Studies on Resistive Plate Chambers (RPC) for INO and scintillators for reactor antineutrino detection

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Introduction

Neutrino oscillation has been one of the most fascinating topics in Particle physics. The determination of neutrino mass and precision measurement of the oscillation parameters will help us understand the origin of the universe and as to why there is more matter than antimatter. Antineutrinos emitted from the core of the reactors can be used to monitor them remotely and determine the state of the fuel burnup in a nuclear reactor in a non intrusive way [1]. It can also be used to check nuclear proliferation. There is a possiblity of the existence of the so called sterile neutrino - A neutrino which does not interact by any of the standard model interactions but only through gravitation and mixing [2]. Detectors used for monitoring can also be used to probe the existence of light sterile neutrinos.

The magnetized Iron Calorimeter (ICAL) detector at the proposed India-based Neutrino Observatory (INO) aims at the precision measurement of neutrino oscillation parameters and determination of neutrino mass hierarchy [3]. It has also been proposed to set up a plastic scintillator based detector array called ISMRAN (India's Scintillator Matrix for Reactor AntiNeutrino) of mass 1 t near the Dhruva research reactor site at a distance of ∼10 m in BARC to understand and develop the technology of reactor monitoring and do possible physics studies.

The thesis has been divided into two parts. The first part focusses on studies related to Resistive Plate Chambers for INO. The second discusses simulations comparing plastic and liquid scintillator detectors for detecting electron antineutrinos produced from the core of nuclear reactors. Background measurements are also discussed.

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PART I - Studies on RPCs for INO

The detector elements in the proposed ICAL detector at INO are RPCs [4]. RPCs are gaseous detectors having resistive electrodes usually made of bakelite or glass. They are fast detectors providing excellent timing and good position resolution.

Plastic Scintillator based Hodoscope

Large number of RPCs (≈30000) are required for the proposed ICAL at INO [3] of ∼4 m^2 area. A setup which can characterize each RPC in a reasonable amount of time for functional parameters such as efficiency, cluster size, strip profile and noise rate for such a large experiment is needed. A cosmic muon hodoscope is a suitable option. The hodoscope at NPD-BARC was constructed to characterize RPCs with cosmic muons, both for the RE4 (4th RPC Endcap disk) upgrade for the CMS experiment during the long shutdown (LS1) and also for the R & D related to RPCs for INO and related experiments [5]. The Hodoscope contains sixteen large area scintillators for characterization of RPCs using cosmic muons as triggers. Using VME based DAQ configured with CERN based software, multiple RPCs can be characterized simultaneously in a fairly automated manner.

Glass RPC with G10 readout

1 m^2 square Glass RPC with G10 readouts operating in the avalanche mode has been characterized using the hodoscope. To reduce the thickness of the RPC, readout based on G10 having a thickness of 1 mm has been explored instead of the familiar polycarbonate foam based readout (∼5 mm thickness). The readout has 32 strips of copper each 1 m long and 3 cm wide. The characteristic impedence of these strips is 5 Ω. Since the preamplification electronics have 50 Ω impedance signals will be distorted due to reflection. Reflection has been reduced by using a matching resistive circuit [6]. RPC has been characterized and

shows an efficiency of ∼95 %. Clustersize is less than 2 strips per event on average [5].

RPC characterization using ANUSPARSH

ANUSPARSH ASIC based preamplifier electronics developed by Electronics Division, BARC is a suitable option for the frontend in the ICAL detector. Efficiency and timing characteristics of the RPC with polycarbonate honeycomb readouts has been tested using these boards and the results are comparable with that measured with G10 using HMC based preamplifiers.

PART II - Scintillators for reactor antineutrino detection

Electron antineutrinos are emitted in the decay chains of fission fragments in core of reactors. Inverse neutron beta decay reaction is a very strong signature used for detecting electron antineutrinos. In a free proton rich detector such as an organic scintillator, a neutrino interacts with a free proton and produces a positron and a neutron. Signal due to the positron is the prompt event and signal due to the cascade of gamma rays generated after the capture of neutron is the delayed event.

Simulation of scintillator geometries

Simulations have been performed on liquid and plastic scintillator based detector geometries using GEANT4 [7]. The plastic scintillator geometry is modular and cubical made of 100 Gd foil wrapped plastic scintillator units each coupled to two 3″ PMTs. The total volume has been fixed to 1 m^3 so that the mass of the detector is ∼1 t. Variations in the granularity have also been considered. The Liquid scintillator geometry has ∼1 m^3 of Gd doped liquid filled in a steel vessel coupled to large area photomultipliers using an acrylic disk. The Gd doping has been considered to be 0.25%.

Performances of the detector configurations for neutron capture, efficiency and resolutions have been compared [8]. Liquid shows the smallest mean capture time (∼12 μs). In case of plastic, granular designs show a moderate capture time (∼30 or 40 μs depending on Gd_2O_3 coat density) and the simple design has a large capture time (∼65 μs)[8].

Under ideal no background condition, with prompt and delayed energy thresholds of 3 MeV, Liquid scintillator geometry shows better efficiency (∼40%) compared to plastic (∼30 %). Considering the issues of safety and the distance at which these detectors would be placed from the reactor, plastic scintillator based geometry appears to be more suitable. The efficiency is lower but still manageable.

Background measurements

To assess the background at the reactor site, measurements with plastic scintillator bars, gamma and neutron detectors have been done. Reactor power correlated background rate has been observed. Combinations of shielding for neutron and gamma have been used to understand the background. Correlated background measurements using plastic scintillator bars, thermal neutron background using Lithium Yttrium Borate (LYBO) [9] and fast neutron background measurement using liquid scintillator with VME digitizer based acquisition have also been performed.

Outlook

Bakelite RPC development for INO and related experiments has been initiated. 1 m × 2 m gas gaps have been procured from General Tecnica, Italy for benchmarking and Indian bakelite RPCs are being made in similar dimension by a local industry. They will be characterized after assembly into RPCs. A prototype called mini-ISMRAN will be setup at the Dhruva reactor hall with 20 Gd foil wrapped plastic scintillator bars together with lead, borated polyethene shielding and muon veto.

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