Impact of heavy quarkonium data from the LHC on nuclear PDFs

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25. October 2021

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nCTEQ
nuclear parton distribution functions

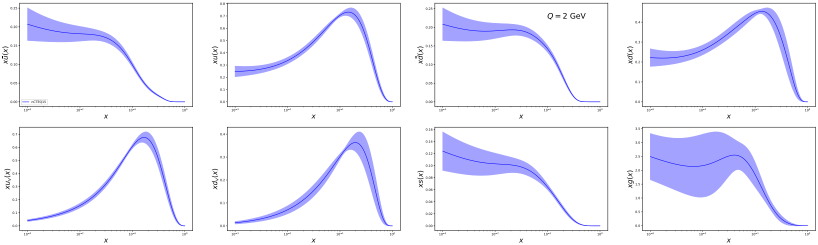
isoQuant SFB1225

Introduction & Theory

PDFs enter any calculation involving hadrons in the initial state

- More precise PDFs mean more precise predictions for observables measured at the EIC

Current main release: nCTEQ15

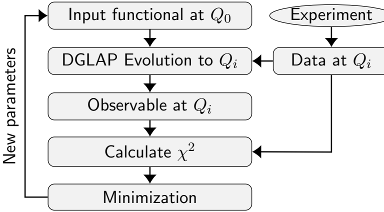


- Large uncertainties on the gluon, especially at low x

Introduction - Nuclear PDF fitting

PDF parameterization:

$$xf_i^{p/A}(x,Q_0) = c_0 x^{c_1}(1-x)^{c_2} e^{c_3 x}(1+e^{c_4}x)^{c_5}$$



Nuclear A dependence:

$$c_k \longrightarrow c_k(A) \equiv p_k + a_k(1 - A^{b_k})$$

Total Nucleus:

$$f_i^{(A,Z)}(x,Q) = \frac{Z}{A} f_i^{p/A}(x,Q) + \frac{A-Z}{A} f_i^{n/A}(x,Q)$$

Open parameters:

$\{a_1^{u_v},\ a_2^{u_v},\ a_4^{u_v},\ a_5^{u_v},\ a_1^{d_v},\ a_2^{d_v},\ a_5^{d_v},\ a_1^{\bar{u}+\bar{d}},\ a_5^{\bar{u}+\bar{d}},\ a_1^g,\ a_4^g,\ a_5^g,\ b_0^g,\ b_1^g,$
$b_4^g,\ b_5^g,\ \boldsymbol{a_0^{s+\bar{s}}},\ \boldsymbol{a_1^{s+\bar{s}}},\ \boldsymbol{a_2^{s+\bar{s}}}\}$

Introduction - Recent updates to nCTEQ15

nCTEQ15: 740 data points

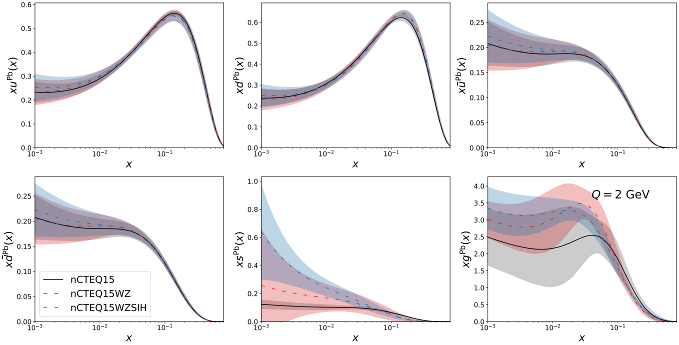
- Mainly DIS and DY data

nCTEQ15WZ: 860 data points

- Added W and Z boson production data to nCTEQ15
- Opened up strange quark parameters

nCTEQ15WZSIH: 948 data points

- Added $\pi^0, \pi^\pm, K^\pm$ production data to nCTEQ15WZ



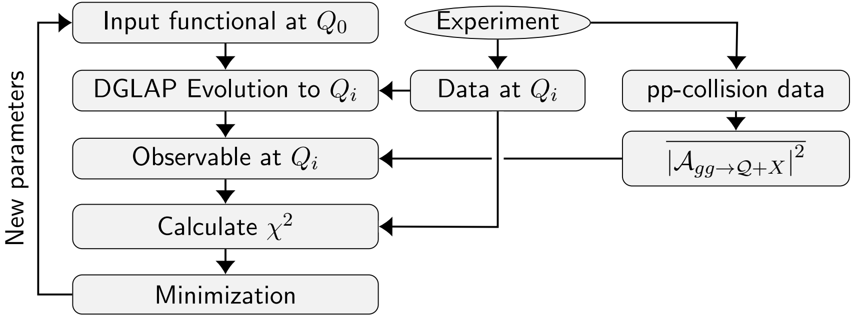
Introduction - Motivation

Why are we interested in quarkonium (and open heavy-flavour meson) production data?

- Sensitivity to gluon PDFs down to very low x values
- Large available data sets from multiple LHC experiments
- Interesting data-driven approach [A. Kusina et al., PRL 121 (2018) 052004; PRD 104 (2021) 014010]
  - Understanding of quarkonium production in pQCD is limited
  - Fast calculation
  - Can quantify theory uncertainties
  - Potentially applicable for any single-inclusive particle production process

Data-driven Approach

$$\sigma(AB \to \mathcal{Q} + X) = \int \mathrm{d}x_1 \; \mathrm{d}x_2 f_{1,g}\left(x_1\right) f_{2,g}\left(x_2\right) \frac{1}{2\hat{s}} \overline{\left|\mathcal{A}_{gg\to Q} + X\right|^2} \mathrm{dLIPS}$$



$$\overline{\left|\mathcal{A}_{gg\to Q+X}\right|^2} = \begin{cases} \frac{\lambda^2 \kappa \hat{s}}{M_{\mathcal{Q}}^2} \exp\left(-\kappa \frac{p_T^2}{M_Q^2}\right) & \text{if } p_T \leq \langle p_T \rangle \\ \frac{\lambda^2 \kappa \hat{s}}{M_{\mathcal{Q}}^2} \exp\left(-\kappa \frac{\langle p_T \rangle^2}{M_Q^2}\right) \left(1 + \frac{\kappa}{n} \frac{p_T^2 - \langle p_T \rangle^2}{M_Q^2}\right)^{-n} & \text{if } p_T > \langle p_T \rangle \end{cases}$$

Analysis

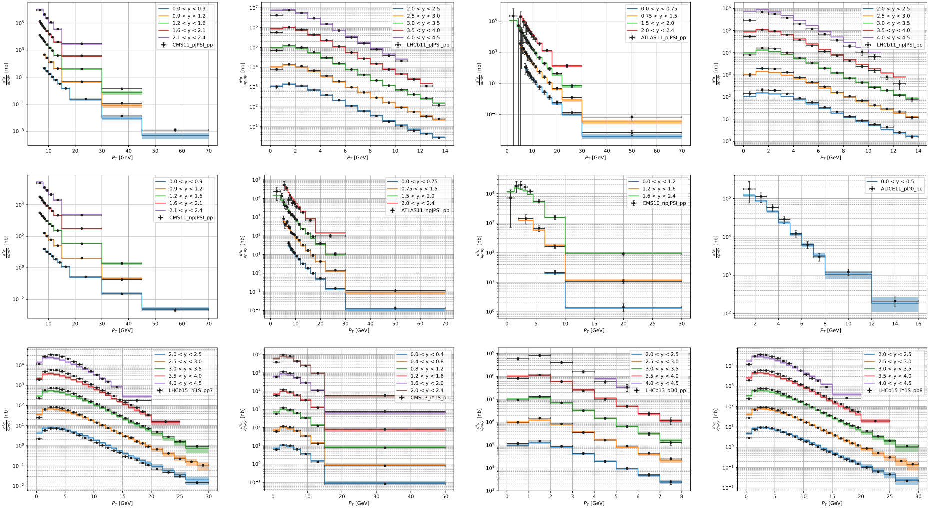
Proton-proton baseline

We use the same data sets as the previously mentioned reweighting study

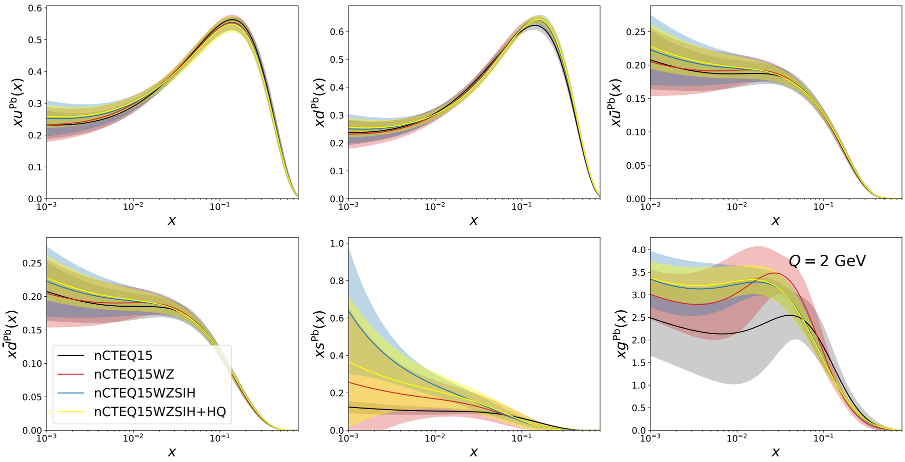
- But we impose cuts to remove data with $p_T < 4$ GeV and outside of $-3 < y_{cms} < 4$

	D^0	J/ψ	$B \to J/\psi$	$\Upsilon(1S)$
κ	0.962±0.109	1.140±0.017	0.443±0.011	0.948±0.005
λ	1.869±0.070	0.271±0.002	0.127±0.002	0.084±0.003
$\langle p_T \rangle$	-0.007±0.392	-0.643±0.185	-0.356±0.360	8.415±0.155
n	1.861±0.162	2.199±0.033	1.540±0.046	2.025±0.067
N_{points}	24 / 47	153 / 174	167 / 188	346 / 440
$\frac{\chi^2}{N_{\text{points}}}$	0.32	0.98	0.92	7.2

Proton-proton baseline

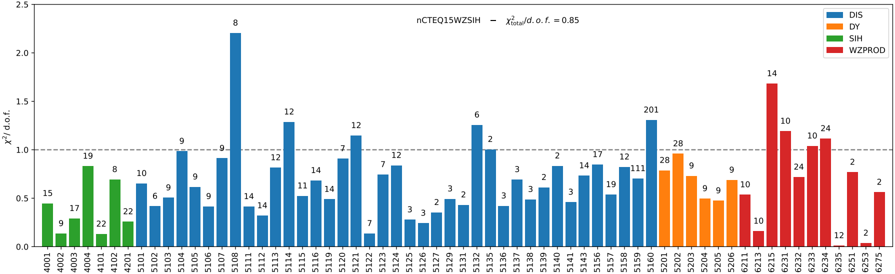


New nuclear PDF fit

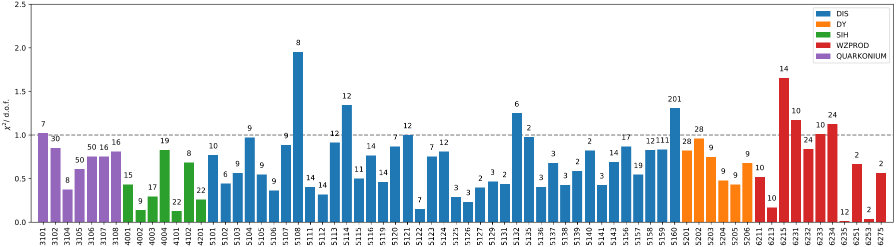


New nuclear PDF fit - χ^2

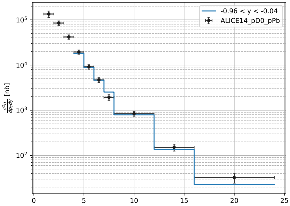
Before:

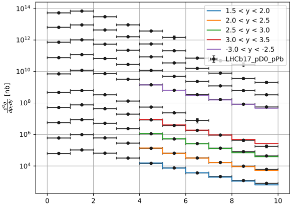


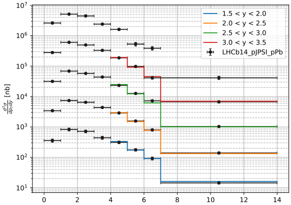
With 177 new Heavy Quark data points:

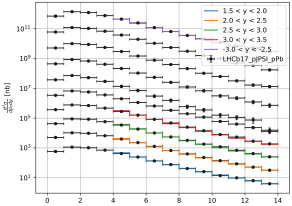


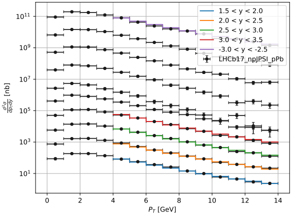
New nuclear PDF fit - data

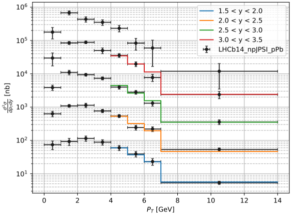


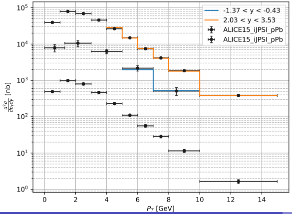












- Only 177 of 499 available points included due to cuts.

Recap and Outlook

Conclusions:

- New data driven approach
- Heavy Quark data helps constrain to low-x gluon PDF and is compatible with data of other processes

Outlook for the future:

- Try different parameterizations of the matrix element to reach a wider kinematic range
- Include all available data sets
- Investigate the dependence on the factorization scale
- Compare with NRQCD

Thanks all !