Electroweak-boson production in p–Pb and Pb–Pb collisions at the LHC with ALICE

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ALICE 研讨会

Outline

1. Introduction and ALICE detector
2. W production with ALICE
3. Conclusions and perspectives

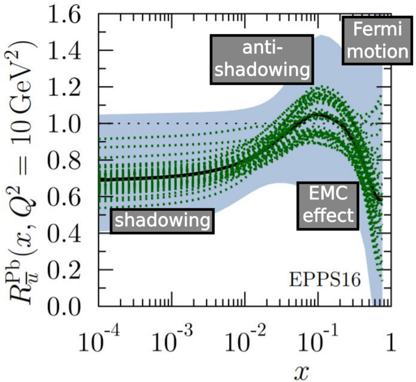
Physics motivation

Z and W bosons: sensitive probes of the nuclear modifications of the parton distribution functions (PDF):

- production well described by perturbative QCD and electroweak theory
- produced in the hard processes, during the initial stages of the collision
- if studied in their leptonic decay: insensitive to the strongly-interacting medium

Production in heavy-ion collisions modified compared to pp collisions following various nuclear effects.

Goal: help constraining the nuclear PDF (nPDF) in models by adding data for their global fits.



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Production cross section: to be compared to the expression obtained with the QCD factorization theorem, expressed at leading order as:

$$\sigma_{AB} \propto \sum_q \frac{4\pi e_q^2 \alpha^2}{9\hat{s}} f_q(x_1, Q^2) f_{\bar{q}}(x_2, Q^2)$$

Nuclear modification factor: investigates the suppression or enhancement of the production due to nuclear effects with respect to pp collisions:

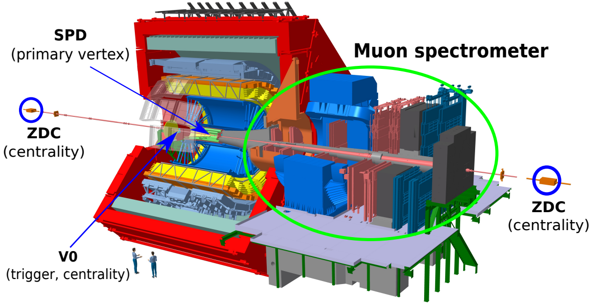
$$R_{\mathrm{AA}} = \frac{1}{\langle T_{\mathrm{AA}} \rangle} \cdot \frac{\mathrm{d}N_{\mathrm{AA}}/\mathrm{d}y}{\mathrm{d}\sigma_{\mathrm{pp}}/\mathrm{d}y}, \qquad R_{\mathrm{pA}} = \frac{1}{A} \cdot \frac{\mathrm{d}\sigma_{\mathrm{pA}}/\mathrm{d}y}{\mathrm{d}\sigma_{\mathrm{pp}}/\mathrm{d}y}$$

with T_{AA}: nuclear overlap function from Glauber model.

W charge asymmetry: sensitive to the down/up ratio and to quark densities in the nucleus:

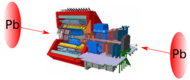
$$A = \frac{N_{\mu^+ \leftarrow W^+} - N_{\mu^- \leftarrow W^-}}{N_{\mu^+ \leftarrow W^+} + N_{\mu^- \leftarrow W^-}}.$$

The ALICE detector



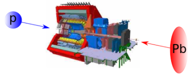
Large rapidities: probing of the low ($\sim 10^{-4}$ to $\sim 10^{-3}$) and high ($\sim 10^{-1}$ to almost unity) Bjorken-x regions

Pb–Pb:



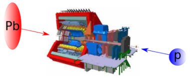
$$2.5 < y_{\mathrm{cms}} < 4$$

p–Pb, p-going:



$$2.03 < y_{\mathrm{cms}} < 3.53$$

p–Pb, Pb-going:



$$-4.46 < y_{\mathrm{cms}} < -2.96$$

W production with ALICE

Collision system	Energy	Luminosity	Year	Analyses
Pb–Pb	5.02 TeV	$\sim$ 225 μb^{-1}	2015	W
p–Pb Pb–p	5.02 TeV	5.03 $\pm$ 0.18 nb^{-1} 5.81 $\pm$ 0.20 nb^{-1}	2013	W
p–Pb Pb–p	8.16 TeV	8.47 $\pm$ 0.18 nb^{-1} 12.77 $\pm$ 0.25 nb^{-1}	2016	W

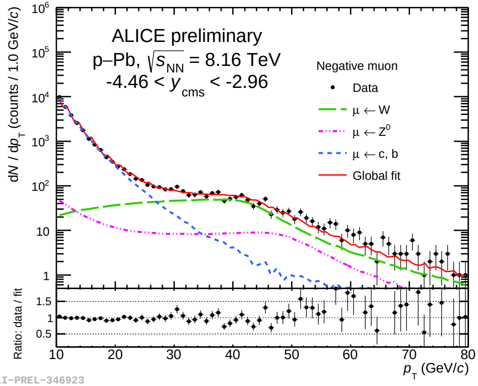
- W in Pb–Pb at $\sqrt{s_{\rm NN}} = 5.02$ TeV: measurement combining the data from the 2015 and 2018 periods.
- W in p–Pb at $\sqrt{s_{\rm NN}} = 8.16$ TeV.

W-boson yield extraction

W extraction: Fit of the single muons p_{T} distribution:

$$f(p_{\mathrm{T}}) = N_{\mathrm{HF}} \cdot f_{\mathrm{HF}}(p_{\mathrm{T}}) + N_{\mu\leftarrow W} \cdot (f_{\mu\leftarrow W}(p_{\mathrm{T}}) + R \cdot f_{\mu\leftarrow Z}(p_{\mathrm{T}}))$$

- $f_X(p_{\mathrm{T}})$: MC templates (FONLL, POWHEG),
- N_X: free parameters,
- R: ratio of the Z to W cross sections from POWHEG.



In the fiducial region:

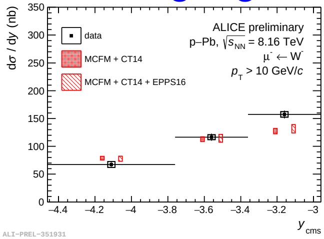
$$\begin{cases} -4 < \eta_\mu < -2.5, \\ p_{\mathrm{T}}(\mu) > 10 \text{ GeV}/c. \end{cases}$$

Raw yield corrected for the acceptance × efficiency of the detector.

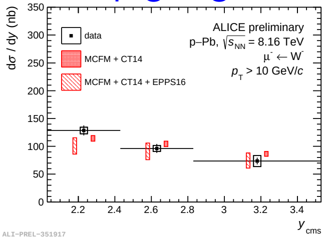
Differential cross sections as a function of rapidity, compared to theoretical predictions.

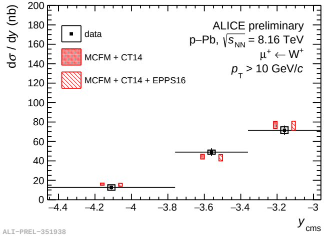
- Deviation from theory for W^{-} at backward rapidity in the most central bin

W^{-} Pb-going

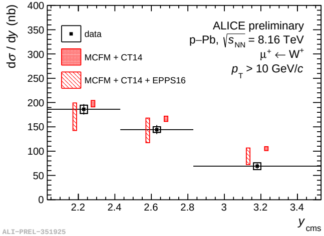


W^{-} p-going





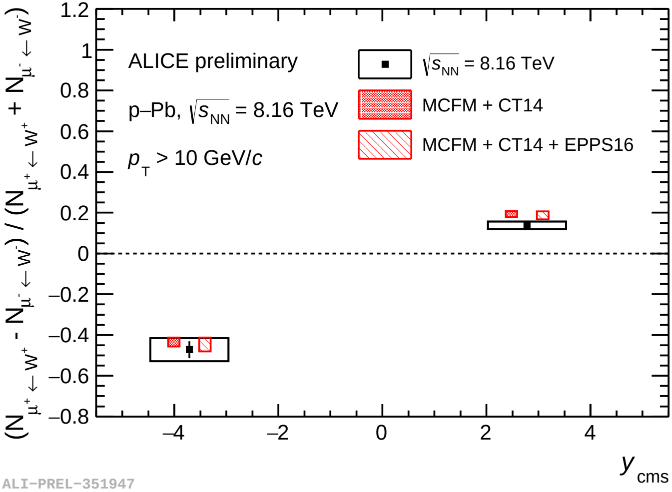
W^{+} Pb-going



W^{+} p-going

$W^{\pm}$ in p–Pb at 8.16 TeV

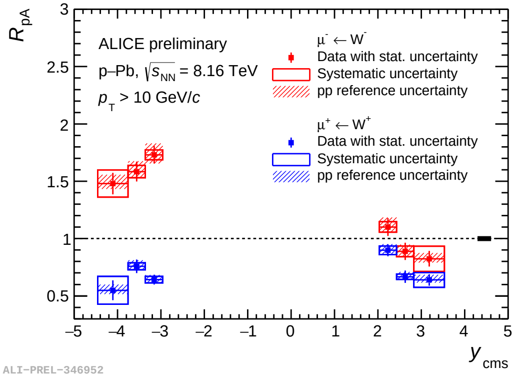
Lepton charge asymmetry compared with theoretical predictions.



$W^{\pm}$ in p–Pb at 8.16 TeV

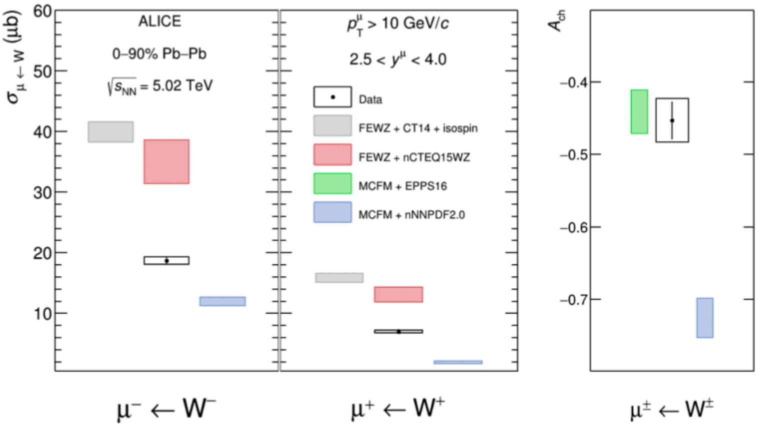
Nuclear modification factor: measured as a function of rapidity.

Reference cross section obtained from calculations with POWHEG and CT10nlo.



Deviation from 1 associated to isospin and nuclear effects.

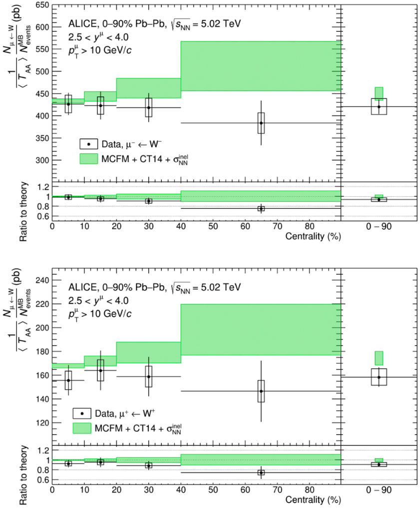
$W^{\pm}$ in Pb–Pb at 5.02 TeV (New)



- Large deviation compared with theory.

$W^{\pm}$ in Pb–Pb at 5.02 TeV (New)

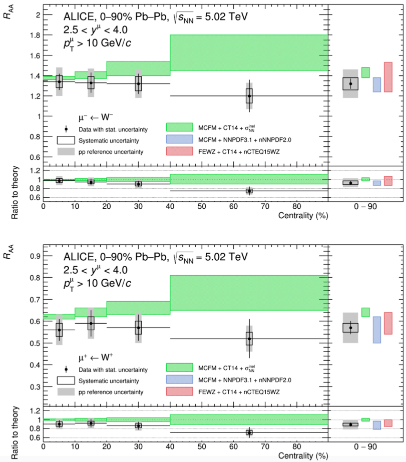
First measurement of W in Pb–Pb at large rapidities.



- Normalized yield: $N_{\mathrm{W}}/(N_{MB}T_{\mathrm{AA}})$
- Cross-section per nucleon.
- Expected scaling of N_{W} with T_{AA}:
- Compared with MCFM+CT14 prediction.

$W^{\pm}$ in Pb–Pb at 5.02 TeV (New)

Nuclear modification factor: using reference cross section from POWHEG + CT10nlo.



- No obvious centrality dependence is observed.
- Consistent with predictions in the 0-90% centrality region.
- MCFM+CT14 over estimate the R_{AA} in peripheral region.

Conclusions and perspectives

In p–Pb:

- significant increase of statistics compared to analyses at 5.02 TeV, deviation of the measured W production from free-PDF calculation observed at large rapidities

In Pb–Pb:

- first measurement of the W production at forward rapidity, merged with the 2018 data
- statistic uncertainty dominates, can have improvement with Run3 and Run4 data

Large amount of measurements at large rapidities provide extra inputs for nPDFs global fits.

Thank you for your attention!

Back-up

PDG 2018:

$$m_Z = 91.1876 \pm 0.0021\ \text{GeV}/c^2$$
$$\Gamma_Z = 2.4952 \pm 0.0023\ \text{GeV}$$
$$BR_{Z\to\mu^+\mu^-} = 3.3662 \pm 0.0066\ \%$$

$$m_W = 80.379 \pm 0.012\ \text{GeV}/c^2$$
$$\Gamma_W = 2.085 \pm 0.042\ \text{GeV}$$
$$BR_{W\to\mu\nu} = 10.63 \pm 0.15\ \%$$

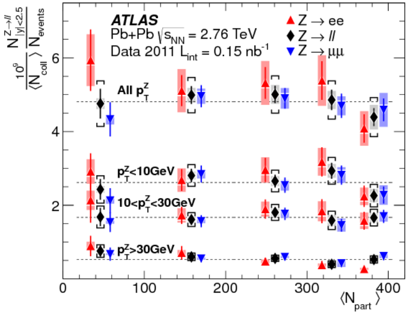
Higher order processes: include gluon and photon initial and final state radiations:

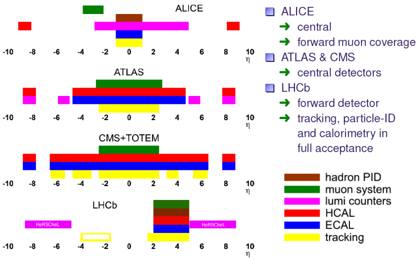
$$q+\bar{q} \to W+g \qquad q+\bar{q} \to Z+g$$
$$q+\bar{q} \to W+\gamma \qquad q+\bar{q} \to Z+\gamma$$
$$q+g \to W+q' \qquad q+g \to Z+q'$$
$$q+\gamma \to W+q' \qquad q+\gamma \to Z+q'$$

Why measuring Z and W in HIC

- Probing the cold nuclear effects,
- reference for hot matter effects,
- calibration of muons and electrons detectors,
- estimator of the collision centrality.

Phys. Rev. Lett. 110, 022301 (2013)





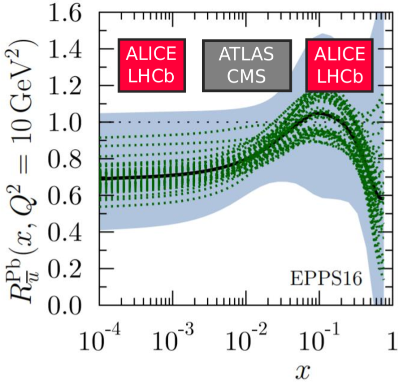
Complementarity of the coverages between the LHC experiments, allow to probe several Bjorken-x ranges.

Z and W at the LHC

Large rapidities: probing of the low ($\sim 10^{-4}$ to $\sim 10^{-3}$) and high ($\sim 10^{-1}$ to almost unity) Bjorken-x regions.

Complementary between the LHC experiments in term of Bjorken-x coverages:

- ALICE and LHCb at high and low-x,
- ATLAS and CMS at mid-x.



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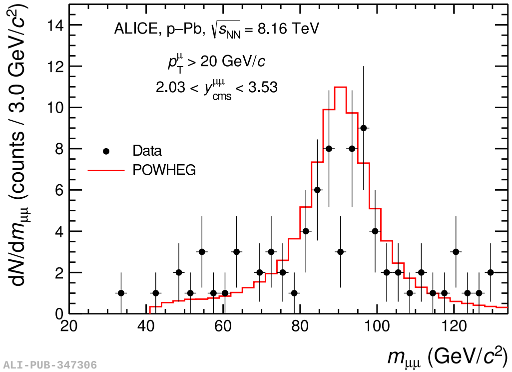
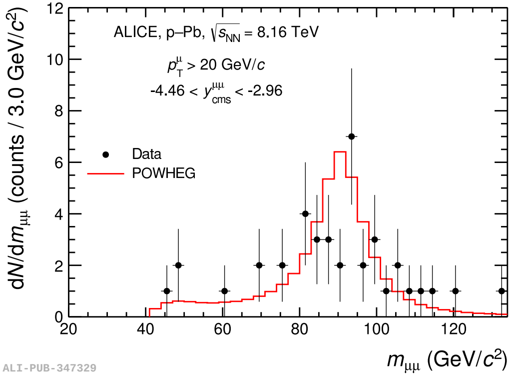
Z signal extraction in p–Pb at 8.16 TeV

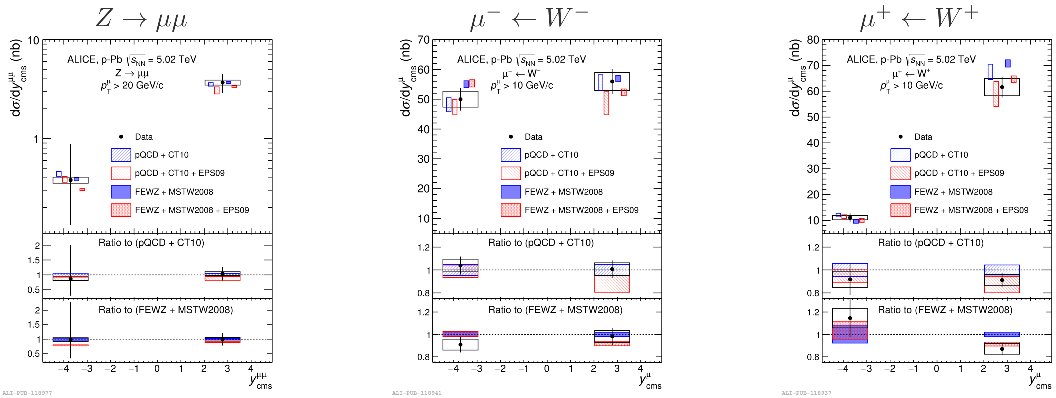
Dimuon invariant mass distribution after selection, compared with simulated distribution scaled to the number of events in the data.





arXiv:2005.11126

$W^{\pm}$ and Z p–Pb at 5.02 TeV



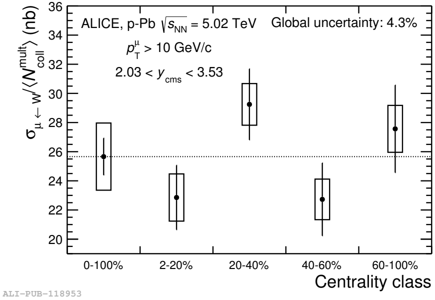
JHEP 1702 (2017) 077

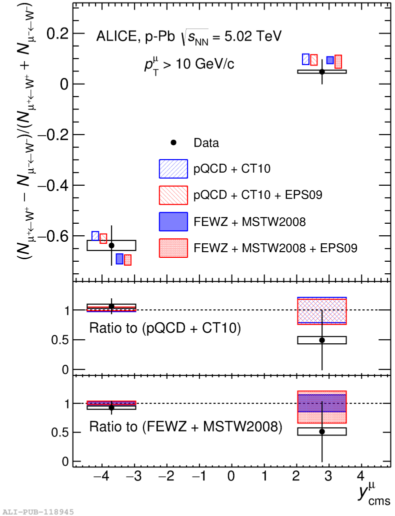
Cross-sections compared to pQCD and FEWZ: agreement with and without including nPDFs.

$W^{\pm}$ and Z bosons results in p–Pb at 5.02 TeV

Lepton charge asymmetry: partial cancellation of uncertainties, still compatible with and without including nPDFs.

Centrality dependence: compatible with constant (within uncertainties), scaling of the cross-section with the number of binary collisions.





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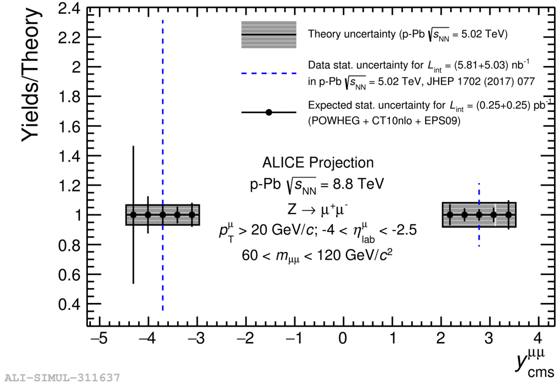
Z uncertainty in run 3

Z uncertainty comparison between run 2 data and run 3 expectation

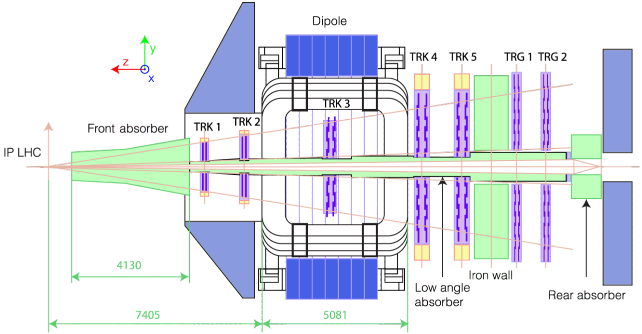
⇒ large reduction of the uncertainty, which becomes of the same order as the one on theoretical predictions.



ALICE-PUBLIC-2019-001

ALICE: muon spectrometer

ALICE Twiki



Trigger: 18 resistive plate chambers in two stations.

Tracking: 10 multi-wire proportional chambers, two-by-two in five stations.

Dipolar magnet: integrated field of 3 T m for charge and momentum measurements.

Absorbing system: background rejection.

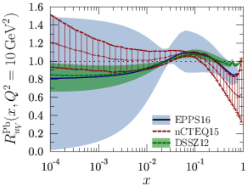
Nuclear effects

Shadowing and **anti-shadowing**: increase or decrease of the production following from constructive or destructive interferences of amplitudes arising from multiple scattering of partons in the nucleus.
EMC effect: not totally understood, believed to come from the modification of the nucleon radius and mass as well as multi-nucleons effects in the nucleus.
Fermi motion: dynamics of the nucleons in the nucleus.

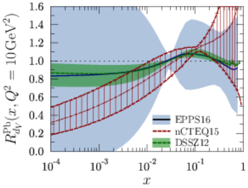
Color glass condensate: gluon density saturation reached in nucleus (from Lorentz contraction).
Cronin effect: broadening of the p_T spectra due to nucleon-nucleon interactions in the nucleus.
Nuclear absorption: breaking of a bound state passing through a nuclei.
Parton energy loss: elastic scattering from displacements inside the nucleus before hard scattering.
Comovers absorption: interaction between comovers as they move away from the interaction point.
Colour screening and sequential dissociation: dissociation of quarkonia bound states when the radius reaches the Debye screening radius.
Regeneration: new bound states created by initially produced quark and antiquarks.

nPDF models

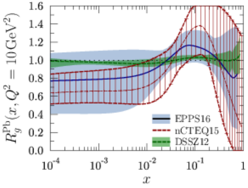
Up (valence):



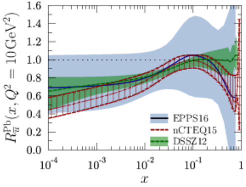
Down (valence):



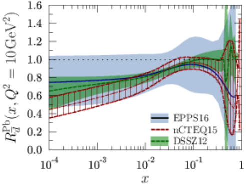
Gluon:



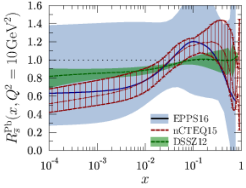
Anti-up:



Anti-down:



Anti-strange:



PoS (HardProbes2018) 014

nPDF models

nPDF set	EPS09	nCTEQ15	EPPS16
Order	NLO	NLO	NLO
Flavour separation		valence quarks	valence + sea quarks
Proton baseline	CTEQ6.1	CTEQ6M-like	CT14NLO
Free parameters	15	35	52
Data points	929	708	1811
Included experimental data			
DIS in l^-+A	✓	✓	✓
Drell-Yan in p+A	✓	✓	✓
RHIC pions d+Au	✓	✓	✓
ν-nucleus DIS			✓
Drell-Yan in π+A			✓
LHC p–Pb dijets			✓
LHC p–Pb W and Z			✓

nPDF models

EPPS16 – nCTEQ15 comparison:

- **Valence quarks**: u and d independently parametrized, both models consistent with one another.
- **Sea quarks**: u, d and s independently parametrized in EPPS16, while not in nCTEQ15 $\Rightarrow$ more uncertainty but less bias (uncertainty mostly comes from strange quark).

Gluons: at large Bjorken-x, smaller uncertainty in EPPS16 due to constrains from LHC dijet data. At small Bjorken-x, smaller uncertainty in nCTEQ15 following from the form of the fit.

PoS (HardProbes2018) 014