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SUMMARY TALK

FOR THE BROOKHAVEN SPIN PHYSICS CONFERENCE, 1982*

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I. INTRODUCTION

When I agreed to accept this job many months ago, I did not realize how difficult a job it would be to summarize the various subjects of this conference. I think my first transparency (Fig. 1) best does that. In the short time available, I will review the following highlights of this conference:

i) Polarized Hyperon Production

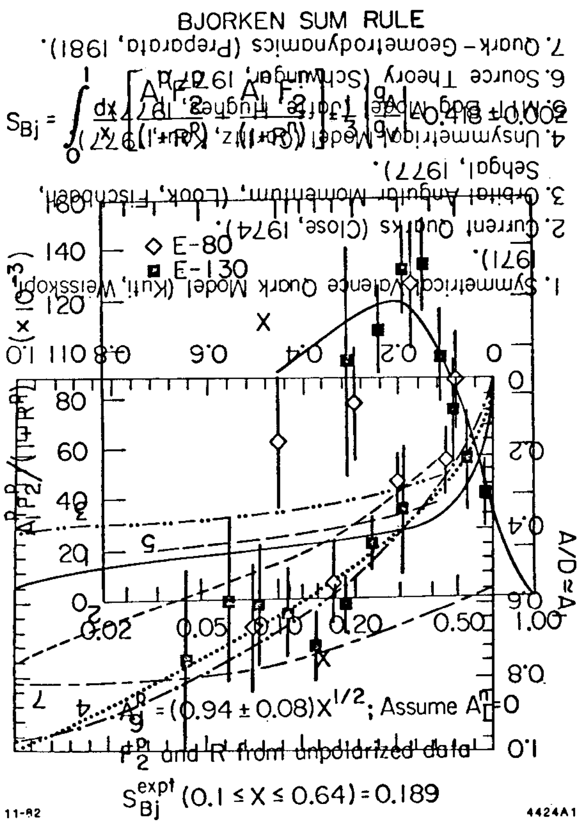
ii) Magnetic Moments

iii) Symmetries

iv) Polarized ep physics

v) Hadronic Processes and QCD

vi) Future Prospects at Colliders.



If I have left out some important topics, let me now apologize for the omission. Covering all of the interesting work presented in the last week in one hour is not possible. So, let's look at some of the interesting topics.

Fig. 1. My one-transparency summary of this conference.

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(Invited talk presented at the 5th International Symposium on High Energy Physics with Polarized Beams and Polarized Targets, Upton, New York, September 15-21, 1982.)

II. POLARIZED HYPERON PRODUCTION

Hyperons produced in proton beams in the reaction

$$p + Z \rightarrow \text{Hyperon} + X$$

have been observed to be significantly polarized, in experiments dating back to 1976.[1] The polarization direction is normal to the plane $\hat{k}_{in} \times \hat{k}_{out}$ where $\hat{k}_{in}$ and $\hat{k}_{out}$ are beam and outgoing hyperon vectors respectively. Observations of transverse polarization in $p + Be \rightarrow \Lambda^o + X$ were reported at the conference in Argonne in 1976. These observations in a 300 GeV p beam at Fermilab showed a negative polarization of about 25% at P_T around 1.5 GeV/c. More results were reported in 1978 at Argonne and 1980 at Lausanne, coming from the CERN PS, the CERN ISR, and Fermilab,[2] and confirm and extend the earlier findings. Additional new and further extended results, which have been reported at this conference, for values of P_T out to 4 GeV/c, continue to show large polarizations at the highest energies and transverse momenta.

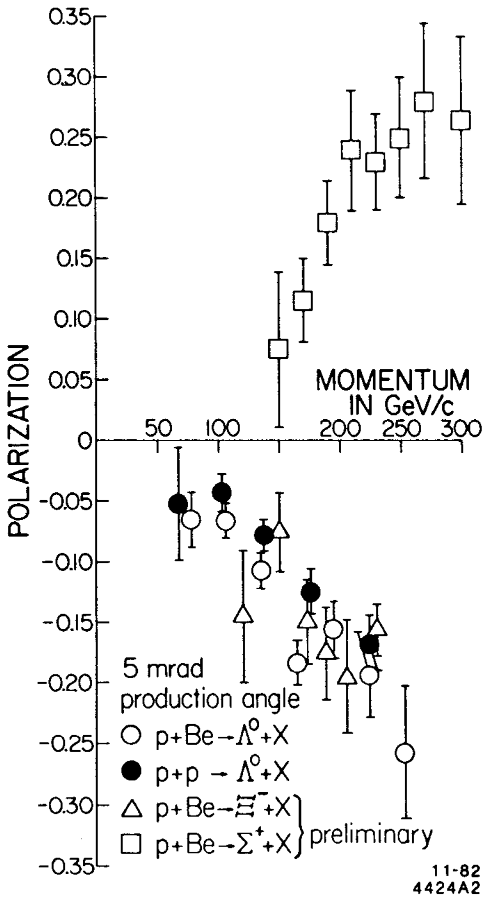

Fig. 2. Representative polarizations for Λ^o, Σ^+ and Ξ^- production (from Ken Heller).

Figure 2 (from Ken Heller) shows an example of the high quality of some of these data. This figure shows typically beautiful data for Λ^o, Σ^+, and Ξ^- at fixed production angle (5 mrad) and varying incident momenta. The most striking feature is the change in sign for the Σ^+ polarization relative to the Λ^o and Ξ^-.

General features of inclusive hyperon production show that the polarization increases in magnitude, approximately linearly with x, up to a value of P_{max} and the value of P_{max} increases with increasing P_T. Asymptotically values of polarization reach the 20-30% range in magnitude. Large polarizations have been observed from targets of protons, Be, Pt and Cu. Polarizations are positive for Σ^+ and Σ^o, negative for Λ^o, Ξ^o and Ξ^-. Measurements of polarization for protons and $\bar{\Lambda}^o$ have been found to be consistent with zero. Figure 3 (from Ken Heller) summarizes some of the available polarization data.

Such large polarizations are not predicted in QCD because of the lack of large phase shifts that are needed. There have been attempts to explain these data in QCD -

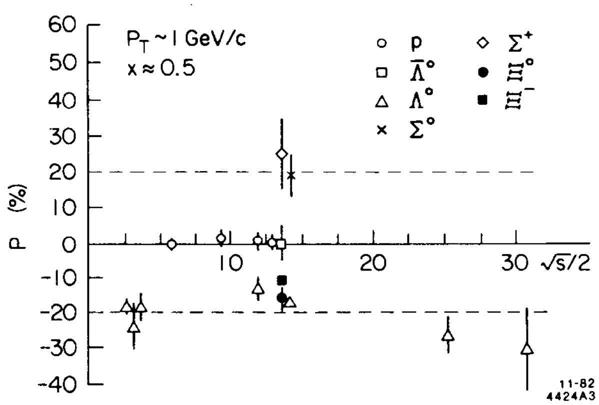

Fig. 3. Summary of hyperon polarizations near $P_T \simeq 1$ GeV/c and $x \approx 0.5$ (from Ken Heller).

related models. In Fig. 3, we see that hyperon polarizations follow a pattern which can be explained by the produced strange quark. That is, if the produced strange quark has a negative transverse polarization, then the sign change between Σ's relative to Λ^0's and Ξ's is explained.[3] Zero polarization for p's and $\bar{\Lambda}^0$'s is consistent with this fact, too. The QCD-related model of Degrand and Miettinen[4] suggest Thomas precession of the strange quark in color fields as a source of transverse spin. Gustafson, at this conference, has presented a related model, in which spin-dependent tunneling from the vacuum, followed by precession of the spin, leads to strange quarks polarized negatively relative to $\hat{k}_{in} \times \hat{k}_{out}$.[4]

In contrast to theory, the experimental situation is quite clean. There is no evidence that the polarization may disappear at the highest energies and transverse momenta, as suggested by some QCD proponents at earlier conferences. Conventional QCD calculations cannot explain these phenomena (although QCD-related models may do so) and this poses, I believe, a serious challenge and a serious problem for QCD. Since there are today already difficult problems for the successful QCD theory to explain, we will for now add inclusive hyperon polarization to the list and expect that eventually hyperon polarization will be explained, not just forgotten.

I would like to mention the talk of Bensinger (Brandies) in which an interesting summary of hyperon polarization from K and π beams was discussed. The additional experimental facts from these processes, as well as a detailed study of polarization in different fragmentation regions may be important to the overall picture.

III. MAGNETIC MOMENTS

Resulting from the observation that hyperons are polarized are some very nice measurements of magnetic moments. At this conference three groups, two at Fermilab and one at Brookhaven, report new measurements of magnetic moments. The first two groups at Fermilab both use the brute force approach; precession of the spin in a magnetic field followed by two body decay in a detector, which analyzes the resultant spin direction. The first of these is Fermilab E8, a Wisconsin, Michigan, Rutgers, Minnesota collaboration. Their experiment, described by Dr. Handler in the parallel sessions, has an integrated field strength of 5-6 tesla-meters. They report magnetic moments for Σ^+, Σ^- and Ξ^-. The second group, E497 at Fermilab, is a Fermilab-Yale collaboration. Drs. Marriner and Cooper reported measurements for the Σ^+ and Σ^-. This experiment used an integrated field strength of approximately 20 tesla-meters, giving an impressive 400^o precession for the Σ^+ measurement. Both of these experiments had the ability to flip the direction of the hyperon spin by targeting the incident proton beam at a small angle relative to the axis of the detectors. Systematic errors were studied and found to be small. A third group reported measurements of the Σ^- magnetic moment. This group, a Brookhaven, Boston University, William and Mary collaboration, as reported by Dr. Roberts, look for the fine structure splitting in the exotic atom formed when lead captures the Σ^- at rest. The x-ray spectra from radiative transitions show lines which are split due to the magnetic moment of the Σ^-. The x-rays are detected in a germanium detector which is calibrated using nearby x-rays from K^- capture.

The new results of these three experiments are given in Table I. Errors on these values are incomplete at the time of this meeting, and we look forward to their published results soon. Lee Pondrom presented a summary of these new results and other magnetic moments in the context of quark model predictions, and I refer you to his talk for details. The experiments are much better than the quark model predictions. The static quark model fails at the level of ±0.2 to 0.3 nuclear magnetons. Clearly a nonrelativistic static model is incomplete, and we heard discussions of orbital effects, exchange currents, meson clouds, etc., which go beyond the simple static model.

Thanks go to the experimenters for these beautiful measurements. These are indeed impressive experiments and important results. We look forward to future experiments which may bring us the magnetic moment of the Ω^-.

The status of anomalous magnetic moments for the electron, positron and muon were described by Kinoshita. Impressive precision in the measurements for the electron and positron were shown, and correspondingly impressive efforts in the calculations to α^4 (891 diagrams involved!) were shown. The agreement between experimental and theoretical values was reported to be $(-251 \pm 154) \times 10^{-12}$. The positron anomalous moment was reported equal to the electron at the 10^{-10} level. The muon magnetic moment measurements agree with calculations at the 10^{-8} level. Both the electron and muon calculations are sensitive to new particles such as in supersymmetry schemes.

Table I. New measurements of hyperon magnetic moments (preliminary)

	$\mu(\Sigma^+)$	$\mu(\Sigma^-)$	$\mu(\Xi^-)$
FNAL E8	2.31 ± .027 ± ?	- .89 ± .14	-.69 ± .04
FNAL E497	2.368 ± .013 ± .04	-1.180 ± .028	coming soon
BNL E723		-1.0 to -1.1	

Kinoshita remarked that in the case of the electron magnetic moment, agreement rules out light supersymmetric electron partners of mass less than 15 GeV. Present calculations are limited by the uncertainty on the value of the fine structure constant, α. These results show how high precision experiments probe effects at high energies.

IV. SYMMETRIES (MOSTLY ABOUT PARITY VIOLATION)

Tests of symmetries in the interactions between particles is a topic of fundamental interest. One of these, parity non-conservation, is by now a mature, broad field of research, with significant experimental tests being reported in atomic physics, nuclear physics, medium energy physics, high energy physics, and predicted effects at future collider experiments with $\bar{p}p$, pp, ep and e^+e^- beams, when polarized beams become available. In each of these fields, the physical processes responsible for the breakdown of parity invariance are the weak interactions, and all experimental results are presently consistent with standard electroweak predictions, to the accuracy of the errors.

At this conference, we have heard a new result, a progress report, by the Los Alamos group from LAMPF, to study polarized protons scattering from a water target. This experiment, described by Dr. Nagle, is designed to test the weak interactions in the nucleon-nucleon system at 800 MeV, an energy range not yet investigated.

The nucleon-nucleon system is not well described yet at high energies. The Los Alamos group, earlier at the ZGS at 5.6 GeV observed a positive asymmetry, $A_L = (26.5 \pm 6) \times 10^{-7}$.[5] Theoretical calculations of this parameter do not predict this large an effect.[6] The Los Alamos group reports at this conference, at 800 MeV, $A_L = (6.6 \pm 3.2) \times 10^{-7}$ with contributions from systematic effects such as beam position, current, and transverse beam polarization of $\pm 3 \times 10^{-7}$. Null tests with a lead target, or with no target, were consistent with zero at the 6×10^{-7} level of error. This group plans further measurements on water and hydrogen targets.

Dr. Simonius reported excellent agreement at lower energies between experiments and theory. The current results in $\vec{p}p$ are given in Table II. These small asymmetries are consistent, within errors, between experiments, and consistent with the theoretical prediction of -2.7×10^{-7} at 45 MeV.[7]

Table II. Reported parity violation asymmetries, A_L, in p-nucleon scattering

Group	A_L	E
Los Alamos	$(-1.7 \pm 0.8) \times 10^{-7}$	15 MeV
SIN	$(-2.3 \pm 0.8) \times 10^{-7}$	45 MeV
Berkeley	$(-1.3 \pm 2.3) \times 10^{-7}$	46 MeV

Parity nonconservation has long been observed in nuclear levels.[8] A recent contribution to these studies was reported by Gruebler from Zürich. This group produces polarized $^{19}F^*$ in the reaction ^{22}Ne (p,α) $^{19}F^*$ and observe the angular asymmetry A_γ relative to the axis of polarization. Their reported results are $A_\gamma = (-4.5 \pm 3.6) \times 10^{-5}$. Simonius reported that the earlier results ($P_\gamma = (-1.3 \pm .45) \times 10^{-6}$) from the Leningrad group of Lobashov et al.[9] in the reaction $np \to d\gamma$, which were difficult to explain, have now been repeated and are found to be much smaller. This new work has not yet been published. A related experiment at Grenoble[10] studies the capture of polarized neutrons on protons. The asymmetry $A_\gamma = (.6 \pm 2.1) \times 10^{-7}$ is consistent with theoretical estimates.

The primary untested region in nucleon-nucleon interactions lies between 45 MeV, where the weak interactions are understood, and 5.6 GeV where experiment and theory disagree. Medium energy tests around 300 MeV, are needed to fill in the picture.

No new results at high energies were reported at this conference. We did hear of one very nice atomic physics result on cesium from the Paris group,[11] reported at the Paris International Conference on High Energy Physics this past summer. They measured the parity violating amplitude, $\mathrm{Im}(E_1^{pv}/\beta) = -1.34 \pm .22 \pm .11$ (mV/cm), compared to standard model predictions of -1.7 in this same parameter. No new results on optical rotation in bismuth were reported. We were all disappointed that Dr. Barkov was not available to present any new results.

Dr. Gubler of TRIUMF reported on early tests and plans to look at isospin symmetry breaking by a novel technique using polarized beam and target at 500 MeV. They plan to compare the asymmetry parameter $A(\theta)$ in elastic scattering for unpolarized neutrons scattering from polarized protons with that for polarized neutrons from unpolarized protons. The asymmetry has a zero near 42°, and the experiment is sensitive to small shifts, $\simeq \pm .05^\circ$, while isospin breaking effects can be an order of magnitude larger.

V. SPIN STRUCTURE OF THE PROTON

Final results on polarized e^- polarized p inelastic scattering experiments by the Yale-SLAC collaboration were presented by Dr. Oppenheim.[12] These results include final radiative corrections and a comparison of these data with Bjorken[13] and Ellis-Jaffe[14] sum rules.

The Yale-SLAC experiment measures an experimental asymmetry which is related to the spin dependent structure functions A_1 and A_2 by

$$A_{exp} = P_e P_T f D (A_1 + \eta A_2)$$

where P_e, P_T are the beam and proton polarizations, f is the fraction of nucleons in the target which are available for polarization, D and η are kinematical factors. The structure function A_2 arises from the interference between transverse and longitudinal virtual photons, and is expected to be small, limited by $\sqrt{R} \simeq .5$ coming from positivity constraints. The structure function A_1 is the helicity dependent asymmetry $(\sigma_{1/2} - \sigma_{3/2})/(\sigma_{1/2} + \sigma_{3/2})$ where $\sigma_{1/2}$ and $\sigma_{3/2}$ refers to helicity = 1/2 and 3/2 initial state, respectively. A_1 is expected to exhibit conventional scaling behavior, $A_1 \to 2xg_1/F_2$. The Bjorken sum rule

$$\int_0^1 \left[A_1^p F_2^p/(1+R_p) - A_1^n F_2^n/(1+R_p)\right] \frac{dx}{x} = \frac{1}{3}\left|\frac{g_A}{g_V}\right|$$

relates the integral of the proton and neutron A_1's to the vector and axial couplings measured in nucleon beta decay. The sum rule has the value .418 but cannot be evaluated experimentally because of the lack of neutron data. The Yale-SLAC experiment measured only polarized proton inelastic scattering. Progress on improved proton and neutron polarizations in NH_3 and ND_3 targets were reported at this conference, and may hasten the day we should see more of these important measurements made. The Ellis-Jaffe sum rules

$$\int_0^1 g_1^p \, dx = \frac{1.78}{12}\left|\frac{g_A}{g_V}\right| = .372$$

$$\int_0^1 g_1^n \, dx = -\frac{.22}{12}\left|\frac{g_A}{g_V}\right| = -0.046$$

are less rigorous theoretically, but more readily measured experimentally. The experimental value is reported to be $\int_0^1 g_1^p \, dx = .33 \pm .10$, in good agreement with the Ellis-Jaffe value for the proton. The experimental error includes reasonable guesses on the uncertainty of the extrapolation to $x = 0$. Future experiments should be expected to fill in the data at low x. One of these experiments, the European Muon Collaboration at CERN, is reported to be planning to take low x data. In Bjorken's talk we heard how polarized e polarized p beams in a future ep collider could also contribute to the spin dependent structure functions.

Such data are necessary for understanding experiments with polarized protons. I would like now to describe some of the results we learned at the theory workshop held during this conference. Calculations of various asymmetries in polarized protons scattering on polarized protons (or antiprotons) in the hard scattering model[15,16] require input as to the polarization of the constituents. These calculations were described in Hidaka and others. Two models of quark polarizations are shown in Fig. 4, for the different constituents versus x. The two models are the "Conservative SU(6)" and the "Carlitz-Kaur" model. These models satisfy the Bjorken sum rule and include polarization of gluons, estimated by a QCD bremsstrahlung mechanism. How well these two models satisfy the existing data is shown in Fig. 5. The Carlitz-Kaur model is a fair approximation to the data, while the other is not. Other models not shown here are also compared to the data in Ref. 12.

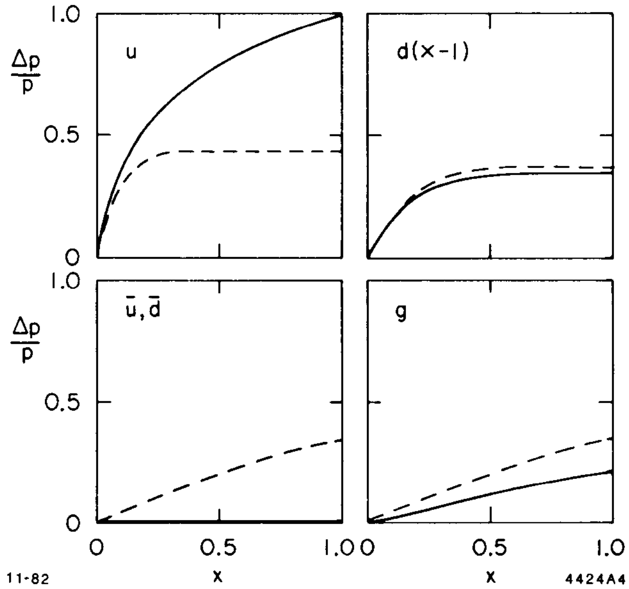

Fig. 4. Model calculations of u, d, ū, d̄ and g polarizations vs x in a polarized proton. Solid line is the Carlitz-Kaur model; the dashed line the "Conservative SU(6)" model (from Hidaka, Ref. 16).

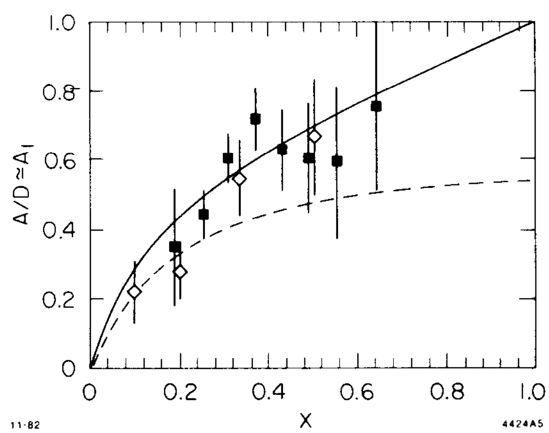

Fig. 5. Proton spin structure function A_1; the solid line is the Carlitz-Kaur model predictions; the dashed line is the "Conservative SU(6)" model (from Hidaka, Ref. 16). The data points are the Yale-SLAC data from Ref. 12.

The gluon polarization is not measured in these experiments, since the virtual photon does not couple to gluons. Gluons however, are expected to carry some polarization, analogous to virtual photon bremsstrahlung in QED. In the literature we find the decomposition of the electromagnetic current in the form[17]

$$j^{\mu}_{em} \sim \varepsilon^{\mu}_{s} + \frac{1}{\sqrt{2(1-y)}} \varepsilon^{\mu}_{L}$$

$$\times \sqrt{2(1-y)} \ \varepsilon^{\mu}_{R}$$

for bremsstrahlung from a left-handed polarized electron, where $y = (E-E')/E$ is the fraction of energy radiated, and ε^{μ}_{s}, ε^{μ}_{L}, ε^{μ}_{R} are longitudinal, left circular, and right circular polarization vectors. Near y = 1 the virtual photon is near 100% left circularly polarized; for lower y, it is elliptically polarized.

Measurement of gluon polarization is a difficult, unresolved experimental question. What processes should be studied to measure this parameter? Gluons seem to play an important role in pp scattering, and Hidaka suggested one process, asymmetries in inclusive Ψ production from polarized beams scattering from polarized targets, which is sensitive to gluon polarization. These experiments are difficult, and for the time being, we must be satisfied with models of nucleon constituent polarizations which are essentially untested by experiments.

VI. HADRONIC PROCESSES AND QCD

Hard scattering processes were the main topic of consideration in the theory workshop. Helicity conservation at the quark-gluon vertex in hadronic processes has implications for the spin effects. Figure 6 illustrates a polarized quark radiating soft gluons to other quark lines (not shown). The vector coupling of the gluon to the quark preserves the helicity of the quark across the vertex. For a polarized quark undergoing many interactions through soft gluons, the helicity of the quarks remains unchanged. This results in the expectation $\Sigma\lambda_i = \Sigma\lambda_f$ where λ_i and λ_f represent initial and final state constituent helicities.[18] Such relations can be tested in exclusive processes.

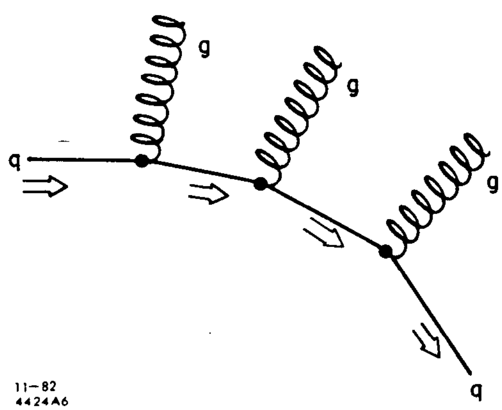

Fig. 6. Polarized quark radiating gluons to other constituents, not shown. Helicity of the quark is conserved at the qqg vertices.

Soft gluon corrections lead to renormalization of rates in strong processes. This renormalization has been used to explain the differences between experimental and theoretical rates in the Drell-Yan process where discrepancies of factors of 2-3 exist. Soft gluon corrections should not alter the helicities of the quarks, so considerable interest in the theory workshop focussed on the conjecture that QCD corrections to spin asymmetries should be small. Hidaka argues that double spin asymmetries in pp collisions should be a good test of QCD.

Calculations of effective luminosities and QCD subprocess cross sections show which constituents are expected to be important in hadronic processes. Consider a collider process where p and $\bar{p}$ (or p) beams collide. The effective CMS energy-squared between partons 1 in one beam and 2 in a the other beam, is

$$\hat{s} = x_1 x_2 s$$

where x_1, x_2 are the fraction of total momentum carried by 1 and 2, and s is the total CMS energy-squared.

Each beam is a mixture of quarks, antiquarks, and gluons carrying a full spectra of momenta up to the maximum. For each constituent type, there is a flux and a distribution in momenta. Interactions with constituents of the other beam occur, and can be characterized by an effective luminosity given in Fig. 7.[19] These curves show the

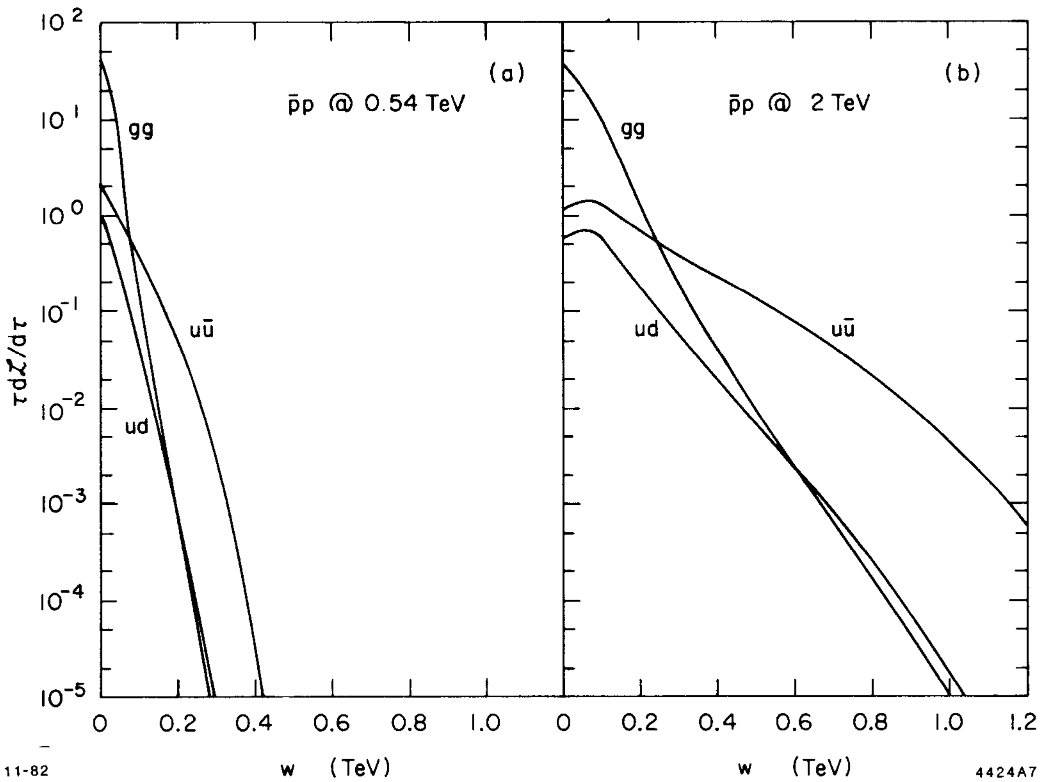

Fig. 7. Effective constituent-constituent luminosity in a $\bar{p}p$ collider beam for the CERN collider (a) and a future Fermilab collider (b). τ is the product x_1x_2 for the interacting constituents (Ref. 19).

estimated relative luminosities at the CERN $\bar{p}p$ collider and at a future Fermilab collider for gg, $u\bar{u}$ and ud incident beams contained within the p and $\bar{p}$ beams at $\sqrt{s}$ = .54 TeV and 2.0 TeV. The luminosity is largest for gg interactions below 0.1 $\sqrt{s}$ and for $\bar{u}u$ and $\bar{d}d$ at higher $\sqrt{\hat{s}}$. Below these lie the contributions from a valence quark from one beam interacting with a sea quark from the other (ud for $\bar{p}p$ and $\bar{u}d$ for pp colliders). QCD subprocess cross sections are shown in Fig. 8.[15] These processes are ranked according to total cross-section:

(1) $gg \to gg$

(2) $qq \to qq$

(3) $q\bar{q} \to q\bar{q}$

(4) $qq' \to qq'$

(5) $q\bar{q} \to gg$

(6) etc.

With only the leading ones shown. Babcock, Mondsay and Sivers tabulate seven processes. Event rates are the product of luminosity times cross section. Except at the highest $\sqrt{s}$ values, we therefore expect $gg \to gg$ scattering to dominate the events at $\bar{p}p$ colliders.

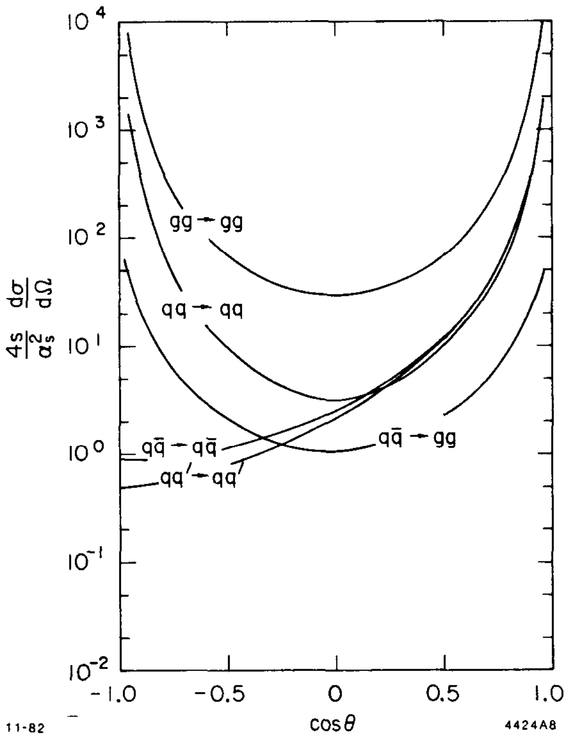

Fig. 8. Constituent cross section vs cosθ in the center-of-mass systems (Ref. 15).

Hard scattering events appear to occur at the highest energies. Figures 9(a) and 9(b) show typical events from the UA2 calorimeter at the CERN $\bar{p}p$ collider. The event in (b) shows the calorimeter cells unfolded, with the height of the bars proportional to energy deposited. Two distinct clusters are evident, with $\Delta\phi \simeq 180^\circ$ consistent with two-body scattering. Data of this type, shown at the 1982 Paris conference, are strong support for the hard scattering picture.

Spin dependences of these basic QCD subprocesses have been calculated in lowest order QCD and for the leading four are shown in Fig. 10.[15] The basic subprocess has an asymmetry, $a_{\ell\ell}$, defined

$$a_{\ell\ell} = \frac{\sigma(++) - \sigma(+-)}{\sigma(++) + \sigma(+-)}$$

where + and - refer to the incoming helicity of the constituents involved in the subprocess. This quantity, $a_{\ell\ell}$, is the parameter shown in Fig. 10, for four subprocesses, versus $\cos\theta_{CMS}$. The connection between $a_{\ell\ell}$, at the subprocess level, to $A_{LL} = [\sigma(++)\ \sigma(+-)]/[\sigma(++) + \sigma(++)]$, where +,- refer to the incoming helicity of the beams, is complicated. Here A_{LL} refers to some exclusive hadronic process to which several subprocesses may contribute. A_{LL} must be related to $a_{\ell\ell}$ by summing over contributing subprocesses, integrating over momenta spectra of the contributing constituents, polarizations of the constituents and perhaps fragmentation functions. These factors come from models, theoretical guesses, and approximations, but are for the most part poorly tested or verified by experiment. Polarization of the constituents of the proton is predicted in models, but presently tested only by the pioneering Yale-SLAC experiment.[12] Progress in the spin dependence of hadronic process depends critically on improving our understanding of constituent polarization within polarized protons. The gluon constituents are experimentally elusive, yet according to calculations important to pp and $\bar{p}p$ collider experiments.

Hidaka, at the conference theory workshop presented a shopping list of exclusive processes to be looked at by a future polarized pp collider. The double spin asymmetries, A_{LL}, can in some cases be quite large. The confidence in these calculations can be improved

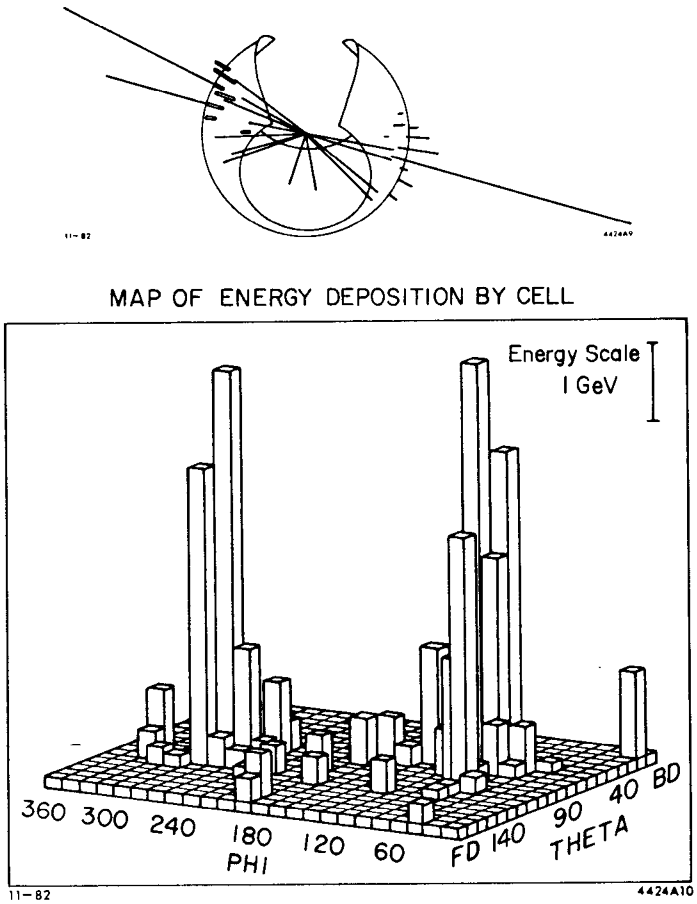

Fig. 9. Two events from the CERN UA2 collaboration. The lengths of the lines or bars represent energy deposition in the detector segments. Two-jet topologies are evident.

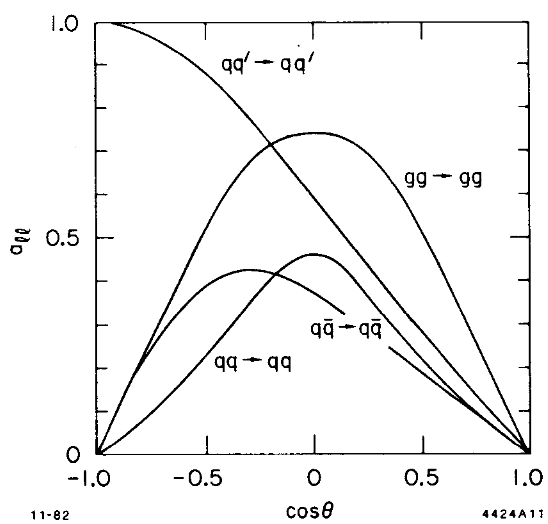

Fig. 10. Constituent asymmetries for four constituent subprocesses (Ref. 15).

only through future experimental and theoretical hard work. Taken as a whole, the exclusive processes represent an important experimental program and a thorough test of QCD.

Single polarized beam experiments are experimentally much easier to carry out. Parity violation asymmetries for high masses can be very large. Lindfors, in his talk at this conference, described experiments at $\bar{p}p$ colliders which show asymmetries as large as 20%. These parity violation effects are of course expected to be large in the standard electroweak interactions. Not all single polarized beam asymmetries need involve electorweak effects. John Ralston, in the theory workshop, discussed the possibility of phase shifts in the strong interactions coming from higher order QCD. He suggests looking at the Drell-Yan process for such spin-dependent effects. In the virtual photon rest frame, the produced μ pair are collinear while the incoming beam and target vectors are not, but define a plane. The angle ϕ is defined as the angle between that plane, and another formed by the initial beam direction and the outgoing muons. Imaginary parts of the QCD amplitude lead to $P \sin\phi$ terms in the cross section, and oscillations in the energy dependence. Such effects would be extremely interesting, if observed. Generally single beam polarization effects are difficult to obtain from QCD.

VII. FUTURE PROSPECTS AT COLLIDERS

The importance of colliders to the future of particle physics is clear. At this conference we have heard in a number of talks of the importance of polarization to colliders. In the ep collider concepts, polarization of the beams is unquestionably of great physics importance. The physics which is obtained from polarized e or polarized p beams is extensive. Bjorken discussed some aspects of the physics unique to polarized beams at an ep collider. Electron-proton colliders offer very high mass and Q^2 ranges from experiments. The event topologies are expected to show highly collimated jets. Both neutral current and charged current events are expected to occur with useful rates. At the HERA design luminosity, events for which $Q^2 > 10^4$ $(\mathrm{GeV}/c)^2$ occur at the rate of 3000 per month. The high event rate at large Q^2 can be expected to extend the Q^2-range of data an order of magnitude. Polarized protons scattering from unpolarized e^+ or e^- beams, in charged current events, allow for the determination of constituent quark polarization in the polarized nucleon. Longitudinally polarized electron or positron beams, in charged current reactions, are sensitive to right-handed weak currents. In the standard model, right handed currents do not exist. Extended gauge models exist which agree with present data for electroweak processes and contain right-handed currents resulting from additional gauge bosons sufficiently massive to suppress contributions at low energies. Propagator effects are small at $Q^2 \simeq 0$, but for high Q^2, the charged current polarization asymmetry

$$A^{cc} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \simeq -\left[1 - 2\left(M_L^2 + Q^2\right)^2 / \left(M_R^2 + Q^2\right)^2\right] \quad ,$$

where σ_R (σ_L) is the cross section for right- (left-) handed incident electrons, and M_L and M_R are the masses of the charged vector bosons, may have significant effects. One does not need fully polarized e^- beams to make such measurements. But accurate knowledge of the e^- polarization is required if the beams are not fully polarized. An obligation for the experimenters using polarized beams is to provide accurate monitoring of the polarization. The sensitivity for effects of heavy gauge bosons (beyond the standard set) will be limited by the accuracy in the measurements of beam polarization. Figure 11

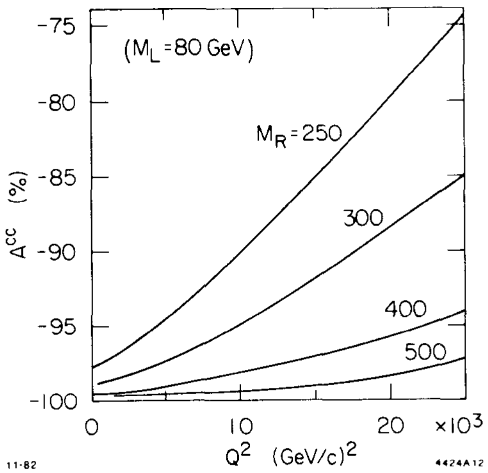

Fig. 11. Charged current event asymmetries vs Q^2 and M_R, the mass of an hypothesized (right-handed) W_R boson.

shows the deviations from -100% for different assumed values of mass for W_R. Polarized beams at ep colliders provide a simple direct test for right-handed currents. One simply looks for a deviation of A^{cc} from -100% that increases with increasing Q^2.

Neutral current events at ep colliders test the lepton and quark coupling to the Z^o. Polarization asymmetries at $Q^2 \simeq 10^4\ (GeV/c)^2$ are sizeable fractions of unity, and careful measurements will be sensitive to interference terms from high mass neutral gauge bosons (Z_2^o) lying above 500 GeV. As in the case of right-handed currents, neutral gauge bosons beyond those of the standard model may exist and may be discovered by these means. Proposals such as the HERA Project offer exciting new laboratories for new physics phenomena. Polarization of the beams is one of the most important tools available for studying the structure of the forces.

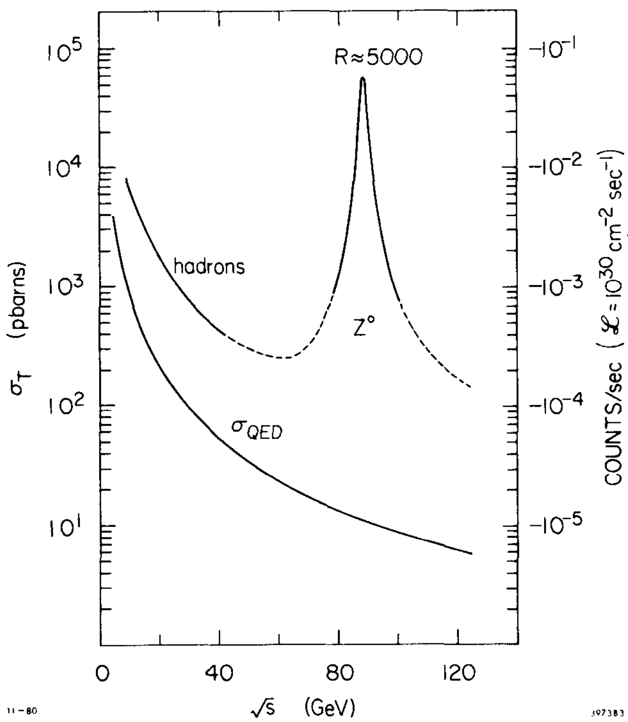

Fig. 12. Cross sections in lowest order for e^+e^- annihilation. The presence of the Z^o-pole is important for future experiments. Without it data will be sparse.

Finally, I want to mention e^+e^- colliders. We have several active proposals to build laboratories for studying e^+e^- collisions at $\sqrt{s}$ up to 100 GeV and beyond. The LEP project at CERN, the SLC project at SLAC, and CESR II at CORNELL are examples. These machines are neutral current factories. Figure 12 shows the expected cross section based on a standard Z^o gauge boson of mass around 90 GeV. The existence of the Z^o-pole enhances the event rates by a factor of 5×10^3 over conventional QED μ-pair rates. Without this enhancement, event rates will be very low and experimental work much more difficult.

Polarization of the beams significantly improves the ability to measure neutral current couplings. It also provides sensitive tests for new physics, as in the case of ep colliders, by permitting observation of interferences with massive gauge bosons above the standard Z^o. Polarization measurements will be sensitive to masses beyond 500 GeV. The Z^o-pole is an oasis of event-rate which is important to experiments. Without it's wealth of information, peering into the high energy "desert" beyond may be very difficult. As the highway signs in the West admonish, it may be the "Last chance for gas before the desert."

Figure 13 is taken from the SLC workshop report on polarization.[20] It shows the sensitivity of A_L to the mass of a second Z boson. Small, but significant deviations form standard model values (marked S.M.) are possible, but require careful experimental measurements of beam polarization. Even in the absence of new physics beyond the standard model, polarization measurements provide an accurate measurement of $\sin^2\theta_W$. Both A_L and $M(Z^o)$ are subject to radiative effects. Taken together these are an excellent test of electroweak radiative corrections.

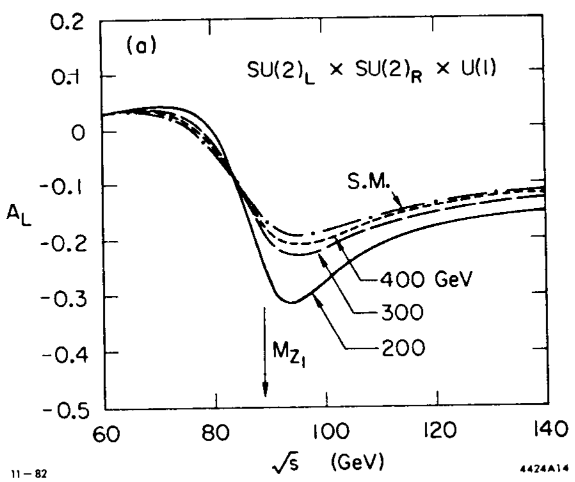

Fig. 13. Polarization asymmetry A_L in e^+e^- annihilation vs $\sqrt{s}$ for various assumed masses of a second Z^o boson.

Let me then conclude. The future for spin physics is very exciting at the highest energies where we expect large spin effects. The $\bar{p}p$ and pp collider projects provide excellent laboratories for QCD effects. Polarization asymmetries may be little affected by soft-gluon effects. The ep and e^+e^- colliders are excellent laboratories for electroweak gauge models. So convince your local machine builders to include (longitudinally) polarized beams in the designs.

We have listened for a full week about the effects of spin in particle physics. We have heard how spin may be used as a tool for many beautiful measurements and tests. Let me emphasize that very little is yet known about the origins of intrinsic spin in the fermions. Dr. Yang's comment at the opening of this conference emphasizes this point ... "the whole story isn't in yet."

We have all worked hard to make this conference a success. I personally wish to thank the organizers for their efforts at bringing this conference to Brookhaven and Westhampton, and for the workshops that were so productive and well-integrated into the conference. We all look forward to the next conference in Marseille in 1984.

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