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ESS WS SCINTILLATOR SYSTEM DESIGN AND TEST RESULTS

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Abstract

The European Spallation Source (ESS) in Lund, Sweden, is a pulsed neutron source based on a linac. The ESS linac has been designed to accelerate protons to 2 GeV with a peak current of 62.5 mA and deliver a 5 MW beam at 14 Hz to a rotating tungsten target for neutron production [1].

The ESS Super Conducting Linac (SCL) Wire Scanner (WS) systems are based on scintillator detectors with wavelength shifting (WLS) fibers. The scintillators are mounted on the beam pipe [2]. The detectors are coupled to long haul optical fibers which carry the signals to custom front end electronics sitting in controls racks at the surface [3]. The main questions are the coupling and the signal loss from scintillators to photodetector. It is known from simulations that we may end up below the noise level if coupling efficiency is not as high as expected, several test campaigns were planned and executed to demonstrate experimentally each stage in the acquisition chain and ramp up readiness for a validation test before installation in ESS tunnel. The scintillators type, WLS and acquisition chain have been characterised at the Institute for High Energy Physics (IHEP), Protvino; the Proton Synchrotron Booster (PSB), CERN, Switzerland; Cooler Synchrotron (COSY), Forschungszentrum Jülich Institut für Kernphysik (IKP), Germany, and Spallation Neutron Source (SNS), Oak Ridge National Laboratory (ORNL), USA. The test results of this type of system design, differing from the standard approach where photomultipliers are coupled to the scintillator installed close to WS under radiation, will be presented. The results may be of interest for such as medicine or safety, where the signal could be transferred away from the place of measurement to photodetectors location.

INTRODUCTION

In high energy physics experiments, WLS fibers are used to collect the light from a scintillator in order to reduce calorimeter geometry complexity. The same approach is exploited for the ESS WS in SCL to protect the photodetector from radiation. The light generated by the scintillator is collected by two WLS and is transported by 60 m optical fiber to the readout electronics, which have been developed and delivered by Elettra [3].

The photodetectors either avalanche photodiode (APD) and photodiode (PD) are in an optical front end (OFE) enclosure installed in the area with less radiation compared to the accelerator tunnel [4] (Fig. 1.).

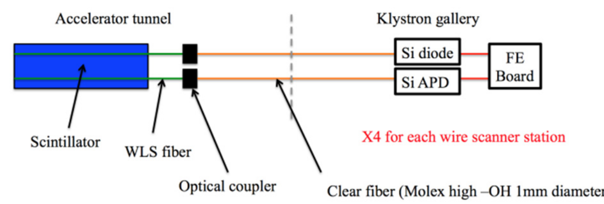

Figure 1: The SCL WS signal processing.

The signal of a scintillator depends on the wire position, but summing the signal from 4 scintillators, positioned in a frame-like shape around of beam pipe, the variation of the deposited energy will decrease. The signal from each scintillator will be acquired on a ~~dedicated~~ acquisition channel, the beam sizes will be reconstructed by summing the signal from all the scintillators.

DETECTOR SPECIFICATIONS AND TEST IN PROTVINO

First of all, the scintillator and WLS assembly differing from fish-tails or adiabatic ones is the important aspect. The plastic scintillator has the peak emission in the visible range of light. The WLS shifts the blue light to green light, their absorption peak matches the peak emission of the scintillator. Another relevant aspect is the actual physical coupling between WLS and optical fiber which transports the WLS light to two detectors. A large diameter gradient-index fiber was chosen. It is expected to be affected by modal dispersions and the constraints on the time resolution; however, it is worth noticing that the SCL WS timing requirement is 1 µs. To maximize the coupling with WLS, we chose a 1 mm core diameter long haul clear fibre to optical front-end unit: Molex multi-mode optical fiber 1000/1035.

The main detector features are listed as follows:

- Plastic organic scintillator SC-201 from Protvino and BC-408 from Saint-Gobain were investigated. Organic

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scintillators are faster and cheaper, but degrade with radiation.

- The overall dimensions of the detector shall not be more than 250 x 60 x 50 mm due to the limited space for installation.
- The reflective material is Tyvek with reflection coefficient 0.96.
- The groove holding a wavelength-shifting fibers has a depth of 2 mm, a length of 250 mm, and a width of 1.5 mm, the centre of the groove at 10 mm for the guide edges.
- The WLS fiber consists of: 1 mm core fiber, multi-cladding structure, type Kuraray Y-11 (200), blue to green light shifter, re-emitted light peaks at 476 nm, absorption peak 430 nm. The geometry of the WLS fibre in the scintillator has been optimized to a maximum signal intensity. The optical WLS termination is 1060 µm SMA905.
- The optical glue (BC-600) optimizes the optical coupling with the WLS. The absolute value of the light output (LO) of a fiber with glue is about twice as large as that of a no-glued fiber. However, the relative drop in the LO of a fiber with glue is noticeably steeper than a non-glued fiber after a dose of approximately 10 kRad (Fig. 2).

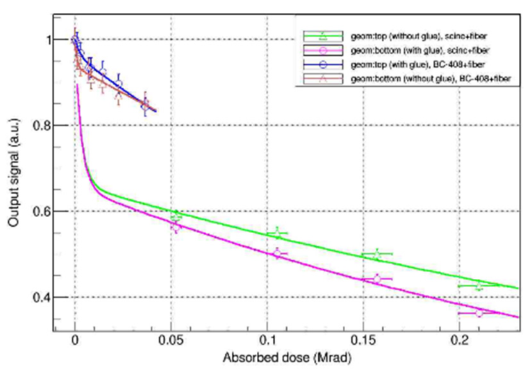

Figure 2: Relative light output as function of the absorbed dose for BC-408 and SC-201 scintillators.

After investigation and tests for the production of the detectors, the BC-408 scintillator was chosen for its better in light output and radiation resistance [5]. Each finished module was tested using the cosmic ray muons and radioactive β- source (Fig. 3).

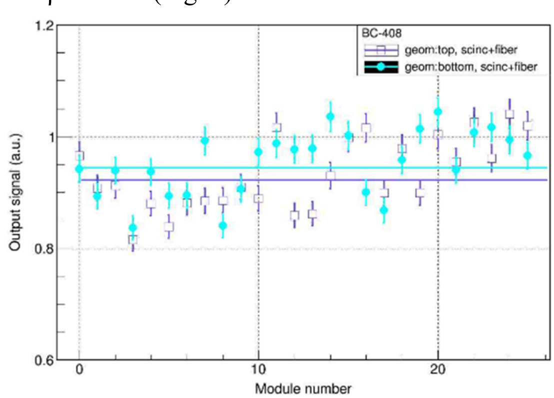

Figure 3: The relative light output for each of the tested detector.

SCINTILLATOR TEST AT ESS

The detector prototype was tested in the ESS optics lab with a photodiode and a light source This test demonstrated the expected functionality of the scintillator with the WLS.–The scintillator was illuminated by a 365 nm diode, was pulsed at 900 Hz, with a duty cycle equal to 0.5 and the signal was measured by an oscilloscope (Fig. 4).

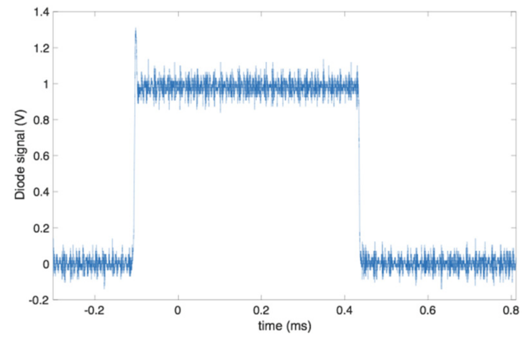

Figure 4: The signal trace of scintillator.

FIRST BEAM TEST AT CERN

The test was carried in PSB [6] with beam energy 1.4 GeV. The scintillator with the WLS and additionally a light-emitting diode (LED) was installed close to the WS, using an already existing long-haul fibre with diameter 65 µm for transport a light to surface photodetectors (Fig. 5).

Figure 5: The installation in PSB at CERN.

The signal of the scintillator was evaluated by a photomultiplier at the surface (Fig. 6).

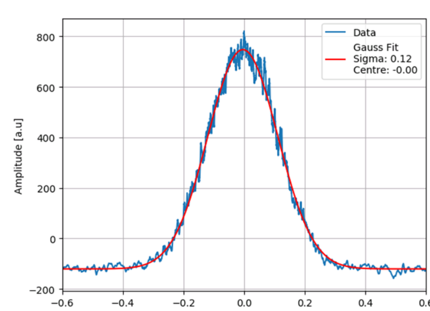

Figure 6: The beam profile, measured by a scintillator.

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TESTS CAMPAIGN IN COSY

A test campaign at COSY [7] allowed to make the first assessments of the detector's performances, to fine tune the system and demonstrate experimentally that the whole acquisition chain concept from detector to electronics in rack is viable. The full acquisition chain was tested with protons, deuterons and H- in injection beams. In the injection area installation, which is close to beam loss monitors we already detected a response from photodetectors, while using the beam parasitically. The test at Faraday cup (FC) location for 20 ms, 4 µA beam pulse gave the clear signals (Fig. 7).

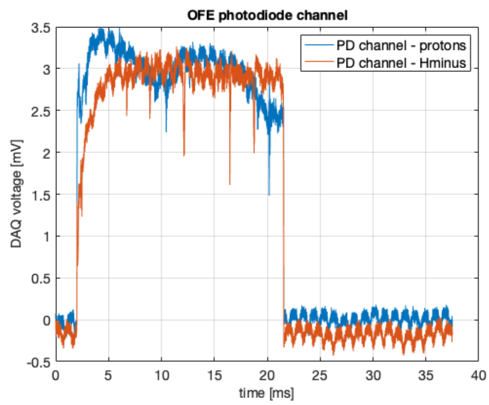

Figure 7: The signals at the FC location at COSY.

In summary, the tests campaign in COSY experimentally validated the proof of concept in question and demonstrated readiness for a final verification test with detectors installed by a wire scanner system in SNS.

VERIFICATIONS IN SNS

In order to make the first verifications of the complete acquisition chain and signal processing of the ESS WS system, tests with beam were performed at the SNS [8]. In particular, the four scintillators were installed exactly as in the frame-like ESS configuration, coupled to long haul fibers and the acquisition electronics (Fig. 8).

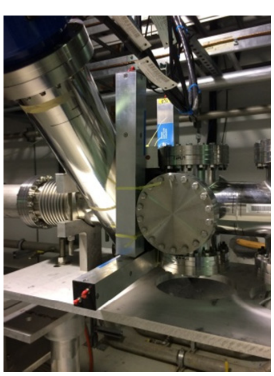

Figure 8: The installation of scintillators at SNS.

The measurements were performed with the H- beam of SNS, at a rate of 1 Hz and pulses of 10 µs.

Fig.9 shows two examples of waveforms acquired by one scintillator: one with no saturation in the Region Of Interest (ROI), and another one with clear saturation when the wire is in the beam core. Further tests, simulations and analysis will continue to reconstruct the beam profile.

The results of the SNS tests point out that the system is promising for the intended use at ESS.

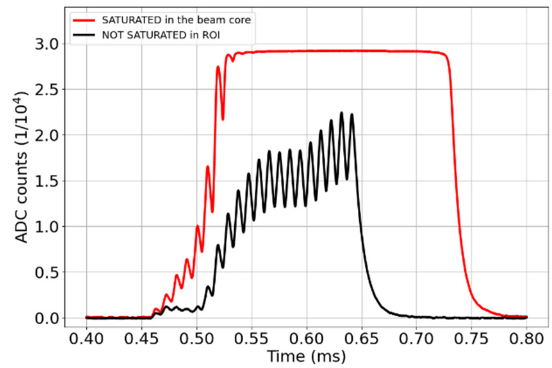

Figure 9: Two examples of scintillator signals during the SNS test.

CONCLUSION

The history of the tests for the WS detector and signal proceeding of the ESS Superconducting linac was summarized. The tests took place at CERN, COSY, IHEP, ESS and SNS. We took a successful road from concept to proof and verification of this approach of detector signal proceeding. We are confident with scintillator coupled with the acquisition system for ESS WS conditions, however there are still some questions regarding the detector as well as the signal degradation due to the radiation environment. Dedicated studies are planned in relation to the photodetectors signal amplitude, which is expected to be the limiting factor for some WS locations in the ESS SCL.

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