

Mini betas at DESY

Klaus Steffen seated on one of the mini-beta quadrupoles at DESY's PETRA electron-positron collider.

(Photo P. Waloschek)

After two and a half years of operation, the PETRA electron-positron ring at DESY has reached a remarkable level of performance. In April, the rate of useful particle collisions recorded in the four running experiments was nearly three times higher than last year. The number of events collected per day now corresponds

two months of running back in 1979. Peak luminosity has reached 1.6×10^{31} per cm^2 per s and luminosity per day is well over 700 events per nanobarn.

A major improvement of the machine was achieved with the addition of focusing quadrupole magnets in so-called 'mini beta' sections. These have been installed to squeeze the beam in the four collision regions and are now in routine operation.

The ideas developed at DESY to improve focusing have proved to be feasible and moreover compatible with the requirements of the experiments mounted at the collision regions. In practice, the new mini beta sections have not degraded any

machine parameters; in particular the beam lifetime of several hours has remained unchanged. This confirms previous calculations and increases confidence that the PETRA machine is now well understood.

The present techniques used at PETRA to achieve record electron-positron collision rates have come a long way in the twenty years since Bruno Touschek proposed counter-rotating beams of electrons and positrons stored in a single machine.

By improving the focusing at the crossing points to reduce the transverse dimensions of the stored beams, the 'target density' of one beam seen by the other is increased. This procedure has been used in all electron-positron storage rings over the last ten years, and is also profit-



ably applied in the CERN Intersecting Storage Rings to improve the proton-proton collision rate (see March issue, page 59).

But it is not only the transverse dimensions of the beam at the interaction point which are important. The beam divergence is also relevant because of the effects of one beam on the other. The electromagnetic field of one bunch affects the particles in one travelling in the opposite direction and causes a nonlinear focusing disturbance. Above a critical current, one beam may destroy the other (usually the weaker). This is usually referred to as the beam-beam limit, and can be reduced by increasing the beam divergence at the collision point.

To attain high luminosities near the beam-beam limit, a small beam size and a large beam divergence are required at the collision point. The ratio of beam size to divergence is

usually called the beta value, so this parameter should be particularly small at the collision point.

In electron storage rings, beam size could be reduced in principle by increased quadrupole focusing everywhere. This reduces the product of beam size and beam divergence which, according to a general beam transport law, for a given machine is constant around the ring. Instead, the beta ratio can be made locally very small by focusing the beam with strong divergence into a narrow spot (beam waist). In machines without low beta sections, a reduction of the beam cross-section (over the whole machine) has never provided significant gains in luminosity, due to the limitations imposed by beam-beam interactions.

Initially, it was considered essential to leave a lot of free space for the experiments and place the quadrupoles far from the crossing points.

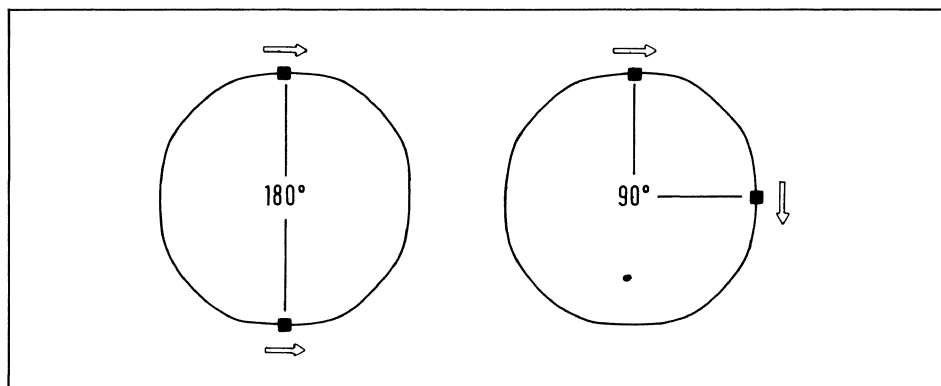
Two possible schemes worked out for PETRA by Gerhard Ripken to compensate for the effects of the magnetic fields of detectors without using compensating magnets. Mutually opposite detectors need fields which are equal and opposite. Detectors at 90 degrees need their fields to be equal and in the same sense.

The high beam divergence then led to the construction of quadrupole lenses with large aperture.

Though it was always understood that the luminosity could be improved by reducing the space between the final focusing elements, it was only after quantitative arguments had been presented at DESY by Klaus Steffen that the situation was sufficiently clarified and the present successful system was found. The stored beam has a natural energy spread and increased focusing introduces an energy dependent disturbance to the particle orbits, called 'chromaticity'. This depends critically on the length of the sections with high beam divergence and must be compensated by sextupole magnets placed around the ring. These sextupoles introduce nonlinear effects which end up reducing the useful aperture available for stable particle trajectories. This eventually results in a drastic reduction of the beam lifetime.

A geometry and system of beam optics which takes all this into account has now been tried out at PETRA. In this 'mini beta' system, the beta value at the four interaction points has been reduced, and at the same time the distance between the quadrupoles either side of the intersection has been reduced from 15 to 9 metres. As expected from chromaticity considerations, there was no deterioration of beam lifetime or other machine parameters. The higher divergence of the beams merely increased the background for the experiments and required better adjustment of the beam positions. Up to threefold gains in luminosity were measured.

In the past, the quadrupoles used for low beta sections were placed rather far from the crossing points and had to have large apertures. Now the problem is to make them



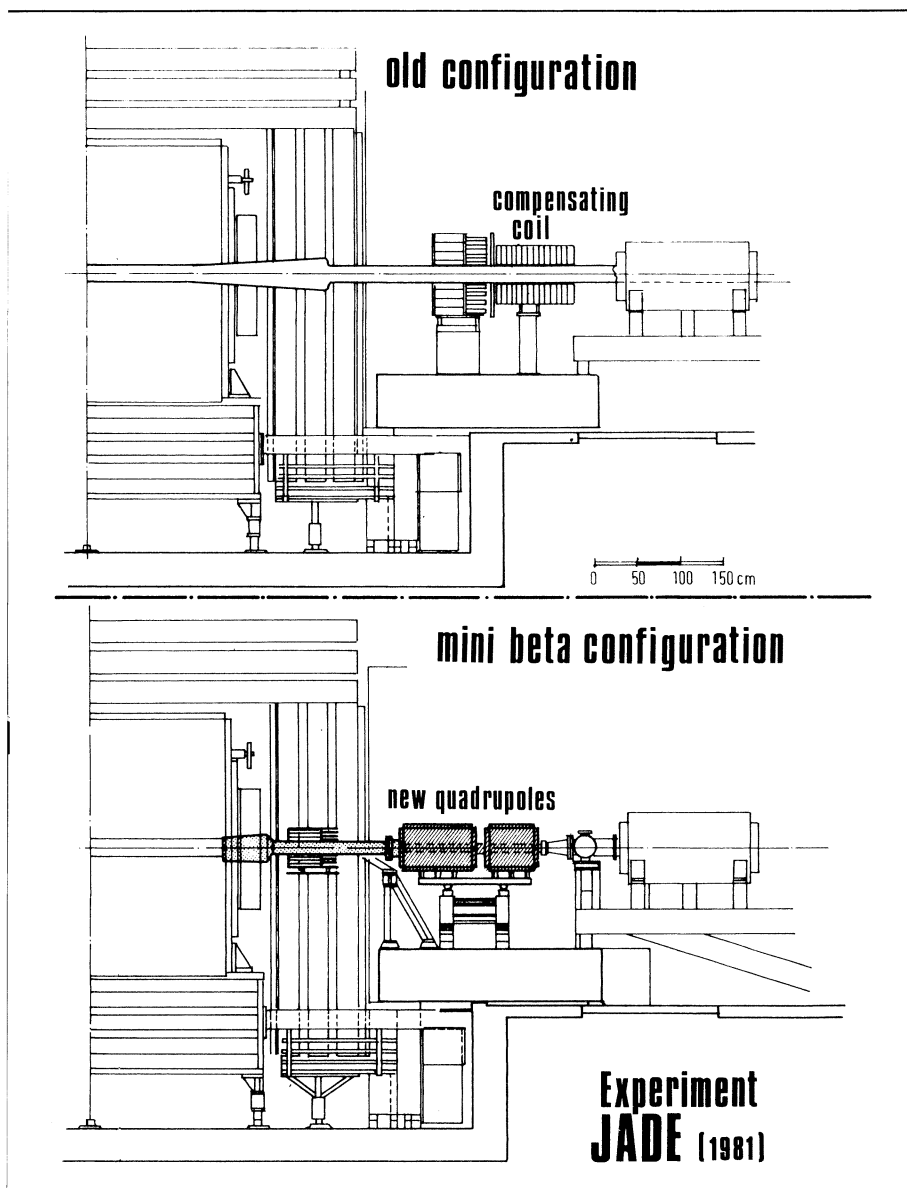
small and place them as near as possible to the crossing points. However there are limits to which the focal length of these quadrupoles and the gap between them can be reduced while still leaving enough space for the experiments. The strength of the quadrupoles is limited by steel saturation, or, in the case of superconducting magnets, by breakdown effects. For high luminosity, the bunch length (which depends mainly on the accelerating frequency) should not be much longer than the low beta beam waist, otherwise parts of the bunches cross over where their transverse dimensions are not small. Eventually, beam-beam effects limit the extent to which the beam can be squeezed.

In the new PETRA configuration, conventional quadrupoles of sufficient aperture reach beta values of about 5 cm without excessive chromatic distortion. For smaller betas (or higher energies) stronger quadrupoles are required, and these can be built using superconducting techniques. Future plans, recently reported by Klaus Steffen and Gus Voss, already include slim superconducting devices without iron yokes and which are likely to provide further significant luminosity improvements. These may even be made compatible with the magnetic fields of the detectors and placed inside

them. These developments are certainly interesting for experiments using the next generation of storage rings, like LEP, to compensate for the low reaction cross-section expected at very high energies.

Along the beam pipe near to the bunch crossing points, the space available for focusing magnets is limited by the requirements of the experiments. Fortunately most reactions in which an electron and a positron annihilate into an intermediate virtual photon can be analysed while ignoring a small cone around the incident beams. Other types of interaction require the observation of particles emerging very near to the beams. These include most of the electromagnetic interactions (like the elastic scattering used to monitor luminosity) and some higher order processes in which the incoming particles emit photons which then interact themselves (two-photon physics).

Measurements near to the beam are in any case quite difficult due to the geometrical requirements of the vacuum pipe and to the high background level in this region. In addition, in many detectors so-called 'compensation coils' impose further limitations. Placing strong quadrupoles in the same regions would cause further complications. For PETRA, a solution has been found which completely eliminates the



Substitution of the compensation coils of the JADE detector at PETRA. The new quadrupoles have resulted in a threefold increase in luminosity.

Piwinski and Albin Wrolich tried this configuration and, with the help of the experimental groups, it worked first time.

Since then, studies and preparations have been undertaken to substitute all compensation coils at PETRA with quadrupoles and to add quadrupoles to Mark-J. These modifications were carried out at JADE and TASSO last winter so that these detectors can now compensate each other. CELLO still keeps its compensation coils, but quadrupoles have been added at Mark-J, with the excellent luminosity results already mentioned.

A system to increase DORIS luminosity using the mini beta scheme has been proposed by Klaus Wille. Following these ideas, the new ARGUS detector is being built with an integrated system of quadrupoles and compensation coils. The second DORIS interaction region will also be provided with new quadrupoles, bearing in mind a non-magnetic experiment like LENA, which could be proposed in the near future. The distance between the new quadrupoles will be 236 cm, compared with the original 512 cm. The new configuration, called DORIS II, should be ready next summer to provide a tenfold increase in luminosity.

compensation coils and makes space available for new quadrupoles.

Compensation coils are used to cancel the effects of magnetic detector fields on the beam. In particular, longitudinal fields like those of the usual solenoid magnets, placed in regions of high beam divergence, must be compensated to avoid coupling vertical and horizontal oscillations of the beam particles. Particles moving not exactly parallel to the (longitudinal) field describe helical trajectories not foreseen with the usual beam optics. These must be corrected by other longitudinal fields.

These problems have been investigated at DORIS and PETRA. In January 1980 Gerhard Ripken, who had earlier studied the problem for DORIS, proposed trying to compensate the longitudinal fields of different detectors with each other, with-

out recourse to compensation coils. He used a storage ring simulation program called PETROS to check his ideas.

For PETRA, the result was that detectors at 90 or 180 degrees to each other around the ring stood a good chance of mutually compensating. Detectors opposite each other should have the same (integrated) longitudinal fields in opposite directions, while detectors at 90 degrees should have the same fields, but in the same direction (as seen by a circulating particle). The situation at PETRA is complicated by the fact that one of the detectors (Mark-J) has no field on the beam at all. The other three can be adjusted so that two pairs compensate each other: JADE with half the field of CELLO (at 90 degrees) and TASSO with the other half of CELLO (also at 90 degrees). All three fields are directed the same way long the beam. Anton