/lmg - 0035a

PS/BT/Note 84-6
PS/LPI/Note 84-24
20.6.1984.

# DESIGN OF THE $e^+$ AND $e^-$ BEAM TRANSFER LINES BETWEEN EPA AND PS

A. Krusche

One of the EPA ring design features is a common extraction point for both the $e^+$ and $e^-$ beams[1]. The positioning with respect to the PS was chosen to allow a reasonably direct transfer for injection into PS straight sections 92 ($e^+$) and 74 ($e^-$)[2]. It was also assumed that the former beam path for neutrino production could be used.

An early feasibility study[3] showed already a principle solution to the transfer problems, but pressure for cost minimization lead to a complete review and different approach.

The aim of the present design study was therefore to achieve highest simplicity in the beam transfer line layout and to avoid any costly civil engineering work.

## 1. GENERAL DESIGN PRINCIPLES

Matching requirements of the characteristic functions between electron machines are normally much less important than between proton machines. Actually, the PS will impose some time after injection its own equilibrium beam size on both the $e^-$ and $e^+$ beams*). The matching requirements could hence be relaxed so as not to lose beam at and after injection into the PS. The described layout here is nevertheless based on a near to perfect transverse matching, resulting in a gain of margins and hence operational ease. As it turns out there is no extra price to pay for this additional performance.

The $e^-$ trajectory has to be forced through an existing wall passage, with little choice left for the arrangement of bending magnets. In the case of the $e^+$ trajectory it was desirable to join the PS in the most direct way.

In both transfer channels one has now got to solve the problem of an equipment free drift length over some 25 meters. The solution found is similar for both channels: a first quadrupole doublet (near EPA) provides simultaneously horizontal and vertical focusing. Starting with fairly high $\beta$ values (Twiss parameter $\beta$), the waist of the beam envelope lies within the long drift length or even beyond it. A second quadrupole doublet then receives the beam on the PS side of the wall and prepares it for matching into the PS.

The more general approach of splitting the transfer line into a regular, repetitive structure and a matching part could not be adopted here, the lines are too short and the imposed long wall passages forbid regularity. Instead, each focusing element participates in both the transfer function and transverse matching. With the element position as a variable one can satisfy not only the transverse matching requirements but also group the quadrupoles into families of the same strength. The so achieved savings in power supplies is obviously paid with a very much reduced flexibility in case of an eventual rematch of the line.

The bending magnet dipoles are of the straight type, strong vertical focusing occurs and fringe field corrections have to be taken into account (see annex). The beam passage through the stray field of the PS main magnet is, due to the high deflection angle of the PS injection septum magnets, very short and not critical (checked with tracking program TRAJ, W104).

## 2. RESULTS

### 2.1 $e^+$ transfer line

The layout is shown in Figure 1. Only two bending magnets are required to determine the trajectory. Five quadrupoles in total, grouped in three families are sufficient to satisfy the beam optical requirements. A perfect match of the characteristic functions is possible, but accepting a harmless vertical emittance blow-up of ≈ 20% saved one power supply.

A beam dump facility is obtained by simply stopping the first bending magnet BH 10. The beam is then lost in the wall (Figure 1).

Figure 2 shows the behaviour of the characteristic functions and the beam size (the vertical beam size is exaggerated and assumes 100% hor./vert. coupling in EPA). The highest (Twiss) ß is not exceeding 50 m, beam size is small everywhere, standard EPA vacuum chamber dimensions of 100 x 38 $mm^2$ in the bending magnets and 100 mm ∅ elsewhere will give ample space margins. Details of the optical calculations, matching parameters, line geometry and a magnetic element listing are found in the appendix.

### 2.2 $e^-$ transfer line

The layout is shown in Figure 3. Four bending magnets are needed to fix the trajectory, the first two bendings have the same strength. A first quadrupole (QF 11) controls the dispersion function Dx such that the drift through the wall is practically dispersion free. With unpowered bendings BH 10, 20 the beam can be dumped into the wall, the quadrupole QF 11 must then be slim enough to let the beam pass by.

Only six quadrupoles grouped in three families are needed to achieve a perfect match to the PS characteristic functions. Two tricks have permitted to set four quadrupoles to the same current : QD 32, at half the strength, is raised to full current by series-parallel connection of its excitation coils; QF 11, a quadrupole of a different make is matched to the same current (but a different strength). Figure 4 shows the beam size and the characteristic functions. The highest (Twiss) ß is less than 180 m, beam dimensions are small everywhere, vacuum chamber dimensions are the same as in the $e^+$ transfer line. More information about optical calculations, matching parameters, geometry and magnetic elements are found in the appendix.

## 3. SAFETY

Accidental beam transfers between EPA and the PS zones (and vice versa) are prohibited by two sets of two double beam stoppers, combined with power interlocks on relevant bending magnet supplies[5)] (see Figure 1 and Figure 4).

## 4. BEAM OBSERVATION AND STEERING PROCEDURE

Beam observation is based upon TV screens placed at key points in the transfer lines. In addition, pick-ups of the magnetic type (used also in EPA) are located at the EPA exit and near the PS injection points. Without beam destruction they provide information on beam position and beam intensity, too. The scheme retained so far is shown in Figure 1 and Figure 4. Beam steering in the horizontal plane is then easily done with the horizontal bending magnets available anyhow. PS orthogonal injection steering is done with the last bending magnet and the respective PS injection septum magnet. No additional horizontal trimming magnets are required.

Vertical PS injection steering, in turn needs a pair of vertical trim dipoles in each transfer line (Figures 1 & 4). No other vertical steering through the lines themselves is proposed here, the vertical aperture margins are comfortable enough to absorb the expected trajectory imperfections. But in case of necessity one can give the horizontal bending magnets a slight tilt to produce vertical steering deflections.

## ACKNOWLEDGEMENTS

The design of the beam transfer lines provoked last minute changes of the EPA building layout and needed rather precise knowledge of the EPA/PS topography. B. Nicolai, L. Petty, and J.P. Quesnel have been very helpful in overcoming the difficulties.

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Distribution :

BT Group Scientific Staff
LPI Group Sientific Staff
PS-LEP

# APPENDIX

## LIST OF MAGNETIC ELEMENTS IN $e^+$ EPA-PS BEAM TRANSPORT

### Dipoles*)

| Name | Type | θ [mrad] | Bℓ [Tm] | I [A] |
|---|---|---|---|---|
| SM 00 | Septum | 235.62 | 0.47153 | ≈ 16700 |
| BH 10 | Straight | 192.0 | 0.38427 | ≈ 261 |
| BH 20 | Straight | 320.4 | 0.64126 | ≈ 436 |
| DV 20 | MDV (SPS) | ± | | 0.38 A/mrad |
| DV 21 | MCV | ± | | ∿ 7 A/mrad |
| SM 92 | Septum | 180.0 | 0.36025 | ≈ 12758 |

*) at E = 600 MeV; precise currents follow after magnetic measurements.

### Quadrupoles

Calculated for type "Terwilliger ISR" at E = 600 MeV :
$B\rho$ = 2.0013843; GL = 1.8 T at I = 131 A, $\ell_m$ = 0.38 m

| Name | K [$m^{-2}$] | Gℓ [T] | I [A] |
|---|---|---|---|
| QD 11 | 1.00297 | 0.76278 | 55.513 |
| QF 12 | -0.92136 | 0.70072 | 50.997 |
| QD 13 | 0.92136 | 0.70072 | 50.997 |
| QF 14 | -1.00297 | 0.76278 | 55.513 |
| QF 21 | -0.37109 | 0.28222 | 20.540 |

Quadrupoles with equal strength will be connected in series to a common power supply.

## LIST OF MAGNETIC ELEMENTS IN $e^-$ EPA-PS BEAM TRANSPORT

Dipoles*)

| Name | Type | θ [mrad] | Bℓ [Tm] | I [A] |
|---|---|---|---|---|
| SM 00 | Septum | 235.62 | 0.47157 | 16700 |
| BH 10 | Straight | 372.99 | 0.74650 | 507.5 |
| BH 20 | Straight | 372.99 | " | " |
| BH 30 | Straight | 149.00 | 0.29821 | 202.7 |
| BH 40 | Straight | 294.32 | 0.58905 | 400.5 |
| DV 40 | MDV, SPS | ± | | 0.38 A/mrad |
| DV 41 | MCV | ± | | ∿ 7 A/mrad |
| SM 74 | Septum | 180.00 | 0.36025 | 12758 |

*) values for E = 600 MeV; precise currents follow after magnetic measurements.

Quadrupoles

Calculations for E = 600 MeV (Bρ = 2.0013843)

a) Type "ISR, Terwilliger" : Gℓ = 1.8 T at I = 131 A; ℓm = 0.38 m

b) Type "SPS, Q50" : Gℓ = 5.975 T at I = 120 A; ℓm = 0.536

c) Type "ISR, Terwilliger", but excitation coils series/parallel.

| Name | Type | K [$m^{-2}$] | Gℓ [T] | I [A] |
|---|---|---|---|---|
| QF 11 | b) | -1.95887 | 2.10118 | 42.203 |
| QF 21 | a) | -1.93082 | 1.46844 | 106.870 |
| QD 22 | a) | 1.38221 | 1.05121 | 76.505 |
| QF 31 | a) | -0.76250 | 0.57990 | 42.203 |
| QD 32 | c) | 0.38125 | 0.28995 | 42.203 |
| QF 41 | a) | -0.76250 | 0.57990 | 42.203 |

## BEAM OPTICS OF BENDING MAGNETS

### 1. Edge focusing

The AGS program assumes equal entrance and exit angle of half the bending angle $\theta$ for straight magnets. In order to include different magnet poleface rotation angles $\varepsilon$ the magnets are sandwiched by thin quadrupole lenses with a corrective force of

$$k = \frac{\theta}{\ell} \left(\mathrm{tg}\, \varepsilon - \mathrm{tg}\, \frac{\theta}{2}\right).$$

### 2. Fringe field correction

Following TRANSPORT[6]) the spatial extent of the fringe fields can be approximated by a correction angle $\psi$ in the vertical focusing term

$$K_V = -\frac{\theta}{\ell}\, \mathrm{tg}\, (\varepsilon - \psi)$$

where

$$\psi = K_1 \cdot g \cdot \frac{\theta}{\ell} \left(\frac{1 + \sin^2\varepsilon}{\cos\varepsilon}\right)$$

with $K_1 = 0.5$ and $g$ = magnet gap height
$\ell$ = magnetic length

This correction term can be introduced into a special AGS version called PSAGS, ID = PS 028 RISS[7]).

The following table summarises the properties as used in the beam transport calculations :

## BEAM OPTICAL CORRECTIONS FOR DIPOLE MAGNETS

### a) $e^+$ Beam Transport

| Magnet | θ [°] | ℓm | $\epsilon_1$ | $\epsilon_2$ | $k_1 [m^{-1}]$ | $k_2 [m^{-1}]$ | ψ [rad] |
|---|---|---|---|---|---|---|---|
| SM 00 | 13.5° | 0.42 | 0° | 13.5° | -0.0664 | 0.0683 | 0.0051 |
| BH 10 | -11° | 0.56 | 5.5° | 5.5° | 0 | 0 | -0.0078 |
| BH 20 | 18.36° | 0.56 | 9.18° | 9.18° | 0 | 0 | 0.0133 |
| SM 92 | -10.31° | 0.42 | 10.31° | 0° | 0.03931 | -0.03867 | -0.0039 |

### b) $e^-$ Beam Transport

| Magnet | θ [°] | ℓm | $\epsilon_1$ | $\epsilon_2$ | $k_1 [m^{-1}]$ | $k_2 [m^{-1}]$ | ψ [rad] |
|---|---|---|---|---|---|---|---|
| SM 00 | 13.5° | 0.42 | 0° | 13.5° | -0.0664 | 0.0683 | 0.0051 |
| BH 10 | 21.37 | 0.56 | θ/2 | θ/2 | 0 | 0 | 0.0158 |
| BH 20 | 21.37 | 0.56 | " | " | 0 | 0 | 0.0158 |
| BH 30 | -8.53 | 0.56 | " | " | 0 | 0 | -0.0060 |
| BH 40 | +16.86 | 0.56 | " | " | 0 | 0 | 0.0120 |
| SM 74 | -10.31° | 0.42 | 10.31° | 0² | 0.0393 | -0.0386 | -0.0039 |

## TRANSVERSE MATCHING AND BEAM SIZE PARAMETERS

a) Equilibrium beam in EPA at ejection (entrance of ejection septum magnet).

Horizontal : $\beta_H$ = 14 m; $\alpha_H$ = 0.016; $D_x = D_x' = 0$
emittance $\epsilon_o$ (1σ) = 0.14 π mm.mrad (no coupling hor./vert.).

Vertical : $\beta_V = 3.14$ m; $\alpha_V = 0.07$

emittance $\varepsilon_o$ (1σ) = 0.07 π mm.mrad (100% coupling hor./vert.).

Energy spread : ΔE/E/1σ) = $0.6\ 10^{-3}$.

b) Ellipse parameters in PS (exit of injection septum magnet) :

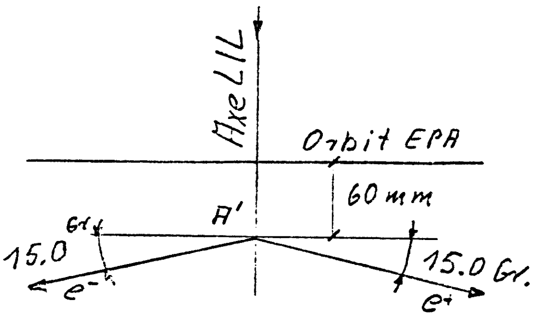
Horizontal : $\beta_H = 12$ m; $\alpha_H = -0.0131$; $D_x = 2.3$ m; $D'_x = 0$

Vertical : $\beta_V = 22$ m; $\alpha_V = -0.017$;

GEOMETRY

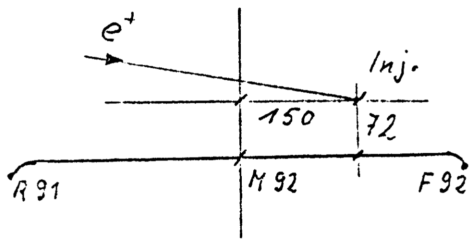
- EPA, Beam transfer line and PS medium planes are at the same level.
- Data in CERN coordinates (angles in Grad!).

Ejection point of EPA :

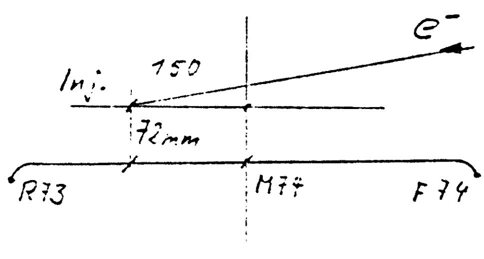



A' :
X = 2114.51536
Y = 2102.34344
"Gisement" ejection ray $e^+$: 238.2385 Gr
"Gisement" ejection ray $e^-$: 8.2385 Gr

$e^+$ Injection point PS ss 92 : X = 2085.05560
: Y = 2045.08304
"Gisement" injected ray : 246.4151 Gr




$e^-$ Injection point PS ss 74 : X = 2083.44916
: Y = 2153.04015
"Gisement" injected ray : 331.4968 Gr



<u>Virtual bending points of trajectories</u> :

<u>$e^+$ trajectory</u> :

| | X | Y |
|---|---|---|
| Magnet : BH 10 | 2113.21545 | 2100.44601 |
| BH 20 | 2093.17889 | 2054.17690 |

<u>$e^-$ trajectory</u> :

| | X | Y |
|---|---|---|
| BH 10 | 2114.81218 | 2104.62421 |
| BH 20 | 2113.89655 | 2108.30872 |
| BH 30 | 2097.85771 | 2130.93922 |
| BH 40 | 2090.35203 | 2145.80479 |

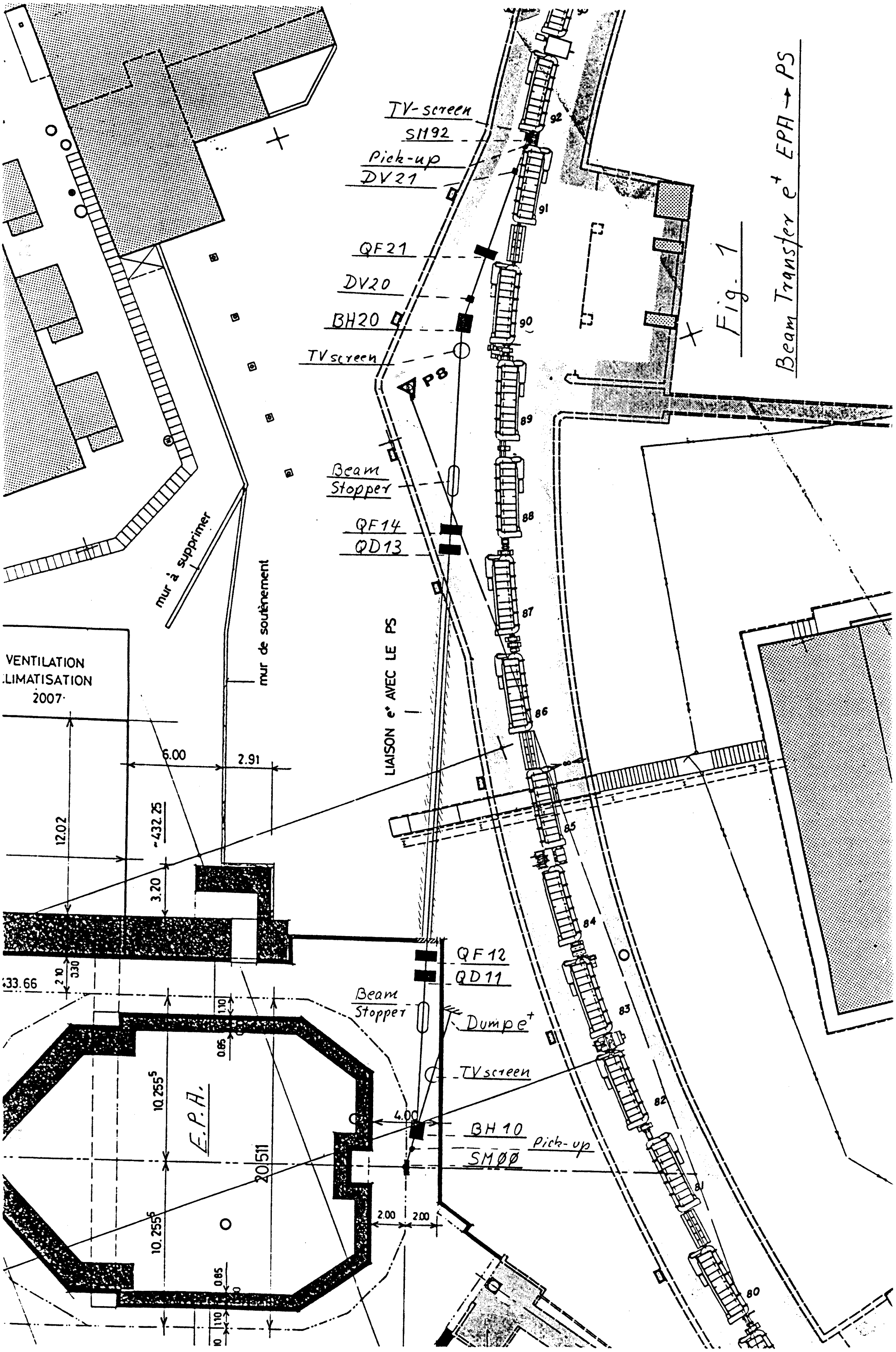



Fig. 1

Beam Transfer e+ EPA → PS

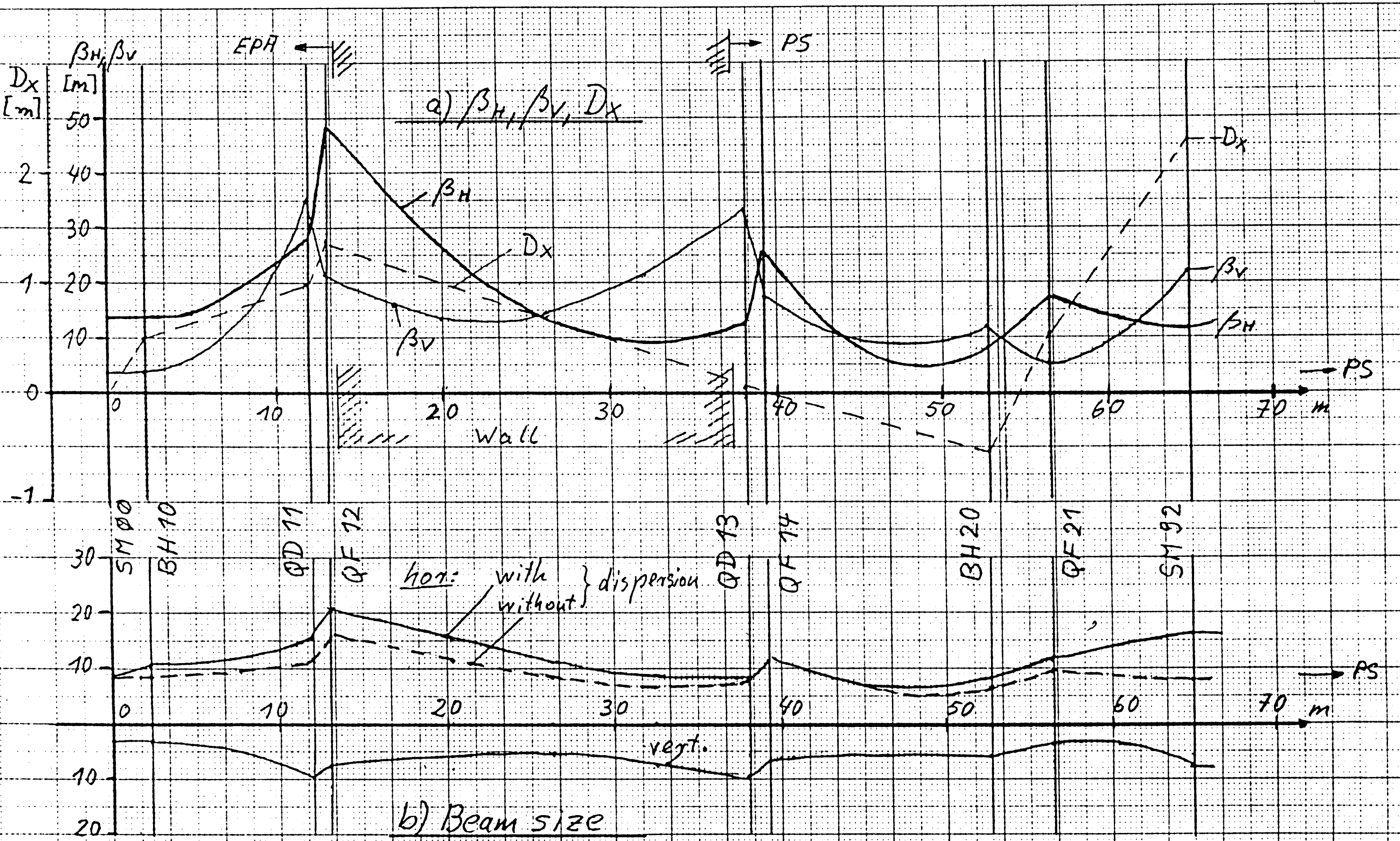



Fig. 2 : $e^+$ Beam Transport EPA → PS

a) Characteristic Functions

b) Full Beam size ($\pm 3\sigma$)

$\Delta E/E = 6 \cdot 10^{-4}$ ; $\varepsilon_H(1\sigma) = 0.14\,\pi$ µrad·m ; $\varepsilon_V = 0.07\,\pi$ µrad·m

*** BT EPA-PS E+ 14/3/84 ******** AGS VERSION 84.03 19/06/84 10.36.11.

PS AGS, PS 028 R135.

BETATRON FUNCTION TRACKING WITH DP/P = 0.00000 PER MILLE , STRAIGHT Magnets

| NO | ELEMENT | LENGTH | ANGLE | GRADIENT | BETAV(M) | BETAH(M) | ALPHAV(R) | ALPHAH(R) | MUV/2PI | MUH/2PI | Dx ~~ALPHAP~~ | Dx' ~~ALPHAP'~~ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | INITIAL ψ: | | | EPA : | 3.14000 | 14.00000 | .07000 | .01600 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 1 | F | .0100 | 0.00000 | -6.64000 | 3.14072 | 13.99039 | -.14170 | .94445 | .00051 | .00011 | 0.00000 | 0.00000 |
| 2 | SM00 0.0051 | .4200 | .23562 | 0.00000 | 3.14857 | 13.22779 | .12350 | .88818 | .02183 | .00498 | .04925 | .23672 |
| 3 | D | .0100 | 0.00000 | 6.83000 | 3.14398 | 13.21907 | .33505 | -.01583 | .02233 | .00510 | .05164 | .24016 |
| 4 | | 1.7932 | 0.00000 | 0.00000 | 3.08293 | 13.52067 | -.30110 | -.15190 | .12034 | .02658 | .48349 | .24016 |
| 5 | BH10 -.0076 | .5600 | -.19200 | 0.00000 | 3.42159 | 13.71319 | -.29337 | -.19401 | .14792 | .03308 | .56356 | .04757 |
| 6 | | 9.2039 | 0.00000 | 0.00000 | 35.71100 | 23.69445 | -3.21485 | -.89045 | .30450 | .11837 | 1.00139 | .04757 |
| 7 | QD11 | .3800 | 0.00000 | 1.00297 | 33.04169 | 28.05047 | 9.89691 | -11.12089 | .30622 | .12077 | 1.09330 | .44199 |
| 8 | | .6178 | 0.00000 | 0.00000 | 21.95546 | 43.48890 | 8.04669 | -13.86696 | .30987 | .12359 | 1.36638 | .44199 |
| 9 | QF12 | .3800 | 0.00000 | -.92136 | 18.78778 | 48.19760 | .65573 | 2.03013 | .31292 | .12488 | 1.44075 | -.05494 |
| 10 | | 6.7221 | 0.00000 | 0.00000 | 13.41124 | 25.70558 | .14409 | 1.31584 | .38251 | .15546 | 1.07146 | -.05494 |
| 11 | | 6.0000 | 0.00000 | 0.00000 | 14.42216 | 13.74079 | -.31258 | .67829 | .45351 | .20718 | .74184 | -.05494 |
| 12 | | 6.0000 | 0.00000 | 0.00000 | 20.91317 | 9.42662 | -.76926 | .04074 | .50965 | .29556 | .41223 | -.05494 |
| 13 | | 5.9892 | 0.00000 | 0.00000 | 32.85769 | 12.75013 | -1.22510 | -.59566 | .54633 | .38754 | .08321 | -.05494 |
| 14 | QD13 | .3800 | 0.00000 | -.92136 | 29.53782 | 15.03301 | 9.57069 | -5.67600 | .54823 | .39201 | .06746 | -.02885 |
| 15 | | .6680 | 0.00000 | 0.00000 | 18.15036 | 23.60201 | 7.47660 | -7.15199 | .55283 | .39765 | .04819 | -.02885 |
| 16 | QF14 | .3800 | 0.00000 | 1.00297 | 15.13644 | 25.57526 | .83401 | 2.21237 | .55656 | .40005 | .03404 | -.04471 |
| 17 | | 13.1369 | 0.00000 | 0.00000 | 12.55586 | 7.22359 | -.63757 | -.81541 | .75753 | .69136 | -.55333 | -.04471 |
| 18 | BH20 0.0133 | .5600 | .32042 | 0.00000 | 12.10876 | 8.19114 | 1.39810 | -.94228 | .76476 | .70276 | -.48899 | .27848 |
| 19 | | .6000 | 0.00000 | 0.00000 | 10.51888 | 9.40485 | 1.25170 | -1.08057 | .77323 | .71365 | -.32190 | .27848 |
| 20 | DV20 | .0100 | 0.00000 | 0.00000 | 10.49387 | 9.42649 | 1.24926 | -1.08287 | .77338 | .71382 | -.31912 | .27848 |
| 21 | | 2.7007 | 0.00000 | 0.00000 | 5.52592 | 16.95659 | .59025 | -1.70533 | .83108 | .74808 | .43298 | .27848 |
| 22 | QF21 | .3800 | 0.00000 | -.37109 | 5.39844 | 17.34700 | -.24881 | .69634 | .84226 | .75158 | .52631 | .21054 |
| 23 | | 5.0000 | 0.00000 | 0.00000 | 12.80413 | 12.52356 | -1.23233 | .26835 | .94496 | .80666 | 1.57900 | .21054 |
| 24 | DV21 | 3.0000 | 0.00000 | 0.00000 | 21.96849 | 11.68389 | -1.82245 | .01155 | .97358 | .84655 | 2.21062 | .21054 |
| 25 | D | .0100 | 0.00000 | 3.93100 | 21.99632 | 11.68826 | -.95963 | -.44871 | .97365 | .84668 | 2.21316 | .29749 |
| 26 | SM92 -.0039 | .4200 | -.18000 | 0.00000 | 22.12711 | 12.08108 | .65306 | -.49165 | .97668 | .85228 | 2.29974 | .11700 |
| 27 | F PS : | .0100 | 0.00000 | -3.86700 | 22.12261 | 12.08625 | -.20296 | -.02524 | .97675 | .85241 | 2.30046 | .02805 |

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

TIME = 0.000 SECONDS

Fig. 3 $e^+$ Transfer Line

**** BT EPA-PS E+ 14/3/84 ******** AGS VERSION 84.03 19/06/84 10.36.11

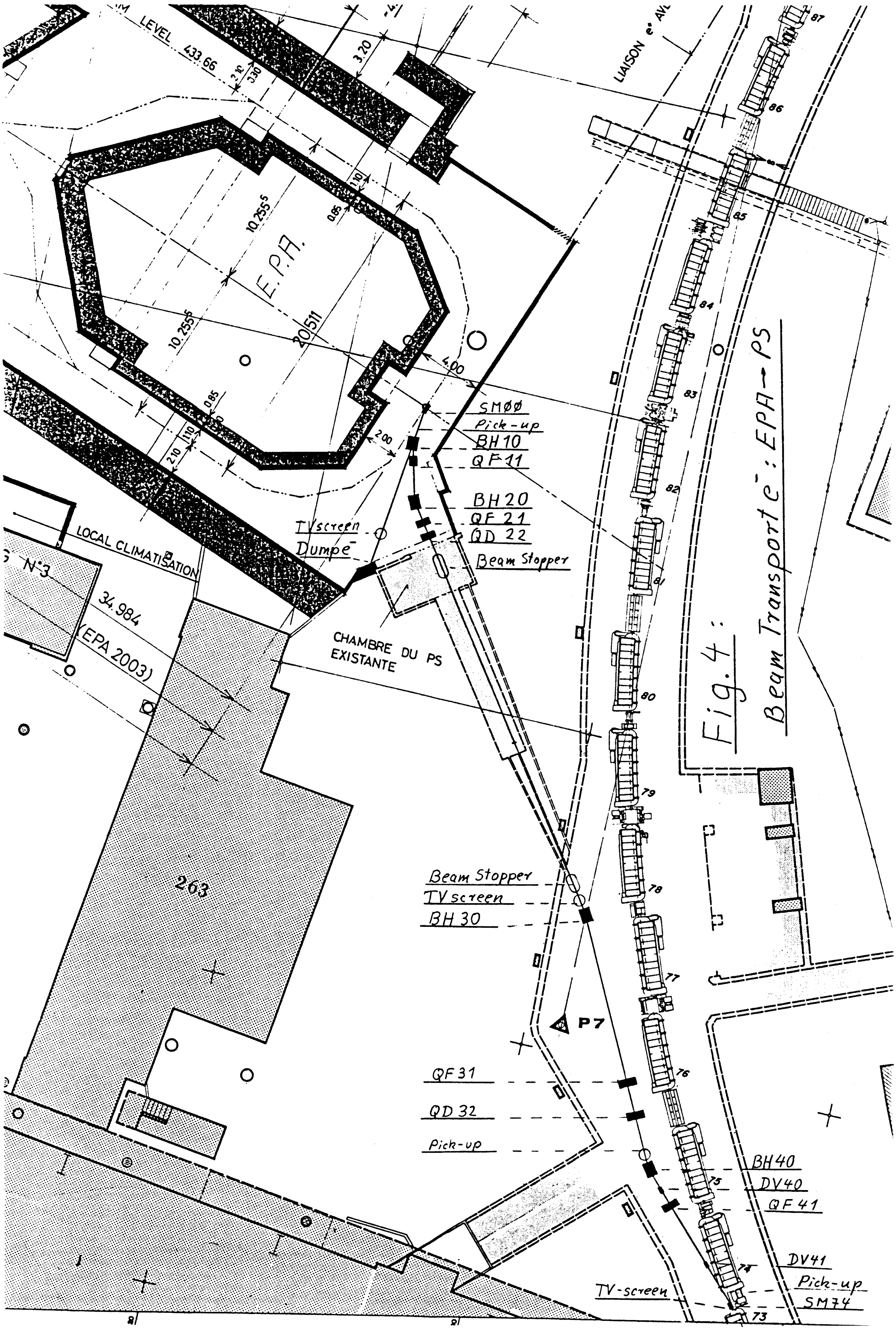



Fig. 4: Beam Transporté: EPA→PS

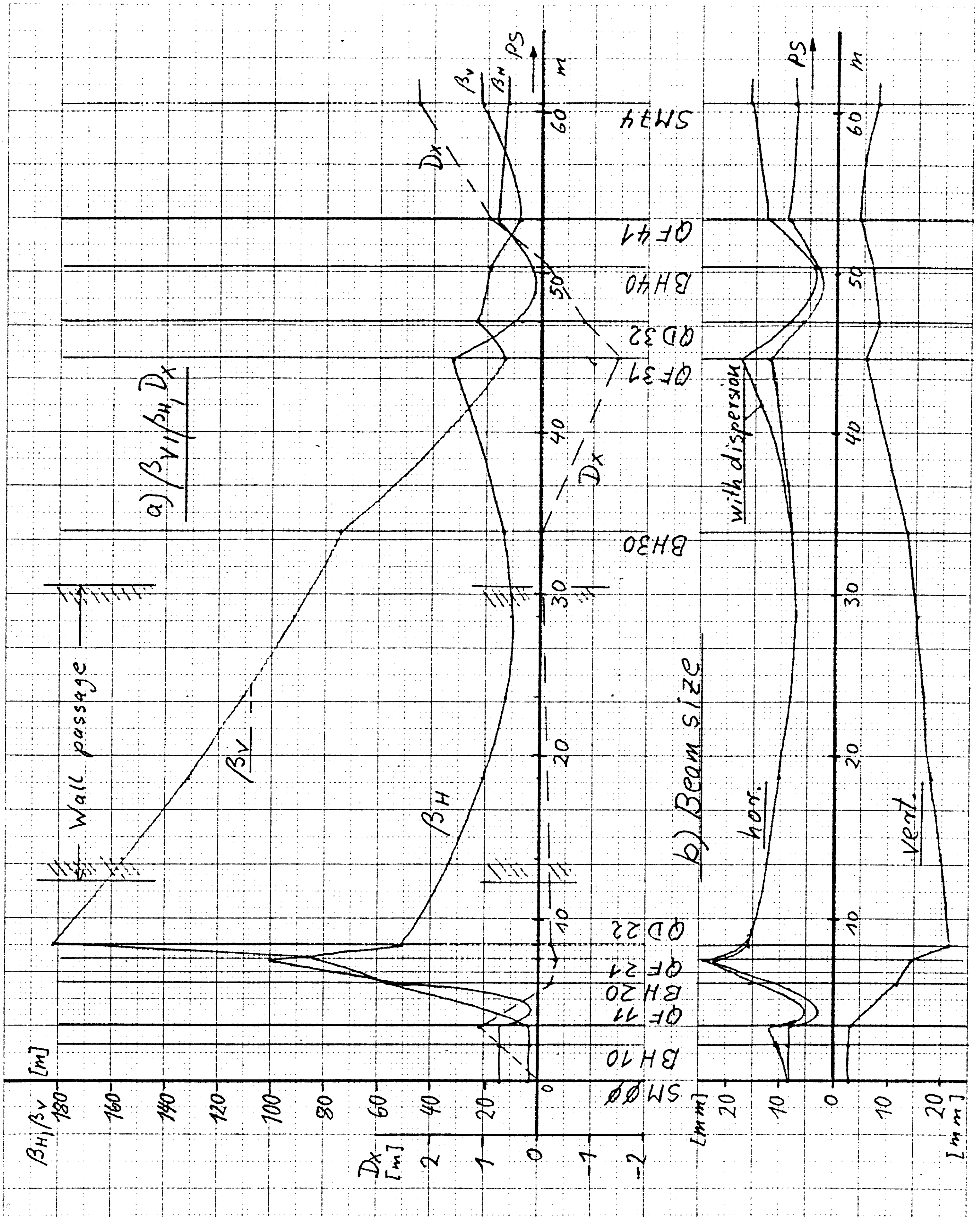



Fig. 5: Beam Transport EPA → PS ($e^-$)

a) Characteristic functions

b) Full Beam Size ($\pm 3\sigma_0$)

$\Delta E/E(1\sigma) = 6 \cdot 10^{-4}$; $\varepsilon_H(1\sigma) = 0.14\,\pi\,\mu rad\,m$; $\varepsilon_V = 0.5 \cdot \varepsilon_H$

TIME = 0.000 SECONDS

***** BT EPA - PS E- 8/5/84 ****************  AGS VERSION 84.03  19/06/84 10.43.17.

*PSAGS, PS02E RISS.*

BETATRON FUNCTION TRACKING WITH DP/P = 0.00000 PER MILLE ; *STRAIGHT MAGNETS*

| NO | ELEMENT | LENGTH | ANGLE | GRADIENT | BETAV(M) | BETAH(M) | ALPHAV(R) | ALPHAH(R) | MUV/2PI | MUH/2PI | $D_x$ (~~ALPHAP~~) | $D_x'$ (~~ALPHAP'~~) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | INITIAL *ψ:* | | | *EPA :* | 3.14000 | 14.00000 | .07000 | .01600 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 1 | F | .0100 | 0.00000 | -6.64000 | 3.14072 | 13.99039 | -.14170 | .94445 | .00051 | .00011 | 0.00000 | 0.00000 |
| 2 | SM00 *0.0051* | .4200 | .23562 | 0.00000 | 3.14865 | 13.22779 | .12372 | .88818 | .02183 | .00498 | .04925 | .23672 |
| 3 | D | .0100 | 0.00000 | 6.83000 | 3.14406 | 13.21907 | .33489 | -.01583 | .02233 | .00510 | .05164 | .24016 |
| 4 | | 1.7957 | 0.00000 | 0.00000 | 3.08197 | 13.51991 | -.30031 | -.15171 | .12020 | .02655 | .48289 | .24016 |
| 5 | BH10 *0.0157* | .5600 | .37299 | 0.00000 | 3.12398 | 13.70856 | .23010 | -.19310 | .14908 | .03294 | .71752 | .61754 |
| 6 | | .4500 | 0.00000 | 0.00000 | 2.98515 | 13.89768 | .07842 | -.22715 | .17262 | .03813 | .99541 | .61754 |
| 7 | QF11 | .5360 | 0.00000 | -1.95887 | 5.00195 | 7.61769 | -4.52182 | 9.65851 | .19692 | .04567 | 1.02902 | -.49806 |
| 8 | | .5000 | 0.00000 | 0.00000 | 10.59569 | 1.05352 | -6.66567 | 3.46983 | .20786 | .07391 | .77999 | -.49806 |
| 9 | | 1.0000 | 0.00000 | 0.00000 | 28.21473 | 6.49120 | -10.95337 | -8.90752 | .21707 | .51146 | .28193 | -.49806 |
| 10 | | .7440 | 0.00000 | 0.00000 | 46.88673 | 26.59691 | -14.14341 | -18.11627 | .22032 | .52048 | -.08863 | -.49806 |
| 11 | BH20 *0.0157* | .5600 | .37299 | 0.00000 | 57.21716 | 50.12477 | -3.11753 | -24.88799 | .22204 | .52286 | -.25789 | -.12069 |
| 12 | | 1.0509 | 0.00000 | 0.00000 | 63.97670 | 116.10614 | -3.31442 | -37.89573 | .22481 | .52505 | -.38472 | -.12069 |
| 13 | QF21 | .3800 | 0.00000 | -1.93082 | 86.57829 | 111.99885 | -61.59106 | 47.63068 | .22566 | .52556 | -.37608 | .16509 |
| 14 | | .4320 | 0.00000 | 0.00000 | 147.96602 | 74.59560 | -80.52262 | 38.90849 | .22627 | .52631 | -.30477 | .16509 |
| 15 | QD22 | .3800 | 0.00000 | 1.38221 | 179.63842 | 59.96909 | 2.79461 | 2.10968 | .22662 | .52725 | -.27085 | .01638 |
| 16 | | 4.8771 | 0.00000 | 0.00000 | 153.54570 | 41.55278 | 2.55543 | 1.66639 | .23130 | .54282 | -.19094 | .01638 |
| 17 | | 5.0000 | 0.00000 | 0.00000 | 129.21746 | 27.16121 | 2.31022 | 1.21192 | .23695 | .56660 | -.10902 | .01638 |
| 18 | | 5.0000 | 0.00000 | 0.00000 | 107.34134 | 17.31429 | 2.06501 | .75746 | .24371 | .60362 | -.02709 | .01638 |
| 19 | | 5.0000 | 0.00000 | 0.00000 | 87.91733 | 12.01201 | 1.81980 | .30300 | .25190 | .65997 | .05483 | .01638 |
| 20 | | 5.0539 | 0.00000 | 0.00000 | 70.77582 | 11.27097 | 1.57194 | -.15637 | .26211 | .73148 | .13764 | .01638 |
| 21 | BH30 *-0.006* | .5600 | -.14900 | 0.00000 | 67.60901 | 11.47375 | 4.02527 | -.20708 | .26340 | .73930 | .10514 | -.13289 |
| 22 | | 10.7491 | 0.00000 | 0.00000 | 10.47246 | 26.42754 | 1.29022 | -1.18409 | .32958 | .84518 | -1.32332 | -.13289 |
| 23 | QF31 | .3800 | 0.00000 | -.76250 | 10.65244 | 24.47092 | -1.78111 | 6.14272 | .33541 | .84752 | -1.30071 | .25079 |
| 24 | | 2.3899 | 0.00000 | 0.00000 | 21.40284 | 4.15048 | -2.71718 | 2.35997 | .36071 | .88562 | -.70135 | .25079 |
| 25 | QD32 | .3800 | 0.00000 | .38125 | 22.29165 | 2.75585 | .42129 | 1.37721 | .36345 | .90371 | -.62456 | .15518 |
| 26 | | 2.1914 | 0.00000 | 0.00000 | 20.69888 | 1.76748 | .30554 | -.92619 | .37972 | 1.17266 | -.28449 | .15518 |
| 27 | BH40 *0.0122* | .5600 | .29432 | 0.00000 | 18.76555 | 3.11012 | 3.00888 | -1.50635 | .38424 | 1.21048 | -.11702 | .45165 |
| 28 | | 1.0000 | 0.00000 | 0.00000 | 13.28353 | 7.17394 | 2.47314 | -2.55747 | .39433 | 1.24443 | .33463 | .45165 |
| 29 | DV40 | .2000 | 0.00000 | 0.00000 | 12.31570 | 8.23897 | 2.36600 | -2.70769 | .39682 | 1.24857 | .42496 | .45165 |
| 30 | | 1.0000 | 0.00000 | 0.00000 | 8.11944 | 14.82546 | 1.83026 | -3.81880 | .41276 | 1.26299 | .87660 | .45165 |
| 31 | QF41 | .3800 | 0.00000 | -.76250 | 7.63159 | 16.09232 | -.49968 | .60821 | .42059 | 1.26684 | .99728 | .17765 |
| 32 | | 3.9174 | 0.00000 | 0.00000 | 14.05939 | 12.63352 | -1.14116 | .27473 | .48231 | 1.31113 | 1.69321 | .17765 |
| 33 | DV41 | 3.0000 | 0.00000 | 0.00000 | 22.38008 | 11.75132 | -1.63241 | .01934 | .50936 | 1.35073 | 2.22616 | .17765 |
| 34 | D | .0100 | 0.00000 | 3.93000 | 22.40394 | 11.75556 | -.75345 | -.44344 | .50943 | 1.35086 | 2.22837 | .26518 |
| 35 | SM74 *-.0039* | .4200 | -.18000 | 0.00000 | 22.34861 | 12.14381 | .88315 | -.48597 | .51242 | 1.35643 | 2.30145 | .08469 |
| 36 | F *PS:* | .0100 | 0.00000 | -3.87000 | 22.33960 | 12.14884 | .01793 | -.01676 | .51249 | 1.35656 | 2.30185 | -.00438 |

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

TIME = 0.000 SECONDS

*Fig. 6 : e⁻ Transfer Line*

***** BT EPA - PS E- 8/5/84 ****************  AGS VERSION 84.03  19/06/84 10.43.17