in Ch 9.2, we get an approximated pixel to pixel resistance of 1.4*10^{12} Ω. For a single pixel to all its neighbours we get accordingly 2.4*10^{11} Ω. Note that this value does not significantly contribute to the cross talk between neighbours, this mainly occurs by parasitic capacitive coupling.
10 Signal development and rate limitation

10.1 Single electron charge signal distribution
Especially for inclined tracks through GridPix/Gossip, a large fraction of the pixel hits originate of a single ionization electron. Especially for these events the efficiency is largely determined by the shape of the charge signal spectrum that extends until zero. For single electron events several investigators have shown that basically the gas amplification spectrum should have the shape of an exponential decay. However, in cases where the collision history of the drifting electrons starts to play a role, i.e. when the probability on a non-elastic collision is not very small, the distribution of the gas amplification of a single electron in a high amplification field is better described by the Pólya distribution:

\[ P(x) = \frac{m^n}{\Gamma(m)} x^{m-1} e^{-mx} \]

where \( x \) is the value of the resulting charge signal and \( m \) is the Pólya distribution factor (pdf), \( m \) being a number \( \geq 1 \) with a value depending on the applied counter gas, the electric field in the amplification region and the electrode geometry.

The charge signal distribution for different Pólya factors is shown in fig. 32. From cluster density measurements and tracking tests at Nikhef we mostly found values for pdf between 2 and 3 [11].

![Single electron charge signal distribution for different Polya Distribution Factors (pdf)](image)

Fig. 32. Single electron charge signal distribution for three values of pdf.

10.2 The time structure of the charge signal from Gossip
Basically collecting the electrons from the avalanche between the amplification grid and the pixel chip is a very fast process that proceeds in less than 1 ns. However, initially most of the charge signal is trapped by the positive ionic counter charge in the gas that is created during the avalanche. The full charge signal gradually becomes available during collection of the positive ions by the grid. Although this process proceeds much faster than for most other gaseous detectors, ion collection is still a limiting factor in the charge collection speed.
Fig. 33 shows a calculation of the ionic drift in the amplification gap. After 1 ns the electron avalanche has just been finished, the electrons being all collected by the anode, while a cloud of ions still remains with the highest density at about 5 µm from the anode.

During the drift process of the ions towards the grid, gradually the counter charge spreads over more pixels while even so the ions at the start of the avalanche are collected by the grid. The resulting time structure of the charge signal consists of a delta peak containing about 12% of the total charge signal from the avalanche electrons that are created within one free path to the anode followed by a tail carrying the majority of the charge. The charge signal lasts until the full ionic charge is collected by the grid (see fig. 34).

The shape of the time structure function was calculated by simply assuming parallel-plate geometry with infinite size electrodes. In practise, with a limited size anode pad, part of the avalanche charge will gradually be induced onto the neighbouring pads as the ionic cloud drifts further away from the pixel pad, leading to a faster decay of the current than depicted in the figure.

The duration of the anode current signal is thus determined by the drift velocity of the ions in the amplification gap. For electronic drift there is a wealth of measurements on drift velocity in most commonly used drift chamber gases, while there are reliable simulations tools as well. But the ionic drift velocity is less frequently investigated while theoretically derived expressions suffer from an unknown effect from charge transfer.
Fig. 35 depicts an overview by Ellis at al. from literature [12] and [13] of the drift velocity of various ions in helium, neon and argon. If we assume that the ionic mobility will not depend on the electric field, then we can extrapolate the drift velocities measured at lower fields to the applied field of ~100 kV/cm.

Extrapolating the fit through the argon measurements (red dashed line) gives a drift velocity of about 2.5 \( \mu \text{m/ns} \) at this field. Therefore at least for the argon based mixtures one may hope to complete the ion collection after 25 ns across the 50 \( \mu \text{m} \) high amplification gap. Helium and neon based mixtures are even considerably faster but are less attractive because of a low cluster density. The drift velocity of ions in krypton and xenon (not plotted here) is a bit lower. However, for the selected DME/CO2 mixture the ionic drift velocity is hard to predict. We do not plan to build a dedicated setup for this but will study this empirically by recording the shape of the analogue preamp signal for single electron events and compare this with test pulses with various widths.

Note that although the charge signal from a single electron shows a wide distribution in the magnitude of the charge signal, the duration of all signals will be all quite alike. The broad variation of the charge is merely caused by Poisson statistics in the first steps of the avalanche which hardly contribute to the final signal.

10.3 Rate limitation of Gossip

In principle the MIP rate of Gossip may be limited by five different physical effects:

10.3.1 Occupancy per pixel

We have seen that the charge collection time amounts \(~25\) ns due to the ionic drift in the amplification gap plus 0–20 ns electronic drift time in the drift gap. Naively one would thus expect that as soon as the avalanche is created and ionic charge is collected by the grid (i.e. about \(10+25 = 35\) ns), the pixel cell is ready to accept a new single electron event. This assumption would thus give for the B-layer rate of 27 kHz per pixel (Ch 9.2) an occupancy of about 1 \%, neglecting dead time of the DAQ.
10.3.2 Rate effects due to ionic drift in the avalanche gap

Due to drifting avalanche ions, the electric field in the avalanche gap will be affected. Assuming an ion crossing time of 40 ns and a current density of 9.0 µA/cm² (Ch 9.2), a charge of 0.36*10⁻¹² C/cm² is present in the 50 µm high avalanche gap. This results in a change of 2 V/cm on the avalanche field of about 100 kV/cm which may be neglected.

10.3.3 Ionic space charge in the drift volume

Chefdeville [14] has shown that, depending on electrode geometry and drift field, about 1% of the avalanche ions is not collected by the grid but enters the drift space. Assuming a drift field of 2 kV/cm, ions remain for about 24 µs in the drift gap, thus creating a counter field preventing newly created ionization electrons to enter the amplification gap. The static charge induced by a drift field of 2 kV/cm amounts 177 pC/cm². This equals the charge of to 1.1*10⁹ ions per cm² or 1.1*10¹¹ ions per cm² that are created in the avalanches by 3.8*10⁶ MIPs/cm². Thus for the ionic space charge in the drift gap the limiting rate for MIP rate is about 160 GHz/cm², well above the particle rate at the ATLAS B-layer at the sLHC (Ch 9.1).

10.3.4 Rate limitation by the voltage drop across the SiNProt layer

For the conditions of the ATLAS B-layer at the sLHC, the bulk resistivity should not exceed 1.6*10⁹ Ω.cm (Ch 9.3).

10.3.5 Rate limitation by sparking

The sparking limit at various rates was studied by Fonte et al. [15] using 6 keV X-rays. For the argon based gas mixtures they used, this implies primary ionization clusters of ~200 electrons. At rates lower than 10 Hz the maximum avalanche size is confined to the Raether limit of 10⁸ electrons. Ivaniouchenkov et al. [16] measured somewhat lower values (2–6*10⁶ electrons) for various electrode geometries (PPAC, Micromegas, thick wire MWPC) while also GEM is reported to give similar a value.

For high rates a strong decrease of this number is observed by Fonte et al. in fig. 36.

Fig. 36. Rate limit by sparking using 6keV X-rays. The B-layer sLHC rate is indicated by the vertical red line.

According to these measurements the avalanche size would be limited to 3*10⁵ electrons at the sLHC rate of 0.9 GHz/cm² at the B-layer. For a gain of 5000 (Ch 9.2) this amount of charge corresponds to 60 primary electrons on average. Given the actual average number of 12.5 primary electrons for the Gossip working point (Ch 4.2) we would thus have a safety factor of almost 5 and a theoretical maximum rate of about 4 GHz/cm². But it is well possible that the wide charge signal distribution will reduce this number substantially.

This assumption is confirmed by a simple rate test done at Nikhef [17] at 2 GHz/cm² MIP irradiation (see fig. 37) where the gas gain was increased until breakdown. A dummy detector without a spark protection layer was used that had already received an irradiation dose of 3*10¹⁵ cm⁻² (10.5 C/cm²). A gain of 1000
could just not be reached because of permanent HV breakdown. Before irradiation there were no severe sparking problems at a gain of 1000. The figure shows that for gains above 25 there is a pure exponential relation as can be expected from the Townsend curve.

![Gas gain of Gossip 23](image)

**Fig. 37.** Collected current as a function of the grid voltage at a MIP rate of 1.6 GHz/cm².

However, since no SiNProt layer had been used as a discharge quencher, possibly a much better result would have been obtained with such a layer. This is confirmed by an experiment with a Gossip detector where the ionization is induced by UV light. For this test the anode current could be raised to 60 µA/cm², largely above the limiting value of 1.5 µA/cm² from the measurement of Fonte et al.

### 10.3.6 Conclusion on rate limitation for Gossip

Comparing the five possible sources of rate limitation, we see that sparking will be the main limiting effect. More experiments using detectors with SiNProt are needed to verify the sparking limit for chips equipped with this layer.
11 Radiation tolerance

11.1 Introduction
The process of ageing under irradiation of gaseous detectors cannot directly be compared with radiation damage in the bulk material of solid-state detectors. In gaseous detectors the detecting medium itself (gas) is permanently refreshed, so bulk ageing is not an issue here. However, gaseous detectors may suffer from other ageing phenomena

1. Deposits on the electrodes;
2. Ageing of the construction materials: under study by the CERN GDD group. We do not intend to do specific material research at this stage of the research project apart from superficially investigating the integrity of our prototype sensors after irradiation;
3. Radiation damage of CMOS pixel FE chips. Since this is a common issue for all detector technologies, we do not plan to start specific research on this issue;
4. Spark damage on the electrodes. Preventing this problem is studied in the SiNProt development (see Ch 1.2).

11.2 Electrode deposits
Formation of a deposit on the anode surface is the most common ageing phenomenon in gaseous detectors. In case of rapid ageing the deposit has the structure of a thin insulating polymer layer. As a result during operation a potential difference is created across the layer, leading to a decrease of the amplification field and thus to a (rate dependent) decrease of gas gain. Often a soft and closed homogeneous layer is formed but in a later stage cracks in the layer by outgassing may be occur as well. Apart from a polymer layer also inorganic compounds, often in the form of spikes or grains may be created.

Since for gaseous detectors ageing phenomena mostly occur near the anode, the radiation tolerance is generally quantified in units of charge per unit of anode surface. For one-dimensional detectors using a wire or strip as anode, ageing is quantified in units of C/cm along the anode; for two-dimensional Micro-pattern gas detectors like GridPix using pads on a pixel chip as an anode, ageing is quantified in C/cm² of anode surface.

There are three main reasons why GridPix/Gossip detectors will suffer less ageing for the same radiative dose compared to other technologies of gaseous detectors.

1. The gas gain of GridPix detectors is less compared to MWPCs: 5-10 k vs 20–100 k.
2. Especially for Gossip the volume of sensor gas per unit of anode surface is much smaller than for technologies like wire chambers. As an example, for wire chambers a common value is 1 cm³ of sensor gas along each cm of anode wire of 20 µm thickness. This corresponds to 3.2*10⁵ cm³ sensor gas per cm² of anode surface. But for Gossip there is only 0.1 cm³ of sensor gas volume per cm² of anode surface, a difference of more than 6 orders of magnitude.
3. In the avalanche high temperatures occur in the vicinity of the anode that may induce dissociation of organic molecules. These temperatures depend on the density of the avalanche and on the strength of the avalanche field. Fig. 38 shows that for the wire chamber and even more for the Micro Strip Gas Chamber (MSGC) the electrical field peaks to values exceeding 10 kV/mm at a few µm from the anode while for a Micromegas or InGrid amplification structure the field changes stepwise to a more moderate value of 8 kV/cm. Because of this, the electron avalanche temperature is less high for the InGrid /Micromegas amplification, making it less sensitive for ageing by dissociation products.
The assumption on the influence of the electrical field in the vicinity of the anode is confirmed by experience with ageing at MSGCs where extremely high sensitivity on minor traces of pollutants has been observed, while with micropattern detectors using Micromegas or GEM encouraging results were obtained under less clean gas conditions [17], [18].

In principle plasma chemists can describe the mechanism [19] that leads to the formation of a polymer from certain organic molecules in the gas mixture. But in many cases rapid ageing is not caused by the intended organic gas molecules but rather by traces of easily dissociative pollutants, often in the ppb range. This phenomenon cannot yet be explained.

11.3 Gas composition, ageing-related compounds, ageing prevention

From the abundance of literature on wire chamber ageing it is known that certain gases have a relatively high chance on polymerisation while for others this is a less likely process. On the other hand, many results are contradictory, so we may best confine ourselves to a few common guidelines. Hydrocarbons like isobutane is have often shown rapid aging behaviour while a gas like DME (dimethyl-ether) is considered to be safe. And of course non-hydrocarbon gases like argon or CO\textsubscript{2} principally cannot polymerize provided that they are sufficiently clean.

Ageing problems are often tried to cure using additives like CF\textsubscript{4}, iso-propanol, water and even oxygen although no commonly usable recipe has come forward. CF\textsubscript{4} has the ability to effectively trap free electrons at higher field strength while oxygen basically always has this property in a bit lesser degree.

An important step forward on understanding ageing of gaseous detectors has been recently set by Kurvinen et al. [20] who identified for the first time in a controlled and reproducible way compounds that cause deposits with inherent loss of gain. Investigated were traces of toluene, xylene and styrene. While the damage with styrene was permanent, the damage for the other compounds disappeared gradually under irradiation after the pollutant had been removed from the chamber gas.

With this new knowledge, the risk of ageing of Gossip/GridPix detectors in sLHC can be reduced by the following measures:

1. Take an inventory of all gaseous compounds that may be present in the gas of (future) detector systems. They may originate both from the incoming gas and from outgassing of the construction materials.
2. Investigate the ageing effect of all these compounds.
3. Remove harmful compounds from the chamber gas by applying gas purifiers and skipping materials like many plastics and epoxies that may emit harmful gases. In future we intend to use only ceramics and metals for detector construction to avoid this problem.

11.4 Ageing facilities

From Ch 9.1 we learned that the total dose on the ATLAS B-layer, placed at 37 mm from the beam axis of the sLHC, is $3.4 \times 10^{16}$ charged hadrons/cm$^2$. On the other hand, Ch 10.3.5 shows that the maximum operating rate of Gossip for MIPs at a gain of 5000 might be limited to 4 GHz/cm$^2$ and possibly even to a considerable lower value. While there is still uncertainty on the maximum rate Gossip can sustain, we cannot hope that this would be several orders of magnitude above the sLHC rate for the ATLAS B-layer of 0.9 GHz/cm$^2$.

To calculate the time needed to do an ageing test, we assume as a first approach a rate of 2 GHz/cm$^2$. At this rate it takes more than 6 months to reach the specified dose. Because of this long duration and the limitations in the maximum rate, we are limited in the choice of potential irradiation facilities. The GIF (or the future GIF++) gammy ray facility at CERN does not provide sufficient rate. The present 24 GeV/c PS beam (IRRAD-3 & IRRAD-5) has probably just the maximum rate (2 GHz/cm$^2$) that can be tolerated but we cannot claim it for many months of continuous running at a constant rate. The upgraded PS beam will have a too high rate (66 GHz/cm$^2$).

![Calculated particle rate as a function of the distance d to a $^{90}$Sr source](image)

*Fig. 39. Calculated rate from the Nikhef $^{90}$Sr irradiation facility. The rate has been verified by measurements with an ionization chamber.*

Therefore in practise studying Gossip ageing is only possible using a radioactive source with a constant rate. Often research groups use 6 keV X-rays from a $^{55}$Fe source or an X-ray tube. However these X-rays produce clusters of about 200 electrons which are much bigger than the average ionization hits from a MIP in Gossip (Ch 4.2), so ageing results obtained in this way are not very conclusive. The best possible simulation of the sLHC environment at the ATLAS B-layer is obtained using electrons from a strong $^{90}$Sr source (2.28 MeV β endpoint energy), which is for electrons near the minimum-ionizing point.
The local facility at Nikhef (5 GBq $^{90}$Sr) provides a rate of 2 GHz/cm² across an area of about 10 mm² (see fig. 39). Fortunately for most ageing tests we do not have to wait until the full sLHC dose has been administered. A few percent of the rated dose generally is sufficient to get an indication of the radiation tolerance of the test sample. The full dose test will only be applied on the favourite configuration.

11.5 **Concluding remarks on radiation tolerance**

The most severe thread on ageing of gas avalanche detectors is the rapid decrease of gain caused by a polymer on the anodes. The best remedy is still adequate gas filtering (molecular sieve) and using safe, non-outgassing, construction materials. Basically Gossip may have an extremely high radiation tolerance without a known fundamental upper limit, by far exceeding the radiation tolerance of any solid state detector. But practice has shown that there is always the risk on rapid ageing from an unexpected pollutant. Performing a multitude of ageing experiments gradually will give more and more knowledge and confidence on the way to operate the Gossip detector in an extremely high rate environment.
12 GridPix as Tracker / LVL1 trigger

12.1 Motivation

According to different scenarios of the sLHC operation, the track density per bunch crossing may increase up to by factor of 20 with respect to the nominal LHC luminosity. This will certainly create substantial problems with the track reconstruction in the Inner Detector area, leading to an increase of the rate of fake tracks. In addition the processing time for track reconstruction (at the HLT level as well) will increase by a power of 3 of the track density.

Another and possibly the most important problem of the experiments at the sLHC is an increase of the lepton trigger rate by at least an order of magnitude. Preliminary studies over the past years indicate that the L1 Calorimeter and Muon triggers alone may be under huge pressure at sLHC. At preset the only way to sustain this pressure is to rise up L1 Pt thresholds to the level at which the trigger rate reaches the sustainable L1 readout bandwidth of about 100 kHz. This actually unavoidably affects a physics quality of the taken data.

In the present ATLAS detector no ID tracking information is used when the L1 decision is made. However, given that in the current ATLAS setup much of the rejection power of the L2 trigger comes from combining tracking information with the Calorimeters and Muon information, the fast Inner Detector track trigger has the potential to add important information to the L1 trigger decision, so that the purity of interesting physics events in the L1 is enhanced and the Pt threshold can be kept similar to those at LHC.

If constructing a L1 track trigger was easy it would already has been implemented in ATLAS. There are evidently many technology challenges that have to be solved so that such a trigger can be built. On the other hand, since we want to profit from the higher luminosity, downgrading the performance of the ATLAS detector is not an option.

The situation described above is an actual motivation for the present R&D work on using GridPix tracker data for the L1 trigger. We propose to build two outer layers of the Inner Detector from GridPix detectors combining the best properties of the silicon and gaseous detectors.

![Possible layout: Two layers interleaved with moderator or dense TR radiator.](image)

**Why is that interesting?**

**A vector tracking!**

1. Precision space points \( x, y \)
2. Vector direction \( \phi, \eta \)

![A vector tracking diagram](image)

Fig. 40. Possible layout of the GridPix tracker for the ATLAS Inner Detector upgrade for sLHC

A layout out of such a detector is shown in fig. 40. Here the GridPix tracker occupies the outer radii of the Inner Detector from 850 to 1150 mm. It consists of two layers separated by ~200 mm. Because of the much lower particle rate than for the B-layer (less than 7 MHz/cm\(^2\) at \( R = 850 \text{ mm} \) vs 900 MHz/ cm\(^2\) at...
R =37 mm), the GridPix detector may have a drift gap as big as 16 mm without suffering from occupancy problems. Taking into account the larger diffusion at this distance, a pixel pitch of ~ 100 µm would be adequate for precise track reconstruction in a single detector layer. Note that the track fitted through the GridPix measurements automatically implies a high accuracy space point and a layer track segment, greatly facilitating vector tracking.

The expected electron collection time for the GridPix Tracker is about 250 ns, implying that the ionization in the drift gap originates from 10 bunches. However, fake tracks can be largely avoided by using criteria for track completeness: a track should contain continuous ionization across the full drift length.

The operation principle of the GridPix tracker is shown in fig. 41. The detector is designed such that the particles always cross the chamber at certain angle. After the electrons are collected and amplified, the charge signal is detected by the pixel array enabling reconstruction of the track image as shown in the picture. Knowing the chamber geometry and the track image, one obtains the most important parameters of the real track such as the crossing point with the pixel plane and the track angle \( \theta \) in the pixel plane. With less accuracy it can provide a value for angle \( \phi \) as well.

The basic advantages of this detector would be:

- reconstruction of the track vector
- possibility for a L1 trigger for high Pt tracks
- low Pt track suppression (low Pt track blind detector)
- a very good multi track resolution
- powerful pattern recognition ability
- precise space point measurements

and as an option

- dE/dX measurements
- enhanced particle ID with use of the transition radiation detector

Note that because of the larger drift distance it will not be practical to use the very slow gas mixture of Gossip, so we have to switch to a more useful mixture like Ar/isobutane 80/20 at the expense of an increased diffusion and Lorentz angle.

12.2 Test beam studies of the GridPix tracker and Transition Radiation detector.

The potential of this technology has been demonstrated by a testbeam experiment in T9 (5 GeV electrons and pions). The GridPix detector was made from a TimePix chip having 55*55 µm² pixels, an InGrid mesh and a drift cathode at 16 mm distance. For each pixel, the arrival time of the charge signal was measured with a period of 10 ns. The detector was filled with a Xe/CO₂ 70/30 gas mixture. A threshold
as low as 1.3 primary electron was obtained for the highest gain the chamber could sustain. Note that for a proper operation of the detector a threshold as low as 0.3 primary electron should be used.

Since no reference telescope was available, we had to compare the data with itself. To do this, the 256 rows of the chip were subdivided in 64 bins of 4 rows each. The recorded data were split into a set from the odd bins and a set from the even bins. Through both sets a track was fitted. By comparing both fitted tracks, the accuracy of the crossing point and the track angle was obtained. This method gives the best accuracy that may obtained by the track fitting, neglecting systematic errors like deviations in the drift field. The measurement was verified by a MC simulation.

![Graph](image)

**Fig. 42.** Intrinsic space point accuracy of the GridPix detector as a function of the electronics threshold from tracks fitted with the odd-even method. The two lower curves are simulations for a halved diffusion.

*Fig. 42 and fig. 43 show that the measurement and MC agree well. An accuracy of 30 µm was obtained while 20 µm would have been possible with the proper threshold. The angular resolution obtained was of the order of 0.5º.*
Fig. 43. Intrinsic angular resolution (degrees) of the Grid Pix detector as a function of the electronics threshold using the odd-even method. The two lower curves are simulations for a halved diffusion.

12.3 Particle Identification properties

Adding an appropriate radiator in front of the detector would induce particles with gamma factors above 1000 to produce transition radiation. Subsequently, the amount of detected transition radiation can be used to distinguish the different kinds of particles. This method works especially well for separating electrons and pions up to a momentum of about 100 GeV. It also may be a powerful instrument for identifying high Pt muons and long living heavy particles predicted by different models.

An example of the potential in e-π separation is shown fig. 44 of data from a test beam experiment at T9 with a mixed pion/electron 93/7 beam of 5 GeV. The particles were individually identified by a preshower counter, a calorimeter, and a Cherenkov counter. Here an 18 cm thick radiator was placed in front of the GridPix detector that is described in 12.2. The radiator contained a structure of polypropylene foils of 15 µm thickness that were about 200 µm apart. The magnitude of the charge signals of the data sets was calculated from the measured the time over threshold (ToT). Fig. 44 shows the calculated signal amplitudes for each pixel and their projection on the pixel plane for pion and electron events.
Fig. 44. Signal amplitude detected by each pixel for the pion and electron events. On the 2D projection the amplitude (deduced from the ToT measurement) is expressed in the colour code.

For the analysis, two methods for the electron-pion separation were tried.

1. **Total energy method.** In this method the totally collected charge from the track is calculated. The electron/pion separation is done applying the cut to the summed charge signal from the track.

2. **Cluster counting method.** Here the number of X-ray induced clusters is counted for which the collected charge exceeds a certain level. Note that basically the cluster size from an X-ray event (> 100 primary electrons) by far exceeds the cluster size from the regular MIP ionization, apart from delta clusters.

For the test beam experiment, the cluster counting method gave slightly better e-π separation than the total energy method (fig. 45).

It is obvious that using two detector layers would give much better e-π separation. This is shown in the analysis from the measured data in fig. 46 where a second GridPix detector was used that has been placed after the first one. While for a single GridPix the rejection power is 1:7 at an electron detection efficiency of 90%, for a two layer set-up this is already 1:50.
TRD with two detector layers (total thickness ~ 40 cm) allows to achieve rejection factor of ~ 50 for 90% electron efficiency.

Fig. 46. Measured pion rejection power for two detector layers using the cluster counting method.
Fig. 47 shows that the pixel size has direct impact on the detector performance. Here a MC simulation of the momentum accuracy in one layer as a function of the pixel size is shown for a GridPix detector as described in Ch 12.2, assuming a diffusion of 210 \( \mu \text{m/}\sqrt{\text{cm}} \). The figure shows that for pixel sizes up to 150 \( \mu \text{m} \) the accuracy is hardly affected. In Z direction the demands (occupancy) on the pixel size are even less stringent. Here one may allow a 250 \( \mu \text{m} \) pitch.

The method of identifying bunches in the drift region is illustrated by the measurement in fig. 48. Here two full tracks are displayed belonging to the required BC as well as two partial tracks for an earlier and a later BC respectively.

Fig. 47. Test beam measurement showing two in-time tracks having ionization across the full drift length as well as two out-of-time tracks. The dot colours indicate the measured drift time.

12.5 Conclusion

The data pre-processing at the FE level offers a natural possibility of the realization of the L1 trigger for high \( P_T \) tracks. This information exists: it just needs to be sent out as a trigger. Fig. 47 clearly demonstrates that already with a single layer the GridPix Tracker allows to reconstruct the particle with \( P_T \) of 20 GeV with 25% accuracy making feasible to have an energy cut at the L1 track trigger at this level.

More precise information may be deduced from the data of the track segments from both layers of the proposed GridPix tracker. Combining these segments would give a fairly precise particle momentum measurement for a 100 GeV particle with an accuracy of \( \sim 20\% \). And adding data from the L1 Calorimeter trigger will substantially increase the fraction of interesting events in the data stream. The test beam measurements also show that for a two-layer tracker, reliable \( e-\pi \) separation is also possible by counting the number of gamma clusters generated by a suited transition radiation radiator.

Of course the presented results from the test beam experiment should be only treated as a proof of principle of the GridPix detector. Further steps require significant R&D efforts to optimize the detector parameters, tracker layout, performance in sLHC conditions, and development of frontend electronics with track fitting capabilities.
13 Concluding remarks

“Gas or solid state, that’s the question”

This report has shown that there are a lot of good things on the gaseous pixel detectors GridPix and Gossip who are presented here: relaxed cooling at room temperature, a potential for excellent radiation tolerance, low material budget, low costs. In addition, the benefits of the absence of bias current and the negligible detector capacity are not easily overestimated. But, like so many other things, a price has to be paid for all these benefits.

All gaseous detectors for single particles are avalanche detectors. The gas avalanche requires careful tuning using an additional HV line. One is often close to a breakdown, so spark damage has to be prevented. This report shows that we have this problem well under control.

Avalanches are also known to have a risk on rapid ageing by forming of a polymer on the anode. Constructing the detector from exclusively metals and ceramics while flushing with well cleaned gas will prevent this problem, but constant monitoring during running remains necessarily. But for the rest, GridPix and Gossip offer an outlook to extremely high radiation tolerance, well suited for the requirements of the ATLAS B-layer at the sLHC. In contrast to this, for solid state detectors radiation damage at the sLHC environment is a real nuisance, but a very predictable one based on hard physical principles.

Dedicated frontend electronics for these gaseous pixel detectors are different from electronics optimized for solid state detectors, although solid state pixel chips can still be used with reduced performance for GridPix/Gossip. When designing a Gossip/GridPix pixel chip, one has to address the question whether track fitting on the frontend level is a desired option. This will reduce the data stream to a rather moderate level at the cost of increased pixel length in X direction for the digital circuitry.

Position resolution, being limited by the statistics of minor primary ionization, will never meet the theoretical potentials of silicon in this aspect. However, the simulations for a realistic frontend configuration have shown that for Gossip a value of 12 μm may be obtained.

At the outer radii of the ATLAS Inner Detector, GridPix detectors with drift gaps in the cm range might be operated successfully. They could be very helpful in rapidly providing data for a L1 trigger to reduce its rate. Using a radiator and a high Z gas mixture (xenon based) they may also serve as a TRT.

To continue the development of Gossip/GridPix, most urgently rate and radiation tolerance have to be investigated using realistic Gossips equipped with a SiNProt layer. In addition more experimental data should be collected to get more knowledge on the processes determining position resolution, preferably with the favourite gas mixture. Photolithographic and fine-mechanical techniques (MEMS technology) have to be developed to create multi-chip structures with reliable electrical connections for the InGrids and the cathode foil. On a longer term intelligent frontend design (local track fitting) will also require vast amount of human power.

The new technologies for services that are mentioned in this report: CO2 cooling, composite stave technology, serial powering, and possibly IfLink and light powering, have a much wider area of application than gaseous pixel detectors alone. But the Gossip/GridPix technology profits most from them because of its low mass and low power.
The present GridPix/Gossip collaboration in ATLAS requires significant enlargement from institutes of the ATLAS collaboration to address these tasks in a reasonable time scale.
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