How to Extract the Gluon Polarization using RHIC Probes: a Critical Analysis.

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The total amount of the proton spin carried by gluons is of crucial importance to achieve a precise understanding of the proton structure. This contribution is given by the first moment of the polarized gluon distribution $\Delta G(x, Q^2)$, which is presently, very poorly known. This is due to the fact that Deep-Inelastic Scattering (DIS) experiments do not allow a direct determination of the gluon properties, because of the absence of photon-gluon coupling. Moreover, unlike unpolarized DIS at HERA, polarized DIS experiments, so far, have given access to a rather limited Q^2 range. As a consequence, the numerous next-to-leading order (NLO) analysis of the data, on the spin-dependent structure function $g_1(x, Q^2)$, leave $\Delta G(x, Q^2)$ largely unconstrained.

It is the purpose of this talk to show that polarized proton-proton collisions at RHIC-BNL offer several new options, which will yield the gluon polarization in a rather broad kinematic domain, in particular with very large Q^2 values. The spin observable we will mainly consider is the double helicity asymmetry A_{LL}, corresponding to the case where the two initial protons are longitudinally polarized, for single or double inclusive reactions. Considerations will be given to the energy dependence of A_{LL}, as well as its p_T and rapidity behaviours. We will examine in turn, the different probes which have been proposed in the literature namely, direct photon production, single-jet and dijet productions, charmonium and heavy quark productions. We will discuss in some cases the effects of NLO corrections and more generally the theoretical uncertainties related to the choice of the set of polarized parton distributions. In the case of double inclusive production (i.e. direct photon + jet or dijet), since A_{LL} is directly proportional to $\Delta G(x, Q^2)$, it is easier to extract it from the data and one can also study rapidity correlations. For charmonium and heavy quark productions, the dynamicl mechanism is still subject to discussions and the NLO corrections remain to be completed, so the predictions appear to be less reliable. Finally, one should also keep in mind that in single particle inclusive production (i.e. π or Λ), since the subprocess gluon-quark is important, these reactions might also be excellent and simple probes for the determination of the gluon polarization.

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(event rates for $\Delta\eta=3$ $\Delta E_T^{\gamma}=5$ GeV) $\sqrt{s}=500$ GeV

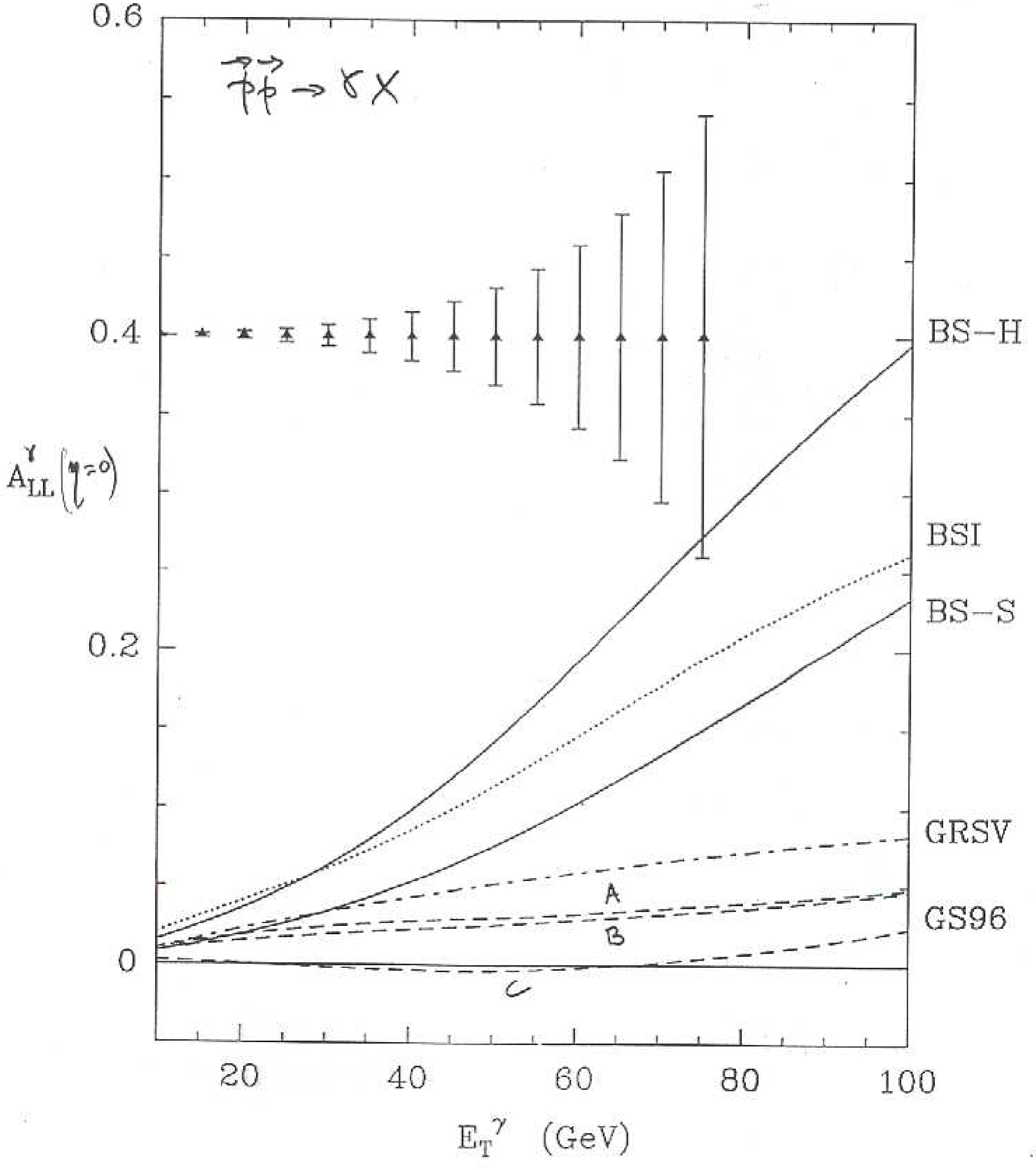

Fig 1

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NP B509 297 (1998)

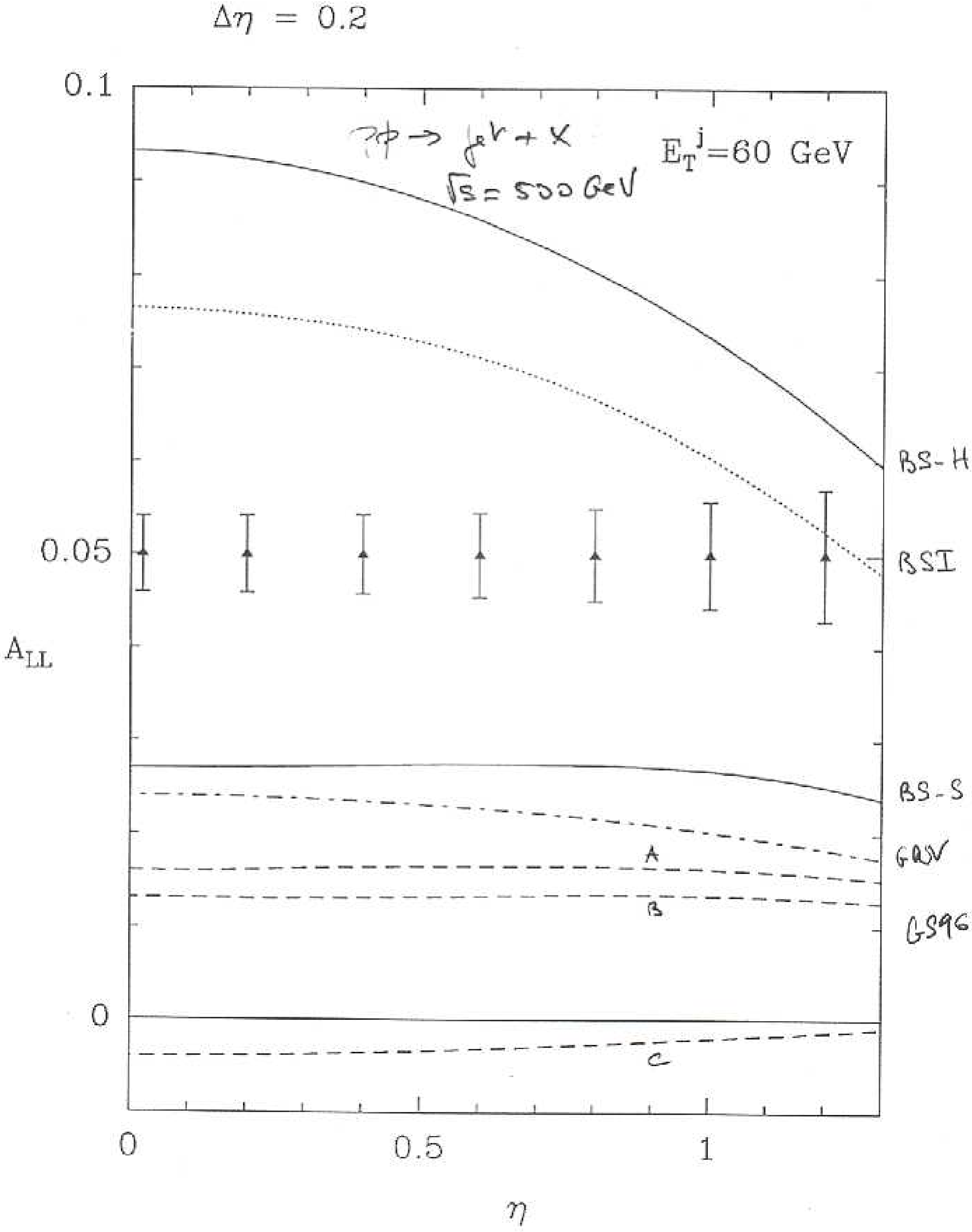
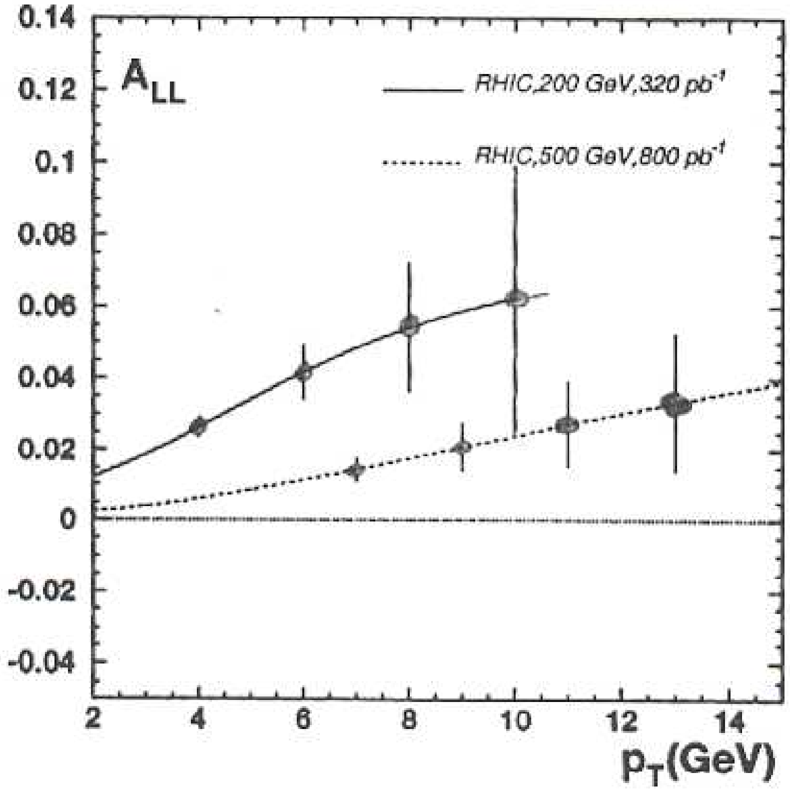


Fig 4 a

$p\vec{p} \to J/\psi + X$

NLO GS DISTRIBUTIONS



O. TERYAEV, A. TKABLADZE
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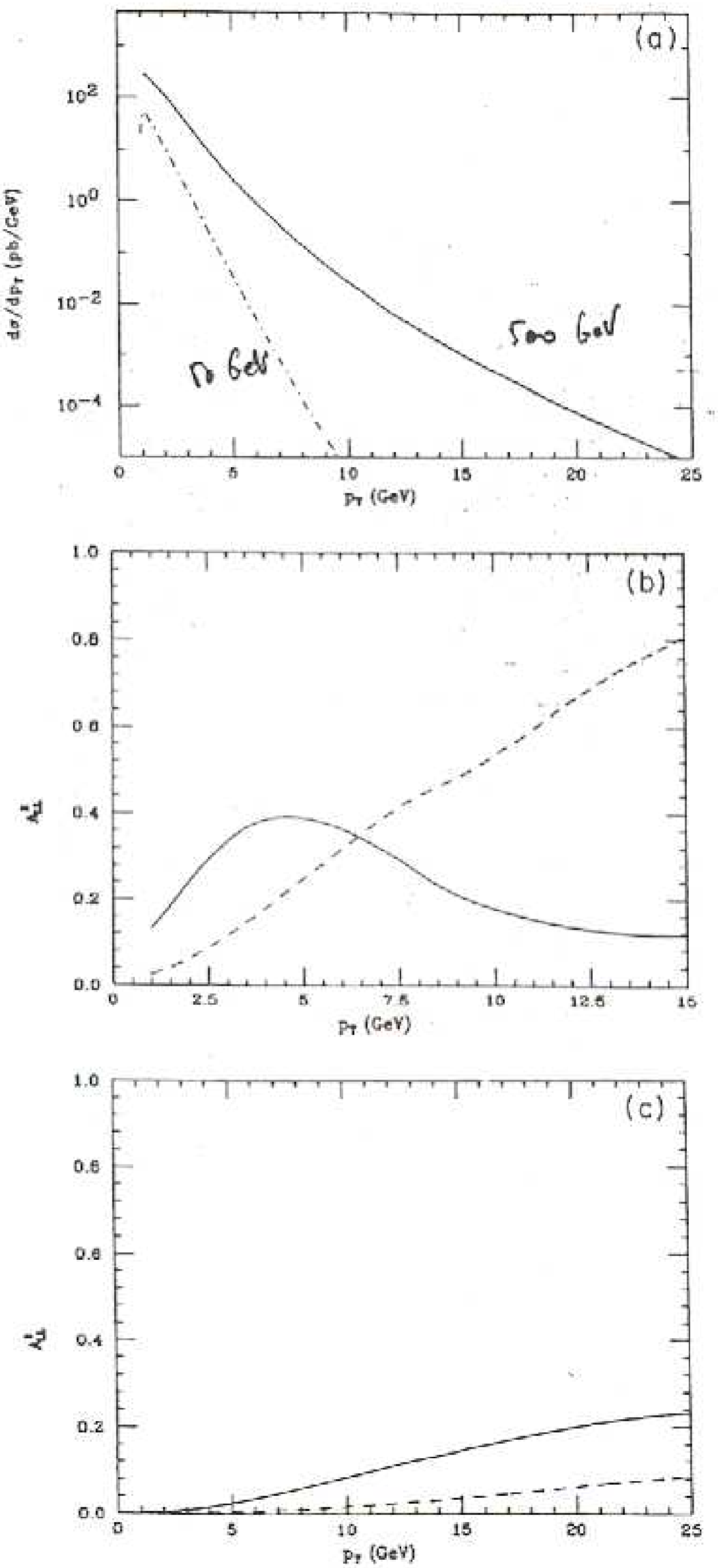

11,000 ev

50 GeV

86,000 ev

500 GeV

FIG. 3. p_T distribution, $\frac{d\sigma}{dp_T}$ vs p_T (a) for RHIC at $\sqrt{s} = 500$ GeV (solid line) and at $\sqrt{s} = 50$ GeV (dot-dashed line), and A_{LL}^2 vs p_T for RHIC at $\sqrt{s} = 50$ GeV (b) and at $\sqrt{s} = 500$ GeV (c) for large $\Delta g(x, Q^2)$ (solid line) and for moderately large $\Delta g(x, Q^2)$ (dashed line).

$pp \to J/\psi + \gamma + X$

M.A. DONCHESKI AND C.S. KIM
PRD 49 (1994) 4463

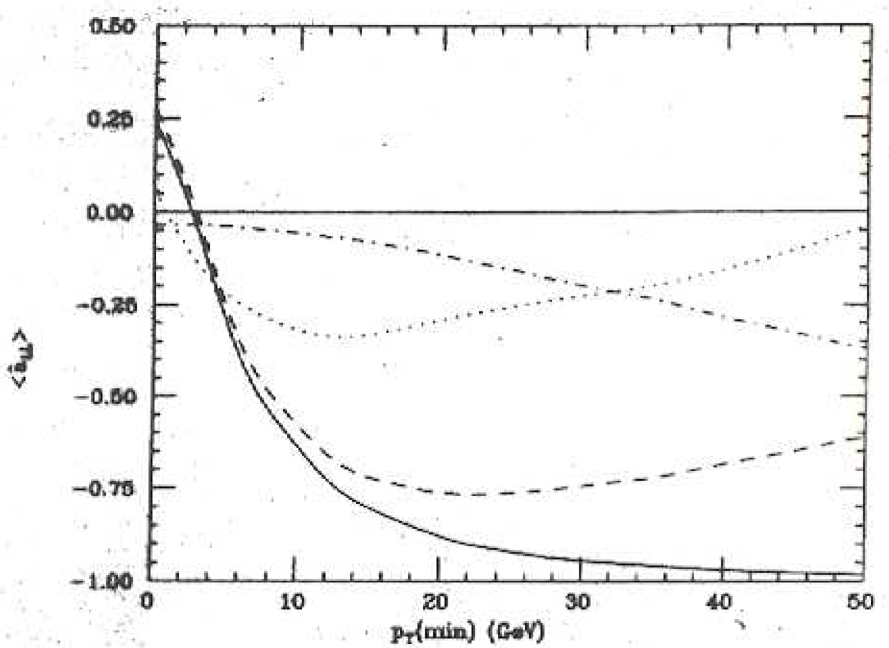

Fig. 3. The average asymmetry, $\langle \hat{a}_{LL} \rangle$, for b-quark production in pp collisions at $\sqrt{s} = 500\,\text{GeV}$ using only $2 \to 2$ processes. Solid line: total $2 \to 2$, dashes: gg, dot-dashes: $q\bar{q}$. The dotted line corresponds to the $2 \to 2$ contributions taken together with the 'regularized' $2 \to 3$ subprocesses described in the text.

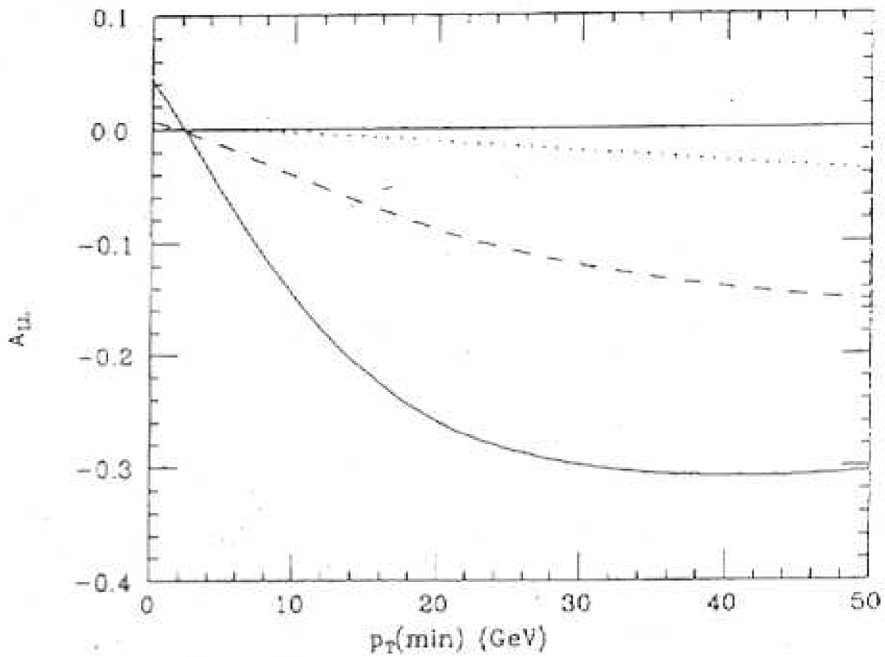

Fig. 4. The observable asymmetry A_{LL} in the integrated b-quark cross-section $\sigma(p_T > p_T(\text{min}))$, vs. $p_T(\text{min})(\text{GeV})$, assuming $\Delta G(x, Q^2) = x^\alpha G(x, Q^2)$, where $\alpha = 1.0\,(0.5, 0.25)$: dots (dashes, solid). The sea quarks are assumed unpolarized for simplicity.

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x-Dependent Polarized Parton Distributions for RHIC

Gordon P. Ramsey, Loyola University Chicago and Argonne National Lab

Talk given at the BNL/RIKEN Spin Workshop, April 27-29, 1998

Using QCD motivated constraints and polarized deep-inelastic scattering (PDIS) data, we have constructed x-dependent polarized parton distributions for each quark flavor. These satisfy positivity constraints and are evolved using the NLO DGLAP equations. Three models of the polarized gluon are used to allow representation in terms of different factorization prescriptions. [See hep-ph/9803351 for details].

The polarized valence distributions are constructed using a modified SU(6) model, with a spin dilution factor to modify the small-x behavior of the polarized valence quarks. The one free parameter is fixed by the Bjorken Sum Rule. The polarized sea is constructed using the following assumptions:
(1) the SU(3) symmetry is broken by suppressing the strange sea polarization, using information from PDIS experiments [see Phys. Rev. D55, 1244 (1997)].
(2) the polarized sea is generated from the unpolarized flavors assuming that $\eta(x) = [\delta q(x)]/[xq(x)] = a + bx^{1/2}$, where a and b are free parameters, and $\langle\eta\rangle = \langle\delta q\rangle/\langle xq\rangle$. This ensures that the overall spin carried by each constituent, obtained from data, is preserved.
(3) the free parameters are determined from six sets of g_1 data, two each of proton, neutron and deuteron, then averaged for each sea flavor of light quarks.

The three polarized gluon models used to determine the anomaly term in the factorization prescription are shown in the following transparencies. The distributions are generated at Q_0^2 of 1 GeV^2 and then evolved using the NLO DGLAP evolution equations with 3 flavors, until reaching the charm threshold, where the fourth flavor is included. The overall parametrization is shown in the following transparencies along with a plot of g_1^p, showing the SMC data and the distributions using the three polarized gluon models.

x-Dependent Polarized Parton Distributions

Gordon P. Ramsey

Loyola University Chicago
Argonne National Lab

References

GR: Phys. Rev. D55, 1244 (1997)

GGR: hep-ph/9803351

Collaborators

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M. Goshtasbpour, CTPM and SBU (Iran)

SEA Parametrizations:

1.. Polarized to unpolarized sea ratio ($Q^2 = 1$ Gev^2):

$$\eta_i(x) \equiv \frac{\Delta q_i(x)}{x q_i(x)} = a_i + b_i x^{1/2}$$

for each quark flavor, i. Here a_i and b_i are free parameters, fixed by theoretical arguments or data.

2. Broken SU(3) Sea flavors
$\Delta \overline{u} = \Delta u_s = \Delta \overline{d} = \Delta d_s = (1+\epsilon)\Delta \overline{s} = (1+\epsilon)\Delta s$

3. γ_5 anomaly: $\langle p \mid \bar{q}\gamma^\mu \gamma_5 q \mid p \rangle$
For each quark flavor: $\Delta q_5 = \Delta q_c - \frac{\alpha_s}{4\pi}\hat{\gamma} \otimes \Delta G$

Refs: Efremov and Teryaev; Altarelli and Ross
Carlitz, Collins and Mueller; Berger and Qiu

$\hat{\gamma}$ is convention dependent
physical observables are related to Δq_5
Δq_c do not evolve with Q_2 in LO

$$\sum_i (\langle \Delta q_5^i \rangle - \langle \Delta q_c^i \rangle) = \frac{N_f \alpha_s(Q^2)}{2\pi} \langle \Delta G(Q^2) \rangle \equiv \Gamma(Q^2)$$

Polarized Gluon Models:

1. Moderate:
$\Delta G(x, Q^2) = xG(x, Q^2)$

2. Zero (GI factorization):
$\Delta G(x, Q^2) = 0$

3. Instanton Induced (negative):
$\Delta G(x, Q^2) = 7(1-x)^7[1 + 0.474 \ln(x)]$

All at $Q_0^2 = 1 \text{ GeV}^2$.

CTEQ parametrization for the unpolarized gluon

Gauge invariant factorization equivalent to results obtained for model 2

The resulting functions $\eta(x)$ for each gluon model are:

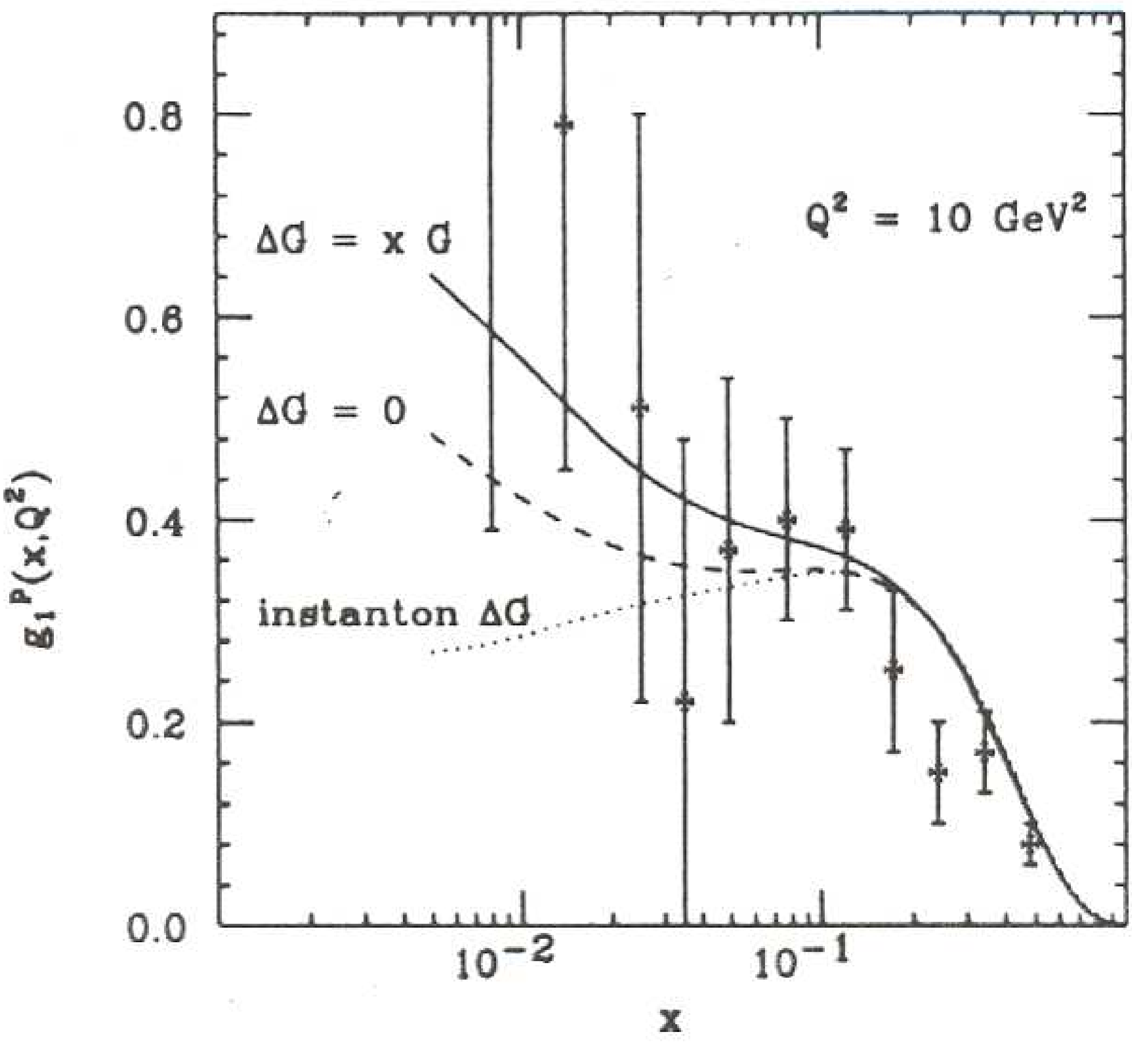
Quantity	$\eta_{u,d}(x)$	$\eta_s(x)$
$\Delta G = xG$	$-2.49 + 2.8\sqrt{x}$	$-1.67 + 2.1\sqrt{x}$
$\Delta G = 0$	$-3.03 + 3.0\sqrt{x}$	$-2.71 + 2.9\sqrt{x}$
$\Delta G < 0$	$-3.25 + 3.1\sqrt{x}$	$-3.31 + 3.3\sqrt{x}$

$$\Delta q_i(x) = -Ax^{-0.143}(1-x)^{8.041}(1-B\sqrt{x})\left[1 + 6.112x + P(x)\right]. \qquad \textbf{(4.1)}$$

Flavor	ΔG	A	B	$P(x)$
$<\Delta u>_{sea}$	xG	0.317	1.124	$-0.278x^{0.644} - 1.682x^{0.937}(1-x)^{-3.368}(1+4.269x^{1.508})$
$<\Delta d>_{sea}$	xG	0.317	1.124	$+0.278x^{0.644} - 1.682x^{0.937}(1-x)^{-3.368}(1+4.269x^{1.508})$
$<\Delta s>$	xG	0.107	1.257	$-3.351x^{0.937}(1-x)^{-3.368}(1+4.269x^{1.508})$
$<\Delta u>_{sea}$	0	0.386	0.990	$-0.278x^{0.644}$
$<\Delta d>_{sea}$	0	0.386	0.990	$+0.278x^{0.644}$
$<\Delta s>$	0	0.173	1.070	0
$<\Delta u>_{sea}$	Neg	0.414	0.954	$-0.278x^{0.644} - 10.49x^{1.143}(1-x)^{-1.041}(1+0.474\ln x)$
$<\Delta d>_{sea}$	Neg	0.414	0.954	$+0.278x^{0.644} - 10.49x^{1.143}(1-x)^{-1.041}(1+0.474\ln x)$
$<\Delta s>$	Neg	0.212	0.997	$-20.89x^{1.143}(1-x)^{-1.041}(1+0.474\ln x)$

Key Elements:

1. Separate sea and valence
2. BSR is Basis for valence
3. Include NLO QCD corr. to BSR
4. Separate strange sea (mass effect, ϵ)
5. Separate parametrization for each flavor
6. Different factorizations included
7. 3 Different Gluon Models
8. NLO DGLAP evolution
9. All evolution in x-space
10. Positivity holds
11. Excellent agreement with data
12. Results Compared with others


0.8
0.6
0.4
0.2
0.0
$\Delta G = x\ G$
$\Delta G = 0$
instanton ΔG
$Q^2 = 10\ GeV^2$
$g_1^{\,p}(x,Q^2)$
10^{-2}
10^{-1}
x