SCATTERING OF H^- STRIPPED ELECTRONS FROM SEM GRIDS AND WIRE SCANNERS AT THE CERN LINAC4

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Abstract

At the CERN LINAC4, wire grids and scanners will be used to characterize the H^- beam transverse profiles from 45 keV to 160 MeV. The wire signal will be determined by the balance between secondary emission and number of charges stopped in the wire, which will depend on the wire material and diameter, the wire polarization and the beam energy. The outermost electrons of H^- ions impinging on a wire are stripped in the first nanometers of material. A portion of such electrons are scattered away from the wire and can reach the neighboring wires. In addition, scattered electrons hitting the surrounding beam pipe generate secondary electrons that can also perturb the measurement. Monte Carlo simulations, analytical calculations and a laboratory experiment allowed quantifying the amount of scattering and the scattered particles distributions. The experiment was based on 70 keV electrons, well reproducing the case of 128 MeV H^- ions. For all the LINAC4 simulated cases the predicted effect on the beam size reconstruction results in a relative error of less than 5%.

INTRODUCTION

When H^- ions interact with matter the outer electron is stripped almost immediately. These electrons can be considered free with an energy of: $E_e = E/1836$ where E is the energy of the H^- beam. For LINAC4 the stripped electrons energy ranges from about 25 eV at the source exit to about 87 keV. Some data about electron scattering can be found in literature [1, 2, 3] for the energy range and materials considered for LINAC4. For electron energies below the MeV range, the proportion of backscattered electrons is around 10 % for low Z materials and up to 50 % in case of materials with higher density.

TWO WIRE SIMULATIONS

The Monte Carlo code FLUKA [4] code was used to simulate an electron beam hitting two parallel wires of the same material and diameter separated of 500 μm. This was done for H^- energies above 50 MeV. Below such energy, the corresponding electron energy is not properly simulated by FLUKA. A beam composed of 10^6 electrons, with a rectangular shape of width equal to the wire diameter was sent to one wire in order to investigate the amount of scattered particles reaching the second wire. The simulation was repeated for 27 keV and 87 keV electrons (corresponding to 50 MeV and 160 MeV H^- energy respectively) and 33 μm Carbon wires or 40 μm Tungsten wires. Fig 1 shows the angular distribution of the particles emerging from the first wire for the four simulated settings. At the position of the second wire (i.e. 90^o or symmetrically 270^o), the ratio of particles varies from 2×10^{-4} to 3×10^{-3}. It drops for angles between 90^o and 270^o and reaches its minimum for an angle equal to 180^o. For Tungsten the angular distribution is independent of the beam energy and at 180^o the flux is less than 10^{-5} for both energies. For Carbon, at the lowest energy, the flux is around 10^{-5} at 180^o. At 87 keV some electrons have enough energy to cross the wire and 44 % of the particles exiting the wire have angles between 150^o and 210^o. Table 1 shows the percentage of scattered electrons emerging from the first wire and how many of them reach the second wire. At both energies, about 55 % of incident electrons are scattered on a Tungsten wire and in the worst case less than 0.7 % reach the side wire. For a Carbon wire and 27 keV electrons, about 17 % of the impinging particles are scattered, while at 87 keV the amount of scattered electrons is hardly distinguishable from the ones traversing the wire. At both energies, it can be estimated that the percentage of scattered electrons reaching the second wire is below 0.3 %. Even if these results (wire cross talk below 1 %) arise from a simplified case not considering Secondary Emission (SE) electrons, the scattering coefficients determined with the FLUKA simulations agree very well with the data found in literature [3]. Both the scattering coefficients and the scattering angles are also in agreement with similar studies performed at INR with GEANT4 [5].

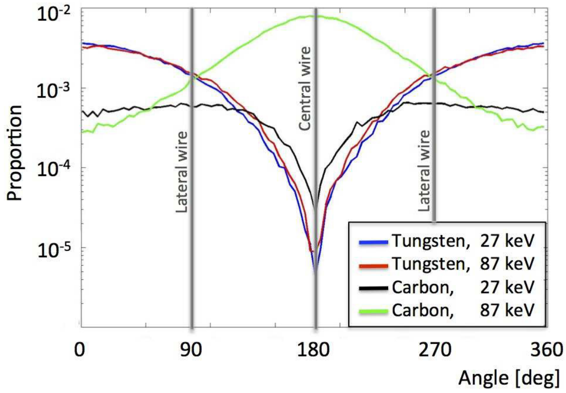

Figure 1: Angular distribution of particles emerging the wire, normalized to the number of primary electrons.

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	Carbon (33 μm)		Tungsten (40 μm)	
Energy [keV]	27	87	27	87
$\frac{N_1}{N_{tot}}$	17 %	N.A.	55 %	55 %
$\frac{N_2}{N_{tot}}$	0.24 %	0.05 %	0.6 %	0.66 %

N_{tot} = electrons hitting the first wire, N_1 = scattered electrons emerging form the first wire, N_2 = scattered electrons emerging from the first wire and reaching the second.

Table 1: Percentage of scattered particles that emerging from the first wire reach the second.

ELECTRON GUN MEASUREMENTS AND SIMULATIONS

An experimental measurement of electron scattering was performed by means of a 70 keV electron beam (4.3 ns pulse length and about 5 nC pulse charge) reproducing the case of 128 MeV H^- ions. A set of three 40 μm tungsten wires was mounted on a fork support with 0.5 mm pitch. The electron beam was collimated on the central wire through a 0.4 mm slit, so that the lateral wires could be reached only by the electrons scattered by the central wire. Each wire was connected to an electronic acquisition channel, composed of an integrating amplifier and an ADC (Analog to Digital Converter). The typical signals of the central and lateral wires, at the integrator output, as the beam is passing through the collimator, are shown in Fig. 2. The negative peak represents the integral of the negative and positive peak induced by the beam charge when approaching and drifting away from the conductive wires. The integral is non zero due to wake-field ringing, as discussed below. The integral of the wire signals as sampled by the ADC are shown in Fig 3. Since the sampling time was 6 μs, the negative peak provided by the integrator cannot be seen, with only the tail sampled. The decay time constant generated by the integrator itself is now visible, as the ADC signal is shown on a much larger time scale. The lateral wire signals are actually the cross-talk signals we are interested in, due to the electrons scattered by the central wire. I this case, we defined the *cross-talk* among wires as the ratio between the lateral and the central wire, averaged over the first 3 ADC samples. Using the raw data shown in Fig 3, the cross talk observed is about 7 %, whereas if it is accounting for the offset subtraction of individual ADC channels, this value decreases to about 4 %.

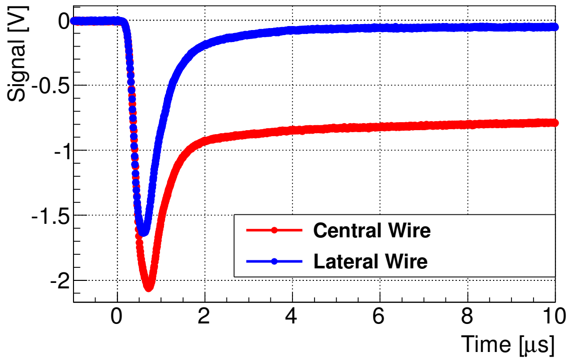

Figure 2: Signals of the central and one lateral Tungsten wires as recorded by a scope at the integrating amplifier output.

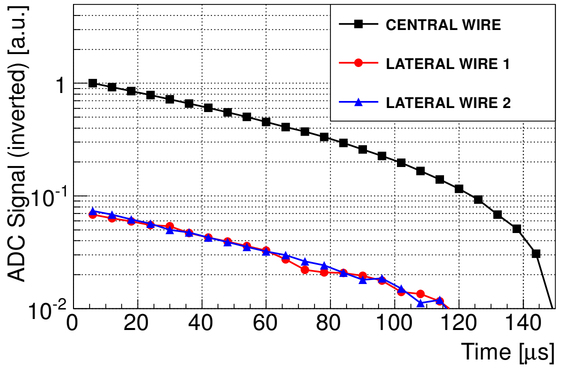

Figure 3: Central and lateral wire signals as sampled by the ADC.

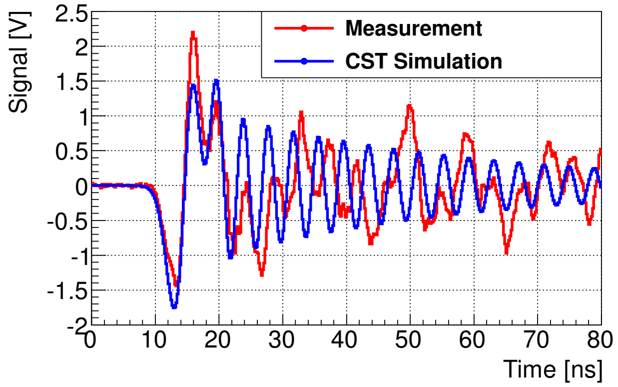

Figure 4: Lateral wire signal before integration, as sampled by a scope and simulated with CST Particle Studio

The wakefield effect on the wire signal shape could be demonstrated through a wakefield simulation performed with the CST Particle Studio software [6] in the case of a lateral wire, modeled with the tank and fork geometries. The lateral wire signals as sampled by a scope and calculated by the simulations are shown in Fig 4. The simulations reproduce with an acceptable accuracy the measurements, considering that the simulations consisted of a simplified geometry and perfectly conducting materials. The fact that in the simulations only the two ideal peaks (negative and positive as the beam passes close to the wire) sur-

Wire Pol.	Cross-Talk		Central wire signal*	
	Meas.	Simul.	Meas.	Simul.
0 V	4 %	1.4%		
20 V	13.5 %	7 %	+ 27 %	+ 12 %
50 V	15.4 %	14.4 %	+ 36.5 %	+ 35.5 %
100 V	N.A.	13.0 %	N.A.	+ 39.0 %

* w.r.t. 0 V polatization

Table 2: Cross-talk and signal intensity measured for different polarization voltages of the tungsten wires.

vive when deleting the wire fork structure, confirms that the signal ringing is due to wakefield effects.

The scattered electron energy is too high to foresee any polarization to suppress them. However, a polarization can be applied to any wire in order to suppress SE electrons and enhance the wire signal. The effect of such polarization on the wire cross-talk was studied in the electron gun experiment and benchmarked with a very detailed model including: i) FLUKA simulations to estimate the location of SE sources (wires, collimator in front of the wire), ii) analytical models predicting the SE yield and iii) CST particle studio simulations to account for EM fields and track the electrons. The results are summarized in Table 2. Both measurements and simulations agree that the cross-talk between wires increases with polarization voltages. Even though SE is more and more suppressed (see the central wire signal in the table), the field lines created by the biased wires result in more secondary electrons trapped by the lateral wires. With no polarization and with 20 V the measured cross-talk is larger than that predicted by the simulations. This could well be related to effects other than scattered electrons, such as coupling in the electronics channels. With 50 V wire polarization, the agreement between measurement and simulations is remarkably good, within 1 %. In the laboratory setup, it was not possible to exceed 50 V due to the HV power supply module used.

Using the cross-talk results presented above, we calculated the effect of the cross talk among wires due to scattered and SE electrons on the accuracy of a wire grid profile measurement. This was done assuming a Gaussian beam. The results are shown in Fig. 5 for different beam sizes and for a wire grid pitch of 0.5 mm. With a cross-talk of 5 %, which is a realistic estimation with no wire polarization, the error is less than 4 % even for a σ=0.5 mm beam, smaller than what expected at LINAC4.

CONCLUSIONS AND OUTLOOK

Simulations of electron scattering between two wires reproduced the scattering coefficient data found in literature for Carbon and Tungsten. For both materials the number of electrons scattered from one wire and reaching the neighboring one is below 1 % of those incident on the first wire. A laboratory experiment supported by analytical calculations, EM simulations and particle tracking provided results for Tungsten wires when considering also SE electrons and wire polarizations to suppress them. The overall result yields an acceptable uncertainty (below 4%) on the beam profile determination with wire grids due to Tungsten wires cross-talk. This also applies to the Carbon wire grids and the wire scanners (Carbon and Tungsten) foreseen for LINAC4, as will be discussed in a more complete note [7], that will also study wire cross-talk in case of a multi bunch beam. A source of uncertainty could arise from the fact that the electron beam was considered as representative of the H^- beams interacting with the wires with the consequent scattering of stripped electrons. For the moment, however, we could not find any phenomena (e.g. space charge from H^-) that would invalidate this assumption.

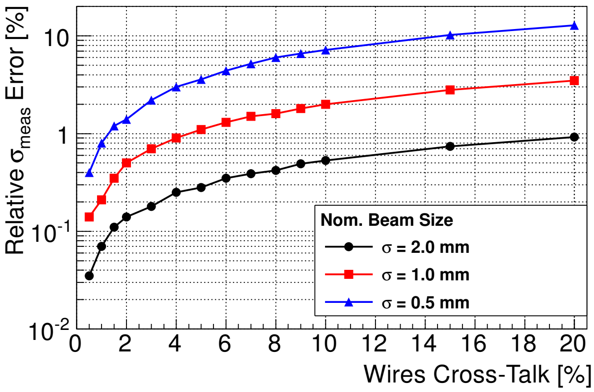

Figure 5: Estimated beam size error as a function of the cross-talk, for three typical beam sizes.

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