NAL PROPOSAL No. 302

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Test of C at Small Distances

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May 14, 1974

Test of C at Small Distances

It is proposed to test C at small distances by comparing the energy spectra of positive and negative π and K mesons emitted at 90° in the c.m. system of $\bar{p}$-p interactions

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After 10 years the fundamental source of the CP violation observed in neutral K decay remains unknown. A large number of experiments have been done searching for C, CP, and/or T violation in other systems. These searches have been conducted in the fond hope that there is a massive violation in some system which only happens to manifest itself as a tiny effect in the K system. An appraisal of the situation by Wolfenstein shows that, with a few exceptions, the previous experiments in systems outside the K meson are still too insensitive by about an order of magnitude to have reasonable expectation of seeing an effect.

The present proposal addresses the problem on a very general basis. On the presumption that the violation is a short distance phenomenon it seeks to test for violations of discrete symmetries at the highest possible momentum transfers. No particular theoretical model is invoked. We do not speculate whether the effect in K-decay is milliweak, electromagnetic, or millistrong. We simply speculate that the violation of CP could be a short distance phenomenon and correspondingly, it is fruitful to test the discrete symmetries at the shortest distances, at the highest momentum transfers. All tests of C, CP and T, with one exception, have been made at around the momentum transfer in K decay - $q^2 \sim m_\pi{}^2$. The one exception was the test of T in particular electromagnetic channels at CEA and SLAC. (Rock, et al. Phys. Rev. Letters 24, 748 and Chen, et al. Phys. Rev. Letters 21, 1279). The highest q^2 involved in these tests was 1 BeV^2/c^2 with an experimental accuracy in the asymmetry measurements of around 3 to 5%.

Various tests of discrete symmetries in $\bar{p}\,p$ and $e^+ e^-$ interactions have been discussed (Pais, Phys. Rev. Letters 3, 242 and Pais and Treiman, Phys. Rev. 187, 2076) and measurements made at low energy (Dobrzynski, et al. Phys. Lett.

22, 105 and Baltay, et al. Phys. Rev. Letters 15, 591). Here we propose to test C in $\bar{p}$ p interactions by comparing the spectra (to the highest possible energy) of positive and negative π and K mesons produced at 90° in the centre of mass.

The $\bar{p}$ Beam

We propose using 200 BeV $\bar{p}$'s produced by 400 BeV protons. Of critical importance is the guarantee that the interaction products originate from $\bar{p}$ interactions and not π^- or K^-. To accomplish this we require that the $\bar{p}$ in a particular RF bucket be unaccompanied by a π^- or K^-. This requires not only a Cerenkov counter in the negative beam to tag the $\bar{p}$'s but also a specific Cerenkov tag on the π^-'s and the K^-'s so that those RF buckets containing π's or K's in addition to the $\bar{p}$ can be eliminated. The requirement of no π^- or K^- accompanying the $\bar{p}$'s sets a limit on the total negative particle flux that can be tolerated in the beam. The $\bar{p}$ rate with no accompanying particle in the same RF bucket is maximized with, on the average, one negative particle per RF bucket. We take 50×10^6 RF buckets per pulse with an effective duty cycle of 30% or 15×10^6 particles/pulse. With a limit set on the maximum particle flux it is clearly desirable to have as large a $\bar{p}/(\pi^- + K^-)$ ratio as possible. Published data (Cronin-Piroue, et al. and Baker, et al.) suggest dramatic increases in the $\bar{p}/\pi^-$ ratio with $p_\perp$. We take the $\bar{p}/\pi^-$ results of Cronin-Piroue at p of 1.1 BeV, assume the same x dependence in the ratio as observed by Baker et al. at much lower $p_\perp$ * and arrive at the following 200 BeV secondary beam of negative particles. (We assume scaling and use the $p_\perp$ distribution, $\frac{dN}{dp_\perp} \alpha \; p_\perp e^{-\frac{p_\perp}{b}}$.

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* These results disagree somewhat with ISR values. If we accept the ISR results, the $\bar{p}/\pi^-$ ratio increases by 2 over that used here.

momentum = 200 BeV

$p_\perp$ = 1.1 BeV

$\frac{\Delta p}{p}\, d\Omega = 2 \times 10^{-6}$ (same as Cronin-Piroue, et al.)

$\frac{\bar{p}}{\pi^-} = .033$

π^- flux = $14 \times 10^6/10^{12}$ protons on target

K^- flux = $3 \times 10^6/10^{12}$

$\bar{p}/10^{12}$ protons = $.47 \times 10^6$

$\bar{p}$ unaccompanied by π^- or K^- = $.17 \times 10^6/10^{12}$ protons

Because of the requirement that the $\bar{p}$ be unaccompanied by a K or π in the same RF bucket, the effective $\bar{p}$ rate is relatively insensitive to the pion rate. For example, dropping the pion flux by a factor of four decreases the $\bar{p}$ rate by a factor of two. The main uncertainty in the above $\bar{p}$ flux calculation is the assumption about the x-dependence of the $\bar{p}/\pi^-$ ratio at high $p_\perp$.

Experimental Apparatus

The experimental apparatus for identifying and measuring the secondaries from $\bar{p}$ p interactions is shown in relation to the "$\bar{p}$ beam" in the accompanying figure. The apparatus consists of two magnetic spectrometers viewing the target each at ∿ 97 milliradians in the laboratory, an angle that corresponds to 90° in the c.m. Each spectrometer magnet operates at a $p_\perp$ of 1 BeV. They are taken to be 18 D 72 magnets with an 8" gap. They combine to a $d\Omega$ of 2×10^{-3}. The threshold Cerenkov counters for separating π's from K's operate to 50 GeV or approximately 5 BeV $p_\perp$. Track delineation before and after the magnets is done by wire proportional chambers. Because of the large angle at which the target is viewed by the spectrometer, we would restrict its fiducial length to 3'. With unpolarized antiprotons, the experiment can be done using one arm of the spectrometer. However, should the $\bar{p}$'s be polarized, the two arms provide a check. Furthermore, in previous charge asymmetry measurements (e.g. Ke_3^o decay), it has been highly desirable to have right-left symmetry in the detector. The main experimental challenge is in guaranteeing the same momentum cuts for plus and minus particles because of the anticipated steeply falling spectrum.

Rates

An experimental objective is to measure the momentum distribution of secondary particles at 90° in the c.m. However, as a measure of the sensitivity of the experiment we assume the distributions are the same for $\bar{p}$ p as for p p interactions. For a 3 ft. H target we get (for 0.16×10^6 $\bar{p}$/pulse) a pion flux of

1.8×10^4/hr	above	1 BeV $p_\perp$
340/hr	above	2 BeV $p_\perp$
6/hr	above	3 BeV $p_\perp$
.07/hr	above	4 BeV $p_\perp$

Four hundred hours of data acquisition leads to pion asymmetry measurements of .25% at 2 BeV $p_\perp$, and 2.0% at 3 BeV $p_\perp$. The accuracy in the corresponding K asymmetries is down by a factor of ~ 2.

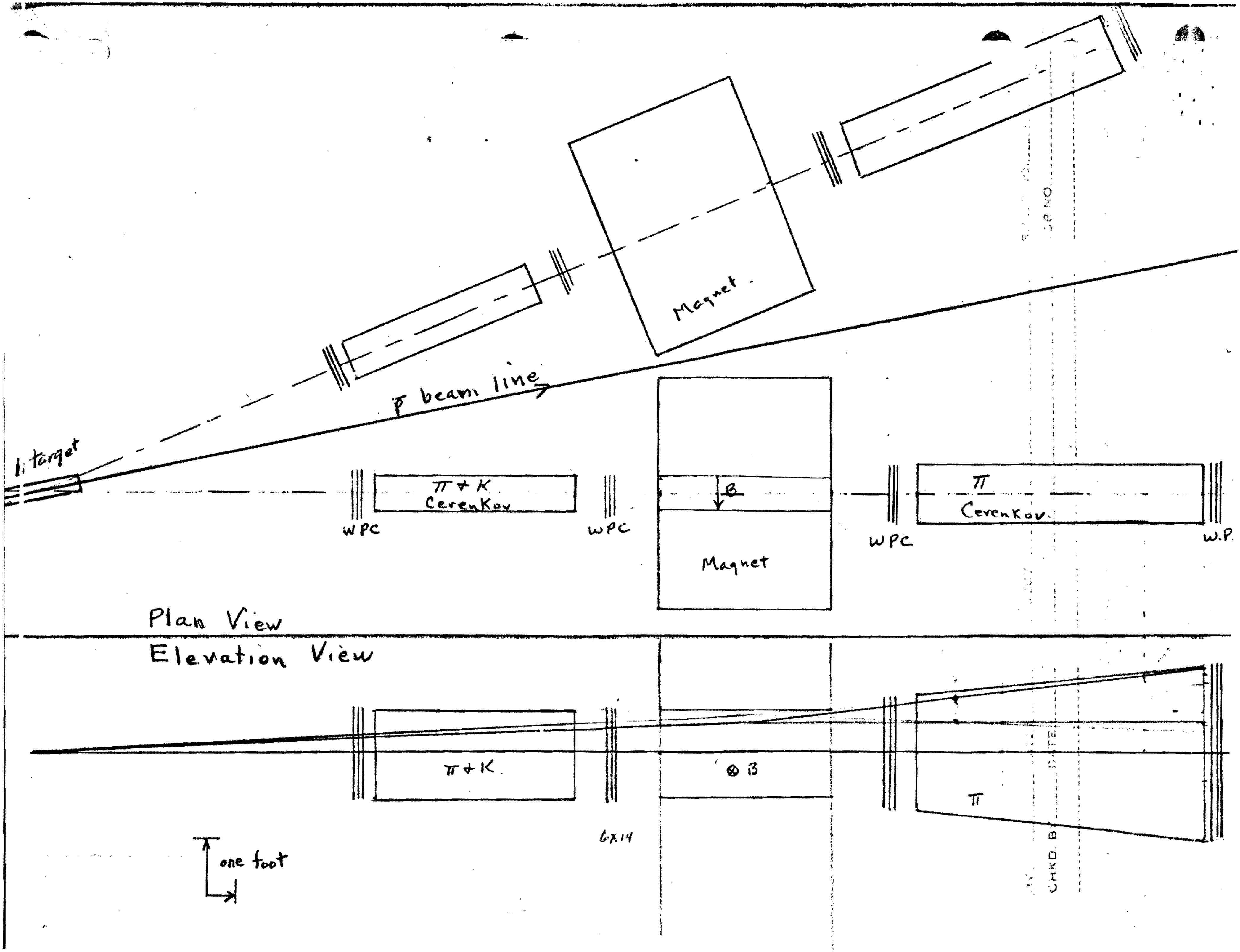
Experimental Byproducts

In addition to the charge asymmetries, this experiment unavoidably measures inclusive cross sections for π and K production at 90° in the centre of mass for negative incident particles. There has recently been considerable theoretical and experimental interest in inclusive spectra at large transverse momenta, since it might be expected that such events are due to fundamental processes, such as interactions of quarks or partons. If this quark picture has merit, then differences in inclusive particle spectra produced with different incident particles have particular significance. The Chicago-Princeton collaboration has measured 90° inclusive cross sections in proton-nucleon interactions for $p_\perp$ up to 8 GeV/c. Under the conditions stated above, the present experiment measures π and K spectra to about 4.5 GeV/c in transverse momentum, if the slope in $p_\perp$ is the same for $\bar{p}$-p as for p-p collisions.

Finally, we are not insensitive to the fact that the double arm spectrometer described here could also observe the decay of high mass objects, with masses up to ∿ 10 GeV.

Resources

Given the negative beam and floor space we anticipate that (aside from the spectrometer magnets, which we hope to scrounge) we can assemble the apparatus, Cerenkov counters, and wpc's, within our usual laboratory budget.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p̄ beam line
Magnet
π + K
Cerenkov
WPC
WPC
B
Magnet
WPC
π
Cerenkov.
W.P.
Plan View
Elevation View
π + K
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ADDENDUM TO FNAL EXPERIMENT 302.

SEARCH FOR CHARM PRODUCTION IN 200 GEV/c HADRON INTERACTIONS.

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Introduction

We wish to extend the utilization of the two arm spectrometer of experiment 302, which will be set up in the downstream end of Proton West, by performing a high sensitivity charm search. This will require the addition to the original design of a third spectrometer arm close to the target region and downstream μ filters in each of the two arms.

The basic limitation in searching for charmed objects produced in hadronic channels has been the high background level from conventional strong interaction sources. We propose to enhance the signal to background ratio by capitalizing on the existence of charm levels (D^*,D; Σ_c,Λ_c) with mass separation only slightly larger than a pion mass.

As an example we discuss in detail the search for $D^{*\pm}$. The charmed vector mesons $D^{*\pm}$ have been detected at SPEAR1) and are seen to decay predominantly to $D^o\pi^\pm$ final states with a measured Q value of 5.7 ± 0.5 MeV. In the limit of zero Q value the pion has the same velocity as the D^o in the laboratory. A symmetric double arm spectrometer, as that of E-302, selects, through their two body final states, D^o's within a restricted momentum interval. Thus the pion accompanying the D^o's from D^* decay are well collimated and have a central momentum of $\frac{m_\pi}{m_D} \times p_D$. In the proposed experiment we will require a pion in the appropriate kinematic region as a constraint in the selection of the events, both at the trigger and analysis level.

We have performed a similar experiment at BNL using 10.5 GeV/c pions. We measured $\sigma B = 7 \pm 17$ nb for the reaction

$$\begin{array}{l} \pi^- + p \to D^{*-} + \Lambda_c^+ \\ \qquad\qquad\quad \lfloor\!\!\to \pi^- + \bar{D}^o \\ \qquad\qquad\qquad\qquad \lfloor\!\!\to K^+ + \pi^- \end{array} \tag{1}$$

In the BNL experiment the requirement of the extra pion in the trigger reduced the trigger rate by a factor of 30. Reconstruction reduced the background another factor of 6 for a total reduction in background of 180. Superior momentum analysis of the soft pion, proposed in this experiment, should permit additional off-line discrimination against background of another factor of 5, leading to an overall background suppression of 1000. To make the extrapolation from BNL to Fermilab energies we have assumed that the production of background follows the usual scaling laws.

Countering the substantial decrease in background is a suppression in signal which arises from losses in the competing D^* decay channels of $\gamma + D^-$ and $\pi^0 + D^-$. With the Q-value at 5.7 MeV, this loss should not exceed a factor of 2.[2)] With the background reduced by almost ~ 1000 and the signal reduced by ~ 2, the net gain in the ratio of signal to background is expected to be about 500. Of course, here we measure σ for the production of D^* as opposed to D^0. The ratio of the cross sections for D^* and D^0 production is large at SPEAR for reasons not yet understood. One cannot expect the same mechanisms to hold in hadron production. However, given the small mass difference between D's and D^*'s, it is reasonable to assume that they will be produced in comparable amounts at Fermilab energies.

This experiment requires the addition of one magnet to the E-302 setup in the target region of the experiment to analyze the soft pions. Assuming 10^7 interactions/pulse we can achieve a sensitivity of 1.5 nanobarns in σB (6 nb at the 4σ level) for $D^{*\pm}$ production in 400 hours of data taking.

The same technique allows the concurrent study of the production of the charmed baryon detected through the following decay chain:

$$\Sigma_c \rightarrow \Lambda_c + \pi_s$$
$$\qquad \hookrightarrow \Lambda + \pi_h$$
$$\qquad\qquad \hookrightarrow P + \pi_s$$

with P and π_h in the two arms and the slow pions (π_s) in the third arm. In this case both the detection efficiency and the background are somewhat lower leading to an estimated error of 2.5 nb for σB (10 nb for a 4σ effect).

We finally point out that a beam intensity as low as $5\ 10^8$ particles (P,π) per pulse is adequate for this experiment, making possible for it to be run at an early stage of the Proton West area beam development.

<u>The Spectrometer</u>

The spectrometer configuration proposed for E-302 with the additional magnet-chamber system for the charm search is shown in Fig. 1 (a and b). Figure 2 shows the set-up in the planned location at the downstream end of the new experimental hall in Proton West.

The double arm spectrometer will use two BM109 magnets with the gap opened to 14". The wider aperture will increase the acceptance for two body final states by a factor of four. Moreover it will substantially increase the sensitivity to other interesting decay modes such as those with ϕ's in the final state. With the wide gap, the magnet can be operated at a maximum $p_\perp$ of ~ 700 MeV/c. Correspondingly the error in the mass measurement at 1.86 GeV is expected to be σ_m = 5 MeV.

Particle identification will be achieved with three Cerenkov counters per arm, two upstream and one downstream of the BM109 magnets. The characteristics and operational modes of the counters are summarized in Table I. Counters 1 and 3 are standard threshold counters, while Counter 2 is operated in an hybrid differential/threshold mode. It will be built according to a new scheme developed by our group$^{3)}$ which makes possible the utilization of a differential counter in a comparatively large phase space beam.

The third spectrometer magnet is a large aperture one located about two meters downstream of the target along with a set of trigger hodoscopes and MWPC's. It will be run with a $p_\perp$ of 400 MeV/c. (A possible candidate for this magnet exists at BNL (Henry Higgins) and is shown in Fig. 1.) The MWPC's for the third arm are designed to accept all slow pions from the cascade decay of the $D^{*\pm}$ where $D^o \rightarrow \pi K$ enters the double arm spectrometer. Even so their size is quite small (.5 m x 1. m active area). With a 3-4 mm wire spacing we will achieve a resolution in the Q value of $\sigma_Q = 1$ MeV.

It will be desirable to collimate the third arm magnet aperture to inhibit direct viewing of the chambers from the target. A carefully designed magnet/collimator system in the target area will also help in the suppression of backgrounds leading to systematic errors in the C-conjugation part of the experiment.

Finally we plan to add a μ filter at the end of the two arms. In the 400 hours of the charm cross-section measurement ~ 500 $\Psi \rightarrow \mu\mu$ decays will be collected which will provide the experiment with a valuable calibration signal.

Beam, Trigger Rate and Cross Section Estimates

The maximum useful luminosity is set by the ability of the chambers closest to the target to operate in a high intensity environment. Based on the experience of the Fermilab-Michigan-Purdue group a luminosity of 10^7 interactions/pulse at 400 GeV/c is acceptable. We can operate with a pion or proton beam of $5 \times 10^8 - 10^{10}$ particles/pulse, preferably at a momentum of 200 GeV/c. The beryllium target will be of a length appropriate to yield the required interaction rate. The transverse dimensions of the beam are not critical, a 1 cm^2 beam spot would be quite adequate.

Based on the data of Ref. 4 we expect $\sim$ 800 di-hadron events/10^7 interacting particles with both laboratory momenta greater than 7 GeV/c ($\sim$ 1/2 of the D^o momentum). From our BNL experiment and scaling the particle production cross section to FNAL energies we estimate that a X30 suppression factor can be achieved in the trigger rate through the extra requirement of the slow pion. This brings the trigger rate down to $\sim 30/10^7$ interactions.

The sensitivity achieved in 400 hours of running at 10^7 interactions/pulse is 10 events/nb. For this calculation we have folded in the spectrometer acceptance of 6.5×10^{-4} at the D^o mass, determined by a Monte Carlo simulation which assumes a production cross section:

$$\frac{d\sigma}{d\,x\,dp_\perp} = (1-|x|)^3 \; p_\perp \, e^{-1.5\, p_\perp} .$$

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Given the current interest and importance of these experimental results we suggest prompt scheduling. We could begin installation in the spring of 1978 in anticipation that the first beam will become available in the high intensity Proton West area in summer 1978. We request, for this part of the experiment, 100 hours of beam for tune up and testing and 400 hours at 200 GeV/c for data taking.

References

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					Thresh. π/K	3.5 - 11
					Differential π/K	11 - 20
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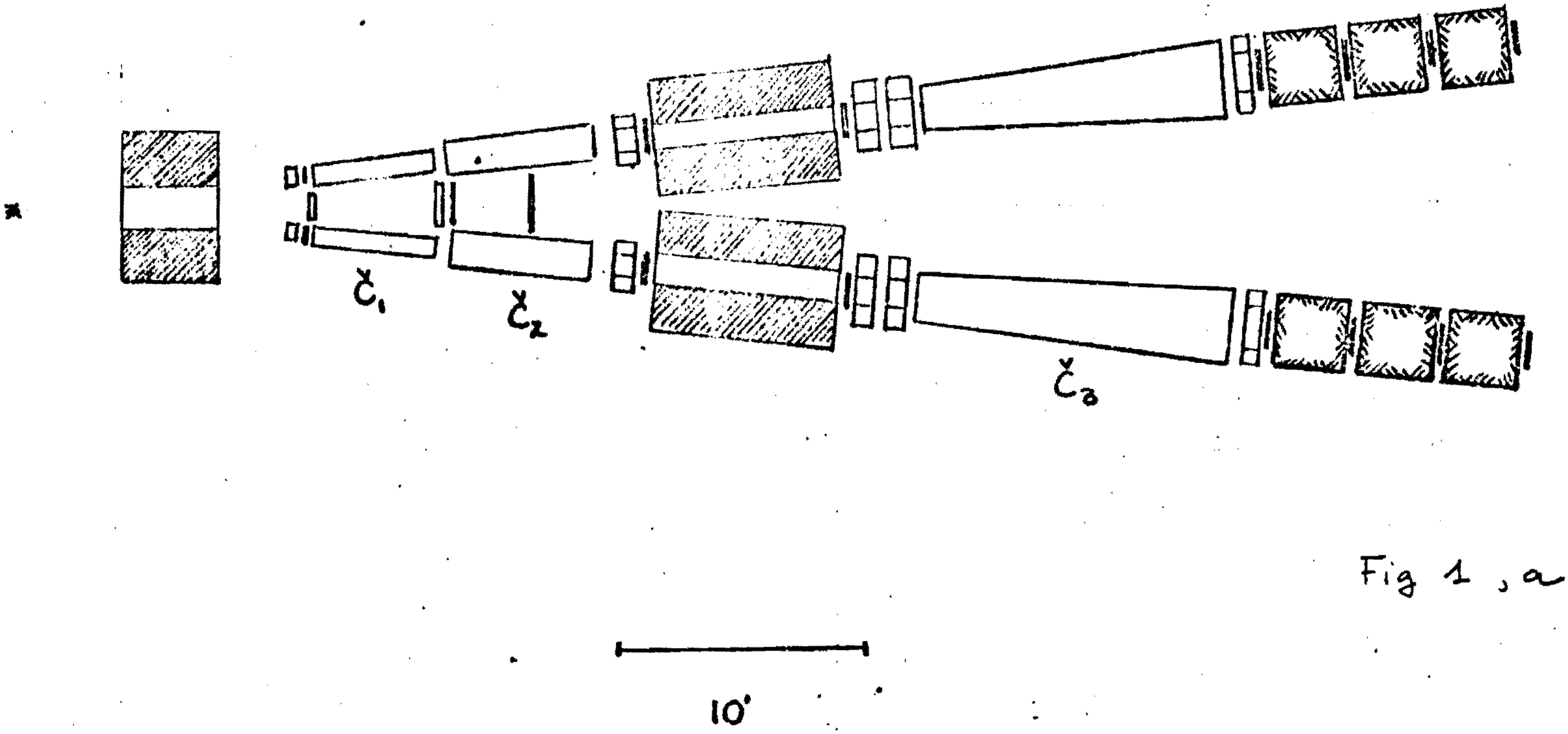
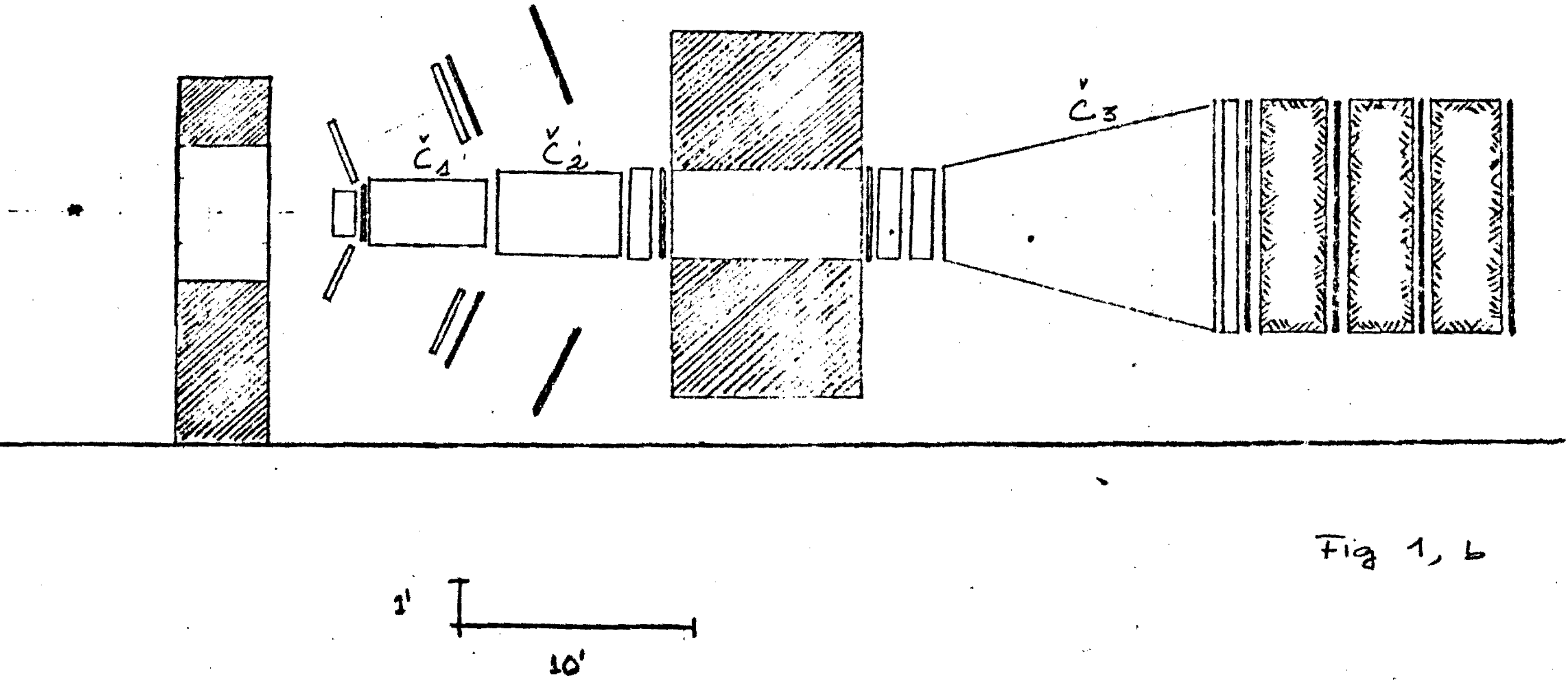


Fig 1 , a



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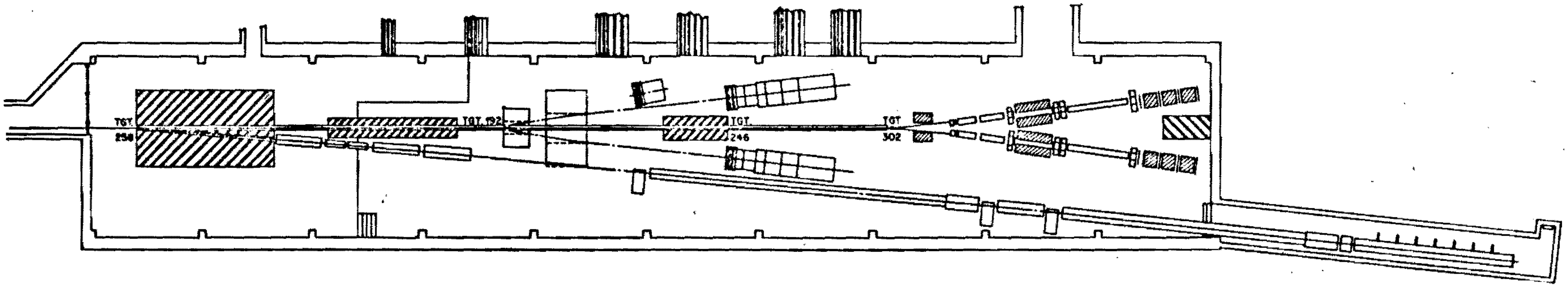

Fig. 2

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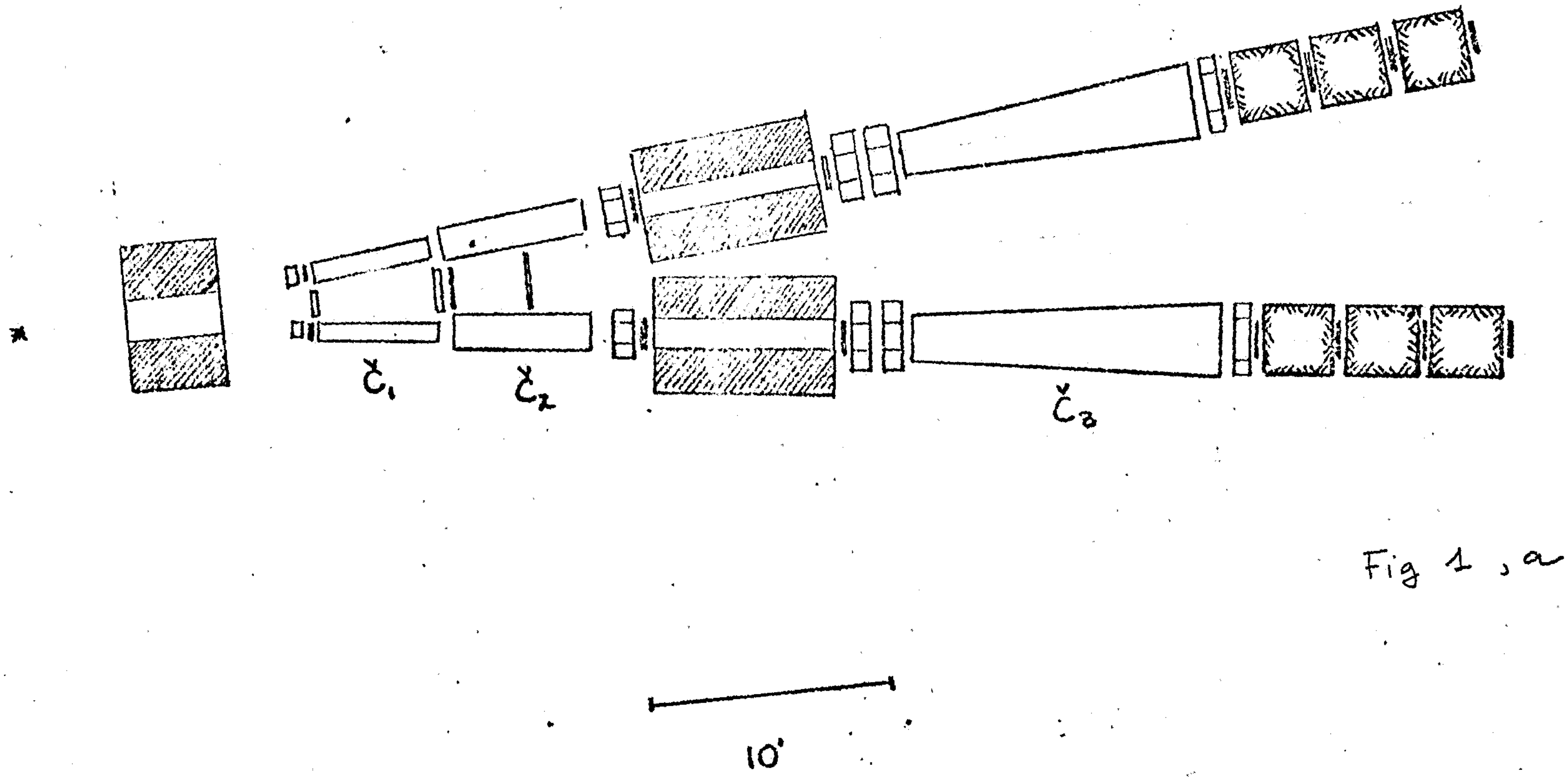

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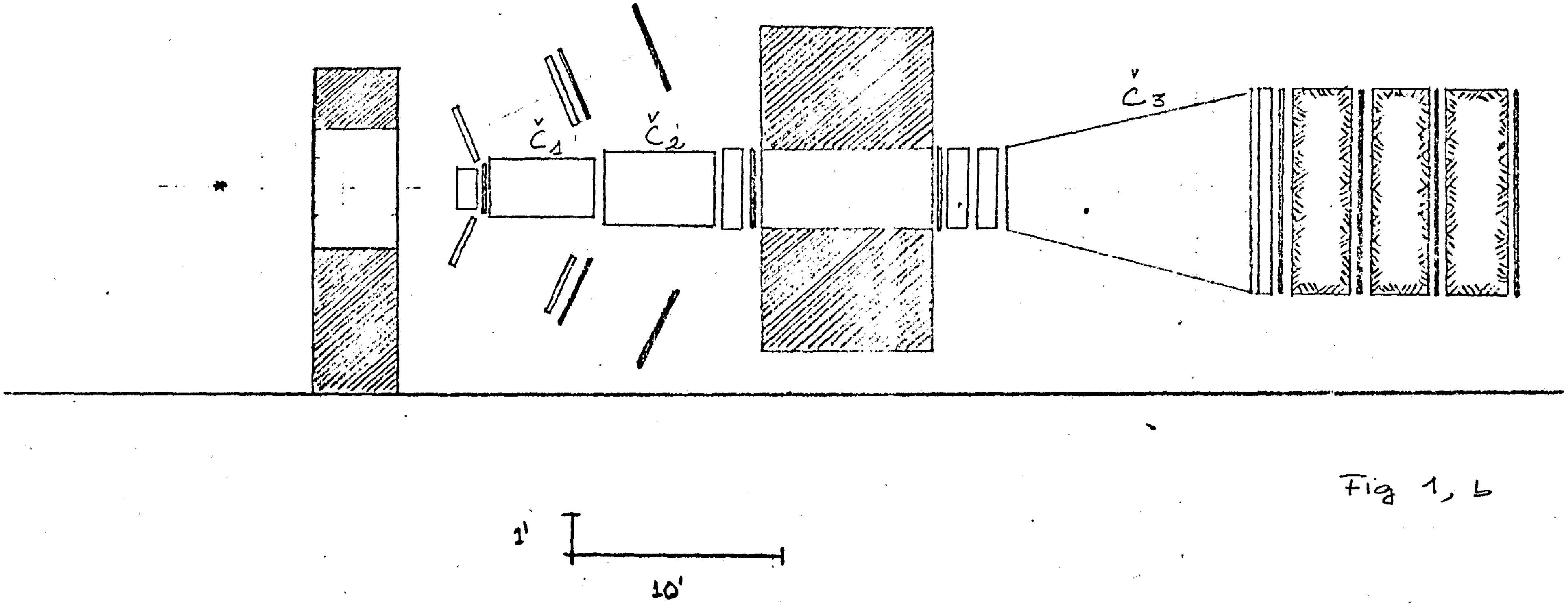

Fig 1, b

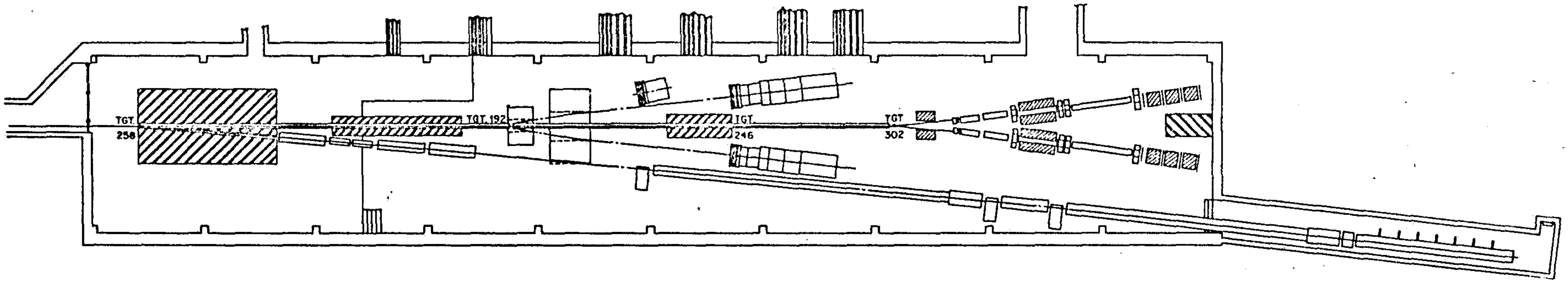

Fig. 2