Workshop on Testing QCD Through Spin Observables in Nuclear Targets

April 18, 19 & 20, 2002, Charlottesville, VA

Sponsored by Jefferson Lab, the International Spin Physics Committee and the Institute of Nuclear and Particle Physics at the University of Virginia

Program
Testing QCD Through Spin Observables In Nuclear Targets

April 17, 2002 - Wednesday
Location: Zehmer Hall

1800 – 2000 *Reception*

April 18, 2002 - Thursday
Plenary Session - Morning Schedule

Chair: D. Crabb

0800 – 0845	***Coffee / Registration***	
0845 – 0900	Welcome	R. Sundberg – Associate Dean UVA
0900 – 0910	Welcome	G. Cates – UVA
0915 – 1000	Introduction	X. Ji – Maryland
1000 – 1045	Quark Orbital Angular Momentum in Inclusive and Exclusive Scattering	J. Ralston – Kansas
1045 – 1115	***Coffee Break***	

Chair: X. Song

1115 – 1200	Spin Physics at RHIC (experimental)	M. Perdekamp – BNL-Riken
1200 – 1245	Nucleon Form Factors using Spin Degrees of Freedom	M. Jones – Jefferson Lab
1245 – 1400	***Lunch Break***	

New Initiatives - Afternoon Schedule

Chair: D. Day

1400 – 1440	Overview of Spin Physics in BLAST	J. Calarco – UNH
1440 – 1505	MAD Spin Physics – its it crazy?	A. Saha – Jefferson Lab
1505 – 1530	Measurement of the Proton Form Factors in BLAST	J. Seely – MIT
1540 – 1600	***Coffee Break***	

Chair: G. Warren

1600 – 1630	Pion Electroproduction in Deep Inelastic Scattering at Jefferson Lab	H. Avagyan – Jefferson Lab
1630 – 1650	A New Experiment to Measure G_e^N at High Momentum Transfer	K. McCormick – Jefferson Lab
1650 – 1705	A Proposed Measurement of the Neutron d_2^n Matrix Element	X. Jiang – Rutgers University
1705 – 1735	Jefferson Lab 12 GeV Spin Program	N. Liyanage – UVA

Polarized Beams and Targets - Afternoon Schedule

Chair: D. Crabb

1400 – 1430	Status of Polarized ^{3}He targets	T. Averett – W & M
1430 – 1500	New Results with Polarized Solid Deuteron Target	W. Meyer – Bochum
1500 – 1520	Nuclear Targets and Sources	B. Clasie – MIT
1520 – 1540	Effective nucleon polarization in polarized targets	O. Rondon – UVA
1540 – 1600	***Coffee Break***	

Chair: G. Cates

1600 – 1635	Review of polarized, internal deuteron targets	B. von Przewoski – IUCF
1635 – 1650	Application of sol-gel coatings to high pressure polarized ^{3}He nuclear targets	A. Tobias – UVA
1650 – 1720	Status and prospects for Polarized D with the Sphice HD Target System	M. Lowry – BNL

1830 – 2130 Banquet at UVA Bayly Art Museum

April 19, 2002 – Friday

Plenary Session – Morning Schedule

Chair: W. Melnitchouk

0900 – 0945	Spin Structure Functions in Chiral Quark-Soliton Modeks	H. Weigel – Tuebingen
0945 – 1030	Experimental Aspects of Gluon Contributions to Spin Structure Functions	P. Bosted – Massachusetts
1030 – 1115	***Coffee Break***	

Chair: H. Weber

1115 – 1200	QCD Aspects; Twist 3 Extraction, Quark Spin Rotation in DVCS	A. Belitsky – Maryland
1200 – 1245	Spin Physics at RHIC (Theoretical)	M. Stratmann – Regensburg
1245 – 1400	***Lunch Break***	

Inclusive, Exclusive and Semi-inclusive Asymmetries – Afternoon Schedule

Chair: O. Rondon

1400 – 1430	Azimuthal asymmetries in semi-inclusive DIS: Are they interrelated?	K. Oganessian – INFN, DESY
1430 – 1500	Where is the Nucleon Spin? The Spin Structure of the Nucleon After a Decade of Measurements	J. Lichtenstadt – Tel Aviv
1500 – 1515	Status of the RSS experiment on the deuteron	P. McKee – UVA
1515 – 1540	Experimental program at HIGS	B. Norum – UVA
1540 – 1600	***Coffee Break***	

Chair: J. Ralston

1600 – 1630	Spin structure Functions of the Deuteron in CLAS	S. Kuhn – ODU
1630 – 1650	Recent Measurements of Longitudinal and Transverse Unpolarized Structure Functions, and Their Impact on Spin Asymmetry Measurements	E. Christy – Hampton

---

Spin in Few Body Systems – Afternoon Schedule

Chair: J.P. Chen

1400 – 1430	Spin Physics with ^{3}He	W. Korsch – Kentucky
1430 – 1450	Precision measurement of A_1^n at high x with ^{3}He	X. Zheng – MIT
1450 – 1510	Precision g_2^n measurement with ^{3}He	K. Kramer – W&M
1510 – 1535	Spin structure functions of the proton and deuteron from SLAC experiments E155 and E155x	P. King - Maryland
1540 – 1600	***Coffee Break***	

Chair: P. Bosted

1600 – 1640	Deep Inelastic Scattering from Few Body Nuclei	W. Melnitchouk- JLAB
1640 – 1700	Complete Analysis of Spin Structure Function g_1 of ^{3}He	F. Bissey – Adelaide
1700 – 1730	Recent Results on the Helicity Structure of the Nucleon from Hermes	M. Beckmann – DESY

April 20, 2002 – Saturday

Plenary Session – Morning Schedule

Chair: TBA

0900 – 0945	Overview of Experiments using Polarized ^{3}He and Deuteron Targets	Z. Meziani – Temple
0945 – 1030	Spin Structure Functions from SLAC Experiments E142 and E154	G. Cates – Virginia
1030 – 1115	***Coffee Break***	

Chair: S. Liuti

1115 – 1200	Probing Short Range Dynamics in Exclusive Scattering	M. Sargsian – FIU
1200 – 1245	Theoretical Aspects of Transversity	S. Drago – Ferrara
1245 – 1330	***Lunch Break***	

Plenary Session – Afternoon Schedule

Chair: P. Kabir

1330 – 1415	Workshop Summary (Experimental)	A. Deshpande – BNL-Riken
1415 – 1500	Workshop Summary (Theoretical)	M. Strikman – Penn State

INTRODUCTION TO HIGH-ENERGY SPIN PHYSICS

XIANGDONG JI
Department of Physics
University of Maryland
College Park, Maryland 20742

High-energy spin physics has emerged as an important subfield of hadron physics since the EMC measurement of the quark spin contribution to the spin of the nucleon fifteen years ago. In this introductory talk, I discuss a few topics of recent interest: polarized gluon distribution, generalized parton distributions and deep-virtual Compton scattering, and transversity distribution.

Let me start by thanking the colleagues at UVa for organizing this wonderful workshop. The experimentalists at the Institute of Nuclear and Particle Physics here have made impressive contributions to the field of high-energy spin physics in the last decade. They played a significant role in a series of SLAC experiments which have laid the foundation for our understanding of the spin structure of the nucleon today.

This is supposed to be an introductory talk. However, it would be impossible for me to cover all of the many interesting subjects which will be discussed in the course of the workshop. Instead, I will focus on a few topics in high-energy spin physics which I have personally involved with. The outline of the presentation is as follows: I start with a big question and discuss the lesson we learn from the EMC measurements. Following this, I introduce the gluon helicity distribution and discuss its measurements in the near future. A major part of my talk will be devoted to the spin structure of the nucleon and related topics such as generalized parton distributions and deep exclusive processes such as deeply-virtual Compton scattering (DVCS). Towards the end of my talk, I briefly review the current understanding about the transversity distribution.

One of the most important and difficult questions in modern physics is how the nucleon (or hadronic matter) is made of quarks and gluons? Unlike the question about the existence of quark-gluon plasma or Higgs bosons, the answer does not lie in a single set of experiments or a single set of theoretical calculations. How does one make progress then? Experimentally, we

Exploring the Micro-Structure of the Proton: from Form Factors to DVCS

John P. Ralston[a] and Pankaj Jain[b]

[a] Department of Physics and Astronomy,
University of Kansas, Lawerence, KS 66045, USA
[b] Physics Department, I.I.T. Kanpur, India 208016

Abstract: For a long time people made the mistake of thinking the proton was understood. New experiments, ranging from form factors to deeply virtual Compton scattering, promise a new era of highly informative studies. Among the controversial topics of the future may be such basic features as the physical size of the proton, the role of quark orbital angular momentum, and the possibility of making "femto-photographic" images of hadronic micro-structure.

Reflections on the First Form Factor

Apology: Hadronic physics is still something young. And yet, people thought they understood the proton for a long time. This was not right, but persisted because so little was known. When little is known, we cannot even find out what *might be known*.

Now we face a new time, an era promising informative measurements on how hadrons are made. We should stand back, and assess how hadronic physics came *not to be understood* up to this point. I apologize in advance for needing to explain things gone awry at an elementary level. I will review some history, from ancient to current day, to set the stage for new developments exploring the three-dimensional micro-structure of hadrons.

Rethinking the thinking about form factors led to the question: what was the first form factor? Newton gave us the gravitational form factor of the Earth. College students should repeat the integration exercise, assuming a uniform density. You cannot cheat and use Gauss' Law, because Gauss was not yet born.

The claims about the form factor were probably met with some skepticism by the gentlemen of the Royal Society. First, the form factor describes an incredibly unnatural theory with an exceedingly small and arbitrary parameter. The theory explained little new in terms of phenomena: things falling to the Earth being already known. The main parameter was made absurdly small to escape from direct observation of the claimed universal force. Then there had to be absurdly large parameters, such as the mass of the Sun, to compensate the small parameter. The theory's author sidestepped direct tests, and based results on astronomical data... and we all know how unreliable that kind of data can be! Following indirect arguments, and inventing private mathematical methods to justify it, Newton claimed that the entire Earth form factor could just be considered "the same as a point mass at the center", *a perfectly incredible result.*

NUCLEON HOLOGRAM WITH EXCLUSIVE LEPTOPRODUCTION

A.V. BELITSKY
Department of Physics, University of Maryland, College Park, MD 20742-4111, USA

D. MÜLLER
Fachbereich Physik, Universität Wuppertal, D-42097 Wuppertal, Germany

Hard exclusive leptoproductions of real photons, lepton pairs and mesons are the most promising tools to unravel the three-dimensional picture of the nucleon, which cannot be deduced from conventional inclusive processes like deeply inelastic scattering.

1. From macro to micro

Why do we see the world around us the way it is? Human eyes can detect electromagnetic waves in a very narrow range of wavelength, $\lambda_\gamma \sim 0.4 - 0.7\mu\text{m}$, which we call visible light. The light from a source, say the sun, is reflected from the surface of macro-objects and is absorbed by the eye's retina which transforms it into a neural signal going to the brain which forms the picture. The same principle is used in radars which detect reflected electromagnetic waves of a meter wavelength. The only requirement to "see" an object is that the length of resolving waves must be comparable to or smaller than its size. The same conditions have to be obeyed in case one wants to study the microworld, e.g., the structure of macromolecules (DNA, RNA) or assemblies (viruses, ribosomes). Obviously, when one puts a chunk of material in front of a source of visible light, see Fig. 1, the object merely leaves a shadow on a screen behind it and one does not see its elementary building blocks, i.e., atoms. Obviously, visible light is not capable to resolve the internal lattice structure of a crystal since the size of an individual atom, say hydrogen, is of order $r_{\text{atom}} \sim (\alpha_{\text{em}} m_e)^{-1} \sim (10\ \text{KeV})^{-1}$ and the light does not diffract from it. Therefore, to "see" atoms in crystals one has to have photons with the wavelength $\lambda_\gamma \leq r_{\text{atom}}$, or equivalently, of

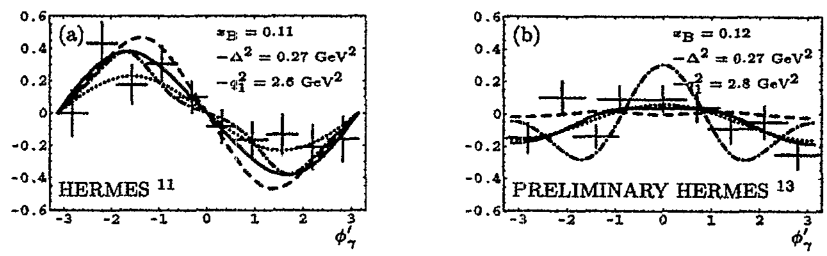


Figure 6. Beam spin asymmetry (a) in $e^+p \to e^+p\gamma$ and unpolarized charge asymmetry (b) from HERMES with $E = 27.6$ GeV are predicted making use of the complete twist-three analysis for input GPDs from Ref. [8]: model A without the D-term (solid) and C with the D-term (dashed) in the Wandzura-Wilczek approximation [10] as well as the model B with the D-term (dash-dotted) and included quark-gluon correlations. The dotted lines on the left and right panels show $0.23 \sin \phi'_\gamma$ and $-0.05{+}0.11 \cos \phi'_\gamma$ HERMES fits, respectively. Note that a toy model for quark-gluon correlations while only slightly changing the beam asymmetry, however, strongly alter the charge asymmetry.

dimensional shape of GPDs, see Fig. 5. Unfortunately, the cross section for DVCS lepton pair production is suppressed by $\alpha_{\rm em}^2$ as compared to DVCS and also suffers from resonance backgrounds, see, e.g., [14].

Finally, perturbative next-to-leading (NLO) and higher-twist effects are shortly discussed. Estimates of the former are, in general, model dependent. NLO contributions to the hard-scattering amplitude [15] of a given quark species are rather moderate, i.e., of the relative size of 20%, however, the net result in the DVCS amplitude can be accidentally large [8,16]. This can be caused by a partial cancellation that occurs in tree amplitudes. Evolution effects [17] in the flavor non-singlet sector are rather small. In the case of gluonic GPD models we observed rather large NLO corrections to the DVCS amplitude for the naive scale setting $\mu_F^2 = -q_1^2$ [8]. For such models one also has rather strong evolution effects, which severely affect LO analysis. However, one can tune the factorization scale μ_F so that to get rid of these effects. The renormalon-motivated twist-four [18] and target mass corrections [19] await their quantitative exploration.

References

1. D. Müller et al., Fortschr. Phys. 42 (1994) 101; X. Ji, Phys. Rev. D 55 (1997) 7114; A.V. Radyushkin, Phys. Rev. D 56 (1997) 5524.
2. M. Diehl, hep-ph/0205208;
3. M. Diehl et al., Nucl. Phys. B 596 (2001) 33; S.J. Brodsky, M. Diehl, D.S. Hwang, Nucl. Phys. B 596 (2001) 99.
4. X. Ji, Phys. Rev. Lett. 78 (1997) 610.

DEEP INELASTIC SCATTERING FROM LIGHT NUCLEI

W. MELNITCHOUK[1], A. W. THOMAS[2]
[1] *Jefferson Lab, 12000 Jefferson Avenue, Newport News, VA 23606*
[2] *Department of Physics and Mathematical Physics, and Centre for the Subatomic Structure of Matter, University of Adelaide, 5005, Australia*

We review recent developments in the study of deep inelastic scattering from light nuclei, focusing in particular on deuterium, helium, and lithium. Understanding the nuclear effects in these systems is essential for the extraction of information on the neutron structure function.

1. Introduction

For the past 20 years the nuclear EMC effect — the nuclear medium modification of the nucleon structure functions — has posed a serious challenge to models of the nucleus which involve quark degrees of freedom. Although the basic features of the EMC effect can be understood within a conventional nuclear physics framework, a quantitative description over the entire range of Bjorken-x appears beyond the capacity of a single mechanism. This has led to an assortment of nuclear models and effects which have been postulated to account for the medium modifications of the structure functions.

An impressive array of data on nuclear structure functions has by now been accumulated from experiments at CERN, SLAC, DESY (Hermes), Fermilab, Jefferson Lab and elsewhere, for a broad range of nuclei, and the quality of recent data exploring extreme kinematics, both at low x and high x, is pushing nuclear models to their limits. Surprisingly, the EMC effect in the lightest nuclei — in particular the $A = 2$ and $A = 3$ systems, where microscopic few-body calculations with realistic potentials are more feasible — is still unknown, leaving the determination of the A dependence of the effect incomplete. In addition, the absence of data on the EMC effect in deuterium and helium nuclei prevents the unambiguous determination of the structure function of the free neutron, for which these nuclei are often used as effective neutron targets.

Here we review the foundations of the conventional approach to deep

$^{3/2}_{3}g_1$. Deep inelastic scattering from the ^{7}Li–^{7}Be mirror nuclei can also be used to explore the medium modifications of the Bjorken and Gottfried sum rules.[29,31] Studies with these nuclei may one day be undertaken at radioactive beam facilities, such as those proposed at RIKEN or GSI. The merits of using other nuclear targets, such as nitrogen, have been elaborated by Rondon.[32]

6. Conclusions

The unprecedented quality of recent data on few body nuclear structure functions from new generations of accelerators is demanding better understanding of nuclei in extreme kinematic regions, such as at large x, where the effects of relativity and nucleon substructure play a more prominent role. This challenge is being met by concurrent progress being made in the theory of DIS from few body nuclei, especially deuterium and $A = 3$ nuclei.

In addition to more accurately determining the response of these nuclei to electromagnetic probes, an important practical necessity lies in controlling the nuclear corrections when extracting information on the structure of the neutron, for which light nuclei are often used as effective neutron targets. While much of the focus has been on the F_2 structure function, there is a growing need to understand the nuclear effects in other structure functions, such as g_1 and g_2, as well as the new structure functions available for higher spin nuclei — both in the deep inelastic and resonance regions. The interplay between theoretical developments and anticipated future data promises to provide even deeper insights into the quark structure of nuclei.

Acknowledgments

We are grateful to F. Bissey and S. Liuti for providing their light-cone momentum distribution functions. This work was supported by the U.S. Department of Energy contract DE-AC05-84ER40150, under which the Southeastern Universities Research Association (SURA) operates the Thomas Jefferson National Accelerator Facility (Jefferson Lab) and by the Australian Research Council.

References

1. D. F. Geesaman, K. Saito and A. W. Thomas, *Ann. Rev. Nucl. Part. Sci.* **45**, 337 (1995).
2. W. Melnitchouk, A. W. Schreiber and A. W. Thomas, *Phys. Rev.* **D 49**, 1183 (1994), nucl-th/9311008.
3. F. Gross and S. Liuti, *Phys. Rev.* **C 45**, 1374 (1992).

SPIN PHYSICS AT RHIC - A THEORETICAL OVERVIEW

MARCO STRATMANN

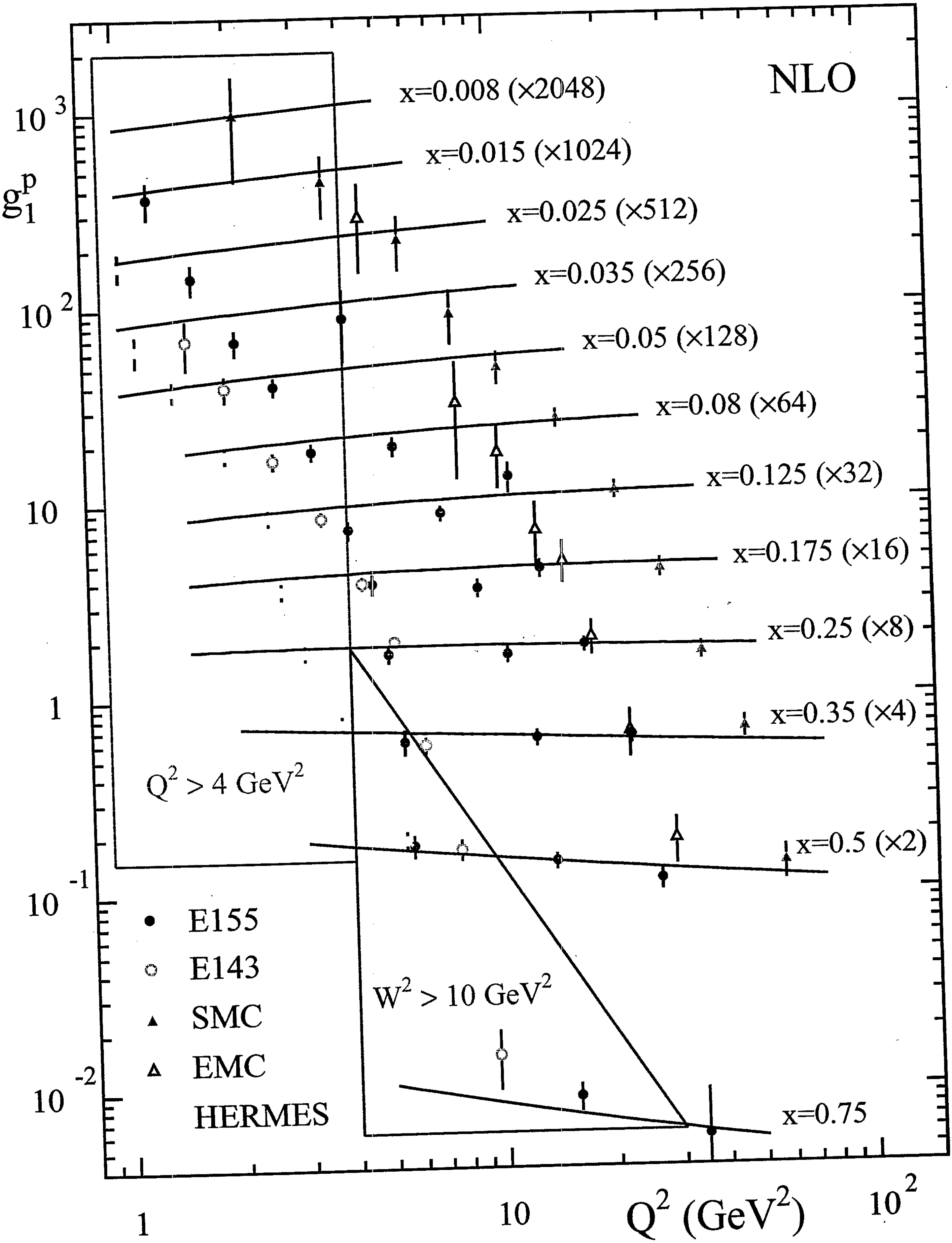
Inst. for Theor. Physics, Univ. of Regensburg, D-93040 Regensburg, Germany
E-mail: marco.stratmann@physik.uni-regensburg.de

We review how RHIC is expected to deepen our understanding of the spin structure of longitudinally and transversely polarized nucleons. After briefly outlining the current status of spin-dependent parton densities and pointing out open questions, we focus on theoretical calculations and predictions relevant for the RHIC spin program. Estimates of the expected statistical accuracy for such measurements are presented, taking into account the acceptance of the RHIC detectors.

1. Lessons from (Un)polarized DIS

Before reviewing the prospects for spin physics at the BNL-RHIC we briefly turn to longitudinally polarized deep-inelastic scattering (DIS) and what we have learned from twenty years of beautiful data[1]. Figure 1 compares the available information on the DIS structure function $g_1(x, Q^2)$ to results of a typical next-to-leading order (NLO) QCD fit. From such types of analyses a pretty good knowledge of certain combinations of different quark flavors has emerged, and it became clear that quarks contribute only a fraction to the proton's spin. However, there is still considerable lack of knowledge regarding the polarized gluon density Δg, which is basically unconstrained by present data, the separation of quark and antiquark densities and of different flavors, and the orbital angular momentum of quarks and gluons inside a nucleon. In addition, spin effects with transverse polarization at the leading-twist level, the so-called 'transversity' densities, have not been measured at all. Apart from orbital angular momentum RHIC can address all of these questions as will be demonstrated in the following[2].

There is also an important difficulty when analyzing polarized DIS data in terms of spin-dependent parton densities: compared to the unpolarized case the presently available kinematical coverage in x and Q^2 and the statistical precision of polarized DIS data are much more limited[1]. As a consequence, one is forced to include data into the fits from (x, Q^2)-regions where fits of unpolarized leading-twist parton densities start to break down, see Fig. 1. Data from RHIC, taken at 'resolution' scales Q^2 where perturbative QCD and


NLO
x=0.008 (×2048)
x=0.015 (×1024)
x=0.025 (×512)
x=0.035 (×256)
x=0.05 (×128)
x=0.08 (×64)
x=0.125 (×32)
x=0.175 (×16)
x=0.25 (×8)
x=0.35 (×4)
x=0.5 (×2)
x=0.75
Q² > 4 GeV²
W² > 10 GeV²
E155
E143
SMC
EMC
HERMES
g₁ᵖ
Q² (GeV²)
10³
10²
10
1
10⁻¹
10⁻²
1
10
10²

SPIN STRUCTURE FUNCTIONS IN CHIRAL QUARK SOLITON MODELS

H. WEIGEL*

Institute for Theoretical Physics
Tübingen University
D-72076 Tübingen, Germany
E-mail: herbert.weigel@uni-tuebingen.de

In this talk I review studies of hadron structure functions in bosonized chiral quark models. Such models require regularization and I show that the two–fold Pauli–Villars regularization scheme not only fully regularizes the effective action but also leads the scaling laws for structure functions. This scheme is consistent with other computations of the pion structure function in that model. For the nucleon structure functions the present approach serves to determine the regularization prescription for structure functions whose leading moments are not given by matrix elements of local operators. Some numerical results are presented for the spin structure functions and the role of strange quarks is addressed.

1. Introduction

In this talk I review the computation of hadron structure functions in the Nambu–Jona–Lasino (NJL) model[1]. This is a particularly simple model for quark interactions with the important feature that the quarks can be integrated out in favor of meson fields[2]. The resulting effective action for these mesons possesses soliton solutions[3]. According to the large–N_C picture[4] of Quantum–Chromo–Dynamics (QCD) these solutions are interpreted as baryons. Quantization of the soliton then also yields baryon wave–functions in such meson models. The construction of hadron wave–functions is not possible in QCD. This represents the main obstacle for the computation of hadron properties from first principles. As the model adopts the symmetry properties of QCD, the current operators in the model correspond to those of QCD. As a consequence matrix elements of the current operators as computed in the model are physical. In particular it is interesting to analyze the hadronic tensor that parameterizes the deep–inelastic–scattering (DIS)

*Heisenberg–Fellow

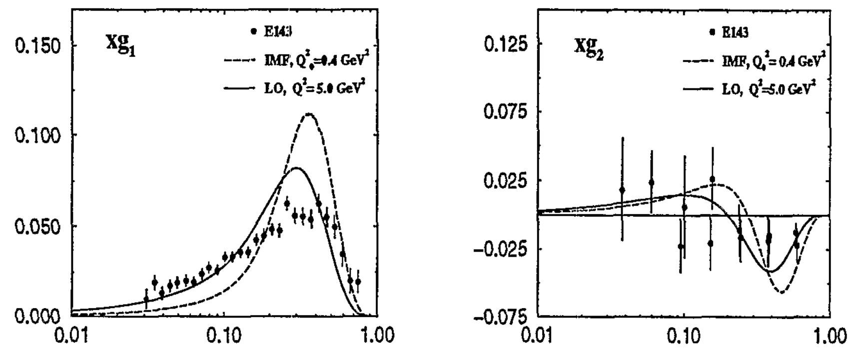


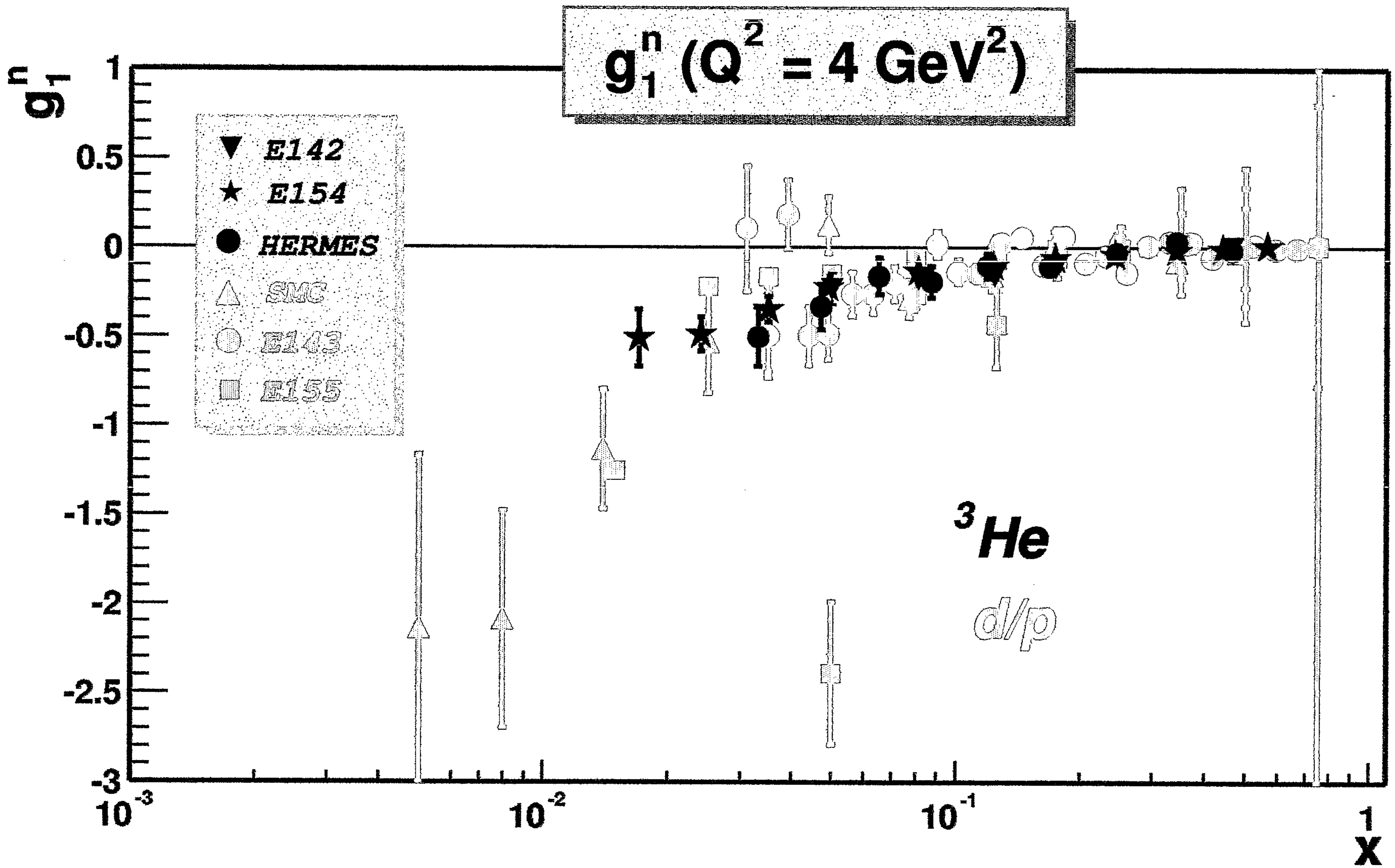
Figure 1. Model predictions for the polarized proton structure functions xg_1 (left panel) and xg_2 (right panel). The curves labeled 'RF' denote the results as obtained from the valence quark contribution to (20). These undergo a projection to the infinite momentum frame 'IMF' (22) and a leading order 'LO' DGLAP evolution[21]. Data are from SLAC–E143[24].

and evolved analogously to $g_1(x)$ (which also is twist–2). The remainder, $g_2(x) - g_2^{WW}(x)$ is twist–3 and is evolved according to the large–N_C scheme of ref.[23]. Finally, the two pieces are again put together at the end–point of the evolution, Q^2. In figure 1 I compare the model predictions for the linearly independent polarized structure functions of the proton to experimental data[24]. In figure 2 I compare the model predictions for both the proton and the neutron (in form of the deuteron) not only to the recently accumulated data but also to other model predictions. Surprisingly the twist–2 truncation, *i.e.* eq (23) with the data for $g_1(x)$ at the right hand side gives the most accurate description of the data. However, also the chiral soliton model predictions reproduce the data well. Bag model predictions have a less pronounced structure.

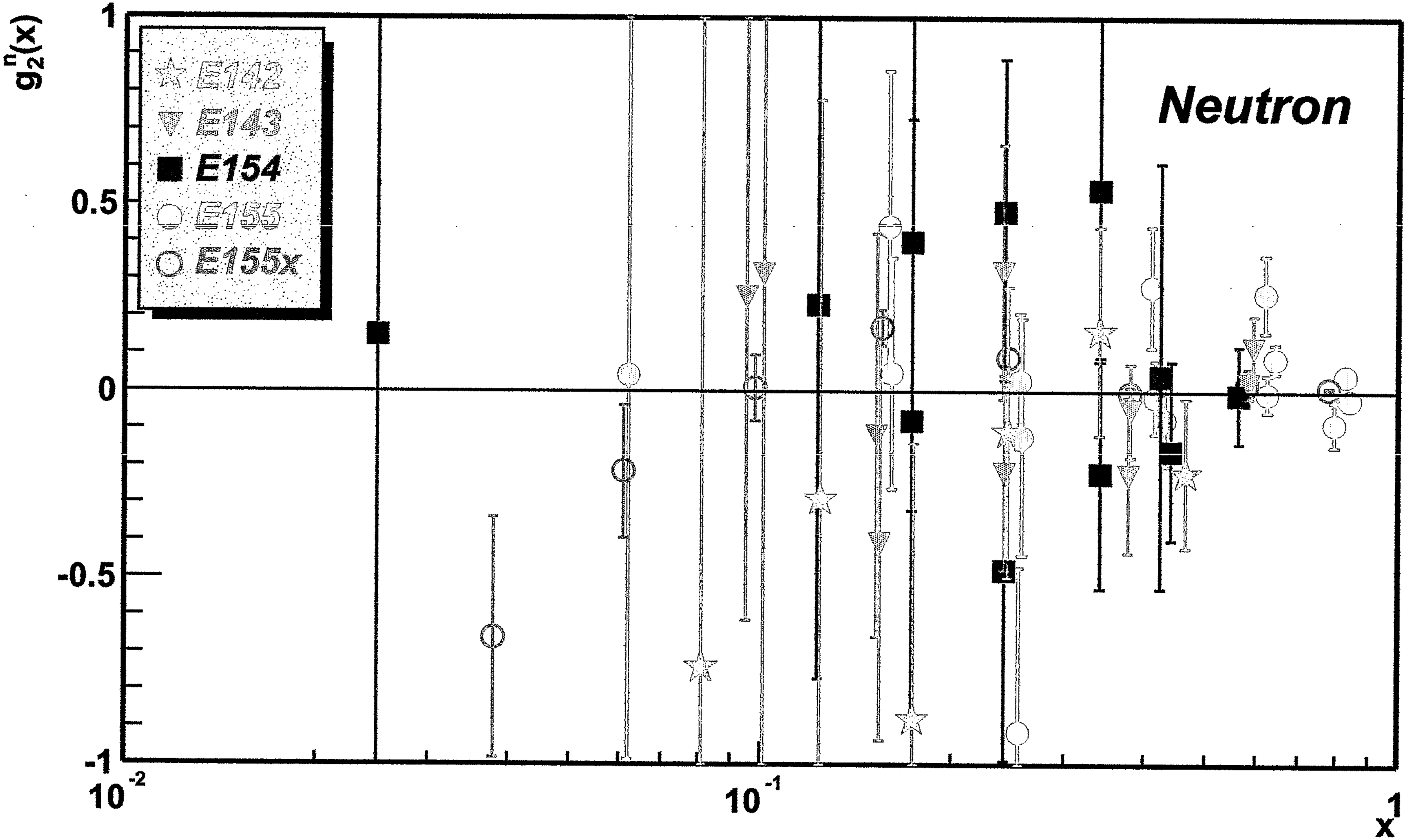
As mentioned in section 4, the chiral soliton model can be generalized to three flavors. Appropriate projection gives a prediction for the strangeness contribution to structure functions[7]. In figure 3 this contribution is shown for the spin structure function $g_1(x)$. The interesting feature is that $g_1^{(s)}(x)$ has both positive and negative pieces. This is a nice example showing that a small $\Delta s = \int_0^1 dx\, g_1^{(s)}(x)$ (strange quark contribution to the nucleon spin) does not imply that strangeness structure function itself is small.

7. Conclusions

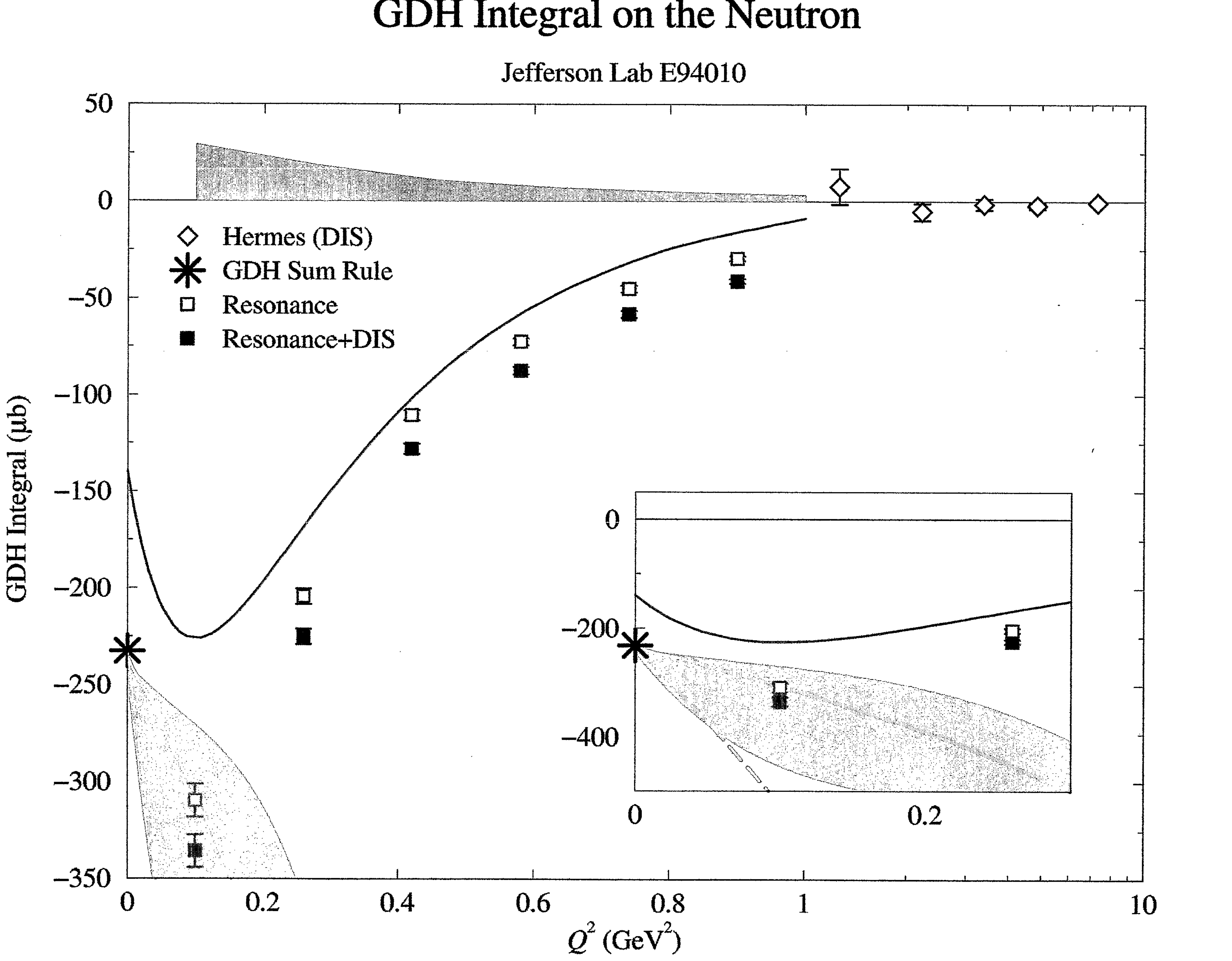
I have presented studies of the nucleon spin structure functions in chiral soliton models. For this purpose I considered the bosonized NJL model as a simplified model for the quark flavor dynamics. Although the bosonized version is an effective meson theory, it has the interesting feature that the



g_1^n (Q^2 = 4 GeV^2)
g_1^n
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
E142
E154
HERMES
SMC
E143
E155
^{3}He
d/p
10^{-3}
10^{-2}
10^{-1}
1
x

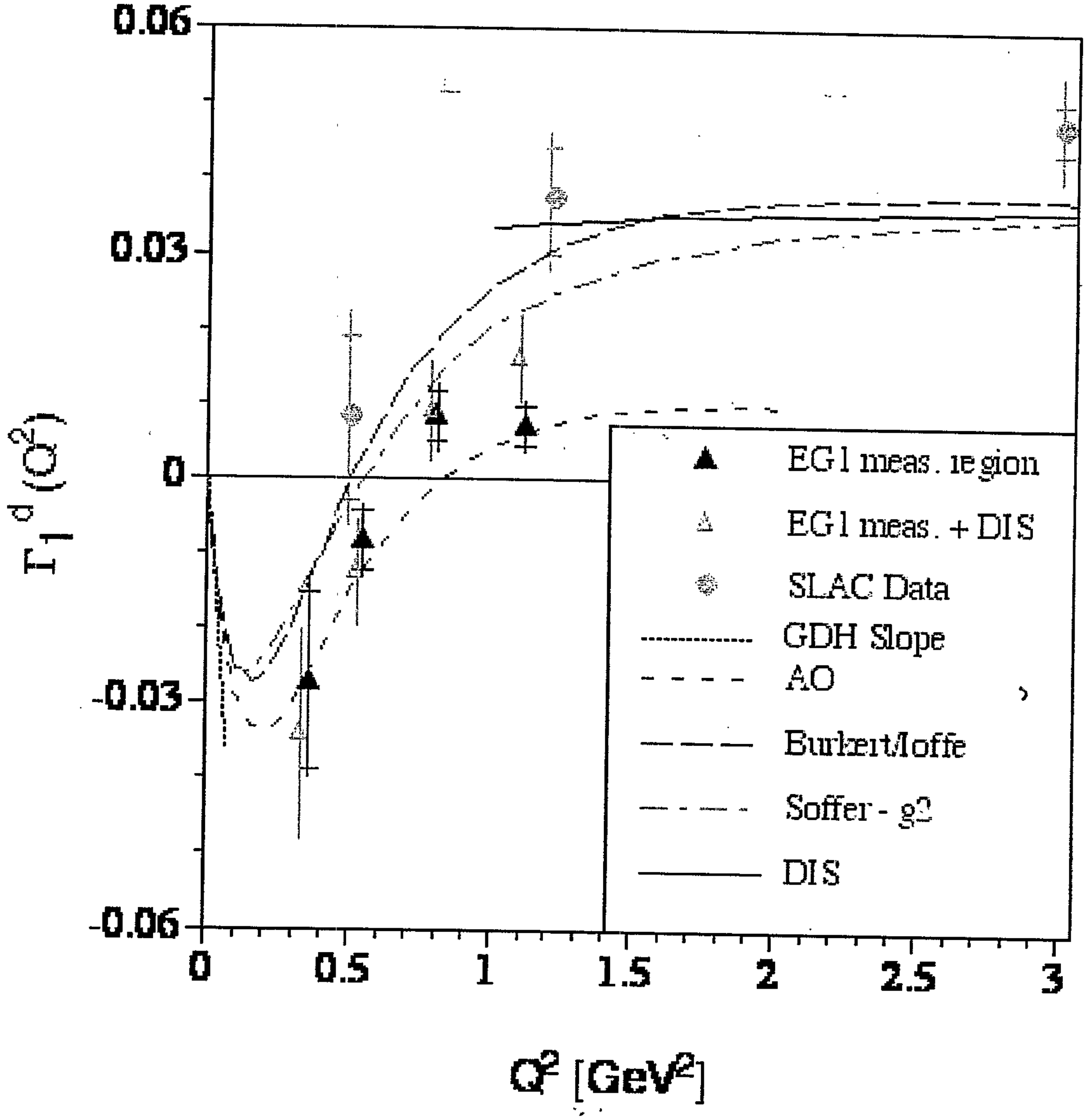


$g_2^n(x)$
E142
E143
E154
E155
E155x
Neutron
1
0.5
0
-0.5
-1
10^{-2}
10^{-1}
1
x



GDH Integral on the Neutron
Jefferson Lab E94010
Hermes (DIS)
GDH Sum Rule
Resonance
Resonance+DIS
GDH Integral (μb)
50
0
−50
−100
−150
−200
−250
−300
−350
0
0.2
0.4
0.6
0.8
1
10
Q² (GeV²)
0
−200
−400
0
0.2

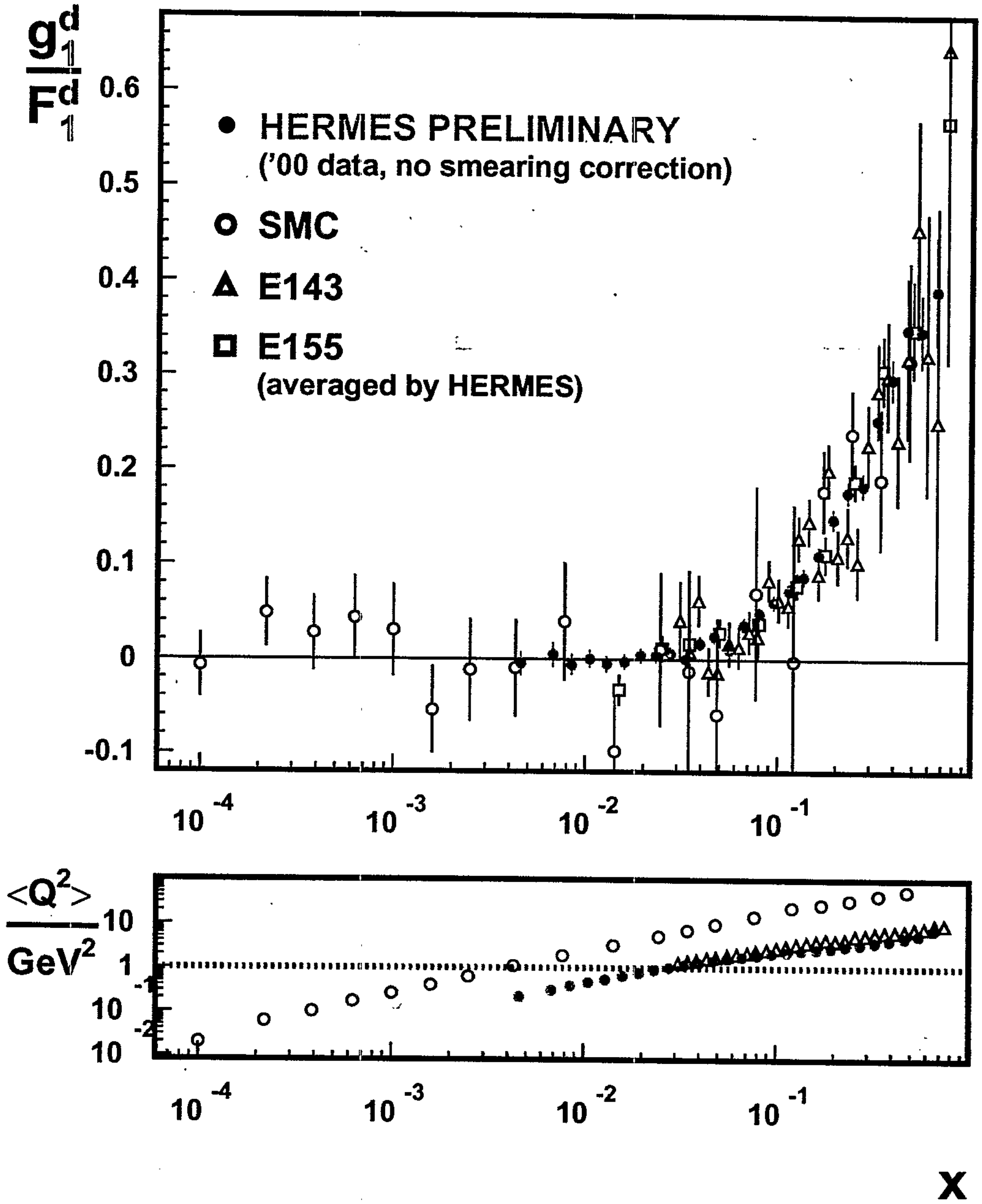
Integral Γ_{1d}



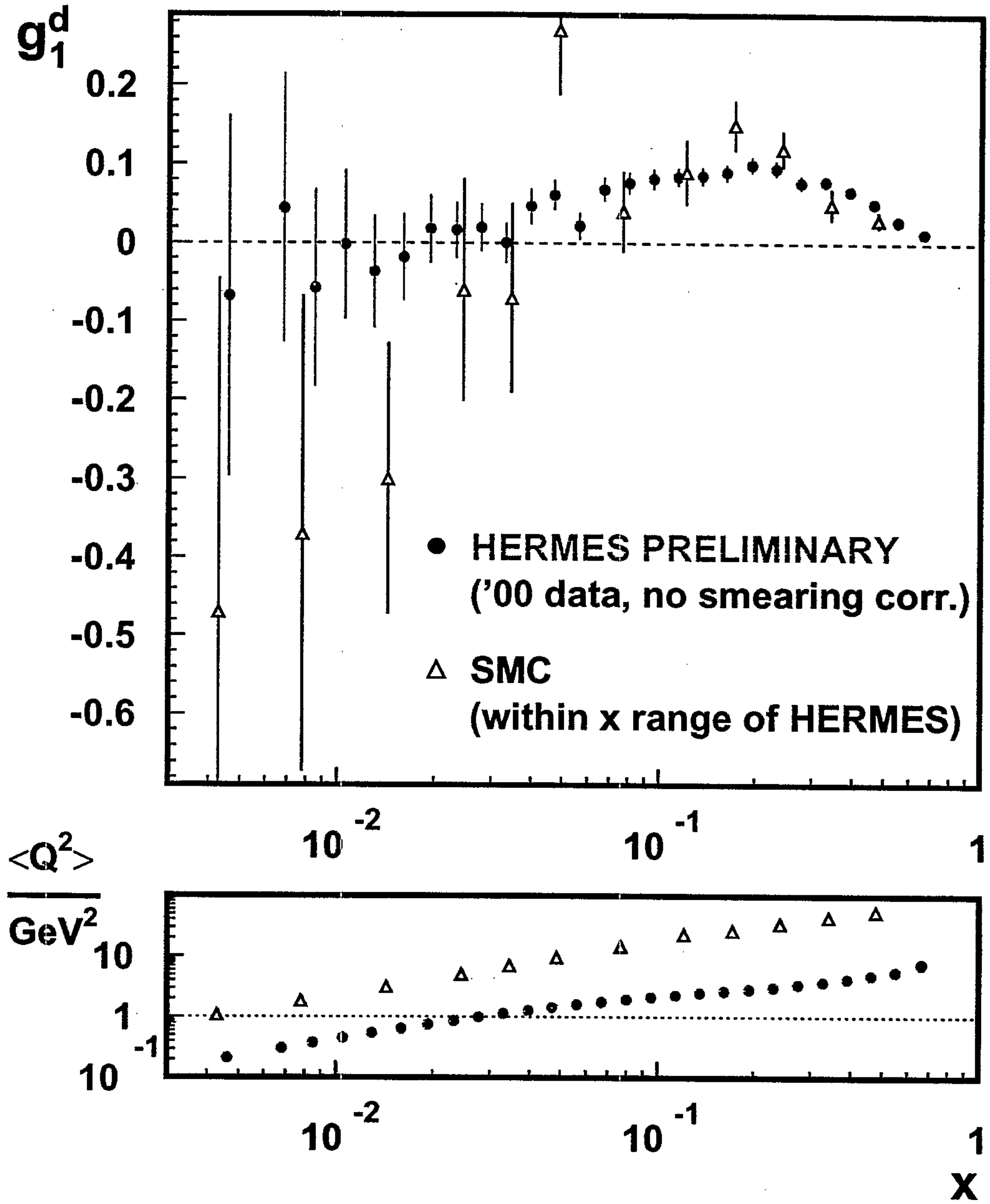
Nuclear Effects

	Deuterium↑	**^{3}He↑**
0^{th} order approximation	p↑n↑	p↑p↓n↑
D-state, S' state etc.	$\mu_D = \mu_p + \mu_n - 0.022$	$\mu_{He} = \mu_n - 0.214$
Fermi motion	$p_{RMS} = 130$ MeV/c	$p_{RMS} = 170$ MeV/c
Binding Effects	E_{bound}-$E_{free} \approx$-10MeV	E_{bound}-$E_{free} \approx$-20MeV
Tensor Polarization	$P_{zz} \approx 0.1$	n.a.
"EMC" Effects Final State interactions Coherent processes	$\rho \approx 0.063$ N/fm^3	$\rho \approx 0.094$ N/fm^3
Pre-existing Δ's ?	$P_{\Delta\Delta} < 0.5\%$	$P_{N\Delta} \approx 2\%$?
Pion excess?	2% ?	5% ?
Other exotic compon.?	??	??

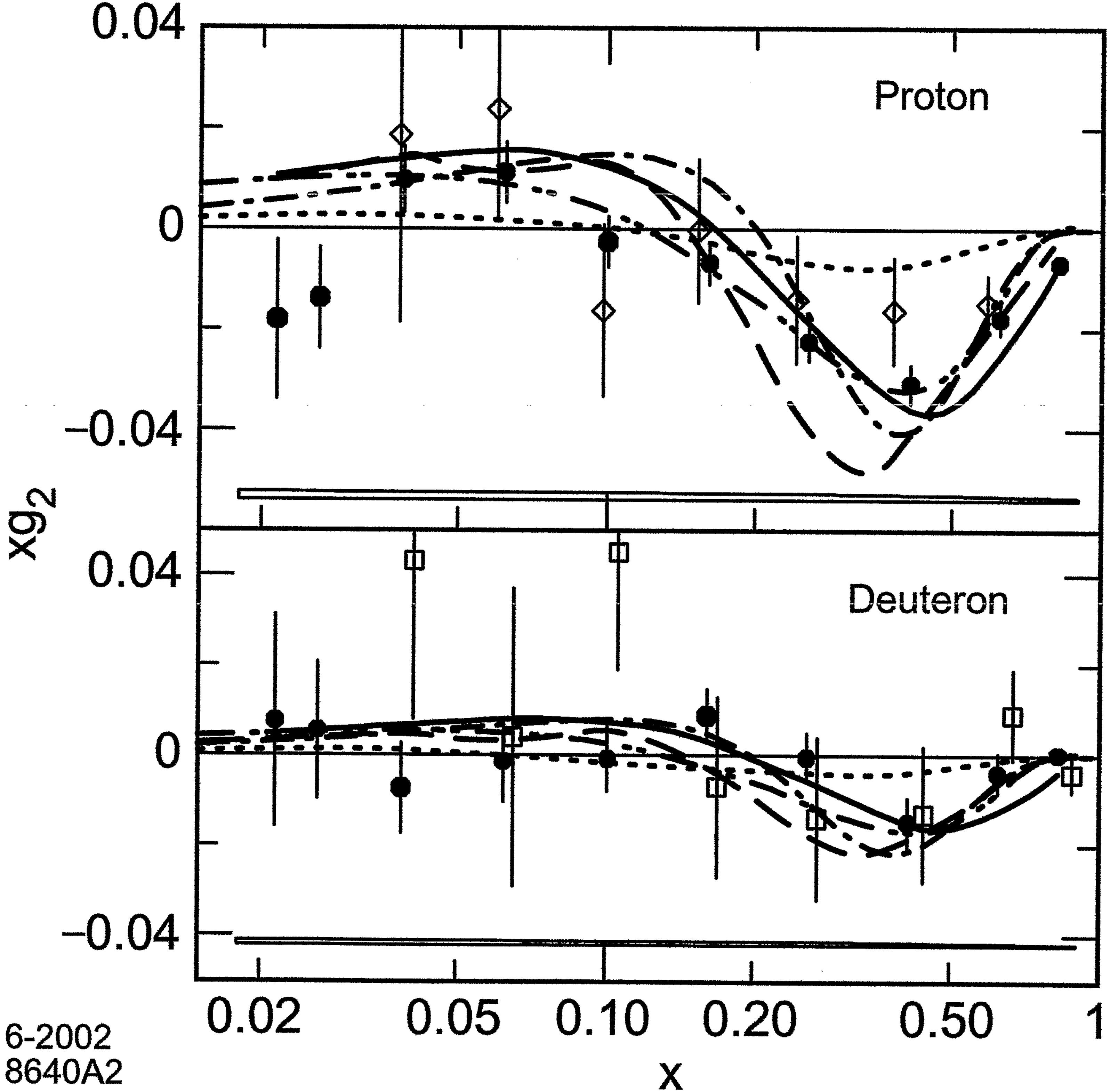
Claim: Most of these effects (except D/S' state) are minor for integrals and for high Q^2 and W (DIS). Extracting information in the resonance region requires careful attention to "unfolding" procedure.



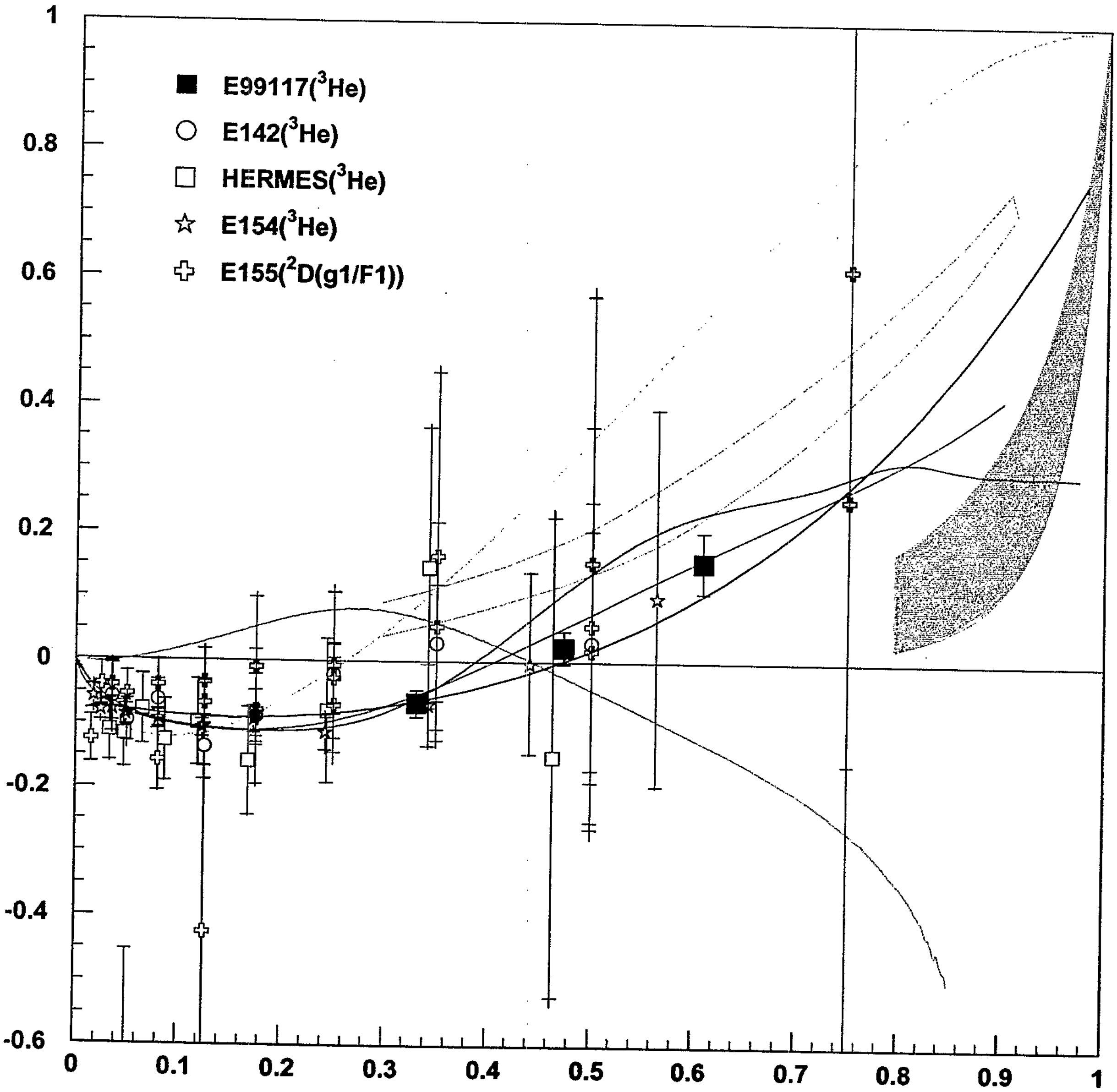
g_1^d / F_1^d
HERMES PRELIMINARY
('00 data, no smearing correction)
SMC
E143
E155
(averaged by HERMES)
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
10^{-4}
10^{-3}
10^{-2}
10^{-1}
$\langle Q^2 \rangle$ / GeV^2
10
1
10^{-1}
10^{-2}
x



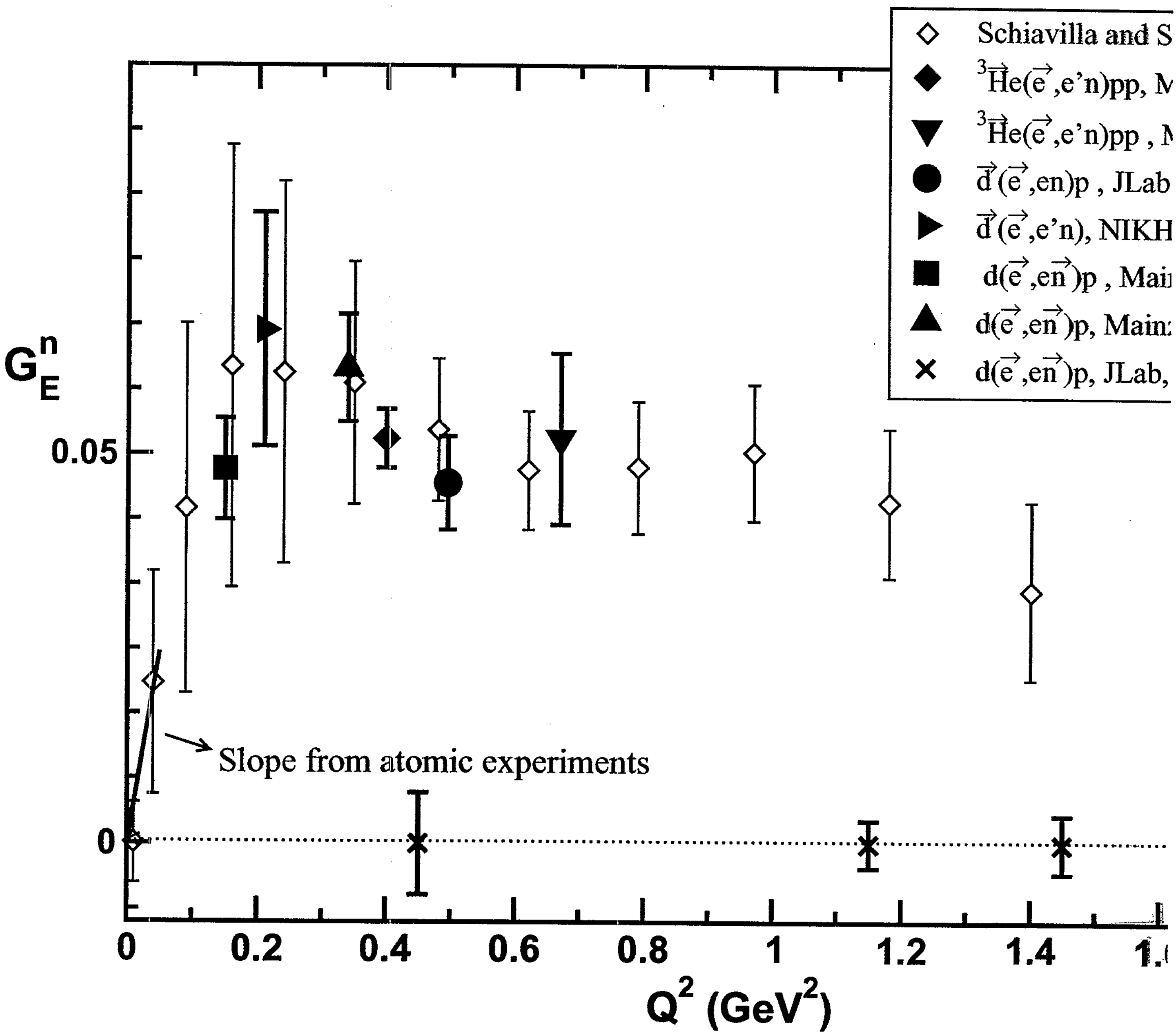
g_1^d
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
● HERMES PRELIMINARY
('00 data, no smearing corr.)
△ SMC
(within x range of HERMES)
10^{-2}
10^{-1}
1
$\langle Q^2\rangle$ / GeV^2
10
1
10^{-1}
10^{-2}
10^{-1}
1
x



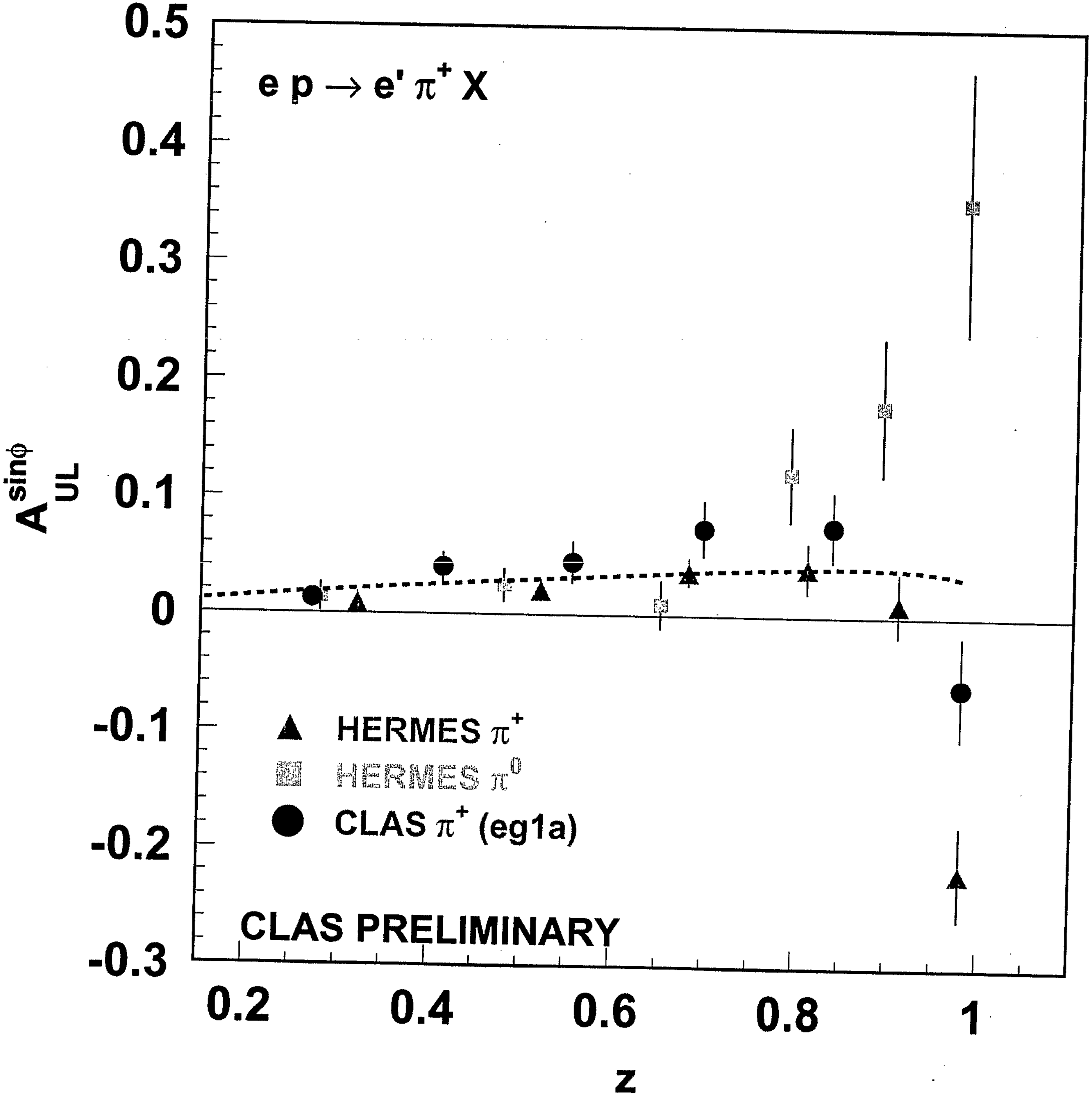
Proton
Deuteron
xg_2
0.04
0
−0.04
0.02
0.05
0.10
0.20
0.50
1
x
6-2002
8640A2



E99117(^{3}He)
E142(^{3}He)
HERMES(^{3}He)
E154(^{3}He)
E155(^{2}D(g1/F1))
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1



Schiavilla and S
$^3\vec{He}(\vec{e},e'n)pp$, M
$^3\vec{He}(\vec{e},e'n)pp$, M
$\vec{d}(\vec{e},en)p$, JLab
$\vec{d}(\vec{e},e'n)$, NIKH
$d(\vec{e},e\vec{n})p$, Mai
$d(\vec{e},e\vec{n})p$, Main
$d(\vec{e},e\vec{n})p$, JLab,
G_E^n
0.05
0
Slope from atomic experiments
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Q^2 (GeV^2)



e p → e' π+ X
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
A UL sinφ
HERMES π+
HERMES π0
CLAS π+ (eg1a)
CLAS PRELIMINARY
0.2
0.4
0.6
0.8
1
z

REVIEW OF POLARIZED INTERNAL DEUTERIUM TARGETS

B. VON PRZEWOSKI
Indiana University Cyclotron Facility,
Milo B. Sampson Lane,
Bloomington, IN 47408, USA
E-mail: przewoski@iucf.indiana.edu

Today, several polarized, internal deuterium targets are in operation or being commissioned worldwide. Polarized gas from either an atomic beam source (ABS) or laser driven target (LDT) is admitted to an open ended storage cell which enhances the target thickness by approximately two orders of magnitude. ABS technology is mature. Polarizations of up to 85 % of the theoretically possible polarization have been reached. The output of all atomic beam sources in operation today is in the range of 5-7$\cdot 10^{16}$ atoms/s. On the other hand LDT technology is relatively new. Although optically driven sources fulfilled their promise of fluxes up to $\simeq 10^{18}$ atoms/s, the measured nuclear polarization is only $\sim$0.1. Therefore, laser driven sources have not yet reached the figure of merit of atomic beam sources. While the present review concentrates on polarized deuterium targets, it should be mentioned that ABS and LDT alike are capable of producing polarized hydrogen as well.

1. Introduction

Since the first polarized, internal target was commissioned in the VEPP-3 ring at Novosibirsk in 1988[1,2], it was demonstrated repeatedly that stored, polarized beams and internal, polarized targets are experimental tools of choice to measure spin dependent observables with high precision. At present, storage cells fed by atomic beam sources are in operation at VEPP-3, IUCF[3,4,5,6], COSY[7] and DESY. The latter was in use at the TSR[8] before it was installed for HERMES. The ABS formerly installed at NIKHEF[9] has been moved to Bates and is currently being refurbished for BLAST[10]. Laser driven sources are being developed at MIT for RpEX[11] at BLAST and also at Erlangen[12] and Tohoku University[13]. The only LDT that was used in a nuclear physics experiment so far was developed at Argonne and was installed at IUCF until 1999[14,15,16].

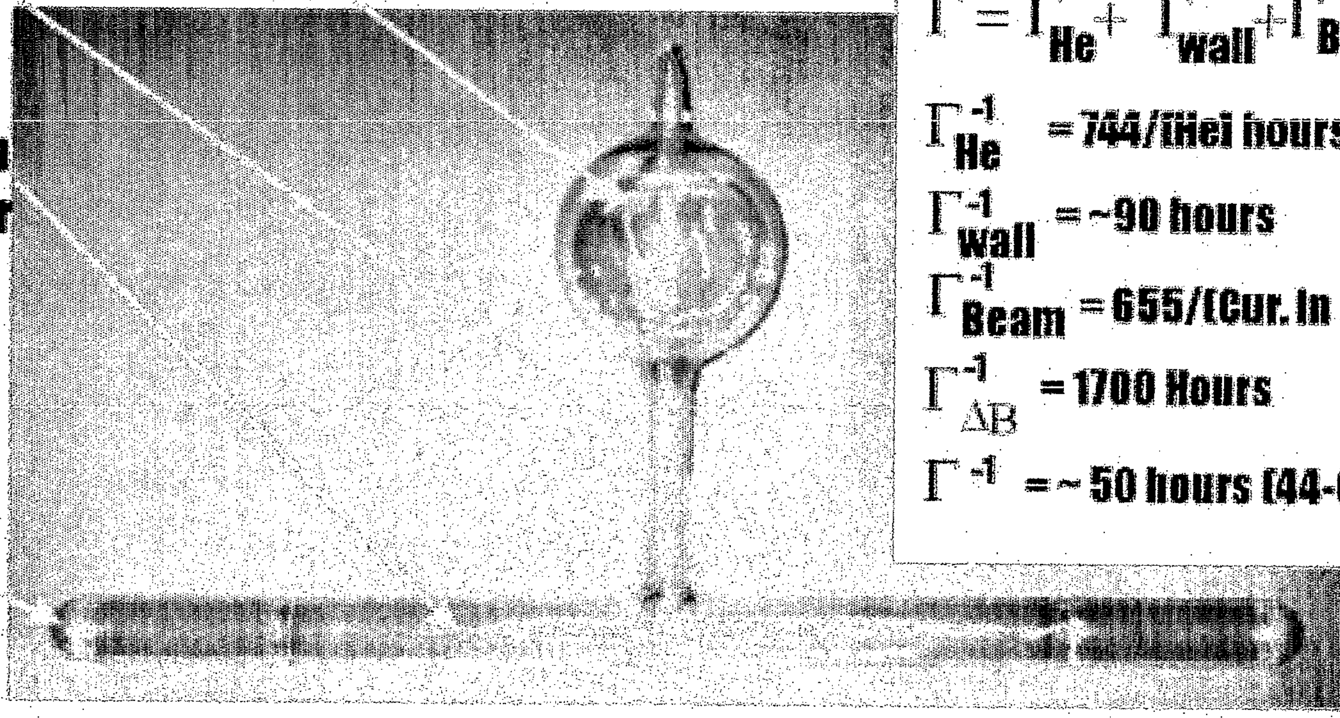
The Polarized ^{3}He Target Cell

Cell made of Aluminosilicate glass (GE 180 or Dow 1720)

Laser Light Polarizes Rubidium Vapor in Pumping Chamber

Electron beam travels through target chamber

End Windows ~100 microns thick



Cell Lifetime

$$P(t) = P_0 e^{-\Gamma t}$$

$$\Gamma = \Gamma_{He} + \Gamma_{wall} + \Gamma_{Beam} + \Gamma_{AB}$$

Γ_{He}^{-1} = 744/[He] hours

Γ_{wall}^{-1} = ~90 hours

Γ_{Beam}^{-1} = 655/(Cur. in uA) hours

Γ_{AB}^{-1} = 1700 Hours

Γ^{-1} = ~ 50 hours (44-64 hours)

Helium Density is 7.5 - 10 atm at room temperature

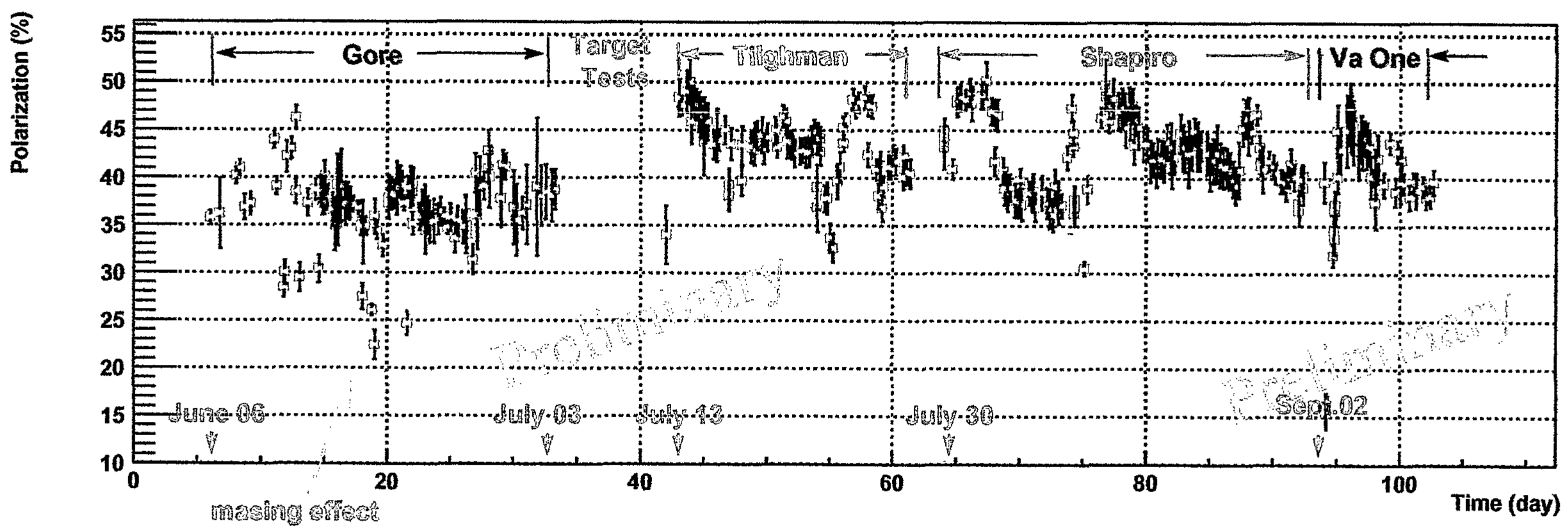
Cell Density is measured optically using pressure broadening of Rb electron states

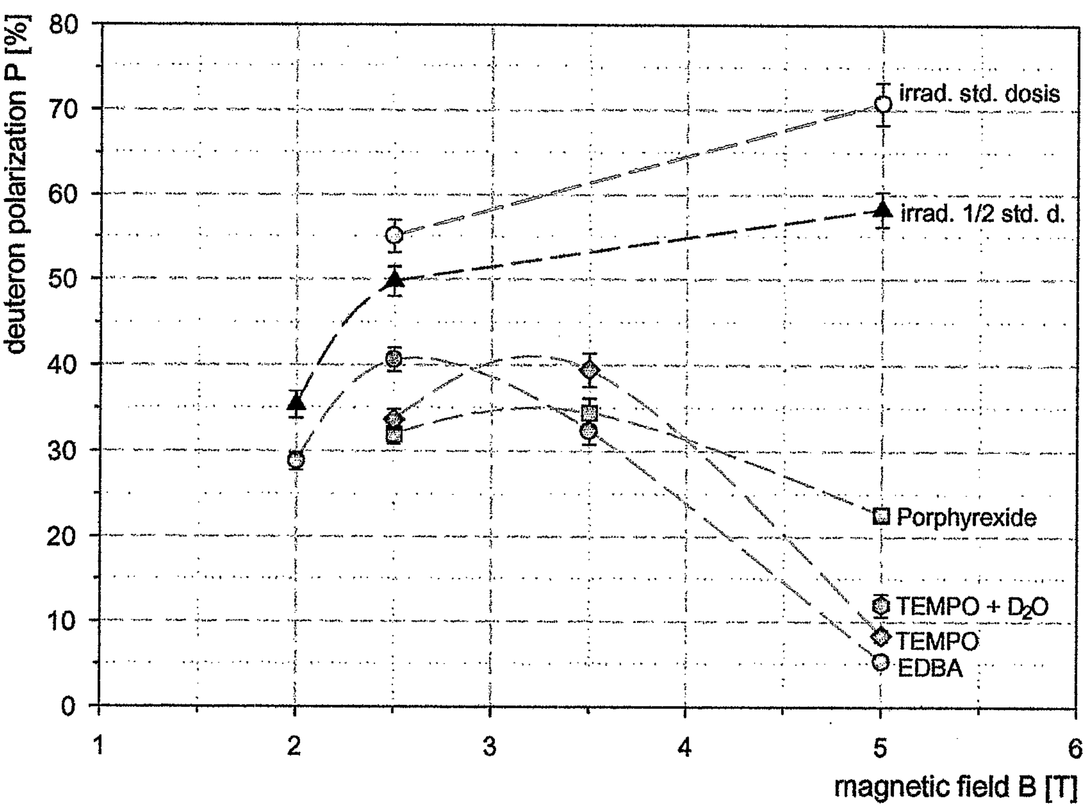
Wall and Window Thickness also measured optically using etalon effect

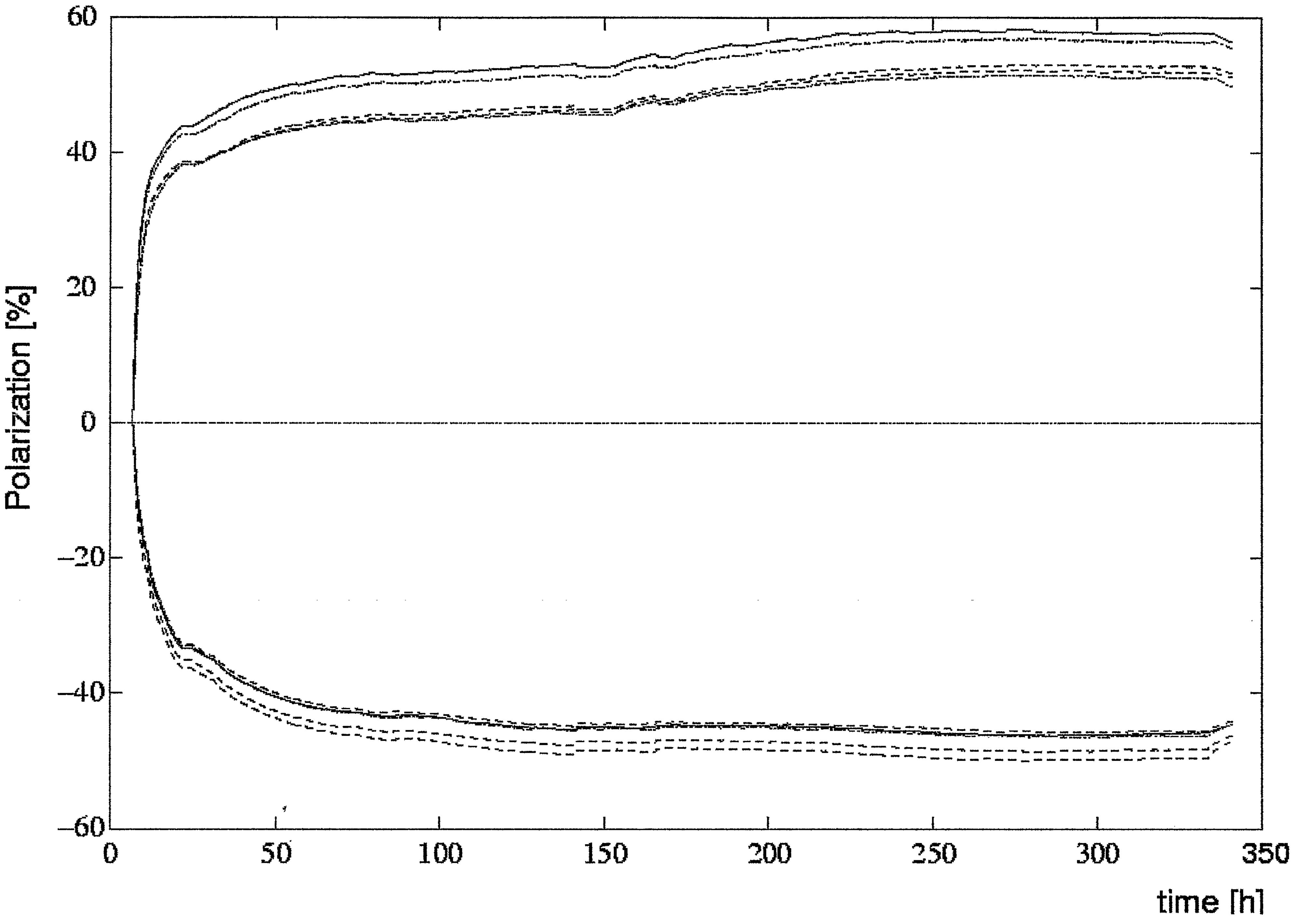
Polarized 3He Target Performance During E99-117/E97-103

Cell Name	Field direction	0°	90°	180°	270°
Gore	June 06 ~ July 03	37%		35%	43%
Tilghman	July 13 ~ July 31	45%		43%	39%
Shapiro	Aug.04 ~ Aug.31	47%	42%		45%
Virginia One	Sept.04 ~ Sept.10	44%	40%		40%

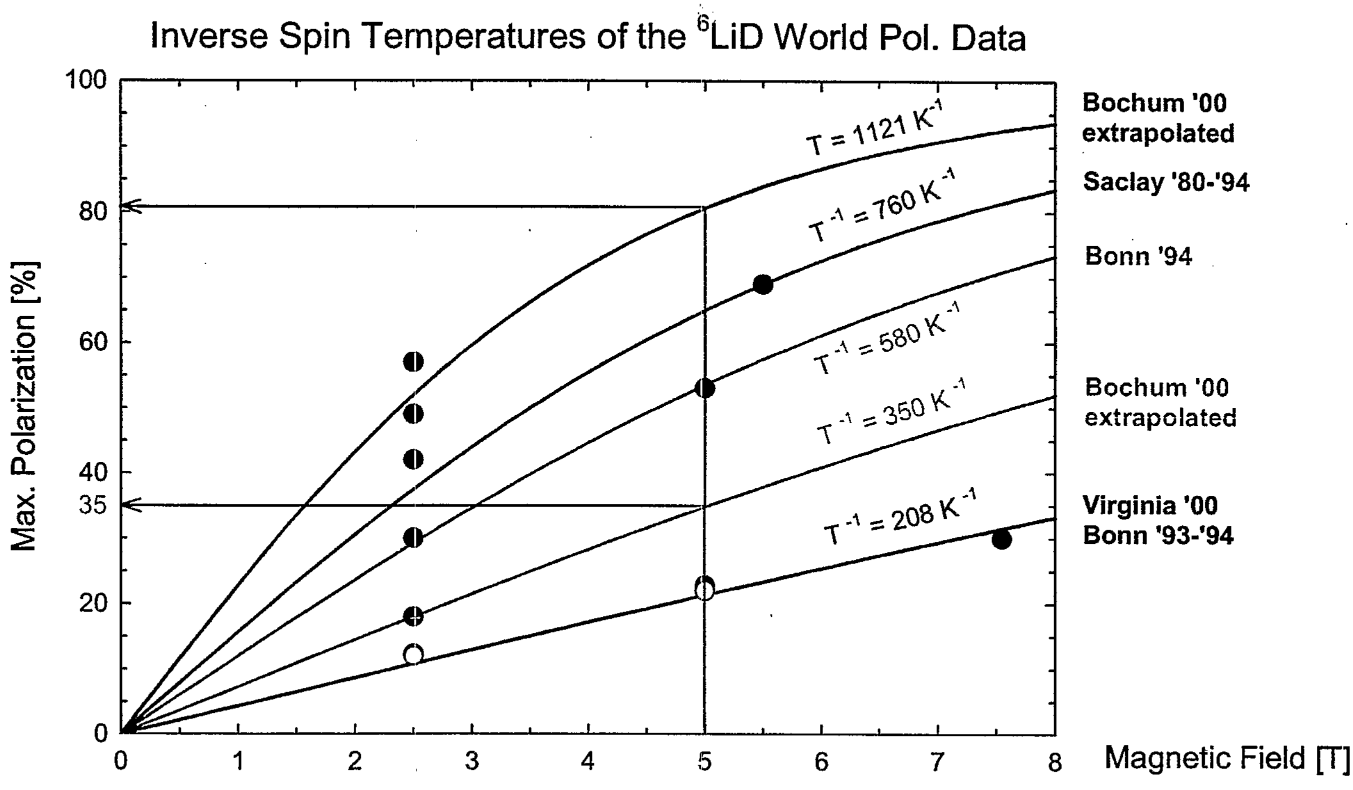
target polarization from EPR (in beam)



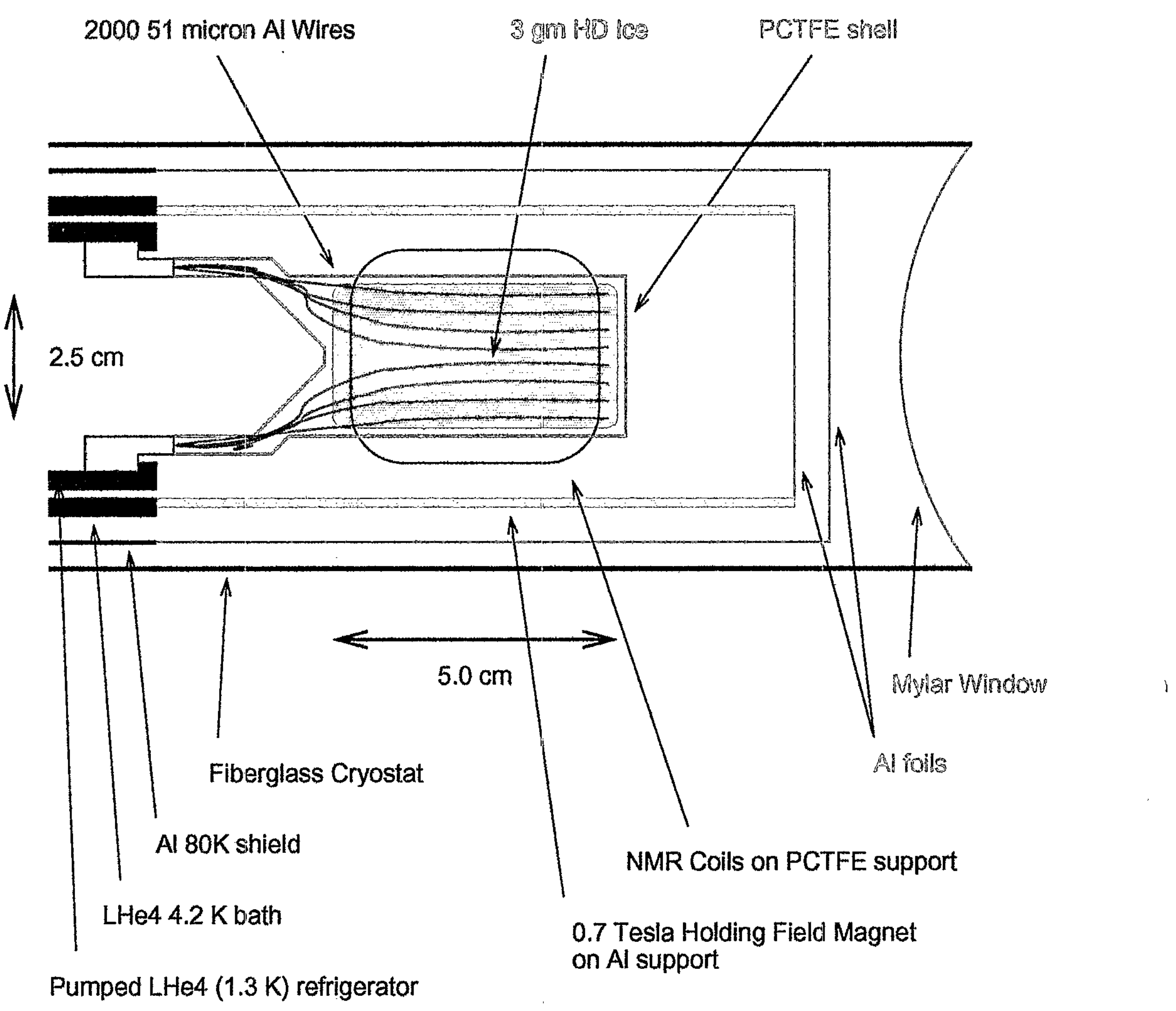

deuteron polarization P [%]
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
magnetic field B [T]
irrad. std. dosis
irrad. 1/2 std. d.
Porphyrexide
TEMPO + D2O
TEMPO
EDBA



60
40
20
0
−20
−40
−60
Polarization [%]
0
50
100
150
200
250
300
350
time [h]



$$P = \frac{4 \tanh (g_d \mu_k \mathbf{B} / 2kT)}{3 + \tanh^2 (g_d \mu_k \mathbf{B} / 2kT)} \sim 4/3\,(g_d \mu_k \mathbf{B} / 2kT)$$

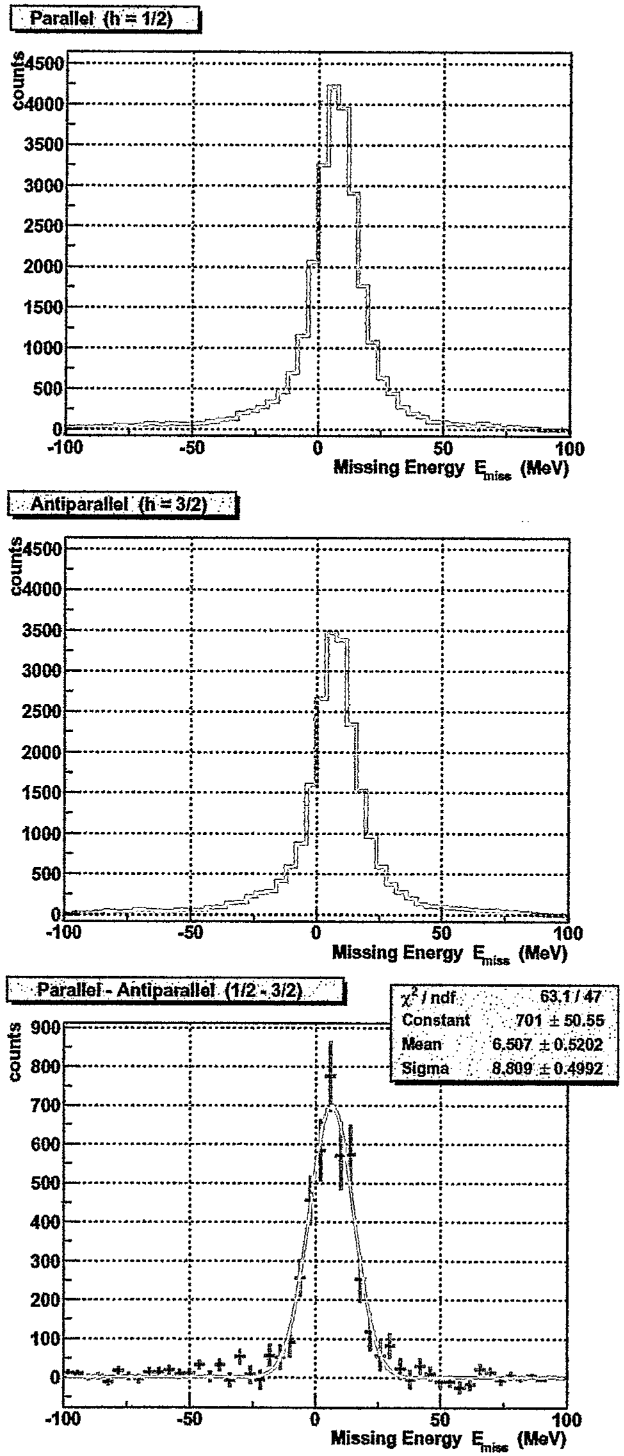


2000 51 micron Al Wires
3 gm HD Ice
PCTFE shell
2.5 cm
5.0 cm
Mylar Window
Al foils
Fiberglass Cryostat
Al 80K shield
NMR Coils on PCTFE support
LHe4 4.2 K bath
0.7 Tesla Holding Field Magnet
on Al support
Pumped LHe4 (1.3 K) refrigerator

γ p → π^+ n

275 MeV < E_γ < 325 MeV

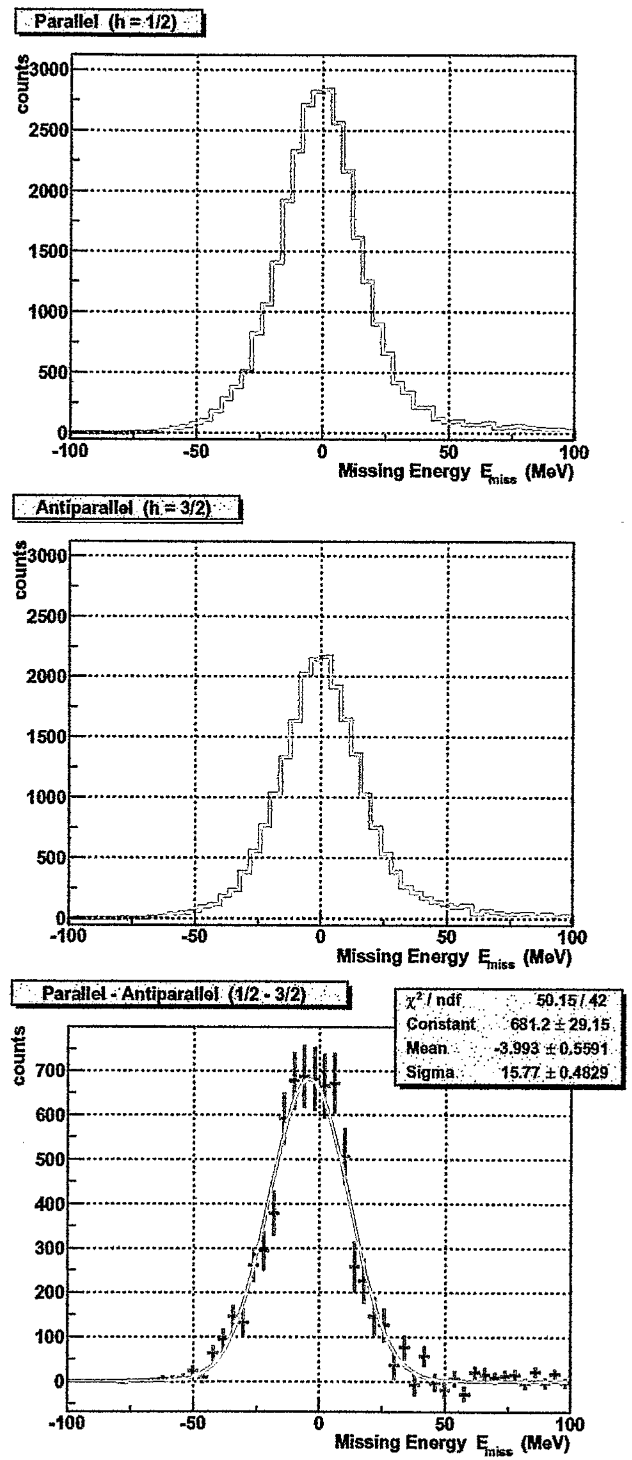
75° < Θ_{π} < 105°



γ p → π^0 p

300 MeV < E_γ < 350 MeV

75° < Θ_{π^0} < 105°



Summary

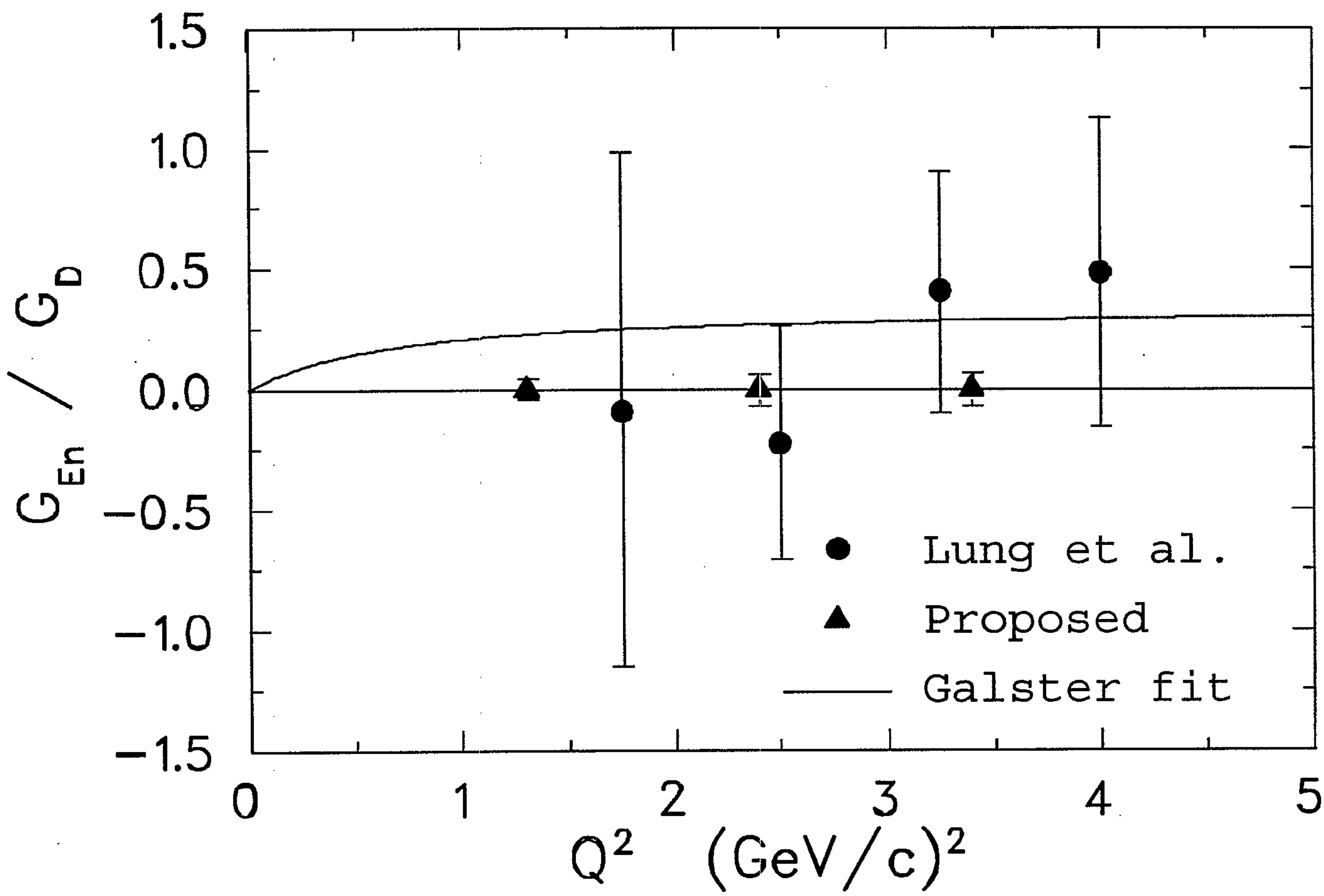
Nucleon Polarizations.

Nuclide	Model independent		Model dependent					
	This work[a]	Ref. [1]	This work	Ref. [2]	Ref. [3]	Ref. [4]	Ref. [5]	Ref. [6]
^{2}H	0.94		0.926					
^{3}H - ^{3}He*	0.93	0.96	0.860	0.865				0.879
^{6}Li	0.85		0.866		0.866	0.86	0.82	
^{7}Li			0.57			0.59		
^{14}N	-0.26		-0.33					
^{15}N	-0.22	-0.24	-0.33					

* $p(n)$ in ^{3}H (^{3}He)

[a] Phys. Rev C 60, 035201 (1999)

[1] Phys. Rev. **182**, 1051 (1969)
[2] Phys. Rev. C **42**, 2310 (1990)
[3] Phys. Rev. C **48**, 2714 (1993)
[4] Phys. Rev. C **56**, 1720 (1997)
[ ] Nucl. Phys. **A405**, 557 (1983)
[6] e-Print Archive: hep-ph/0109069


1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
G_{En} / G_D
0
1
2
3
4
5
Q^2 (GeV/c)^2
Lung et al.
Proposed
Galster fit

Last Summer, Jefferson lab experiment 99-117 used the Hall A polarized ^{3}He target to measure A_1^n with unprecedented precision up to $x \sim 0.61$ [10] The availability of 12 GeV beam and the MAD spectrometer in Hall A will allow the A_1^n measurement to be extended to $x_{Bj} \sim 0.8$ with high precision. The anticipated data are shown in Fig. 1. While an invariant mass cut of $W > 2$ GeV, would allow the deep inelastic continuum to be cleanly accessed, one may extend the measurements of A_1^n to even larger x_{Bj} by using quark-hadron duality in the resonance region. We discuss this in more detail later in this presentation.

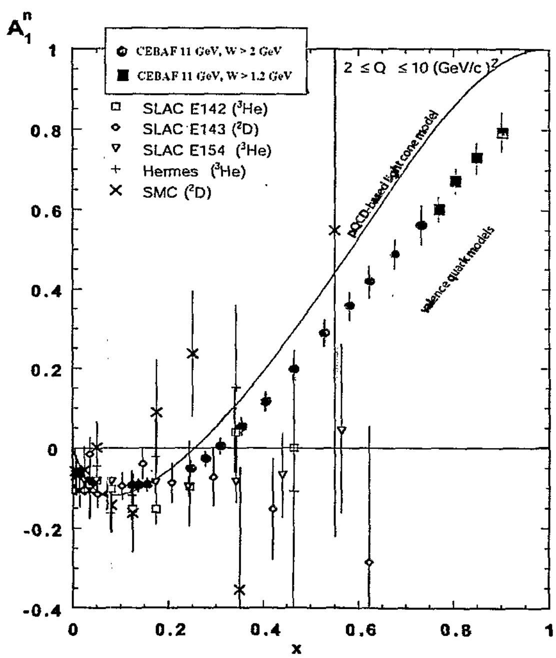


Figure 1. Projected data for a measurement of A_1^n in the large Bjørken-x region, The red filled circles are for the data in the DIS region ($W > 2$ GeV), while the filled squares show the possibility of extending the measurement to higher x_{Bj} by relaxing the invariant mass cut.

The high precision spin structure function measurements in both deep inelastic and resonance regions will allow for a stringent test of parton-hadron duality for spin structure functions. Parton-hadron duality refers to

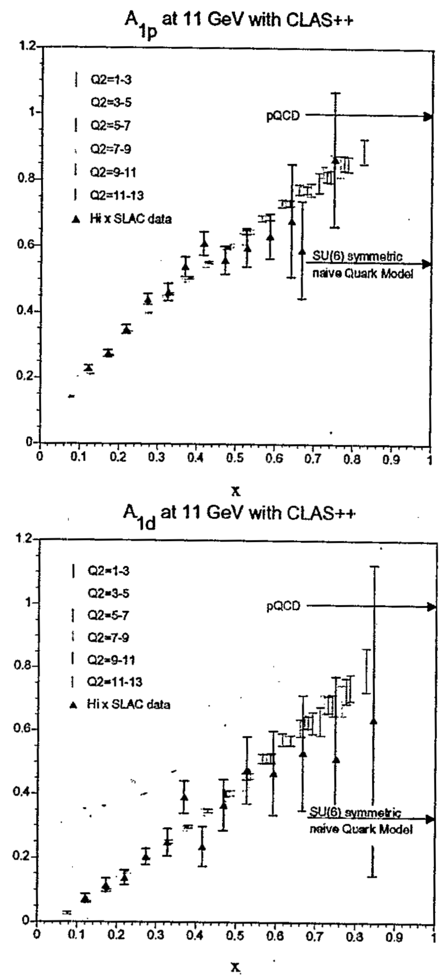
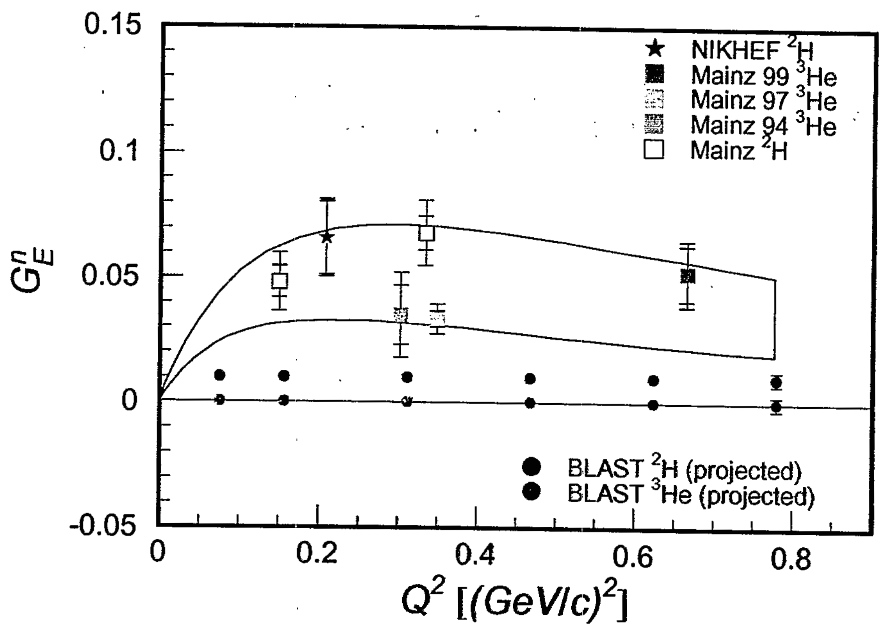
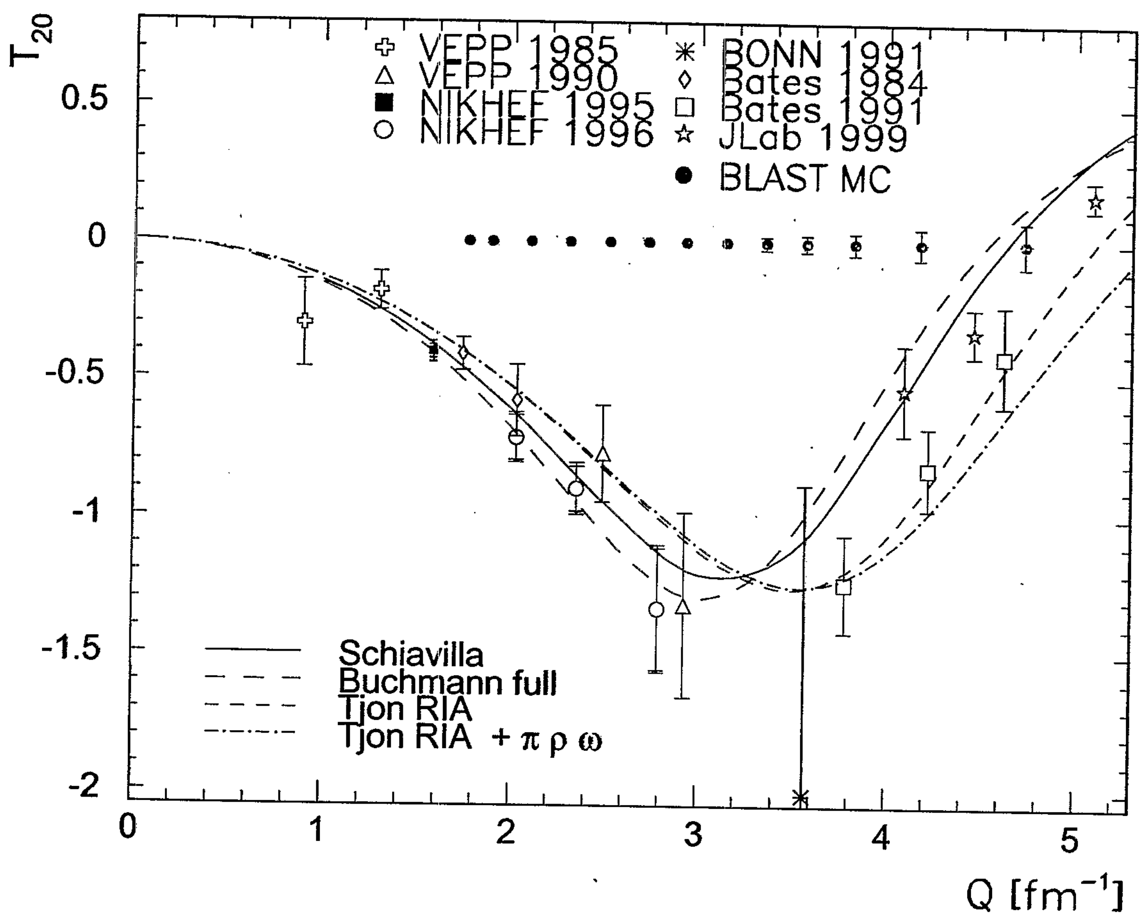


Figure 3. The projected statistical error for A_1^p (top) and A_1^D (bottom) from CLAS with 12 GeV beam at Jefferson Lab compared to existing SLAC data (E130, E143, E155). The errors are for 40 days of running. As indicated, the large acceptance of CLAS allows to gather data from several bins in Q^2 at each value of x_{Bj}.

9. E. Leader, A. V. Sidorov, and D. B. Stamenov, Int. J. Mod. Phys. **A 13** 5573 (1998).
10. See the presentation by X. Zheng at this workshop.



NIKHEF ²H
Mainz 99 ³He
Mainz 97 ³He
Mainz 94 ³He
Mainz ²H
BLAST ²H (projected)
BLAST ³He (projected)
G_E^n
0.15
0.1
0.05
0
-0.05
0
0.2
0.4
0.6
0.8
Q^2 [$(GeV/c)^2$]



T20
0.5
0
-0.5
-1
-1.5
-2
0
1
2
3
4
5
Q [fm^-1]
VEPP 1985
VEPP 1990
NIKHEF 1995
NIKHEF 1996
BONN 1991
Bates 1984
Bates 1991
JLab 1999
BLAST MC
Schiavilla
Buchmann full
Tjon RIA
Tjon RIA + π ρ ω