

# Benchmarking in $p\text{-}\mathcal{A}$ : *is it still possible?*

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Instituto Superior Técnico, Lisbon

# *Outline*

- A small detour: current state of nPDFs
- Definition
- Status after Run I
- Summary & outlook
- Answering the question

*detour: status of nPDFs*

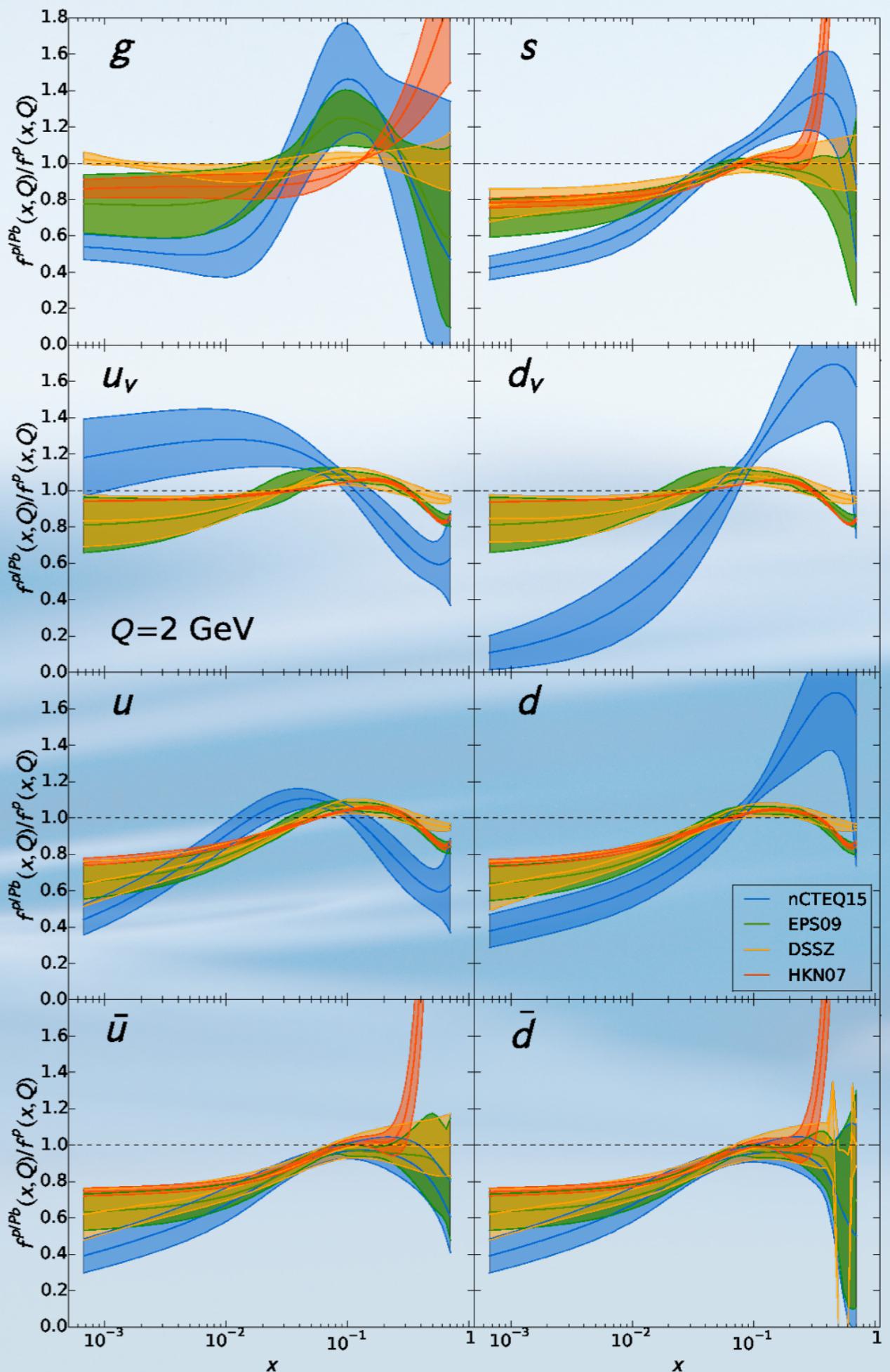
SET		EPS09 JHEP 0904 (2009) 065	DSSZ PRD85 (2012) 074028	nCTEQ PRD93 (2016) no.8, 085037	KA15 PRD93 (2016) no.1, 014026
data type	e-DIS	✓	✓	✓	✓
	D-Y	✓	✓	✓	✓
	hadrons	✓	✓	✓	✗
	v-DIS	✗	✓	✗	✗
# data points	929		1579	740	1479
accuracy	NLO		NLO	NLO	NNLO
proton PDF	CTEQ6.I		MSTW2008	~ CTEQ6.I	JR09
scheme	ZM-VFNS		GM-VFNS	GM-VFNS	ZM-VFNS
comments	huge gluon shadowing/ anti-shadowing found		medium modified FFs	flavour separation considered, <b>not enough sensitivity</b>	deuteron data included

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EPPS: **NLO (with di-jet data)**  
A-Z: **NNLO GM-VFNS**

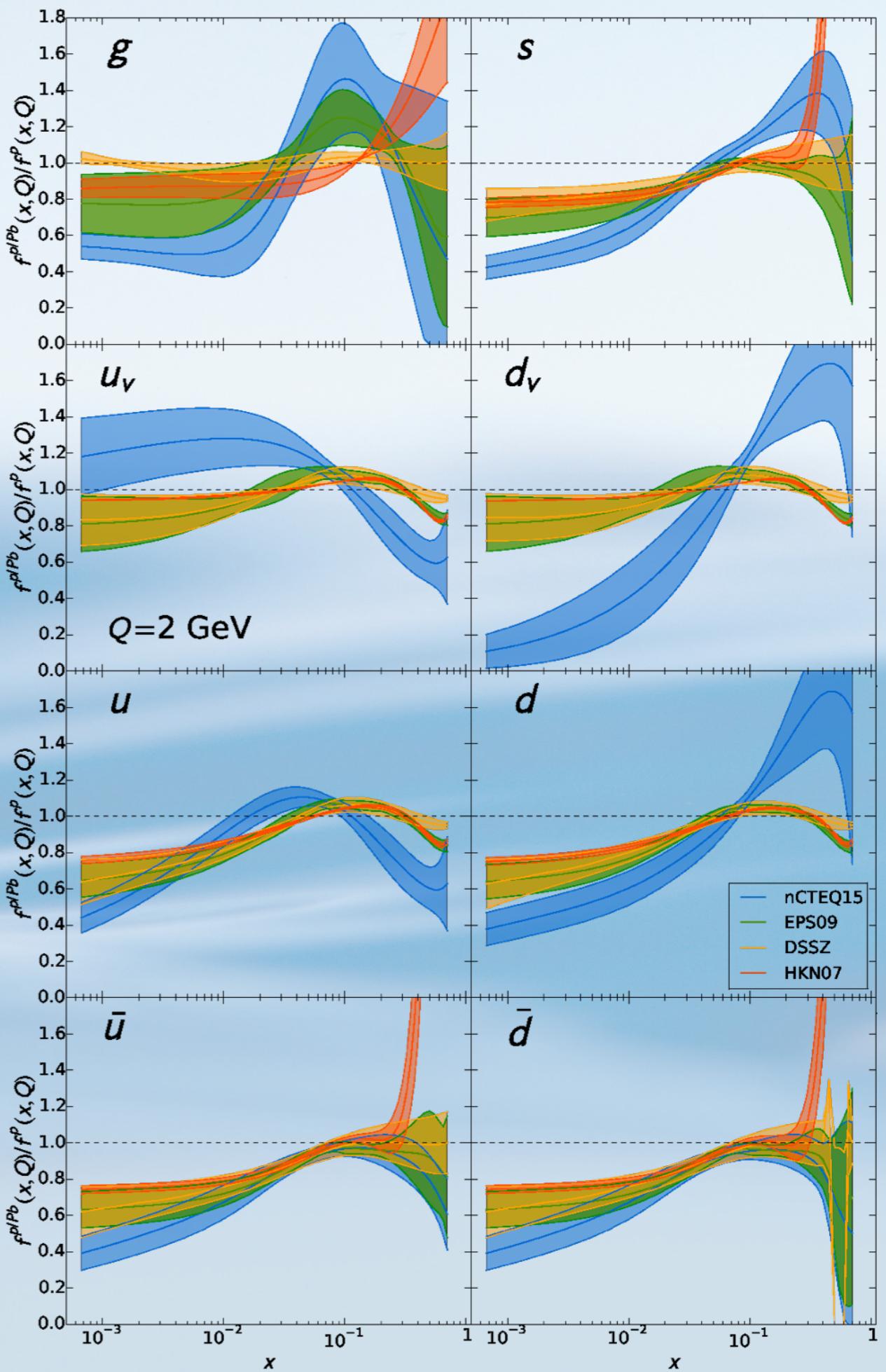
coming soon!

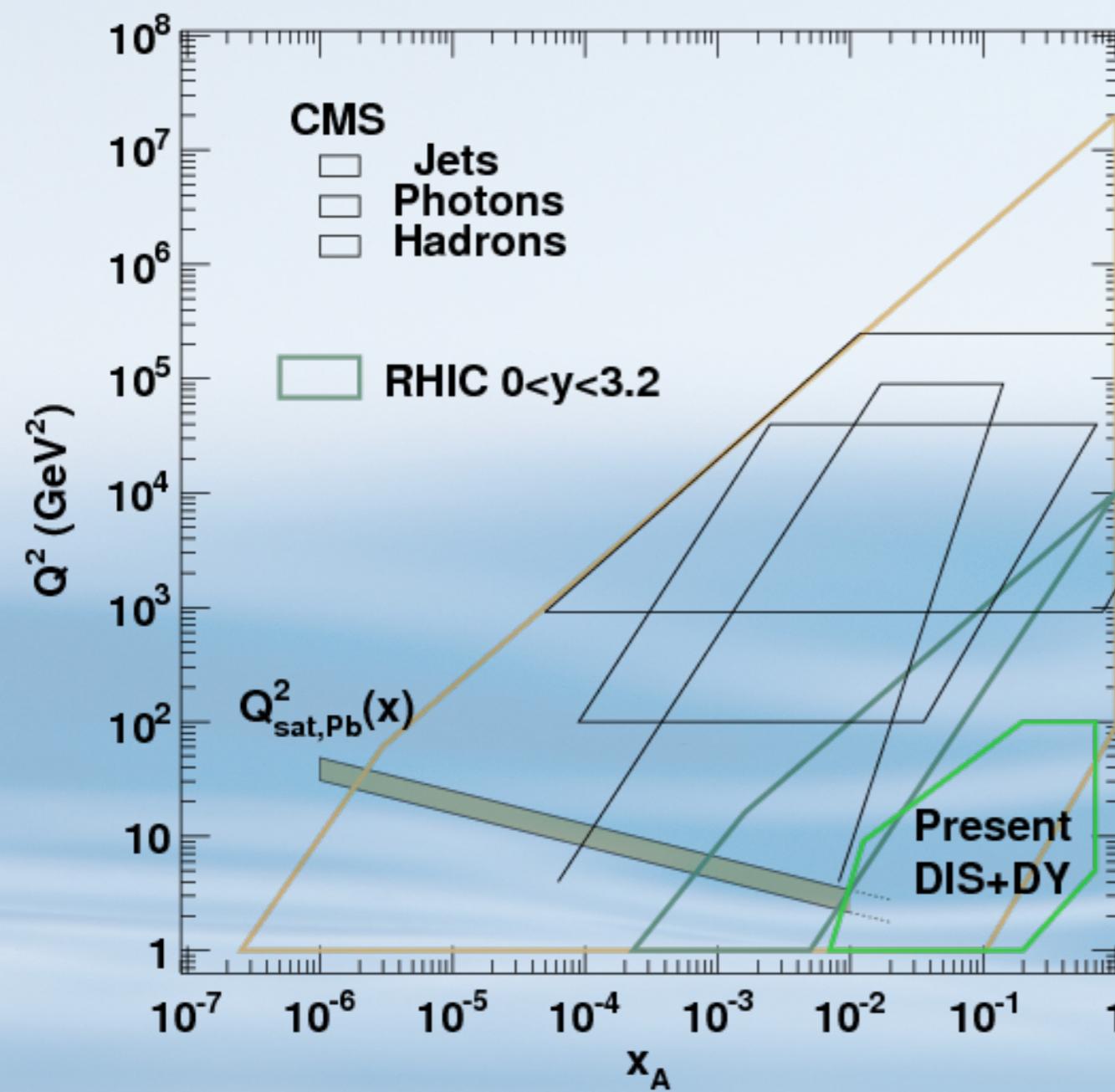
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- Low  $x$ : extrapolations
- No sensitivity to flavour separation
- No sensitivity to gluon density at low nor high  $x$



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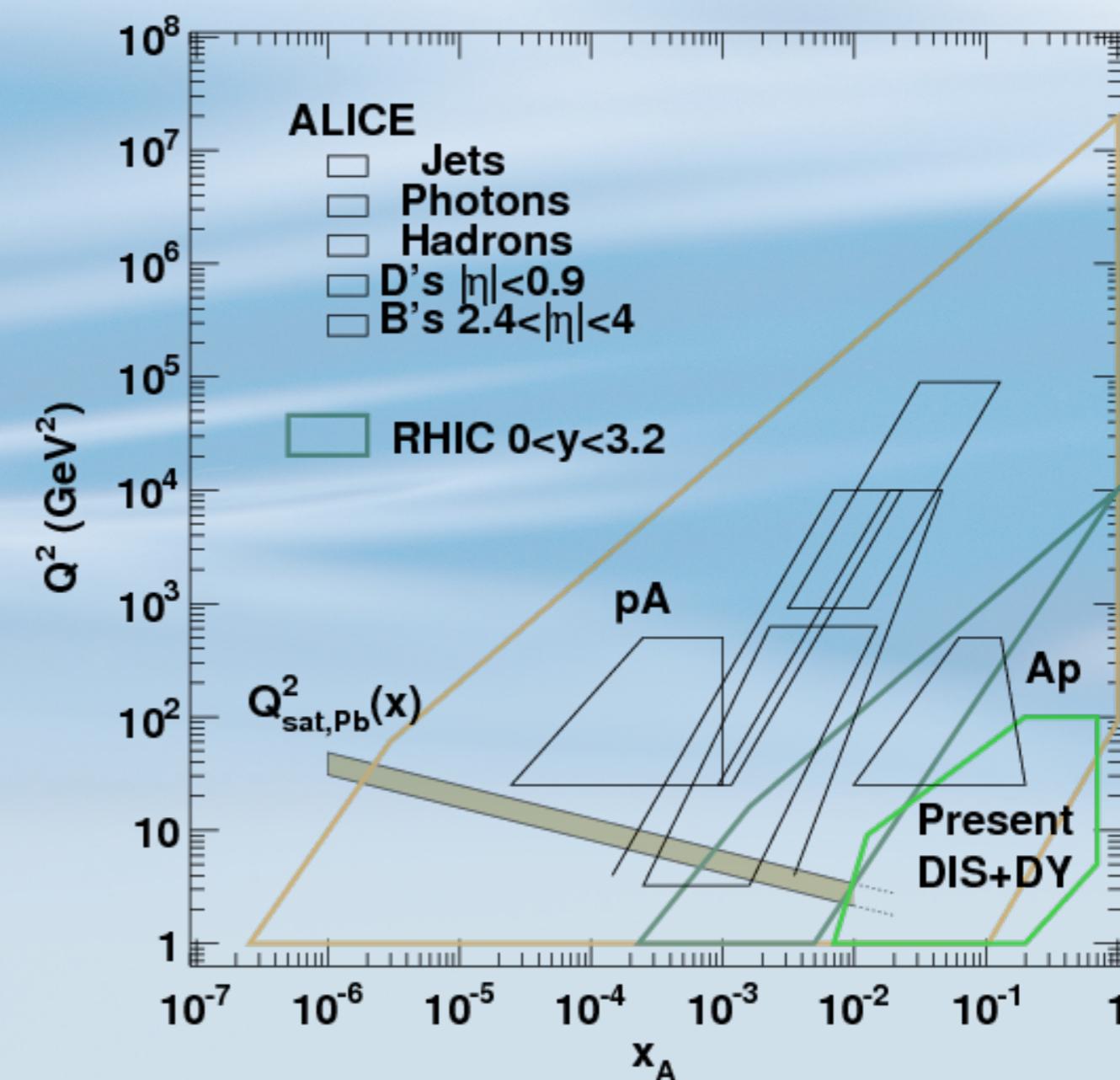
No LHC data  
considered in the fits  
**YET**





up to 4!! o.o.m. in  $x$

almost 4!! o.o.m. in  $Q^2$



“The proton–nucleus program serves a dual purpose. It provides, on the one hand, **baseline measurements** for the nucleus–nucleus program. Experience from previous heavy ion programs (CERN SPS, RHIC) shows that a p+A baseline is essential for the interpretation of some of the main discoveries (e.g. J/ψ-suppression, jet quenching, etc).”

J.Phys. G39 (2012) 015010

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## to benchmark:

1. To test (something) in order to develop a standard.

# $\mathcal{EW}$ and hard probes after Run I

Disclaimer:

- many experimental measurements
- many theoretical results
- and not enough time to cover all



EW bosons



Particle production at high  $p_T$



Jets



Heavy flavours and quarkonia

# $\mathcal{EW}$ bosons

**ALICE:**

J.Phys.Conf.Ser. 612 (2015) no.1, 012009 (W)

**ATLAS:**

Phys.Rev. C92 (2015) no.4, 044915 (Z)  
ATLAS-CONF-2015-056 (W)

**CMS:**

Phys.Lett. B750 (2015) 565-586 (W)  
CMS-HIN-15-002 (Z)

**LHCb:**

JHEP 1409 (2014) 030 (Z)

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CMS-HIN-15-002 (Z)

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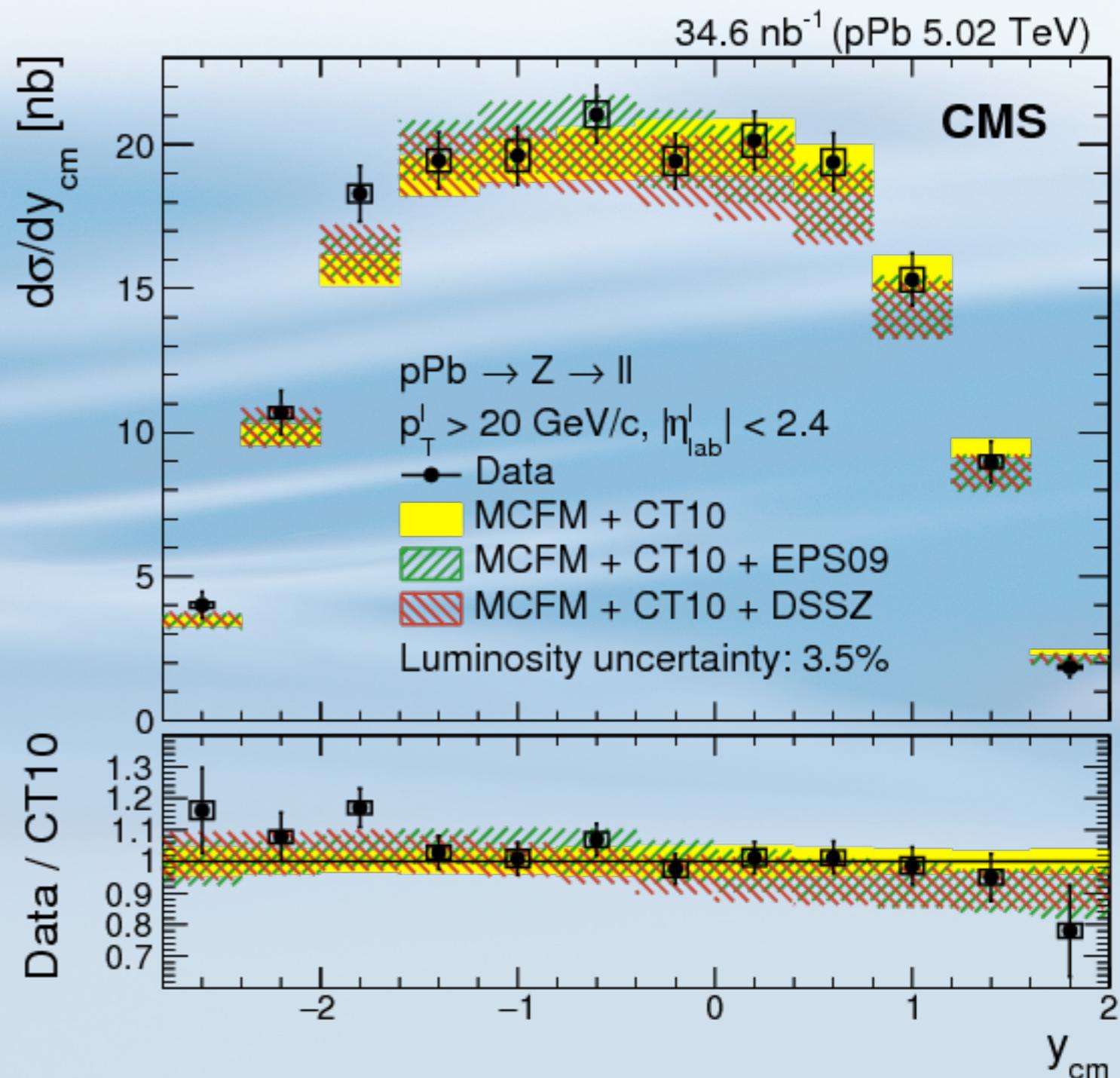
Phys.Rev. C92 (2015) no.4, 044915 (Z)  
ATLAS-CONF-2015-056 (W)

CMS:

Phys.Lett. B750 (2015) 565-586 (W)  
CMS-HIN-15-002 (Z)

LHCb:

JHEP 1409 (2014) 030 (Z)



**Data compatible with  
collinear factorized  
pQCD + nPDFs**

## *After Run I: EW bosons*

- 1- E. Basso, V.P. Gonçalves, M. Krelina, J. Nemchik and R. Pasechnik, arXiv:1603.01893
- 2- N. Armesto, H. Paukkunen, J.M. Penín, C.A. Salgado and PZ, EPJ C76 (2016) no.4, 218
- 3- D.B. Clark, arXiv:1510.09200
- 4- F. Arleo, E. Chapon and H. Paukkunen, EPJ C76 (2016) no.4, 214

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$$q_v \neq q'_v \quad \text{and} \quad \bar{q} \neq \bar{q}'$$

however

$$\frac{q_i^A}{q_i^p} = \frac{q_i'^A}{q_i'^p} \equiv R_i$$

$$i = v, s$$

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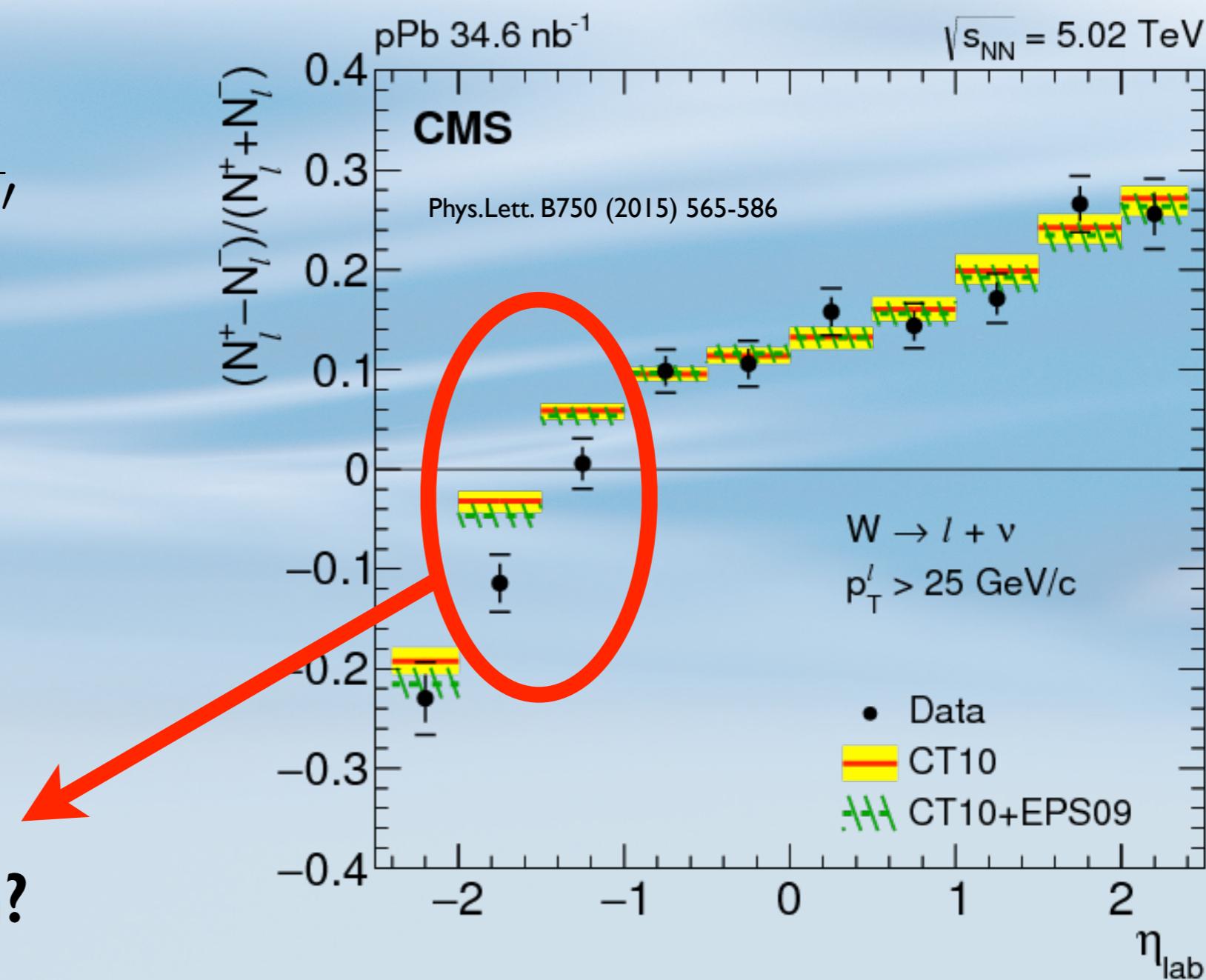
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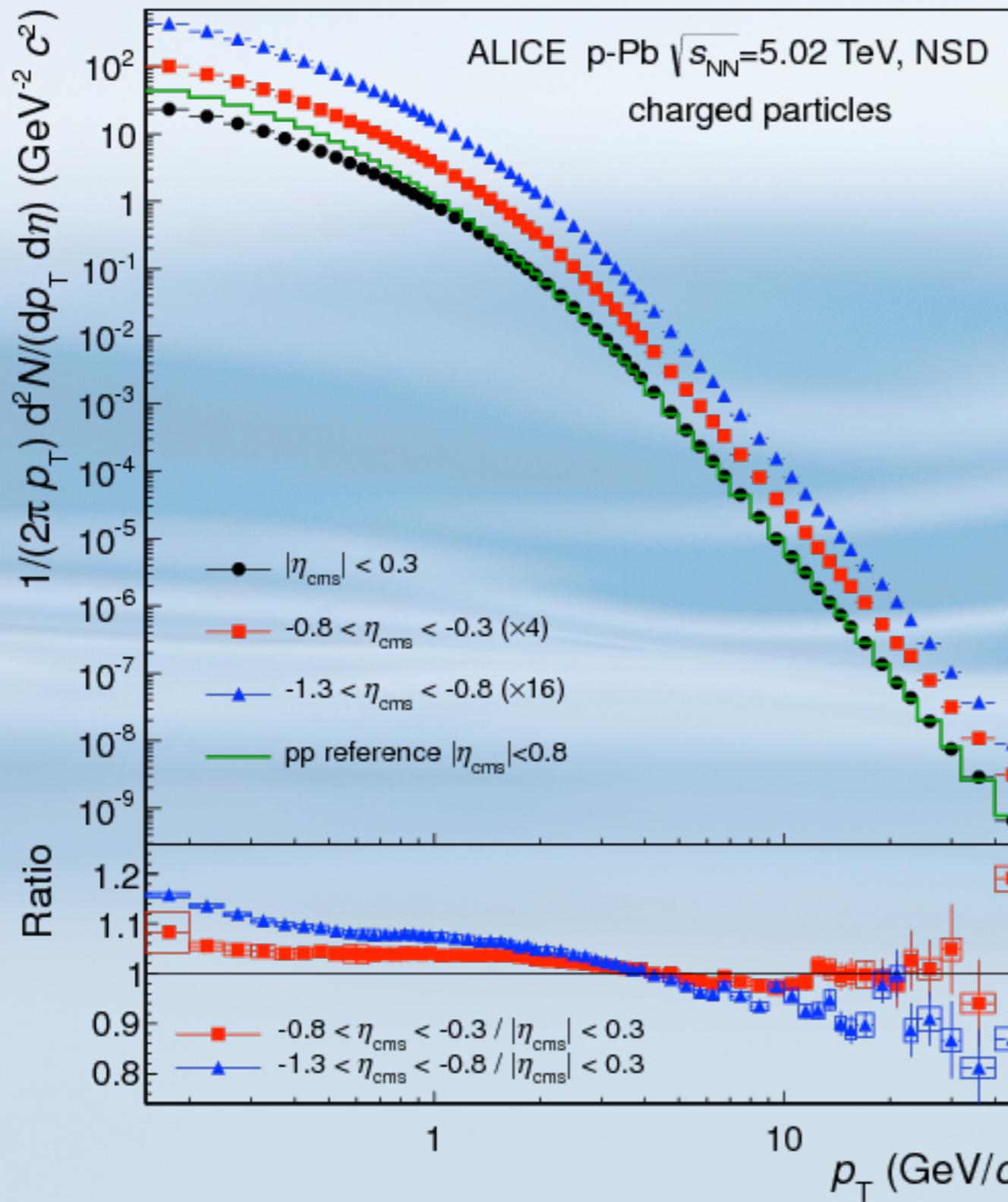
$$\frac{q_i^A}{q_i^p} = \frac{q'^A}{q'^p} \equiv R_i$$

$$i = v, s$$

Flavour decomposition?



# High transverse momentum particles



ALICE:

Phys.Rev.Lett. 110 (2013) no.8, 082302  
Eur.Phys.J. C74 (2014) no.9, 3054

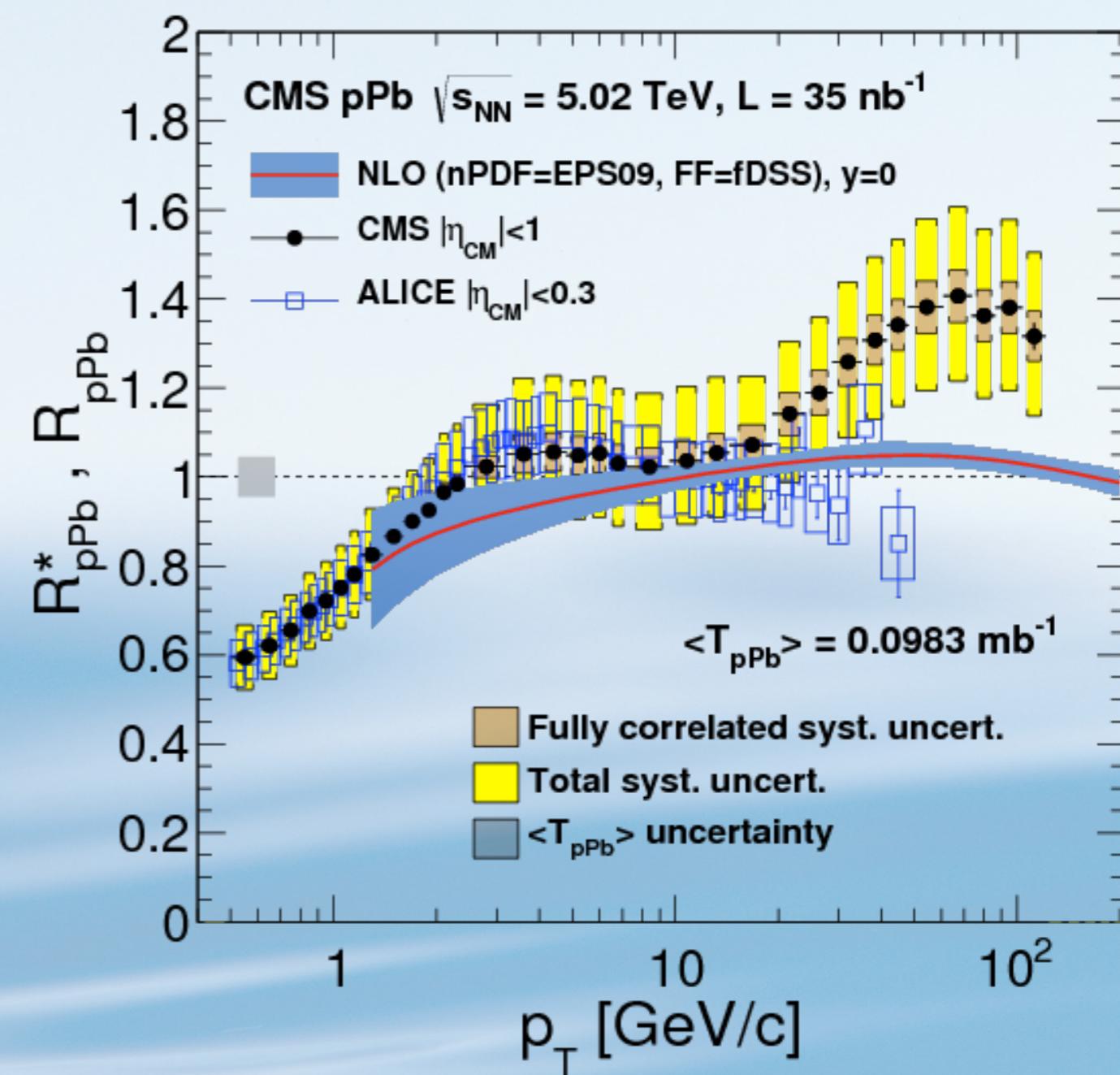
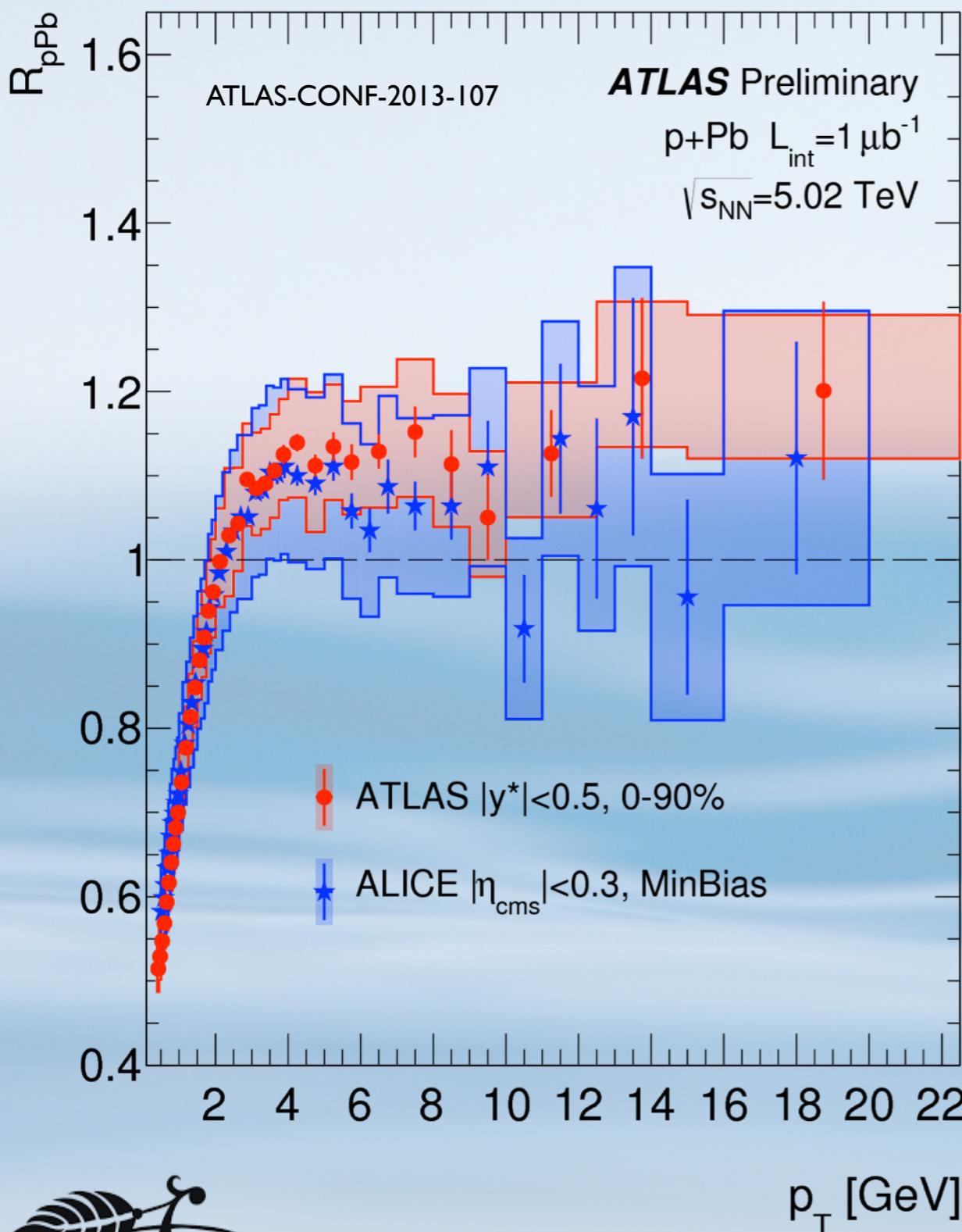
ATLAS:

ATLAS-CONF-2014-029  
ATLAS-CONF-2013-107

CMS:

Eur.Phys.J. C75 (2015) no.5, 237

# After Run I: high $p_T$ particle production

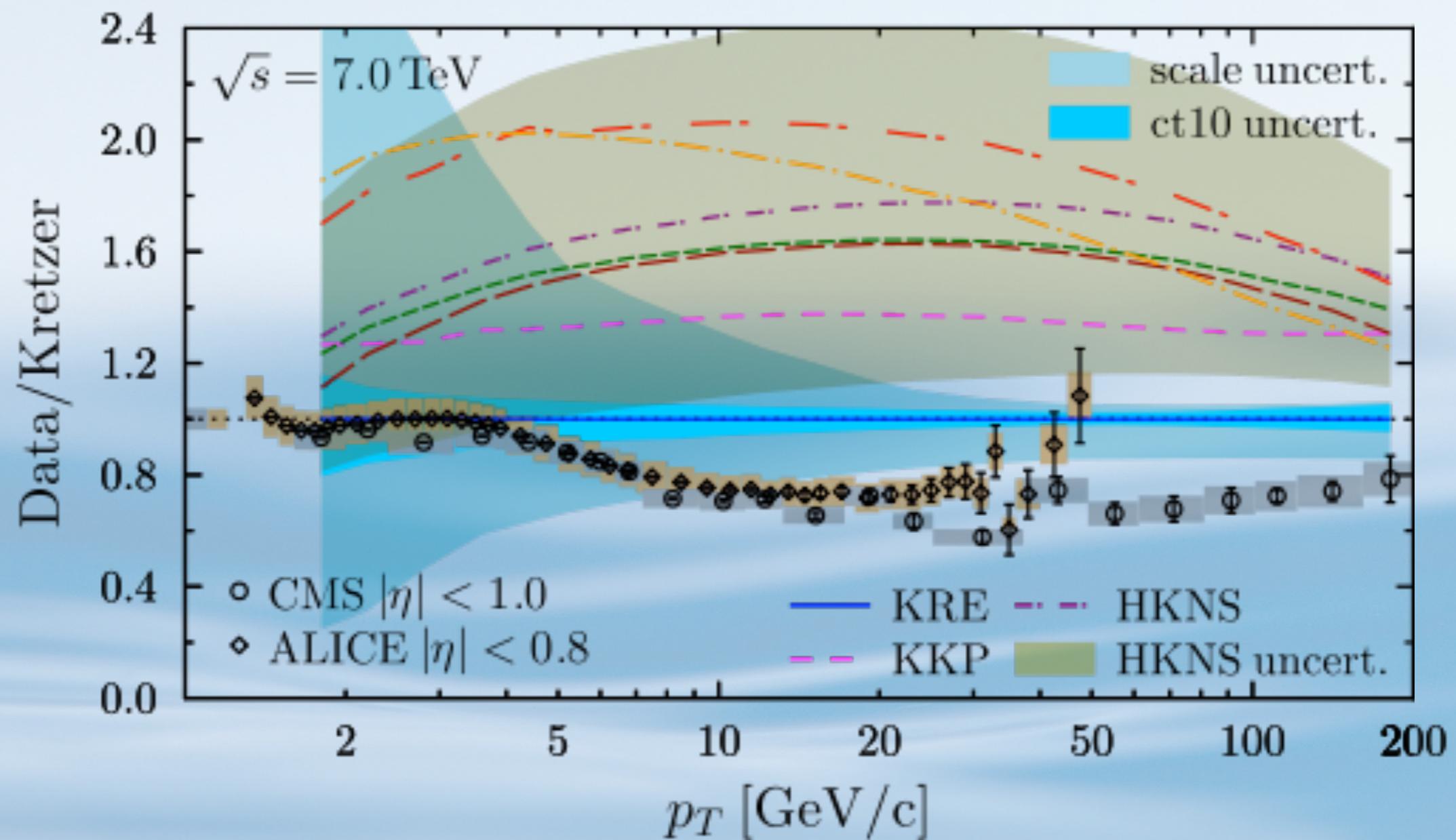


Eur.Phys.J. C75 (2015) no.5, 237

Most likely a pp issue (to be solved soon)



## After Run I: high $p_T$ particle production



D. d'Enterria, K.J. Eskola, I. Helenius and H. Paukkunen, Nucl.Phys. B883 (2014) 615-628

- FFs not reliable for pp
- New careful analyses required

D. de Florian, R. Sassot, M. Epele, R.J. Hernández-Pinto and M. Stratmann, Phys.Rev. D91 (2015) no.1, 014035

# Jets and di-jets

ALICE:

CERN-PH-EP-2016-052, arXiv:1603.03402  
 Phys.Lett. B746 (2015) 385-395  
 Phys.Lett. B749 (2015) 68-81

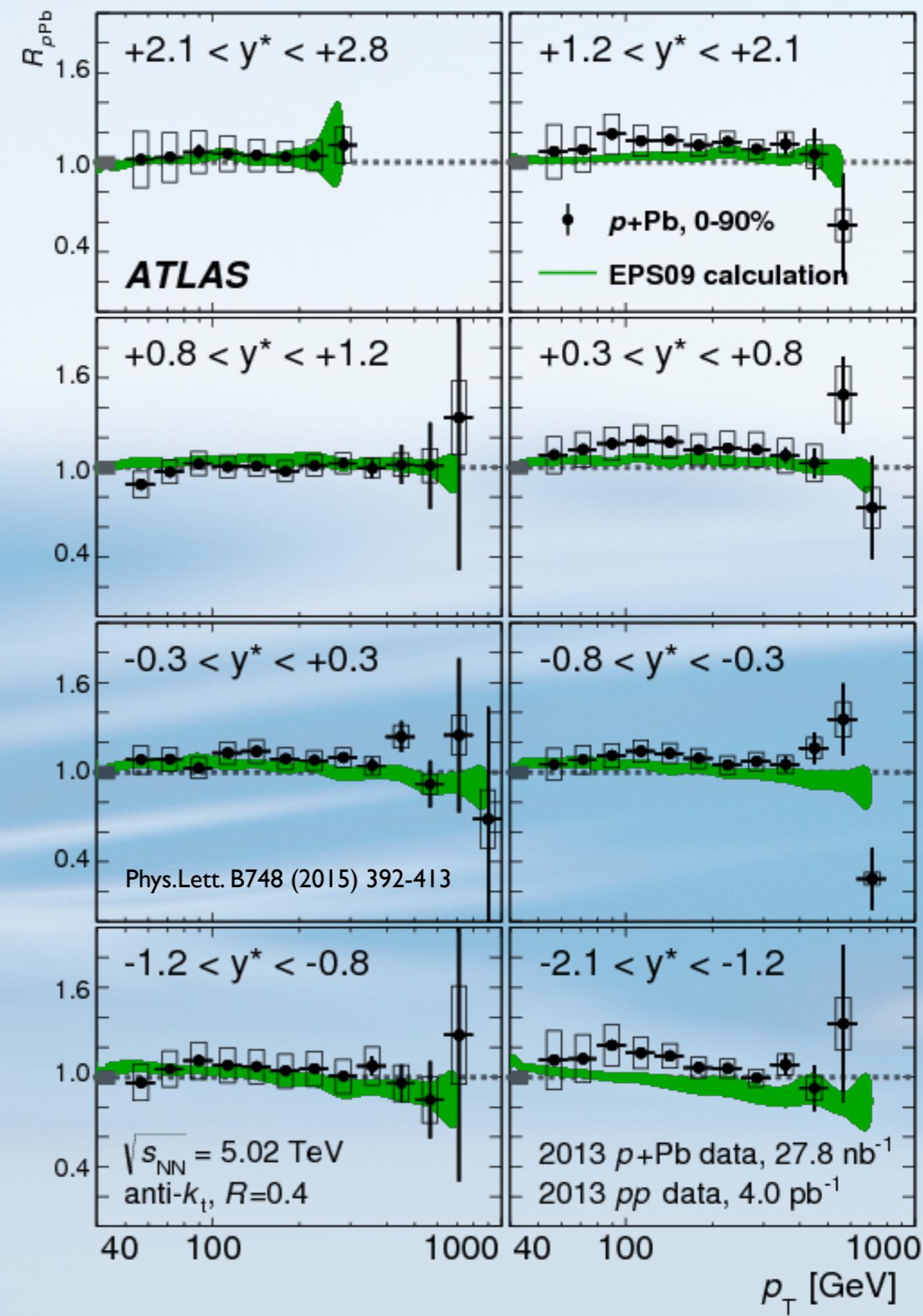
ATLAS:

Phys.Lett. B748 (2015) 392-413

CMS:

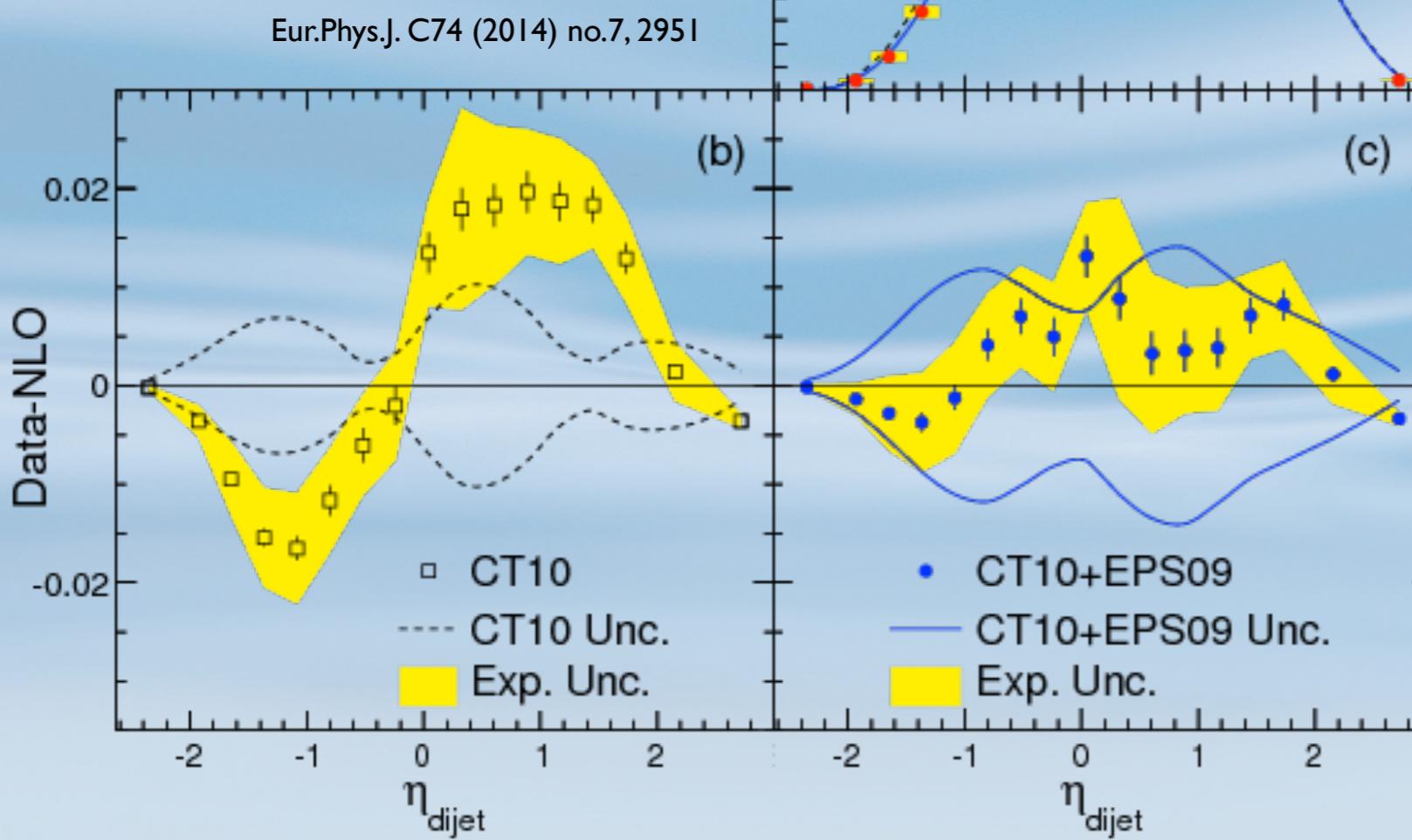
CMS-HIN-14-001, arXiv:1601.02001  
 Phys.Lett. B754 (2016) 59-80  
 Eur.Phys.J. C74 (2014) no.7, 2951

- Data compatible with nPDFs



# After Run I: jets and di-jets

CMS pPb  $35 \text{ nb}^{-1}$   
 $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$   
 $p_{T,1} > 120 \text{ GeV/c}$   
 $p_{T,2} > 30 \text{ GeV/c}$   
 $\Delta\phi_{1,2} > 2\pi/3$   
All  $E_T^{4 < |\eta| < 5.2}$



gluon  
constraining  
power!

H. Paukkunen, K. Eskola and C.A. Salgado,  
Nucl.Phys.A 931 (2014) 331-336

## *After Run I: a first complete analysis*

EW bosons, jet, di-jet and particle production data have been comprehensibly analyzed

N.Armesto, H. Paukkunen, J.M. Penín, C.A. Salgado and PZ, EPJ C76 (2016) no.4, 218

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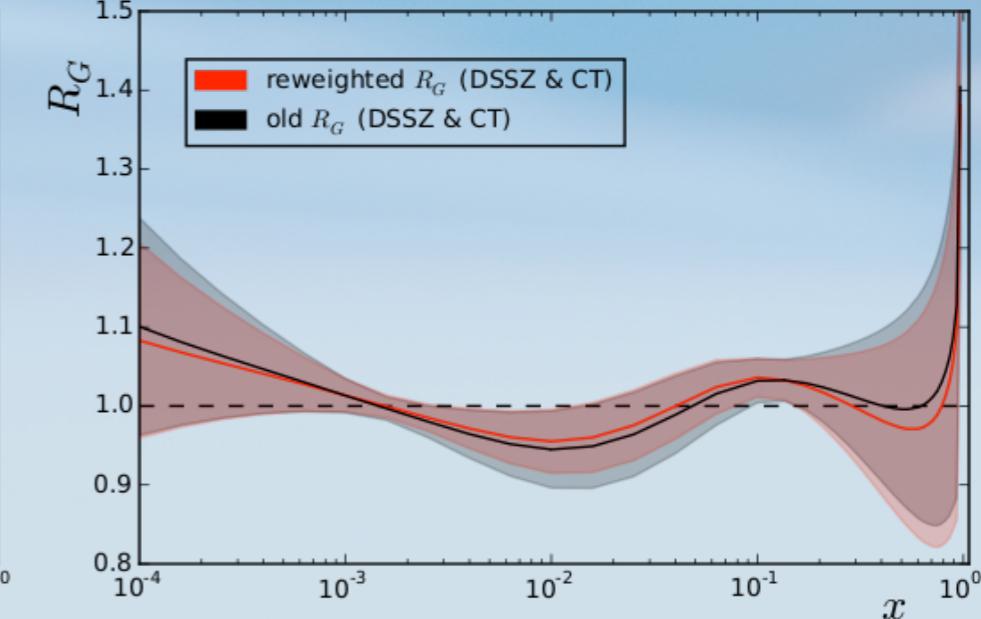
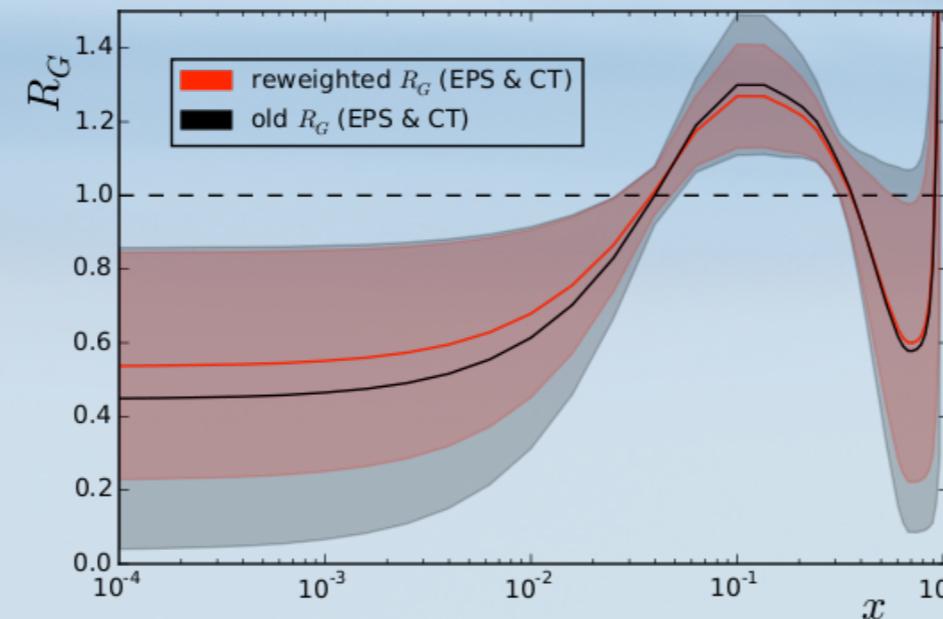
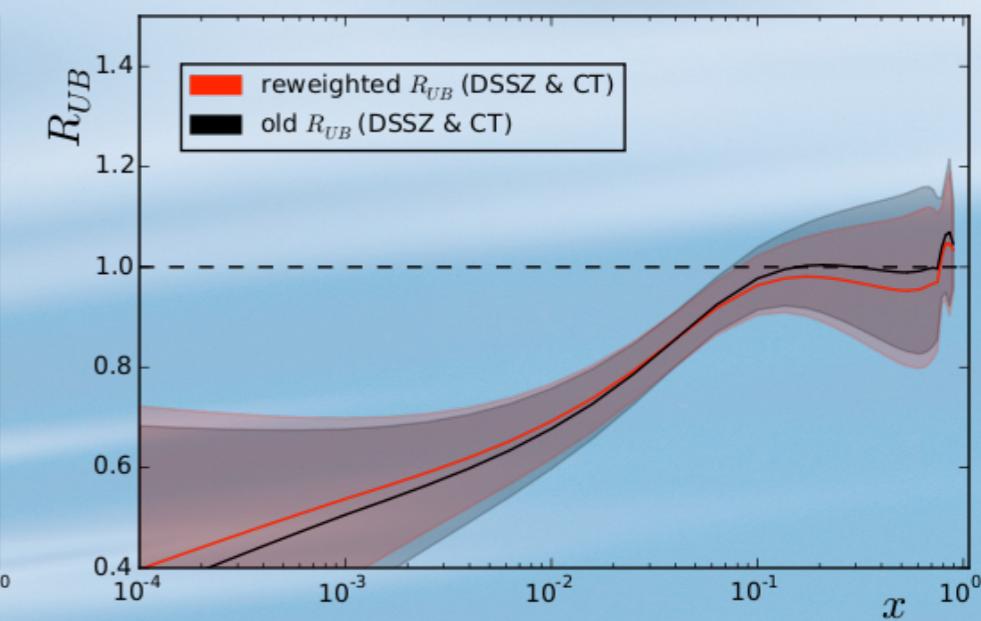
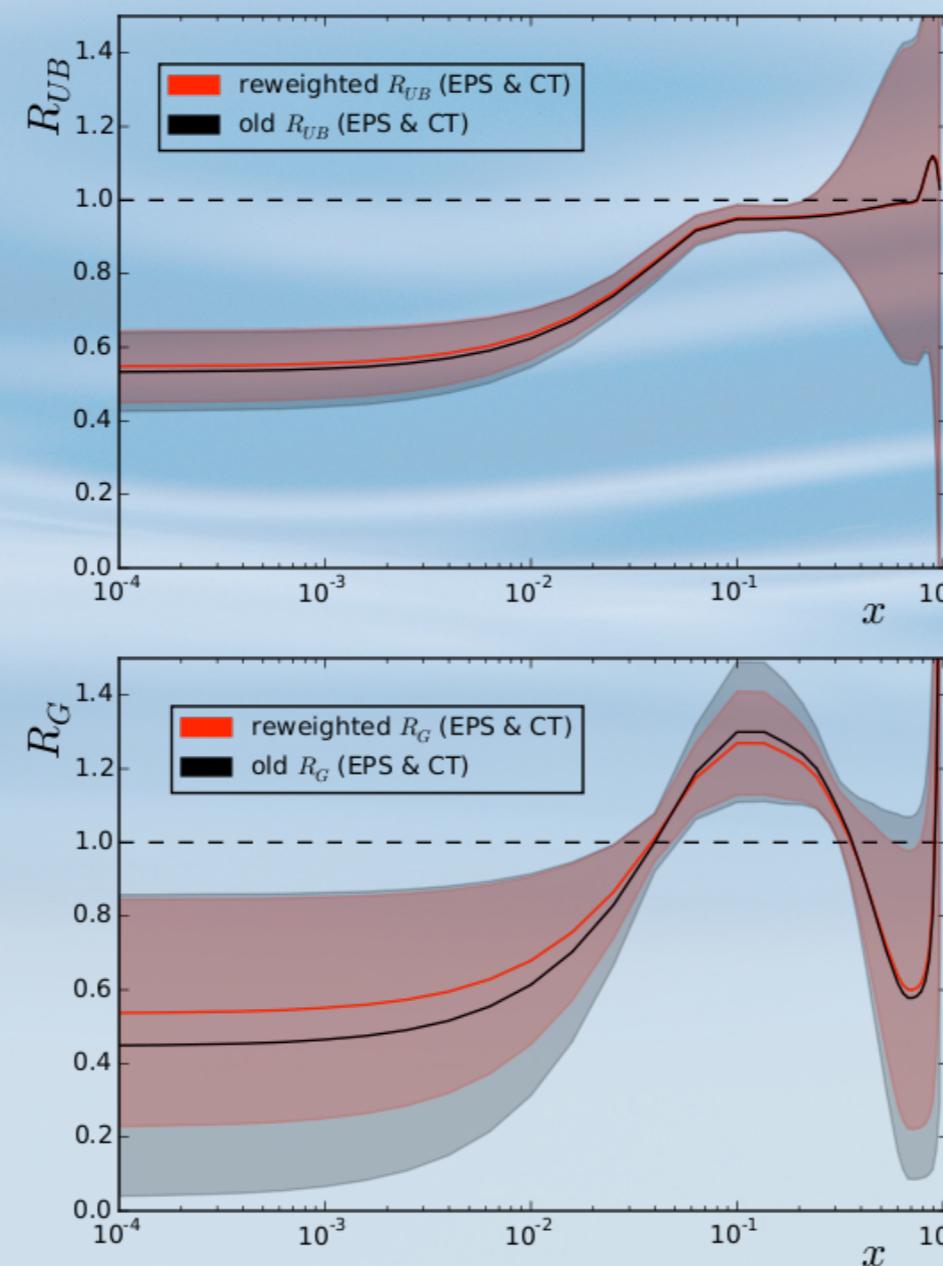
N. Armesto, H. Paukkunen, J.M. Penín, C.A. Salgado and PZ, EPJ C76 (2016) no.4, 218

- 2 sets of proton PDFs  $\times$  2 sets of nPDFs

- No flavour separation in the nPDFs

- No quantitative tension

- Mostly driven by di-jet data



## *After Run I: a first complete analysis*

**Treatment of experimental uncertainties is relevant.**

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**very.** □

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**very.** □

Strong dependence on the proton reference PDFs

pp experimental reference required

low  $p_T$  reach limited by FFs

# Quarkonia and $\mathcal{HF}$

ALICE:

CERN-PH-EP-2016-046, CERN-EP-2016-046, arXiv:1603.02816  
CERN-PH-EP-2016-034, CERN-EP-2016-034, arXiv:1602.07240  
Eur.Phys.J. C76 (2016) no.5, 245  
Phys.Lett. B754 (2016) 81-93  
CERN-PH-EP-2015-161, arXiv:1506.09206  
JHEP 1511 (2015) 127  
JHEP 1506 (2015) 055  
Phys.Lett. B740 (2015) 105-117  
Phys.Rev.Lett. 113 (2014) no.23, 232504  
JHEP 1412 (2014) 073  
JHEP 1402 (2014) 073  
Phys.Rev.Lett. 113 (2014) no.23, 232301

ATLAS:

Phys.Rev. C92 (2015) no.3, 034904  
ATLAS-CONF-2015-050  
ATLAS-CONF-2015-023

CMS:

Phys.Rev.Lett. 116 (2016) no.3, 032301  
JHEP 1404 (2014) 103

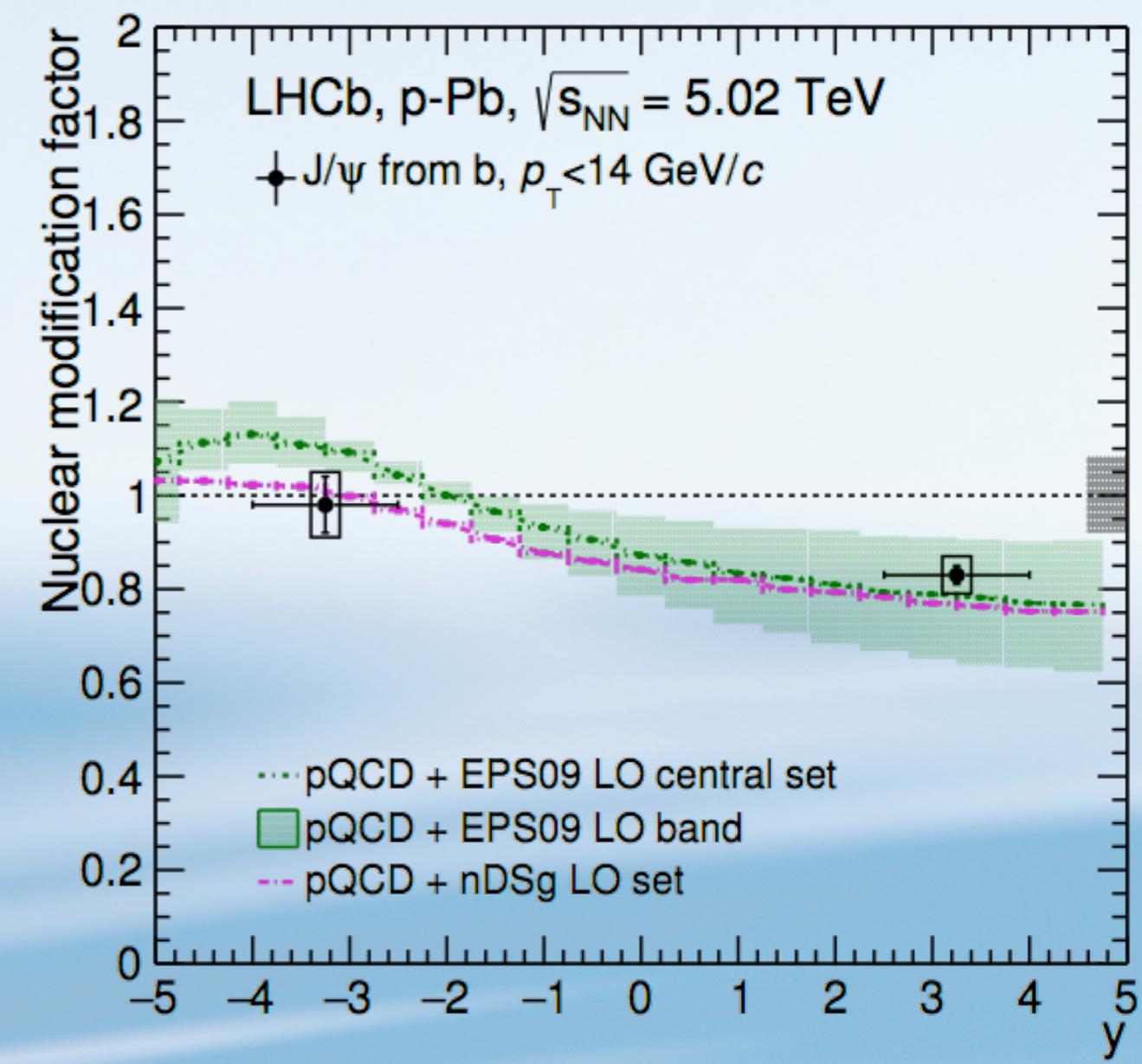
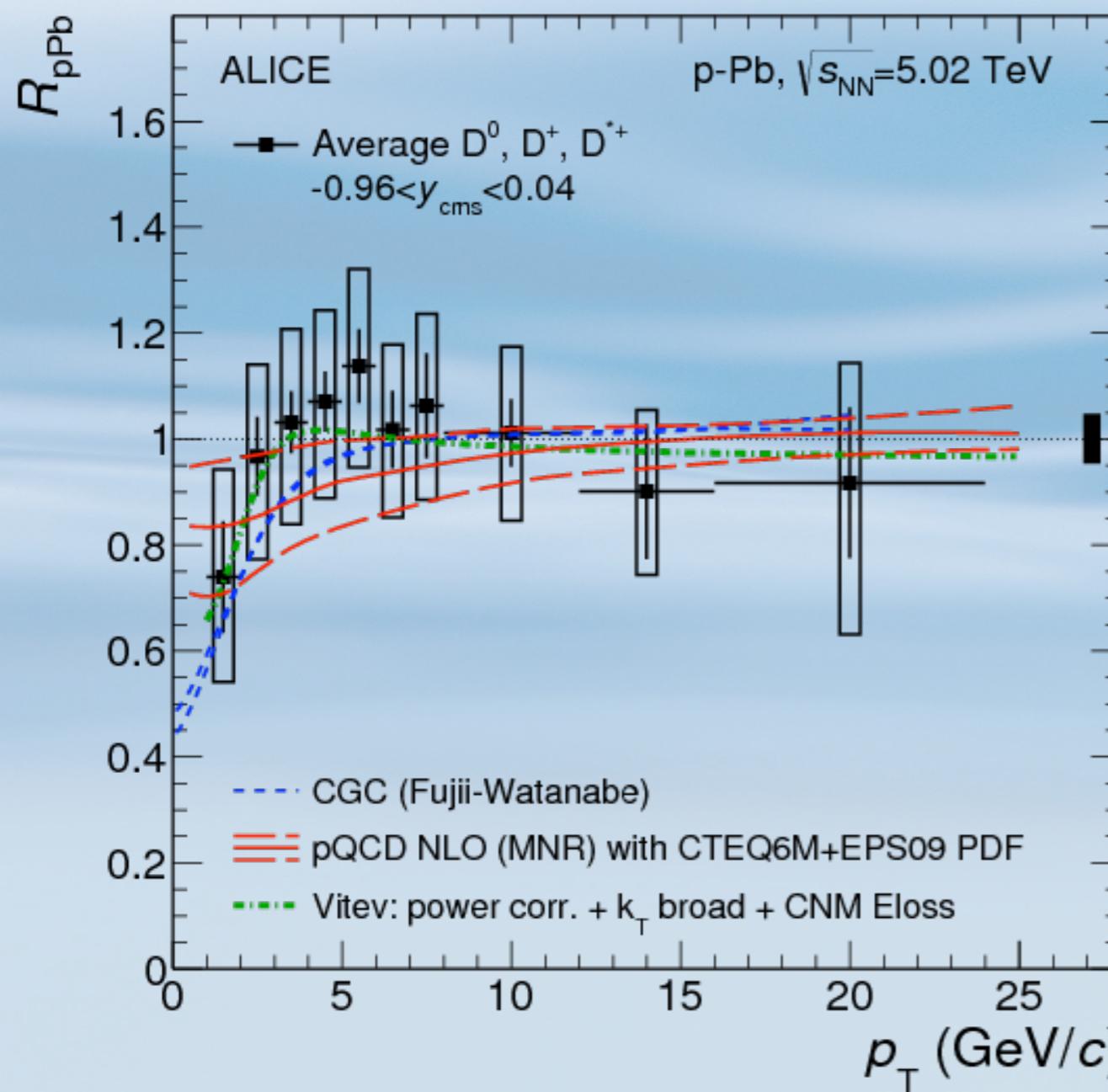
LHCb:

JHEP 1603 (2016) 133  
JHEP 1402 (2014) 072

$J/\psi$ ,  $\psi(2S)$ ,  $\Upsilon(1S)$ ,  $\Upsilon(2S)$ ,  $\Upsilon(3S)$ ,  $\varphi$ ,  $B$ ,  $K^*$ ,  $D$

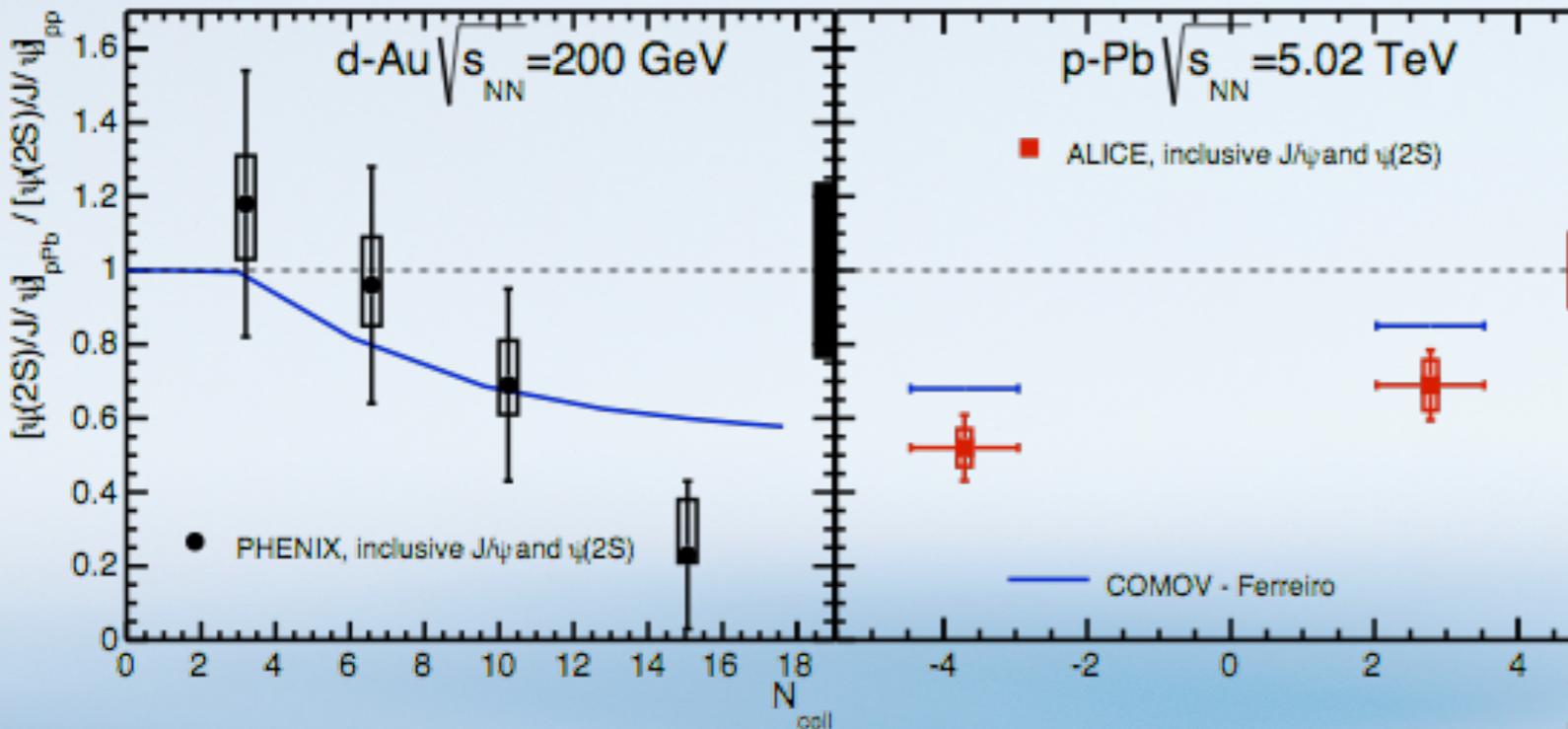
# After Run I: heavy flavour and quarkonia

Phys.Rev.Lett. 113 (2014) no.23, 232301



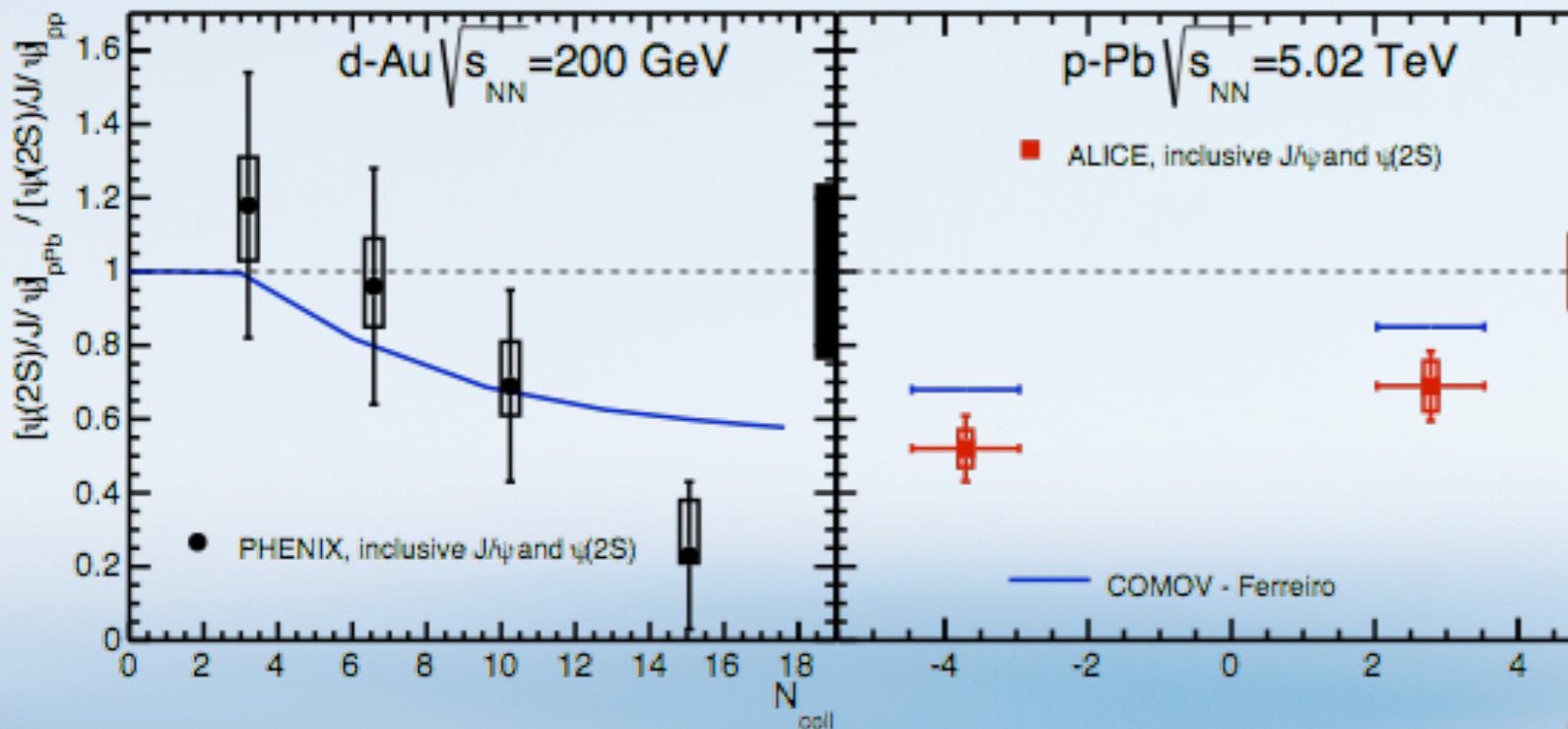
Hint of discriminating  
power between nPDFs...

## After Run I: heavy flavour and quarkonia



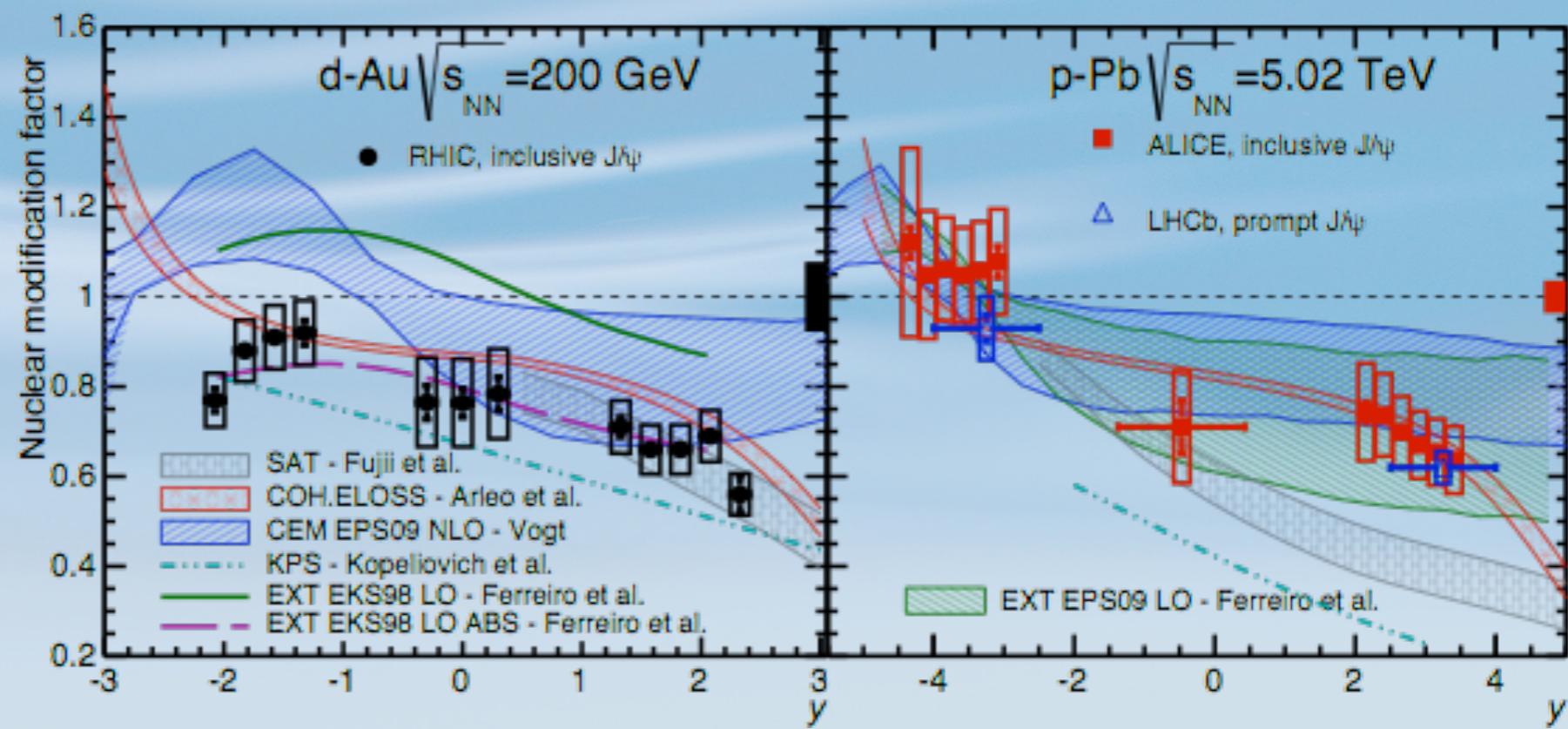
... and very intriguing results...

## After Run I: heavy flavour and quarkonia



... and very intriguing results...

... though not (yet)  
straightforwardly  
useful for nPDFs



# *Summing up*

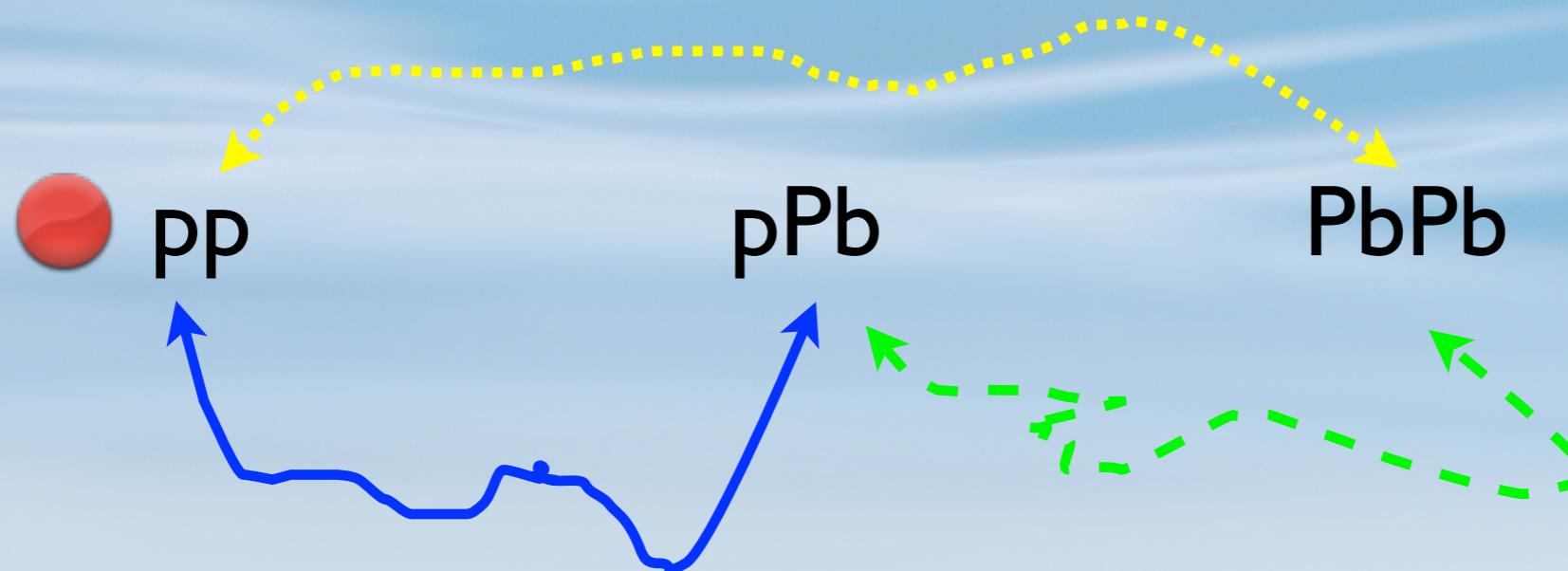
- Huge amount of data at 5TeV
- And many theoretical descriptions...
  - ... some give a good description of data
  - ... and some are not that successful



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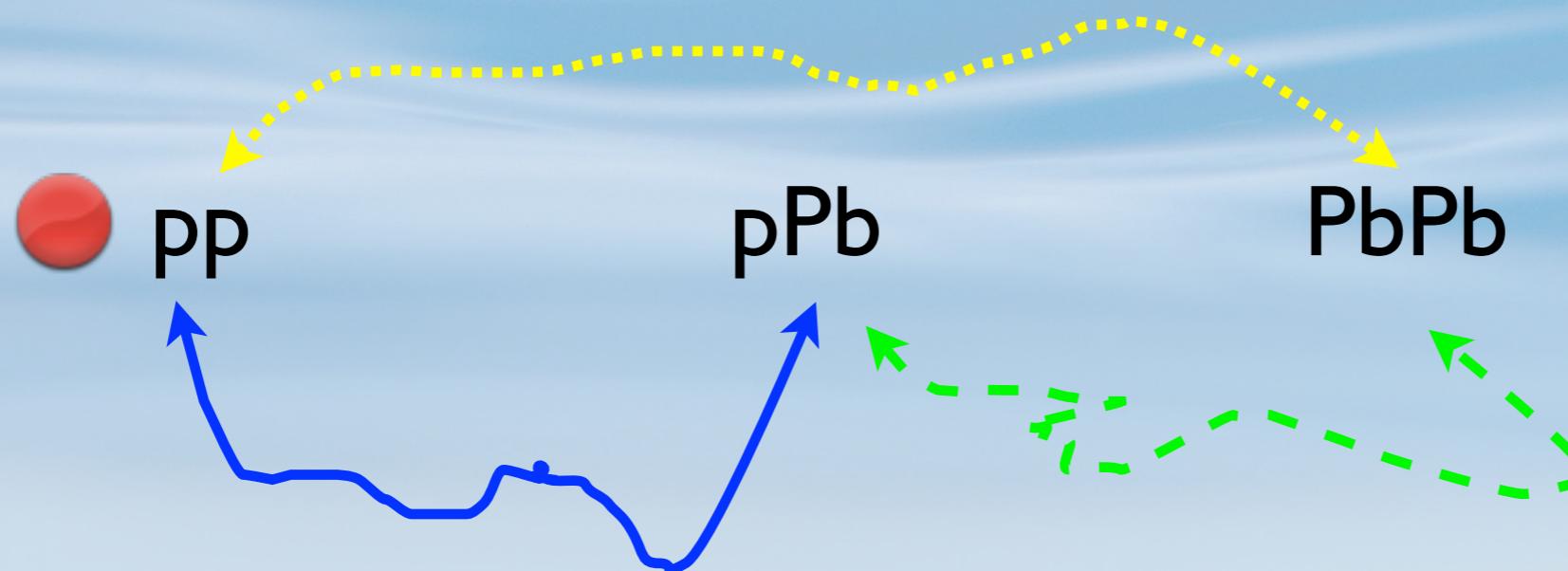
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# Summing up

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And now we'll have the pp reference!

# *Outlook*

- ◆ new NLO & NNLO analyses:
  - more flexible forms
  - relax assumptions
  - new data
- ◆ include LHC
- ◆ centrality data to be carefully studied

“The proton–nucleus program serves a dual purpose. It provides, on the one hand, baseline measurements for the nucleus–nucleus program. Experience from previous heavy ion programs (CERN SPS, RHIC) shows that a p+A baseline is essential for the interpretation of some of the main discoveries (e.g. J/ψ-suppression, jet quenching, etc).”

J.Phys. G39 (2012) 015010

## to benchmark:

1. To test (something) in order to develop a standard.

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2. To measure (something) against a standard.

next pPb run will give  
very exciting  
results!

*Thank you for  
your attention!*