R&D for an autonomous RPC station in air shower detector arrays

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DOI: 10.7529/ICRC2011/V03/0663

Abstract: Resistive plate chambers (RPCs) are planar gaseous detectors that combine low cost with a time resolution around 50 ps for minimum ionizing particles, making them a very competitive solution for large area timing applications in accelerator physics. The RPCs capabilities could be used to measure new shower observables, or to improve resolution of actual observables, namely the sensitivity to the details of the depth development of extensive air showers from muon time distributions. RPCs have been already used in cosmic ray detectors, although there is not much experience on outdoor operation in small isolated stations under hard environmental conditions and little maintenance. Our objective is to investigate whether RPC detectors can operate under harsh field conditions i.e. low energy budget, low cost per unit area, and mechanical toughness. In this paper we present progress on the design of a first prototype.

Keywords: Resistive Plate Chamber; Particle Detection; Timing; Ground measurement

1 Introduction

Resistive Plate Chambers [1] are rugged and reliable gaseous detectors, widely used in High Energy and Nuclear Physics experiments. Significant examples, some covering thousands of square meters, include the muon trackers of the ATLAS and CMS experiments at CERN/LHC ([2, 3]); the ALICE muon arm equally at LHC [4]; the experiments BELLE [5] at KEK, Japan and BABAR [6] at SLAC, USA; the veto [7] and tracker [8] of the OPERA experiment at LNGS, Italy.

RPCs feature also an excellent time resolution of 50 ps [9] and have been massively deployed in large area time-of-flight (TOF) detectors in ALICE [10], FOPI [11] and HADES [12] at GSI, Germany.

In cosmic ray physics, RPCs have been already used in the COVER-PLASTEX [13] and ARGO/YBJ [14] experiments, although confined to indoor conditions.

Due to the extremely low fluxes of UHECR, experiments aiming to the highest energies require extremely large areas, such as the 3000 km^2 covered by 1600 Cherenkov tanks of the Auger Observatory [15]. Under these conditions, single detectors cannot be maintained in a daily, weekly or even monthly basis, stations need to be as autonomous and robust as possible to cope with harsh environment conditions. The current work aims in this direction.

The application of RPCs, providing tracking and timing of numerous particles, on autonomous or semi-autonomous (with some central support station for gas and power) outdoor stations would allow to measure new shower observables, or to improve resolution of actual observables, namely the depth development of extensive air showers from muon time distributions [16] and muon/electromagnetic separation in extensive air showers [17].

It may as well be that RPCs will prove to be a cost effective solution when compared with scintillator-based (much more cost-effective active material) or tank-based (much less weight and infrastructure) detectors.

2 Foreseeable capabilities of an autonomous RPC station for cosmic ray research

Although requirements will vary with specific applications, allowing different tradeoffs, based on reasonable extensions of the state-of-the-art one may enumerate the following expected capabilities.

- 1) Time-measurement of individual particles up to $\sim$ 10 particles/m^2 in each time slot of $\sim$ 200 ns (depending on the amplifier shaping). This implies that $\sim$ 100 individual measuring channels should be available in the same area to limit the particle pile-up to about 10% of the incoming particles.

- 2) Time resolution close to 1 ns, free of crosstalk (see section 5).
- 3) Particle counting up to $\sim$ 1000particles/m^2, with measurement of $\sim$ 100 time channels/m^2.
- 4) Graceful transition from individual particles measurement mode to particle counting mode.
- 5) Single particle angular resolution: $\sim 2.5^\circ$ (see section 3).
- 6) Effective detector area/station: $\sim$ 1 m^2.
- 7) Total area: $\sim$ 100 m^2, requiring low cost/station.
- 8) Good timing in many channels with low power consumption, requiring integrated front-end electronics.
- 9) Reduced gas flow: $\sim$ 1 kg/year, requiring very good gas tightness and chamber cleanliness.
- 10) Automatic operation in remote locations.
- 11) Weather-resistant.

It is clear that all points enumerated above should be demonstrated in practice. Considering the present stateoftheart one may note that:

- a) Characteristics 1 to 8 seem well in reach.
- b) R&D must be made concerning point 9. Such RPC doesnt exist today (see section 4).
- c) Although RPCs are intrinsically quite relaxed on the operating parameters, there is not much experience on outdoors operation in small isolated stations. Therefore, points 10 and 11 will require realistic tests to be performed and iterated with system improvements.

3 Concept of a generic RPC station

The concept of a generic standalone RPC station is shown in Fig. 1.

The detectors will be housed in a thermal box made out of Al-polyurethane foam sandwich, which is a very light, rigid and insulating material. The box will be made almost air-tight for maximum thermal insulation. For summertime operation, a shutter will be opened and a controlled ventilator will provide a flow of ambient air. It should be noted that the RPCs are not particularly sensitive to the environment, enjoying quite wide efficiency plateaux, but it is advisable anyhow to keep some reasonable control on the inner conditions. All power-dissipative elements are kept inside, warming up the detectors, as well as the 3kg gas (R134a[1]) bottle, which adds thermal inertia to the internal environment.

The 1 m^2 RPCs are readout by metallic pads placed in a rectangular matrix with a pitch of $\sim$ 10 cm. The RPCs are placed 1m apart vertically, thus defining each pair of pads a cone of acceptance of $\sim 2.5^\circ$ FWHM, allowing some localization of the particle's path. If a more accurate track definition is needed, a third RPC plane may be added and/or the number of pads increased, at the expense of using more front-end electronics.

The front-end electronics will be based on available integrated low-power readout chips, for instance APV25 [18] or MAROC3 [19], which provide the needed time resolution on 64 or 128 channels. The charge-integrating principle of operation of these chips allows to reject crosstalk between pads, as crosstalk is of capacitive origin and doesn't transfer any net charge. The analog data output is serialized and requires a single ADC channel.

A single board computer will collect the data, control the high-voltage and diagnostics and handle the communications.

It is clear that if standalone operation is not required the communications and the gas and power supplies may be advantageously housed at a nearby station.

4 The detector

The major hurdles to be overcome in this application are the need for a very clean system, allowing a very low gas renewal flow and resilience to the environmental conditions. Of these, one of the most vexing is humidity, which may cause serious difficulties to the high-voltage insulation.

To overcome these problems we developed RPCs that are completely contained within a gas-tight enclosure, which includes also the high-voltage distribution. This way both problems are solved within, independently of the external conditions.

In figure 2 it is shown an example of such device, with 0.5×1 m^2 and two gas gaps of 0.35 mm delimited by 2mm thick glass sheets. The readout electrodes are external to this volume and can be of any shape.

The evolution of the dark current as a function of the time after the gas flow was reduced to 1kg/year at the nominal applied voltage of 5600 V is displayed in figure3. The chamber stabilizes at a dark current around 80 nA, which is a quite reasonable value for an area of 0.5m^2. It is evident a correlation between the background current and the ambient temperature, most likely via the well known dependence of the gas gain with the pressure and temperature,

$$G = G\left(\frac{E}{n}\right) = G\left(\frac{E}{p/kT}\right), \qquad (1)$$

where G is the gas gain, E is the applied field strength and n, p and T are, respectively, the gas numeric density, pressure and temperature.

1. A common refrigeration gas, mostly composed by $C_2H_2F_4$.

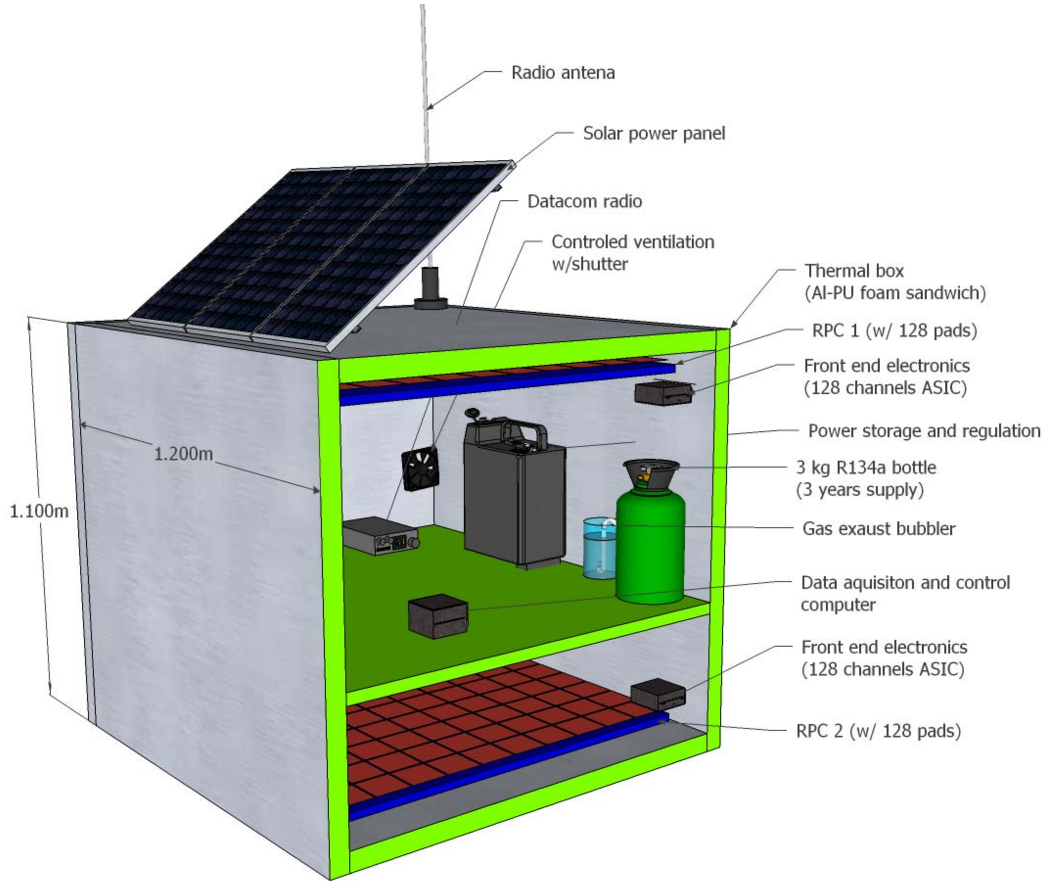

Figure 1: Conceptual representation of a tracking standalone RPC station. It is clear that if standalone operation is not required the communications and the gas and power supplies may be advantageously housed at a nearby station.

5 Investigation of the time resolution achievable with charge amplifiers

There is a question whether frontend chips which provide only the signal shaping (e.g. APV25) and no discrimination are suitable for this application. To determine this we collected the chamber signal in two opposite pads connected to charge amplifiers featuring a 50ns peaking time. The waveforms were measured with a digital oscilloscope at a sampling rate of 40MS/s, as shown in figure 4, and we tried to extract the time information from these samples. The whole arrangement is quite similar to the operation mode of the APV25 chip.

It was also taken in consideration that in reality these signals might have been collected at different stations with asynchronous sampling clocks, which must be correlated by time-stamping. The samples were interpolated and the time information for each signal was taken as the peaking time. The time difference between both pads is shown in figure 5, yielding an rms resolution of $0.88\text{ns}/\sqrt{2} = 0.62$ ns per channel, clearly sufficient for the purpose in view.

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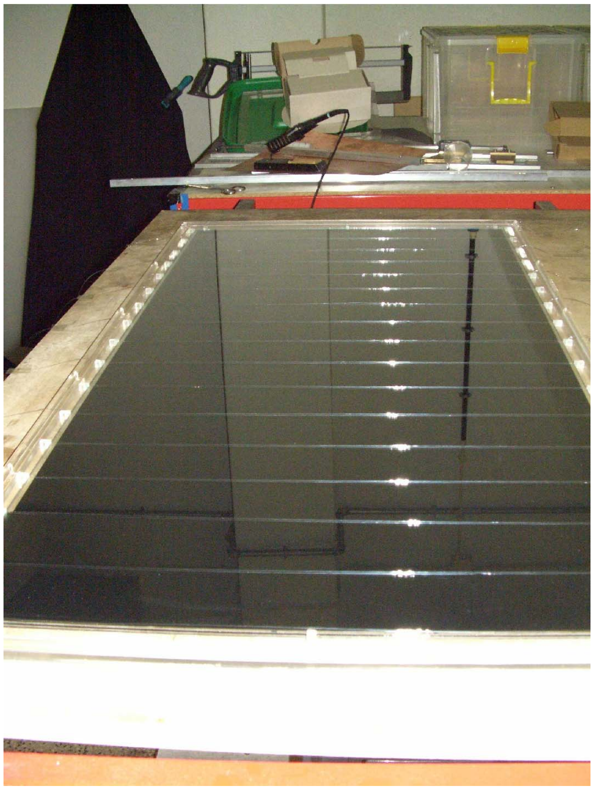

Figure 2: Double-gap RPC module with $0.5 \times 1\text{m}^2$. The RPC is completely contained inside an impermeable high-voltage and gas enclosure.

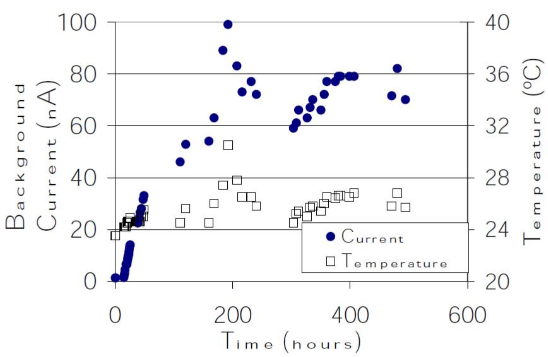

Figure 3: Evolution of the dark current as a function of time after the gas flow was reduced to 1 kg/year, at the nominal working voltage of 5600 V.

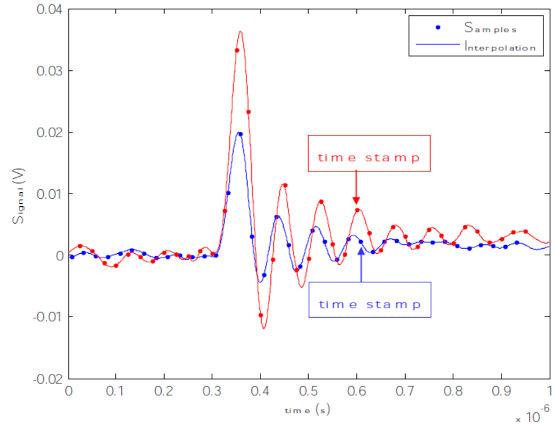

Figure 4: Typical waveforms from a charge amplifier with 50ns peaking time, measured with a digital oscilloscope at a sampling rate of 40MS/s and then interpolated. Note the asynchronous samples. This particular amplifier suffered from some ringing, but this is irrelevant to the measurement.

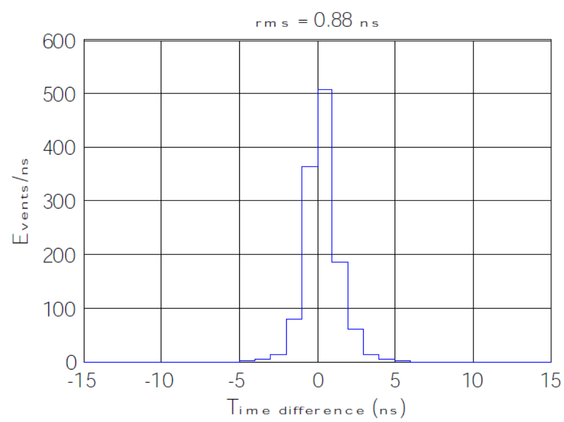

Figure 5: Distribution of the measured time difference, with an rms of 0.88ns.

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