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A PROPOSAL FOR A GENERAL PURPOSE SEPARATED PARTICLE BEAM FOR USE WITH THE BRITISH NATIONAL HYDROGEN BUBBLE CHAMBER IN THE EAST EXPERIMENTAL AREA OF THE C.E.R.N. PROTON SYNCHROTRON

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Summary

The purpose of this report is to discuss a proposal for a general purpose separated particle beam from an internal target for use with the British National Hydrogen Bubble Chamber in the East Experimental Area of the CERN Proton Synchrotron.

The factors which it was necessary to take into account in designing the beam are discussed in some detail. The reasons for choosing the proposed layout are stated and an estimate of the intensity and purity of various particle beams is made.

Beams of antiprotons of momenta up to 8 GeV/c, and of pions and protons up to around 10 GeV/c, of reasonable intensity and purity should be readily obtainable. However it may be necessary to modify the proposed layout, by using a special magnet near the target, in order to obtain useable K-meson beams, in the momentum range 3 to 5 GeV/c. The difficulties inherent in delivering K-meson beams from an internal target to the bubble chamber should be resolved when an ejected proton beam for use on an external target becomes available.

1. Introduction

The 1.50 metre National British Bubble Chamber (N.B.C.) is expected to begin operation in the east experimental area of the CERN Proton Synchrotron (PS) either towards the end of 1962 or in the early part of 1963.

At the present time it is envisaged that the first beam to be used by the NBC will be a high energy scattered out proton beam. H. Geibel of CERN has undertaken to design such a beam which will be a particularly useful beam to have in the early stages for two reasons. First it will be possible to run parasitically so that valuable machine time would not be lost through intermittant operation of the NBC. Second, because it is a high energy beam it will be useful for examining chamber distortions.

The choice of the second beam for the east area has not yet been made. However a study has been made of various possible separated particle beams using internal targets that could be built using beam transport equipment that either will or could be available at the end of this year.

In this report we discuss a proposal for a general purpose separated beam for use with the NBC. The major beam transport requirements are for 12 Quadrupole Magnets, 6 Bending Magnets, and 30 metres length of Electrostatic Separator. Particles produced in a target placed in the straight section 61 of the PS and making an angle of 9^{o} with the circulating beam, are accepted by the beam transport system, and a selected number delivered over a total flight path of 180 metres to the bubble chamber.

If we demand at least 10 particles per pulse for a circulating beam of 1.0 x 10" protons, and that the number of contaminating μ-mesons should not exceed the number of wanted particles, then it should be possible to obtain beams of $K^{\pm}$ mesons in the momentum range 3 to 5 GeV/c, antiprotons of momenta up to 8 GeV/c and pions and protons with momenta up to 10 GeV/c. The proposed beam is seen to be complementary to a certain extent to beams existing or proposed for the North and South experimental areas.

2. Summary of Factors involved

We discuss now in some detail the various factors that had to be taken into account in designing the beam.

a) Availability of Beam Transport Equipment

The standard beam transport equipment expected to be available to users of the PS at the end of 1962 is indicated in Table 1. It has to be borne in mind that this equipment has to be shared among the various beams in the three experimental areas.

Table 1

Type of Equipment	Number Available
1 Metre Quadrupole Magnet	22
2 Metre Quadrupole Magnet	16
1 Metre Bending Magnet	9
2 Metre Bending Magnet	18
Electrostatic Separator	40 - 50 metres

Viewed in this light it is obvious that as yet there is no surplus of beam handling equipment so that careful attention must be paid to design so as to achieve the desired end result with the minimum amount of equipment.

b) The circulating proton beam

With the present injection system a circulating proton beam of 3 x 10" protons per pulse is theoretically obtainable. Although this intensity has been obtained on occasions in the past, experience indicates that to be safe the design of experiments should be based on a circulating beam of 1.0 x 10" protons per pulse.

The repetition rate of the PS is variable and may be adjusted to suit the experiment in progress. A higher repetition rate is usually obtained at the expense of a lower final proton energy. For example, if there is a "flat top" of duration 100 milliseconds, then for a 2 second repetition time the final proton energy is 19.2 GeV, while for a 5 second repetition time the proton energy is 26.0 GeV.

Although a higher proton energy means larger fluxes of secondary particles this must be balanced against the larger number of pictures that can be taken at the greater repetition rate for lower energies. It appears that a cycling time as low as 3 seconds might be obtained for the NBC but as yet this is purely conjectural.

c) Available Targets

The target will be located in straight section 61 in a position equivalent to that of target 1. The requirement of a short burst length ∿ 1 millisecond necessary for bubble chamber operation, restricts the type of target and the mode of target operation used.

When the separators are being used the most suitable target seems to be the "point source", consisting of an aluminium rod of diameter 2 mm aligned along the secondary beam direction. If the mode of operation known as "Beam Jump" is used, a burst length of about one millisecond is obtained with 85 o/o beam consumption. The fraction of consumed protons undergoing nuclear interactions is uncertain but preliminary estimates indicate that it is around 50 o/o.

For unseparated beams two other targets giving a rather diffuse source are available. One is a finger target which cuts through the circulating beam at high speed. A burst length of 0.3 to 1 milliseconds is obtainable and the beam consumption is variable between 0.5 o/o and 50 o/o. The other target is a bar target which "cuts in" with beam steering. The burst length is 0.9 milliseconds and the beam consumption 100 o/o.

More details concerning targets and circulating beam properties can be found in the PS Users Handbook from which the above details were obtained.

d) Choice of Production Angle

Behr and Hagedorn [1)] have made calculations, based on statistical theory, of the laboratory momentum distribution at various laboratory angles of secondary particles produced in 25 GeV proton-proton collisions. Examination of their curves indicates that in general the intensity at production of a given type of particle increases as the production angle decreases.

This trend also appears in the experimental data, not only for the nucleon-nucleon but also for the nucleon -nucleus collision [2,3,4)]. For example in Figure 1 we give data on the angular distribution at different momenta, of π^0 mesons produced in proton-proton collisions at 23.1 GeV (K.E.). These curves are based on the results of Fidecaro et al [2)].

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Thus it would appear that to obtain the highest particle fluxes the production angle should be made as small as possible.

However in going to small angles one comes up against two problems. First as the angle decreases, it is necessary because of the geometry of the PS to move the first beam transport quadrupole further from the target. This leads to a reduction in the solid angle acceptance of the beam transport system which to some extent counteracts the increased production.

Second, at small angles the effects of the non linear fringing magnetic field of the PS Magnet units becomes important. Aberrations due to the fringing field become serious for 3 to 4 GeV/c particles at around 8°.

However Petrucci at CERN has designed a special magnet which can be placed close to the target. It has a solid angle acceptance of about 4×10^{-4} steradians and can select particles of 3 GeV/c produced at 5°. Similar magnets could be used at higher momenta but with a greater production angle. The possibility of using such magnets is discussed in more detail in section 5 of this report.

e) Fluxes of secondary particles at production

Information on the production of secondary particles in high energy nuclear interactions over a wide range of production angles and momenta has been obtained both at Brookhaven [3] and CERN [4]. Brookhaven give rather lower figures for absolute rates of production than CERN but the two laboratories are in reasonable agreement over the ratios of the various secondary particles at production. In recent work with the Van der Meer fast antiproton beam at CERN and with a separated antiproton beam at Brookhaven the experimental fluxes showed good agreement with those calculated from the Brookhaven data.

In Table 2 we give the expected flux of π^- mesons for a production angle of 9°, a circulating beam of 10" protons at 25 GeV and assuming that 50 o/o of the protons undergo a nuclear interaction in the target. In addition various particle ratios at production are also given. We have assumed an equal number of π^+ and π^- are produced. The other ratios have been obtained by smoothing out the experimental data.

Table 2

Momentum in GeV/c	Flux of π^- /sterad/GeV/c /10" protons	Production Ratios K^-/π^-	K^+/π^-	P^-/π^-	P^+/π^-
3	2.2×10^{10}	0.07	0.13	0.014	0.56
4	1.2×10^{10}	0.07	0.15	0.014	0.71
5	5.2×10^{9}	0.07	0.20	0.014	0.81
6	2.2×10^{9}	0.07	0.28	0.014	1.00
7	9.0×10^{8}	0.07	0.28	0.014	1.23
8	3.4×10^{8}	0.07	0.28	0.014	1.72
9	1.3×10^{8}	0.07	0.28	0.014	2.35
10	4.6×10^{7}	0.07	0.28	0.014	2.90

Since the angular distributions of pions obtained at Brookhaven have essentially the same shape as the angular distributions of π^0 mesons of Fidecaro et al [2)] it is suggested that the curves of Figure 1 may be used in conjunction with the data of Table 2 to determine fluxes at other production angles.

f) Flight Path and Decay Loss

The total flight path from target to bubble chamber is 180 metres. In Table 3 we give the probability of survival of K and π mesons as a function of momentum. These figures are based on the lifetime:

$$\tau_{\pi^{\pm}} = 2.56 \times 10^{-8} \text{ secs.} \qquad \tau_{K^{\pm}} = 1.224 \times 10^{-8} \text{ secs.}$$

and the masses:

$$M_{\pi^{\pm}} = 139.63 \text{ MeV} \qquad M_{K^{\pm}} = 494.0 \text{ MeV}$$

Table 3

Momentum in GeV/c	Probabilities of Non-Decay	
	$K^{\pm}$	$\pi^{\pm}$
3	3.19×10^{-4}	0.337
4	2.36×10^{-3}	0.443
5	8.07×10^{-3}	0.519
6	1.78×10^{-2}	0.580
7	3.15×10^{-2}	0.626
8	4.88×10^{-2}	0.665
9	6.14×10^{-2}	0.695
10	8.97×10^{-2}	0.720

g) Solid Angle and Momentum Bite

With a production angle of 9° and using standard quadrupole lenses the maximum possible solid angle of the beam transport system is approximately 3.0×10^{-4} steradians. However if the beam is restricted to the linear part of the quadrupole field, i.e. to within 7 cm of the beam axis, then the maximum solid angle acceptance is 2.0×10^{-4} steradians. If the first quadrupole is chosen to be horizontally focussing this solid angle will be made up of $\pm$ 10 milliradians horizontally and $\pm$ 5 milliradians vertically.

The angular acceptance of $\pm$ 5 m.rad. may have to be reduced because of the limited phase space acceptance of an electrostatic separator in the vertical plane. Let us consider a separator with plate separation of 100 mm with an electric field strength of 50 kV/cm. Let us further assume that the wanted particles must not, but that the unwanted particles can, touch the plates.

Now with a 2 mm diameter target and with an angular acceptance of 10 m.rad. the phase space area at the target is 20 mm. m.rad. in the vertical plane. Under the assumptions made above the phase space acceptance for a parallel beam separator is the product of the aperture and angular deflection, assuming "just separation" of the final images [5]. This implies an angular deflection of 0.20 m.rad. for "just separation". In practice it is necessary to have more than "just separation" to obtain a pure beam. However it is instructive to determine the length of separator required to produce a relative deflection of 0.20 m.rad. between different pairs of particles. Table 4 gives some data on this point.

Table 4

Momentum in GeV/c	Length for "just separation" in metres		
	π - p	K - p	π - K
3	2.57	3.53	9.62
4	5.93	8.04	22.8
5	11.6	15.7	44.6
6	20.0	27.2	77.0
7	31.8	43.2	122
8	47.4	64.2	182
9	67.6	91.6	260
10	92.7	126	356

The size of the momentum bite we can permit depends to a large extent on how much chromatic aberration can be tolerated in the final image. A very rough guide to the amount of chromatic aberration in an image at a distance L from the target is given by

$$c = 2 \cdot \frac{\delta P}{p} \cdot \theta \cdot L$$

where c is the aberration in mm., L is in metres, $\frac{\delta P}{p}$ is the momentum bite and θ is the angular spread at the target.

Careful design can reduce the relative importance of chromatic aberration. We shall defer further discussion of the above points until section 4 where we examine the characteristics of the proposed beam.

To give some idea of what the beam should do let us examine the fluxes of the various particles arriving at the bubble chamber assuming a solid angle acceptance of 2 x 10^{-4} steradians and a total momentum bite of 1 o/o. These are given in Table 5.

Table 5

Momentum in GeV/c	Particle Fluxes					
	$\pi^{\pm}$	p^{+}	p^{-}	K^{+}	K^{-}	$\mu^{\pm}$
3	4.4×10^{4}	7.4×10^{4}	1800	5	3	990
4	4.2×10^{4}	6.8×10^{4}	1300	34	16	630
5	2.7×10^{4}	4.2×10^{4}	730	82	29	300
6	1.6×10^{4}	2.8×10^{4}	390	140	34	130
7	7.9×10^{3}	1.5×10^{4}	170	110	28	55
8	3.6×10^{3}	9.4×10^{3}	77	72	19	21
9	1.6×10^{3}	5.5×10^{3}	33	40	10	8
10	6.6×10^{2}	2.6×10^{3}	13	23	5	3

The final column gives the numbers of muons within the 1 o/o momentum bite produced by pions within the momentum bite and gives some idea of the contamination that might occur.

3. Layout of the Proposed Beam

Although the exact positions of the various beam transport components have not been finalised the approximate layout of the proposed beam is indicated in Fig. 2. Various features of the beam and some of the reasons for choosing this particular layout are discussed in detail below.

Particles produced at an angle of 9^{o} to the circulating proton beam in a "point source" target in the PS straight section 61 are accepted by the system. The particles are brought to a double focus in the lens Q4 by the lens triplet Q1, Q2, Q3. Dispersion is produced by the bending magnets M1 and M2 and momentum analysis is carried out at Q4. Using Q4 the beam becomes essentially dispersion free after passing through the bending magnets M3 and M4. The lenses Q5 and Q6 bring the beam out parallel in the vertical plane, just filling the aperture of the electrostatic separator. The lenses Q7 and Q8 bring the beam back to a double focus for mass analysis. The behaviour of the beam in the horizontal plane within the separator is variable and can be adjusted to give a suitable horizontal image at the mass slit. The lenses and bending magnets beyond the mass slit are used for cleaning up the beam and to produce a suitable image in the bubble chamber. We now discuss some of these points in more detail under various headings.

a) Production Angle

The suggested production angle for the beam is 9°. This is based on considerations of the effect of the fringing magnetic field of the PS on particle trajectories. Below 9° the effects on particles emitted in different parts of the solid angle acceptance is such as to cause an appreciable enlarging of images in the beam transport system, a situation which in general cannot be tolerated in separated particle beams. Some idea of fringing field effects on particles of different momenta can be obtained by referring to curves given in the CERN Report PS/Int. EA 60-10 [7)] (also reproduced in the PS Users Handbook).

Also it is found at small angles when fringing field effects are important that a beam transport system which is correctly aligned for particles of a particular sign and momentum at a particular circulating beam energy, will not be correctly aligned for other particles at different machine energies.

b) Solid Angle Acceptance

If the beam is confined to within 7 cm of the optic axis then the maximum solid angle acceptance, defined essentially by the first two quadrupoles, is for a production angle of 9°, about 2.0×10^{-4} steradians. It is proposed that the first quadrupole shall be horizontally focussing so that the angular acceptances will be $\pm$ 10 milliradians horizontally and $\pm$ 5 milliradians in the vertical plane. A collimator placed near the target will confine the beam to these angles.

The beam transport system is designed to cope with solid angles up to 2×10^{-4} steradians. However the separator will sometimes provide a further limitation to the angular acceptance in the vertical plane. The currents in the quadrupoles of the first triplet Q1, Q2, Q3 can be varied to give different angular magnifications at the first double focus in Q4 and thus various angular spreads can be made to just fill the separator aperture. It should be possible to vary the vertical angular acceptance of the separator, simply by adjusting the triplet, between about 4 and 10 milliradians. A collimator with the same aperture as the separator will be placed before the latter.

c) Dispersion and Momentum Analysis

The dispersion introduced by the bending magnets M1 and M2 enables a momentum analysis to be performed at the first double focus. The bending angle produced by M1 and M2 which are 2 metre bending magnets is 8°. By using two magnets it is possible to go to 10 GeV/c without aberrations being introduced. Adjustable collimators will be placed before and after Q4 to give a variable momentum bite.

The bending magnets M3 and M4 also produce a total bend of 8°, and thus it should be possible to run the four bending magnets off a single generator making for great stability of the horizontal image at the mass slit. Using Q4 it is possible to arrange that the beam is dispersion free after M4 thus reducing the total spread in the horizontal plane and hence aberrations. By having a dispersion free image at the mass analysis slit we can make the slit small in cross section, thus reducing μ-meson contamination in the beam.

Further dispersion and momentum analysis is introduced after the mass slit chiefly for the purpose of cleaning up the beam.

d) Separation

Separation of secondary particles of different mass is carried out using the available separator tanks in a single stage. Using the quadrupole lenses Q5 and Q6, the beam is made to pass through the separator in the "parallel" condition, and just fills the vertical aperture of the separator. The lenses Q7 and Q8 bring the beam to a double focus in the horizontal plane at the mass slit.

The "parallel" mode of operation has beam chosen rather than the "focussed" mode, as used in the Van der Meer fast antiproton beam [6)], for two reasons. First the phase space acceptance is greater in the "parallel" than in the "focussed" mode by a factor $(1+\ell/L)$ where ℓ is half the length of the separator and L is the distance from the centre of the separator to the mass slit. Second in certain cases a greater physical separation of images at the mass slit is obtained. This is done by choosing the positions and field strengths of the lenses Q7 and Q8 in such a way that the image principal plane is located before the centre of the separator. The maximum ratio of separations in the "parallel" and "focussed" cases is given by the formula $R = 2(L-\ell)/L$ where L, ℓ have the same meaning as before.

In the proposed beam a single stage of separation is used but it is worthwhile considering the possibility of using two stages. In such a system for example the first stage could be used to separate K mesons from pions and protons, the second stage being used to eliminate the decay muons which passed through the first mass slit.

If the values of solid angle acceptance chosen are those which enable us to just completely separate strongly interacting particles at the mass slit in a single stage system, then clearly if these same values are used in a multistage system only partial separation will occur at intermediate mass slits. Further the pions that manage to pass through the intermediate slits are just those pions that have the greatest probability of producing contaminating muons in a single stage system.

In addition, to maintain the phase space acceptance of the separators, it would be necessary to have "parallel" operation in both stages, involving the use of additional quadrupole lenses. It was decided that the possible reduction in muon contamination (probably less than a factor 2) did not warrant the use of the additional quadrupole lenses that a two stage system would imply. It might also be mentioned that additional vertical bending magnets would be required if "Ramm" separator tanks were used.

4. Characteristics and Properties of the Beam

In this section we shall give an estimate of the fluxes in and purity of various particle beams, that might be obtained using the layout described in the previous section. Some of the beam characteristics not discussed in the previous section will also be dealt with here.

a) Particle Fluxes

Much of the information needed for the calculation of particle fluxes has already been given in section 2 of this report. In particular Table 5 gives an estimate of fluxes based on a solid angle acceptance of 2×10^{-4} steradians and a momentum bite of $\pm$ 1/2 o/o. From this table one can obtain some idea of the constitution of unseparated beams.

The above solid angle and momentum bite may not be acceptable in a separated beam. To calculate reasonable values for these quantities it is necessary to take into account the effect on the final image of a) linear magnification of target, b) chromatic aberration, c) non-linear aberration, d) stability of separator field, e) coulomb scattering in residual air and mylar windows.

Providing the aperture of the separator is filled in parallel beam operation then the separation to magnification ratio is determined and cannot be altered by any arrangement of quadrupole lenses after the separator. The actual separation of particles by the mass slit is most easily performed when the physical separation of images is large.

With the arrangement described it is envisaged that the physical separation of images will be 100 times the relative angular deflection produced by the separator. In Table 6 the expected separations for various types of particle are given, based on a separator length of 30 metres.

Table 6

Momentum in GeV/c	Separation in mm	
	π - K	π - P
3	62	233
4	26	101
5	13	52
6	8	30
7	5	19
8	3	13
9	2	9
10	1	6

The linear magnification of the system is variable and is in our particular case equal numerically to the vertical angular acceptance in milliradians.

The chromatic aberration depends on the magnification of the different stages, on the type of stage and on the solid angle and momentum bite. In Table 7 we give the chromatic aberration at the mass slit in millimetres as a function of the vertical angular acceptance and the momentum bite. This should be added linearly to the image size to obtain the total spread due to magnification and chromatic aberration.

Table 7

Vertical angular acceptance in m.rad.	Chromatic aberration in mm. for the momentum bites		
	± 1/4 o/o	± 1/2 o/o	± 1 o/o
4	5.2	10.5	21.0
5	5.3	10.6	21.2
6	5.9	11.9	23.8
7	7.1	14.2	28.4
8	8.4	16.8	33.6
9	9.7	19.4	38.8
10	10.9	21.8	43.6

The non-linear aberrations are difficult to evaluate but it is hoped that by restricting the beam to the linear region of magnetic fields of the beam transport elements they may be reduced to negligible proportions.

The stability of the separator field is of importance when voltage fluctuations are of the same order as the difference in velocity of the particles to be separated (velocity of light units). It is hoped that the separator voltage will be held steady to less than one part in a thousand which means that the effect only becomes really serious above 6 GeV/c for π-K separation and above 8 GeV/c for π-$\bar{P}$ separation.

By having the beam in vacuum up to the mass slit and having mylar windows only at foci it is hoped that the enlarging of the image from this source will be negligible.

Taking into account the various effects outlined above we arrive at the solid angle and momentum bite estimates given in Table 8, for complete separation of particles at the mass slit.

Table 8

Momentum in GeV/c	π-K separation		π-P separation	
	Ω in sterad.	δP/P o/o	Ω in sterad.	δP/P o/o
3	2.0×10^{-4}	± 0.85	2.0×10^{-4}	± 4.8
4	1.1×10^{-4}	± 0.50	2.0×10^{-4}	± 1.8
5	8.0×10^{-5}	± 0.10	2.0×10^{-4}	± 0.66
6	.	.	1.4×10^{-4}	± 0.50
7	.	.	8.0×10^{-5}	± 0.43
8	.	.	8.0×10^{-5}	± 0.14

Using these values of solid angle and momentum bite then the fluxes of Table 5 are modified to give us the flux estimates of K^+, K^-, P^- contained in Table 9.

Table 9

Momentum in GeV/c	Estimated Fluxes at NBC		
	K^+	K^-	P^-
3	9	5	17000
4	19	9	4700
5	7	3	960
6	.	.	270
7	.	.	58
8	.	.	17

It is perhaps worthwhile estimating the fluxes of antiprotons which could be obtained using a shorter length of separator. Table 10 gives the estimated antiproton fluxes when 10 and 20 metres of electrostatic separator of aperture 100 mm and electric field strength 50 kV/cm are used.

Table 10

Momentum in GeV/c	Flux of Antiprotons	
	= 10 metres	= 20 metres
3	4700	11000
4	1000	2600
5	220	580
6	.	39
7	.	.
8	.	.

b) Purity of the Beam

The solid angles and momentum bites used in the calculation of fluxes given in Tables 9 and 10 were chosen so that only one sort of strongly interacting particle should be present after the mass slit. However in order to decide on the feasibility of a given beam account must be taken of the μ-meson contamination.

With a suitable disposition of collimators and bending magnets between the mass slit and bubble chamber the contaminating μ-mesons can be restricted to those occupying the same phase space and momentum bite as the wanted particles.

Using the solid angles and momentum bites of Table 8 we have calculated the number of contaminating μ-mesons to be compared with the fluxes of K^+, K^-, P^- of Table 9. The method of calculation is discussed in Appendix 1, the results of the calculation being given in Table 11. Because of the simplified method of calculation used the figures given are not exact but it is unlikely that they are more than a factor 2 in error.

The purity of the antiproton beams is reasonably good but the impurity of the kaon beams may not be tolerable.

Table 11

Momentum in GeV/c	Muon Contamination	
	K-Beams	P^--Beam
3	27	450
4	6.2	88
5	0.24	11
6	.	2.8
7	.	0.65
8	.	0.055

Ways of improving both the fluxes and purity of the K-meson beams are discussed in the next section.

5. Limitations of Beam and Possible Improvements

Designing a general purpose beam necessarily involves compromise and it follows therefore that the proposed beam layout will not be the ideal one for all particles at all momenta. In particular one could argue that the K-meson beams have neither sufficient intensity nor purity for use with the NBC. Modifications to the layout of Figure 2 might enable marginal improvements in beam intensity and purity to be made.

It is clear from Figure 1 that if a smaller production angle than 9^o were used then a useful increase in intensity could be obtained. Now G. Petrucci [8)] at CERN has designed a special magnet which accepts secondary particles of momentum 3 GeV/c at an angle of 5^o. It is essentially a C-shaped magnet with hyperbolic pole-pieces and a neutral pole, the latter also serving to reduce the stray field in the PS Vacuum Chamber to negligible proportions. The effectively quadrupolar field bends and focusses the particles produced at the small angle in such a way that they miss the PS Fringing Field.

The magnet which has a solid angle acceptance of $4x10^{-4}$ steradians has been designed for use with the Lundby beam in the North Experimental Hall of the PS. The magnet should be ready by the end of February 1962. If the magnetic field measurements give an indication that any aberrations will be small then it may be worthwhile constructing a similar magnet for use in the East experimental area.

At momenta greater than 3 GeV/c the magnet accepts particles at slightly larger production angles. It may also be necessary to replace some of the pole pieces but this is arranged to be a simple operation.

From Figure 1 it may be estimated that the special magnet will yield an increase in intensity of the order of a factor 3 over the momentum range for which it is used.

The beam emerges parallel in both planes from the magnet, which could be followed by a bending magnet and a lens triplet (or doublet), to bring the beam to a double focus in Q4, the rest of the beam layout being the same as already proposed.

However it is unlikely that really intense beams of K mesons will be available at the NBC until there is an ejected beam. This could be used with an external target. Even allowing for the loss of particles at ejection and the lower efficiency of an external compared with an internal target a considerable gain in K-meson intensity will arise from two sources. First it will be possible to use particles produced around 0^{o}, a resulting gain of a factor 10 or more being deduced from Figure 1. Second, the flight path from Target to bubble chamber can be made much smaller with a consequent smaller decay loss. If a flight path of 120 metres is taken as reasonable for a separated beam then at 3 GeV/c the gain from this source would be a further factor of 14.5.

It should perhaps be remarked that by using Radio Frequency (R.F.) Separators in conjunction with the ejected beam it should be possible to obtain separated secondary particle beams at much higher momenta than hitherto[9].

6. Conclusions

Using the proposed beam layout it seems certain that beams of antiprotons up to 8 GeV/c momentum, and of pions and protons up to around 10 GeV/c, of sufficient intensity and purity for use with the NBC could be readily obtained. The only changes necessary in going from type of particle to another would be changes in magnet currents and in the openings of adjustable collimators. It should be possible to calibrate the beam for the whole range of particles at the beginning and have magnet currents and collimator openings tabulated.

The situation with regard to $K^{\pm}$ - mesons is less certain. The intensity and purity of these beams with the proposed layout may not be adequate. However by using a special magnet near the target and by modifying the early stages of the beam useable K-meson beams could be obtained.

It may however be best to perform pion, proton and antiproton experiments first with the NBC, and wait until the ejected beam is available before embarking on K-meson experiments.

7. Acknowledgments

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The computations on the beam were done on the CERN Mercury Computer using the excellent beam optics programme "TRAMP" [10] of Messrs. J.D. Gardner and D. Whiteside of NIRNS, England.

Appendix 1

A First Order Estimate of μ-Meson Contamination

We indicate here how an approximate estimate of the number of contaminating μ-mesons in the beams arriving at the bubble chamber can be made. We consider first unseparated beams and then consider the effects of separation on contamination.

Let us consider a paraxial pion at the nominal beam momentum. The probability that the decay muon will fall within the momentum bite $\pm \delta P/P$ is given by

$$F = 2.34 \quad \delta P/P \tag{1}$$

These muons are essentially uniformly distributed over a cone with solid angle

$$\Omega_o = FC \tag{2}$$

where 1/C is the probability per unit solid angle at small angles.

Let us suppose we have a mass slit of area A. The solid angle subtended at a distance ℓ along the axis is

$$\Omega = A/\ell^2 \tag{3}$$

Now we will have $\Omega = \Omega_o$ when $\ell = \ell_o$ (say) ie. the cone of particles within the momentum bite just fill the mass slit when

$$\ell_o = \sqrt{\frac{A}{FC}} \tag{4}$$

For $\ell \leq \ell_o$ all the particles in the cone will pass through the mass slit whereas for $\ell > \ell_o$ only a fraction ℓ_o^2/ℓ^2 get through.

Let λ be the decay length for pions. Then if $\lambda \gg \ell_o$ it is easy to show that for a pion in the region of the mass slit the probability that it will decay and that the muon is in the momentum bite and will pass through the mass slit is

$$p \approx 2 F \ell_o/\lambda \tag{5}$$

If N is the total number of pions still surviving at a distance ℓ_o from the mass slit then the number of contaminating muons will be

$$N_\mu = Np \tag{6}$$

This is our estimate of the muon contamination for unseparated beams.

These ideas are simply extended to separated beams as follows. Let S be the separation at the mass slit. Then we introduce a low value cut off to ℓ at ℓ_o' such that the radius of the cone of particles within the momentum bite is equal to the separation, ie.

$$\ell_o' = \sqrt{\frac{\pi}{FC}} \cdot S \qquad (7)$$

It is easy to show that the number of contaminating muons $N\mu'$ in this case is given by

$$N\mu' = \frac{\ell_o}{2\ell_o'} \cdot N\mu \qquad (8)$$

It is the values of $N\mu'$ calculated in this way that are given in Table 11.

However for reference the values alloted to the various parameters are given in Table 12 for the K beams and Table 13 for the antiproton beams.

It must be emphasised that thus is only meant to be a first order calculation. However it seems unlikely that the estimates of contamination should be more than a factor 2 in error.

Table 12

Momentum in GeV/c	F	C Sterad	A_2 m^2	ℓ_o metres	λ metres	N	$N\mu$	S metres	ℓ_o' metres	$N\mu'$
3	1.99×10^{-2}	1.23×10^{-3}	1.24×10^{-3}	7.12	165	1.0×10^{5}	170	6.2×10^{-2}	22.2	27
4	1.17×10^{-2}	6.96×10^{-4}	5.2×10^{-4}	8.00	220	2.9×10^{4}	25	2.6×10^{-2}	16.1	6.2
5	2.34×10^{-3}	4.46×10^{-4}	2.6×10^{-4}	15.79	275	2.6×10^{3}	0.70	1.3×10^{-2}	22.6	0.24

Table 13

Momentum in GeV/c	F	C sterad	A $metres^2$	ℓ_o metres	λ metres	N	$N\mu$	S metres	ℓ_o' metres	$N\mu'$
3	$1.12x10^{-1}$	$1.23x10^{-3}$	$4.66x10^{-3}$	5.80	165	$6.9x10^5$	5500	$2.33x10^{-1}$	35.2	450
4	$4.22x10^{-2}$	$6.96x10^{-4}$	$2.02x10^{-3}$	8.29	220	$2.2x10^5$	700	$1.01x10^{-1}$	33.0	88
5	$1.55x10^{-2}$	$4.46x10^{-4}$	$1.04x10^{-3}$	12.25	275	$4.8x10^4$	66	$5.2x10^{-2}$	35.2	11
6	$1.17x10^{-2}$	$3.10x10^{-4}$	$6.0x10^{-4}$	12.85	330	$1.4x10^4$	12	$3.0x10^{-2}$	28.0	2.8
7	$1.00x10^{-2}$	$2.26x10^{-4}$	$3.8x10^{-4}$	12.96	385	$3.3x10^3$	2.3	$1.9x10^{-2}$	22.3	0.65
8	$3.3x10^{-3}$	$1.74x10^{-4}$	$2.6x10^{-4}$	21.28	440	$4.9x10^2$	0.16	$1.3x10^{-2}$	30.2	0.055

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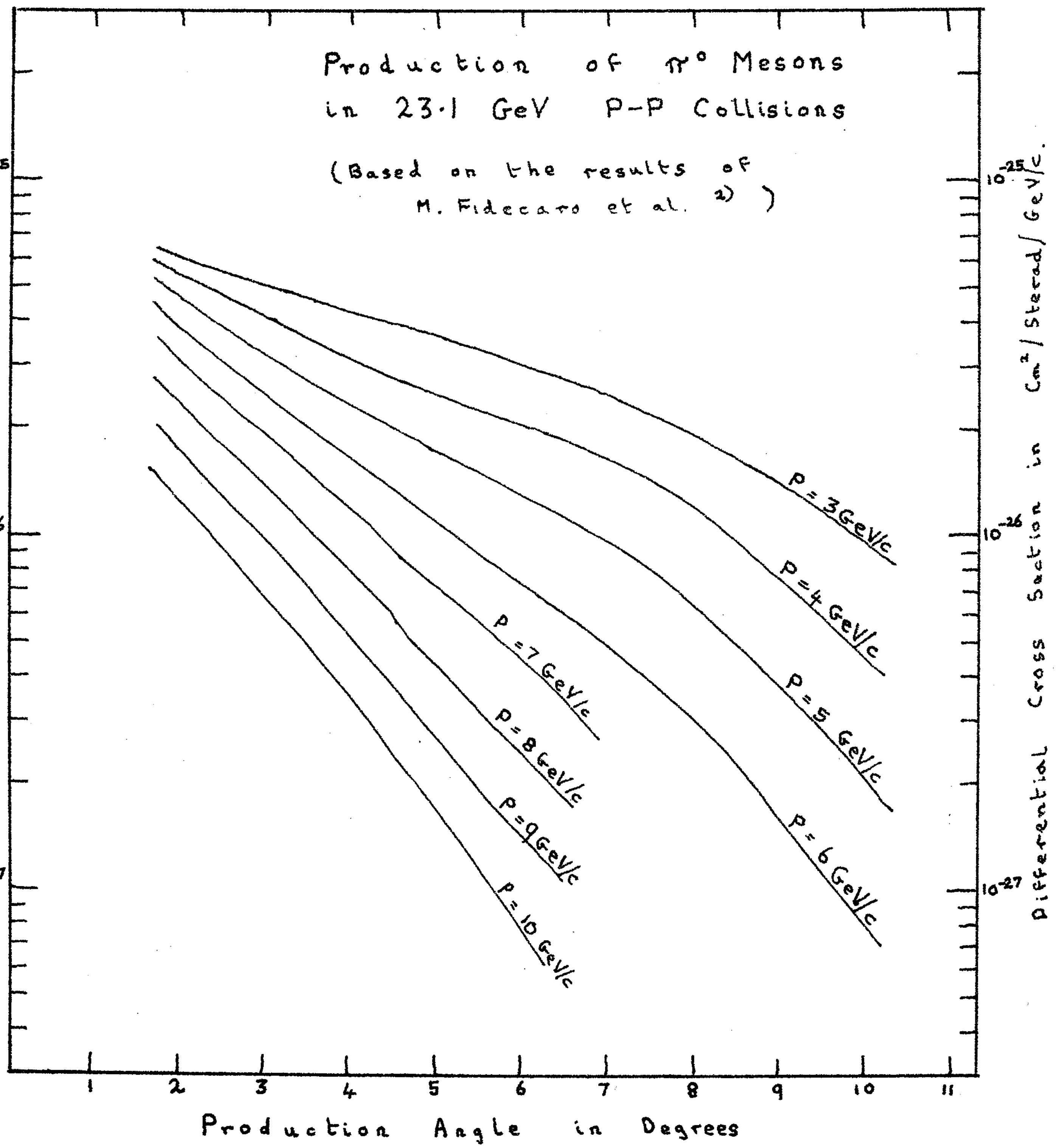
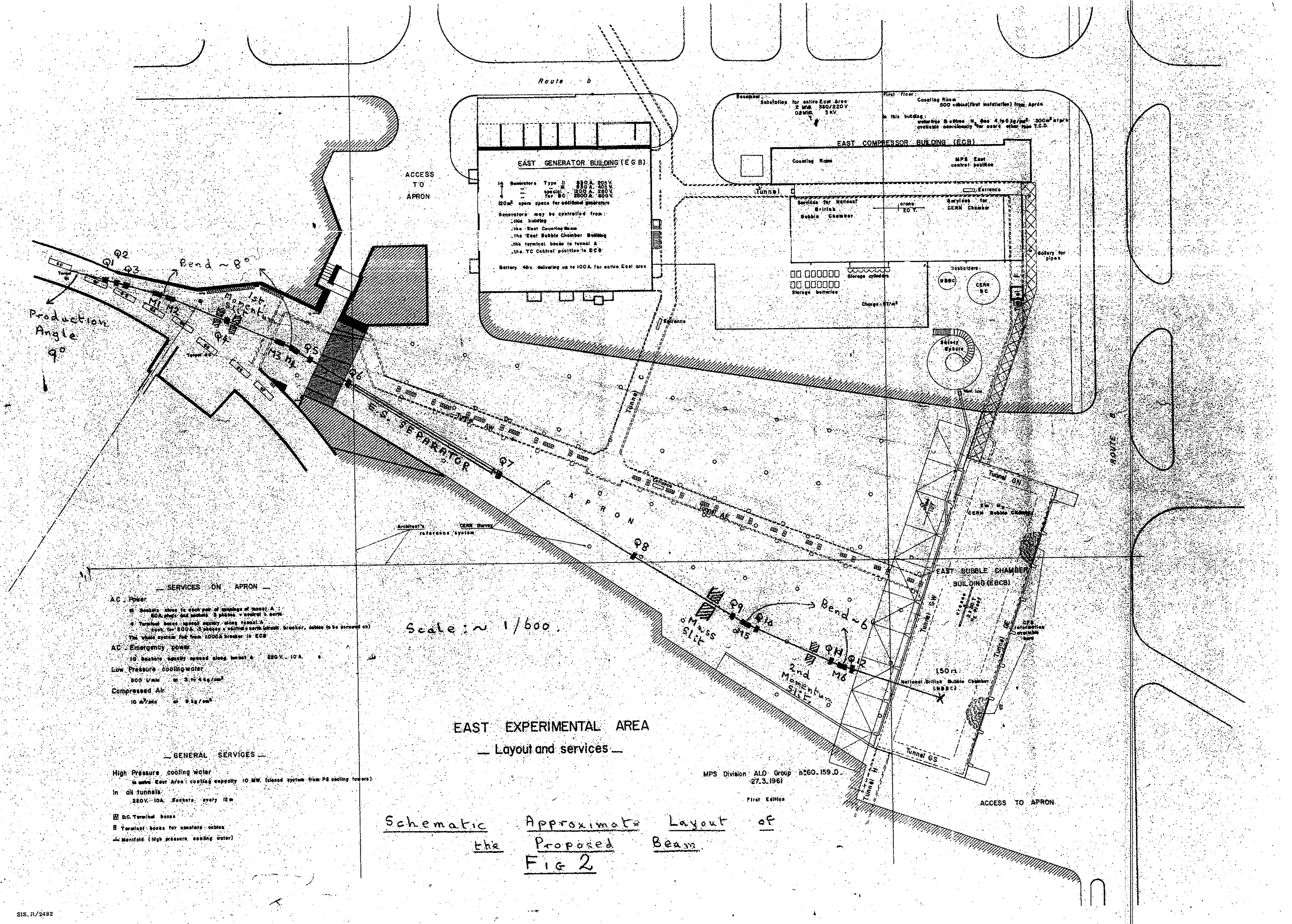

Production of π° Mesons
in 23·1 GeV P-P Collisions
(Based on the results of
M. Fidecaro et al. 2))
p = 3 GeV/c
p = 4 GeV/c
p = 5 GeV/c
p = 6 GeV/c
p = 7 GeV/c
p = 8 GeV/c
p = 9 GeV/c
p = 10 GeV/c
10^-25
10^-26
10^-27
1
2
3
4
5
6
7
8
9
10
11
Production Angle in Degrees
Differential Cross Section in Cm²/Sterad/GeV/c

FIG. 1



Schematic Approximate Layout of the Proposed Beam

Fig 2