Towards the ultimate PDFs at the HL-LHC and the LHeC

Juan Rojo

VU Amsterdam & Nikhef Theory group

Based on Abdul-Khalek, Bailey, Harland-Lang, Gao, JR

arXiv:1810.03639 (EPJC) + ongoing work

PDF4LHC Working Group meeting

CERN, 13/12/2018

Motivation

- In the framework of the update of the **European Strategy for Particle Physics**, a CERN Yellow Report will evaluate the physics potential of the **HL/HE-LHC**

- In this context, we have quantified the **impact of HL-LHC data on PDFs** by means of projections based on extrapolations from available Run I and Run II measurements.

- Our goal is to assess what is the **ultimate precision** that can be expected for PDFs from hadron collider data, and study the implications for LHC phenomenology

- We have also studied how these HL-LHC constraints compare with the corresponding ones expected from the **Large Hadron electron Collider** (LHeC)

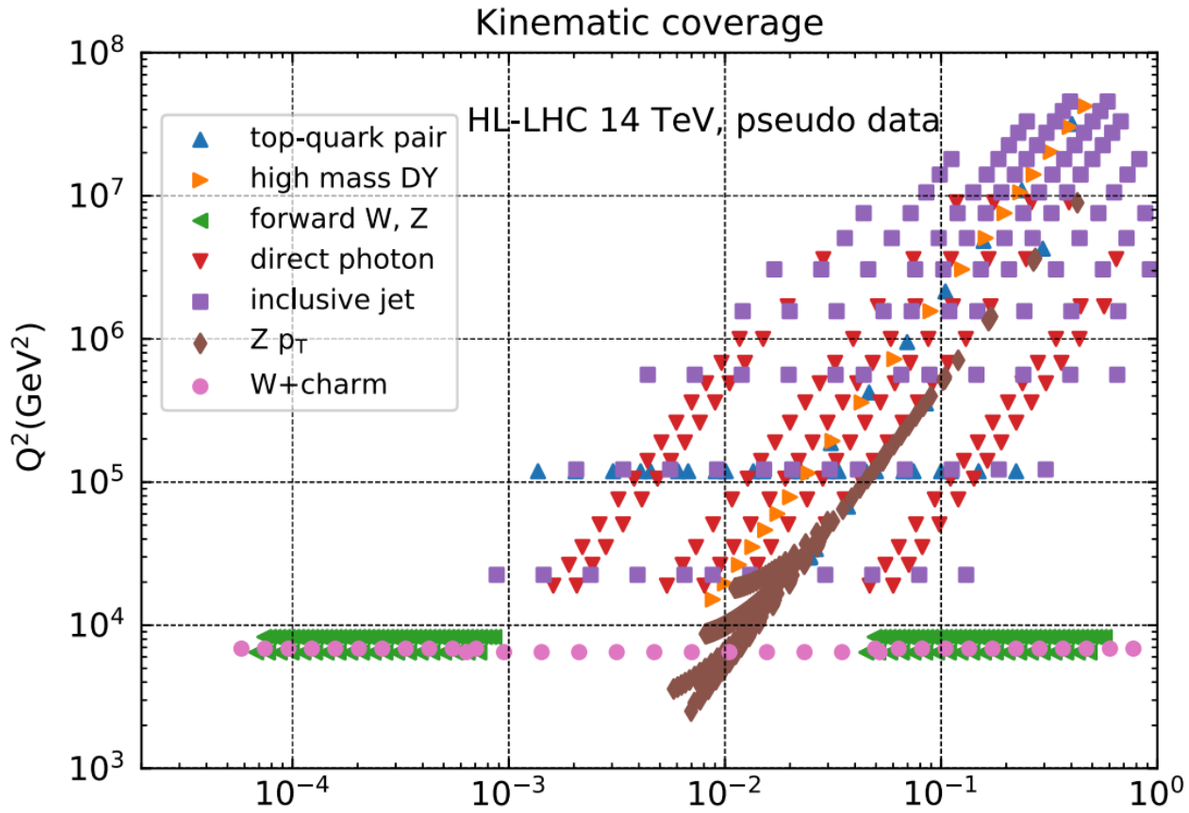
HL-LHC pseudo-data

- Emphasis on processes sensitive to the **high-p_T region** and not already limited by systematics

- Consider different scenarios (conservative & optimistic) for reduction of systematic errors at HL-LHC

- Quantify impact of HL-LHC data by means of the **Hessian profiling of PDF4LHC15** NNLO

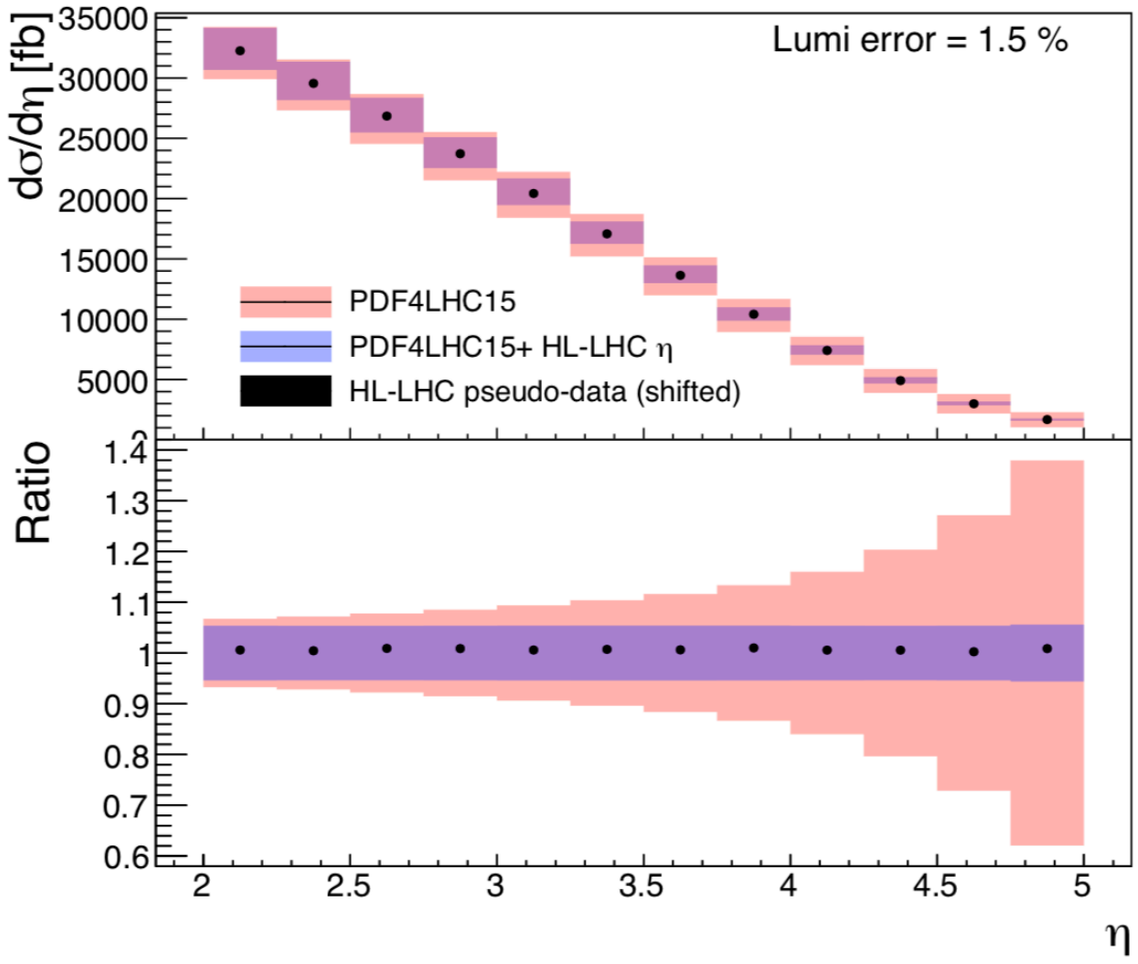
- Assume ***L= 3 ab^{-1}*** for ATLAS and CMS and ***L= 0.3 ab^{-1}*** for LHCb



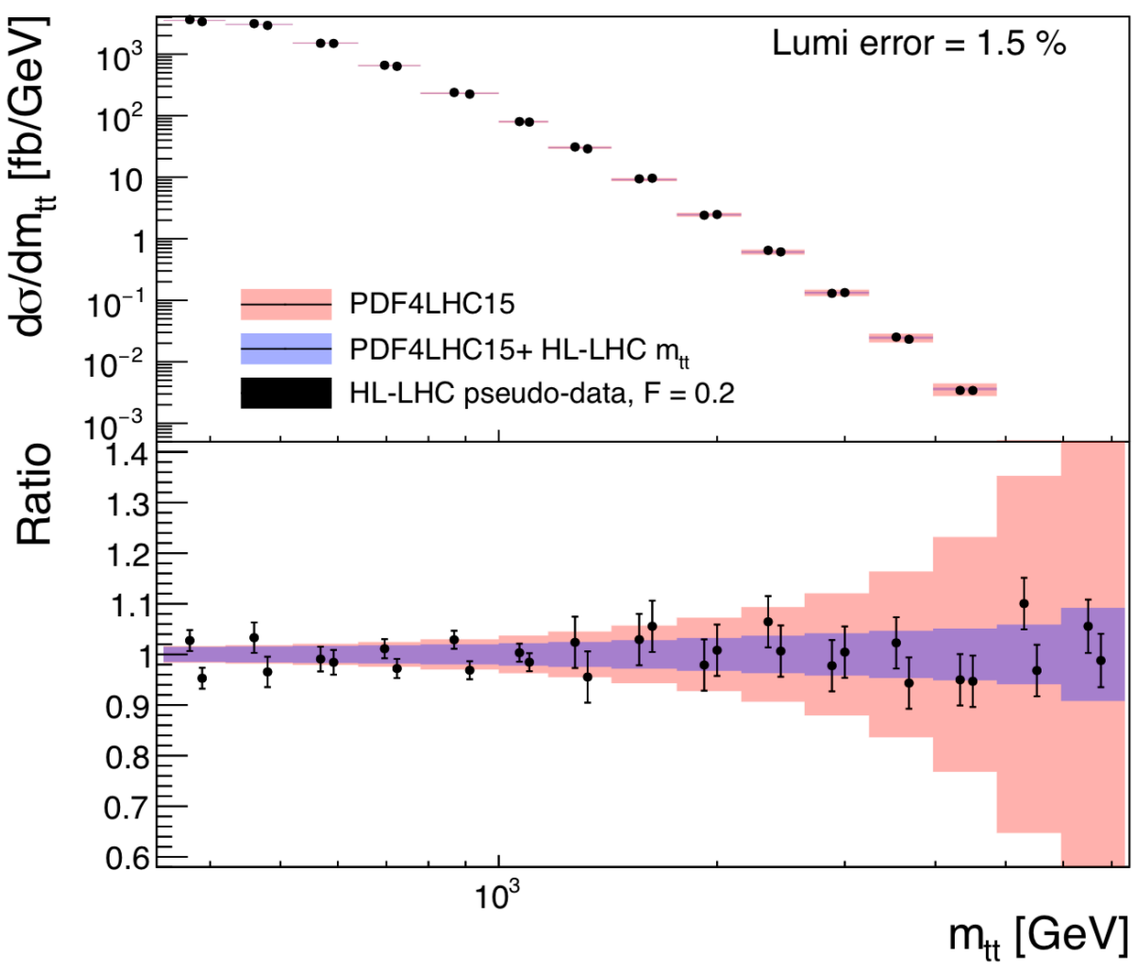
Process	Kinematics	N_{dat}	f_{corr}	f_{red}	Baseline
$Z\ p_T$	$20\,\text{GeV} \le p_T^{ll} \le 3.5\,\text{TeV}$ $12\,\text{GeV} \le m_{ll} \le 150\,\text{GeV}$ $\lvert y_{ll}\rvert \le 2.4$	338	0.5	(0.4, 1)	[52] (8 TeV)
High-mass Drell-Yan	$p_T^{l1(2)} \ge 40(30)\,\text{GeV}$ $\lvert\eta^l\rvert \le 2.5,\ m_{ll} \ge 116\,\text{GeV}$	32	0.5	(0.4, 1)	[47] (8 TeV)
Top quark pair	$m_{t\bar{t}} \simeq 5\,\text{TeV}, \lvert y_t\rvert \le 2.5$	110	0.5	(0.4, 1)	[50] (8 TeV)
W+charm (central)	$p_T^{\mu} \ge 26\,\text{GeV},\ p_T^{c} \ge 5\,\text{GeV}$ $\lvert\eta^{\mu}\rvert \le 2.4$	12	0.5	(0.2, 0.5)	[24] (13 TeV)
W+charm (forward)	$p_T^{\mu} \ge 20\,\text{GeV},\ p_T^{c} \ge 20\,\text{GeV}$ $p_T^{\mu+c} \ge 20\,\text{GeV}$ $2 \le \eta^{\mu} \le 4.5,\ 2.2 \le \eta^{c} \le 4.2$	10	0.5	(0.4, 1)	LHCb projection
Direct photon	$E_T^{\gamma} \lesssim 3\,\text{TeV}, \lvert\eta_{\gamma}\rvert \le 2.5$	118	0.5	(0.2, 0.5)	[55] (13 TeV)
Forward W, Z	$p_T^{l} \ge 20\,\text{GeV}, 2.0 \le \eta^{l} \le 4.5$ $60\,\text{GeV} \le m_{ll} \le 120\,\text{GeV}$	90	0.5	(0.4, 1)	[49] (8 TeV)
Inclusive jets	$\lvert y\rvert \le 3,\ R = 0.4$	58	0.5	(0.2, 0.5)	[61] (13 TeV)
Total		768			

HL-LHC constraints on PDFs

Projected forward W+charm data



Projected invariant $t\bar{t}$ mass data

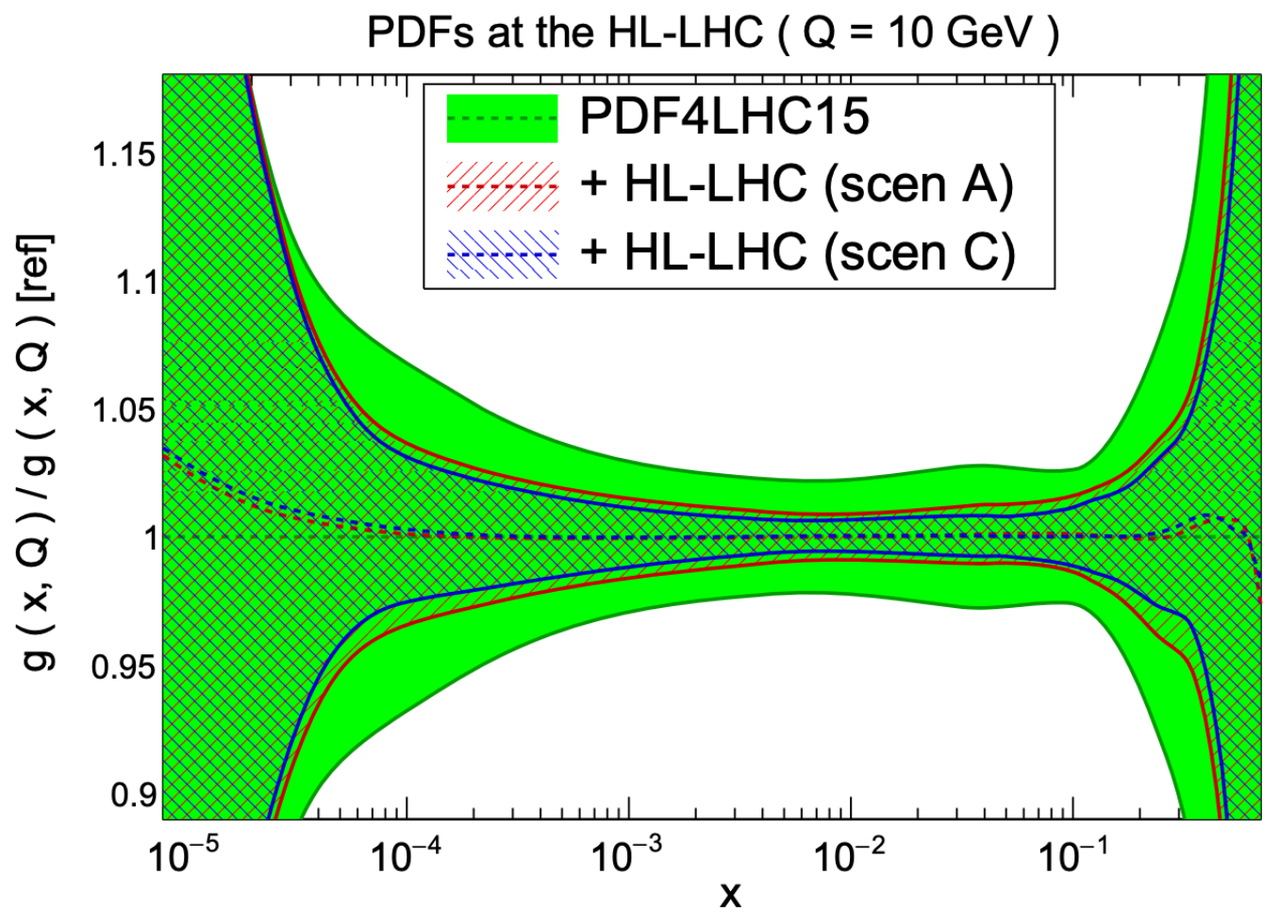


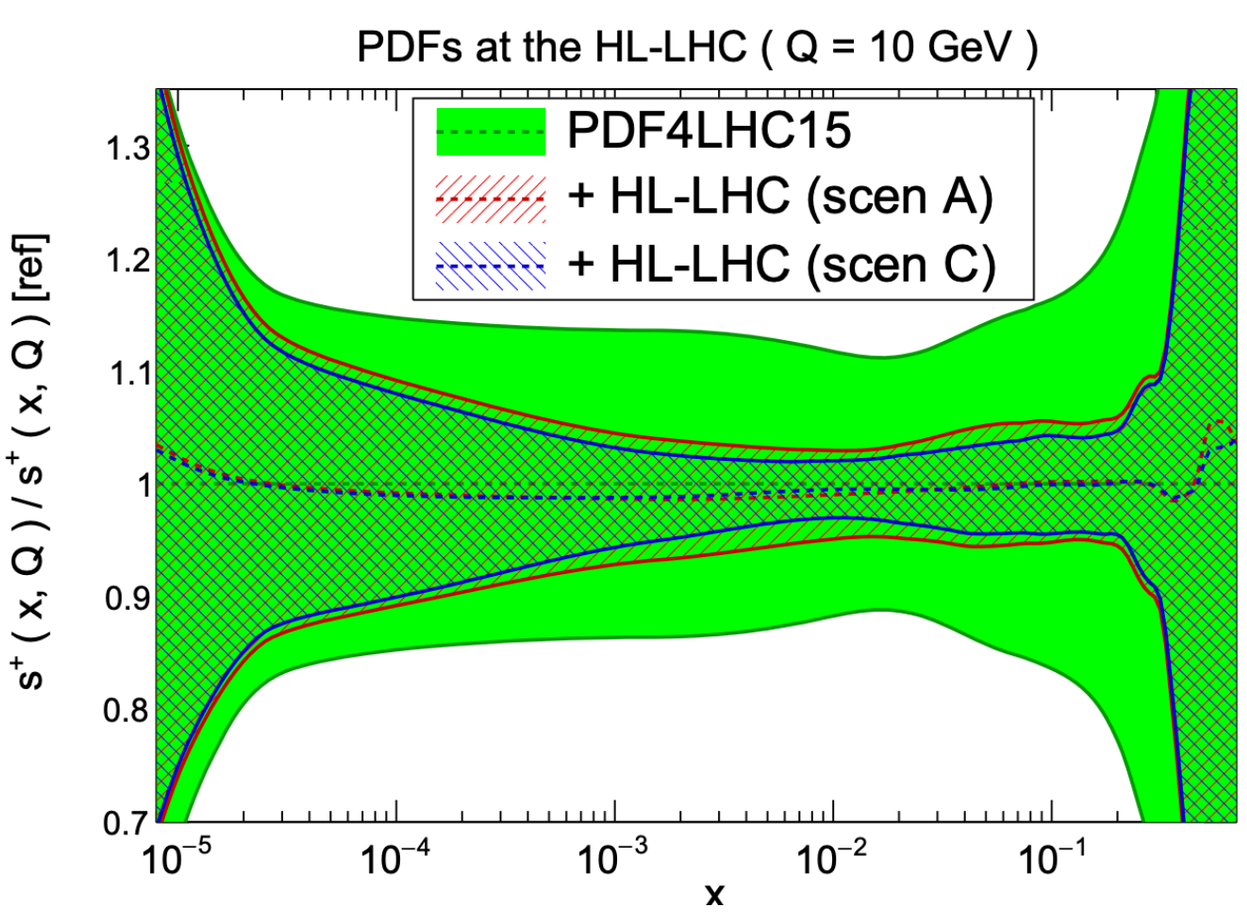
Forward W+charm

Top quark pair production

HL-LHC measurements will be specially useful to constrain the **gluon** and **quark flavour separation** in the large-*x* region, including strangeness

HL-LHC constraints on PDFs



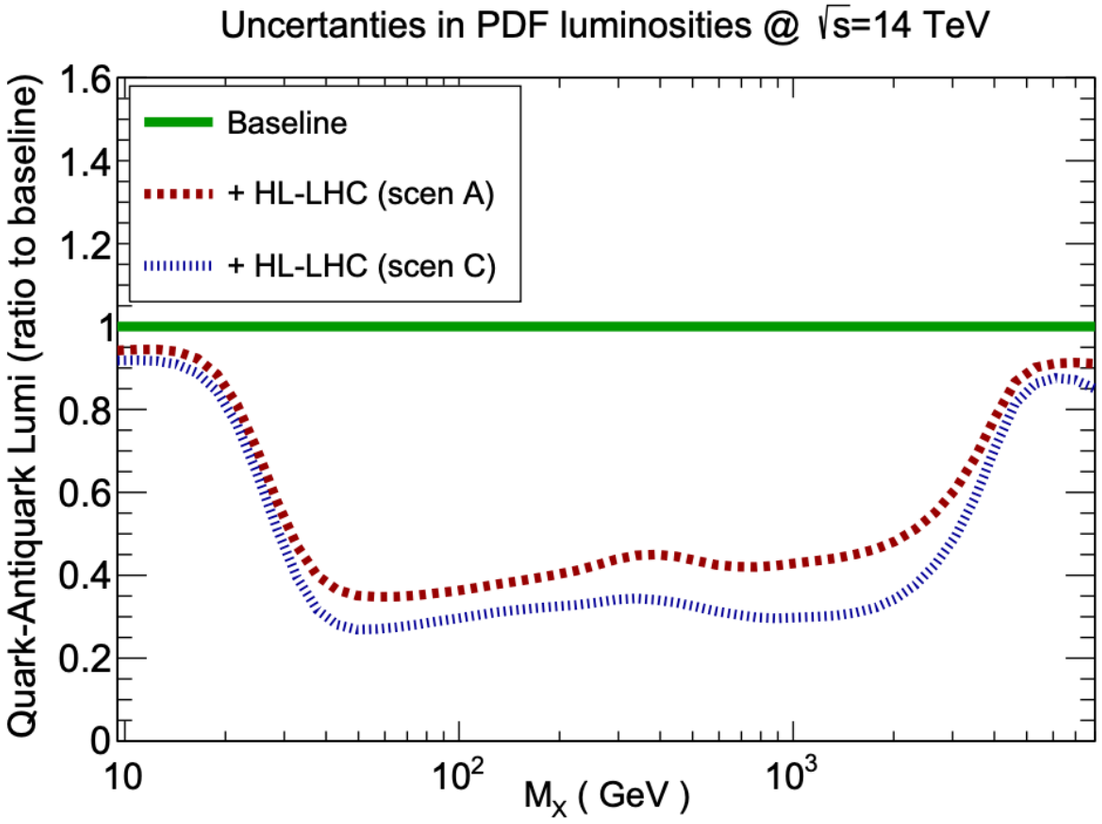


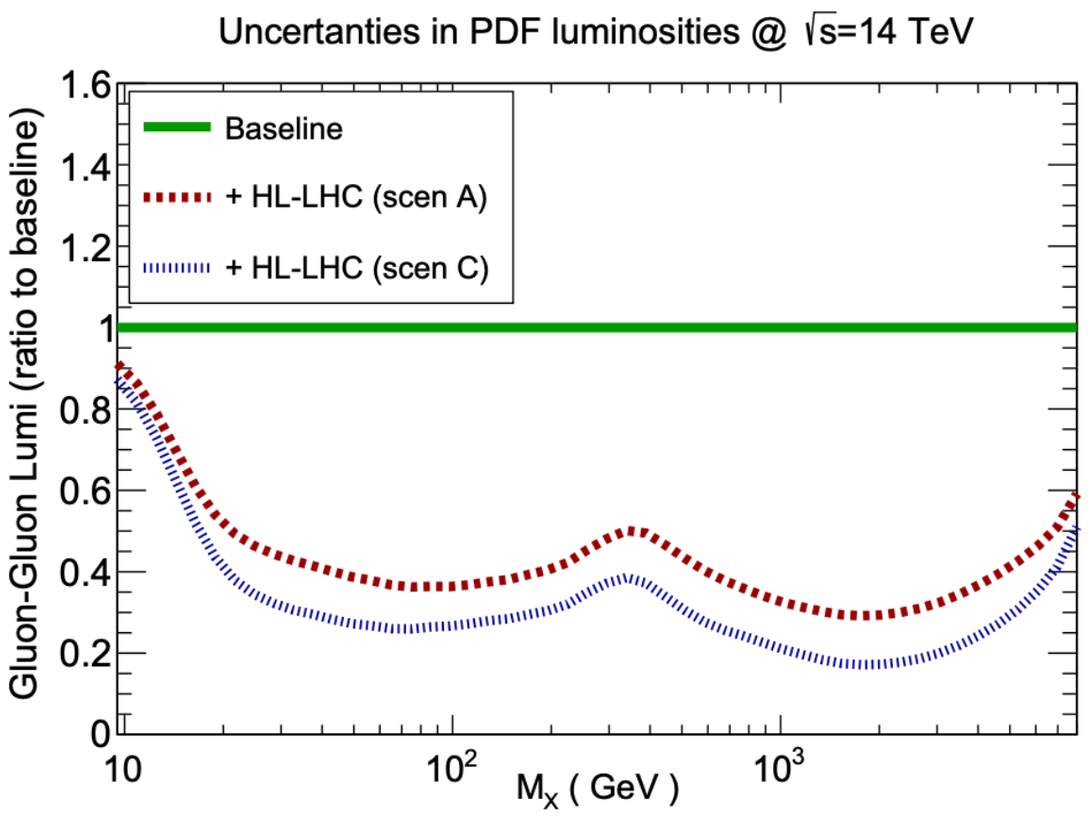
HL-LHC measurements will be specially useful to constrain the **gluon** and **quark flavour separation** in the large-*x* region, including strangeness

HL-LHC constraints on PDFs

Reduction factor *for PDF uncertainties in luminosities as compared to PDF4LHC15*

Ratio to baseline	10 GeV $\leq M_X \leq$ 40 GeV	40 GeV $\leq M_X \leq$ 1 TeV	1 TeV $\leq M_X \leq$ 6 TeV
gluon–gluon	0.50 (0.60)	0.28 (0.40)	0.22 (0.34)
gluon–quark	0.66 (0.72)	0.42 (0.45)	0.28 (0.37)
quark–quark	0.74 (0.79)	0.37 (0.46)	0.43 (0.59)
quark–antiquark	0.71 (0.76)	0.31 (0.40)	0.50 (0.60)
strange–antistrange	0.34 (0.44)	0.19 (0.30)	0.23 (0.27)
strange–antiup	0.67 (0.73)	0.27 (0.38)	0.38 (0.43)





HL-LHC constraints on PDFs

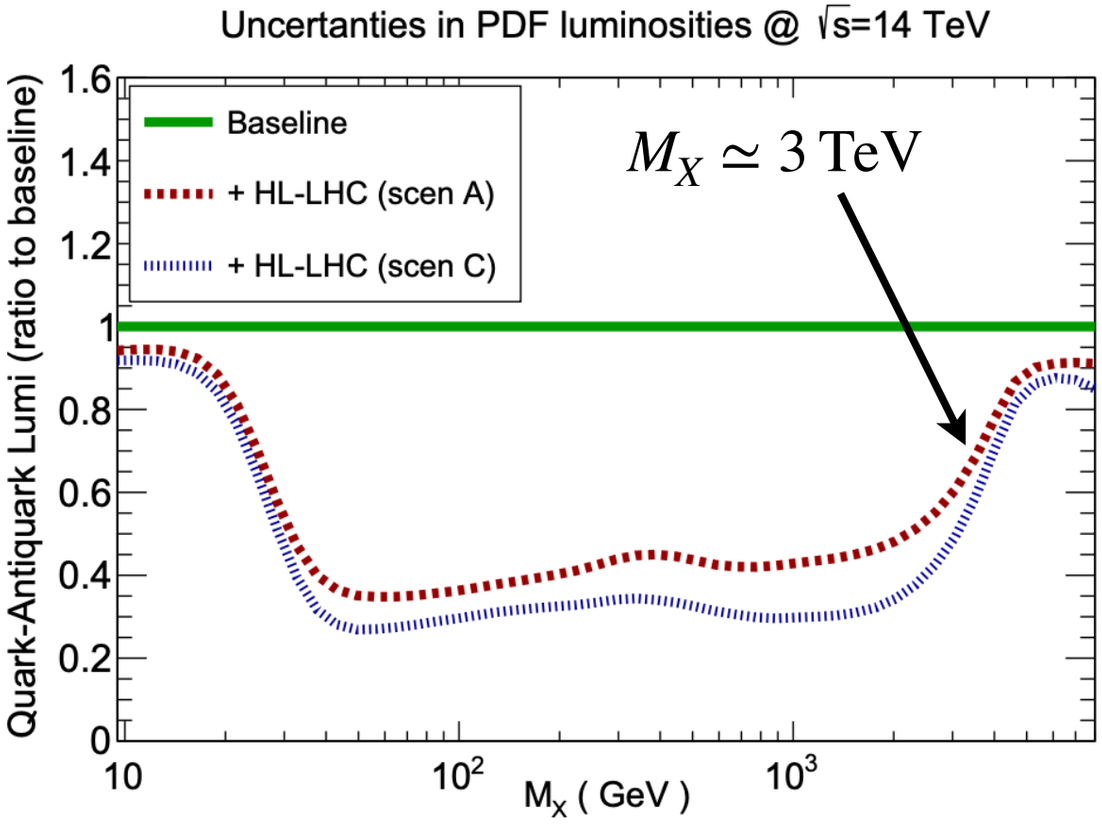
Reduction factor *for PDF uncertainties in luminosities as compared to PDF4LHC15*

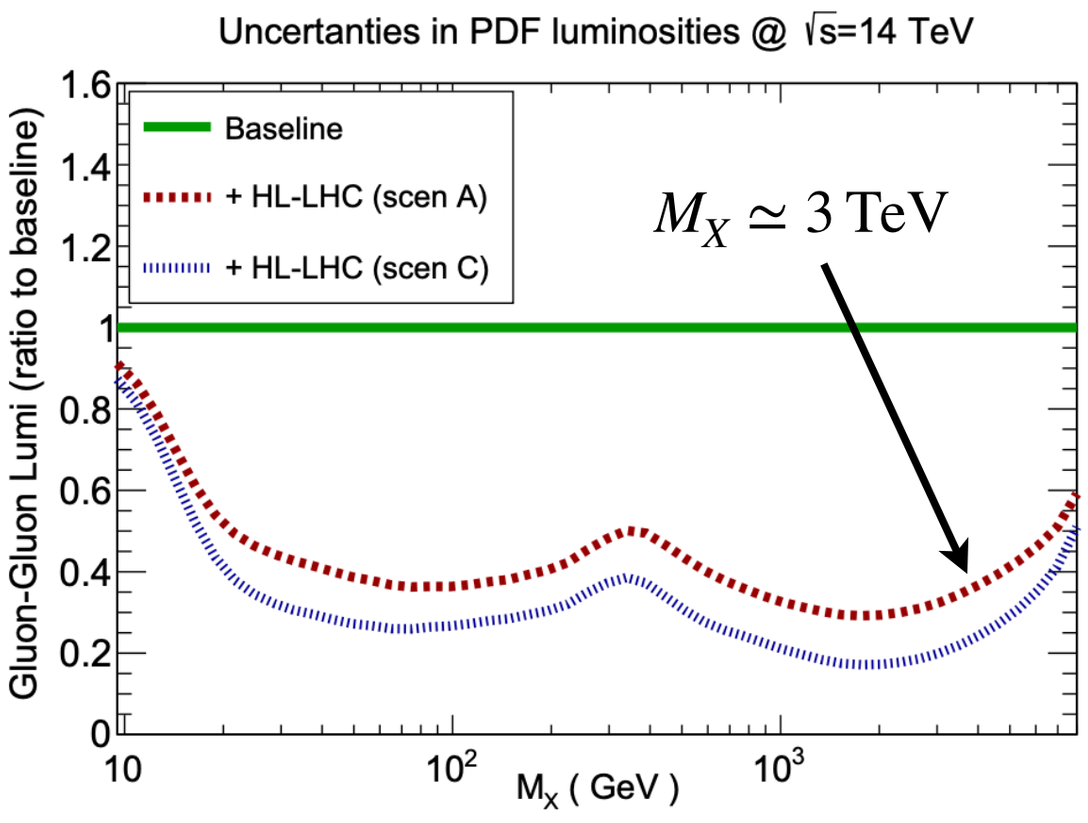
Ratio to baseline	$1\ \text{TeV} \leq M_X \leq 6\ \text{TeV}$
gluon–gluon	0.22 (0.34)
gluon–quark	0.28 (0.37)
quark–quark	0.43 (0.59)
quark–antiquark	0.50 (0.60)
strange–antistrange	0.23 (0.27)
strange–antiup	0.38 (0.43)

Special care will be needed to **disentangle**

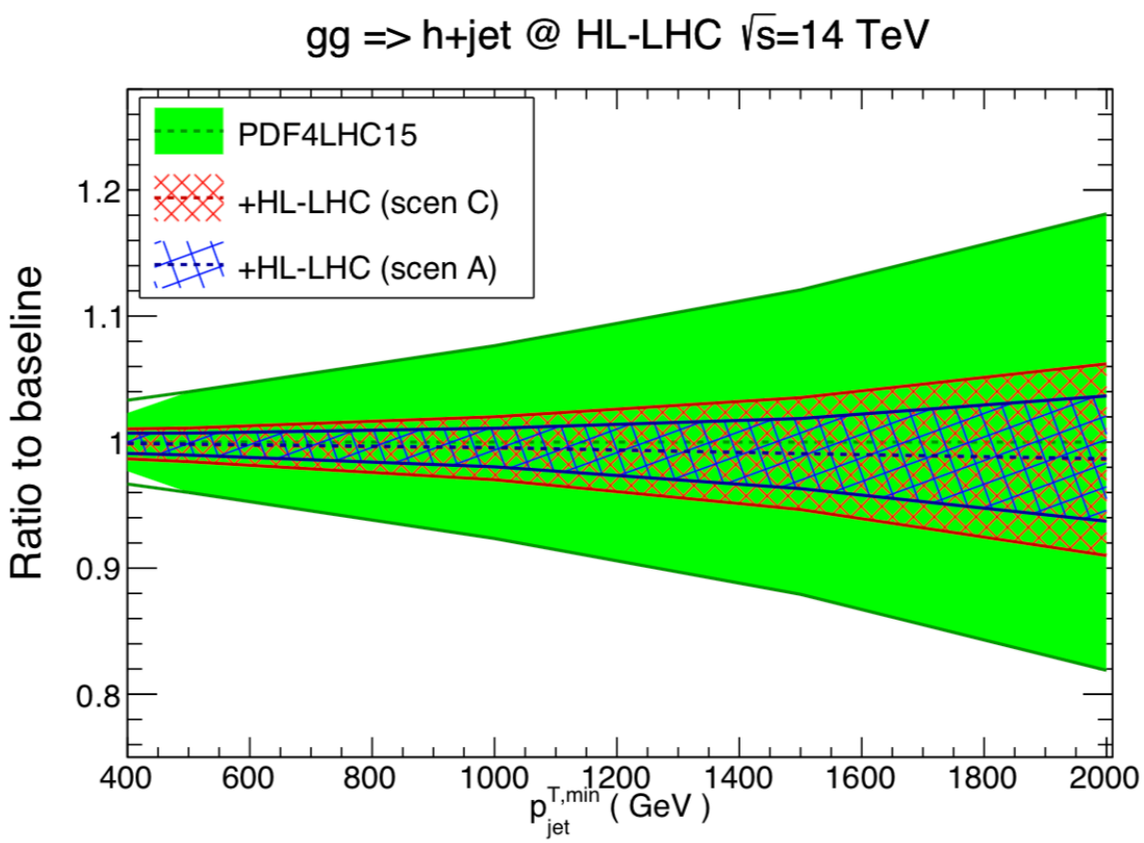
potential BSM effects from LHC measurements

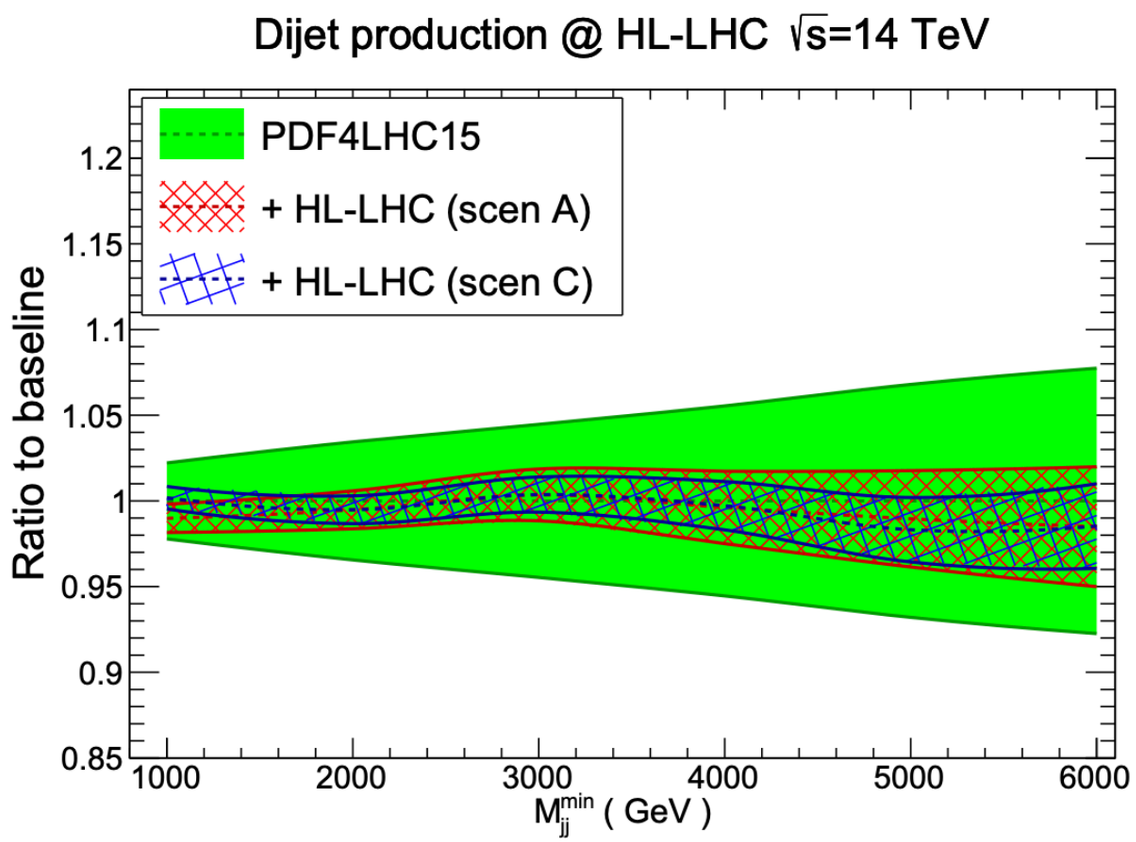
also used to constrain the PDFs

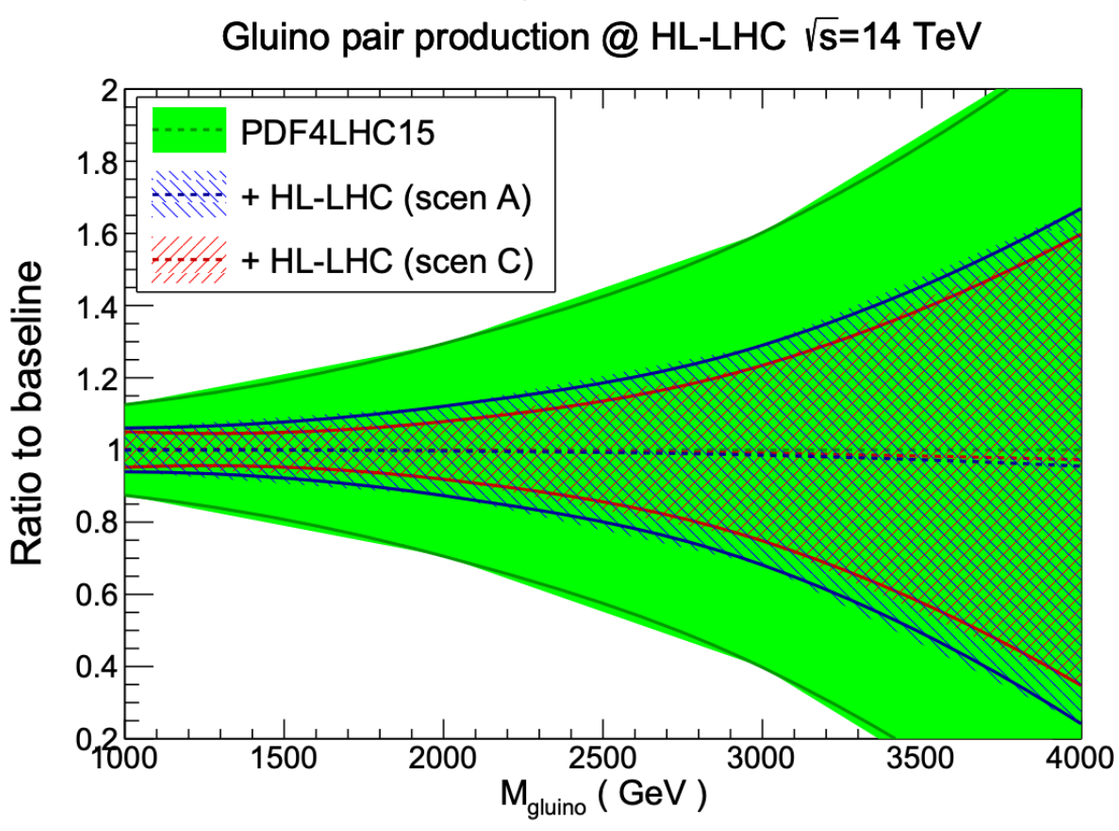


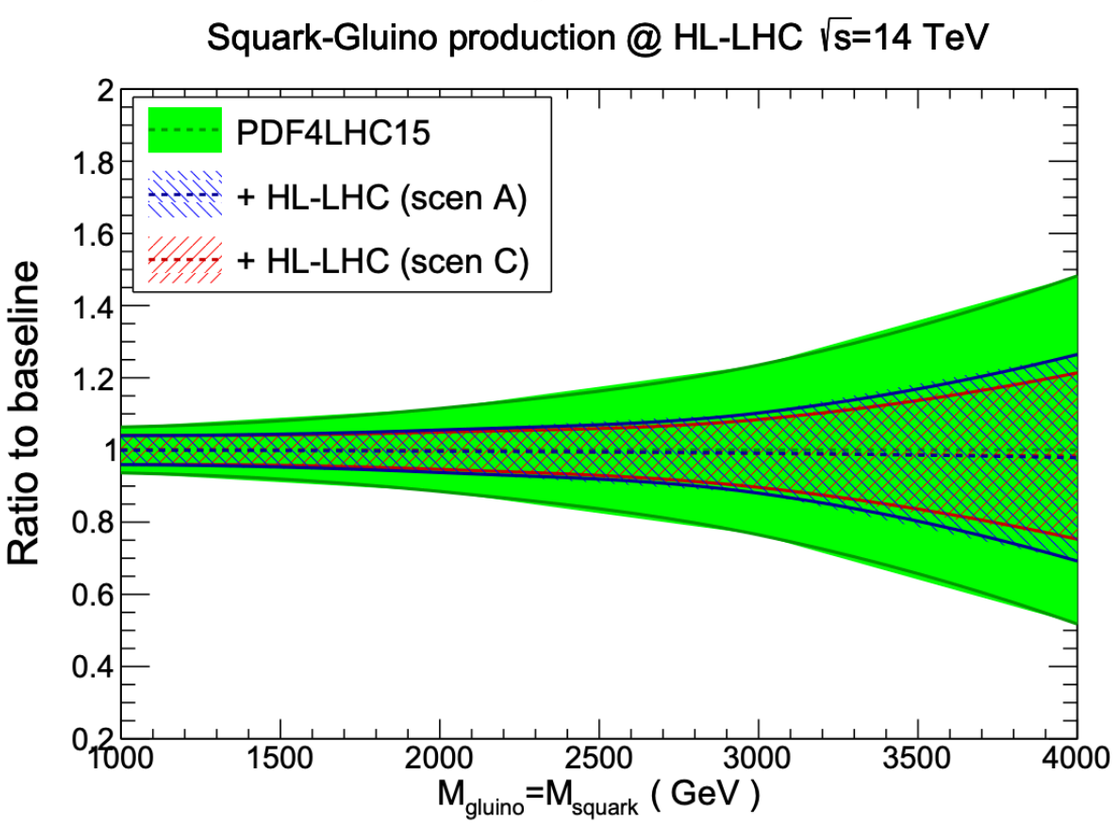


Impact on phenomenology





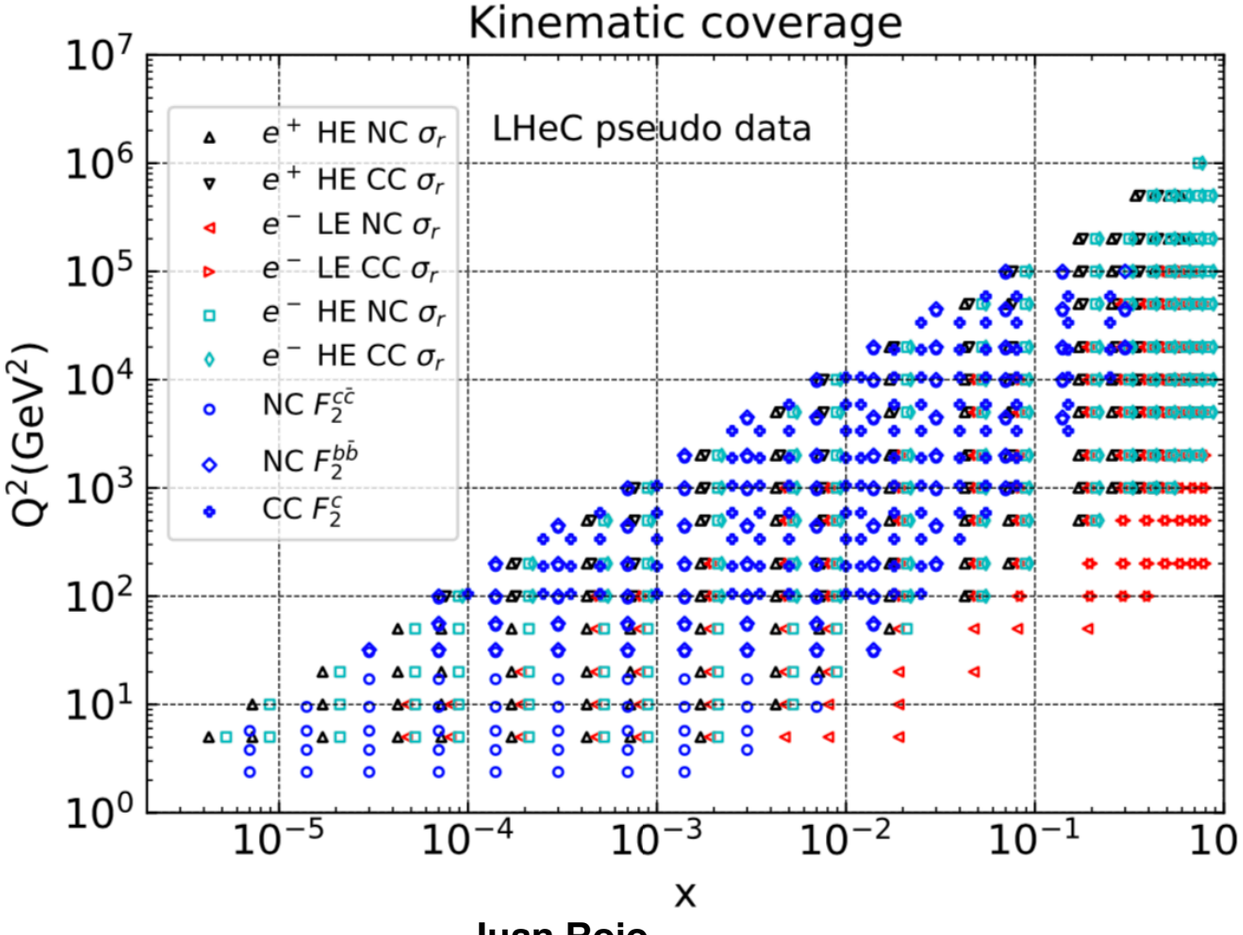


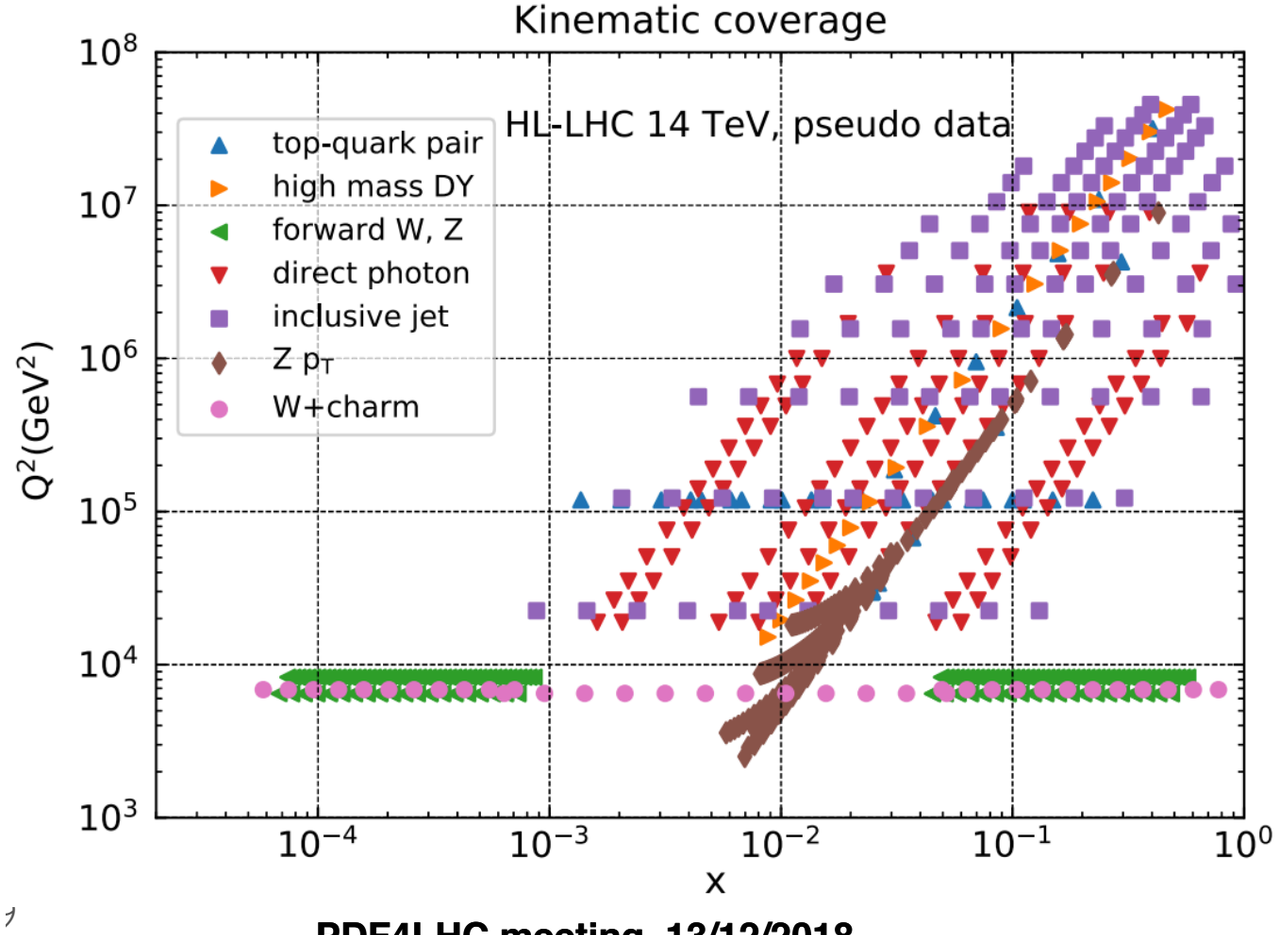


LHeC constraints on PDFs

Applied the same strategy to quantify the PDF constraints expected from the **LHeC**

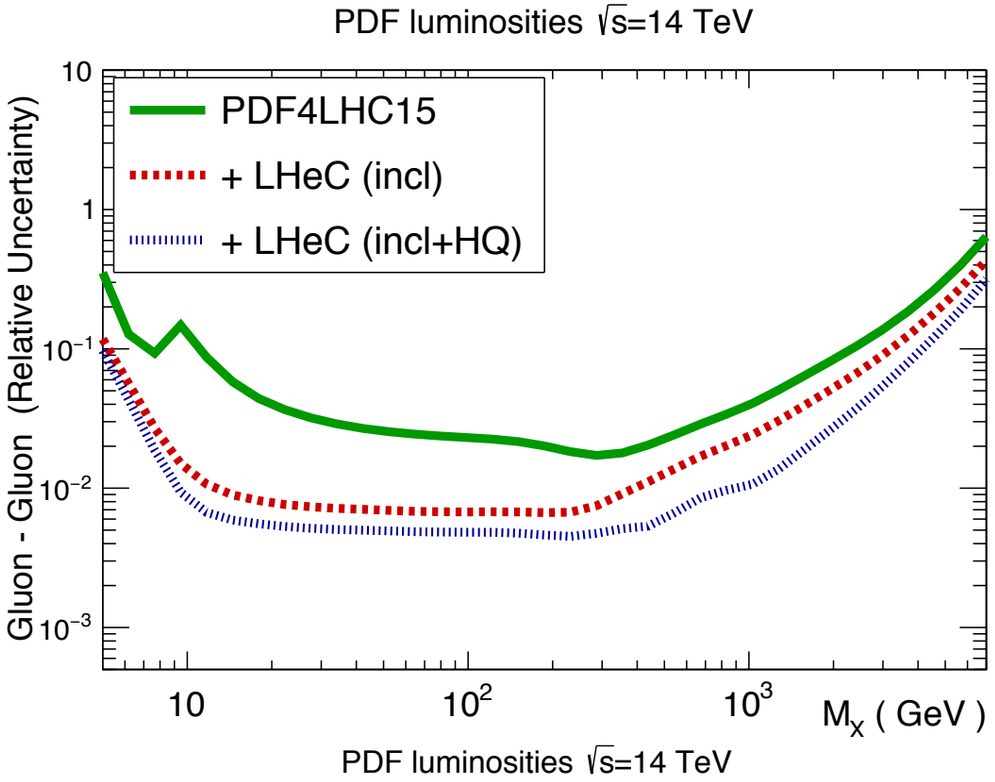
- Electron and positron NC and CC **inclusive cross-sections** (for low and high proton energy)
- **NC DIS charm and bottom** structure functions: extra information on gluon PDF
- **CC strange production** structure functions (the ``dimuon'' process): strangeness
- LHeC pseudo-data provided with **full correlation model** for the systematic uncertainties

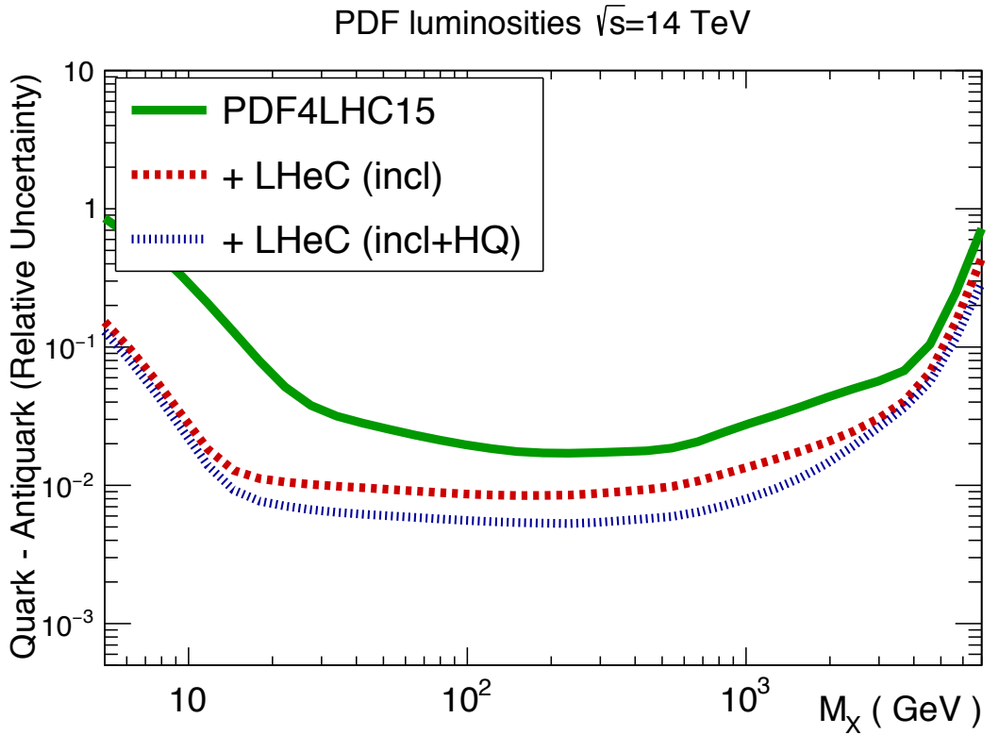


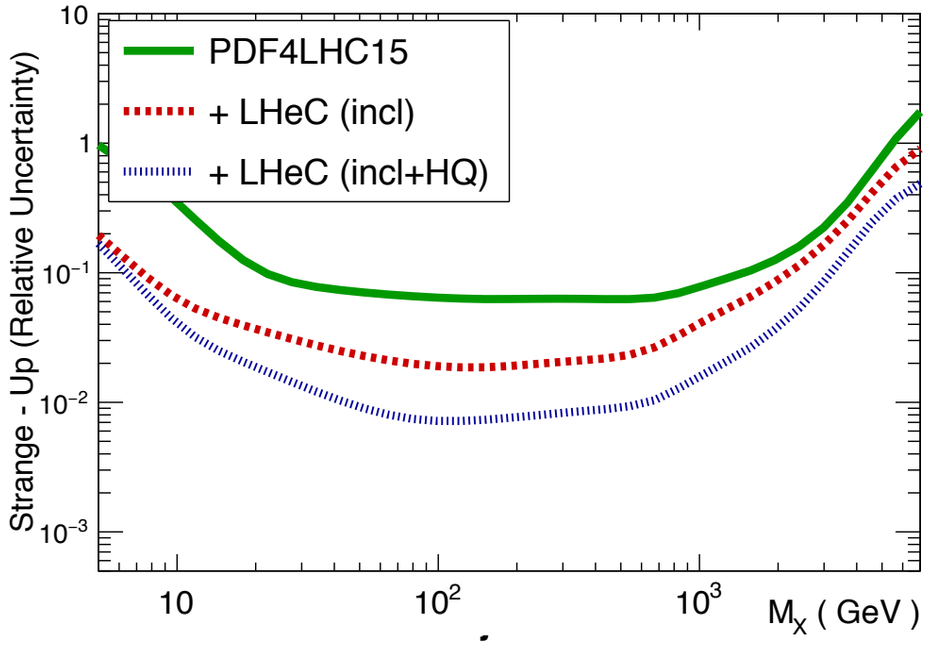


Inclusive vs semi-inclusive data

Compare impact of **inclusive structure function** data only as compared to adding as well **semi-inclusive measurements**: NC charm and bottom and CC strange structure functions



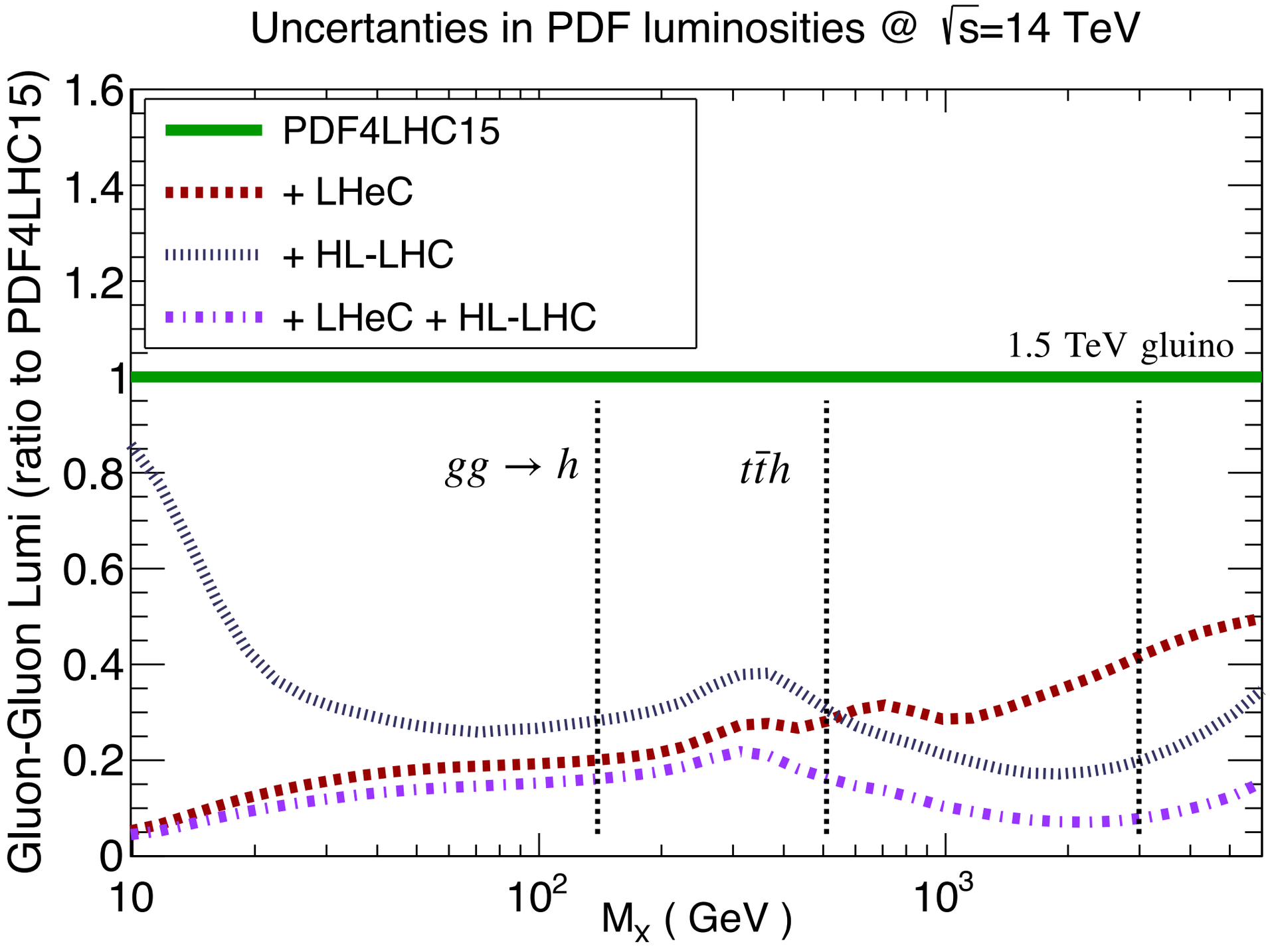




- Semi-inclusive data allow useful constraints on **gluon** and **quark flavour separation**
- Additional information on the gluon would be provided by **jet production measurements**

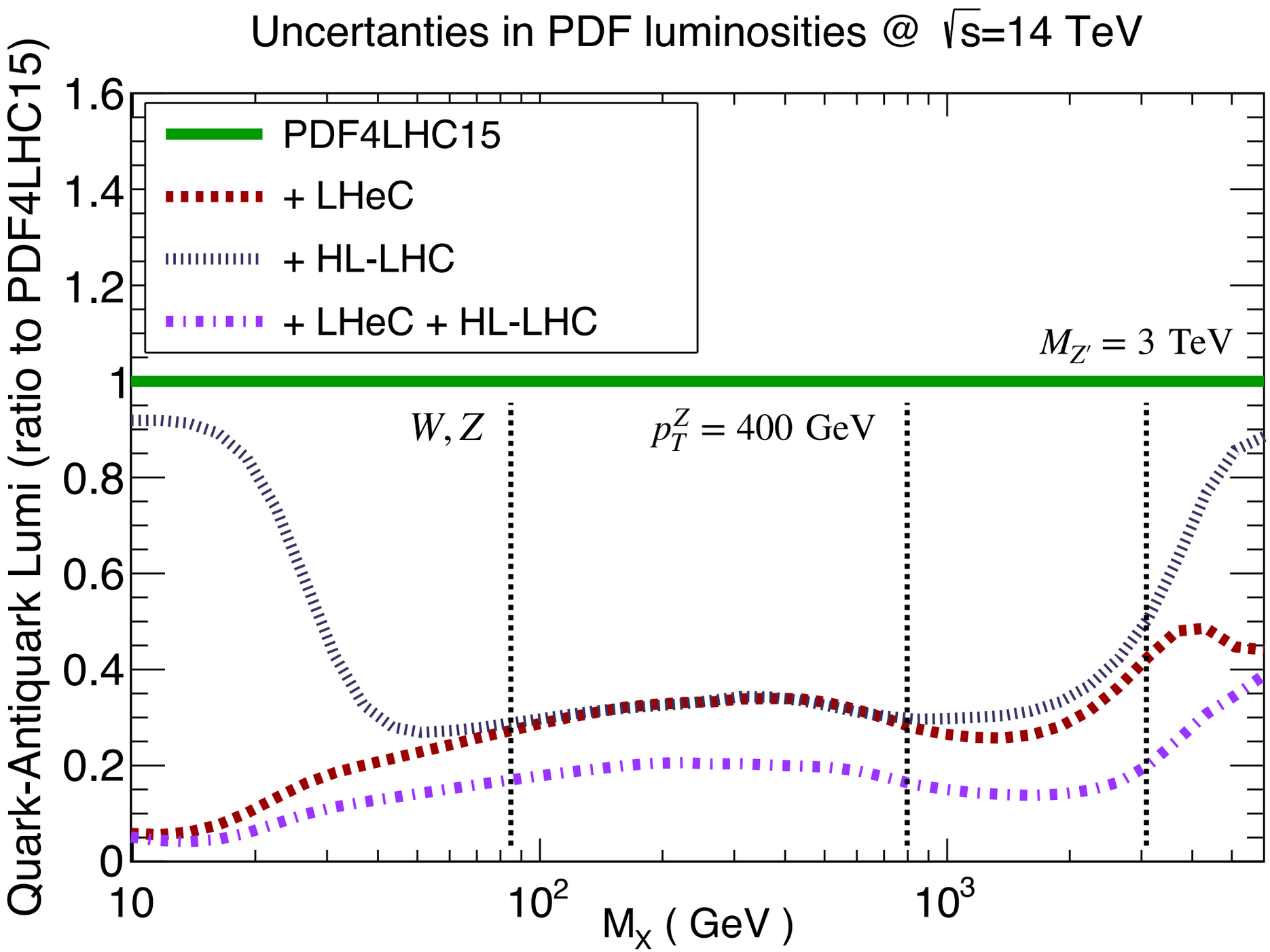
HL-LHC + LHeC combination

Compare the effects of the adding separately **LHeC and HL-LHC** to PDF4LHC15



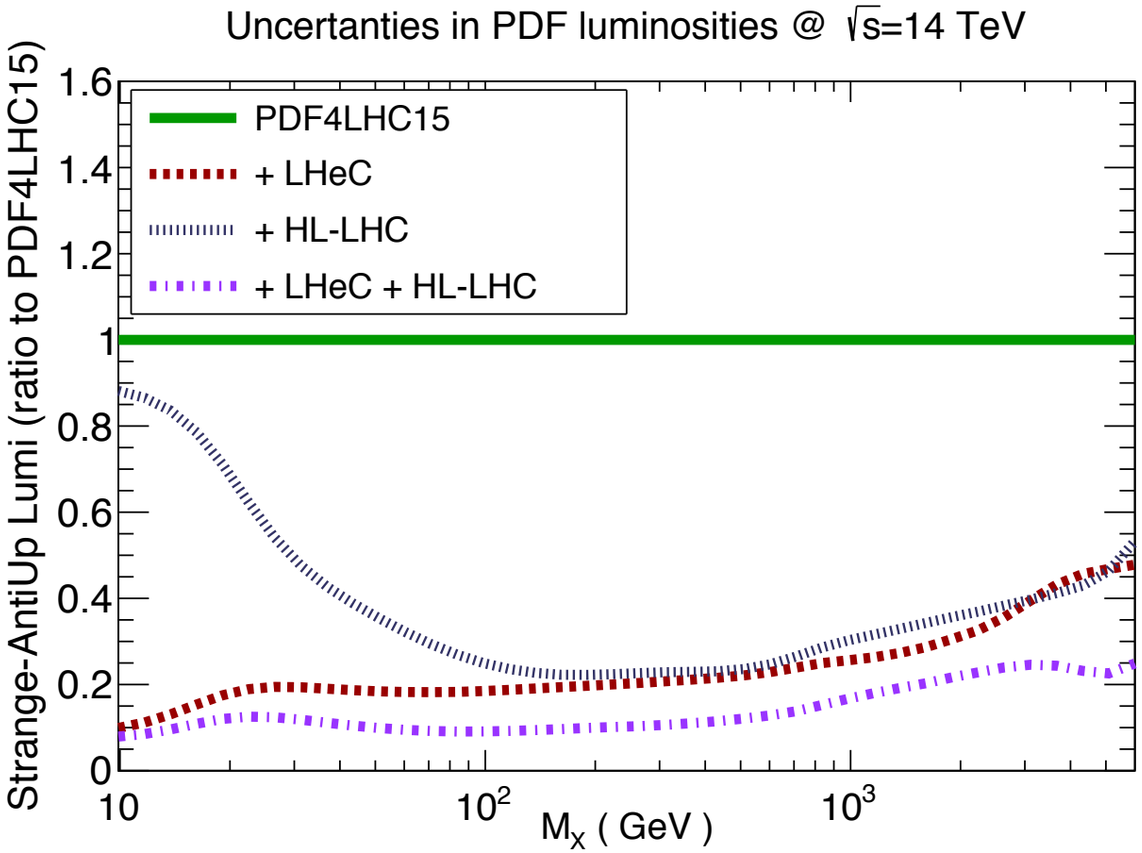
HL-LHC + LHeC combination

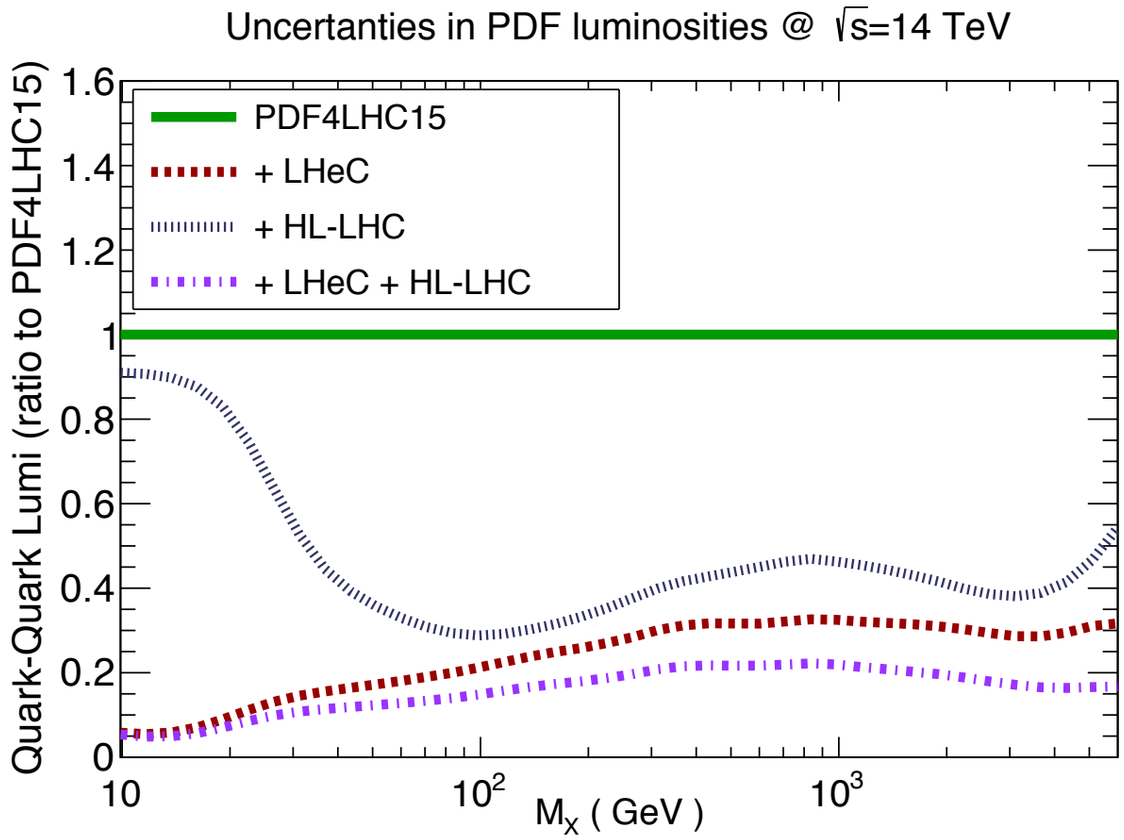
Compare the effects of the adding separately **LHeC and HL-LHC** to PDF4LHC15



HL-LHC + LHeC combination

Compare the effects of the adding separately **LHeC and HL-LHC** to PDF4LHC15





- The information provided by the LHeC would be **comparable or superior** to that provided by HL-LHC measurements when added on top of a global PDF fit

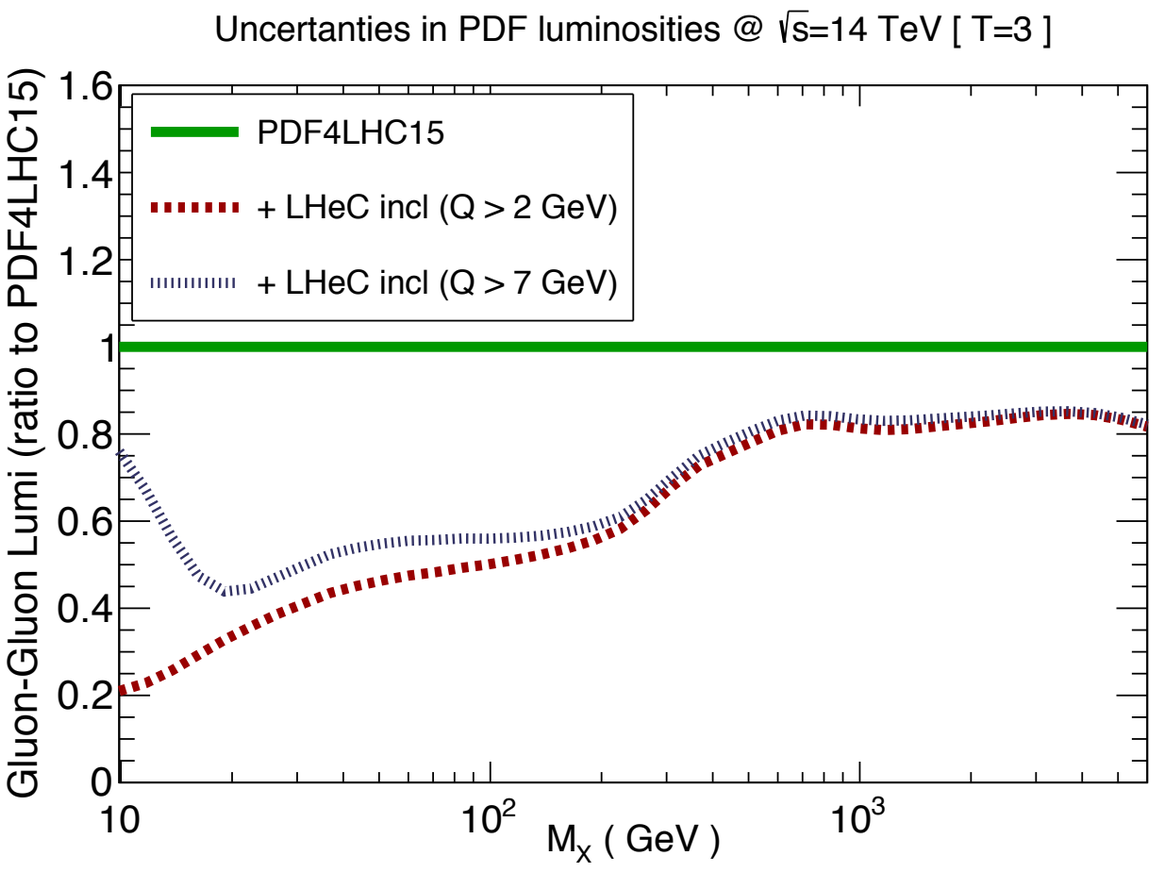
- Crucial **complementarity,** also since LHC data might contain **contributions from bSM effects,** and DIS has completely different theoretical and experimental systematics than p+p collisions

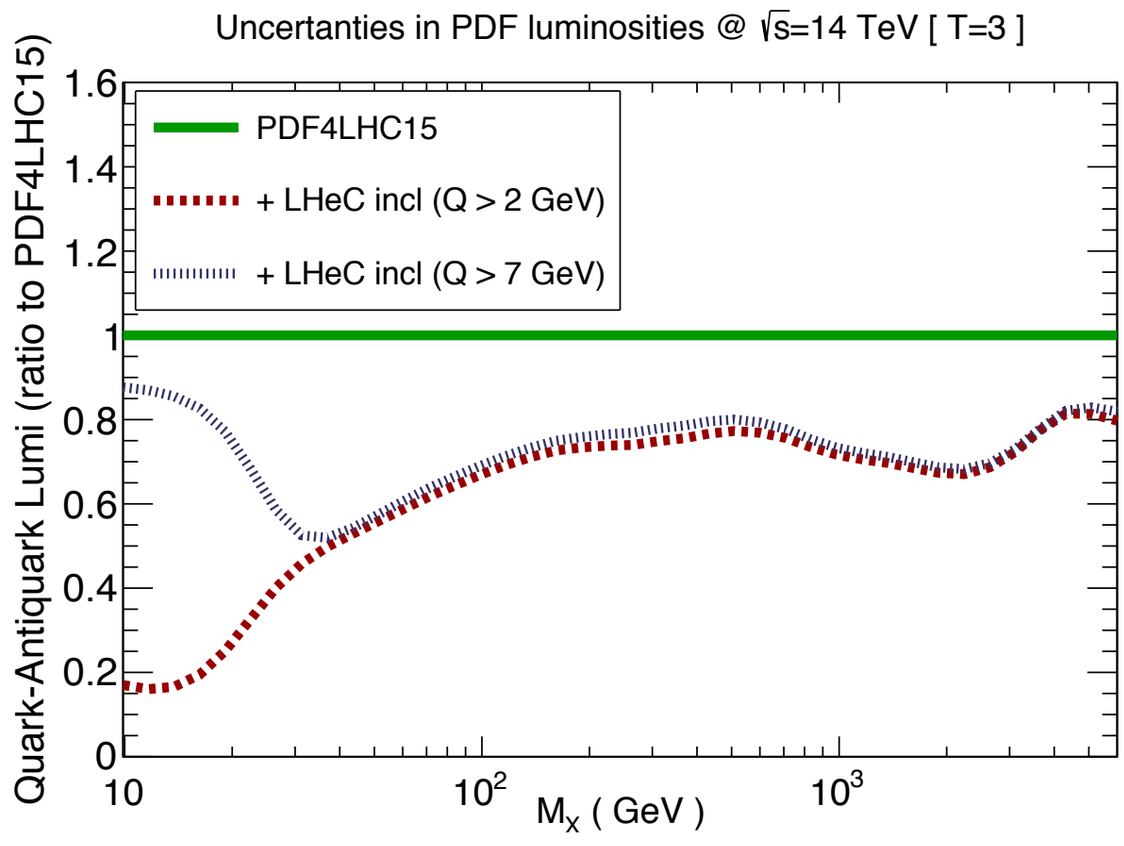
The impact of the low-*x* data

PDF4LHC15 is the combination of three different global fits with

different heavy flavour schemes and **heavy quark masses**

How is LHeC impact modified if we **include only Q > 7 GeV** in profiling?





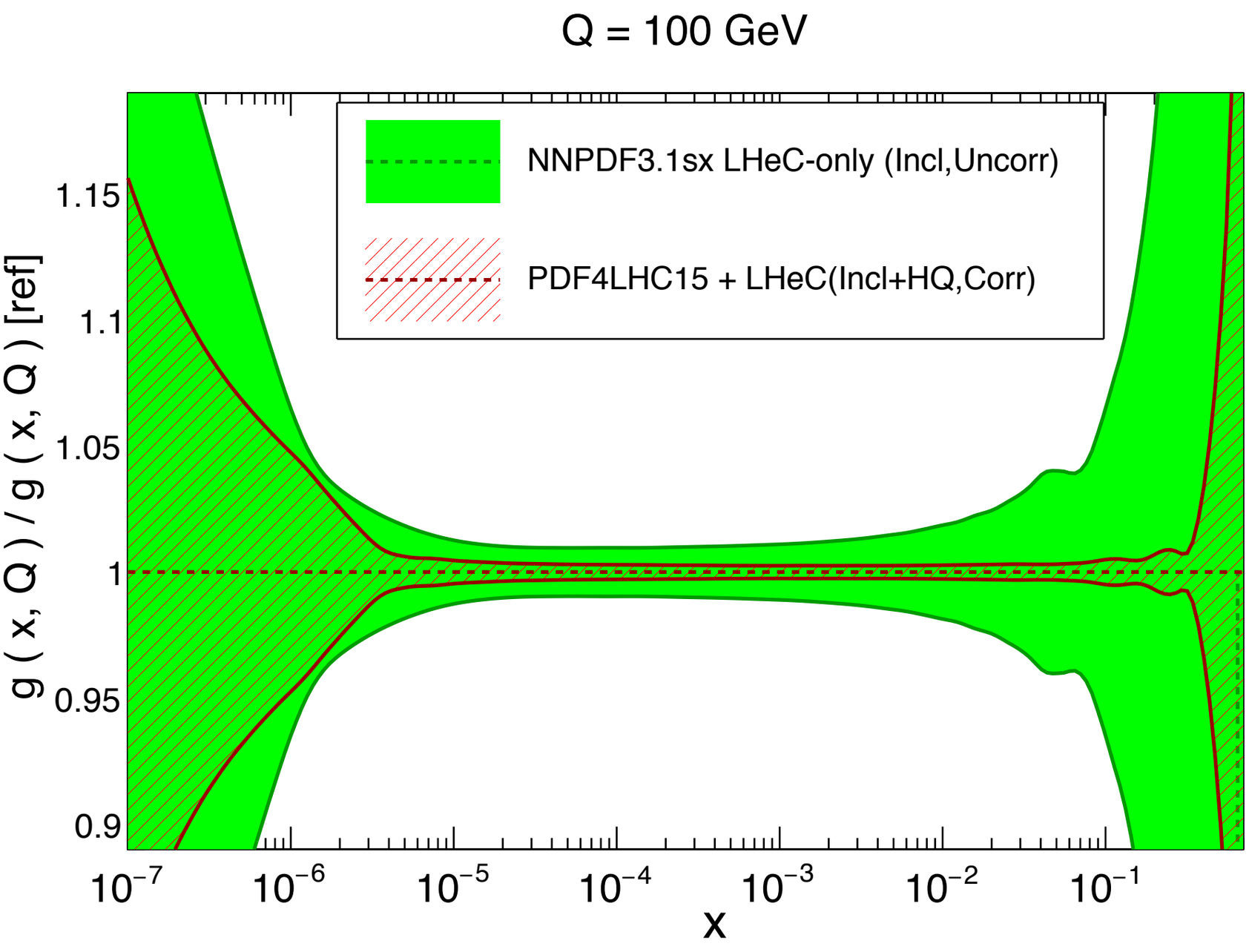
Results essentially unchanged for **M_X > 40 GeV**

The use of PDF4LHC15 as a prior is robust to gauge the impact of LHeC constraints for **electroweak** and **TeV-scale processes**

Comparison with NNPDF fits

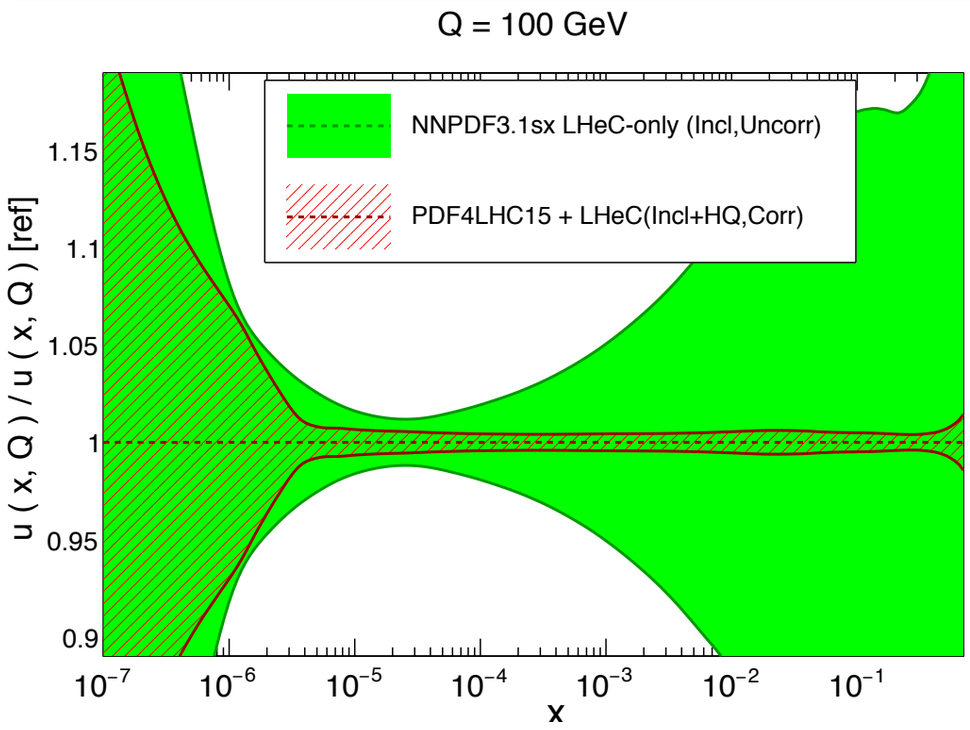
Compare results of **PDF4LHC15 profiling** with the **direct NNPDF fits** with LHeC pseudo-data produced in the context of the BFKL paper

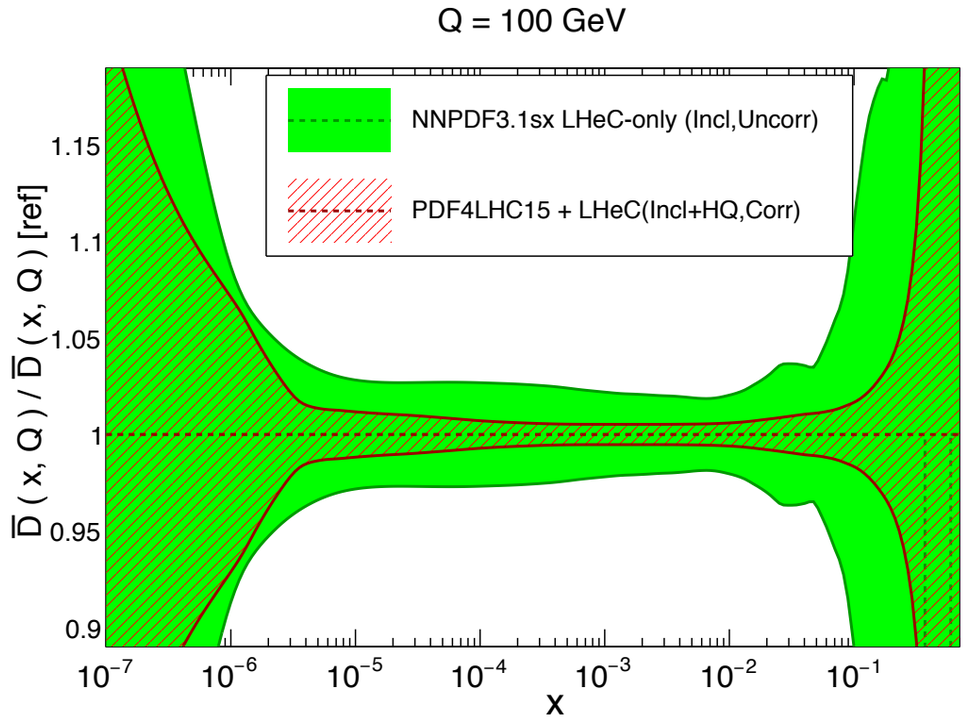
Ball et al 17

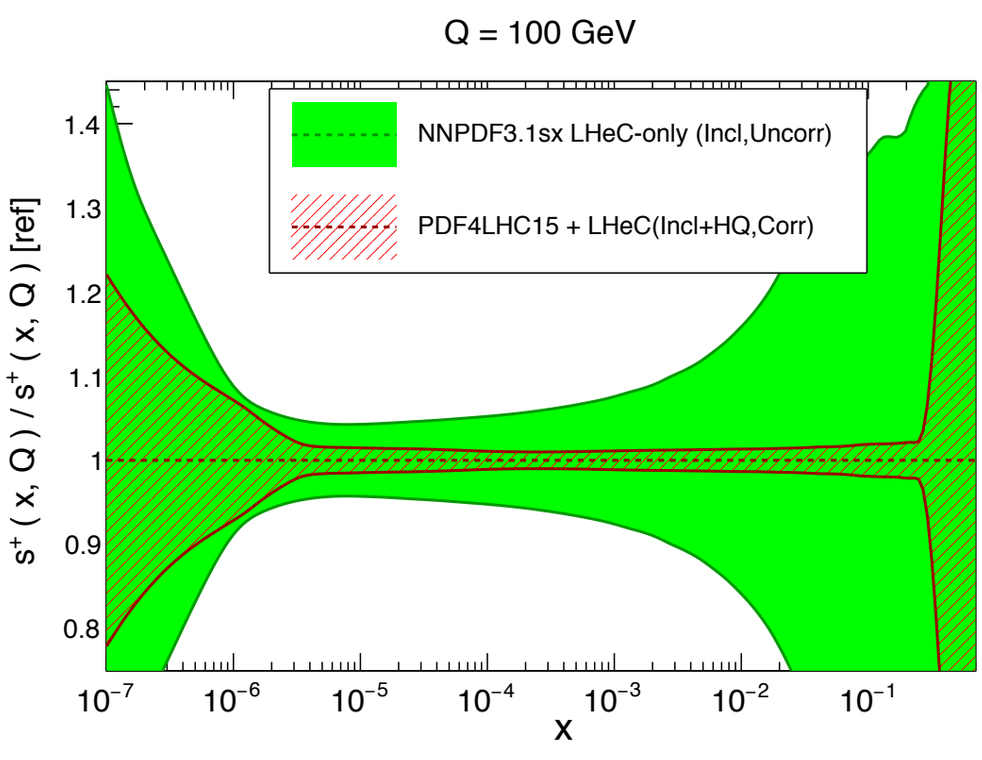


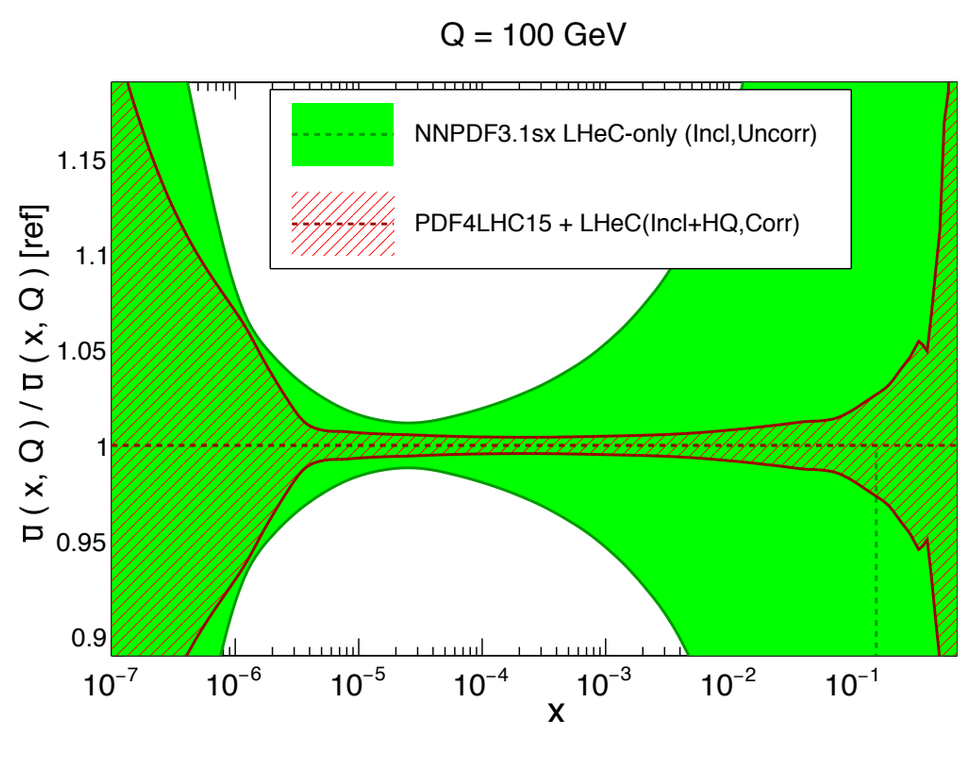
Comparison with NNPDF fits

Compare results of **PDF4LHC15 profiling** with the **direct NNPDF fits** with LHeC pseudo-data produced in the context of the BFKL paper









Summary and outlook

- We have presented a systematic estimate of the **impact of future HL-LHC measurements** on the PDFs

- PDF uncertainty reduction on LHC xsecs between a **factor 2 and 5,** depending on assumptions on systematic errors, the mass region, and the partonic combination

- Only a subset of the possible PDF-sensitive measurements from the LHC has been included, and potential inconsistencies are partially accounted by the use of ***T=3***

- The PDF4LHC15_HLLHC sets are **publicly available** and have been used for several studies in other sections of the HL/HE-LHC Yellow Report.

- The LHeC would provide **fully independent and complementary PDF information**, with different theory and experimental systematics and reduced risk of BSM contamination, when added on top of a global PDF fit