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A COMBINED E.S. AND R.F. SEPARATED PARTICLE BEAM FOR THE EAST EXPERIMENTAL AREA OF THE CERN PROTON SYNCHROTRON

PRELIMINARY REPORT

Summary

Proposals have already been made for separated particle beams in the East Experimental Area of the C.E.R.N. Proton Synchrotron, based on either Radio Frequency or Electrostatic Separators. In this preliminary report we discuss briefly the results of an attempt to combine both sorts of beam in a single beam channel, with a view to making the most efficient use of the available beam transport equipment.

The requirements for both standard and non standard beam transport equipment are presented, and targetting requirements are also discussed. Then follows a brief description of the beam. Finally an estimate of particle fluxes and performance of the beam is given.

It is concluded that positive and negative pions and kaons, protons and antiprotons, should be available over the major part of the momentum range up to around 15 GeV/c, at a sufficient intensity for bubble chamber use.

It is hoped to give more complete specifications of the beam in a future report.

1. Introduction

In this report we discuss a proposal for a general purpose separated particle beam which incorporates both Electrostatic (E.S.) deflecting tanks and Radio Frequency (R.F.) deflecting cavities in its design. It is intended to be primarily for use with the British National Hydrogen Bubble Chamber (N.B.C.) in the East Experimental Area of the CERN Proton Synchrotron (P.S.).

Preliminary proposals have already been made for separated particle beams using either E.S.[1)] or R.F.[2)] separators, the two types of beam yielding particles in rather different momentum ranges. It seems desirable to have both sorts of beam in order to have particles available over as wide a range of momenta as possible.

The preliminary designs showed that rather large amounts of beam transport equipment would be required by both the E.S. and R.F. beams. An attempt has been made therefore, to combine the two in such a way that the greater proportion of the beam transport equipment is common to both beams. It is possible that a lengthy period of testing and development may be necessary before the R.F. separator cavities become fully operational. Therefore the R.F. beam should perhaps, at least in the early stages, be regarded as a test beam for the R.F. separators. From this point of view, it seems of importance that in the proposed design, the number of additional beam transport elements required by the R.F. beam is small.

The design of the R.F. beam is based on two deflecting cavities. The E.S. beam has been designed with a single stage of separation. However, it may readily be converted into a two stage system, if the purity of beams obtained with the single stage system, is insufficient.

The beam should provide good coverage of the momentum range up to 15 GeV/c for pions, kaons, antiprotons and protons. This is due in part to the fact that, by the proposed use of targets within the P.S. Magnet Unit 60, rather than in the standard target position in straight section 61, essentially zero angle production is obtainable for negative particles, if required.

The full specifications of the beam may form the subject of a future report. Here we shall only give an outline of the properties of the beam, and only discuss in any detail those aspects of the beam not discussed in the earlier reports.

2. Beam Transport Requirements

A complete list of all the beam transport elements required is given in Table 1. The approximate distance of the centre of each element from the standard target position in straight section 61 of the P.S. is indicated. We also specify in the table which elements are necessary for the R.F., single stage E.S. (E.S.1) and two stage E.S. (E.S.2), beams respectively. The layout of the combined beam between the target and the bubble chamber is shown in Figure 1.

The requirements for standard CERN Quadrupole and Bending Magnets are summarised in Table 2. Where possible 1 metre magnets are used in preference to the 2 metre magnets the choice being governed by the ability of the beam to transport particles of up to 15 GeV/c momentum between target and bubble chamber in the desired manner. A non standard base is required for the last 1 metre Quadrupole magnet (Q 17) as we wish to be able to adjust both the height and tilt of the axis over a wide range of values.

We now discuss briefly our requirements for the various non standard elements in the beam.

The iron beam pipe was suggested by Hereward$^{3)}$ as a means of eliminating the undesirable effects of the P.S. fringing field, thus enabling smaller production angles ($\sim 6^{\circ}$) to be used than would have otherwise been possible. The internal dimensions of the pipe should be such as to permit total angular acceptances at the target of up to 10 and 20 milliradians in the vertical and horizontal planes respectively.

It is suggested that all the collimators be of the adjustable aperture variety. It is suggested also that it should be possible to carry out any adjustment to or determination of the apertures remotely. Suitable materials from which to construct the collimators, which should be in vacuum tight boxes, are iron, copper or brass.

The sextupole lens should be made as short as possible and have a useful aperture of about 5 cm diameter.

The septum slit is a device which is used to increase the physical separation of images already possessing some small amount of separation. Such a device which would meet our requirements has already been constructed by the N.P.A. Division at CERN$^{4)}$.

Finally we note that although three deflecting tanks have been specified for E.S. 1 and four for E.S.2, nevertheless these beams could function on fewer tanks, if absolutely necessary, though rather less efficiently.

3. Targets

The beam has been designed to cover as much of the momentum range up to 15 GeV/c as possible. In order to obtain reasonable particle intensities at the higher momenta it is necessary to go to very small production angles. Using the Hereward beam pipe and a target in the standard target position in straight section 61 the minimum angle attainable is between 5° and 6°.

One way of obtaining even lower production angles, at least for negative secondary particles is to place the target within the magnet unit 60. By a suitable choice of radial ans azimuthal position of the target at any particular momentum essentially zero angle production can be obtained. The focussing and dispersive effects of the P.S. Field turn out to be small and to a good approximation can be ignored when considering the design of the beam. Details of calculations on the above points will be published in the near future5).

The targetting requirements of the E.S. and R.F. beams are rather different. The standard type of point source target operated in short burst conditions should suffice for the E.S. beam. The cross section should be made as small as possible consistent with a good target efficiency.

Special targetting techniques are necessary for the R.F. beam since the R.F. cavities are only under power for a few microseconds. Only one traversal of the target is possible so that for high efficiency the cross section of the target should be about the same as that of the circulating proton beam. The optimum target thickness is probably about that which is equivalent to one interaction length of material.

The target should be placed at say 2 cm inside the equilibrium orbit at the chosen azimuthal position inside magnet unit 60. It is proposed that the fast kicker magnet which will be located in straight section 97, be used to kick the beam towards the inside of the ring. The beam reaches the target azimuth for the first time after 0.64 revolutions but as this corresponds to exactly 4 betatron wavelengths the beam arrives undisplaced. A further complete revolution equivalent to 6 1/4 betatron wavelengths is necessary to bring the beam onto the target.

4. Description of the Beam

We have attempted to design a general purpose separated particle beam to cover the momentum range up to 15 GeV/c. However the design of the single stage E.S. beam (E.S.1) was optimised for $\sim$ 5 GeV/c K-mesons and of the R.F. beam (R.F.) for $\sim$ 10 GeV/c K-mesons. We shall consider the properties of the three individual beams E.S.1, E.S.2 and R.F. separatcly.

a) The E.S.1 Beam

The schematic layout of the single stage E.S. Beam is shown in Figure 2. Various ray traces through the system are shown in Figure 3, and in Table 3 we give the values of the more important optical parameters of the beam, when the latter is operated in the mode suggested for 5 GeV/c k-mesons.

The E.S. 1 beam may be divided essentially into three sections. In the first section the beam is defined and preliminary momentum analysis carried out. Particle separation takes place in the second section. In the final section there is a second momentum analysis and the imaging conditions of the beam in the bubble chamber are there determined.

Imaging is done at different points in the horizontal and vertical planes throughout the beam. Simple considerations show that this leads to a reduction in background and in any case the first foci must be separated so that a sextupole lens can be used to reduce chromatic aberration in the vertical plane.

The bending angles in the first four bending magnets (M1 - 4) are the same enabling them to be powered by a single generator at low moments. The strengths of the two lenses Q3, Q4 are so chosen that the dispersion produced by the second pair of bending magnets exactly compensates that produced by the first pair. This dispersion free property of the system enables the width of the beam in the horizontal plane to be kept quite small even when transmitting large momentum bites.

Parallel beam separation is used as this gives the maximum phase area acceptance. The lenses Q10, Q12 are well separated to give good physical separation of the images of wanted and unwanted particles at the mass slit. When the separation becomes small (e.g. at 5 GeV/c between K and π and at 8 GeV/c between π and P) then the septum slit can be used to advantage. This will give roughly an extra 10 mm of useful separation at 6 GeV/c.

The axis of the N.B.C. is about 40 cm. below that of the beam. Advantage is taken of this fact, and the fact that there is a good vertical image at the mass slit, in order to perform a final momentum analysis of the beam as close as possible to the bubble chamber, so as to reduce off momentum background to a minimum. The necessary dispersion for the momentum analysis is produced mainly by the vertical bending magnet (M 7).

The steering of the beam into the bubble chamber is accomplished by using this magnet together with a second vertical bending magnet (M 8) and the quadrupole magnet (Q 17), the height and tilt of the axis of this last element being variable.

b) The E.S.2 Beam

The schematic layout of the two stage E.S. Beam is shown in Figure 4. The various ray traces are shown in Figure 5,and Table 4 lists the values of the chief optical parameters of the beam.

The two stage beam differs from the single stage beam essentially only in the separation stage. Focused beam separation is used as this gives the best physical separations in the limited lengths available for each stage.

c) The R.F. Beam

The schematic layout of the R.F. beam is shown in Figure 6. Ray traces through the system are shown in Figure 7 and a summary of the important optical properties is given in Table 5.

The theory underlying the design of this two cavity system is essentially that discussed by Schnell[2)], although in order to obtain compatibility between the R.F. and E.S. Beams it has been necessary to depart somewhat from the original Schnell design in several places.

The R.F. Beam may also be considered as consisting of three sections with essentially the same functions as in the E.S. beams. Exactly the same momentum analyser is used as the first stage of the beam.

However, the method used for the separation of particles in the R.F. Beam is rather different from that employed in the E.S. beams. The net deflection of a given sort of particle is dependant on the relative phases of the R.F. power in the two cavities. By carefully adjusting the relative phase it is possible in general to give the wanted particles a larger net angular deflection than any of the unwanted particles, the latter being stopped by a central beam stopper.

We note that because of symmetry pairs of lenses constituting the quadruplet between the cavities may be run off a single generator.

In the final part of the beam momentum analysis is carried out in the horizontal plane with the dispersed image falling in the bubble chamber. It was thought preferable to place the off momentum contaminating particles in a known region of the bubble chamber rather than risk producing a general uniform background through inefficient collimation.

5. Particle Fluxes

Fidecaro et al[6)] have deduced the momentum distribution at various production angles, of π^o mesons produced in 23.1 GeV (K.E.) proton-proton collisions from a study of γ-ray spectra. The corresponding distributions for π^- mesons have been obtained from a bubble chamber study [7)] of 24.2 GeV/c proton-proton collisions. Within the poorer statistics of the latter experiment the distributions for π^0 and π^- mesons are essentially the same, as might perhaps have been expected on grounds of charge independance. We shall use the results of Fidecaro et al as the basis of our flux estimates.

Our estimates of the expected fluxes of $\pi^{\pm}$, K^+, K^-, P^- at the bubble chamber for a production angle of 6° are given in Figure 8. For the π mesons we use directly the 6° curve of Fidecaro et al, corrected for decay loss between target and bubble chamber. To obtain the fluxes of the other particles we have used the particle ratios obtained by Baker et al8) for a production angle of 4.75°. A certain amount of interpolation and extrapolation has been necessary, but the estimates should nowhere be much more than a factor 2 in error.

A solid angle acceptance of 1.0×10^{-4} steradians was taken, this being essentially the maximum acceptance for the beam if one restricts oneself to the good field region of the quadrupole magnets. Although much larger momentum bites than the assumed ± 1 o/o can be transported it was thought that this would be the maximum that could be tolerated in the majority of nuclear physics experiments.

The fluxes are given in terms of 10^{10} inelastic nuclear interactions. Recent estimates9) of the efficiency of point source targets operated under short burst conditions, indicate that it is not much greater than ~ 10 o/o, so that at least for the E.S. beam, the fluxes will refer essentially to $\sim 10^{11}$ circulating protons, which is now generally taken as the norm when evaluating the performance of beams.

The average increase in the flux of pions per degree decrease in production angle below 6°, estimated from the results of Baker et al. and Fidecaro et al. is given in Figure 9. For the heavier particles (K^+, K^-, P^-) the rate of increase is probably less. For example Baker et al. find that the ratios of the fluxes of these particles to the fluxes of pions decrease by approximately a factor 2 in going from 9° to 4.75° production angle.

It is perhaps worth noting that for particles which possess an isotropic angular distribution in the centre of mass system, and in the absence of angle-energy-correlations in this system, then the flux per unit solid angle at high momenta should tend to a constant value at small angles in the laboratory.

Bubble chamber results7) 10) show that these conditions pertain more closely for K-mesons than for pions, so that the gain in intensity obtained by reducing the production angle will probably be much less marked for kaons than for pions.

6. Performance of the Beams

In calculating the fluxes quoted in the previous section a solid angle acceptance of $1{\cdot}0 \times 10^{-4}$ steradians and a momentum bite of ± 1 o/o were assumed. They would apply to a circulating beam of 1×10^{11} protons if the target efficiency were only 10 o/o.

Preliminary estimates indicate that in the E.S.1 beam something approaching the above maximum values of momentum bite and solid angle should be realisable up to about 5 GeV/c for K-mesons and up to about 8 GeV/c for protons, antiprotons and pions, above which momenta the efficiency of separation drops rather rapidly.

However the R.F. beam can take over at these momenta if necessary. By adjusting the relative phase of the R.F. voltage in the two cavities the wanted particles can in general be given a larger net deflection than any of the unwanted particles. Maximum efficiency is obtained when the phase slip between the unwanted particles in travelling between the cavities is some multiple of 2π so that they can be made to suffer a zero net deflection. These conditions apply at 6·7, 8·6, 10·6, 14·9 GeV/c for K mesons, at 5·4, 7·7 GeV/c for protons (or antiprotons), and at 7·4, 9·1, 12·9 GeV/c for pions. At other momenta the efficiency will be less than maximum, because a larger beam stopper is required to intercept the unwanted particles.

We may conclude that if one uses the lowest possible production angles then beams of $\pi^{\pm}$, $K^{\pm}$, $P^{\pm}$ of more than 10 particles per pulse should be available over the major part of the momentum range up to 15 GeV/c.

More detailed estimates of expected fluxes and beam purity may be published in a future report when the design of the beam has been finalised.

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Table 1

LIST OF BEAM TRANSPORT ELEMENTS

Element			Distance from S.T.P. (m)	Required by			Remarks
No.	Description	Symbol		E.S.1	E.S.2	R.F.	
1	Beam Pipe	B.P.	4·0	*	*	*	
2	Horizontal Collimator	C 1	6·5	*	*	*	
3	Vertical Collimator	C 2	7·5	*	*	*	
4	2 m. Quadrupole	Q 1	9·1	*	*	*	
5	2 m. Quadrupole	Q 2	11·9	*	*	*	
6	2 m. Bending Magnet	M 1	14·7	*	*	*	
7	2 m. Bending Magnet	M 2	17·5	*	*	*	
8	1 m. Quadrupole	Q 3	23·1	*	*	*	
9	Horizontal Collimator	C 3	25·8	*	*	*	
10	Sextupole Magnet	Sx.	26·6	*	*	*	
11	Horizontal Collimator	C 4	27·4	*	*	*	
12	Vertical Collimator	C 5	30·6	*	*	*	
13	Vertical Collimator	C 6	32·6			*	Angle Defining Slit
14	1 m. Quadrupole	Q 4	34·1	*	*	*	
15	2 m. Bending Magnet	M 3	39·7	*	*	*	
16	2 m. Bending Magnet	M 4	42·5	*	*	*	
17	2 m. Quadrupole	Q 5	45·3			*	
18	1 m. Quadrupole	Q 6	47·6	*	*	*	
19	1 m. Quadrupole	Q 7	53·6	*	*	*	
20	Vertical Collimator	C 7	54·7	*	*	*	
21	Separator Magnet	MS 1	55·5	*	*		Special
22	E.S. Tank	S 1	62·1	*	*		10 m. Ramm type
23	R.F. Cavity	RF 1	70·6			*	Length 3 m.
24	E.S. Tank	S 2	79·1	*	*		10 m. Ramm type
25	Separator Magnet	MS 2	85·7		*		Special
26	1 m. Quadrupole	Q 8	87·4			*	
27	1 m. Quadrupole	Q 9	89·2			*	
28	Septum Slit	S.S.	91·0		*		
29	Vertical Collimator	C 8	92·0		*		

Table 1 (continued)

Element			Distance from S.T.P. (m)	Required by			Remarks
No.	Description	Symbol		E.S.1	E.S.2	R.F.	
30	E.S. Tank	S 3	96·8	*			10 m. Ramm type
31	1 m. Quadrupole	Q 10	104·5	*	*	*	
32	1 m. Quadrupole	Q 11	106·3	*	*	*	
33	Separator Magnet	MS 3	108·0	*	*		Special
34	E.S. Tank	S 4	114·6		*		10 m. Ramm type
35	R.F. Cavity	RF 2	123·1			*	Length 3 m.
36	1 m. Quadrupole	Q 12	126·6	*			
37	E.S. Tank	S 5	133·3		*		10 m. Ramm type
38	Separator Magnet	MS 4	139·4		*		Special
39	1 m. Quadrupole	Q 13	140·7			*	
40	1 m. Quadrupole	Q 14	143·2			*	
41	Beam Stopper	B.S.	144·8			*	
42	Septum Slit	S.S.	144·8	*			
43	Vertical Collimator	C 9	145·8	*	*		Mass Slit
44	2 m. Bending Magnet	M 5	149·7	*	*	*	
45	2 m. Bending Magnet	M 6	152·5	*	*	*	
46	1 m. Quadrupole	Q 15	154·8	*	*	*	
47	Vertical Collimator	C 10	156·1			*	
48	1 m. Quadrupole	Q 16	160·1	*	*	*	
49	1 m. Bending Magnet	M 7	161·9	*	*	*	Vertical
50	1 m. Bending Magnet	M 8	168·0	*	*	*	Vertical
51	Vertical Collimator	C 11	170·0	*	*		
52	1 m. Quadrupole	Q 17	175·0	*	*	*	Special base

Table 2

REQUIREMENTS FOR STANDARD C.E.R.N. MAGNETS

Element	Requirements			
	Total	E.S.1	E.S.2	R.F.
1 metre Quadrupole Magnet	14	10	9	12
2 metre Quadrupole Magnet	3	2	2	3
1 metre Vertical Bending Magnet	2	2	2	2
2 metre Horizontal Bending Magnet	6	6	6	6

Table 3

OPTICAL PROPERTIES OF THE E.S.1 BEAM

Beam operated in the mode suggested for 5 GeV/c K-mesons (See Figure 3).

1. Target
    - a) Height = 1 mm.
    - b) Width = 2 mm.
2. Angular acceptances at Target
    - a) Vertical = ± 2·5 m. rad.
    - b) Horizontal = ± 7·5 m. rad.

∴ Solid Angle Acceptance = $7{\cdot}5 \times 10^{-5}$ sterad.

3. Horizontal Momentum Analysis at 1st horizontal focus
    - a) Dispersion = 0·7 cm / o/o $\delta P/_P$
    - b) Magnification relative to target = 2·09
    - c) Image size = 4·2 mm
    - d) Momentum resolution = ± 0·3 o/o $\delta P/_P$.
4. Vertical Momentum Analysis at 3rd vertical focus
    - a) Dispersion = 0·35 cm / o/o $\delta P/_P$
    - b) Magnification relative to target = 0·91
    - c) Image size = 0·91 mm
    - d) Momentum resolution = ± 0·13 o/o $\delta P/_P$.
5. Particle Separation at the 2nd vertical focus
    - a) Effective length of separators = 27 m.
    - b) Electric Field strength = 50 kV/cm.
    - c) Relative angular deflection of π and K = 0·12 m. rad.
    - d) Separation at mass slit = 7·6 mm.
    - e) Additional separation intreduced by Septum Slit = 10 mm.
    - f) Image size = 2·3 mm.
    - g) Chromatic Aberration = 3·4 mm/m. rad/ o/o $\delta P/_P$.
    - h) Chromatic Aberration for ± 1 o/o $\delta P/_P$
        - (i) Without Sextupole = 17 mm.
        - (ii) With Sextupole = 5·1 mm.

Table 4

OPTICAL PROPERTIES OF THE E.S. 2 BEAM

Beam operated in the mode shown in Figure 5.

1. Target

   Same as E.S. 1.

2. Angular acceptances at target

   Same as E.S. 1.

3. Horizontal Momentum analysis

   Same as E.S. 1.

4. Vertical Momentum analysis, at 4th vertical focus
   - a) Dispersion = 0·35 cm / o/o $\delta P/_{P}$.
   - b) Image size = 0·97 mm.
   - c) Momentum resolution = ± 0·14 o/o. $\delta P/_{P}$

5. Particle Separation
   - a) Length of Separator in each stage = 18 m.
   - b) Field Strength = 50 kV/cm.
   - c) Drift length for separation
     - (i) 1st stage = 21·4 m.
     - (ii) 2nd stage = 21·8 m.
   - d) Magnification of
     - (i) 1st stage = 0·87
     - (ii) 2nd stage = 1·96
   - e) Magnification relative to target at
     - (i) 1st mass slit = 1·27
     - (ii) 2nd mass slit = 2·49

Table 5

OPTICAL PROPERTIES OF THE R.F. BEAM

Beam as operated to produce 10·6 GeV/c K-mesons (see Figure 7).

1. Target

$\sim$ 7 mm diameter

2. Angular acceptances at target

(i) Vertical = ± 3·5 m. rad.

(ii) Horizontal = ± 7·0 m. rad.

$\therefore$ Solid Angle acceptance = $1 \cdot 0 \times 10^{-4}$ sterad.

3. Momentum analysis at 1st horizontal focus

Same as E.S. 1

4. Magnification relative to the target, in the horizontal plane, at

(i) Momentum analysing slit = 2·1

(ii) Inside 1st R.F. Cavity = 3·5

(iii) Inside 2nd R.F. Cavity = 3·5

(iv) At bubble chamber = 2·4

5. Magnification relative to the target in the vertical plane, at

(i) Inside 1st R.F. Cavity = 3·2

(ii) Inside 2nd R.F. Cavity = 3·2

6. Loss of wanted particles at beam stopper = 36 o/o

$\therefore$ Efficiency = 64 o/o (maximum).

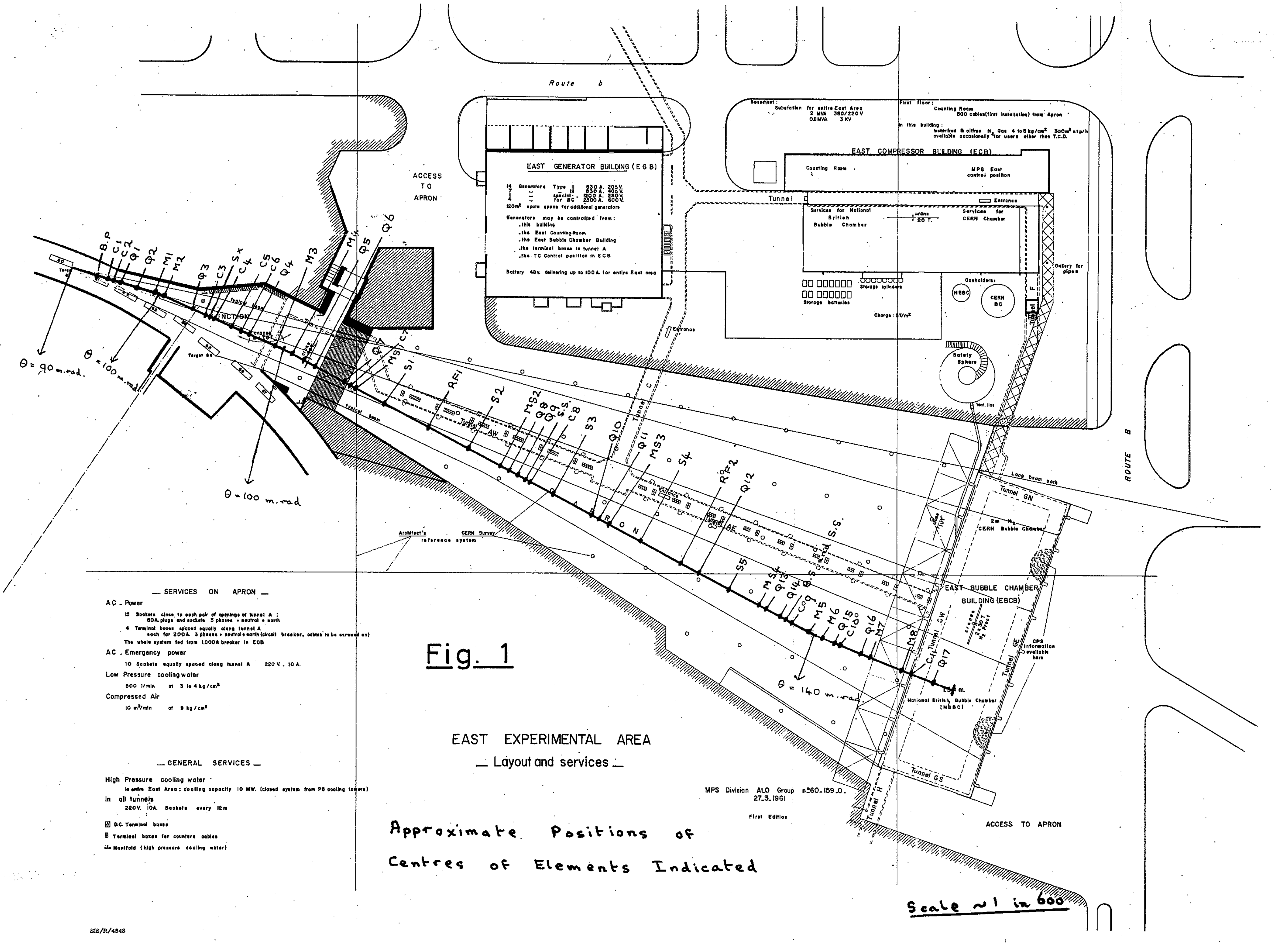


Fig. 1

EAST EXPERIMENTAL AREA
— Layout and services —

MPS Division ALO Group n°60-159.0.
27-3-1961

First Edition

Approximate Positions of
Centres of Elements Indicated

Scale ~ 1 in 600

— SERVICES ON APRON —

AC - Power
- 15 Sockets close to each pair of openings of tunnel A: 60A plugs and sockets 3 phases + neutral + earth
- 4 Terminal boxes spaced equally along tunnel A each for 200A. 3 phases + neutral + earth (circuit breaker, cables to be screwed on)
- The whole system fed from 1,000A breaker in ECB

AC - Emergency power
- 10 Sockets equally spaced along tunnel A 220 V. - 10 A.

Low Pressure cooling water
- 600 l/min at 3 to 4 kg/cm²

Compressed Air
- 10 m³/min at 9 kg/cm²

— GENERAL SERVICES —

High Pressure cooling water
- In entire East Area: cooling capacity 10 MW. (closed system from PS cooling towers)

In all tunnels
- 220V. 10A. Sockets every 12 m

▨ D.C. Terminal boxes

▤ Terminal boxes for counters cables

⊥ Manifold (high pressure cooling water)

SIS/R/4548

E.S.1. Beam

SCHEMATIC LAYOUT

with positions of centres of elements indicated.

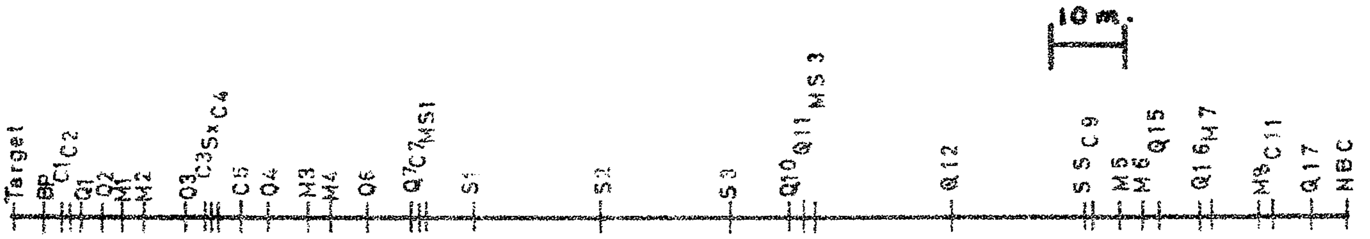


Fig. 2

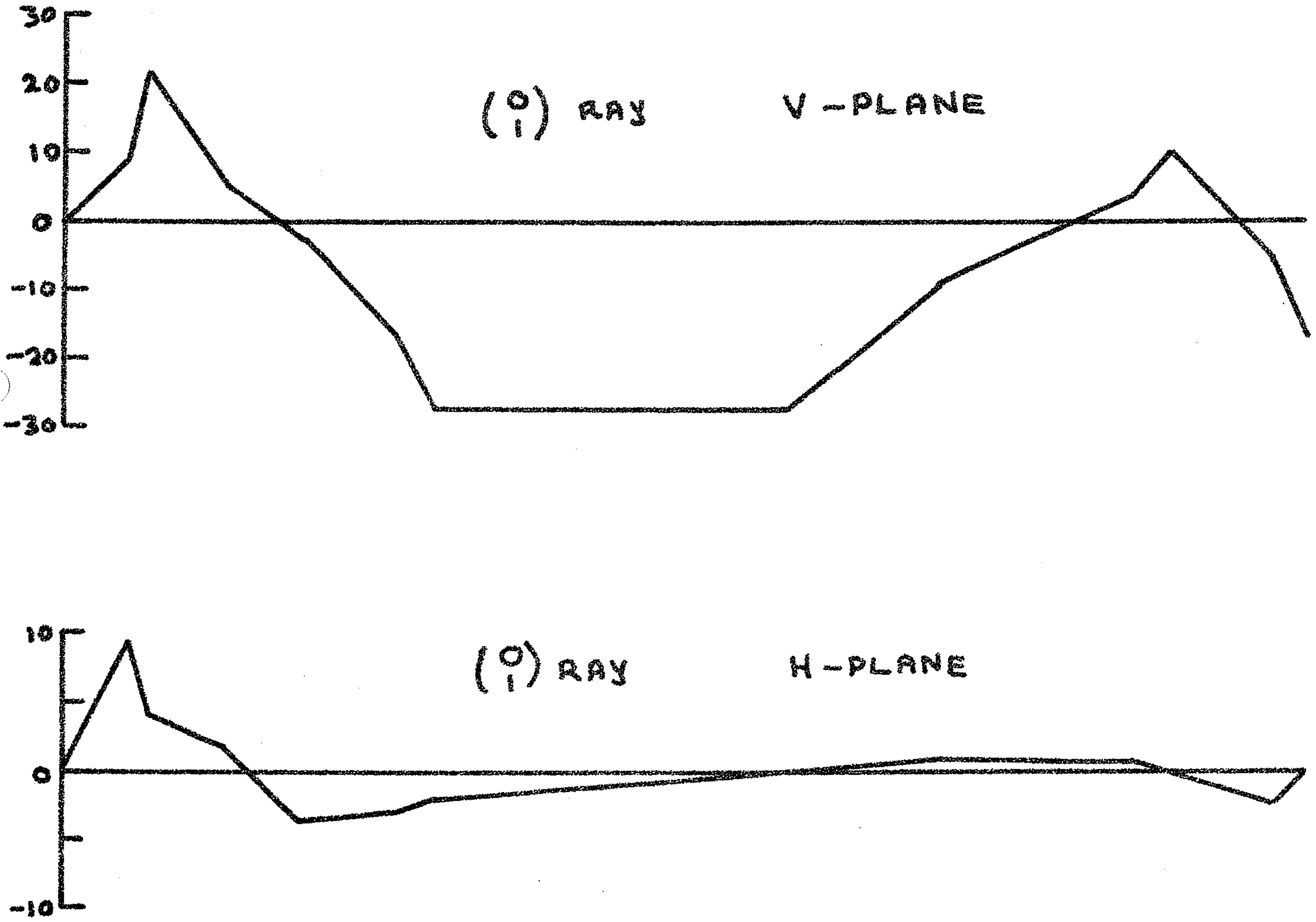


Fig. 3

PS/3367/sg

E.S.2. Beam

SCHEMATIC LAYOUT

with positions of centres of elements indicated.

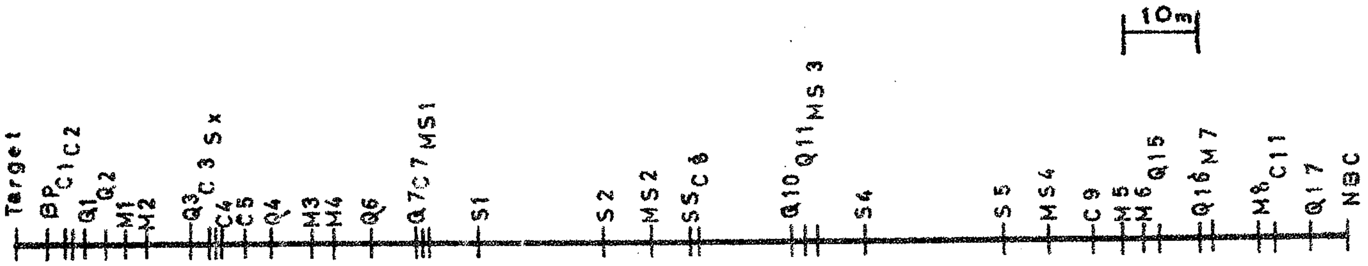


Fig. 4.

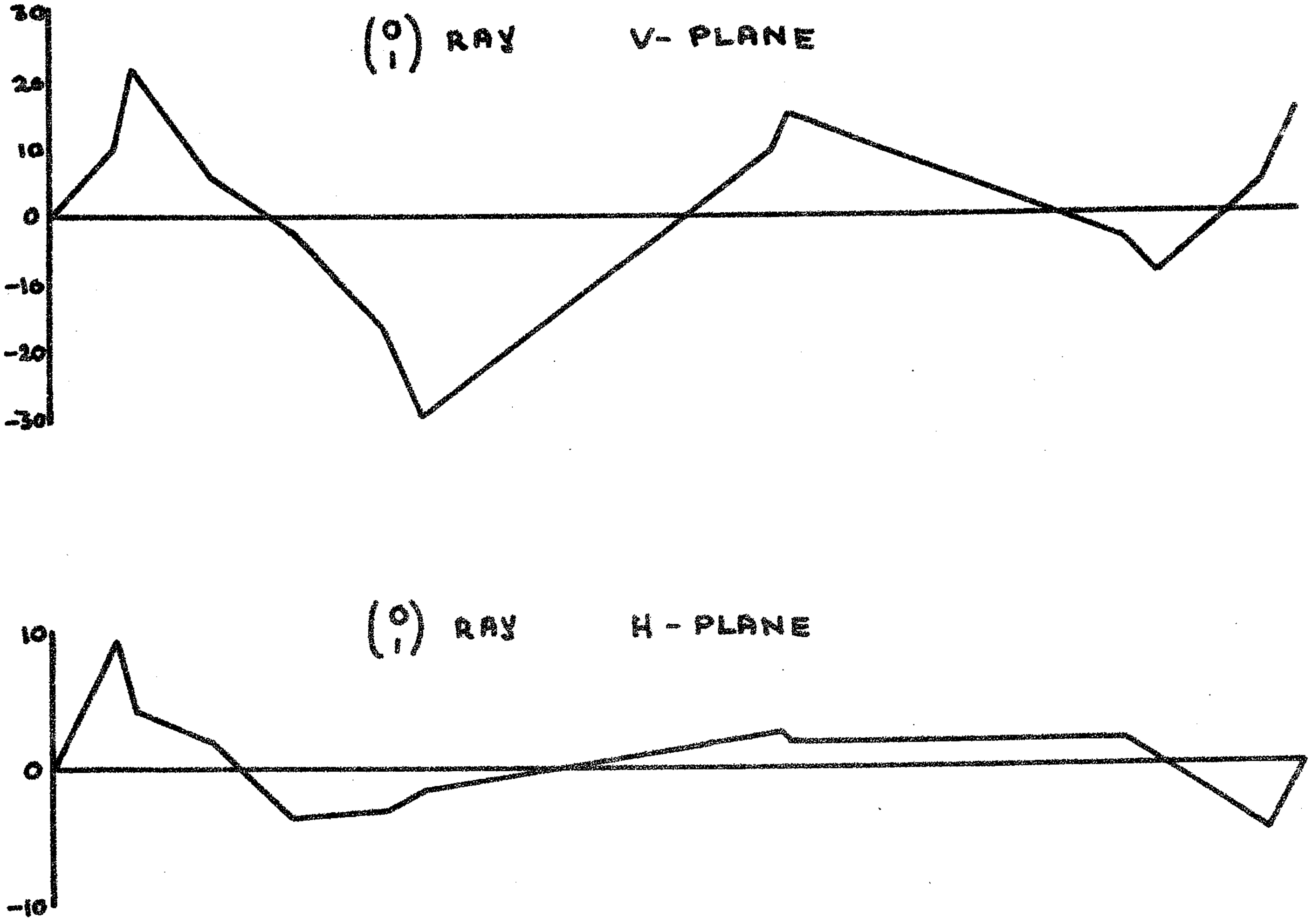


Fig. 5.

PS/3367/jc

R.F. Beam

SCHEMATIC LAYOUT

with positions of centres of elements indicated.

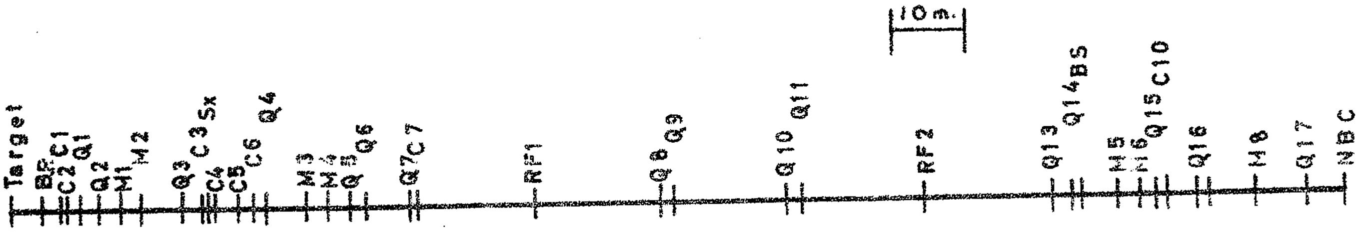


Fig. 6.

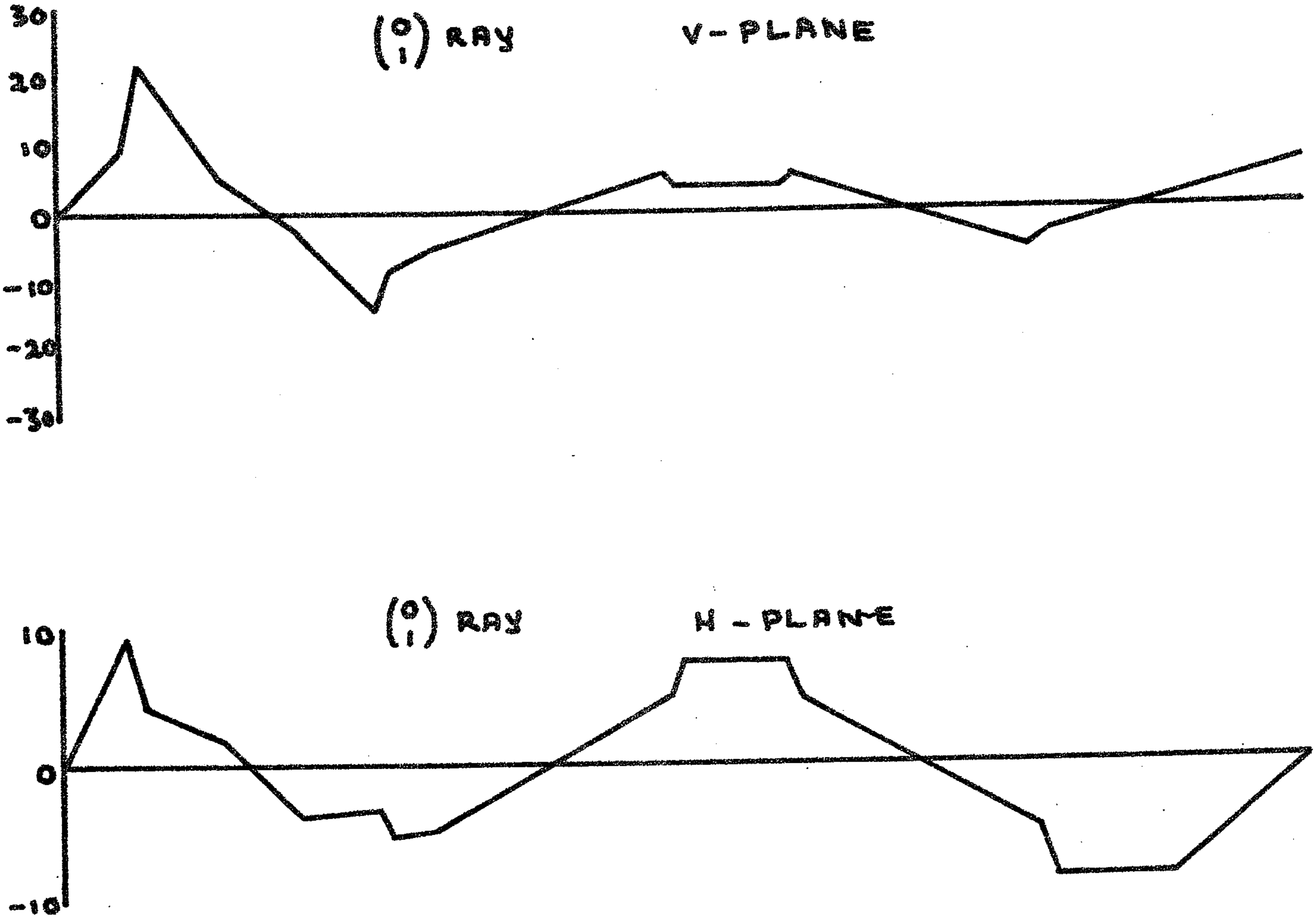


Fig. 7.

PS/3367/jc

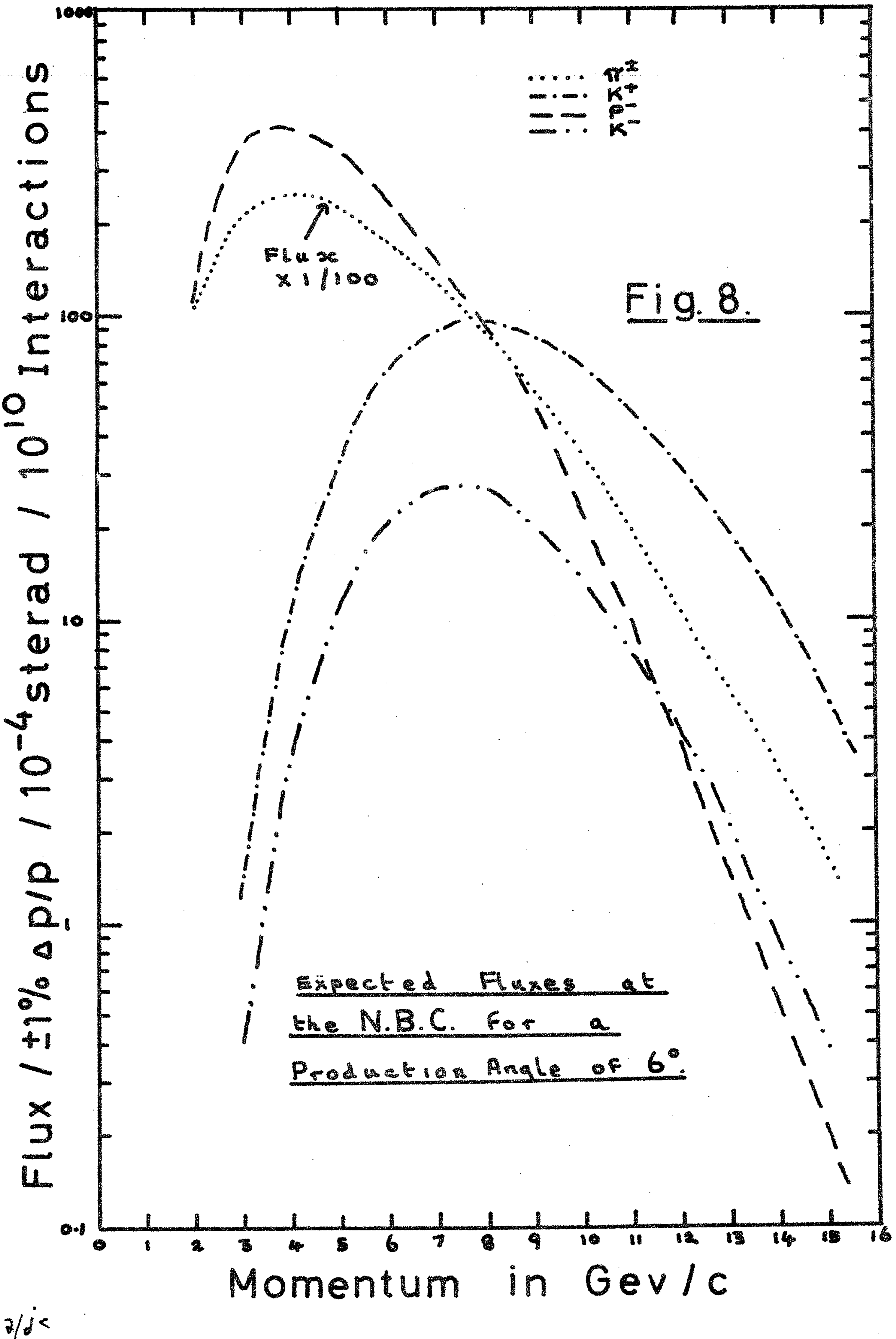
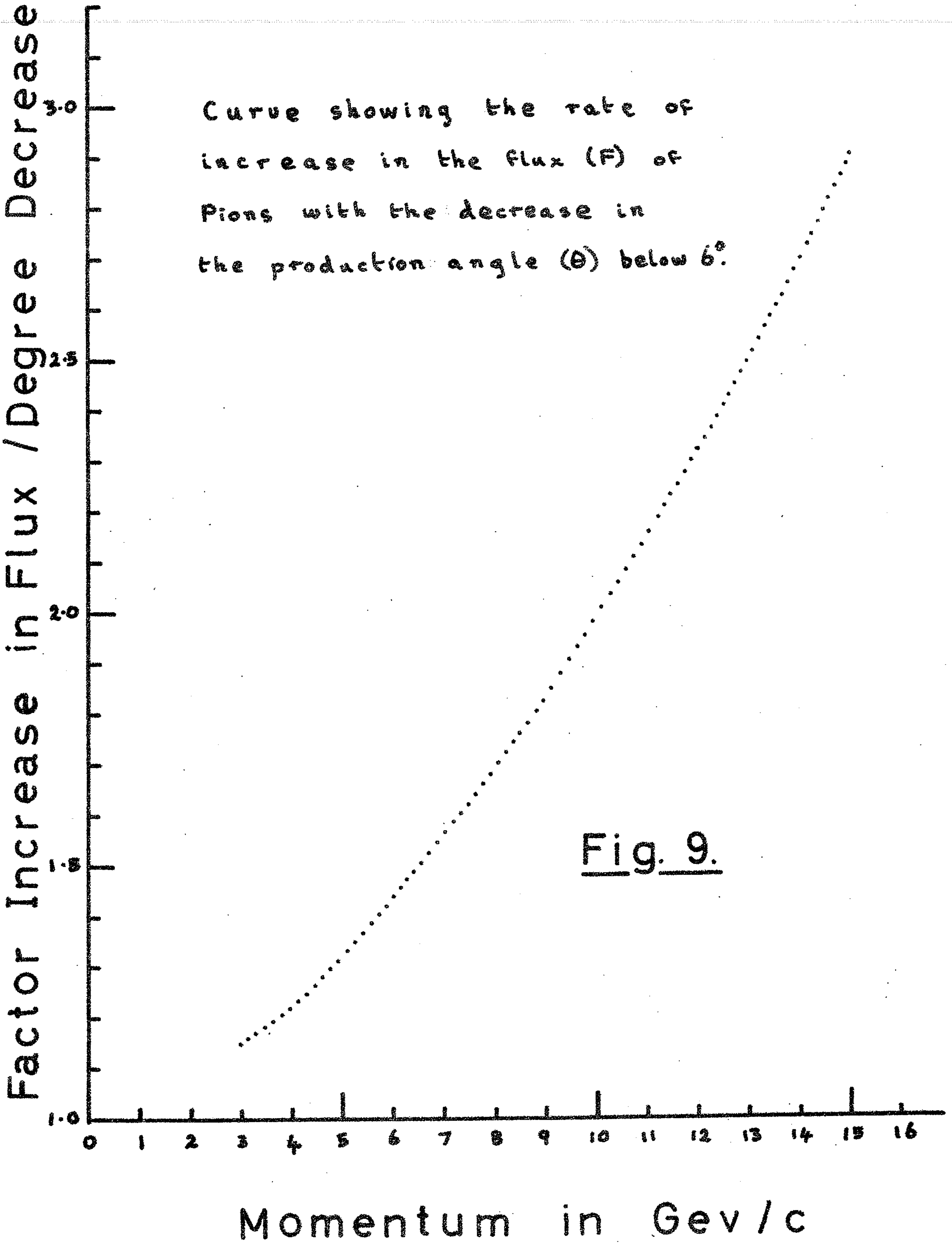


Fig. 8.

Expected Fluxes at the N.B.C. for a Production Angle of 6°.

PS/3367/jc



Curve showing the rate of increase in the flux (F) of Pions with the decrease in the production angle (θ) below 6°.

Fig. 9.

PS/3367/jc

CERN/TC/NBC 62-2
Corr.
23.7.1962

Erratum

In the Internal Report "A Combined E.S. and R.F. Separated Particle Beam for the East Experimental Area of the CERN Proton Synchrotron" - CERN/TC/NBC 62-2, an error has been made in the labelling of the ordinate in Figure 9.

Instead of "$dF/d\theta$" it should read "Facotr Increase in Flux/Degree Decrease". A corrected version of Figure 9 is enclosed herewith.

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PS/3367/sg