LCLS PhotoInjector Beamline - 135 MeV Configuration

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Abstract

The second linac section L0-2 will be run with 24MV/m instead of the 30.5 MV/m previously specified. This reduced gradient will minimize the production of dark current and improve reliability.

We present the results from PARMELA computations which show that the emittance through the entire LCLS injector with a 1nC bunch charge is preserved at 135 MeV as it was with the previously designed 150 MeV.

Additional focusing has also been added in the 1 m section from L0-1 to L0-2 to reduce the unacceptably large betatron functions at the exit of L0-2.

1 135 MeV vs 150 MeV

1.1 Evolution of the PhotoInjector beamline design

The choice of 150 MeV had been made several years ago, but had never been documented in details. The September 2000 design of the LCLS was based on the new "Ferrario's" working point based on a gun accelerating gradient of 140MV/m and an exit energy of 150 MeV. In October 2001, the Photoinjector beamline had been modified to run the gun at 120 MV/m. A new tuning was studied for which the best combination of accelerating fields were found to be18 MV/m and 30.5 MV/m respectively in L0-1 and L0-2. During the spring of 2002, several experiments confirmed that the thermal emittance for copper cathode could be as large as 0.6 mm.mrad per mm radius spot size []. A new optimization was then worked out at the begining of 2003 including that thermal emittance. The optimal accelerating fields for reaching the smallest emittance at 150 MeV were found to be 19.6 MV/m for L0-1 and 28.7 MV/m for L0-2. However, an accelerating gradient of 28.7MV/m will possibly generate a too large dark current at the exit of L0-2 likely to produce noise on the OTR screens and decrease the reliability of the injector. The amount of dark current produced remains to be quantified accurately. Measurements will be performed at the GTF for accelerating gradient up to 25 MV/m.

Time Step in L0-1	$\varepsilon_n[mm.mrad]$	α	$\beta[m]$	$\sigma[mm]$	CPU time [s]
5°	0.935	-0.44	26.0	0.303	16885
1°	0.94	-3.7	47.7	0.412	52872
0.5°	0.98	-3.9	48	0.422	78870

Table 1: Evolution of Twiss parameters at the end of L0-2 for various integrated time steps;Simualtions with 200 k particles

Time Step in L0-1	$\varepsilon_n[mm.mrad]$	α	$\beta[m]$	$\sigma[mm]$	CPU time [s]
5°	1.064	-0.57	26.58	0.327	396
2.5°	1.044	-3.22	46.06	0.4266	503
1°	1.044	-4.29	52.56	0.4557	821
0.5°	1.045	-4.44	53.43	0.4597	1345
0.25°	1.045	-4.48	53.56	0.4603	2454

Table 2: Evolution of Twiss parameters at the end of L0-2 for various integrated time steps; Simulations were done with 5k particles

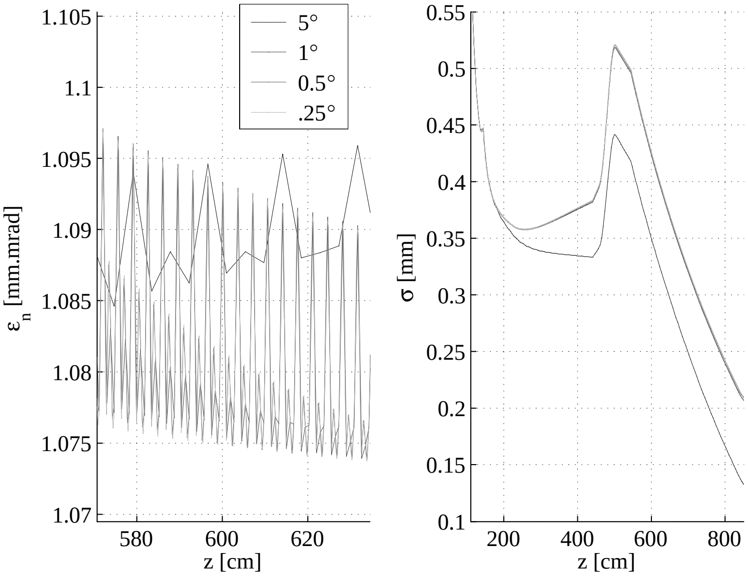
By reducing the exit energy down to 135 MeV, the second accelerating section gradient is reduced to 24 MV/m, eliminating any risk of problematic dark current. In this study, we checked that the emittance is not damaged in the 10 m of matching section for an energy of 135 MeV. We start by describing numerical problems encountered while doing PARMELA simulations. We then describe the new tuning for the matching section of the injector beamline.

1.2 Time steps in PARMELA simulations of linac sections

PARMELA simulations have shown a dependency of beam size at the exit of L0-2 as a function of the time step size along the two linac sections L0-1 and L0-2. The beam travelling through the linac structure sees defocusing and focusing kicks at each iris which should exactly cancel but for the entrance and exit irises. If the sampling rate used in PARMELA is too small, this exact cancellation does not occur. The iris is 5.842 mm long corresponding to 19 degrees S-Band. It was noticed that a sampling rate of 5 degrees S-Band is not adequate (see figure **??**). Sampling rate with steps smaller or equal to 1 degree are sufficient. In table 1, we show the evolution of beam sizes and twiss parameters at the exit of L0-2 when varying the time step in L0-1 and L0-2. All these tracking runs were done up to 135 MeV with 200k particles. Of particular importance is the exit betatron function, which is underestimated with time stpes larger than 5 degrees. Figure 1 shows the evolution of emittance, beam size and Twiss paramters along the beamline for theses 3 situations.

The PARMELA runs performed using only 5k particles tend to give emittance values higher by ~10% than those obtained from runs with larger number of particles. The problem of time step in L0-1 is similar to that observed with

200k particles. Accordingly, it was studied in more details as runs with 5k particles are 40 times faster than those with 200k particles. A too low sampling for the time steps chages the beam size value but not the emittance. The convergence on the beam size is obtained for time steps equal or smaller than 1 degree S-Band. The increase of emittance for time steps of 0.5° for 200k particles is not yet understood, but is only a 3% effect. As a conclusion, what is belived to be our "most valid PARMELA run" corresponds to time steps of 1° with 200k particles.



Evolution of emittance and beam size for different time steps

1.3 Tuning of matching section

The matching has been studied using MAD (i.e., without space charge). In the matching section, the beam is focused to perform an optimal 3 screen emittance measurement. It is then matched through the 35 degrees dog-leg bends (DL1) to the entrance of L1-1.

1.3.1 Three screen emittance measurement

Paul Paragraph- can you please explain the 60 degrees phase advance formula? I think it is the occasion to put it down

The distance of the 3 screens ...

See reference [P.Emma and M.Woodley] .

1.3.2 Matching to Linac 1

Paul Paragraph- Description of double dog-leg

2 PARMELA Runs

2.1 Run at 135 MeV

Our "most valid PARMELA run" gives a beam with small transverse rms value and strong divergence at the exit of L0-2. With the smaller time steps (1 degree), however, the β-functions at the exit of L0-2 reaches ˜100m (see figure 2a) and generate a large σ_x/σ_y aspect ratio, which further amplifies space charge forces.

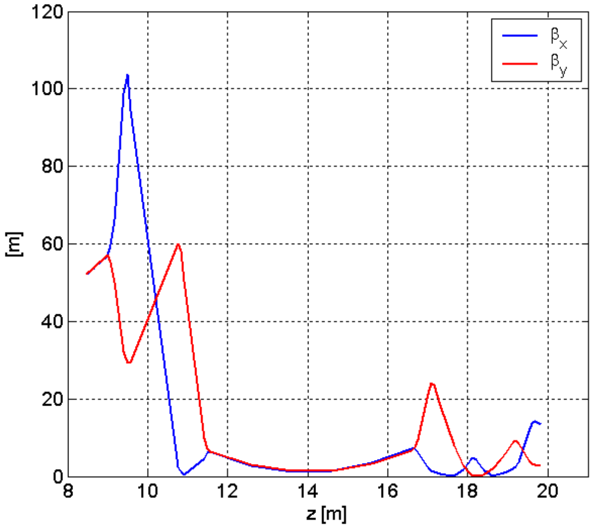


Figure 2a-Betatron functions without QA quadrupoles

For this reason, two quadrupoles (QA01 and QA02) are added in the drift between the two linac sections. These quadrupoles are standard 15 cm long quadrupoles of the same family as the QM and QE. The beam divergence is reduced at the exit of L0-2 and the betatron functions do not exceed 35 m (see figure 2b). In addition, the four quadrupoles, after the exit of L0-2, have reduced strengths. The PARMELA run, with space charge, is shown in figure 3. The waist is moved from 9.5m to 10 m. Additional tuning should be performed to obtain the waist at the OTR32 location when space charge is present.

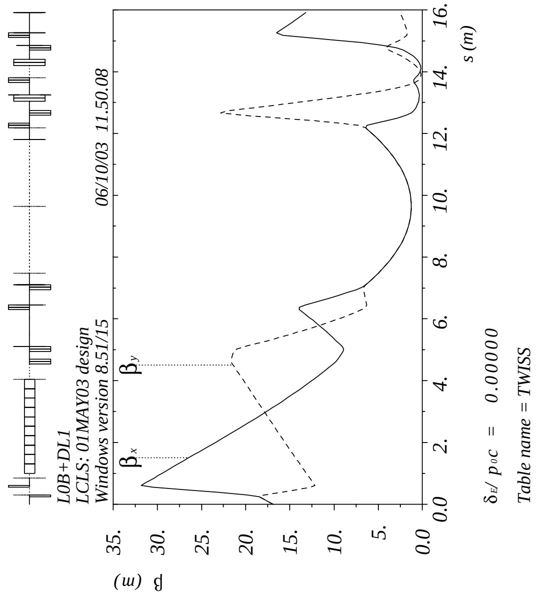


Figure 1: Figure 2b- Mad Output for betatron functions with quadrupole QAs included

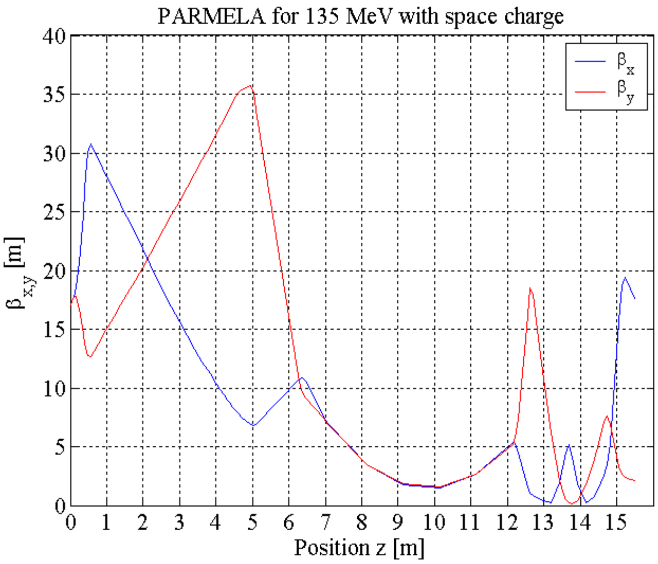


Figure 3-Betatron function from PARMELA (including space charge) for nominal tuning at 135 MeV, z = 0 at the exit of L01

Since the beam aspect ratio (σ_x/σ_y) in L0-2 does not exceed 2, PARMELA computations can still be done using the SCHEFF (2D) routine. Indeed the correction made using a form factor for elliptical beam is valid when the beam aspect ratio does not exceed 2. After the waist, at s ˜ 10 m, the dog-leg computation is done using the full 3D computation (SPCH3D).

Figure 5 shows that the emittance does not increase by more than 2% with 1nC over the 15 m injection. There is a small transfer from vertical emittance into the horizontal emittance.

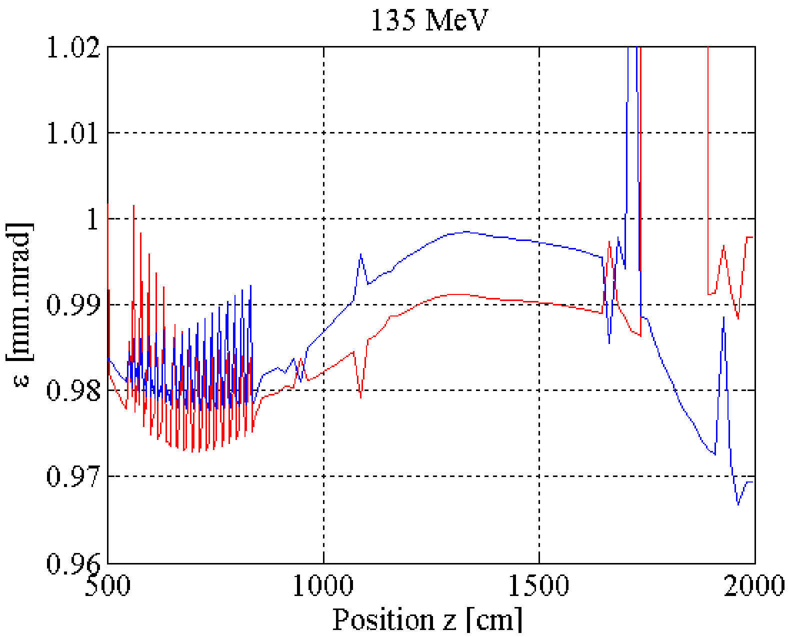


Figure 4- Evolution of emittance in matching section for 135 MeV at 1nC; run with 200k particles and spch3d

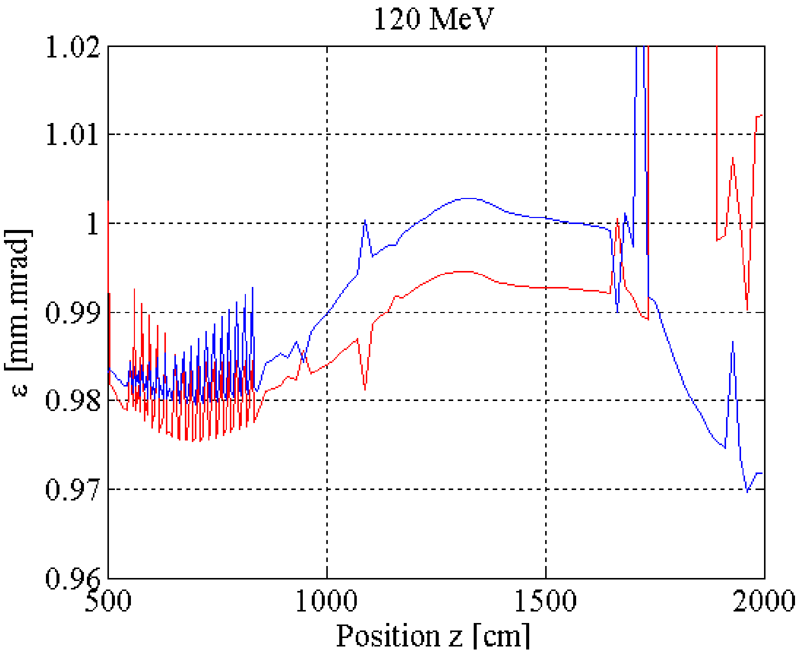


Figure 5- Evolution of emittance in matching section for 120 MeV at 1nC; run with 200k particles and spch3d

2.2 Minimum energy acceptable

A configuration was studied for an exit energy of 120 MeV. Both linac sections were then at 19 MV/m. The emittance is acceptable at the end of L0-2 with 0.98 mm.mrad, and it only very slightly deteriorates in the matching section. It reaches 1.0 mm.mrad at the entrance of L1, as shown in Figure 6. As a test teh exit energy was temporarily reduced to 110 MeV to see a large emittance deterioration. In this case, the gradient in the linac L0-2 is 15.67 MV/m. The emittance increases from 1.07 mm.mrad from the exit of L0-2 to 1.277 mm.mrad at the entrance of L1 for the 5k particle run. The emittance is shown in figure 7. The emittance evolution for the same conditions are given for the 120 MeV in figure 8.

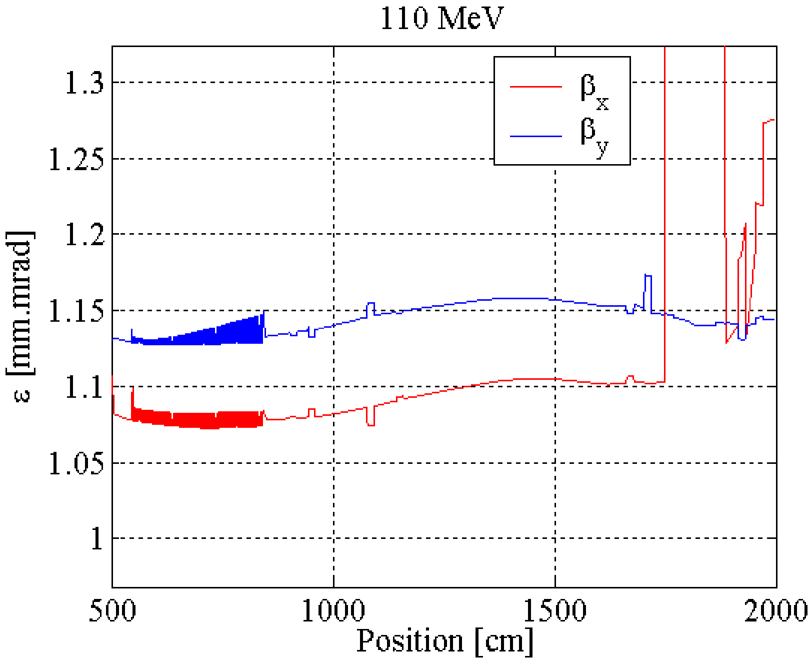


Figure 6- Evolution emittance for 110 MeV ; run with 5k particles

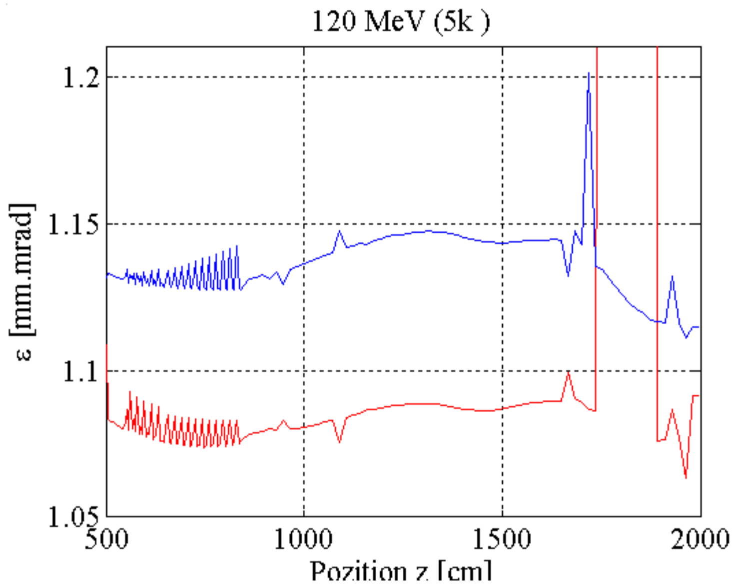


Figure 7- Emittance evolution for 120 MeV with 5k particles

3 Conclusion

The photoinjector beamline has been modified to accomodate a lower gradient in L0-2. With 24 MV/m in L0-2, the exit energy is 135MeV. It was checked that the emittance growth occuring in the matching section is very small and that the emittance will still be acceptable in the presence of errors specified in the table of requirements.

Measurements will be performed this summer at the GTF to insure that a gradient of 24MV/m does not produce intolerable dark current.

Two standard quadrupoles, QA01 and QA02, have been added in the drift between L0-1 and L0-2. With these new quadrupoles, the beam size and, above all, the divergence is much smaller at the end of L0-2. The matching requires weaker quadrupole strengths and more dynamic range is available with six matching quads, prior to the diagnostic section, to allow empirical beam matching from injector to linac.