August 24, 2001

Letter of Intent for a Ring Based PEP-N

Contributors:
Y. Cai, S. DeBarger, S. Ecklund, S. Heifets, A. Kulikov, S. Metcalfe, H. Schwarz, J. Seeman, M. Sullivan, U. Wienands
Stanford Linear Accelerator Center, Menlo Park, CA 94025, USA
M. Biagini
INFN, Frascati, Italy
V. Azzolini
Ferrara University, Ferrara, Italy
M. Placidi
CERN, Geneva, Switzerland
I. Koop, D. Shatilov
BINP, Novosibirsk, Russia

I. Abstract

This is an updated version of the LoI presented at the EPAC Meeting on November 2000. The PEP-N project is a proposed new $e^+ e^-$ collider at SLAC to operate in the center of mass energy range of 1.0 GeV to 3.1 GeV. PEP-N consists of a new Very Low Energy electron Ring VLER (< 800 MeV) to collide with the PEP-II e^+ Low Energy Ring LER (3.1 GeV) parasitically to PEP-II operation for BaBar. Since the e^+ ring has a fixed energy, the very low energy ring needs an energy range of 100 MeV to 800 MeV. This collider would likely be placed in Experimental Hall 12 of the PEP-II complex and have its own dedicated 800 MeV e^- injector. The peak luminosity should reach 2 x 10^{31}/cm^2/s at 800 MeV.

II. Introduction

We discuss the parameters for an "$e^+ e^-$ --> N Nbar or multi-hadrons" collider based at PEP-II [1,2]. The plan is to collide the 3.1 GeV LER e+ beam against a 0.1 to 0.8 GeV electron beam stored in a new very low energy ring (VLER). The PEP-II LER is assumed to be operated for full BaBar operation with design parameters. The small electron storage ring has a circumference of 45.36 m and is located in straight section IR12 of PEP-II. The electrons are injected from a 40 m-long linac also located in IR12 of PEP-II. The luminosity of this collider, called PEP-N, is estimated to be above 10^{31}/cm^2/s at a VLER energy of 500 MeV without affecting BaBar data collection. The location of PEP-N is shown in Fig. 1.

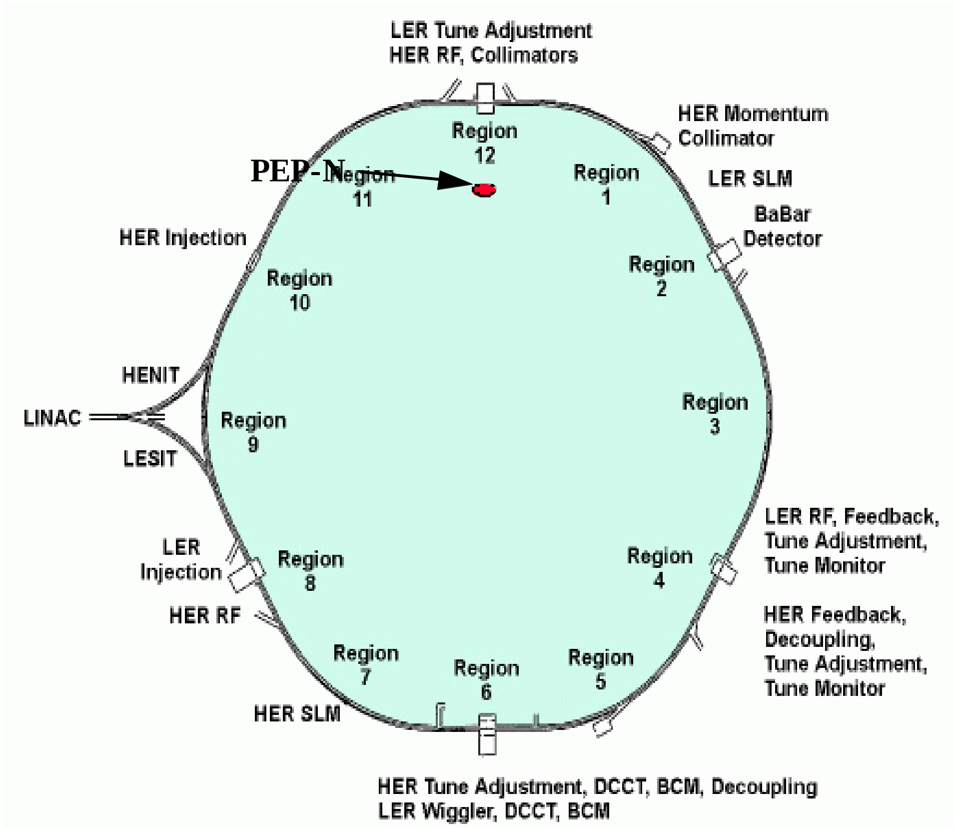

Fig. 1: PEP-II Layout with PEP-N location in IR12.

The collider straight section IR12 in PEP-II is relatively large, has good floor space both inside and outside the radiation enclosure, and has a large counting house. Both PEP-II rings are relatively simple in this straight section. The hall is 20 m along the beam line and about 12 m wide inside the radiation wall.

The optimized parameters for PEP-N are listed in Table 1. A sketch of the hall layout with the ring and injector is in Fig. 2.

Table 1: PEP-N Parameters

Parameter	Units	LER e+	VLER e-
Energy	GeV	3.1	0.8
Circumference	m	2200.	45.36
Total current	mA	2140.	140.
Number of bunches		1658	36
Current per bunch	mA	1.3	3.9
Bunch spacing	m	1.26	1.26
Bunch length	mm	11.0	10.0
ΔE/turn	KeV	700.	22.
RF frequency	MHz	476.	476.
Ion clearing gap	%	5.	0.
RF voltage	MV	4.8	0.1
Rel. energy spread	$x10^{-3}$	0.61	0.36
Synchrotron tune		0.045	0.011
Horizontal emittance	nm-rad	25.	250.

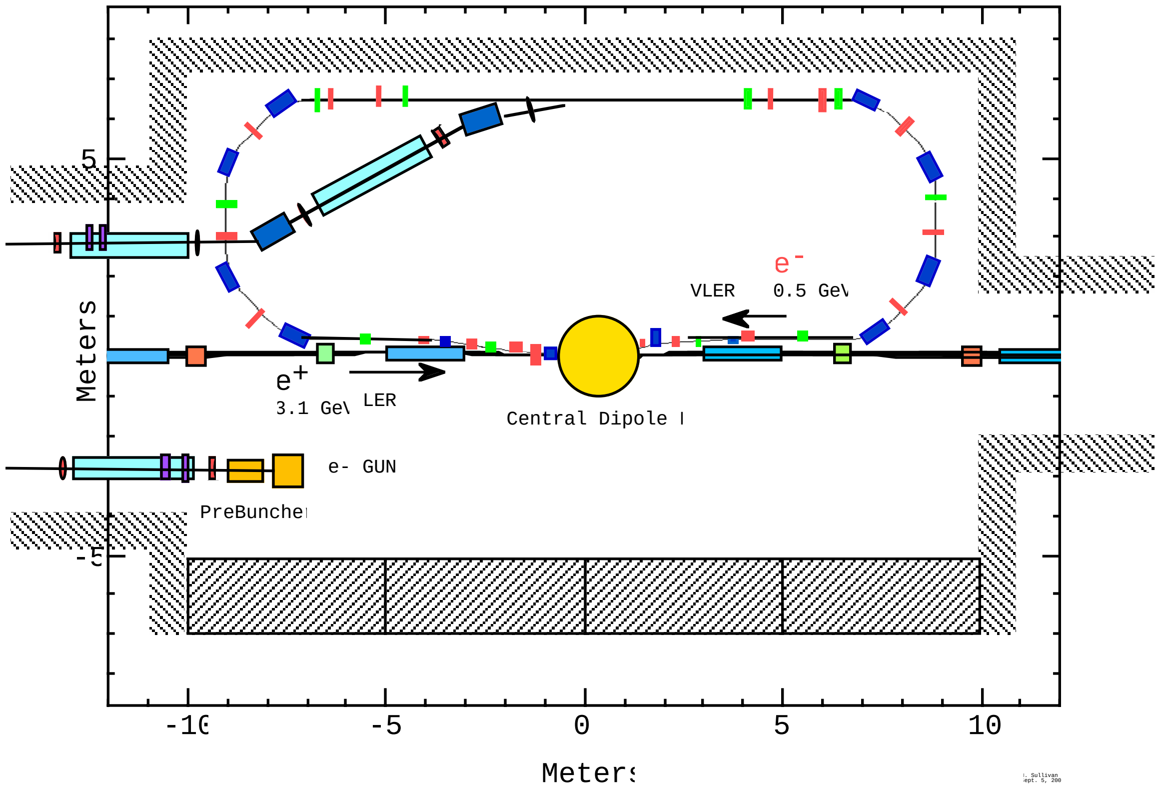

Fig. 2: Hall 12 layout with VLER ring and injector.

III. Collisions

The beam–beam interaction will ultimately determine the peak luminosity of PEP-N. To determine the peak, the maximum beam-beam tune shifts are assigned to each ring. Then, the beam parameters are adjusted to maximize the luminosity within the tune shift limit constraints. The circumference of the very low energy ring VLER had to be carefully chosen. The harmonic number of the LER is 3492 which equals 2x2x3x3x97. Thus, to have each VLER bunch collide with the same set of LER bunches always, the VLER circumference should be 22.7 m (2200m / 97) or 61.1 m (2200 m / 2 / 2 / 3 / 3). The IR12 hall has a rectangular size of 20 m by 7 m for a maximum possible circumference of about 54 m. If one designs a ring with a realistic combination of bending magnets, interaction point, and RF-injection-feedback straight section, a minimum circumference of about 30 m is needed [3]. Thus, we could not keep the above clocking constraint and were forced to choose a circumference in between. We chose 45.36 m which is 72 RF buckets. Therefore, every bunch in one ring collides with every bunch in the other ring, eventually. Sometimes, a bunch has no collision on a given turn depending on the location of the gaps in the LER bunch trains.

For PEP-N an important constraint is that the beam-beam performance for PEP-II and BaBar should not be affected. This implies that the LER of PEP-II should be operated for optimum luminosity for the BaBar detector. For the LER, this assumption translates into keeping the beam emittances, the number of bunches, and the total charge the same as for the design of PEP-II. The allowed parameters that can be adjusted are the local beta functions at the collision point in IR12. The allowed tune shift parameter for the LER should be small compared to the ones measured in IR2 which is about 0.03 to 0.06. Thus, we selected 0.004. In reality, the empirically determined maximum tune shift parameter may well be significantly higher, which may allow a higher luminosity for PEP-N.

The optimized parameters for collisions in PEP-N are shown in Table 2 for beam energy of 800 MeV [4,5]. The parameters change with energy. The total beam current is varied in VLER to keep the tune shifts constant for the LER. The beta functions in the LER are varied with different VLER energies to keep the VLER tune shifts constant.

Table 2: PEP-N Collision Parameters

IR Parameter	Units	Design
cm Energy	GeV	3.1
Crossing angle	mrad	0.0
Luminosity @ 800 MeV	$x10^{30}/cm^2/s$	20.
Number of bunches		36
VLER current	mA	140
VLER current	mA	2146.
β_y*/β_x* (VLER)	cm	2.85/30
β_y*/β_x* (LER)	cm	33/151
Uncoupled emittance (VLER)	nm	500
Optimum coupling (VLER)	%	100.
IP rms beam size σ_y/σ_x (VLER)	μm	85/274
IP rms beam size σ_y/σ_x (LER)	μm	26/272
Horizontal beam-beam tune shift (+/-)		.004/.06
Vertical beam-beam tune shift (+/-)		.004/.06
$\Sigma_{x,y}$	μm	88/386
IP dipole length	m	1.5
IP dipole field	T	0.3 - 0.42

Early in the days of B-Factory design, Keil and Hirata discovered [6,7] that having rings of different diameters introduces additional coherent transverse beam-beam resonances. These calculations do apply to PEP-N but, as understood at present, are ameliorated by several features. The first is that the beam-beam coupling in one of the rings (LER) is very small, which strongly reduces the resulting driving force. Second, because of the very high order factors in the coupling, the tune spreads in the beam will strongly damp the resonances. Every bunch in each ring collides with every bunch in the other ring but only after 97 LER turns or 4650 VLER turns. Third, both rings have very strong active transverse bunch-by-bunch feedback systems which would damp any coherent excitation. However, single particle tracking studies in the VLER have shown that, due to the ion gap in the bunch pattern in the LER, resonances occur about every 0.02 in tune in both planes. This fact may cause problems for the VLER as the beam-beam tune shifts are larger than 0.02. The circumnference ratio is about 49 to 1, making these resonances very high order and, thus, quite weak. Further simulationsa are underway.

The shortest beam lifetime for VLER from luminosity related particle loss is calculated for 800 MeV which is the worst case. A 200 minute lifetime is expected.

IV. Interaction Region design

Three majors collision designs were considered:

1) a very large angle collision (> 100 mrads),

2) a small angle collision, similar to KEKB,

3) head-on.

The very large angle collision design would be an interesting accelerator to build but it was considered very risky and had a high probability of not producing the required luminosity as well as introduce perturbations on the LER that might adversely affect B-factory running.

The smaller angle collision (~20 mrad total angle) presents two difficulties. One is that the magnetic elements needed for the VLER would take up most of the small angle acceptance of the detector. This is important since the energy asymmetry in PEP-N is very large over most of the E_{cm} range of interest. The LER energy is held constant at 3.1 GeV while the VLER has an energy range of about 100-800 MeV. The detector angular acceptance in the forward boost direction is 100 mrad along the beam direction. In addition, a crossing angle collision means that the beam must be brought back over the LER beam in order to keep the small storage ring on one side of the LER beam line. This is especially difficult because it has to be done very soon after the collision. There is not much space in the ±10m long interaction region hall to get the beam back to the other side of the LER.

This left the head-on solution as the best choice for the collision. The beams are brought into collision and separated by a large horizontal dipole field located at the interaction point that insures that the VLER stays on the same side of the LER beam line. This same magnetic field serves as the detector field. A sketch of the detector dipole is in Fig. 3.

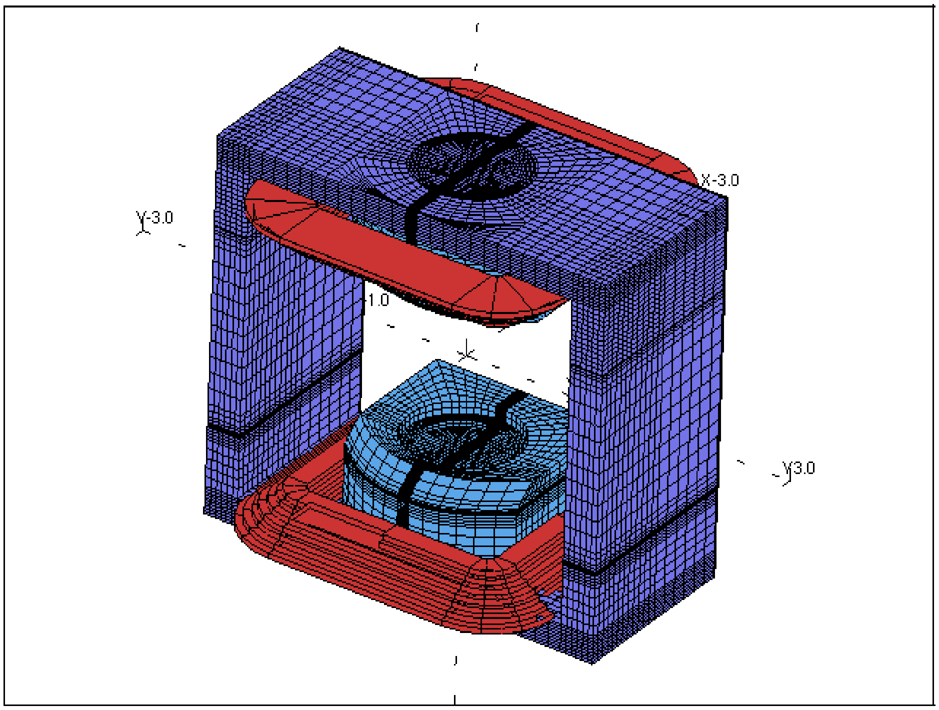

Fig. 3: Detector dipole

The present working design uses a field model that has a maximum field strength of 0.3 T. Fig. 4 is a plot of the field from this magnet along the z axis.

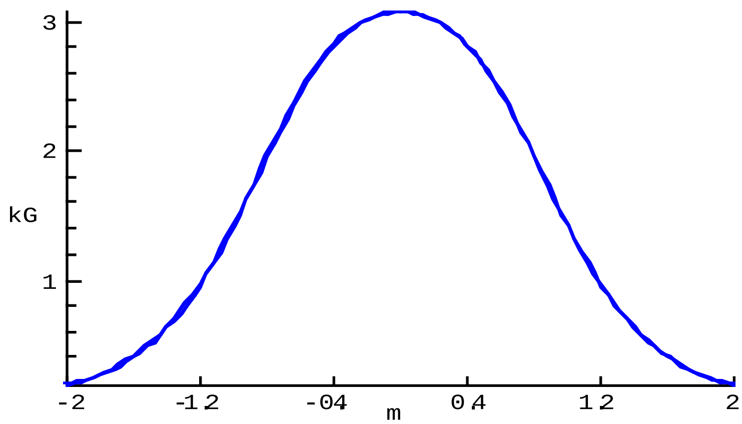

Fig. 4: Plot of the magnetic field from the central dipole magnet. The field extends out to at least 2 m from the center. We will shield the accelerator beam pipes as much as possible to minimize the integrated strength of this magnet.

The IP is located –25 cm from the center of the field. The 0.3 T field corresponds to an accelerator design that has a 557 MeV beam energy for the VLER. Placing the collision point –25 cm from the center of the magnet increases the amount of detector field in the boost direction and minimizes the amount of upstream magnetic field. This lowers the amount of upstream bending (and hence synchrotron radiation) in the LER.

IV.1 Downstream beam lines

The downstream side of the collision point is in the direction of the LER. This is the side where most of the physics particles go. On this side, the VLER is deflected horizontally 192 mrads while the LER is deflected 34 mrads. This results in a separation of 26.7 mm between the two beams at the first parasitic crossing, 0.63 m from the IP, which translates into 38 σ_x for the VLER and 68 σ_x for the LER. This large separation makes any beam-beam effect from the parasitic crossing negligibly small. The beams are separated enough to allow each beam to enter a separate beam pipe about 1.3 m from the IP. The first accelerator element after the central dipole field is a vertically focusing quadrupole (QDI1) for the VLER located 1.5-1.7 m from the IP. QDI1 is constructed from permanent magnet material. The compactness of the permanent magnet design permits this magnet to be 1.5 m from the IP and yet not have any effect on the nearby LER beam. The small design also maximizes the solid angle acceptance of the detector. Following QDI1 is a horizontal bending magnet (B0VL). This magnet starts the reverse bend on the VLER that brings the VLER back parallel to the LER. The next VLER element is a horizontally focusing quadrupole (QFI2) located 2.5-2.8 m from the IP. This magnet is far enough away to no longer interfere with the LER and it has only a minor impact on the detector solid angle.

Following QFI2 is another quad QDI3 from 3.3-3.6 m. A reverse bend horizontal dipole (B1VL) at 3.7-4.1 m straightens out the VLER orbit to be parallel to and 40 cm from the LER followed by one more matching quad (QFI4) at 4.2-4.5 m.

The downstream LER beam line includes 3 horizontal dipole bend magnets to correct the orbit back to the nominal trajectory and to match dispersion.

IV.2 Upstream beam lines

The upstream side of the IP has very similar magnet placement as the downstream side, however the beams are not separated as quickly so the implementation is different. On this side the beam separation at the first parasitic crossing is 22.8 mm which is $32\sigma_x$ for the VLER and $58\sigma_x$ for the LER, still large enough to make parasitic tune shifts negligible. Moving out from the IP we find that the first accelerator element is a horizontal dipole magnet (1-1.3 m) that both beams travel through. This magnet can be used to add or subtract to the central dipole field and is used to maintain the VLER orbit when the VLER energy is changed. The next element is QDI1 (1.5-1.8 m). However, on this side of the IP this large aperture magnet is seen by both beams and is a normal steel magnet. The center of this horizontally defocusing magnet is positioned close to the LER beam minimizing the bend for this beam and maximizing the bend for the VLER. The extra horizontal kick from this magnet separates the beams enough so that the next element (QFI2, 2.5-2.8 m) can be a septum quadrupole with a field-free drift region for the LER. The rest of the magnets in the VLER are essentially the same as the downstream side with the VLER beam parallel to and offset from the LER design trajectory by 40 cm. The LER beam line includes four horizontal dipole magnets to steer the LER back to the nominal orbit and to close dispersion. Figures 5 and 6 are layout pictures of the interaction region.

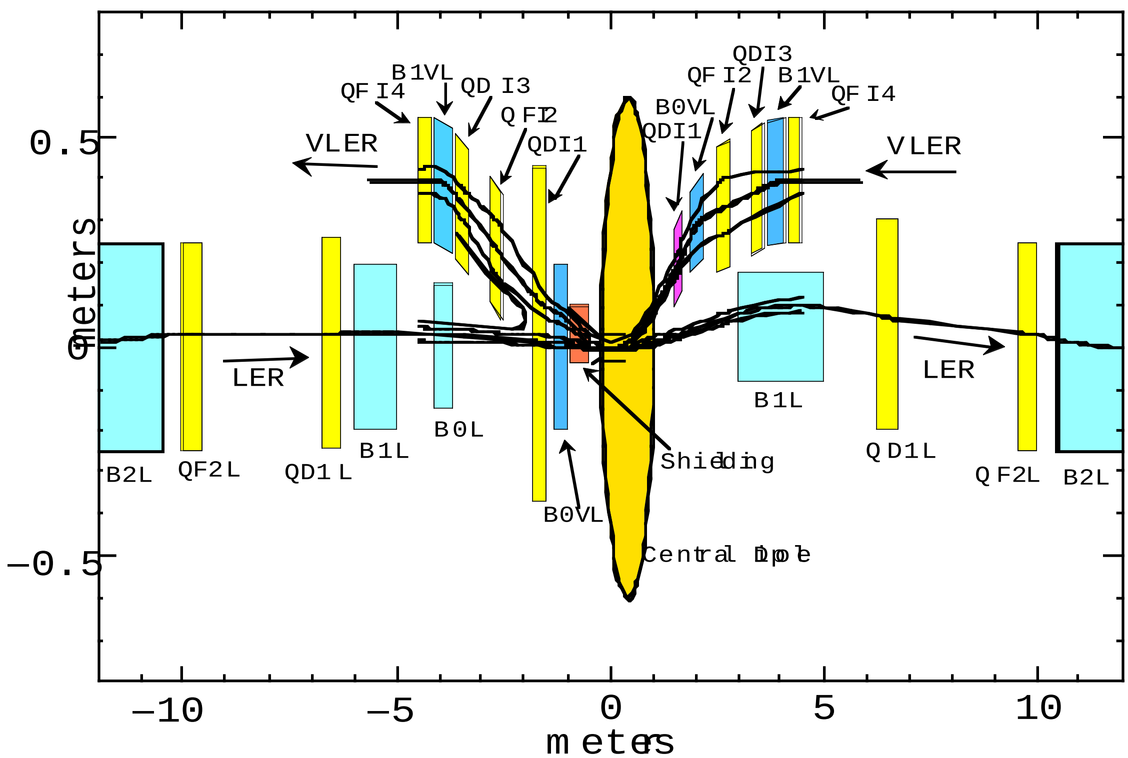

Fig. 5: Layout of the interaction region. Please note the exaggerated left hand scale.

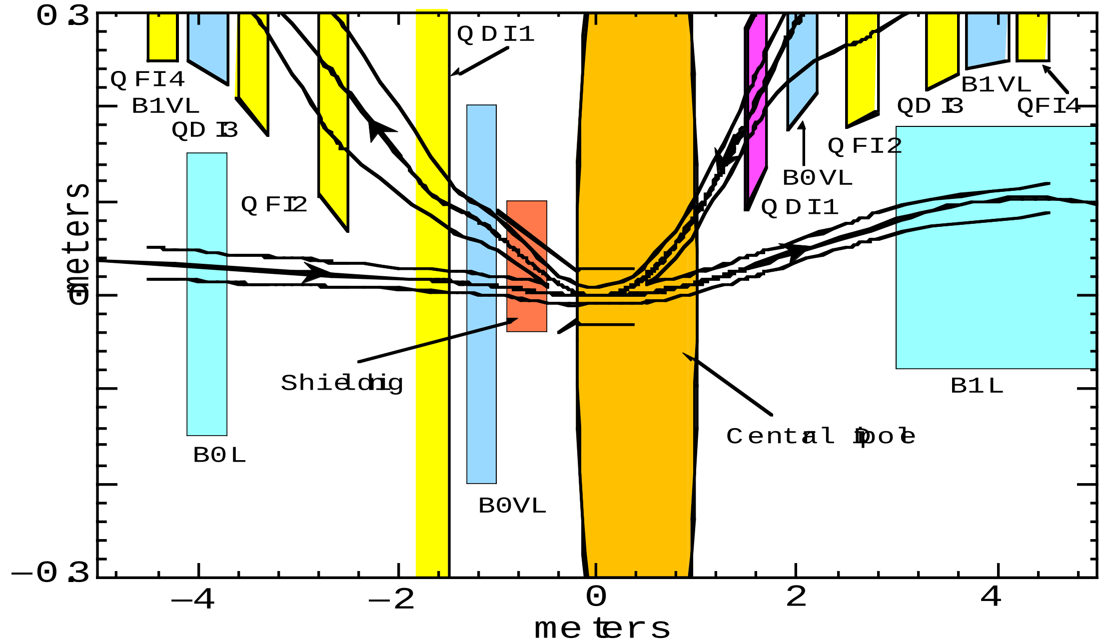

Fig. 6: Close up of the interaction region.

IV.4 Synchrotron radiation

The 780 MeV VLER design has the highest levels of synchrotron radiation. However, the fact that the IP is −25 cm upstream from the center of the main field and that we use the offset QDI1 magnet to further separate the beams means that the upstream LER has relatively weak bending magnets. The main source of synchrotron radiation power comes from the two closest of the four dipole magnets on the LER beam line. The strength of these magnets for the 780 MeV VLER is 2.1 and 2.0 kG and they generate 465 and 1054 W respectively with a 2.14 A LER beam. The critical energies of these bend magnets are 1.36 and 1.3 keV. The power levels are low enough to not pose a problem for beam pipe cooling. More complete studies need to be made, but synchrotron radiation power does not seem to be an issue. Figure 7 shows the fan of radiation coming from these magnets.

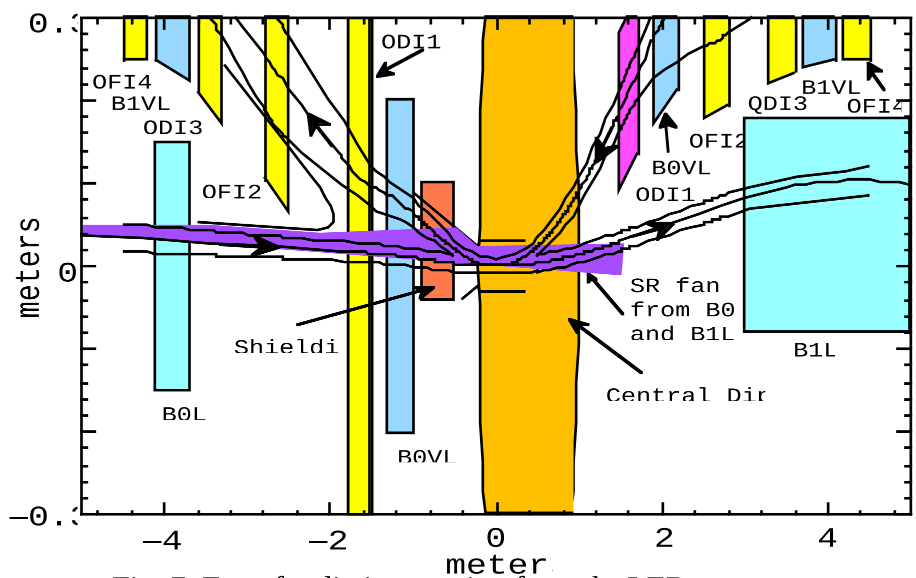

Fig. 7: Fan of radiation coming from the LER magnets.

IV.3 Changing the center-of-mass energy

The LER energy is fixed by PEP-II at 3.1 GeV. In order to change the E_{cm} we must change the energy of the VLER. The interaction region baseline design of PEP-N has a 557 MeV VLER and a 3 kG central dipole field. In order to reach the J/ψ resonance the VLER energy must be increased to 780 MeV. In order to maintain the beam orbits and get the beams to separate properly we proportionally increase the field of the central dipole to 4.2 kG. Decreasing the VLER energy from the 557 MeV deign point is done differently. The detector collaboration prefers a higher central magnetic field while the accelerator designers prefer a lower central field. With this in mind the present design tries to maintain 3 kG as a minimum value for the central field. Therefore, in order to lower the VLER energy and maintain the central field at 0.3 T, passive shielding is added to the beam pipe to subtract some of the central field from the VLER beam. With this technique, we should be able to lower the VLER energy to about 200 MeV.

In order to go still lower in VLER energy, the present strategy would be to rebuild the beam pipes in the interaction region allowing for a much larger angle of separation through the use of the unshielded central field of 3 kG. Once again, we would add passive shielding to the VLER beam pipe as the VLER energy is. We note here that this strategy is still preliminary and further refinements will no doubt be forthcoming.

V. VLER ring

The VLER storage ring has been designed in order to meet the following requirements:

- to operate with an energy variable between 100 and 800 MeV;
- to provide the flexibility to keep the beam emittance constant while varying the energy;
- to collide with LER without perturbing the BaBar operation;
- to fit in the Hall 12 (20 m x 7 m), leaving enough space for the injection line from the Linac;
- to allow for head-on collisions with a minimum impact on the detector;
- to have reasonable lifetimes.

All these requirements are fulfilled by the present baseline design at 500 MeV. The ring circumference was chosen to be a multiple of the LER bunch spacing. However, for lack of space, we could not choose a VLER length that is a sub-multiple of the LER length. As a consequence the e^- bunches will collide with many different e^+ bunches.

V.1 Lattice design

The ring has a two-fold symmetry with a circumference of 45.36 m. This is 36 times the LER by 2 bunch spacing. The beams collide head-on and are brought into and out of collision by the detector magnetic field. The ring layout is sketched in Fig. 8. The dimensions are the actual hall size (20 m x 7.16 m), the yellow circle is the detector field. The main lattice parameters are summarized in Table 3.

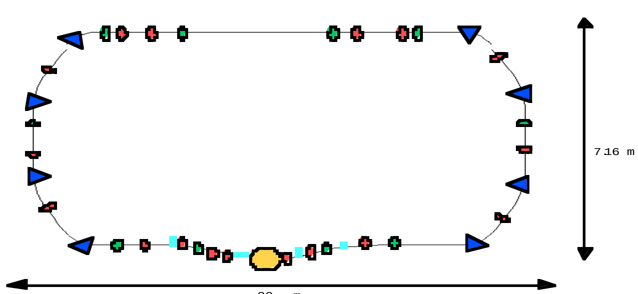

Fig. 8: Ring layout.

Table 3: Ring Lattice Parameters

Parameter	Units	VLER
Energy	MeV	100 - 800
Circumference	m	45.36
Beam current	mA	140.
Harmonic number		72
Revolution frequency	MHz	6.6
Bunch spacing	nsec	4.2
Bunch charge	$x10^9$	.15 - 3.7
IP β_x	m	0.3
IP β_y	m	0.0285
IP η_x	m	0.
Max IR β_x	m	60. - 80.
Max IR β_y	m	100.
Max IR η_x	m	2. - 4.
Betatron tune (ν_x/ν_y)		3.55/3.65
Horizontal emittance ε_x	nm	250
Vertical emittance ε_y	nm	250
IP horizontal beam size σ_x	mm	274.
IP vertical beam size σ_y	mm	84.
Horizontal damping time	ms	1000. - 5.
Coupling factor $\kappa = \varepsilon_y/\varepsilon_x$		1.
Momentum compaction @ 500 MeV, 100kV		.05
Bunch length @ 100 kV	cm	1.2 - 0.7
Synchrotron tune		.011
Relative energy spread	$x10^{-4}$	3.6
Dipole field @ 800 MeV	T	1.635
Energy loss/turn	KeV/turn	.02 - 22.
Max quad gradient @ 800 MeV	T/m	10.

The ring lattice consists of two straight sections and two arcs. In the IR the detector is shifted downstream the collision point by 25 cm in order to increase the detector coverage for boosted particles. The focusing at the IP and along the IR is provided by two QD-QF doublets. The first quadrupole in the doublet is a permanent magnet on the downstream side. This design maximizes the detector solid angle. The first quadrupole on the upstream side is a shared magnet that helps to separate the beams. The IP beta functions were chosen in order to optimize both luminosity and beam-beam tune shifts: $\beta_x^* = 30$ cm, $\beta_y^* = 2.85$ cm. The other straight will house the injection kickers, septum, feedbacks and one RF cavity. In the injection straight there are four QD-QF doublets, which will be used for tune adjustments and for maintaining nearly symmetric optical functions between the two arcs. The horizontal dispersion vanishes at the IP as well as in the RF/injection region. Due to the limited available space, a FODO cell solution as in the LER and HER arcs of PEP-II was not possible. A compact arc design has been chosen which allows for both emittance control with energy and dispersion suppression in the RF and injection straights.

Each arc houses four dipoles, interleaved with 4 quadrupoles**.** The philosophy is to construct eight 1.28 m long dipoles with a peak field of 1.635 T at 800 MeV. Each dipole is segmented into sixteen, 0.08 m long steel pieces, to allow the magnet length to be shortened to increase the field at lower energies. The long magnet coils will not change even though some of the segments are removed. The segments will be removed when going to low energies, in order to keep four symmetrical sub-magnets. This will maintain the curvature of the beam trajectory, therefore the vacuum chamber will not need to be changed. This design increases synchrotron radiation at low energies, shortening the damping times, and allowing for higher beam-beam tune shifts with corresponding higher luminosity. The effect of this design on the damping times, beam current, beam-beam tune shifts and luminosity are clearly visible from the plots in Figs. 9 to 12. The continuous line refers to the normal dipole design while the segmented one refers to the new one.

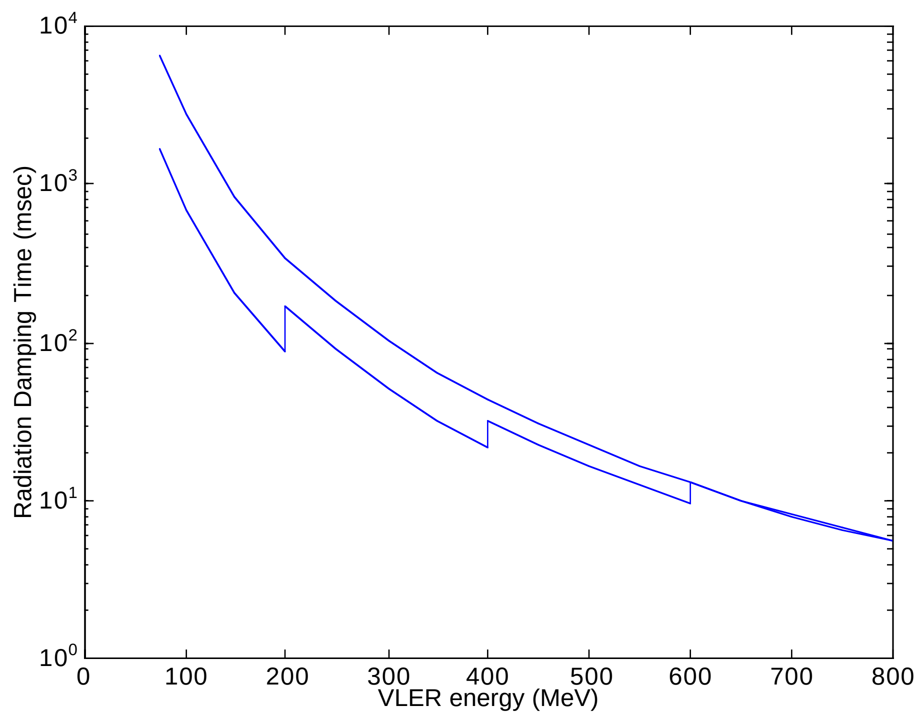

Fig. 9: VLER radiation damping times versus beam energy.

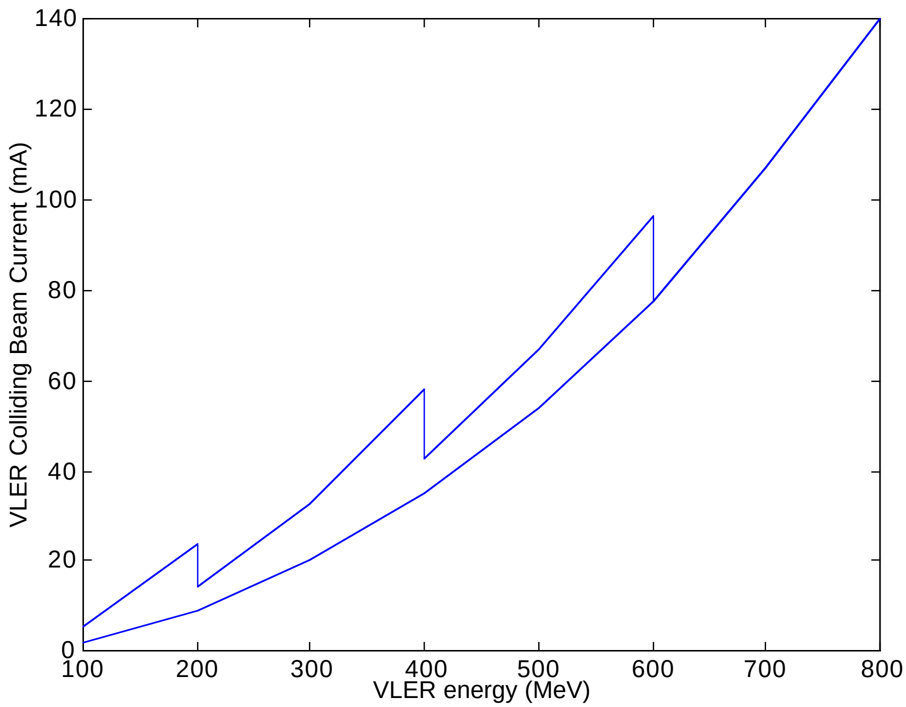

Fig. 10: VLER beam current versus beam energy.

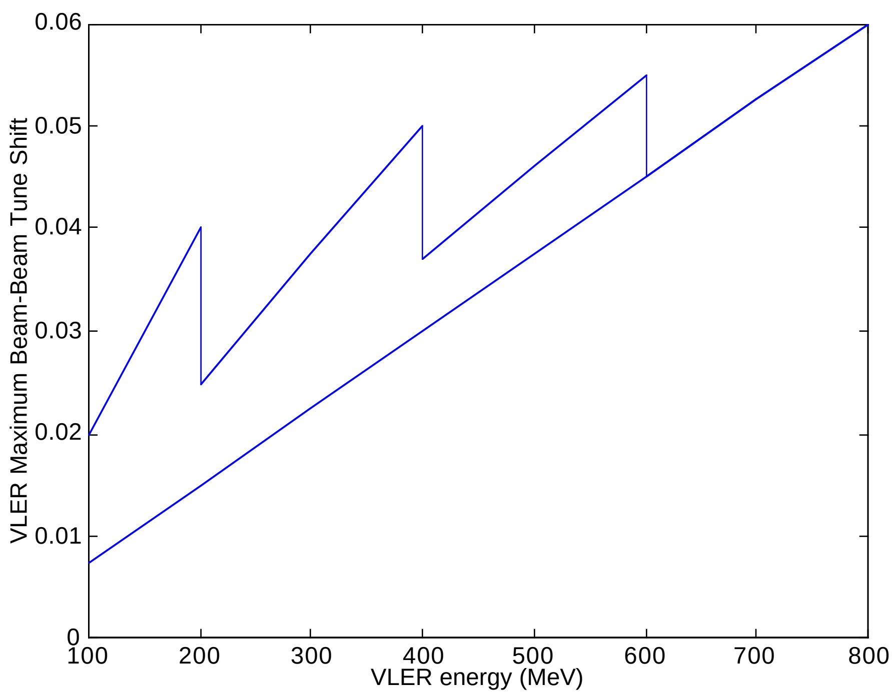

Fig. 11: PEP-N allowed beam-beam tune shift versus VLER energy.

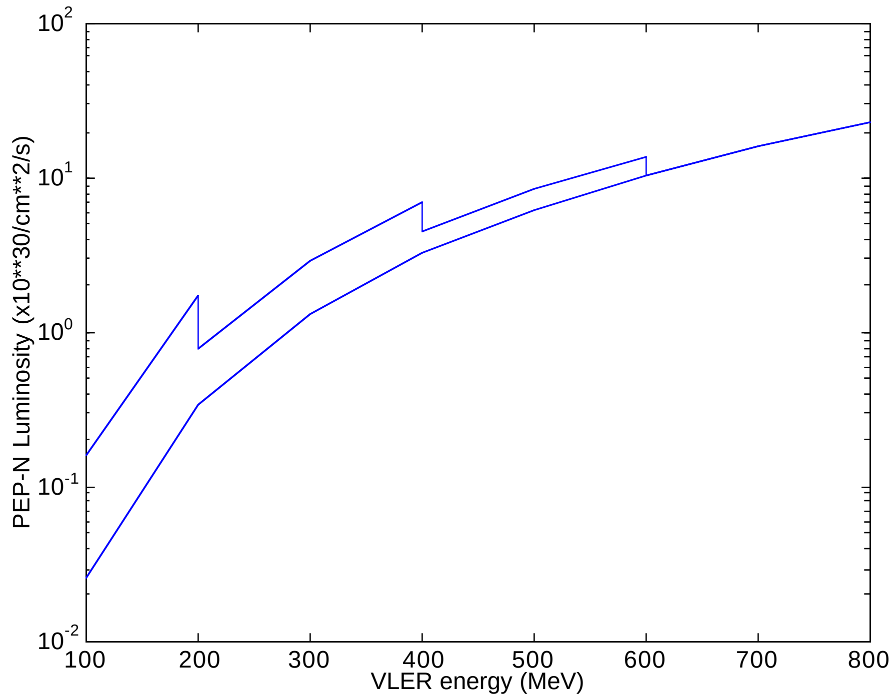

Fig. 12: PEP-N luminosity versus VLER energy

The above calculations do not take into account fringe fields. A sketch of the dipole is shown in Fig. 13 and its parameters are listed in Table 4.

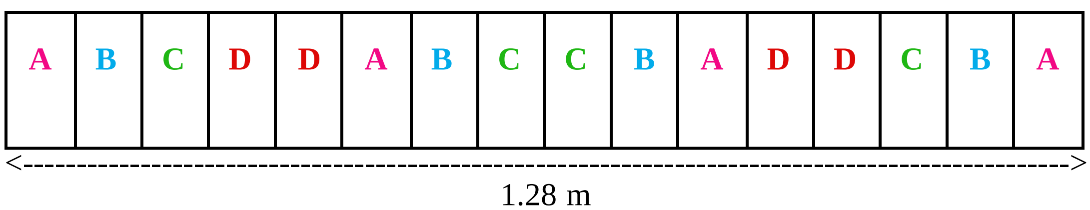

Fig. 13: Segmented dipoles sketch

Table 4: Segmented dipoles parameters

Energy Range (MeV)	**Segments**	**# Ring Magnets**	**θ_{mag} (rad)**	**L_{mag} (m)**	**Peak B (T)**
100 - 250	A	32	0.196	4*0.08	1.635
250 - 500	A + B	32	0.196	4*0.16	1.635
500 - 750	A + B + C	32	0.196	4*0.24	1.635
750 - 1000	A + B + C + D	8	0.785	1.28	1.635

The possibility of installing a 7.5 T, 1 m long super-conducting wiggler in the RF/injection straight will also be studied.

The total number of normal conducting quadrupoles in the ring is 24. They will be individually powered, to allow maximum lattice flexibility. Some extra space is available for closed orbit correctors, emittance-coupling skew quadrupoles and sextupoles. Optical functions are presented in Fig. 14 for the 500 nm, 500 MeV lattice.

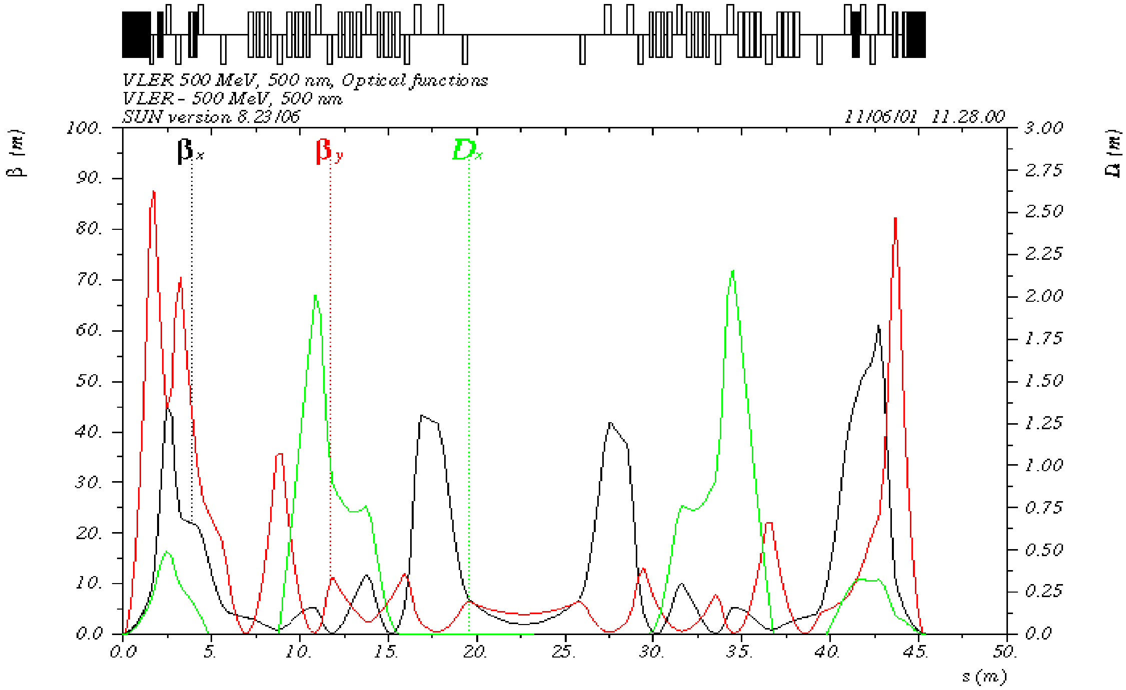

Fig. 14: Optical functions for the 500 MeV lattice (β_x black, β_y red, η_x green).

V.2 Dynamic aperture

Due to the high natural chromaticity and the limited space available for sextupoles the optimization of the dynamic aperture has to be carefully studied. Four families of sextupoles are foreseen: three for chromaticity correction in the arcs, where the betatron functions in the two planes are quite well separated and the dispersion is maximum, and one in the injection straight to correct the beam tune shift with the particle amplitude. Due to space issues the phase shift between sextupoles will probably not be optimized to exactly cancel chromatic and geometric aberrations. The dynamic aperture with a fast tracking program was computed for a previous version of the 500 MeV lattice, with a lower emittance. Particles with initial conditions confined in a region of ($\pm 10\ \sigma_x^*$, $+10\ \sigma_y^*$) at nominal coupling, and for three fixed energy deviations, corresponding to $\Delta p/p$= ($-10\ \sigma_E/E$, 0, $+10\ \sigma_E/E$), were tracked for $3\mathrm{x}10^5$ turns, corresponding to one transverse damping time. Magnet errors and synchrotron oscillations have not been included yet. The results are promising since the stable area was larger than $\pm 10\ \sigma_x$.

V.3 Beam lifetime

In an electron storage ring, the multiple Coulomb scattering of the charged electrons within a bunch leads to the growth of emittance in all three dimensions. The growth rates are proportional to the fourth power of the inverse of beam energy [8]. Hence, at the lower end of the energy range (100 MeV), this effect could become the dominant factor in determining the equilibrium beam size.

To estimate the effect of the intrabeam scattering, the growth rates of emittance in all three dimensions as a function of energy were computed using MAD [9]. The lowest energy design lattice was used in the calculation, as it is the more problematic case for this effect. At all energies, the bunch length was fixed at 1 cm, the horizontal emittance was kept at the constant value of 250 nm, and the vertical emittance was assumed 10% of the horizontal one. The values of the charge per bunch at different energies were interpolated based on the design values. The growth rate turns out to be small compared to the damping rate due to the synchrotron radiation when the energy is larger than 200 MeV, and it increases rapidly once the energy drops below 200 MeV. This result indicates that below 200 MeV it might be an issue to maintain a reasonable beam size and beam lifetime since there is no equilibrium distribution if the growth rate is larger the damping rate. However the larger vertical emittance (50% of the horizontal in the present design), and smaller damping times can help in decreasing the growth rate.

The lifetime of the electron beam due to the Touschek effect was estimated as a function of the VLER energy using the simple formula by Le Duff [10] for flat beams. At all energies, the momentum acceptance is calculated with a fixed RF voltage of 100 kV. The results of calculation are shown in Fig. 15 as a function of the number of particles per bunch.

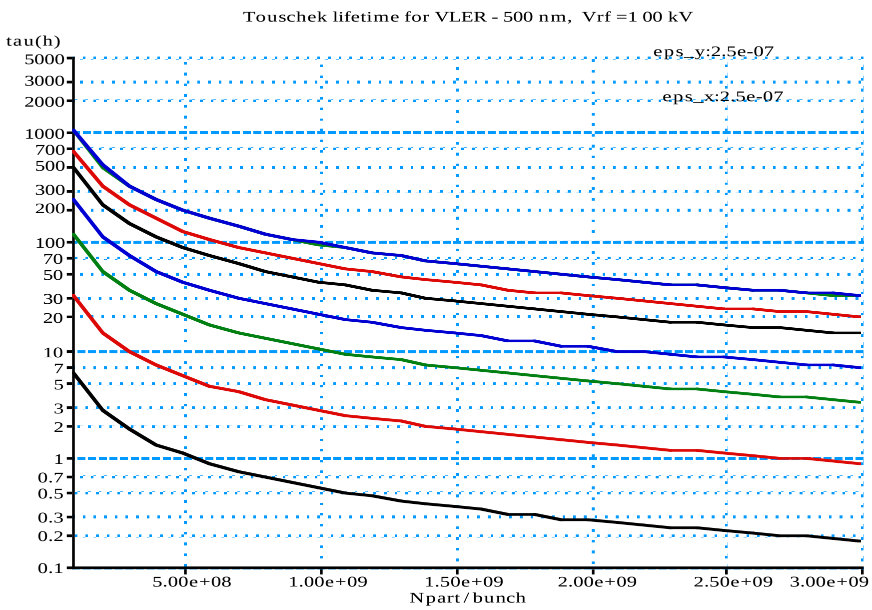

Fig. 15: Touschek Lifetime at different beam energies.

Each curve refers to an energy value, ranging from 100 MeV (the lowest) up to 800 MeV in 100 MeV steps (700 MeV and 800 MeV curves overlap). Given the design charge per bunch at each energy, the shortest beam lifetime is larger than 2 hours for 100 MeV. A tracking of Touschek lost particles, taking into account the dynamic aperture and the real lattice at each energy will also be performed. However even with a 30 min. lifetime at the lowest operating energy, a gain in integrated luminosity could come from the possibility of inject in less than 5 minutes with the detector on, if the injection background rate can be kept low. This is shown in Figure 16 where the ratio between average luminosity and peak luminosity as a function of the Run time in hours (1 h) for three different injection times, 3 min. (upper line), 6 min. (medium line), and 12 min. (lower line), is plotted.

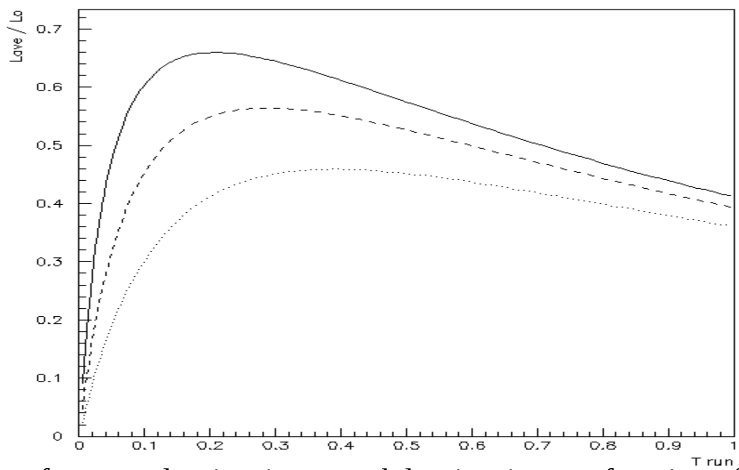

Fig. 16: Ratio of average luminosity to peak luminosity as a function of the run time.

The VLER design presents some special features that will require dedicated studies. For example the lattice design at low (100 MeV) and high (800 MeV) energies, with constant emittance can present difficulties. Chromaticity correction and dynamic aperture have still to be addressed. The Touschek lifetime can be a problem at very low energy, but possible solutions are a longer bunch length, a larger RF momentum acceptance, a fast and efficient injection. The long damping times at lower energies are an issue, but segmented dipoles and a wiggler will help.

VI. RF System

The RF system for the VLER is much simpler than that of PEP-II. Only a single cavity is needed to provide the required RF voltage of about 100-150 kV for a beam energy of 500-800 MeV. A prototype RF cavity was built for PEP-II several years ago. This cavity operated successfully at full PEP-II parameters and produced 800 kV. With the addition of HOM dampers this cavity is ready for PEP-N. At full beam energy, the power the RF system needs to deliver to the beam is 3.0 kW with a voltage of 100 kV. At 100 kV the RF power going into the cavity wall is 1.32 kW and the reflected power is 0.68 kW. Thus, the total power needed is about 5.0 kW. PEP-II klystrons deliver 1.2 MW. So a much smaller power source is sufficient. A voltage of 100 kV is sufficient to deliver the required bunch lengths of about 0.8 to 1.3 cm.

VII. Vacuum System

The vacuum system is relatively simple as the synchrotron radiation power is low. The vacuum system for the PEP-N VLER must provide for a good beam lifetime, have a low beam impedance, and dissipate synchrotron radiation power. This system must be as reliable as the PEP-II system as the two systems are connected.

The vacuum system will likely be aluminum cylindrical chambers with stainless-steel ConFlat flanges. The diameter in the quadrupoles and drift sections will be 3.5 inches or 90 mm. This provides for a beam-stay-clear of over 10 sigma. This size is the same as the PEP-II straight section chambers allowing many common components. For example, VLER can use the straight section bellows modules as-is. The chambers in the dipole magnets will be flattened to 70 mm x 100 mm to match the aperture.

The synchrotron radiation power is about 3000 W. Thus, each dipole produces about

375 W. This power is distributed over about 1 m of chamber or about 4 W per cm. At this power level only modest water cooling is needed.

There will be six sputter ion pumps to hold the vacuum pressure when PEP-N is not running. The dipole magnets will have distributed ion pumps (DIP) used during operation. There are sufficient spare DIP units from PEP-II HER construction to build the eight units needed for PEP-N. The position monitor buttons are the same.

The injection and transverse feedback systems need ceramic chambers. The PEP-II ceramic chamber design works for VLER except shorter units are needed. The ceramics will have an internal metal coating as in PEP-II.

VIII. Injection System

A new 800 MeV linac would inject bunches of 3.6×10^9 electrons into every second ring RF bucket spaced 4.2 ns apart, as in PEP-II. The linac would be mounted on the accelerator floor of IR12 wrapped on itself to form four 12 m “girders”. Injection could be at 120 Hz if needed but 1 Hz is planned. At 1 Hz, the injection time is 36 seconds.

The injection system for the VLER is an 800 MeV linear accelerator combined with a pulsed thermionic gun. The electrons are emitted from a gun and accelerated in four 12 m section accelerators that exist at SLAC. Each four-section accelerator is powered by a klystron and modulator removed from the linac in Sector 20. Each section is SLEDed to produce 250 MeV of acceleration as is routine in the SLAC linac. The linac is mounted on the accelerator floor of the IR12 hall inside the radiation shielding. There is one 180 degree bend in the linac. The beam is injected into the ring using a transient orbit bump in the ring with three pulsed dipoles. The injected beam enters through a DC septum. A sketch of the injection section in VLER is presented in Fig.17.

This injector needs to produce up to 3.6×10^9 electrons per pulse in a single bunch. The gun and accelerator can easily produce ten times the charge per bunch and accelerate several such bunches simultaneously, if needed. The linac pulse rate will be 1 Hz to save costs on the power source and radiation shielding. The klystron and accelerator sections could be operated up to 120 Hz if needed.

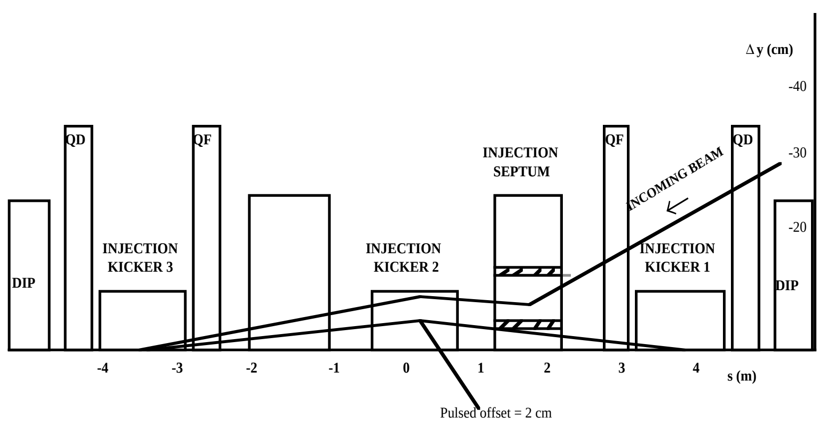

Fig. 17: Injection straight section in VLER with a pulsed orbit bump

IX. LER modifications

The LER ring would have to be slightly modified for this collider. The present LER quadrupole at the location of the collision point would be moved and reinstalled about 6.3

m upstream. A new symmetrical quadrupole will be added 6.3 m downstream. Three dipoles downstream and four upstream are foreseen to adjust the positron trajectory at the IP and correct the horizontal dispersion.

The IP beta functions in the LER are about a meter rather than about centimeters in traditional colliders. Thus, the chromaticity in the LER should not change very much and the present LER sextupoles are sufficient. The beam-beam tune shifts for the LER from PEP-N will be very low, about 0.004, which should not affect PEP-II operations.

X. Schedule and costs

The intent is to install the PEP-N accelerator and the detector in summer down times which are about two to three months per year. Approximately, two to three down times are needed.

PEP-N will operate in a “parasitic mode” for about 9 months per year. If the average peak luminosity over different energies is about 3 x $10^{30}/cm^2/s$ over the year and the ratio of average to peak luminosity over long times including down times is about 0.5, then an integrated luminosity of about 35 pb^{-1} is expected each year.

Historically, PEP-II was installed in a similar fashion with the HER being installed first and the LER second. These accelerators were installed with an average of about 5 m of HER beamline installed per working day and 10 m of LER installed per day. To install VLER in a single nine week down, less than a meter of accelerator beamline need to be installed per day.

A rough schedule is shown in Table 5. The first summer installation will include the injector, VLER support floor, VLER cables, and modifications to the LER and HER rings. The second summer down concentrates on the installation of the VLER ring, the interaction region magnet, and the physics detector.

Table 5: Approximate PEP-N Schedule

Spring 2002	PEP-N proposal approved
Summer 2002	Injector gun, linac and transport lines installed VLER support floor installed VLER cables installed LER modifications HER modifications
October 2002	First injector beam tests
Summer 2003	VLER ring installed Detector magnet installed Detector installed
October 2003	First VLER injected beam tests
January 2004	First collisions

A cost estimate for PEP-N is shown in Table 6. The estimates are divided into categories for the modifications of LER, VLER ring, injector and transport system, utilities, controls, and modifications of HER.

The sources for cost estimates are PEP-II actual construction costs including inflation, discussions with local experts on various subsystems, recent costs of Accelerator

Improvement Projects at SLAC, SLAC shop rates, and recent purchases of industrial components.

For each sub-component there is an estimate for all sub-parts. For example, a dipole magnet has costs for magnet construction, supports, cabling, and power supplies. Where accelerator components already exist, costs for refurbishing are included.

As most all components are already designed and many built, the engineering, design, and layout costs concentrate on manufacturing and installation. Many of the individual costs already include the engineering and design effort.

Given the increased peak energy of the ring and linac from 500MeV to 800 MeV, the expected costs increased from 9.9 M$ last year to about 15.5 M$ this year.

Table 6: PEP-N cost estimate

Component	**Status**	**Items**	**Cost per item**	**Total Cost (k$)**
LER costs:				
IP orbit dipole (correction)	Existing dipole magnets	4	1	4
IP Orbit dipole supports		4	5	20
IP Orbit dipole cables		2	3	6
IP Orbit dipole power supplies		2	15	30
Move ring quadrupole		1	15	15
Additional ring quadrupole		1	15	15
Additional ring quad power supplies		2	15	30
Additional ring quad power cables		2	3	6
Additional low pressure vacuum cham.		20 m	2.5	50
VLER Costs:				
Dipole main ring		8	40	320
Dipole main ring supports		8	8	100
Dipole main ring cables		1	20	20
Dipole main ring power supply		1	100	100
Quadrupole main ring	Die and some laminations exist	20	20	400
Quadrupole main ring supports		20	5	100
Quadrupole main ring cables		10	6	60
Quadrupole main ring power supplies		10	24	240
Permanent magnet quadrupoles		2	50	100
Permanent magnet quad support		2	7	14
Sextupole	Some laminations exist	8	15	120
Sextupole supports		8	5	40
Sextupole cables		4	5	20
Sextupole power supply		4	20	80
Dipole corrector magnets	Ycors exist, Xcors backlegs	16	0	0
Dipole corrector supports		8	1	8
Dipole corrector cables		16	1	16
Dipole corrector power supplies		16	1.2	20

Skew quadrupole		2	10	20
Skew quadrupole supports		2	5	10
Skew quadrupole cables		2	3	6
Skew quadrupole power supply		2	10	20
RF cavity	Existing PEP-II prototype	1	80	80
RF cavity support		1	10	10
RF power driver 2000 W		1	100	100
RF controls		1	200	200
RF phase control		1	10	10
RF temp control		1	40	40
Position monitors	Use existing PEP-II design	18	5	90
Vacuum system		45 m	10	450
Vacuum controls		1	150	150
Tune monitor		1	35	35
Synchrotron light monitor		1	60	60
Current monitor		1	40	40
Longitudinal feedback system		1	350	350
Transverse feedback system		1	250	250
Installation		1	600	600
Alignment		1	150	150
Magnets interlocks		1	150	150
Injector linac and transport:				
Gun and pulser		1	250	250
Clean accelerating structures	3-m structures exist	16	5	80
Accelerator supports		16	5	80
Relocate accelerator waveguide	Waveguides exist	16	5	80
Accelerator waveguide H_2O plumbing		16	5	80
Dipoles (DR style)	Design exist	12	10	120
Dipole supports		12	5	60
Dipole cables		2	5	10
Dipole power supply		2	20	40
Quadrupoles	Linac quads A and B exist	32	1	32
Quadrupole supports		32	2	64
Quadrupole power supplies		32	4	128
Quadrupole cables		32	1	32
Dipole correctors	Linac dipole corrs exist	32	1	32
Dipole corrector supports		32	2	64
Dipole corrector power supplies		32	2	64
Dipole corrector cables		32	2	64
Position monitors		20	4	80
Current toroid	Exist	2	10	20
Profile monitor	Exist	2	10	20
Vacuum system		20 m	5	100
Vacuum controls		1	50	50
Relocate klystron	Exists from linac sector 20	4	20	80
Relocate klystron modulator	Exists from linac sector 20	4	20	80

Relocate klystron controls		4	20	80
Klystron power supply		4	20	80
Septum		1	50	50
Kicker		3	40	120
Kicker pulser		1	50	50
Kicker cable		1	10	10
Kicker ceramics		3	15	15
Linac installation		1	500	500
Linac alignment		1	100	100
Building and Utilities:				
VLER floor		1	250	250
Water heater for linac 112 deg		1	100	100
Holes in shield wall		3	10	30
Extra radiation shielding		1	100	100
AC power installation		1	100	100
Water distribution system		1	100	100
Accelerator Controls:				
Micro-computer	Use existing PR12	1	3	3
CAMAC crates		3	7	21
PPS interlocks		1	150	150
Control-power supply racks (dou. bay)		5	12	60
Software database work		1	150	150
HER costs:				
Steering correctors	Ring correctors exist	2	0	0
Steering corrector power supplies		2	1	2
Steering corrector cables		2	1	2
Move HER quadrupole		1	10	10
Additional HER quadrupole		1	15	15
New HER quadrupole power supplies		2	25	50
New HER quad power supplies cables		2	4	8
New HER vacuum chamber		1	10	10
Engineering and Design costs:				
Engineer		3 yr	90	270
Designer		5 yr	75	375
Drafter		5 yr	70	350
Project itemized total (k$)				**9,666**
Project contingency (30%) (k$)				**2,900**
Project indirects (30%) (k$)				**2,900**
Total project (k$)				**15,466**

XI. References

[1] “PEP-II Conceptual Design Report”, SLAC–418, June 1993.
[2] J. Seeman *et al*, “PEP-II Performance”, EPAC 2000, Vienna, June 2000.
[3] “PEP-N Letter of Intent,” PEP-II AP Note: 2000.05, Sept. 2000.
[4] M. E. Biagini, *et.al*., "A Low-Energy Ring Lattice Design for the PEP-N Project", Proc. PAC2001.
[5] M. Sullivan *et al*, “PEP-N Interaction Region,” Proc. PAC2001.
[6] K. Hirata and E. Keil, “Coherent Beam-Beam Interaction Limit in Asymmetric Ring Colliders”, Physics Letters B, Vol. 232, N. 3, p. 413, December 1989.
[7] K. Hirata and E. Keil, “Barycentre Motion of Beams due to Beam-Beam Interaction in Asymmetric ring Colliders”, NIM A292 (1990) 156-168.
[8] A. Piwinsky, “Intrabeam scattering”. Proc.CAS CERN 87-03.
[9] H. Grote, F. Ch. Iselin, CERN/SI/90-13(AP).
[10]J. Le Duff, “Single and multiple Touschek effect”, Proc.CAS CERN 89-01.