Development of a Thermal Response Model for Wire Grid Profile Monitors and Benchmarking to CERN LINAC4 Experiments

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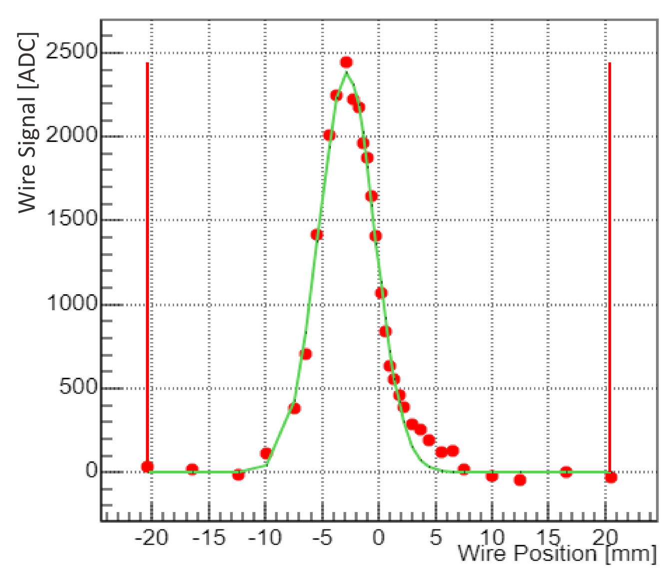
ABSTRACT

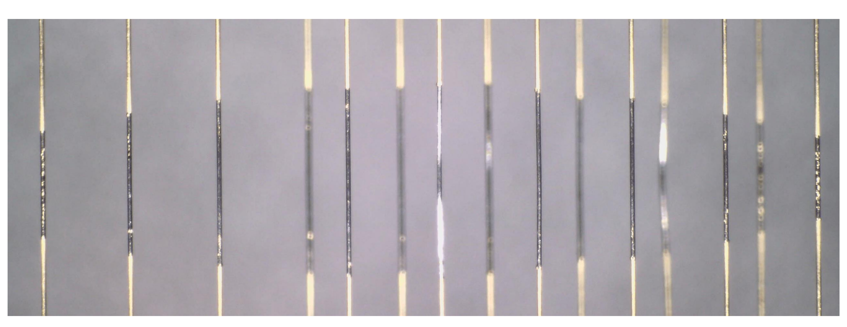
The operation of wire grids as beam profile monitors, both in terms of measurement accuracy and wire integrity, can be heavily affected by the thermal response of the wires to the energy deposited by the charged particles. A comprehensive model to describe such interaction has been implemented including beam induced heating, all relevant cooling processes and the various phenomena contributing to the wire signal such as secondary emission and H- electron scattering. The output from this model gives a prediction of the wire signal and temperature evolution under different beam conditions. The model has been applied to the wire grids of the CERN LINAC4 160 MeV H- beam and compared to experimental measurements. This successful benchmarking allowed the model to be used to review the beam power limits for operating wire grids in LINAC4.

Wire Grid Systems

Wire Grid Profile monitors, are widely used for transverse beam profile measurements in particle accelerators. A signal is generated in each wire because of the interaction with the particle beam. This signals are then used to reconstruct the beam profile. In most cases wire grids are remotely movable, they are inserted into the beam line only when needed.

For a given wire grid detector design and material, the beam power density can generate very high temperatures in the Wire Grid, which perturb the measurement accuracy and damage the detectors. A thorough understanding of the wire temperature evolution is therefore necessary.





Simulation Model

Intensity Model:

The charge generated in the wire per incident particle can be summarized by the following equitation:

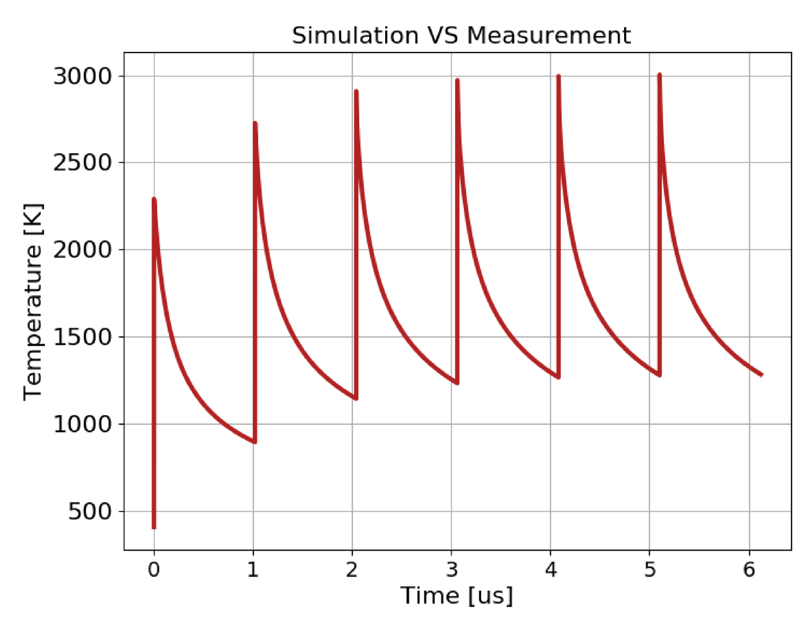
$$Q\left(\frac{e}{Proj}\right) = Q_{dep} + Q_{SE}$$

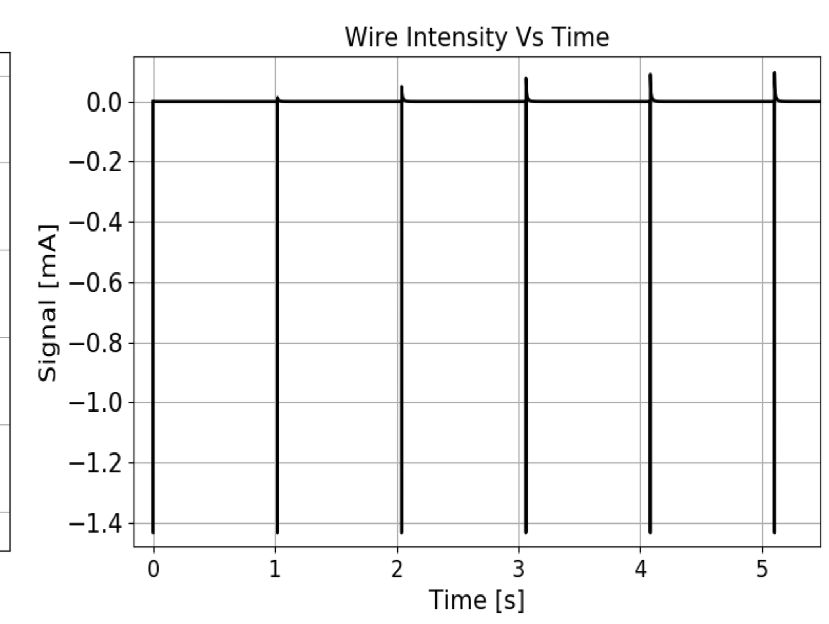
The term Q_{dep} refers to the charge generated in the wire due to charge deposition of the incident particle. When a particle passes through the interface of a material, secondary particles can be emitted due to the energy transferred by the primary one. Q_{SE} refers to the charge generated due to the effect of secondary particle emission.

Thermal Model:

During operation, the beam of particles deposits some energy on the wire material, which is translated into a temperature increase (ΔT_{Ht}). Various cooling mechanisms occur during and after the beam passage. For this model, the considered mechanisms were Radiative Cooling (ΔT_{Rd}), Thermionic Cooling (ΔT_{Th}), Conductive Cooling (ΔT_{Con}) and Sublimation cooling (ΔT_{Sub}). The temperature variation of the wires for each time step can be written as follows

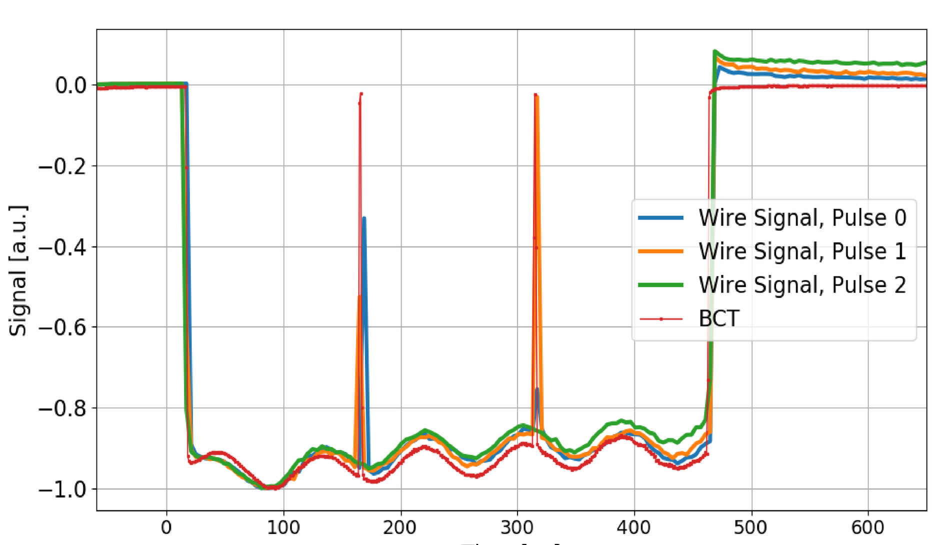
$$\Delta T_{Tot} = \Delta T_{Ht} - \Delta T_{Rd} - \Delta T_{Th} - \Delta T_{Con} - \Delta T_{Sub}$$

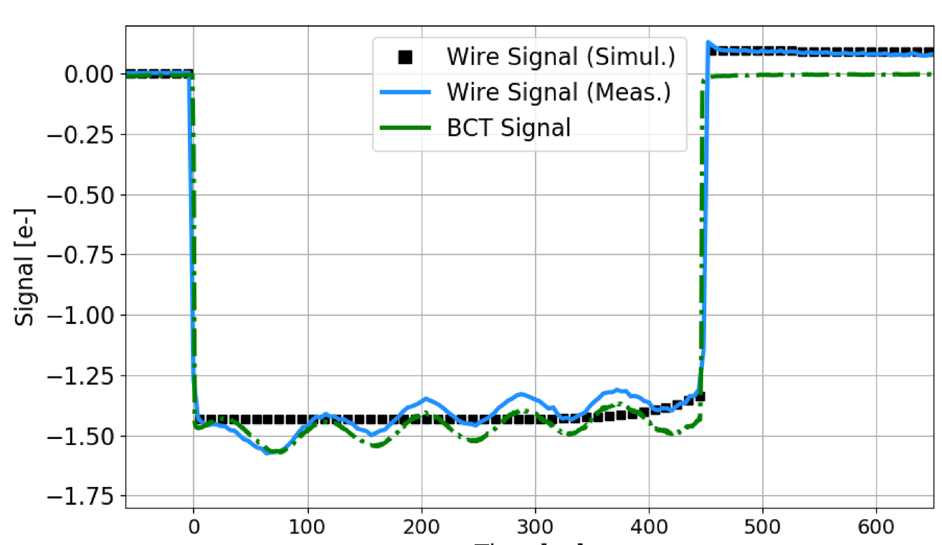




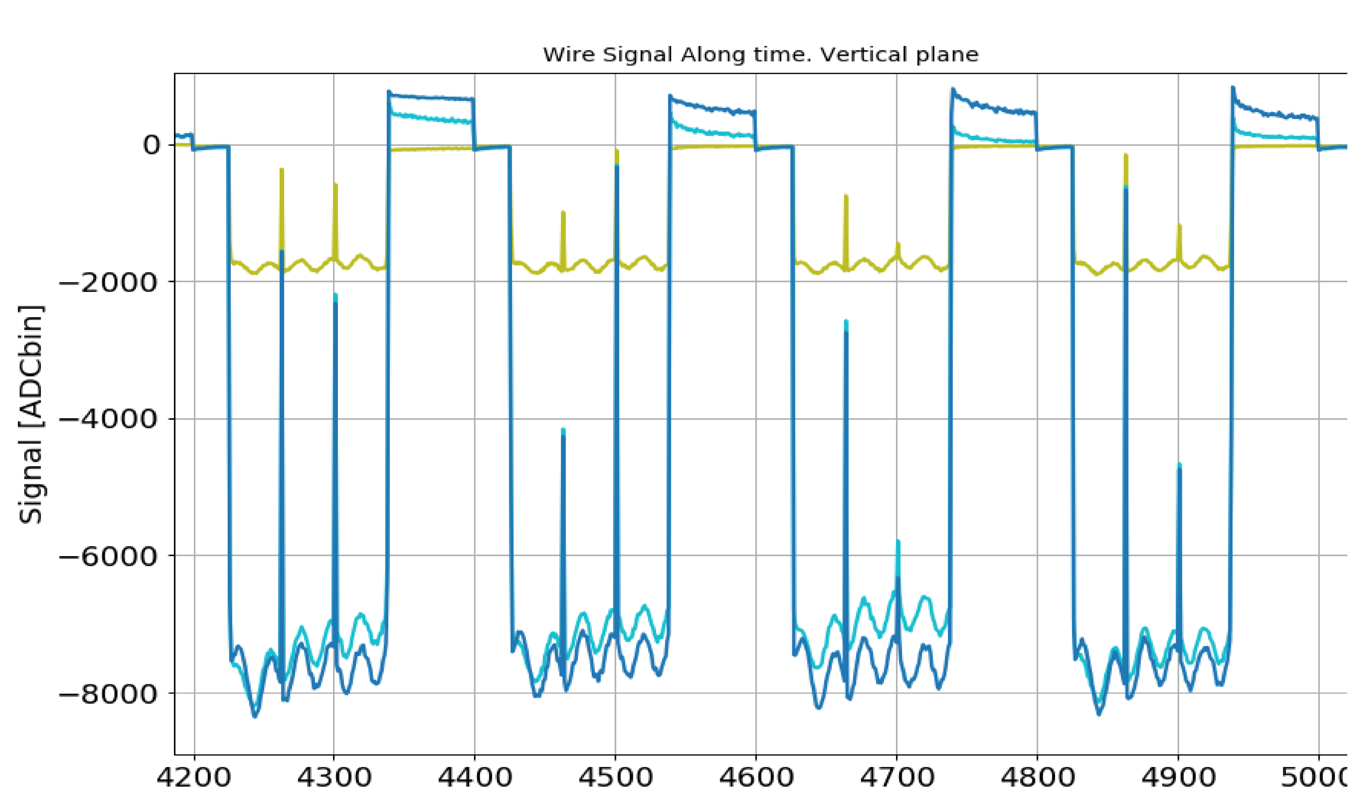
Model Benchmarking and Results

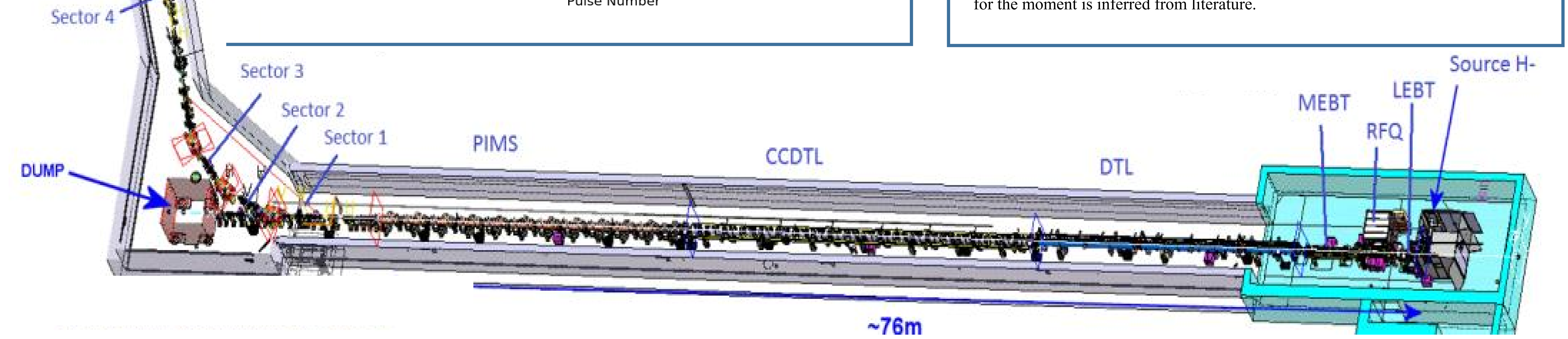
For model bench-marking, the simulated results were compared with experimental temperature measurements.





The temperature of the wires was measured indirectly by means of thermionic emission process. The measurements presented here were performed with one of the wire grids located at 160 MeV LINAC4 section. The simulations do not include neither a variable beam intensity during the pulse (e.g. the modulations from the source) nor the intensity 'holes' due to the chopper settings. Despite this, the model successfully reproduces the measured signals. The agreement in terms of wire signal versus beam current is well within 10%.

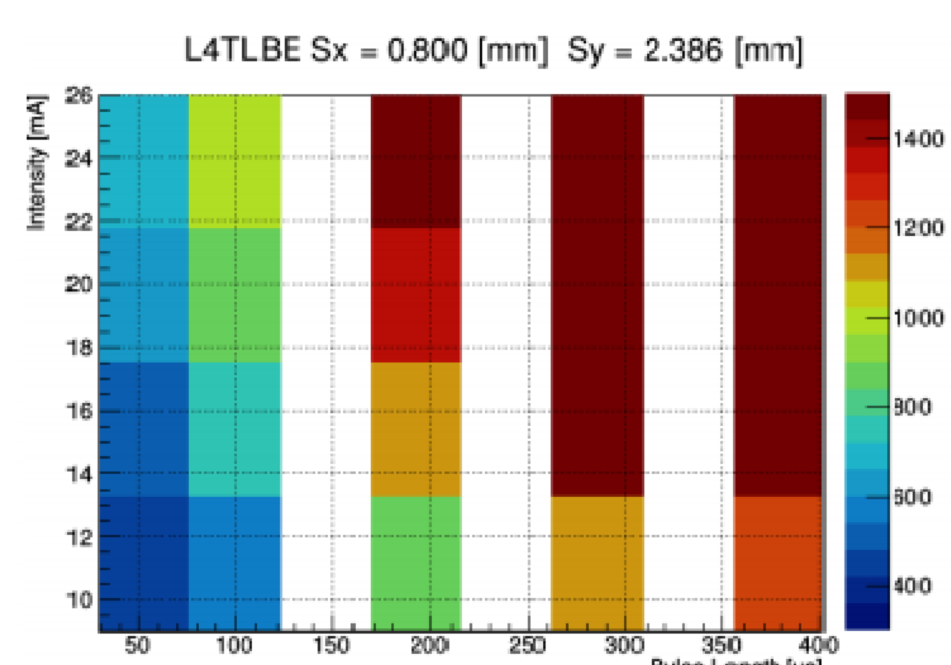




Model Applicability: LINAC4 power limits.

The implemented code is able to simulate a great variety of cases, such as different particle types, beam energies and characteristics as well as different detector materials and geometries.

Heretofore, we concentrated our effort in using this simulating tool to re-calculate the LINAC4 beam power limits at 160 MeV, to minimize the risk of overheating and damaging the tungsten wires. The temperature limit set for tungsten wires at LINAC4 was 1400 K due to the gold coating of the wires.



Outlook

A first version of a comprehensive model simulating wire grids electrical signals and thermal cycles induced by the LINAC4 H- beams was bench-marked to beam based experiments at 160 MeV. The model proved to reproduce well the occurrence of Thermionic emission, which can be used as an indirect wire temperature measurement.

The obtained results already give a high degree of confidence in the simulation of the beam power limits for a safe operation of grids at the LINAC4 top energy. As a continuation of this work, the model will be applied to other wire grid and beam parameters. In parallel it is planned to experimentally enhance the accurate determination of some key parameters (e.g. material's surface emissivity) that for the moment is inferred from literature.