699

Letter of Intent

Study of Spin-Dependent Asymmetries Using Calorimeter Triggered High p_T Events with Polarized Beam and Polarized Target

ANL-Kyoto-LAPP-LBL-LeHigh-Pennsylvania-Rice-
Saclay-Trieste-Wisconsin Collaboration

There are substantial reasons, both theoretical,[1] and experimental,[2] to expect significant spin effects in high p_T interactions at Fermilab energies. Some of these are best observed by calorimeter techniques.

We have done rate calculations assuming a calorimeter similar to that used in E609. The actual calorimeter to be used will be determined as scheduling and technical developments dictate. These rough estimates of cross section and polarization indicate that a good exploratory experiment up to p_T of about 6 GeV/c with an accuracy of a few percent for A_{LL} can be done in 1000 hours. (A_{LL} is the longitudinal spin-spin asymmetry, defined by

$$A_{LL}(s,x,p_\perp) = \frac{Ed^3\sigma(\rightleftarrows)/dp^3 - Ed^3\sigma(\rightrightarrows)/dp^3}{Ed^3\sigma(\rightleftarrows)/dp^3 + Ed^3\sigma(\rightrightarrows)/dp^3},$$

where $\rightrightarrows$ ($\rightleftarrows$) refers to parallel (anti-parallel) helicities).

This experiment can provide valuable constraints on the relative contributions from different QCD subprocesses. Both polarized beam and polarized target are needed for this measurement.

We expect to submit a new, detailed proposal within a few months.

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(312) 972-6311.

28 May 1981

Letter of Intent

Addendum

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Addendum to Letter of Intent on "Study of Spin-Dependent Asymmetries Using Calorimeter Triggered High-$p_{\perp}$ Events with Polarized Beam and Polarized Target" (Proposal 699 - Van Rossum) describes more details of experiments to be proposed.

SUMMARY

We propose an experiment to measure the spin dependence of high-$p_{\perp}$ jet production in pp, and $\overline{p}p$ (second-round experiments) collisions. It will measure the single-spin asymmetry A_N, for which the beam is transversely polarized, and the double-spin asymmetry A_{LL}, for which both beam and target are longitudinally polarized.

A calorimeter will be used to select events with large transverse energy flow. Measurements of the asymmetries A_N and A_{LL} to ± 1 and 5% respectively can be made at 400 GeV/c for single jets of $p_{\perp} \lesssim 6$ GeV/c, and for double jets having total transverse energy of 10 GeV.

We will run with a liquid-hydrogen target during the single-spin measurement and with a longitudinally polarized target during the double-spin measurement. Proton induced reactions will be studied at 400 GeV/c, and possibly both proton and antiproton induced reactions at 200 GeV/c, where the $\overline{p}$ flux is highest.

I. Introduction

Since the observation of a strong s dependence and apparent power law $p_\perp$ dependence in high transverse momentum events, there has been a large investment by the high energy physics community in both experimental and theoretical aspects of high-$p_\perp$ reactions. This has helped develop the notion that hadron constituents are fundamental in the high-$p_\perp$ reactions. QCD has evolved into a theory explaining many aspects of high energy reactions including the observed unpolarized, large-$p_\perp$ phenomena.

SLAC polarized electro-production data with polarized target have confirmed theoretical beliefs that fast constituents within the proton retain the information of their parents' spin. The recent data shown in Fig. 1 are considered evidence that large-x quarks in the proton have a high probability of retaining the helicity of the parent proton.[1]

II. Physics Goals for High-$p_\perp$ Experiments

Since the only known way of studying parton-parton scattering in hadron collisions is through the investigation of the properties of large-transverse-momentum events, we propose to measure spin asymmetries in high-$p_\perp$ events using polarized beams and a polarized nucleon target. These asymmetry measurements will provide further checks on the validity of QCD first-order perturbation theory. A measurement of the asymmetries in $pp \to cX$ or $\bar{p}p \to cX$, with c a high $p_\perp$ hadron or a jet-like event, is related to the fundamental $2 \to 2$ parton processes via the spin-weighted distribution functions[2-4] as shown in Fig. 2.

Recently progress has been made in understanding the observed $p_\perp$ behavior of inclusive hadron production at moderate values of $p_\perp$ within the framework of QCD.[5] As a guide to the experimenters, it may be worthwhile to look at asymmetry predictions based on the lowest-order QCD.

Deep inelastic electro-production can only measure the spin dependence of the quarks within the nucleon, and therefore the spin properties of gluons are not yet established. But experiments are being proposed which will enable us to learn about the gluon polarization from asymmetry measurements in polarized J/ψ production. Although the gluon fragmentation functions are expected to fall off faster at high z than the quark fragmentation functions, gluons are still responsible for 70-80% of the single-jet triggers at $x_\perp = 0.3$.[2,6] Thus for jet production with $x_\perp \lesssim 0.3$, the subprocesses $qG \to qG$ and $GG \to GG$ are relatively more important than the subprocess $qq \to qq$. Jet asymmetry measurements where both the beam and target are polarized will provide new experimental information on the gluon spin distribution which cannot be probed directly in ep scattering.

At the moderate values of $x_\perp$ where we will measure the single-jet cross sections, the estimates for gluon polarization within the nucleons will be very dependent on particular models specifying the extent to which qG and GG contribute to the underlying scattering. However, we can get an idea of the gluon polarization by comparing several $p_\perp$ regions and using an average over x of quark polarization determined from the SLAC ep experiments.

In contrast, the fundamental scattering process for a two-jet high-$p_\perp$ trigger is expected to contain a larger amount of $qq \to qq$.[7] This can be seen as follows. With a single jet trigger there is no constraint on the direction of the unobserved jet and thus no tight constraint on the x value of the constituents involved scattering for the unobserved jet. (The $p_\perp$ of the two jets must be similar within ~ the parton initial transverse momentum, k_T, for the two jets by momentum conservation.) A two-jet trigger can be used to enrich the data sample for events with the two jets more nearly back-to-back in the proton-proton center-of-mass. The back-to-back requirement constrains x_1 to be similar in magnitude to x_2 and thus both x's will be large for large-$p_\perp$ events. Since the gluon distribution within the hadrons fall faster in x than do the quark distributions, the single jet triggers have a high component of $qG \to qG$ while the two-jet triggers will tend to favor $qq \to qq$ at high $x_\perp$.

Since the double-jet trigger requires both underlying constituents to have almost the same x, the measured asymmetry should directly reflect the polarization of the constituents at a given $x_\perp$ ($= x_1 = x_2$). Thus, with some estimate of the subprocess contributions, polarized gluon structure functions should be readily obtainable.

Single-spin asymmetries with only the beam polarized normal to the scattering plane will be measured; i.e.,

$$A_N \equiv P = \frac{Ed^3\sigma\uparrow/dp^3 - Ed^3\sigma\downarrow/dp^3}{Ed^3\sigma\uparrow/dp^3 + Ed^3\sigma\downarrow/dp^3}$$

for the process $p\uparrow p \rightarrow cX$ with c one or two jets at high $p_\perp$. The first-order QCD model predicts zero polarization. Experimental results at 24 GeV/c show up to a 50% asymmetry[8] in the measurement of $pp\uparrow \rightarrow \pi^0 X$ (see Fig. 3). It is important to extend this or similar measurements to higher energy. By using transversely polarized beams and a hydrogen (or nuclear*) target the disadvantage of polarization dilution in polarized targets is avoided for single-spin physics measurements.

With longitudinally polarized beam and target, we propose to measure the double-spin asymmetry, A_{LL},

$$A_{LL}(s,x,p_\perp) = \frac{Ed^3\sigma(\overset{\rightarrow}{\leftarrow})/dp^3 - Ed^3\sigma(\overset{\rightarrow}{\rightarrow})/dp^3}{Ed^3\sigma(\overset{\rightarrow}{\leftarrow})/dp^3 + Ed^3\sigma(\overset{\rightarrow}{\rightarrow})/dp^3} ,$$

where $\overset{\rightarrow}{\leftarrow}$ ($\overset{\rightarrow}{\rightarrow}$) refers to parallel (anti-parallel) helicities.

The asymmetry A_{LL} for single jets is predicted to be significant,[4] ranging from 2–10% at $x_\perp \approx 0.4$ (where our statistical uncertainty will be less than 1%) depending on the parton spin distributions used in the calculation. Indeed, the spin distribution which predicts the largest asymmetry is in best agreement with the SLAC $\overset{\rightarrow\rightarrow}{ep}$ data. A_{LL} for both π° and jet triggers is shown is Fig. 4 for pp collisions and in Fig. 5 for $\bar{p}p$ collisions. This experiment can

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* The non-trivial A-dependence of large $p_\perp$ hadron or jet production seen in unpolarized reactions is a clue that the fundamental scattering may not be incoherent. The study of the A-dependence of large $p_\perp$ production with polarized beams will contribute to clarify the nature of the A-dependence. Since the unpolarized A-dependence for jet and single particle production both show an anomaly[9], it may suffice to measure jet asymmetry rather than single-particle asymmetry in order to get to higher $p_\perp$.

provide valuable constraints on the relative contributions from different QCD subprocesses. The predicted A_{LL} for $\bar{p}p$ is smaller because the large $q\bar{q} \rightarrow GG$ process contributes a negative asymmetry.

The proposed experiment will be able to measure, with adequate statistics, the region out to $x_{\perp} = 0.4$ for single-jet triggers at $p_{lab} = 400$ GeV/c. Negative values for A_{LL} in pp collisions would seriously modify our understanding of the low order contributions to parton subprocessses, since all subprocesses $qq \rightarrow qq$, $qG \rightarrow qG$ and $GG \rightarrow GG$ contribute positive asymmetries. Large asymmetries would also contradict fundamental assumptions. If A_{LL} for $pp \rightarrow \text{Jet} + X$ is found to be positive while A_{LL} for $\bar{p}p \rightarrow \text{Jet} + X$ is negative, we can conclude that a large amount of $q\bar{q} \rightarrow GG$ contributes to jet production. We note that theoretically, A_{NN}, when beam and target are polarized normal to the scattering plane, is expected to be negligible.[10]

The double-spin asymmetries we wish to measure are predicted to be only weakly dependent on energy[3] for fixed $x_{\perp}$ above $\sqrt{s} = 20$ GeV and are maximum at $\theta_{c.m.} = 90°$, decreasing by only about 10% at $\theta_{c.m.} = 70°$.[4] We thus propose to measure the average of A_{LL} for $70° \lesssim \theta_{c.m.} \lesssim 110°$ and only at 400 GeV/c for incident protons and possibly at 200 GeV/c for incident p's and $\bar{p}$'s.

From the above discussion and weighted by the ease of performing certain measurements, we list in Table I an expected priority of experiments.

In Section V, we present rate and running-time estimates for the two high-priority measurements.

Table I
Expected Experimental Measurements

Reaction	Measurement	Beam Polarization	Target
pp → (jet-like) + X	$P = A_N$	$\vec{N}$	LH_2
pp → (jet-like) + X	A_{LL}	$\vec{L}$	$\vec{L}$
$\bar{p}p$ → (jet-like) + X	A_{LL}	$\vec{L}$	$\vec{L}$
pp → (jet-like) + X	A_{NN}	$\vec{N}$	$\vec{N}$

Note: (jet-like) means simultaneous measurements of single and double jet events.

III. Design Features of the Experiment

In the proposed experiment, emphasis will not be on the rigorous definition of jet structure but in measuring the differences in cross section for different initial helicity states of high $p_\perp$ hadronic final states. Our detector, therefore, must possess at least the following three capabilties:

1) It must be able to trigger efficiently and in an unbiased fashion on both single and double high-$p_\perp$ jet-like events over a large kinematic region.

2) The transverse momentum of the jets must be measured with resolution equal or better than the proposed bin width, $\Delta p_\perp$.

3) In order to reduce systematic errors, the triggering efficiency must be kept constant and uniform to a large degree. Additionally, we will need to reverse beam and target polarizations frequently to average over any time dependent gains or beam steering. This reversal time should be much less than the time scale of variations within the detector.

Particles belonging to jet-like events can extend over a wide range of angle and momentum. Our acceptance will be centered at 90°, and we will have an adequate angular acceptance to study a range of two-jet kinematics.

The conditions for selecting high $p_\perp$ jet-like events (item 1 above) are the following:

a) The total transverse energy flow must be large.

b) The energy distribution peaks in small $\Delta\theta\Delta\phi$ regions.

c) The energy distribution drops by a large factor before reaching the edge of the detector.

Requirement (a) includes double-jet events with two large transverse energy deposits at about opposite azimuthal angles. Requirements (b) and (c) are necessary conditions to insure that our detector does not falsely create jet-like events. An ideal triggering detector is the highly segmented, good resolution hadron calorimeter designed and used by the Fermilab-Lehigh-Pennsylvania-Wisconsin group in Fermilab experiments E-395 and E-609.[11]

The calorimeter will be situated such that the entire azimuth will be covered between $40° \lesssim \theta_{c.m.} \lesssim 125^0$. The small block size of the calorimeter modules will enable us to sample small rapidity regions, $\Delta y \approx 0.4$. The fine block system will also allow good energy resolution of the the jet events. It has been shown that a detector of finite size causes a bias in the selection of narrow jets.[12] We therefore need to have a large fiducial region to reconstruct all jets as completely as possible. Experimentally we will define the jet axis and the $p_\perp$ of the jet by sorting events according to the total $p_\perp$ within a given solid angle $\Delta\Omega$ around a trial jet axis. Several values of $\Delta\Omega$ will be used, roughly between 1 and 2 sr. Experience from E395 has shown us that only about 10% of the jet $p_\perp$ will remain outside such a solid angle trigger region. If the $p_\perp$ within the solid angle is corrected statistically for missing jet $p_\perp$ and added background $p_\perp$, the jet momentum may be determined to a few percent. Although our triggers and offline event reconstruction do not include all jet members, the systematic error in transverse momentum for a given species of jet will be practically independent of beam or target polarizations. This point will be checked by using different values of $\Delta\Omega$.

We therefore conclude that for $p_\perp$ uncertainties of about $\pm$ 0.3 GeV/c in jet momentum, the E-609 calorimeter satisfies the criteria for efficiently triggering on jet-like events in an unbiased manner.

Uniformity of the calorimeter response from module to module is known to be better than $\pm$ 4%. Gain fluctuations of this magnitude could exist with a time constant of about 24 hours. In order to average over gain fluctuations, which cause varying triggering efficiencies, the beam polarization will be reversed as often as possible, preferably every spill. Similarly, to reduce systematic effects, the target polarization will be reversed every few hours.

The polarized beam will be run at 3×10^7 protons/spill at 400 GeV/c with a 10% interaction length target. We will trigger simultaneously with a "single-jet" and a "double-jet" trigger, both having more than one $p_\perp$ threshold. ($\bar{p}$ induced jets can be studied at 200 GeV/c with an intensity of 3×10^6 antiprotons/spill. To get similar acceptance at 200 GeV/c, the calorimeters will have to be moved 30% closer to the target.)

IV. Apparatus

A. Beam

The polarized beam line in the meson lab will be used. The characteristics of the beam are assumed to be those as detailed in Fermilab Proposal E-581. In particular, we assume:

1) $\Delta p/p = 5\%$, divergence < 1 mrad,

2) Polarization $\simeq 50\%$, longitudinal or transverse spin,

3) 3×10^7 protons/spill at 400 GeV/c and
   3×10^6 antiprotons/spill at 200 GeV/c,

4) Tevatron II duty factors,

5) Beam size $\lesssim 2$ cm diameter.

Beam hodoscopes of either narrow scintillator or proportional chambers will define the beam angle to $\pm$ 0.1 mrad ($\Delta p_\perp = \pm$ 0.04 GeV/c at 400 GeV/c). This measurement is important so that we are able to monitor beam position stability. A systematic change in beam direction, correlated with beam spin reversal, can create a false asymmetry, the magnitude of which depends on the relative calibration scales of the calorimeter modules.

However, this false asymmetry changes sign when target polarization is reversed.

Corrections to detector efficiency for varying instantaneous rates are important in the measurement of small asymmetries. This requires monitoring, and keeping constant, the instantaneous rates of beam and halo for opposite beam polarizations.

B. Target

For the single-spin asymmetry measurements, we will use a liquid hydrogen target 2 cm in diameter by 45 cm in length (10% absorption length).

For spin correlation measurements, the choice of polarized target is mainly dictated by the ability to attain large effective polarization, or equivalently, large signal to background. This requirement means that the degree of nucleon polarization should be high and that the ratio of polarizable nucleons to unpolarized nucleons is large. Furthermore, for high $p_\perp$ events, the anomalous A^α effect enhances events from heavier, unpolarized nuclei in the target, causing a reduction in the effective polarization at high $p_\perp$. It is therefore desirable for any unpolarized nucleons in the target to be in the form of light nuclei rather than heavy ones.

We will use a Li^6D target which has an effective nucleon polarization of about 30%, assuming no anomalous A dependence. The effective nucleon polarization drops to about 15% when $\alpha = 1.5$. This material has a density of 0.58 gm/cm^3 and a polarized nucleon to unpolarized nucleon ratio of

~ 0.5. However, we note that Li^6D is an isoscalar target where both protons and neutrons are polarized.*

A 10% interaction-length (8 cm) target with a diameter of 2 cm will be used. It will be polarized longitudinally in a superconducting solenoid magnet. The polarization will be reversed frequently as a consistency check on the data obtained by beam spin reversal and also as a crucial technique to eliminate systematic errors in the spin-spin measurements.

C. Detectors

We intend to make use of a calorimeter, with wire chambers as shown in Fig. 6.

The calorimeter at the downstream end of the experiment consists of lead-scintillator sandwiches for electromagnetic detection and steel scintillator sandwiches for hadron detection.

The calorimeter modules will be wired into a trigger matrix so that their output will be proportional to the energy deposited weighted by their mean lab angle ($p_\perp$). We intend to use the calorimeter subtending from 30° to about 140° in the center-of-mass, with a full 2π azimuthal coverage between $40° \lesssim \theta_{c.m.} \lesssim 125°$. It is important to have a uniform detector at opposite ϕ-angles to reduce false asymmetry measurements.

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* In Section II we have discussed the double-spin asymmetry predictions for polarized proton targets. Corresponding predictions for isoscalar targets can be calculated from the same $2 \to 2$ parton scattering amplitudes and the same spin-weighted distributions functions for u and d quarks, and gluons in protons and neutrons.

The energy resolution of the calorimeter was determined by E-395 to be

$$\frac{\Delta E}{E} = \frac{0.75}{\sqrt{E}} \quad \text{for hadrons}$$

$$= \frac{0.14}{\sqrt{E}} \quad \text{for electrons.}$$

From detailed studies and Monte Carlo calculations of E-395, a typical $p_\perp$ resolution for 4 or 5 GeV/c $p_\perp$ multi-particle groups is estimated to be ± 8%. This is within the uncertainty of the jet $p_\perp$.

D. Shield

To eliminate background from neutral particles coming along the beam direction, a shield is necessary just ahead of the LH_2 or polarized target. E-395 had such a shield, which did eliminate such background.

The shield must effectively remove all neutrals which come from interactions in our upstream beam counters, or from other upstream interactions or halo particles. The shield thickness must reduce spurious events, in which low $p_\perp$ could simulate high $p_\perp$, to a level on the order of a few events a day. With a beam flux up to 10^8 per second of spill, this requires a shield with attenuation about 10^9.

The shield must be in the same area upstream of the target as the snake magnets and the actual configuration of the shield will depend upon the magnets used in the snake. If eight BM105 magnets are used, they will constitute the bulk of the shield, requiring only a limited amount of iron around the last two, concrete around the upstream ones, and concrete and lead plugs in the unused portions of the gaps. If superconducting magnets are used, a shield similar to that used in E-609 will be required between the magnets and the target and concrete near the magnets.

We expect to put scintillation counters in the shield to monitor the left-right asymmetry of the remaining charged particles. Veto counters at the downstream edge of the shield will detect muons which have penetrated the shield.

V. Logistics

A. Triggers

With the large aperture calorimeter our triggers can be varied. The jet triggers will include a two-jet trigger as well as one-jet trigger. We await the outcome of E-609 before deciding on a final "best" trigger to determine jets and minimize trigger biases.

The trigger matrix which will allow us to use the outputs of all modules to form these varied triggers is now being constructed for E-609 and will be operational before this experiment begins.

B. Rates

For the geometry described in Section IV we can estimate the yields from the observed single-jet cross section and E-395 data on double-jet production. The error in the asymmetry measurements for a total of N raw events (sum of both beam polarizations) is

$$\Delta A_N = \frac{1}{P_B} \frac{1}{\sqrt{N}} \quad \text{for single spin measurements}$$

$$\Delta A_{LL} = \frac{1}{P_B P_T} \frac{1}{\sqrt{N}} \quad \text{for double spin measurements.}$$

The fiducial area used in these calculations corresponds to $65° < \theta_{c.m.} < 105°$, or about $\Delta\Omega = 4$ steradians. Table II lists the relative parameters for the beam and target for the single spin, A_N, and double spin, A_{LL}, measurements.

In order to estimate the effective target polarization, we can easily parameterize the A^α dependence of the target by assuming

$$P_{eff} = \frac{\left(2 \frac{\rho_D}{A_D} K_D + 2 \frac{\rho_{Li}}{A_{Li}} K_{Li}\right) \quad P_{NMR}}{\frac{\rho_D}{A_D} \; A_D^{\alpha} + \frac{\rho_L}{A_{Li}} \; A_{Li}^{\alpha} + \frac{\rho_{He}}{A_{He}} \; A_{He}^{\alpha}}$$

where the ρ_i's are the densities of the various target materials in Li^6D We obtain the approximate result for $1 \lesssim \alpha \lesssim 2$.

$$P_{Target} = P_{NMR} \; (.43/\alpha^2)$$

where $P_{NMR} \sim .75$.

For jet production[9] $\alpha(p_\perp)$ appears to be approximately $1 + (p_\perp/8)$. This results in the approximate effective polarizations shown in Table II used in the rate calculations.

Single-Jet Trigger

The single-jet cross-sections can be written as[13]

$$E \frac{d^3\sigma}{dp^3} = 100 \; e^{-3(p_\perp - 2.9)} \mu b/GeV^2 \text{ at } 400 \text{ GeV/c, and}$$

$$100\ e^{-3.6(p_\perp - 2.33)}\ \mu b/GeV^2 \text{ at } 200 \text{ GeV/c}$$

We assume $\sigma(\bar{p}p) = \sigma(pp) = \sigma(pn) = \sigma(\bar{p}n)$.

Table II

Parameters Assumed in Rate Calculation

	A_N	A_{LL}
Target	LH_2	Li^6D
Target length	45 cm	8 cm
Target density	0.072 g/cm^3	.58 g/cm^3
Effective target polarization	—	$0.33\ /(1 + p_\perp/8)^2$
Protons/hour at 200 or 400 GeV/c	1.8×10^9	1.8×10^9
Antiprotons/hour at 200 GeV/c	1.8×10^8	1.8×10^8
Beam polarization	0.5	0.5
$\Delta\Omega_{Fiducial}$	~ 4 sr.	~ 4 sr.
$\Delta p_\perp$	~ 0.33 GeV/c	~ 0.33 GeV/c

Assuming 100% operating efficiency, the expected errors on A_N for 100 hours of running and for A_{LL} for 500 hours of running are listed in Tables IIIa and IVa.

Double-Jet Trigger

We propose to take double-jet and single-jet triggers simultaneously. We can make a rough estimate of the double-jet rates from data taken in E-395. From the approximate relation for identical single-jet and double-jet detectors,

$$\sigma_{\text{double-jet}} (E_\perp) \approx \sigma_{\text{single-jet}} (p_\perp = E_\perp/2 + 1)$$

where $E_\perp$ is the total double-jet transverse energy, we show the expected errors on A_N and A_{LL} in part (b) of Tables III and IV. The A-dependence of the target polarization is assumed to be identical for double and single-jet events, as well as is the energy dependence of the above "rule-of-thumb" for double-jet cross sections.

Table III

Error in A_N for 100 Hours of Beam on Target at 400 GeV/c

a. Single-Jet Events			b. Double-Jet Events		
$p_\perp$ (GeV/c)	pp → Jet + X N_{evt}	ΔA_N(%)	$E_\perp$ (GeV)	pp → Jet-Jet + X N_{evt}	ΔA_{LL}(%)
3	$1.0 \cdot 10^8$	< 1.0	4	1×10^8	< 1
4	$6.9 \cdot 10^6$	< 1.0	6	6.9×10^6	< 1
5	$4.3 \cdot 10^5$	< 1.0	8	4.3×10^5	< 1
6	$2.6 \cdot 10^4$	1.2	10	2.6×10^4	1.2
7	$1.5 \cdot 10^3$	5.2	12	1.5×10^3	5.2

Table IV

Error In A_{LL} for 500 Hours of Beam on Target at 400 GeV/c

a. Single-Jet Events			b. Double-Jet Events		
$p_\perp$ (GeV/c)	pN → Jet X N_{evt}	ΔA_{LL}(%)	$E_\perp$ (GeV/c)	pN → Jet-Jet X N_{evt}	ΔA_{LL}(%)
3	$5.2 \cdot 10^8$	< 1.0	4	$5.2 \cdot 10^9$	< 1
4	$3.4 \cdot 10^7$	< 1.0	6	$3.4 \cdot 10^8$	< 1
5	$2.1 \cdot 10^6$	< 1.1	8	$2.1 \cdot 10^7$	< 1
6	$1.3 \cdot 10^5$	5.1	10	$1.3 \cdot 10^6$	2.0
7	$7.4 \cdot 10^3$	25	12	$7.4 \cdot 10^4$	8.0

Run Plan

We request a total of 800 hours to complete the following measurements:

System check out and calibration:	200 hours
Polarization at 400 GeV/c: (polarized proton beam)	100 hours
Spin-spin asymmetry at 400 GeV/c (polarized proton beam)	500 hours

At 400 GeV/c, this would provide an A_{LL} measurement to ± 5% in small bins of $\Delta p_\perp$ = 0.33 GeV/c for single-jets with $p_\perp \lesssim 6$ GeV/c and for double-jets with $E_\perp \lesssim 10$ GeV. Likewise, polarization can be measured with an accuracy of ± 5% at a single-jet $p_\perp \lesssim 7$ GeV/c and double-jet $E_\perp \lesssim 12$ GeV.

VI. Remarks

We realize that this experiment might be improved by the use of a large low-field magnet. This is because measurement of Z (fractional momentum) of leading π^+ in jets would allow us to obtain an enriched sample of quark-quark scattering events (as opposed to quark-gluon). Spin effects are predicted to be large for qq scattering because the leading quarks are known to carry a significant fraction of the proton polarization.

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Figure Captions

Figure 1 Experimental values of $(\sigma_{1/2} - \sigma_{3/2})/(\sigma_{1/2} + \sigma_{3/2})$ vs. x. $\sigma_{1/2}(\sigma_{3/2})$ is the total photon-proton absorption cross section when the z component of angular momentum of the photon plus proton is 1/2 (3/2). The photon is the virtual photon in deep inelastic ep scattering at $Q^2 \approx 4$ $(\mathrm{GeV}/c)^2$.

Figure 2 Hard scattering model for initially polarized protons with helicities λ_A and λ_B.

Figure 3 The measured asymmetry in $pp\uparrow \to \pi^0 + X$ as a function of $p_\perp$ in the Feynman x range 0-0.1. Data is from Ref. 7.

Figure 4 Asymmetry, A_{LL}, for reactions $pp \to (\pi^0$ or Jet$) + X$ as a function of $x_\perp$ for

(a) conservative SU(6) distributions,

(b) diquark distributions, and

(c) Carlitz-Kaur distributions.

Figure 5 Asymmetry, A_{LL}, for reactions $\overline{p}p \to (\pi$ or Jet$) + X$ as a function of $x_\perp$ for

(a) conservative SU(6) distributions,

(b) diquark distributions, and

(c) Carlitz-Kaur distributions.

Figure 6 Plan view of the proposed spectrometer. Not shown is the beam polarimeter downstream of the calorimeter.

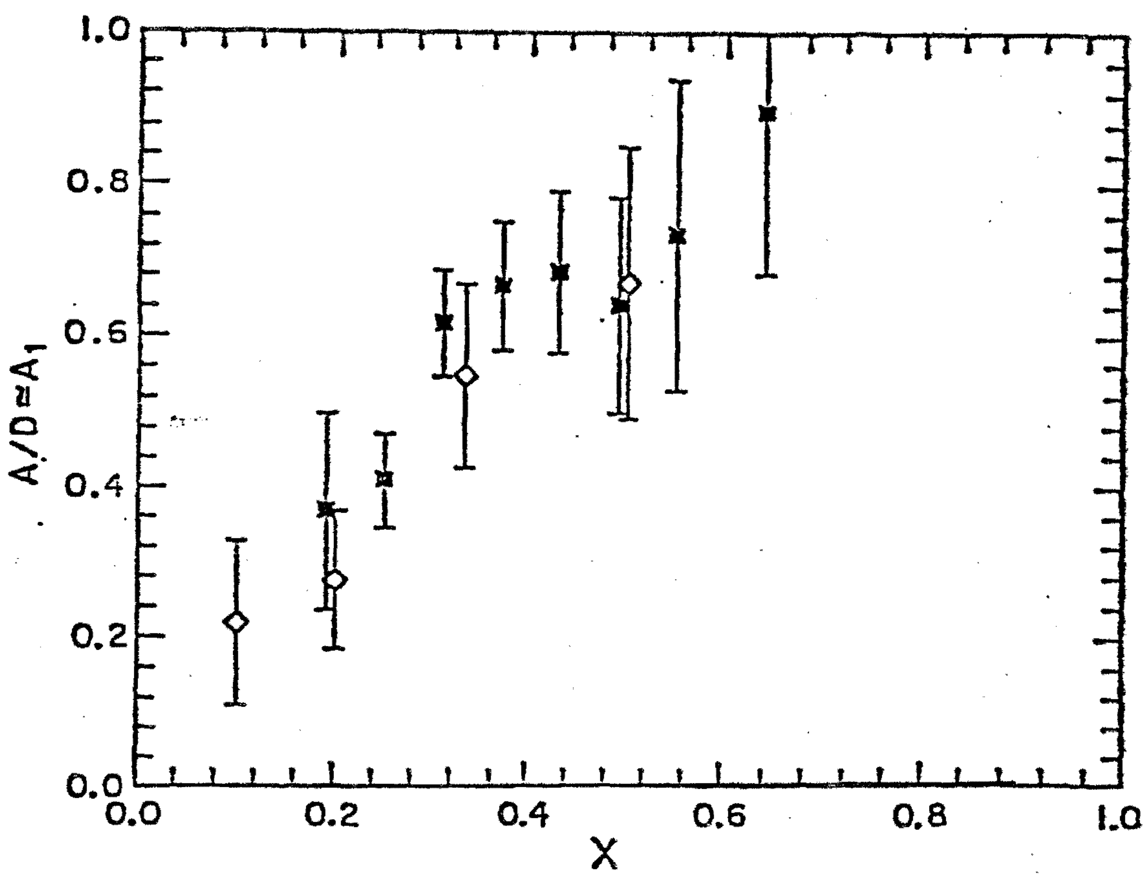

Figure 1

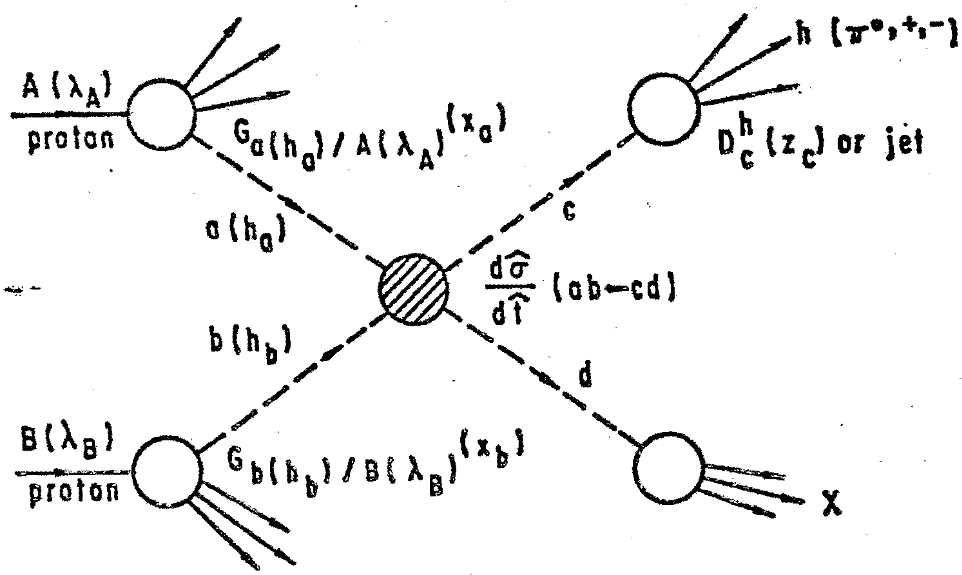
A (λ_A)
proton
$G_{a(h_a)/A(\lambda_A)}(x_a)$
a (h_a)
b (h_b)
B (λ_B)
proton
$G_{b(h_b)/B(\lambda_B)}(x_b)$
h (π°,+,-)
$D_c^h(z_c)$ or jet
c
$\frac{d\hat{\sigma}}{d\hat{t}}$ (ab→cd)
d
X

Figure 2

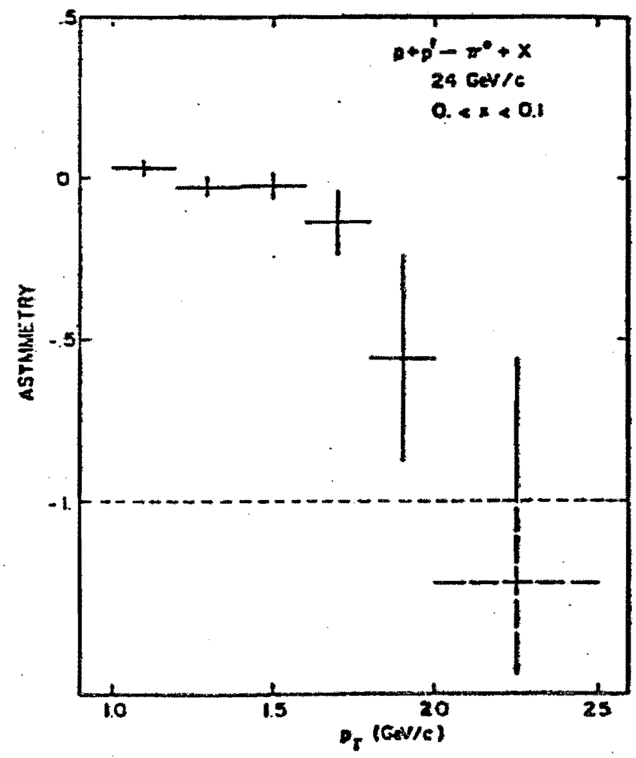

Figure 3

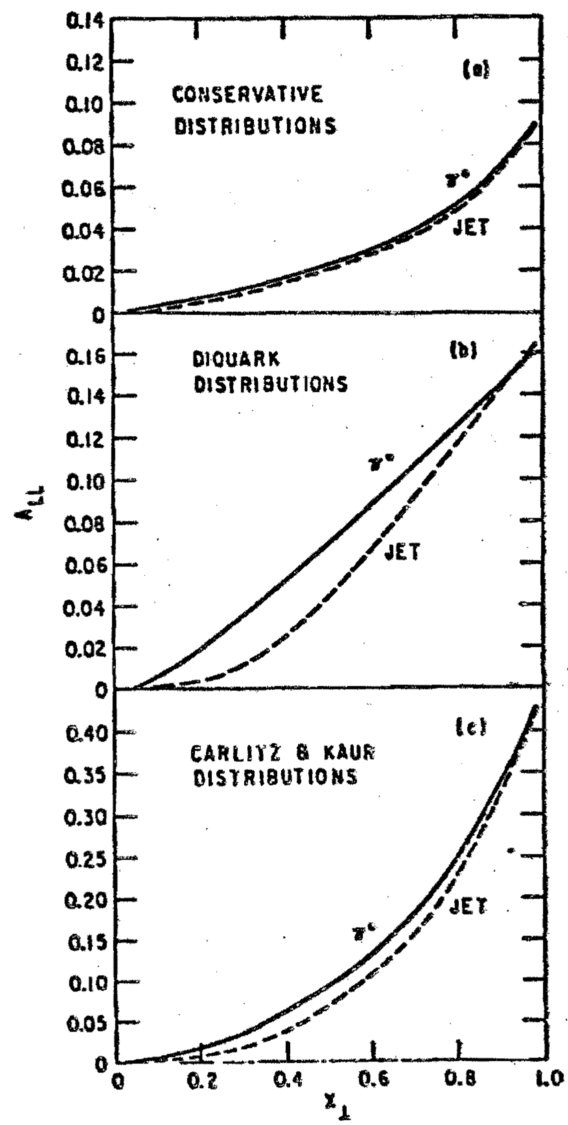
CONSERVATIVE DISTRIBUTIONS
(a)
JET
DIQUARK DISTRIBUTIONS
(b)
JET
CARLITZ & KAUR DISTRIBUTIONS
(c)
JET
A_{LL}
$x_{\perp}$
0
0.2
0.4
0.6
0.8
1.0

Figure 4

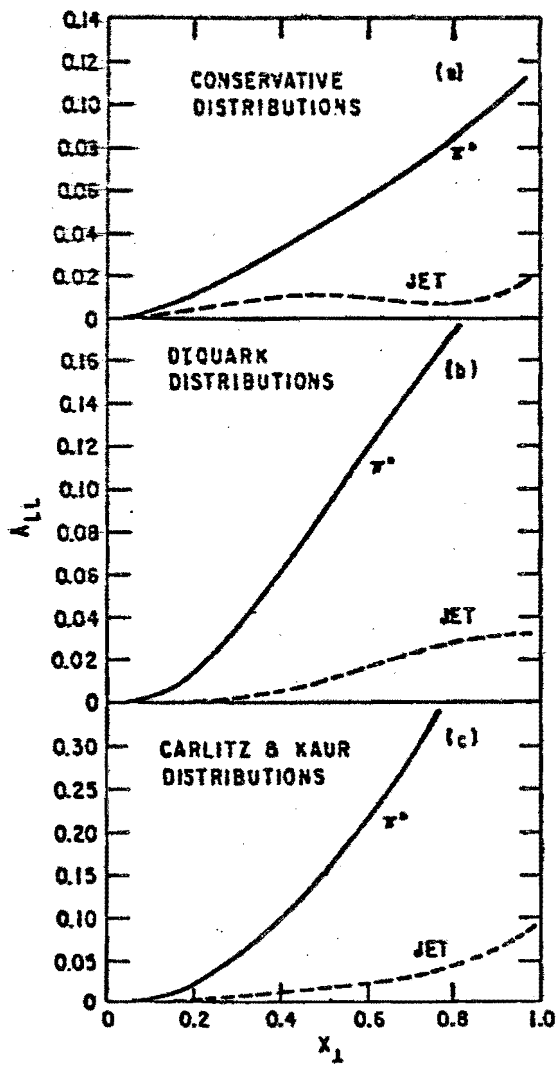
CONSERVATIVE DISTRIBUTIONS
(a)
DIQUARK DISTRIBUTIONS
(b)
CARLITZ & KAUR DISTRIBUTIONS
(c)
JET
A_{LL}
$x_\perp$
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.05
0.15
0.20
0.25
0.30
0.2
0.4
0.6
0.8
1.0

Figure 5

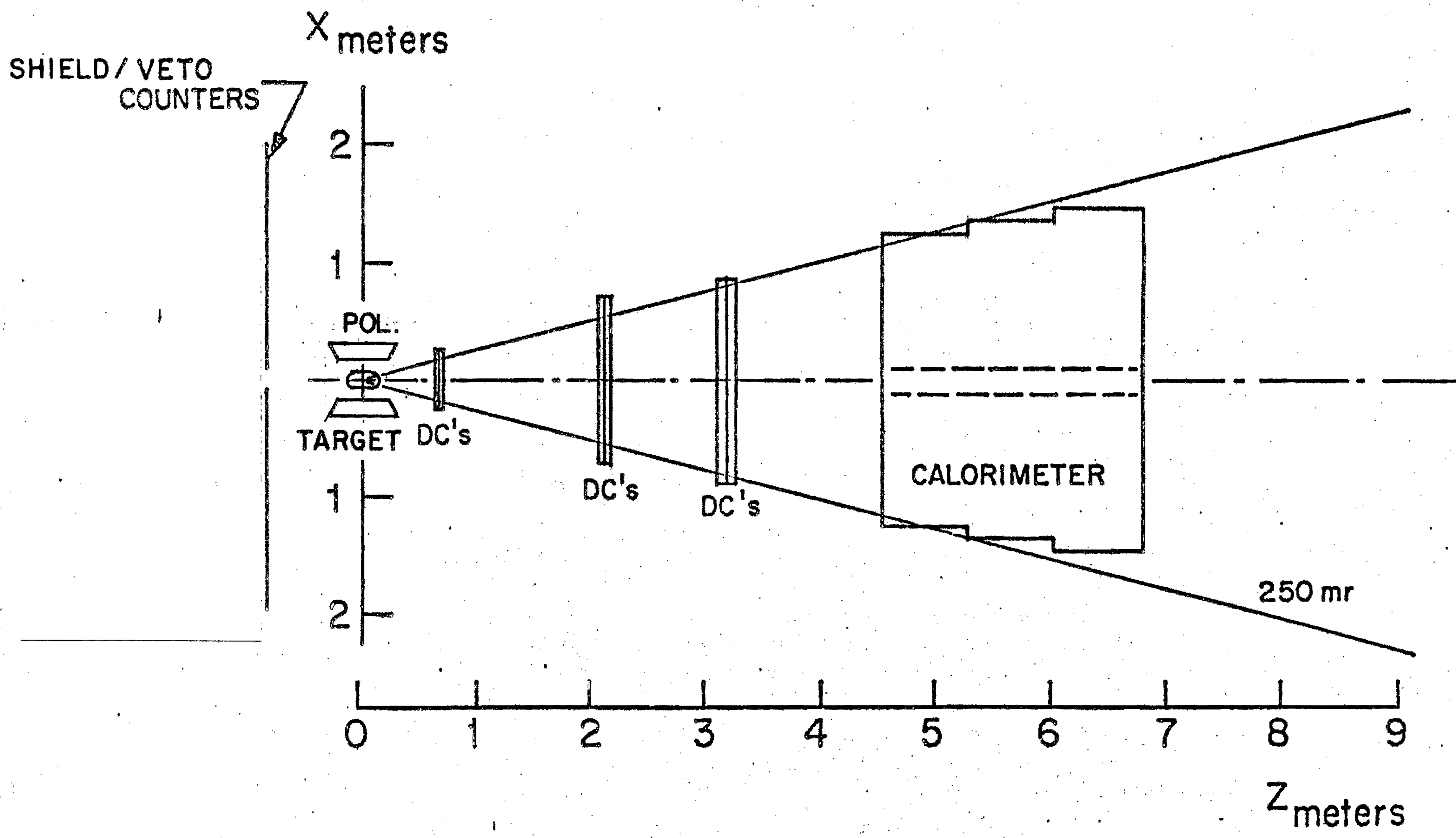

Fig. 6 Plan view of experimental layout (Phase I)