SINGLE SPIN ASYMMETRY IN INCLUSIVE REACTIONS

P^P -> PI+, PI-, AND P +X AT HIGH P-PERP

AT 13.3 AND 18.3 GeV/c.

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Abstract

Data are presented for the left-right asymmetry in inclusively produced pi+, pi-, and p with transverse-polarized proton beams of 13.3 and 18.3 GeV/c incident on a LH2 target. At both energies the asymmetry in pi+ production grows steadily up to the kinematic limit, whereas the pi- and p asymmetries are consistent with zero over the measured range of p-perp: 1.1-2.2 GeV/c.

Inclusive reactions at large transverse momenta are, in general, well understood in terms of hard scattering between elementary constituents of hadrons in the framework of perturbative QCD. The situation gets relatively worse when such theories are called upon to describe spin phenomena. This could be due to the lack of understanding of the hadronic wave functions and the helicity conserving QCD sum rule that sets a strict limit on spin-flip amplitudes, being propotional to the constituent quark mass divided by the available energy in the center of mass, leading to predictions of very low if not zero spin effects.

This workshop aims to exploit the full potential of the new polarized proton beam at FNAL. To this end, we present these data taken at the AGS as a precurser to what might be expected at Fermilab assuming that such spin effects persist at higher energies and larger transverse momenta.

The measurement of the left-right asymmetry in inclusively produced hadrons has been carried out since the first appearance of transverse polarized proton beams at the Argonne 12 GeV synchrotron (ZGS) in 1975. Most of the measurements to date have been done at transverse momenta below 1.0 GeV/c [1], with the exception of two pi-zero asymmetry experiments at CERN [2] and Serpukov [3] extending to p_t=2.0 and 3.0 GeV/c at x_f=0 and beam momenta of 24 and 40 GeV/c respectively. Both of these experiments utilized unpolarized beams incident on polarized targets with the disadvantage of having to apply large corrections to the measured raw asymmetries. The current experiment extends the charged pion and proton data to regions of high p_t with sufficient statistics to map the behavior of the asymmetry over a large range of p_t and x_f at two energies.

The data were taken in the winter of 1986, during the second run of the polarized proton beam at the Brookhaven AGS, using an apparatus located in the C-1 beam line. The beam intensity and polarization were stable at both energies, yielding approximately 10**7 protons per pulse on target and polarization in the range 45 to 60%. Beam polarization monitoring involved a combination of devices. A "fishing-line" polarimeter [4] internal to the synchrotron was used periodically by the AGS operators to measure the polarization of the beam prior to extraction. Our experiment included a pair of two-arm non-magnetic polarimeters consisting of sets of "forward" and "side" scintillators to measure the single spin asymmetry A_n in pp elastic scattering near t = -.3 (GeV/c)**2, where A_n is locally maximum. The analyzing power of this reaction has been thoroughly studied, and is now used regularly as a polarization monitor. Our polarimeter accumulated events amounting to a three sigma beam polarization measure -ment each hour.

The experiment running concurrently in the D line [4], operated a two-arm magnetic polarimeter which accumulated statistics more rapidly than ours, and we have chosen to normalize to the D line polarimeter after checking for consistency between the two devices. We have also verified the need for a 5% correction factor, since depolarizing effects in the C1 beamline are smaller by this amount than in the D line [5].

The experimental apparatus, fig.1, differed little from that used in previous unpolarized elastic and quasi-elastic scattering experiments at large momentum transfer done by our group [6]. A vertical bend magnetic spectrometer measured the product particle of the inclusive reaction.
A recoil arm consisting of large proportional-drift chambers is not used in inclusives running except to extract a small sample of elastic events. The spectrometer consisted of a 48D48 magnet preceded and followed by proportional and drift chambers for tracking and scintillation hodoscopes for triggering. Two Cerenkov counters following the magnet were both set

to a threshold of gamma = 21.5 for this run to insure efficiency for pion identification. The trigger included logic matrices on scintillator and drift chamber elements in the bend direction to select particles with a minimum momentum. The vertical acceptance was +/- 3.5 degrees and the horizontal +/- 2.5 degrees, and the target was a meter of liquid hydrogen.

Data for positive and negative particles were collected separately by reversing the polarity of the analyzing magnet. The asymmetry parameter measured in this experiment is defined as follows: $A_n = 1/P(Nu-Nd)/(Nu+Nd)$, where Nu and Nd are the number of particles that scatter to the left looking downstream, with the beam polarized up and down respectively, and P represents the average beam polarization. As is the case with all such parameters, acceptance and beam flux factors cancel out as long as the beam polarization remains stable. The AGS polarization was reversed from up to down alternately on successive spills, so that "left" and "right" data are acquired in the same apparatus which is stationary to one side of the beam. Since there are intensity variations, the beam monitors sum the relative up and down fluxes on a spill by spill basis.

Our primary beam flux monitors included (1) a gas ionization chamber located upstream of the target and (2) the rate of primary event triggers,a four-fold coincidence of the spectrometer hodoscope planes with no trigger matrix (momentum) requirement. The latter was experiment-deadtime gated, and was not prone to saturate. It operates on the assumption that the bulk of event triggers are low p_t inclusives at low x_f of various particle types, and have no net asymmetry. This assumption, and the consistency of the monitors, was checked by comparing (1) and (2), which showed agreement in the up/down ratio of .3%.

The data for all reactions and both energies are displayed in Figure 2 as a function of p_t. The pi+ asymmetry at 13.3 GeV/c is sizeable, with a linear growth from zero near p_t of 1.0 to approximately .25 at the highest transverse momentum. The behavior at 18.3 GeV/c is similar. The pi- and p inclusives show little or no asymmetries at similar kinematic settings. It should be noted that since no Cerenkov identification of kaons was performed, the p inclusive data is likely to contain between 3% and 8% kaon contamination. It is doubtful that the removal of this contamination would change the conclusion that the asymmetry is zero.

These asymmetries exhibit no apparent dependence on Feynman x. As one illustration, fig. 3, the positive pion data was divided into various narrow strips in x_f and plotted in overlay as a function of p_t. The p_t of each datum corresponds to actual central value of the bin. Thereafter, at each value the points have been spread slightly for visibility. It becomes clear that the asymmetry is independent of x_f in this kinematic region. This is different from the polarization of inclusive lambda production from protons where it is found to have a strong x_f dependence and little or no dependence on transverse momentum above 1.0 GeV/c. On the otherhand, kaon induced lambda polarization shows an x_f dependence [7] similar to our positive pion data.

The similarity of the p_t plots for pi+ at the two energies further suggests an underlying scaling behaviour in some kinematic variable, and figure 4 confirms this. As a function of x_t, the asymmetry data for 13.3 and 18.3 GeV/c coincide. Over this rang of incident energy, the asymmetry scales with x_t. The same applies to the pi- and p data.

The purpose of Figure 5 is to display the current pi+ data in the context of other measurements of the asymmetry in this reaction by other experiments. Included are results from an earlier Argonne experiment [1], Dragoset et al, and a second AGS experiment that ran at the same time as ours, Moss et al.[8]. This diplot in x_f and x_t hints at the possible differences in the theoretical explanations for low and high transverse momentum behavior. For example, Dragoset et al. explain the data in the region below $p_t = 1.$ ($x_t = .3$) in terms of u channel baryon exchange, which can account for the change of sign about $x_t = .2$. Outside of this region, the data have a tendency to reach a maximum value at high x_f or high x_t: in the vicinity of the elastic limit. This may be indicating that the relevant or simplest kinematic variable in this case is $x_r = (x_f^2 + x_t^2)^{1/2}$

One impetus for doing high p_t scattering experiments is to explore a kinematic region where PQCD might be applicable. What does this theory predict for the present experiment? For massless quarks coupling to vector gluons, any arbitrary Feynman diagram conserves helicity [9], implying that any single spin asymmetry will be zero , which clearly disagrees with the high asymmetry in the pi+ data. If the measured asymmetries are a "low energy" effect, one would expect them to get smaller with increasing energy, as the PQCD amplitudes begin to dominate. Even this is at odds with the data, which show no decrease. It should also be noted that nothing in the simplest PQCD argument can account for the pi+, pi- difference. On the other hand, one could hypothesize that at transverse momenta below 4.0 GeV/c, PQCD is not yet applicable.

The current results could be explained if one invoked a quark-diquark structure for the proton. The assumption is that the proton consists of a scaler (ud) diquark and an unpaired u-quark, the latter being the carrier of the spin information. An additional piece of information comes from the hyperon polarization experiments, i.e. the sea-quarks are preferentially polarized down. Thus positive pions are preferentially produced when an up polarized u-quark pairs with a down polarized d-quark from the sea. Thus the sensitivity to the proton polarization. On the other hand, the negative pions draw upon a paired d-quark from the proton to couple with a u-bar quark from the sea. This leads to a lack of sensivity to the proton beam polarization. The growth of the asymmetry in pi+ production with p_t leads to an additional conclusion that the quark-diquark content of the proton increases with transverse momentum. This effect has been observed in high p_t inclusive production at ISR energies [10].

Our results may be summarized as follows. The pi- and p asymmetries are small or zero. The pi+ asymmetry is large. Its energy dependence scales with x_t and grows from zero at low x_t to about 25-30% as x_t -> 1. The asymmetries in this kinematic region show no x_f dependence, and, in light of the inclusive data to date, we conclude that the relevant kinematic variable may be x_r and that the asymmetry grows with x_r. While various phenominological approaches seem to adequately describe some aspects of the inclusive results in the beam fragmentation region, here we cite the work of DeGrand and Miettinen [10], there remains a void in the understanding of spin effects in the hard scattering domain.

REFERENCES

* Now at FNAL.

** Now at the University of Rochester.

1. R.D. Klem et al. Phys. Rev. Lett. 36,(1976) 929.
   W.H. Dragoset et al. Phys. Rev. D18, (1978) 3939.

2. J. Antille et al. Phys. Lett. 94B, (1980) 523.

3. V.D. Apokin et al. Asymmetry In The Inclusive Reaction pi- p^ -> pi0 + x at High p_t at 40 GeV/c. The proceedings of The VII International Symposium on High Energy Spin Physics. Protvino, USSR, 1986. Vol 2 page 83.

4. Fatah Khiari et al. Ph.D. Thesis, University of Michigan 1986.
   F.Z. Khiari et al. The Acceleration of Polarized Protons to 22 GeV/c and the Measurement of Spin-Spin Effects in P^+P^->P+P UM-HE-87-36, April 8,1988.

5. G.M. Bunce, BNL 29856 (1981).

6. B. Baller et al. Phys. Rev. Lett. 60,(1988) 1118.
   S. Heppelmann et al. Phys. Rev. Lett. 55,(1985) 1824.

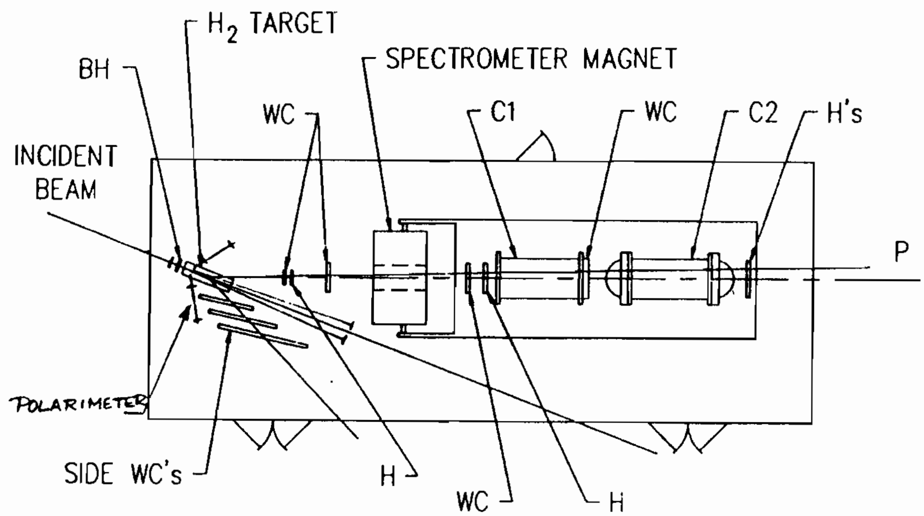
7. T. Haupt et al. Z. Phys. C 28,(1985) 57.

8. R. Moss, Ph.D. Thesis, Rice University, Feb. 1988.

9. E. Leader, High Energy Spin Physics, proceedings of the 2nd conference on Intersections Between Particle and Nuclear Physics. Lake Louise, Canada 1986, D. Geeseman editor. p 257-271.

10. A. Breakstone et al. Z. Phys.C. 28,(1985) 335.

11. T.A. DeGrand and H.I. Miettinen, Phys. Rev. D23, (1981) 1227; 24, (1981) 2419; 31,(1985) 661(E); DeGrand et al. Phys. Rev. D32, (1985) 2445.



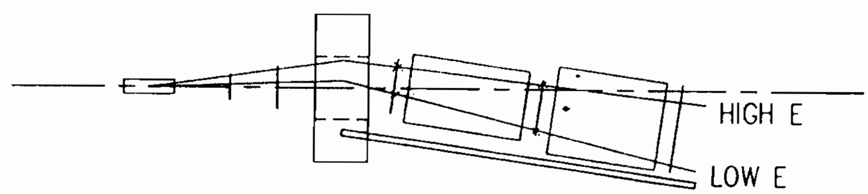


Figure 1. The Layout of the Apparatus Plan and Side Views.

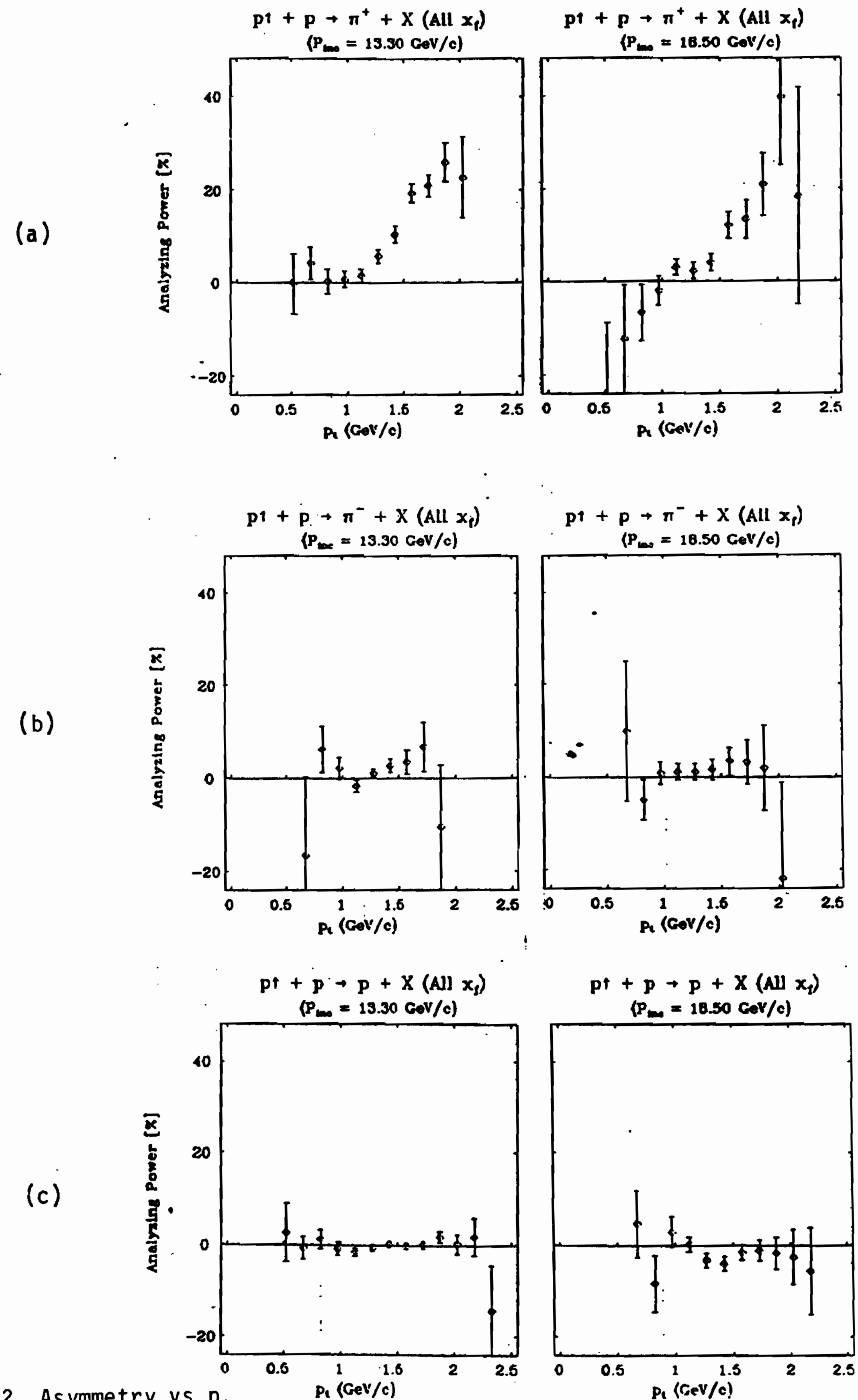


Figure 2. Asymmetry vs p_t

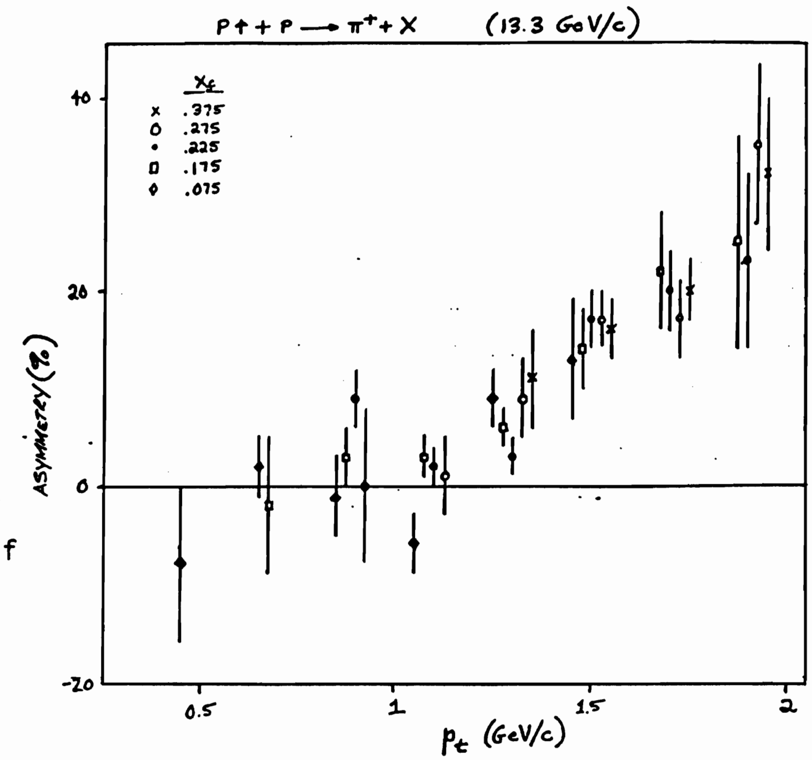


Figure 3.
Asymmetry vs p_t for various slices in x_f

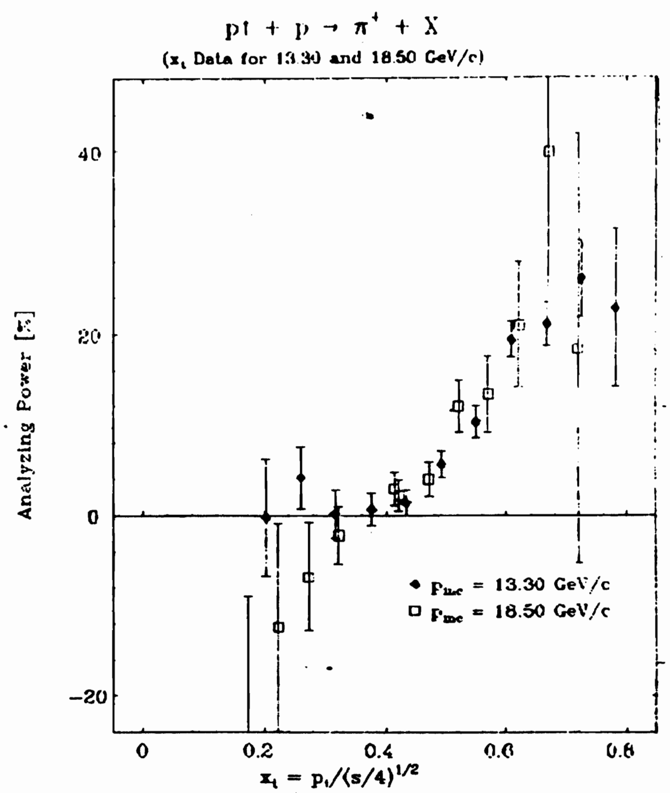


Figure 4.
Asymmetry vs x_t for 13.3 and 18.3 GeV/c.

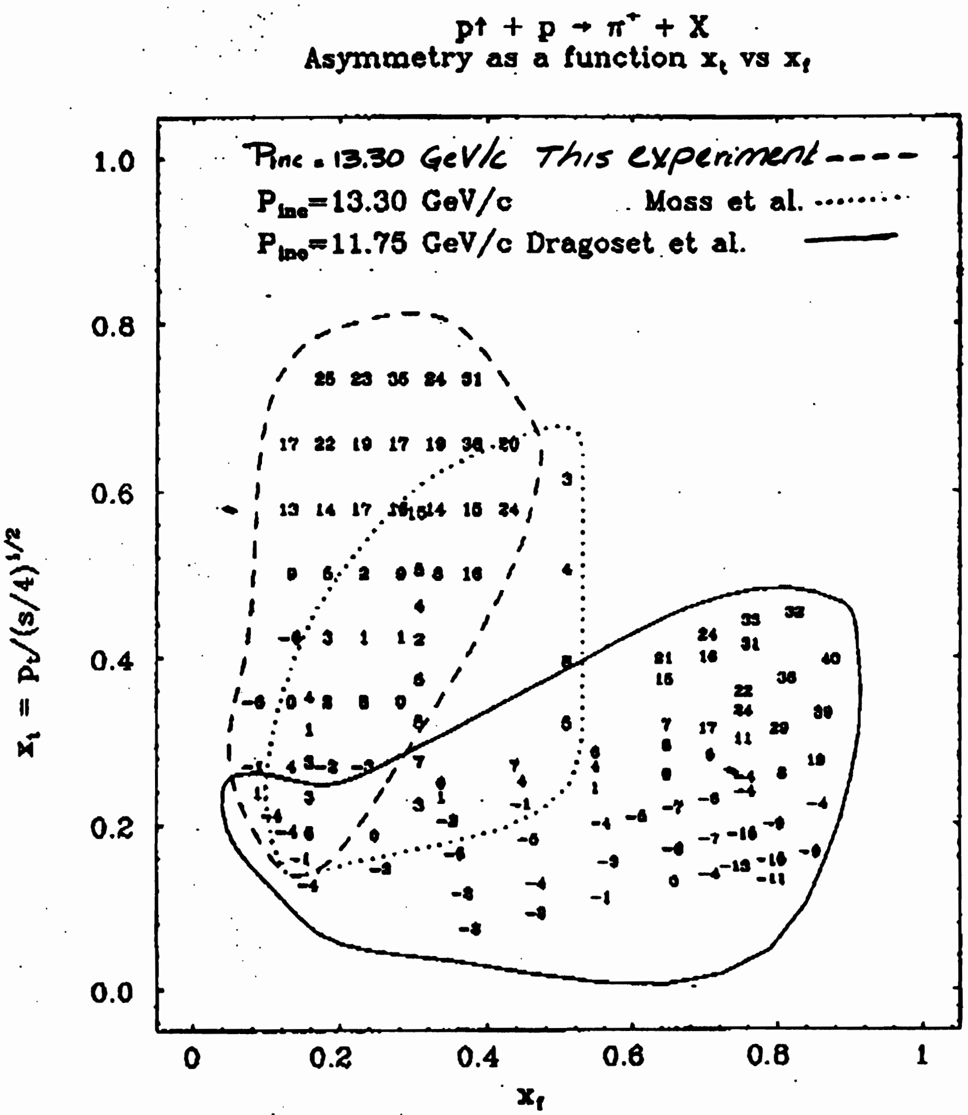


Figure 5.
A diplot of the Asymmetry vs x_t and x_f