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INTERACTION REGION DESIGN OF AN ASYMMETRIC COLLIDER

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Abstract We report upon a feasibility study of an asymmetric $e^+ - e^-$-collider with beam energies of 12 GeV and 2.3 GeV. Emphasis is put on linear lattice design, especially on the layout of the interaction region. The PETRA storage ring is to be used to store the high energy beam. For the low energy beam, a new storage ring of 144 m circumference is needed. The luminosity of the facility is expected to be of the order of $\mathcal{L} \approx (1-4) \cdot 10^{33} cm^{-2} s^{-1}$.

INTRODUCTION

A facility in which e^+-e^- beams collide with different beam energies, $(E_{\rm el}/E_{\rm pos} > 3)$ would provide the possibility to measure CP violation and rare decays in the B-quark system[1]. Luminosities, $\mathcal{L}$, of several 10^{33} cm^{-2}s^{-1} are required. In this paper we report on a study in which the use of the PETRA storage ring for such a facility is investigated. It is an update of the work which has been presented earlier[1,2]. The basic concept is to exploit the existence of a large storage ring. This allows one to operate the asymmetric collider near the optimum Lorentz-boost for the detection of decay vertices of the B-Mesons, namely $\beta\gamma = 1$. Beam energies of 12 GeV for the electrons and 2.33 GeV for positrons stored in a 144 m circumference ring appear to be the best compromise between optimum Lorentz boost, high luminosity, and tolerable synchrotron radiation power losses.
The main factors in attaining the high luminosity are the high multibunch beam currents in both beams, high single bunch currents in the low energy beam, operation with many bunches requiring quick beam separation, strong low-β focussing, synchrotron radiation generated in the beam separators, and finally large total synchrotron radiation power loss of the beam. Practical solutions using currently available accelerator technology are discussed in this report.

LUMINOSITY

The luminosity of an asymmetric e^+-e^- storage ring is given by

$$\mathcal{L} = \frac{I_i \ \gamma_i \ \Delta\nu_i \ (1 + \sigma_z/\sigma_x)}{2er_o\beta^*_{zi}} \qquad (1)$$

The parameters in this expresssion are the total beam current I_i, the maximum tolerable strength of the beam beam interaction parameterized by the linear beam beam tune shift $\Delta\nu_i$ and the minimum vertical β-function at the interaction point(IP). These quantities are limited in either the electron $(i = 1)$ or positron beam$(i = 2)$. σ_z/σ_x is the aspect ratio of the beams at the IP, e is the elementary charge and r_0 is the classical electron radius. This equation has been derived under the assumption that the dimensions of the electron and the positron beam at the IP are the same. That is essential in order to achieve high

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[1] K. Balewski, C. Geyer, G. Hemmie, B. Holzer, E. Jaeschke, R.-D. Kohaupt, D. Krämer, H. Nesemann, D. Proch, J. Sekutowics and F. Willeke

tune shifts[3]. The beam emittances are fixed by these assumptions. It is assumed that they do not impose any further limitation. This requires flexibilty in the lattice design and genereous magnet apertures. Rewriting the luminosity equation by inserting numbers for the limiting quantities yields

$$\mathcal{L} = 1.00 \cdot 10^{33} cm^{-2} s^{-1} \frac{I}{230\ mA} \frac{E_i}{12\ GeV} \frac{\Delta\nu_i}{0.06} \frac{4\ cm}{\beta^*_{zi}} \frac{(1+\sigma_z/\sigma_x)}{1.12} \quad (2)$$

$$\varepsilon_{xi} = 0.8 \cdot 10^{-7} radm \cdot \frac{I_i}{230\ mA} \frac{240}{n_{bi}} \frac{0.06}{\Delta\nu_i} \quad (3)$$

(n_{bi} is the number of bunches in beam i.)

LOW-β FOCUSSING, INTERACTION REGION LAYOUT AND LATTICE DESIGN

Small β-functions at the IP will be necessary for large luminosity. This leads to large β-function values in the low-β quadrupoles and that generates a large chromaticity which is the reason for a limited dynamic aperture and, in addition, requires a large aperture. In order to limit these effects, low-β quadrupoles for the low energy beam are placed as close as possible to the IP. Because of the different energies of the two beams, the high energy beam can only be focussed after the beams have been separated. On the other hand, the different stiffnesses of the beams allow one the use of effective magnetic separators. Sudden bunch separation however causes the high energy beam to emit high power synchrotron radiation towards the colliding beam detector. The chromaticity limit of the β^*-value seems to be much more restrictive in the high energy beam. This dilemma is very much alleviated by the fact that in the high energy ring with its large circumference much more additional chromaticity can be tolerated than in the low energy ring, because the sextupoles needed to compensate the chromaticity are more evenly distributed. The dynamic aperture limitation due to chromaticity compensating sextupoles can be expressed in good approximation by

$$n = n_0 \frac{1}{1 + \xi^*/N_c\xi_c}$$

where n is the dynamic aperture in units of the rms beam size, n_0 is the dynamic aperture one would obtain without the additional chromaticity of the insertion, N_c is the number of FODO-cells, ξ_c is the chromaticity per FODO cell and ξ^* is the additional chromaticity of the insertion ($\xi_y/\xi_x = const$ has been assumed). This is the reason, why in principle, in an asymmetric collider, one can obtain the same β^*-values as in a symmetric collider for both beams.

In the present solution we obtain $\beta^*_{z1} = 4\ cm$, $\beta^*_{z2} = 2\ cm$, for the electron and positron respectively. These β^*_z values are close to the bunch length limit, ($\sigma_s \simeq 1.5cm$) the chromaticity limit and the aperture limit. The low-β quadrupoles are made from rare earth permanent magnet material (CoSm). They are very compact (outer diameters 200 mm and 350 mm for the vertical and the horizontal focussing quadrupole), so that they can be placed as close as 60 cm to the IP inside the colliding beam detector. The high energy beam is focussed by conventional quadrupole magnets, except for the first half of the vertical low-β quadrupole which is also a CoSm permanent magnet. It can be placed immediately after beam separators. The problem of synchrotron radiation can be solved by using combined function magnets to separate the beams. Both beams enter the separator where the field is low. Whereas the low energy beam is deflected quickly into the high field region, the high energy beam stays in the low field region. In this arrangement the synchrotron

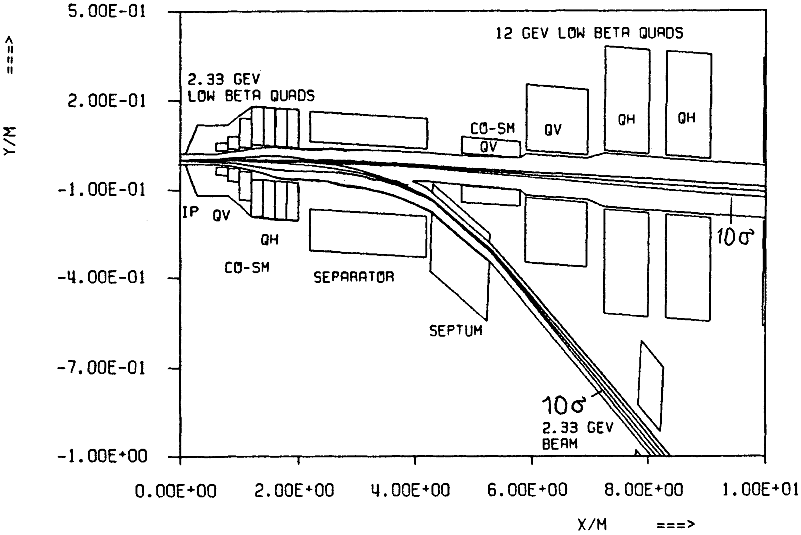

Figure 1: Layout of the Interaction Region using Permanent Magnetic Quadrupoles and a Combined Function Separator

radiation emitted by the high energy beam has a critical energy of 29 KeV and the total power emitted upstream of the detector is 4.4 KW. Primary and secondary photons can be masked out by a collimator system. Background conditions in this situation are expected to be tolerable. Complete beam separation is done by a conventional septum magnet. The beams are separated by $2 \times 6.5\sigma$ at a distance of 2.4 m from the IP so that it is possible to store up to 480(65) bunches in the high(low) energy ring.

The lattice of the high energy ring is similar to the existing PETRA lattice. The low energy ring with 144 m circumference has a 90^o FODO structure consisting of 36 cells including straight sections for rf-cavities and injection elements. Fig. 1 shows the layout of the interaction region, Fig. 2 shows the cross section of the magnetic elements close to the interaction point and Fig. 3 gives an overview of the low $2.33GeV$-lattice. Beam emittances in both rings can easily be varied by changing the focussing to adapt to beam currents corresponding to $(0.5 - 3) \cdot 10^{33}$ cm^{-2}s^{-1} luminosity.

The vacuum system of the high energy ring has to absorb 15 Wcm^{-1} corresponding to $I = 230mA$ and $\mathcal{L} = 10^{33}cm^{-2}s^{-1}$. In the low energy ring this number is 24 Wcm^{-1}. Thus beam currents for luminosities of several $10^{33}s^{-1}cm^{-2}$ can be handled with standard cooling techniques.

BEAM-BEAM TUNE SHIFT AND MAXIMUM BEAM CURRENTS

Vertical beam-beam tune shifts of $\Delta\nu = 0.014, 0.024, 0.04$, have been achieved in PETRA at $7GeV$, $11GeV$ and $17GeV$ colliding beam operation[4] with 4 beam-beam collisions per revolution. Scaling the maximum tune shift with the squarroot of the damping decrement per beam-beam crossing, for a 12 GeV electron beam with one crossing per revolution one expects a tune shift of $\Delta\nu = 0.047$. Since the colliding beam performance in PETRA was suffering somewhat from imperfection resonances due to perturbed machine symmetry, we expect that the tune shift in the asymmetric collider will be $\Delta\nu \simeq 0.06$ for the high energy beam. For the low energy beam with its high collision frequency, we only expect

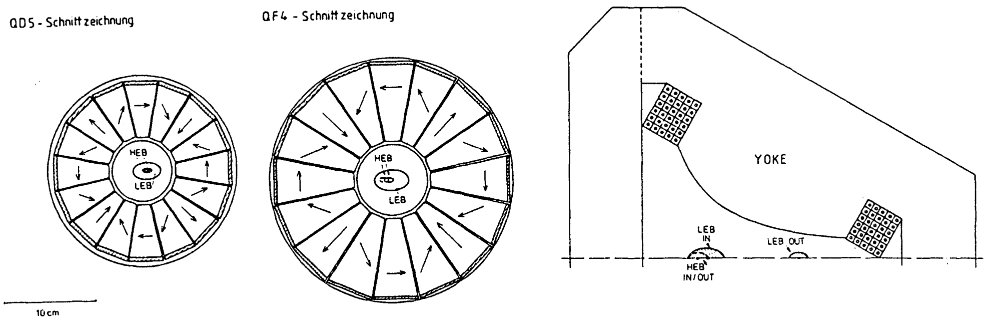

Figure 2: Cross Section of the Low β Fosussing Elements and of the Beam Separator

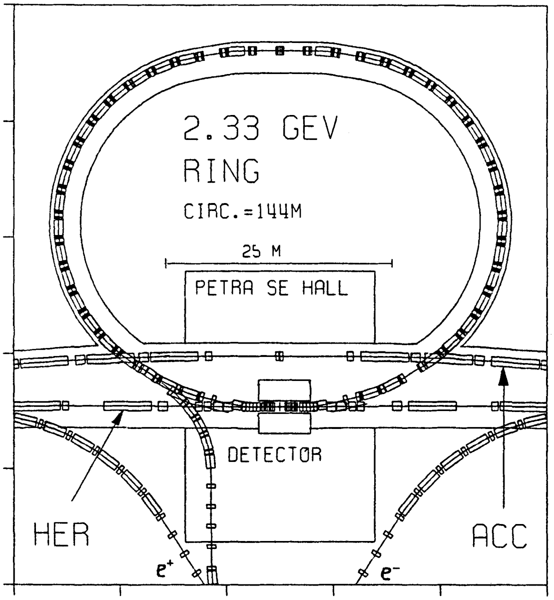

Figure 3: Lattice of the Low Energy Ring; Shown is also the Interaction Region with the High Energy Ring(HER) and an Additional Accelerator Ring (ACC) for Acceleration of Electron and Protons which is Located in the HER Tunnel

to achieve a tune shift of $\Delta\nu = 0.03$.
Owing to the high number of bunches in the two rings, single bunch current limitations become only important for ultra high luminosities. In PETRA, we know that the mode coupling instability threshold, which limits the single bunch currents occurs, at about 10 mA for a bunch length of 1 cm (7 GeV[5]). This would allow total currents of about 1.4 A and would correspond to luminosities above $7 \cdot 10^{33}$ $cm^{-2}s^{-1}$. The bunch lengthening threshold occurs at even higher bunch currents. For the low energy ring we have much less information. Assuming the same impedance per unit length as we have in PETRA we expect a single bunch current of 1 A to be still below the mode coupling threshold[6].

However multibunch instabilities which are driven by parasitic modes of the rf-cavities are much more important. In order to suppress these instabilities, the rf-structure consists of single cell copper cavities with reduced R/Q. In addition, the parasitic monopole modes are damped with higher order mode couplers. The transverse dipole modes are strongly supressed by eight longitudinal slots filled with ferrites. Only one important longitudinal and one important transverse dipole mode remain. These modes can be tuned independently of the fundamental mode in order to minimize their impact on the beam. An rf-structure consisting of 21 cavities enables storage of 288 mA in 240 bunches and this is still below the instability threshold in the high energy ring. The same cavity is foreseen for the low energy ring. The instability threshold occurs at $I = 2.75\ A$.
The conclusion is that with the present status of rf-cavity development, beam currents are still restricted by multibunch instabilities driven by monopole and dipole modes. The threshold currents correspond to a luminosity of $\mathcal{L} = 1.24 \cdot 10^{33} cm^{-2}s^{-1}$. The cavity development program is in progress. For details see ref.[7]. Multibunch instability calculations are described in ref.[6]. Using the PETRA/HERA multibunch feedback[8], we are confident of raising the instability threshold currents by a factor of at least 2.

Table 1: Main Parameters of the Asymmetric B-meson Factory

	High Energy Ring	Low Energy Ring
Particles	electrons	positrons
Beam Energy E/GeV	12	2.33
Circumference L/m	2304	144
Harmonic Number	3840	240
Beam Current I/mA	200 – 1000	1000 – 5000
Number of Bunches	192 – 480	12 – 30
Particles per Bunch	$(5.0 - 10) \cdot 10^{10}$	$(2.5 - 5.) \cdot 10^{11}$
Hor. Emittance $\varepsilon_x/radm$	$(0.7 - 1.4) \cdot 10^{-7}$	$(1.4 - 3.2) \cdot 10^{-7}$
$\varepsilon_z/\varepsilon_x$	0.1	0.10
$\beta_x^*/m, \beta_z^*/m$	0.40, 0.04	0.20, 0.02
Tunes Q_x, Q_z, Q_s	25.70, 23.8, 0.047	7.78, 7.72, 0.033
Chromaticities ξ_x, ξ_z	−51.6, −54.9	−17.9, −20.7
Beam-Beam Tuneshift $\Delta\nu_x$	0.06	0.03
Beam-Beam Tuneshift $\Delta\nu_z$	0.06	0.03
Long. Damping Time τ_s/ms	9.5	5.0
Circumferential Voltage U/MV	20.	3.0
Bunch Length σ_s/mm	14.5	9.2
Beam Power Loss P_{syn}/MV	2.3 – 11.6	0.22 – 11.2

Luminosity $\mathcal{L} = (0.5 - 5.) \cdot 10^{33} cm^{-2}s^{-1}$

SUMMARY

A consistent design of an asymmetric B-Meson factory has been carried out for beam energies of 2.33 GeV and 12 GeV. The important design parameters are listed in Table I.

The lattices are designed for luminosities of $\mathcal{L} = (0.5 - 5) \cdot 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$. Maximum beam currents required for such luminosities appear to be feasible.
In order to make the operation of the collider as independent as possible from the HERA operation, a new ring has to be installed in the PETRA tunnel. At present, several different scenarios are being considered and are based on the present lattice design for the high energy ring.

References

[1] H. Nesemann, M. Reidenbach, W. Schmidt-Parzefal, H.-D. Schulz and F. Willeke, "Ideas for Future B-Physics at DESY", DESY 89/80 (1989)

[2] H. Nesemann, W. Schmidt-Parzefal and F. Willeke, "The Use of PETRA as a B-Factory", Proceedings of the European Particle Acc. Conf., Rome 1988, p. 439 (1988)

[3] Lynn Evans, private communication

[4] A. Piwinski, "Review of Mini Beta Luminosities in PETRA at Different Energies", DESY 81-066 (1981)

[5] R.D. Kohaupt, "Measurement on the vertical blow up in PETRA", DESY M/VM/82/14

[6] K. Balewski, to be published

[7] C. Yinghua, D. Proch, J. Sekutowicz, "The Slotted Cavity-A Method of Broadband HOM Damping" Internat. Conf on High Energy Accelerators, Tsukuba (1989)

[8] PETRA/HERA Feedback Group, to be published