THE ROLE OF HADRONIZATION PROCESSES IN DETERMINATION OF FRAGMENTATION FUNCTIONS*

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We present the results of a global fit to data from different hadronization processes such as single-inclusive electron–positron annihilation and semi-inclusive deep inelastic scattering to calculate pion and kaon fragmentation functions. We perform an improvement to the pion and kaon fragmentation functions at next-to-leading order (NLO), by including recent single-inclusive electron–positron annihilation data from BaBar and Belle at $Q = 10.54$ GeV and $Q = 10.52$ GeV, respectively. Our main purpose is to show how much imposing of these new data in our analysis improves the fragmentation functions of pion and kaon at NLO.

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1. Introduction

Fragmentation functions (FFs) are the key quantities in calculation of hadron production cross sections, investigating properties of quarks in heavy ion collisions and spin physics. In order to study the properties of the top quark at the LHC, one of the proposed channels is to consider the energy spectrum of outgoing mesons from top quark decays, in which having the required information about the FFs is crucial.

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The FFs are generally studied in electron–positron annihilation, lepton–hadron and hadron–hadron scattering processes. Among all, the best processes which provide a clean environment to determine the fragmentation functions is e^+e^- annihilation processes [1, 2]. The FFs are global functions which are independent of hadronization processes and there are already several theoretical studies on QCD analysis of FFs which used special parametrization and different experimental data in their global analysis. Recent extracted FFs are related to SKMA [3], AKK [4], DSSV [5] and HKNS [6].

In our global analysis, we apply single inclusive electron–positron annihilation (SIA) and semi-inclusive deep inelastic scattering (SIDIS) data. We also apply, for the first time, recent SIA data which are reported from the Belle Collaboration [1] at $\sqrt{s} = 10.52$ GeV and the BaBar Collaboration [2] at $\sqrt{s} = 10.54$ GeV.

This paper is organized as follows. In Section 2 we describe our formalism and parametrization form for fragmentation densities. In Section 3 we introduce our experimental data applied in the global fit. Also the effect of Belle and BaBar data on FFs determination is explained. Our conclusion and results are given in Section 4.

2. Formalism

The FFs are the low energy components of the hadronization processes and they have an important role in the non-perturbative QCD. According to the factorization theorem, the cross section of e^+e^- annihilation, lepton–nucleon DIS, and hadron–hadron collisions can be generally expressed in terms of perturbatively calculable partonic cross sections, parton distribution functions (PDFs) and FFs. In the typical scattering process of $A + B \to H + X$, the production of hadron H can be expressed as

$$\begin{aligned} d\sigma &= \sum_{a,b,c} \int_0^1 dx_a \int_0^1 dx_b \int_0^1 dz f_{a/A}(x_a,\mu) f_{b/B}(x_b,\mu) \\ &\quad \times d\hat{\sigma}(a+b \to c+X) D_{c\to H}(z,\mu)\,, \end{aligned} \tag{1}$$

where a and b are incident partons in the colliding initial hadrons A and B respectively, $f_{a/A}$ and $f_{b/B}$ are the PDFs at the factorization scale μ, c is the fragmenting parton and X stands for the unobserved jets. Here, $D_{c\to H}(z,\mu)$ is the fragmentation function which can be obtained by evolving from the initial FF $D_{c\to H}(z,\mu_0)$ using the DGLAP group equations. The FFs and PDFs are related to the low energy components of QCD processes which are universal functions and can be used to make predictions.

There are several approaches to extract the FFs from data analysis. In our analysis we adapt the zero-mass variable-flavour-number (ZM-VFN) scheme [7]. This scheme works best for high energy scales, where $m_Q = 0$ is a good approximation.

We choose very flexible parametrization form for the pion and kaon FFs at NLO considering SIA data and SIDIS data. At the initial scale μ_0, this parametrization contains a functional form as

$$D_i^H\left(z,\mu_0^2\right) = N_i z^{\alpha_i}(1-z)^{\beta_i}[1-e^{-\gamma_i z}] \tag{2}$$

which is an appropriate form for the light hadrons. This new parametrization form covers a wide kinematic range of z because of the extra term $[1-e^{-\gamma_i z}]$

TABLE I

The individual χ^2 values in the NLO for each collaboration and the total χ^2 fit for π^+.

Collaboration	Data properties	$\sqrt{s}$ GeV	Data points	Relative normalization in fit	χ^2(NLO)
Belle [1]	untagged	10.52	78	1.001	12.5
BaBar [2]	untagged	10.54	38	0.928	138.3
TPC [13]	untagged	29	12	0.992	5.7
TASSO [14]	untagged	34	8	1.049	7.9
	untagged	44	5	1.049	6.9
TOPAZ [15]	untagged	58	4	1.015	1.6
ALEPH [8]	untagged	91.2	22	1.001	31.7
OPAL [11]	untagged	91.2	22	1.020	33.5
SLD [12]	untagged	91.2	29	1.015	31.7
	uds tagged	91.2	29	1.015	62.3
	c tagged	91.2	29	1.015	26.8
	b tagged	91.2	29	1.015	85.2
DELPHI [9, 10]	untagged	91.2	17	0.991	15.9
	uds tagged	91.2	17	0.991	13.2
	b tagged	91.2	17	0.991	48.8
HERMES [16]	SIDIS(p,π^+)	1.10–3.23	9	1.063	10.3
	SIDIS(p,π^-)	1.10–3.23	9	1.063	4.6
	SIDIS(d,π^+)	1.10–3.2	9	1.063	18.6
	SIDIS(d,π^-)	1.10–3.2	9	1.063	22.3
COMPASS [17]	SIDIS(d,π^+)	1.07–5.72	10	1.071	12.8
	SIDIS(d,π^-)	1.07–5.72	10	1.071	5.61
COMPASS [18]	SIDIS(p,π^+)	1.07–7.45	12	1.011	10.5
	SIDIS(p,π^-)	1.07–7.45	12	1.011	7.6
TOTAL			436		611.52
(χ^2/ d.o.f.)					1.47

which controls medium z region. The free parameters N_i, α_i, β_i and γ_i are determined by global fitting χ^2 using the SIA and SIDIS data whence the FFs can be determined in the initial scale. The results for pion and kaon FFs are determined in LO and NLO which we published in Ref. [3]. The individual χ^2 results in the NLO for each collaboration and the total χ^2 fit for π^+ are presented in Table I. The initial scale μ_0 is different for partons. For the light-quarks FFs (u, d, s) and g into $\pi^\pm/K^\pm$-mesons, we choose the starting scale $\mu_0^2 = 1$ GeV^2 and it is taken to be $\mu_0^2 = m_c^2$ and $\mu_0^2 = m_b^2$ for charm and bottom-quarks.

3. QCD analysis of experimental data

In our global fit, we take SIA data from LEP [8–11], SLAC [2, 12, 13], DESY [14], and KEK [1, 15] and SIDIS data from HERMES05 [16] and COMPASS [17, 18]. The experimental data of Belle and BaBar collaborations are available at the scales of $Q = 10.52$ GeV and $Q = 10.54$ GeV, while the scales of the other SIA experimental data are from 29 GeV to 91.2 GeV and most of them are limited at $Q = M_Z$.

The Belle and BaBar collaborations report on the last data containing a pure $e^+e^- \to q\bar{q}$ sample, where $q = u, d, s, c$, since the center-of-mass energies are below the threshold to produce a $b\bar{b}$ pair. These two collaborations reported the differential cross sections at $z > 0.7$, while as other previous results have not covered these regions.

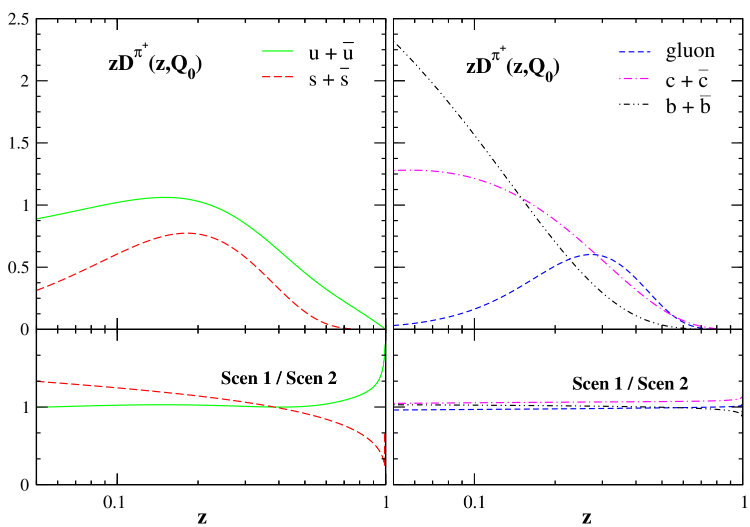

Fig. 1. Upper panels: fragmentation functions for π^+ at $Q_0^2 = 1$ GeV^2, m_c^2 and m_b^2 at NLO. Bottom panels: ratios of our fragmentation functions from scenario 1 to the ones of scenario 2.

We present the NLO FFs of pion and kaon in the initial scale μ_0 in Figs. 1 and 2. The ratio of extracted FFs by including these new data (scenario 1) to ones without including them (scenario 2) are also presented in Figs. 1 and 2 to show how much imposing of these new data modify the pion and kaon FFs in our analysis. According to these figures, adding the Belle and BaBar sample data change the light quark FFs more than the gluon and heavy quark FFs. It could be expected that b quark FFs do not change considerably, which is certified in the figures, because the center-of-mass energies of Belle and BaBar data are below the threshold energy of $b\bar{b}$ pair production.

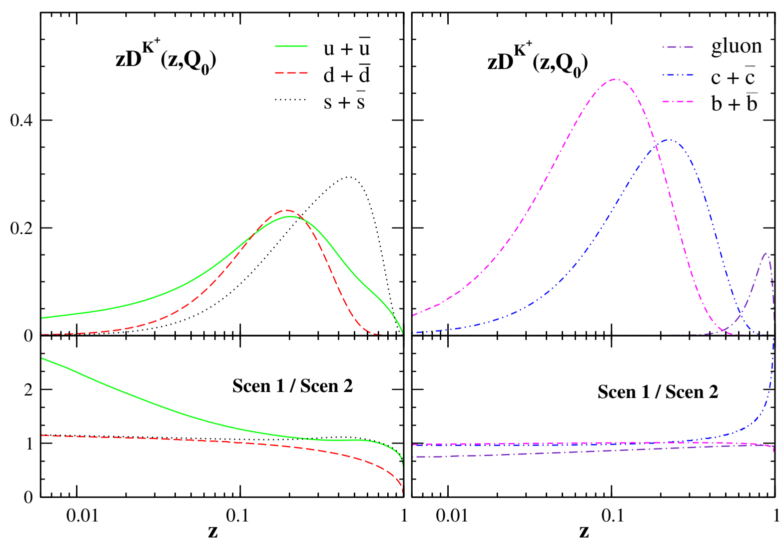

Fig. 2. Upper panels: fragmentation functions for K^+ at $Q_0^2 = 1$ GeV^2, m_c^2 and m_b^2 at NLO. Bottom panels: ratios of our fragmentation functions from scenario 1 to the ones of scenario 2.

4. Conclusions

We have calculated the partonic fragmentation functions of pion and kaon at LO and NLO approximations from global QCD analysis of single-inclusive electron–positron annihilation $e^+e^- \to (\gamma, Z) \to H + X$ and double spin asymmetry from semi-inclusive deep inelastic scattering data, $\vec{l}(l) + \vec{N} \to l'(l') + H + X$. In comparison with other groups, we applied spin asymmetry data ($A_1^{N,H}$) in our analysis of the fragmentation functions so that adding the SIDIS data in a global fit leads us to testing the universality of parton fragmentation functions. On the other hand, recent SIA data from the Belle and BaBar collaborations are also added into our analysis to show how much adding of the recent SIA data improves the results obtained for partonic FFs.

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