A SEARCH FOR η_c IN HADRONIC INTERACTIONS

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Abstract

It is proposed to search for the production of the η_c in 400 GeV/c proton-nucleus collisions. The decay chain $\eta_c \rightarrow \phi + \phi \rightarrow K^+K^-K^+K^-$ would be detected in the E288 double arm spectrometer in the P-center experimental area. The theoretically estimated production cross section and branching fraction for this mode can be combined with the known ϕ production spectrum as measured in E357 and the known single-arm hadron rate as observed in E494 to estimate a sensitivity for this mode. We calculate that 5 $\eta_c \rightarrow 4\ K^\pm$ events will be seen in a 40 MeV wide bin superimposed on a smooth background of 1 event from non-resonant ϕ production in only 100 hours of data taking.

John: I think this should be tried as a 1-2 week quickie (then see if more). It surely will not slow up hyperon — the only question is the P-lab work load.
Len

The decay $\psi \rightarrow \gamma\, \chi(2830) \rightarrow 3\gamma$ has been seen at DESY but not at SLAC in e^+e^- interactions,[1] and the $\chi(2830) \rightarrow \gamma\gamma$ has been observed at Serpukhov[2] in $\pi^- p$ interactions. Whether the $\chi(2830)$ state is the pseudoscalar "hidden charm" partner of the $\psi(3096)$ is not clear.[3] It has been suggested that the $\chi(2830)$ could be an exotic state, while the η_c mass is higher, much closer to the ψ, thus suppressing the $\psi \rightarrow \gamma\, \eta_c$ radiative decay. The pseudoscalar η_c should couple directly to two gluons, and hence be produced in hadronic collisions more copiously than the vector ψ.[3] It is expected that the η_c will couple to two vector mesons in its decay, e.g., $\eta_c \rightarrow \phi\phi$. The $\phi \rightarrow K^+K^-$ decay mode is a kinematically favorable mode for clean experimental triggering, and it is hoped that this $\eta_c \rightarrow \phi\phi \rightarrow K^+K^-K^+K^-$ channel will lead to a favorable signal to background in the $\phi\phi$ effective mass spectrum for the proposed experiment.

Apparatus

The most recent configuration of the E288 apparatus currently residing in P-Center is shown in Fig. 1. For this search the necessary modifications to this apparatus are minimal. Figure 2 shows the detectors with which we propose to search for the η_c by detecting a K^+K^- pair from one ϕ in one arm and the K^+K^- pair from the second ϕ in the other arm. HS is a modification of H1 from E288, and HU and HD are modifications of H3 from E288. The Cerenkov counter will remain in place and be filled with CO_2 at atmospheric pressure. The E288 steel magnet and the detectors downstream of it will not be used in this search. Clearly, the largest job for Fermilab involves removing the Be absorber from the target box.

The single arm ϕ trigger for the proposed setup is $\overline{C} \cdot HS \cdot HU \cdot HD$. The feasibility of this trigger for the $\eta_c \to \phi\phi \to 4\ K$ decay chain has been studied by Monte Carlo simulation of the apparatus. We assume the η_c production dynamics are the same as ψ production for these purposes. The laboratory momentum of the four kaons is shown in Fig. 3 and demonstrates that the Cerenkov counter will adequately discriminate between kaons of the η_c decay chain from pions from other sources. Figure 4 shows the vertical distribution of kaons at the (HU,HD) plane, and demonstrates a clear spatial separation of positive and negative kaons. Figure 5 shows the vertical distribution at the HS counter of one of the two kaons in one arm, and demonstrates that at least one of the two kaons will strike this small counter. Thus, the requirements of the trigger are satisfied for $\eta_c \to \phi\phi \to 4\ K$.

Rates

The proposed apparatus is quite similar to previous experiments E494 and E357. By examining the hadron rates observed in those experiments it can be estimated what singles rates will be observed in the proposed setup. Various extrapolations to our geometry (including the effects of the neutral particles in the aperture) yield a rate of single arm charged hadron trigger rate of 2 to 5 x 10^6/pulse with 10^9 interactions/pulse in the target. In E494 and E288 we have successfully run our detectors at 2 x 10^6/pulse. The single rates in an individual counter may be a factor of five higher than these trigger rates. By requiring two particles in each arm, the trigger rate due to random four particle coincidences is estimated to be ~100/pulse for 3 x 10^8 interactions/pulse.

Expected Yield

Following the suggestion of Lipkin that

$$\sigma B(\eta_c \to \phi\phi) \simeq \sigma B(\psi \to \mu\mu),$$

we have calculated the expected event rate. The acceptance for the $\eta_c \to 4$ K decay chain was calculated by assuming that the η_c is produced with a p_T and y distribution similar to the ψ. Since our apparatus accepts events only in a very small region around $p_T = 0$, $y = 0$ (see Fig 6) we are very insensitive to these assumed distributions; however, we are indeed assuming that $B_{\phi\phi} \left.\frac{d\sigma(\eta_c)}{dy}\right|_{y=0} \simeq B_{\mu\mu} \left.\frac{d\sigma(\psi)}{dy}\right|_{y=0} = 10$ nb. The expected number of η_c's in 100 hours of running with 3×10^8 interactions per pulse is 100 hr x 360 pulses/hr 3x 10^8 interactions/pulse x (10^{-32} cm^2/33 x 10^{-27} cm^2/interaction) x (2 x 10^{-5} x 0.32 x 0.24), which yields 5 η_c in 100 hours. The last three factors take into account the geometry of the apparatus, Fig 7, a 68% loss due to decays of the 4 kaons (the average kaon momentum is ~9 GeV/c), and the branching fraction $(\phi \to K^+K^-)^2 = (0.486)^2$.

Resolution

The invariant mass resolution for the η_c is based on the E494/E288 analysis (with the Be absorber removed) and a $p_\perp$ kick of 0.3 GeV/c in the magnets. The contribution to $\Delta M_\eta / M_\eta$ from the various sources are

- 0.26% multiple scattering
- 0.18% momentum measurement error
- 0.09% opening angle
- 0.10% natural width of the ϕ

Adding these contributions in quadrature yields 0.34% for $\Delta M/M$ or $\approx$ 40 MeV FWHM at M = 3100 MeV.

Expected Non-Resonant $\phi\phi$ Background

The $\phi\phi$ background at the η_c mass has been estimated from the inclusive ϕ production measurements of E472[4] and the dihadron correlation measurements of E357 and E494.[5] The correlation function R relates the invariant six-fold differential $\phi\phi$ cross section to two invariant three-fold differential ϕ cross sections as

$$E_1 \, E_2 \frac{d^6\sigma}{dp_1{}^3 \, dp_2{}^3} = \frac{R}{\sigma_{in}} \; E_1 \frac{d^3\sigma}{dp_1{}^3} \; E_2 \frac{d^3\sigma}{dp_2{}^3} \quad .$$

From E472, E $d^3\sigma/dp^3 \simeq 2.2 \times 10^{-29}$ cm^2/GeV^2 for p Be $\rightarrow \phi x$ near $y = 0$ and $p_\perp \simeq 1.17$ GeV/c. The ϕ momentum in the η_c center of mass frame is 1.17 GeV/c. From E357 and E494, the dihadron correlation function near $p_{\perp 1} \simeq p_{\perp 2} \simeq 1.17$ GeV/c is $R \simeq 2$ to 3 independent of particle species. Assuming the same correlation for $\phi\phi$ pairs one obtains[6]

$$E_1 \; E_2 \frac{d^6\sigma}{dp_1{}^3 \; dp_2{}^3} \simeq 6.6 \times 10^{-33} \text{ cm}^2/\text{GeV}^4$$

for p Be $\rightarrow \phi\phi x$.

The transformation of the six-fold differential cross section into an appropriate four-fold differential cross section yields the cross section for the background (B):

$$E_B \frac{d^4\sigma}{dM_B \; dp_B{}^3} \approx 1.12 \times 10^{-31} \text{ cm}^2/\text{GeV}^3.$$

This is evaluated with the constraints that the $\phi\phi$ background pair be produced at $y = 0$ with net $p_\perp = 0$ and invariant mass equal to 3.1 GeV = M_{η_c}. An integration over the 40 MeV mass resolution of the apparatus yields

$$E_B \frac{d^3\sigma}{dp_B{}^3} = 4.5 \times 10^{-33} \text{ cm}^2/\text{GeV}^2$$

for $\phi\phi$ background in p Be collisions.

With the assumption that the A dependence of the ψ is linear and that the $\eta_c \rightarrow \phi\phi$ cross section is equal to the $\psi \rightarrow \mu\mu$ cross section (35×10^{-34}/nucleon at $p_\perp = 0$, $y = 0$)[7] one obtains

$$E \frac{d^3\sigma(\eta_c \to \phi\phi)}{dp^3} = 3.2 \times 10^{-32}\ \mathrm{cm}^2/\mathrm{GeV}^2$$

in p Be collisions. This yields signal/background = 7; i.e. ~1 background event in 100 hours in the bin with ~5 η_c's.

Preparations

There are only two time-consuming items needed before running the η_c search: the removal of the Be absorber and the modifications to the trigger counters. The Proton Lab has estimated that the Be removal will take about one week if given a reasonable priority. The trigger counter modification and the checking-out and tuning-up of the apparatus will take two weeks. We assume that the first weekend we get beam will be devoted to turning-on and tuning-up the apparatus after the long hiatus since E288 stopped data-taking. In the second weekend of running, we should be able to see the η_c if the production cross section times $\phi\phi$ branching fraction is larger than one-half that predicted. We believe this opportunity to possibly see the η_c justifies quick approval and the interruption in the charged hyperon installation of two weekends.

REFERENCES

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[3] C. Quigg and J. L. Rosner, Phys. Rev. D 16, 1497 (1977); H. J. Lipkin, H. R. Rubinstein, N. Isgur, Weizmann Institute Preprint WIS-78/23 Ph.; K. Gottfried, in Proc. Intl. Symp. on Lepton and Photon Interactions at High Energies, edited by F. Gutbrod, Hamburg 1977, DESY, Hamburg, 1977, p. 667; H. Thacker, private communication.

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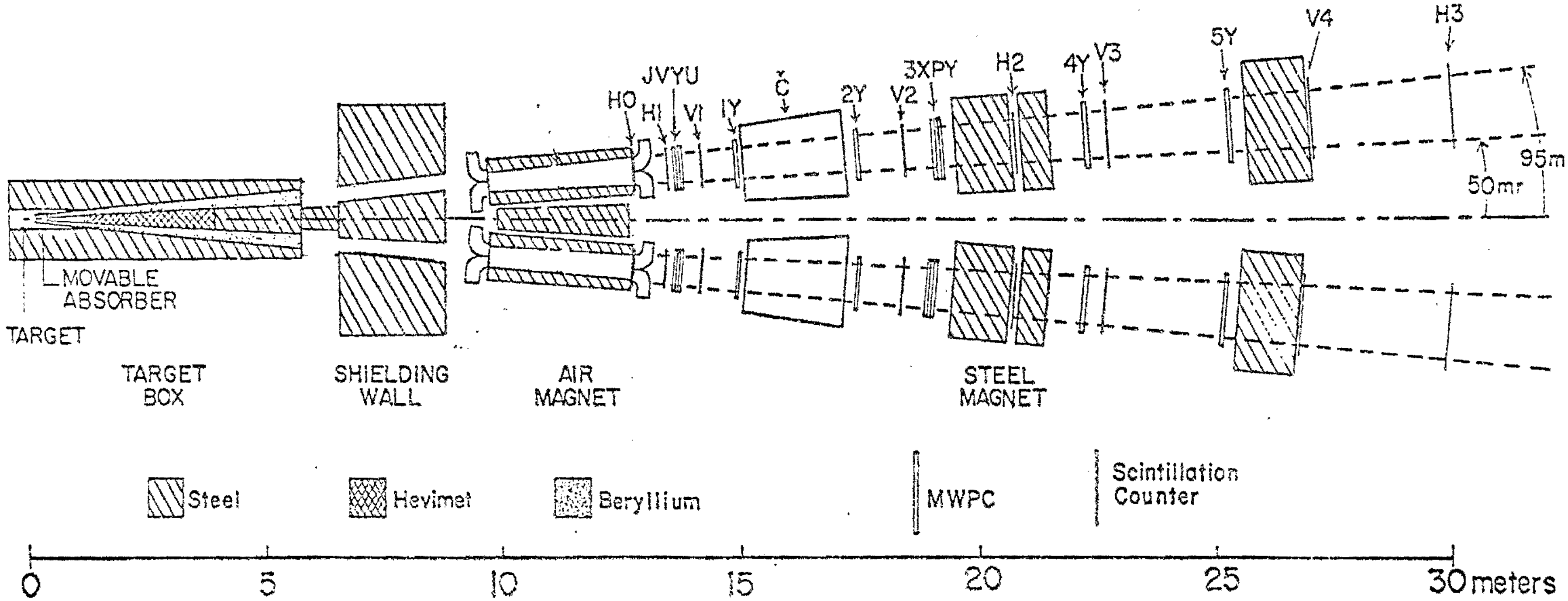
[5] D. A. Finley, PhD thesis, Purdue University (1978) and R. J. Fisk, PhD thesis, SUNY at Stony Brook (1978).

[6] We use σ_{in} = 219 mb for Be.

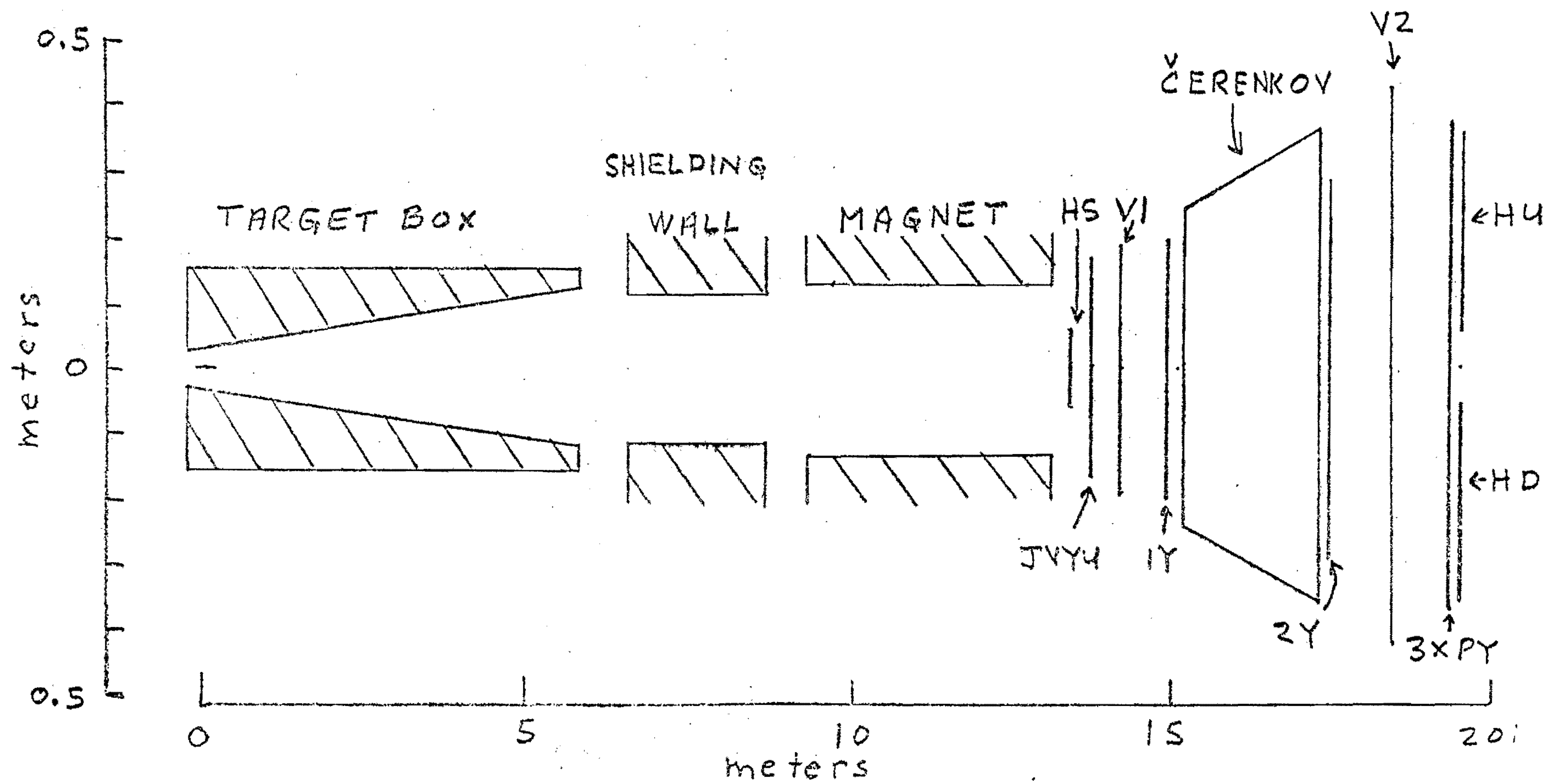
[7] B. C. Brown et al., Fermilab Preprint 77/54-Exp (June 1977).



PLAN VIEW OF APPARATUS

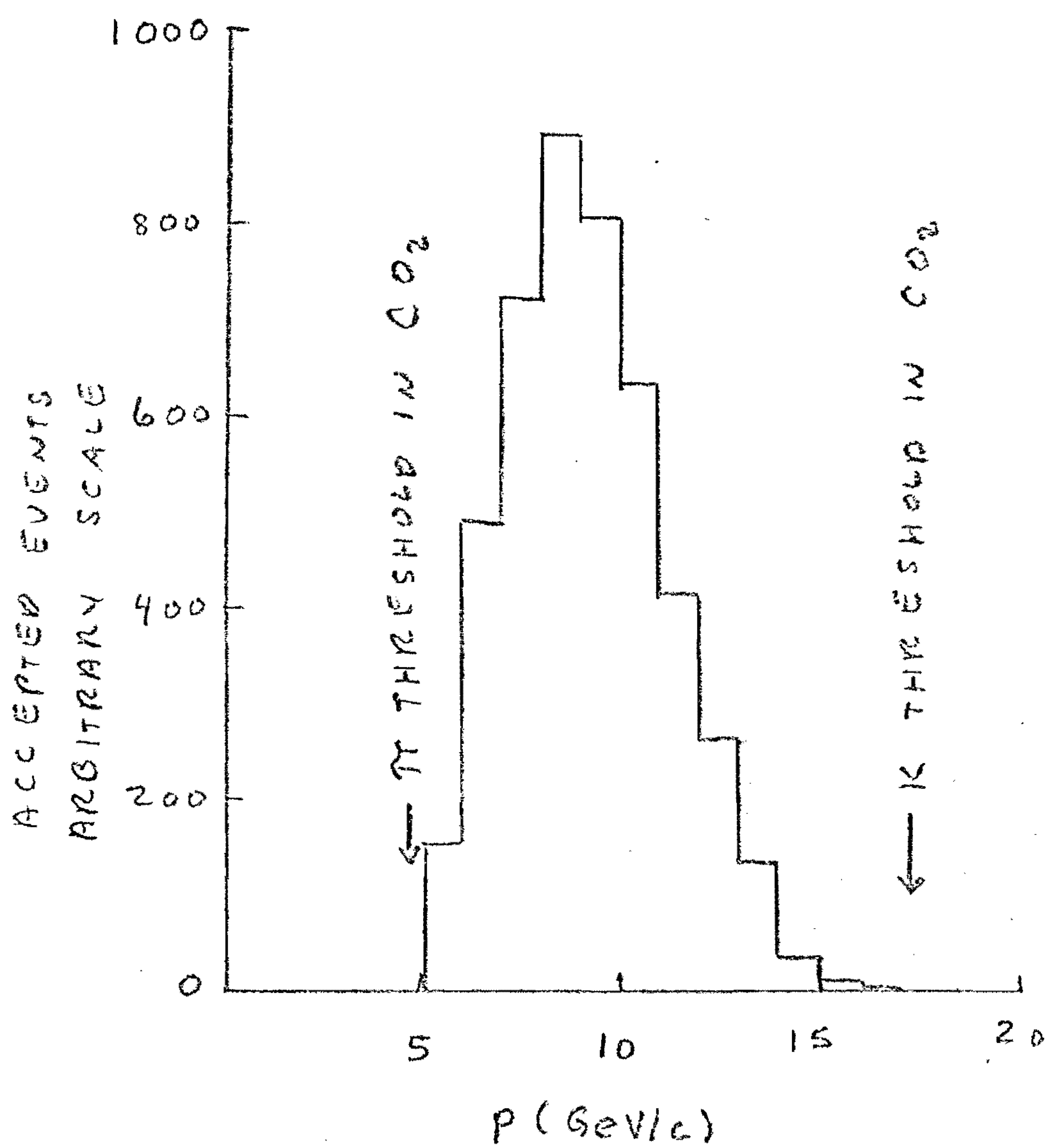
FIGURE 1.

Fig. 2. SIDE VIEW SCHEMATIC



$\eta_c \to \phi\phi$

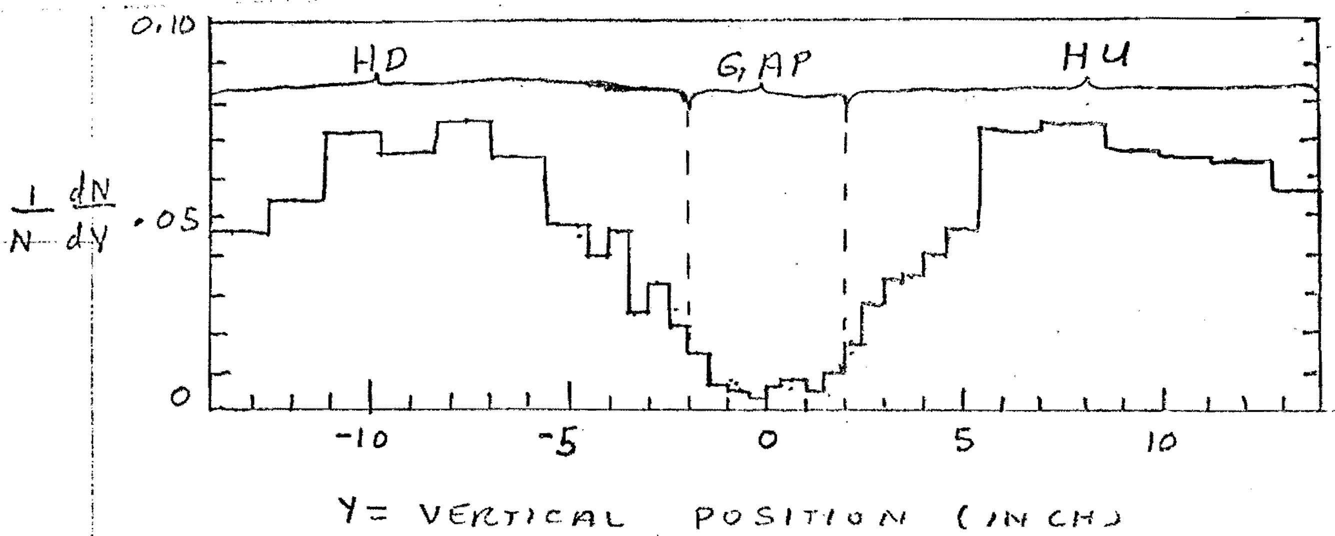
Fig. 3. KAON MOMENTUM DISTRIBUTION



$\eta_c \rightarrow \phi\phi \rightarrow 4K$

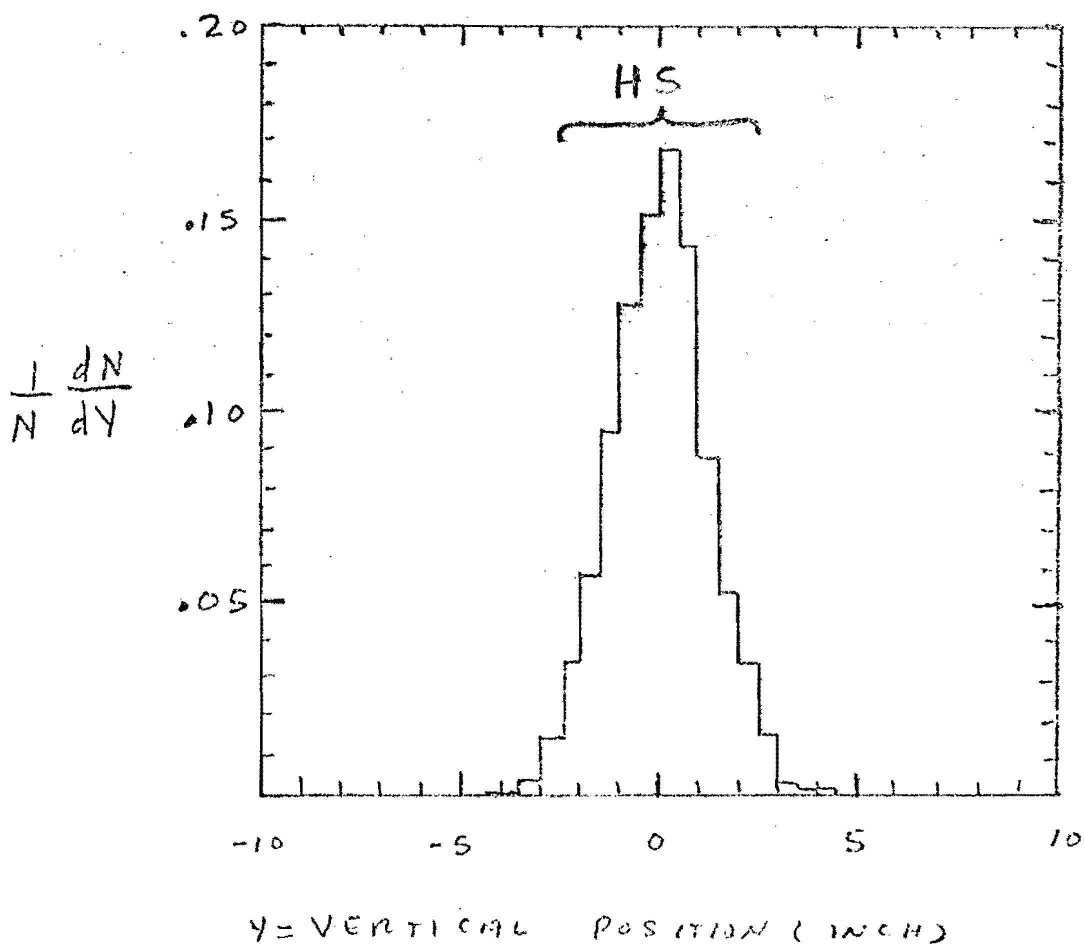
$M_\eta = 3.1$ GeV

Fig. 4. KAON SPATIAL DISTRIBUTION AT HU, HD

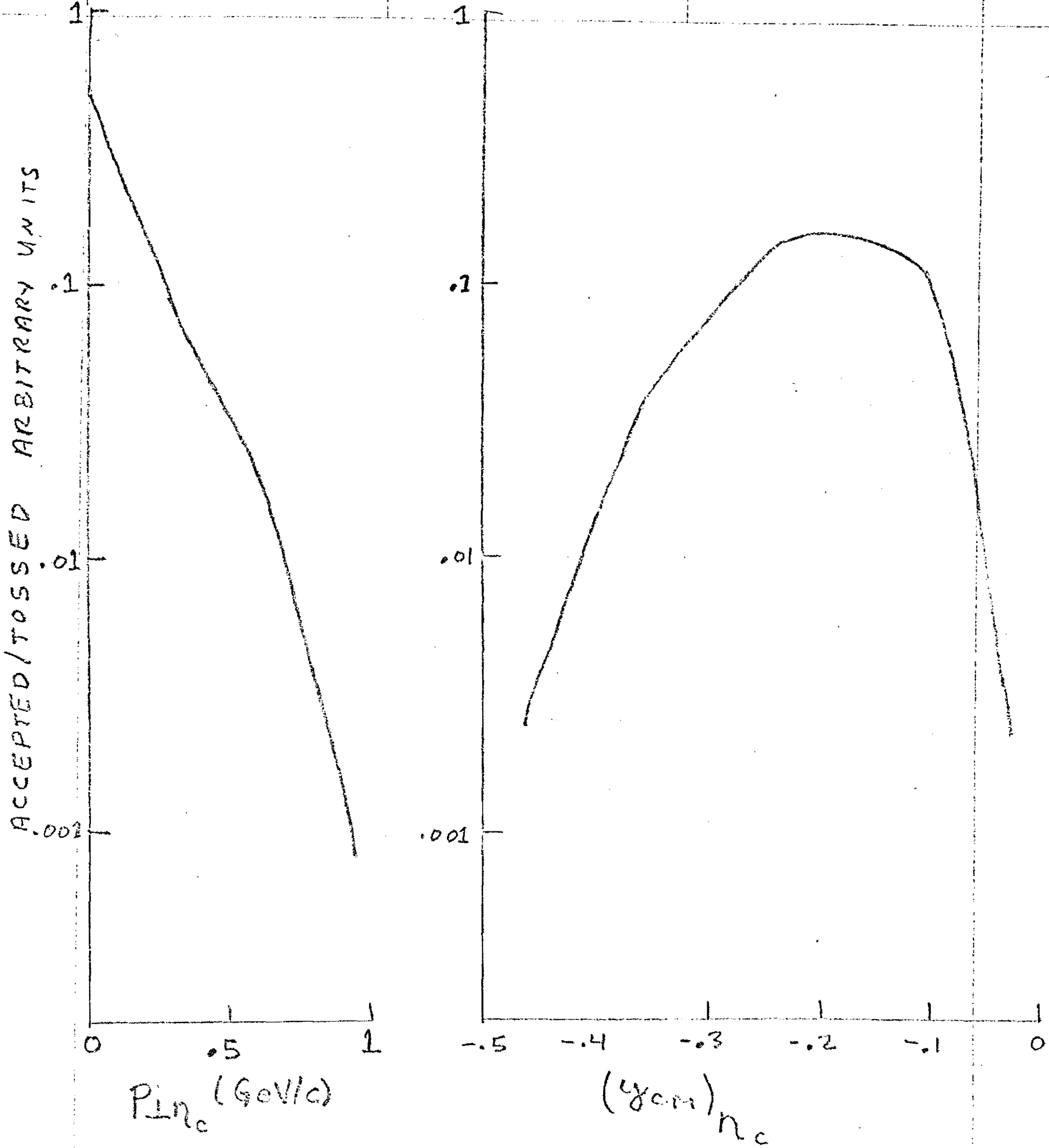


$\eta_c \to \phi\phi \to 4K$ $M = 3.1$ GeV

Fig. 5 KAON SPATIAL DISTRIBUTION AT HS*



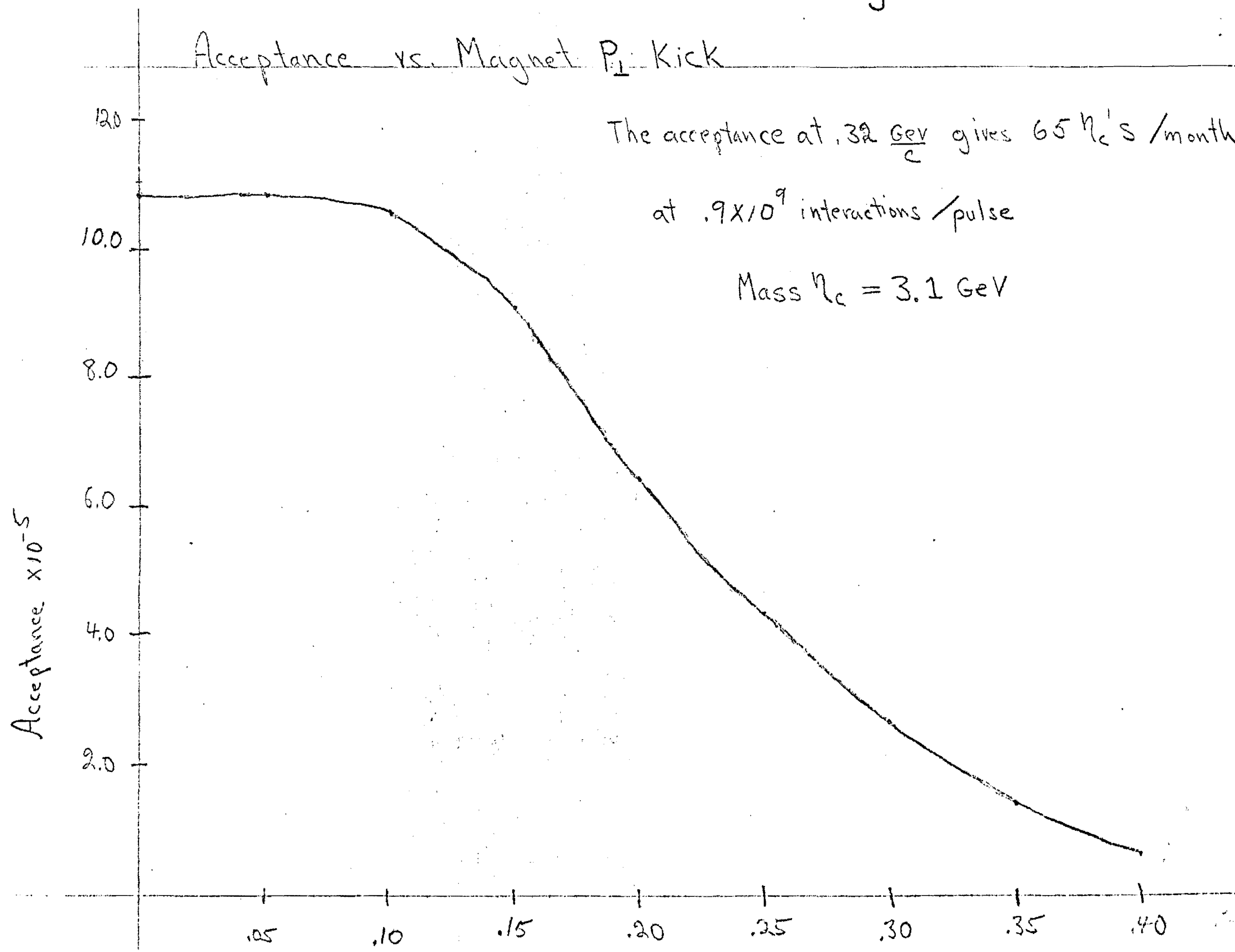
* OF THE TWO KAONS IN AN ARM, ONLY THE KAON WITH COORDINATE CLOSEST TO Y=0 IS SHOWN.



$\eta_c \to \phi\phi \quad M_\eta = 3.1$ GeV

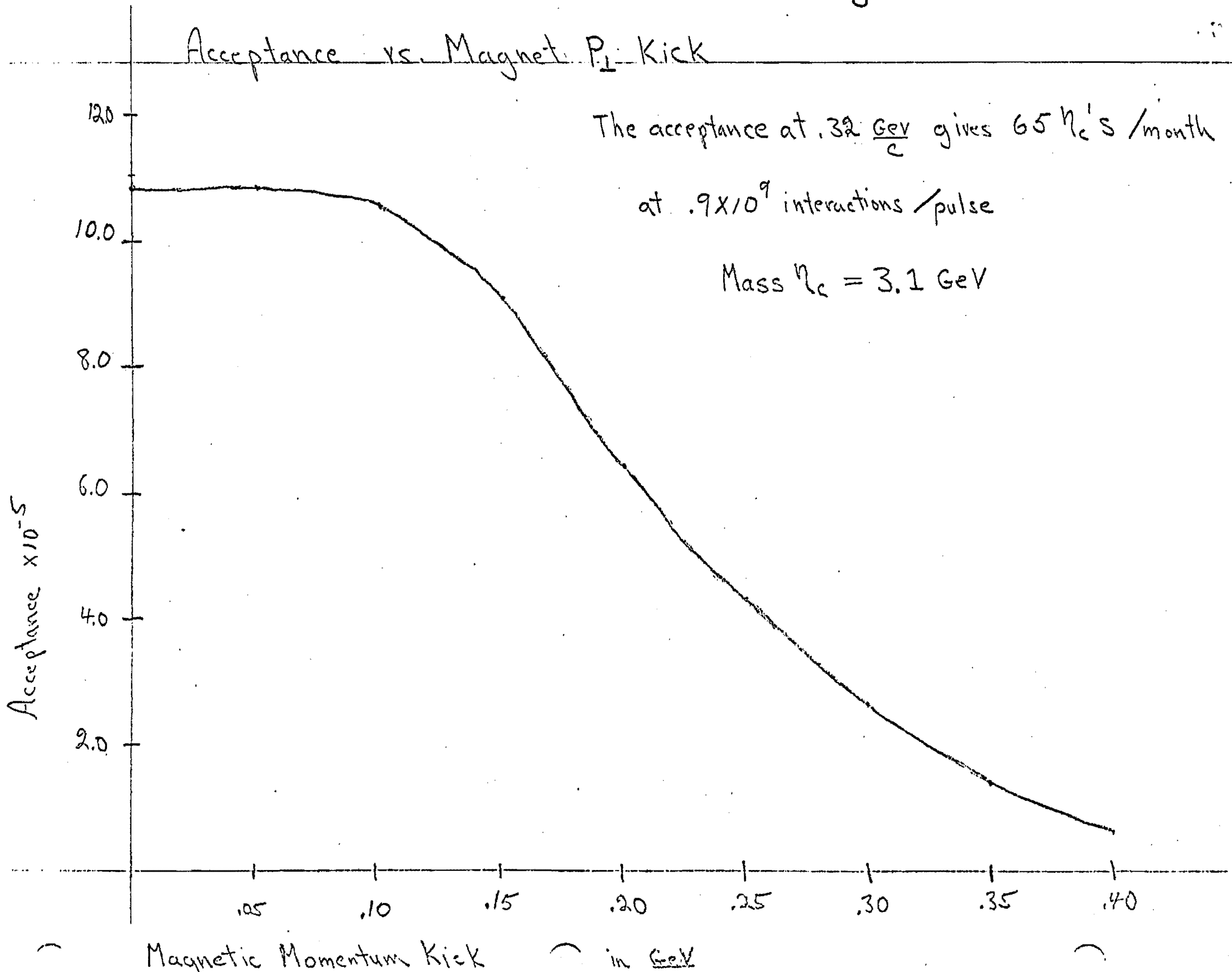
Fig. 6

Figure 7



Acceptance vs. Magnet $P_\perp$ Kick
The acceptance at .32 Gev/c gives 65 η_c's /month
at .9X10^9 interactions /pulse
Mass η_c = 3.1 GeV
Acceptance X10^-5
12.0
10.0
8.0
6.0
4.0
2.0
.05
.10
.15
.20
.25
.30
.35
.40

Figure 7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12.0
10.0
8.0
6.0
4.0
2.0
Acceptance X10^{-5}
.05
.10
.15
.20
.25
.30
.35
.40
Magnetic Momentum Kick in GeV