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A PROPOSAL TO STUDY PHOTOPRODUCTION OF ϕ MESONS

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<u>Introduction:</u> In the ~100 BeV/c region the most interesting physics on photoproduction can be classified into two groups:

a) Studying strong interactions at high energies;
b) studying electromagnetic interactions at large momentum transfers, $P_\perp > 2$ GeV or $|q^2| > 4$ GeV^2.

Because the tagged photon intensity is $\approx 10^5$ per pulse and $\frac{\Delta E}{E} \approx 5$ %, it is not possible to probe electromagnetic properties such as the parton distribution with reactions of the type

$$\gamma + P \rightarrow \pi^+ + X \quad \text{or} \quad \gamma + P \rightarrow \gamma' + X \text{ etc.}$$

in any meaningful way. These types of experiments are best done with high intensity photon beams where one can probe into very large momentum transfers.

For the reactions which use high energy but the low intensity of the tagged photon beam the most interesting reaction is to study photoproduction of ϕ mesons by detecting the K^+K^- decay mode and recoil protons in

$$\gamma + P \rightarrow \phi + P, \quad \phi \rightarrow K^-K^+$$

I. PHYSICS:

Of all the known strong interactions the reaction

$$\gamma + P \rightarrow \phi + P \qquad (1)$$

is the best approximation to have a pure Pomeron exchange. The reaction $PP \rightarrow PP$ has a non-diffractive OPE contribution and the reaction $\pi P \rightarrow \pi P$ has a non-diffractive ρ exchange contribution beside the Pomeron exchange in each case.

Because of the large (≈ 50 %) decay corrections of $\phi \rightarrow K^+K^-$ in the few GeV region and because of the contribution of

$$\gamma + P \rightarrow \phi + 2\pi + P \qquad (2)$$

which dominates over (1) at electron accelerator energies, reaction (1) has not yet been studied systematically. However, the low energy data on phtoproduction of ϕ has already brought many surprising results which can be summarized as follows:

a) Contrary to most of the reactions like $\pi P \to \pi P$, $PP \to PP$ where one has the diffractive slope $b = 8\text{-}10\ GeV^{-2}$ the slope for reaction (1) is measured to be $b = 4\ GeV^{-2}$.[1) It would be interesting to measure b of (1) as a function of photon energy to see whether it increases with increasing energy and if it eventually reaches $b = 8\text{-}10\ GeV^{-2}$.

b) Contrary to the πP and PP total cross-sections $\sigma_{\pi P} \approx 30$ mb, $\sigma_{PP} \approx 40$ mb, the total ϕ nucleon cross-sections $\sigma_{\phi N}$ as measured by the attenuation method off a nuclear target is only $\sigma_{\phi N} \approx 10$ mb.[2) This value agrees well with the quark model predictions $\sigma_{\phi N} = 2(\sigma_{K^+P} - \sigma_{\pi^+P}) + \sigma_{\pi^-P}$.[4) It also fits with the vector dominance model prediction.[3)

$$\left.\frac{d\sigma}{dt}\right|_{t=0} = \frac{\alpha}{16\pi} \left(\frac{\gamma_\phi^2}{4\pi}\right)^{-1} \sigma_{\phi N}^2 \ (1+\beta_\phi^2) \qquad (3)$$

where $\frac{\gamma_\phi^2}{4\pi}$ is the γ-ϕ coupling strength and β_ϕ is the ratio of the real to imaginary part of the ϕ scattering amplitude.

In the energy region $20 < E_\gamma < 195$ GeV/c models which predict an $(\ln s)^2$ increase in PP total cross-section[6) would give a faster increase in σ_{K^+P} cross-section than the $\sigma_{\pi^\pm P}$. We have applied the Cheng-Walker-Wu analysis[7) of the high energy total cross-section to ϕ photoproduction and found a $\sigma_{\phi N}$ increase of 20 % from $E_v = 20$ to $E_v = 195$ GeV.

From (3) we would then expect a $\left.\frac{d\phi}{dt}\right|_{t=0}$ $(\gamma P \to \phi P)$ increase of 40 % from $E_v = 20$ to $E_v = 195$ GeV.

c) In many diffractive reactions like $PP \to PP$, dips are observed at $-t \approx 1\text{-}2\,(GeV/c)^2$. No structures have been seen in $\gamma P \to \phi P$ at low energies. It would be interesting to see if, for this pure Pomeron process, dips exist at high energies where one can perform a clean experiment with good t resolution and with little background.

Technically, the ϕ is also the cleanest and easiest vector meson to be measured precisely. Reactions like $\gamma + P \rightarrow P + \rho$ and $\gamma + P \rightarrow \omega + P$ are plagued by non-resonant backgrounds, $\rho\omega$ interference etc. The results of $\gamma + P \rightarrow \rho + P$ are highly model dependent. The best experiment to date measured ρ production with a linearly polarized photon beams and the S.L.A.C. Bubble Chamber with well defined photon energies, and measuring all the final state particles, yield a $\frac{d\sigma}{dt}_{t=0}(\gamma+P \rightarrow \rho + P)$ [5] which has a ~ 30 % uncertainty depending on models of ρ width and background shapes. Also, $\gamma P \rightarrow \omega P$ is difficult to measure because one has to detect three pions one of which is a π^0.

ϕ meson has a mass of 1019.5 and width of 4.3 MeV, decays 47 % of the time into K^+K^-. The narrow width of ϕ ensures that the cross-sections are independent of detailed assumptions of Breit-Wigner and background shapes. The small Q value available for $\phi \rightarrow K^+K^-$ ensures that all the K^+K^- pairs have small opening angles $\theta \approx 1^o$. This needs only a very small and simple detector.

We note that because of the small Q value for vector mesons decaying into K^-K^+ + hadrons or $P\bar{P}$ + hadrons the same spectrometer will detect $\gamma + P \rightarrow V^o + P$ up to a V^o mass of ≈ 7 GeV for the highest photon energies.

II DESCRIPTION OF THE SPECTROMETER:

Fig. 1 shows the views of the spectrometer: photons from the tagged photon beam are incident on a 1m liquid hydrogen target. Three sets of chambers surround the H_2 target ensuring that for t<.1 GeV no particles leave the target and for t>.1 GeV they measure the coplanarity angle of recoil protons. Two standard Argonne or BNL beam magnets, such as the BM109 with opposite magnetic fields bend particles horizontally, refocusing particles with same production angle at a point 120' downstream from the target. Low energy e^+e^- (<3 GeV) produced at the target are swept away by the first magnet before they can reach the first proportional chamber A. For an e^- beam of intensity 4×10^7/pulse and a 1 % tagging target, there are less than 1.6×10^5 particles in chamber A, thus the single rates in the chambers are tolerable. The momentum of the particles are measured by proportional chambers A, B, C, D and drift chambers E, F. The production angles of the particles are determined by their positions in the last chambers D, E, F as well as from trajectories reconstructed back to the target. There are two Cerenkov counters to ~~separate kaons~~ and protons from other particles. The first one, situated between B and C is 55' long and has a threshold corresponding to 106 GeV/c K's to distinguish K and P from π and e. (see Appendix) A second Cerenkov counter of 40' length with threshold set for 150 GeV/c P's is used to distinguish K's from P's. Each counter has 16 cells with the new high gain RCA 31000M phototubes for multiple particle identifications. Shower counters behind the last chambers further discriminate against $e^\pm$ by measuring the shower energy of the e. For $e^\pm$ energies >6 GeV, we have achieved a rejection of 10^{-3}. Additionally, we have the constraint that $E_e = K + E_{e'}$, where E_e, K and $E_{e'}$ are respectively the energies of the electron beam, the tagged photon (or e^+e^- pair) and the recoil electron.

A Monte Carlo program was used to calculate the resolution of the spectrometer and we have: for 100 GeV ϕ at $t = .1\ GeV^2$ $\Delta t = .01\ GeV^2$

$$\Delta m = \pm 8\ MeV \qquad \Delta P = \pm 6\ GeV$$

We note that the t resolution can be even much better by moving the magnets slightly apart. This will be done only if a dip is found in the t distribution.

III. THE EVENT RATE AND BACKGROUNDS:

For 10^{13} incident protons at 400 GeV one expects about 10^7 electrons at 200 GeV and 4×10^7 electrons at 160 GeV[8].

Photons are produced by using a 1 % r.l. tagging target. We used a Monte Carlo program to calculate the event rate of $\gamma + P \rightarrow P + \phi$
$\quad\quad\quad\quad\quad\quad\quad\quad \hookrightarrow K^+K^-$.

With 480 hours of running at 200 GeV e^- beam and 120 hours at 160 GeV e^- beam, we expect to get 1.1×10^5 $\phi \rightarrow K^+K^-$ events. The t distribution is shown in Fig. 2a. It can be seen that $d\sigma/dt$ can be measured to a value of t up to 2 GeV^2. The events distribution as a function of incident photon energy is shown in Fig. 2b. We see it is possible to cover the region $20<k<195$ GeV. For high mass vector mesons decaying into K^+K^- or $P\bar{P}$ mode, we have used the same production cross-section as the ϕ photoproduction cross-section. The event rate as function of vector meson is shown in Fig. 3a. The t and k distributions corresponding to various values of masses of vector mesons decaying into K^+K^- mode are shown in Fig. 3b and 3c respectively.

To discriminate against inelastic events for $|t|\gtrsim 0.1$ GeV^2, three sets of chambers around the LH_2 target measures the scattering angles of the recoil proton. This provides two useful constraints: coplanarity and two independent measurements of t. Monte Carlo results show coplanarity requirement rejects the backgrounds of $\gamma P \rightarrow N^* + \phi$ and $\gamma P \rightarrow 2\pi + \phi + P$ to <.1 % level, assuming they have the same cross-section as ϕ production.

Appendix

The Threshold Cerenkov Counters

We use two threshold Cerenkov counters to distinguish the K's and P's from all other particles (see Fig. 1). The first one will identify pions and electrons while the second will identify kaons in addition. Thus a kaon will give a positive count only in the second counter while a proton will give a positive count in neither counter. This arrangement is identical to the one we have adopted at BNL for the experiment to study

$$PP \rightarrow \bar{P}P + \ldots$$

$$\text{and} \quad PP \rightarrow K^+K^- + \ldots$$

The length of the first counter is 55 feet and the second one is 40 feet.

From these parameters we find that in the first counter we can separate π's from K's with an efficiency of greater than 99 % up to a momentum of 106 GeV/c and in the second counter we can separate K's from P's with the same efficiency up to 150 GeV/c. At these energies the Cerenkov angle is very small. The 16 cells in each counter will enable us to identify multiple particle final states.

The maximum momentum a kaon from a 195 GeV ϕ decay can have is 120 GeV/c. This means that kaons from ϕ decay will not look like protons and even for higher mass mesons decaying into K^+K^-, the kaons will not look like protons. However, asymmetric decays of ϕ mesons of 195 GeV/c energy will have one of the kaons looking like a pion. But even with a kaon counting on one side only, the high mass resolution of the system for K^+K^- pairs makes it possible to have a fairly clean separation of $\pi^+\pi^-$ and K^+K^- up to the maximum possible photon energy of 195 GeV.

All the Cerenkov counters will be simple He boxes. The pressure of the front pair of counters will be at 4.6 psia and the rear at 8.2 psia. With appropriate mylar window thicknesses, the overall effect of knock ons will be 2.0 % in the front counters and 3.0 % in the rear counters. However, this should not prove to be a problem since we expect the rate of $\bar{P}P$ pairs to be considerably lower than K^+K^- pairs so that the latter is not seriously contaminated.

References

1. A Silverman
   Proc. IVth Int. Symp. on electron/photon interactions at high energies, Daresbury 1969, see also ref. 4

2. ibid

3. ibid

4. G. Wolf
   Proc. Vth Int. Symp. on electron/photon interactions at high energies, Cornell 1971.

5. ibid

6. H. Cheng and T. T. Wu, Phys. Rev. Letts. 23, 1311 (1969)

7. Walker, Chèng, and Wu, N.A.L. report 1973.

8. C. Halliwell et al. Nucelar Instr. Methods 102, 51 (1972)

Figure Captions

1a. Plan view of the spectrometer showing the two dipole magnets, M_1 & M_2 and the gas threshold Cerenkov counters C_K and C_P. A, B, C and D, are proportional wire chambers and E and F are drift chambers.

1b. Side view of the spectrometer.

2. (A) Expected number of events for production of ϕ decaying into K^+K^- as a function of t in bins of 0.1 $(GeV/c)^2$.

   (B) Expected number of events for production of ϕ decaying into K^+K^- as a function of K, the incident photon energy, in 20 GeV bins.

3. (A) Expected number of events for production of heavy vector mesons decaying into $\bar{P}P$ and K^+K^- assuming the same production cross-section as the ϕ and branching ratios of unity. The vertical scale is events per 480 hours with an initial electron beam of 200 GeV/c.

   (B) Expected number of events for heavy vector mesons of 3 and 5 GeV/c^2 decaying into K^+K^- as a function of K, the incident photon energy, in 20 GeV bins.

   (C) Expected number of events for 3 and 5 GeV/c^2 vector mesons decaying into K^+K^- as a function of t in bins of 0.1 $(GeV/c)^2$.

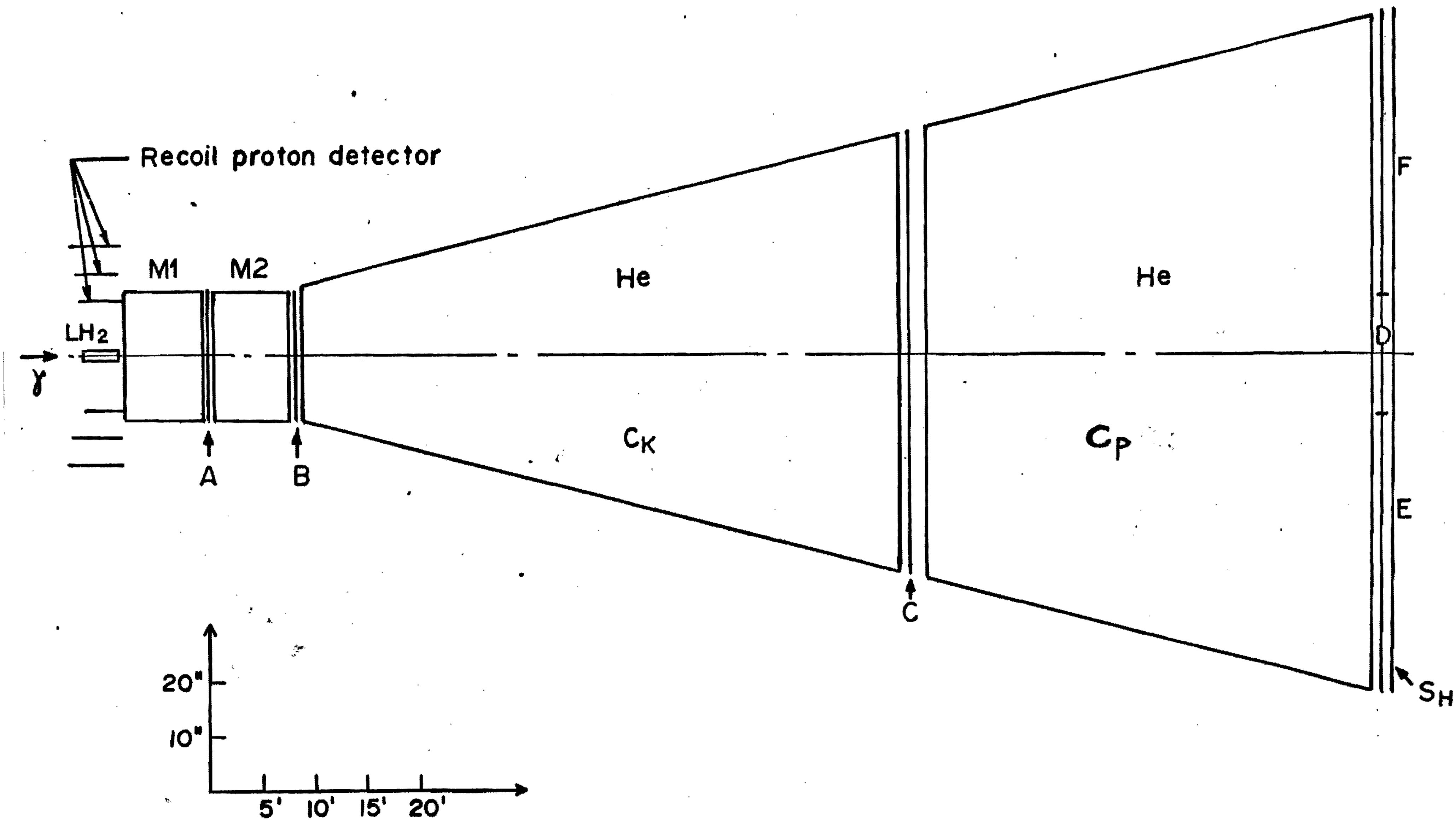
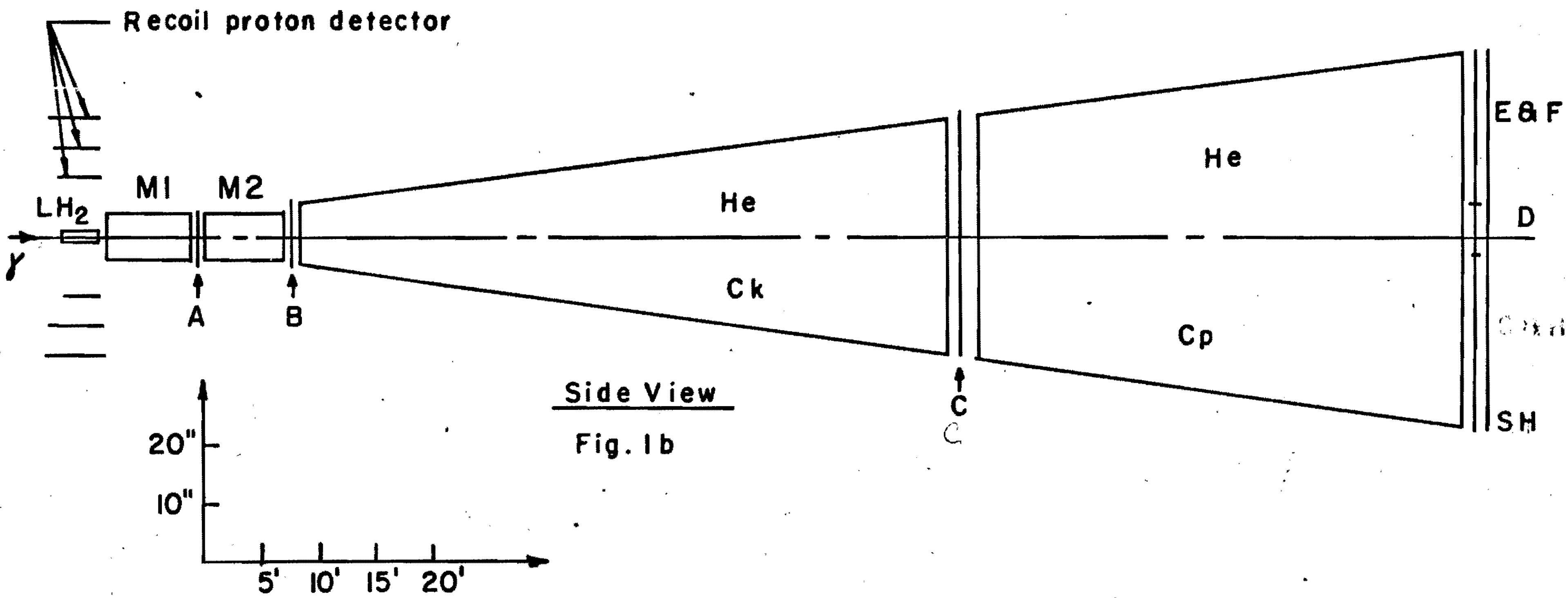
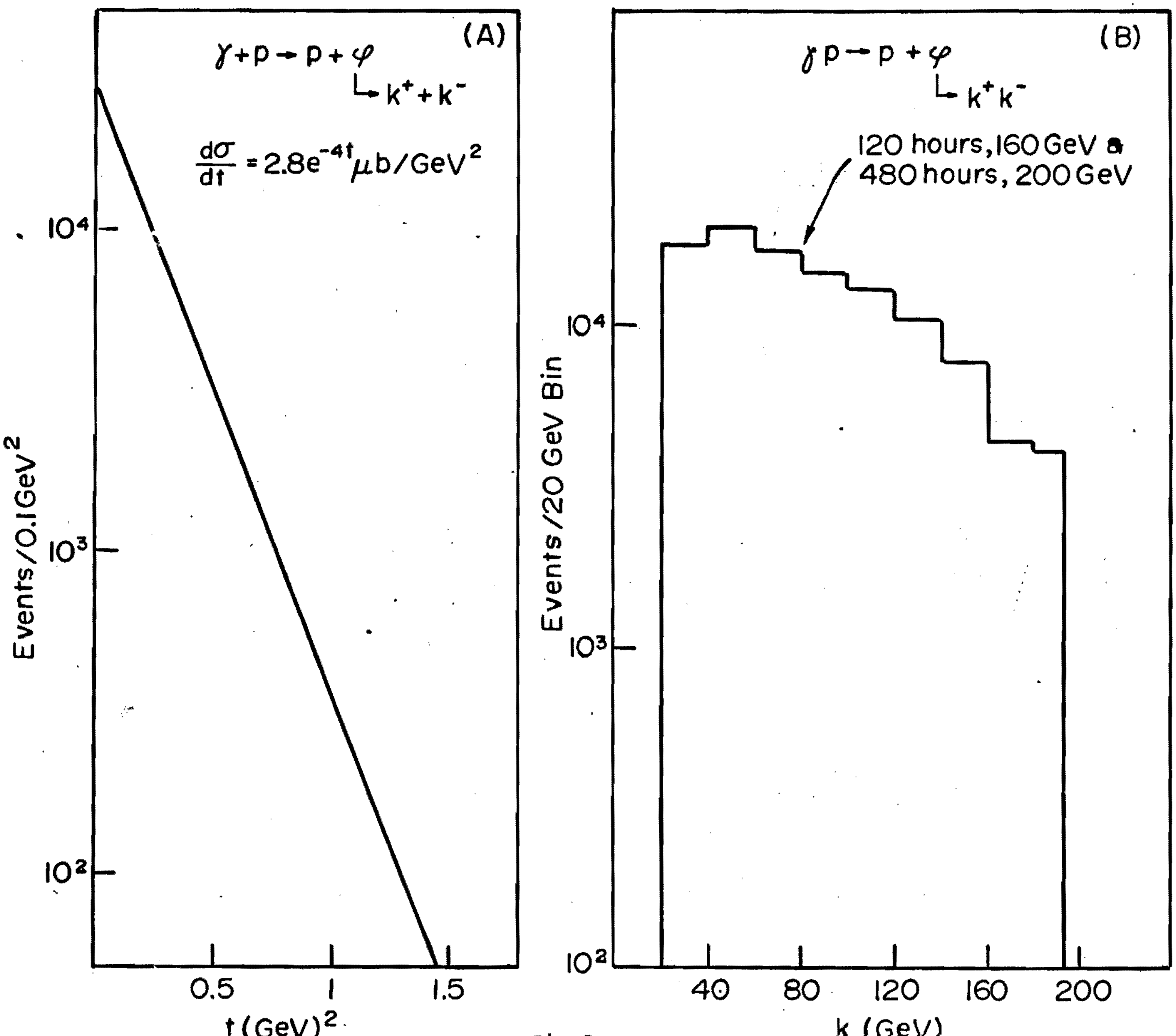


Fig.1a Top View of the Spectrometer



Side View

Fig. 1b



(A)
γ+p → p+φ
↳ k⁺+k⁻
dσ/dt = 2.8e^{-4t} μb/GeV²
10⁴
10³
10²
Events/0.1GeV²
0.5
1
1.5
t (GeV)²
(B)
γp → p+φ
↳ k⁺k⁻
120 hours, 160 GeV &
480 hours, 200 GeV
10⁴
10³
10²
Events/20 GeV Bin
40
80
120
160
200
k (GeV)

Fig. 2

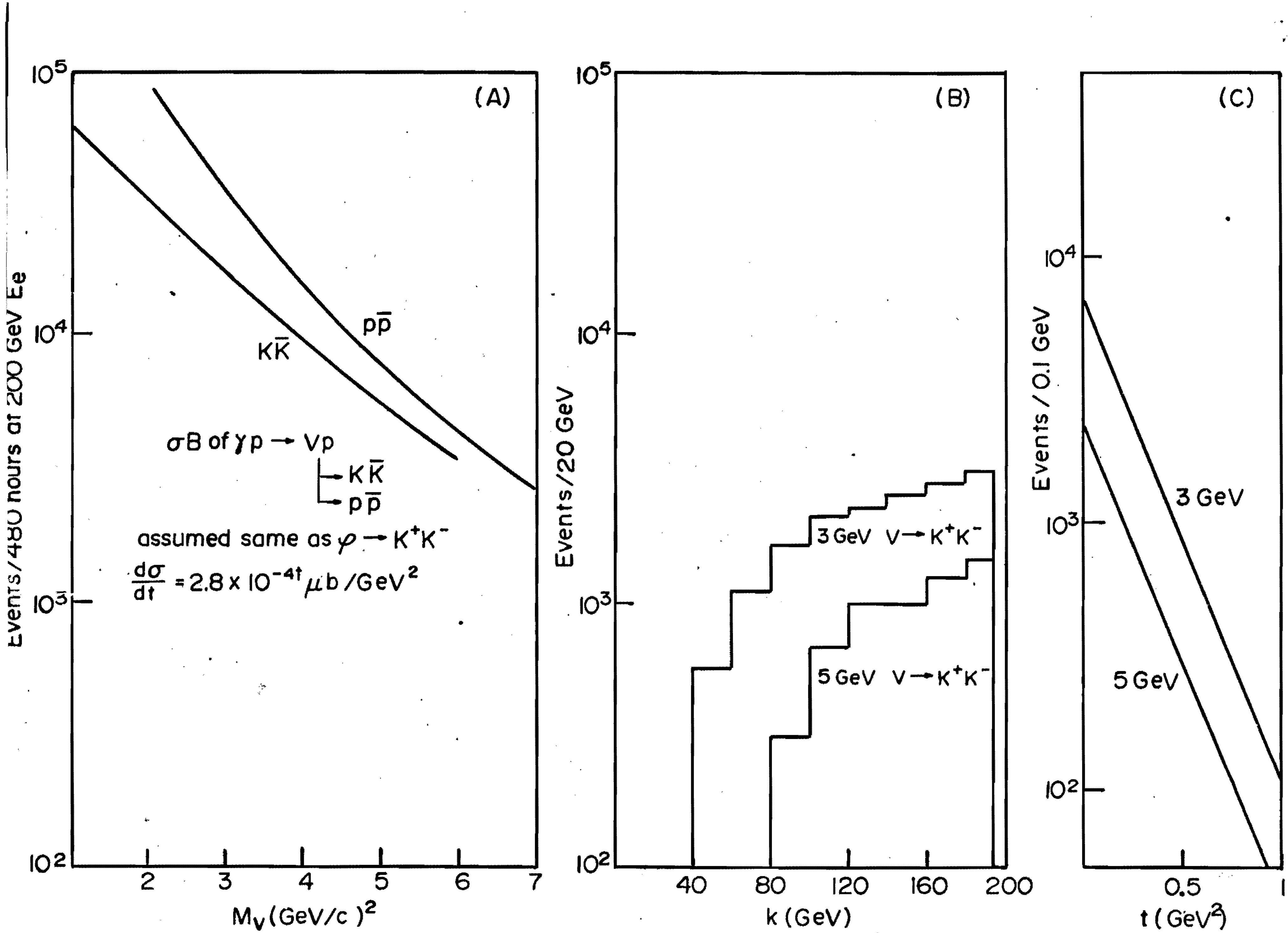

(A)
(B)
(C)
Events/480 hours at 200 GeV Ee
pp̄
KK̄
σB of γp → Vp
→ KK̄
→ pp̄
assumed same as φ → K⁺K⁻
dσ/dt = 2.8 x 10^-4t μb/GeV²
Mv (GeV/c)²
Events/20 GeV
3 GeV V → K⁺K⁻
5 GeV V → K⁺K⁻
k (GeV)
Events/0.1 GeV
3 GeV
5 GeV
t (GeV²)

Fig.3