OPTICS DESIGN FOR FACET*

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Abstract

FACET is a proposed facility at SLAC National Accelerator Laboratory. It will provide high energy, tightly focused and compressed electron and positron bunches for beam driven plasma wakefield acceleration research and other experiments. FACET will be built in the SLAC linac sector 20, where it will be separated from the LCLS located immediately downstream and will take advantage of the upstream 2 km linac for up to 23 GeV beam acceleration. FACET will also include an upgrade to linac sector 10, where a new e+ compressor chicane will be installed. The sector 20 will contain a new optics consisting of two chicanes for e+ and e- bunch length compression, a final focus and an experimental line with a dump. The e+ and e- chicanes will allow the transport of e+ and e- bunches together, their compression and proper positioning of e+ witness bunch behind the e- drive bunch at the plasma Interaction Point. The new optics will mostly use the existing SLAC magnets to minimize the project cost. Details of the FACET optics design and results of particle tracking simulations are presented.

INTRODUCTION

The high energy electron and positron beams from the SLAC linac have been in demand by researchers from many scientific communities. In the last decade, the SLAC Final Focus Test Beam (FFTB) facility provided highly focused and compressed bunches for experimental research in beam and plasma physics, ultra-short-pulse x-ray generation, laboratory astrophysics, and specialized accelerator diagnostic techniques. SLAC is the only place in the world that can provide the high peak current, high energy electron and positron beams that make this research possible. The FFTB has been dismantled to make way for the construction of the Linac Coherent Light Source (LCLS). Several options for FFTB replacements were studied [1, 2], and the FACET project (Facility for Advanced Accelerator Experimental Tests) was selected as the most cost-effective. When built, it will provide high energy, tightly focused and compressed e- or e+ bunches to experiments requiring these beam qualities.

The FACET new beam optics will be installed in sector 20 of the SLAC linac. This location is ideal for FACET since it provides the highest possible beam energy from the upstream 2 km linac and the necessary separation from the LCLS located downstream. The sector 20 optics is designed to accommodate two compressor chicanes for e+ and e- beams, a Final Focus (FF) section, and experimental section with a dump. This new optics will mostly use the existing SLAC magnets to minimize the project cost. FACET will also include modification of the compressor chicane in sector 10 which will include the second chicane for positron beam compression. The latter capability is not currently available anywhere else. The schematic of the SLAC accelerator complex is shown in Fig. 1 with the FACET modification areas highlighted in red.

FACET is specified to provide electron and positron bunches with up to 23 GeV energy and $> 2\cdot 10^{10}$ particles (3.2 nC charge). In the present proposal, only one chicane will be installed in sector 20. This will allow to deliver either e- or e+ bunches. As an upgrade, the second chicane can be included to allow the e- and e+ bunches delivered simultaneously which is necessary for plasma wakefield acceleration experiments with the drive and witness bunches.

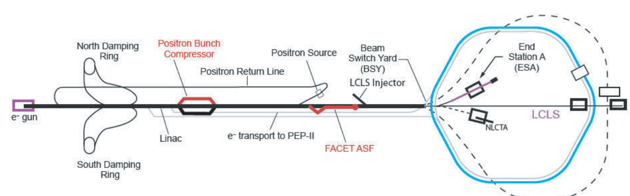

Figure 1: FACET at the SLAC accelerator facility.

FACET OPTICS IN SECTOR 20

A plan view of the new FACET optics to be installed in Sector 20 is shown in Fig. 2. The lattice consists of the chicane section followed by the Final Focus and the experimental area with a dump. The beam Interaction Point is 2 m downstream of the last FF quadrupole. In the present proposal, the lower chicane will be built first to provide transport and bunch compression either for electrons or positrons. All initial experiments can be carried out with this single line.

At a later date it is proposed that the upper chicane be added to allow a simultaneous transport of both e- and e+ bunches for a drive and witness bunch arrangement in plasma wakefield experiment. In this option, a low charge e+ bunch is accelerated one-half s-band wavelength ahead of a stronger e- bunch in the linac. In sector 20, the e+ and e- bunches are separated into the lower (e-) and upper (e+) chicanes, where they obtain the same compression and a specified 52.7 mm path length difference. The latter results in the e+ witness bunch coming out of the chicane slightly behind the e- bunch at a position where it can be accelerated by the electron driven plasma wakefield at the IP. The distance between the e+ and e- bunches can be adjusted by slight variation of the trajectory in the upper chicane.

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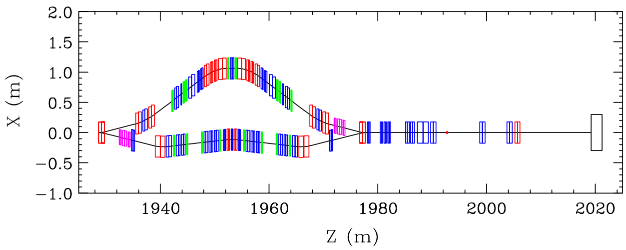

Figure 2: FACET horizontal layout in sector 20. The IP is at Z=1992.7 m. The upper chicane is an upgrade option.

The capability of simultaneous transport of e+ and e- beams places constraints on the chicane optics. Since the e+ and e- share the linac quadrupoles this leads to opposite focusing and a special transformation property, where the horizontal matrix M_x^- and beta function β_x^- for electrons are the same as the vertical matrix M_y^+ and beta function β_y^+ for positrons, and vice versa. Therefore, to avoid a betatron mismatch, the e+ and e- chicanes are designed to have the same property, i.e. $M_x^- = M_y^+$ and $M_y^- = M_x^+$. In addition, the e+ and e- chicane focusing and bending are adjusted to provide the same linear matrix term $R_{56} = 4$ mm necessary for the final bunch compression, the specified 52.7 mm path length difference, the cancellation of the first order dispersion, and sufficient separation between the e+ and e- magnets. Finally, the sextupoles are included in each chicane to minimize chromatic aberrations at IP caused by the large beam energy spread: $d\beta/d\delta$, the second-order dispersion, and the second-order momentum compaction term $T_{566} < 100$ mm. A wiggler section consisting of three vertical bends is included in each chicane to generate synchrotron radiation suitable for measuring the beam energy.

The FACET Final Focus section is located downstream of the chicanes and contains 5 quadrupoles: a matching doublet and a FF triplet which focuses the beams to a small round spot at the IP. These quadrupoles provide a sufficient range for tuning of IP beta functions which may be needed for optimizing the IP beam spot in presence of nonlinear aberrations and magnet errors as well as for a match to plasma focusing. Optics in the experimental area consists of a quadrupole doublet located 6 m after the IP, followed by a vertical bend magnet. These two quadrupoles can be adjusted to focus the extracted beam to a second focal point, and the bend magnet creates a 14 mrad vertical deflecting angle directing the beams to the dump. Beta and dispersion functions in the lower (e-) and upper (e+) lines in sector 20 are shown in Figs. 3, 4.

The linac sector 19 will be used for betatron match to the new optics in sector 20. Six out of eight quadrupole strengths in sector 19 will be adjusted, while the other two quads must remain at the nominal strength since they provide a fixed deflection for the electron beam directed into the e+ production line attached to sector 19. The changes of beta functions in sector 19 require that optics in the e+ production line is re-matched as well to maintain the small beam size at the target. This is achieved with adjustment of six quadrupole strengths in the production line.

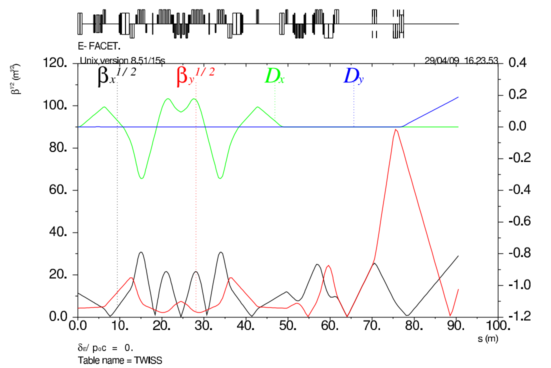

Figure 3: β functions and dispersion in the lower line (e-) in sector 20. The IP is at S=64.1 m, where $\beta^* = 6$ cm.

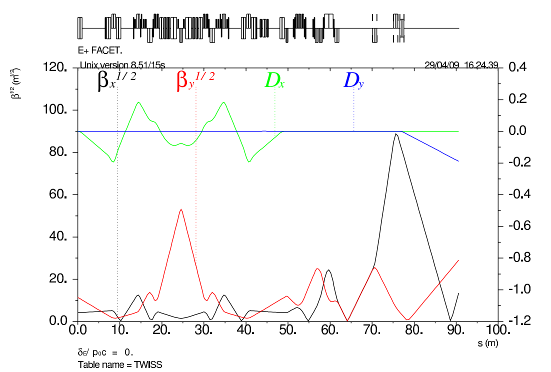

Figure 4: β functions and dispersion in the upper line (e+) in sector 20. The IP is at S=64.1 m, where $\beta^* = 6$ cm.

The simulated beam distribution at the IP, when only the lower chicane is installed, is illustrated in Fig. 5–7. It is obtained using DIMAD [3] particle tracking for a 23 GeV beam with the initial Gaussian x-y distribution at entrance into the sector 20, corresponding to normalized emittance of $\gamma\epsilon_x = 50\mu$m, $\gamma\epsilon_y = 5\mu$m, and with realistic longitudinal distribution optimized for a full bunch compression using LiTrack code [4] taking into account the bunch momentum compaction to the 2nd order and the linac wakefield. The IP beta functions were set to $\beta_x^* = 1.5$ cm, $\beta_y^* = 15$ cm. In this case, the final IP bunch length is $\sigma_z = 20\mu$m and the IP spot size is $\sigma_x = 13.6\mu$m, $\sigma_y = 8.8\mu$m, based on a Gaussian fit. One can see that the compressed bunch energy spread is very large causing non-linear chromatic beam size growth. The synchrotron radiation in the strong chicane bends and amplitude dependent sextupole aberrations contribute more to the beam size growth. Further optimization of the sextupole non-linear compensation is in progress in order to reduce the beam spot size to the desired 10 μm level.

Similar level of focusing and compression can be achieved in the FACET option with both sector 20 chicanes installed. However, in this case, since the focusing in the shared Final Focus is opposite for positrons and electrons, the round beam spot for both beams at the IP will be achieved using identical symmetric x/y emittance and

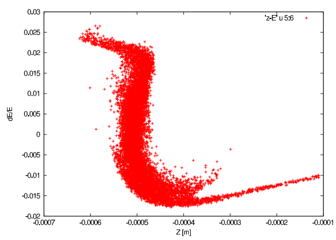

Figure 5: Longitudinal phase space at IP for FACET with a lower chicane in sector 20.

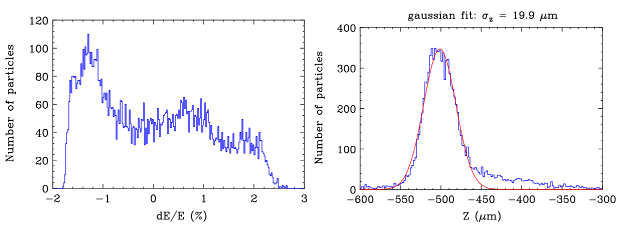

Figure 6: Energy spread and bunch length profile at IP for FACET with a lower chicane in sector 20.

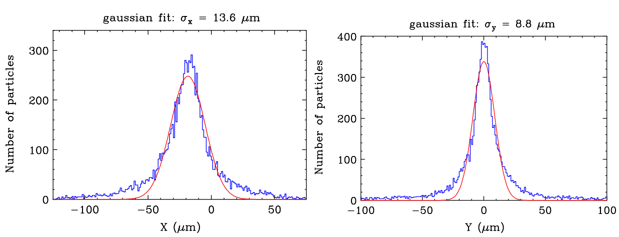

Figure 7: X and Y beam profile at IP for FACET with a lower chicane in sector 20.

IP β functions for both beams: $\gamma\epsilon_x = \gamma\epsilon_y = 25\mu$m (fully coupled beam in damping ring) and $\beta_x^* = \beta_y^* = 6$ cm.

COMPRESSOR CHICANE IN SECTOR 10

The existing four bend chicane in linac sector 10 can only be used for electron bunch compression. This is because positrons are produced by first accelerating electrons, which must pass through the same section of the linac. This limitation can be overcome by adding a chicane for the positron beam, placed mirror symmetrically on the opposite side of the electron chicane as shown in Fig. 8. This requires two additional bending magnets because the first and the last bends will be shared by the two beams. Since the proposed positron chicane will have the same design as the existing electron chicane, the electrons and positrons will attain the same bunch compression.

In the two chicane configuration, the first and last bends must have a very large horizontal aperture of $\sim$21 cm to accommodate the separating beam trajectories. This requires two new magnets to be built. The existing first and last bends in the present chicane will be relocated into the 2nd and 3rd positions in the new positron chicane since their design meets the specifications for these positions.

The symmetric e+ and e- chicanes produce the same focusing for both beams rather than opposite focusing as in

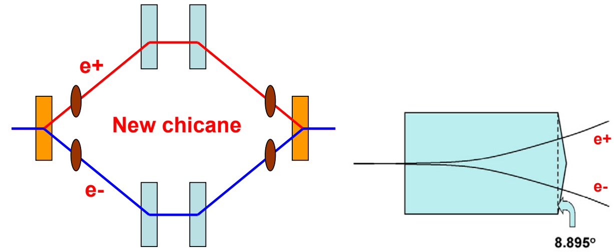

Figure 8: Layout of e+ and e- compressor chicane in sector 10 (left). Pole face design for the new outer bends (right).

the shared linac optics. This mismatch can cause a large β beating for positron beam. The compensation requires at least two variable focusing strengths in each chicane. The adopted solution is to use the chicane quadrupole correctors as one focusing variable, and adjustment of edge focusing in the two new bends as the second focusing strength. It was determined that the pole face on one side of the bend should have angle of $8.895°$ with respect to the rectangular configuration as shown in Fig. 8 to provide the correction. In this solution, the β beating is suppressed to a few % which is acceptable.

The large ± 8.75 cm trajectories in the outer bends require tight tolerance on multipole field to avoid large feed-down effects. Tracking simulation determined that the sextupole field in the two new bends must be within the level of $B_2/B_0 = 0.2\%$ at r = 10 cm in order to keep emittance growth effect from each bend below 2%, assuming that the feed-down orbit is corrected. This specification is the same as for the existing chicane bends, and therefore is achievable.

Additional modification in sector 10 chicane is adjustment of β functions. It is desirable to make them identical for e+ and e- to assure that bend tolerance specifications are the same in both chicanes. This can be done by adding an additional quadrupole in front of the chicane and adjustment of quadrupole strengths in sectors 10 and 11.

All six bends in the two chicanes will be powered in series. The built-in trim windings will allow a fine field correction in non-identical bends, and the included quad correctors can compensate residual dispersion.

SUMMARY

The FACET facility is proposed as a replacement for the FFTB, which has been dismantled to make way for the LCLS at SLAC. FACET will provide a means for compressing and focusing bunches of high energy electrons or positrons and delivering them to an experimental area in the sector 20 of the SLAC linac.

REFERENCES

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