WIRE GRID AND WIRE SCANNER DESIGN FOR THE CERN LINAC4

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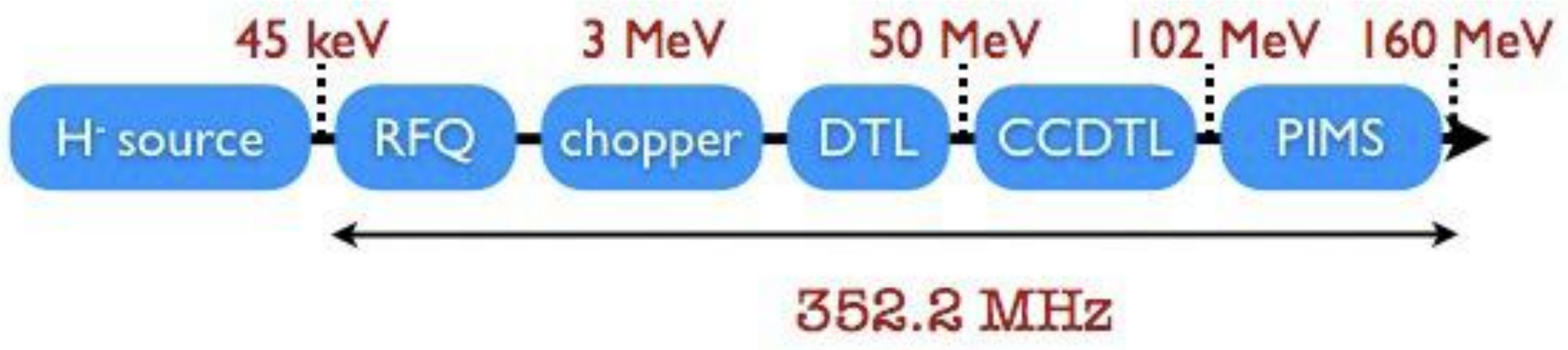
INTR0DUCTION

As part of the CERN LHC injector chain upgrade, LINAC4 will accelerate H- ions from 45 keV to 160 MeV. A number of wire grids and wire scanners will be used to characterize the beam transverse profile. This paper covers all monitor design aspects intended to cope with the required specifications. In particular, the overall measurement robustness, accuracy and sensitivity must be satisfied for different commissioning and operational scenarios. The physics mechanisms generating the wire signals and the wire resistance to beam induced thermal loads have been considered in order to determine the most appropriate monitor design in terms of wire material and dimensions.
In order to measure beam profiles along the linac, several SEM grid and wire beam scanner (WS) monitors will be installed between the RF cavities from 50 MeV to 160 MeV. Two wire scanners will also be installed at the chopper located in the 3 MeV Chopper line.
The SEM grids are retractable devices that will be inserted into the beam in a single step, while WS are driven by stepping motors that will allow slow scans of the particle distribution over multiple beam injections.



NET CHARGE DEPOSITED ON THE WIRE

One of the phenomena providing the wire signal is Secondary Emission (SE), a surface effect generating escaping electrons as

-the H- ions enter the wire and
-the same ions or their dissociated products exit the wire.

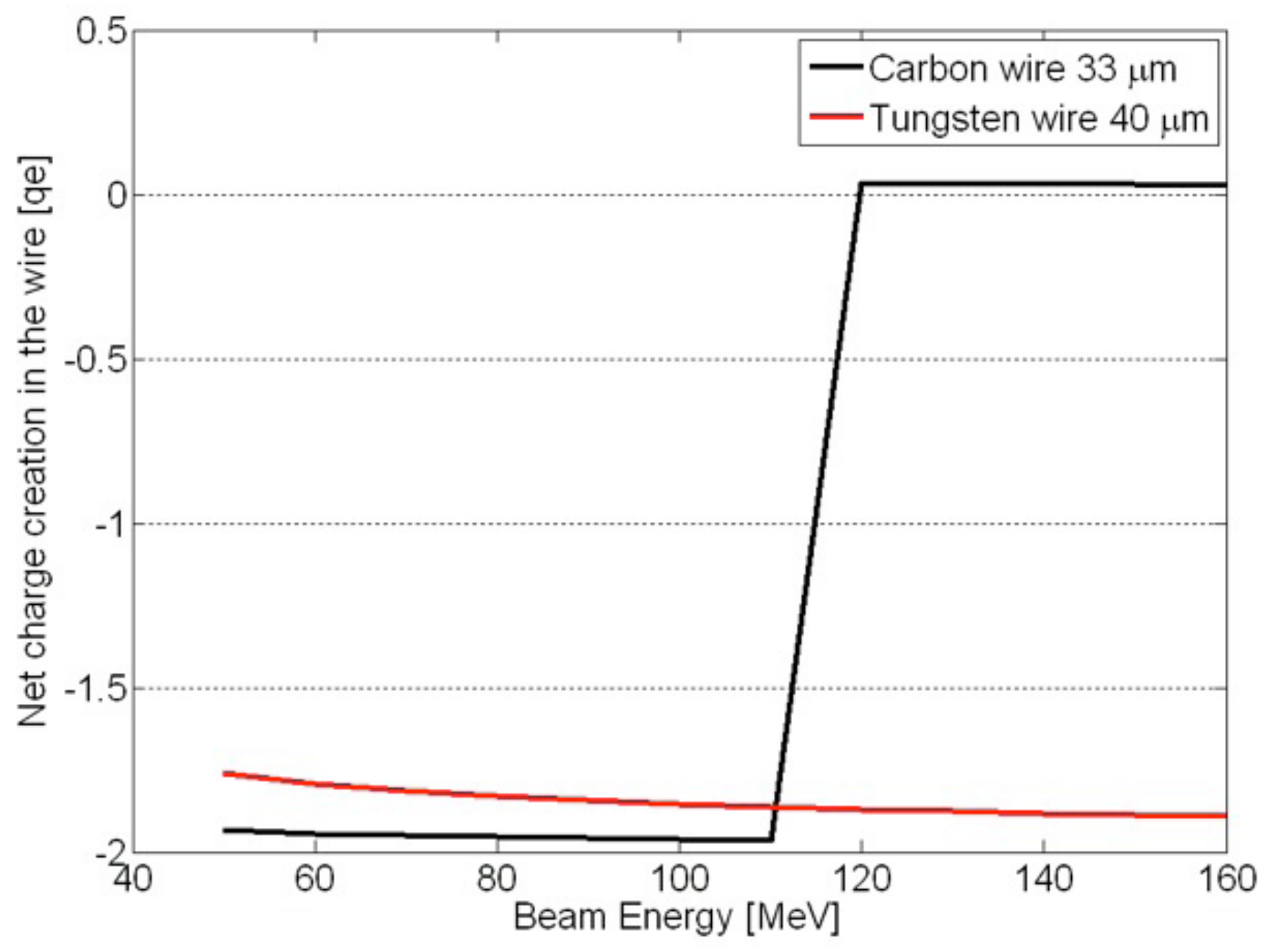
Depending on the ion energy, the wire material and diameter, the signal can have a contribution from direct charge deposition of the ions or their dissociated products.
If for NI ions hitting the wire, Np protons escape after the ion stripping and Ne stripped electrons are stopped into the wire, the charge created on the wire is given by:

$$Q = Ye + \eta Ys + (1-\eta) - 2\mu$$

where Ye and Ys are the SE Yield (SEY) of H- ions and of protons traversing the wire surface, η=Np/NI and µ=Ne/NI.
Above 50 MeV, η≅1 and Ye≅Ys=Y.

The parameter µ depends on the electron energy E and on the electron range in the wire material at that energy.

For the LINAC4 SEM grid and WS monitors, two types of wires are presently considered: 40 µm diameter Tungsten wires and 33 µm diameter Carbon wires.



Net charge left on the wire by each H- ion as function of energy and for the two wire types.

At 3 MeV the range of protons in tungsten is about 30 µm about and 73 % of the protons are stopped inside the 40 µm tungsten wire, the contribution to the signal is about -0.18 electrical charges (q) per H-.
For carbon the range of protons is about 100 µm and all protons will exit the wire. Consequently, the wire signal is given by SE of entering H-, SE of exiting protons and direct charge deposition of electrons. This results in about -1.259 q per H- ion hitting the wire, considerably higher than the one for tungsten.

For H- ions between 50 and 160 MeV, the electron range is below the wire diameter for Tungsten, while it becomes of the order of the wire diameter for Carbon for ion energies of about 100 MeV.

Above 110 MeV the Carbon wire signal changes polarity and is reduced of least a factor 50. For Tungsten, the signal polarity is always negative and the net charge almost constant with energy.
Since SE electrons have energy of few eV, biasing the wire can neutralize the SE effect on the wire signal. With a relatively low bias (e.g. +100 V) such electrons can be attracted back on the wire. Applying such a bias to Tungsten wires would result in having a net charge equal to -2 q (from the stripped electrons) at all energies.

The same applies for 33 µm Carbon wires only below about 100 MeV , choosing larger diameter wires would imply the bias effectiveness also for Carbon wires. For H- above 110 MeV, the range of stripped electrons in Carbon is of the order of 50 µm and a 100 µm diameter wire would be enough.
In addition, the wire bias would minimize the signal variation with time due to the SE effect changes with the wire aging. Avoiding electron SE would allow comparing the absolute charge deposition at different energies, even though the ultimate accuracy could be perturbed by the creation of high energy electrons (δ rays) for which a reasonably low bias would not be sufficient.

WIRE CURRENT

The average beam current foreseen for the LINAC 4 nominal operation is 40 mA, while the transverse RMS beam sizes are expected to be 1 mm in one plane and 2 mm in the other in most of the inter-tank regions where SEM grids and WS will be installed .
Starting from such parameters, the expected wire current has been calculated for a wire sampling the beam core and for the plane where the beam size is minimum (i.e. maximum wire signal). Four possible wire types have been simulated: a 33 µm or 100 µm Carbon wire and a 40 µm or 100 µm Tungsten wire, every time with a 100 V bias.
For biased 100 µm wires, the signal is constant with energy and its maximum, after applying the beam parameters results to be -3.2 mA.
Considering that the monitors need to sample the beam halo down to the electronics noise level (few nA), the values of the maximum current gives an indication of the required system dynamic range. The table confirms that small diameter Carbon wires give a very small signal for energies above 100 MeV.
In the chopper line, the transverse RMS beam sizes are around 3 mm in the both plane for the first WS, and 3.7 and 1.8 mm for the second WS. The beam intensity at this location varies from 40 to 65 mA.

I beam [mA]	**40**	**65**
I_max WS 1 [mA]	-0.35	-0.57
I_max WS 2 [mA]	-0.6	-0.97

Expected Maximum Current at the Chopper WS

Energy [MeV]	**50**	**57**	**79**	**86**	**100**	**115**	**129**	**145**	**160**
Carbon	-1.053	-1.053	-1.053	-1.053	-1.053	0.0025	0.0023	0.0022	0.0021
Tungsten	-1.276	-1.276	-1.276	-1.276	-1.276	-1.276	-1.276	-1.276	-1.276

Expected Maximum Current for a 33 µm Carbon Wire and 40 µm Tungsten Wire

THERMAL LOAD

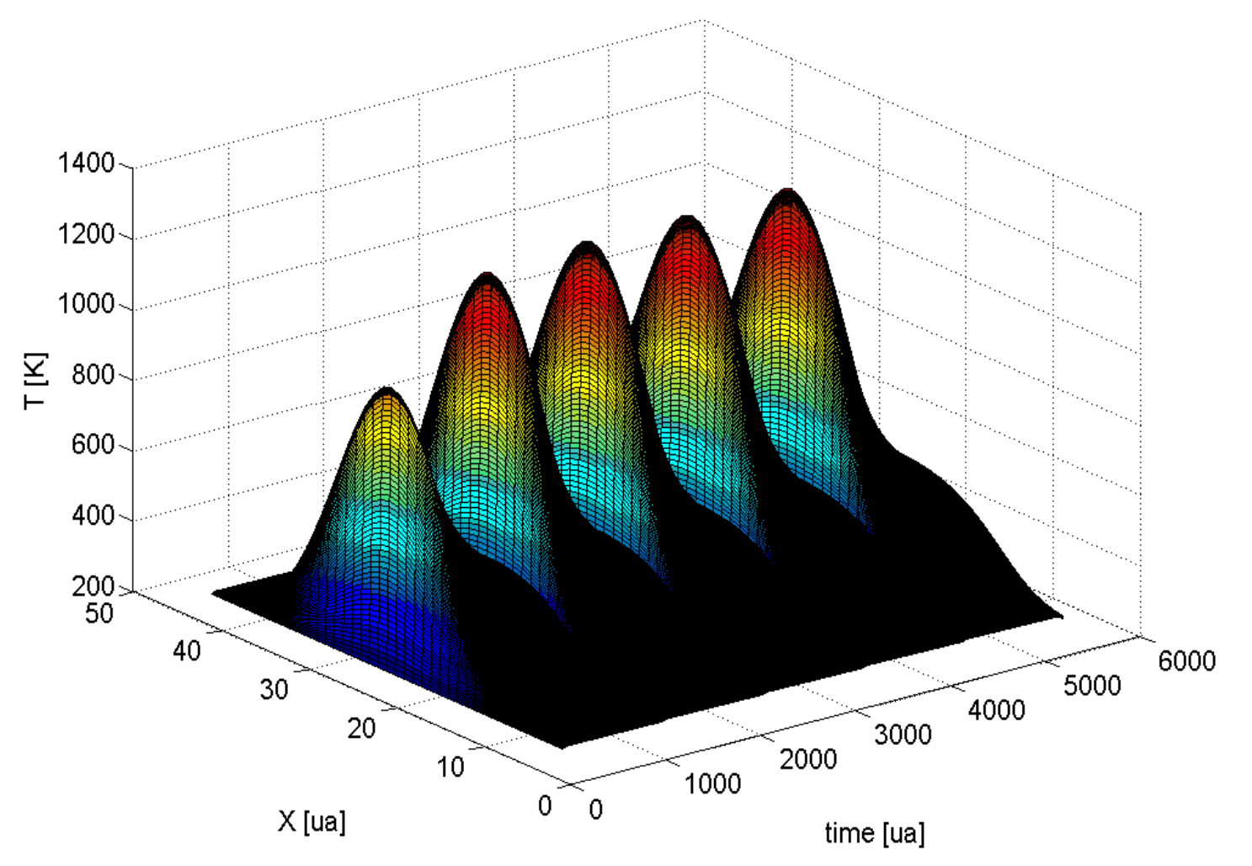
Thermal effects at 3 MeV.

At low energy the power deposition varies along the wire depth. Consequently, the wire has been divided in slices along which the energy deposition can be considered constant. Since at 3 MeV Carbon is expected to give a higher signal, only this material has been simulated, assuming a 33 µm wire

Intensity [mA]	**65**	**65**	**65**	**40**	**40**
Pulse length [µs]	**50**	**100**	**400**	**100**	**400**
Tmax WS1 [K]	1359	2175	6893	1550	4520
Tmax WS1 [K]	1871	3178	div.	2174	7000

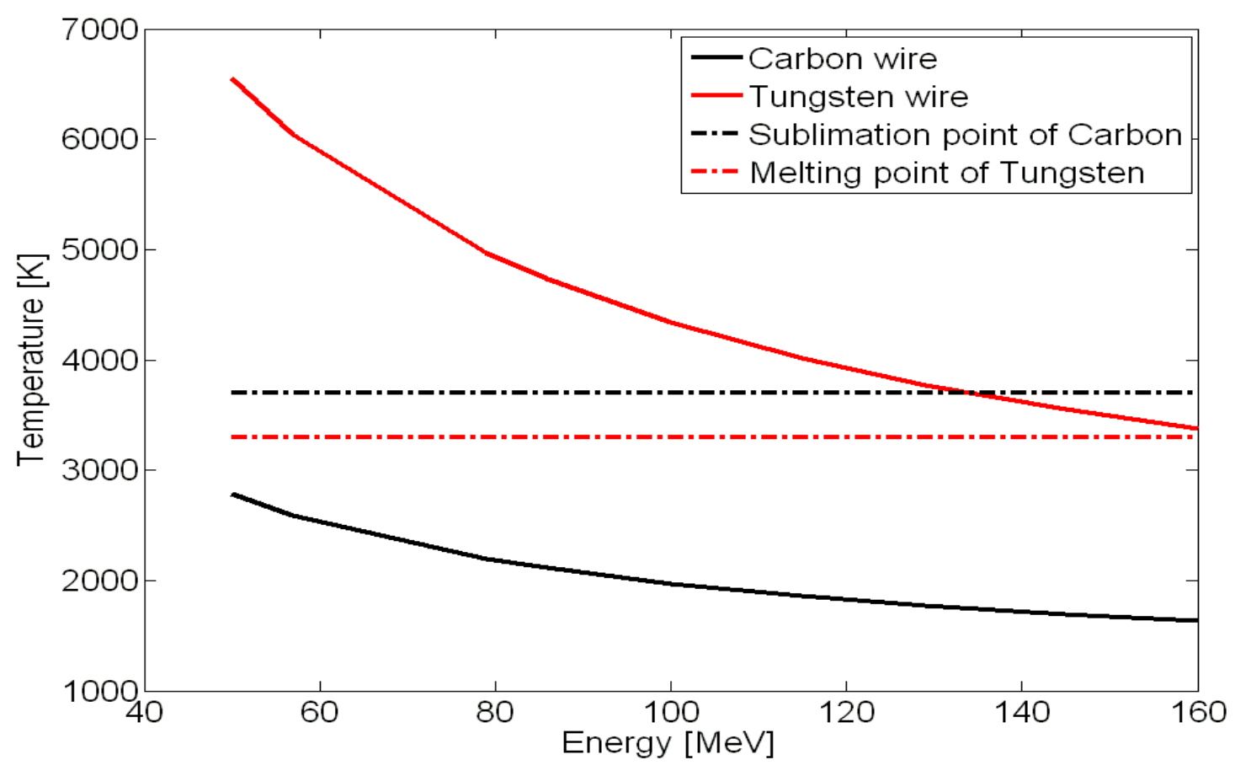
Maximum Carbon wire temperature at 3 MeV.

Since Carbon sublimation occurs at about 3900 K, both wires would not survive to the full pulse length. Therefore the pulse length during the WS measurements should be reduced to 100 µs. For WS 2, a maximum average current of 40 mA is also advisable.



Evolution of the temperature along several pulses for the WS1 in case of a 65 mA and 50 µs beam.

Thermal effects above 50MeV.



Temperature evolution for 100 µm diameter Carbon and Tungsten wire as function of beam energy, for a LINAC4 40 mA, 400 µs pulse and typical beam sizes at the monitors locations.

The LINAC 4 average beam current after chopping will be 40 mA, with a pulse length of 400 µs and a repetition rate of 1 Hz.
Carbon would survive at all energies, a 100 µm Tungsten wire would exceed its melting point in all cases. When considering a 33 µm Carbon wire or a 40 µm Tungsten wire, the temperature is reduced by about 200 K at each energy.