INFRARED MODIFIED QCD COUPLINGS AND BJORKEN SUM RULE

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Abstract

We test the recently proposed «Massive» Perturbation Theory (MPT) for the description of the Γ_1^{p-n} data at low momentum transfers. The MPT constructed on the two grounds: the first is pQCD with only one parameter added, an effective «glueball mass» $m_\rho \le M_{gl} \le 1$ GeV; serving as an infrared «regulator»; the second stems out of the ghost-free Analytic Perturbation Theory comprising non-power perturbative expansion that makes it compatible with linear integral transformations. It is regular in the low-energy region and could serve as a practical means for the analysis of data below 1 GeV up to the IR-limit. We study the non-perturbative Bjorken sum rule higher twists correction by using the MPT, the integral representation for infinite sum of higher twists coefficients and the QCD-inspired model for the Q^2-dependence of the generalized Gerasimov-Drell-Hearn sum rule.

Introduction

The perturbative QCD (pQCD) is a firmly established part of the particle interaction theory. Starting with gauge-non-invariant quantization, it correlates several dozen of experiments at quite different scales from a few up to hundreds of GeV. At the same time, pQCD meets troubles in the low-energy domain, below a few GeV, at the scales marked by the QCD parameter Λ_{QCD}. To avoid the unwanted singularity of the QCD running coupling in the low energy region, several modifications (for example, [1-3]) of the pQCD have been devised. Recently, one of them, the Analytic Perturbation Theory ([4] and a latter review paper [5]) (APT), has proved to be good [6] in describing the polarized $\Gamma_1^{p-n}(Q^2)$ moment of the Bjorken Sum Rule (BSR) down to a few hundred MeV. To approach the global fitting of data, one needs a modified perturbation theory (MPT) with two essential properties: correspondence with common pQCD in ultra-violet limit (that is above a few GeV) and regularity and finiteness of the modified effective coupling $\alpha^{MPT}(Q^2)$ and matrix elements in the low-energy domain. As a primary launch pad for this construction, the above-mentioned APT seems good. It satisfies the first condition and, partially, the second one. To exempt the APT-like scheme from its last drawback – the singularity (infinite derivatives) in the infra-red limit, one has to disentangle it from the ultra-violet logs. To this goal the infra-red regulator has been introduced just by the shift of the Q^2 scale [7], $\ln(Q^2/\Lambda^2_{QCD}) \to \ln\left[(Q^2+M^2_{gl})/\Lambda^2_{QCD}\right]$, with the only fitting parameter added, an effective glueball mass, M_{gl}.

Description of the methods

Let us briefly discuss methods of the QCD analysis of the Γ_1^{p-n} data base on the MPT. Away from the large Q^2 limit, the BSR is given by a double series in powers of α_S and in powers of $1/Q^2$ and can be written as

$$\Gamma_1^{p-n}(Q^2) = \frac{|g_{A/V}|}{6}\left(1-\Delta_{Bj}(Q^2)\right) + \sum_{i=2}^{\infty}\frac{\mu_{2i}}{Q^{2i-2}}, \qquad (1)$$

where $|g_{A/V}| = 1.2723$ [8] is the nucleon axial charge, μ_{2i} are the higher twist (HT) coefficients, $\Delta_{Bj}(Q^2)$ is the perturbative correction, which at the four-loop (N^3LO) level in the massless case reads

$$\Delta_{Bj}(Q^2) = 0.318\alpha_S + 0.363\alpha_S^2 + 0.652\alpha_S^3 + 1.804\alpha_S^4 .$$

In the framework of MPT perturbative α_S-series replaced by expansions over MPT functions A_k:

$$\sum_k c_k\alpha_S^k \to \sum_k c_k A_k , \qquad (2)$$

where $A_1(Q^2) \equiv \alpha^{MPT}(Q^2)$ is MPT running coupling, which is the two-loop massive renormalization group solution in the denominator representation (for details, see [10]) has a following form

$$A_1(Q^2) \equiv \alpha^{MPT}(Q^2) = \frac{\alpha_0}{1+\alpha_0\beta_0 L^* + \alpha_0\beta_1 \ln\left[1+\alpha_0\beta_0 L^*\right]/\beta_0}, \quad L^* = \ln\left(\frac{Q^2+M^2_{gl}}{\Lambda^2_{QCD}}\right). \qquad (3)$$

The MPT preserves an essential APT feature, namely, the non-polynomiality of perturbative expansion over a set of higher functions A_k ($k>1$). These functions are connected by the differential recurrent relations (at NLO)

$$\beta_0 A_{k+1}\left(Q^2\right) = -\frac{Q^2+M_{gl}^2}{k}\frac{d}{dQ^2}A_k\left(Q^2\right) - \beta_1 A_{k+2}\left(Q^2\right). \tag{4}$$

In the following analysis, we use the natural condition $\Gamma_1^{p-n}\left(Q^2=0\right)=0$, which is motivated by finiteness of the the spin-dependent cross-sections in real photon limit. In the spirit of [11,12], where Gerasimov-Drell-Hearn and Burkhardt-Cottingham sum rules considered for the purpose of a smooth continuation of $\Gamma_1^{p,n}\left(Q^2\right)$ to the non-perturbative region $0 \le Q^2 \le \Lambda_{QCD}^2$, we obtain slope of Γ_1^{p-n} moment at the IR-limit $Q^2=0$:

$$\frac{d}{dQ^2}\Gamma_1^{p-n}\left(Q^2=0\right) = \frac{-\left(\mu_p-1\right)^2+\mu_n^2}{8M^2}, \tag{5}$$

where $\mu_p = 2.79$ and $\mu_p = -1.91$ are proton and neutron magnetic moments [8], respectively, and $M=0.938$ GeV is a nucleon mass. We use the non-perturbative series summation procedure proposed in [13]. This procedure allows to represent a non-perturbative operator product expansion series introducing a single free parameter m_{ht}

$$\sum_{n=1}^{\infty}\mu_{2n+2}^{p-n}\left(\frac{m_{ht}^2}{Q^2}\right)^n \to \frac{\mu_4^{p-n}+m_{ht}^2}{Q^2+m_{ht}^2}. \tag{6}$$

We use the conditions (5) and (6) to connect the free parameters M_{gl}, m_{ht} and μ_4^{p-n}. As a result we obtain an approach with only one free parameter – effective «glueball mass» M_{gl}

$$\Gamma_1^{p-n}\left(Q^2\right) = \frac{\left|g_{A/V}\right|}{6}[1-0.318A_1\left(Q^2,M_{gl}^2\right)-0.363A_2\left(Q^2,M_{gl}^2\right)- \\ -0.652A_3\left(Q^2,M_{gl}^2\right)-1.804A_4\left(Q^2,M_{gl}^2\right)+\ldots]+\frac{\mu_4^{p-n}+m_{ht}^2}{Q^2+m_{ht}^2}. \tag{7}$$

Results of fit and discussion

Using expression (9) fitted to the low Q^2 data [14-16], we can extract the HT coefficients μ_4^{p-n} and parameters of «effective glueball mass» M_{gl} and parameter m_{ht} in the HT sum. In the Table 1 we present our result for the coefficient μ_4 obtained in different PT orders.

Table 1 - Central values of the extracted parameters.

Order	M_{gl}^2, GeV^2	m_{ht}^2, GeV^2	μ_4, GeV	$\chi^2_{d.o.f.}$
LO	0.782	0.736	-0.170	6.24
NLO	0.954	0.724	-0.146	6.71
N^{2}LO	0.648	0.039	0.025	5.11
N^{3}LO	0.546	0.143	-0.055	0.73

One can see that the value $\mu_4^{MPT} = -0.055$ is compatible with previously extracted $\mu_4^{MPT} = -0.050(2)$ [6]. Figure 1 shows the fits curves in various orders of MPT and for comparison four-loop APT curve from [6].

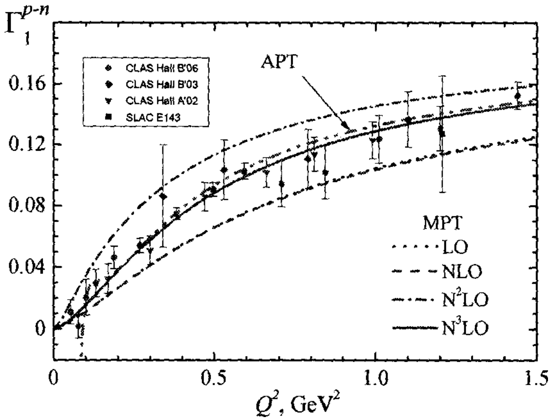

Figure 1. – The fit of the Γ_1^{p-n} data in different orders of the MPT and the for-loop APT.

In conclusion we stress, that MPT approach combined the IR-frozen and the non-polynomiality of perturbative expansions is a next step for understanding low-energy QCD. The MPT together with a duly modified HT sum allows one to fit the data on Γ_1^{p-n} down to the IR limit $Q^2 = 0$.

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THREE-JET CROSS SECTION MEASUREMENT IN PROTON-PROTON COLLISIONS AT 7 TEV CENTER-OF-MASS ENERGY WITH ATLAS DETECTOR

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Abstract

ATLAS experiment collected the integrated luminosity of $\int\mathcal{L} = 4.6\,\text{fb}^{-1}$ in proton-proton collisions in the 2011 year of data taking with the centre-of-mass energy of 7 TeV. The measurement of the double-differential three-jet cross-section, using collected data, provide a valuable input for the determination of parton density functions. The measurement is performed as a function of absolute rapidity separation between three-leading jets. A comparison of the measured data to the theory prediction at the next-to-leading order accuracy corrected for non-perturbative effects, is