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Electron Bypass Line (EBL) Design
Electrons to A-line bypassing LCLS

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Introduction

Forty one years ago, September 20, 1966, the first beam entered End Station A, passed on through, and was terminated in Beam Dump East. This beam had an energy of 18.4 GeV, a record for the time. Since then, the SLAC ESA has been a mainstay facility for many high-energy physics and test beam experiments involving countless hours of data taking.

Heretofore, it was assumed that with the completion and commissioning of the LCLS facility, beams from the main injector would no longer be available to this well equipped experimental facility. Fortunately, it has become clear that a bypass beamline design calling for modest modifications and using existing, soon to be surplus, components will enable continued utilization of this important facility.

EBL Geometrical Solution, Connecting HENIT to A-line

Beams to the ESA were originally intended to be interlaced (time multiplexed) with other beams to End Station B and elsewhere (Ref 1.). As shown, in plan view, in Figure 1. the Pulsed Magnets (PMs), PM1 through PM5, placed at the end of the linac, served the purpose of directing beams (0° or ±0.5° bend angles) into the three major channels including the A-line (shown in green). A long vacuum chamber allowed these beams to diverge, entering the beam lines through ports in the Tune-Up Dump, D-10. This 70 meter vacuum chamber is very large, well engineered and extremely difficult to modify. Thus, it is clear that the best solution for providing beam to A-line is to extend its trajectory upstream to a point where a beamline bypassing the LCLS injector could be brought into coincidence.

The existing 12 GeV PEP-II HENIT beam line (dashed blue line), which bypasses the linac from about Sector 10 through Sector 30 and supplies up to 12 GeV electrons for injection into the PEP-II High Energy Ring (HER), is perfectly suited for this continuation into the A-line. Note that its offset on the south side of the linac by approximately the same distance as the offset (0.62 m) of the entrance to the A-line in D-10 on the north. Thus, the length of the drift between a new magnet necessary to match the 0.5° bend would cause the dispersion at the entrance to the A-line to about double (0.63m to 1.23m). A better solution is to use two such horizontal bend magnets (bending 0.25° each) separated by the negative of the optical Identity matrix to cause the dispersion to be equal to zero throughout the subsequent drift. The A-line, without modification, has the dispersion matching capability to accommodate this desirable feature. A lattice consisting of two FODO cells with 90° of phase advance per cell placed between the two magnets will accomplish the desired matrix transformation. Note, that for this geometry, the choice of the placement of the downstream bend, the given offset of the HENIT beam line and the needed 0.25° equal bends, now uniquely determines the separation of the two equal strength horizontal bending magnets, thus, the length of the FODO cells is now also uniquely determined. The separation of the effective bending points of the two magnets is 43.2 m and the resultant length of each FODO cell is 21.6 m. The two bending magnets are referred to as BBH1 and BBH2. The FODO cell lattice is then extended upstream to accomplish a 2π phase advance and

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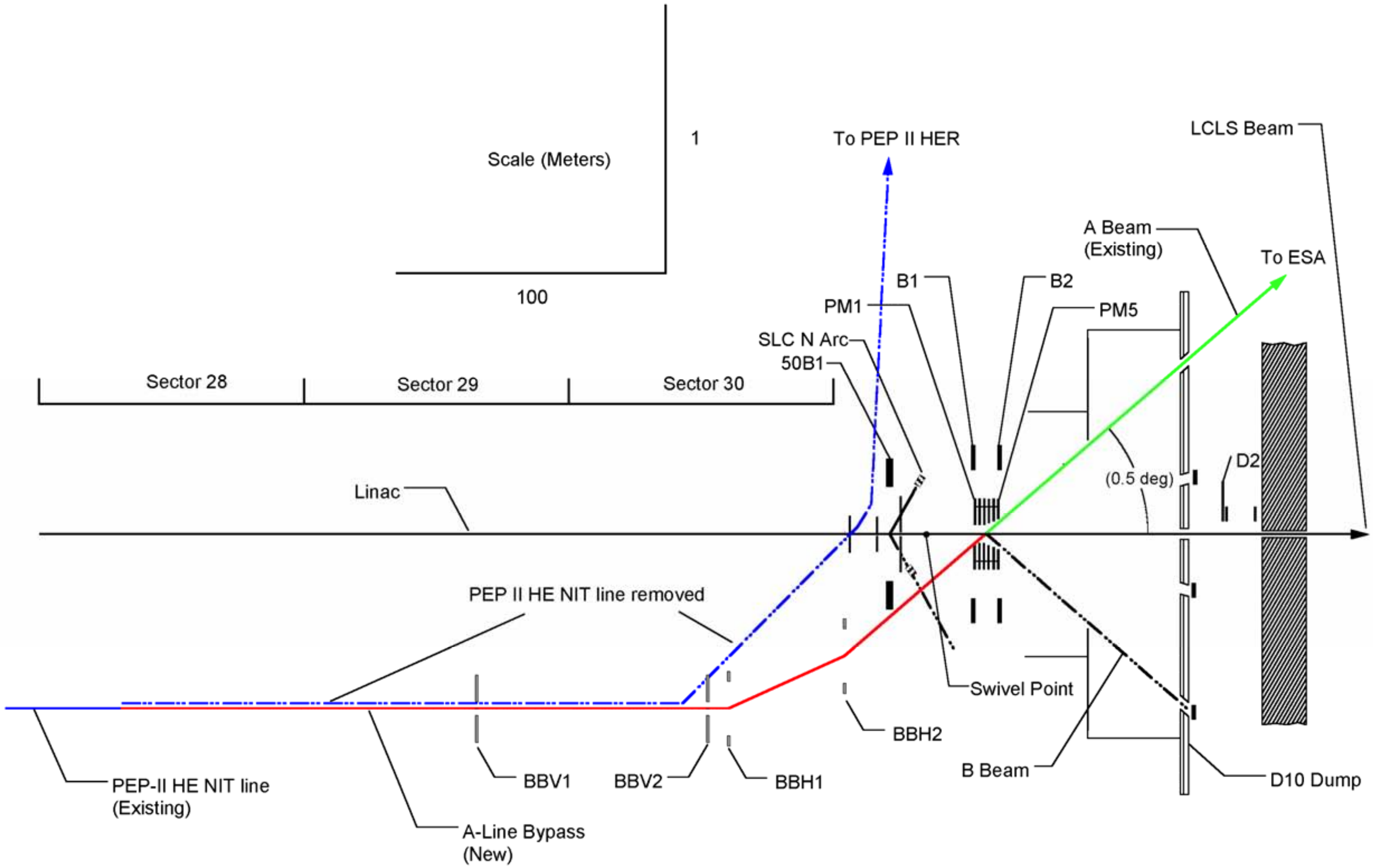

Figure 1. Plan view of layout of proposed HENIT to A-line Bypass.
Note unequal scales, 100::1

an Identity matrix transformation in order to image two equal strength vertical bending magnets, BBV1 and BBV2 needed to bring the elevation of the EBL line (0.64m) down to match the height of the A-line. Again, dispersion outside the intervening region is zero.

There is one final feature of the geometry that needs to be accommodated. In the design of the accelerator, to minimize excavation, the linac was caused to pitch downward by about 47 feet in its length of 10,000 feet. To compensate for this downward pitch and to cause the A-line to be perpendicular to local gravity in the ESA, the entire beam line was rolled (clockwise as seen by the beam) about the linac axis by 10.4 milliradians. Thus, after a horizontal bend of 24.5°, in this rolled plane, the vertical pitch had been removed and the beam was horizontal. One result, is that while the linac and A-line obviously have the same elevation at the PMs, however, at the Tune-up Dump, D10, the A-line is about 7 mm higher than the linac. Thus, considering the PMs height as the central pivot (like a teeter totter), the A-line elevation at the first horizontal bend magnet, BBH1, will be about 9 mm below the elevation of the linac. The necessary vertical bend to accommodate this change in elevation is 125 μ-radians, which will be accomplished by two small vertical bends placed near each of the horizontal bending magnets, thus again, canceling all dispersion.

At this point, the lattice parameters are completely determined by the requirement to match geometry with a minimum number of bending magnets without generating dispersion. These EBL FODO cell parameters are: L_{Cell} = 21.6 m, Quadrupole spacing = 10.8 m, β_{max} = 36 m, β_{min} = 6 m, $\mu_{x,y} = \pi/2$, focal length = ± 7.54 m, GL = ± 53.0 kG at the nominal energy of 12.0 GeV.

With the lattice determined, there remains a degree of freedom to be utilized without changing the required overall geometry shown in figure 1. While leaving the bend magnets in their fixed positions, the entire ensemble of quadrupoles can be slid, in trombone fashion, up and down the beamline without affecting the required cancellation of dispersion. This procedure provides a way to avoid existing critical components for the linac and LCLS. The placement of elements was tracked in three dimensions using the design program, Solid Edge, and a solution found that avoided any major conflicts.

EBL Optical Solution, matching to HENIT and A-line

Also, shown in Figure 1. is a special optical matching point established during the design of SLC. It is located on the linac axis just downstream of the location of the magnet 50B1, the magnet that was used to deflect the 50 GeV electrons and positrons in opposite directions into the SLC North Arc and South Arc, respectively. It is aptly referred to as the swivel point because the optical matching caused both beams to be brought to a round beam waist, where $\beta_x = \beta_y$ = 14 m and $\alpha_x = \alpha_y = 0$, for both electrons and positrons. Thus, one could imagine rotating around the beam axis, as with a swivel, while the beam parameters for both oppositely charged beams remained invariant. Clearly, this allowed the optics in the North and South Arcs to be identical, i.e., starting with the same initial conditions (note that a 90° rotation will not change the initial conditions but will change the polarity of the quadrupoles, just what is desired for an oppositely charged beam).

The linac optical match to the SLC swivel point became an established starting configuration for setting up beams to other experiments such as those in A-line. This match utilized linac quadrupoles and the matching quads 50Q1, 50Q2 and 50Q3 upstream of the bend magnet 50B1. Thus, to duplicate the optical match to the A-line, new equivalent matching quadrupoles must be provided in the EBL line. The placement of the last horizontal bend magnet BBH2 was carefully chosen to not only accommodate the geometry, as described earlier, but to also allow adequate transverse and longitudinal space to accommodate placement of these necessary quadrupoles. Four independently powered quadrupoles downstream of BBH2 provide adequate degrees of freedom to optically match the EBL lattice parameters to those of the swivel point.

With the lattice and matching quadrupoles that accomplish the task of connecting geometrically and optically to the existing A-line completed, it remained to match the HENIT optics to the new lattice. The HENIT beam line and new EBL lattice are co-axial and separated by a drift region of about 130 m. Four matching quadrupoles are placed in the drift and match the HENIT FODO cell parameters to the EBL parameters described above. A change in strength was also required for the last HENIT quadrupole QB15.

The EBL, as described, consists of four bending magnets, eight matching quadrupoles and fourteen lattice quadrupoles as listed in Table 1. Note that in Table 1. The EBL elements have been matched with existing magnets. Utilizing existing magnets for construction will be discussed in the next section.

Table 1. EBL Magnets

Bends						
Element Name	**Type**	**Bend Angle (degrees)**	**BL (kG-m) at 12 GEV**	**Existing Magnet Type**	**Length (m)**	**Aperture (mm)**
BBV1, BBV2	Vertical	.250	1.749	1.0D38.37	.975	25.4
BBH1, BBH2	Horizontal	.436	3.045	2.0D37.37	.949	50.8
Quadrupoles						
Element Name	**Type**	**Focal Length (m)**	**GL (kG) at 12 GeV**	**Existing Magnet Type**	**Length (m)**	**Aperture (mm)**
QB15	QD	-52.9	7.6	2Q4	0.1	50.8
QBM01	QF	31.9	38.3	2Q20	0.5	50.8
QBM02	QD	-17.6	21.1	2Q20	0.5	50.8
QBM03	QF	11.7	14.1	2Q20	0.5	50.8
QBM04	QD	-6.7	8.1	2Q20	0.5	50.8
QBL05, 07, 09, 11, 13, 15,17	QF	7.54	53.1	2Q20	0.5	50.8
QBL06, 08, 10, 12, 14, 16, 18	QD	-7.54	53.1	2Q20	0.45	20.6
QBM19	QD	10.6	12.7	0.813Q17.7	0.45	20.6
QBM20	QF	-7.0	8.4	0.813Q17.7	0.45	20.6
QBM21	QD	5.5	6.6	0.813Q17.7	0.45	20.6
QBM22	QF	-6.0	7.2	0.813Q17.7	0.45	20.6

The four figures following illustrate the optical functions for the matched solution. Figures 2. and 3. Show the beta and dispersion functions covering a length of 2250 meters from Sector 12 of the linac to the Beam Dump East, the termination of the A-line. The new connecting region, EBL, is between 1500 m and 1850 m. The A-line optical functions are for the beam line configuration used for the experiment E-158 recently completed. Figures 4. and 5. Show only the new components for the proposed EBL, which match the βmax = 350 m, βmin = 59 m of the HENIT to the $\beta x = \beta y$ = 14 m at the swivel point.

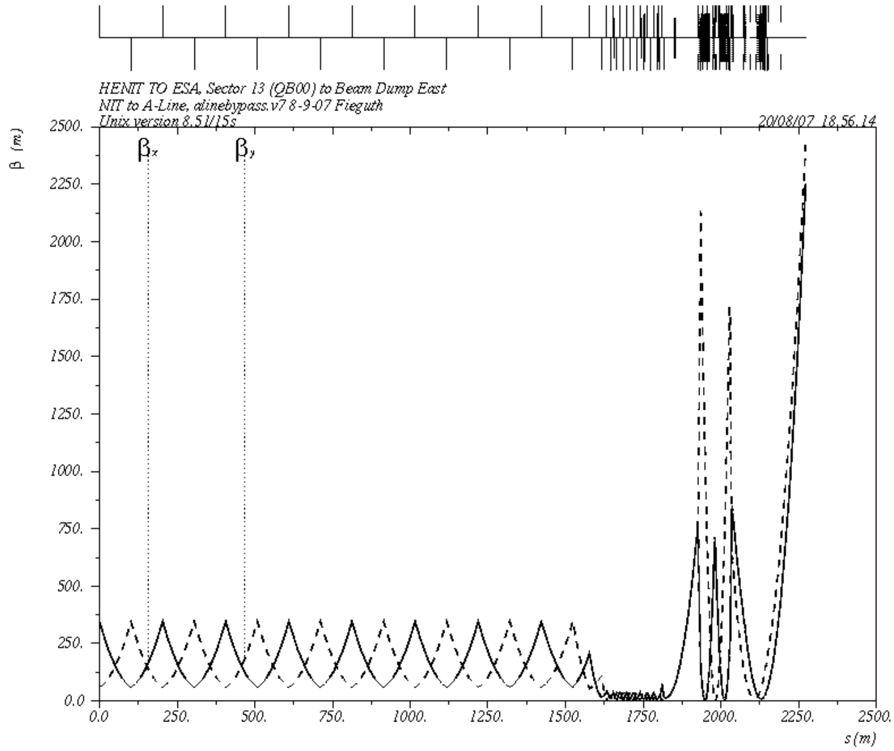

Figure 2. Beta Functions of EBL lattice, match and bends connecting HENIT lattice to Aline ending at Beam Dump East

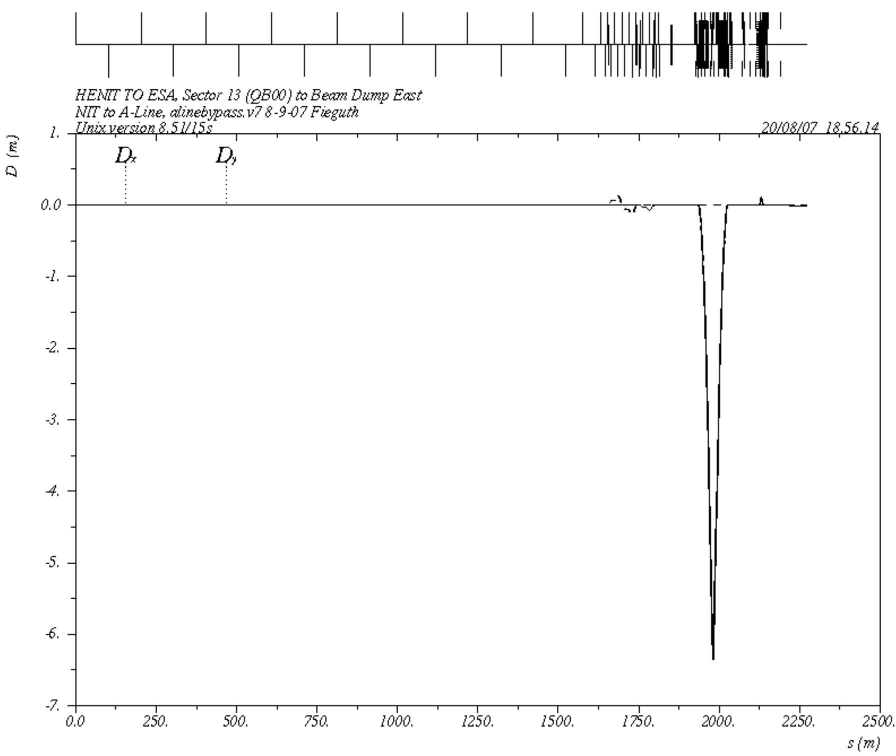

Figure 3. Dispersion Functions of EBL lattice, match and bends connecting HENIT lattice to Aline ending at Beam Dump East

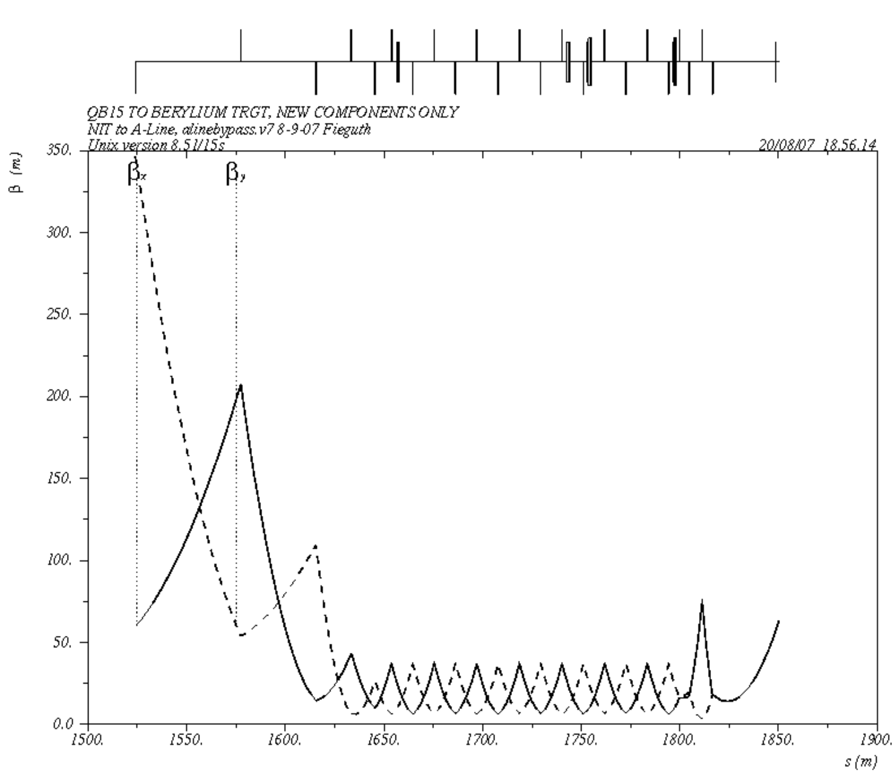

Figure 4. Beta Functions of EBL lattice, match and bends, showing only the proposed additional components

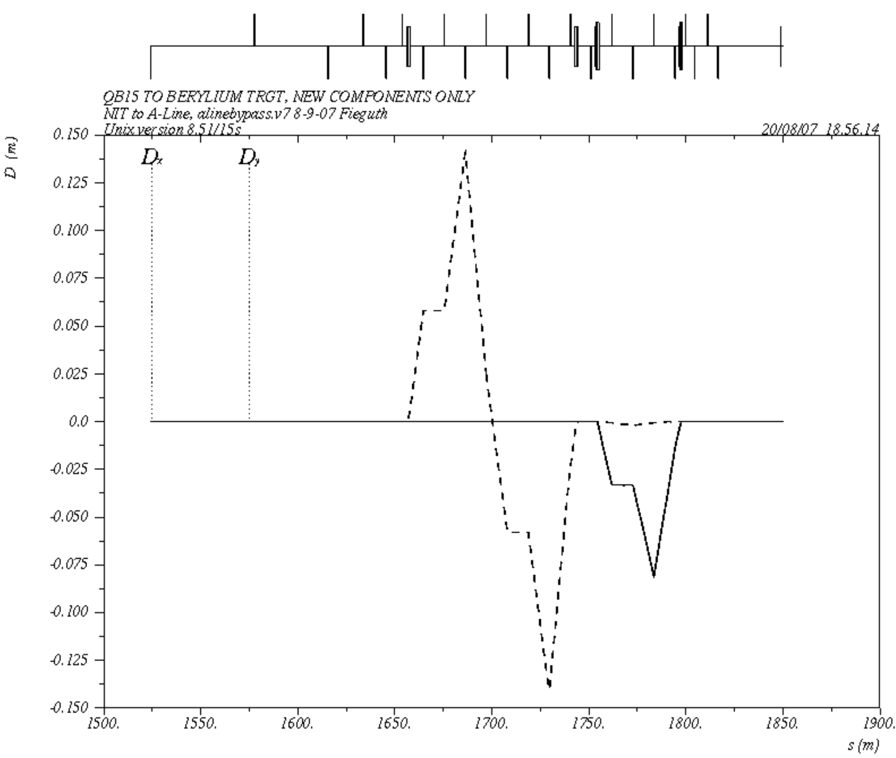

Figure 5. Dispersion Functions of EBL lattice, match and bends, showing only the proposed additional components

Utilizing Existing Components

It is interesting to note that the lattice arrived at in the manner described above, is almost equal, in all respects, to that of the existing lattice in the arc region of PEP-II high energy electron injection line.

The existing PEP-II electron injection transport line (Ref 2.), consists of two major sections. The first, upstream section resides in the linac housing and here is referred to as the HENIT lattice, having one quadrupole per sector, L_{cell} = 203.2 m. The second major part is that residing in the PEP-II injection tunnel, which arcs down to the HER ring and has lattice components that have been in place since PEP was first constructed. PEP-II construction left this part largely intact. The lattice of this section, it turns out, has optical parameters very near to those just described for the proposed EBL lattice and is comprised of many suitable optical components, 40 quadrupoles and many bend magnets that can be utilized for EBL purposes. The lattice parameters for the three lattices, the PEP-II HENIT line in the linac housing, the PEP-II Arc lattice and the proposed EBL are given in Table 2.

Table 2. FODO Lattice parameters for PEP-II and proposed EBL

		PEP-II HENIT	**PEP-II Arc Lattice**	**Proposed EBL**
Parameter	**Unit**			
L_{cell}	m	203.2	17	21.6
Quad spacing	m	101.6	8.5	10.8
β_{max}	m	350	28.5	36
β_{min}	m	59	5	6
Focal length	m	72	5.9	7.5
Phase Advance		$\pi/2$	$\pi/2$	$\pi/2$
GL	kG	4.2 at 9 GeV	51 at 9 GeV	53 at 12 GeV

A study of the suitability of PEP-II Arc lattice components for use in the proposed EBL has concluded that most components, such as bend magnets, quadrupoles, orbit corrector magnets, beam position monitors and their support structures can be relocated and used. In many cases the modification to the support structures involves only lengthening or shortening the cylindrical pedestal. At the same time, power supplies with their existing control systems can also be utilized but without the need for relocation; it will be only necessary to re-cable them to the new location of the components, which will be closer, hence, with shorter cable runs. Vacuum pipes and some diagnostic instruments will require modification. Figures 6. and 7. show typical existing magnets, quadrupoles, beam position monitors and orbit correctors and how they may be used for the EBL. Figure 8. is an isometric view generated by Solid Edge showing how conflicts are avoided between EBL components and critical linac and LCLS components.

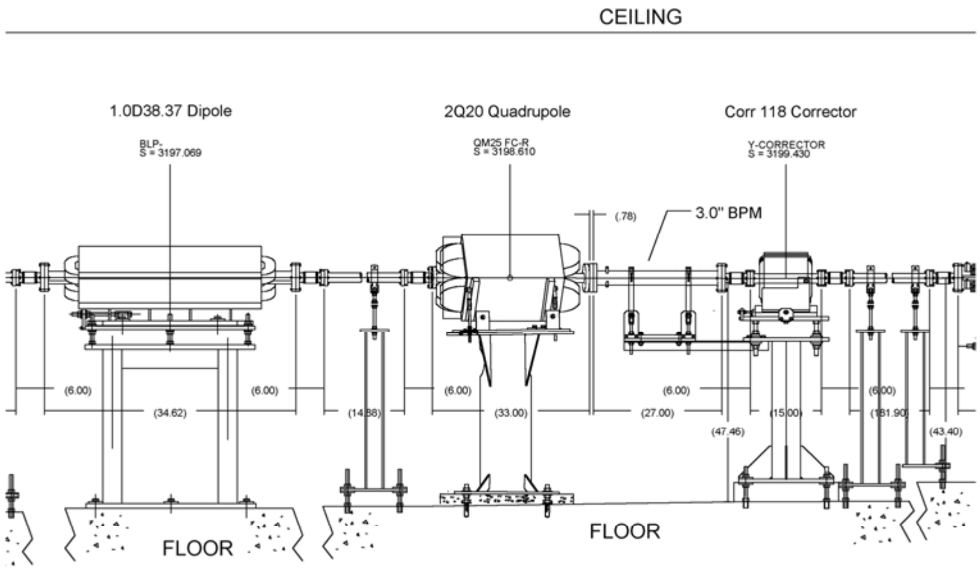

Figure 6. Typical PEP-II Arc lattice components, showing a bend magnet, quadrupole, BPM, Corrector magnet and supporting stands. Modification of the supports will make them suitable for use in the EBL.

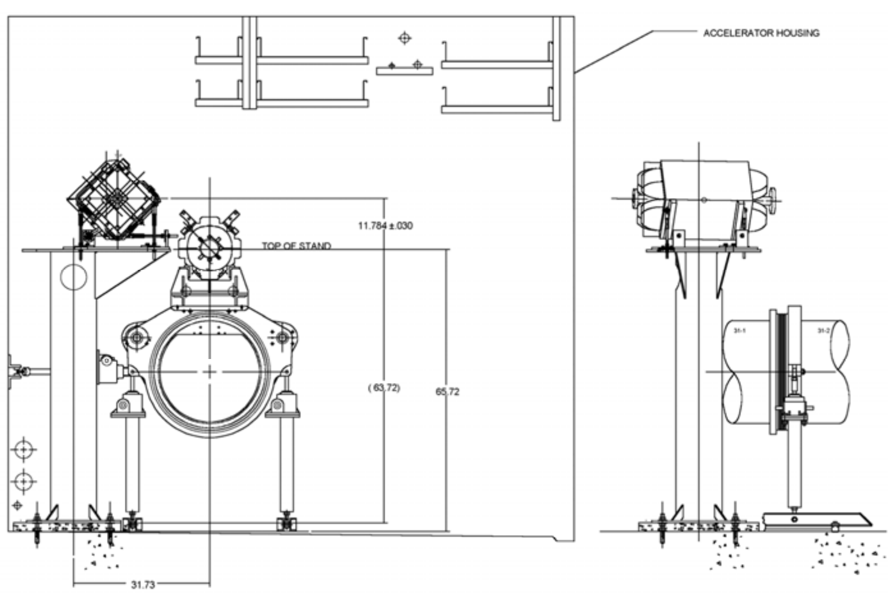

Figure 7. A typical cross section, looking downbeam, for beginning of PEP-II Arc. The EBL elements will utilize the same supports, modified, but on the other side of the linac.

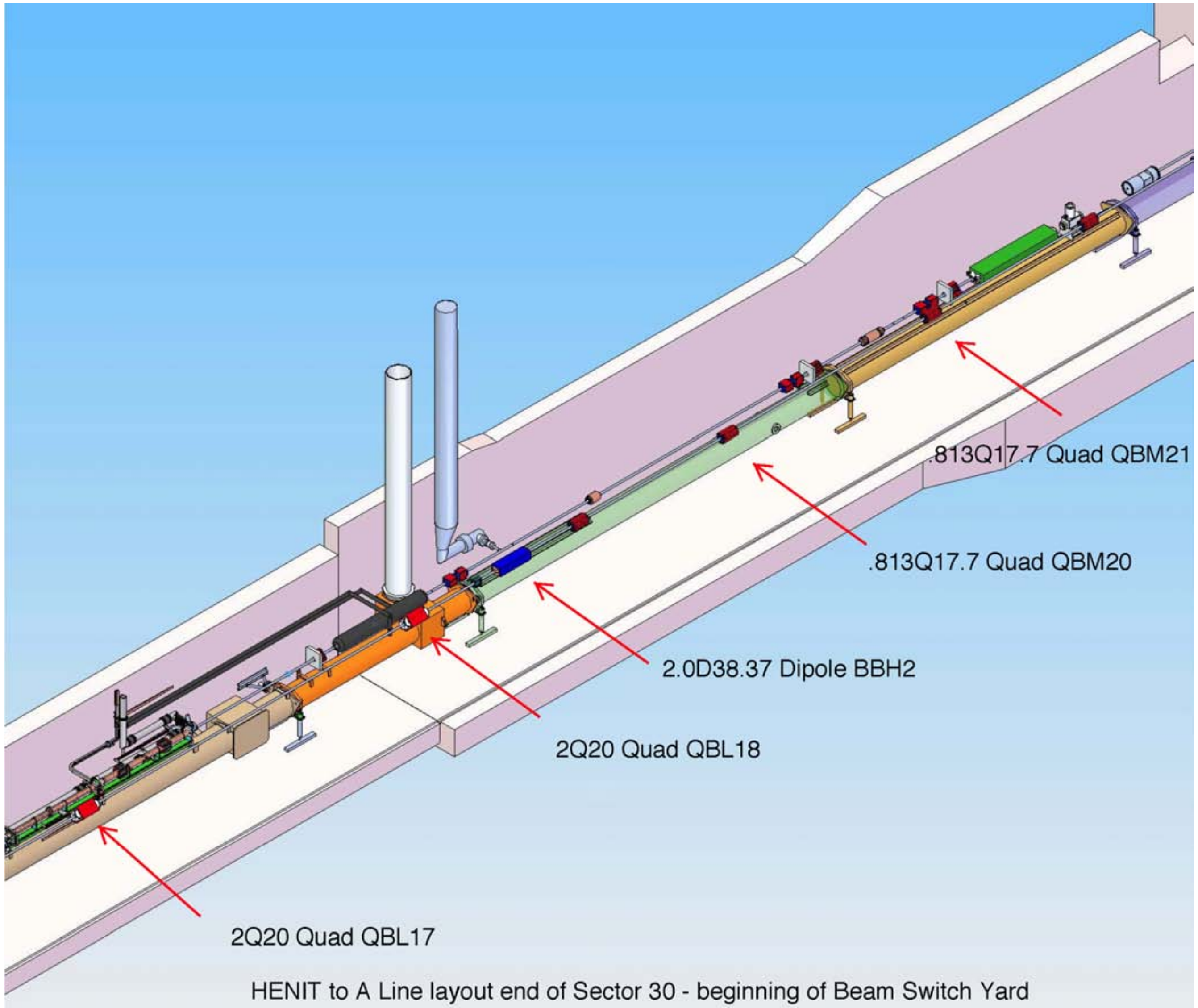

Figure 8. Solid Edge model of the region at the end of the linac, showing critical components, e.g. RF waveguide, refrigerator baffle, vacuum manifolds, and optical components important to either LCLS or the proposed EBL. Major space conflicts are avoided.

Emittance, Beam Size and Beam Stay Clear:

It is expected that, as in the past, the beams to ESA will vary in intensity, repetition rate and power in order to meet the various needs of the different experiments. It will be desirable to provide both damped short pulse length beam from the Damping Ring and long pulse length beams from the CID Injector. It must be assumed that the power will exceed that currently delivered to the HER. In Table 3. some nominal values for the parameters of these two sources are assumed and compared. The beam emittances are given and monochromatic and chromatic beam sizes are calculated. These rms values are used to evaluate the Beam Stay Clear (BSC) specifications for the vacuum chambers. In general it can be seen that the maximum beam sizes are sub-millimeter and thus the BSC specification will be easily met by utilizing existing 50.8 mm bore quadrupoles, 50.8 mm vacuum pipe and the large 76.2 mm OD beam position monitors from the PEP-II arc lattice. The worst case occurs at the small aperture quadrupole, QBM21, (collimator radius, A = 8.0 mm, see collimators below) where there exists the point of largest beta ($\beta_x = 74$ m). Here, $A = 23\sigma_x$ for a beam from the Damping Ring, a value considered to be acceptable.

Machine Protection Devices, Collimators and Acceptance

Due to the higher expected power shown in Table 3. protection devices are essential. It will be necessary to protect bending magnets, quadrupoles, vacuum pipe and magnet chambers from damage due to an errant beam. Beam miss-steering, improper magnet settings, and energy mismatch are the principle causes of such damage. It is expected that several low power collimators with protective ion chambers or other radiation detectors, capable of shutting off the beam after a few pulses, will protect most components. Subsequent to errant beam detection the beam will be limited to operate at a repetition rate of one Hz until the problem is corrected.

The maximum energy acceptance of the HENIT beamline has been defined to be $\Delta P/P = \pm 3.3$ % by a series of protection collimators at the point of extraction from the linac in Sector 10. Thus, if the EBL is properly set up, the maximum excursion of the beam due to dispersion will be $X_{max} = D_{x,max} \times \Delta p/p = 80 \times 0.033 = 2.6$ mm and $Y_{max} = D_{y,max} \times \Delta p/p = 140 \times 0.033 = 4.6$ mm. These deviations are small compared to the 25.0 mm radius of the vacuum pipe and will not be of any concern.

On the other hand, it will be possible for the bend magnets to have an incorrect setting and be miss-matched to the energy of the beam. There are two pairs of bend magnets, the vertical pair and the horizontal pair. One power supply will provide current to each magnet pair connected in series and can be independently set to values from zero to maximum. Thus, in each case, the downstream magnet of the pair will have the same strength as the upstream magnet and it is then only necessary to stop the beam from excursions caused by the upstream magnet. For the pair of vertical bending magnets a single collimator (labeled PCY1) with an outside radius of 60 mm and an aperture of 9.0 mm radius placed 7.0 m downstream of the first vertical bend will provide protection to all downstream components for a miss-setting of the vertical magnets power supply between zero (tripped off) up to 85% of nominal current (also the symmetrical case of 115% to 200%). For the situation, in which the power supply drifts between $\Delta I/I = \pm 15.0$ % of nominal, the maximum excursion of the beam downstream will be $Y_{max} = D_{y,max} \times \Delta I/I = 140 \times \pm 0.15 = \pm 21$ mm and will not strike the 25 mm radius beam pipe. The beam pipe between the first vertical bend and the protection collimator PCY1 must have a radius of ≥60 mm to accommodate the beam excursion of 53 mm for the case when the power supply has tripped off and has zero current.

Table 3. Typical beam parameters expected for beams transporting through HENIT and EBL to ESA.

						HENIT		**Proposed EBL**	
Source	**Beam Current (electrons)**	**Rep Rate (Hz)**	**Beam Power (kW) at 12 GeV**	**Invariant Emittance (m-rad)**	**Geometric Emittance At 12 GeV (m-rad)**	**σ_{max} (mono-chromatic) (μm)**	**σ_{min} (mono-chromatic) (μm)**	**σ_{max} (mono-chromatic) (μm)**	**σ_{min} (mono-chromatic) (μm)**
Damping Ring	2×10^{10}	60	2.5	$\gamma\varepsilon_x = 5\times10^{-5}$	$\varepsilon_x = 2\times10^{-9}$	860	350	280 500*	110
				$\gamma\varepsilon_y = 0.5\times10^{-5}$	$\varepsilon_y = 2\times10^{-10}$	270	110	90 700*	40
CID Gun Long pulse	2×10^{11}	60	25	13×10^{-5}	5.5×10^{-9}	1400	570	450 830*	180

* For $(\delta p/p)_{rms} = 0.005$

For the horizontal bend magnets a similar consideration will result in a protection collimator (PCX1) placed 7 m downstream of the first horizontal bend magnet with an outside radius of 40 mm to accommodate the 31 mm offset of the beam for zero magnet current and an aperture of 8.0 mm radius will allow a deviation from nominal current of $\Delta I/I = \pm 25$ %. As with the vertical case the maximum horizontal excursion of the beam downstream will be $X_{max} = D_{x,max} \times \Delta I/I = 80 \times \pm 0.25 = \pm 20$ mm and will not strike the 25 mm radius beam pipe.

Other collimators will be required to protect sensitive components with small apertures. For instance, the vacuum chambers in the bend magnets will be protected by appropriately sized collimators placed immediately upstream. Two such collimators, PCBV1 and PCBV2, each with $r_{aperture}$ = 20 mm, and two others, PCBH1 and PCBH2, each with $r_{aperture}$ = 10 mm will protect the four bend magnets in EBL. In addition, the four matching quadrupoles downstream of the last bend magnet will have small apertures (r = 8.7 mm) and will have protection collimators with $r_{aperture}$ = 8 mm. These devices are PCQBM19, PCQBM20, PCQBM21 and PCQBM22.

In addition to these necessary protection collimators, one of the five existing protection collimators, PC145, at the PMs will have to be enlarged horizontally in order to accommodate the beam which is now entering the PM group off-axis instead of being centered as before. A second collimator, PC155, further downstream can be removed as the magnet it was protecting is no longer in place. These protection collimators can be seen in Figure 1. located at the PMs.

The proposed protection collimators and their functions are listed in Table 4. The requirement for and placement of other protective collimators is being studied.

Table 4. EBL Protection Collimators

Name	Location	Purpose: Protect element	Aperture Radius (mm)	Outside Radius If specified (mm)
PCY1	7 m d/s BBV1	Magnet miss-set	9.0	≥60.0
PCX1	7 m d/s BBH1	Magnet miss-set	8.0	≥40
PCBBV1	u/s BBV1	magnet & chamber	20.0	tbd
PCBBV2	u/s BBV2	magnet & chamber	20.0	tbd
PCBBH1	u/s BBH1	magnet & chamber	10.0	tbd
PCBBH2	u/s BBV2	magnet & chamber	10.0	tbd
PCQBM19	u/s QBM19	magnet & chamber	8.0	tbd
PCQBM20	u/s QBM20	magnet & chamber	8.0	tbd
PCQBM21	u/s QBM21	magnet & chamber	8.0	tbd
PCQBM22	u/s QBM22	magnet & chamber	8.0	tbd
PC145 exists	u/s PM1	PM1	enlarge	tbd
PC155 exists	d/s PM1	Remove	n/a	n/a

Orbit Correctors and Beam Position Monitors

Other possible causes for an errant beam striking a vulnerable beam element are: uncorrected accumulated deflections from quadrupole alignment errors, correctors that are too strong for their intended use and correctors adding coherently to the amplitude of a betatron oscillation. It can be expected that the orbit correctors and Beam Position Monitors (BPM) for the existing PEP-II Arc lattice will also be adequate for use in the EBL. As used now the orbit correctors are placed only at quadrupoles where $\beta = \beta_{max}$. This means that the X correctors are placed near horizontally focusing quadrupoles and alternate with the Y correctors placed at the defocusing quadrupoles. Such an arrangement in shown in Figure 6. where a quadrupole is followed by a BPM followed by a corrector. For the lattice quadrupoles, it has been estimated (for the X-Plane, as the estimate for the Y-Plane is identical) that for a conservative alignment tolerance of δx_{rms} = 500 microns, the random walk offset at the last lattice quadrupole due to the focusing quadrupoles will be Δx_{rms} = 5 mm. The same offset due to the defocusing quadrupoles will be Δx_{rms} = 2 mm, which does not contribute when added in quadrature. The needed corrector strength is assumed to be twice the estimated rms strength or 135 μ-radians. At this strength a single corrector is capable of moving the beam position by 5 mm at the following BPM. This is sufficient to correct for miss-alignments and yet is estimated that it is unlikely to lead to coherent additions to a betatron oscillation to strike the beam pipe. Given these estimates the current PEP-II Arc orbit correctors (Type Cor 118, as shown in Figure 6.) are found to have a strength about 2.5 times what is necessary. It may be desirable to place software limits on the range of these devices instead of using more costly measures to avoid striking the beam pipe. Further study of this subject is underway but at this point it is assumed that with care taken during commissioning followed by placeing software limits on the correctors, will allow safe operation of the beam through the lattice quadrupoles without the added cost of radiation detection or collimators at each lattice quadrupole.

Power Supplies

The power supplies for the PEP-II Arc magnets are located in the klystron gallery at Sector 30. This is an ideal location for supplying power to the EBL magnets most of which require shorter cable runs than those existing. In Table 5. and Table 6. The PEP-II power supplies have been paired with appropriate EBL magnets. Noteworthy is the fact that these power supplies when so paired are mainly capable of providing current for 24 GeV. This may become important in the future if the extraction point from the linac is moved from Sector 10 to Sector 18. The controls for these power supplies are all in place and operating.

Beam Diagnostics and Instrumentation.

In addition to the utilization of the BPMs covered earlier, other beamline ancillary components will also be used. These are wire scanners, toroids, protection ion chambers. Figures 9. and 10. are schematic layouts of the EBL line showing a tentative placement of most components.

Summary

It has been shown that a simple modification of the HENIT, using existing components, soon to be surplus, will provide a 12 GeV beam to ESA. Earlier work (Ref. 3) has shown that such a facility will be immediately useful and, furthermore, electron beams of higher energy, beams of hadron particles and other useful capabilities all become real possibilities for the future.

References

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2. T. Fieguth, "The Optical Design of the PEP-II Injection Beamlines", Proceedings of 5^{th} European Particle Accelerator Conf. p. 2471-3, (1996), SLAC-PUB-7171.
3. R. Arnold et al., "SLAC Test Beams beyond FY08", Internal Document, May 24, 2007

TABLE 5. EBL BEND MAGNET POWER SUPPLIES matched to existing Power Supplies

Proposed Electron Bypass Line (EBL)						Existing Power Supplies		
Power Supply Name	**Element Name**	**Type**	**Existing Magnet Type**	**Required Current (Amps) at 26 GeV**	**Volts**	**Power Supply Name**	**Element Name**	**Power Supply Type (A/V)**
PSBBV	BBV1, BBV2 in series	VERT	1.0D38.37	209	23	LGPS 6155	BV1A	EMI/ESS 40/375
PSBBH	BBH1, BBH2 in series	HORZ	2.0D37.37	248	28	LGPS 6195	BV1B	EMI/ESS 40/375

TABLE 6. EBL QUADRUPOLE POWER SUPPLIES matched to existing Power Supplies

Proposed Electron Bypass Line (EBL)						Existing Power Supplies		
Power Supply Name	**Element Name**	**Type**	**Existing Magnet Type**	**Required Current (Amps) at 26 GeV**	**Volts**	**Power Supply Name**	**Element Name**	**Power Supply Type (A/V)**
PSQB15	QB15	QD	2Q4	tbd	tbd	tbd	tbd	tbd
PSQBM01	QBM01	QF	2Q20	40	5	LGPS 6320	QM25	EMI/ESS 20/125
PSQBM02	QBM02	QD	2Q20	60	7	LGPS 6330	QM26	EMI/ESS 20/125
PSQBM03	QBM03	QF	2Q20	85	10	LGPS 6340	QM27	EMI/ESS 20/125
PSQBM04	QBM04	QD	2Q20	160	18	LGPS 6310	QM24	EMI/ESS 40/250
PSBQF	QBL05, 07, 09, 11, 13, 15, 17 in series	QF	2Q20	140	110	LGPS 6120	QA08-32	EMI/ESS 100/100
PSBQD	QBL06, 08, 10, 12, 14, 16, 18 in series	QD	2Q20	140	110	LGPS 6130	QA09-23	EMI/ESS 100/100
PSQBM19	QBM19	QF	.813Q17.7	38	5	LGPS 6350	QM28	EMI/ESS 20/125
PSQBM20	QBM20	QD	.813Q17.7	58	7	LGPS 6360	QM29	EMI/ESS 20/125
PSQBM21	QBM21	QF	.813Q17.7	74	9	LGPS 6370	QM30	EMI/ESS 20/125
PQBM22	QBM22	QD	.813Q17.7	68	8	LGPS 6380	QM31	EMI/ESS 20/125

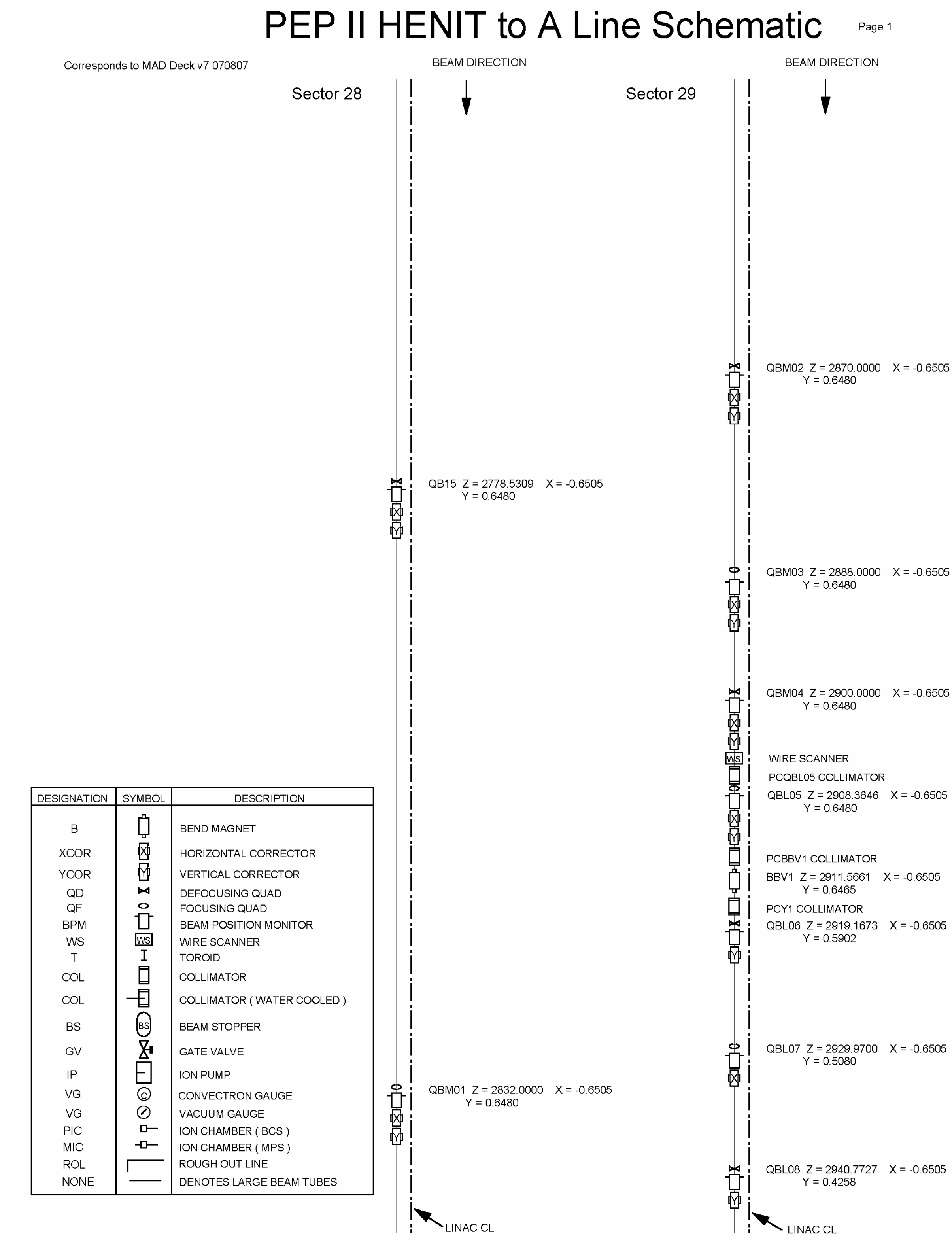

Figure 9. The schematic (page 1/2) showing the location of components starting with the last HENIT quadrupole QB15, located 0.65m to the south and 0.648m above the linac accelerating waveguide.

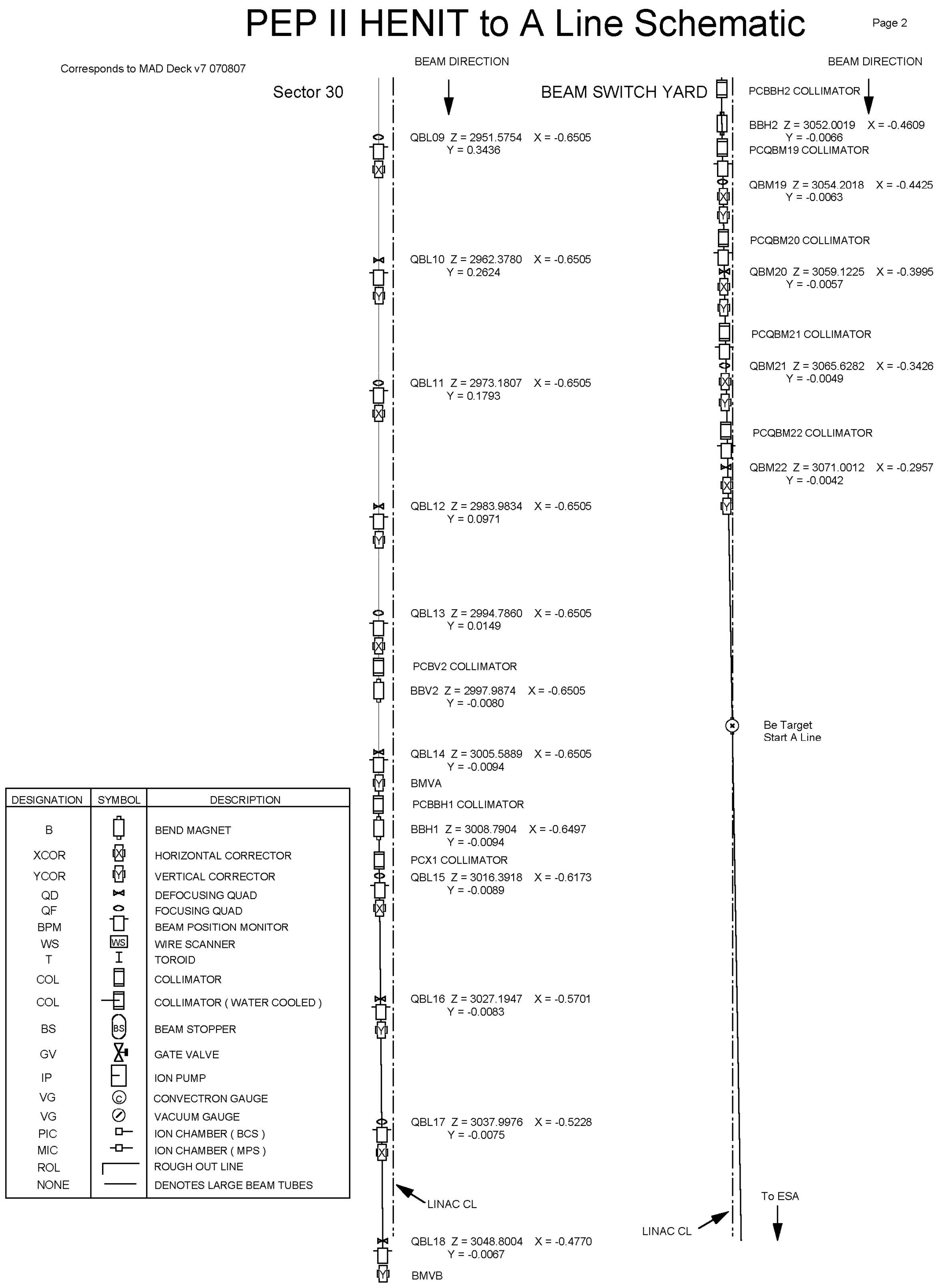

Figure 10. The schematic (page 2/2) showing the location of lattice components and horizontal bends causing the beam to cross the LCLS beam at the location marked “Be Target” (an insertable target)