NAL PROPOSAL No. 213

Scientific Spokesman:

J. G. Rushbrooke
Department of Physics
Cavendish Laboratory
Cambridge CB2 3RQ
England

PROPOSAL TO STUDY HIGH-ENERGY π^+ K^+ AND K^- INTERACTIONS IN THE NAL 15 FOOT HYDROGEN BUBBLE CHAMBER

R. E. Ansorge, J. R. Carter, W. W. Neale,
J. G. Rushbrooke and B. R. Webber

April 1973

PROPOSAL TO STUDY HIGH-ENERGY π^+ K^+ AND K^- INTERACTIONS IN THE NAL 15 FOOT HYDROGEN BUBBLE CHAMBER

April 1973

Cambridge University Bubble Chamber Group

R.E. Ansorge, J.R. Carter, W.W. Neale,
J.G. Rushbrooke and B.R. Webber.

ABSTRACT

By installing a certain number of high field dipole and quadrupole magnets in the enclosure situated about 200 metres from the 15 foot hydrogen bubble chamber at NAL it becomes possible to produce beams of kaons and positive pions of usable flux and purity in addition to the normal negative pion and proton beams.

It is proposed to carry out a survey of the interactions of π^+, K^+ and K^- mesons with protons using the 15 foot bubble chamber. A series of exposures of 50,000 pictures each, covering the energy range 50 - 200 GeV is suggested, making possible a study of inclusive processes, topological and multiplicity distributions, diffractive processes and elastic scattering.

1. Introduction

An important part of the current program of hadron-physics at NAL is the study of proton and π^- interactions at very high energies using hydrogen bubble chambers. Bubble chamber methods are particularly suitable for studies of inclusive processes for both single particles and produced resonances, and for topological, multiparticle and elastic cross-section measurements. Survey experiments in the 30" chamber are already yielding important results on pp interactions at 200 and 300 GeV [1],[2],[3], and on π^-p interactions at 200 GeV [4]. These studies are likely to be continued under the more favourable conditions offered by the NAL 15' chamber as soon as this becomes available.

Clearly it would be highly desirable to extend the 15 foot chamber program to include studies with high energy π^+, K^+ and K^- beams. It has been suggested that use could be made of tagged beams [5]. The DISC Cerenkov counter and wire chambers which are part of the instrumentation of the hadron beam line could be used for this purpose. Although at low momenta positive pions can form a substantial fraction of transmitted particles the kaon component never amounts to much more than one per cent. With, say, ten incident particles per picture this would seem to be an inefficient way to do kaon physics.

R.F. separated beams for BEBC at CERN are currently under discussion, but are not at present envisaged at NAL. In any case they would probably only yield K^+ up to 75 GeV/c and K^- up to 100 GeV/c.

Even with only 10^{11} protons incident on the hadron beam target the existing hadron beam line can deliver in excess of 10^5 negative pions per pulse over quite a wide range of momenta [5]. A significant increase in π^- flux could be achieved by placing additional quadrupoles near the target. It is proposed to modify the beam line in the vicinity of the "cleaning slits' about 200 metres from the bubble chamber. The negative pions would be focussed onto a target and energetic positive particles, chiefly π^+, selected. High field dipole and quadrupole magnets would be used to achieve the required momentum analysis and large solid angle acceptance. The $K^\pm$ beams would differ from the π^+ beams in that K^o, $\overline{K}^o$ beams would first be produced and these used to give K^+, K^- beams of the desired flux and purity. More details of these beams will be given in section 4 and flux estimates in section 5. However, a separate detailed report is in course of preparation [6]. It is hoped that with a circulating proton beam of 300 GeV, positive pions would be available in excess of 200 GeV and $K^\pm$ beams up to 100 GeV. With higher energy circulating protons these energies would be proportionately greater. It is proposed to use the DISC Cerenkov counter to positively identify and tag the wanted particles.

However, before discussing beam details the physics case will be discussed in section 2 and possible methods for analysing the events discussed in section 3.

The details of this proposal are contained in Table 1.

2. Physics Interest

(a) The proposal is to survey a new energy range in $K^\pm p$ and $\pi^+ p$ scattering, and so the general features of the interactions are of considerable interest. Topological cross-sections, multiplicity distributions and average multiplicity can readily be obtained from the scanning of the pictures, and used as a test of high energy models.

Particle Type	Beam Momentum (GeV/c)	No. of K Pictures	Particles/ Picture	Particles entering chamber	†Total Inter-Actions	†Elastic Scatters
π^+	200	50	10	500,000	65,000	9,800
K^+	50 and 100	50	8	400,000	45,000	7,000
K^-	50 and 100	50	8	400,000	49,000	7,000

TABLE 1 : DETAILS OF INITIAL PROPOSAL

based upon 300 GeV primary protons. A π^+ beam of 300 GeV and $K^\pm$ beams of 200 GeV can be obtained with 500 GeV primary protons.

† Numbers based on a fiducial length of 2m and the following cross-section estimates:

$\sigma_T(\pi^+p)$ = 23.3 mb, $\sigma_{el}(\pi^+p)$ = 3.5mb, $\sigma_T(K^+p)$ = 19mb,

$\sigma_{el}(K^+p)$ = 3mb, $\sigma_T(K^-p)$ = 21mb, $\sigma_{el}(K^-p)$ = 3mb.

(b) Inclusive Processes

For $K^+(K^-)p$, a $K^o(\overline{K}^o)$ is produced in some 30% of the interactions [7]. This has the advantage of identifying the leading particle, and ∿ 3,500 events at 50 GeV/c and ∿ 2,200 at 100 GeV/c are expected from the reactions

$$K^+p \rightarrow K^o_{seen}\ X$$

$$K^-p \rightarrow \overline{K}^o_{seen}\ X\ ,$$

in which the V^o decay is visible in the chamber.

In K^+p and π^+p scattering there is on average more than one negative track per event, and nearly all these are pions, so that good statistics can be obtained for

$$K^+p \rightarrow \pi^-X$$

$$\pi^+p \rightarrow \pi^-X$$

Examples of other processes in which the outgoing particle can be identified are:

$$\pi^+p \rightarrow (K^o/\overline{K}^o)X$$

$$\pi^+p \rightarrow \Lambda^oX$$

$$K^+p \rightarrow \Lambda^oX$$

$$K^-p \rightarrow \Lambda^oX$$

Results concerning proton fragmentation can further be compared with the high energy pp data now available [2].

Two particle correlations may be studied in reactions such as:

$$\pi^+p \rightarrow \pi^-\pi^-X$$

$$K^+p \rightarrow \pi^-\pi^-X$$

$$K^+p \rightarrow K^o\pi^-X$$

$$K^-p \rightarrow \overline{K}^o\pi^-X \qquad \text{etc.}$$

(c) Resonance Production

For events in which an outgoing K^o or $\overline{K^o}$ has been identified, a search can be made for $K\pi$ resonance formation. A K* of mass ∿ 1800 MeV and spin parity 3^- is expected to accompany the K*(890) and K*(1420), in analogy with the non-strange meson series ρ, f, g. Such a resonance and possibly higher mass resonances, might be found at the increased energy of this experiment.

Resonances produced by diffraction dissociation could be studied by the missing-mass technique, using an identifiable slow proton as analyser. For example, from the reactions

$$K^{\pm}p \rightarrow (K\pi\pi)^{\pm}p$$

it may be possible to gain new information on the nature of the Q and L enhancements, and to observe any higher mass resonances that may occur. Similarly, a study can be made of the three-pion states produced by diffraction dissociation in π^+p scattering.

Events with a slow proton allow an investigation of peripheral Δ^{++} production, and the Δ^{++} can itself be used as an analyser for missing-mass studies. The inclusive Δ^{++} spectra will be obtained and can be compared with the results from high energy proton-proton interactions [3].

More generally, in all events where particles can be identified, invariant mass distributions will yield information on resonance production.

(d) Elastic Scattering

The total elastic cross-sections can be obtained to a statistical accuracy of ∿ ± 1.5% (systematic errors will be dominant). The differential cross-section measurements will extend down to $|t| \sim 0.02$ GeV^2, and the slope in t can be determined to within ∿ ± 1.5%. The statistics do not allow a separate study of the slope for $|t| \sim 0.1$ GeV^2, to test for shrinkage, but this region is covered by another NAL proposal [8] to measure elastic scattering of the long-lived hadrons.

The π^+p and $K^\pm p$ total cross-sections will also be extracted in the course of the analysis, but probably with systematic errors of a few percent.

(e) A new range of beam energy opens up the possibility of observing new or still rare processes. The large bubble chamber is especially suited for such an investigation.

3. Analysis of the Events

We have considered the problem of analysing events at high energy in a separate proposal to study Σ^-p interactions [9]. We conclude that the elastic channel may be fitted with negligible contamination, and this is supported by the fact that elastic scattering has been successfully studied in 200 GeV π^-p interactions in the 30" chamber [4].

With the kaon beams, a $K^\pm/\pi^\pm$ ambiguity of $\sim$ 50% is to be expected in 4C fits to the reaction $K^\pm p \rightarrow (K\pi\pi)^\pm p$ [10], in addition to the 4C-1C ambiguity, and so it is unlikely that useful fits to 4C inelastic channels can be obtained. For the π^+ beam, the track inversion ambiguity is much less, and some inelastic 4C fitting may be possible. We do not, however, rely on this, and the physics case outlined in Section 2 applied to unfitted events in all but the elastic channel.

4. Beam Details

Lach and Pruss [5] have described in detail the beam line at NAL which provides the 15 foot bubble chamber with hadrons. It is about 1000 metres long, can transport particles with momenta up to 500 GeV/c, has a solid angle acceptance of 0.25 microsteradians, and a momentum resolution of better than 0.1% though it can transmit up to 1%. It is proposed to modify the beam line near the target and in the enclosure about 200 metres from the chamber.

By placing additional quadrupole magnets close to the target it becomes possible to match a much larger solid angle acceptance into the system although this is at the expense of momentum resolution. It is intended in this way to boost the transmitted π^- flux by up to a factor 50 enabling the range of possible π^+, K^+ and K^- momenta to be extended.

Two intermediate dispersed images of the target are produced before the π^- beam is brought to an undispersed focus in both planes in the enclosure about 200 metres from the chamber. At present the enclosure contains two collimators which act as "cleaning slits".

It is proposed that these collimators be replaced by the equipment described below. The π^- are brought to a focus on a target. It will be found that the energetic positive particles are chiefly π^+ and the energetic neutral hadrons chiefly K^o, $\overline{K}^o$. The π^+ can be selected directly but to obtain K^+ and K^- it is necessary further to intercept the neutral kaons with another target after the charged particles have been swept to one side. The equipment to select the π^+ from the π^- target and the $K^{\pm}$ from the neutral kaon target will be the same and will be called the "Charged Particle Link". The kaon beams will need in addition the "Neutral Particle Link".

(a) <u>Charged Particle Link</u>

As it stands the final section of the hadron beam line is straight, i.e. it has no bending magnets. Furthermore the solid angle acceptance is small. For both of these reasons it is not adequate as it stands as a selector of the π^+, K^+ and K^- beams.

The solid angle acceptance can be boosted by matching into the final stage using a quadrupole doublet. To achieve dispersion while still pointing the beam at the bubble chamber a pair of bending magnets is needed, one at the target and the other at a place where the beam is wider. Rough momentum analysis is carried out by the existing beam line quadrupoles whose apertures act as collimator openings. A dispersed but focussed beam can be produced in the bubble chamber, the resolution depending on the angular acceptance in the horizontal plane, but typically being $\sim \pm$ 1% $\delta P/P$.

(b) Neutral Particle Link

Since the neutral particles cannot be focussed, the link must be short in order to keep the target spot small. Another requirement is that pions from K^o_s decay should be swept away from the acceptance of the charged link. It is proposed to use two high field pulsed dipole magnets bending in the vertical plane. Any muons arriving with the π^- will be swept into the ground.

The two high field dipoles will together have a total bending power of about 10 Tasla -metre. Although the lateral displacement of the high energy charged particles at the end of the 1.1 metre long link is not great nevertheless the angles through which they are bent make it essentially impossible for them to produce contamination of the final charged beam.

In Figure 1 an attempt has been made to illustrate the functions and properties of the charged and neutral links.

(c) Equipment

At RHEL Elliott and others [11] have produced pulsed dipoles having a field of 10-15T when the aperture in the bending plane is 20 mm. They have also built pulsed quadrupole magnets giving a gradient of 500 T/m over a 20 mm diameter useful aperture.

It would be possible to base the design of the charged and neutral links exclusively on these pulsed magnets. Estimates of fluxes of π^+, K^+ and K^- based on such a design show that the ranges of momenta made available and beam purity obtained, exceed those obtained using superconducting elements [6]. The charged link could probably be based on either type of magnet but the requirements of the neutral link are such that the pulsed dipoles with their higher fields ($\sim$ factor 2) are needed to minimise the length of the link and the contamination due to pions from K^o_s decay.

The DISC Cerenkov counter in conjunction with wire chambers should enable the tagging of particles according to mass to be carried out efficiently.

5. Particle Fluxes

(a) π^-:

The Hagedorn-Ranft Thermodynamic Model [12] gives a good fit to experimental data at momenta below 30 GeV/c. We have used the predictions of this model at higher momenta.

(b) π^+:

The production of π^- in π^+p collisions and of π^+ in π^-p collisions is similar and at large x does not appear to change much with incident momentum [13]. At $x \sim 0.8$ for example, $\frac{1}{\sigma_{tot}} \frac{d\sigma}{dx}(\pi^- \to \pi^+) \gtrsim 0.03$. With a momentum bite of say $\pm 5\%$ (i.e. $\delta x \sim 0.1$) and allowing for a target efficiency of $\sim$40% and losses in the π^+ beam line one obtains a figure of 10^{-3} for the number of π^+ with 80% of the incident π^- momentum per incident π^-.

The conclusion we reach is that for a circulating proton beam at 300 GeV beams of positive pions of 10 π^+ per pulse should be obtainable up to at least 200 GeV/c. With a 500 GeV circulating beam it should be possible to obtain π^+ beams up to at least 330 GeV/c.

(c) $\underline{K^o, \overline{K}^o}$:

The best data available on neutral kaon production in πp collisions are those of Crennel et al [14] on K^o_s production in π^+p collisions at 22 GeV/c. This is substantiated by the somewhat cruder data from 10 GeV/c $\pi^-p \rightarrow K^o_s$ of Bigi et al [15], and from 16 GeV/c $\pi^+p \rightarrow K^o_s$ of Bartke et al [16] It is also hoped that information will soon become available from the NAL 200 GeV/c π^-p bubble chamber experiment [4].

(d) $\underline{K^+, K^-}$:

The K^+ are at the end of the chain

$$p \rightarrow \pi^- \rightarrow K^o \rightarrow K^+.$$

and the K^- at the end of the chain

$$p \rightarrow \pi^- \rightarrow \overline{K}^o \rightarrow K^-.$$

Data are not available in useable form on $K^o \rightarrow K^+$ or $\overline{K}^o \rightarrow K^-$ but copious data exist on the reverse processes $K^+ \rightarrow K^o$, $K^- \rightarrow \overline{K}^o$ [17]. It seems reasonable to assume, as we have done, that $\frac{d\sigma}{dx}(K^o \rightarrow K^+) \approx \frac{d\sigma}{dx}(K^+ \rightarrow K^o)$ and that $\frac{d\sigma}{dx}(\overline{K}^o \rightarrow K^-) \approx \frac{d\sigma}{dx}(K^- \rightarrow \overline{K}^o)$.

Using these fluxes and assuming scaling, in the sense that $\frac{d\sigma}{dx}(\pi^- \rightarrow K^o, \overline{K}^o)$ and $\frac{d\sigma}{dx}(K^o, \overline{K}^o \rightarrow K^{\pm})$ are independent of beam momentum, the fluxes of $K^{\pm}$ reaching the 15' HBC have been calculated. The fluxes of $\pi^{\pm}$ background produced by the processes

$$K^o p \rightarrow \pi^{\pm} X$$

and $$\overline{K}^o p \rightarrow \pi^{\pm} X$$

occurring at the last target have also been estimated in an analogous way, by assuming from isospin symmetry that

$$K^o p \rightarrow \pi^{\pm} X \sim K^+ p \rightarrow \pi^{\mp} X$$

and $$\overline{K}^o p \rightarrow \pi^{\pm} X \sim K^- p \rightarrow \pi^{\mp} X$$

and using published data for these inclusive $K^{\pm}p$ reactions [18].

As an example, detailed results for 50 and 100 GeV/c K^+ beams obtained by using 300 GeV protons are presented in Fig. 2. It is interesting to give the K^+ flux and K^+/π^+ ratio as a function of the intermediate π^- momentum, whence we see that a suitable operating point would be for $p_{\pi^-} \sim 125$ GeV/c. In practice we envisage setting the final stage of momentum analysis to select $K^{\pm}$ of required momentum and tuning the π^- momentum for optimum conditions in the bubble chamber (as indicated by the DISC Cerenkov).

We believe that beams of ∿ 10 particles per burst should be obtainable up to at least 100 GeV/c using 300 GeV circulating protons with a 10% share of the extracted beam i.e. 10" interacting protons. With 500 GeV protons one might hope in the same way to obtain $K^{\pm}$ beams up to 200 GeV/c.

Because of the π background of typically $\gtrsim$ 20% it seems essential to use particle tagging making use of the DISC Cerenkov counter and wire chambers existing in the beam line [5].

A more detailed report [6] on the material of sections 4 and 5 is in course of preparation, as mentioned above.

6. Measuring Facilities.

It is envisaged that these surveys will be done as a collaboration involving American and possibly further British groups.

The Cambridge group has 2 semi-automatic Sweepnik measuring devices and 3 conventional measuring machines with on line computer connection all capable of modification to handle 70 mm film. Two large scan tables (designed for BEBC film) will also be available for the experiment.

It is expected that the measurement requirement of ∿ 150 k events could be readily fulfilled in ∿ 1 year.

REFERENCES

[1] G. Charlton et al., Phys. Rev. Letters 29 (1972) 515.

[2] G. Charlton et al., Phys. Rev. Letters 30 (1973) 574.

[3] F.T. Dao et al., Phys. Rev. Letters 30 (1973) 34.

[4] NAL Proposal No. 137 'Study of π^-p Interactions at High Energy', F.R. Huson (NAL, LBL, Univ. of Calif.), and private communcation, F.R. Huson.

[5] NAL Internal Report TM-285 "Hadron Beams in the Neutrino Area" J. Lach and S. Pruss.

[6] R.E. Ansorge et al, Cavendish Internal Report.

[7] Aachen-Berlin-CERN-London-Vienna and Brussels-CERN Collaborations. Nuclear Physics B30 (1971) 381.

[8] NAL Proposal No. 69A "Elastic Scattering of the Long-Lived Hadrons", N. Willis (Yale, NAL).

[9] Proposal No. 122 to Study High Energy Negative Hyperon Interactions in the NAL 15' HBC, Cambridge University Bubble Chamber Group.

[10] 300 GeV Working Group, CERN/ECFA, 72/4, Vol. I, Page 33.

[11] R.T. Elliott and P.S. Flower, "Pulsed magnets for a Σ-experiment in the CERN 2m HBC", Nimrod (PD) 72-4.

[12] H. Grote, R. Hagedorn and J. Ranft, Atlas of Particle Production Spectra, CERN 1970.

[13] T. Ferbel, Proc. of Int. Symposium on Multiparticle Process, Zakopane 1972, p.121.

[14] D. Crennel et al, see LBL-80 p.497.

[15] A. Bigi et al, Nuovo Cimento 33, 1249 (1964).

[16] Bartke et al, Nuovo Cim. 24, 876 (1962).

[17] J.V. Beaupre et al, and see LBL-80 p.479.

[18] LBL-80. pp.417, 696.

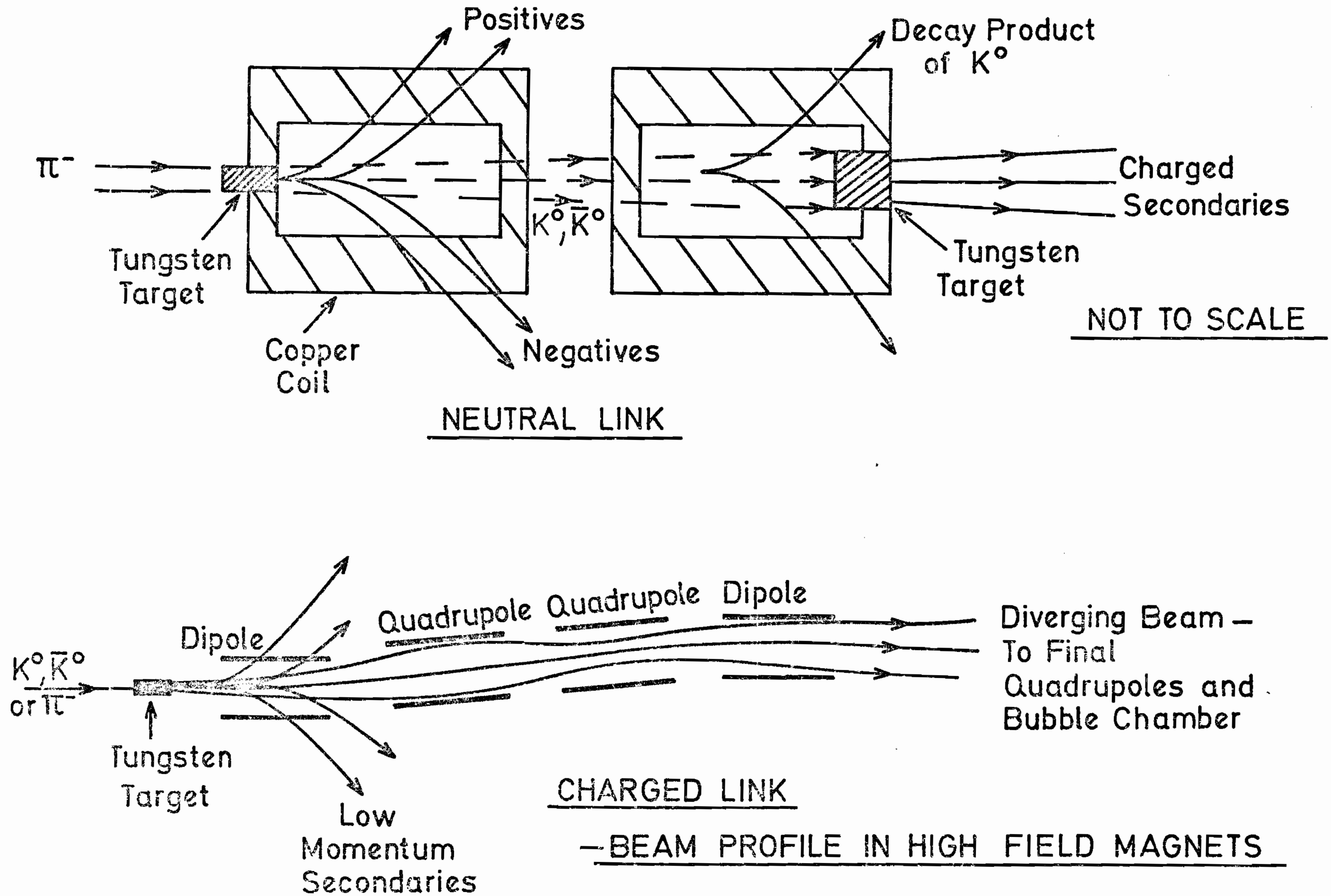
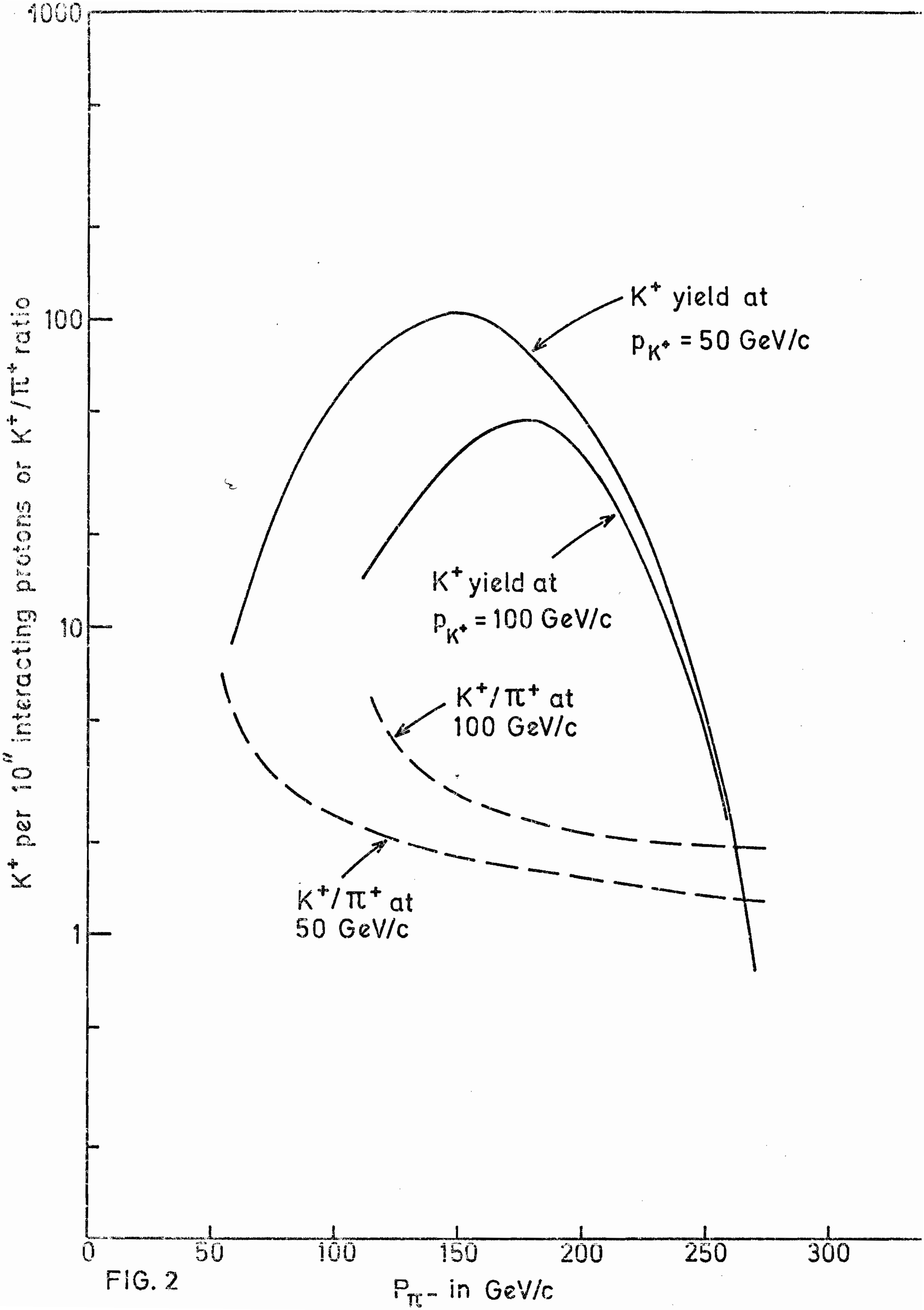

Positives
Decay Product of K°
π^-
Charged Secondaries
$K^o,\bar{K}^o$
Tungsten Target
Tungsten Target
Copper Coil
Negatives
NOT TO SCALE
NEUTRAL LINK
Quadrupole
Quadrupole
Dipole
Dipole
$K^o,\bar{K}^o$ or π^-
Diverging Beam — To Final Quadrupoles and Bubble Chamber
Tungsten Target
Low Momentum Secondaries
CHARGED LINK
— BEAM PROFILE IN HIGH FIELD MAGNETS

FIG. 1



1000
100
10
1
K⁺ per 10¹¹ interacting protons or K⁺/π⁺ ratio
K⁺ yield at
p_K⁺ = 50 GeV/c
K⁺ yield at
p_K⁺ = 100 GeV/c
K⁺/π⁺ at
100 GeV/c
K⁺/π⁺ at
50 GeV/c
0
50
100
150
200
250
300
P_π⁻ in GeV/c

FIG. 2