Heavy Quark(onium) in pA/SMOG

Hua-Sheng Shao

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LABORATOIRE DE PHYSIQUE THEORIQUE ET HAUTES ENERGIES

Work with M. Cacciari, A. Kusina, J.-P. Lansberg and I. Schienbein **(arXiv:1711.sooon)**

Implications of LHCb measurements and future prospects

CERN, Geneva

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IMPLICATIONS OF LHCb MEASUREMENTS AND FUTURE PROSPECTS

CERN, GENEVA

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Heavy Quark(onium) in pA

what data teach us ?

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IMPLICATIONS OF LHCB MEASUREMENTS AND FUTURE PROSPECTS

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Introduction

COLD NUCLEAR MATTER EFFECTS

- **Initial state effects**
  - Modification of parton flux (e.g. shadowing) in nuclear PDF
  - Coherent or incoherent energy loss Arleo and Peigne '12; Sharma and Vitev '13
  - Colour filtering of intrinsic heavy-quark pair Brodsky and Hoyer '89
  - Saturation/small x/coherence effects Ducloué et al. '15; Kharzeev et al. '09; ...
  - ...
- **Final state effects**
  - Coherent energy loss Arleo and Peigne '12
  - Break up in the nuclear matter: absorption effect Gerschel and Hufner '88; Vogt '99
  - Break up by comoving particles Ferreiro '15; Capella and Ferreiro '00'05; Gavin and Vogt '90
  - ...

Cold nuclear matter effects are crucial to understand AA data
Reference to disentangle genuine QGP effect in AA collisions

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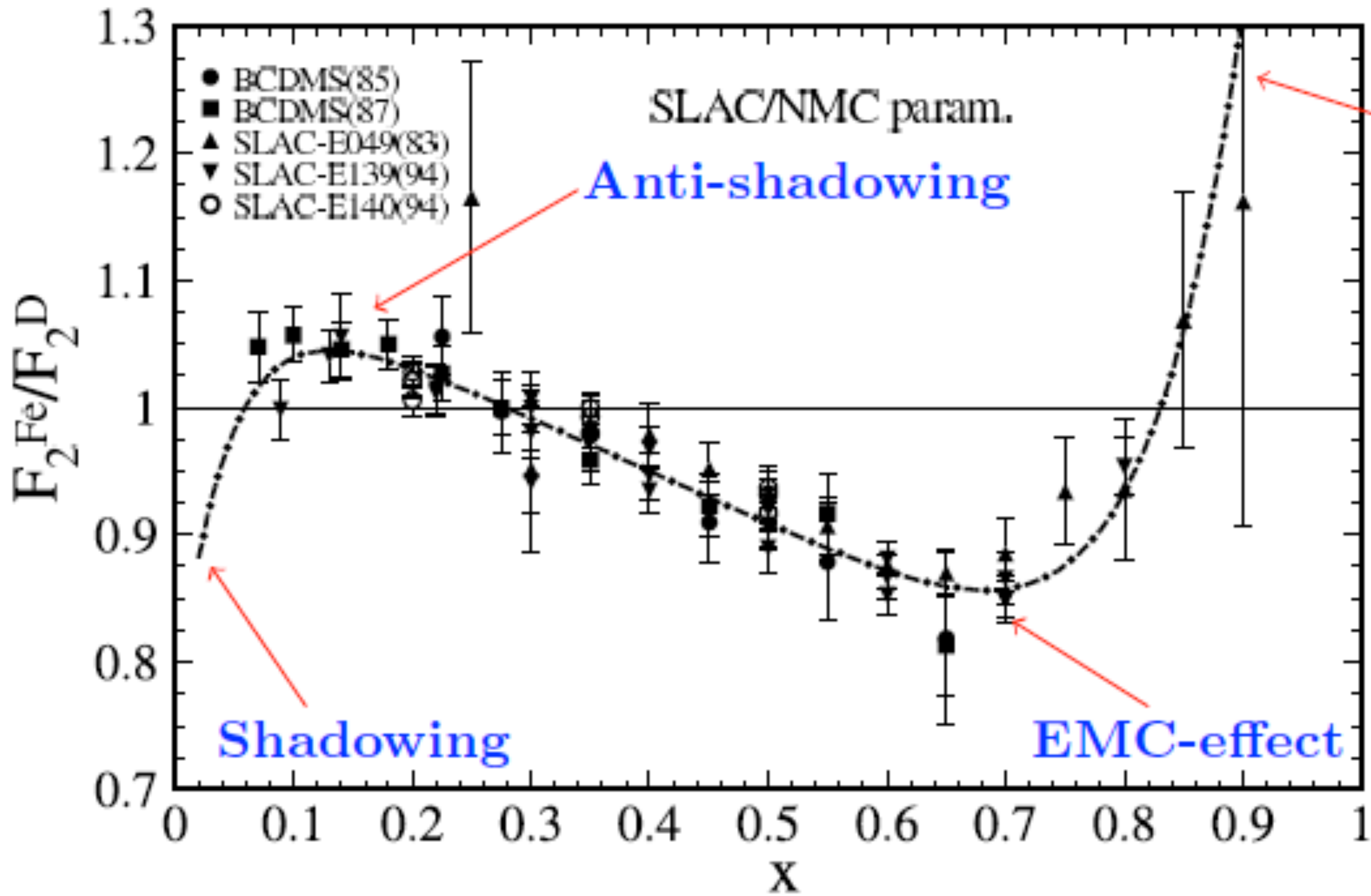
NUCLEAR PDF

- **Cross-sections in nuclear collisions are modified**

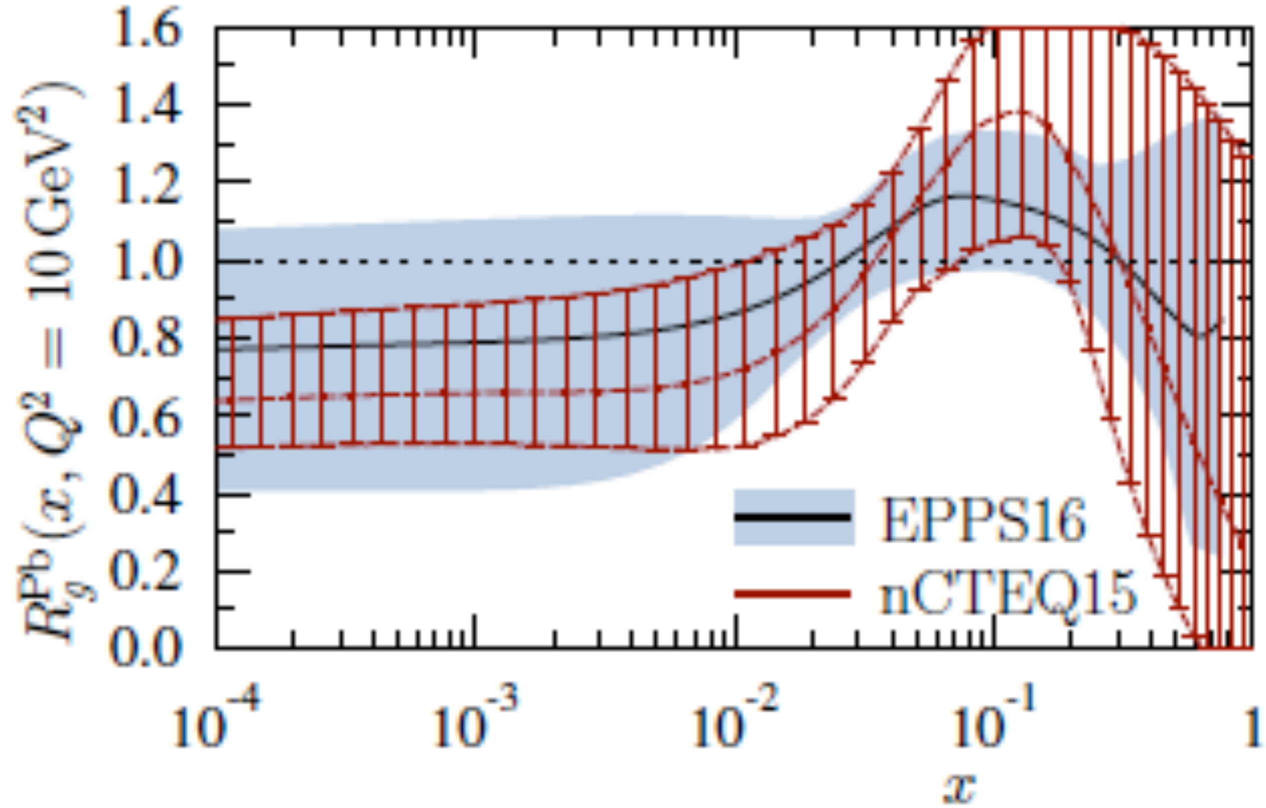


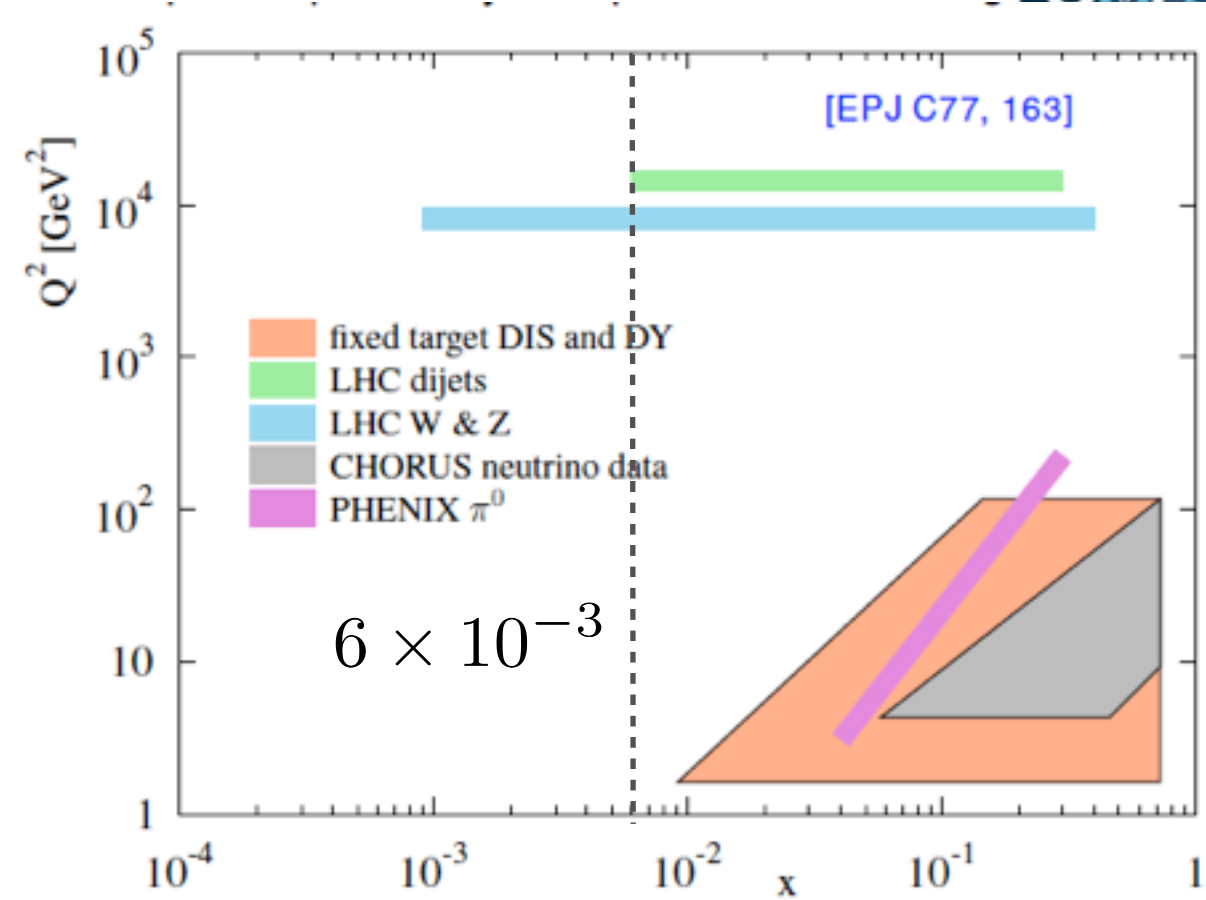
- $x \lesssim 10^{-2}$: shadowing
- $x \sim 10^{-1}$: anti-shadowing
- $0.3 \lesssim x \lesssim 0.7$: EMC effect
- $x \gtrsim 0.7$: Fermi motion

Such a modification can be translated into universal objects: nuclear PDFs (nPDFs)

TYPICAL GLUON NUCLEAR PDFS

Eskola, Paakkinen, Paukkunen, Salgado '16





- For the gluons, only the shadowing depletion is established although its magnitude is still discussed.
- The gluon antishadowing not yet observed although used in many studies; hence, absent in some nPDF fit.
- The gluon EMC effect is even less known, hence the uncertainty there.
- The heavy-quark production at the LHC may help to understand better the gluon density in nuclei.

Automating of computing nPDF effects

AN AUTOMATED CODE TO EVALUATE NPDF EFFECTS

Lansberg, HSS '17

- Partonic scattering cross section fit from pp data with a Crystal Ball function parametrizing $|\mathcal{A}_{gg\to\mathcal{H}X}|^2$

Kom, Kulesza, Stirling '11

$$\overline{|\mathcal{A}(k_1k_2\to\mathcal{H}+k_3)|^2}=\frac{\lambda^2\kappa s x_1 x_2}{M_{\mathcal{H}}^2}\exp\left(-\kappa\frac{\min(P_T^2,\langle P_T\rangle^2)}{M_{\mathcal{H}}^2}\right)\left(1+\theta(P_T^2-\langle P_T\rangle^2)\frac{\kappa}{n}\frac{P_T^2-\langle P_T\rangle^2}{M_Q^2}\right)^{-n}$$

- It is in principle can be applied to any single-inclusive particle production as long as knowing the fraction of initial partonic luminosity in priori (e.g. gluon-gluon dominance for heavy-flavour production at high-energy collisions).
- Applied to open/hidden charm/beauty hadrons (J/psi, Y, D and B)
- It is a way to evade the quarkonium-production-mechanism controversy (at least to some extent).
- The key point to compute nPDF effects is to have a partonic XS
- It can be validated with state-of-the-art pQCD computations (e.g. FONLL, GM-VFNS)
- Any nPDF set available in LHAPDF 5 or 6 can be used
- Not yet interface to a Glauber model (no centrality and no combination with other CNM effects)

AN AUTOMATED CODE TO EVALUATE NPDF EFFECTS

Lansberg, HSS '17

- Extensive comparisons directly with data

  makes sense only when nPDF are the dominant CNM

- One can test this hypothesis by comparing our curves with data

  Global agreement $\overset{?}{\Rightarrow}$ only nPDFs matter

- One can go further in the theory-data comparison with reweighting
- Bonus: since the pp yields are fit, the procedure sometimes hints a normalisation issues (bar R_{FB}) which could otherwise be misinterpreted as nuclear suppressions or enhancements.
- It allows one to study different nPDF sets AND the scale uncertainties as well as a better control of the theory uncertainties
- Last but not least: it allows one to study different nPDF sets AND the scale uncertainties as well as a better control of the theory uncertainties
- Disclaimer: it does not provide any insight on the production mechanisms but provides us efficient and controlled (inter/extra)polations of the differential XS in the space (x_1,x_2,y,p_T).

FITTING THE PP DATA

Lansberg, HSS '17

- Starting with the J/psi

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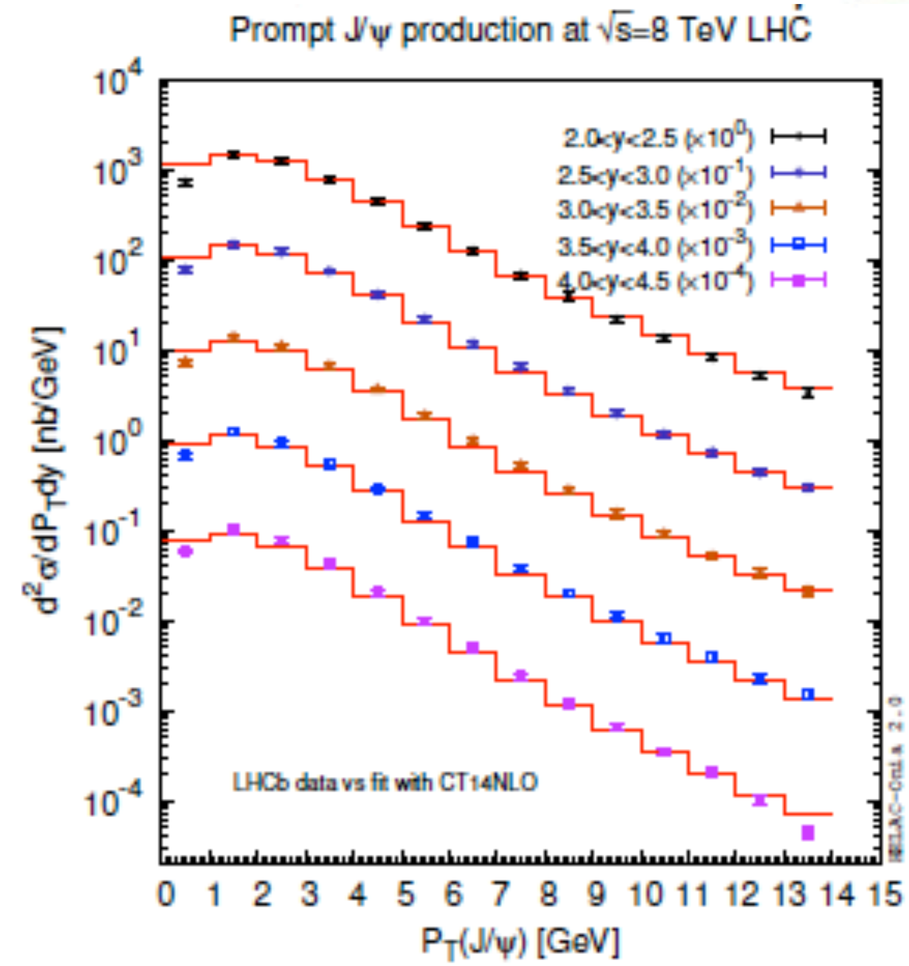

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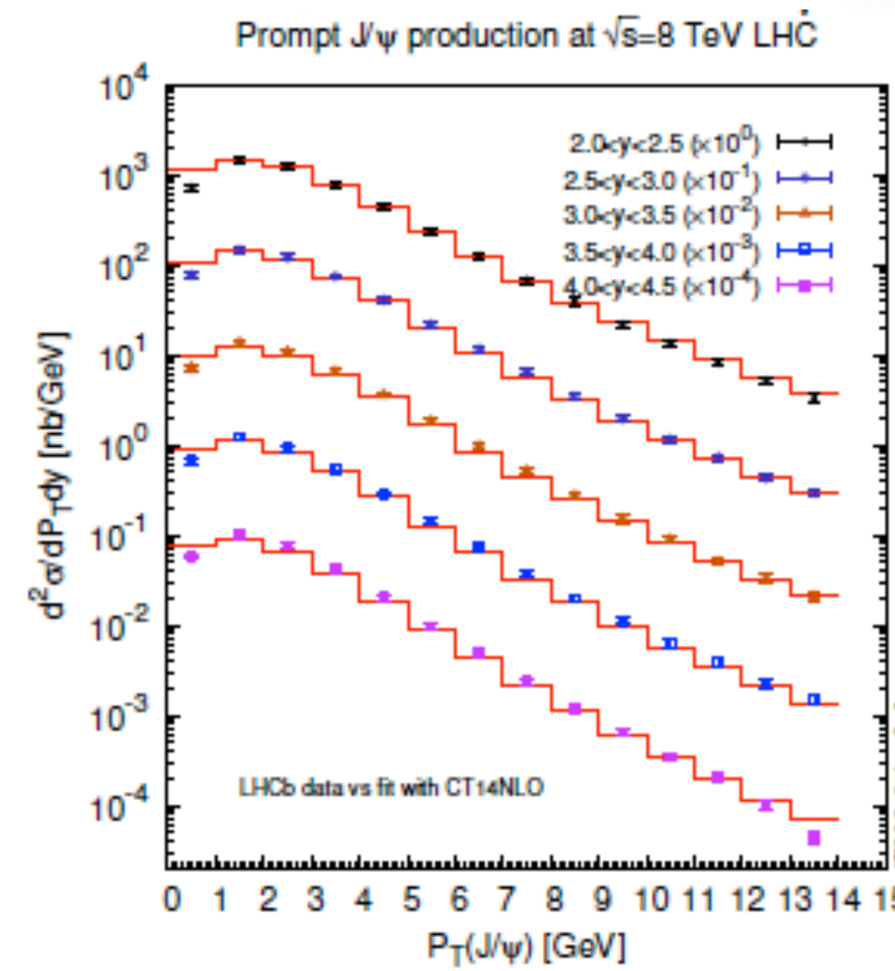

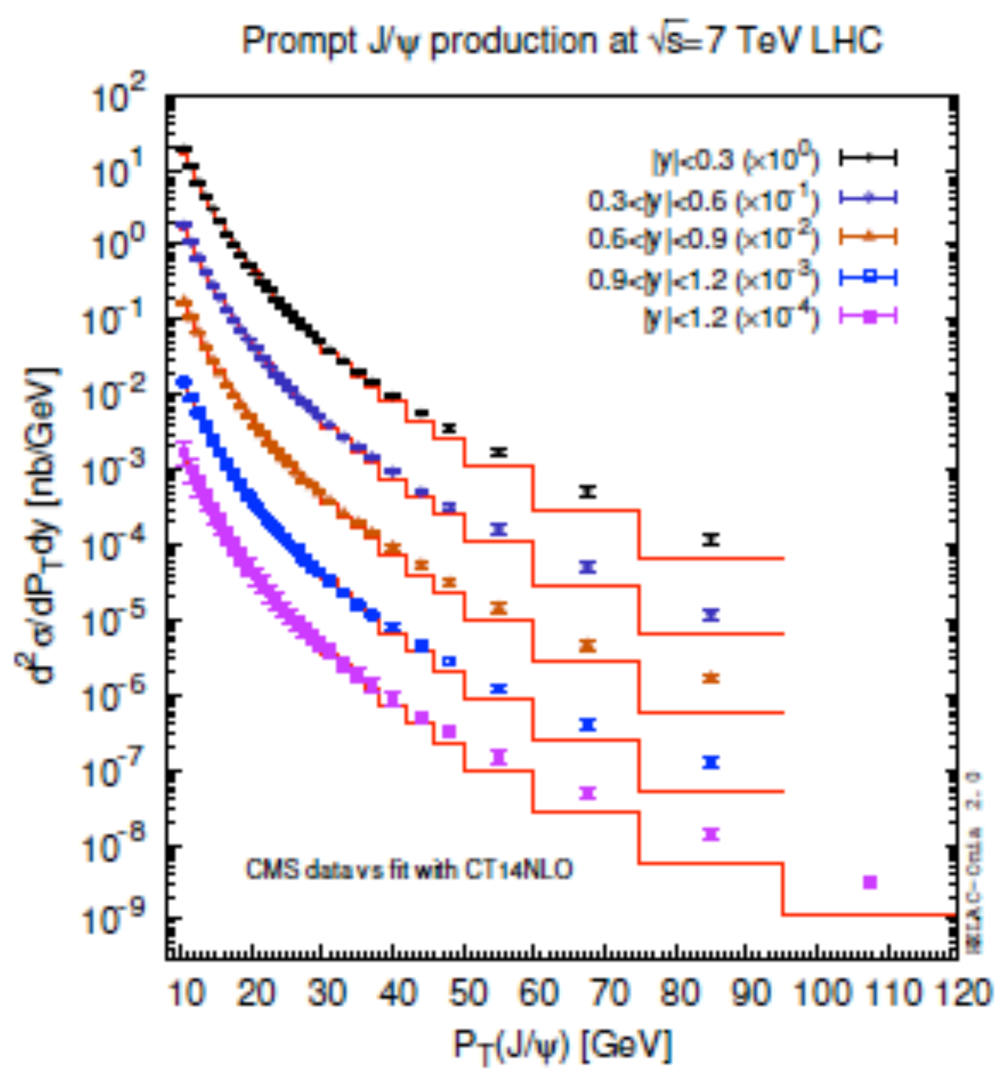

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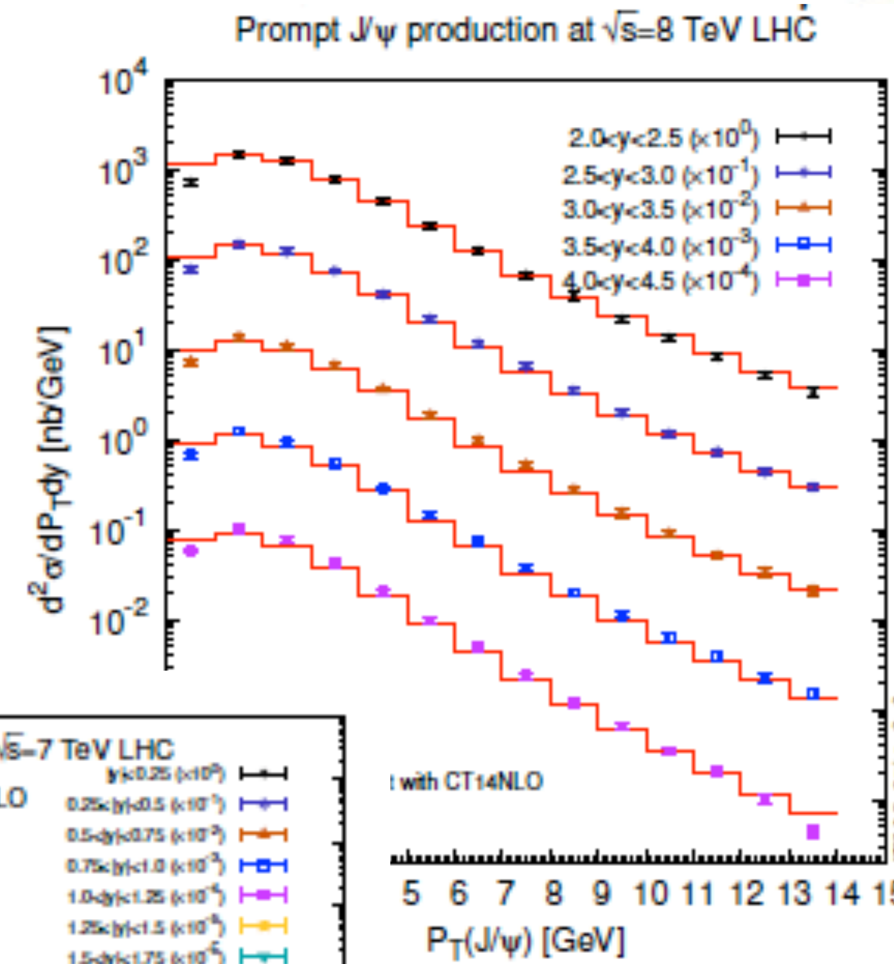

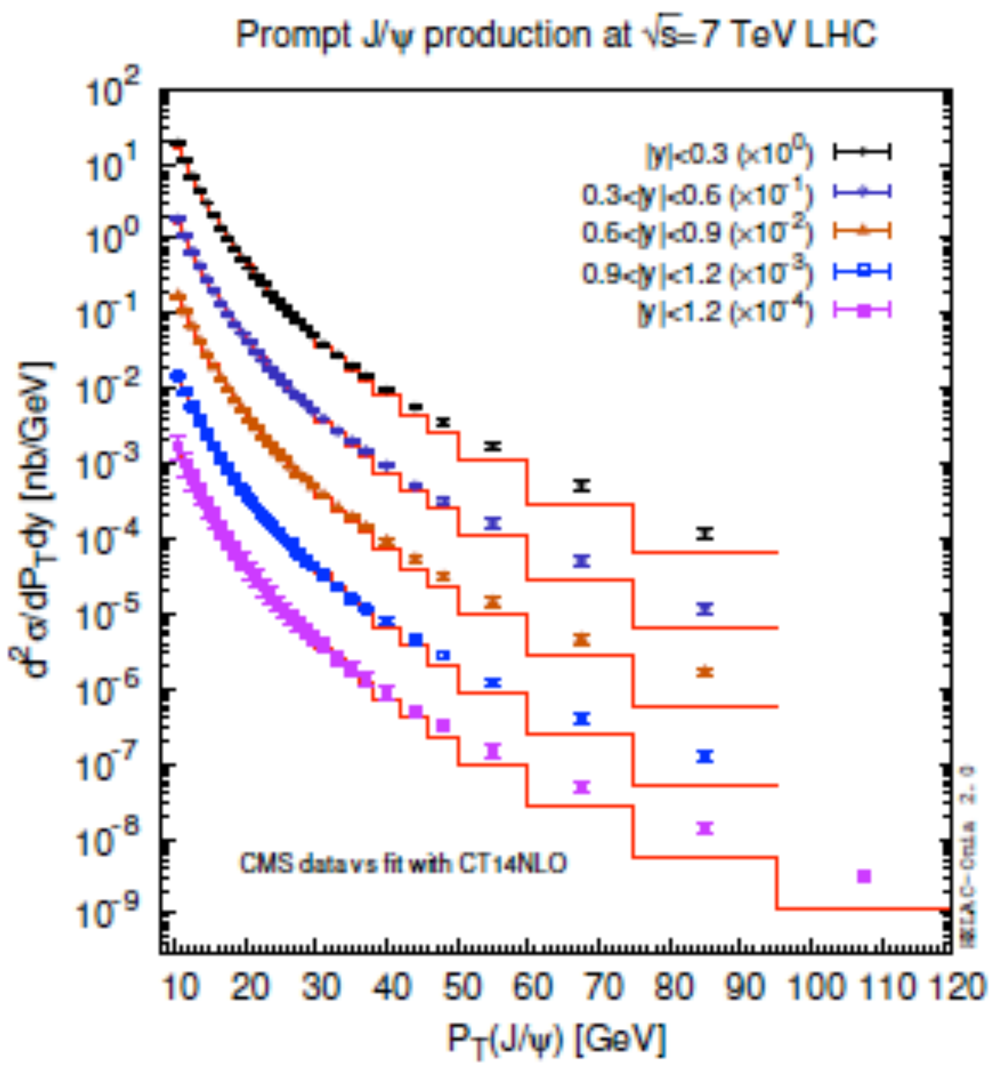

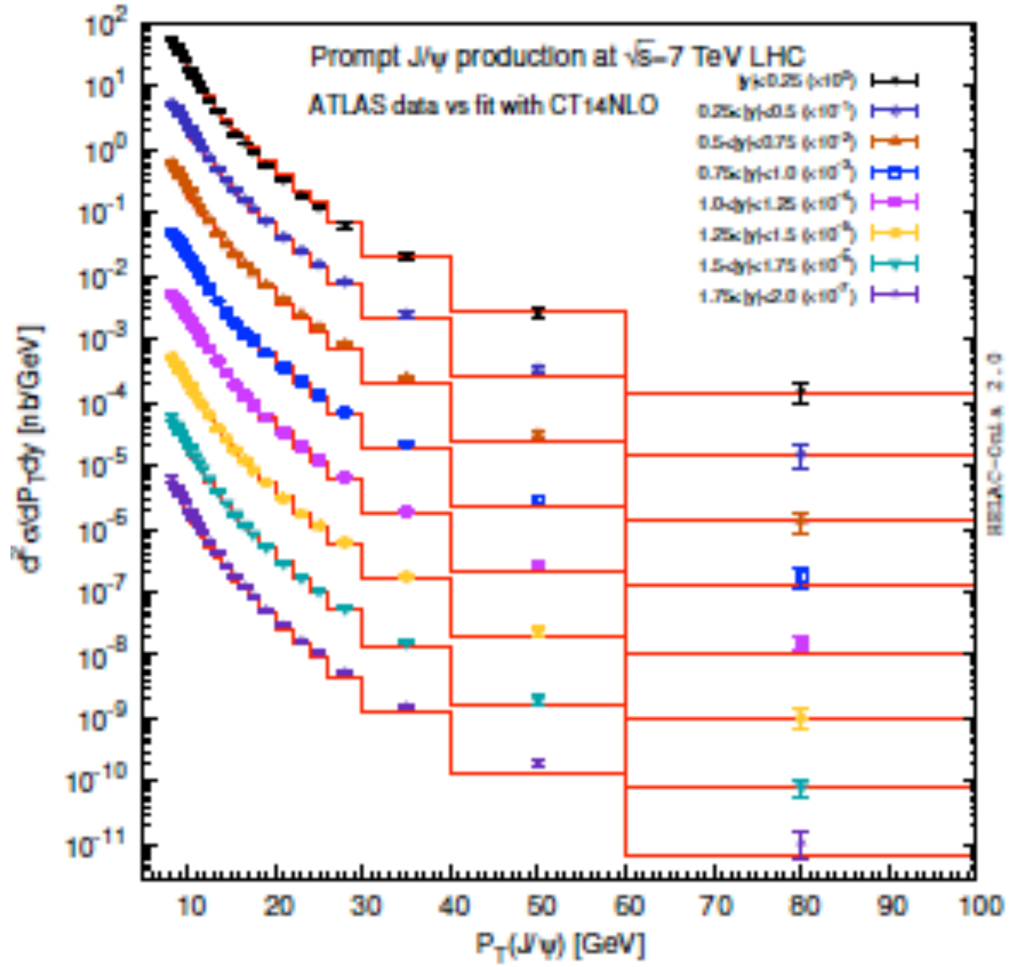

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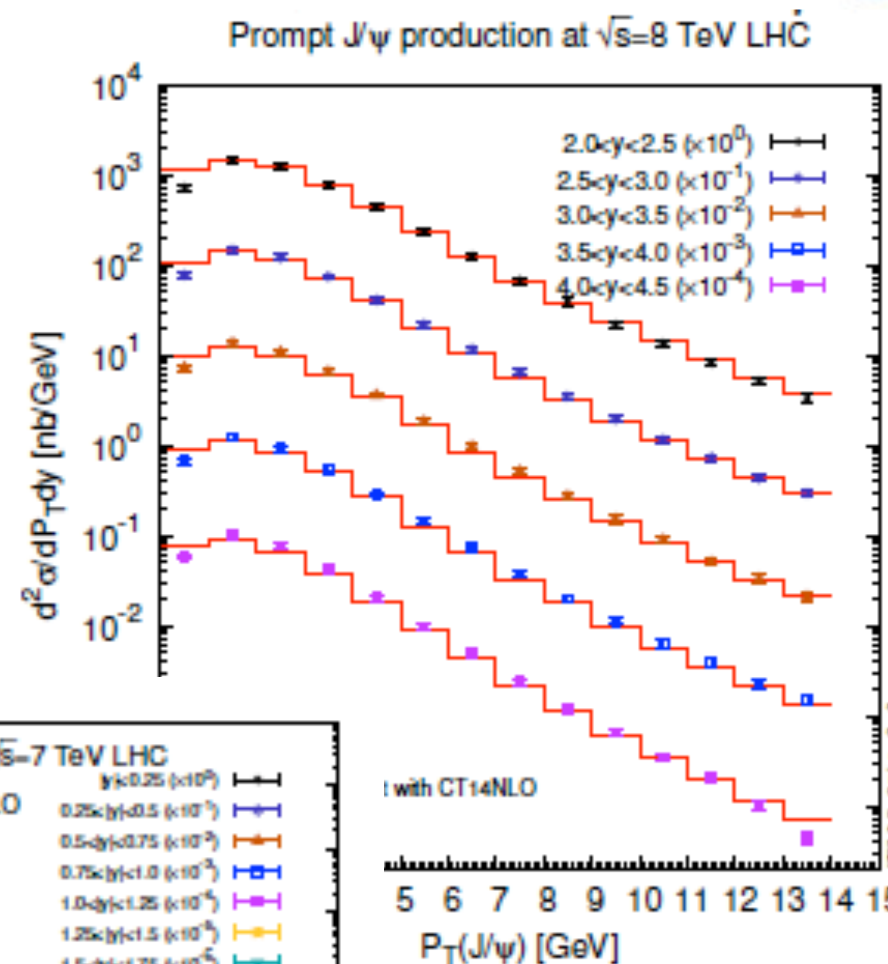
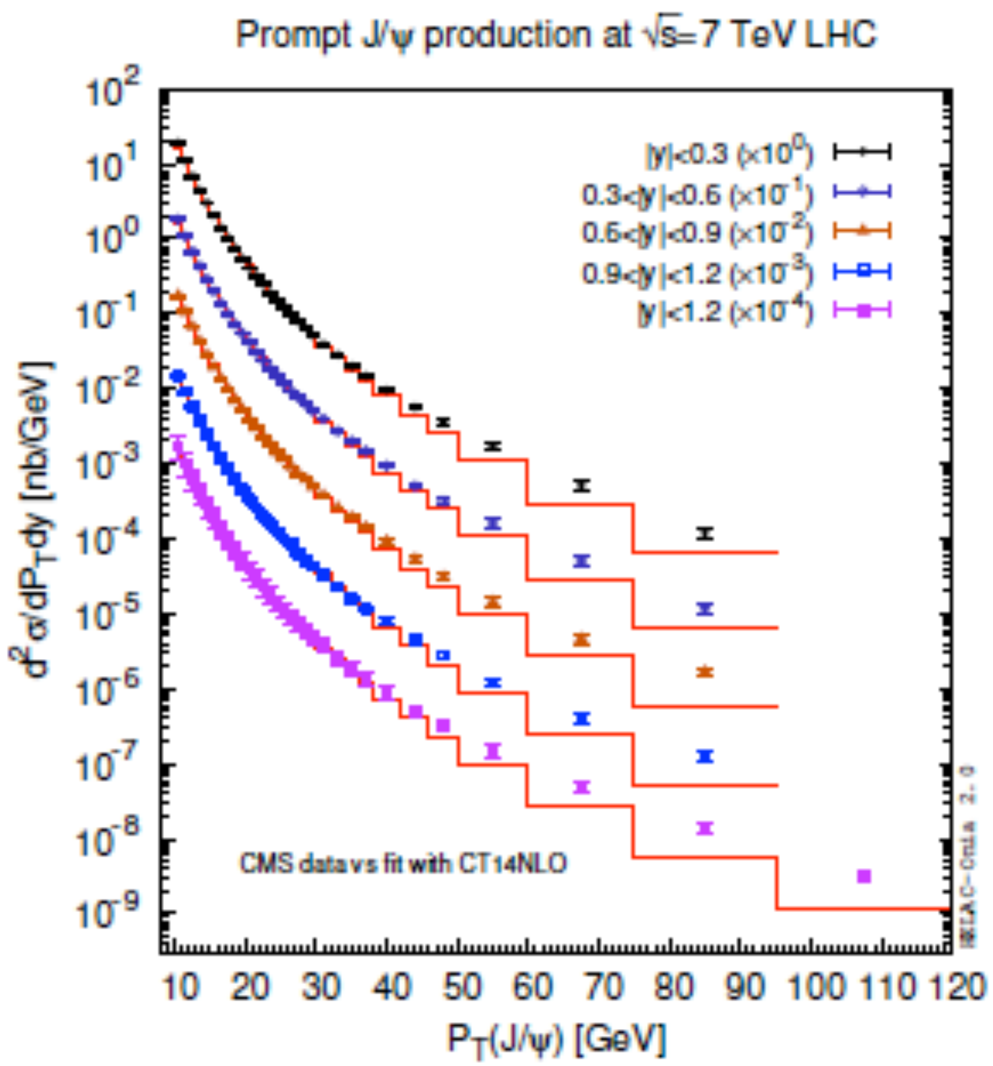
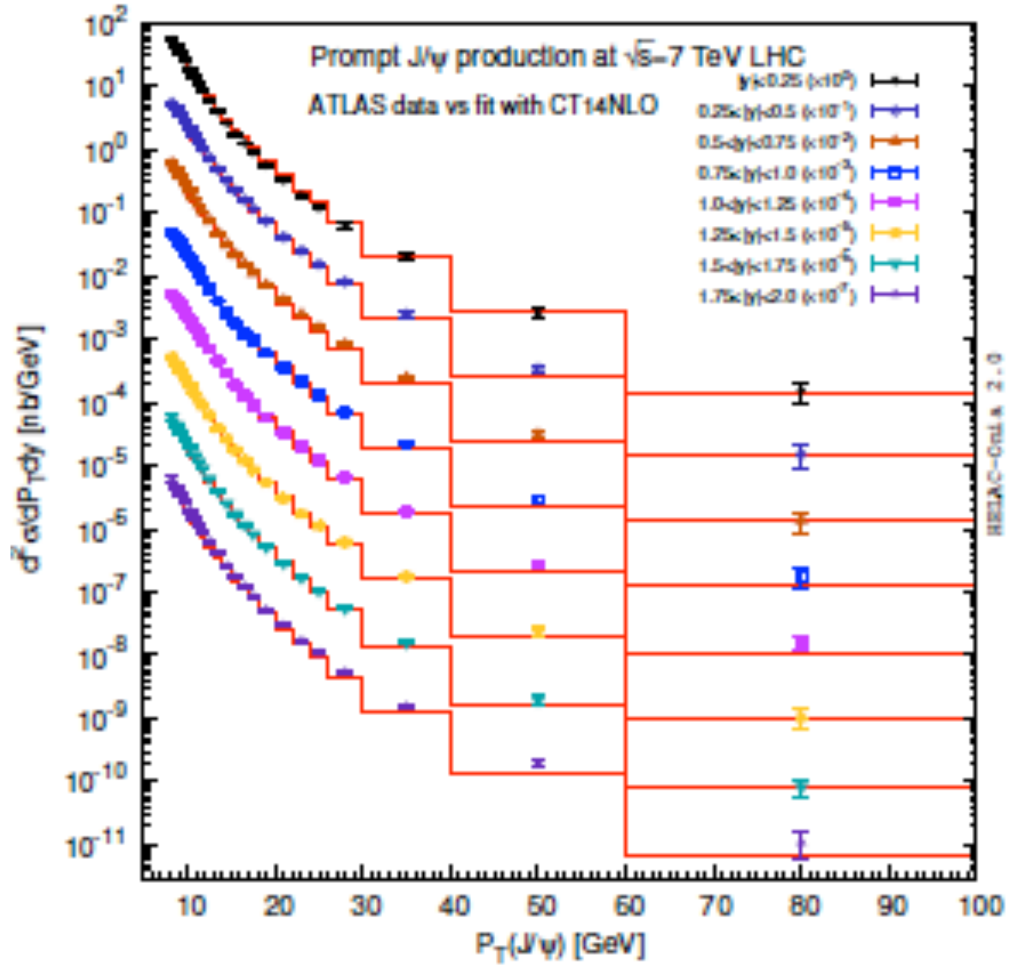
FITTING THE PP DATA

Lansberg, HSS '17

- Starting with the J/psi
- Extremely good fit of the LHCb data (bar may be the 1st bin)
- Not as good at high p_T with CMS ...
- But very good with ATLAS
- Tension between CMS - ATLAS ?



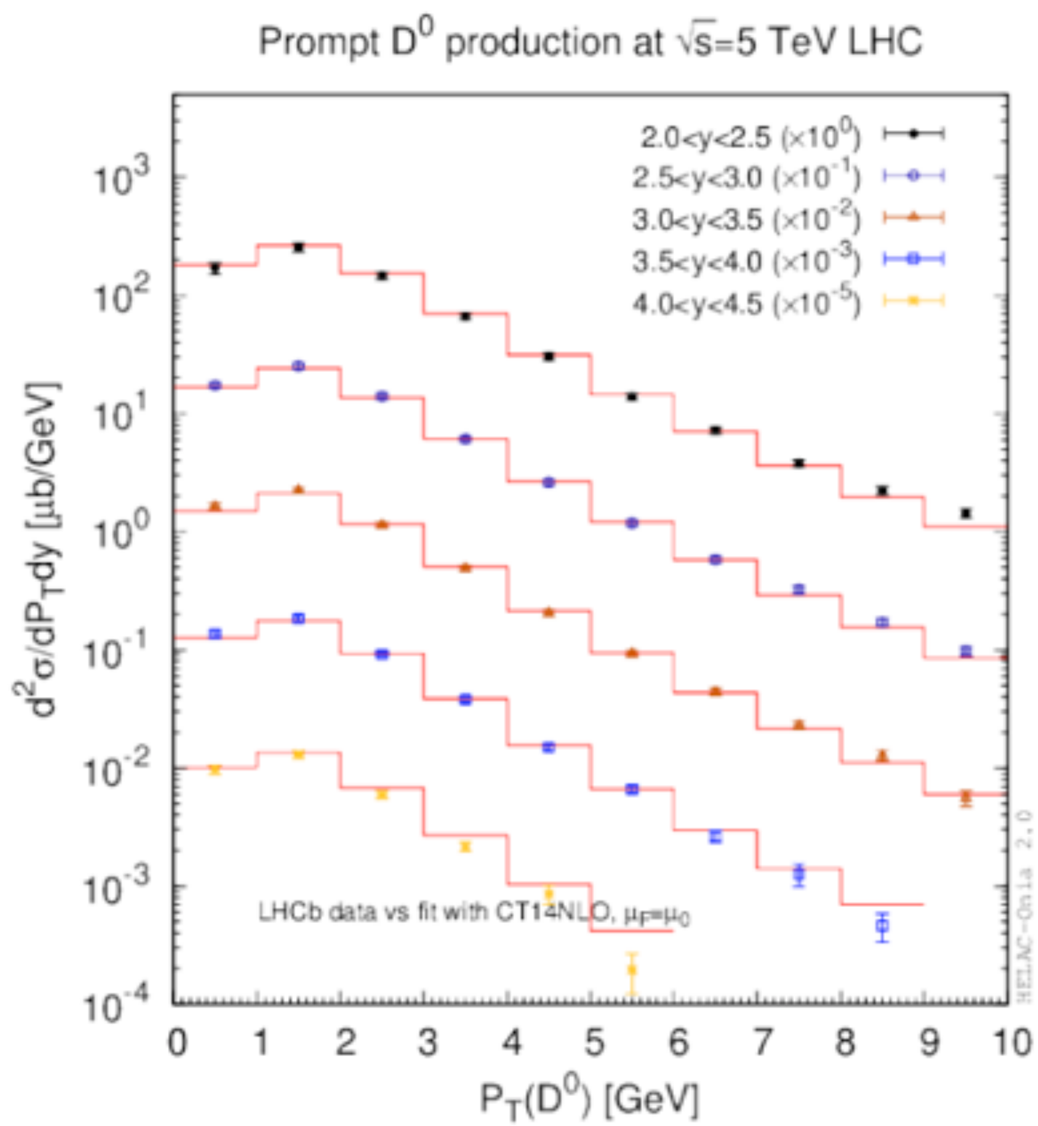




FITTING THE PP DATA

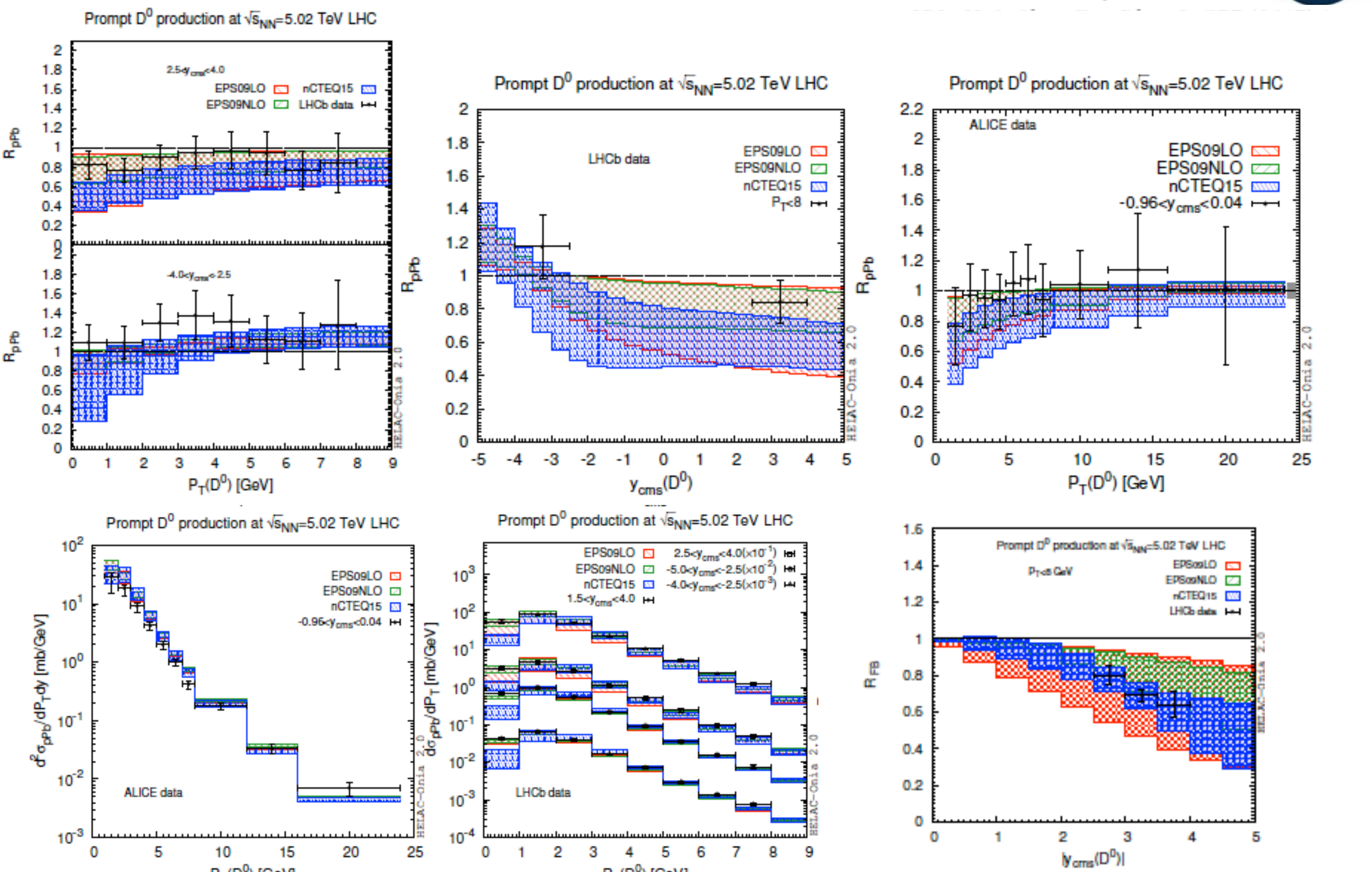
Lansberg, HSS '17

- Above exercises can be used also for Y, eta_c, D, B etc
- Especially, one can compare with relatively well-understood pQCD computations for open charm/beauty
- For example, extremely good fit for D^0 measured by LHCb



RESULTS FOR PA: D^0

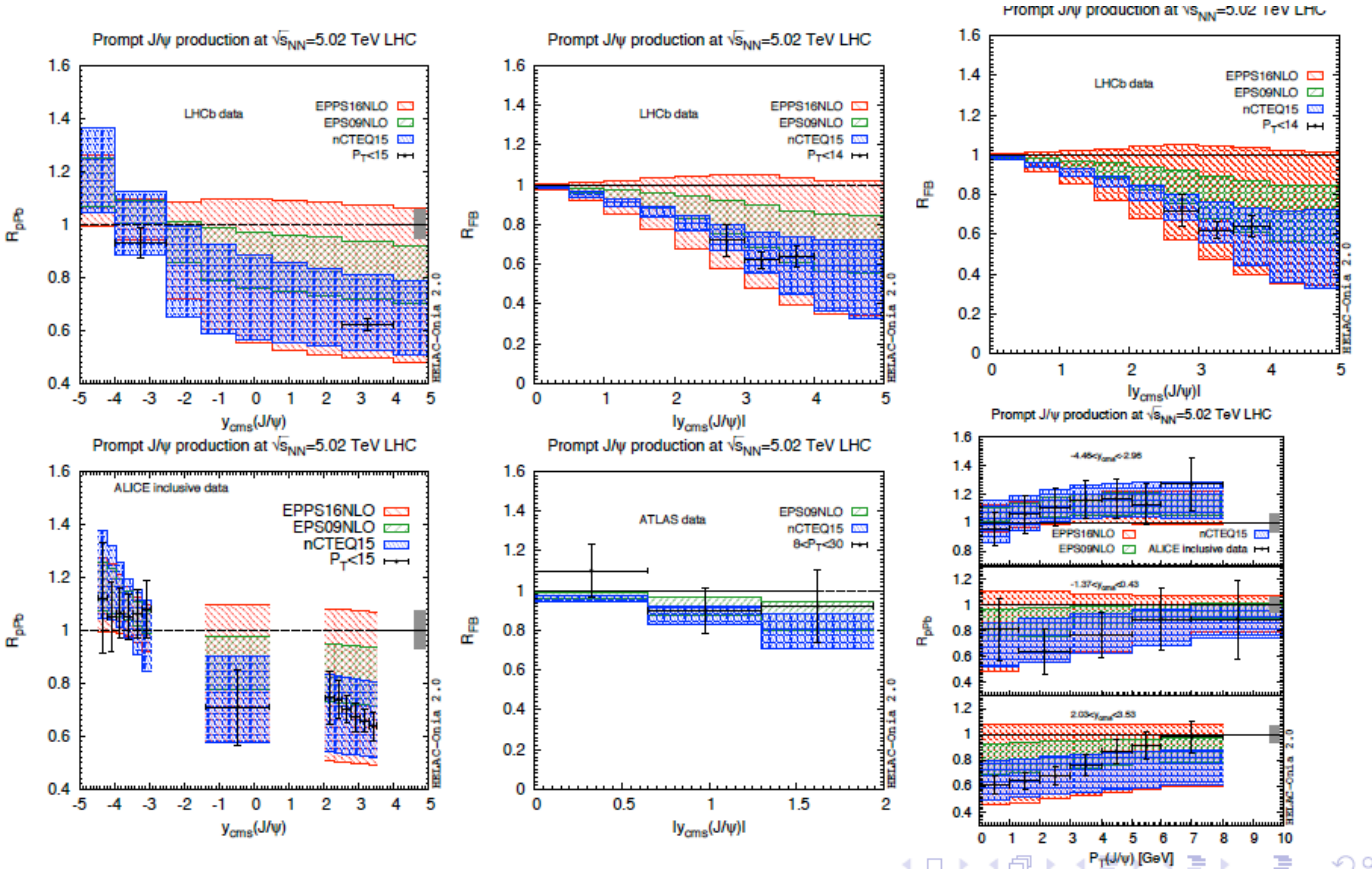
Lansberg, HSS '17



RESULTS FOR PA: J/PSI

Lansberg, HSS '17

- nCTEQ15, EPPS16, EPS09 etc



First step toward the inclusion of HF data in an nPDF fit: reweighting

REWEIGHTING FOR HESSIAN PDFS

Giele, Keller '98; Ball et al. '11; Sato, Owens, Prosper '14; Paukkunen, Zurita '14;

1. Convert Hessian error PDFs into replicas

$$f_k = f_0 + \sum_i^N \frac{f_i^{(+)} - f_i^{(-)}}{2} R_{ki},$$

2. Calculate weights for each replica

$$w_k = \frac{e^{-\frac{1}{2}\chi_k^2/T}}{\frac{1}{N_{\rm rep}} \sum_i^{N_{\rm rep}} e^{-\frac{1}{2}\chi_k^2/T}}, \qquad \chi_k^2 = \sum_j^{N_{\rm data}} \frac{(D_j - T_j^k)^2}{\sigma_j^2}$$

3. Calculate observables with new (reweighted) PDFs

$$\langle \mathcal{O} \rangle_{\rm new} = \frac{1}{N_{\rm rep}} \sum_{k=1}^{N_{\rm rep}} w_k \mathcal{O}(f_k),$$

$$\delta \langle \mathcal{O} \rangle_{\rm new} = \sqrt{\frac{1}{N_{\rm rep}} \sum_{k=1}^{N_{\rm rep}} w_k \left(\mathcal{O}(f_k) - \langle \mathcal{O} \rangle\right)^2}.$$

REWEIGHTING FOR HESSIAN PDFS

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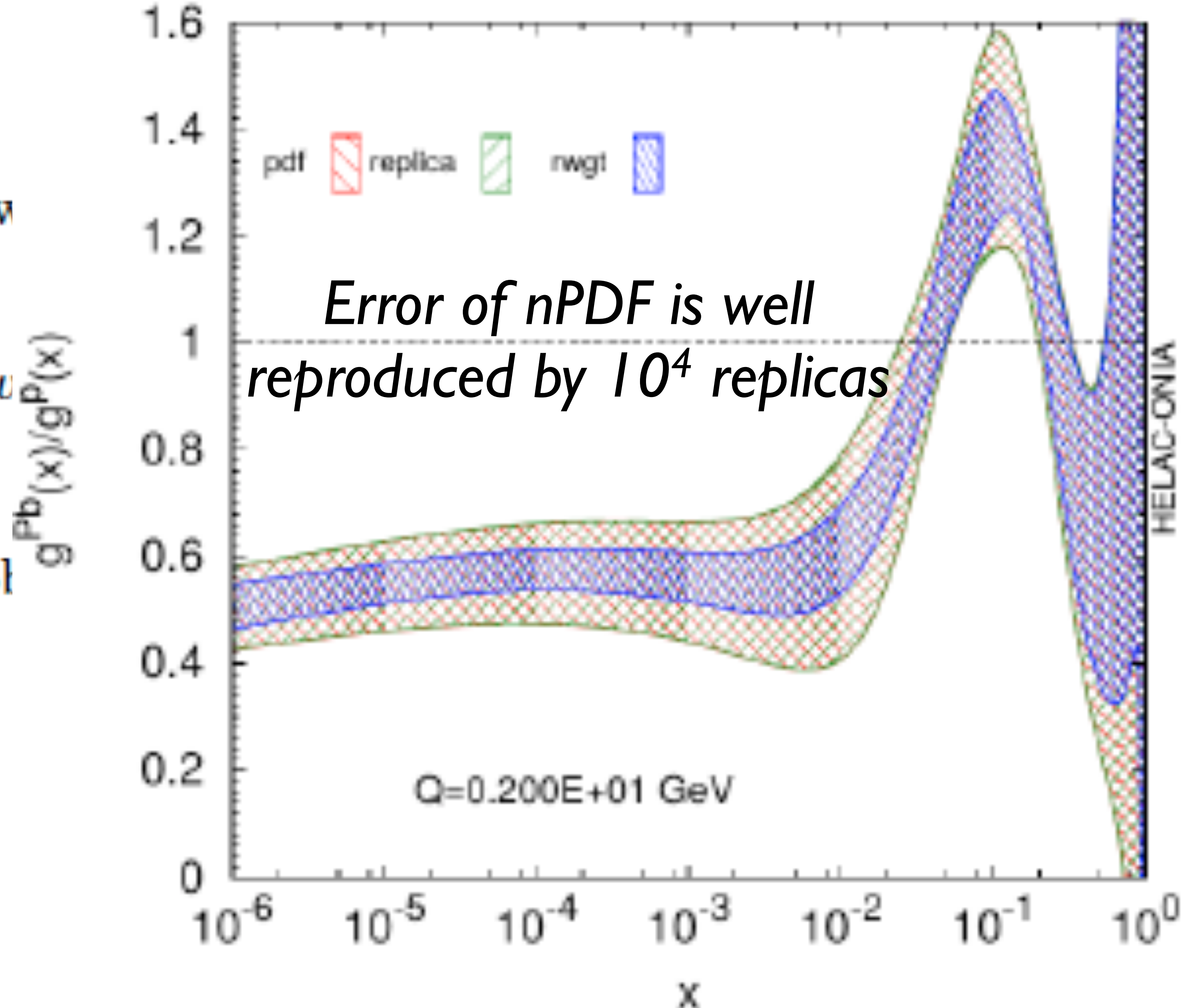
1. Convert Hessian error PDFs into replicas

$N \quad (+) \quad (-)$

2. Calculate w

$w \quad \cdots \quad - T_j^k)^2 / \sigma_j^2$



3. Calculate ol

$N_{rep} \quad k=1$

USED DATA SETS

Cacciari, Kusina, Lansberg, Schienbein, HSS '17

	D^0	J/ψ	$B \to J/\psi$	$\Upsilon(1S)$
μ_0	$\sqrt{4M^2_{D^0} + P^2_{T,D^0}}$	$\sqrt{M^2_{J/\psi} + P^2_{T,J/\psi}}$	$\sqrt{4M^2_B + \left(\frac{M_B}{M_{J/\psi}} P_{T,J/\psi}\right)^2}$	$\sqrt{M^2_{\Upsilon(1S)} + P^2_{T,\Upsilon(1S)}}$
p+p data	LHCb (1)	LHCb (2; 3)	LHCb (2; 3)	ALICE (4), ATLAS (5), CMS (6), LHCb (7; 8)
R_{pPb} data	ALICE (9), LHCb (15)	ALICE (10; 11), LHCb (16; 12)	LHCb (12)	ALICE (13), ATLAS (14), LHCb (17)

[1] LHCb, R. Aaij et al., JHEP **06**, 147 (2017), 1610.02230.
[2] LHCb, R. Aaij et al., Eur. Phys. J. **C71**, 1645 (2011), 1103.0423.
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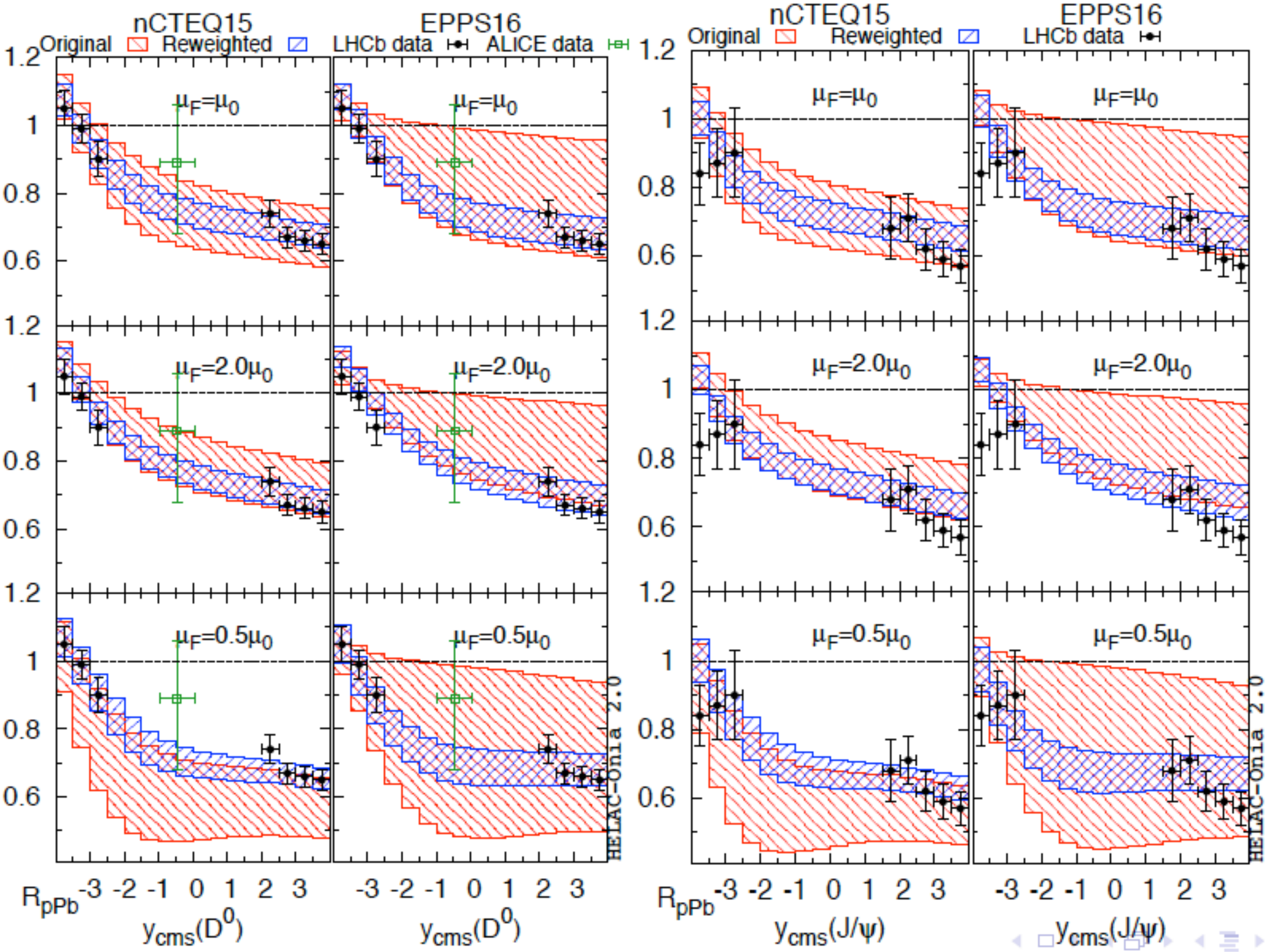
[4] ALICE, B. B. Abelev et al., Eur. Phys. J. **C74**, 2974 (2014), 1403.3648.
[5] ATLAS, G. Aad et al., Phys. Rev. **D87**, 052004 (2013), 1211.7255.
[6] CMS, S. Chatrchyan et al., Phys. Lett. **B727**, 101 (2013), 1303.5900.
[7] LHCb, R. Aaij et al., Eur. Phys. J. **C72**, 2025 (2012), 1202.6579.
[8] LHCb, R. Aaij et al., JHEP **11**, 103 (2015), 1509.02372.
[9] ALICE, B. B. Abelev et al., Phys. Rev. Lett. **113**, 232301 (2014), 1405.3452.
[10] ALICE, J. Adam et al., JHEP **06**, 055 (2015), 1503.07179.
[11] ALICE, B. B. Abelev et al., JHEP **02**, 073 (2014), 1308.6726.
[12] LHCb, R. Aaij et al., (2017), 1706.07122.
[13] ALICE, B. B. Abelev et al., Phys. Lett. **B740**, 105 (2015), 1410.2234.
[14] The ATLAS collaboration, (2015), ATLAS-CONF-2015-050.
[15] LHCb, R. Aaij et al., (2017), 1707.02750.
[16] LHCb, R. Aaij et al., JHEP **02**, 072 (2014), 1308.6729.
[17] LHCb, R. Aaij et al., JHEP **07**, 094 (2014), 1405.5152.

REWEIGHTING RESULTS: D^0 AND J/PSI

68% CL

Cacciari, Kusina, Lansberg, Schienbein, HSS '17

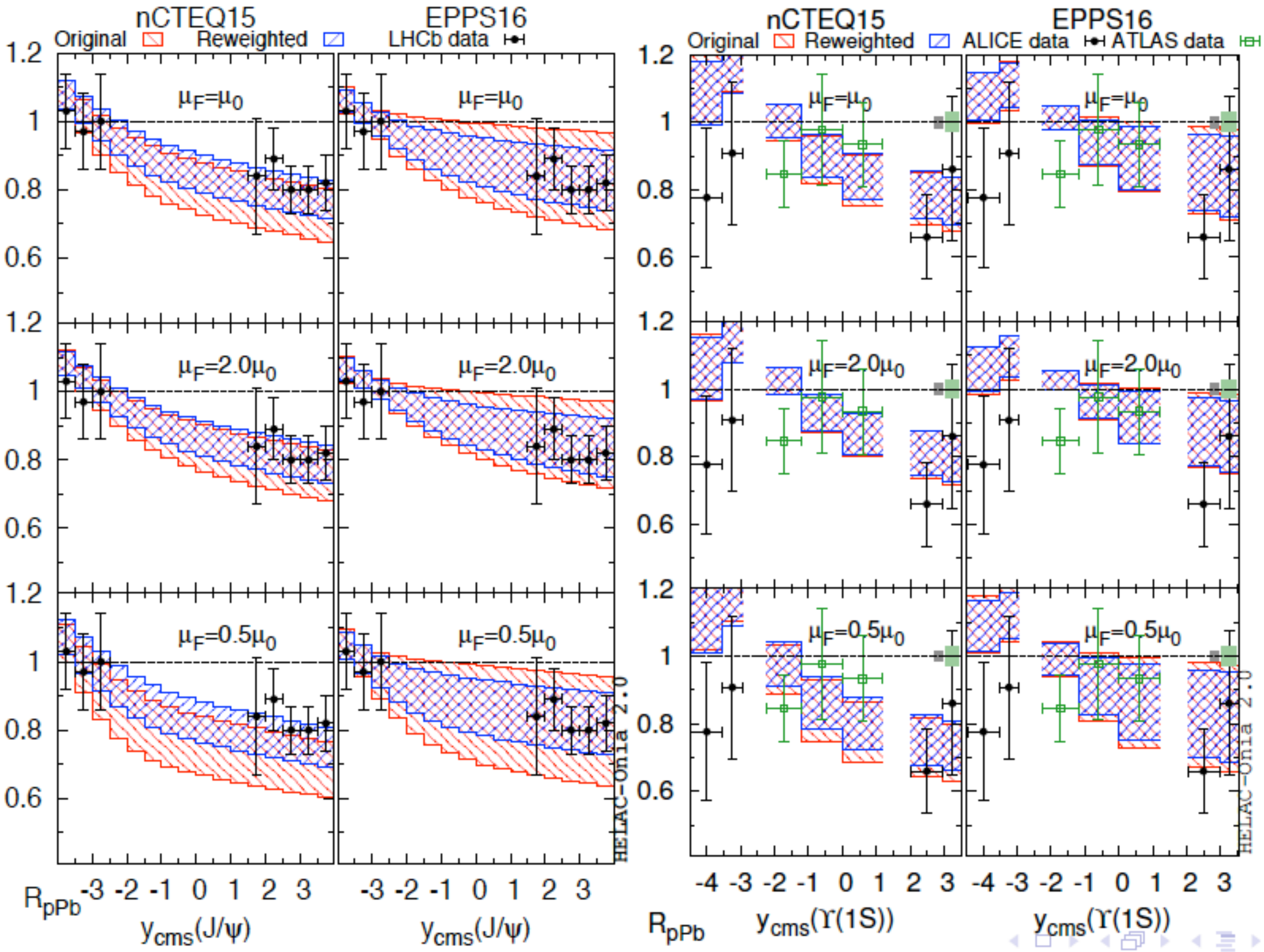


Changing the scale has two effects:
1) the uncertainty tends to increase at low μ_F
2) since the shadowing suppression (in/de)creases for (de/in)creasing μ_F, the reweighted nPDF from data shifts within the original uncertaities

REWEIGHTING RESULTS: B->J/PSI AND Y

68% CL

Cacciari, Kusina, Lansberg, Schienbein, HSS '17

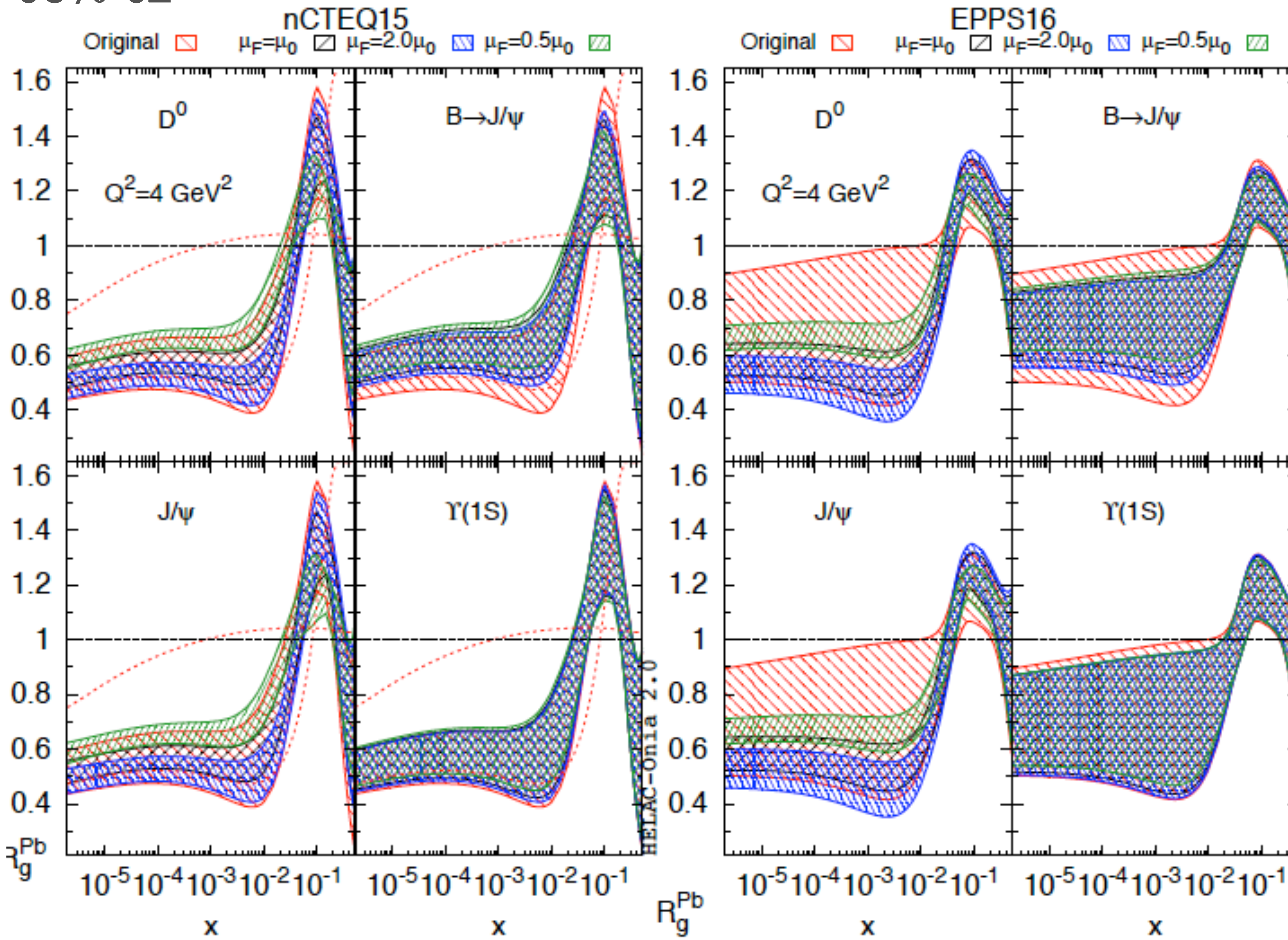


Compared to the D and J/ψ cases,
1) the scales uncertainties are smaller, but
2) the data are not yet as precise

RESULTS OF REWEIGHTED NPDFS

68% CL

Cacciari, Kusina, Lansberg, Schienbein, HSS '17



- Global coherence of the data constrains: necessary condition to assume a shadowing-only approach
- First clear exp. obser. on gluon shadowing at low x_{bj}: visible reduction of EPPS16 uncertainties; confirmation of nCTEQ15 extrapolation (reduction after including two similar-good extreme cases)

- The scale ambiguity for D and J/psi production is now the dominant uncertainty
- B or non-prompt J/psi are promising if precision of the data can be improved

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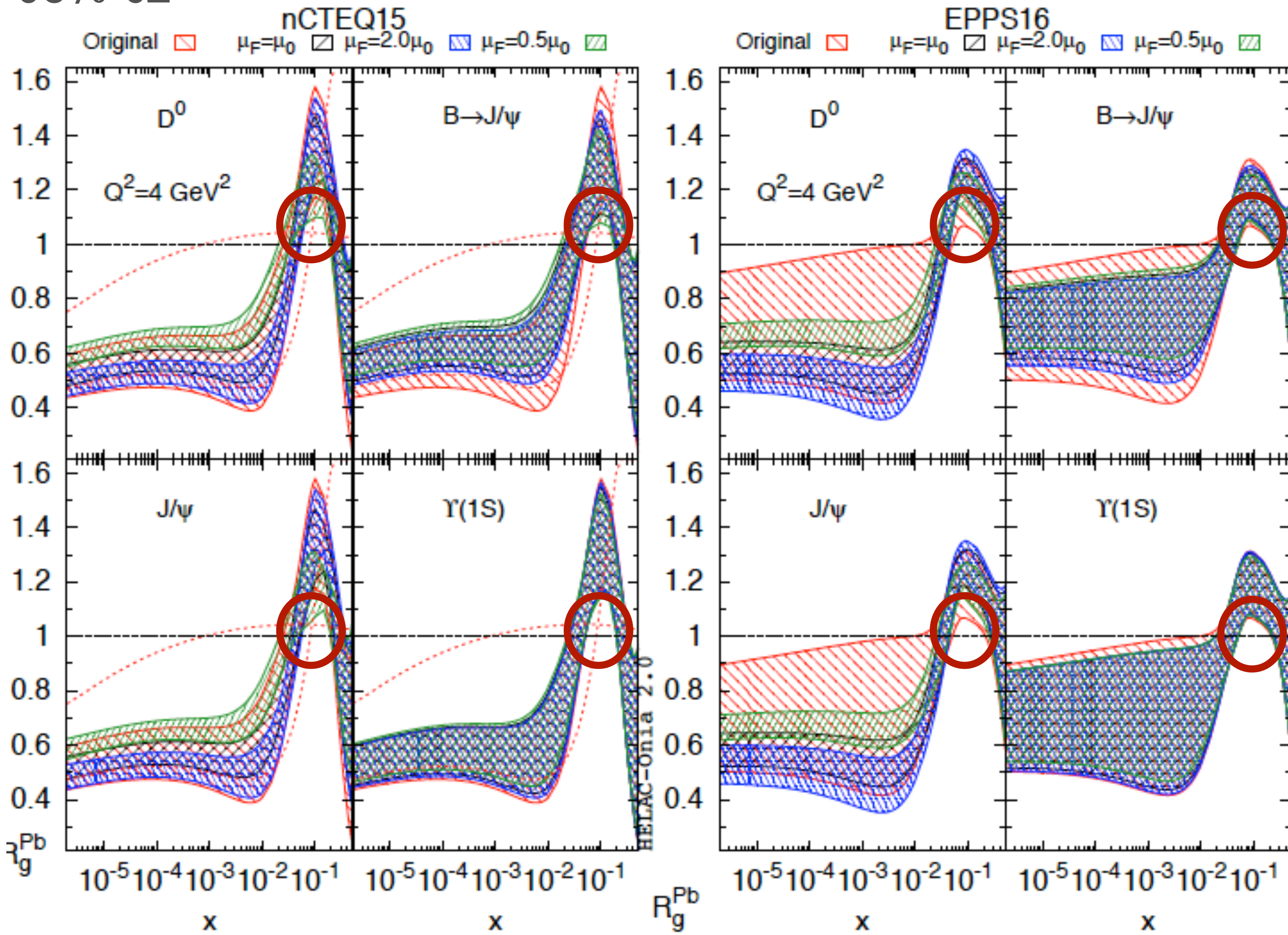

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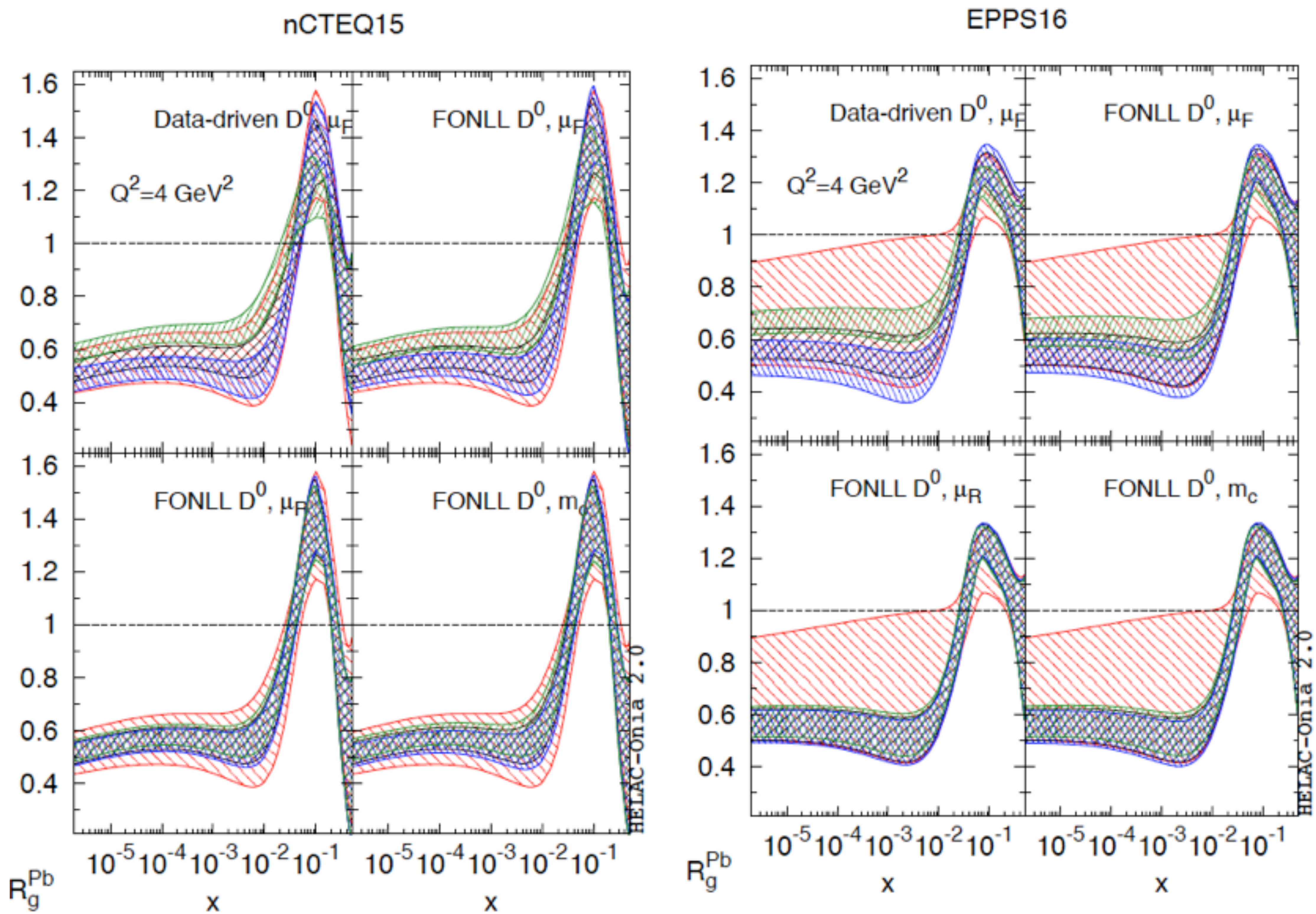
- The scale ambiguity for D and J/psi production is now the dominant uncertainty
- B or non-prompt J/psi are promising if precision of the data can be improved
- Confirmation of the existence of a gluon anti-shadowing: $R_g(0.05 \lesssim x <\lesssim 0.1) > 1$

VALIDATE WITH FONLL FOR OPEN CHARM/BEAUTY

Cacciari, Kusina, Lansberg, Schienbein, HSS '17



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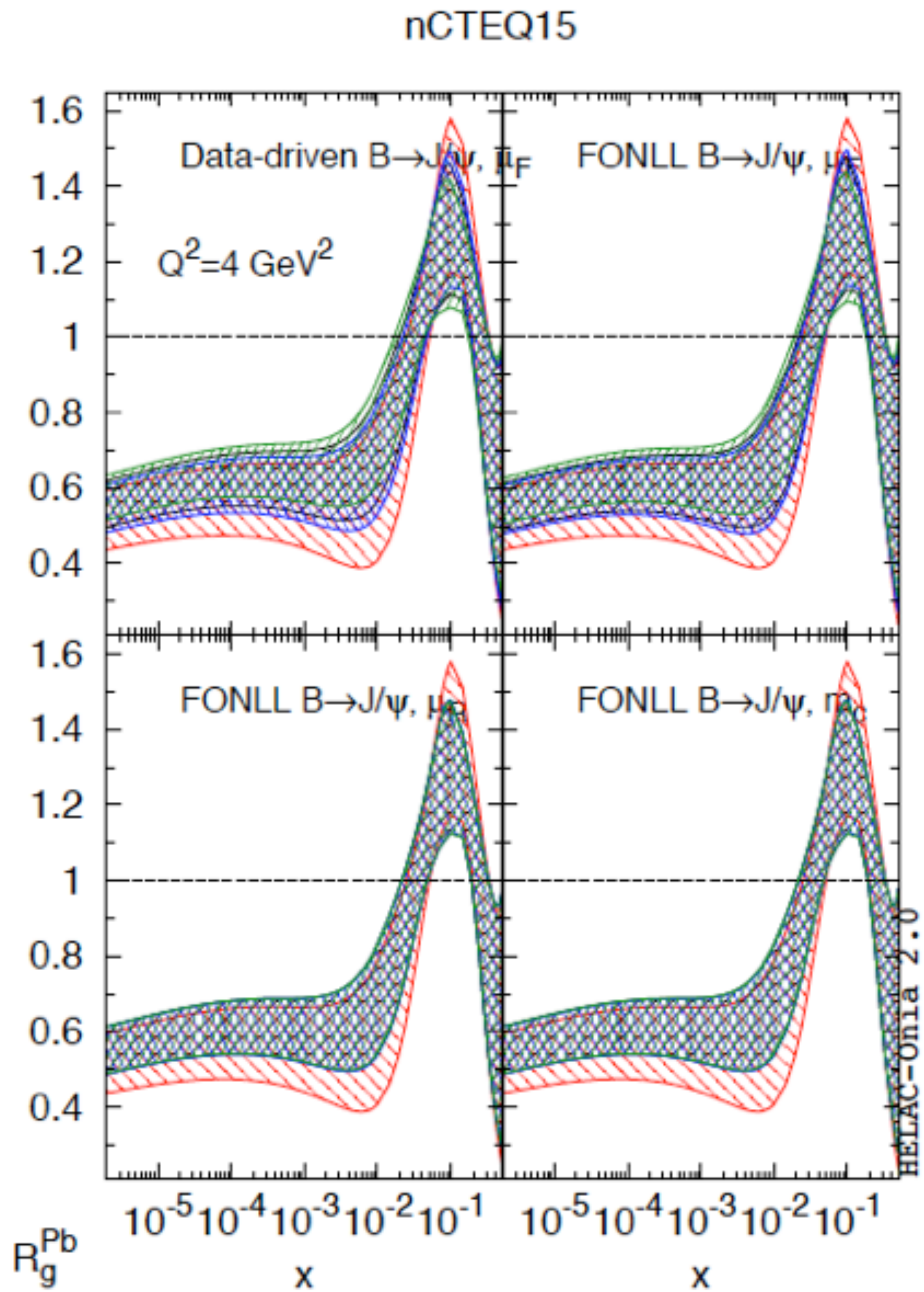

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CONCLUSIONS

- Gluon nPDFs at low x are extrapolated: no low x data used in fits

  $\rightarrow$ need for new constraints at $x \leq 10^{-3}$
- We have proposed a quick and robust method to evaluate nPDF effects, which is complementary to full but time consuming pQCD computations
- With standard theory-data comparisons, and with (n)PDF Bayesian reweighting technique, we tested and validated a shadowing-only hypothesis with HF (D, J/psi, B->J/psi, Y) LHC data
- Under this hypothesis, we call for an experimental observation of shadowing and anti-shadowing
- We thoroughly considered the scale uncertainty in pA for the 1st time
- For charm, it induces uncertainties as large as the reweighted nPDF err
- Other HF hadrons as well as the HF leptons could be added to the list as well as other differential data [no drastic change expected with the current data]

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Thank you for your attention !