EXPERIMENTS: BEAM SURVEYS AND SEARCH FOR PARTICLES

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ABSTRACT

A beam survey that includes a search for quarks and measurement of charged hyperon yields is described.

Because the earliest experiments at every new accelerator include surveys of the yields of π's, K's, and $\bar{p}$'s at various angles, and since such survey apparatus has a reasonable probability of detecting new charged particles (if they are relatively stable), a search for new particles has been combined here with beam surveys. This report was planned to include:

1. A new look at beam surveys,
2. A specific plan for a quark search based on fractional charges, and
3. Special consideration of beam surveys of short-lived particles (such as hyperons).

In the short time available, it was not found possible to improve in any major way the report of E. J. N. Wilson of the CERN ECFA Group (CERN/ECFA 67, Vol. I, pp. 201-211). In this informal note, we have included for the reader's convenience a copy of their report as Appendix I. It is clear that maximum possible use of such apparatus should be made in looking for new particles. However, it is our opinion that if the search for fractionally charged quarks fails, it is likely that a specific design of greater sensitivity than beam survey equipment will be needed to detect integrally charged quarks. Such a design has not been completed at this time.

This report consists, therefore, only of the aforementioned Appendix and two original accounts:

1. A design for a quark search, assuming fractional charges, by L. Leipuner (for which see SS-19, Vol. IV).

2. A design for a hyperon beam survey and search for short-lived particles by Gordon Bingham, which follows.

HYPERON BEAM SURVEY AND PARTICLE SEARCH

Figure 1 shows an ideal hyperon beam setup. It requires a special short "hot box" equipped with a magnetic field. Some rates are shown in Table I and were obtained using the Hagedorn-Ranft curves in the 1968 Summer Study. The beam requires a strong magnetic field in the hot box; it requires working in a possibly high muon background, and it excludes most other beams unless we are prepared to set up two beam lines, one line as shown in Fig. 1 for hyperons and another line on the opposite side of the proton beam for long-lived particles.

The above questions bring up the larger one--what are the boundary conditions likely to be imposed on the proposed experiment? I assume we should plan it for Station 1, as this is where the first beam is likely to arrive. If NAL insists on using a Maschke box, with maybe only one magnet in the front end (as is the case for Station 2) then Fig. 1 is not possible. I would assume we should attempt the experiment whenever "usable beam" becomes available so that actual rates could be 1-2 orders of magnitude below those calculated on the basis of 10^{13} interacting protons.

In the face of these uncertainties I looked at what would happen if we tried to use just one beam line behind a Maschke box to do everything. The setup is shown in Fig. 2. It is supposed to use standard bending magnets. The quadrupoles should be capable of gradients of the order of 600 kG/m in order to search for quarks of apparent momentum about 450 BeV/c. For a 5 cm bore, 15 kG would be required at the pole tip. The bending magnets are capable of deflecting 150 BeV/c through 12 mrad, but I have used only 4 mrad so that it is possible to look for quarks in the same beam. I assumed a momentum bite of about 4% was satisfactory. It is necessary to put a collimator in M3 and M4. QF and QD render the beam parallel (within ±0.1 mrad) before it passes through two DISC counters with $\delta\beta/\beta = 5\times10^{-6}$. This resolution should separate Ξ^- from Σ^-. (See p. 392, CERN/ECFA 67/16, Vol. I.) Two DISCS are necessary because the ratio of unwanted to wanted particles is 10^8 to 10^{10}. The beam is brought to a final dispersed image at a distance of 84 meters from EPB target. An analyzer magnet to deflect the low momentum hyperon decay products has also been shown. It would be used to get improved rejection if that were necessary.

The rates are shown in Table II. The Σ^- rate may be satisfactory. The Ξ^- is probably too low. The Ω^- are too low. These comments are especially true if we surmise that the initial beam could be down by 1-2 orders of magnitude. If one wishes to keep to the single beam setup because of its simplicity and low cost and small interference with other likely experiments, then one must somehow "telescope" the Maschke box and the four bending magnets and quadrupole doublet. The reduction of 18 meters in the flight path and the improved solid angle could result in an Ω^- flux increase by a factor 10^3 or more. This would be almost enough Σ^+ and Ω^- to do a rough measurement, which is possibly all we could hope for in this experiment. Such a measurement of these hyperon rates would be useful because present estimates are uncertain by orders of magnitude.

Notice that the neutral beam in Fig. 2 needs more thought since it interferes in M4, QF, and QD. I have not tried to see how the monopole experiment would fit in, but perhaps it would. I assume the quark search fits in if, in fact, the quadrupoles can focus the higher momenta to be explored. In this connection, solid-state detectors to study the dE/dx should be considered. They would fit in with our beam size (few cms at largest), have better resolution than scintillators, are thin and so have less chance of inducing reactions with neutrals, and can operate at 20 Mc/sec without too much damage to the sort of resolution we would want.

SUMMARY

We should try to get a better idea of the constraints likely to be imposed on our experimental setup. The fact that the accelerator will probably "start up" with reduced beam means that the large Maschke box shielding will probably be unnecessary during that period. Thus it might be possible to "telescope" the Maschke box and the front end of the Fig. 2 beam line. This would very possibly allow one beam line which could do everything. Otherwise it is necessary to use two charged lines (simultaneous or separate experiments) in order to measure the Ω^-, Σ^+, and possibly Ξ^- rates along with the long lived charged rates.

Table I. Hyperon Beam Properties. Assumed Production Angles (HR Curves): Negatives 0 mrad, Positives 2 mrad. Assumed Yields: $\Sigma^-/\Sigma^+ = 1/2$, $\Xi^-/\Sigma^- = 0.1$, $\Omega^-/\Xi^- = 0.1$ Secondary Beam 150 GeV/c.

Particle	Mean Decay Path (m)	No. Decay Paths to A	Decay Factor	$d^2N/dpd\Omega$ per sr	Yield at Target/10^{13} Interact. p	Yield at A
π^-	8470		1	3×10^{12}	5.4×10^7	
π^+	8470		1	5×10^{12}	9.0×10^7	
K^-	1125		1	2×10^{12}	3.6×10^5	
K^+	1125		1	7×10^{11}	1.3×10^7	
p	∞		1	3×10^{14}	5.4×10^9	
$\bar{p}$	∞		1	4×10^9	7.2×10^4	
Σ^-	6.2	2.26	0.104	2.5×10^{13}	4.5×10^8	4.7×10^7
Σ^+	3.1	4.52	0.011	1.5×10^{13}	2.5×10^8	2.7×10^6
Ξ^-	5.2	2.7	0.067	2.5×10^{12}	4.5×10^7	3.0×10^6
Ω^-	2.96 ± 1.5	4.75	0.0079	2.5×10^{11}	4.5×10^6	3.5×10^4

Table II. Yields in Combined Beam System. Assumed Production Angles (HR Curves): Negatives 0 mrad, Positives 2 mrad. Assumed Yields: $\Sigma^-/\Sigma^+ = 1/2$, $\Xi^-/\Sigma^- = 0.1$, $\Omega^-/\Xi^- = 0.1$. Secondary Beam 150 GeV/c.

Particle	Mean Decay Path (m)	No. Decay Paths to A	Decay Factor	$d^2N/dpd\Omega$ per sr	Yield at Target/10^{13} Interact. p	Yield at A
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π^+	8470		1	5×10^{12}	7.5×10^6	
K^-	1125		1	2×10^{10}	3.0×10^4	
K^+	1125		1	7.0×10^{11}	1.1×10^6	
p	∞		1	3.0×10^{14}	4.5×10^8	
$\bar{p}$	∞		1	4.0×10^4	6.0×10^3	
Σ^-	6.2	8.4	2.3×10^{-4}	2.5×10^{13}	3.7×10^7	8.0×10^3
Σ^+	3.1	16.8	5.2×10^{-8}	1.5×10^{13}	2.3×10^7	1.0
Ξ^-	5.2	10.0	4.5×10^{-5}	2.5×10^{12}	3.7×10^6	1.6×10^2
Ω^-	2.96 ± 1.5	17.3	3.0×10^{-8}	2.5×10^{11}	3.7×10^5	1.0×10^{-2}

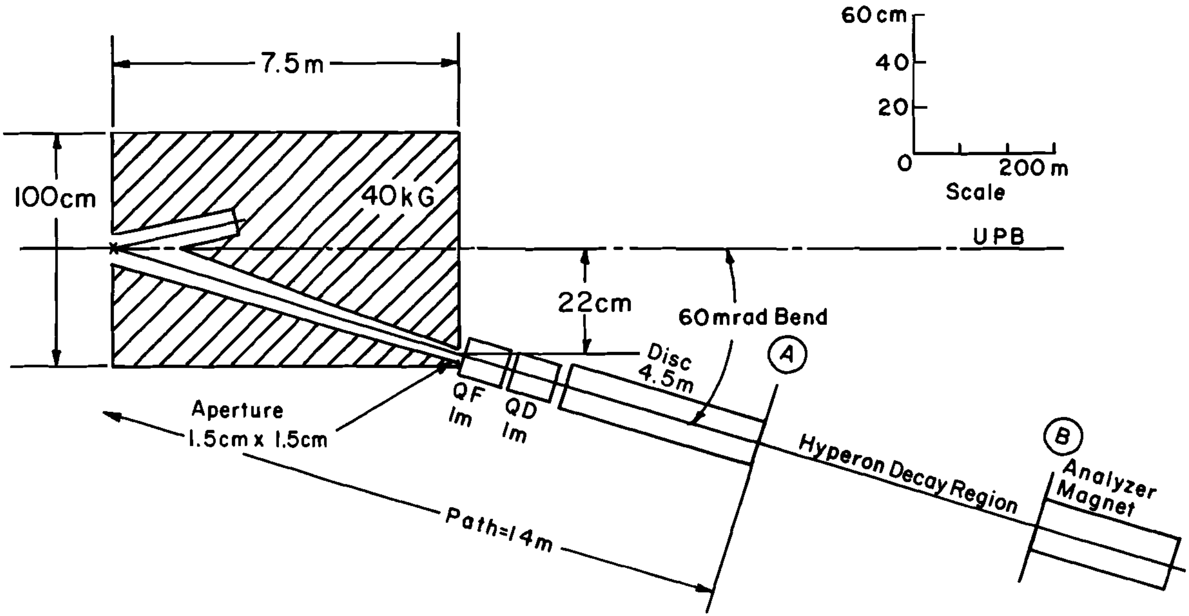

Fig. 1. Ideal 150 GeV/c hyperon beam. Solid angle 4 μsr, p/p = 3%.

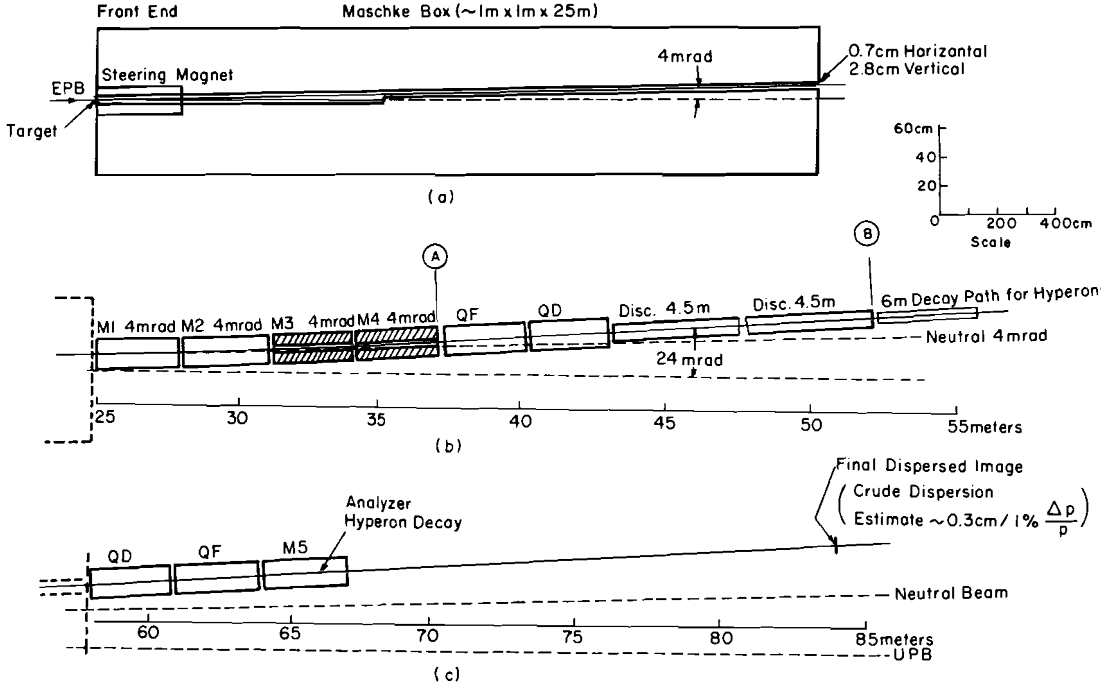

Fig. 2. Sketch for a combined beam system at 150 GeV/c. a) Target box, with magnet and narrow channel, b) Optics of hyperon beam, showing successively dipoles, quadrupole focusing pair, and two DISC counters, c) Analysis of hyperon decay products.

CERN/ECFA/66WG2/US/SG3/EJNW-2

EXPERIMENT TO MEASURE THE PRODUCTION OF STABLE PARTICLES
AT 300 GeV/c

by

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1. Introduction

This note describes in outline an experiment to measure the differential cross section for production of K,π and p of both charges from a target in the 300 GeV external proton beam (EPP). The spectrum of production angles and secondary momenta to be investigated (40 to 240 GeV and 0 to 1·25°) spans three orders of magnitude of production cross section. In addition to a broad survey of this spectrum, a more detailed investigation of the variation of production with target material and dimensions at a few representative angles and momenta is envisaged. This information is essential for the efficient planning of experiments, optimisation of beam design, and especially for the solution of the complex problems of beam sharing from target stations in the EPB.

In designing the experiment, care has been taken to minimize the complexity of the beam, notably by dispensing with quadrupole focussing. A solution has been found which enables almost the entire spectrum of angles and momenta to be explored from a target shared with a variable high momentum beam.

2. Beam Layout

The beam contains no quadrupoles since sufficient counting rate may be achieved without their aid and the calculation of solid angle is simplified by their absence. (Figure 1)

The beam emerges from the first magnet (M1) of an EPB target quartet of the kind described in Reference 1. The same target provides zero degree secondaries of variable high momentum to a second beam, B2, which has complete control over the first magnet. (Figure 2) B2 can be considered the main user of the target. The production experiment beam, B1, passes first through a magnet M5 which directs particles of the desired production angle, α, and momentum, p, to the centre of bend of M6, the first of the pair of magnets which provides the momentum analysis. A counter telescope, $S_1..S_n$, defines the solid angle and momentum acceptance. If the S counters are 1 cm square then, in the beam layout shown (Figure 1), they define an acceptance $\int \omega d(\Delta p/p)$, of 2% x $3{\cdot}3.10^{-9}$ sterad.

The beam passes through a hole in the EPB shielding between two 2 m magnets M6 and M7, each of which bends 5 milliradians. M7 must follow the hole in order to sweep away low momentum background passing through it. M6 is placed before the hole so that particles originating from the target, of momenta considerably different from p, are deflected away from the hole. These particles may be of a momentum at which production is considerably greater than at p and might, otherwise after scattering from the walls of the hole be directed into the telescope, adding significantly to the observed rate.

3. Spectrum of Angles and Momenta

The spectrum of angles and momenta to be studied has been chosen with the aid of predictions of π^+ production by Hagedorn and Ranft (Figure 14, Ref. 2). The maximum value of $d^2N/dp d\Omega$ predicted is $\sim 50\pi^+$/GeV/Steradian/ interacting proton. The boundary of the spectrum is the line which corresponds to $d^2N/dpd\Omega$ equal to 10^{-3} of this peak value, i.e. 0.5 π^+/GeV/steradian/interacting proton. This boundary is shown as a curve on a plot of production angle versus momentum in Figure 3.

In order to establish the functional dependence of $d^2\sigma/d\Omega dp$ on α and p it is suggested that production should be measured at fifteen momenta in the range 30 to 240 GeV/c and that between four and six angles should be studied at each momenta. A possible selection of angles and momenta is shown as an array of dots in Figure 3. (72 measurements in all).

Predictions of K^- and $\bar{p}$ production suggest that the spectrum of angles and momenta corresponding to three orders of magnitude in $d^2\alpha/d\Omega dp$ for these particles is more limited than for π^+. K^- and $\bar{p}$ production may not therefore be investigated at all the points shown in Figure 3.

It is suggested that in planning the experiment a more widely spaced mesh of points might first be established for several target materials and lengths, followed by a full survey of one or more of the more interesting targets.

4. Collection from the Target

The trajectory of particles from the target into the production experiment beam is shown in detail in Figure 2. The magnet M1 is controlled by the high momentum variable momentum beam B2 which shares the same target as the production experiment. M1 is set to bend particles which are produced at zero degrees and which are of the momentum p_o required by B2 through a fixed angle θ_o. As p_o is varied, M1 will sweep the EPB across the horizontal gap, 2h, of a sandwich magnet, M2. M2, the second magnet in the target station quartet (Ref. 1) is set to bring the EPB centre line parallel to its original trajectory. Two further magnets M3 and M4 (Figure 1) restore the EPB to its original direction.

The magnet M5 and the magnets in the quartet have a vertical aperture of less than 1 cm. Like the other sandwich magnet M2, M5 is energised by a single conductor whose width we shall ignore. In practice the conductors of M5 and M2 may be slightly inclined in plan view to subtend the minimum angle at the centre of M1. The return yokes of all the magnets may be positioned to avoid the beams and are not shown in Figure 2.

Secondaries of momentum p and production angle α, destined for the production experiment are bent by an angle $\theta_1 = p_o\theta_o/p$ into M5. This magnet bends them through an angle θ_2 to direct them to the centre of bend of M6 (Figure 1). Since M6 is a considerable distance away and subtends an angle $2\theta_o$ at the centre of M1, we can approximate this requirement by demanding that the trajectory on exit from M5 makes an angle $2\theta_o$ w.r.t. the EPB entrance direction.

Thus: $\alpha + \theta_1 + \theta_2 = 2\theta_o$ .... (1)

Also for the beam to lie within the aperture of M5 :

$3h > x = l\ (\alpha + \theta_1) > h$ .... (2)

The final restriction on the geometry is that the bend in M5 should be within the capacity of that magnet, i.e.

$\theta_2 < \theta_o p_{o(max)} / p$ .... (3)

These restrictions may be reduced to the following two expressions :-

$3 > \alpha/\theta_o + p_o/p > 1$ .... (4)

$\alpha/\theta_o > 2 - (p_o + p_{o(max)})/p$

The latter condition is most restrictive when $p_o = p_{o(max)}$ and it then becomes :

$\alpha/\theta_o > 2(1 - p_o/p)$ .... (5)

In the particular situation considered

$p_{o(max)}$ = 240 GeV/c

θ_o = 10 milliradians

l = 10.5 metres

h = $l\theta_o$ = 10.5 cm

The restrictions on α implied by Equations 4 and 5 have been calculated for a number of values of p/p_o using the above assumptions. Figure 4 shows the accessible region of the spectrum. It must be remembered that positive and negative values of α are indistinguishable from the production point of view and so the modulus of α is plotted in Figure 4. It can be seen that almost all the required angles and momenta (shown as dots) are accessible when B2 is tuned to maximum momentum. When the B2 momentum is lowered the highest useful and accessible point in the spectrum is also lowered but lower momentum points become accessible. This system therefore allows B1 to operate almost independently of B2.

B1 can only accept particles of opposite charge to B2 but this seems an unavoidable penalty that one must pay for sharing a target with another beam. Preferably B2 should be a beam demanding positive and negative particles for the same experiment or for consecutive experiments.

5. Counting Rates

In predicting counting rates it is assumed that the intensity of the EPB is 10^{13} p.p.p. and the maximum fraction of these protons interacting in the target is 30%. The assumed solid angle and momentum bite of the beam is 2% x 3·3 x 10^{-9} sterdian.

Table I gives estimates of accepted secondaries per pulse at the peak of the production curve (H) and at a point on the boundary of the spectrum (L). These estimates are based upon the predictions in Ref. 2.

It can be seen that, apart from the edges of the K^- and $\bar{p}$ spectrum, only a few bursts are necessary to reduce the statistical error to a few per cent and most of the time absorbed by the experiment will be spent in changing conditions. Data taking time can be reduced at the edges of the K^- and $\bar{p}$ spectrum or the spectrum extended by simply increasing the area of $S_1 \ldots S_n$.

6. Detection Equipment

Meunier et al. (Ref. 3) have shown that a gas DISC Cerenkov counter with Cerenkov angle, $\theta_c = 44$ milliradians and length 2 m is adequate for $(\pi\mu) - K - p$ resolution up to 200 GeV/c. Extrapolating these figures we would need a 3 m long counter working at $\theta_c = 35$ mr to reach 240 GeV/c. Two such counters C1 and C2 would be desirable for simultaneous identification of $\pi\mu$ and K in positive beams and of K and $\bar{p}$ in negative beams. Another advantage of using two counters is that they can be used to measure each others efficiency.

Meunier also quotes a 32 m long gas DISC capable of resolving π-μ up to 100 GeV/c. This, C3, would fill the remainder of the space in the telescope.

A few meters of steel after S_n could be used as a muon filter at momenta above 100 GeV/c. Its efficiency for muon transmission could be extrapolated from measurements below 100 GeV/c where comparison is possible with the DISC. A counter S_o following the filter would count the muons and veto them from the $(\pi\mu^o)$ channel. The fraction of strongly interacting particles penetrating the filter could if necessary be checked by measuring the ratio (Scp)/p.

7. Shielding

Figure 1 shows the arrangement of shielding suggested. The detection equipment is separated from EPB by a 10 m wall of steel pierced by a hole two or three cm in diameter through which the beam passes. The shielding transverse to the EPB has been calculated from Thomas' formula (Ref. 4) on the following assumptions.

EPB loss rate = 3% in 100 metres
EPB intensity = 10^{13} p.p.s.
EPB energy = 300 GeV/c

Radiation level outside shield = 1 millirem/hour

More reliable estimates of EPB loss rates and detailed design of shielding downstream of the target to mop up useless pions before they can decay into muons may considerably modify this scheme.

8. Conclusion

The particle production experiment described above would cover the production spectrum of immediate interest using a beam which could operate in a substantially parasitic manner from the same target as a 240 GeV/c zero degree beam of variable momentum.

Such surveys of particle production have proved invaluable during the first years of operation of existing accelerators (Ref. 5), and have given information which has led to savings in machine time out of all proportion to that which they absorb.

It is therefore suggested that this experiment should be amongst the first to be mounted on the accelerator.

The beam which is shown in Figure 1 could be subsequently modified by inserting two bending magnets after M5 to restore the beam to the line joining the centres of M1 and M6 at all momenta. A quadrupole doublet or triplet, placed prior to M6, would focus the beam. Thus the beam might be converted into a high flux variable momentum beam which would be useful for extending the measurements of the production spectrum of particles to momenta and angles where the counting rate would otherwise be too low. Alternatively the beam might be used for other experiments requiring a variable momentum.

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TABLE I

Expected Counting Rates
(Particles/burst)

p	L		H
		-	5×10^6
π^+	10^3	-	10^6
π^-	200	-	$2{\cdot}5 \times 10^5$
K^+	100	-	2×10^5
K^-	1	-	10^4
$\bar{p}$	1	-	10^3

The lower figure (L) is taken at the spectrum boundary (1·25° 80 GeV/c) and the higher figure (H) at the peak of the production curves. Decay of particles in flight is neglected in calculating the above estimates.

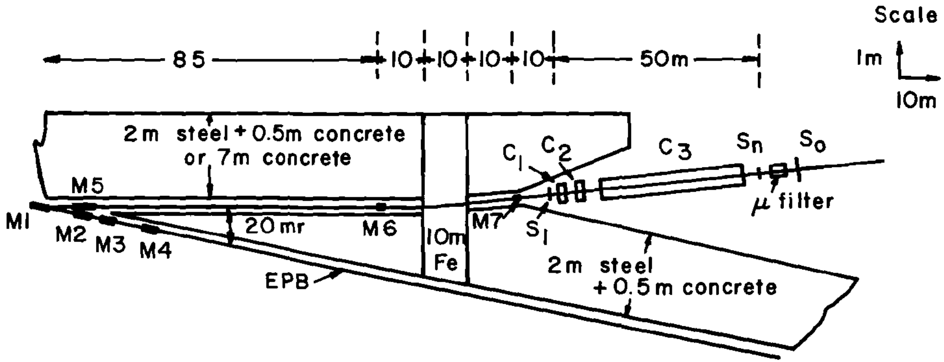

Fig. 1. Shielding proposed for beam layout.

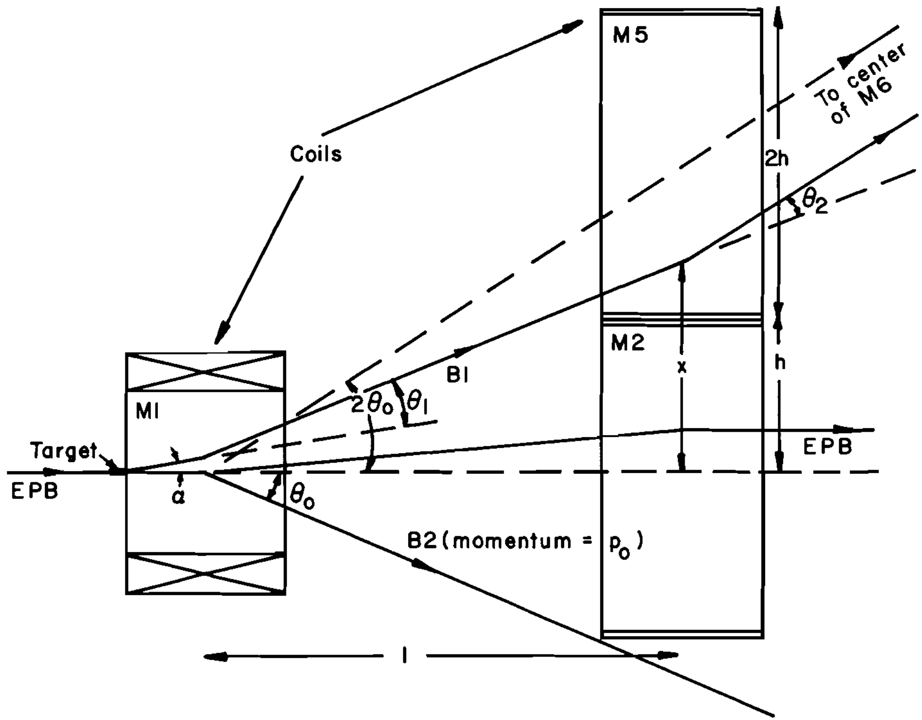

Fig. 2. By means of a dispersing magnet, a single target provides particles produced at 0° to two beams.

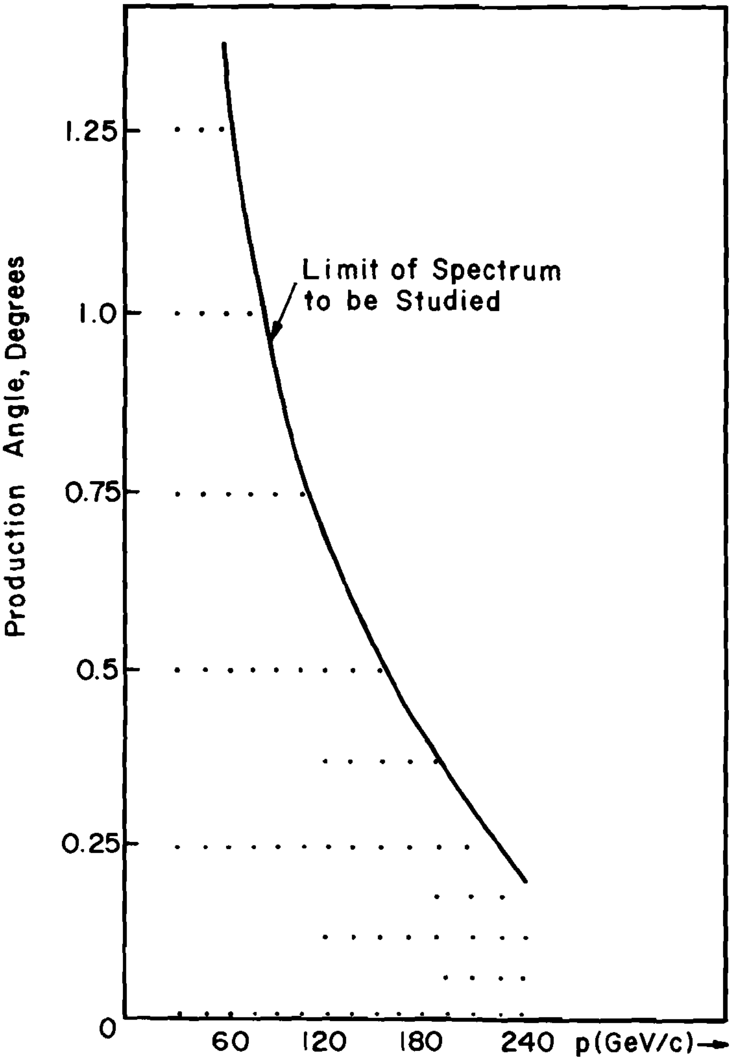

Fig. 3. A possible selection of production angles and momenta to be studied is indicated by dots.

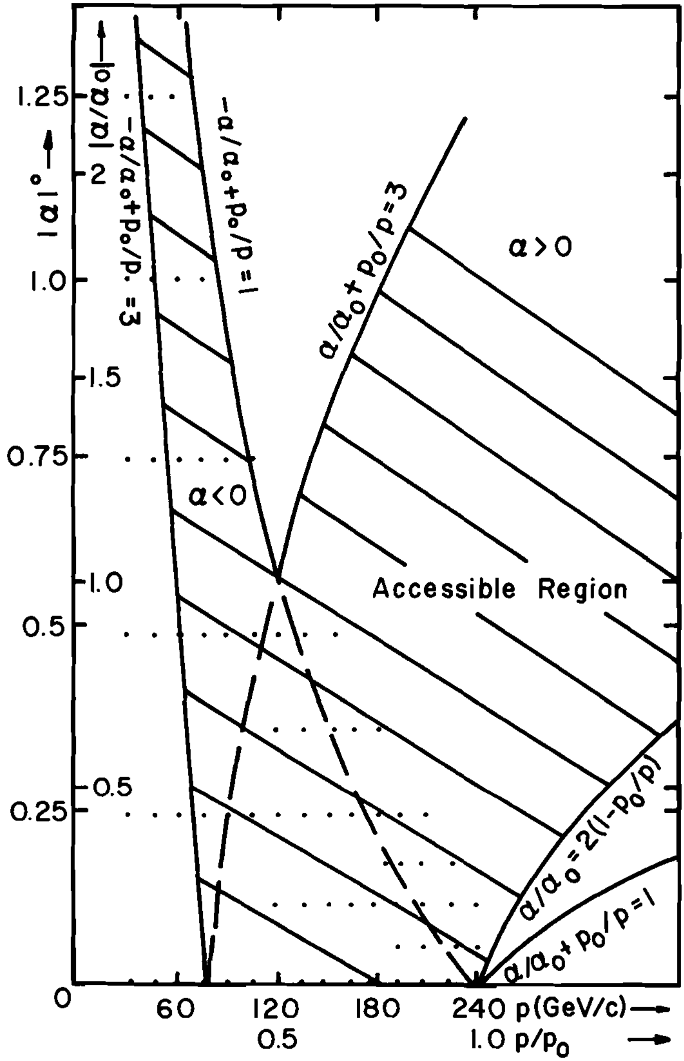

Fig. 4. Regions of α accessible to measurement.