Summary of RPC 2007, the IX International Workshop on Resistive Plate Chambers

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Abstract

This summary highlights the success stories and open issues for the widely employed Resistive Plate Chamber (RPC). Many experiments were represented, each having its own specific requirements for the operation of the detector. The general focus is on the understanding of operational characteristics, namely studies of electrode material, gas systems, aging and long term performance. Simulations of electric field and transport parameters are reported, along with performance at high rates, focused on timing and time-of-flight systems. There are important issues related to operation of large RPC systems and their commissioning, QA and QC procedures. Finally, RPCs are now being used in diverse applications such as Calorimetry with analogue readout and in Astrophysics.

CERN-PH-EP-2009-001
20/01/2009

Invited paper at the IXth International Workshop on Resistive Plate Chambers, Mumbai India, February 2008

Submitted for publication in Nuclear Instrumentation and Methods A
January 15 2009

1. Introduction

Resistive Plate Chambers (RPCs) invented by Yuri Pestov [1] as glass gaseous parallel-plate detectors that combine good spatial resolution with a time resolution appropriate for fast space-time particle tracking. In one of the most popular versions, the electrodes are made out of phenolic resin (bakelite) as introduced by Santonico, with a bulk resistivity of $10^{10} - 10^{12} \Omega\text{cm}$, separated by few mm of gas gap delimited by the bakelite surfaces which are coated on the outside surface, with conductive graphite paint to form the HV and ground electrodes respectively. The read-out is performed by means of aluminum strips separated from the graphite coating by an insulating PET film as shown in Fig. 1. RPCs have been demonstrated to operate in streamer mode, i.e. the electric field inside the gap is kept high enough to generate limited avalanche multiplication localized near the crossing of the ionizing particle, however, the rate capability obtained in such operational conditions is limited ($\sim 100 \text{ Hz/cm}^2$). A significant improvement was achieved by operating the detector in the so-called avalanche mode; the electric field across the gap and the gas amplification is reduced yet the lower gain in the avalanche mode is compensated by the use of signal amplification at the front-end level. The substantial reduction of the charge produced in the gap improves by more than one order of magnitude the rate capability ($\sim 1 \text{ kHz/cm}^2$). A typical RPC is capable of tagging the time of an ionizing event in times of the order of few 10ns, permitting bunch crossing identification at LHC, while using special techniques few 10s of picoseconds of time resolutions have been demonstrated [2]. A fast dedicated muon trigger detector, based on RPCs can therefore identify unambiguously the relevant BXs with which the muon tracks are associated, even in the presence of the high rate and background expected at LHC. Signals from such detectors directly provide the time and the position of a muon hit with the required accuracy.

Fig.1 Schematic of a Resistive Plate Chamber (RPC)

A very large number of Resistive Plate Chambers (RPCs) has been employed in both accelerator and non accelerator experiments. The present situation was highlighted at this conference. There were over 60 contributions in plenary talks, with 130 participants from groups discussing diverse applications of RPCs. In this paper an attempt is made to highlight some success stories and open issues. Several experiments were represented namely ATLAS, CMS and ALICE at LHC, PHENIX, BABA, BELLE, ARGO – YBJ, OPERA, INO, HARP, FOPI HADES, with particular and largely different requirements for the detector operation. This Workshop was devoted to the understanding of general operational characteristics namely studies of electrode material, gas systems, aging and long term performance. Several groups reported on field calculations and transport parameters. Performances at high rates were presented, focused on timing and time of flight systems. Several reports covered the growing importance of large system aspects, commissioning, Quality Assurance (QA) and Quality Control (QC) procedures. There were also reports of diverse applications such as in the field of Calorimetry with digital readout, and in Astrophysics.

2. Transport parameter studies for operational gas mixtures

Extensive studies of electron transport and amplification properties in the gas mixture filling RPCs have been performed as a function of the electric field in saturated avalanche mode. Drift velocity experimental measurements have been compared to the values calculated by the program MAGBOLTZ [3] and a satisfactory agreement was found. The evaluation of charge amplification was found to be complicated by space charge effects typical of the RPC operating in a regime of saturated avalanche. Charge spectra distributions follow an exponential decreasing curve for an electron avalanche charge less than $\sim 10^6$ electrons. Larger amounts of charge start to saturate, assuming a Polya shape [4]. The effective Townsend coefficient as a function of voltage was evaluated at small distances from the anode, where an exponential behavior of the charge spectra is expected, and was found in agreement with the calculation from MAGBOLTZ [5].

Fig. 2 Good agreement between experimental results on drift velocity measurements with MAGBOLTZ calculations (a) [5], and Townsend Coefficient Calculations at different HV (b) [4]

3. Electrode study

The quality of the inner surface treatment for plastic laminate (phenol/melamine plastic laminate) RPCs had a considerable improvement with respect to that used in the first series of Babar chambers and also in the second series of LHC-like chambers used to replace part of the old Babar RPCs. As was reported high temperature combined with poor construction led to linseed oil droplets making shorts and causing sparks and high current, which in turn also led to the evaporation of the graphite layer. The graphite evaporation was first observed by Aielli and co-workers [7]. The major emphasis has been on quality assurance and quality control at various stages of construction, resulting in a major improvement of the performance of the Babar RPCs.

Fig. 3 (a)

Fig. 3(b)

Fig.3. Surface quality of (a) Beijing phenol/melamine plastic laminate and (b) Italian LHC like phenol/melamine plastic laminate. Comparison of the three photos in (b) demonstrate the successive surface improvement due to the deposition of a uniform linseed oil layer. The scale is in μm .

Effects of gas flow were also studied in great detail. Typically the chambers that were connected later in a given series showed effects due to HF production [8], with the Fluorine ion attached in the bulk of the phenol/melamine plastic laminate. The role of humidity is also non-negligible, though adding water to the gas mixture is necessary to keep the resistivity of the Bakelite in the desired range, detailed studies have been made by Va'vra [8]. Tests at the Gamma Irradiation Facility at CERN (GIF) [9] have shown that

there is no negative effect of the humidity up to 50% at least in these detectors. Combined with the HF production, this leads to the transition from avalanche to streamer mode more easily than previously thought.

There has also been an effort to find alternative sources of phenol/melamine plastic laminate. In Figure 3 we can compare the quality of the phenol/melamine plastic laminate samples from Beijing and Italy, non-oiled and oiled. The oil uniformity is of the order of 3-10 μm . Phenol/melamine plastic laminate found in India has also been presented along with a novel concept of coating it with silicon oil instead of linseed oil. Literature however suggests that the presence of silicon oil in a gaseous detector is detrimental to its performance [10], hence this idea should be pursued with prudence after demonstrating that it can sustain long term operation, for example with tests at the GIF [9].

A check of the linseed oil polymerization is obligatory in any production chain and this is done by random sampling. Fig. 4 shows the polymerized surfaces of the gaps produced in Korea. The spacer bonding was checked and the chloroform quality control tests for linseed oil polymerization yielded positive results. These were gaps from the production of RPCs for the CMS experiment at CERN.

Fig, 4 (a) The linseed oil coated phenol/melamine plastic laminate surface is much better protected from HF vapor attack in the CMS RPC gaps examined at CERN [11]. (b) After 24 hours of exposure there is no sign of any discolouration.

The OPERA experiment has a unique possibility of comparing the performances of phenol/melamine plastic laminate and glass RPCs. Quality control tests on Opera RPCs [12] were also conducted in a stringent manner and the glass RPCs were built in an external firm.

4. Simulations of fields and performance parameters, Electric Field Calculations

Fig. 5 (a) The effect of an oil drop of 1 mm diameter and 0.2 mm height on the electric field, and (b) Field at the edges of the RPC, the three lines show fields in three different heights of the gap, centre and two extremes; the field decreases at the edge, the spacer button is on the left as shown in cartoon on top [13]

Several advances have been made in simulations of electric field and analytic solution of the RPC time response function. A general solution for electric fields using the boundary element method calculations in RPCs was developed, which allows the calculation of space charge effects, weighting fields, induced signals, field fluctuations and crosstalk. The objective is to produce a plug-and-play model for the community.

In Fig 5 is shown the effect of an oil drop on the electric field. Regions of field as much as twice the nominal operation field can lead to the transition from avalanche to streamer. In the Fig 5 (b) fields at the edge of the RPCs can be much higher than nominal if any linseed oil drops remain un-polymerized. Hence extreme care must be taken during construction to ensure complete polymerization of the linseed oil. Any remaining defects can lead to sparks and severe damage as has been observed [14].

An analytic expression for the RPC time-response function, allowing the inclusion of realistic electron cluster size distributions, in order to respect elementary physics processes, was also presented [6,15].

5. Gas system studies

Gas systems of the large experiments are rather complex and contain several stages. The operational gas of the RPC has tetrafluoroethane as part of the mix. This is an expensive gas and simple operation can easily lead to consumption costing of the order of hundreds of thousands of dollars per annum. Typically the plastic laminate is melamminic with phenolic resins offering a wide range of bulk resistivities, and at high rates the production of various contaminants and impurities may take place. During the operation several different kinds of filters are needed in the gas system, and due to financial reasons closed loop systems have been opted for the large experiments like ATLAS and CMS. Several long term tests have been performed at the GIF which validated the RPC technology for production and construction for these two experiments. Nevertheless open questions about the gas system remain. These will deal with the

fraction of recirculation for the gas mixture, better configuration and efficiency of the purifiers and filters, and the regeneration process reported in detail [16].

A gas gain monitoring system has been developed for the CMS RPC closed loop gas system which provides a fast and sensitive response. Comprising a system of reference RPC chambers, this system monitors efficiency with cosmic rays continuously and provides a reference for the gas exhausted back into the closed loop. New ideas for recuperating the gas by separating the mixture components via condensation were also proposed [17].

6. Aging and Long Term Performance

A first report on the aging tests of Korean RPCs was reported. A set of RPCs oiled and non-oiled were exposed to neutron irradiation. No effects were reported on the efficiencies of the oiled RPCs. The efficiencies after two weeks of irradiation are shown in Fig. 6. The oiled RPCs have the best performance.

Fig 6. First cosmic ray measurements made after neutron irradiation to Korean oiled and non-oiled RPCs [18]

Aging and long term performance of glass RPCs were also presented [19] demonstrating that the deposit distribution on the electrodes surface depends on the surface polarity and that there is more uniformly on the anodes than on the cathodes as shown in Fig. 7. With an integrated charge of $\sim 30 \text{ mC/cm}^2$ about two years of nominal operation in the laboratory of a small (few cm^2) detector, they conclude that the deposits studied are mainly oligomers of tetrafluorethylene and are derived from tetrafluorethane. It was also noted that the presence of SF_6 in the gas mixture does not affect the composition of the deposits and all deposits observed on glass electrode surfaces could be chemically removed.

Fig.7. Deposit distribution on electrode surfaces [19]

Improving the efficiency of glass RPCs by the use of high temperature for high rate applications was also presented. Glass has an exponential resistivity temperature coefficient with a factor of 10 per 25 deg C.

From the INO experiment, which use Japanese glass RPCs operated in avalanche mode since two years and stable currents, noise and efficiencies were reported and the correlation of data with temperature effects is being studied. Details may be found in [20].

From the ARGO-YBJ experiment [21] an interesting result concerning the temperature dependence of the RPC operating point was reported. The detector has worked stably for 3 years. In particular the current measured shows extremely stable trends during the last 4 months of continuous operation after the detector completion. The RPC current is correlated with the temperature, which affects the gas density and therefore the operating voltage. The linear correlation is a maximum if a 70 minutes delay of the measured RPC current with respect to the temperature of the hall in which the experiment is housed is accounted for and needs to be considered when housing a large RPC array.. Hence a regular measurement of the slope of the linear fit (typical value: 50 - 60 nA /°C) is a good tool to check the system stability.

7. Time of Flight and Particle Identification

Timing RPCs for time of flight measurements at the HARP experiment was presented by Wotschack [22]. These are glass RPCs with a stack of four gaps, with an overall system TOF resolution of 175 ps, based on a similar setup a new ToF barrel was used in the FOPI experiment for the first Ni-Ni run [23]. The HARP RPC TOF extends the p/π separation up to a momentum of $\sim 1500\text{MeV}/c$. as shown in Fig. 8.

Fig. 8 Four stack HARP RPC and TOF measurements [20]

The glass RPCs used for the ALICE TOF have a time resolution ~ 50 ps as reported in [24] while that for RPCs at HADES have been demonstrated to be ~ 100 ps, and those at OPERA ~ 1.8 ns.

8. RPC for MUON Trigger – Commissioning

It must be stressed that a total of $\sim 15000\text{m}^2$ of sensitive surface area of RPCs has been deployed for Muon trigger in ATLAS and CMS. Installation and commissioning, a formidable task, has been performed and cosmic tests have demonstrated that these detectors are ready to provide trigger at the LHC as shown in Fig. 9.

Fig. 9: The ATLAS Shaft (dense shadow of the big and small) visible from cosmic ray shadows by 2d reconstruction offered by the ATLAS Muon RPCs on the right hand side [25].

Similarly for the CMS RPC Commissioning appropriate diagnostic systems and tests procedures have been developed.

9. Outlook and Next Steps

Following the tradition, this workshop was a very successful one elucidating the successes of thousands of square metres of phenol/melamine plastic laminate RPCs and hundreds of square metres of glass RPCs in various experiments and studies. The complete ARGO RPC carpet has been fully operational since October 2007 and the angular resolutions are as expected and a standalone RPC apparatus is turning out to be a crucial tool for cosmic ray astrophysics. Some ideas to be followed are analog readout for digital calorimetry using for example resistive readout pads. For the high rate RPCs one could consider using TMAE or DME in the gas. A combination of micro-pattern detectors [26] with the micro-RPC [27] using a CsI cathode could be used for improving the applications for photo detection for example PET [28]. The large experience that is gathering up on aging studies suggests that a chemical model of ion transport and charge exchange should be embarked upon in order to understand the key role of the various parameters.

I would like to acknowledge the useful discussion and comments by R. Santonico, F. Sauli and D. Abbaneo and the careful reading of the manuscript by K. Gill.

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