



# Towards Ultimate PDFs at the HL-LHC

**Juan Rojo**

VU Amsterdam & Nikhef Theory group

*Based on*

*Abdul Khalek, Bailey, Gao, Harland-Lang, JR, arXiv:1810.03639*

**Higgs @ HL/HE-LHC WG meeting, 22/10/2018**

# Strategy

Generate **NLO APPLgrids** and the corresponding pseudo-data for HL-LHC  
Explore different options for **binning** and **systematic uncertainties**



Quantify the impact of the individual processes on the  
**PDF4LHC15** set using Hessian Profiling



**Combine all pseudo-data** and perform a joint profiling to construct the  
PDF4LHC\_HLLHC sets in different scenarios for the pseudo-data



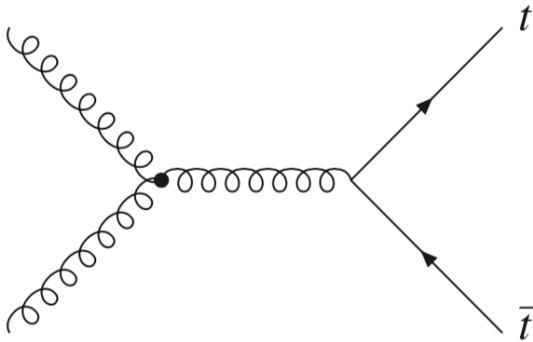
Make the resulting sets **available via LHAPDF**

*What is the **ultimate precision** that can be expected for PDFs from **hadron collider data**?*

# PDF-sensitive processes @ HL-LHC

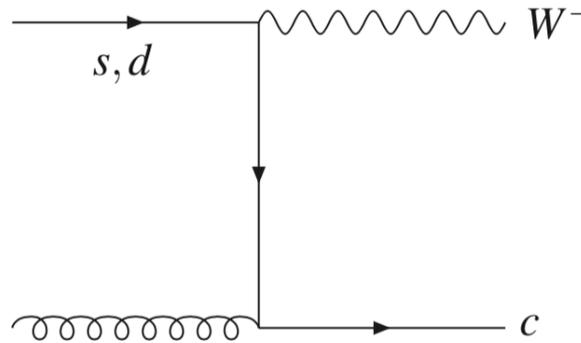
*large-x gluon*

Top quark pair production



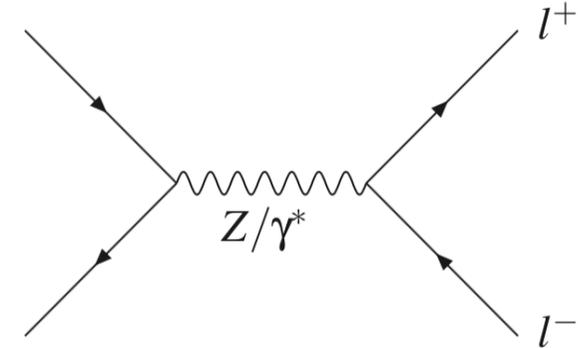
*strangeness*

$W + c$  production

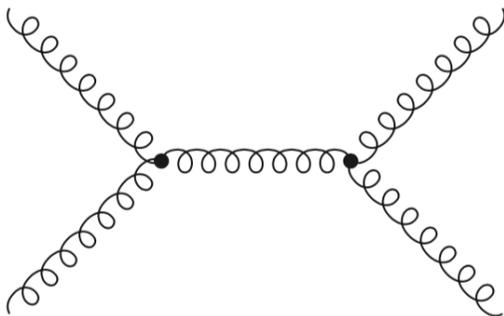


*antiquarks*

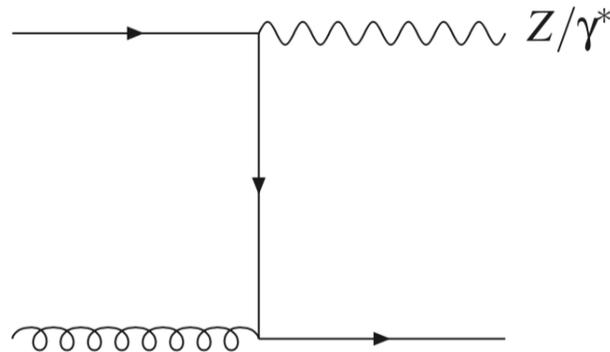
Drell-Yan production



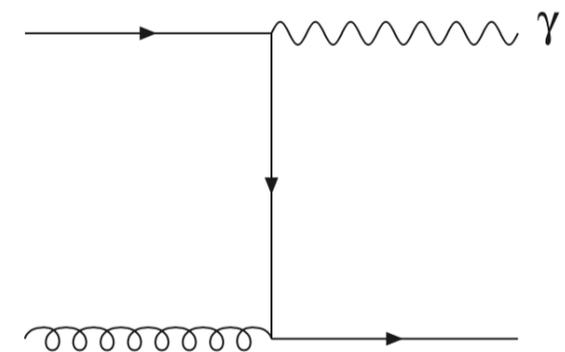
Jet production



$Z p_T$



Direct photon production



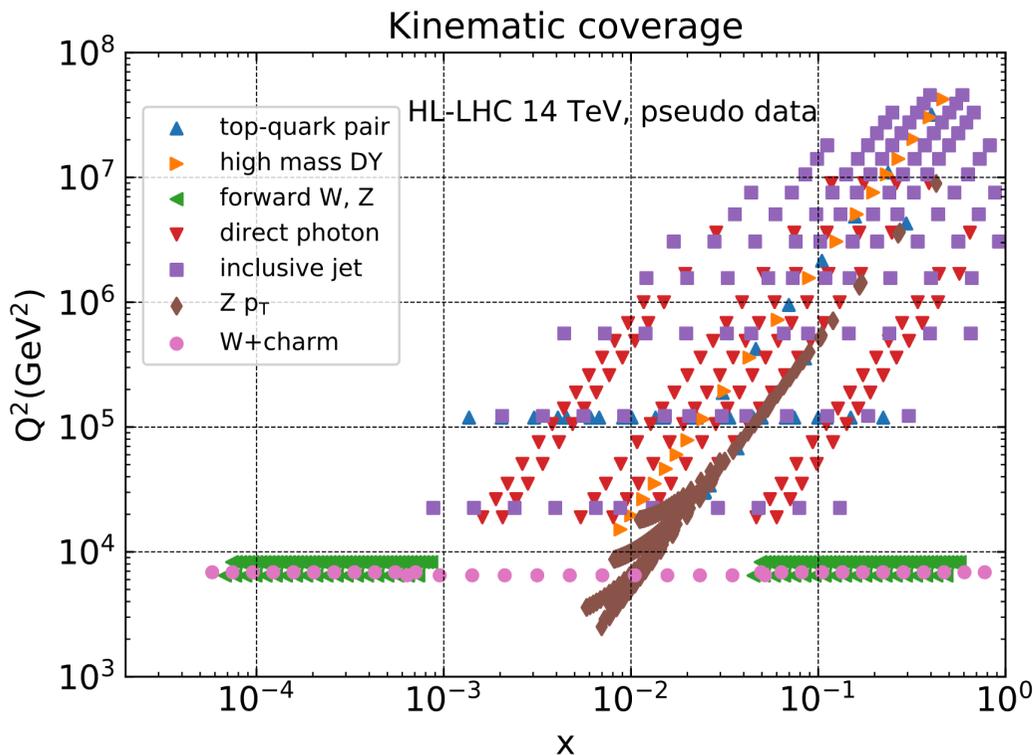
*large-x gluon*

*medium-x gluon*

*medium-x gluon*

# PDF-sensitive processes @ HL-LHC

- Wide kinematic coverage in  $x$  and  $Q$
- Total of 424 pseudo-data points generated
- Constraints on medium and large- $x$  antiquarks, gluon, strangeness....



Process	Kinematics	$N_{\text{dat}}$
Z $p_T$	$20 \text{ GeV} \leq p_T^l \leq 3.5 \text{ TeV}$ $12 \text{ GeV} \leq m_{ll} \leq 150 \text{ GeV}$ $ y_{ll}  \leq 2.4$	162
high-mass Drell-Yan	$p_T^{l(2)} \geq 40(30) \text{ GeV}$ $ \eta^l  \leq 2.5, m_{ll} \geq 116 \text{ GeV}$	21
top quark pair	$m_{t\bar{t}} \simeq 5 \text{ TeV},  y_t  \leq 2.5$	26
W+charm (central)	$p_T^\mu \geq 26 \text{ GeV}, p_T^c \geq 5 \text{ GeV}$ $ \eta^\mu  \leq 2.4$	6
W+charm (forward)	$p_T^\mu \geq 20 \text{ GeV}, p_T^c \geq 20 \text{ GeV}$ $p_T^{\mu+c} \geq 20 \text{ GeV}$ $2 \leq \eta^\mu \leq 5, 2.2 \leq \eta^c \leq 4.2$	12
Direct photon	$E_T^\gamma \lesssim 3 \text{ TeV},  \eta_\gamma  \leq 2.5$	53
Forward W, Z	$p_T^l \geq 20 \text{ GeV}, 2.0 \leq \eta^l \leq 4.5$ $2.0 \leq y_{ll} \leq 4.5$ $60 \leq m_{ll} \leq 120 \text{ GeV}$	90
Inclusive jets	$ y  \leq 3, R = 0.4$	54
Total		424

# HL-LHC pseudo-data

- Theoretical predictions computed at **NLO QCD** theory (sufficient for a pseudo-data analysis)
- Starting with PDF4LHC15, generate **HL-LHC pseudo-data** with a sensible binning, taking recent 8 TeV and 13 TeV LHC measurements as reference
- Explore different assumptions for the expected reduction of experimental **systematic uncertainties** (no attempt to construct an explicit correlation model)

$$\sigma_i^{\text{exp}} = \sigma_i^{\text{th}} \times \left( 1 + r_i \cdot \delta_{\text{tot},i}^{\text{exp}} \right)$$

**MCFM+PDF4LHC15**

**Systematic error from reference LHC measurement**

$$\delta_{\text{tot},i}^{\text{exp}} \equiv \left( \left( \delta_{\text{stat},i}^{\text{exp}} \right)^2 + \left( f_{\text{corr}} \times f_{\text{red}} \times \delta_{\text{sys},i}^{\text{exp}} \right)^2 \right)^{1/2}$$

**Total exp error**

**Total stat error**

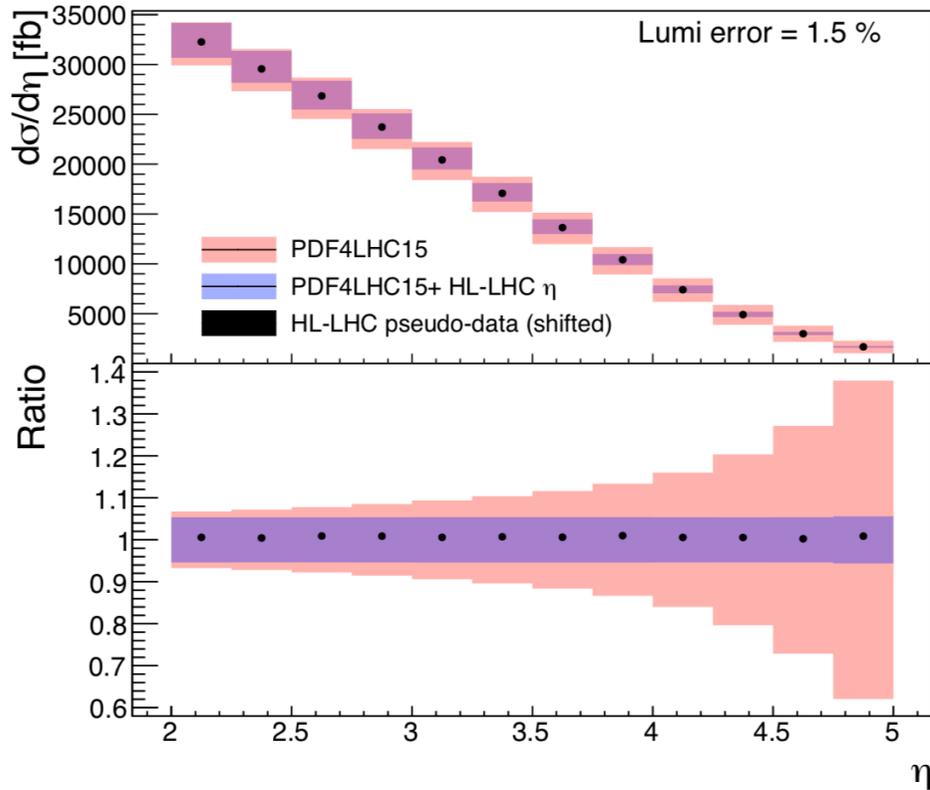
**effective correlation**

**Assumed reduction of exp systs**

$$\delta_{\text{stat},i}^{\text{exp}} = (f_{\text{acc}} \times N_{\text{ev},i})^{-1/2}$$

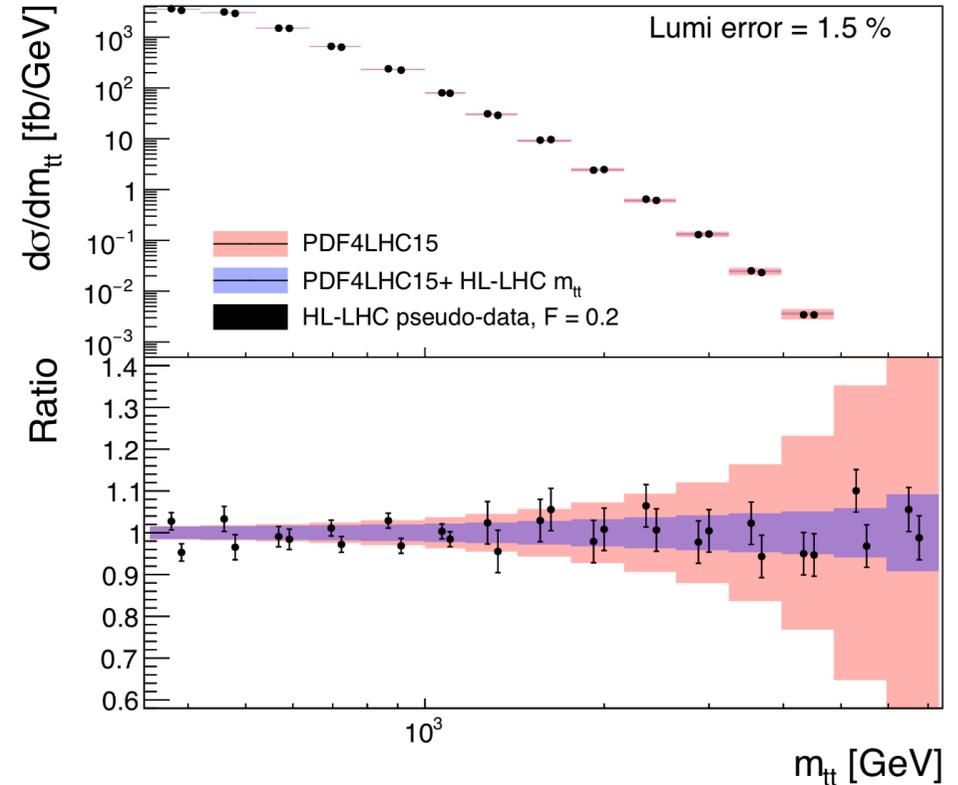
# HL-LHC constraints on PDFs

Projected forward W+charm data



*Forward W+charm*

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



*Top quark pair production*

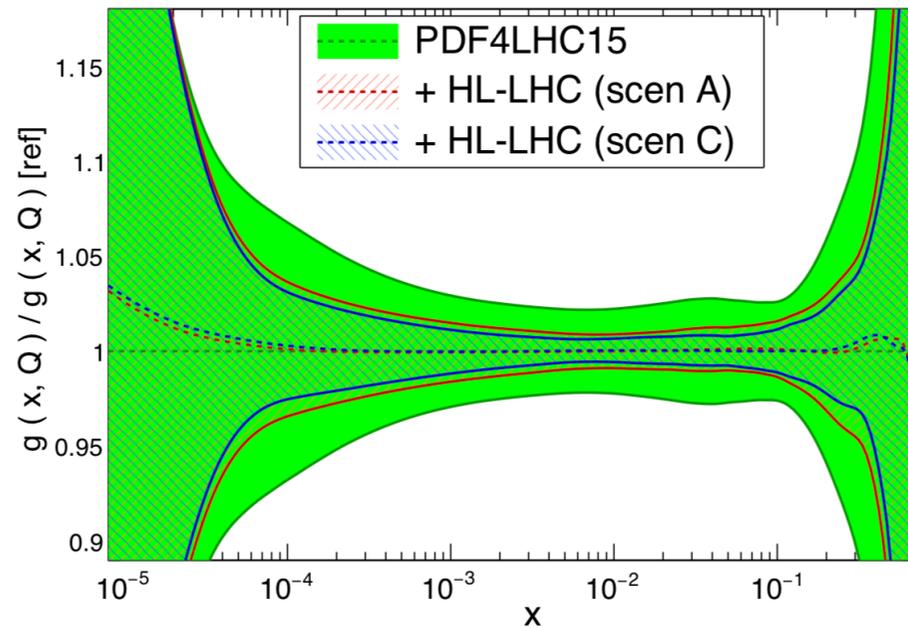
HL-LHC measurements will be specially useful to constrain the **gluon** and **quark flavour separation** in the large- $x$  region, including strangeness

# HL-LHC constraints on PDFs

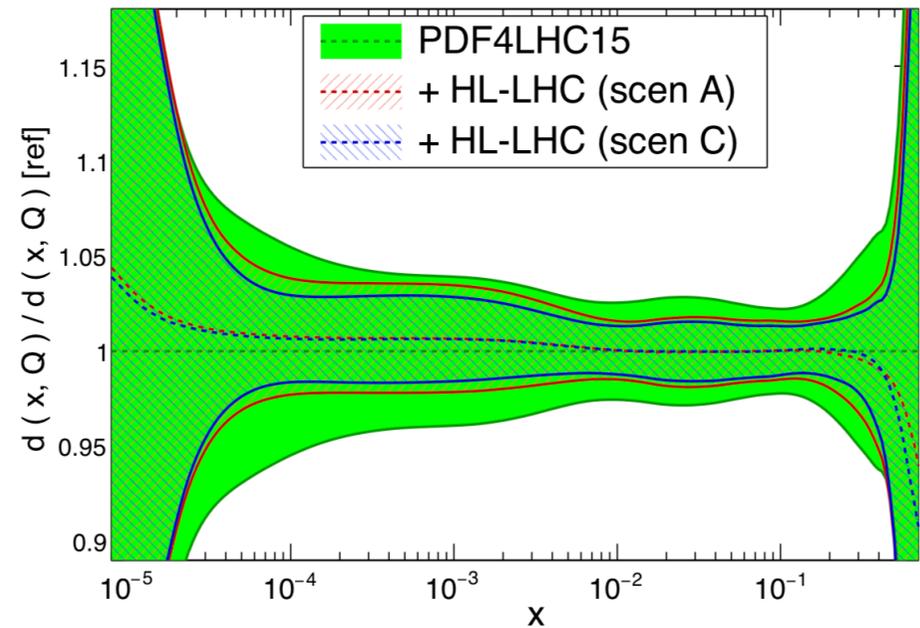
**Reduction in PDF uncertainties** as compared to PDF4LHC15

Ratio to baseline	$10 \text{ GeV} \leq M_X \leq 40 \text{ GeV}$	$40 \text{ GeV} \leq M_X \leq 1 \text{ TeV}$	$1 \text{ TeV} \leq M_X \leq 6 \text{ TeV}$
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)

PDFs at the HL-LHC (  $Q = 10 \text{ GeV}$  )

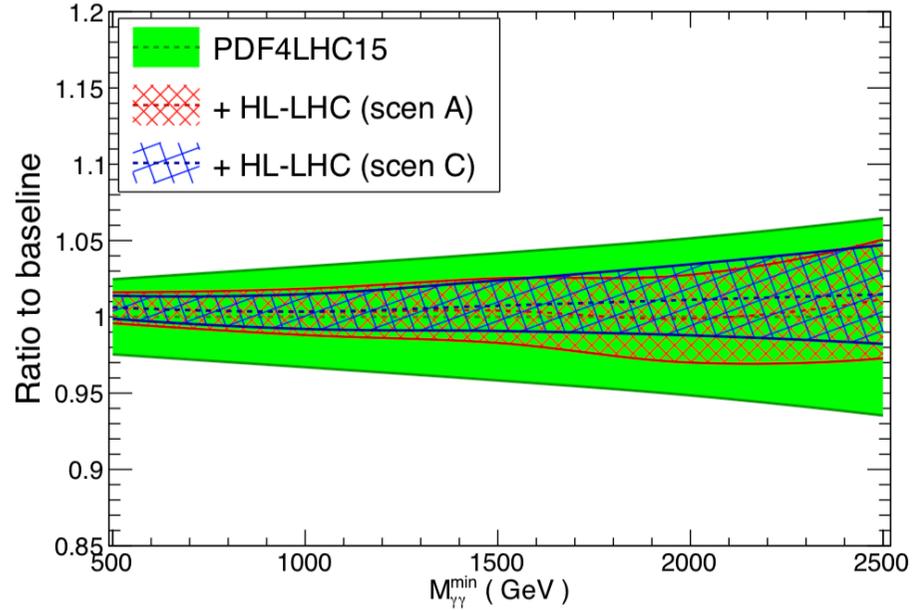


PDFs at the HL-LHC (  $Q = 10 \text{ GeV}$  )

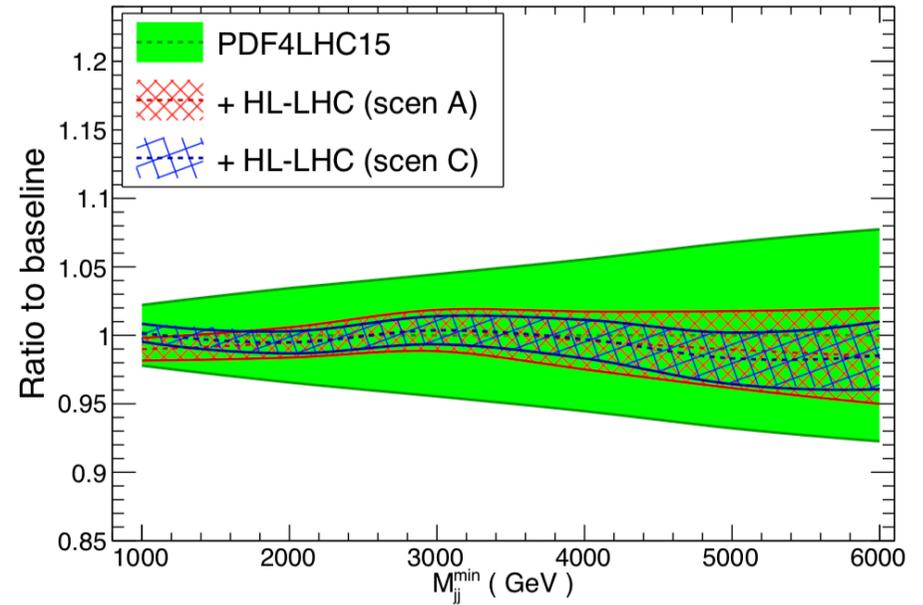


# Phenomenology

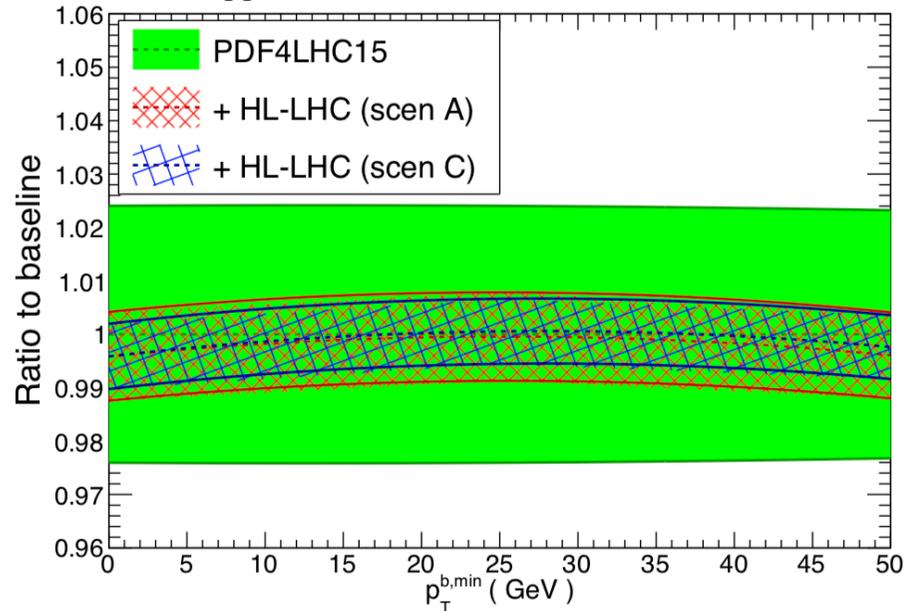
Di-photon production @ HL-LHC  $\sqrt{s}=14$  TeV



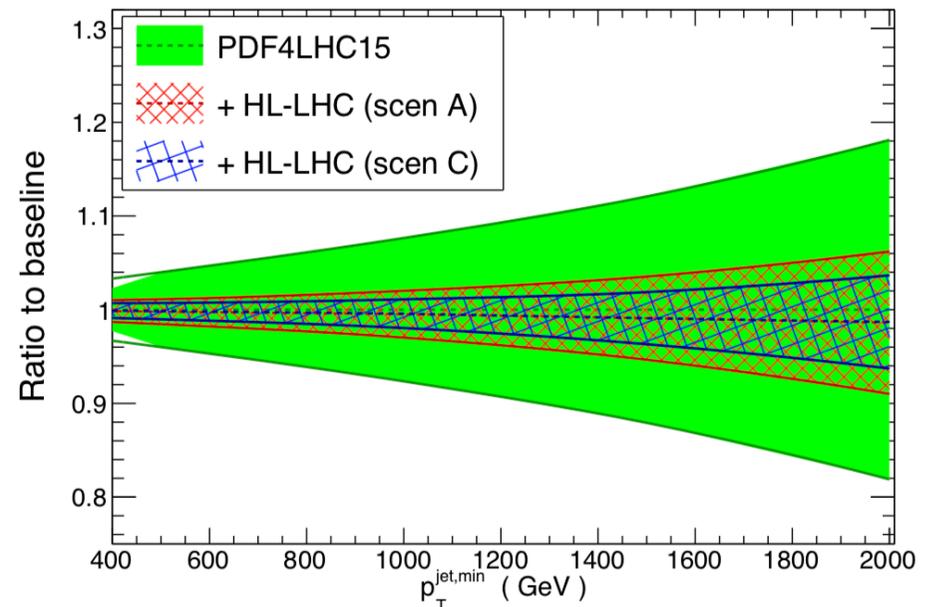
Dijet production @ HL-LHC  $\sqrt{s}=14$  TeV



$gg \Rightarrow h \Rightarrow b\bar{b}$  @ HL-LHC  $\sqrt{s}=14$  TeV



Higgs production in gluon fusion @ LHC  $\sqrt{s}=14$  TeV



# Summary and outlook

- Systematic quantification of the **impact of HL-LHC measurements** on the PDFs
- The **PDF uncertainty reduction** on LHC cross-sections ranges between **a factor 2 and a factor 5**, depending the specific mass region and partonic combination
- Our results represent an **upper bound** on the potential impact of HL-LHC measurements, since only a subset of the possible PDF-sensitive measurements has been included
- The **PDF4LHC15\_HLLHC sets** are available in LHAPDF format, and already being used in several HL-LHC projections (*e.g.* inclusive jet production, determination of  $M_W$ )

`https://data.nnpdf.science/HLLHC\_YR/PDF4LHC15\_nnlo\_hllhc\_scen1.tgz`

`https://data.nnpdf.science/HLLHC\_YR/PDF4LHC15\_nnlo\_hllhc\_scen2.tgz`

`https://data.nnpdf.science/HLLHC\_YR/PDF4LHC15\_nnlo\_hllhc\_scen3.tgz`