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

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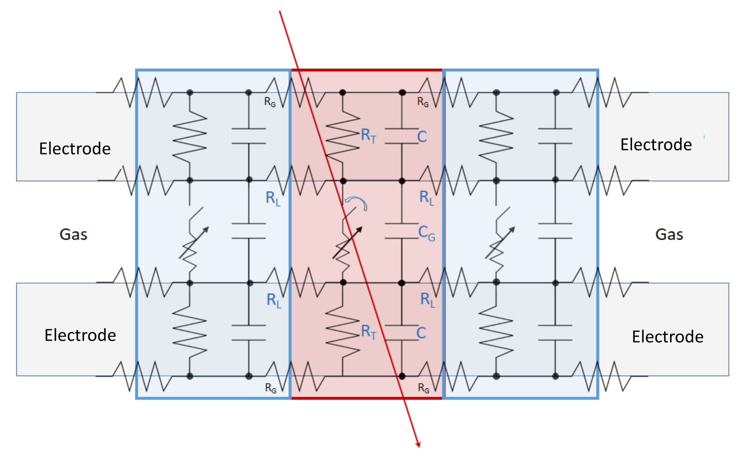
Abstract

A new kind of particle detector based on RPC-like structure is under development. Semi-Conductive electrodes with resistivity ρ up to 10^8 Ω·cm have been used to improve the RPC rate capability. The aim is to obtain detector with sub-nanosecond time resolution capable of working in high rate environment (rate capability of the order of MHz/cm²). In this poster the results on two different detector structures are presented: one with 1mm gas gap and both SI(Semi-Insulating)-Gallium Arsenide electrodes ($\rho \sim 10^8$ Ω·cm), and the other characterized by 1.5mm gas gap, one SI-GaAs electrode and one intrinsic Silicon ($\rho \sim 10^4$ Ω·cm) electrode.

Figure 1: Unit cells diagram of an RPC detector



Charge amplifier technical specifications

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}

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 parallel directions with respect to electrode surface. $\mathbf{R_G}$ is 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 high enough (applied electic field **E** greater than 5 kV/mm for 95%/4.5%/0.5% of $C_2H_2F_4$ - iC_4H_{10} - SF_6 gas mixture), a ionizing particle crossing a unit cell triggers an avalanche multiplication process. This process can be seen as the closure of the switch in the equivalent circuit of the unit cell involved in the discharge. The resistance $\mathbf{R_T}$ dumps the voltage across the gas gap proportionally to the current generated in the avalanche discharge. **The resistance R_L>>R_G restricts the transfer of energy from adjacent cells**.

When a charged-particle flux Φ crosses an RPC detector, the simultaneous ignition of many unit cells occurs and the 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 τ (order of microseconds) described by the relation

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

At this stap the unit cell can be considered inefficient.

To prevent the detector from losing efficiency as the flux rises, it is necessary to minimize the voltage drop on the electrodes and reduce the dead time τ in such a way to fix the V_{gas} value.

For this purpose two strategies have been combined during the test:

- **Reduction of the average charge $< Q >$ using charge amplifier with high signal-to-noise ratio[2];**
- **Replacement of the standard insulating electrodes with Semi-Insulating electrodes with lower resistivity ρ and thickness d.**

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.

Prototype 1

The Prototype1 is made of **two SI-GaAs** electrodes spaced by a PET circular crown 1mm thick.

Both electrodes are 400 µm thick and have a resistivity ρ of the order of **10^8 Ω·cm**. The electrical contact with the high voltage electrode surface is made of Silver ions paint, while the one with the electrode connected to ground is made of Graphite layer. The gas gap is filled with a gas mixture consisting of: $C_2H_2F_4$ - iC_4H_{10}- SF_6 (95%/4,5%/0,5%). The signal is read on a pad placed under the low-voltage electrode. The detector is placed in series with a 100 MΩ resistance in order to avoid that the power dissipated in the electrode due to any anomalous electric discharge may damage the crystal.

The prototype characterization was carried out at the Beam Test Facility (BTF) of the National Laboratories of Frascati with **450MeV electrons**. The average multiplicity of particles per bunch was fixed at 0.3 for the whole duration of the test. Two silicon detectors optimized for time of flight measurements [3] have been used as the trigger reference. The trigger-time resolution has been measured during the test, resulting in (180 ± 4) ps.

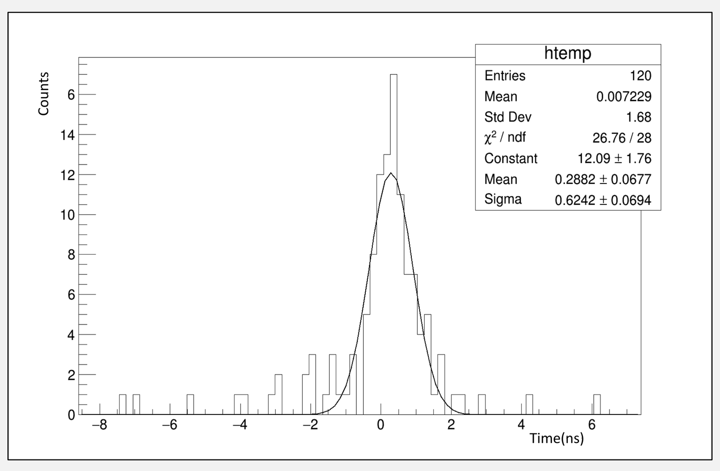


Figure 2: time difference with respect to the trigger detector corrected for the time -walk effect (HV = 5630V)

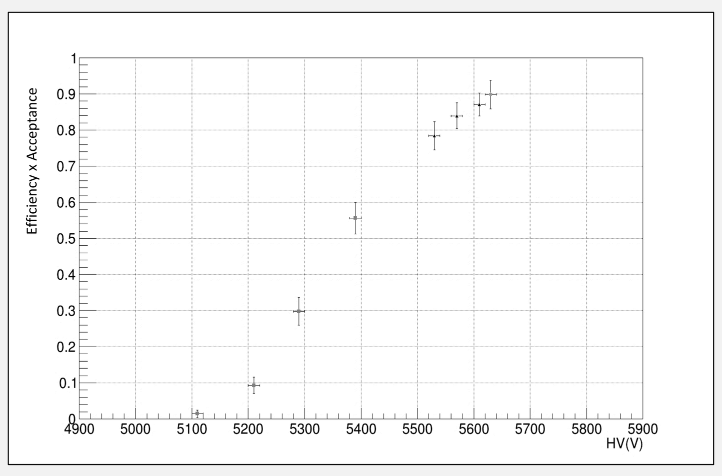


Figure 3: 'efficiency times Acceptance' (1mm gas gap)

Time Resolution

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

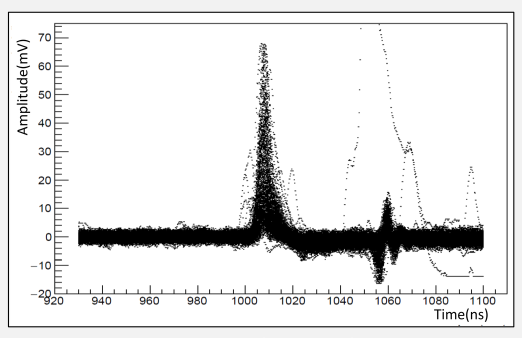


Figure 4: pulse samples

Prototype 2

The Prototype2 is made of one **SI-GaAs electrode** (resistivity $\rho \cong 10^8$ **Ω·cm**) and one intrinsic **Silicon electrode** (resistivity $\rho \cong 10^4$ **Ω·cm**) spaced by a PET circular crown 1.5 mm 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: **Ar-iC_4H_{10} (40%-60%)**. The signal is read on a pad placed under the low-voltage electrode. The detector is placed in series with a 100 MΩ resistance in order to avoid that the power dissipated in the electrode due to any anomalous electric discharge may damage the crystal.

The prototype characterization was carried out at INFN Laboratories of University of Rome Tor Vergata with **atmospheric muons**.

Two scintillators have been used as the trigger reference. The trigger-time resolution has been measured during the test, resulting in (456 ± 14) ps.

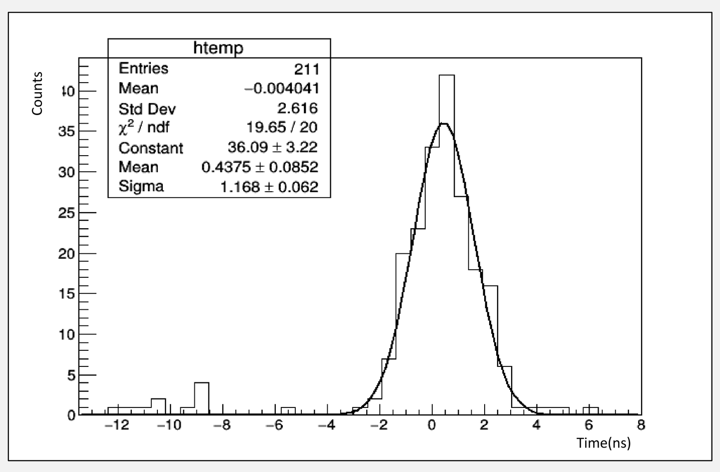


Figure 5: time difference with respect to one of the trigger detector corrected for the time-walk effect

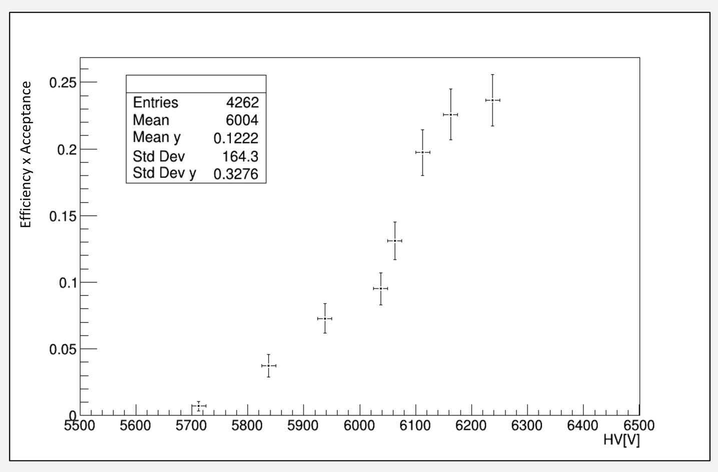


Figure 6: 'efficiency x acceptance' (1.5mm gas gap)

Time Resolution

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

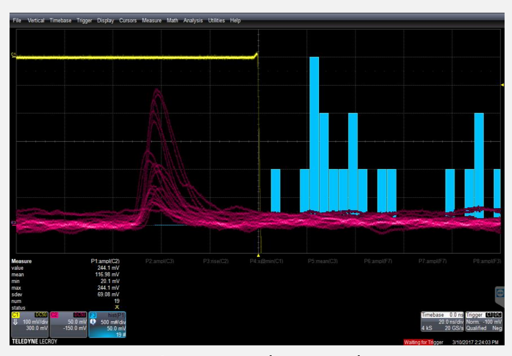


Figure 7: pulse samples

Conclusions

These results provide a solid foundation for the development of new type of RPC detector. The measured efficiency and time resolution are compatible with the ones obtained with a "standard" RPC detector with a similar gas gap. Next and crucial step is the measurement of the rate capability. Further studies are needed to investigate the detector stability and the interactions be occur at the gas-semiconductor interface.

[1] R.Santonico, R. Cardarelli, NIM 187, 1981, 377-380.

[2] R.Cardarelli et al. Jinst,10.1088/1748-0221/8/01/P01003, IOP for SISSA Medialab, 7/2013.

[3] M.Benoit et al. Jinst, IOP for SISSA Medialab, 9/2016.

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