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# AKK update: Improvements from new theoretical input and experimental data

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**Abstract**

We perform a number of improvements to the previous AKK extraction of fragmentation functions for $\pi^{\pm}$, $K^{\pm}$, $p/\bar{p}$, $K_S^0$ and $\Lambda/\bar{\Lambda}$ particles at next-to-leading order. Inclusive hadron production measurements from $pp(\bar{p})$ reactions at BRAHMS, CDF, PHENIX and STAR are added to the data sample. We use the charge-sign asymmetry of the produced hadrons in $pp$ reactions to constrain the valence quark fragmentations. Data from $e^+e^-$ reactions in regions of smaller $x$ and lower $\sqrt{s}$ are added. Hadron mass effects are treated for all observables and, for each particle, the hadron mass used for the description of the $e^+e^-$ reaction is fitted. The baryons' fitted masses are found to be only around 1% above their true masses, while the values of the mesons' fitted masses have the correct order of magnitude. Large $x$ resummation is applied in the coefficient functions of the $e^+e^-$ reactions, and also in the evolution of the fragmentation functions, which in most cases results in a significant reduction of the minimized $\chi^2$. To further exploit the data, all published normalization errors are incorporated via a correlation matrix.


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## 1. Introduction

In perturbative QCD, fragmentation functions (FFs) $D_i^h(x, M_f^2)$, which can be interpreted as the probability for a parton $i$ at the factorization scale $M_f$ to fragment to a hadron $h$ carrying away a fraction $x$ of its momentum, are a necessary ingredient in the calculation of single hadron inclusive production in any reaction. Interest in FFs is widespread, to be found for example in

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the study of the proposed hot quark gluon plasma (QGP) of the early universe currently being sought in heavy ion collisions, in investigating the origin of proton spin, and in tests of QCD such as theoretical calculations for recent measurements of inclusive production in $pp$ collisions at RHIC.

From the factorization theorem, the leading twist component of any single hadron inclusive production measurement can be expressed as the convolution of FFs, being the universal soft parts containing the final state, with the equivalent productions of real partons, which are perturbatively calculable, up to possible parton distribution functions (PDFs) to account for any hadrons in the initial state. Thus, by using these data to constrain the FFs, predictions for future measurements can be made from current data. An exception to this possibility occurs when some new measurement depends on any regions of the FFs' function space that has not yet been constrained by experiment. For this reason, a failure to describe some data does not imply irrefutably that there are relevant physics effects which have been neglected in calculations. In particular, the apparent inconsistencies within this framework of universality occurring between charge-sign unidentified hadron production in $e^+e^-$, the contribution from gluon fragmentation is much less than from quark fragmentation, and in $pp(\bar{p})$ reactions may be attributed to the large experimental uncertainties on the gluon fragmentation determined from $e^+e^-$ reaction data only, rather than to neglected effects in the description of both reactions such as higher twist, heavy quark masses, resummation at large and small $x$, and higher order terms in the perturbative approximation, or to the less well understood hot QGP invoking parton energy loss. A combined fit of FFs to data from $e^+e^-$ and $pp(\bar{p})$ reactions would prove the optimum method of verifying consistency between the two types of reactions, since a successful fit to both types of data would imply that these apparent inconsistencies in fact lie within the experimental and theoretical uncertainties and so are not inconsistencies at all. Success is expected for identified particles in general, since good agreement is found [1] for the theoretical calculation for $pp \to \pi + X$ data, where $\pi = \pi^0$ [2] and $\pi^\pm$ [3], using FFs for $\pi^\pm$ constrained by data for $e^+e^- \to \pi^\pm + X$ processes, and data for the production of $\pi^\pm$ is generally more accurate and plentiful than for the production of other particles due to the high abundance of $\pi^\pm$ in the particle sample. In other words, the current theoretical state of the art is adequate in the kinematic regions studied. The strongest caveat to this argument is the possible importance of hadron mass effects, which are not so important for $\pi^\pm$, being the lightest hadrons, but which may be relevant for other particles. Therefore, for the other particles it may be necessary to account for hadron mass effects in the theory. Furthermore, in this connection, it may also be necessary to account for contamination of the sample from decays of unstable particles.

It is important to note in the discussion above that, due to insufficient information on the systematic effects, even a failure to fit certain data points in such a *global* fit does not necessarily suggest other physics effects, unless the theory cannot describe data from different experiments which are consistent with one another.

Since our previous fits [1,4], a number of measurements have been published by collaborations at RHIC and by the CDF Collaboration at the Tevatron, which allow for a number of extensions in the knowledge of fragmentation: Because the gluon FF only appears at next-to-leading order (NLO) in the $e^+e^- \to h^\pm + X$ cross section but at leading order (LO) in the $pp(\bar{p}) \to h^\pm + X$ cross section, inclusion of these data in the purely $e^+e^-$ sample would significantly improve the constraints on gluon fragmentation, and may therefore give an FF set suitable for predictions of future measurements at e.g. the LHC and RHIC. Furthermore, these *charge-sign unidentified* measurements provide much needed constraints on the separation between the light quark flavour FFs due to the differences between the light quark flavour PDFs. Previously, the only