STUDY FOR AN ASYMMETRIC B-FACTORY

DESY B-Factory Study Group [1]

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SUMMARY

We report upon a feasibility study for an asymmetric $e^+ - e^-$ collider with beam energies of 10 GeV and 2.8 GeV. The PETRA storage ring is to be used to store the high energy beam. For the low energy beam, a new storage ring of 288 m circumference is to be built. The facility is designed for a peak luminosity of $\mathcal{L} = 3 \cdot 10^{33} cm^{-2} s^{-1}$.

1. INTRODUCTION

The study work at DESY on an asymmetric double ring $e^+ - e^-$ collider concentrates on designs with a high asymmetry of the beam energies E_1, E_2 (E_1/E_2 between 3.6 and 5.1). Using the existing PETRA ring at DESY for the high energy (HE) 10 GeV electrons and a new small ring for low energy (LE) positrons at an energy of 2.8 GeV allows to operate the asymmetric collider near the optimum Lorentz boost of $\beta \cdot \gamma = 0.6$ for the investigation of CP violation in the b-quark system [1].

The luminosity $\mathcal{L}$ of an asymmetric collider is given in equation (1). The current (I_1), the maximum tolerable tune shift ($\Delta\nu_1$), the beam energy in units of the restmass γ_1 and the vertical beta function at the interaction point β^*_{y1} refer to the high energy beam. κ is the aspect ratio of the beam dimensions, r_0 the classical electron radius and e the elementary charge.

$$\mathcal{L} = \frac{I_1 \cdot \Delta\nu_1 \cdot \gamma_1 \cdot (1 + \kappa)}{2 e r_0 \beta^*_{y1}} \qquad (1)$$

The luminosity is proportional to the product of the beam energy, beam current and tune shift.

According to measurements in PETRA [2] the beam-beam tune shift limit becomes larger for higher energies. Experimental data fit well the law $\Delta\nu \sim \gamma^{3/2}$.

Thus the required current in the HE ring decreases considerably as the energy asymmetry of the collider increases. The design of the LE ring is to be optimized so that the corresponding increase in the LE beam current does not limit the performance.

The total beam currents in both rings will be limited by coupled bunch instabilities unless they are damped by a broadband feedback system. Any B-factory with large luminosities relies on the technical feasibility of such very powerful damping systems.

At DESY we considered carefully two designs with different energy asymmetries, E_1/E_2 being 5.1 (investigated in [3]) and 3.6. Since in the lower asymmetry a higher current is needed to maintain the luminosity the reduction of the rf power to balance the synchrotron radiation losses is much lower than naively expected from the law $P \sim \gamma^4$. Moreover for low asymmetry the internal damping of the beam is reduced in the high energy beam. This drastically reduces the instability threshold for higher order coupled bunch modes for which there will be no feedback available. Therefore one is forced to reduce the cavity impedance but this increases the rf power dissipated in the cavities. Higher order coupled bunch instabilities are expected to limit the maximum beam current in low asymmetry solutions whereas the beam currents in high asymmetry solution will be limited only by the amount of available rf power. Therefore in the designs studied at DESY the reduction of rf power due to reduction of asymmetry from 5.1 to 3.6 amounted to only 30%. We draw the conclusion that the dependence of luminosity on the energy asymmetry is very weak.

The two beams have to be separated quickly after head-on collision. This is necessary to avoid parasitic beam-beam crossings and to focus the HE beam close to the interaction point IP without damaging the low energy beam. Since for low asymmetry the beams differ less in rigidity, separation becomes more difficult and requires more space assuming the synchrotron radiation power generated in the separator magnets remains constant. Furthermore the low beta quadrupoles for the low energy beam become less effective with lower asymmetry which has to be balanced by making them longer. As a result, the β- function at the IP, β^*, has to become larger which requires another increase in beam current to maintain the luminosity. All these problems are solvable if a magnetic separation at a high asymmetry is used.

The synchrotron radiation background problem is reduced considerably in a high asymmetry situation. For constant beam separation the magnetic fields can then be weaker which reduces the sum of the radiated power from both high and low energy beams. This eases the shielding of the detector for scattered photons from the high energy beam. The small magnetic rigidity allows to use permanent magnet low beta quadrupoles for the LE beam. They are very compact so that it is possible to place them close to the IP. For low asymmetry designs one is forced to use superconducting quadrupoles which imposes a large technical problem arising from the need to shield the cold beam tube (at liquid He temperature) from the large amount of synchrotron radiation power generated in the interaction region.

MAIN PARAMETERS AND LAYOUT

The design is based on the present PETRA lattice and a new additional small storage ring of 288m circumference for the positrons. The beam energies are 10 GeV and 2.8 GeV respectively and - assuming that a beam-beam tune shift of $\Delta\nu = 0.04$ can be reached in both rings - the beam currents for a luminosity of $\mathcal{L} = 3 \cdot 10^{33}$ are 1.2 A in the HE and 2.2 A in the LE machine. The vertical β-function at the interaction point is $\beta^*_{y,HE} = 4cm$ and $\beta^*_{y,LE} = 2cm$ respectively, with an aspect ratio of the beam cross section of one to ten.

The high energy ring is identical with the PETRA storage ring. The low energy ring consists of two half rings and two S-shaped insertions. One hosts the interaction region, the other one the rf cavities. This asymmetric arrangement allows for both head-on collisions with a magnetic beam separation and collisions at a finite crossing angle (fig 1). The layout of the interaction region is based on the use of two permanent magnetic quadrupoles. Because of their high fields and small overall dimensions they provide early focussing of the low energy beam. They are off-centre with respect to the head-on collision axis and

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act as combined function magnets. These two permanent magnets are followed by a conventional large aperture Panofsky-type quadrupole within which the LE beam is deflected to the high field region and quickly separated completely from the HE beam. This leads to a fast separation of more than 10 σ at a distance of 2.4 m from the interaction point with a minimum production of synchrotron radiation background and allows to distribute the total beam current over 480 (60) bunches in the HE (LE) ring. The last element of the separation scheme is a magnetic septum that affects only the LE beam and guides it to the normal FODO structure in the arcs.

The HE beam is focussed by conventional quadrupole magnets except for the half of the first low beta quadrupole which is a permanent magnet as well.

The horizontal emittances for both beams are adjusted to $1 \cdot 10^{-7} radm$ and $2 \cdot 10^{-7} radm$ respectively.

The layout of the LE ring at its location at the PETRA SE-hall is shown in fig. 2. The main parameters of the B-meson factory are listed in table I.

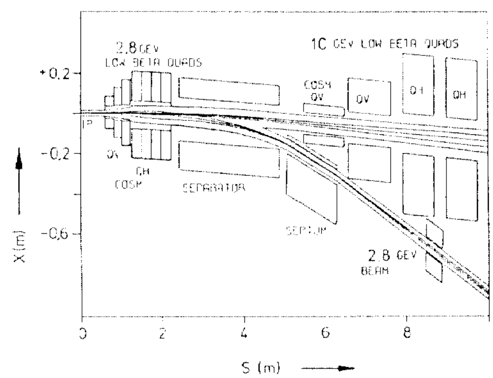


Figure 1: Layout of the Interaction Region and Beam Separation

Table 1: Main Param. of the Asym. B-meson Factory	HE-Ring	LE-Ring
particles	Electrons	Positrons
Beam Energy E/GeV	10	2.8
Circumference L/m	2304	288
Harmonic Number	3840	480
Beam Current I/A	1.2	2.2
Number of Bunches	480	60
Particles per Bunch	$1.2 \cdot 10^{11}$	$2.5 \cdot 10^{11}$
Hor. Emittance $\varepsilon_x/radm$	$1.2 \cdot 10^{-7}$	$2.3 \cdot 10^{-7}$
$\varepsilon_z/\varepsilon_x$	0.10	0.10
$\beta_x^*/m, \beta_z^*/m$	0.40, 0.04	0.20, 0.02
Tunes Q_x	25.70	9.19
Q_z	23.8	9.28
Q_s	0.047	0.033
Chromaticities ξ_x, ξ_z	-51.6, 54.9	-18.8, -23.1
Beam-Beam Tuneshift $\Delta\nu_x$	0.04	0.04
Beam-Beam Tuneshift $\Delta\nu_z$	0.04	0.04
Long. Damp. Time τ_s/ms	16.5	9.1
Circumf. Voltage U/MV	9	2.7
Bunch Length σ_s/mm	16.5	14.1
Power Loss P_{syn}/MW	5.6	0.66
Luminosity $\mathcal{L} = 3 \cdot 10^{33} cm^{-2} s^{-1}$		

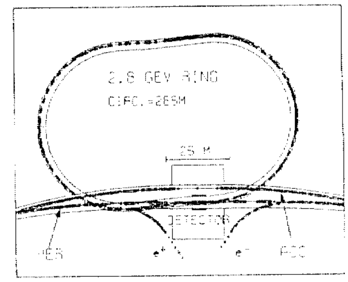


Figure 2: 2.8 GeV positron ring and interaction region located at the PETRA SE-hall

RF-CONCEPT AND MAXIMUM BEAM CURRENT

The rf requirements of high input power and low parasitic impedance can be fullfilled by normal conducting 500 Mhz single cell cavities. It has been shown that an effective damping of the parasitic resonances is possible by applying a passive damping system [4].

Possible current limitations are due to single bunch and coupled bunch instabilities.

Coupled bunch instabilities are driven by parasitic modes of the cavities. The cavities have only one important longitudinal and one transverse resonance. The 18 monocell cavities of the high energy ring set the threshold current of 120 mA in 480 bunches.

In the case of the low energy ring the two important modes are less strongly damped but tuned by special antennas to reduce their influence on the beam. This allows to store a total current of 500 mA in 60 bunches.

Single bunch instabilities are caused by the broadband impedance of the ring. The contribution of the cavities has been calculated. The impedance of the vacuum chamber was estimated by using existing measurements and calculations of the impedance of PETRA. Using these impedances neither transverse nor longitudinal single bunch instabilities are of importance up to the design currents of 1.2 A in 480 bunches of the high energy ring and up to 2.2 A in the 60 bunches of the low energy ring.

The current in both rings is limited by coupled bunch instabilities. An active damping has to be installed in both rings to achieve the design current.

BEAM-BEAM INTERACTION

We follow the HERA concept in assuming that each beam in an asymmetric collider has individual beam-beam tune shift limits according to the beam energy, damping time, energy spread and collision frequency. We however impose the condition that the beam cross section at the IP must be the same for both beams in order to balance the nonlinear effects of the beam-beam interaction. This is suggested by experience with hadron colliders [5].

In order to make an estimate of the HE ring beam-beam tune shift limitation, we make use of extensive studies which have been performed on beam-beam interaction at PETRA [2]. These experiments indicate, that within the energy range of 7 GeV to 17 GeV the maximal tolerable tune shift scales as $\Delta\nu = 0.5 \cdot \sqrt{\delta}$ as proposed by Talman and Keil [6]. In addition scaling the tune shift with the square root of the number of crossing points is considered to be an experimentally well established scaling law [7].

For a beam energy of 10 GeV and one beam beam crossing per revolution we are therefore confident that a beam-beam tuneshift in PETRA of $\Delta\nu = 0.04$ can be achieved.

Using the same scaling law for the low energy beam we arrive at the same number $\Delta\nu = 0.04$ for the maximum tolerable beam beam tune shift.

Recently it has been demonstrated that in a double ring collider with different circumferences of the two rings, the coherent beam beam interaction is enhanced by the fact that one bunch in one ring interacts with several bunches in the other one [8]. A coupled system with many degrees of freedom is formed which is - in the model of rigid bunches with a linear beam beam force - subject to many additional linear sum-resonances. The width of the resonances increases with the strength of the beam beam tuneshift parameters and the resonances overlap covering the whole tune range for a certain tune shift limit. We have investigated this effect for the present design where each bunch of the LE ring is coupled to eight bunches in the HE ring respectively. Fig. 3 shows a comparision of this effect for the cases of one to one and one to eight bunches. Plotted is the tune shift for which the motion becomes linearly unstable versus the tune of the LE beam. The number of resonances is multiplied but as their widths have decreased the total accessible range of tunes is only reduced by a factor of two for the anticipated tune shift values of $\Delta\nu = 0.04$.

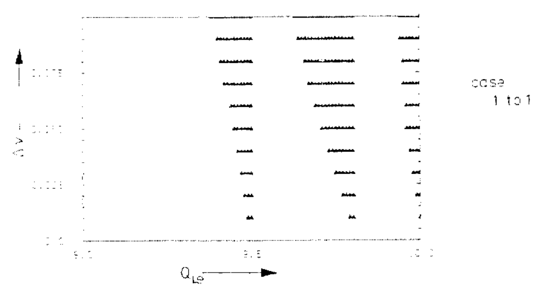
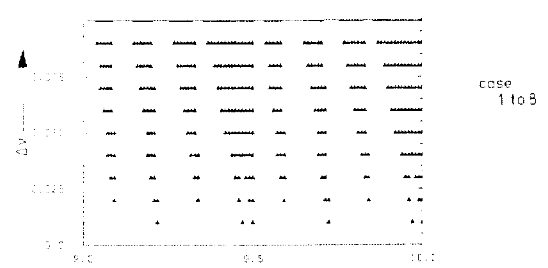


Figure 3: Coherent Tune Shift Limit versus Tune for Equal Circumferences and for a Ratio of 1 to 8 in the Circumferences of the two Rings.



The space between the resonances appears to be sufficient for operation. The "eight to one case" offers in some respect even more freedom to adjust the tune of the LE ring. Concerning the HE ring, the coherent beam-beam interaction did not impose a performance limitation for PETRA as an $e^+ - e^-$ collider, though the achieved tune shift exceeded the level for which linear instability was expected by a factor of two for certain operation points [9].

We therefore - according to our present knowledge- do not consider coherent beam-beam interaction to impose a performance limitation for an asymmetric collider.

SYNCHROTRON RADIATION BACKGROUND

The fast separation in combination with the large beam currents generates high synchrotron radiation in the interaction region. In order to keep this radiation background as small as possible the separation is done by combined function magnets. The HE beam stays in the low field region which leads to a drastic reduction of the radiated power. The total amount of synchrotron radiation power produced in the separation magnets upstream from the detector is 3.7 kW for the LE beam and 15 kW for the HE beam. The maximum critical energies of the emitted spectra are 2.4 keV and 27 keV respectively.

With the present arrangement of the magnets and the synchrotron radiation masks, half of the synchrotron radiation power of the HE beam (6.9 kW) will travel through the interaction region without hitting any collimator. Even for this reduced synchrotron radiation power, one needs a very efficient collimator system to shield the detector. Fig. 4 shows the collimator system and the total synchrotron radiation power on the different collimators. The detector beam pipe can be shielded against primary synchrotron radiation. The amount of scattered photons coming from the edges of the masks will have to be reduced by optimizing the position and material of the collimator system to reach a synchrotron radiation background as low as 10^9 photons per second with energies above 1 keV as required by the experiment[10].

We have calculated the power deposited at the interaction region caused by higher order modes and transient fields to be 14 kW.

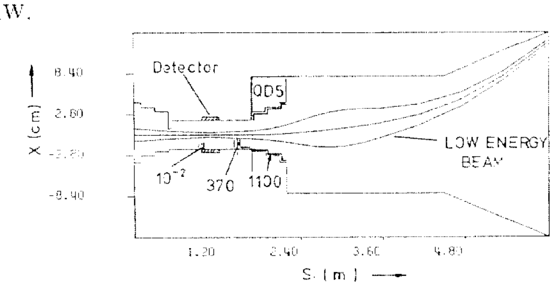


Figure 4: Synchrotron Radiation Masking System. Plottet are the Collimators, the First Permanent LE Quadrupole, QD5 and the 10 σ Envelopes of the LE Beam. The Radiation Power hitting the Masks is given in Watts

References

[1] H. Nesemann et al. DESY 89/80 (1989)
W. Schmidt-Parzefall, Workshop on Beam Dyn. Issues of High Lum. Asym. Collider Rings, Berkeley (1990)

[2] A. Piwinski, DESY 81-066 (1981)

[3] K. Balewski et al, 14^{th} Int. Conf. on High Energy Acc. Tsukuba, Aug. 1989

[4] C. Yinghua, D. Proch, J. Sekutowicz, Internat. Conf on High Energy Accelerators, Tsukuba (1989)

[5] L. Evans, private communication

[6] E. Keil and R. Talman, CERN-ISR-TH/81-33 (1981)

[7] D. Rice, Workshop on Beam Dyn. Issues of High Lum. Asym. Collider Rings, Berkeley (1990)

[8] K. Hirata and E. Keil, CERN/LEP-TH/89-76 (1989)

[9] A. Piwinski priv. com.

[10] W. Schmidt Parzefall priv. com.