Including EW-boson production data into TUJU nuclear PDFs

Snowmass 2021 discussions

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Outline

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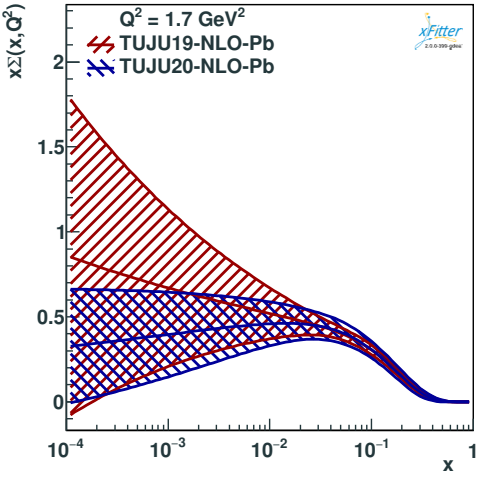
1. Available nuclear PDF sets
2. Introduction to TUJU19
3. Status of TUJU20
4. Summary & Outlook



Modern nuclear PDF sets

EPPS16 [EPJC 77 (2017) 3, 163]

- Long tradition (since 90's)
- NLO analysis, SACOT-χ GM-VFNS, CT14 as a baseline
- Most "global" fit, includes already several LHC data sets

nCTEQ15 [PRD 93 (2016) 8, 085037]

- Builds upon CTEQ proton PDF analysis
- NLO analysis, SACOT-χ GM-VFNS, CTEQ6-like baseline
- Fixed-target DIS and DY, π^0 (d+Au)

nNNPDF2.0 [JHEP 09 (2020) 183]

- Based on neural networks
- NNLO for DIS only (nNNPDF1.0)
- NLO with LHC data for $W^{\pm}$ and Z

TUJU19 [PRD 100 (2019) 9, 096015]

- Open-source framework (XFITTER 2.0.1N: Nuclear Daiquiri)
- Proton baseline fitted in the same framework, aim for a combined fit in future
- NLO and NNLO fits available but only DIS data so far

TUJU19: Fitting framework

Proton baseline PDF

- Use similar parametrization as in HERAPDF2.0

  $$xf_i^p(x,Q_0^2) = c_0 x^{c_1}(1-x)^{c_2}(1+c_3 x+c_4 x^2)$$

- Parametrization scale $Q_0^2 = 1.69\ \text{GeV}^2$
- Kinematical cuts for data
  - $Q^2 > 3.5\ \text{GeV}^2$
  - $x < 0.7$
  - $W^2 > 12\ \text{GeV}^2$
- Assume $\bar{u} = \bar{d} = \bar{s} = s$

Nuclear PDFs

- A-dependent parameters

  $$c_k(A) = c_{k,0} + c_{k,1}(1 - A^{-c_{k,2}})$$

  where $c_{k,0}$ from proton baseline
- Same kinematical cuts for data
- For an average nucleon

  $$f_i^{N/A}(x,Q^2) = \frac{Zf_i^{p/A}(x,Q^2)+(A-Z)f_i^{n/A}(x,Q^2)}{A}$$

  where $f_i^{n/A}$ using Isospin symmetry ($f_u^{n/A} = f_d^{p/A}$)
- Assume $\bar{u} = \bar{d} = \bar{s} = s$

TUJU19: Proton baseline fit

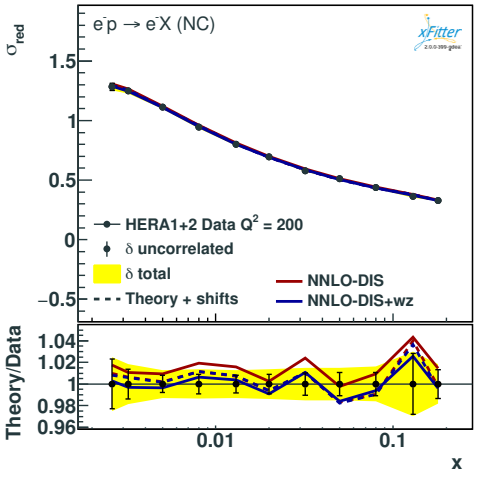
Fit to DIS data

- BCDM (327 data points)
- Combined HERA (1145)
- NMC-97 (100)

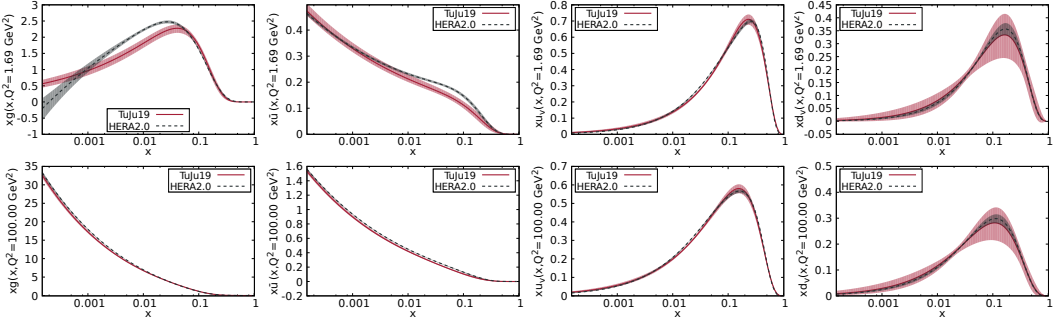
⇒ 1572 data points

- Resulting χ^2 (χ^2/N_{df})
  - NLO: 1846 (1.18)
  - NNLO: 1909 (1.22)

  (13 free parameters)

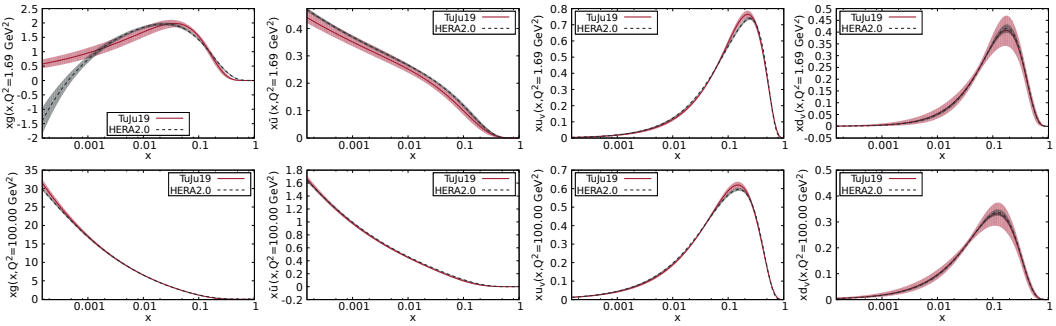


Comparison to HERAPDF2.0 at NLO



- In general a good agreement with HERAPDF2.0 [Eur.Phys.J.C 75 (2015) 12, 580]
- Some differences in small-x gluons at the initial scale, more terms in HERAPDF2.0 parametrization
- Larger uncertainties due to larger $\Delta\chi^2$, 1.0 in HERAPDF2.0, 20 in TUJU19

Comparison to HERAPDF2.0 at NNLO



- Comparisons similar to the NLO results

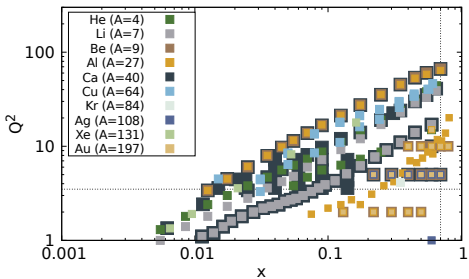
Applied data

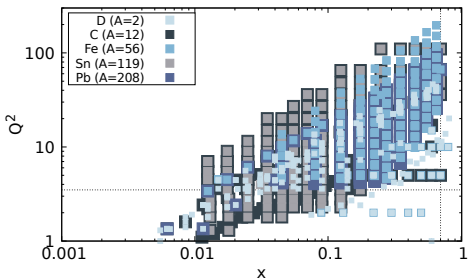
- Nuclear-target DIS, ratios between different A (616 points)
- Neutrino DIS, absolute dσ with Fe and Pb targets, both, neutrino and antineutrino beams (1736)

$\Rightarrow$ 2352 data points

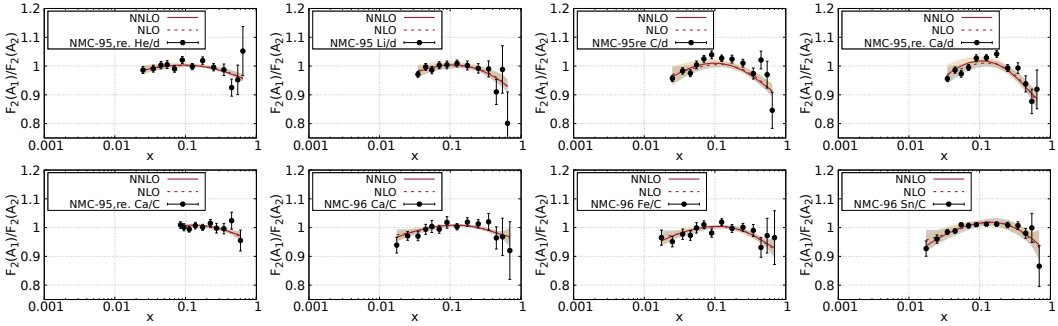
- Resulting χ^2 (χ^2/N_{df})
  - NLO: 2072 (0.887)
  - NNLO: 2014 (0.862)

  (16 free parameters)



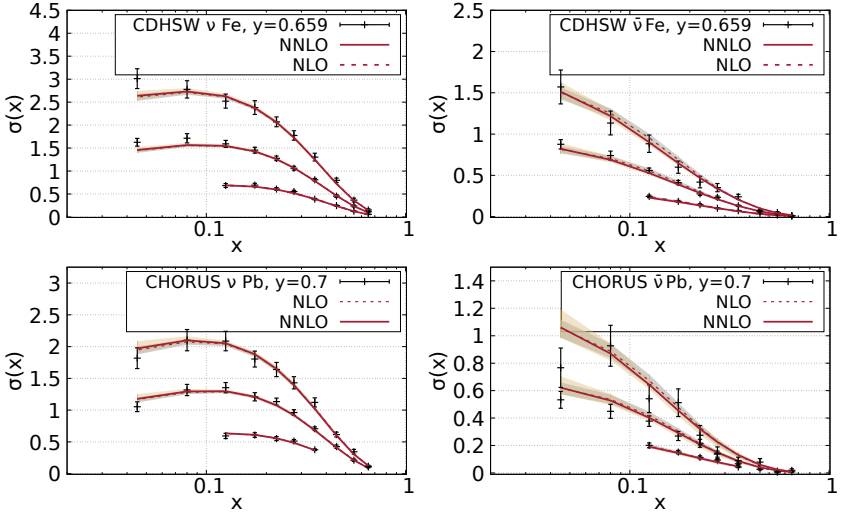


TUJU19: Nuclear PDF results



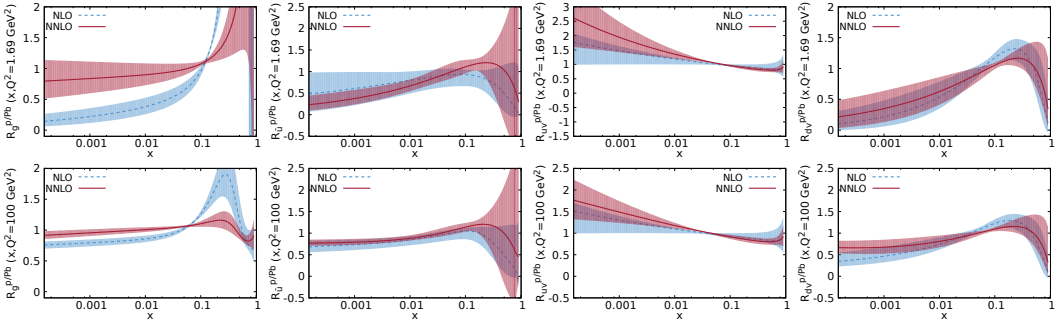
- Sample comparisons to NMC data at NLO and NNLO
- Uncertainty analysis with $\Delta\chi^2 = 50$

TUJU19: Nuclear PDF results



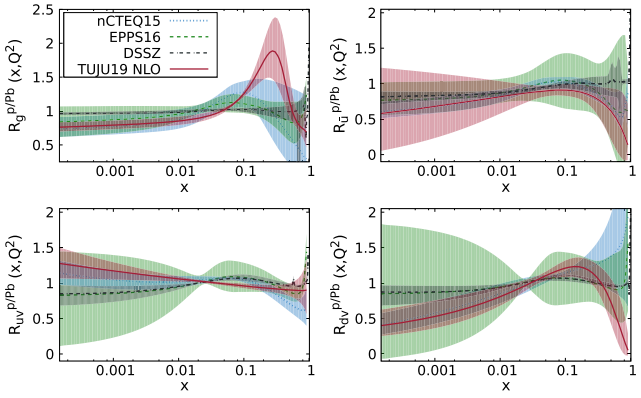
- Sample comparisons to (anti-)neutrino data

TUJU19: Nuclear modification ratios



- Gluons: Stronger shadowing in NLO analysis, also larger antishadowing effect
- Sea quarks: Less small-x suppression in NLO fit
- Valence quarks: Very different modification for u and d,
  nuclear data sensitive only to a certain combination of these

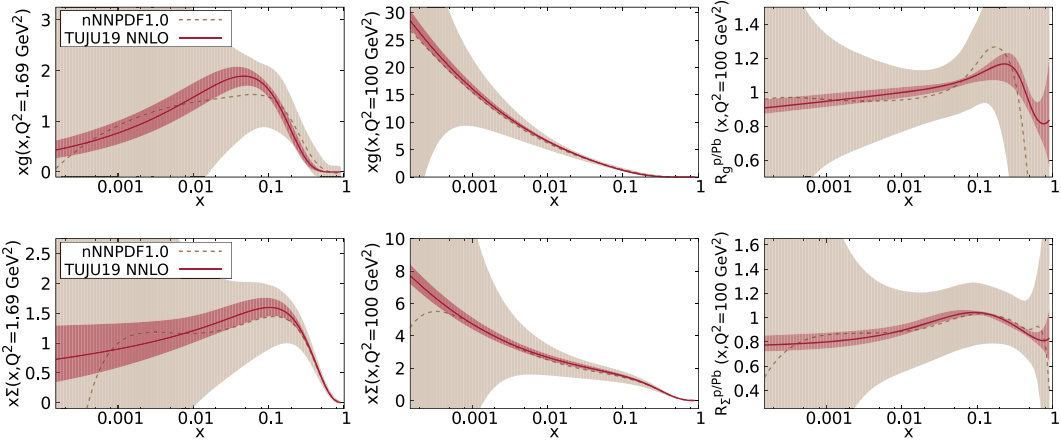
Comparison to other analyses at NLO



Comparison to NLO analyses

- Smaller uncertainty for gluons, larger for sea quarks
- Similar valence-quark modification as in nCTEQ15
- Reasonable agreement within uncertainties

Comparison to other analyses at NNLO



- Central results in a very good agreement for both and PDF and the ratio
- Much wider uncertainties in the nNNPDF1.0 due to NN framework and less data

LHC data for nuclear PDF analyses

Currently available LHC data in p+Pb

- Charged particles and π^0 (ALICE, CMS)
- Direct photons (ATLAS)
- Dijets in (CMS)
- D^0-mesons in (LHCb)
- EW-bosons in p+Pb (ATLAS, CMS)

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- Charged particles and π^0 (ALICE, CMS)
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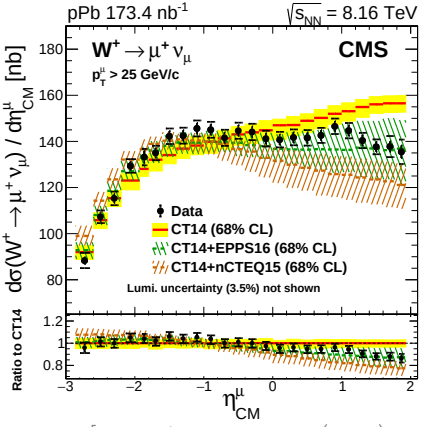
- D^0-mesons in (LHCb)
- EW-bosons in p+Pb (ATLAS, CMS)
  - *Z* from CMS Run I
  - *Z* from ATLAS Run I
  - W^+ from CMS Run II
  - W^- from CMS Run II



[CMS: Phys.Lett.B 800 (2020) 135048]

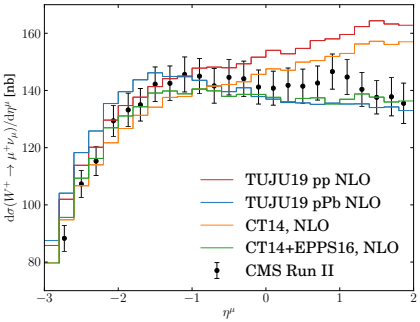
Fitting EW-boson data

Further constraints for

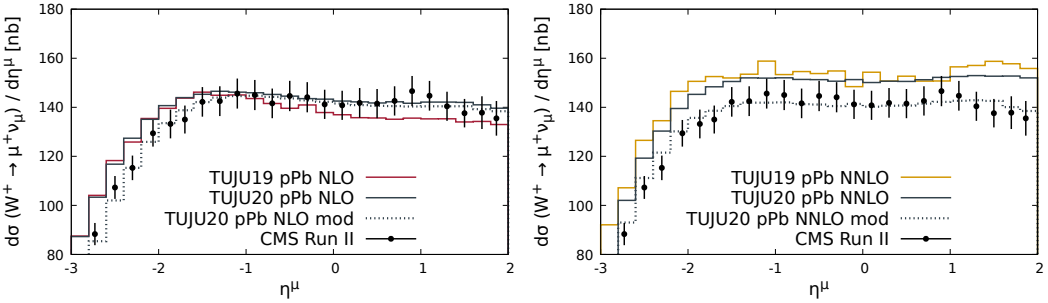
- Sea quarks ($q\bar{q} \to Z$)
- Flavour dependency ($u\bar{d} \to W^+$, $d\bar{u} \to W^-$)
- Gluons at higher orders

Calculation framework

- NNLO calculations publicly available [MCFM 8.0, EPJC 77 (2017) 1, 7]
- Heavy computations, need interpolation grids for fitting
- Include EW data also for proton baseline, implemented in xFitter

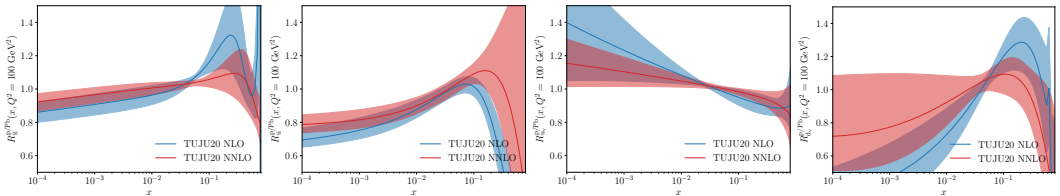


TUJU20 preliminary results



- Good fit when systematic shifts are accounted for (dashed)
- Differences to TUJU19 results rather small, especially at NNLO
- Now 2426 data points, $\chi^2/N_{df} = 0.970$ (NLO) and $\chi^2/N_{df} = 0.895$ (NNLO)

TUJU20 preliminary results



- Better mutual agreement between NLO and NNLO as in TUJU19
- Still very different u_V and d_V modifications
- So far no converged fits if releasing condition $\bar{u} = \bar{d} = \bar{s}$

Summary & Outlook

TUJU19:

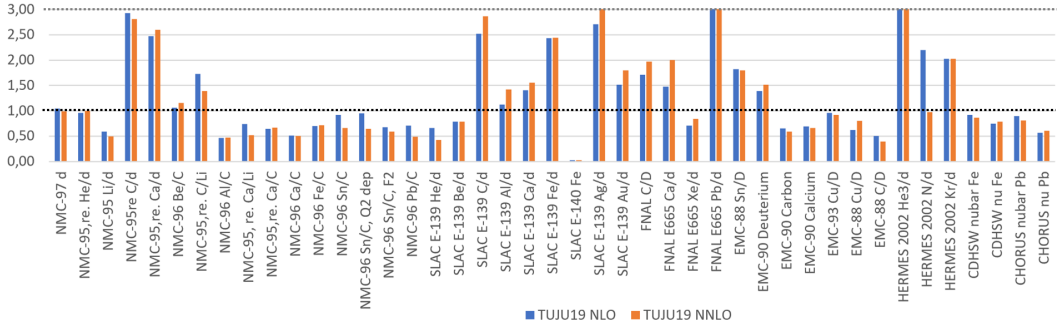
- A new open-source QCD analysis of nuclear PDFs at NLO and NNLO based on xFitter
- Based on DIS data with charged-lepton and (anti-)neutrino beams
- Reasonable agreement with other analyses, similar valence-quark mofications as in nCTEQ15

TUJU20:

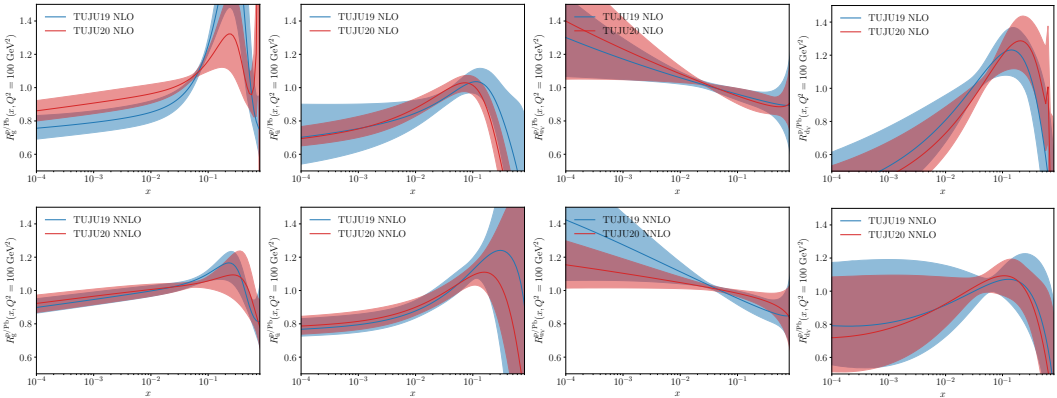
- Re-analysis with the new EW-boson data in p+Pb collisions at the LHC
- Converged fits but results still preliminary
- Some effects for gluons and sea quarks at NLO
- Still very different valence-quark modifications

Backup slides

TUJU19: χ^2/N_{df} for different data sets



TUJU20 preliminary results



- Weaker gluon shadowing when EW-boson data included at NLO
- Smaller sea quark uncertainties at NLO
- NNLO results very similar as without the EW data