Global Analysis of Fragmentation Functions for Eta Mesons

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(Dated: October 27, 2008)

The eta fragmentation functions, previously unavailable in the literature, have been parameterized by fitting experimental data from electron-positron annihilation as well as proton-proton collisions within a next-to-leading-order perturbative QCD framework. Fragmentation functions have been obtained for the $SU(3)$ light flavor singlet, charm, beauty, and the gluon. Uncertainties have been extracted using the Lagrange multiplier and Hessian matrix techniques.

PACS numbers: 13.87.Fh, 13.85.Ni, 12.38.Bx

I. INTRODUCTION

The first parameterization of the eta fragmentation functions (FFs) is presented. The parameterization was found by fitting experimental data from electron-positron annihilation and proton-proton collisions over a wide range of energies. The fits are calculated within a next-to-leading-order perturbative QCD (NLO pQCD) framework, following the technique described in [1, 2]. The availability of eta FFs permits NLO pQCD calculations of eta production to be performed for the first time. Such calculations are currently of particular interest in extracting information on the spin structure of the nucleon from measurements of spin asymmetries in eta production performed at the Relativistic Heavy Ion Collider (RHIC) [3]. The extraction of the eta FFs may also shed light on the apparently universal ratio of eta to neutral pion production across a wide range of collision systems and energies [4].

II. METHOD AND DATA

The method that has been used in this work follows that of [1], which presented FFs for pions and kaons based on fits to $e^+ + e^-$, semi-inclusive deep-inelastic scattering (SIDIS), and $p+p$ data. However, a simpler functional form for the FFs has been used in this analysis due to the smaller quantity of experimental data on eta production. Only the light flavor singlet ($u = d = s$), charm, beauty, and gluon FFs have been extracted because no flavor-tagged $e^+ + e^-$ or SIDIS data exist. The anti-quark FFs are assumed to be equal to their quark counterparts.

The functional form used to parameterize the FFs at an input scale of μ_0 is given by

$$D_i^\eta(z, \mu_0) = N_i z^{\alpha_i}(1-z)^{\beta_i}(1+\gamma_i z), \tag{1}$$

where the index i represents the $SU(3)$ light flavor singlet, charm, beauty, or the gluon, z is the energy fraction of the parton carried by the final-state hadron, and N_i is a normalization factor imposing conservation of momentum such that

$$\sum_H \int_0^1 dz z D_i^H(z, \mu_0) = 1, \tag{2}$$

where H denotes all final-state particles produced in the hadronization process. The initial scale, μ_0, for the DGLAP evolution [5–8] is taken as [1 GeV][double check].

The parameters describing the fragmentation functions $D_i^\eta(z, \mu_0)$ in Eq. (1) are determined by a χ^2 minimization for N experimental data points, where

$$\chi^2 = \sum_{j=1}^{N} \frac{(T_j - E_j)^2}{\delta E_j^2}. \tag{3}$$

E_j represents the experimentally measured value of a given observable, δE_j is its associated uncertainty, and T_j is the theoretical estimate for the given observable with a given set of parameters for the FFs. The experimental uncertainties are taken as the quadratic sum of published statistical and systematic uncertainties.

A total of 16 data sets are included in this analysis. Electron-positron annihilation data are used from ARGUS [9] at $\sqrt{s} = 10$ GeV, HRS [10] and MARK II [11] at $\sqrt{s} = 29$ GeV, JADE [12, 13] and CELLO [14] at $\sqrt{s} = 34 - 35$ GeV, and ALEPH [15–17], L3 [18, 19], and OPAL [20] at $\sqrt{s} = 91.2$ GeV (M_Z). Preliminary points from BABAR at $\sqrt{s} = 10.54$ GeV [21] were also included. The availability of $e^+ + e^-$ data in three approximate energy regions of 10, 30, and 90 GeV helps to constrain the Q^2 evolution of the fragmentation functions. [Does it do so significantly?] Proton-proton collision data are used from PHENIX [4?] at $\sqrt{s} = 200$ GeV. All hadronic collision data are for eta production at midrapidity.

Given that the range of applicability for FFs is limited to medium-to-large values of energy fraction z, as discussed e.g. in [1], data points with $z < 0.1$ are excluded from the fit. In order to avoid mass effects, a requirement of $\beta = p/E > 0.85$ was also imposed. In the case of the hadronic collision data, all points have transverse momentum (p_T) greater than 2 GeV/c.

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TABLE I: Data used in the NLO global analysis of eta fragmentation functions, the individual χ^2 values for each set, the fitted normalizations, and the total χ^2 of the fit.

experiment	rel. norm. in fit	data points fitted	χ^2
ARGUS [9]	1.0	6	
BABAR [21]	1.0	24	
HRS [10]	1.0	13	
MARK II [11]	1.0	7	
JADE '85 [12]	1.0	1	
JADE '90 [13]	1.0	3	
CELLO [14]	1.0	4	
ALEPH '92 [15]	1.0	8	
ALEPH '00 [16]	1.0	18	
ALEPH '02 [17]	1.0	5	
L3 '92 [18]	1.0	3	
L3 '94 [19]	1.0	8	
OPAL [20]	1.0	9	
PHENIX 2γ [4]	1.0	12	
PHENIX 3π [4]	1.0	6	
PHENIX '05 prelim. [**?**]	1.0	19	
TOTAL:			

TABLE II: Parameters describing the NLO fragmentation functions for eta mesons, $D_i^{\eta}(z, \mu_0)$, in Eq. (1) at the input scale $\mu_0 = 1\,\text{GeV}$.

flavor i	N_i	α_i	β_i	γ_i
$u = d = s$				
c				
b				
g				

A. Uncertainties

Calculation of the uncertainties in the fragmentation functions follows the Lagrange multiplier method, as done in [1, 2]. The uncertainties obtained are associated with both the experimental data input to the fit as well as the theoretical or phenomenological assumptions of the fitting procedure.

[Add more on merits/deficiencies of method?]

[From [1]: "For all hadronic data from RHIC, an additional 5error is assigned in quadrature to δE_i in evaluations of χ^2 in Eq. (21) as a rather conservative estimate of the theoretical uncertainties related to the choice of the factorization and renormalization scales in (14)." Should we increase uncertainty on hadronic data at RHIC in a similar fashion?]

III. RESULTS

The parameters from Eq. (1) obtained for the flavor singlet, charm, beauty, and gluon are given in Table II, and their success in simultaneously describing the various data sets fitted can be seen in Figures 1-3. [One for lower-energy e+e-, one for LEP, one for hadronic data.]

[Discuss agreement or lack thereof with various data sets]

[We note that the main constraint on the gluon-to-eta FF comes from the hadronic collision data.] [Comment on getting gluons from Q^2 lever arm, with relevant scale ranging from low-pT hadronic data to Z mass?]

[Also compare to AFS proton-proton data at lower energy, not included in fit.]

A. Comparison to neutral pion FFs

It has been noted [4] that the ratio of eta to neutral pion production over a wide range of energies and collision systems for transverse momenta $p_T \gtrsim 2$ GeV/c in hadronic collisions and scaled momentum $x_p = 2p_{had}/\sqrt{s}$ in $e^+ + e^-$ annihilation appears to be universal and constant as a function of p_T (x_p), with a value of approximately 0.5. [As expected for extraction of FFs for the eta and neutral pion based on subsets of the available world experimental data, the ratio of the eta FFs obtained in the present work compared to those of neutral pions given in [1] is consistent with this ratio of 0.5, giving values of [] for the light flavor singlet contribution and [] for the gluon. [Compare to other pi0 FFs in addition to DSS?]]

[Comment on possible differences in the ratio between the singlet and the gluon? Is a change in ratio predicted at very high Q2?? If so, would be an interesting prediction, if e.g. within reach of LHC.]

[Speculate on possible flavor-specific differences, e.g. strange? But need to be careful with initial assumptions on flavor that go into pi0 fits.]

IV. CONCLUSIONS

A first parameterization of the fragmentation functions for eta meson production has been presented. A NLO pQCD framework has been utilized to simultaneously fit world data from electron-positron annihilation and proton-proton collisions over center-of-mass energies ranging from 10 to 200 GeV, yielding fragmentation functions for the $SU(3)$ light flavor singlet, charm, beauty, and the gluon. [Comment on uncertainties] [Comment on relationship to neutral pions.]

The availability of FFs for the eta meson obtained at NLO makes NLO pQCD calculations of eta production possible for the first time[, with potential applications for][Different physics, e.g. nucleon spin structure and

FIG. 1: Comparison of results for the electron-positron annihilation cross section into eta mesons with selected data sets used in the fit. See also Tab. I.

FIG. 2: Comparison of results for the electron-positron annihilation cross section into eta mesons with data sets from the LEP experiments. See also Tab. I.

medium effects in heavy ion collisions, but what about physics in $e^+ + e^-$?].

Acknowledgments

The research of CAA is supported by the U.S. Department of Energy (grant DE-FG02-88ER40415A022); [JPS; MS]. [Others to acknowledge? Werner? Frank? Guy from BABAR who gave us the data points? (First name David, ask Frank for last name if want to include him.)]

[1] D. de Florian, R. Sassot, and M. Stratmann, Phys. Rev. **D75**, 114010 (2007), hep-ph/0703242.
[2] D. de Florian, R. Sassot, and M. Stratmann, Phys. Rev. **D76**, 074033 (2007), 0707.1506.
[3] F. Ellinghaus and J. Seele (PHENIX), RIKEN Accel. Prog. Rep. **39** (2006).
[4] S. S. Adler et al. (PHENIX), Phys. Rev. **C75**, 024909 (2007), nucl-ex/0611006.
[5] V. N. Gribov and L. N. Lipatov, Yad. Fiz. **15**, 781 (1972).
[6] L. N. Lipatov, Sov. J. Nucl. Phys. **20**, 94 (1975).
[7] Y. L. Dokshitzer, Sov. Phys. JETP **46**, 641 (1977).
[8] G. Altarelli and G. Parisi, Nucl. Phys. **B126**, 298 (1977).
[9] H. Albrecht et al. (ARGUS), Z. Phys. **C46**, 15 (1990).
[10] S. Abachi et al. (HRS), Phys. Lett. **B205**, 111 (1988).
[11] G. Wormser et al., Phys. Rev. Lett. **61**, 1057 (1988).
[12] W. Bartel et al. (JADE), Z. Phys. **C28**, 343 (1985).
[13] D. Pitzl et al. (JADE), Z. Phys. **C46**, 1 (1990).
[14] H. J. Behrend et al. (CELLO), Z. Phys. **C47**, 1 (1990).
[15] D. Buskulic et al. (ALEPH), Phys. Lett. **B292**, 210 (1992).
[16] R. Barate et al. (ALEPH), Eur. Phys. J. **C16**, 613 (2000).
[17] A. Heister et al. (ALEPH), Phys. Lett. **B528**, 19 (2002), hep-ex/0201012.
[18] O. Adriani et al. (L3), Phys. Lett. **B286**, 403 (1992).
[19] M. Acciarri et al. (L3), Phys. Lett. **B328**, 223 (1994).
[20] K. Ackerstaff et al. (OPAL), Eur. Phys. J. **C5**, 411 (1998), hep-ex/9805011.
[21] F. Anulli (2004), hep-ex/0406017.

FIG. 3: Comparison of results for the cross section for eta production in proton-proton and proton-antiproton collisions. See also Tab. I.