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DORIS II/III - a 5.8 GeV e^+e^- STORAGE RING WITH HIGH LUMINOSITY

by

K. Wille

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e^+e^- STORAGE RING
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*) Talk to be held at the "Workshop on DORIS-Experiments" at DESY, Hamburg, Feb. 10-11, 1981

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1) Introduction

At the positron-electron storage ring DORIS a new generation of detectors, the magnetic detector ARGUS and the improved crystal detector LENA are under construction. In addition, the attached synchrotron radiation laboratory HASYLAB came into operation last year. This triggered a study to investigate improvement possibilities for the DORIS storage ring leading to a more effective use of the new experimental facilities.

The results of this study are presented here and are preceded by a brief review of DORIS history.

2) The Original DORIS Design

The DORIS storage rings were designed for a maximum beam energy of 3.5 GeV$^{1...5)}$ and were built in the form of two concentric superimposed rings as shown in Fig. 1.

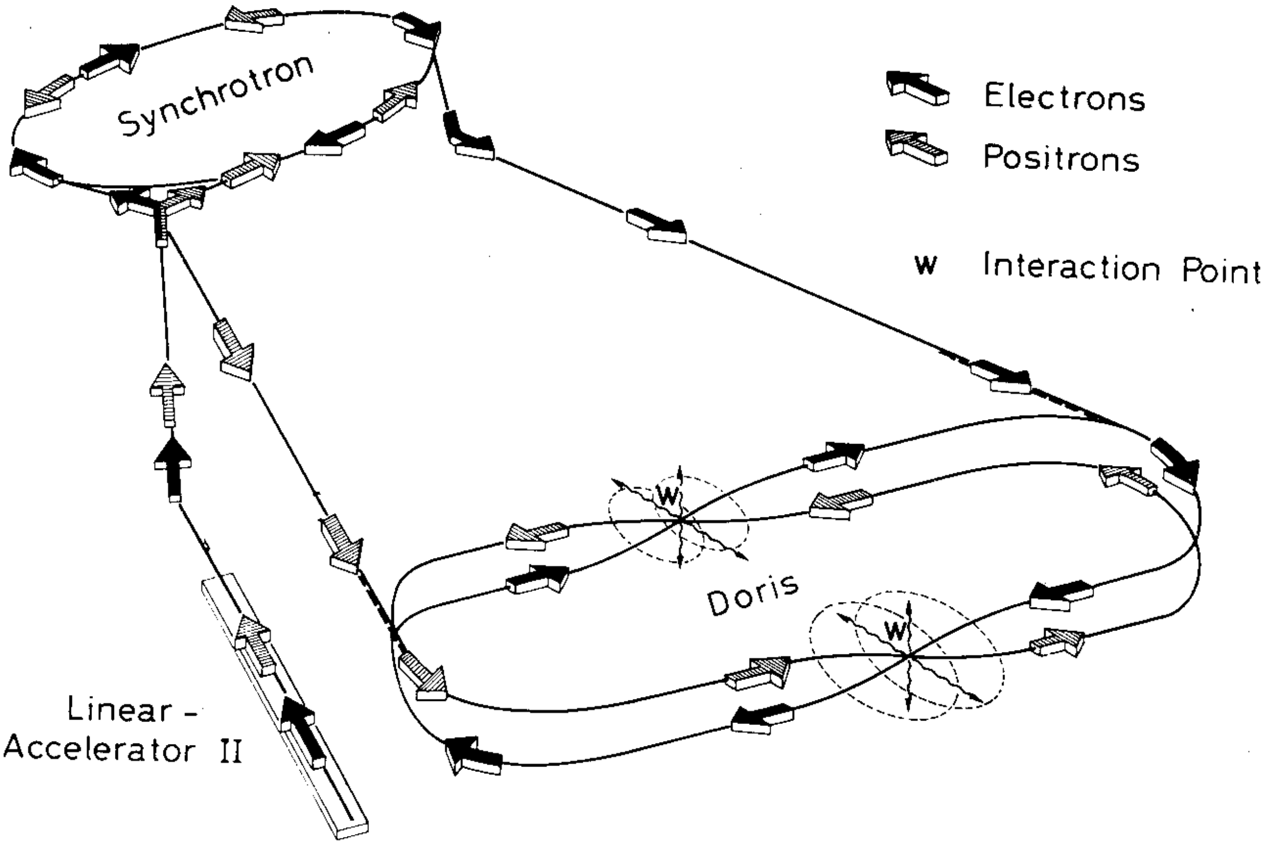
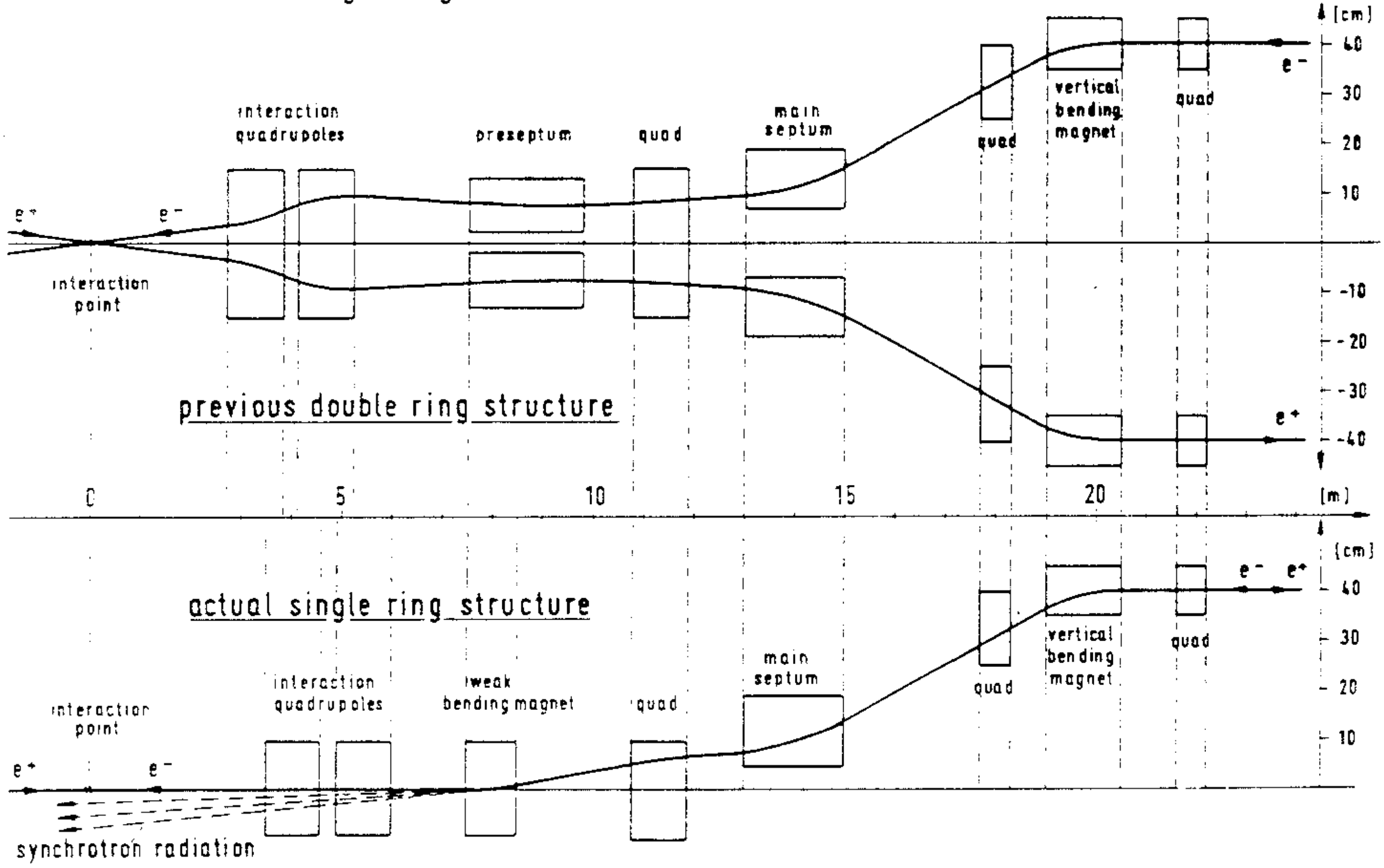


Fig. 1: Layout of the original double ring

The beams intersected each other at a 24 mrad angle to avoid the limitation in luminosity due to the beam-beam space charge effects at lower energies. With the original DORIS arrangement each beam could contain up to 480 bunches and yielded high luminosities in the low energy range.

The magnetic lattice is shown in Fig. 2. A characteristic of this lattice is the pattern of three double bending magnets with two straight section insertions containing three quadrupoles each. The injection elements were clustered around the long symmetry axis. The long straight sections between the interaction points and the first horizontal bending magnets were equipped with RF-cavities, vertical bending magnets and interaction region quadrupoles. These quadrupoles had originally a beam-focusing and bending function (Fig. 3).

Fig. 3 Comparison of the vertical bending in the double and the single ring structure



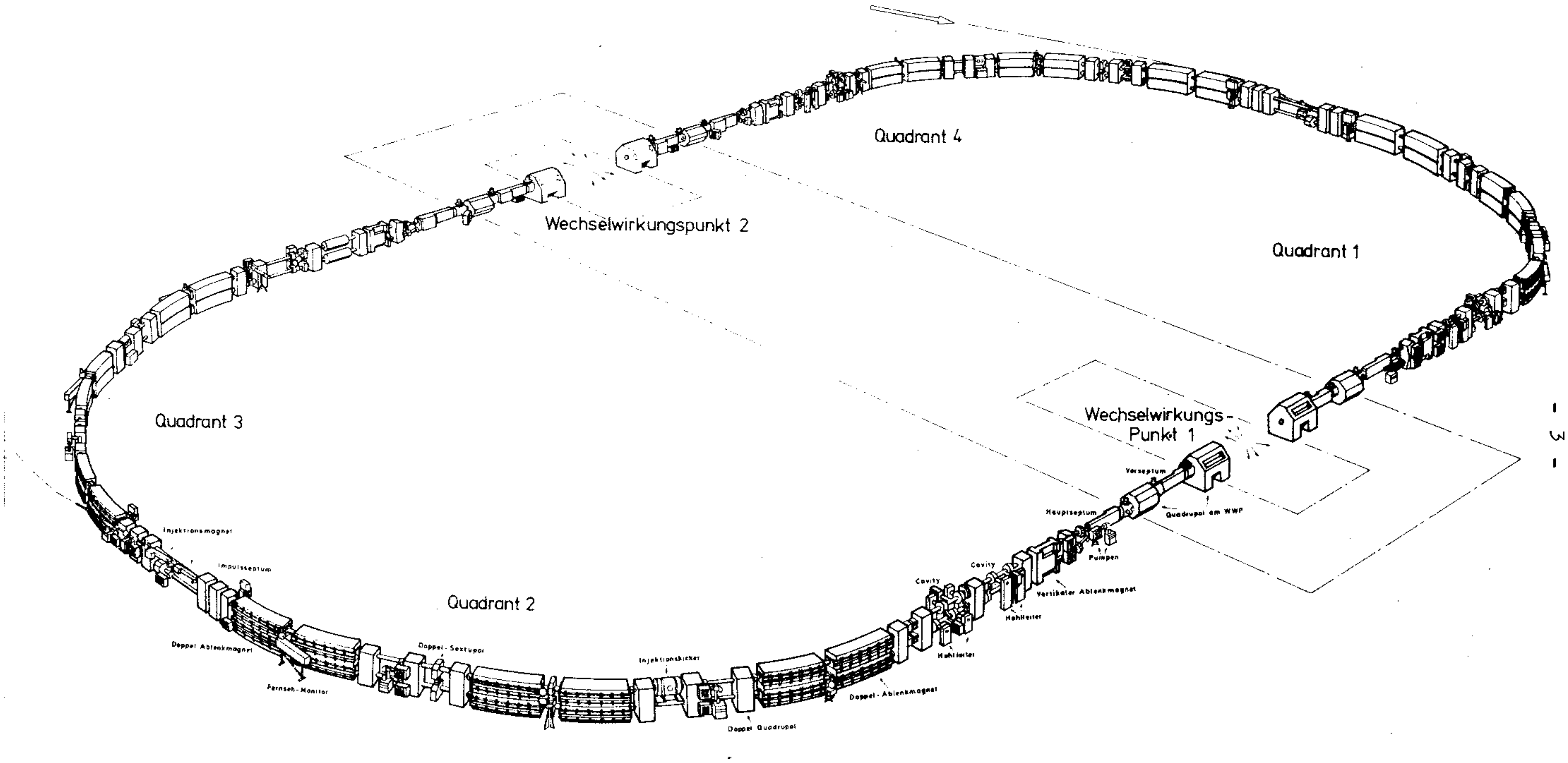


Fig. 2 Magnetic lattice of DORIS

Three groups of four one-cell mode-damped cavities were installed in each ring and were powered with three 250 KW klystrons. The total RF-power available in the machine was 1.5 MW. This double storage ring was operated until 1977 mainly in the 1.8 to 2.5 GeV energy range. The achieved luminosity values are shown in Fig. 4.

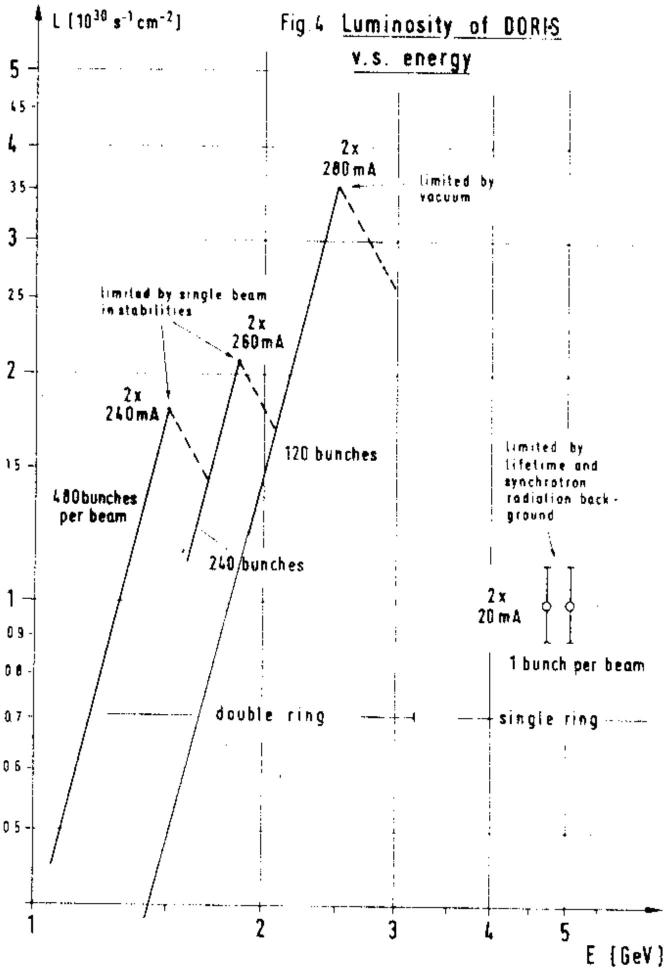


Fig. 4 Luminosity of DORIS v.s. energy

After the discovery of the Y-resonance by L.M. Lederman and his collaborators[6,7] we tried to produce the QQ-bound state in a e^+e^--reaction with DORIS. The main problem was the considerable increase of energy from 3.5 to 5.1 GeV. The two upper half-rings had to be combined into a single ring facility operating with only one bunch per beam in head-on collision[8] (Fig. 5).

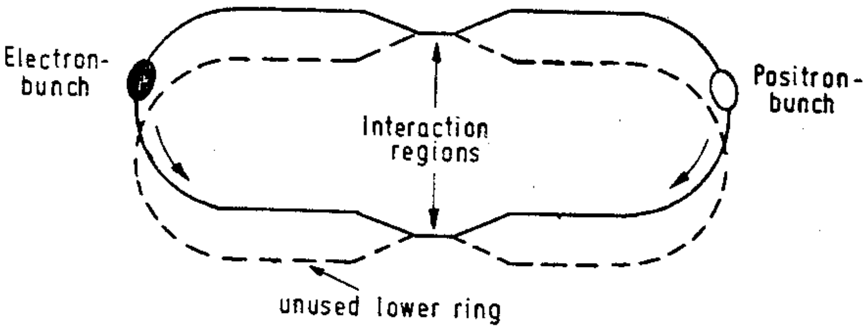


Fig. 5: The DORIS single ring concept

All the magnet and cooling power was connected to this single ring, but we could not avoid saturation effects in some magnets, especially in the main bending magnets as shown in Fig. 6.

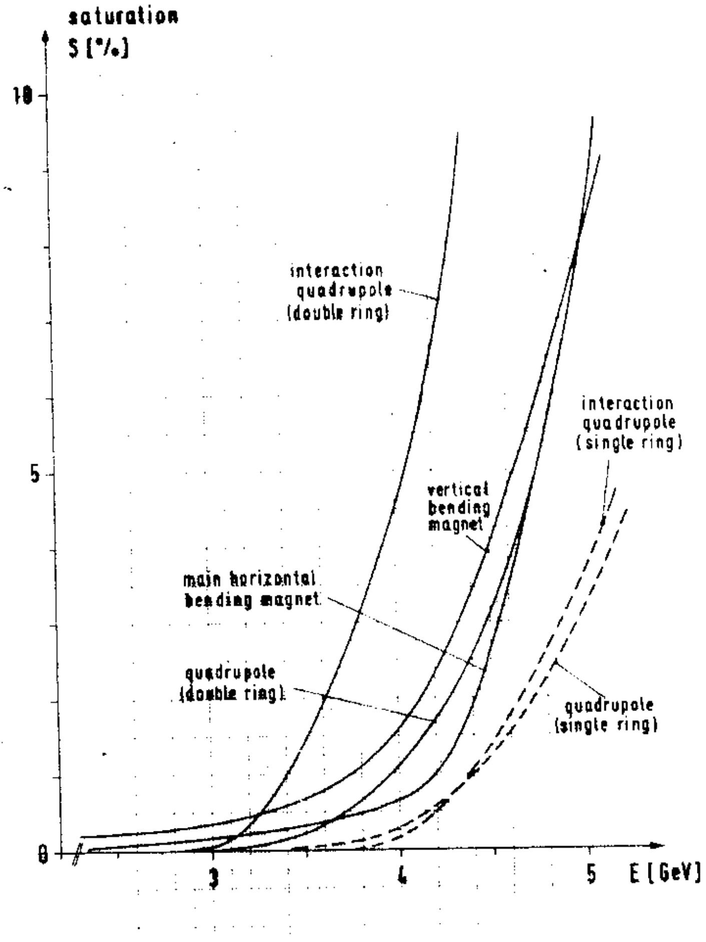


Fig. 6: Saturation of the most excited magnets in the double and the single ring structure

It was necessary to compensate the saturation effects of the individual magnets with the help of a computer by using individual sets of correction functions.

The necessary accelerating voltage of about 16 MV at 5.1 GeV was generated in 8 five-cell cavities[9)] as used in the PETRA storage ring. They were powered by 5 of the 6 available klystrons (Fig. 7).

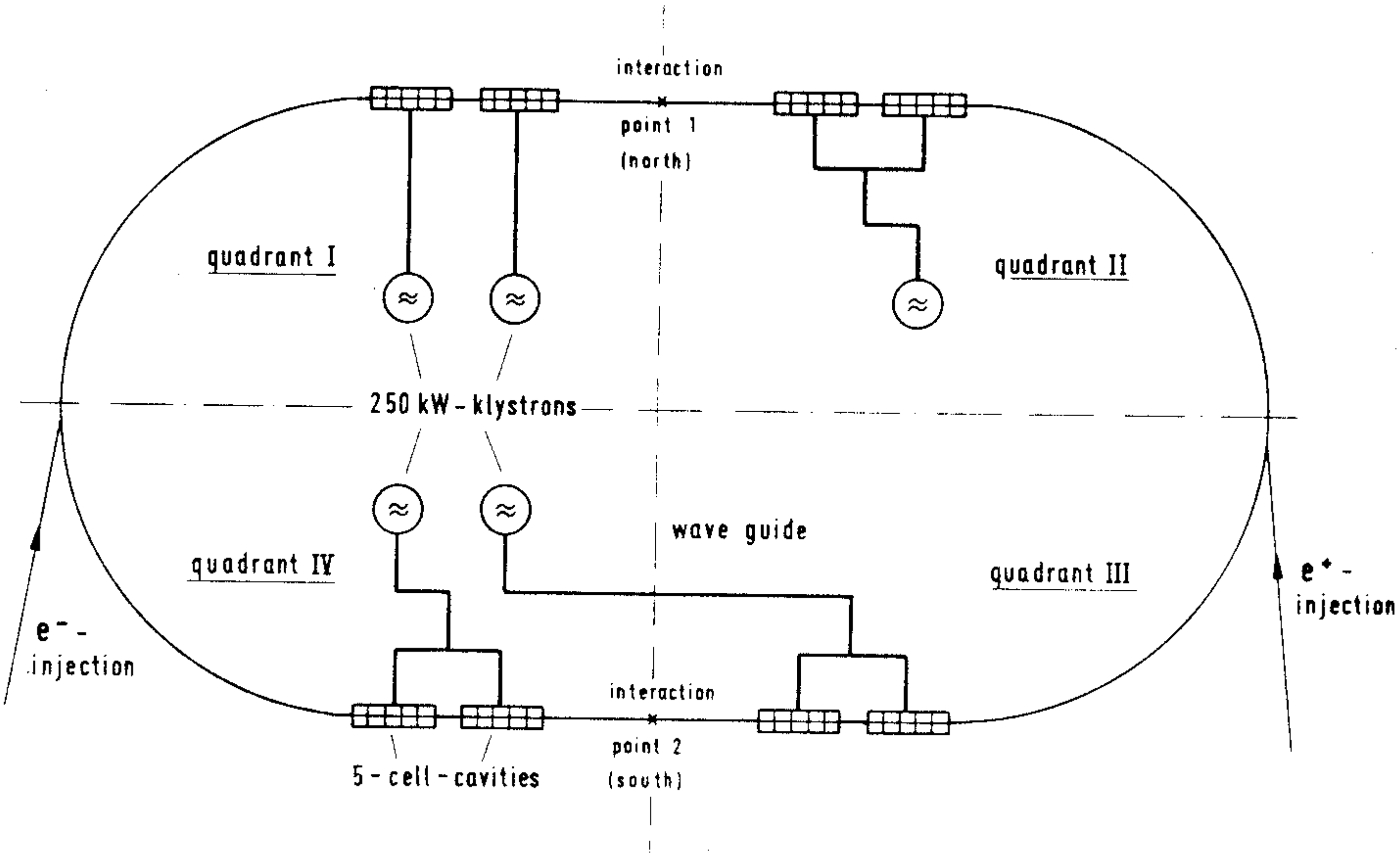


Fig. 7 **Arrangement of PETRA - cavities in DORIS for single ring operation at 5 GeV**

Because of the original double ring concept we did not eliminate the vertical bending. This feature had the important advantage that the weak vertical bending magnets produce only little synchrotron radiation in the interaction region (Fig. 3). It was relatively easy to shield the experiments and obtain acceptable background rates.

This set-up was nevertheless only an improvisation and it had some significant disadvantages:

a) The vertical beta-function ($\beta_z^* \approx 0.3$ m) in the interaction regions was relatively large and yielded a luminosity of only $L \approx 1 \cdot 10^{30} cm^{-2} sec^{-1}$ at 4.7 GeV. Because of the limited sextupole compensation in the machine it was not possible to increase this value by decreasing the β_z^*-value.

b) Because of the mechanical layout of the original double ring there was no space in the machine to install electrostatic separation plates. Therefore we could not separate the two beams during the injection and this limited the maximum accumulated bunch current to 20 mA.

c) The minimum pulse duration of the injection kicker magnets was 1.5 μs which is longer than the revolution time. Therefore the kickers acted not only on the corresponding beam but also, unfortunately with the wrong timing, on the beam circulating in the opposite direction. The adjustment of the timing was therefore very critical. Wrong timing produced a dynamic blowup of the beam during the injection and also limited the maximum current.

d) Because of the large number of discontinuous radiation absorbers inside the vacuum chambers the electromagnetic field around the beam was distorted. This made it very difficult to measure the beam position with regular position monitors. Without the help of an adequate monitoring system it took much time and effort to get sufficient acceptance in the machine.

This is still the present situation at the storage ring DORIS. It is clear that for effective future experimental runs the machine must be significantly upgraded. Therefore we studied and designed several improvements to the machine which are described below.

3) DORIS II, an e^+e^- Storage Ring with Mini-Beta Sections

First of all a significant increase of the luminosity is desired for the future high energy experiments at DORIS. The luminosity is given by

$$L \sim \frac{I^2}{\sigma_x^* \sigma_z^*}$$

where

$$\sigma_x = E\sqrt{\hat{\varepsilon} \cdot \beta_x^*}$$

$$\sigma_z = E\sqrt{\hat{\varepsilon}_x \cdot k \cdot \beta_z^*}$$

E : energy [GeV]
$\hat{\varepsilon}_x$: emittance at 1 GeV
k : betatron coupling
β_x^*, β_z^*: betafunction in the interaction points
r_e : classical electron radius
N_B : no of particles per bunch
γ : $E:E_0$ (E_0=rest energy of the electron

Because of the beam-beam effect the maximum current of the beam is limited at

$$I_{max} \sim \frac{E(\sigma_x^* + \sigma_z^*)\sigma_z^*}{\beta_z^*} \cdot \Delta Q$$

ΔQ: max. linear tune shift acceptable by the machine.

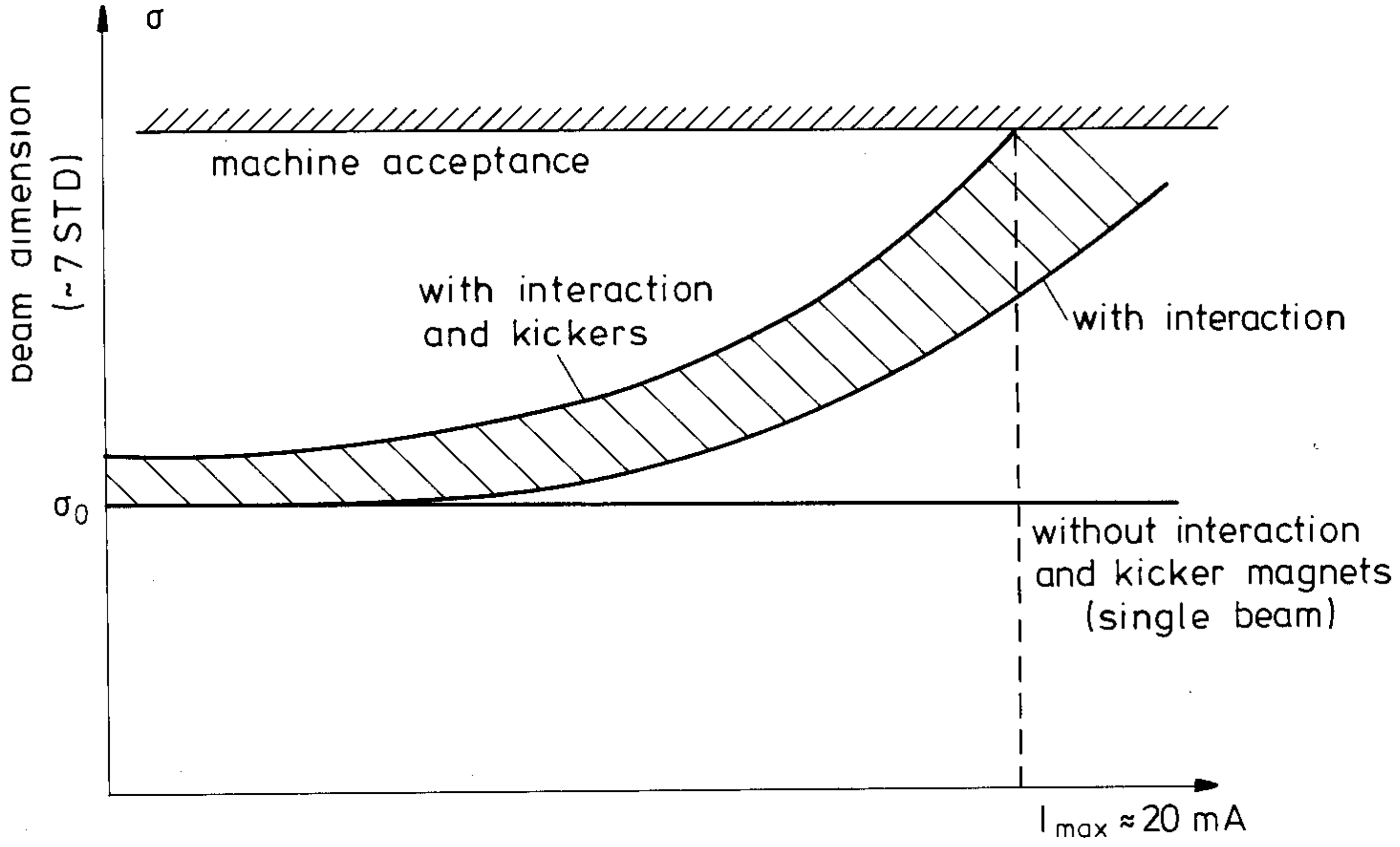
$$\Delta Q_{x,z} = \frac{r_e\ N_B\ \beta_{x,z}}{2\pi\gamma\sigma_{x,z}(\sigma_x+\sigma_z)}$$

The maximum ΔQ limits the currents and consequently the luminosity at lower energies. A good empirical value measured in most of the e^+e^- storage rings is

$$\Delta Q \approx 0.025$$

But at energies above 4 GeV this effect is not the only factor. The problems are sketched in Fig. 8.

With a single beam the dimensionsare nearly independent of the current and the maximum accumulated currents in the machine are only limited by transverse coherent instabilities. With a feedback system we were able to damp the oscillations and thus it was possible to reach currents up to 50 mA in one single bunch. But with two colliding beams we observed a transverse blowup of the beams with increasing bunch current. This effect was studied at DORIS and also very intensively at PETRA during the last year.[10,11,12)



As pointed out before, in the existing injection system it is not possible to match the kicker timing for both beam directions at the same time with the desired accuracy. Therefore the uncompensated residual beam excitation produced an additional beam blowup. If the total beam size reaches the acceptance value then the beam lifetime becomes very short and the beam accumulation stops.

In the present DORIS machine the limit is at about 2 x 20 mA at 4.7 to 5 GeV. It is obvious what one has to do in order to increase the maximum beam currents:

a) Increase of the acceptance
   The most important requirement for a large acceptance is a well adjusted beam orbit. This requires an accurate position monitor system.

b) Separation of the beam during injection
   The installation of electrostatic plates next to the interaction quadrupoles allows for the separation of the beams thereby avoiding the beam blowup during injection.

c) New kicker magnets with short pulses
The injection kicker magnets should act only on one beam at a time. Therefore the kicker pulse length should be $\tau \leq 0.75$ μs to avoid its acting on the beam circulating in the opposite direction.

d) Limitation of the beam blowup due to interaction
This effect is mainly dependent on machine tune and on orbit distortions. As shown in PETRA the blowup can be minimized by careful orbit adjustments. Here also it is necessary to have a good position monitor system.

In a conservative estimate we expect that with all these improvement measures we will obtain a 20 to 30 mA increase in the maximum bunch current resulting in a luminosity increase by a factor of two. Since this is not enough gain we have investigated optics which produce much smaller beam dimensions at the interaction points.

$$\sigma_{x,z} = E\sqrt{\varepsilon_{x,z}\ \beta^*_{x,z}}$$

The beam emittance in DORIS is now kept as small as possible, so that a further reduction of the transverse beam dimension can only be obtained by a significant decrease of the beta functions. This is not possible with the present magnetic lattice for the following reason:

The expression for the beta function in the space between the interaction point and the first quadrupole is

$$\beta(s)=\beta^* + \frac{s^2}{\beta^*}$$

β^*: beta function at the interaction point
s: distance to the interaction point

s normally has values of several meters in order to provide sufficient space for the large detectors (e.g. s=3.47 m in DORIS).

The consequences are large beta functions in the first quadrupoles resulting in very large beam dimensions and requiring large aperture magnets. The beams also become very sensitive to magnetic field errors.

A second problem is the chromaticity. It is defined by

$$\xi = \frac{\Delta Q}{\Delta p/p} \qquad \text{Q: tune of the machine}$$

and given by the relation

$$\xi = \frac{1}{4\pi}\oint k(s)\cdot\beta(s)\cdot ds \qquad \text{k(s): quadrupole strength}$$

Therefore the interaction quadrupoles contribute the largest share of the chromaticity. The chromaticity is inversely proportional to the β_z^* value. It must be compensated with sextupoles to avoid the head-tail instability. Since strong sextupoles reduce the acceptance of the machine the natural chromaticity has to be kept as small as possible.

The solution to this problem is the "Mini-Beta" concept[13,14,15] where the strict separation of machine and experiment is abandoned. A special strong focusing quadrupole magnet is mounted at a small distance from the interaction point. It is easily seen that the small s-value results in acceptable beta function values.

The "Mini-Beta" arrangement of DORIS II is shown in Fig. 9.

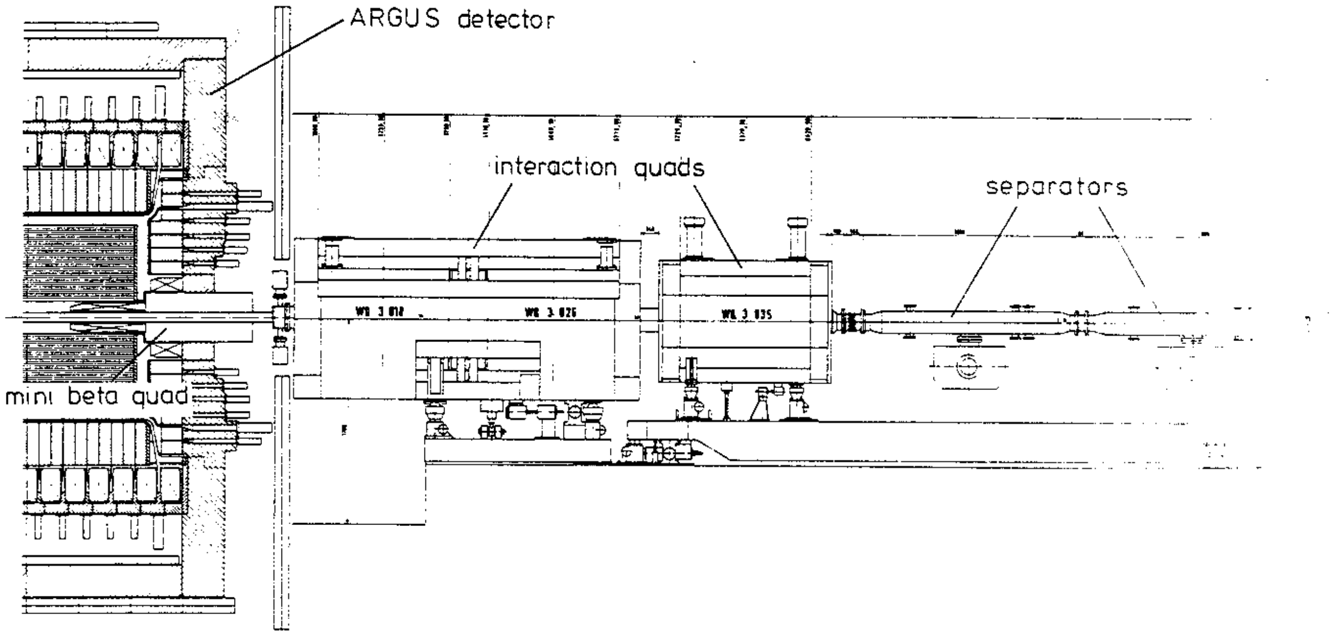


Fig. 9: Mini Beta arrangement in the interaction region

A relatively large focusing strength is needed in the first quadrupole. This is obtained by making the aperture rather small (90 mm) which prevents iron saturation at higher energies (Fig.10).

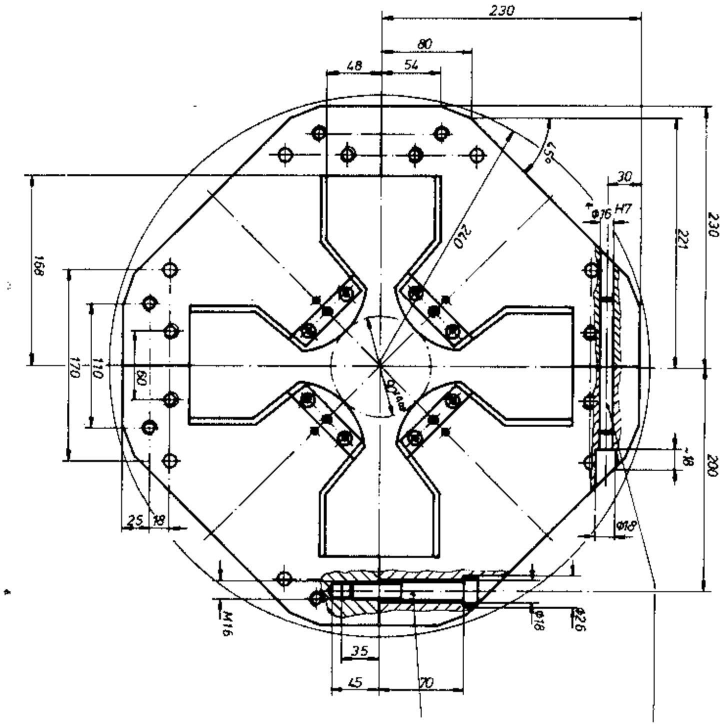


Fig. 10: Cross section of the "mini beta" quadrupole

The horizontal focusing is done with the existing large aperture doublet. The two magnets in each doubletare connected in series so that an operation with relatively low quadrupole strengths is possible. An additional vertical focusing quadrupole is also provided. There is enough space left between this focusing triplet and the next magnets to permit the installation of the electrostatic separation plates mentioned above. They are essentially like the ones installed in PETRA.

Now some remarks on the mini-beta optics:

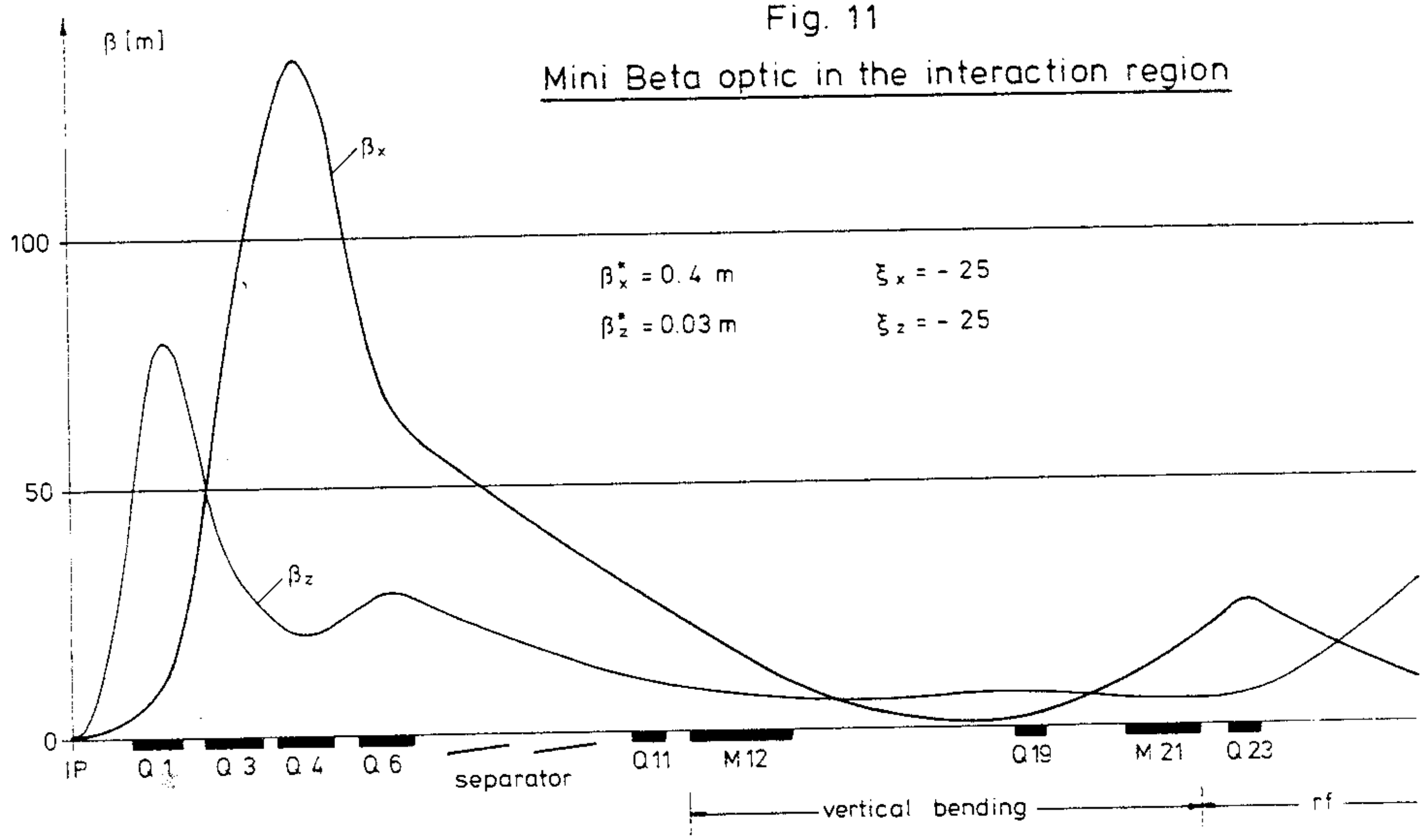
With the mini-beta scheme as described here it is possible to reduce the beta function values in the interaction points to

$$\beta_x^* = 0.4 \text{ m}$$
$$\beta_z^* = 0.03 \text{ m}$$

This represents a significant decrease compared to the previous values. Fig. 11 shows the betafunctions in the experimental straight sections.

Fig. 11

Mini Beta optic in the interaction region



The maximum beta values of 135 in the horizontal and of 80 m in the vertical plane are rather conservative.

We have decided to keep the vertical bending sections to preserve the low synchrotron radiation level in the experimental region (Fig. 12).

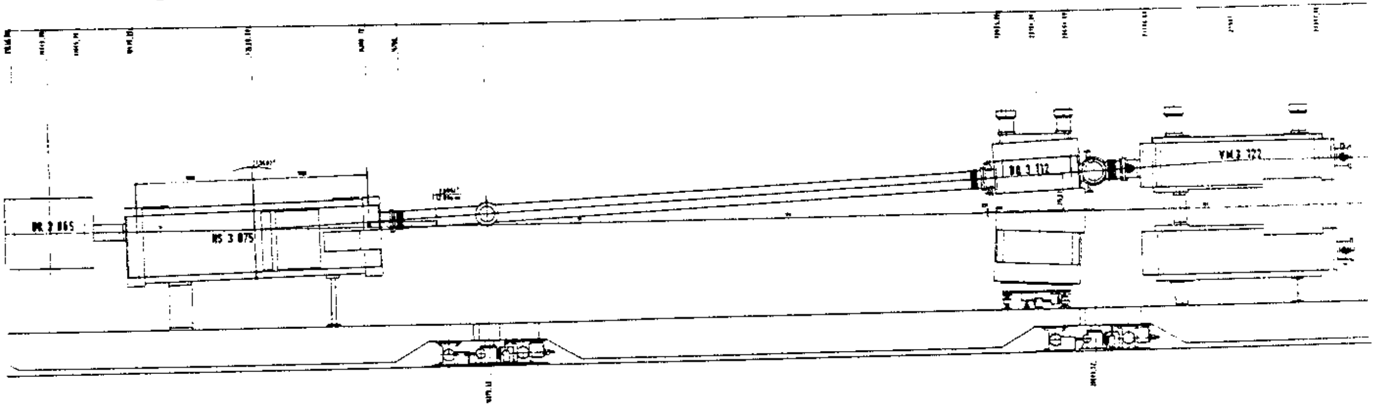


Fig. 12: Layout of the vertical bending

The radiation is produced in the first week vertical bending magnet (Fig. 13). The separation plates are tilted in beam direction to avoid direct synchrotron light on the plates. The background problems will be further reduced by means of vertical remotely adjustable collimators between the interaction quadrupoles.

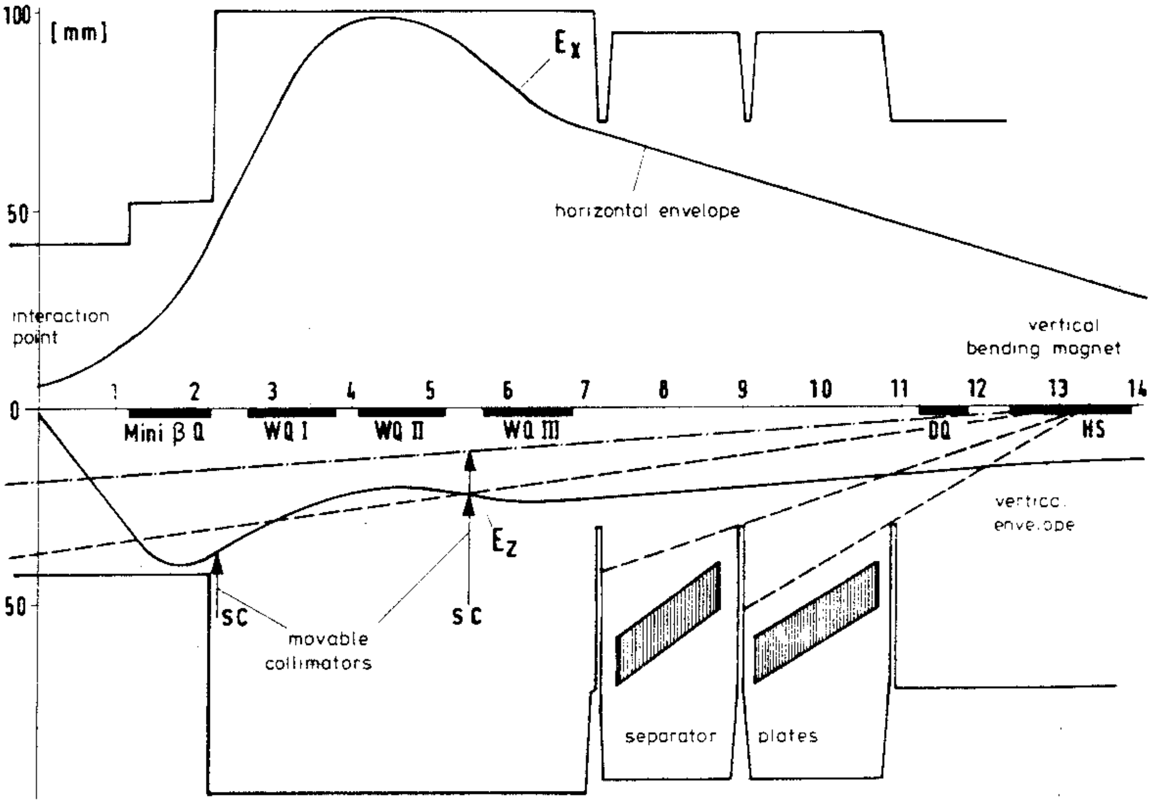


Fig. 13: Synchrotron radiation of the vertical bending magnet

The complete optic of a quadrant is shown in Fig. 14. The beta function values in the arc are typically 25 m or less.

The handling of the dispersion function, that is the orbit of a particle with an energy deviation $\frac{\Delta p}{p}=1$, is a problem. The emittance of the beam

$$\varepsilon = E^2 \hat{\varepsilon} \qquad \hat{\varepsilon}\text{: Emittance at 1 GeV}$$

depends on the dispersion by the relation:

$$\hat{\varepsilon} \approx \frac{\left\langle \frac{D^2}{\beta}(1+\alpha^2) \right\rangle}{\langle \rho \rangle} \qquad \alpha = -\frac{\beta'}{2} \qquad \rho = 12.2 \text{ m}$$

At DORIS the bending radius ρ is relatively small and as a consequence at higher energies the emittance of the beam reaches values comparable with the acceptance. This makes it necessary to keep the dispersion in the bending magnets as small as possible.

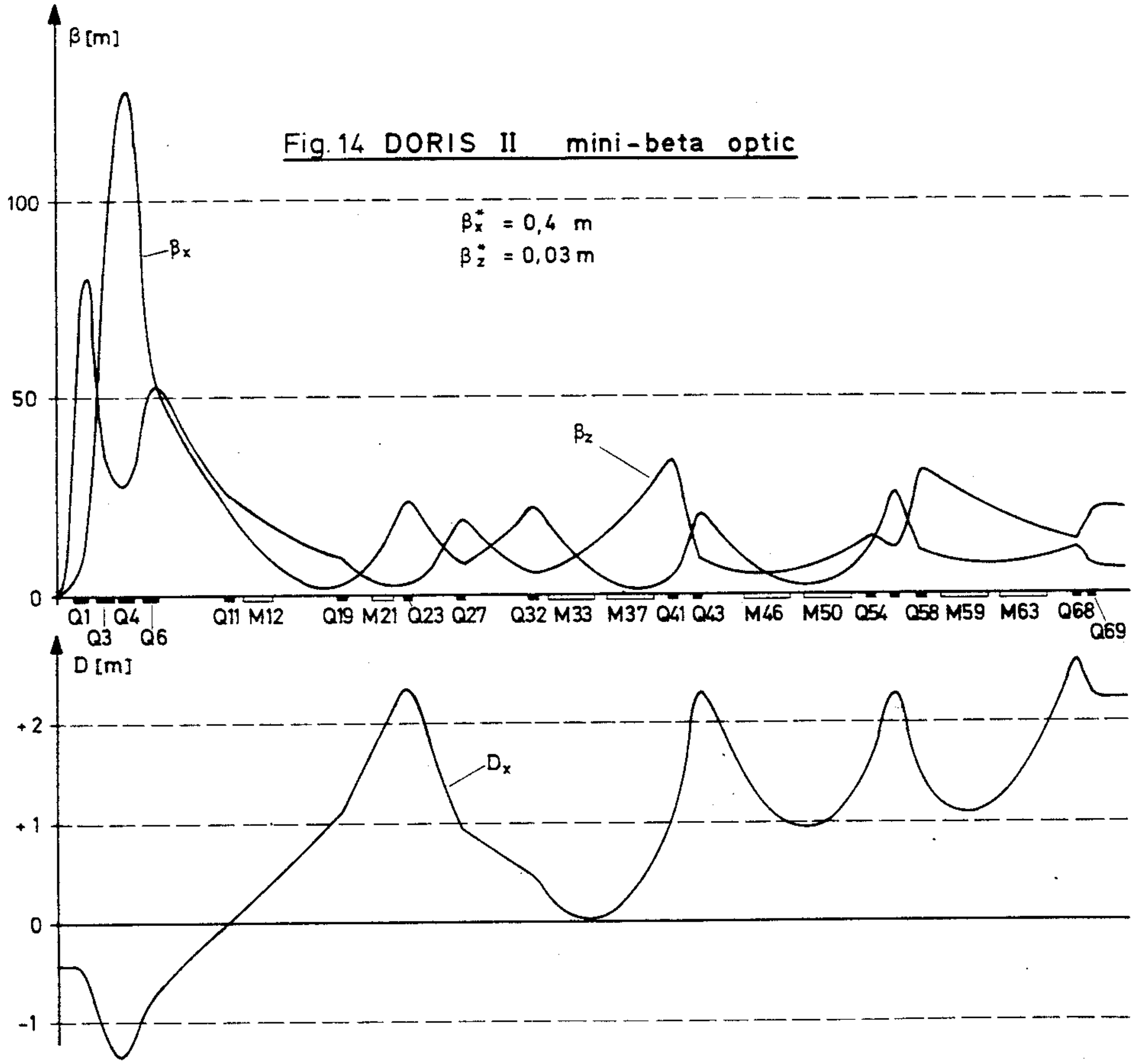


Fig. 14 DORIS II mini-beta optic

Because of this important requirement it is not possible with the present DORIS lattice to avoid dispersion at the interaction points and in the cavities. The horizontal beam dimension is therefore

$$\epsilon_x = \sqrt{\epsilon_x \beta_x^* + (D_x^* \frac{\Delta p}{p})^2}$$

A dispersion of D*=30 cm compared with a no-dispersion case reduces the luminosity at DORIS by a factor of 1.25.

The main optical parameters are:

betafunctions in the interaction point: $\beta_x^* = 0{,}4$ m
$\beta_z^* = 0{,}03$ m
dispersion in the interaction point: $D_x^* = 0{,}30$ m
$D_z^* = 0{,}03$ m
machine tune : $Q_x = 7{,}21$
$Q_z = 5{,}16$
emittance at 1 GeV : $\hat{\varepsilon} = 2{,}5 \cdot 10^{-8} \pi$ mrad
chromaticity : $\xi_x \approx -25$
$\xi_z \approx -25$

The chromaticity of the mini-beta optic is higher than that of the present optic. In order to correct these larger chromaticities a more effectively distributed sextupole system has been developed. The new machine design includes new kicker magnets and new vacuum chambers with reliable position monitors. The kicker magnets are sketched in Fig. 15. The design is based on the strip line technique[16)] because of its characteristic low inductivity. The pulser and the feed through are of coaxial type. With this design we have measured the required 0.75 µs pulse length.

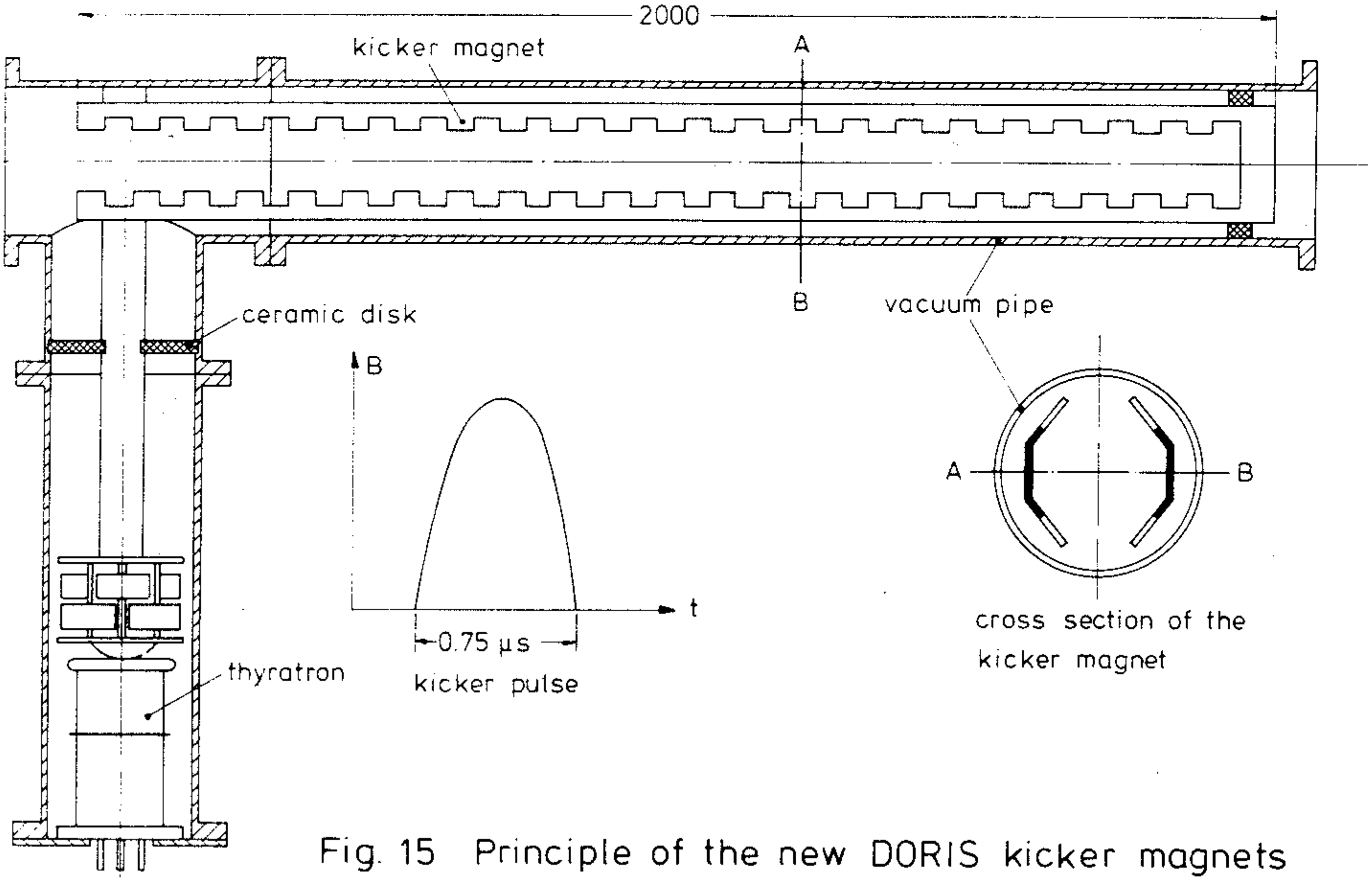


Fig. 15 Principle of the new DORIS kicker magnets

The concept of the new vacuum chambers with position monitors is shown in Fig. 16.

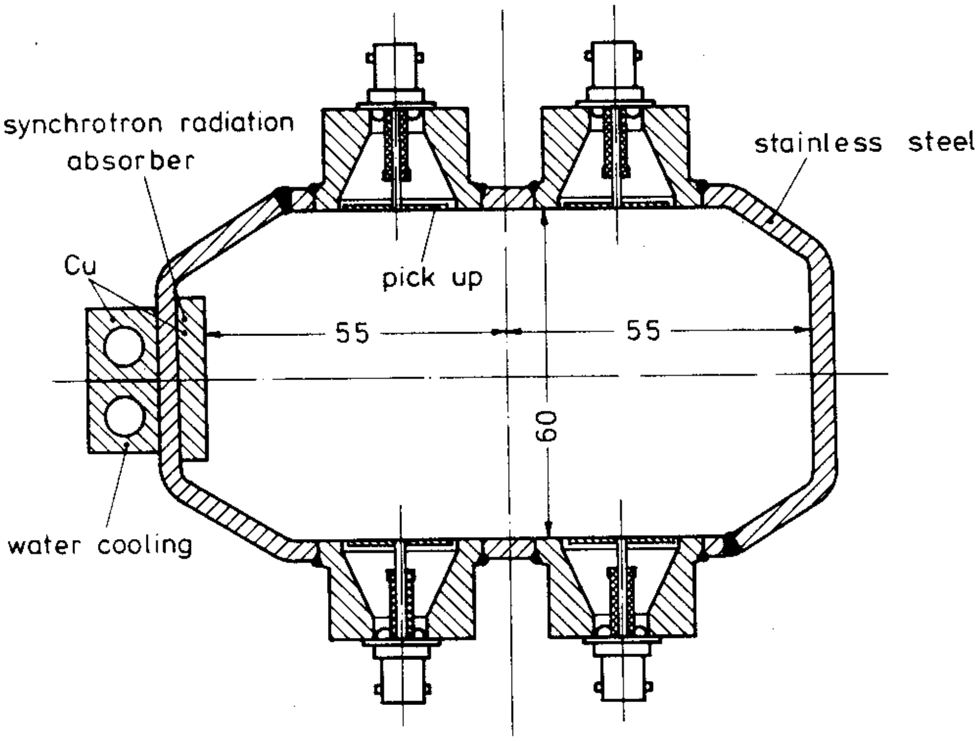


Fig. 16 Principle of the new vacuum pipe with position monitor

The many short chambers with the large number of flanges and individual absorbers are replaced by long simple chambers with integrated synchrotron radiation absorbers. The monitors consist of simple plates similar to those used in PETRA.

The design of many of the new components mentioned so far already started approx. one year ago. The project was called DORIS II.

Besides the higher reliability of the machine we mainly expect a significant increase in luminosity as shown in Fig. 17.

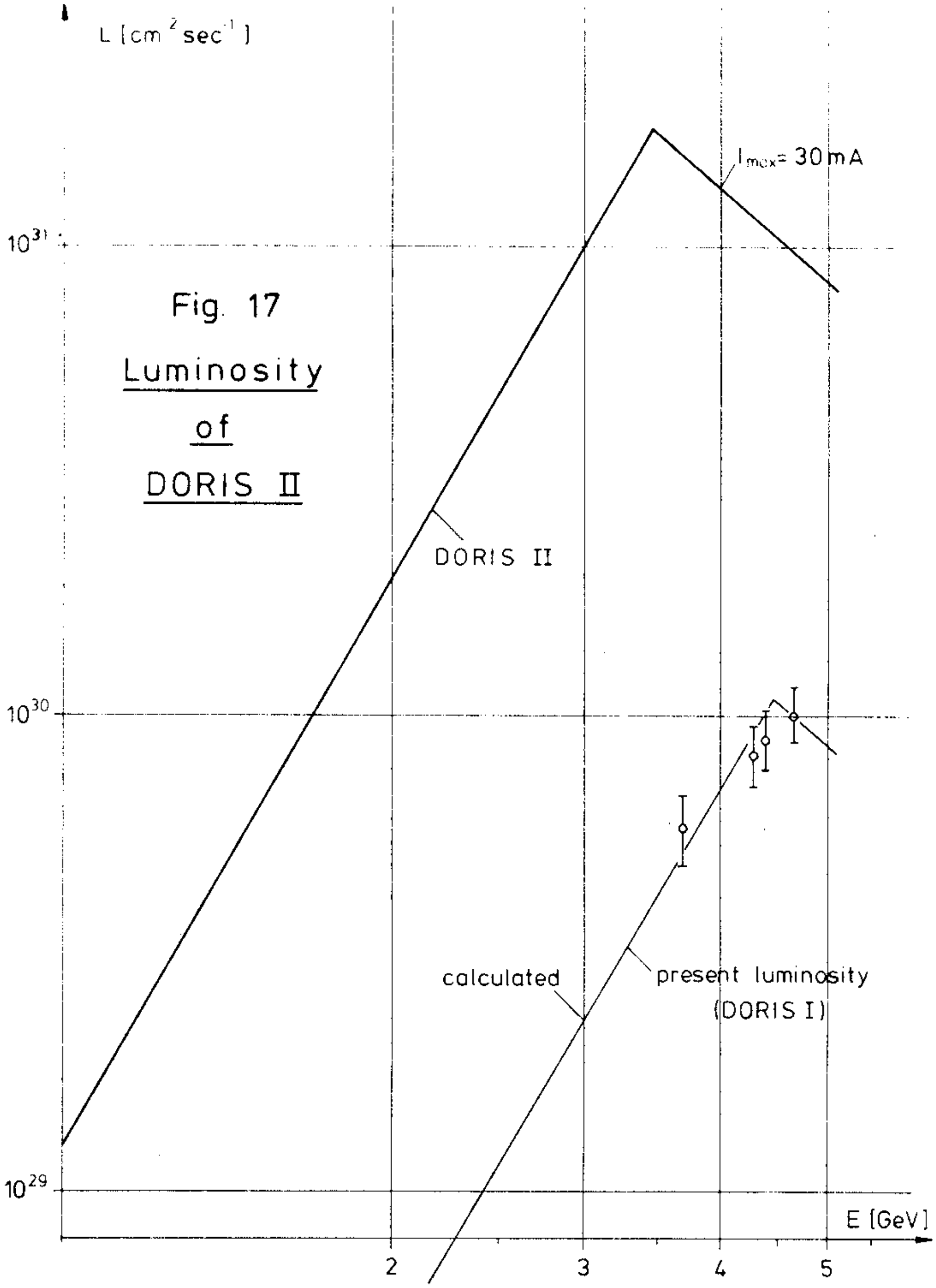


Fig. 17

Luminosity of DORIS II

4) DORIS III, a 5.8 GeV Storage Ring

The maximum energy of DORIS II is 5.1 GeV. It is limited mainly by the horizontal bending magnets. Looking at the particle reactions in this energy range (Fig. 18) one can easily see that the experimentors are unhappy with this energy limit because several interesting reactions would occur outside of the DORIS energy range. Therefore we have studied possibilities of upgrading the DORIS energy to above 5.5 GeV.

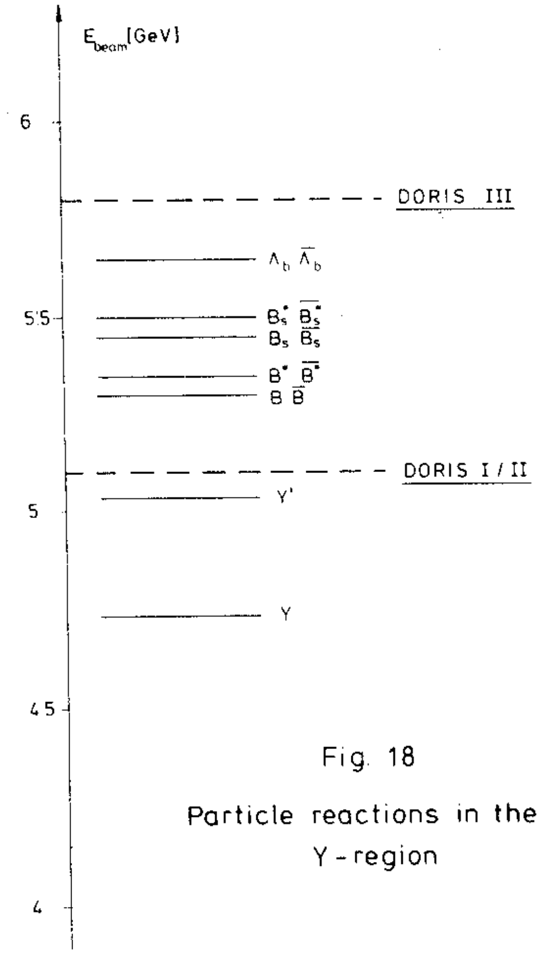


Fig. 18

Particle reactions in the Υ-region

Detailed computer calculations have shown that a further increase in the magnetic field in the existing bending magnets above 5.1 GeV is not possible. Therefore we have studied a new magnetic lattice with 7 bending magnets per quadrant (Fig. 19). The additional 4 magnets would be available from the now unused lower part of the double ring. With a maximum saturation of 7.5 % an energy of E=5,8 GeV can be reached.

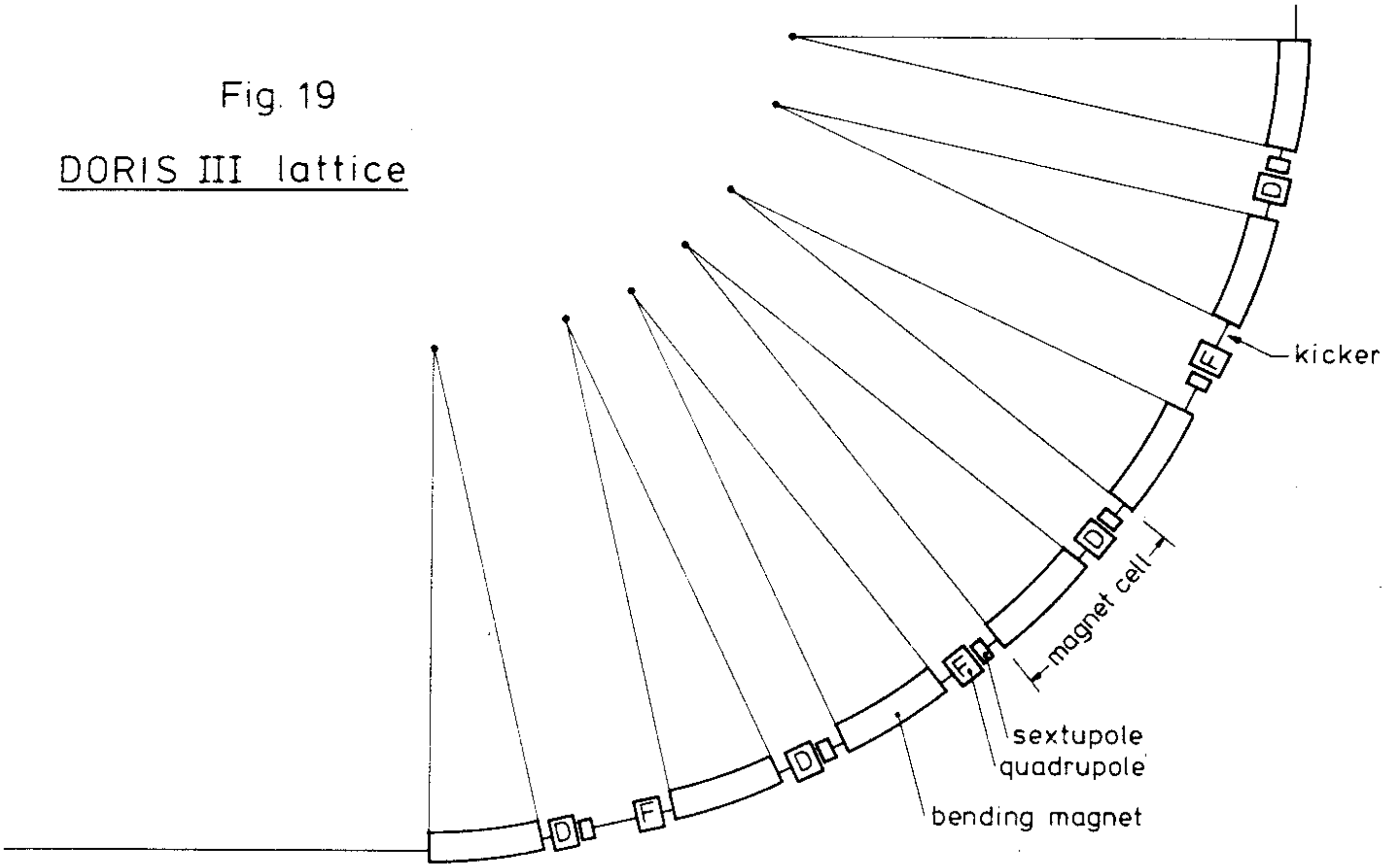


Fig. 19

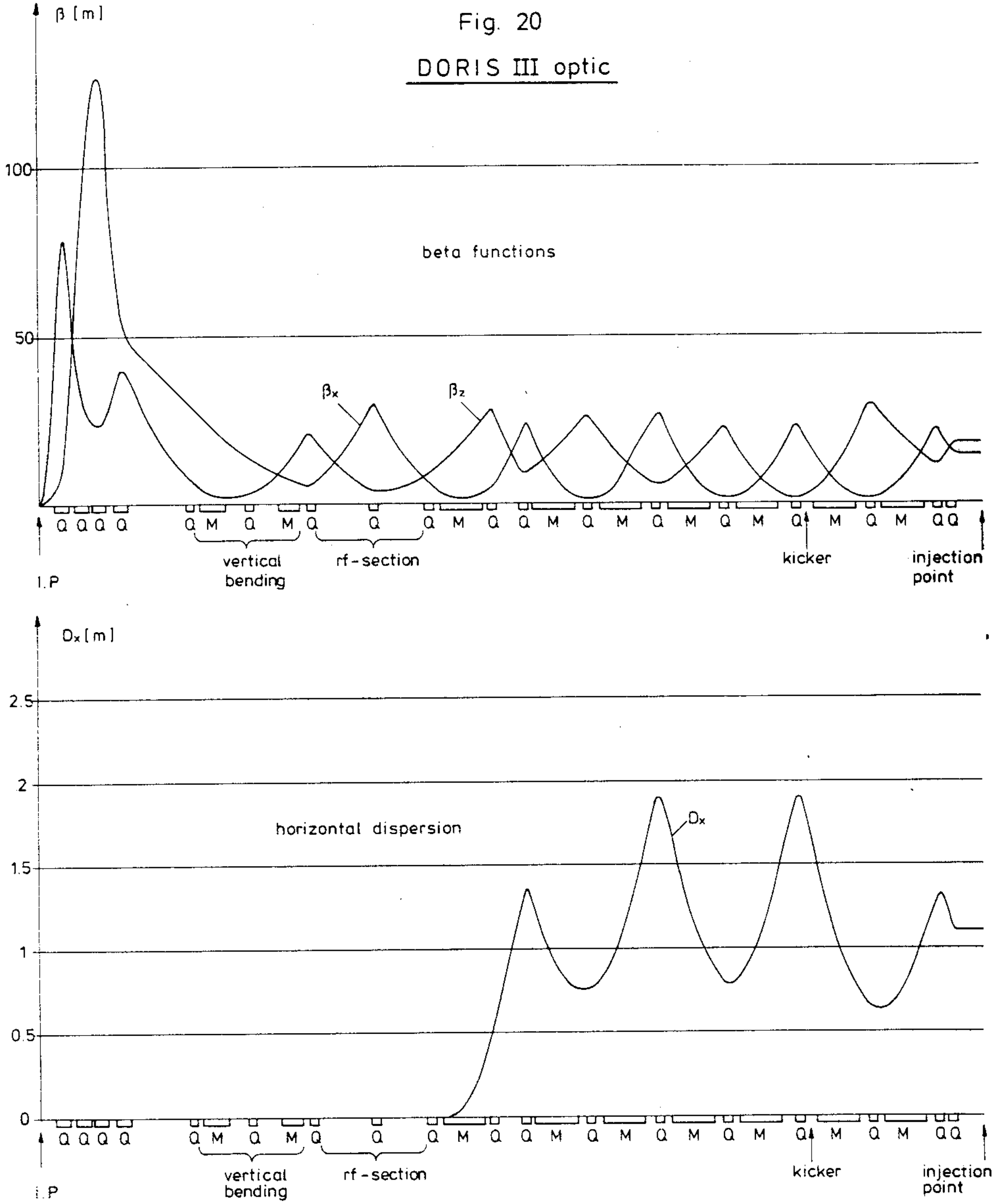
DORIS III lattice

This lattice was named DORIS III. The interaction regions as well as the straight sections with the RF-cavities and the vertical bending magnets are identical with the DORIS II concept. The magnet arrangement in the arc is quite different. It is mainly a FODO structure with a typical magnetic cell structure consisting of a bending magnet, a quadrupole and a sextupole.

Between the first and the second bending magnet there is a long straight section with two quadrupoles and one sextupole. This is used to match the dispersion function. In this manner we could get both - a small emittance and zero dispersion in the long straight interaction region section. The optic is shown in Fig. 20.

Fig. 20

DORIS III optic



In order to store a beam current of 2 x 30 mA at 5.8 GeV one needs a total accelerating voltage of 17 MV and an RF power of 1.25 MW. At present 6 klystrons have been installed in DORIS and only two more 5-cell cavities of the PETRA type would be required (Fig. 21).

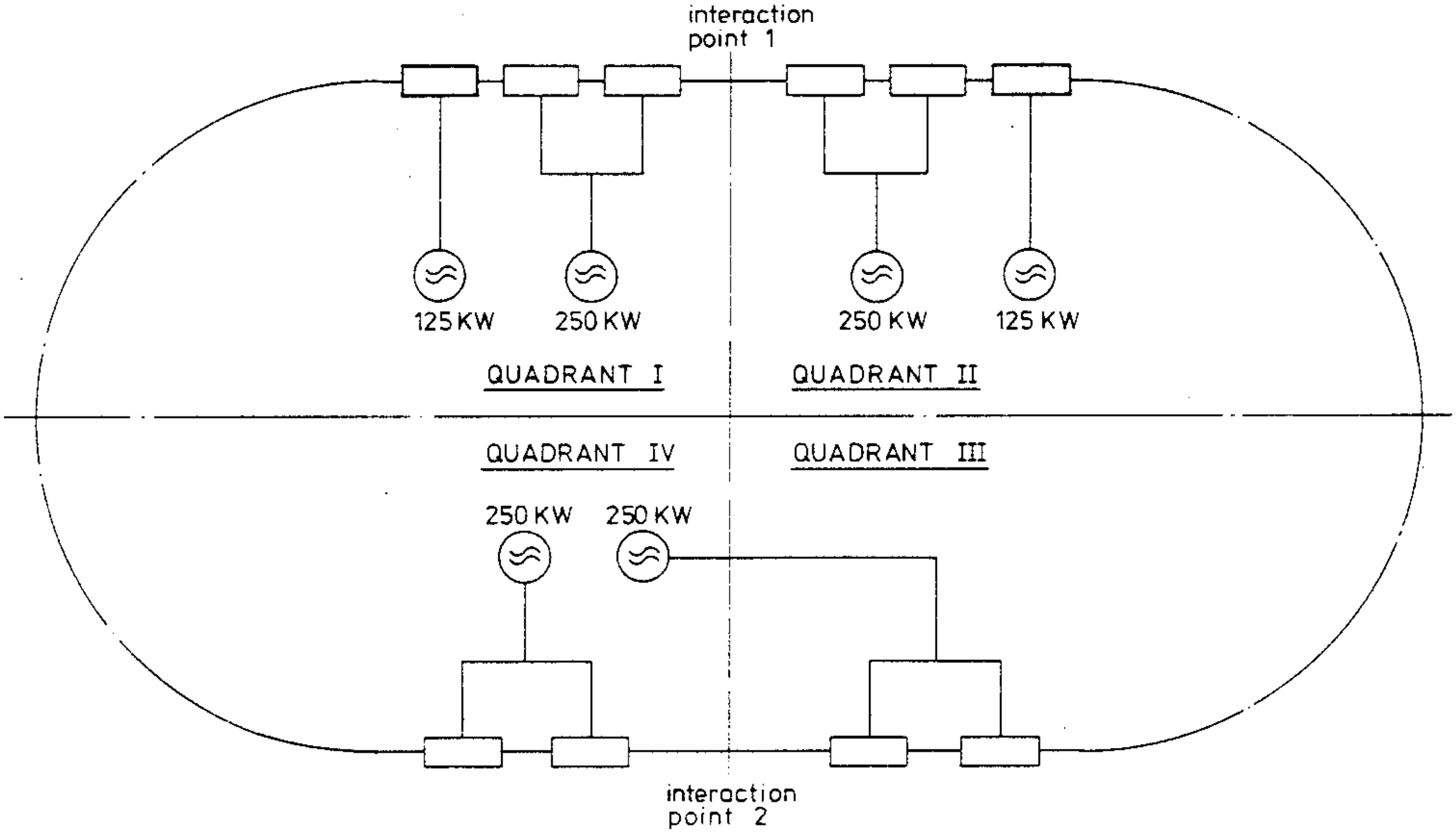


Fig. 21 Arrangement of the rf-system with a total power of $P_{rf} = 1.25$ MW

DORIS III includes all the other improvements of the DORIS II project such as new injection kickers, a better position monitor system, separation plates etc.

Because of the zero dispersion at the interaction point, the luminosity of DORIS III in the energy range above 4 GeV becomes somewhat higher than in DORIS II as shown in Fig. 22.

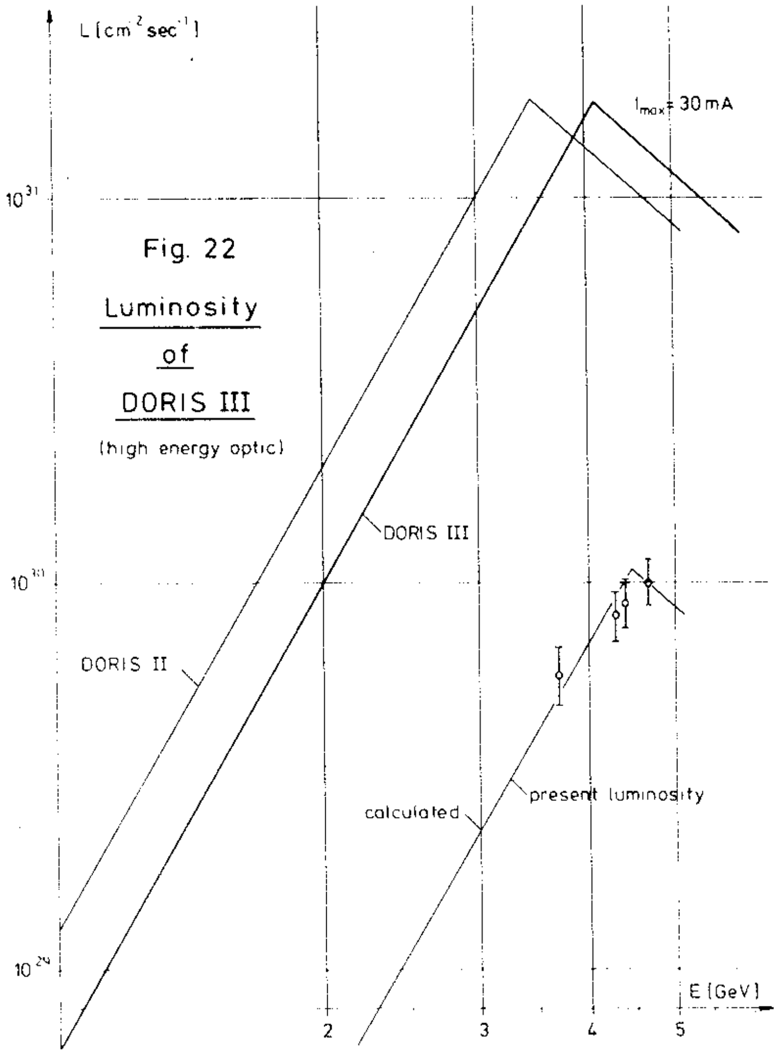


Fig. 22

Luminosity of DORIS III

(high energy optic)

5) Energy Saving

The existing DORIS machine has a power consumption (magnets and rf) of

N = 10.8 MW at 5.1 GeV

DORIS III has a reduced power consumption because of the larger bending radius and the reduced strength of the large aperture interaction quadrupoles.

N = 10.6 MW at 5.8 GeV

This is still too high. Today electrical power is very expensive and it will cost even more in the future. Therefore we have looked for measures aiming at reducing the power consumption of the machine.

The magnets are a big consumer. They were originally designed for a maximum energy of 3.5 GeV. The field of a bending magnet is

$$B \sim \frac{nI}{g}$$

nI: current through the coils
g : gap height

For fixed B the power consumption of the magnet goes as

$$N \sim g^2$$

The present gap height is

$$g_{\text{DORIS II}} = 78 \text{ mm}$$

It can be reduced to

$$g_{\text{DORIS III}} = 60 \text{ mm}$$

As a second step we will install two sets of coils in each magnet. Most of the coils will be taken from the unused magnets of the lower ring. This doubles the conductor cross-section. (Fig. 23)

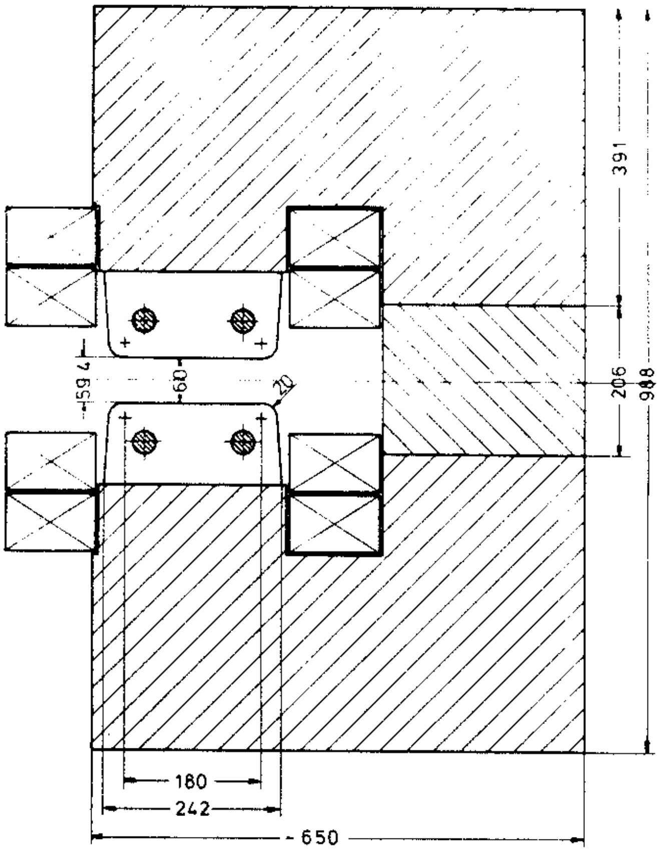


Fig. 23 DORIS - dipole

These modifications reduce the power consumption of the magnets to 30 % of the original value.

The strength of a quadrupole is given by

$$k \sim \frac{I}{R^2} \qquad R = \text{pole radius}$$

For a given strength k the power consumption goes as

$$N \sim R^4$$

The present DORIS quadrupoles have a large aperture

$$R_{DORIS} = 80 \text{ mm}$$

which is not necessary for the optic. Replacing these magnets with PETRA quadrupoles with radius

$$R_{DORIS} = 50 \text{ mm}$$

and a bigger conductor cross-section reduces the power consumption by a factor of 10!

Finally if one takes 8 newly developed 7-cell cavities with higher shunt impedances and driven by only 4 klystrons instead of the 10 five-cell cavities with 6 klystrons, a saving of 20 % in electric power for the rf is possible.

A comparison of the power consumption between the present machine and the energy saving version of DORIS III is shown in Fig. 24.

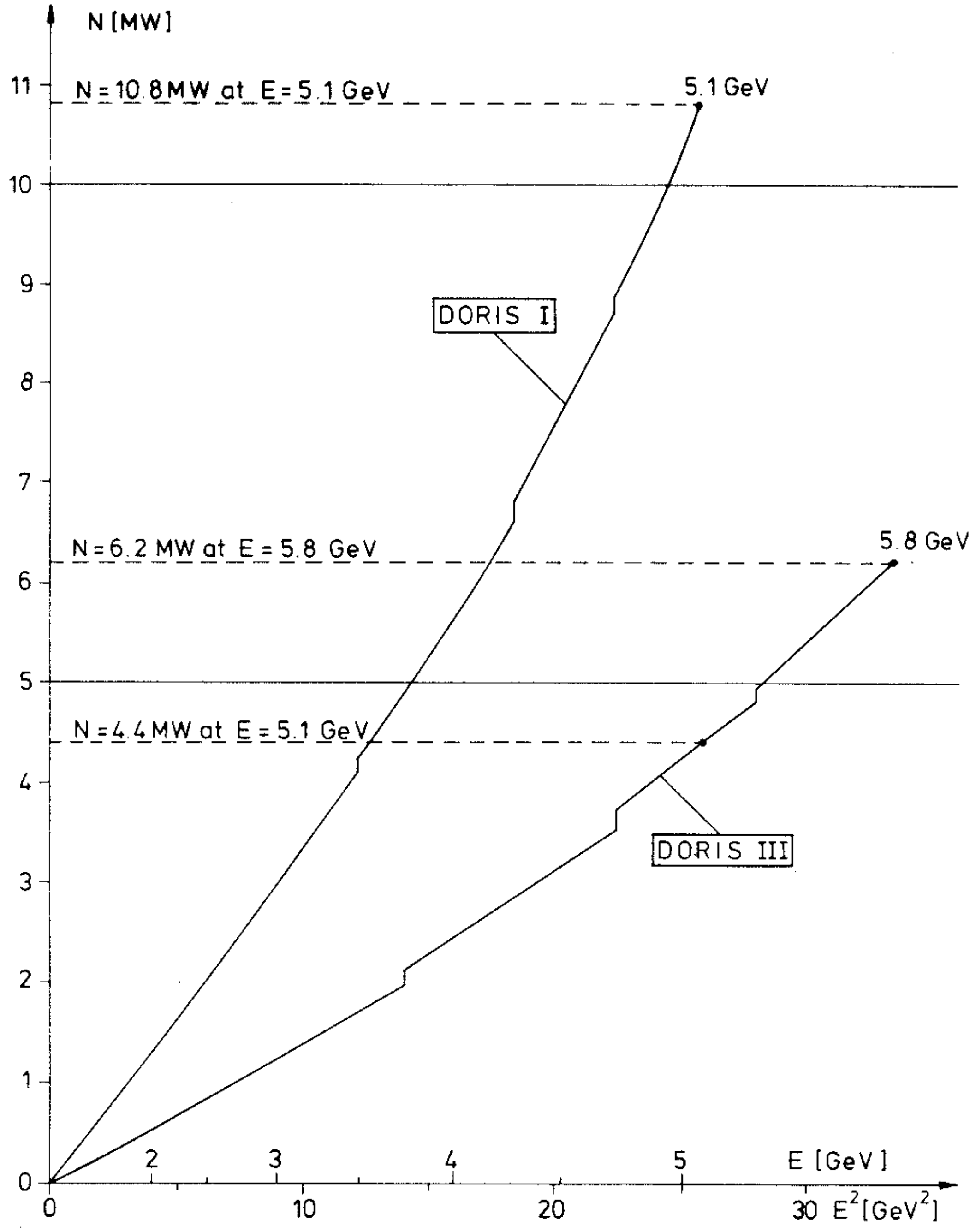


Fig. 24 Total power consumtion of DORIS (magnets and rf - System)

6) Compromise: DORIS II with a beam energy of 5.6 GeV

DORIS III is obviously the best design as far as machine characteristics are concerned, but unfortunately the concept has two significant disadvantages:

a) The position of the bending magnets is quite different from that of DORIS I. Therefore most of the HASYLAB synchrotron radiation beams would have to be changed. The total number of 35 split beams at HASYLAB make the situation even more complicated as seen in Fig. 25. Some of the light beams cross the iron yoke of quadrupoles and sextupoles and considerable modifications would be necessary.

b) The total cost of the DORIS III project with the new quadrupole magnets and completely new supports for all magnets amounts to approximately

DM 4.500.000,-

This sum might not be available before the end of 1982 because highest priority has been given to upgrading PETRA's energy.

Therefore we have looked for a compromise:

The modification of the bending magnets permits the reduction of the pole width and a consequent reduction in flux density in the magnet yoke. We have chosen a pole profile which provides a good field up to 5.6 GeV in the DORIS II structure (that is, with 6 magnets per quadrant)(Fig. 23). The magnet saturation at this energy is about 7 %.

The DORIS quadrupoles will be modified using the same technique of shimming as shown in Fig. 26.

These modifications are much less expensive than the building of new magnets. The quadrupoles have a higher gradient and a lower power consumption.

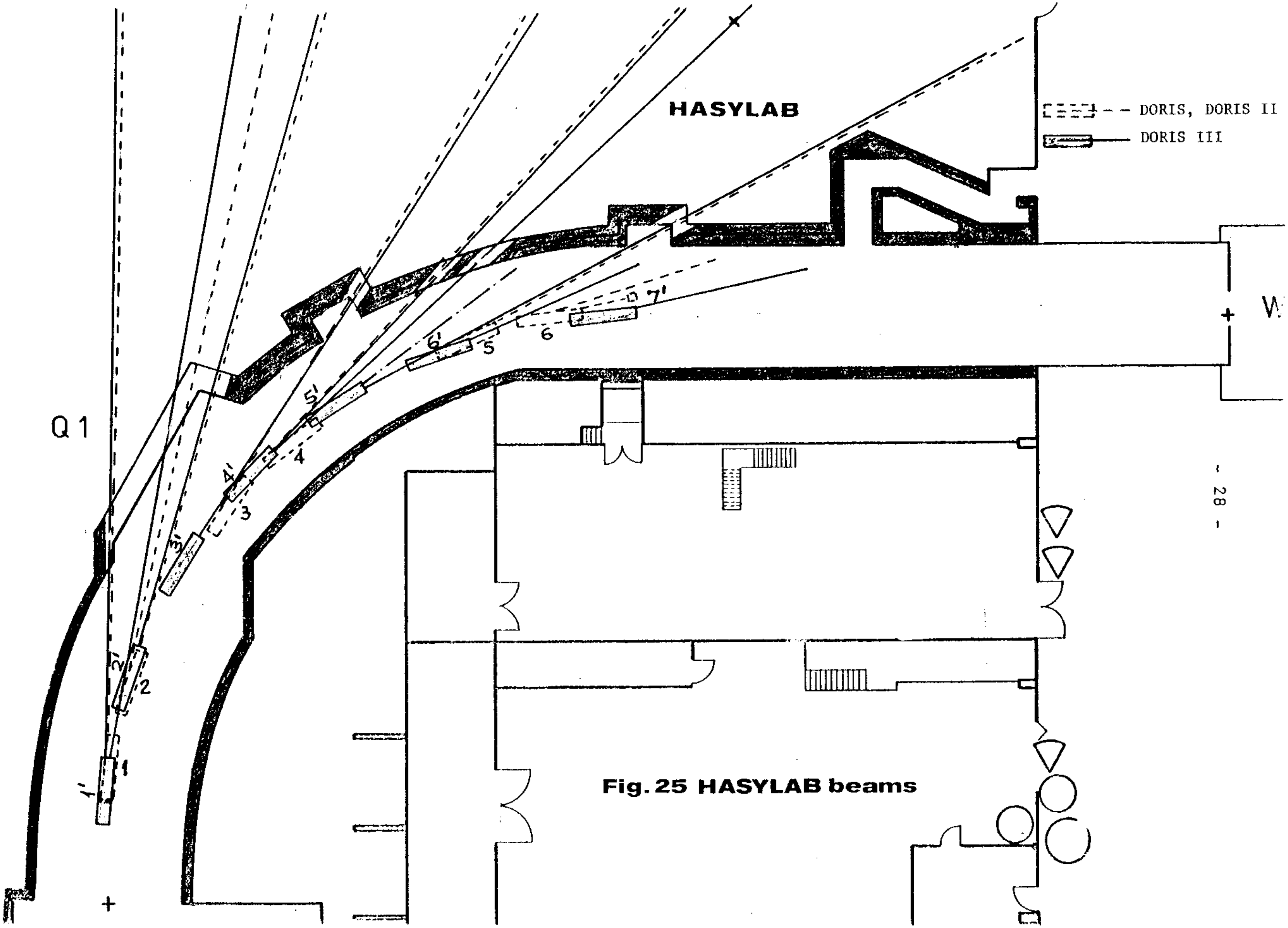


Fig. 25 HASYLAB beams

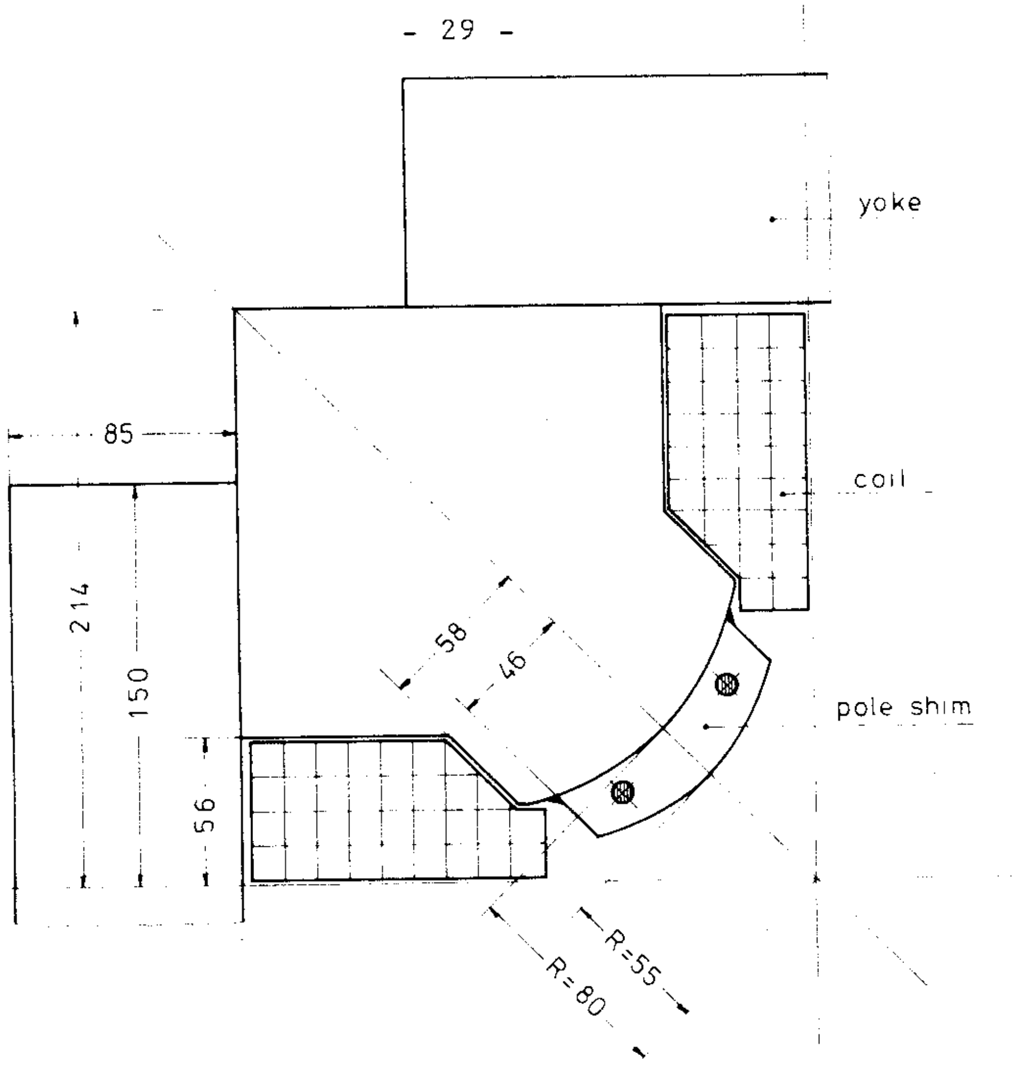


Fig. 26 DORIS - quadrupole

The compromise between the DORIS II and DORIS III concepts can be summarized as follows:

a) The magnetic lattice remains exactly the same as for DORIS II and does not conflict with the HASYLAB installation.

b) The power consumption for a given energy is only 50 % of the value for DORIS I.

c) The maximum energy is E = 5.6 GeV, which covers most of the interesting y-physics.

d) The luminosity is the same as calculated for DORIS II.

e) The costs will be less than half the cost of DORIS III.

This compromise has the best chance to be realized in the middle of 1982.

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7) References

1. DESY Storage Ring Group: DORIS, Present Status and Future Plans, Proceedings of the IXth International Conference on High Energy Accelerator, Stanford 1974
2. G. Mülhaupt: The first Operational Experience with the Double Storage Ring DORIS, Proceedings of the IVth International Accelerator Conference, Moskau 1974
3. H. Wiedemann: Speicherung von Elektronen und Positronen in DORIS bei DESY, Physikalische Blätter, 30. Jahrgang, Mai 1974 (Heft 5)
4. K. Wille: Betriebserfahrungen mit dem Elektron-Positron-Doppelspeicherring DORIS, Kerntechnik, 18. Jahrgang (1976) No. 1
5. DESY Storage Ring Group: DORIS - A Status Report, Proceedings of the Xth International Conference on High Energy Accelerators, July 11-17, 1977 Serpukhov b. Moskau
6. S.W. Herb et al.: Phys. Rev. Letters 39 (1977) 252
7. W.R. Innes et al.: Phys. Rev. Letters 39 (1977) 1240
8. The DORIS Storage Ring Group: DORIS at 5 GeV, DESY 79/08, February 1979
9. H. Gerke, H.P. Scholz, M. Sommerfeld, A. Zolfaghari, Das PETRA-Cavity, Internal Report DESY PET-77/08, Aug. 1977
10. The PETRA Storage Ring Group: PETRA, Proceedings of the 11th International Conference on High-Energy Accelerators, Geneva, July 7-11, 1980
11. A. Piwinski, Synchro-Betatron Resonances, Proceedings of the 11th International Conference on High-Energy Accelerators, Geneva, July 7-11, 1980
12. A. Piwinski, Computer Simulations of the Beam-Beam Interaction, DESY 80/131, December 1980
13. K. Steffen, Internal Report, DESY M-79/23, May 1979
14. K. Wille, Interner Bericht, DESY M-79/29, July 1979
15. H. Nesemann, J. Susta, F. Wedtstein, K. Wille, DORIS II, an e^+e^- Storage Ring with Mini Beta Sections, Proceedings of the 11th International Conference on High-Energy Accelerators, Geneva, July 7-11, 1980
16. G. Stange, Internal Report, DESY M-80/07, August 1980