nPDF studies in pPb collisions at 8.16 TeV with the CMS detector

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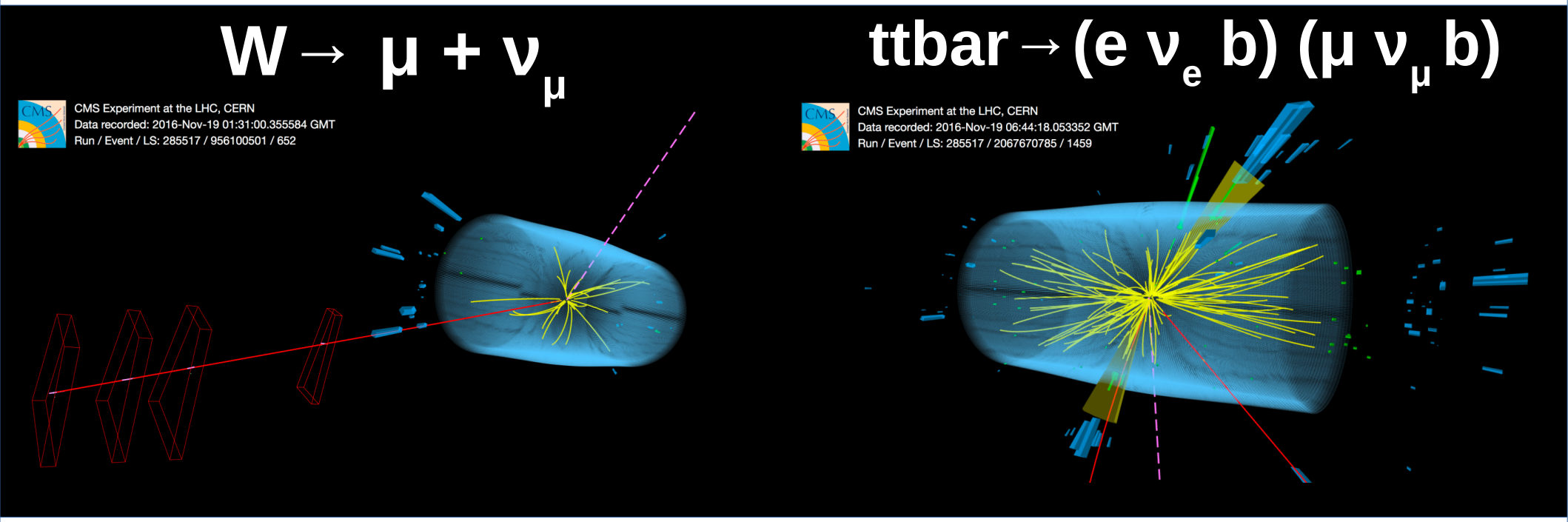
27th International Conference on Ultrarelativistic Nucleus-Nucleus Collisions

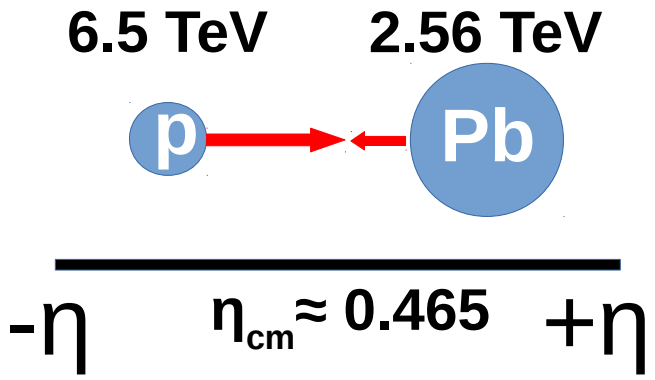
W bosons and top quarks in pPb

CMS-PHO-EVENTS-2016-009-26

CMS-PHO-EVENTS-2016-009-19



- Proton-lead asymmetric collisions
- Center-of-mass frame rapidity boost ≈ 0.465
- Define forward-backward ratios:
  - $R_{FB} = \frac{N(\eta_{CM}>0)}{N(\eta_{CM}<0)} = \frac{N(p-going)}{N(Pb-going)}$

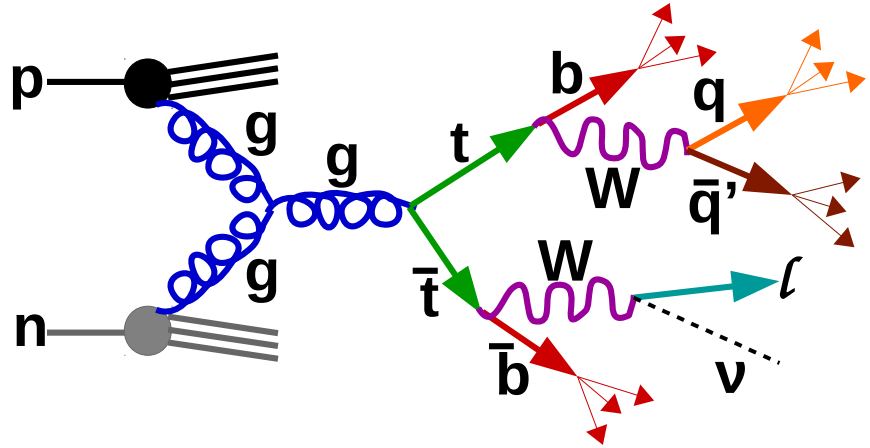


Top quarks in pPb collisions

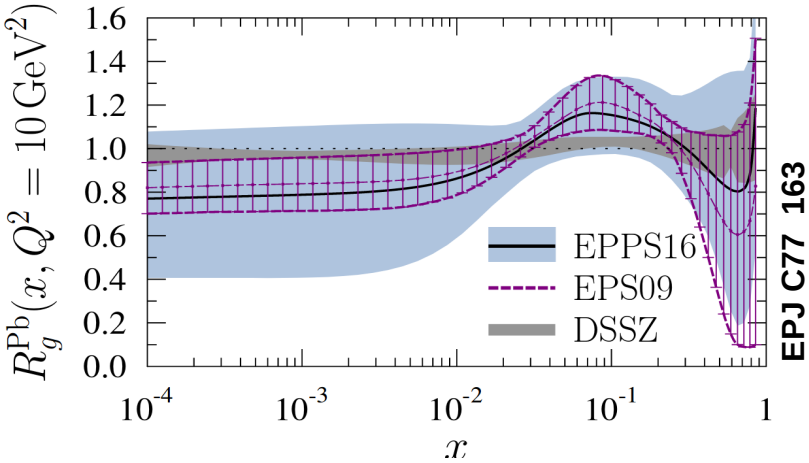
Dominant production modes:

gluon → ttbar

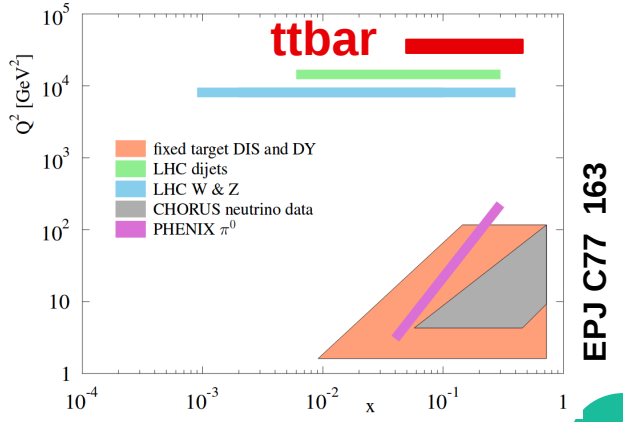
- Top quarks decay before interacting with the medium



- Measurement of top quark and dijet production probe modifications to gluon PDF



- Top quarks constrain the high x (**x>0.05**) and high Q ($\mathbf{Q^2 \sim m^2_{top}}$) region



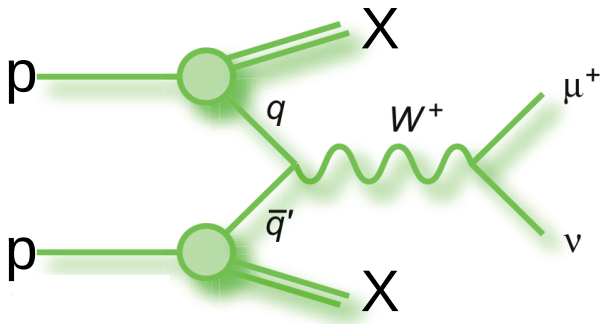
Poster, G. Krintiras on top quarks, INI-12

Talk, D. Tapia Takaki on dijets, Mon. 17:50

W bosons in pPb collisions

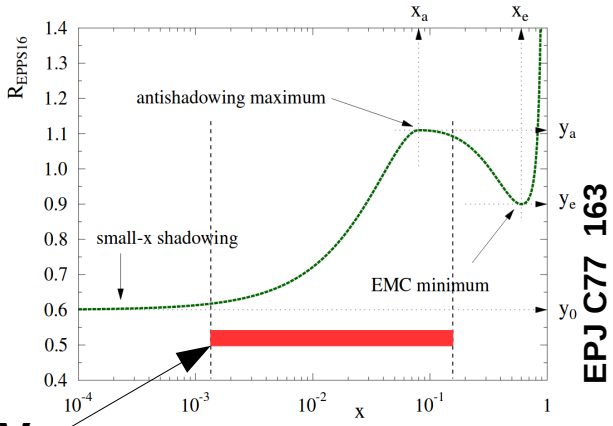
Dominant production modes:

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

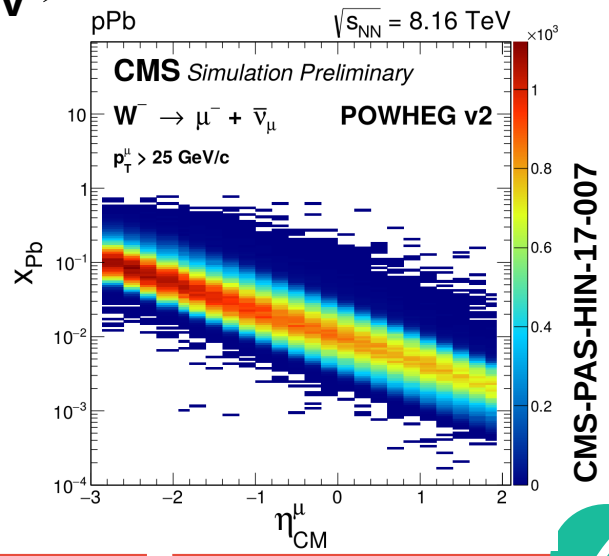


- Reflects interactions between **valence and sea quarks**

- Quarks behave differently inside bound nucleons compared to free-nucleons → **nuclear PDF effects.**



W in pPb @ 8.16 TeV

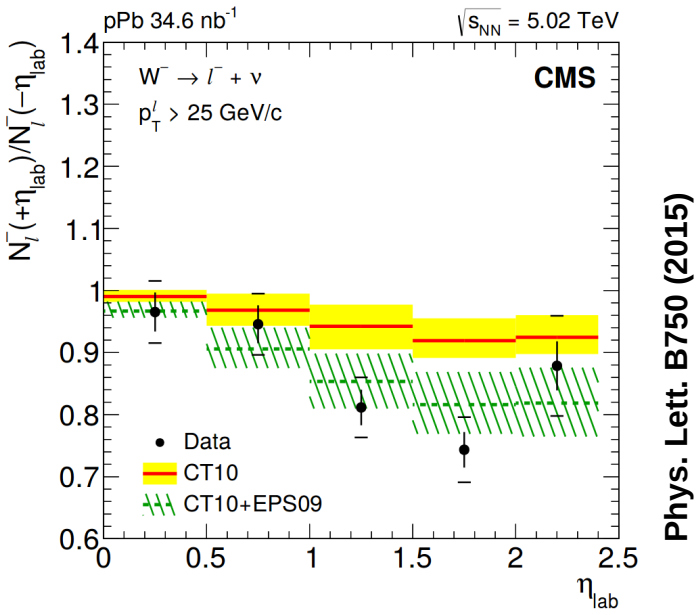


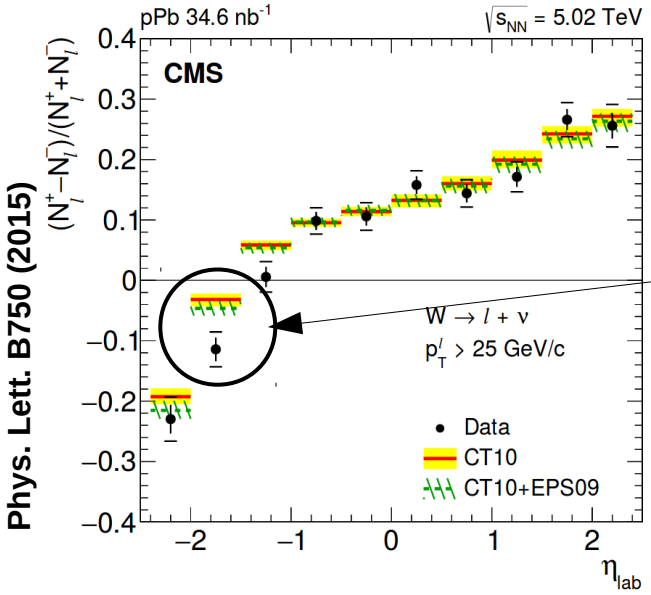
- W production in pPb @ LHC probe the quark nPDFs in $10^{-3} < x < 10^{-1}$ @ **high Q^2**

Poster, H. Kim on W boson, ELW-16

W bosons in pPb collisions

- Measurement of **W production @ 5.02 TeV** by CMS helped to improve nPDF sets (CMS data included in EPPS16) and provided a hint of nuclear modifications with poor significance



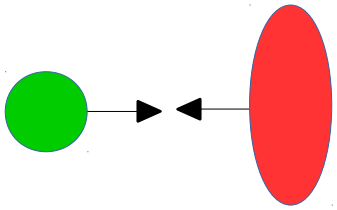


- **Small deviation** observed in **charge asymmetry @ backward region** : possible different modification of up and down quark PDF in the nucleus?

- **W boson** yield **increased** by **~10x** in **2016** data w.r.t. 2013, due to increase of **~2x** in **xsec** and **~5x** in **lumi**

Year	$\sqrt{s_{NN}}$	Luminosity (CMS)
2013	5.02 TeV	35 nb^{-1}
2016	8.16 TeV	174 nb^{-1}

Outline



- **Top quark production in pPb at 8.16 TeV**
  - Phys. Rev. Lett. 119 (2017), 242001

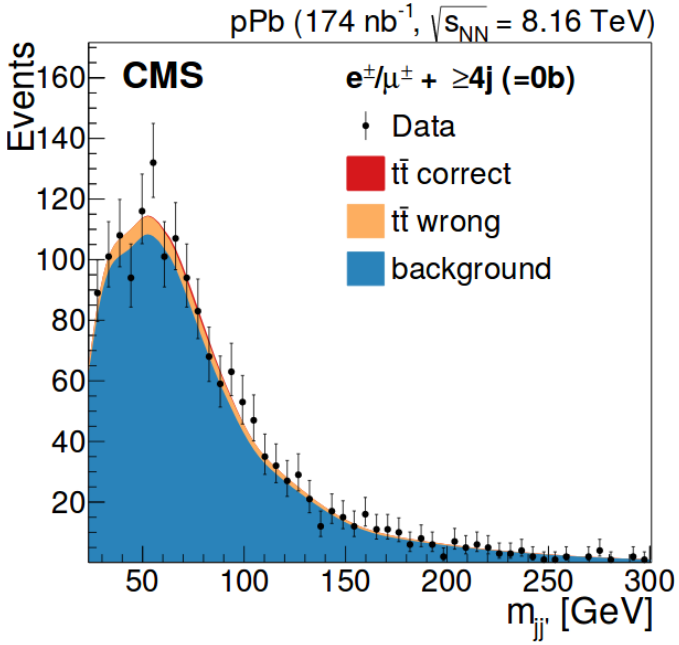
- **W boson production in pPb at 8.16 TeV**
  - CMS-PAS-HIN-17-007

Top quarks in pPb at 8.16 TeV

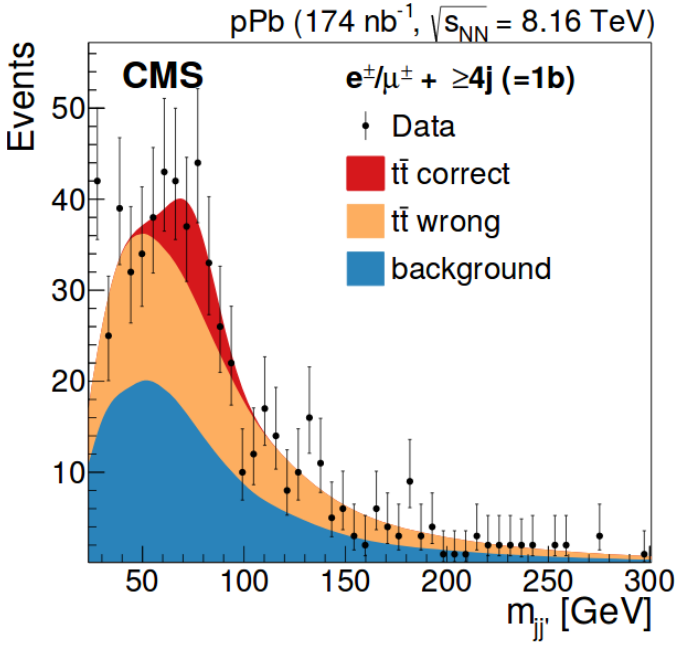
Top quarks in pPb

Phys. Rev. Lett. 119 (2017), 242001

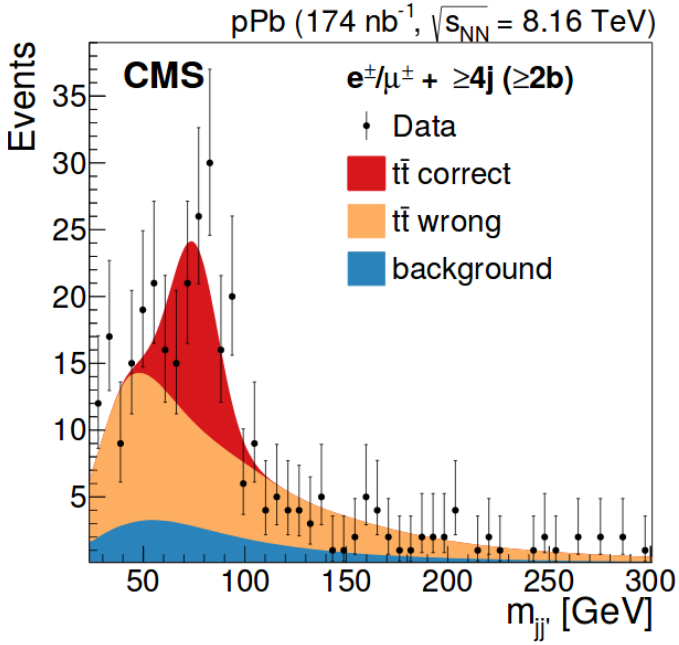
0 b-tagged jets



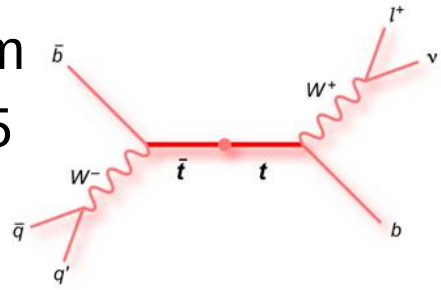
1 b-tagged jet



>=2 b-tagged jets

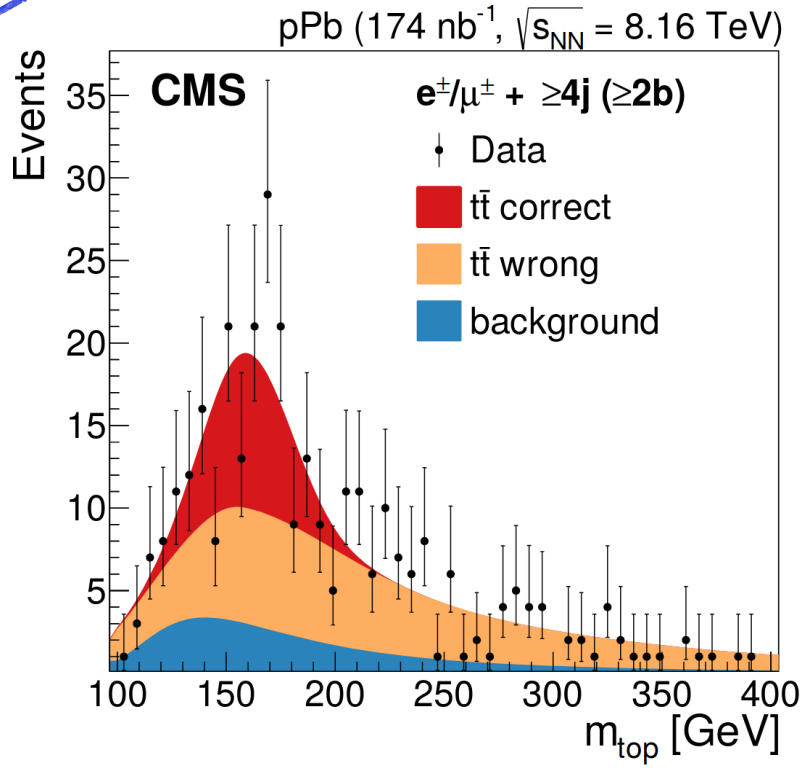


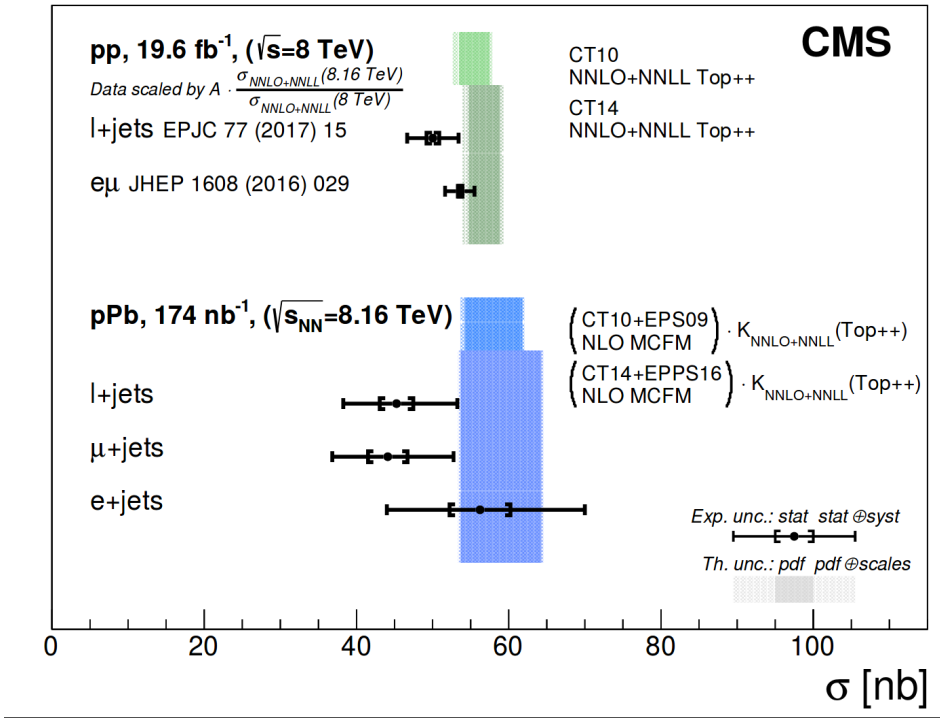
- **Decay channel:** >=4 jets + lepton (μ or e) + missing momentum
- **Jet Selection:** Anti-k_T (ΔR=0.4) jet with p_T > 25 GeV/c & $|\eta|$<2.5
- **B-quark tagger:** Based on combined secondary vertex
- **Lepton Selection:** Isolated lepton with p_T > 30 GeV/c & $|\eta|$<2.1
- **Extraction:** Fits of the **W→jj'** mass using functional forms in different b-jet and lepton flavor categories, **without relying on simulation**



Top quarks: cross section

Phys. Rev. Lett. 119 (2017), 242001



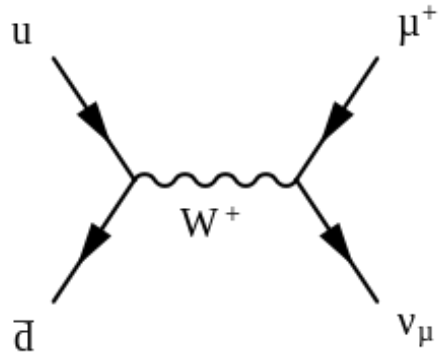


- **First observation** (**>5σ**) of **top quark** production in **pPb** collisions!
- Inclusive cross section (45±8 nb) in agreement with NNLO+NNLL pQCD interfaced to NLO proton/nuclear PDF calculations

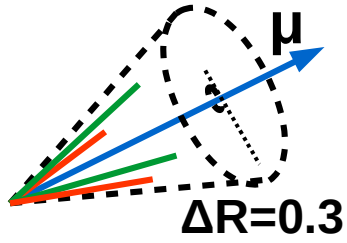
W bosons in pPb at 8.16 TeV

W bosons in pPb

CMS-PAS-HIN-17-007



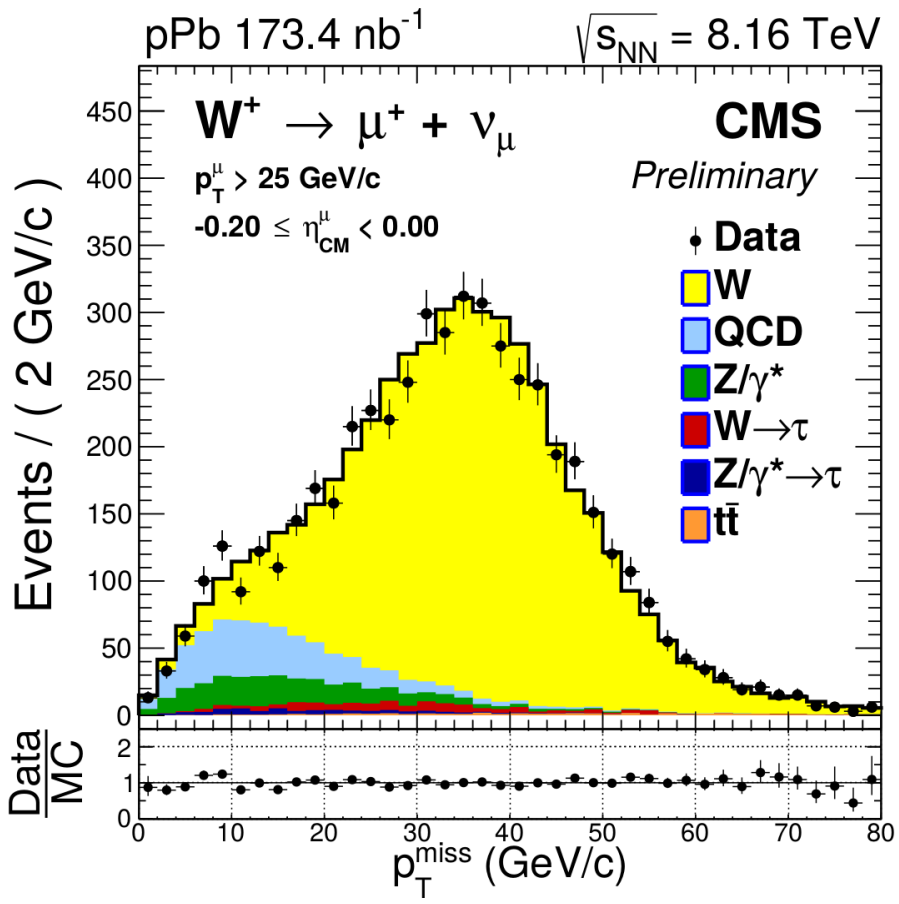
- **Decay channel:** muon + missing momentum
- Objects reconstructed with the **Particle Flow (PF) algorithm**
- **Muon selection:** Leading isolated muon with p_T > 25 GeV/c and $|\eta|$<2.4
- **Muon isolation:** Sum of p_T of PF particles (γ , $h^{\pm}$ & h^0) around the muon < 15% of muon p_T (**suppress multi-jet bkg**)



- **Event selection:**
  - **Veto Z→μ⁻ μ⁺ :** Reject events with μ^- μ^+ pairs, $p^{\mu^-}_T$ > 15 & $p^{\mu^+}_T$ > 15 GeV/c
- **Dominant backgrounds:** QCD jet→muon passing isolation, and Z→muon + (missing muon)

W bosons in pPb

CMS-PAS-HIN-17-007



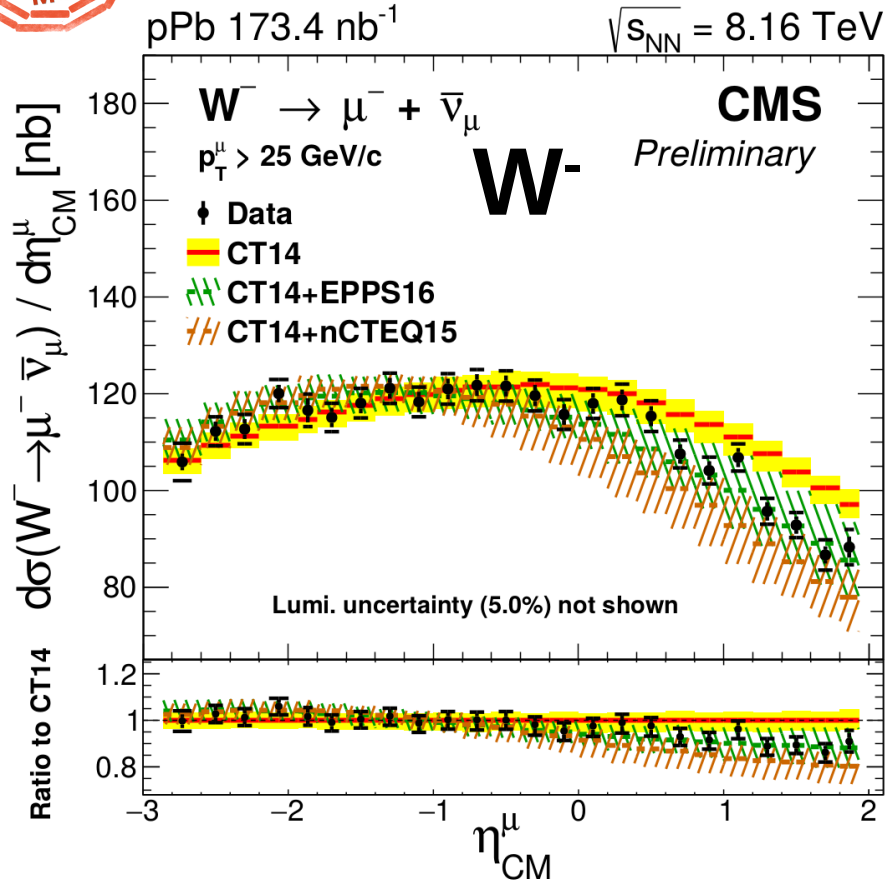
- **Simulation:** pPb NLO POWHEG v2 including CT14+EPPS16 nPDF
- **Signal and electroweak background:** Template from **simulation**
- **QCD multi-jet background:** **Data-driven** functional form
- **Extraction:** Fits of the **missing p_T** distribution in 24 bins of muon η_{CM}

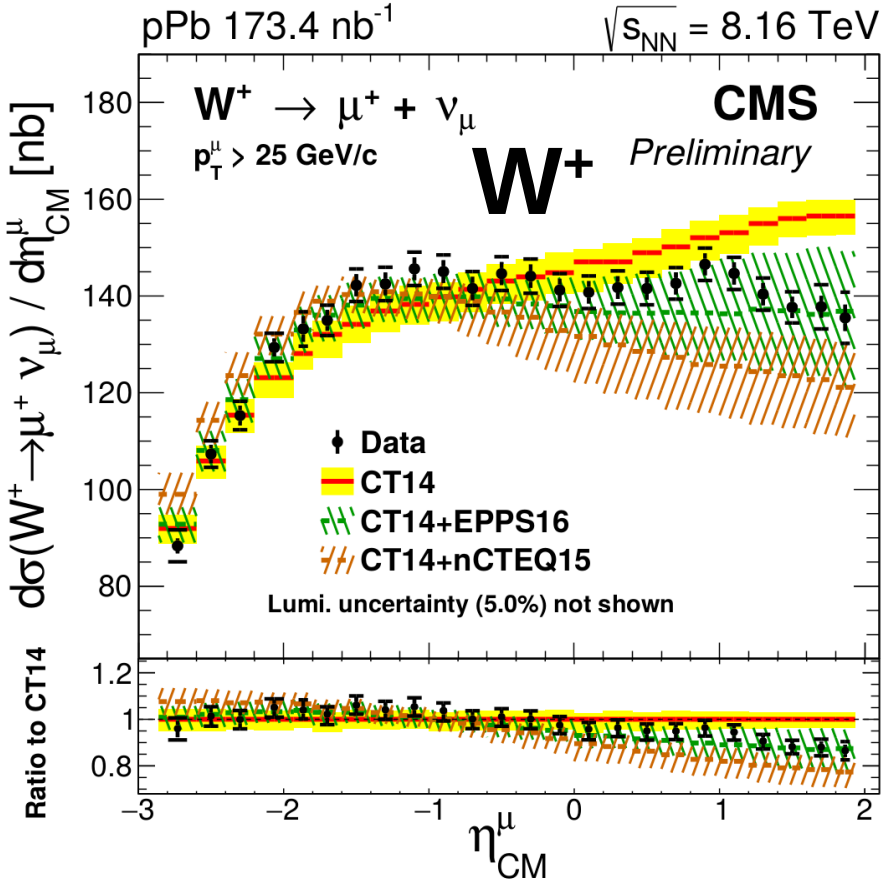
W boson: cross section

CMS NEW RESULT QM18

CMS-PAS-HIN-17-007

$P(\chi^2) =$ <0.01% CT14 , 79% nCTEQ15 , 96% EPPS16





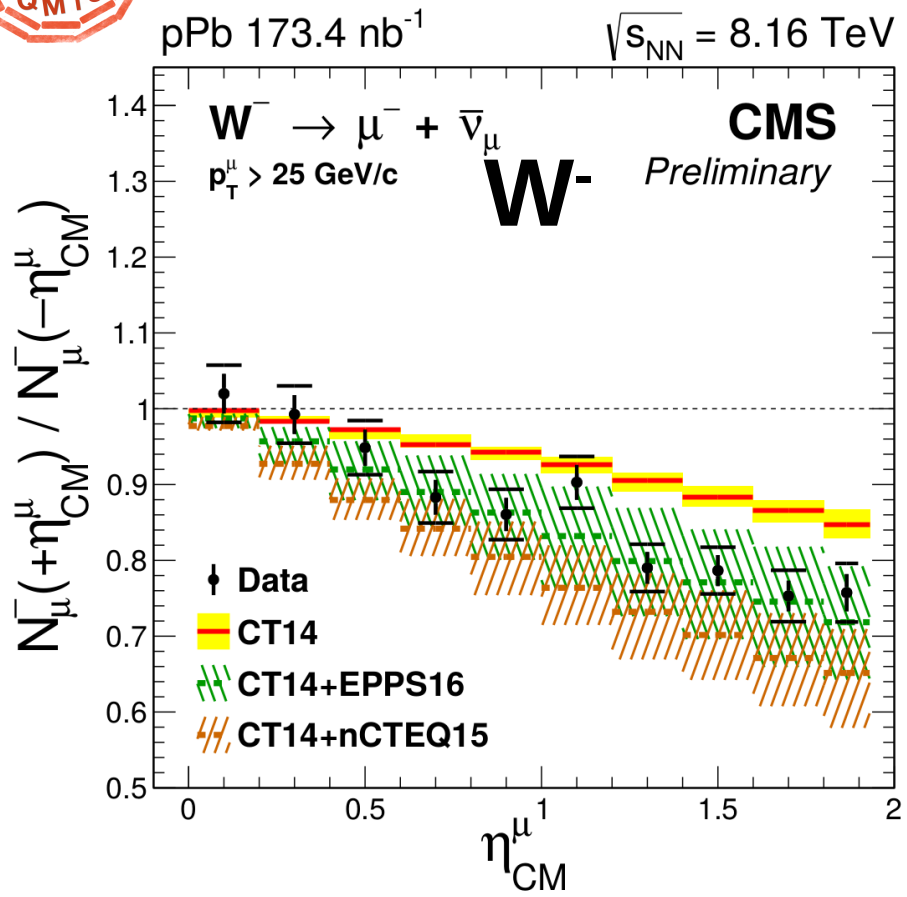
- $\eta_{CM} < 0$ **(large** x_{Pb}**)**: Results **agree** with **PDF** and **nPDF** calculations
- $\eta_{CM} > 0$ **(small** x_{Pb}**)**: Results **favor** the **nuclear PDF** calculations

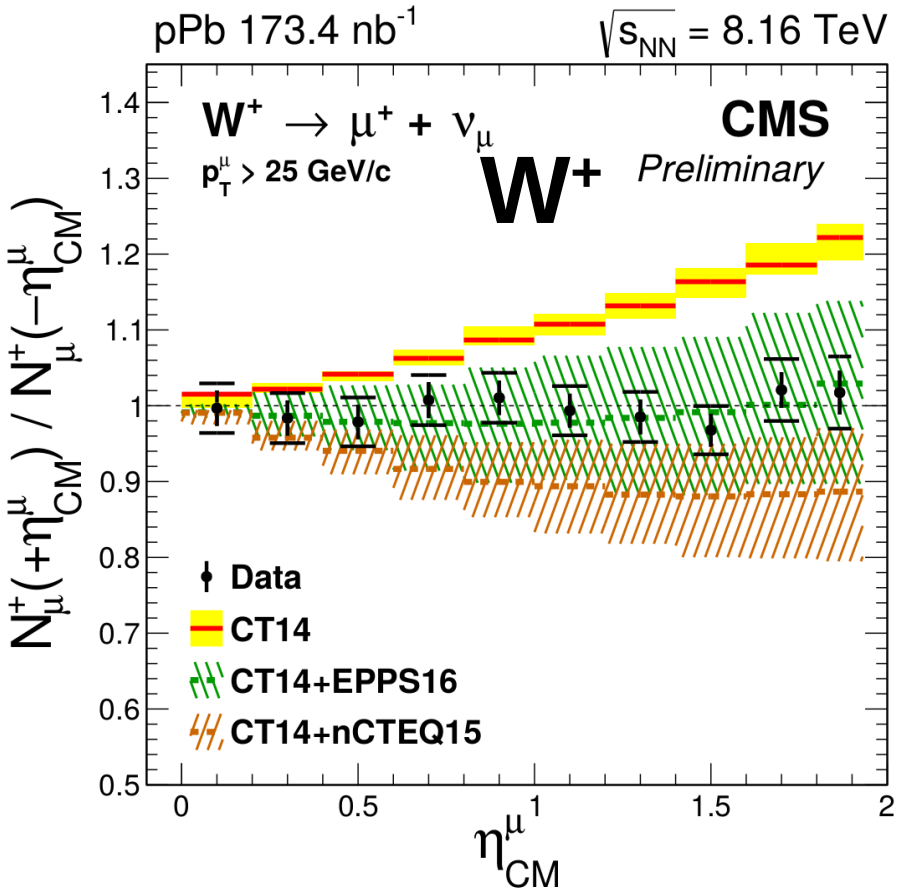
W boson: forward-backward ratio

CMS NEW RESULT QM18

CMS-PAS-HIN-17-007

$P(\chi^2)$ = <0.01% CT14 , 83% nCTEQ15 , 95% EPPS16





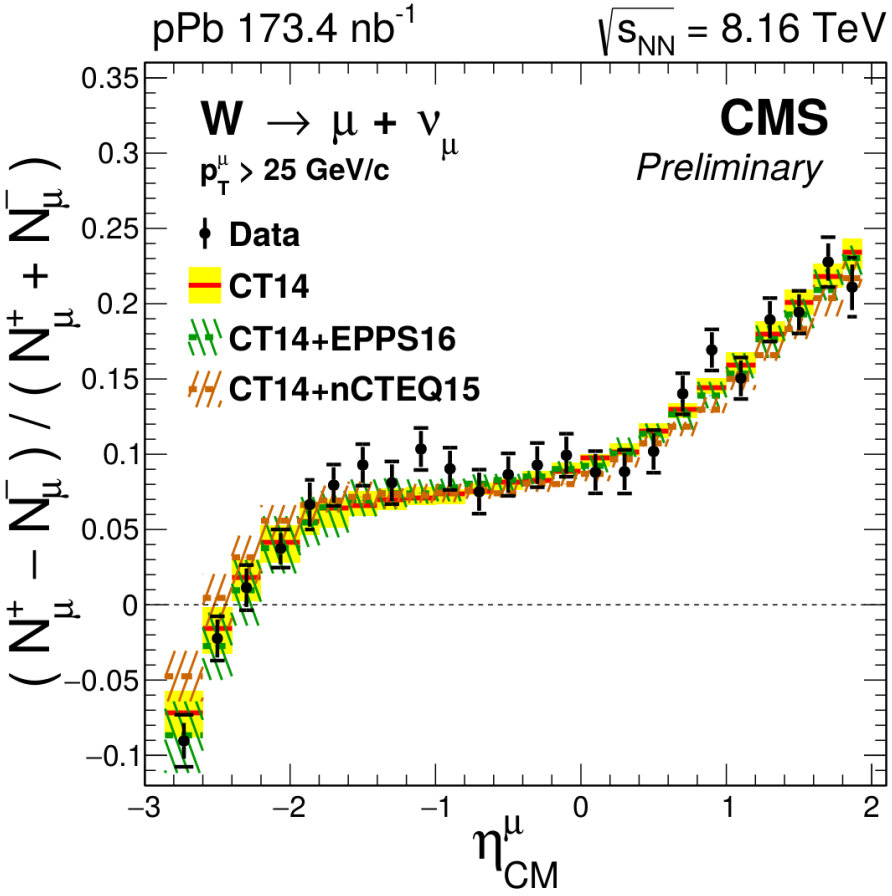
- Uncertainties fully correlated in η_{CM} cancels (correlations included)
- **Exclude** (**>7σ**) **free-nucleon PDF** calculations
- Experimental uncertainties smaller than nPDF uncertainties

W boson: charge asymmetry

CMS NEW RESULT QM18

CMS-PAS-HIN-17-007

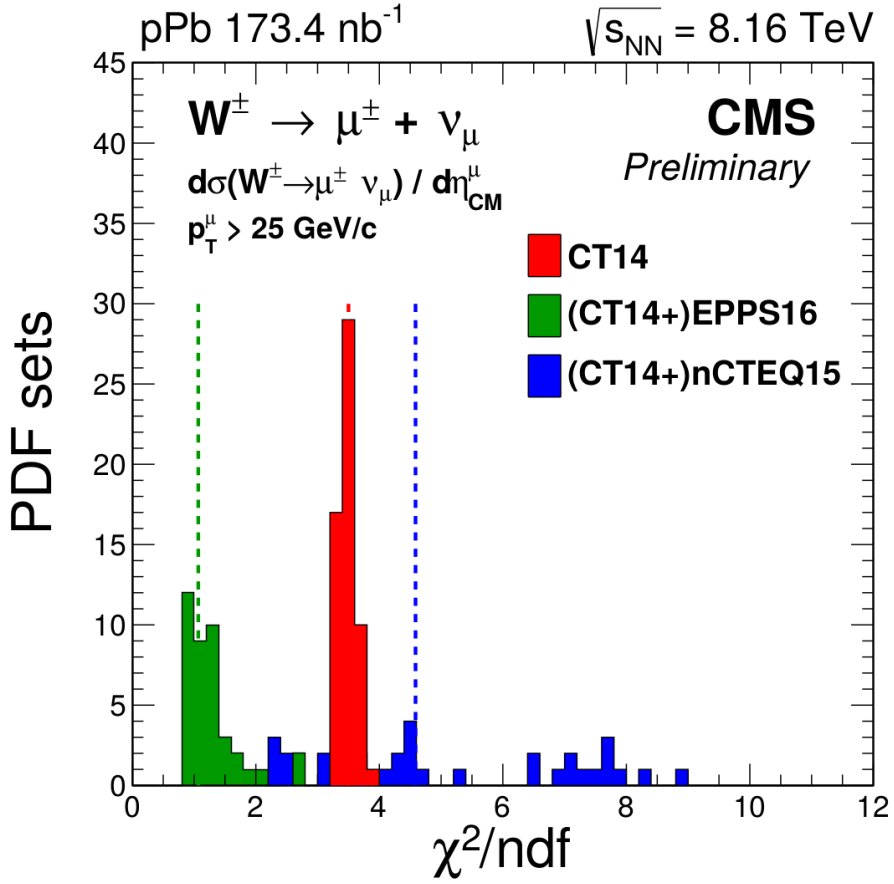
$P(\chi^2)$ = **54% CT14** , **23% nCTEQ15** , **80% EPPS16**



- nPDF effects cancel, except for different up / down quark modification
- **All (n)PDF** calculations **reproduce** the **measurements**

W boson: PDF comparison

CMS-PAS-HIN-17-007

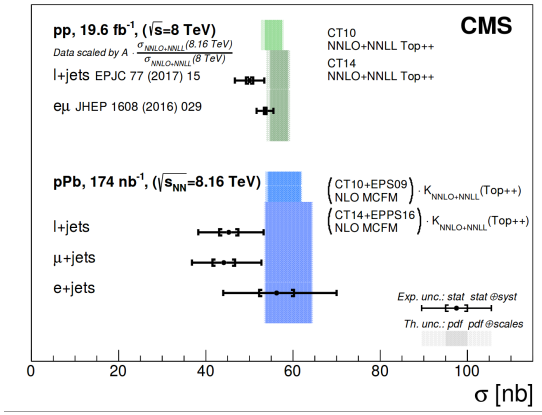


- Compute χ^2 test between the measurements and each individual PDF set
- Good agreement between data and EPPS16 nPDF

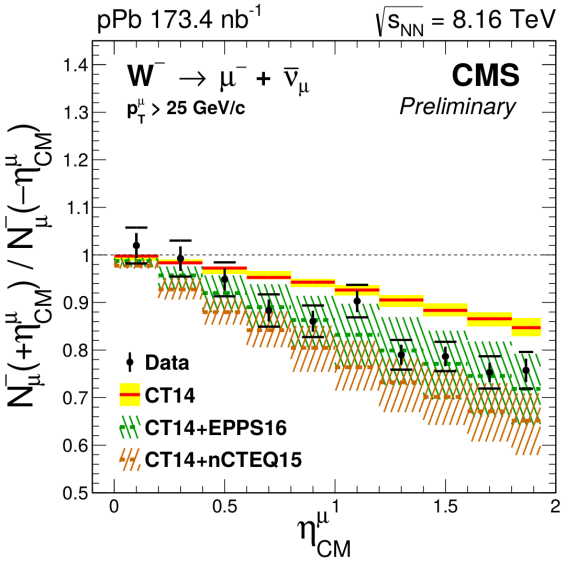
Summary

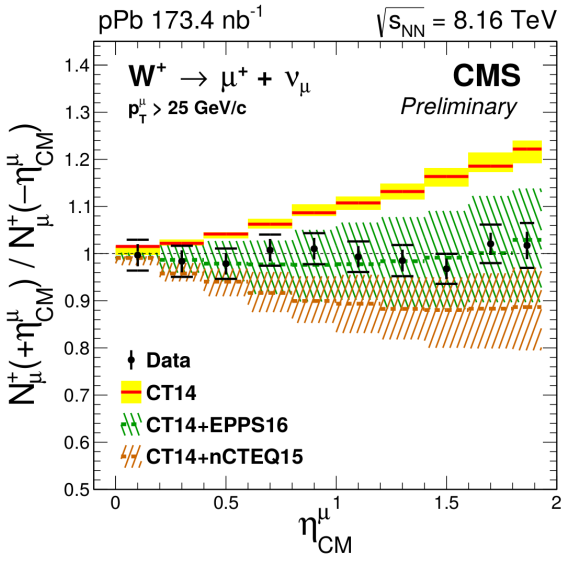
Probing gluon nPDF:

- **First observation** of **top quark** production in **pPb** . Opens a new window of opportunities



Probing quark nPDF:



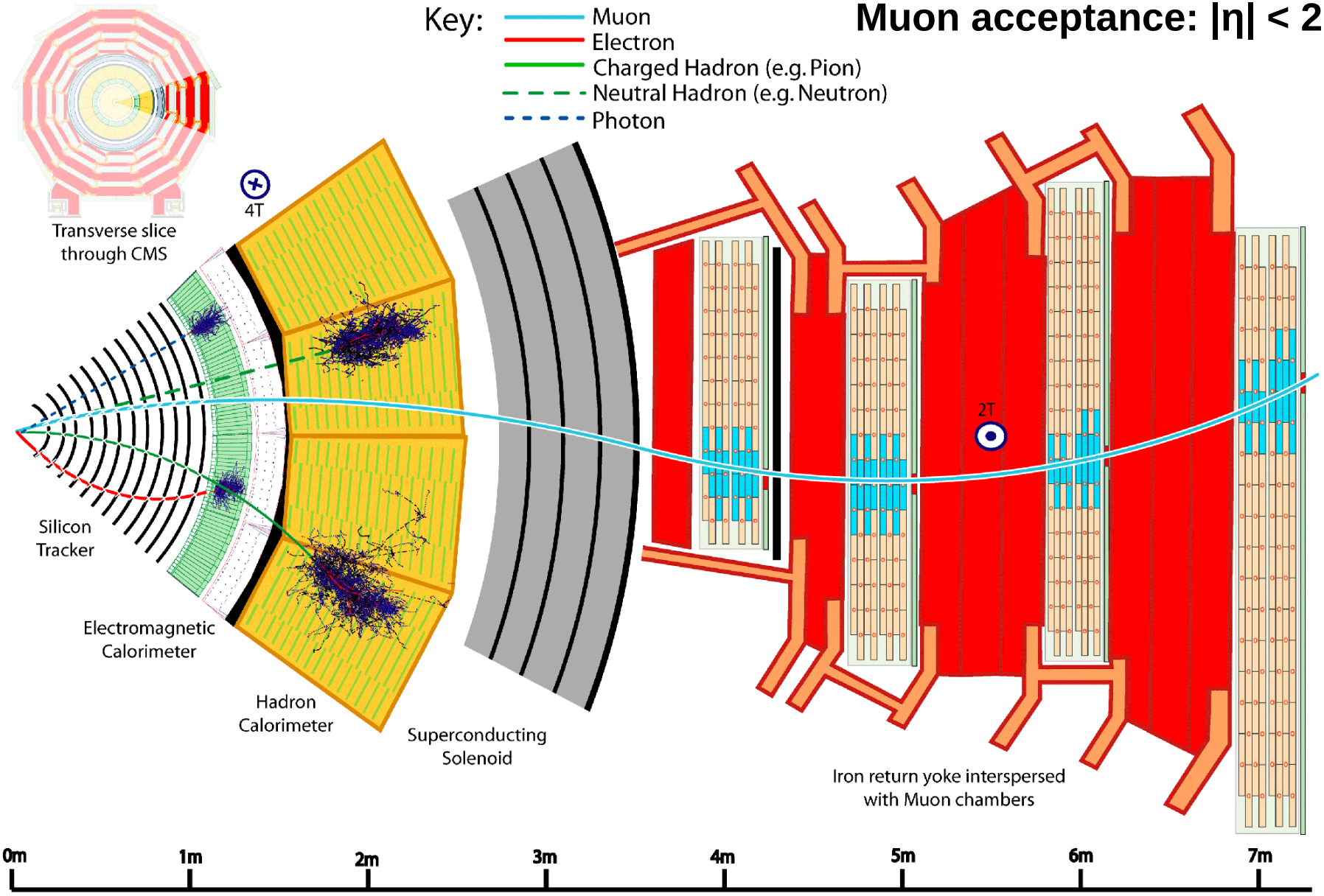


- **Observation** of **nuclear modifications** of the **(anti) quark** PDFs
- **Experimental uncertainties smaller** than nPDF uncertainties
- Good agreement with EPPS16 nPDF calculations

Thank you for your attention!

BACKUP

CMS detector

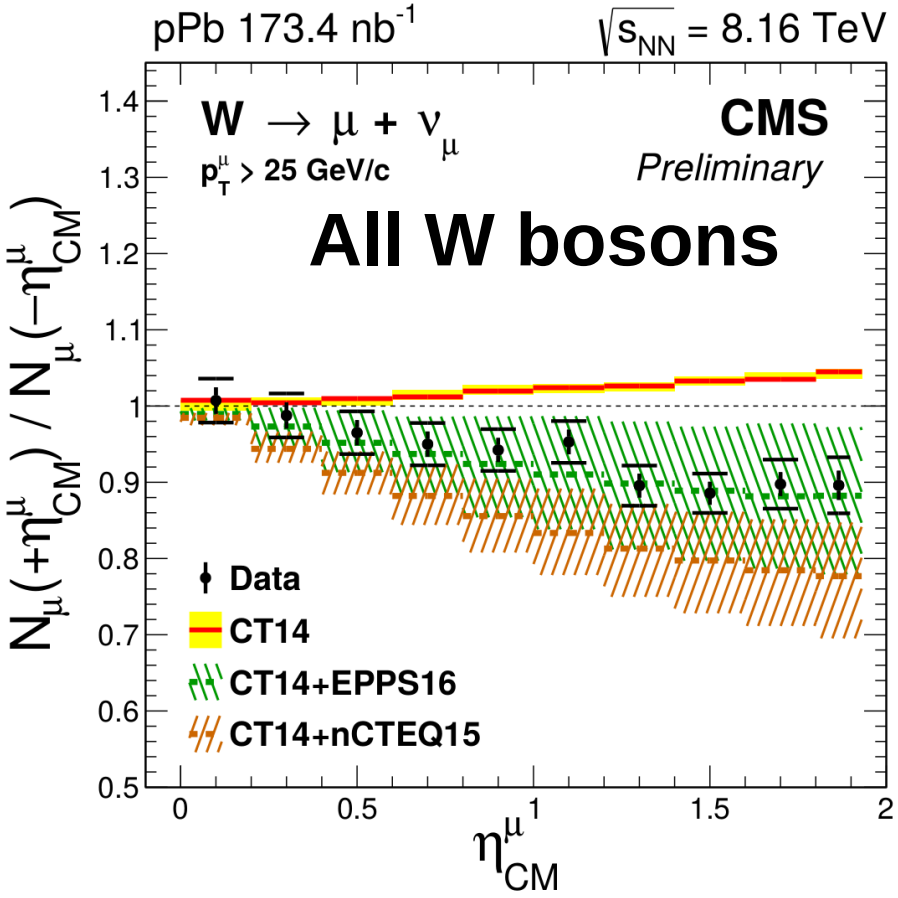


W boson: forward-backward ratio

CMS NEW RESULT QM18

CMS-PAS-HIN-17-007

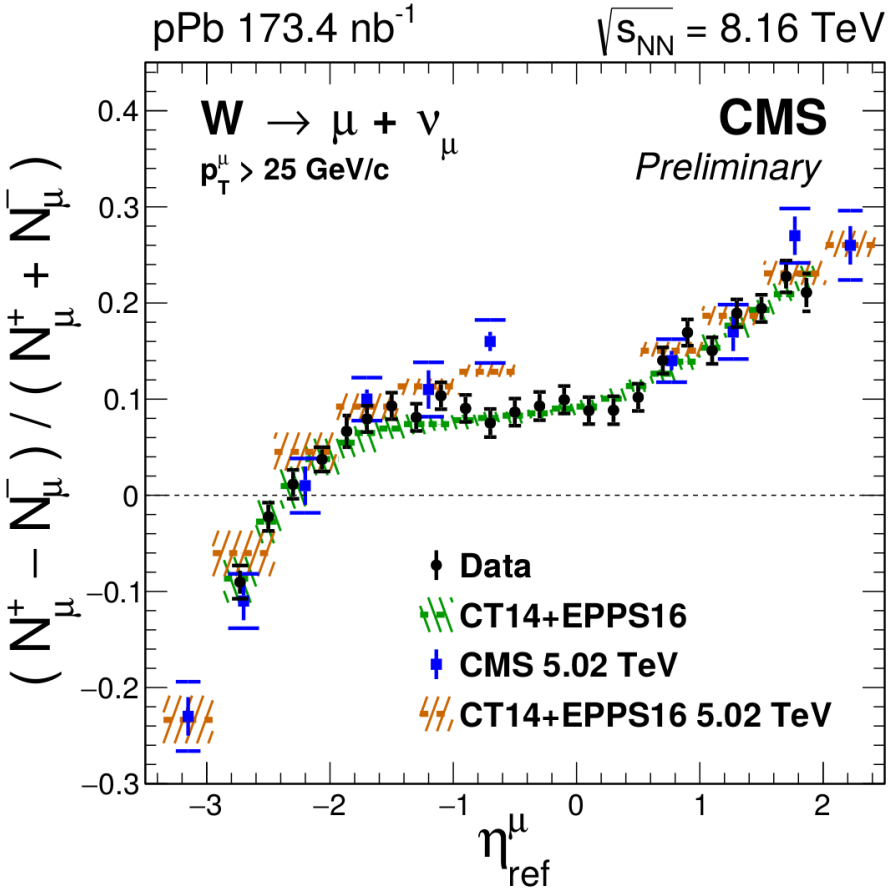
$P(\chi^2)$ = <0.01% CT14 , 90% nCTEQ15 , 99% EPPS16



- **Strongly deviate from CT14** calculations **favoring EPPS16**
- Experimental uncertainties significantly smaller than nPDF uncertainties

W boson: charge asymmetry

CMS-PAS-HIN-17-007

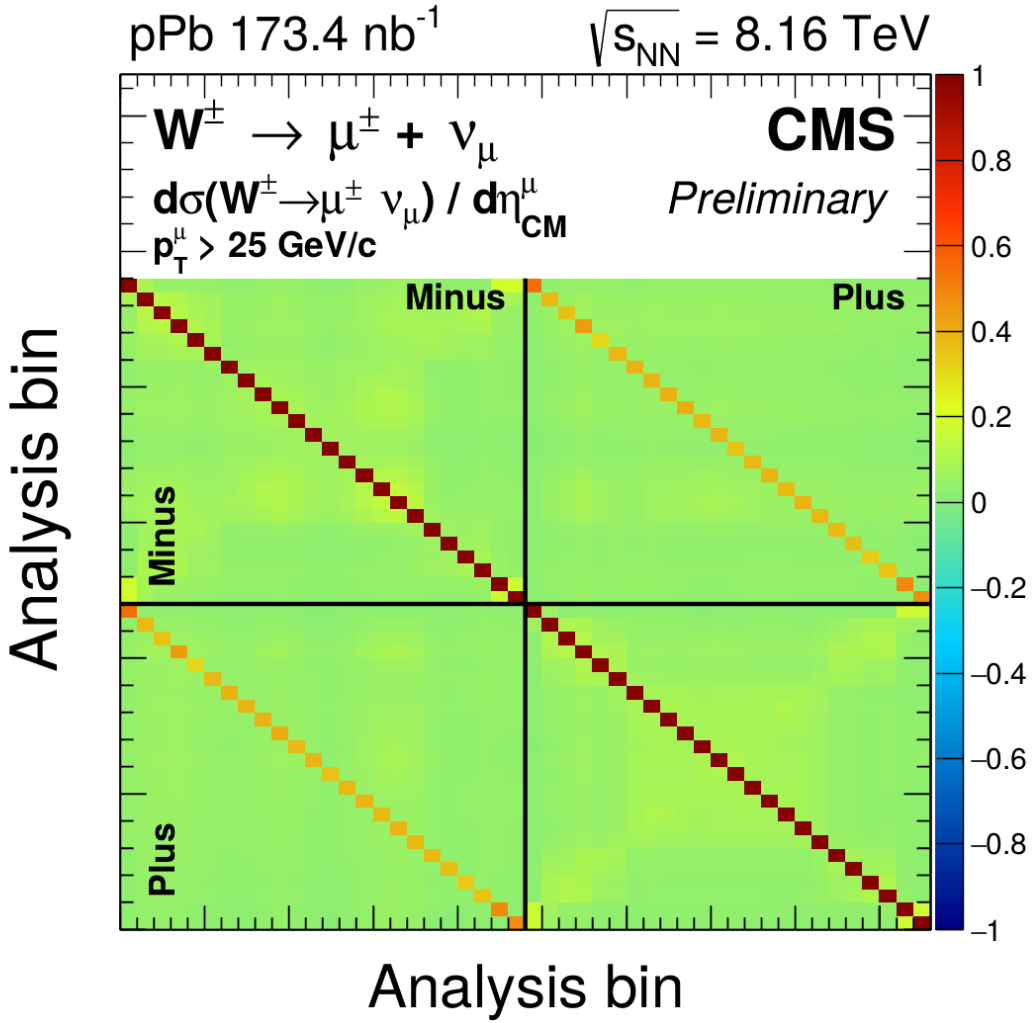


$$\eta^{\mu}_{\mathrm{ref}} = \eta^{\mu}_{\mathrm{CM}} \pm \ln\left(\frac{8.16\ \mathrm{TeV}}{\sqrt{s_{\mathrm{NN}}}}\right), \eta^{\mu}_{\mathrm{CM}} \gtrless 0$$

- Good agreement between measurement at 8.16 TeV and 5.02 TeV after shifting the η_{CM} taking into account the difference in energy

W boson: correlation matrix

CMS-PAS-HIN-17-007



- W boson cross section measurement almost uncorrelated in muon pseudorapidity, while a bit correlated in muon charge