Construction and Test of a Large NeuLAND Prototype Array*

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NeuLAND (new Large-Area Neutron Detector) is the next-generation neutron detector integrated into the R3B experiment, and is a key instrument for a major part of the physics program. NeuLAND features a high detection efficiency, a high resolution, and a large multi-neutron-hit resolving power, achieved by a highly granular design with a total of 3000 plastic scintillator bars [1]. In January 2013 the Technical Design Report [2] has been approved by FAIR, following the recommendation by the Expert Committee Experiments (ECE) at its first meeting in November 2012.

Here we report about the progress of the NeuLAND project, which was dominated in 2012 by the transition from prototypes to mass production. During the previous year 200 NeuLAND modules and their readout were purchased and brought into operation.

A number of the final size NeuLAND bars have been available for in-beam tests at the ELBE accelerator. There, bunches of 30 MeV electrons with a time definition of better than 20 ps impinged on the detectors to be tested. The number of electrons per bunch was reduced to one, enabling sensitive timing measurements with the accelerator RF signal as time reference [3]. As single 30 MeV electrons are close to minimum ionizing particles, this method gives an upper limit for the time resolution to be expected in NeuLAND, where the signal will mainly stem from protons.

Several NeuLAND bars of the final geometry have been tested at ELBE, using the recommended one inch photomultipliers, in several cases Tacquila electronics, and in others commercial electronics with 25 ps time-to-digital converters. The ELBE data show a time resolution of $\sigma = 130$ ps when a cut on a narrow slice of the charge / time over threshold signal is applied, consistent with the data from earlier proton experiments. When the whole charge distribution without any cuts is used instead and a walk correction is applied, the resolution worsens somewhat, to $\sigma = 170$ ps. This upper limit is very close to the required value of 150 ps. For some initial NeuLAND bars with deficient polishing, time resolutions of $\sigma > 200$ ps and a significantly suppressed charge spectrum were found at ELBE. The latter point was subsequently also observed in tests with radioactive sources and with LED's.

As consequence from the systematic ELBE data, a detailed quality check procedure was developed to verify a satisfactory light output, which turned out to be closely related to the surface treatment of the NeuLAND bars. The quality-control procedure for each bar contains, besides an optical inspection, a measurement of the light output, which is then related to the light output of a reference bar with a proven very good performance. For this relative measurement light emitted by an LED is illuminating the bar on one readout side. On the opposite readout side the

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light is detected by using a photomultiplier (PM) of the same type as foreseen for the final assembly.

In late autumn the experiment S406 in Cave C was carried out using deuteron beams for calibration and benchmarking of both the existing LAND detector [4] and NeuLAND prototypes. For the latter 150 NeuLAND bars were mounted in a special array with 15 layers of ten vertical bars each. The bars in the array have been tested using cosmic rays, and in the best cases a time resolution of $\sigma_t^{Cosm.} = 130$ ps has been reached. The photographs in figure 1 detail the assembly and transport to Cave C prior to the beam time.

Figure 1: NeuLAND test array: after insertion of 100 scintillator bars (left) and transport of the assembly including 150 bars and its readout electronics to Cave C (right).

During the beam time the NeuLAND array was exposed to fast "mono-energetic" neutrons originating from quasi-free breakup reactions of deuterons impinging on a CH_2 target at six different beam energies. The collected data sets for neutrons at 200, 300, 500, 800, 1000 and 1500 MeV will serve to determine the efficiency of the NeuLAND test array as a function of neutron energy and thus be an important cross-check for the simulations carried out during the NeuLAND design phase [2, 5]. Another crucial parameter for NeuLAND is the time resolution. The measurement at 1500 AMeV was carried out at two different distances from the breakup target. At this high beam energy the time of flight variation due to the intrinsic momentum distribution of the knocked-out proton in the deuteron is rather small with ($\sigma_t^{int.} \approx 100$ ps) at 5 m distance. The measurement at 5 and 10 m distance therefore allow to disentangle the contribution from the ToF resolution of the detector and the width related to the wave function of the deuteron. While the results on neutron response demand a careful off-line analysis, on which we will report later, the online analysis of primary deuterons hitting the NeuLAND array results in a promising time resolution of $\sigma_t^D = 115$ ps.

Together with the NeuLAND test array two different large-size MRPCs (Multigap Resistive Plate Chambers) [6, 7], which were developed during the design phase of NeuLAND, were exposed to the neutron flux, allowing a characterization of these detectors.

In the same experiment, after removal of NeuLAND from the setup, LAND was calibrated using 200 to 1500 MeV neutrons as well. For the lower energy settings several parasitic experiments were carried out using the fast protons stemming from the break-up process. Behind ALADIN a ToF-Wall served for proton detection and various CsI and NaJ detectors were mounted for investigations of proton detection with the future R3B calorimeter CALIFA and with the existing Crystal Ball.

Approaching the step of mass production of NeuLAND double-planes an adaption of the HV supply and a redesign for the readout board of TacQuila electronics is underway. A cost-effective possibility for the HV supply of the 6000 PM's of NeuLAND has been developed by PNPI. It foresees one master HV supply per 3000 PM's providing 1.5-2 kV. Via distributor boards with adjustable attenuators for 50 PMs each, the supply voltage can be regulated downwards for the individual channels. A slow control via an FPGA based control board is provided via ethernet from a host computer. The design has been completed, and we are about to order the first demonstrator devices. An adaptation of the voltage divider stage of the PM with respect to a reduction of power-consumption was already realized by the provider. For the readout electronics we will move from the TAC27-ASIC based time measurement to an FPGA TDC measurement, which is much more flexible, and has been proven to be technologically feasible by GSI. This will enable a measurement of time over threshold, thus providing an additional independent energy measurement and will feature multi-hit capability. The design can be based on building blocks available for the FEBEX readout series, which also allows to avoid specialized VME boards, that became in the mean time more difficult to acquire. The FEBEX readout chain is set up via fibre optics so that grounding problems will be minimized.

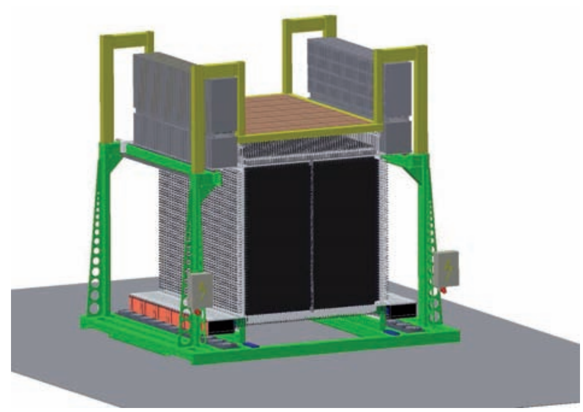

Figure 2: Technical drawings of the NeuLAND base frame together with its 30 double-planes and adjacent boxes for read-out electronics and HV-supply.

After construction and realization of the support structure for the NeuLAND test array the detailed design of the holding structure for the planes and the base frame of NeuLAND has been reinvestigated. As detailed in the NeuLAND TDR, we foresee to arrange the 3000 scintillator bars in double-planes with 50 vertical and 50 horizontal bars, respectively. Fig. 2 shows the technical drawings for the frame loaded with all planned 30 double-planes.

It was decided to adapt also the read-out electronics, HV distribution and monitoring system to this modular design of the double-planes. This allows the collaborators to build individual and fully functional double-planes which can be tested separately and immediately used once mounted in the base frame. Fig. 3 displays a front view of one double-plane. The boxes on top, left and right contain the read-out electronics and will be connected via a read-out bus. The boxes at the bottom comprise the HV distribution system.

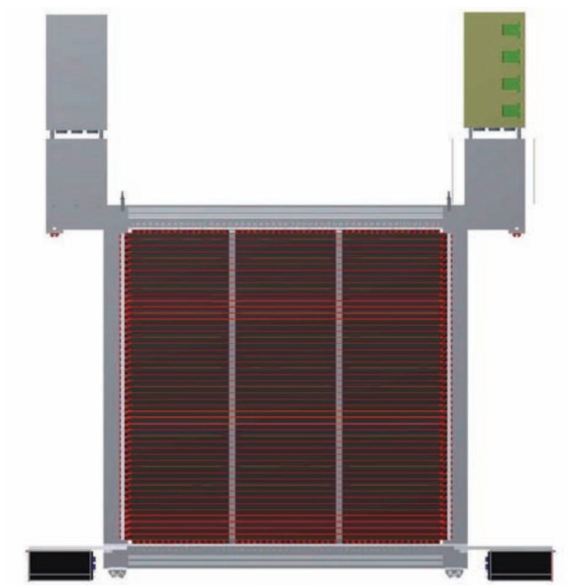

Figure 3: Technical drawings of one NeuLAND double-plane.

The next step is the assembly of NeuLAND double-planes and its inclusion into the detector frame. During 2013 a 20% NeuLAND demonstrator shall be accomplished and exposed to beams at GSI in beginning of 2014.

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