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QUARKS AND GLUONS IN THE NUCLEON

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Organizers

Toshiaki Shibata and Koichi Yazaki

RIKEN BNL Research Center

Building 510, Brookhaven National Laboratory, Upton, NY 11973, USA

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November 11, 1997 - Organizer - Miklos Gyulassy

Volume 4 - Inauguration Ceremony, September 22 and Non-Equilibrium Many Body Dynamics - BNL- 64912
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July 21 - August 22, 1997 - Organizers: T.L. Trueman and Elliot Leader

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June 23-27, 1997 - Organizer - Miklos Gyulassy

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Preface to the Series

The RIKEN BNL Research Center was established this April at Brookhaven National Laboratory. It is funded by the "Rikagaku Kenkysho" (Institute of Physical and Chemical Research) of Japan. The Center is dedicated to the study of strong interactions, including hard QCD/spin physics, lattice QCD and RHIC physics through nurturing of a new generation of young physicists.

For the first year, the Center will have only a Theory Group, with an Experimental Group to be structured later. The Theory Group will consist of about 12-15 Postdocs and Fellows, and plans to have an active Visiting Scientist program. A 0.6 teraflop parallel processor will be completed at the Center by the end of this year. In addition, the Center organizes workshops centered on specific problems in strong interactions.

Each workshop speaker is encouraged to select a few of the most important transparencies from his or her presentation, accompanied by a page of explanation. This material is collected at the end of the workshop by the organizer to form a proceedings, which can therefore be available within a short time.

T.D. Lee
July 4, 1997

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List of Participants

Name	*Institution*	`E-mail address`
Abe, Koya	Tohoku Univ., Japan	abek@awa.tohoku.ac.jp
Akimoto, Hidemi	Waseda Univ., Japan	akimoto@mn.waseda.ac.jp
Asakawa, Eri	Ochanomizu Univ., Japan	eri@fs.cc.ocha.ac.jp
Asakawa, Takashi	Univ. of Tsukuba, Japan	
Dokshitzer, Yuri	INFN, Milan, Italy	yuri@mi.infn.it
Fukuda, Tomokazu	KEK Tanashi, Japan	fukuda@jhfpc1.kek.jp
Goto, Yuji	RIKEN, Japan	goto@bnl.gov
Hamagaki, Hideki	CNS, Univ. of Tokyo, Japan	hamagaki@cns.s.u-tokyo.ac.jp
Horikawa, Yataro	Juntendo Univ., Japan	horikawa@sakura.juntendo.ac.jp
Ichihara, Takashi	RIKEN, Japan	ichihara@rikaxp.riken.go.jp
Ichikawa, Atsuko	Kyoto Univ., Japan	ichikawa@ne.scphys.kyoto-u.ac.jp
Imai, Kenichi	Kyoto Univ., Japan	imai@kytvax.scphys.kyoto-u.ac.jp
Imoto, Michiko	Nihon Univ., Japan	
Ishida, Muneyuki	Univ. of Tokyo, Japan	ishida@hep-th.phys.s.u-tokyo.ac.jp
Ishihara, Masayasu	RIKEN, Japan	ishihara@rikaxp.riken.go.jp
Ito, Sachiko	RIKEN, Japan	ito@rikaxp.riken.go.jp
Ji, Xiandong	Univ. of Maryland, USA	xdj@quark.umd.edu
Kanazawa, Yasunobu	Niigata Univ., Japan	yasu@nt.sc.niigata-u.ac.jp
Kawane, Fukashi	Nihon Univ., Japan	kawane@gaea.jcn.nihon-u.ac.jp
Kharzeev, Dmitri	RIKEN BNL Center, USA	kharzeev@bnl.gov
Kitagawa, Hisashi	Univ. of Tsukuba, Japan	kitagawa@rikaxp.riken.go.jp
Kodaira, Jiro	Hiroshima Univ., Japan	kodaira@theo.phys.sci.hiroshima-u.ac.jp
Kohama, Akihisa	Univ. of Tokyo, Japan	kohama@nt.phys.s.u-tokyo.ac.jp
Koike, Yuji	Niigata Univ., Japan	koike@nt.sc.niigata-u.ac.jp
Kumano, Shunzo	Saga Univ., Japan	kumanos@cc.saga-u.ac.jp
Kuriki, Masao	KEK Tanashi, Japan	mkuriki@insuty.tanashi.kek.jp
Kurita, Kazuyoshi	RIKEN, Japan	kurita@bnl.gov
Mao, Yajun	RIKEN, Japan	mao@rikaxp.riken.go.jp
Masaike, Akira	Kyoto Univ., Japan	masaike@kytvax.scphys.kyoto-u.ac.jp
Matsuda, Masanori	Hiroshima Univ., Japan	masa@ue.ipc.hiroshima-u.ac.jp
Matsuda, Tatsuro	Miyazaki Univ., Japan	matsuda@phys.miyazaki-u.ac.jp
Meng, Jie	RIKEN, Japan	meng@rikaxp.riken.go.jp
Mine, Takuma	Suginami-ku, Tokyo, Japan	
Miyama, Masanori	Saga Univ., Japan	96td25@edu.cc.saga-u.ac.jp
Miyashita, Takuya	Kyoto Univ., Japan	takuya@pn.scphys.kyoto-u.ac.jp
Mizuno, Yoshiyuki	RCNP, Osaka Univ., Japan	ymizuno@rcnp.osaka-u.ac.jp
Morii, Toshiyuki	Kobe Univ., Japan	morii@kobe-u.ac.jp
Naruki, Megumi	Kyoto Univ., Japan	naruki@pn.scphys.kyoto-u.ac.jp
Nasuno, Takashi	Hiroshima Univ., Japan	nasuno@theo.phys.sci.hiroshima-u.ac.jp
Nishiguchi, Fumiaki	RIKEN, Japan	

Name	*Institution*	`E-mail address`
Ohishi, Ryutaro	Univ. of Tsukuba, Japan	
Oka, Makoto	Tokyo Inst. of Technology, Japan	oka@th.phys.titech.ac.jp
Okamura, Hiroyuki	Univ. of Tokyo, Japan	okamura@phys.s.u-tokyo.ac.jp
Oyama, Ken	Univ. of Tokyo, Japan	oyama@nucl.phys.s.u-tokyo.ac.jp
Ozawa, Kyoichiro	Kyoto Univ., Japan	ozawa@pn.scphys.kyoto-u.ac.jp
Saito, Naohito	RIKEN, Japan	saitoh@rikaxp.riken.go.jp
Sakemi, Yasuhiro	Tokyo Inst. of Technology, Japan	sakemi@nucl.phys.titech.ac.jp
Schierholz, Gerrit	DESY, Germany	gsch@x4u2.desy.de
Shibata, Toshiaki	Tokyo Inst. of Technology, Japan	shibata@nucl.phys.titech.ac.jp
Tabaru, Tsuguchika	Kyoto Univ., Japan	tsugu@pn.scphys.kyoto-u.ac.jp
Takahashi, Hitoshi	Kyoto Univ., Japan	thitoshi@ne.scphys.kyoto-u.ac.jp
Takano, Shigemichi	Chiba-ken, Japan	
Taketani, Atsushi	RIKEN, Japan	taketani@rikaxp.riken.go.jp
Takeuchi, Sachiko	Med. and Den. Univ. of Tokyo, Japan	sachiko.hlth@med.tmd.ac.jp
Tanaka, Kazuhiro	Juntendo Univ., Japan	tanakak@phys.sakura.juntendo.ac.jp
Tochimura, Hiroshi	Hiroshima Univ., Japan	tochi@theo.phys.sci.hiroshima-u.ac.jp
Tojo, Junji	Kyoto Univ., Japan	tojo@ne.scphys.kyoto-u.ac.jp
Toki, Hiroshi	RCNP, Osaka Univ., Japan	toki@miho.rcnp.osaka-u.ac.jp
Tokushuku, Katsuo	KEK Tanashi, Japan	toku@tanashi.kek.jp
Torii, Hisayuki	Kyoto Univ., Japan	torii@nehpl.scphys.kyoto-u.ac.jp
Tsurugai, Tatsumasa	Meiji Gakuin Univ., Japan	tsurugai@gen.meijigakuin.ac.jp
Wakasa, Tomotsugu	RIKEN, Japan	wakasa@nucl.phys.s.u-tokyo.ac.jp
Watanabe, Yasushi	RIKEN, Japan	watanaby@rikaxp.riken.go.jp
Yamaji, Shuhei	RIKEN, Japan	yamajis@rikaxp.riken.go.jp
Yamanishi, Teruya	Fukui Univ. of Technology, Japan	yamanisi@rcnp.osaka-u.ac.jp
Yazaki, Koichi	Univ. of Tokyo, Japan	yazaki@phys.s.u-tokyo.ac.jp

Introduction

The Riken Symposium on "Quarks and Gluons in the Nucleon" was held on November 28 and 29, 1997 at Nishina Memorial Hall, Riken, Saitama, Japan. It had been approved as an activity at Riken of the RIKEN-BNL Research Center and can be regarded as one of the series of workshops which had so far been held at BNL.

The purpose of the symposium was to discuss the quark and gluon structure of the nucleon as probed experimentally by hard processes with lepton and hadron beams and studied theoretically by perturbative QCD, lattice QCD and effective models on the one hand and to stimulate research activities in the fields related to RHIC and RHIC-SPIN projects on the other hand.

We had 18 talks (7 experimental, 9 theoretical, an opening and a summary) and 2 discussion sessions. About 50 including 5 from abroad participated in the symposium.

The meeting was started by M.Ishihara, who stressed the importance of this kind of activities in his opening address. The first day was mainly devoted to the spin structure of the nucleon and we had a discussion session on "Experimental observables and theoretical definitions ".

Soon after the EMC result came out in 1987 there was an argument that the observed quantity is not purely the quark spin contribution but the quark spin cotribution modified by the gluon spin due to the Adler-Bell-Jackiw triangle anomaly. The first question in the discussion session was whether this re-interpretation is necessary or not. The answer was No. If one applies the re-interpretation the gluon spin contribution needs to be 2 or 3, which then has to be largely conpensated by the angular momentum in order to obtain back the spin 1/2 of the nucleon. One simply shifts the problem from one place to the other, and does not solve the nucleon spin problem itself by the re-interpretation.

It was also argued that the angular momentum which arises from the transverse momentum is not negligible even in a frame where the nucleon is flying with a high velocity. It was strongly requested to carry out experiments which provide informations on the gluon spin contribution to the nucleon spin. RHIC-SPIN is one of the promising candidates to do it. The hot discussion continued in the reception party in the evening.

The second day was mainly devoted to hard processes and lattice QCD, and the following questions were chosen for the discussion session.

(1) Are there any experimental indications for new physics beyond QCD ?

(2) To what extent can we rely on perturbative QCD ?

(3) What is physical meaning of the quenched approximation in the lattice QCD ?

The answer to the question (1) was clear and negative. Although there have been several results (event excesses in inclusive jet production and di-jet production at CDF experiments) which, at first sight, looked exotic, they seem to be explainable within the conventional framework and cannot be regarded as evidence for new physics.

There were some discussions on the question (2). The underlying assumption in analyzing hard processes is the validity of the factorization theorem in the region of several GeV to 1 TeV but it becomes more and more difficult to justify the assumption when the process involves more and more structure functions and fragmentation functions. In the small x experiments at ZEUS/HERA, Q^2 becomes also small. In treating the perturbative parts, it was not clear to which order the perturbative expansion would make sense. A general consesus seemed to be that the so-called next-to-leading-order calculations were still meaningful.

The question (3) was chosen since the lattice structure function calculations had been and in the near future would be possible only in the quenched approximation. It was argued that the approximation was not the valence quark approximation but it was not clear whether the sea quark effects were treated in a systematic way.

We will not repeat here what were discussed in the invited talks since each speaker has given us an excellent summary in the form of 5 most important transparencies and a one-page explanation, the assembly of which constitute the main part of this proceedings. We had lively and intensive discussions on all the talks.

Finally, we would like to thank the RIKEN-BNL Research Center and its director, Prof. T.D.Lee, for approving this symposium and the RIKEN Project Office for making it possible. We are also grateful to the Advisory Committee for many important suggestions and comments at the stage of making the scientific program, all the speakers for their stimulating talks and all the participants for interesting discussions. Special thanks are due to those who helped us in the registration, microphone services etc. during discussions and coffee breaks. Thanks to Brookhaven National Laboratory and to the U.S. Department of Energy for providing facilities.

Toshi-Aki Shibata and Koichi Yazaki

Recent Topics On
The Nucleon Spin Structure

X. D. Ji

1. From the polarized DIS data, one can extract the fraction of the nucleon spin carried by quark and gluon helicities: $\Delta\Sigma = 0.2 \pm 0.1$, $\Delta G = 1.0 \pm 1.0$ at $Q_0^2 \sim 1\ \text{GeV}^2$.

2. Small value of $\Delta\Sigma$ indicates a significant sea quark polarization. $p + \vec{p} \to W^{\pm} X$ at RHIC provides a clean process to probe it.

3. Gluon helicity ΔG grows logarithmically with the probing scale. Direct γ production at RHIC is a promising process to probe ΔG.

4. Orbital angular momentum evolution equation has been worked out by Ji, Tang & Hoodbhoy. It has interesting implications.

5. Quark & gluon orbital angular momentum may be probed in the deeply virtual Compton process.

- Available DIS Data

	Target	$\langle Q^2 \rangle$ (GeV²)
EMC	p	10
SMC	p, d	10
E142	^{3}He	2
E143	p, d	3
E154	^{3}He	5
E155	p, d	5
HERMES	^{3}He, p	3

- FITS:
  - Neglect higher-twist
  - Parametrize x dependence at $Q^2 = Q_0^2$
  - Next-to-leading order evolution in Q^2.
  - Constraints from β-decay + SU(3) symmetry.

- RESULTS:

  Parametrization-dependent (low x region)

  $\Delta\Sigma$ = [illegible] ± [illegible] ... Δ[illegible] = [illegible] ± [illegible]

  ΔG = [illegible] ± [illegible]

  [illegible]

SEA QUARK POLARIZATION

$$\Delta\Sigma = \Delta u + \Delta d + \Delta s + \Delta\bar{u} + \Delta\bar{d} + \Delta\bar{s} \doteq 0.2$$

Using β-decay result:

$$\Delta u + \Delta d - 2\Delta s + \Delta\bar{u} + \Delta\bar{d} - 2\Delta\bar{s} = 0.57$$

$$\Rightarrow \quad \underline{\Delta s + \Delta\bar{s} = -0.12}$$

★ There is a Significant Sea Contribution to $\Delta\Sigma$. ($\Delta\Sigma = \Delta\Sigma_v + \Delta\Sigma_s$, $\Delta\Sigma_v \sim \Delta\Sigma_{QM}$)

Looking for Sea quark pol.:

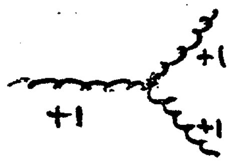
- SMC Semi-inclusive data
  large error
- HERMES Semi-inclusive data

- RHIC spin*
  $\vec{p} + \vec{p} \longrightarrow W^{\pm} + X$
  Clean

$\Delta G(Q^2)$ DEPENDS STRONGLY ON THE RESOLUTION SCALE:

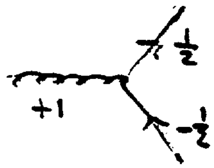
$$\Delta G(Q^2) \sim \ln Q^2 \xrightarrow{Q^2\to\infty} \infty$$

Consider a gluon of helicity +1 at Scale Q_0^2. At $Q^2 > Q_0^2$, the internal structure of the gluon is probed.

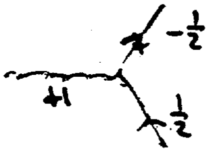


+1 $\qquad \int_0^1 \frac{dx}{x(1-x)}$

−1 $\qquad \int_0^1 dx \left(\frac{x^2}{1-x} + \frac{(1-x)^2}{x}\right)$



−1 $\qquad \frac{n_f}{2} \int_0^1 x^2 dx$



−1 $\qquad \frac{n_f}{2} \int_0^1 (1-x)^2 dx$

Net change of helicity from $Q_0^2 \to Q^2$:

$$\Delta h\,(Q_0^2 \to Q^2) \sim 11 - \frac{2n_f}{3} = \beta_0 > 0$$

if QCD is asymptotically free

Evolution Eq.

$$\frac{d}{d\ln Q^2}\begin{pmatrix} L_q \\ L_g \end{pmatrix} = \frac{\alpha_s}{2\pi}\begin{pmatrix} -\frac{4}{3}C_F & \frac{n_f}{3} \\ \frac{4}{3}C_F & -\frac{n_f}{3} \end{pmatrix}\begin{pmatrix} L_q \\ L_g \end{pmatrix}$$

$$+ \frac{\alpha_s}{2\pi}\begin{pmatrix} -\frac{2}{3}C_F & \frac{n_f}{3} \\ -\frac{5}{6}C_F & -\frac{11}{2} \end{pmatrix}\begin{pmatrix} \Delta\Sigma \\ \Delta G \end{pmatrix}$$

- Complementary to DGLAP Equation for $\Delta\Sigma$ & ΔG. Completely determine the evolution of the nucleon Spin Structure.

- Conservation Law.

$$\frac{d}{d\ln Q^2}\left(\frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g\right) = 0$$

- Asymptotic Solution

  $Q^2 \to \infty$

$$\frac{1}{2}\Delta\Sigma + L_q = J_q = \frac{1}{2}\frac{3n_f}{16+3n_f} \sim \frac{1}{4}$$

$$\Delta G + L_g = J_g = \frac{1}{2}\frac{16}{16+3n_f} \sim \frac{1}{4}$$

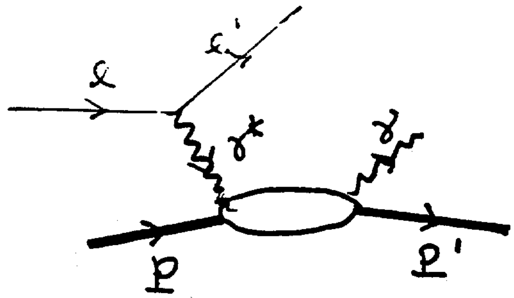
  — half of the helicity carried by gluons!

  — $\ln Q^2$ growth of ΔG is cancelled by L_g.

Deeply Virtual Compton Scattering

X.D.: '97 Phys.Rev.Lett

- Virtual Compton process

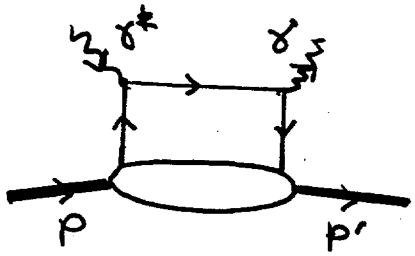


- Deeply Virtual limit

Virtual photon in Bjorken Limit

$$\begin{cases} Q^2 = -q^2 \to \infty \\ q^0 \to \infty \end{cases} \qquad Q^2/q^0 \to \text{fixed}$$

"Single-quark Scattering"



- **BRAHMS** has two arms; one for central region and another for forward angular region. Its uniqueness is in the wide rapidity coverage with the both arms.

- **STAR** has TPC (time projection chamber) as a central tracking device, and SVT (silicon vertex tracker) placed near the colliding region. Event-by-event analysis is possible to determine particle yields and particle spectra. STAR has great sensitivity in the event-by-event topologies.

- **PHENIX** has four arms; two central arms for measuring electrons and photons as well as hadrons, and two muon arms for measuring muon-pairs. PHENIX tries to cover as many observables as possible, in order to address the relevant QGP signatures.

4 Physics Observables

Many QGP signatures have been proposed. A few of the observables are picked up here, which we will be able to study extensively at RHIC.

Particle yields and spectra are the ones which we will measure in the first days when the experimental run starts at RHIC. They are the basic quantities which reflects upon the initial conditions of the colliding system. Rather large variation still exists in the prediction of the particle yields among the model calculations, and theorist have started working on this in order to investigate the causes of this difference.

Property of low-mass vector mesons are considered to change in the hadronic environment due to the (partial) chiral-symmetry restoration. Enhancement in the low-mass region in the invarient spectrum of electron-positron pairs in the CERN-SPS NA45 experiment with S and Pb beams has been reported, and one possible interpretation is with the mass shift of ρ meson.

J/ψ suppression has been the hot topic in the heavy ion studies, and the new results with Pb beams by the NA50 collaboration clearly deviates from the tendency expected from the ones with proton and S beams. So far, sufficient explanations are not given to this by the models based on the hadronic intereactions.

RHIC Project and Heavy Ion Program

Hideki Hamagaki
Center for Nuclear Study (CNS)
School of Science, University of Tokyo
(hamagaki@cns.s.u-tokyo.ac.jp)

1 Introduction

Primary goal of High Energy Heavy Ion Collisions is to study nuclear matter at extreme conditions, such as high temperature and/or high baryon density. Ultimately, we would hope to reveal and investaige the new phase of nuclear matter; quark gluon plasma (QGP), existence of which is predicted by the lattice-QCD calculations. Recent lattice-QCD calculations predict the critical temperature of $\approx$ 150 MeV. The order of phase transtion is still not well established.

The study has intimate connection to Cosmology; the phase transition from QGP pahse to hadron phase would occur around 10-100 micro-seconds after the Big Bang. If the order of the phase transition is first-order, the phase transition could be the cause of primordial black holes and strage nuggets, both of which have beeen considered to be the dark-matter candidates. It has also been argued that the phase transition would affect the Big Bang Nucleosynthesis. Neutron stars are another object; interim structure has been the hot topics.

2 RHIC

RHIC (Relativistic Heavy Ion Collider) is the first collider of heavy ions dedicated to the studies of heavy ion programs, and is now under construction at Brookhaven Nation Laboratory, USA. RHIC has two independent rings with circumferrence of about 3.8 km. Collisions of Au ions with maximum energy of 100 GeV/nucleon will become possible. Maximum energy (per ring) is 250 GeV in case of proton beams, and the asymmmetric collisions such as p + A may also be possible. RHIC will be completed in early 1999.

3 Experiments at RHIC

There are four approved experiments at RHIC: the large-scale ones are STAR and PHENIX, and the small-scale ones are PHOBOS and BRAHMS.

- **PHOBOS** is literally a table-top-sized experiment with the silicon drift chambers as tracking devices. Its size makes it possible to measure particles with small momentum, which is unique among the experiments.

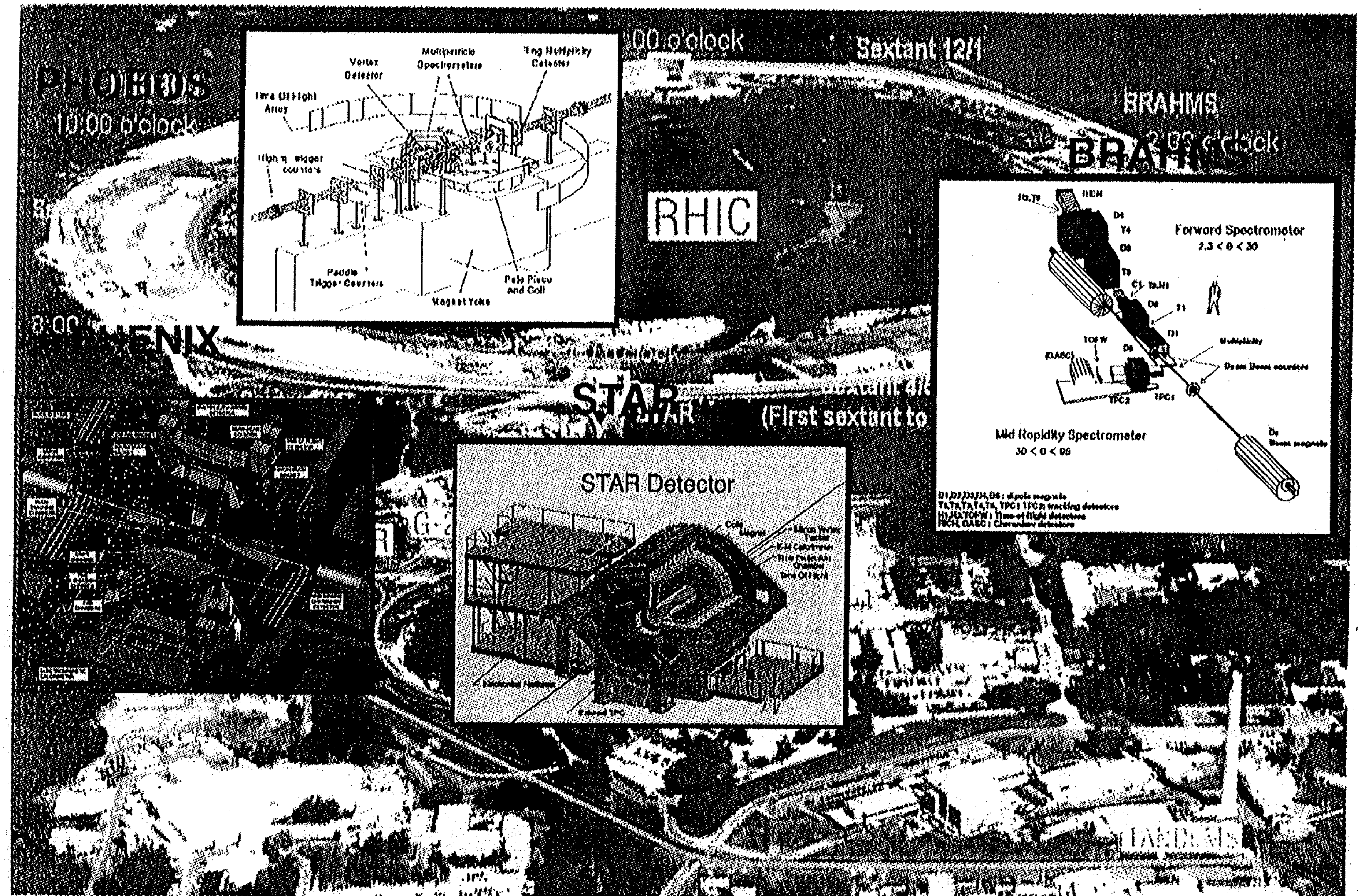
Hamagaki

Summary

- Primary goal of High Energy Heavy Ion Collisions
  - Relation to cosmology
  - Lattice-QCD results
- Brief Introduction of RHIC project
  - energy, luminosity
  - expected initial energy density
- RHIC Experiments
  - PHENIX, STAR, PHOBOS, BRAHMS
  - Interesting measurements

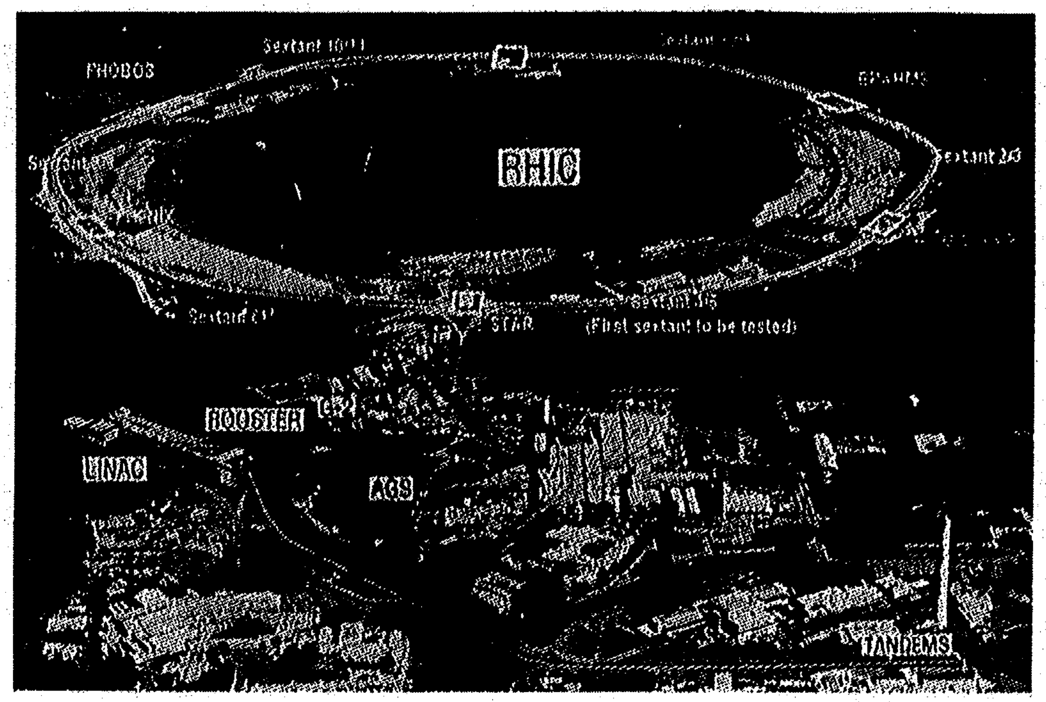
Observables and Signatures at PHENIX

- Reaction Dynamics and Equilibration
  - net baryon number, particle yields ----- baryon/energy stopping
  - particle spectra ----- freezeout temperature, transverse flow
  - strangeness production ----- chemical equilibrium
- Nature of Phase Transition
  - First order
    - second rise in p_T <-- latent heat
    - $dN/dy d\phi$ large-scale fluctuation <-- super-cooling
    - large source size and τ from HBT <-- lifetime of mixed phase
    - ρ meson ($\rightarrow \ell^+ \ell^-$) enhancement <-- lifetime of mixed phase
  - Second order
    - isospin fluctuations; $N(\pi^0)/(N(\pi^+)+N(\pi^-))$
- J/ψ, ψ', Υ suppression ----- Debye Screening
- Vector meson properties (ρ, ω, ϕ) ----- Chiral Symmetry Restoration
- Thermal Radiation ----- system evolution: T & life time
- Jet Quenching ----- energy loss in QGP and hadron gas


PHOBOS
10:00 o'clock
Sextant 12/1
BRAHMS
2:00 o'clock
BRAHMS
RHIC
PHENIX
STAR
(First sextant to
Vertex Detector
Multiparticle Spectrometer
Ring Multiplicity Detector
Paddle Trigger Counters
Pole Piece and Coil
Magnet Yoke
Forward Spectrometer
Mid Rapidity Spectrometer
STAR Detector

RHIC (Relativistic Heavy Ion Collider) at BNL, USA

- Two rings (length ~3.8 km)
- To be completed in 1999
- The first colliding machine primarily for heavy ion physics



	CM Energy
Au + Au	200 AGeV
p + p	500 GeV

p + A is also possible

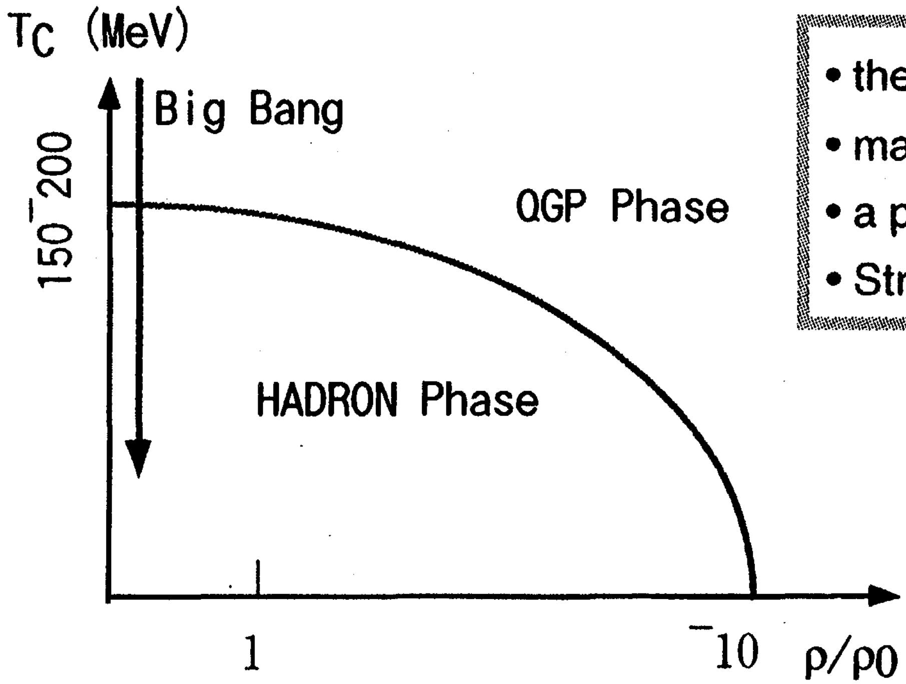
Physics Program
Heavy Ion Physics
Polarized proton

Primary Goal of Relativistic Heavy Ion Collisions

- Study of nuclear matter at extreme conditions

  Ultimate goal = Quark gluon plasma (QGP)

  We know very little on the properties of the nuclear matter, except a narrow region around ($\rho = \rho_0$; $T = 0$)



- theoretical guidance = lattice-QCD
- many body problem of soft-QCD
- a part of modern Hadron Physics
- Strong relation with cosmology

SPIN Experiments at PHENIX

Yajun Mao†
Radiation Laboratory, RIKEN
Wako, Saitama 351-01, Japan
E-mail: mao@rikaxp.riken.go.jp

The Relativistic Heavy Ion Collider (RHIC) is under construction and will be completed before the end of this century at Brookhaven National Laboratory. Besides heavy ion collision, RHIC will also provide us polarized proton-proton collision up to $\sqrt{s}$=500GeV at a high luminosity of $2\times10^{32}\text{cm}^{-2}\text{sec}^{-1}$. The polarization rate will be as high as 70%. This offers an unique opportunity for us to study spin physics at RHIC. Our major goals of the spin physics study at RHIC are elucidation of the spin structure of the nucleon and precise tests of the symmetries.

The PHENIX detector system is one of the two large detector systems at RHIC. Its basic design concept is to detect photons and leptons with high momentum resolution and low background. The detector system may be described as a spectrometer covering the central rapidity region (Central Arm) and two endcap muon spectrometers (Muon Arms). The Central Arm is composed of several charge particle tracking subsystems, RICH and TOF for particle identification and electromagnetic calorimeters to measure photon and electron with fine segmentation. A test experiment at KEK to investigate the performance of PHENIX muon identifier has verified its pion/muon rejection capability obtained from simulation. The powerful capability to detect lepton , photon and hadron of PHENIX ensures to us precise measurements of the physical processes related to spin physics at RHIC.

Since hadron reactions with photon or lepton final states, such as prompt photon production and lepton production through weak boson production, play major roles in spin physics, the PHENIX is suitable for the spin physics at RHIC. We will study the gluon inside a nucleon as a spin carrier via the prompt photon production, open heavy quark and heavy quarkonium productions, and jet productions. The flavor-tagged anti-quark polarization can be studied through the $W^{\pm}$ production and inclusive anti-quark polarization can be investigated via Drell-Yan process. Moreover, the parity violation will be studied for various reaction channels. With several simulation calculations and a test experiment, we have studied the capability of the PHENIX detector for the spin physics. Based on these studies, the scope of the spin physics with the PHENIX detector system is presented.

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†Permanent Address: *China Institute of Atomic Energy, P. O. Box 275(49), Beijing 102413, China*

Spin Experiments at PHENIX

Yajun Mao
RIKEN/CIAE

1. Spin physics ---- a hot issue

- *Why spin physics?*
- *"Spin Crisis"*
- *How to Measure Spin at PHENIX*

2. PHENIX at RHIC

- *Overview of the PHENIX Detector System*
- *Momentum Resolution of Muon Tracking*
- *The Performance of PHENIX Muon ID*

3. Measure Spin at PHENIX

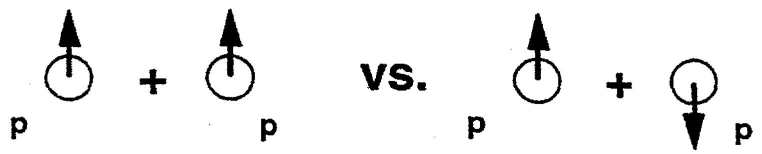
- *Approach to Access Spin Structure Function*
- *Measurement of Gluon Polarization*
- *Measurement of Anti-quark Polarization*
- *Other Possible Measurement*

4. Summary

How to Measure Spin at PHENIX

$E \leq 250$ GeV

- Always compare



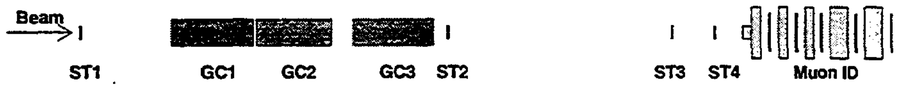
and measure asymmetry.

- Polarization can be longitudinal or transverse *(A_{LL} , A_{TT})*
- Single spin asymmetry(e.g., $p^{\uparrow} + p$ or $p^{\uparrow} + A$) can also be studied *(A_L , A_N)*

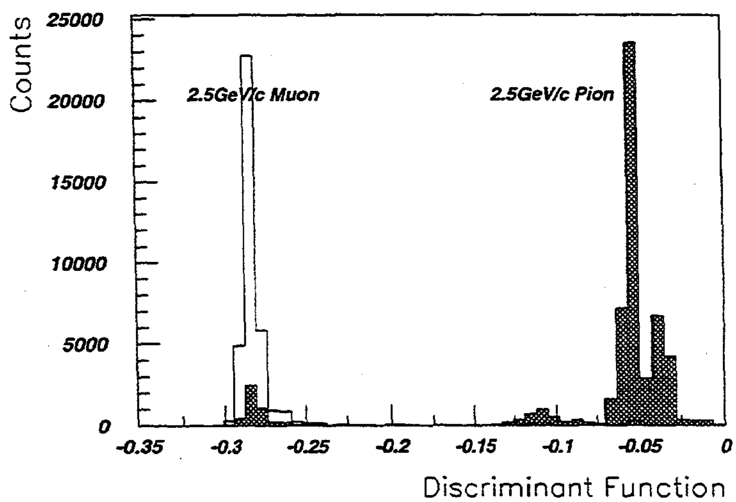
Typical Examples

- gluon + gluon ⟶ jet + jet
- gluon + quark ⟶ high-energy γ
- quark + anti-quark ⟶ $\mu^+\mu^-$ (Drell-Yan)
  ⟶ $W^{\pm} \rightarrow e^{\pm}$ (or $\mu^{\pm}$) $+\nu$
  ⟶ $Z^0 \rightarrow \mu^+\mu^-$

KEK Muon ID Test for PHENIX Experiment



Experimental Setup



$$DF=\sum c_i x_i + \sum a_{ij} x_i x_j$$

Last_Plane
Num_Tube
Max_Num
BF_Ratio
X_Chi
Y_chi

Discriminant Analysis with Quadratic Function

Gluon Helicity Distribution: Δg

asymmetry	measure	$\sqrt{s}$	detector required*
$A_{LL}(pp \to \gamma X)$	$\Delta g \times g_1$	200/500 GeV	EMCal+Trk
$A_{LL}(pp \to \pi^0 X)$	$\Delta g \times \Delta g / \Delta g \times \Delta q$	200/500 GeV	EMCal
$A_{LL}(pp \to c\bar{c}X)$	$\Delta g \times \Delta g$	200 GeV	Muon+EMCal
$A_{LL}(pp \to b\bar{b}X)$	$\Delta g \times \Delta g$	500 GeV	Muon+EMCal
$A_{LL}(pp \to \text{quarkonium}X)$	$\Delta g \times \Delta g$	200/500 GeV	Muon+EMCal

Anti-quark Helicity Distribution: $\Delta\bar{q}$

asymmetry	measure	$\sqrt{s}$	detector required*
$A_{LL}(pp \to \gamma^* X)$	$\Delta q \times \Delta\bar{q}$	50(?) GeV	Muon
$A_L(pp \to W^+ X)$	$\Delta u, \Delta\bar{d}$	500 GeV	Muon/EMCal
$A_L(pp \to W^- X)$	$\Delta d, \Delta\bar{u}$	500 GeV	Muon/EMCal

Flavor Decomposition of Quark/Anti-quark Helicity Distribution: $\Delta q_i/\Delta\bar{q}_i$

asymmetry	measure	$\sqrt{s}$	detector required*
$A_L(pp \to W^+ X)$	$\Delta u, \Delta\bar{d}$	500 GeV	Muon/EMCal
$A_L(pp \to W^- X)$	$\Delta d, \Delta\bar{u}$	500 GeV	Muon/EMCal

Quark/Anti-quark Transversity Distribution: $\delta q/\delta\bar{q}$

asymmetry	measure	$\sqrt{s}$	detector required*
$A_{TT}(pp \to \gamma^* X)$	$\delta q \times \delta\bar{q}$	50-500 GeV	Muon

Parity Violation in Standard Model and in Beyond SM

asymmetry	measure	$\sqrt{s}$	detector required*
$A_L(pp \to \text{jet}X)$	compositeness scale	500 GeV	EMCal+Trk
$A_L(pp \to \gamma^*/ZX)$	γ/Z interference	500 GeV	Muon

Higher twist effects in Polarization Phenomena

asymmetry	measure	$\sqrt{s}$	detector required*
$A_N(pp \to \gamma X)$	higher-twist	200/500 GeV	EMCal+Trk
$A_N(pp \to \gamma^* X)$	higher-twist	50-500 GeV	Muon
$A_N(pp \to \pi^0 X)$	higher-twist	200/500 GeV	EMCal

TABLE II. Spin physics with PHENIX detector system. In the column of "detector required", BB and MVD are always assumed.

Summary

- Polarized Proton Program with PHENIX Detector System will provide a unique information on:
  - the spin structure of the proton
    ΔG, $\Delta qbar$
  - symmetry tests
  - QCD selection rule
  - Single transverse spin asymmetry
- PHENIX activites for Spin Physics
  - detector construction is progressing
  - physics working groups established
- Continual Support from Theorists Needed!
- RHIC Operation will start from October, 1999!

New SMC result on the spin structure function $g_1(x)$ of the proton

on behalf of Spin Muon Collaboration (CERN NA47)
Tatsuro MATSUDA
Faculty of Engineering, Miyazaki University

A new measurement of the virtual photon proton asymmetry A_1^p from deep inelastic scattering of polarized protons in the kinematic range $0.0008 < x < 0.7$ and $0.2 < Q^2 < 100GeV^2$ was done by Spin Muon Collaboration (CERN NA47) last year(1996)[1]. Adding this new data to our previous data(1993), the statistical uncertainty of our measurement has improved by a factor of 2. The spin-dependent structure function g_1^p is determined for the data with $Q^2 > 1GeV^2$. The precision of the data and the available Q^2 range do not allow a direct determination of the Q^2 dependence of A_1^p, therefore the Q^2 dependence of g_1^p is estimated from a perturbative QCD evolution in next-to-leading order in the Adler-Bardeen scheme as performed in our previous publications [2] and we determine $g_1^p(x)$ at a constant Q^2. At $Q^2 = 10GeV^2$, in the measured range we find,

$$\int_{0.003}^{0.7} g_1^p(x)dx = 0.139 \pm 0.006(stat) \pm 0.008(stys) \pm 0.006(evolv).$$

At the unmeasured high x range, we assume constant $A_1^p = 0.7 \pm 0.3$ which is consistent with the data and cover the upper bound $A1 \leq 1$, we obtain

$$\int_{0.7}^{1} g_1^p(x)dx = 0.0015 \pm 0.0006.$$

For the unmeasured low x range, we consider two approaches. First, the behavior of g_1^p is consistent with a Regge behavior $g_1^p \sim x^{-\alpha}$ and we assume g_1^p =constant at $10GeV^2$. The constant, 0.69 ± 0.14, obtained from the three lowest x data points, leads to

$$\int_{0}^{0.003} g_1^p(x)dx = 0.002 \pm 0.002 \ (Regge\ assumption).$$

Second, alternatively we calculated the low x integral from the QCD fit which is already done in the Q^2 evolution and this is

$$\int_{0}^{0.003} g_1^p(x)dx = -0.011 \pm 0.011 \ (QCD\ analysis).$$

The uncertainty in the low x integral is obtained using the same procedure as for the estimation of the uncertainty in the QCD evolution and gives rather big one. Finally we obtained the corresponding values for the first moment

$$\Gamma_1^p(Q_0^2 = 10GeV^2) = \int_0^1 g_1^p(x)dx = 0.142 \pm 0.006(stat) \pm 0.008(syst) \pm 0.006(evolv) \ (Regge).$$

$$\Gamma_1^p(Q_0^2 = 10GeV^2) = 0.130 \pm 0.006(stat) \pm 0.008(syst) \pm 0.014(evolv) \ (QCDanalysis).$$

respectively. We find that the Ellis-Jaffe sum rule is violated. We confirm the Bjorken sum rule at the one standard deviation level.

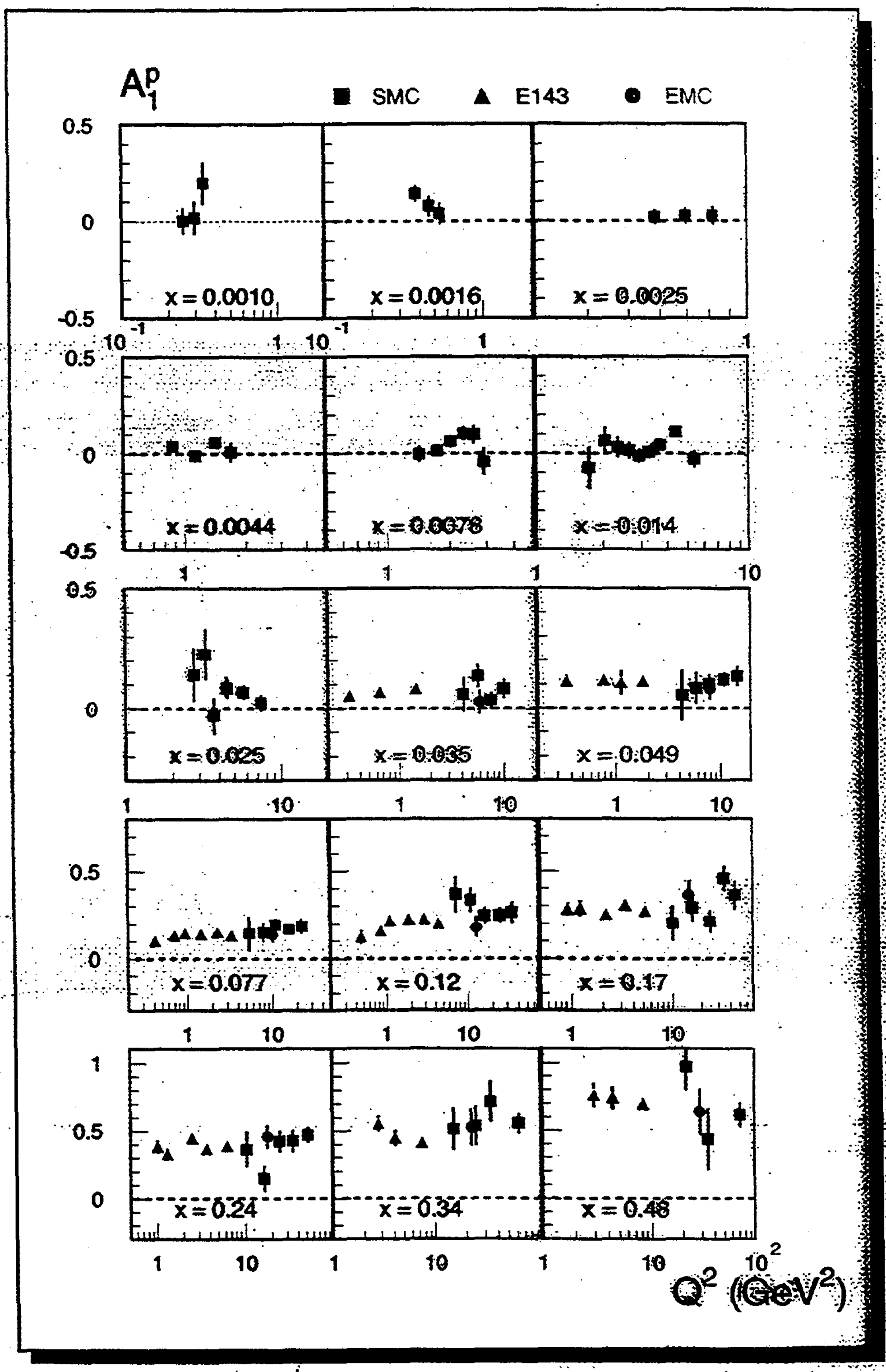
References

[1] B. Adeva et al., Phys.Lett.B412(1997)414.

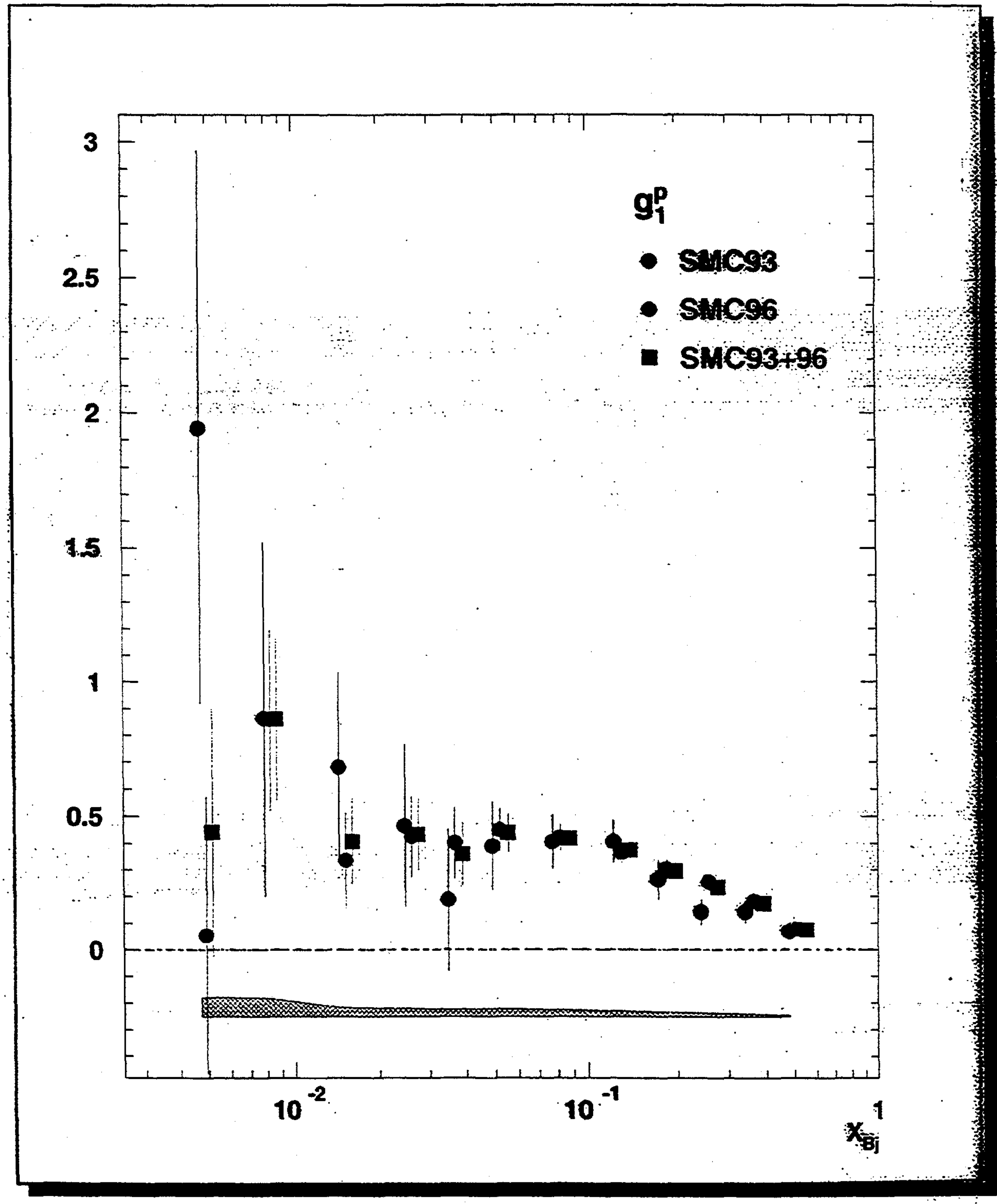
[2] D. Adams et al., Phys.Rev.D56(1997)5330.

T. Matsuda

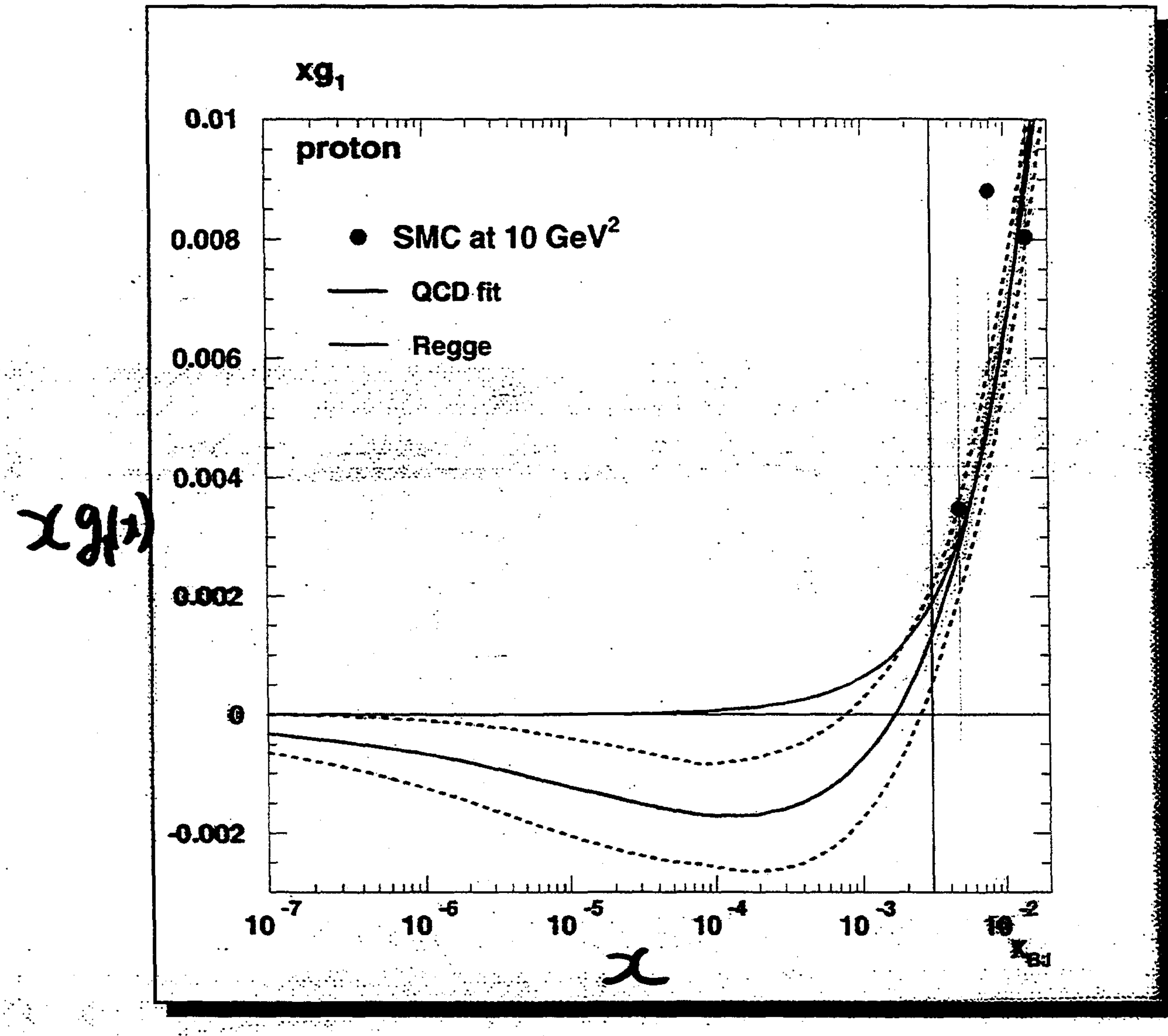
A_1^p vs Q^2



g_1 vs x



Low x extrapolation



- Contribution to 1st moment (at Q_0^2=10GeV^2)
  (0.0 < x < 0.003)

$$\int_{0.0}^{0.003} g_1^p\left(x, 10\mathrm{GeV}^2\right)dx = \begin{cases} 0.002 \pm 0.002 \text{ (Regge)} \\ \quad : 100\% \text{ uncertainty} \\ -0.011 \pm 0.011 \text{ (QCD)} \\ \quad : \text{from error analysis} \end{cases}$$

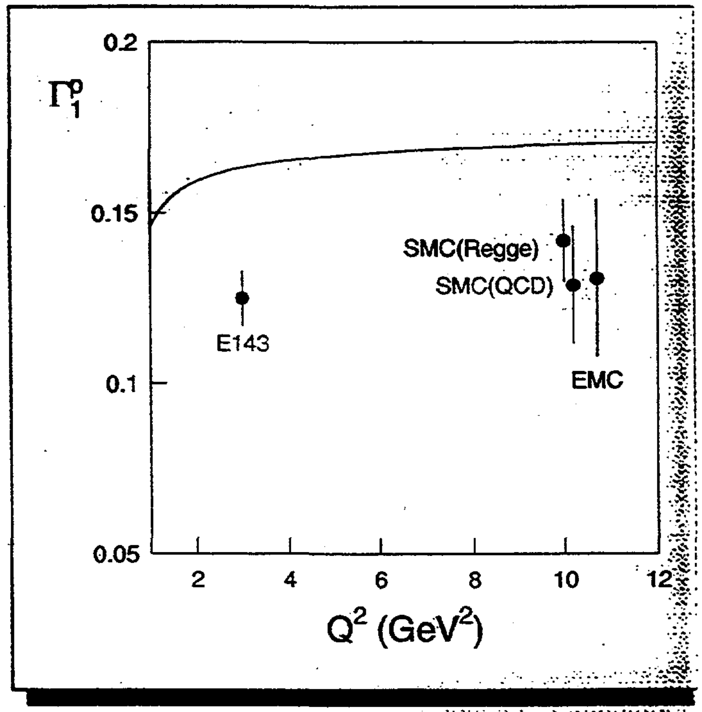
Sum rules

at $Q_0^2 = 10 GeV^2$

$$\Gamma_1^p\left(10GeV^2\right) = \begin{cases} 0.142 \\ 0.130 \end{cases} \pm 0.006 \pm 0.008 \pm 0.014 \begin{matrix} (\text{Regge}) \\ (\text{QCD}) \end{matrix}$$

- <u>Ellis-Jaffe sum rule</u>

$\Gamma_1 p = 0.170 \pm 0.004$:Theory



- <u>Bjorken sum rule</u>

$\Gamma_1 p - \Gamma_1 n = 0.186 \pm 0.003$: Theory

SMC deuteron (Phys. Lett. B396 (1997) 338)

$\Gamma_1 d = 0.041 \pm 0.008$ (Regge assumption)

$\Gamma_1 p - \Gamma_1 n = 0.195 \pm 0.029$ (Regge)

We obtained consistent result with an accuracy of 15%.

Gluon contribution

• In QCD improved QPM (AB-scheme) :

$$a_0(Q^2) = \Delta\Sigma - n_f \frac{\alpha_s(Q^2)}{2\pi} \Delta g(Q^2)$$

Assumption $a_s = 0$, $\Delta\Sigma = a_u + a_d + a_s = a_8$

from $a_0 = 0.34 \pm 0.17$ (Regge)
$a_0 = 0.22 \pm 0.17$ (QCD)

$$2 < \Delta g\ (10\text{GeV}^2) < 3$$

• **NLO QCD Analysis :**

$\Delta g(1\text{GeV}^2) = 0.9 \pm 0.3(\text{exp.}) \pm 1.0(\text{theory})$

$$\Delta g(10\text{GeV}^2) \approx 1.7$$

$\Delta g > 0$ with large uncertainty

Recent results from polarized deep inelastic scattering at SLAC

M. Kuriki

Summary:

The Deep Inelastic Scattering, DIS between polarized leptons and polarized nucleus is a powerful tool to study the spin of nucleon. The spin-dependent structure functions, g1 and g2 are extracted from the cross section asymmetry of the polarized DIS.

SLAC has a long history of DIS experiments. In 1976, the first polarized DIS experiment, E80 was carried out. In 1992, the first measurement of the neutron spin structure functions was performed using the polarized 3He gas target. In 1993, E143 collaboration measured the spin structure functions of proton and deuteron with the various beam energy to study its Q2 dependence. In 1995, E154 collaboration measured the neutron spin structure again with the higher accuracy and higher energy beam than those for E142. In 1997, E155 collaboration measured the proton and deuteron spin structure functions with the higher beam energy than that for E143.

Both for E143 and E154, the polarized electron was produced by the strained GaAs photo-cathode. The electron polarization was up to 85%. The polarized electron was accelerated by the two mile length Linac up to 29 or 48 GeV without any depolarization. The target was placed in ESA experimental hall. The scattered electron was observed by a couple of the single arm spectrometers.

From E143 results, g1/F1 was found to be independent of Q2 where Q2>1.0 (GeV/c)^2, so that we combined the data at Q2>1.0 (GeV/c)^2 which have different Q2 under this assumption.

The integral of g1 at Q2=3.0 (GeV/c)2 was determined. The integrals of proton and deuterium were not consistent with the prediction of Ellis-Jaffe. The Bjorken sum rule was confirmed.

Total quark spin content was determined to be 0.32+-.10 from proton data and 0.38+-.08 from deuteron data. The strange sea polarization was found to be significantly negative.

g2 of proton and deuterium were measured and well described by g2ww.

g1 in the resonance region was studied. It was the first determination of g1 integral at Q2 below 2.0 (GeV/c)^2.

From E154 results, g1 of neutron at Q2=5.0 (GeV/c)^2 down to x=0.02 was determined, but it was hard to determine the integral due to the strong x dependence at low x.

A2 of neutron was significantly smaller than the sqrt(R) positivity limit over most of the measured range. g2 is generally consistent with g2ww.

E155 performed the experiment of DIS of 48 GeV electron beam off LiD or NH3 target. The analysis is in progress. E155 was approved an extension to take g2 data. This will be a two month dedicated run in 1999.

M. Kurtz

Integrals

- Square approximation for the measured region. $(0.03 < x < 0.8)$.
- Regge type extrapolation, $g_1 \propto x^{\alpha}(0 < \alpha < 0.5)$ toward $x = 0$.
- Extrapolation with $g_1 \propto (1-x)^3$ toward $x = 1$.
- We take $\alpha_s(M_Z) = .118 \pm .003$ and $3F - D = .58 \pm .032$ for the theoretical inputs.

	Measured $\int_{0.03}^{0.8} g_1 dx$	high x $\int_{0.8}^{1.0} g_1 dx$	low x $\int_{0}^{0.03} g_1 dx$	Total $\int_0^1 g_1 dx$	Theory $\int_0^1 g_1 dx$
Proton	$+.121 \pm .003 \pm .006$	$+.001 \pm .001$	$+.011 \pm .007$	$+.133 \pm .003 \pm .009$	$+.159 \pm .005$
Deuterium	$+.045 \pm .003 \pm .003$	$+.001 \pm .001$	$+.001 \pm .006$	$+.047 \pm .003 \pm .006$	$+.065 \pm .004$
Neutron	$-.024 \pm .008 \pm .006$	$+.001 \pm .001$	$-.010 \pm .015$	$-.032 \pm .008 \pm .016$	$-.018 \pm .004$
Bjorken	$+.143 \pm .009 \pm .010$	$+.001 \pm .001$	$+.021 \pm .018$	$+.165 \pm .009 \pm .021$	$+.177 \pm .004$

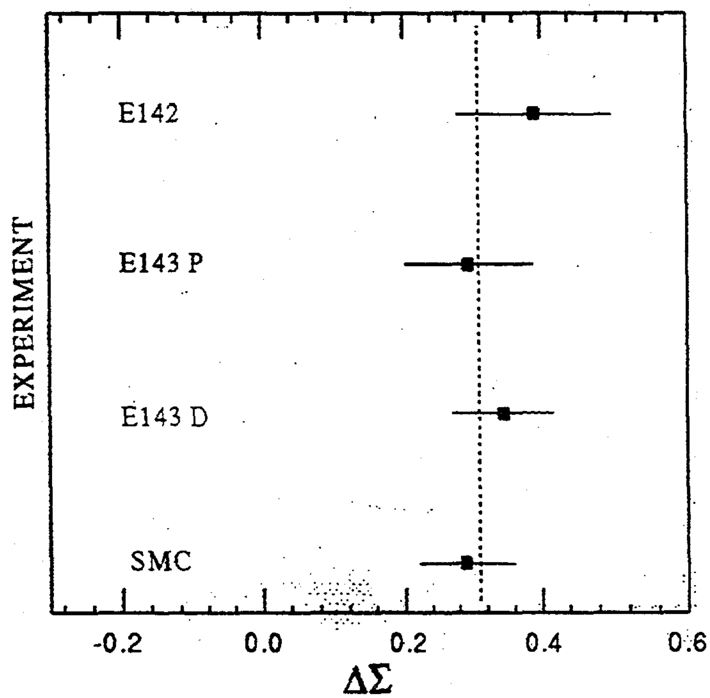
- Ellis-Jaffe sum rules for Proton and Deuteron are violated.[1]
- Bjorken sum rule is consistent to our result.

Quark Spin

- Quark spins evaluated by Q^2 dependent pQCD [illegible] corrections.

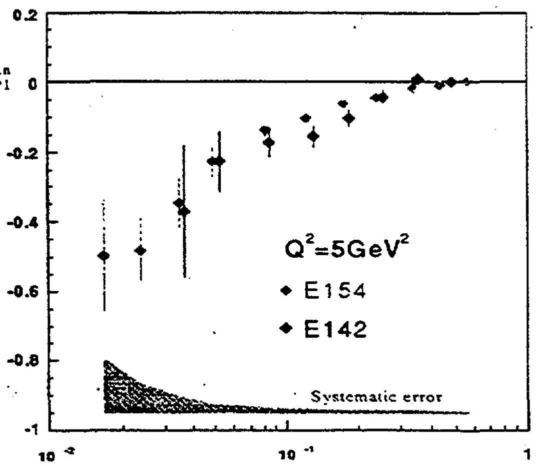
TARGET	Σ	Δu	Δd	Δs
Proton	$.32 \pm .10$	$.83 \pm .03$	$-.42 \pm$ [illegible]	[illegible] $\pm .04(.06)$
Deuterium	$.38 \pm .08$	$.85 \pm .05$	$-.41 \pm .05$	$-.07 \pm .03(.06)$

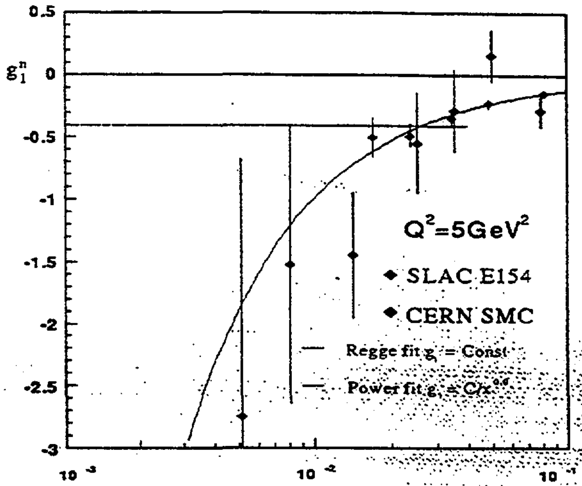
- Total quark spin was 30-40% of the nucleon spin.
- Strange quark is significantly polarized opposite to the nucleon spin.[2]



g_1 of neutron

- g_1 at the fixed $Q^2 = 5(GeV/c)^2$ was evaluated under the assumption that g_1/F_1 is independent of Q^2.



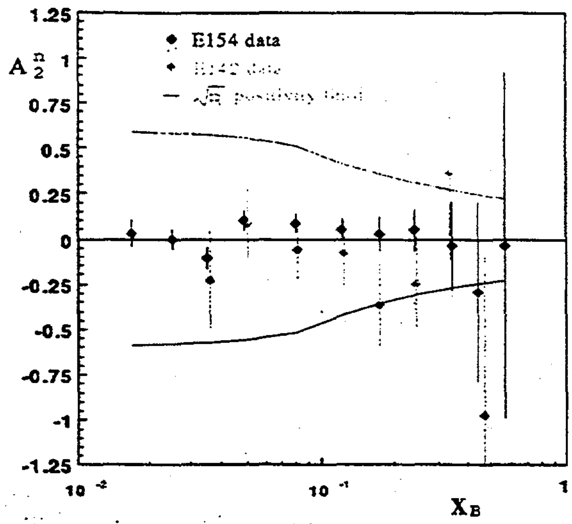


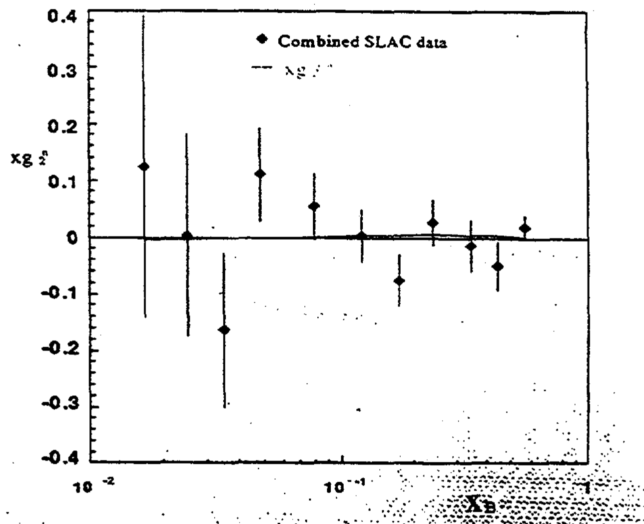
- Strong x dependence at low x is incompatible with the simplest Regge theory
  $\Rightarrow$ the new data do not adequately constrain the low-x region.

- NLO pQCD analysis of the world polarized DIS data [5] made
  - $\Gamma_1^n \equiv \int_0^1 g_1^n dx = -0.058 \pm 0.004(stat.) \pm 0.007(syst.) \pm 0.007(evol.)$ which is significantly different from Ellis-Jaffe sum rule, $\Gamma_1^n = -0.019 \pm 0.004$.
  - $\Gamma_1^p - \Gamma_1^n \equiv \int_0^1 g_1^n dx = 0.171 \pm 0.005(stat.) \pm 0.010(syst.) \pm 0.006(evol.)$ which is consistent to Bjorken sum rule, $\Gamma_1^p - \Gamma_1^n = 0.182 \pm 0.003$.

[5] Phys.Rev.Lett.79:26-30,1997

g_2 of neutron[5]





- A_2^n is significantly smaller than the $\sqrt{R}$ positivity limit over most of the measured range.

- g_2^n are generally consistent with the twist-2 Wandzura-Wilczek prediction.

- Twist-3 matrix element d_2^n was evaluated to be -1.0 ± 1.5 at $Q^2 = 3.0(GeV/c)^2$ averaging the SLAC data.

[5] Phys.Lett.B404:377-382,1997

Summary

- Experiments at SLAC has contributed to understand the spin structure of nucleon.
- SLAC and CERN experiments are complementary
  - SLAC : High statistical measurement
  - CERN : Covering lower X region
- E143
  - Measurements were made of g_1^p and g_1^d at beam energies of 29.1, 16.2, and 9.7 GeV, and g_2^p and g_2^d at beam energy of 29.1 GeV.
  - Q^2 dependence of g_1/F_1 was found to be small at $Q^2 > 1.0(GeV/c)^2$.
  - Using the full data sets Γ_1^p and Γ_1^d at $Q^2 = 3.0(GeV/c)^2$ were evaluated to be $+.133 \pm .003 \pm .009$ and $+.047 \pm .003 \pm .006$ respectively.
  - Bjorken sum rule was confirmed at $Q^2 = 3.0(GeV/c)^2$.
  - Quark spin was found to be 30% - 40% of the nucleon spin.
    The strange sea quark was polarized opposite to the nucleon spin direction.
  - g_2 of proton and deuteron was measured and well described by g_2^{WW}.
  - g_1 in the resonance region was studied. It is the first determination of Γ_1 at Q^2 below $2.0(GeV/c)^2$.
  - The complete analysis for E143 data will be appeared in early 1998.
- E154
  - g_1 and g_2 of neutron were measured at beam energy of 48.3 GeV.
  - Γ_1^n was determined to be [illegible] $\pm$ [illegible] (syst.) $\pm$ [illegible]

Spin dependent Structure Functions of the Nucleon from HERMES

Yasuhiro Sakemi
Department of Physics, Tokyo Institute of Technology
Oh-okayama, Meguro, Tokyo 152, Japan

for the HERMES collaboration

Summary

HERMES is an experiment at HERA designed for the study of the spin dependent structure of the proton and neutron by deep inelastic scattering. Two novel techniques are employed at HERMES; internal targets of polarized gas in a storage cell, and the coincidence measurement of the hadrons together with the deep inelastic scattered positrons. At HERMES we investigate the contributions of the various quark flavours and of gluons to the spin of the nucleon.

The data taking started in 1995 with the positron beam energy of E = 27.5 GeV. In 1995, HERMES measured the spin dependent structure function ${g_1}^n(x)$ with a polarized ^{3}He target. The Ellis-Jaffe integral of $\Gamma_1^n = -0.037 \pm 0.013_{stat.} \pm 0.005_{syst.} \pm 0.006_{extrapol.}$ is obtained at $Q^2 = 2.5\ (\mathrm{GeV}/c)^2$ [1]. The data with a polarized hydrogen target was obtained in 1996 and 1997 to determine the spin dependent structure function ${g_1}^p(x)$. As the first result of semi-inclusive measurement, the hadron and pion asymmetries have been extracted from the 1995 and 1996 data.

The conversion of the existing threshold type Čerenkov detector into a Ring Image Čerenkov detector, which is now in preparation, will further improve the particle identification capability of HERMES to perform precise measurements of the various spin dependent distributions of the partons.

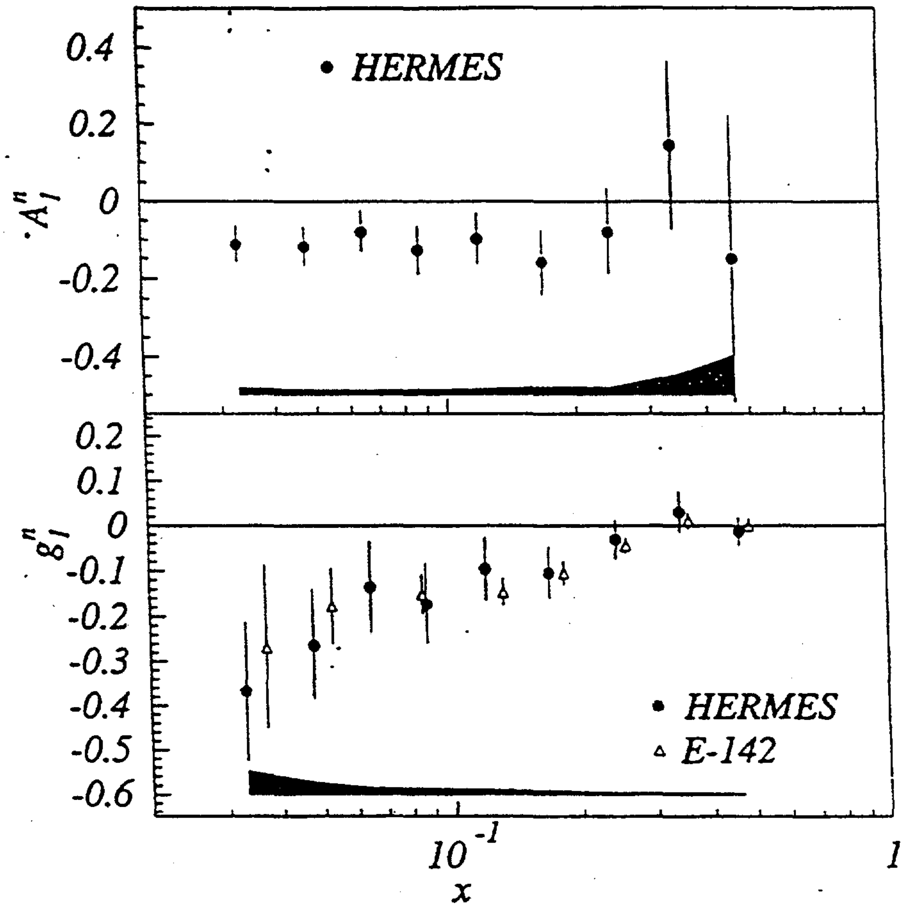
References

[1] K. Ackerstaff, *et al.* HERMES collaboration, Phys. Lett. **B404** (1997) 383.

SAKEMI.

First HERMES Results

Spin Asymmetry $A_1^n(x)$ and Spin Structure Function $g_1^n(x)$ of the Neutron:



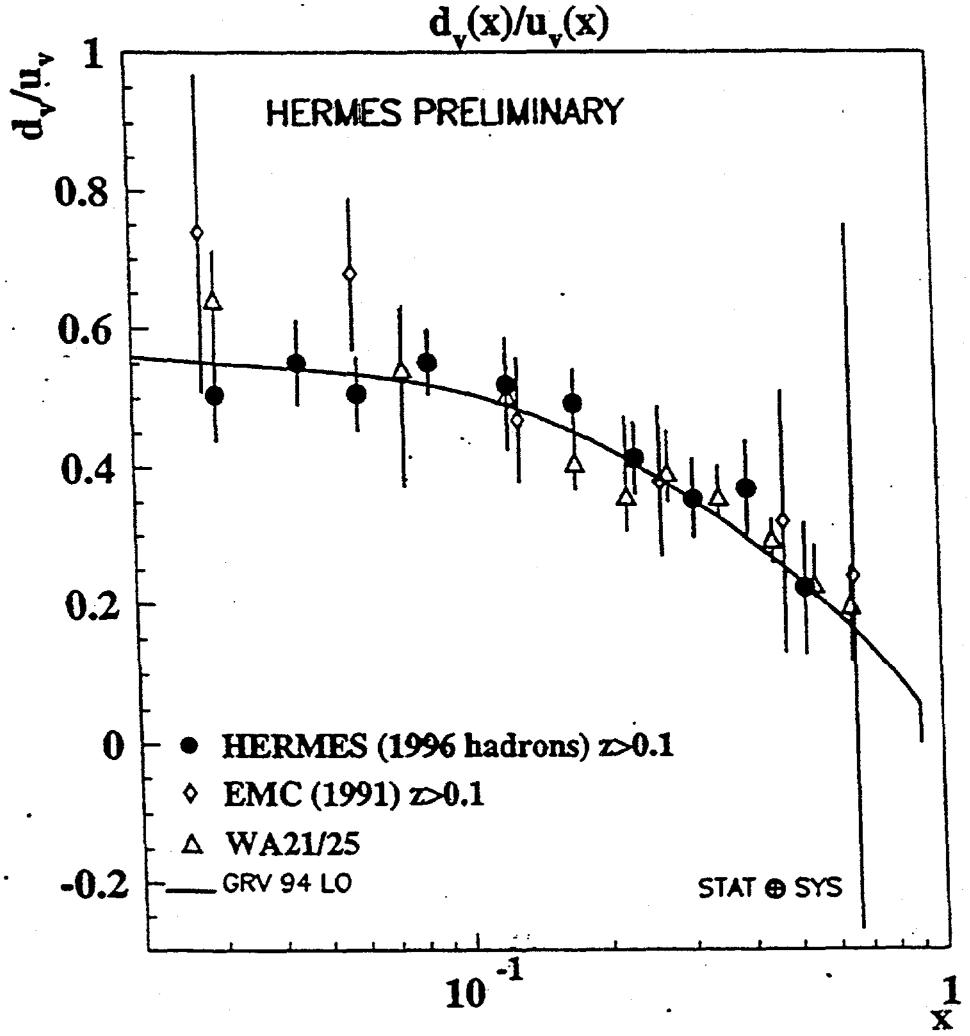
Ellis-Jaffe Sum (HERMES at $Q^2 = 2.5$ (GeV/c)^2):

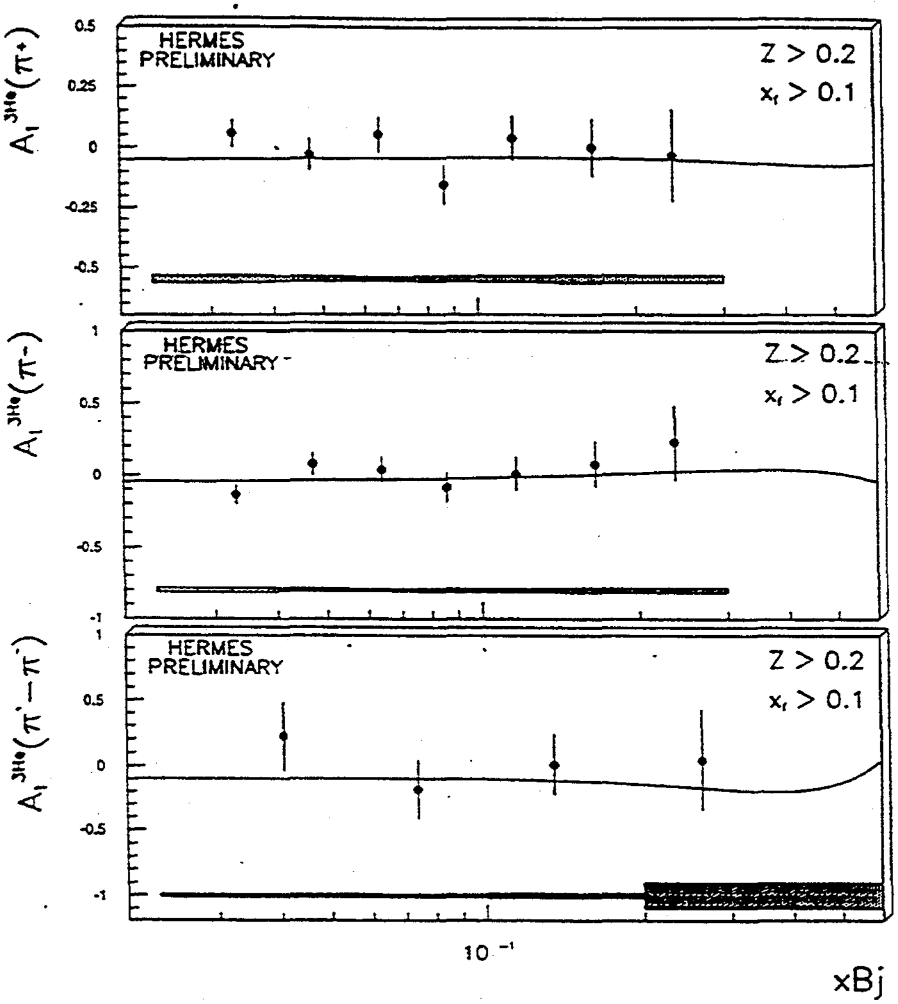
$$\int_0^1 g_1^n(x)\,dx = -0.037 \pm 0.013_{stat.} \pm 0.005_{syst.} \pm 0.006_{extrapol.}$$

(Phys. Lett. B404, 383 (1997))

HERMES preliminary $\frac{d_v(x)}{u_v(x)}$ vs x

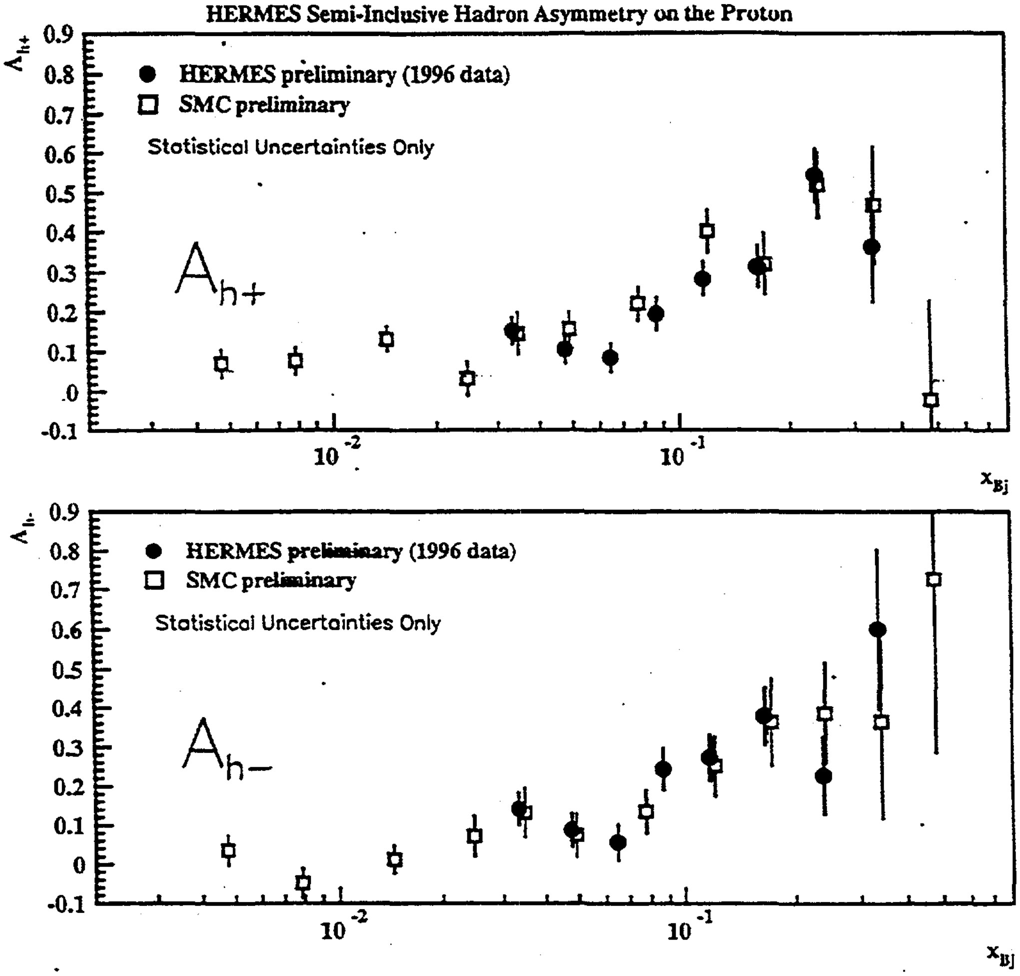
unpolarized H + D data



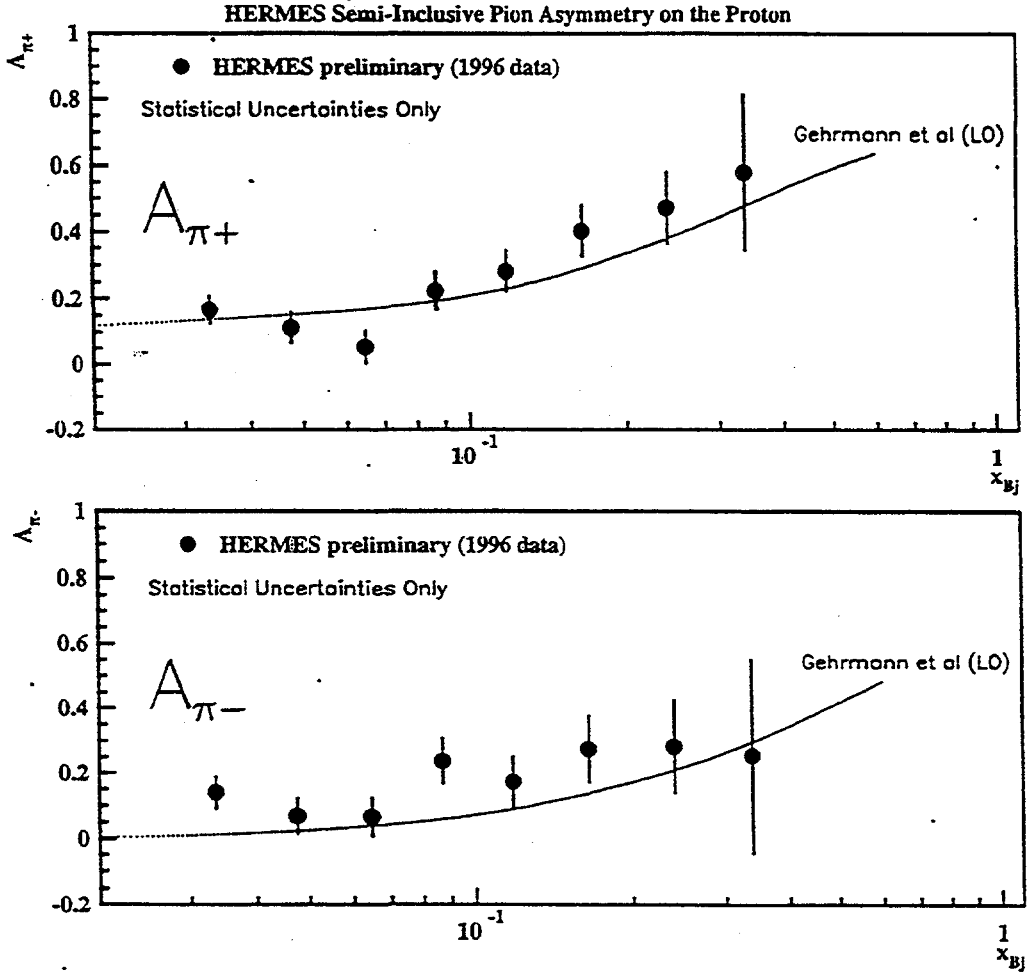


HERMES
PRELIMINARY
Z > 0.2
$x_f > 0.1$
$A_1^{3He}(\pi^+)$
$A_1^{3He}(\pi^-)$
$A_1^{3He}(\pi^+ - \pi^-)$
10^{-1}
xBj

HERMES Semi-Inclusive Hadron Asymmetry on the Proton



HERMES Semi-Inclusive Pion Asymmetry on the Proton



KUMANO

Analyses of the nucleon spin structure functions

Y. Goto[(a)], N. Hayashi[(a)], M. Hirai[(b)], H. Horikawa[(c)], S. Kumano[(b)], M. Miyama[(b)], T. Morii[(c)], N. Saito[(a)], T.-A. Shibata[(d)], E. Taniguchi[(d)], and T. Yamanishi[(e)]

(RHIC-Spin-J working group on parametrization)

(a) Institute of Physical and Chemical Research
(b) Saga University
(c) Kobe University
(d) Tokyo Institute of Technology
(e) Fukui University of Technology

http://www.rarf.riken.go.jp/rarf/rhic/theory/pol-pdf.html

We discuss the activities of the RHIC-Spin-J working group on parametrization. This collaboration intends to obtain optimum polarized parton distributions for explaining all the available experimental data. We should be able to complete our first work in a few months. It includes complete next-to-leading-order analyses of the g1 structure functions. The obtained distributions will be used for experimental studies at RHIC. Furthermore, once new experimental results are obtained at RHIC or at other facilities, we try to reanalyze the data for getting updated distributions.

We work in three subgroups: data analysis, parametrization, and Q^2 evolution. The data analysis subgroup (Y. Goto, N. Hayashi, N. Saito, T.-A. Shibata, and E. Taniguchi) collects all the available experimental data and investigate their systematic uncertainties. The parametrization group (H. Horikawa, T. Morii and T. Yamanishi) tries to understand meaning of obtained parameter values. The third subgroup (M. Hirai, S. Kumano, and M. Miyama) contributes to the Q^2 evolution program. This subgroup develops an efficient program for numerical solution of the evolution equations.

RHIC-Spin-J Working Group

Purpose: to find optimum polarized parton distributions

- Data analysis group

  (Y. Goto, N. Hayashi, N. Saito, E. Taniguchi, and T.-A. Shibata)

  They collect all the available experimental data and investigate their systematic uncertainties.

- Parametrization group

  (H. Horikawa, T. Morii, and T. Yamanishi)

  They study the meaning of obtained parameter values.

- Q^2 evolution group

  (M. Hirai, S. Kumano, and M. Miyama)

  They develop an efficient program for numerical solution of the evolution equations.

Available experimental data

	exp. group	# of data	exp. group	# of data
g_1^p:	E130	8	EMC	10
	E143	28	E143-Q^2	25
	SMC	12		
g_1^d:	E143	21	E143-Q^2	21
	SMC	12		
$g_1^n(^3He)$:	E142	8	E154	11
	HERMES	9		

Total = 165 data points

Fitting procedure

$$A_1(x,Q^2) = \frac{g_1(x,Q^2)}{F_1(x,Q^2)} \quad , \qquad F_1(x,Q^2) = \frac{F_2(x,Q^2)}{2\,x\,[\,1 + R(x,Q^2)\,]}$$

$$g_1(x,Q^2) = \frac{1}{2}\sum_q e_q^2 \left\{ \int_x^1 \frac{dy}{y}\,\Delta C_q(x/y,Q^2)\,[\,\Delta q(y,Q^2) + \Delta\bar{q}(y,Q^2)\,] + \int_x^1 \frac{dy}{y}\,\Delta C_g(x/y,Q^2)\,\Delta g(y,Q^2) \right\}$$

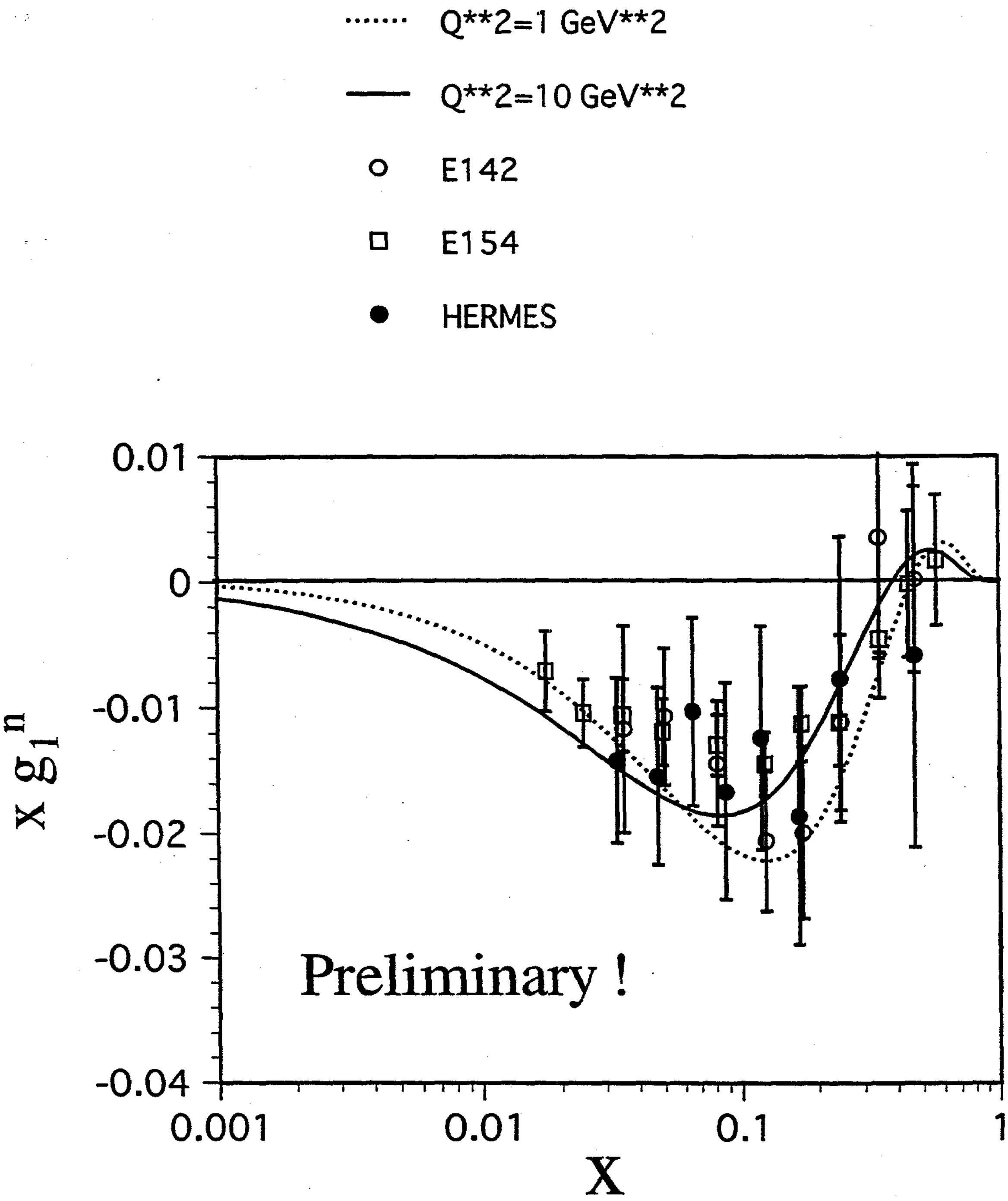
$$x\,\Delta f_i(x,Q_0^2) = A_i\,\eta_i\,x^{\alpha_i}\,(1-x)^{\beta_i}\,(\,1 + \gamma_i\,x + \rho_i\,\sqrt{x}\,)$$

$$F_2(x,Q^2) = \sum_q e_q^2\,x \left\{ \int_x^1 \frac{dy}{y}\,C_q(x/y,Q^2)\,[\,q(y,Q^2) + \bar{q}(y,Q^2)\,] + \int_x^1 \frac{dy}{y}\,C_g(x/y,Q^2)\,g(y,Q^2) \right\}$$

$x\,f_i(x,Q_0^2)$: CTEQ, GRV, or MRS

minimize $\chi^2 = \sum \frac{(A_1^{data} - A_1^{calc})^2}{(\sigma_{A_1^{data}})^2}$ with MINUIT

Neutron structure function g_1^n



Summary

Unpolarized parton distributions: well known

Polarized distributions:

Sea-quark & gluon distributions ???

Studies of the current status of Δp

(RHIC-Spin-J working group)

- LO analysis is almost finished.
- NLO program is ready.
- Optimum NLO distributions should be obtained in the near future.

↓

Application to various spin asymmetries at RHIC

(Drell-Yan, W, direct photon, ...)

↓

RHIC completion: reanalysis with new data !

Q^2-evolution of the chiral-odd structure functions: $h_1(x, Q^2)$, $h_L(x, Q^2)$

Yuji Koike

Graduate School of Science and Technology, Niigata University, Ikarashi, Niigata 950-21, Japan

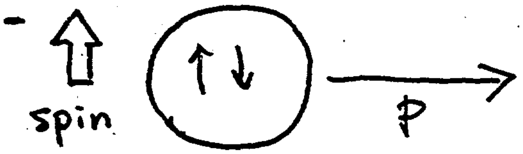
Abstract

In the first part of my talk, I discussed the recently completed next-to-leading order (NLO) Q^2 evolution of the transversity distribution $h_1(x, Q^2)$. The two-loop anomalous dimension for the corresponding twist-2 operator turns out to be larger than the nonsinglet anomalous dimension of the helicity distribution $g_1(x, Q^2)$, especially at small n (spin). This brings even more significant difference in the Q^2-evolution between h_1 and g_1 in the small x region to the leading order (LO) Q^2-evolution.

In the second part of my talk, I discussed the generic feature of the LO Q^2 evolution of the twist-3 distributions, in particular, $h_L(x, Q^2)$. The evolution equation for the twist-3 distibutions is generally very completed due to the increasing number of the quark-gluon-quark operators with n. However, at $N_c \to \infty$ or $n \to \infty$. it can be shown that it is reduced to a very simple DGLAP equation with slightly different anomalous dimension from the twist-2 distributions. The correction to this equation is of $O(1/N_c^2 \cdot \ln(n)/n)$ level.

1. "Transversity distribution" $h_1(x,Q^2)$

Y. Koike

- chiral-odd ⇒ no mixing with gluon distribution
- 

  Nonrelativistic

  ⇒ $h_1(x,Q^2) = g_1(x,Q^2)$

- Places to see $h_1(x,Q^2)$

  Drell-Yan : $\vec{P}_\perp + \vec{P}_\perp \to \ell^+\ell^- + X$ (Ralston-Soper '79)

  Semi-inclusive DIS :

  $e + \vec{P}_\perp \to e' + \vec{B}(\vec{\Lambda}) + X$ (Artru-Mekfi '90, Jaffe-Ji '9…)

  $\vec{e}_\parallel + \vec{P}_\perp \to e' + \pi + X$ (Jaffe-Ji '93)

  $e + \vec{P}_\perp \to e' + \pi^+\pi^- + X$ (Jaffe-Jin-Tang '97)
  $(K\bar{K})$

NLO Q^2-evolution

For $f_1(x,Q^2)$, $g_1(x,Q^2)$, NLO analysis standard.

For $h_1(x,Q^2)$, completed by recent works.

- Hayashigaki-Kanazawa-Koike, hep-ph/9707208, Phys.…

  Feynman gauge, MS($\overline{MS}$) scheme, two-loop anomalous dim.

  (cf. Floratos-Ross-Sachrajda ('77) for f_1)

- Vogelsang, hep-ph/9706511

  Light-cone gauge, MS($\overline{MS}$) scheme, two-loop splitting function

  (cf. Curci-Furmanski-Petronzio ('80) for f_1)

- Subsequently confirmed by Kumano-Miyama, hep-ph/9706420 (revised) in Feynman gauge.

Simplification of twist-3 Q^2-evolution at $N_c \to \infty$

γ^n_{ij} : function of $C_F = \frac{N_c^2 - 1}{2N_c}$ and $C_G = N_c$

★ Replacement of $C_F \to \frac{N_c}{2}$ (i.e. $N_c \to \infty$) gives $\left(L \equiv \frac{\alpha_s(Q^2)}{\alpha_s(\mu^2)} \right)$

$$\begin{cases} \mathcal{M}_n[\tilde{h}_L(Q^2)] = L^{\gamma^h_n/2\beta_0} \mathcal{M}_n[\tilde{h}_L(\mu^2)] \\ \mathcal{M}_n[\tilde{g}_2(Q^2)] = L^{\gamma^g_n/2\beta_0} \mathcal{M}_n[\tilde{g}_2(\mu^2)] \end{cases}$$

(Balitsky-Braun-Koike-Tanaka P.R.L 77 ('96)

(Ali-Braun-Hiller, P.L. B266 (

γ^h_n, γ^g_n : Lowest eigenvalues of ano. dim. matrix at $N_c \to \infty$

$$\begin{cases} \gamma^h_n = 2N_c\left(S_n - \frac{1}{4} + \frac{3}{2(n+1)}\right) \\ \gamma^g_n = 2N_c\left(S_n - \frac{1}{4} + \frac{1}{2(n+1)}\right) \end{cases} \qquad S_n \equiv \sum_{j=1}^{n} \frac{1}{j}$$

★ Correction : $O(1/N_c^2) \sim 10\%$ practically enough!

- The same simplification for $e(x, Q^2)$

EX.

$$\mathcal{M}_5[\tilde{h}_L(Q^2)] = [\,0.416\,\underline{a(\mu)} + 0.193\,\underline{b(\mu)}\,]\, L^{12.91/\beta_0}$$

$$+ [\,0.013\,\underline{a(\mu)} - 0.050\,\underline{b(\mu)}\,]\, L^{18.05/\beta_0}$$

$N_c \to \infty$ ↓ $1/N_c^2$-suppressed

$$\mathcal{M}_5[\tilde{h}_L(Q^2)] = \left[\frac{3}{7} a(\mu) + \frac{1}{7} b(\mu)\right] L^{13.7/2\beta_0}$$

($a(\mu)$, $b(\mu)$: matrix element

★ Complete prediction for Q^2-evolution : $h_L(x, Q_0^2) \to h_L(x, Q$

★ Convenient tool for experiment & model building.

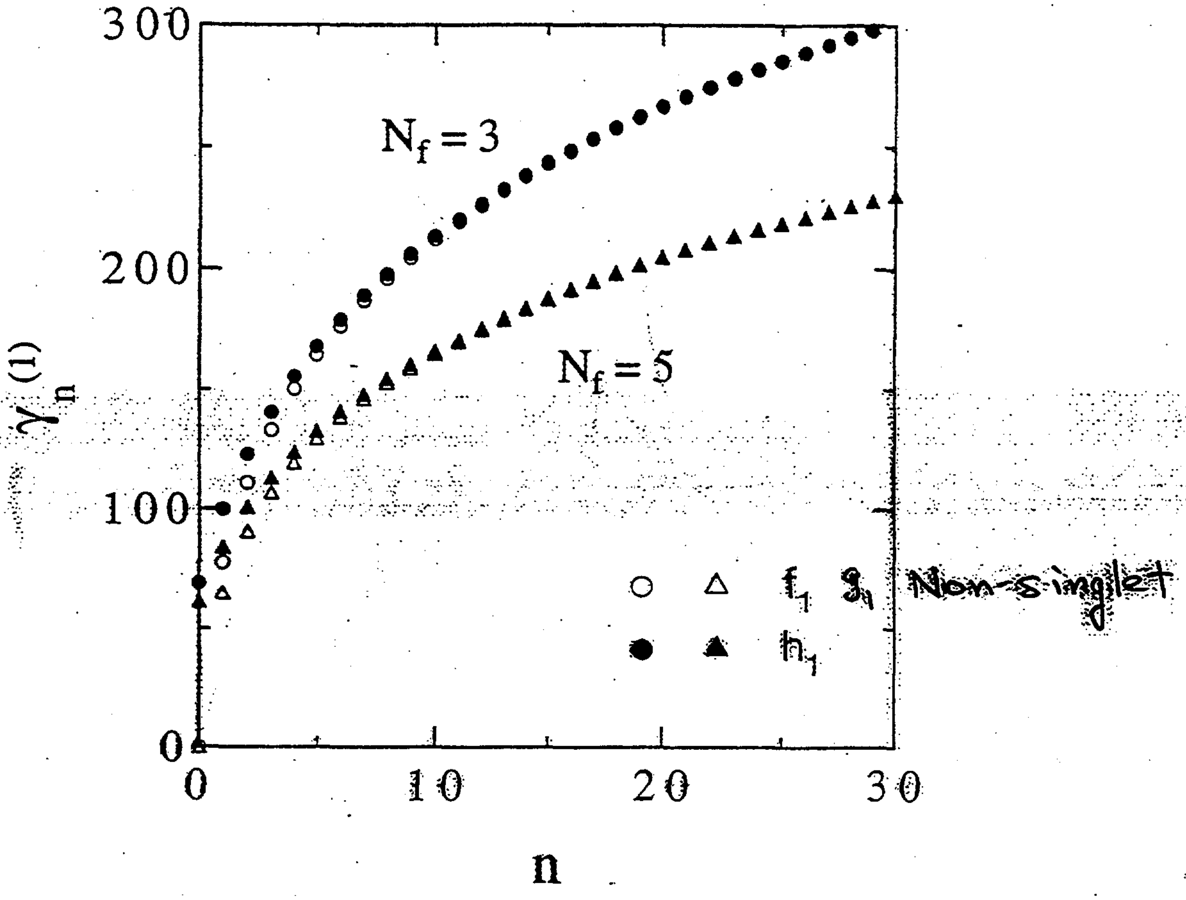


Fig.7

★ $\gamma_n^{h(1)} > \gamma_n^{f(1)}$ for all n, especially at small n.

→ difference in small-x behavior

2. Twist-3 distribution $h_L(x,Q^2)$ (and $g_2(x,Q^2)$)

- Twist-3 distributions represent quark-gluon correlations in the nucleon.

$$h_L(x,Q^2) = 2x\int_x^1 dy \frac{h_1(y,Q^2)}{y^2} + \tilde{h}_L(x,Q^2)$$

$$g_2(x,Q^2) = \int_0^1 dy \frac{g_1(y,Q^2)}{y} + \tilde{g}_2(x,Q^2)$$

↑ twist-2 "purely twist-3" (Wandzura - Wilczek '7?)

$$\tilde{h}_L(x,Q^2) = \frac{iP^+}{M}\int_{-\infty}^{\infty}\frac{dz^-}{2\pi} e^{-2ixP\cdot z}\int_0^1 u\,du\int_{-u}^{u} t\,dt \;\times$$

$$\langle PS_\parallel | \bar{\psi}(uz)\, i\gamma_5 \sigma_{\mu\alpha}\, gG_\nu{}^\alpha(tz) z^\mu z^\nu \psi(-uz) | PS_\parallel \rangle$$

(and similarly for $\tilde{g}_2$) "quark-gluon-quark correlation"

- $h_L(x,Q^2)$ and $g_2(x,Q^2)$ are "measurable" higher twist.

$$\sigma(Q^2) \sim A(\ln Q^2) + \frac{M}{Q} B(\ln Q^2) + \cdots$$

($A(\ln Q^2)$ crossed out → 0; $B(\ln Q^2)$: g_2, h_L)

g_2 : transversely polarized DIS

h_L : Drell-Yan : $\vec{P}_\parallel + \vec{P}_\perp \to l^+ l^- + X$

- Q^2-evolution : New test of QCD beyond twist-2 level.

4. Summary & Outlook

$h_1(x, Q^2)$: twist-2

- NLO Q^2-evolution completed ⇒ all twist-2 NLO Q^2-evo. completed.

- Expected DGLAP asymptotics $(x \to 0)$ is different between LO and NLO Q^2 evolutions. ⇔ g_1, f_1.

- NLO Q^2-evolution of h_1 : different from that of $g_1^{NS}(x, Q^2)$ (and $f_1^{NS}(x, Q^2)$) in the small-x regio

- Prediction for a physical cross section in NLO level

  ⇒ Convolution of NLO parton density and NLO hard cross section in the parton level.

Ex. A_{TT} in Drell-Yan

$$\sigma_{TT}(Q^2) \sim H(x, y, Q^2, \mu^2) \otimes h_1(x, \mu^2), \bar{h}_1(y, \mu^2)$$

studied by Martin-Schäfer-Stratmann-Vogelsang (hep-ph/9710300)

- modest, but not negligible NLO

Nuclear Transparency in High-Energy Quasi-elastic Processes

RIKEN / U.Tokyo Akihisa KOHAMA

1. Intoduction: A phenomenon "color transparency" was predicted by Brodsky and Mueller in the early 80's as a candidate of observing the effects of internal dynamics of the proton in high-energy nuclear reactions. It was speculated that the initial- and/or final-state interactions of a proton involved in a high-momentum transfer reaction with a nuclear target would be suppressed, and that the nuclear medium would look transparent. We define the nuclear transparency, $T(q)$, which is a measure of the initial-/final-state interactions. We examine the nuclear transparency for the quasi-elastic $(e, e'p)$ and $(p, 2p)$ processes in a relativistic harmonic oscillator model for the internal structure of the proton.

2. Relativistic Harmonic Oscillator Model: A proton in a nuclear target is struck by the incident electron/proton and then propagates through the residual nucleus suffering from soft interactions with other nucleons. We call the proton "dynamical" when we take into account of internal excitations, and "inert" when we freeze it to the ground state. We assume that the interaction of the proton with the nuclear medium depends on the transverse size, *i.e.*, $\hat{V} = -ic_0\,(\hat{\mathbf{r}}_\perp^2 + \hat{\mathbf{s}}_\perp^2)$. c_0 is a constant. $(e, e'p)$: T.Iwama, A.Kohama, and K.Yazaki, *hep-ph/9706208.*

3. Differences between $(e, e'p)$ and $(p, 2p)$: In $(e, e'p)$ the transferred momentum and the recoil momentum has the same direction. In $(p, 2p)$ the direction of the transferred momentum and that of the outgoing momentum are different.

4. Numerical Results of Electron Scattering: We calculate the time development of the dynamical proton in the nuclear matter. ν is a parameter which controls the longitudinal-transverse correlation between the quarks in the struck proton. The effect of the internal dynamics is observed, which is in accord with the idea of the "color transparency".

5. Numerical Results of Hadron Scattering: We calculate the time development of the dynamical proton in the nuclear matter taking into account the effect coming from the difference between the outgoing momentum and the transferred momentum. When the transverse component of q gets larger, we obtain the dramatic momentum dependence.

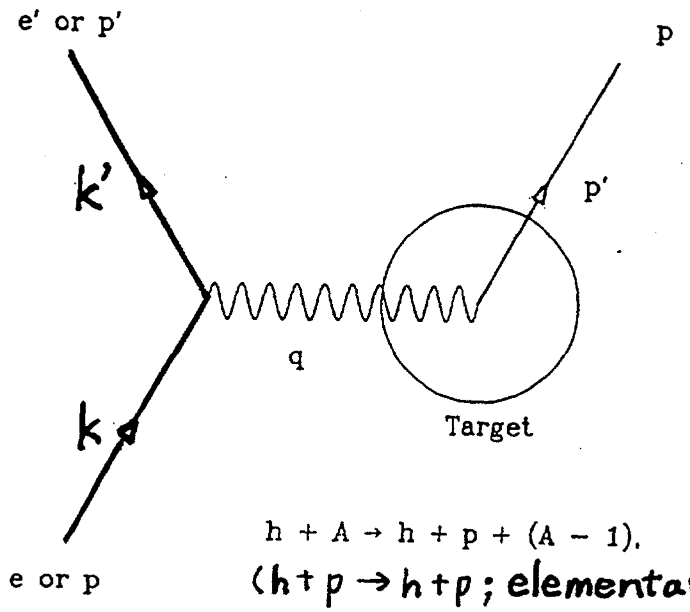
Summary: We have applied the 4-dimensional harmonic oscillator model to calculate the nuclear transparency of the $(e, e'p)$ and $(p, 2p)$ reaction. We have obtained the color transparency for the $(e, e'p)$ process, reflecting the internal dynamics. The dynamical correlation between quarks in the struck proton is crucial. For $(p, 2p)$, though the actual calculation has not been carried out, we have found that the hard scattering operator can excite the transverse mode of the internal motion of the outgoing proton. This is a new mechanism for the "color transparency". There is a possibility of a dramatic incident momentum dependence in the $(p, 2p)$. This feature looks independent of the hadronic models.

▫▫▫ Nuclear Transparency ▫▫▫

$$T(q) \simeq \frac{1}{Z}\frac{d\sigma_A}{d\Omega}/\frac{d\sigma_p}{d\Omega}.$$

$$\text{where} \quad \frac{d\sigma_A}{d\Omega} = \int k'^2 dk' \int d\mathbf{p}' \frac{d\sigma_{hA}}{dk' d\mathbf{p}'}.$$

$$-q^2 > \text{several } (\text{GeV}/c)^2.$$



h + A → h + p + (A − 1), h = e or p

(h + p → h + p ; elementary process)

Nucleus becomes **transparent** to the struck proton.

⇕

FSI becomes weaker compared to that of the conventional multiple-scattering theory.

4-dimensional Harmonic Oscillator Model

Relativistic Wave Equation

$$(P^2 - \hat{M}^2)|\Psi;\mathbf{P}\rangle = 0.$$

Mass Operator

$$-\hat{M}^2 = \eta\left(\hat{p}_r^2 + \hat{p}_s^2 + \alpha^2(\hat{r}^2 + \hat{s}^2)\right) + C.$$

where

$$\hat{r}_\mu = \frac{1}{\sqrt{6}}(\hat{x}_{2,\mu} - \hat{x}_{3,\mu}), \quad \hat{s}_\mu = \frac{1}{3\sqrt{2}}(-2\hat{x}_{1,\mu} + \hat{x}_{2,\mu} + \hat{x}_{3,\mu}).$$

$$\hat{p}_{r,\mu} = \sqrt{\tfrac{3}{2}}(\hat{p}_{2,\mu} - \hat{p}_{3,\mu}), \quad \hat{p}_{s,\mu} = \frac{1}{\sqrt{2}}(-2\hat{p}_{1,\mu} + \hat{p}_{2,\mu} + \hat{p}_{3,\mu}).$$

Constraints

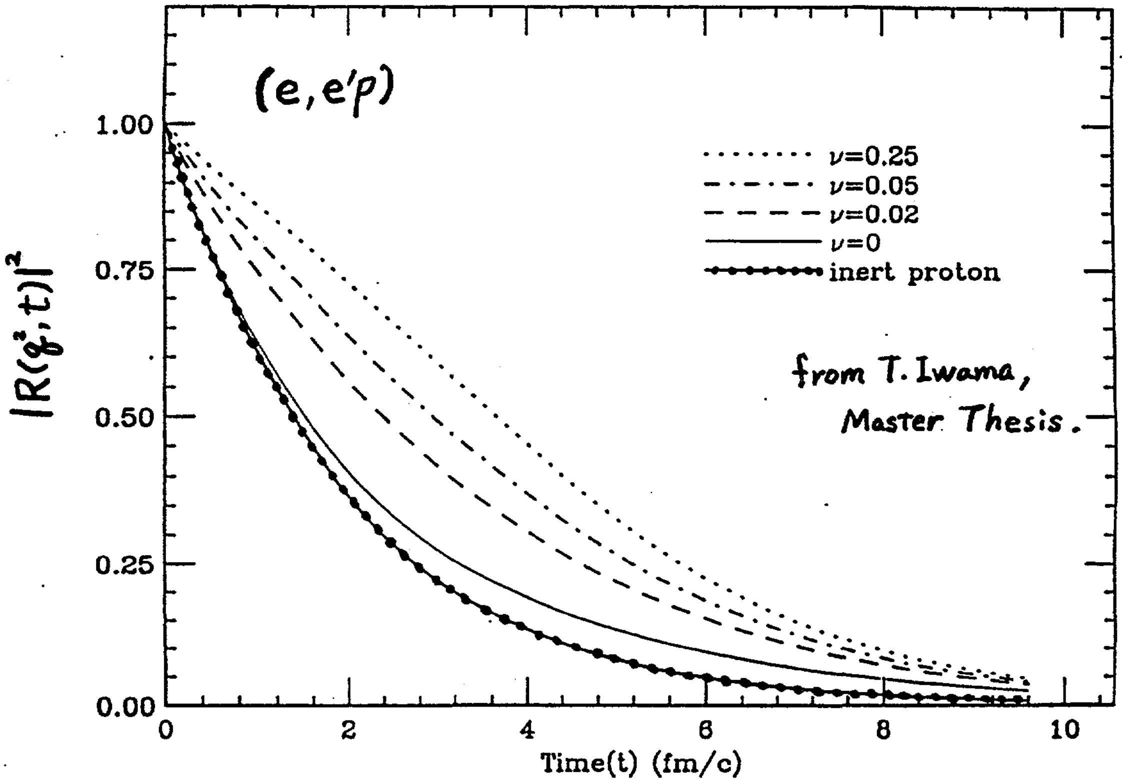
Excitations in the time-direction are prohibited.

$$P\cdot(-i\hat{p}_{r\mu} + \alpha\hat{r}_\mu)|\Psi;\mathbf{P}\rangle$$
$$= P\cdot(-i\hat{p}_{s\mu} + \alpha\hat{s}_\mu)|\Psi;\mathbf{P}\rangle = 0.$$

ref. T.Takabayashi,
Suppl. Prog. Theo. Phys., **Extra Number** (1965) 339-382.

ref. K. Fujimura, T. Kobayashi, and M. Namiki,
Prog. Theo. Phys., 43 (1970) 73-79.

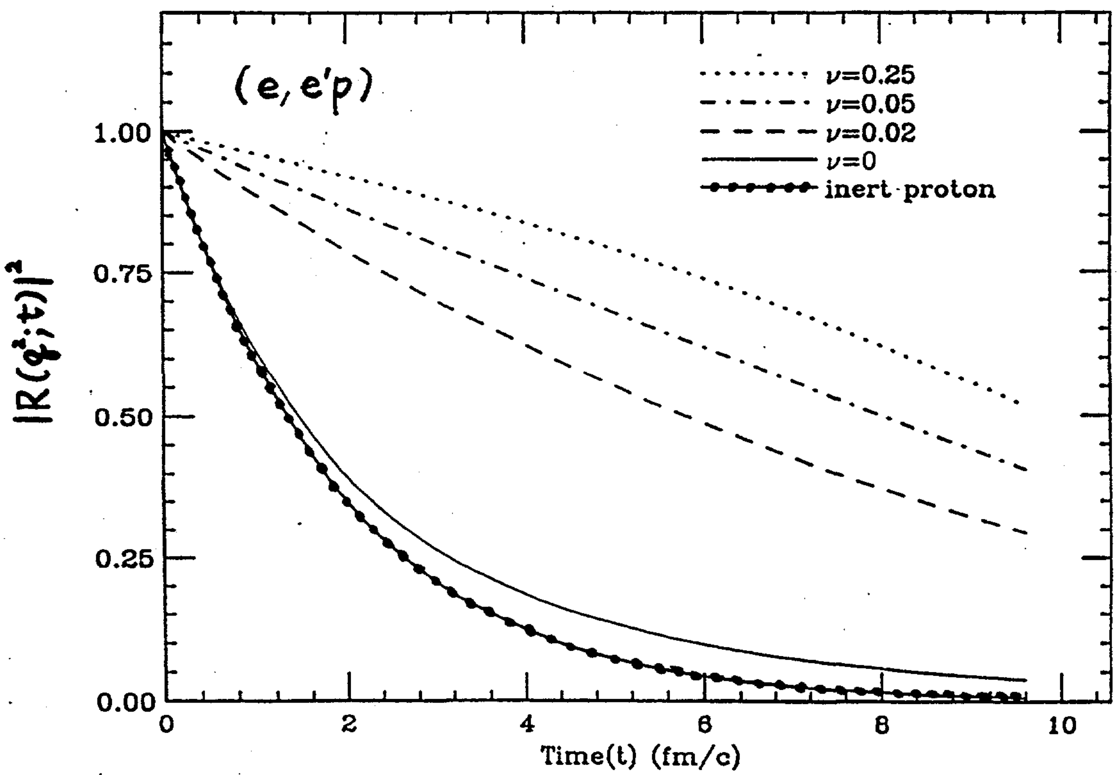
Fig.7: Survival Probability:Q^2=20(GeV/c)^2



$$R(q^2;t) \equiv M^{(i)}_{eA}(q^2,t)/M^{(i)}_{eA}(q^2,0).$$

i = dynamical, or inert.

Fig.8: Survival Probability:Q^2=100(GeV/c)^2



Proton Survival Amplitude

$(e, e'p)$

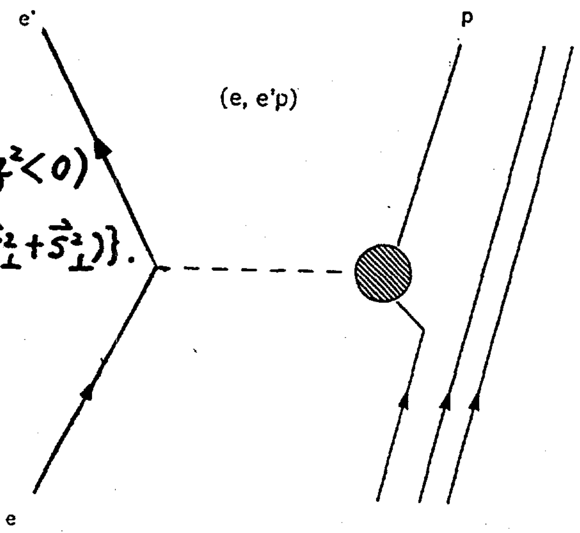
$$M_{\rm eA}^{(D)}(q^2, t) \equiv \langle \phi_0; \mathbf{q} | e^{-i\hat{H}t}\, \hat{O}(q) | \phi_0; \mathbf{0} \rangle,$$

where $\quad q_\mu = k_\mu - k'_\mu.$

$$\hat{O}(q) = \exp\{-i\sqrt{2}\, q\cdot s\} \quad (q^2<0)$$

$$\Rightarrow \exp\{-i\sqrt{2}\, q\cdot s\} \times \exp\{\nu q^2 (\vec{r}_\perp^{\,2} + \vec{s}_\perp^{\,2})\}.$$

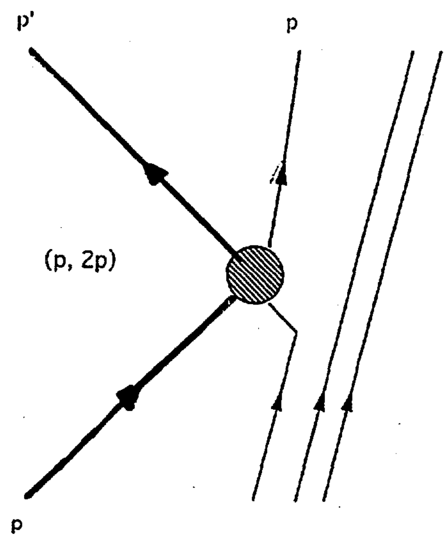
$$F_{ep}(q^2) \Rightarrow F^{\nu}_{ep}(q^2).$$



$(p, 2p)$

$$M_{\rm pA}^{(D)}(P_f, P_i; t_3, t_2, t_1) \equiv \tilde{M}_{\rm pA}^{(D)}(P_f, P_i; t_2, t_1) \times M_{\rm eA}^{(D)}(q^2, t_3),$$
$$\tilde{M}_{\rm pA}^{(D)}(P_f, P_i; t_2, t_1) \equiv \langle \phi_0; \mathbf{P}_f | e^{-i\hat{H}t_2}\, \hat{T}_{\rm pp}(P_f, P_i)\, e^{-i\hat{H}t_1} | \phi_0; \mathbf{P}_i \rangle,$$

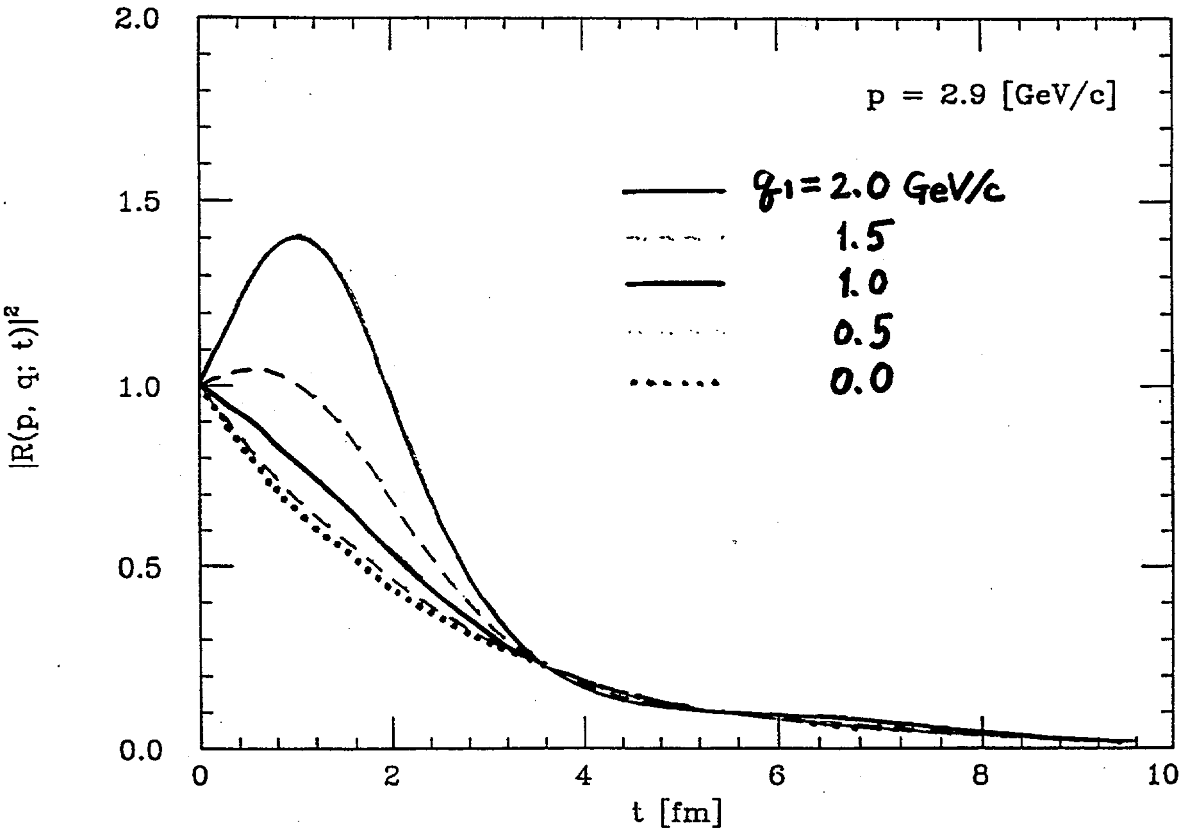
where $\quad q_\mu = P_{i,\mu} - P_{f,\mu}.$



▫▫▫ An Estimate of the "Transverse Blow" ▫▫▫

$$R(p,q;t) \equiv \langle \phi_0; p | e^{-i\hat{H}t}\, \hat{O}(q) | \phi_0; 0\rangle \Big/ \langle \phi_0; p | e^{-i\hat{H}_0 t}\, \hat{O}(q) | \phi_0; 0\rangle,$$

where $\mathbf{p} = (0,0,p)$, $q_\mu = (q_0, q_1, 0, q_3)$.



Hard processes in and beyond perturbation theory

Yu. Dokshitzer
INFN, Milan and
NPI, St. Petersburg

Perturbative QCD approach to describing cross sections of, and multi-particle production in, various hard interactions is in a quite healthy state. Moreover, for such global characteristics of final states as inclusive energy spectra of particles inside jets, multiplicity flows between jets in multi-jet events, etc., observed hadron spectra prove to be mathematically similar to the underlying quark/gluon spectra originating from small-distance parton cascades. What makes these similarities so amazing, is the fact that the characteristic features ("hump-backed plateau", ratios of multiplicity flows) are beared by hadrons (mainly, pions) with momenta below 1 GeV! Local Parton-Hadron Duality concept works; no significant reshuffling of energy-momentum takes place at the stage of transforming QCD partons - quarks and gluons - into final hadrons.

Another surprizing "friendliness" of confinement (hadronization) effects can be seen in recent theoretical and experimental activity that aims at triggering and quantifying genuine non-perturbati effects in hard processes and, in particular,

$1/Q$ power corrections to various jet shape observables. The ratios of $1/Q$ terms in thrust and invariant jet mass distributions, jet broadening, so-called C-parameter etc. stay under perturbative control.
The absolute magnitude of these $1/Q$ contributions can be related with an effective infrared-finite QCD coupling.

Y. Dokshitzer

Conclusions (phenomenology)

pQCD-motivated technology for triggering and quantifying genuine non-perturbative (confinement) effects is under construction.

These show up as power-behaving contributions to Infrared/Collinear-safe observables, jet shapes in particular.

From within Perturbation theory the leading powers can be detected, and the *relative* magnitude of power terms predicted.

The absolute values of new dimensional parameters, which we find phenomenologically these days, can be related to the shape of the effective interaction strength (effective QCD coupling) in the infrared region.

Headache: *how to define the splitting*
Observable = few PT orders + powers ?

At the moment, the best phenomenology offers is

"Let me put it less definitely, that is more precisely..." (M.A. Birman, Lectures on Functional Analysis, Leningrad University, 1972)

- J/ψ production; its propagation in nuclei.

- Rear events, especially in ion-ion collisions.

- Production of "isolated" (smaller?) hadrons in jets.

- High-t scattering. "Who" participates in, and "who" mediates the scattering?

- Hadronization of a "pure" glue

- Inclusive energy spectra of *identified* hadrons from *identified* (u, d, s vs. c vs. b vs. g) jets.

- Two-particle correlations (M^2, energy, rapidity).

Perspective:
Hadron physics is forever, because its today's devotion to high energies is *temporary*. High energies provide a time span to watch vacuum being excited and think about it for some time (Lorentz dilatation). Once the vacuum structure has been understood (the most important and the most difficult step to make), the hadron physics will turn back to small and medium energies.

Conclusions
("What am I doing this for?")

The epoch of basic QCD tests is over.

To understand hadron structure via hadron interactions.

The 13 puzzles are with us.

News:
Small-distance (perturbative QCD) approach, talking quarks and gluons, works too often too well.

Hadronization effects, when viewed *globally* seem to behave surprizingly friendly: they either stay *invisible* (inclusive energy and angular hadron spectra) or allow being quantified (power effects).

The major goal:
studying an interface between small and large distances

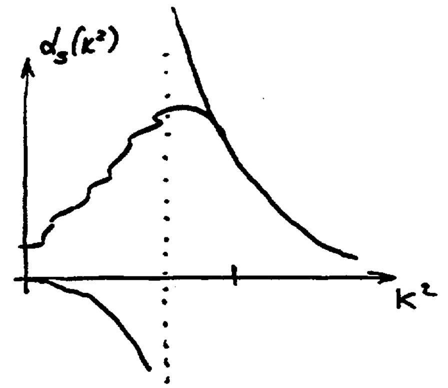
- Laboratory: *almost*-photo-production at HERA; interaction with a proton of a photon with small virtuality $0 < Q^2 < 4\,\mathrm{GeV}^2$ or so.
- Diffraction phenomena aiming at "smaller hadrons" (Q^2-dependence of vector meson production).

Procedure: Pushing fwd Sterman-Weinberg wisdom in a search for confinement

1. Choose an Infra-red/Collinear Safe observable (to reduce the BB-impact)

2. Get hold of the best elaborated PT prediction
   typically: 2 loops + all logs + proper attention paid to $\alpha_s(k^2)$ of internal (floating) scale

3. Enjoy its Beauty



4. Observe that it has no sense

5. Force it to have one

6. Confront with Experiment

7. See what you have done: try to quantify
   $\Rightarrow$ (log) moments of $\alpha_{eff.}(k^2)$

8. Check Universality ($\simeq 20\%$)

9. Pray it shows up

10. Throw away the whole thing if it doesn't.

Examples: HQ inclusive energy spectra $\langle x_E \rangle (W, M_Q)$
$Q_\perp$-distr. of DY pairs down to $Q_\perp = \emptyset$ P.P. (80)
Energy-Energy Correlations in e^+e^- DDT + CT
Differential Thrust distr. $\frac{d\sigma}{dT}(T)$ $\langle 1-T \rangle$
Differential Jet Rates $R_n(y_{cut})$

etc. etc.

Puzzle of

Objects: quarks/gluons=Truth but hadrons=Reality.
Rules: sacred (*bal tosif, bal tigra*) but absent.
Responsibility: gluons crucial but quarks dominate.
Scales: finite interaction radius but $m_G \equiv 0$.
Binding; Relativity; Multiplicity: Strongly interacting (practically) massless particles, hence $N >> 1$, $v \approx 1$ but Additive quarks, NQM.
Goals & Means: Colourless world by means of coloured quarks and gluons (Gribov copies).
Perturbation: α_s small but all orders essential,

$$\frac{\alpha_s}{\pi} \ln^{(2)} Q^2 \sim 1 .$$

Evolution: QFT but classical probabilities.
Freedom: Quarks imprisoned but fly away 10^3 fm.
Confinement: Inevitable but elusive (LPHD).
Coupling: "Strong interactions" but

$$\left\langle \frac{\alpha_s}{\pi} \right\rangle_{\text{infr.}} \approx 0.2 .$$

Quarkonium Production in Nuclear Collisions

D. Kharzeev
RIKEN-BNL Research Center

1. Interactions of quarkonium in hadron gas — tightly bound onium states are safe in hadron gas at all reasonable densities

2. In hot deconfined matter, quarkonia are easily broken by interactions with hard gluons.

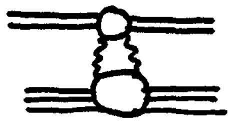
3. Glauber theory explains the minimum bias E_T distributions in nucleus-nucleus collisions at CERN SPS

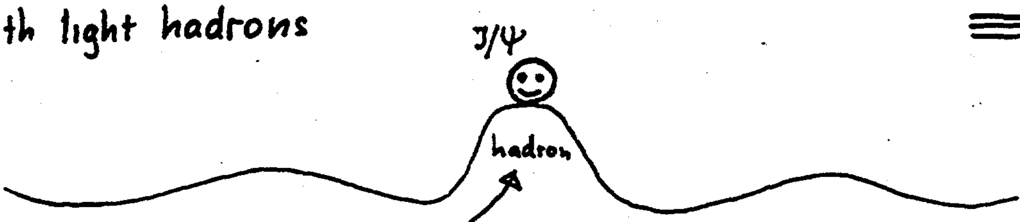
4. as well as D-Y-associated $\frac{d\sigma^{DY}}{dE_T}$

5. However there is a dramatic deviation of J/ψ production in Pb-Pb collisions from Glauber predictions.. <u>Why?</u>

Kharzeev

- Quarkonium interactions with light hadrons





gluons inside
a slowly moving
light hadron
cannot dissociate J/Ψ:
threshold suppression
of J/Ψ dissociation

D. K., H. Satz
PLB334(94)155

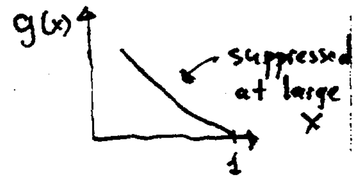
$$F_{\psi h} = i \int d^4x \, e^{iqx} \langle h | T\{ J(x) J(0) \} | h \rangle =$$

$$= \sum_n C_n(Q, m_Q) \langle O_n \rangle$$

$$\langle O_n \rangle = \int_0^1 dx \, x^{n-2} g(x, Q^2 = \epsilon_0^2)$$

in the first approximation,

$$\sigma_{\Phi h}\left(\frac{\lambda_0}{x}\right) \sim g(x, Q^2 = \epsilon_0^2)$$



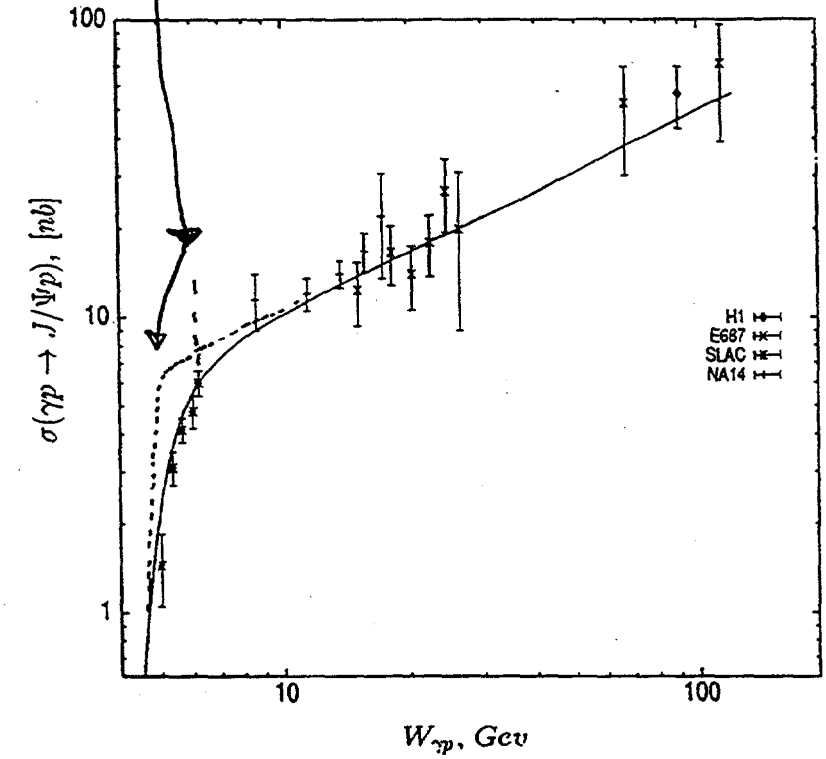
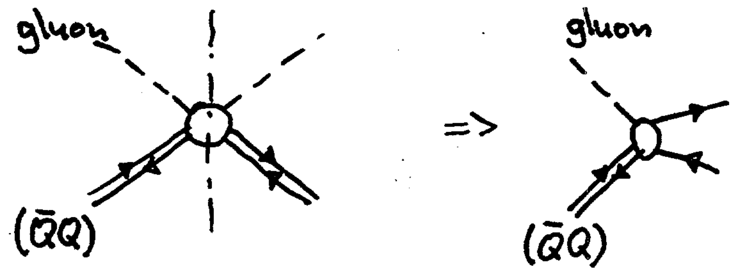
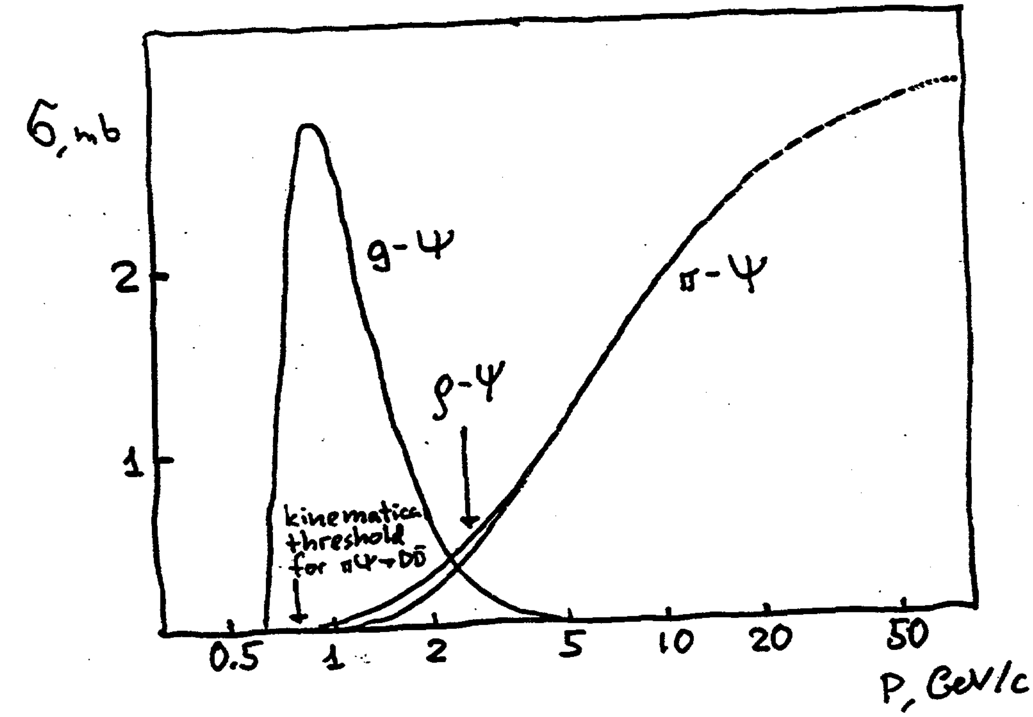


Figure 2. J/ψ photoproduction cross section; the curve is the theoretical prediction [20].

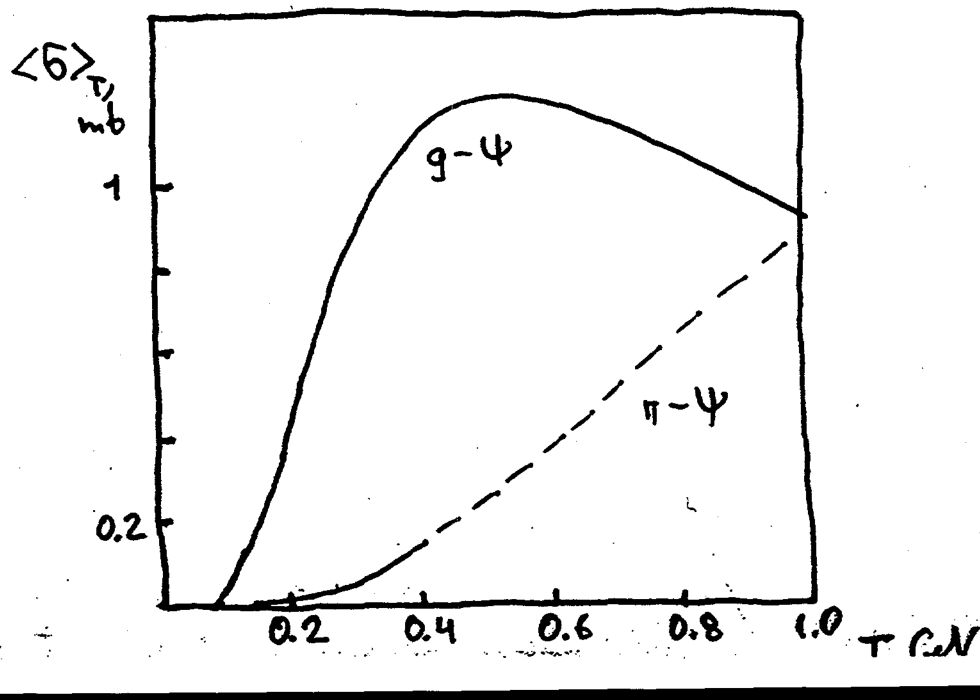
from
D. K., H. Satz
A. Syamtomov,
G. Zinovjev
CERN-TH/96-72
hep-ph/9605448
+ PLB, in press
+ PLB389(96)595

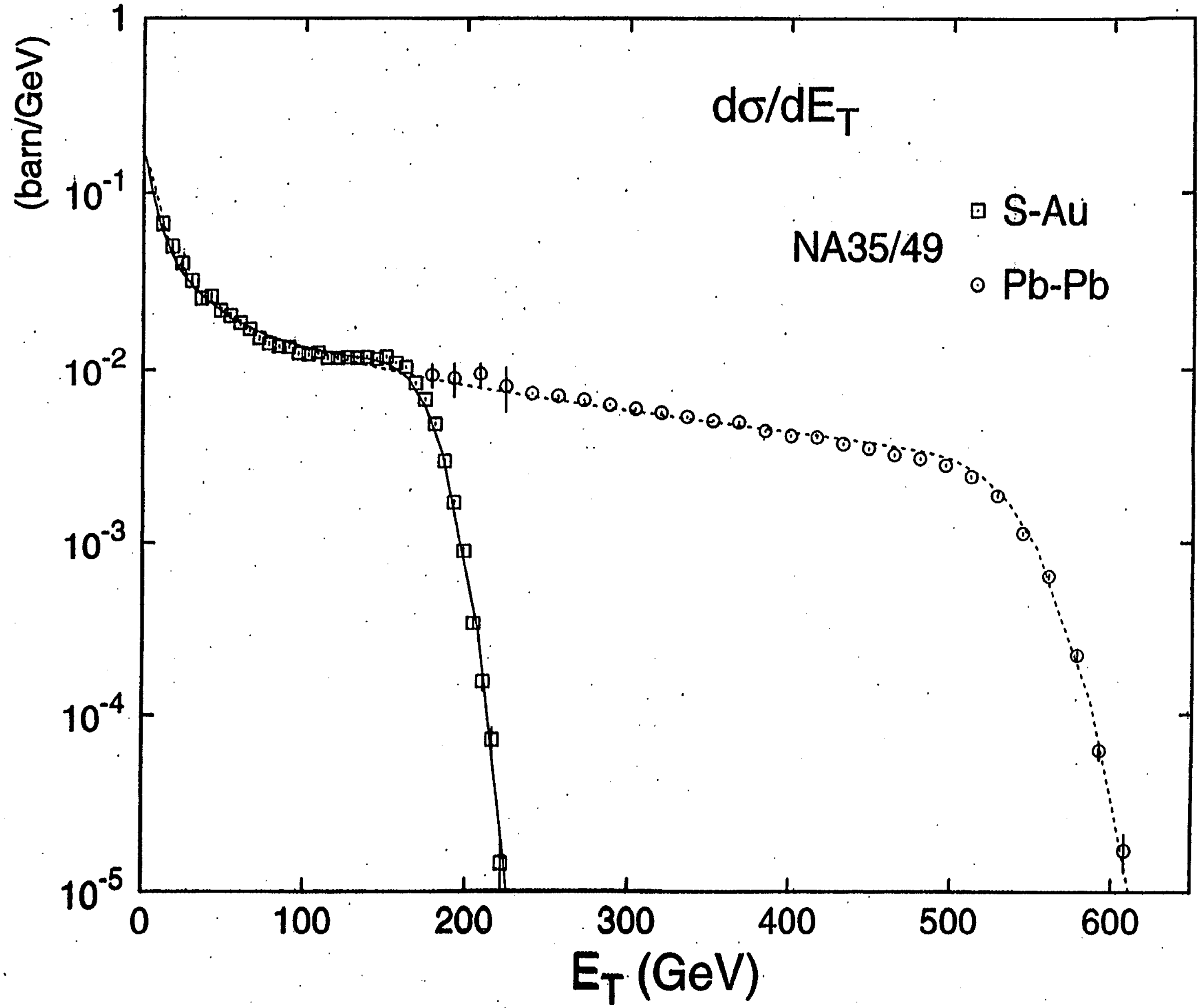
Quarkonium in Hot Deconfined Matter

- 



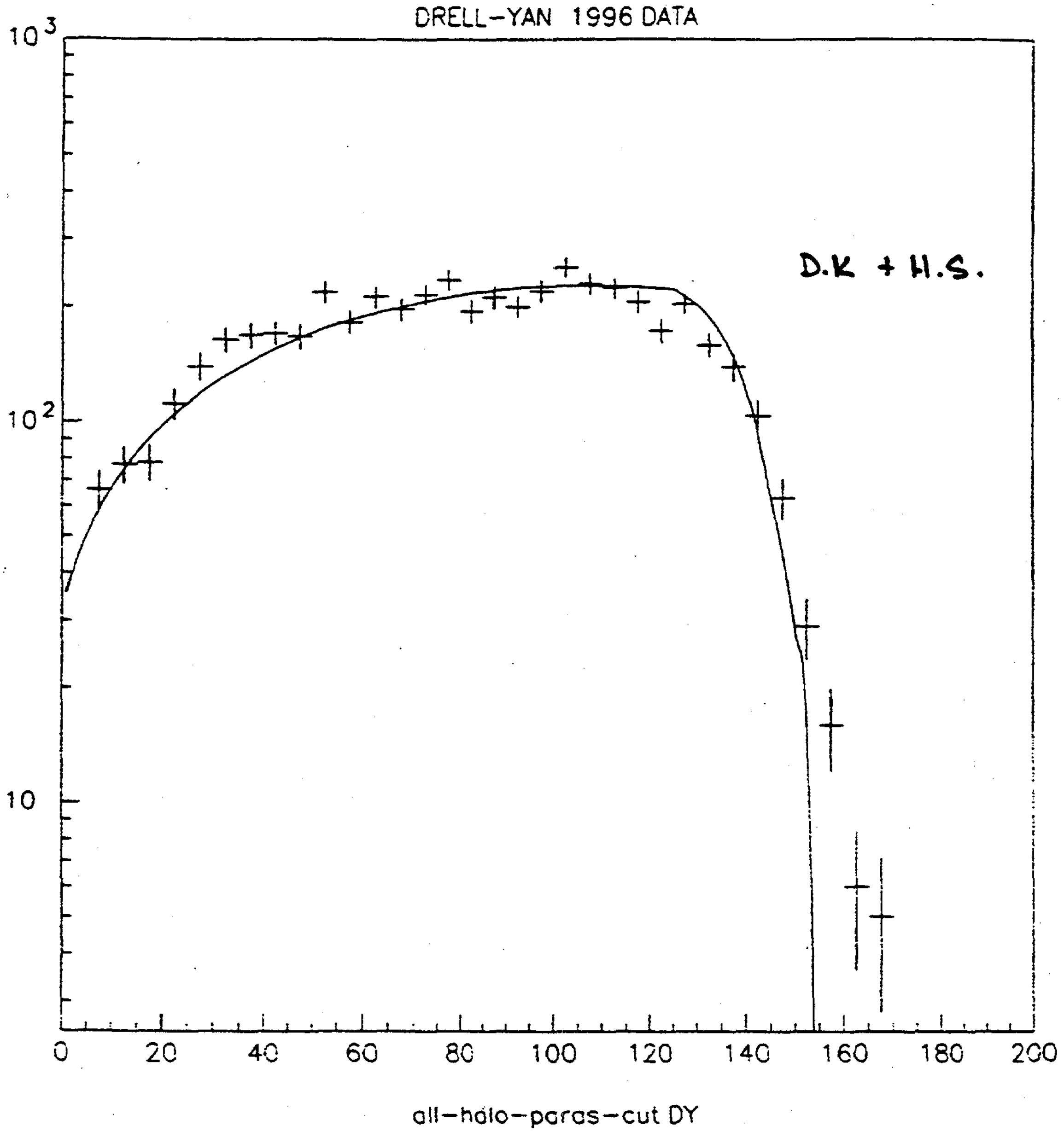
- Thermally averaged g-ψ cross section





(barn/GeV)
dσ/dE_T
NA35/49
S-Au
Pb-Pb
1
10^-1
10^-2
10^-3
10^-4
10^-5
0
100
200
300
400
500
600
E_T (GeV)

M. Gonin, NAS



DRELL-YAN 1996 DATA
10^3
10^2
10
0
20
40
60
80
100
120
140
160
180
200
all-halo-paras-cut DY
D.K + H.S.

Recent QCD Results from CDF

Takashi Asakawa

Institute of Physics, University of Tsukuba

Tsukuba, Ibaraki 305, Japan

(The CDF Collaboration)

1 Introduction

The Tevatron collider has produced collisions of antiprotons and protons at a center of mass energy of 1800 GeV. We have recently collected a large sample of data with the CDF detector during the Run I collider experiment. We recorded 20 pb^{-1} of data in 1992/93 (Run IA) and 90 pb^{-1} of data in 1994/95 (Run IB) respectively. This summarizes a sampling of recent QCD analyses. These include inclusive jet E_T spectrum, dijet angular distributions, other interesting analyses of jet productions, photon productions, and W charge asymmetry.

2 Jet Production

The inclusive jet cross section for the jet E_T range of $15 < E_T < 415$ GeV and the η range of $0.1 < |\eta| < 0.7$ has been compared with NLO QCD predictions (see Fig.1). The observed spectrum is in excellent agreement with NLO QCD below E_T of 200 GeV. Above 200 GeV the measured cross section begins to deviate from the QCD predictions. A similar excess has been observed in the dijet mass distribution for $M_{jj} > 400$ GeV/c^2. Angular distributions of dijet events show good agreement with QCD predictions (see Fig.2). Properties of multijet (N_J=3,4,5,6) events have been compared with QCD predictions and found to be well described by the predictions. In the multijet analysis a set of kinematical variables which span the multi body parameter space are defined, and observed distributions of the variables are compared with LO QCD, HERWIG parton shower MC, and the phase-space model predictions. Shown in Fig.3 is the $\cos\theta^*$ distribution of three-jet events which were collected with the $\sum E_T$ trigger asking $\sum E_T^{\rm jet} > 420$ GeV, where θ is the scattering angle of the leading jet. Data agree with both QCD predictions very well.

3 Photon Production

The inclusive photon cross section and the diphoton cross section have been compared with NLO QCD predictions. Events are selected by requiring photons to have $p_t > 10$ GeV/c and $|\eta| < 0.9$. The distribution of diphoton system p_t compared to NLO QCD and PYTHIA parton shower MC is shown in Fig.4. We see PYTHIA gives a better description of the observed spectrum for the low p_t region. This result suggests the need to include k_T or parton shower effects in the model.

4 W Charge Asymmetry

The lepton charge asymmetry in the W production has been measured (see Fig.5). The observed asymmetry data of W events constrain the ratio of u and d quark momentum distributions over the range $0.006 < x < 0.34$ at $Q^2 \approx M_W^2$.

Comparison between Run IA and IB

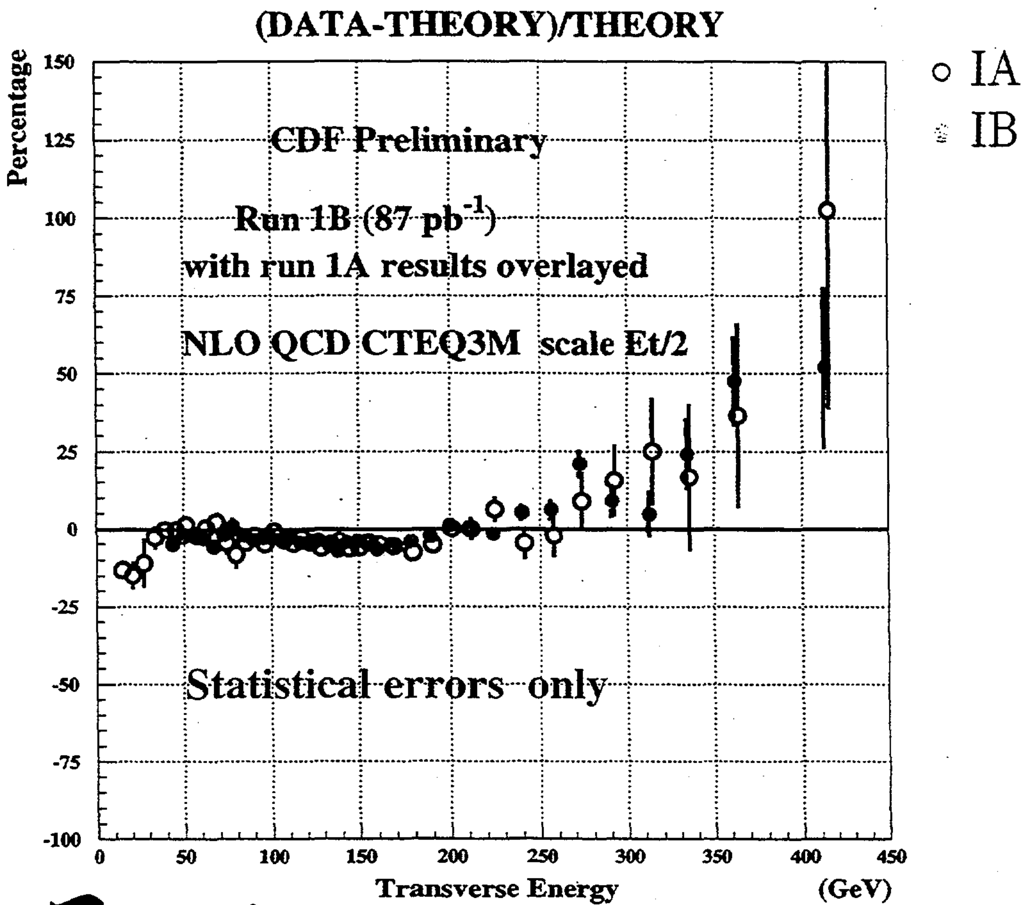


Fig. 1

- Good agreement between Run IA and IB
- Good agreement of data with NLO QCD below E_T of 200 GeV
- Possible non-exotic explanations:
  - PDF's (Not enough gluons at large X)?
  - Higher order QCD corrections?

χ Distributions

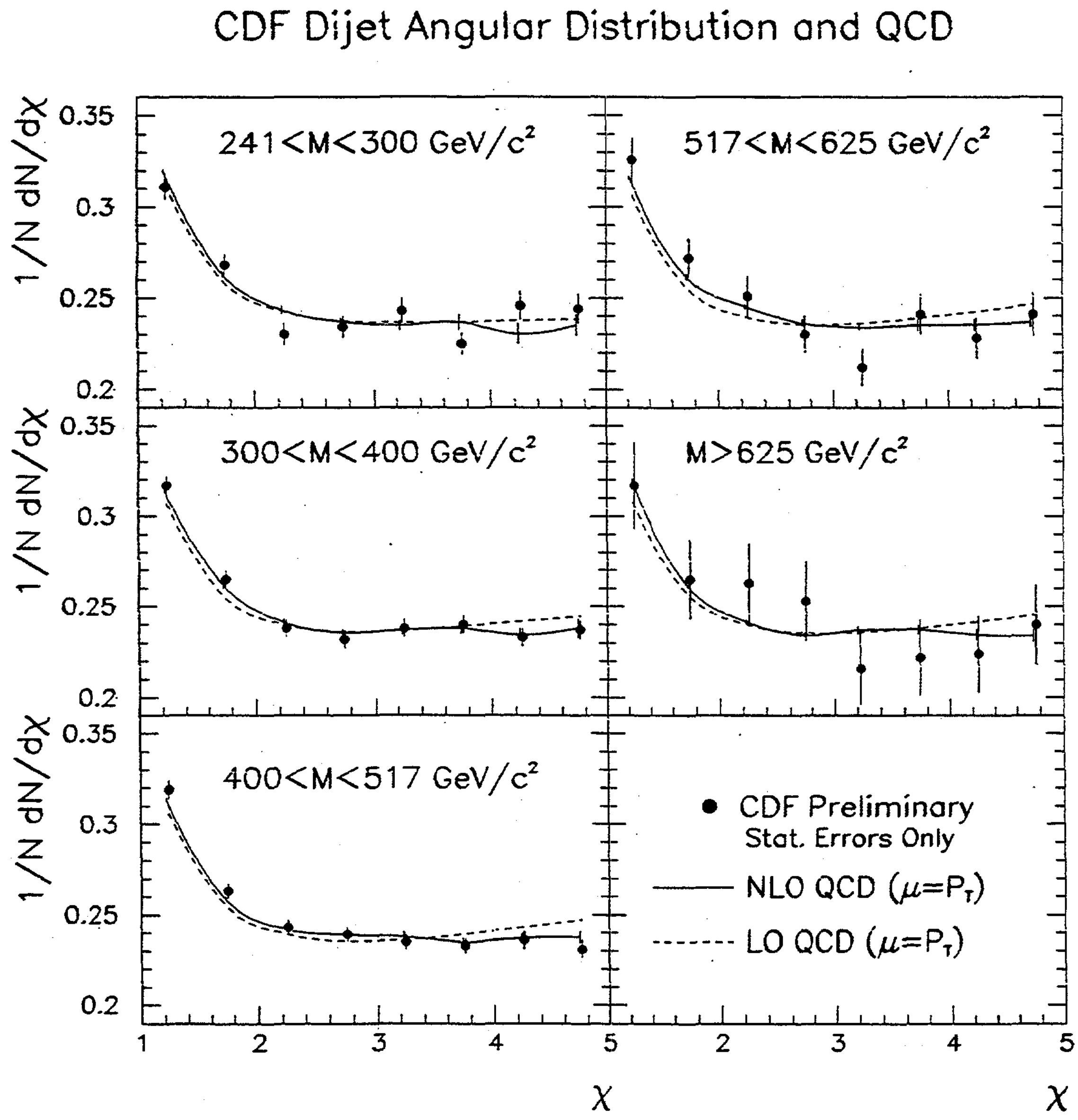
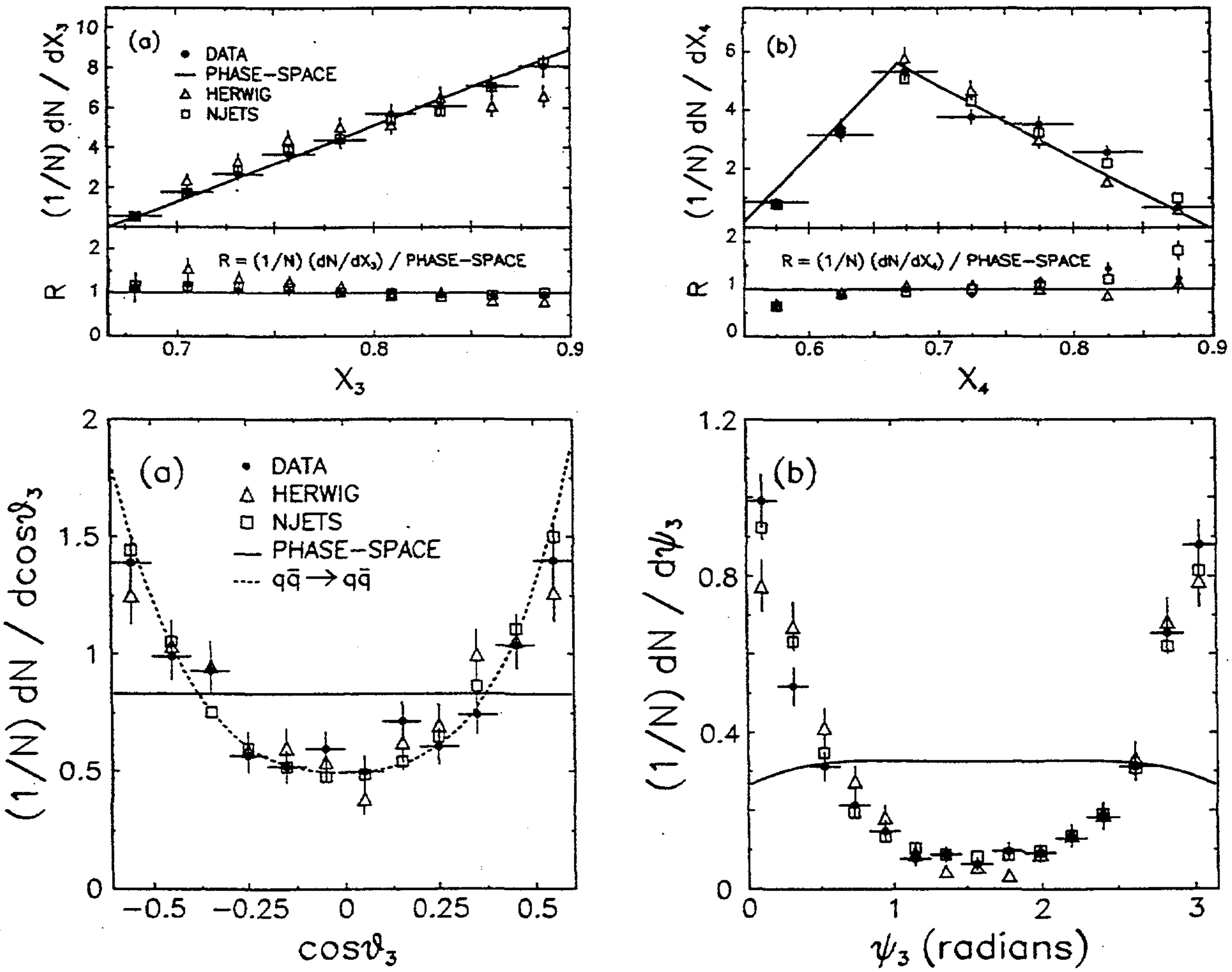


Fig.2

Three-Jet Events

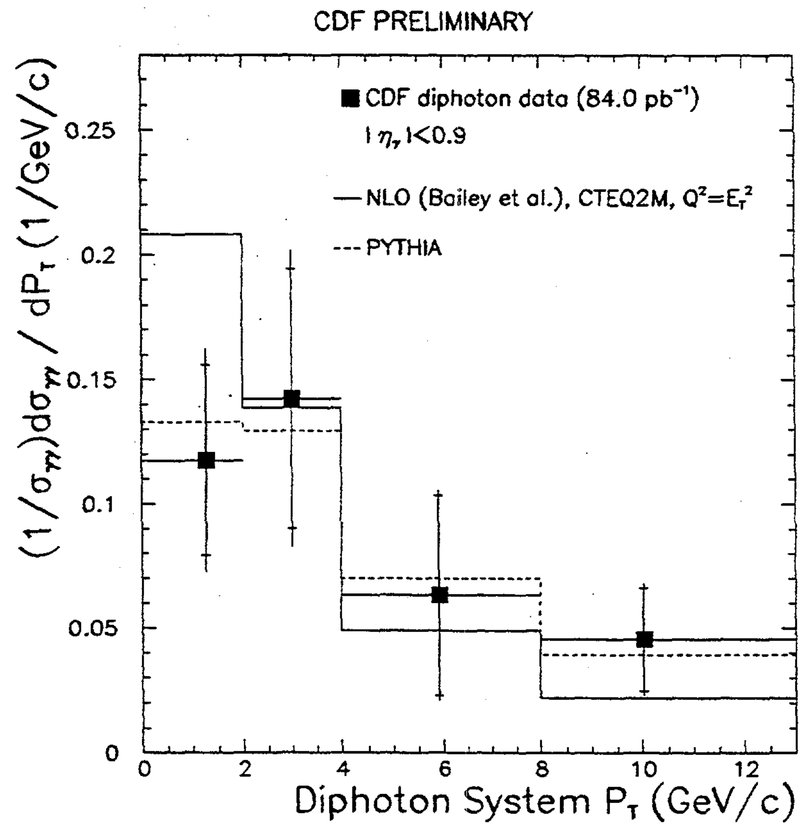


Both QCD predictions give a good description of the observed distributions of 3-jet events.

Fig.3

$p_t(\gamma\gamma)$ result

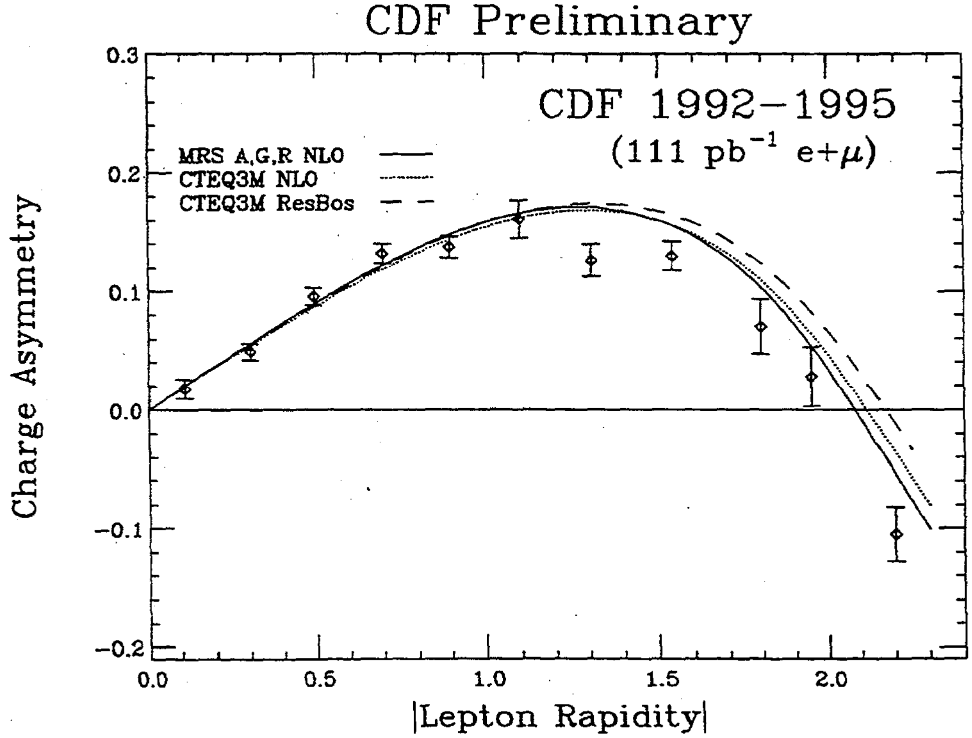
- Compared to NLO QCD and PYTHIA (parton shower M.C.).



- NLO QCD underestimates k_T effect.
- PYHTIA gives a better description of the observed data. $\Rightarrow$ consistent to the inclusive photon results.

Fig. 4

- The fully corrected charge asymmetry.
  - Data from all the detectors for possitive and negative y_l are combined.
  - The statistical and systematic errors are added in quadrture.
  - NLO QCD calculations use PDF's that have been extracted with the inclusion of the Run IA (92') CDF asymmetry data (20 pb^{-1}).



- **These PDF's are in good agreement with the new data in the region $|y_l| < 1.1$ which is used in the W mass determination.**
- **For $|y_l| > 1.1$ predictions are generally higher than CDF data.**
  $\Rightarrow$ indicating that the PDF parameterization should be modified in the range $0.006 < x < 0.34$.

Fig.5

Recent results from ZEUS/HERA

T. Tsurugai

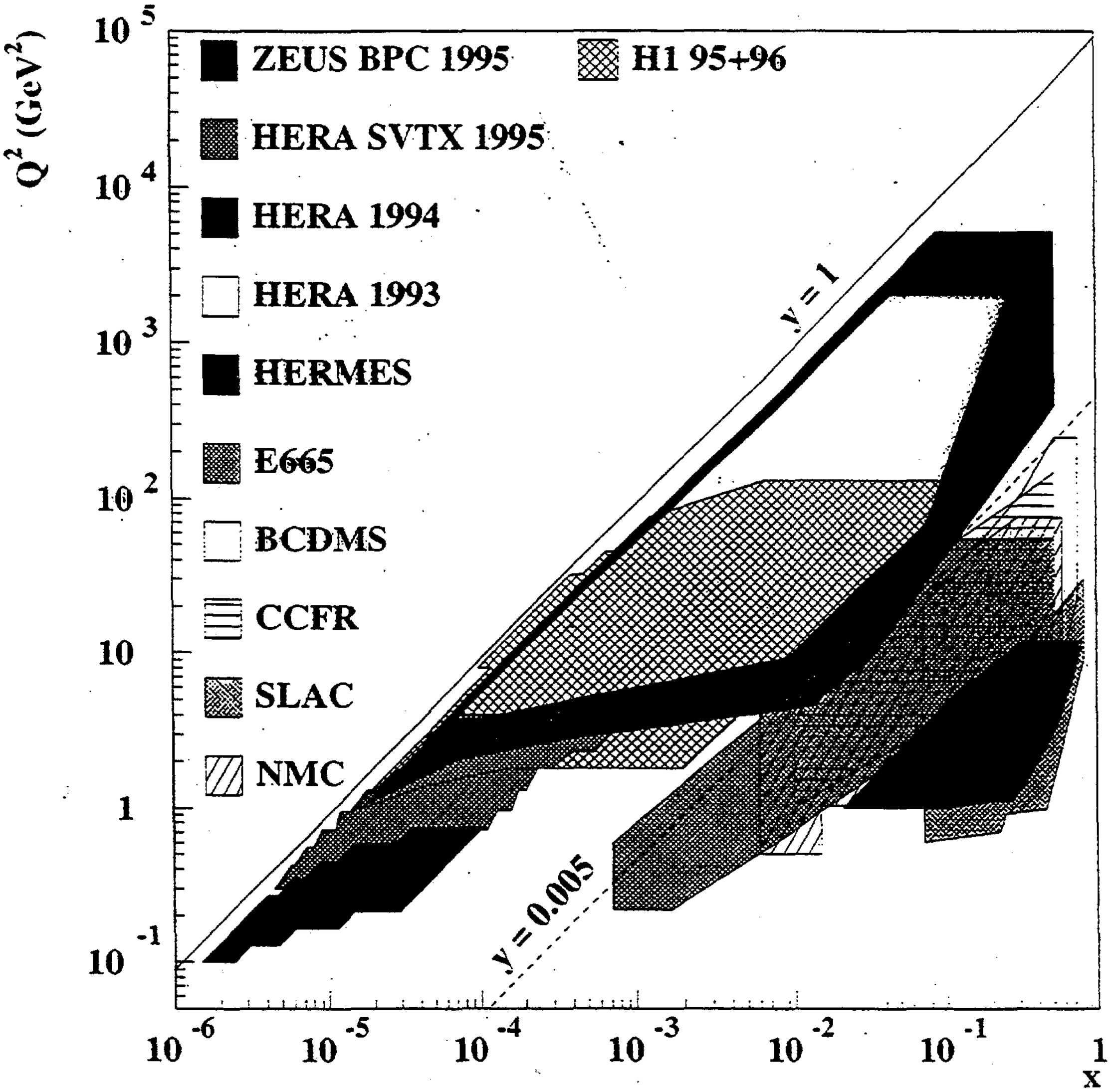
(Meiji-Gakuin University)

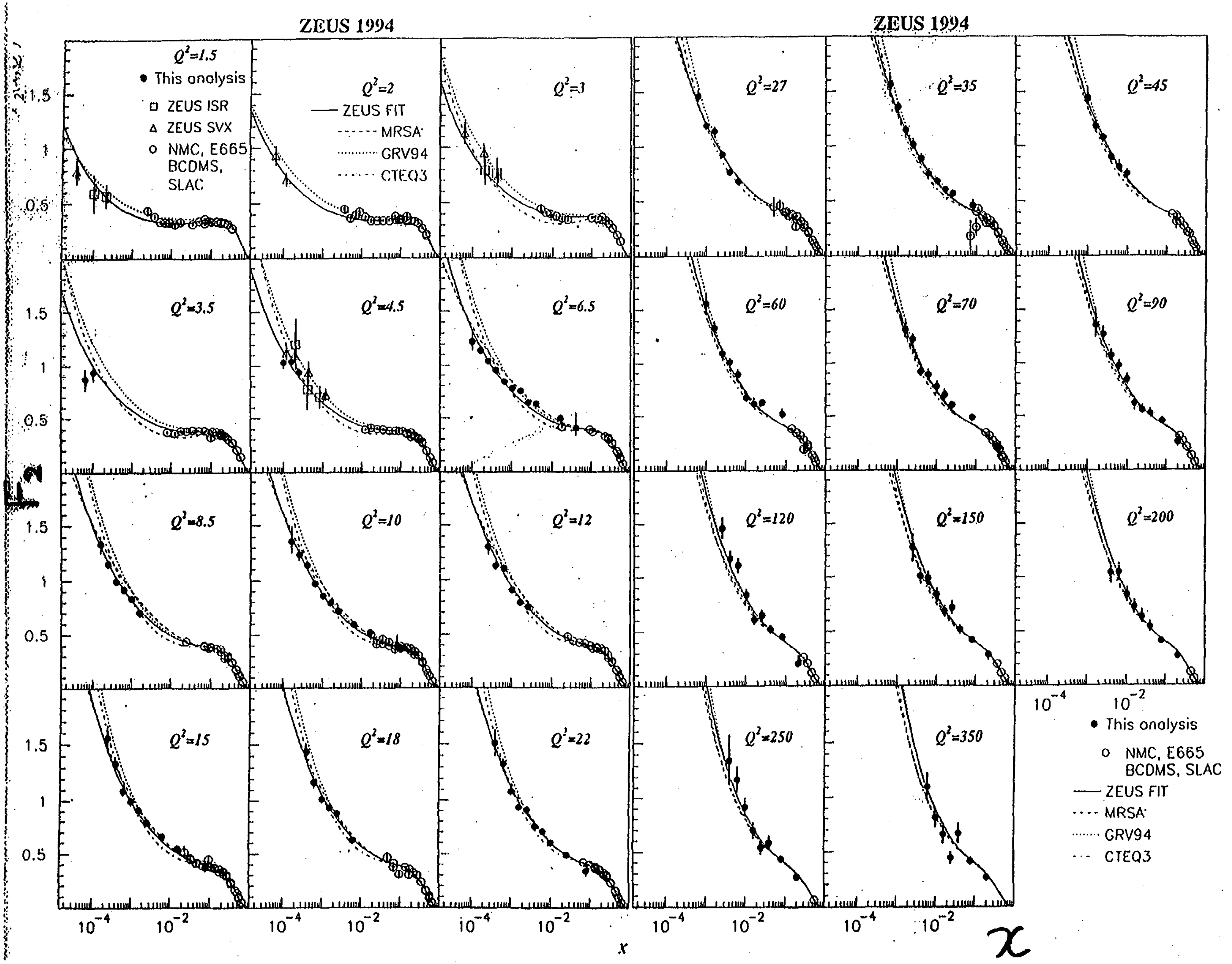
for ZEUS collaboration

1. Introduction
2. HERA and ZEUS
3. Kinematics
4. Physics results
   - F_2 Measurement
5. Summary

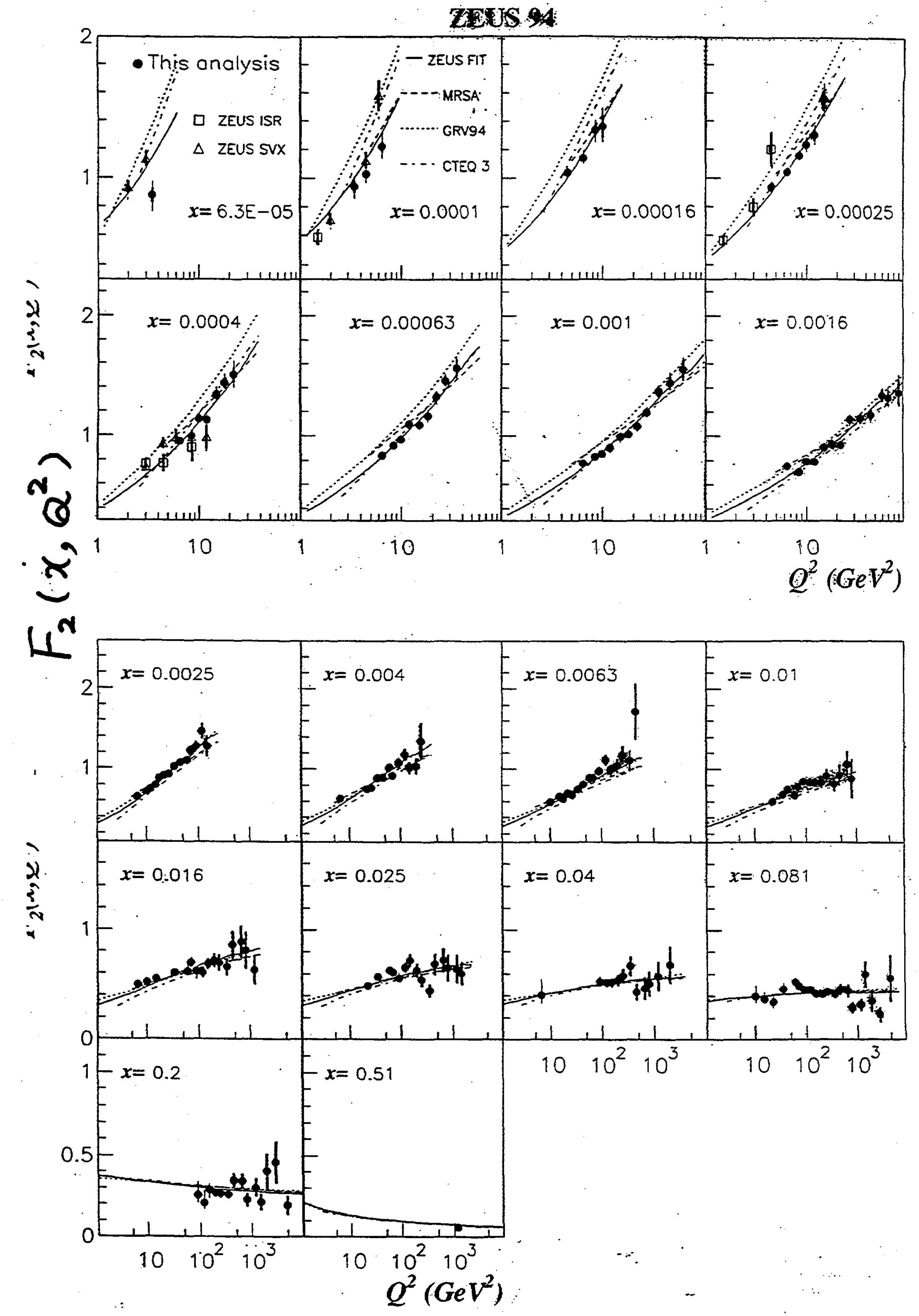
Introduction

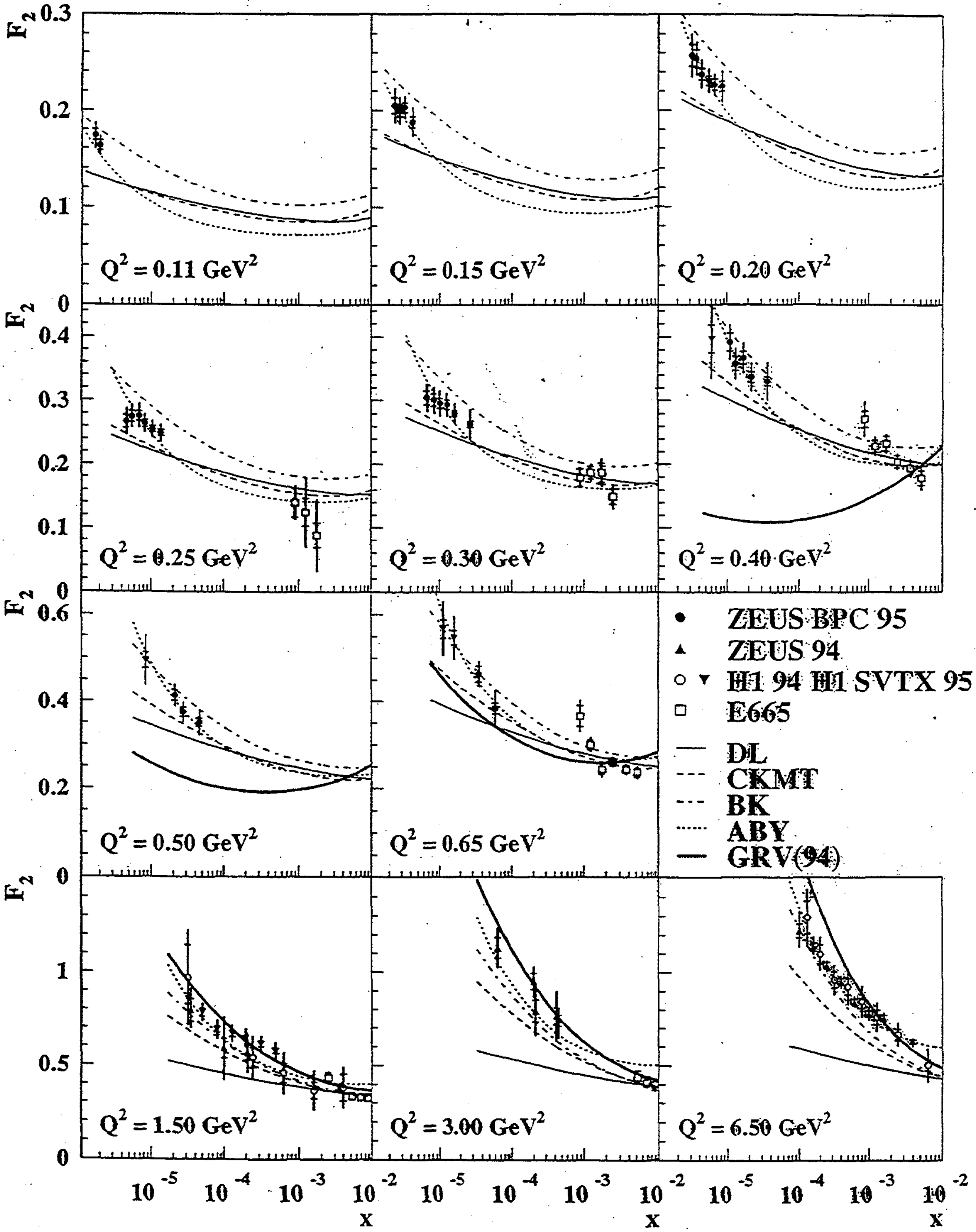
F_2 measurements from fixed target experiments and HERA span 5 orders of magnitude in Q^2, x





ZEUS 1994
ZEUS 1994
Q^2=1.5
Q^2=2
Q^2=3
Q^2=3.5
Q^2=4.5
Q^2=6.5
Q^2=8.5
Q^2=10
Q^2=12
Q^2=15
Q^2=18
Q^2=22
Q^2=27
Q^2=35
Q^2=45
Q^2=60
Q^2=70
Q^2=90
Q^2=120
Q^2=150
Q^2=200
Q^2=250
Q^2=350
This onolysis
ZEUS ISR
ZEUS SVX
NMC, E665 BCDMS, SLAC
ZEUS FIT
MRSA'
GRV94
CTEQ3
0.5
1
1.5
10^{-4}
10^{-2}
x
F_2


ZEUS 94
This analysis
ZEUS ISR
ZEUS SVX
ZEUS FIT
MRSA
GRV94
CTEQ 3
x= 6.3E−05
x= 0.0001
x= 0.00016
x= 0.00025
x= 0.0004
x= 0.00063
x= 0.001
x= 0.0016
x= 0.0025
x= 0.004
x= 0.0063
x= 0.01
x= 0.016
x= 0.025
x= 0.04
x= 0.081
x= 0.2
x= 0.51
$F_2(x, Q^2)$
Q^2 (GeV^2)



F2
0.3
0.2
0.1
0
0.4
0.6
0.5
1
Q² = 0.11 GeV²
Q² = 0.15 GeV²
Q² = 0.20 GeV²
Q² = 0.25 GeV²
Q² = 0.30 GeV²
Q² = 0.40 GeV²
Q² = 0.50 GeV²
Q² = 0.65 GeV²
Q² = 1.50 GeV²
Q² = 3.00 GeV²
Q² = 6.50 GeV²
ZEUS BPC 95
ZEUS 94
H1 94 H1 SVTX 95
E665
DL
CKMT
BK
ABY
GRV(94)
10⁻⁵
10⁻⁴
10⁻³
10⁻²
x

Summary

- HERA structure function data
  F_2 measured with high precision
  over wide kinematic range

- F_2 rises rapidly as x decreases

- F_2 well described by pQCD (DGLAP evolution) for $Q^2 > 1$ GeV^2

- Extension to low Q^2 region exhibits transition from pQCD to SOFT regime

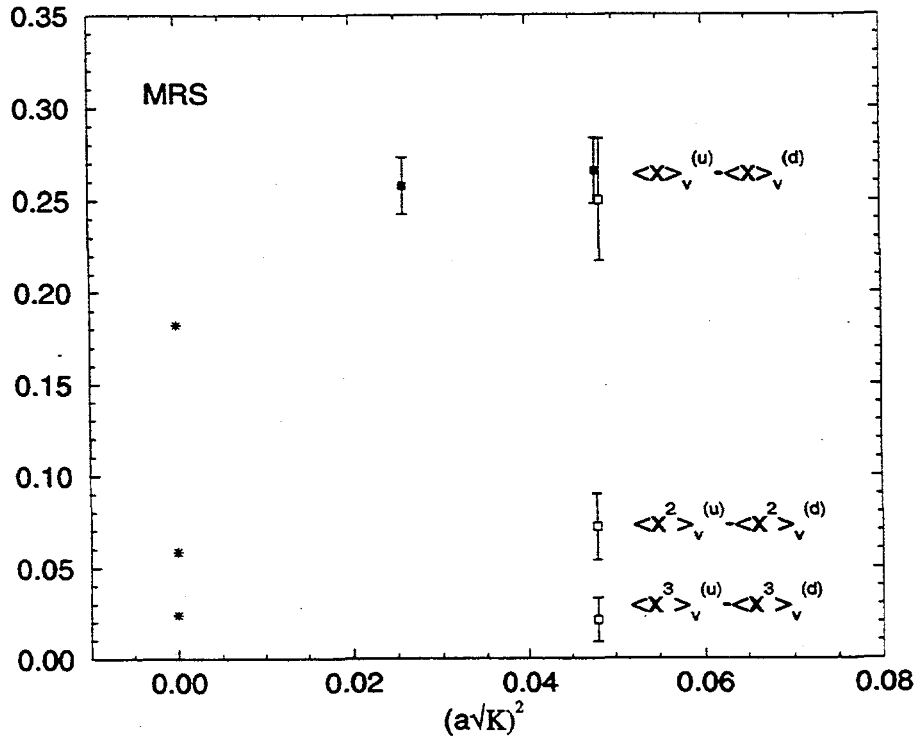
Status of Lattice Structure Function Calculations

Gerrit Schierholz

There is significant interest in an ab initio calculation of the nucleon structure functions. The theoretical framework of such a calculation is the operator product expansion. While the Wilson coefficients, and hence the evolution of the structure functions, can be computed perturbatively, the hard part of the calculation is the determination of the forward nucleon matrix elements of the operators. This is a non-perturbative problem, and the technique to solve it is lattice QCD. Two years ago we have made an effort to compute the nucleon matrix elements of all relevant operators of leading twist up to spin four. Initially the calculation was done for one value of the coupling β. Recently the calculations have been extended to cover several values of β so that an extrapolation to the continuum limit can be performed. In that limit we find, by and large, good agreement with the experimental results. A particular highlight is the axial vector coupling of the nucleon, $g_A = \Delta u - \Delta d$. Of particular interest to this workshop is the structure function h_1. Its first moments δu and δd, are found to be approximately equal to Δu and Δd, respectively. This shows that a non-relativistic description of the spin structure of the nucleon is quite adequate. The x-dependence of the structure functions carries valuable information about the dynamics of quarks and gluons which is not immediately available from the moments. A first attempt of constructing nucleon structure functions from a few lower moments by an inverse Mellin transform looks promising. The program for the next years is to compute the gluon distribution functions. A further topic is to estimate the effect of higher twist matrix elements. And finally one wants to include dynamical fermions.

Unpolarised results

- $\langle x^n \rangle^{(u)} - \langle x^n \rangle^{(d)}$ - Scaling Plot



- Anomalous dimension $\Rightarrow$ scale to a common scale

$$\langle x \rangle|_{\mu} = \left(\frac{\alpha_{\overline{MS}}(\mu)}{\alpha_{\overline{MS}}(\mu_0)} \right)^{C_F \frac{\gamma_0}{2b_0}} \langle x \rangle|_{\mu_0}$$

  Scale $\beta = 6.2$ result to $\beta = 6.0$ where $\mu \sim 1.95\text{GeV}$ gives about a $\sim 4\%$ increase in result

- $\langle x \rangle_v^{(u)} - \langle x \rangle_v^{(d)}$ seems to be constant $>$ phenomenological value (?). Higher moments better

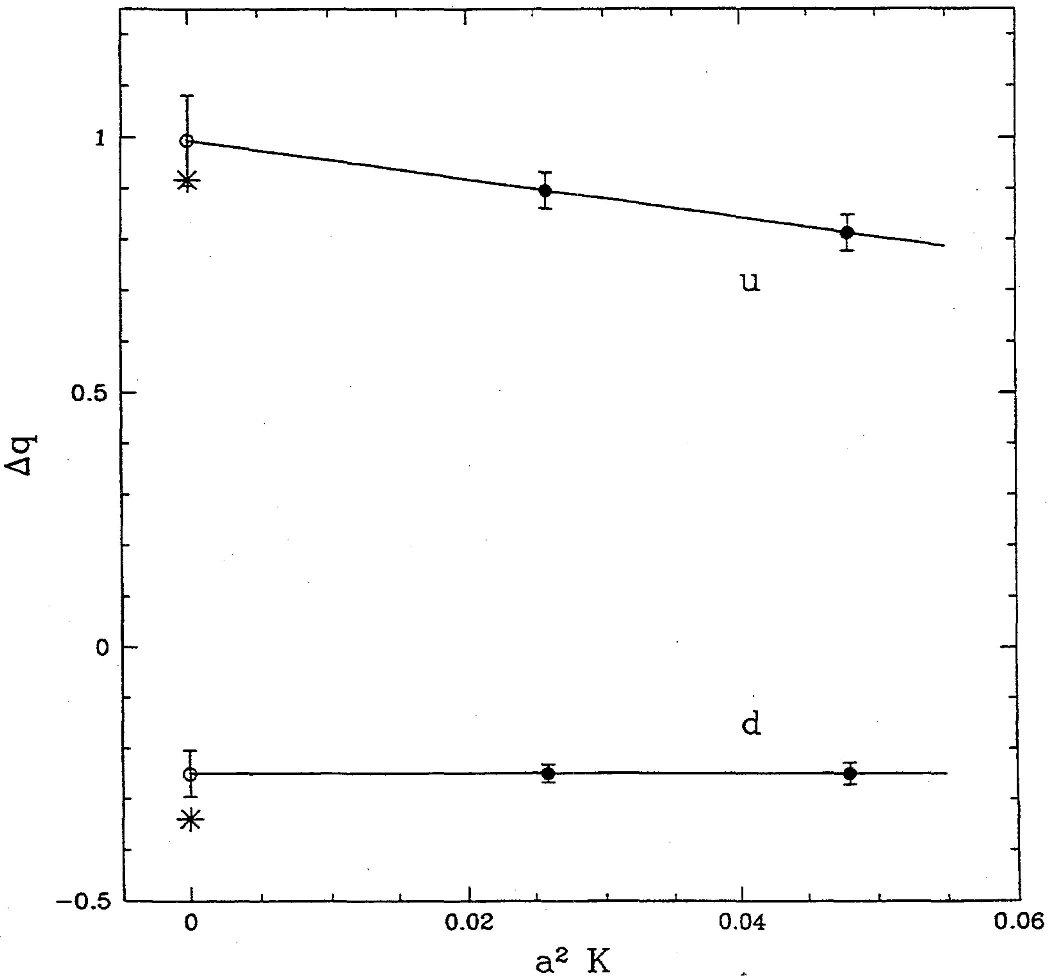


Figure 1: The quenched moments Δu and Δd plotted as a function of a^2. The lattice spacing is given in units of the string tension, K. The lattice data are denoted by ●, the extrapolated values by ○. The phenomenological values [8] are denoted by $\ast$.

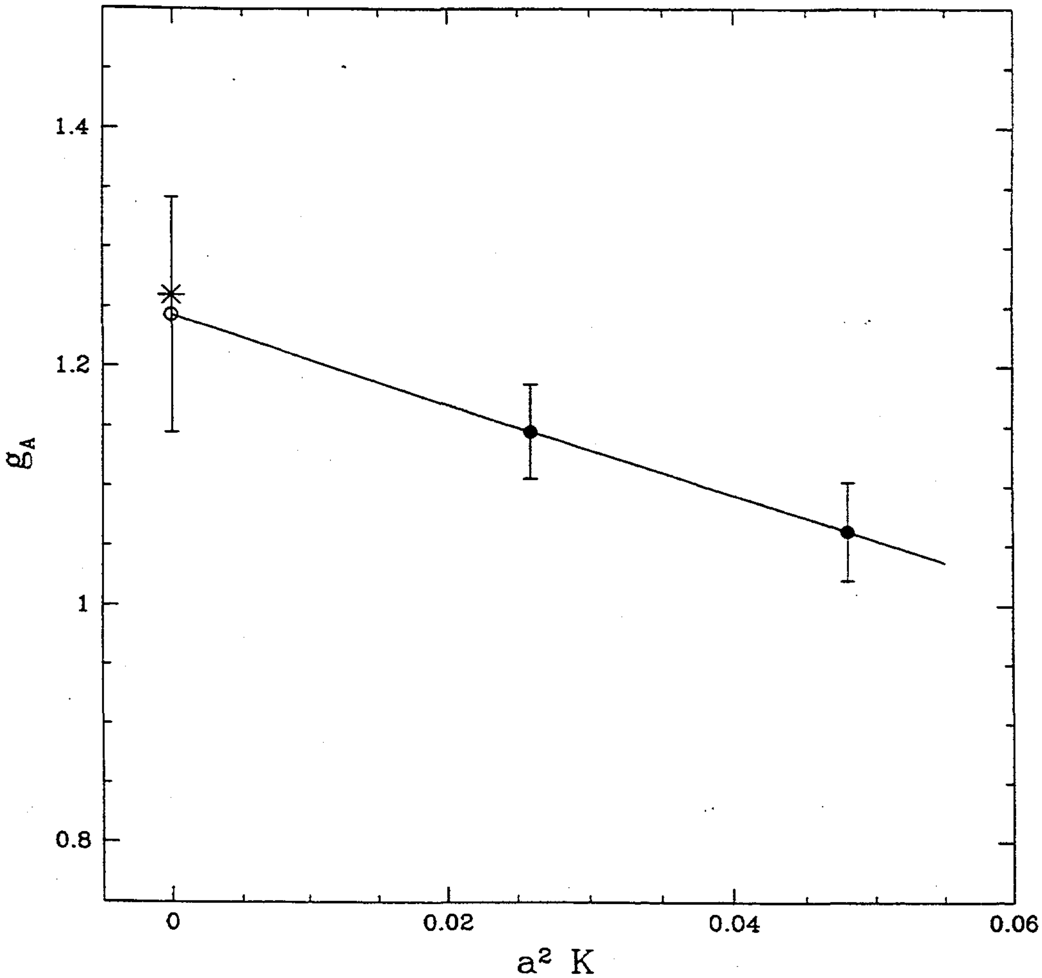


Figure 2: The axial vector coupling of the nucleon g_A as a function of a^2. The lattice spacing is given in units of the string tension, K. The lattice results are denoted by ●, the extrapolated values by ○. The experimental value is denoted by $*$.

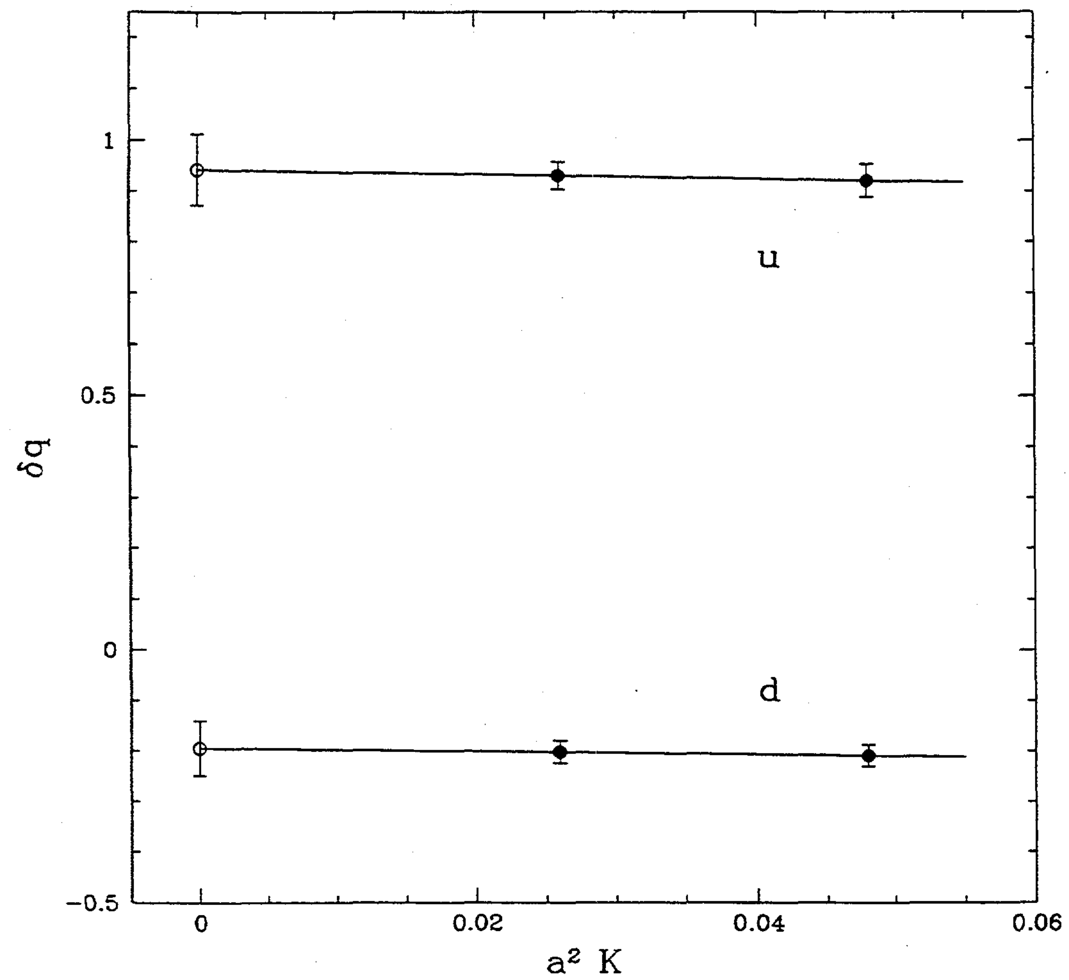


Figure 3: The quenched moments δu, δd as a function of a^2. The lattice spacing is given in units of the string tension, K. The lattice results are denoted by ●, the extrapolated values by ○. The numbers are renormalized at the scale $\mu^2 = 4$ GeV^2.

Operator differs from that of Δq by γ_0

$\delta q = \Delta q$ in non-relativistic limit

Summary & outlook

By and large agreement with experiment and theoretical expectations

Except perhaps for d_2 ⇐ better data

Rho structure functions give valuable information about quark binding effects

Precision calculation feasible

Gluon distributions

$J \Leftarrow \Theta_{\mu\nu}$

Power corrections renormalons, higher twist

Dynamical fermions require teraflop computer

Higher-twist light-cone wave functions of vector mesons in QCD

Kazuhiro TANAKA

Department of Physics, Juntendo University, Inba-gun, Chiba 270-16, Japan

We present a systematic study of light-cone wave functions (distribution amplitudes) of vector mesons in QCD. These wave functions contribute as a "long distance part" for hard exclusive processes involving vector meson in the final state. The higher-twist wave functions are relevant for understanding preasymptotic corrections to hard exclusive amplitudes. We give operator definitions of quark-antiquark wave functions up to twist-4 and quark-antiquark-gluon wave functions of twist-3, based on matrix elements of nonlocal light-cone operators between the vacuum and the vector meson state. A detailed operator product expansion analysis is performed for the twist-3 wave functions, and the constraints from the QCD equations of motion are solved, giving relation between the quark-antiquark and the quark-antiquark-gluon wave functions. We introduce conformal expansion as a powerful framework for systematic treatment of the higher-twist wave functions. A complete set of twist-3 wave functions is constructed, which satisfies all (exact) equations of motion and constraints from conformal expansion. The renormalization scale dependence of the wave functions is worked out in the leading logarithmic approximation. We also take into account the SU(3) flavor violation effects induced by quark masses. Nonperturbative input parameters, which appear in a few low order terms in the conformal expansion, are calculated from QCD sum rules. Based on these developments, we construct models for the wave functions of ρ, K^*, and ϕ mesons up to twist-3, which satisfy all QCD constraints. Some immediate applications of our results will be to exclusive semileptonic and radiative B decays and to hard electroproduction of vector mesons at HERA.

Hard processes in QCD

light-cone nonlocal operators

$$\bar{\psi}(z)\Gamma\lambda^a \underbrace{}_{P e^{ig\int_{-z}^{z} dx_\mu A_\mu}} \psi(-z)$$

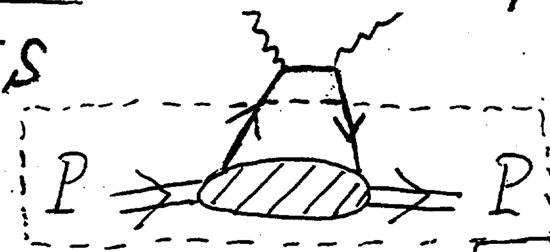
$z^2 = 0$; $z^\mu = (\overset{+}{0}, \overset{-}{z^-}, \overset{\perp}{0_\perp})$

λ^a: flavor matrix

$\Gamma = \gamma^\mu, \gamma^\mu\gamma_5, \sigma^{\mu\nu}, 1, \gamma_5$

Inclusive

DIS



structure functions

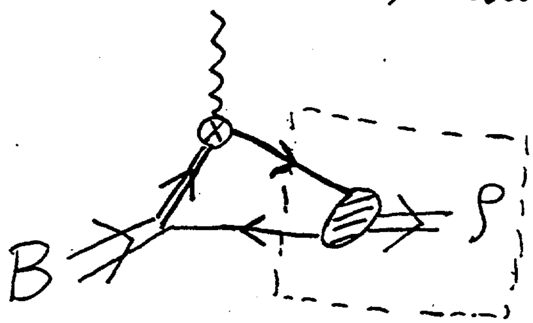
$$\langle P|\bar{\psi}(z)\Gamma\lambda^a\psi(-z)|P\rangle$$

Exclusive

heavy meson (semileptonic / radiative) decay

$B \to \rho e \nu$

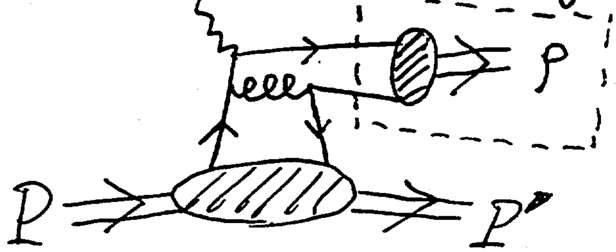
$B \to \rho + \gamma$



distribution amplitudes (wave functions)

$$\langle 0|\bar{u}(z)\Gamma d(-z)|\rho^-\rangle$$

electroproduction of vector meson



Higher twist distribution amplitudes

- preasymptotic corrections $1/Q^2$
- new information on QCD and hadron structure

$\langle PS|\bar{\psi}(z)\Gamma\psi(-z)|PS\rangle$ Jaffe–Ji ('92)

twist	spin ave.	$S_{\parallel}$	$S_{\perp}$	LC-proj.
2 $O(1)$	f_1	g_1	h_1 (chiral-odd)	+ +
3 $O(1/Q)$	e (chiral-odd)	h_L (chiral-odd)	g_T	+ −
4 $O(1/Q^2)$	f_4	g_3	h_3 (chiral-odd)	− −

$\langle 0|\bar{u}(z)\Gamma d(-z)|\rho^-(P,\epsilon)\rangle$ Ball, Braun, Koike & Tanaka ('97)

twist	$\epsilon_{\parallel}$	$\epsilon_{\perp}$	LC-proj.
2 $O(1)$	$\phi_{\parallel}$	$\phi_{\perp}$ (chiral-odd)	+ +
3 $O(1/Q)$	h_L, e (chiral-odd)	$g_{\perp}^{(v)}, g_{\perp}^{(a)}$	+ −
4 $O(1/Q^2)$	g_3	h_3 (chiral-odd)	− −

$$\left(\psi = \underset{\text{good}}{\psi_+} + \underset{\text{bad}}{\psi_-}\right)$$

$x_\mu \to z_\mu$: $\xi = 2u - 1$

$$-i(p\cdot z)\int_0^1 du\, e^{i\xi p\cdot z}\,\xi\, \boxed{h_L(u)} - 2\int_0^1 du\, e^{i\xi p\cdot z}\left(\boxed{h_L(u)} - \phi_\perp(u)\right)$$

$$= (p\cdot z)^2 \int_{-1}^{1} dt\, t \int \mathcal{D}\alpha\, e^{-ip\cdot z(\alpha_2-\alpha_1+t\alpha_3)}\, \Phi_{3T}(\alpha_1,\alpha_2,\alpha_3)$$

$$+\left(1-\frac{f_\rho}{f_\rho^\perp}\frac{m_u+m_d}{m_\rho}\right)(p\cdot z)^2\int_0^1 du\, e^{i\xi p\cdot z}\, \underline{e(u)}$$

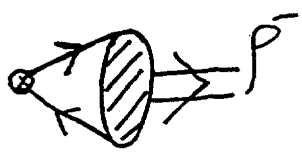
$$+i\,\frac{m_u-m_d}{m_\rho}\frac{f_\rho}{f_\rho^\perp}(p\cdot z)\int_0^1 du\, e^{i\xi p\cdot z}\,\phi_\parallel(u)$$

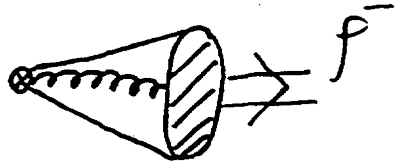
$$\left(1-\frac{f_\rho}{f_\rho^\perp}\frac{m_u+m_d}{m_\rho}\right)\int_0^1 du\, e^{i\xi p\cdot z}\,\boxed{e(u)}$$

$$= i(p\cdot z)\int_0^1 dv\, v\int_{-1}^{1} dt \int \mathcal{D}\alpha\, e^{-i(p\cdot z)v(\alpha_2-\alpha_1+t\alpha_3)}\,\Phi_{3T}(\alpha_1,\alpha_2,\alpha_3)$$

$$+\int_0^1 dv\int_0^1 du\, e^{i\xi v(p\cdot z)}\,\boxed{h_L(u)}$$

$$-\frac{m_u+m_d}{m_\rho}\int_0^1 dv\int_0^1 du\, e^{i\xi v(p\cdot z)}\,\phi_\parallel(u)$$

$\phi_\perp$ 

Φ_{3T} 

$\phi_\parallel$

QM: <u>*partial wave expansion*</u> (rotational symm.

$$\Psi(\mathbf{r}) = \sum_{\ell, m} a_{\ell m}(r)\, Y_{\ell m}(\theta, \varphi)$$

$$\left[-\frac{1}{2M}\left\{\frac{1}{r^2}\frac{d}{dr}r^2\frac{d}{dr} - \frac{\ell(\ell+1)}{r^2}\right\} + U(r)\right] a_{\ell m}(r) = E\, a_{\ell m}(r)$$

1-dim. Schrödinger eq.

Separation of angular (θ, φ) and radial (r) deg. of freedom

QCD: <u>*conformal expansion*</u> (conformal symm. $m_q = 0$

$$\phi(u, \mu^2) = 6u(1-u) \sum_{n=0}^{\infty} a_n(\mu^2)\, P_n^{(1,1)}(2u-1)$$

$\mu \sim k_\perp$

$$\left(\mu\frac{\partial}{\partial\mu} + \beta(g)\frac{\partial}{\partial g} + \gamma_n(g)\right) a_n(\mu^2) = 0$$

RG eq.

Separation of long. (u) and trans. ($\mu \sim k_\perp$) deg. of freedom

$n \sim$ "conformal spin"

Conformal group

$\psi(z)$, $G_{\mu\nu}(z)$

- P_μ, $M_{\mu\nu}$ (Poincaré)
- D (dilatations)
- K_μ (special conf. transf.)

collinear subgroup

$$z \to \frac{az + b}{cz + d}$$

Summary

light-cone DA of vector mesons

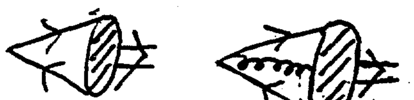
- classification up to twist-4

  chiral-odd: $\phi_\perp, h_L, e, h_3$ chiral-even: $\phi_\parallel, g_\perp^{(v)}, g_\perp^{(a)}, g_3$

- OPE for twist-3 DA : h_L, e

  QCD EOM: $h_L = h_L^{WW} + h_L^{g} + h_L^{\delta_+} + h_L^{\delta_-}$

  $e = e^{WW} + e^{g} + e^{\delta_+} + e^{\delta_-}$



$\propto m_u, m_d$

- conformal expansion of 2-, 3-particle DA

  order by order treatment

- renormalization

  all relevant anom. dim. are fixed

  3-part. DA: complicated mixing of many $\bar{u}Gd$ op.

  $\left.\begin{matrix} N_c \to \infty \\ n \to \infty \end{matrix}\right\}$ no complicated mixing in h_L^{g}, e^{g}

- SU(3) flavor violation effects due to quark masse[s]

  ρ, K^*, ϕ

Powerful framework to investgate the higher twis[t] effects in exclusive processes $\left\{\begin{matrix}\text{heavy meson deca[y]} \\ \text{electroproduction}\end{matrix}\right.$

all informations predictable by pQCD

$a_2^\perp, a_4^\perp, \dots ; \omega_{1,0}, \omega_{2,0}, \omega_{3,0}, \dots$ $\left\{\begin{matrix}\text{QCD sum rule} \\ \text{lattice}\end{matrix}\right.$

Dual Ginzburg-Landau Theory and Quark Nuclear Physics

Hiroshi Toki
RCNP Osaka University, Ibaraki, Osaka 567, Japan

We would like to discuss here the construction of an effective theory for non-perturbative phenomena, which is to be used to calculate the structure function at low momentum scale to evolve to high momentum scale by perturbative QCD. We name the research field to describe hadrons and nuclei in terms of quarks and gluons as Quark Nuclear Physics (QNP). In QNP, the most essential phenomena are color confinement and chiral symmetry breaking. We should construct a model which describe both of these phenomena to be a candidate of the model of QNP.

We model color confinement as due to the dual Meissner effect, where the QCD vacuum is the dual superconductor and dislikes the color electric field.[1-3] Taking the analogy with the superconductor where the cooper pair with electric charge to condense, we ought to have color monopoles in QCD and to realize their condensation. 't Hooft showed it possible to create the color monopole field by taking a particular gauge as the abelian gauge.[4] In this gauge, QCD reduces into QED with color monopole fields living in the color abelian space. We can then construct the DGL lagrangian by assuming three important points from QCD as; 1) presence of color monopole fields, 2) presence of the Higgs term for monopole condensation and 3) abelian dominance to neglect the non-abelian gluons.[5-7]

We apply now the DGL lagrangian to various phenomena.

1. Color confinement (Linear potential)

We can work out the static quark-antiquark potential in the straightforward way and find a linear potential. We find the linearly rising potential, which compares well with experiment.[7] We can then compare with the lattice QCD results, which also tell the goodness of the abelian dominance for the linear potential.[8]

2. Chiral symmetry breaking

We can work out the behavior of quark property by using the Schwinger-Dyson equation. We take the rainbow approximation and introduce the infrared cut-off of the scale of hadron size as caused by the area law behavior of the action.[9] We get a very reasonable numbers for chiral symmetry breaking. We can compare with the lattice QCD results as demonstrating the abelian dominance and even the monopole dominance.[10]

3. Recovery of phase transition at finite temperature

We work out both the recovery of the monopole condensation and also the chiral symmetry breaking at finite temperature. We could show the ability of the DGL theory provides the recovery of these symmetries.[11]

We can apply the DGL theory to many non-perturbative phenomena. It is certainly a exciting challenge to get the structure functions with the DGL theory and compare with expimental data. We believe it very important to find 0^+ glueball around 1.5GeV in order to check the DGL assumption that the QCD vacuum is the dual superconductor.

1. Y. Nambu, Phys. Rev. D10 (1974) 4262
2. G. 't Hooft, Conference Proceedings "High Energy Physics" ed. A. Zichichi (1975)
3. S. Mandelstam, Phys. Rep. C23 (1976) 245
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8. S. Kitahara, Y. Matsubara and T. Suzuki, Prog. Theor. Phys. 93 (1995) 1
9. S. Sasaki, H. Suganuma and H. Toki, Prog. Theor. Phys. 94 (1995) 373
10. O. Miyamura, Phys. Lett. B353 (1995) 91
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Dual Ginzburg-Landau Theory and Quark Nuclear Physics

H. Toki (RCNP-Osaka)

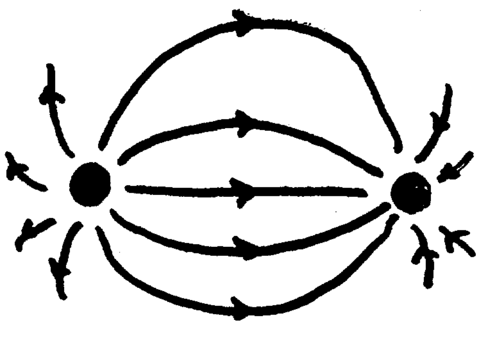
Quark Nuclear Physics

describe hadrons and Nuclei in terms of quarks and gluons

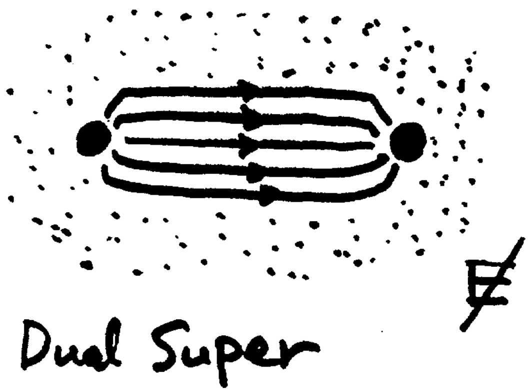
Color Confinement

Chiral Symmetry Breaking ... NJL

Modeling Confinment (Nambu, tHooft)



Normal



Dual Super

QCD monopole

t'Hooft (1981)

QCD $\xrightarrow{\text{Abelian gauge (MA)}}$ QED + QCD monopole

$$\mathcal{L}_{QCD} = \bar{q}(i\gamma_\mu \partial^\mu - e\gamma_\mu A^\mu)q + \frac{1}{4} G_{\mu\nu} G^{\mu\nu}$$

$\Downarrow$ Abelian gauge

1. QCD monopole
2. Higgs term (condensation)
3. Neglect Non-Abelian

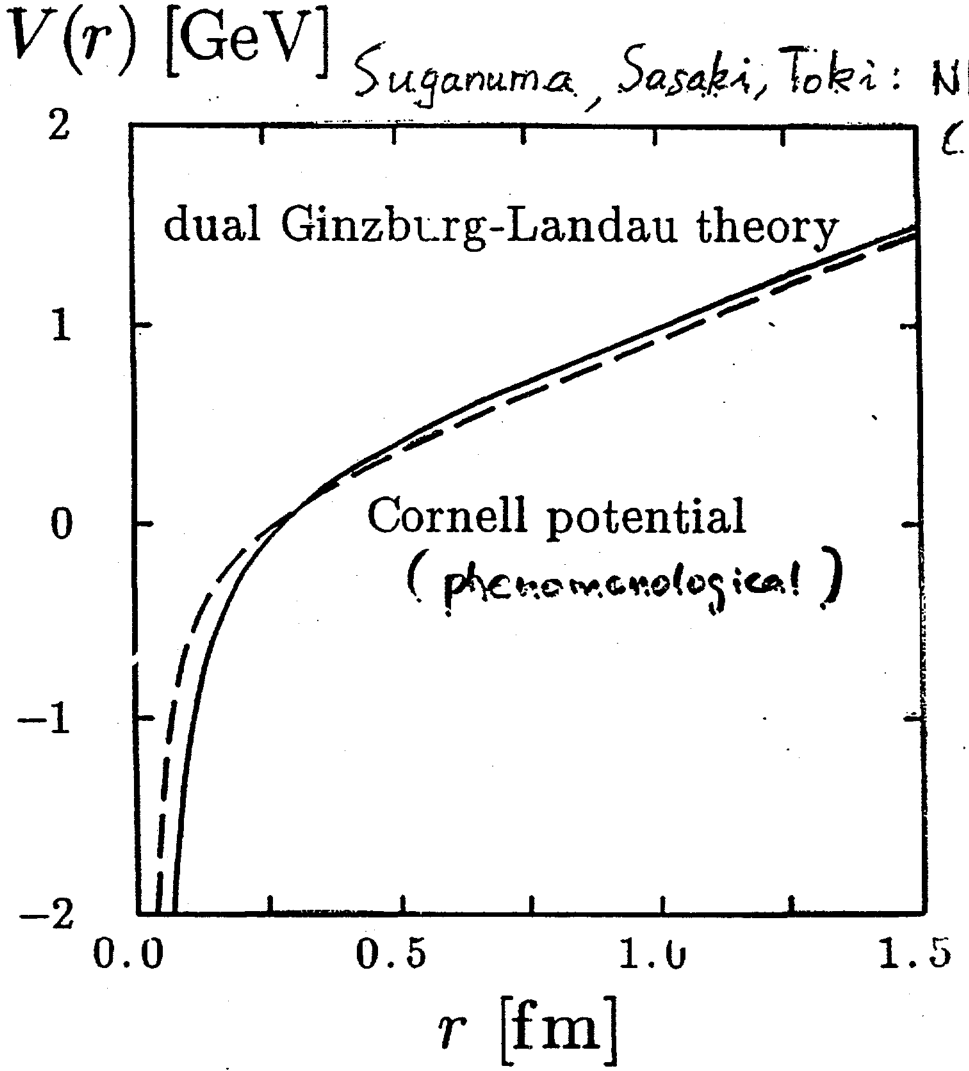
$$\mathcal{L}_{DGL} = \mathcal{L}_{gluon}(A, B) + \bar{q}(i\gamma_\mu \partial^\mu - m_0 - e\gamma_\mu A^\mu)q + |\partial_\mu \chi + g B_\mu \chi|^2 + \lambda(|\chi|^2 - v^2)^2$$

(A^μ: gluon; χ: Monopole; B_μ: dual gluon)

Suzuki et al, PTP(1989)

Suganuma et al, NPB(1995)

Suganuma, Sasaki, Toki: NPB435 (1995) 207.



Glueballs

$m_B(1^+) \sim 0.5\,\text{GeV}$

$m_\chi(0^+) \sim 1.5\,\text{GeV}$

e, λ, v
(parameters)

Fig. 1

2. Chiral Symmetry Breaking

$$S^{-1} = S_0^{-1} + \int \frac{d^4 k}{(2\pi)^4} Q^2 \gamma_\mu S \gamma_\nu D^{\mu\nu}$$

for simplicity

$$S^{-1} = i\not{p} - M(p^2)$$

Landau gauge → Full Dynamical Method (Gogohia)

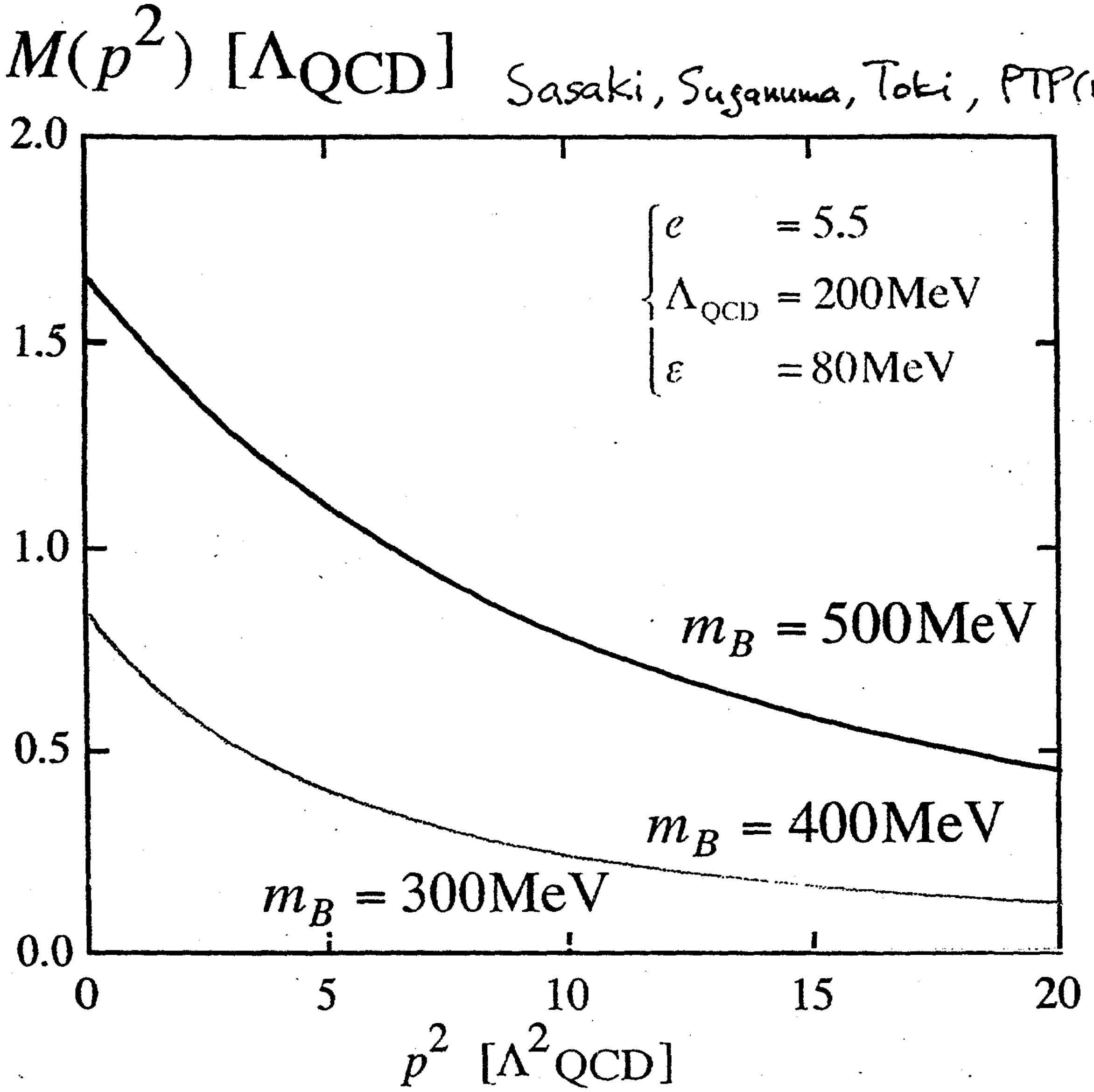
$$\frac{1}{(n\cdot q)^2} \to \left\langle \frac{1}{(n\cdot q)^2 + a^2} \right\rangle_{av}$$

↑ a: hadronic scale ~ 100 MeV

 $= \int d[A]\, d[q]\, \bar{q} q\, e^{-S(A,q)}$

QCD-monopole condensation effects on DχSB

Sasaki, Suganuma, Toki, PTP(1996)



- $m_B \lesssim 200$MeV *no nontrivial solution* : $M(p^2) = 0$
- $m_B \gtrsim 300$MeV *dynamical chiral symmetry breaking*

$\Rightarrow$ QCD-monopole condensation provides a large contribution to DχSB

S. Umisedo, H. Suganuma, H. Toki (1996).

Effective Potential approach

SUMMARY

– Ten Years of Spin Physics –

JIRO KODAIRA*

Dept. of Physics, Hiroshima University

Higashi-Hiroshima 739-8526, JAPAN

Abstract

1987, exactly ten years ago, the EMC data resulted in the excitement of not only particle physicists but also nuclear physicists. After ten years, our understanding on the spin structure of hadrons has been much improved. Many "ill-defined" questions become "well-defined" ones and we now what is a problem and what is not. At this symposium, beautifull reviews on the spin physics last ten years and reports on recent progress are already presented by many participants. So I only make a brief comment on the following subjects.

- Spin Crisis was a Crisis of our Wisdom
- g_1 Measurement and Gluon Distribution
- New Structure Functions
- Perturbative QCD
- Phenomenology and Non-perturbative Aspects
- Spin and New Physics

*Supported in part by the Monbusho Grant-in-Aid for Scientific Research No. C-09640364.

SUMMARY

TEN YEARS

OF

SPIN PHYSICS

November 29, '97
at RIKEN SYMPOSIUM

J.Kodaira (HIROSHIMA)

- Spin Crisis was a Crisis of our Wisdom
- g_1 Measurement and Gluon Distribution
- Structure Functions : New
- Perturbative QCD
- Phenomenology and Non-perturbative Aspects
- Spin and New Physics

Xiangdong Ji
Discussion Session
(22. Nov.)

1. Crisis

Spin-dependent Structure Function :
Fourier Transform of

$$\langle P, S|\bar{\psi}(\lambda n)\gamma^5\gamma^\mu\psi(0)|P, S\rangle$$
$$= -2M(S\cdot n)p^\mu \hat{g}_1(\lambda) - 2MS_\perp^\mu \hat{g}_\perp(\lambda) + M^3(S\cdot n)n^\mu \hat{g}_3(\lambda)$$

Structure Function:

$$\hat{g}_1(\lambda) \to g_1(x) \quad , \quad \hat{g}_\perp(\lambda) \to g_1(x) + g_2(x)$$

Polarized Gluon:

$$\Delta g(x) = \frac{i}{4\pi x P^+}\int d\xi^- e^{-ix\xi^- P^+}$$
$$\times \ \langle P^+ S_{||}|G^{+\alpha}(\xi^-)\,\mathrm{WLO}\,\tilde{G}_\alpha{}^+(0)|P^+ S_{||}\rangle + (x \to -x)$$

where,

$$\mathrm{WLO} = \mathcal{P}\exp\left(ig\int_0^{\xi^-} dy^- A^+(y^-)\right)$$

The first moment of $\Delta g(x)$

$$\Gamma \equiv \int dx \Delta g(x) = \frac{1}{4P^+}\int d\xi^- \varepsilon(\xi^-)$$
$$\times\langle P^+ S_{||}|G^{+\alpha}(\xi^-)\,\mathrm{WLO}\,\tilde{G}_\alpha{}^+(0)|P^+ S_{||}\rangle$$

Can NOT be expressed in terms of Local Operator !!

But choose light-cone gauge

$$n\cdot A \propto A^+ = 0 \quad , \quad \mathrm{WLO} = 1 \quad ; \quad G_a^{+\alpha}A_a^\alpha$$

Therefore

$$\Gamma = \frac{1}{4P^+}\int d\xi^- \varepsilon(\xi^-) \langle P^+S_{||}|\frac{\partial}{\partial\xi^-}A^\alpha(\xi^-)\widetilde{G}_\alpha{}^+(0)|P^+S_{||}\rangle$$
$$= -\frac{1}{2P^+}\langle P^+S_{||}|A^\alpha(0)\widetilde{G}_\alpha{}^+(0)|P^+S_{||}\rangle$$

We get LOCAL OPERATOR !!
and
$A^\alpha(0)\widetilde{G}_\alpha{}^+(0)$ is Chern Simons Current k^+ !!
and
This is a Definition of Parton Density !!

Very Important Note:

Renormalization scheme dependence :

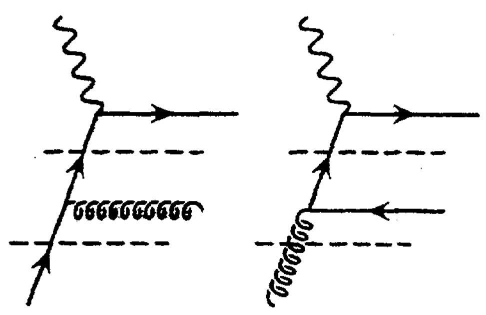
One CAN change the definition of parton densities

$$f_{a,N} \to f'_{a,N} = \sum_b U_{ab,N}(\alpha_s) f_{b,N}$$

with

$$\gamma_{ab}(N) \to \gamma'_{ab}(N) = \left[\beta(\alpha_s)\left(\alpha_s\frac{\partial}{\partial\alpha_s}U\right)U^{-1} + U\gamma U^{-1}\right]_{ab,N}$$

Graphically,



What is important ?:

Just want to interpret the QCD results intuitively and/or economically.

Definition of parton distribution can depend on one's convention.

Spin Sum Rule :

$$\frac{1}{2} = L_q + L_g + \frac{1}{2}\Delta\Sigma + \Gamma$$

where L is "orbital angular momentum"
In QCD, above (physical) decompositon is IMPOSSIBLE !!

Start from Angular Momentum Operator

$$J^i = \frac{1}{2}\epsilon^{ijk}\int d^3x M^{0jk} \equiv J^i_q + J^i_g$$

One can show up to Equation of Motion and Super-potential,

$$\begin{aligned}\vec{J}_q &= \int d^3x \bar{\psi}\left(\vec{\gamma}\gamma^5 + \gamma^0[\vec{x} \times i\vec{D}]\right)\psi \\ \vec{J}_g &= \int d^3x \left(\vec{x} \times (\vec{E} \times \vec{B})\right)\end{aligned}$$

Q^2 evolution.

total $\vec{J}$ is conserved quantity but $\vec{J}_q$, $\vec{J}_g$ depend on Q^2.

$$J_{q,g}(Q^2)2\vec{S} \equiv \langle P, S|\vec{J}_{q,g}(Q^2)|P, S\rangle$$

one get,

$$J_q(Q^2) = \frac{1}{2}\frac{3n_f}{16+3n_f} + \left(\frac{\ln Q_0^2/\Lambda^2}{\ln Q^2/\Lambda^2}\right)^{2(16+3n_f)/(33-n_f)} \left[J_q(Q_0^2) - \frac{1}{2}\frac{3n_f}{16+3n_f}\right]$$

$$J_g(Q^2) = \frac{1}{2}\frac{16}{16+3n_f} + \left(\frac{\ln Q_0^2/\Lambda^2}{\ln Q^2/\Lambda^2}\right)^{2(16+3n_f)/(33-n_f)} \left[J_g(Q_0^2) - \frac{1}{2}\frac{16}{16+3n_f}\right]$$

This is the same result for the momentum fraction
carried by quark and gluon
since
Angular Momentum ~ Energy Momentum (Tensor)

- The first moment of $\Delta g(x) \leftrightarrow$ Non-local Ope.
  Local Ope. only in Particular (light-cone) Gauge.

- DIS Measures "Helicity Distributions" of Partons.

- Definition of parton distribution can depend on one's convention

- Spin Sum Rule is a "Static Property" of Nucleon.
  Nothing to do with DIS Exp.!!

2. Gluon Distribution Function

- Data at "Low Q^2"

  Y. Mao
  T. Matsuda
  M. Kuriki
  Y. Sakemi

  $\Updownarrow$

  NLO DGLAP Analysis may be enough

  Small $x \leftrightarrow$ No Theory !!

- Gluon Distribution Function $\delta g(x)$

  S. Kumano

  $\Updownarrow$

  Very Much ambiguous !!

- How to mesure $\delta g(x)$
  - Heavy Flavor Production ??
  - Jet Production ??
  - Hadron-Hadron Process $(\delta g(x))^2$??
  - ...

Higher-Order Corrections in QCD !!

Not only Gluon but Flavor Separation : IMPORTANT

$\Updownarrow$

What Process and How precise Calculation !?

3. New Structure Function

- Chiral-odd and/or Transversity Distribution Function

  $\Downarrow$

  NLO Calculations have been done

  $\Downarrow$

  Realistic Phenomenology and Experimental Feasibility !?

Y. Koike

- "Fracture Function"??

  May be able to get more informations

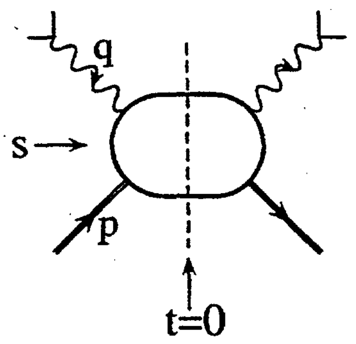
- $\cdots$

T. Tsurugai

- Small x : Still Controversial ??

General Remarks

Small Q^2 !?



$$Q^2 = -q^2 \; , \; x = \frac{Q^2}{2p \cdot q}$$

$$\begin{aligned} s &= (q+p)^2 \\ &= -Q^2 + 2p \cdot q + m_P^2 \\ &\simeq Q^2 \left(\frac{1}{x} - 1 \right) \end{aligned}$$

$$x \ll 1 \rightarrow s \gg Q^2 (m_P^2)$$

$$s \gg \text{external "mass"} \Longleftrightarrow \text{Regge Limit}$$

In Perturbation Theory

What Scales are Relevant ?

$$s \; , \; Q^2 \; , \; \mu^2 (\geq \Lambda^2_{\mathrm{QCD}})$$

– DGLAP

finite x $\Leftrightarrow s \simeq Q^2 \gg \mu^2$: two-scale

$$\ln Q^2 / \mu^2$$

– Small x

$x \ll 1$ $\Leftrightarrow s \gg Q^2 \gg \mu^2$: three-scale

$$\ln Q^2 / \mu^2 \; , \; \ln Q^2 / s \simeq \ln x$$

(Re)summation not only $\ln Q^2/\mu^2$ (mass singularity) but also $\ln x$ (infrared singularity)

Y. Dokshitzer

4. Perturbative QCD

- Resummation

  Physics near the Edge of Phase Space (Soft Region)

  $\Updownarrow$

  A Lot of Remarkable Progresses

  $\Downarrow$

  What Nexts !!

  - Event Shape Parameter
  - Power Corrections
  - ...

hard vs soft

5. Phenomenology and (Non)perturbative Aspects

- Higher Twist Effects

  ⇓

  Theoretical Developments

  ⇓

  Realistic Phenomenology and Experimental Feasibility !?

Y. Koike

K. Tanaka

- Lattice Simulation of Composite Operators
  - Lower Moment of Structure Functions
  - Axial Vector Current
  - Tensor Charge
  - ...

G. Schierholz

Tsukuba Univ. Group

- *Characteristic Aspects of QCD*

A. Kohama

H. Toki

- *J/ψ Production*

D. Kharzeev

T. Asakawa
Discussion Session
(Today)

6. Spin and New Physics

Spin Degree of Freedom is now Available !!

Spin Physics should be not only a Test of QCD
but also
a Clue to New Physics

New Projects

H. Hamaguchi

e.g. RHIC

will help us to have Better

Understandings of Nature !!

RIKEN Symposium on

Quarks and Gluons in the Nucleon

November 28-29, 1997

Nishina Hall, RIKEN

Hirosawa, Wako, Saitama, 351-01

Japan

Scientific Program

November 28 (Fri)

Morning

Session 1 (Chair : K. Imai)

9:30 M. Ishihara, "Opening address"

9:40 X.D. Ji, "Review and recent topics on the nucleon spin structure"

10:30 break

Session 2 (Chair : A. Masaike)

10:50 H. Hamagaki, "RHIC project"

11:20 Y. Mao, "Spin experiments at PHENIX"

11:50 lunch

Afternoon

Session 3 (Chair : N. Saito)

13:20 T. Matsuda, "New SMC result on the spin structure function $g_1(x)$ of the proton"

13:50 M. Kuriki, "Recent results from polarized deep inelastic scattering at SLAC"

14:20 Y. Sakemi, "Spin dependent structure functions of the nucleon from HERMES"

14:50 break

Session 4 (Chair : T. Morii)

15:10 S. Kumano, "Analyses of the nucleon spin structure functions"

15:40 Y. Koike, "Q^2 evolution of the chiral-odd spin structure functions $h_1(x,Q^2)$ and $h_L(x,Q^2)$"

16:10 A. Kohama, "Nuclear transparency in high energy quasi-elastic processes"

RIKEN BNL Center Workshops

Title:	**Physics with Parallel Processors**
Organizers:	R. Mawhinney/S. Ohta
Dates:	April/May 98 (tentative)
Title:	**RHIC Spin Physics**
Organizers:	G. Bunce/M. Tannenbaum
Dates:	April 27–29, 1998
Title:	**Quarkonium Production in Relativistic Nuclear Collisions**
Organizer:	D. Kharzeev
Dates:	Sept. 28–Oct. 2, 1998
Title:	**Dynamics of Chiral Fields in Nuclear Collisions**
Organizer:	D. Rischke
Date:	Week of April 27th
Title:	**QCD Spectroscopy**
Organizers:	M. Pennington/W. Marciano
Dates:	TBA
Title:	**Polarized Parton Distributions and Event Generators**
Organizers:	TBA
Date:	Summer (tentative)
Title:	**QCD Vacuum and Phase Transitions**
Organizer:	E. Shuryak
Date:	Early spring
Title:	**Semiclassical Fields in QED and QCD**
Organizers:	A. Baltz/D. Rischke/L. McLerran
Date:	Early fall
Title:	**Quantum Fields in and out of Equilibrium**
Organizers:	R. Pisarski/H. de Vega
Date:	Week of October 26th
Title:	**Many-Fermion Systems ... (Bielefeld follow-up)**
Organizers:	M. Creutz/M. Gyulassy
Date:	November 1998
Title:	**Many-Fermion Systems at Finite Densities**
Organizers:	T. Blum/M. Creutz
Date:	early '99
Title:	**Spin Physics Mini-Workshops**
Organizers:	N. Samios/R. Jaffe
Date:	Quarterly

For information please contact:

Ms. Pamela Esposito
RIKEN BNL Research Center
Building 510A, Brookhaven National Laboratory
Upton, NY 11973, USA
Phone: (516)344-3097 Fax: (516)344-4067
E-Mail: rikenbnl@bnl.gov
Homepage: http://penguin.phy.bnl.gov/www/riken.html

RIKEN BNL RESEARCH CENTER

QUARKS AND GLUONS IN THE NUCLEON

NOVEMBER 28-29, 1997
NISHINA MEMORIAL HALL, RIKEN, SAITAMA, JAPAN

Li Keran

Nuclei as heavy as bulls
Through collision
Generate new states of matter.
T. D. Lee

Speakers:

T. Asakawa	J. Kodaira	G. Schierholz
Y. Dokshitzer	Y. Koike	S. Sumano
H. Hamagaki	M. Kuriki	K. Tanaka
X. Ji	Y. Mao	H. Toki
D. Kharzeev	T. Matsuda	T. Tsurugai
A. Kohama	Y. Sakemi	

Organizers: T. Shibata
K. Yazaki