Development of high resolution gas filled detector for high energy physics experiments

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Resistive Plate Chamber (RPC) is one of the most widely used large area gas filled detectors in experimental high energy physics with a potential to be used in PET imaging. Main characteristics of RPC, which have made it highly attractive are excellent time resolution (∼ 1-2 ns for single-gap and ∼ 50 ps for multi-gap) and good position resolution (1 cm to ∼ 100 μm) coupled with the low cost of fabrication. Till now, RPCs have found their applications in HEP experiments like STAR, ALICE, ATLAS, CMS, BELLE, BaBar, BESIII and neutrino experiments *e.g.* OPERA.

The single gap RPC, first developed by R. Santonico and R. Cardarelli is a gas-filled charged particle detector consisting of two parallel plate electrodes made of resistive materials such as bakelite or glass (bulk resistivity $\sim 10^{10}$ - 10^{11} Ω cm) enclosing the gas volume [1]. A uniform gap of 2 mm is maintained by spacers made of materials like polycarbonate whose resistivity is more than the resistivity of the electrode plates. By applying a d.c. high voltage to these electrodes, an electric field is generated across the gas gap. A passing charged particle creates an avalanche in the gas. High resistivity of the electrodes prevents discharge to spread over entire gas volume. The created electron and positive ion pairs while traveling towards the respective electrodes induces signal on the pickup strips placed over the electrode plates. The generated charge is deposited on a small region of the electrode plate and the spot is slowly recharged by current flowing through the plate. If the electric field is even more intense, a 'spark' breakdown can be initiated by the avalanche.

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In the conventional single gap RPC a gas mixture of argon, isobutane (iso-C_4H_{10}) and tetrafluroethane (R-134a) in widely varying proportions is used at atmospheric pressure in the streamer mode of operation [2]. The isobutane is used to prevent the spread of secondary streamer by quenching the photons and R-134a is used to limit the streamer size from spreading in transverse direction. In the avalanche mode of operation, mixtures of R-134a with 2-5% of isobutane are used. The single gap RPC first developed has been replaced by its variants, where electrode materials, gap thickness and geometry have been changed.

The main topic of this thesis is R&D on bakelite based RPC for the Iron Calorimeter (ICAL) in India-based Neutrino Observatory (INO) [3]. INO is being planned to determine the oscillation parameters precisely using atmospheric neutrinos. For effective separation of upcoming and downgoing neutrinos and background rejection, ICAL requires highly efficient sensitive detectors with ∼ 2 ns time resolution. Current effort is a development complimentary to the development of glass-based RPCs in other collaborating institutes.

In this work, we have developed a number of RPCs making use of the bakelites available locally. Entire effort can be divided into following steps: (a) Characterization of different grades of bakelite in terms of resistivity (bulk and surface) and other electrical properties and thereby choosing the electrically suitable bakelite for RPC, (b) fabrication of RPCs (10 cm × 10 cm and 30 cm × 30 cm), detailed procedure involved building of components like button and edge spacers, gas nozzles, pick-up strips, graphite coating arrangement by adjusting the resistivity, connection of high voltage leads, (c) testing of the RPCs

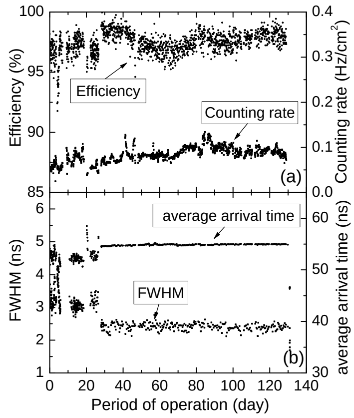

FIG. 1: Results of long term test.

in a cosmic ray stand by measuring the efficiency, count rate, time resolution and long term stability in the streamer mode of operation. It was observed that for a particular grade of bakelite (Superhylam) even though an efficiency $> 90\%$ is reached, but it reduces slowly with time coupled by an increase in count rate while in some other grade (P-120) efficiency increases with high voltage, reaches a maximum and then starts to decrease with continuous increase of count rate. (d) As an effort to improve the performance by making the surface smooth, a thin layer of silicone coating is applied on the inner surfaces of the electrodes [4, 5]. (e) One such silicone coated RPC is tested for a long duration showing $\sim 96\%$ efficiency for a period of operation of more than 130 days. The time resolution measured for the RPCs reaches ~ 2 ns [6] and the measured charge content is ~ 100 pC at an applied high voltage of 8 kV [7]. Results of the long term test are shown in FIG. 1. (f) Consistency of results are established by making and testing several such RPC modules. (g) Operating the detectors in avalanche mode and studying the properties like efficiency, time resolution, charge content. Various compositions of gases are also used for further study. (h) Finally, 1m $\times$ 1m RPC modules are built for use in a prototype calorimeter.

The work started from scratch and at the end silicone-coated bakelite-based RPCs working in streamer mode have been established as an alternative to glass-based RPC working in avalanche mode. Apart from being less expensive, larger pulses and less number of electronic components in streamer mode of operation makes bakelite-based RPCs more attractive.

In addition to the RPC development, this work includes the installation and operation of a 35 ton prototype magnet for ICAL. The ICAL-prototype is installed at VECC as a facility for testing different types of RPC (bakelite and glass) in a ~ 1.5 Tesla magnetic field.

All the activities are part of the R&D effort towards building ICAL detector in INO. In this context, the development and satisfactory performance of bakelite-based RPCs open up new avenue for sensitive detectors in ICAL. ICAL needs about 27000 RPCs and there is always a possibility of using more than one types of electrode materials. Bakelite-based RPCs are attractive from the point of view that the materials are locally made. The work presented in this thesis is likely to open up the horizon for the active detectors for ICAL.

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