# WIRE SCANNER SYSTEMS AT THE EUROPEAN SPALLATION SOURCE (ESS): TESTS AND FIRST BEAM COMMISSIONING RESULTS

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## *Abstract*

The ESS beam instrumentation includes 3 different type of Wire Scanners (WS). Double wires systems are deployed in the Medium Energy Beam Transfer (MEBT) part of the Normal Conducting Linac (NCL), and single wires and flying wire instruments are being tested and installed in the higher energy sections of the ESS linac. First beam tests results from the MEBT systems will be presented. The superconducting linac (SCL) WS shower detection systems are based on scintillator detectors coupled to long haul optical fibers, which carry the signals to custom front end electronics sitting in controls racks at the surface. The acquisition chain have been characterized at IHEP (Protvino, Russia), Elettra (Trieste, Italy), CERN PSB, COSY (IKP, Germany) and SNS (USA) before installation in the ESS tunnel. The test results of this system design, differing from the standard approach where photomultipliers are coupled to the scintillator will be presented.

## INTRODUCTION

The ESS is since 2018 in a phase of commissioning with beam of the NCL [1, 2], while installation in the high energy sections progresses. When running at full installation completion, a 62.5 mA proton beam at a repetition rate of 14 Hz and pulse length of 2.86 ms will be accelerated up to 2 GeV, resulting in an average beam power of 5 MW. Wire scanners are part of the ESS beam diagnostics design to measure the beam profile and transverse halo at a number of locations along the Linac (Fig. 1).

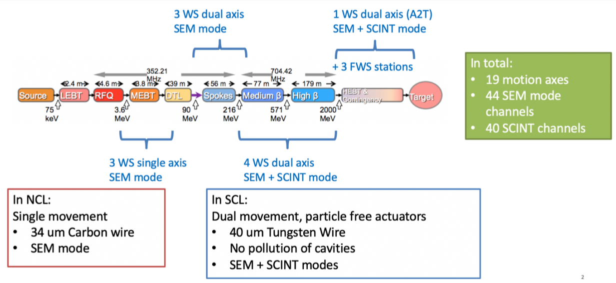

Figure 1: ESS LINAC WS installation layout.

The overall system architecture and installation status is first presented, before introducing beam commissioning results in the MEBT. Last but not least, the first tests results with beam of the WS scintillator detectors and their complete data acquisition chain are presented.

## WS SYSTEM STATUS

The WS system measurement principle consists of moving a wire across the beam in step by step mode or at constant speed while monitoring a signal proportional to the number of particles interacting with the wire. Key specifications of the system include a time resolution of 1 µs, an accuracy of ±0.1 mm and a dynamic range of $10^3$.

At low energy, the mode of detection is based on Secondary Emission (SE), while at energies above 200 MeV, the primary mode of detection will be the measurement of the hadronic shower created in the wire. These high-energy secondaries are detected with scintillator detectors installed around the beam pipe.

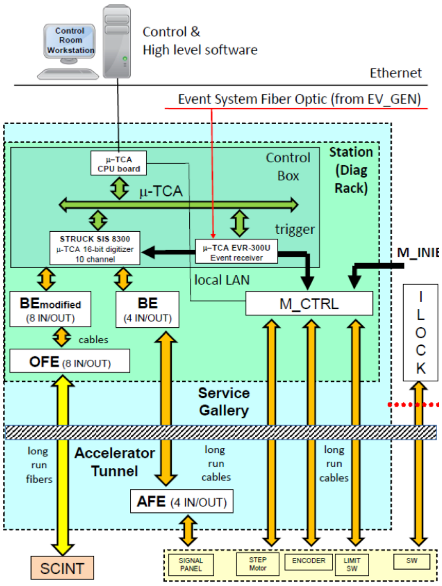

Figure 2: WS signal acquisition chain.

The beam power at ESS is a challenge for this type of interceptive diagnostics. The ESS WS are therefore only used in beam modes where the beam power is reduced, in order to preserve the device integrity by limiting thermal load. Carbon wires are used on double-wire actuators in the MEBT, while the high energy stations on Linac Warm Units (LWU) are equipped with single tungsten wire forks to measure each transverse plane. These actuators are assembled and tested in ISO class 8 clean rooms to allow final installation on the

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high purity LWUs. Flying wire systems [3] are deployed in the High Energy Beam Transfer (HEBT). No Scintillator detectors are installed downstream the actuators at stations in the MEBT, the system relies only on the SEM mode in this section as scintillators yield is insufficient at an energy of 3.62 MeV. The transverse beam profile is reconstructed by plotting the detectors signal vs the wire transverse position.

The MEBT actuators are a delivery from ESS Bilbao, while the high energy actuators were designed and delivered by Danfysik (single wire actuators) and CERN (Flying wire, or Fast Wire Scanner). The complete data acquisition system is a delivery from Elettra Sincrotrone Trieste in Italy [4]. It relies on an analog and Optical Front End (OFE) installed on the accelerator structure by the WS actuator, combining low and high gain channels in order to maximize dynamic range. Differential signals are then acquired by a back-end installed in control racks, connected to a microTCA based digitizer system(Fig. 2). The software control system is based on EPICS. A system self-test verifying the wire integrity is made possible by injecting current pulses through the wire using the front-end and back-end electronics and reading the pulses back through the complete acquisition chain. The motion part of the control system is based on EtherCAT hardware and on an open source motion control framework for EPICS environment [5]. All of the systems' components, including rack electronics have been acceptance tested and are either installed on the machine in the NCL or ready for installation in the cold LINAC. 70% of the beam line actuators are installed and locally tested on LWUs in the SCL, and the 3 MEBT systems are fully deployed and have been tested with beam at ESS after a set of verification activities in 2022.

## MEBT WS BEAM STUDIES

Following successful deployment and testing without beam, the 3 MEBT wire scanners were tested with a 5 µs, 1 mA pilot beam pulse at a 1 Hz repetition rate. WS locations in the MEBT are depicted on Fig. 3.

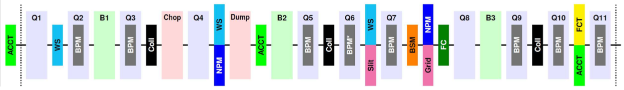

Figure 3: ESS MEBT layout.

Once wire integrity was tested, bias voltage, acquisition and motion parameters such as region of interests, scanning speed and range were optimized. Higher beam currents allowed to tune the parameters of the gain switching mechanism implemented in the beam detection algorithm that, by mixing and re-scaling low gain and high gain samples, overlaps and fits the acquired points to a single beam profile plot for each scanned plane. Scans were performed on all 3 stations in parallel in order to assess whether scanning with WS1 had an impact on measurements with the downstream stations. No measurable effect was detected, as can be seen on Fig. 4.

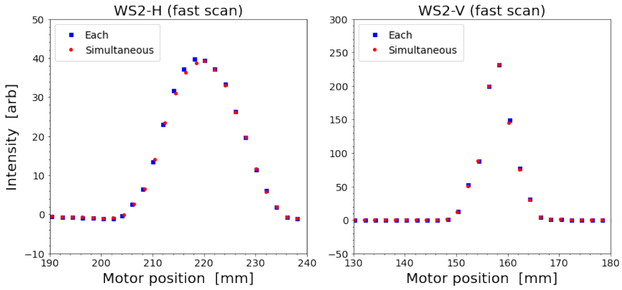

Figure 4: Beam profile scan result with MEBT WS2: running scans on all 3 MEBT stations in parallel

Once initial performance assessments were complete, the system was tested as part of higher level measurement sequencers and automated data evaluation tools, such as the one depicted on (Fig. 5) where the machine model and WS measurements (RMS beam profile) are reported. This is a configuration with special optics to avoid high density beam to the MEBT FC, and with all bunchers off. The comparison shows how close the fit is at this stage of the machine commissioning, taking into account recent emittance measurements in the MEBT.

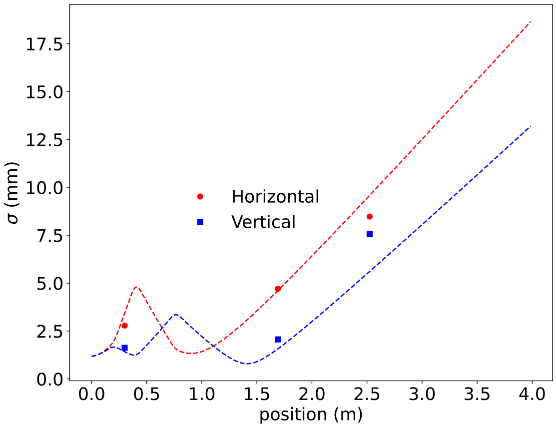

Figure 5: WS measurement data comparison with machine model

In parallel to commissioning with beam in the normal conducting part of the machine and in order to fully validate the system design in the high energy sections, scintillator detectors and the corresponding signal acquisition chain were tested at different facilities.

## WS SYSTEM IN THE SCL

In the ESS superconducting LINAC and downstream, 8 WS stations will be installed along the beam line. Each station is equipped with two linear actuators to sample separately the transverse planes. The 5 stations in the elliptical sections and in the transfer line to the target will be used in shower detection mode in addition of the SE signal from the wire. Scintillator detectors are positioned 400 mm on the LWUs downstream the wire. In an approach that differs from standard system layouts, no photomultiplier tube is coupled to the detector on the beam line, but long haul optical fibers (up to 60 m) carrying signals directly from the scintillators to a custom front end electronics sitting in controls racks at the surface as depicted on Fig. 6.

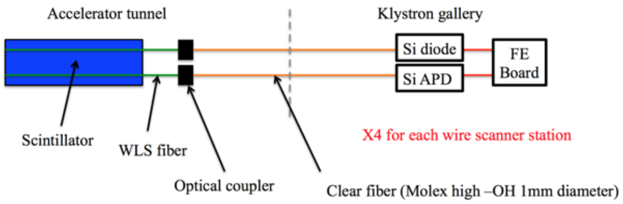

Figure 6: Conceptual design of the ESS wire scanner shower detector.

The scintillator detectors used at ESS were produced and tested at the Institute for High Energy Physics (IHEP) in Protvino (Russia). The detector is based on Saint Gobain BC-408 material, wavelength shifting fibers (WLS) are coupled to long haul clear fibers of the same core diameter to optimize coupling. Optical glue is used at the WLS interface in the detector to optimize light collection. Each detector is wrapped in Tyvek paper and an aluminium housing eventually provides mechanical protection. All prototypes as well as detectors in the first series production were tested at IHEP using cosmic rays muons and/or a radioactive (90Sr+90Y) β- source before delivery to ESS. Detectors were tested at COSY (Juelich, Germany) first as a completely parasitic experiment, with a detector installed next to one of the beam loss monitors in the COSY ring. No measurable signal was detected over the course of the experiment, and the detector was then relocated to the injection line downstream the Faraday Cup. Dedicated beam time was then allocated to the experiment, and secondary showers from protons, deuterons and hydrogen anions were detected. The detector is visible in blue on Fig. 7. The complete acquisition chain was deployed for this vertical test, including long haul fibers and the optical front-end and back-end.

Tests results for a 20 ms 4 µA beam pulse at the FC show no difference in signal amplitude at both the low and high gain channels of the OFE as can be seen on Fig. 8. This experiment allowed a first validation of the acquisition chain where scintillator detectors are directly coupled to photodiodes using long haul fibers. A vertical test where the detector is installed downstream a wire scanner in the ESS final configuration will serve as final validation.

## CONCLUSION

Wire scanners in SE mode were including in a series of beam studies at ESS, allowing for a full verification of the system's performances in this configuration. In parallel, the detectors used for shower measurement mode in the high energy LINAC as well as the rest of the corresponding signal acquisition chain have been extensively tested at COSY and are now deployed at SNS (Oakridge, USA) for a validation in conditions as close as possible to their final installation at ESS.

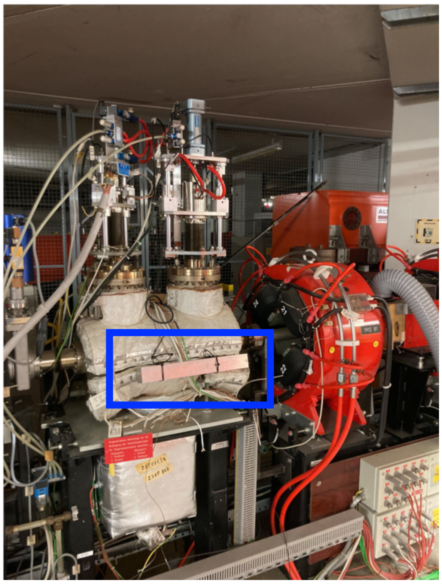

Figure 7: Scintillator detector installed at COSY.

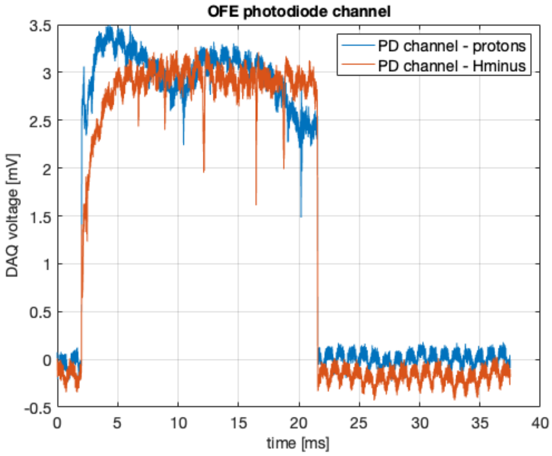

Figure 8: OFE low gain channel signal for a 20ms protons vs H- beam pulse

## ACKNOWLEDGEMENTS

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