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Summary of 13th International Symposium on High Energy Spin Physics

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To summarize the new results presented at the 13th International Symposium on High Energy Spin Physics, which was held at IHEP-Protvino during 7-12 September 1998, I will subdivide them into the topics of: spin physics history; polarized beams and Siberian snakes; polarized targets, jets and sources; nucleon structure function experiments; electro-weak spin experiments; hadronic spin experiments; spin theory; and finally future polarized beam facilities.

1 History

Professor Fidecaro gave a very interesting lecture about the early history of polarization from about 1937 to 1960. He mentioned a number of milestones in the field including: the first thoughts about double scattering experiments in 1937 by Schwinger and Rabi; the first consideration of methods to polarize beams by Hammermesh, Schwinger, Wolfenstein and Rose during 1946-1949; and the first ideas about polarized targets by Rose in 1949. At this time, people were not yet building polarized beams and targets, but they were starting to think about them. Then in 1949 Wolfenstein published the first theory of reactions involving polarized protons; he defined what we now call the Wolfenstein parameters. Fidecaro also mentioned the multi-hundred MeV polarization experiments which occurred during 1951-1953 by Wouters *et al.* at Berkeley and by Oxley *et al.* at Rochester. Then in 1954 Fermi stressed the importance of polarization in nuclear reactions in a Varenna lecture and in a paper. [Owen Chamberlain, who was Fermi's student, often said that this paper inspired him to start working in polarization.] The existence of Dubna was announced at a 1956 International Atomic Energy Commission Meeting in CERN; until 1956, the Dubna accelerator was not known in the West because it was secret. However, some Russian physicists, including Professor Nurushev who is here today, were doing polarization experiments at Dubna in the early 1950's unknown to the rest of the world. In 1959 Jacob and Wick developed a relativistic formalism for dealing with spin polarization. We also heard about the 1960 Basel Symposium producing the Basel Convention for polarization parameters.

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Professor Fidecaro's lecture gave an excellent description of this early period of our history. The next important step in our history was the development of polarized proton targets; Abragam, Jeffries, Chamberlain and Borghini were leaders in this development during the late 1950's and early 1960's.

2 Polarized Beams

The first high energy polarized beam was accelerated at the ZGS which is shown in Fig. 1; the development work occurred during 1969 to 1973 and then the ZGS ran primarily as a polarized proton beam until 1979. The ZGS had some intrinsic and imperfection depolarizing resonances, but they were rather weak and relatively easy to overcome; moreover, the polarization hardware requirements were modest. This was fortunate because, at that time, we did not really know very much about overcoming subtle or strong depolarizing resonances. Then in the later 1970's, polarized proton beams of a few GeV were accelerated at Saclay in France and at KEK in Japan. This period moved High Energy Spin Physics into a new phase because the resources of large laboratories were then focused on improving the performance and reliability of polarized hardware such as polarized ion sources.

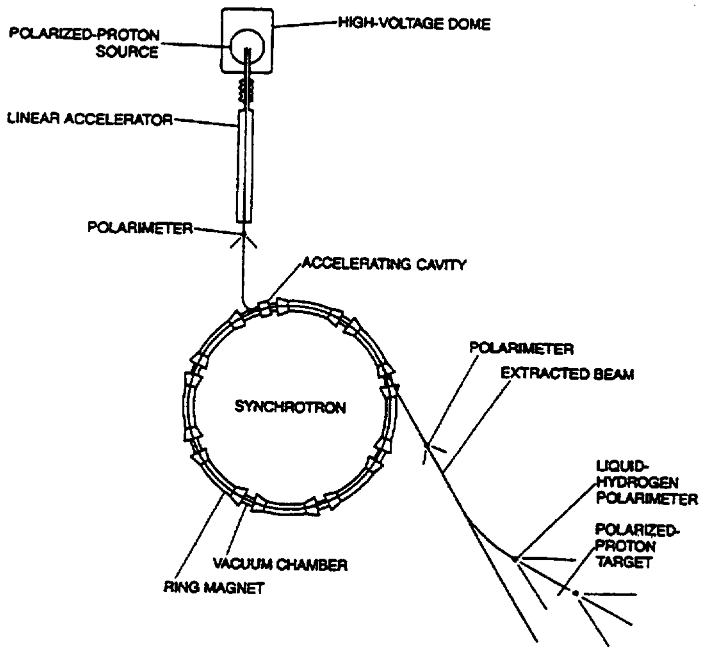


Fig. 1 ZGS Polarized Proton Beam

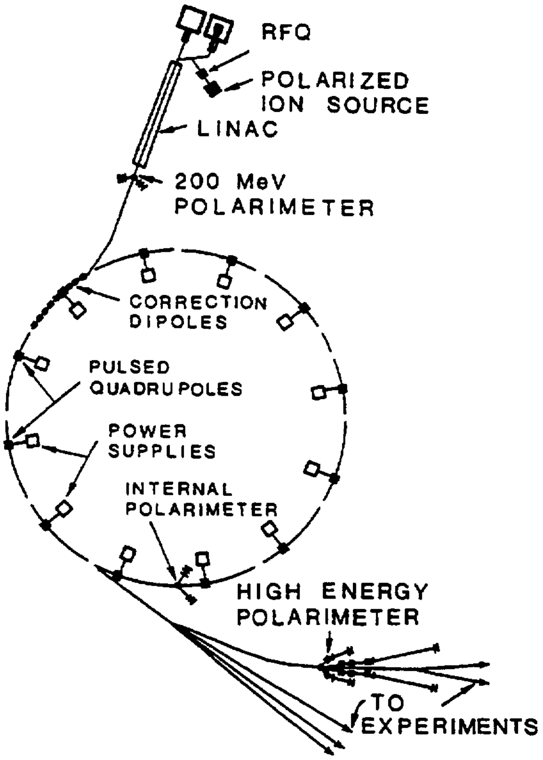


Fig. 2 AGS Polarized Proton Beam

The planning for accelerating a higher energy polarized proton beam started at the 1977 Ann Arbor Workshop; the AGS polarized beam first operated in 1984 and still runs periodically. The AGS beam polarization was much harder to maintain, because the AGS is a strong focusing accelerator with many strong depolarizing resonances. The intrinsic depolarizing resonances were overcome using twelve very expensive 20-Mega-Watt 1.6-μsec-risetime pulsed quadrupole magnets as shown in Fig. 2. The 45 imperfection depolarizing resonances were individually corrected using the AGS's 96 small correction dipoles to form the appropriate k^{th} harmonic of horizontal field for each $G\gamma = k$ imperfection resonance. This difficult job cost about 10 Million 1980 dollars for hardware (about \$20 Million now). Moreover, each polarized beam tune-up required up to seven weeks of dedicated beam time at about \$1 Million per week.

Now I move from history to our September 1998 Symposium where Dr. Roser discussed: the different kinds of spin depolarizing resonances in strong focusing accelerators; the depolarizing resonance condition; the spin tune which is the number of spin rotations in each turn around a ring; and Siberian snakes. One had dealt with depolarizing resonances at the ZGS, AGS and KEK by individually correcting each resonance. With a depolarizing resonance occurring every 523 MeV, this technique clearly was reaching its energy limit; at the AGS rate of one resonance per day, individually correcting the 36,000 depolarizing resonances at the 20 TeV SSC would require almost 100 years.

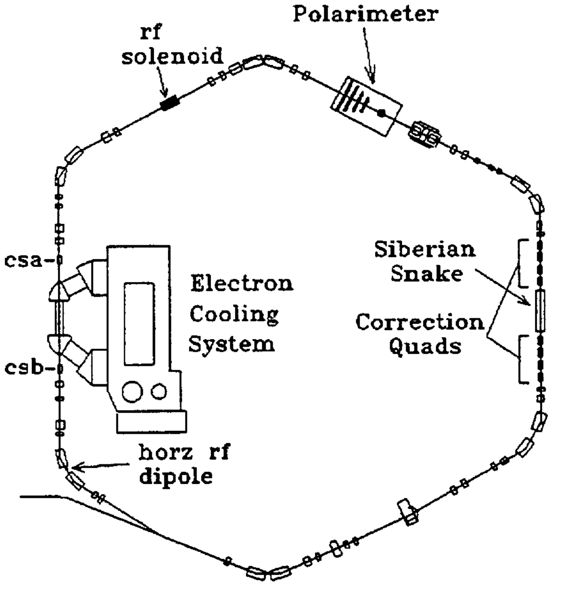


Fig. 3 Siberian snake in IUCF Cooler Ring

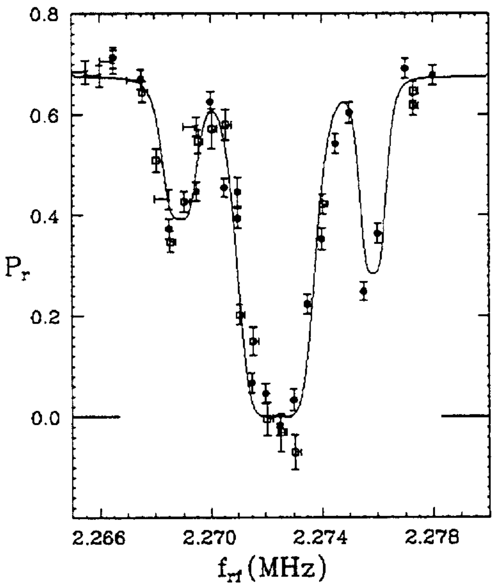


Fig. 4 Second-order Depolarizing Resonance with Full Siberian Snake

Fortunately in 1976, two clever Siberians, Derbenev and Kondratenko, had proposed the idea of Siberian snakes which should simultaneously overcome all depolarizing resonance by forcing the spin tune to be exactly one half and thus moving all the resonances essentially out of existence. We installed a Siberian snake in the IUCF Cooler Ring in 1989 as shown in Fig. 3. It demonstrated for the first time that a Siberian snake really could overcome depolarizing resonances. Dr. Roser (who was very active in the early IUCF experiments) also showed in Fig. 4 some recent IUCF data on the discovery of a second-order rf synchrotron depolarizing resonance in the presence of a full Siberian snake; this is the first higher-order depolarizing resonance observed with a full snake. He also discussed the recent demonstration of a 97% spin-flip efficiency with the full snake on.

Dr. Roser and his colleagues have installed a 5-10% partial warm Siberian snake in the Brookhaven AGS; this solenoidal partial snake has overcome about 45 imperfection depolarizing resonances at the AGS as shown in Fig. 5. Their most recent run also used an rf dipole to overcome the intrinsic depolarizing resonances; this technique was partly successful, but their solenoidal partial snake probably causes some depolarization due to its strong x-y coupling. Thus, in 1999, they plan to replace it with a helical partial snake, which should eliminate most of this coupling. Fig. 5 shows some recent data along with the calculated polarizations for the existing solenoidal partial snake and the planned helical partial snake; the polarization should be over 70% at the transfer energy.

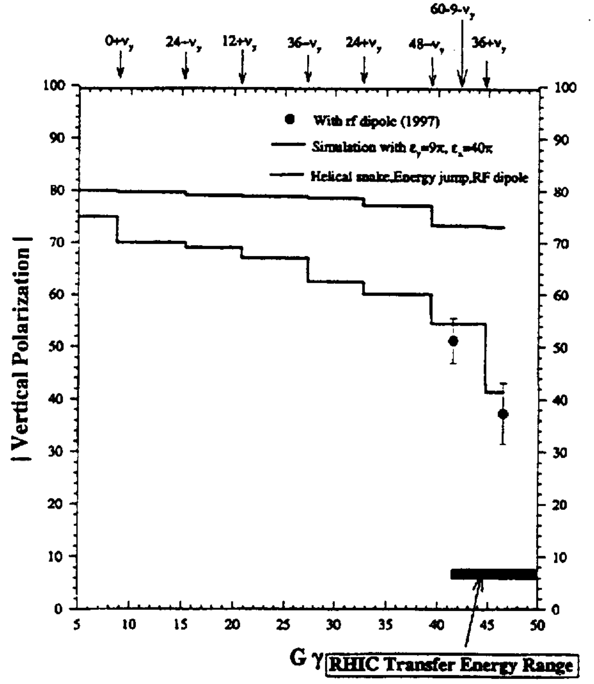


Fig. 5 AGS Proton Beam Polarization

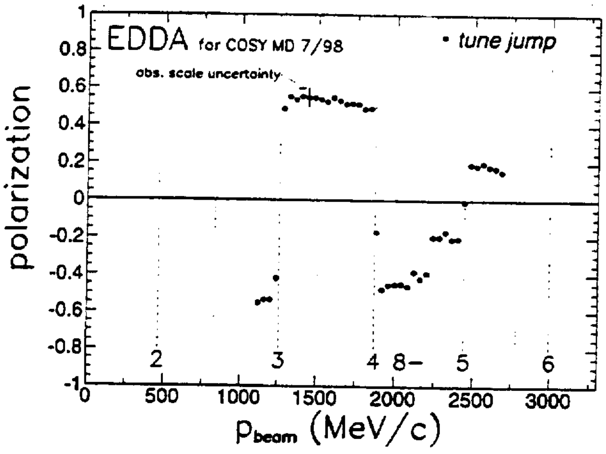


Fig. 6 COSY Proton Beam Polarization

The 3.3 GeV/c COSY proton ring at Jülich, Germany has recently been trying to accelerate a polarized beam without using a Siberian snake, but instead using a pulsed quadrupole to tune-jump through the intrinsic resonances. Fig. 6 shows that this tune-jump did improve the polarization, but at 2.7 GeV/c there is still significant depolarization.

Dr. Roser discussed the naive limit ($N = 2\varepsilon$) for the number N of Siberian snakes required in a high energy proton ring with a maximum resonance strength of ε . Being cautious and exact as always, he used the word naive which is certainly correct because 2ε is indeed the lower limit of how many snakes one needs to overcome the depolarizing resonances. I would say that ε should be significantly smaller than $N/2$ so that the snakes can totally dominate the spin motion. Thus, if ε is about 1.8 at HERA, then installing only four snakes in HERA ($N/2 = 2$) would give very little safety factor.

Dr. Barber lectured this morning on polarized electron beams. The most important idea in polarized electron beams came from two very bright Russians, Sokolov and Ternov; in 1963 they developed the idea of self-polarization of electrons. This works because there is a small difference in the electron's synchrotron radiation rate depending on whether the electrons' magnetic moments are parallel or anti-parallel to the ring's magnetic field; this self-polarization is very efficient at high energy where the electrons in a ring can quickly polarize themselves. Since the idea was first proposed in 1963, it has changed from an abstract idea with little practical application into the technique which is used to polarize the world's two great electron rings HERA and LEP. In addition to spin experiments, this electron beam polarization has allowed very precise calibrations of the beam energy and thus the masses of the intermediate bosons. Dr. Barber discussed the electron polarization in the HERA and LEP rings and showed some slides about the polarized electron beams at SLC, Jefferson Lab, and ELSA; please consult his manuscript for his slides about polarized electron facilities.

3 Polarized Targets, Sources and Jets

Professor Crabb reported on the 15-16 April 1998 Solid Polarized Target Workshop of 34 experts, which he organized at Virginia. He briefly discussed several state-of-the-art polarized targets including the SMC polarized target which is shown in Fig. 7. It is an impressive very long frozen spin PPT which operates with its upstream half polarized in one direction and its downstream half polarized in the other direction; these directions are often reversed to further reduce the systematic errors.

Another state-of-the-art polarized target is the Virginia solid PPT that oscillates between SLAC and Jefferson Lab, which each paid for part of it. This target, which operates at 5 T and 1 K, is shown in Fig. 8. It is similar to the Michigan solid PPT, which is not surprising since Crabb was a leader in building both; these two PPT's both work very well. Their cooling power of 1 Watt allows them to operate in beams of over 10^{11} per second, with a proton polarization of over 90%. Thus, for high beam intensity experiments, they seem almost ideal polarized targets.

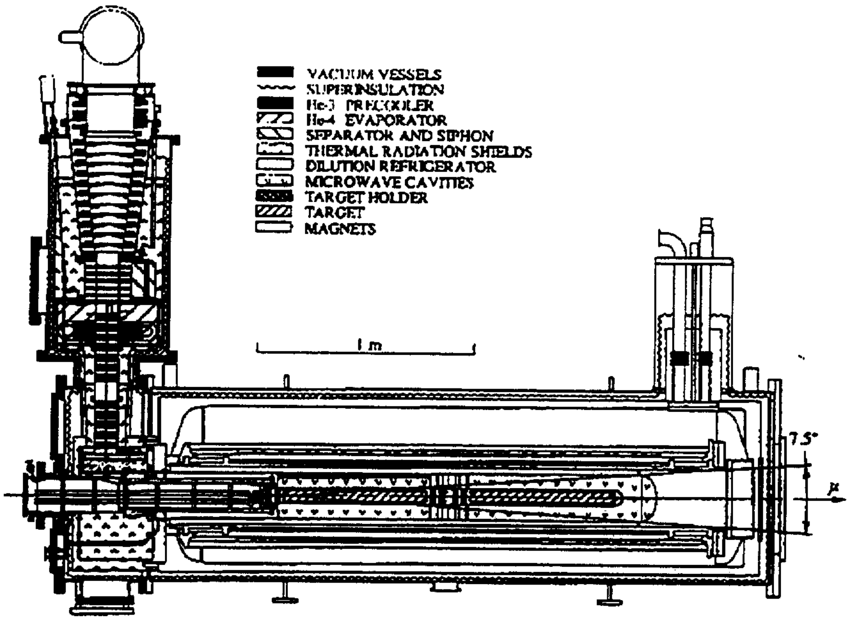


Fig. 7 SMC Solid Polarized Proton Target

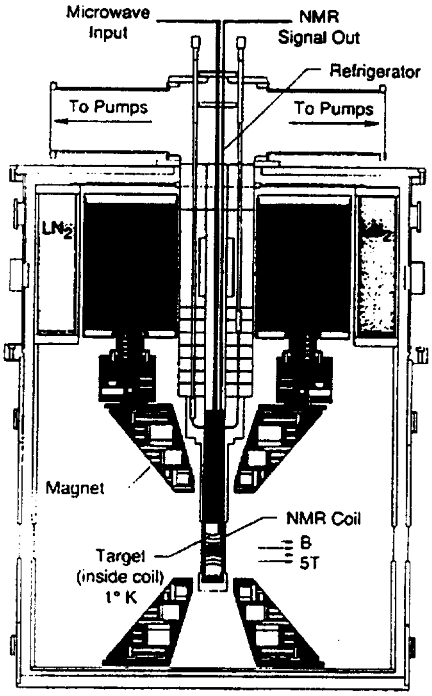


Fig. 8 Virginia Solid PPT

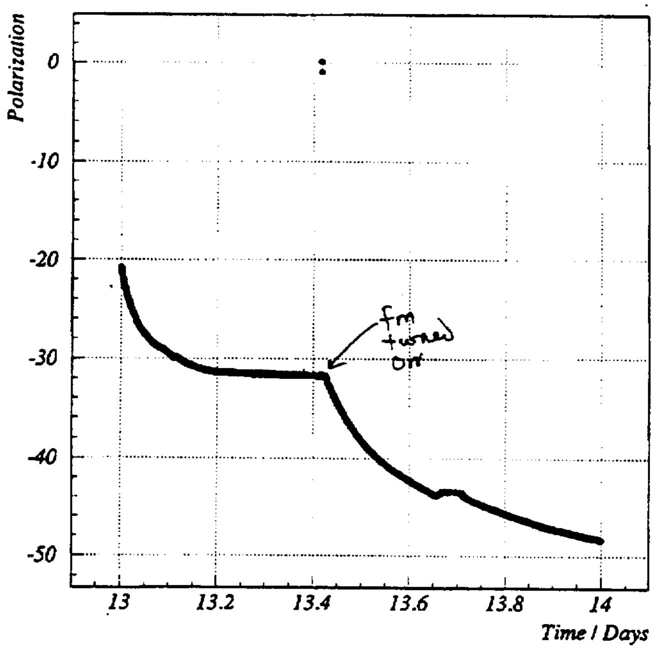


Fig. 9 Lithium Deuteride Polarization

However, this field is certainly not yet stagnant because there are several very interesting new results. Recent Virginia studies with Lithium Deuteride found only a 32% polarization with the microwaves at fixed frequencies. However, when the microwave frequency was varied over a small range, then the polarization reached almost 50% as shown in Fig. 9. This rather remarkable result is not yet understood, but it does occur experimentally.

Crabb also mentioned the interesting new result by Professor Masaike's team at Kyoto, which has been working for years to develop a high temperature polarized target. At liquid nitrogen temperature, they now have a rather interesting target; it uses a 0.3 T magnetic field and some complex chemical materials: either napthalene ($C_{10}H_8$) or p-terphenyl ($C_{18}H_{14}$) doped with pentacene ($C_{22}H_{14}$). At liquid nitrogen temperature, they obtained for napthalene a 30% polarization and for p-terphenyl a 19% polarization. This may be important because it is much easier to produce high cooling power at liquid nitrogen temperatures, than at liquid helium temperatures. If one could increase the polarization by another factor of two or three, then these targets might become widely used, although their hydrogen contents is not very high. This new result suggests that there may be many different ways to polarize protons and I look forward to further progress by the Kyoto Group.

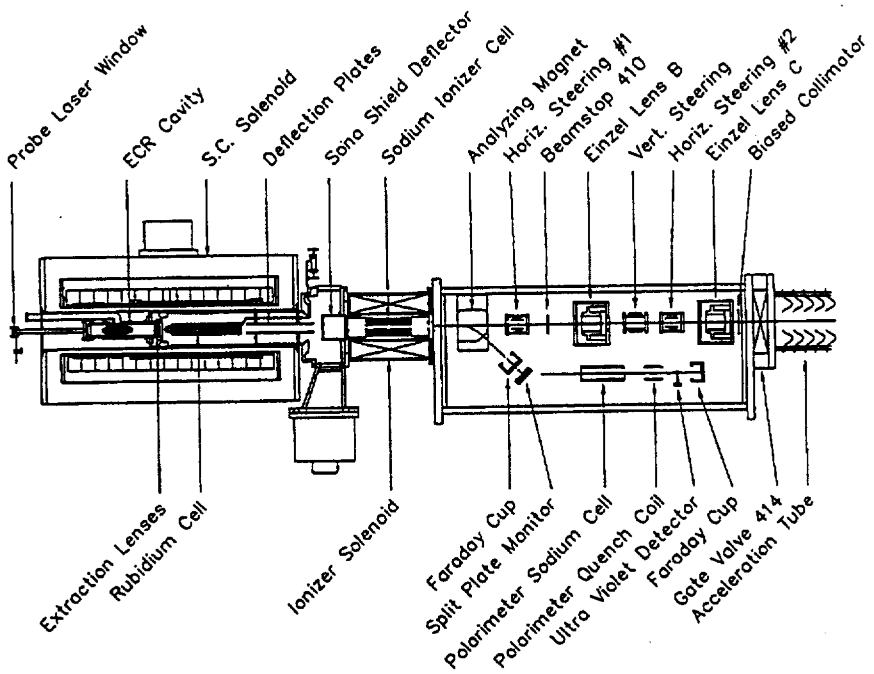


Fig. 10 TRIUMF $H_\uparrow^-$ Optically Pumped Polarized Ion Source

Two very competent competing groups are working on polarized proton sources. Professor Zelenski, from INR-Troisk, and his TRIUMF colleagues have developed an optically pumped polarized ion source (OPPIS) which is now producing almost 2 mAmp of $H_\uparrow^-$; they hope to soon increase this intensity significantly. The TRIUMF OPPIS source is shown in Fig. 10. This higher intensity polarized H^- source R&D is being supported both by DESY through SPIN@HERA and by Brookhaven which is paying TRIUMF to convert an existing KEK OPPIS into a higher intensity $H_\uparrow^-$ source for RHIC.

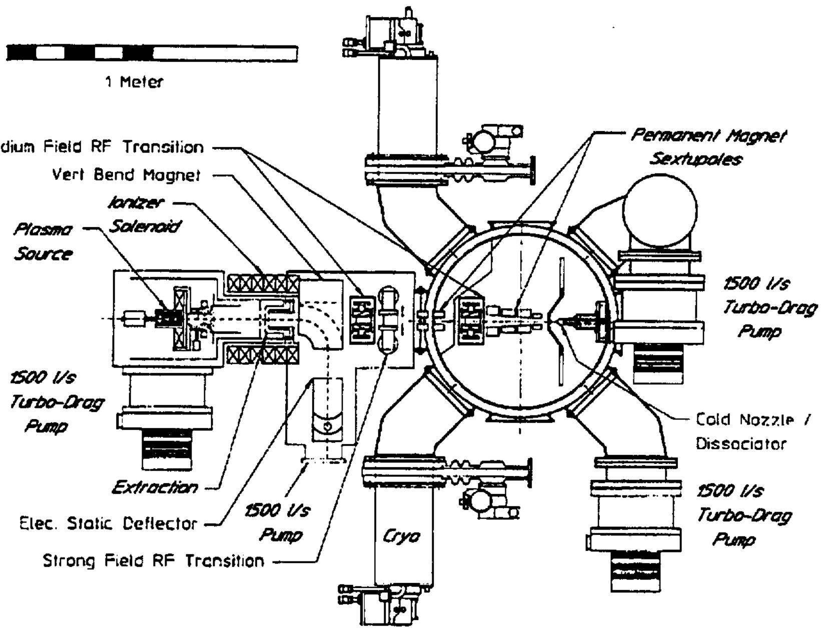


Fig. 11 IUCF/INR Atomic Beam Type $H_{\uparrow}^{-}$ Source

Dr. Belov, who is working at INR-Troisk, is an expert on atomic beam type polarized sources; his source at INR is now producing over 1 mAmp of highly polarized H^{-}. His INR team is now building some similar components to improve the new IUCF polarized source, as shown in Fig. 11. With these two very capable Russians from INR-Troisk developing two totally different polarized ion source techniques, the intensity of each source type has grown by about a factor of 10 since the 1986 SPIN Symposium in Protvino.

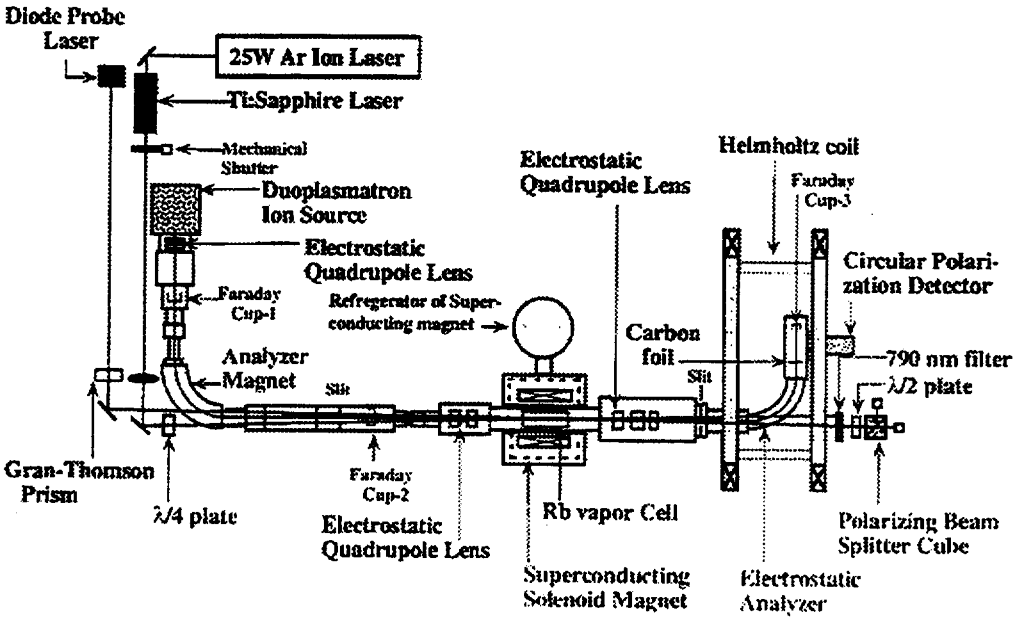


Fig. 12 RCNP ^{3}He Polarized Source

Professor Tanaka from Kobe reported on his ^3He polarized source development; as shown in Fig. 12, this source uses a 25 W Ar laser, a Rb vapor cell and other sophisticated hardware. Until now, Helium polarized beams have been used mostly at lower energy accelerators; there is now also some interest in possibly accelerating polarized ^3He ions at COSY and perhaps DESY.

Professor Mamaev, who spoke immediately before me, was kind enough to give me a summary of his successful LE98 Workshop in St. Petersburg just before this Symposium. It was attended by 54 physicists and was especially focused on polarized electron sources. Since we just heard his very clear review, I will not try to repeat it.

Dr. Burtin, who described his group's experiment at Jefferson Lab (formerly CEBAF), also briefly discussed the accelerator's GaAs polarized electron source, which is shown in Fig. 13 and is now producing 100 μA of electrons with a 40% polarization.

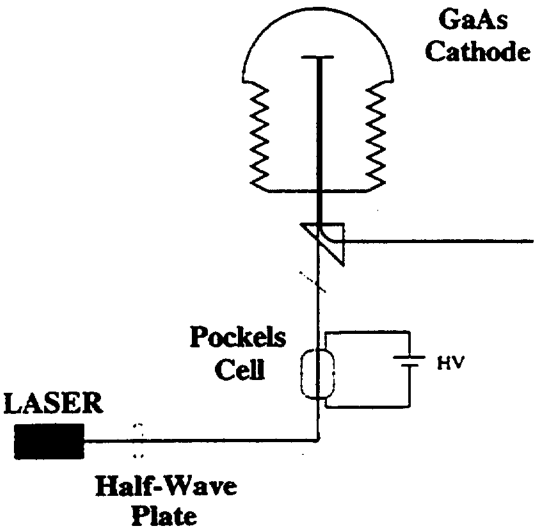


Fig. 13 Jefferson Lab GaAs $e_\uparrow$ Source

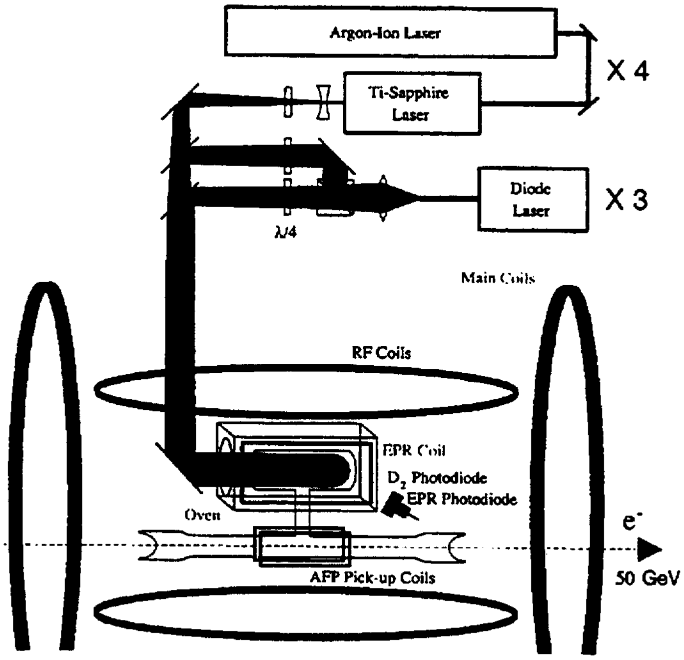


Fig. 14 SLAC E-154 $^3He_\uparrow$ Target

An institute which has not presented many accelerator papers at SPIN98 but did much of the pioneering work on polarized electron sources is SLAC. Professor Hughes did talk about his polarized ^3He target which is used in E-154 at SLAC. As shown in Fig. 14, this target uses an Argon-Ion Laser, a Ti-Sapphire Laser and a Diode Laser to polarize the Helium atoms.

Dr. Bruell discussed the polarized proton storage cell which is being used as a polarized internal target in the HERMES experiment at HERA. As shown in Fig. 15, this target uses an atomic beam type $H^0_\uparrow$ source but increases the target thickness by using the storage cell tube which causes the atoms to escape more slowly; they eventually do escape, but the slowing down increases the target thickness by about a factor of 10. The polarization is 80-90% for $H_{\uparrow}^{0}$ or $D_{\uparrow}^{0}$ and the thickness is over 10^{14} atoms cm^{-2}.

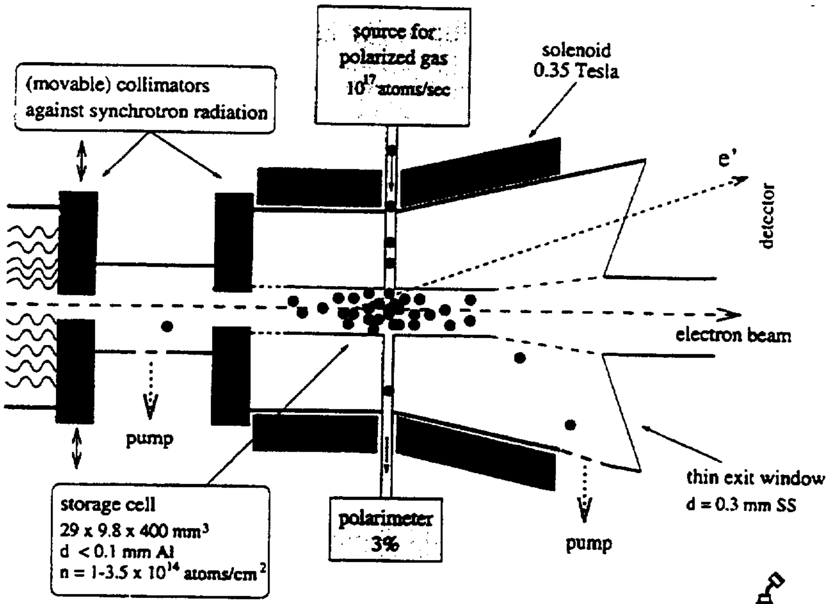


Fig. 15 HERMES $H_{\uparrow}^{0}$ Storage Cell Target

Dr. Luppov discussed the Mark II Ultra Cold Jet, which is now being developed at Michigan. As shown in Fig. 16, this Jet has a high field of 12 T, a low temperature of about 0.3 K, a superfluid ^4He-coated "quasiparabolic" mirror, a focusing superconducting sextupole, and an rf transition unit. We hope that this Jet can produce a thickness of about 10^{13} proton-spin-polarized hydrogen atoms cm^{-2} by late 1999. All of the major hardware now exists, but much development work is still needed to get the Jet working properly. [In October 1998, the Jet produced its first electron-spin-polarized beam].

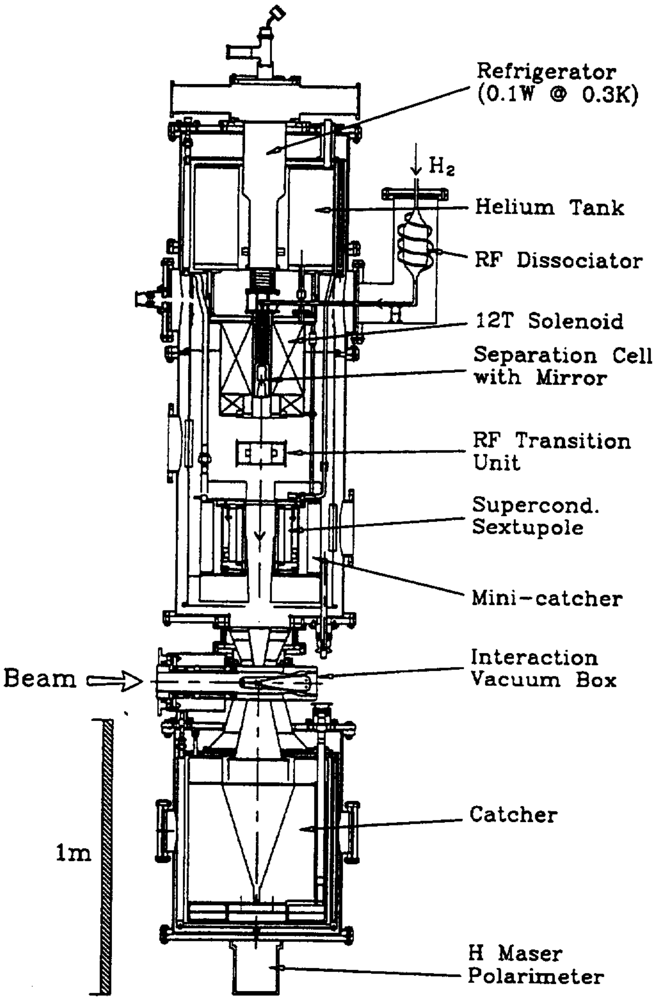


Fig. 16 Ultra-Cold Polarized Proton Jet

4 Nucleon Structure Functions

Professor Gabathuler presented a very nice history of nucleon structure functions (or form factors), starting in 1975 with some experiments at rather large values of Bjorken x. The 1985 EMC experiment found some interesting problems with the structure functions. Then in 1992 the SMC experiment started to see clear deviations from the Ellis-Jaffe sum rule but not the Bjorken sum rule; these deviations acquired the perhaps unfortunate name "Spin Crisis". Since then, many experiments have studied the "Spin Crisis"; much of the new data presented at this Symposium was from these experiments.

Gabathuler clearly defined the 1966 QCD Sum Rule of Bjorken, and the 1974 Quark Parton Model Sum Rule of Ellis and Jaffe:

$$\text{Bjorken} \qquad \int_0^1 g_1^p(x)dx - \int_0^1 g_1^n(x)dx = \tfrac{1}{6}\, g_a/g_v;$$

$$\text{Ellis-Jaffe} \qquad \begin{aligned} &\int_0^1 g_1^p(x)dx = \tfrac{1}{18}(9F - D) \;\approx\; 0.17; \\ &\int_0^1 g_1^n(x)dx = \tfrac{1}{18}(6F - 4D) \approx -0.02\,. \end{aligned}$$

The proton, deuteron and neutron data in Fig. 17 clearly disagrees with the Ellis-Jaffe sum rule. This disagreement was perhaps already known at the SPIN 94 Symposium, but the more precise data presented at this Symposium certainly better confirms the disagreement with the Ellis-Jaffe sum rule and the agreement with the Bjorken sum rule.

Professor Savin discussed the SMC experiment at CERN, which scatters muons, polarized in a helicity state, from the long polarized proton target shown in Fig. 7. He also presented some new measurements of the proton and deuteron form factors. Fig. 18 compares the SMC proton form factors, which have good precision at small x-values, with some SLAC E-143 and EMC data.

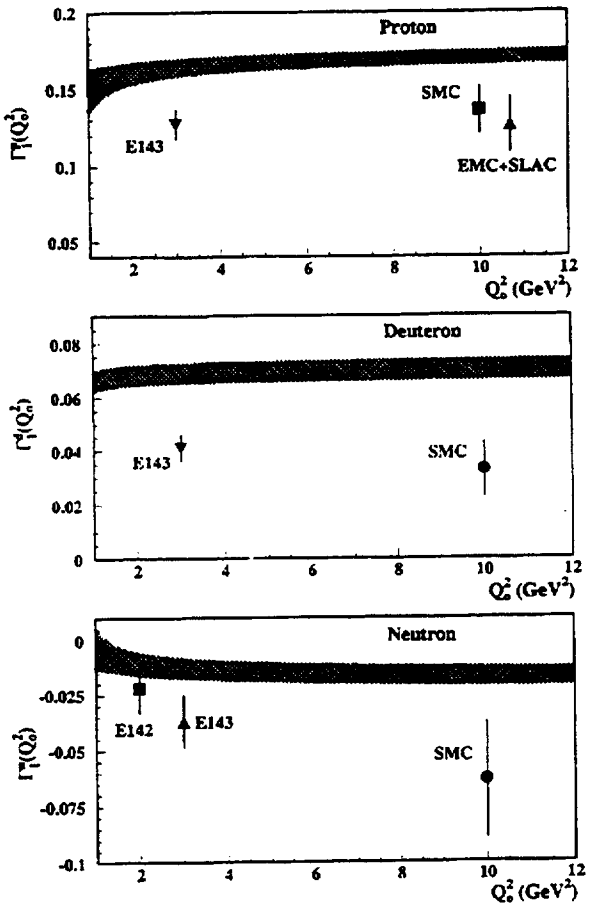


Fig. 17 Tests of Ellis-Jaffe Sum Rule

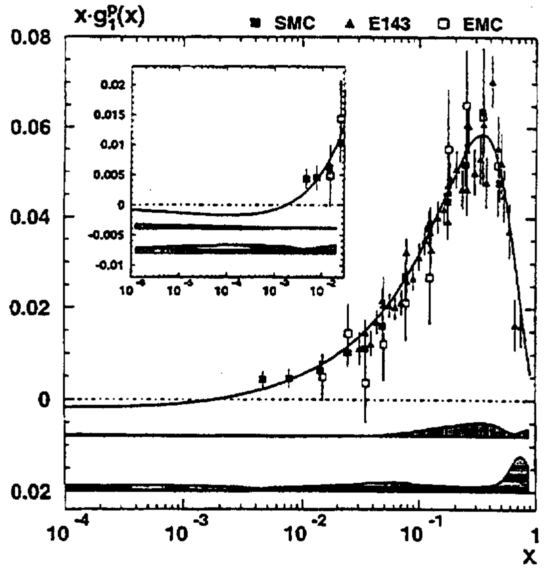


Fig. 18 SMC Proton Form Factors

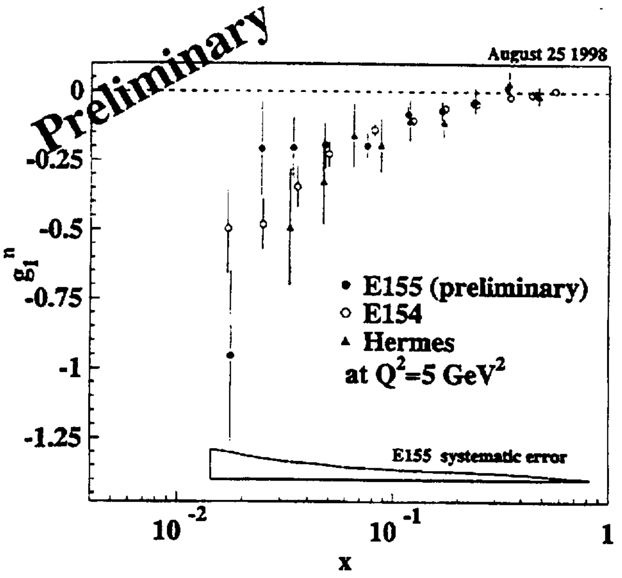


Fig. 19 E-154 & E-155 Neutron Data

Professor Hughes discussed the E-154 and E-155 experiments at SLAC which use polarized targets and long spectrometers to study the nucleon structure functions. Fig. 19 shows some preliminary data on the neutron structure functions. Both E-154 and E-155 have somewhat smaller neutron errors than HERMES, but all the neutron data is much less precise than the proton data. A similar graph of the proton structure function at $q^2 = 5$ (GeV/c)^2 compared the E-155 preliminary data with the E-143 and SMC data; for protons all the experiments seem to have comparable precision and range.

Dr. Bruell discussed the HERMES experiment, including its polarized pro-

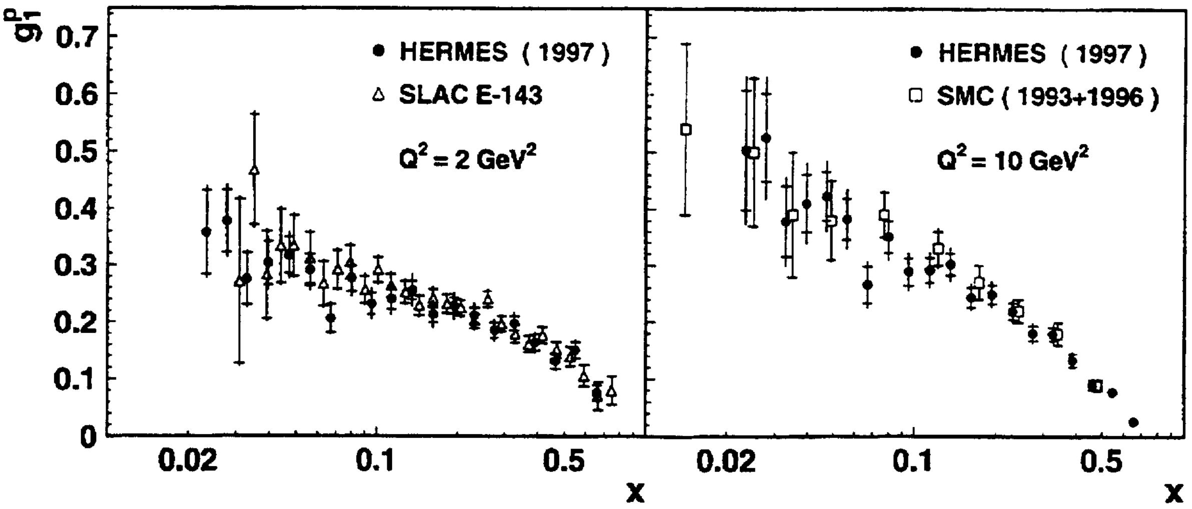


Fig. 20 HERMES Proton Form Factors

ton storage cell target, its polarized electron beam with about a 50% polarization, and its magnet and detector. She also presented some 1997 HERMES data; Fig. 20 shows that the proton structure function data from E-143, SMC, and HERMES are now in rather good agreements. The HERMES data seem slightly better at low x and low q^2.

The agreement between all the nucleon structure function data is now rather good. Thus, the so-called "Spin Crisis" is now clearly not an experimental problem. The general conclusion that has emerged from this extensive study of the nucleon structure functions is that, in the Standard Model, about 1/3 of each nucleon's spin appears to be carried by the quarks. While there are many different theories, there is not a good understanding of where, in the Standard Model, the rest of the spin resides.

5 Electro-Weak and Other Spin Experiments

In recent years the polarized electron-positron experiments have dominated the program at SLAC's first linear collider SLC. The LEP facility is not really using its polarized beam for experiments, but only for very precise energy calibrations. The most recent summary of the SLC and LEP data on the Weinberg angle $\sin^2\theta_W$ is shown in Fig. 21. The current LEP average is shown by dashed lines for 1σ and 2.2σ, while the latest SLC result is shown to be $\sin^2\theta_W = 0.23101 \pm 0.00031$. The earlier data had some small disagreements;

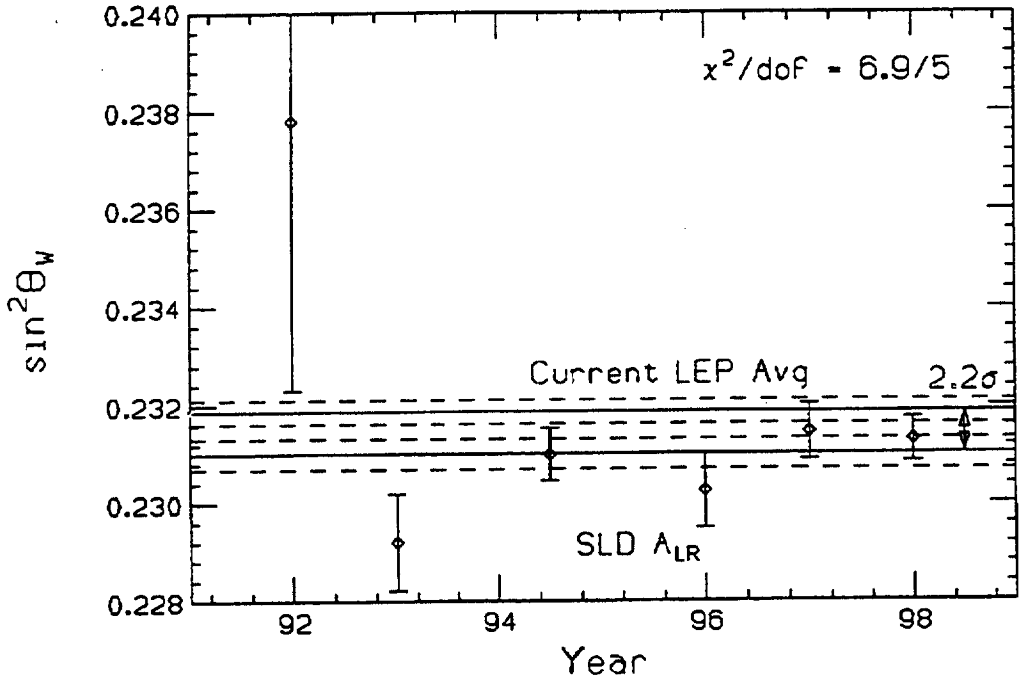


Fig. 21 SLC & LEP $\sin^2\theta_W$ Data

the two experiments now seem to agree rather well with each other; thus, as expected, science seems to find the truth by requiring reproducibility. It seems impressive that the single SLC experiment with a polarized beam has obtained only a slightly larger error than all four unpolarized LEP experiments combined. This is a good example of polarization's ability to reduce errors.

The OPAL Collaboration studied the longitudinal polarization in Λ production. As shown in Fig. 22, they found that fragmentation did not destroy the Λ polarization. Instead they found that, at x values above 0.3, there are rather large polarizations, of about $-33 \pm 8\%$, which seem to persist from low energies to high energies, while at small x the Λ polarization goes to zero.

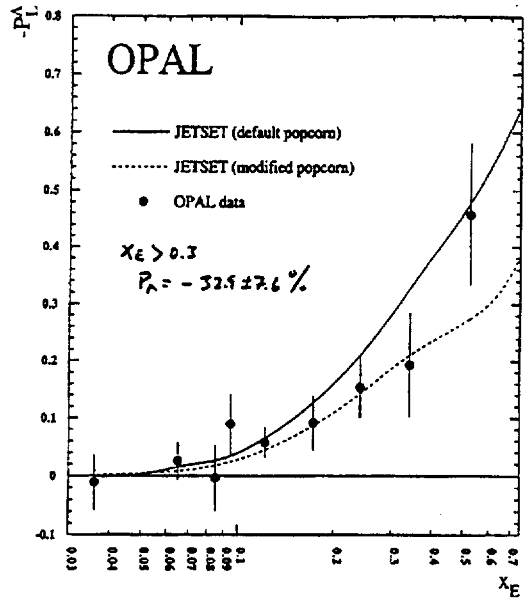


Fig. 22 OPAL Data on Λ Polarization

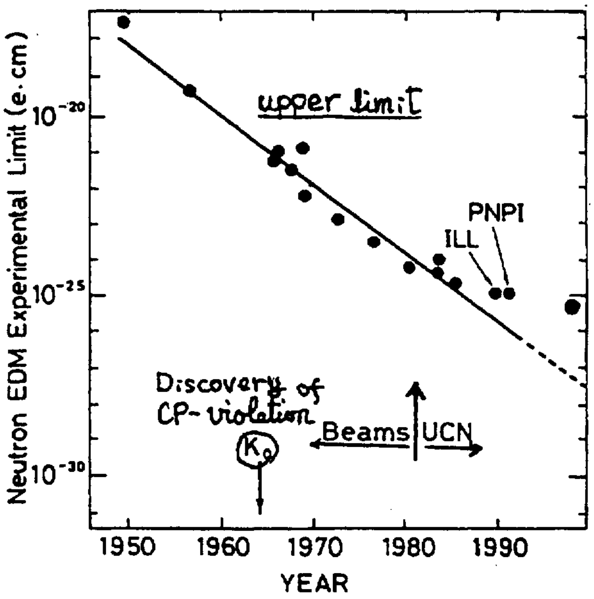


Fig. 23 Neutron EDM Limit

Professor Masaike gave a summary about spin and symmetry conservation at low energy. Several groups are actively working on parity violation experiments; the TRIUMF experiment's preliminary result for 221 MeV p-p scattering is $A_L = (3.4 \pm 6.7)10^{-8}$. Other groups are looking for time reversal violations; the neutron electric dipole moment (EDM) experiments are a very good way to search for T violation. Fig. 27 summarizes all neutron EDM data from 1949 up to 1998; during this time the EDM upper limit dropped from about 3 10^{-18} to 6 10^{-26} e·cm. Professor Masaike seemed disappointed by the 1985 deviation from this limit's exponential decrease, but it seems not surprising that progress becomes more difficult near the 10^{-25} level. Moreover, many clever people have worked hard to reach this level; Professor Ramsey has been a leader in these incredibly precise measurements for five decades. However, Professor Masaike's Kyoto team may succeed at further extending this limit on the neutron's electric dipole moment.

Dr. Burtin's team is searching for parity violation in polarized electron-proton scattering at Jefferson Lab; they measure the parity violating longitudinal asymmetry in e-p elastic scattering. Their preliminary result at $\theta = 12^o$ and $q^2 = 0.47$ $(\mathrm{GeV/c})^2$ is:

$$A_{PV} = [-14.7 \pm (1.9)_{stat} \pm (1.1)_{syst}]10^{-6}$$

This rather small error is dominated by the 7% error in the beam polarization; since Jefferson Lab just started operating, this seems an impressive result.

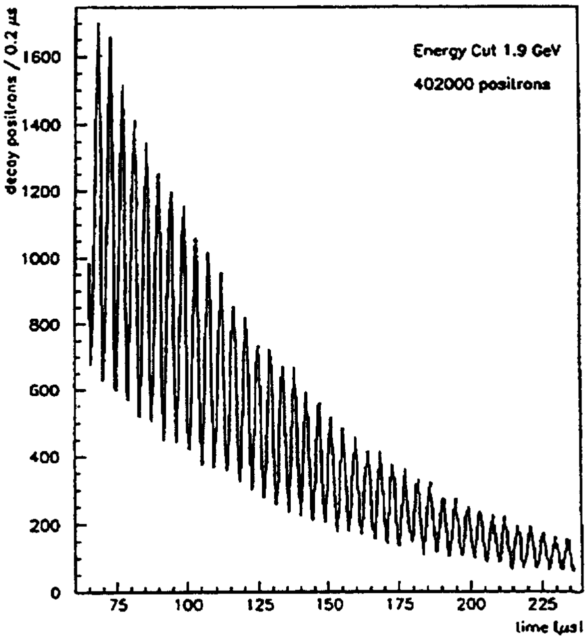


Fig. 24 Muon Decay into Positrons

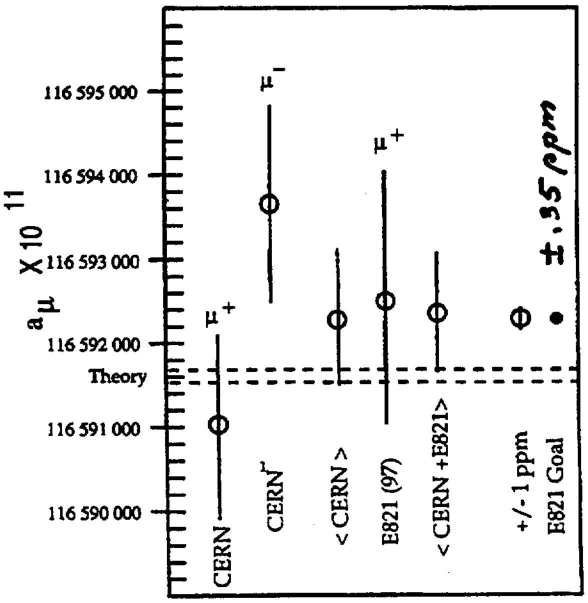


Fig. 25 Muon Magnetic Moment Data

The very interesting Brookhaven muon $g-2$ experiment E-821 was discussed in a parallel session by Professor Orlov; this Symposium was his first visit to Protvino in 24 years. He described the Muon $g-2$ Storage Ring which is now running at Brookhaven. One measures the oscillations in time of the number of muons decaying into positrons, as shown in Fig. 24; the oscillation frequency is related to the muon's magnetic moment. By measuring many oscillations, one can measure g_μ (or a_μ) with great precision. [Different people call the muon's magnetic moment g_μ or a_μ.] The E-821 goal is to measure g_μ to 0.35 parts per million. Fig. 25 shows this goal along with the CERN data and preliminary E-821 data. The combined CERN and E-821 g_μ data disagree with the prediction's dashed band by about 1σ.

6 Hadron Spin Experiments

Dr. Bravar gave a very nice review of this field which is again becoming quite active. He first discussed the history starting with two p-p elastic spin experiments by the Michigan group, which are shown in Fig. 26. The 1978 ZGS experiment on A_{nn} found a totally unexpected large difference between the parallel and anti-parallel cross sections at large $P_\perp^2$. Then the 1985 and 1990 AGS experiments found a large transverse one-spin asymmetry A_n at high $P_\perp^2$, where QCD predicted that A_n should be zero.

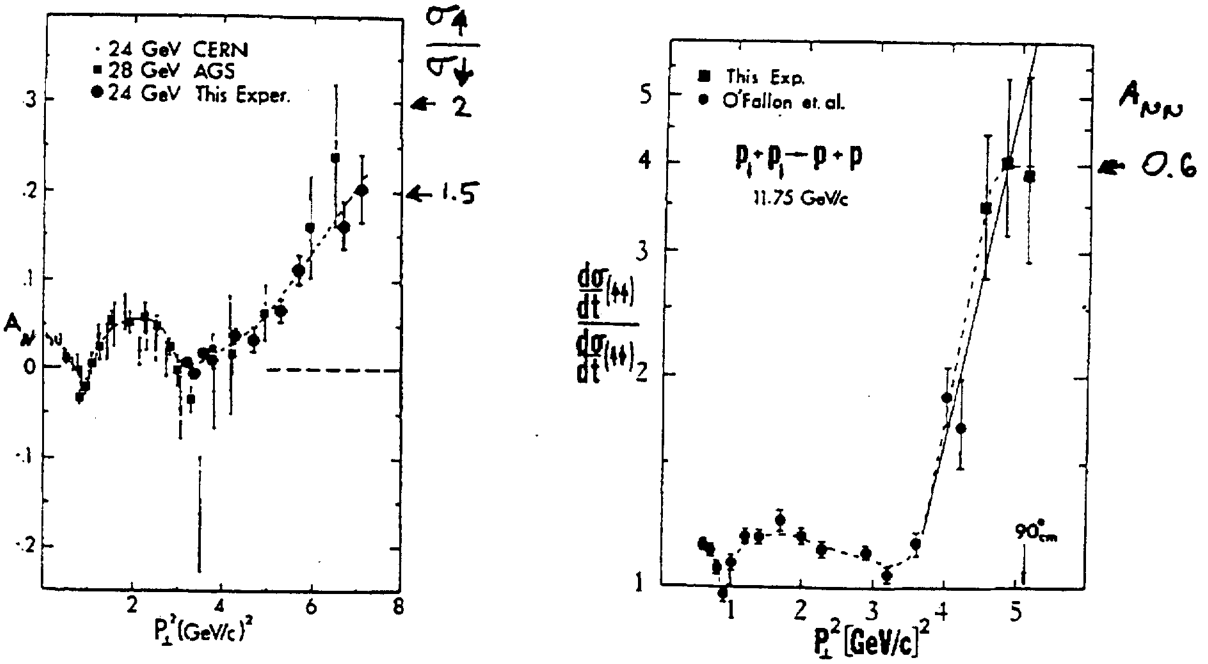
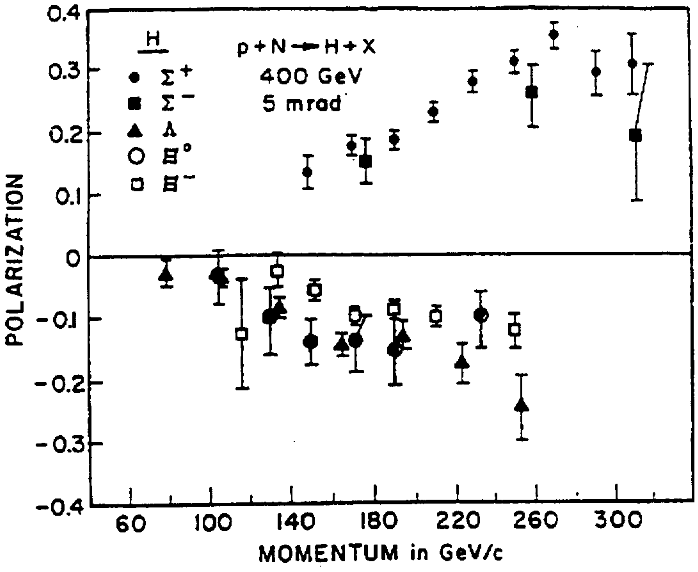


Fig. 26 Proton-proton Elastic Data on A_n (AGS 1985, 1990) and A_{nn} (ZGS 1978)

He also discussed the classic Fermilab hyperon polarization experiments which used self-analyzing hyperon decays to find large transverse polarizations. As shown in Fig. 27, this experiment fixed the angle at 5 mrad and varied the hyperons' momentum; note that their polarizations are maximum near 300 GeV/c, which corresponds to $P_\perp = 1.5$ GeV/c. Note that the polarizations of the Λ, Ξ^0, and Ξ^- are all negative, while the polarizations of the Σ^- and Σ^+ are both positive. It is especially noteworthy, that at large transverse momenta, these hyperons all have large polarizations, but some have positive polarizations while others have negative polarizations. Professor Anderson and his colleagues at Lund developed a model which provides a fairly good explanation of these polarizations in terms of the strange quark's behavior.

Dr. Bravar also discussed some more recent data from E-704 at Fermilab where his group saw large asymmetries in inclusive pion production at 200 GeV. As shown in Fig. 28, the π^0 data has small asymmetries, but the π^+ and

π^- asymmetries are certainly large. Also note that the spin effects are largest at high $P_\perp$ and at high x values.



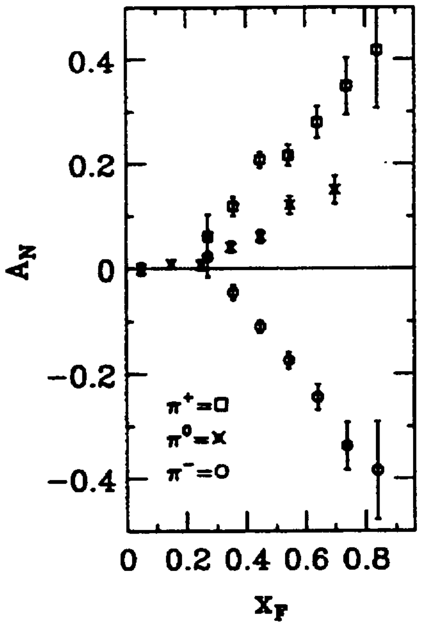
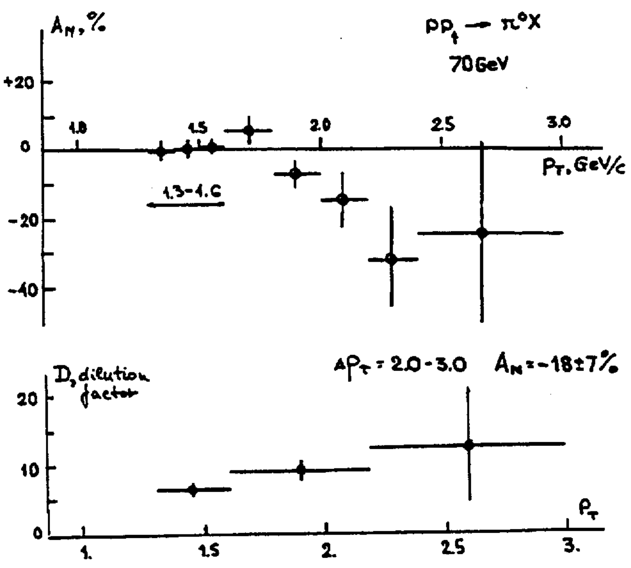


Fig. 27 Inclusive Hyperon Polarization

Fig. 28 Inclusive Pion A_n at 200 GeV

The PROZA experiment at U-70 measured π^0 production asymmetries at 70 GeV as shown in Fig. 29. Notice that A_n is certainly consistent with being different than zero at large $P_\perp$. The experimenters are quite sensible in showing their large dilution factors, since inclusive dilution factors are difficult to measure and can have large errors. With a solid polarized target the inclusive dilution factors are typically more than 10; this causes large errors in A_n .



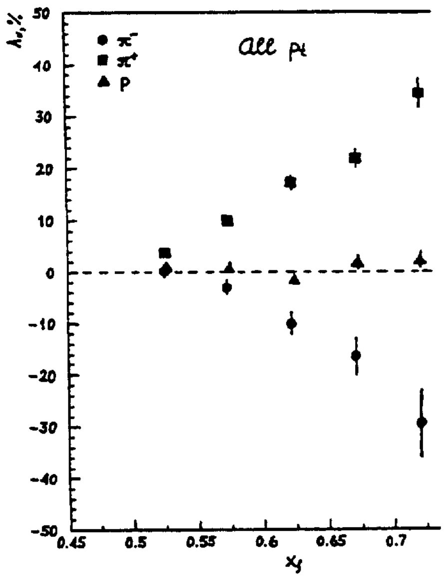


Fig. 29 Inclusive π^0 A_n at 70 GeV

Fig. 30 Inclusive Pion A_n at 24 GeV

There was also some new data from an AGS inclusive experiment in early 1998. The inclusive pion asymmetries with 24 GeV protons are shown in Fig. 30; there are large positive asymmetries for π^+ production, large negative asymmetries for π^- production and about zero asymmetry for inclusive protons. This 24 GeV data is somewhat similar to the E-704 data; this possible similarity may be important in the design of an inclusive polarimeter for RHIC.

In a parallel session, Professor Vigdor showed some data from the now-shut-down Saclay accelerator, which measured the Λ polarization in exclusive Λ production with a 2.85 GeV polarized proton beam. The spin transfer parameter D_{nn} describes the spin transfer from the beam proton to the Λ. As shown in Fig. 31, D_{nn} is very large and changes rapidly as a function of transverse momentum. This new data shows that D_{nn} in this exclusive channel is larger than in inclusive Λ production.

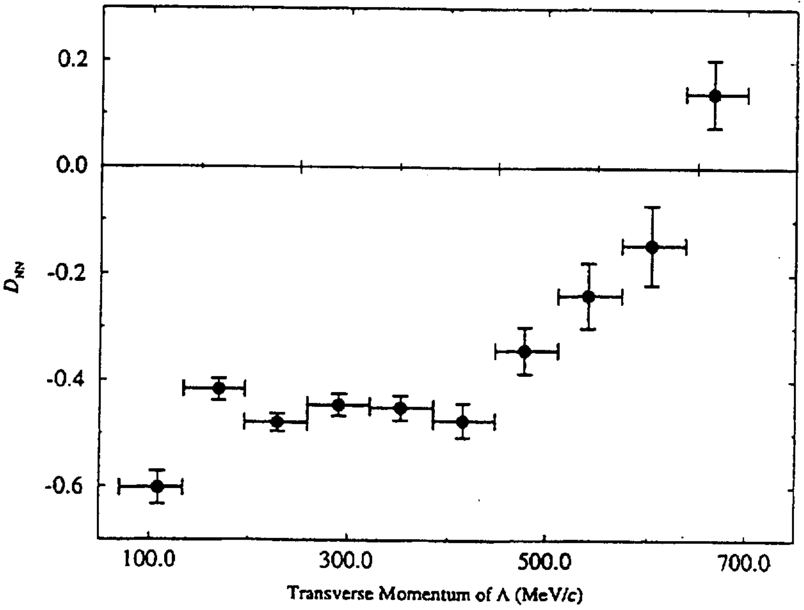


Fig. 31 Exclusive Λ Polarization at 2.85 GeV

The large transverse asymmetries and polarizations observed in the polarized proton-proton elastic and inclusive experiments seem to contradict the QCD inspired belief that there should be no large transverse spin effects at high $P_\perp$. Perhaps this contradiction, along with the missing 2/3 of the nucleon's spin in the polarized electron-nucleon experiments may eventually lead to a better theory of strong interactions.

7 Theory

The theory section contained many interesting talks; I will only be able to briefly review a few of them. Professor Petrov discussed the nucleon "Spin Crisis". He noted there are now three theoretical schools (which he noted sounds like philosophical schools): one school believes that the quark spin is the main contribution to the nucleon spin; the second school believes that it is not the main contribution; and the third school believes that it has nothing to do with the nucleon spin. Professor Efremov also briefly discussed the structure function theories during his review of the Spin '97 Workshop at Dubna, which he helped to organize. His discussion was focused on the nucleon spin problem in which he has made significant contributions. He stressed that the Ellis-Jaffe sum rule is certainly violated while the Bjorken sum rule is not violated.

Professor Cheng talked on the same problem and he asked the question: "What carries the spin of the proton?". It is certainly an important question. An even more fundamental question "What is the spin?" was asked by C.N. Yang at the 1982 SPIN Symposium after the unexpectedly large A_{nn} was found in the ZGS elastic experiment. Both questions have been studied again during the nucleon structure function studies; however, neither question is yet answered.

Two of our organizers, Professors Tyurin and Troshin, discussed in a parallel session how their Unitarity Model is related to nucleon structure functions. As shown in Fig. 32, their predictions seem to be in reasonable agreement with the data. They also made some predictions on the asymmetry of jet production in polarized p-p collisions at RHIC. Some other people have made different predictions. It is certainly interesting that many theorists are making different predictions before RHIC has any data; soon we may see which predictions are correct.

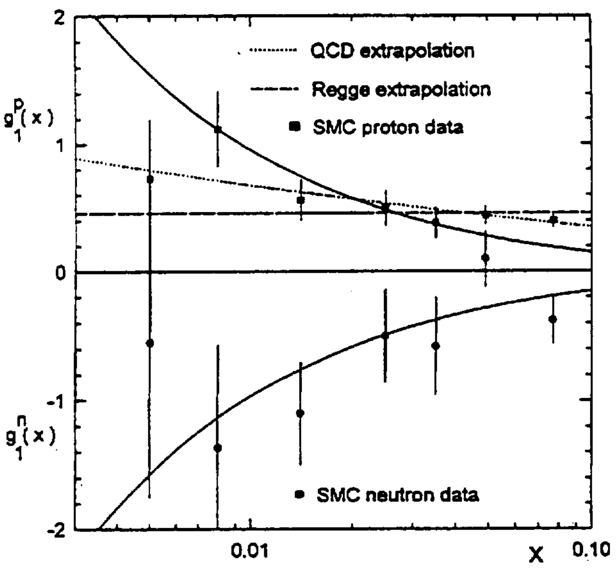


Fig. 32 Unitarity Model Predictions

Professor Ratcliff, who summarized the 1996 Spin Symposium, gave a nice lecture which was partly focused on hard scattering and transverse polarization. In simple QCD the transverse polarization should be zero at high $P_\perp$, but experimentally it is not zero. Apparently with twist 2 there should be no transverse spin effects; however, twist 3 or higher can give significant transverse spin effects. He discussed how the difficult-to-calculate higher twist amplitudes can contribute to the polarization.

L.D. Soloviev, the former Director of IHEP, discussed his new Massive Spinning Quark (MSQ) Model which assumes that the spinning quarks are connected by strings. Using this model he obtained a set of mass values different from those of the Potential Model. The MSQ Model seems in better agreement with the experimental masses of most mesons than the Potential Model. It is certainly not yet clear if this model is correct, but it seems an interesting variation of the Standard Quark Model which seriously includes spin.

8 Future Polarized Beam Facilities

Professor Efremov mentioned that the superconducting Nuclotron at Dubna is now developing a plan to accelerate polarized protons as well as polarized deuterons to 9 GeV; this could provide a unique polarized beam capability.

Professor Ejiri discussed the facilities at RCNP in Osaka. They include the well known 0.4 GeV Cyclotron, which often operates with polarized protons, and the new 8 GeV Laser-Electron-Photon-Laboratory, which should soon produce 3.5 GeV polarized photons, as shown in Fig. 33. He also discussed RCNP's state-of-the-art detectors and polarimeters. We can see these facilities, when RCNP hosts the SPIN 2000 Symposium in October 2000.

Recall the recent beam polarization data from the 3.3 GeV/c COSY ring in Jülich shown in Fig. 6. With Prof. van Oers' help, COSY is organizing a Workshop in November on how to improve their beam polarization and intensity, and to plan their future polarization experiments.

Recall that Dr. Burtin briefly discussed the new Jefferson Lab 4.4 GeV electron accelerator which runs with polarized electrons about half of the time. His very simple overview of Jefferson Lab is shown in Fig. 34; its GaAs polarized electron source was shown in Fig. 13. Jefferson Lab is a major new facility for medium energy electron polarization experiments with several polarized targets.

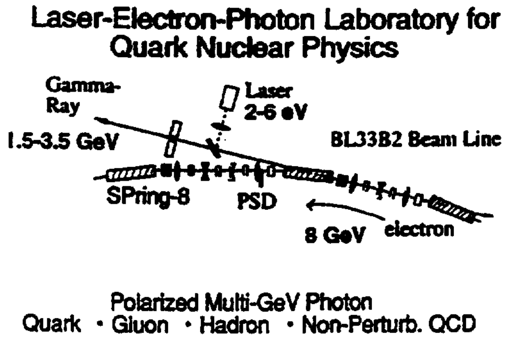


Fig. 33 RCNP LEPL

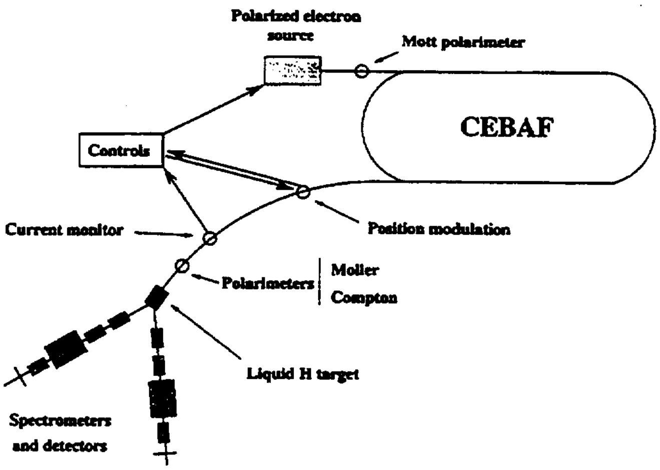


Fig. 34 Jefferson Lab Electron Ring

One of the most interesting new polarized facilities is RHIC, which was shown in Fig. 35 by Dr. Roser. RHIC was built to study Relativistic Heavy Ion Collisions at energies of about 100 GeV/A; it should start running in 1999. Fortunately, RIKEN in Japan has provided about \$20 Million to add 4 Siberian snakes and some other polarization hardware. This should allow RHIC to also study polarized proton collisions at energies up to 250 GeV in each ring starting around 2000; this will be the world's first use of transverse Siberian snakes. The RHIC staff is now fabricating 4 superconducting "helical" transverse snakes, two for each ring. Recall that TRIUMF is upgrading a KEK OPPIS to replace the existing AGS polarized ion source.

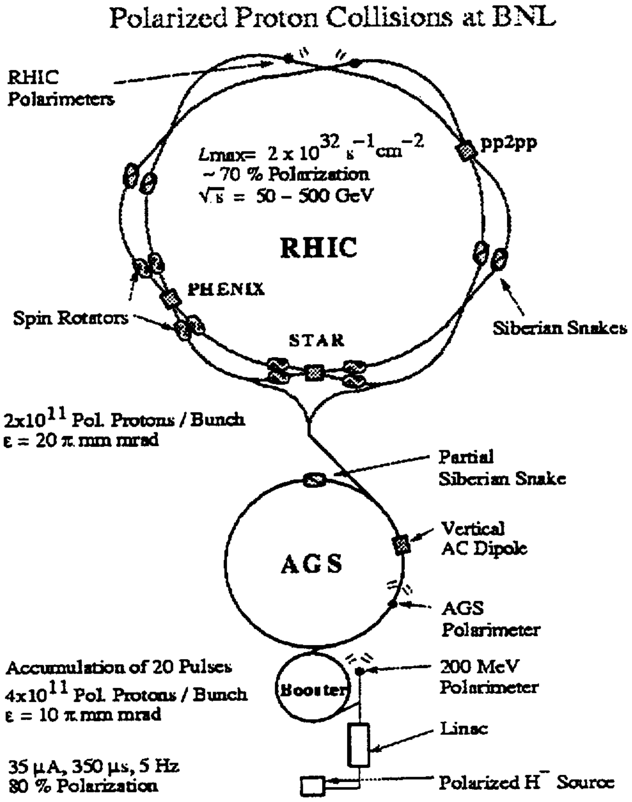


Fig. 35 RHIC with 250 GeV $p_\uparrow$

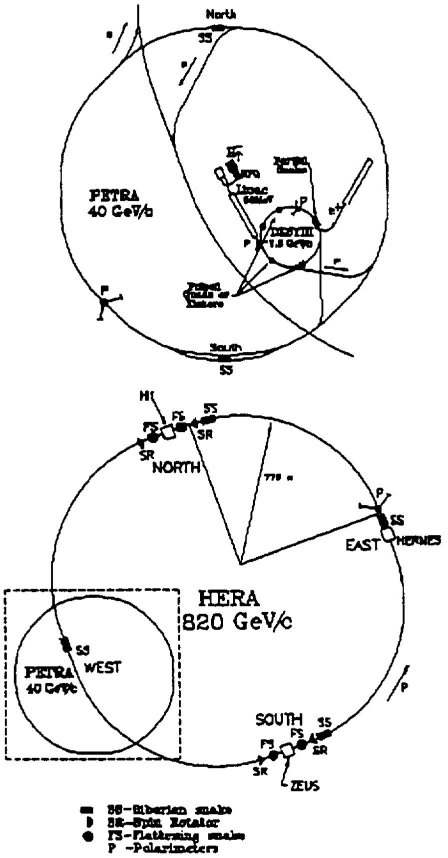


Fig. 36 Polarized Protons at HERA

Professors Penzo and Vigdor discussed the RHIC polarized proton experiments. Most of these spin experiments will occur in RHIC's two large general purpose collider-detectors PHENIX and STAR. The experiments plan to use longitudinally and sometimes transversely polarized protons to study Jet production at high $P_\perp$ and other fundamental processes. There will be spin rotators surrounding each large detector to allow experiments with the spin directions either longitudinal, radial or vertical. Thus, RHIC should have an excellent capability for a wide variety of polarized proton experiments at $\sqrt{s}$ up to 500 GeV, with a planned luminosity of 2 10^{32}cm^{-2}s^{-1}.

Dr. de Roeck discussed the plans to possibly accelerate polarized protons to 820 GeV at HERA for collisions with its already polarized 30 GeV electrons. DESY has hosted a series of Workshops in 1997 to develop and evaluate the physics potential of polarized protons at HERA. With HERA's electrons and protons both polarized, there would be a huge low-x-range increase for the proton structure functions, which have been so actively studied in recent years. He also discussed some experiments at very high q^2. This work will be summarized at a 17-20 May 1999 Workshop in Hamburg.

The Workshop will also include the accelerator physics aspects of accelerating polarized protons at HERA. The DESY Directors have been supporting two efforts to evaluate this challenging acceleration task: the DESY Polarization Team led by Dr. Barber and the SPIN@HERA Collaboration led by Michigan. The DESY Polarization Team has focused on the difficulty of maintaining polarization near 800 GeV where there are some very strong depolarizing resonances. Fortunately HERA has 4 long straight sections where one could easily install 4 Siberian snakes. However, it is not yet clear if 4 snakes would be adequate to overcome HERA's rather strong depolarizing resonances. HERA's planned luminosity upgrade may reduce its emittance and rms orbit distortions enough to weaken all its depolarizing resonances to ε below perhaps 1.2. Then four snakes should be adequate and the DM25 Million polarized proton upgrade could proceed. Otherwise one must install a few extra Siberian snakes in HERA's arcs; the perhaps 2 extra snakes would be inexpensive, but it might be expensive and difficult to change HERA's arcs to make empty spaces for these snakes. This important point is why I earlier stressed Dr. Roser's "naive" limit of $\varepsilon < N/2$.

I will end by discussing some spin projects here at IHEP. The 21 km UNK facility was just moved into a standby status. Therefore, Dr. Solovianov has moved much of the equipment for the large UNK experiment NEPTUN to the nearby 70 GeV U-70 proton accelerator for the recently approved RAMPEX experiment, which will measure inclusive spin effects. RAMPEX has had several engineering runs; the first data run with its frozen spin polarized target should occur early in 1999. The spin parameters A_n and D_{nn} will be measured for $p + p_\uparrow$ and $\pi^- + p_\uparrow$ inclusive production of $\pi^\pm$, $K^\pm$, $p^\pm$, π^0, K_s^0, ϕ and Λ. The spin parameter A_n will also be measured for double inclusive pion production such as

$$p + p_\uparrow \rightarrow \pi^+ + \pi^- + \text{anything}.$$

IHEP-Protvino has been very active in the SPIN Collaboration which has helped to design polarized proton beams for SSC, the Fermilab Main Injector and HERA. The Collaboration may now become active again at Fermilab in a 3-pronged effort:

1. Measure A_n in 120 Gev p-p elastic scattering at $P_\perp^2$ up to 12 $(GeV/c)^2$ using Michigan's solid PPT and the new Main Injector.
2. Possibly measure A_n and A_{nn} in 3 TeV elastic and inclusive p-p collisions with the Ultra-Cold Jet at Fermilab's suggested 3 TeV Booster.
3. Help accelerate 150 GeV polarized protons in the Main Injector and the possible 3 TeV Booster for the suggested 50 TeV - 50 TeV VLHC.

Accelerating polarized protons in the 3 TeV Booster would be much easier than in the Tevatron, because a totally new ring could easily have 10 or 14 empty spaces for Siberian snakes. Installing six snakes in the Tevatron would require creating 6 empty spaces for them by changing the Tevatron lattice.

Finally let me thank Prof. Tyurin and his colleagues for efficiently organizing this Symposium during an exciting week in Russia's history and for giving me the difficult but interesting task of trying to review the status of Spin Physics in 1998. It may be appropriate for an American to end the 13th International Spin Symposium by borrowing, from an earlier talk by the Russian Head of IHEP's Theory Division, a quotation by a famous French Physicist

> "... le spin est certainement un des éléments les plus essentiels,
> *peut-être même le plus essentiel*, de l'existence des particules."
> Louis de Broglie