Constraining nuclear PDFs with CMS

Émilien Chapon
on behalf of the CMS experiment

CERN

DIS 2017
25th International Workshop on Deep Inelastic Scattering and Related Topics

Nuclear Parton Distribution Functions

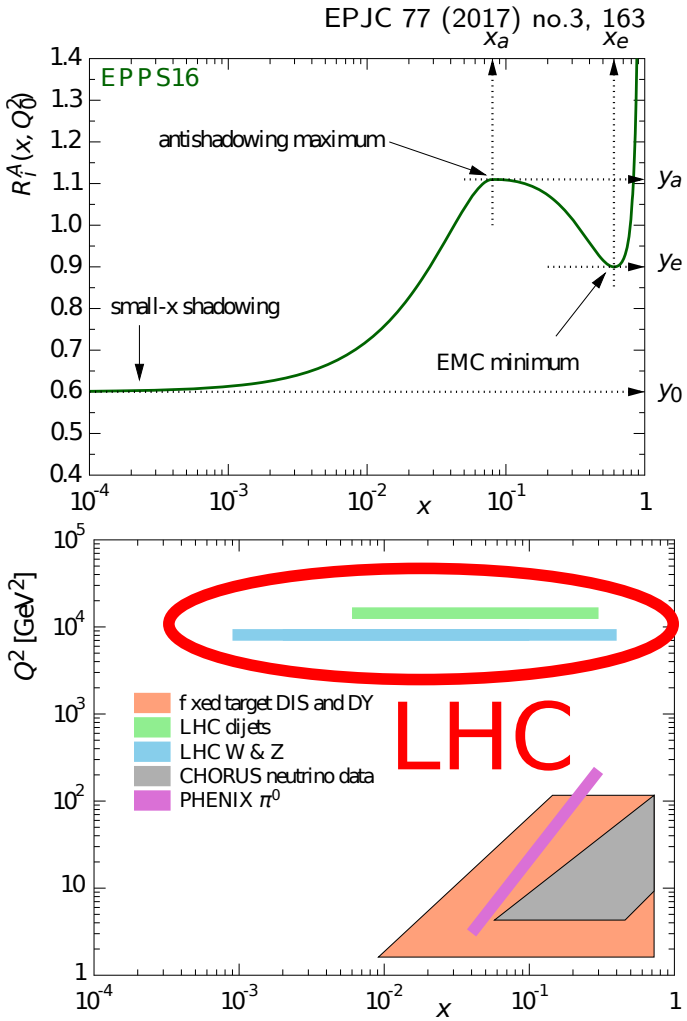
$$f_i^{p/A}(x, Q^2) = R_i^A(x, Q^2) f_i^p(x, Q^2)$$

Impact of nPDFs on LHC observables

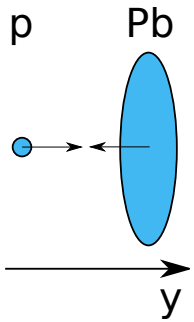
- Important for most heavy-ion observables
- Up to $20 - 30\,\%$ modification compared to a free proton PDF

Impact of the LHC on nPDFs

- New range of (x, Q^2) accessible
- First nPDF to include LHC data: EPPS16



Which processes constrain nPDFs?



Using pPb data rather than PbPb because:

- no "hot medium" (QGP) effects, no jet quenching (a priori)
- probing a single x_{Pb}

NB: only 5 TeV (Run-I) pPb results for now

Process	**Z**
	PLB 759 (2016) 36
nPDF	q, $\bar{q}$
x range	$10^{-3} - 10^{-1}$
Q^2 range	M_Z^2
Comments	resolved final state
In EPPS16?	✓

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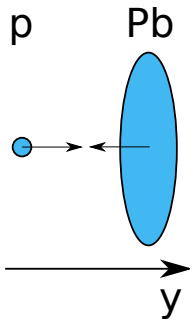

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	PLB 759 (2016) 36	PLB 750 (2015) 565
nPDF	q, $\bar{q}$	q, $\bar{q}$
x range	$10^{-3} - 10^{-1}$	$10^{-3} - 10^{-1}$
Q^2 range	M_{Z}^2	M_{W}^2
Comments	resolved final state	10× larger yield than Z "Isospin effect:" pp vs pn
In EPPS16?	✓	✓

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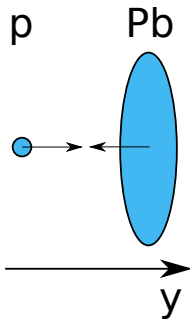

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Process	**Z**	**W**	**Dijet**
	PLB 759 (2016) 36	PLB 750 (2015) 565	CMS-PAS-HIN-16-003
nPDF	q, $\bar{q}$	q, $\bar{q}$	g
x range	$10^{-3} - 10^{-1}$	$10^{-3} - 10^{-1}$	$10^{-3} - 10^{-1}$
Q^2 range	M_{Z}^2	M_{W}^2	$10^3 - 10^4$ GeV^{-2}
Comments	resolved final state	10× larger yield than Z; "Isospin effect:" pp vs pn	
In EPPS16?	✓	✓	✓

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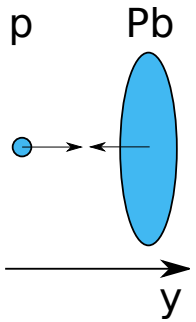

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Process	**Z**	**W**	**Dijet**	**Quarkonia**
	PLB 759 (2016) 36	PLB 750 (2015) 565	CMS-PAS-HIN-16-003	1702.01462, 1605.06966
nPDF	q, $\bar{q}$	q, $\bar{q}$	g	g
x range	$10^{-3} - 10^{-1}$	$10^{-3} - 10^{-1}$	$10^{-3} - 10^{-1}$	$10^{-4} - 10^{-2}$
Q^2 range	M_{Z}^2	M_{W}^2	$10^3 - 10^4$ GeV^{-2}	$10^2 - 10^3$ GeV^{-2}
Comments	resolved final state	10× larger yield than Z; "Isospin effect:" pp vs pn		pPb: possible other effects; Ultra-peripheral PbPb: how to use it for nPDF?
In EPPS16?	✓	✓	✓	X

Z boson: event kinematics

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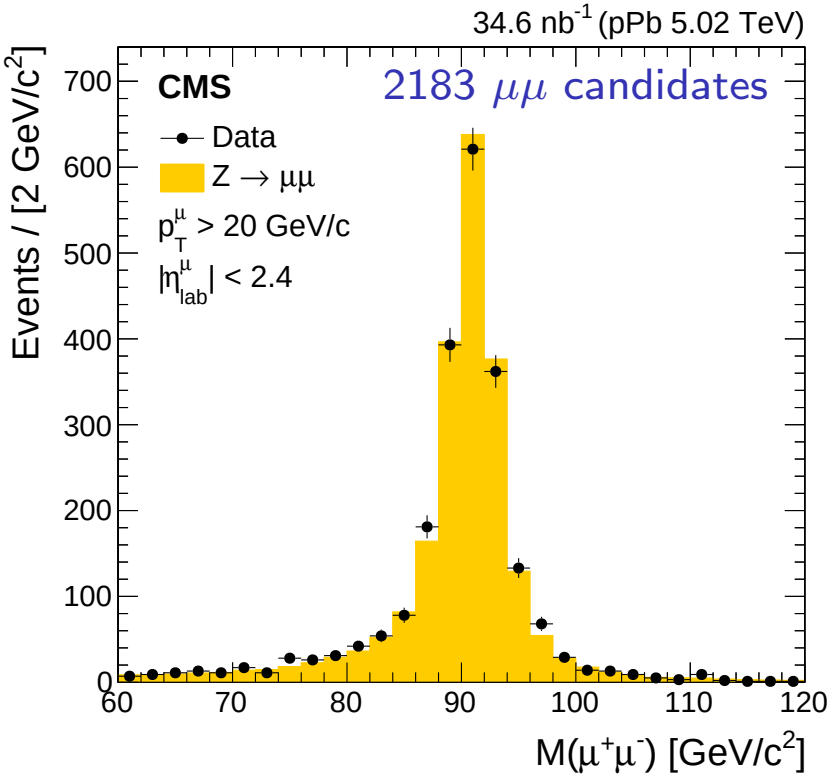

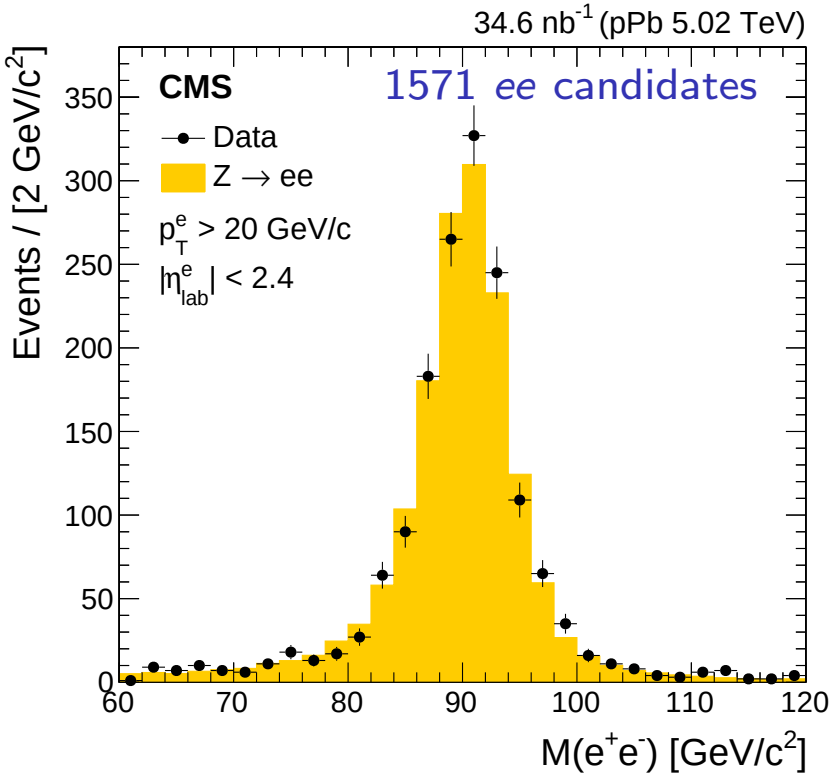

- Electron and muon channels
- $|\eta^{\ell}| < 2.4$, $p_T^{\ell} > 20\,\mathrm{GeV}/c$ (fiducial region)

Z boson: fiducial cross section vs. rapidity

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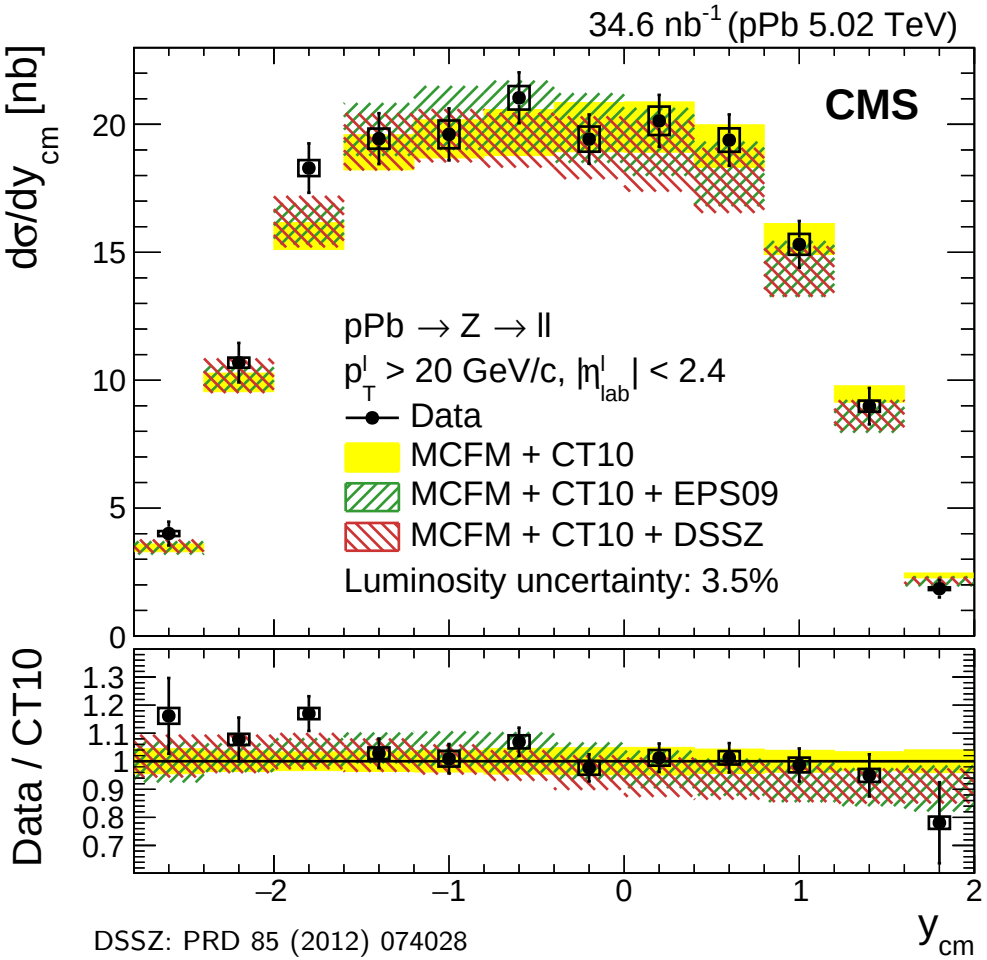

- Also available: acceptance-corrected results
- Comparison with MCFM with and without nPDFs (DSSZ, EPS09)

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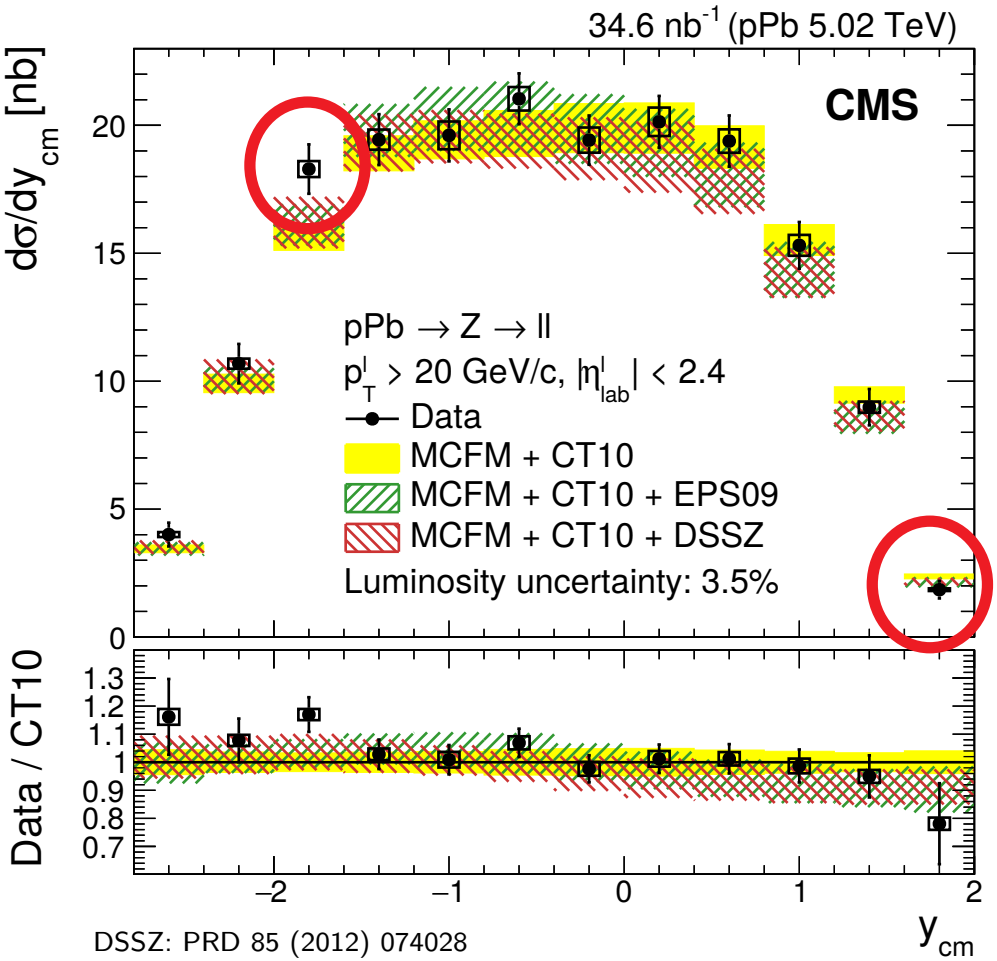

- Also available: acceptance-corrected results
- Comparison with MCFM with and without nPDFs (DSSZ, EPS09)
- Nuclear effects most prominent in the forward and backward regions (different x regions)

Z boson: foward-backward asymmetry

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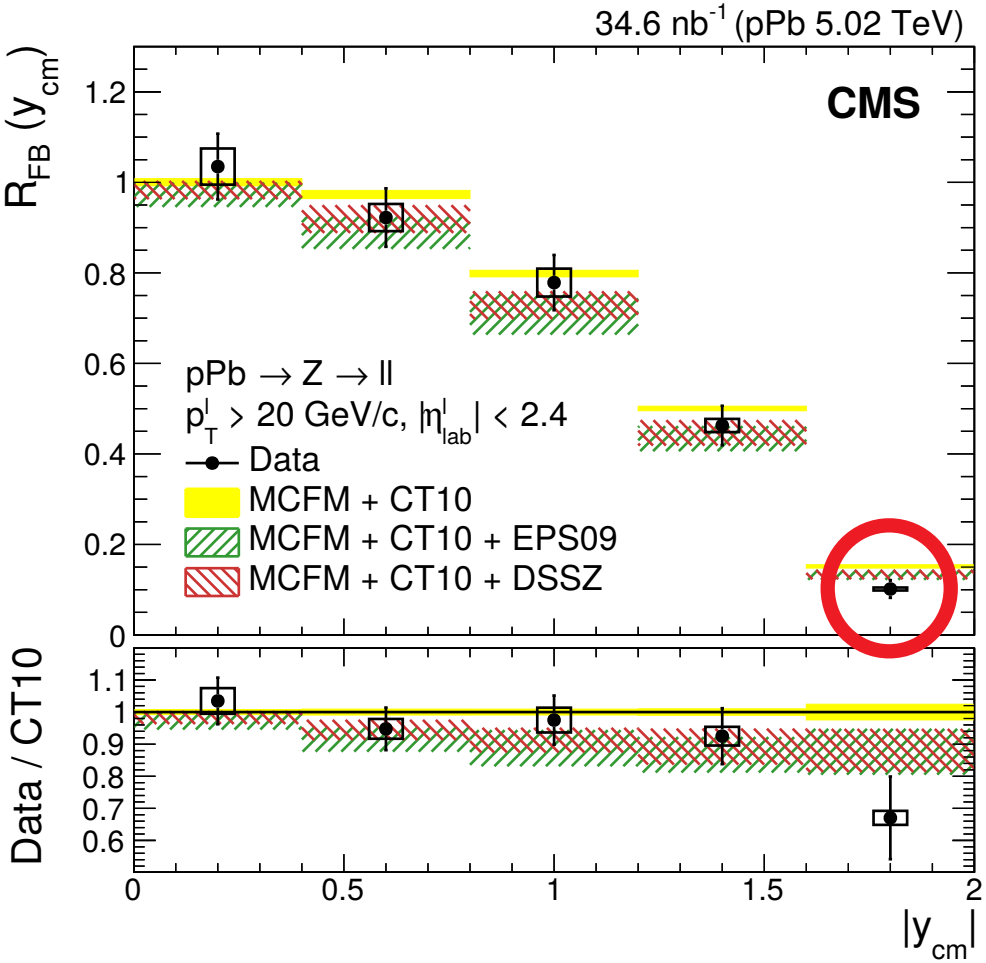

$$R_{FB} = \frac{\frac{d\sigma}{dy}(+y_{c.m.})}{\frac{d\sigma}{dy}(-y_{c.m.})}$$

- Improved sensitivity to nPDFs
- Hint of nuclear effects?

Z boson: foward-backward asymmetry

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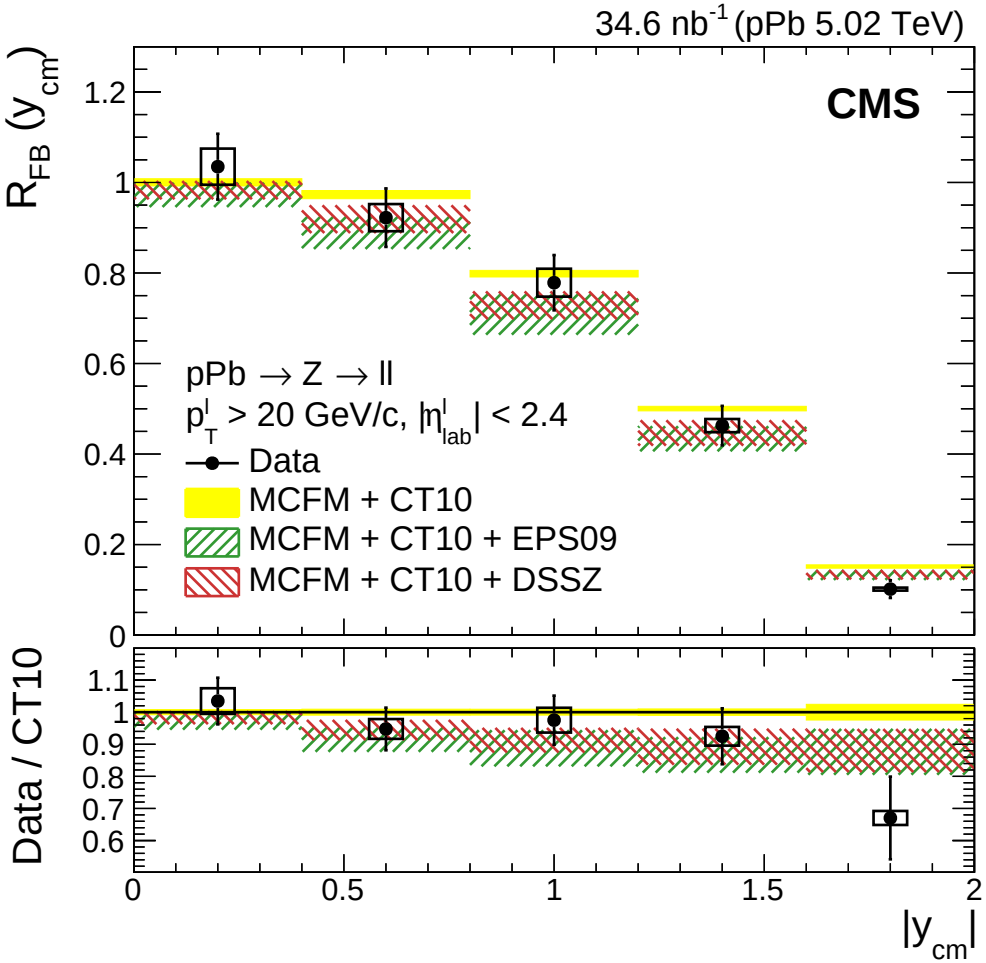

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W boson: event kinematics

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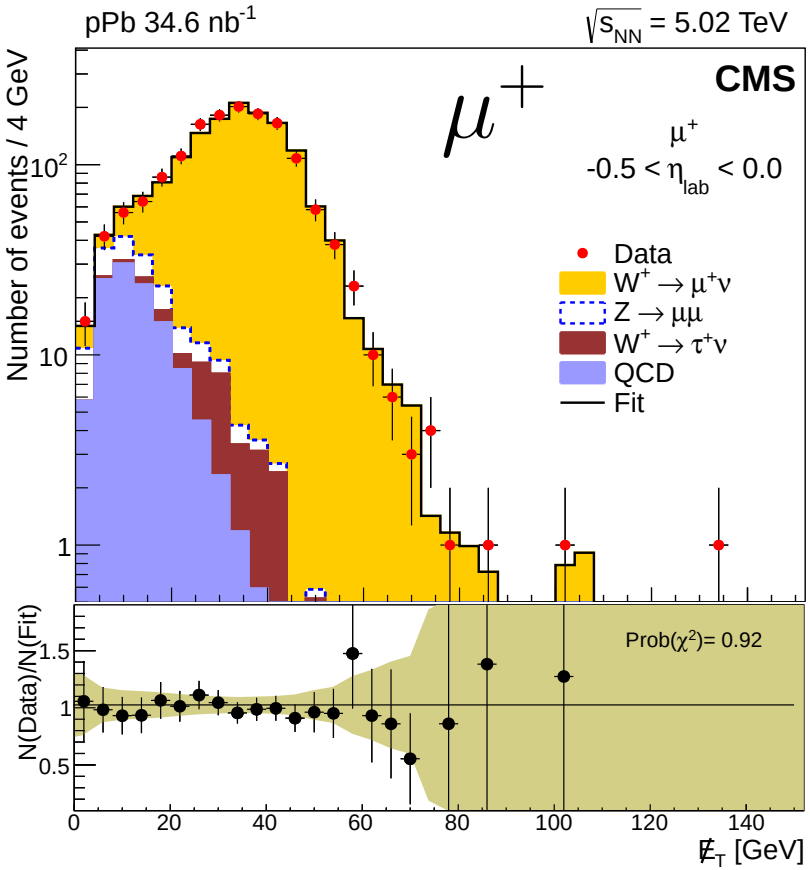

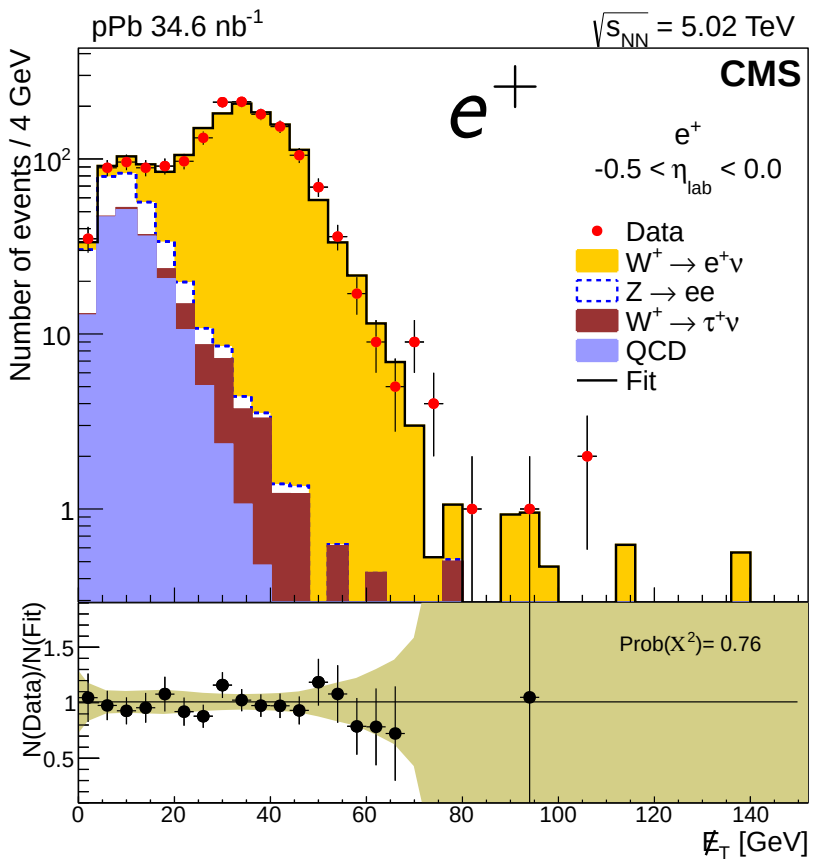

- Electron and muon channels ($p_T > 25\,\text{GeV}$, $|\eta^\ell| < 2.4$)
- No $\not{E}_T$ cut: extract signal through a $\not{E}_T$ fit

W boson: cross section

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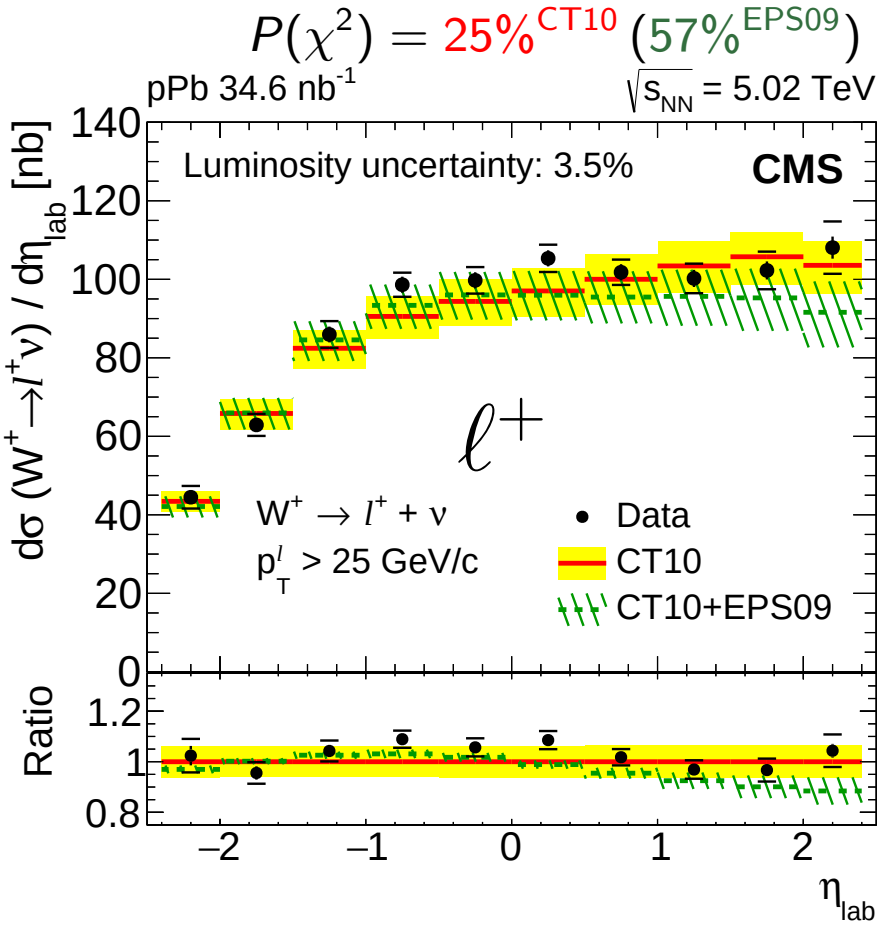

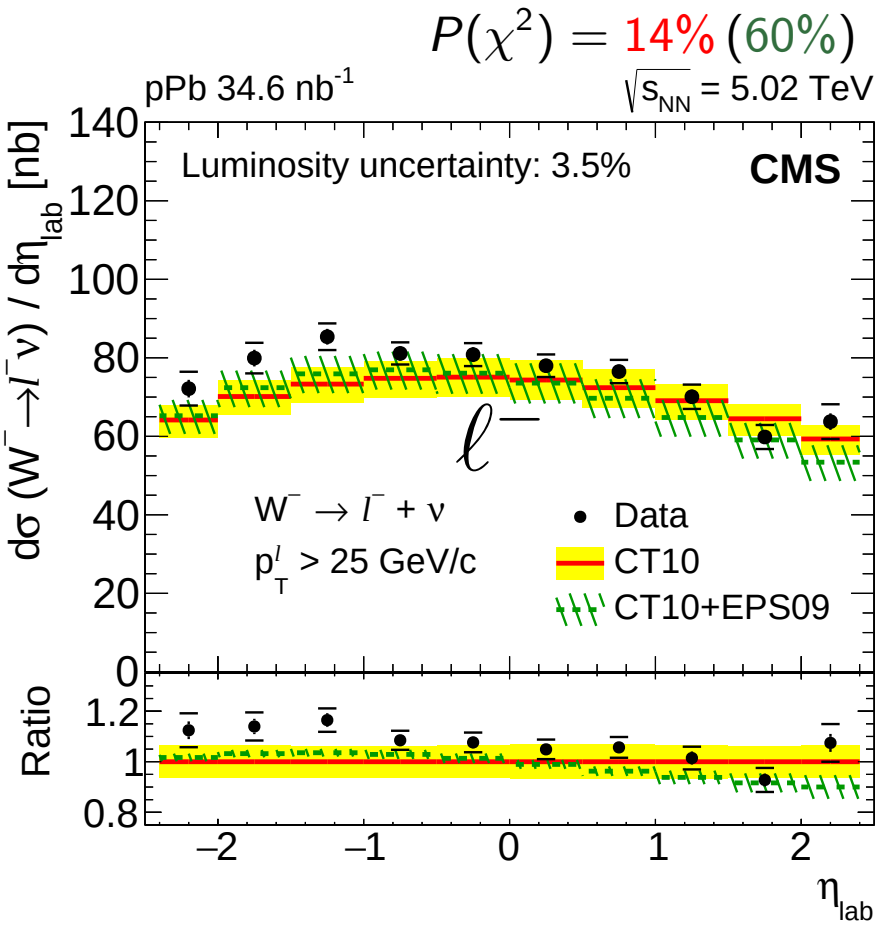

- Poor discrimination between CT10 and CT10+EPS09: build asymmetries

W boson: charge asymmetry $(N^+ - N^-)/(N^+ + N^-)$

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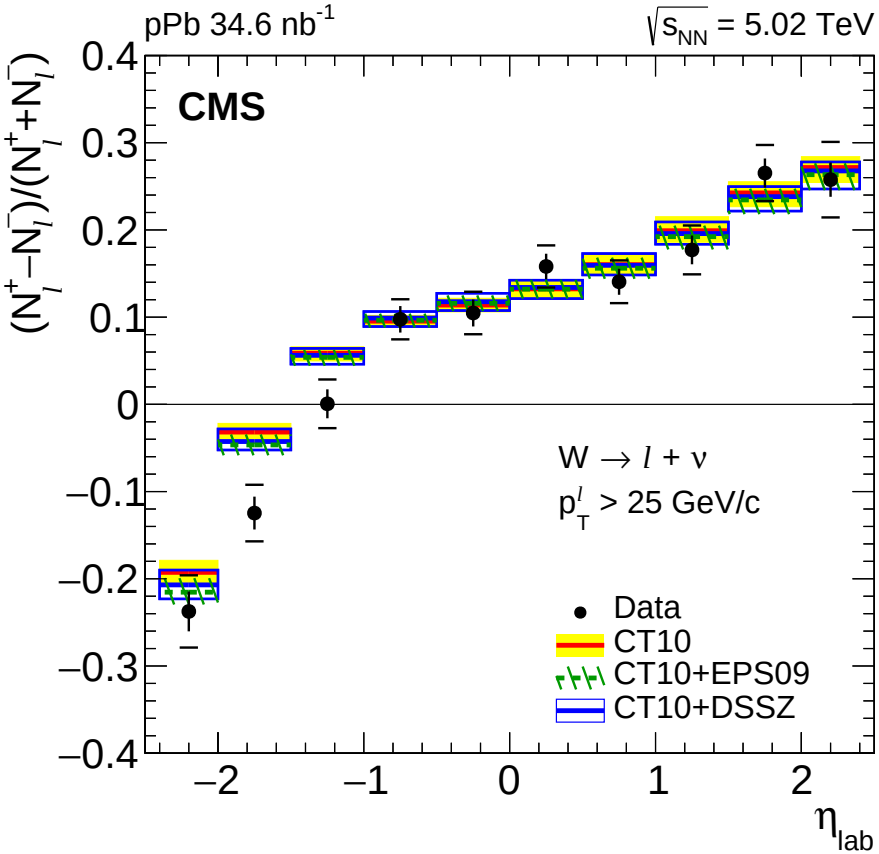
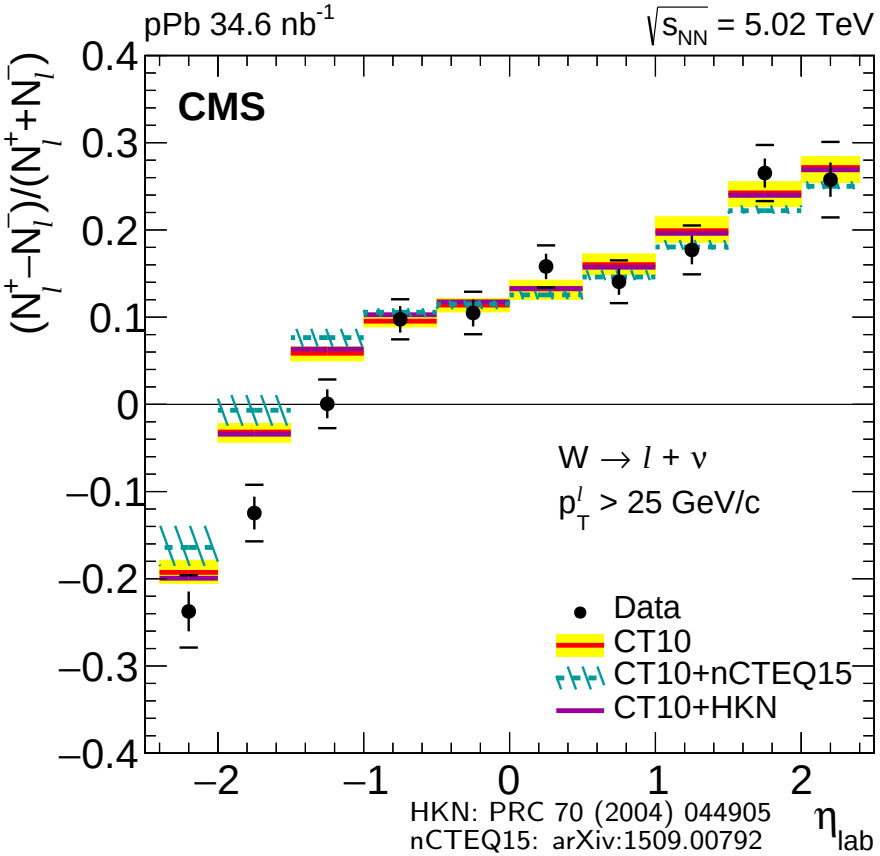
$P(\chi^2) = 12\%^{\text{CT10}}\ (35\%^{\text{EPS09}})$

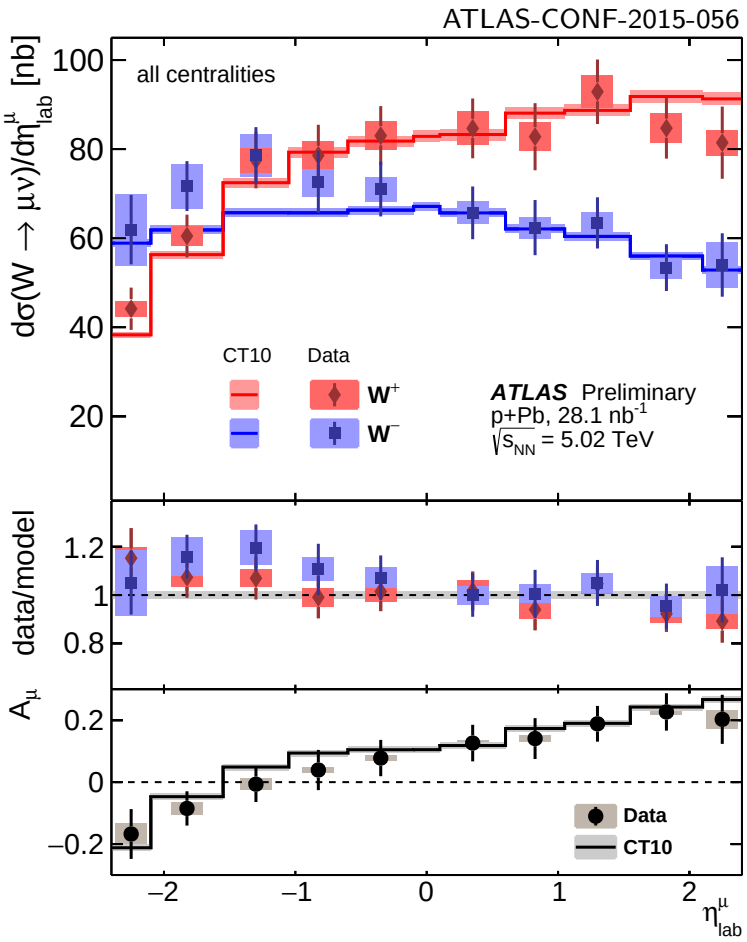


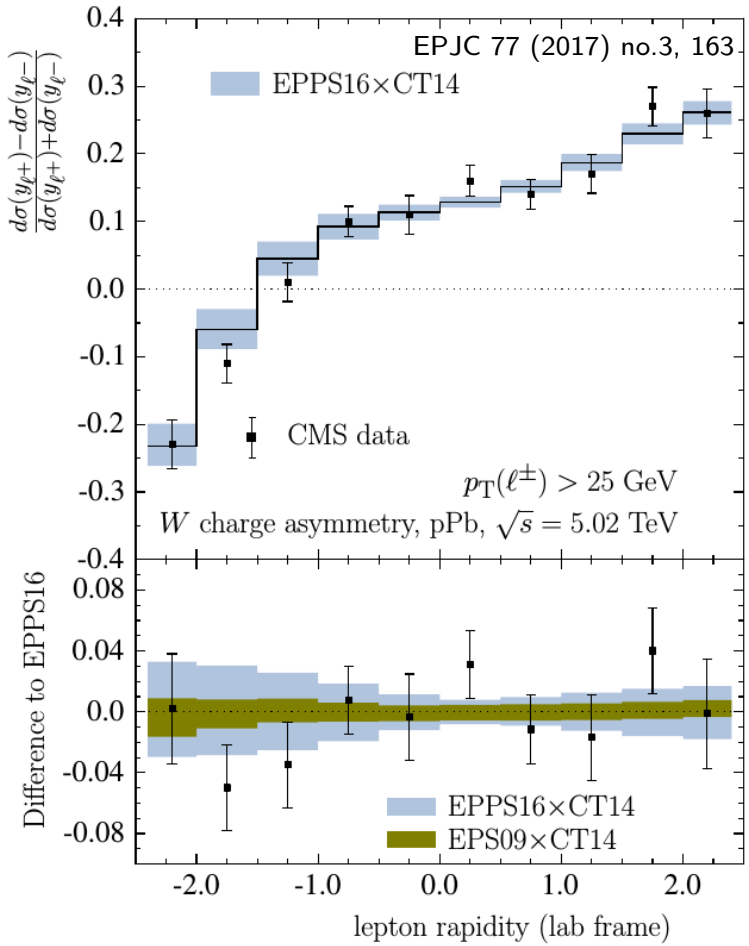


Comparing with different nPDFs

- Small deviation at large negative η: different u vs. d quark modification?
  - Not included in EPS09 / DSSZ / HKN
  - Allowed in nCTEQ15 (but wrong direction)
  - Allowed in EPPS16

W boson: charge asymmetry $(N^+ - N^-)/(N^+ + N^-)$





Similar results from ATLAS in pPb

Compatible with EPPS16 (larger uncertainties than EPS09)

See also comparison with PbPb and other systems in H. Paukkunen's talk.

W boson: forward-backward asymmetry $N^{\pm}(+\eta_{\text{lab}})/N^{\pm}(-\eta_{\text{lab}})$

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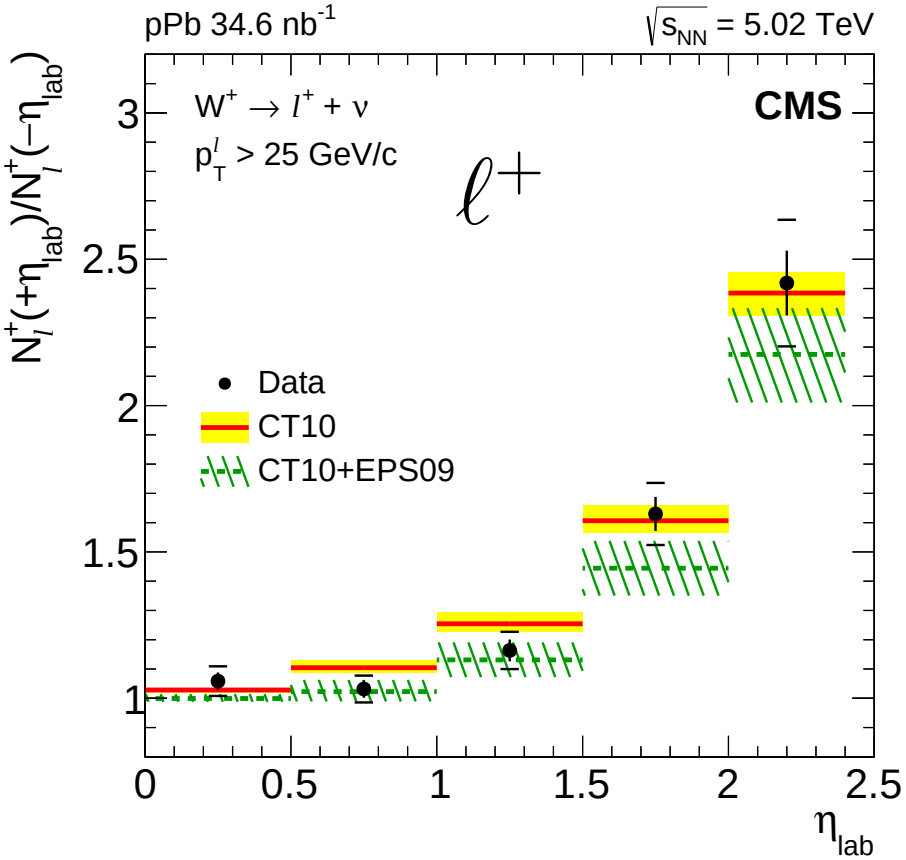
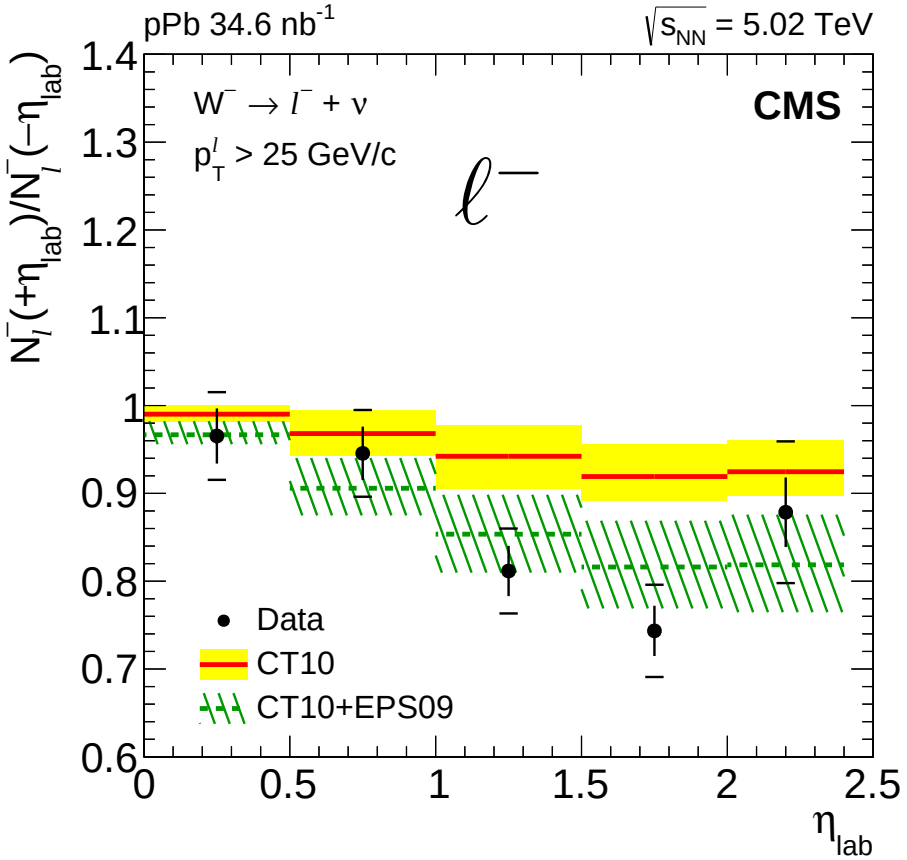
$P(\chi^2) = 68\%^{\text{CT10}}\ (68\%^{\text{EPS09}})$



$P(\chi^2) = 8.4\%\ (63\%)$



- F/B asymmetries are more sensitive to nuclear modifications.
- Negative leptons favor EPS09
- Unclear conclusion for positive leptons

W boson: forward-backward asymmetry $N(+\eta_{\text{lab}})/N(-\eta_{\text{lab}})$

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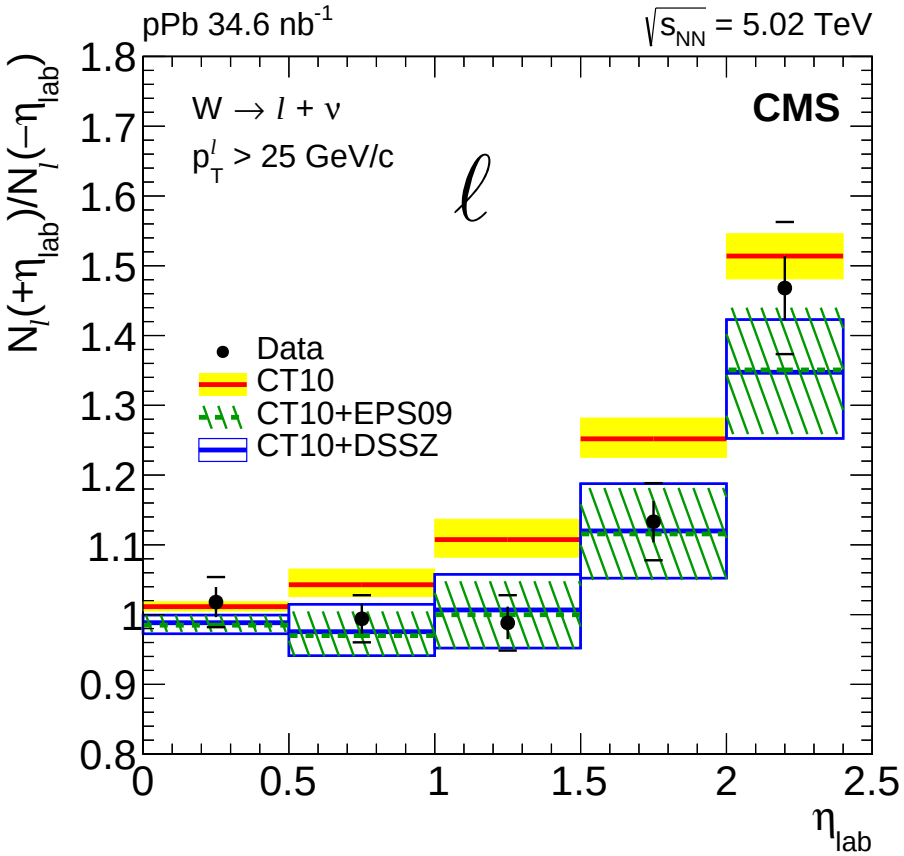
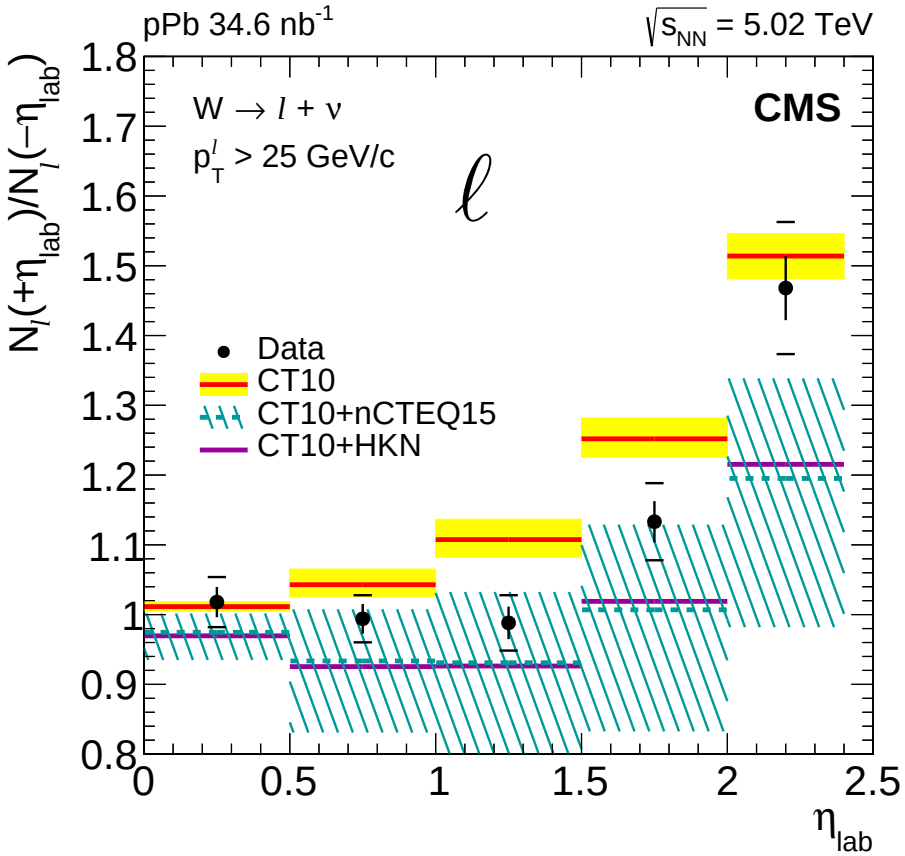
$P(\chi^2) = 29\%^{\text{CT10}}\ (83\%^{\text{EPS09}})$

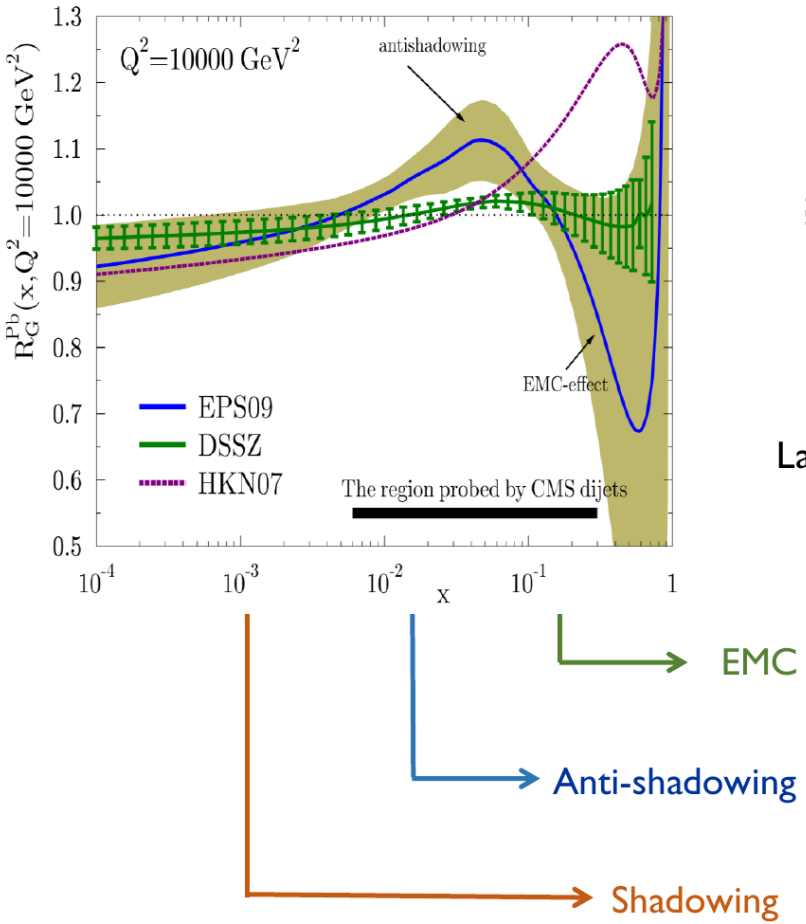


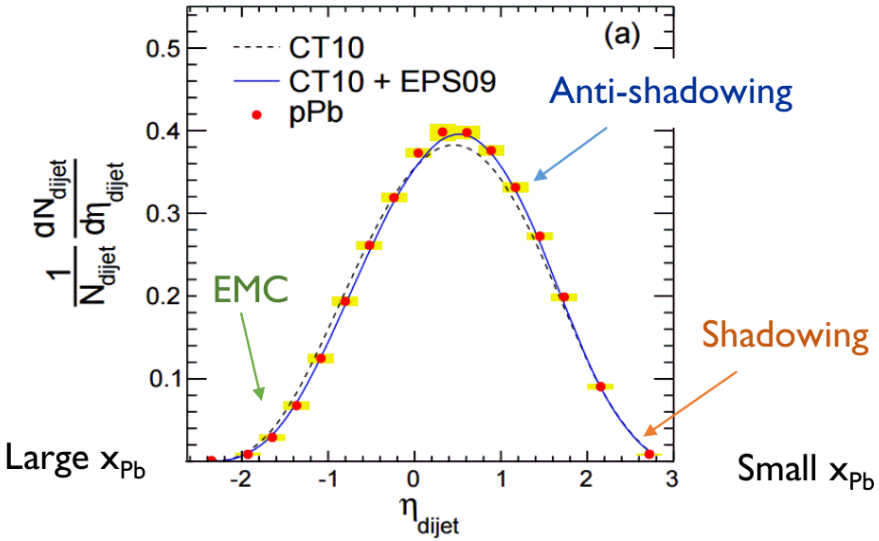


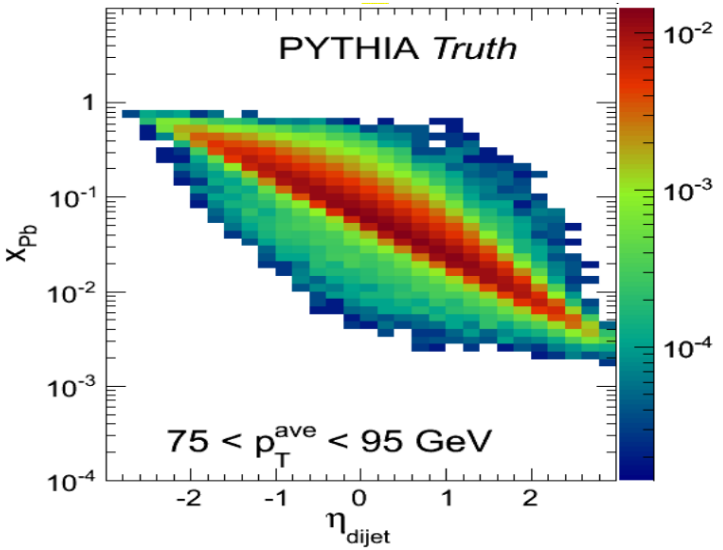
- Favoring the presence of nuclear modifications of PDFs

Dijets in pPb: x_{Pb} vs η_{dijet}

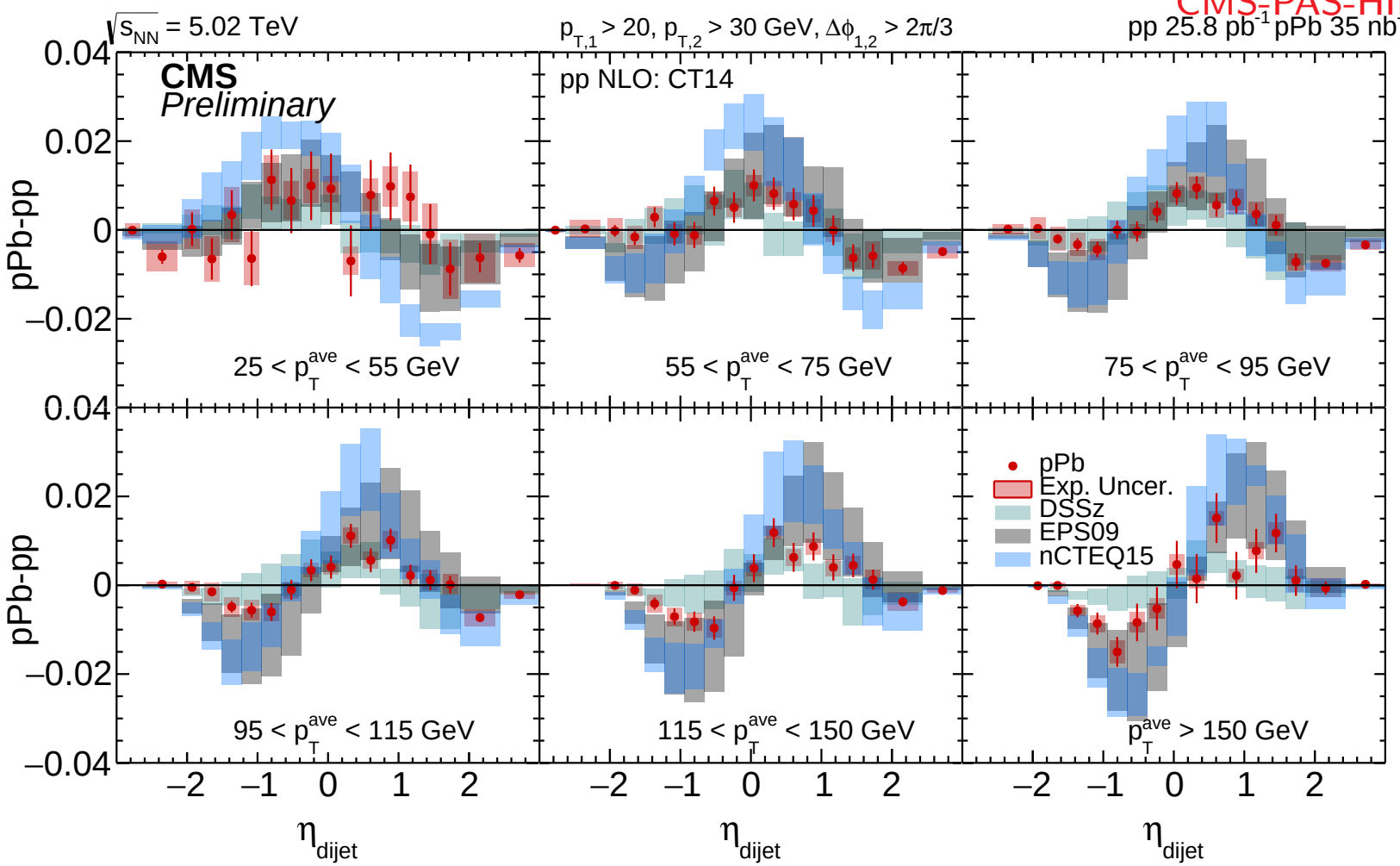
CMS-PAS-HIN-16-003





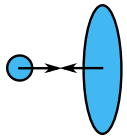


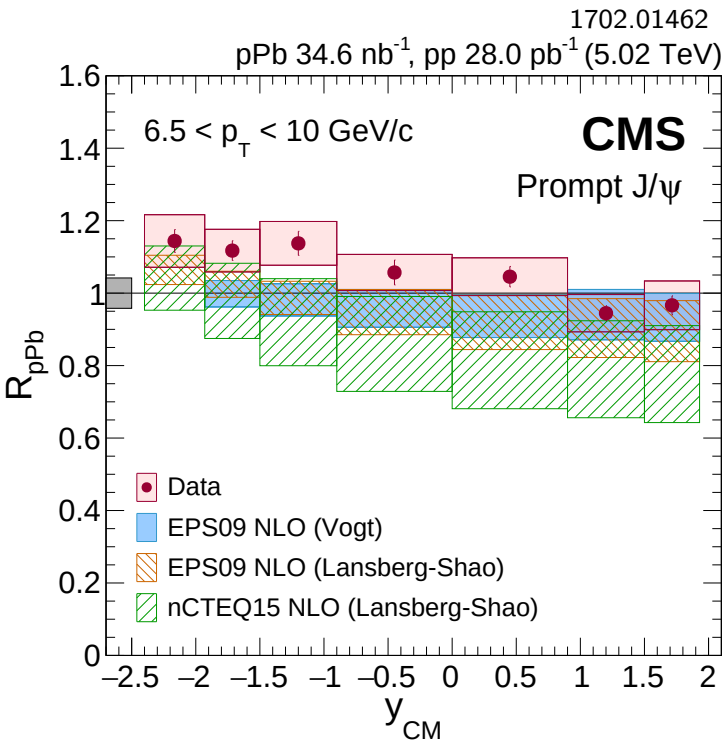
Dijets in pPb: pPb-pp difference



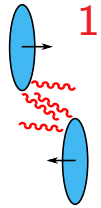
- None of DSSZ, EPS09 or nCTEQ15 describe the data
- Significant constraints on EPPS16

J/ψ production (NOT included in nPDF fits)





pPb: sizeable nPDF effects, but also E-loss, comovers, etc.



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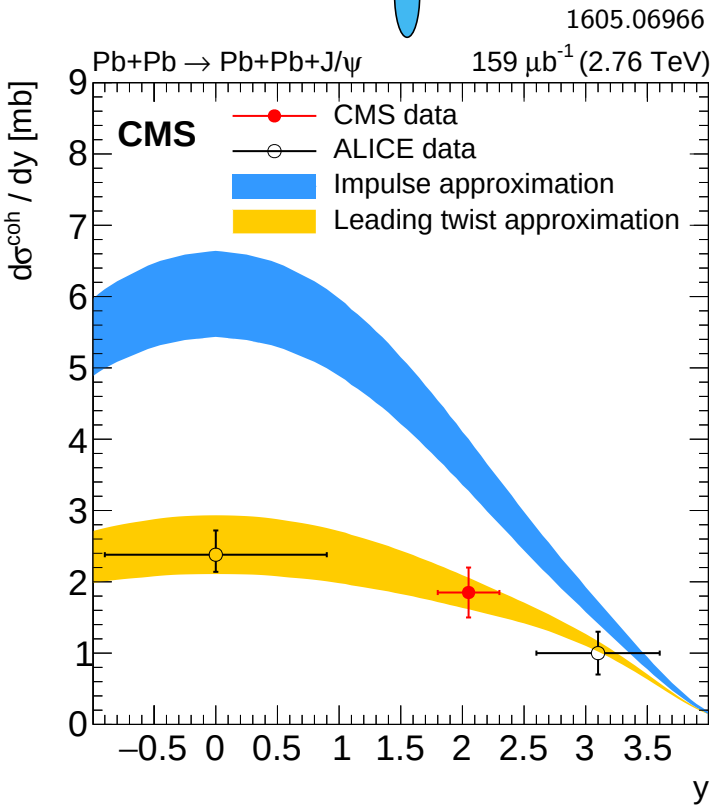
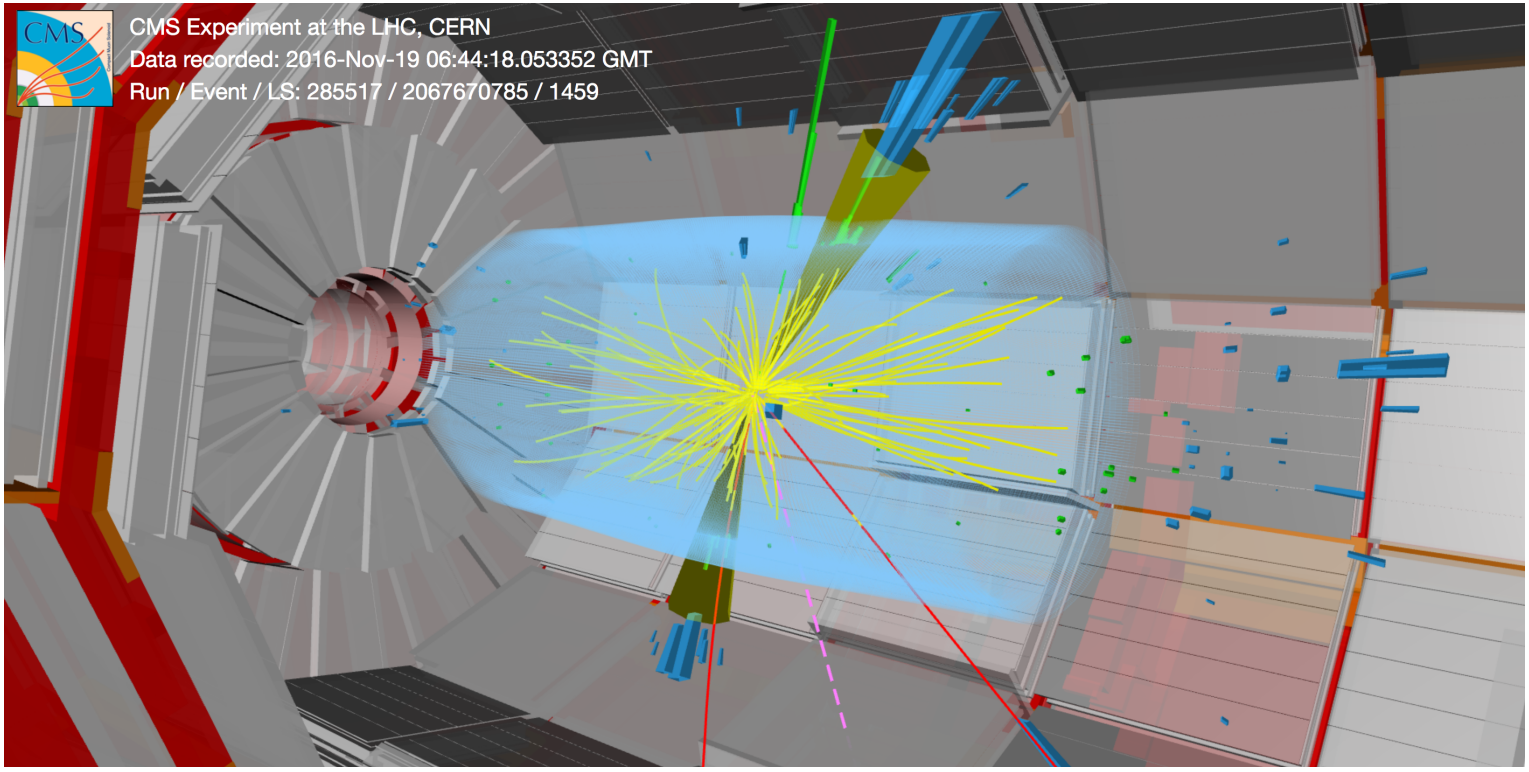


Ultra-peripheral PbPb ($\gamma A \to$ J/ψ): "shadowing"? Relation to NLO nPDF? (see also 1603.01919)

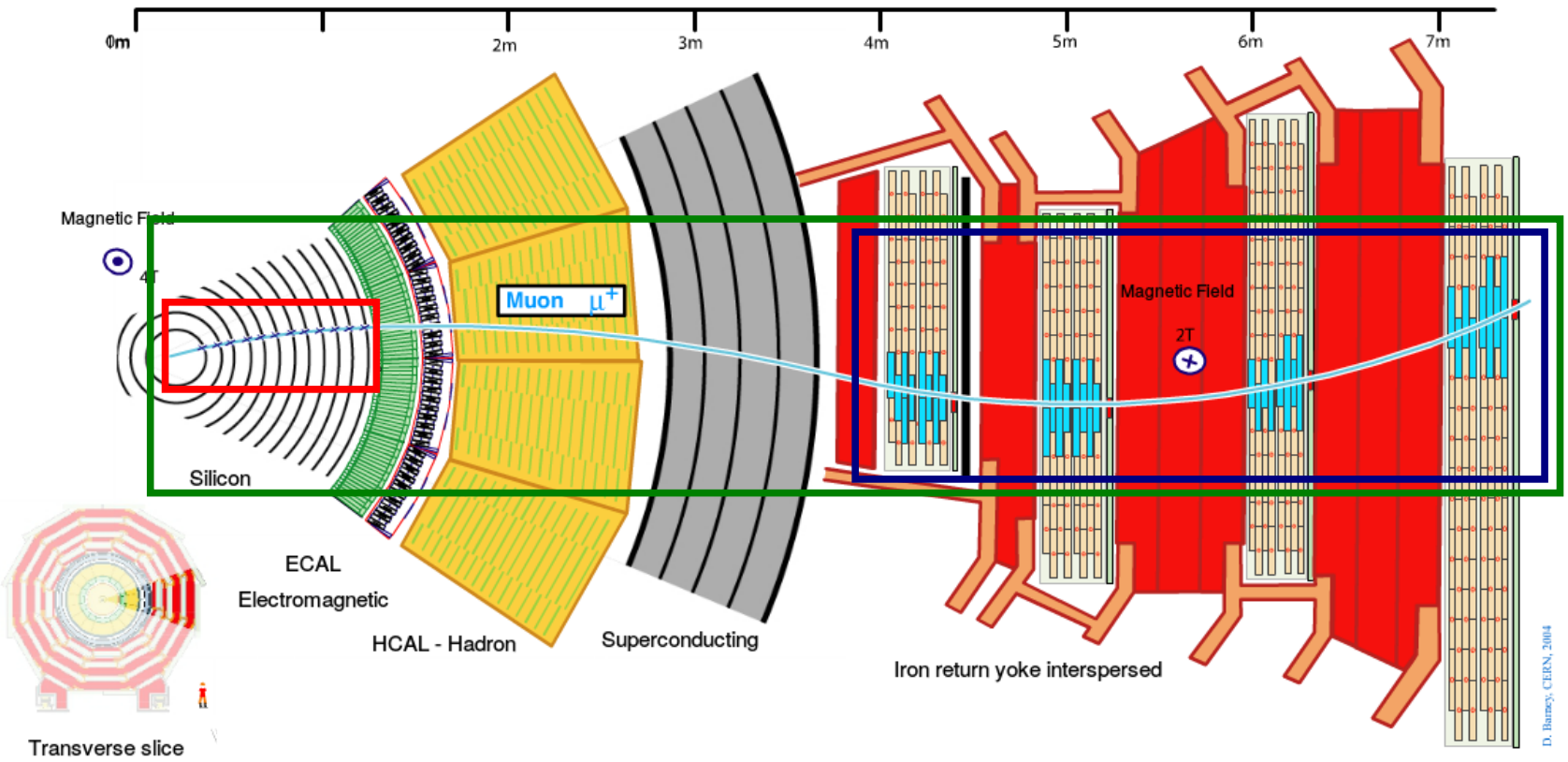
Summary

- nPDF are a crucial input to all heavy ion observables
- Probing uncharted (x, Q^2) territory at the LHC
- First constraints from Run-1 included in EPPS16
- $\sim 10\times$ more data from 2016 pPb $\rightarrow$ better precision, new processes
  - top quark, Drell-Yan, W/Z+X, etc.



Additional material

Electrons and muons in the CMS experiment



- *Muon reconstruction*: silicon tracker + muon sub-detectors
- *Electron reconstruction*: tracks associated with an ECAL cluster
- $\not{E}_T$ *reconstruction* thanks to the hermetic detector
  - using silicon tracks (PbPb) or particle flow (pPb)

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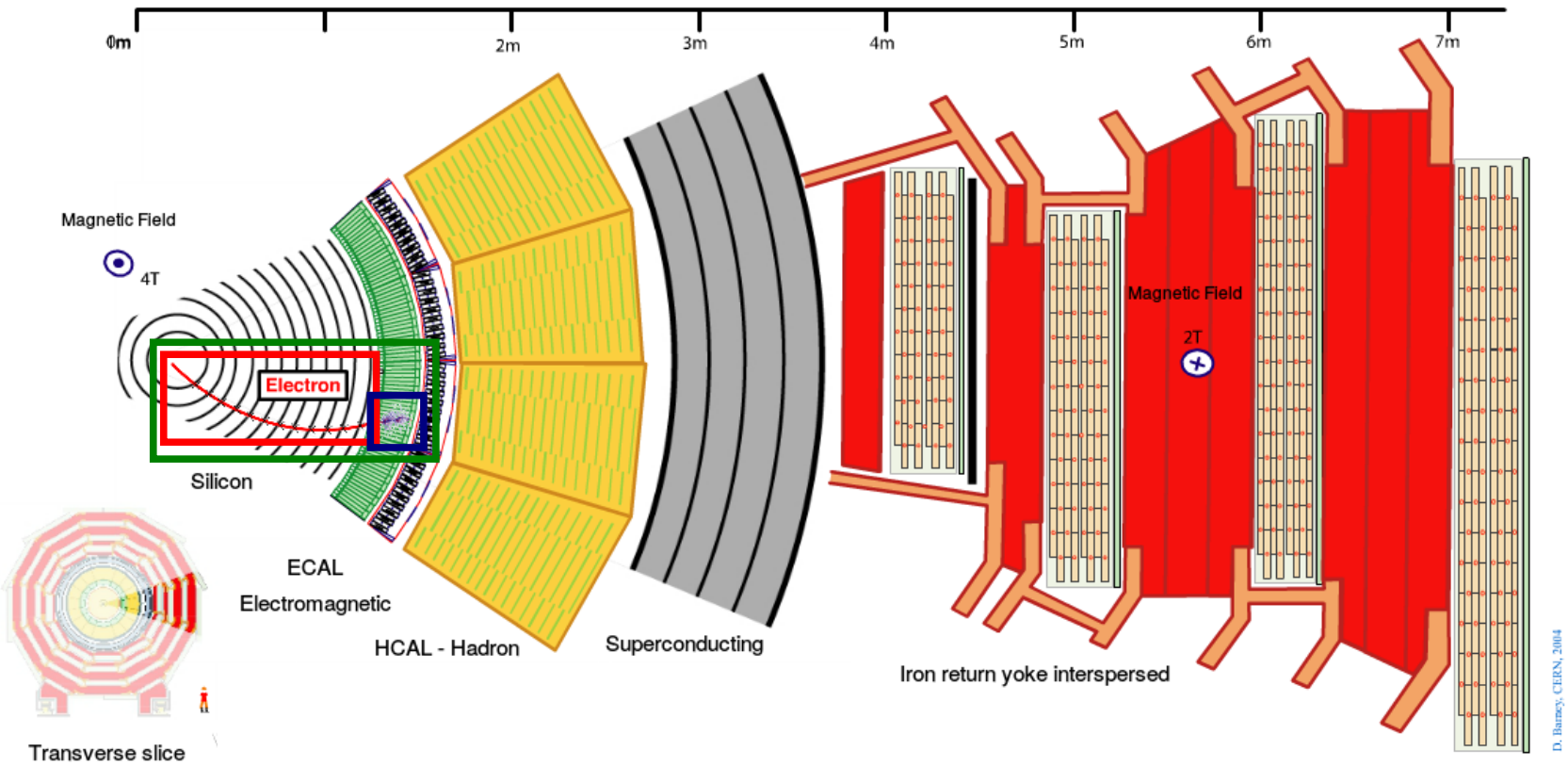

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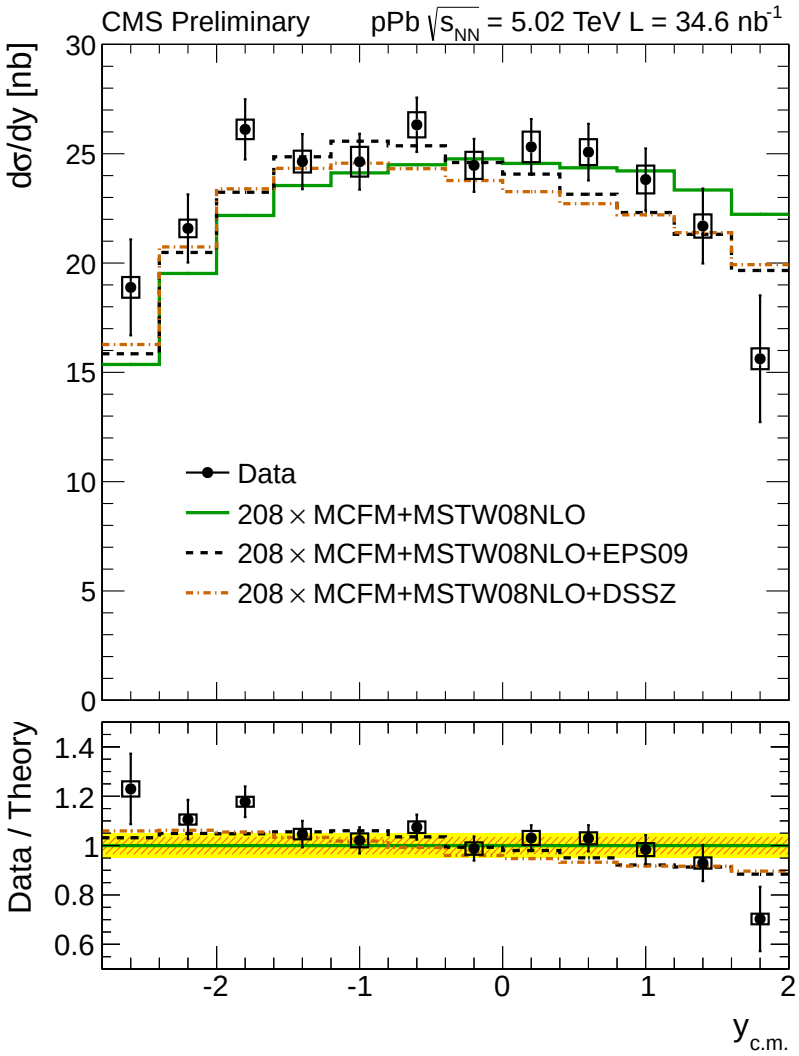
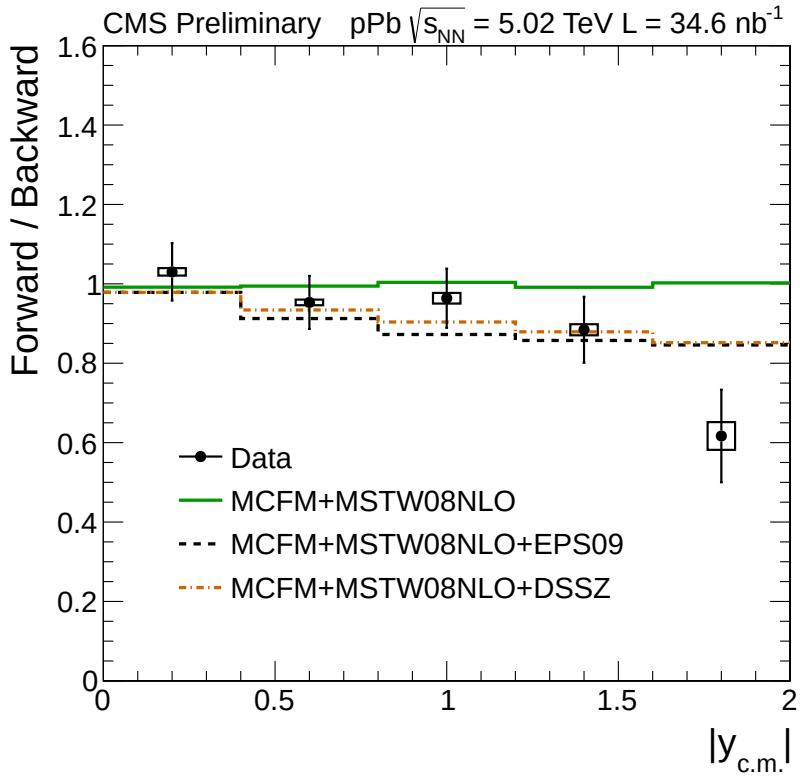
Z in pPb: acceptance-corrected resutls





Z boson: fiducial cross section vs. p_T

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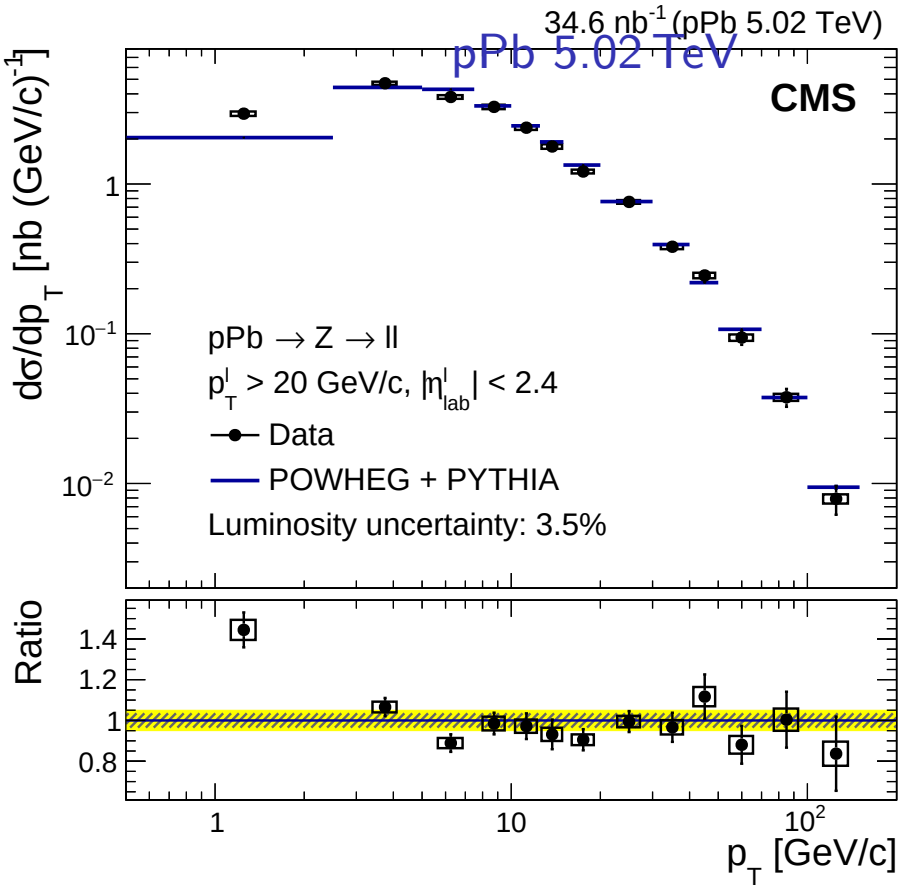

- Modification of the p_T spectrum from nPDF expected to be small

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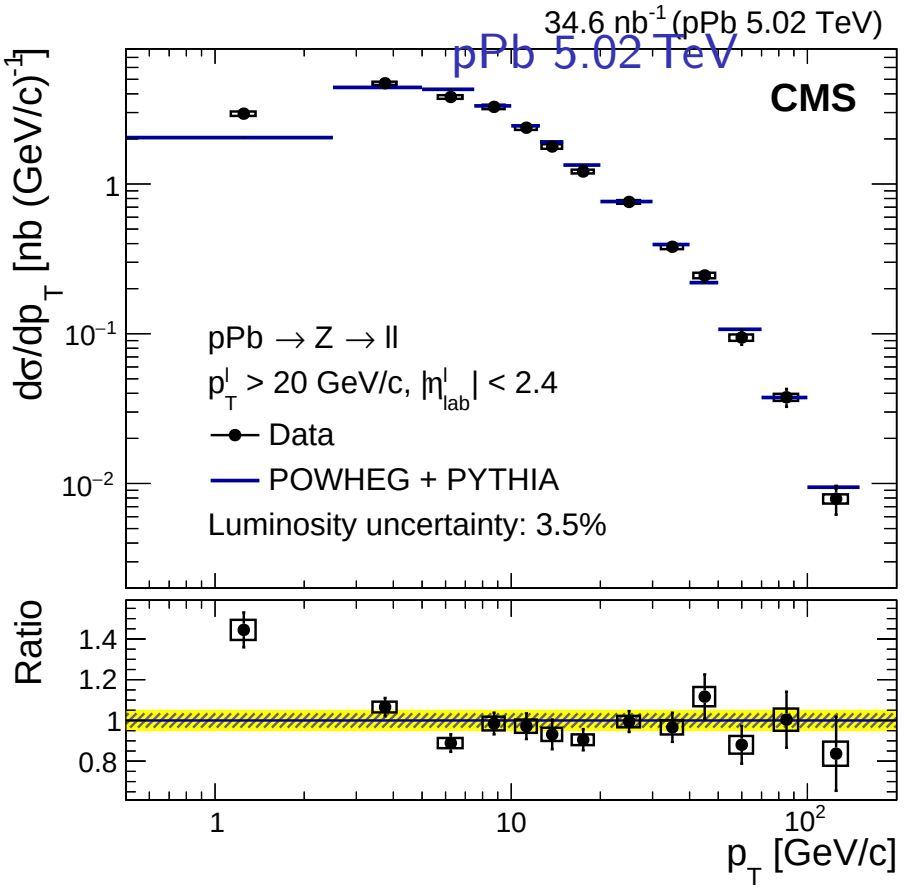
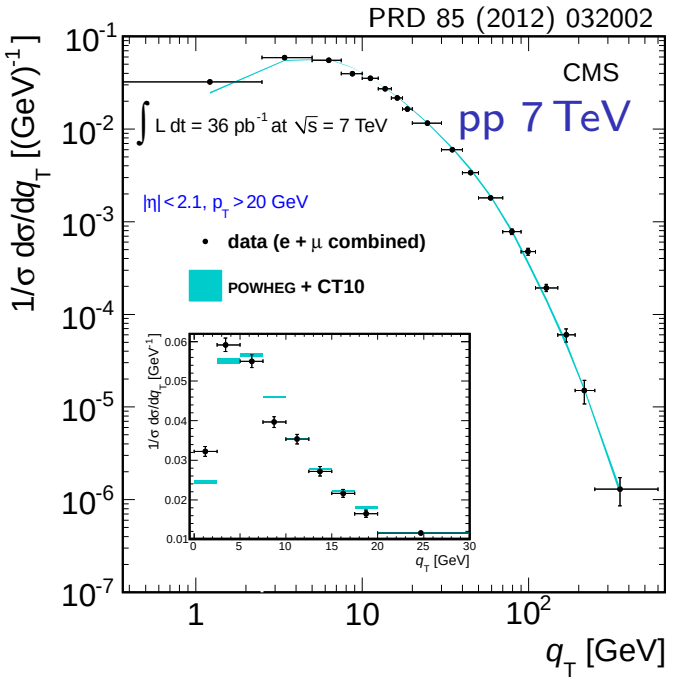


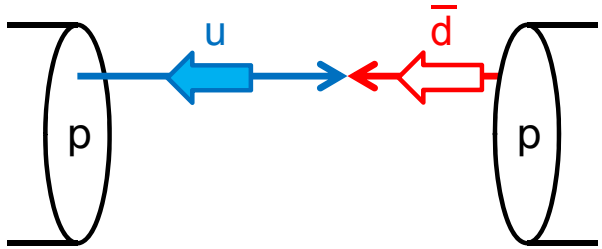
- Modification of the p_T spectrum from nPDF expected to be small
- Deviations at low p_T consistent with 7 TeV and 8 TeV pp results



W production

Leading order

$$u\bar{d} \to W^+, \quad d\bar{u} \to W^-$$



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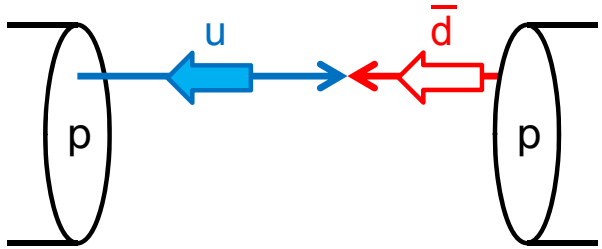
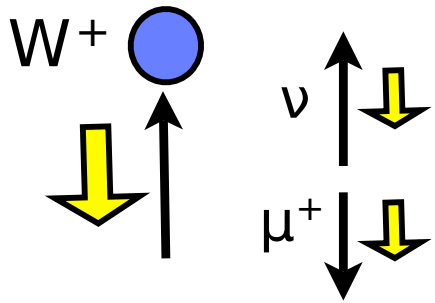


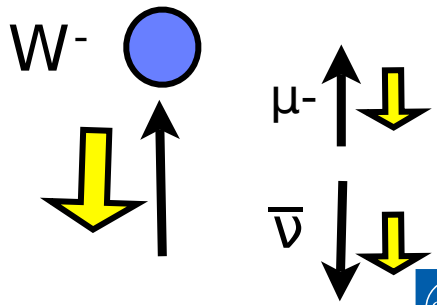
Yields

- Expect 2× more W^+ than W^- in pp.
- Expect more W^- than W^+ in PbPb.



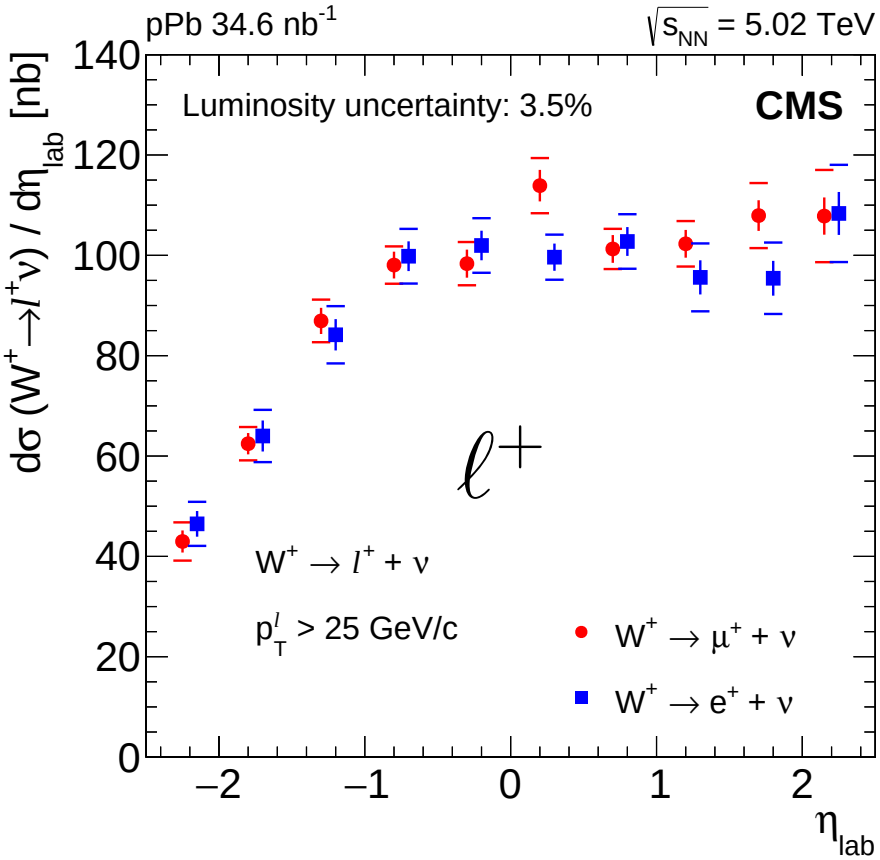
Rapidity

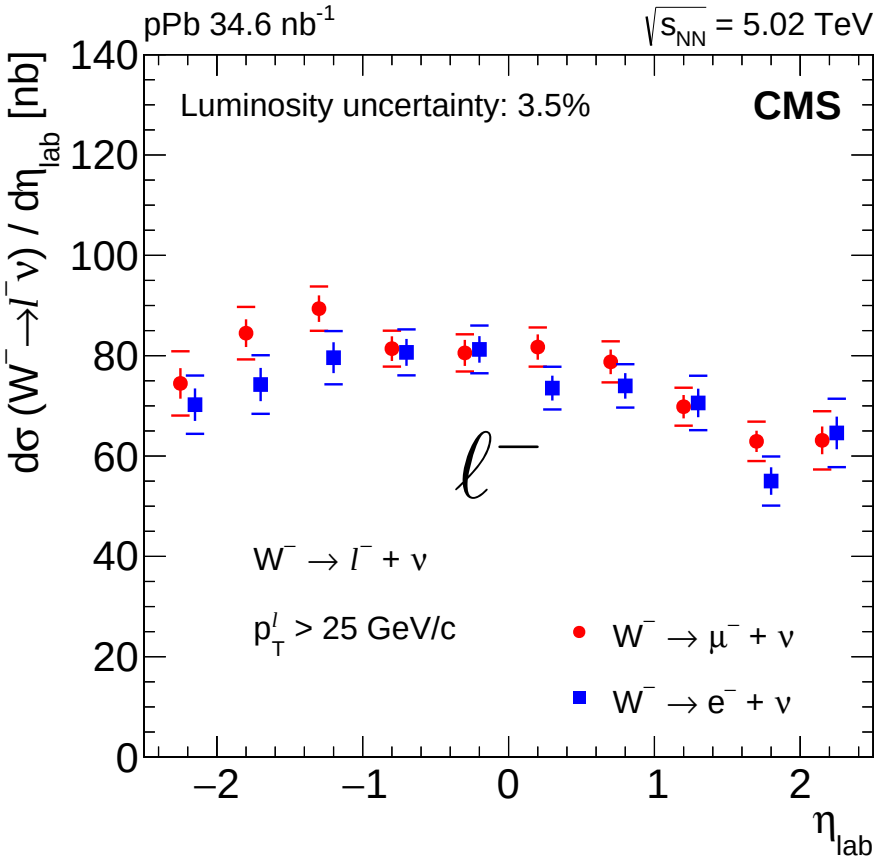
- W boosted towards the valence quark.
- Spin conservation + parity violation: μ^+ (μ^-) boosted back to (away from) midrapidity.
  - $\Rightarrow$ different rapidity distributions between μ^+ and μ^-.



W boson: cross section

PLB 750 (2015) 565





- Good agreement between the electron and muon channels
- Combine the two channels for a better precision

Charge asymmetry in pp