THE INSTANTON CONTRIBUTION TO THE POLARIZED AND UNPOLARIZED GLUON AND QUARK DISTRIBUTION IN NUCLEON

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DESY (ZEUTHEN)
AND
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1. WHAT IS THE INSTANTON?

2. QUARK-GLUON AND QUARK-QUARK INTERACTIONS INDUCED BY INSTANTON.

3. GLUON POLARIZATION INDUCED BY INSTANTONS

4. SEA QUARKS POLARIZATION INDUCED BY INSTANTONS

5. "SPIN CRISIS" AND INSTANTON.

6. INSTANTON CONTRIBUTION TO THE UNPOLARIZED STRUCTURE FUNCTIONS.

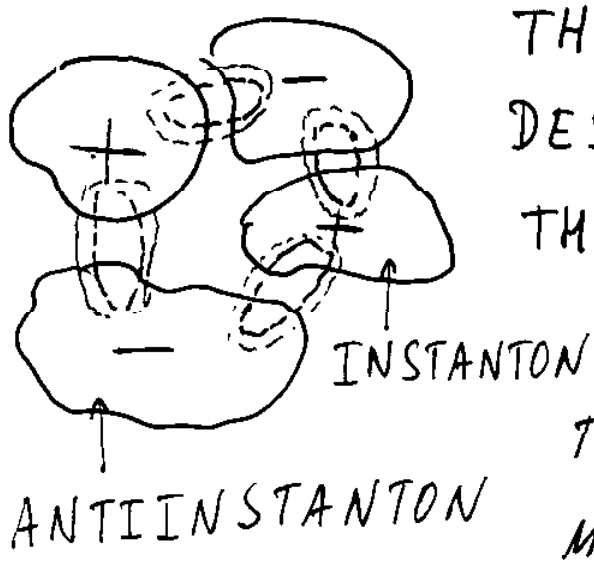
INSTANTONS AND HIGH Q^2 AND X EVENTS AT HERA;

HIGH E_t JETS EXCESS AT TEVATRON

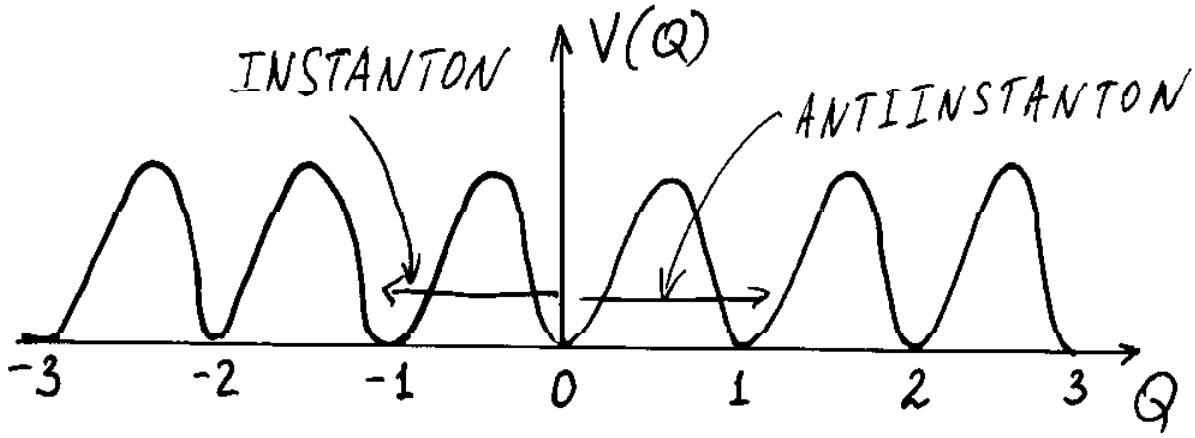
① WHAT IS THE INSTANTON?

$\boxed{\text{VACUUM IN QCD} \neq \text{EMPTY PLACE}}$

THE INSTANTON IS NONPERTURBATIVE FLUCTUATION OF THE GLUON VACUUM FIELD



THE INSTANTONS DESCRIBE $\Longrightarrow$ THE TUNNELING TRANSITION BETWEEN THE VARIOUS CLASSICAL MINIMA OF QCD POTENTIAL



Q - IS THE "TOPOLOGICAL CHARGE"

$$Q = \frac{\alpha_s}{8\pi} \int d^4x \; G^a_{\mu\nu}(x) \; \tilde{G}^a_{\mu\nu}(x)$$

AXIAL ANOMALY $\Rightarrow$ THE CONNECTION BETWEEN THE CHANGING OF TOPOLOGICAL CHARGE AND QUARK'S HELICITIES NONCONSERVATION

$$\boxed{\Delta \Sigma_q = -2 N_f \cdot \Delta Q}$$

NUMBER OF FLAVOURS

THE POSSIBILITY OF THE MOTION ALONG Q COORDINATE MEANS THE NONCONSERVATION OF THE QUARK'S HELICITIES

(2) QUARK-GLUON AND QUARK-QUARK INTERACTIONS INDUCED BY THE INSTANTONS

a) QUARK-GLUON CHROMOMAGNETIC INTERACTION INDUCED BY THE INSTANTONS

(KOCHELEV '96)
PHYS. REV. LETT.

LAGRANGIAN:

$$\mathcal{L} = -i\mu_a \sum_q \frac{g}{2m_q} \bar{q}\, \sigma_{\mu\nu} t^a q\, G^a_{\mu\nu}$$

μ_a IS THE ANOMALOUS QUARK CHROMOMAGNETIC MOMENT INDUCED BY INSTANTONS

$$\boxed{\mu_a = -\frac{f\pi}{2\alpha_s(\rho_c)}}$$

$f = n_c \pi^2 \rho_c^4$, – IS THE PACKING FRACTION OF INSTANTON IN THE VACUUM, n_c IS THE DENSITY OF INSTANTONS –

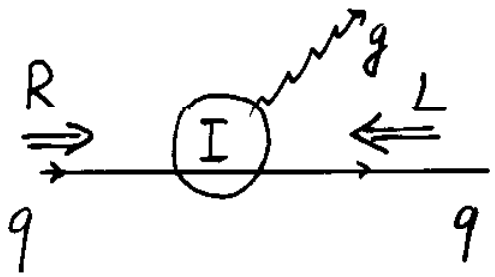
$$n_c \approx \langle 0 | \alpha_s G^a_{\mu\nu} G^a_{\mu\nu} | 0 \rangle / 16\pi,$$

$\rho_c \approx 1.6 \div 2\ \mathrm{GeV}^{-1}$ IS THE AVERAGE SIZE OF THE INSTANTON

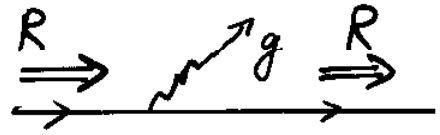
(SHURYAK '84, DYAKONOV AND PETROV '86)

INSTANTON LIQUID MODEL FOR THE QCD VACUUM

$$\mathcal{L}_{NONPERT} = -i\mu_a \sum_q \frac{g}{2m_q} \bar{q}\sigma_{\mu\nu} t^a q G^a_{\mu\nu} \qquad \mathcal{L}_{PERT} = g\bar{q} t^a \gamma_\mu q A^a_\mu$$



SPIN - FLIP



NONSPIN-FLIP

B) <u>QUARK-QUARK INTERACTION INDUCED BY INSTANTONS</u>

(t' Hooft '76)

<u>LAGRANGIAN</u>:

$(N_f = 2)$

$$\mathcal{L}_{eff} = \int d\rho\, n(\rho) \left(\frac{4}{3}\pi^2\rho^3\right)^2 \cdot \{\bar{u}_R u_L \bar{d}_R d_L \cdot$$

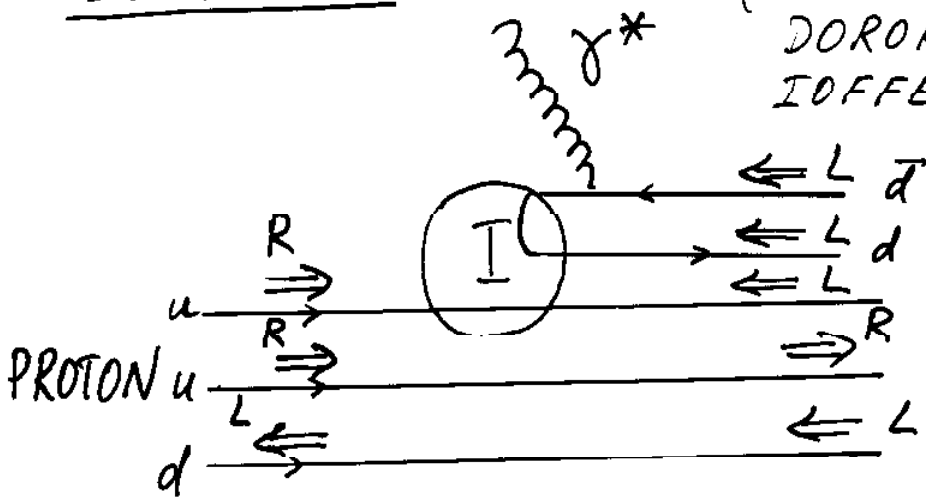
$$\left[1 + \frac{3}{32}\left(1 - \frac{3}{4}\sigma^u_{\mu\nu} \otimes \sigma^d_{\mu\nu}\right)\lambda^a_u \otimes \lambda^a_d\right] +$$

$$(R \leftrightarrow L)$$

ANTIINSTANTON CONTRIBUTION

TWO PRINCIPAL DISTINCTIONS BETWEEN THE INSTANTON VERTEX AND PERTURBATIVE VERTEX

① FLIP QUARK HELICITY ⇒ THE FUNDAMENTAL MECHANISM OF THE ELLIS-JAFFE SUM RULE VIOLATION (FORTE '89, DOROKHOV, KOCHELEV; IOFFE, KARLINER '90)



NEGATIVE SEA QUARKS POLARIZATION INDUCED BY INSTANTONS

② INSTANTON VERTEX DIFFERS FROM ZERO ONLY FOR THE DIFFERENT QUARK'S FLAVORS

$$\boxed{\Delta\bar{d} \approx -2\Delta\bar{u}}$$

⇓

FLAVOUR ASYMMETRY OF THE SEA QUARKS IN PROTON $\boxed{\bar{d} \approx 2\bar{u}}$ (DOROKHOV, KOCHELEV '91)

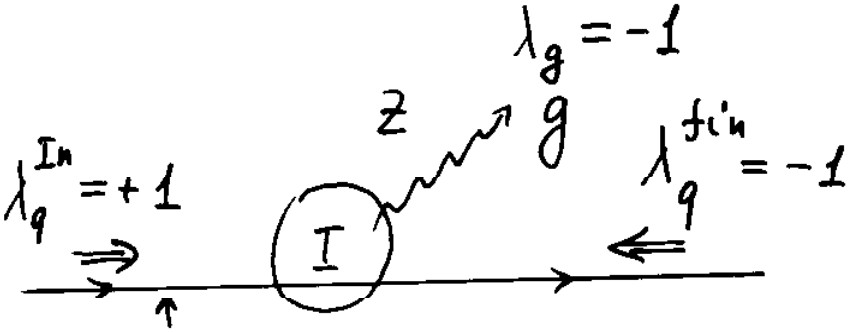
⇓

MECHANISM OF THE GOTTFRIED SUM RULE VIOLATION

③ GLUON POLARIZATION INDUCED BY INSTANTONS

(KOCHELEV'97)

ALTARELLI – PARISI METHOD '77



VALENCE QUARK

RESULT FOR THE SPLITTING FUNCTION

$$\boxed{P_{q+G\lambda}(z) = \frac{C(1-\lambda)}{z} \int_0^{\rho_c^2 Q^2} d\beta \, F^2(\beta, z),}$$

WHERE $\beta = p_\perp^2 \rho_c^2$, $C = \frac{|\mu_a|}{8}$,

$\mu_a = -0.2 \div -0.4$ IS THE

ANOMALOUS QUARK CHROMOMAGNETIC

MOMENT INDUCED BY INSTANTONS,

F IS THE INSTANTON FORM FACTOR

FEATURE: IT IS NON-ZERO ONLY IF THE EMITTED GLUON HAS THE OPPOSITE HELICITY COMPARED TO THE INITIAL QUARK HELICITY

$\Downarrow$

NEGATIVE GLUON POLARIZATION IN PROTON !!!

SIMPLE CONVOLUTION MODEL TO ESTIMATE THE GLUON POLARIZATION

$$\Delta G^{I}(x) = \int_{x}^{1} \frac{dy}{y} \Delta P^{I}_{G,q} \, \Delta q_{V}\left(\frac{x}{y}\right)$$

$$\Delta P_{G,q} = P_{G_+,q_+} - P_{G_-,q_+}$$

$$\boxed{\Delta P^{I} < 0 \; !!!}$$

GLUON POLARIZATION INDUCED BY THE PERTURBATIVE QCD VERTEX

$$\Delta P^{PERT}(z) = \frac{\alpha_s}{2\pi} \, \frac{1-(1-z)^2}{z} \log\left(\frac{Q^2}{M^2}\right)$$

$$\boxed{\Delta P^{PERT} > 0 \; !!!}$$

VALENCE QUARK POLARIZATION:

$$\Delta u_V(x) = 3.7\,(1-x)^3$$

$$\Delta d_V(x) = -1.3\,(1-x)^3$$

NORMALIZATION: $\Rightarrow$ DATA ON THE WEAK DECAY CONSTANTS OF HYPERONS

$$g_A^3 = \Delta u_V - \Delta d_V = 1.25$$

$$g_A^8 = \Delta u_V + \Delta d_V = 0.6$$

RESULT:

$$\boxed{\begin{array}{l} \Delta G = -0.66 \text{ FOR } \rho_c = 2\,\text{GeV}^{-1} \\ \Delta G = -0.35 \text{ FOR } \rho_c = 1.6\,\text{GeV}^{-1} \end{array}}$$

$\Downarrow$

LARGE NEGATIVE GLUON POLARIZATION INDUCED BY INSTANTONS

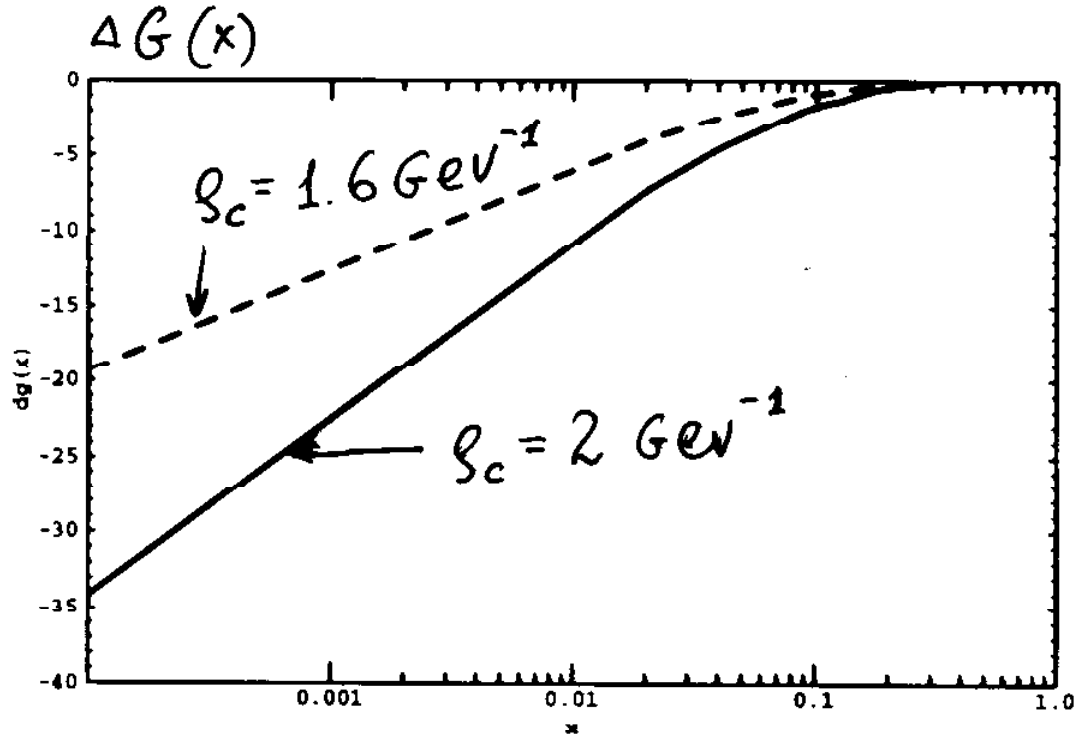


Figure 1: *x dependence of the gluon polarization induced by instantons. The solid line is obtained for an average instanton size of $\rho_c = 1.6\ GeV^{-1}$, the dashed one for $\rho_c = 2\ GeV^{-1}$.*

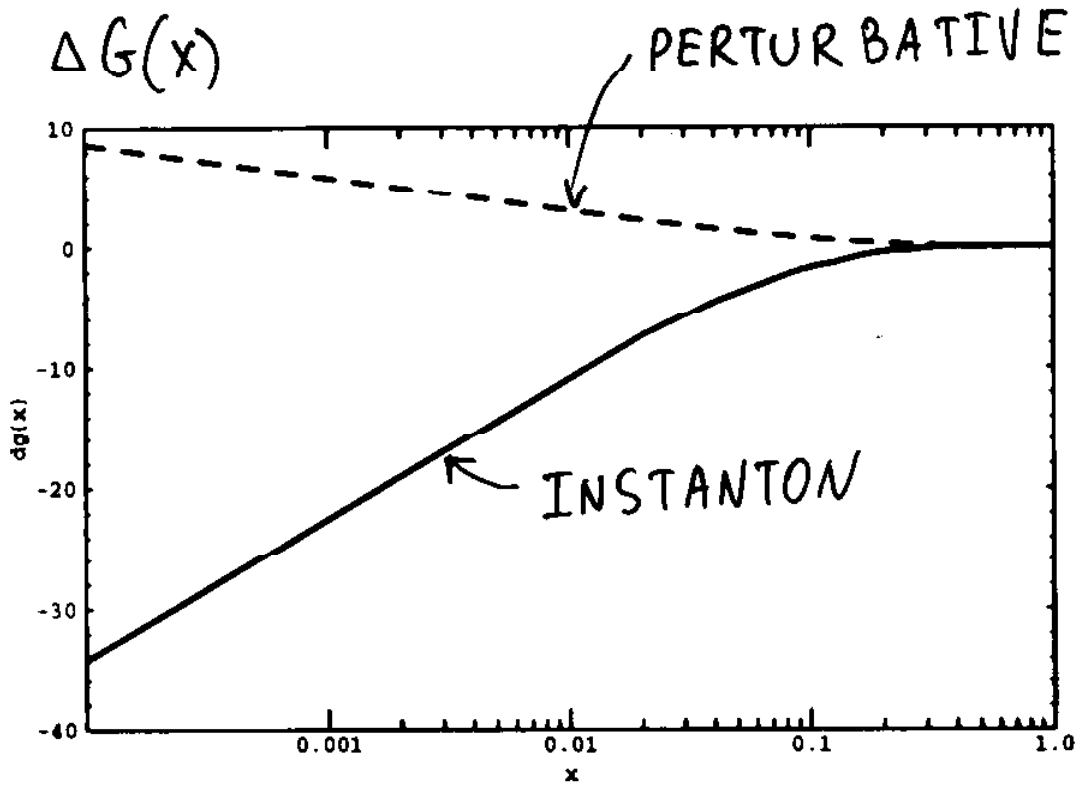
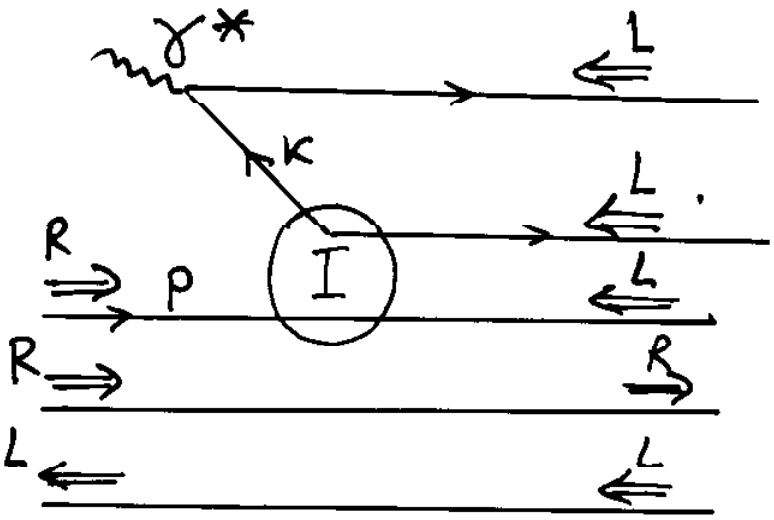


Figure 2: *x dependence of the gluon polarization induced by instantons (solid line) and perturbative vertex (dashed line),* $\rho_c = 2\ GeV^{-1}$.

(4) SEA QUARKS POLARIZATION INDUCED BY INSTANTONS



$S = (p+k)^2$

LANDSHOFF'S APPROACH

SEA QUARK DISTRIBUTION DETERMINES BY THE ANTIQUARK-QUARK CROSS SECTION THROUGH THE INSTANTON

$$f_q(x) = \frac{1}{(2\pi)^3} \int_{S_0}^{Q^2/x} dS \int_{k^2_{min}}^{k^2_{max}} dk^2 \, \frac{\mathrm{Im}\, T_{\bar{q}q}(S,k^2)}{(k^2-m_q^2)^2} \cdot$$

$$\cdot \left(-x + \frac{m_q^2 - k^2}{S - m_q^2 - k^2} \right)$$

WHERE

$$\mathrm{Im}\, T_{\bar{q}q}(S, k^2) = 2 p_{c.m.} \sqrt{S}\, \sigma_{tot}^{\bar{q}q}.$$

IN INSTANTON LIQUID MODEL

$$\sigma_{\bar{q}q}^{INST}(S, k^2) = \frac{4\pi^7 n_c^2 \rho_c^{12}}{81(S-k^2)^2}\left(945 S^3 - 213 k^2 S^2 + 144 k^4 S - 25 k^6\right)$$

FOR $N_f = 2$ $\sigma_{\bar{q}q}^{INST}(S) \longrightarrow S$ AT LARGE S

FOR $N_f = 3$ $\sigma_{\bar{q}q}^{INST}(S) \longrightarrow S^4$

<u>FAST GROWTH</u> OF INSTANTON INDUCED QUARK-QUARK AND QUARK-GLUON CROSS-SECTIONS IS THE <u>FUNDAMENTAL</u> REASON OF THE <u>LARGE INSTANTON CONTRIBUTION</u> <u>TO THE GLUON</u> AND <u>TO THE SEA QUARKS POLARIZATION</u>

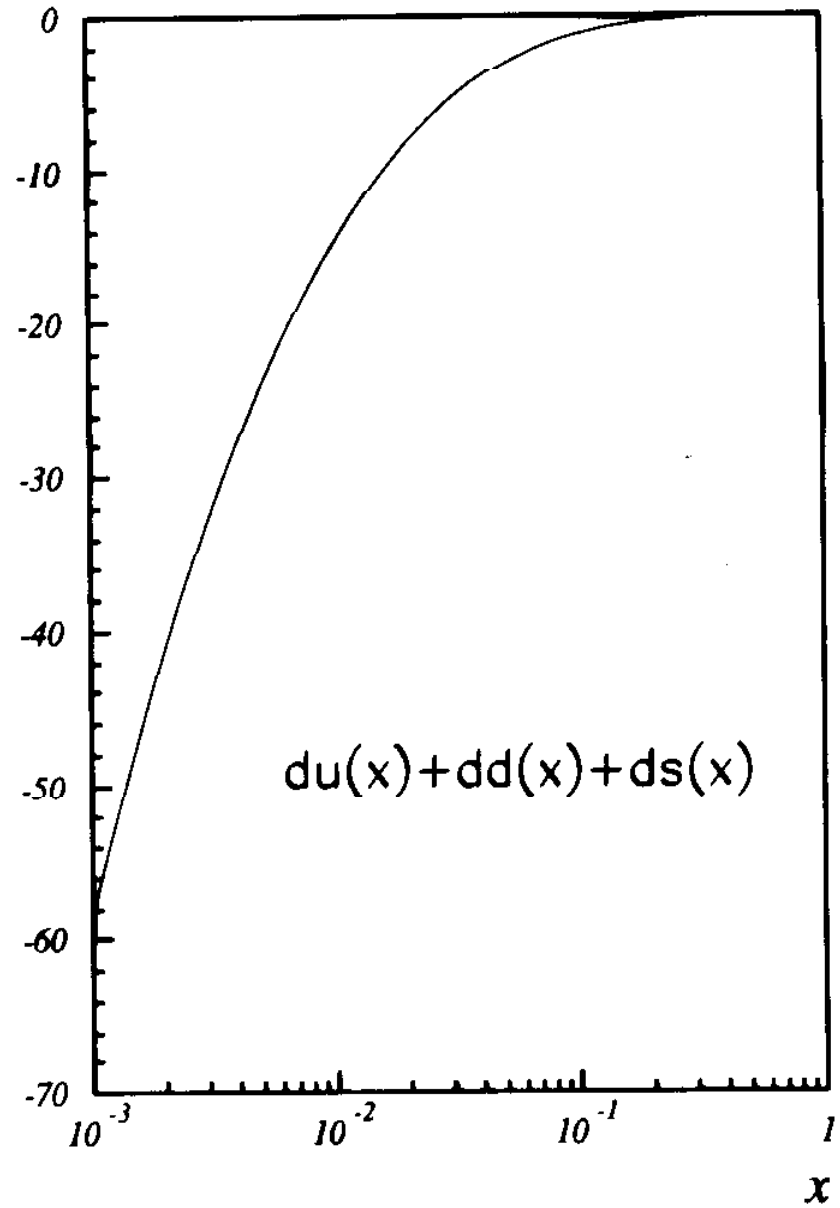


Figure 5: *x dependence of the instanton contribution to the quark sea polarization for $\rho_c = 2\ GeV^{-1}$.*

5 "SPIN CRISIS" AND INSTANTONS

ANOMALOUS BEHAVIOUR OF $g_1^{\{p,n\}}$

TWO DIFFERENT CONTRIBUTION TO $g_1^{\{p,n\}}$ INDUCED BY INSTANTON

① GLUON CONTRIBUTION DUE TO AXIAL ANOMALY

$$\delta g_1^{glu}(x) = \sum_q e_q^2 \int_x^1 \frac{dy}{y} \Delta P^A(y) \Delta G^I\left(\frac{x}{y}\right)$$

WHERE

$$P^A(y) = \frac{\alpha_s}{4\pi}(2y-1)\left(\log\frac{(1-y)}{y} - 1\right)$$

$$\Delta G^I < 0 \Rightarrow \delta g_1^{glu}(x) > 0$$

<u>POSITIVE</u> CONTRIBUTION FROM <u>NEGATIVE</u> GLUON POLARIZATION

② SEA QUARKS CONTRIBUTION

$$\delta g_1^{sea}(x) = \sum_q \frac{e_q^2}{2} \Delta q_s^{INS}(x)$$

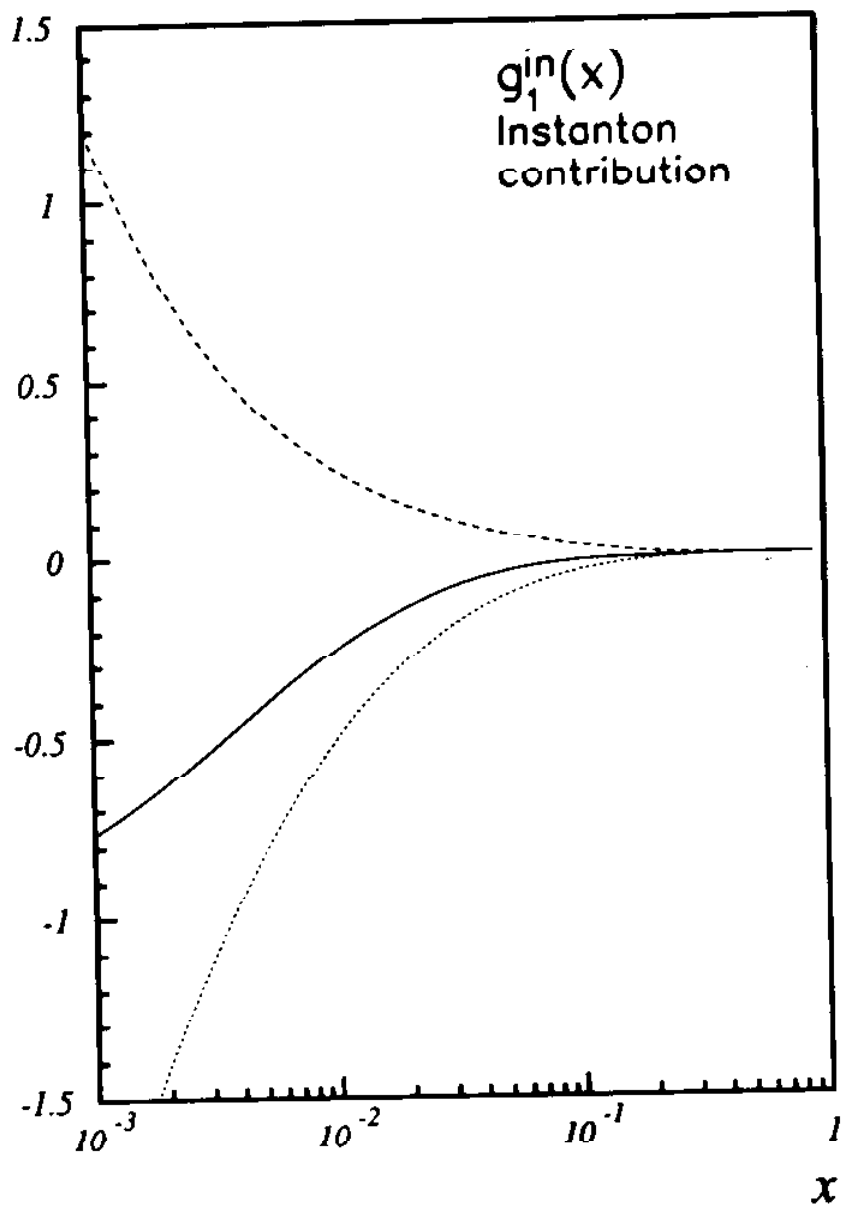


Figure 8: *x dependence of the instanton contribution to spin-dependent structure function $g_1^{p,n}(x)$ induced by instantons for $\rho_c = 2\ GeV^{-1}$. The dashed line is the contribution from gluons, dotted line is the contribution from the sea quarks and the solid line is the total contribution.*

NEGATIVE CONTRIBUTION FROM NEGATIVE SEA QUARKS POLARIZATION

THE TOTAL CONTRIBUTION HAS THE VERY STRONG DEPENDENCE ON THE PARAMETERS OF THE INSTANTON MODEL AND CAN BE NEGATIVE AT HIGH X AND POSITIVE AT LOW X.

6 INSTANTON CONTRIBUTION TO THE UNPOLARIZED STRUCTURE FUNCTIONS

INSTANTONS AND HIGH Q^2, X EVENTS AT HERA.

TWO CONTRIBUTIONS TO $F_2(x)$

a) FROM GLUONS

$$G_I(x) = -\Delta G_I(x)$$

$$\delta F_2^g(x) = x \sum_q e_q^2 \int_x^1 \frac{dy}{y} P_{qg}(y)\, G_I\left(\frac{x}{y}\right)$$

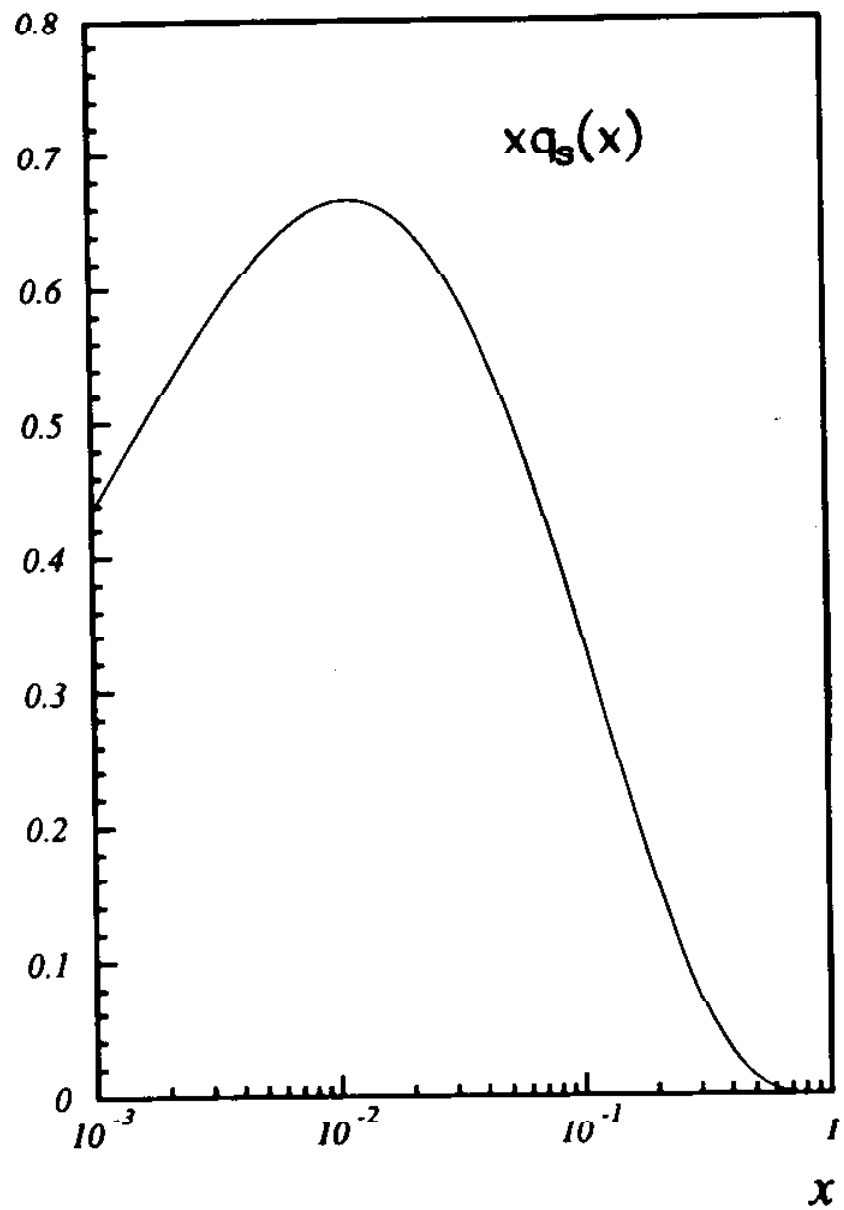


Figure 4: ***x dependence of the instanton contribution to the quark sea distribution for $\rho_c = 2\ GeV^{-1}$.***

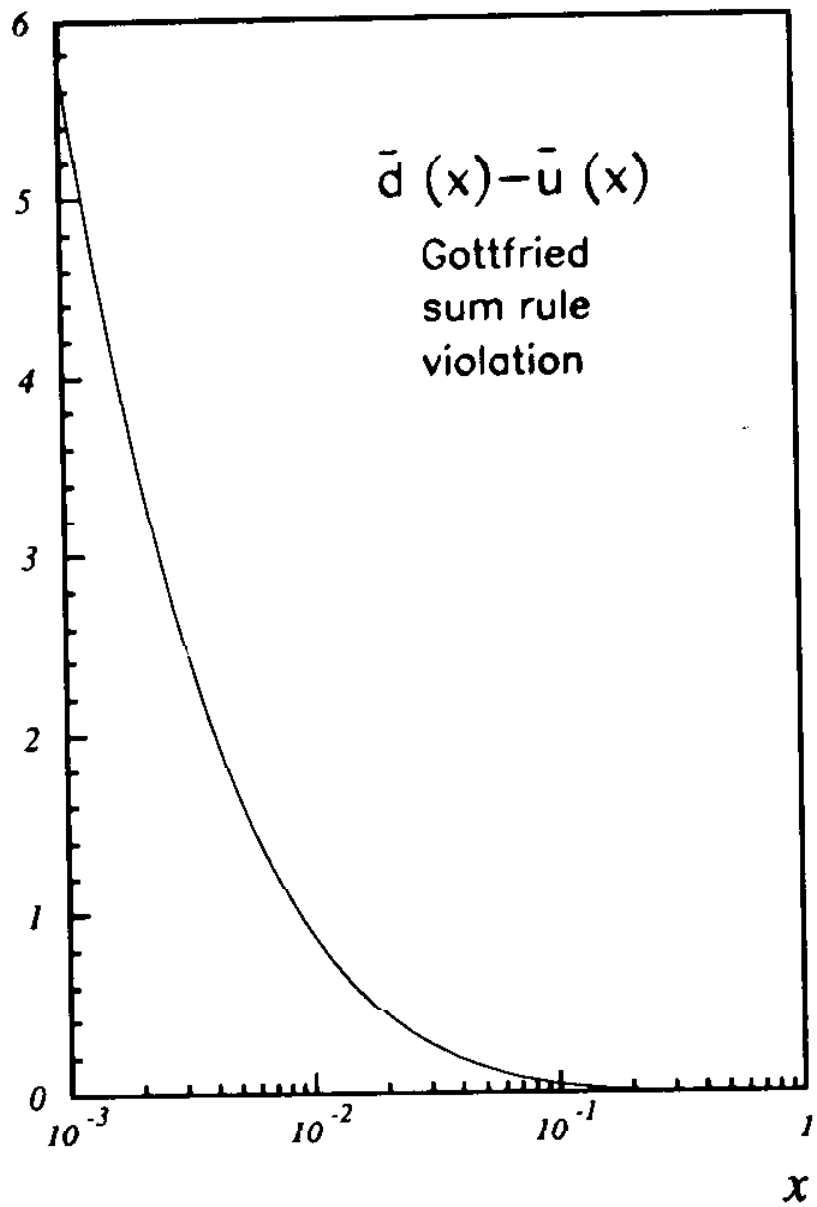


Figure 6: *x dependence of the instanton contribution to flavor asymmetry of the quark sea induced by instantons for $\rho_c = 2\ GeV^{-1}$.*

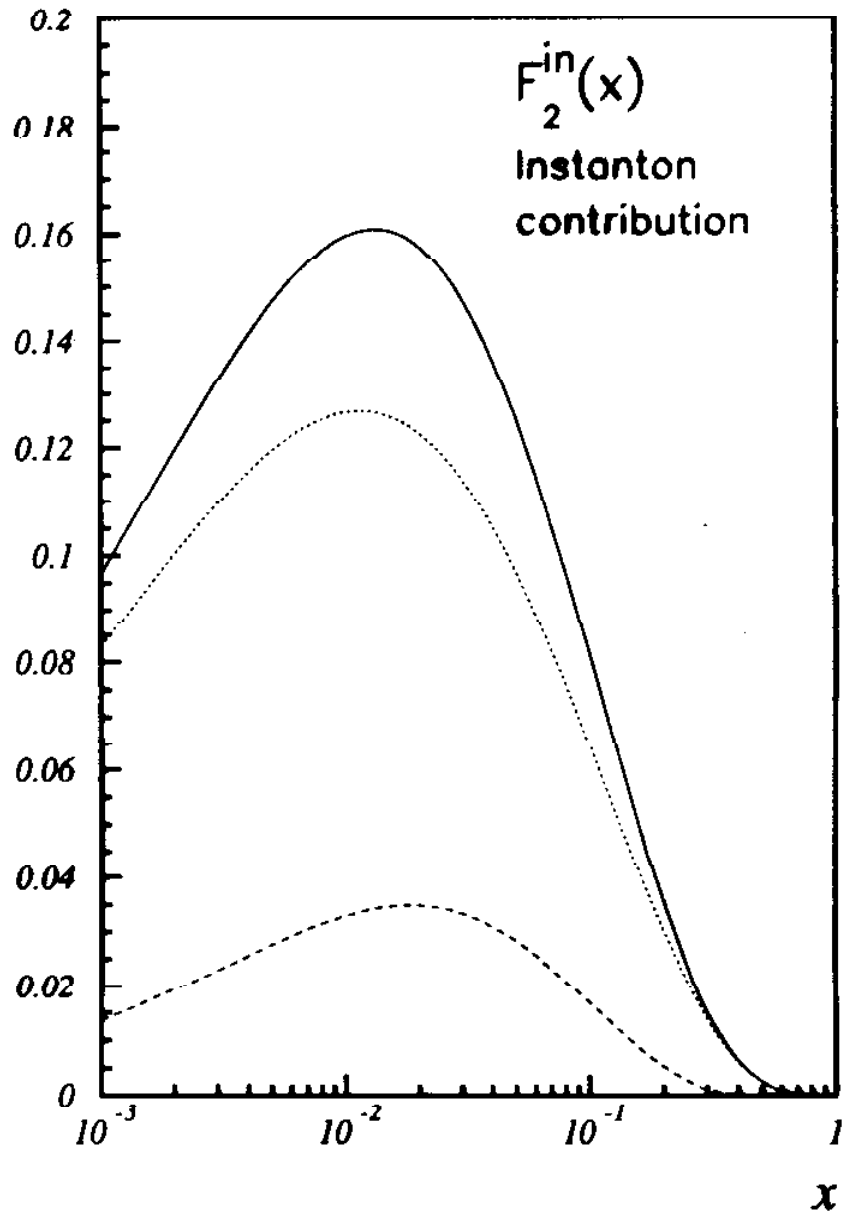


Figure 7: *x dependence of the instanton contribution to structure function $F_2(x)$ induced by instantons for $\rho_c = 2\ GeV^{-1}$. The dashed line is the contribution from gluons, dotted line is the contribution from the sea quarks and the solid line is the total contribution.*

WHERE

$$P_{qg}(y) = \frac{\alpha_s}{2\pi}\left(1+(1-y)^2\right)\log(Q^2\rho_c^2)$$

b) FROM SEA QUARKS INDUCED BY INSTANTONS

$$\delta F_2^{\bar{q}} = x\sum_q e_q^2\,\delta q_I^s$$

<u>HARD QUARK SEA</u> INDUCED BY INSTANTONS

(BRODSKY'S INTRINSIC HARD CHARM?)

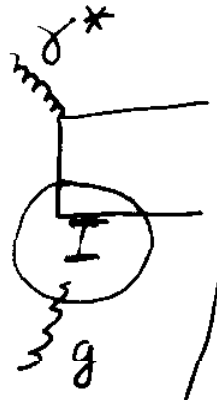
<u>HIGH Q^2, x ANOMALOUS EVENTS AT HERA AND HIGH $E_\perp$ JETS EXCESS AT TEVATRON</u>

Q^2 <u>DEPENDENCE OF INSTANTON CONTRIBUTION</u>

1. IN DILUTE GAS APPROXIMATION

(BALITSKY, BRAUN, '93 ;

RINGWALD, SCHREMPP '96)



INSTANTON CONTRIBUTION - 1

TO <u>COEFFICIENT</u> <u>FUNCTIONS</u>

HUGE SUPPRESSION FACTOR

$$\boxed{M = A(N_f, N_c) \cdot e^{-\frac{4\pi}{\alpha_s(\mu)}} \approx e^{-120}}$$

FOR $\mu^2 \approx Q^2 \approx 10^4\ GeV^2$

A.R. WHITE '97 COLOUR SEXTET

QUARK VERSION OF STANDARD MODEL

LARGE NUMBER OF QUARKS $\Rightarrow$

LARGE PREFACTOR $A(N_f, N_c) \Rightarrow$

<u>ENHANCEMENT</u> OF INSTANTON

CONTRIBUTION <u>ONLY</u> AT THE

<u>ELECTROWEAK</u> <u>SCALE</u>

a) OUR APPROACH

<u>INSTANTON</u> <u>CONTRIBUTION</u> TO THE

<u>PARTON</u> <u>DISTRIBUTION</u>

INSTANTON LIQUID MODEL

$\mu^2 \approx 1/\rho_c^2 \approx 0.25\ GEV^2$

SUPPRESSION FACTOR <u>IS ABSENT</u>!!!

Q^2 DEPENDENCE & NONPERTURBATIVE PART

a) AT LOW Q^2

$$\delta q^I, \delta G^I \sim Q^2$$

$$(\delta q^I(0) = \delta G^I(0) = 0 \text{ AT } Q^2 = 0)$$

DUE TO QUARK SPIN-FLIP

STRONG Q^2 DEPENDENCE

AT LARGE $Q^2 \to \log(Q^2 \rho_c^2)$

FOR PERTURBATIVE PART WE HAVE

WEAK Q^2-DEPENDENCE $\sim \log(Q^2/\Lambda^2)$

$\Downarrow$

AS THE RESULT $\Rightarrow$ TOTAL Q^2 EVOLUTION OF PARTONIC DISTRIBUTIONS

SHOULD BE RATHER COMPLICATED

$\Downarrow$ $\qquad\qquad$ $\Downarrow$

HERA HIGH Q^2, x ANOMALY $\qquad$ TEVATRON ANOMALY

$\Uparrow$ $\qquad\qquad$ $\Uparrow$

INSTANTON CONTRIBUTION TO QUARK DISTRIBUTION FUNCTIONS $\qquad$ INSTANTON CONTRIBUTIO TO GLUON DISTRIBUTIO

CONCLUSION

INSTANTON CONTRIBUTION TO THE SPIN- AND FLAVOUR DEPENDENT PARTON DISTRIBUTIONS IS LARGE

ΔG IS NEGATIVE

$\Delta\bar{u} + \Delta\bar{d} + \Delta\bar{s}$ IS NEGATIVE

$$\Delta\bar{d} \simeq -2\Delta\bar{u}$$

$$\bar{d} \approx 2\bar{u}$$