

## Comment on “New Limits on Intrinsic Charm in the Nucleon from Global Analysis of Parton Distributions”

Intrinsic heavy quarks in hadrons emerge from the nonperturbative structure of a hadron bound state [1] and are a rigorous prediction of QCD [2,3]. Lattice QCD calculations indicate significant intrinsic charm and strangeness probabilities [4,5]. Since the intrinsic heavy quarks carry significant fractions of the hadron’s momentum, they lead to a large array of novel physics phenomena [6–8]. Accurate determinations of the heavy-quark distributions in the proton are needed to interpret Tevatron and LHC measurements as probes of physics beyond the Standard Model [9,10]. Determinations [9,11,12] of the momentum fraction carried by intrinsic charm quarks in the proton typically limit  $\langle x \rangle_{\text{IC}} \sim \mathcal{O}(1\%)$  at 90% C.L., consistent with the EMC analysis of their charm structure function data [13] and the large rate for high- $p_T$   $\bar{p}p \rightarrow c\gamma X$  reactions at the Tevatron [14]; however, a precise determination has proven elusive.

The recent Letter by Jimenez-Delgado *et al.* (JDHLM) [15] reports  $\langle x \rangle_{\text{IC}} = (0.15 \pm 0.09)\%$ . The authors include low-energy data from the  $ed(p) \rightarrow e'X$  SLAC experiment [16] in their global fit and find strong constraints on intrinsic charm, although only 157 of 1021 data points have  $W^2$  in excess of the charm hadronic threshold:  $W_{\text{th}}^2 \approx 16 \text{ GeV}^2$ . The SLAC measurements of  $ed(p) \rightarrow e'X$  have an overall normalization (systematic) error of  $\pm 1.7(2.1)\%$  and a relative normalization error of typically  $\pm 1.1\%$  [16].

It is challenging to identify the contribution from charm quarks to the inclusive structure function if only the scattered electron is detected. In addition to the valence and sea-quark distributions, there are other contributions which need to be determined to high accuracy in order to discern the intrinsic charm component at the level claimed by JDHLM; this includes higher-twist corrections at high  $x$  and the strange and bottom quark contributions, as well as the accurate implementation of the suppression of charm production at threshold and nuclear target effects. Their analysis depends on uncertain parameters and theory assumptions. For example, JDHLM model higher-twist effects as an isospin-independent, phenomenological multiplicative factor on top of a leading-twist structure function with target-mass corrections [17]. Their higher-twist model does not include enhancements at  $x \sim 1$  from hard subprocesses where multiple quarks interact [18,19]. Such processes depend strongly on the diquark charges, making them quark flavor (isospin) sensitive, and they contribute in the same large  $x$  domain as the charm signal. In addition, the target-mass-corrected structure functions used by JDHLM remain nonzero as  $x \rightarrow 1$  [17], which is problematic, and they neglect other intrinsic quark contributions [7,20].

JDHLM assess their parton distribution function (PDF) errors using a tolerance criteria of  $\Delta\chi^2 = 1$  at  $1\sigma$ ; however, the actual value of  $\Delta\chi^2$  depends on the number of parameters to be simultaneously determined in the fit—their

assessment of a single parameter error requires that the other parameters be fixed at their values at the global  $\chi^2$  minimum [21]. JDHLM report  $\langle x \rangle_{\text{IC}} = (0.15 \pm 0.09)\%$  [15] corresponding to  $\Delta\chi^2 = 1$  at  $1\sigma$  (68% C.L.) and also  $\langle x \rangle_{\text{IC}} \lesssim 0.5\%$  at  $4\sigma$ . In order to set a  $4\sigma$  limit, all of the other parameters must be varied so as to yield a minimum  $\chi^2$  as the parameter of interest is changed [22–25]. We note that Refs. [26,27], e.g., contain 25 PDF parameters in leading twist, and Ref. [27] contains 12 more higher twist parameters. Since one would expect nontrivial correlations and near degeneracies in a many-parameter fit, the apparent agreement of the  $4 \times 1\sigma$  assessment with the  $4\sigma$  limit suggests that the other parameters were not properly varied as  $\langle x \rangle_{\text{IC}}$  was changed, making the reported limit too severe.

It is clear that the SLAC single-arm measurements cannot unambiguously identify an intrinsic charm contribution to the nucleon structure function even at the 1% level because of statistical and systematic uncertainties, both experimental and theoretical. JDHLM have excluded the EMC measurements of the charm structure function [13], citing a “goodness of fit” criterion. However, statistical criteria alone cannot exclude data sets. The fit to the EMC iron target data would be improved by including the QCD nuclear effects described in Refs. [28,29].

In summary, JDHLM claim that the momentum fraction carried by intrinsic charm quarks in the proton is  $\langle x \rangle_{\text{IC}} = (0.15 \pm 0.09)\%$ ; we do not find this conclusion warranted.

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