Test bench for measurements of NOvA scintillator properties at JINR

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ABSTRACT

The NOvA experiment was built to study oscillation parameters, mass hierarchy, CP-violation phase in the lepton sector and θ_{23} octant, via ν_e appearance and ν_μ disappearance modes in both neutrino and antineutrino beams. These scientific goals require good knowledge about NOvA scintillator basic properties.

The new test bench was constructed and upgraded at JINR. The main goal of this bench is to measure scintillator properties (for solid and liquid scintillators), namely α/β discrimination and Birk's coefficients for protons and other hadrons (quenching factors). This knowledge will be crucial for recovering the energy of the hadronic part of neutrino interactions with scintillator nuclei.

α/β discrimination was performed on the first version of the bench for LAB-based and NOvA scintillators. It was performed again on the upgraded version of the bench with higher statistic and precision level. Preliminary result of quenching factors for protons was obtained. A technical description of both versions of the bench and current results of the measurements and analysis are presented in this work.

INTRODUCTION

NOvA is a long baseline (810 km) neutrino experiment that studies various parameters of neutrinos. It consists of two main elements: the Fermilab accelerator complex (NuMI – Neutrinos at the Main Injector) as the neutrino source, and two detectors. For more details see [1].

The NOvA experiment uses two detectors: a 330 metric-ton near detector at Fermilab (near Chicago) and a much larger 14 metric-kiloton far detector in Minnesota just south of the U.S.-Canada border. The NOvA detectors are assembled with modules of extruded PVC (**P**oly**v**inyl **C**hloride) which is coated with titanium dioxide to enhance reflectivity. The technology is similar to that used commercially for garage doors and fencing. Modules of 32 cells are assembled by gluing two 16-cell extrusion together (See Fig. 1). Each cell has an interior size of 3.8 cm transverse to the beam direction and 5.9 cm along the direction. The length of the modules ranges from 15.6 m for the far detector to 4.2 m for the NOvA near detector.

What is a scintillator?

One of the methods of detecting ionizing radiation in experimental physics is to use scintillators. A charged particle passing through a substance deposits its energy within. Part of this energy goes to photon production. For some substances (scintillators) this portion is significant, so that generated light can be detected and measured by photosensors or photodetectors. The spectrum and intensity of the light signal depends on the intensity of the energy release, and the type of passing particle and attributes of the scintillator, see [2] and [3]. Many scintillators, depending on radiation length, are sensitive not only to charged particles, but also to gamma-radiation and neutrons. These are the main attributes
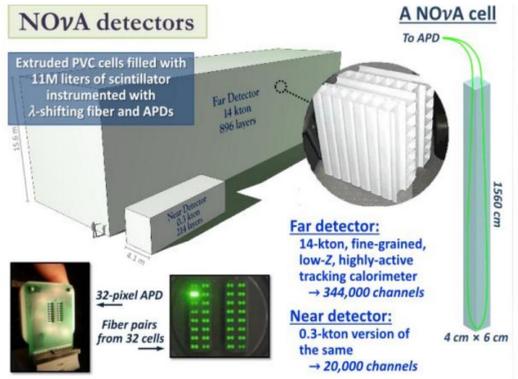

Figure 1. General design of NOvA detectors

of scintillators: light yield, the spectral composition of radiation, energy resolution, decay time, radiation resistance, radiation length and quenching factors – Birks Law.

Birks Law

For our work the most important attribute is the Quenching factor.

The scintillation response, S, of organic crystals depends on the nature and energy, E, of the incident ionizing particle, of residual range r. The specific fluorescence, $\frac{dS}{dr}$, is not in general proportional to the specific energy loss $\frac{dE}{dr}$. Quenching effect means that molecules are damaged by the particle and by the "excitons" produced by it. By considering this effect it is possible to show that:

$$\frac{dS}{dr} = \frac{A\frac{dE}{dr}}{1 + kB\frac{dE}{dr}} \tag{1}$$

Where A and kB are constants, which have been evaluated for scintillator from observations of S and E, and the range-energy data. The method used for evaluating the relative response is applicable to ionizing particles of any nature or energy, and also to the different organic scintillation crystals or liquids.

The quenching factor is a very important attribute of any scintillator. If we do not know the quenching factor, we cannot say what kind of particle passed through the scintillator and what primary energy it had. So, for example, in large neutrino experiments (Daya-Bay, JUNO, NOvA, DANSS) it is very important to know the precise value of the quenching factor for the scintillators.

METHODICAL ASPECT OF THE MEASUREMENT AND HARDWARE SETUP (SEE FIG. 3)

The first version of the test bench consists of a few components (see Fig. 2 and 3). First is the Black Box with three sections. The top and bottom sections are used like a muon telescope. A muon telescope helps one to divide the light from muons and radioactive sources. Light is measured by PMTs (**P**hoto**m**ultiplier **t**ubes) and digitized by ADCs

(**A**nalog-to-**d**igital **c**onverters). Inside the middle section it is possible to place scintillator samples and all necessary radioactive sources (for α/β ratio measurements). Second is the neutron source (Am-Be) with the NaI crystal. And the final component is scintillators and different radioactive sources (see Fig. 3).
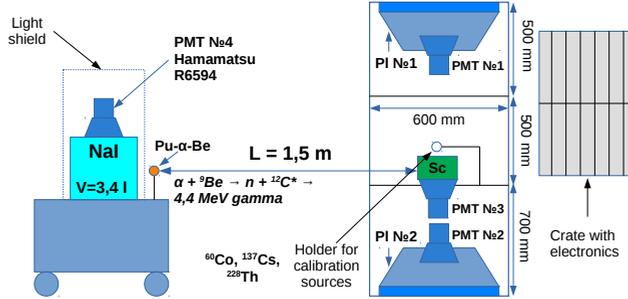

Figure 2. First version of the test bench

Firstly we have to measure the α/β ratio for a scintillator (see Fig. 3). This procedure is necessary for the calibration of our ADC and testing of our method. After that it is possible to measure the quenching factors for different hadrons. In the case of NOvA we want to measure Birk's coefficients for protons with energy in the range of 1-14 MeV. But it is not so easy to deliver protons with this energy inside the scintillator. We have to use a neutron source and measure the energy of recoil protons. Recoil protons are produced in the liquid scintillator by neutron-proton scattering events using a neutron generator ING-27 with a monochromatic energy distribution or a Am-Be source with continuous spectrum. Hence, the proton light output function can be determined from the position of the recoil proton edge in the pulse-height spectra produced by mono-energetic neutrons (see Fig. 5). In the case of a continuous spectrum it is possible to use the time-of-flight method for speed/energy determination. It is rather crucial to have a GEANT4 model for our bench and measurement process. With its help we can compare theoretical and measured spectra, which allows one to extract all necessary parameters.

EXPERIMENTAL SETUP OF THE UPGRADED TEST BENCH

With this hardware configuration (see Fig. 2) we had a problem with precision level. It is mostly connected with the electronics. So we decided to upgrade the test bench.

In addition to the existing part we added several components. The first is a Black metal box with sealing rubber and all necessary connectors. It is used to isolate the inner structure of the box from light. The second is a PMT with divider and teflon cuvette. Additional cuvette and PMT increases the statistic and allows us to cross-check the measurement process and result. The PMT and cuvette are put inside the box in a vertical orientation (see Fig. 6). The third is all support electronics like ADC (with higher sampling – it gives us required precision level), High-Voltage source and laptop with required software.

MEASUREMENTS

We repeated α/β ratio measurements using the same method (see Fig. 3) but on the new version of the bench with higher statistic and precision level. Also we performed a
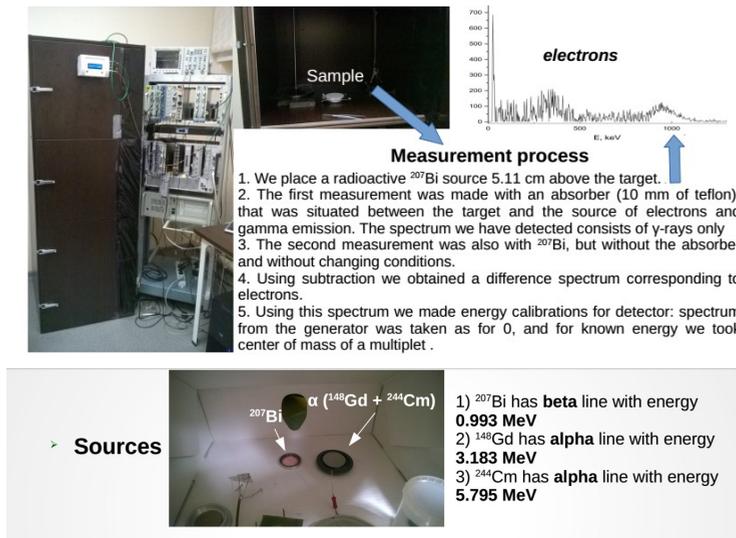
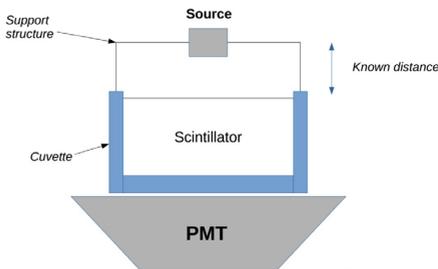**Figure 3.** Radio-Chemical Lab bench and measurements. Radioactive sources

Figure 4. α/β ratio (evaluation of the quenching factor)
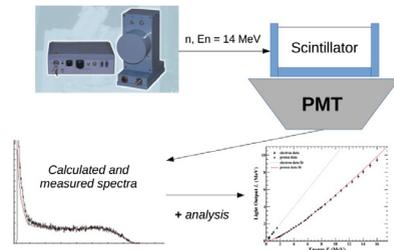
Figure 5. Measurement with a neutron source ING-27

measurement of the quenching factor for recoil protons using a Am-Be neutron source (see Fig. 2). The resulting curve is pretty well described by Birks Law (1 and Fig. 8).

Results

Preliminary results are as follows (see 7 and 8):

For the Gd+Cm source quenching factors for LAB-based scintillator (α) are equal to **22,2** for Gd (energy 3,183 MeV) and to **16,5** for Cm (energy 5,795 MeV). For the NOvA scintillator they are equal to **23,58** and **17,6**. Using these numbers and (1) one can evaluate the real energy of an α particle.

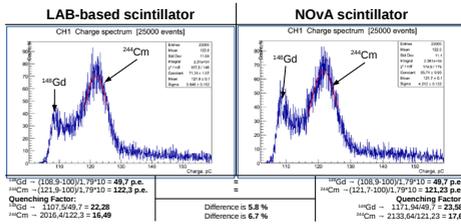**Figure 6. General design of new version of the bench**
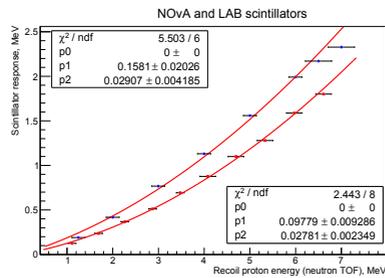

Figure 7. Resulting spectra for α sources

Figure 8. LAB-based(blue) and NOvA(red) light response for recoil protons

CONCLUSION

We performed measurements with α and β sources on the test bench at the Radio-Chemical Lab. Due to a problem with precision level we decided to upgrade the test bench. In addition to the existing part we added a new sensitive part and better electronics. The resolution $(\frac{\delta E}{E})$ of the upgraded bench has been increased by 30%. We performed the measurement (α/β evaluation) for LAB-based scintillator and NOvA scintillator on the upgraded bench. We performed measurements with a Am-Be neutron source and got the first resulting curve. This curve is pretty well described by Birks Law.

ACKNOWLEDGMENTS

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