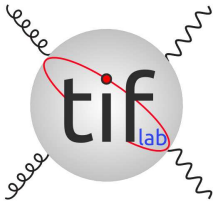


THE TOTAL GG→H CROSS-SECTION: YR4 AND BEYOND

STEFANO FORTE
UNIVERSITÀ DI MILANO & INFN

UNIVERSITÀ DEGLI STUDI
DI MILANO

LES HOUCHES

JUNE 6, 2017

THE YR4 RECOMMENDATION

$$\sigma(m_H = 125.1) = 16.82 \text{ pb}$$

$$\Delta^{\text{PDF}+\alpha_s} = 3.3\%; \qquad (\Delta^{\text{PDF}} = 1.9\%, \quad \Delta^{\alpha_s} = 2.7\%)$$

$$\Delta^{\text{th}}(\text{F}) = {}^{+4.4}_{-7.0}\% \qquad \text{or} \qquad \Delta^{\text{th}}(\text{G}) = \pm 4.0\%$$

F-UNCERTAINTIES AND G-UNCERTAINTIES

- HOW SHOULD ONE DEFINE THEORY UNCERTAINTIES?
- YR1 (2011): ASSUME THU HAVE FLAT DISTRIBUTION, COMBINE AS ENVELOPE

  $\Rightarrow$ DESTROYS STATISTICAL INTERPRETATION
- YR4/GGF (2016):
  - F UNCERTAINTY:

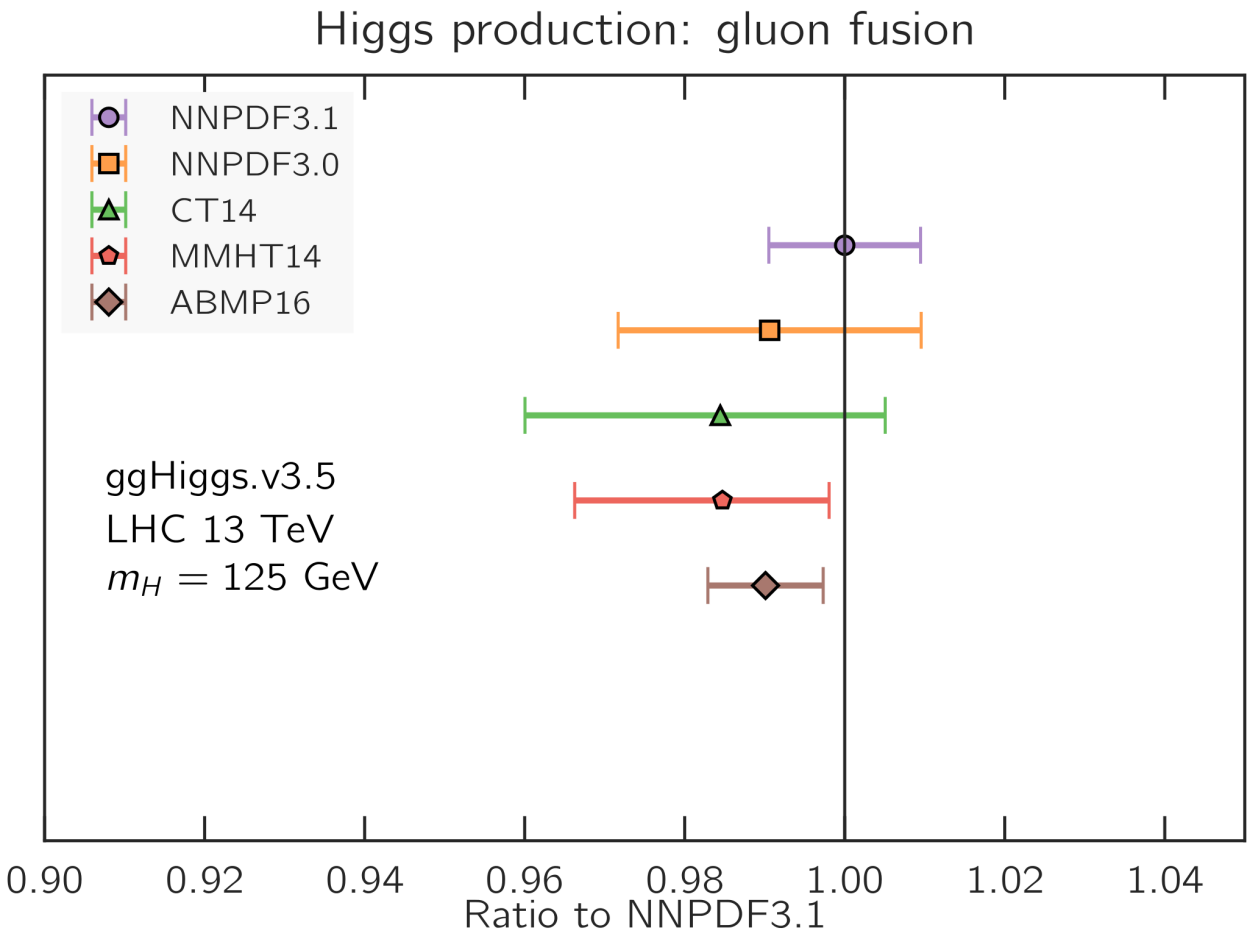
    100% RANGE OF FLAT DISTRIBUTION OBTAINED AS ENVELOPE OF RANGES

    $\Rightarrow$: DEVOID OF STATISTICAL MEANING
    - COMBINATION OF FLAT DISTRIBUTIONS IS NOT FLAT

      TWO FLAT $\Rightarrow$ TRIANGULAR; MANY FLAT $\Rightarrow$ GAUSSIAN
    - σ OF FLAT DISTRIBUTIONS ADD IN QUADRATURE
    - σ OF FLAT DISTRIBUTION EQUALS HALF-WIDTH$/\sqrt{3}$
  - G UNCERTAINTY: STANDARD GAUSSIAN, COMBINE IN QUADRATURE

PDFs (& α_s)

NEXT GENERATION PDFs



- NOMINAL PDF UNCERTAINTY DOWN TO $\sim 1.5\%$
- α_s UNCERTAINTY HAS NOT IMPROVED IN 20 YEARS

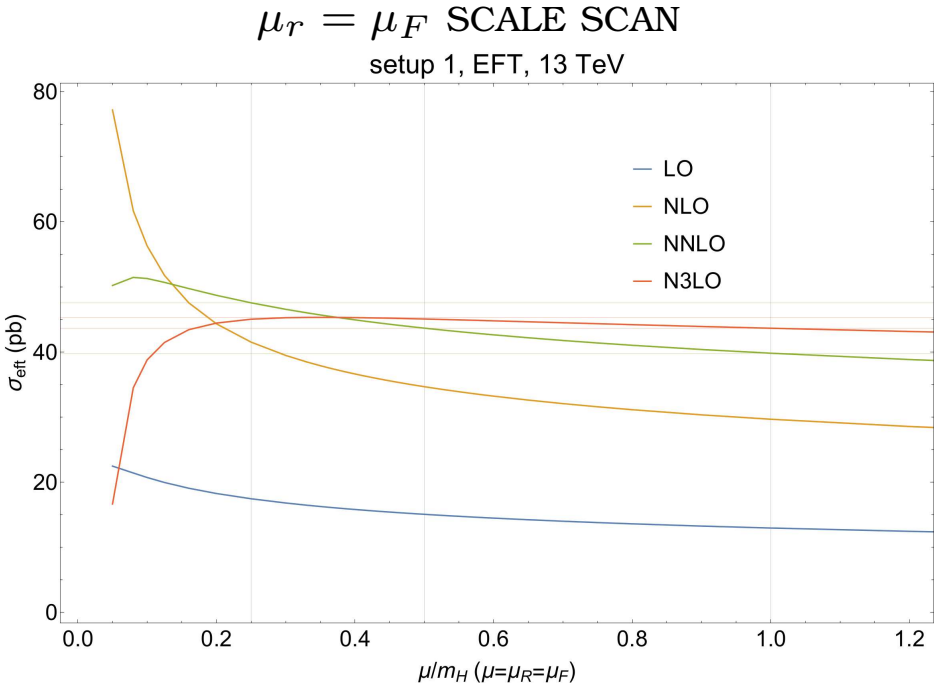
THEORY UNCERTAINTIES: SUMMARY

uncertainty	F	G
higher orders	$^{+0.2}_{-2.4}\%$	$\pm 3.0\%$
finite top mass	$\pm 1\%$	
c, b interf. w. top	$\pm 0.8\%$	$\pm 1.5\%$
electroweak	$\pm 1\%$	$\pm 2.5\%$
N^3LO PDFs	$\pm 1.2\%$	
eikonal expansion	$\pm .4\%$	
total	$^{+4.4}_{-7.0}\%$	$\pm 4.0\%$

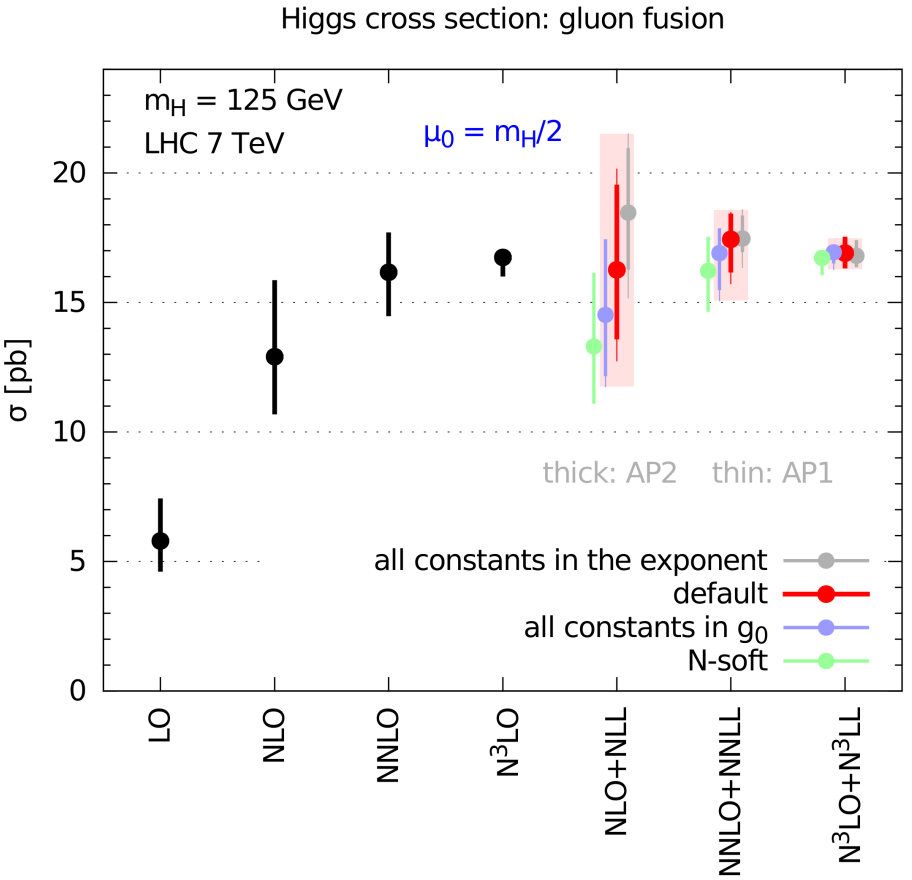
MISSING HIGHER QCD ORDERS

7-POINT SCALE VARIATION

$\mu_r = \mu_F$ SCALE SCAN



(Anastasiou et al, 2016)

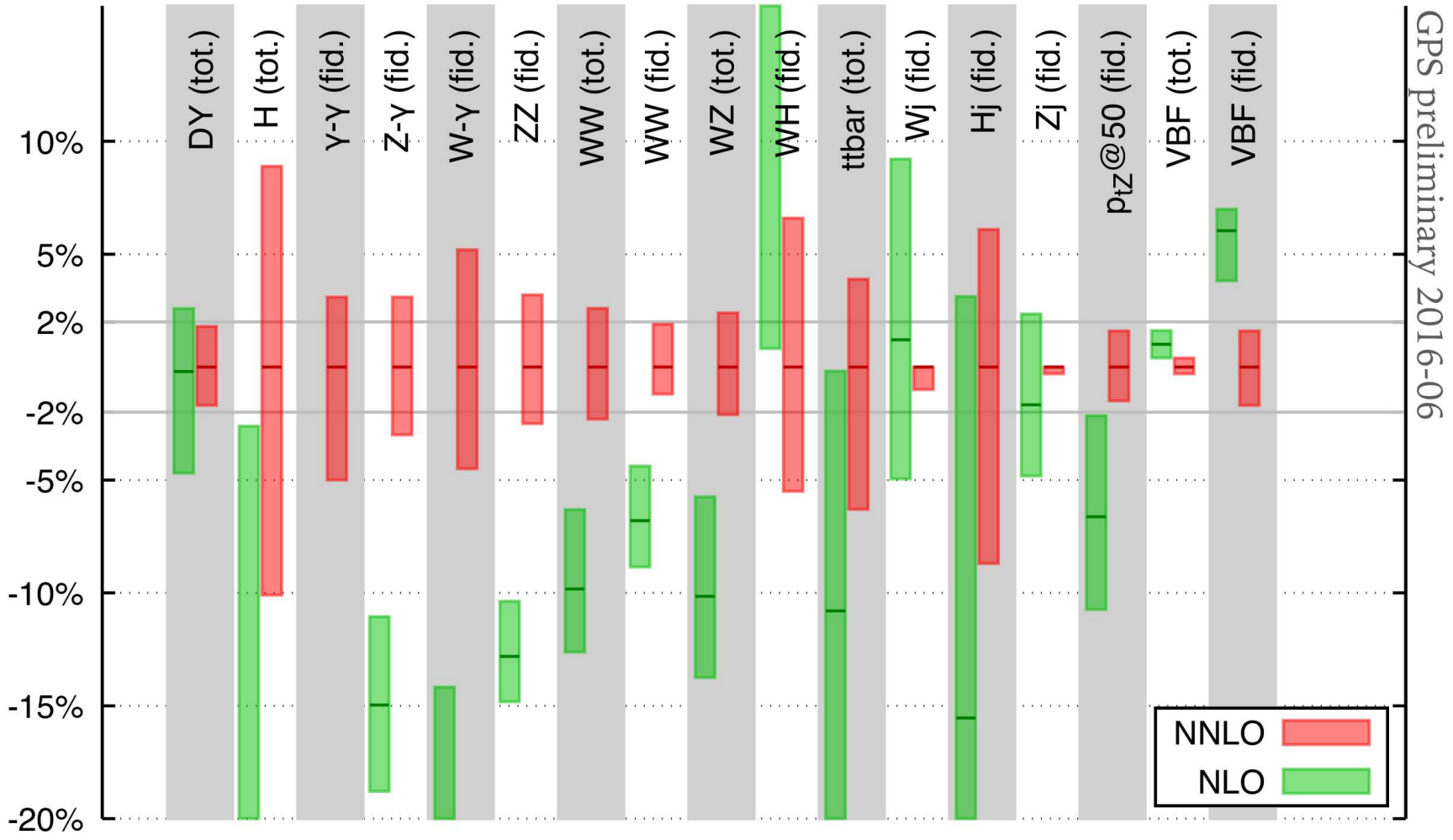


(Bonvini et al, 2016)

- F-UNCERTAINTY: SCALE SCAN WITH $\mu_R = \mu_F$
- G-UNCERTAINTY SYMMETRIZED N^{3}LO 7-POINT, VERY CLOSE TO N^{3}LO+N^{3}LL 7-POINT

MISSING HIGHER QCD ORDERS

CAN WE TRUST SCALE VARIATION?

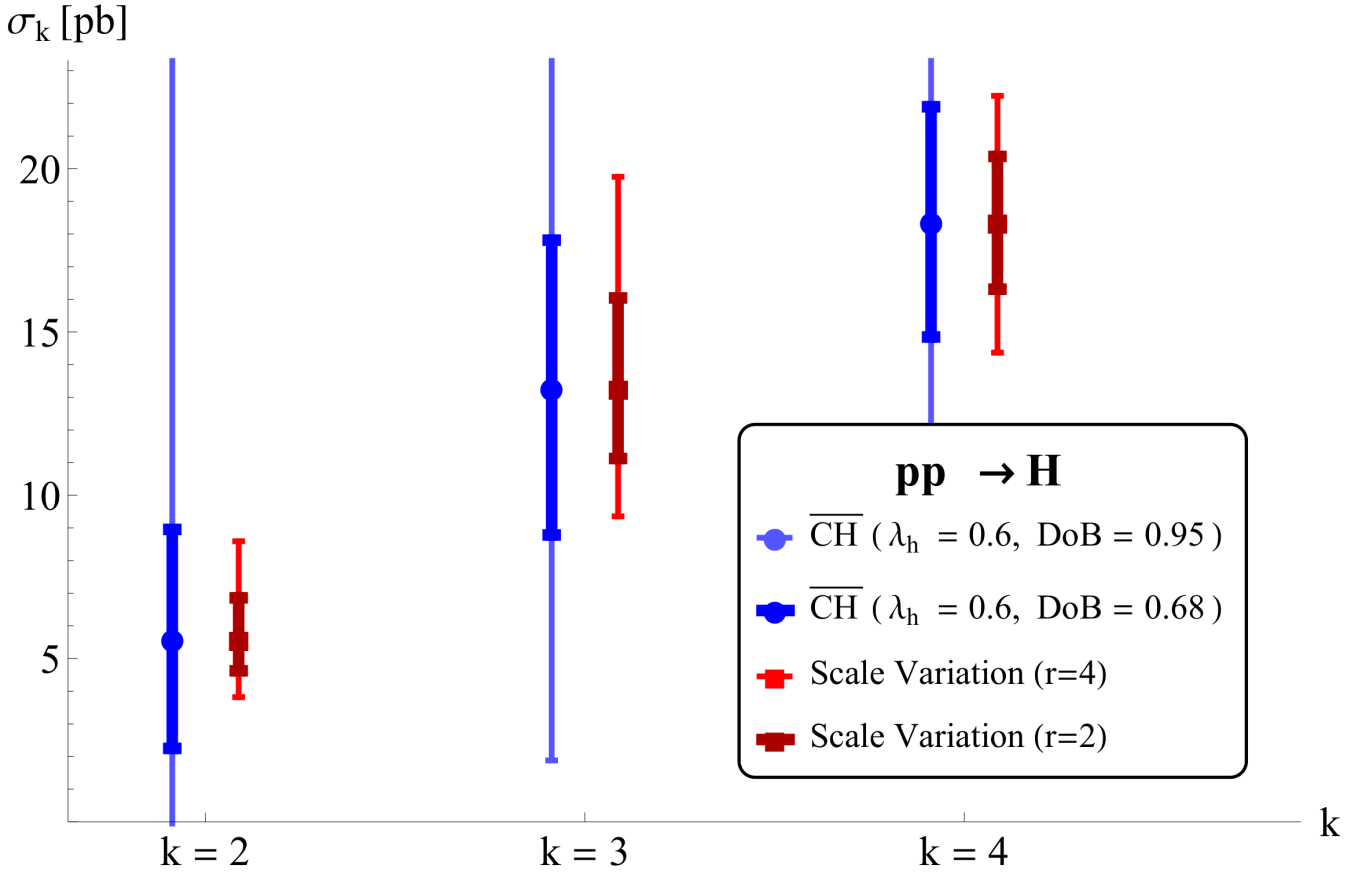


G. Salam, 06/2016

- NNLO WITH 7-POINT NLO SCALE VARIATION BAND IN 3/17 CASES

MISSING HIGHER QCD ORDERS

CAN WE DO BETTER THAN SCALE VARIATION?



(Bagnaschi, Cacciari et al., 2015)

- CACCIARI-HOUDEAU: BAYESIAN INFERENCE
  BASED ON BEHAVIOUR OF PREVIOUS ORDERS

- DEPENDS ON DEGREE OF BELIEF AND CHOICE OF EXPANSION PARAMETER

HEAVY QUARK MASSES

- FINITE TOP MASS EFFECTS KNOWN EXACTLY AT NLO, APPROXIMATELY AT NNLO, ESTIMATED RESIDUAL UNCERTAINTY: 1% (Harlander et al, 2008-2009)

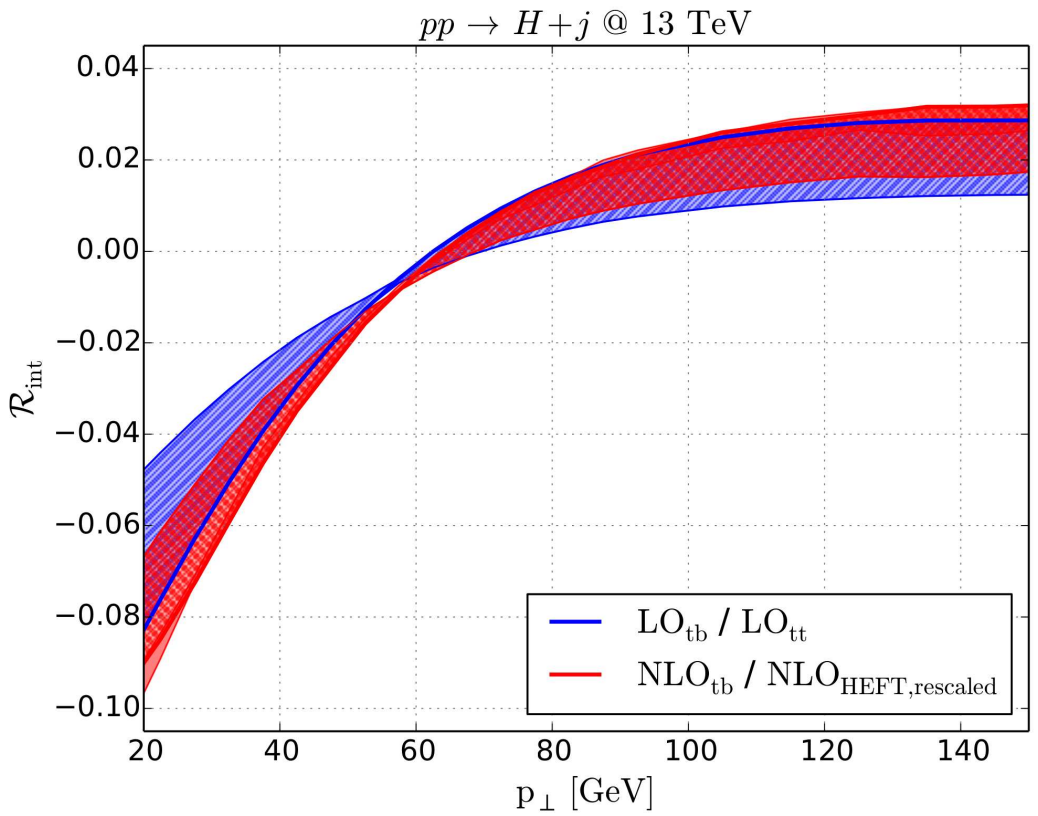
- b,c INTERFERENCE WITH t SIZABLE AT NLO:
  - F: $\delta(tbc)^{\overline{\rm MS}} = \pm \left| \frac{\delta\sigma^{NLO}_{ex;t} - \delta\sigma^{NLO}_{ex;t+b+c}}{\delta\sigma^{NLO}_{ex;t}} \right| (R_{LO}\delta\sigma^{NNLO}_{EFT} + \delta_t\hat{\sigma}^{NNLO}_{gg+qg,EFT}) = \pm 0.3\,\text{pb}$, with $\delta\sigma_X^{N^kLO} \equiv \sigma_X^{N^kLO} - \sigma_X^{N^{k-1}LO}$

    INTERFERENCE ASSUMED TO DECREASE WITH CONVERGING EXPANSION
  - G: $\delta(tbc)^{\overline{\rm MS}} = \pm \left| \sigma^{NLO,\overline{\rm MS}}_{ex;t+b+c} - \sigma^{NLO,OS}_{ex;t+b+c} \right| = 0.7\,\text{pb}$

    INTERFERENCE ASSUMED TO BE ESTIMATED BY SCHEME DEP. OF LAST KNOWN ORDER

INTERFERENCE: PROGRESS

NLO INTERFERENCE CONTRIBUTION TO p_T SPECTRUM



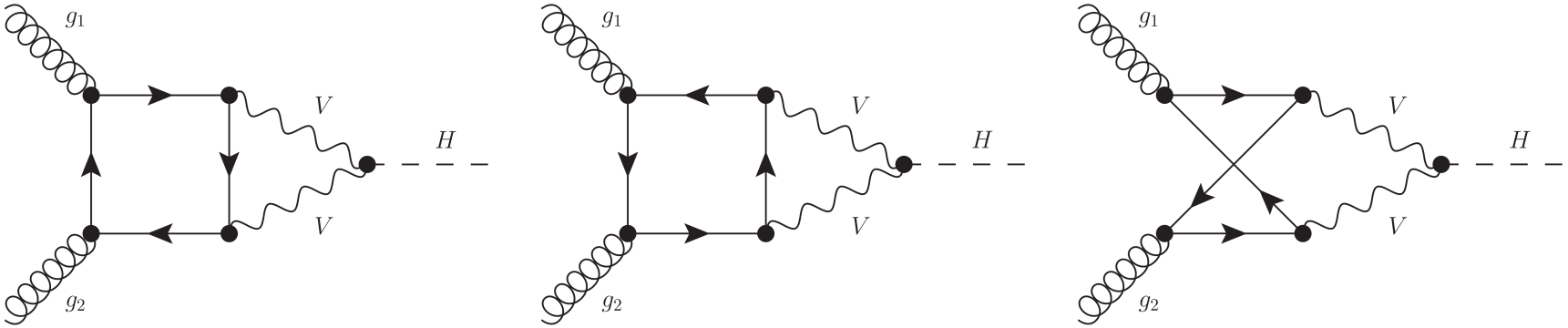
- SIZABLE NLO tb INTERFERENCE CONTRIBUTION TO SPECTRUM, AS LARGE AS 10% FOR $p_T \sim 20$ GeV (Lindert, Melnikov, Tancredi, Wever, 2017)
- $A^b_{gg\to Hg} \sim m_b^2/m_H^2 \ln^2(p_T^2/m_b^2) \Rightarrow$ SUDAKOV-LIKE NON-SUDAKOV DOUBLE LOGS FROM BOTTOM LOOPS, RESUMMED TO ALL ORDERS IN ABELIAN LIMIT (Melnikov, Penin, 2016)

ELECTROWEAK CORRECTIONS

- EW CORRECTIONS TO GLUON FUSION OF ORDER 5% IF MULTIPLICATIVE, 2% ADDITIVE
- WHAT IS THE MIXED QCD-EW? ONLY KNOWN FOR $m_z, m_W \gg m_H$ EFT
  - F: MIXED SMALLER THAN RESCALED DIFFERENCE BETWEEN ADD. AND MULT., BY RELATIVE SIZE OF NON-SOFT CROSS-SECTION $\sim 40\%$ I.E. 1%
  - G: UNCERTAINTY OF ORDER OF DIFFERENCE BETWEEN MULTIPLICATIVE OR ALTERNATIVES (ADDITIVE OR EFT) I.E. 2.5%

ELECTROWEAK CORRECTIONS

PROGRESS

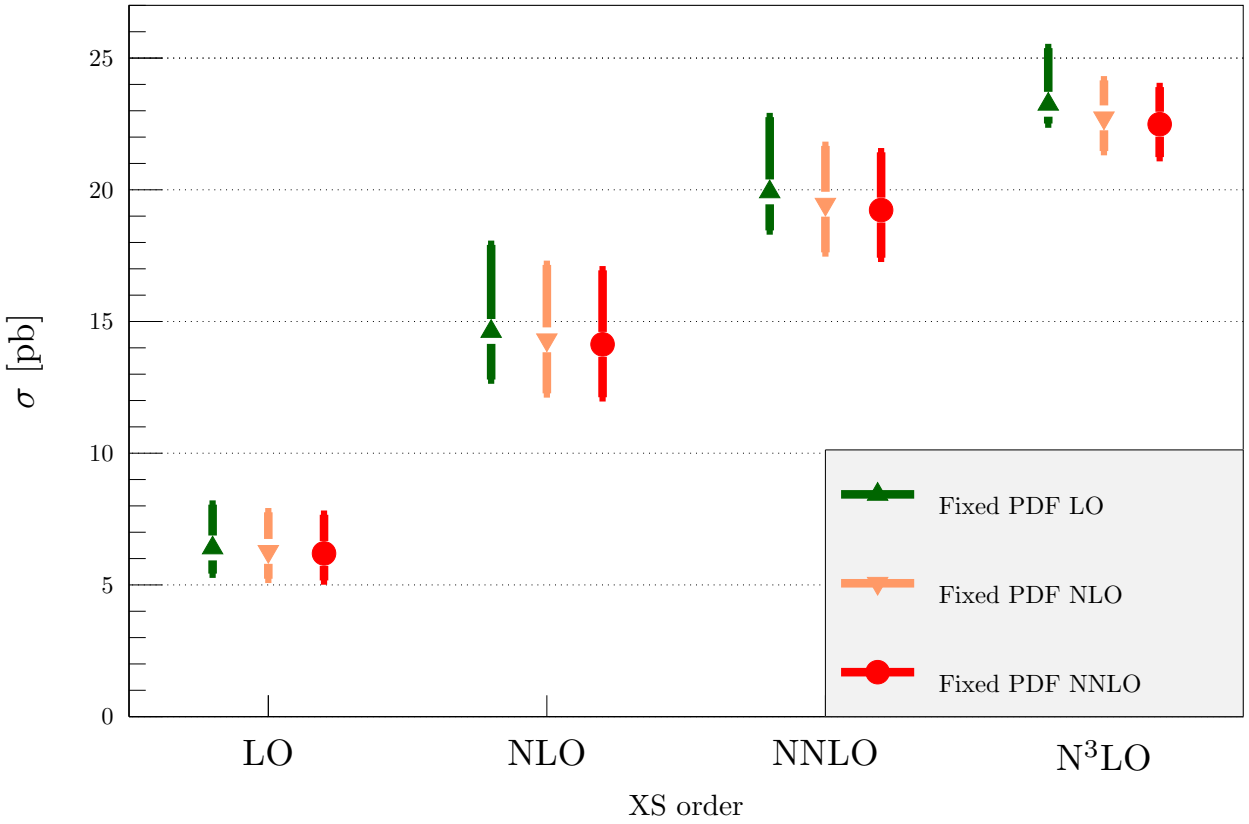


- FORM FACTOR COMPUTED UP TO $O(\epsilon^2)$ IN DR

  (Bonetti, Melnikov, Tancredi, 2017)

N^{3}LO PDFs

DEP. ON PERTURBATIVE ORDER: PDF VS. MATRIX ELEMENT



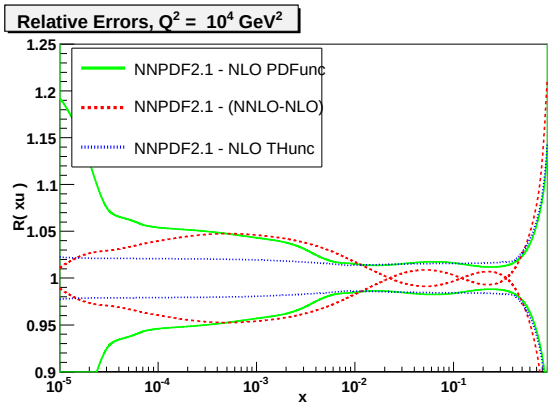
(s.f., Isgrò, Vita, 2014)

- TOTAL CROSS-SECTION DEPENDS WEAKLY ON PERTURBATIVE ORDER OF PDF
- UNCERTAINTY CONSERVATIVELY ESTIMATED AS 1/2 NNLO-NLO PDF SHIFT

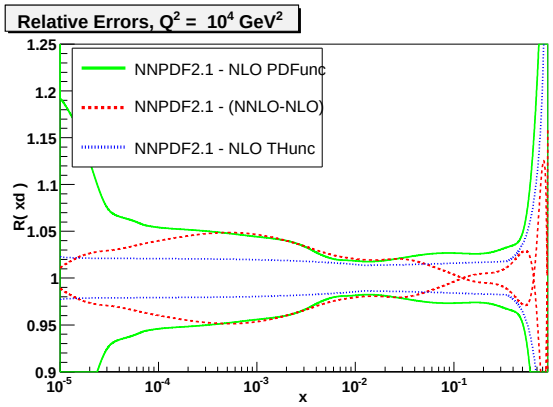
THEORETICAL UNCERTAINTIES ON NLO PDFs?

NLO PDF UNC. VS NLO-NNLO SHIFT VS NLO CACCIARI-HOUDEAU (NNPDF2.1)

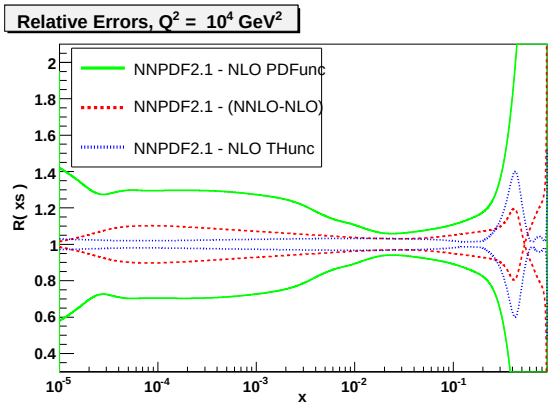
UP



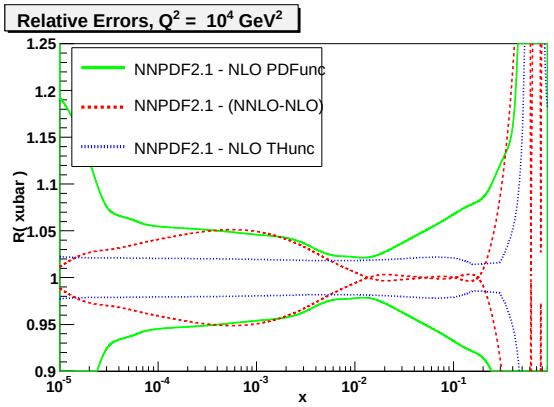
DOWN



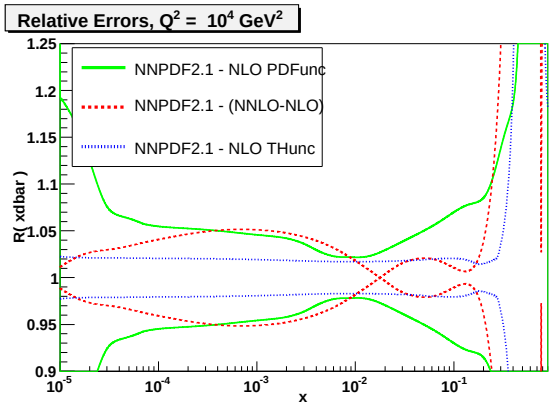
STRANGE



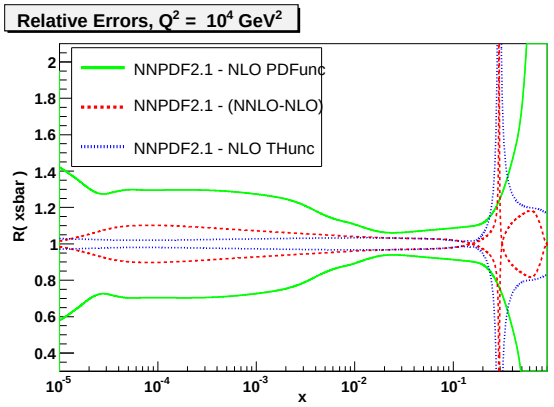
ANTIUP



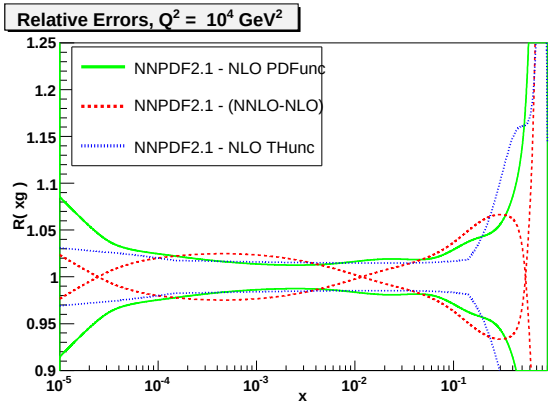
ANTIDOWN



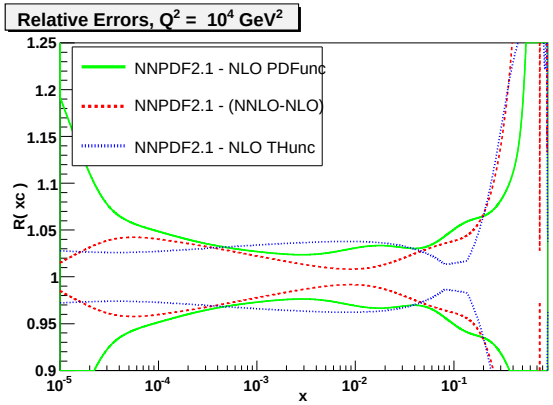
ANTISTRANGE



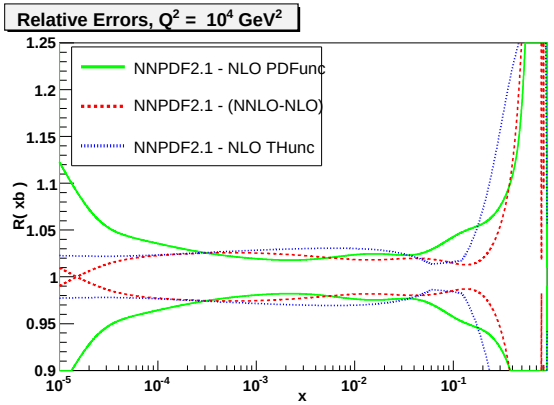
GLUON



CHARM



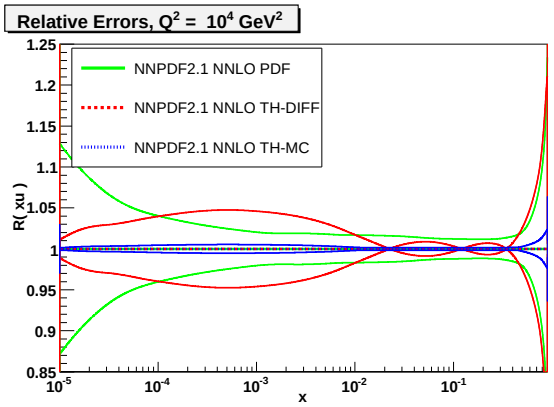
BOTTOM



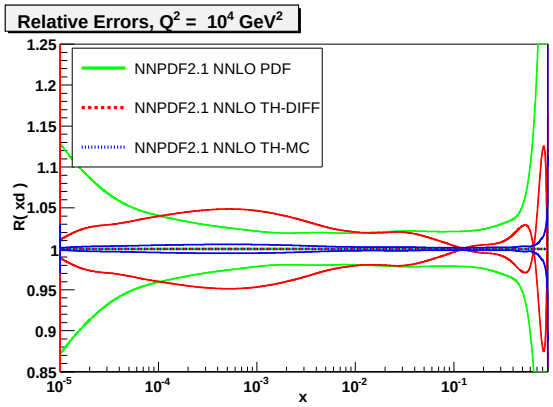
THEORETICAL UNCERTAINTIES ON NNLO PDFs!

NNLO PDF UNC. VS NLO-NNLO SHIFT VS NNLO CACCIARI-HOUDEAU (NNPDF2.1)

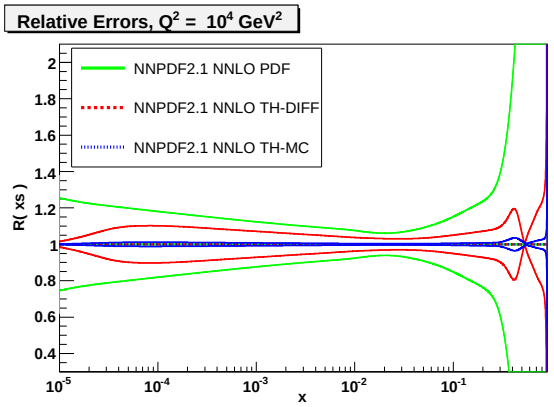
UP



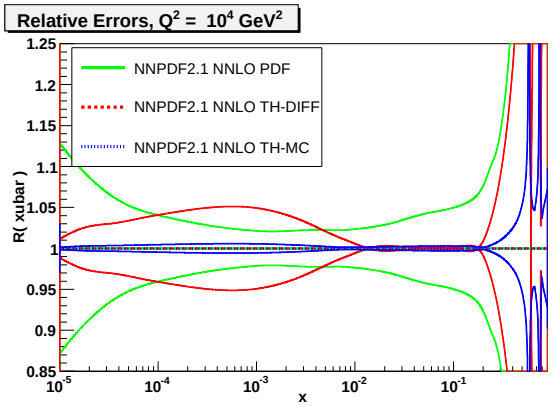
DOWN



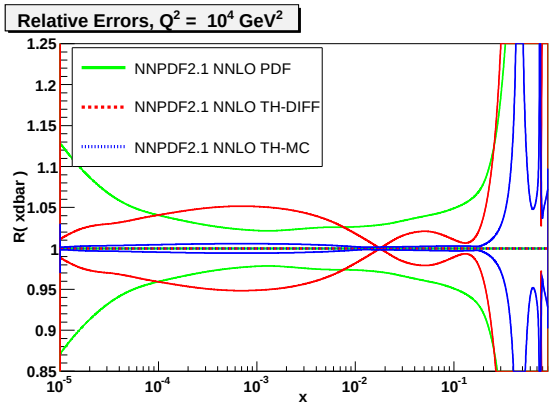
STRANGE



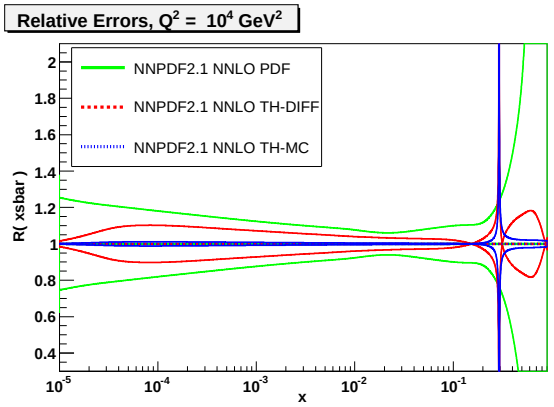
ANTIUP



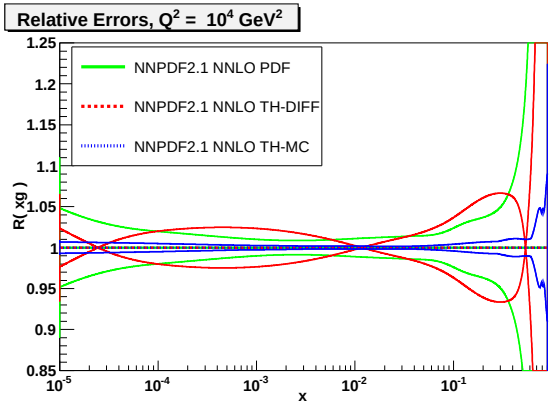
ANTIDOWN



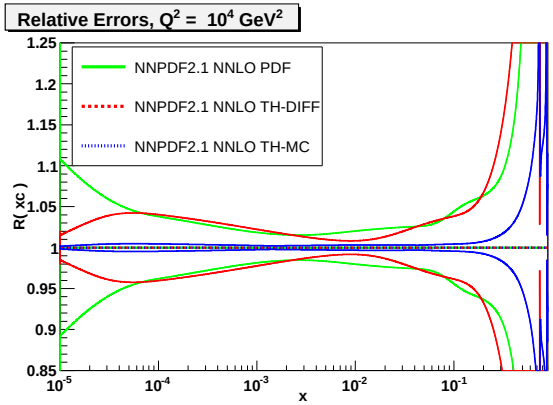
ANTISTRANGE



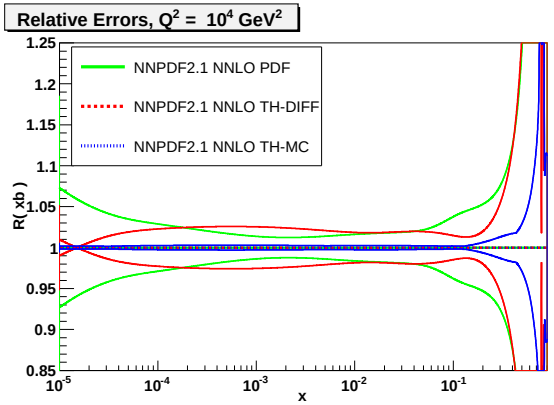
GLUON



CHARM



BOTTOM



PROGRESS?

THE PREVIOUS TWO SLIDES WERE PRESENTED AT PDF4LHC IN 2011 (!)

WISHLIST

- STEADY COMPUTATIONAL PROGRESS: MASS EFFECTS, EW CORRECTIONS,. . .
- THEORY UNCERTAINTIES ON PDFS
- ACCORD ON TREATMENT OF THEORY UNCERTAINTIES?

there is nothing new under the sun
but there are lots of old things we don't know

Ambrose Bierce

there is nothing new under the sun
but there are lots of old things we don't know

Ambrose Bierce

discovery consists of looking at the same thing as everyone else
and thinking something different

Albert Szent-Györgyi