Higgs cross section updates for HL-LHC (Report 5)

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(on behalf of WG1)

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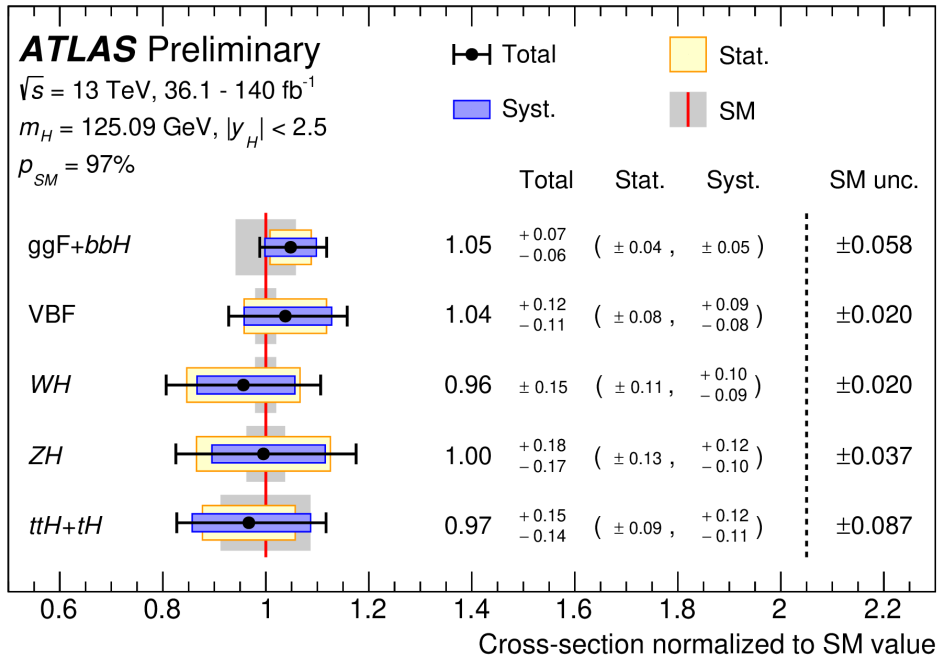
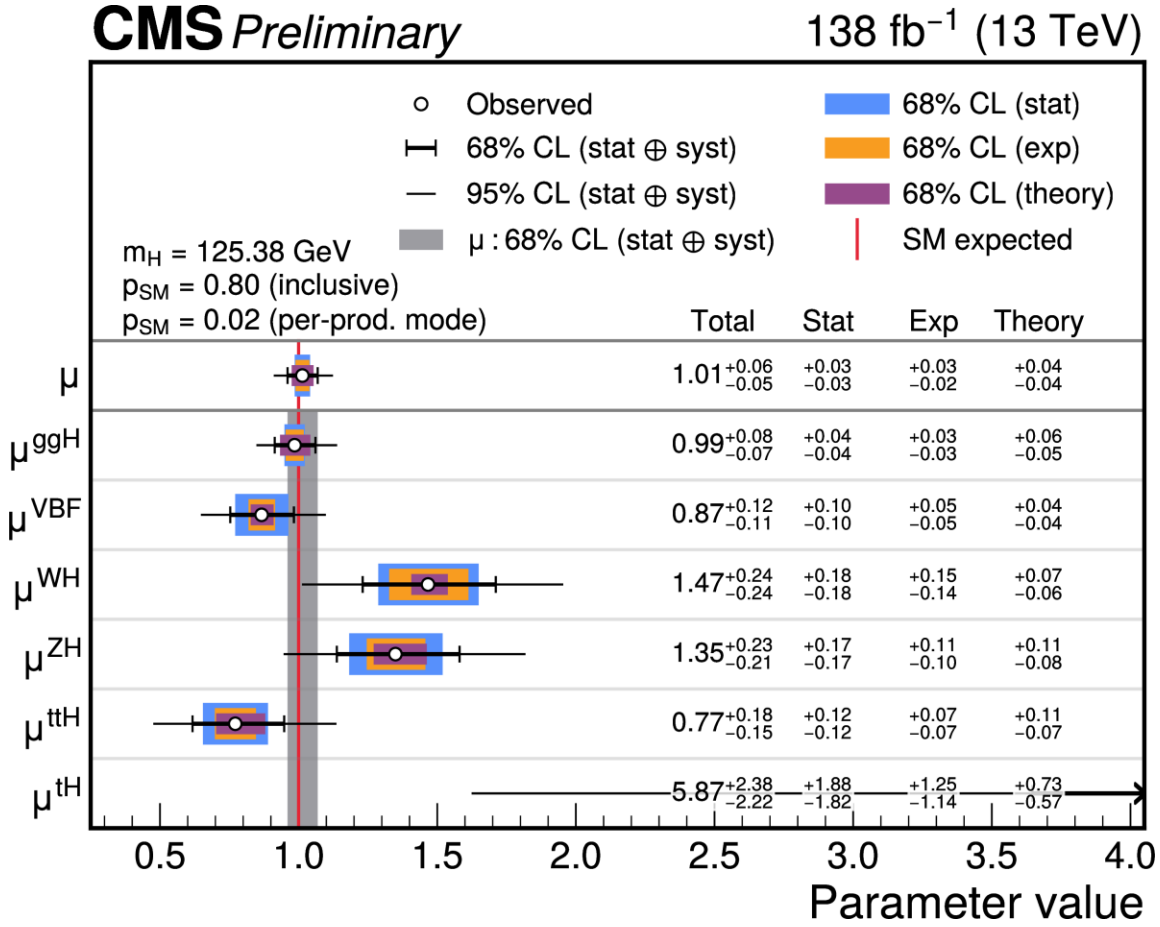
THE ROYAL SOCIETY



ATLAS-CONF-2025-006



CMS-PAS-HIG-21-018

Impressive results from both ATLAS and CMS in measuring Higgs signal strengths. Overall **good** agreement with theory (SM) predictions.

ATLAS-CONF-2025-006

$$\mu = 1.023^{+0.056}_{-0.053} = 1.023 \pm 0.028\ (\text{stat.})\ ^{+0.026}_{-0.025}\ (\text{exp.})\ ^{+0.039}_{-0.036}\ (\text{sig. theo.})\ \pm 0.012\ (\text{bkg. theo.})$$

@140 fb^{-1} theory uncertainties are already a factor two larger than exp. Situation need to improve dramatically for HL-LHC…

CMS-PAS-HIG-21-018

$$\mu = 1.014^{+0.055}_{-0.053}$$

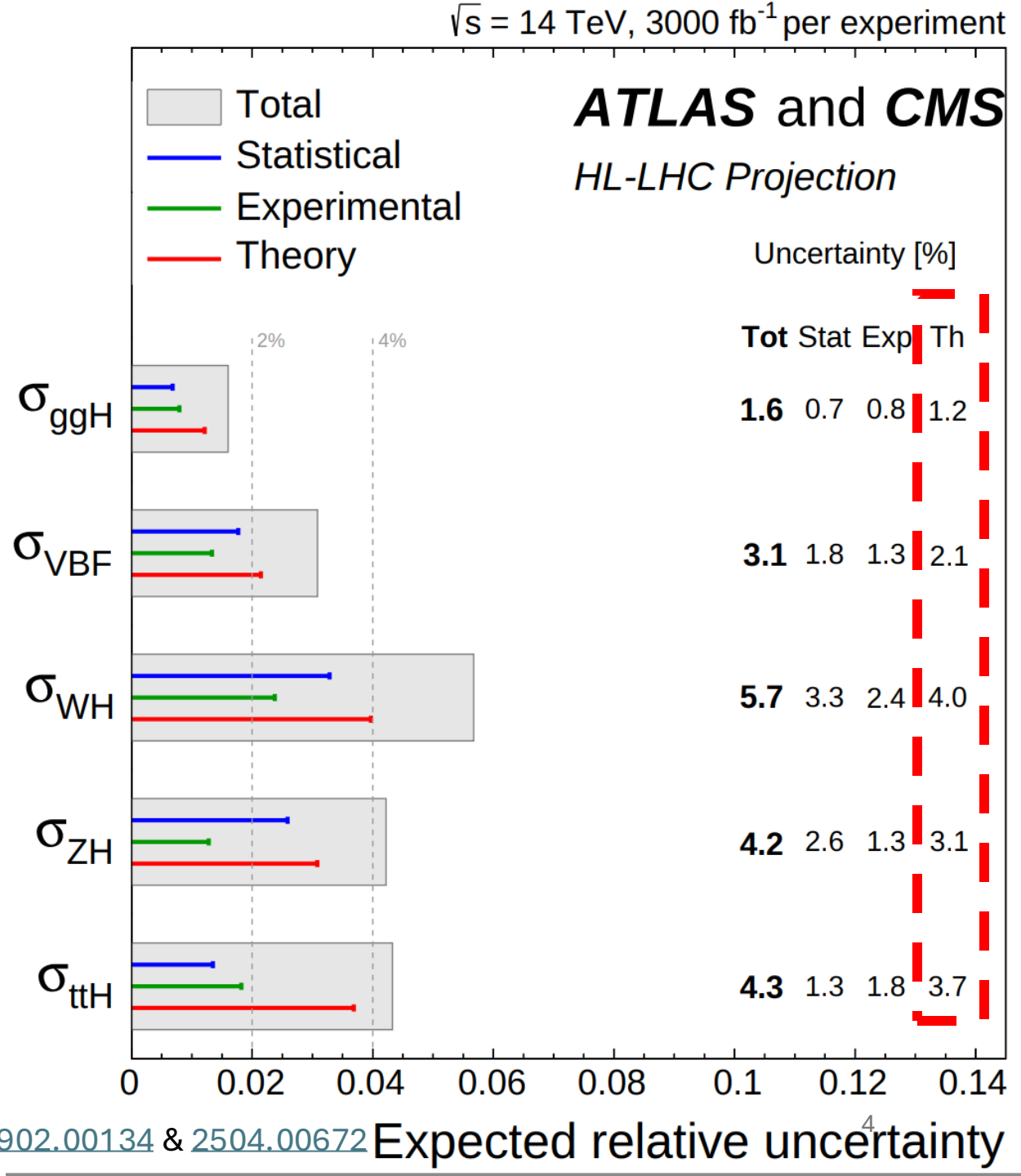
$$= 1.014^{+0.040}_{-0.039}(\text{theory})^{+0.025}_{-0.024}(\text{exp}) \pm 0.028(\text{stat})$$

Theory uncertainties dominate the signal strength extraction!

HL-LHC projections

Even in optimistic scenario, theory predictions dominate the uncertainty. Theory syst. assumed to be cut in half.

So how are we actually doing, ~6-7 years down the line and ~5 years before the HL-LHC starts…?



HL-LHC reports → 1902.00134 & 2504.00672

Progress included in R5 since 2019/YR4

- ggF: Exact HTL@N3LO, exact heavy quark mass results at NNLO. [See S. Jones' talk]
- VBF: N3LO structure functions, LuxQED photon, eikonal non-factorisable corrections.
- ZH: NLO ggZH production – still to be included. [See talks by S. Chatterjee, D. Grau, and B. C. Aveleira]
- ttH: NNLO+NNLL with approx. two-loop virtuals. [See A. Kuleza's talk]

- All processes: PDF4LHC15 -> PDF4LHC21

None-exhaustive list: See plenary/parallel talks for more specific updates!

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  aNNLO ←

  Comment from Vitaly Magerya: "Pease don't call it NNLO, as it discourages people from computing the exact thing!"

- All processes: PDF4LHC15 -> PDF4LHC21

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Updated numbers (PDF4LHC21, no QED PDF)

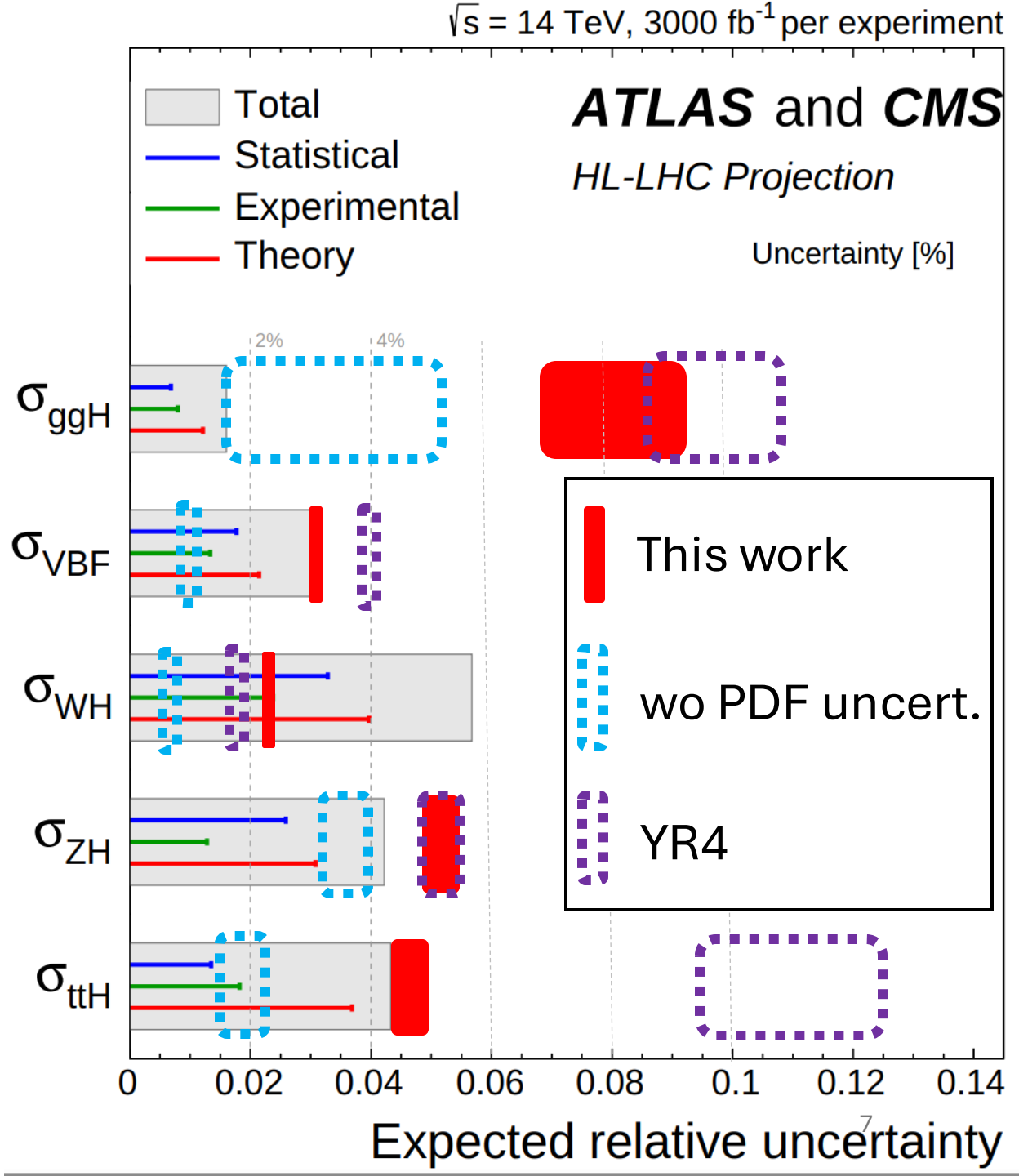
$\sqrt{s}$ [TeV]	Production cross section (in pb) for $m_H = 125$ GeV					
	ggF	VBF	WH	ZH	$t\bar{t}H$	tH
13.6	$52.1^{+6.9\%}_{-9.5\%}$	$4.11^{+3.3\%}_{-3.3\%}$	$1.47^{+2.4\%}_{-2.6\%}$	$0.954^{+5.6\%}_{-5.0\%}$	$0.592^{+4.3\%}_{-5.0\%}$	$0.085^{+8.5\%}_{-18\%}$
14	$54.5^{+7.0\%}_{-9.5\%}$	$4.32^{+3.3\%}_{-3.3\%}$	$1.52^{+2.3\%}_{-2.5\%}$	$0.995^{+5.6\%}_{-4.9\%}$	$0.639^{+4.3\%}_{-5.0\%}$	$0.092^{+8.0}_{-17\%}$

Uncertainties dominated by:

- ggF: PDF+α_s (1.6%+2.1%), PDF-TH (2.3%), and scale uncertainty (0.32-3.3%).
- VBF: PDF (2.1%) uncertainty.
- WH: PDF (1.6%) uncertainty.
- ZH: gg-induced scale uncertainty (4%). Recent results not included here (~factor 2 reduction). See also talk by S. Chatterjee.
- ttH: PDF+α_s (2.2%+1.6%).
- tH: scale uncertainty (6-15%).

Overall nice progress!!

Caveat: ATLAS+CMS projections include theory background uncertainties!



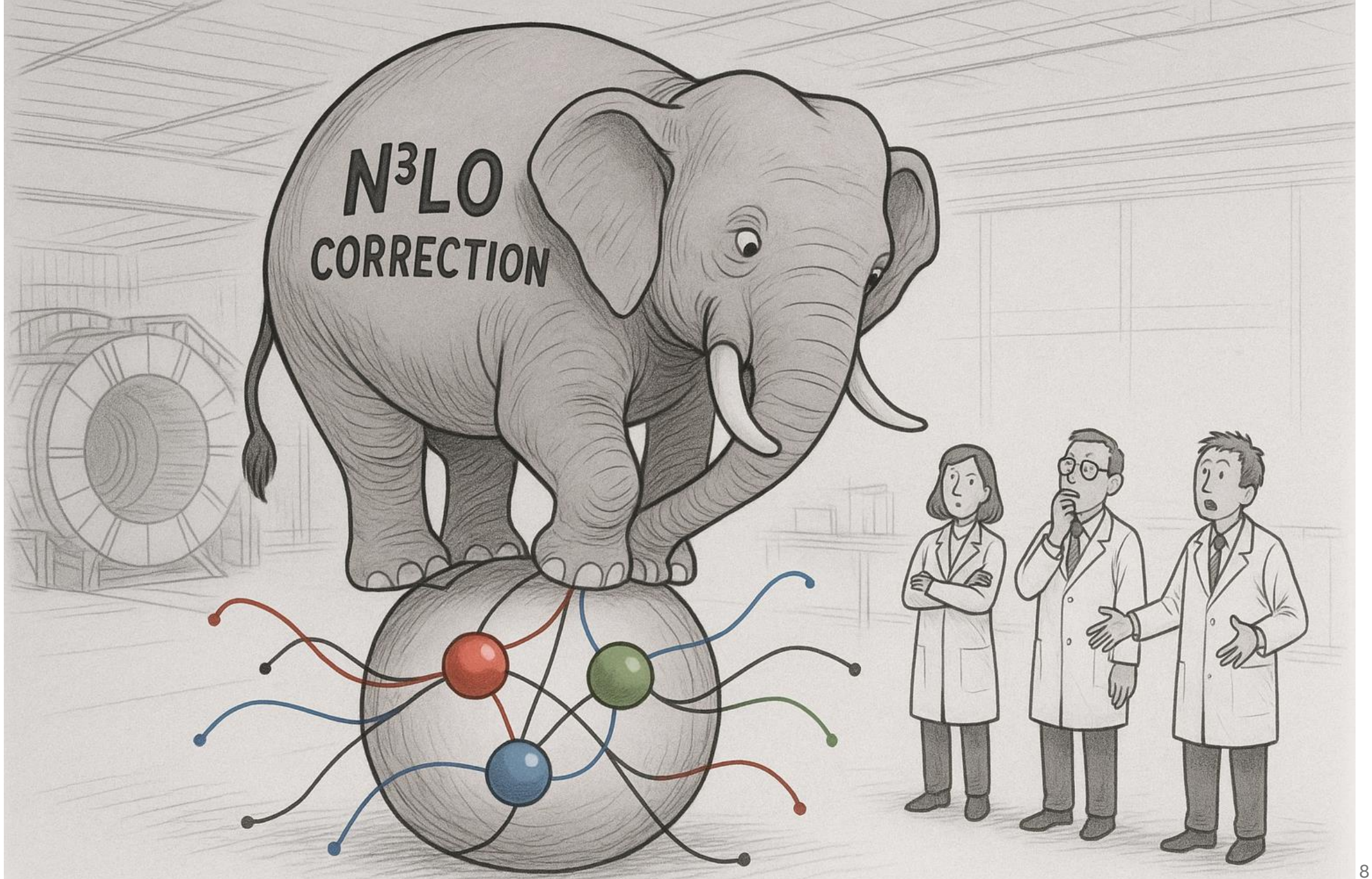
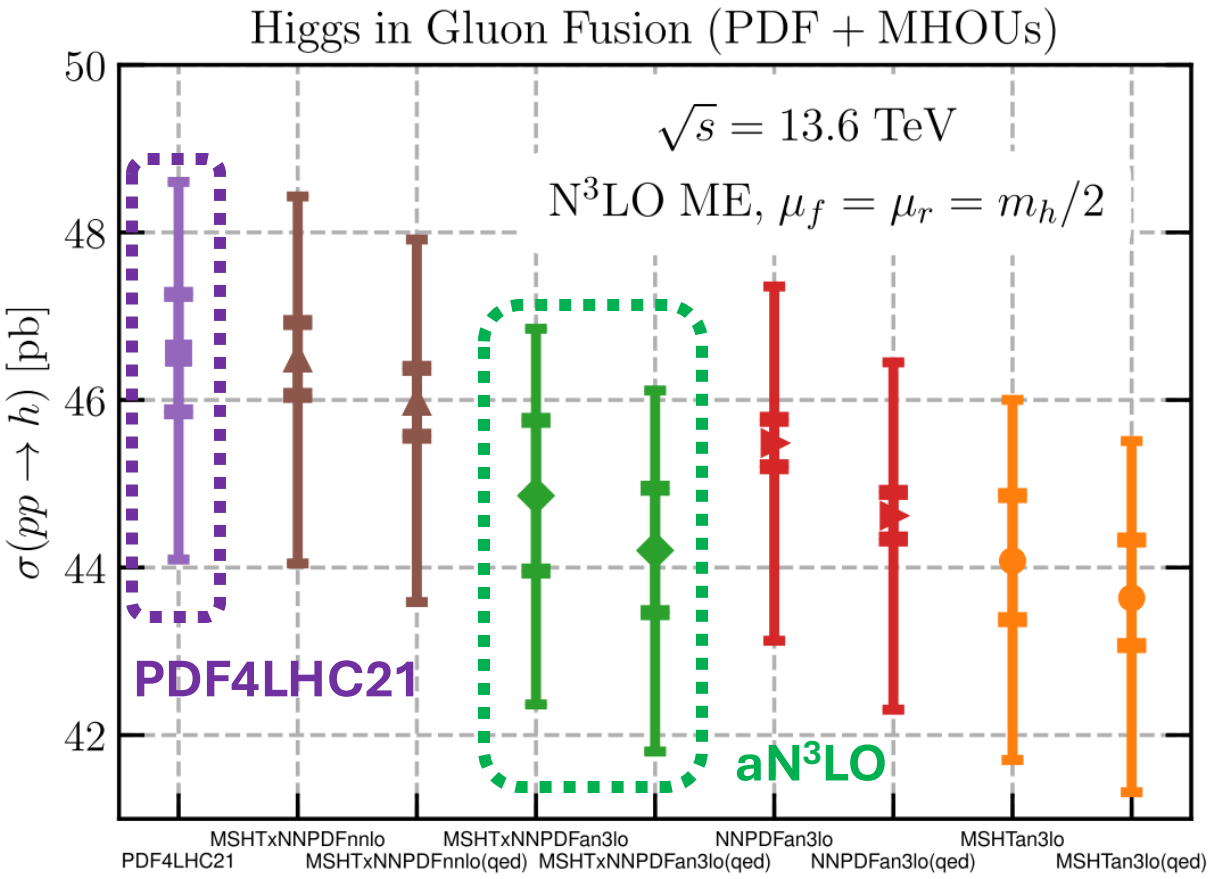
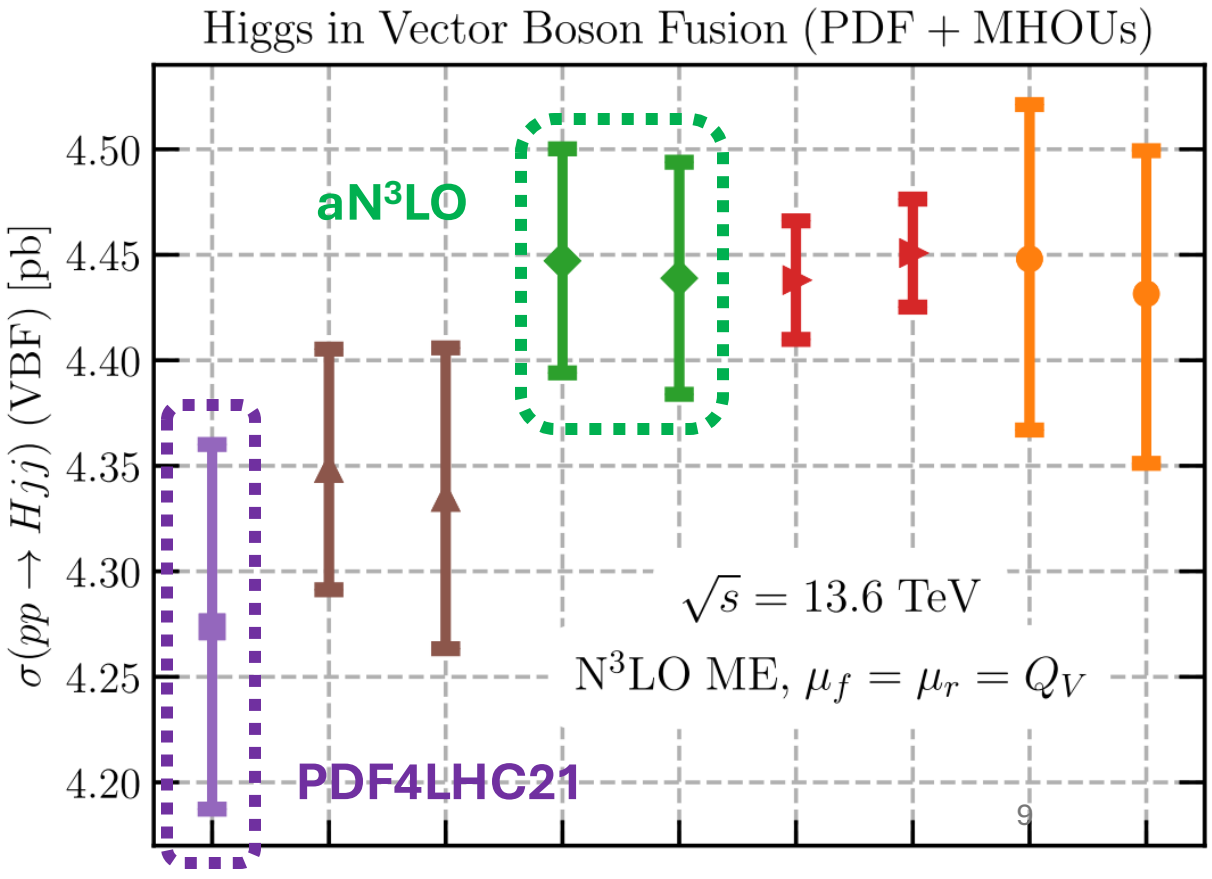


Image generated with OpenAI's DALL·E (ChatGPT).

The elephant in the room

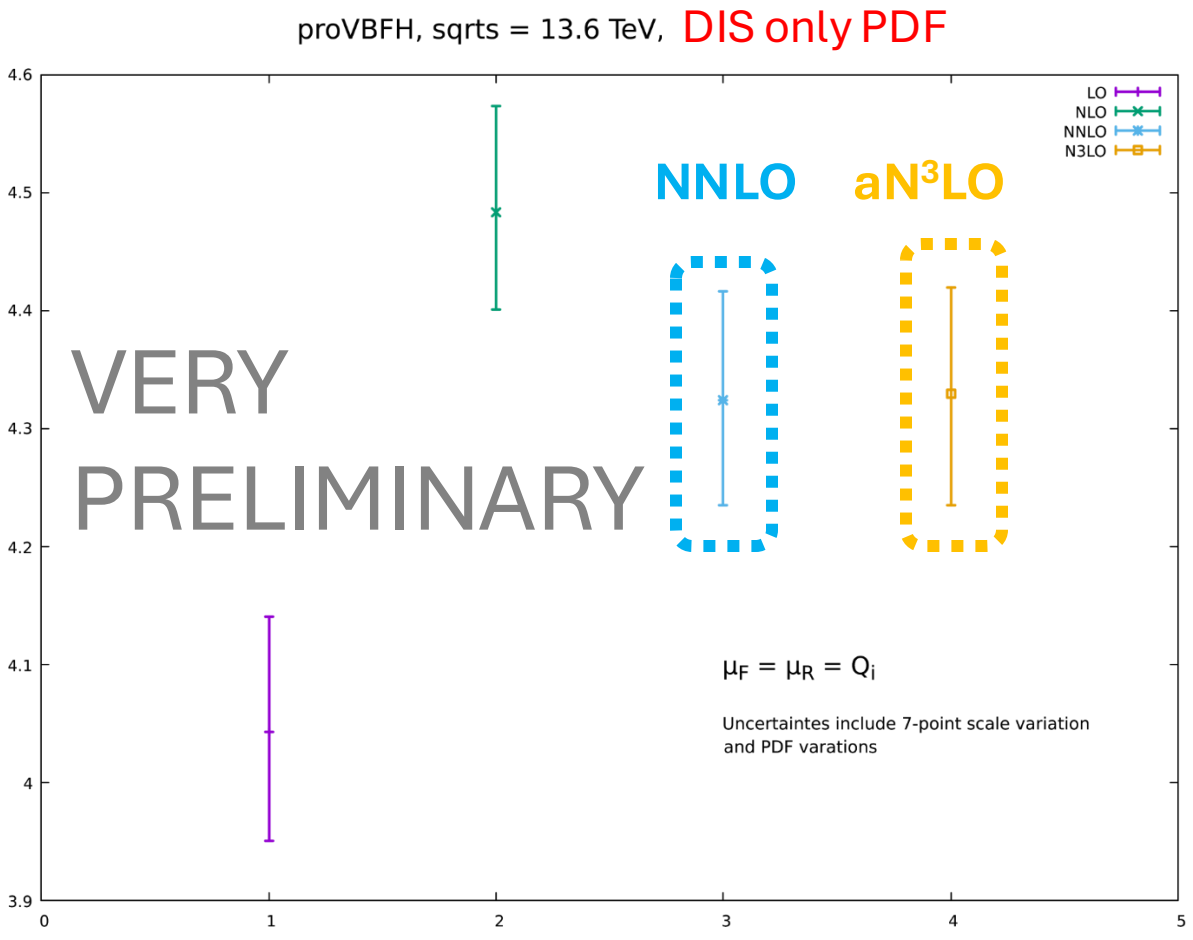
N³LO PDF corrections to Higgs production found to be larger than expected [MSHT+NNPDF]

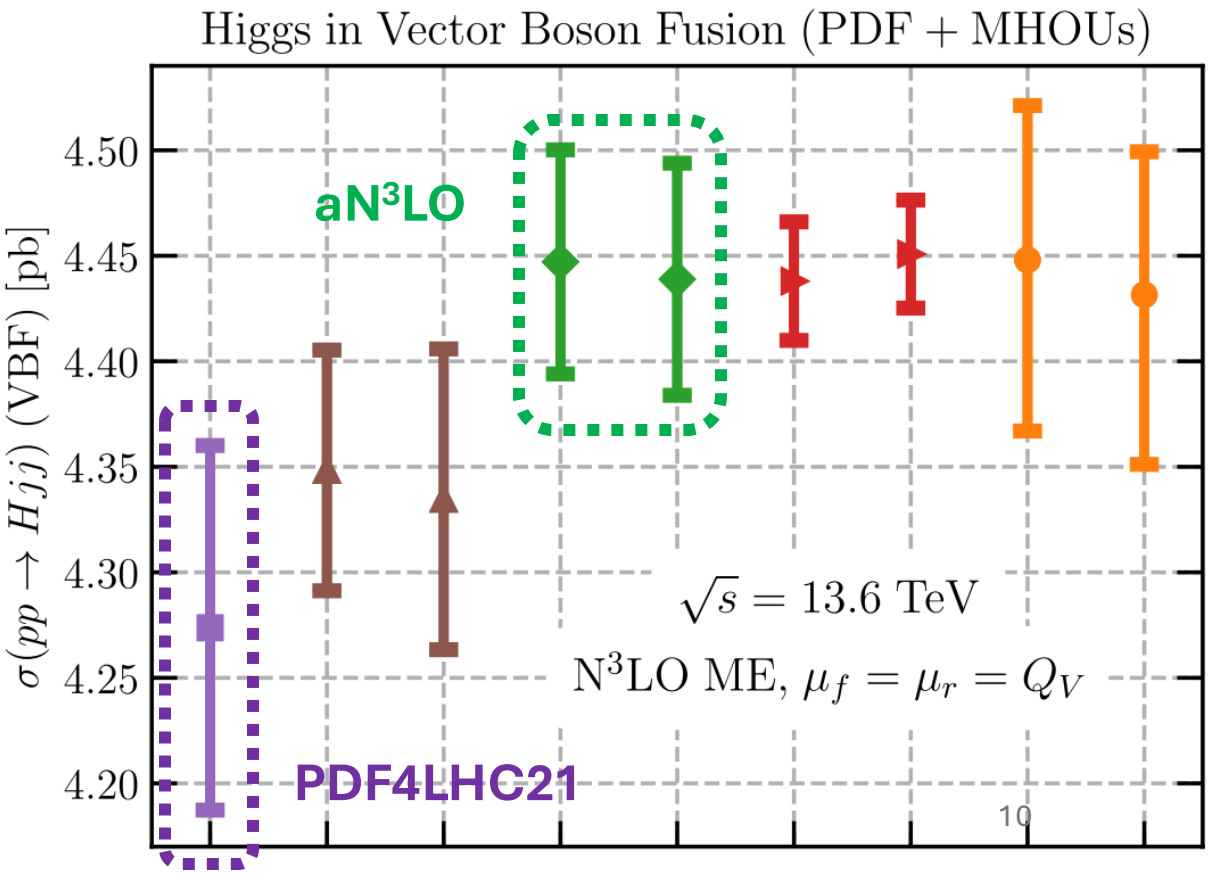




The elephant in the room

Using a PDF fit with DIS data only, the effect in VBF seems to disappear (it persists in ggF).





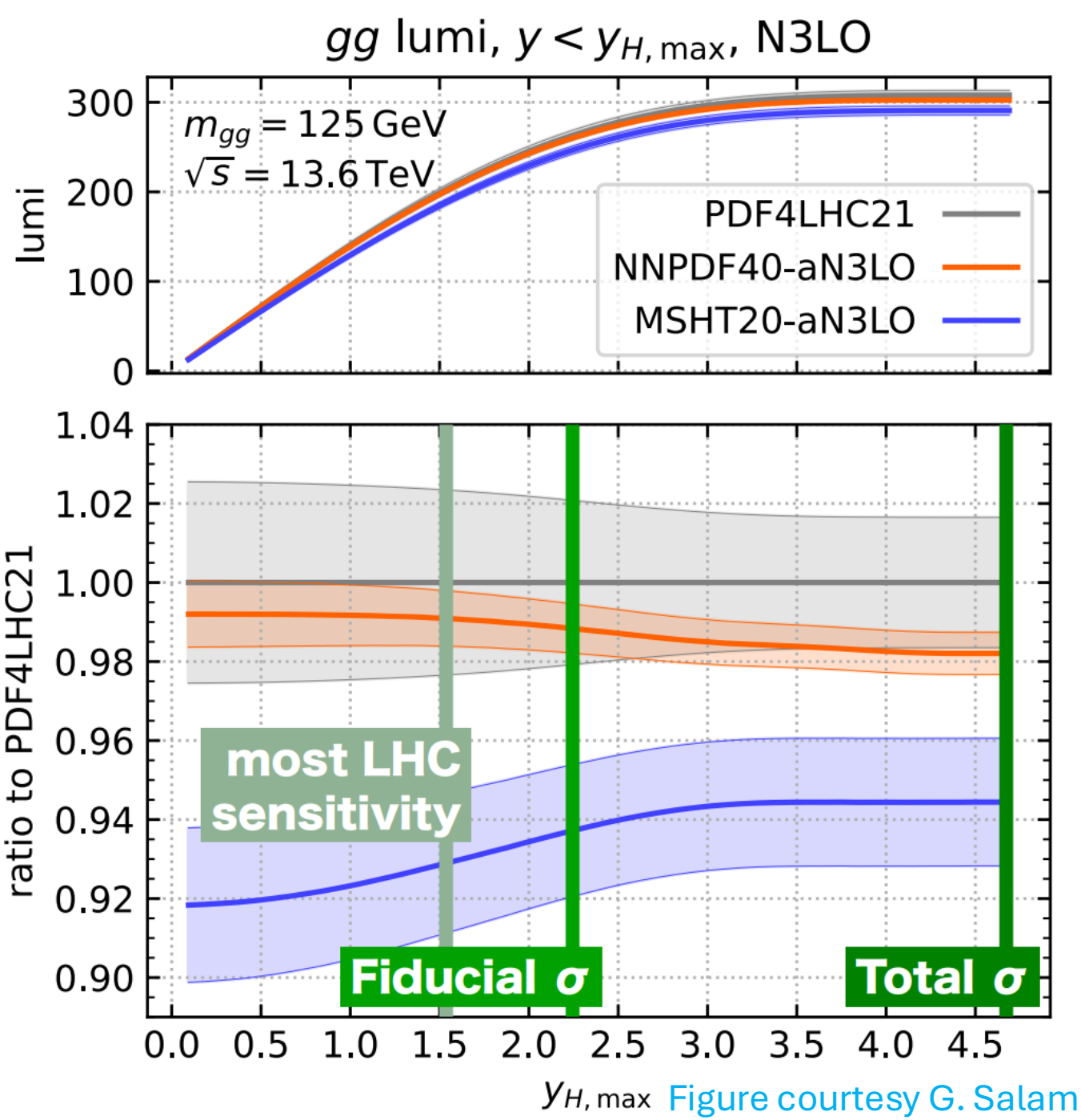


Figure courtesy G. Salam

Sizeable differences between MSHT and NNPDF determinations (less so with recent MSHT update)

Effect of aN^{3}LO appears even larger at central rapidities, where most of LHC sensitivity is…

Methodological differences still to be resolved? What about CT?

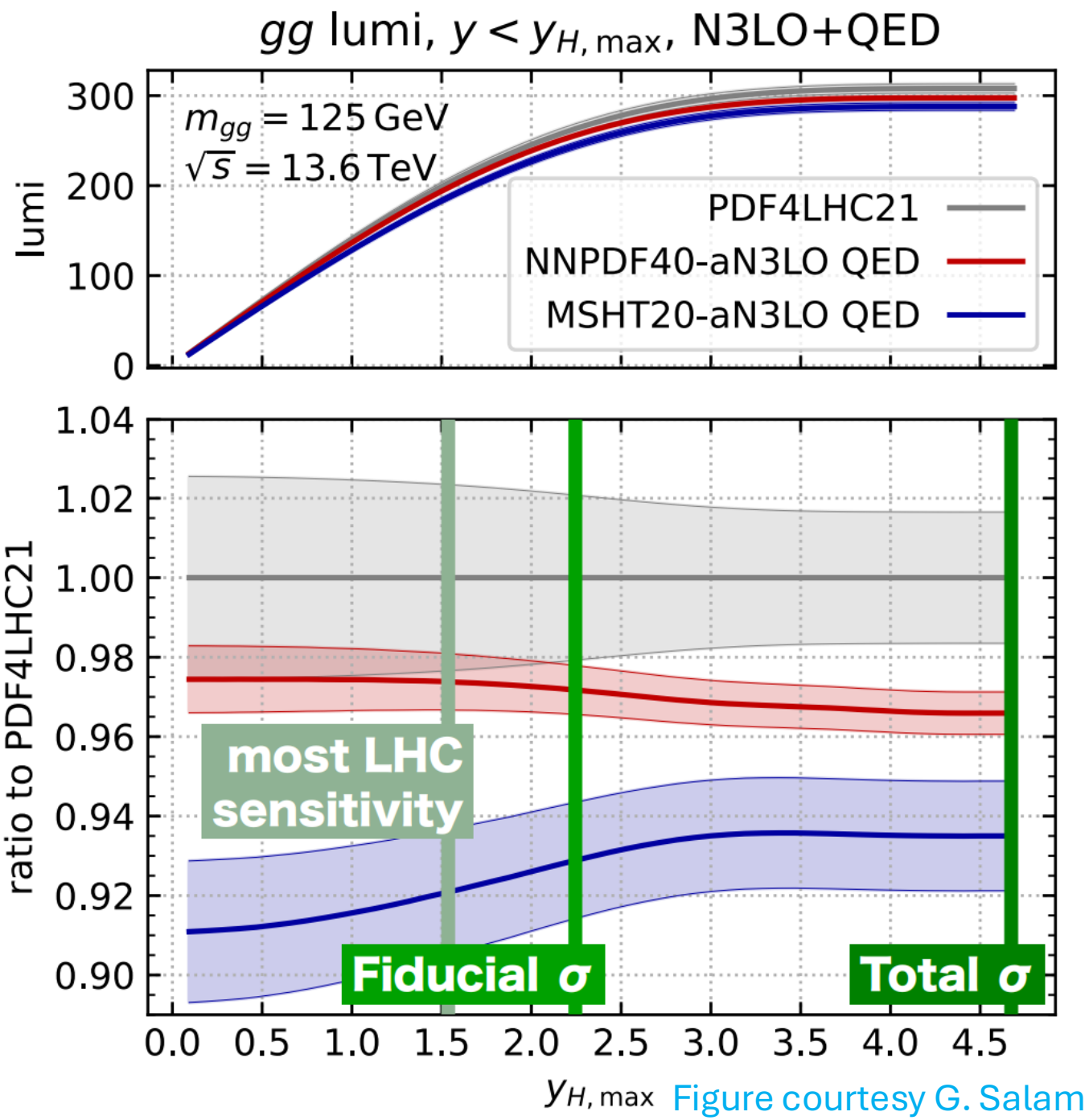


Figure courtesy G. Salam

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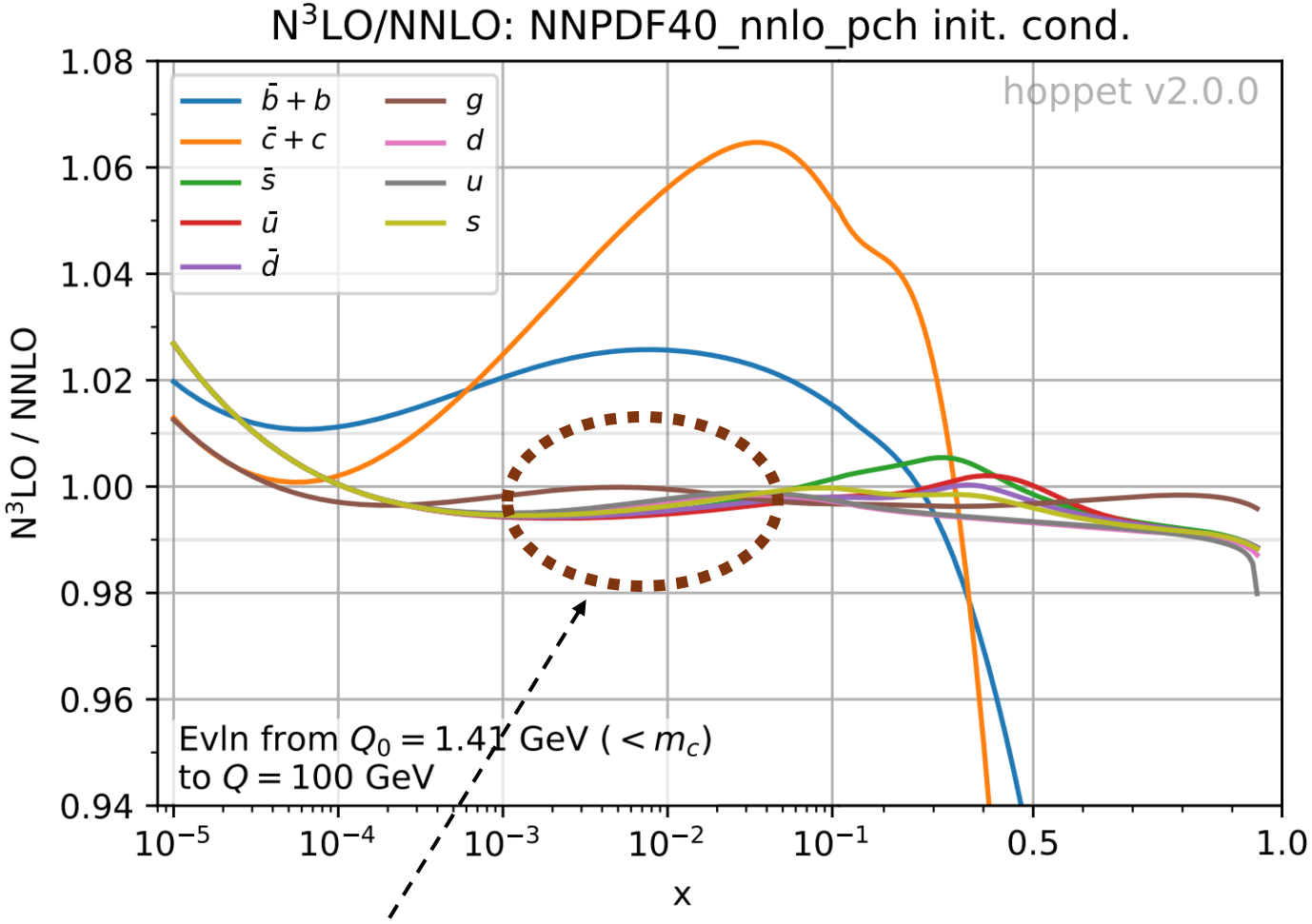
Methodological differences still to be resolved? What about CT?

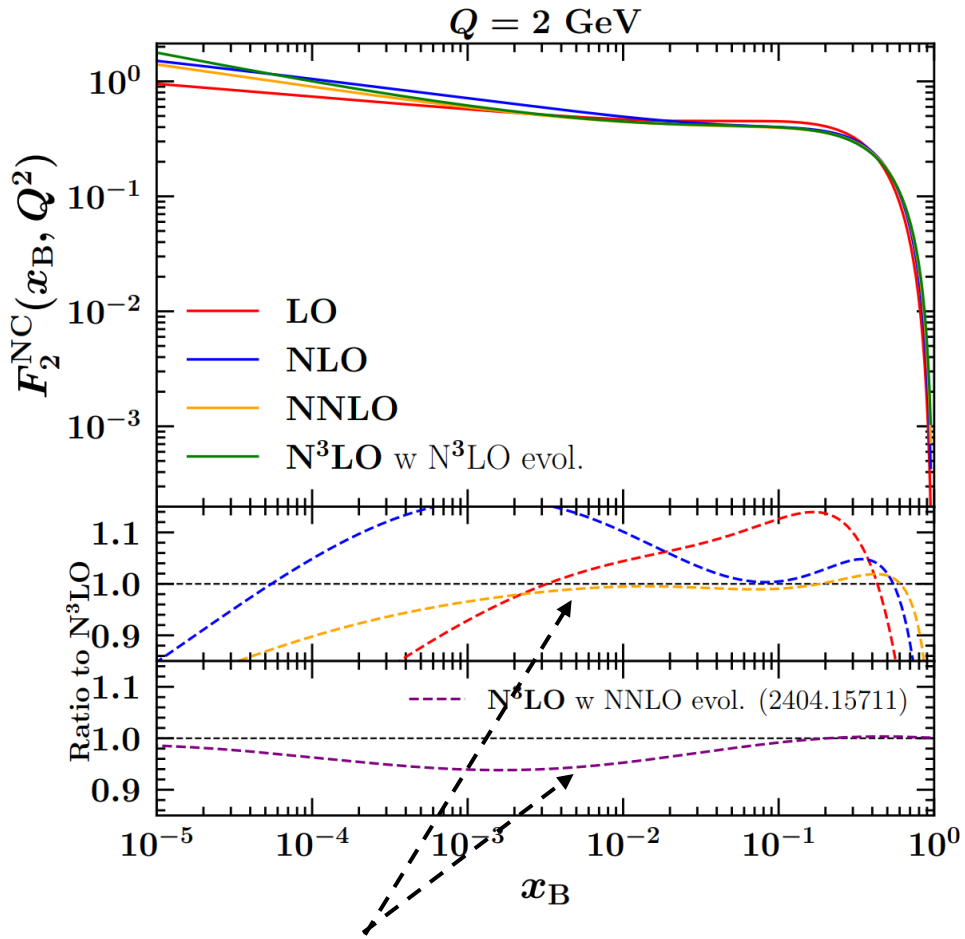
QED effects cannot be ignored at this level (see also talk by TJ Hobbs)

Recent updates in both NNPDF and MSHT seem to ameliorate this effect. [Cf. G. Magni talk at HIGGS.]

Where does the effect come from?



Impact of aN^{3}LO evolution on gluon around M_H appears tiny



At low-Q impact much larger, but balanced by hard coefficient functions

Plots obtained with HOPPET (2510.09310)

aN^{3}LO and QED

- For now the cross section updates do not fully include aN3LO and QED effects
  - Decision taken to wait for PDF4LHC recommendation including CT
  - In ggF PDF-TH uncertainty inflated by a factor 2 to accommodate this. QED effects implemented according to 2508.06603.
  - Other channels mostly ignore issue for now (shifts covered by other uncertainties).
- Will provide update when new PDF4LHC recommendation is available (cf. R. Thorne's talk)

PDF uncertainties

Uncertainties associated with the PDF fit itself are expected to be reduced as more LHC data enters the fits

E_{CM}	Current	Scenario 1	Scenario 2	Scenario 3
13 TeV	±1.85%	±0.78%	±0.69%	±0.59%
14 TeV	±1.85%	±0.78%	±0.68%	±0.58%
27 TeV	±1.95%	±0.81%	±0.72%	±0.61%

Systematics same as 8 TeV LHC

Systematics improved by factor 0.4

For ggF already reduced from 1.85% (PDF4LHC15) to 1.6% (PDF4LHC21). Can expect another factor 2-3 by the end of HL-LHC.

Table 21 in 1902.00134

Some practical points

- Predictions will be made available here (very soon):

  https://gitlab.cern.ch/LHCHIGGSXS/LHCHXSWG1/crosssections

- Version control to ensure most up-to-date numbers are available, while keeping a log of changes (will create tags upon each update)
- We try to include recommendations on the use of the numbers but also on how to cite them to give credit to the many theorists who did the calculations
- Accompanying paper to appear on CDS/arXiv/SciPost later