

Experimental constraints on nPDF

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GDR-QCD / WG1 Kick-off meeting

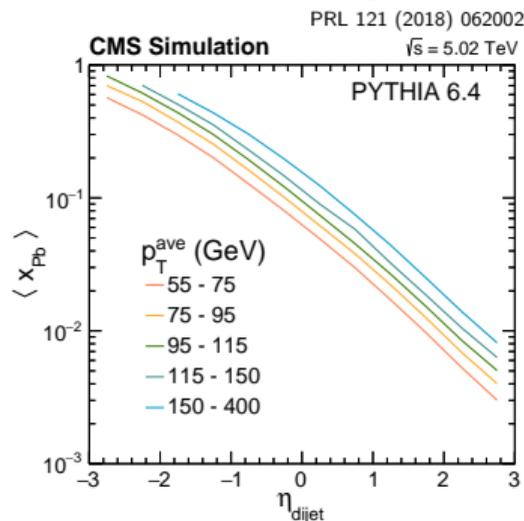
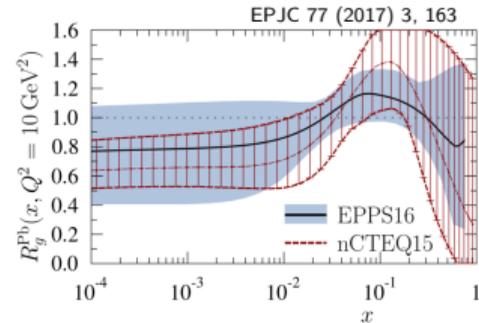
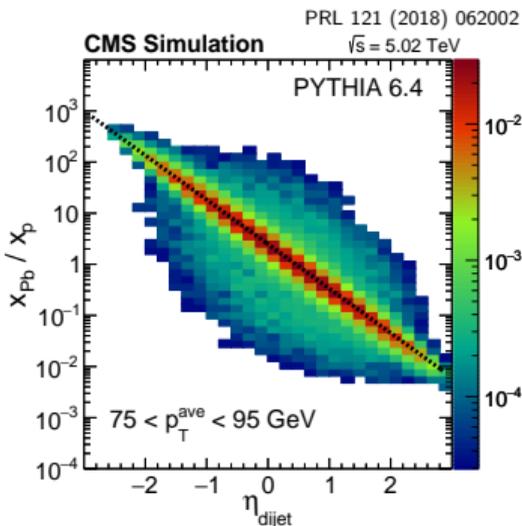
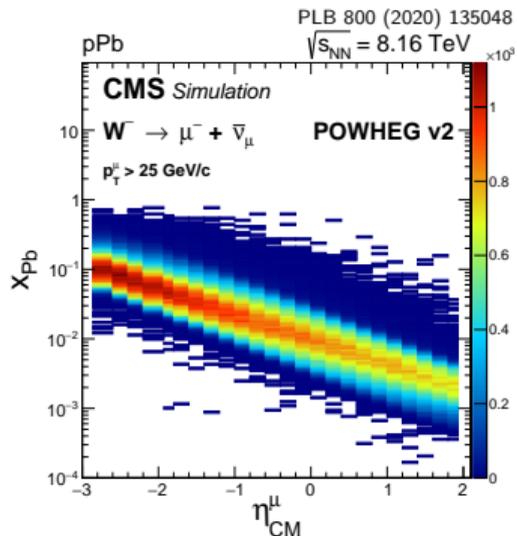
June 21–23, 2021





Partonic content in the initial state

- Needed for \sim any cross section or R_{AB} prediction
- In pPb: correlation between measured kinematics and probed x_{Pb}
- PbPb can add some information



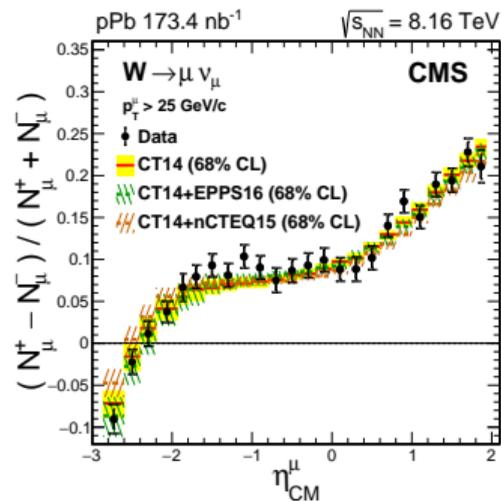
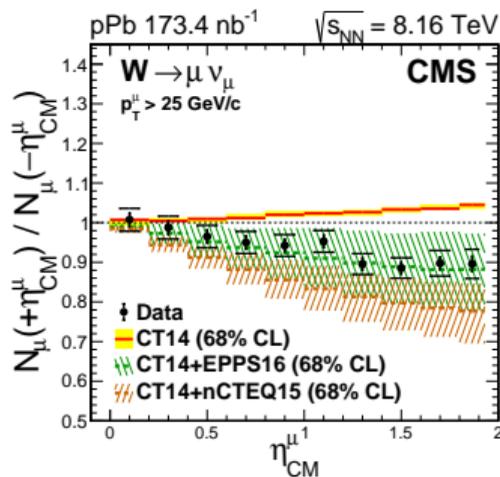
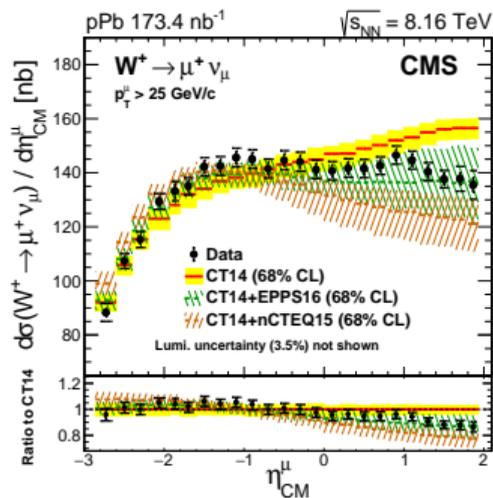


| | DSSZ12 | KA15 | nCTEQ15 | EPPS16 | TUJU19 | nNNPDF1.0 | nNNPDF2.0 |
|--|------------------------------------|--------------------|--------------------------------|--------------------|--------------------------------|--------------------------------|--------------------------------|
| Order | NLO | NNLO | NLO | NLO | NNLO | NLO & NNLO | NLO & NNLO |
| Neutral current DIS $\ell + A/\ell + d$ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Drell-Yan dilepton $p + A/p + d$ | ✓ | ✓ | ✓ | ✓ | | | |
| RHIC pions $d + Au/p + p$ | ✓ | | ✓ | ✓ | | | |
| Charged current DIS $\nu + A$ | ✓ | | | ✓ | ✓ | | ✓ |
| Drell-Yan dilepton $\pi + A$ | | | | ✓ | | | |
| LHC jet data (5 TeV) $p + Pb$ | | | | ✓ | | | ✓ |
| LHC W, Z data (5, 8 TeV) $p + Pb$ | | | | ✓ | | | ✓ |
| Q_0 | 1.0 | 1.41 | 1.3 | 1.3 | 1.3 | 1.0 | 1.0 |
| Q cut in DIS | 1.0 | 1.0 | 2.0 | 1.3 | 1.87 | 1.87 | 1.87 |
| Datapoints | 1579 | 1479 | 708 | 1811 | 2336 | 451 | |
| Error analysis | Hessian | Hessian | Hessian | Hessian | Hessian | Monte Carlo | Monte Carlo |
| Free Proton Baseline | MSTW08 | JR09 | CTEQ6.1 | CT14nlo | HERA2.0 | NNPDF3.1 | NNPDF3.1 |
| Heavy quark effects | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ |
| Flavour separation | ✓ | | Some | ✓ | | | ✓ |
| Parametrization | Modification Ratio in Mellin space | Modification Ratio | Proton pdf parametrised with A | Modification Ratio | Proton pdf parametrised with A | Neural Network With A as input | Neural Network With A as input |
| Reference | PR.D.100.096015 | PR.D.93.014026 | PR.D.93.085037 | EPJ.C77.163 | PR.D.100.096015 | EPJ.C79.471 | |



W bosons in pPb

- CMS W bosons (8.16 TeV):
 - Experimental uncertainties smaller than nPDF ones
 - Inconsistent with free proton PDF, better agreement with EPPS16 than nCTEQ15 (amount of shadowing)

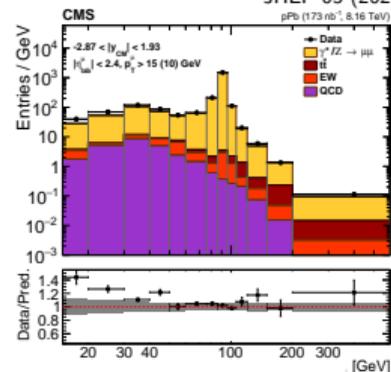
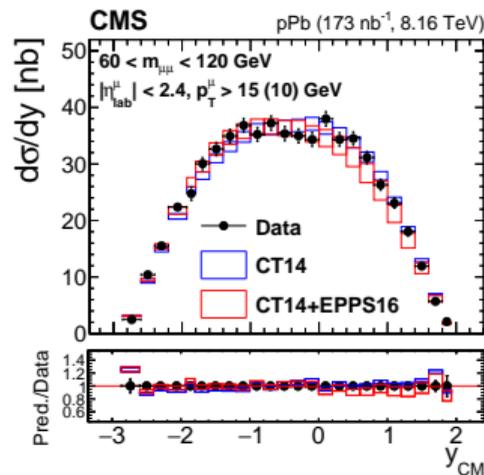
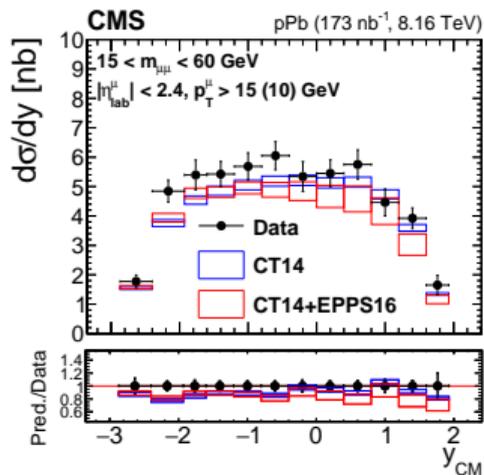
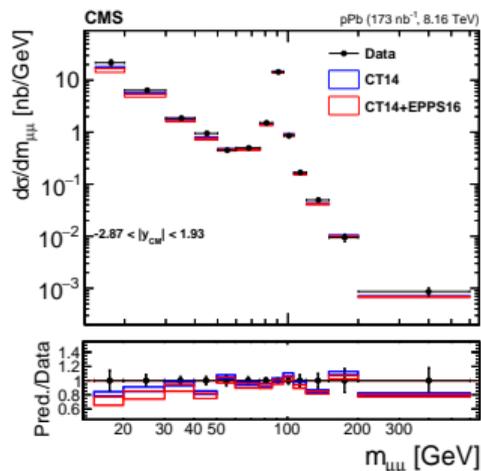




Drell-Yan in pPb

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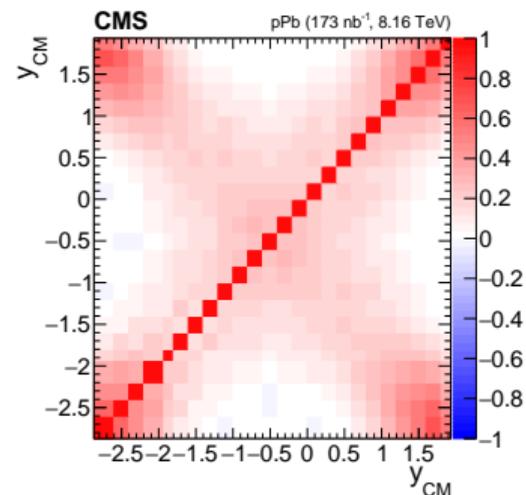
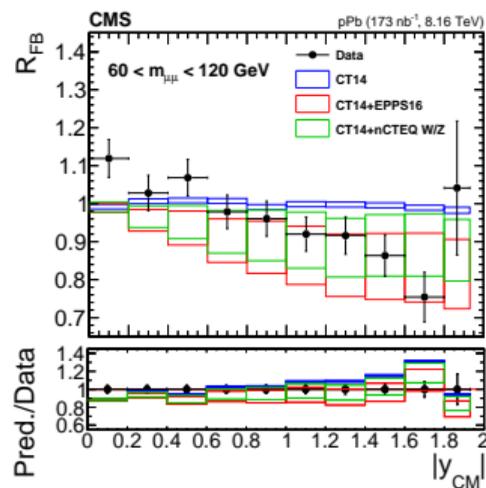
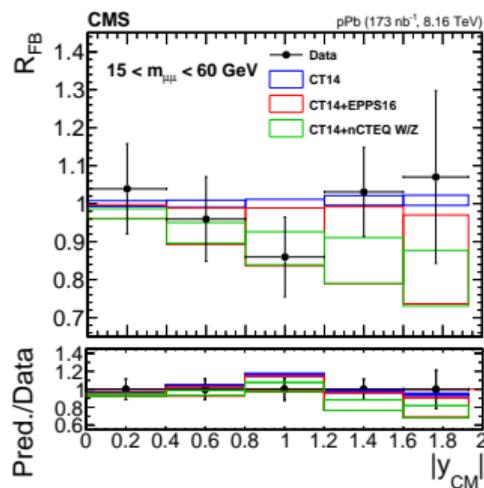
- Drell-Yan process in pPb collisions for $15 < M < 600$ GeV
- Cross sections provided with and without correcting for single muon cuts
- Complementary with W boson measurements:
 - Adding mass dependence (different scales Q^2)
 - Adding p_T (and ϕ^*) dependence





Drell–Yan in pPb

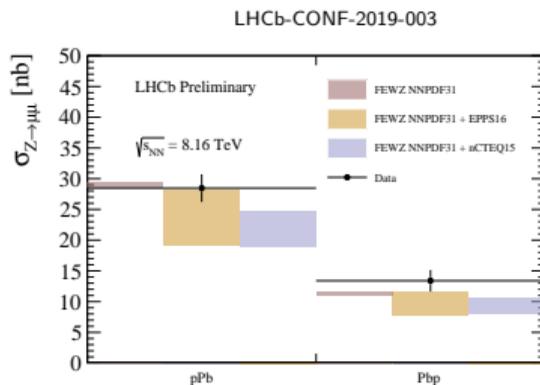
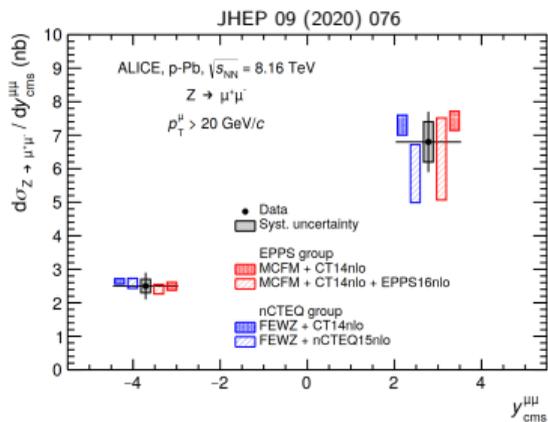
- Forward-backward ratio, $15 < M < 60$ GeV: little discrimination with current data
- Forward-backward ratio, $60 < M < 120$ GeV: good agreement with EPPS16 / nCTEQ/WZ
- Correlation matrices for systematic uncertainties also available





W and Z bosons in pPb

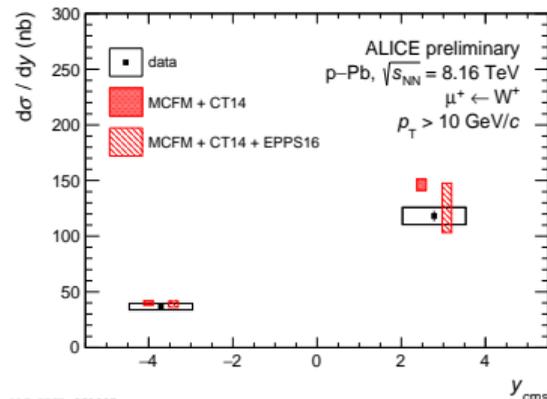
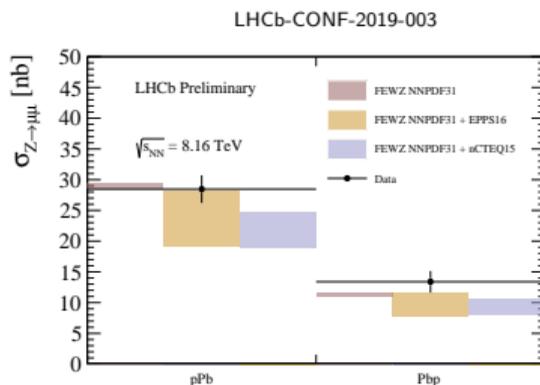
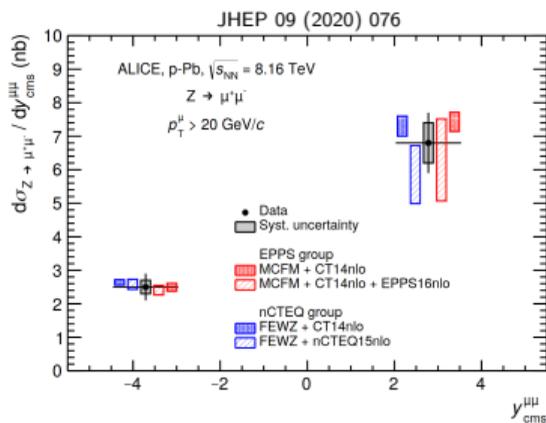
- Z bosons in ALICE and LHCb: no evidence for nPDF effects





W and Z bosons in pPb

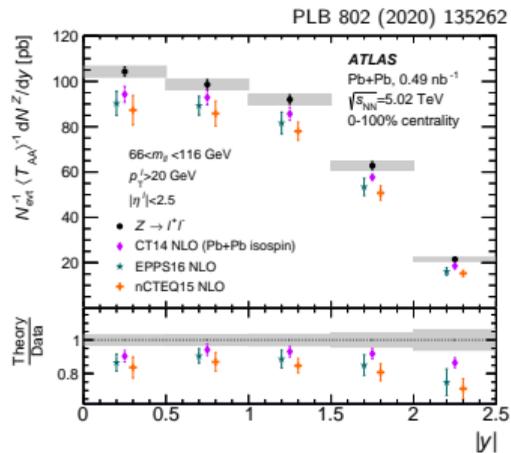
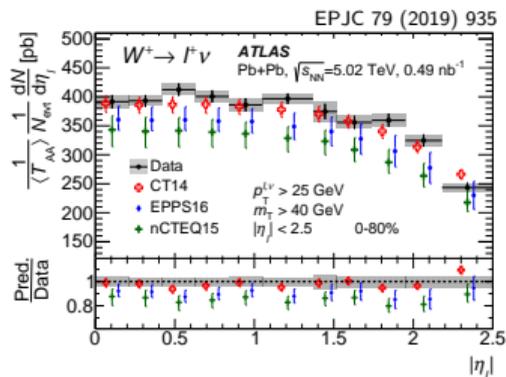
- Z bosons in ALICE and LHCb: no evidence for nPDF effects
- W bosons in ALICE: some suppression in the forward direction



W and Z bosons in PbPb



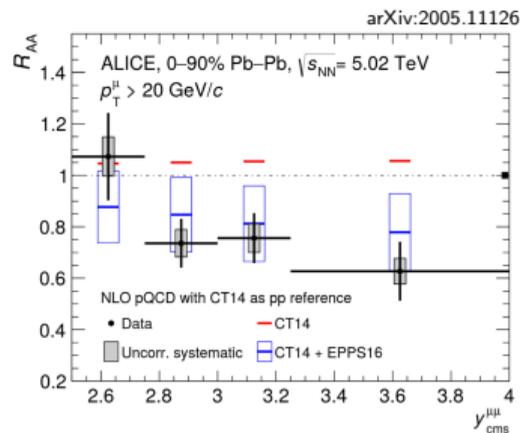
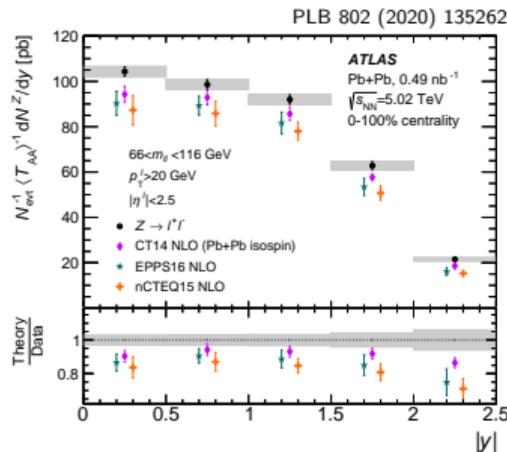
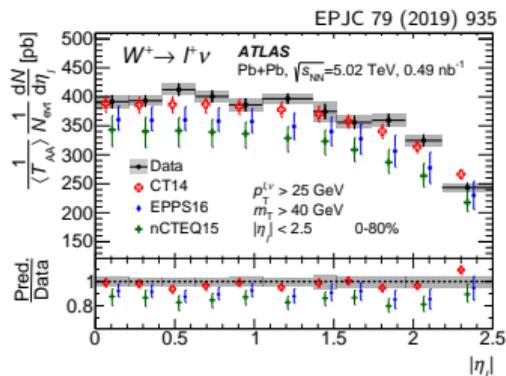
- ATLAS W and Z bosons: normalisation better described without nPDF?





W and Z bosons in PbPb

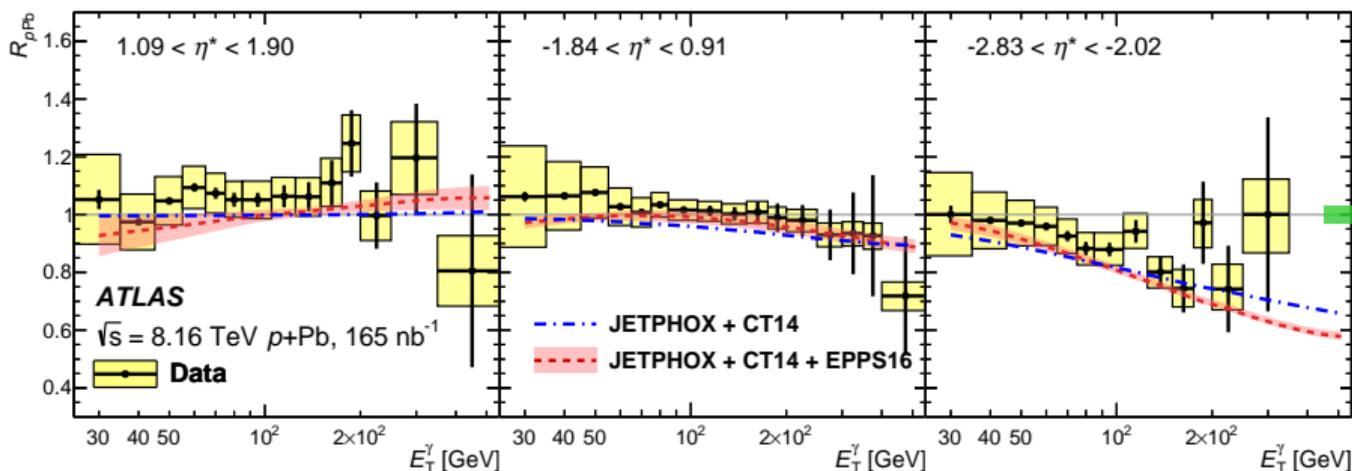
- ATLAS W and Z bosons: normalisation better described without nPDF?
- ALICE Z bosons: evidence for nuclear effects

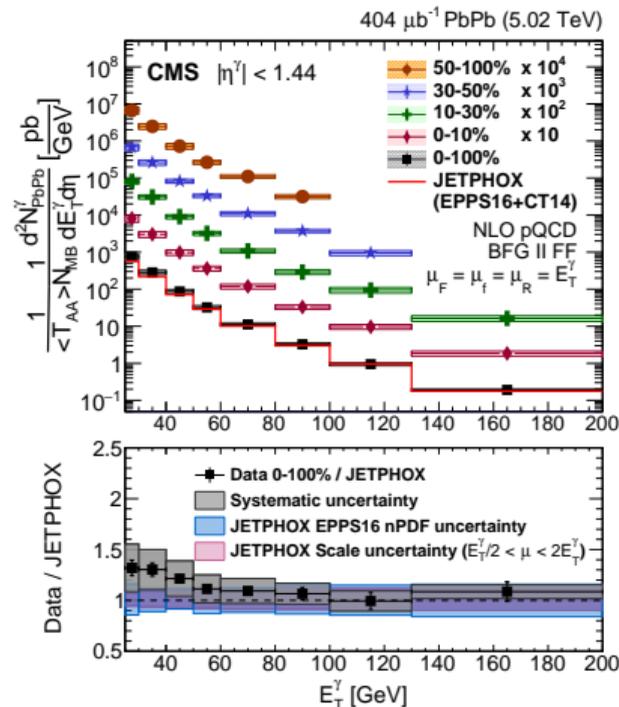




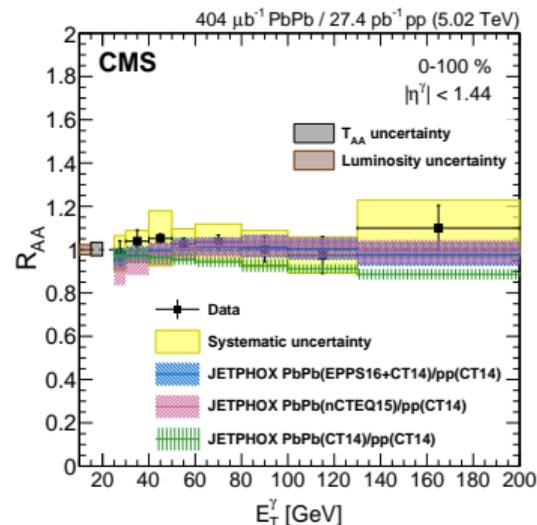
Photons in pPb

- Photons also expected to be sensitive to initial state (isospin + nPDF)
- Limited nPDF constraints within current precision





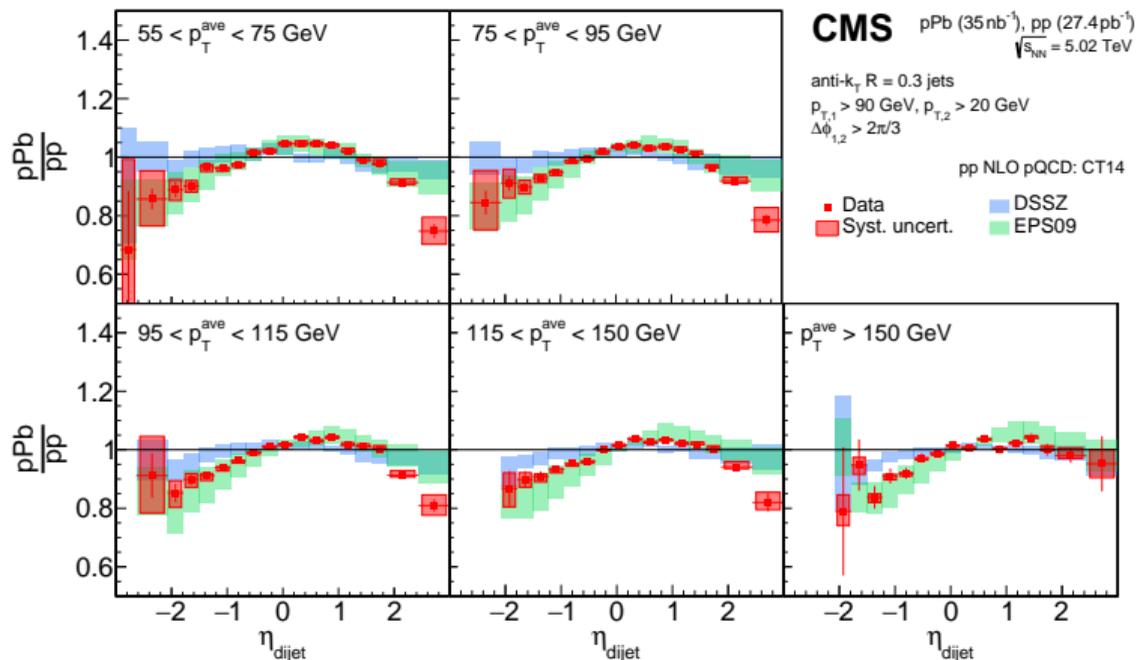
- Sizeable scale and systematic uncertainties in absolute cross sections
- Both are reduced in ratio to pp (R_{AA})





Dijets in pPb

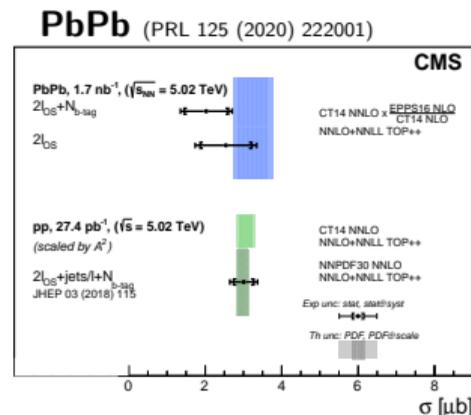
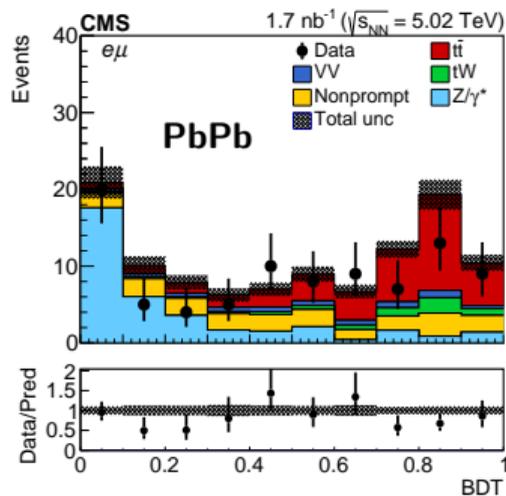
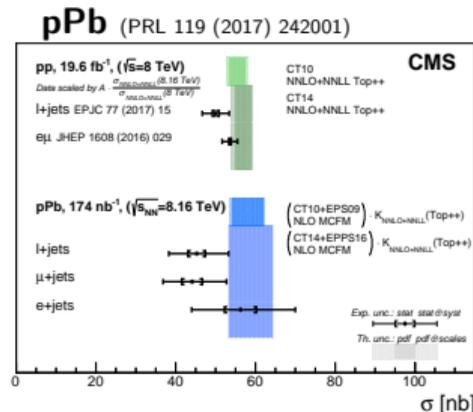
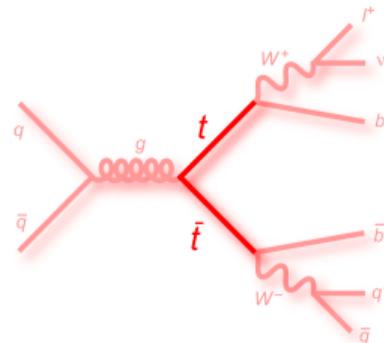
- Probing gluon nPDF over a wide range of x_{Pb} , from shadowing to anti-shadowing and EMC
- pPb data already included in EPPS16
- pPb/pp less sensitive to pp modelling



Top quarks



- First measurements in pPb and PbPb
- Production sensitive to gluon nPDFs (higher x and Q^2 than dijets)
- Data consistent with expectations (within large uncertainties)



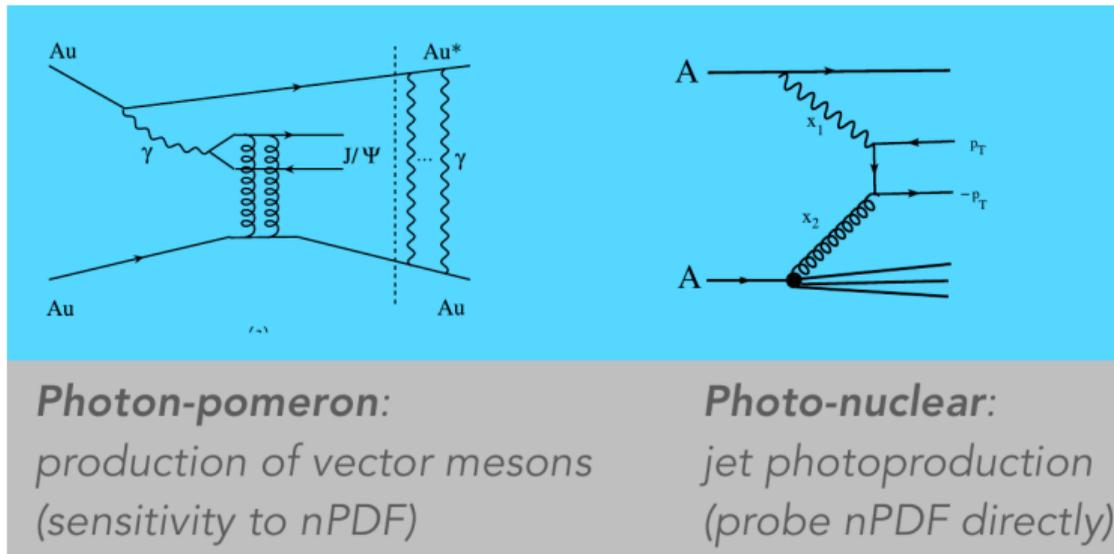


Ultra-peripheral collisions

Using the lead ions as a source of quasi-real photons

- Can be used as a probe of the projectile structure
- Sensitivity to nPDF

P. Steinberg



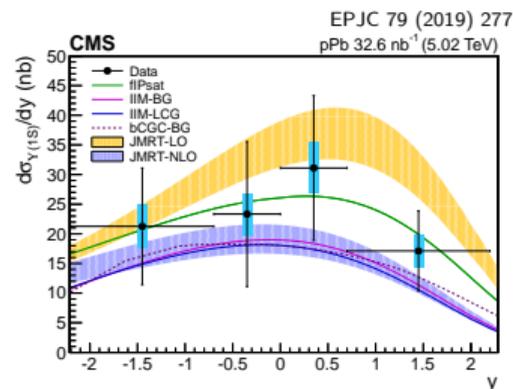
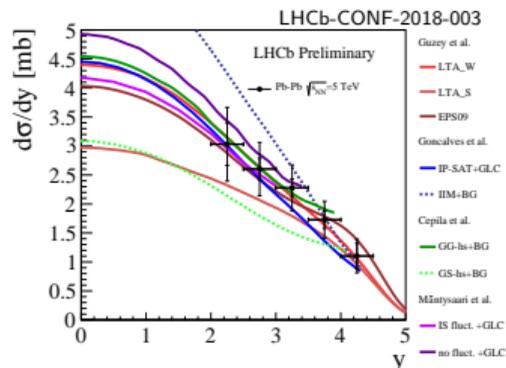
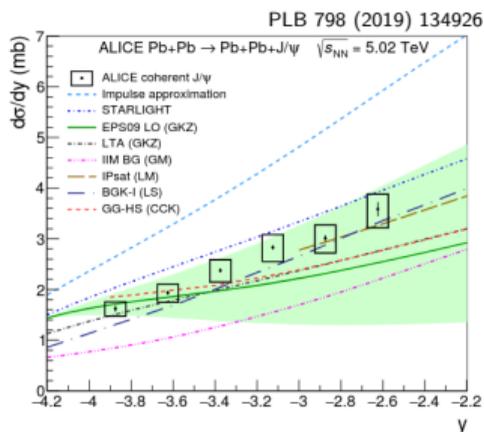
Photon-pomeron:
production of vector mesons
(sensitivity to nPDF)

Photo-nuclear:
jet photoproduction
(probe nPDF directly)



Quarkonia in γp and γPb collisions

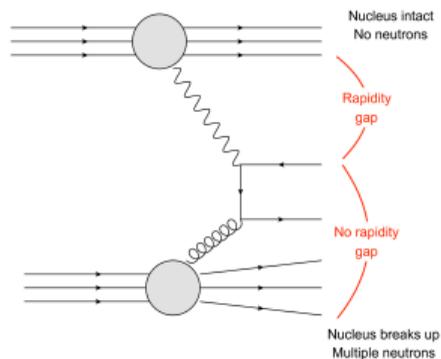
- Coherent J/ψ in PbPb (ALICE and LHCb)
- Coherent $\Upsilon(1S)$ in pPb (CMS)
- Good agreement with models (NLO pQCD, gluon saturation)



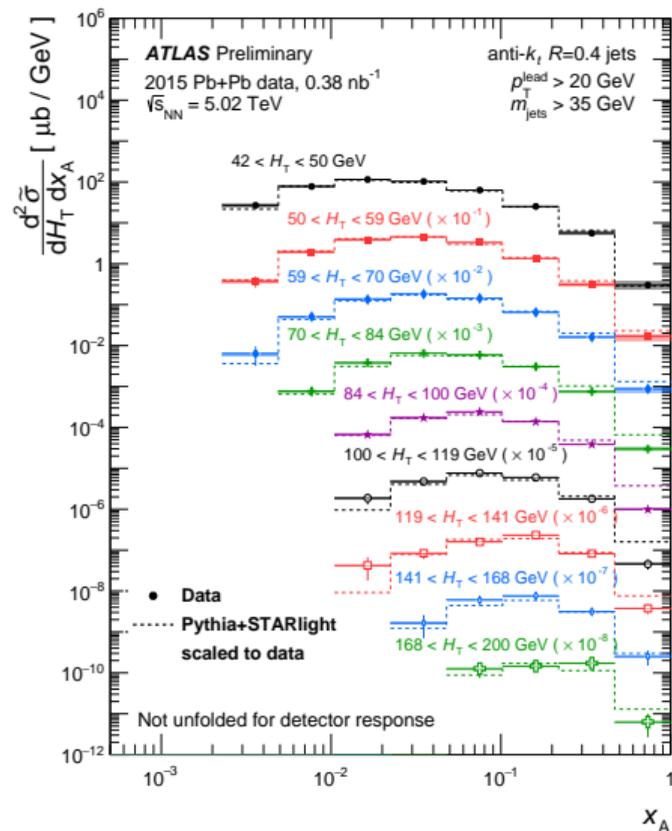
Photonuclear dijets



ATLAS-CONF-2017-011



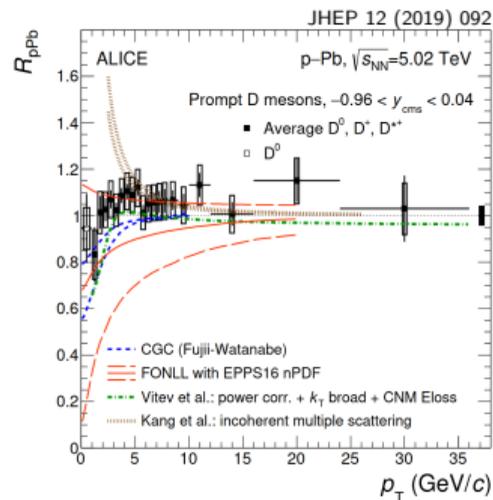
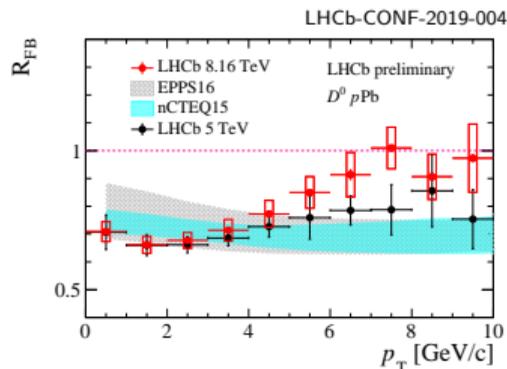
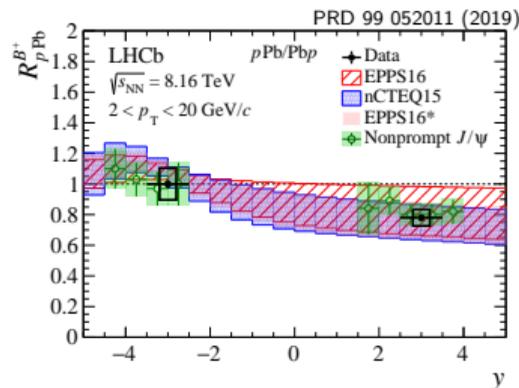
- Selecting γ Pb interactions using ZDC + rapidity gaps
- Comparison with PYTHIA (γ spectrum reweighted to STARLIGHT)
- Sensitivity to nPDF



Open heavy flavour



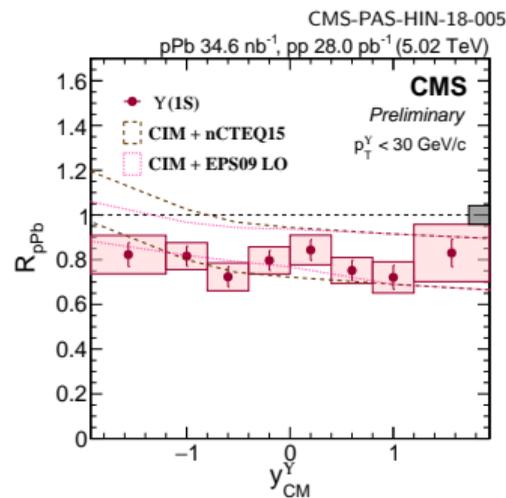
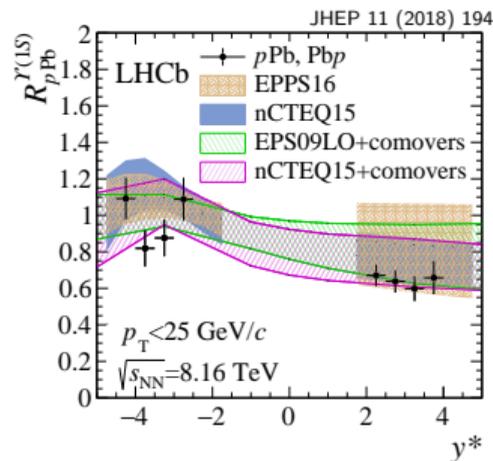
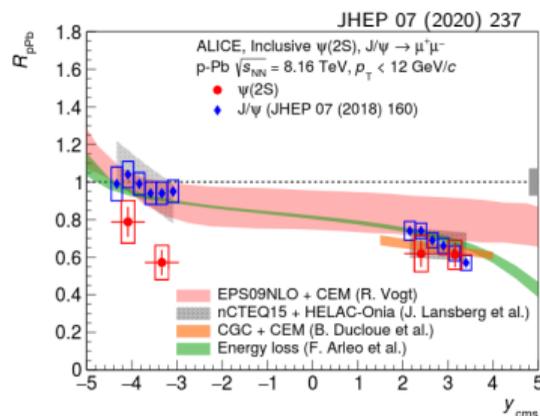
- Heavy flavour mesons mostly produced in gluon fusion
- Sensitivity to gluon nPDFs at very small x
- Large cross sections: excellent experimental precision
- Importance of higher twist / factorisation-breaking effects?





Similar story with quarkonia

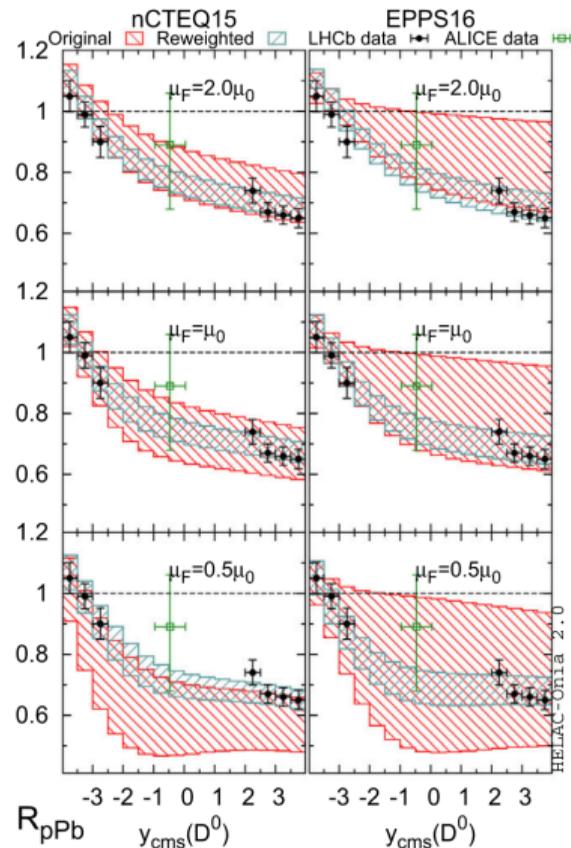
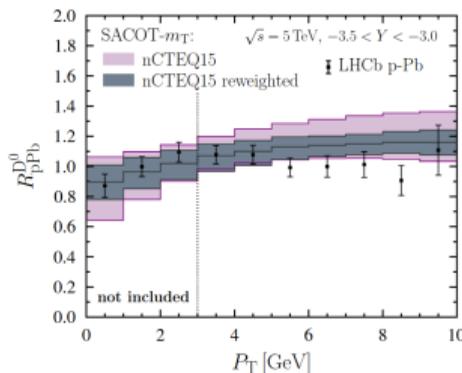
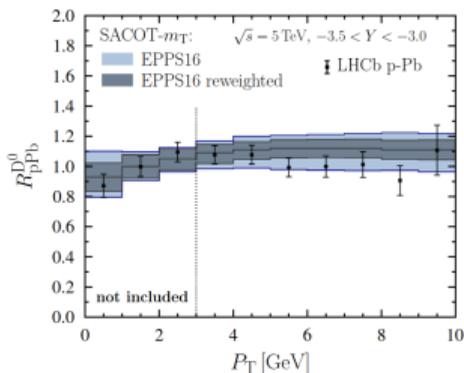
- Remember: excited states more suppressed than ground states \rightarrow can we trust the ground state for nPDF?





Heavy flavour and nPDF

- Several groups proposed using heavy flavour production to constrain nPDFs
 - PRL 121 (2018) 052004, JHEP 05 (2020) 037
- Expect large impact on low- x gluons
- Some caveats (reliability of nPDF factorisation? Understanding of production, fragmentation?)

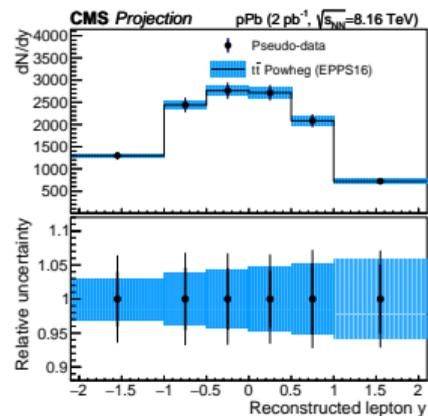
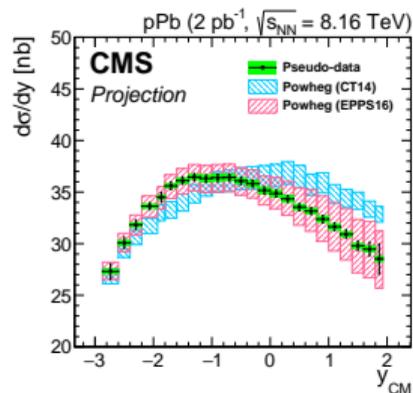




Future measurements

Many future experiments / facilities planned with sensitivity to nPDF:

- HL-LHC

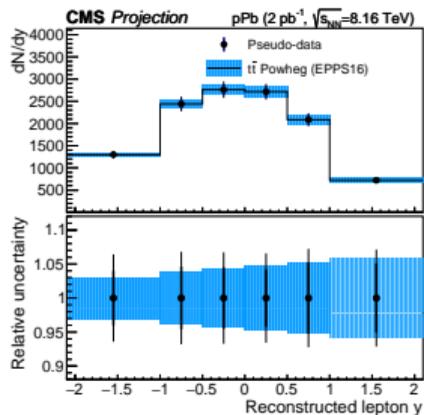
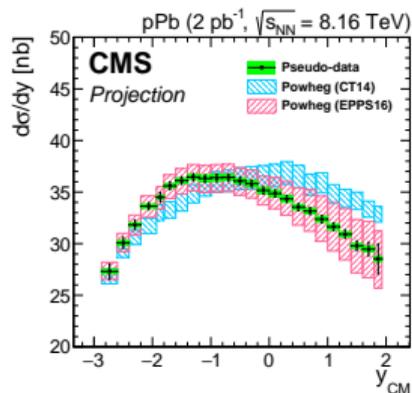
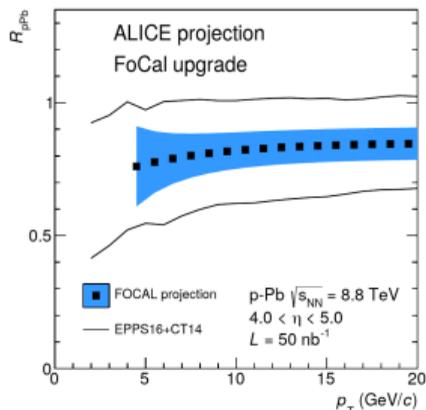




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- FOCAL (ALICE)

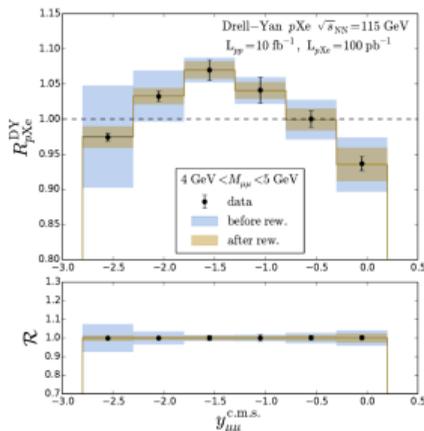
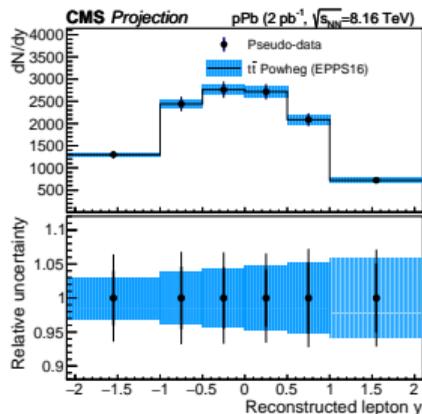
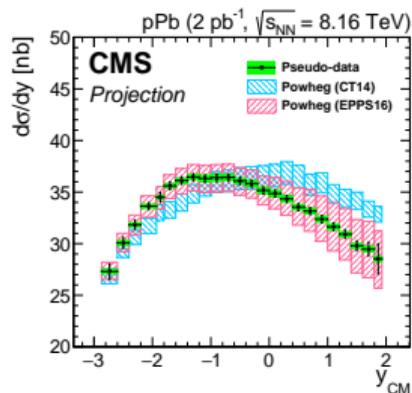
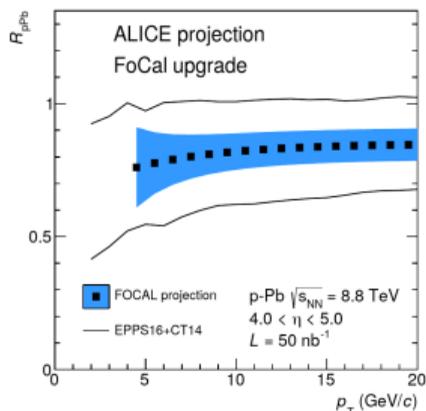




Future measurements

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- SMOG2 (LHCb)

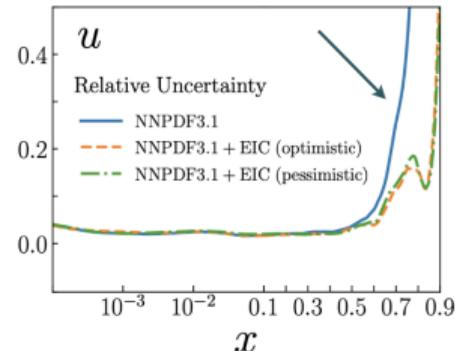
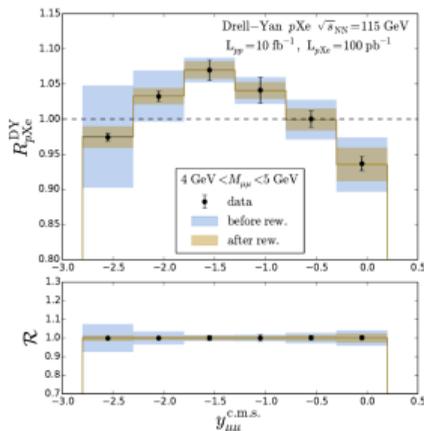
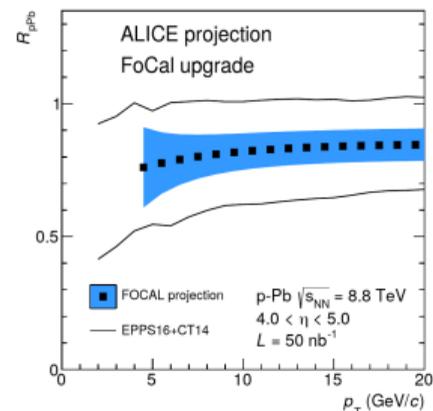
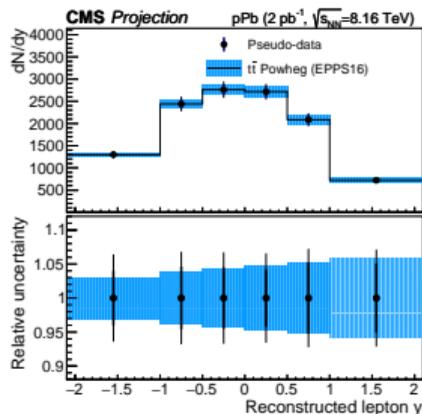
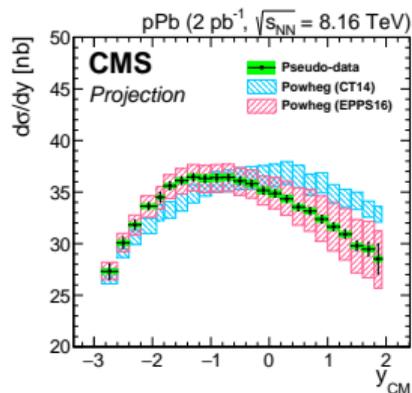


Future measurements



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- HL-LHC
- FOCAL (ALICE)
- SMOG2 (LHCb)
- EIC
- ...





- Increasing number of experimental measurements sensitive to the initial state
- Uncertainties often small
 - Further improvement expected for Runs 3–4 of the LHC
- Nuclear PDF interpretation not always straightforward
 - Partonic process modelling, geometric scaling, factorisation breaking, ...
- Bright future for nPDF studies