

# Nuclear PDF constraints from p-Pb collisions at the LHC

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# Nuclear PDFs and LHC p-Pb data

- 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

heavy gauge boson production (W, Z), jets, isolated photons,...

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

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

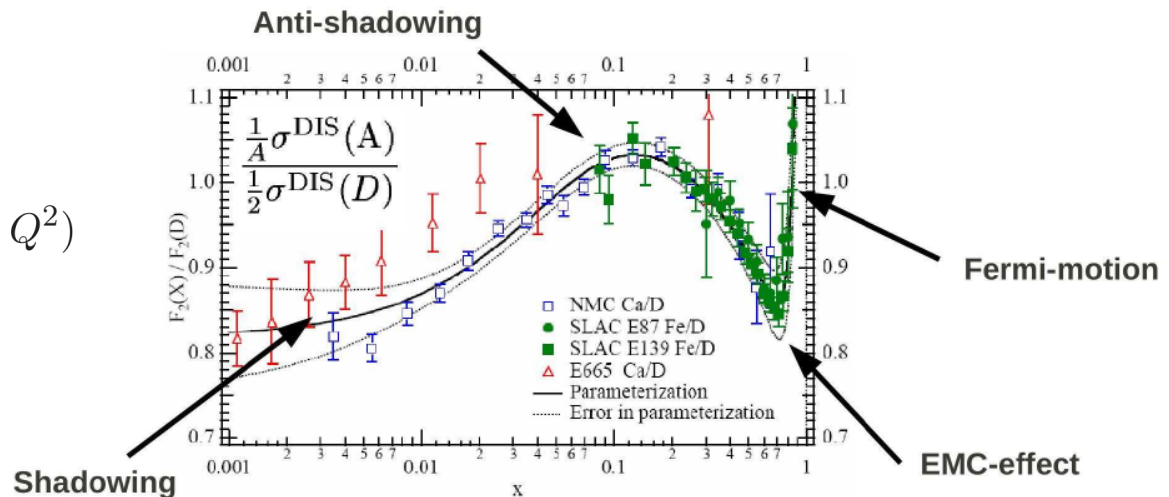
- Two types of effects are involved:

“trivial” isospin effect

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

“non-trivial” nuclear modifications

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



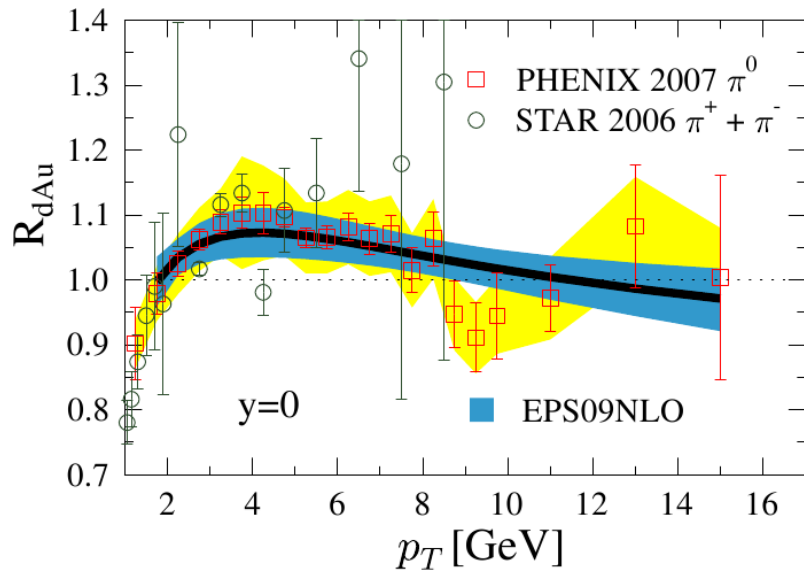
## Available analyses of nuclear PDFs

	HKN07	EPS09	DSSZ	NCTEQ15
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 <sup>2</sup>	1.69 GeV <sup>2</sup>	1 GeV <sup>2</sup>	4 GeV <sup>2</sup>
datapoints	1241	929	1579	740
free parameters	12	15	25	16
error analysis	✓	✓	✓	✓
error tolerance $\Delta\chi^2$	13.7	50	30	35
Free proton baseline PDFs	MRST98	CTEQ6.1M	MSTW2008	“CTEQ6.1M-like”
Heavy quark treatment	ZM-VFNS	ZM-VFNS	GM-VFNS	GM-VFNS

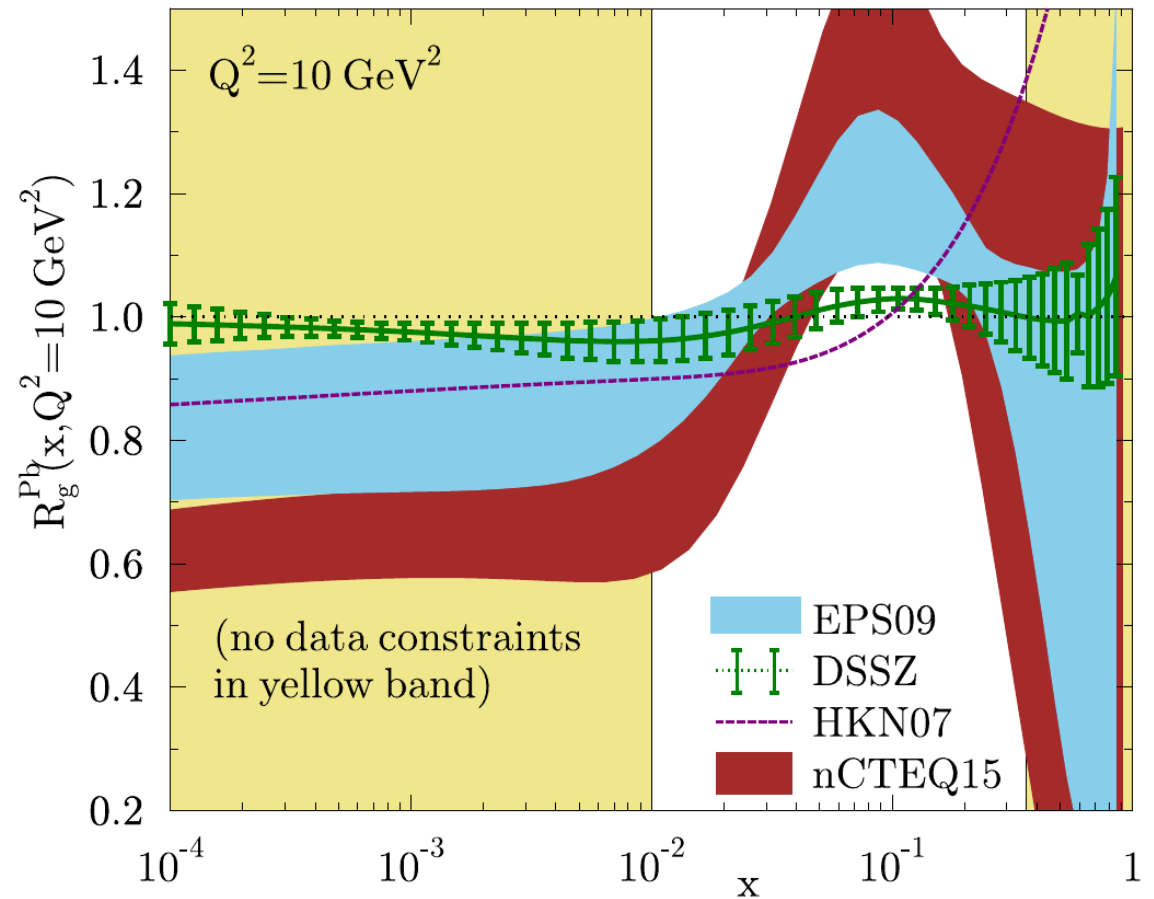
**References:** HKN07: Phys.Rev. C76 (2007) 065207 ; EPS09: JHEP 0904 (2009) 065 ; DSSZ: Phys.Rev. D85 (2012) 074028 ; nCTEQ15: arXiv:1509.00792

# Available analyses of nuclear PDFs: Gluons

- Large differences in gluons
- EPS09 and nCTEQ15 alike
  - antishadowing around  $x=0.1$  from RHIC pion data

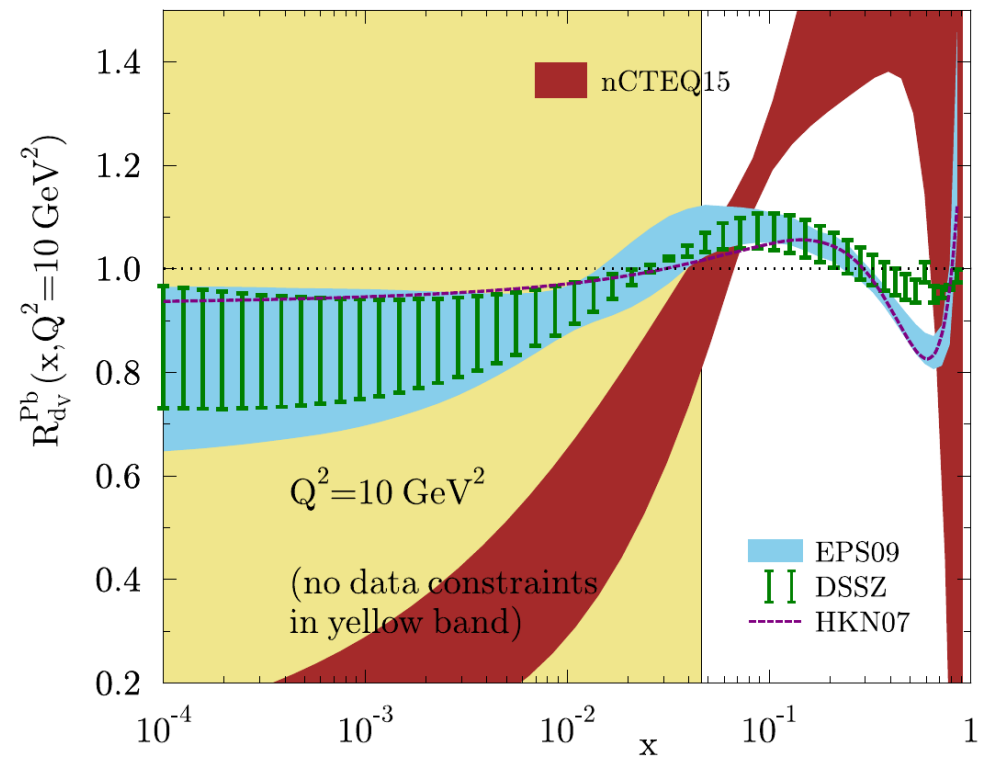
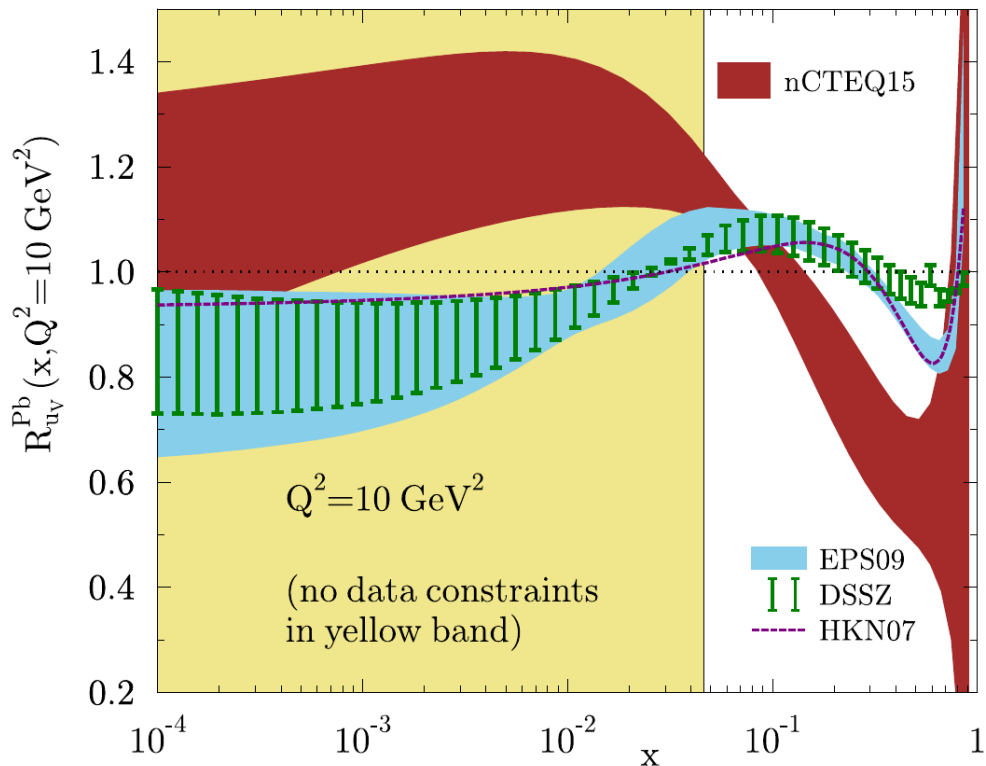


- Almost no effect in DSSZ
  - assumed functional form
  - medium modified fragmentation functions for pions
- HKN07 clearly different
  - assumed functional form



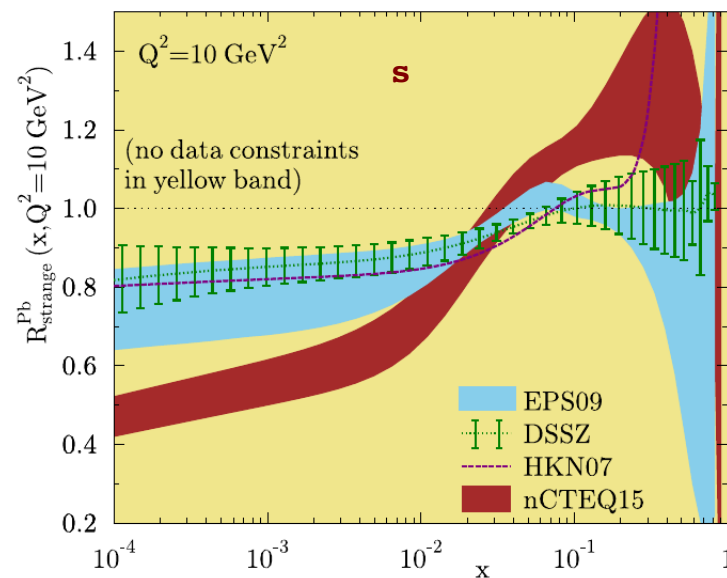
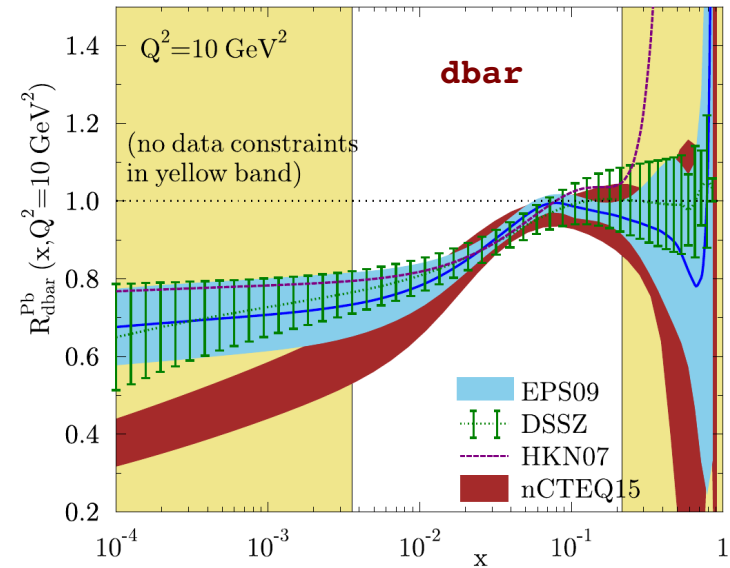
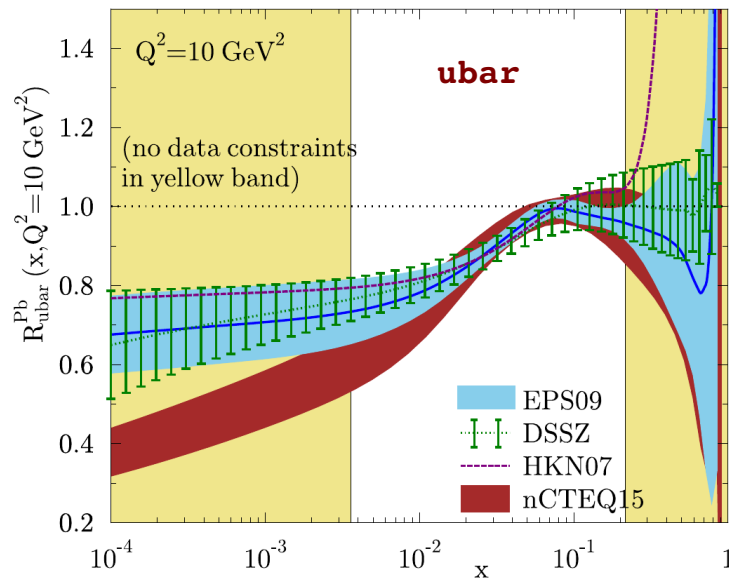
# Available analyses of nuclear PDFs: Valence quarks

- **EPS09, DSSZ and HKN07:**
  - assumed  $R_{uV} = R_{dV}$  at parametrization scale
  - difference between DSSZ and EPS09/HKN07 at large  $x$  is a known misinterpretation of iso-spin effects (in DSSZ analysis)
- **nCTEQ15:**
  - free  $R_{uV}$  and  $R_{dV}$ .
  - The differences appear to originate from DIS data involving very light nuclei (He, Li).
  - Non-smooth  $A$  dependence of EMC effect for light nuclei?



# Available analyses of nuclear PDFs: Light sea quarks

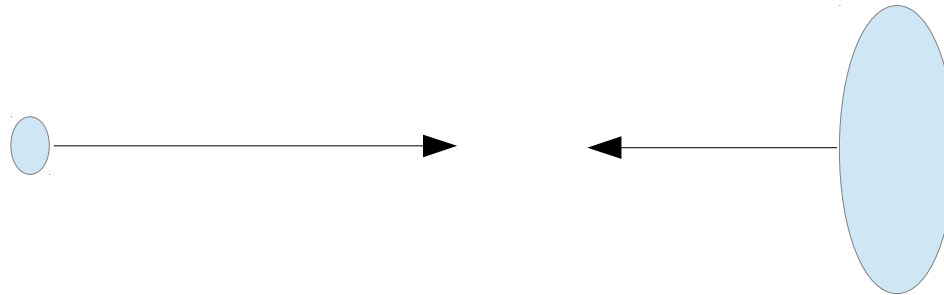
- **A fair agreement in the data-constrained region for u & d**  
- strange quark distributions follow mostly from assumptions



**Do the LHC p-Pb data support nuclear effects in PDFs?**

# Rapidity shift in p-Pb collisions

- The interpretation of LHC p-Pb data is sometimes complicated by the rapidity shift:



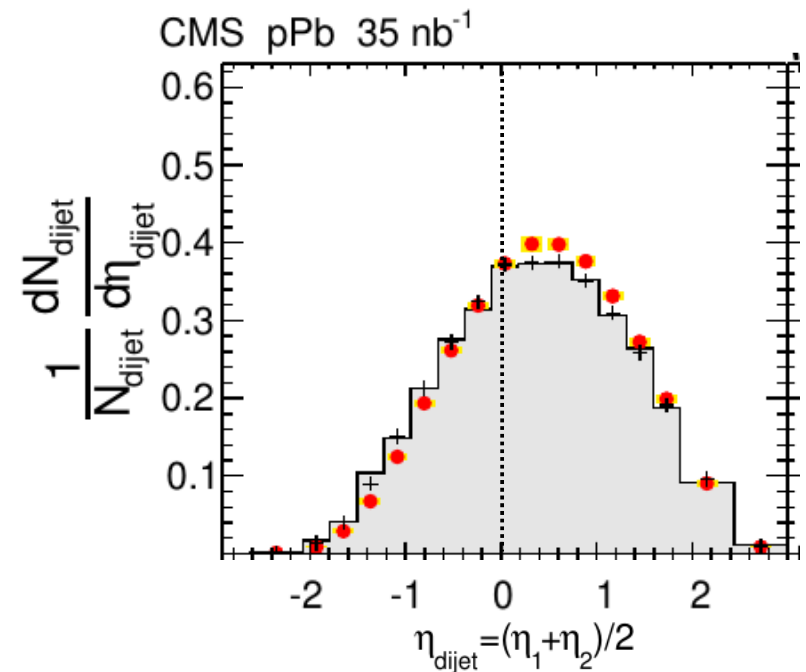
Proton beam with  $E_p = 4\text{TeV}$

Lead beam with  $E_{Pb}/A = 4\text{TeV} (82/208) = 1.58\text{TeV}$

- The center-of-mass of proton-nucleon system moves with a rapidity

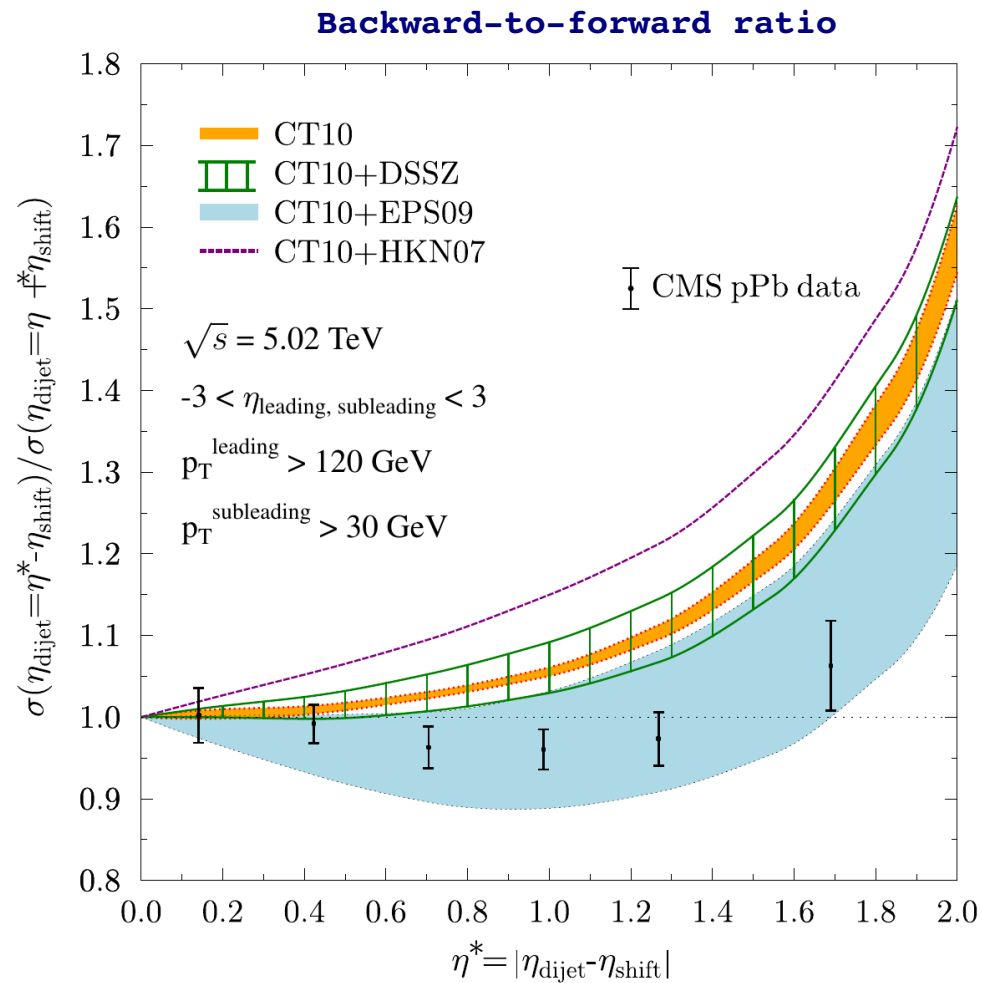
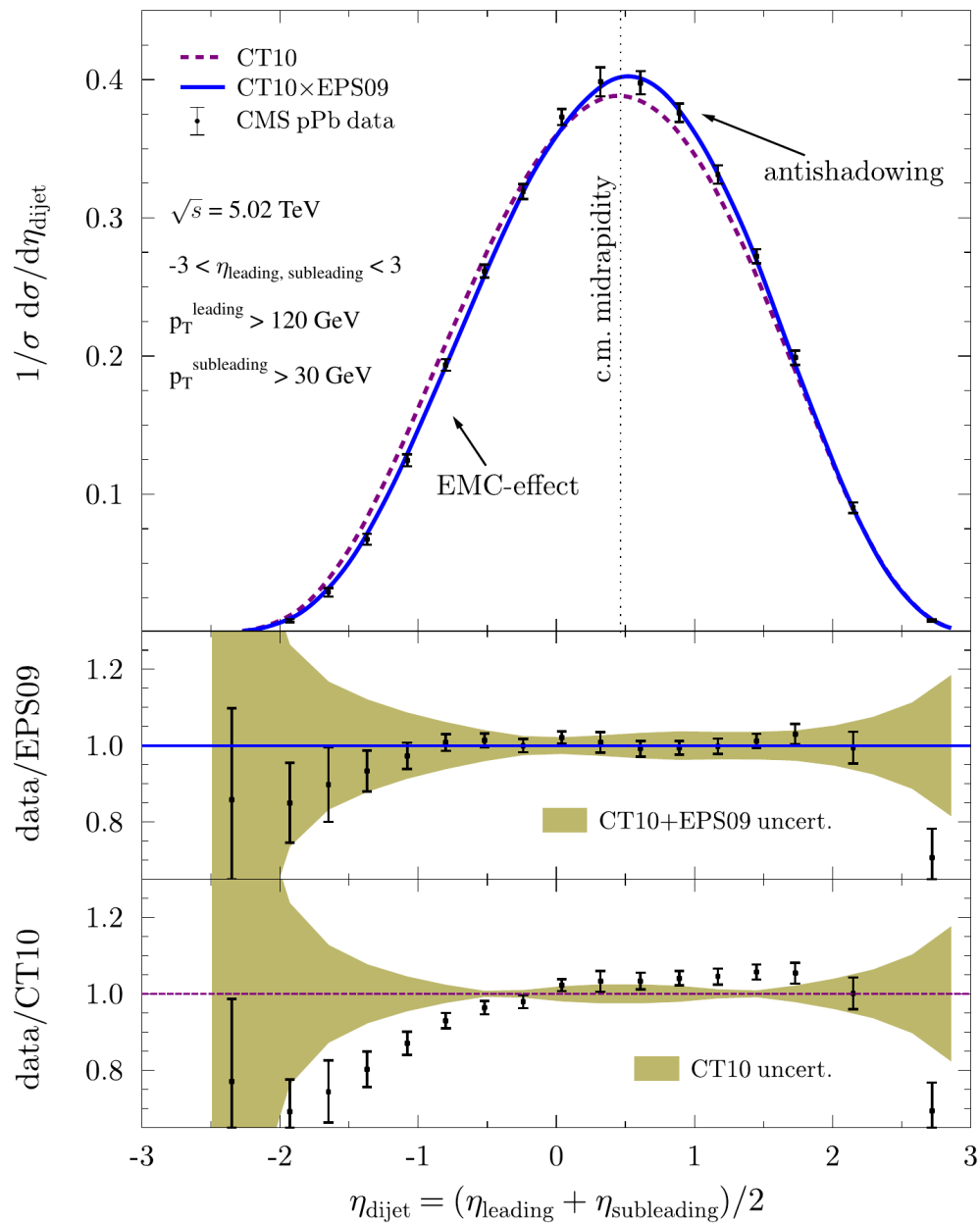
$$\eta_{\text{shift}} \equiv 0.5 \log (E_{Pb}/E_p) \approx -0.465$$

- Leads sometimes to asymmetric rapidity distributions even in the absence of any nuclear effects (forward-to-backward ratios  $\neq 1$ )



# Dijets in p-Pb: CMS data

- **Dijet measurement by CMS is so far the most-constraining single data set**  
 - a clear preference for gluon antishadowing (incompatible with DSSZ and HKN07)

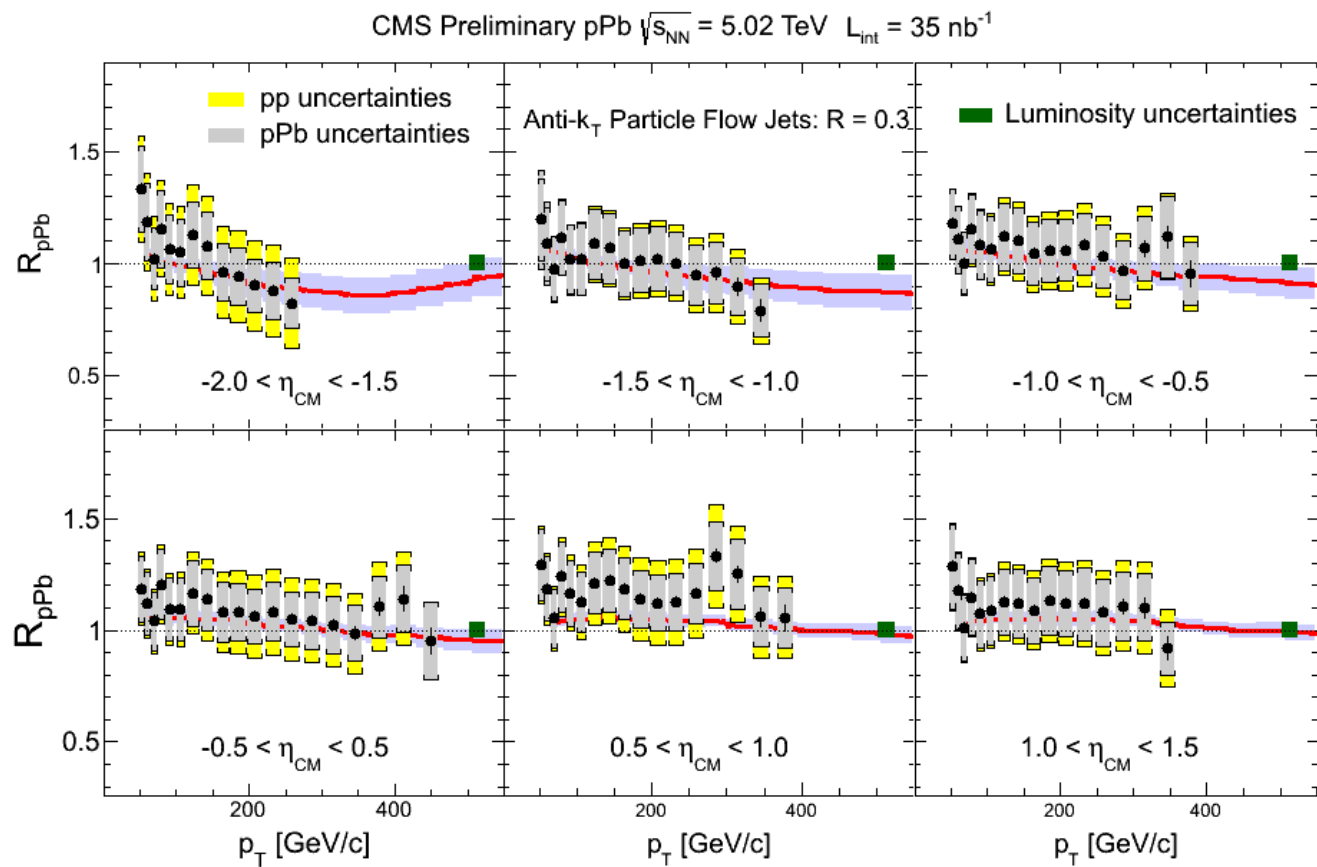
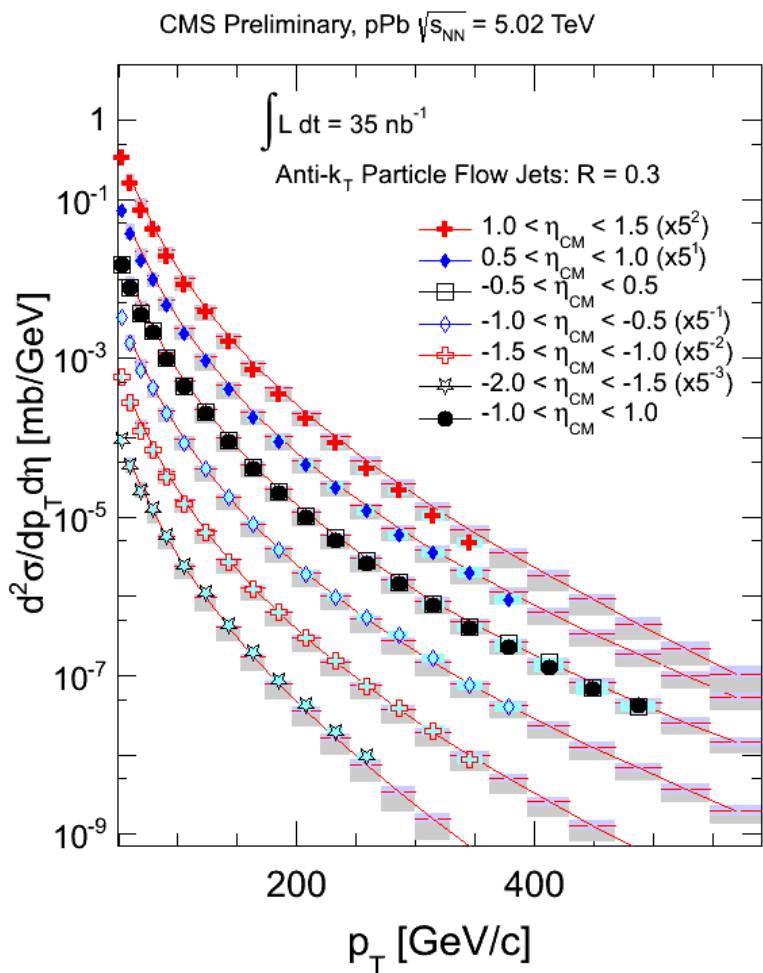


CMS data: *Eur.Phys.J. C74 (2014) 7, 2951*

Calculations: *JHEP 1310 (2013) 213*

# Inclusive jets in p-Pb: CMS data

- Carry essentially the same information as the dijet measurement
  - nuclear modification factor comes with large p-p baseline uncertainty
  - appear compatible with EPS09

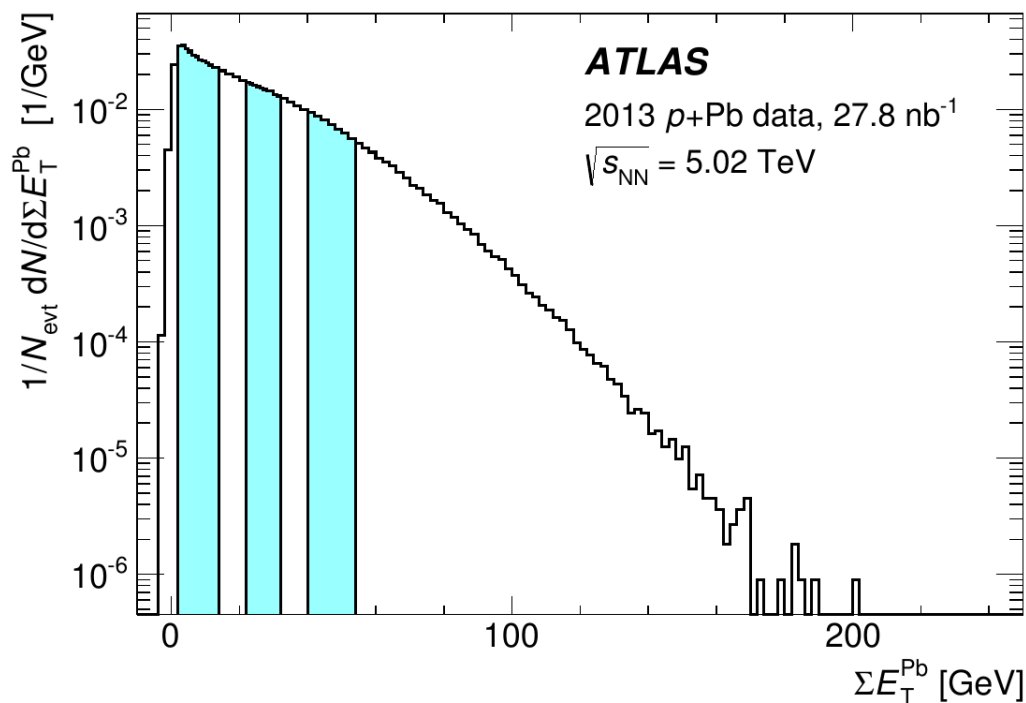


# Inclusive jets in p-Pb: ATLAS data

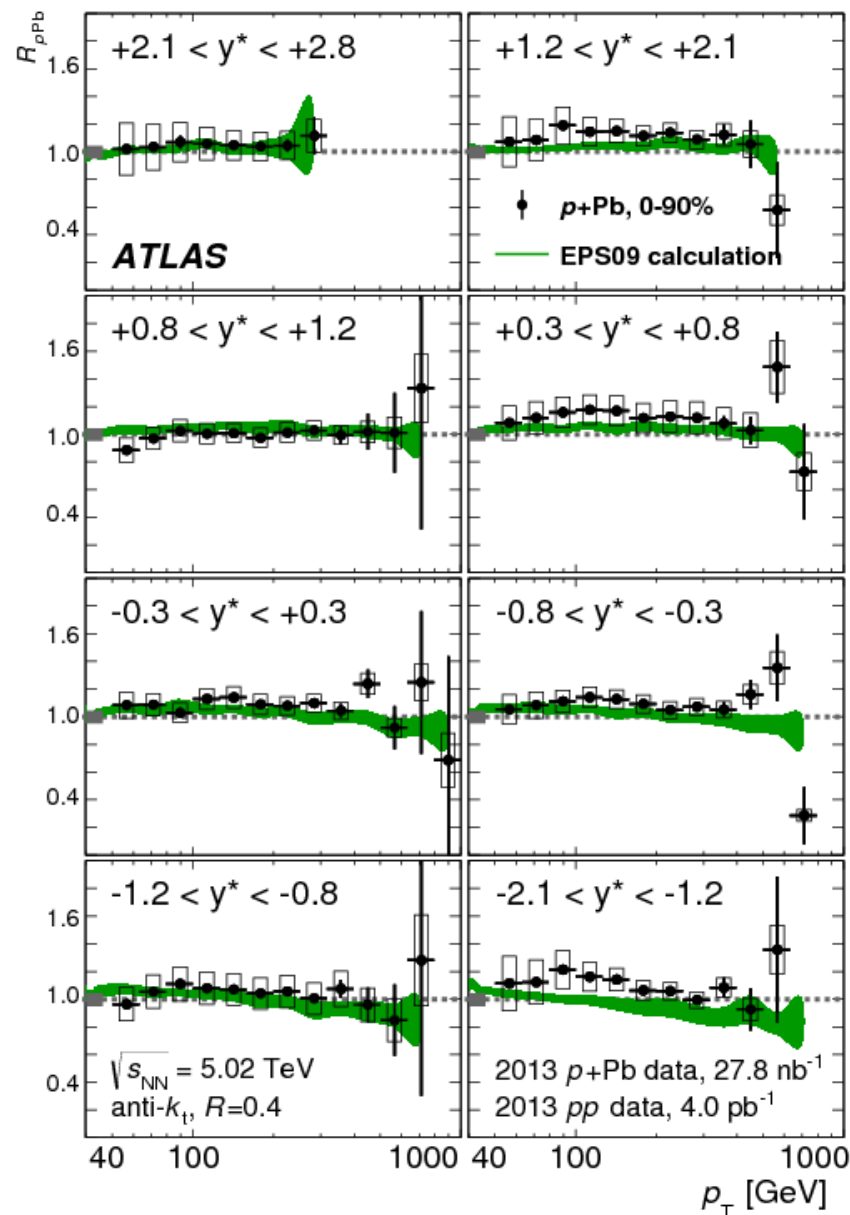
- **ATLAS measurement roughly compatible with the expectations**

*Phys.Lett. B748 (2015) 392-413*

- **However, the measurement is not "minimum bias" but rather within "0-90% centrality class"**  
 - require certain minimum energy-deposit at backward direction

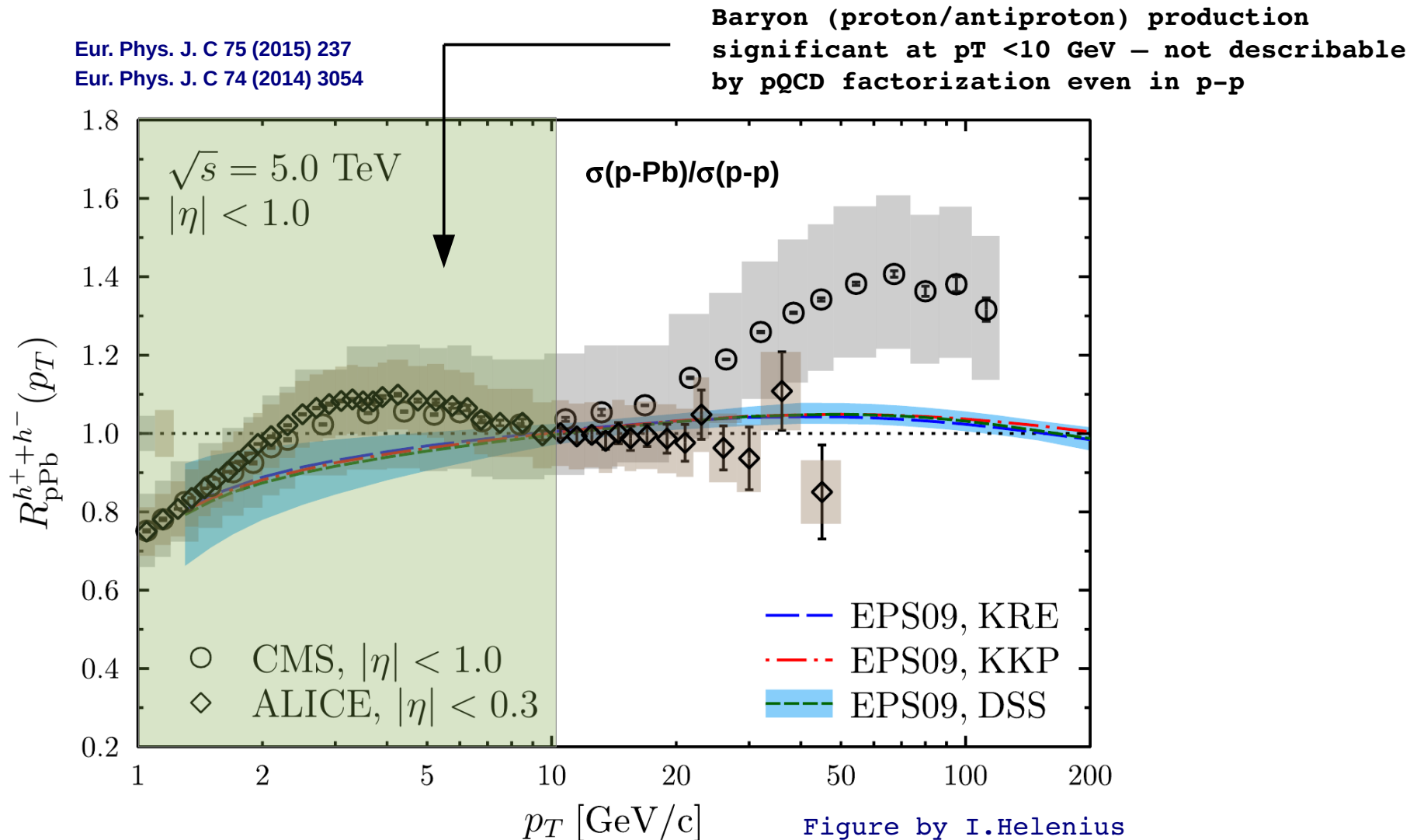


- **May cause a delicate bias on the hard process e.g. via energy-momentum conservation**



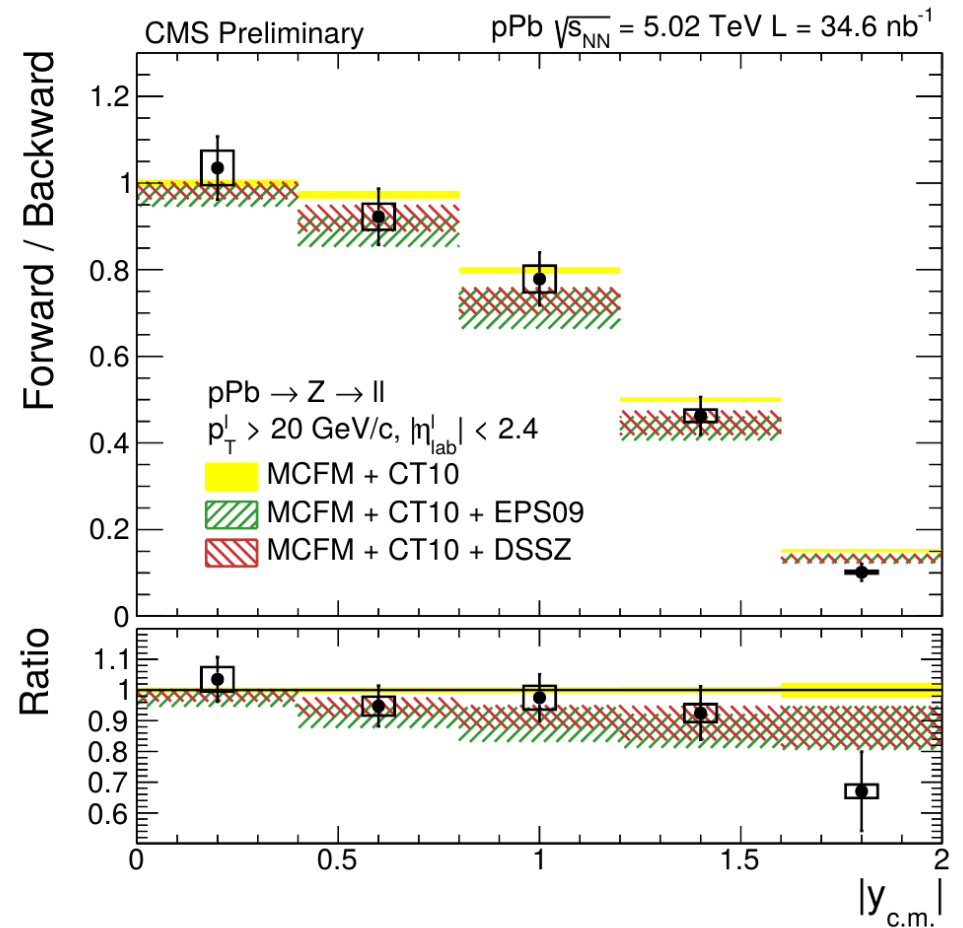
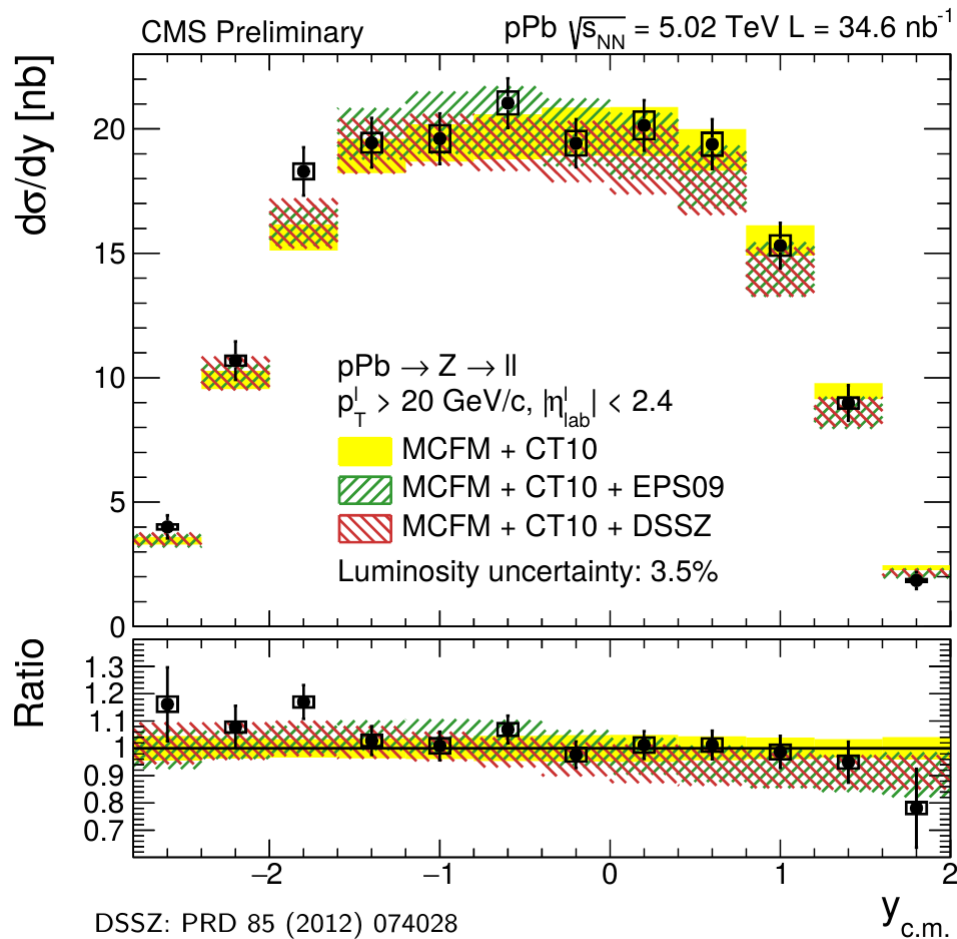
# Inclusive charged-hadron production

- **Completely unexpected 40% increase of p-Pb yield at high  $p_T$** 
  - non-universal parton-to-hadron fragmentation functions?
  - data issue?
- **Large baseline uncertainty for not having the p-p cross-sections at 5.02TeV**



# Z production in p-Pb: CMS

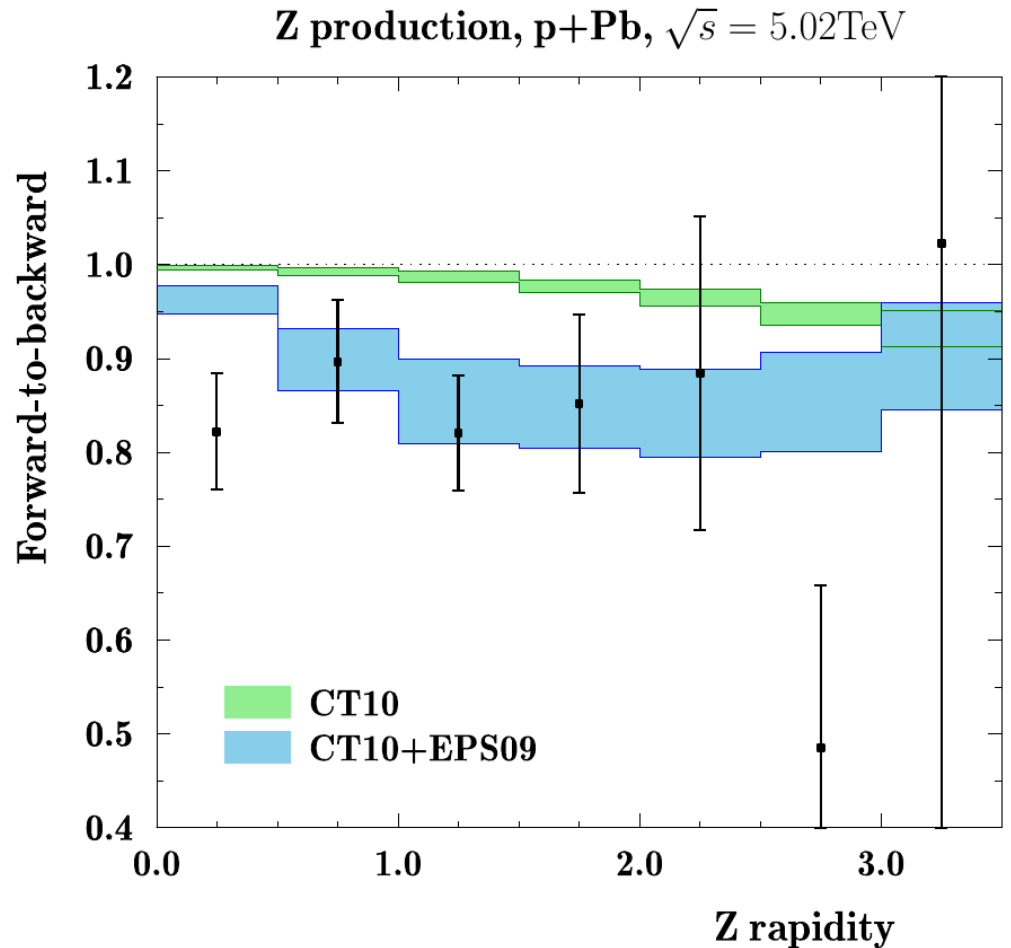
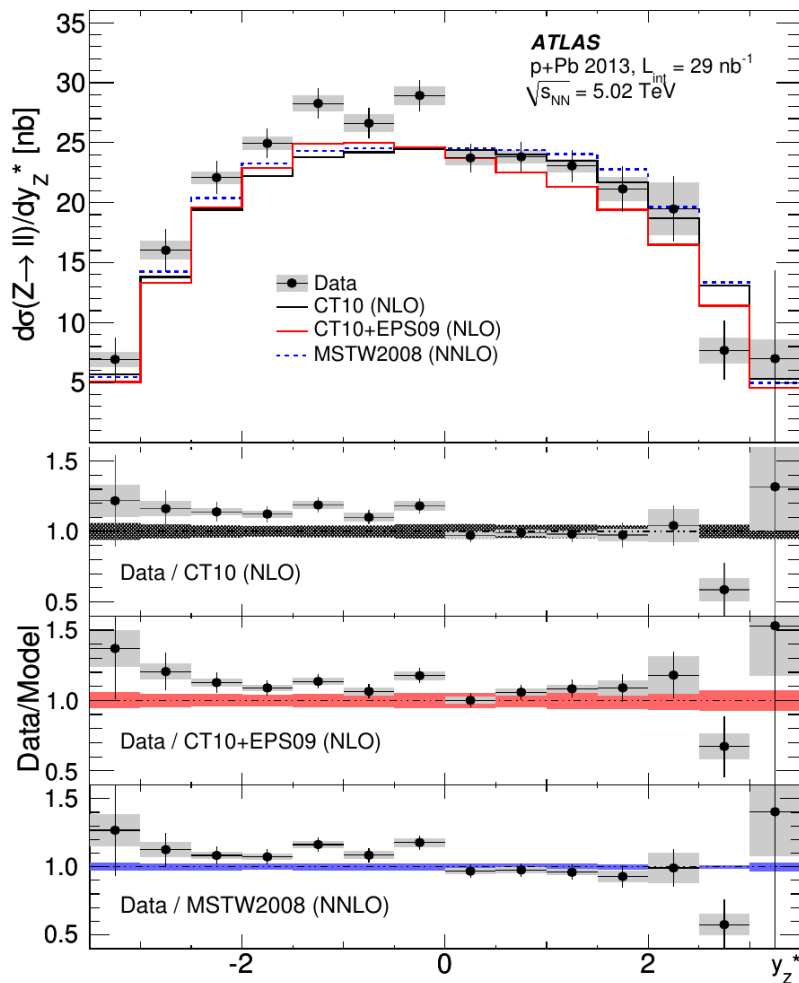
- **CMS measurement statistically limited**
  - weakly favoring EPS09/DSSZ nuclear effects on top of CT10
- **The effect of non-symmetric acceptance well visible**
  - Forward-to-backward ratio clearly different from unity



# Z production in p-Pb: ATLAS

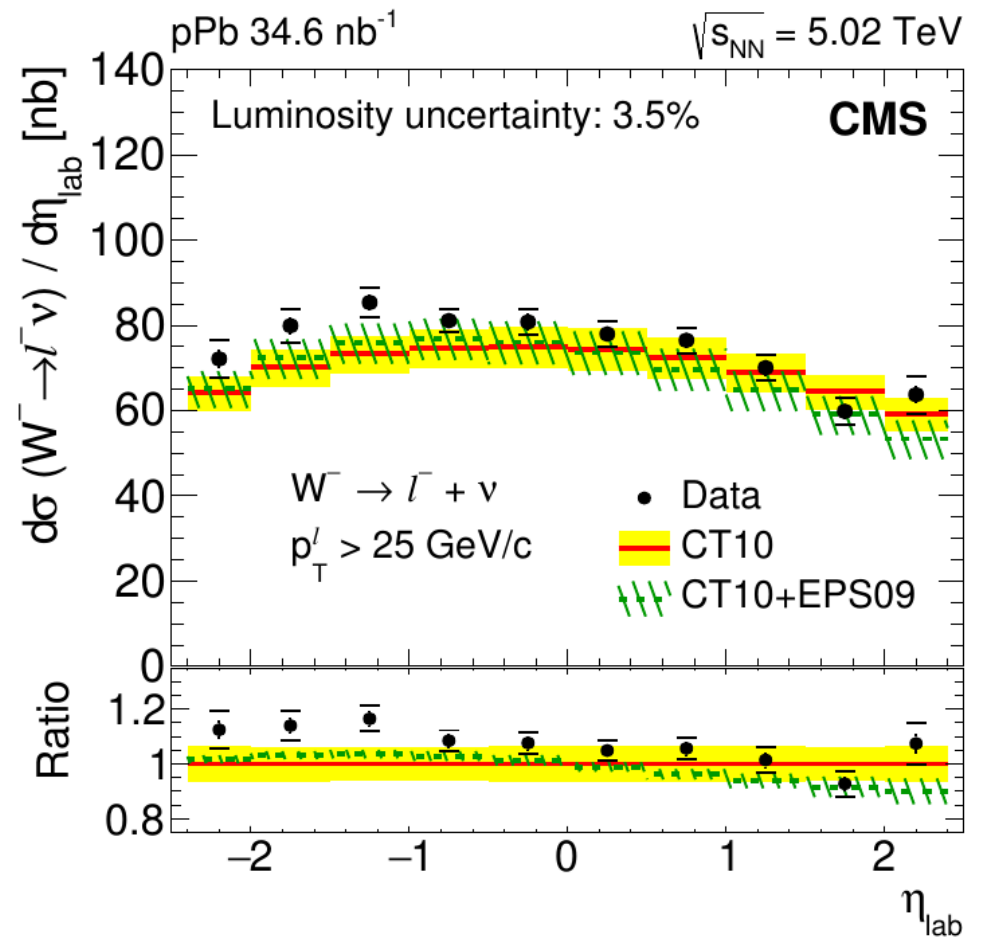
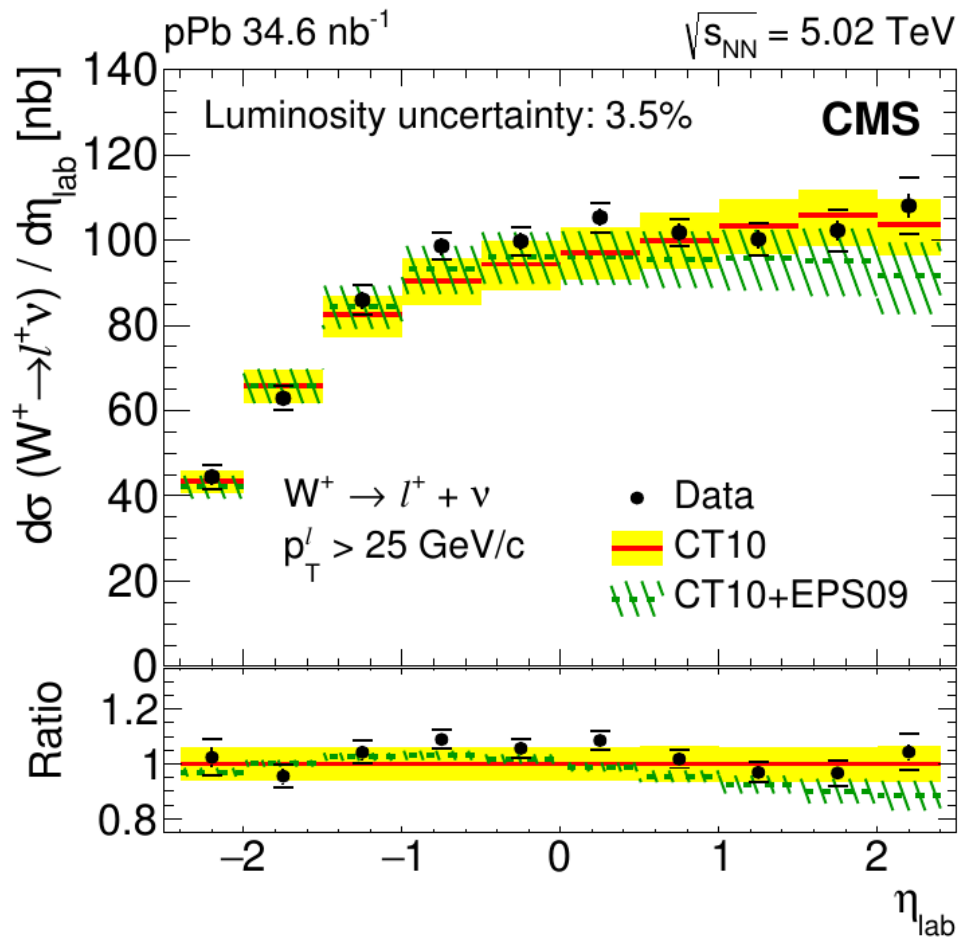
- Also ATLAS measurement statistically limited
  - Favor CT10+EPS09 over CT10-only
- Wider acceptance (+acceptance correction) in comparison to CMS measurement
  - Forward-to-backward ratio closer to unity

arXiv:1507.06232



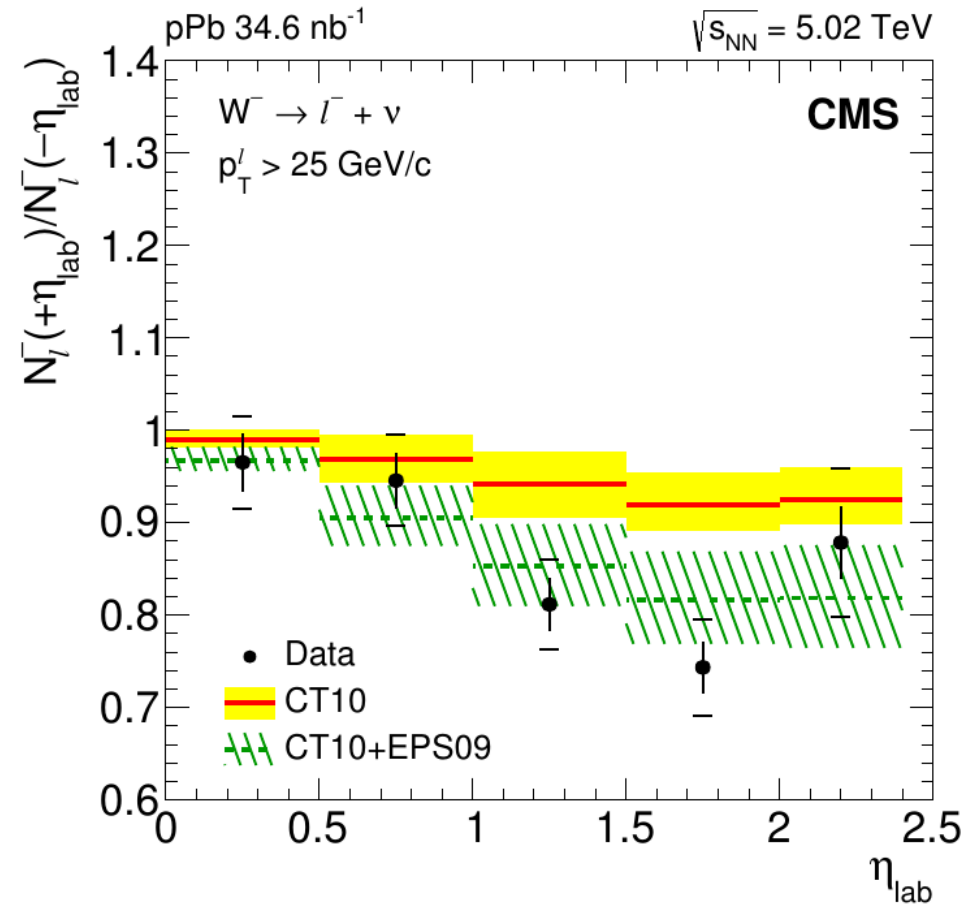
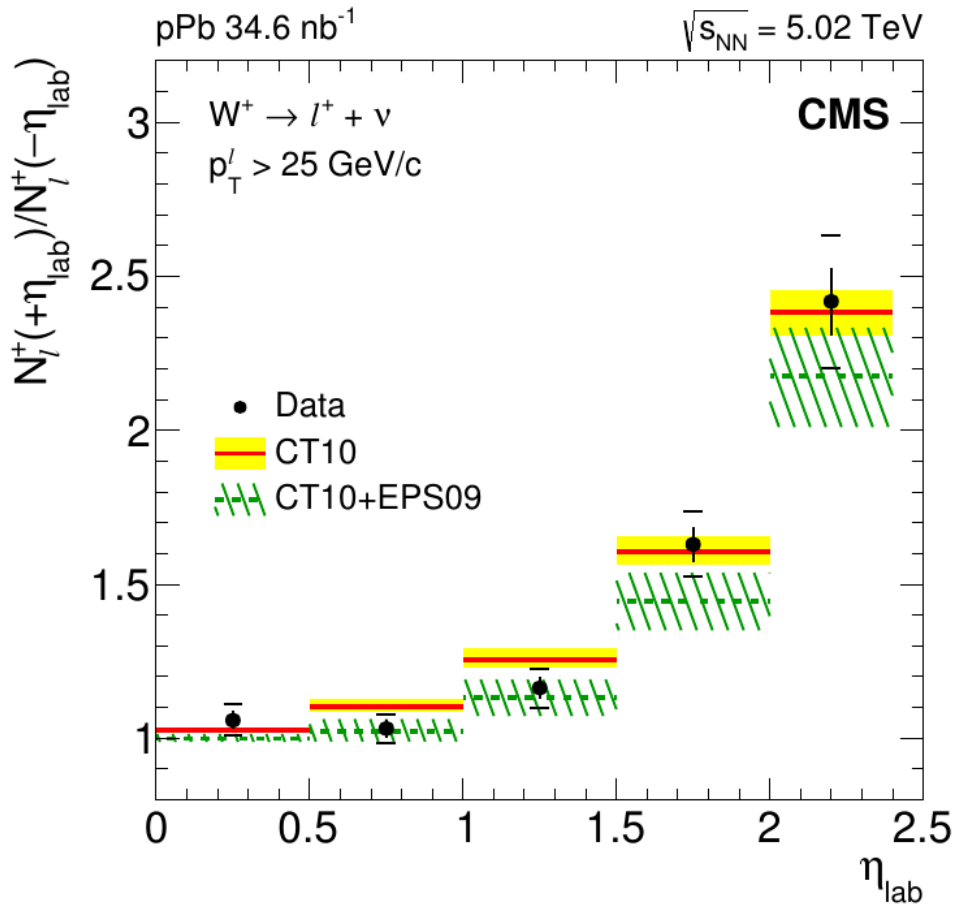
# W production in p-Pb: CMS

- Absolute cross-sections appear to more or less agree with the expectations



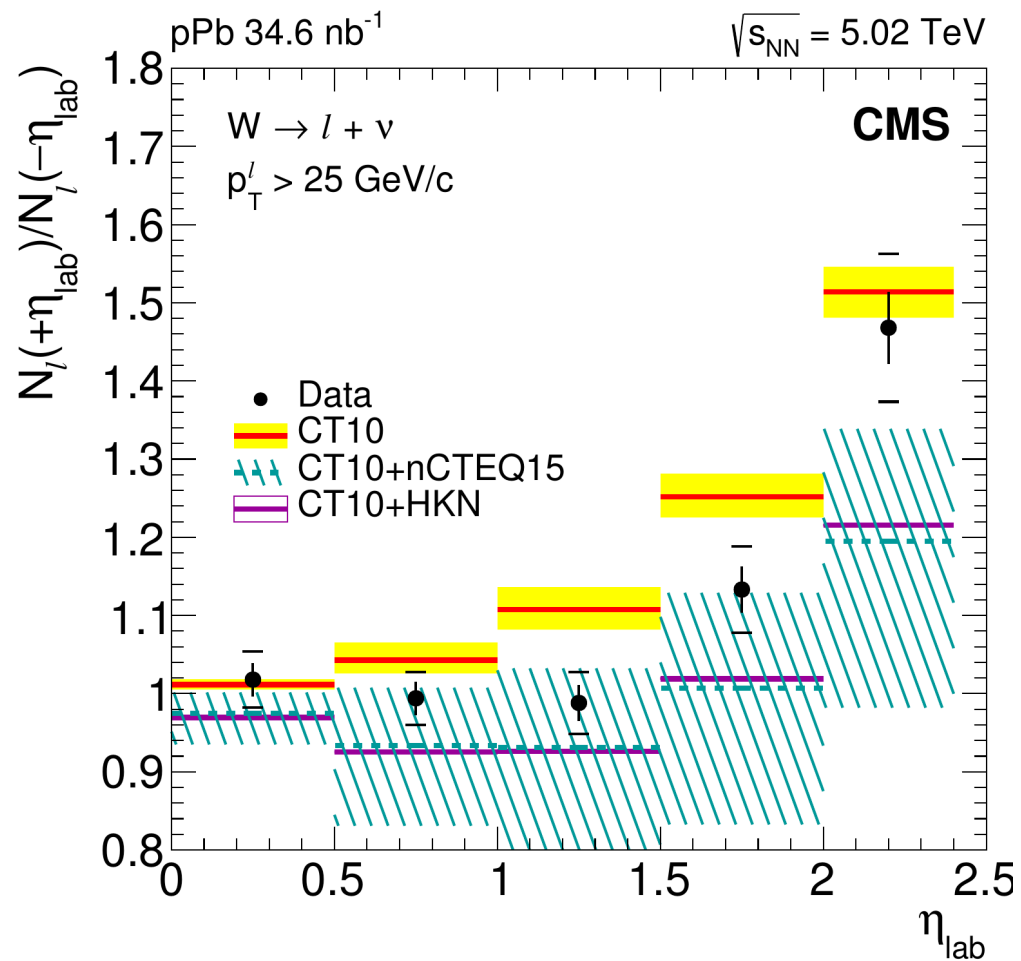
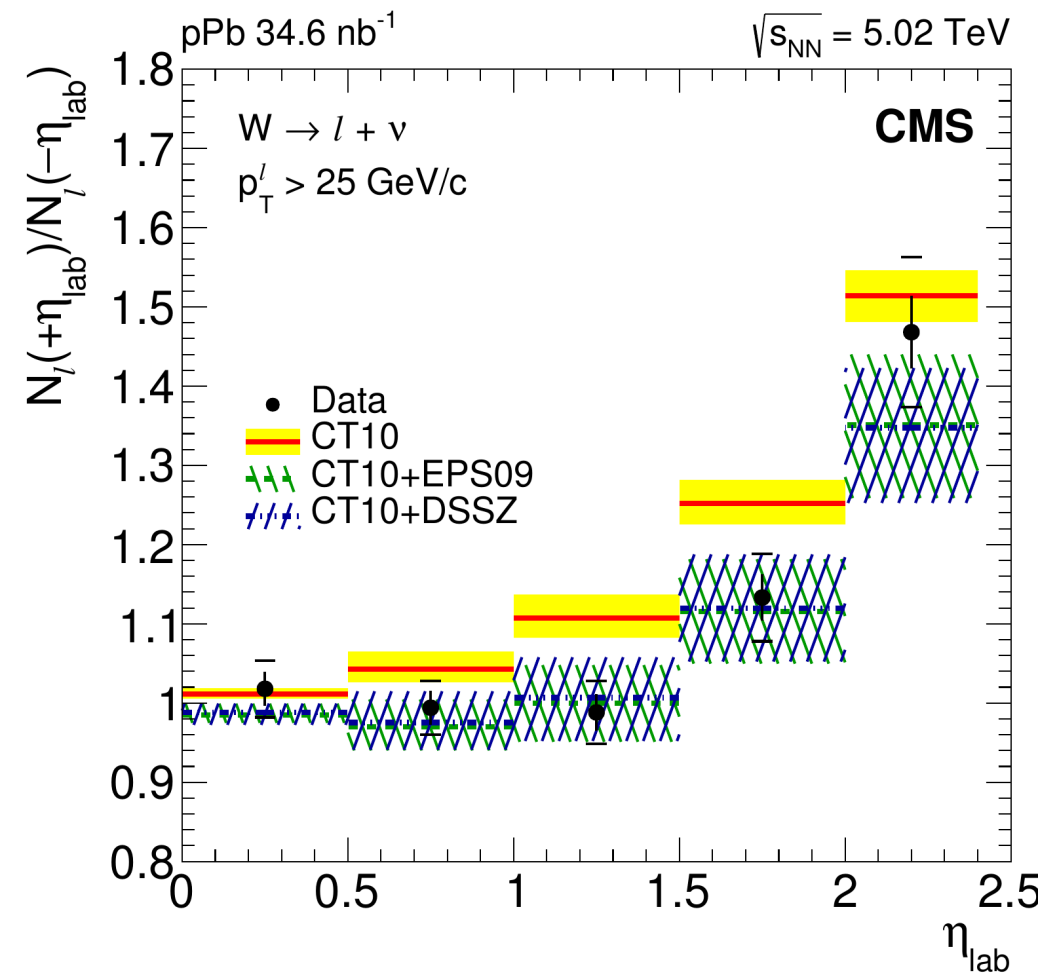
# W production in p-Pb: CMS

- **Forward-to-backward ratios**
  - Preference for nuclear PDFs



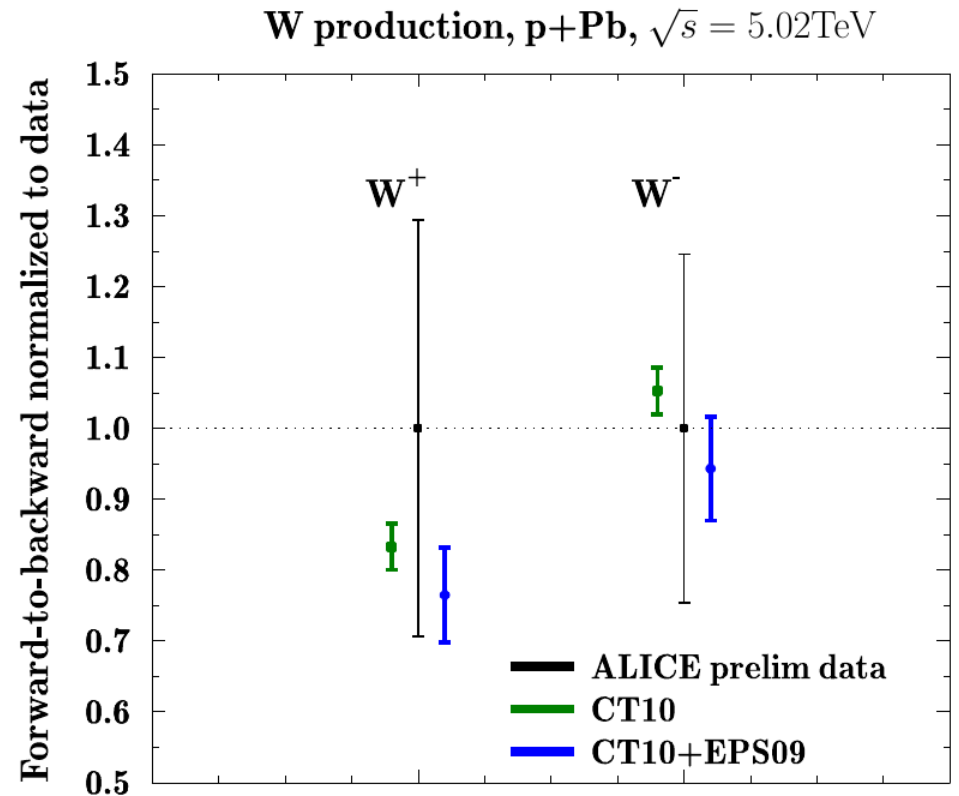
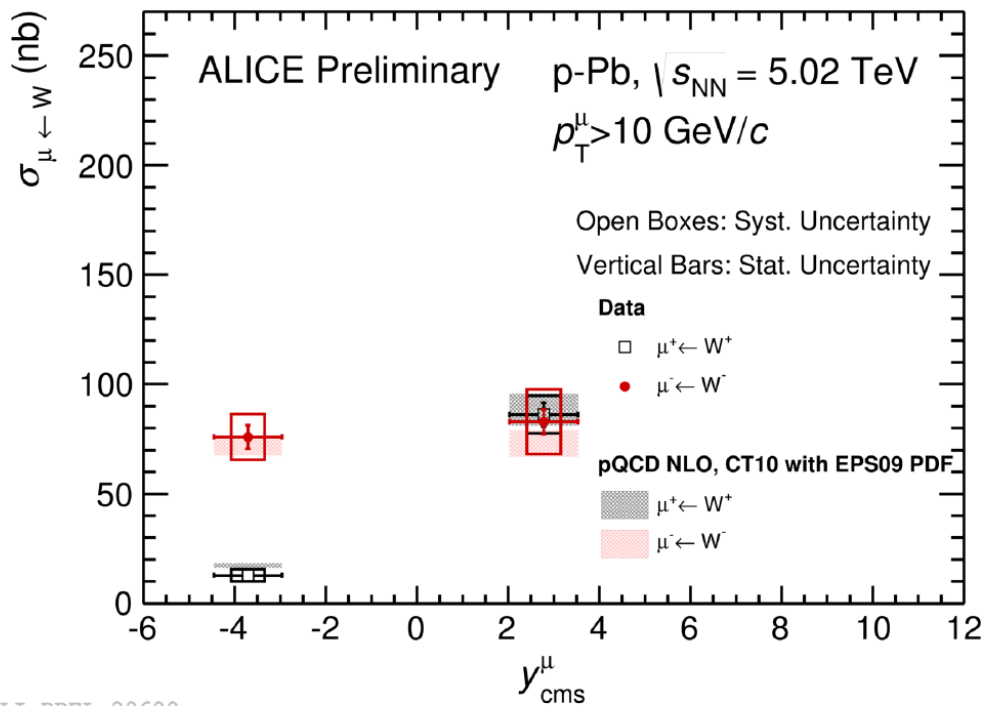
# W production in p-Pb: CMS

- **Forward-to-backward ratios for the sum of all leptons**
  - incompatible with CT10-only calculation (very similar with MSTW2008, NNPDF2.3)
  - good agreement with DSSZ and EPS09
  - fair agreement with nCTEQ15
  - possibly further constraints for the flavor dependence?



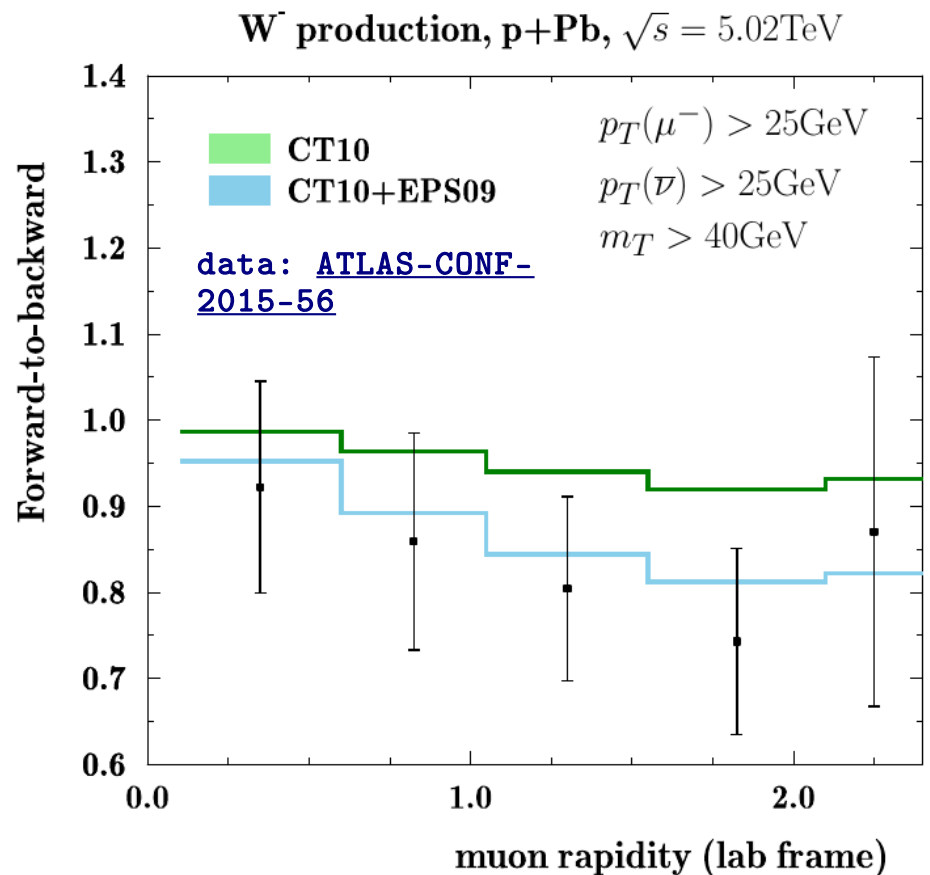
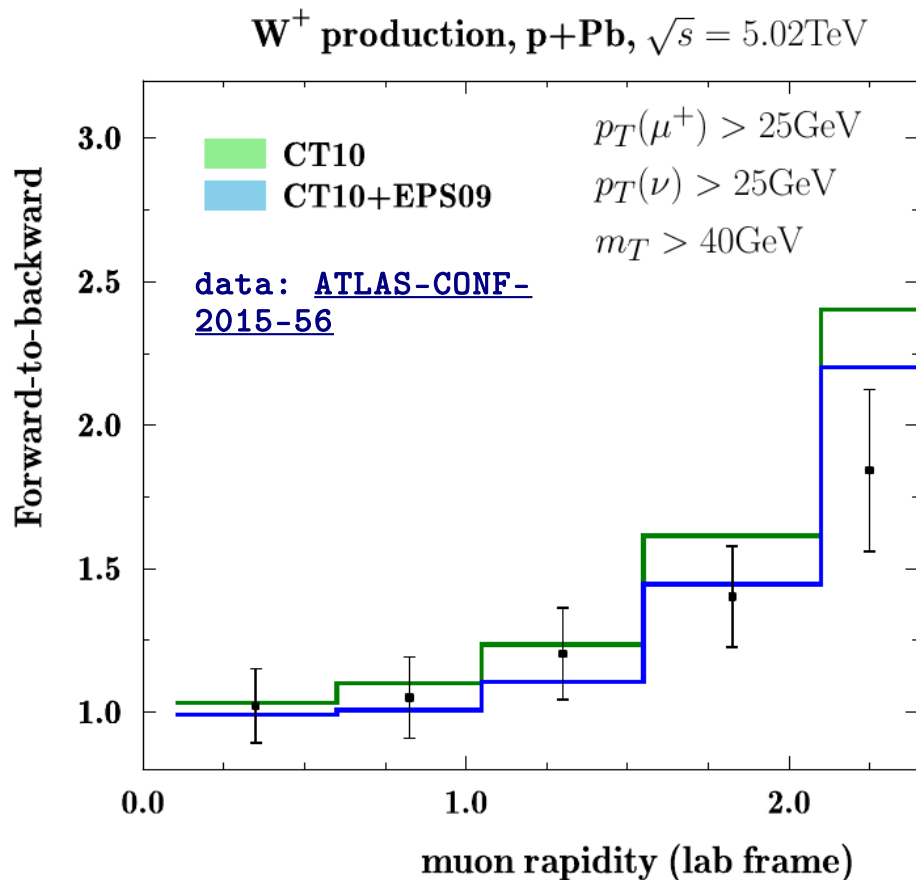
# W production in p-Pb: ALICE

- **Only muon channel available from ALICE**
  - only couple of data points with large uncertainties
  - compatible with NLO calculations (with/without nuclear corrections)



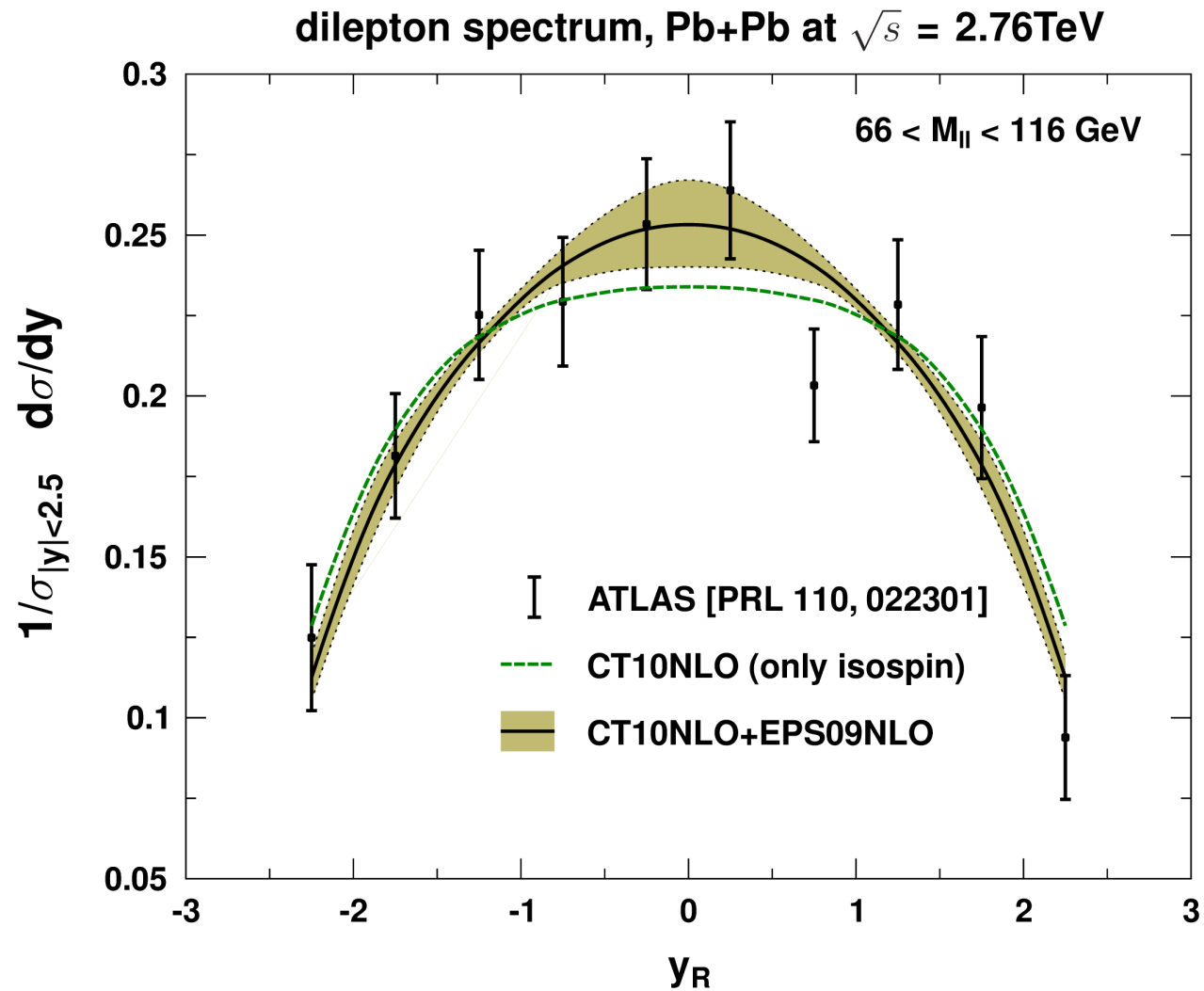
# W production in p-Pb: ATLAS

- Only muon channel currently available (electron channel will still come)
  - Statistics will still improve
- Slight preference for nuclear effects in the asymmetry ratios



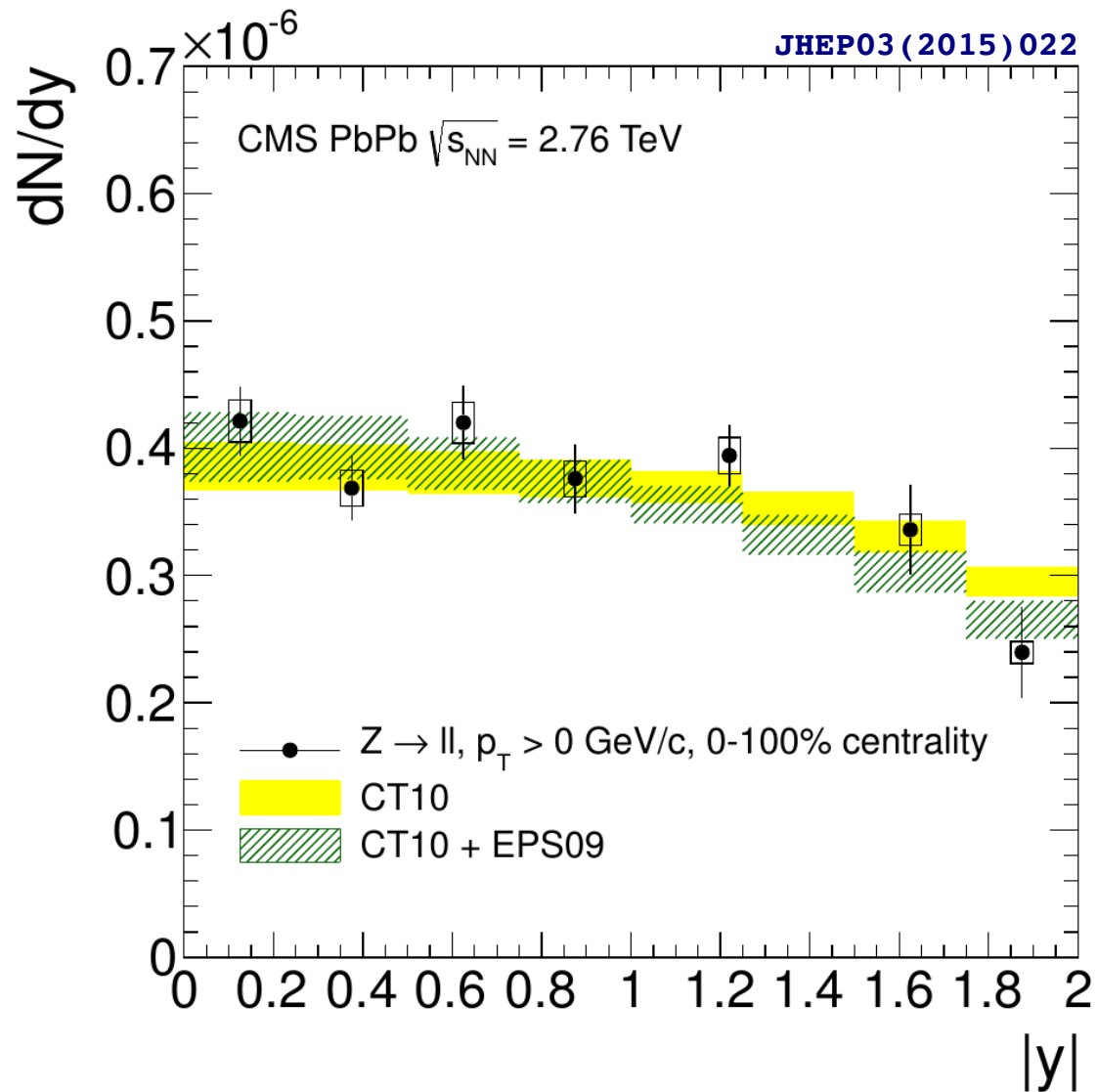
# Z bosons in Pb-Pb: ATLAS

- **Z bosons well measurable even in Pb-Pb:**
  - more statistics would be needed to decide whether we see effects of PDF nuclear modifications



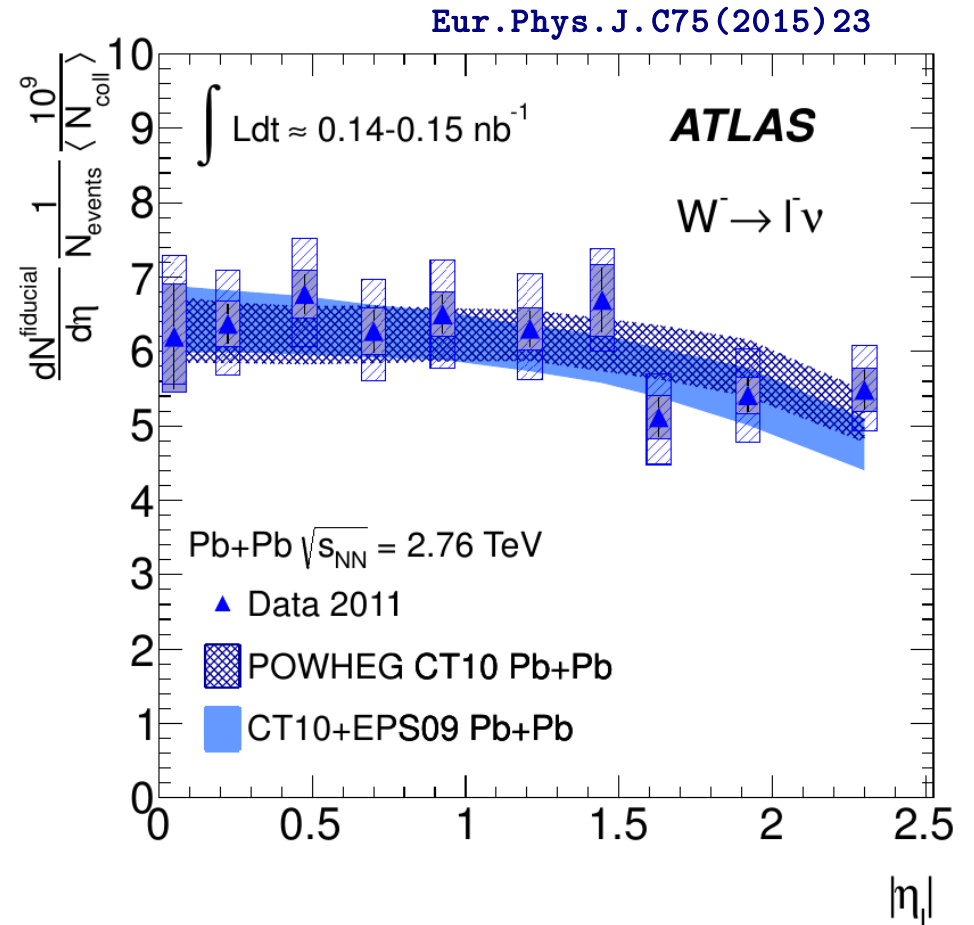
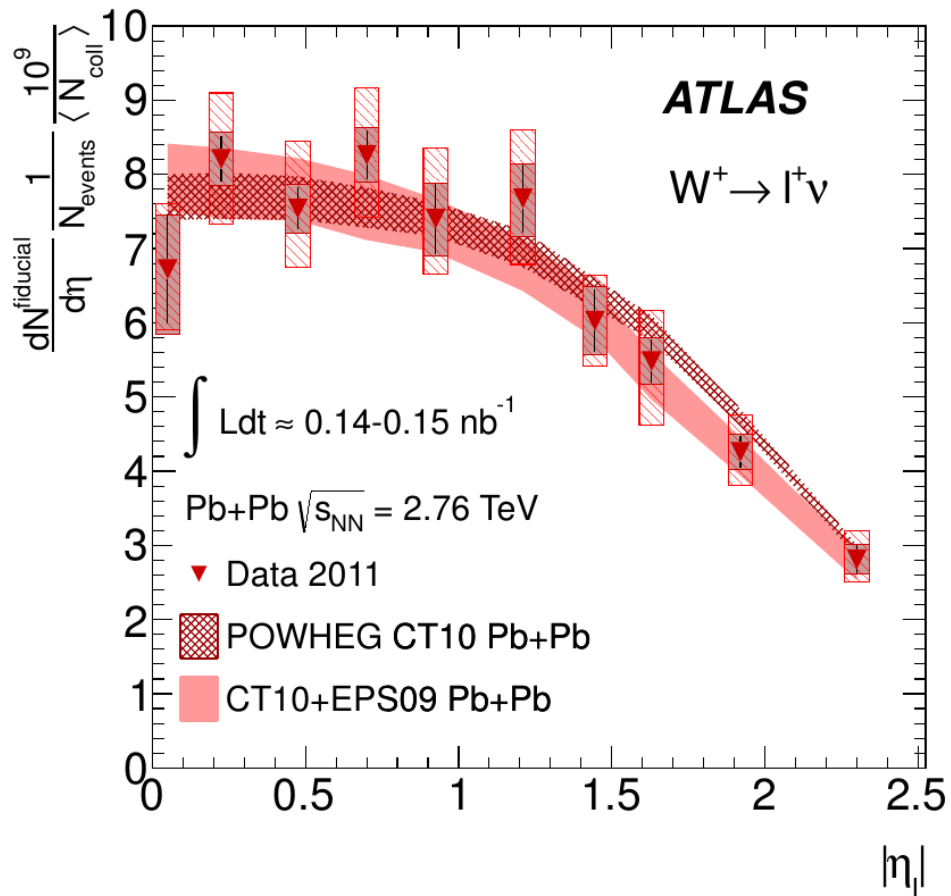
# Z bosons in Pb-Pb: CMS

- **Z bosons well measurable even in Pb-Pb:**
  - more statistics would be needed to decide whether we see effects of PDF nuclear modifications



# W bosons in Pb-Pb: ATLAS data

- The existing Pb-Pb data compatible with the pQCD expectations  
- data not precise enough to resolve nuclear mods



# Summary

- Various sets of p-Pb data in the stage of becoming finalized
- The CMS dijet data distinguish between available nPDF fits
  - indicate antishadowing for gluons
  - consistent with the CMS inclusive jet measurements
  - ATLAS jet data plagued by the "centrality" selection
- Electro-weak observables
  - W production looks promising - could facilitate flavor separation to some extent
  - Z statistically limited
- Inclusive charged-hadron yield enhanced at high-pt
  - origin not understood (data issue, fragmentation functions,...)
- Also other available observables (J/Psi, Upsilon, D meson,...) sensitive to nuclear mods in PDFs but more model dependent