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# 120/15 GeV/c p-e Storage Ring PETRA

## Model 1 Layout

by

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## Introduction

This report describes a first model layout of a 120/15 GeV/c proton-electron colliding beam facility PETRA*) (Proton Electron Tandem Ring Accelerator system) based on the scheme and beam parameters given in references (1) and (2). The system consists of a 4 GeV/c synchrotron SYN*) for pre-acceleration of electrons and protons, a 15 GeV/c electron storage ring ESR*) which also serves as a 120 GeV/c proton accelerator, and a 120 GeV/c proton storage ring PSR*).

The model layout was untertaken to study the beam geometry required in the ESR-PSR system, to find and design a simple solution and to obtain from this model a consistent set of orbit and beam parameters. The design is preliminary and not meant as a serious proposal;**) in view of the very restrictive requirements, however, we feel that a more optimized solution may not look too much different.

## Design requirements and considerations

For a maximum proton momentum of 120 GeV/c in the ESR and PSR, and using the normal cell structure of reference (2) with a bending field of 16,8 kG along 82.5 % of the orbit length, the average radius of the circular machine sections is $\overline{R}$ = 290 m. Wanting four identical low $\beta$ interaction regions with a free length of 20 m, we need four straight sections of about 160 m which, symmetrically inserted in the ring, give the machine dimensions shown in Fig.1 with an orbit length of 2462 m and four identical superperiods.

For calculation of beam envelopes, the effective cross-sectional area of both beams at interaction point (IP) is taken to be 0.1 mm$^2$ with amplitude functions of $\beta_{x,z}$ = 0.5 m for electrons and $\beta_{x,z}$ = 2 m for protons (ref.(1)). Assuming circular beams, the corresponding emittance of the

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*) In this report, before baptism, the abbreviations PETRA, SYN, ESR, PSR are used as short notations for the system and its constituents, respectively.

**) A more serious proposal will have to await the outcome of the e-p machine studies in DORIS now scheduled to begin in 1975.

electron beam, including tails, is

$$\varepsilon_{x,z} = \frac{(6.5\cdot\sigma_{x,z})^2}{\beta_{x,z}} \approx 2 \text{ mrad mm}$$

Allowing a beam radius of $6.5\cdot\sigma_{x,z}$ also for protons, we have a proton beam emittance of

$$\varepsilon_{x,z} \approx 0.5 \text{ mrad mm.}$$

The crossing angle will be of the order of $2\,\delta = 2\cdot 0.5$ mrad. In view of its smallness, we design the machines for head-on collision and assume that the crossing angle can be easily obtained as an S-shaped horizontal or vertical closed orbit distortion as shown in ref.(1).

The strong divergence of the electron beam at IP (± 2 mrad) calls for placing a focusing quadrupole doublet as close to the IP as possible. Since the protons are eight times more rigid, they are not much affected by this doublet. Immediately behind the doublet, the electrons must be separated from the protons by a (common) bending magnet. After a drift space, they can then enter a septum-type magnet which bends them further away.
In order to have a low synchrotron radiation level around the I.P, the first (common) magnet must not be too strong. Its effect on the protons is small again and not treated here, causing a closed orbit distortion that can be compensated. The first quadrupole doublet for proton focusing can be placed where the separation between the two beams has reached a sufficient value ($\sim$ 30 cm).

So far, the principal geometry is rather straightforward and allows little variation. We shall now discuss the orientation of the two rings with respect to each other. Arranging both machines in the horizontal plane and demanding that each machine have four identical quadrants, the PSR would be inside the ESR or vice versa. In both cases, for a radial spacing of the order of 1 m, the difference in orbit length between the two machines would be of the order of 6 m. In order to have the option of a bunched proton beam operation, however, one would like the two machines to be of equal or only slightly different length. In the range of full to half proton energy, the length difference required for isochronism is of the order of 10 to 50 cm. In a horizontal arrangement, nearly or precisely equal lengths can be obtained by making the two machines cross in two or all four IP's, but this means giving up the exact fourfold periodicity.

A vertical arrangement of the two machines offers several advantages. At a vertical spacing of the order of 1 m, the ESR will be of the order of 10 to 50 cm longer than the PSR, owing to the effect of the bends around the IP's and its partial cancellation by Rf bypasses which will be described below. With identical magnet structures in the circular parts of PSR and ESR, a vertical assembly is a very economic scheme, requiring one adjustable support for each double magnet only and making optimum use of a circular tunnel cross section with good access to both rings (see Fig.3).

Another important point that could affect the two-ring geometry is the necessity to have in the ESR a bypass for accelerating protons that, in the vicinity of each IP, takes these protons away from the PSR beam line. This bypass is needed because the first (common) magnet, which separates the 15 GeV/c electrons from the 120 GeV/c protons, cannot be energized to 120 GeV/c without throwing the proton beam out.

We have considered several types of ESR bypasses for proton acceleration. In a horizontal concentric ring arrangement, the bypass could lead around the whole experimental hall, either inside or outside, but this turns out to be a very expensive solution, requiring a sizeable fraction of extra bending magnets and tunnel. In a vertical ring arrangement, the bypass, at an offset of about 4 m, could be placed below the floor of the experimental area which is thought to be 3 m below IP, but this scheme, again, is expensive.

The simplest solution is to lead the bypass for proton acceleration through the same interaction pipe, either at an angle with respect to the PSR beam line, or with a lateral offset of the order of several centimeters. In both cases, the first (common) bending magnet would not be energized. The offset-scheme works equally well for a vertical arrangement of the two machines or a concentric horizontal arrangement, while the angle-scheme calls for a horizontal scheme with four crossings.

## Description of PETRA Model 1 layout

Weighing the various arguments discussed in the previous paragraph we have, for the model layout, decided in favour of the vertical two-ring arrangement shown schematically in Fig. 1, assuming that some difficulties due to the vertical bends in the ESR can be overcome, which indeed is the case.
The vertical dispersion caused by the vertical bending magnets can be made small at the IP and zero in the circular ring sections by optical matching with comfortably small amounts of focusing.

The layout of the ESR and PSR rings is shown in Fig.2. Starting from the IP, the ESR structure consists of the quadrupole doublet Q1, Q2, the (common) 4 m separating magnet M1 followed by a 5 m drift space, the 2 x 4 m septum-type magnets M2, M3 which bend the beam fully upward and, after a drift space holding additional quadrupoles Q3, Q5, the 2 x 4 m bending magnets M4, M5 which turn the beam horizontal again at a vertical displacement of 80 cm above PSR. The interacting electron beam is shown in detail in Fig.4 as beam no.(2) or (3), respectively. Beam no.(2) has a bending field at the IP (2x1m; $\rho$ = 200m; 2,5kG at 15 GeV/c). It allows collision at zero crossing angle and gets much more rapidly away from the proton beam, which may be important for reducing the long range forces. In addition, of course, the transverse magnetic field at IP may be desirable for certain types of experiments.

Changing the ESR from the collision mode into the bypass mode for proton acceleration is achieved by switching off the (common) bending magnet M1 as well as quadrupoles Q1, Q2 and adjusting the strengths of the septum-type magnets M2, M3 such that the bypass beam, labelled no.(1), is traversing parallel to the PSR beam at a vertical displacement of 8 cm. - In all modes of operation, the radius of curvature is not smaller than 350 m in the (common) magnet M1 and not smaller than about 130 m for electrons and 200 m for protons in all other vertical bending magnets M2 to M5.

The bypass beam no.(1), being so close to the stored proton beam, permits a simple injection from ESR into PSR. At the injection kicker 1 indicated in Fig.4, a vertical kick of only 1 mrad is needed to make the beam intersect the PSR plane at the position of injection kicker 2. In addition, an even smaller horizontal kick must be given to the beam in order to place it on the proper off-energy orbit at kicker 2, as given by the horizontal dispersion which, during injection,is generated at that point (PSR injection optics). In the collision mode, of course, the PSR dispersion is zero throughout the long straight section.

According to ref.(2), an electron accelerating structure of high shunt impedance and a length of about 4 x 20 m is required in the ESR, that must not be seen by the protons. This calls for incorporation of an electron rf bypass in each ESR quadrant, of which a simple scheme with rather moderate extra bending strength is shown in Fig.2 or, at a larger scale, in Fig.5. The rf bypass shortcuts 1 1/2 cells of the circular structure and about 30 m of the straight section. The dispersion generated by the additional 4 m bending magnet inserted in the straight section can be matched into the normal cell structure with reasonably small quadrupole strengths. In the rf bypass region, a tunnel width of about 6 m seems adequate (see Fig.3).

Looking at the ESR and PSR optics in some more detail, we refer to Fig.6 which, for the indicated magnet positions and strengths, shows the horizontal and vertical beam envelopes and dispersions ($^{\Delta p}/_{p}$ = 2%)

for the following modes of operation:

- ESR 15 GeV/c $e^-$collision mode, $\beta_o = 0.5$ m,
  - (a) upstream side of IP, without rf bypass
  - (b) downstream side of IP, with rf bypass.
- (c) ESR 120 GeV/c bypass mode for p-acceleration, $\beta_o = 8$ m .
- (d) PSR 120 GeV/c proton collision mode, $\beta_o = 2$ m .
- (e) PSR 120 GeV/c proton injection mode, $\beta_o = 8$ m .

In the ESR, it would be desirable to strictly confine the vertical dispersion to the vertical bending region and have it identically vanish in the interaction region as well as in the periodic ring structure. This could, however, only be achieved by producing a narrow vertical focus between the two magnet groups M1, M2, M3 and M4, M5, respectively, since they are bending in opposite directions. With an available drift space of about 10 m, this is an unfeasable concept.

Therefore, we must accept a vertical dispersion either in the interaction region or in the ring structure, at least. In our model, we have chosen the former, since the latter would be a nuisance for matching and would cause, for electrons, a quantum excitation of vertical betatron oscillations in the horizontal bending magnets. The vertical dispersion turns out to be of the order of 0.25 m in the $e^-$ collision mode, which seems acceptable, and of the order of 0.5 m in the bypass mode for proton acceleration, where it might cause trouble at injection into PSR. It must be investigated if one can tolerate the additional PSR beam height that is caused by a vertical dispersion of 0.5 m in the injected beam. In case one cannot, the ESR bypass optics must be modified to have no dispersion in the interaction region and, instead, a vertical dispersion all around the ring.

At injection, a large horizontal dispersion is needed in the PSR at injection kicker 2 in order to place the injected beam on an off-energy orbit that is sufficiently separated from the stacked beam. In our model, the dispersion value is 1.1 m at this point (see Fig.6, (e)).

In the other ESR and PSR modes of operation, the periodic horizontal dispersion of the ring structure is matched to vanish in the long straight section by introducing an additional quadrupole in the last normal cell and by somewhat detuning the next regular quadrupole (Fig.6; (a),(c),(d)). Only in the ESR rf bypass, the horizontal dispersion, before being matched in the last bypass bending magnet, somewhat extends into the straight region (Fig.6,(b)).

The rf bypass beam is separated from the normal ring structure by increasing the strength of two bending magnets to twice its normal value (see Fig.5). The increasing separation calls for parallel pole plates, i.e. for a homogeneous field in at least the second of these magnets. We therefore have, in the rf bypass optics (b), converted these two magnets into zero gradient magnets. This detail has been neglected in the optics of the bypass mode for proton acceleration (c); it can easily be accounted for by slightly changing the quadrupole focusing in that region.

The maximum values of the amplitude function in the collision mode are about 800 m in the ESR and about 1700 m in the PSR, respectively. - As revealed by Fig.6, the matching of beam envelopes and dispersions has not been done very accurately. The optics is, however, accurate enough for deriving a consistent set of Model 1 orbit and beam parameters, that will be given in a subsequent note.

Acknowledgement.

We wish to thank D.Degèle and R.Rossmanith for discussions.

References:

(1) M.Tigner, Technische Notiz DESY, S1-MT-2/73 (1973)

(2) H.Gerke, R.D.Kohaupt, H.Wiedemann,
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Figures:

# PETRA
# Double Ring Scheme

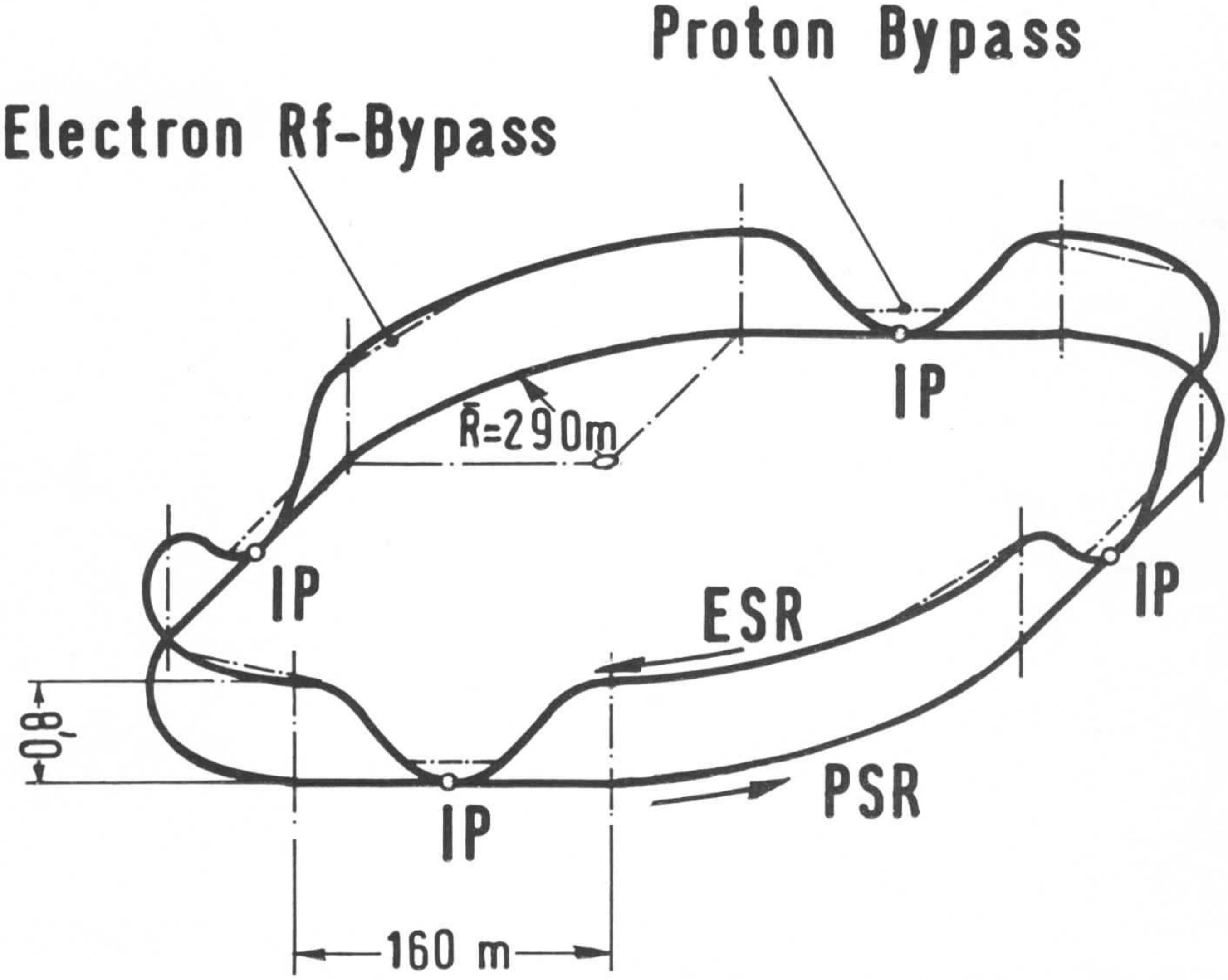
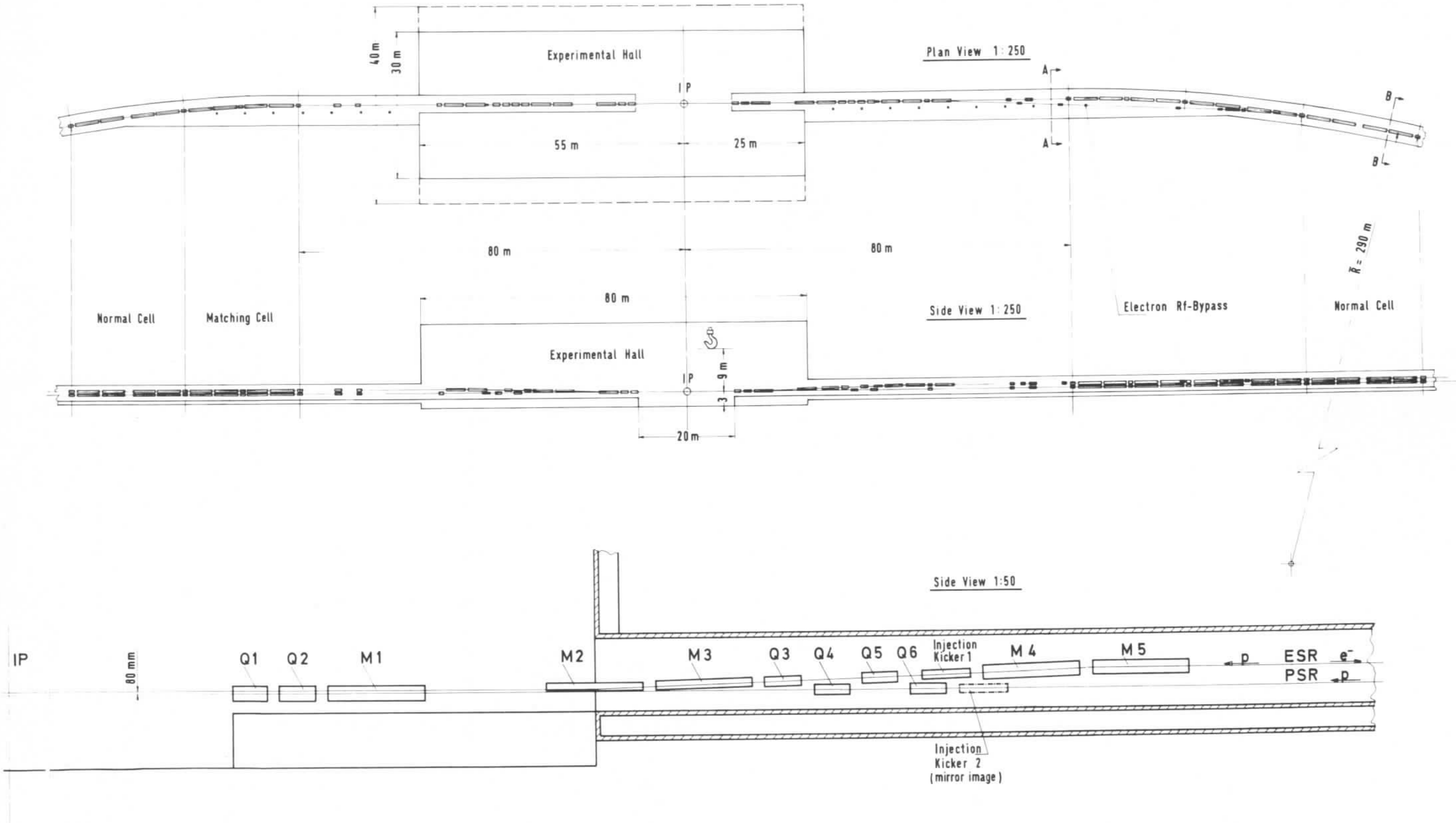



Fig. 1

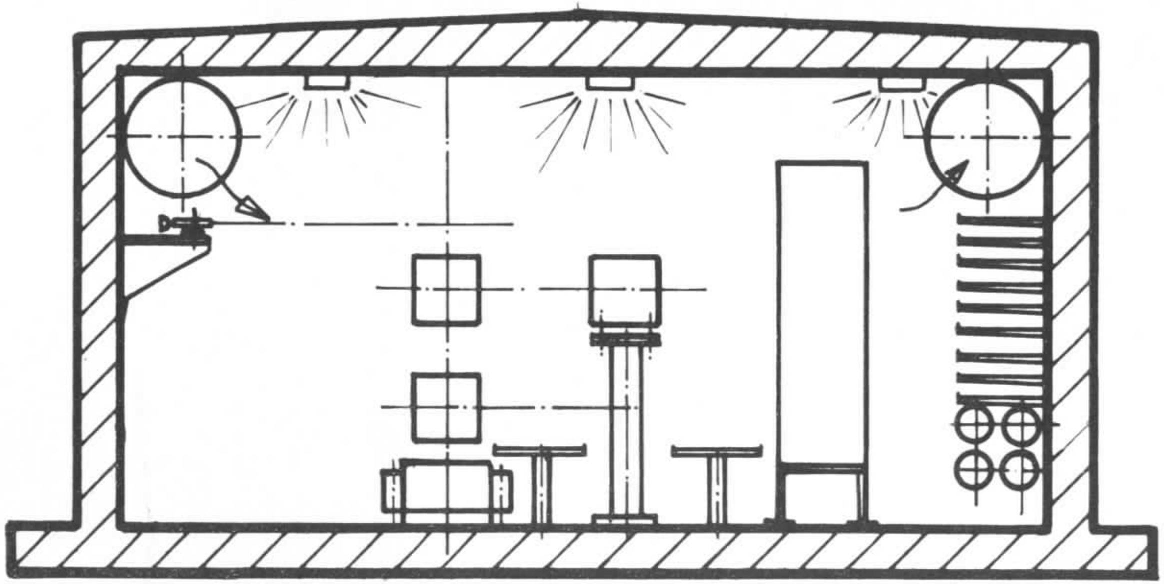
23.8.73 MK

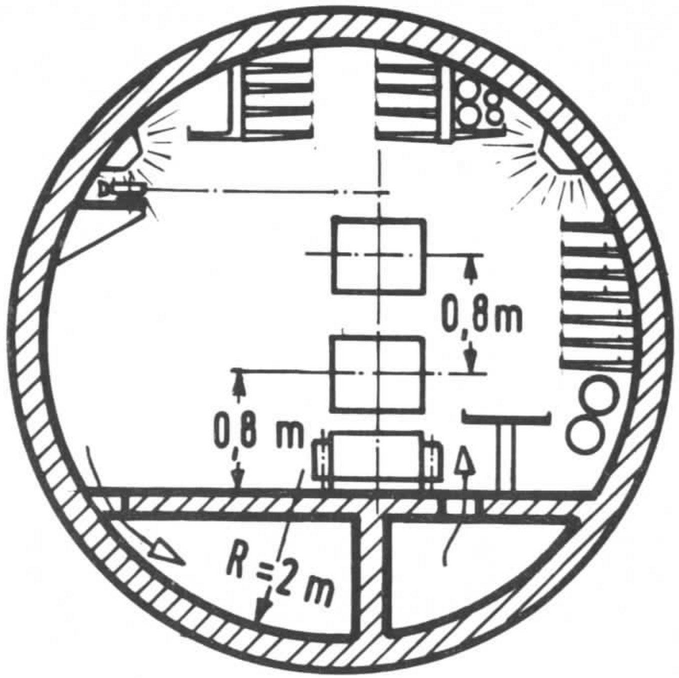



PETRA
Layout

Fig. 2

Section AA 1:50 Section BB






# Tunnel Cross-Sections

(see Fig. 2)

Fig. 3

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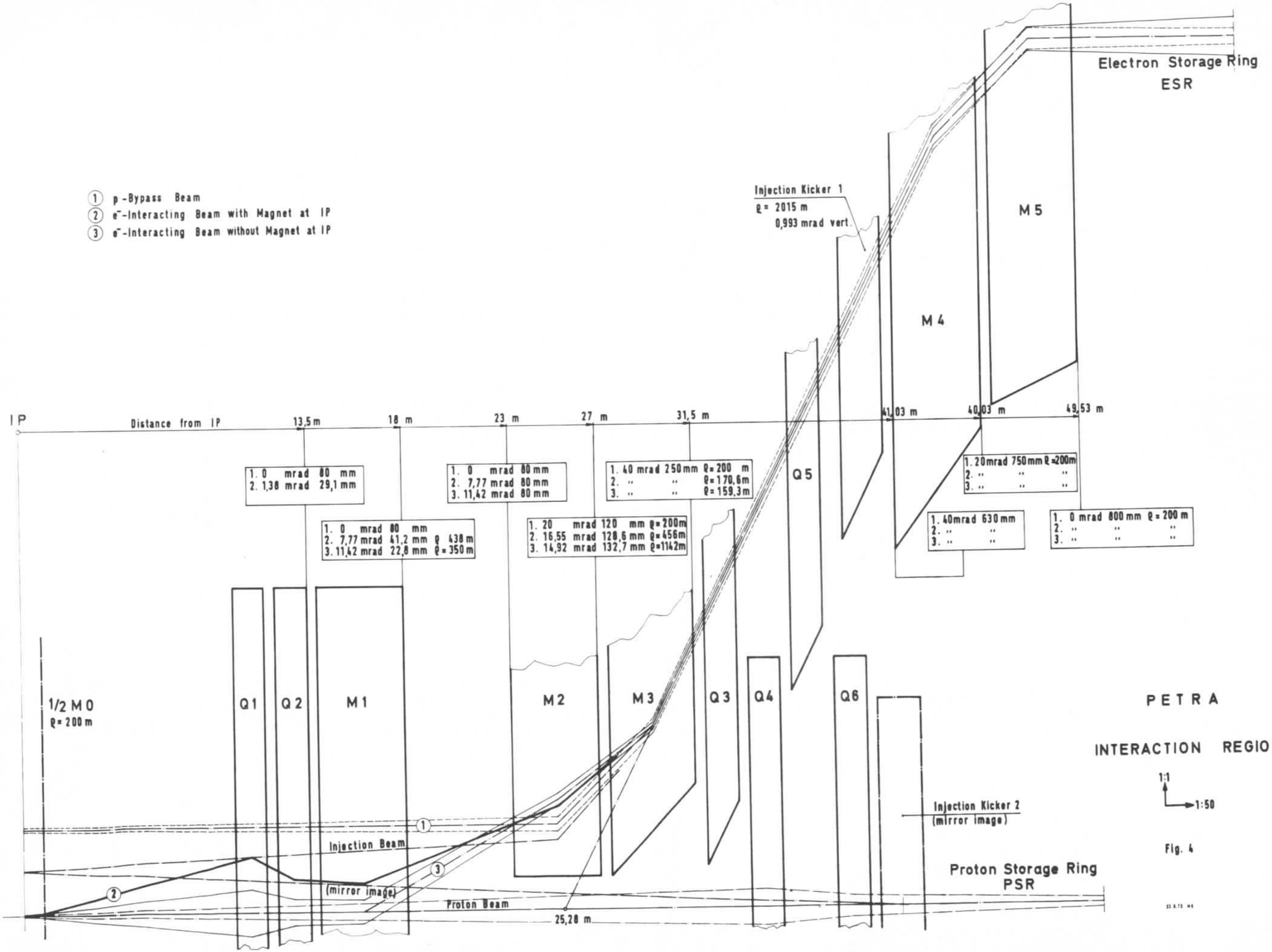


PETRA

INTERACTION REGION

Fig. 4

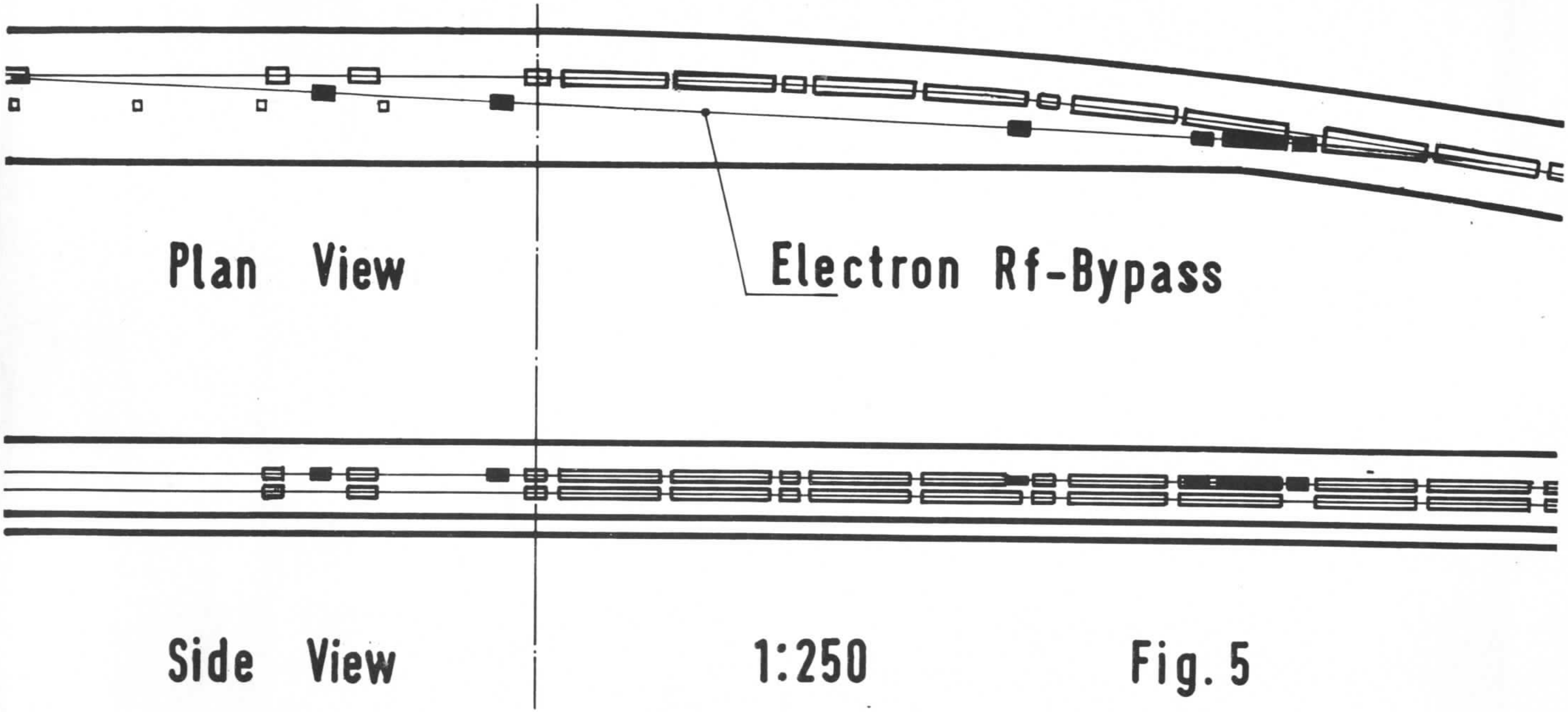


Fig. 5

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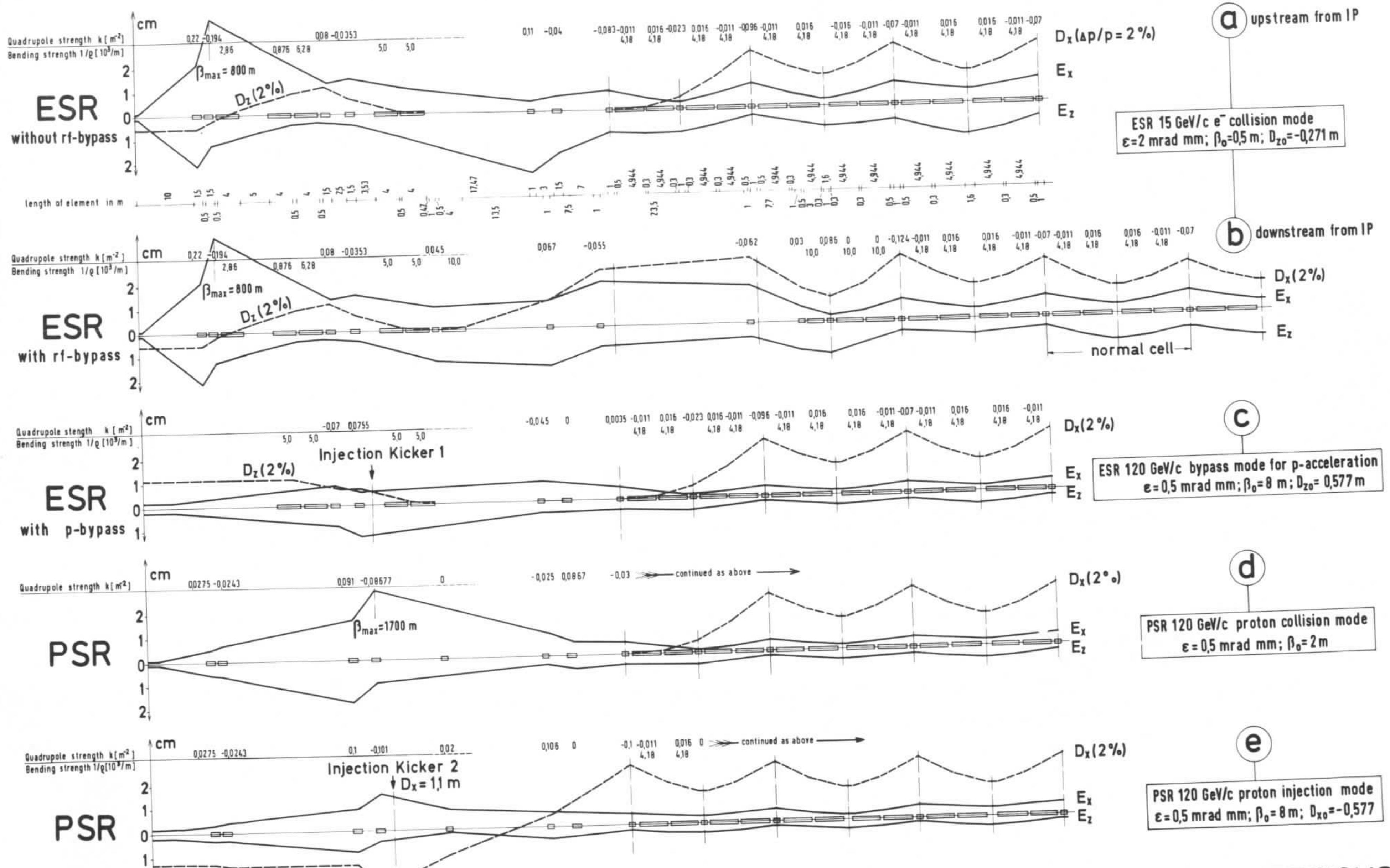

PETRA: BEAM ENVELOPES AND DISPERSIONS

Fig. 6