TESLA photo-injector simulations giving high quality beams

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Abstract

To obtain high brightness beams for the TESLA FEL project, operating in the VUV region, a photo-injector providing high quality beams is needed : $\varepsilon_r < 1$ mm.mrad, $\varepsilon_z < 20$ mm.KeV [1]. The beam dynamics is simulated by the numerical code ATRAP [2], using the Liénard-Wiechert's equations to describe the self electromagnetic field. The influence of the different parameters on the beam quality at the gun exit is presented.

1 INTRODUCTION

To minimize the multipole components of the electromagnetic field in the RF cavity, a design with a coaxial input coupler, figure 1, is proposed [3]. The quality optimization

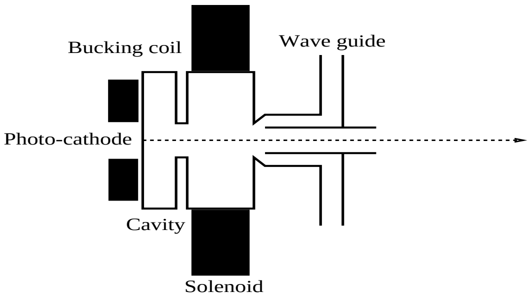

Figure 1: General scheme of the TESLA FEL gun.

is all the more difficult since many parameters play a role in the beam dynamics. For a photo-injector with a solenoid, there are 6 main parameters [4], three of them characterize the space charge field (Q, σ_r, σ_t) the others deal with the accelerating and focusing fields (E_0, ν_{rf}, B_0). Fortunately we have some constraints given by the project, the beam charge is 1 nC, the beam length at the wiggler entrance is 50 μm, the micro pulse rise time of the laser Nd:YLF is 5 ps then the pulse length σ_t = 3 ps. Furthermore, the rf peak field on the cathode must be high enough to limit the space charge effects on the beam quality, but not too high to avoid a too strong defocusing effect of the rf field, we have taken E_0 = 50 MV/m. To optimize the transverse emittance, the uniform longitudinal distribution is the best [5], but unfortunately the laser beam distribution is close to a gaussian. We have choosen a superposition of 3 gaussian pulses, to have a quasi flat top distribution (figure 2 case 1). Changing the distance between the gaussian centers, we take into account some fluctuations, ± 5% on the flat top (figure 2 case 2), which is the more realistic case. The different parameters are summarized in the table 1.

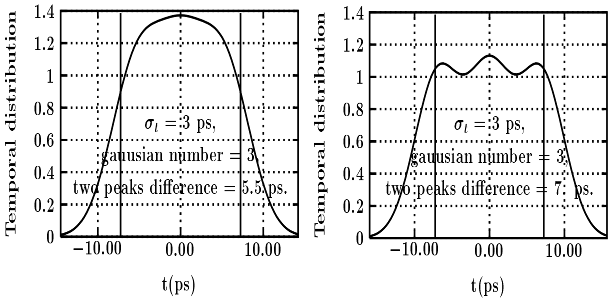

Figure 2: Beam temporal distribution, cases 1,2.

Table 1: The ATRAP simulation parameters.

Charge	1 nC
E_0	50 MV/m
Initial thermal emittance	0. mm.mrad
Radial profile	uniform
Temporal profile	gaussian superposition
number	3
σ_t	3 ps
Δpeak$^{(1)}$	case 1 : 5.5 ps
	case 2 : 7 ps
Launch phase$^{(2)}$	-34^0

(1) Δpeak is the gap between two gaussians centers.

(2) Launch phase is the phase gap between the beam center exit and the maximum peak field on the cathode.

2 TRANSVERSE RMS EMITTANCE

Since particles in the beam tails contribute weakly to the FEL interaction, it is attractive to calculate the transverse emittance by two methods. The first, takes into account all the electrons, the second, 50% of the length. For the gaussian superposition, the length is defined by 2(Δ peak+3σ_t). The definition of the transverse rms emittance is :

$$\epsilon_r = \frac{1}{2mc}\sqrt{<r^2><p_r^2> - <rp_r>^2} \qquad (1)$$

2.1 On the total beam length

- Gaussian superposition, Δpeak = 5.5 ps.
  In figure 3, the minimum value of ε_r in the drift space

after the gun exit, is plotted for different beam radii in function of the solenoid peak field. There are 2 local minima for each curve, but the second, for the greater value of the magnetic field, corresponds to an unstable solution, due to cross overs. Afterwards, we will consider only the first minimum, for the smallest value of the magnetic field. The emittance minimum is close to 1.7 mm.mrad, for $1. < R < 1.5$ mm, which is greater than the acceptable limit.

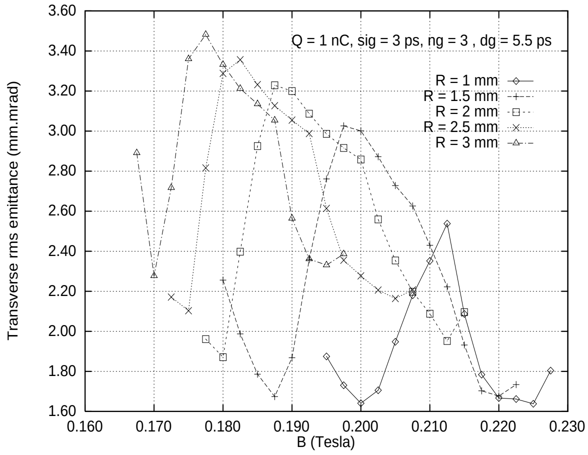

Figure 3: Minimum Transverse rms emittance versus the magnetic peak field.

- Gaussian superposition, Δpeak = 7 ps.
  For this case, (figure 4) the curves evolution is the same as "case 1". The minimum is better, ϵ_r = 1.4 mm.mrad for R = 1.5 mm and B = 0.19 Tesla.

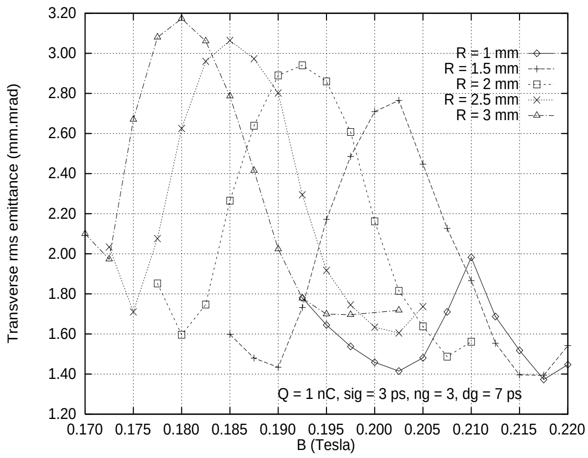

Figure 4: Minimum Transverse rms emittance versus the magnetic peak field.

2.2 *On 50% of the beam length*

The 50% of the beam length is shown in the figure 2, between the two vertical lines which represent respectively 0.8 and 0.75 nC. In figures 5,6 is plotted the minimum transverse rms emittance versus the magnetic peak field. For the case 1, the minimum is between 0.5 and 0.6 mm.mrad, if we consider only the points before the cross over. For the case 2, the minimum is close to 0.45 mm.mrad and stable with the magnetic field. This is very attractive, because we can optimise the longitudinal emittance without changing the transverse emittance. To have 1 nC in 50% beam length, for the case 2, we have taken 1.3 nC for the charge beam and we obtain ϵ_r = 0.59 mm.mrad for B = 0.1925 Tesla and ϵ_r = 0.53 mm.mrad for B = 0.1975 Tesla. Figure 7 shows the

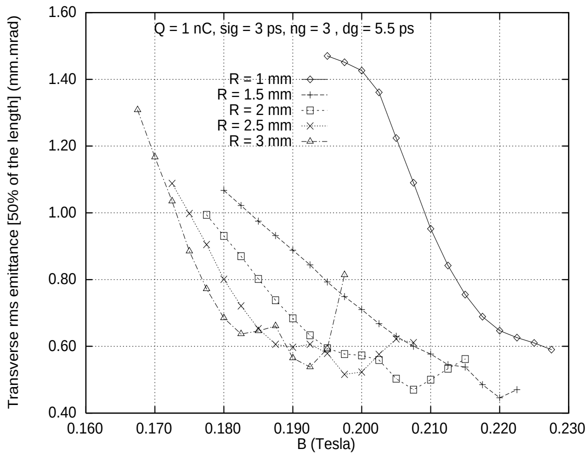

Figure 5: Minimum Transverse rms emittance, 50% of the length, versus the magnetic peak field.

transverse phase space for the case 2 with R = 2 mm and B = 0.19 Tesla, for 100% and 50% of the beam length, at z = 1.17 m close to the minimum of $\varepsilon_r^{50\%}$. We see that the beam tails contribute for 80% of the transverse emittance.

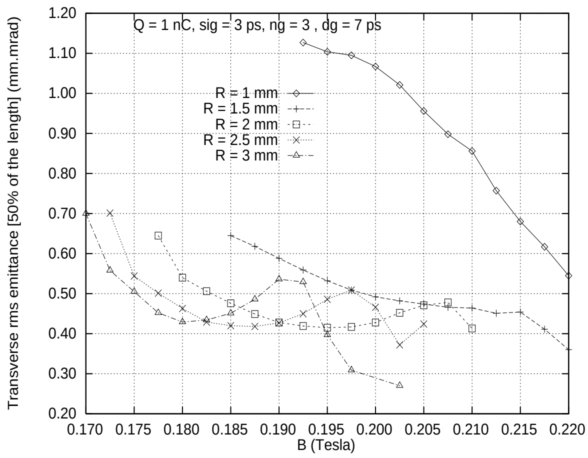

Figure 6: Minimum Transverse rms emittance, 50% of the length, versus the magnetic peak field.

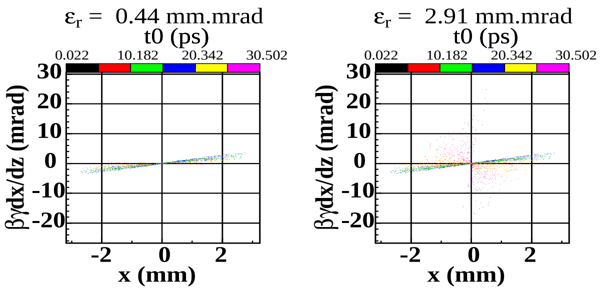

Figure 7: Transverse phase spaces for the case 2, with R = 2 mm and B = 0.19 Tesla. In the left figure, we consider the total length, and 50% of the length in the right figure.

3 LONGITUDINAL RMS EMITTANCE

Figures 8 and 10 show the longitudinal rms emittance, ε_z, when the radial emittance is minimum, as a function of the magnetic peak field for the cases [1,2]. These different curves have large fluctuations , because :

- all these points are not at the same position, ε_r minimum moves with the magnetic field,
- the longitudinal emittance is greatly dependent on the rms radius evolution.

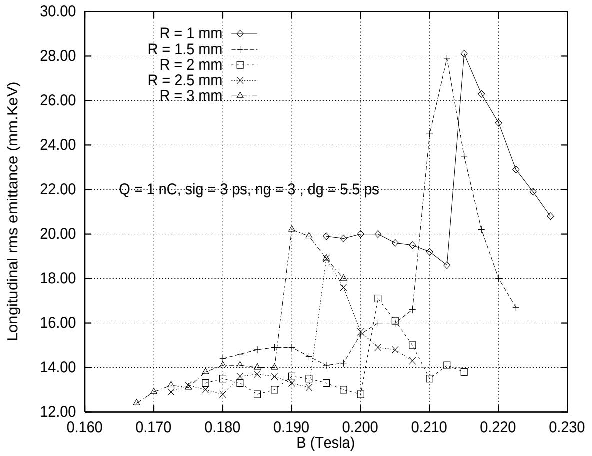

Figure 8: ε_z for the total length, when ϵ_r is minimum, versus the magnetic peak field, for the case 1.

For the case 1, figure 8 show that we can achieve our objective $\epsilon_z < 20$ mm.KeV, for $1.5 < R < 3.$ mm. For the case 2, the second condition is reached only for R = 1.5 and 3 mm, and respectively for a magnetic peak field close to 0.19 and 0.2 Tesla. If we consider only 50% of the beam length, $\epsilon_z^{50\%}$ = 4.7 mm.KeV, for the two cases with R = 2 mm and respectively B = 0.185 and 0.19 Tesla. There is a factor three between the longitudinal emittances for the total length (see figures 8, 10) and for $\epsilon_z^{50\%}$. The longitudinal phases spaces, for the two precedent cases, shown in figure 9, are almost linear except for the edges, and confirm the small values of $\epsilon_z^{50\%}$. Extrapolating these results for the different radii and magnetic peak field, we find that $\epsilon_z^{50\%}$ is always smaller than 20 mm.KeV.

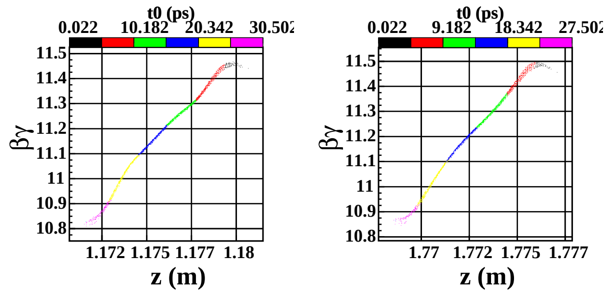

Figure 9: Longitudinal phase space for the cases 1,2.

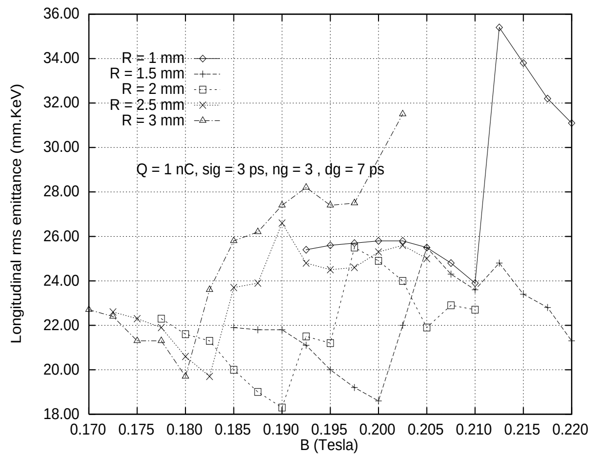

Figure 10: ε_z for the total length, when ϵ_r is minimum, versus the magnetic peak field, for the case 2.

4 CONCLUSION

The results exposed in this paper, show that we can have $\epsilon_r < 1$ mm.mrad and $\epsilon_z < 20$ mm.KeV at the TTF gun exit with a charge of 1 nC. An unconventional temporal distribution like a gaussian superposition with $\sigma_t = 3$ ps, and a flat top fluctuation close to 5% gives 0.5 mm.mrad for the transverse rms emittance, if we consider only 50% of the beam length. We have proved [5] that, using a proper matching of the beam into a 9 cell SC TESLA cavity, one can accelerate the beam up to 15 MeV, decreasing even further ϵ_r, at the booster exit.

5 REFERENCES

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