Intrinsic Charm in the Proton

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Introduction

Do heavy quarks contribute to the proton PDFs at low scales?

We look a the charm PDF in `NNPDF4.0` [1]:

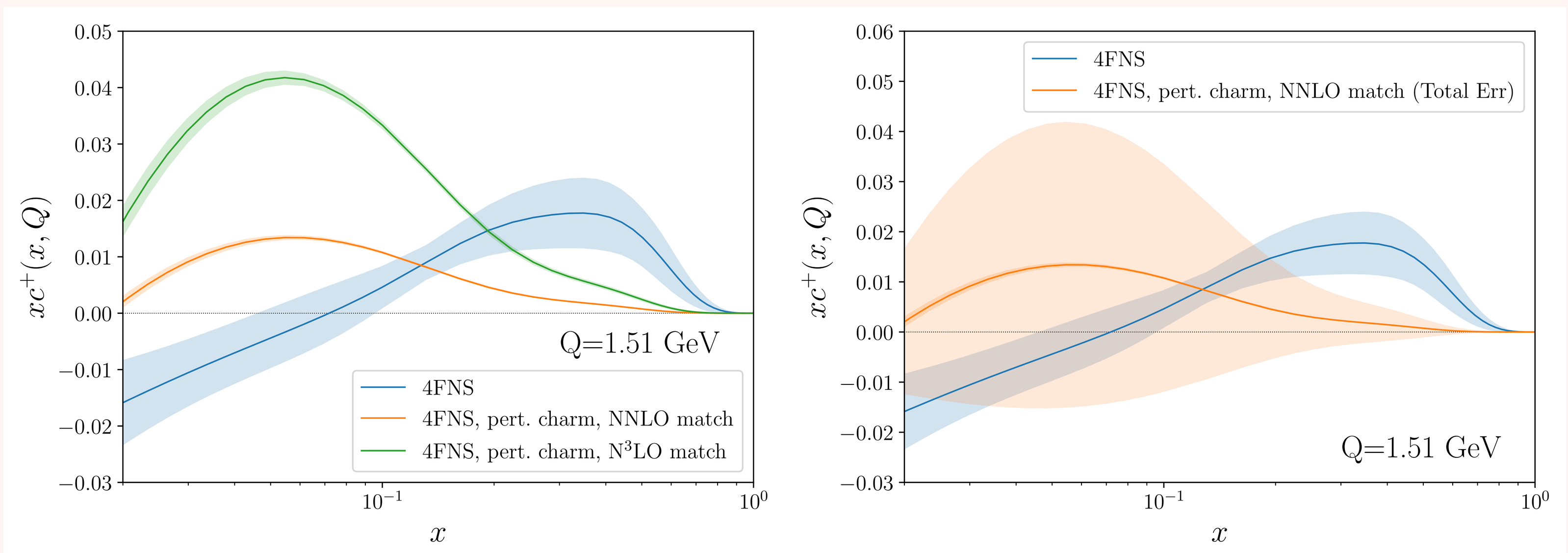
- The charm PDF is parametrized as an independent combination at scale $Q = 1.65\ GeV$, and $n_f = 4$ (4FNS):

$$xc^+(x, Q_0, \Theta) = \frac{1}{4}\left(x^{\alpha_\Sigma}(1-x)^{\beta_\Sigma} NN_\Sigma(x,\Theta) - x^{\alpha_{T_{15}}}(1-x)^{\beta_{T_{15}}} NN_{T_{15}}(x,\Theta)\right) \quad (1)$$

- We always assume: $c(x, Q) = \bar{c}(x, Q) \to c^- = 0$.
- At the fitting scale, we observe that constrain are coming mainly from collider data. `NNPDF4.0` is consistent with EMC data.

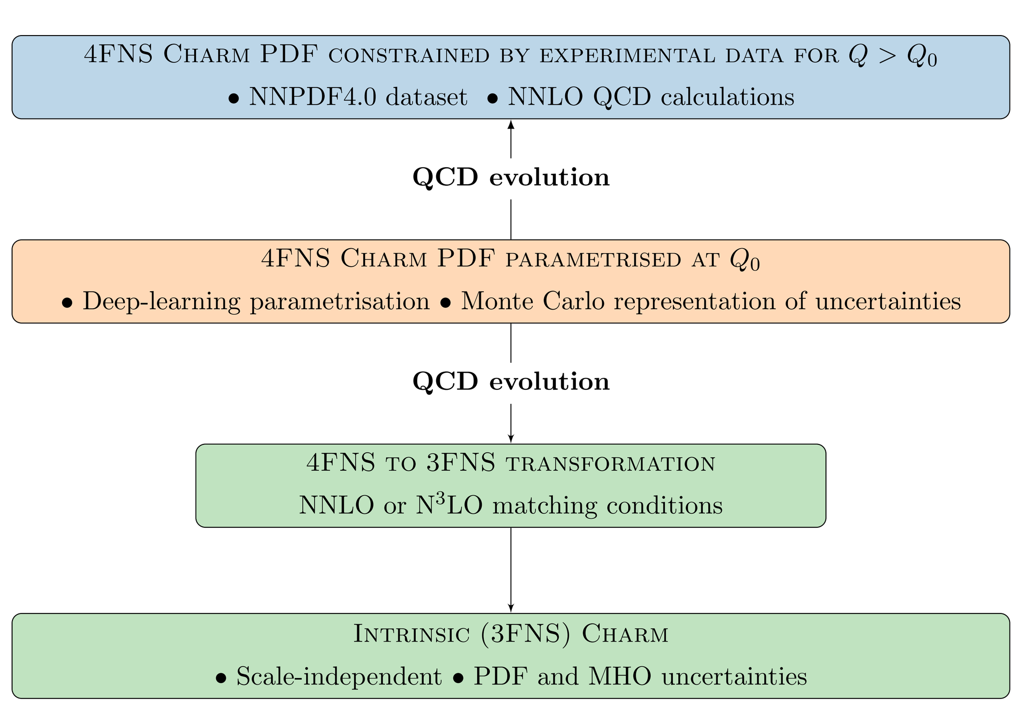
Fitted or Pertubative?

- **Perturbative charm (PC)** functional form is fully determined by the DGLAP evolution and the initial boundary conditions on gluons and light quarks.



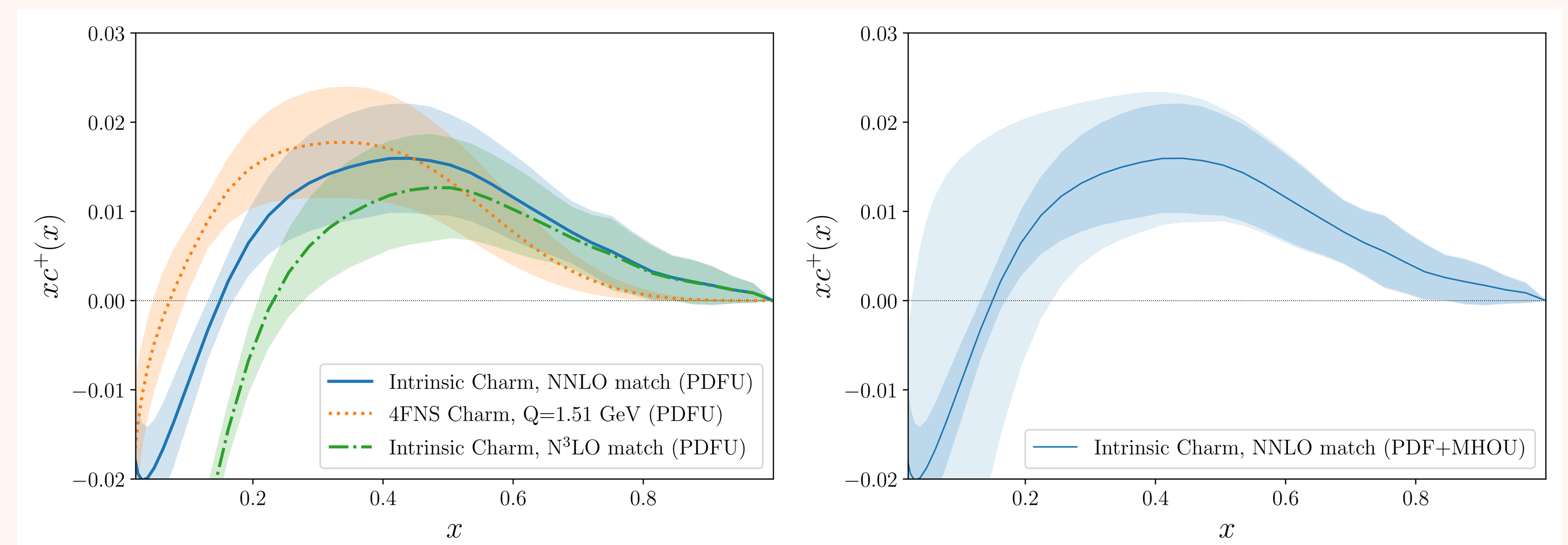
- PDF uncertainties are clearly not the dominant source of uncertainties. Needs to **estimate MHOU**. PC is also highly correlated to the mass value.
- Fitted charm is favored by data: $\chi^2_{fitted\ ch} = 1.17, \chi^2_{pert\ ch} = 1.19$ mainly due to a worsening of the LHC W, Z and top pair data sets.
- Fully perturbative charm is not compatible with the fitted one especially at large x, even is MHOU (N^{3}LO - NNLO) are considered.

From 4FNS to 3FNS



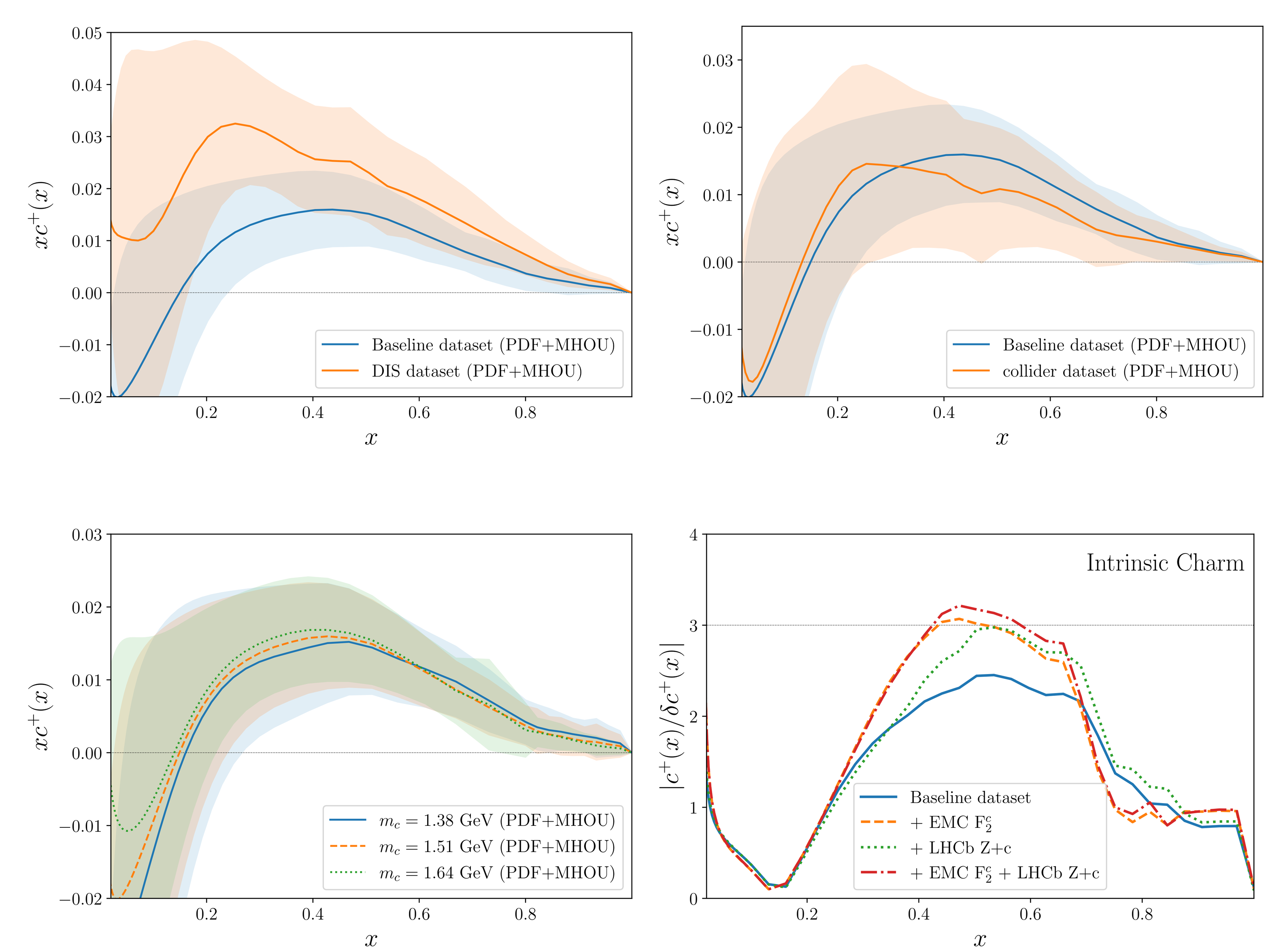
The Intrinsic Charm

- Below the charm mass scale the perturbative charm is vanishing by definition.
- Fitted charm in 4FNS contains both the intrinsic and the perturbative components.
- To obtain the **Intrinsic charm (IC)** we start from the fitting scale we evolve the `NNPDF4.0` baseline to $Q = m_c = 1.51\ GeV$. When passing the heavy quark threshold we need invert the matching conditions.
- The remaining part of the charm PDF is the intrinsic component, which is **scale independent**



IC stability

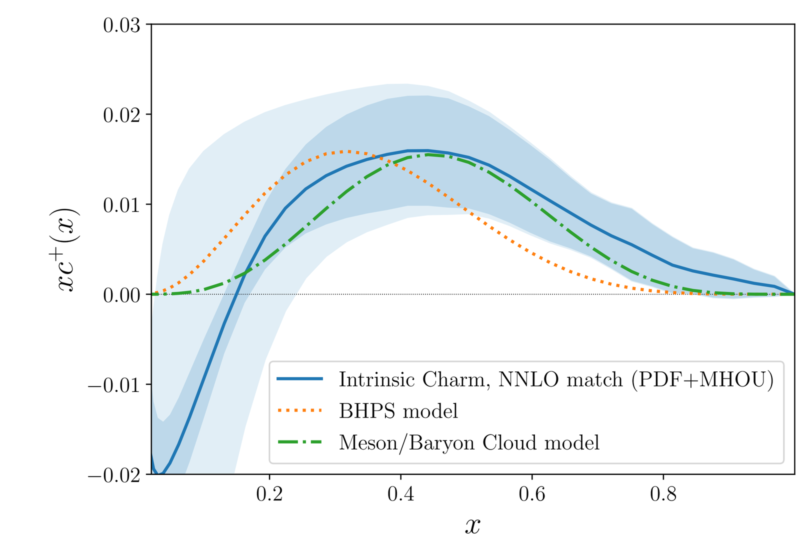
- IC valence-like peak at large-x is a stable feature.
- IC vanishes for $x \to 0$. In this region the effect of MHOU is large.
- IC is stable upon mass variation in the range $m_c = 1.51 \pm 0.13\ GeV$.
- The momentum faction carried by the IC component is: $0.62 \pm (0.28_{pdf} \pm 0.54_{mhou})\%$
- In our best estimation (`NNPDF4.0+EMC+LHCb Zc`) we reach a 3σ **local evidence**.



Comparison with models

The determination of the IC can be compared to some non perturbative models:

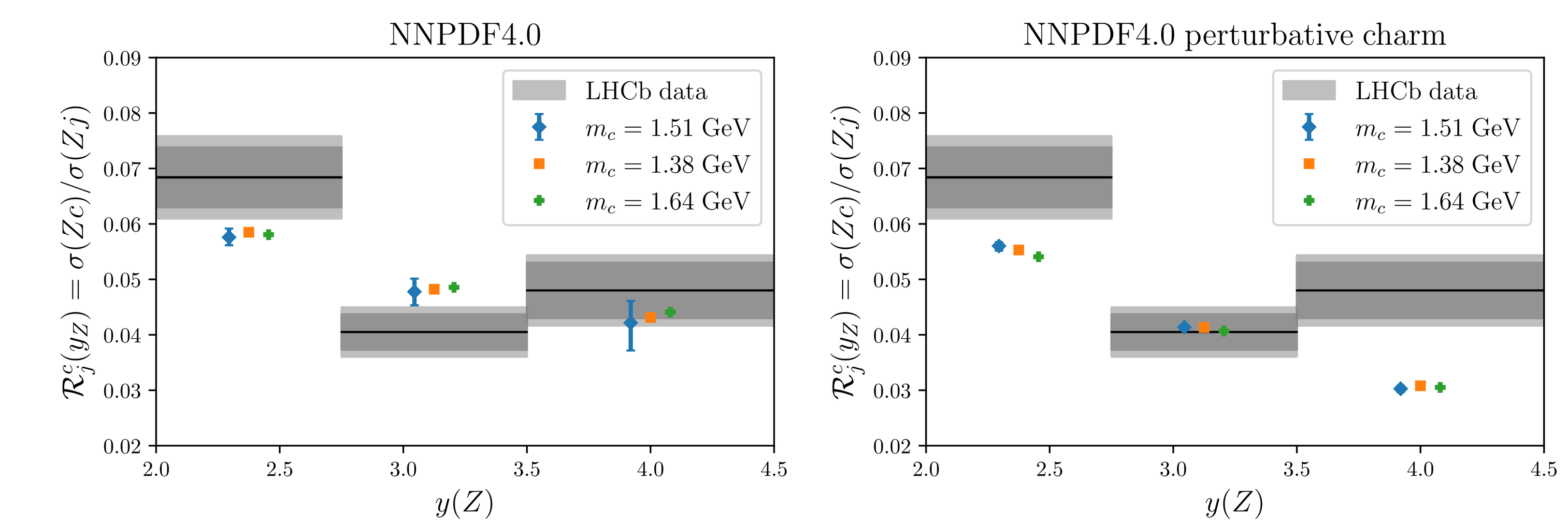
- **BHPS** [2]: the proton fluctuate with to a pentaquark state $p \to uudc\bar{c}$. It assumes $c = \bar{c}$.
- **Meson Baryon** model [3]: fluctuations to a charmed baryon plus meson state (ex: $p \to \lambda_c^+ + \bar{D}_0$). It can account for $c, \bar{c}$ asymmetry.



Reasonable agreement is found with both models. However, the analysis is not yet conclusive in this respect and there are still some limitations (ex: is $c^- \neq 0$?, mass corrections)

Impact on LHC observables

We validate our observation of IC testing the impact on prediction for: **Z + c production at LHCb** [4]



- Better agreement is found with the `NNPDF4.0` fitted charm especially in the **forward region**
- High correlation with the charm PDF and LHCb observable.
- Predictions are also stable upon charm mass variation

References

[1] R. D. Ball et al., *The Path to Proton Structure at One-Percent Accuracy*, `arXiv:2109.02653`.

[2] S. Brodsky, P. Hoyer, C. Peterson, and N. Sakai, *The intrinsic charm of the proton*, *Physics Letters B* **93** (1980), no. 4 451–455.

[3] T. J. Hobbs, J. T. Londergan, and W. Melnitchouk, *Phenomenology of nonperturbative charm in the nucleon*, *Phys. Rev. D* **89** (2014), no. 7 074008, [`arXiv:1311.1578`].

[4] LHCb Collaboration, R. Aaij et al., *Study of Z Bosons Produced in Association with Charm in the Forward Region*, *Phys. Rev. Lett.* **128** (2022), no. 8 082001, [`arXiv:2109.08084`].