Presentation 54

Separator System

By W. Kalbreier

54.1 Introduction

The LEP experiments committee at its meeting in Cogne in September 1990 recommended that the increase of the LEP luminosity by doubling the number of bunches should be given a high priority.

However, no budget money was available for the two proposals presented – the pretzel scheme or the alternative mid-arc separation scheme – which would allow to increase the number of bunches from $4e^+ \times 4e^-$ to $8e^+ \times 8e^-$.

A way out was found by L. Evans following the famous advice of Lord Rutherford " if you do not have money, think ! " He proposed to re-use the electrostatic separators from the SPS which would become available by the end of 1990 with the termination of the high luminosity $p\bar{p}$ runs.

A rapid feasibility study showed that due to their layout and the available number of units their use for a horizontal pretzel separation scheme in LEP was favoured. As a result, the implementation of a low cost version called *crash pretzel* was launched aiming at an installation of four separators before the start-up in 1991 and allowing valuable machine development experiments in the course of this year. The full pretzel scheme after the installation of four additional separators will become available for the start-up in 1992 allowing for colliding beams with $8e^+ \times 8e^-$.

Furthermore it is planned to install four trim separators in order to maintain the necessary flexibility in the change of the LEP tunes.

54.2 Adaptation of the SPS separators for LEP

The layout of the SPS separators is shown in the figs. 54.1, 54.2. The main parameters of the separator units are:

length of separator tank	3380 mm
electrode length	3000 mm
electrode height	160 mm
min. gap width	20 mm
max. gap width	160 mm
the electrode gap can be varied remotely.	
one electrode connected to h.v.of max.	300 kV
second electrode connected to ground	
electrodes from titanium-alloy (TA6V)	
no electrode cooling	

The installation of these separators in the SPS is shown in Figure 54.3. the main difficulty comes from the difference in the beam heights which are 1.20 m for the SPS and only 0.80 m for LEP.

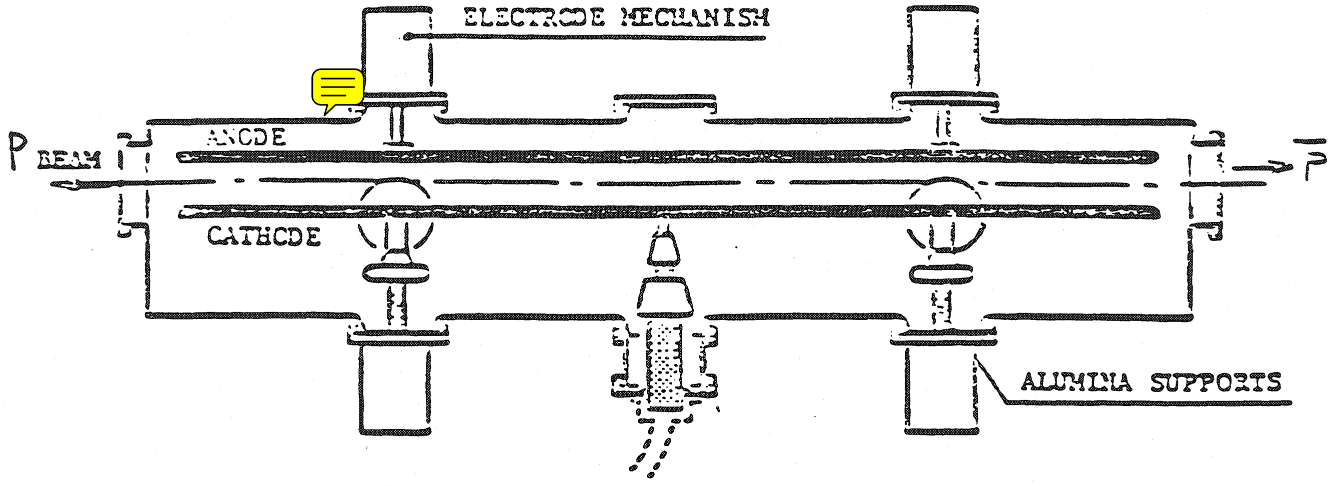


Figure 54.1: Top view of the ppbar separator unit from the SPS.

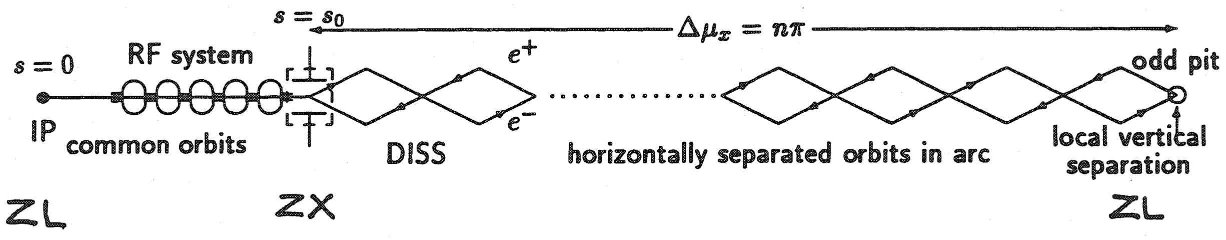
Therefore, the SPS separator support and the arrangement of vacuum pumps are incompatible with an installation in LEP.

A solution to these problems could be found by using the same type of support as for the vertical LEP separators (ZL) (see Figure 54.4) and in constructing new T-shaped manifolds for the connection of the vac-ion and the sublimation pumps below the tank (see Figure 54.5).

The equipment available from the SPS is as follows:

separators incl. spares	11
300 kv generators (Pantak)	8
160 kv generators (Passoni & Villa)	4
hv resistors	16
commutation switches	2
various hv connection cables	
bake⁻out jackets	
control electronics	

The schematic layout of the pretzel scheme in one octant is shown here:



For operation of LEP with 8e$^+$ × 8e$^-$ the mid-arc collision is avoided since the pretzel orbits of the e$^+$ and e$^-$ bunches are arranged such as to have opposite amplitudes. From injection up to the top energy all collisions in the "standard" LEP interaction points are suppressed by the vertical beam separation system which creates compensated local bumps in the eight insertions.

The complete scheme requires the installation of eight electrostatic separators ZX in the four even points. They will be positioned at both ends of the long straight sections between QS10 and

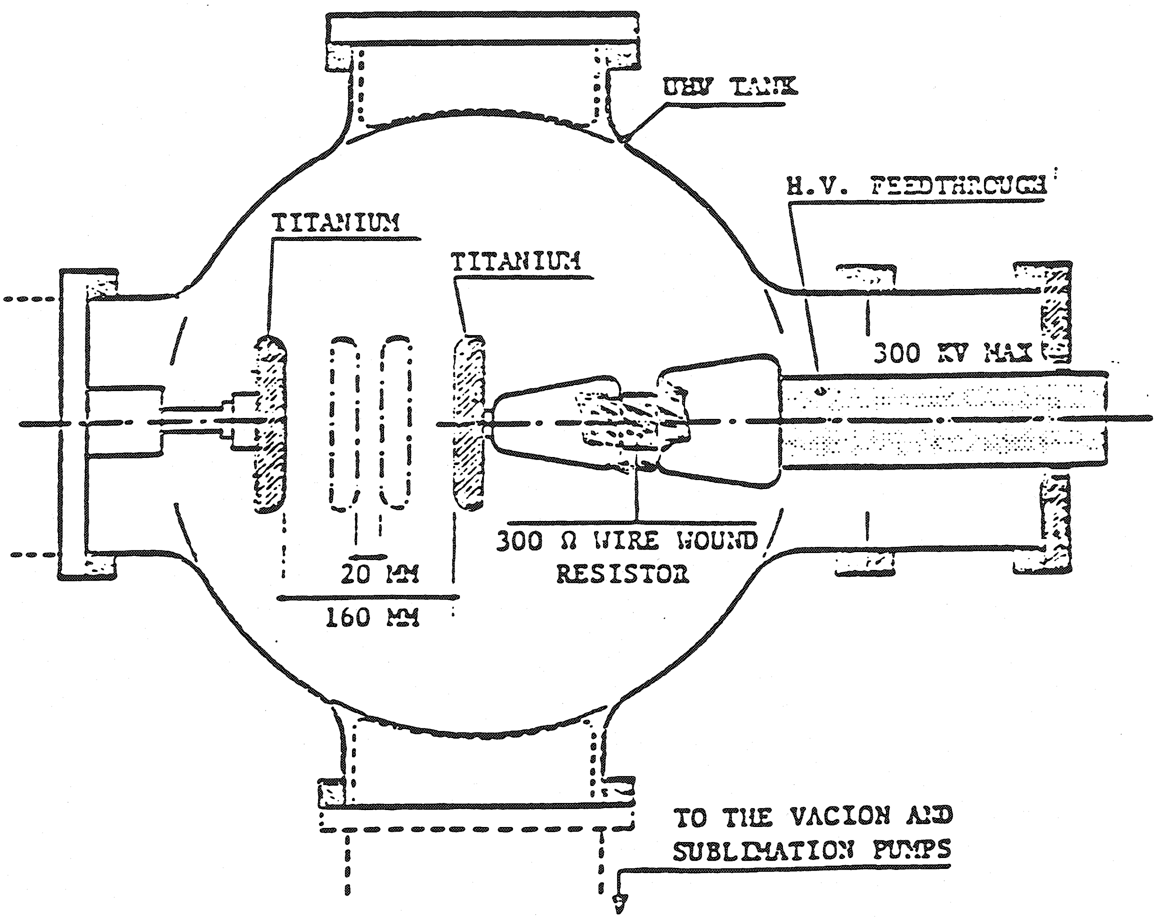


Figure 54.2: Cross section of the ppbar separator unit (horizontal electric field).

QS11.

In the points 2 and 6 this implies the removal of two Cu RF cavities per installed separator.

There is a draw-back of this scheme: since the pretzel orbits extend over a whole quadrant little flexibility is left for changing the LEP tune. Therefore it is envisaged to add four trim separators ZXT in the straight sections of the odd points in order to regain flexibility.

54.3 Pretzel phases and status report

54.3.1 PHASE 1: CRASH PRETZEL

The phase 1 - called because of its urgency *crash pretzel* - started in October 1990 and aimed at the installation of four separators ZX by the end of February 1991. Their positions are located in the long straight sections RA23, RA47, RA63,and RA87, respectively.(see Figure 54.6)

At present four Cu RF cavities have been dismounted in RA23 and RA63 (see Figure 54.7) and the fabrication and installation of the special vacuum chambers around the ZX (see Figure 54.8) is terminated.

The work on the separator system turned out to be quite significant:

54.3.1.1 separator units After the modification and reassembly the separators are baked at 220°C and have then to pass the H.V. conditioning test in the laboratory.

After installation in the tunnel they are baked again and the final H.V. conditioning takes place.

The installation of the H.V. circuit proceeds as follows:

RA23,63: the H.V. generators are located in the klystron gallery next to ZX
RA47,87: the H.V. generators are located in new H.V. zones situated at level 0 in the caves US45 and US85 respectively, and connected via a 300m long cable with the separator (see Figure 54.9)

The status of the four installed separators is :

RA23,47,67:	the h.v. conditioning is terminated
RA87:	the h.v. conditioning will be finished by end of February 1991.

54.3.1.2 Controls of the separators The extremely short time scale did not allow construction of new control electronics right now. Instead the existing electronics is used (recuperated from the SPS including the MPX-crates). A more thorough modernisation might be carried out in early 1992, during the next shut-down. The control electronics is integrated in the ZL-zones located in the underground caves US25,45,65,85 at level "1" .

A sketch of the ZX control system is given in the Figure 54.10. The VME based "device stub controller" (DSC) will perform the local process control. Its CPU, running under OS-9, is connected to a regional Ethernet, which itself is linked via a gateway to the Token Ring. The access to the equipment is done via the 1553 bus using the new 1553-to-MPX interfaces. The main functions comprise the control of the H.V. generators, the spark counters, the electrode motors, and the switches to reverse the polarity. A TG3 card will permit the use of machine timing events to trigger the required voltage increase during the energy ramping in order to keep the pretzel amplitudes independant of energy. The system will be controllable from the PCR by means of a menu- and character-based application program on the Apollos.

The status of the controls is:

The electronics is installed in RA23, 47, 63 and will be installed in RA87 by the end of February 1991.

A DSC development version has been delivered. The necessary four series DSCs will be received in the middle of february 1991.

The work on the application software has started.

The main parameters of the pretzel separation system are given in the following Table 54.1. The arguments which lead to the minimum separation gap and to the maximum operating field are outlined in the following chapters.

Energy (GeV)	**46.5**	**93**
max.deflection angle per unit (mrad)	0.129	0.065
field length per unit (m)	3.0	3.0
min. operating gap width (mm)	125	125
max. operating field (kV/cm)	20	20
max. operating voltage (kV)	250	250
max. conditioning voltage (kV)	300	300
total number of zx units for phase 1	4	4
total number of zx units for phase 2	8	8
min. required separation in units of hor. beam width	5	5

Table 54.1: Main parameters of the ZX separators for the pretzel scheme.

Separator polarity:

An important requirement to the separation system is that the pretzel bump in each LEP quadrant must be antisymmetric with respect to the odd point. This leads to a specific separator polarity which is different for 60° and 90° lattices, respectively. For LEP200 with a higher beam energy there is a second requirement that the pretzel amplitudes must be in phase with the "energy sawtoothing".

The separator kicks and the associated polarity of the H.V. generators for the present 60° lattice for LEP100 have already been shown in Figure 54.6. For the transition from the 60° to the 90° lattice it will therefore be necessary to commute to the H.V. generators to opposite polarity (see Figure 54.11). In RA23 and RA87 this can be carried out by remotely controlled commutation switches (from the SPS). In RA47 and RA63 an intervention in the ZX H.V. zones in US45 and the klystron gallery UA63 is needed – this does not require access to the machine. The changeover will take less than two hours.

Already this year beam tests will be possible with $1e^+ \times 1e^-$ to $3e^+ \times 3e^-$ and the bunches will be injected such as to meet only in those mid-arc points which lie inside the pretzel orbits.

54.3.1.3 Acknowledgements How is it possible that we get ready in time with such an ambitious "crash pretzel" programme, inspite of the heavy workload imposed by the SPS and LEP shutdown period? The answer is twofold: firstly we have an excellent collaboration with the involved groups from AT, MT, ST and SL divisions. Secondly there is a high motivation and enthusiasm in the LEP separator team - both for CERN staff and the personnel from contract labour. This motivation allowed vital overtime work to be carried-out during evenings, weekends and even during the Christmas holidays.

54.3.2 PHASE 2 FULL PRETZEL

The aim of phase 2 is the installation of four additional separators in the next winter shutdown so that for the start-up in 1992 the pretzel orbits could be extended over the entire LEP machine (Figures 54.12, 54.13). The separator are located in the long straight sections RA27, RA43, RA67, and RA83 This will require the removal of four additional Cu RF cavities in RA27 and RA67 and the fabrication and installation of special vacuum chambers around the ZX units.

Work for the separation system:

- The assembly, installation, and H.V. conditioning of four ZX units will have to be carried out. The H.V. generators installed in the klystron galleries UA23 and UA63 will have to be transfered to the new ZX H.V. zones in US25 and US65.
- In total six H.V. cables each 300 m long will have to be pulled: from RA23,27 to US25; from RA43 to US45 from RA63, RA67 to US65; and from RA83 to US85.
- The installation of the associated control electronics and eventually its modernisation will have to be accomplished.
- The use of the Pretzel separation system for physics will only be feasible if the 300 kV generators from Pantak can be made more reliable. The problem lies with the regulation and power units (RPU). This has already lead in the past at the SPS to the replacement of the Pantaks for the $p\bar{p}$ operation by LEP type H.V. generators from Passoni & Villa. Therefore, it is vital to replace the RPU's by new ones to be ordered from Passoni & Villa, whereas the H.V. stacks from Pantak could be kept because they are sufficiently reliable.
- Beam tests will be feasible from 1992 onwards and- - if successful – physics with $8e^+ \times 8e^-$.

54.3.3 PHASE 3 FULL PRETZEL WITH TRIM ZXT

The aim of phase 3 is the installation of four "trim" separators called ZXT each in one of the long straight sections of the odd points. These units are to maintain the required flexibility in the change of the LEP tune. At present it is envisaged to install two units in the next winter shutdown in 1992 and - because they still need to be constructed - the remaining two units in the subsequent shutdown 1993 at the latest. The optimum position is at present under study. It should be stressed, that because of a reduced beam height of only 650 mm in the points 3, 5, and 7 this will necessitate carving a groove of 150 mm depth at each separator position. Again special vacuum chambers will have to be fabricated and installed around these trim units.

Work on the trim separators:

- Since there are not enough separators available from the SPS to cover the entire trim system, the fabrication of two ZXT separators and all their associated equipment will have to be carried out.
- The assembly, installation, and H.V. conditioning of four ZXT separators will have to be realised.
- Four 160 kv generators (Passoni & Villa recuperated from the SPS) will have to be installed in the new ZXT H.V. zones in US15, UJ33, UJ56, and UJ76. Four H.V.cables each of about 300m length will have to be pulled between the H.V. zones and the ZXT.
- The entire control electronics will have to be constructed and installed in the ZL zones of the corresponding underground caves.

54.4 Performance limitations of pretzel separators

54.4.1 ELECTRICAL BREAKDOWNS

The main performance required from electrostatic separators is to deflect the beam whilst reducing the number of the electric breakdowns to a strict minimum. This is an important feature, since MD measurements carried out with the vertical LEP separators at 20 GeV showed that a spark caused the complete loss of all stored bunches for both a single beam or e^+ and e^- beams.

Sparks can occur due to (i) pure H.V. processes and (ii) external sources e.g. synchrotron radiation or x-rays. The main effect of the first type is field emission of electrons and the subsequent electrode outgassing. For a constant gap the spark rate is increasing exponentially with the electric field. In the case of the pretzel separators the synchrotron radiation (SR) is originating from the main and the weak dipoles, whereas the X-rays could come from the adjacent Cu RF cavties.

The spark rate as a function of the electric field is shown in Figure 54.14 for the current vertical separators (ZL):

- curve a: no beam,
- points b,c: normal beam operation at a pressure of $< 1.0\ 10^{-10}$ Torr,
- point e : normal beam operation at a pressure of $3.0\ 10^{-9}$ Torr due to a leak in a ZL,
- curve d: electrodes exposed to SR from SC quadrupoles during an MD due to smaller gap.

The first results obtained for the ZX (without beam) are also indicated.

54.4.2 OPERATION REQUIREMENT

For a reliable operation with minimum disturbance we need to aim at a spark rate of the pretzel separation system of less than one spark in two days. This corresponds to a spark rate per ZX of less than $2 \cdot 10^{-3}$ per hour. This can only be achieved according to Figure 54.14 if the following conditions can be met:

1. The electric field is limited to ≤ 20 kV/cm.
2. If the spark rate of the ZX is increased due to x-rays from the adjacent Cu RF cavities the corresponding RF station feeding these units must be switched off.
3. The electrodes must be protected from any direct SR and the scattered SR should be kept as low as possible.

The first two conditions seem to be compatible with the LEP requirements. As it will be shown by G. von Holtey the last condition is the most difficult one and will need more studies and MD's during this year. At present we are not really sure whether the envisaged ZX performance can be achieved.

54.5 The protection of the ZX electrodes from SR photons

54.5.1 THE LEP200 CASE

The effect of SR from the main and weak bends has been investigated by G. von Holtey. Horizontal collimators will be needed in order to protect the sc cavities and the ZX electrodes from the intense direct SR photons. These collimators however, will only be available from 1993 onwards.

54.5.2 THE SITUATION IN 1991

Points 2 & 6:

Fixed lead masks will be placed around the stainless steel vacuum chamber of 100 mm diameter situated between the ZX and QS11. Due to their large gap of 125 mm the electrodes will be screened by the lead masks. A high intensity of scattered SR photons will hit the electrodes.

Points 4 & 8:

Between the ZX and QS11 a standard Al-chamber of 131 mm width is installed. At a nominal gap of 125 mm the external electrode will be hit by direct SR photons. However, the external electrode could be opened further up to 80 mm to arrive in the shadow of the mask. In order to improve the situation it is planned to replace these Al-chambers by stainless steel ones equipped with lead masks in June of this year.

54.6 The impact of SR photons on the electrodes

Unfortunately we do not have a quantitative knowledge of the effect of SR photons hitting H.V. electrodes. It is well known, however, that under the impact of SR photons, electrons can be liberated which are then accelerated by the electric field. When these electrons impinge on the anode surface they provoke a local heating. As a consequence gas molecules are desorbed and the vacuum pressure increases.

The correlation between spark rate and vacuum pressure is also rather complex and depends furthermore on the vacuum quality, but a poorer vacuum tends to increase this rate.

O. Gröbner has made an order-of-magnitude estimate of the induced pressure rise for the separators in RA47 and RA87, which are at present not protected by the lead masks. Based on the SR calculations of G. von Holtey the photon intensity per external electrode and nominal gap at a beam energy of 20 GeV is $5\cdot 10^{14}$ s^{-1} per mA beam current.

According to measurements at DCI with a critical energy 3 keV this would produce a photoelectron current of $12\cdot 10^{-6}$ μA per mA beam current.

When these electrons are impinging on the anode the following gas desorption rate is produced: $2.3 \cdot 10^{-8}$ Torr·l/s per mA beam current

With the installed pumping speed of about 1000 l/s of CO, CO_2, the pressure increase should be: $< 3 \cdot 10^{-11}$ Torr per mA beam current, $< 2 \cdot 10^{-10}$ Torr for 8 bunches of 0.75 mA

54.6.1 CONCLUSION

- This small global pressure rise will not become a serious performance limitation for the ZX.
- The effect of the instantaneous local pressure rise at the electrode surface on the spark rate might however be significant.
- Therefore this effect will be investigated in the lab by heating the electrodes and irradiating them with laser light, but the true answer will come this year from MDs with ZX irradiated by SR in the LEP tunnel.

54.7 Effects of higher order mode losses

At the SPS with the long proton bunches higher order mode (HOM) losses are negligible and therefore no measurements have been carried out with the $p\bar{p}$ separator units.

In order to make an estimate of the HOM losses for the Pretzel separator units we have to refer to the bench measurements made for the vertical LEP separators (ZL) by H. Henke. They resulted in a loss factor k_{hom} = 0.43 V/pC for an r.m.s. bunch length of 2.0 cm.

Assuming the ZX units have the same loss factor , the total loss factor per separator P_{hom} can be calculated as follows:

$$P_{hom} \; = \; 2n_b \, k_{hom} i_b^2 \, T_r \; = \; 38.2 \; 10^6 \; n_{tot} \; i_b^2$$

where n_{tot} is the sum of the e^+ and e^- bunches, i_b the bunch current and T_r the revolution frequency.

Extrapolation from measurements at CESR/Cornell show that approximately 80% of the total power is dissipated on the two electrodes. Thus the loss per electrode is given by $P_{el} = 0.40 \; P_{hom}$. In Figure 54.15 the HOM loss per electrode is shown as a function of the total number of bunches for different bunch current parameters. For the present LEP intensity and 4 e^+ × 4 e^- bunches the loss per electrode is only about 20 W. For a successful Pretzel operation with 8 e^+ × 8 e^- bunches and a nominal bunch current of 0.75 mA this loss would rise to about 140W.

Without any direct electrode cooling the steady-state temperature of the electrodes has been calculated assuming that the induced heat is radiated away. The result is shown in Figure 54.16 as a function of HOM losses per electrode. For the polished surfaces of the electrodes and the inner wall of the vacuum tank the emissivities are unfavourably low – between 0.10 and 0.15. Therefore without direct cooling, temperatures of 50 to 80° could be reached for the present LEP intensities, possibly increasing to 130 to 200° for the nominal Pretzel parameters.

An elevated electrode temperature results in a significant increase of its outgassing rate. Based on measurements of the outgassing rates as a function of temperature by F. Lenormand and assuming an effective pumping speed of about 500 l/s, the dependance of the partial vacuum pressure on the electrode temperature has been evaluated (Figure 54.17).

Neglecting the hydrogen partial pressure – which is less important for background considerations of the LEP experiments – it can be stated that for electrode temperatures $\leq$ 200°C the total vacuum pressure in the separator will remain below the LEP design presure limit of 2 10^{-10}Torr.

Thus – on the basis of the above mentioned assumptions – we might expect that for bunch currents of up to 0.74 mA and a Pretzel operation of $8e^+ \times 8e^-$, direct electrode cooling for the new ZX separators may not be required.

It is planned, however, to carry out HOM bench measurements with a ZX unit in Spring 1991 and furthermore to perform MD experiments with a single beam but a high number of bunches in the course of 1991 in order to clarify from which intensity upwards a direct cooling might become necessary.

54.8 ZX budget estimation

Main pretzel scheme with 8 ZX	
Total price including the upgrading of the Pantak generators	950 kCHF
Trim pretzel scheme with 4 ZXT	
Total price including the construction of two ZXT and the associated equipment for four units	1'130 kCHF
GRAND TOTAL	2'080 kCHF

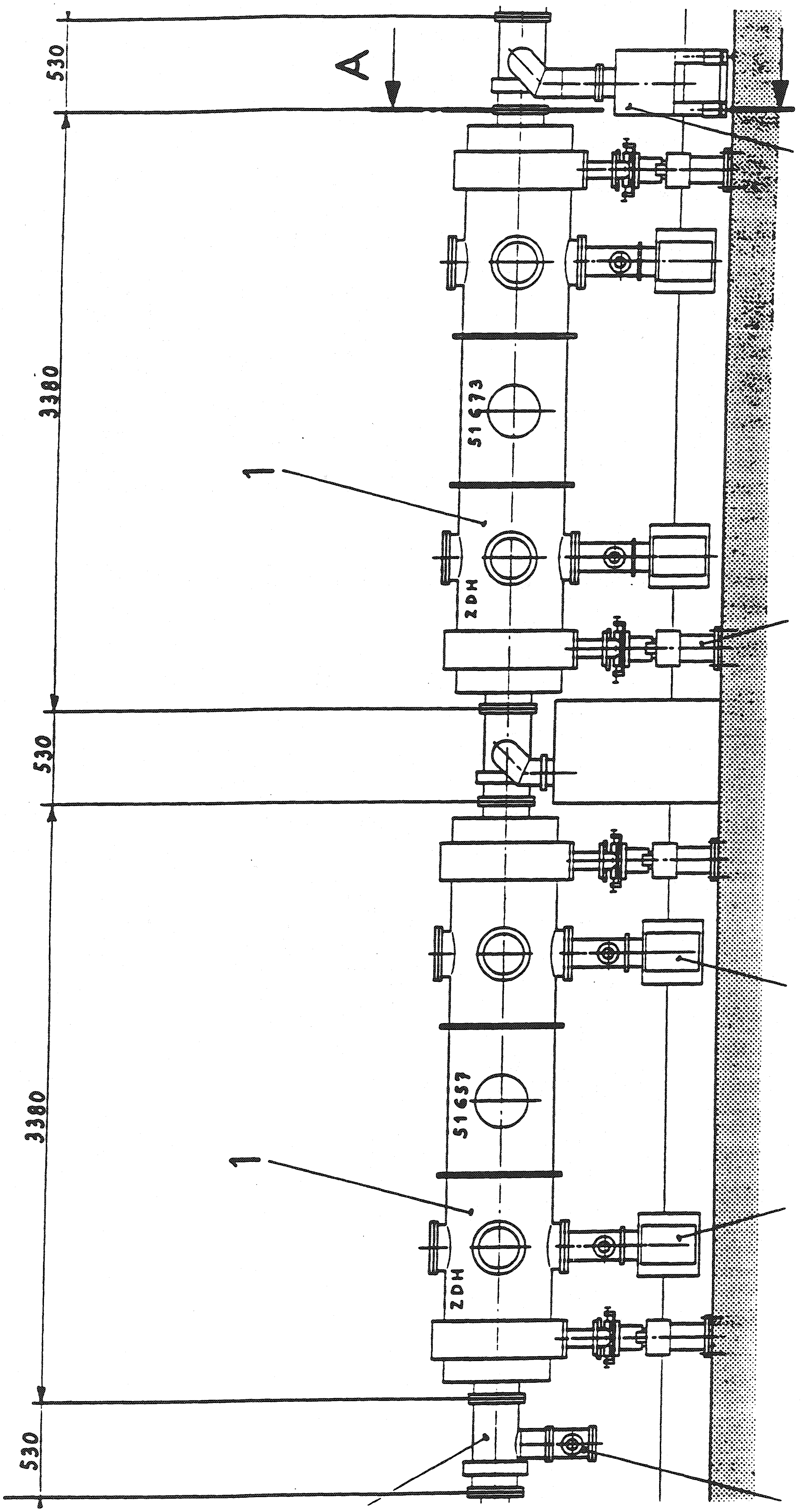


Figure 54.3: Horizontal ppbar separators installed in LSS5 of the SPS.

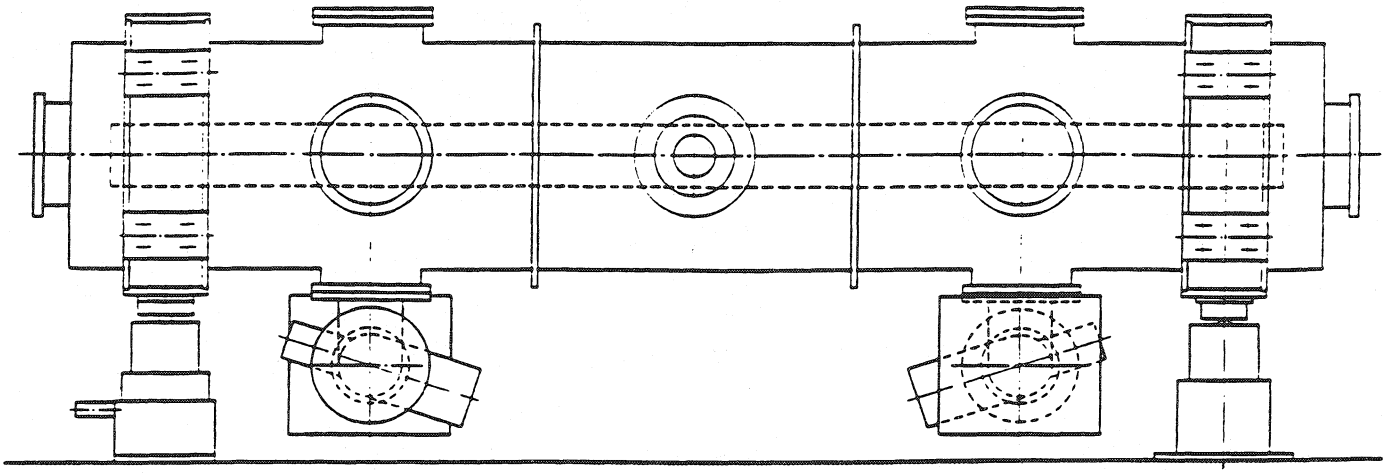


Figure 54.4: Side view of the modified ppbar separator ZX as installed in LEP.

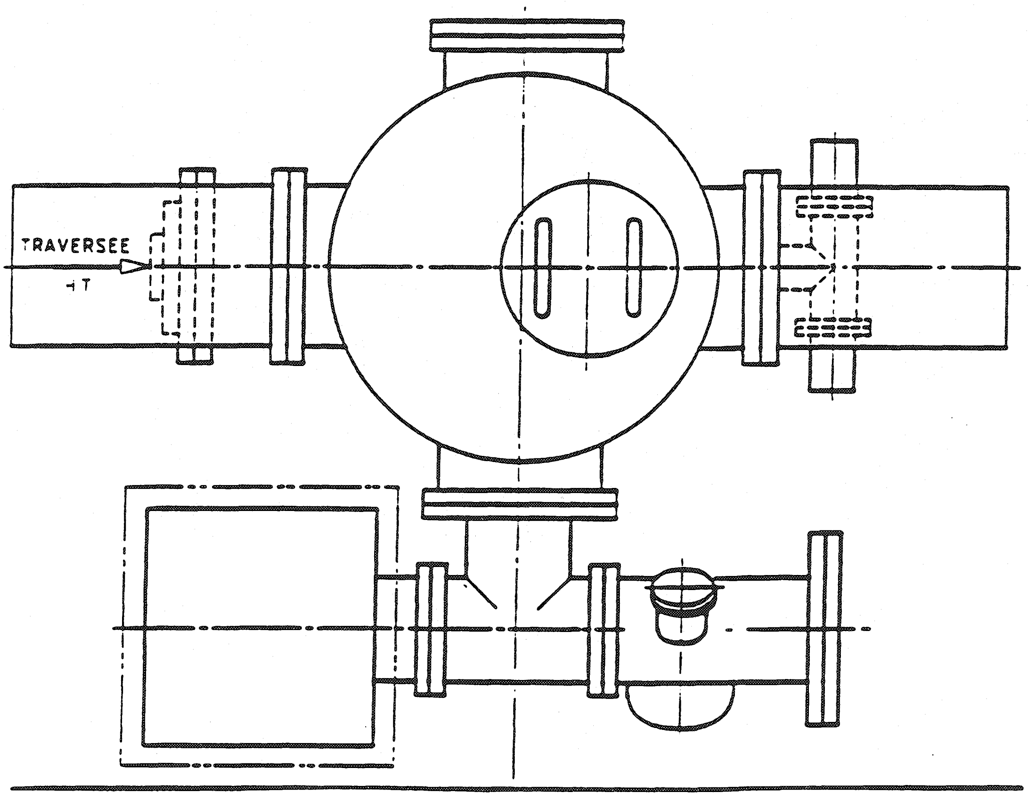


Figure 54.5: Cross section of the modified ppbar separator ZX as installed in LEP.

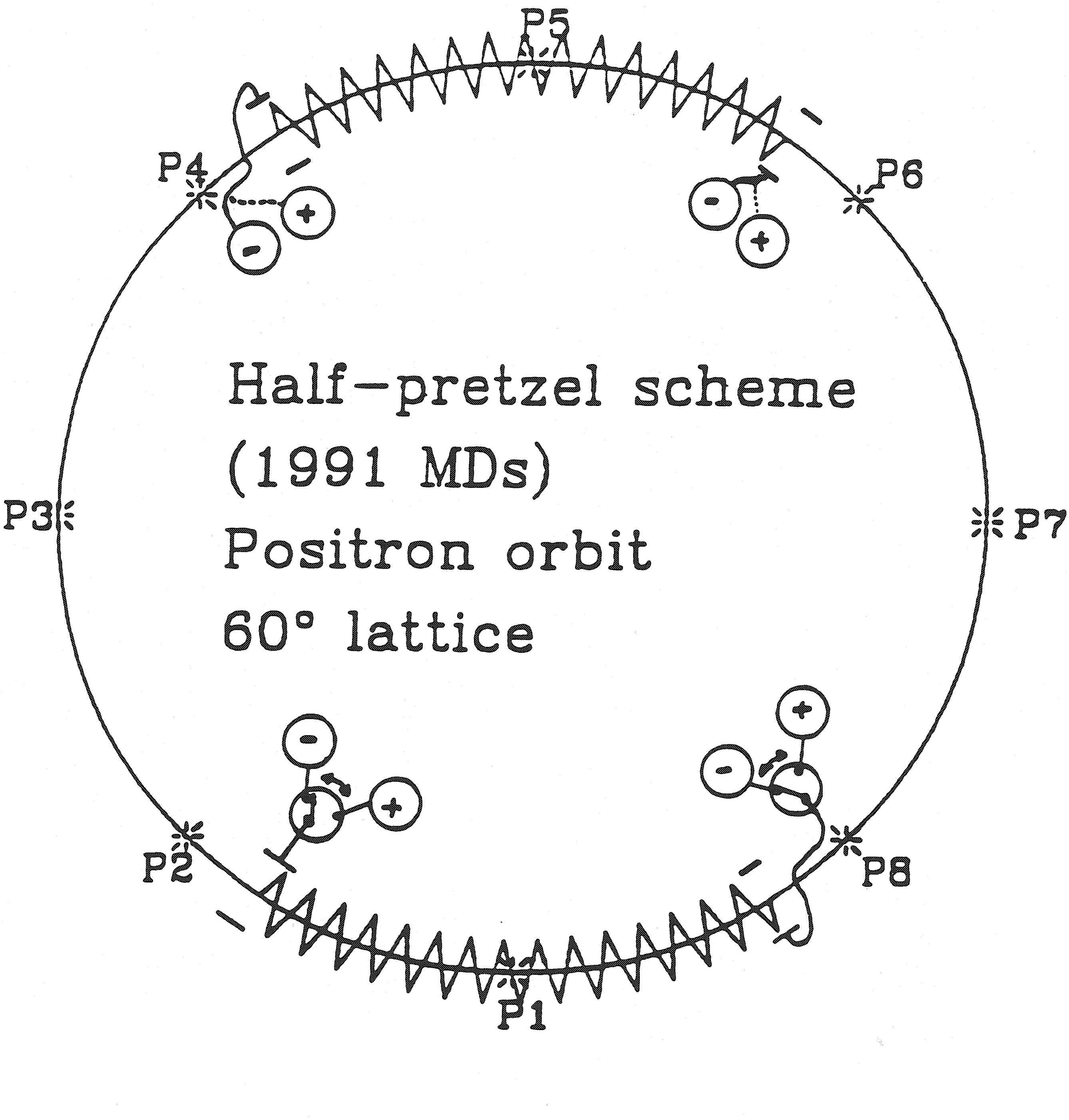


Figure 54.6: The LEP Pretzel separation scheme Phase 1 for 60° lattice as it will be available for machine development experiments in 1991.

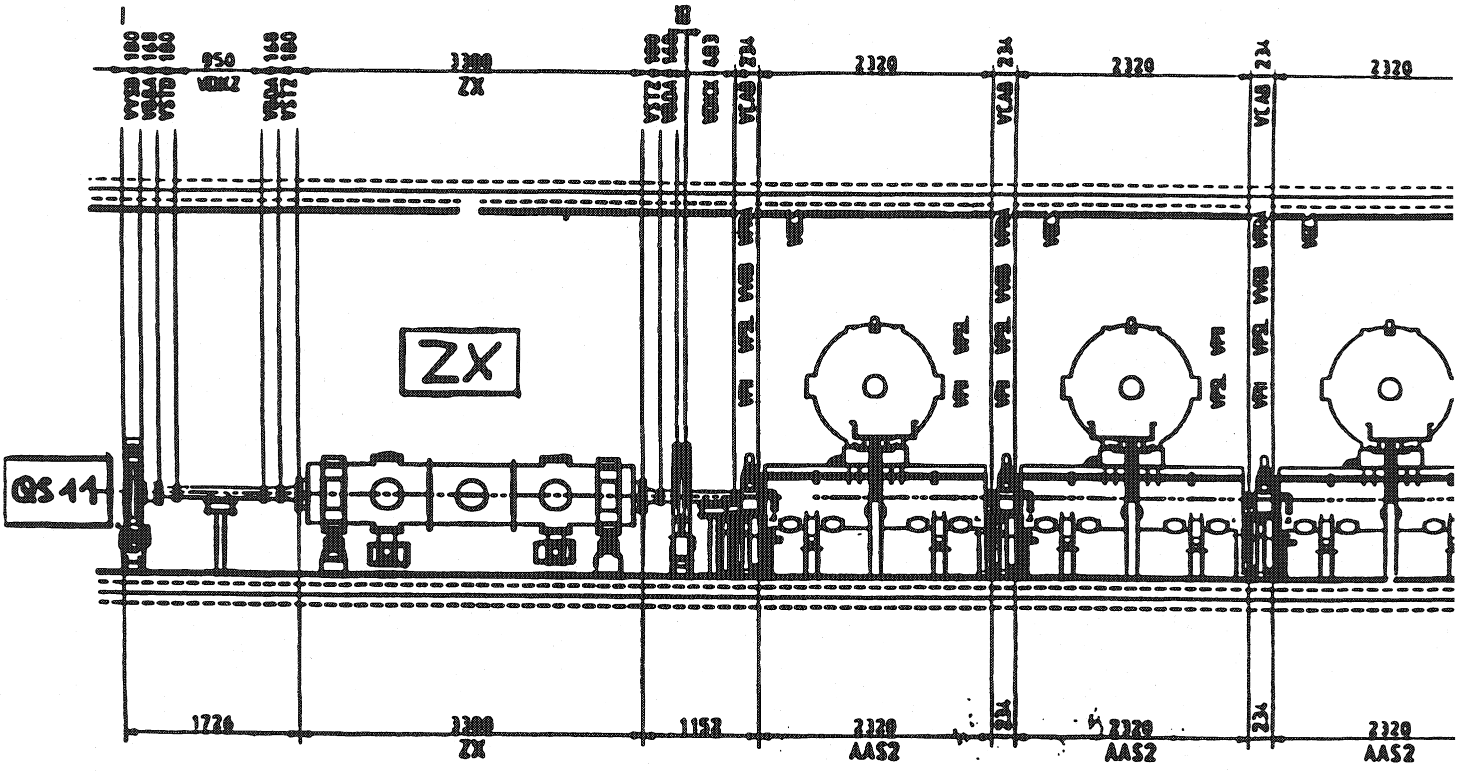


Figure 54.7: The separator units as installed in the LEP Points 2 (RA23) and 6 (RA63) after the demounting of the Cu RF cavities.

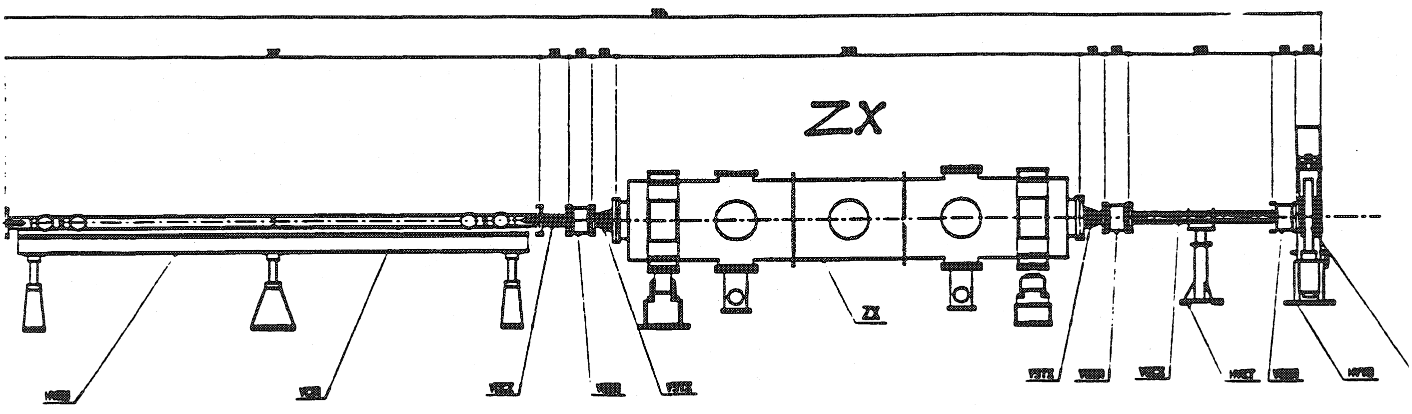


Figure 54.8: The separator units ZX and the new vacuum chambers as installed in the LEP Points 4 (RA47) and 8 (RA87).

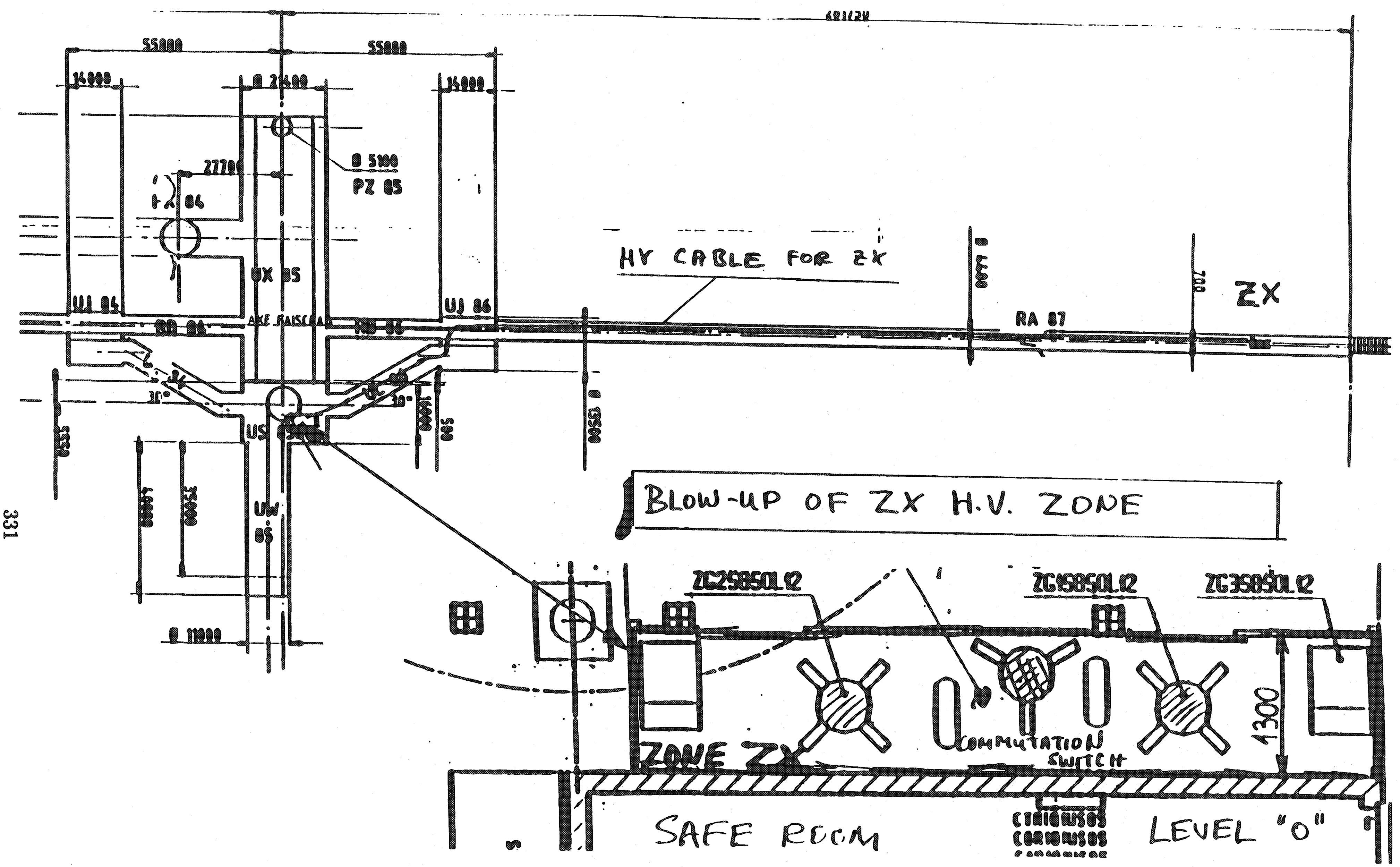


Figure 54.9: The powering of the separators in RA47 and RA87 from the new ZX H.V. zones situated at level 0 in US45 and US85, respectively.

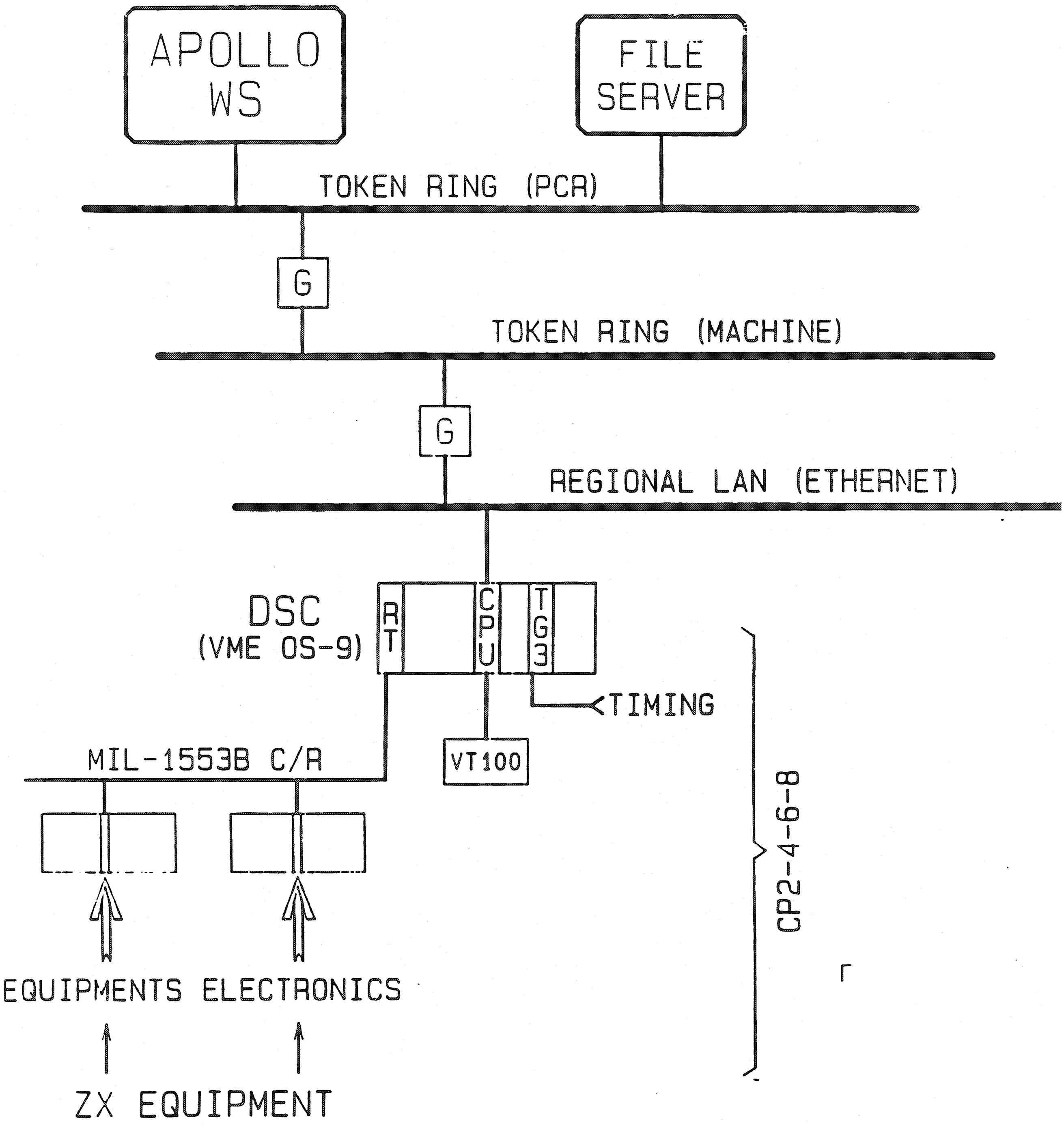


Figure 54.10: Schematic layout of the ZX control system.

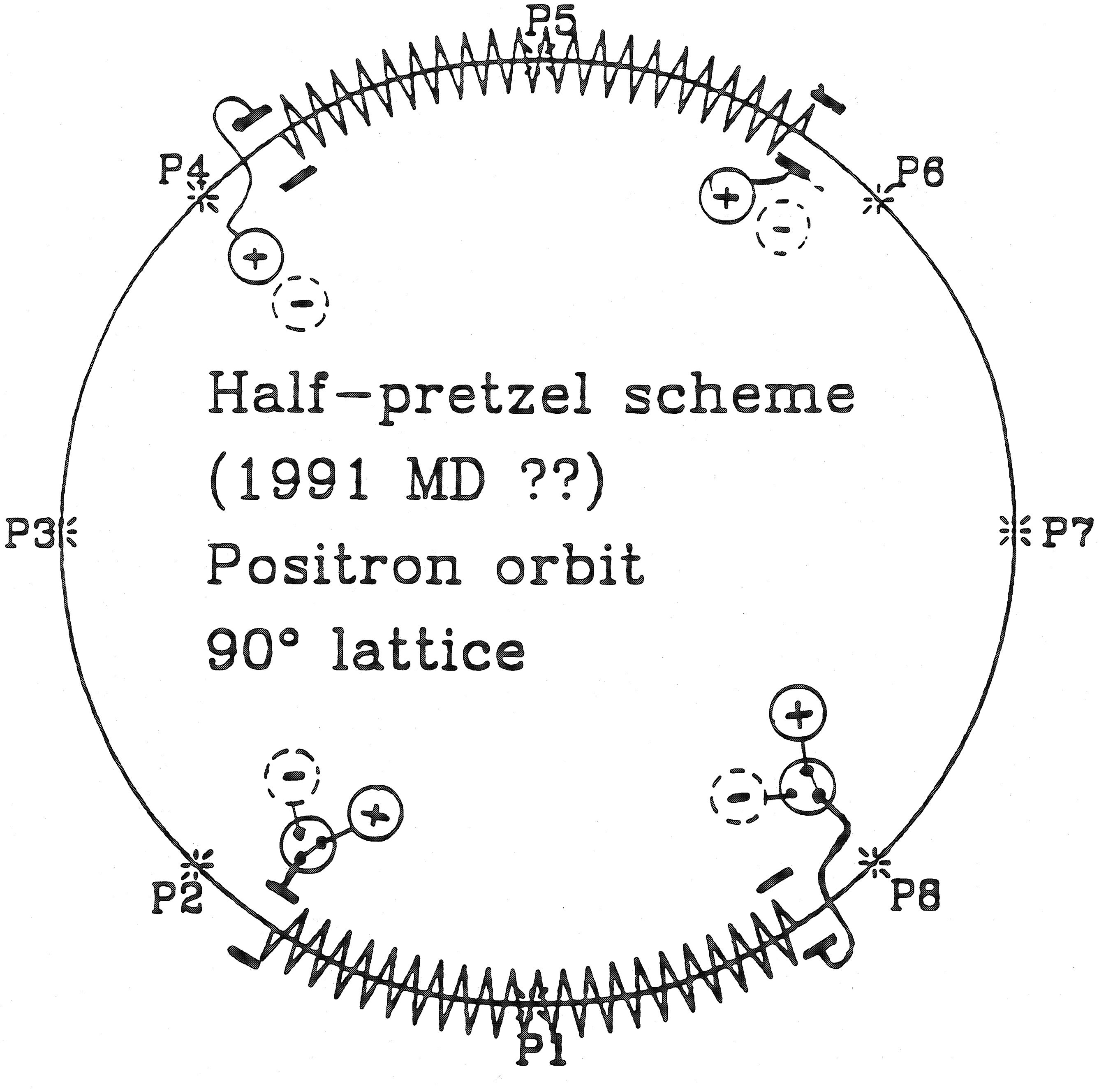


Figure 54.11: The LEP Pretzel separation scheme Phase 1 for the 90° lattice as it will be available for machine development experiments in 1991.

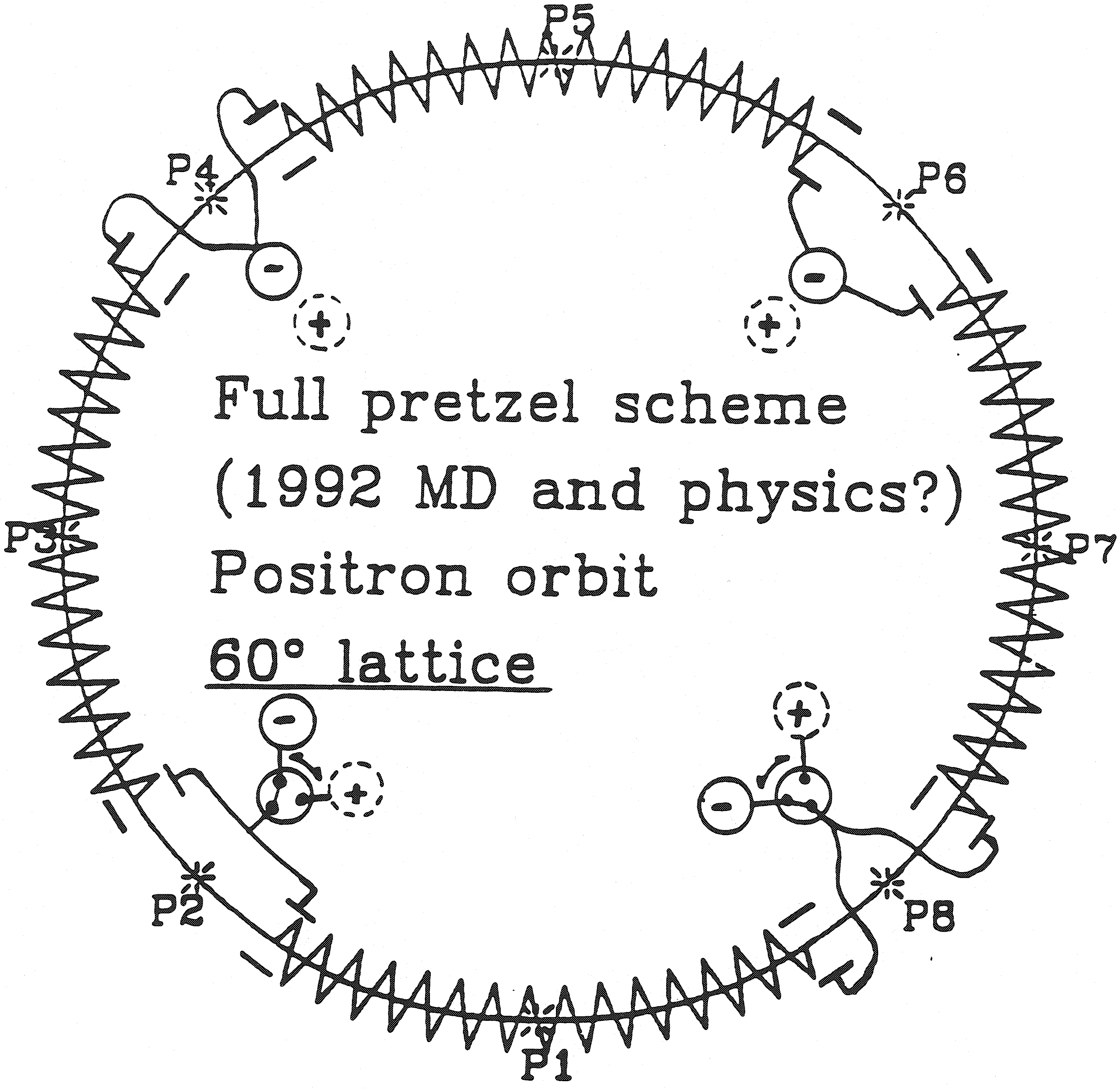


Figure 54.12: The LEP Pretzel separation scheme Phase 2 for the 60° lattice as it will be available for the startup in 1992.

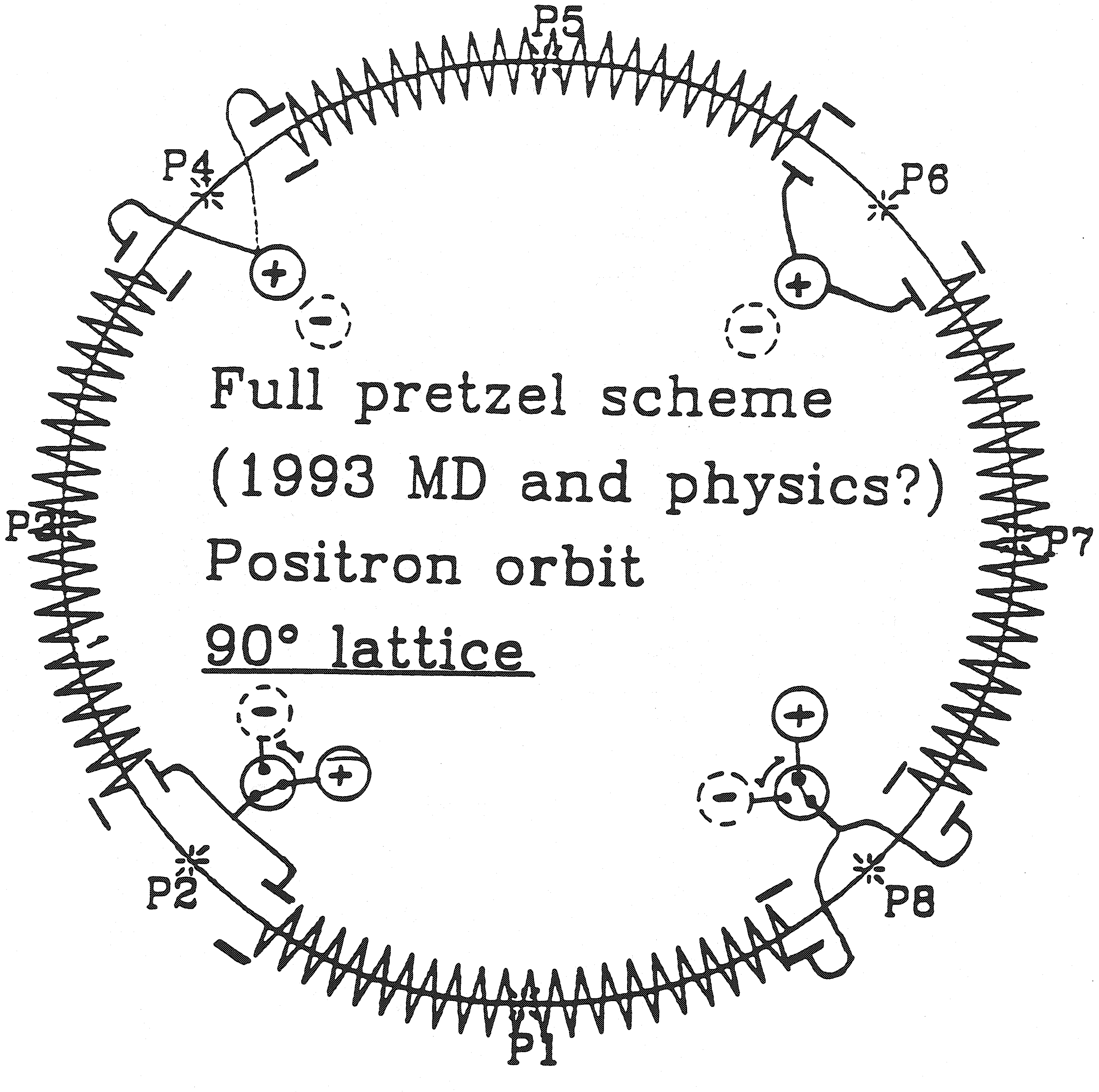
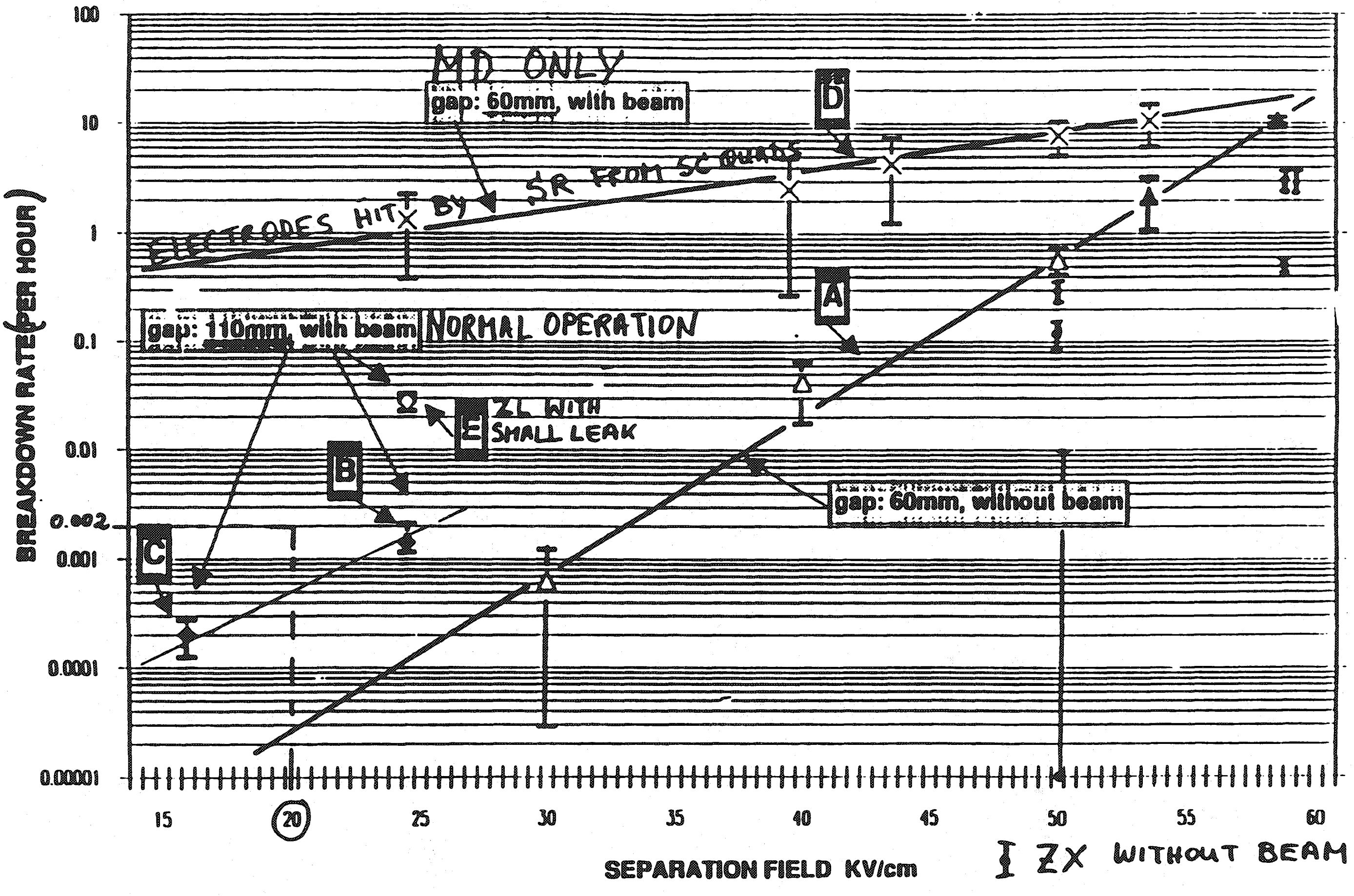


Figure 54.13: The LEP Pretzel separation scheme Phase 2 for the 90° lattice as it will be available for the startup in 1992.



The spark-rate as a function of the electric field strength for the current vertical LEP separators (ZL): curve A: no beam;
points B, C: normalbeam operation at a pressure of < 1.0 10**-10 Torr;
point E: normal beam operation at a pressure of 3 10**-9 Torr;
curve D: due to a smaller gap the electrodes were exposed to direct synchrotron radiation from the SC low-beta quadrupoles during a machine experiment
The corresponding points for the pretzel separators (without beam) are marked with ZX.

Figure 54.14: The spark rate as a function of the electric field strength for the current vertical LEP separators (ZL).

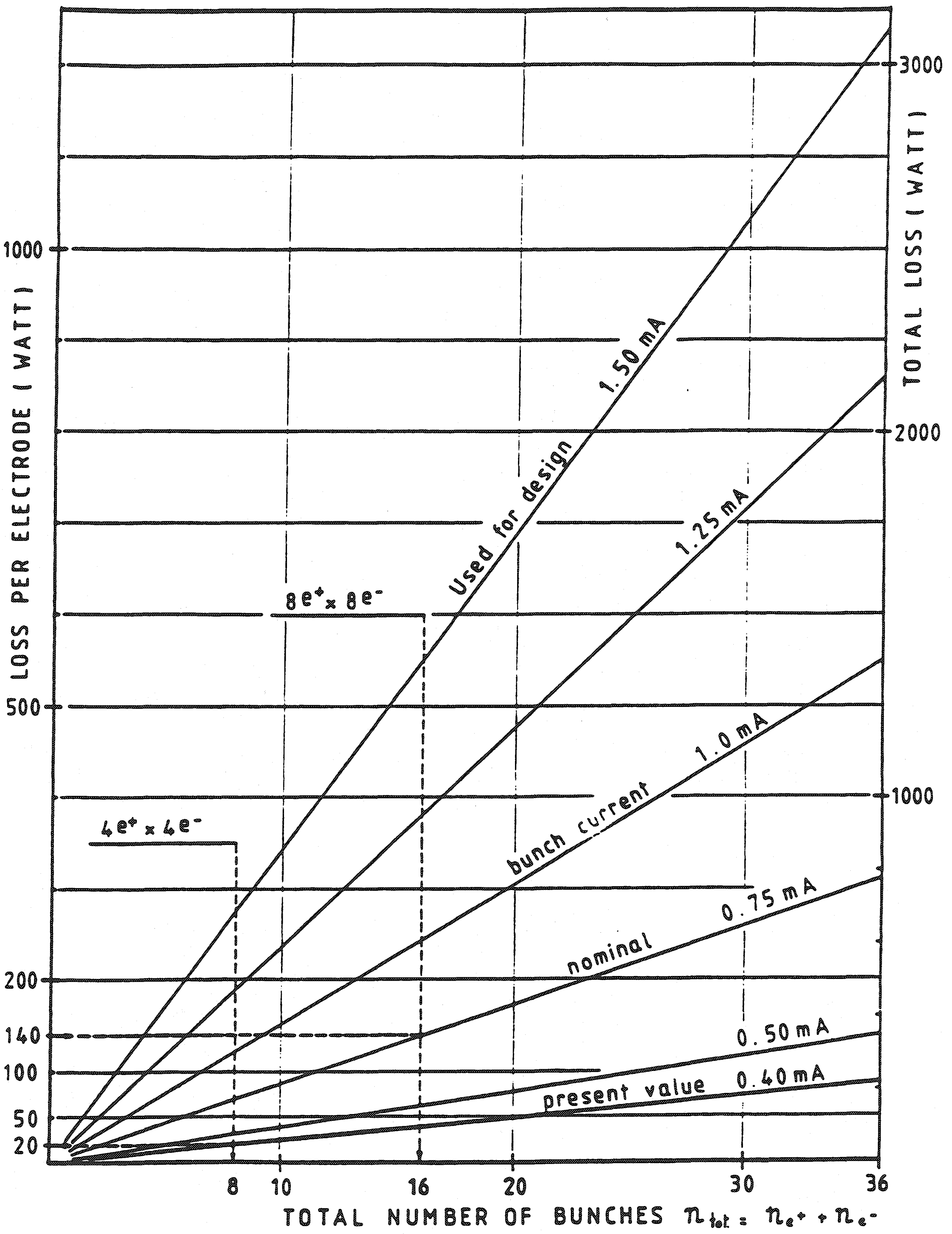
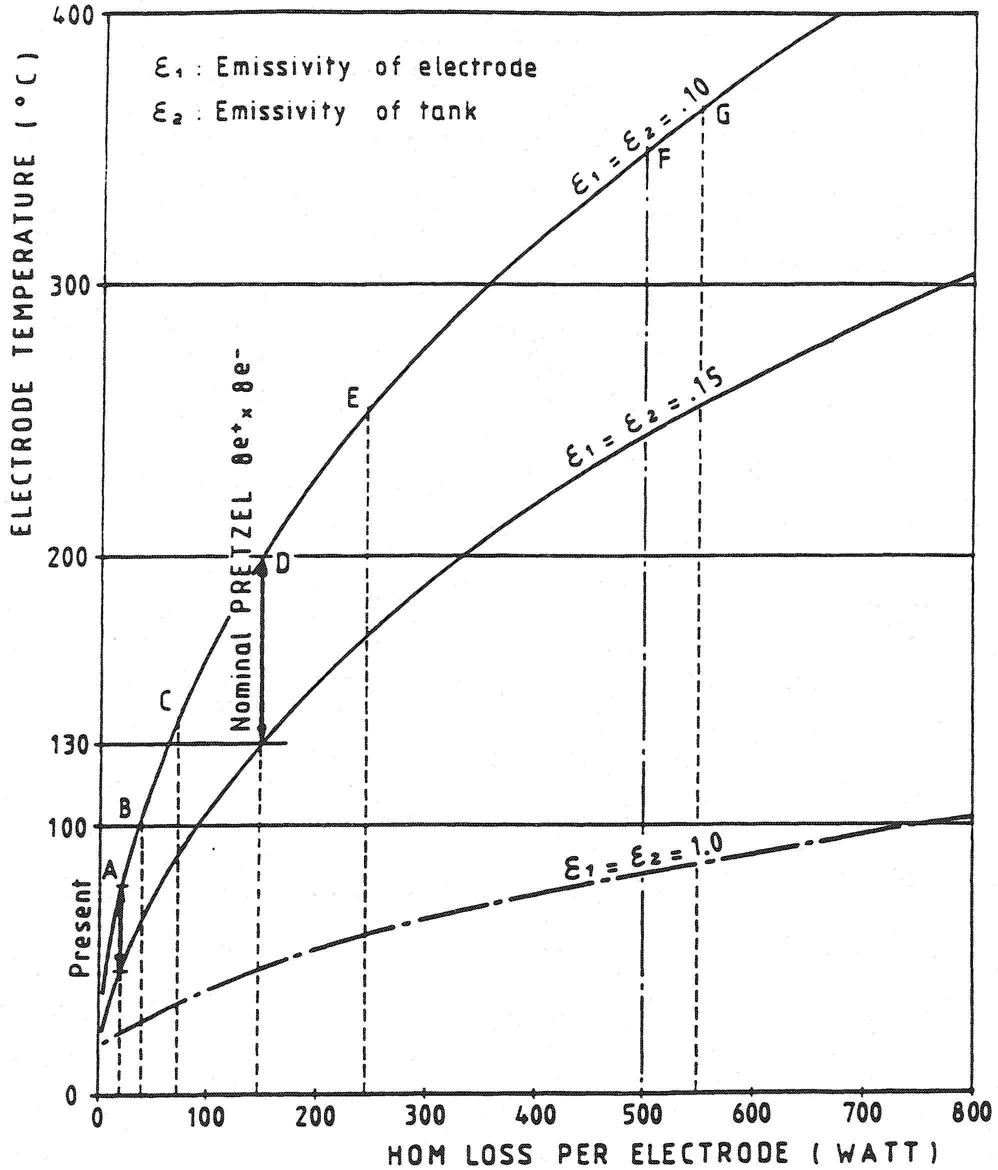


Figure 54.15: Higher order mode losses per electrode in LEP electrostatic separator (ZL) as a function of the total number of bunches for different bunch currents.



point A: i-b = 0.40 mA; 4e+ x 4e-; present LEP operation
point B: i-b = 0.40 mA; 8e+ x 8e-;
point C: i-b = 0.75 mA; 4e+ x 4e-;
point D: i-b = 0.75 mA; 8e+ x 8e-; pretzel with nominal LEP current
point E: i-b = 1.0 mA; 8e+ x 8e-;
point F: i-b = 1.5 mA; 4e+ x 4e-; ZL design with k-hom = 0.78V/pC
point G: i-b = 1.5 mA; 8e+ x 8e-;

Figure 54.16: Without direct electrode cooling the steady state temperature of electrodes, cooled by thermal radiation only, is given as a function of the higher order mode losses.

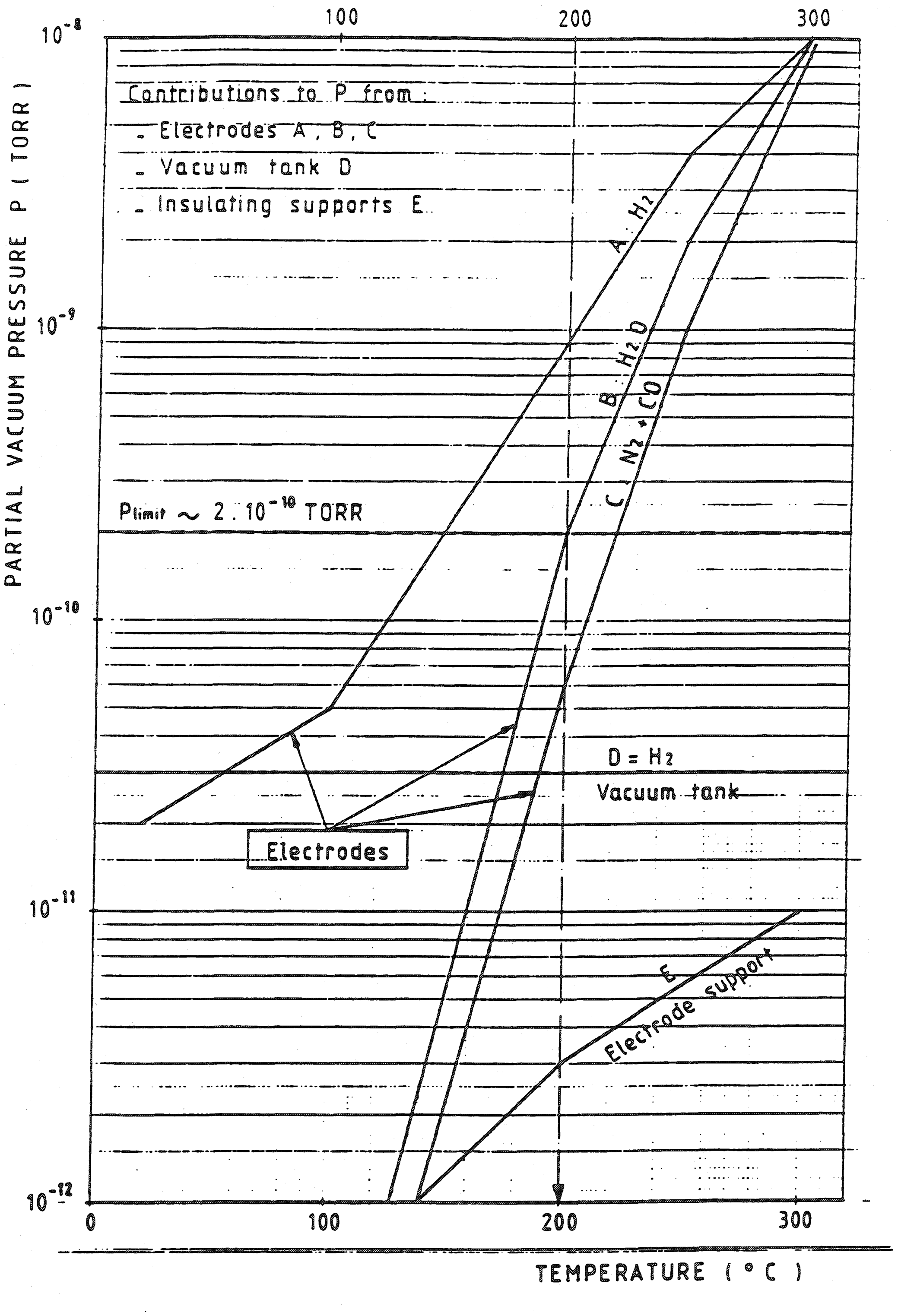


Figure 54.17: Variation of the partial vacuum pressure on the electrode temperature.