

# The LHC p+Pb run from the nuclear PDF perspective

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The logo for DIPSI 2014. The letters 'DIPSI' are in a dark blue, bold, sans-serif font. The letter 'I' is replaced by a stylized particle detector or accelerator component, also in dark blue. The year '2014' is in a light green, bold, sans-serif font.

DIPSI 2014

# The LHC p+Pb run from the nuclear PDF perspective

- The Pb+Pb run with 2.76TeV and p+Pb run with 5.02TeV c.m energy allow to test the factorization and pQCD tools in nuclear environment using various hard processes like heavy gauge boson production (W, Z), jets, isolated photons,...

- At RHIC, the c.m. energy 200GeV has limited the processes and their kinematic reach

$$\sigma^{A+B \rightarrow \mathcal{O}} = \sum_{i,j} \underbrace{f_i^A(\mu_{\text{fact}}^2)}_{\substack{\text{nuclear PDFs, obey} \\ \text{the usual DGLAP}}} \otimes \underbrace{\hat{\sigma}^{i+j \rightarrow \mathcal{O}}(\mu_{\text{fact}}^2, \mu_{\text{ren}}^2)}_{\substack{\text{usual pQCD} \\ \text{coefficient functions}}} \otimes \underbrace{f_j^B(\mu_{\text{fact}}^2)}_{\substack{\text{nuclear PDFs, obey} \\ \text{the usual DGLAP}}}$$

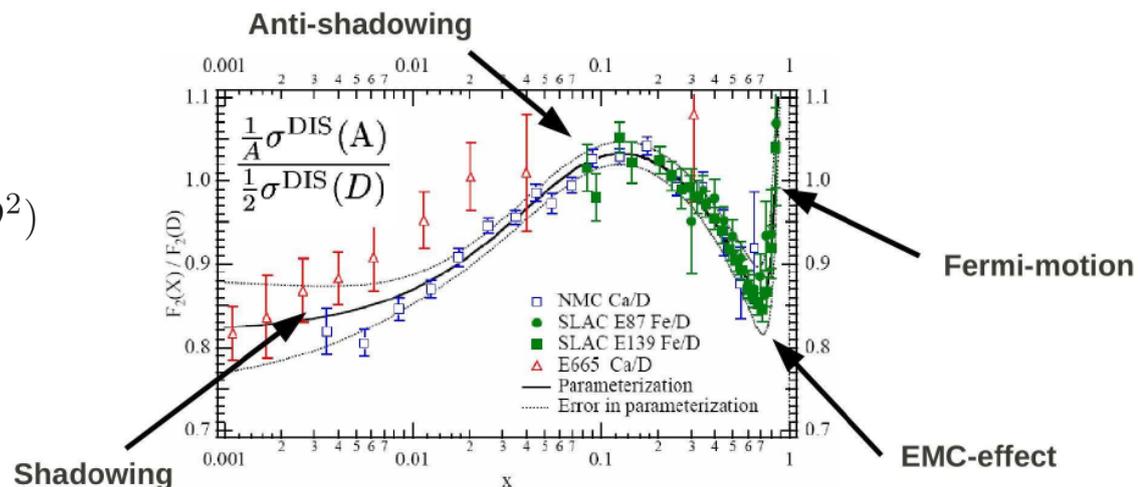
- Two types of effects expected:

“trivial” isospin effects

$$f_i^A(x, Q^2) = \left(\frac{Z}{A}\right) f_i^{\text{p},A}(x, Q^2) + \left(\frac{N}{A}\right) f_i^{\text{n},A}(x, Q^2)$$

“non-trivial” nuclear modifications

$$f_i^{\text{p},A}(x, Q^2) = R_i^A(x, Q^2) f_i^{\text{p}}(x, Q^2)$$

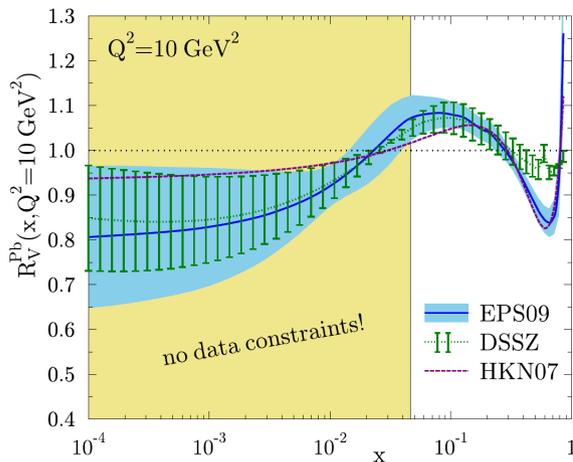


# Contemporary nuclear PDF fits

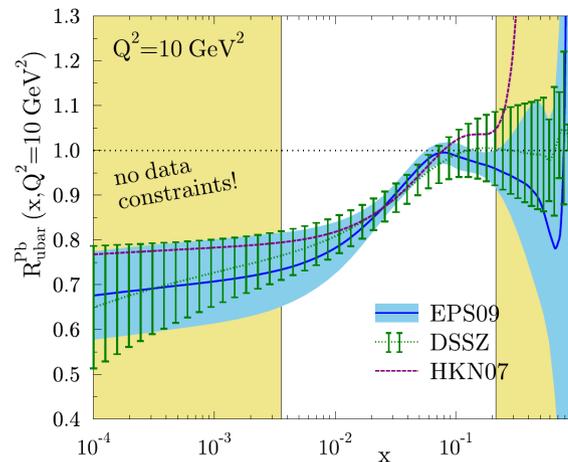
	HKN07	EPS09	DSSZ	NCTEQ
Order in $\alpha_s$	LO & NLO	LO & NLO	NLO	NLO
Neutral current DIS $\ell+A/\ell+d$	✓	✓	✓	✓
Drell-Yan dilepton $p+A/p+d$	✓	✓	✓	✓
RHIC pions $d+Au/p+p$		✓	✓	
Neutrino-nucleus DIS			✓	
$Q^2$ cut in DIS	1 GeV	1.3 GeV	1 GeV	2 GeV
datapoints	1241	929	1579	708
free parameters	12	15	25	17
error analysis	✓	✓	✓	✓
error tolerance $\Delta\chi^2$	13.7	50	30	35
Free proton baseline PDFs	MRST98	CTEQ6.1	MSTW2008	CTEQ6M-like
Heavy quark treatment	ZM-VFNS	ZM-VFNS	GM-VFNS	GM-VFNS

$$f_i^{p,A}(x, Q^2) = R_i^A(x, Q^2) f_i^p(x, Q^2)$$

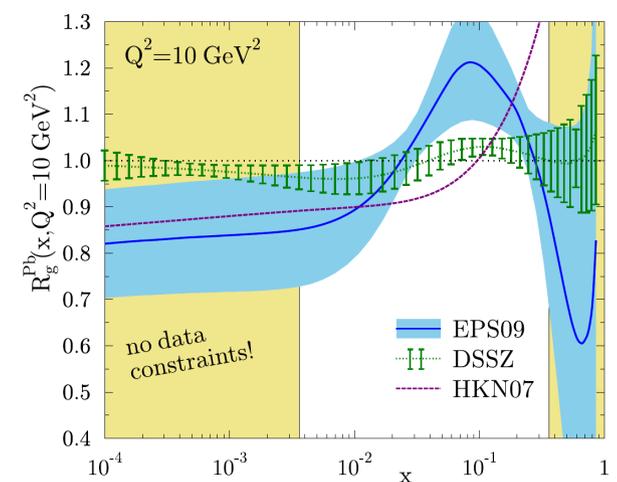
**up valence**



**up sea**



**gluons**



# The CMS p+Pb dijets

- Dijets binned in dijet “pseudorapidity”

$$\eta_{\text{dijet}} \equiv (\eta_1 + \eta_2)/2,$$



pseudorapidities of  
the individual jets

- Analogous to dilepton rapidity distribution
- Proton beam with  $E_p = 4\text{TeV}$
- Lead beam with  $E_{\text{Pb}} = (82/208) * 4\text{TeV} = 1.58\text{TeV}$



- The midrapidity shifts by

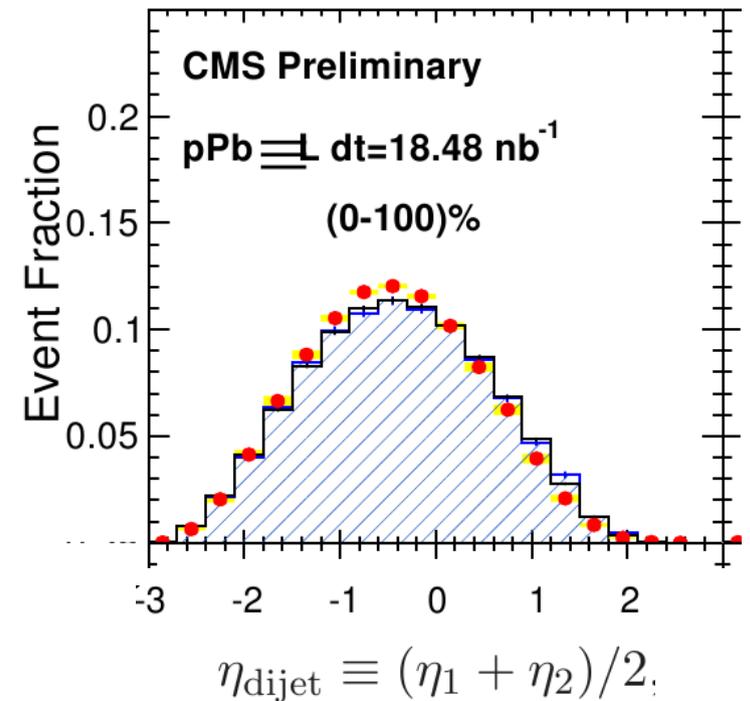
$$\eta_{\text{shift}} \equiv 0.5 \log (E_{\text{Pb}}/E_p) \approx -0.465$$

- Some extra “tweaking” needed to include such shifts to NLO Monte-Carlo tools

$p_{T,1} > 120 \text{ GeV}/c$  anti- $k_T$ (PFlow)  $R=0.3$

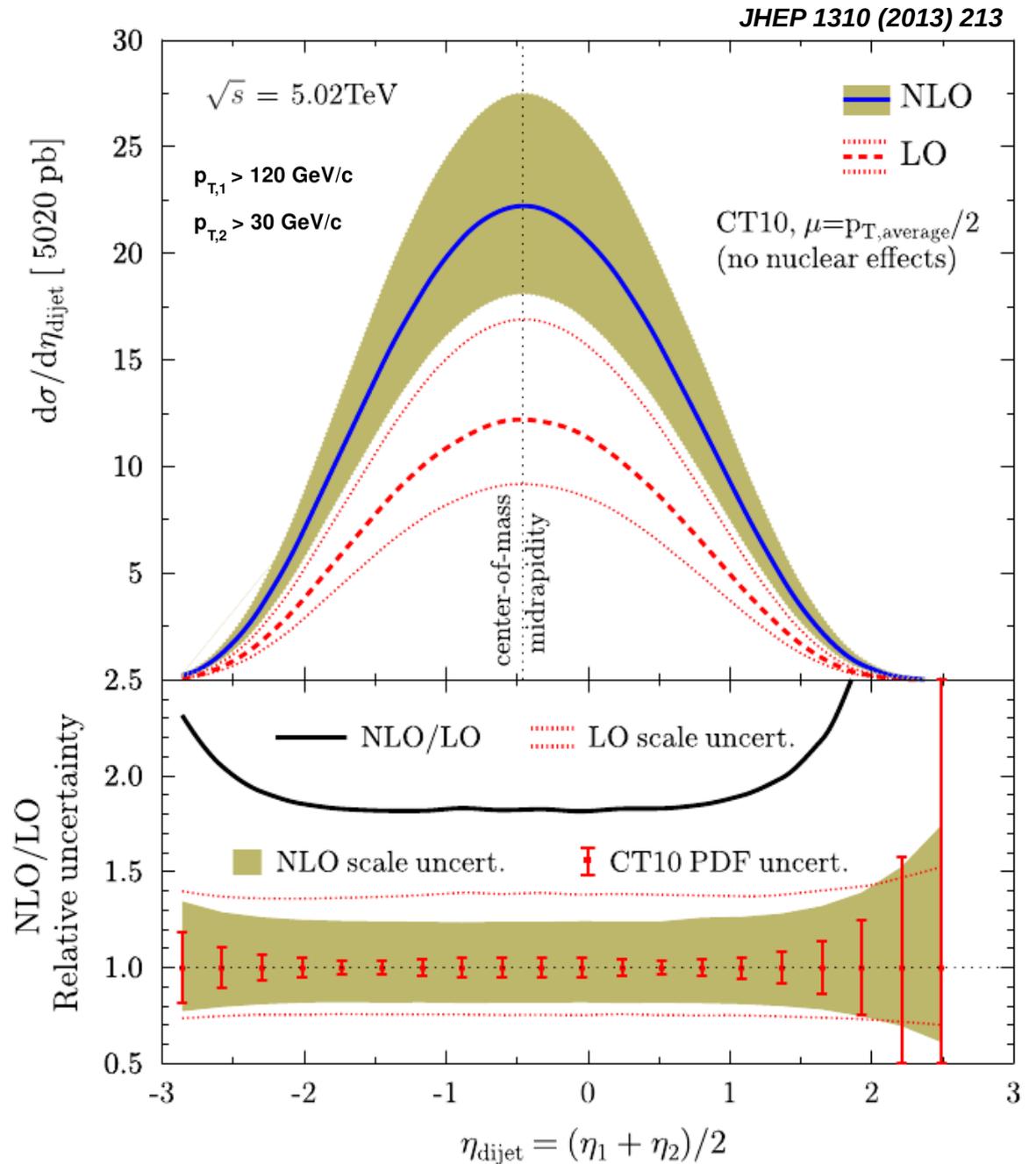
$p_{T,2} > 30 \text{ GeV}/c$   $\Delta\phi_{1,2} > 2\pi/3$

arXiv:1401.4433



# The CMS p+Pb dijets

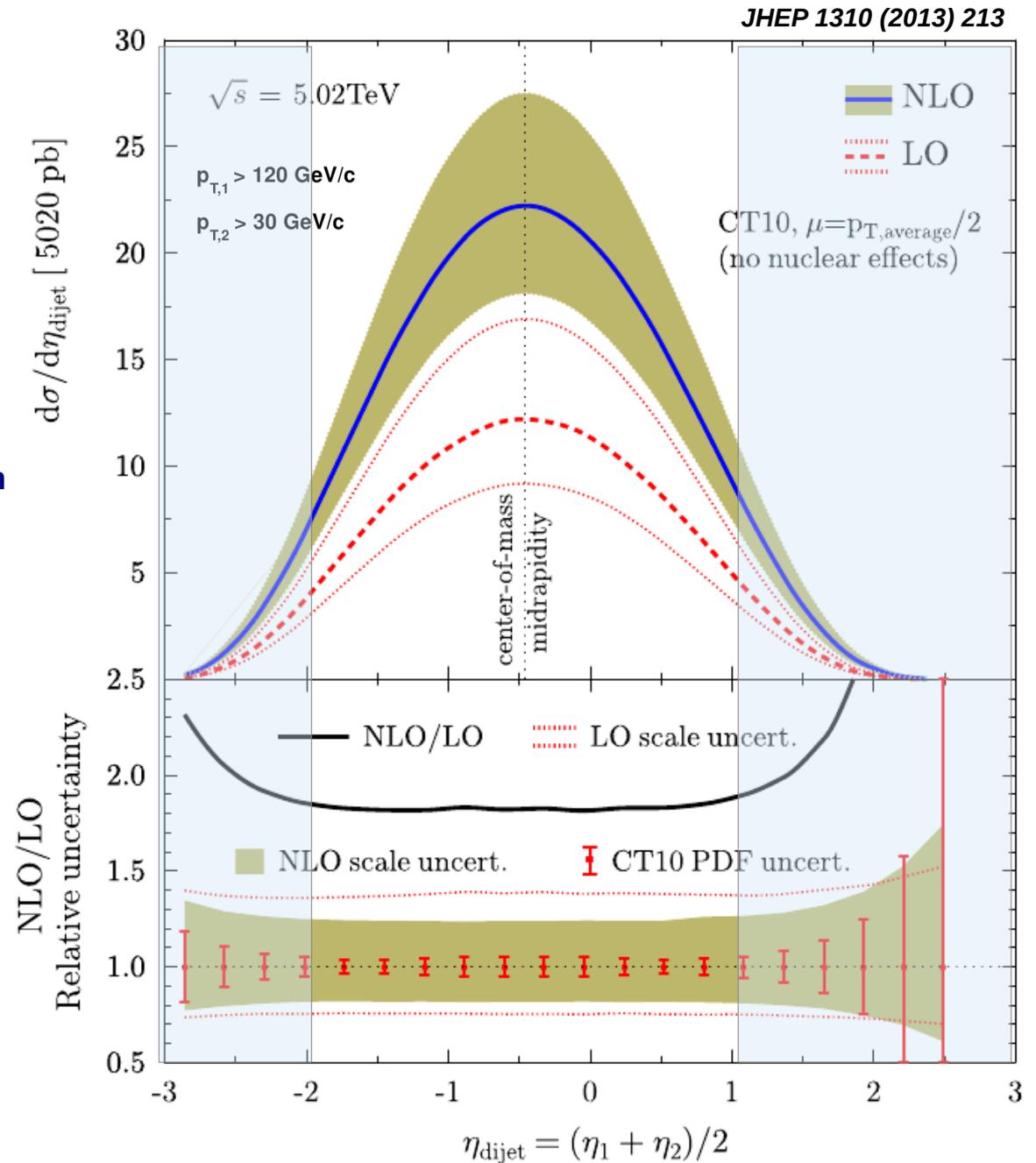
- Large NLO correction and scale uncertainty for the absolute spectrum (no cut on dijet mass)
- Can one extract any precision physics out of this?



# The CMS p+Pb dijets

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- Can one extract any precision physics out of this?
- The NLO correction is almost constant for  $-2 < \eta < 1$

Normalize by the total cross section



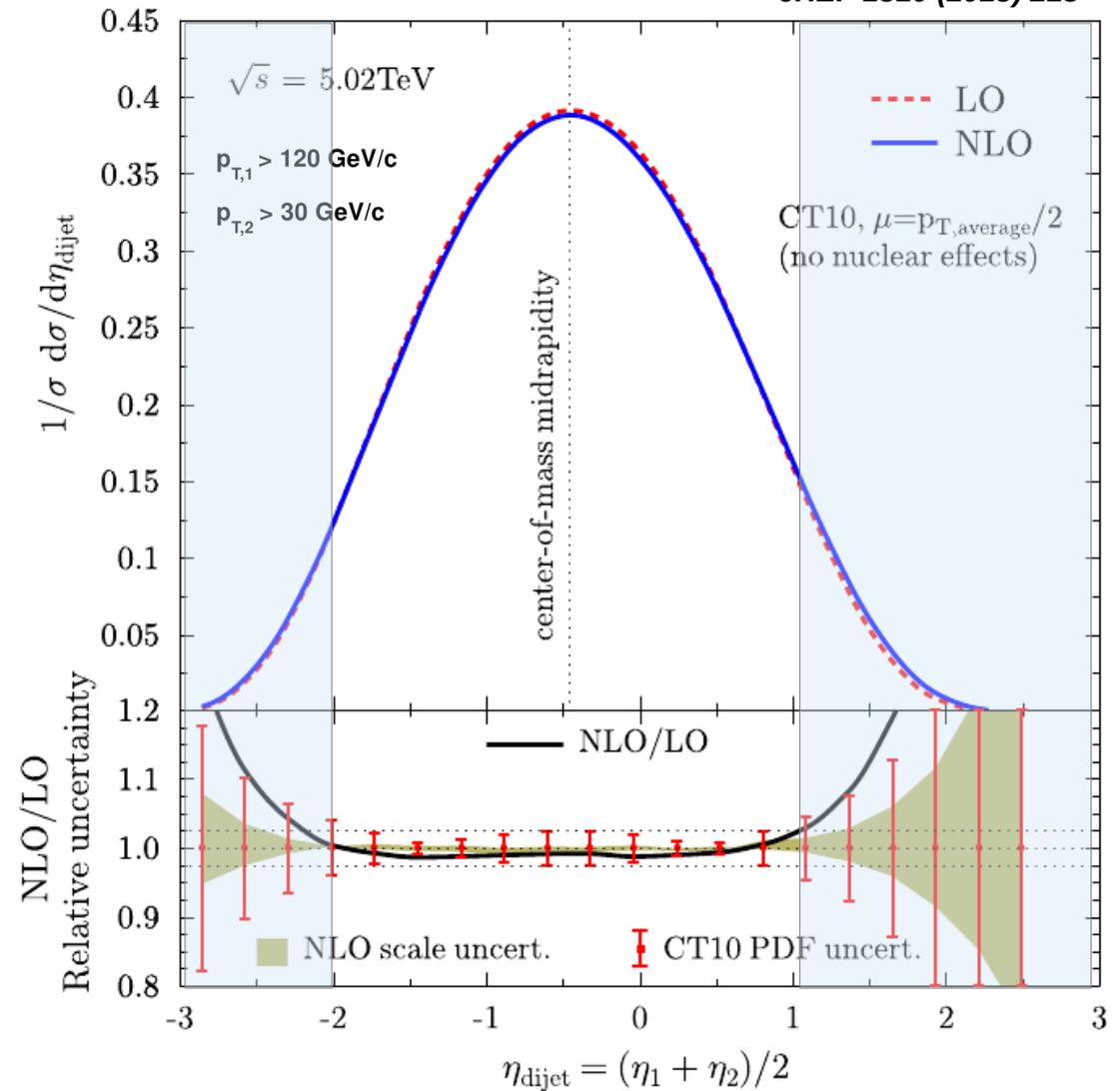
# The CMS p+Pb dijets

JHEP 1310 (2013) 213

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Normalize by the total cross section

- Normalized distribution (in the central region) appears stable against QCD corrections
- Reduction of the baseline errors
- Expect also the non-perturbative corrections to partly cancel



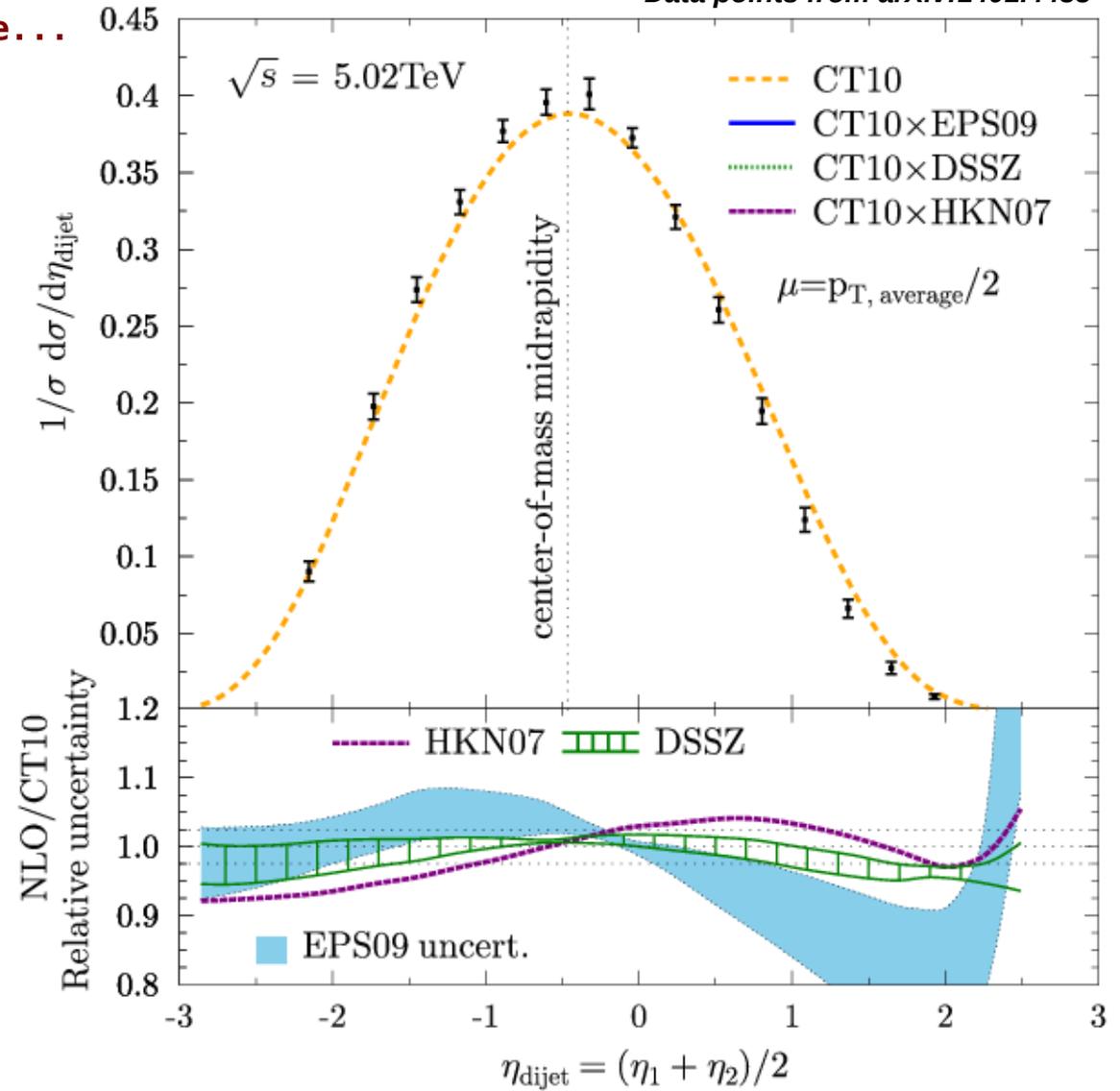


# The CMS p+Pb dijets

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Data points from arXiv:1401.4433

- CT10 alone is close but not quite...



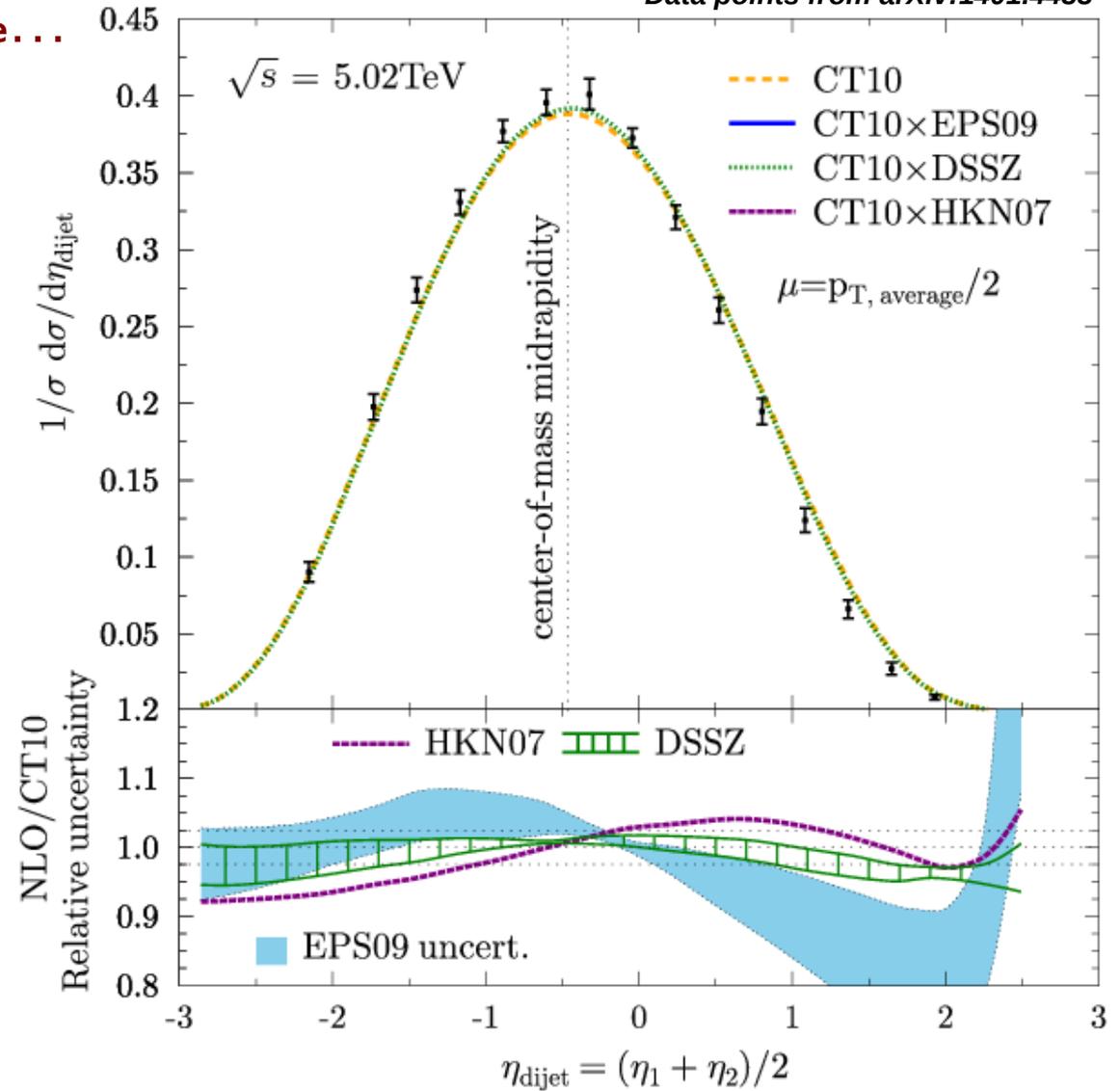
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CT10+DSSZ : almost no effects



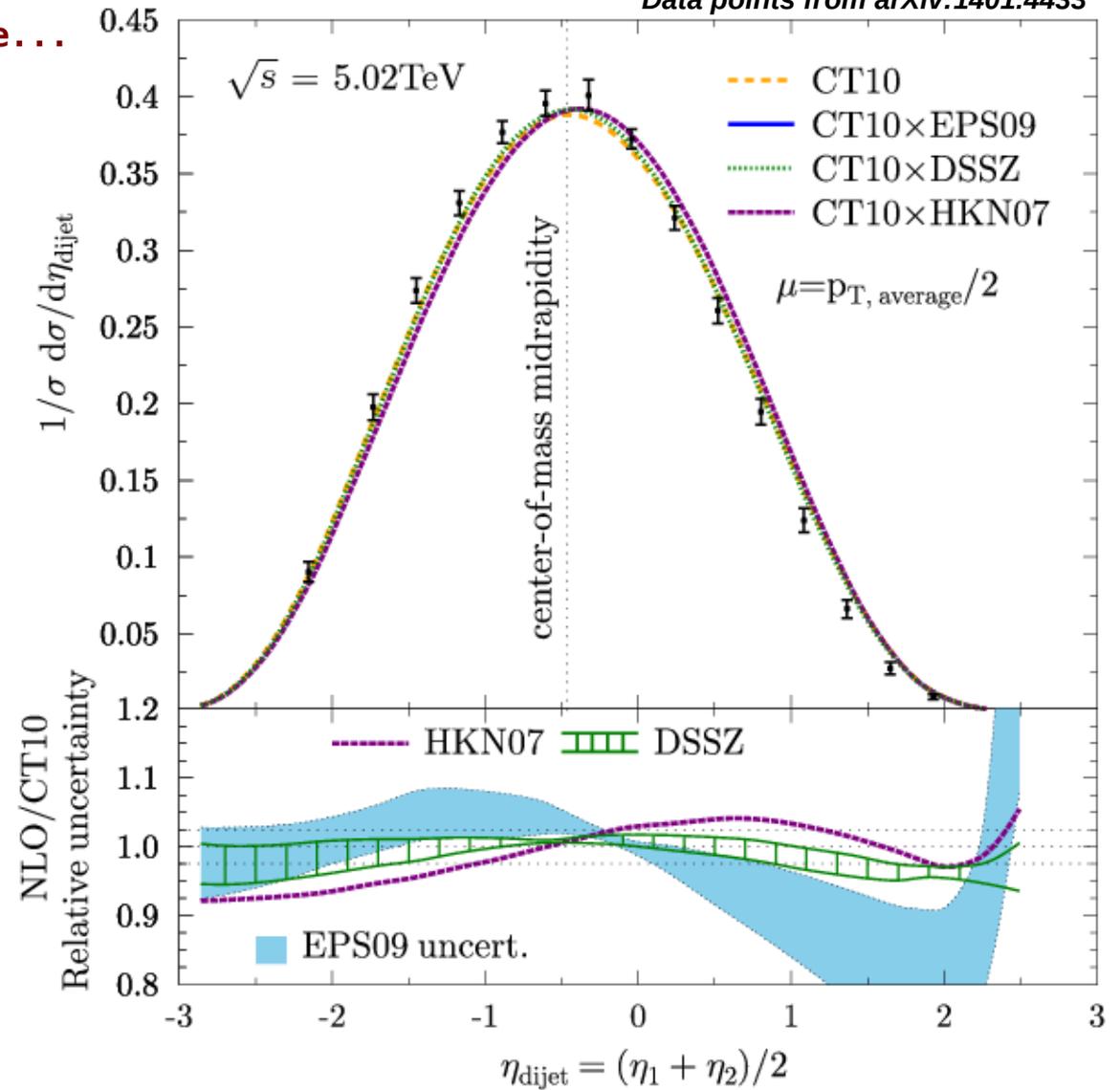
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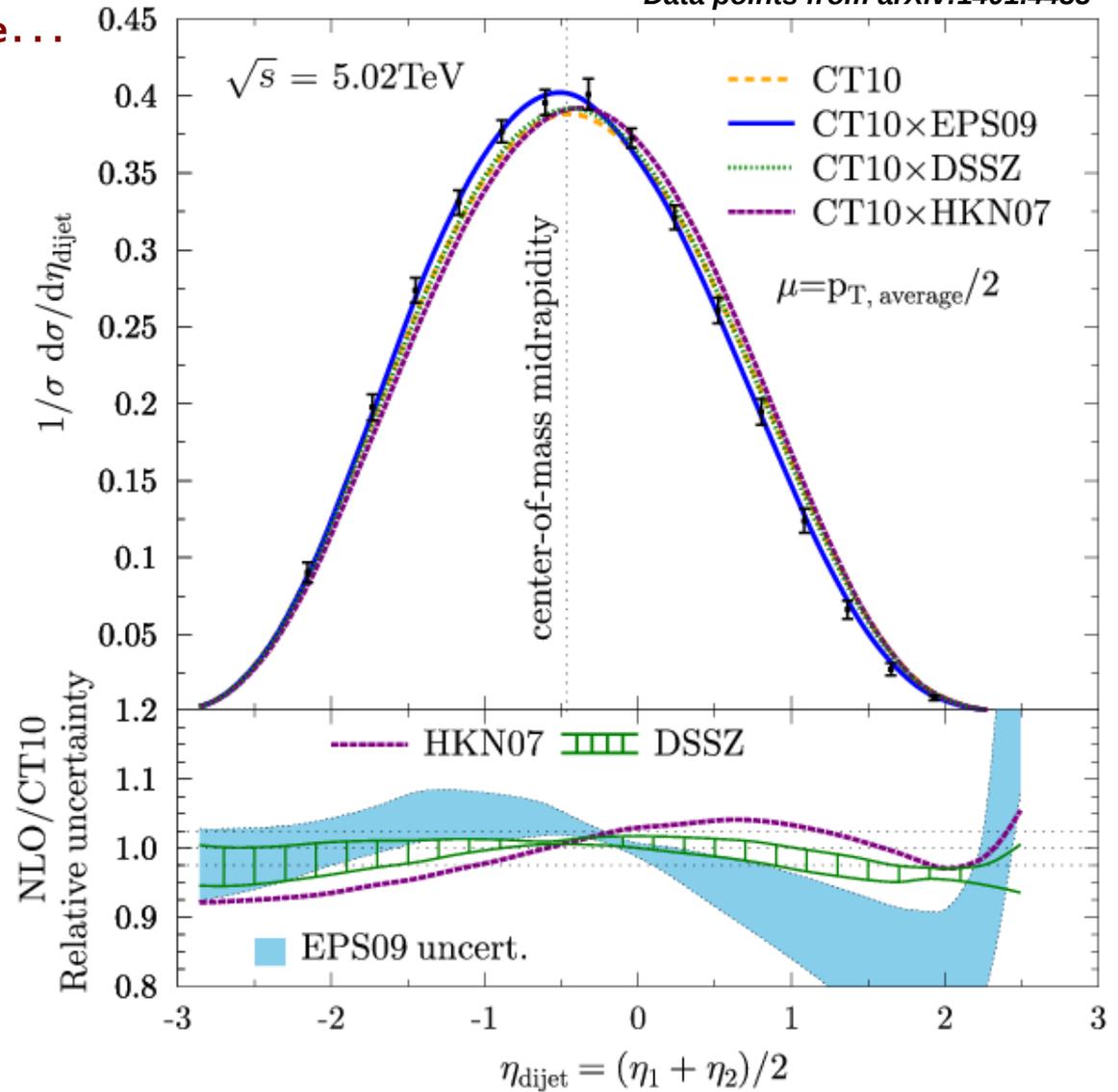
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CT10+EPS09: OK



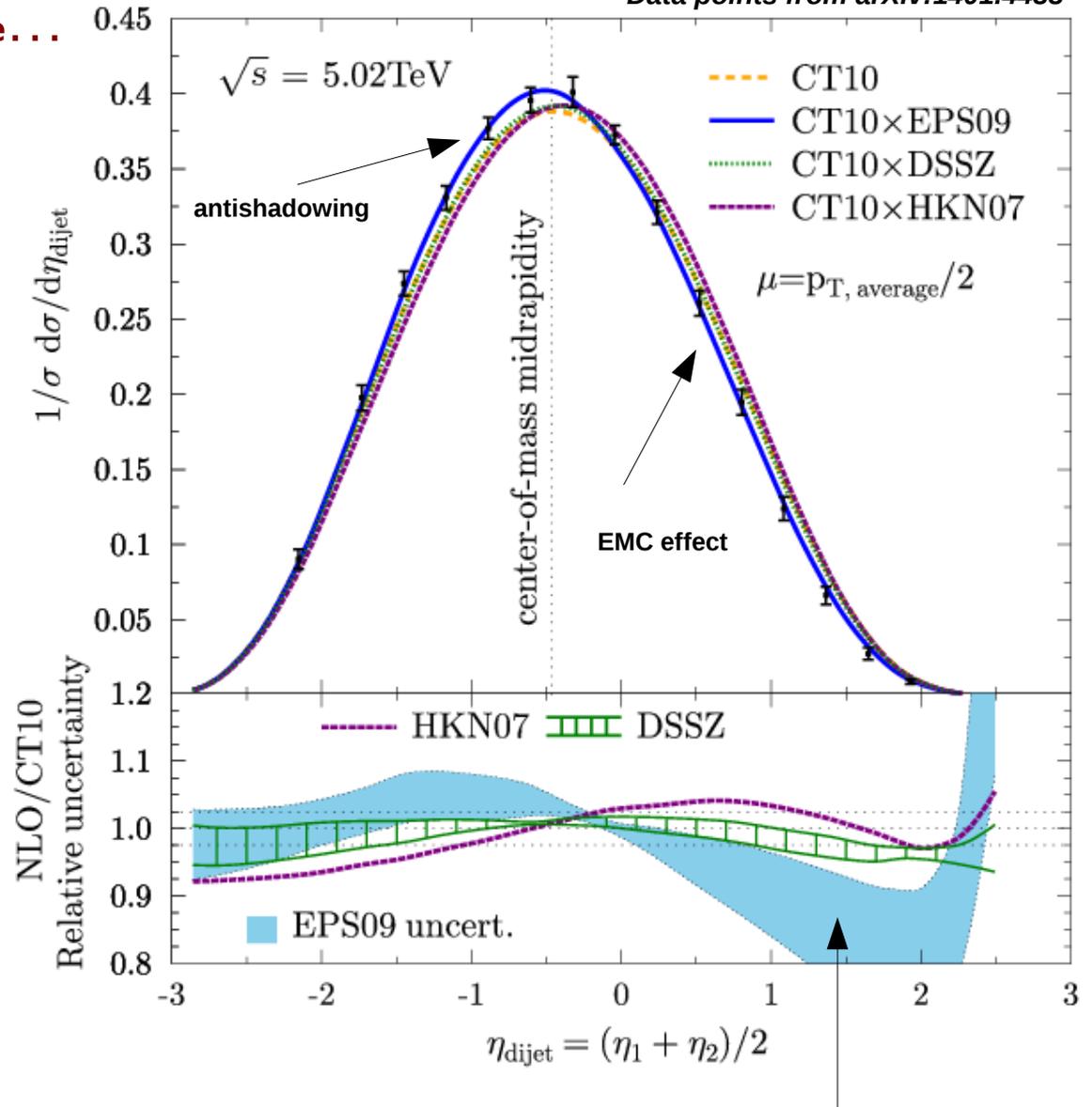
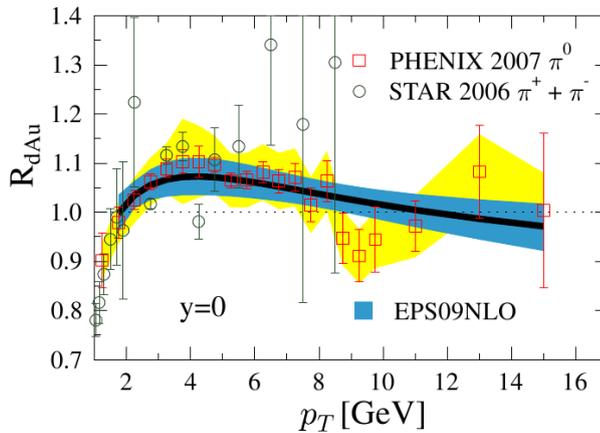
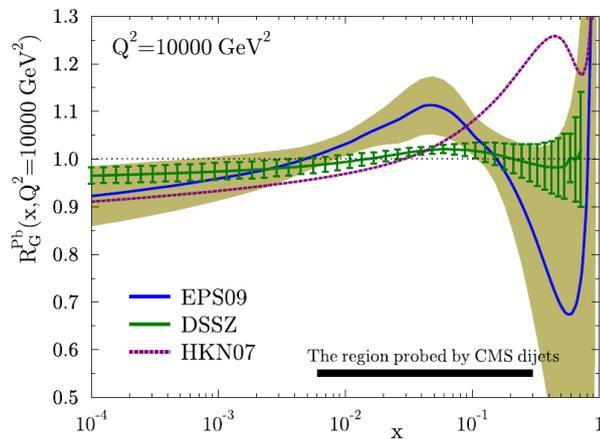
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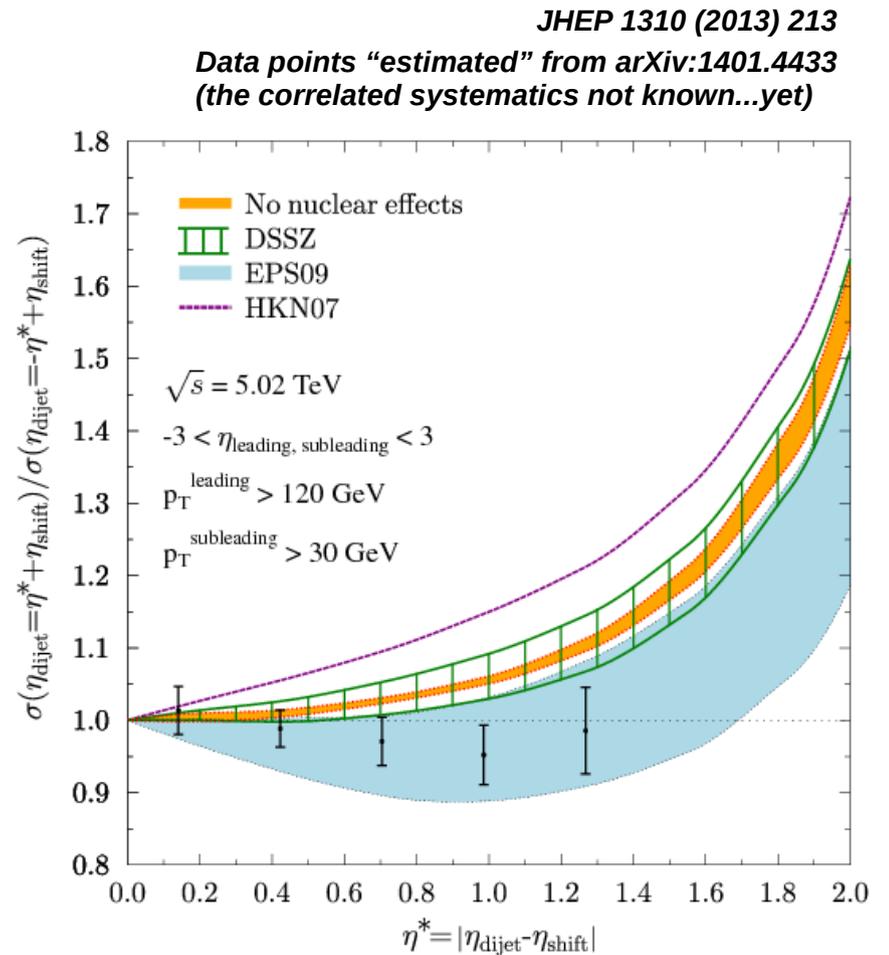
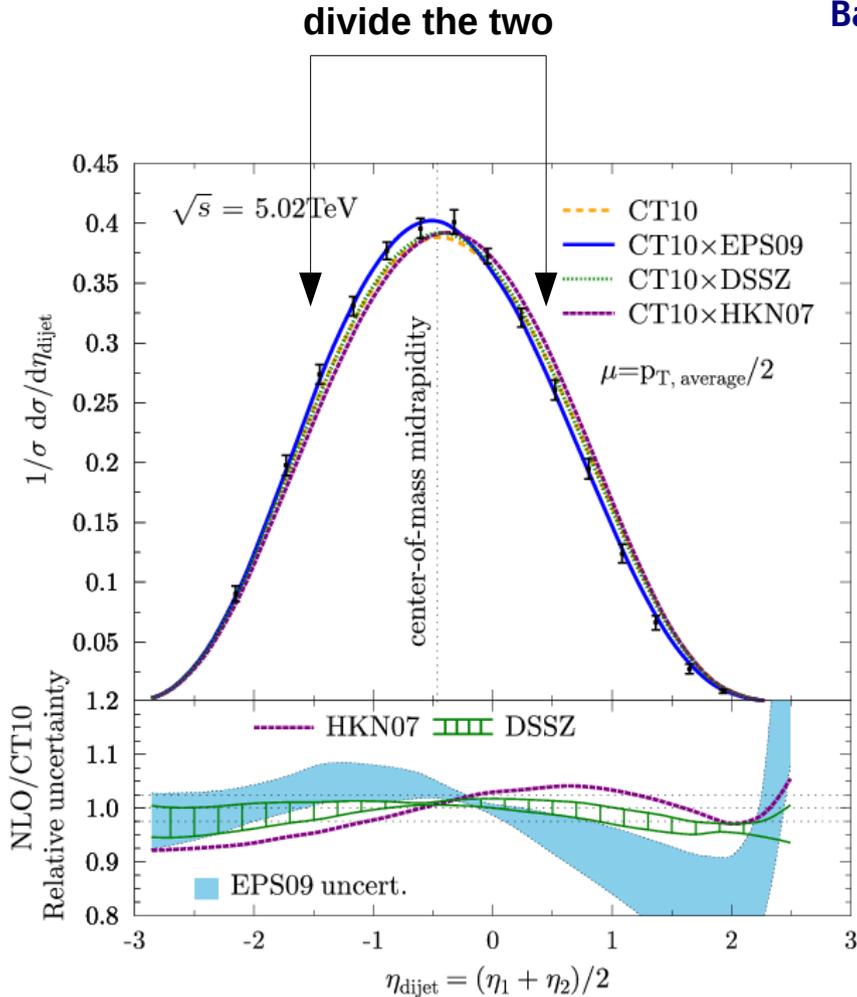
- The data support gluon antishadowing + EMC effect
- Predicted in EPS09 by the low- $p_T$  RHIC pion data

Valence quarks become important here – constraints for the up vs. down flavor separation?

# The CMS p+Pb dijets

- Forward-to-backward asymmetry extracts the nuclear modification explicitly

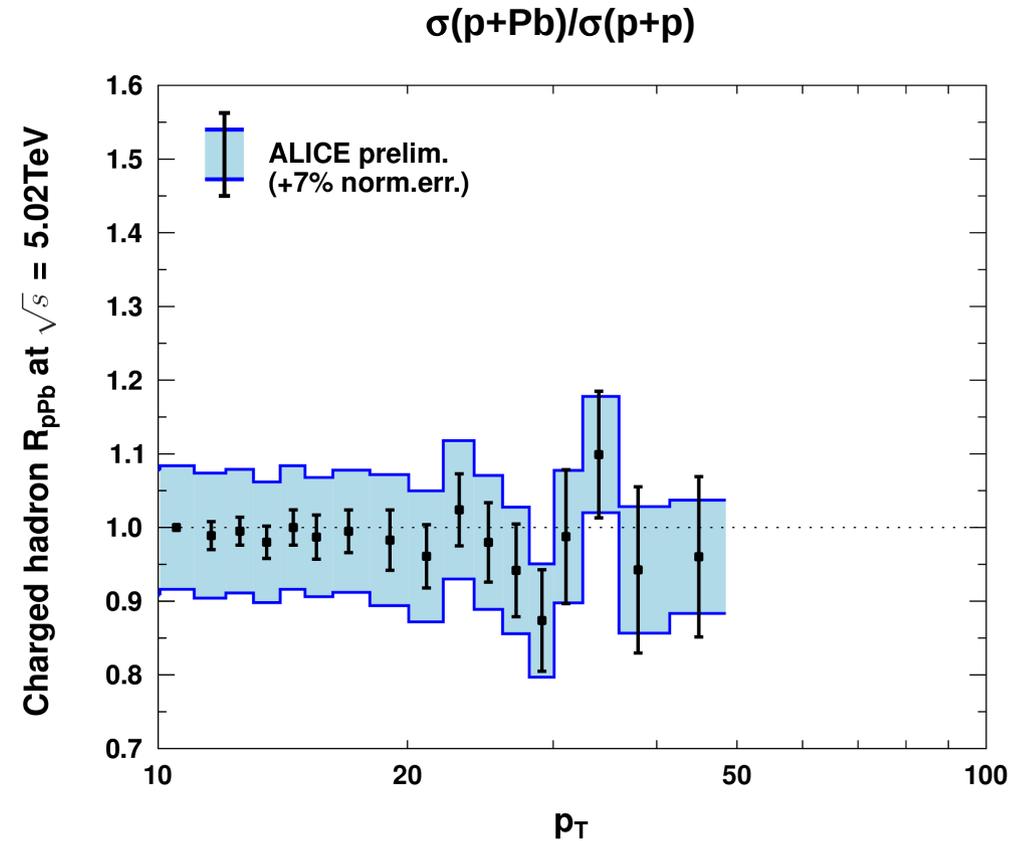
Even more robust against NNLO corrections!  
 Baseline > 1 for asymmetric cuts in the c.m. frame



- Clear preference for the existence of gluon antishadowing & EMC effect

# Inclusive charged hadron production in p+Pb

- Large baseline uncertainty for not having the p+p cross-sections at 5.02TeV
- Model-dependent absolute normalization
- Only the region  $p_T > 10$  GeV is “safe” from the non-perturbative baryons
- Preliminary ALICE data consistent with  $R_{pPb}=1$



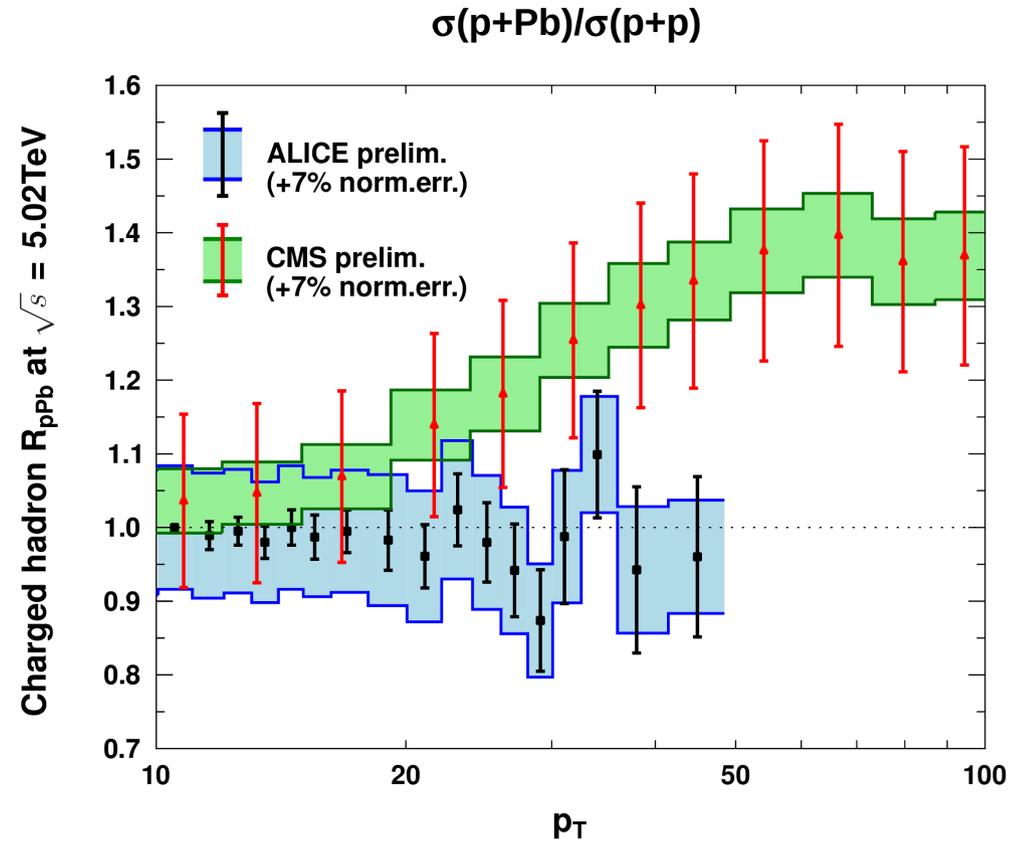
Data points from :

CMS-PAS-HIN-12-017

ALI-PREL-67304

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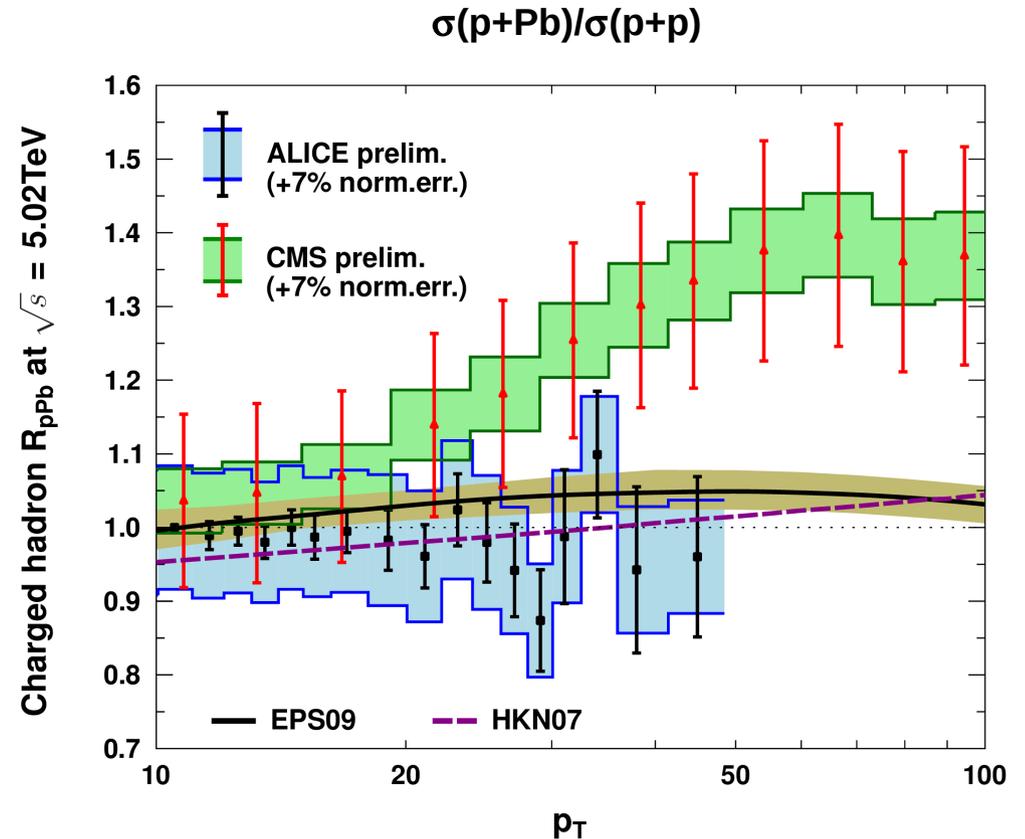
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- Preliminary ALICE data consistent with  $R_{pPb}=1$
- Preliminary CMS data shows a tremendous rise at high  $p_T$ !
- EPS09 & HKN07 consistent with the ALICE data within the large errors
- For the moment these data provide no concrete constraints



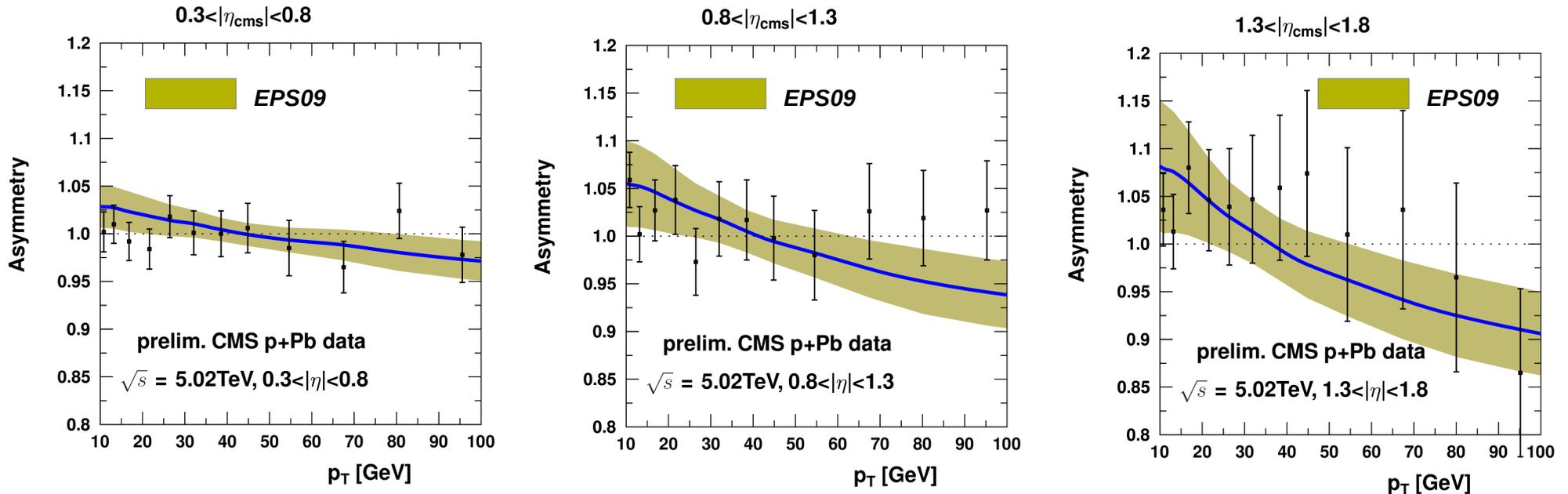
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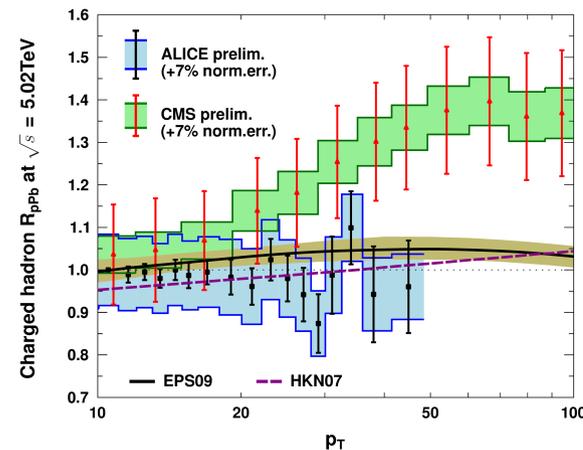
- Forward-to-backward ratio overcomes the normalization and baseline uncertainties
- A delicate interplay between shadowing – antishadowing – EMC effect



- Ratios consistent with unity – maybe a slight preference for EPS09-like behaviour
- The high- $p_T$  enhancement of CMS data appears to be independent of the rapidity...

Data points from :

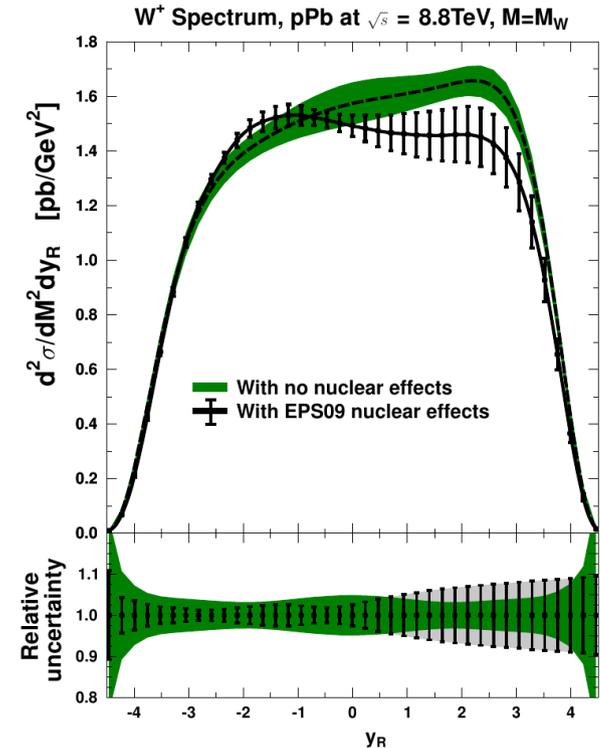
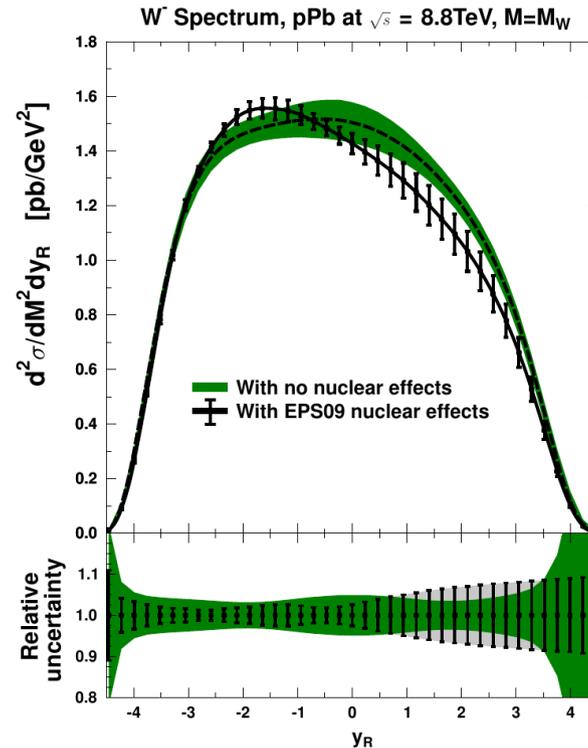
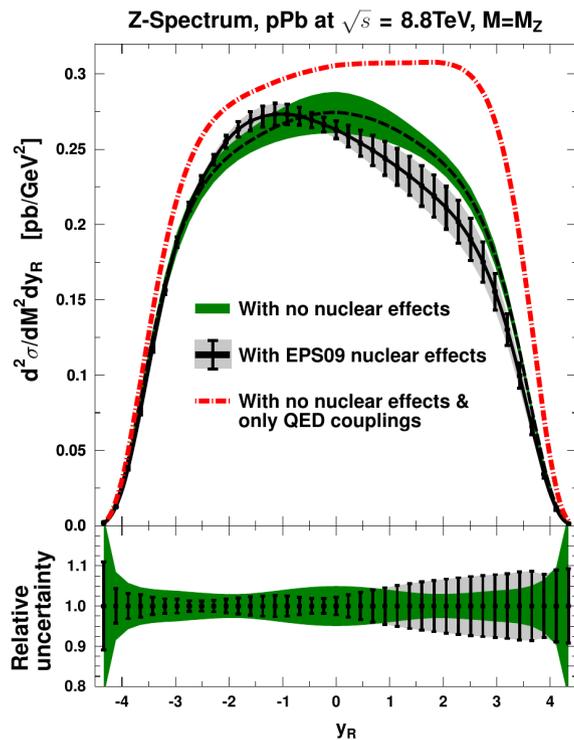
CMS-PAS-HIN-12-017



# Significant effects for W and Z expected in p+Pb

- No p+Pb data available yet (probably announced in Quark Matter 2014...)
- Sensitivity to the sea and valence quarks

JHEP 1103 (2011) 071

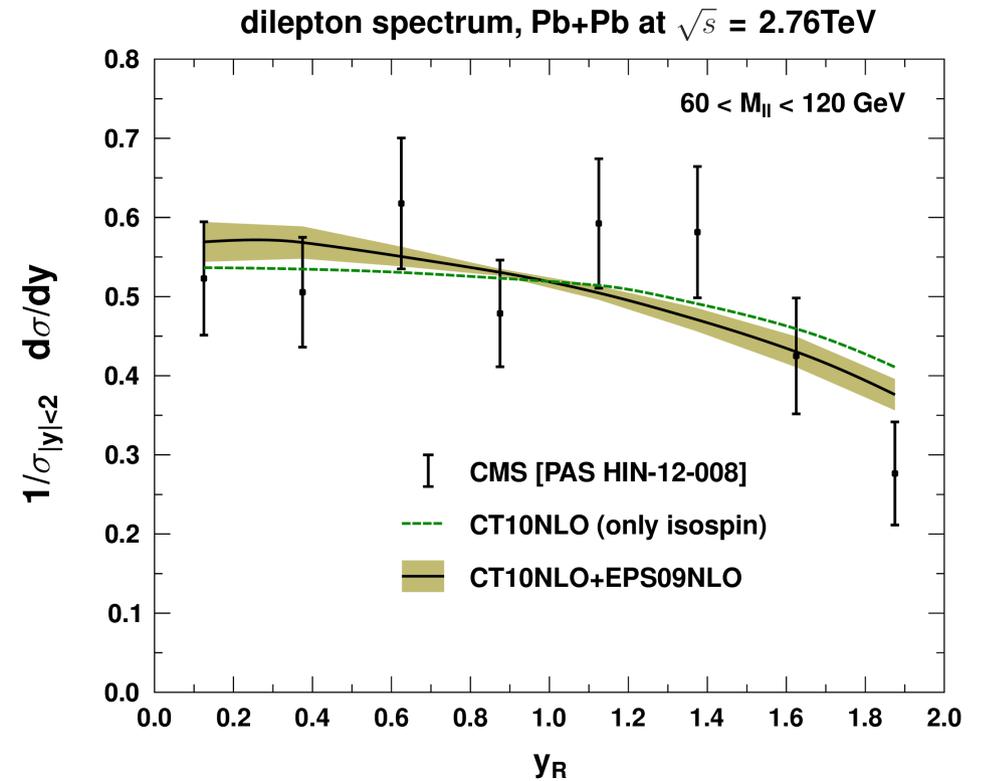
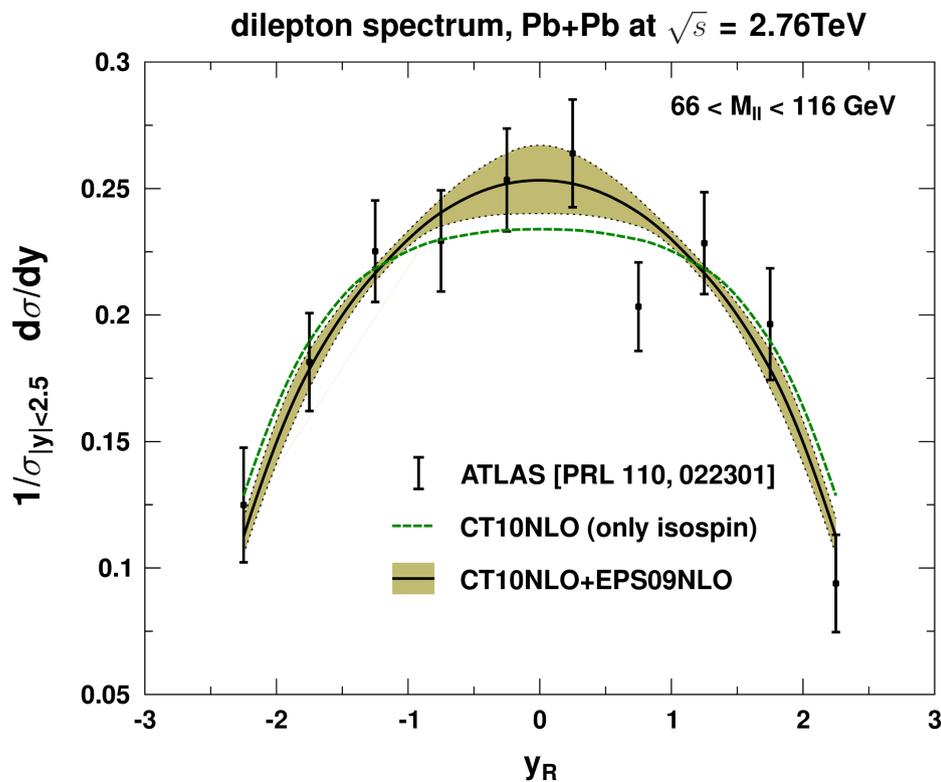


- The forward/backward asymmetries should be powerful (cancellations between systematic errors)
- Should help in constraining the flavor separation (currently unconstrained)

# Z bosons in Pb+Pb

- The existing Pb+Pb data is well in line with the pQCD expectations

...a bit more precise data would be needed to decide whether we see effects of nuclear PDFs or not...

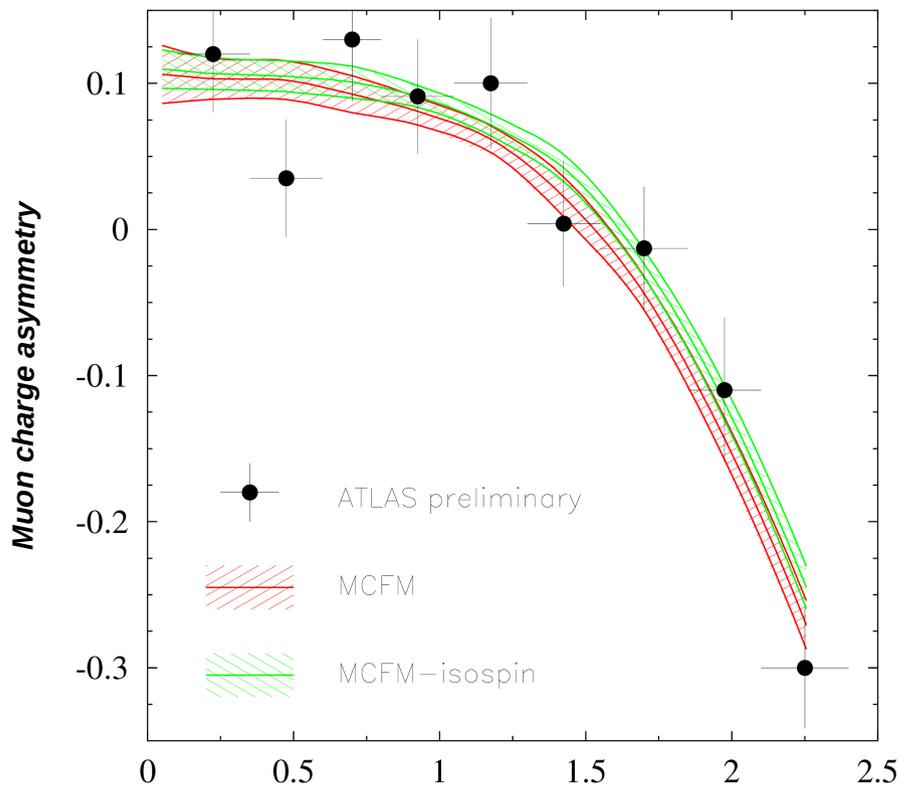


# W bosons in Pb+Pb

- The existing Pb+Pb data for lepton charge asymmetry also as expected from pQCD

...large difference in comparison to p+p  
mainly driven by the isospin effects

Plot by P. Zurita, data points ATLAS-CONF-2013-106

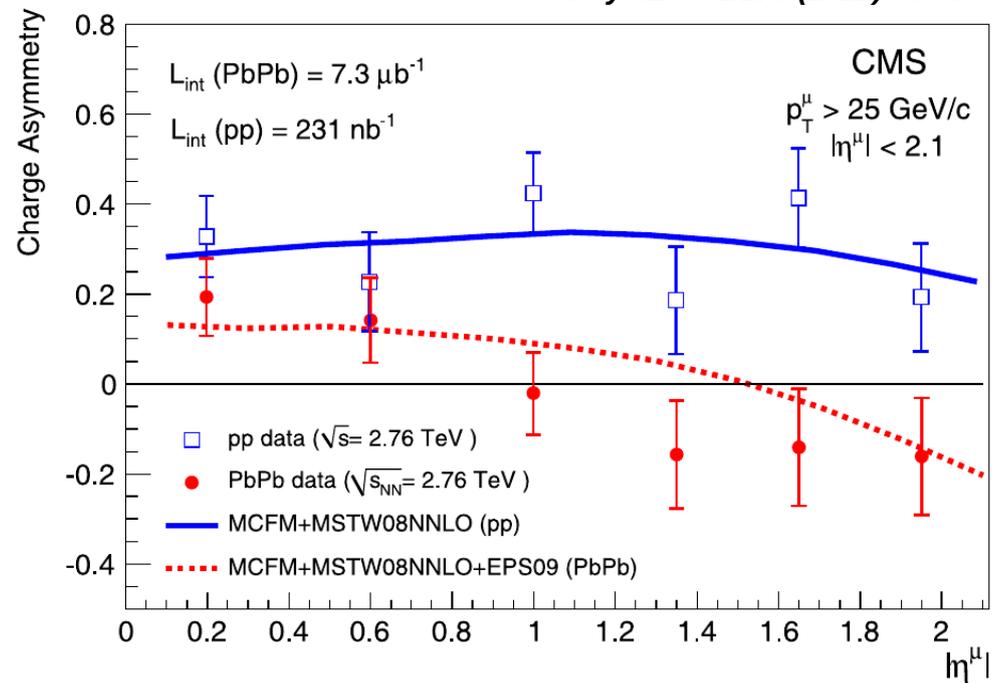


**CT10NLO+EPS09**



**CT10NLO (only isospin)**

Phys.Lett. B175 (2012) 66-87



# Summary

- The data from LHC p+Pb run expected to probe various aspects of nPDFs

Are they really universal?

- Already the very first CMS dijet data appears to distinguish between available parametrizations

Indicates antishadowing for gluons

- The charged hadron production underscores the need for having independent measurements from LHC experiments

The CMS data hints for unforeseen effects at large  $p_T$  – the ALICE data show no sign of such

- Even in Pb+Pb – the worst case scenario for factorization – the Z and W data are in line with pQCD predictions

The low statistics prevent any detailed conclusions

- Tons of new experimental results expected to be announced in Quark Matter 2014 two weeks from now...

Serious tests for the nPDFs ahead – success or total disaster?

# The CMS p+Pb dijets

- Estimate the implications for EPS09 by the Hessian reweighting

- The baseline (CT10NLO) errors accounted for as correlated systematic errors

- The small  $\chi^2$  in comparison to  $\Delta\chi^2 = 50$  of EPS09

➔ relatively small effects

- Give these data more weight to better see “what the data wants”

- The (preliminary) data is completely consistent with EPS09 – would improve the large-x gluons

- Complementary to the RHIC pion data (heavily weighted in EPS09)

