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Reply to Comment on "New limits on intrinsic charm in the nucleon from global analysis of parton distributions"

P. Jimenez-Delgado[1], T. J. Hobbs[2], J. T. Londergan[3], W. Melnitchouk[1]
[1] *Jefferson Lab, 12000 Jefferson Avenue, Newport News, Virginia 23606, USA*
[2] *Department of Physics, University of Washington, Seattle, Washington 98195, USA*
[2] *Department of Physics and Center for Exploration of Energy and Matter, Indiana University, Bloomington, Indiana 47405, USA*
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We reply to the Comment of Brodsky and Gardner, pointing out a number of incorrect claims about our fitting methodology, and elaborate how global QCD analysis of all available high-energy data provides no evidence for large intrinsic charm in the nucleon.

Our recent global PDF analysis [1] of all available high-energy data strongly disfavored models with large intrinsic charm (IC) in the nucleon, finding the momentum fraction carried by charm quarks $\langle x \rangle_{\rm IC}$ to be at most 0.5% at the 4σ CL. Brodsky and Gardner (BG) claim [2] that because our analysis uses $\mathcal{O}(30)$ parameters, as is typical in such fits, one must adopt a much larger tolerance criterion than the $\Delta\chi^2 = 1$ used. In fact, it is well known that for Gaussian distributions parameter errors in χ^2 fits are determined by $\Delta\chi^2 = 1$, irrespective of the number of parameters [3, 4]. The parameter m in Table 38.2 of Ref. [3], for example, is the dimensionality of the error regions for joint distributions, and has nothing to do with the total number of parameters in the fit.

The parameter errors and χ^2 profiles related to one-dimensional probablility distributions are correctly evaluated using $m = 1$, which gives $\Delta\chi^2 = 1$ at the 68% CL. Errors on other quantities are then computed using standard error propagation techniques, and can be used to produce error regions of different dimensionalities with the appropriate $\Delta\chi^2$ criteria [3, 4]. Apparently, BG have confused the dimensionality of error regions with the number of independent parameters in a fit: their claims about $\Delta\chi^2$ are simply wrong.

Tolerance criteria $\Delta\chi^2 > 1$ are used by some PDF groups [5–7] to account for tensions among different data sets, while other groups [8, 9] use the standard $\Delta\chi^2 = 1$. The χ^2 profiles in [1] were presented as a function of $\langle x \rangle_{\rm IC}$, so that values of $\langle x \rangle_{\rm IC}$ for different tolerance choices can be easily compared. BG also suggest that our single parameter errors were obtained by fixing the other parameters at the χ^2 minimum. This is not true: the χ^2 was minimized with respect to all other parameters in the fit, as is standard procedure in global fits.

Inclusive DIS cross sections, such as those measured at SLAC [10], receive contributions from all quark flavors, and cannot by themselves provide significant constraints on charm. The power of global fits, however, lies in the correlations between different observables within the framework of perturbative QCD. While the bulk of the data from SLAC at large x lie below the charm threshold, cross sections below threshold constrain light quark distributions, indirectly impacting the determination of IC. Our analysis also accounts for the suppression of charm production below and near the hadronic charm threshold [1, 2]. In addition to the SLAC data, we also find that the NMC [11] and HERA [12] inclusive cross sections disfavor nonzero values of IC.

Recently some PDF analyses [6, 8, 9] have relaxed the conventionally more restrictive W^2 and Q^2 cuts to better constrain large-x PDFs. Such analyses benefit from increased statistics at large x, but require careful treatment of $1/Q^2$ and nuclear corrections. Our analysis employs the standard treatment of target mass corrections (TMCs) [13], higher twists [8], and nuclear effects [6]. BG incorrectly assert that we model higher twists as isospin independent, and that our TMCs are problematic at $x \to 1$. In fact, our higher twists do depend on isospin (see Table III of Ref. [8]), while the threshold problem of TMCs at $x = 1$ is relevant only at very low W^2 [13], well below the cuts made in PDF analyses. It is also not true that we neglect intrinsic strangeness and bottom: the s and $\bar{s}$ PDFs are parametrized model-independently at the input scale, and, given our results for IC, intrinsic bottom is negligible [14].

Our analysis [1] also considered a fit including data from the EMC measurement of F_2^c [15] – sometimes cited as evidence for large IC. The EMC data have strong tension with other measurements, and give a very large overall $\chi^2_{\rm dof} \gtrsim 4$, with a Q^2 dependence incompatible with perturbative QCD. Several EMC points at $x \gtrsim 0.2$ lie above all global fits, including ones with IC [1], while at $x \lesssim 0.02$, where charm distributions are strongly constrained by HERA data [16], the EMC data significantly underestimate global fits. No reasonable amount of nuclear corrections or $\Delta\chi^2$ tolerance can reconcile the EMC data with the rest of the global data set, without invoking a very peculiar shape for IC that is strongly at variance with all models considered [1, 17]. Consequently, no modern QCD analyses [5–9, 18] include the EMC charm data. MSTW [5] compared their PDFs with the EMC measurements, and concluded that "If the EMC data are to be believed, there is no room for a very sizable intrinsic charm contribution." We agree with this conclusion.

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