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SUMMARY OF THE 8th INTERNATIONAL SYMPOSIUM ON HIGH ENERGY SPIN PHYSICS*

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INTRODUCTION

This series of conferences on high energy spin physics dates back to Argonne, 1974, and the first use of the polarized proton beam at the ZGS. This conference is unique in that it is concerned both with the technology of spin and with particle physics: particle physicists need to know what experiments might be possible and target/beam/source physicists want to know what their work will lead to, and get new ideas. In many cases, and I believe that this is central to the success of spin physics and of this conference series, these are the same people.

This summary will have three basic parts: where we are now relative to Argonne in 1974; a discussion of new experiments and theory--there were many new and intriguing results presented here; and new ideas for polarized sources, beams, and targets which point toward an exciting future program of particle physics.

In preparing for this summary, I looked through the previous proceedings for this series.[1-7] (I might add that this series includes discussion by Dirac[1], Yang,[5] Thomas[5] and Chamberlain[6] on spin.) One particularly striking comment, in light of the results presented here, was Prescott's conclusion of his 1982 summary:[5]

> "We look forward to future experiments which may bring us the magnetic moment of the Ω^-."

A RECENT HISTORY OF SPIN

Table I shows a list of important experimental results concerning spin dating from 1974 (the selection is obviously a personal one) and also the dates of when certain major spin facilities became available. The polarized proton beam at the ZGS demonstrated spin resonance-jumping techniques and resulted directly in the surprising discovery of a very large A_{NN} in pp elastic scattering at 90° CM. At the same time inclusively produced Λs were discovered polarized at FNAL. By 1978 the final report of the muon g-2 experiment at CERN was published, parity violation was observed for longitudinally polarized electrons scattering from deuterium at SLAC, the $(c\bar{c})$ spectrum was being mapped, and the lambda magnetic moment was measured to 0.8% using the high energy polarized Λs. A large asymmetry was observed for π^0 produced from a polarized target. The eD parity violation experiment was made possible by the development of a gallium arsonide-based polarized electron source

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for the SLAC linac. Snakes, a means of automatically correcting the effects of spin resonances in proton accelerators, were invented in 1977. Although they have not been used yet, the technique is required to accelerate polarized protons above 30 GeV or so.

TABLE I

	Experimental Results	Some Facilities
1974		$p\uparrow$ ZGS
1976	$A_{NN}(pp)$, $\Lambda\uparrow$ †	GaAs Source
	$(g-2)_\mu$, $\vec{e}D$, μ_Λ, $(c\bar{c})^*$, $p\uparrow \to \pi^0$	Snakes
1980	A_1^p, $A_L(\vec{p}\ H_2O)$, μ_{Ξ^0}, $K^- \to \Lambda\uparrow$	
	$\mu_{\Sigma^\pm}$, Ξ^-	NH_3 target
1984	$A_N(pp)$, $\pi^- p \to \rho^- \pi$, 90°, $P_\Lambda\ (p_T, x)$	EMC polarized tgt $p\uparrow$ AGS
	$p\uparrow \to \pi^+$, $(b\bar{b})^*$	
1988	A_1^p (low x), μ_{Ω^-}, $K/\pi \to \Lambda\uparrow$ $\pi^- p\uparrow \to \pi^0$, $p\uparrow/\bar{p} \to \pi^0$, $p\uparrow \to \Lambda\uparrow$, $\Sigma\uparrow$, Γ, $\alpha(\Sigma, \Xi)$, μ_e/e, A_L, (6q)?	$p\uparrow$, $\bar{p}\uparrow$ FNAL $p\uparrow$ KEK partial snakes

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† $\uparrow$ Indicates transverse and $\to$ indicates longitudinal polarization.

The 1980 spin meeting at Lausanne included the results from SLAC on the proton spin structure probed with longitudinally polarized electrons and the anomalously large parity violation result from the ZGS of longitudinally polarized protons scattered from water. In 1980 and 1982 more precise hyperon magnetic moments were presented, the results of the observation that most hyperons are produced polarized at high energy. The ammonia polarized proton target appeared in 1982; it was much less susceptible to radiation damage and therefore capable of accepting much higher intensity beam. Around 1984 the very large EMC polarized target allowed the measurement of the proton spin structure functions using high energy polarized muons as probes. Polarized protons were successfully accelerated in the AGS. The NH_3 target led to the observation of a surprisingly large A_N at high p_T in pp elastic scattering. A systematic study of hyperon polarization led to a report by Heller that the kinematic dependence factors into p_T and x_F depenaence. Helicity violation was seen for 90° exclusives for $\pi^- p \rightarrow \rho^- p$ (and for pp A_N).

By 1986 the AGS polarized proton beam allowed inclusive polarization to be measured without a large target correction, necessary for polarized targets. A large π^+ asymmetry was observed at large p_T (with no π^- asymmetry) and many results were reported here both on asymmetries produced by a polarized proton beam and on spin transfer from the proton to a produced hyperon. These experiments are from the AGS and from FNAL where polarized proton and antiproton beams from lambda/antilambda hyperon decay became available last year. The EMC results on the proton spin structure function at low x was published this year. The $b\bar{b}$ system of states was mapped, the splitting very similar to the $c\bar{c}$ system. New hyperon lifetimes, branching ratios and asymmetry parameters were presented here. Precise (null) measurements of parity violation were presented at this conference. Very recent observations of narrow structure in possible dibaryons channels were shown and discussed. And, fulfilling Prescott's challenge in 1982, 25,000 polarized Ω^- hyperons were used to make the first measurement of the Ω^- magnetic moment.

The future, of course, can be seen in today's ideas and technology. A polarized proton beam is now available at lower energy at KEK. A very new idea of using partially excited snakes (!) may make the very severe job of tuning out resonances obsolete at AGS and KEK energies, which may make polarized proton beams much more readily available. Considerable work has already gone into ensuring longitudinally polarized electrons at the SLC and HERA. Not all is bright--the SLC is way below its design luminosity; LEP did not design-in polarized electrons (special wigglers are necessary) and it is difficult to do so now; the snake technique is being questioned for handling certain weak resonances at very high energy. If snakes work, about 8 would be needed per ring at the SSC, a not-too-extravagant number. A very nice report has been prepared on spin effects at the proposed colliders (e^+e^- and pp) which was reported on by Taxil here. Many large effects would be expected and spin observables are often by far the most sensitive ones to distinguish between mundane and new effects. An important point here is that 1% measurements of asymmetry are often required, often in calorimeter (jet) data. To do this, it is not enough that the beams be polarized--frequent polarization reversal will be important to negate systematic effects (changing calibrations, for example). My guess is that for proton storage rings it will not be sufficient to reverse the polarization each fill.†

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† One way to do this for protons would be to fill parts of each ring with oppositely polarized protons and keep track of which bunches cause each event.

PROTON SPIN STRUCTURE FUNCTION

The results from the EMC group on the asymmetry (A_{LL}) from longitudinally polarized high energy muons scattered from a longitudinally polarized hydrogen target was the major discussion topic at this conference. The new results, at low x where x is the struck quark momentum fraction, allowed them to accurately integrate the structure function, the asymmetry divided by x, over x=0 to 1. The integral measures the integrated quark asymmetry (the difference between spin parallel and antiparallel quarks relative to the proton spin) and is related through two sum rules to g_A/g_V in beta decay. The integral and the beta decay results do not agree. If the difference is attributed to a strange quark asymmetry in the proton, one obtains a net quark asymmetry near zero--hence the catch phrase that valence quarks do not carry the proton spin. This was discussed very nicely by Pondrom and Close. It was pointed out by Soffer that one can place a bound on the strange quark contribution from other results, and it cannot be so large. A gluon contribution, previously neglected, may be important (Carlitz, Leader). All the uncertainties allow, in fact, for a very reasonable quark asymmetry after all (Sivers). In any case, the neutron structure functions and the transverse structure function $g_2(x)$ are important pieces to the puzzle and should be measured. A proposal has recently been submitted to CERN to do $\vec{\mu}\,\vec{n}$. Both Pondrom and Close noted that the earlier SLAC data at large x were confirmed by the CERN result--as expected, the quark spins are strongly correlated with the proton spin at large x. With respect to the above controversy, a pQCD model fit to A_1^p, which is constrained by the sum rules, is a very poor fit at low x (10σ roughly). One approach to the issue, ignoring it due to a 2σ difference between the integral and the sum rule expectation, seems to me to be Panglosian. Also, and it should be emphasized, Preparata showed a fit to $A_1^p(x)$, derived from a fit to the unpolarized structure function $F_2(x)$, which was published 4 years ago and which is in excellent agreement with the data. My own view is that it is instructive in physics to focus on problems, not on agreements, and that there may, indeed, be a problem with the perturbative approach.

ASYMMETRIES FROM TRANSVERSELY POLARIZED PROTONS

An interesting question, brought up by Heppelmann, "Is there a link between the large x longitudinal spin structure function and large x inclusive <u>transverse</u> spin effects?" Soffer has noted[8] that the parton model transverse quark asymmetry, summed over the quarks, equals the sum of the structure functions $g_1 + g_2$. The Wandzural-Wilczek sum rule connects these to the large x behavior of the longitudinal structure function g_1:

$$\Delta q^T(x) = \sum_i e_i^2\, \Delta q_i{}^T(x) = g_1(x) + g_2(x)$$

$$g_1(x) + g_2(x) = \int_x^1 \frac{dx'}{x'}\, g_1(x') \quad .$$

Therefore, a large value of $g_1(x)$ at large x (as seen in the Yale/SLAC data) implies a large transverse quark asymmetry. What is seen in the data?

A model was proposed to connect pion and kaon asymmetries, produced by polarized protons, to hyperon inclusive polarization results, extracting the transverse quark asymmetries. Such a model might be useful, at the least, in providing a framework for comparing different experimental results. It may also provide new information on transverse quark asymmetries, which have not been measured.

The approach consisted of three steps:

1. Use the lambda polarization results to obtain the polarization of the s quark from the sea, P(s).
2. Assume that this is the polarization of any quark pulled from the sea: $P(s)=P(\bar{d})=P(\bar{u})=\varepsilon$. For $P > 1$ and large x, $\varepsilon \approx -.3$ or so.
3. Then the observed asymmetry from polarized protons factors into two parts--the quark asymmetry of the spectator quark in the produced particle and the polarization of the sea quark in that particle. To produce a spin -0 pion, these contributions must be opposite in sign:

$$A_N = \Delta q^T(-P(s)) = .3\Delta q^T$$

Table II shows the results from several experiments, most presented at this conference, along with the derived transverse quark asymmetries. For most experiments, the produced particle is near the kinematic limit, or large Bjorken x, and at $P_\perp > 1$ where the hyperon polarization is maximum. The data can be seen to be consistent with a large transverse u-quark asymmetry. And this is consistent with the Yale/SLAC longitudinal structure function data through the sum rule described above. (Note that the sign of the measured asymmetry is taken to be positive for a polarized proton incident along the $\hat{z}$ axis and transversely polarized along $+\hat{y}$, producing more particles in the $+\hat{x}$ direction, where $(\hat{x}, \hat{y}, \hat{z})$ form a right-handed coordinate system.)

TABLE II

Reaction	A_N(model)	Experiment Results	Reference	Quark Asmmetry
$p\uparrow \to \pi^-$	$.3\Delta d^T$	0	Heppelmann	$\Delta d^T = 0$
$p\uparrow \to \pi^+$	$.3\Delta u^T$	+ .3	Heppelmann	$\Delta u^T = +1$
$p\uparrow \to \pi^0$	$.3(\Delta u^T+\Delta d^T)$	+.1, +.5	Nessi-Tedaldi, Ref. 9	$\Delta u^T+\Delta d^T)$ $= +1/3, +5/3$
$\pi^- p\uparrow \to \pi^0$	$.3(\Delta u^T+\Delta d^T)$	+.5	Vasiliev	$(\Delta u^T+\Delta d^T)$ $= +5/3$
$p\uparrow \to K^0_S$	$.3\Delta d^T$	-.1	M. Nessi	$\Delta d^T = -1/3$

INCLUSIVE HYPERON POLARIZATION

In the previous section we assumed that hyperon polarization was a measure of the polarization of quarks pulled from the sea. There is now a considerable body of data on hyperon polarization which is consistent with this general picture--in particular the polarization of Σs is opposite from Λs and Ξs as expected from their SU(6) wave functions. However, despite this regularity in the data, I believe that there is no model for the polarization so far that withstands scrutiny. There are several new results on polarization transfer for production at 0^0 (Fig. 1).

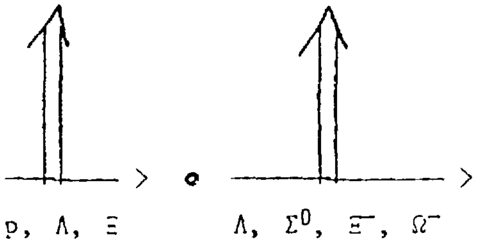

Figure 1

For the polarization transfer experiments, no transfer is expected for $p\uparrow \to \Lambda\uparrow$, and significant transfer is anticipated for the others. The results are consistent with this, although the magnitudes do not agree with any model. This is summarized in Table III.

TABLE III

Reaction	Expect (SU(6))	Result (D_{NN})	Reference
$p\uparrow \to \Lambda\uparrow$	near 0	0	M. Nessi
$p \to \Sigma^0\uparrow$	+ large	+ .3	M. Nessi
$\Lambda\uparrow/\Xi^0\uparrow \to \Xi^-\uparrow$	+ large	+ .5	Johns
$\Lambda\uparrow/\Xi^0\uparrow \to \Omega^-\uparrow$	+ large	+ .2	Johns

The models were presented in the session summary by Kroll. An evident conclusion is that experimental results are way ahead of models!

A remarkable experiment was presented here which led to the first measurement of the Ω^- magnetic moment. The experiment, at FNAL, had two phases. In the first phase, the experimenters produced Ω^-s directly from unpolarized protons, at moderate p_T. They collected 50,000 unpolarized Ω^-s, with which it is difficult to measure a magnetic moment. They then switched gears and reconfigured their experiment to produce Ω^- at 0^0 with a neutral beam consisting of polarized Λs and Ξ^0s (and neutrons). This was successful, giving 25,000 Ω^-s with -7% polarization. The measured Ω anomalous moment is one standard deviation from 0, giving $\mu_{\Omega^-} = -2 \pm .2$ in proton magnetons.

HYPERON DECAY

A number of new results on hyperon decay were presented here. A new Ξ^0 lifetime (a 5σ improvement!) (Thorne), and Ξ^- asymmetry parameter ($\Xi^- \to \Lambda\pi^-$) will further test the importance of $\Delta I = 3/2$ contributions, although considerably more data are needed and more theoretical work--see Rudaz's summary of this section. Rudaz presented an argument (the Pati-Woo theorem) that qualitatively explains the dominance of $\Delta I = 1/2$ amplitudes due to color symmetry requirements. Branching ratios and asymmetry parameters were given based on 85 $\Xi^0 \to \Sigma\gamma$ events (Teige) and 139 $\Xi^0 \to \Lambda\gamma$ events (James). Results from 400 $\Sigma^+ \to p\gamma$ events, an AGS experiment, have been submitted for publication recently.[10] Rudaz noted that these are not understood theoretically--that a calculation for single quark decay gives too small a branching ratio for the radiative decays.

BARYON MAGNETIC MOMENTS

Johns presented the first Ω^- measurement, and there are new precise measurements of Ξ^- (Johns) and Σ^- (Miller). Franklin explained in his summary that we know that a free quark model works well--one derives quark moments and adds them according to the SU(6) wave function for the baryon--but only at a 20% level. Relativistic treatment and other proposed fixes do not improve agreement beyond offering additional unconstrained parameters. Only QCD-based models (perhaps lattice or bag models) are likely to break this impasse, and these are not available yet.

SYMMETRY LAWS

Three precise experiments were reported, two testing parity violation in low energy p-D scattering (45 MeV-Lang; 800 MeV-Mischke) at a 10^{-7} level and one testing CPT via comparison of the magnetic moment anomalies of electrons and positrons to 10^{-8} (Shatunov). All three results are consistent with 0. The parity violation results at lower energy can be fit with a meson-exchange model, although the model prediction is an order of magnitude smaller than the earlier experimental result at 6 GeV.

A new measurement, potentially very important, of the neutron electric dipole moment was reported by Pendlebury on an experiment at Grenoble. A non-zero value violates time reversal invariance and parity conservation. The new result is 1.4 to 2 σ negative ($\mu_e/e = -0.7 \pm 0.5 \times 10^{-25}$ cm) depending on the selection of the date set, and is consistent with an earlier 2.3 σ result from Leningrad (See Franklin's summary of this section). Standard model expectations depend on G_w^2 and are 7 orders of magnitude smaller. On the other hand, extensions of the standard model predict a dependence linear in G_w, with a magnitude of about 10^{-25} cm.

DIBARYONS

Dibaryons have a controversial history--both in this conference series and elsewhere. Silbar, in his summary of this section, noted that narrow structures have been seen very recently around two mass regions--2.1 GeV and 2.7 GeV. The 2.1 GeV results, reported by Gazzaly, showed structure in A_N for the reaction ^{3}He $(p\uparrow,d)X$. Structure in this same region had been seen earlier in the cross section by a group at Saturne. Although this was not clear in the Gazzaly cross section data, peaks in A_N are seen in the new data with $\lesssim$ 50 MeV widths and regular spacing. At 2.7 GeV, Lomon had predicted structure based on a phase analysis of earlier data. A very comprehensive 3-spin program was carried out at Saturne (Lehar et al.), and this showed narrow peaks in A_N for $pp \rightarrow pp$, $\lesssim$ 10 MeV wide, for three angles. These results are quite new and will obviously need to be scrutinized.

EXCLUSIVES AT LARGE ANGLE

Most of the recent large angle exclusive results do not directly involve spin and were not presented at this conference. However, several new theoretical advances/ideas were.

Zhang (and Farrar) presented early results from their ambitious program to develop computer code to help them calculate large angle exclusive observables, starting with perturbative QCD diagrams. The approach, described by Zhang, is to convolute basic perturbative diagrams such as pure gluon exchange, quark exchange, and annihilation, with hadronic wave functions. The approach grew out of the successful dimensional counting explanation of the energy dependence of fixed large angle exclusive cross sections. The code helps calculate the 2000-odd first-order diagrams for meson-baryon scattering, obtained by attaching four gluons in all possible ways. In convoluting the diagrams with the wave functions the integration over quark momenta is complicated by certain regions where the quarks go on-shell and the integration is unstable. They avoid this by introducing a cut-off and checking the stability of the result. The integration for low x presumably involves a non-perturbative region--Isgur and Llewelyn Smith[11] would argue a very large part of the cross section. (It must be noted, however, that dimensional counting works extremely well and that this successful rule isn't likely to be fortuitous.) The program code now works, and it will clearly be an important tool in understanding the importance of pQCD in exclusive processes.

A diquark model was presented by Kroll and Anselmino which introduces helicity non-conservation into the pQCD picture above. A_N, A_{NN} and the ρ^- results require helicity flip at gluon-quark vertices, which is normally suppressed by $m_q/\sqrt{s}$ in a pQCD picture with m_q presumably very small. If, however, a vector diquark exists with a separation small compared to the probing energy $\sqrt{s}$, helicity flip would be allowed. So far, they have fit the proton form factors and then obtain excellent fits to A_{NN} and the ρ^- helicity violation.

The massive quark model, which views the interaction as an exchange of towers of mesons instead of a perturbative approach, can fit a large A_{NN} and predict the ρ^- helicity violation. A large A_N results from an interference with diffractive effects, and higher energy predictions for this were presented by Bourrely.

A particularly intriguing conjecture was presented by de Teramond (with Brodsky). They suggest that the peaking of A_{NN} near 12 GeV, observed oscillation in the behavior of the 90° pp elastic cross section about s^{-10}, and a new result on color transparency may be linked. They suggest a possible threshold effect (charm) at that energy which adds in a non-perturbative part to the cross section there. The effect shows up at 90° because other backgrounds have become small. One consequence of this conjecture is that the ocillation in the cross section should appear only near 90°, near 12 GeV, and not be present at smaller angles (otherwise A_{NN} would not turn on near 90°). Carroll has plotted existing cross section data normalized by $(s/s_0)^{10}$, $s_0 = 20$ GeV^2 versus energy, for different angles (Fig. 2). Indeed, the data show a bump at 12 GeV

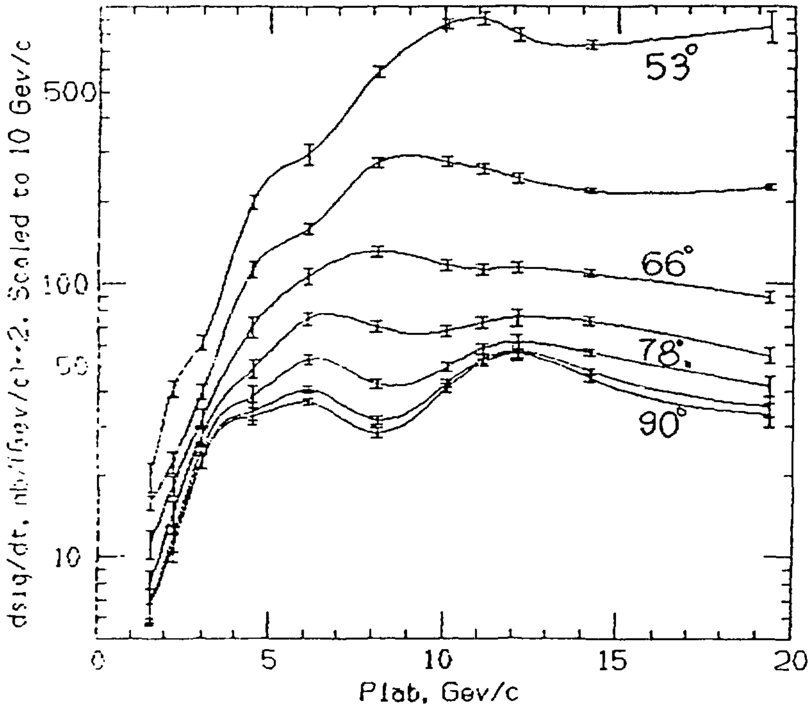

Fig. 2. pp elastic cross section data, scaled to 10 GeV.

and 90° which disappears at smaller angle. (The plot also shows very nicely the fixed p_T turn-on of dimensional scaling.) This conjecture has stimulated several ideas for testing it--higher momentum measurements of A_{NN} and color transparency, a search for charm near 12 GeV and 90°, and whether the correlation of these effects might be due to another mechanism.[12] An intriguing experimental idea is that color transparency might filter out non-perturbative processes, leaving, for example, helicity-conserving A_{NN} and $\pi^- p \rightarrow \rho^- p$ events. A $\pi^+ n \rightarrow \rho^\circ p$ experiment scattering pions from neutrons in a nucleus has been proposed for the AGS. Presumably these events would show no helicity non-conservation.

FUTURE SPIN PHYSICS SOURCES, BEAMS, TARGETS

Much of the future depends on spin technology which is ready today (GaAs electron sources, $\vec{d}$ targets), soon (major improvements in the above, including $\vec{n}$ targets from ^{3}He), or will require development from ideas presented in this conference series (snakes, storage cell targets, high intensity proton sources). A follow-up experiment has been proposed to the proton spin structure function measurement using a polarized neutron (d) target at CERN in the muon beam. Experiments with transversely polarized electrons and protons/neutrons have been suggested in light of the EMC results. SLC and HERA have planned ahead for polarized electrons. At the SLC, sitting on the Z^0 mass, they will have an order of magnitude improvement in sensitivity to $\sin^2\theta_w$ due to spin (A_{LR}) versus without it (A_{FB}). Venzegnassi argued that A_{LR} for hadronic production should be equal to A_{LR} from $\mu^+\mu^-$ pairs when on the Z^0 mass. Statistics then available (x10) may give significant sensitivity to the Higgs mass. Polarized protons for HERA are being discussed, either beam or a gas target. LEP, on the other hand, may not have polarized electrons at all due to decisions made during construction.

A_{NN} and A_N will be measured at higher energy and p_T for pp elastic scattering and for pn elastic. These will require a major improvement in the present AGS experiment, either a large increase in solid angle or more intense beams with a radiation insensitive target and running time with the polarized beam. If partial snakes work, polarized protons should be more available at the AGS and KEK.

A number of interesting physics possibilities were presented by Taxil, from a recently completed study of very high energy colliders (e^+e^- and pp). To do this, they needed to estimate low x quark and gluon asymmetries. For illustration, they divided the parton contributions to the proton spin following $\int\Delta q_{valence}:\int\Delta G:\int\Delta q_{sea} = .75:.20:.05$. They then convoluted the often maximal subprocess (quark-quark, quark-gluon) asymmetries with the parton asymmetries. Considering pp colliders, A_L isolates parity violating physics: $W^\pm$ and W^+W^- production tests of the standard model, search for $W_R^\pm$, and compositeness (20% effects for $\mu^+\mu^-$ pair production). A_{LL} is sensitive to supersymmetry (10% effects for jet production). The experiments with polarized protons require snakes in order to reach high energy, maintaining polarizarion.

They require high luminosity. (Note: present source intensities may be sufficient to give polarized luminosity in colliders equal to unpolarized beams. This is due to the inherent capabilities of colliders to stack polarized protons during the filling process.) They also require polarimeters (see Underwood's talk) and, very importantly, they require frequent polarization reversal. This future "program" is summarized in Table IV. The following sections will discuss work and ideas which, hopefully, will make this program possible.

TABLE IV

Experiment	Comments
$\vec{\mu}\ n$	Polarized D target
$e\uparrow p\uparrow,\ n\uparrow$	Transverse polarization $g_2(x)$
$\vec{e}^- e^+$ on Z^0	$\delta A_{LR} \sim 8\,\delta\sin^2\theta_W$ Sensitivity to Higgs SLC will have $\vec{e}^-$ LEP: $\vec{e}^-$ not easy anymore
$\vec{e}p,\ \vec{e}\vec{p}$	HERA will have $\vec{e}$; $\vec{p}$ possible
A_{NN} (pp)	24 GeV, 90°
$(g-2)_\mu$	1/3 ppm
$p\uparrow \overset{(-)}{p}(\uparrow) \to W$, jet, $\mu^+\mu^-$, ...	400 GeV, 2 TeV, 40 TeV Frequent polarization reversal in collider is very important.

Electron sources. The present basic GaAs source (circularly polarized light stimulates polarized electron emission) has high intensity, long life, and P = 50% (see summary of this section by Sinclair). It may be possible to reach P = 100% with a different material which removes a degeneracy in the valence band. P = 80%, 1 μA have been reached so far.

Electron storage ring resonances. Prescott's summary described the development of modeling, leading to a very precise match of the observed spin resonances at SPEAR. Buon has developed a simpler model which reproduces resonances well (semi-classical representation of random successive photon emission).

Proton sources. Development of higher intensity polarized proton sources is underway at many laboratories (Saturne, PSI, TUNL, BNL, INR, KEK, TRIUMF). Kubischta emphasized that sources are highly machine-dependent with respect to energy, emittance, and pulse length. A 10 mA, H^- source was reported 2 years ago[7] which has a 10 μsec pulse width and a 1 Hertz repetition rate. Present lower current sources (.3 mA) but with a much longer pulse length (1.5 msec) given an equivalent proton flux at Saturne (Arvieux). In any case, major intensity improvements are almost in hand.

p,n targets. Ammonia is the standard with $P(H) \approx 60\%$ to 90% and 17% H ($P(D)$ in ND_3 is 30% to 50%). Gas targets with a thickness of $10^{12}cm^{-2}$ are available, with $10^{14}cm^{-2}$ possible with various approaches (Court, Haeberli). An interesting target with neutron polarization and with no polarized proton background is ^3He. Very thick targets (10^{14} to $10^{20}cm^{-2}$) may be possible, with $P(n) = 60\%$.

Snakes. Roser gave a very nice presentation on just how a series of magnets which precess the proton spin by 180° about the horizontal effectively cancel spin resonance effects over two turns around the machine. These resonance effects, due to horizontal focussing fields and to imperfection fields which beat with the machine tune or periodicity, are stronger with increasing energy. There are also many of them--at the AGS there are about 40 between 0 and 24 GeV, and each needs to be tuned out with special dipoles and special pulsed quadrupoles. This is difficult--commissioning took 3 weeks of running time during the last AGS polarized proton run, followed by a 3 week physics run.

Several new ideas or considerations on snakes have come up this year. A potentially very important idea of Roser's was discussed and blessed at the snake workshop--that a snake would work fine on weaker low-energy resonances if it canceled resonance effects over perhaps 20 turns around the machine, instead of 2. This would be done with a "partially excited snake" (baby snake?) which might precess the spin 10° each pass instead of 180°. This device would be more compact and the beam excursions during the spin manipulations would be much less. This is important at lower energy where these deviations from the nominal orbit can be too large to be practical. The baby snake would be a passive device and the individual resonances would not be tuned. It would still be necessary to tune out the resonances that beat with the machine tune, but there are only a few of these and jumping intrinsic resonances is straightforward. If this idea works out, polarized protons would be available much more readily at lower energy, and polarized injectors for larger machines such as the SSC would be far more stable.

S.Y. Lee estimates that 8 or so adult snakes will be needed to tame a 20 TeV ring, which seems manageable. However, a potentially serious snag came up: do snakes in fact correct the weaker resonances from imperfection fields which can be quite strong at very high energy?

This, of course, points up a lesson. The snake idea has been around since 1977, but it has never been tested. Fortunately, however, a test has just begun at Indiana by the Michigan group.

CONCLUSION

We do spin physics because the technique is often a useful one--spin often provides a higher resolution probe of dynamics. We also do it because the response of physical systems to spin is often very beautiful. Part of the beauty is that spin phenomena crystallize the realization that "the real world (the world probed by our detectors) is a world of relativity and quantum mechanics."[13] I have certainly enjoyed this conference series (I thank Alan Krisch for that) and this meeting at Minnesota (I thank Ken Heller and the Minnesota contingent for their evident hard work).

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