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A Study of the Forward Production of Massive Particles

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A Study of the Forward Production of Massive Particles

1. Introduction

An important class of hadron reactions remains largely unexplored by modern high sensitivity, high resolution experiments. These are reactions which proceed through non-diffractive t-channel exchanges to produce a high-mass particle in the forward direction. Although the cross sections are in the nanobarn range these processes have unique kinematic features which may substantially improve the signal-to-background levels compared with the much-studied region near $x = 0$. The kinematics is also well suited to high sensitivity studies where a selective trigger is essential.

The proposed experiment is designed to use a beam of 10^{10} pions/pulse and offers ~ 8 % acceptance for two body decays within the accepted mass bite. This yields a sensitivity of about 2400 events/picobarn in a 1000 hr. run. The mass resolution is 0.5%.

We propose to use a high flux pion beam at 50 GeV and to study the mass spectrum from 1 to 4 GeV/c^2. The 2-body final states $K\pi$, $p\bar{p}$, lepton-hadron, and lepton-lepton would be detected.

Although the experiment is a sensitive search in a relatively unexplored kinematic region, there are some obvious reactions of interest. These include $\pi N \rightarrow DC$ (with $D \rightarrow K\pi$) (associated production of a charmed meson and charmed baryon) and $\pi N \rightarrow \eta_c N$ (with $\eta_c \rightarrow p\bar{p}$). The rate of detected events is estimated to be over 100 events/hour both reactions. The former reaction is of particular interest since if it were detected with sufficient cross section the charmed baryon mass spectrum could be studied by missing mass techniques.

2. Apparatus

The detector exploits the fact that the forward going particle carries almost all the energy of the incident beam and is produced with a transverse momentum of only a few hundred MeV/c. Thus the P_T of the decay products is largely determined by the mass of the parent.

The detector consists of two parts, shown schematically in Fig. 1. The first part magnetically selects pairs of particles in a mass region of interest while the second part analyzes the pair-mass with high resolution and identifies the mass of each track.

The mass selecting system is shown in detail in Fig. 2. It is a set of dipoles located just after the target which causes secondaries of a given P_T to cross the beam axis a fixed distance downstream. Since the secondaries from the 2-body decays of interest have nearly equal and opposite P_T both particles cross the beam axis at the same downstream point (~ 9 m from the target). An adjustable collimating slit ~ 20 cm x 60 cm aperture is located at this point. The mass of the selected system is determined by the fields in the magnets while the accuracy is determined by the slit aperture in the bend plane. The transverse position of a particle at the slit is given by

$$x = \frac{L}{P_L} \left(P_T - \frac{\Delta P_T}{2}\right)$$

where ΔP_T and L are the P_T - kick and length of the dipole system and P_T and P_L are the transverse and longitudinal momenta of the particle.

The downstream face of the mass selecting system is well shielded except for the small exit aperture. A hevimet plug is located in the neutral secondary beam, half-way through the dipoles, to protect the analyzing spectrometer from neutrals. The plug is far enough downstream so it does not intercept the non-interacting beam. This beam is bent to one side and transported downstream to a dump behind the detector. An important feature of this system is that no detector element of the downstream spectrometer views the target directly.

The mass selection system has been designed with standard ANL beam-line dipoles. The gap height in the four magnets is 6-in., 15-in., 22.5-in., and 30-in. to accommodate the divergence in the non-bend plane.

Downstream from the mass slit is a high resolution spectrometer. The exact design will depend on the magnet available. Figure 1 shows a design based on a magnet with a 2-m wide aperture, a 1-m high gap and a P_T-kick of 0.5 GeV/c. For a given mass setting of the upstream magnets two regions 60 cm by 1 m are illuminated on the entrance aperture of the analyzing magnet. The position of these regions varies with the mass setting.

It should be noted that for the trigger, the momentum of tracks entering the analyzing spectrometer is already closely correlated with position.

Thus fairly precise requirements on the mass and total momentum of the triggering pair can be imposed at the trigger level. It would be expected to have a two level trigger, the first using standard NIM electronics and the second based on a custom digital processor. The data acquisition system would be designed to handle ~1000 events/pulse.

Gas Cerenkov counters are used for π, K, $\bar{p}$ separation. A lepton identifier is placed at the downstream end of the detector.

The mass resolution of the system is limited by multiple scattering in the 0.2 absorption length beryllium target to ~ 7 MeV/c at the D mass.

3. Beam

A high flux pion beam with good spot size is required. The new M1 beam is particularly attractive. It appears that at a momentum as low as 50 GeV/c the horizontal and vertical acceptance of this beam can be each doubled by using a tune with half the wavelength of the standard tune. This increases the low momentum flux by at least a factor of 4 and leads to a yield at 50 GeV/c of over 10^{10}/pulse for 5 x 10^{12} interacting protons. If fluxes larger than this are available the momentum bite of the beam would be reduced.

Muons are a potentially serious problem with this beam and must be carefully handled. At 50 GeV/c over 20% of the pions and 80% of the kaons decay in the first 960 feet. Spoilers are probably required and possibly a sharp bend just before the target.

4. Rates

The acceptance of the mass selection system is determined for the reaction $\pi N \to DC$, $D \to K\pi$, by Monte Carlo calculation, using the t-distribution estimated by Field and Quigg[1] of $e^{-3.5\,t}$. We find an 8% acceptance. Assuming that the analyzing spectrometer has complete acceptance for these events the event rate/hour/picobarn of production cross section ($B\sigma$) is:

$$\frac{10^{-36}\,(\text{cm}^2/\text{pb}) \times (2 \times 10^{9})\,(\text{interacting}\,\pi/\text{pulse}) \times 300\,(\text{pulse/hr}) \times 0.08\,(\text{acceptance})}{20 \times 10^{-27}\,(\text{cm}^2)}$$

= 2.4 ev/pb/hr.

Thus in a 1000 hour experiment one could hope to collect 2400 events per picobarn.

The total cross section for $\pi N \to D\,C$ where C is any system with a mass less than 3.5 GeV/c^2 is estimated by Field and Quigg to be 2.5 nb at E_{inc} = 50 GeV. This yields an event rate from D's in the $K\pi$ channel of

2500 pb x 0.018 (probability of D to $K\pi$) x 2.4 ev/hr/pb

= 108 events/hr.

It should be noted however that the cross section to particular charmed baryon channels are estimated to be ~ 300 times smaller.

The $K\pi$ coincidence background is a major concern and is very difficult to estimate. The contribution from one exclusive channel, namely $\pi p \to K^*(1780)n$, $K^* \to K\pi$, is estimated to be 400 pb if 1% of this cross section lies in the mass bite of interest.[2] The contribution through this channel from the K-component of the beam is about 15% of the above due to the small fraction of kaons which reach the target.

We are investigating methods to improve the signal to background ratio for D production in the $K\pi$ channel. One possibility is the Fitch method of detecting a coincident pion arising from $D^* \to D^0\pi$. The Q-value in this decay is only about 6 MeV so that the pion comes off close to the D^* direction. In this experiment the pion would be detected by bringing it out in a channel through the spacer plates used to open up the gaps of the mass selecting dipoles.

A second interesting reaction with cross section estimates available[1] is $\pi p \to \eta_c n$. If one assumes that $|\langle \frac{u\bar{u} + d\bar{d}}{\sqrt{2}} | \eta_c \rangle|^2$ is 1% as suggested, then $\sigma(\pi p \to \eta_c n) \sim 80$ nb at 50 GeV. If the branching rato of η_c to $p\bar{p}$ is taken to be the same as the J/ψ (2×10^{-3}) then the event rate is

$$80 \times 10^3 \text{ (pb)} \times (2 \times 10^{-3}) \times 2.4 \text{ (ev/pb)}$$

$$= 380 \text{ events/hr.}$$

5. Request

We request 1000 hours of data taking in a 50 GeV pion beam with 10^{10} pions/pulse and a good spot size. The latter is necessary for good mass resolution. We would need the mass selecting and analyzing magnets, an on-line computer system and PREP electronics. We would expect to supply the PWC's, scintillator hodoscopes, Cerenkov counters, and special triggering logic.

6. Conclusion

This experiment would explore a unique class of reactions which have received little attention at Fermilab. It is designed to exploit the high sensitivities offered by the high flux pion beams. The experiment is sensitive to several reactions of current topical interest as well as having more general capabilities. In particular the mass spectrum of lepton-hadron final states is largely unstudied and could reflect semi-leptonic decays of a more massive system.

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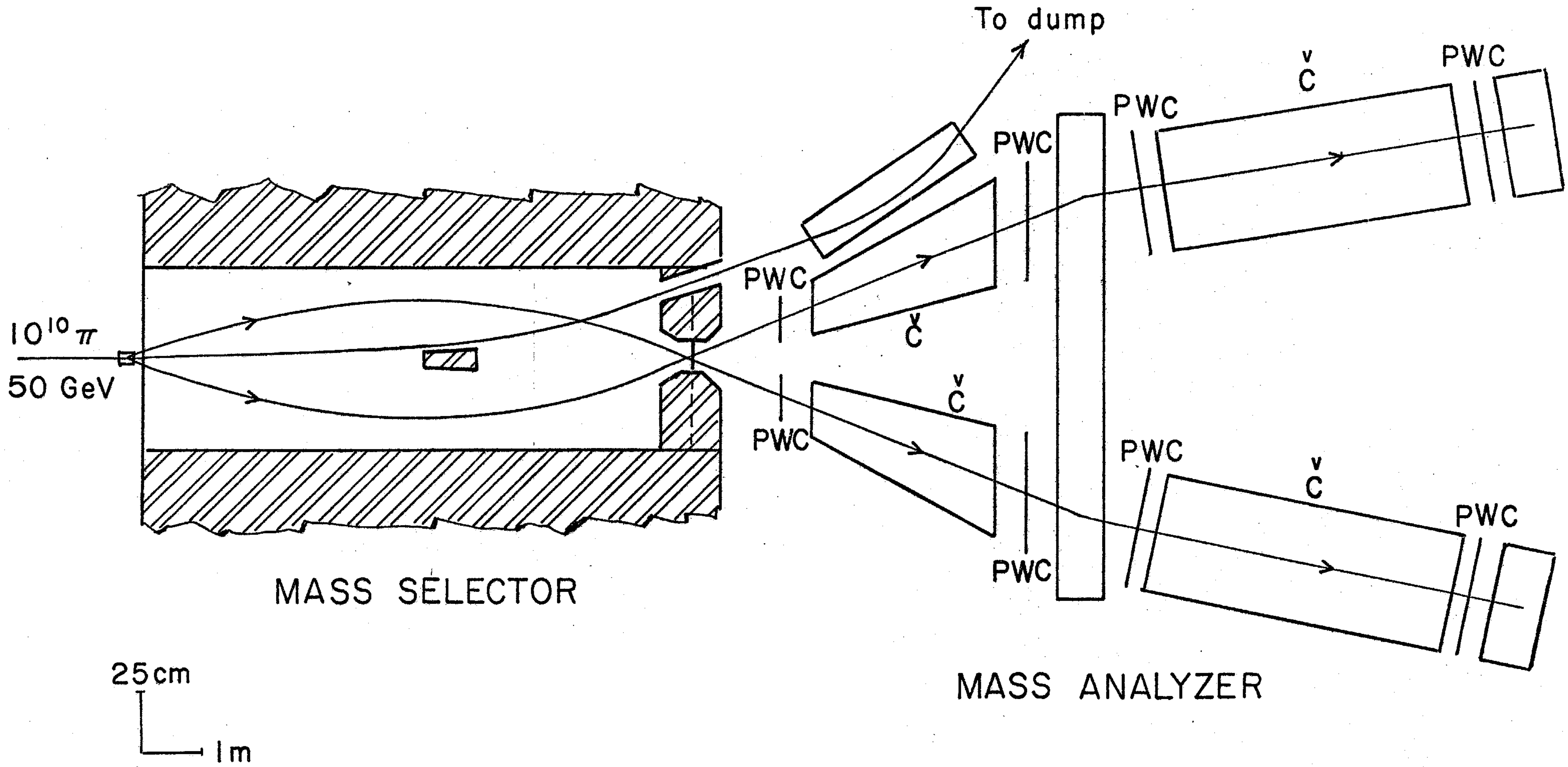
To dump
PWC
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$10^{10}\pi$
50 GeV
PWC
PWC
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PWC
PWC
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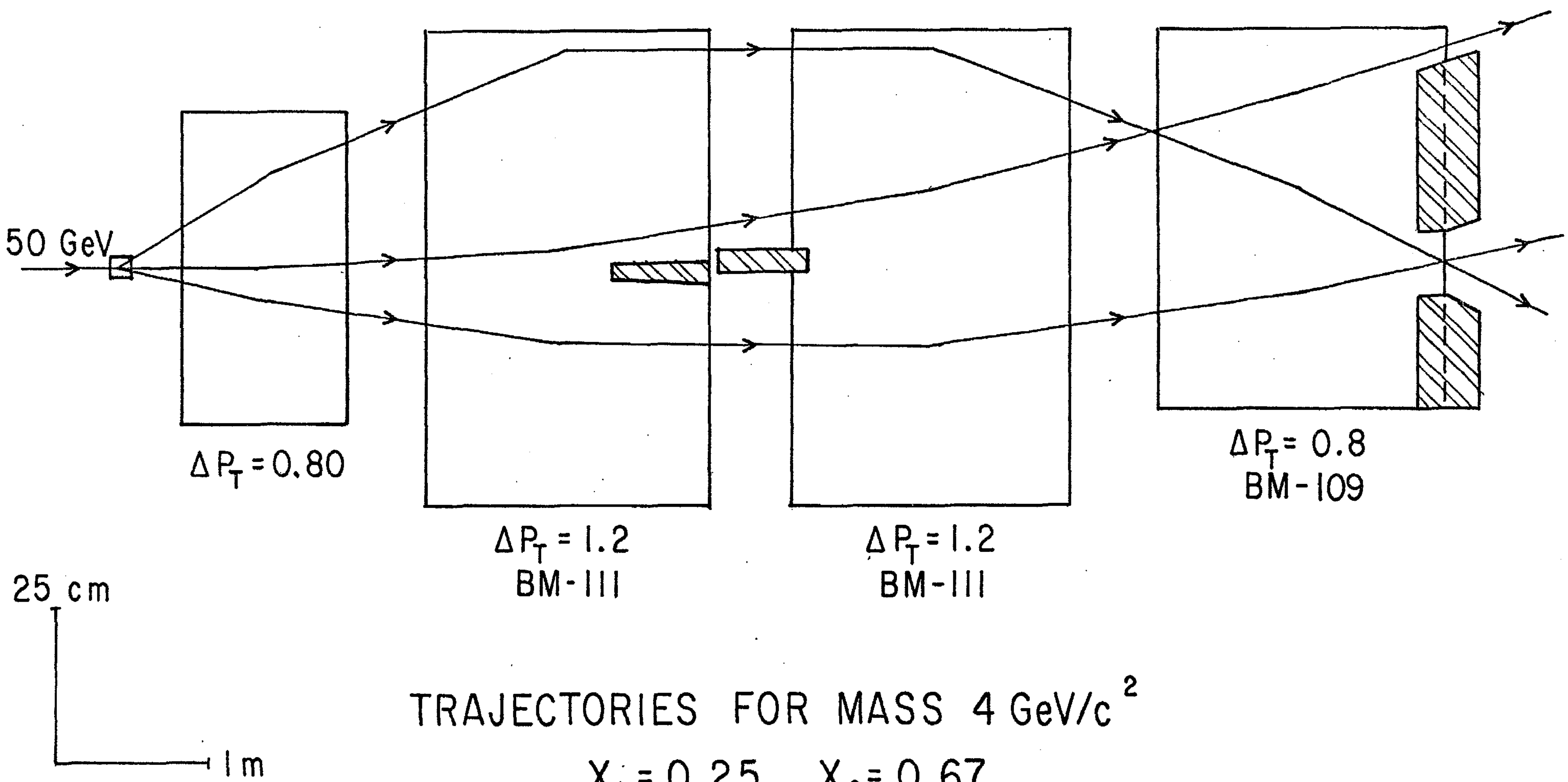
PWC
MASS SELECTOR
MASS ANALYZER
25cm
1m

Figure 1



TRAJECTORIES FOR MASS 4 GeV/c^2

$X_1 = 0.25$, $X_2 = 0.67$

Figure 2

ADDENDUM TO PROPOSAL 615

A First Phase to Study Forward Produced μ-pairs

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ADDENDUM TO P-615

I. INTRODUCTION

There have been a number of developments in P-615 since its review by the PAC.

First, we find that the P-West beam would be acceptable and the overall cost of the experiment would be reduced by a factor of ~ 2.5 from earlier estimates of the Meson Department. The details are outlined below.

Second, new physics results have come to light which suggest that an important first phase of the experiment is a study of μ-pairs produced in the forward direction. This measurement is technically easier than the hadron pair study and the physics issues are well defined. A desire to study this channel was expressed in the original proposal although the case was not developed. We are still very much interested in forward hadron pairs but would propose this as a Phase II study. Presently approved experiments are poorly suited to study forward μ-pairs because they contain toroidal field geometries and/or beam dumps which lead to poor acceptance at large x_F.

II. PHYSICS MOTIVATION

There is mounting evidence that μ-pair production in πN interactions occurs through quark-antiquark annihilation. If this is the mechanism, it offers a method of measuring the quark structure function of the pion. Tests of the model and a structure function determination were done in Fermilab's E-444.[1,2] The structure function is obtained from a measurement of the cross section in terms of Feynman-x of the μ-pair (x_F) and the pair mass M. The x-values of the two annihilating quarks (x_1 and x_2) are given by energy-momentum conservation, neglecting transverse momenta, as

$$x_1 x_2 = M^2/s$$

$$x_1 - x_2 = x_F$$

Berger and Brodsky[3] have pointed out that in the kinematic region where the x of the quark from the pion (x_1) becomes large, the quark goes off shell.

More explicitly, the quark's Q^2 goes like $k_T^2/(1-x_1)$ where k_T is the quark transverse momentum. Thus the kinematic region $x_1 \to 1$ probes the "far-off-shell, short distance internal dynamics of the hadron wave function."[3] It is reasonable to expect that in this high momentum transfer limit one may understand the process in terms of a model based on QCD.

Berger and Brodsky invoke a simple model involving single-gluon exchange between the valence quarks of the pion. They conclude that the cross section for the $\pi N \to \mu^+\mu^- + \ldots$ should go like

$$(1-x_1)^2\ (1+\cos^2\theta)\ +\ \frac{4}{9}\ \langle k_T^2\rangle/M^2\ \sin^2\theta$$

in the large x_1 region. The first term is the scaling component of the cross section and corresponds to transverse polarization of the virtual photons. The second term is explicitly scale breaking and is identified with longitudinal polarization.

These predictions have been compared with the E-444 data. If a $\sin^2\theta$ component develops in the angular distribution for large x_1 and if the distribution is fit by $1+\alpha\cos^2\theta$, α should decrease as x_1 becomes large. Figure 1 shows the angular distribution for three different lower bounds on x_F. Since the data fall very rapidly with x_F the mean value of x_F for each plot is close to the lower bound. Moreover, since M^2 and s are fixed, x_1 increases with x_F. The anticipated trend is observed. In Fig. 2 the value of α is plotted as a function of x_F and compared with the predictions of the model for two different masses. The data themselves are characterized by a mass of ~4 GeV. The data are consistent with expectations.

In our recent publication[2] we find a good phenomenological fit to the structure function at large x by the form $(1-x)^1$. We have tried the alternative form suggested by Berger and Brodsky of

$$\bar{q}(x) \sim (1-x)^2\ +\ \frac{2}{9}\langle k_T^2\rangle \frac{1}{M^2}$$

and obtain an equally good representation. The value obtained for $\langle k_T^2\rangle$ is ~1.2 GeV in agreement with expectations.

We conclude that existing data is in accord with the model.

Obviously better quality data at high x is indicated, especially since this is the region where quantitative understanding may be possible. If we are ever to test QCD it must be in a relatively clean situation, such as this, where one mechanism is expected to dominate. Theoretical work is underway at SLAC to determine the extent to which the model predictions reflect the basic assumptions of QCD and how other effects might enter.

To observe clearly the scale breaking term requires good acceptance at large x_F. In addition it is important to have good acceptance in $\cos\theta$ to isolate the structure function components associated with transverse and longitudinal photon polarization. The general form of the cross section in terms of structure functions, even in the forward direction, is much more complicated than the predictions of this simple model.[4]

To evaluate existing detectors for such a study we note that at M=8 GeV, E_{inc} = 250 GeV the two terms in the structure function given above are equal at $x_1 = 0.94$, or $x_F = 0.8$. For an exactly symmetric μ-pair with ($\cos\theta = 0$) and with zero p_T the muons have a lab angle of 32 mr. For $\cos\theta = 0.5$ the angle is 16 mr. The lower limit of the acceptance in E-326 is 30 mr and in Telegdi's CERN experiment, it is 32 mr. The acceptance in E-605 is limited to $x_F \lesssim 0.5$ because of the beam dump.[5] These acceptance difficulties are reduced at higher masses but as we will see below the small production cross section at high x_F precludes the use of much higher masses.

III. APPARATUS

We propose to use the apparatus described in P-615 with a hadron filter installed in the mass selector magnets. Figure 3 shows the detector. A nuclear target of ~50% interaction probability would be used just upstream of the mass selector. At a later stage a hydrogen/deuterium target might be used but this is not envisaged at the present time. A drift distance of ~1 m. separates the target from the filter to permit isolation of the production point during analysis.

(1) Hadron Filter

The filter would be a low Z material such as beryllium or carbon of as short a length as is consistent with an acceptable downstream counting rate. Detailed studies of this length are now underway but if the filter were beryllium extending 8.5 meters (23 absorption lengths), then the charged hadron flux at the downstream face with the magnetic field off would be ~2×10^6 for 10^{10} incident pions at 100 GeV.[6] A high density carbon filter gives the same flux but leads to a 35% deterioration in mass resolution. We expect that the field will further reduce the charged hadron flux and that distance between the shield and detectors will effectively reduce the rates.

(2) Muons in the Beam

To avoid the muon component of the beam we divide the detector elements at beam height and provide a gap in the median plane. The height of the gap grows with distance from the target to match the divergence of the beam (~1 mr). The multiple scattering angle of beam muons at 75 GeV (the lowest energy we expect to use), induced by the hadron filter is 1.0 mr.

(3) Mass Selection Magnets

A collimator at the downstream end of the mass selector, as described in P-615, is suitable for studying hadron pairs but is of no value when muons are involved. It would be removed. In this mode of operation the mass selector sweeps out low p_T and low x_F muons and hence provides a cutoff on low mass pairs. Higher mass pairs are accepted with an efficiency of ∿20% at M = 8 GeV and $x_F = 0.9$ for a 250 GeV beam. The higher mass acceptance is limited by the width of the mass selector magnets. The efficiency falls to ∿10% at M = 11 GeV.

(4) Muon Background from Hadron Decay and Low Mass Pairs

We have done a Monte Carlo calculation to estimate the muon flux through the detector from the decay of hadrons produced in the target and hadron filter. Production cross sections for $\pi^{\pm}, K^{\pm}$ were parameterized as a function of x_F and p_T. Muons from the decays of these hadrons were tracked through the mass selection magnets, including the flux return yokes. With the selector magnets energized at 18 Kg and 2×10^9 interacting pions of 250 GeV we find that the detector sees 6×10^4 single muons from hadron decay.

To estimate the muon flux from low mass μ-pair production we have used our own measurements from E-331. With the same conditions as above we find that the detector sees 4×10^3 single muons from pairs. and 240 low mass pairs. The tracks of the pairs diverge sharply and can be easily identified and eliminated using the trigger logic of the downstream spectrometer.

We conclude that muon fluxes from these sources are entirely acceptable. Without the sweeping of the mass selection magnets these fluxes would be more than two orders of magnitude larger.

(5) Muon Halo of the Beam

Our colleagues with the E-326 experiment have made detailed studies of the muon halo in P-West. They conclude that with a beam energy of 200 GeV and 10^{13} incident protons, the muon halo is $\sim 10^6/m^2$. This flux is manageable but accidental triggers involving halo muons must be guarded against.

(6) Acceptance and Resolution

As outlined below an important aspect of the experiment involves measuring the pion structure function with data of two different mass values but the same M^2/s. This involves masses of 4 GeV at 75 GeV incident energy and masses of 7.3 GeV at 250 GeV incident.

Shown in Figures 4 and 5 are the acceptances at two different incident energies as a function of x_F, p_T, and the CM decay angles cosθ and ϕ. In the large x_F region of interest, the efficiency is 20% at the higher energy and 8% at the lower setting. These are very substantial values for the interaction rate employed.

The mass resolution is dominated by multiple scattering in the hadron filter. We estimate a mass resolution with a carbon filter of ∿150 MeV and roughly independent of pair mass. This resolution depends on fitting the pair trajectories to a common production point as was done in E-331 and E-444.

IV. MEASUREMENT STRATEGY

The goal of the study is to measure the pion structure function with high precision at large x. The method is set out in our recent publications from E-444.[2] It amounts to measuring

$$\frac{d^2\sigma}{dx_1 dx_2} = \frac{4\pi\alpha^2 s}{9M^4} f^\pi(x_1)\, g^N(x_2) \qquad , x_1x_2 = M^2/s$$

$$x_1 - x_2 = x_F$$

where $f^\pi(x_1) = x\bar{u}^\pi(x_1)$

and $g^N(x_2) = \frac{4}{9} x_2 u^N(x_2) + \frac{1}{9} x_2\, \bar{d}^N(x_2)$

It is of particular interest here to isolate the scale breaking term in $f^\pi(x_1)$ predicted by QCD ($1/M^2$ term). This is done by measuring the pion structure function using data with at least two different masses. Unless care is taken the nucleon structure function contributes differently at different masses since $x_1x_2 = M^2/s$. To avoid uncertainties associated with the nucleon structure, one must keep x_2 fixed by varying s with M^2. Thus the scale breaking term is isolated by subtracting structure functions measured at different M and s but fixed M^2/s. We would propose to take data at E_{inc} ~75 GeV and E_{inc} ~250 GeV and to determine the structure function from data with M~4 at 75 GeV and M~4 x $\sqrt{250/75}$ = 7.3 GeV at 250 GeV. If the scale breaking term varies like $1/M^2$, its size changes by a factor of 3.3. Figure 6 shows the expected errors on the structure function measured at the two different beam energies if Berger and Brodsky's analysis is correct. The statistical errors correspond to 600 hours at E_{inc} = 250 GeV and 200 hours at E_{inc} = 75 GeV with 10^{13} incident protons per pulse, and 300 pulses per hour.

V. COSTS

The cost of the experiment is substantially reduced by using the P-West beam and experimental area. Costs directly attributable to the M1 location which would not apply in P-West amount to $830K, leaving $484K according to the Meson Department's impact statement. John Peoples indicates that the spectrometer analyzing magnet may be considered as Research Division equipment and not charged explicitly to this experiment. This reduces the cost to $324K. Most of this is in the mass focusing magnets and we are working with Ron Fast toward further reductions. Inevitably there will be some added costs unique to P-West. Thornton Murphy is investigating the adequacy of presently installed power. Should more power be needed, he estimates ~$180K for installation and bus work.

The physics disadvantages of P-West appear tolerable. The hadron pair mass resolution would be degraded by 30% because of the larger beam spot. Since the beam has a smaller total bend, muon halo is more troublesome although it appears that careful work with spoilers as done for E-326 can make it acceptable.

Additional costs not contained in present estimates include an on-line computer, PREP electronics and the hadron filter.

The requested amount of running time is 1000 hours.

VI. CONCLUSIONS

The study of pion induced μ-pairs in the forward direction is an important first phase for the detector. This kinematic region is one of the most interesting, yet existing detectors have poor capability here. In the proposed study, this experiment will be able to exploit the full potential of the P-West pion beam with good resolution and good acceptance.

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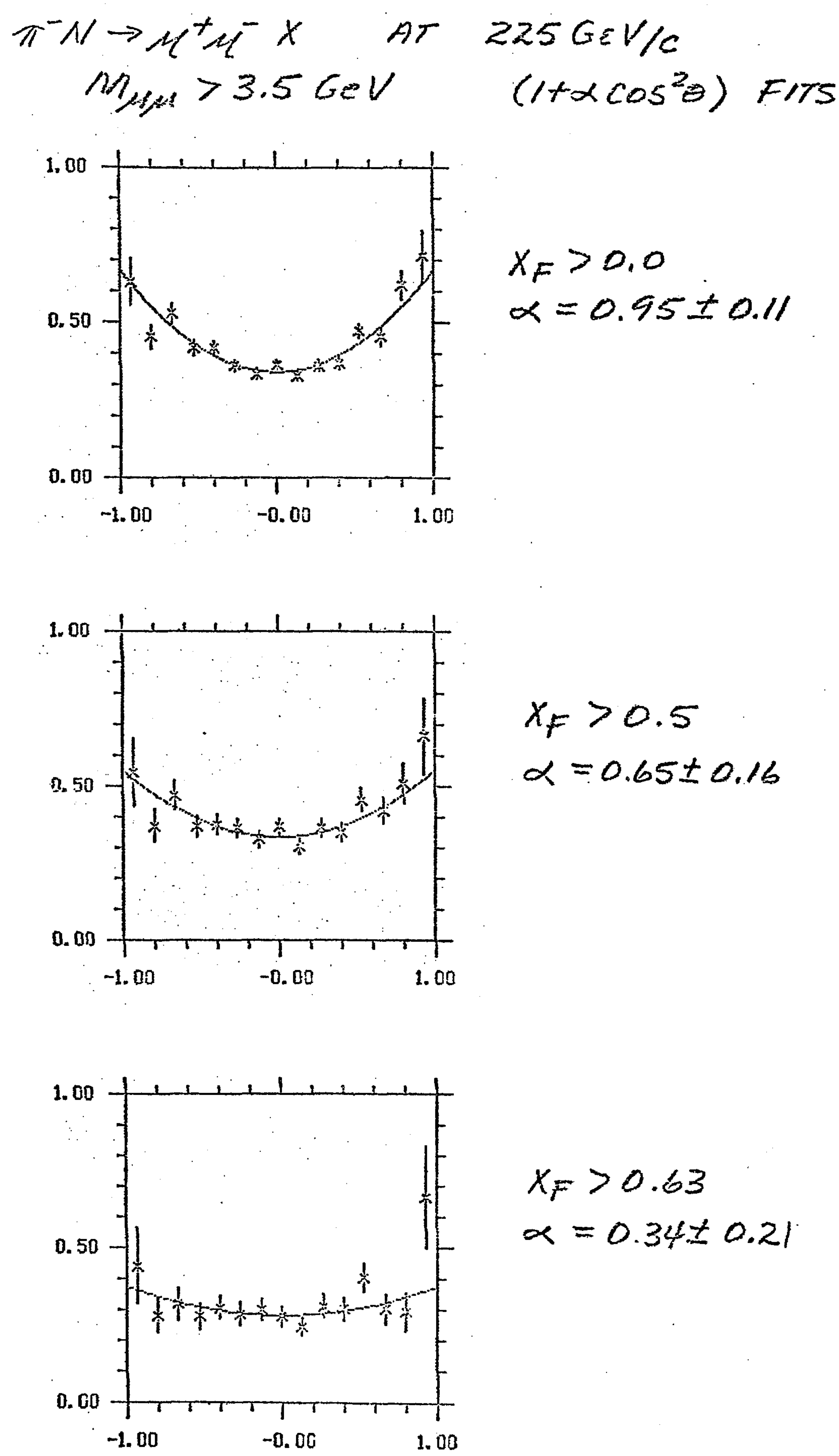


Figure 1. Results from E-444 on decay angular distributions versus x_F.

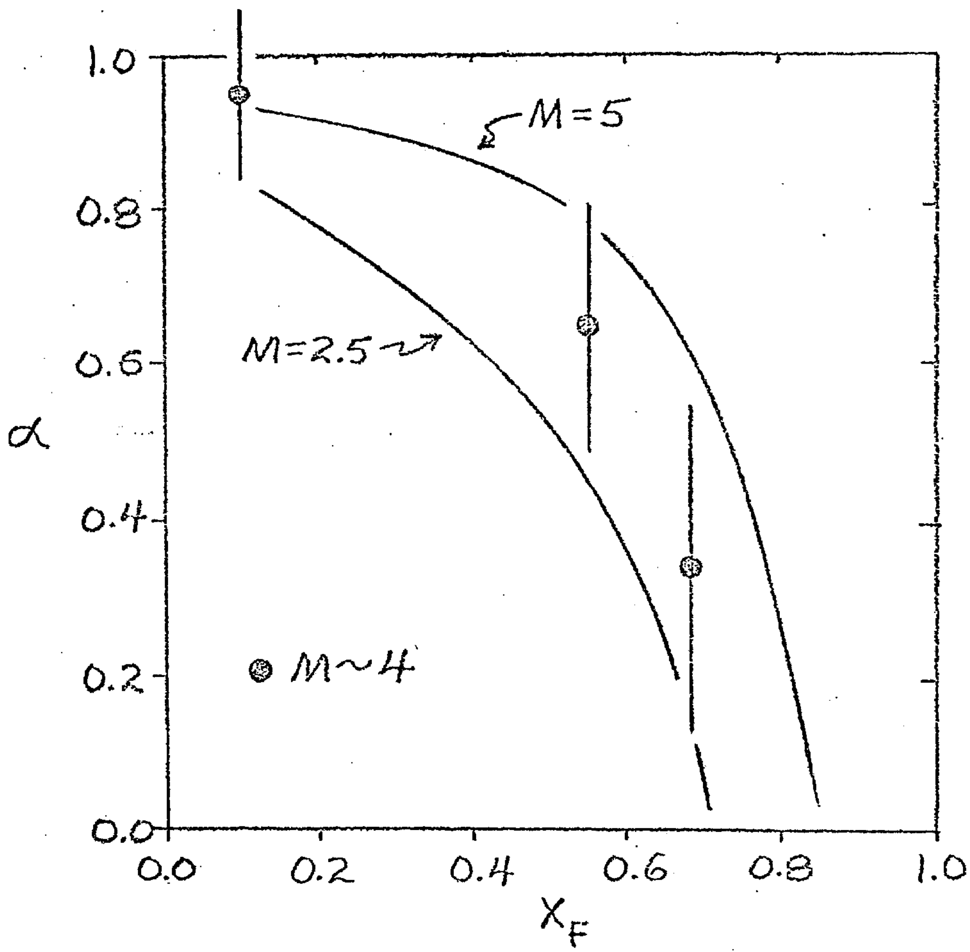
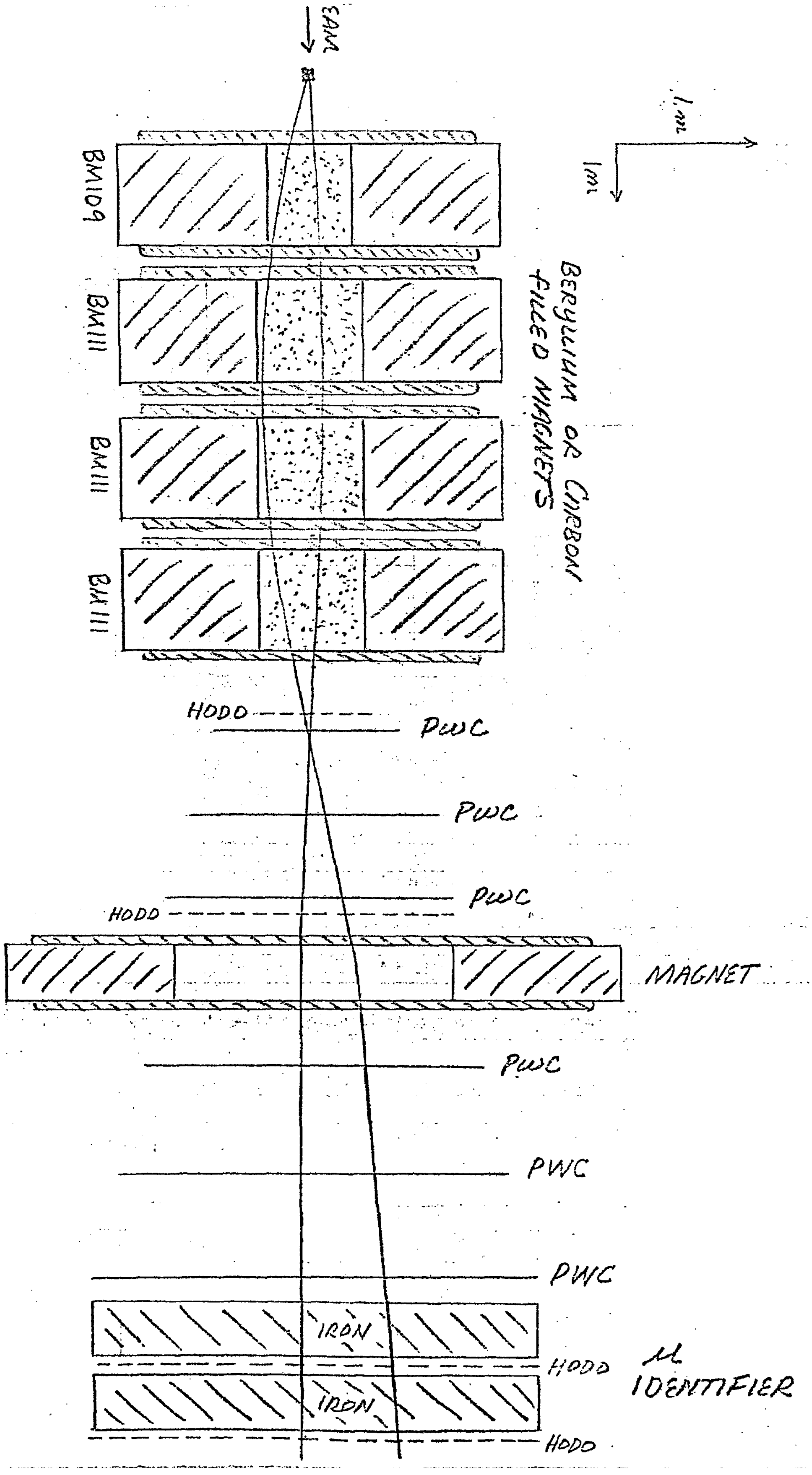


Figure 2. Angular distribution parameter α as a function of x_F compared with the model predictions of Berger and Brodsky. The data are characterized by a mean mass of 4 GeV.


EAM
1m
1m
BM109
BM111
BM111
BM111
BERYLLIUM OR CARBON FILLED MAGNETS
HODO
PWC
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MAGNET
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IRON
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μ IDENTIFIER
IRON
HODO

Figure 3.

Figure 4. Detection efficiency at a mass of 8 GeV and an incident energy of 250 GeV.

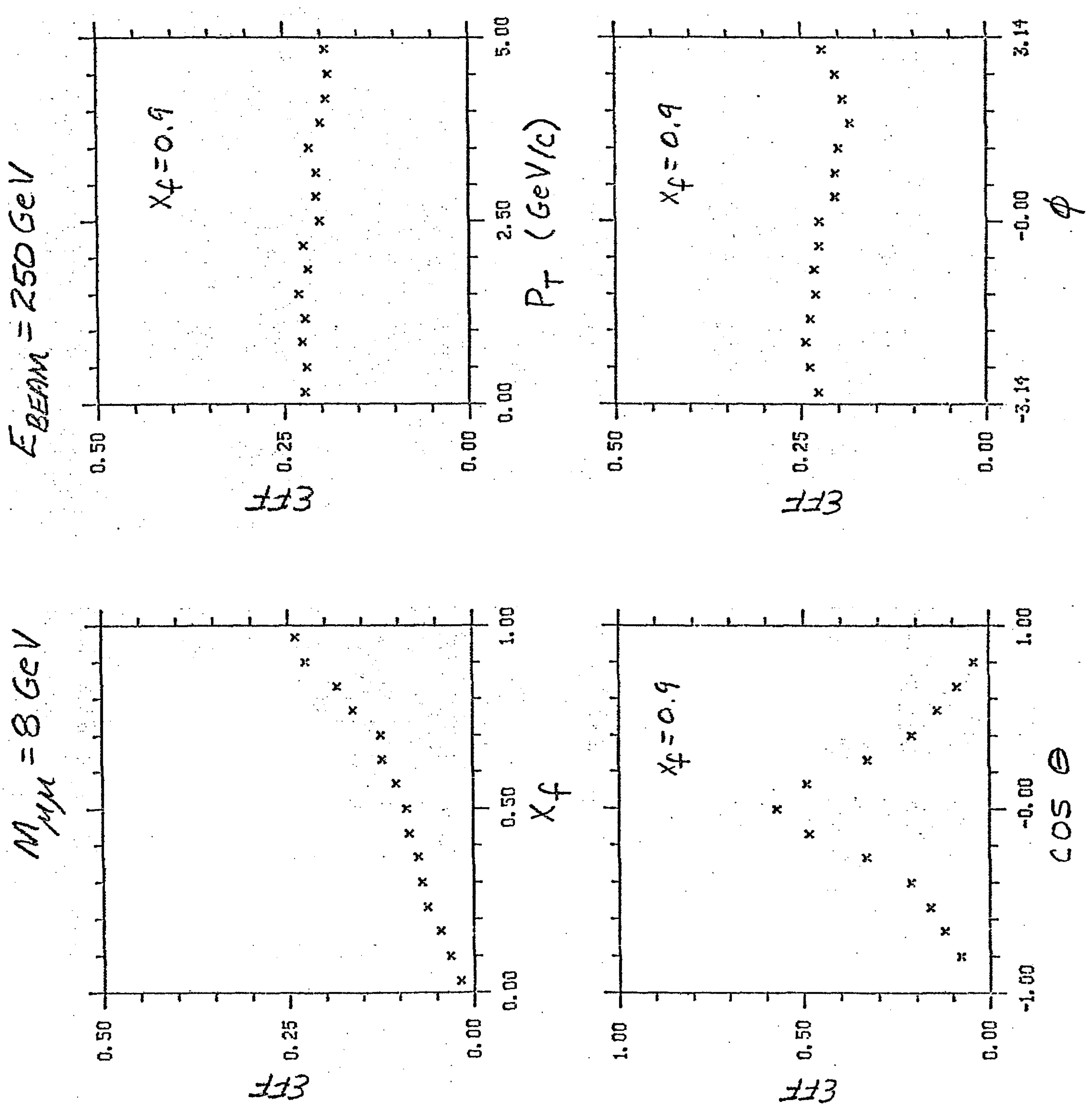
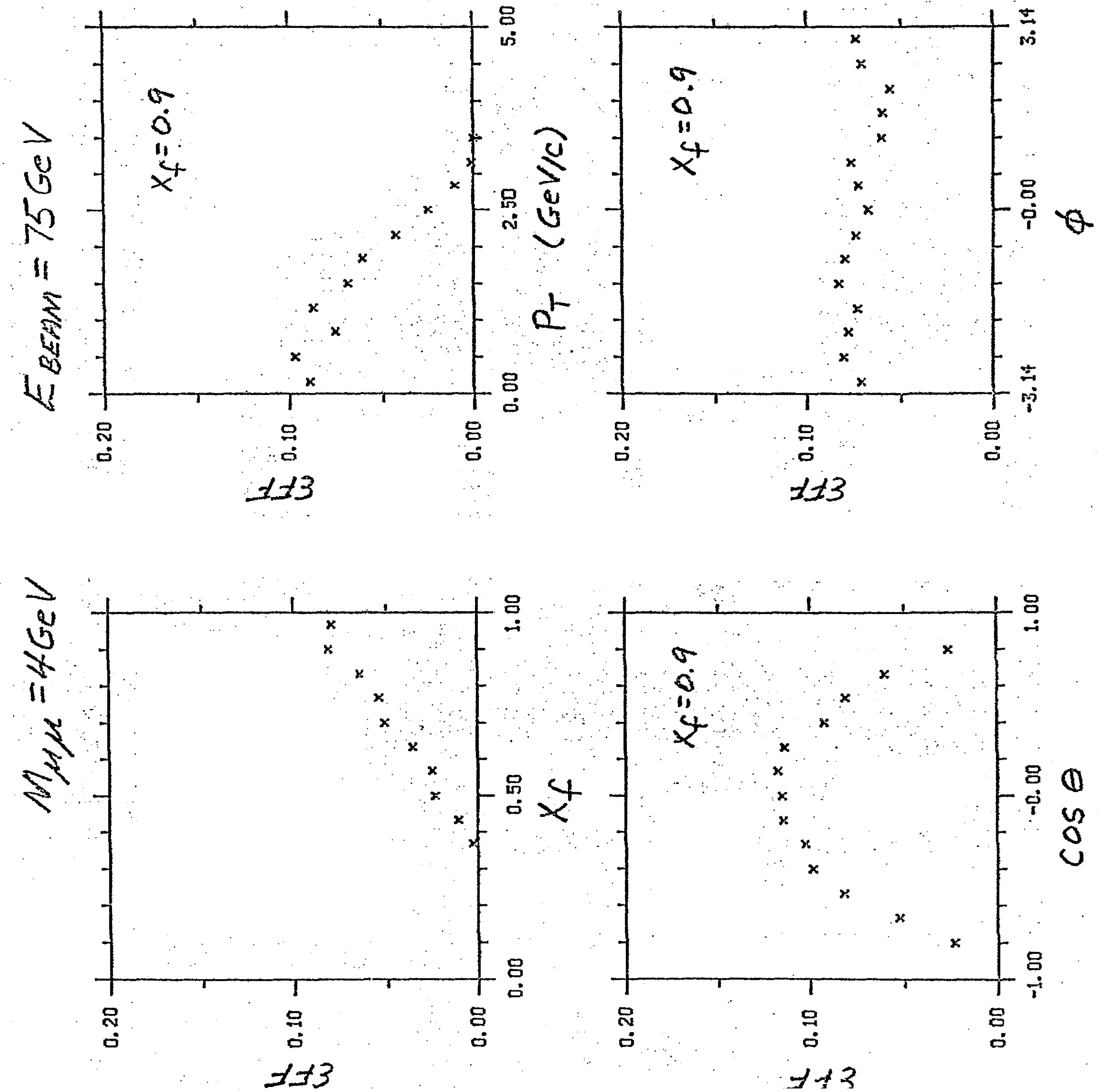


Figure 5. Detection efficiency at a mass of 4 GeV and an incident energy of 75 GeV.



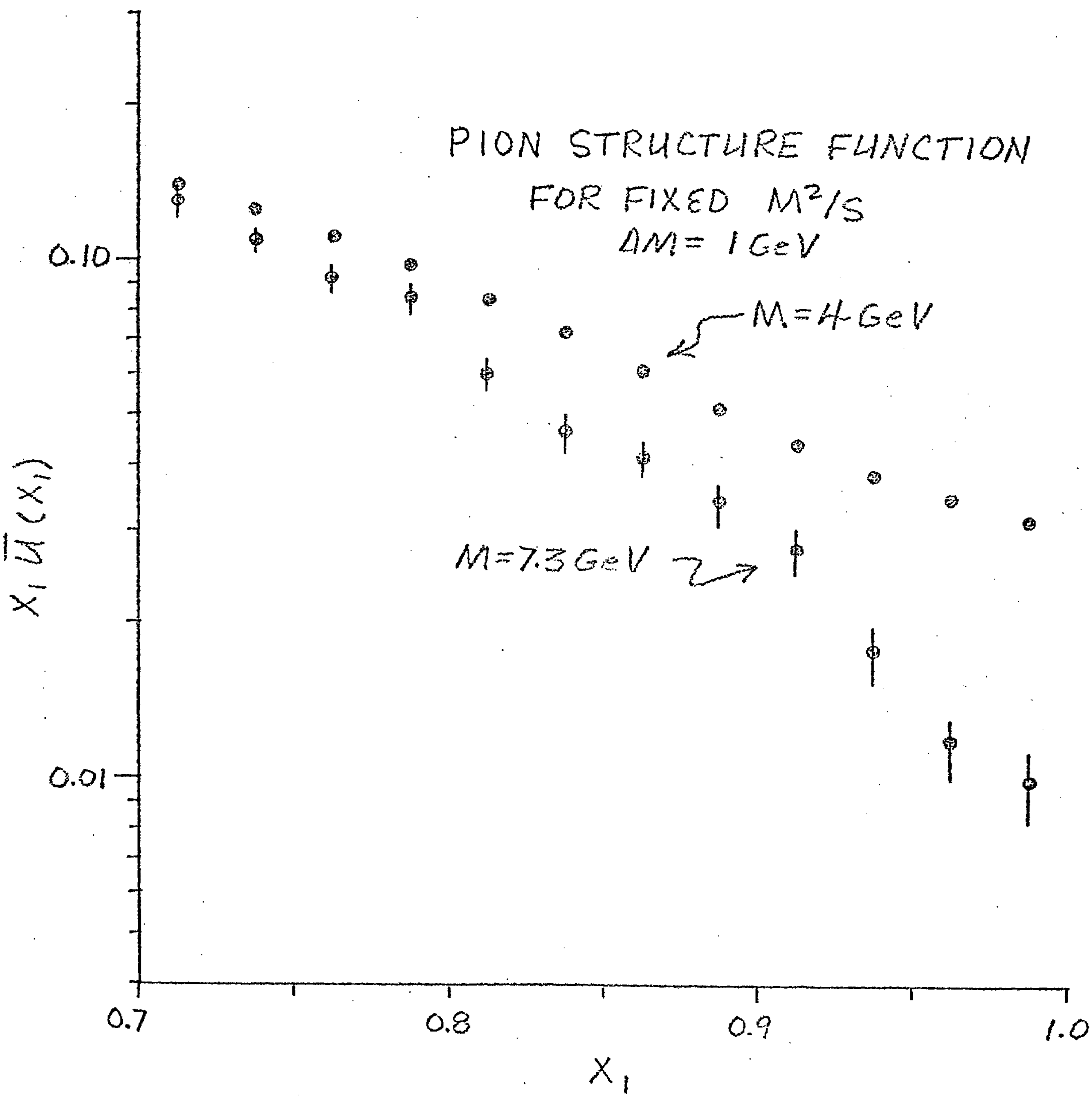


Figure 6. Expected precision on the pion structure function. The dependence on mass is scale breaking. The curves shown are for the model of Berger and Brodsky.

Supplement to Proposal 615

A Study of the Forward Production of Massive Particles

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Supplement to P-615

I. INTRODUCTION

This supplement is intended to provide details about the experiment beyond those given in the original proposal. Among the items discussed in more detail are acceptances, resolution, counting rates, specific physics goals and how the experiment might be implemented.

II. APPARATUS

The schematic of the detector is reproduced from the original proposal in Fig. 1. For performance calculations we have taken the mass selection magnet to be 8.5 m long, 0.76 m (30 in.) wide, and with a final gap height of 0.76 m. The field is taken as uniform with a maximum value of 15.7 kG. As mentioned in the proposal, this system could be based on 4 ANL beam line dipoles with the gaps opened and additional excitation. The cost of this and other alternatives are being estimated by the Meson Department and should be available by the March PAC meeting. For purpose of comparison we note that this magnet system has less than one-half the field volume of the M2 magnet requested in P-605.

The analyzing magnet shown in Fig. 1 is similar to the magnet designed for E-516 (Nash). It has a P_T kick of 0.5 GeV/c and an aperture of 2 m x 1 m. The field volume of this magnet is less than one-tenth the volume of the P-605 analyzing magnet.

(a) Acceptance

The acceptance of the system has been studied as a function of several parameters.

The acceptance is most directly controlled by changing the aperture of the downstream slit and the field in the mass selecting dipole. Figure 2 shows the absolute acceptance as a function of slit width at a mass of 1.86 and 4.0 GeV for a series of field settings. The field is characterized by a constant, S, which is the P_T kick of the mass selector compared to twice the maximum P_T available from the particle decay. Thus for S=1, decays which are exactly transverse to the beam and in the bend plane are brought to a focus at the slit. The acceptance calculation assumes a t-distribution for the forward going particle of $dN/dt \sim e^{-3.5|t'|}$ as suggested by Field and Quigg for associated charmed meson, charmed baryon production.

It is seen from Fig. 2 that the acceptance grows linearly with slit width. As discussed below, the single arm fluxes rise faster than linear as the slit width is opened and these rates impose the upper limit on the opening.

It is also relevant to consider the shape of the mass acceptance for various slit openings and a fixed magnetic field. This is given in Fig. 3. In considering these shapes it should be recalled that the mass resolution is ~8 MeV/c^2.

For the calculations discussed below we adopt a slit width of 20 cm. and a field setting of S=0.90.

Massive forward going particles may be produced with a fairly broad t-distribution. Figure 4 shows the acceptance as a function of $|t'| = |t-t_{min}|$. For comparison, a t-distribution of $e^{-3.5|t'|}$ is plotted. The acceptance in t is good, falling a factor of four over the same interval in which the trial distribution falls a factor of 10.

Figure 5 shows the acceptance at different mass settings for fixed slit width and S-value. It should be possible to open the slit at the higher mass settings since the single particle backgrounds are smaller at these P_T values.

(b) Mass Resolution

For the resolution calculation we assume that the PWC system indicated in Fig. 1 provides 2 X and 2 Y measurements at each of the two detector stations upstream of the analyzing magnet. At the two downstream stations 1 X and 1 Y measurement is used. The wire spacing is taken to be 1.6 mm, similar to other PWC's built at the Enrico Fermi Institute. A target of 0.2 absorption lengths of beryllium (7.4 cm.) is used.

With this system we obtain a resolution which is limited by the incident beam size and multiple scattering in the target. With a beam size of σ_x = 0.75 mm. (see Cary report) and no multiple scattering, the resolution is σ_m = 2 MeV at M = 1.86 GeV (0.1%). With the same beam size and multiple scattering σ_m = 8 MeV (0.4%). With a beam of σ_x = 1 cm. and multiple scattering the mass resolution is σ_m = 16 MeV (0.9%). No contribution is included for uncertainty in the field integrals but fortunately the track trajectories in this experiment are contained in only a small fraction of the phase space volume which could be transported by the magnets.

The mass resolution is plotted as a function of mass in Fig. 6 with the small beam size and multiple scattering included.

III. COUNTING RATES

An item not discussed in the original proposal is the single arm counting rate to be expected at 2×10^9 interacting pions/pulse. Figure 7 shows the expected single arm rate as a function of slit width if the mass acceptance is centered at 1.86 GeV. To calculate these rates, measured single particle inclusive cross sections are parametrized in the appropriate region of x_F and P_T and used as input to a Monte Carlo simulation of the mass selector. A single arm flux of $4 \times 10^6 / 2 \times 10^9$ interacting pions is obtained with a slit width of 20 cm.

It should be noted that a simple arm-to-arm coincidence is not used since most random two particle combinations lie outside the kinematic regions of interest (x_F, M, P_T of the pair). Instead, fast matric logic together with hardware processors will be used to select pairs of interest. This technique has already been exploited by this group in its μ-pair studies (E-444).

If the field in the mass selecting dipole is raised to center the acceptance at a 4 GeV mass, the single arm fluxes fall by over two orders of magnitude.

IV. IMPLEMENTATION

The cost estimates given in this section are current best estimates developed in consultation with the Meson Department. More accurate figures may appear by the time of the PAC meeting.

(a) Mass Selection Dipole

As described above one way to construct this magnet system is to base it on four ANL beam line dipoles with the gaps of three, opened and additional coils added. The cost of copper coils for this option has been estimated by the Meson Department at $300K. The additional machined steel costs $12K ($250/ton) so that, with labor included, the new cost for this magnet system is put at $325K. The question of power is discussed below but the conclusion is that with the beam operating at 50 GeV and focused to an upstream enclosure, there are sufficient power supplies and electrical energy from the present configuration of the M1 line.

Naturally we would be happy to consider other alternatives for constructing this magnet but they should be competitive with the cost and time scale of this solution.

(b) Analyzing Magnet

A magnet similar to the one required has been designed for E-516 (Nash) in the Tagged-Photon Lab. This magnet has an aperture of 72 in. x 32 in. (1.82 m x 0.81 m) and a P_T kick of 0.46 GeV/c. The area of the aperture is ~75% of that used for the efficiency calculations above, and the P_T kick is over 90% of that used. The proposed experiment could certainly be tailored to use a magnet of these dimensions.

The cost of this magnet is ~$200K and the power requirement is 475 kw.

(c) Location

A solution which would permit the experiment to coexist with P-605 would be to build an upstream experimental enclosure, similar to that considered for P-586 (McCarthy). A beam can be constructed from existing M1 components which would produce high flux pions to this upstream enclosure and with minor modifications deliver 400 GeV protons to the Meson Detector Building for Phase I of P-605.

The idea is to concentrate most of the quadrupoles in the upstream section and relatively few in the downstream section where only primary protons are to be transported. Since the beam is to be operated at 50 GeV for P-615, the extra electrical power would be used for the mass selecting dipoles.

An example of a possible beam configuration is the first half of the beam described in the Cary report. The exact design must be tailored to the existing tunnels.

VI. PHYSICS GOALS

The primary goal of this experiment is to scan the two particle mass spectrum from 1.5 to 5 GeV. Special emphasis will be given to $K\pi$ masses close to 1.86 GeV (charmed meson production) and to $\bar{p}p$ masses in the range 2.8 to 3.1 GeV where the η_c may be expected.

Figure Captions

Fig. 1. A schematic drawing of the apparatus.

Fig. 2. Acceptance at mass settings of 1.86 and 4.0 GeV for various slit widths and field settings. The constant S is the P_T kick of the magnet compared to that required for perfect focussing of an exactly transverse decay in the bend plane.

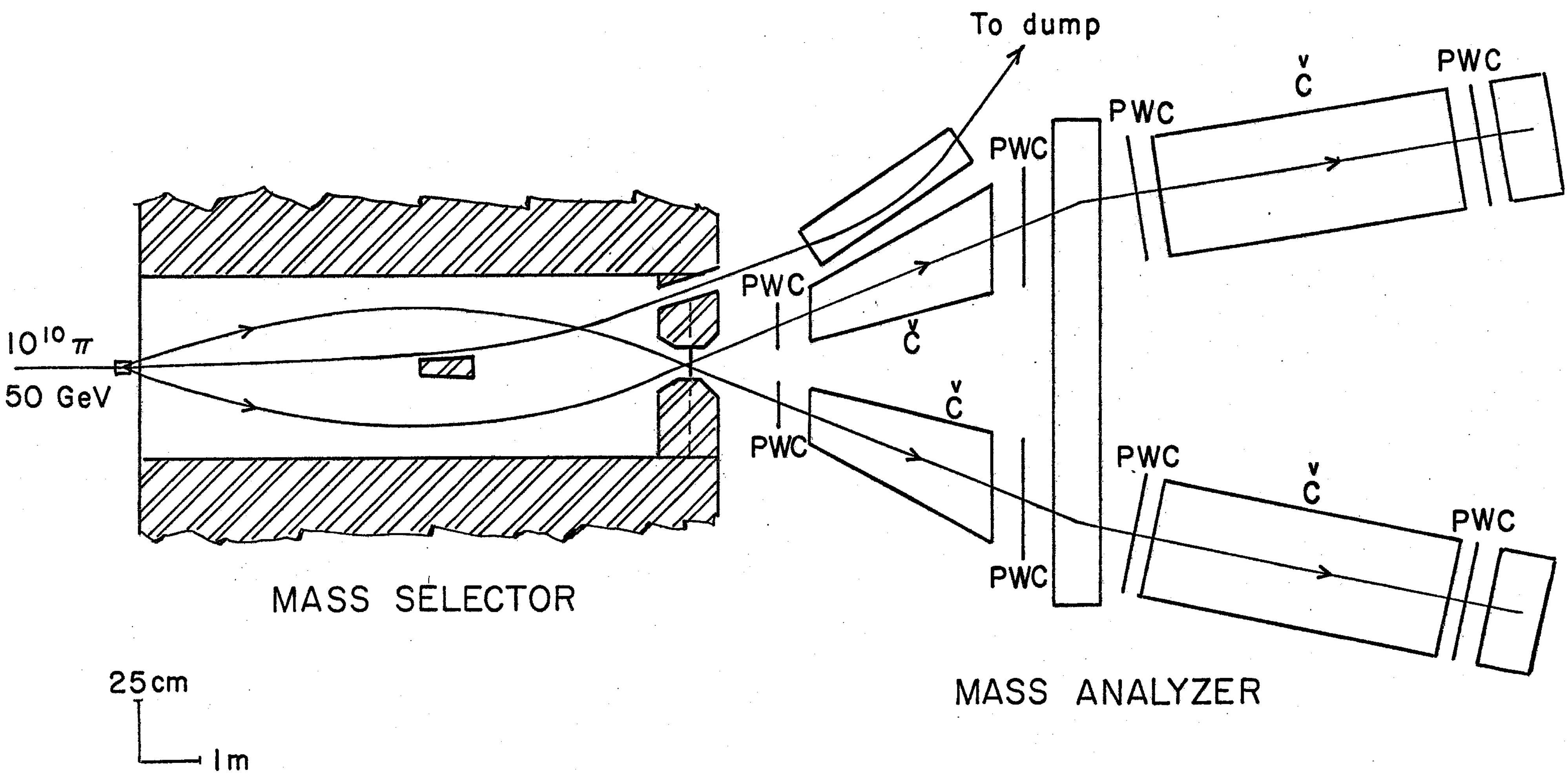
Fig. 3. Shape of the mass acceptance as a function of slit width for a given field setting. All curves have been normalized to the same peak amplitude. The relative normalizations can be obtained from Fig. 2.

Fig. 4. Acceptance as a function of $|t'|$ of the forward going particle. For comparison a possible t' distribution for production is also shown. A slit width of 20 cm. and an S-value of 0.9 has been used for these calculations.

Fig. 5. Acceptance for various mass settings at a fixed slit width of 20 cm. and a field setting of S=0.9.

Fig. 6. Mass resolution as a function of mass. A beam size of $\sigma_x = 0.75$ mm and a 0.2 absorption length beryllium target are assumed.

Fig. 7. Single arm counting rate as a function of slit width for 2×10^9 interacting pions per second of spill.



To dump
PWC
Č
PWC
PWC
PWC
PWC
PWC
Č
Č
Č
PWC
PWC
10^{10} π
50 GeV
MASS SELECTOR
MASS ANALYZER
25cm
1m

Figure 1

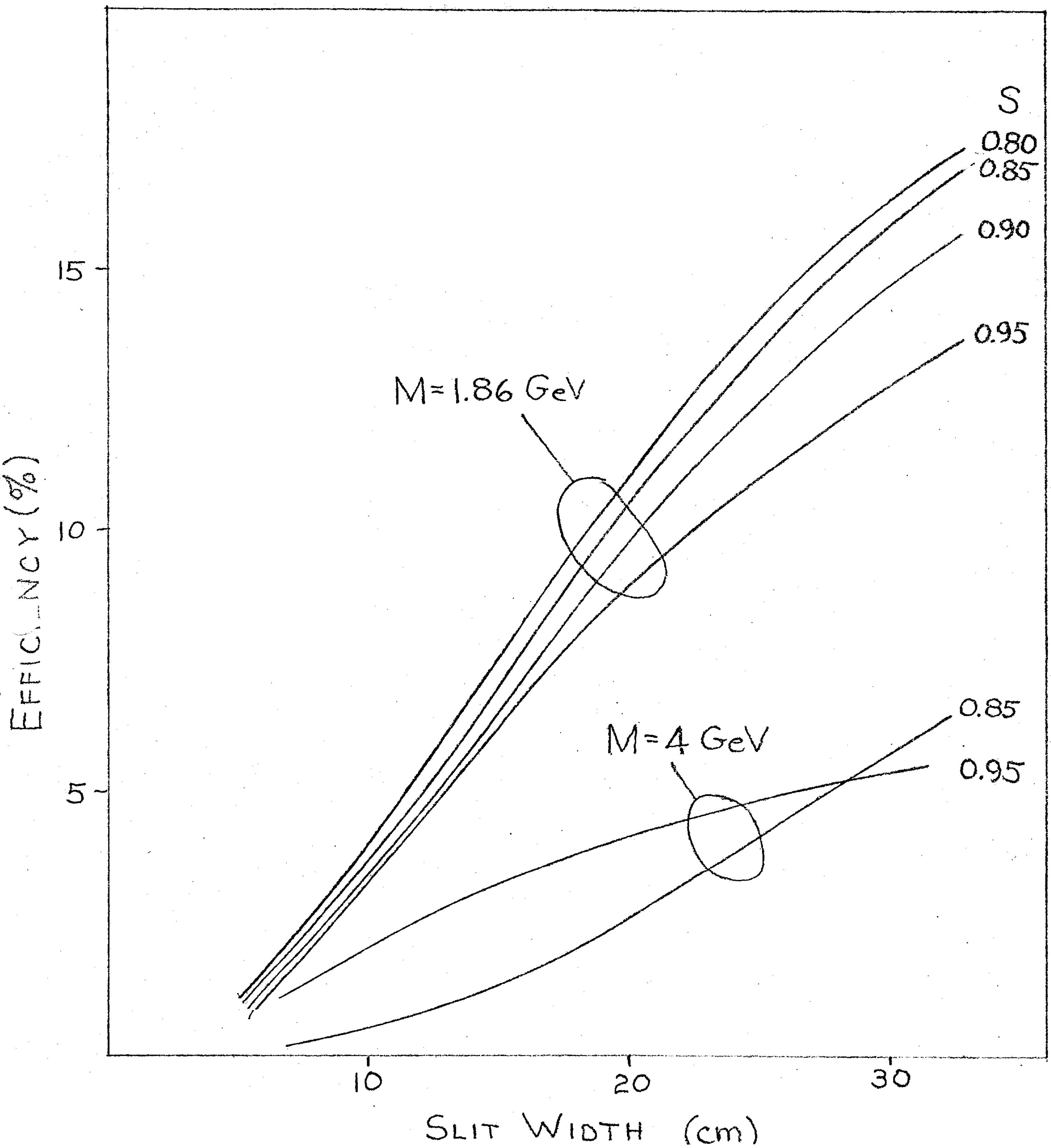
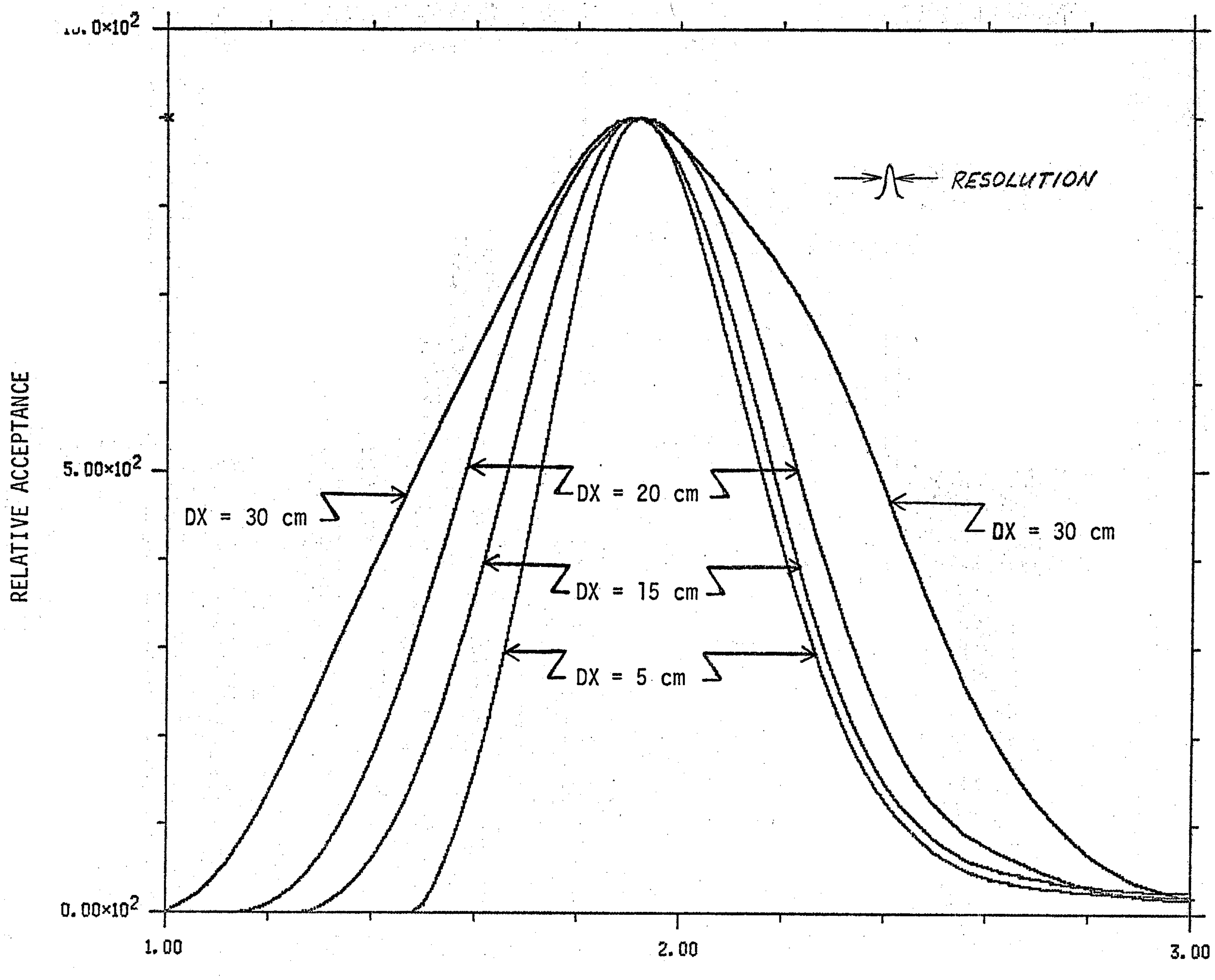

S
0.80
0.85
0.90
0.95
M=1.86 GeV
0.85
0.95
M=4 GeV
15
10
5
EFFIC...NCY (%)
10
20
30
SLIT WIDTH (cm)

Figure 2



RELATIVE ACCEPTANCE
5.00×10²
0.00×10²
1.00
2.00
3.00
Mass (GeV)
RESOLUTION
DX = 30 cm
DX = 20 cm
DX = 15 cm
DX = 5 cm
DX = 30 cm

Fig. 3

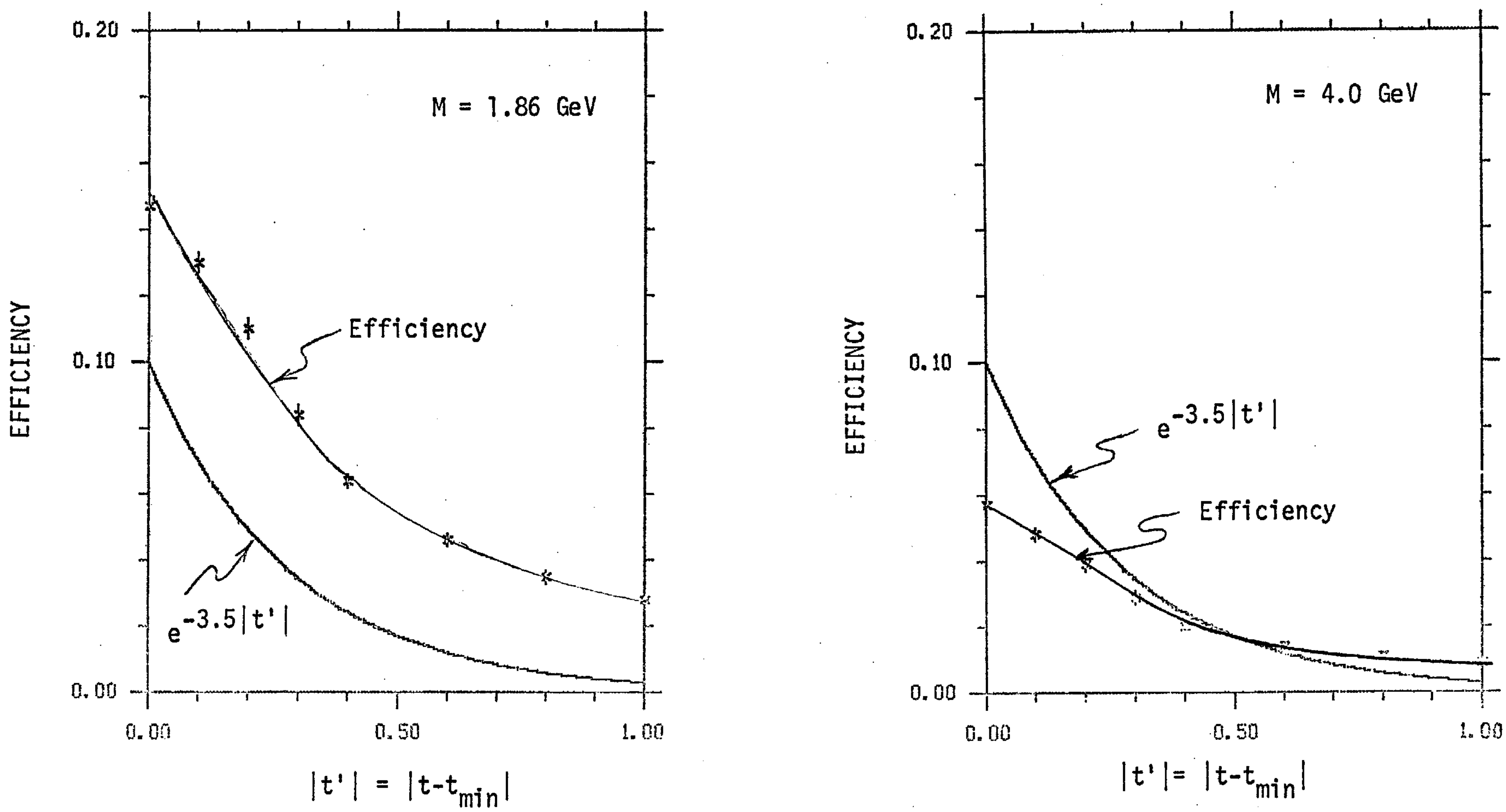

EFFICIENCY
0.20
0.10
0.00
M = 1.86 GeV
Efficiency
$e^{-3.5|t'|}$
0.00
0.50
1.00
$|t'| = |t-t_{min}|$
EFFICIENCY
0.20
0.10
0.00
M = 4.0 GeV
$e^{-3.5|t'|}$
Efficiency
0.00
0.50
1.00
$|t'| = |t-t_{min}|$

Fig. 4

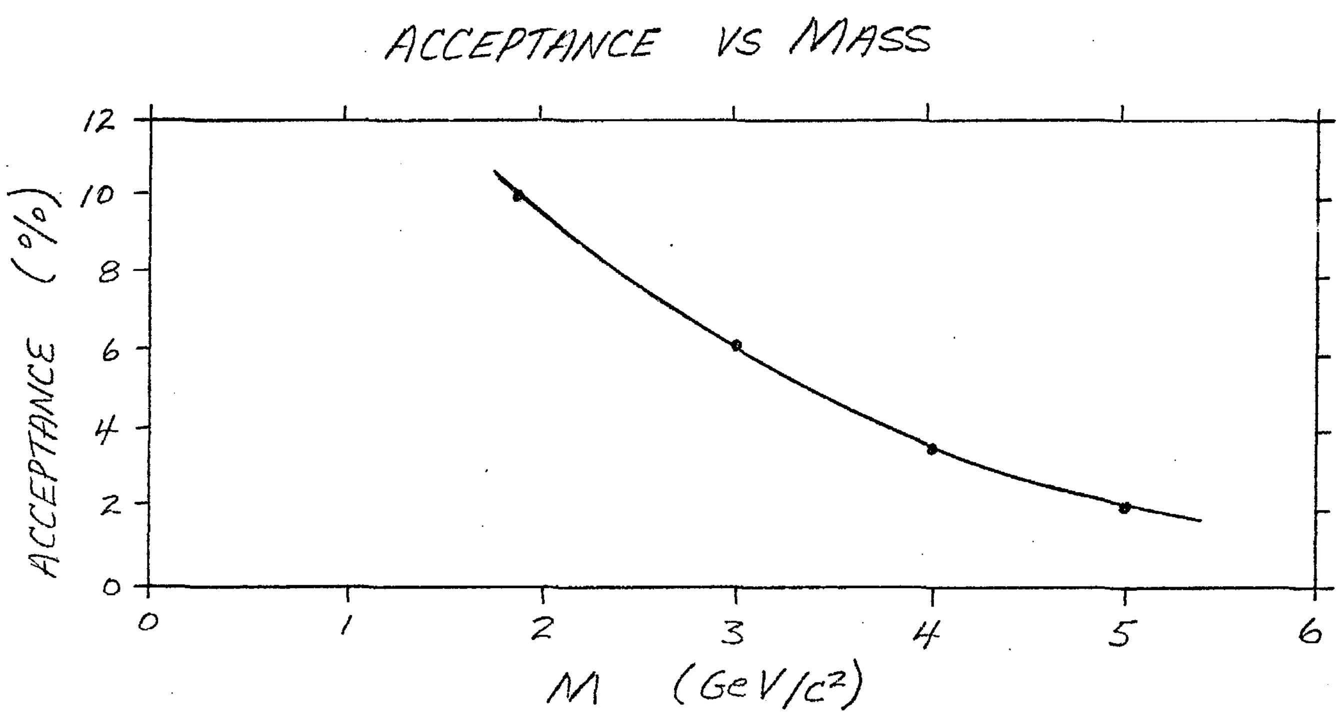


Fig. 5

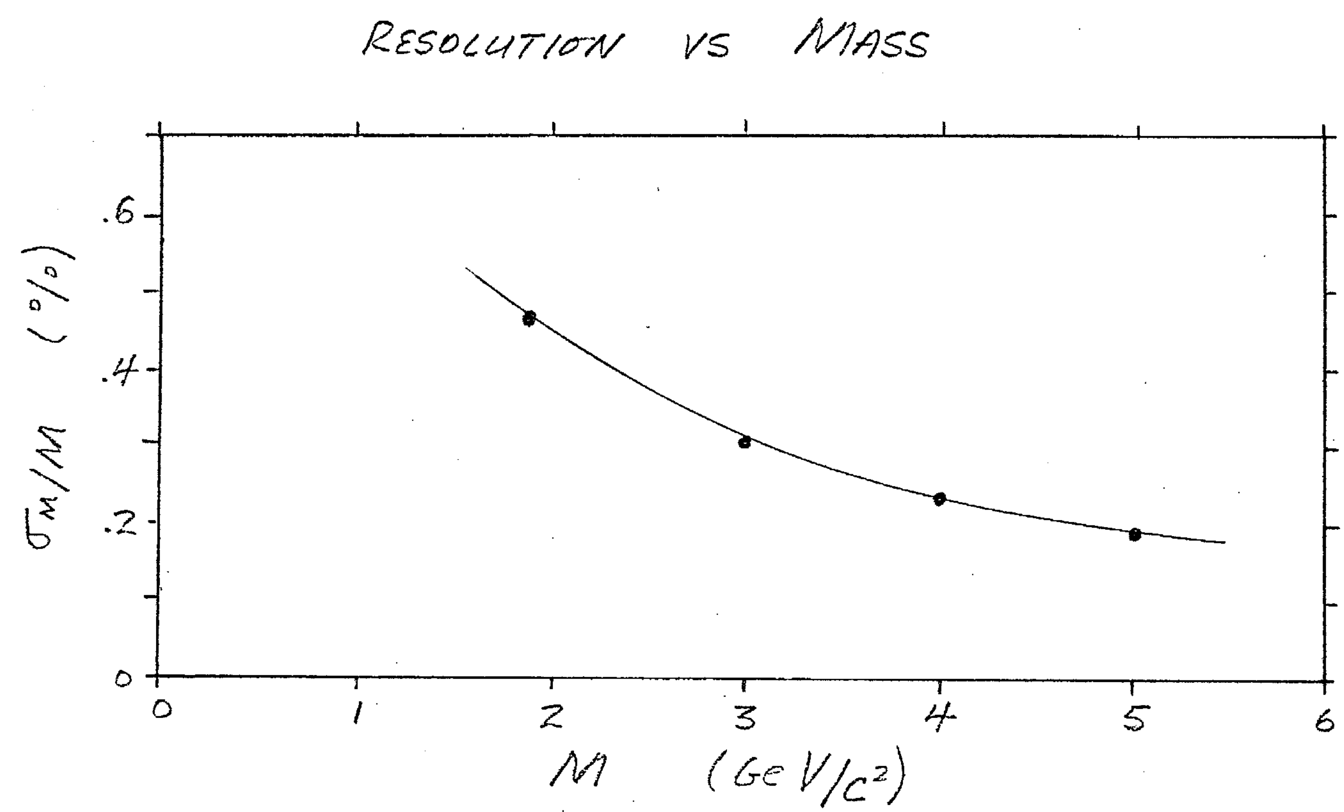


Fig. 6

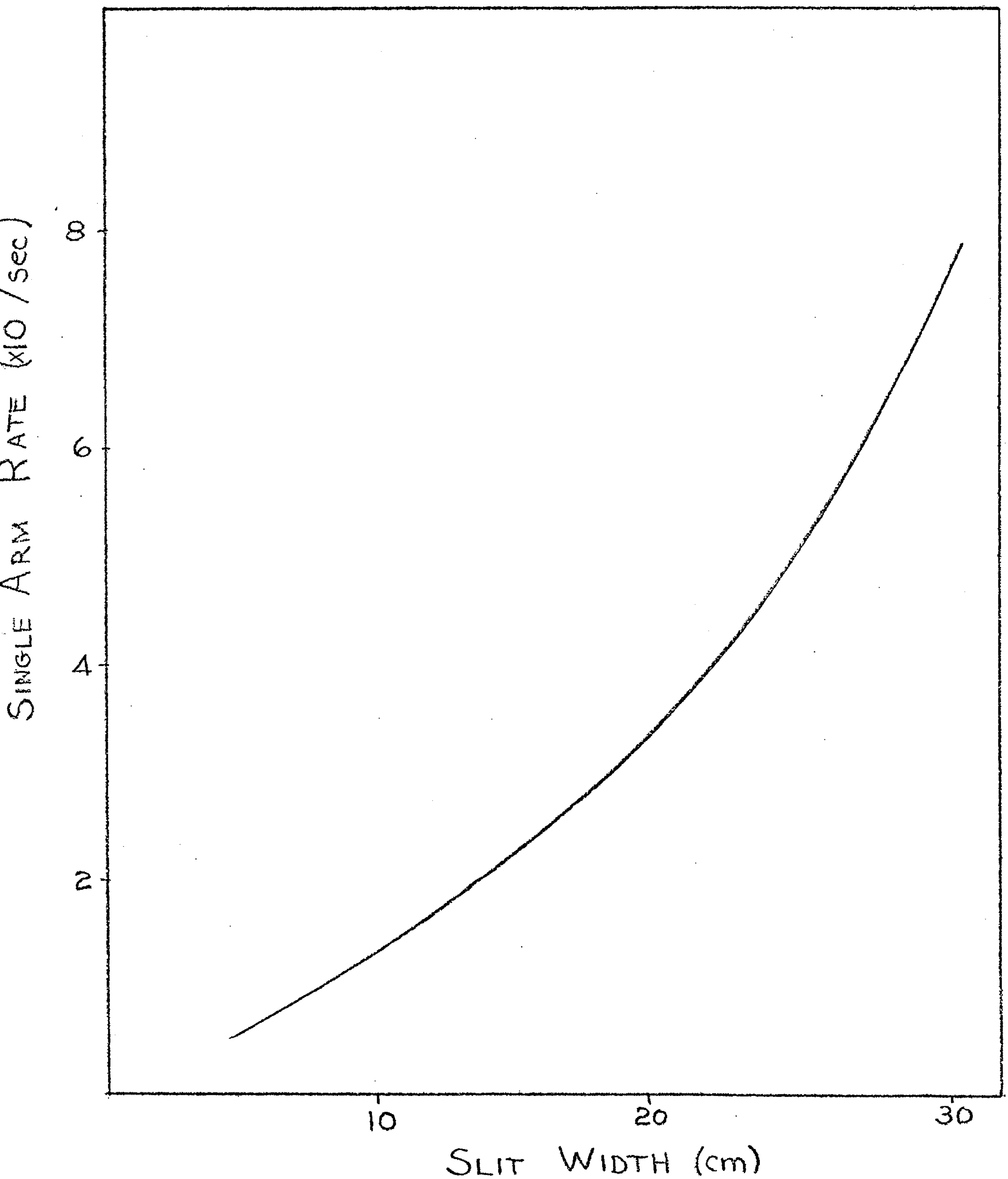


Figure 7