Probing gluon nPDF with heavy quark(onium)

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LPTHE
LABORATOIRE DE PHYSIQUE THEORIQUE ET HAUTES ENERGIES

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

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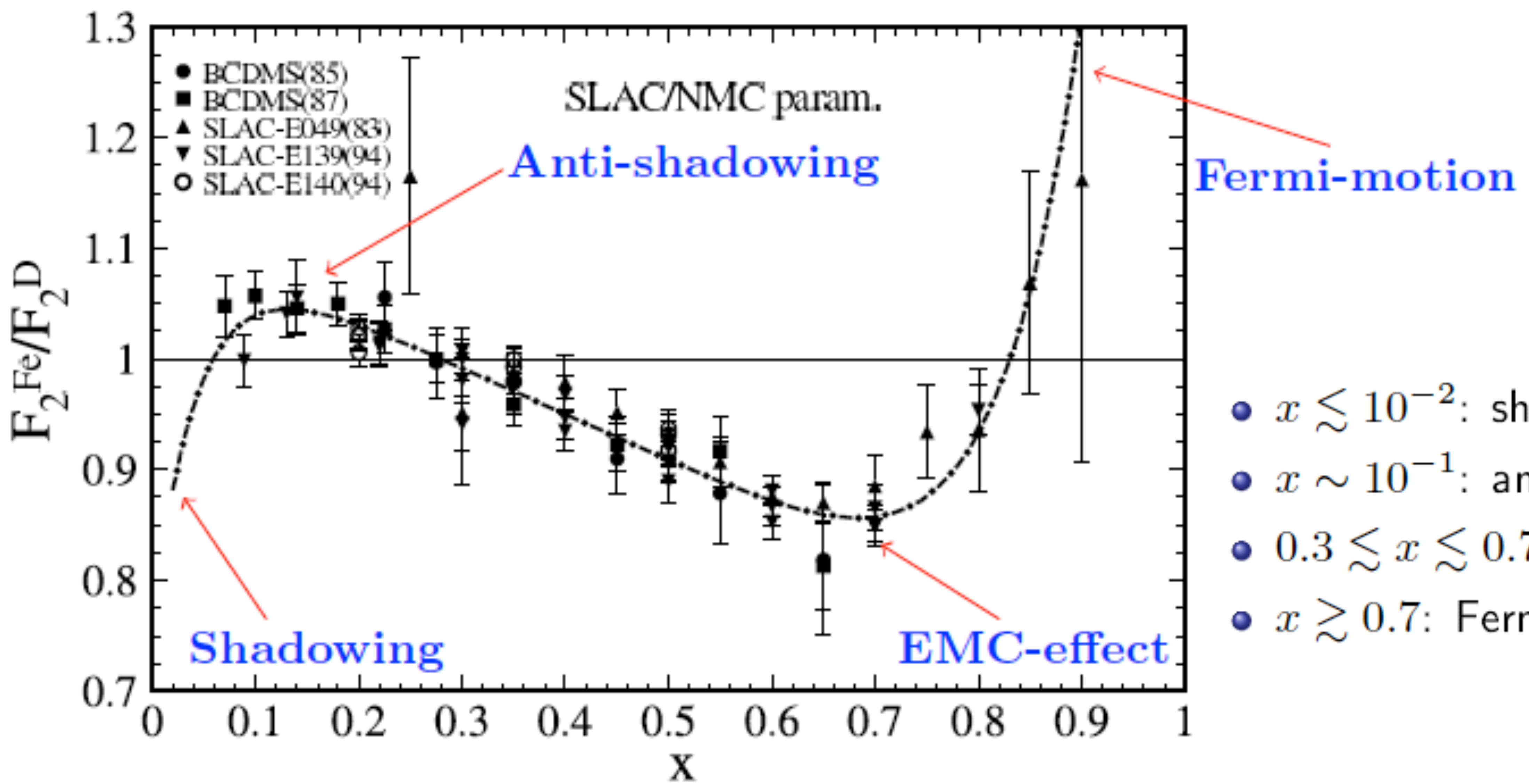
NUCLEAR PDF

- **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)

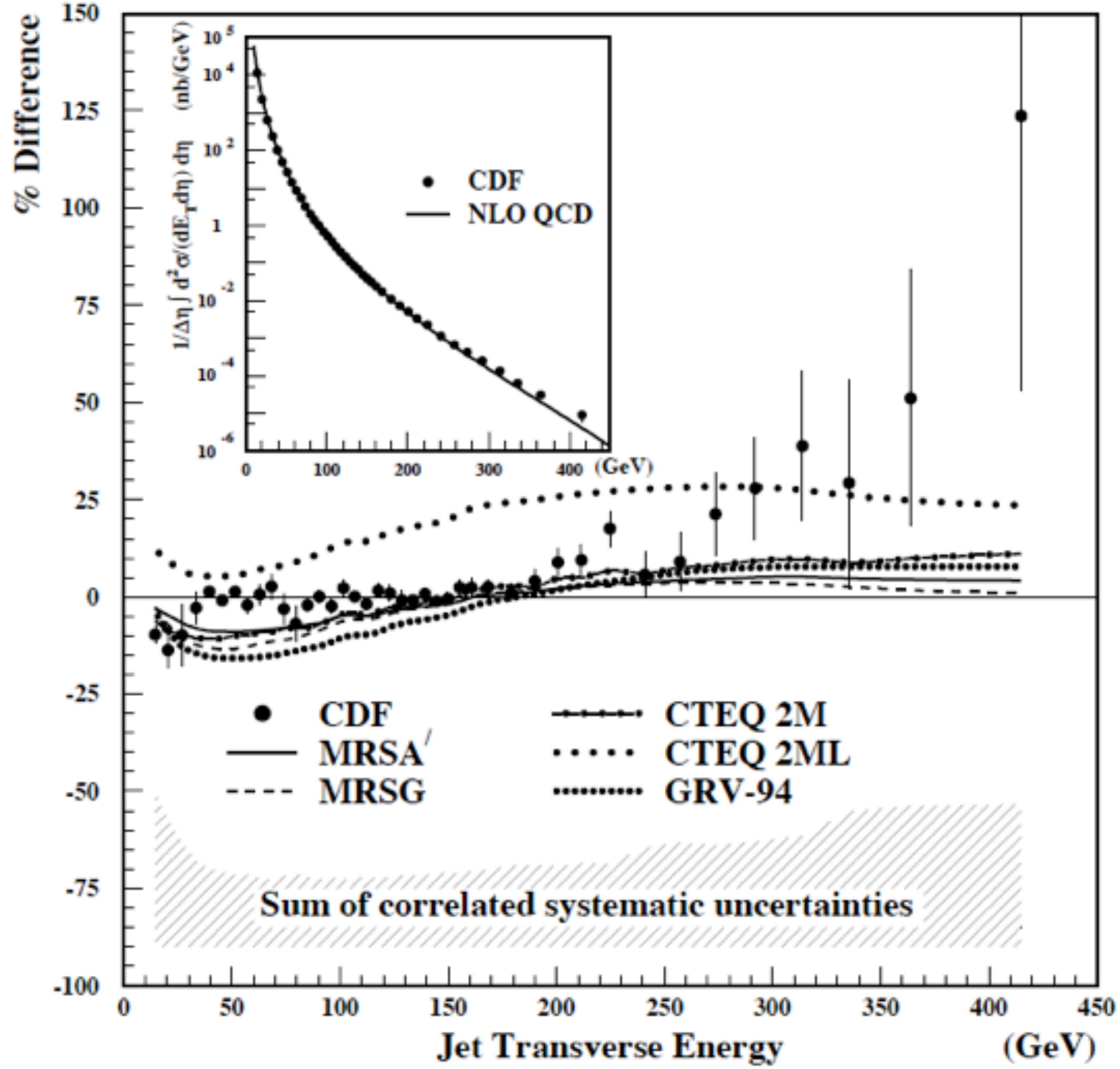
A LESSON FOR PDF (20 YEARS AGO)

hep-ex/9601008

Inclusive jet cross section in $\bar{p}p$ collisions at $\sqrt{s} = 1.8$ TeV

(CDF Collaboration)

- High-pT excess in inclusive jet by CDF was initially triggering a lot of BSM studies, like quark compositeness.



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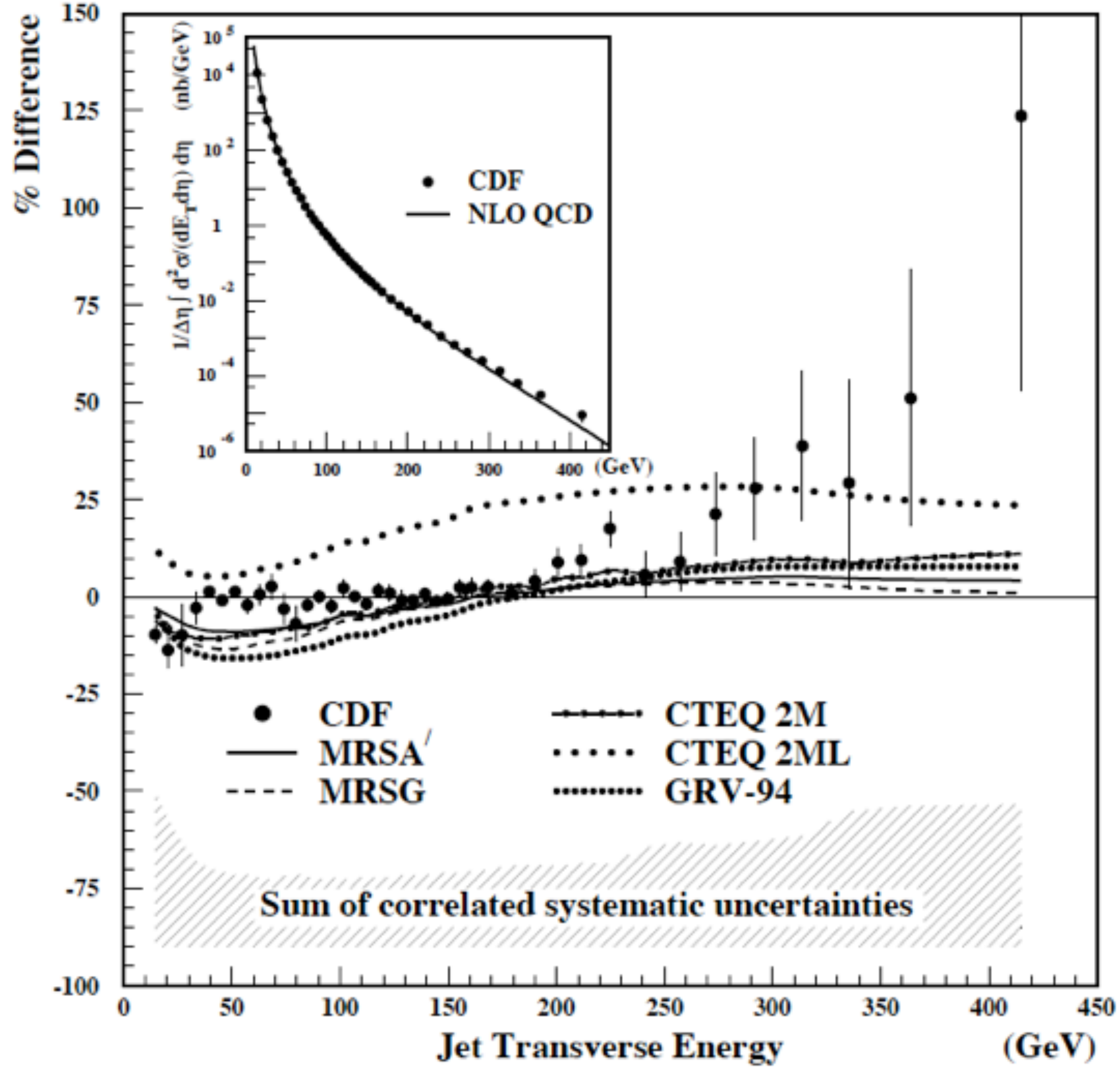

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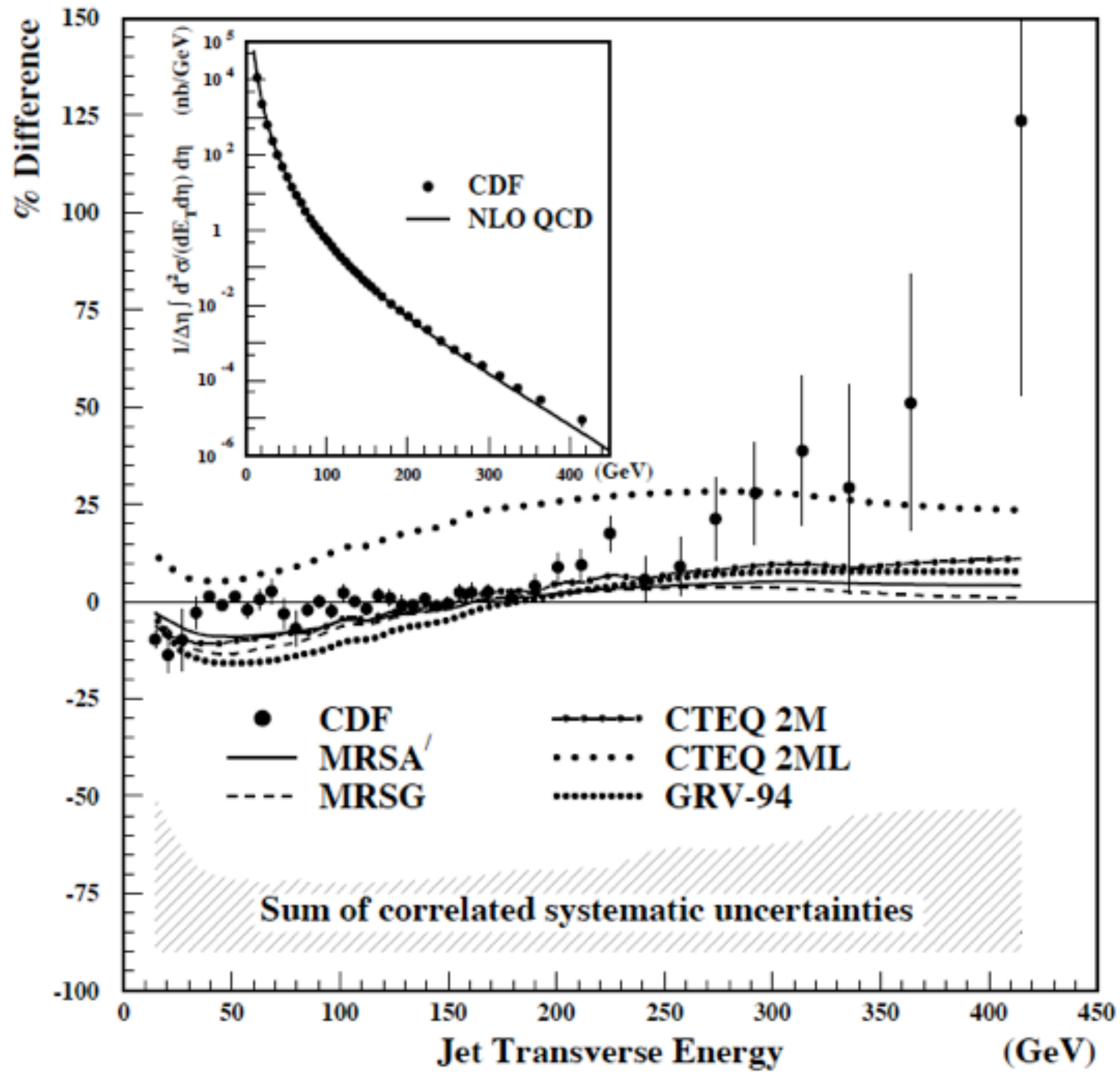

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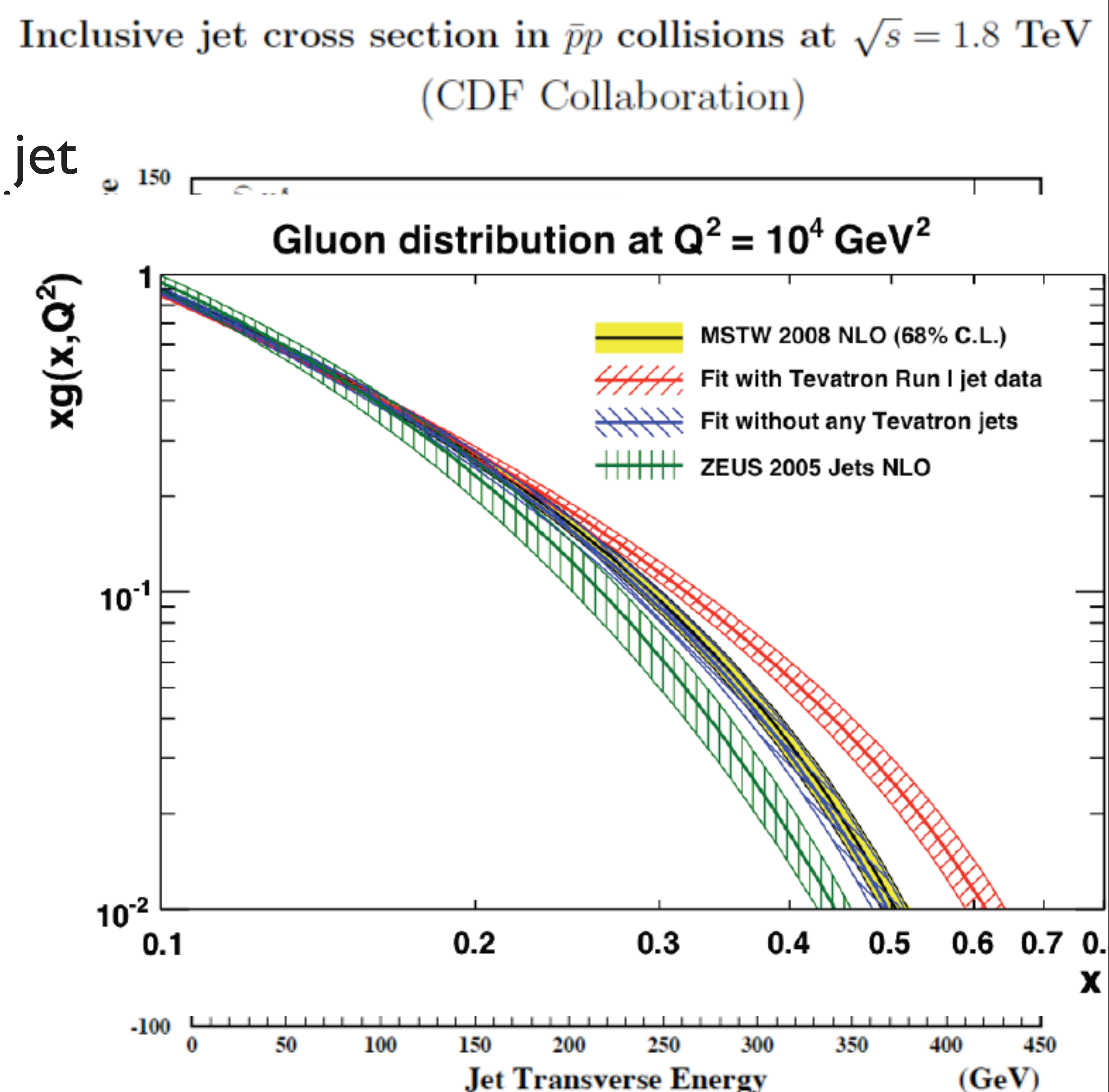

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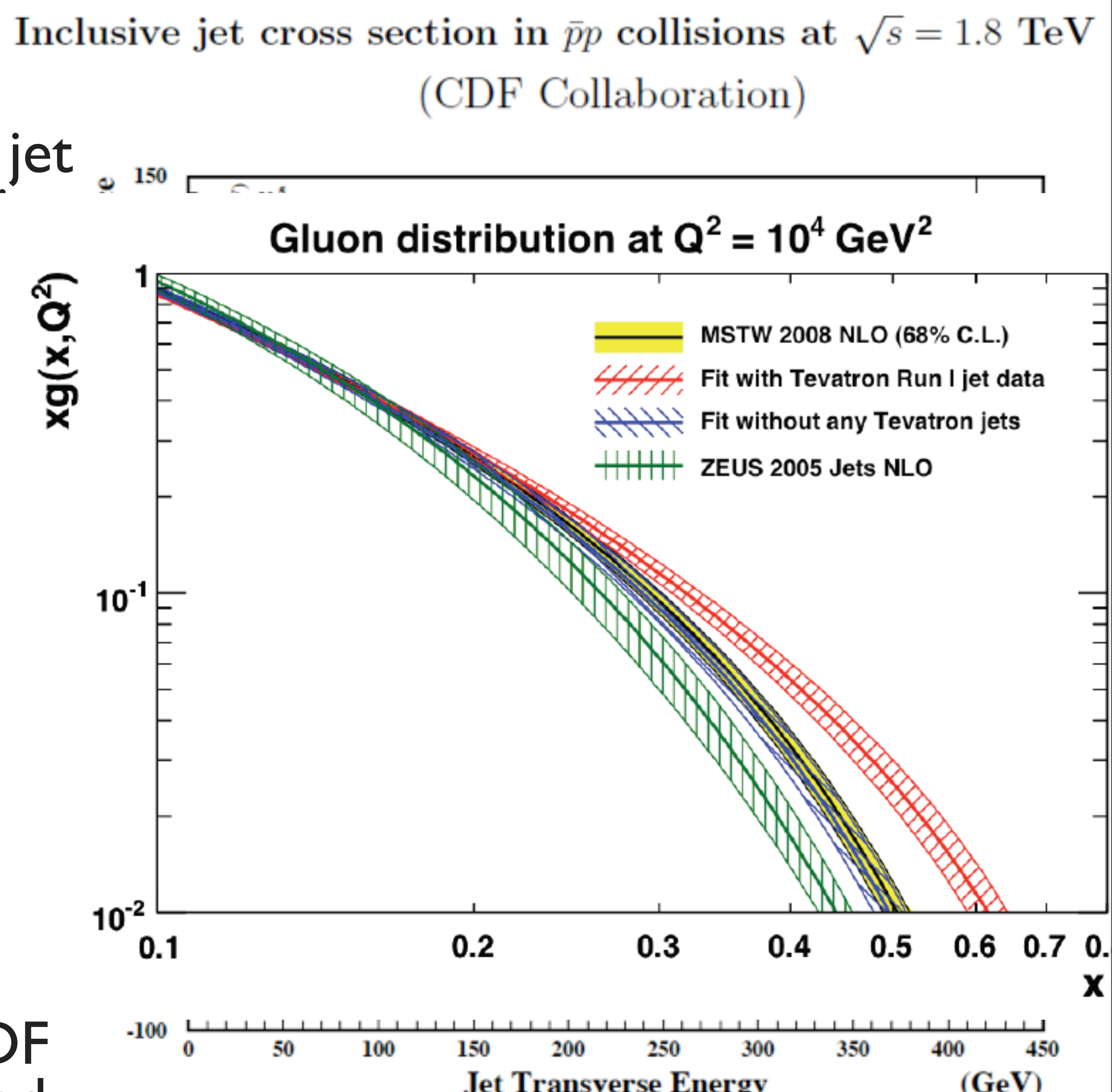
- Similarly, the conclusions based on nPDFs without taking into account the nPDF errors should be reexamined.



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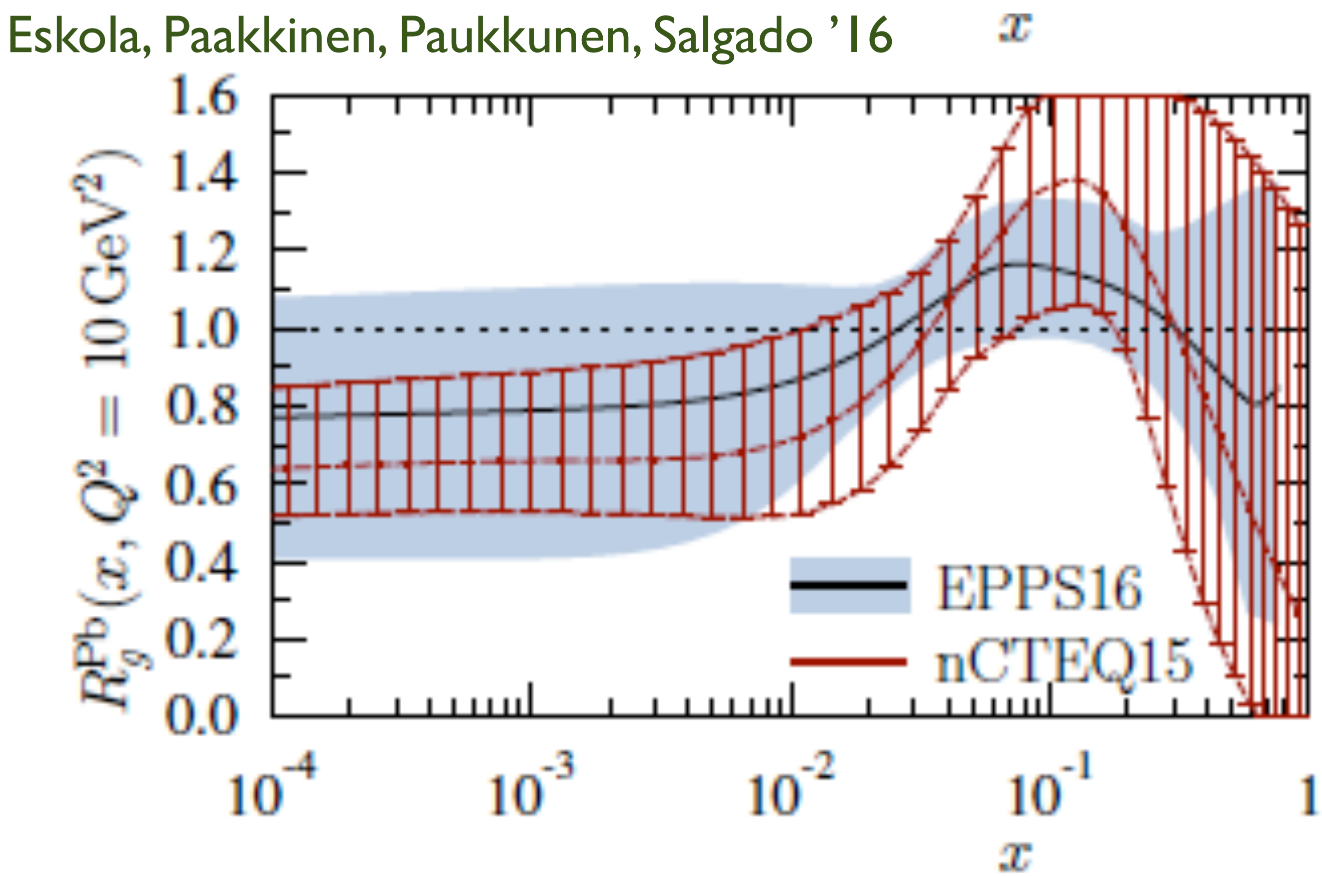
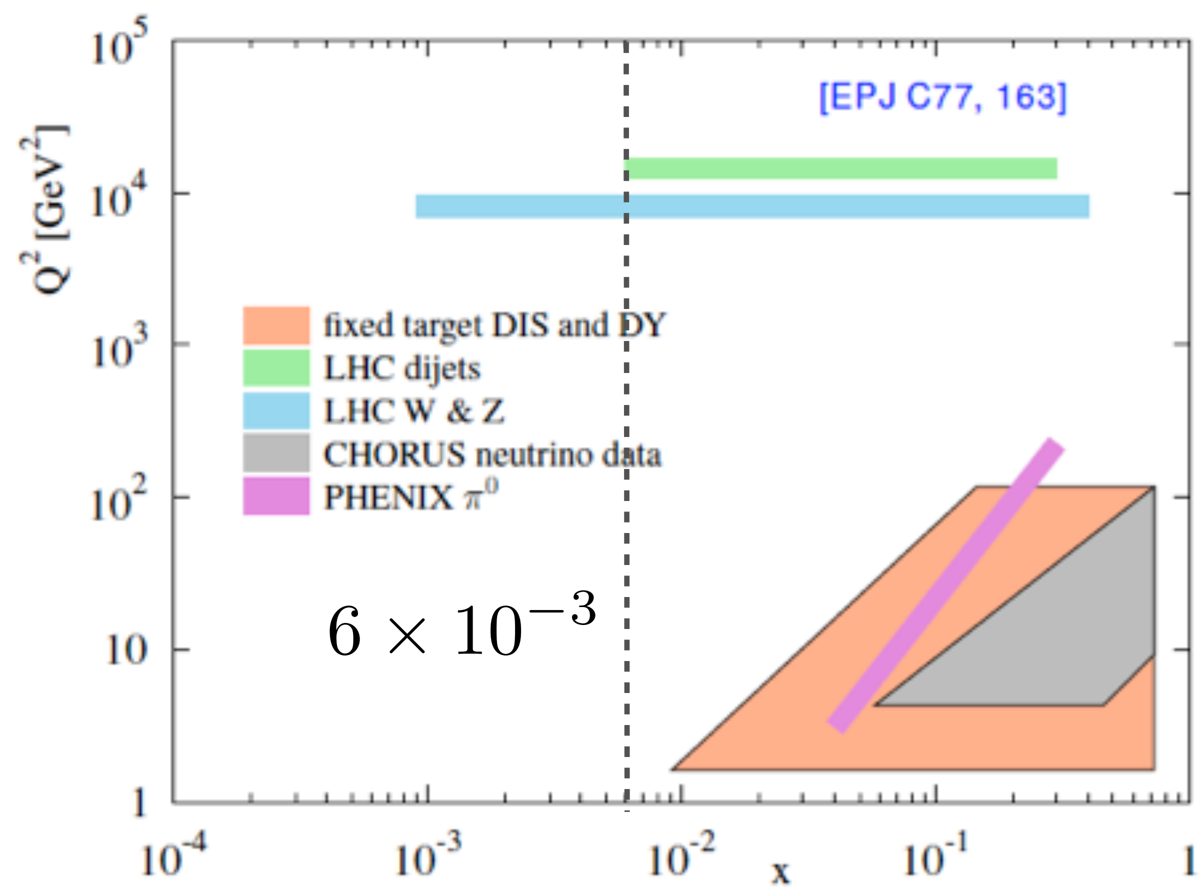
TYPICAL GLUON NUCLEAR PDFS





- 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

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

- 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).

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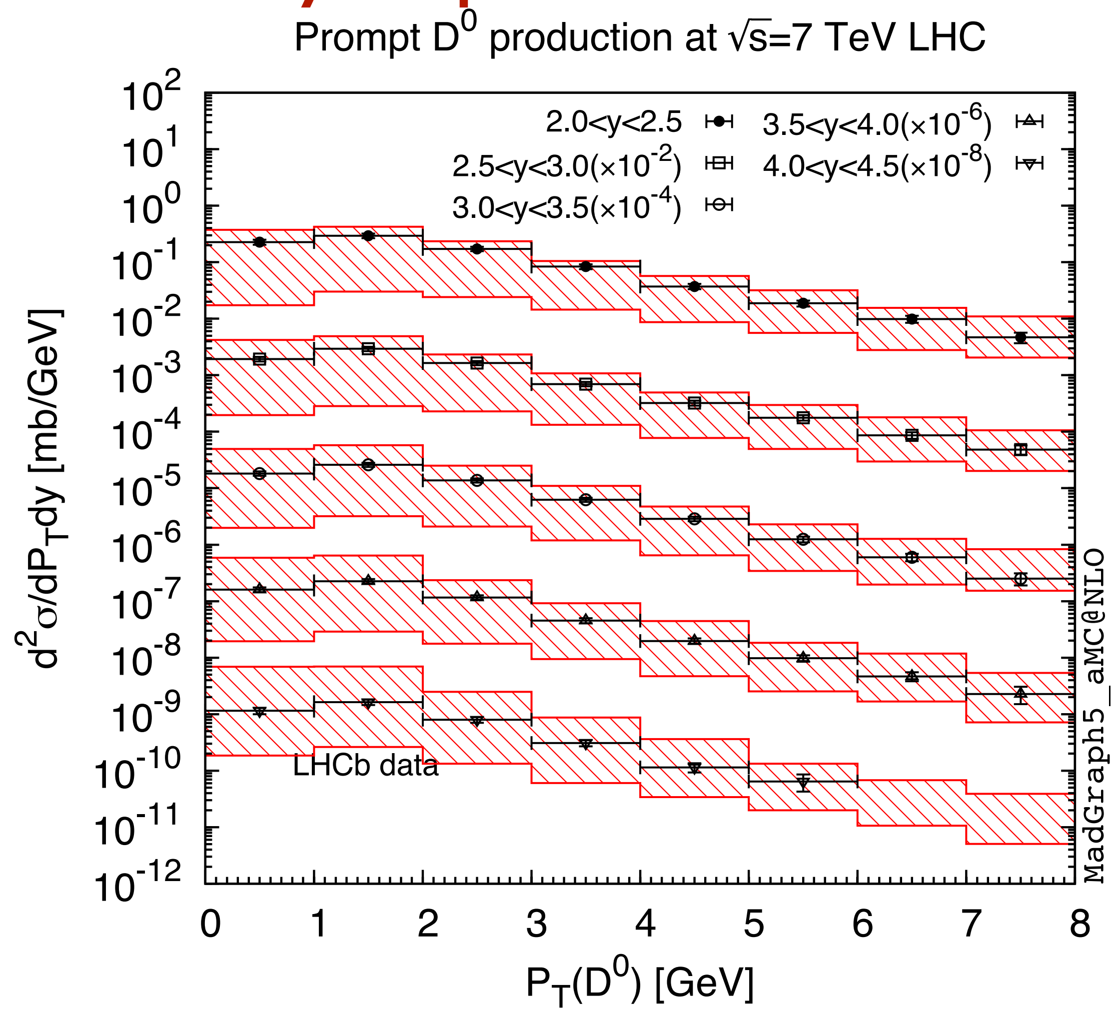

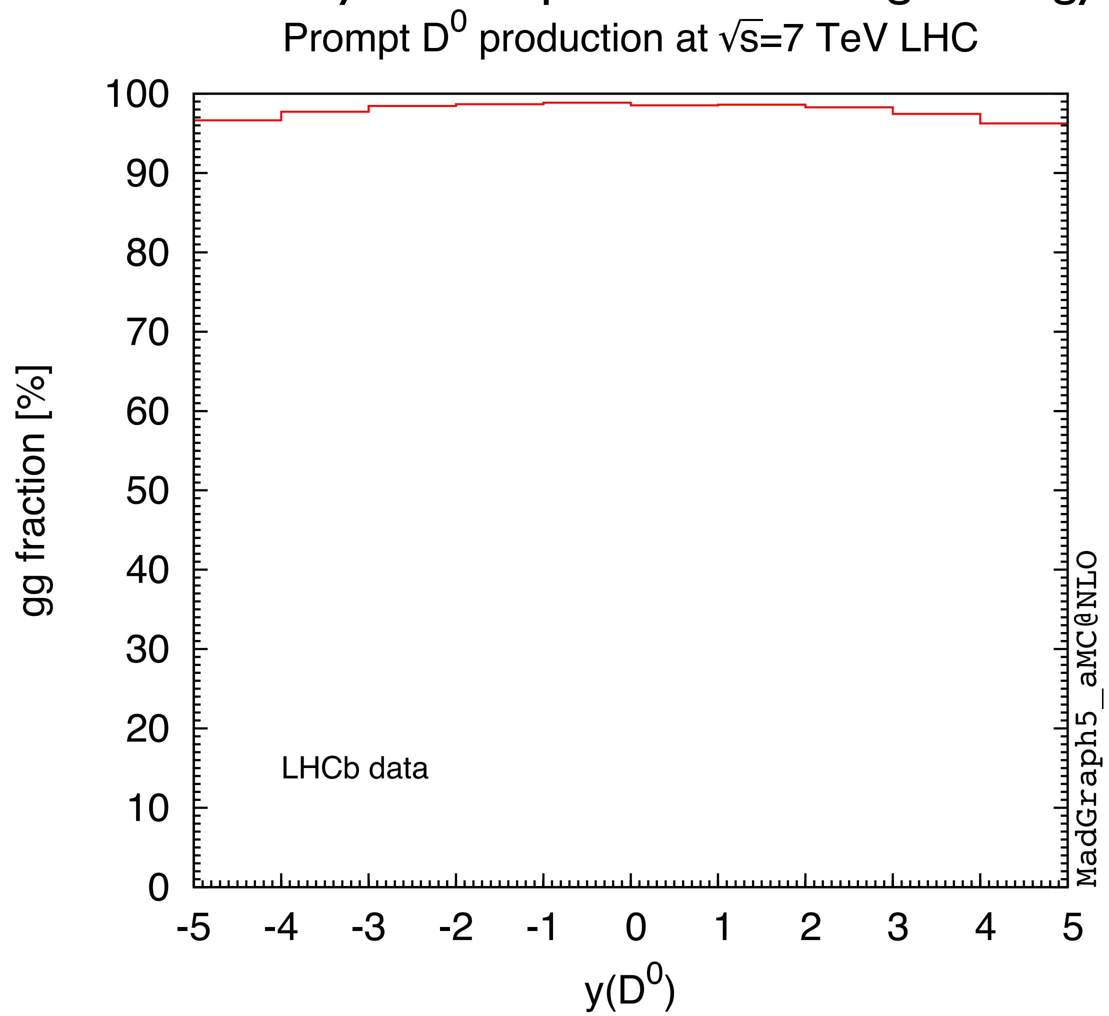

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- It is in principle can be applied to any single-inclusive particle production as long as knowing the fraction of initial partonic luminosity in priori (e.g. gluon-gluon dominance for heavy-flavour production at high-energy collisions).
- Applied 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 $\stackrel{?}{\Rightarrow}$ 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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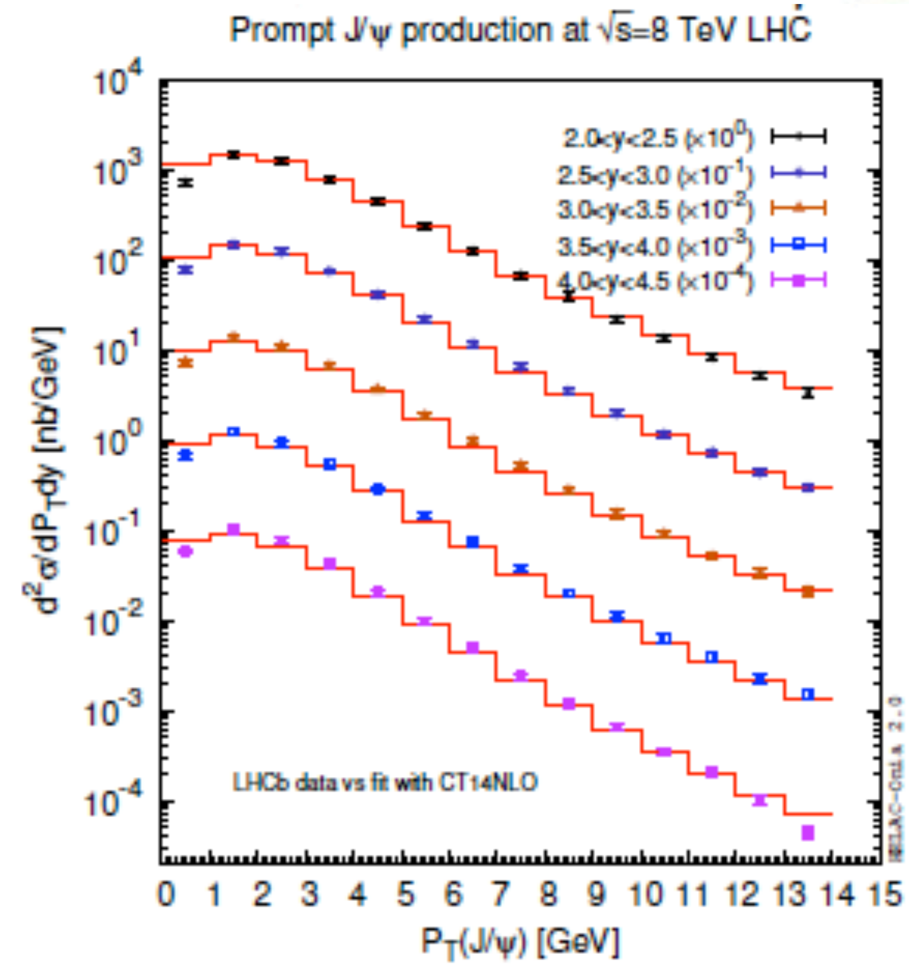
- Extremely good fit of the LHCb data (bar may be the 1st bin)



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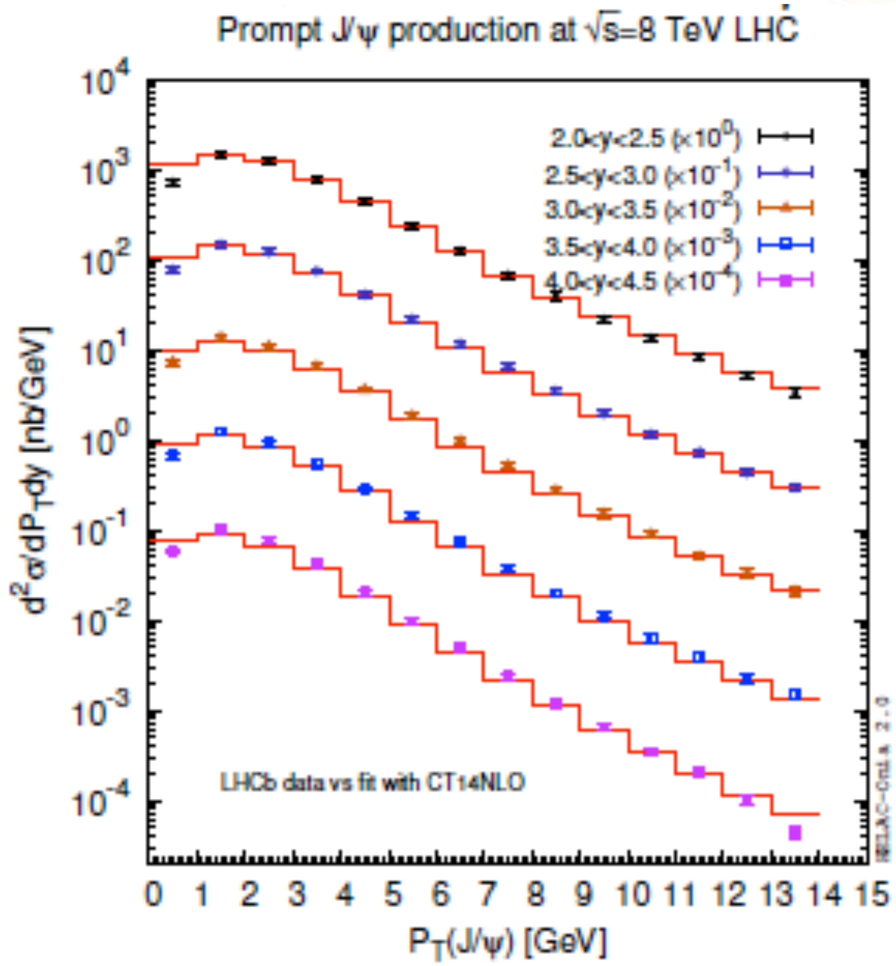

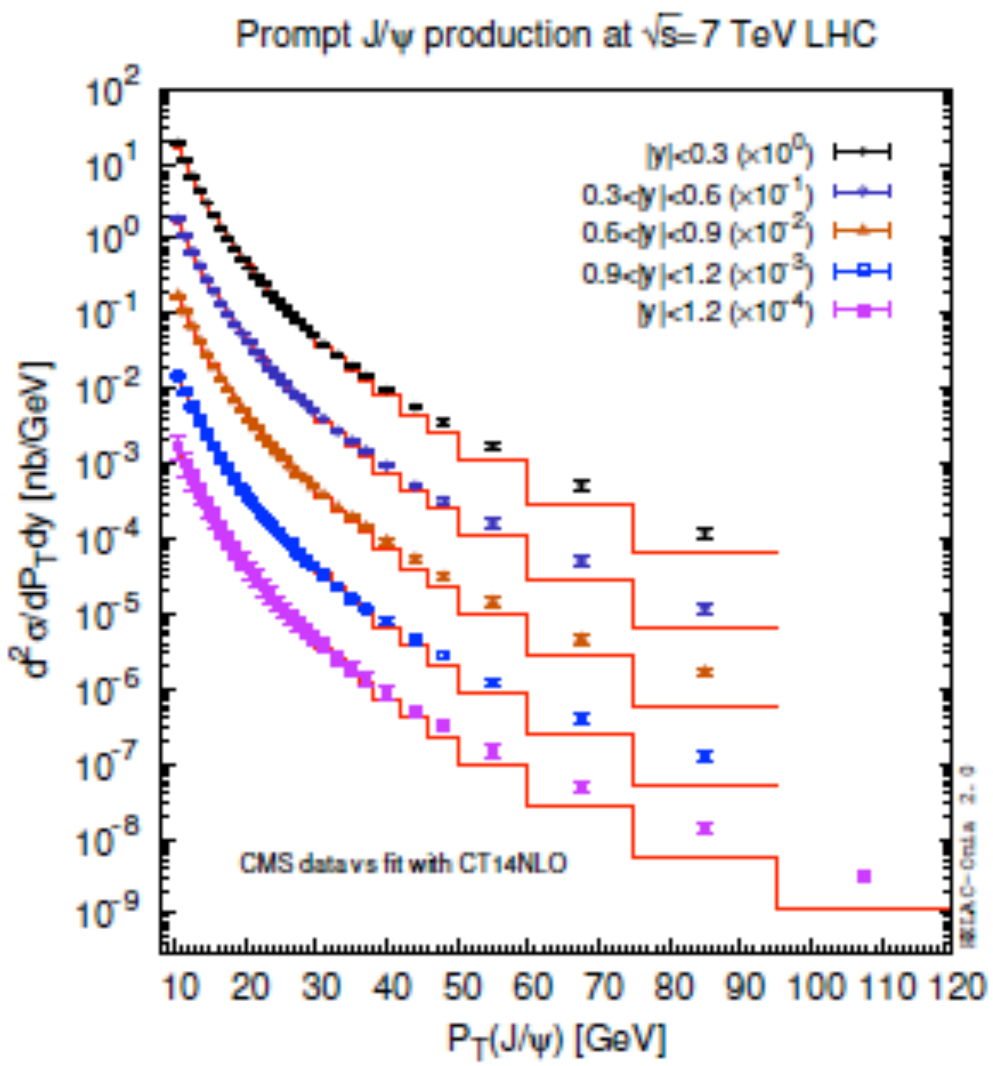

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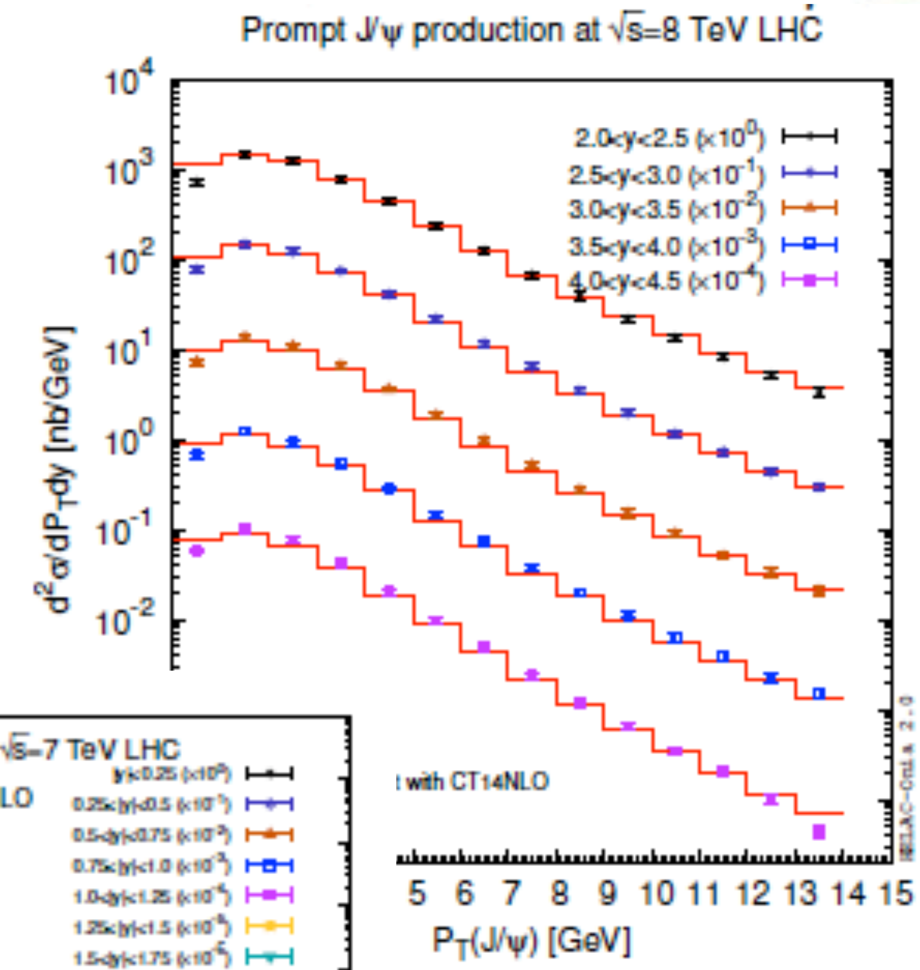

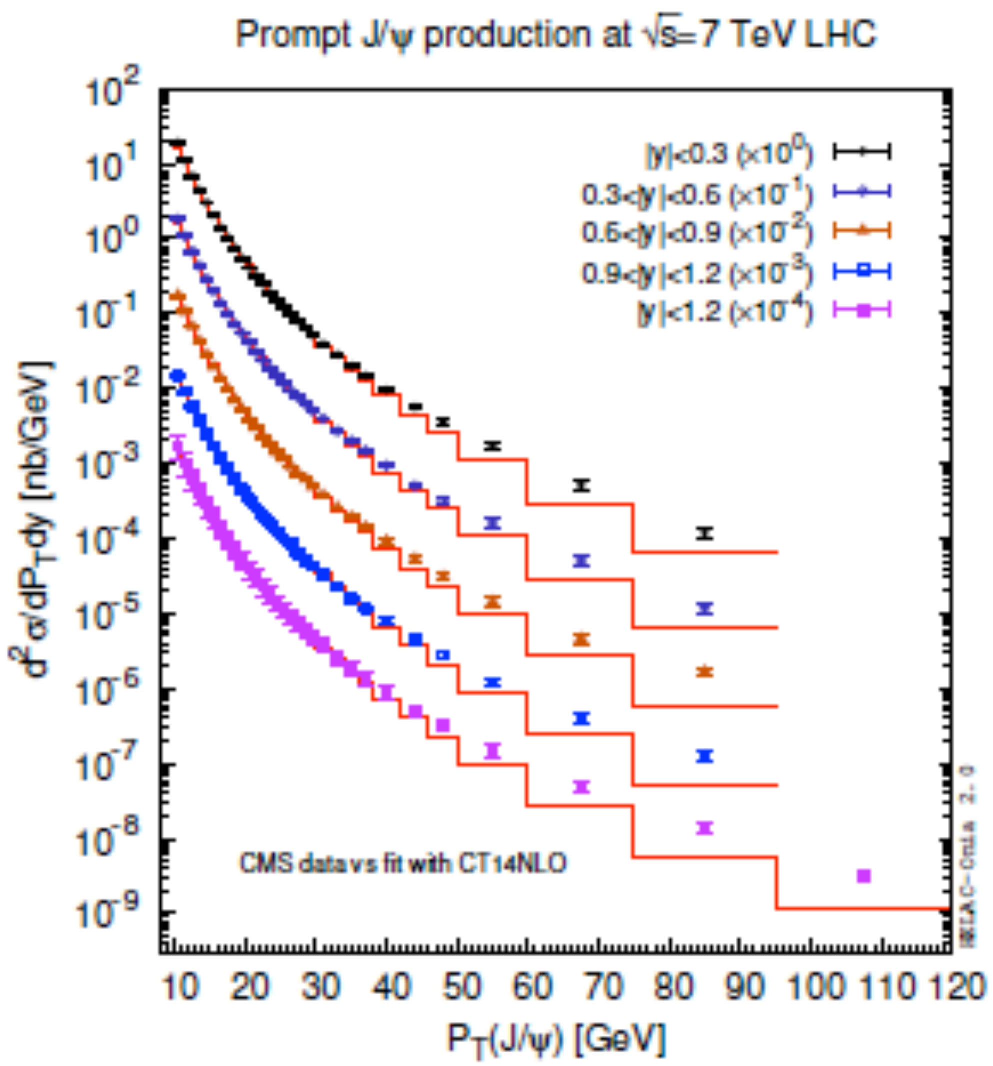

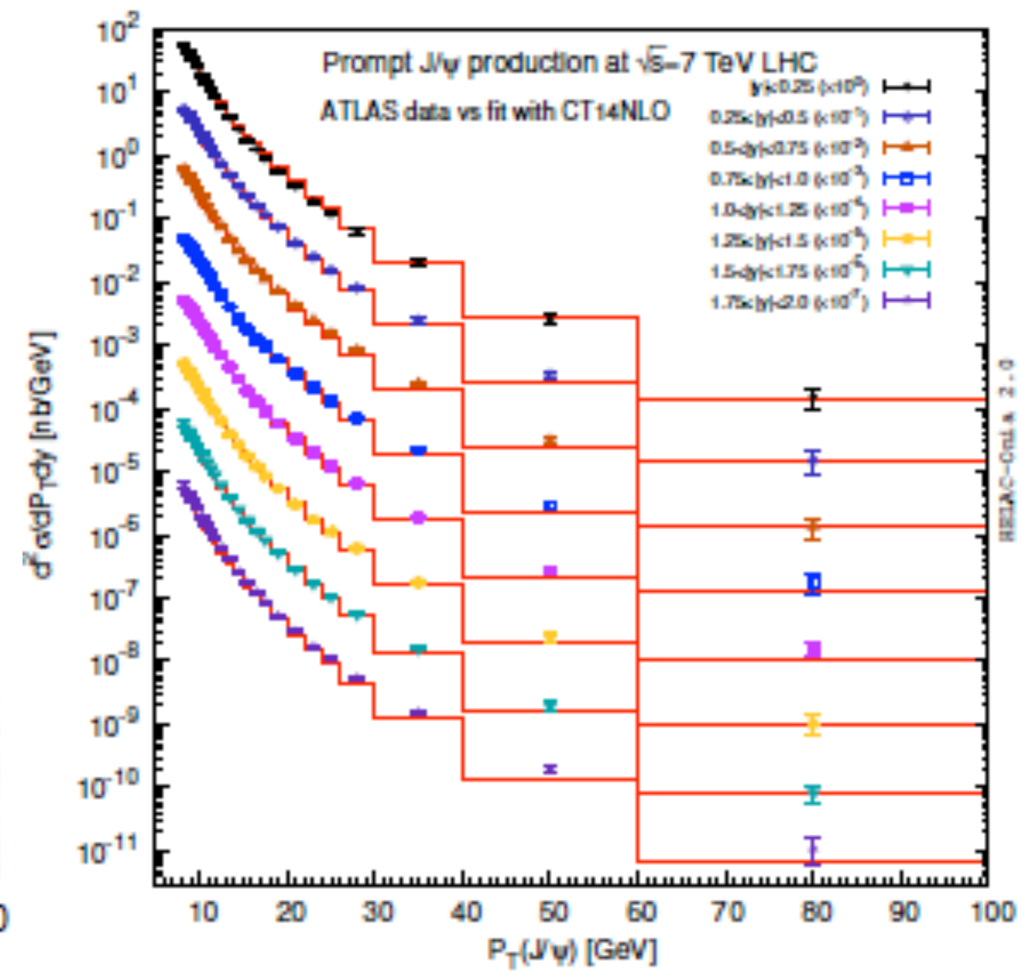

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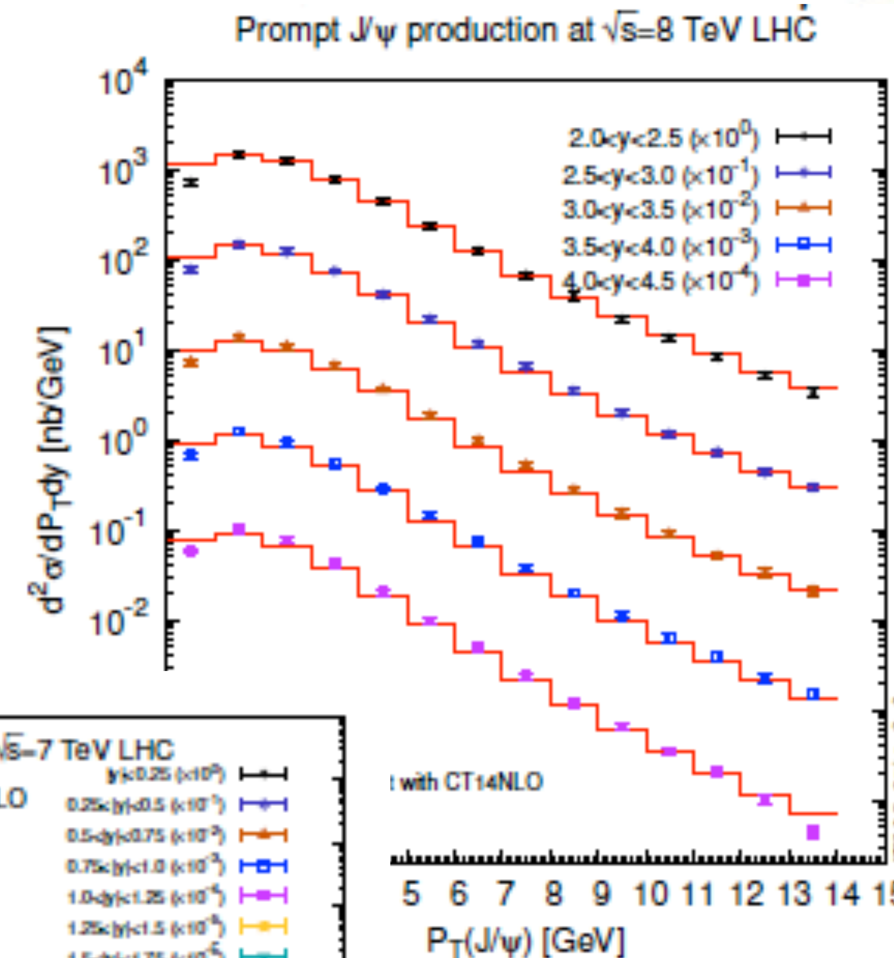
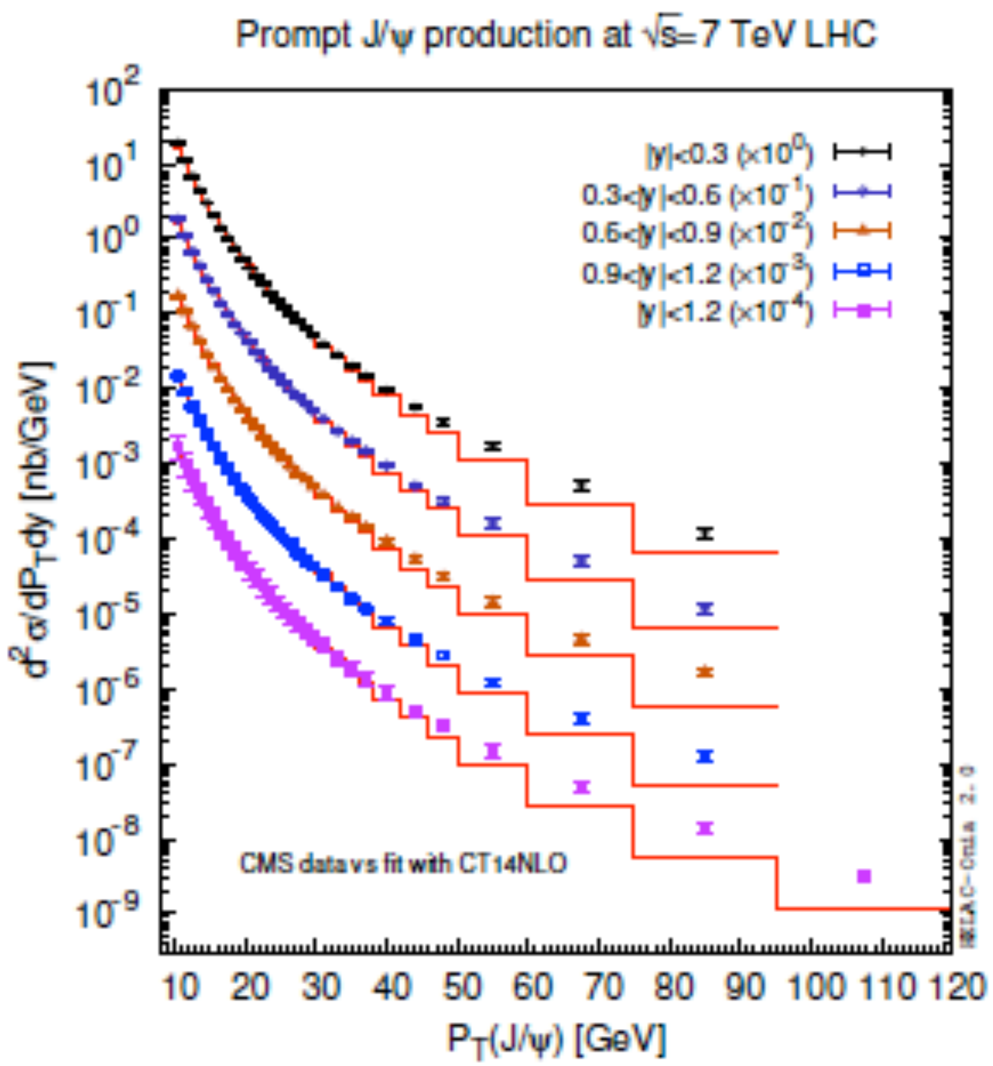
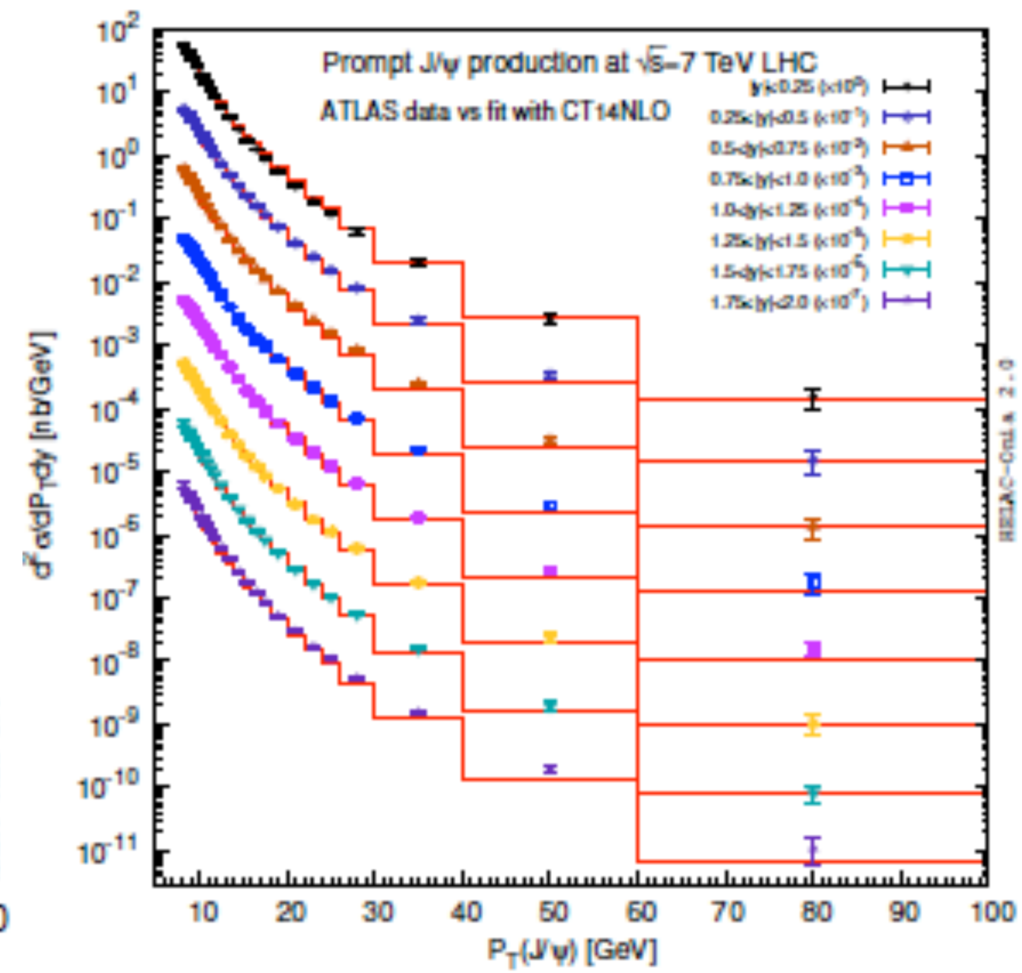
- But very good with ATLAS
- Tension between CMS - ATLAS ?



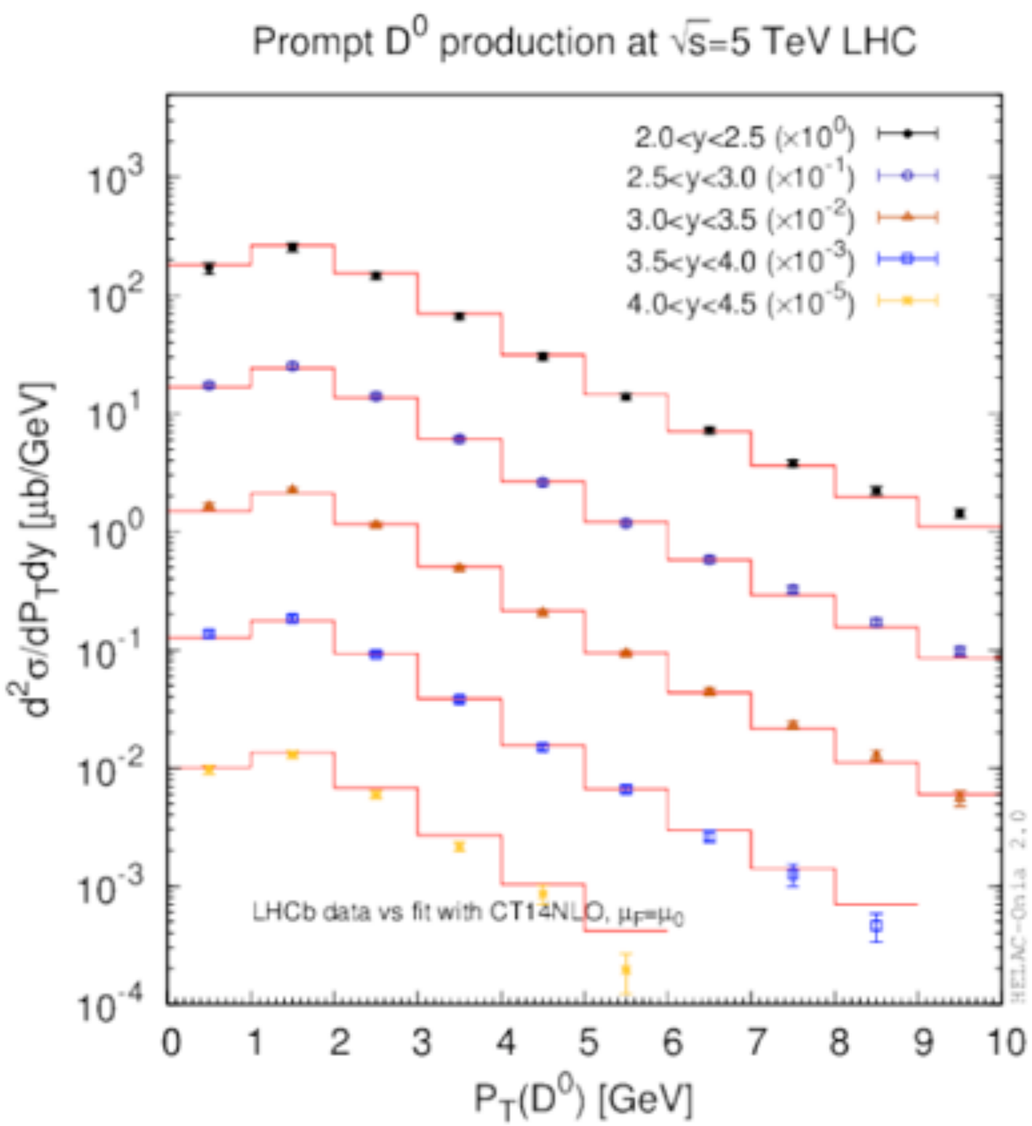




FITTING THE PP DATA

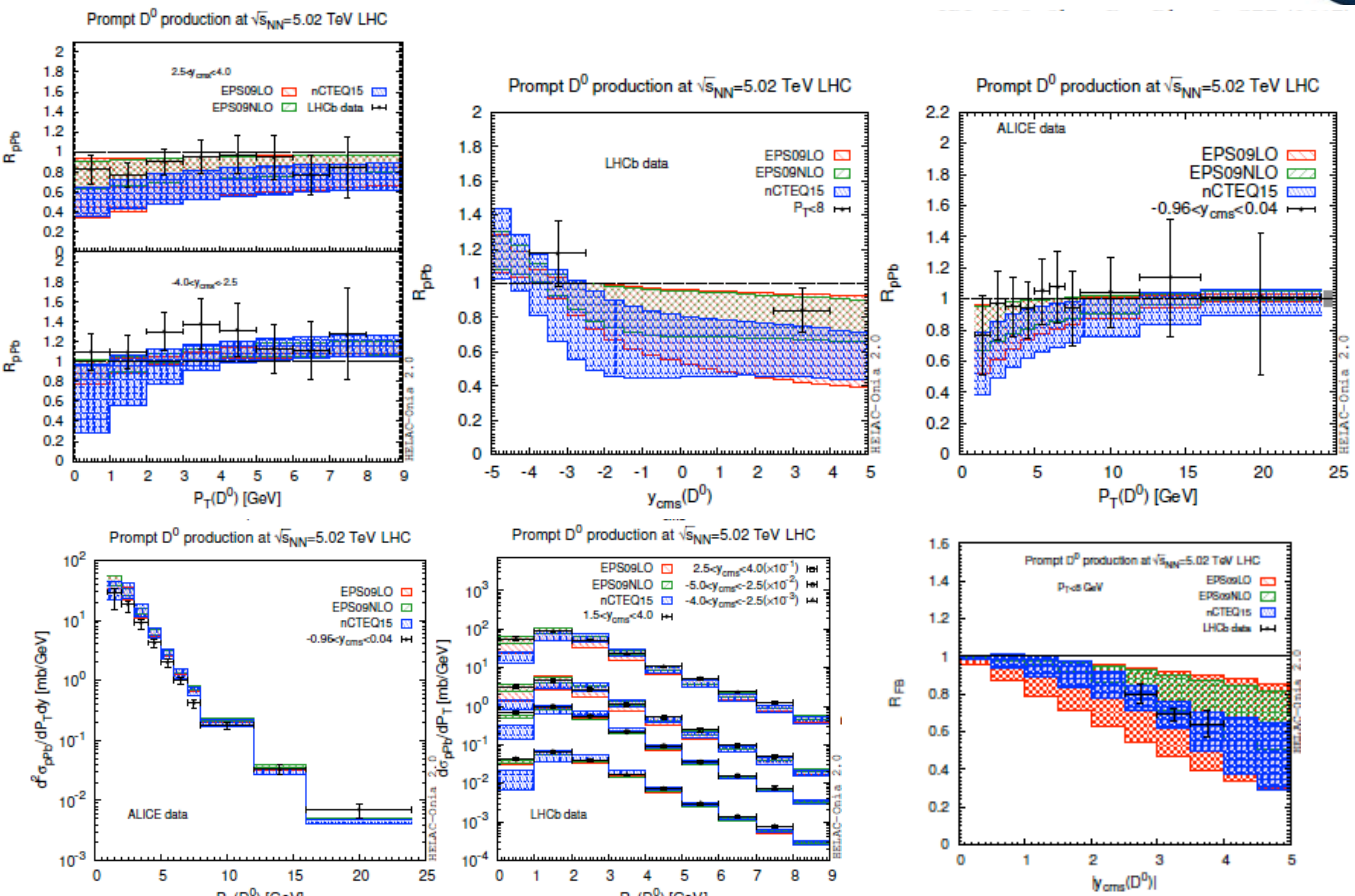
Lansberg, HSS '17

- 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

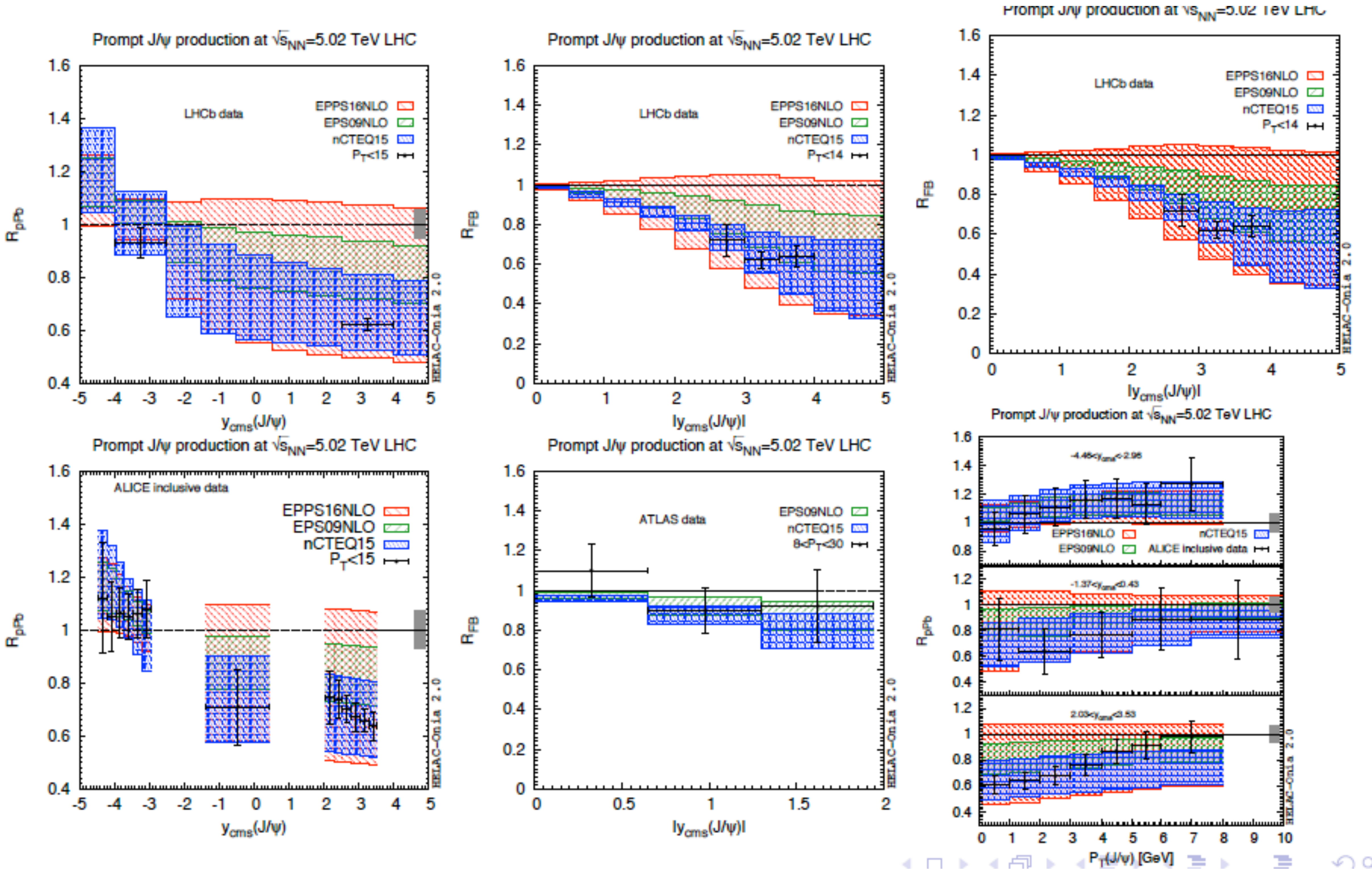
Lansberg, HSS '17



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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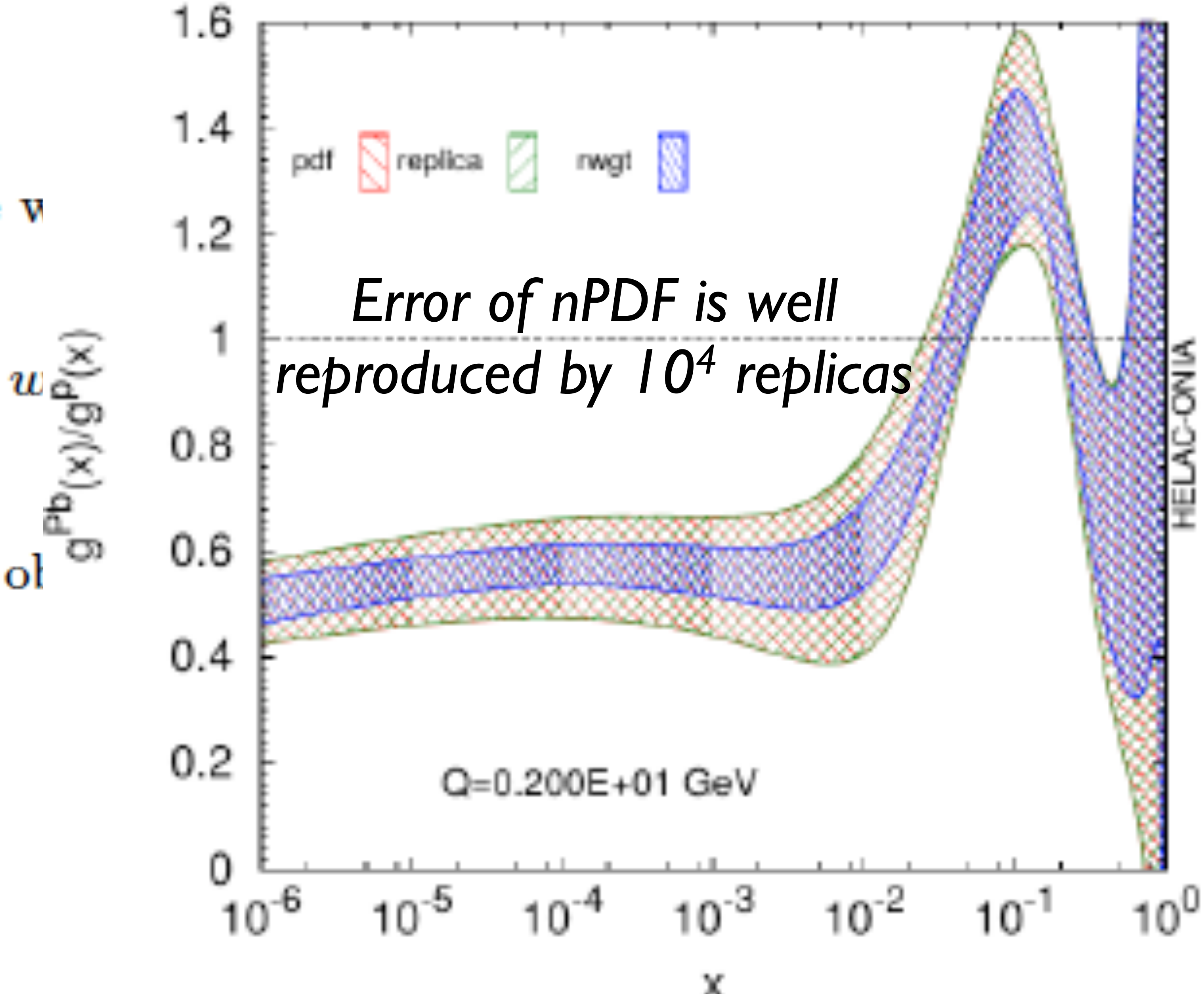
1. Convert Hessian error PDFs into replicas

2. Calculate w

w ... $- T_j^k)^2$ / σ_j^2



3. Calculate ob

N_{rep} $k=1$

USED DATA SETS

Kusina, Lansberg, Schienbein, HSS '17

	D^0	J/ψ	$B \to J/\psi$	$\Upsilon(1S)$
μ_0	$\sqrt{4M_{D^0}^2 + P_{T,D^0}^2}$	$\sqrt{M_{J/\psi}^2 + P_{T,J/\psi}^2}$	$\sqrt{4M_B^2 + \left(\frac{M_B}{M_{J/\psi}} P_{T,J/\psi}\right)^2}$	$\sqrt{M_{\Upsilon(1S)}^2 + P_{T,\Upsilon(1S)}^2}$
$p+p$ 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.
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[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.
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[9] ALICE, B. B. Abelev et al., Phys. Rev. Lett. **113**, 232301 (2014), 1405.3452.
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[15] LHCb, R. Aaij et al., (2017), 1707.02750.
[16] LHCb, R. Aaij et al., JHEP **02**, 072 (2014), 1308.6729.
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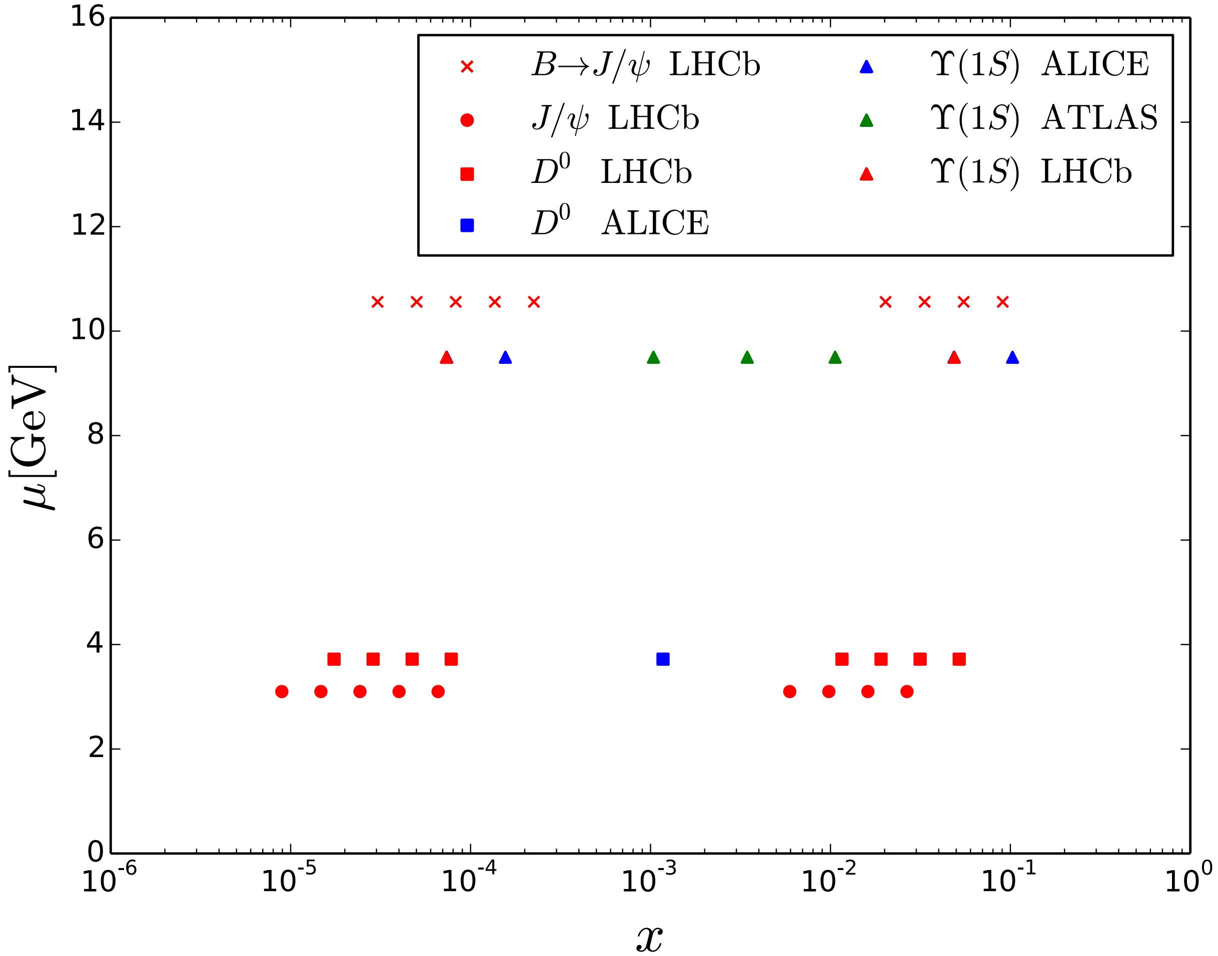

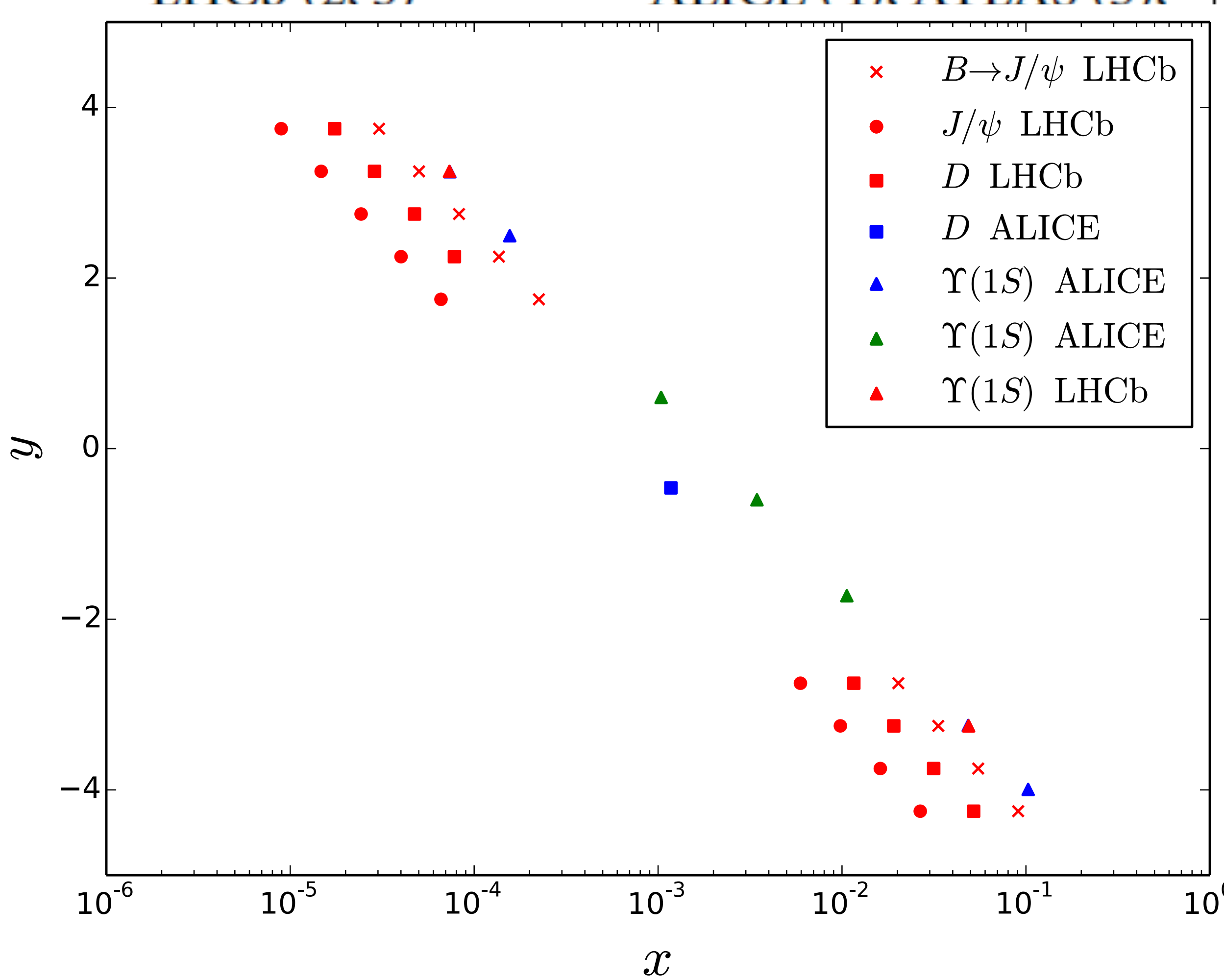

[13] ALICE, B. B. Abelev et al., Phys. Lett. **B740**, 105 (2015), 1410.2234.
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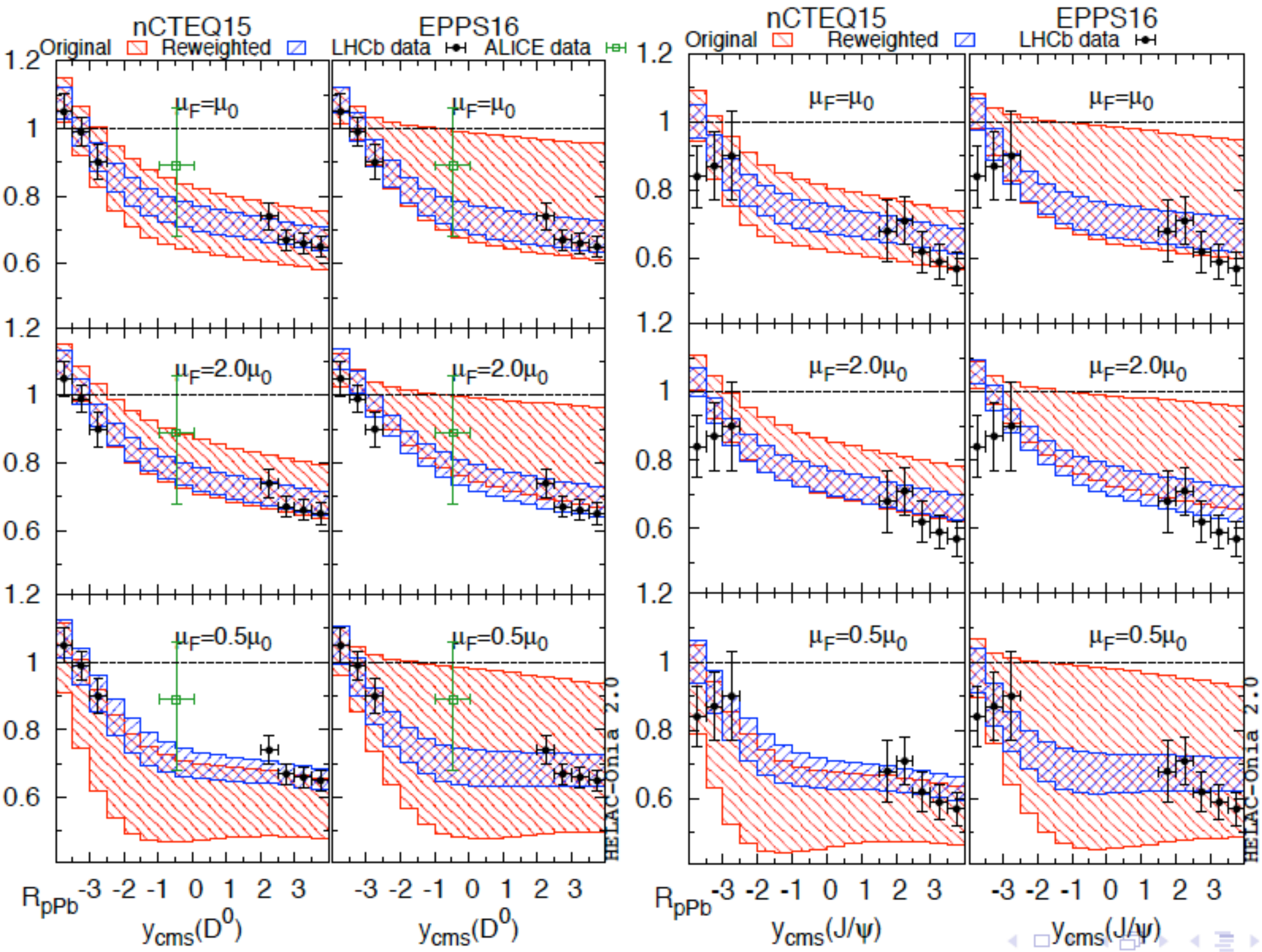
REWEIGHTING RESULTS: D^0 AND J/PSI

68% CL

Kusina, Lansberg, Schienbein, HSS '17

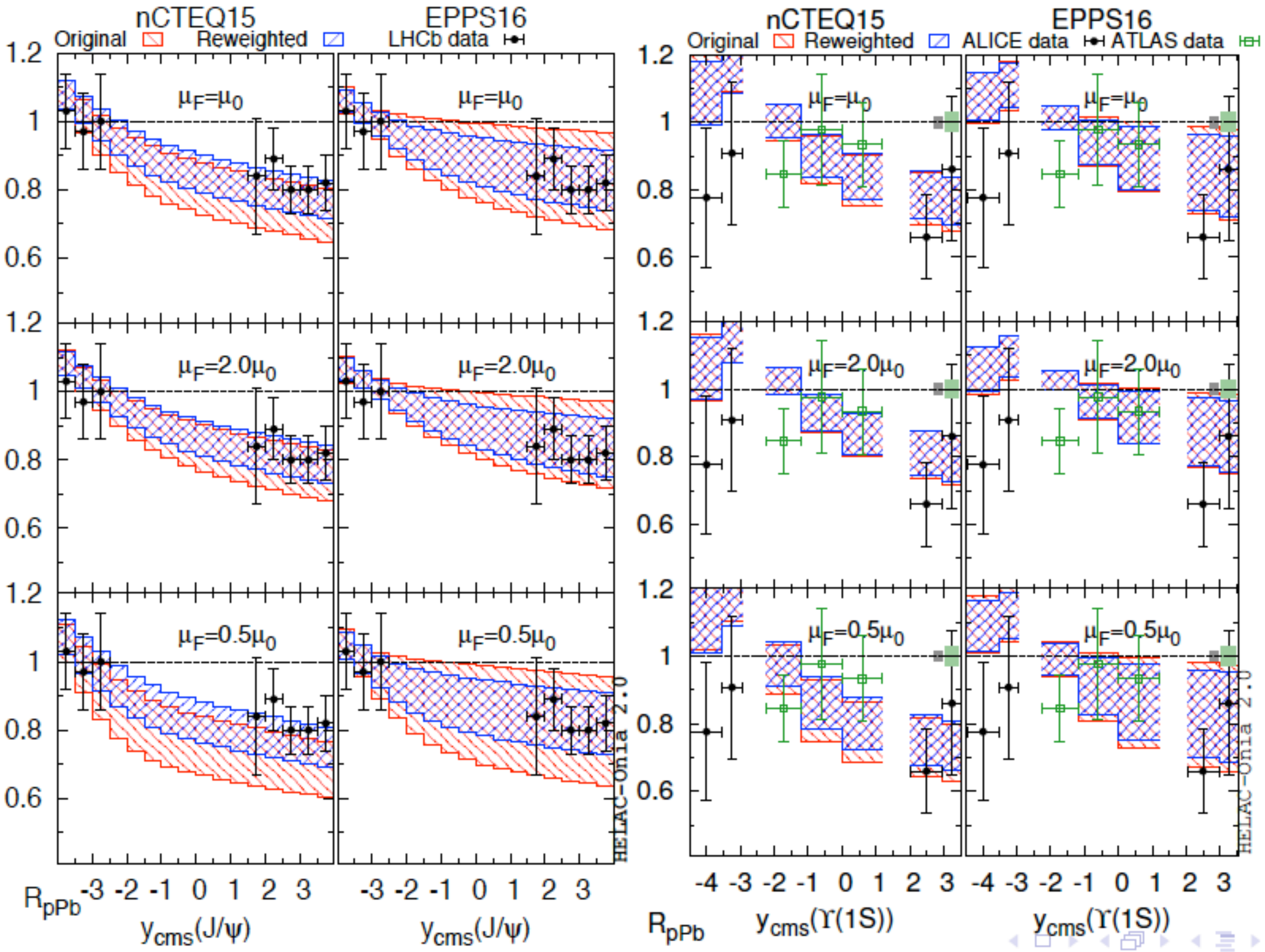


Changing the scale has two effects:
1) the uncertainty tends to increase at low μ_F
2) since the shadowing suppression (in/de)creases for (de/in)creasing μ_F, the reweighted nPDF from data shifts within the original uncertaities

REWEIGHTING RESULTS: B->J/PSI AND Υ

68% CL

Kusina, Lansberg, Schienbein, HSS '17

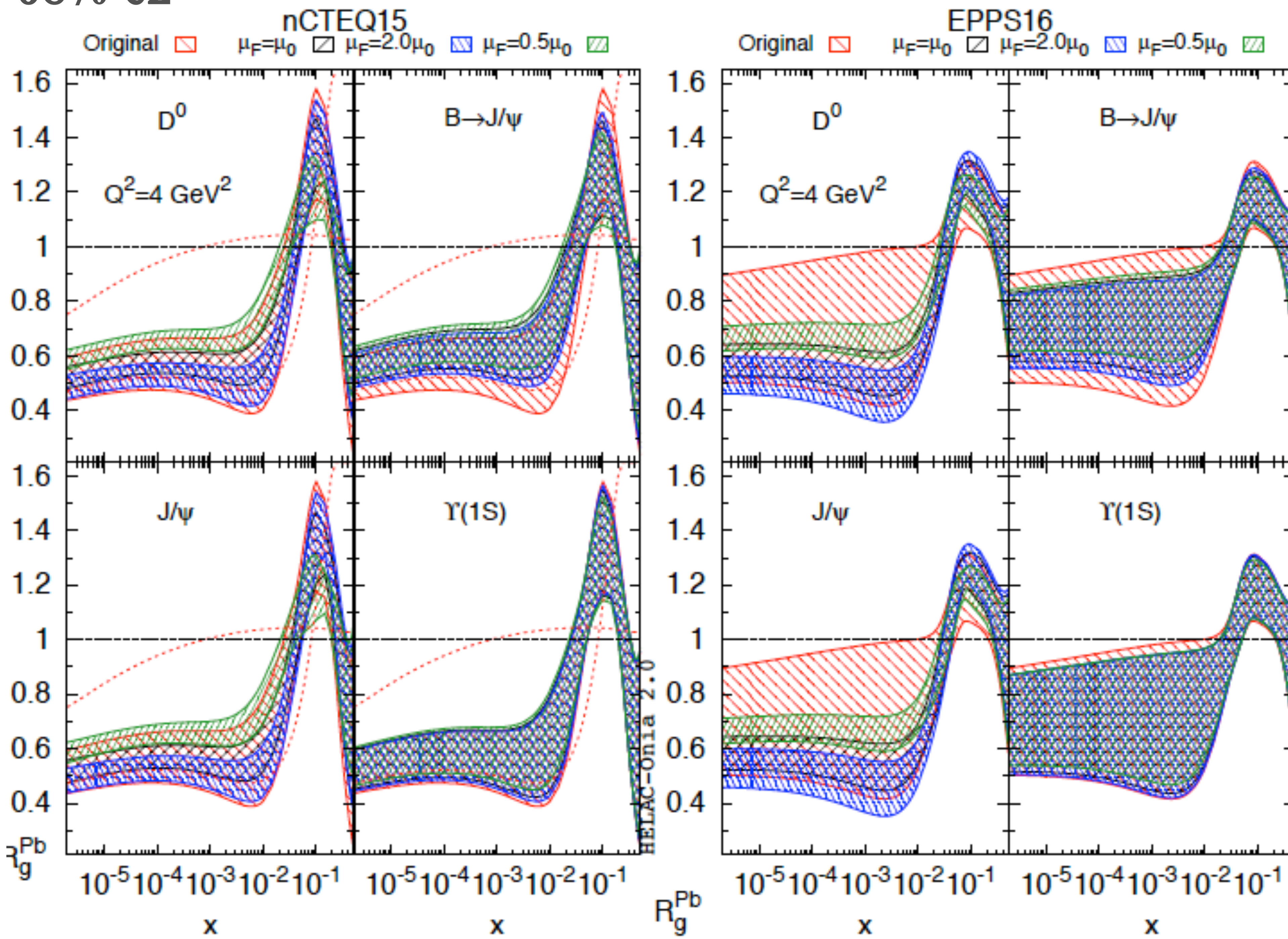


Compared to the D and J/ψ cases,
1) the scales uncertainties are smaller, but
2) the data are not yet as precise

RESULTS OF REWEIGHTED NPDFS

Kusina, Lansberg, Schienbein, HSS '17

68% CL



- 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
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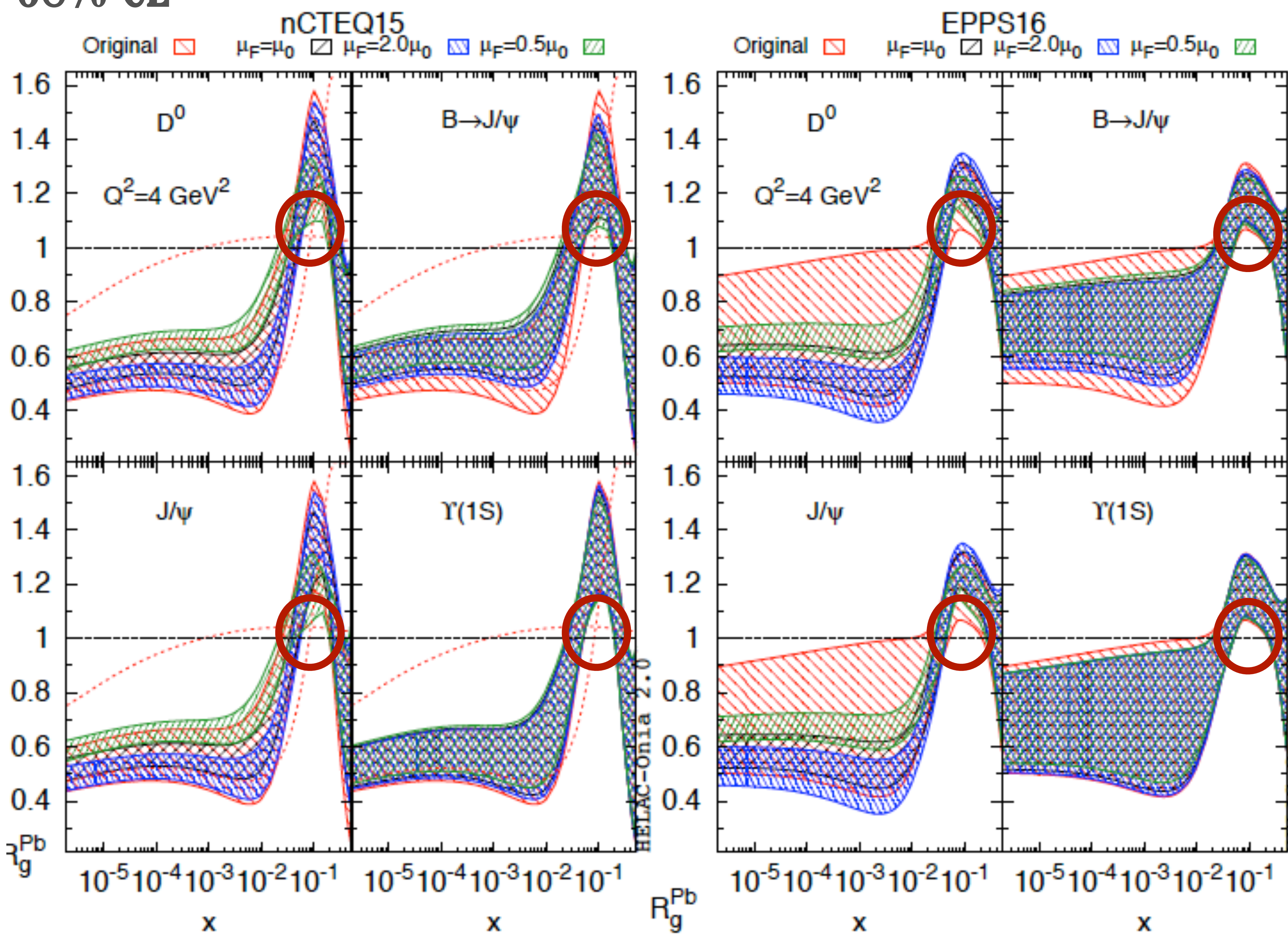

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- B or non-prompt J/psi are promising if precision of the data can be improved
- Confirmation of the existence of a gluon anti-shadowing: $R_g(0.05 \lesssim x <\lesssim 0.1) > 1$

RESULTS OF REWEIGHTED NPDFS

Kusina, Lansberg, Schienbein, HSS '17

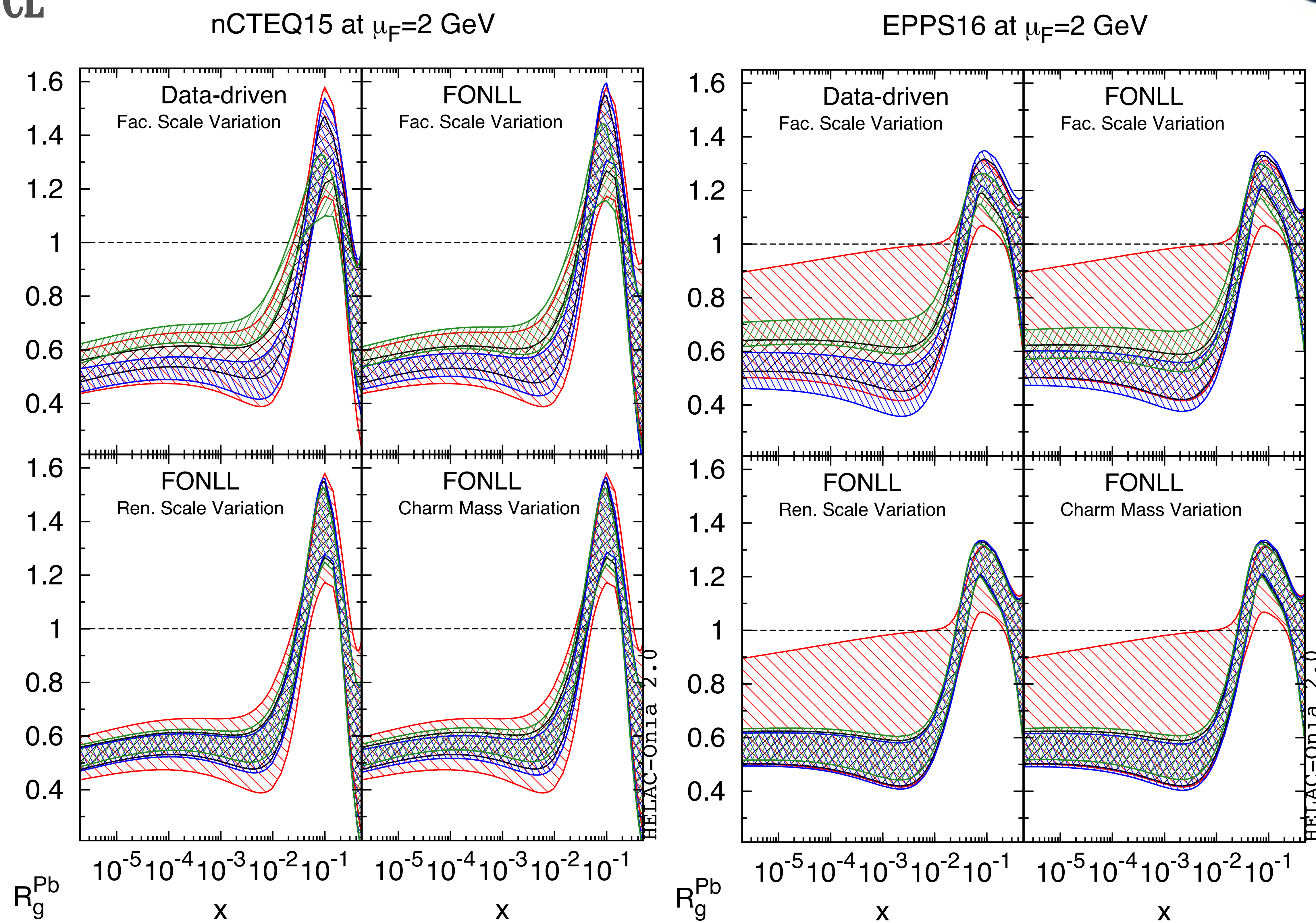
		D^0	J/ψ	$B \to J/\psi$	$\Upsilon(1S)$
	N_{data}	38	71	37	12
Original nCTEQ15	$\xi = 0.5$	142	131	39	14
	$\xi = 1.0$	39	63	23	11
	$\xi = 2.0$	63	90	15	11
Reweighted nCTEQ15	$\xi = 0.5$	56	46	14	13
	$\xi = 1.0$	56	53	11	11
	$\xi = 2.0$	56	46	9	11
Original EPPS16	$\xi = 0.5$	53	62	9	10
	$\xi = 1.0$	140	150	7	10
	$\xi = 2.0$	218	220	8	11
Reweighted EPPS16	$\xi = 0.5$	37	59	7	10
	$\xi = 1.0$	37	59	7	10
	$\xi = 2.0$	37	59	7	11

- The chi2 are improved in general !

VALIDATE WITH FONLL FOR OPEN CHARM/BEAUTY

Kusina, Lansberg, Schienbein, HSS '17

68% CL

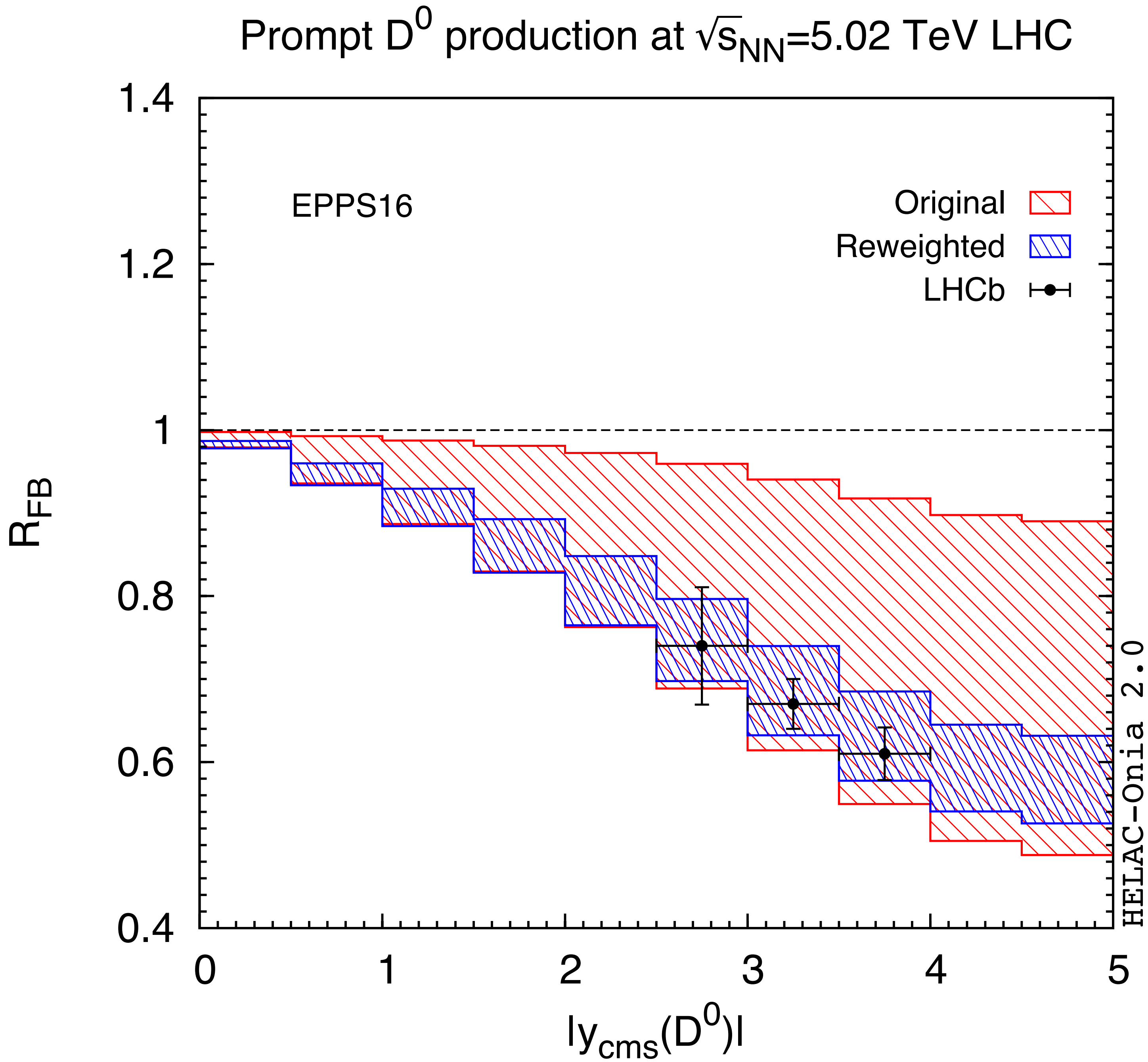


- Validated with the state-of-the-art pQCD calculations !

PREDICTIONS & CONSISTENCES

68% CL

Kusina, Lansberg, Schienbein, HSS '17



- Other observables: e.g. R_{FB}

PREDICTIONS & CONSISTENCES

Kusina, Lansberg, Schienbein, HSS '17

- Other observables: e.g. R_{FB}
- Consistent with other measurements.

			Original	Reweighted			
				D^0	J/ψ	$B \to J/\psi$	$\Upsilon(1S)$
PHENIX J/ψ ($N_{data} = 74$)	nCTEQ15	$\xi = 0.5$	265	–	134	–	–
		$\xi = 1.0$	189	–	176	–	–
		$\xi = 2.0$	231	–	205	–	–
	EPPS16	$\xi = 0.5$	133	–	138	–	–
		$\xi = 1.0$	207	–	167	–	–
		$\xi = 2.0$	263	–	209	–	–
LHC W/Z ($N_{data} = 102$)	nCTEQ15	$\xi = 0.5$	248	218	230	212	229
		$\xi = 1.0$		254	271	214	238
		$\xi = 2.0$		317	332	219	243
NMC F_2^{Sn}/F_2^C ($N_{data} = 111$)	nCTEQ15	$\xi = 0.5$	65	93	98	86	70
		$\xi = 1.0$		65	66	78	67
		$\xi = 2.0$		62	62	71	65
NMC F_2^{Pb}/F_2^C ($N_{data} = 14$)	nCTEQ15	$\xi = 0.5$	8	8	8	8	7
		$\xi = 1.0$		7	6	7	7
		$\xi = 2.0$		9	8	7	8

PREDICTIONS & CONSISTENCES

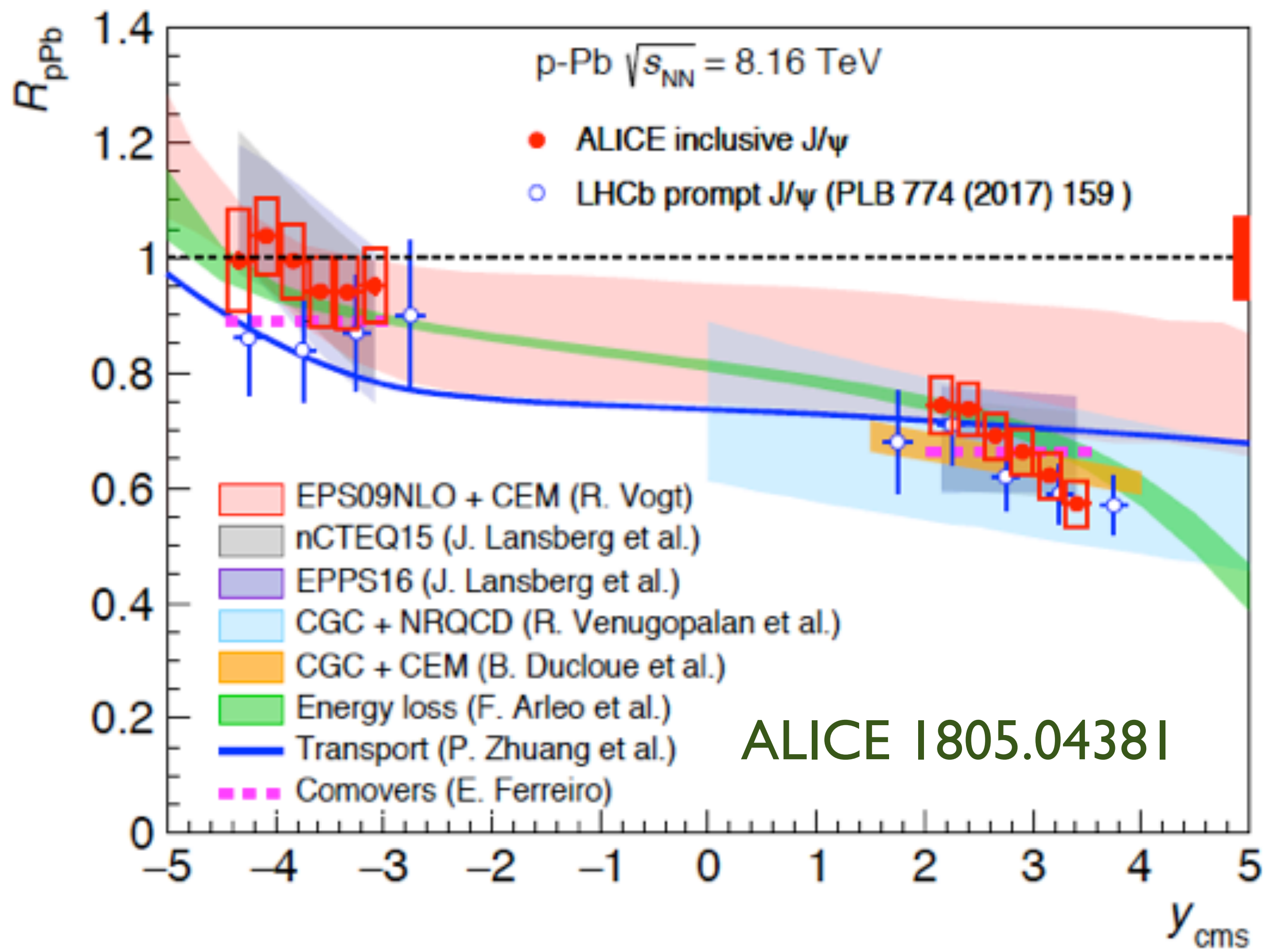
Kusina, Lansberg, Schienbein, HSS '17

- Other observables: e.g. R_{FB}
- Consistent with other measurements.
- Reweighting method is still reasonable from the large number of surviving nPDFs

		D^0	J/ψ	$B \to J/\psi$	$\Upsilon(1S)$
nCTEQ15	$\xi = 0.5$	3063	3423	6584	9508
	$\xi = 1.0$	5573	5906	7859	9830
	$\xi = 2.0$	5353	5479	8625	9929
EPPS16	$\xi = 0.5$	3116	3304	7914	9724
	$\xi = 1.0$	3979	4204	8444	9875
	$\xi = 2.0$	4226	4462	8783	9932

PREDICTIONS & CONSISTENCES

Kusina, Lansberg, Schienbein, HSS '17



- Other observables: e.g. R_{FB}
- Consistent with other measurements.
- Reweighting method is still reasonable from the large number of surviving nPDFs
- New LHC measurements versus our new predictions start to appear.

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 !