Soft Pomeron structure and Chromomagnetic quark-gluon interaction

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Quark-gluon interaction induced by instantons

Instanton model for QCD vacuum

Instantons are strong fluctuations of vacuum gluon fields (review was done in the talk by Prof. Musakhanov)

$$A_\mu^a = \frac{2}{g_s}\eta_{a\mu\nu}\frac{(x-x_0)_\nu}{(x-x_0)^2+\rho^2}$$

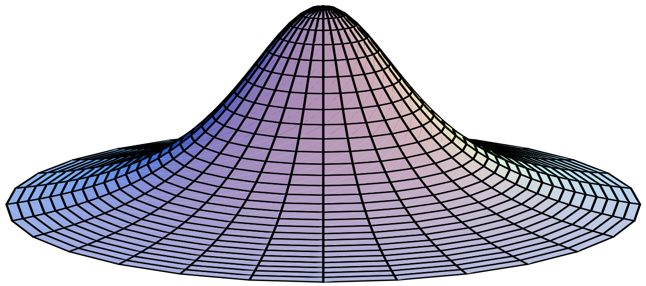
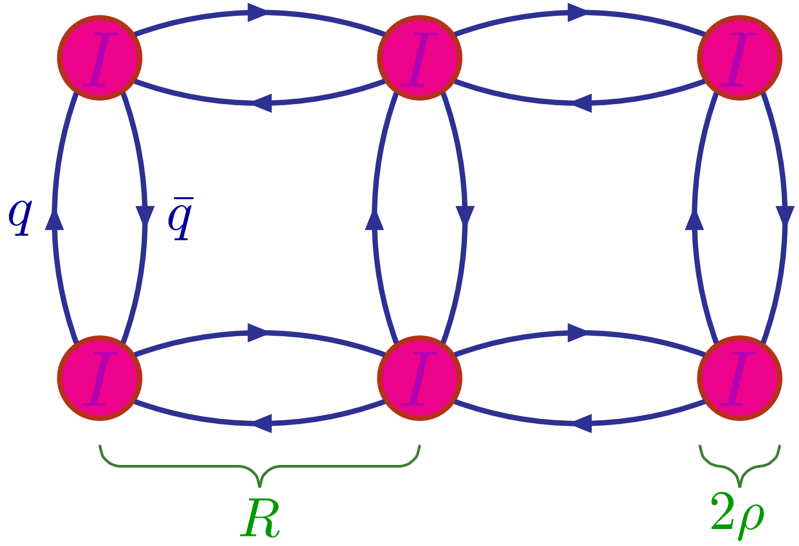


Figure 1: Instanton solution in QCD.

Instanton liquid model for QCD vacuum [Shuryak, Diakonov, Petrov ...]



One can introduce the "density" of instantons

$$n_I(\rho) \sim exp\left(-\frac{2\pi}{\alpha_s(\rho)}\right)$$

R - distance between instantons

$\rho \approx 0.3$ fm - instanton size

If $R >> \rho \rightarrow$ vacuum is a "gas" of instantons

If $R \approx 3\rho \rightarrow$ vacuum is an instanton "liquid"

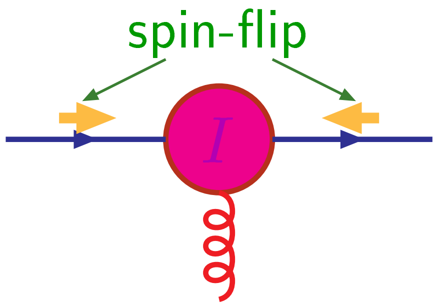
•In the general case, the interaction vertex of massive quark with gluon can be written in the following form:

$$V_\mu(k_1^2, k_2^2, q^2)t^a = -g_s t^a[\gamma_\mu F_1(k_1^2, k_2^2, q^2) + \frac{\sigma_{\mu\nu} q_\nu}{2M_q} F_2(k_1^2, k_2^2, q^2)],$$

- Anomalous quark chromomagnetic moment (AQCM):

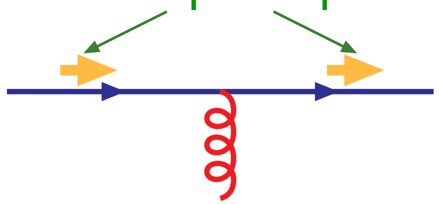
$$\mu_a = F_2(0, 0, 0).$$

AQCM within instanton model for QCD vacuum [N.K. (1996)]



$$\Delta\mathcal{L} = -\imath\mu_a \frac{g_s}{4m_q^*}\bar{q}\sigma_{\mu\nu}t^a q G^a_{\mu\nu}$$

$\mu_a \approx -0.4$ [N.K. 1996]
$\mu_a \approx -1.6$ [Diakonov 2002]



pQCD quark-gluon vertex

$$\Delta\mathcal{L} = g_s\bar{q}\gamma_\mu t^a q A^a_\mu$$

Effective instanton induced quark-gluon vertex in local limit (small instanton size) $\rho \to 0$

$$V^a_\beta = -\int dU d\rho \left\{ \frac{2\pi^2\rho^2 n_I(\rho)}{M_q} \bar{q}_R U[I + \frac{i\bar{\eta}_{b\mu\nu}\tau^b\sigma_{\mu\nu}}{4}]U^\dagger q_L Tr[\lambda^a \hat{A}_\beta] \right\},$$

where

$$\hat{A}_\beta = -iq_\alpha \bar{\eta}_{c\alpha\beta} \frac{2\pi^2\rho^2}{g_s} U\tau^c U^\dagger$$

is amputated instanton field and U is present the orientation of the instanton in $SU(3)_c$ color space.

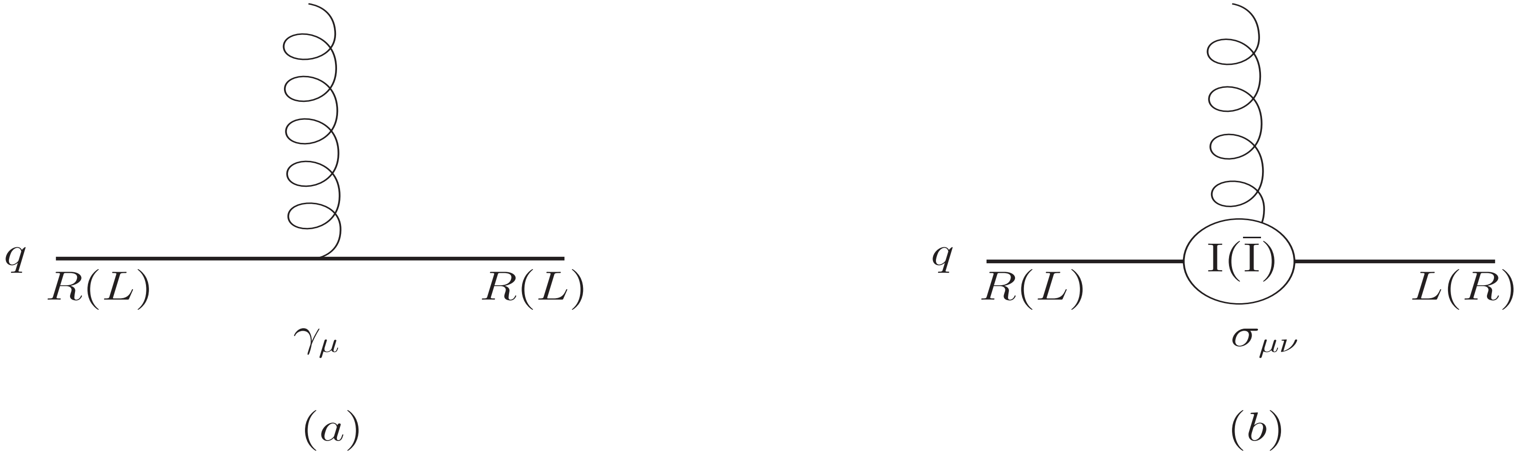


Figure 2: The quark-gluon coupling: a) perturbative and b) nonperturbative. Symbols R and L denote quark chirality and symbol $I(\bar{I})$ denotes instanton (antiinstanton).

The shape of form factor $F_2(k_1^2, k_2^2, q^2)$ is fixed:

$$F_2(k_1^2, k_2^2, q^2) = \mu_a \Phi_q(\mid k_1 \mid \rho/2)\Phi_q(\mid k_2 \mid \rho/2) F_g(\mid q \mid \rho) \ ,$$

where

$$\begin{aligned}\Phi_q(z) &= -z\frac{d}{dz}(I_0(z)K_0(z) - I_1(z)K_1(z)),\\ F_g(z) &= \frac{4}{z^2} - 2K_2(z)\end{aligned}$$

are the Fourier-transformed quark zero-mode and instanton fields, respectively, and $I_\nu(z)$, $K_\nu(z)$,are the modified Bessel functions and ρ is the instanton size.

The value of AQCM is determined by the effective density of the instantons $n(\rho)$ in nonperturbative QCD vacuum (N.K. (1996))

$$\mu_a = -\pi^3 \int \frac{d\rho n(\rho)\rho^4}{\alpha_s(\rho)}.$$

Within Shuryak's instanton liquid model

$$n(\rho) = n_c\delta(\rho - \rho_c),$$

leads to AQCM which is proportional to the packing fraction of instantons $f=\pi^2 n_c\rho_c^4$ in vacuum

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

By using the following relation between parameters of the instanton model

$$f=\frac{3}{4}(M_q\rho_c)^2,$$

we obtain

$$\mu_a=-\frac{3\pi(M_q\rho_c)^2}{4\alpha_s(\rho_c)}.$$

The dimensionless parameter $\delta=(M_q\rho_c)^2$ is one of the main parameters of the instanton model. It is proportional to the packing fraction of instantons in QCD vacuum $\delta\propto f\ll 1$, and is rather small. For a fixed value of average instanton size $\rho_c^{-1}=0.6$ GeV it changes from $\delta^{MF}=0.08$ for $M_q=170MeV$ in the mean field approximation to $\delta^{DP}=0.33$ for $M_q=345$ MeV within Diakonov-Petrov model. For the strong coupling constant at the scale of instanton average size

$$\alpha_s(\rho_c)\approx 0.5,$$

we obtain the following values for AQCM:

$$\mu_a^{MF} \approx -0.4, \quad \mu_a^{DP} \approx -1.6$$

in the mean field approximation and in the DP approach, respectively.

Formula for AQCM can be rewritten in the following form:

$$\mu_a = -\frac{3}{8} S_0 \delta,$$

where $S_0 = 2\pi/\alpha_s(\rho)$ is the Euclidean instanton action. The typical value of this action is large

$$S_0 \approx 10 \div 15$$

and leads to the compensation of the δ smallness effect on AQCM.

Recent calculation within Dyson-Schwinger approach (Craig Roberts et al. (2010)) gives for AQCM $\mu_a \approx -0.5$.

Fine pomeron structure

•Pomeron is effective colorless exchange between hadrons (quarks) which gives a dominated contribution to the high energy cross sections: $\sigma \approx s^{\alpha(0)-1}$

•Two types of pomerons: "soft" (Landshoff and Nachtmann (low virtuality of quark and gluons and intercept $\alpha_{soft}(0) \approx 1.08$) and "hard" Balitsky ,Kuraev, Lipatov and Fadin (BFKL) pomeron (large virtualities and intercept $\alpha_{hard}(0) \approx 1.4$).

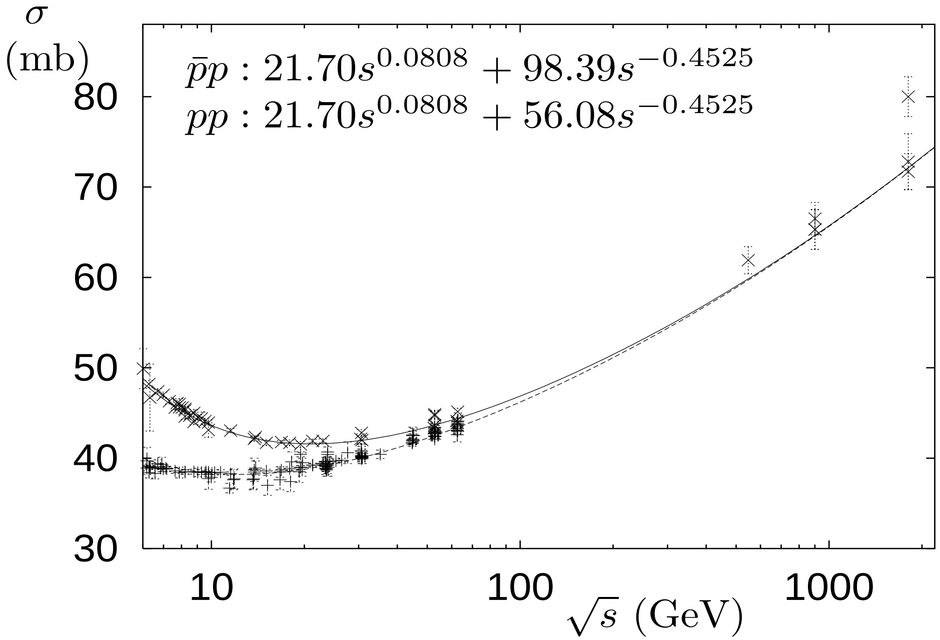


Figure 3: Soft Pomeron in pp and $\bar{p}p$ total cross sections.

Form factor in the first term in general quark-gluon vertex might be chosen in the form

$$F_1(k_1^2, k_2^2, q^2) = \Theta(\mid k_1^2 \mid -\mu^2)\Theta(\mid k_2^2 \mid -\mu^2)\Theta(\mid q^2 \mid -\mu^2),$$

where μ is the factorization scale between perturbative and nonperturbative regimes. In our estimation below we will use $\mu \approx 1/\rho_c \approx 0.6$ GeV.

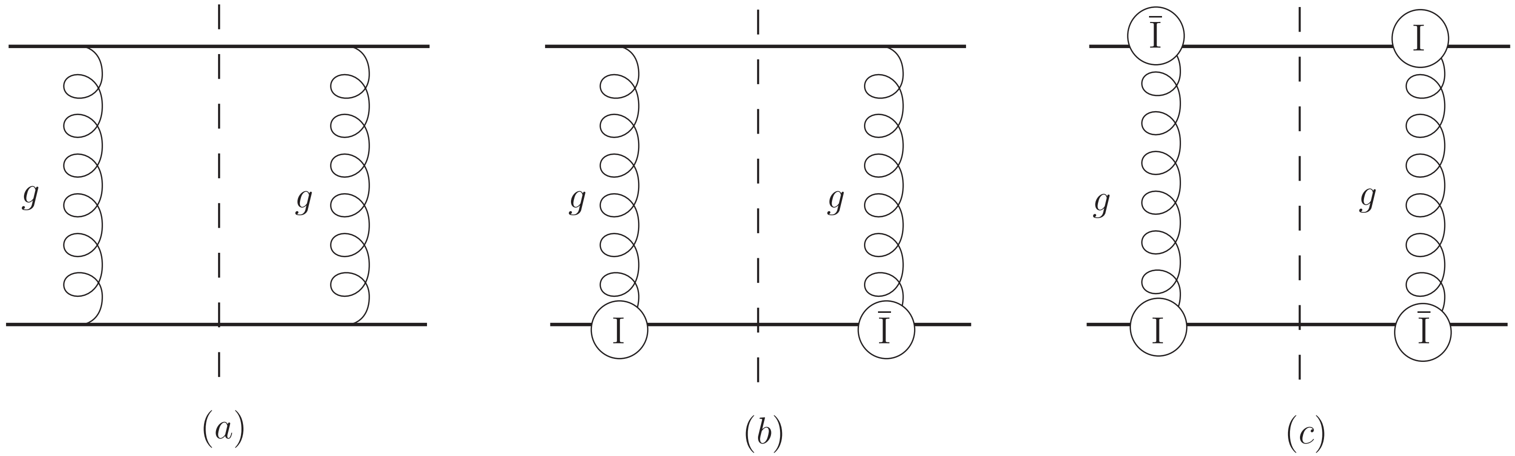


Figure 4: The fine pomeron structure in the model with perturbative and nonperturbative interactions: a) perturbative contribution, b) interference perturbative and nonperturbative vertices, c) nonperturbative contribution. The symbol I ($\bar{I}$) denotes instanton (antiinstanton).

The total contribution to quark-quark cross section for the quarks with small virtualities is

$$\sigma^{total} = \sigma^{pert} + \sigma^{mix} + \sigma^{nonpert}, \qquad (1)$$

where

$$\sigma^{i} = \int_{q^2_{min}}^{\infty} \frac{d\sigma^{i}(t)}{dt} dq^2, \qquad (2)$$

$$\frac{d\sigma(t)^{pert}}{dt} = \frac{8\pi\alpha_s^2(q^2)}{9q^4}$$
$$\frac{d\sigma(t)^{mix}}{dt} = \frac{\alpha_s(q^2)\pi^2 \mid \mu_a \mid \rho_c^2 F_g^2(|q|\rho_c)}{3q^2}$$
$$\frac{d\sigma(t)^{nonpert}}{dt} = \frac{\pi^3\mu_a^2\rho_c^4 F_g^4(|q|\rho_c)}{32}, \qquad (3)$$

where $q^2 = -t$ and $q^2_{min} \approx 1/\rho_c^2$ for perturbative and mixed contributions and $q^2_{min} = 0$ for pure nonperturbative contribution.

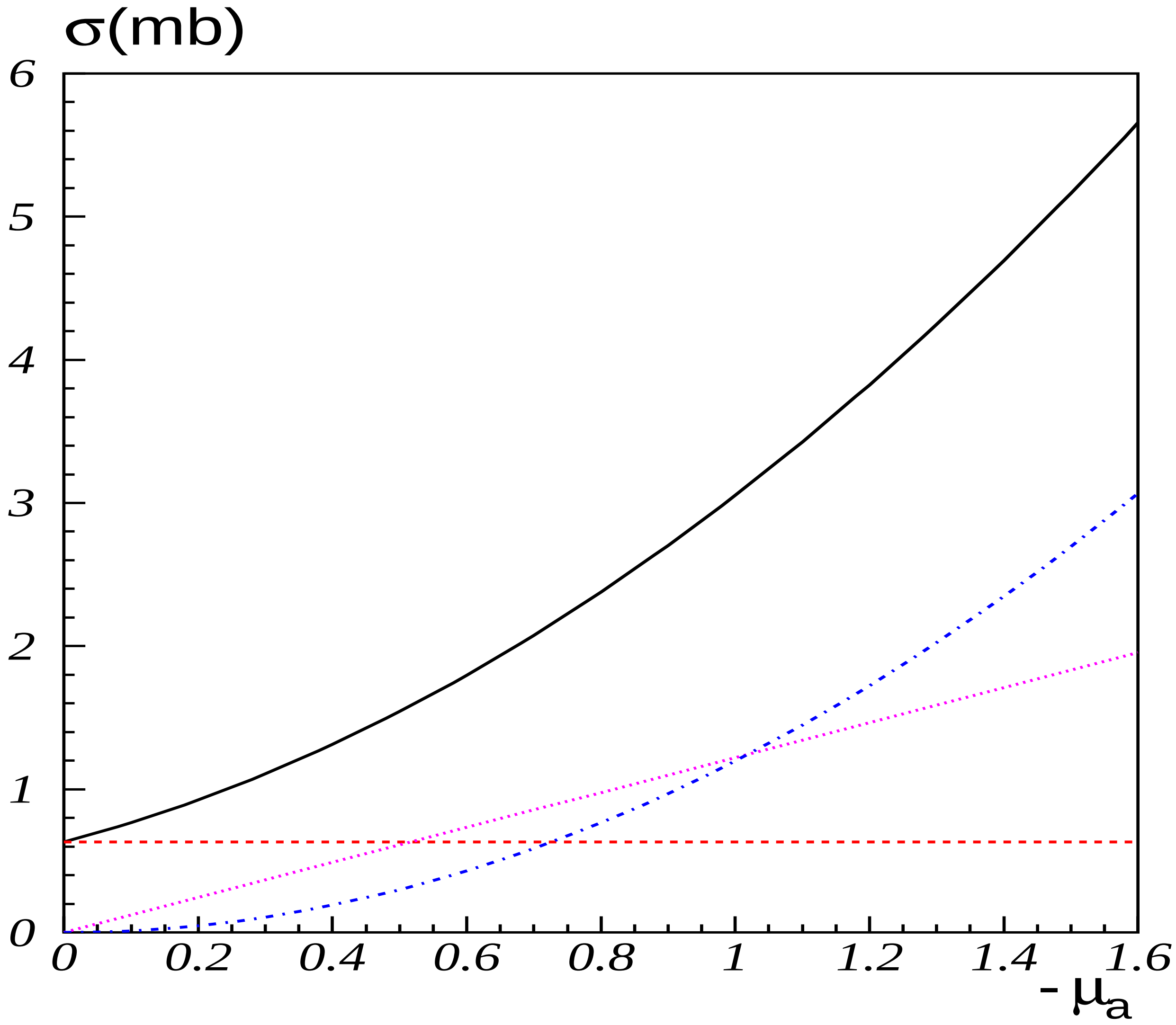


Figure 5: The contibution to the total quark-quark cross section as a function of AQCM: perturbative (dashed line) , mixed (dotted line), nonperturbative (dashed-dotted line) and their sum (solid line).

For the strong coupling constant, the following parametrization was:

$$\alpha_s(q^2) = \frac{4\pi}{9\ln((q^2+m_g^2)/\Lambda_{QCD}^2)},$$

where $\Lambda_{QCD} = 280$ MeV and the value $m_g = 0.88$ GeV was fixed from the requirement $S_0 = 2\pi/\alpha_s(q^2 = 1/\rho_c^2) \approx 12$ as in Shuryak-Diakonov-Petrov instanton liquid model. This form for $\alpha_s(q^2)$ describes the frozen coupling constant in the infrared region, $\alpha_s(q^2) \to constant$ as $q^2 \to 0$.

From hadron spectroscopy (Faustov, Galkin, Ebert) obtained $\mu_a \approx -1$. In our calculation it corresponds to the value of dynamical quark mass $M_q = 280$ MeV. For such μ_a we have got $\sigma_{qq}^{tot} = 3.05$ mb.
That number is not far away from $\sigma_{qq}^{exp} = 4$ mb (inelastic $\sigma_{pp(\bar{p})}^{exp} \approx 36$ mb in the energy range where $pp(p\bar{p})$ cross sections are approximately constant).

Gluon distribution in nucleon induced by anomalous chromomagnetic interaction

The anomalous quark-gluon interaction structure should also manifest itself in the structure of gluon distribution in nucleon. One of the ways to show it is in the use of a DGLAP-like approach with the modified quark splitting function $\mathcal{P}_{Gq}$ according with the general quark-gluon vertex.

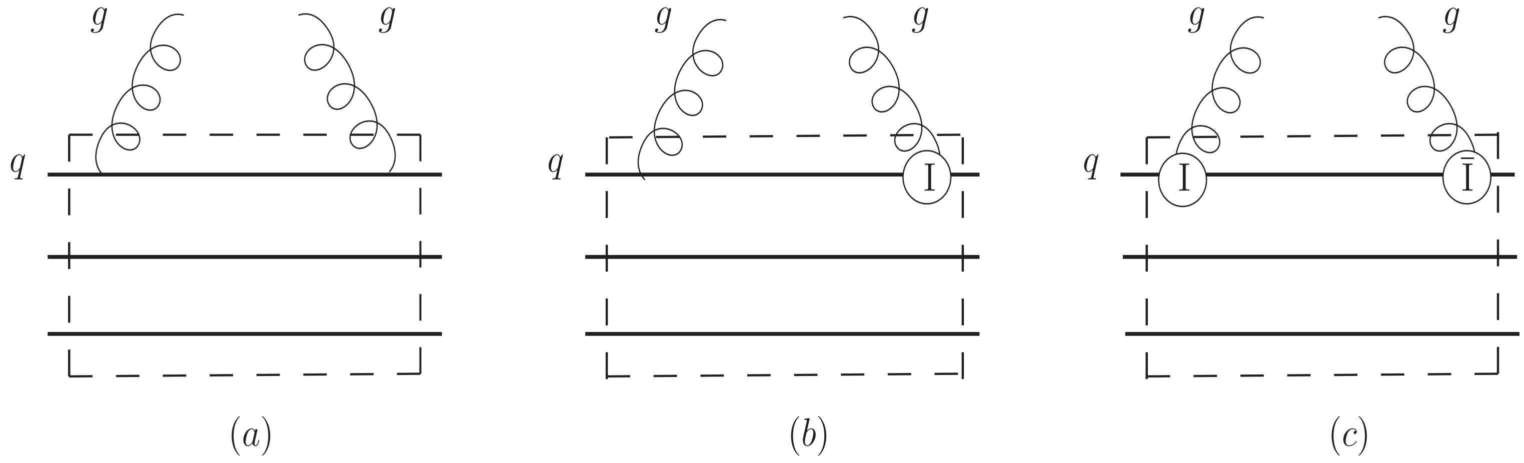


Figure 6: The diagrams contributing to nucleon gluon distribution: a) "hard"-perturbative, b) "hard-soft" interference perturbative and nonperturbative exchanges, c) "soft"-nonperturbative part.

To calculate unintegrated distribution, we use the convolution model formula

$$f(x,k_\perp^2) = N_q k_\perp^2 \int_x^1 \frac{dy}{y} \mathcal{P}_{Gq}(x/y, k_\perp^2) q_V(y),$$

where $N_q = 3$ is the number of valence quarks in nucleon, q_V is the valence quark distribution function in nucleon, $\mathcal{P}_{Gq}$ is the quark splitting function as defined by Altarelli and Parisi. The splitting function is given by the formula

$$\begin{aligned}\mathcal{P}_{Gq}(z,k_\perp^2) &= \frac{C_F z(1-z)k_\perp^2}{8\pi^2(k_\perp^2+M_q^2z^2)^2}\sum_\lambda Tr[(\hat{k}_C+M_q)U_\mu(t)(\hat{k}_A+M_q)\\ &\times \bar{U}_\rho(t)]\epsilon_\mu(\lambda)\epsilon^*_\rho(\lambda),\end{aligned}$$

where $U_\mu(t)=V_\mu(0,0,t)$, k_A (k_C) is momentum of initial (final) quark, $t=q^2=(k_A-k_C)^2$, $\bar{U}=\gamma_0 U^\dagger\gamma_0$ and λ is gluon helicity. In the infinite momentum frame

$$\begin{aligned}k_A &= (P, P+\frac{M_q^2}{2P},\vec{0}_\perp)\\ k_C &= ((1-z)P+\frac{k_\perp^2+M_q^2}{2(1-z)P},(1-z)P,-\vec{k}_\perp)\\ q &= (zP-\frac{k_\perp^2+M_q^2z}{2(1-z)P},zP,\vec{k}_\perp),\end{aligned}$$

the result for splitting function is

$$\begin{aligned}\mathcal{P}_{Gq}(z,k_\perp^2) &= \frac{C_F k_\perp^2}{2\pi z(k_\perp^2+M_q^2z^2)^2} \\ &\times [(\sqrt{\alpha_s(\mid t\mid)}\Theta(\mid t\mid-\mu^2)+\sqrt{\alpha_s(1/\rho_c^2)}\mu_a F_g(\mid t\mid))^2 z^2 \\ &+ 2((1-z)\alpha_s(\mid t\mid)\Theta(\mid t\mid-\mu^2)+\frac{\alpha_s(1/\rho_c^2)\mu_a^2k_\perp^2}{4M_q^2}F_g^2(\mid t\mid))],\end{aligned}$$

where $\mid t\mid=(k_\perp^2+M_q^2z^2)/(1-z)$ is the gluon virtuality. The integrated distribution is given by

$$g(x,Q^2)=\int_0^{Q^2}\frac{dk_\perp^2}{k_\perp^2}f(x,k_\perp^2),$$

For estimation we use a simple form for valence quark distribution

$$q_V(x)=1.09\frac{(1-x)^3}{\sqrt{x}}$$

with the normalization $\int_0^1 q_V(x)dx=1$.

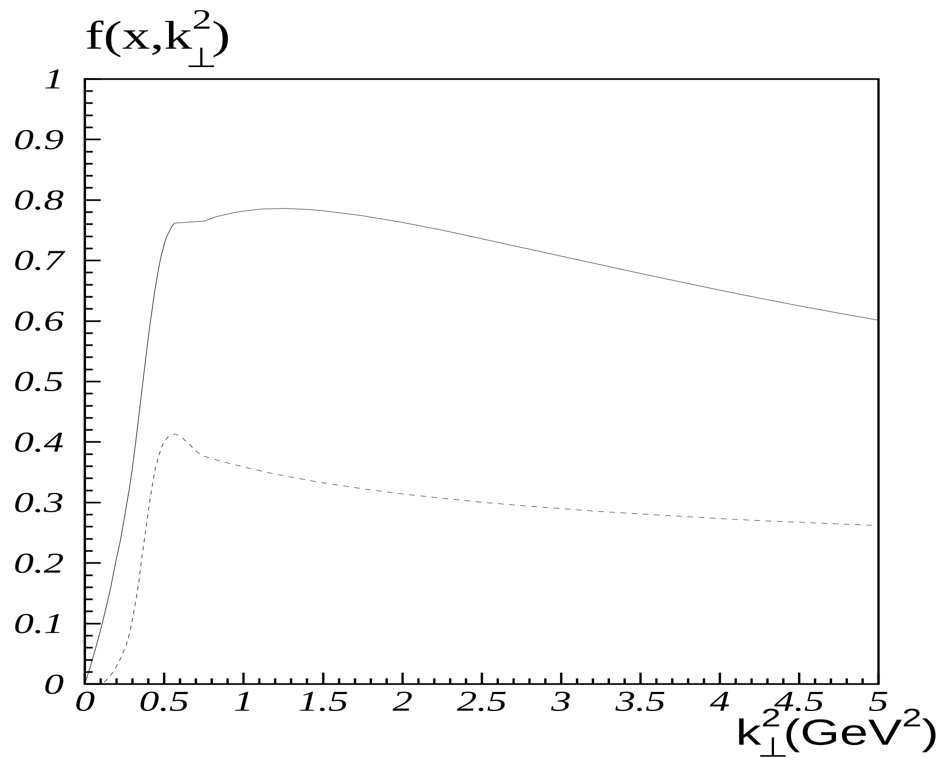


Figure 7: The unintegrated gluon distribution at $x = 10^{-2}$: solid (dashed) line is total (perturbative) contribution.

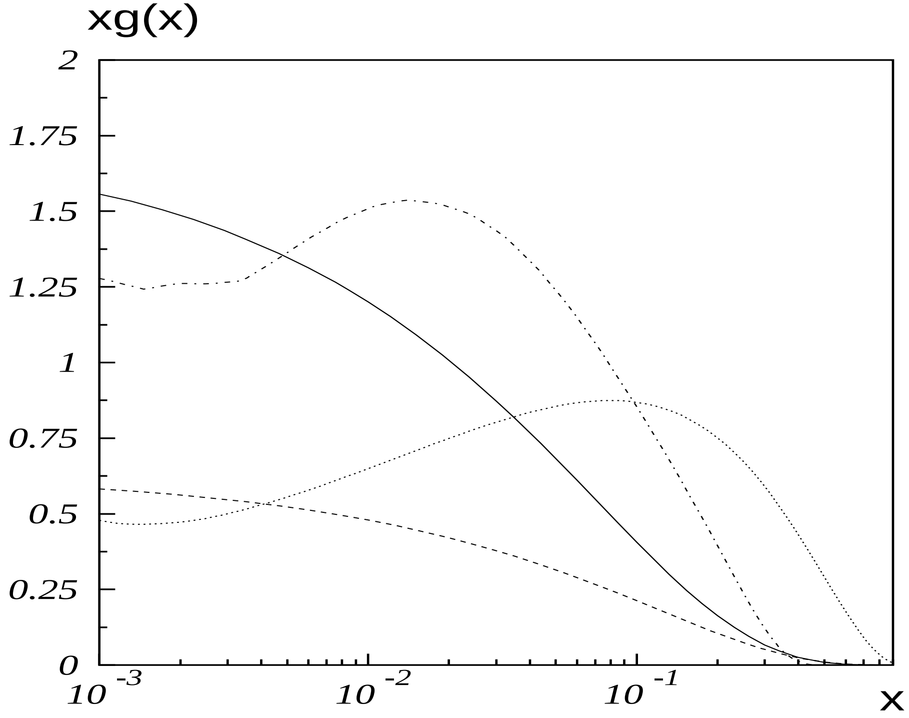


Figure 8: Perturbative (dashed line) and total (solid line) contributions to gluon distribution at $Q^2 = 1 GeV^2$ in comparison with some of the phenomenological fits: dotted line is ALEKHIN02LO set and dashed-dotted line is MSTW2008LO fit.

CONCLUSION

- **Instantons induce large anomalous quark-gluon chromomagnetic spin-flip interaction**

- **This interaction gives the dominating contribution to the soft pomeron exchange and to gluon distribution in nucleon for the small virtuality of quark and gluons**

- **Internal spin structure of soft and hard Pomerons is different**

- **That feature should gives a strong influence to the spin effects in the diffraction (N.K., N.Nikolaev, N.Korchagin work in progress)**

Thank you for your attention!