# PEP-N: A 0.8 GeV × 3.1 GeV Collider at SLAC

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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 $2 \times 10^{31}$ cm$^2$/s.

## 1. PEP-N COLLIDER

We discuss the parameters for an "$e^+e^- \rightarrow N\overline{N}$ 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 Figure 1.

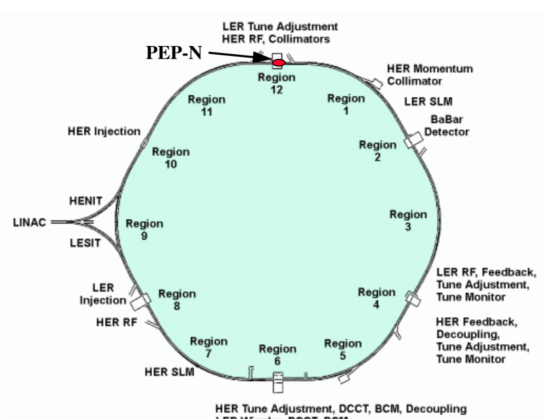


Figure 1: PEP-II Layout with PEP-N location in IR12.

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.

A new 800 MeV linac would inject bunches of $3.6 \times 10^9$ 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 VLER circumference is about 45.3 m. The collision point is located in the center of the IR12 straight, but could be displaced a meter if the detector needs additional longitudinal space. A large bore dipole at the IP is used to separate the beams in the two rings and for detector momentum analysis. The vacuum system is relatively simple as the synchrotron radiation power is low.

The RF system is a single cavity (which exists as the prototype cavity for PEP-II). The VLER has two straights: one for the IP and one injection-RF-feedback straight.

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 would be added 6.3 m downstream. The IP beta functions in the LER are about a meter rather than about centimeters in traditional colliders. Thus, the chromaticity in the LER will 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. PEP-N will operate in a "parasitic mode" for about 9 months per year. If the average peak luminosity over different energies is about $3 \times 10^{30}$ 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.

Table I PEP-N Parameters

| Parameter | LER $e^+$ | VLER $e^-$ |
|---|---|---|
| Beam energy (GeV) | 3.1 | 0.8 |
| Circumference (m) | 2200 | 45.36 |
| Number of bunches | 1658 | 36 |
| Total current (mA) | 2140 | 140 |
| Current per bunch (mA) | 1.3 | 3.9 |
| Bunch spacing (m) | 1.26 | 1.26 |
| Bunch length (mm) | 11.0 | 10.0 |
| $\Delta E$/turn (KeV) | 700 | 22 |
| RF frequency (MHz) | 476. | 476. |
| Ion clearing gap (%) | 5 | 0 |
| RF voltage (MV) | 4.8 | 0.1 |
| Rel. energy spread ($10^{-3}$) | 0.61 | 0.36 |
| Synchrotron tune | 0.045 | 0.011 |
| Emittance ($x$) | 50 | 250 |
| Betatron tune ($\nu x/\nu y$) | 24.62/23.58 | 3.55/3.65 |

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.

## 2. PEP-N 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 $2 \times 2 \times 3 \times 3 \times 97$. 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

Table II PEP-N Collision Parameters

| IR Parameter | Design |
|---|---|
| C-M energy (GeV) | 1.0–3.1 |
| Crossing angle (mrad) | 0.0 |
| Luminosity ($\times 10^{30}$ at 800 MeV) | 20 |
| Number of bunches | 36 |
| VLER current (mA) | 140 |
| LER current (mA) | 2146 |
| Beam–beam parameter ($y+/-$) | 0.004/0.06 |
| Beam–beam parameter ($x+/-$) | 0.004/0.06 |
| $\beta y*/\beta x*$ (cm/cm) VLER | 3/30 |
| $\beta y*/\beta x*$ (cm/cm) LER | 44/151 |
| Optimum coupling (%) VLER | 100% |
| IP rms beam $\sigma y/\sigma x(\mu m)$ VLER | 85/274 |
| IP rms beam $\sigma y/\sigma x(\mu m)$ LER | 26/272 |
| $\Sigma x$, $y$ (microns) | 88/386 |
| Detector dipole field ($T$) | 0.15 |
| Detector dipole integrated field ($T-m$) | 0.3 |

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 II 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.

Early in the days of B-Factory design, Keil and Hirata discovered [6,7] that having rings of different diameters introduces additional 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 is very small, LER, 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.

The shortest beam lifetime for VLER from luminosity related particle loss is calculated for 500 MeV which is the worst case. A 300 minute lifetime is expected.

## 3. PEP-N 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

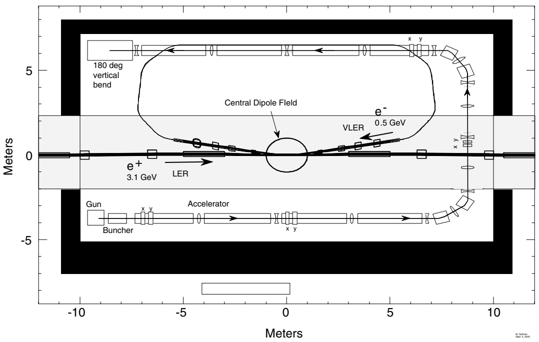


Figure 2: PEP-N layout in IR12 of PEP-II.

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.

## 4. PEP-N VACUUM SYSTEM

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 × 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.

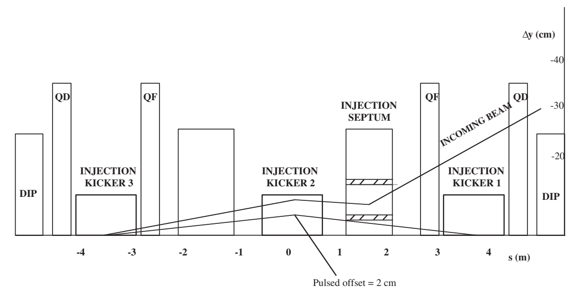


Figure 3: Injection straight section in VLER with a pulsed orbit bump

## 5. PEP-N INJECTION

The injection system for the VLER is an 800 MeV linear accelerator combined with a pulsed thermionic gun. A layout of the injection system is shown in Figure 2. The injection straight section in VLER is shown in Figure 3. 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.

This injector needs to produce up to 3.6 × 109 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.

## REFERENCES

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