Development of a new front-end electronics in Si and SiGe technology for the Resistive Plate Chamber (RPC) detector for high rate experiments

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The Resistive Plate Chamber (RPC)[1]-[2] detector front-end for high rate experiments is being developed. A mixed technology in Silicon and Silicon-Germanium is used in order to enhance its performances: a preamplifier in Silicon with a very low inner noise (1000 e- rms) and a new kind of discriminator in SiGe technology with a threshold of the order of 1 mV. The main feature of this new kind of Front-End is the great ability to discriminate the signal from the noise with a minimum threshold of few femtoCoulomb.
Following the results of the simulation on the RPCs rate capability and the performances of the Front-End will be shown, along with the advantages and the huge rate capability gain that the RPC detector can achieve with this new Front-End.

RPC rate capability and possible improvements for high rate experiments

The **RPC rate capability** is mainly limited by the current that can be driven by the high resistivity electrodes. It can be improved working on a number of highly interconnected parameters.

$$V_{gas} = V_a - R \cdot I$$

$$V_{gas} = V_a - \rho \cdot \frac{d}{S} \cdot \langle Q \rangle \cdot S \cdot \Phi_{particles} = V_a - \rho \cdot d \cdot \langle Q \rangle \cdot \Phi_{particles}$$

There are several possible ways to increase the detectable particle flux:
1. Decrease the electrode resistivity; large technological effort, with the risk of increasing the material cost of the detector and its operating current, causing a possible ageing problems due to the more current driven.
2. Reduce the electrode thickness; similar effect obtained with the reduction of the resistivity. The difference can be found in the bigger amplification of the induced signal and therefore in the improvement of the signal to noise ratio.
3. **Reduce the average charge per count Q. This method is the only one that permits to increase the rate capability while operating the detector at fixed current.**

This final approach requires:
- Very sensitive FE electronics with an excellent signal to noise ratio
- High suppression of the noise originated both by the detector itself and by external sources
- Very careful optimization of the chamber structure as a Faraday cage.

The rate capability of the RPC was simulated in order to understand the behavior of the detector under different rate of incident particles and with different average charge per count produced inside the gas gap.

$$V_{gas} = V_a - \rho \cdot d \cdot \langle Q \rangle \cdot \Phi_{particles} \cdot \varepsilon$$

From this simulation is possible to see:
1. The efficiency value under different conditions of incident flux (see Fig. 1)
2. The rate capability gain that could be achieved if the average charge per count is reduced by a factor 10 with the same incident flux condition. The rate capability could be increased from 1 KHz/cm² (the actual limit) to 10 KHz/cm². (see Fig. 2)

Voltage applied	8.8 → 10.6 KV
Gas mixture	97% C2H2F4, 2.5% iso-butane, 0.5% SF6
Gas Gap	2 mm
Electrodes resistivity	10^{10} Ωcm
Electrodes thickness	1.8 mm
Incident flux	1 → 10^6 Hz/cm
Average charge per count	Data fit from real measurements
Efficiency parameter	Data fit from real measurements

Table 1: Simulation parameters

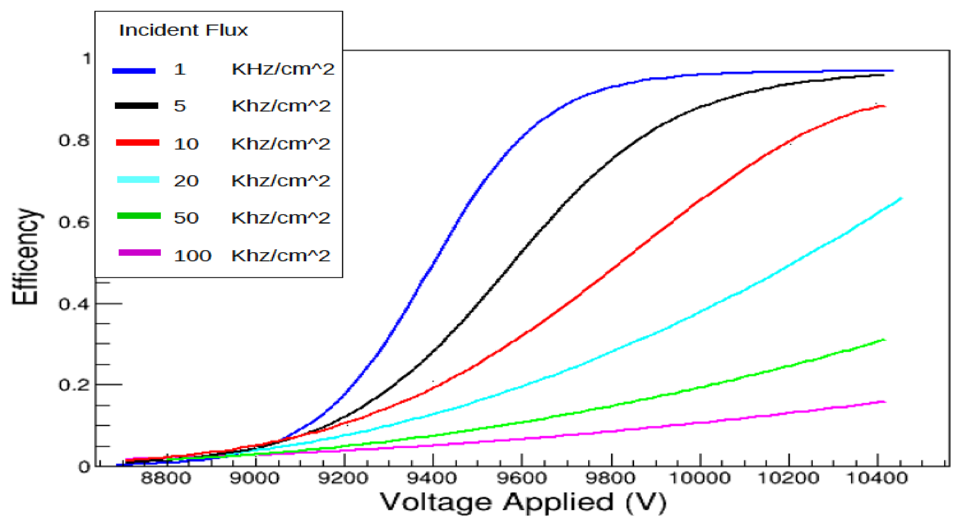

Figure 1: The simulation of the efficiency of a standard RPC under different conditions of incident flux.

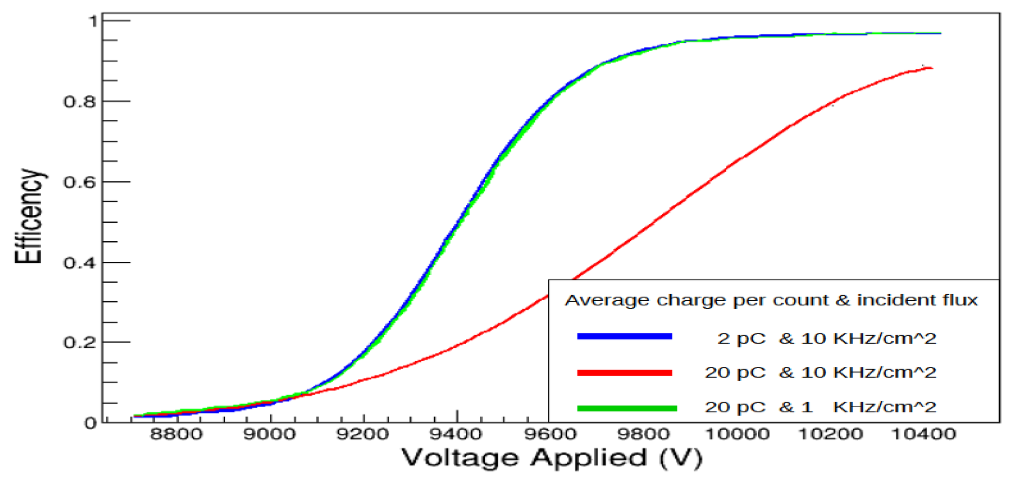

Figure 2: Efficiency as function of the average charge per count produced inside the gas gap

The new RPC Front-End for high rate environments

The new Amplifier developed for the RPCs is made in **Silicon Bipolar Junction Transistor** technology. It is based on the concept of a fast charge integration with the possibility to match the input impedance to a transmission line [3]-[4]. The working principle of this amplifier is shown in Figure 3. The performance of the silicon BJT amplifier are shown in the following table.

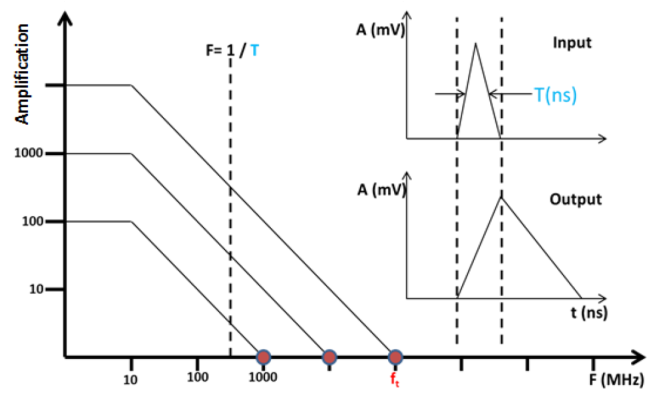

Figure 3: Operating principle of custom charge amplier in Silicon technology

Voltage supply	3–5 Volt
Sensitivity	2–4 mV/fC
Noise (independent from detector)	4000 e^- RMS
Input impedance	100–50 Ohm
B.W.	10–100 MHz
Power consumption	10 mW/ch
Rise time $\delta(t)$ input	300–600 ps
Radiation hardness	1 Mrad, 10^{13} n cm^{-2}

Table 2: Performance of custom charge amplifier in Silicon BJT technology

The principle of SiGe heterojunction bipolar transistor (HBT)[5] is to introduce a Silicon-Germanium impurity in the base of the transistor. The advantage of this device is that the band structure introduces a drift field for electrons into the base of the transistor, thus producing a ballistic effect that reduces the base transit time of the carriers injected in the collector. The net effect is to improve the transition frequency and to introduce a directionality in the charge transport allowing a much lower value of B-C capacitance; hence a much higher charge amplification can be achieved.

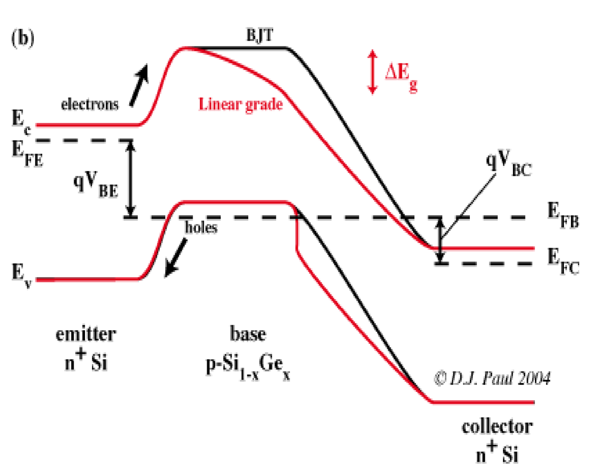

Figure 7: Band structure of a silicon bipolar transistor (black line) and a linearly Ge graded SiGe HBT (red line). Bias applied.

The new full-custom Discriminator circuit dedicated to the RPCs for high rate environment is developed by using **the Silicon-Germanium HJT technology.**
The main idea behind this new discriminator is the limit amplifier. If the signal surpasses the threshold, it will be amplified until saturation giving as output a square wave.
The main features are:
- Optimal characteristic function with the possibility of an easy regulation of the threshold from a minimum value of few mV (see Fig. 4)
- Very small transition region of around 300 µV, practically negligible when the discriminator is used within the RPC (see Fig 4).
- Time-over-threshold measurement directly with the discriminator (see Fig 5).
- Minimum pulse width of 3 ns; for shorter signal the discriminator goes into a charge regime with a threshold in charge (see Fig 6).

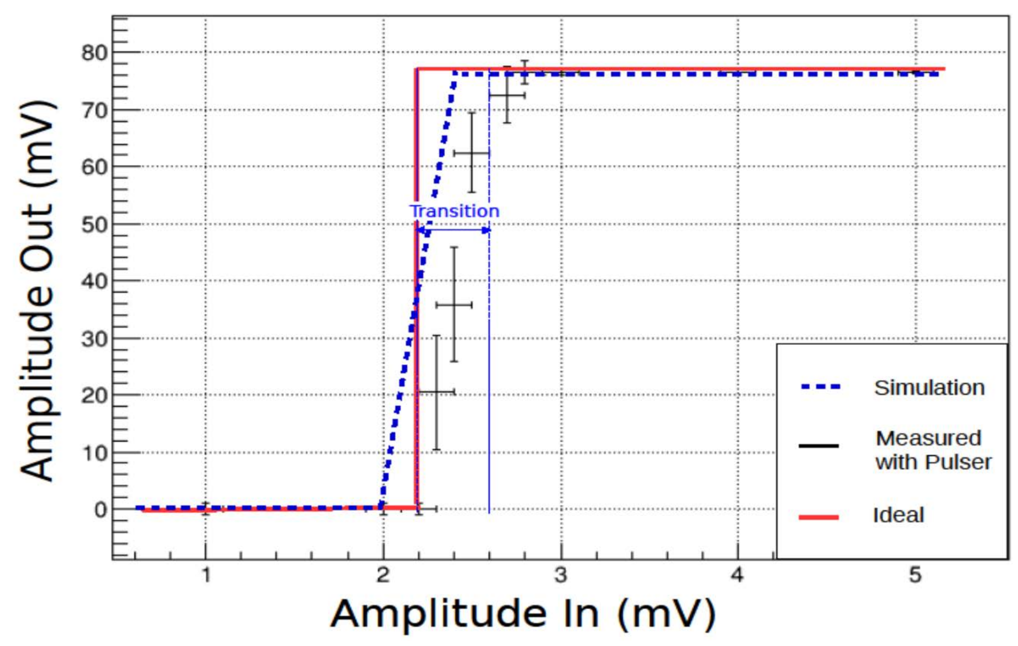

Figure 4: Characteristic function of the discriminator in Si-Ge HJT technology

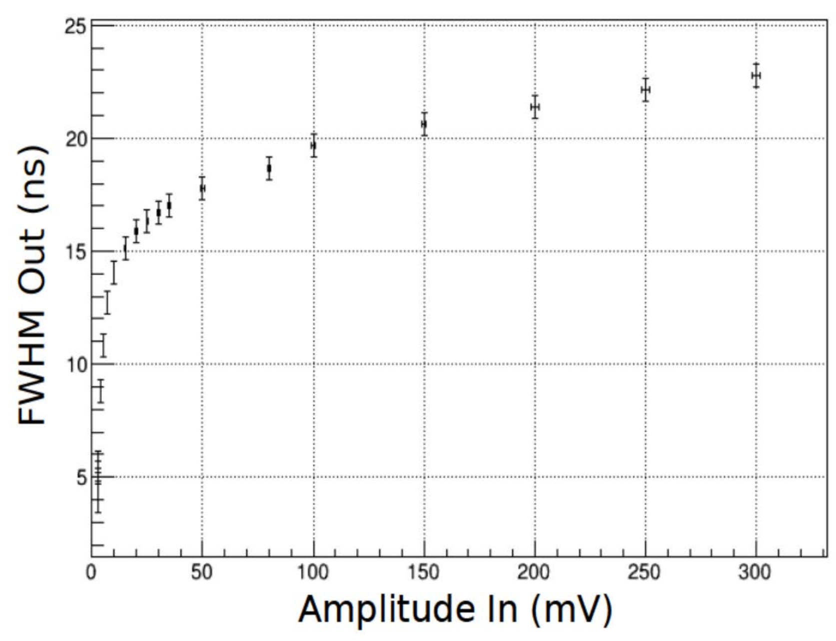

Figure 5: Dynamic of the time-over-threshold of the discriminator prototype in SiGe HJT technology.

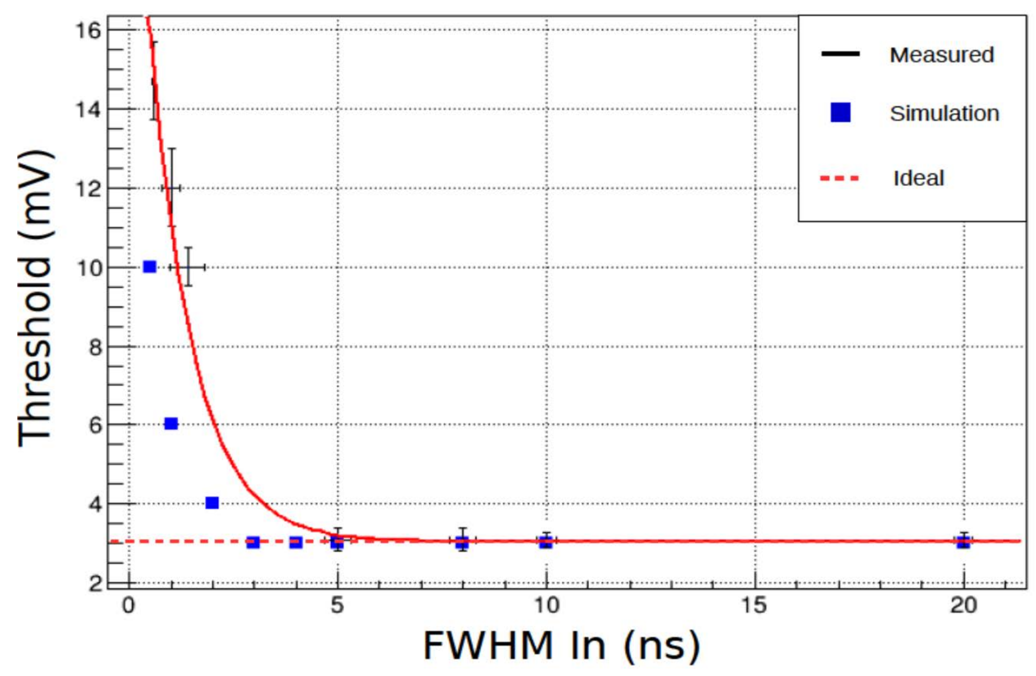

Figure 6: Minimum pulse width of the new Si-Ge prototype compared with the simulated and the ideal behavior of a discriminator.

Conclusion: The simulation realized shows the possibility to achieve the desired rate capability, passing from 1 KHz/cm² to 10 KHz/cm², if the average charge per count is reduced.
A new full-custom discriminator circuit is completely developed. The performances achieved by this discriminator are:
1. **Threshold from a minimum value of 1 mV**
2. **Time-over-threshold measurement achievable directly with the discriminator**
3. **Minimum pulse width of 3 ns**

The new Discriminator in SiGe technology along with the new Amplifier in Si technology will be able to detect signals of around 25µV , which corresponds to a prompt charge of 1 fC.
Eventually, thanks to all these features, this new full custom Front-End electronics will allow the Resistive Plate Chamber detector to work with higher rate of incident particles.

References:
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