On the inclusion of open charm data in PDF fits

S. Alekhin, <u>Maria Vittoria Garzelli</u>, S.-O. Moch

University of Tuebingen, Institute for Theoretical Physics,
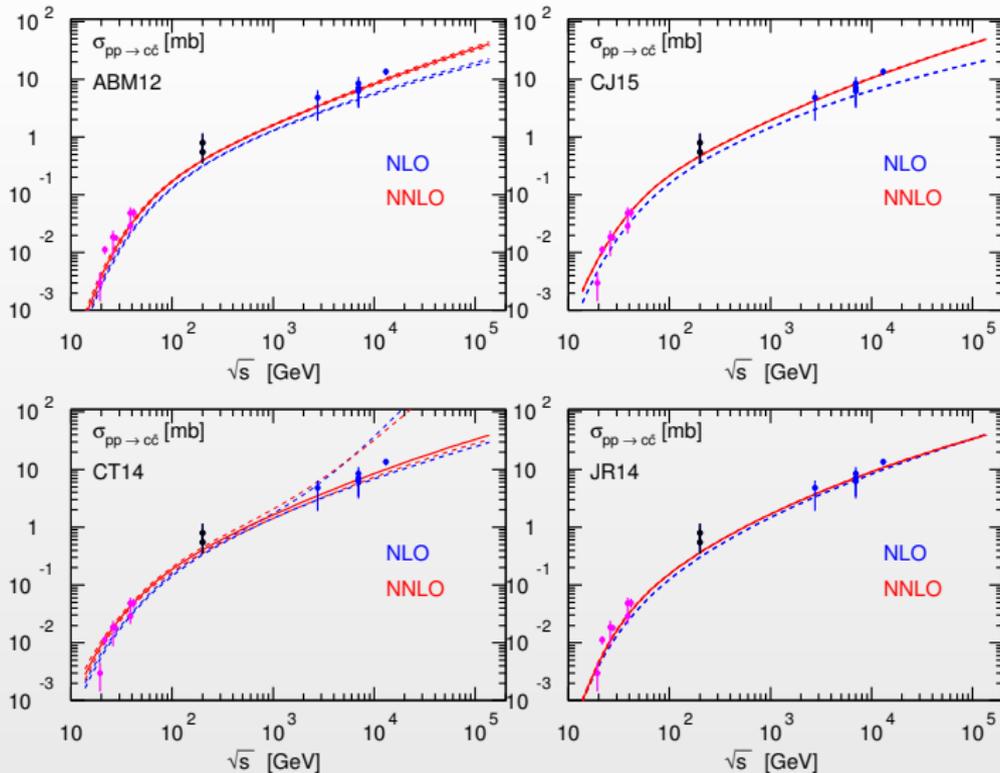University of Hamburg, II Institute for Theoretical Physics

REF 2018 Workshop, IFJ-PAN Kraków, Poland,
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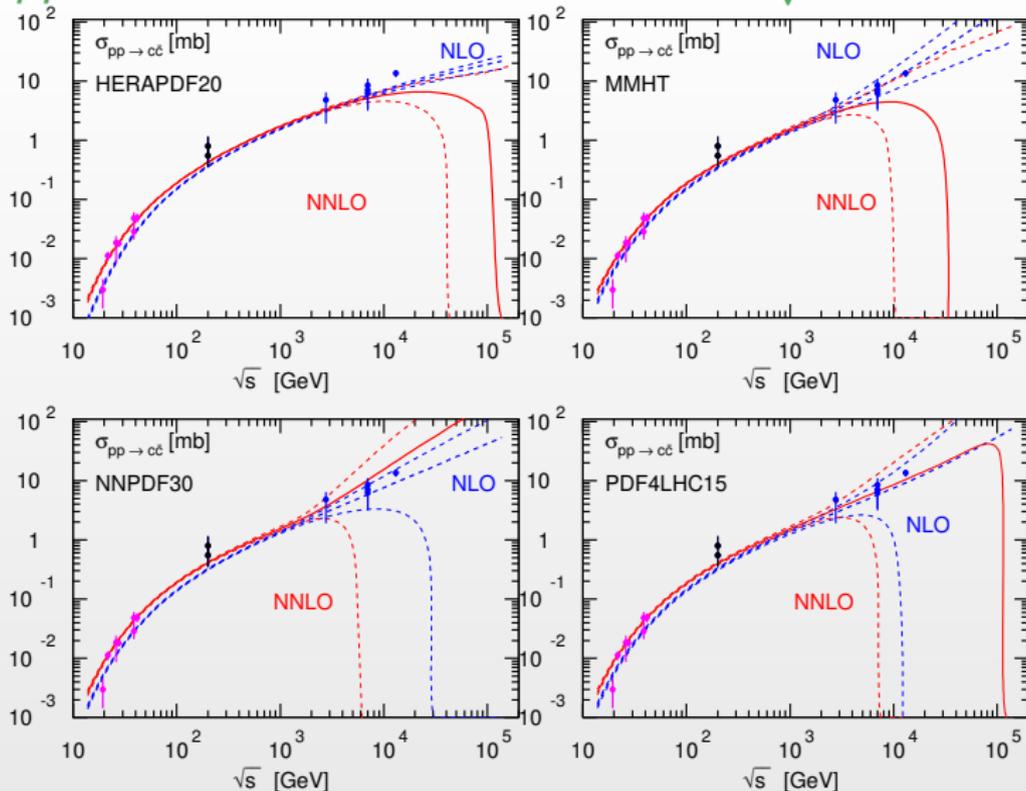# Total $pp \to c\bar{c} + X$ cross section vs. $\sqrt{s}$

$\mu_R = \mu_F = 2m_c(m_c), \quad m_c(m_c) = 1.27$ GeV
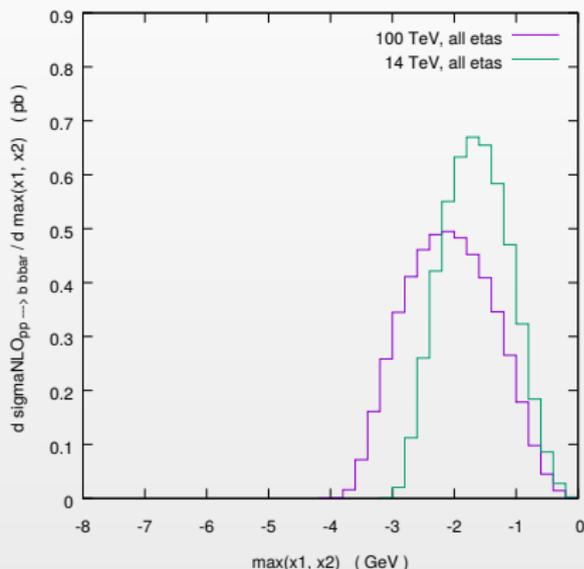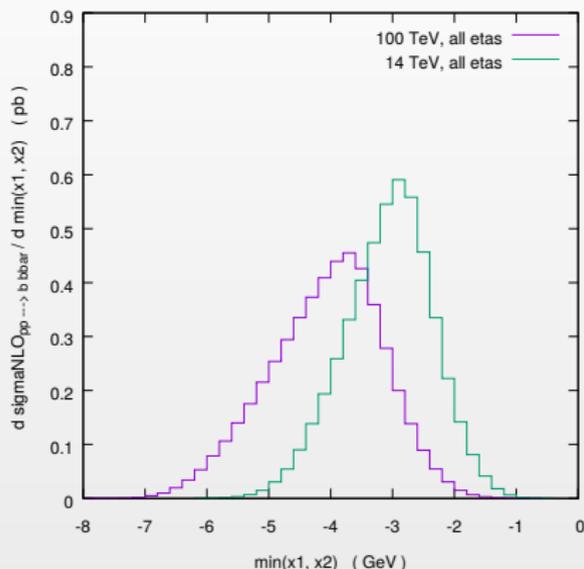
exp. data from fixed target experiments and colliders

Total $pp \to c\bar{c} + X$ cross section vs. $\sqrt{s}$

from A. Accardi et al. EPJC 76 (2016) 471
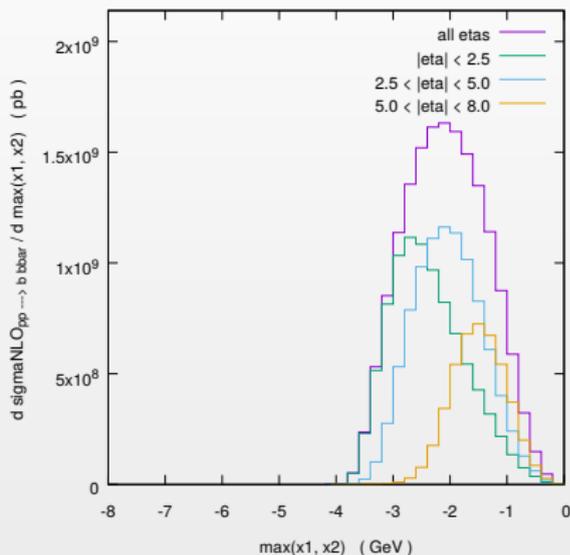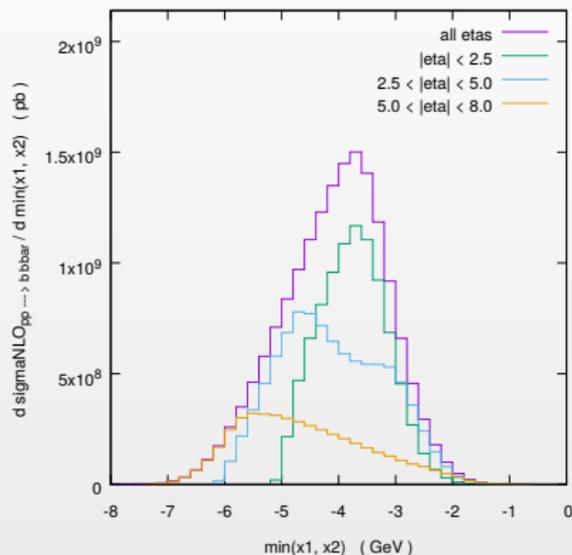
Negative cross-sections for some PDF sets!

$\sigma(pp \to b\bar{b})$: contributions from initial state partons with different Bjorken-x

* At 100 TeV, $\min(x_1, x_2)$ and $\max(x_1, x_2)$ span a wider range than at 14 TeV.
* At 100 TeV, $\min(x_1, x_2)$ is peaked around $\sim 10^{-4}$, whereas $\max(x_1, x_2)$ is peaked around $\sim 10^{-2.5}$

$\sigma(pp \to b\bar{b})$ in different pseudorapidity ranges:

contributions from initial state partons with different Bjorken-x

* We ask for at least 1 b-jet with $|\eta|$ in a fixed interval.

* At larger $|\eta|$, $\min(x_1, x_2)$ and $\max(x_1, x_2)$ span a wider range than at smaller $|\eta|$.

* What about PDFs at $x \sim 10^{-6}$?

x coverage of HERA and LHCb experiments
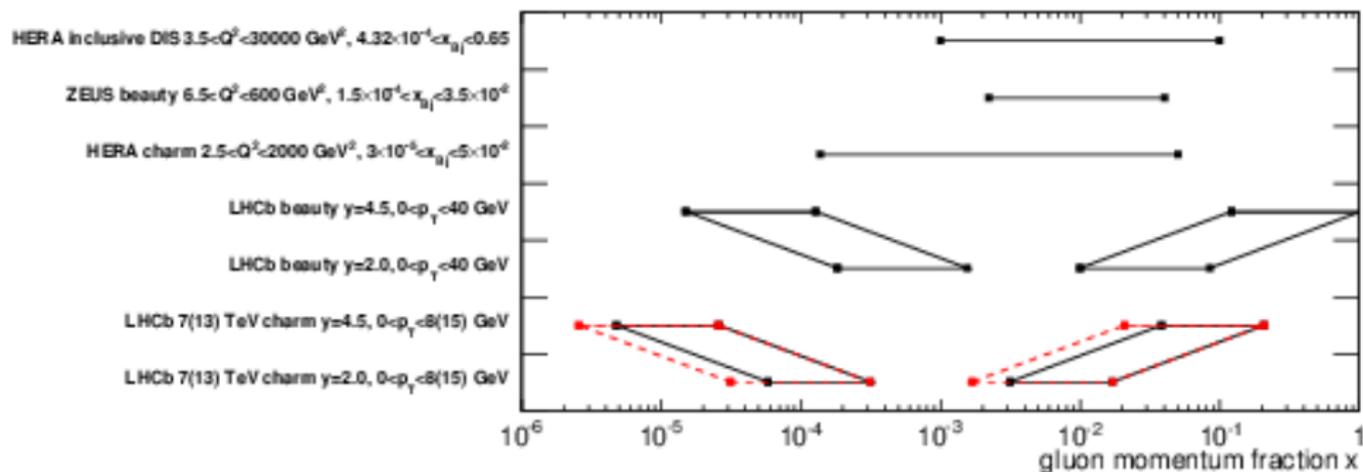
LHCb data allows to cover x regions uncovered by HERA data,
both at low x's (especially open charm data)
and at large x's (especially open bottom data).

Larger rapidities of the emitted quark and/or larger collision energies
correspond to more extreme x's

The PROSA PDF fit

The PROSA PDF fit [EPJC 75 (2015) 471] is the first one appeared in the literature which has proposed the following
basic <u>idea</u>: use the data on D-meson and B-meson hadroproduction at LHCb to constrain PDFs (especially gluon PDFs) at low x's.

<u>Data sets</u>:

Open charm data at 7 TeV: D-meson p_T distributions in the range $[0, 8]$ GeV, in five equal-size rapidity bins between $2 < y < 4.5$. [arXiv:1302.2864]

Open bottom data at 7 TeV: B-meson p_T distributions in the range $[0, 40]$ GeV, in five equal-size rapidity bins between $2 < y < 4.5$ [arXiv:1306.3663]

These data are considered together with all HERA data used for the HERAPDF1.0 PDF fit:
− NC and CC inclusive DIS combined HERA-I data,
− $c\bar{c}$ DIS combined HERA data and $b\bar{b}$ DIS ZEUS data.

Follow-up fits (made by reweighting recent NNPDF PDF fits):
- R. Gauld, J. Rojo, L. Rottoli, J. Talbert, JHEP 1511 (2015) 009
- R. Gauld, J. Rojo, PRL 118 (2017) 072001
- V. Bertone, R. Gauld and J. Rojo, arXiv:1808.02034

PROSA PDF fit: comparison between three variants
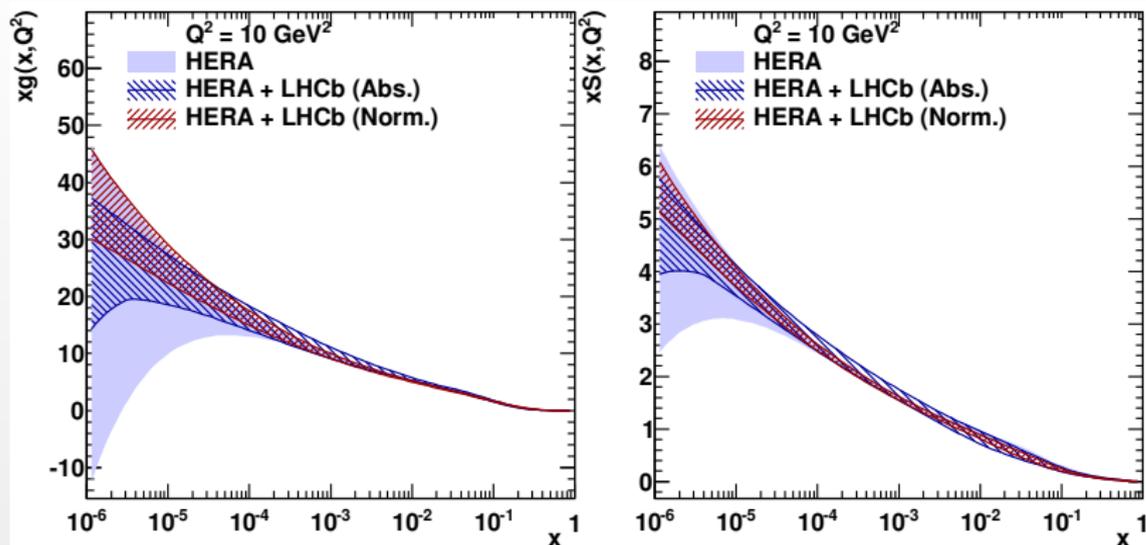
Three <u>variants</u> of the PDF fit:

1) one only with HERA data;

2) one also including LHCb absolute differential cross-sections;

3) another one with reduced uncertainties: for each fixed LHCb p_T bin, use the ratios of
   distributions $(d\sigma/dy)/(d\sigma/dy_0)$ in different rapidity bins
   (i.e. normalized to the central bin $3 < y_0 < 3.5$):
   in the ratios theoretical uncertainties partly cancel.

Theory predictions with PROSA PDFs wrt to absolute and normalized LHCb data at 7 TeV
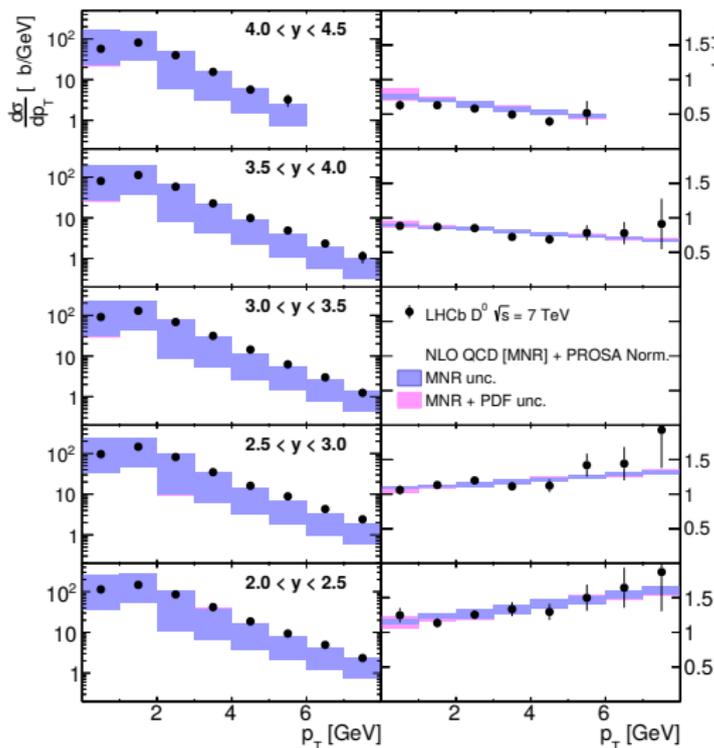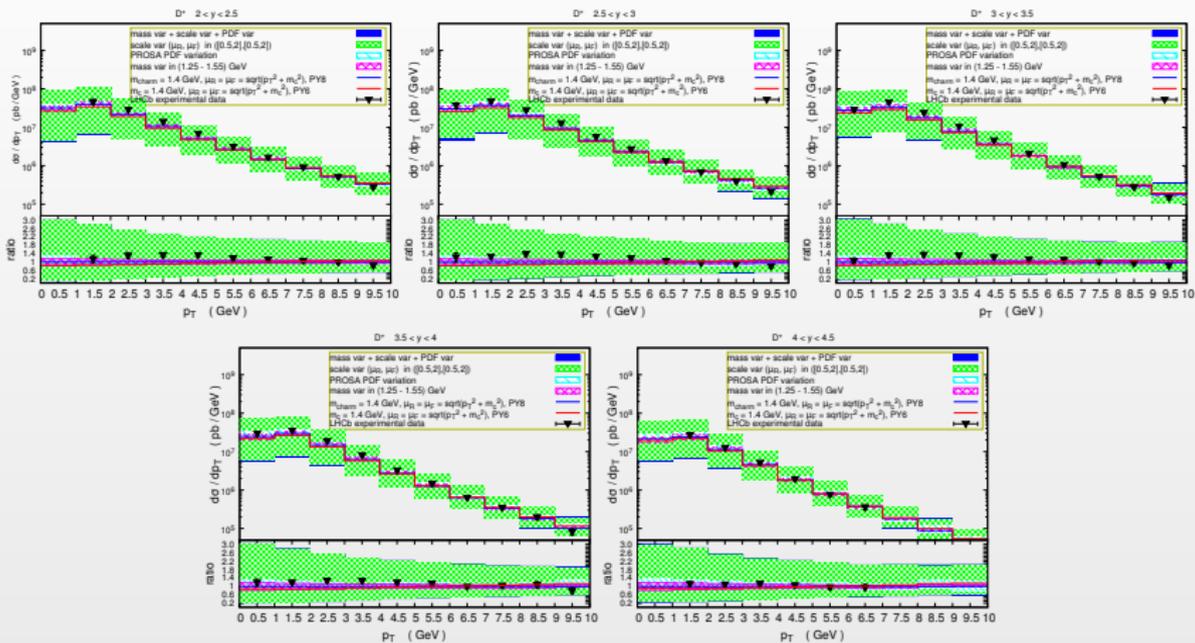

* theory uncertainties are reduced in the ratios $(d\sigma/dp_T)_{y=y_1}/(d\sigma/dp_T)_{y=y_0}$.

* The PROSA PDF version using HERA + LHCb normalized data in the fit is used for making predictions for the absolute $d\sigma/dp_T$ at $\sqrt{s} = 7$ TeV.
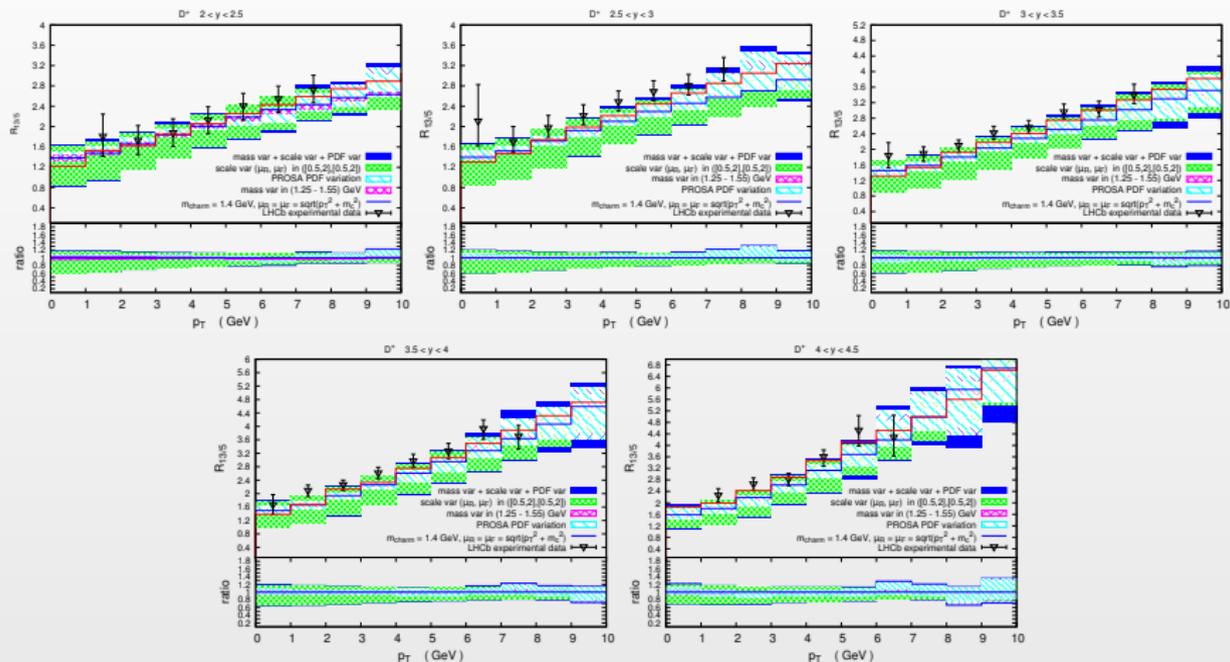
from O. Zenaiev,
EPJC 77 (2017) 151

Performances of PROSA PDF fit with respect to LHCb data non included in the fit ($D^{\pm}$ at $\sqrt{s} = 5$ TeV)

These data are not included in the PROSA PDF fit:
good agreement theory/experiment within large (μ_R, μ_F) uncertainty bands.

Performances of PROSA PDF fit wrt to LHCb data

on ratios of p_T-distributions of $D^{\pm}$ at $\sqrt{s} = 13$ and 5 TeV

These data are not included in the PROSA PDF fit.

Are we fully satisfied ?

Of course, not.

∗ Only LHCb open-charm and open-bottom data at $\sqrt{s} = 7$ TeV have been included so far in the PROSA PDF fit, while further data ($\sqrt{s} = 5$ and 13 TeV) exist.

∗ Agreement with theory predictions within very big uncertainty bands does not provide warranty that the shape of the experimental distributions is reproduced by the theory.

∗ The PROSA PDF fit does not include further LHC or TeVatron data. It is interesting to investigate the inclusion of open charm data on the more comprehensive (or global) PDF fits (e.g. the ABMP16 fit), including data from a larger number of experiments.

Further investigations: considering other PDF fits

∗ Several updated PDF fits are present on the market:
ABMP16, CT14, NNPDF3.1, MMHT, CJ15....

∗ So far, besides the PROSA fit, only some variants of the NNPDF
fit have included the LHCb open-charm data. While the PROSA
fit includes LHCb data from the very beginning, the NNPDF fits
have been reweighted a posteriori with LHCb data.

∗ Further studies are certainly welcome!

∗ In the following we consider the case of the ABMP16 PDF fit,
which includes:
- (HERA I + II) combined H1 + ZEUS inclusive NC + CC DIS data.
- heavy-flavour DIS data.
- Drell-Yan and top production data at the LHC.
- higher-twist effects.

See *S. Alekhin, J. Bluemlein, S.O. Moch, R. Placakyte, PRD 96 (2017) 014011*
,   EPJC 78 (2018) 477

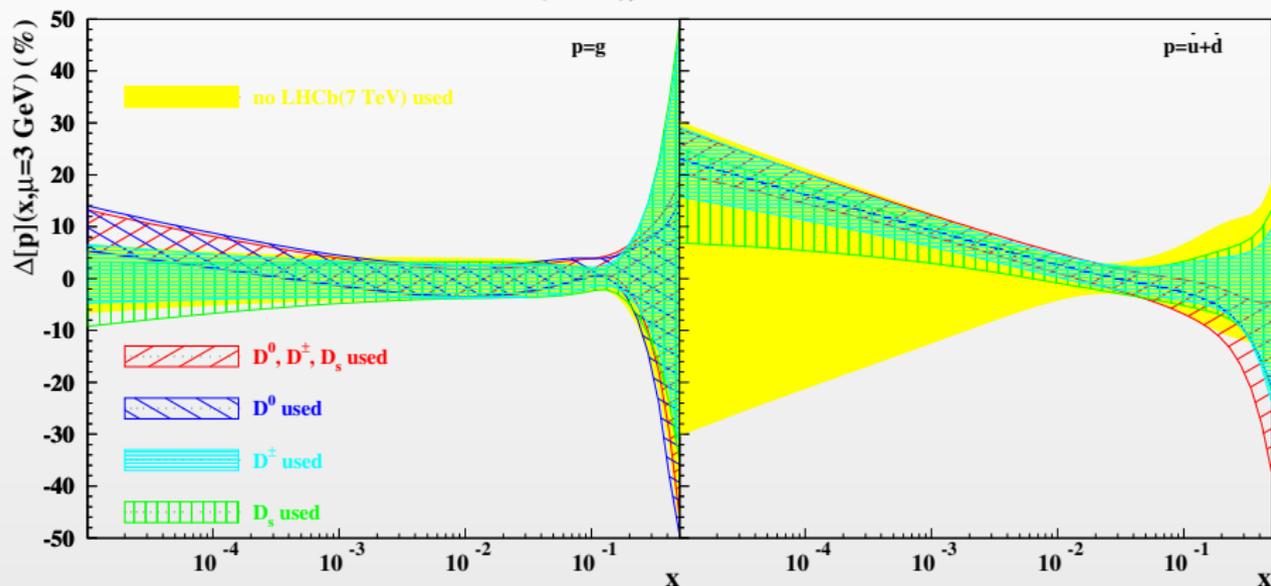# Comparison data/theory for the $pp \to D^0 + X$ LHCb data
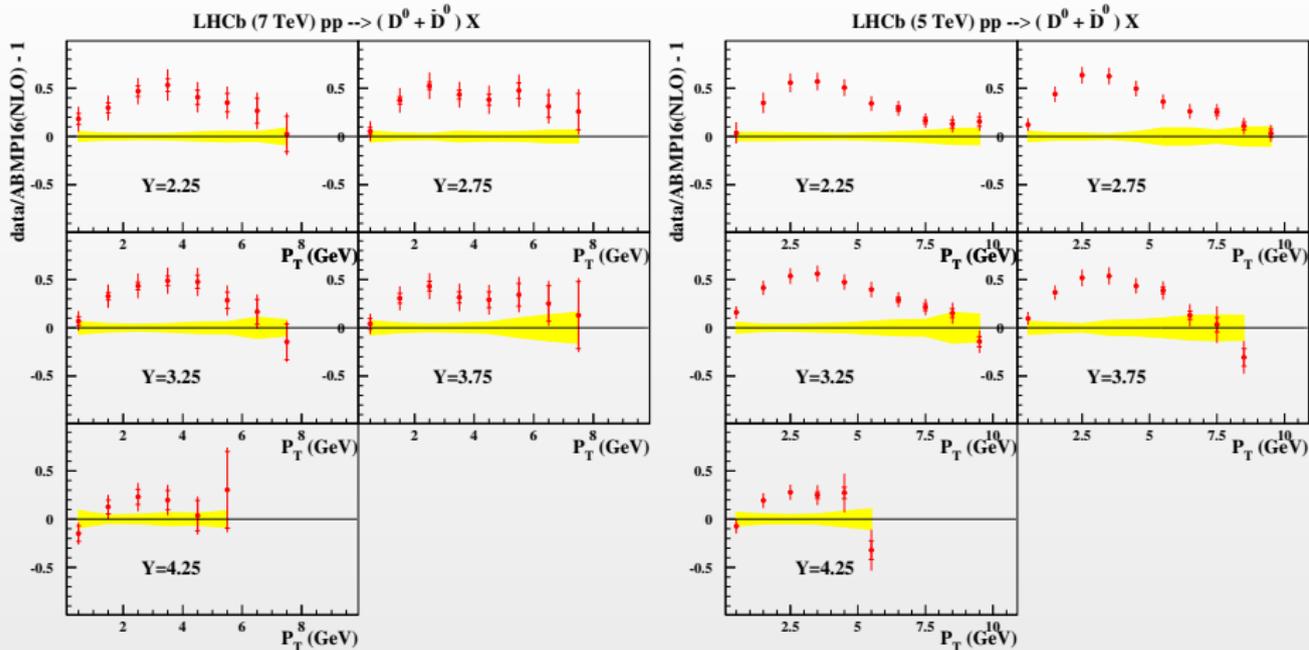
* Similar trend observed in the pulls at different $\sqrt{s}$.

* Data overestimate the theory predictions for $p_T \sim 3 - 4\,GeV$.
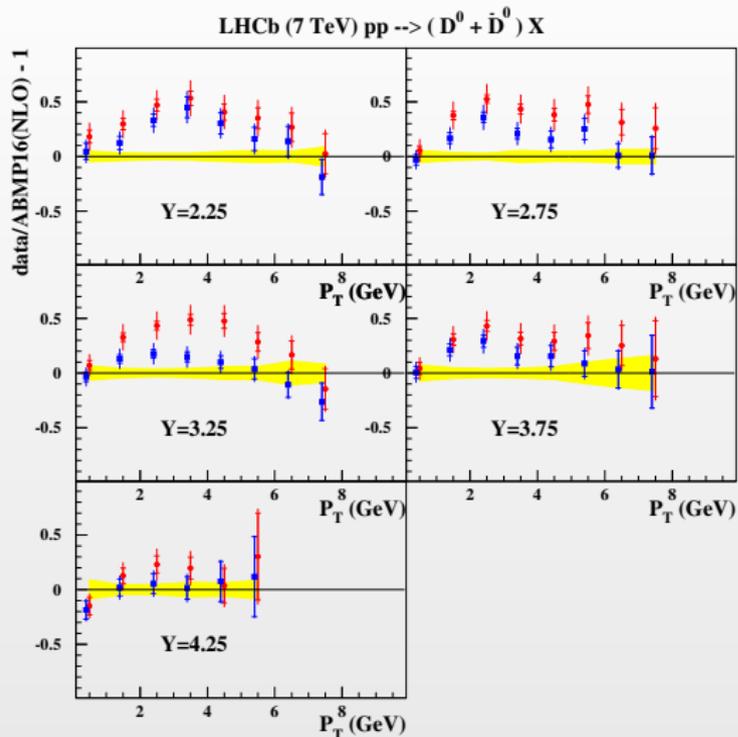
Modifications of the ABMP16 gluon and sea PDFs

after inclusion of the LHCb open-charm data at $\sqrt{s} = 7$ TeV

LHCb(7 TeV), HERA included

* Modifications of the fit driven by the inclusion of the D^0 data.

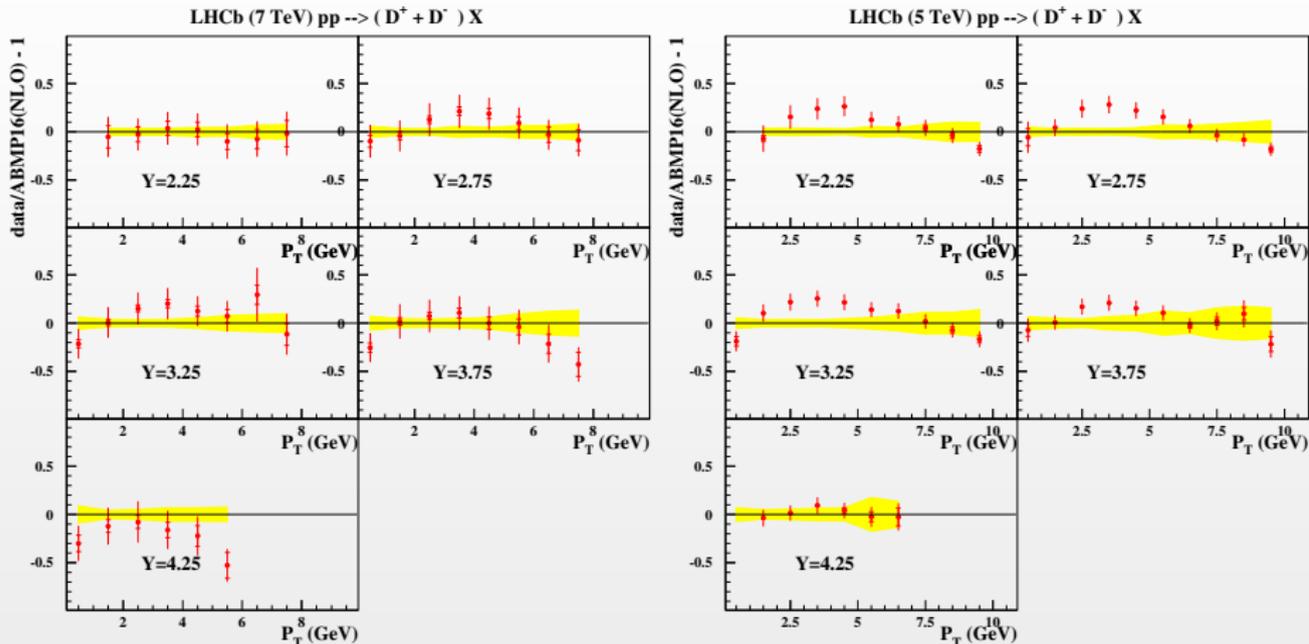* Slight increase of the gluon and sea quark PDFs at small x's.

Pulls for the $pp \to D^0 + X$ LHCb data at $\sqrt{s} = 7$ TeV

LHCb (7 TeV) pp --> ($D^0 + \bar{D}^0$) X

* The ABMP16 PDF fit including the D^0 LHCb data performs slightly better than the one before inclusion of these data.

* But discrepancies are still present at small y.

$*$ Puzzle: at small rapidities the $D^{\pm}$ data at $\sqrt{s} = 7$ TeV turn out to be described better than those at 5 TeV, whereas we do not expect significant modifications of the physics: are the experimental data at different energies compatible among each other ?

Further investigations: adding data from other experiments

* LHCb open-charm data
  ($2 < y < 4.5$)

* ATLAS (and CMS)
  open-charm data
  ($|y| < 2.5$)

* CDF open-charm data ($|y| < 1$)

* ALICE open-charm data
  ($|y| < 0.5$)

+ further open-bottom data
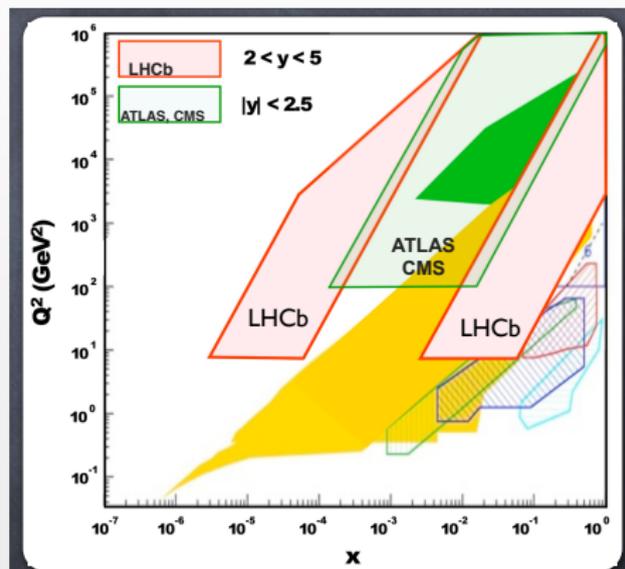
Different experiments span (Q^2, x) regions partially overlapping:
good for verifying their compatibility and for cross-checking their
theoretical description.

Pulls for the LHCb, ALICE, CDF open-charm data
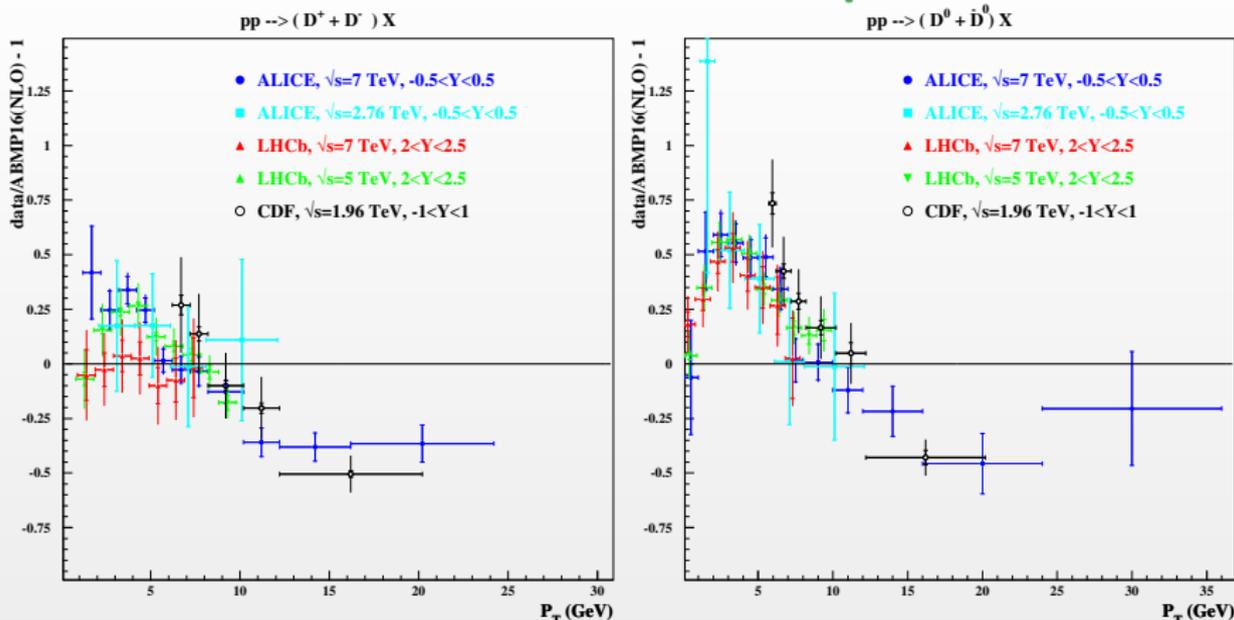
* Fluctuations for $D^\pm$, while a trend is visible for D^0.

* In case of D^0, data at a fixed p_T seem to be reproduced similarly well/bad, indipendently of the $\sqrt{s}$ and of the y probed.

* This implies that the difference in shape between theory predictions and exp. data can not be washed out by modifying PDFs at low x's.

Temptative explanations of the discrepancies data/theory at $p_T \sim 3$ GeV

* PDF effect ?
  No, because for the D^0 we see similar discrepancies at different $\sqrt{s}$.

* FFNS vs. VFNS effect ?
  Unlikely to be so large for $p_T \sim 3$ GeV, see the next slides.
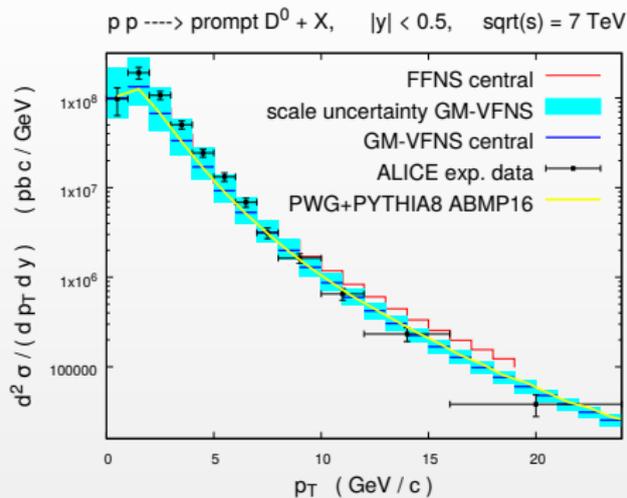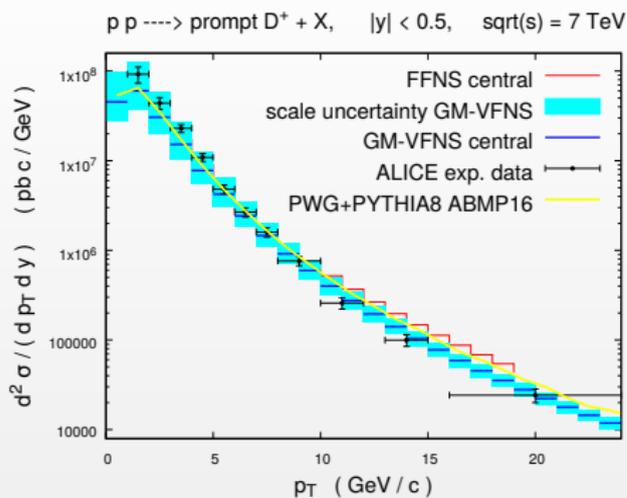
* Fragmentation Function / Hadronization effect ?
  Unlikely to be so large, see the next slides.

* Higher-order effects ?
  Possible modification of shapes, because scale variation uncertainty.
  is very large.

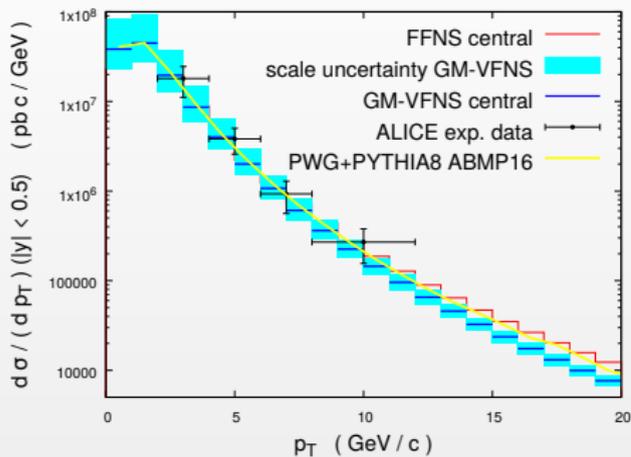* Alternatively, one could think to a combination of small effects.

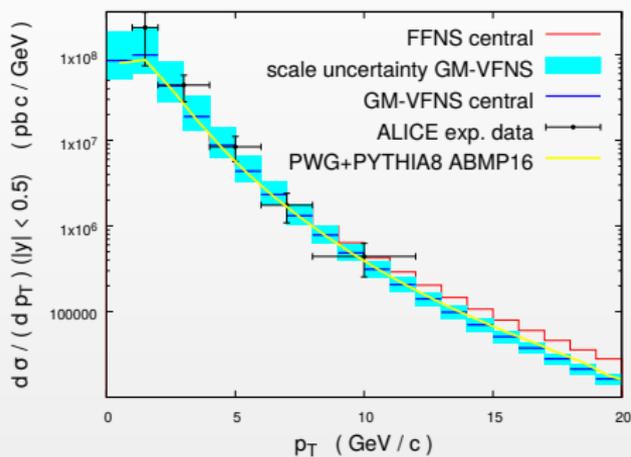# Theory predictions vs. ALICE exp. data at $\sqrt{s} = 7$ TeV

* GM-VFNS + FF predictions and POWHEGBOX + PYTHIA predictions compatible among each other up to $p_T \sim 20$ TeV.

* Very different treatment of fragmentation.

* FFNS + FF predictions overestimate data at large p_T.

* POWHEGBOX + PYTHIA agrees better with $D^{\pm}$ than with D^0 data.

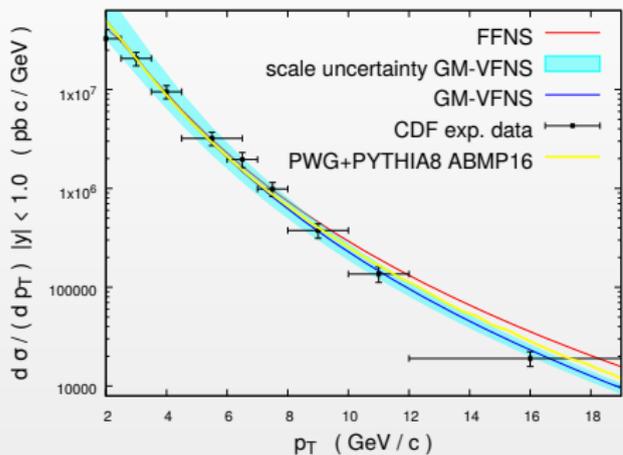# Theory predictions vs. ALICE exp. data at $\sqrt{s} = 2.76$ TeV

* GM-VFNS + FF predictions and POWHEGBOX + PYTHIA predictions compatible among each other for small for p_T, up to at least 10 GeV.
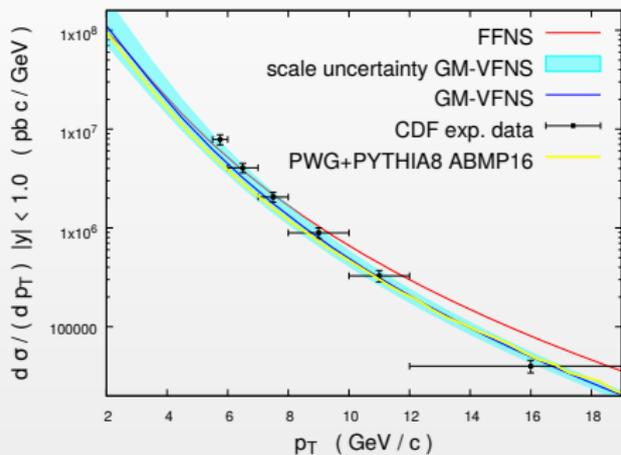
* POWHEGBOX + PYTHIA agrees slightly better with $D^{\pm}$ data than with D^0 data.

Theory predictions vs. CDF exp. data at $\sqrt{s} = 1.96$ TeV

p antip ----> prompt D^+ + X, |y| < 1.0,   sqrt(s) = 1.96 TeV

p antip ----> prompt D^0 + X, |y| < 1.0,   sqrt(s) = 1.96 TeV

FFNS
scale uncertainty GM-VFNS
GM-VFNS
CDF exp. data
PWG+PYTHIA8 ABMP16

* Similar observations as before.

* Analogous picture for other experiments....

Summary and Conclusions

∗ LHCb open charm data have the potentiality to constrain gluon and sea quark PDF at low x's.

∗ Incorporation in PDF fits so far limited to very few cases (PROSA, recent NNPDF variants, ABMP preliminary).

∗ Compatibility with other open charm data under investigation.

∗ Theory predictions plagued by large scale uncertainty.

∗ Still under investigation: how to reconcile shapes of distributions with experimental data ?

∗ Ratios of theory predictions wash out differences which, however, still need to be clarified!

∗ Possible use of the same data, together with data on D-meson correlations, in TMD PDF fits.