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RESULTS OF MACHINE PHYSICS STUDIES ON PETRA IN 1979

by

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Introduction

During the year of 1979, about 30% of the total running time of the electron-positron storage ring PETRA was devoted to machine studies and improvements. This report compiles the machine physics results of these studies. Some of the material has been described separately in "Vorläufigen Mitteilungen". In such cases only a brief summary will be given here. All work on PETRA was oriented toward getting better conditions for colliding beam physics experiments. Correspondingly, the report focuses on the effects that determine luminosity and maximum energy. First measurements of polarization will also be described. Nothing will be said about experimental background problems, because of their strong dependence on the particular detectors. Most of the material should only be considered to be of very preliminary nature, requiring still a great deal of work. Of particular interest are those three main effects which were not anticipated in this form in the original proposal and which may well be the most important ones for any new large electron storage ring:

1.) The limitation of single bunch currents by a transverse instability not yet evaluated in the literature,

2.) the occurrence of strong satellite resonances which depend on bunch current and on beam position, and

3.) the observation of incoherent beam-beam effects that are considerably different from those usually assumed.

Maximum single bunch currents

The maximum single bunch currents are limited by a vertical instability. Beyond a certain threshold current, the vertical beam size is enlarged in an erratic way. When the current is increased, small vertical blow-ups may become large enough to cause a loss of part of the beam. The instability

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causes no signals on the displacement monitors and is not affected by the transverse feedback system. This indicates that there is no motion of the center of charge within the accessible frequency band up to a few GHz. A good deal can be said about this instability by recalling its history :

August 78: Shortly after the first start-up of PETRA, maximum single bunch currents of 5 mA* were observed. There were 16 5-cell rf cavities installed at that time.

October 78: In an effort to understand the limiting vertical instability, 12 of the 16 rf cavities were shorted by smooth inner tubes of the same diameter as the adjoining vacuum chambers. There was no significant change in the observed maximum single bunch current of 5 mA.

November 78: After reducing the large values of vertical beta function at the electrostatic plate system near each interaction region, i.e. at the only other significant disturbance of the otherwise very smooth PETRA vacuum envelope, the single bunch current could be increased to 18 mA.

March 79 : In order to permit high energy runs, the 12 cavity shorts were removed and 16 more cavities were installed. This reduced the maximum single bunch current from 18 mA to 8.5 mA.

Nov. 79 : After reducing the average value of vertical beta functions at the location of the rf cavities, it was possible to increase the peak current to 11.4 mA.

Like most other storage rings, PETRA exhibits the head-tail instability when the chromaticity becomes negative. Using a transverse feedback system, it is possible to run the machine at negative values of the chromaticity. This allows to check, whether the vertical single bunch instability is of a higher mode head-tail type. Although there seems to be a dependence of maximum current on chromaticity (1) (6.5 mA at $\xi_z = +4$, 9.6 mA at $\xi_z = -1$ in one particular experiment), the limiting instability still persists at negative chromaticities. This indicates that the effect cannot be described simply by any of the standard head-tail type models.

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* A single bunch current of 1 mA corresponds to $4.8 \cdot 10^{10}$ electrons or positrons per bunch.

As was to be expected, there is a strong dependence of maximum current on injection energy. In one particular experiment we found 5.5 mA at 5 GeV, 11.0 mA at 6 GeV and 15 mA at 7 GeV (1). This seems to be consistent with an E^3-dependence of maximum current on energy E, as one would expect if the instability were stabilized by Landau-damping. But reproducibility and accuracy of these measurements is not good enough to exclude an E^4-dependence, as might be expected if the stabilizing force is radiation damping. Also the simple E^3 or E^4 power laws may be modified by dependences on bunch length.

Although there is no theory yet which describes this instability, it is felt that a higher harmonic rf system may produce a considerable improvement. Such a system was first proposed for PETRA in 1976 (2) and is being constructed at present. By cancelling the gradient of the accelerating field at the location of the bunch, it greatly increases the bunch length and introduces an extremely strong dependence of synchrotron frequency on momentum deviation. Both effects may greatly influence the current limiting single bunch instability.

Maximum current with more than one bunch

With more than one bunch in the PETRA storage ring, bunch-bunch interactions have been observed occasionally. Such interactions probably work through higher modes in the rf cavities. They do not present any problem because they can easily be damped by the transverse feeback system or by the strong head-tail damping that exists with positive chromaticity (at bunch currents of 6 mA and chromaticities of + 3, damping times of 3 to 5 ms have been observed (1)).

The main problem arises when strong electron and positron bunches influence each other during injection through their electromagnetic fields at the interaction regions. During injection and acceleration both beams are separated by electrostatic fields. Although the vertical separation is typically 4 mm at the interaction points, focusing effects produced by one beam on the other are strong enough to shift the Q-values for incoherent motion by as much as

ΔQ_x = +0.006 per mA of the opposing beam

ΔQ_z = -0.0004 per mA " " " "

The shift of the horizontal betatron frequency may be large enough to move the working point onto one of the many satellite resonances (see next chapter), with subsequent loss of beam. The largest currents obtained under those circumstances were 2 x 8 mA of positrons against 2 x 8 mA of electrons. In order to obtain these currents, careful adjustment of Q-values during injection was necessary.

Among the possible improvements of this situation are higher separator voltages (the ΔQ-changes are inversely proportional to the square of the separator voltages), special injection optics with smaller horizontal beta-functions at the interaction point (the ΔQ-changes are proportional to β^*), higher injection energies (the strength of satellite resonances seems to decrease with energy) and compensation of satellite resonances.

Satellite resonances

One of the most outstanding beam dynamics features in PETRA is the unexpected strength of the current-dependent satellite resonances (Fig.1). Depending on the particular operating conditions (machine acceptance, beam energy, current, orbit adjustment etc.) even crossing the fifth satellite of an integral resonance may lead to significant current losses. To avoid such losses, careful control of Q-values during injection and acceleration is necessary: An automatic Q-control device which continously measures and readjusts horizontal and vertical betatron frequencies and synchrotron oscillation-frequency helps at the present time to overcome the great difficulties which this effect otherwise causes.

The strength of the satellite resonances seems to have increased after the number of rf cavities was increased from 4 to 32. There are no quantitative comparative measurements, though. It also appears that smaller machine acceptances lead to a larger beam loss on any of these resonances.

Since the strength and thereby the width of the satellite resonances increases with single bunch current, the currents may be limited, if the Q-values have not been chosen right. Fig.2 shows a measurement of the maximum obtainable single bunch current as function of horizontal Q-value for two different optics. Only in the flat portions at 13.5 mA and 5.5 mA, respectively are the single bunch currents limited by vertical instabilities.

At all other Q-values, satellite resonances seem to limit the obtainable single bunch current (the asymmetric shape of these curves is still not understood).

There are 4 known mechanisms to cause such satellite resonances: 1) Chromaticity 2) Dispersion at the rf cavities 3) Variation of amplitude function with energy at the rf cavities 4) Deflecting modes in the rf cavities. The machine studies aimed at finding out which of these mechanisms applies and what measures to take for improving the situation.

1) Chromaticity causes a modulation of the betatron frequency by the phase oscillation. This results in a large number of sidebands with decreasing amplitude. The betatron amplitude will grow whenever one of the sidebands coincides with an integral resonance. Since the phase oscillation may be very nonlinear due to the distortion of the rf-field by the bunch field (potential well depression), the amplitude of the higher sidebands may be very current dependent. It was found however that the strength of the satellite resonances does not appreciably depend on the chromaticity, thereby ruling out this mechanism.

2) Dispersion in the cavities will lead to an excitation of coupled synchro-betatron oscillations (3). Since PETRA has been designed with zero dispersion at the location of the accelerating cavities, only spurious dispersions could contribute to this effect. Turning on or off 3 out of 4 double transmitters of PETRA did not significantly change the strength of the observed 3rd to 5th satellite resonances. At first sight this result seems to speak against an excitation via the mechanism of dispersion. But then one has to remember that the higher order side bands may only depend on the rf distortion by the bunch and may not be much affected by the main rf voltage.

In order to test whether spurious dispersion is responsible for the satellite resonances, such dispersion was artificially created by asymmetric beam bumps at the 4 interaction regions. Asymmetric beam bumps create large displacements at the high beta quadrupoles and are particularly effective in creating dispersion around the whole ring. Such dispersion would be superimposed on any spurious dispersion that exists in the rf accelerating sections. By choosing the right bump combination and thereby the correct phase angle of the dispersion vector at the cavities, it should be possible to tune out the effect of the spurious dispersion, so that the strength of the satellites approaches zero. The strength of the satellites was determined by measuring the residual current after slowly moving the Q-value through the resonance. Fig.3 shows the result of such a measurement. The residual current indeed seems to be a very strong function of the asymmetric beam bump amplitude and this seems to indicate that residual dispersion may well be one of the causes for satellite resonances. This result, however, is not unambiguous since asymmetric beam bumps,because of the large displacements they produce in the high beta regions, may also cause satellite resonances through excitation of higher deflecting modes in these regions, where the vacuum chambers are very irregular.

3) Satellite resonances may be excited by the fact that the amplitude function at the location of the rf cavities varies with momentum (4). Such a mechanism creates resonances spaced by half the synchrotron frequency. Since these resonances have not been seen, this mechanism can be excluded.

4) Vinokurov et.al. (5) and Sundelin (6) have shown that intense bunches may excite deflecting modes if the bunches do not pass through the center of cavities or other irregularities. The strength of the deflecting field seen by a particle is a function of its phase position in the bunch. The betatron and phase oscillations, therefore, are coupled by this mechanism. The strength of the satellite resonances, in this model, depends critically on the orbit distortions in the rf cavities. By producing intentionally two orthogonal distortions over part of the rf straight sections (rf beam bumps) , it should be possible to compensate the excitation produced in other parts of the ring. The dispersion generated by such rf beam bumps is very small and can be neglected.

By observing the surviving current after crossing a satellite and optimizing it by means of two orthogonal rf beam bumps, it was indeed possible to dramatically affect the strength of the satellite resonance (Fig.4). This shows that this mechanism may well be the dominating - if not the only -

cause of the observed satellite resonances. It also shows that the apparent extreme sensitivity of satellite strength against changes in orbit position makes it very difficult to eliminate this effect in a practical sense by orbit control during injection and acceleration. A significant improvement of this situation may be expected when the higher harmonic cavity is put into operation. The large increase in bunch length should reduce the excitation of higher cavity modes, and the very strong dependence of phase oscillation frequency on amplitude should suppress any resonance behaviour.

Coupling

In order to get the highest possible luminosity, particularly at high colliding beam energies, it is important to have a small beam height, i.e. small vertical beam emittance ε_z or small coupling factor $K = \varepsilon_z/\varepsilon_x$. Despite its name, the coupling factor K is not so much determined by betatron coupling between the horizontal and vertical planes (except when one is very near to a difference resonance), but to a large extent by genuine quantum excitation in the vertical plane produced by spurious vertical dispersion. Some of the machine physics runs were devoted to developing a technique for minimizing K. The coupling factor was determined by measuring the frequency splitting between the two modes of coherent betatron oscillations, when one electron bunch collides with one position bunch. In order to extract from such measurements the value of the vertical beam size, it is important that the betatron oscillations be excited with as small an amplitude as detectable. This technique has been described in (7). In order to get small values of the coupling factor, a good orbit correction is prerequisit. The standard PETRA orbit correction routines result in residual orbit distortions with rms values smaller than 2 mm. After such a correction, K-values of 10 to 20% are typical. The spurious vertical dispersion, which is the main cause for this "coupling", can be further reduced by asymmetric vertical beam bumps at the four interaction regions. These bumps are very effective in producing vertical dispersion all around the ring, and small orbit distortions of this type may be the main contribution to the spurious dispersion. But any dispersion produced by other vertical kicks in the ring can also be reduced to some extent by operating these bumps. The technique, then, is to operate the

4 asymmetric beam bumps at the four interaction regions one after the other and minimize each time the value of K. Fig.5 shows a measurement of K versus beam bump current before and after such optimization. The optimum values of 8.5% and 2.3% were also confirmed by luminosity measurements at small currents. As shown in this example, K-values smaller than 5% can be routinely achieved with this method.

Incoherent beam-beam interaction

In the original PETRA proposal, the standard assumptions about incoherent beam-beam interactions were made: Colliding bunches exert on each other linear and nonlinear focusing forces of which the linear part can be expressed as

$$\Delta Q_{z,x} = \frac{r_e N_e \beta_{z,x}}{2\pi\gamma\,\sigma_{z,x}(\sigma_x+\sigma_z)}$$

r_e = classical electron radius
N_e = no. of particles per bunch
β = value of beta function at I.P.
γ = energy in units of rest energy
σ = standard deviation of beam size

At a certain ΔQ-limit assumed to be the same in both planes, the beam size suddenly increases, and the luminosity and even life time goes down. Assuming further that ΔQ_x is made equal to ΔQ_z by choosing a ratio of vertical to horizontal beta functions at the interaction points equal to the coupling factor K, and with $\sigma_z << \sigma_x$, the space charge limited luminosity can be expressed as

$$L = \frac{\Delta Q^2\,\pi\,\gamma^2\,\varepsilon_x\,f\,n}{r_e^2\,\beta_z}$$

f = circumferential frequency

n = no. of bunches in each beam

It is further assumed that the ΔQ limits were independent of the number of interaction regions and had values of 0.06.

This original picture does not seem to describe the facts at the PETRA storage ring as they have been observed so far.

As soon as two bunches collide, an increase in vertical beam size is observed. If the bunches have unequal currents, the beam size increase of the weaker beam is larger than that of the opposing stronger beam. Whether there is any threshold for this effect at all, seems questionable and is difficult to decide, since measurements of small vertical beam heights are very difficult. Reliable numbers can only be gotten through luminosity measurements, which at very small currents have large statistical errors.

A good empirical description seems to be (8)

$$\sigma_{z1}^{2} = \sigma_{zo}^{2} + \left(\frac{a \cdot i_2}{\sigma_{z2}}\right)^2$$

$$\sigma_{z2}^{2} = \sigma_{zo}^{2} + \left(\frac{a \cdot i_1}{\sigma_{z1}}\right)^2$$

$\sigma_{1,2}$ = vertical beam size of beam 1,2

σ_{zo} = vertical beam size for zero current in the opposing beam

a = constant

with σ_x being independent of current. It would lead to a dependence of vertical beam size on the current in the opposing bunch as shown in Fig.6, which does not seem to be inconsistent with observations. Such dependence then allows to express the luminosity as a function of current (8), and this expression, as it turns out, can be matched to the observed luminosity. Figs.7, 8 and 9 show the specific luminosity as measured with 2 bunches in each beam at energies of 6, 11 and 15.3 GeV, respectively. Considering the large systematic and statistical errors of an individual luminosity measurement (at least 10%), the analytical description seems satisfactory. It uses two free parameters: The specific luminosity at zero current, and the parameter "a". It was further assumed that there was a 10% unbalance between the currents in the opposing bunches (the balance was not carefully controlled in these measurements). The empirically found parameter "a" varies with the 4th power of energy, as shown in Fig.10. Due to their limited accuracy, the measured luminosities would also permit a somewhat different power dependence.

It thus appears that the usual description of space charge effects by the linear tune shift may not be very practical : The vertical tune shift is a nonlinear function of current and may also be very different for the two opposing bunches, even if the currents are nearly equal. The maximum values of the vertical tune shift that could be reached are much smaller than originally assumed (Fig.11).

The measurements shown in Figs. 7, 8 and 9 were made with 2 bunches in each beam,i.e. there were 4 interaction regions. Most of the high energy physics runs in 1979 were done in this mode. Test runs were also made with only one bunch in each beam and with 4 bunches in each beam. Many of the results are summarized in (9). Although these measurements are often contradictory, it was consistently observed that for larger currents the specific luminosities are always larger with one against one bunch than with two against two bunches. Fig.12 shows a typical comparison.At a single bunch current of .8 mA L_{sp} is almost twice as large for the one against one bunch case, and the total luminosity per collision point is therefore not increased by going to two times two bunches. Since there are twice as many collision points, however, the luminosity-total in all interaction regions has still increased by a factor of 2.

In the case of 4 against 4 bunches there are 8 collision points, but particle detectors are only installed at four of them at present.If one wanted to avoid excessive space charge effects, it would be advantageous to separate the beams electrostatically at the unused interaction regions. When this was tried it was found that asymmetries in the electrostatic plate system left residual deflections at the 4 active interaction regions, thereby greatly affecting the measured luminosities and presumably also the space charge effects. Without any electrostatic separation, i.e. with 8 interaction regions, first indications are that not only the specific luminosity but also the absolute luminosity per interaction region was smaller than in the case of two against two bunches or one against one bunch. But these results are so preliminary that they might not have too much significance. In order to get some idea of the time constants involved in this incoherent beam-beam blow up, a real image of the beam cross section was produced on a horizontal slit by using the visible synchrotron light emitted by the beam. The width of the slit was matched to the image of the beam height under the condition that both beams are separated at the interaction points. Fig.13 shows how the amount of light decreases, i.e. the beam height increases, when the beams are brought together at the interaction points. The second trace on this picture shows the electrostatic separation voltage as a function of time. At t=0 the voltage is switched off and decays with a time constant of about 2.4 ms. The initial slow change of light intensity through the slit may be due to a small vertical motion of the beam at the place of observation due to imperfect electrostatic beam bumps at the interaction regions. After 10 ms the light level suddenly decreases within one millisecond, indicating a rather sudden vertical blow-up. A rough estimate indicates that at this time the beam separation is about one standard deviation of the initial distribution. If these first preliminary findings hold up under better control of the experiment, one must assume that the blow-up occurs in a time short as compared to the radiation damping time (which in this case was 170 ms). This would exclude diffusion models for the explanation of the space charge effects and make the latter look more like a resonance blow-up.

Optics checks

Some of the machine time was used to verify the results of optics calculations in order to make sure that no unknown effects had changed the machine significantly.

The beta values at a large number of quadrupole locations were compared with theoretical predictions. Beta values were determined by measuring the change of betatron frequency for small changes in the focal strength of the lenses. Fig.14 shows such a comparison. The agreement must be considered excellent. Larger deviations at places of small beta values are probably due to measuring errors.

The symmetry of the storage ring was checked by comparing the beam displacements produced by steering coils in symmetrical locations. From these measurements one might estimate that beta values in presumably symmetrical locations do not deviate by more than ± 10%.

The spurious vertical dispersion was measured by observing the change in vertical beam position upon changing the radio frequency. The results of such a measurement are shown in Fig.15. They are in good agreement with results of the "PETROS" optics program which simulates machine imperfections, applies the orbit correction procedure and determines the effects of remaining orbit distortions.

The machine imperfections also affect the horizontal dispersion. Fig.16 shows a comparison between the theoretical dispersion curve (dashed line) and the measured dispersion (solid line). The deviations are of similarly acceptable magnitude as in the vertical plane.

Machine acceptance

It is important that the machine acceptances be as large as possible. Large acceptances will increase injection efficiencies, reduce the effect of satellite resonances and increase the current limits for single bunches as given by vertical instability. For the colliding beam case it is equally important to have large machine acceptances, since one can then work with a larger beam emittance and a correspondingly higher luminosity whenever it is limited by space charge effects.

After a standard orbit correction procedure, acceptances are limited by resonances. These resonances are mainly caused by the distributed sextupole magnets needed for chromaticity control. Sextupole magnets are arranged in 6 families which can be powered separately. The distribution of sextupole strength in the ring can be chosen such as to satisfy different criteria. Of 4 different injection optics studied, the first one,M 501.2.1., groups all sextupoles into two families such as to correct the linear component of the horizontal and vertical chromaticity. The second optics, M501.2.2, also uses only two groups of sextupoles, but leaves out a certain number of those magnets. With the remaining magnets again the linear components of chromaticity are being corrected. In the third arrangement, M501.6.1., the linear chromaticity component is corrected in the horizontal plane, whereas in the vertical also the quadratic dependence of betatron frequency on momentum is compensated. Furthermore the dependence of beta function on energy is compensated to first order at the interaction point in both planes. In the fourth optics, M501.6.4, chromaticity is corrected in both planes up to third order. All these optics have been simulated in the beam tracking program "LIMATRA" to determine the theoretical acceptance as a function of energy (10). The results for $\frac{\Delta E}{E} = 0$ are given in the table, Fig.17. As an amplitude cutoff, the LIMATRA program used the "mechanical acceptances" of PETRA as given by the vacuum chamber envelope, the good field region of certain magnets and the beta functions at these locations, and worked with a fixed initial coupling of K = 0.05. For this emittance coupling, the overflow always occured in the horizontal plane, and thus the tracking results give a prediction for the horizontal acceptances. In the first and the fourth optics, the predicted acceptance is close to the mechanical acceptance (Fig.17), while for the other 2 optics it is smaller and is clearly limited by the sextupole field nonlinearities.

The actual machine acceptances were determined by exciting betatron oscillations in one plane at a time, with amplitudes large enough to cause a small reduction in lifetime. Machine scrapers were then used to find the aperture at which further lifetime decreases could be observed. From this aperture and the known value of betas at the place of the scrapers the acceptance can be calculated. Fig.17 shows the result of these measurements. In addition, the emittances for a luminosity optics at 19 GeV are given in Fig.17. This luminosity optics is not suitable for a direct comparison with the indicated machine acceptances because it has smaller beta values at the interaction points, requires consequently stronger chromaticity corrections and has therefore presumably smaller acceptances than the injection optics which were here investigated. Still, it may be comforting to know that the measured acceptances are large as compared to the requirements at 19 GeV. The agreement between beam tracking calculations and actual measurements can only be called surprizing, considering the fact that the given calculated values do not include momentum deviation and that measurements were only done in one plane at a time. Also, machine imperfections were not included in the beam tracking. The remarkable result of the measurements is, that the sextupole arrangement which corrects chromaticity up to third order seems to be best.

rf studies

In trying to go to the highest energies it is important to understand the rf acceleration system with all its losses, inefficiencies and imperfections. By measuring the klystron output power, the cavity input power, the cavity voltages and the synchrotron frequency one can get a consistent picture of the rf system. On the basis of this picture one can extrapolate that, with 60 cavities and an output power of 600 kW from each of the 8 klystrons, a zero current energy of 18.7 GeV should be reachable. With a current of 10 mA in the machine, an energy of 18.5 GeV should still be possible.

Higher order mode losses

By measuring the phase position of a high current single bunch and by comparing it with the phase of a low intensity bunch preceding the high intensity bunch, it is possible to determine the losses caused by the excitation of higher modes in the rf cavities and in other incidental structures (1).

A measurement of the loss parameter as a function of bunch length is shown in Fig.18. The coefficient k, which describes the higher order mode voltage as a function of bunch charge, can also be expressed in terms of an effective impedance. The impedances found for bunch lengths (1 st.d.) of 1 cm, 1.5 cm and 2 cm are 715 M Ω , 453 M Ω , and 323 M Ω , respectively. These values apply to the condition of 32 5-cell cavities in PETRA and are mostly determined by losses in the cavities. For typical operating conditions of 4 times 5 mA they correspond to about 45 kW higher order mode loss and are not yet significant.

Bunch lengthening

At large single bunch currents, a certain bunch lengthening is observed (11;1) which is much smaller than originally expected from turbulent bunch mode theories. The observed lengthening at 10 mA and 6 GeV was measured with only 4 installed rf cavities (11) and was found to be $s/s_o = 1.8$. With 32 installed cavities and otherwise comparable conditions, $s/s_o = 2.5$ was found. At an energy of 13.8 GeV and 7 mA with 32 installed cavities, no lengthening could be observed ($s/s_o = 1$). So far, bunch lengthening in PETRA has had no significant consequences.

Beam polarization

At energies of 10 GeV and higher, lifetimes begin to exceed the build-up times for beam polarization in the absence of depolarizing resonances (12). In order to measure beam polarization, a special apparatus was constructed and installed during 1979 (13;14). This apparatus is designed to measure small asymmetries in the Compton backscattering of circularly polarized laser photons. The asymmetries are directly related to transverse beam polarization in the storage ring.

Most of the tests necessary to assure the proper operation of this setup could be successfully concluded during 1979 : Measurements of the rates and energy spectra of the backscattered laser photons, measurements of the vertical beam profile of the photon beam for making sure that it corresponds to theoretical expectations and is narrow enough to show backscattering asymmetries should they exist, comparison of the photon beam profiles with linearly polarized and circularly polarized laser photons and comparison with theory, checks of the gas bremsstrahlung background and the beam-beam single bremsstrahlung background and reduction of these backgrounds to a tolerable level. All these tests were consistent with expectations for a properly working polarization measurement setup. A first measurement of polarization under controlled and satisfactory conditions at an energy of 13.86 GeV was performed toward the end of the year. Fig.19 shows the asymmetry A as a function of the vertical distance from the median plane as it would be expected for 92% polarization (the maximum possible degree,solid line),and the measured numbers. From this measurement a polarization larger than 20% can be excluded with a 95% confidence level.

This measurement was done at a particular beam energy and under particular orbit conditions. Although these conditions were thought to be favorable for beam polarization, one must be careful in drawing premature conclusions. Much more work will be necessary to make definite statements about beam polarization in PETRA.

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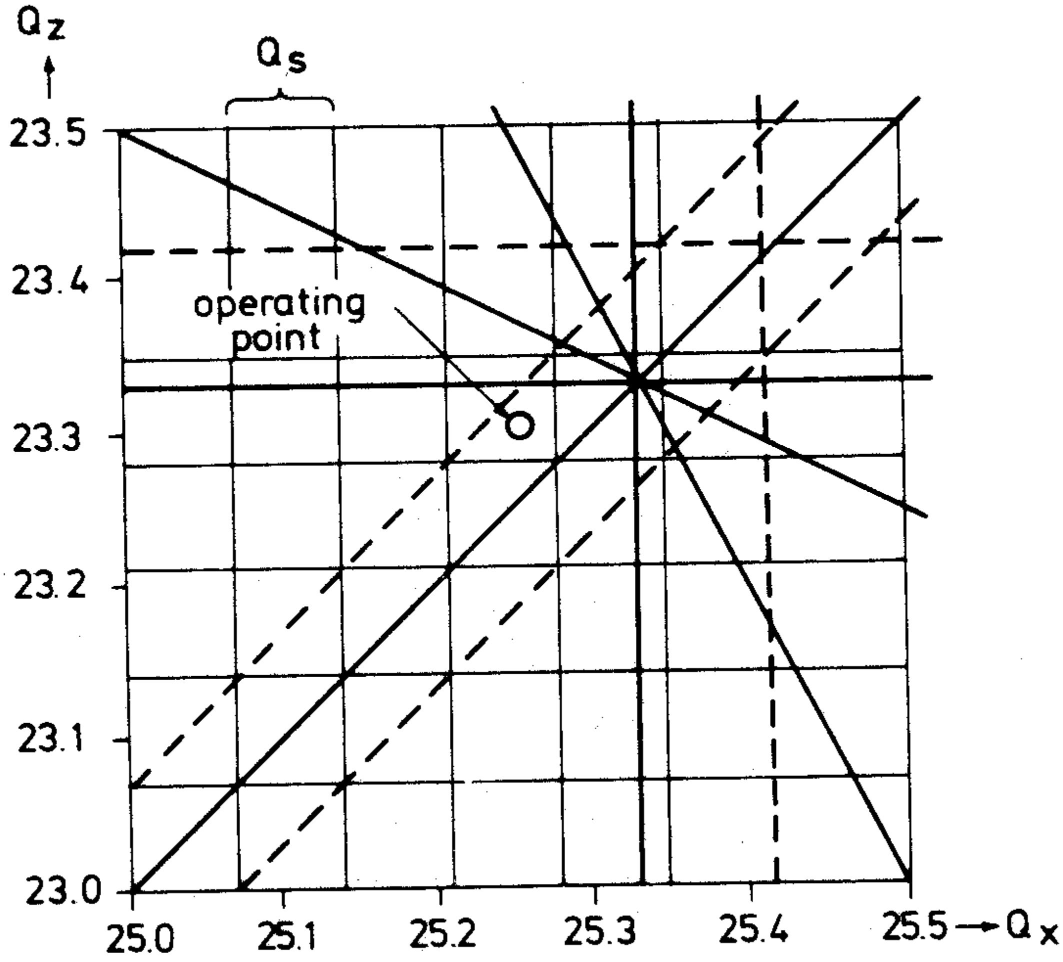

Fig.1 PETRA resonance plot. Solid lines: Resonances causing current loss. Dashed lines: Resonances causing only changes in beam size.

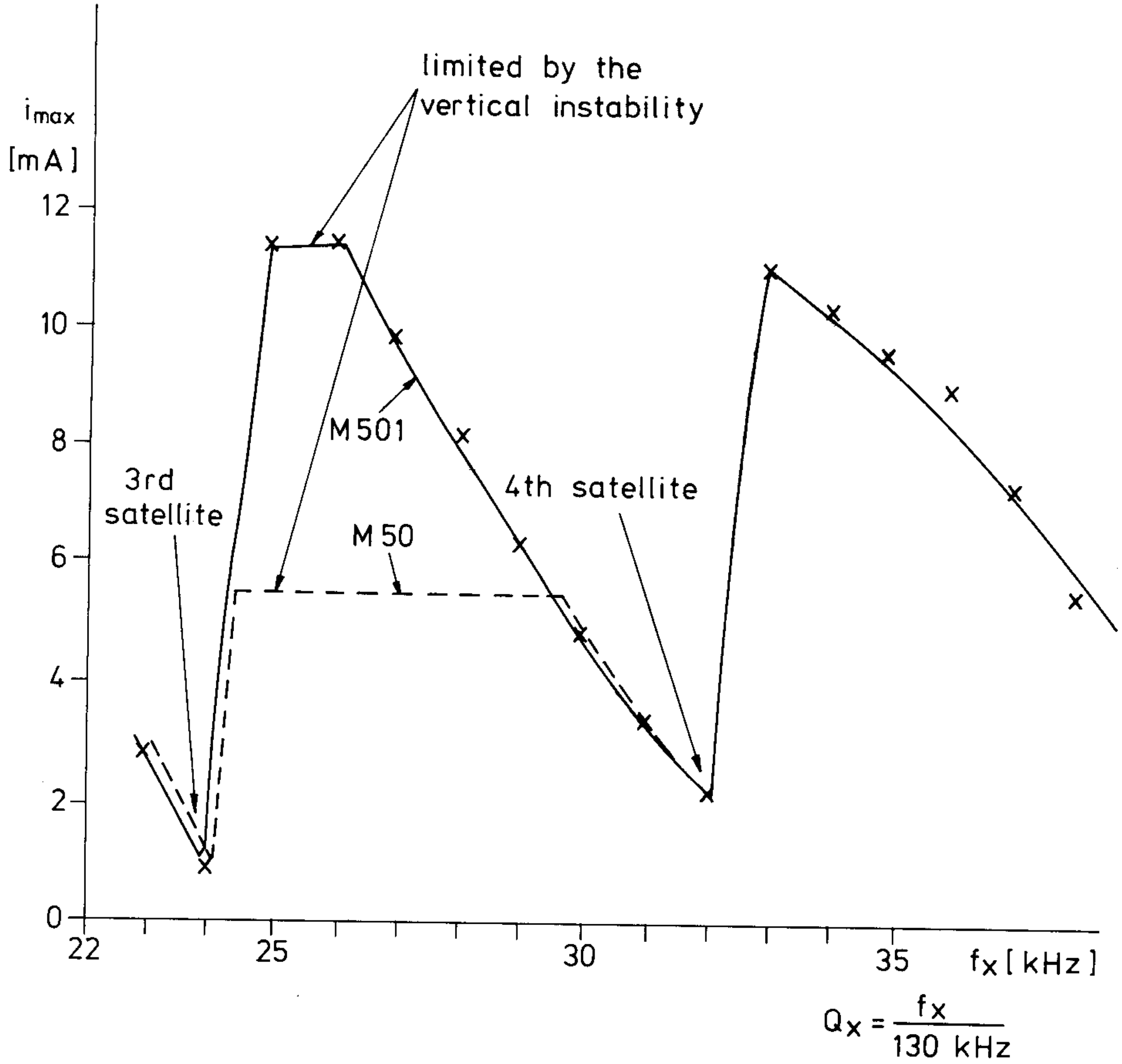

Fig.2 Maximum single bunch current as a function of horizontal betatron frequency for two different optics (M 501 and M 50)

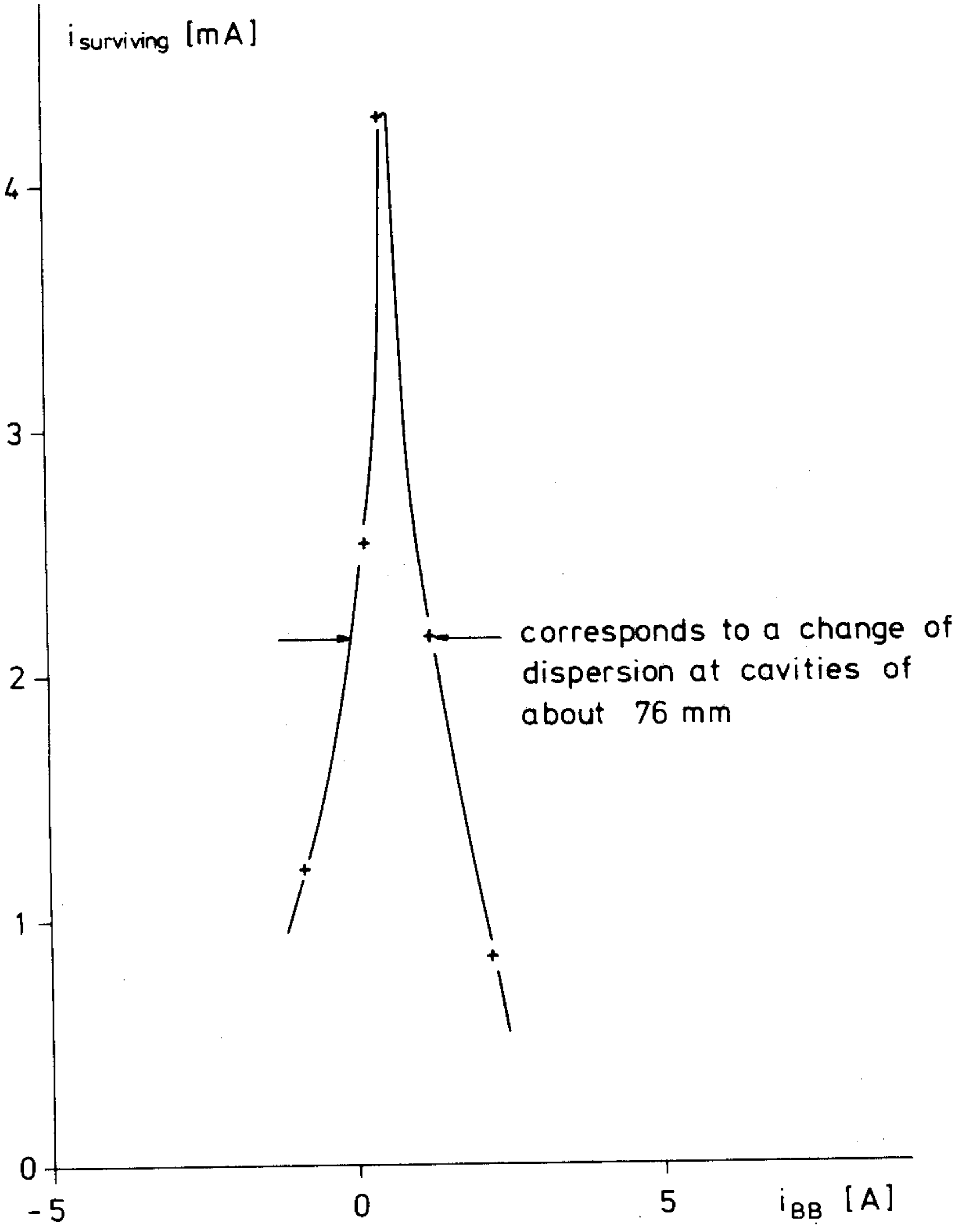

Fig. 3 Surviving current as function of asymmetric beam bump current. 1 A corresponds to $(D_x^2 + (\alpha_x D_x + \beta_x D'_x)^2/\beta_x = 0{,}21$ mm

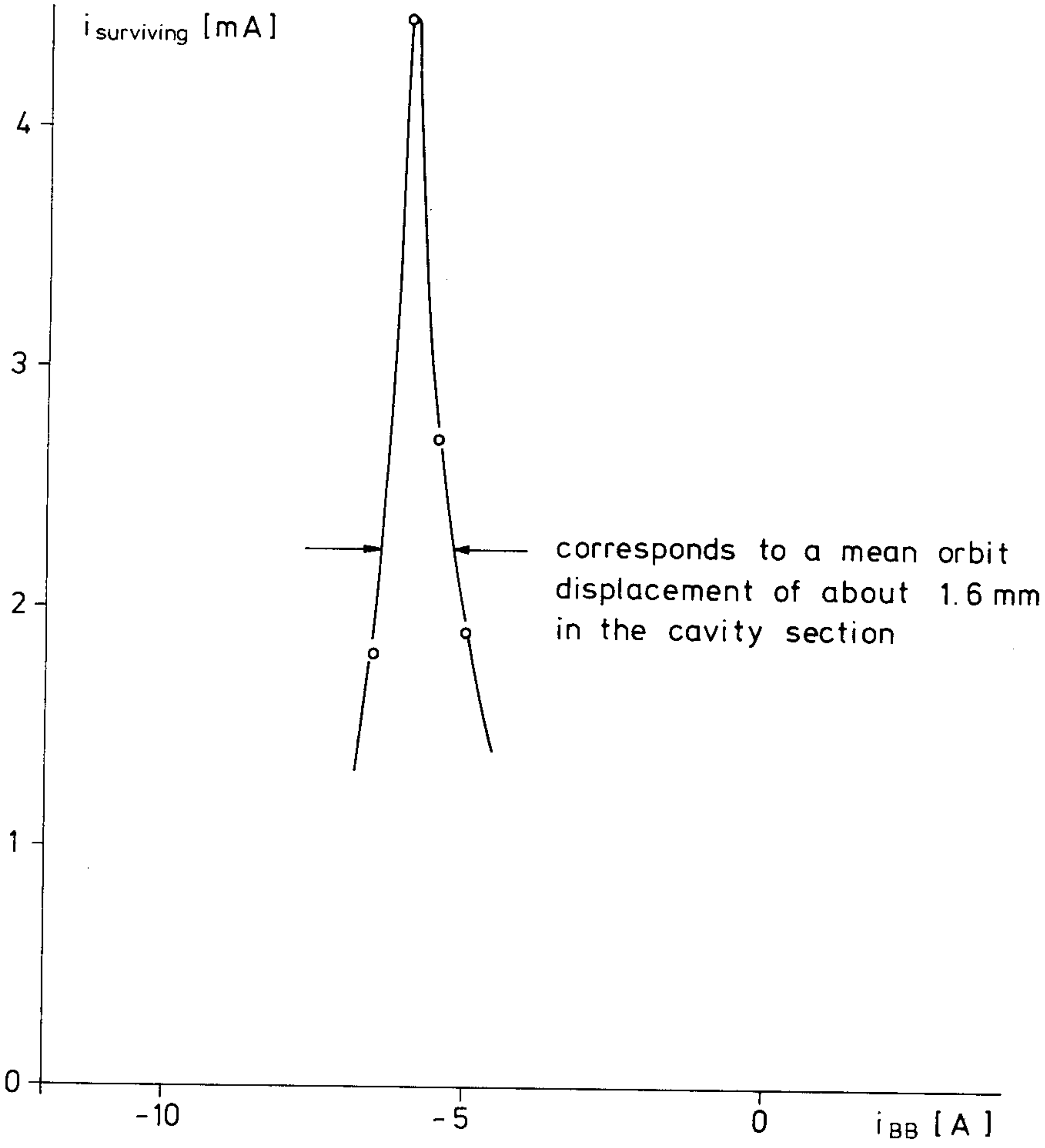

Fig.4 Surviving current as function of cavity beam bump current.
1 A corresponds to a mean orbit displacement of 1.3 mm.

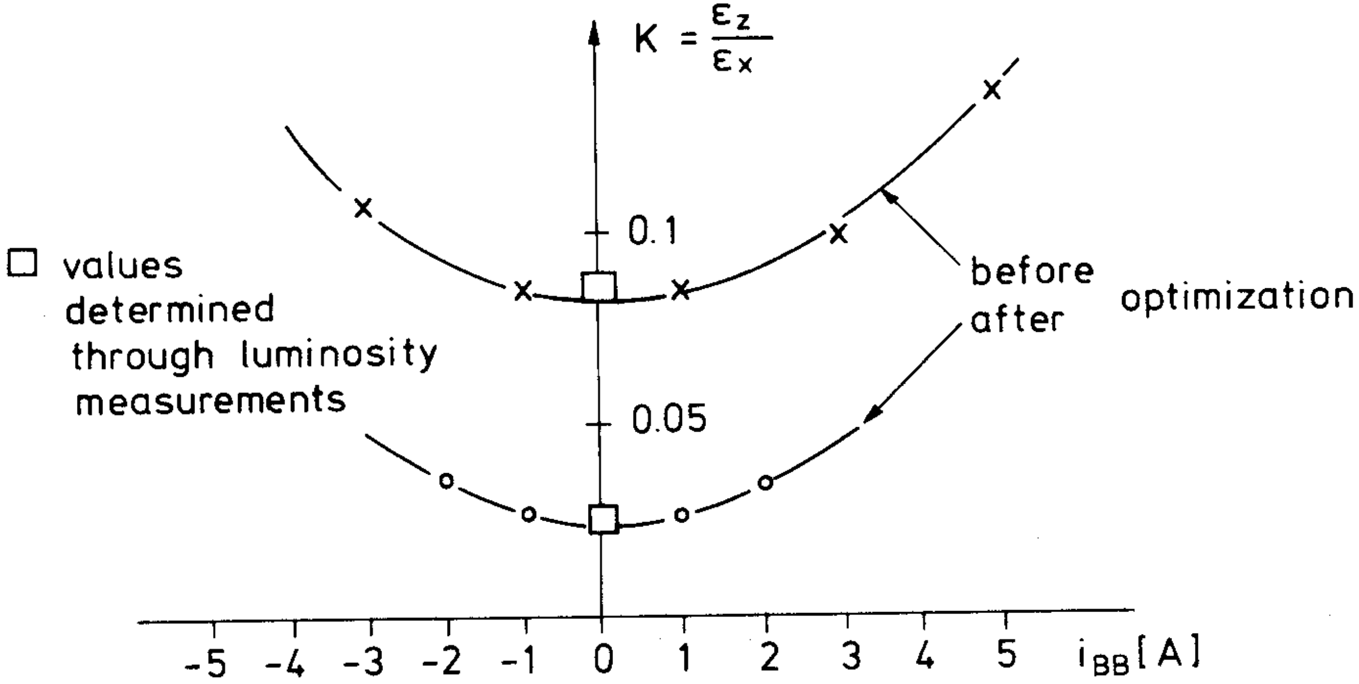

Fig.5 Coupling K as function of asymmetric beam bump current.

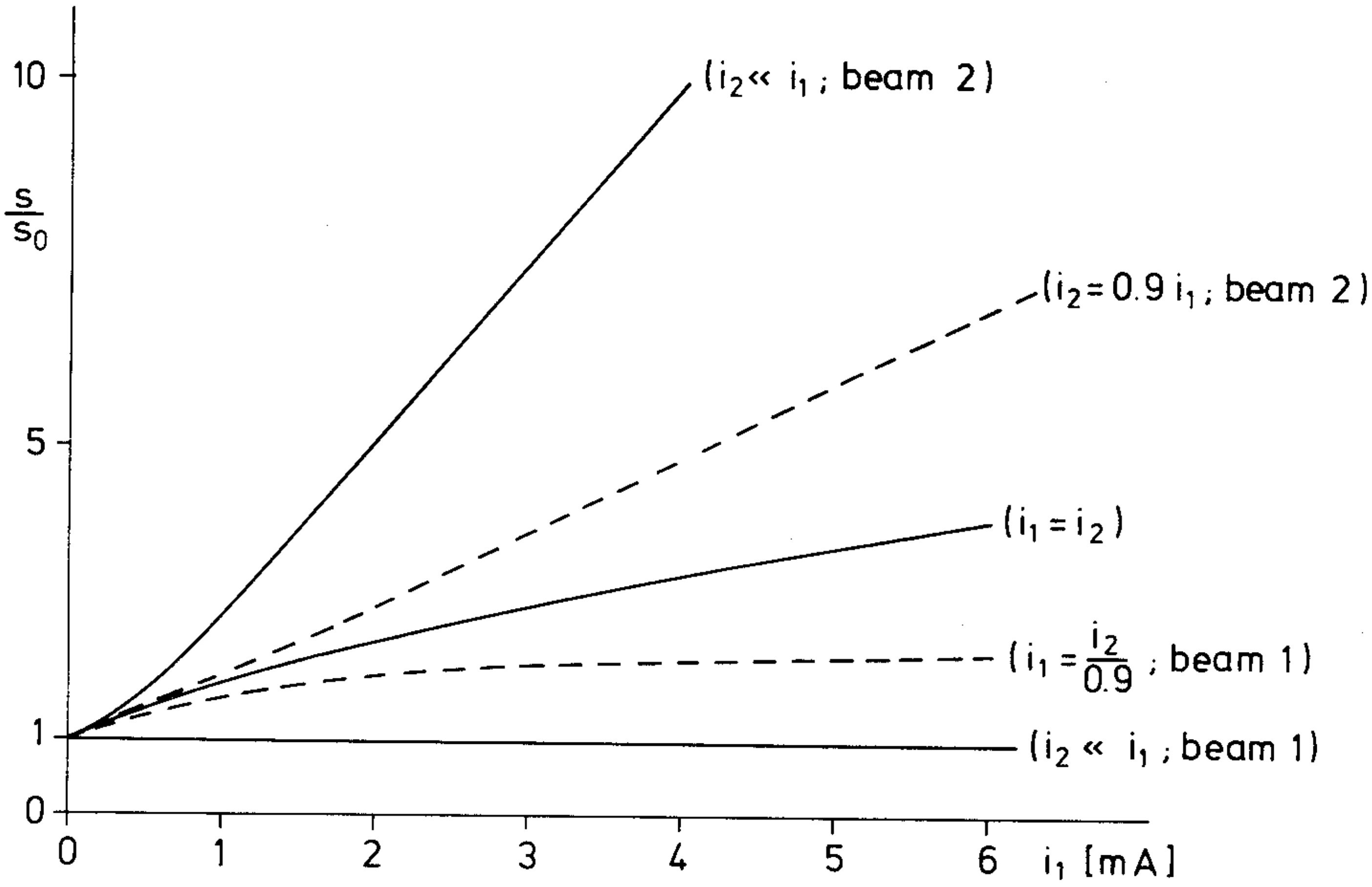

Fig.6 Relative beam height as a function of bunch current for various current ratios of colliding bunches.

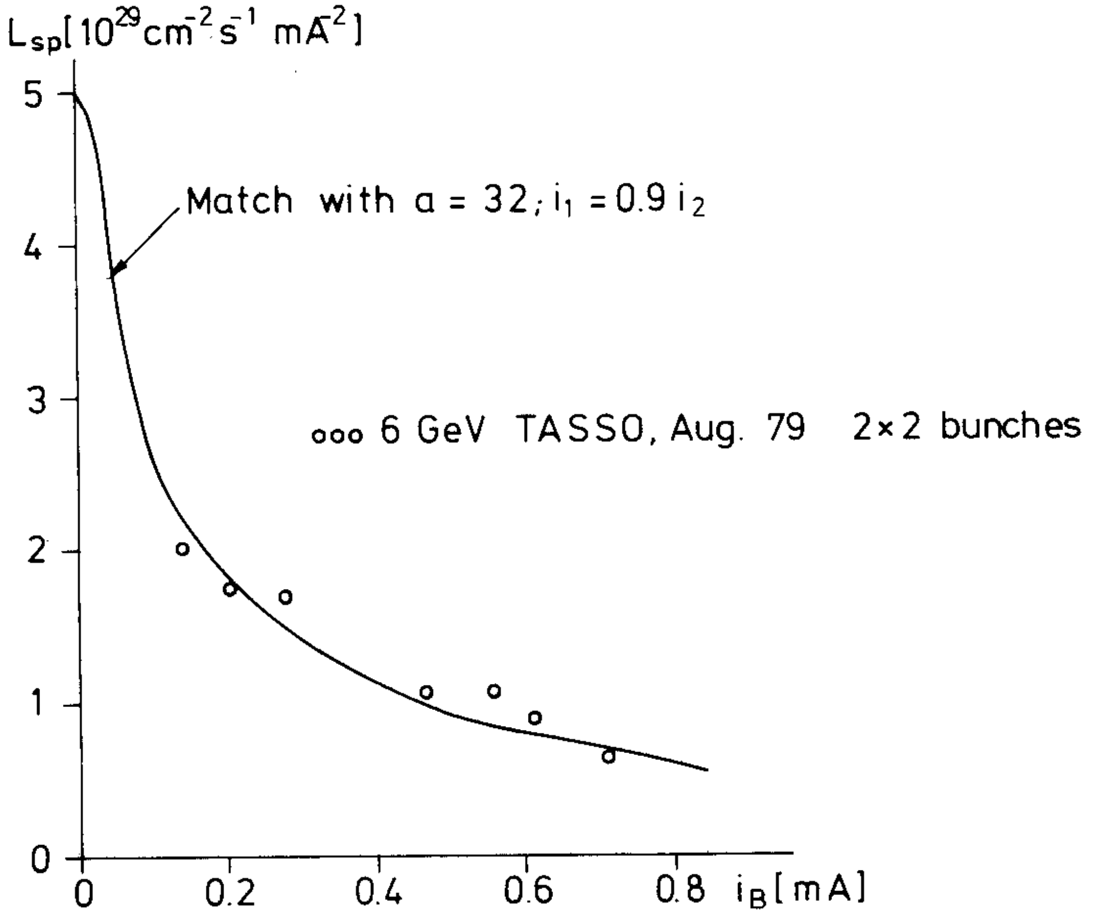

Fig.7 Specific luminosity as a function of bunch current at 6 GeV.

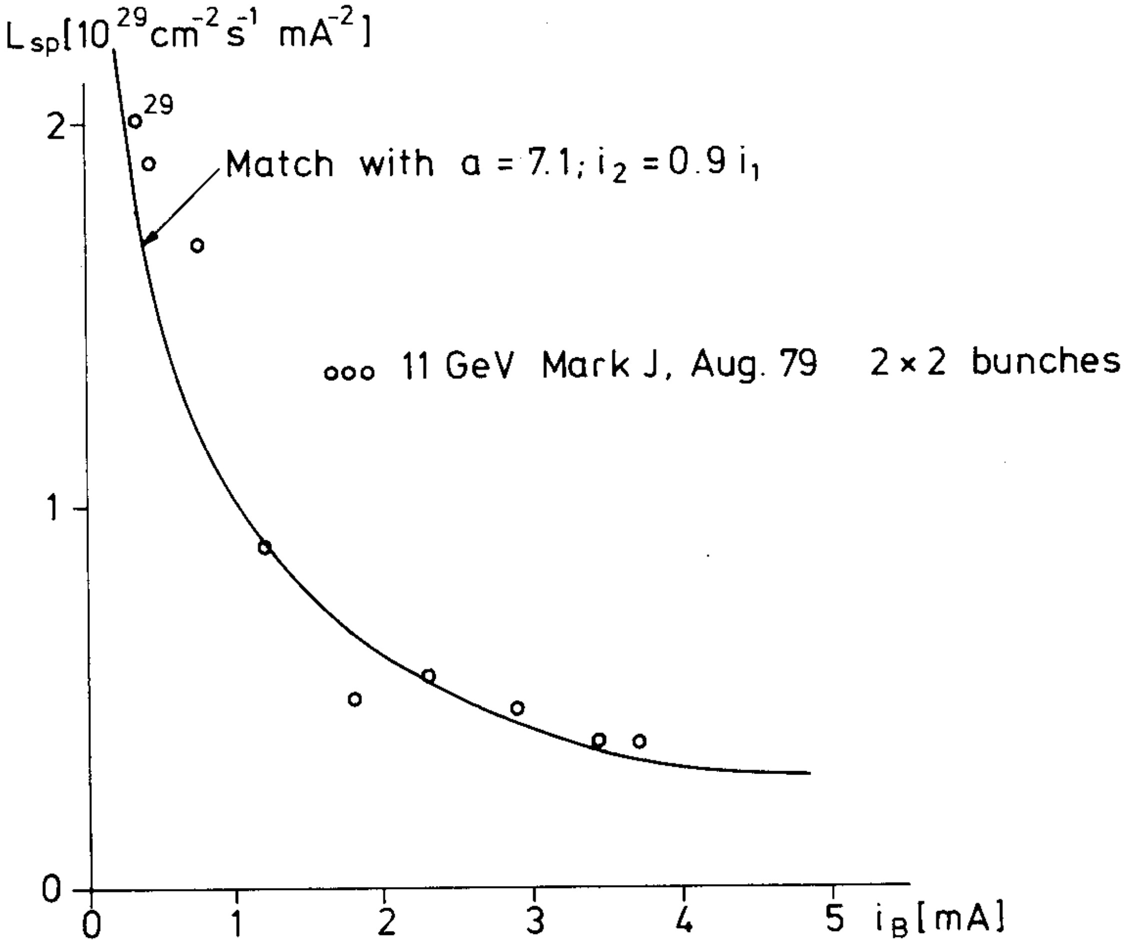

Fig.8 Specific luminosity as a function of bunch current at 11 GeV.

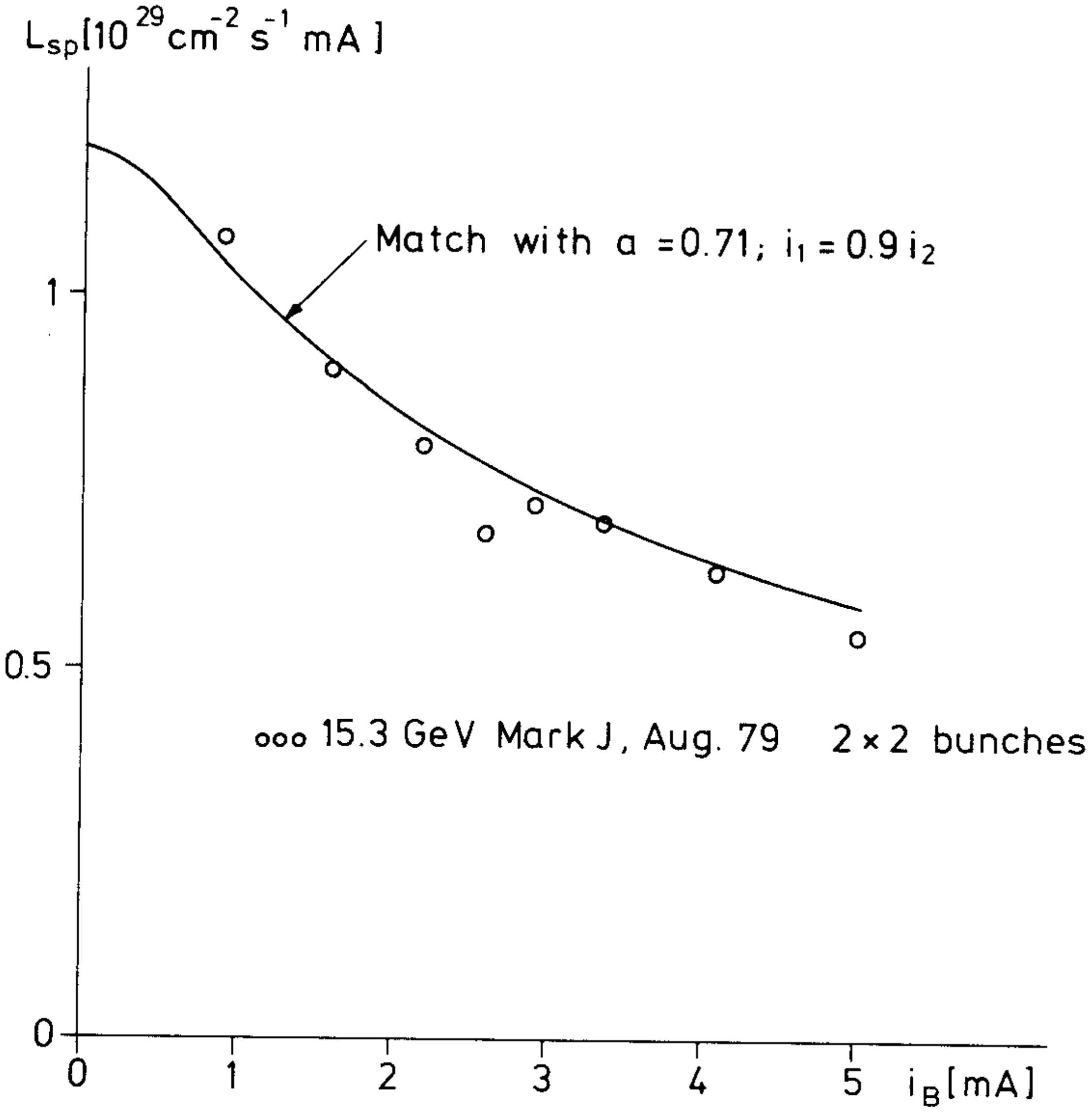

Fig.9 Specific luminosity as a function of bunch current

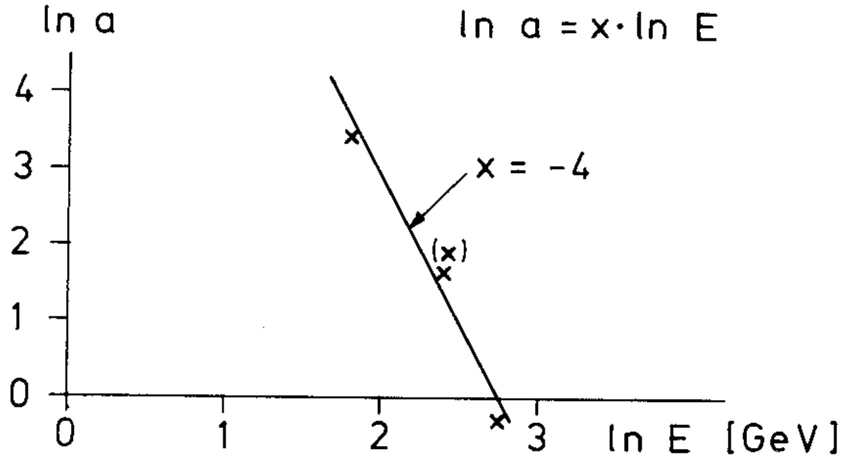

Fig.10 Dependence of interaction strength parameter "a" on energy.

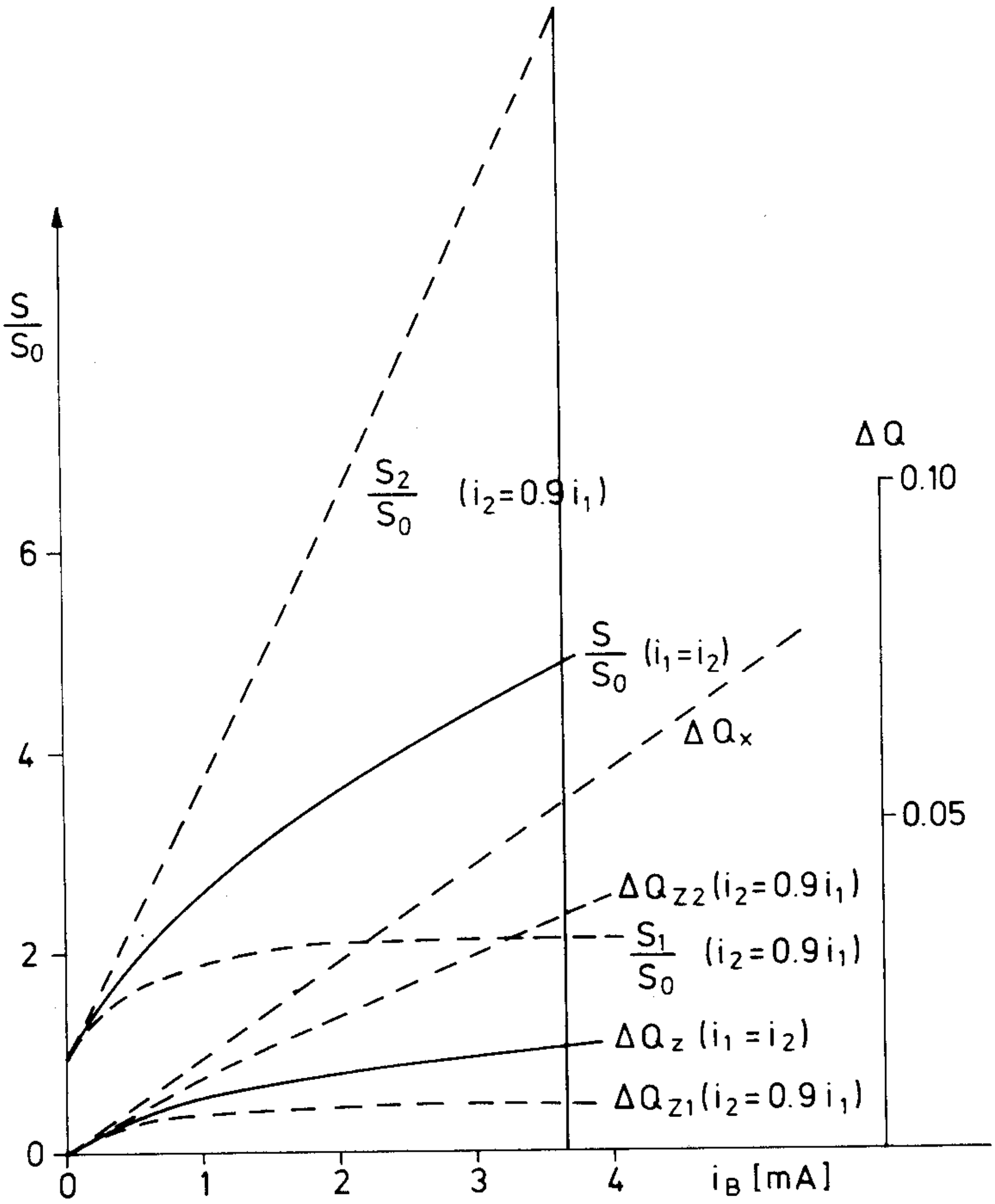

Fig.11 Relative beam height and Q-shifts for beams 1 and 2 for the case $i_1=i_2$ (solid lines) and $i_2=.9i_1$ (dashed line). Beam parameters are the same as in Fig.8.

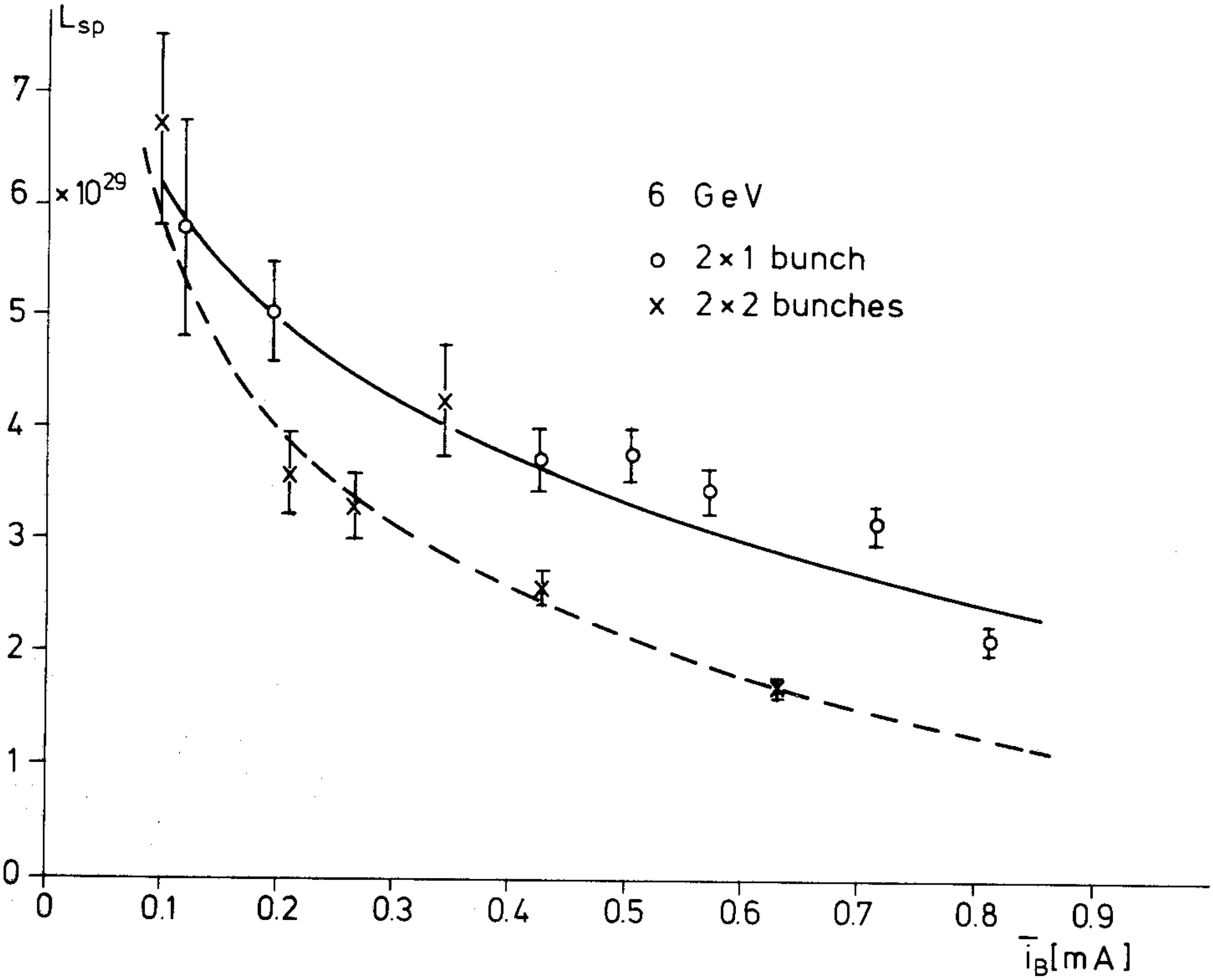

Fig.12 Specific luminosity for the case of 2 x 1 bunch ($L_{sp} = \frac{L}{i_1 i_2}$) and of 2 x 2 bunches ($L_{sp} = \frac{L}{i_1 i_3 + i_2 i_4}$) as a function of single bunch current

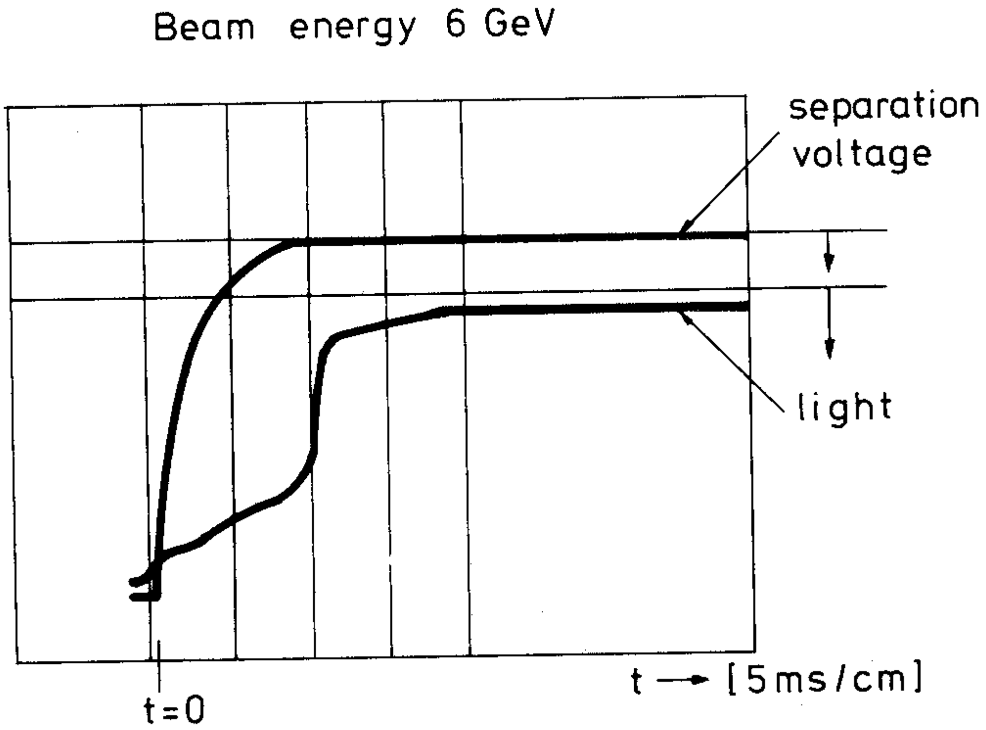

Fig.13 Increase of beam height when beams are made to collide, as indicated by a decrease of synchrotron light intensity.

Quadrupole circuit

	β_x Meas.	β_x Theory	β_z Meas.	β_z Theory
Q OH	45.5	49.3	1.2	2.5
Q IH	9.5	13.5	23.1	32.7
Q 2H	25.8	25.5	24.6	24.2
Q 3H	13.9	14.7	47.5	47.7
Q 4H	31.1	28.9	21.4	23.2
Q 3L	17.3	18.0	35.1	33.2
Q 4L	39.9	42.7	10.7	7.0
Q 5L	2.8	3.2	16.1	16.0
Q 0	22.5	24.4	6.1	4.8
Q 4K	31.1	36.1	58.6	55.7
Q 2K	189.0	200.7	89.1	99.2
Q 1K	32.5	34.9	313.0	330.8

Fig. 14

Comparison of calculated and measured values of the amplitude functions at the location of different quadrupoles.

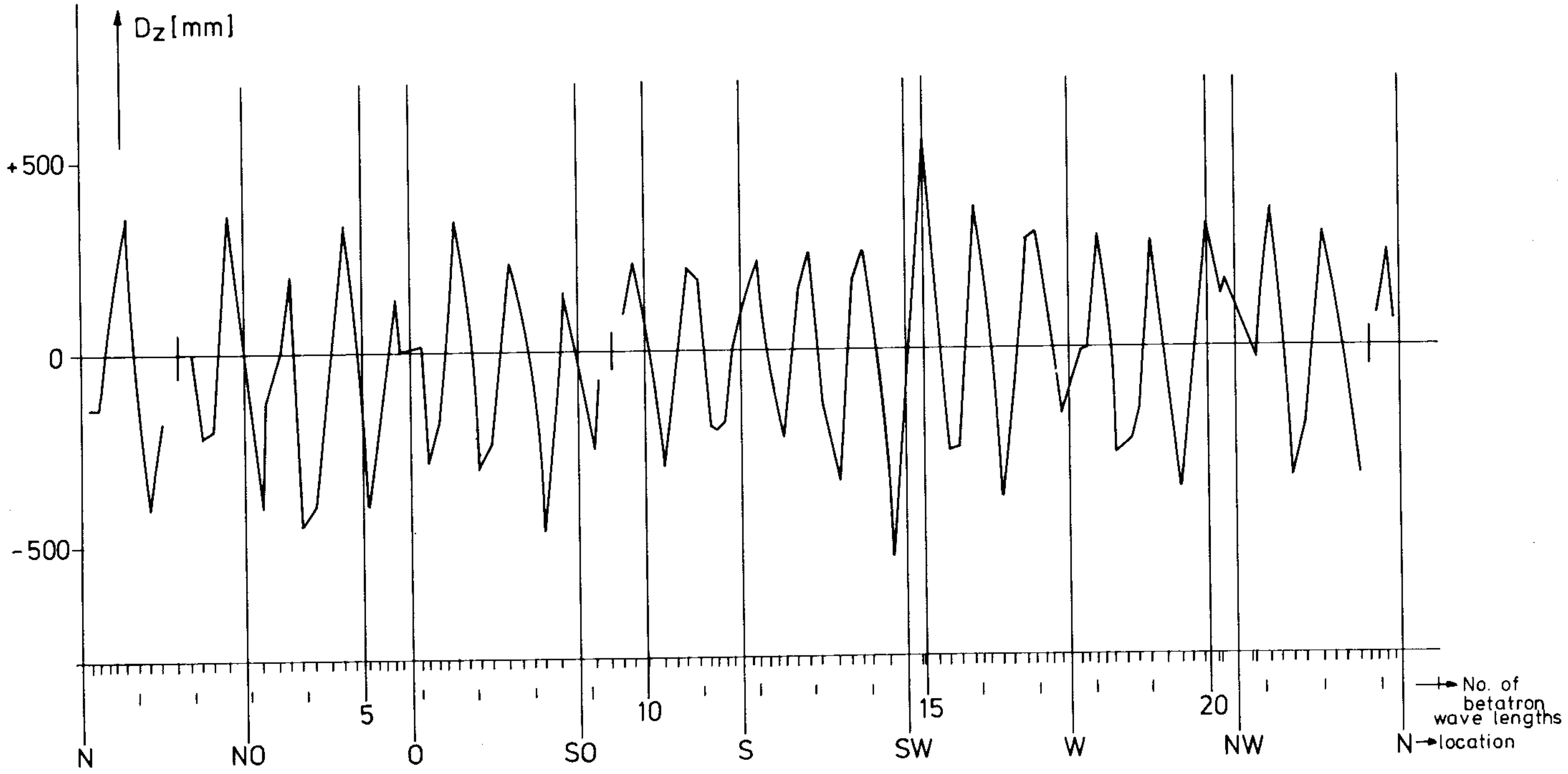

Fig. 15 Spurious vertical dispersion in the PETRA lattice.

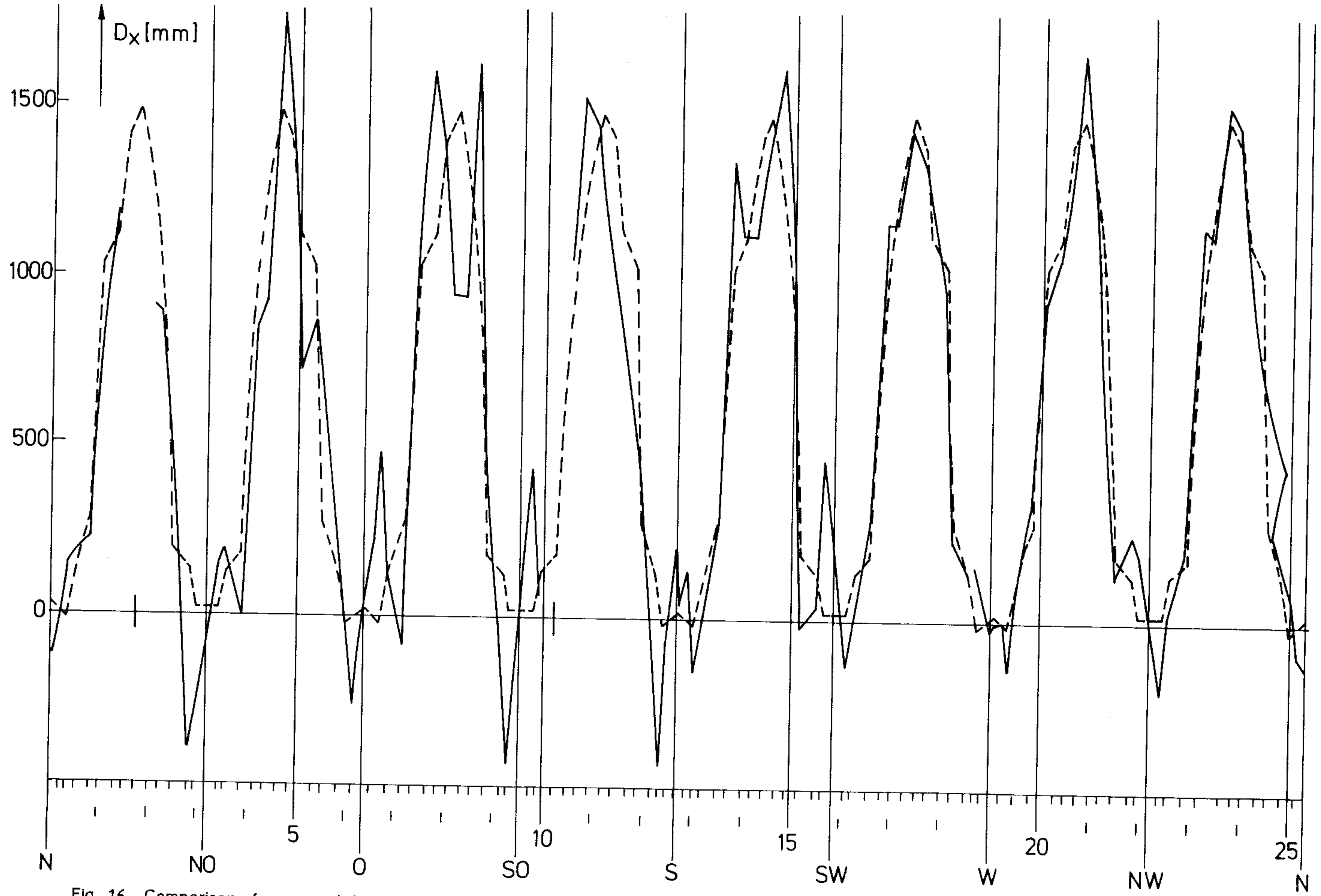

Fig. 16 Comparison of measured dispersion (solid line) with the design dispersion (dashed line)

	Acceptances [π mm mrad]		
Sextupole distribution	Tracking $\frac{\Delta E}{E}=0, K=0.05$	Experiment a_x	a_z
M 501.2.1	34	30	7
M 501.2.2	25	13	10
M 501.6.1	27	16	5
M 501.6.4	29	37	9

Mechanical Acceptances : $\begin{cases} a_x = 37 \ \pi \text{ mm mrad} \\ a_z = 17 \ \pi \text{ mm mrad} \end{cases}$

Beam emittances for
luminosity optics (V25) at 19 GeV
(for 6.5 st. d. and K = 0.2) $\begin{cases} \varepsilon_x = 8.3 \ \pi \text{ mm mrad} \\ \varepsilon_z = 1.7 \ \pi \text{ mm mrad} \end{cases}$

Fig.17 Measured machine acceptances and results from beam tracking.

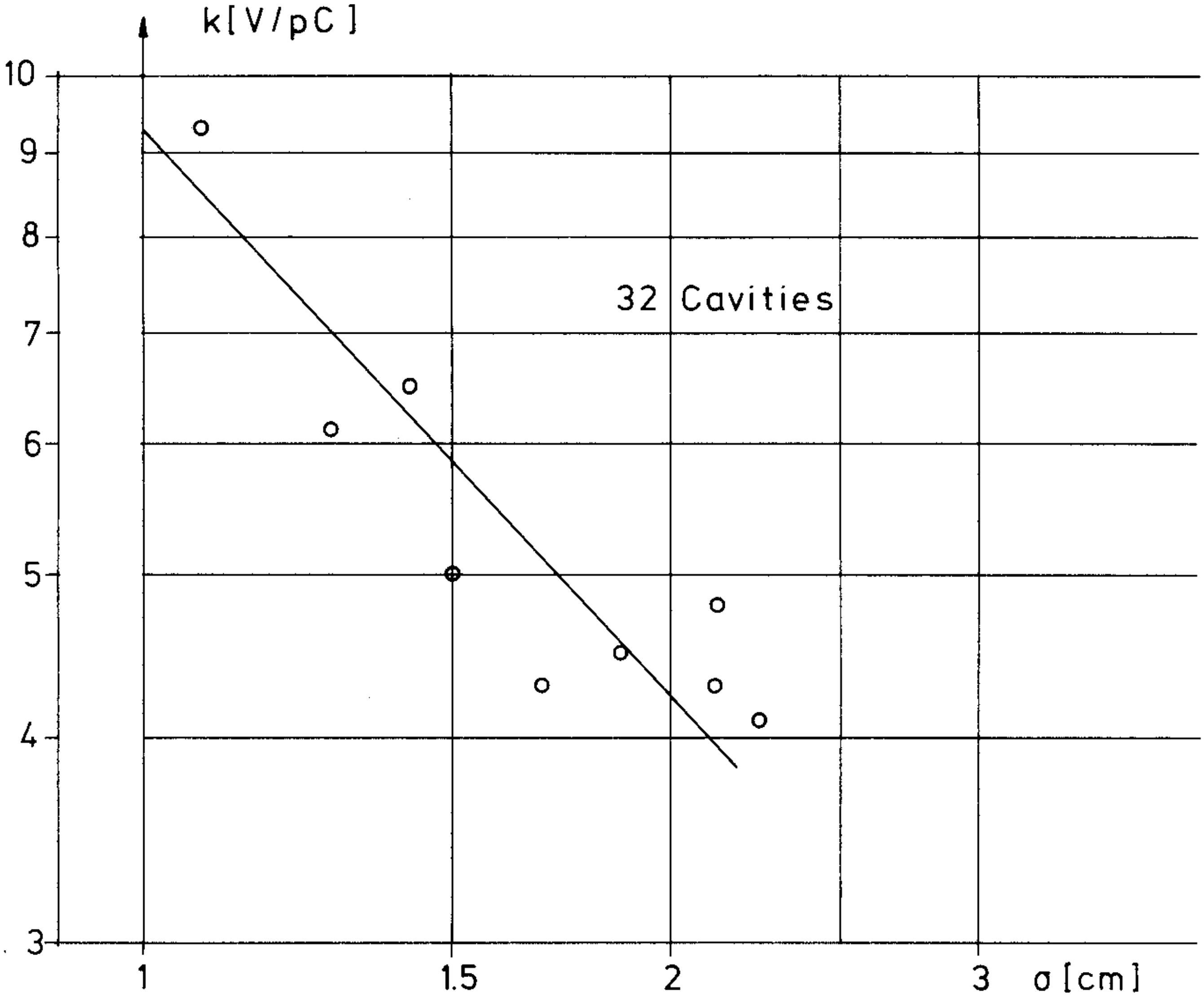

Fig.18 Loss parameter "k" as a function of bunch length σ

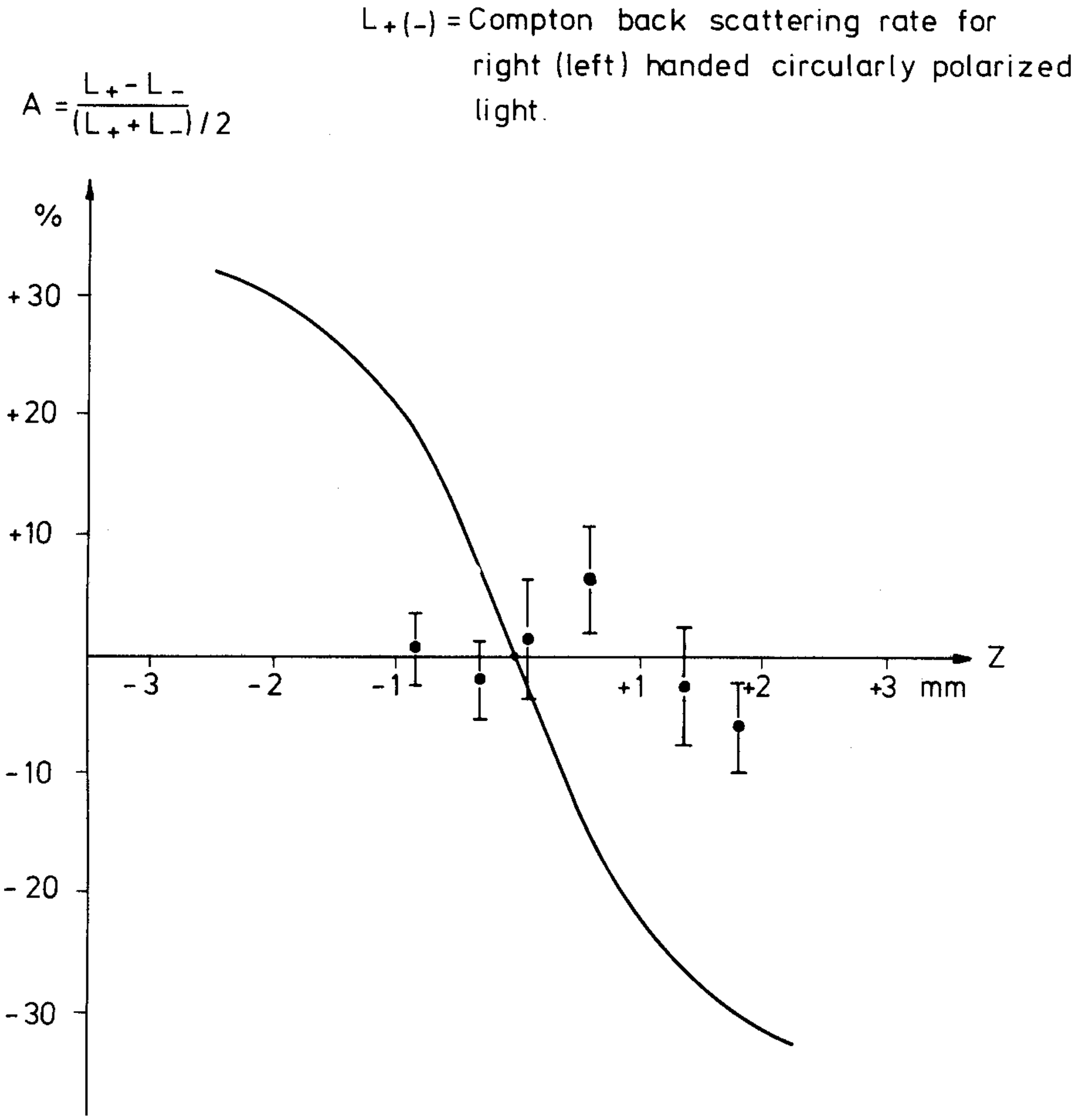

Fig.19 Expected asymmetry A as a function of vertical distance to median plane (solid line) and first measurements.