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Chopper Line Studies

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Summary

In the layout of the LINAC4, a Medium Energy Beam Transport (MEBT) is placed between the RFQ and the DTL, comprising a chopper and matching the beam parameters to the DTL

1. - Introduction

In the layout of the LINAC4, a Medium Energy Beam Transport (MEBT) is placed between the RFQ and the DTL, comprising a chopper and matching the beam parameters to the DTL.

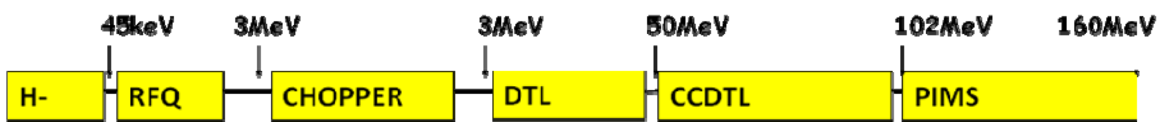


Figure 1.1.- Schematic layout of LINAC4

The aim of this chopping system is to modify the time structure of the beam, in order to avoid losses at high energy during the injection into the PS Booster. The Linac bunches that would fall in the unstable area of the RF bucket of the ring are removed at low-energy (3MeV), which is below activation threshold [1]. LINAC4 is foreseen to operate in two stages:

- As an injector of the PS Booster: the chopping scheme consists of removing 133 bunches out of 355, that will fit into the PSB RF bucket at the frequency of 0.99 MHz.
- As frontend of the SPL (injector of the PS2- 40MHz); the chopping scheme consists of removing 3 consecutive bunches out of 8.

The main goal of the following note is to study the fate of none properly chopped bunches of the LINAC4 in order to identify the location and the level of the losses. The limit of 1W/m is universally accepted for hands-on maintenance in linear accelerators [2].Different modeling of the chopper has been used to obtain the most consistent and realistic data.

Calculations were done with PathManager[3] and TraceWin [4] multi-particle codes. The results obtained with both codes are similar, therefore, only PathManager simulations are presented in this note.

2. - Chopper Description

The chopper consists of two chopper units, each made of two 0.4 m parallel deflecting plates (see figure 2.1).

The structure of these plates consists of a double-meander stripline (see figure 2.2); as the stripline does not completely cover the deflector plate, the voltage seen by the beam is reduced with respect to the one applied to the plates.

The field coverage factor, which is the ratio of the effective voltage to the applied voltage, is equal to 0.76 in the center plane [5].

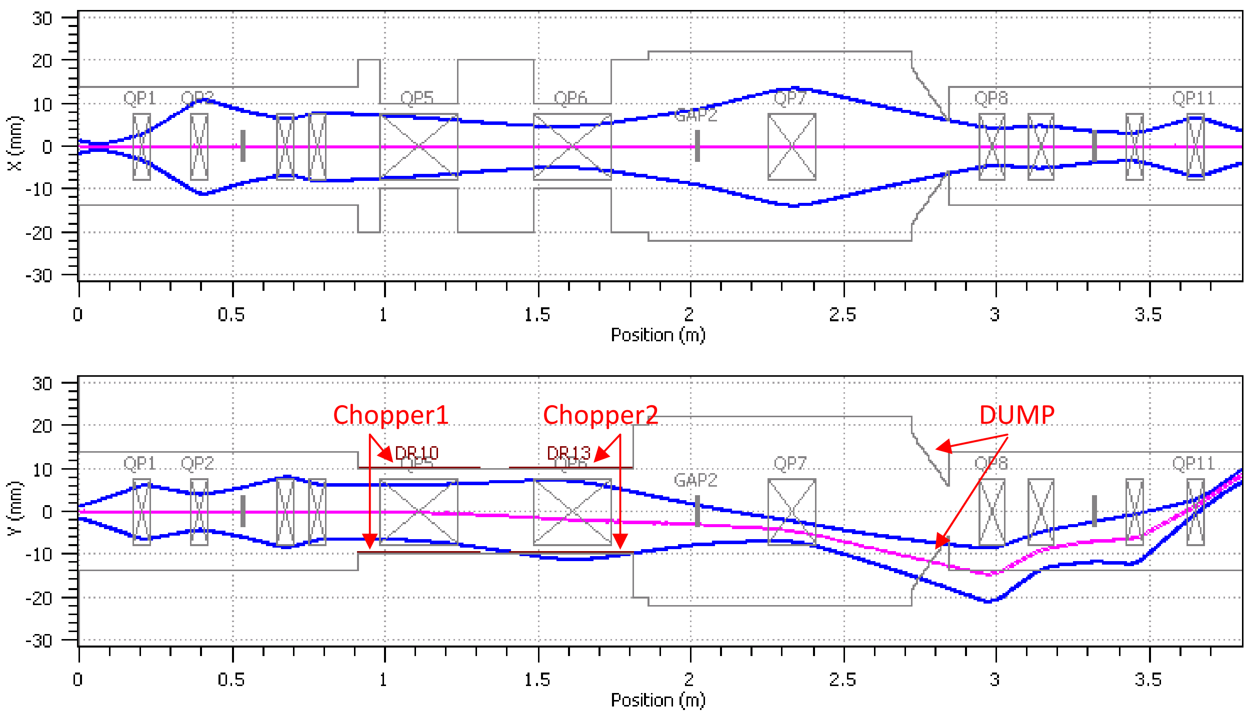


Figure 2.1- Beam envelopes in the chopper line and the location of chopper units (TraceWin).

The bunches deflected by the chopper are collected in the dedicated beam dump, placed about 1m downstream the second chopper plate.

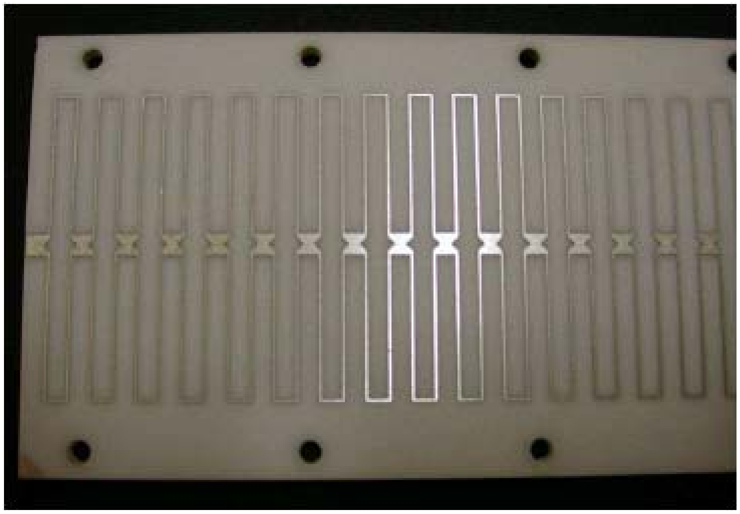
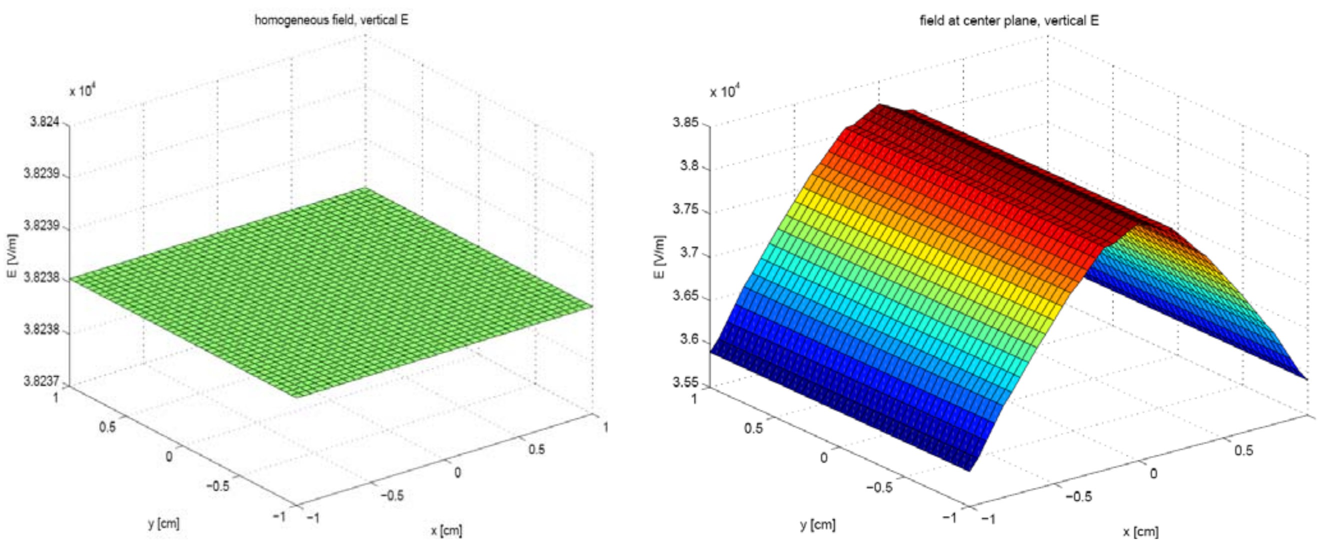


Figure 2.2- Implementation of chopper plate, alumina ceramic plates with printed meander structure.

In the following sections two different ways of simulating the system are presented, the first one assuming constant field between the plates, and the second one using the field maps obtained from the electromagnetic simulation of the stripline plates. Figure 2.3 shows the electric field distribution for both approaches [5]. In addition, simulations varying the voltage applied to the deflecting plates and tracking of the beam along the LINAC4 (up to the end of the transfer line to the PSB) were carried out.



(a) (b)

Figure 2.3- Field maps for constant field (a) and EM simulation of meander line (b).

3. - Constant Field

A preliminary study assuming uniform field was performed. Simulations have been performed with Path Manager using a vertical kick, applied in the middle of each chopper plate.

3.1.- Voltage 700 V

A distribution with 907008 particles is used as an input beam. The voltage applied to the chopper plates is 700 V. 392 (0.0043%) particles are transmitted to the output of the DTL.

The following figure shows the distribution of losses along the MEBT and the DTL. Note that the main part of the beam (98.22%) is collected in the dump and a total of 99.95% is lost in the MEBT.

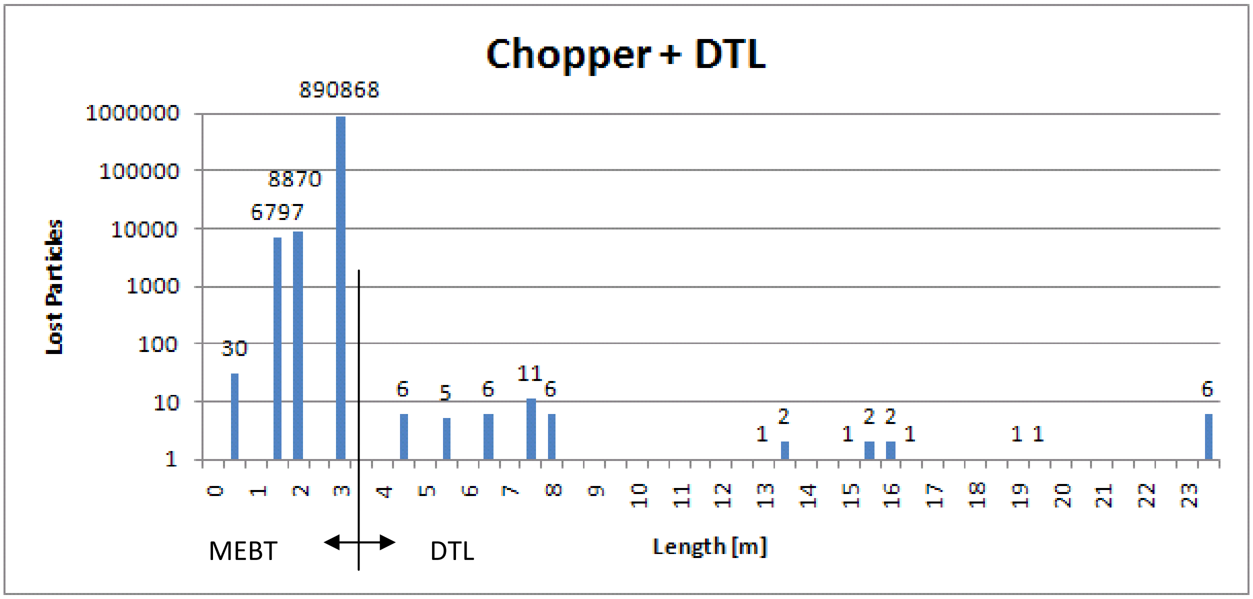


Figure 3.1.1.- Number of particles lost per unit length in the line (700 V, constant field).

The losses in terms of beam power along the MEBT are presented in figures 3.1.2 and 3.1.3. These losses are scaled for two different duty-cycle values corresponding to the two scenarios explained above.

In the dump 890868 particles are lost, resulting in 69.87 W for 0.1% duty cycle and a chopping scheme of 133/355 (PSB duty-cycle), and around 2.9 kW for 5% duty cycle and a chopping scheme 3/8 (SPL duty-cycle).

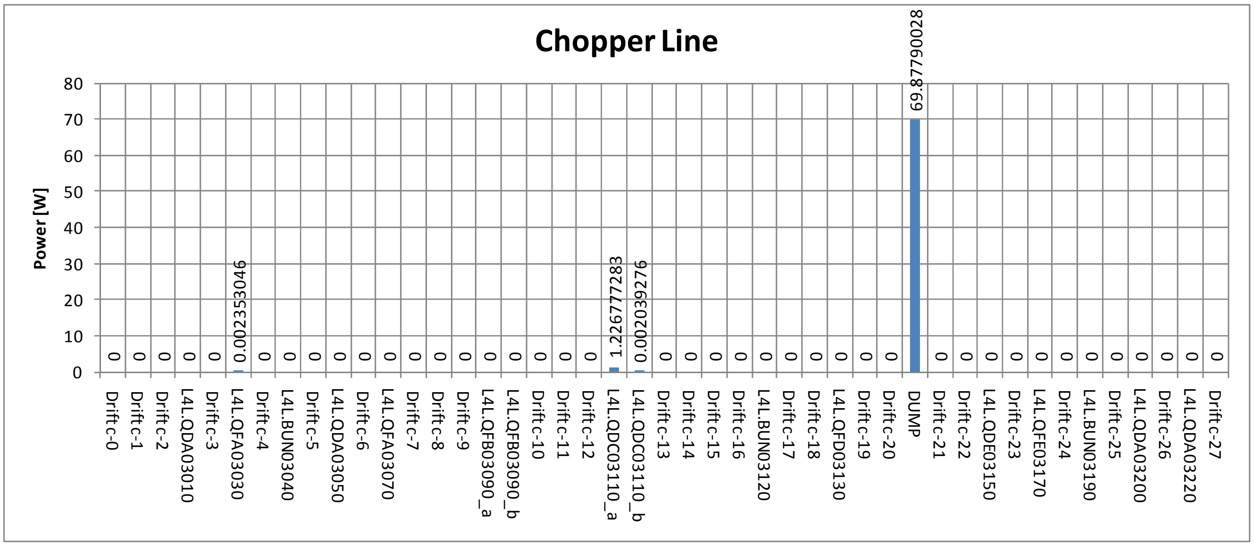


Figure 3.1.2.- Beam power loss map [watts] in the Chopper Line for 0.1 % duty cycle (700 V, constant field).

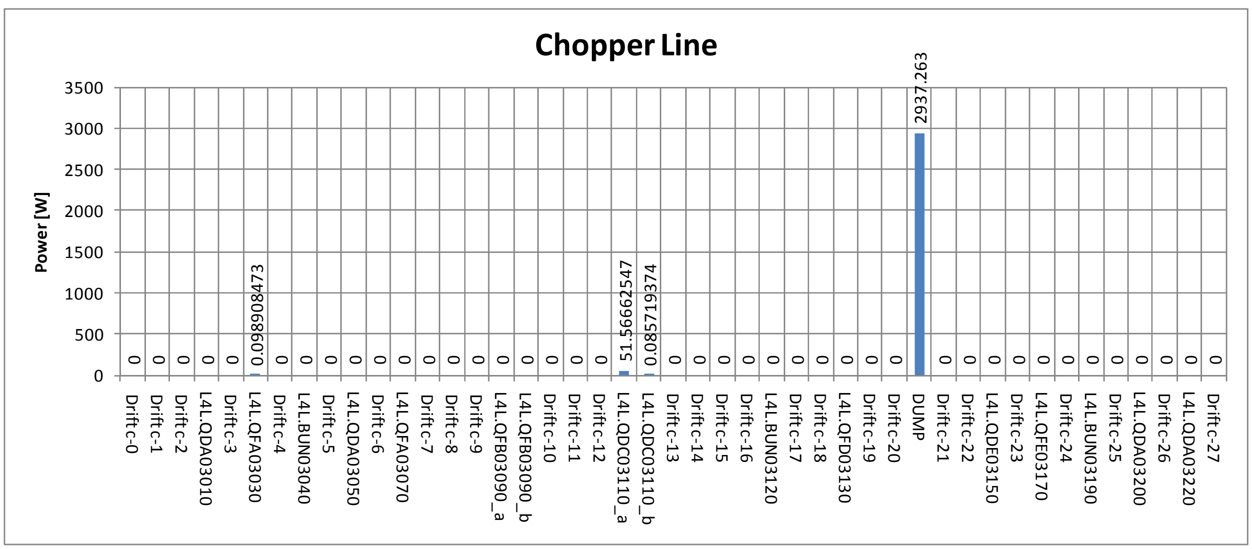


Figure 3.1.3.- Beam power loss map [watts] in the Chopper Line for 5 % duty cycle (700 V, constant field).

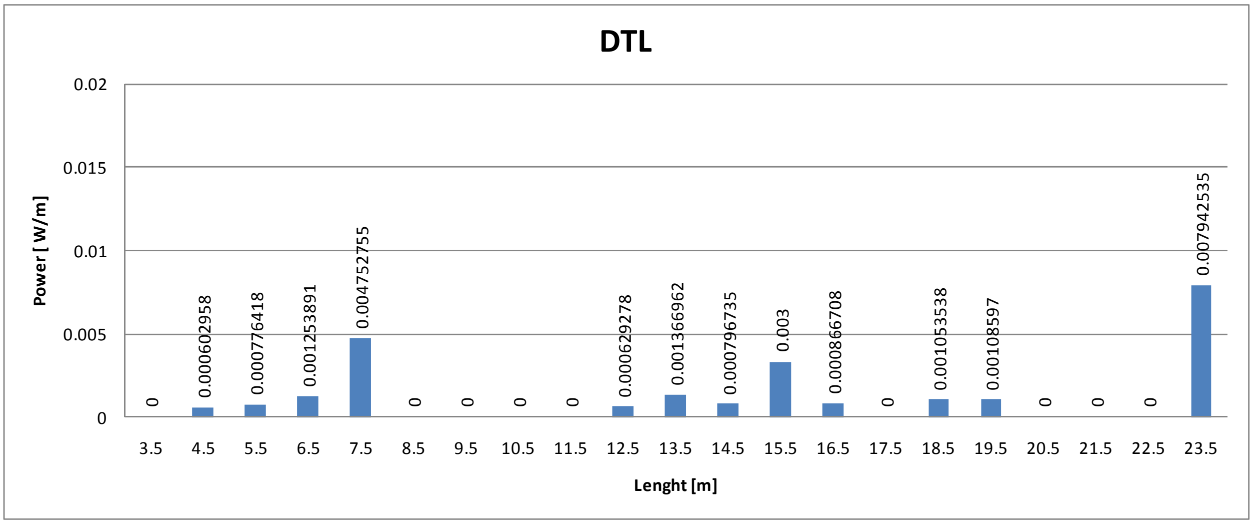


Figure 3.1.4.- Beam power loss map [watts per meter] in the DTL for 0.1 % duty cycle (700 V, constant field).

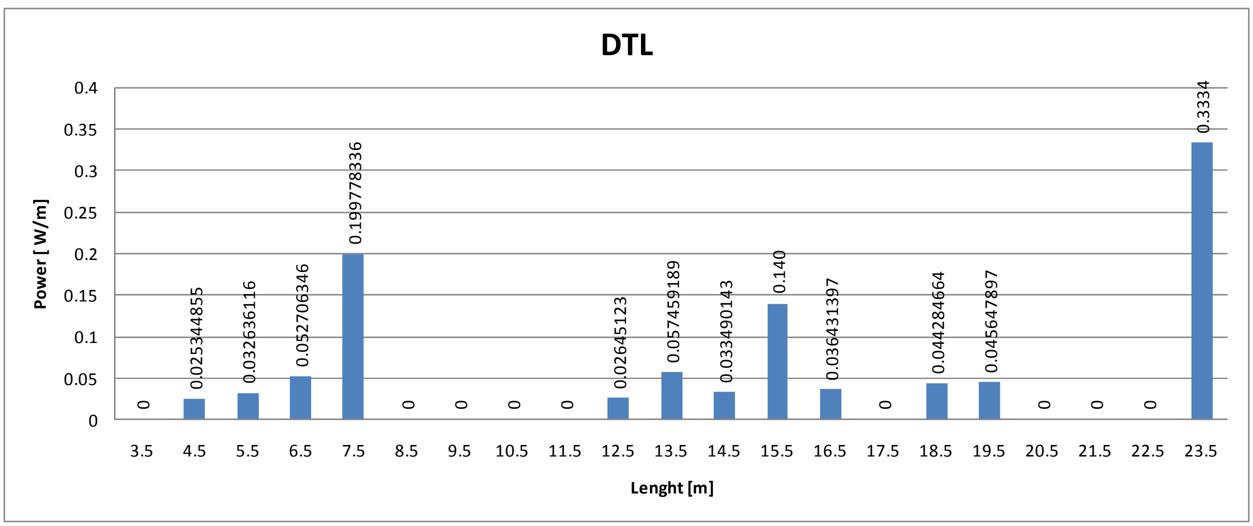


Figure 3.1.5.- Beam power loss map [watts per meter] in the DTL for 5 % duty cycle (700 V, constant field).

Figures 3.1.4 and 3.1.5 show the beam power losses per meter in the DTL. Note that the value is below the limit of 1W/m for hands-on operation in both cases.

In the CCDTL and PIMS there are no losses. In the transfer line only one particle over 907008 is lost (see below beam tracking).

The beam excursion of the partially chopped beam along the MEBT and the DTL is presented in Figure 3.1.6

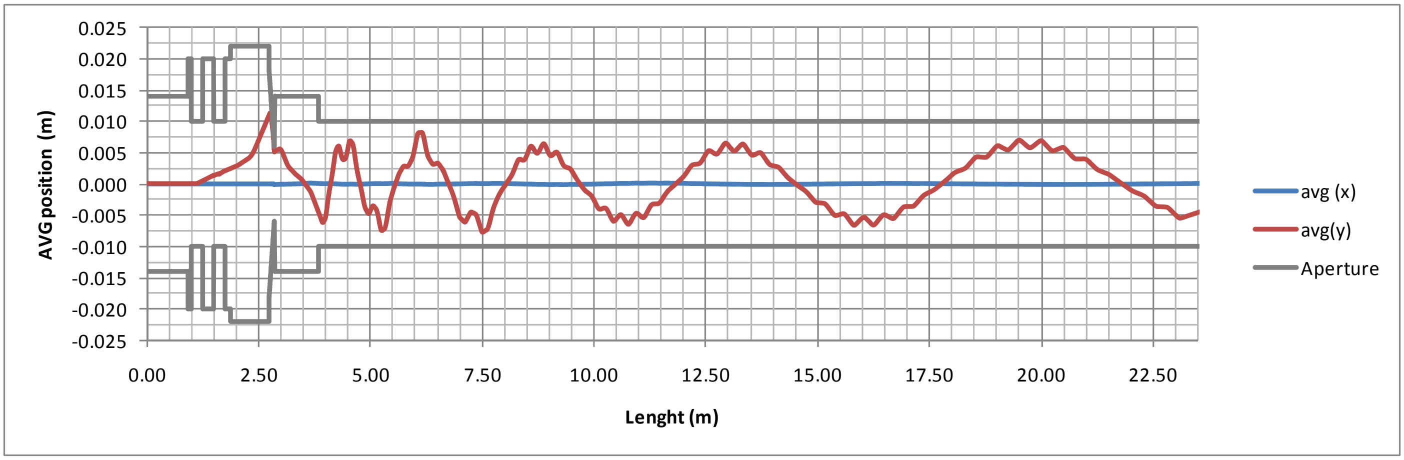


Figure 3.1.6.- Partially chopped beam center excursion vs length (Chopper+DTL, 700 V, constant field).

3.2 Beam tracking

The beam was tracked from the output of the RFQ up to the end of the Transfer line.

The transverse phase-space plots of the beam at strategic location are show in the figures of this section.

The number of particles in the input beam is 907008. After the dump 443 particles (~ 0.048 %) remain alive (see figure 3.2.1). The dump has a conical shape with 6mm radius at the end.

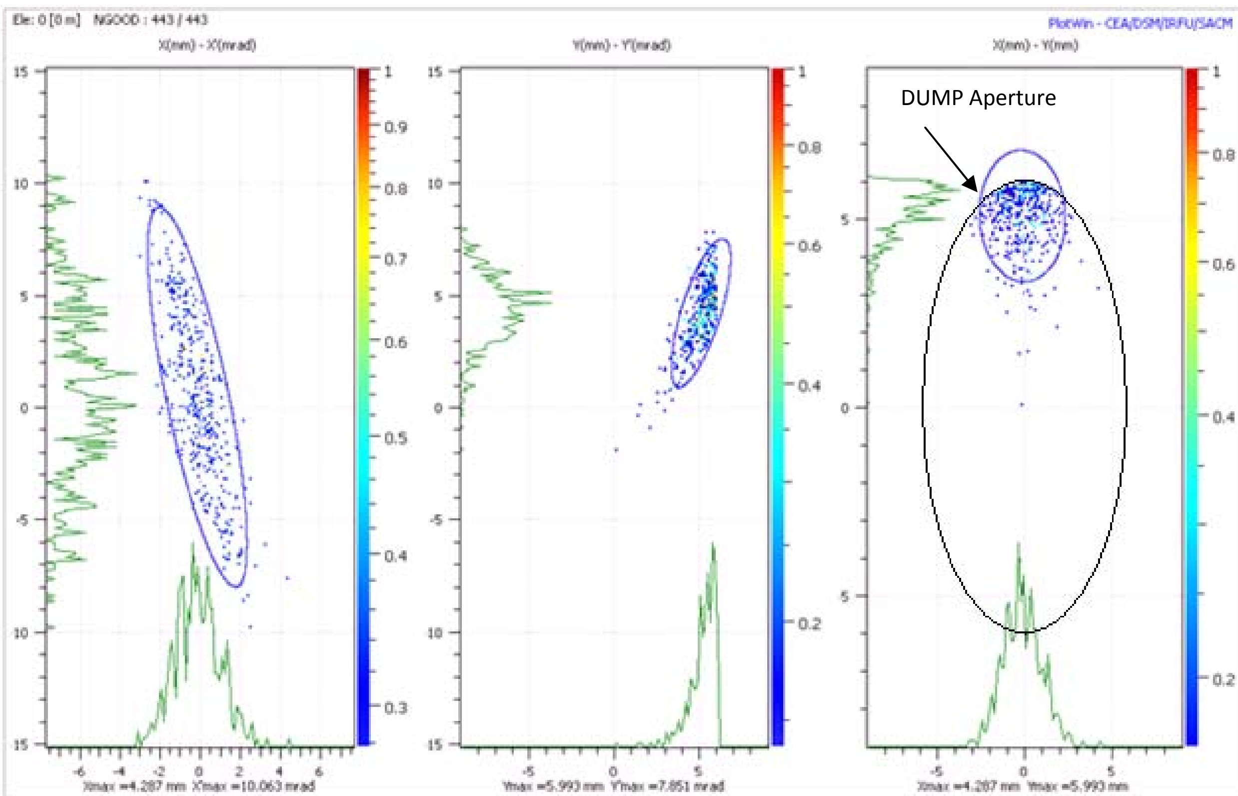


Figure 3.2.1.- The chopped beam after the dump (700 V, constant field).

Out of the 443 particles transmitted through the dump, 51 are lost in the DTL. There are no losses in the CCDTL (see figures 3.2.2, 3.2.3).

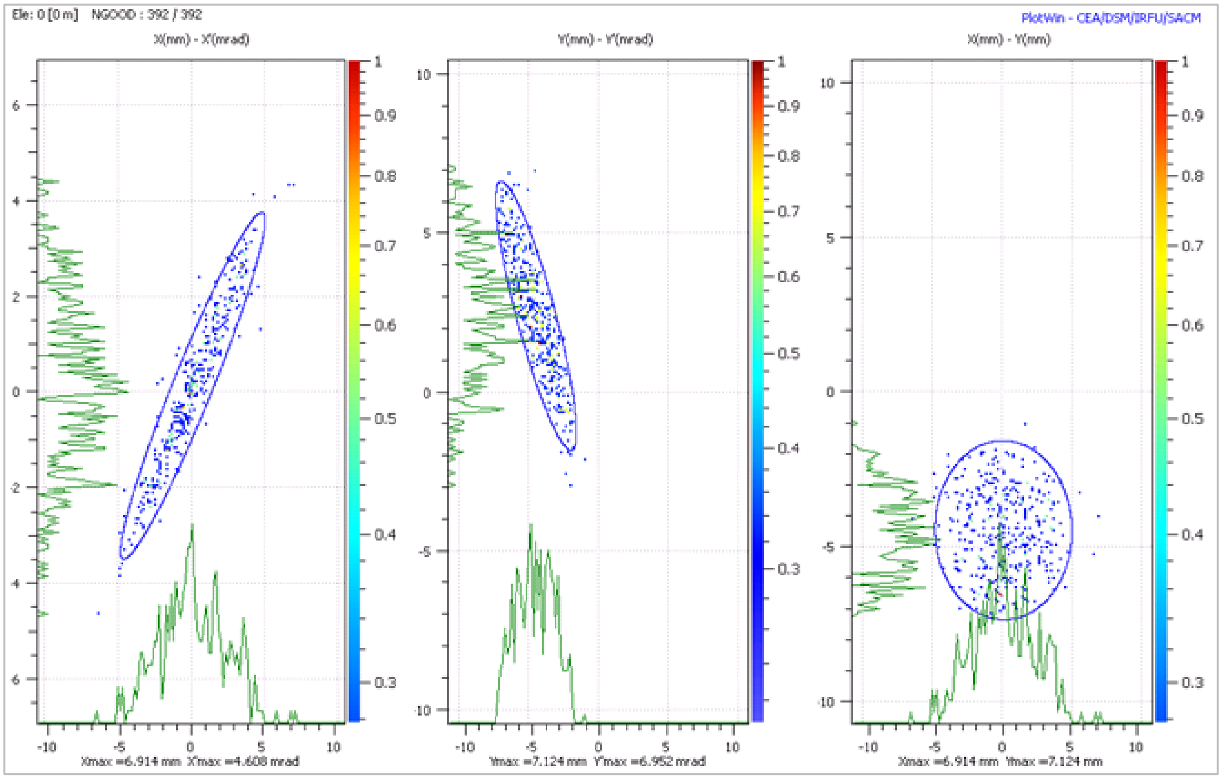


Figure 3.2.2.- DTL output beam (700 V, constant field).

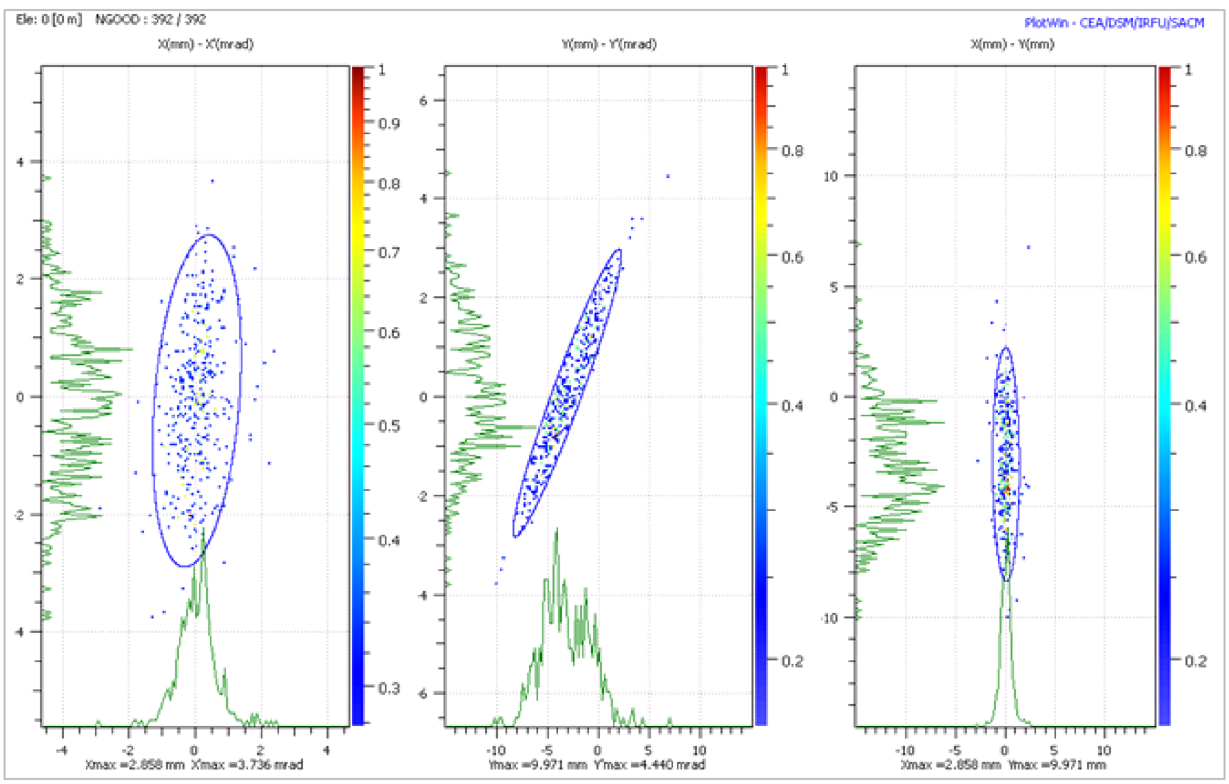


Figure 3.2.3.- CCDTL output beam (700 V, constant field).

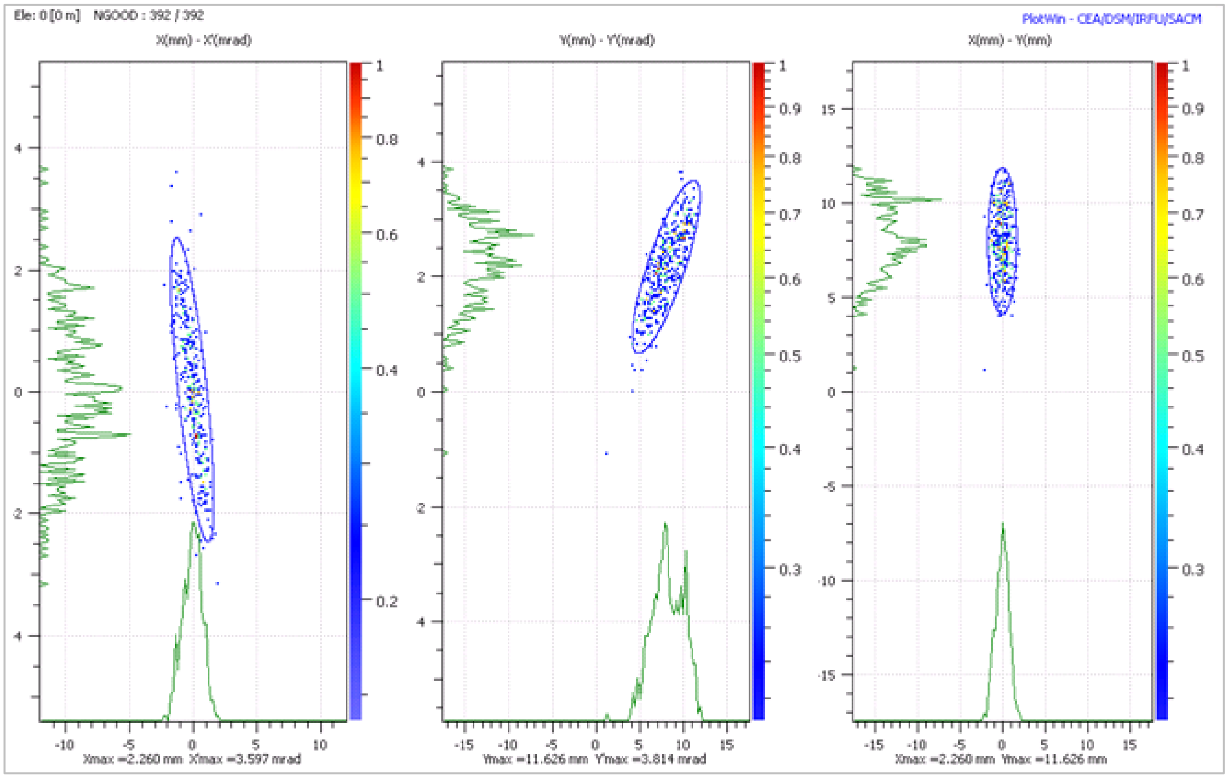


Figure 3.2.4.- PIMS output beam (700 V, constant field).

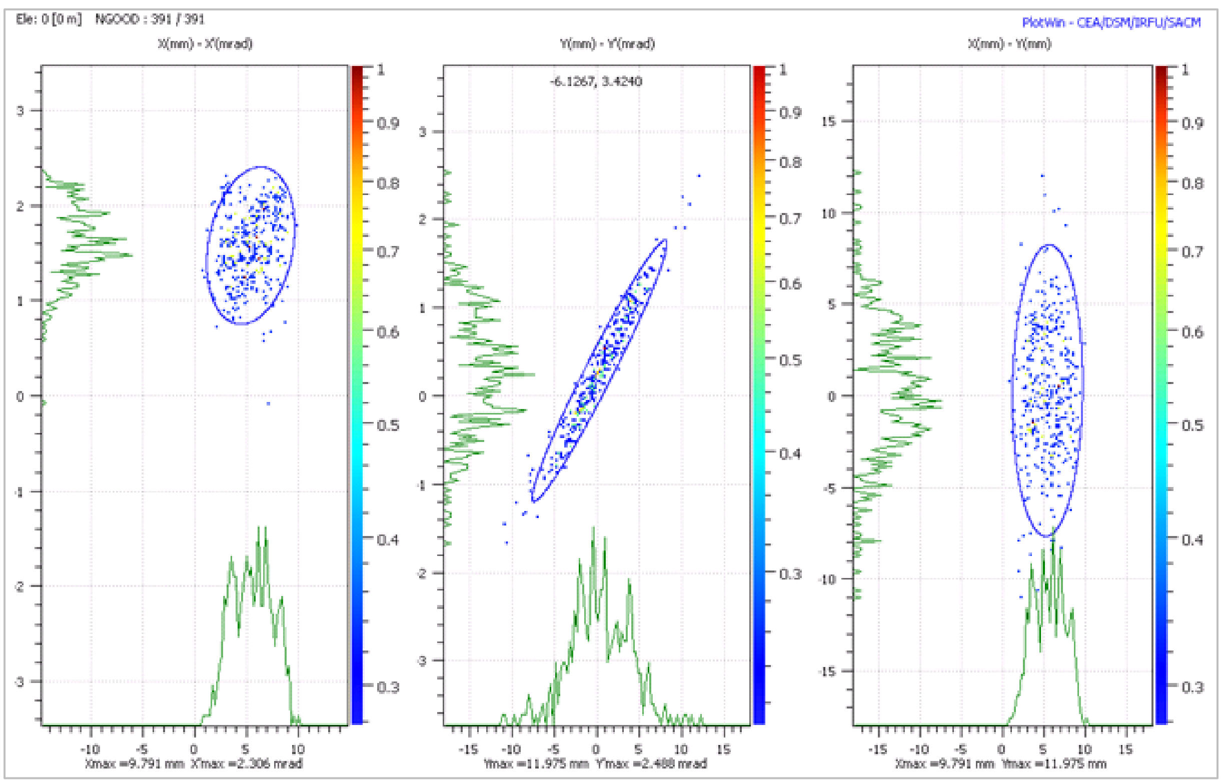


Figure 3.2.5.- TL output beam (700 V, constant field).

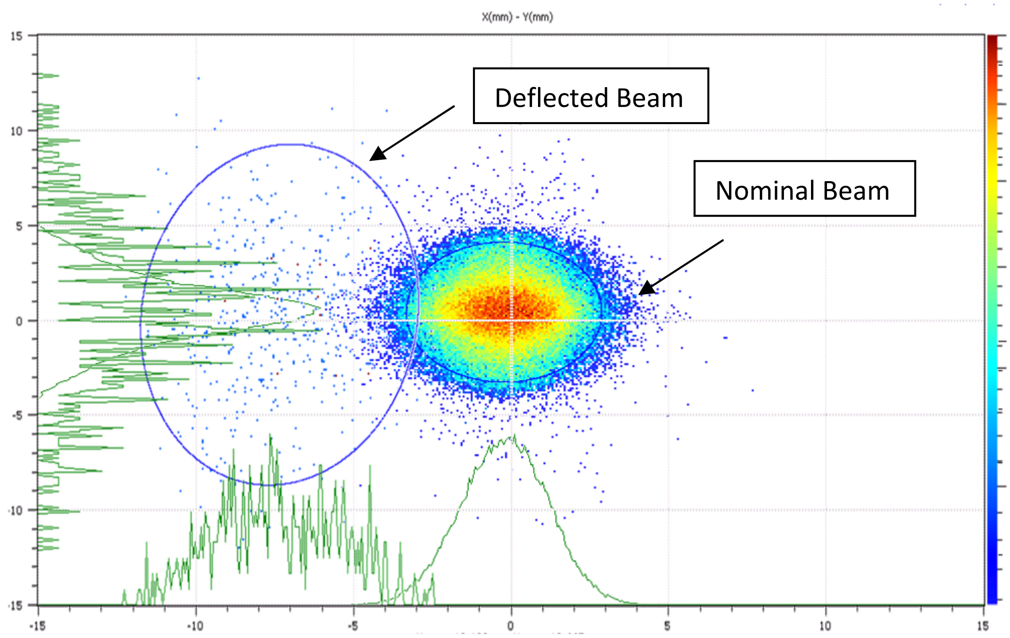


Figure 3.2.6.- TL output beam (Nominal beam and deflected beam superimposed)(700 V, constant field).

There is no particle lost in the PIMS, and there are 391 remaining particles at the end of the transfer line (see Figure 3.2.4, 3.2.5).

3.3.- Variation of the applied voltage

The following simulations have been done in order to determine the chopping efficiency applying different voltages to the plates for the same input beam. The results are summarized in the table below.

Voltage	N.Particles (Input Chopper)	N.Particles (Output DTL)	% Alive
0 V	907008	860799	94.9%
500 V	907008	43107	4.75%
600 V	907008	3363	0.37%
700 V	907008	392	0.04%

Table 1.- Chopping efficiency for different voltages (constant field).

This preliminary study was done assuming a constant field between the chopper plates, therefore the obtained results are optimistic. However, it is interesting to compare these results with the other approach using field map to establish the deviation of this method.

4. - Field Maps

In order to obtain a chopper model closer to the reality, and to determine the deviation of the calculations assuming constant field (above cases), simulations with field maps were performed.

These field maps were obtained from the electromagnetic simulations of the RF structure.[5]

4.1.- Voltage 700 V

The same input distribution as in section 3 (907008 particles), have been used. The voltage applied to the chopper plates is 700 V. 592 (0.0065%) particles are transmitted to the output of the DTL.

The following figure shows the distribution of the lost particles along the MEBT and the DTL; in the dump 888430 are lost. Note that the main part of the beam 97.95% is collected in the dump and a total of 99.92 % is lost in the MEBT.

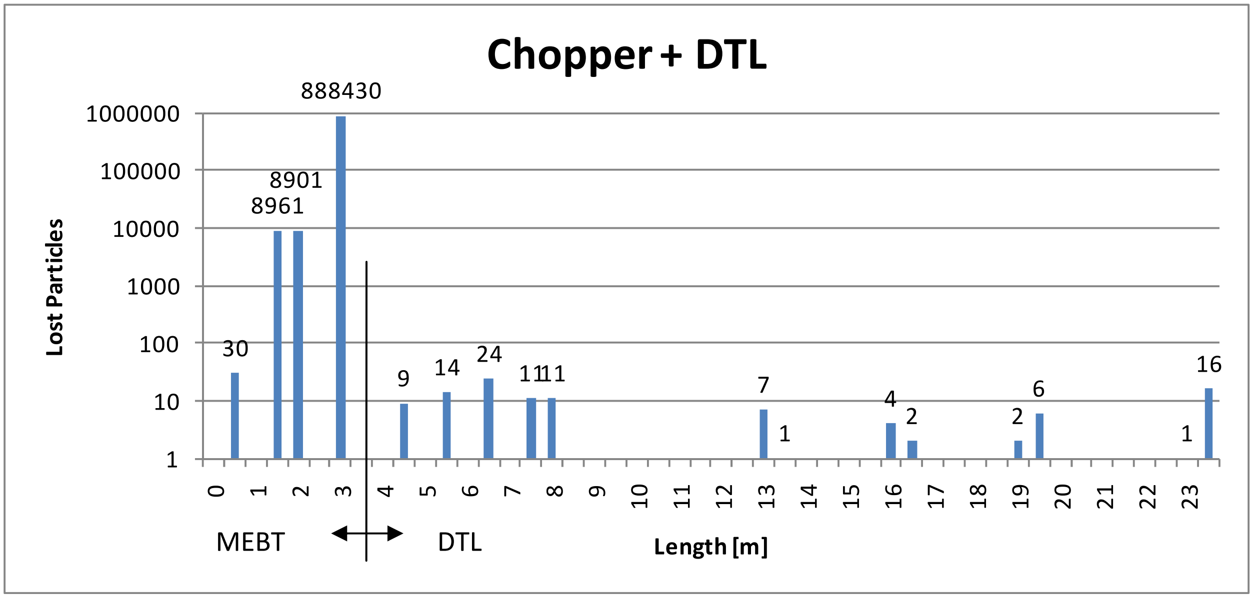


Figure 4.1.1.- Number of particles lost per unit length in the line (700 V, field maps).

The losses in terms of beam power along the MEBT are shown in figures 4.1.2 and 4.1.3. These losses are scaled for two different duty-cycle values corresponding to the two scenarios explained above.

In the dump 888430 particles are lost, resulting in 69.65W for 0.1% duty cycle and a chopping scheme of 133/355 (PSB duty-cycle), and around 2.9 kW for 5% duty cycle and a chopping scheme 3/8 (SPL duty-cycle).

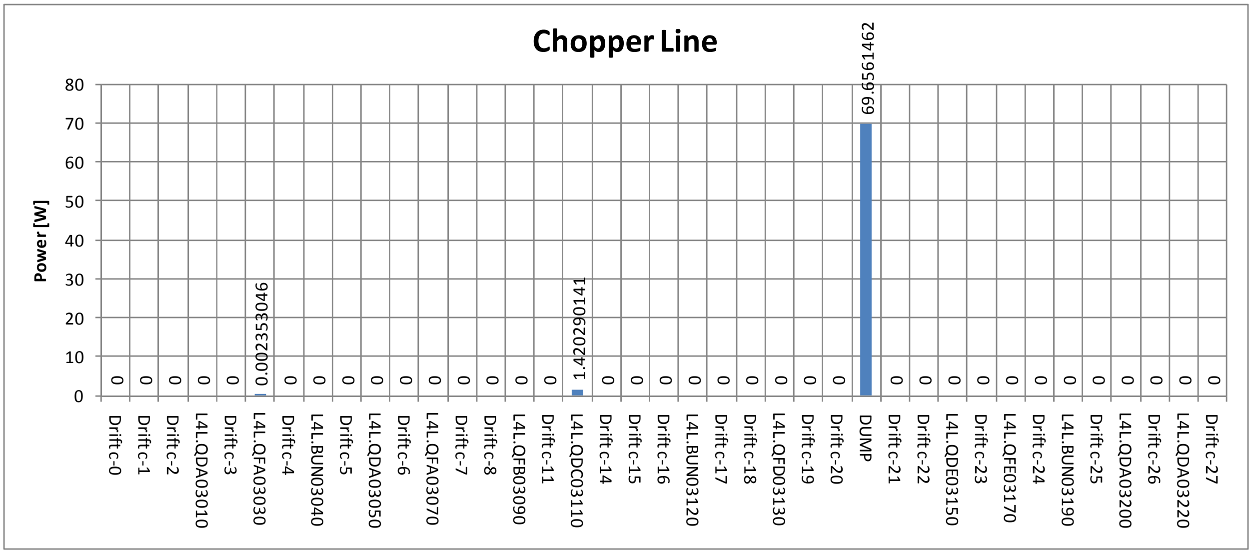


Figure 4.1.2.- Loss Beam power loss map [watts] in the Chopper Line for 0.1 % duty cycle (700 V, field maps).

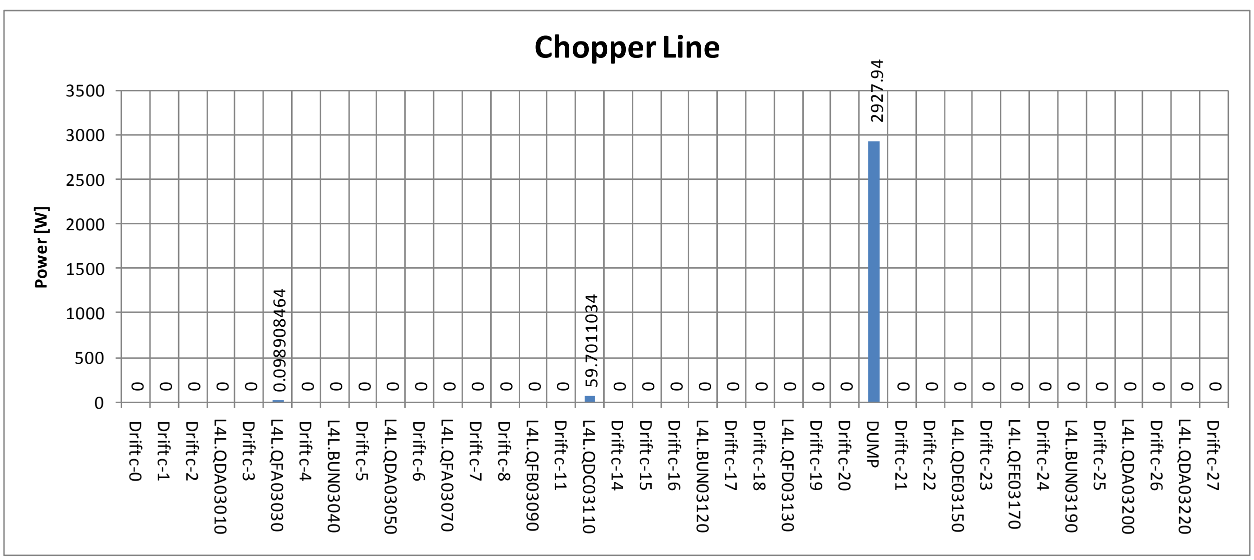


Figure 4.1.3.- Beam power loss map [watts] in the Chopper Line for 5 % duty cycle (700 V, field maps).

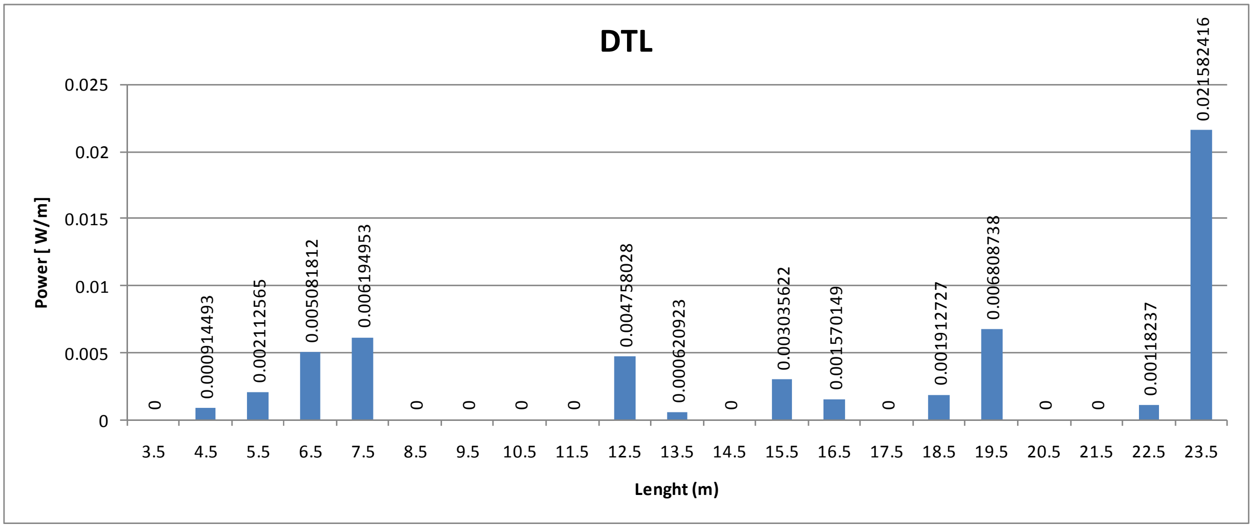


Figure 4.1.4.- Beam power loss map [watts per meter] in the DTL for 0.1 % duty cycle (700 V, field maps).

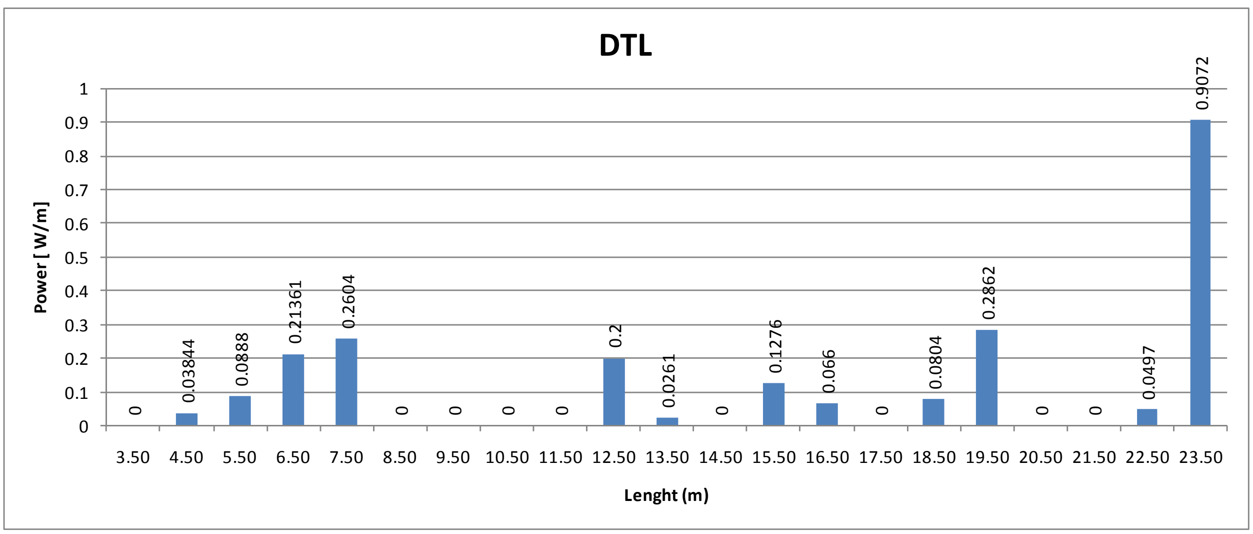


Figure 4.1.5.- Beam power loss map [watts per meter] in the DTL for 5 % duty cycle (700 V, field maps).

Figures 4.1.4 and 4.1.5 show the beam power losses per meter in the DTL. Note that the value is below the limit of 1W/m for hands-on operation in both cases.

In the CCDTL and PIMS there are no losses. In the transfer line, 63 particles are lost out of 907008, resulting in about 0.25 W (see below beam tracking).

The beam excursion of the partially chopped beam along the MEBT and the DTL is presented in Figure 4.1.6

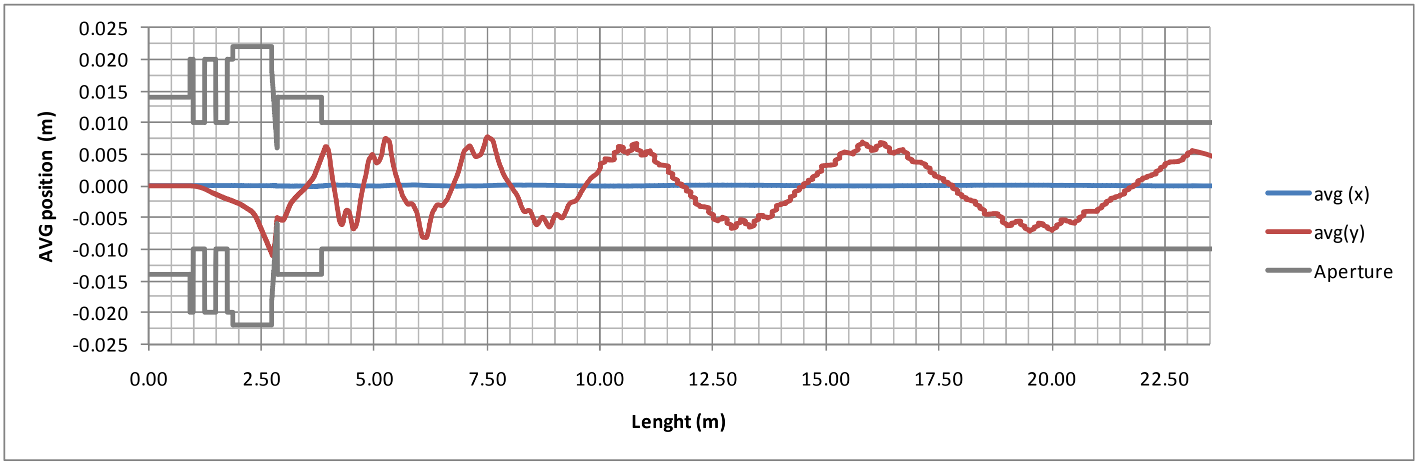


Figure 4.1.6.-. Partially chopped beam center excursion vs length (Chopper+DTL, 700 V, field maps).

4.2.- Beam Tracking

The beam was tracked from the output of the RFQ up to the end of the Transfer line.

The transverse phase-space plots of the beam at strategic location are show in the figures of this section.

The number of particles in the input beam is 907008. After the dump 685 particles (~ 0.075 %) remain alive (see figure 4.2.1). The dump has a conical shape with 6mm radius at the end.

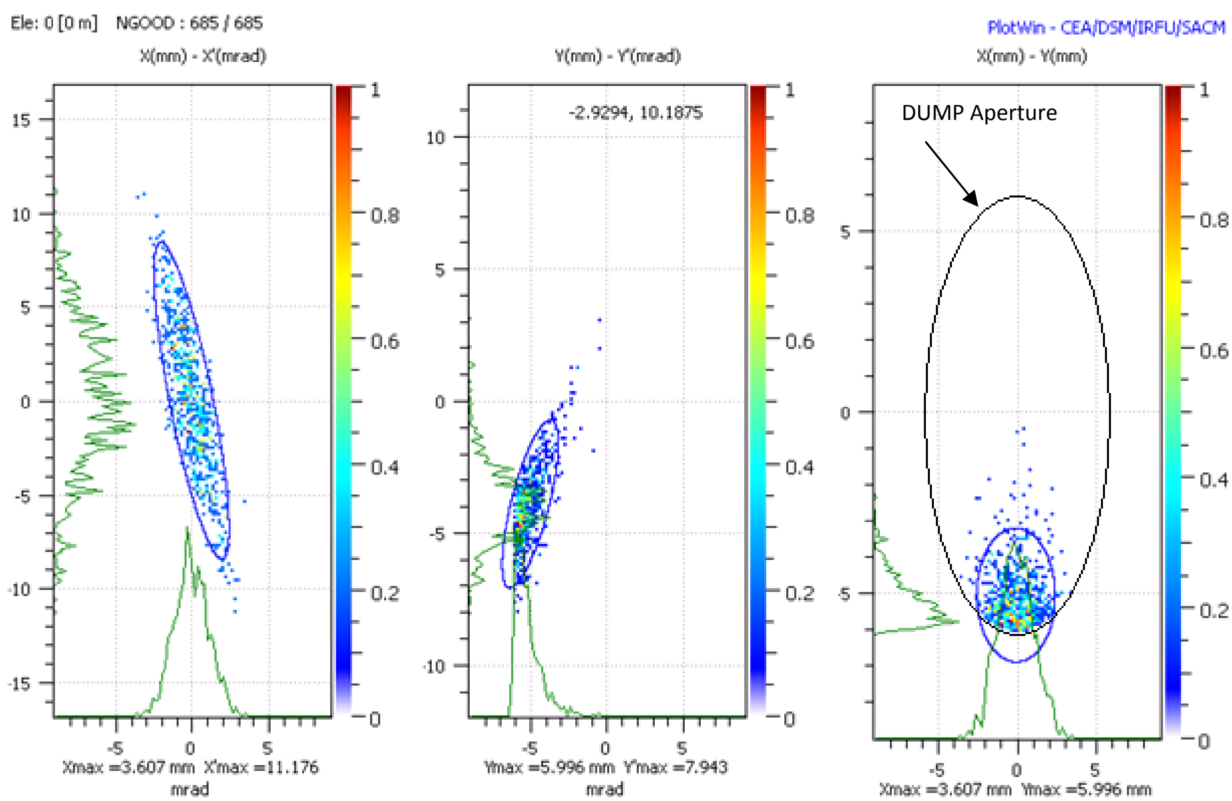


Figure 4.2.1.- The chopped beam after the dump (700 V, field maps).

Out of the 685 particles transmitted through the dump, 93 particles are lost in the DTL. There is no loss in the CCDTL (see figures 4.2.2, 4.2.3).

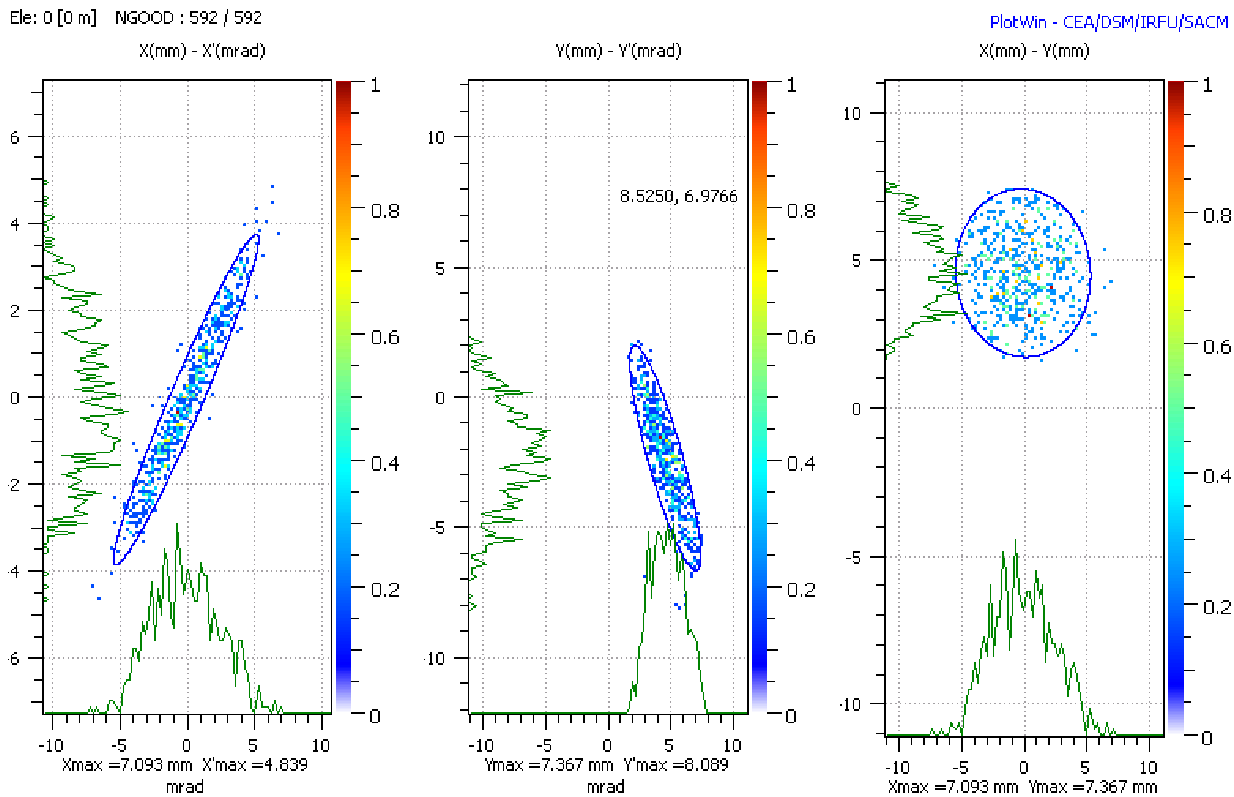


Figure 4.2.2.- DTL output beam (700 V, field Maps).

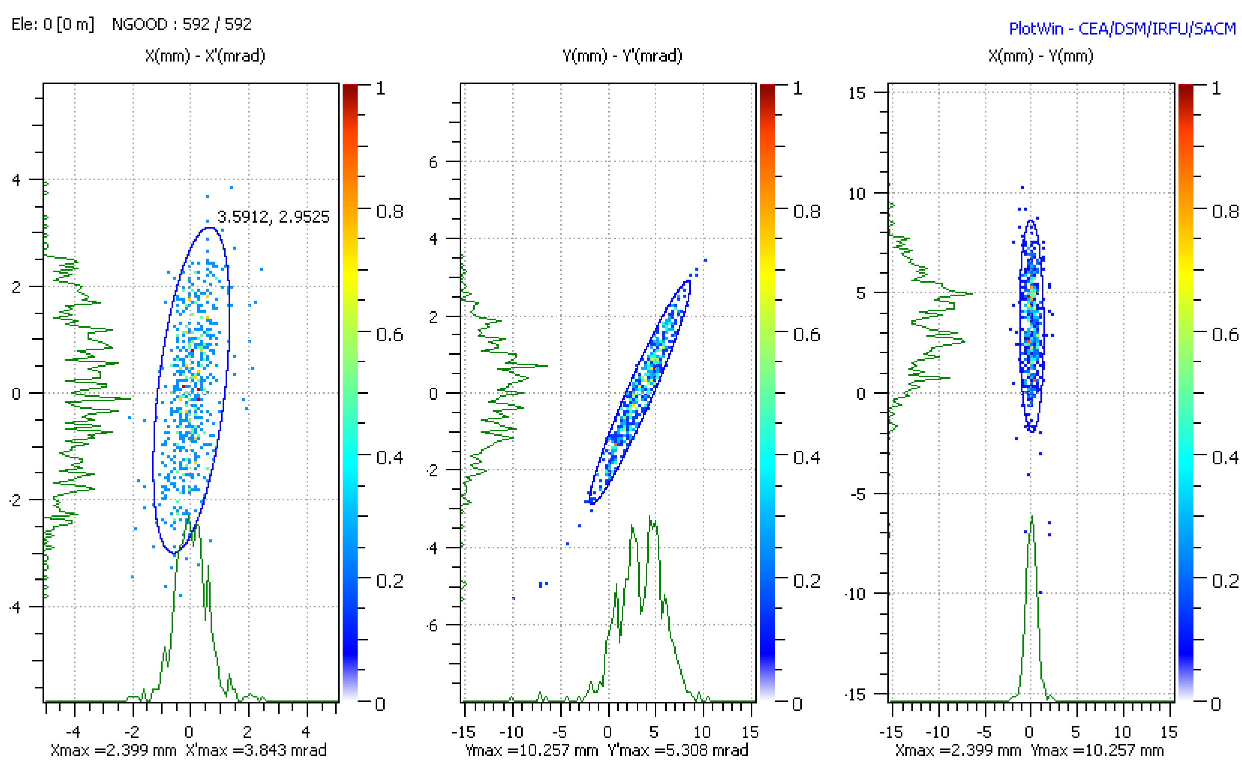


Figure 4.2.3.- CCDTL output beam (700 V, field maps).

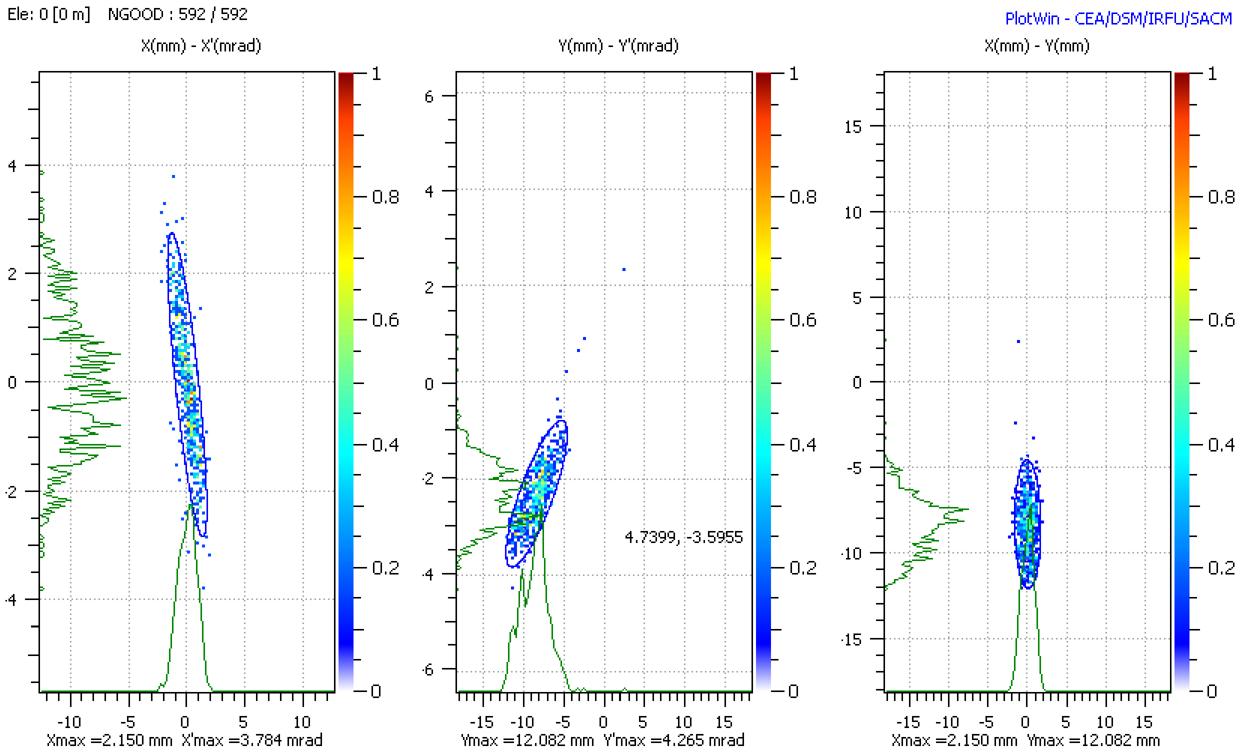


Figure 4.2.4.- PIMS output beam (700 V, field maps).

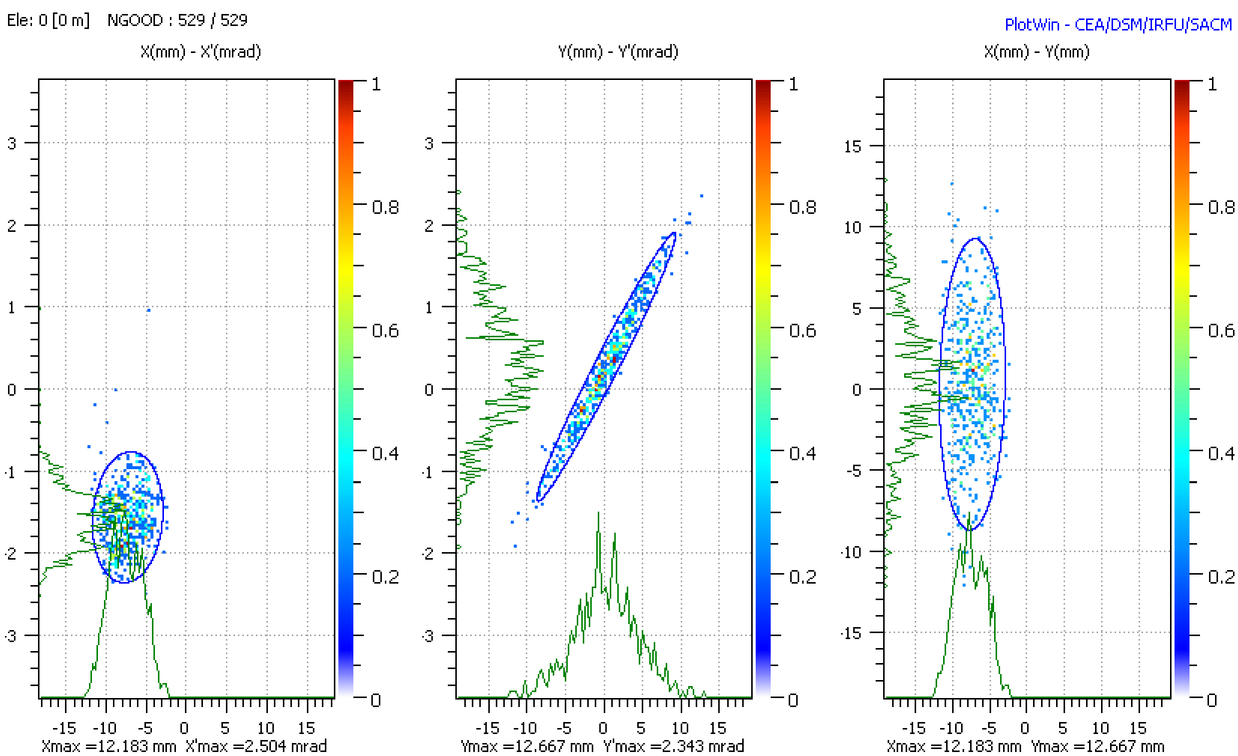


Figure 4.2.5.- TL output beam (700 V, field maps).

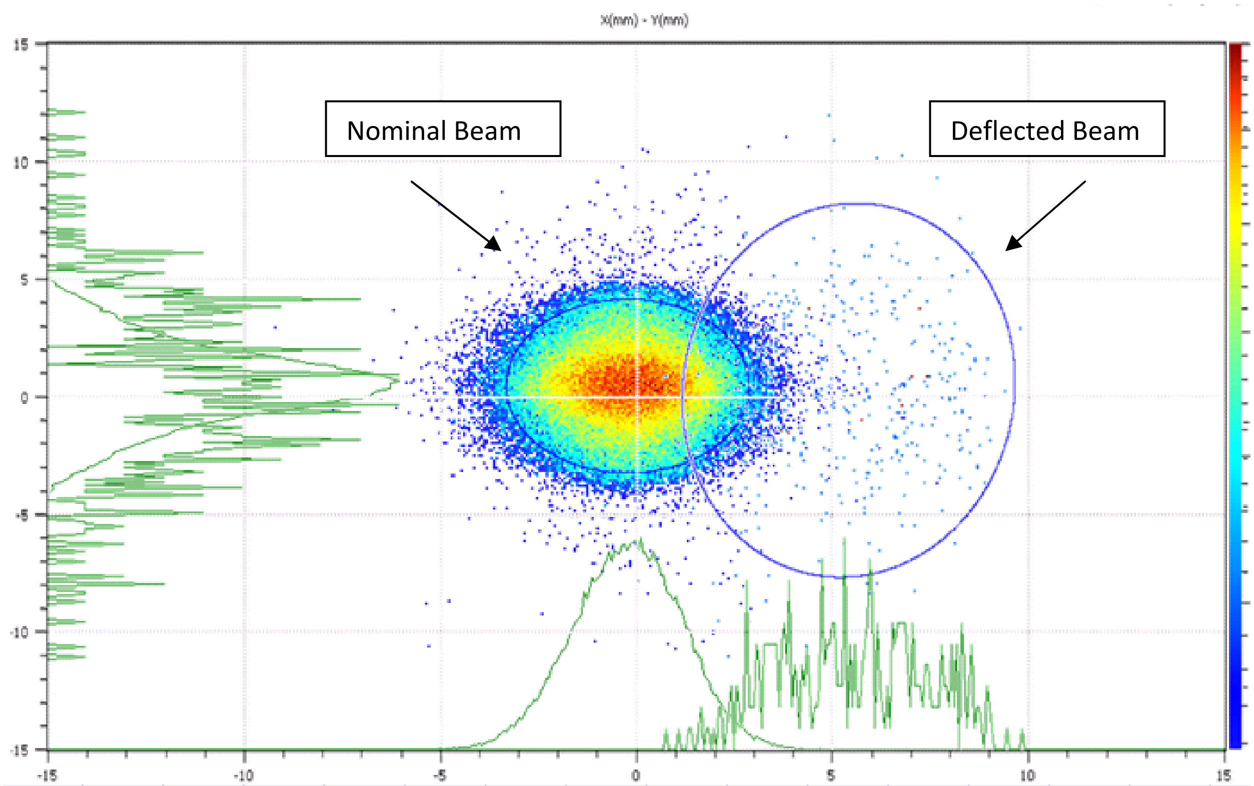


Figure 4.2.6.- TL output beam (Nominal beam and deflected beam superimposed) (700 V, field maps).

There is no particle lost in the PIMS, and 529 remaining particles at the end of the transfer line (see Figure 4.2.4, 4.2.5).

4.3.- Variation of the applied voltage

The following simulations have been done in order to determine the chopping efficiency applying different voltages to the plates for the same input beam. The results are summarized in the table below.

Voltage	N.Particles (Input Chopper)	N.Particles (Output DTL)	% Alive
0 V	907008	860799	94.9%
500 V	907008	55007	6.06%
600 V	907008	5903	0.65%
700 V	907008	592	0.06%

Table 2.- Chopping efficiency for different voltages (field maps).

5.- Conclusions

In this note, two different methods of simulating the chopping in LINAC4 were studied in order to determine the chopping efficiency, the level of the losses and their locations along the LINAC.

Although the hotspots obtained with both methods are similar, it can be concluded that the results obtained using the field maps are more realistic and they provide pessimistic results in terms of chopping efficiency.

Assuming ±700 V applied to the chopper plates, there are losses along all the DTL. The maximum beam power loss is located in the last meter of the DTL; 0.021W/m for 0.1% duty cycle, and 0.90 W/m for 5% duty cycle.

No losses of the partially chopped beam are expected in the CCDTL and PIMS and the worst case in the transfer line is 0.25 W/m.

77.2% of the partially chopped beam (at the output of the dump) is transmitted along the LINAC up to the end of the transfer line.

6.- References

[1] F. Gerigk, M. Vretenar editors, “LINAC4 Technical Design Report”, CERN-AB-2006-084 ABP/RF

[2] N.V Mokhov and W.Chou editors, “Beam Halo and scraping”, Proc. 7th ICFA mini-workshop on high intensity and high brightness hadron beams, Interlaken resort, Wisconsin, United States, 1999

[3] A. Perrin and J.F Amand, Travel v4.07, users manual,CERN (2003).

[4] R.Duperrier, N. Pichoff, D. Uriot, “CEA Saclay codes review”, ICCS Conference 2002, Amsterdam

[5] T. Kroyer, F. Caspers, E. Mahner, “The CERN SPL Chopper Structure: A Status Report”, CERN-AB-2007-004, CARE-Report-06-033-HIPPI