Impact of Heavy Quark Masses on Parton Distributions and LHC Phenomenology.

Juan Rojo

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Outline

In this talk:

- The impact of heavy quark mass effects on PDFs
- Implications for LHC phenomenology

In yesterday's afternoon talk (Joint SF+EWK session):

- The Tevatron lepton asymmetry data and PDFs
- PDFs with LHC data: the impact of CMS, ATLAS and LHCb W lepton asymmetry measurements

In yesterday's morning talk (Joint SF+HQ session):

- Towards NNLO NNPDFs and NNLO Higgs production
- The impact of NMC data in Higgs production
- Precision NLO determination of $\alpha_S\left(M_Z^2\right)$ from NNPDF2.1

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THE FONLL GENERAL-MASS SCHEME

S. Forte, E. Laenen, P. Nason, J. R.,
Nucl.Phys.B834:116-162,2010. arXiv:1001.2312

J. R. et al., in the Les Houches SM and NLO Multileg Working Group:
Summary report, arXiv:1003.1241

Original formulation for hadronic collisions: M. Cacciari, M. Greco, P. Nason,
JHEP 9805:007,1998, hep-ph/9803400

FONLL in a nutshell

- Express the massive result $F^{(n_l)}$ in terms of the massless PDFs and α_s non trivial from $\mathcal{O}\left(\alpha_s^2\right)$

$$F^{(n_l)}(x, Q^2) = x \int_x^1 \frac{dy}{y} \sum_{i=q,\bar{q},g} B_i\left(\frac{x}{y}, \frac{Q^2}{m^2}, \alpha_s^{(n_l+1)}(Q^2)\right) f_i^{(n_l+1)}(y, Q^2),$$

- Define massless limit of the massive computation as

$$F^{(n_l,\,0)}(x, Q^2) \equiv x \int_x^1 \frac{dy}{y} \sum_{i=q,\bar{q},g} B_i^{(0)}\left(\frac{x}{y}, \frac{Q^2}{m^2}, \alpha_s^{(n_l+1)}(Q^2)\right) f_i^{(n_l+1)}(y, Q^2),$$

$$\lim_{m\to 0}\left[B_i\left(x, \frac{Q^2}{m^2}\right) - B_i^{(0)}\left(x, \frac{Q^2}{m^2}\right)\right] = 0$$

- The FONLL approximation is then

$$F^{\mathrm{FONLL}}(x, Q^2) \equiv F^{(d)}(x, Q^2) + F^{(n_l)}(x, Q^2),$$
$$F^{(d)}(x, Q^2) \equiv \left[F^{(n_l+1)}(x, Q^2) - F^{(n_l,\,0)}(x, Q^2)\right]$$

Important technical advantage: PDFs and α_s expressed always in the (n_l+1) scheme

FONLL in a nutshell

- Far from threshold, $Q^2 \gg m^2$ $F^{(n_l,\,0)}(x,Q^2) \sim F^{(n_l)}(x,Q^2) \to$ the massless computation recovered
$$F^{\rm FONLL}(x,Q^2) \sim F^{(n_l+1)}(x,Q^2)$$

- Near threshold the "difference term" is formally higher order but unreliable, so it can be corrected by mass suppressed terms, using for example a damping factor (FONLL default)
$$F^{(d,\,th)}(x,Q^2) \equiv f_{\rm thr}(x,Q^2) F^{(d)}(x,Q^2), \quad f_{\rm thr}(x,Q^2) = \Theta(Q^2 - m^2)\left(1 - \frac{Q^2}{m^2}\right)^2 ,$$
or some form of $\chi-$scaling,
$$F^{(d,\,\chi)}(x,Q^2) \equiv F^{(d)}(x,Q^2) = x \int_{\chi(x,Q^2)} \frac{dy}{y} C\left(\frac{\chi(x,Q^2)}{y}, \alpha(Q^2)\right) f(y,Q^2),$$
$$F^{(d,\,\chi,v2)}(x,Q^2) \equiv F^{(d)}(\chi(x,Q^2),Q^2), \quad \chi = x\left(1 + \frac{4m^2}{Q^2}\right).$$
The choice of threshold prescription represent an intrinsic ambiguity of the matching procedure. Can this ambiguity be minimized?

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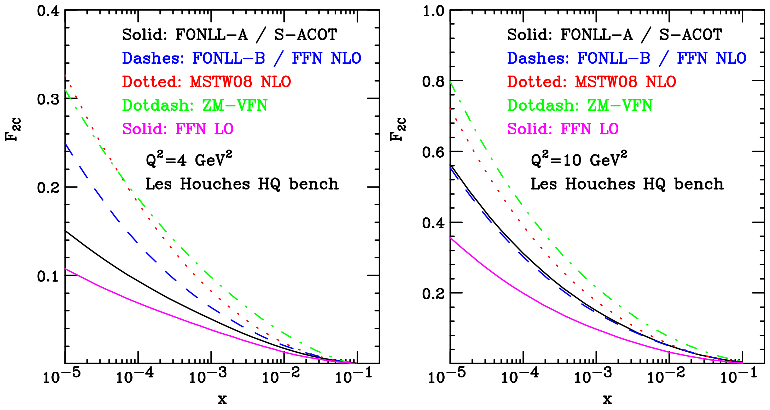
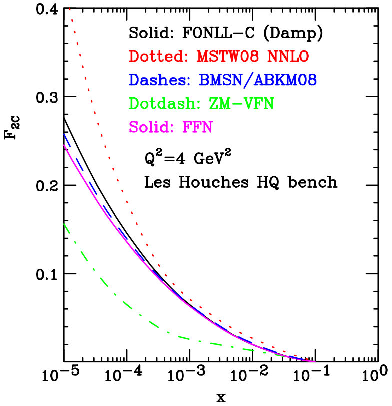
- Various FONLL schemes for different ordering of the perturbative expansion can be defined:
  1. Scheme A $\to \mathcal{O}(\alpha_s)$ in massless and in massive
  2. Scheme B $\to \mathcal{O}(\alpha_s)$ in massless and $\mathcal{O}(\alpha_s^2)$ in massive
  3. Scheme C $\to \mathcal{O}(\alpha_s^2)$ in massless and in massive

LH HQ benchmarks: F_2^c NLO schemes summary



FONLL-A identical to S-ACOT (with same threshold prescription)
FONLL-B very close to FFN $\mathcal{O}\left(\alpha_s^2\right)$

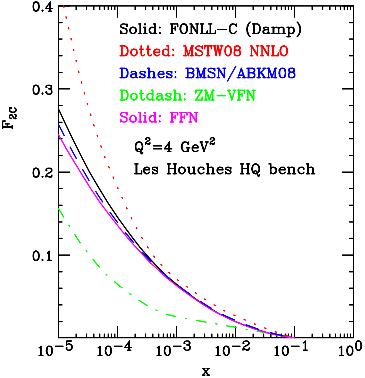
LH HQ benchmarks: F_2^c NNLO schemes summary

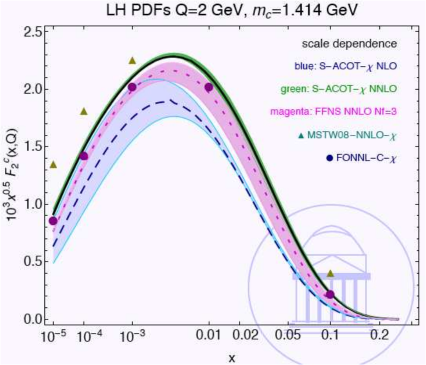


Differences between GM-VFN reduced at NNLO

The FONLL-C GM-VFN scheme and S-ACOT NNLO

- NNPDF2.1 NNLO based on FONLL-C for NNLO DIS structure functions
- S-ACOT-χ NNLO (used in CT NNLO) close FONLL-C-χ (reasonable numerical agreement)





J. Rojo, LH HQ benchmarks M. Guzzi, LH QCD 2011

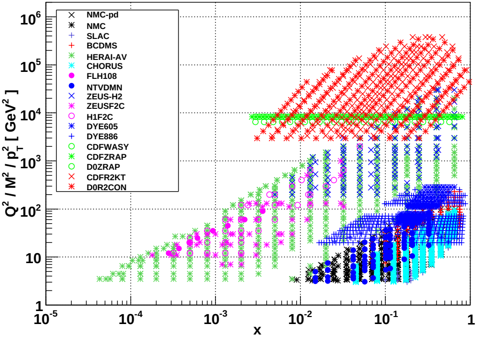
IMPACT OF HEAVY QUARKS ON PDFs: THE NNPDF2.1 SET

arXiv:1101.1300, NPB in press

NNPDF2.1

- NNPDF2.1: an unbiased NLO global analysis with HQ effects
- Based on the FONLL-A GM-VFN scheme

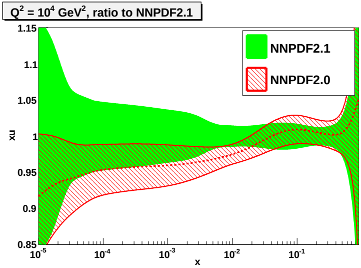
NNPDF2.1 dataset

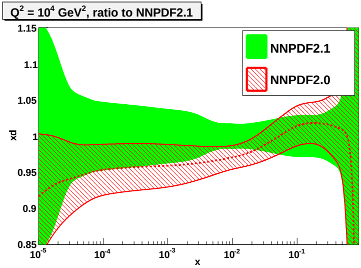


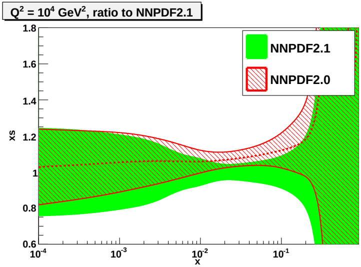
NNPDF2.1: **Global Analysis**

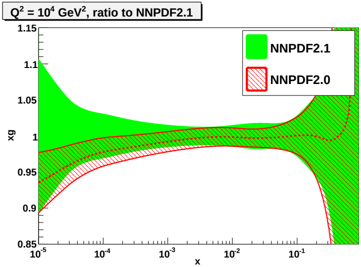
1. Fixed Target DIS
2. Combined HERA–I data, HERA F_2^c
3. Fixed Target DY
4. Tevatron W and Z production
5. Tevatron jet production
6. (LHC W lepton asymmetry)

NNPDF2.1 (GM-VFN) vs NNPDF2.0 (ZM-VFN)

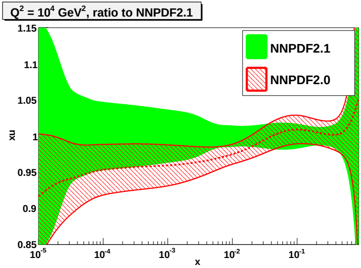


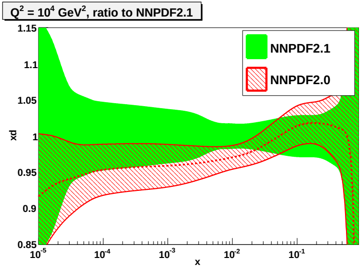






NNPDF2.1 (GM-VFN) vs NNPDF2.0 (ZM-VFN)

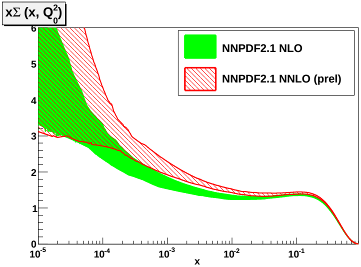


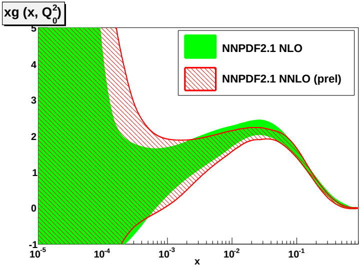


- GM-VFN and ZM-VFN PDFs consistent at 1–sigma
- Harder medium and small–x quarks from HQ mass effects
- Large-x PDFs unaffected

FONLL-C vs. FONLL-A

- Compare NNPDF2.1 NNLO (FONLL-C) and NNPDF2.1 NLO (FONLL-A)
- Harder small-x sea quarks at NNLO, small-x gluon stable
- PDF uncertainties unaffected by GM-VFN NLO $\rightarrow$ NNLO





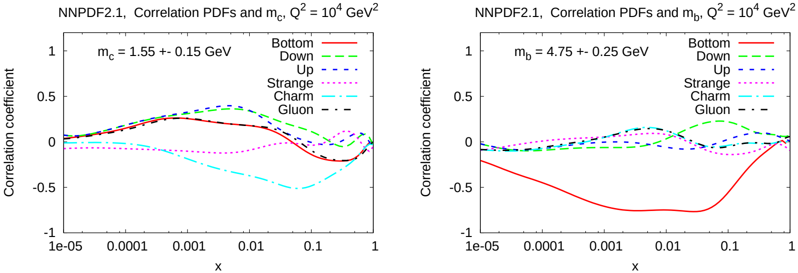
NNPDF2.1 with varying m_h

- NNPDF2.1 fits with varying m_b and m_c have been produced
- Can be used to determine the combined PDF+m_h uncertainty with exact error propagation
- Exact PDF+m_h uncertainty computation keeping all correlations
  Similar to combined PDF+α_s uncertainty

$$\langle \mathcal{F} \rangle_{\rm rep} = \frac{1}{N_{\rm rep}} \sum_{i=1}^{N_{m_c}} \sum_{j=1}^{N_{m_b}} \sum_{k_{ij}=1}^{N_{\rm rep}^{(i,j)}} \mathcal{F}\left({\rm PDF}^{(k_{ij},i,j)}, m_c^{(i)}, m_b^{(j)} \right)$$

$$N_{\rm rep}^{(i,j)} \propto \exp\left(-\frac{\left(m_c^{(i)} - m_c^{(0)}\right)^2}{2\delta_{m_c}^2} - \frac{\left(m_b^{(j)} - m_b^{(0)}\right)^2}{2\delta_{m_b}^2} \right)$$

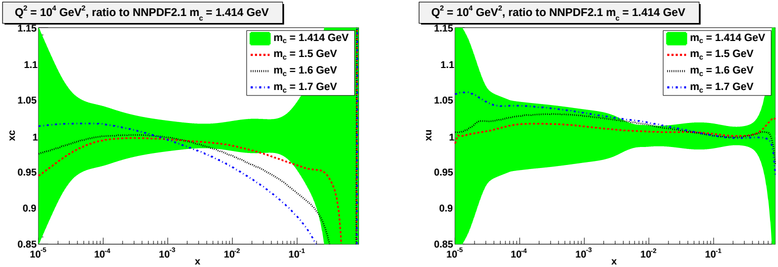
Impact of m_h variations on PDFs



PDF-m_h correlations:

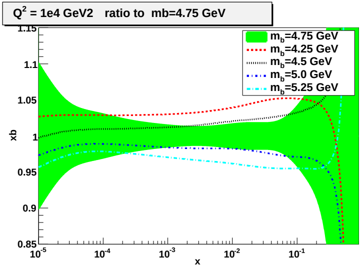
- Light quark harder at small-x
- Charm quark softer at medium-x for larger m_c
- Strong anticorrelation between $b(x, Q^2)$ and m_b for $10^{-4} \geq x \geq 1$

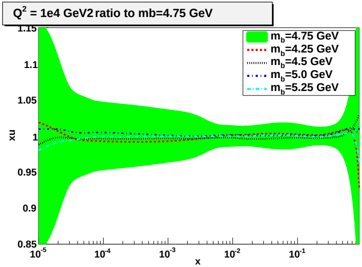
Impact of m_h variations on PDFs



- Charm PDFs modified from different m_c threshold
- Light quark PDFs affected from different GM-VFN predictions for F_2^p when varying m_c

Impact of m_h variations on PDFs



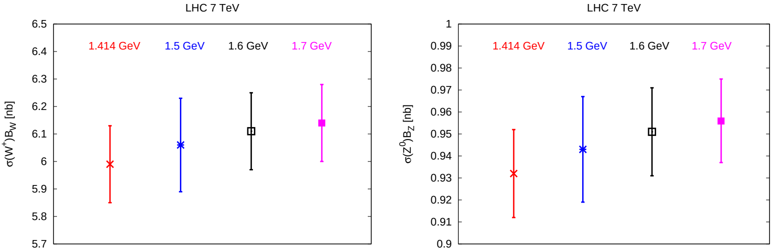


- Only bottom PDF affected by m_b variations
  From different threshold for radiative generation
- Other PDFs unaffected
  $\rightarrow$ m_b uncertainties restricted to b–initiated processes

HEAVY QUARK MASSES AND LHC PHENOMENOLOGY

arXiv:1101.1300, NPB in press

Dependence on m_c

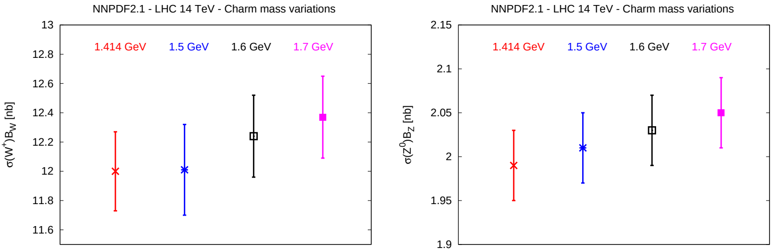


- The W/Z cross sections increase with the m_c used in the PDF fit
  δ_{m_c} is an intrinsic parametric uncertainty of the theory
- At 7 TeV, variations in range $m_c \in [1.4, 1.7]$ GeV at most $\lesssim$1–sigma shift
- At 14 TeV somewhat larger effects
- With the m_c varying NNPDF2.1 sets $\rightarrow$ Compute exact PDF+m_c uncertainty

At NLO pole and MSbar defitions equivalent
At NNLO theo uncertainties reduced using MSbar mass in GM-VFN structure functions

(Alekhin and Moch, arXiv:1011.5790)

Dependence on m_c



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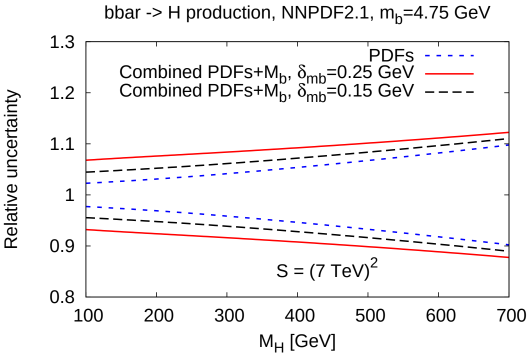
Combined PDF+m_b uncertainties in $b\bar{b} \to H$ production

- Processes initiated by $b(x, Q^2)$ at Born level sensitive to choice of m_b t–channel single-top, MSSM $b\bar{b} \to H$, ...
- Important to compute combined PDF+m_b uncertainties with exact error propagation
- For $b\bar{b} \to H$, assuming $\delta_{m_b} = 0.15(0.25)$ GeV, combined PDF+m_b uncertainty can increase PDF-only uncertainty by a factor up to 2(3) for small m_H



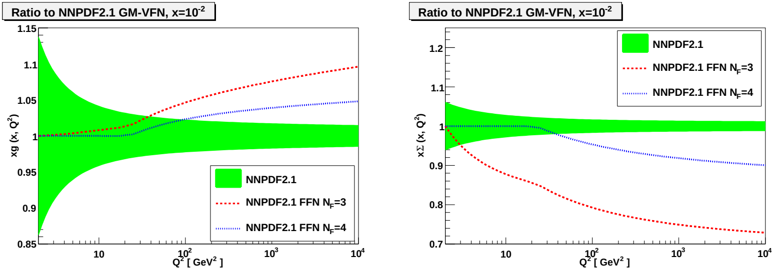
PARTON DISTRIBUTIONS WITH FIXED NUMBER OF FLAVOURS

NNPDF2.1, arXiv:1101.1300, NPB in press

PDFs in FFN schemes

- PDFs in FFN schemes relevant for LHC phenomenology
  e.g. Consistent predictions in 4F schemes, scale setting in VFN scheme comparing to FFN
- The NNPDF2.1 GM-VFN varies NF at HQ thresholds from Nf = 3 to Nf = 6
- FFN scheme sets with Nf = 3, Nf = 4 and Nf = 5 are also provided
- FFN PDFs obtained from GM-VFN PDFs matching at HQ thresholds

$$\mathrm{PDFs}^{\mathrm{N_f}}\left(Q^2 = m_h^2\right) = \mathrm{PDFs}^{\mathrm{N_f}+1}\left(Q^2 = m_h^2\right)$$



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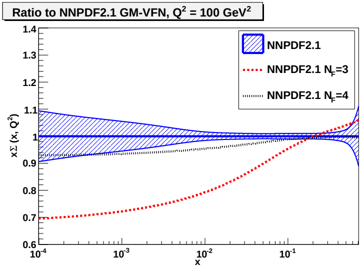

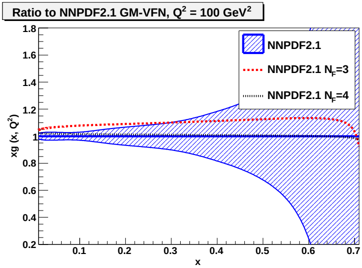

Summary

- FONLL is a flexible General Mass scheme for DIS and hadronic collisions
  Different FFN and ZM perturbative orders can be combined
  The impact of subleading corrections can be systematically studied
- FONLL-A has been implemented in NNPDF2.1 NLO analysis
  Differences with ZM relevant but no dramatic (typically $\lesssim$1–sigma)
- FONLL-C implemented in NNPDF2.1 NNLO
  $\rightarrow$ Harder small-x quarks, gluon stable
- LHC observables like Z and W sensitive to m_c variations, but differences small unless large δ_{m_c} assumed
  Can be further reduced by using MSbar mass
- b–initiated process sensitive to δ_{m_b} uncertainty
- Fixed Flavor Number sets available for consistent use with FFN calculations

Thanks for your attention!

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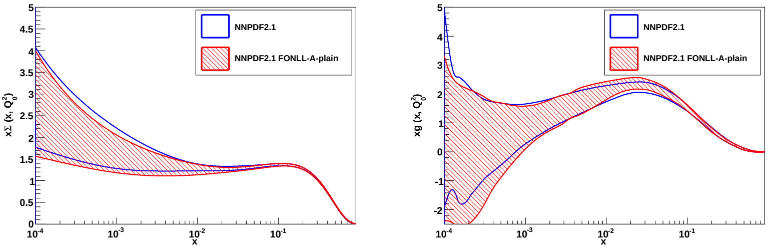
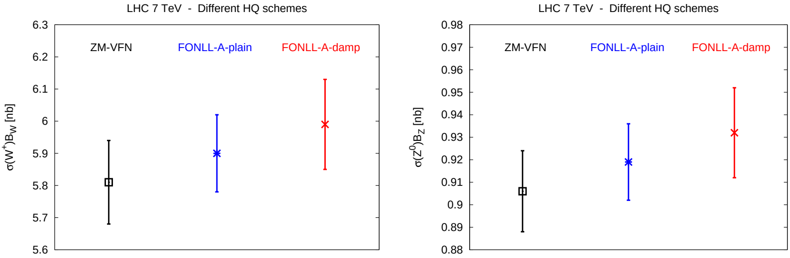
EXTRA MATERIAL

GM-VFN scheme definition



- Compare default GM-VFN with FONLL-A without threshold damping
- Small modifications in PDFs, somewhat softer small-x quarks
- Inherent ambiguity of NLO GM-VFN schemes

GM-VFN scheme definition



- The FONLL-A-plain result interpolates between ZM and FONLL-A Damp
- Estimate of NLO GM-VFN ambiguity