OVERALL SUMMARY

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Let me begin by saying that I am extremely pleased by the results of this workshop. The 38 experimenters, theorists, and accelerator physicists from 23 institutions in Europe and North America have all worked very hard for 10 days. This workshop concentrated on planning for a type of high energy physics, rather than planning for a specific accelerator project at a specific laboratory. We studied polarized proton and deuteron beams and storage rings in considerable detail for the AGS, PS, SPS, Fermilab, ISR and ISABELLE and in some detail for KEK and Serpukhov. Our goal was to seek a feasible way to study spin-spin forces in strong interactions at very high energy. The workshop was more successful in attaining this goal than we had even hoped would be possible.

In 1/2 hour I could not possibly cover all the important new ideas that were developed during the past 10 days. Fortunately the chairmen of the six working groups have already done an excellent job of summarizing the significant contributions of each working group. I will instead just try to list a few topics that I feel need additional work, and list a few of the major highlights which produced the feeling of optimism, that I think we all share.

One extra activity at the workshop was to establish an international organizing committee to insure the continuation of the Symposia on High Energy Physics with Polarized Beams and Polarized Targets. These symposia were held at Argonne in 1974 and 1976 under

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the sponsorship of the ZGS users group. The increased activity in spin studies makes a broader sponsorship now seem appropriate. The IIIrd Symposium will most likely be held at Argonne in October 1978, and the 1980 Symposium will probably be held in Europe. We will soon fix the exact dates, and details. We hope to increase further the participation by people studying spin effects in electron scattering. We also hope to see many of you attending.

A second activity was the effort led by the notation committee under Elliot Leader's chairmanship. Hoping to reduce the confusion caused by different groups using different symbols for the same spin parameter, a major effort was made to agree on a uniform notation. This effort was clearly very painful to many of us, and took much more time and work than I expected. However almost all of us did finally agree on a convention which is published in these proceedings. I hope those few who are not totally happy with every detail of the convention will nevertheless use it. I believe it is ultimately in everyone's best interest to use uniform notation.

PROBLEMS NEEDING EXTRA WORK

I will briefly mention a list of problems that I feel we did not cover in enough detail.

1. Radiation Resistant Polarized Targets

Since spin seems especially important at high-$P_{\perp}^2$ where cross sections are small, high intensity beams are required. At high intensities Polarized Proton Targets suffer radiation damage and will no longer properly polarize. Some studies have been made of "annealing," and there have been searches for radiation resistant materials that are polarizable. More work is clearly needed here and perhaps the polarized target experts should have a workshop on this subject. Perhaps we erred in not inviting them to this workshop.

2. "Low Junk" Polarized Targets

Since the theorists feel that inclusive spin-spin interactions are especially important, one needs "low-junk" polarized proton targets. The "junk" atoms of carbon and oxygen in present targets are very good at producing inclusive pions and protons, which must be subtracted and make precise experiments very difficult. In fact, so far there have been no measurements of inclusive spin-spin forces. Of course, polarized storage rings would totally eliminate this problem, but they do not yet exist. Thus we should again urge the polarized target experts to search for new polarizable materials.

3. Internal Polarimeters

Jumping or avoiding depolarizing resonances will clearly be much more difficult in strong focusing accelerators and storage rings. Thus internal polarimeters will be very important, for they allow resonances to be studied without extracting the beam to an external polarimeter. A gas jet internal polarimeter could simultaneously measure the polarization above and below each resonance. While both the experimenters and accelerator experts did considerable work on this problem, I feel that even more work is needed because of the many interfacing problems.

4. Spin Flip in Storage Rings

The pulse by pulse flipping of the spin at the ZGS is absolutly vital for eliminating systematic errors in high precision experiments. The experimenters made some effort to communicate this to the accelerator people; but I want to stress the need for flipping the spin in storage rings at some regular interval (typically 1 sec to 1000 sec). The accelerator people did some work on this but I do not believe a clearly workable idea emerged.

5. Relation of Large-$P_{\perp}^2$ Spin Effects to Quarks

There was a general feeling that the large spin effects seen in high-$P_{\perp}^2$ p-p interactions are caused by the direct interactions of the spin-1/2 quarks, if they exist. But most of the calculations seemed somewhat model dependent. One should try to search for general relations that only assume that quarks have spin 1/2.

6. Polarized Deuteron Acceleration

One should study more carefully the acceleration of polarized deuterons, especially the need for a well calibrated deuteron polarimeter. Such studies might be tried during the planned polarized deuteron run at the ZGS in late 1978. If some unexpected problem makes polarized proton acceleration at AG machines impossible we should have a detailed polarized deuteron backup plan.

HIGHLIGHTS

1. High Intensity Source

Clearly the major highlight was the apparent breakthrough by the polarized ion source experts [H.F. Glavish, ANAC; E. Chamberlin, Los Alamos; W. Kubishta, CERN; and E.F. Parker, Argonne]. They produced a simple new idea which they believe will increase the polarized source intensity by a factor of about 30. The scheme uses the ANAC atomic beam type source that already exists at Argonne and CERN, but bombards the polarized neutral hydrogen atoms in the ionizer stage with D^- ions instead of electrons. The cross section for:

$$D^- + \underset{\uparrow}{H^\circ} \rightarrow \underset{\uparrow}{H^-} + D^\circ$$

is two orders of magnitude larger than the cross section for the present process:

$$e^- + \underset{\uparrow}{H^\circ} \rightarrow \underset{\uparrow}{H^+} + e^- + e^-$$

Therefore the source experts expect the polarized ion source intensity to increase from its present 50 → 100μa to perhaps 1 → 5ma. This scheme was carefully studied for a week, and I believe no one could find any flaw in the scheme. We are all eager to see if the source experts can get this improvement working in the next 6 months. Notice that the $H_\uparrow^-$ ions can be injected into accelerators with better efficiency than the present $H_\uparrow^+$ ions.

2. Depolarization in Strong Focusing Accelerators

The accelerator experts, led by E.D. Courant (Brookhaven), pointed out that while depolarizing resonances are certainly worse in strong-focusing accelerators than in the weak-focusing ZGS, they may not be as bad as was once feared. In fact, for polarized deuteron acceleration the resonances are not very strong at all. The ratio G_d/M_d is 25 times smaller than G_p/M_p so the depolarizing deuteron resonances are 25 times further apart than the proton resonances. Thus there is only 1 depolarizing deuteron resonance at the PS or AGS which is fairly weak, and there are about 10 at the SPS or Fermilab. Thus polarized deuterons look fairly easy at 30 GeV or indeed at 300 GeV.

However, the experimenters made it clear that they would much prefer polarized protons. The accelerator experts now decided that accelerating polarized protons in strong focusing accelerators might somehow be possible if a sufficient technical effort is made. In fact Professor Courant calculated that, using ZGS-type resonance-jumping schemes [pulsed quadrupoles for intrinsic resonances and pulsed orbit bumps for imperfection resonances], a polarized proton beam could probably be accelerated to almost 25 GeV at either the AGS or PS without very serious depolarization. Much of the new optimism comes from the ZGS success in repeatedly jumping 29 depolarizing resonances with no significant depolarization up to 12 GeV. This gives everyone confidence that the Froissart-Stora equations adequately describe depolarization during acceleration in synchrotrons and can be used to precisely calculate the necessary corrections. Courant compared acceleration to 25 GeV at the AGS (which is rather similar to the PS) with acceleration to 12 GeV at the ZGS. The AGS has about twice as many imperfection resonances and they are each about 10 times stronger than the ZGS imperfection resonances which each typically cause 5% depolarization.

Because the basic AGS periodicity is 12 while the basic ZGS periodicity is 4, there are only 6 or 8 intrinsic AGS resonances compared with the 10 intrinsic ZGS resonances. The AGS intrinsic resonances are estimated to be typically 3 times stronger than at the ZGS, where many are already strong enough to each totally depolarize the beam. A carefully planned program of designing upgraded ZGS-type correction magnets would probably allow polarized protons to be accelerated to almost 25 GeV without serious depolarization. This would probably require additional studies of depolarizing resonances at the ZGS polarized beam, but there seems to be no fundamental problem that some money and a lot of effort and thought could not solve. Some very strong depolarizing resonances (intrinsic and imperfection) occur near 25 GeV in the AGS and near 22 GeV in the PS. It is not clear if they could be passed without great effort.

3. Spin-Spin Forces at High-$P_{\perp}^2$

Two general conclusions about spin and high energy physics were more or less agreed upon by the experimenters led by O. Chamberlain and the theorists led by F.E. Low:

A. To understand fundamental interactions one needs precise spin experiments with both electron and proton accelerators

i) e-p scattering gives information about the "quark" wave function.

ii) p-p scattering gives information about the "quark-quark" interaction.

B. The spin-spin forces in very high energy large-$P_{\perp}^2$ proton proton interactions may be a key to understanding the "quark-quark" force. The spin-spin inclusive experiments may be even more important than the spin-spin elastic experiments.

4. The Siberian Snake

The "Siberian Snake" scheme for eliminating depolarizing resonances recently proposed by Derbenev, Kondratenko and Skrinsky (Novosibirsk), has the protons polarized in the accelerator plane rather than vertically. A solenoid magnet is placed in one straight section and tuned until the polarization vector returns to the same orientation after each pass around the synchrotron. This scheme is simple and elegant in theory. If it works, it could totally eliminate depolarization, even up to full energy, at Fermilab, SPS, or ISABELLE. But it clearly needs much more effort and thought.

EVENT RATES

I will finally discuss the event rates that can be expected for various measurements of spin effects at high $P_\perp^2$. I calculated the rates for elastic and inclusive events at $P_\perp^2 = 3(\mathrm{GeV}/c)^2$ where I expect spin-spin effects will be large even at very high energy. For elastic events I took

$$\sigma = \frac{d\sigma}{dt}\,\Delta t = [10^{-32}\ \frac{\mathrm{cm}^2}{(\mathrm{GeV}/c)^2}]\,[10^{-1}(\mathrm{GeV}/c)^2] = 10^{-33}\mathrm{cm}^2$$

For inclusive events I took

$$\sigma = E\frac{d^3\sigma}{dp^3}\,[P^3\frac{\Delta P}{P}\Delta\Omega] = [2\ 10^{-30}\ \frac{\mathrm{cm}^2}{(\mathrm{GeV}/c)^2}]\,[2\ 10^{-2}(\mathrm{GeV}/c)^2] = 4\ 10^{-32}\mathrm{cm}^2$$

The number of events per day is calculated from the luminosity, L, using

$$\text{Events/day} = 10^5(\text{sec/day})\,L(\text{Protons}^2/\text{cm}^2\text{-sec})\,\sigma(\text{cm}^2)$$

For fixed target experiments L is given by

$$L = I_o \left(\frac{\text{Beam Protons/burst}}{6\ \text{sec/burst}}\right) 4\ 10^{23} \left(\frac{\text{Target Protons}}{\text{cm}^2}\right)$$

The polarized target was taken to be 10 cm long with an effective density of .07. For the polarized gas jet we assumed there were enough multiple traversals ($\sim 10^5$) to give about 10^{28} cm^{-2}/6 sec burst for a luminosity of 2 10^{27}/cm^2-sec. The luminosity for polarized colliding beams was taken to be 10% of the present ISR luminosity of 4 10^{31}. Notice that we limited the unpolarized beam intensity to 3 10^{11} because of radiation damage to the polarized target.

In calculating the errors in A and A_{nn} we took P_B=70% and P_T=70%. The error in the analyzing power is given by

$$\Delta A = \frac{1}{P_T \sqrt{\text{events}}} \quad \text{or} \quad \Delta A = \frac{1}{\sqrt{(P_B^2 + P_T^2)\ \text{events}}}$$

depending on whether one or both of the incident protons are polarized. The error in the spin-spin correlation parameter is

$$\Delta A_{nn} = \frac{1}{P_B P_T \sqrt{\text{events}}}$$

For inclusive processes with colliding beams or gas jets these same formulae give the errors. However for inclusive processes with polarized targets, 90% of the events come from the "junk" oxygen and carbon; thus the errors are much larger.

As can be seen from the error column, either polarized colliding beams or an accelerated polarized beam at FNAL or SPS are necessary to measure very high energy spin-spin interactions at $P_\perp^2 = 3(\text{GeV/c})^2$. However, the hyperon decay beam and the polarized gas jet may be important intermediate steps.

ELASTIC AND INCLUSIVE SPIN EXPERIMENTS AT $p_\perp^2=3(\mathrm{GeV}/c)^2$	s $[\mathrm{GeV}^2]$	Luminosity $[\mathrm{cm}^2\text{-sec}]^{-1}$	$\frac{\text{Events}}{\text{Day}}$ Elastic	$\frac{\text{Events}}{\text{Day}}$ Inclusive	ΔA Elastic	ΔA Inclusive	ΔA_{nn} Elastic	ΔA_{nn} Inclusive
					← Run of 1 Day →			
Unpolarized beam on polarized target [SPS or Fermilab] 3 10^{11}/6 sec burst	~800	2 10^{34}	2 10^{6}	8 10^{7}	0.1%	0.2%	Not Possible	
Unpolarized beam on polarized gas jet [SPS or Fermilab] 3 10^{13}/6 sec burst	~800	2 10^{27}	.2	8	320%	50%	Not Possible	
Polarized protons from hyperon decay on polarized target [SPS or Fermilab] 1.5 10^{6}/6 sec burst	~500	10^{29}	10	400	32%	70%	65%	100%
Polarized Colliding beams [ISR or ISABELLE] 10% of Present ISR Luminosity	~2000	4 10^{30}	400	16,000	5%	1%	10%	1.6%
Polarized beam on polarized target [SPS or Fermilab] 3 10^{11}/6 sec burst	~500	2 10^{34}	2 10^{6}	8 10^{7}	0.07%	0.2%	0.14%	0.2%

CONCLUSION

Perhaps I can best summarize the tone of the workshop by stressing the optimism produced by the source experts and the accelerator experts. If ZGS-type corrections for depolarizing resonances work at the AGS or PS, then one should be able to reach almost 25 GeV without serious depolarization, inject into ISABELLE or ISR, and operate near $s = 2000\ GeV^2$. If the new ion source scheme really gives a factor of 30 gain in intensity, the colliding polarized beam luminosity will be increased 1000-fold to within a factor of 10 of the present ISR luminosity. While both the above sentences start with if, there was a strong feeling that in the 1980's we might be studying p-p inclusive cross sections in pure spin states in clean colliding beam experiments.

I want to conclude by thanking all you distinguished scientists for 10 days of very hard work. I think we are all exhausted; but I also think that the possibility of studying spin-spin forces at very high energy makes it seem worthwhile.

INDIVIDUAL SUMMARIES