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A PROPOSAL TO STUDY CROSS SECTIONS AND POLARIZATION IN NEUTRAL STRANGE PARTICLE PRODUCTION AT HIGH TRANSVERSE MOMENTUM

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I. INTRODUCTION

We propose a measurement of inclusive production cross sections and polarization of Λ° by 400 GeV protons on beryllium at the highest transverse momentum available with the present M2 beam. We will also obtain measurements of K_s° and $\bar{\Lambda}^\circ$ production cross sections. A combination of improved intensity in the M2 beam line, increased solid angle and other factors will allow us to achieve sensitivity at the level of roughly one nanobarn/GeV/sr in the inclusive cross section. Acceptable polarization measurements should be possible where the cross sections are 12 nb/GeV/sr or higher. An extrapolation of the results from Exp. 8 indicates that this will extend the polarization measurements to $p_T = 2.5$ GeV/c.

These measurements can be achieved with the existing pair spectrometer used in Experiments 8, 415 and 440. The steering of the M2 proton beam can be achieved with a magnet configuration similar to that used in Exp. 441 scheduled for June, 1977. Minor modifications to the vacuum and collimator systems are the only changes required.

In the following sections we discuss the physics background, the experimental technique, and the facilities and personnel required for this measurement.

II. PHYSICS

One of the most unexpected and interesting phenomena observed in high energy hadronic collisions is the large polarization of inclusively produced lambda hyperons discovered by the Wisconsin-Michigan-Rutgers collaboration in Exp. 8 at Fermilab.[1] The general behavior of the polarization is that it increases monotonically with transverse momentum of the Λ° to a value of roughly 25% at p_T = 1.5 GeV/c, the highest value available in Exp. 8. (Fig. 1)

Some related developments stimulated by the discovery of strong polarization in inclusively produced lambdas are:

1. Some previously existing data on lambda production by 24 GeV protons at CERN was examined by a group which included several members of the Exp. 8 collaboration and found to exhibit polarization with the same p_T dependence as the Fermilab data.[2] Thus, the effect shows evidence of scaling behavior.
2. The lambda polarization was used in Exp. 440 to measure the magnetic moment of the lambda to an accuracy of about 1%. The polarization measured at 400 GeV in Exp. 440 was consistent with that of Exp. 8 to within about 10% of its value.
3. An analysis of the polarization of $\bar{\Lambda}^\circ$ in Exp. 440 showed <u>no polarization</u> at the 2% level in a kinematic region where the Λ° polarization is about 9%.
4. An Indiana group, working in the internal target area at Fermilab, has preliminary indications of polarization in the process $p + p \rightarrow p$ + anything.[3]

5. The data from Exp. 8 on Λ° p elastic scattering was analyzed for polarization of the final state lambdas. Above 120 GeV, small polarization was found at the level of about 2%.[4] Other measurements also yield small polarization in elastic scattering of hadrons.[5,6,7]

These results make it clear that the polarization is by no means a universal feature of baryon scattering processes. The absence of strong polarization in elastic processes and its presence in inelastic processes suggests that the polarization is a feature of constituent scattering. The coherent nature of elastic scattering averages the spin effects. This view is supported by the fact that the polarization still seems to be growing at p_T = 1.5 GeV/c where the collision is probing distances of order 0.1 fermis. The absence of polarization in $\bar{\Lambda}^\circ$ production may mean that the effect occurs only for leading particles, or it may be a function of which constituents are involved in the collision process. (This can be studied by measuring polarization in Λ° production by mesons - not the subject of the present proposal.)

These polarization studies may provide us with a new probe of strong spin-dependent forces between constituents which is unavailable in more conventional measurements.

Independent of any prejudice one might have about the source of the polarization, there are questions about it which remain to be answered. Does it keep on growing as p_T increases? How big does it get? What is its behavior near x = 1 where Exp. 8 lacks good statistics?

The polarization data from Exp. 8 have been subjected to further scrutiny since the publication of Ref. 1. On general grounds, one expects the polarization of spin-1/2 particles to carry a factor $\sin\theta$ (θ = c.m. production angle) independent of any specific dynamical model. Fig. 2 shows the quantity $\alpha P/\sin\theta$ plotted vs. θ_{lab} for each of three bands of Feynman x. ($\alpha = 0.647 \pm 0.013$ is the assymetry parameter in Λ decay.) No clear trend is visible, and it is possible that the entire dependence on transverse momentum comes through this factor of $\sin\theta$. Fig. 3 shows the same quantity, $\alpha P/\sin\theta$, averaged over θ_{lab} and plotted as a function of x. Also plotted are some preliminary 400 GeV data from Exp. 440. Symmetry considerations require the polarization to be zero at $x = 0$, and this is certainly consistent with the trend shown in Fig. 3. The behavior at high x is not clear. Does $\alpha P/\sin\theta$ continue to rise linearly with x, or does it flatten out as suggested by triple-Regge models?[8]

The detailed kinematic behavior should be studied at higher angles and higher x. How far the measurements can be extended depends on the value of the inclusive cross section. In Fig. 4 we have plotted the "engineering cross section" for inclusive lambda production at 400 GeV. The points represent data taken at 300 GeV in Exp. 8 (Ref 9) and scaled to 400 GeV. The dashed lines are extrapolations of that data based on fits of Ref. 8. Other fits, e.g. exponential in p_T^2 or in $(M^2 + p_T^2)^{1/2}$ give higher yields, but Fig. 4 is probably a reasonable basis for experimental design.

As will be shown in the Sec. IV, we can make cross section measurements to ±20% at a level of 1 nanobarn/GeV/sr, and polarization measurements to ±10% for cross sections above 12 nb/GeV/sr.

The measurements of inclusive production cross sections need to be extended in two directions. First, more accurate measurements in the region $0.9 < x < 0.98$ to verify the triple-Regge behavior[8] suggested by extrapolations of the data from Exp. 8. Second, the measurements at all available x values should be extended to as high values of p_T as possible. Extrapolations of the Exp. 8 data indicate that the cross section measurements can be extended to $p_T = 2.5$ GeV/c. At this value of p_T the Chicago-Princeton group[10] sees substantial deviations from exponential behavior in the pion yields. If the neutral strange particle yields show similar behavior, the cross section measurements might be accurate out to $p_T = 3$ GeV/c or higher. In this range, a comparison with constituent interchange models may be valid.

III. EXPERIMENTAL DETAILS

The principal features of the neutral hyperon beam in the M2 beam line are shown in Fig. 5. Several items require discussion.

A. Proton Beam

With new improvements in shielding, the M2 diffracted proton beam has recently operated at intensities up to 10^{10} protons per synchrotron cycle. Our rate calculations are based on this intensity.

It will be necessary to steer the beam onto the hyperon production target at angles up to 14 milliradians in the vertical plane. This can be accomplished with 5' magnet placed upstream in the M2 line, and four 10' magnets just in front of the target. A 3-magnet system will be installed for Experiment 441 which is scheduled for June, 1977. Some changes in the vacuum and collimation systems will be discussed in Sec. C.

B. Pair Spectrometer

The multi-wire proportional chamber spectrometer shown in Fig. 5 was used in Expts. 8, 415 and 440. It provides clean samples of $\Lambda°$, $\bar{\Lambda}°$ and $K_s°$ with mass resolutions (r.m.s.) of 2, 2, and 6 MeV respectively. It is capable of accepting up to 1200 triggers during a 2-second spill. The "tight" trigger configuration gives better than 70% yield of valid neutral strange particles. Except for a minor change in the trigger to be discussed below, this apparatus will be suitable for the work proposed here.

C. Backgrounds and Modification to Vacuum System

The target empty backgrounds in Expts. 8 and 440 were consisten with air, detectors and other objects known to be in the proton beam.

The noise/signal ratio seemed to improve slightly at higher production angles and was roughly 0.003 at the highest angle of Exp. 8. It is probably unreasonable to hope that this will be true for cross sections at the nanobarn level. Two modifications should improve the noise/signal ratio considerably.

First, the vacuum system around the proton beam should be extended, pass through 2G3 proton steering magnets, and continue to the production target.

Second, a collimator will be required in the proton beam just upstream of the 2G3 magnets. Just upstream of this collimator, the vacuum can be interrupted to accomodate monitors of the proton beam intensity.

This system is intended to prevent "shallow angle production." This can occur if the proton beam produces lambdas in air or other materials far upstream of the target, and these lambdas subsequently pass through the neutral beam collimator. Another source is proton beam halo hitting the production target at shallow angles. In either case, such a background could completely mask the high-x end of the production spectrum for large angles. This type of background, rather than rate, may be the most serious limitation on our sensitivity. Therefore, it is crucial to provide in advance facilities designed to eliminate it.

D. Momentum-Biased Trigger

At the larger production angle, the cross section varies over six to seven orders of magnitude over the Feynman-x range we hope to study. In order to collect one event per hour at the nanobarn cross section level, we would have to take 10^6 events per hour at the millibarn level. Our data collection system cannot accept this rate and would be dead-time limited. In order to avoid this it will be necessary to bias the trigger against the low momentum end of the lambda spectrum. The decay proton carries most of the lambda momentum, and a scintillation counter at the end of the pair spectrometer can easily provide this bias. Techniques for correcting the polarization measurements for the effects of such biases are well understood and are standard parts of our analysis programs.

E. Collimation

The central core of the hyperon beam collimator was recently modified to make it easily removable so that changes in its geometry could be installed. In order to increase the neutral beam intensity, we plan to replace the 4 mm diameter limiting aperture by an 8 mm diameter aperture. Some modification of the collimator is necessary because of the increased transverse spread of production points at the larger angles. An 8 mm aperture is the largest consistent with these considerations.

IV. RUNNING TIME AND SENSITIVITY

Our apparatus accepts a wide band of Λ^o, $\bar{\Lambda}^o$ and K_s^o momenta simultaneously, therefore the running time is based on the smallest cross section we hope to measure at a particular angle, viz. one nanobarn/GeV/sr. In order to achieve ±20% precision, we need 25 events. To calculate this, we use

$$dN = \frac{N_O}{\sigma_{tot}} \frac{d\sigma}{dp\, d\Omega} \Delta p \; \Delta\Omega$$

where

$dN = 25$ = Number of detected Λ^o

$\sigma_{tot} = 270$ mb = Total cross section for protons on Be

$\frac{d\sigma}{dp\, d\Omega} = 10^{-6}$ mb/GeV/sr = desired sensitivity

$\Delta p = 40$ GeV = bin width for $\Delta x = 0.1$

$\Delta\Omega = 8 \times 10^{-6}$ sr = solid angle subtended by neutral beam colimator

Solving this, we find

$N_o = 2.1 \times 10^{13}$ = Number of interacting protons.

If we assume 10^{10} protons per synchrotron cycle, 1/2-interaction-length target, 360 machine cycles per hour, and a 50% duty factor in keeping tapes mounted and spinning, then this figure can be achieved in 24 hours. We assume 4 hours of target-out running, and two hours to reset the apparatus in the proton beam for a new angle. (We assume that the backgrounds are small, and that only short target-empty runs are required. If this is untrue, then the full/empty running time and our sensitivity will be different.) The smaller production angles will require less time, but this is offset by the optimistic estimate of changeover time. We propose to measure the yields and polarizations at six lab angles: 0, 4, 8, 10, 12 and 14 milliradians. Thus our running time should be:

Tune-up, testing modified trigger	70 hours
Physics measurements at six angles	180 hours
Total	250 hours

The uncertainty in the polarization measurement of the same events is given by

$$\Delta P = (3/dN)^{1/2}$$

To obtain $\Delta P = 0.1$ or better, we need 300 events or a cross section of 12 nb/GeV/sr. Suitable magnet reversals will be made during the running which should cancel biases in the longitudinal component of the polarization, P_z. Since the precession angle resulting from the magnetic field of the sweeper is well-understood from Exp. 440, this is sufficient to determine completely the lambda polarization at the production target. This consideration relieves us of the need to measure carefully the transverse component, P_x. (To cancel biases in P_x, it is necessary to run at both positive and negative production angles, thus doubling the running time.)

V. COMPUTER TIME

Based on our experience with previous experiments, we estimate that roughly 150 hours of computer time will be needed on the CDC 6600 systems.

VII. PERSONNEL

This experiment will be staffed by a seasoned group of neutral hyperon freaks who have long experience in running the experimental apparatus and associated analysis programs.

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FIGURE CAPTIONS

Fig. 1 Inclusive lambda polarization at 300 GeV as a function of transverse momentum. (From Refs. 1 and 2)

Fig. 2 The function $\alpha P/\sin\theta_{c.m.}$ for inclusively produced lambdas vs. lab production angle for each of several bands of Feynman x.

Fig. 3 The function $\alpha P/\sin\theta_{c.m.}$ averaged over lab production angle and plotted as a function of Feynman. Data from Experiment 440 at a fixed angle of 7.2 mr (lab) are also plotted.

Fig. 4 The "engineering cross section" for inclusive lambda production. The points represent data from Exp. 8 scaled up to 400 GeV. The solid lines are the fits of Ref. 8, and the dashed lines are extrapolations of those fits.

Fig. 5 An elevation view of the neutral hyperon beam. The 400 GeV diffracted proton beam in the M2 line is incident from the left. It is steered onto the production target by the 2G3 dipole string. A 5.2 meter long magnetic beam channel (the sweeper) removes charged particles and collimates the neutral beam. Neutral strange particles which decay in the vacuum pipe are detected in a pair spectrometer by their charged decay products.

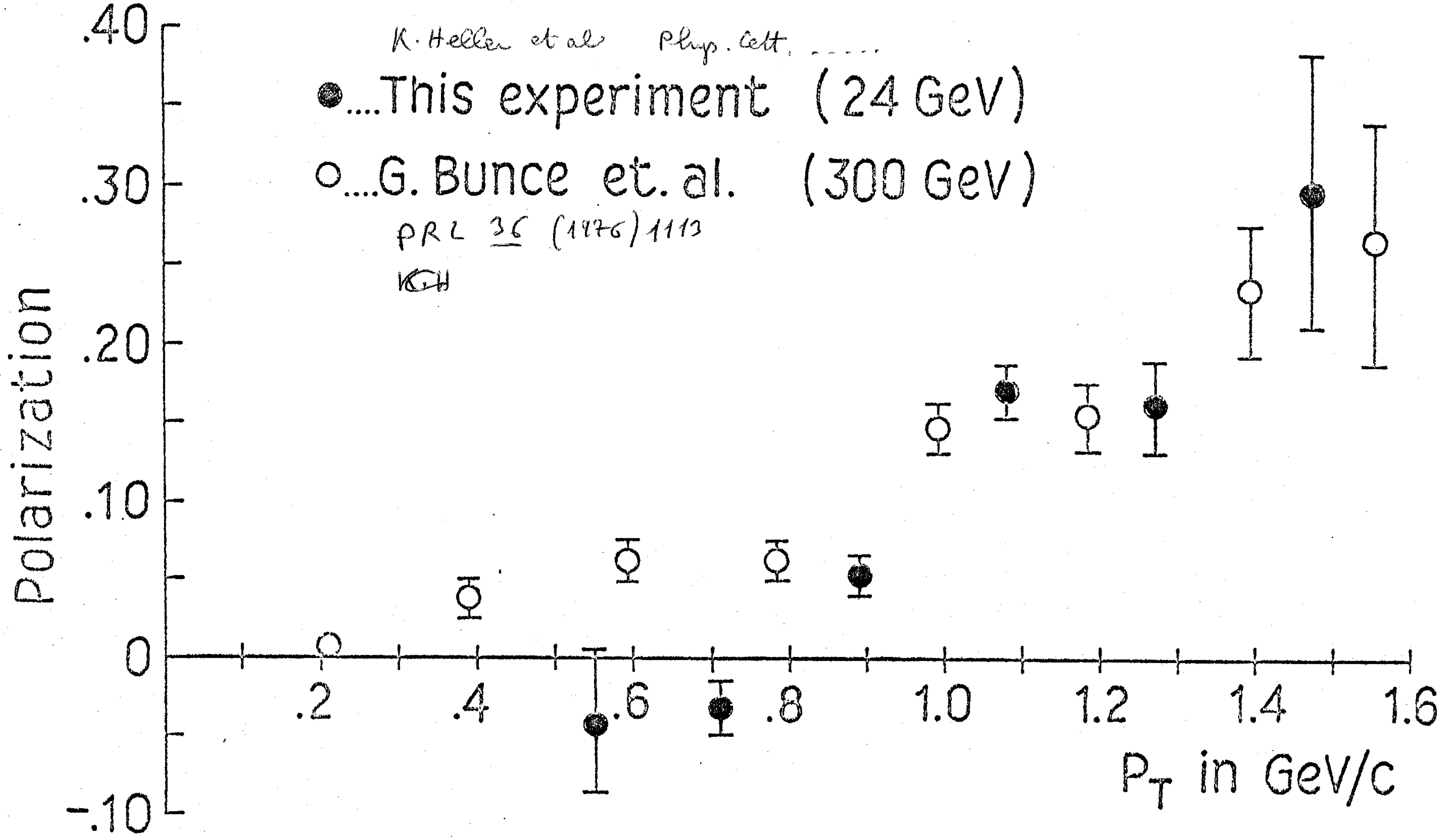
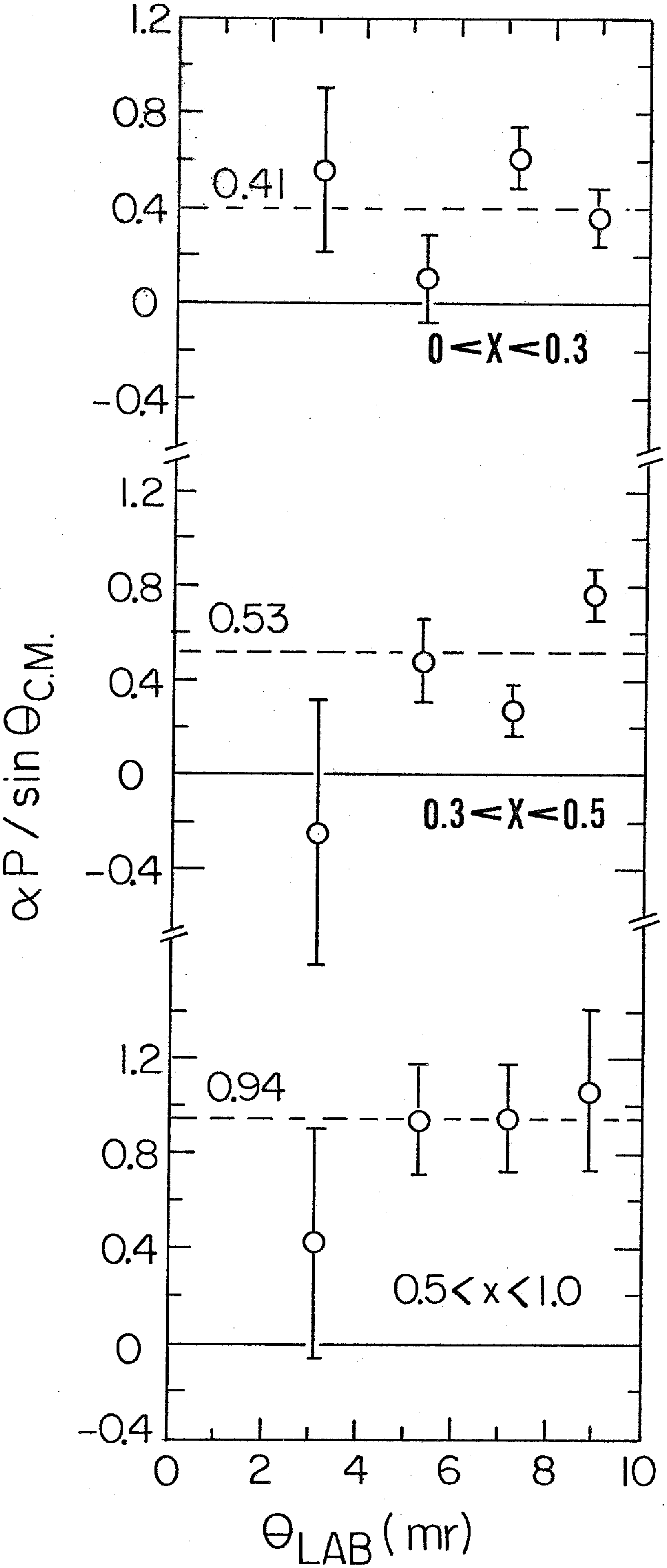

K. Heller et al Phys. Lett. ......
●....This experiment (24 GeV)
○....G. Bunce et. al. (300 GeV)
PRL 36 (1976) 1113
Polarization
.40
.30
.20
.10
0
-.10
.2
.4
.6
.8
1.0
1.2
1.4
1.6
P_T in GeV/c

Fig. 1



1.2
0.8
0.41
0.4
0
0<X<0.3
-0.4
1.2
0.8
0.53
0.4
0
0.3<X<0.5
-0.4
1.2
0.94
0.8
0.4
0.5<x<1.0
0
-0.4
0
2
4
6
8
10
αP / sin θC.M.
θLAB (mr)

Fig. 2

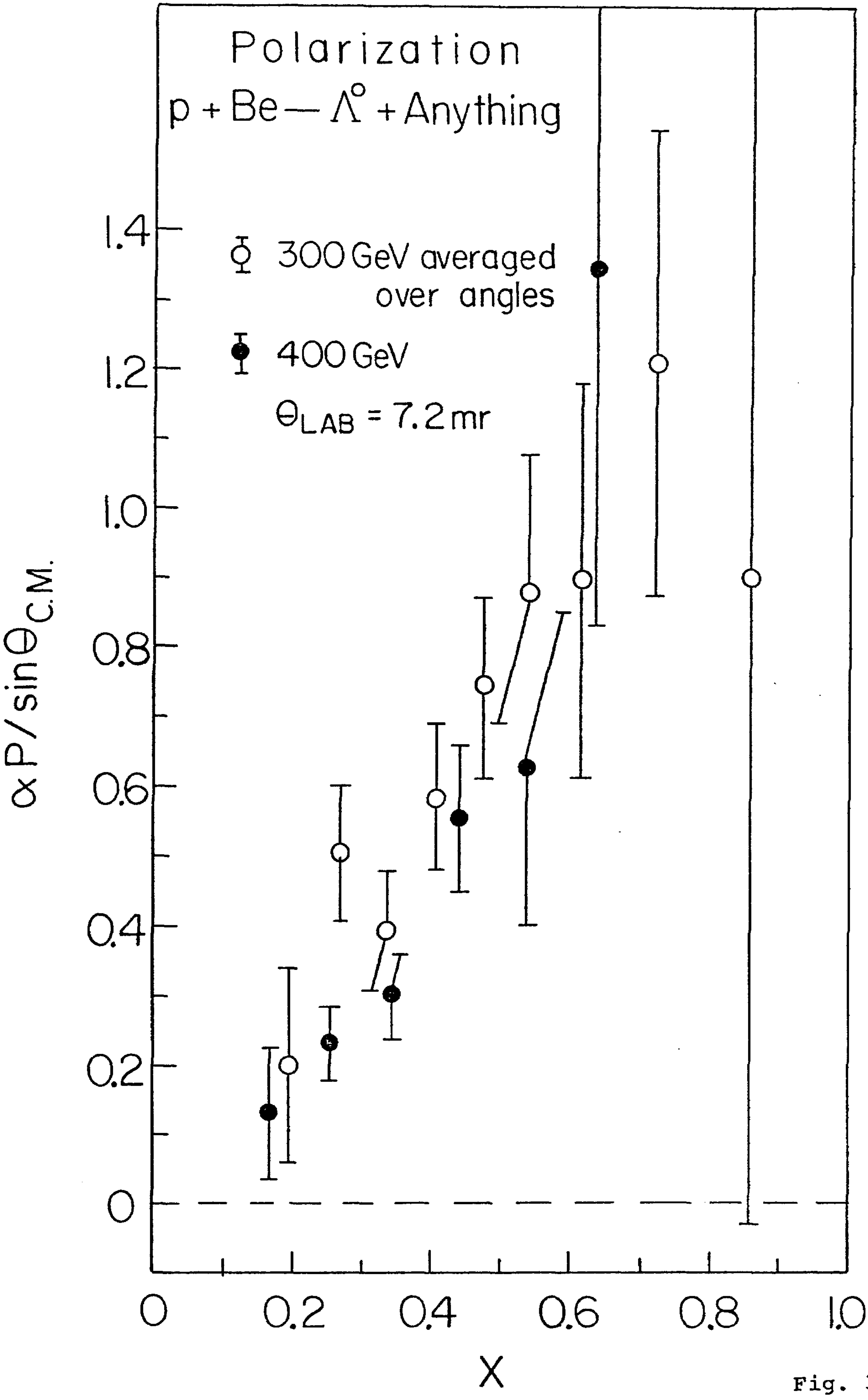
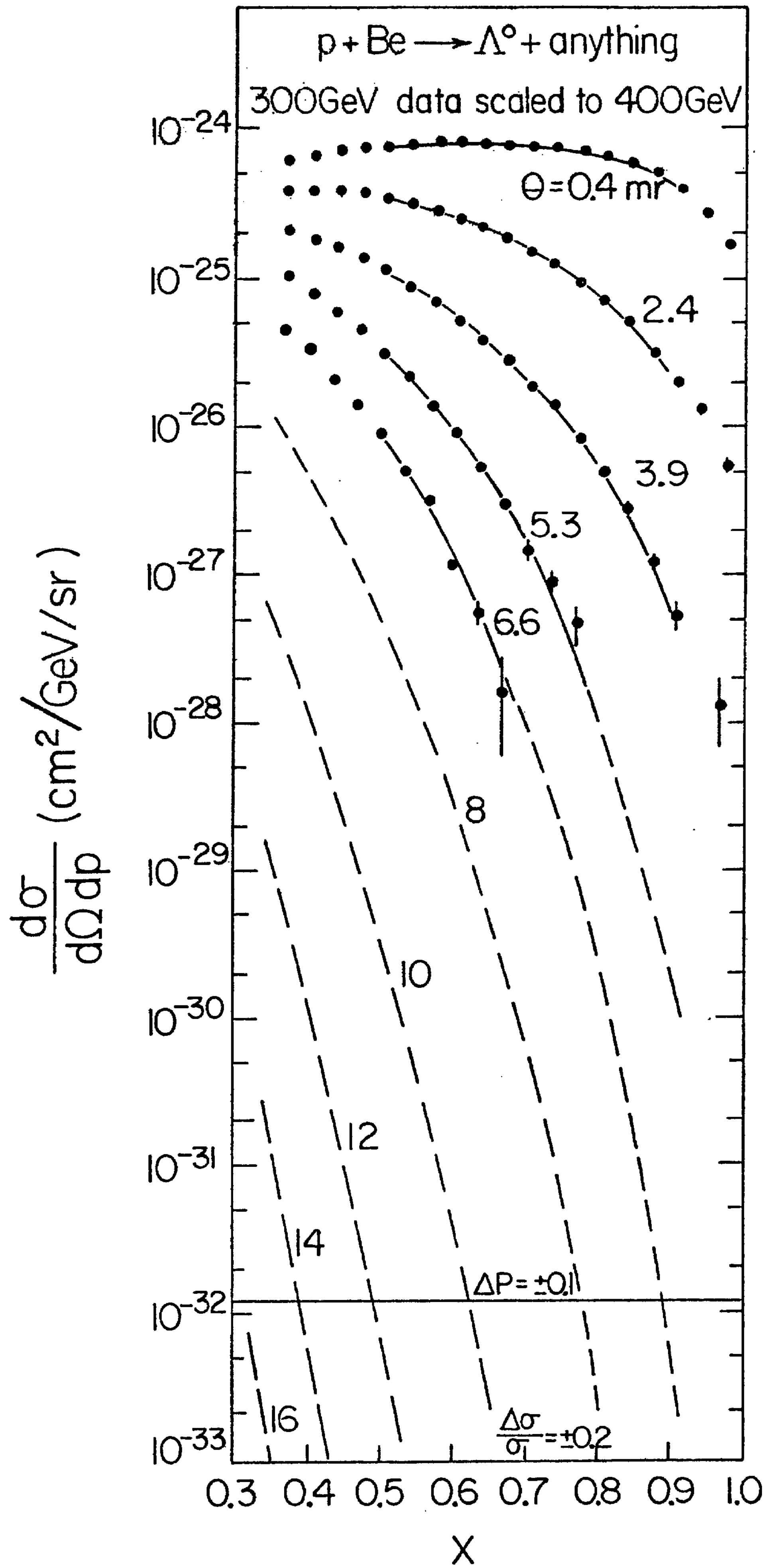

Polarization
p + Be — Λ° + Anything
300 GeV averaged over angles
400 GeV
Θ_LAB = 7.2 mr
αP/sinΘ_C.M.
X
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4

Fig. 3



p + Be ⟶ Λ° + anything
300GeV data scaled to 400GeV
θ=0.4 mr
2.4
3.9
5.3
6.6
8
10
12
14
16
ΔP=±0.1
Δσ/σ₁=±0.2
10⁻²⁴
10⁻²⁵
10⁻²⁶
10⁻²⁷
10⁻²⁸
10⁻²⁹
10⁻³⁰
10⁻³¹
10⁻³²
10⁻³³
dσ/dΩdp (cm²/GeV/sr)
0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
X

Fig. 4

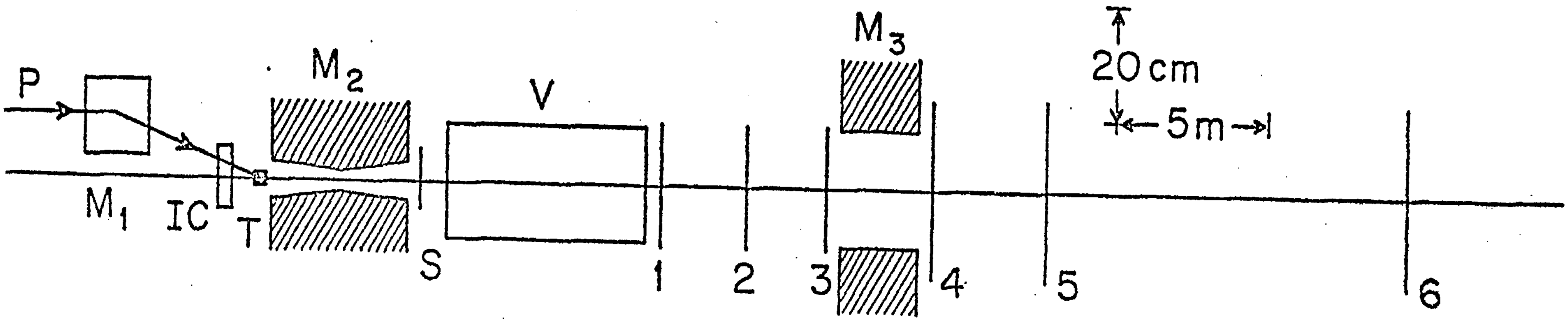


Fig. 5

555