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Development of gaseous particle detectors based on semi-conductive plate electrodes

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Abstract

A new kind of particle detector based on Resistive Plate Chamber structure is under development. Semi-Conductive electrodes with resistivity up to 10^8 Ω·cm are introduced to improve Rate Capability performance. The aim is to obtain a radiation hard detector with sub-nanosecond time resolution capable of working in high rate environment (order of MHz/cm²). In this presentation some results on two configurations under test are described. The first characterized by 1mm gas gap and both SI(Semi-Insulating)-Gallium Arsenide electrodes (~10^8Ω·cm), and the other characterized by 1.5mm gas gap, one SI-GaAs electrode and one intrinsic Silicon (~10^4Ω·cm) electrode. The DC Voltamperometric characterization of a SI-GaAs sample measured applying metal electrodes on the substrate is also reported .

Increase in Rate Capability

An RPC detector can be described as a set of unit cells interconnected according to the diagram in Figure 1. A unit cell is characterized by the gas capacitance $\mathbf{C_G}$, the electrodes capacitances **C** and by $\mathbf{R_T}$ and $\mathbf{R_L}$ resistances, which represent respectively the electrode resistance in the normal and longitudinal directions respect to electrode surface. $\mathbf{R_G}$ represent the resistance of the Graphite layer which distributes the high voltage $\boldsymbol{V}$ on the electrode surface.

If the high voltage across the gas gap $\boldsymbol{V_{gas}}$ is enough, a ionizing particle crossing a unit cell triggers an avalanche multiplication process schematized as the closure of the switch. The resistance $\mathbf{R_T}$ attenuate the voltage across the gas gap proportionally to the current generated in the avalanche discharge. The resistance $\mathbf{R_L}$>>$\mathbf{R_G}$ limit the transfer of energy from adjacent cells.

When a particles flux Φ passes through the detector, the simultaneous ignition of many unit cells occurs, whose cumulative effect causes a voltage drop on the electrodes described by the relation[1]

$$V - V_{gas} = 2\,\rho\, d < Q > \phi_{eff}$$

After the discharge process, the unit cell returns in the initial state with a time constant $\boldsymbol{\tau}$ (order of microseconds) described by the relation

$$\tau \cong \rho\epsilon_0\left(\epsilon_r + 2\frac{d}{g}\right)$$

In this phase the unit cell can be considered inefficient.
To prevent the detector does not lose efficiency as the flux increases, it is necessary to minimize the voltage drop on the electrodes and reduce the dead time $\boldsymbol{\tau}$.

For this purpose in this test was used the combination of two strategies:

- **Reduction of the average charge $< Q >$ using a high Signal to Noise ratio charge amplifier [2];**
- **Replacement of insulating electrodes (resistivity greater of 10^{10}Ω · cm and thickness of 1.8mm) with Semi-Insulating electrodes with resistivity lower of 10^8 Ω · cm and thickness of 400μm.**

1) $< Q >$ = mean charge involved in a single process; ϕ_{eff} = number of process occurring in the detector per unit time ad surface; ρ = electrode resistivity; d = electrode thickness; g = the gas gap; ϵ_0= vacuum permittivity; ϵ_r=relative permittivity.

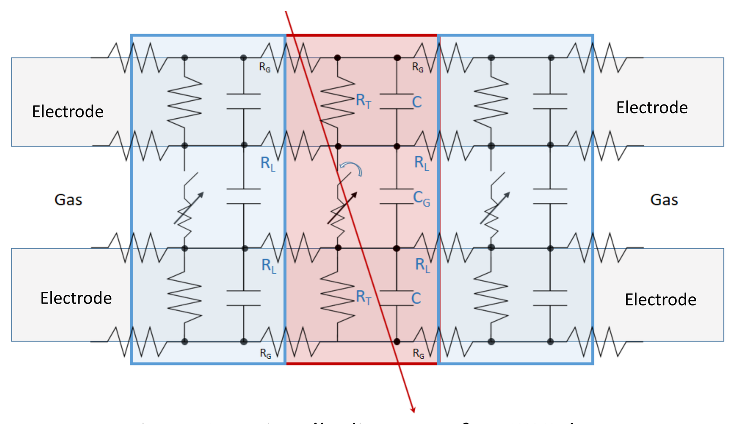

Figure 1: Unit cells diagram of an RPC detector.

Voltage supply	3-5 Volt
Sensitivity	6-7 mV/fC
Noise (up to 20pF input capacitance)	1500 e⁻ RMS
Input impedance	100-50 Ohm
B.W.	10-100 MHz
Power consumption	10 mW/ch
Radiation hardness	1Mrad, 10^{13} n cm^{-2}

Charge amplifier technical specifications

Prototype 1

The Prototype1 is constituted by **two SI-GaAs** electrodes spaced by a PET circular crown 1mm thick. Both electrodes are 400μm thick and have a resistivity on the order of **10^8 Ω·cm**. The electrical contact with the high voltage electrode surface is formed through a layer of paint to Silver ions, while the one with the electrode connected to ground via a layer of Graphite. The gas gap is filled with a gas mixture consisting of: **TFE 95%/iC_4H_{10} 4.5%/SF_6 0.5%.** The signal is read on a pad placed under the low-voltage electrode. The detector is placed in series with a 100MΩ resistance in order to avoid that the power dissipated in the electrode, due to any shock related to edge defects, damage the crystal.
The prototype characterization was carried out at the Beam Test Facility of the National Laboratories of Frascati, using **450MeV electron** beam. The average multiplicity of particles per bunch was fixed at 0.3 for the whole duration of the test. As trigger reference have been used two silicon detectors optimized for time of flight measurements [3] whose time resolution was measured during the test resulting in (180±4)ps.

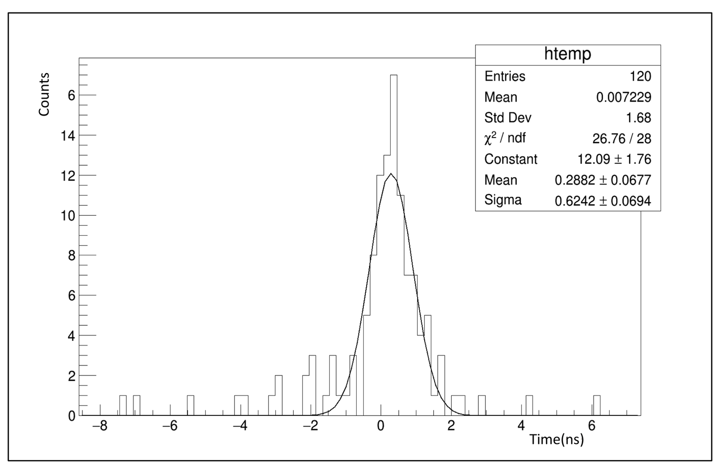

Figure 2: time difference with respect to one of the trigger detectors corrected for the Time Walk effect (HV = 5630V).

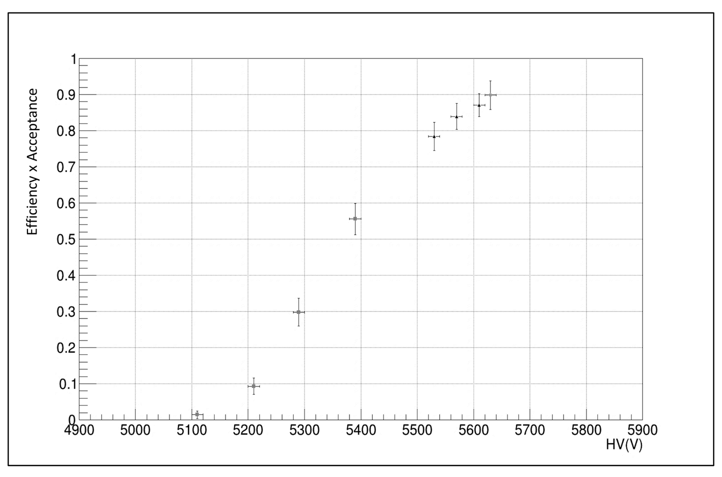

Figure 3: Efficiency x Acceptance, 450MeV electrons, 1mm gas gap.

Time Resolution

$$\sigma^2_{RPC} = \sigma^2 - \sigma^2_{trig} \;\Rightarrow\; \boxed{\sigma_{RPC} = (590 \pm 90)ps}$$

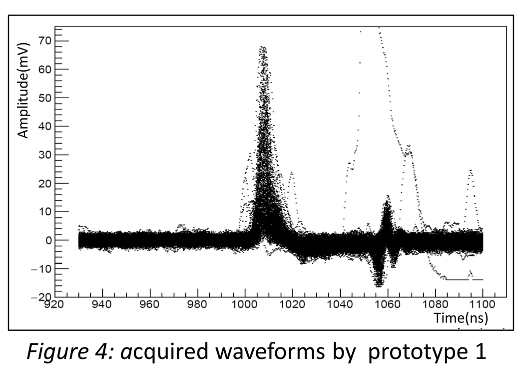

Figure 4: acquired waveforms by prototype 1

Prototype 2

The Prototype2 is constituted by one **SI-GaAs electrode** (resistivity ≅ **10^8 Ω·cm**) and one intrinsic **Silicon electrode** (resistivity ≅ **10^4 Ω·cm**) spaced by a PET circular crown 1.5mm thick.
The electrical contacts with both electrodes is formed through a layer of Graphite. The positive high voltage is placed on the SI-GaAs electrode. The gas gap is filled with a gas mixture consisting of: **Argon 40%/iC_4H_{10} 60%**. The signal is read on a pad placed under the low-voltage electrode. The detector is placed in series with a 100MΩ resistance in order to avoid that the power dissipated in the electrode, due to any shock related to edge defects, damage the crystal.
The prototype characterization was carried out at INFN Laboratories of University of Rome Tor Vergata exploiting **atmospheric muons.**
As trigger reference two scintillators have been used, whose time resolution was measured during the test resulting in (456±14)ps.

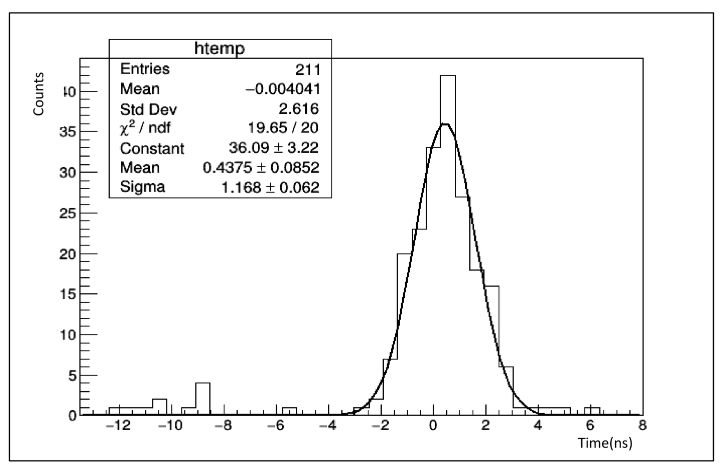

Figure 5: time difference with respect to one of the trigger detectors corrected for the Time Walk effect.

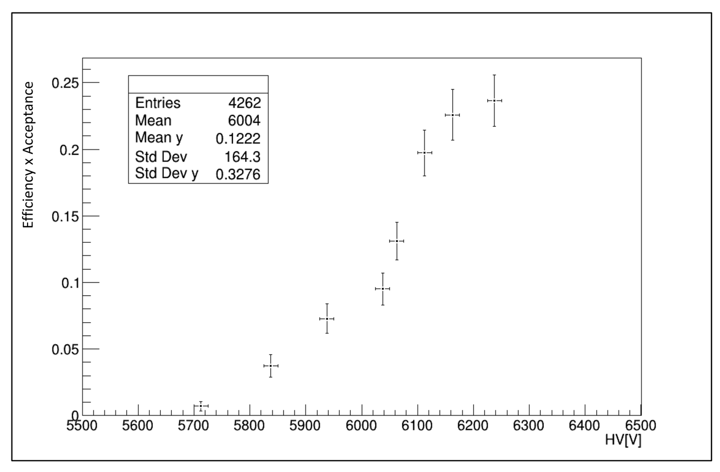

Figure 6: Efficiency x Acceptance, atmospheric muons, 1.5mm gas gap.

Time Resolution

$$\sigma^2_{RPC} = \sigma^2 - \sigma^2_{trig} \;\Rightarrow\; \boxed{\sigma_{RPC} = (1.10 \pm 0.09)ns}$$

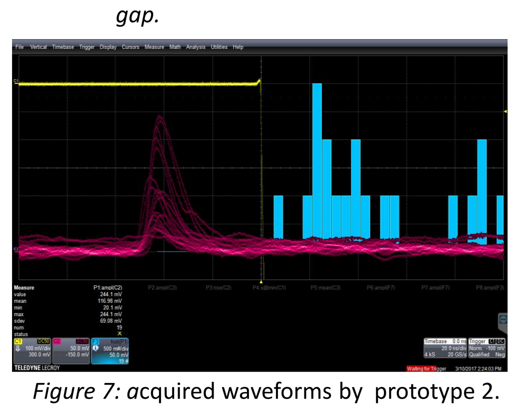

Figure 7: acquired waveforms by prototype 2.

Metastable state in SI-GaAs

From the measurement of the DC voltamperometric characteristic of a sample of SI-GaAs, carried out by depositing metal electrodes on the substrate, it is found that above a critical voltage $\mathbf{V_H}$ the material switch to an **high-conductivity state** that persist as long as the bias voltage is lowered to a shutdown value $\mathbf{V_L}$< $\mathbf{V_H}$.

To perform the measurement the sample is placed in series with a 1MΩ resistance, which in addition to protecting the integrity of the power supply circuit, has the aim to smooth the transition to the high conductivity regime in order to observe the **hysteresis loop** [4][5].

- For values lower than $\mathbf{V_H}$, increasing the voltage (Figure8: black dotted line), the current follows the typical **saturation law of Schottky devices**.
- For voltage values higher than $\mathbf{V_H}$ the transition to the high conductivity regime is observed and the sample shows a **residual resistance of 49Ω**.
- By reducing the voltage (Figure 8: red dotted line), the high-conductivity regime persist for an interval of about 100V lower than $\mathbf{V_H}$.

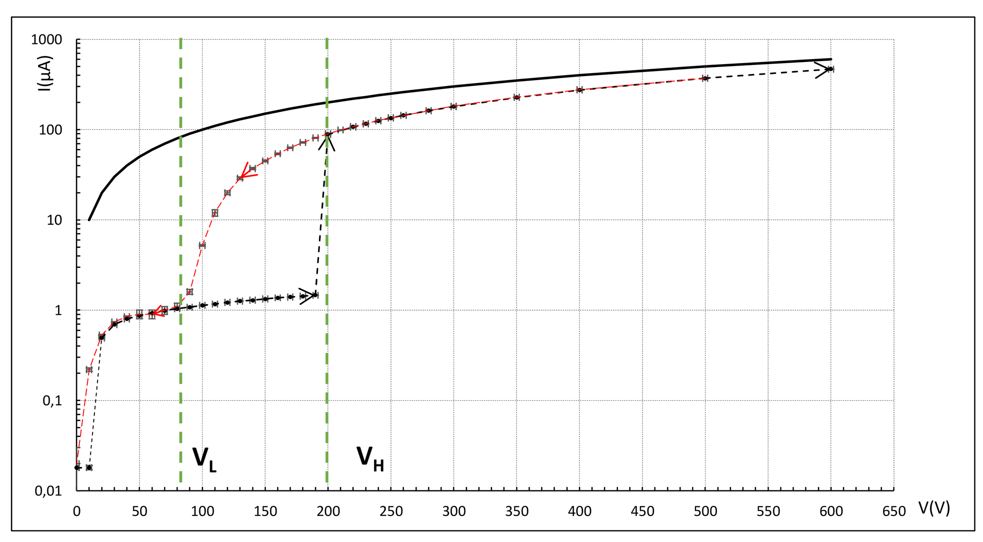

Figure 8: DC Voltamperometric characterization of a SI-GaAs 400μm thick sample .

Conclusions

These results provide a solid foundation for the development of new prototypes. **Efficiency x Acceptance curves, as well as the time resolution, are consistent with what observed in a standard RPC detector**. For an experimental confirm of the increase in terms of Rate Capability a test with a source of photon has been planned. Further investigation will be carried out on the properties of SI-GaAs and processes that occur at the gas-semiconductor interface.

References

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