Prototype developments for a high-resolution neutron detector at R^{3}B

T. Aumann[1], D. Bemmerer[2], K. Boretzky[1], M. Elvers[2,3], J. Endres[3], J. Hehner[1], M. Heil[1],
J.V. Kratz[4], W. Prokopowicz[1], R. Reifarth[5,1], D. Rossi[4], G. Schrieder[1], D. Stach[2], A. Wagner[2],
D. Yakorev[2], A. Zilges[3] for the R^{3}B collaboration

[1]GSI, Darmstadt, Germany; [2]FZD, Dresden, Germany; [3]IKP, Universität zu Köln, Köln, Germany;
[4]Johannes-Gutenberg-Universität, Mainz, Germany; [5]Goethe-Universität Frankfurt, Frankfurt, Germany.

INTRODUCTION

A detector for momentum measurements of high-energy neutrons in the energy range 200 MeV to 1000 MeV is being developed for the R^{3}B experiment at FAIR. The detection principle is based on a combination of converter material and subsequent detection of charged particles from reactions in the converter material. Multi-gap Resistive-Plate Chambers (MRPC) are used for the detection of charged particles. A modular system with about 10'000 electronic channels is considered. The total depth of 1 m, 50% of which are high-Z converter (nuclear interaction length ~17 cm) ensures a detection efficiency close to 100% for neutron energies above 200 MeV. The detector is subdivided into 60 planes with active areas of 2×2 m^2 adding up to a total area of 240 m^2 MRPC modules. A time resolution of the full detector below σ=100 ps and a spatial resolution of less than 1 cm in all three dimensions are desired. In addition, the detector should provide a good efficiency for detecting and reconstructing multi-neutron events.

NeuLAND pre-design based on MRPC

The detection concept for the new neutron detector relies on the combination of converter plus detection material, as also realized in the current detector for fast neutrons LAND (Blaich et al.). A detector composed out of active material only has been considered in the preparatory phase of the R^{3}B Technical Proposal. In principle a dense scintillation material like PbWO4 would be well suited for combining converter and scintillator in one homogeneous layer. However, the high costs as well as the timing properties of the scintillator rule out this option.

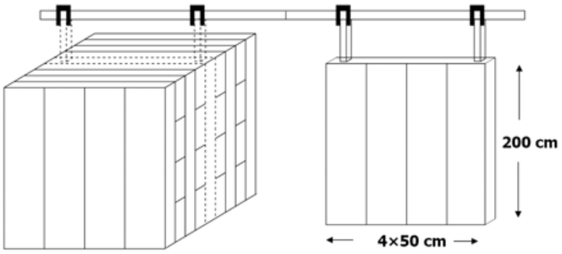

Figure 1: Schematic drawing of the modular structure of the NeuLAND detector.

Resistive Plate Chambers (RPC) are detectors for ionizing particles and presently these types of detectors are used in many different experiments involving cosmic rays and accelerators such as STAR, RICK, CMS and ATLAS at LHC, CERN, AGRO etc. Excellent time resolutions down to σ_t<50 ps were achieved for minimum ionizing particles using multi-gap resistive plate chambers (MRPC). Large detector arrays with high granularity are feasible, thus the MRPC detector systems partly take over the classical application of scintillators for ToF-arrays. A. Blanco et al. showed that a large area MRPC (160 cm ×10 cm, 2 strip readout) can provide good time resolutions of σ_t~50-70 ps and a position resolution of 1.2 cm along the strips using the time difference method. In addition, an efficiency for minimum ionizing particles of more than 95% was achieved.

The present design concept foresees a modular structure of MRPC modules with a size of 200×50 cm^2 each. Four modules build up one detector plane (s. Figure 1).

Prototype development and tests at FZD

The Forschungszentrum Dresden-Rossendorf (FZD) is involved in building and testing MRPC structures capable of sustaining high rates (R. Kotte et al.), as they are expected in the CBM experiment. Now the development of MRPC prototypes with intrinsic neutron converter structure for the NeuLAND detector at FAIR is under investigation. The 40 MeV electron beam from the ELBE facility at FZD with its picosecond time structure is used as a high-intensity defined source of minimum ionizing particles. The timing of the prototypes built at FZD and also at GSI is studied in regular short beamtimes at ELBE.

Based on the R^{3}B-Technical Proposal a first prototype has been developed where design decisions can be verified experimentally. As converter material for producing charged particles from the initial high-energy neutrons, stainless steel has been selected due to its good handling and commercial availability in pre-cut sizes. For the actual MRPC structure, commercial float glass (0.55 mm thick) has been used, with 0.3 mm diameter standard fishing line as spacer. All prototypes tested so far had an active area of 200 x 400 mm. Figure 2 shows the result of a measurment of the time resolution.

---

* Work supported by BMBF (06MZ222I), (06DR134I), (06DA129I)
GSI FuE DR-GROS

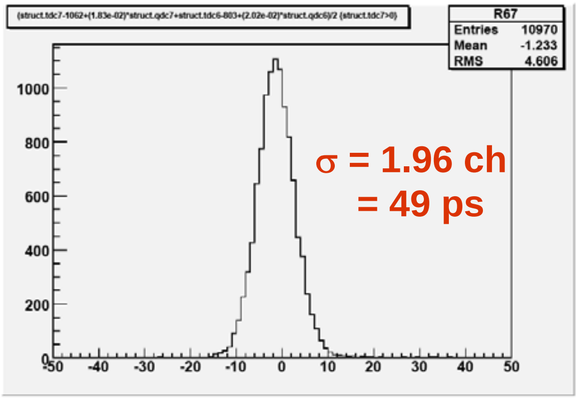

Figure 2: Typical time spectrum of a NeuLAND prototype with single-ended readout after applying a linear walk correction.

Prototype developments and tests at GSI

The prototype constructed at GSI is similar to the FZD type, but addresses some different aspects concerning in particular number of gaps, distances between anodes strips, and impedance matching.

The active area is 400×200 mm^2, subdivided in 8 anode strips, each 400 mm long, 25 mm wide and 4 mm thick Fe-material, acting as the same time as converter for the neutrons. The distance between the anode wires is kept to a minimum value of 0.3 mm, which is essential in terms of converter and detection efficiency. We use 2×4 gaps, built from 0.55 mm glass plates and gap sizes of 0.3 mm using fishing lines as distance holders (Figure 3).

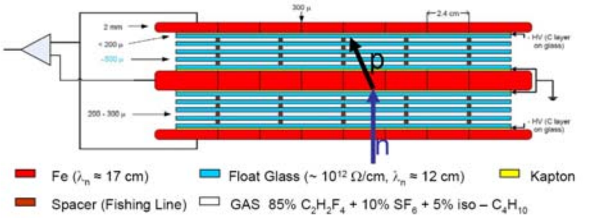

Figure 3: Schematic view of the GSI prototype.

The outer electrodes are 2mm thick Fe-plates, again acting as a converter at the same time. The high voltage is applied through a semiconductive layer which is sprayed on the outer glass plates.

One critical issue addressed is the impedance matching of the anode wires to the frontend electronics. The impedance of the anode wires was determined with a signal analyser to be 9.5 Ω. This valiue has to be compared with the typical input impedance of the electronics is 50 Ω. Measurements of the behaviour of the signal reflection and transmission as a function of the frequency of the signal in case of no impedance matching between anode strips and readout were performed using a network analyser. The transmission was found to be below 10% for most of the frequencies and high frequencies play a dominant role for the excellent timing properties.

In order to improve the signal transmission, the use of transformers or resistor networks for the purpose of adapting the impedances were investigated. For the high bandwidth transformer TC 4-11 a decrease of reflections to values below 10% was found for a wide range of frequencies. Because of this promising result the transformers were coupled to the anode strips using a special type of PCB board. The measurements with the network analyser show that reflection and transmission of the combination of anode strip and transformer board are significantly improved, but not for the full bandwidth (Figure 4).

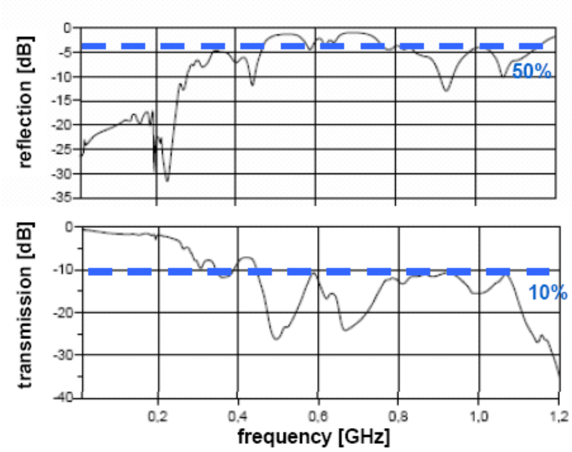

Figure 4: Presented here are the reflection and transmission properties as a function of frequency for the anode strip read out via the transformer board.

Gas recycling concept

The standard gas mixture for timing MRPCs consists of 85% Reclin-134a (1,1,1,2-tetrafluoroethane), 10% SF_6, and 5% isobutane (i-C_4H_{10}). Reclin with its high primary ionization density fulfills the role of the main ionization medium, whereas SF_6 serves as an electron scavenger for low energy electrons and isobutane is used as an UV photon quencher. Although Reclin and SF_6 both are neither flammable nor reactive or toxic, special attention has to be paid when using these gases since they contain a significant global warming potential (factor 103 and 105 versus CO_2 for Reclin, SF_6 respectively). Therefore technical solutions need to be found avoiding the emission of these two gases.

A pre-concept was developed to overcome this difficulty. Two variants of a gas recycling circuit are currently being discussed; both aim for a reuse of the gas mixture for the detector after cleaning and controlling the quality (s. contribution by D. Rossi et al.).

References

A. Blanco et al., IEEE Trans. Nucl. Sci **48** (2001) 1249
T. Blaich et al., NIM **A314** (1992) 136
R. Kotte et al. NIM **A 564** (2006) 155