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Letter of Intent

PEP-N: a 0.5 x 3.1 GeV e^+e^- Collider

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Abstract:

We propose to build a new low energy electron storage ring to be collided with the existing 3.1 GeV Low Energy Ring (LER) of PEP-II in the IR12 straight section. The energy range of the electron ring is 150 to 500 MeV with primary operation at 300 MeV resulting in a center of mass energy range of 1.5 to 2.5 GeV. The expected luminosity at 500 MeV is about 10^{31} $cm^{-2}s^{-1}$. This two ring collider is called PEP-N. PEP-N is to be operated simultaneously with the PEP-II collider and is designed to not interfere with the peak luminosity operation of PEP-II for BaBar data collection.

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Section 1 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 0.15 to 0.5 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 about 35 m and is located in straight section IR12 of PEP-II. The electrons are injected from a 24 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} $cm^{-2}s^{-1}$ at a VLER energy of 500 MeV without affecting BaBar data collection. The location of PEP-N is shown in Figure 1-1.

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 new 500 MeV linac would inject bunches of $2.2x10^9$ electrons into every second ring RF bucket spaced 4.2 ns apart, as in PEP-II. A 5% gap is left empty to help with ions. The linac would be mounted on the floor of IR12 wrapped on itself to form two 12 m “girders”. Injection could be at 120 Hz if needed but 1 Hz is planned. At 1 Hz, the injection time is 26 seconds.

The VLER circumference is about 35.3 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. The IP dipole will be an unused magnet at CERN modified for PEP-N. The dipole 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 relatively low. The RF system is a single cavity (which exists as the prototype cavity for PEP-II). The electron ring has a symmetry of two with a collision straight and an RF-injection-feedback straight.

The LER ring would have to be slightly modified for this collider. The present LER quadrupole at the collision point would be moved and reinstalled about 15 m upstream. A new symmetrical quadrupole would be added 15 m downstream. The IP beta functions in the LER are several to many meters which are larger than those 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.

PEP-N is to be operated when PEP-II is running for BaBar. Thus, 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^{-1} over a 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.

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

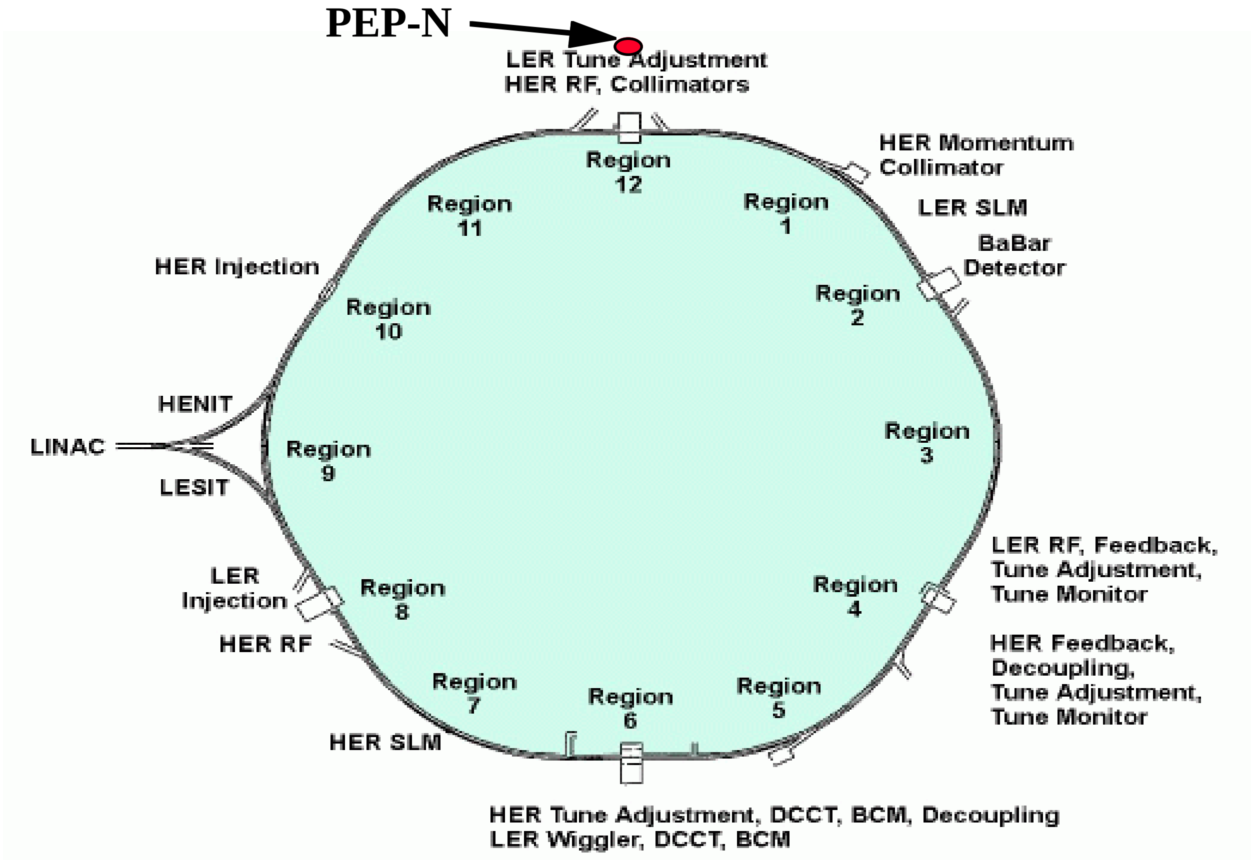

Fig. 1-1: PEP-II Layout with PEP-N location in IR12.

Section 2 List of Accelerator Parameters

The accelerator parameters for the two ring asymmetric collider PEP-N for the Very Low Energy Ring VLER (electrons) and the Low Energy Ring LER (positrons) are listed in Table 2-1 for the VLER energy of 300 MeV and in Table 2-2 for the VLER energy of 500 MeV.

The PEP-N parameters are based on the condition that PEP-N running is completely transparent to PEP-II operation, which implies educated choices for the beam-beam parameters of the two rings. These choices are illustrated in detail in Section 3.

Table 2-1 PEP-N PARAMETERS at 0.3 GeV

VLER : 0.3 GeV e^- Low / High Emittance

Parameter		Units	LER	VLER	
Energy | particle	E	GeV	3.119 | e^+	0.300 | e^-	
CM Energy	E_{CM}	GeV	1.935	1.935	
CM velocity	β_{CM}		0.825	0.825	
Lorentz factor	γ		6104	587	
Transverse emittance	$\varepsilon_x \mid \varepsilon_y$	π nm·rad	49.2 | 1.5	180 | 115	360 | 230
Coupling factor	κ		0.03	0.64	0.64
Momentum compaction	α_c		1.2×10^{-3}	9.3×10^{-2}	9.1×10^{-2}
Partition numbers	$J_x \mid J_s$		0.98 | 2.02	0.55 | 2.45	0.56 | 2.44
Damping times	$\tau_x \mid \tau_y \mid \tau_s$	ms	62 | 60 | 30	227 | 125 | 51	222 | 125 | 51
Natural chromaticity	$\nu'_{xo} \mid \nu'_{yo}$		−60 | − 70	−10 | − 16	−13 | − 19
Circumference		m	2199.330	35.270	
Revolution frequency | time	$f_{rev} \mid T_{rev}$	MHz | μs	0.1363 | 7.336	8.500 | 0.118	
Number of arc dipoles			192	8	
Arc dipoles field		T	0.681	0.823	
IP dipole strength		T m	0.360	0.360	
Arc dipoles bend angle | radius		mrad | m	32.7 | 15.279	740.4 | 1.216	
IP dipole bend angle | radius		mrad | m	34.6 | 57.792	359.9 | 5.560	
Betatron tunes	$\nu_x \mid \nu_y$		38.57 | 36.64	2.55 | 1.51	2.97 | 0.09
Max β-functions (arcs)	$\hat{\beta}_x \mid \hat{\beta}_y$	m	40.0 | 100.3	26.0 | 19.0	31.0 | 30.0
Max dispersion (arcs)	$\hat{\eta}_x \mid \hat{\eta}_y$	m	1.1 | 0.0	2.0 | 0.0	2.0 | 0.0
S.R. energy loss in IP dipole		keV	0.80	0.01	
S.R. energy loss per turn	U_o	keV	761.0 $^{1)}$	0.6	
RF frequency	f_{RF}	MHz	475.99903	475.99903	
RF wavelength	λ_{RF}	m | ns	0.630 | 2.1	0.630 | 2.1	
Harmonic number	h		3492	56	
Number of RF cavities	N_C		6	1	
Number of RF drivers	N_{Kly}		3	1	
Total RF voltage	V_{RF}	MV	5.1	0.10	
Relative energy spread	δ_E		7.7×10^{-4}	2.1×10^{-4}	
Energy spread	σ_E	MeV	2.40	0.06	
Natural bunch length	σ_{so}	mm | ps	11.0 | 36.7	0.62 | 20.7	
Synchrotron tune	ν_s		0.025	0.014	
IP beta functions	$\beta_x^* \mid \beta_y^*$	m	8.00 | 1.75	0.37 | 0.03	
IP dispersion	$\eta_x^* \mid \eta_y^*$	m	0.0	0.0 | 0.0	
IP rms beam sizes	$\sigma_{xo}^* \mid \sigma_{yo}^*$	μm	627.4 | 51.2	258.1 | 58.7	365.0 | 83.1
IP convoluted beam sizes	$\Sigma_{xo} \mid \Sigma_{yo}$	μm		678.4 | 77.9	725.8 | 97.6
IP beta ratio	r_β		0.22	0.08	
IP aspect ratio	r		0.08	0.22	
Bunch spacing	$s_b = 2\lambda_{RF}$	m | ns	1.26 | 4.2	1.26 | 4.2	
Filled | Colliding bunches	K_b		1658 | 26	26 | 26	
Crossing angle	θ_{IP}	mrad	0.0	0.0	
Bunch population	$N_b^\pm$		6.05×10^{10}	5.66×10^{8}	1.13×10^{9}
Bunch current	$I_b^\pm$	mA	1.32	0.77	1.54
Beam current	$I^\pm$	mA	2190.7	20.0	40.0
S.R. power from IP dipole		kW	1.75	2.0×10^{-4}	4.0×10^{-4}
S.R. power (total)	P_{SR}	kW	1667	1.2×10^{-2}	2.4×10^{-2}
Beam-beam parameters	$\xi_x \mid \xi_y$		0.004 | 0.004	0.04 | 0.04	
Specific Luminosity	$\mathcal{L}_s$	$cm^{-2}s^{-1}mA^{-2}$		0.87×10^{29}	0.64×10^{29}
Peak luminosity	$\mathcal{L}$	$cm^{-2}s^{-1}$		2.3×10^{30}	3.4×10^{30}

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Table 2-2 PEP-N PARAMETERS at 0.5 GeV

VLER : 0.5 GeV $\mathbf{e}^-$ Low / High Emittance

Parameter		Units	LER	VLER	
Energy | particle	E	GeV	3.119 | $\mathbf{e}^+$	0.500 | $\mathbf{e}^-$	
CM Energy	E_{CM}	GeV	2.498	2.498	
CM velocity	β_{CM}		0.724	0.724	
Lorentz factor	γ		6104	979	
Transverse emittance	$\varepsilon_x \mid \varepsilon_y$	π nm·rad	49.2 | 1.5	180 | 100	360 | 200
Coupling factor	κ		0.03	0.55	0.55
Momentum compaction	α_c		1.2×10^{-3}	7.2×10^{-2}	8.5×10^{-2}
Partition numbers	$J_x \mid J_s$		0.98 | 2.02	0.66 | 2.34	0.59 | 2.41
Damping times	$\tau_x \mid \tau_y \mid \tau_s$	ms	62 | 60 | 30	41 | 27 | 12	45 | 27 | 11
Natural chromaticity	$\nu'_{xo} \mid \nu'_{yo}$		$-60 \mid -70$	$-10 \mid -17$	$-10 \mid -16$
Circumference		m	2199.330	35.270	
Revolution frequency | time	$f_{rev} \mid T_{rev}$	MHz | μs	0.1363 | 7.336	8.500 | 0.118	
Number of arc dipoles			192	8	
Arc dipoles field		T	0.681	1.372	
IP dipole strength		T m	0.600	0.600	
Arc dipoles bend angle | radius		mrad | m	32.7 | 15.279	740.4 | 1.216	
IP dipole bend angle | radius		mrad | m	57.7 | 34.675	359.8 | 5.560	
Betatron tunes	$\nu_x \mid \nu_y$		38.57 | 36.64	2.7 | 1.3	2.6 | 1.05
Max β-functions (arcs)	$\hat{\beta}_x \mid \hat{\beta}_y$	m	40.0 | 100.3	18.0 | 20.0	18.0 | 17.0
Max dispersion (arcs)	$\hat{\eta}_x \mid \hat{\eta}_y$	m	1.1 | 0.0	1.3 | 0.0	1.7 | 0.0
S.R. energy loss in IP dipole		keV	2.22	0.06	
S.R. energy loss per turn	U_o	keV	762.2 [1)]	4.3	
RF frequency	f_{RF}	MHz	475.99903	475.99903	
RF wavelength	λ_{RF}	m | ns	0.630 | 2.1	0.630 | 2.1	
Harmonic number	h		3492	56	
Number of RF cavities	N_C		6	1	
Number of RF drivers	N_{Kly}		3	1	
Total RF voltage	V_{RF}	MV	5.1	0.10	
Relative energy spread	δ_E		7.7×10^{-4}	3.5×10^{-4}	
Energy spread	σ_E	MeV	2.40	0.18	
Natural bunch length	σ_{so}	mm | ps	11.0 | 36.7	12.0 | 40.0	
Synchrotron tune	ν_s		0.025	0.012	
IP beta functions	$\beta_x^* \mid \beta_y^*$	m	3.88 | 0.83	0.37 | 0.03	
IP dispersion	$\eta_x^* \mid \eta_y^*$	m	0.0	0.0 | 0.0	
IP rms beam sizes	$\sigma_{xo}^* \mid \sigma_{yo}^*$	μm	436.9 | 35.3	258.1 | 54.8	365.0 | 77.5
IP convoluted beam sizes	$\Sigma_{xo} \mid \Sigma_{yo}$	μm		507.4 | 65.2	569.3 | 85.2
IP beta ratio	r_β		0.21	0.08	
IP aspect ratio	r		0.08	0.21	
Bunch spacing	$s_b = 2\lambda_{RF}$	m | ns	1.26 | 4.2	1.26 | 4.2	
Filled | Colliding bunches	K_b		1658 | 26	26 | 26	
Crossing angle	θ_{IP}	mrad	0.0	0.0	
Bunch population	$N_b^\pm$		6.05×10^{10}	1.13×10^{9}	2.26×10^{9}
Bunch current	$I_b^\pm$	mA	1.32	1.54	3.08
Beam current	$I^\pm$	mA	2190.7	40.0	80.0
S.R. power from IP dipole		kW	4.86	2.4×10^{-3}	4.8×10^{-3}
S.R. power (total)	P_{SR}	kW	1670	0.17	0.34
Beam-beam parameters	$\xi_x \mid \xi_y$		0.004 | 0.004	0.05 | 0.05	
Specific Luminosity	$\mathcal{L}_s$	$\mathrm{cm^{-2}s^{-1}mA^{-2}}$		1.38×10^{29}	0.95×10^{29}
Peak luminosity	$\mathcal{L}$	$\mathrm{cm^{-2}s^{-1}}$		7.3×10^{30}	1.0×10^{31}

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Section 3 Beam-Beam Effect and Luminosity

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 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 35.3 m which is 56 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 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 0.04. Thus, we selected 0.004, which is ten times smaller than those in PEP-II IR2, as the maximum allowed beam-beam tune shifts for the LER in PEP-N. In reality, the empirically determined maximum tune shift parameter may well be significantly higher, which may allow a higher luminosity for PEP-N.

The maximum tune shift parameters for the VLER were determined by using data from the VEPP-2M collider at Novosibirsk [4], which operates at similar energies. The relevant data are shown in Figure 3-1. From this figure, the maximum tune shift is set at 0.02 for 150 MeV, 0.04 for 300 MeV and 0.05 for 500 MeV. The allowed tuning variables for the VLER are the currents, emittances, bunch charges, and the beta functions at the collision point.

The optimized parameters for collisions in PEP-N are shown in Table 3-1 for beam energies of 150, 300 and 500 MeV and for two un-coupling emittances of 300 and 600 nm. The beta functions for VLER are fixed at 37 and 3 cm for the horizontal and vertical planes, respectively, at all energies. 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. The results show that the luminosity should be about 10^{31} $cm^{-2}s^{-1}$ at 500 MeV and above 2 x10^{29} $cm^{-2}s^{-1}$ at 150 MeV.

Early in the days of B-Factory design, Keil and Hirata discovered [5,6] 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 26 LER turns or 1746 VLER turns. Third, both rings have very strong active transverse bunch-by-bunch feedback systems which would damp this excitation if it starts. We believe that the Keil-Hirata effect is negligible for PEP-N.

The shortest beam lifetime for VLER from luminosity related particle loss is calculated for 500 MeV which is the worst case. The results are shown in Figure 3-2. A 300 minute lifetime is expected.

Table 3-1: Beam-Beam Parameters for PEP-N at 150, 300, 500 MeV.

Parameter	Units	100 MeV	100 MeV	300 MeV	300 MeV	500 MeV	500 MeV
		Low ε_x	High ε_x	Low ε_x	High ε_x	Low ε_x	High ε_x
E LER	GeV	3.10	3.10	3.10	3.10	3.10	3.10
E VLER	GeV	0.10	0.10	0.30	0.30	0.50	0.50
Beta x LER	cm	3200	3200	800	800	388	388
Beta y LER	cm	700	700	175	175	83	83
Emit x LER	nm	49	49	49	49	49	49
Emit y LER	nm	1.5	1.5	1.5	1.5	1.5	1.5
Beta x VLER	cm	37	37	37	37	37	37
Beta y VLER	cm	3	3	3	3	3	3
Emit x VLER	nm	180	360	180	360	180	360
Emit y VLER	nm	115	230	115	230	100	200
Num Bunch		26	26	26	26	26	26
I LER	mA	2140	2140	2140	2140	2140	2140
I VLER	mA	5	10	20	40	40	80
N LER		6.05E+10	6.05E+10	6.05E+10	6.05E+10	6.05E+10	6.05E+10
N VLER		1.41E+08	2.83E+08	5.66E+08	1.13E+09	1.13E+09	2.26E+09
Sig x LER	µm	1252.2	1252.2	626.1	626.1	436.0	436.0
Sig y LER	µm	102.5	102.5	51.2	51.2	35.3	35.3
Sig x VLER	µm	258.1	365.0	258.1	365.0	258.1	365.0
Sig y VLER	µm	58.7	83.1	58.7	83.1	54.8	77.5
Cap Sig X	µm	1278.5	1304.3	677.2	724.7	506.7	568.6
Cap Sig Y	µm	118.1	131.9	77.9	97.6	65.2	85.1
Luminosity calc	cm^{-2} s^{-1}	2.0E+29	3.5E+29	2.3E+30	3.4E+30	7.3E+30	1.0E+31
ξx LER		0.0041	0.0042	0.0041	0.0041	0.0040	0.0040
ξy LER		0.0040	0.0040	0.0040	0.0040	0.0041	0.0041
ξx VLER		0.0203	0.0203	0.0405	0.0405	0.0502	0.0502
ξy VLER		0.0201	0.0201	0.0402	0.0402	0.0503	0.0503

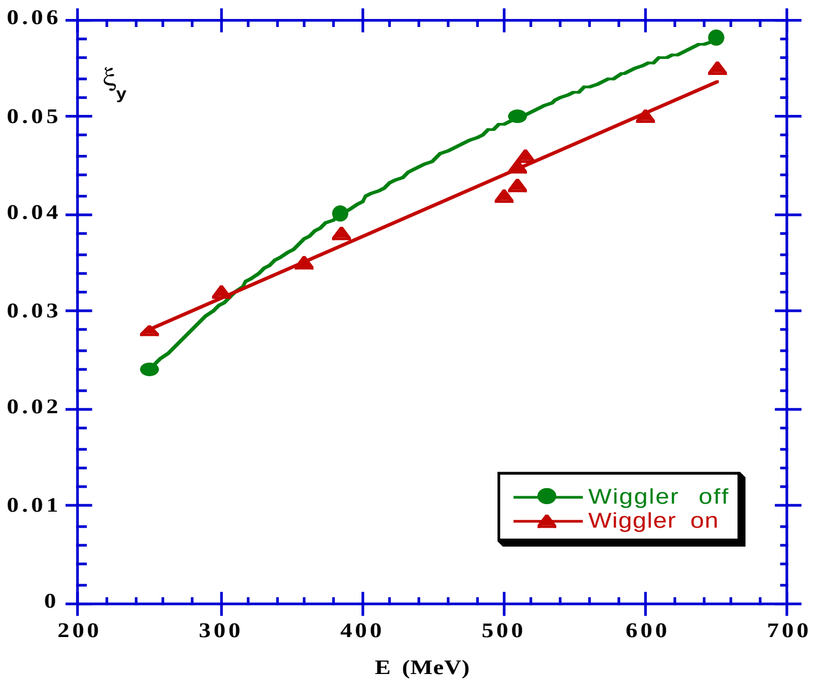

Fig. 3-1: Vertical tune shift parameters versus energy for VEPP_2M with and without a 7.5 T wiggler.

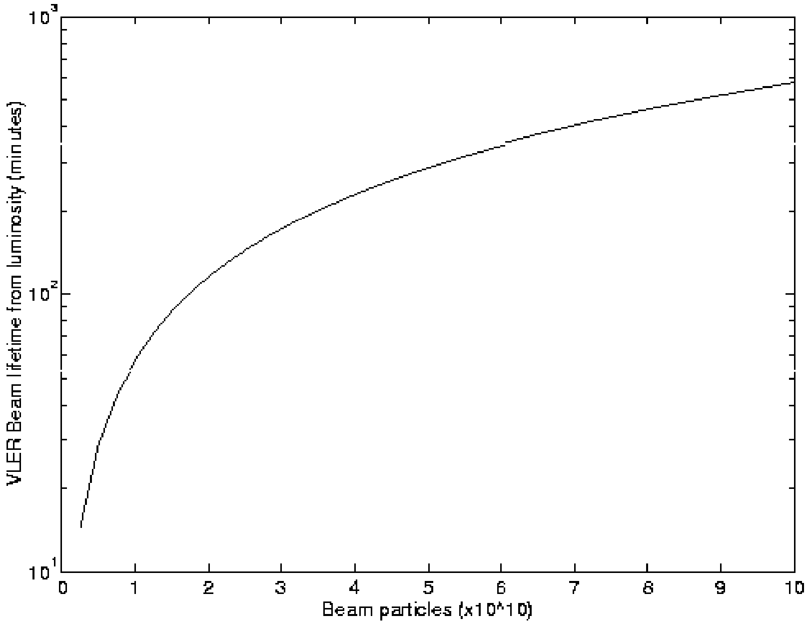

Fig. 3-2: Beam lifetime for the VLER electron beam from luminosity. The number of particles at 500 MeV is 5.8 e+10.