# LHeC impact on PDF determination


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Future of DIS Working Group

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# Introduction

- The present study aims to assess the impact of LHeC data in PDF determination
- We will consider the separate impact of inclusive NC and CC data for various scenarios of LHeC operation
- We will also estimate the impact of other measurements: red $sW \to c$, $F_2^c$ and $F_L$
- The baseline PDF set is **NNPDF2.0**, a global fit of DIS, DY and Jet data $\to$ see M. Ubiali's talk
- For illustration, we will show when required results from **NNPDF1.0** (based on inclusive DIS data) and **NNPDF1.2** (which includes dimuon data to constrain $s, \bar{s}$)

# Bayesian Reweighting

Assessing the impact of new data on PDF fits

- The $N_{\mathrm{rep}}$ replicas of a NNPDF fit give the probability density in the space of PDFs
- **Expectation values** for observables are **Monte Carlo integrals**

$$\langle \mathcal{F}[f_i(x,Q^2)]\rangle = \frac{1}{N_{rep}} \sum_{k=1}^{N_{rep}} \mathcal{F}\left( f_i^{(net)(k)}(x,Q^2) \right)$$

... the same is true for errors, correlations, etc.

- We can assess the impact of including new data in the fit updating the probability density distribution taking into account the new data

# Bayesian Reweighting

## Assessing the impact of new data on PDF fits

- According to Bayes Theorem we have

$$P_{\rm new}(\lambda) = P(\lambda|x^e) = \frac{P(x^e|\lambda)P_{\rm init}(\lambda)}{P(x^e)}\,, \qquad P(x^e|\lambda) = e^{-\frac{\chi^2_{\rm new}(\lambda)}{2}}$$

- Monte Carlo integrals defining observables dependent on PDFs are now given by weighted sums

$$\langle \mathcal{F}[f_i(x,Q^2)]\rangle = \sum_{k=1}^{N_{rep}} w_k \mathcal{F}\left(f_i^{(net)(k)}(x,Q^2)\right)$$

where the weights are given by

$$w_k = \frac{e^{-\frac{1}{2}\chi^2_{\rm new}(\lambda^k)}}{\sum_{i=1}^{N_{\rm rep}} e^{-\frac{1}{2}\chi^2_{\rm new}(\lambda^i)}}$$

(Giele, Keller, Kosower, hep-ph/0104052)

# LHeC STUDIES
# Inclusive Data

# LHeC Scenarios

Different scenarios for **LHeC** under investigation:

| config. | E(e) | E(N) | N | ∫L($e^+$) | ∫L($e^-$) | \|Pol\| | L/$10^{32}$ | P/MW | years | type |
|---|---|---|---|---|---|---|---|---|---|---|
| A | 20 | 7 | p | 1 | 1 | - | 1 | 10 | 1 | SPL |
| B | 50 | 7 | p | 50 | 50 | 0.4 | 25 | 30 | 2 | RR hi$Q^2$ |
| C | 50 | 7 | p | 1 | 1 | 0.4 | 1 | 30 | 1 | RR lo x |
| D | 100 | 7 | p | 5 | 10 | 0.9 | 2.5 | 40 | 2 | LR |
| E | 150 | 7 | p | 3 | 6 | 0.9 | 1.8 | 40 | 2 | LR |
| F | 50 | 3.5 | D | 1 | 1 | -- | 0.5 | 30 | 1 | eD |
| G | 50 | 2.7 | Pb | 0.1 | 0.1 | 0.4 | 0.1 | 30 | 1 | ePb |
| H | 50 | 1 | p | -- | 1 | -- | 25 | 30 | 1 | lowEp |

- Pseudodata are given for all different scenarios at

  `http://liv.ph.ac.uk/~mklein/simdis09.html`

- Pseudodata included: positron and electron beams, Neutral- and Charged-Current reduced cross-sections ($\tilde{\sigma}^{+,-}_{\mathrm{NC,CC}}$)

- NLO pseudodata generated according to NNPDF2.0 central value

- Scenarios studied: A-E

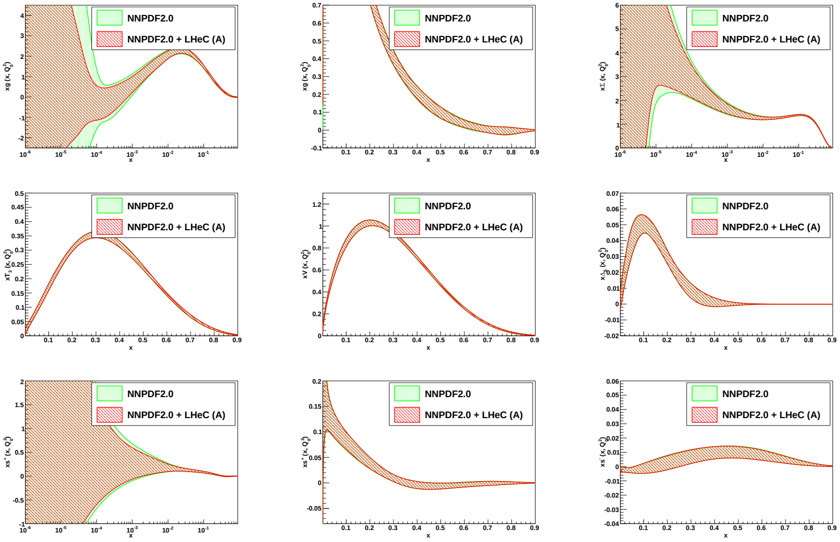
# LHeC Scenarios

## Pseudodata

- The various LHeC scenarios are not exclusive $\rightarrow$ Each scenario assumes 1-2 years of running, while total LHC operation is $\sim$ 10 years
- A reasonable expectation for the **"total LHeC dataset"** includes
  1. Inclusive data: B+C+F+H scenarios (High-$Q^2$ + Low-$x$ + Deuteron run + Lower $E_p$ run)
  2. $F_L(x, Q^2)$ data (from scenario H)
  3. $F_2^c(x, Q^2)$ data (from low-$x$ run)
  4. Strangeness $s, \bar{s}$ determination from $sW \rightarrow c$
- Here we study the impact of each scenario separately $\rightarrow$ The combined impact of the **"total LHeC dataset"** will be presented for CDR

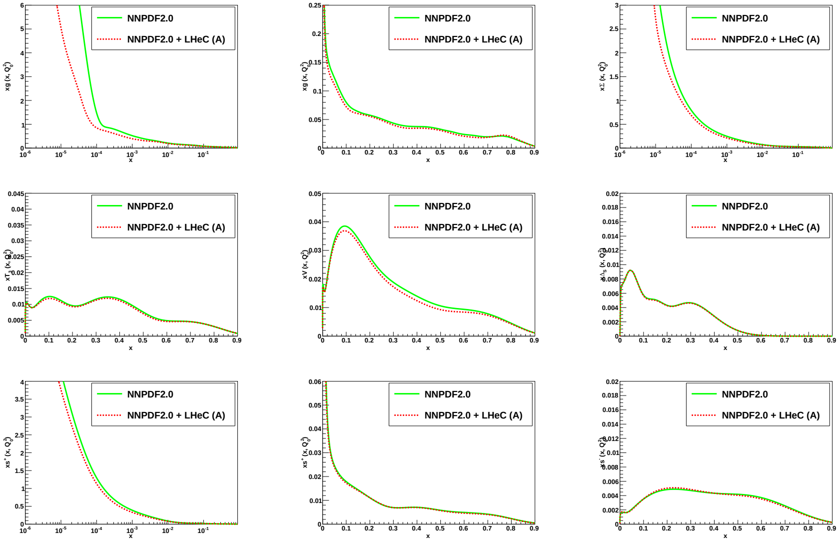
# LHeC Scenarios

Scenario A: $E_e = 20$ GeV, $E_p = 7$ TeV, SPL, 1 year



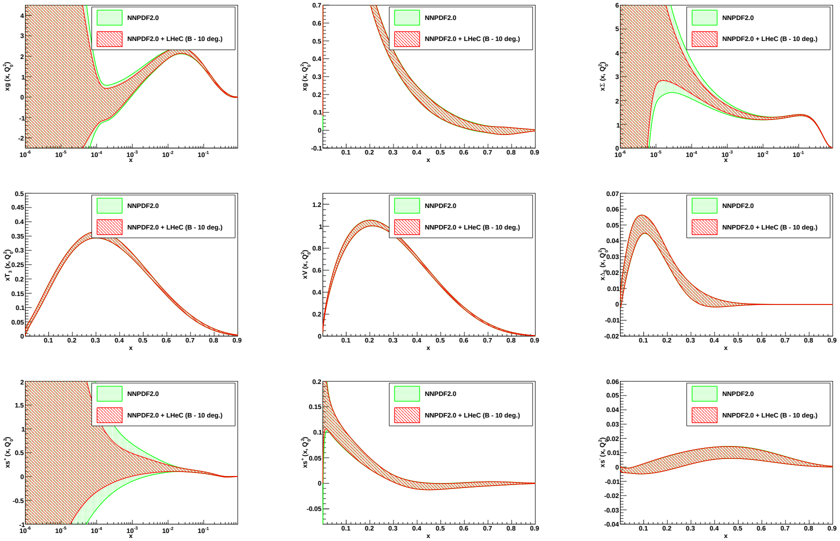
# LHeC Scenarios

Scenario A: $E_e = 20$ GeV, $E_p = 7$ TeV, SPL, 1 year



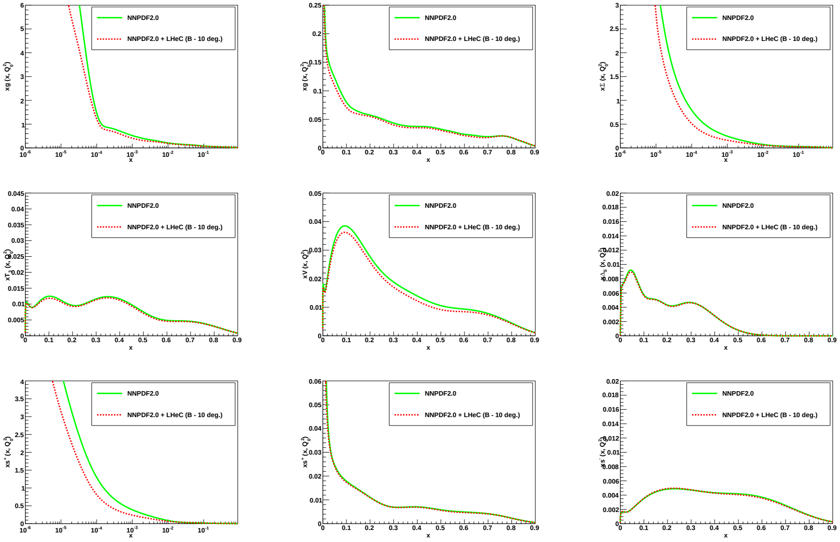
# LHeC Scenarios

Scenario B: $E_e = 50$ GeV, $E_p = 7$ TeV, RR high-$Q^2$, 2 year ($10^\circ$ cut)



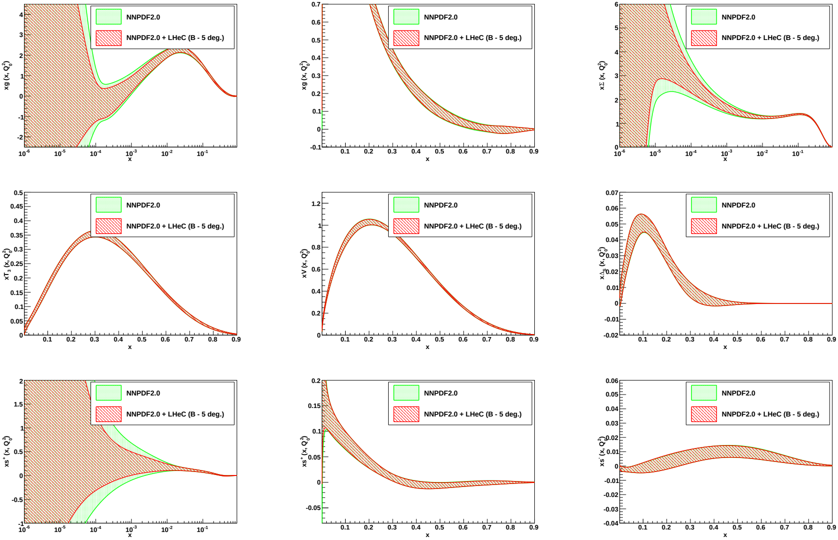
# *LHeC Scenarios*

Scenario B: $E_e = 50$ GeV, $E_p = 7$ TeV, RR high-$Q^2$, 2 year ($10^\circ$ cut)



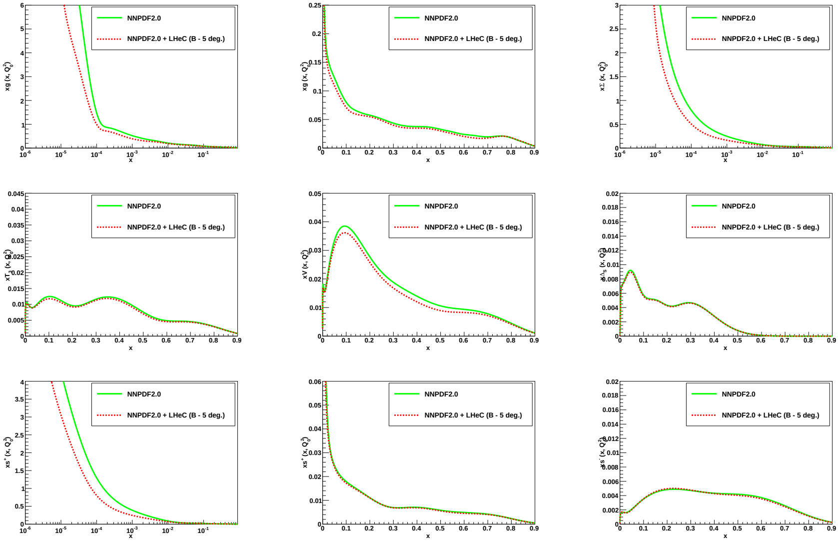
# LHeC Scenarios

Scenario B: $E_e = 50$ GeV, $E_p = 7$ TeV, RR high-$Q^2$, 2 year ($5^\circ$ cut)



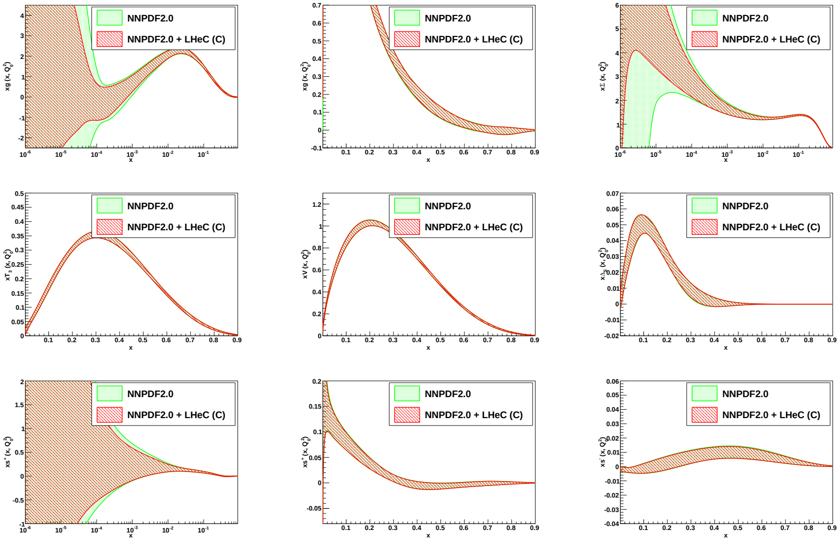
# LHeC Scenarios

Scenario B: $E_e = 50$ GeV, $E_p = 7$ TeV, RR high-$Q^2$, 2 year ($5^\circ$ cut)



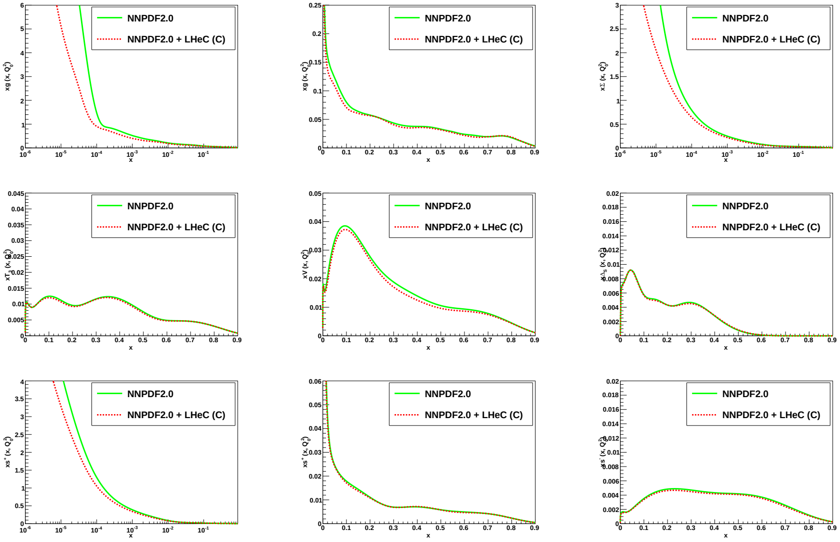
# *LHeC Scenarios*

Scenario C: $E_e = 50$ GeV, $E_p = 7$ TeV, RR low-$x$, 1 year



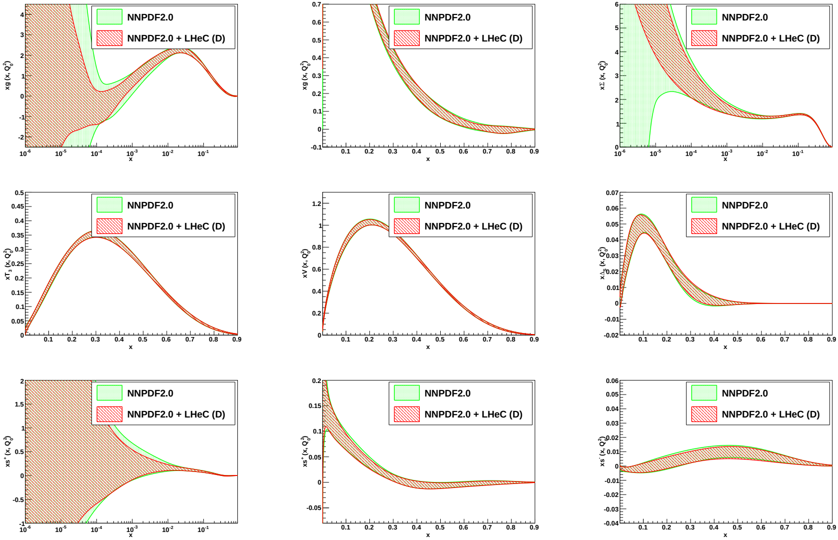
# LHeC Scenarios

Scenario C: $E_e = 50$ GeV, $E_p = 7$ TeV, RR low-$x$, 1 year



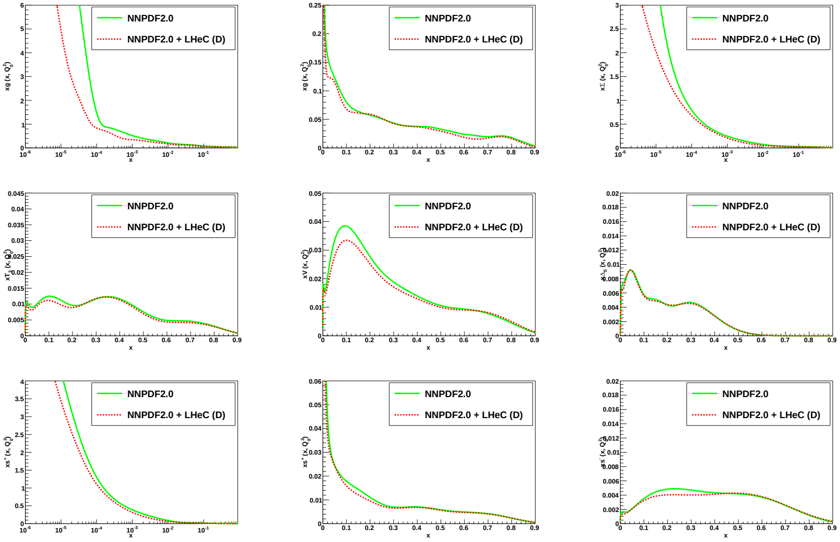
# *LHeC Scenarios*

Scenario D: $E_e = 100$ GeV, $E_p = 7$ TeV, LR, 2 years



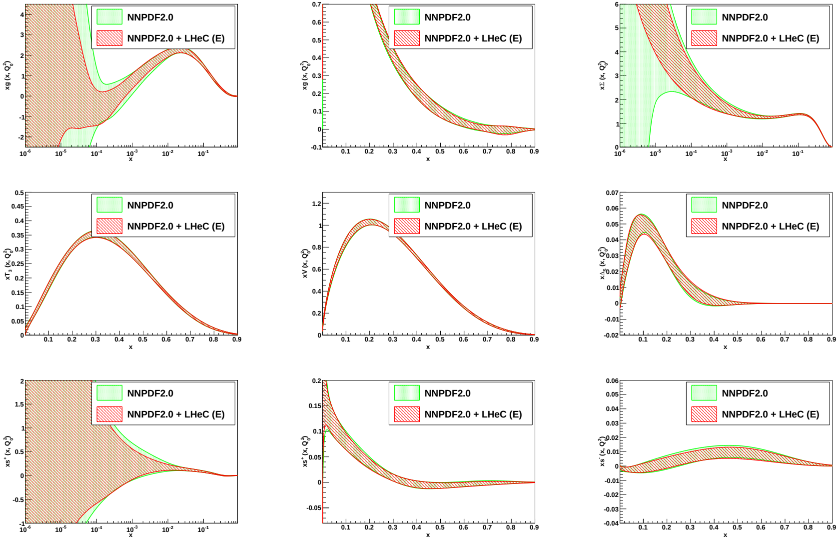
# *LHeC Scenarios*

Scenario D: $E_e = 100$ GeV, $E_p = 7$ TeV, LR, 2 years



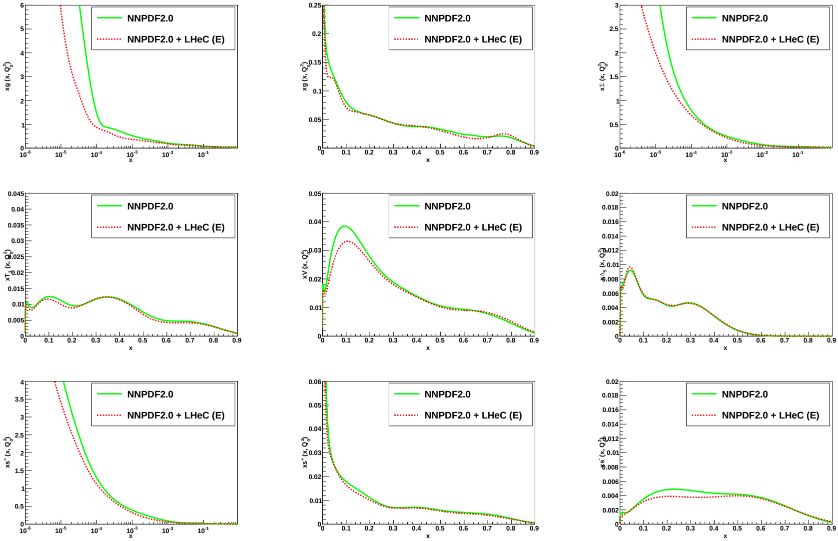
# *LHeC Scenarios*

Scenario E: $E_e = 150$ GeV, $E_p = 7$ TeV, LR, 2 years



# LHeC Scenarios

Scenario E: $E_e = 150$ GeV, $E_p = 7$ TeV, LR, 2 years



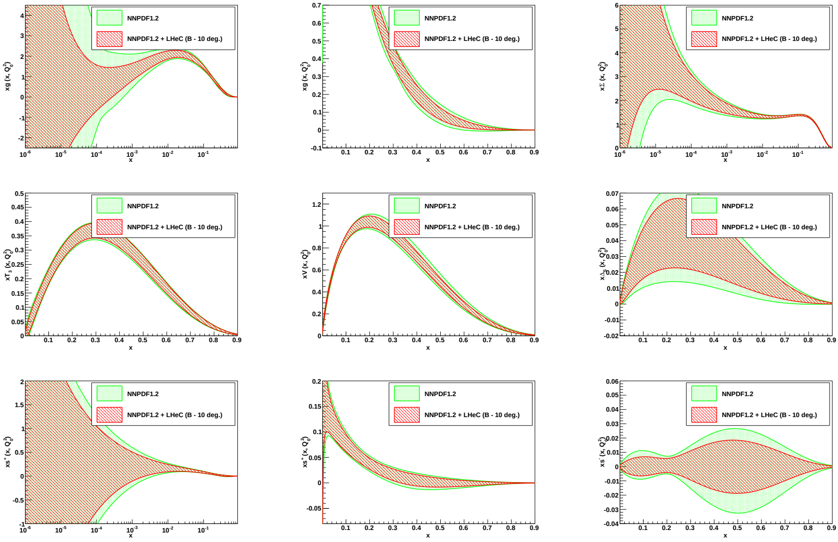
# LHeC Scenarios

## LHeC impact on NNPDF2.0

- For the A-E scenarios, the improvement on PDFs concentrated at small-$x$ - Singlet and gluon
- Large-$x$ valence PDFs from NNPDF2.0 already well constrained from fixed target DIS, Drell-Yan and vector boson production data
- To assess the impact of high-$Q^2$ (large-$x$) LHeC data on a DIS-only fit, revisit scenario B with NNPDF1.2
- As expected, high-$Q^2$ LHeC data has a larger impact in a DIS-only fit than in a global fit

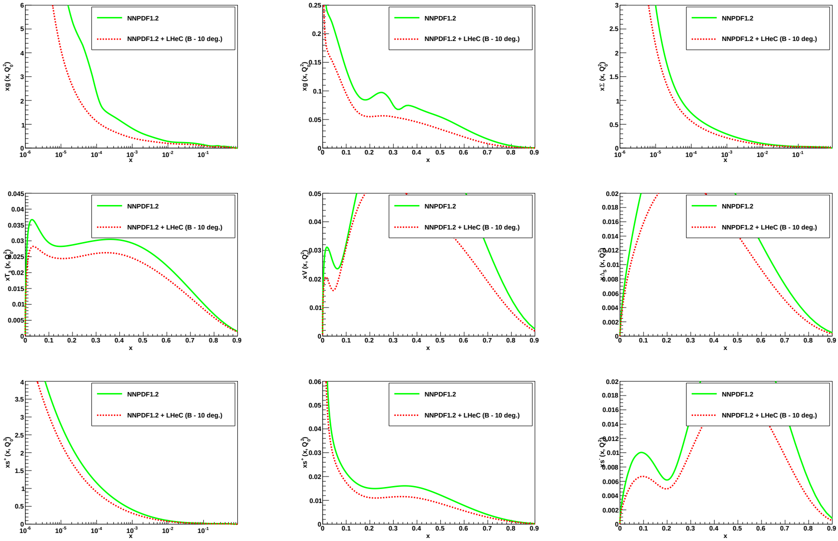
# *LHeC Scenarios - NNPDF1.2*

Scenario B: $E_e = 50$ GeV, $E_p = 7$ TeV, RR high-$Q^2$, 2 year ($10^\circ$ cut)



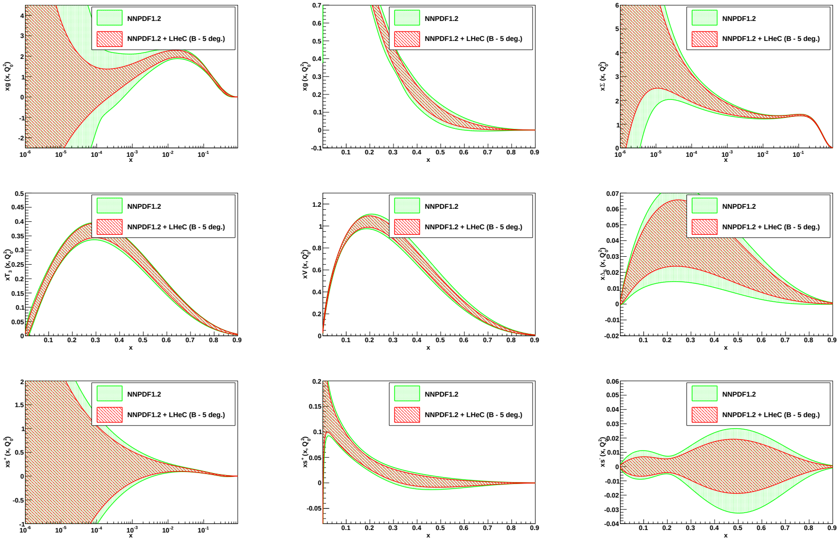
# *LHeC Scenarios - NNPDF1.2*

Scenario B: $E_e = 50$ GeV, $E_p = 7$ TeV, RR high-$Q^2$, 2 year ($10^\circ$ cut)



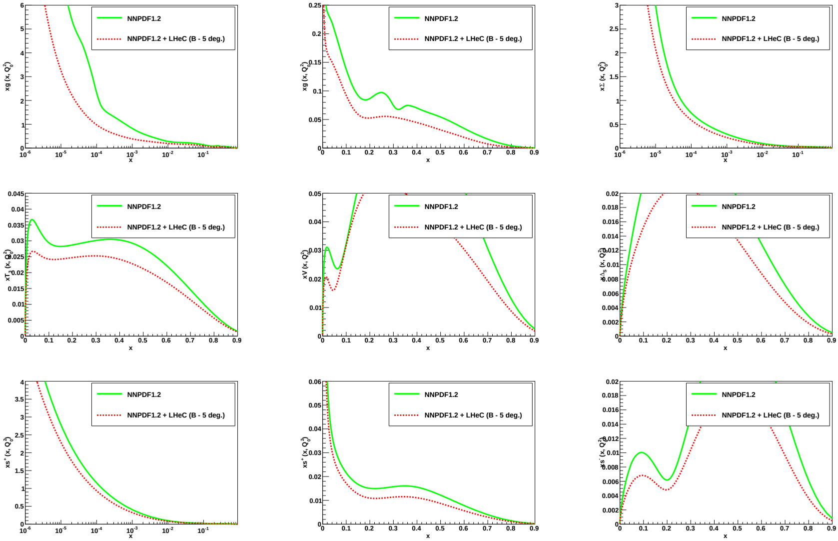
# LHeC Scenarios - NNPDF1.2

Scenario B: $E_e = 50$ GeV, $E_p = 7$ TeV, RR high-$Q^2$, 2 year ($5^\circ$ cut)



# LHeC Scenarios - NNPDF1.2

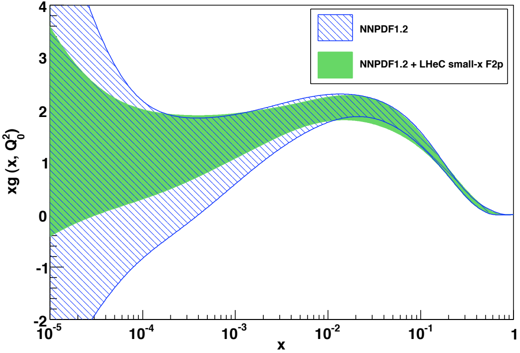
Scenario B: $E_e = 50$ GeV, $E_p = 7$ TeV, RR high-$Q^2$, 2 year ($5^\circ$ cut)



# The longitudinal structure function $F_L(x, Q^2)$

From the lower $E_p$ LHeC runs

Gluon uncertainties with small-$x$ $F_2^p$ LHeC data only

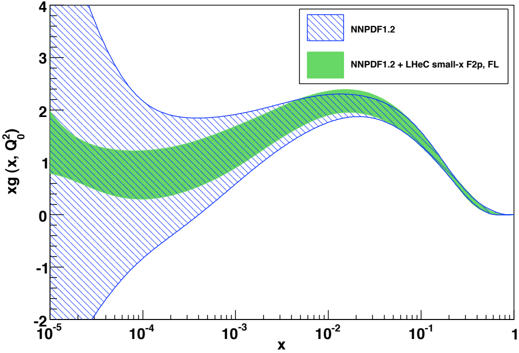



Modest error reduction of gluon at small-$x$, need $F_L$ for more

# The longitudinal structure function $F_L(x, Q^2)$

From the lower $E_p$ LHeC runs

Gluon uncertainties with small-$x$ $F_2^p$ and $F_L^p$ LHeC data



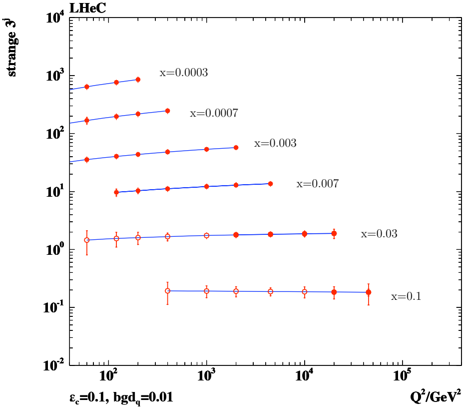

→ Sizable error reduction of gluon at small-$x$ requires LHeC $F_L$ data

# LHeC STUDIES
# Exclusive Data

# Constraints on Strangeness

*Ws* → *c*: Exclusive CC charm production

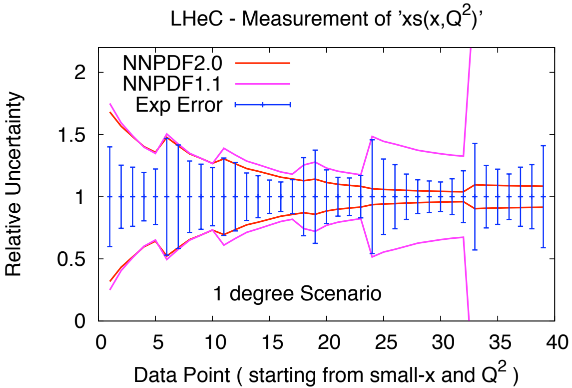
Compare expected accuracy on *′xs(x)′* at LHeC with NNPDF2.0 uncertainties



# Constraints on Strangeness

## $Ws \to c$: Exclusive CC charm production

LHeC errors on $'xs(x)'$ smaller than NNPDF2.0 at small-$x$ $\to$ Impact of LHeC data for strangeness constraints
If compared with NNPDF1.1 (DIS-only fit, free strangeness) LHeC $s$, $\bar{s}$ would constrain strangeness in all the kinematical range

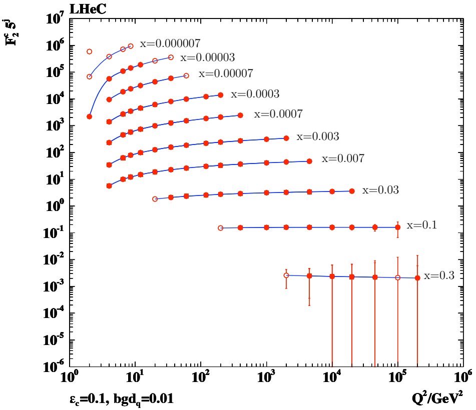



**Important**: Assumed central values for NNPDF2.0 $\to$ Even more significant improvements if current neutrino data has problems!

# *Constraints on the Gluon through $F_2^c(x, Q^2)$*

$\gamma^* g \to c$: NC charm production

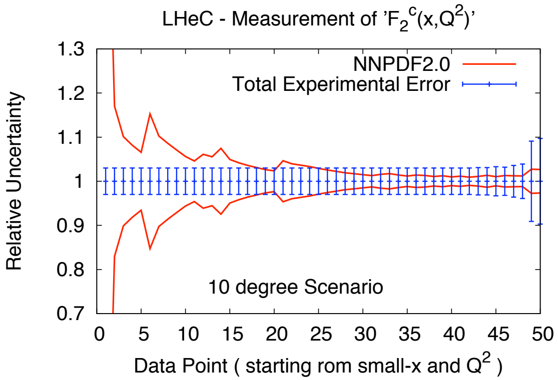
Compare expected accuracy on $F_2^c(x, Q^2)$ at LHeC with NNPDF2.0 uncertainties



# ***Constraints on the Gluon through*** $F_2^c(x, Q^2)$

$\gamma^* g \to c$: NC charm production

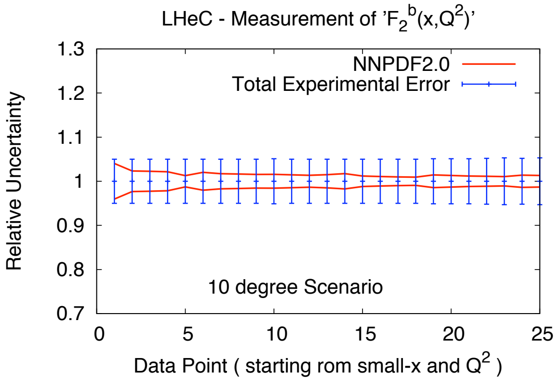
Small-$x$,$Q^2$ $F_2^c$ measurements will provide very important constraints on the small-$x$ gluon



# Constraints on the Gluon through $F_2^c(x, Q^2)$

$\gamma^* g \to c$: NC charm production

Small-$x$,$Q^2$ $F_2^b$ measurements not accurate enough to provide constraints on the small-$x$ gluon




However, $F_2^b$ might be a very useful probe of new small-$x$ HQ production dynamics

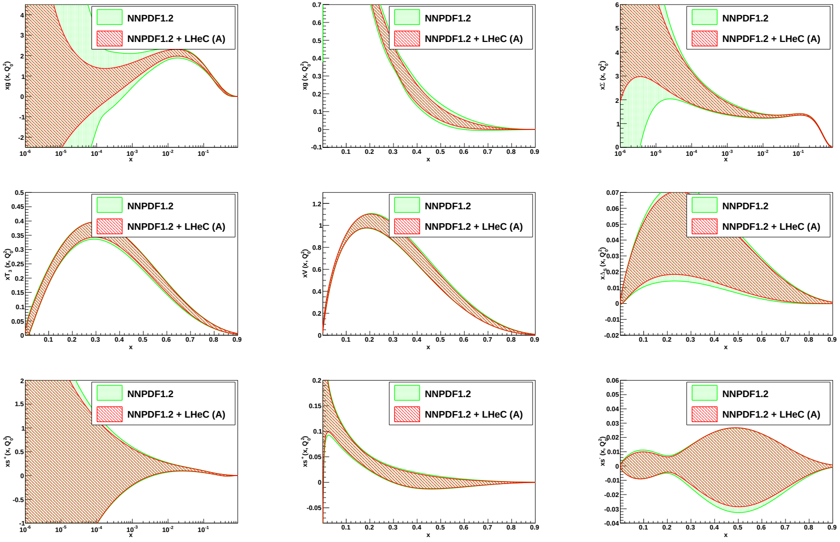
# Conclusions and Outlook

- **Bayesian reweighting** provides an efficient way to assess the impact of including new data in a PDF fit
- Impact of **LHeC**
  - Strong constraint on **gluon at small-x** (scenarios C,D,E)
    $\Longrightarrow$ Opening up of a new kinematic region
  - Impact on **strangeness** (scenario B) concentrated at small-x
    $\Longrightarrow$ Exclusive charm production ($sW \to c$) pins downs small-$x$ strangeness
  - **Valence distributions** mostly unaffected
    $\Longrightarrow$ Strong constraints from fixed target and Drell-Yan data
  - $F_2^c$ very important measurement
    $\Longrightarrow$ Sizable constraints on the low-$x$ gluon
    Complements the potential of $F_L(x, Q^2)$ measurements
  - **Assumption**: Central NNPDF2. values assumed (no new dynamics considered), but LHeC explores a completely new kinematical range
- **Combination of scenarios crucial to assess full impact of LHeC on PDF**
  $\Longrightarrow$ Full study of the impact of the combined LHeC scenarios (B+C+F+H): low-$x$ and large-$Q^2$ data, deuteron runs, low-$E_p$ runs ($F_L$ measurement), $xs(x)$

# Backup Slides

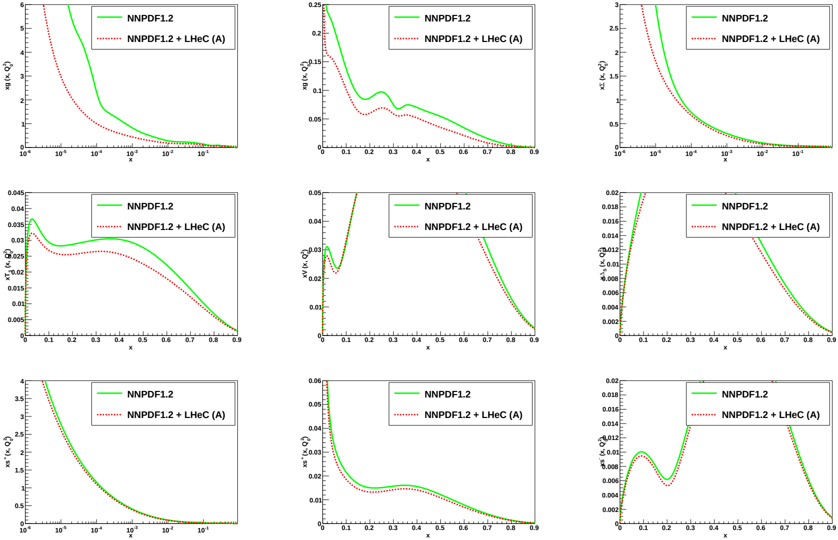
# *LHeC Scenarios - NNPDF1.2*

## Scenario A



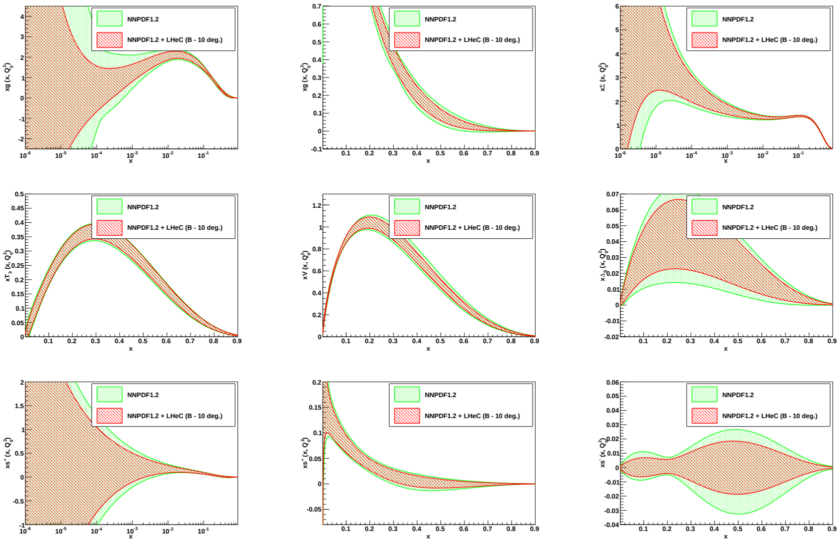
# LHeC Scenarios - NNPDF1.2

## Scenario A



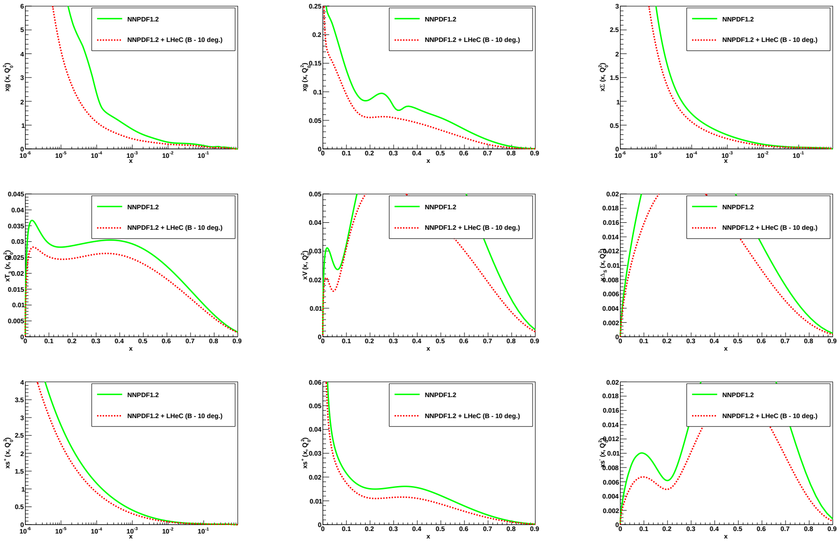
# LHeC Scenarios - NNPDF1.2

## Scenario B (10° cut)



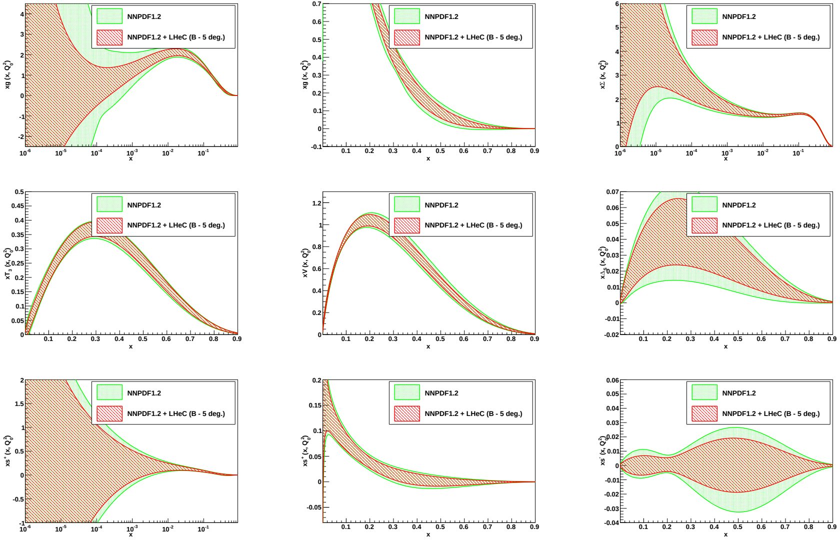
# LHeC Scenarios - NNPDF1.2

## Scenario (10° cut)



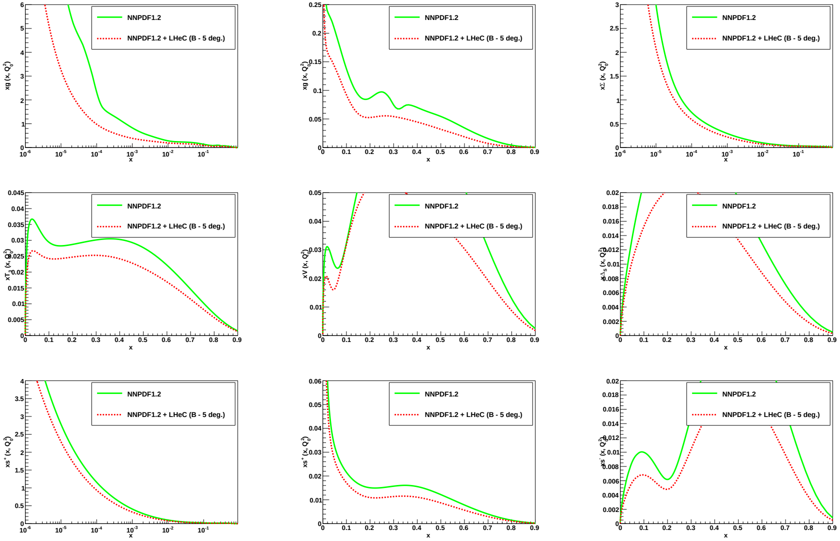
# *LHeC Scenarios - NNPDF1.2*

Scenario B (5° cut)



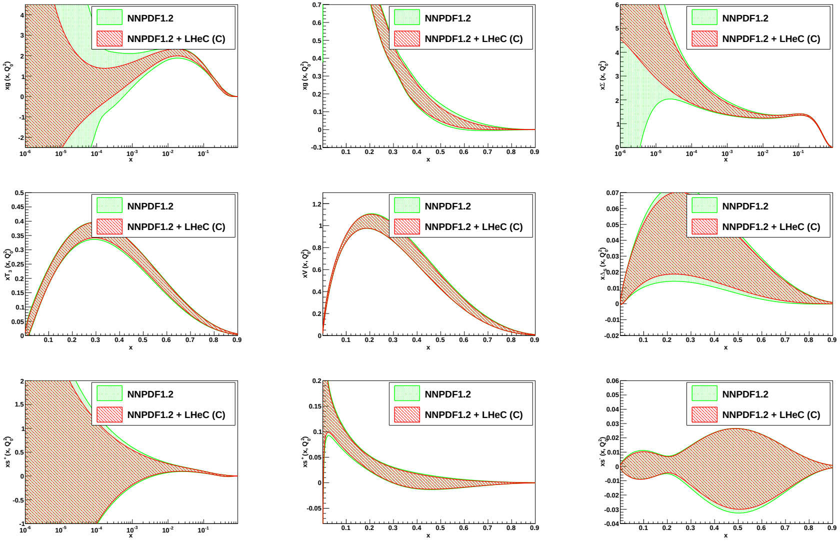
# LHeC Scenarios - NNPDF1.2

## Scenario B (5° cut)



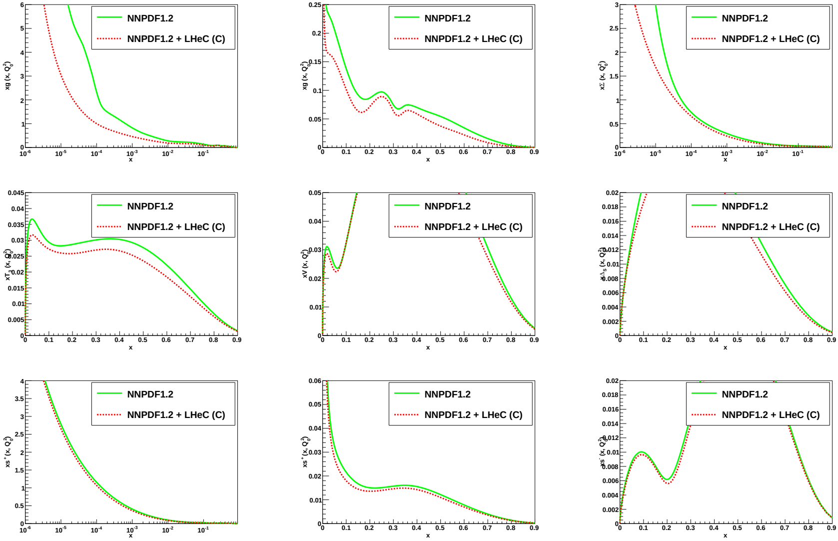
# LHeC Scenarios - NNPDF1.2

## Scenario C



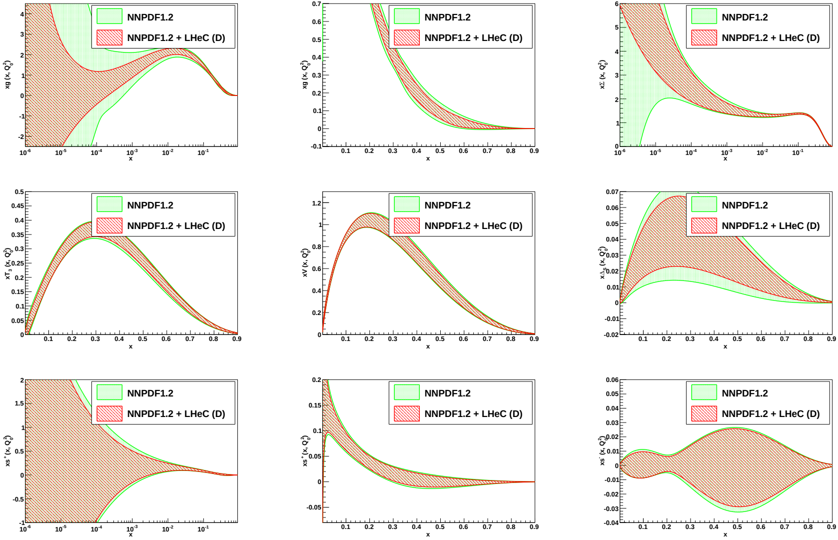
# *LHeC Scenarios - NNPDF1.2*

## Scenario C



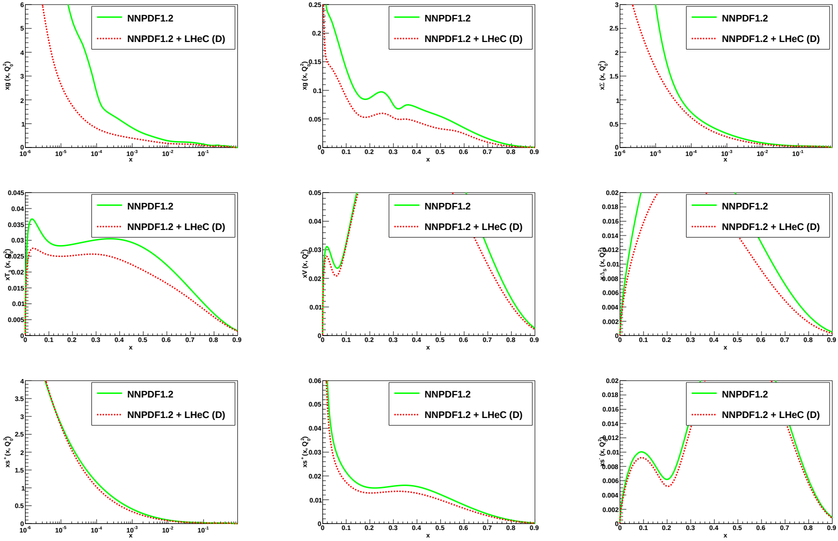
# LHeC Scenarios - NNPDF1.2

## Scenario D



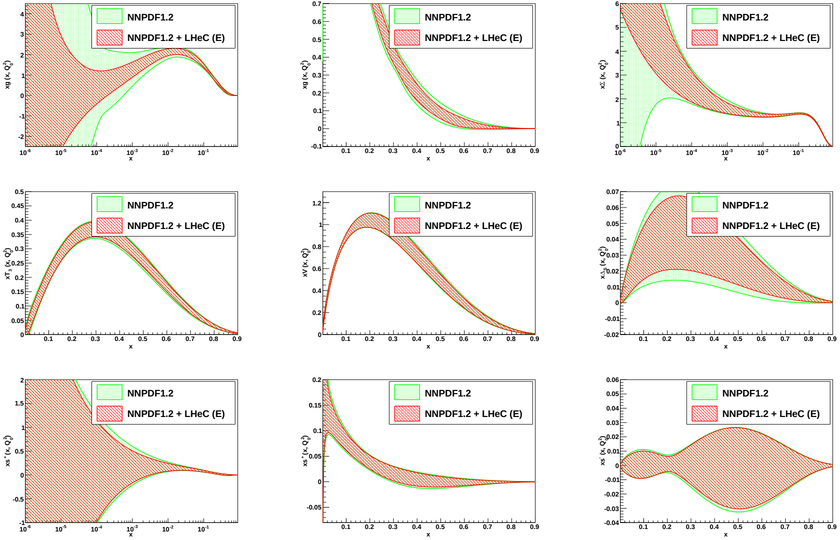
# *LHeC Scenarios - NNPDF1.2*

## Scenario D



# LHeC Scenarios - NNPDF1.2

## Scenario E



# LHeC Scenarios - NNPDF1.2

## Scenario E