CTF3/CALIFES

updated beam dynamics simulations in single bunch mode

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Abstract : Results of beam dynamics simulations that were previously published led to an optimized design for CALIFES (the CLIC/CTF3 probe beam linac and its disnostics beam-line). This report updates the optimized results in single bunch mode taking into account all the available technical data such as actual locations and actual dimensions of CALIFES devices, expected dimensions of the laser spot on the photo-cathode, actual RF-power distribution into Rf-gun and LIL sections, magnetic characteristics of the magnets (dipole and quadrupoles) got from magnetic measurements. . .

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1. Introduction

The probe beam will be an essential component for the two-beam acceleration experiments which are planned in the two-beam test-stand in CTF3 [1]. The required performances of the probe beam, as well as their motivations, are listed in Table 1.

Table 1 : Main beam parameters and motivations.

Energy	~200 MeV	Avoid beam disruption in high RF fields
Energy spread	<± 2%	Measurement resolution
Normalized rms emittance	<20 π mm.mrad	Fit in 30 GHz structure acceptance
Rms bunch length	< 0.75 ps	Acceleration with 30 GHz structure
Number of bunches	1 – 32 - 226	Measure 30 GHz structure transients
Bunch charge	0.6 nC	~CLIC parameters
Bunch spacing	0.667 ns	

CALIFES (Concept d'Accélérateur LInéaire pour Faisceau d'Electrons Sonde), the facility that will generate this probe beam, is now under construction in CLEX building at CERN (figure 1). Beam dynamics simulations were previously performed in order to optimize its design [2]. CALIFES is made of two parts : a linac to generate the required beam and a diagnostics beam-line to measure its main characteristics. The linac consists of a photo-injector [3] followed by 3 LIL accelerating sections, the first one performing bunch compression. The diagnostics beam-line (figure 2) was previously fully described [4]. This line is made, among others, of both a spectrometer and a device for emittance measurements. The spectrometer consists of a dipole and a screen (VPM3) downstream on which the beam is focused by means of the triplet. The device for transverse emittance measurements consists of the triplet and a screen (VPM2) downstream : the transverse Twiss parameters measurements will be performed through beam size measurements for various values of the currents in the quadrupoles.

Figure 1. : CALIFES construction in CLEX building (December 2007).

This report updates the optimized results in single bunch mode taking into account all the available technical data :

- actual locations and dimensions [5] of all the devices,
- realistic RF-power distribution [2],
- expected characteristics of the laser pulse [6],

- actual magnetic characteristics of the magnets [7],[8],[9],[10],
- required charge specification (Table 1).

All the simulation hypothesises are explained in §2. The main optimized results concerning single bunch mode are summarized in §3.

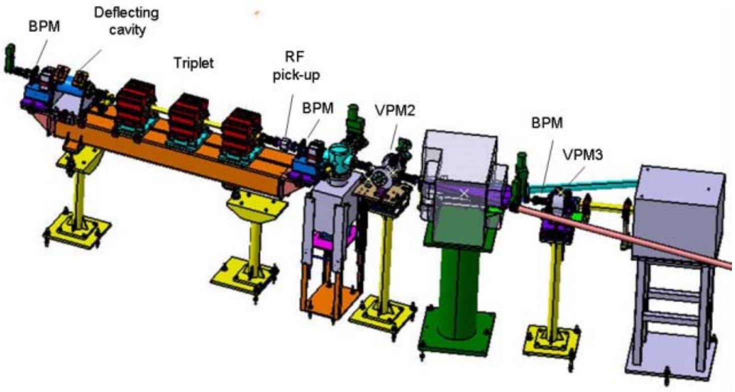

Figure 2. : CALIFES diagnostics beam-line.

2. simulation performing.

2.1. simulation tools.

Two main programs were used for the simulations. The first one is a version of PARMELA modified by Bernard Mouton [11] in order to take into account rf-guns. The second one is a program, previously developed by Bernard Aune [12] to simulate beam transport through matrix product, of which an option is a fit subroutine that computes sets of magnetic parameters corresponding to required beam characteristics.

2.2. electron emission at the photocathode.

To simulate the electron beam generated at the photocathode, a special input card of PARMELA [11] was used. In this case, the electron emission is isotropic into the front hemisphere, the energy distribution is gaussian and the radial and longitudinal distributions of the emitted electrons are truncated gaussians. The total number of electrons in a bunch is used in a special subroutine of PARMELA that takes into account the 3D space charge effects.

All the parameters of the initial electron bunch used for the simulations come from both the expected characteristics for the laser spot [6] and the required charge. They are summarized in table 2. The corresponding distribution is illustrated in figure 3.

Table 2 : Data used to simulate the electron emission at the photo-cathode.

Energy	1 eV
Rms energy spread	±1 meV
Number of electrons	$3.75 \times 10^9 / 1.25 \times 10^9$
Rms radial size	1 mm
Max radial size	3 mm
Rms bunch length	±2 ps
Max bunch length	±6 ps

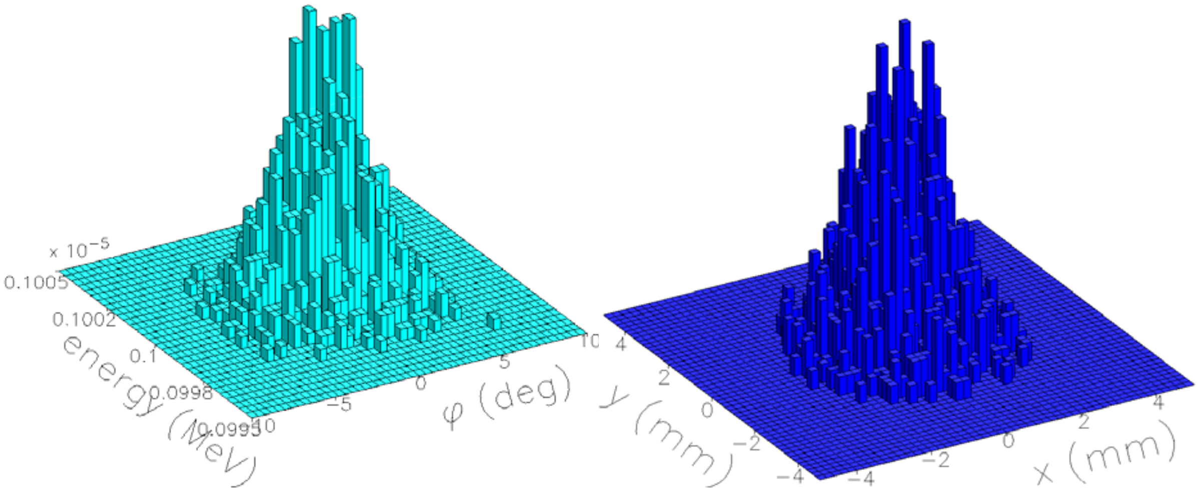

Figure 3. : Electron emission distribution at the photo-cathode.

2.3. electromagnetic field in the RF photo-gun.

The RF photo-gun is a standing-wave cavity [3]. Knowing the normalized electromagnetic field distribution in this cavity is needed to compute the transport through it. This field distribution is read from an output file of SUPERFISH. Both the peak axial electric field and the phase shift of the cell are specified in the input file of PARMELA. Their values are reported in table 3. The normalized axial electric field in the RF photo-gun is shown on figure 4.

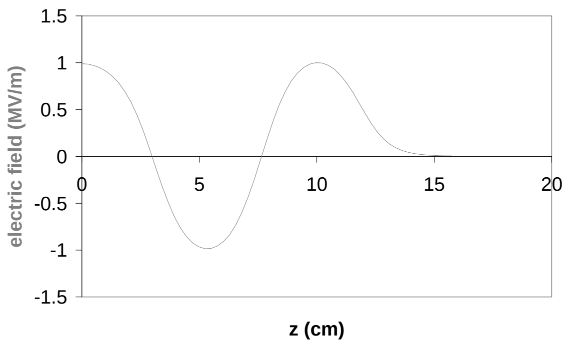

Figure 4. Axial electric field in the RF photo-gun (normalized to 1 MV/m peak)

2.4. electromagnetic field in the LIL sections.

The LIL sections are travelling-wave cavities made of 135 cells. Like for the RF-gun, their action on the electrons is simulated using the electromagnetic field distribution generated by SUPERFISH. Both the peak axial electric field and the phase shift of each cell are specified in the input file of PARMELA. The maximum accelerating field and the phase shift along a LIL section are shown on figure 5. Average accelerating field values and initial phase shift values are reported in table 3.

2.5. RF-power distribution.

The required RF power distribution is 10 MW for the RF-gun, 20 MW for the compression section and 25 MW for each accelerating section [2]. The simulations were performed using electromagnetic field values corresponding to this power distribution. The main parameters used for the simulations are summarized in table 3.

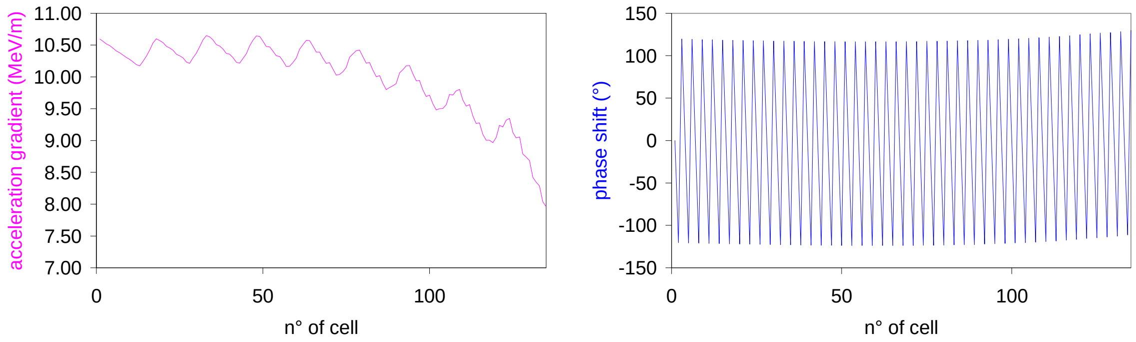

Figure 5. : Maximum accelerating field (normalized to 10 MV/m)
and phase shift along LIL sections.

Table 3 : Data used to simulate the beam transport in the various cavities

RF gun	crest axial electric field	90 MV/m
	phase offset	35°
1st (compression) LIL section	Average accelerating field	12.8 MV/m
	Initial phase shift	-94° to -81°
2nd an 3rd (acceleration) LIL sections	Average accelerating field	16.5 MV/m
	Initial phase shift	0°

2.6. magnetic field along the linac.

In order to limit transverse emittance growth, an external magnetic field has to be applied along the linac. This one is generated by coils mounted around the RF photo-gun and around the first two LIL sections. The magnetic field distribution in the RF photo-gun comes from POISSON simulations [3]. The magnetic field distribution in the LIL sections is computed adding the contributions of all the air coils mounted on them, using their actual dimensions and longitudinal positions. Previous simulations showed that it was unnecessary to apply any external magnetic field in the third LIL section. Several runs were necessary before getting the optimum magnetic field distribution along the linac for each bunch charge value. The axial distribution of the magnetic field used for a bunch charge of 0.6 nC is shown on figure 6.

2.7. magnetic parameters of the quadrupoles.

Table 4 : Main magnetic parameters of the quadrupoles [7],[8],[9]

I(A)	Integrated gradient (T)			Central gradient (T/m)	Magnetic length (m)
Quad n°	22	26	28	22	22
40	0.5238	0.5251	0.5246	-	-
50	-	-	-	2.784	-
100	1.2881	1.2906	1.2891	5.578	0.231
150	1.9387	1.9411	1.9393	8.356	0.232
200	2.5795	2.5808	2.5791	11.202	0.230

The quadrupoles were built according to the Technical Specifications for former quadrupoles for CTF3 [13]. Magnetic measurements were performed at CERN [7],[8],[9] so that magnetic length values and integrated gradient values were available (through calibration curves). The main results of these measurements are summarized in table 4.

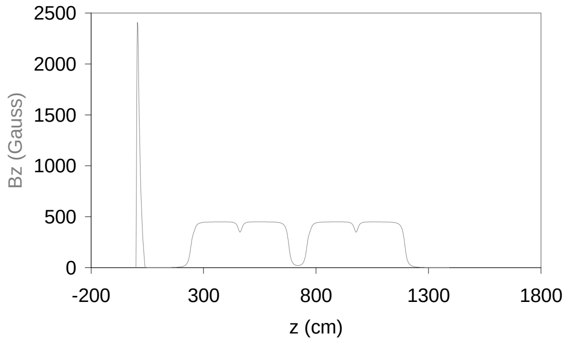

Figure 6. : Axial magnetic field distribution along the linac for a bunch charge of 0.6 nC.

2.8. spectrometer parameters.

The magnet of the spectrometer is an MDX dipole used at 17.5° deflection. Important information such as curvature radius, and intrinsic dispersion came out of previous magnetic measurements [10]. The main parameters of the spectrometer are summarized on table 4.

Table 4 : Main parameters of the spectrometer

Deviation angle α	17.5°
Energy of central trajectory	150-200 MeV
Magnetic rigidity $B\rho$	0.502-0.669 T.m
Integrated magnetic field (here=$B\rho\sin\alpha$)	0.151-0.201 T.m
Magnetic length [10]	471.3 mm
Curvature Radius	1567.3 mm
Intrinsic Dispersion	0.725 mm/%
Dispersion on VPM3	2.25 mm/%
Current [10]	37.17-49.85 A
Central magnetic field [10]	0.319-0.428 T

As this dipole is a rectangular magnet that will be used with 17.5° entrance edge angle and 0° exit edge angle, the entrance fringe field effect was taken into account in the simulations.

3. optimized results.

3.1. optimal electron distribution at the end of the linac

The optimal electron distribution at the end of the linac for a 0.6 nC bunch charge is shown on figure 7. The corresponding beam parameters are reported on table 5.

Due to actual RF-power distribution, the maximum energy remains under the specification by about 30 MeV. Instead, the expected laser-spot characteristics lead to rms bunch length well below the required value. At last, the new required bunch charge (0.6 nC instead of 0.5 nC) leads to increased normalized transverse emittance (12 π mm.mrad instead of 10 π mm.mrad). Note that, according to table 1, this value is still acceptable.

3.2. rms radius, rms bunch length and normalized transverse emittance.

The evolutions of the rms radius, the rms bunch length and the normalized transverse emittance along the linac, from the photocathode to the end of the 3rd LIL section, are shown on figure 9. Due to bunch compression, the transverse emittance drastically increases at the entrance of the first LIL section. Then, accurate magnetic field distribution (figure 6) returns the transverse emittance to an acceptable value.

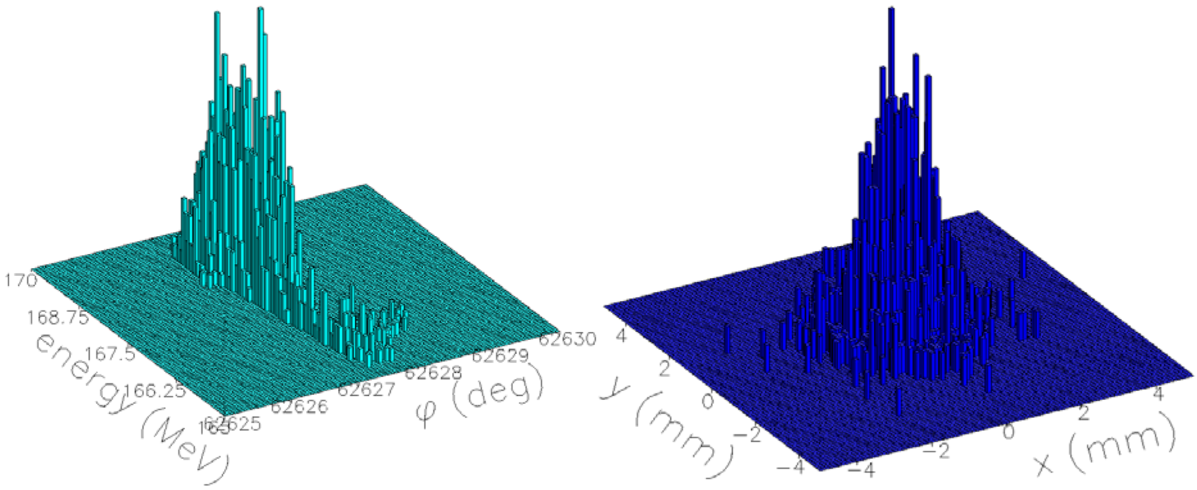

Figure 7. : optimal electron distribution at the end of the linac.

3.3. compression phase range leading to acceptable rms bunch length.

A scan of the compression phase shift was performed around the optimal value in order to evaluate in which phase range the rms bunch length would be acceptable. This showed that the rms bunch length remained within the specifications for compression phase shifts values between -93° and -82° as illustrated on figure 8.

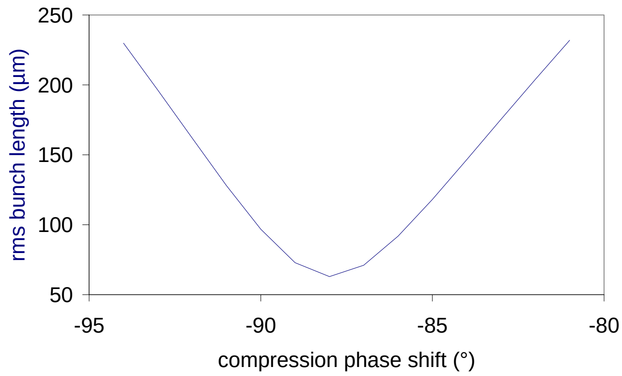

Figure 8. : rms bunch length versus compression phase shift.

3.4. case of a reduced charge of 0.2 nC

In order to control whether the set of the various parameters would fit at reduced charge, a run was performed with a charge of 0.2nC. This showed that only the maximum magnetic field on the RF-gun had to be reduced, the optimum result being obtained with 2200 G instead of 2400

G, in order to take into account the reduced space charge effect. The compared results are summarized on Table 5.

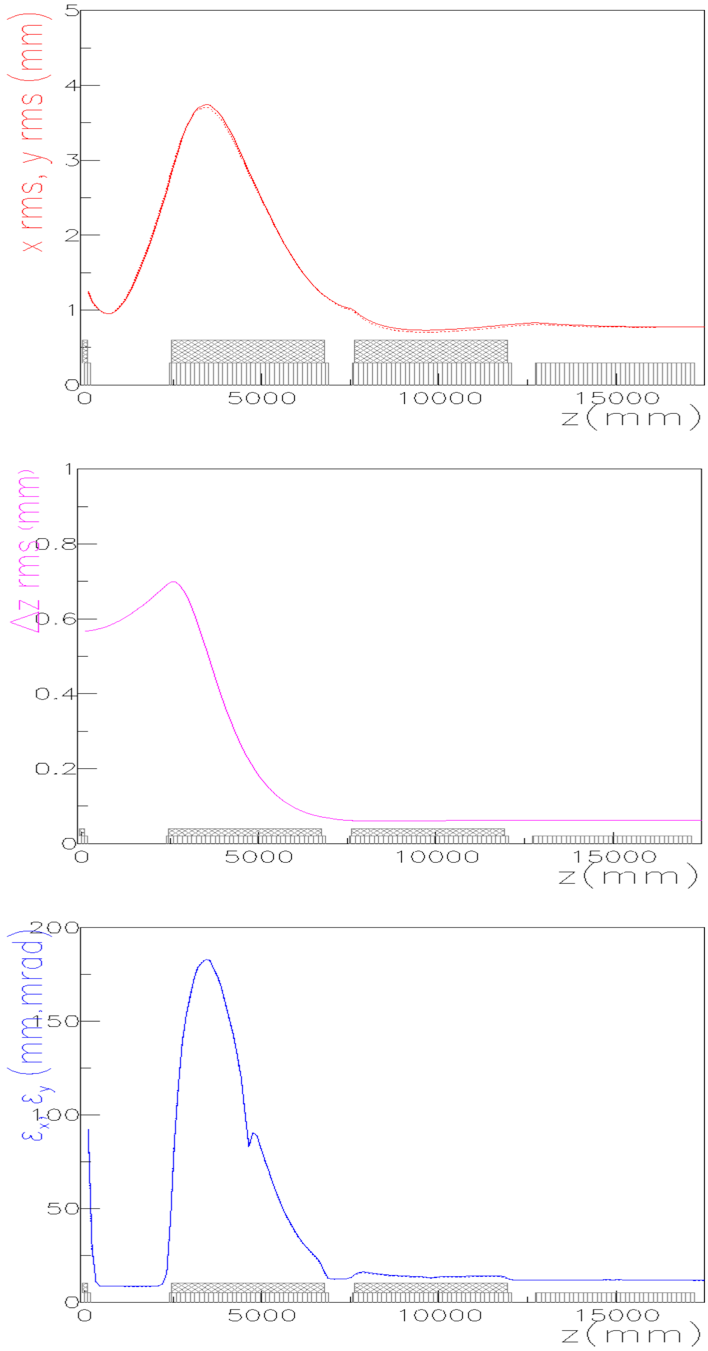

Figure 9. : rms radius, rms bunch length and normalized transverse emittance along the linac.

Table 5 : CALIFES optimized beam parameters in single bunch mode

Bunch charge	0.6 nC	0.2 nC
Energy	~168 MeV	~168 MeV
Energy spread	± 0.6%	± 0.4%
Compression phase shift	-88°	-88°
Rms bunch length	± 0.21 ps	± 0.17 ps
Normalized rms emittance	~12 π mm.mrad	~6 π mm.mrad

3.5. minimum transverse beam size on VPM2.

In order to find sets of currents in the quadrupoles leading to minimum transverse sizes on VPM2, the TRANSE code [12] was used, using both the actual positions and magnetic characteristics of the quadrupoles and the electron beam distribution at the end of the linac given by PARMELA (§3.1). The corresponding electron distribution on VPM2 is shown on figure 10. The optimal result together with the set of currents in the triplet is summarized on the table 6. As the fit values are ~2/3 of the maximum ones, a quad-scan process can be foreseen using the three quadrupoles of the triplet.

Table 6 : minimum transverse sizes on VPM2 with corresponding currents in the quadrupoles

Quad n°	Integrated gradient (T)	Corresponding current (A)	xrms waist size (µm) on VPM2	yrms waist size (µm) on VPM2
22	1.729	133.94		
26	-1.788	-138.33	± 32	± 65
28	1.729	133.93		

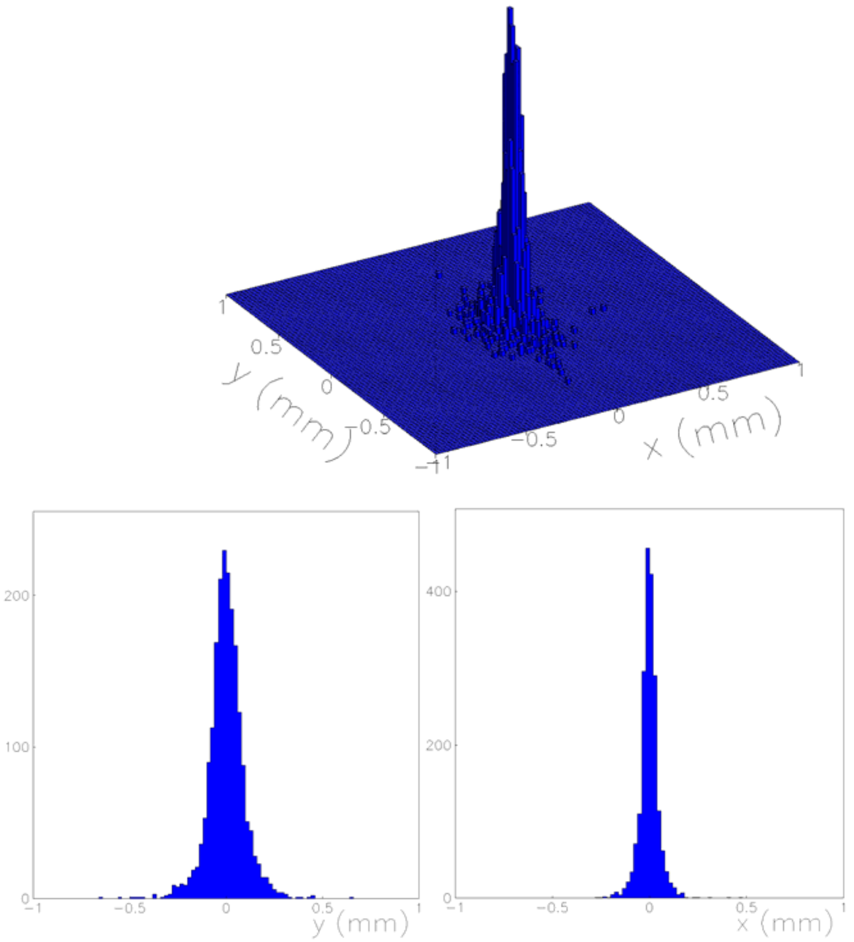

Figure 10. : Optimal electron distribution on VPM2.

3.6. minimum transverse beam size on VPM3.

With the same program [12], a set of currents in the triplet leading to minimum transverse sizes on VPM3 was obtained. The results and fit parameters are summarized on table 7. The corresponding electron distribution on VPM3 is shown on figure 9.

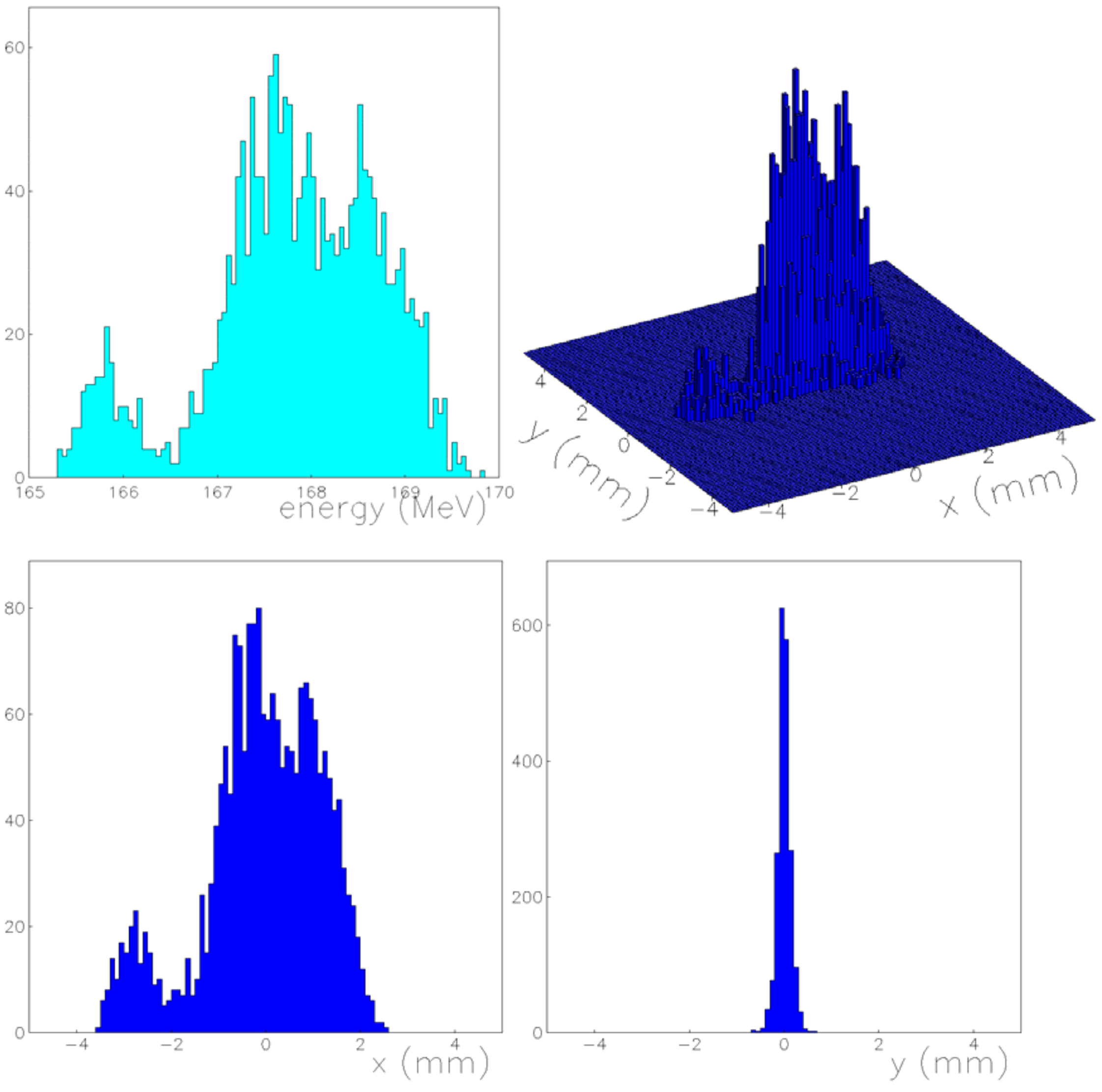

Figure 9. : Optimal electron distribution on VPM3

Table 7 : minimum transverse sizes on VPM3 with corresponding currents in the magnets

Magnetic element	integrated gradient (T)	corresponding current (A)	xrms minimum size (mm) on VPM3	yrms minimum size (mm) on VPM3
Quad n°22	1.529	118.34	± 1.187	± 0.112
Quad n°26	-1.647	-127.41		
Quad n°28	1.529	118.32		
	Integrated field (T.m)			
Dipole	0.169 T	41.8		

4. Conclusion.

Due to new information concerning locations and actual characteristics of all the CALIFES elements, the beam dynamics simulations previously performed in order to optimize the design of CLIC/CTF3 probe beam linac [2] became obsolete. Thus, beam dynamics simulations had to be updated with realistic hypothesises to obtain the optimal characteristics expected for the beam of CALIFES. The present paper summarizes the main results of these simulations. The main discrepancies with the previous results essentially come from the charge increase, the actual power distribution and the expected dimensions of the laser spot. So, the optimized beam energy should be <170 MeV (previously ~180 MeV) and the normalized transverse emittance ~12 π mm.mrad (previously ~10 π m.mrad). However, the required bunch length (225 µm i.e. 0.75 ps) should be achievable on a wider phase range. Finally, the present paper also reports the main results expected with the analysis beam line, i.e the minimal sizes of the electron beam on VPM2 during emittance measurements and on VPM3 during spectrometry experiments, together with the corresponding sets of currents in the magnets.

5. References.

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