

Overview and prospects of nPDF related measurements

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- nPDFs are clearly an important part of understanding nuclear collisions.
- Try to give overview of selected nPDF related measurements.
- Typical observables: electroweak bosons, jet production, quarkonia/heavy-flavour probes, ...
- Also try to give a small look into the future.

Electroweak boson production

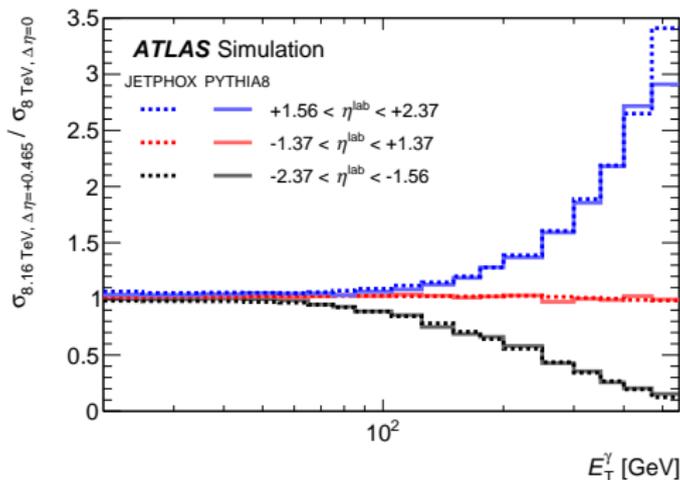
Phys. Lett. B 796 (2019) 230

- Fiducial cross-sections for prompt photon production measured in $p+Pb$ collisions at $\sqrt{s_{NN}} = 8.16$ TeV.

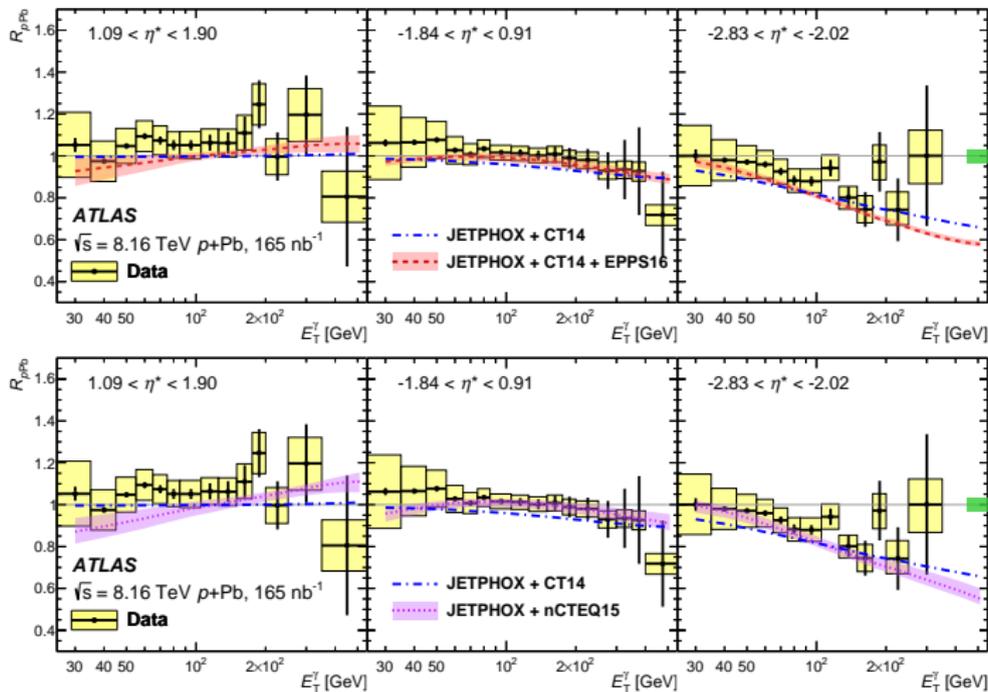
- Information on nPDFs from nuclear modification factor $R_{pPb} = \frac{d\sigma^{pPb \rightarrow \gamma+X}/dE_T^\gamma}{A \cdot d\sigma^{pp \rightarrow \gamma+X}/dE_T^\gamma}$
($A = 208$ is the Pb mass number)

Phys. Lett. B 796 (2019) 230

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- No direct reference measurement in pp collisions, existing results at 8 TeV extrapolated to 8.16 TeV using NLO calculations.

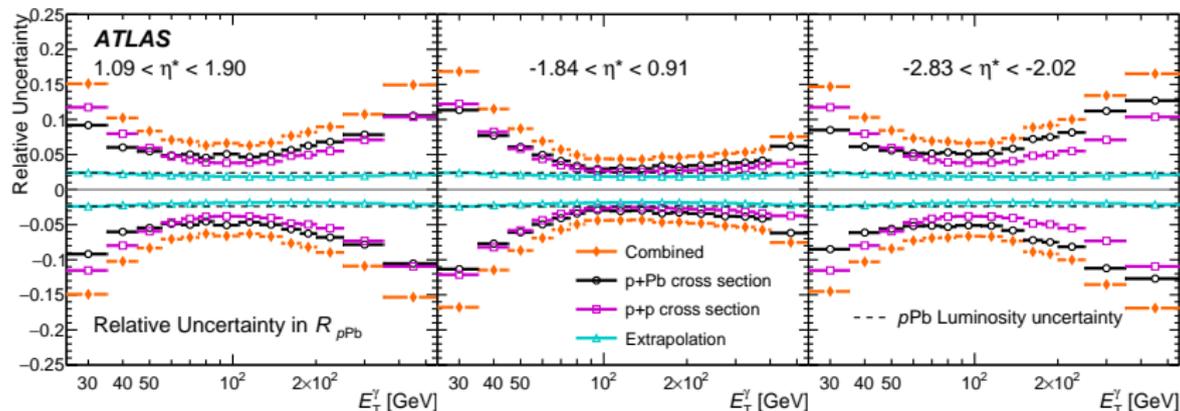


Phys. Lett. B 796 (2019) 230



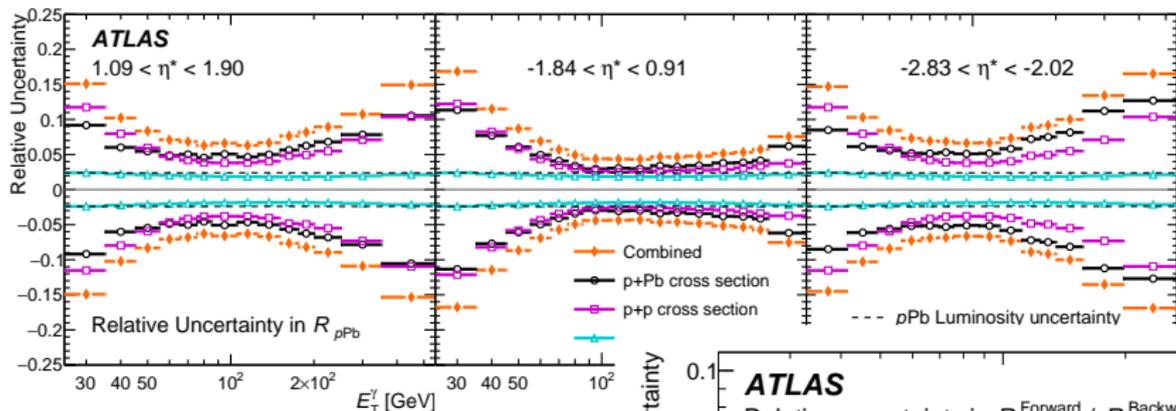
- Slight R_{pPb} decrease at high E_T^γ for backward rapidities points to isospin effect.
- Otherwise no significant modifications - data agree with free-nucleon PDF predictions (CT14) as well as with both nPDF predictions (EPPS16/nCTEQ15).

Phys. Lett. B 796 (2019) 230

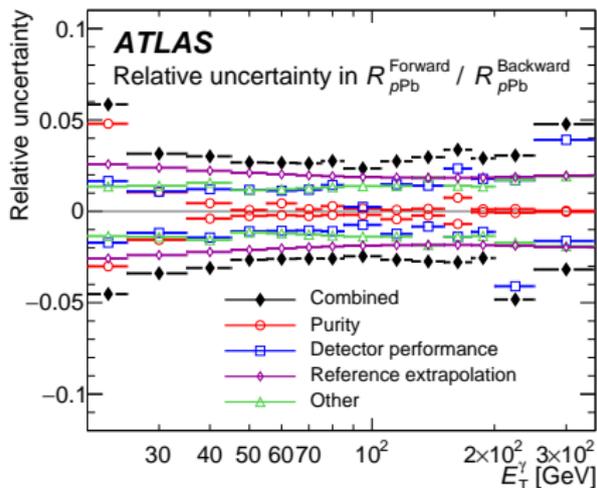


- Significant systematic uncertainties:
5-10% for central rapidities, 7-15% for forward/backward rapidities.

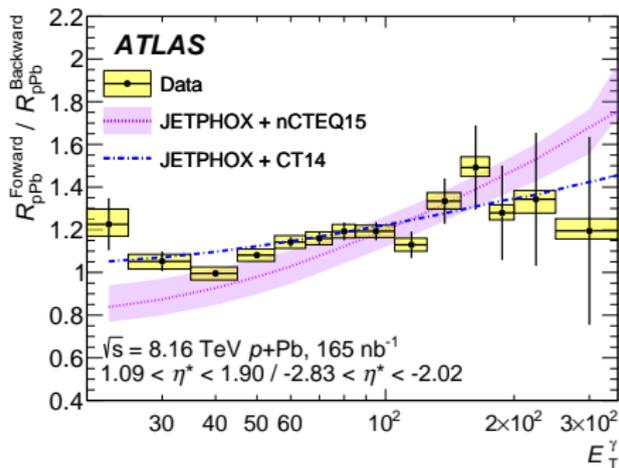
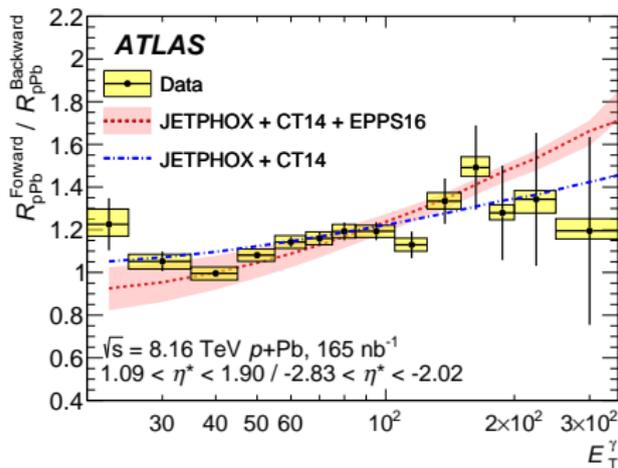
Phys. Lett. B 796 (2019) 230



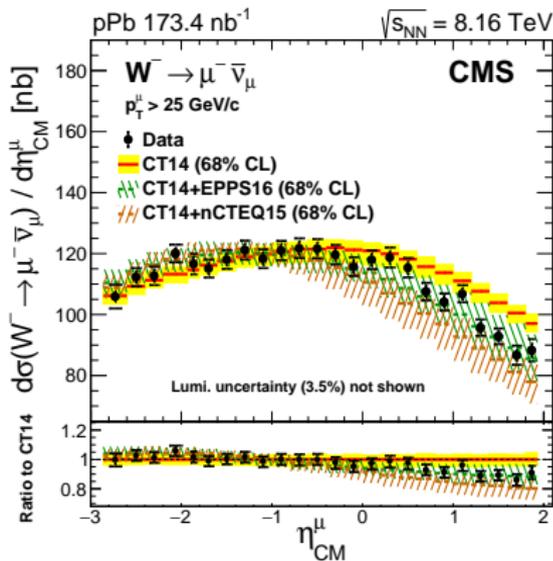
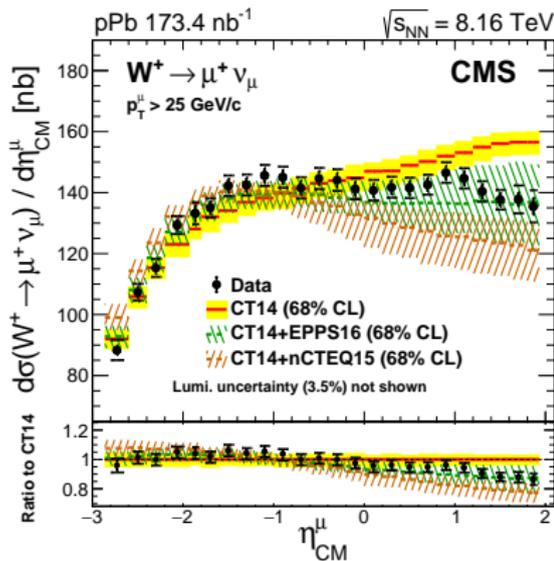
- Significant systematic uncertainties: 5-10% for central rapidities, 7-15% for forward/backward rapidities.
- Taking ratio of R_{pPb} at forward and backward rapidities allows to reduce the impact of systematic uncertainties.



Phys. Lett. B 796 (2019) 230

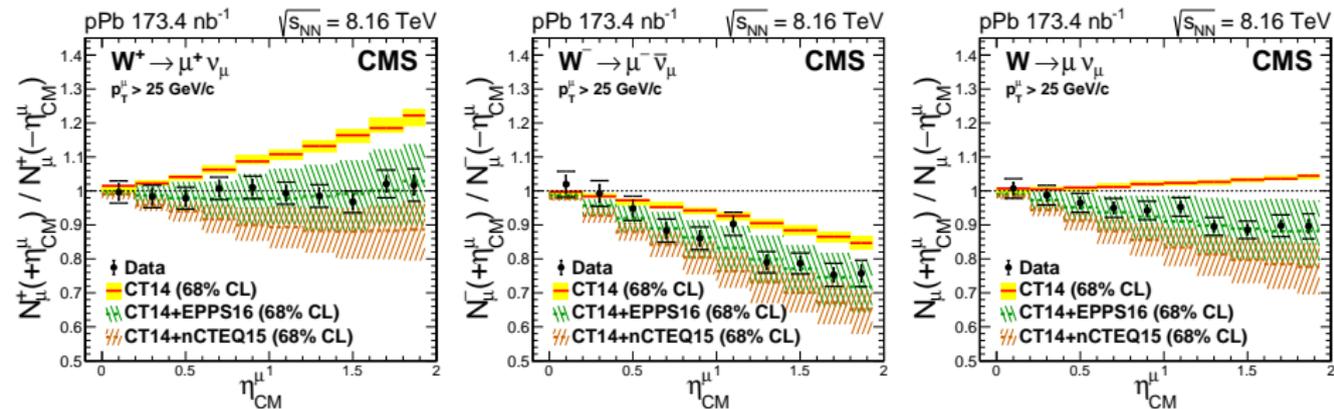


- Benefit from reduced systematic uncertainties most visible for intermediate E_T^γ range.
- Some structure in E_T^γ appears for ratios of forward and backward R_{pPb} .
- The free-nucleon PDF prediction shows the best agreement with data.
- However, data are also mostly compatible with the modest nuclear modifications introduced by nPDFs.



- Fiducial cross-sections for $W^\pm \rightarrow \mu^\pm \nu$ production measured in p+Pb collisions at $\sqrt{s_{\text{NN}}} = 8.16 \text{ TeV}$.
- Some preference for nPDF predictions over CT14 prediction, in particular at forward η .

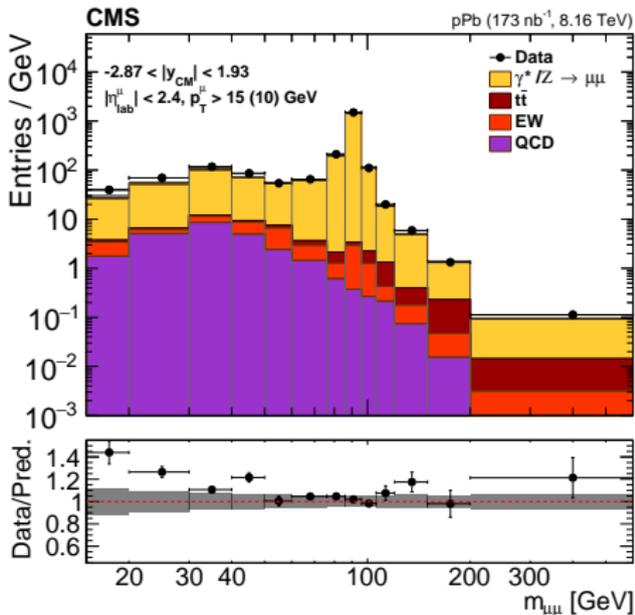
Phys. Lett. B 800 (2020) 135048



- Forward-backward ratios of cross-sections reveal more clearly structure in η .
- Again, benefit from reduction of systematic uncertainties.
- The CT14 prediction is incompatible with data, while nPDF predictions describe it much better.
- In particular the EPPS16 prediction agrees remarkably well with data in terms of central values, although theory uncertainties are sizeable.

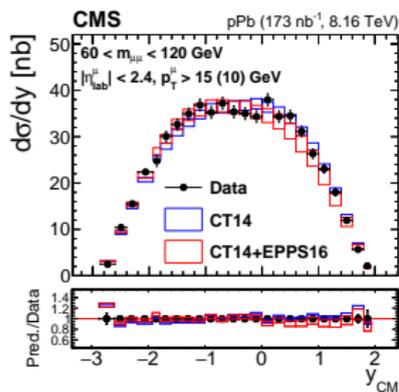
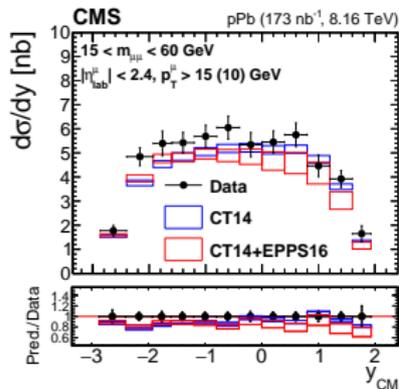
arXiv:2102.13648

- Cross-sections for Drell-Yan dimuon production measured in $p+Pb$ collisions at $\sqrt{s_{NN}} = 8.16$ TeV.
- Wide dimuon mass range covered.
- Observables for $15 < m_{\mu\mu} < 60$ GeV and $60 < m_{\mu\mu} < 120$ GeV:
 - fiducial cross-sections
 - full cross-sections (corrected for acceptance)
 - forward-backward ratios of cross-sections



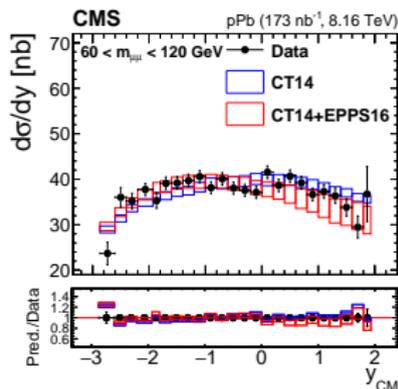
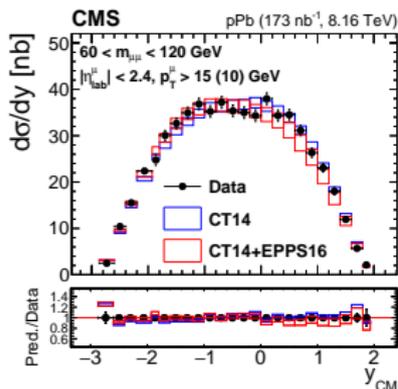
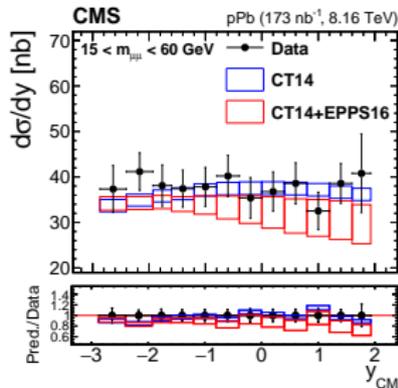
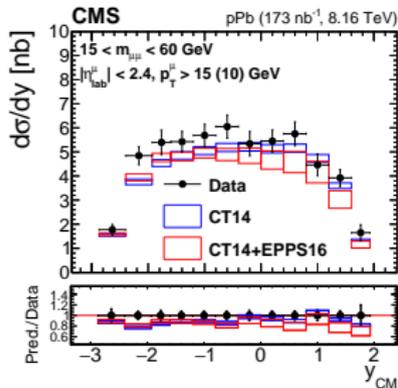
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- fiducial cross-sections
- full cross-sections
- FB ratios



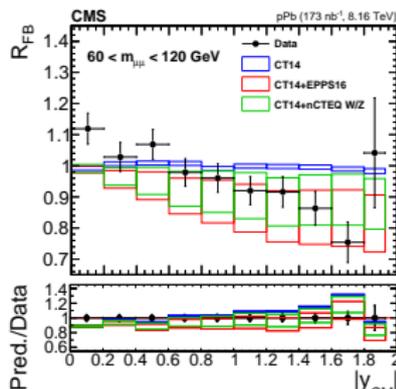
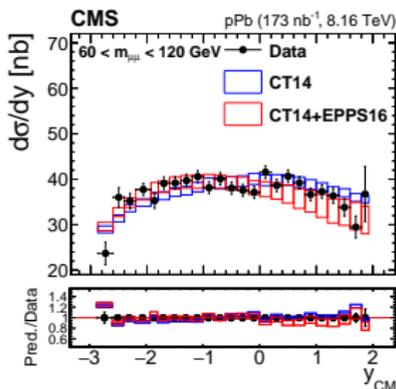
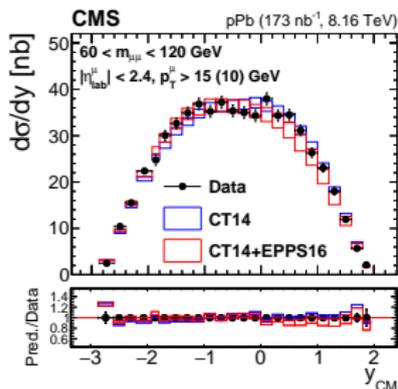
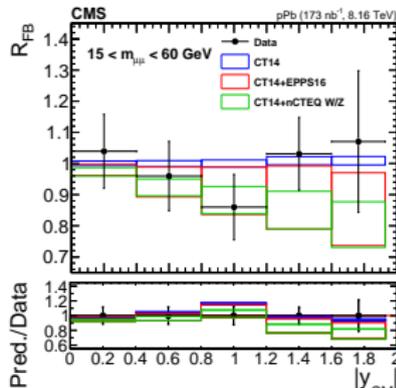
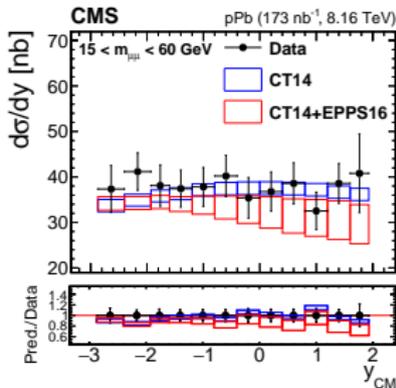
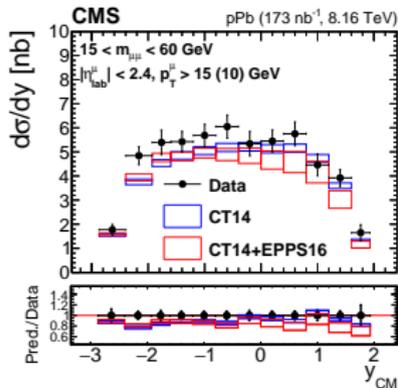
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- fiducial cross-sections
- full cross-sections
- FB ratios



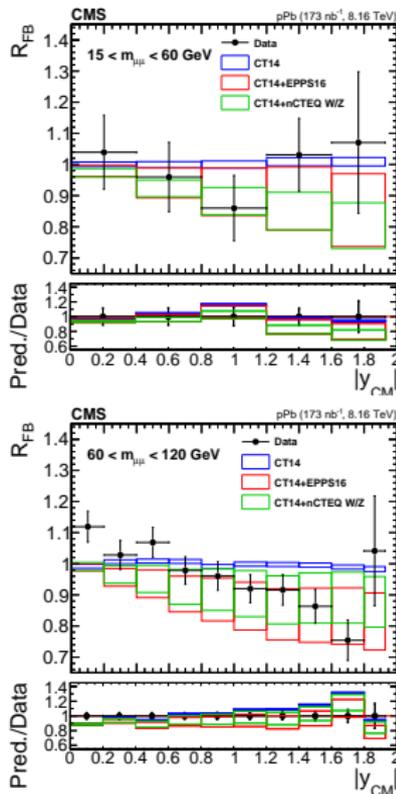
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- fiducial cross-sections
- full cross-sections
- FB ratios



- Conclusions for data at low masses limited due to experimental uncertainties - data well described by CT14 prediction and by nPDF predictions.
- At Z mass peak, data show preference for nPDF predictions - similar to W boson measurement, although more limited by statistics.

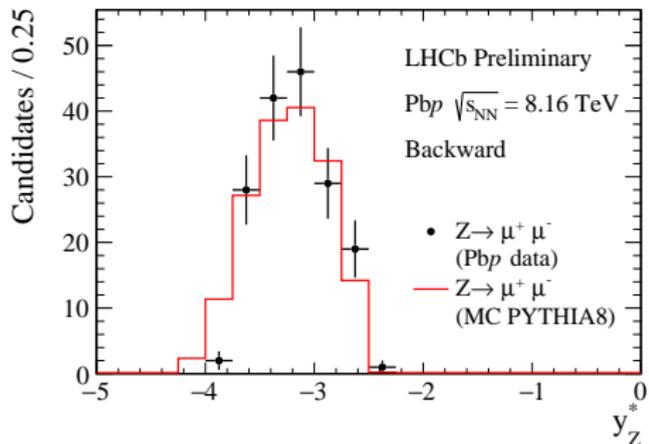
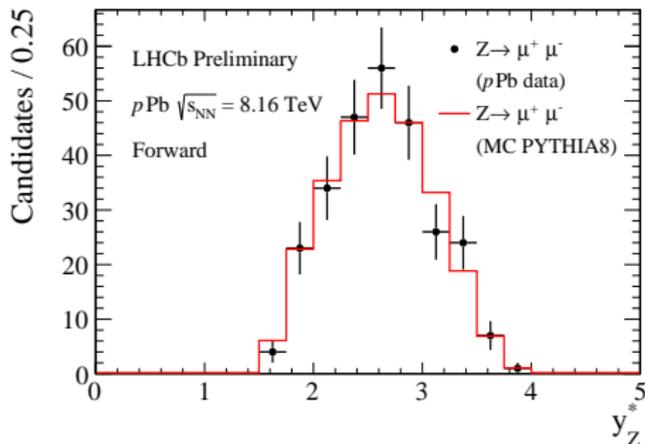
• FB ratios



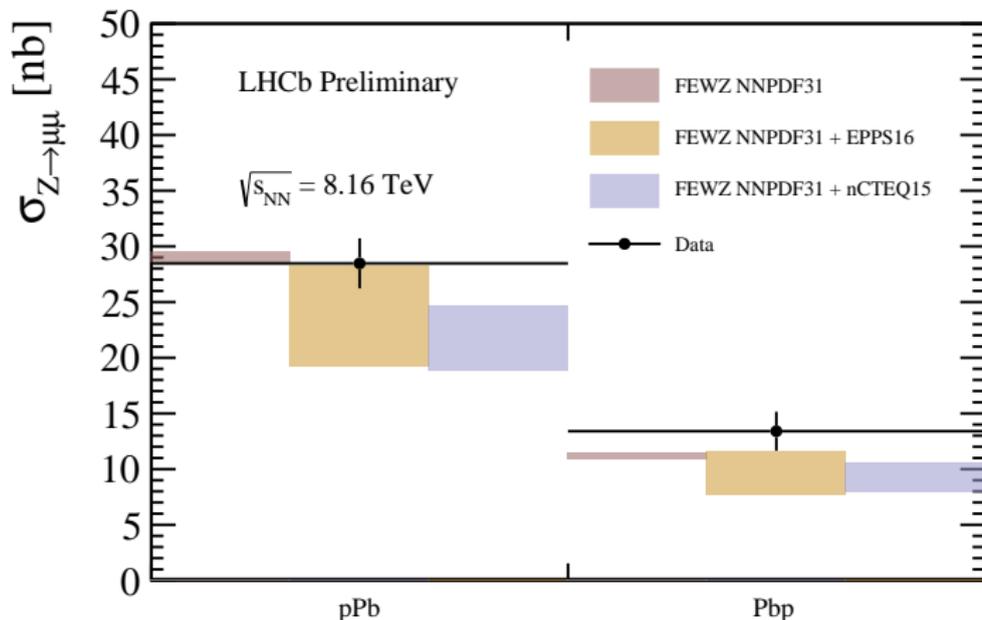
Z bosons in $p+Pb$ (LHCb)

LHCb-CONF-2019-003

- Cross-sections for Z boson production measured in $p+Pb$ collisions at $\sqrt{s_{NN}} = 8.16$ TeV.
- Exploit forward/backward rapidity reach.



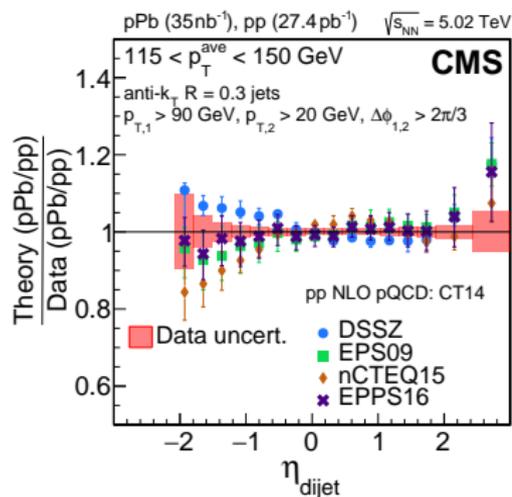
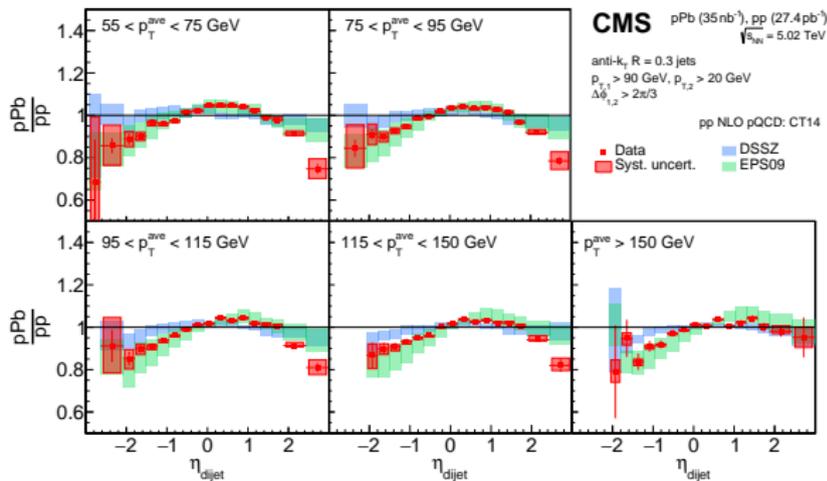
LHCb-CONF-2019-003



- No clear preference for nPDF predictions over free-nucleon PDF prediction.
- In Pbp configuration, all predictions tend to underestimate the measured cross-sections.

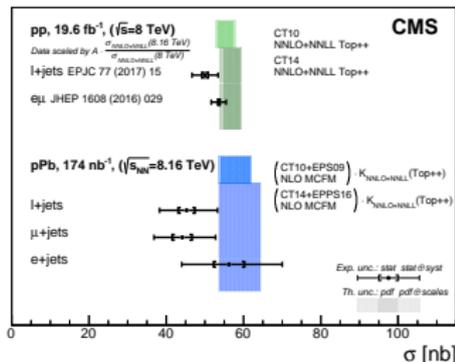
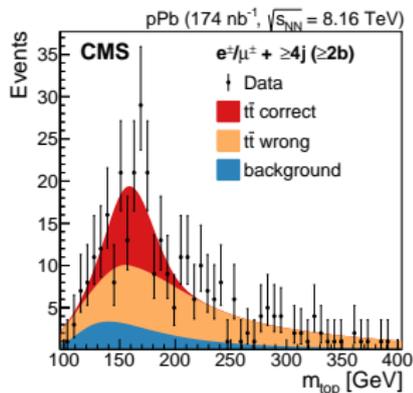
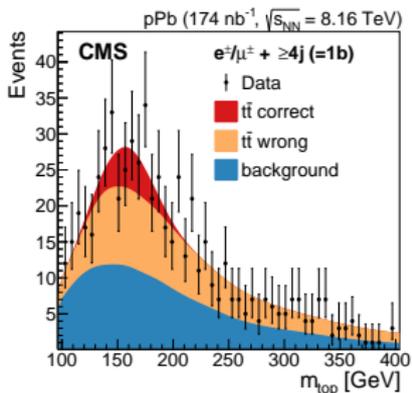
Jet production

Phys. Rev. Lett. 121 (2018) 062002



- Dijet η spectra measured in $p+Pb$ collisions at $\sqrt{s_{NN}} = 5.02 \text{ TeV}$ and compared to pp data at same centre-of-mass energy.
- Data relatively well described by EPS09 prediction, less so by DSSZ prediction.
- Double ratio (theory/data) shows more clearly a spread between predictions using different nPDF sets, in particular at backward rapidities.

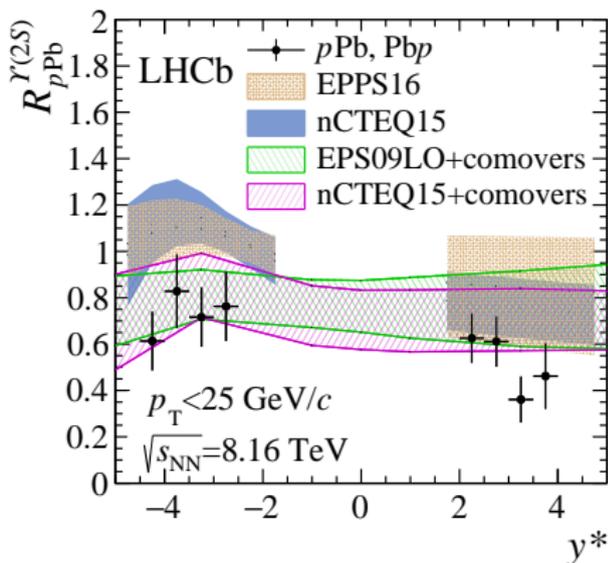
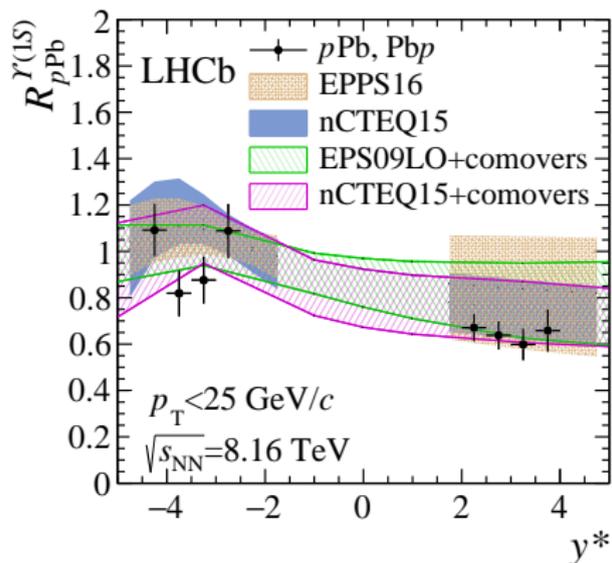
Phys. Rev. Lett. 119 (2017) 242001



- Cross-section for $t\bar{t}$ production measured in $p+Pb$ collisions at $\sqrt{s_{NN}} = 8.16$ TeV.
- First observation - interpretation limited by statistical and systematic uncertainties.
- Inclusive $p+Pb$ cross-section slightly overestimated by nPDF predictions - level of disagreement similar to pp cross-sections at 8 TeV.

Quarkonia / heavy-flavour probes

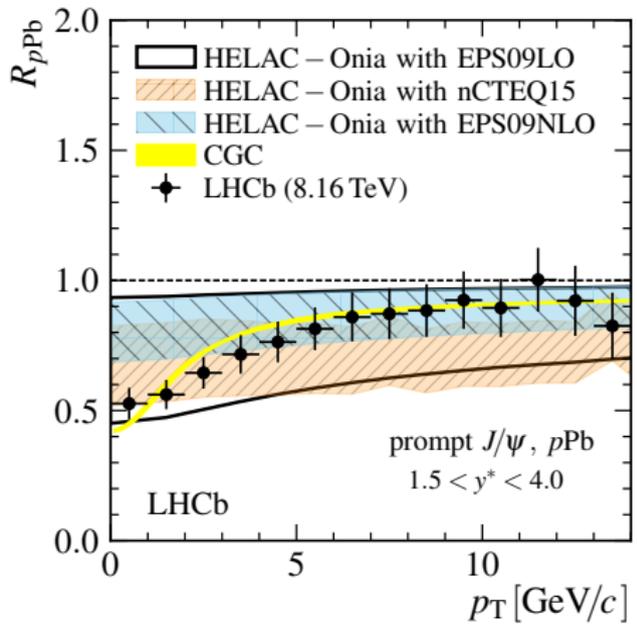
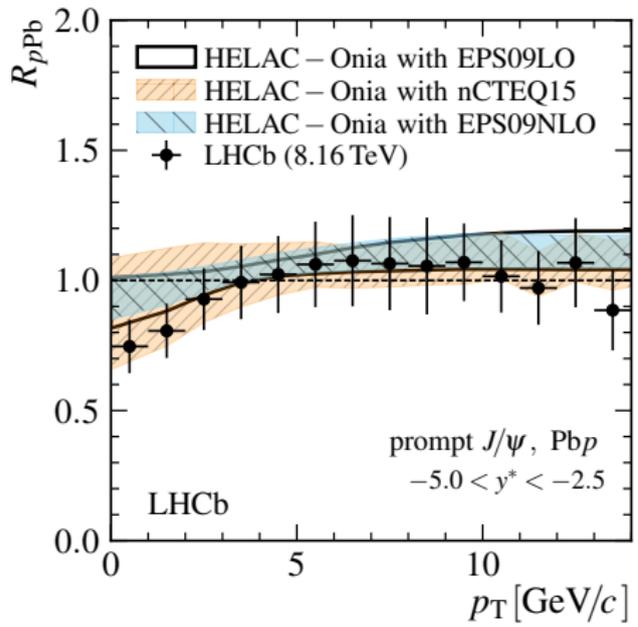
JHEP 11 (2018) 194



- Nuclear modification factors for $\Upsilon(1S)$ and $\Upsilon(2S)$ production measured in $p+Pb$ collisions at $\sqrt{s_{NN}} = 8.16$ TeV.
- Reasonable agreement with nPDF predictions for $\Upsilon(1S)$, but not so much for $\Upsilon(2S)$.
- Inclusion of comovers important to describe the data.

J/ψ mesons in $p+Pb$ (LHCb)

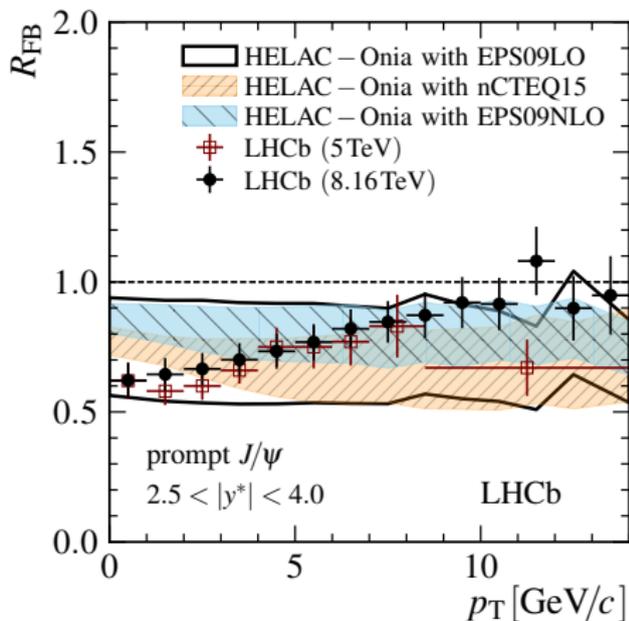
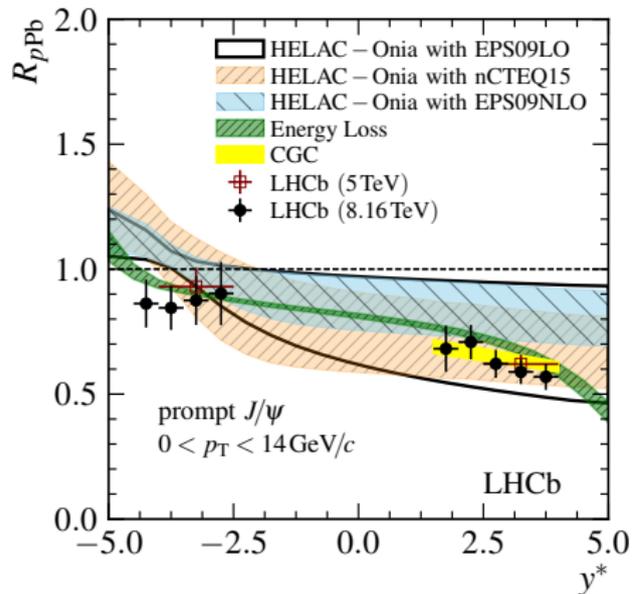
Phys. Lett. B 774 (2017) 159



- Nuclear modification factors for prompt J/ψ production measured in $p+Pb$ collisions at $\sqrt{s_{NN}} = 8.16$ TeV.
- Predictions from nPDFs agree quite well with data, although within sizeable uncertainties - CGC predictions describe forward rapidities as well.

J/ψ mesons in $p+Pb$ (LHCb)

Phys. Lett. B 774 (2017) 159



- Nuclear modification factors at forward rapidities described well by nPDF predictions, while some discrepancy observed at backward rapidities.
- For forward-backward ratio, data agree with nPDF predictions, but trend with p_T seems to be slightly different - size of uncertainties prevents strict conclusions.

- Vibrant physics program of nPDF related measurements at the LHC and beyond.
- Partially already used to improve nPDF sets.
- Will continue into LHC Run 3 and beyond (HL-LHC).
- Also huge opportunities from lighter-ion collisions and EIC.

Additional slides