Neural Network QCD analysis of charged hadron Fragmentation Functions in the presence of SIDIS data

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Abstract

In this paper, we present a QCD analysis to extract the Fragmentation Functions (FFs) of unidentified light charged hadron entitled as `SHK22.h` from high-energy lepton-lepton annihilation and lepton-hadron scattering data sets. This analysis includes the data from all available single inclusive electron-positron annihilation (SIA) processes and semi-inclusive deep-inelastic scattering (SIDIS) measurements for the unidentified light charged hadron productions. The SIDIS data which has been measured by the COMPASS experiment could allow the flavor dependence of the FFs to be well constrained. We exploit the analytic derivative of the Neural Network (NN) for fitting of FFs at next-to-leading-order (NLO) accuracy in the perturbative QCD (pQCD). The Monte Carlo method is implied for all sources of experimental uncertainties and the Parton distribution functions (PDFs) as well. Very good agreements are achieved between the `SHK22.h` FFs set and the most recent QCD fits available in literature, namely `JAM20` and `NNFF1.1h`. In addition, we discuss the impact arising from the inclusion of SIDIS data on the extracted light-charged hadron FFs. The global QCD resulting at NLO for charged hadron FFs provides valuable insights for applications in present and future high-energy measurement of charged hadron final state processes.

Framework

1: Cross-section for SIA and SIDIS:

$$\frac{1}{\sigma_{\rm tot}}\frac{d\sigma^h}{dz} = \frac{1}{\sigma_{\rm tot}}\left[F_T^h(z,Q^2) + F_L^h(z,Q^2)\right],$$

$$\frac{d\sigma^h}{dx\,dy\,dz_h} = \frac{2\pi\alpha^2}{Q^2}\left[\frac{(1+(1-y)^2)}{y}2\,F_1^h(x,z_h,Q^2) + \frac{2(1-y)}{y}F_L^h(x,z_h,Q^2)\right].$$

2: Definition of χ^2:

$$\chi^{2(k)} \equiv \left(\boldsymbol{T}(\boldsymbol{\theta}^k) - \boldsymbol{x}^k\right)^{\rm T}\boldsymbol{C}^{-1}\left(\boldsymbol{T}(\boldsymbol{\theta}^k) - \boldsymbol{x}^k\right).$$

3: Parametrization Form in terms of NN:

$$zD_i^{h^+}(z,Q_0) = (N_i(z,\theta) - N_i(1,\theta))^2\,.$$

Neural network and flavor decomposition and uncertainty

5: Flavor decomposition:

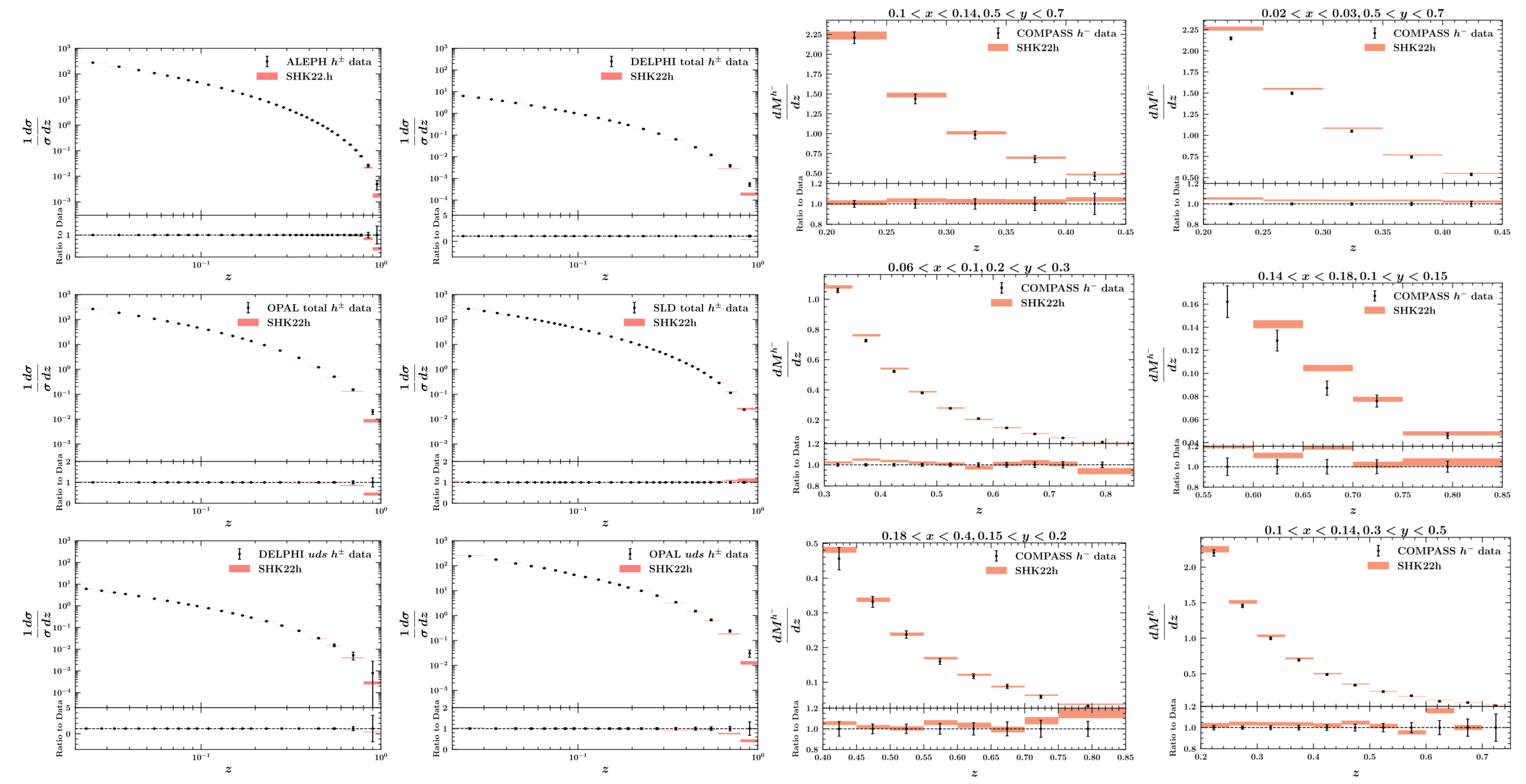
$$D_u^{h^+},\ D_{\bar{u}}^{h^+},\ D_{d+s}^{h^+},\ D_{\bar{d}+\bar{s}}^{h^+},\ D_{c^+}^{h^+},\ D_{b^+}^{h^+},\ D_g^{h^+}\,.$$

6: The Monte Carlo uncertainty estimation:
This method estimates the parameters posterior probability distribution by performing a number of fits on a set of psudo-data. The fit results then *learn* the probability distribution of the experimental results.

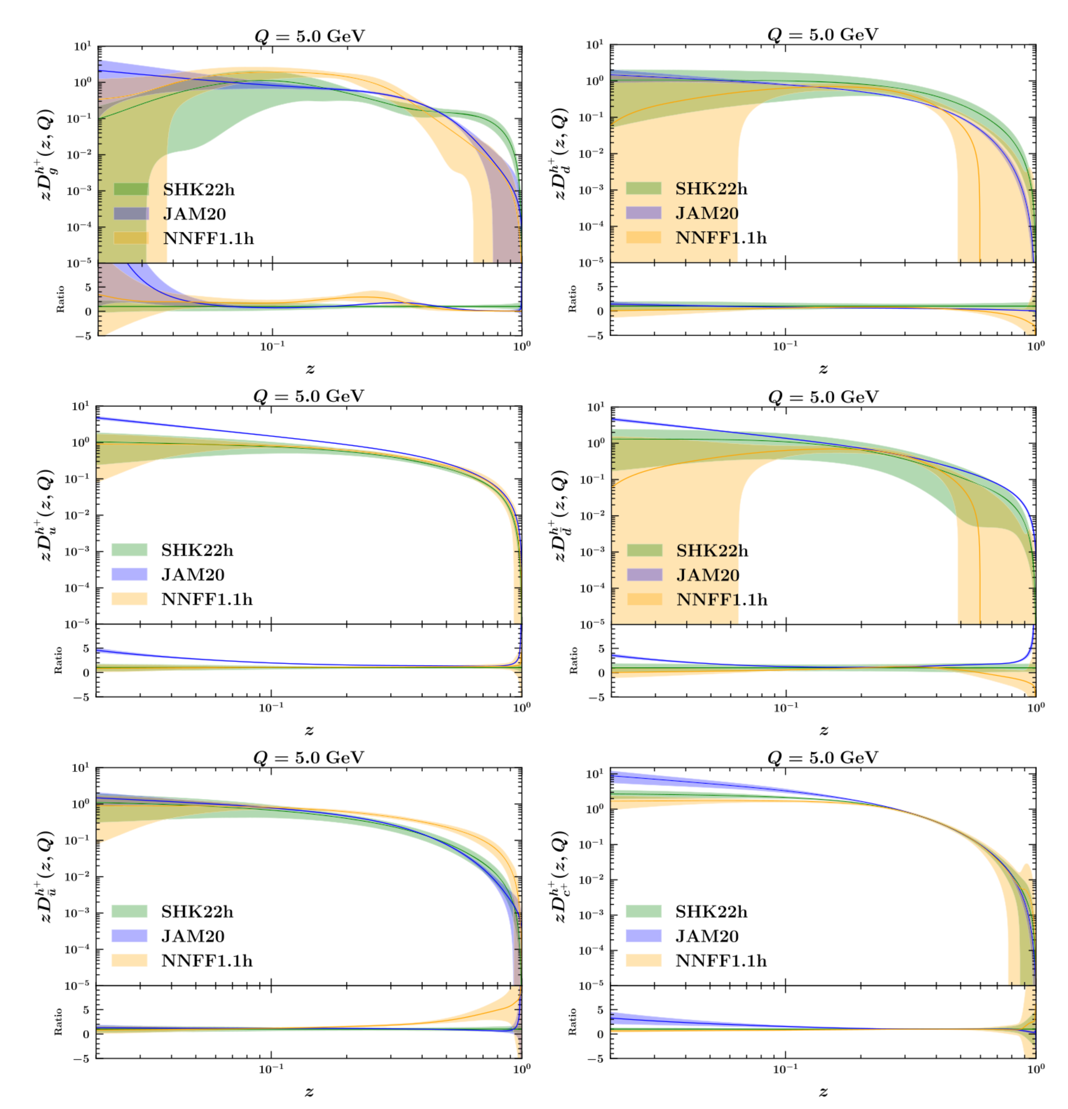
Reference

Phys. Rev. D **105**, 114018 ,(2022).

Fit Quality



Comparison of FFs

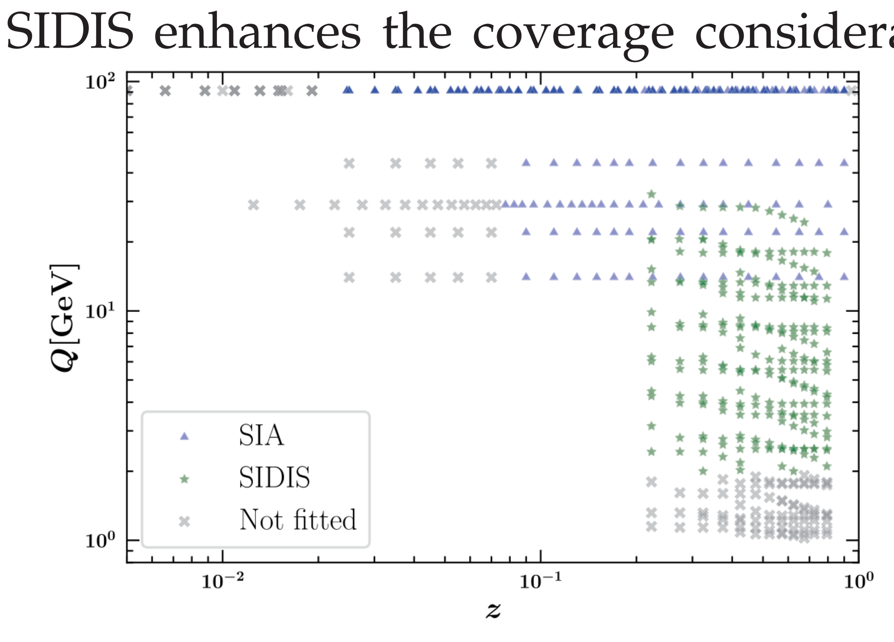


Framework

All datasets with the exception of `TASSO 35 GeV` were used in the **SHK22.h** QCD analysis.

Experiment	$\chi^2/N_{\rm dat}$	$N_{\rm dat}$
TASSO 14 GeV $h^\pm$	1.791	14
TASSO 22 GeV $h^\pm$	1.254	14
TASSO 44 GeV $h^\pm$	2.912	14
TPC $h^\pm$	0.659	21
ALEPH $h^\pm$	0.825	32
DELPHI total $h^\pm$	0.610	21
DELPHI *uds* $h^\pm$	0.380	21
DELPHI bottom $h^\pm$	1.028	21
OPAL total $h^\pm$	1.821	19
OPAL *uds* $h^\pm$	0.794	19
OPAL charm $h^\pm$	0.599	19
OPAL bottom $h^\pm$	0.299	19
SLD total $h^\pm$	1.047	34
SLD *uds* $h^\pm$	0.946	34
SLD charm $h^\pm$	1.034	34
SLD bottom $h^\pm$	1.102	34
COMPASS h^-	0.907	157
COMPASS h^+	1.338	157
Global dataset	**1.079**	**684**

Some data points that needed corrections were removed by the kinematical cuts. The data from SIDIS enhances the coverage considerably.



Discuss and Conclusion

In summary, we have presented a new global QCD analysis of light-charged hadron FFs, `SHK22.h`, by introducing several new features and some methodological improvements. On the methodological front, we have used the Machine Learning framework to extract the `SHK22.h` FFs sets, along with the Monte Carlo uncertainty analysis. This well-established fitting methodology is specifically designed to provide a faithful representation of the experimental uncertainties. This methodology is also useful to minimize any bias related to the parametrization of the light-charged hadron FFs and to the minimization procedure as well.

In terms of the input data sets, in addition to the comprehensive set of high-energy lepton-lepton annihilation (SIA), we have added the lepton-hadron scattering (SIDIS) data sets to our data sample. We have shown that SIDIS data sets have significant effect on the FFs, and more specifically on the gluon FFs and the reduction of its uncertainty. The tension among some of the data sets included in our analysis also studied and discussed in details.

The detailed comparisons to the existing light-charged hadron FFs sets (`NNFF1.1h` and `JAM20`) fully demonstrate a reasonable agreement within the FFs error bands. Although, some discrepancies in flavor dependence were observed, more specifically for the gluon and down-quark FFs. The resulting NLO theory predictions for the SIA and SIDIS cross-sections show very good agreement with the corresponding analyzed experimental data sets, as confirmed by the reported total χ^2 per data point.

Based on our findings in this study, one can conclude that adding the SIDIS data in the light-charged hadron study could lead to a much better level of precision of the extracted FFs.

The parametrizations of the `SHK22.h` light-charged hadron FFs presented in this paper are available in the standard `LHAPDF` format, and can be obtained from the authors upon request.