FUTURE EXPERIMENTS TO STUDY THE INTERNAL SPIN STRUCTURE OF NUCLEONS

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1. Introduction

Our present understanding of the internal spin structure of the nucleon is very incomplete. This has once again been demonstrated at this Spin-Conference by the extensive discussions[1,2] about the many different theoretical approaches to explain the EMC/SLAC results for the spin-dependent structure function g_1^p of the proton[3]:

$$I_1^p = \int_0^1 g_1^p(x)dx = 0.126 \pm 0.010 \pm 0.015$$

and the attempts to answer the question about the origin of the proton spin, i.e. the fractional contributions of quark spins, Δq_f, gluon spins, Δg, and orbital angular momenta, L_z, of quarks and gluons to the angular momentum sum rule

$$\frac{1}{2} = \frac{1}{2}\sum_f \Delta q_f + \Delta g + L_z.$$

Examples for questions being discussed are:

- is the polarised neutron structure function $g_1^n(x)$ large and negative over a large range in x, as one concludes from the EMC/SLAC proton results assuming the validity of the fundamental Bjorken Sum Rule[4]?
- is the singlet axial charge, $\sum_f \Delta q_f$, compatible with zero (0.12± 0.17), as it has been deduced from I_1^p and the Bjorken Sum Rule, using SU(3) flavor symmetry[5]?
- is this equivalent to the statement that the nucleon spin is not due to quark spins?
- is the polarisation of the seaquarks, ΔS, large and negative[5,6]?
- does ΔS just cancel the contribution from the valencequarks ΔV?
- is the gluon polarisation large ($\Delta g \simeq 5$) but compensated by large orbital angular momentum contributions, L_z, of similar magnitude but opposite sign?
- is the nucleon spin mainly due to orbital angular momenta of quarks, $L_z \simeq \frac{1}{2}$?

Note, however, that only the polarised structure function g_1^p of the proton has been measured until now with rather limited statistical and systematic accuracy and that the whole excitement is essentially based on only one number , I_1^p, and the assumption that the Bjorken Sum Rule is satisfied.

For a better understanding of the underlying dynamics much more detailed experimental information is required. Further polarised lepton-nucleon and nucleon-nucleon scattering experiments have to be performed to

- measure the polarised proton structure function $g_1^p(x)$ and its integral I_1^p with much better statistical and systematic accuracy than the previous experiments,
- measure the neutron structure function $g_1^n(x)$ and I_1^n precisely (with either a polarised D or a ^{3}He target),
- test the validity of the Bjorken Sum Rule,
- determine the second polarised structure function $g_2^{p,n}$, which contains further important information since it is sensitive to quark-gluon correlations which appear as twist-3 operators in the operator product expansion[7],
- separate Δg, L_z, ΔS and ΔV and
- measure the additional polarised deuteron structure functions $b_1^d(x)$[8] and $\Delta^d(x)$[9].

2. Proposed new measurements of the spin dependent structure functions

2.1 Kinematics and definitions of variables

The information about the internal spin structure of the nucleons is contained in the structure functions $g_1^{p,n}(x)$ and $g_2^{p,n}(x)$ which can be measured in deep inelastic scattering of longitudinally polarised charged leptons off a polarised proton or neutron target. If one defines α as the angle between the beam momentum vector $\vec{k}$ and the target polarization vector $\vec{P}$ and ϕ as the angle between the polarisation plane formed by $\vec{k}$ and $\vec{P}$ and the lepton scattering plane then the spin-dependent part of the deep inelastic cross section is given by the difference of cross sections for two opposite target polarizations[7]:

$$\frac{d^3(\sigma(\alpha)-\sigma(\alpha+\pi))}{dx\,dy\,d\phi} = \frac{e^4}{4\pi^2 Q^2}\left[\cos\alpha\left(\left[1-\frac{y}{2}-\frac{y^2}{4}\gamma\right]g_1(x,Q^2)-\frac{y}{2}\gamma g_2(x,Q^2)\right)\right.$$
$$\left.-\sin\alpha\cos\phi\sqrt{\gamma(1-y-\frac{y^2}{4}\gamma)}\left(\frac{y}{2}g_1(x,Q^2)+g_2(x,Q^2)\right)\right]$$

The kinematics is described by $\nu = E - E'$, the energy transfer by the virtual photon to the nucleon, and by Q^2, the negative square of the four momentum transfer. $x = Q^2/2M\nu$ and $y = \nu/E$ are the Bjorken scaling variables. E and E' are the energies of the incoming and the scattered lepton and M is the nucleon mass. The quantity γ is defined as $\gamma = \sqrt{Q^2}/\nu$.

Experimentally, the two structure functions $g_1^{p,n}(x,Q^2)$ and $g_2^{p,n}(x,Q^2)$ can be separated by performing two measurements with different orientations α of the target polarisation vector $\vec{P}$, for instance by polarising the target longitudinally ($\alpha = 0$), and measuring the longitudinal asymmetry $A_{\parallel}$ and by polarising the target perpendicular to the beam direction ($\alpha = 90°$), and measuring the transverse asymmetry $A_{\perp}$. In the first case the cross section is dominated by $g_1(x)$, in the second case both polarised structure functions enter with similar weight.

Precise measurements of the polarised structure functions are complicated by the fact that the asymmetries are diluted by several factors:

$$\delta A \simeq (\sqrt{N} \cdot f \cdot D \cdot P^T \cdot P^B)^{-1},$$

where D can be regarded as a depolarisation factor of the virtual photon (which varies between 0.85 at low x and 0.25 at large x), P^T is the target polarisation, P^B is the beam polarisation and f is the fraction of events originating from polarised free nucleons in the target ($f \simeq 3/17$ for NH_3, $f \simeq 10/74$ for butanol but $f = 1.0$ for polarized hydrogen or deuterium gas). For typical values of these quantities (f =0.15, $P^B = P^T$ =0.8, D =0.5) δA is more than 20 times bigger than the expectation from the counting rates N alone. It is evident that the best way to decrease the statistical errors of the asymmetries substantially is to use targets with pure atomic species ($f = 1$ instead of $\simeq 0.15$), while it is much more difficult to increase the luminosity by big factors compared to the previous experiments.

2.2 The four proposed experiments

At present four different polarised lepton nucleon scattering experiments have been proposed which are based on very different and partly innovative technologies and are in many respects complementary. Details of these planned experiments have been presented at this conference in separate contributions[10,11,13,20] and will not be repeated here. Only some relevant aspects will be pointed out.

The SMC collaboration at CERN[10] will use the improved and upgraded EMC/NMC Forward Spectrometer at the polarised muon beam ($\bar{I} = 0.5$ pA, $P^B \simeq 0.8$) and a large polarised target of butanol (f < 0.13, $P^T \approx 0.8$) and deuterated butanol (f < 0.24, $P^T \approx 0.4$). Compared to the EMC target which will be used in the first year of data taking the target will have a 50% larger length ($2 * 60$ cm) and a much better field homogenity ($\pm 10^{-5}$) of the solenoid. The target polarisation will be measured with NMR with an anticipated accuracy of 3%. It is planned to reverse the target spin once every few hours. Most of the time the target will be polarised longitudinally for the measurement of $g_1^{p,n}(x)$. The muon beam polarisation P^B will be measured with an anticipated accuracy of 5% from the spectrum of decay electrons and independently from elastic muon-electron scattering from a magnetized thin iron target. A short run with transverse target polarisation is foreseen to reduce the error arising from the contribution of g_2 to the cross section. The clear advantage of this experiment is that there are only few unknowns, as spectrometer and software chain exist since many years, the target technology is far advanced and well understood and radiative corrections are generally smaller than those for electron scattering experiments. The main disadvantage is the small fraction of polarisable nucleons in the target, the substantial background from additional material (target vessels, ^{3}He/^{4}He bath, rf components etc) and the rather small deuteron polarisation. The experiment has been approved and will start data taking in 1991.

E-142 at SLAC[11] will use the external polarised electron beam from a Ga-As source ($\bar{I} \simeq 10\ \mu A$, $P^B \simeq 0.4$) and a pressurized (10 atm) polarised ^{3}He target ($P^T \approx 0.5$), which to a good approximation is an effective polarised neutron target. The beam polarisation will be reversed on a pulse to pulse basis and will be determined to 5% by Moller-scattering.The target will be a 30 cm long cylindrical glass cell with windows of 0.1 mm thickness. It is based on the technique of ^{3}He polarisation by spin exchange

with a high density laser optically pumped Rb vapor[12]. The scattered electrons will be detected simultaneously by two small solid angle spectrometers under 4.5° (solid angle 0.25 msr) and 7.5° (0.45 msr). Only $g_1(x)$ for the neutron will be measured apart from a short run with transverse target polarisation to reduce the error due to g_2. The advantage of the ^{3}He target is that $A_1^n(x)$ and $g_1^n(x)$ can be obtained directly without the subtraction needed in the case of deuterium and hydrogen. A disadvantage of the high pressure target is the extra target material (glass windows, rubidium vapor, nitrogen admixture) seen by the beam which will cause substantial electromagnetic background. The dilution factor is no longer $f \approx 1/3$ as for a pure ^{3}He target but it becomes $f \simeq 1/(3.86\sigma^p/\sigma^n + 2.860)$ which is even worse than in the case of solid polarised targets. Nevertheless high statistical precision for $g_1^n(x)$ can be obtained in very short running time. Also this experiment has been approved and will presumably start data taking 1992.

The idea of the HERMES experiment at DESY[13] is to use a polarised internal gas target of hydrogen ($f = 1$, $P^T \approx 0.8$), deuterium ($f = 1$, $P^T \approx 0.8$) and ^{3}He ($f = 1/3$, $P^T \approx 0.5$) with the high current ($I_{max} = 60$ mA) longitudinally polarised beam of the HERA electron storage ring. The target is a thin-walled windowless storage cell which is fed by a high intensity source of polarised atoms[14]. By this technique, which has already been proposed ten years ago[15] and has been tested successfully at the VEPP-3 electron storage ring[16] target densities can be achieved which are about two orders of magnitude higher than for a polarised jet target. The target polarisation will be reversed every few seconds. P^T will be measured by RF-spectroscopy with an accuracy of 3%, P^T by Compton backscattering of polarised laser light to 2-3%. The main advantage is that scattering occurs only from polarised atoms and that high statistical and systematic precision can be obtained in short running times. HERMES has the most complete programme of the proposed experiments. For each target species measurements with both longitudinal and transverse targetpolarisation are foreseen which will allow to measure g_1^p, g_1^n, g_2^p, g_2^n, b_1^d, Δ^d and their integrals. The scattered electrons will be detected in a large solid angle Forward Spectrometer. It is very difficult to predict[17] the amount of longitudinal polarisation which can be achieved via the Sokolov-Ternov effect[18] in large storage rings. Polarisation has, however, been observed experimentally at TRISTAN and LEP[19]. Therefore there is good hope that longitudinal polarisation can be achieved at HERA in the near future. HERMES has been approved under the condition that first transverse polarisation of the HERA electron beam has to be demonstrated experimentally, it will start data taking earliest in 1993.

The basic concept of the HELP proposal[20] is very similar to the HERMES proposal as it wants to use the longitudinally polarised circulating 45 GeV electron beam in LEP, an internal polarised jet gas target and a large solid angle Forward Spectrometer. The clear advantage of the jet target is that possible problems connected with the storage cell (like depolarisation of atoms by wall collisions and by the magnetic field of the electron bunches, scattering of synchrotron light from the target cell walls etc) are avoided. No tracking chambers in front of the spectrometer magnet (which in the HERMES case have to stand large background from Moller electrons and scattered synchrotron light) are needed as the target is nearly pointlike. Therefore this is in principle the ideal technique. The luminosity, however, will be smaller by orders of magnitude, since the beam current in LEP is only 3 mA compared to 60 mA at HERA and the (very optimistic) projection

for the thickness of the polarized hydrogen or deuterium jet target is 10^{13} atoms/cm^2 compared to 10^{14} atoms/cm^2 of HERMES. Therefore very long running times would be required to achieve reasonable statistical accuracy even if the beam intensity could be increased by filling more bunches into the LEP ring. The degree of longitudinal polarisation which could be achieved at LEP is similar uncertain as in the HERA case. A written proposal is in preparation. The timescale of a the experiment is still unclear as it will depend very much on the priorities (high luminosity, high energy, high polarisation) which will be defined for the future LEP programme.

2.3 Comparison of the experiments

The main parameters of the four experiments are compared in table 1. The 'Figure of Merit', which is relevant for the statistical precision achievable by the experiments, is defined as

$$FM = I^B \cdot T \cdot (P^B \cdot P^T \cdot f)^2$$

It should be noted that a direct comparison of the Figure of Merit for the deuterium and ^{3}He targets is misleading. While A_1^n can be determined directly from the ^{3}He data, a subtraction of the deuterium and proton data is required in the case of the other targets. In this case the error for the neutron asymmetry is given by $\delta A_1^2 = (1+\sigma^p/\sigma^n)^2 \delta A_1(D)^2 + (\sigma^p/\sigma^n)^2 \delta A_1(H)^2$ and the effective figure of merit for the neutron measurement is more than a factor of 5 worse than for the deuteron alone.

Table 1. The main parameters of the four proposed experiments

Proposal	Beam	P^B	E^B (GeV)	I^B (part./s)	Target	P^T	f	T (cm^{-2})	FM
SMC (CERN)	$\vec{\mu}$	0.8	120	$3.1 \cdot 10^6$	C_4H_9OH	0.8	<0.13	$4.2 \cdot 10^{25}$	1.0
					C_4D_9OD	0.4	<0.24	$4.8 \cdot 10^{25}$	1.0
HERMES (DESY)	$\vec{e}$ (HERA)	>0.5?	35	$3.6 \cdot 10^{17}$	H	0.8	1	$1.0 \cdot 10^{14}$	6.4
					D	0.8	1	$2.0 \cdot 10^{14}$	13.0
					^{3}He open cell	0.5	<0.33	$9.0 \cdot 10^{14}$	2.5*
E142 (SLAC)	$\vec{e}$ (GaAs)	0.4	22.7	$6.0 \cdot 10^{13}$	^{3}He closed cell	0.5	<0.14	$3.6 \cdot 10^{22}$	19.2* (0.14)†
HELP (CERN)	$\vec{e}$ (LEP)	>0.5?	45	$1.9 \cdot 10^{16}$	H	0.95	1	$1.0 \cdot 10^{13}$	0.047
					D jet	0.95	1	$2.0 \cdot 10^{13}$	0.094

* should be increased by a factor of ≈ 5 in comparison to D for the measurement of neutron asymmetries.

† including solid angles of spectrometers

The kinematic range covered by SMC, HERMES and E-142 is compared in fig. 1. Both SMC and HERMES cover a large kinematic range and overlap in most of it. For HERMES the x range extends down to 0.02, for SMC down to 0.01 for standard data

taking with 120 GeV. If part of the data will be taken with a beam energy of 200 GeV and a special small angle trigger will be used, it will possibly be extended down to x = 0.005. Due to the higher beam energy the mean Q^2 of SMC is about a factor of 2.5 higher than for HERMES. The E-142 spectrometers have only a small solid angle and consequently the accessible kinematic range is very limited.

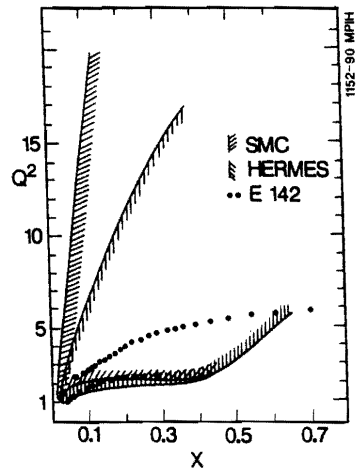


Fig. 1. The x,Q^2 range covered by SMC, HERMES and E-142.

2.4 Anticipated accuracies

SMC has requested 220 days of beam time with a muon energy of 120 GeV with a division of the beam flux in ratio 2/1 between deuterium and hydrogen targets. With the expected statistics collected during this time the following statistical accuracies could be achieved:

$$\delta A_1^p(SMC) \simeq 0.5 \cdot \delta A_1^p(EMC), \qquad \delta A_1^n(SMC) \geq \delta A_1^p(EMC).$$

HERMES intends to run 600 hrs (100 % efficient) with a mean beam current of $\bar{I} \approx 40$ mA for each of the six planned measurements (longitudinal and vertical polarisation; H,D and ^{3}He target). Realistically this corresponds to about 50 days of data taking for each measurement. (This will only be possible if HERMES can take data during normal e-p running. If high electron polarisation can not be achieved together with high proton beam intensity and dedicated running would be required, part of the programme would have to be reduced). The statistical errors for $g_1^{p,n}$ will be about a factor of three smaller than those anticipated for SMC. E-142 will be able to map out the x dependence of g_1^n between x = 0.04 and 0.6 with roughly the same precision as HERMES but 2-3 times more data points.

Fig. 2 shows the anticipated statistical accuracy of $g_1^n(x)$ for HERMES, SMC and E-142. The shape of g_1^n (full curve) has been chosen under the assumption that the EMC/SLAC result for the proton is correct and the Bjorken Sum Rule is fulfilled. Of course many different other shapes leading to the same I_1^n are possible. The error bars for HERMES and E-142 are so small that the x dependence of $g_1^n(x)$, which is essential for constraining theoretical models better, will be well defined even if I_1^n would be substantially smaller than presently estimated (for instance as indicated by the dashed

curve) and it will also allow to determine the integral I_1^n and the Bjorken Sum rule rather precisely. The error bars for SMC will be by about a factor of three larger than those for the other two experiments and a statistically significant measurement will only be possible if I_1^n will not be much smaller than assumed for this figure. The data will extend down to lower x ($x \approx 0.005$) than for the other two experiments. Note, however, that the errors of the low x points are dominated by the statistical errors, as it is shown for the HERMES points, and that the impact of the additional low x points will be marginal as the statistical error bars increase proportional to 1/x: $(\delta g(x) \sim \delta A(x) * F_2(x)/2x)$.

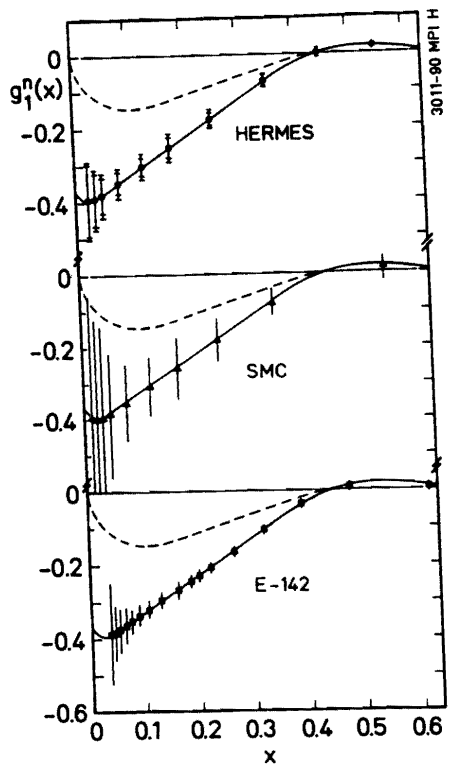


Fig. 2 Projected accuracy for a measurement of $g_1^n(x)$ by HERMES, SMC and E-142

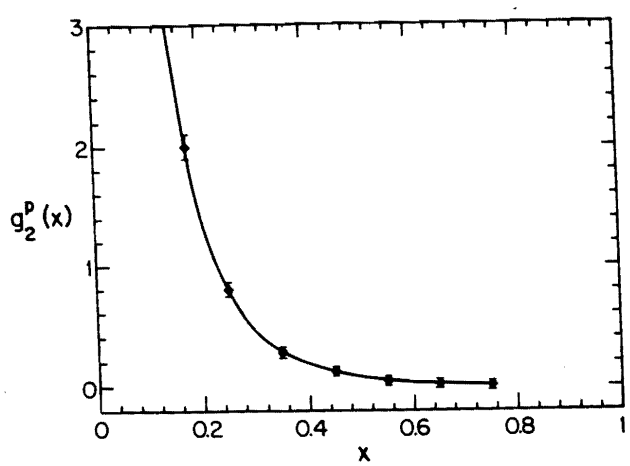


Fig. 3 Projected accuracy for a measurement of $g_2^p(x)$ by HERMES

In fig. 3 the statistical uncertainties are shown for the extracted $g_2^p(x)$ assuming a 600 hours measurement of HERMES for each of the longitudinal and transverse asymmetries for a hydrogen target. The line indicates the positivity limit for $A_2 = \sqrt{R}$. It is obvious that such a measurement will largely reduce the uncertainty in the determination of $g_1^p(x)$ which otherwise would be proportional to the difference between $g_2(x) = 0$ and the positivity limit. The data will constrain the x-dependence of $g_2(x)$ rather well and therefore allow a determination of a quark-gluon correlation function in the nucleon[7].

Table 2 shows the statistical and systematic precision of the Sum Rules which can be extracted from the errors of the structure functions $g_1^p(x)$ and $g_1^n(x)$. The absolute values of the integrals are derived from the EMC/SLAC proton result and from the Bjorken Sum Rule, the percentual errors will of course change according to the values

measured in future experiments. It should be noted that the values given in this table differ partly from those quoted in the different proposals which contain several numerical errors.

Table 2. Anticipated accuracies of the Sum Rules

Integral	Value	Target	Errors(%) HERMES stat.	HERMES sys.	SMC stat.	SMC sys.	E-142 stat.	E-142 sys.
I_1^p	0.126	H	2.3	5.2	5.3	8.2 (6.8)		
I_1^d	0.061	D	6.6	5.2	17.4	12.8 (8.5)		
I_1^n	-0.065	D - H	7.6	11.2	19.2	20.0 (15.5)		
		^{3}He	7.3	7.8			6.5	15 ± 20
$I_1^p - I_1^n$	0.191	2H - D	3.7	7.1	9.0	11.6 (9.6)		
		^{3}He	2.9	4.3				

For the calculation of the systematic errors HERMES has assumed that $\delta P^B/P^B = \pm 2.5\%$, $\delta P^T/P^T = \delta F_2/F_2 = \pm 3\%$, while SMC has assumed $\delta P^B/P^B = \delta F_2/F_2 = \pm 5\%, \delta P^T/P^T = \pm 3\%$ and that the error due to the neglect of A_2 is given by $A_2 \leq \sqrt{R}$. For better comparison to HERMES the values in brackets give the total systematic error under the assumption $\delta F_2/F_2 = \pm 3\%$ and that an exploratory measurement with transverse polarisation reduces the error due to A_2 to half of the above value.

The errors for HERMES are substantially smaller than for SMC , the statistical errors will be small enough to split the data into subsamples for detailed studies of the systematic errors. The Bjorken Sum Rule can be tested with an accuracy of 5-8%.

E-142 will only measure $g_1^n(x)$ and I_1^n and has to rely on the proton results from other experiments for a test of the Bjorken Sum Rule. The systematic error for I_1^n is dominated by the uncertainty in $P^T(5\%)$, $P^B(5\%)$ and the dilution factor f (4%). In addition a theoretical systematic error of 20% has been assumed to take into account unknown nuclear effects in deducing the polarised neutron structure function from ^{3}He.

3. Additional experimental information

Several reactions and channels in polarised lepton-nucleon and nucleon-nucleon scattering (production of open and closed charm[21], single and double jets with large p_t[22], direct photons[23], Drell-Yan events[24] etc) have been proposed and discussed in the literature[25], which in principle could allow to separate the individual contributions to the angular momentum sum rule. Unfortunately, however, the cross sections for most reactions are small and the errors in the asymmetries will be large due to the dilution factors. Furthermore it is unlikely that experiments with polarised proton beams of high energy and polarised proton or deuterium targets will in the near future have sufficient luminosity to study the proposed channels with reasonable sensitivity.

Only few more or less promising reactions are left which possibly could add information to those obtained from the measurement of polarised structure functions.

3.1 Individual polarised quark distributions.

The individual polarised valence and seaquark distributions, ΔV and ΔS, could be deduced from asymmétries in the multiplicities of the difference and the sum of π^+ and π^- produced from proton and deuterium targets in polarised lepton nucleon scattering.[26] Particle identification is not possible for SMC with the present setup and hadron distributions would have to be corrected for proton and kaon contaminations. The HERMES collaboration is investigating the possibility to add Cerenkov counters to the present spectrometer design. This would allow pion, kaon and proton identification and the determination of the polarised strange quark distribution from the yield of kaon production. Such measurements would be very important to clarify the question whether the valence quark spins add up to the value expected in the nonrelativistic quark model and are just compensated by a seaquark polarisation of equal magnitude but opposite sign.

3.2 Orbital angular momentum contributions

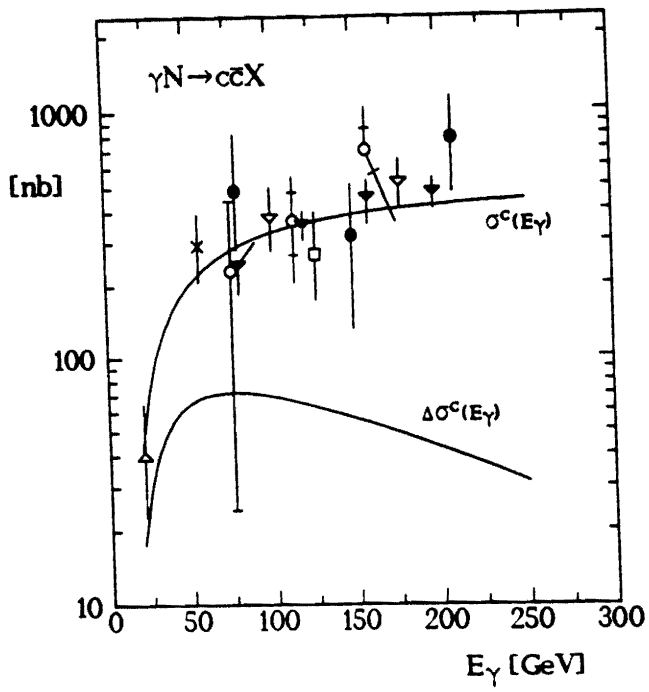
The question whether at least part of the nucleon spin can be attributed to orbital motion of its constituents has been discussed in detail by several authors[27]. Meng et al.[28] argued that such orbital angular momentum contributions should manifest themselves in the Φ distributions of hadrons produced in deep inelastic scattering of unpolarised electrons or muons on a transversally polarised target. The hadrons should be produced preferentially in the plane perpendicular to the polarisation plane if the constituents of the nucleon are performing an ordered - in addition to or instead of the random - motion.

Such an effect could be easily visible in the SMC experiment which, however, has not yet planned a sufficiently long run with transverse target polarisation. As no beam polarisation is necessary for these measurements, HERMES could take a lot of data for such an investigation during normal HERA e-p running. The analysis will, however, be complicated due to the intrinsic Φ asymmetry of the spectrometer.

3.3 Δg from J/Ψ Production

Several people have argued that the gluon polarisation Δg can be determined from the cross section asymmetry in polarized leptoproduction of J/Ψ's[21]. The main problem is, however, that Δg gets most of its contribution from $x < 0.01$[29], which is hardly accessible with present beam energies. It also turns out that due to the small cross sections and the dilution factors the required accuracy can not be achieved with the luminosities of the experiments proposed until now.

The cross section for photoproduction of charm and the difference $\Delta\sigma^c$ for polarised charm production[30] is shown in fig. 4 as a function of the incident photon energy, E_γ. Fig. 5 shows the expected asymmetry as a function of E_γ calculated[30] for $\Delta g \approx 5$. The cross section for charged lepton production of J/Ψ is further down by three orders of magnitude. Typical approximate values are 40 pb at 35 GeV, 320 pb at 120 GeV and 600 pb at 200 GeV.



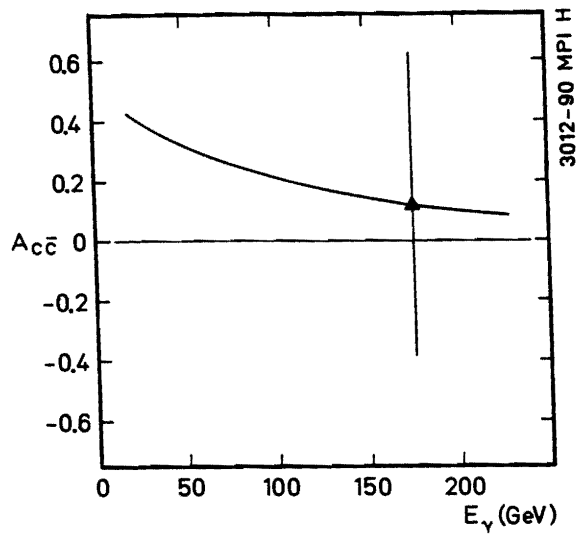


Fig. 4 Cross section for charm photoproduction

Fig. 5 Prediction[30] for $A_{c\bar{c}}$ and expected accuracy from SMC

J/Ψ events can be detected in the SMC experiment via their two muon decay (branching ratio 7%). If the SMC experiment would use all the requested beam time of 220 days to run at 200 GeV then with a total luminosity of $L = 10^{39} cm^{-2}$ about 4200 Ψ's would be accepted by the spectrometer. In the framework of the photon gluon fusion model [31] only the inelastic events can be used to extract the gluon distribution. From the experience of the recent analysis of J/Ψ production by the NMC [32] these are about 38% of the total sample. Taking into account the dilution factors these events correspond toa statistical accuracy for the asymmetry

$$\delta A_\Psi = (\sqrt{N^\Psi_{inel.}} \cdot f \cdot D \cdot p^T \cdot p^B)^{-1} \cong 0.50,$$

which is about five times bigger than the maximal expected asymmetry at $E_\gamma \approx 170$ GeV as one can see from figure 5.

In reality the situation will be even worse since SMC is planning to run most of the time at 120 GeV where the cross section is further down by a factor of two and the spectrometer acceptance for three muon events is essentially zero.

The HERMES experiment has little chance to determine Δg better because of the small cross section at 35 GeV.

Also the investigation of high p_t jets in leptoproduction is not very promising. Detailed studies[30] show that sizeable effects can only be expected for $x < 0.01$. To get rid of nonperturbative effects p_t values of at least 2-2.5 (GeV/c) are required. Measurements of the EMC have shown that at a beam energy of 120 GeV only very few events with a single hadron of such a high p_t value will be accepted.

Therefore polarised lepton scattering experiments can probably little contribute to solve the question of the magnitude of gluon polarisation.

3.4 Δg from $\chi_2(3555)$ hadroproduction

There is general agreement that the $\chi_2(3555)$ state, which has spin 2, is mainly produced by gluon-gluon fusion and that the production cross section in nucleon-nucleon scattering is proportional to the product of gluon distributions in the beam and target nucleons. Therefore the measurement of the two-spin asymmetry A_{LL} for χ_2 production in polarised nucleon-nucleon scattering[33], which is proportional to $\delta g(x_1)*\delta g(x_2)$, should allow the determination of Δg.

Such an experiment has been proposed by the E-704 collaboration at FNAL[35]. As very high beam energy is not required for this reaction, the experiment could be performed with the available polarised proton beam energy of 200 GeV. The sensitive x region for the determination of Δg would be $x_{gluon} = 0.1 \rightarrow 0.3$. The χ_2 would be detected by the decay $\chi_2 \rightarrow J/\Psi + e^+e^- \rightarrow e^+e^- + \gamma$ with a Pb-glass and CsI calorimeter. Within 2500 hours of beam time 15.000 χ_2 events should be recorded. This would correspond to an error in A_{LL} of 5% and should provide Δg (in this x-region) accurate enough to judge whether it is strong, medium or small.

3.5 Δg from direct photons

The same group has proposed[34] to measure Δg via direct photon production[23]. These measurements, however, need a high beam energy of > 500 GeV, as high p_t is required for a reliable determination of the gluon distribution. The group has proposed to upgrade the polarised proton beam at FNAL to this energy (this will probably not be possible before 1995). Depending on the design of the beam line the flux could be $8*10^7 p^{\uparrow}$/spill (per $4*10^{12}$ incident protons), with a beam polarisation $P^B = 0.45 \rightarrow 0.63$. The 20 cm long target would be polarised ^{6}LiD ($f \approx 0.5, P^D \approx 0.7$). Fig. 6 shows the anticipated accuracy for A_{LL}, which could be obtained by a 4.000 hours measurement.

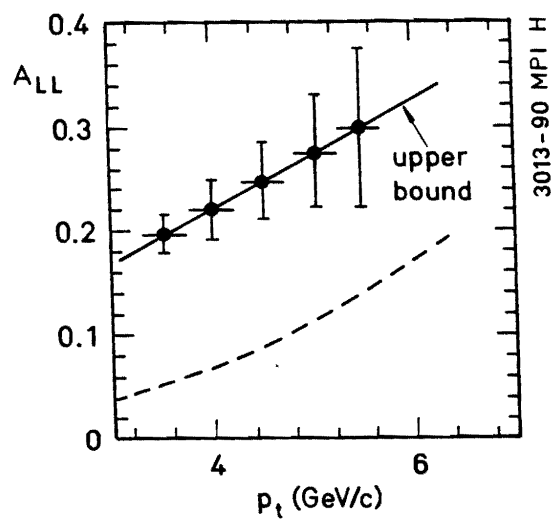


Fig. 6 Anticipated accuracy for A_{LL} in direct γ production[35]

The full curve[36] is the theoretical upper bound for $\Delta g \approx 5$. The main disadvantage of this experiment is the relatively low and limited p_t-range. As only the direct photon will be measured without the recoil jet in coincidence, each p_t bin is fed by a wide range of x_{gluon}. $p_t = 3.5 \rightarrow 5.5$ corresponds to $x_{gluon} = 0.25 \rightarrow 0.4$. As the biggest contribution to Δg is expected from $x < 0.01$[29], only a small fraction might be left in this x-range, which would be difficult to detect. I agree with the argument stated in this proposal: "The essential motivation is to explore the unknown rather than to test a specific theoretical prediction", and believe that these experiments should be performed, as already experimental limits would help to clarify the question about the magnitude and sign of the polarised gluon distribution.

4. Conclusions

The proposed experiments use very different and partly innovative technology and are in many aspects complementary. In a few years from now they hopefully will provide us with detailed informations about the different spin structure functions and will help to substantially improve our understanding of the internal structure of the nucleon.

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