Design of a Kicker with a movable electrode for the FEATHER project.

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The design of a stripline kicker with a movable electrode for the FEATHER project is detailled here. More than 1000 simulations have been done with the POISSON/SUPERFISH code to study the impedance of various electrostatic configurations.

1 Introduction

The FEATHER (FEedback AT High Energy Requirement) [1] project aims at correcting within a few nanoseconds the beam position at a Linear Collider with a beam size of the order of a few nanometers. This will be done through a feedback system as shown on figure 1. The FEATHER project had been described in [2]. To reach this goal, the power required by the kicker must be as low as possible to ensure a fast rise time of the device. Beam tests have shown [1] that currently available kickers require power of a few kilowatts to give a visible effect at the Accelerator Test Facility (ATF) [3]. To reduce the power needed, the gap between the 2 electrodes of the kicker must be reduced, but the impedance of the kicker must remain close from the working impedance of the controling electronics.

The deviation given by a kicker to a beam can be calculated using the following formula:

$$\text{deviation} = \frac{2 \times \text{length} \times \text{potential}}{\text{Energy} \times \text{half-gap}} \times \text{distance}$$

Where length is the length of the kicker, potential is the potential applied on each electrode (with opposite signs), energy is the beam energy, half-gap is the distance between an electrode and the center of the kicker (equivalent to half of the gap between the two electrodes) and distance is the distance

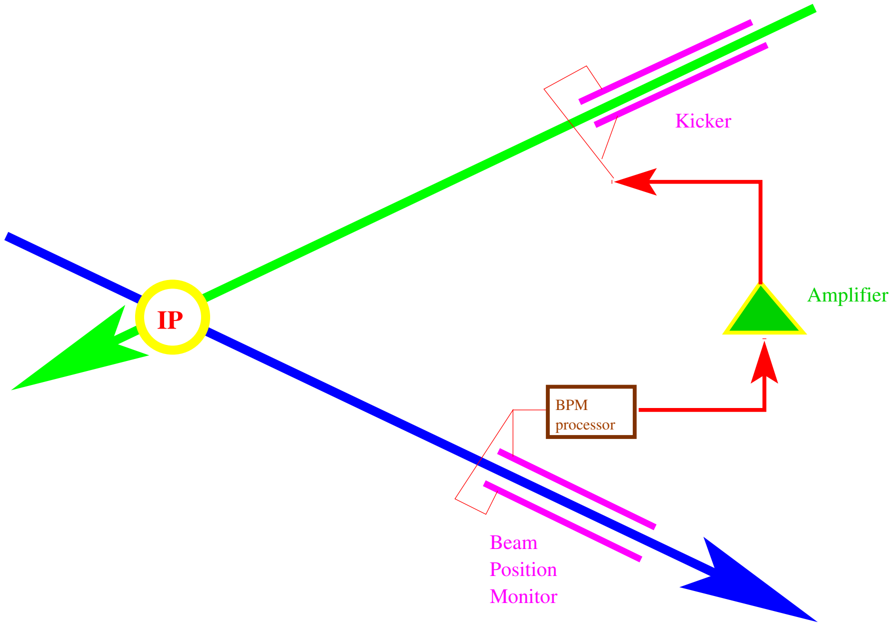

Figure 1: Layout of a simple intra-pulse feedback system proposed by the FEATHER collaboration.

from the kicker to the location where the deviation is measured. The factor 2 comes from the magnetic field contribution to the deviation. The figure 2 shows the potential required to reach a given deviation with different models of kicker.

On this plot, one can see that for the same length of kicker (40 cm) reducing the gap between the electrodes from 10 mm (pink dotted line) to 1 mm (dark blue solid line) reduces by a factor 10 the power needed to give a given deviation to the beam. But a gap of only 1 mm can be a problem in a test facility where one may sometimes have beam with a large offset.

This problem can be avoided by using a "movable electrode" that can be adjusted from a very narrow gap (1 mm) to a very wide gap (10 mm).

The electrostatic simulator "POISSON/SUPERFISH" [4, 5], further described in section 2.1, has been used to study how the impedance of the electrodes of such kicker evolves with various parameters. The detailled results of these studies are presented in section 3 and are summarized in section 4.

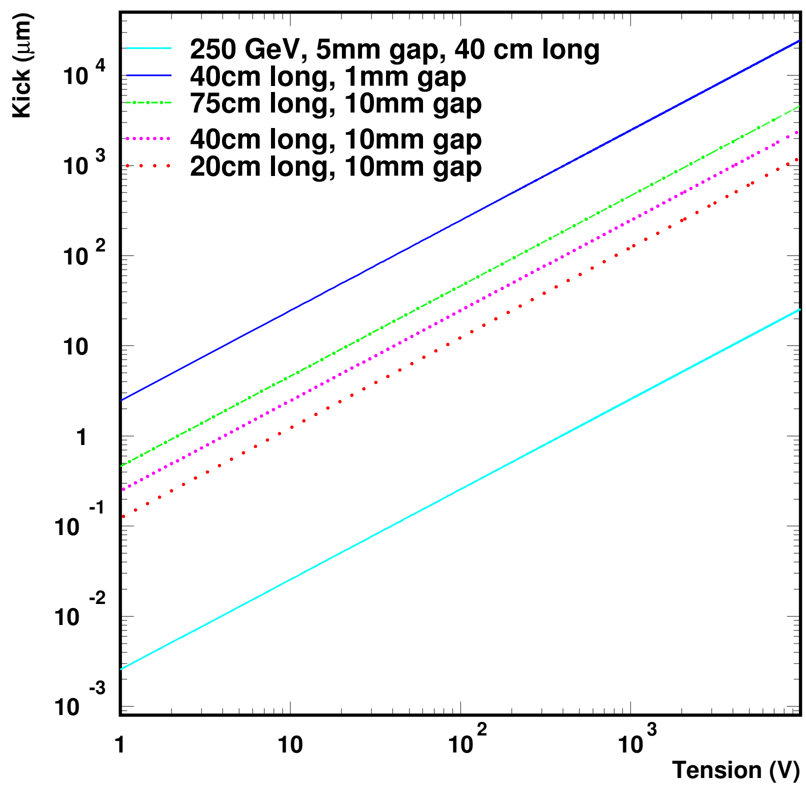

Figure 2: Kick given by a kicker as a function of the potential applied to the upper electrode and (with opposite sign) to the lower electrode. Here the kick is measured 4 meters away from the kicker location. Different models of kicker are presented. Unless otherwise specified the beam has an energy of 1.3 GeV.

2 Simulation method and impedance calculation

All the results presented in this document rely on the POISSON/SUPERFISH electric field simulator whose output was used to compute the impedance of the kicker's electrodes.

2.1 The POISSON simulator

POISSON [4, 5] is an electrostatic field simulator distributed with the SUPERFISH package [6]. POISSON uses an over-relaxation method to solve generalized Poisson's equation in a two dimensional plan.

2.2 Impedance calculation

The impedance was calculated following the method described in [7] using the formulae:

$$Z = \frac{\phi_2 - \phi_1}{\frac{1}{\epsilon}\int_0^{2\pi} E_r a d\phi}$$

As the x and y components of the field are available in the POISSON output, the integral can be calculated by drawing a box (with side parallel to x and y) around the electrode and integrating (using PAW) the x component of the field along the sides parallel to y and the y component of the field along the sides parallel to x.

3 Impedance tuning

3.1 Kicker variables

The variables used to describe the kicker are shown on figure 3. The inside of the kicker consist of a round chamber with 2 electrodes and eventually a "support" behind the electrodes.

Some constraints on the kicker arise from external constraints. The shape of the kicker and the size of the inner chamber are constrained by the beamline. The kicker must be round and the radius of its inner chamber must be greater than 15 mm. As the kicker will be used to do vertical corrections on the beam position only, two electrodes are enough.

The inner chamber of the kicker should be cylindrical shape with along the axis defined as the Z-axis. However, with this design the retracted position of the electrodes is very limited. To lift these limitations, a rectangular cavity has been added at the top and bottom of the pipe (see figure 3).

As the impedance calculation is a two dimensional problem, only the configuration in the XY plan has been studied, it is assumed that this plan is repeated along all the length of the Z-axis. We defined X as the horizontal axis and Y as the vertical axis. Our problem admits both X and Y as symmetry axis.

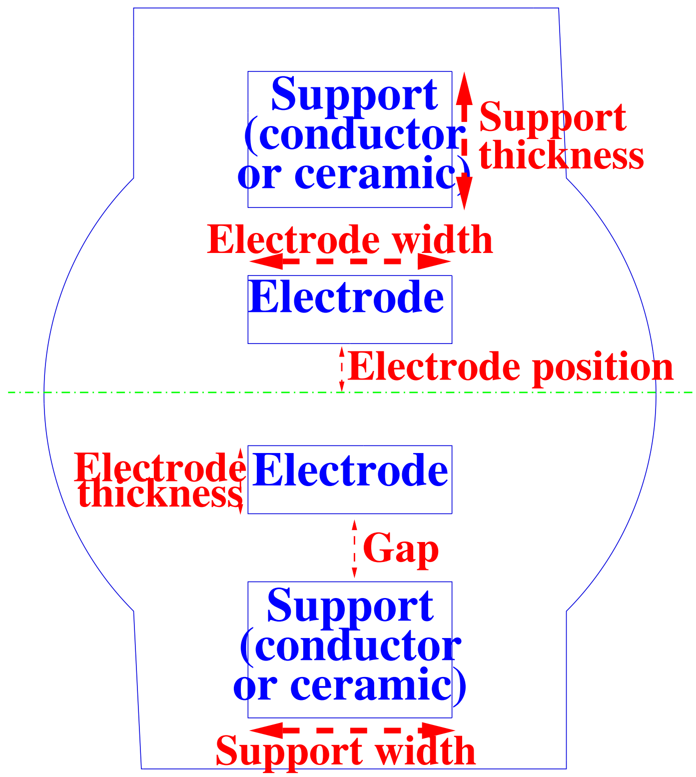

Figure 3: Variables used to describe the kickers used for our studies. The shape of the chamber is not cylindrical to allow the electrode and its support to move away from the beam.

For the calculations the electrodes are assumed to be an homogenous parallelepiped of a conducting material. The edges of the electrodes are parallel to the X, Y and Z axis. The dimensions along these edges are respectively called width, thickness and depth.

The support has the same geometry but can be made either also of perfectly conducting material or of an insulating ceramic.

Four different classes of configurations have been studied. In the first of these, no support is used. In the second class, the support is made of conducting material (at the ground potential) and in the third class the support is made of insulating ceramics. In the last class the support is also made of ceramics, but with bolts fixing the electrode to the support.

3.2 Electrode without support

The simpliest model of kicker is made of only two electrodes in a pipe. Three variables affect the electrodes' impedance in that case: the width, the thickness and the position of the electrodes. How the impedance is affected when each of these three variables varies is shown on figure 4.

As one can see on figure 4 (top) the thickness of the electrode has a very limited influence on the impedance. However, the thinest electrodes have an higher impedance.

The electrode width (figure 4 middle), to the contrary, brings an important contribution to the impedance. The widest electrodes having the lowest impedance.

The impedance is the lowest when the two electrodes are close from each other and increases with the distance between the electrodes (see figure 4 bottom).

Reaching an acceptable impedance of 40 Ohms in "close" position (1 mm from the center which means that the electrodes are 2 mm apart) requires very thin and narrow electrodes which is not rigid enough to remain straigh over 40 cm. Thus it is necessary to hold the electrode with a support.

3.3 Electrode with a conducting support

If the support is made of a conducting material, it must then be separated from the electrode and just hold it from point to point by the mean of hooks.

If the support was at the same potential than the electrode, both would then behave as a "big" electrode and from section 3.2 one can see that the impedance of this big electrode would be very low. Thus the insulator must be at the ground potential and the holding hooks must be insulated.

This time our system can be described by six variables: three for the electrode (width, thickness and position), two for the support (width and thickness) and the gap between the support and the electrode.

3.3.1 Support variables

The figure 5 (upper and middle plots) shows that the dimensions of the support do not affect the impedance of the electrodes even when the support is smaller than the electrodes. Thus only mechanical constraint (support strong enough to hold the electrode) must be considerated.

The gap between the support and the electrode has a bigger influence as can be seen on figure 5 (bottom), especially when the size of the gap

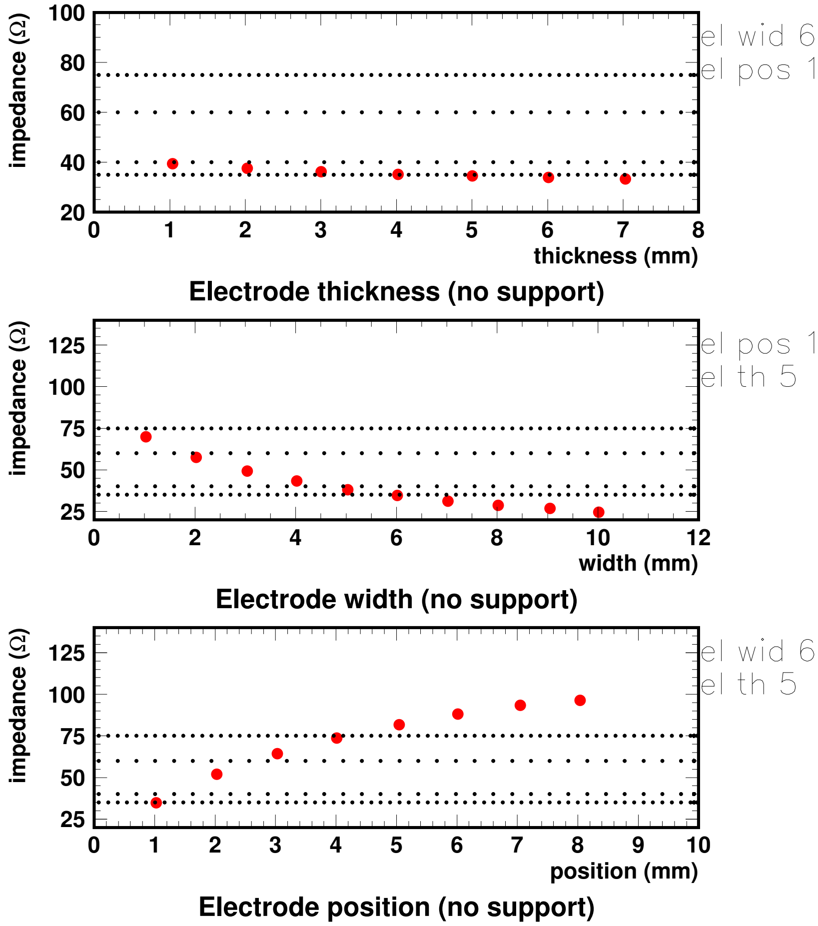

Figure 4: Impedance of the electrodes as a function of their thickness (top), width (middle) or position (bottom) in a kicker without support. The dotted lines shows the upper and lower boundary of the acceptable working range (40-60 Ω, sparsely dotted) and extreme working range (35-75 Ω, densely dotted). The numbers on the left hand side of the plots are the values used for the various variables describing the kicker. Error on the calculation is of the order of 5%.

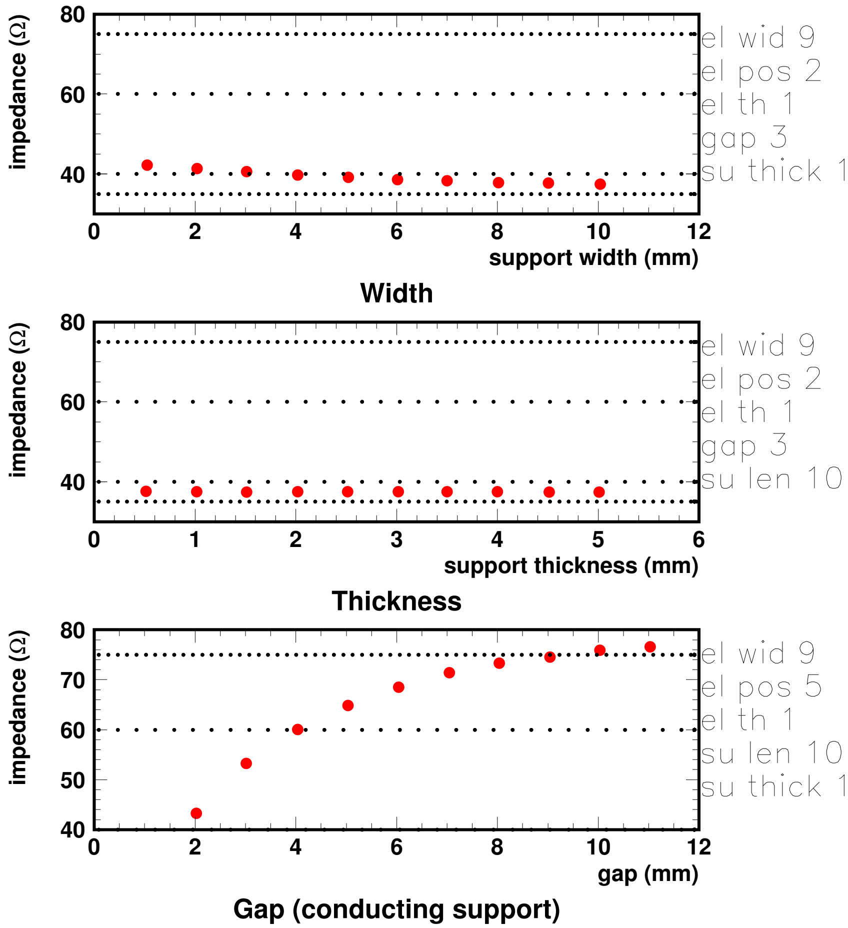

Figure 5: Impedance of the electrodes as a function of the support dimensions (width on the upper plot, thickness on the middle plot) or as a function of the gap between the electrode and the support (bottom plot). The impedance variation is negligible when the support width and thickness are changed. Here the support is made of a conducting material.

is comparable to the distance between the two electrodes (double of the electrode's position).

3.3.2 Electrode variables

Figure 6 shows that the conclusions of section 3.2 remain valid when a conducting support is added, that is:

- The influence of the thickness on the impedance is very limited. Thin electrodes have higher impedances.
- Narrow electrodes have higher impedances.
- Impedance decrease when electrodes become closer.

On the upper middle plot of figure 6 one can note that the impedance decreases by $\sim$ 20 ohms each time the width of the electrode doubles.

The variation of the impedance as a function of the position of the electrode, plotted on figure 6 (bottom plots) shows an interesting pattern: the wider the electrode is, the lower the impedance spawn is.

3.4 Electrode with an insulating support

Instead of using a conducting material for the electrode one can choose to use an insulating material. The figure 7 shows that the impedance follows the same rules than with a conducting supoort (described in section 3.3) when the dimensions of the electrodes are modified. Figures 8 show that the dimensions of the support have almost no influence on the impedance of the electrodes.

Thus to reach the highest impedance possible when the electrodes are at 1 mm from the center, one must choose the smallest and thinnest possible electrode. Even with this choice, it is not possible to reach 50 Ohms and the electrode will only be matched at a lower impedance. The support dimensions are constrained mainly by mechanical stability constraints. A side view of the kicker chosen to be built can be seen on figure 9.

As the electrodes of this device have an impedance lower than 50 Ohms when they are just 1 mm away from the center, we will not be able to operate them in that position, but figure 7 (lower plot) shows that with a position a bit higher than 1 mm the impedance becomes acceptable. Thus the minimal acceptable working position for the electrodes will be a bit more than 1 mm away from the kicker center.

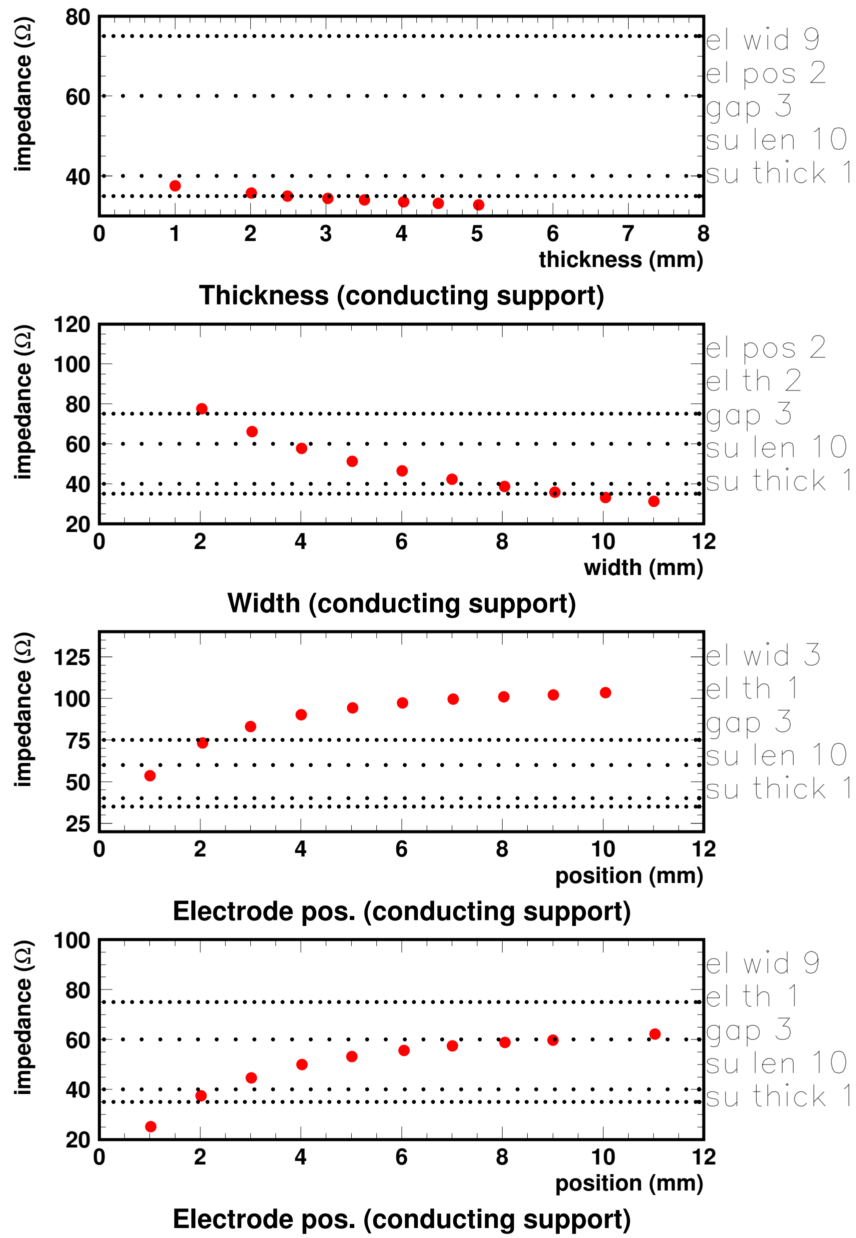

Figure 6: Impedance of the electrodes as a function of the thickness (uppest plot), the width (upper middle plot) or the position (bottom plots) of the electrode. The difference between the two bottom plots is that in one of them the electrode has a width of 3 mm whereas in the other one (the lowest one) the electrode has a width of 9 mm. One can see that the impedance variation is lower in the later case.

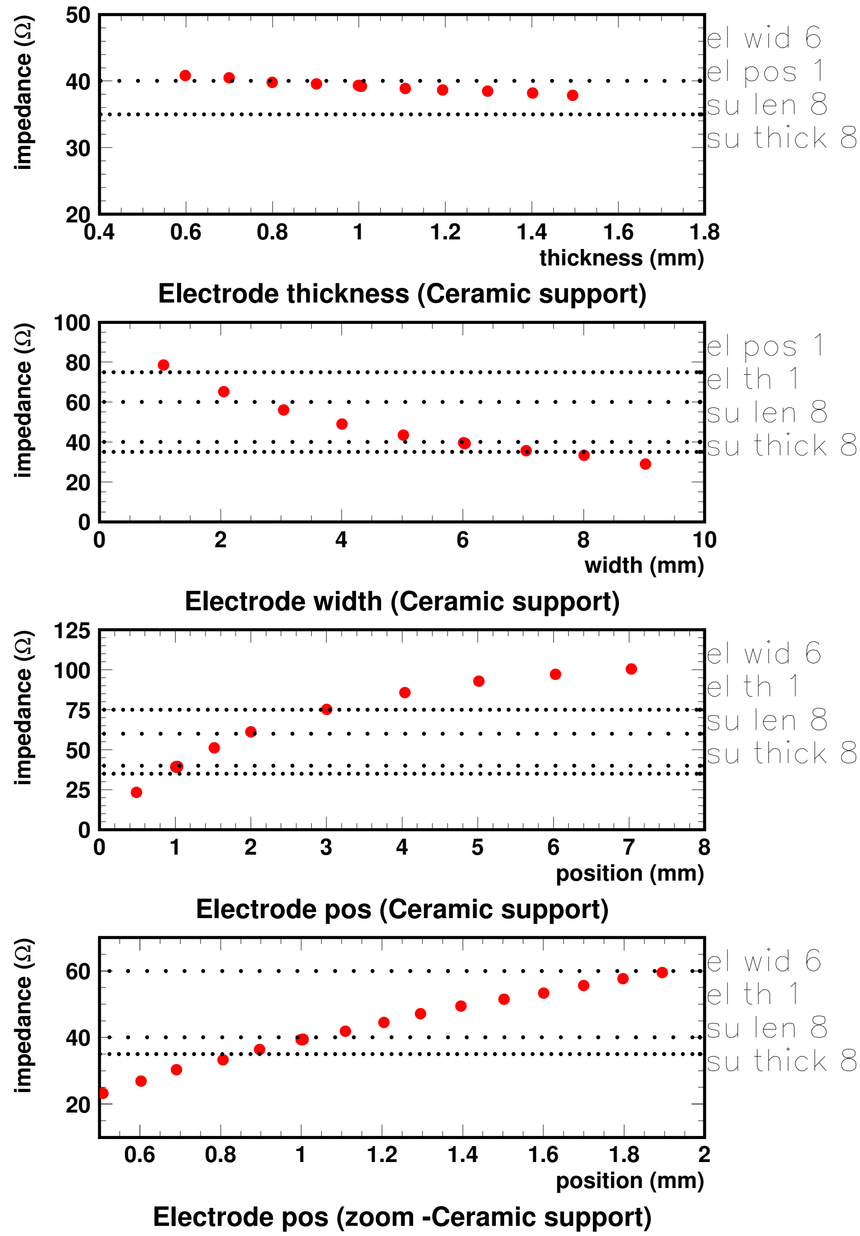

Figure 7: Impedance of the electrodes as a function of the thickness (uppest plot), the width (upper middle plot) and the position (two bottom plots) of the electrode.

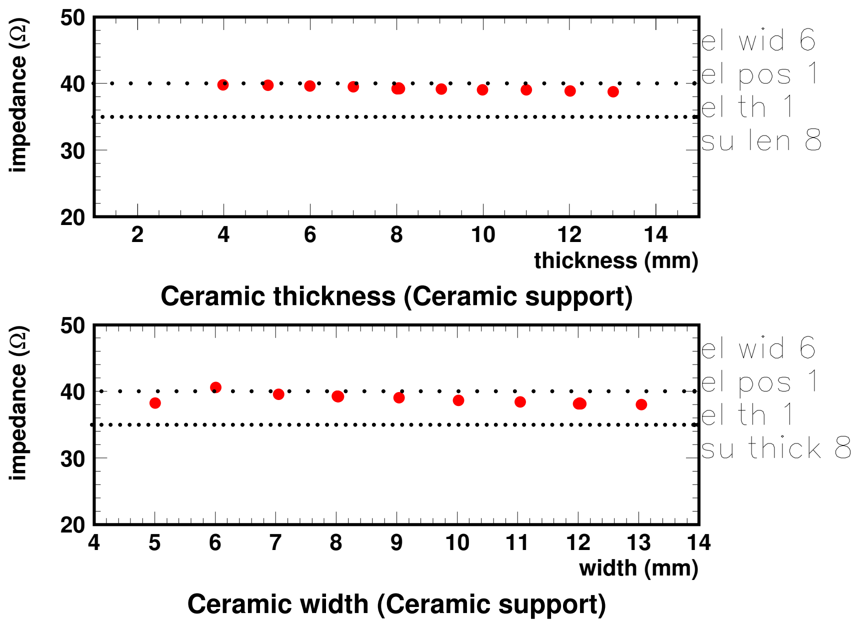

Figure 8: Impedance of the electrodes as a function of the thickness (upper plot) and the width (bottom plot) of the support where the electrode is bolted to its support.

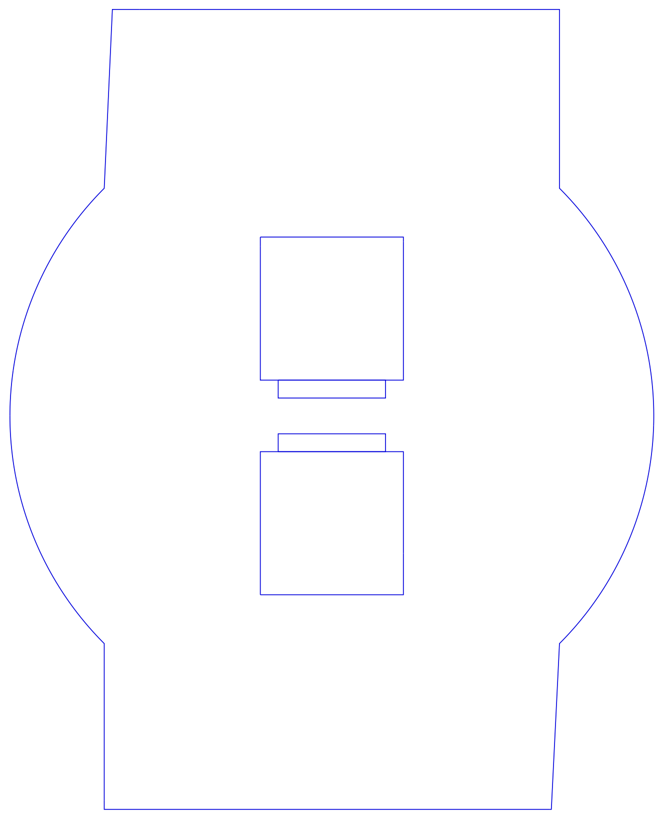

Figure 9: Side view of the kicker with the chosen parameters for the design.

3.5 Effect of the bolts

The electrodes can be stiffened by the support only if there is something holding them together. No glue can be used to reliably attach stainless steel to ceramic, thus bolts must be used, as shown on figure 10.

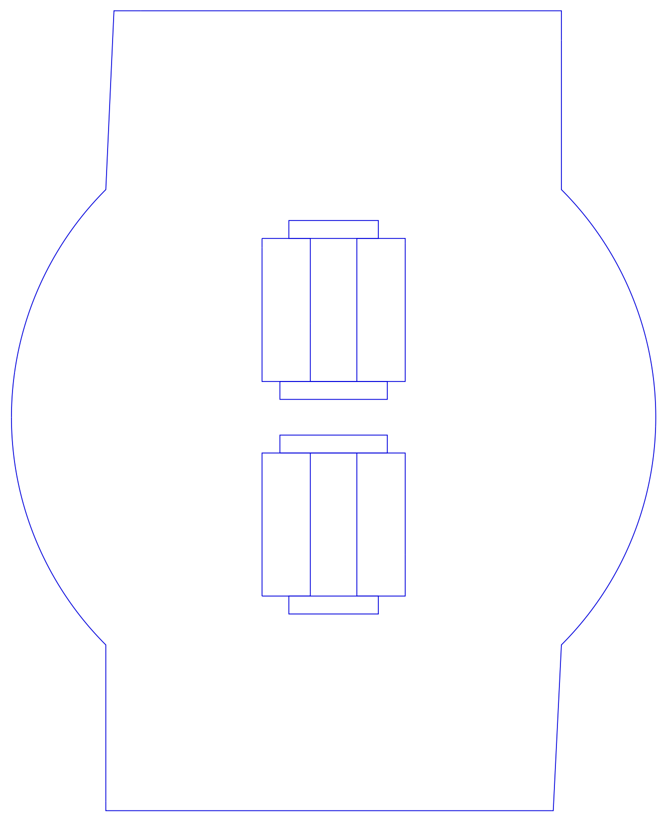

Figure 10: Side view of the kicker with the chosen parameters for the design.

As these bolts are made of a conductor material they will affect the field propagation and thus the impedance of the electrodes. The impedance of the elecrode bolted to the support and the effect of each parameter to this impedance has been studied as shown on figure 11.

The figures 11 and 12 confirm that the effect of the variations of the electrode parameters are the same in the bolted and not-bolted parts, but figure 13 shows that the support parameters now have an effect on the electrode matching. The thinnest and narrowest possible electrode will give the highest possible matching. The values chosen are 8 millimeters for both width and thickness which are the thinnest and narrowest acceptable values to insure mechanical stability.

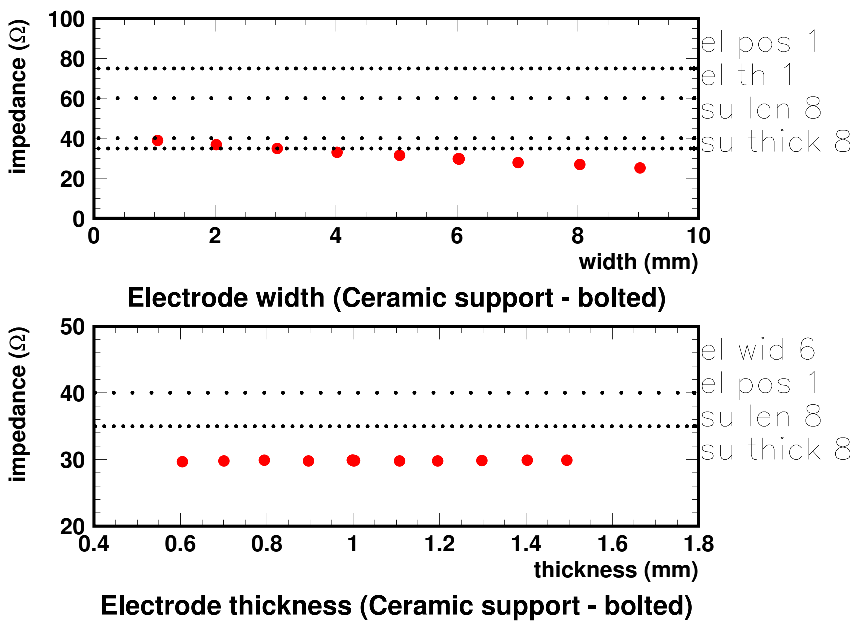

Figure 11: Impedance of the electrodes as a function of the width (top) and thickness (bottom) of the electrode where the electrode is bolted to its support.

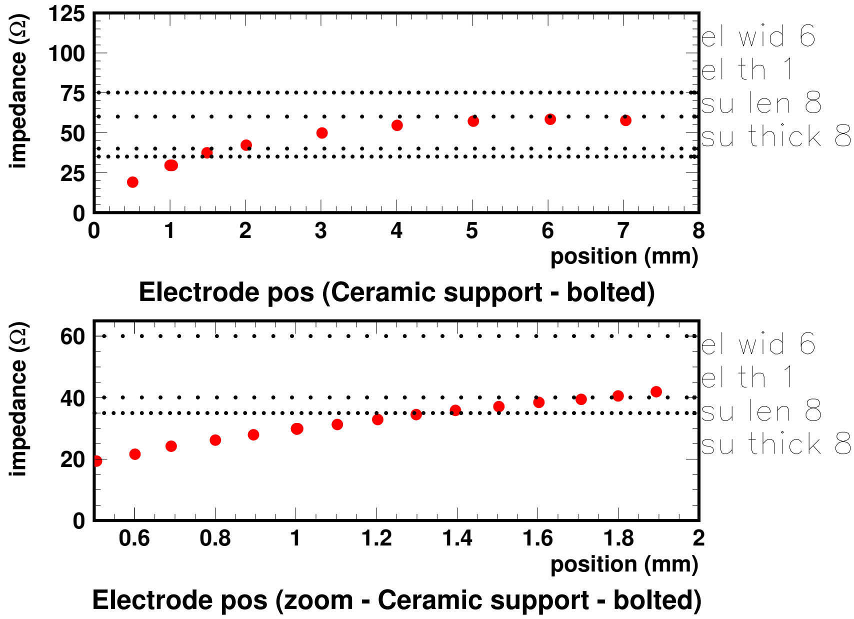

Figure 12: Impedance of the electrodes as a function of the position of the electrode where the electrode is bolted to its support.

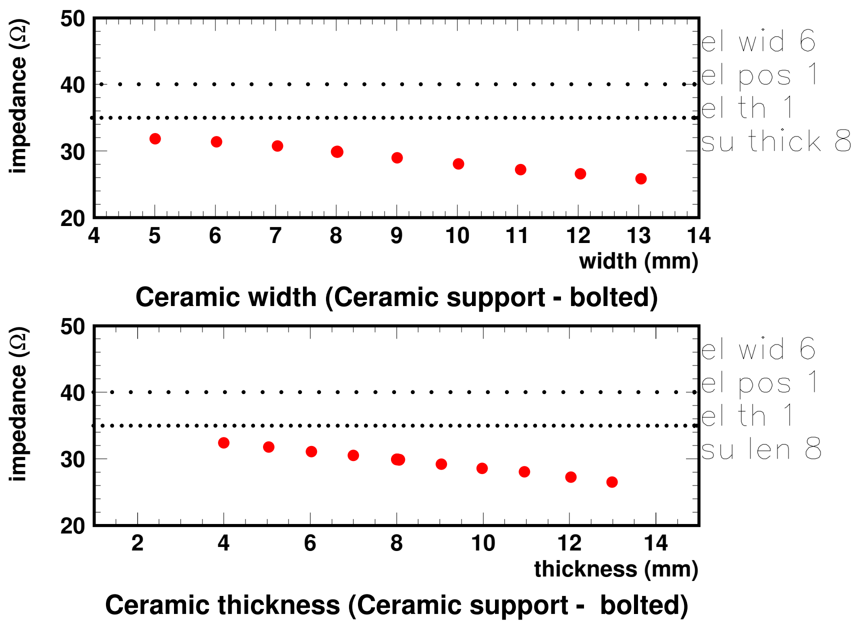

Figure 13: Impedance of the electrodes as a function of the thickness of the support where the electrode is bolted to its support.

4 Conclusions

The parameters chosen for the design of a kicker with a movable electrode are summarized in table 1 and the effect of changes on each of these parameters are summarized in table 2.

Electrode width	6 mm
Electrode thickness	1 mm
Support width	8 mm
Support thickness	8 mm

Table 1: Final parameters chosen for the design of our movable electrode kicker.

Variable	Variation effect
Electrode width	decrease
Electrode thickness	small decrease
Electrode position	increase
Gap	increase
Support width	tiny decrease
Support thickness	tiny decrease

Table 2: How changes on the parameters affect the impedance variation.

5 Acknowledgements

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