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# Top-Loop Induced Higgs-Strahlung

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"Physics at the Terascale"

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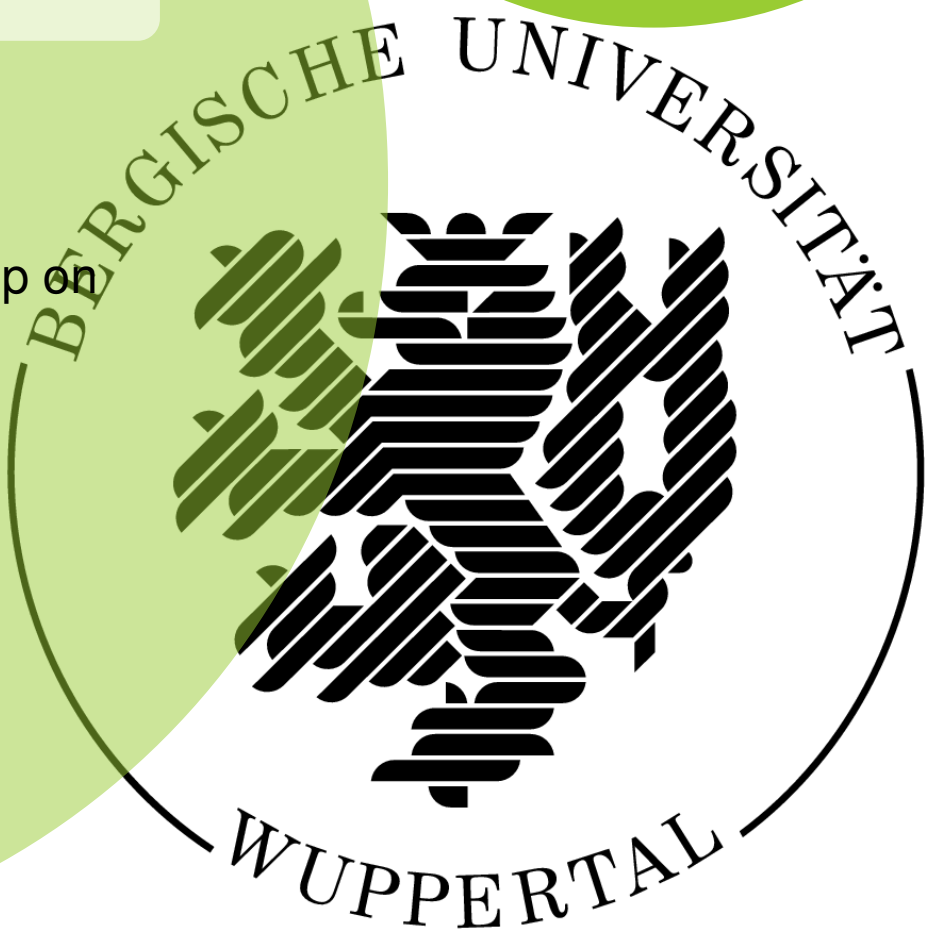
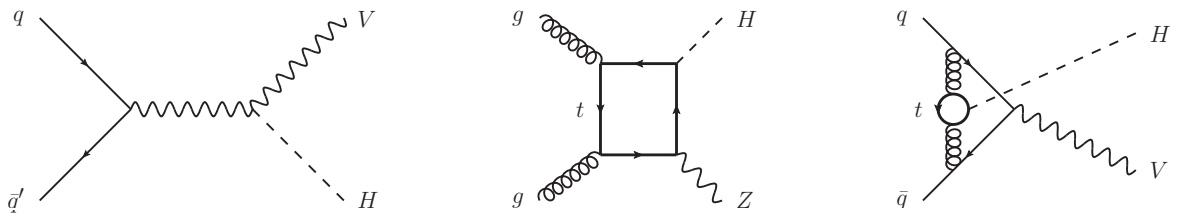
Theoretische Teilchenphysik
Bergische Universität Wuppertal

# Outline

# Goal and Motivation

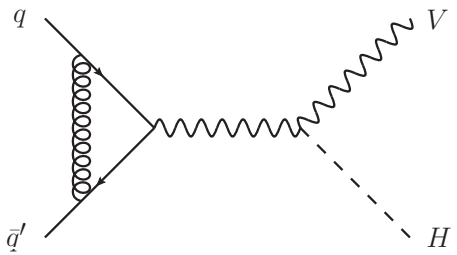


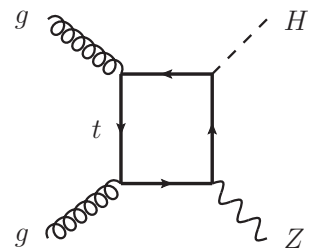

- $M_H \lesssim 160$ GeV difficult to access, since $H \to b\bar{b}$ dominant.
  $\Rightarrow$ Other production channels than $gg \to H$ become relevant.
- Consider production of a SM Higgs in association with a weak gauge boson $pp \to VH$ with $V \in \{W^{\pm}, Z\}$ ("Higgs-strahlung").
- At the Tevatron search channel for a light Higgs.
- At the LHC VH channel is more difficult to use but still useful: idea of Boosted Higgs (Butterworth et al. (2008)), maximal information after discovery.
- Goal: Completion of NNLO QCD prediction of the total inclusive cross section.
- Collaboration with O. Brein, R. Harlander, and M. Wiesemann.

# Different contributions to $\sigma(pp \to VH)$

Bulk of NNLO QCD ($= \mathcal{O}(\alpha_S^2)$) corrections known (Brein, Djouadi, Harlander (2004)):

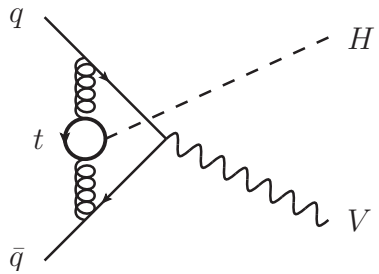
- Drell-Yan-like diagrams: $pp \to V^* \to VH$
  - Includes all NLO corrections.
  - QCD only affects $pp \to V^*$, known to NNLO: Hamberg, Matsuura, van Neerven (1991); Harlander, Kilgore (2002).
  - Total cross section factorizes: $\sigma(pp \to VH) = \int dq^2 \sigma(pp \to V^*) \frac{d\Gamma}{dq^2}(V^* \to VH)$.
- If $V = Z$, subprocess $gg \to HZ$ contributes.
- Numerical calculation with our program `VH@NNLO`.



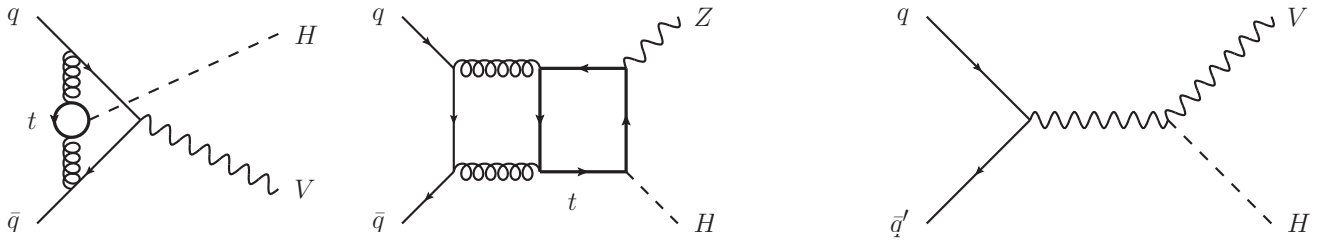

Up to now neglected $\mathcal{O}(\alpha_S^2)$ terms:

- Higgs-strahlung off top loop insertions
- Needed to complete NNLO prediction

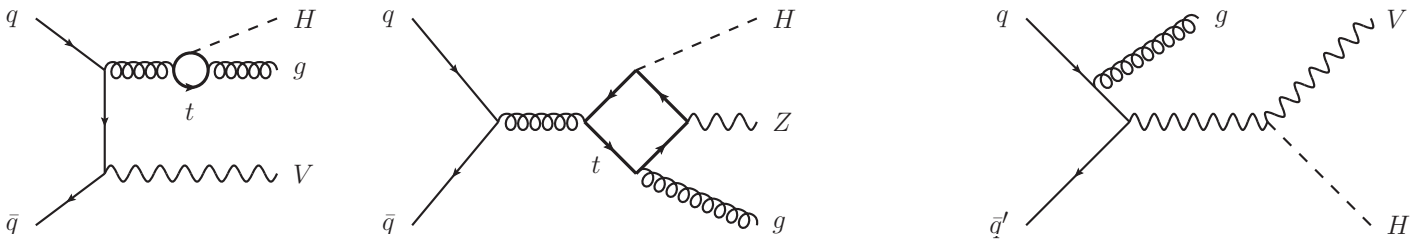


# Higgs-strahlung off top-quark loops

- $V_I$ and $V_{II}$: contributions to $q\bar{q} \to VH$ with either $\bar{q}qV$ or $\bar{t}tZ$ vertex.

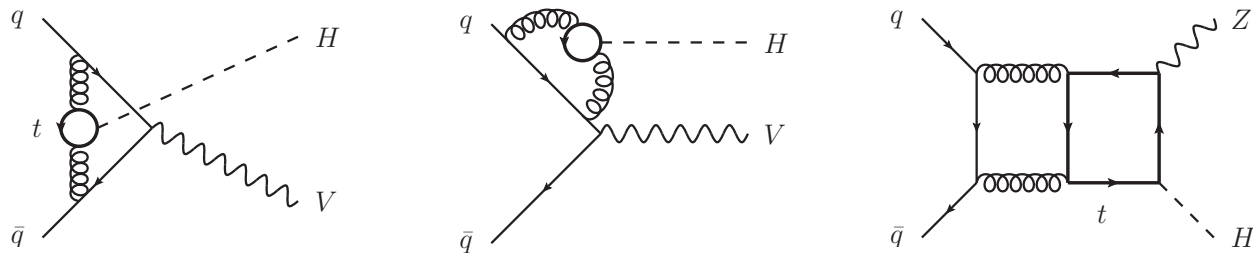



- $R_I$ and $R_{II}$: contributions to $q\bar{q} \to VHg$ and $qg \to VHq$ with $\bar{q}qV$ or $\bar{t}tZ$ vertex.




- Each class of diagrams is finite in itself and can thus be treated separately.

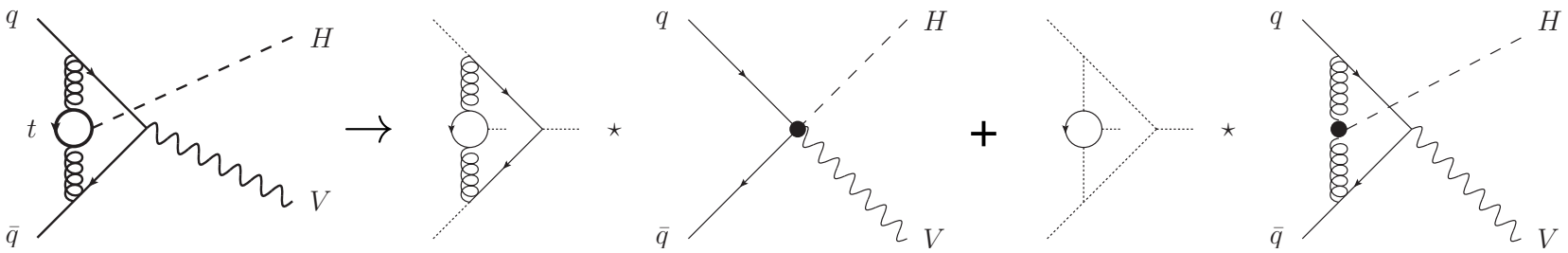
# Virtual corrections




- Higgs radiated off top loop inserted on an internal gluon line.
- To be interfered with tree level diagram.
- Diagrams have 2 loops and 5 scales ($\hat{s}$, $\hat{t}$, $M_H$, $M_V$, $M_t$)
  $\Rightarrow$ exact evalutation extremely difficult
- Simplification: expand in $\frac{1}{M_t}$ and take only leading term.
- Good approximation? $\sqrt{\hat{s}} \ll 2M_t$ not always true,
  but large $\sqrt{\hat{s}}$ are strongly suppressed by parton densities.
- But: $\sqrt{\hat{s}} \geq M_H + M_V$ required.
  $\Rightarrow M_H$ should be chosen small enough.

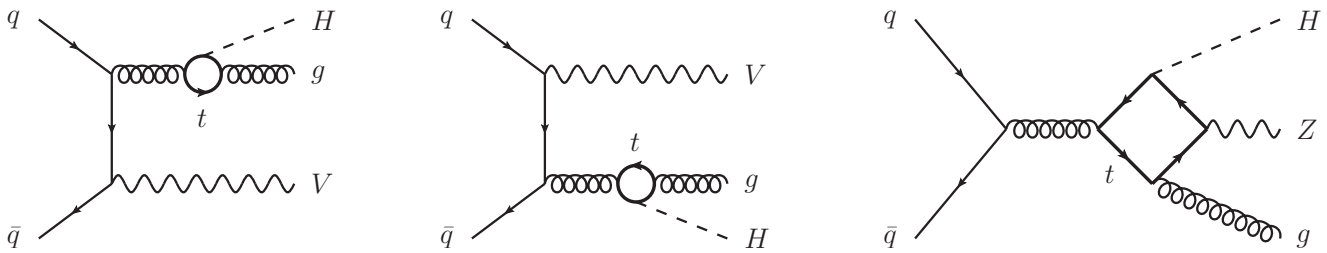
# Asymptotic expansions

- Expansion leads to separation in pairs of subdiagrams and co-subdiagrams.
- Remaining diagrams (one-loop and tadpoles) can be calculated:




- Expansion performed by `q2e/exp` (Seidensticker, 2002)
- Integration with `FORM` (Vermaseren) routines (e.g. `MATAD` (Steinhauser, 2000))

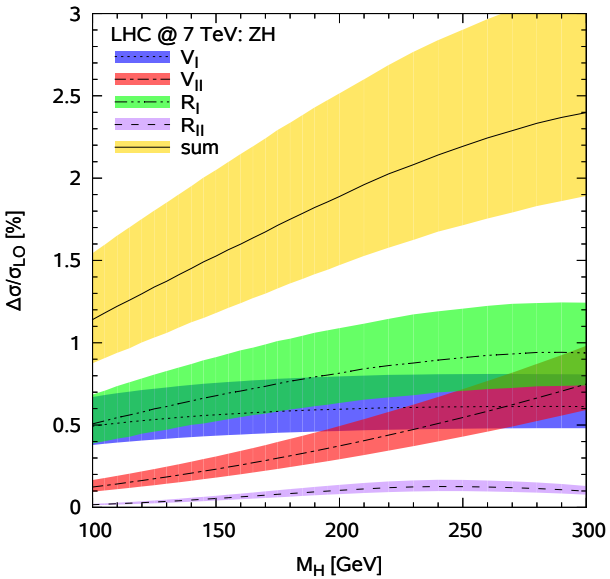
# Real Corrections

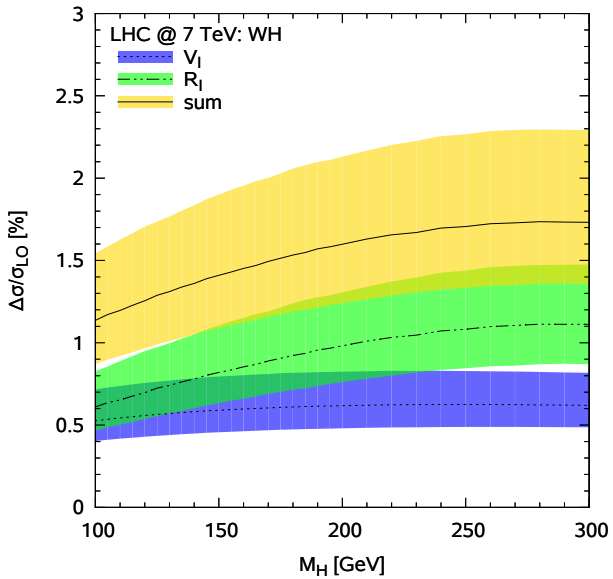


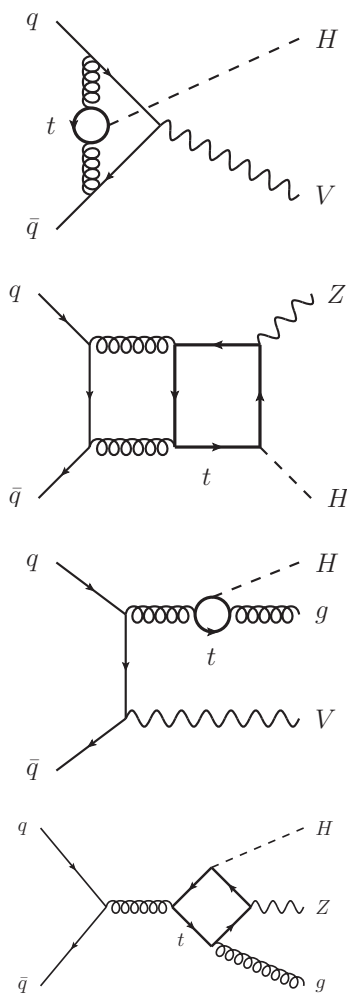

- Higgs radiated off top loop inserted in external gluon line.
- Displayed is the subprocess $q\bar{q} \to VHg$.
- Crossed diagrams for $qg \to VHq$ have to be taken into account as well.
- Exact calculation (i.e. full $M_t$ dependence) feasible, since this is one loop and the phase space integration is finite.
- Comparison of $M_t \to \infty$ and exact result possible:
  deviation for $R_I$ up to 25% / 35% for LHC / Tevatron
  $\Rightarrow$ estimate uncertainty in virtual corrections.

# Numerical Results: LHC@7TeV

Contributions to total cross section:



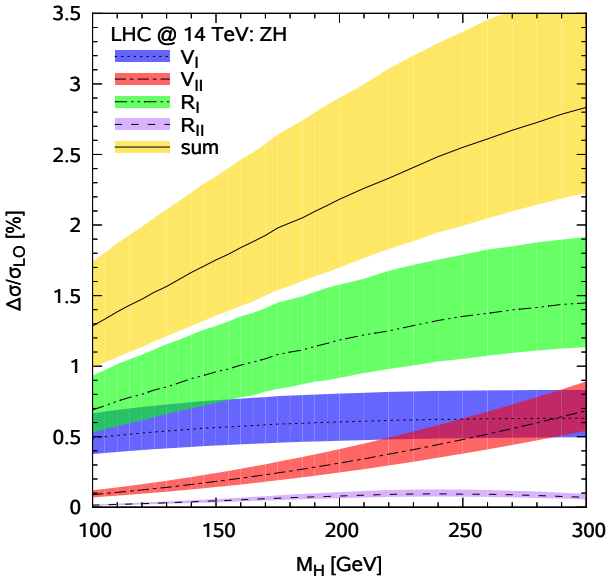



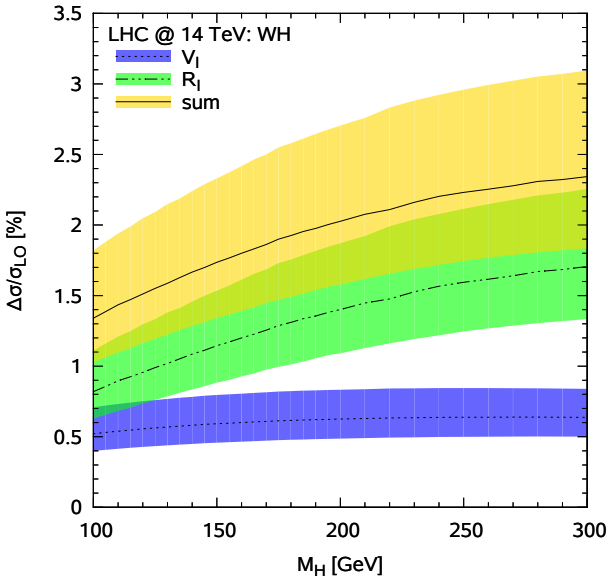



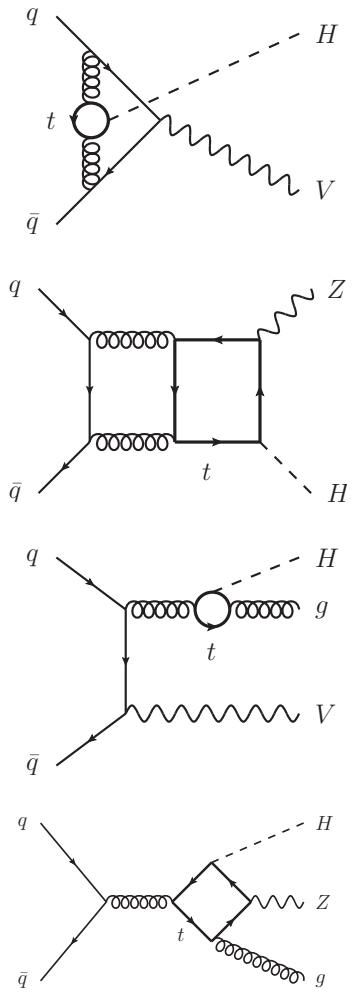

- Uncertainties from $\mu_R$ and $\mu_F$ variation by a factor of $3$ around central scale $\sqrt{(p_H + p_V)^2}$.

# Numerical Results: LHC@14TeV

Contributions to total cross section:



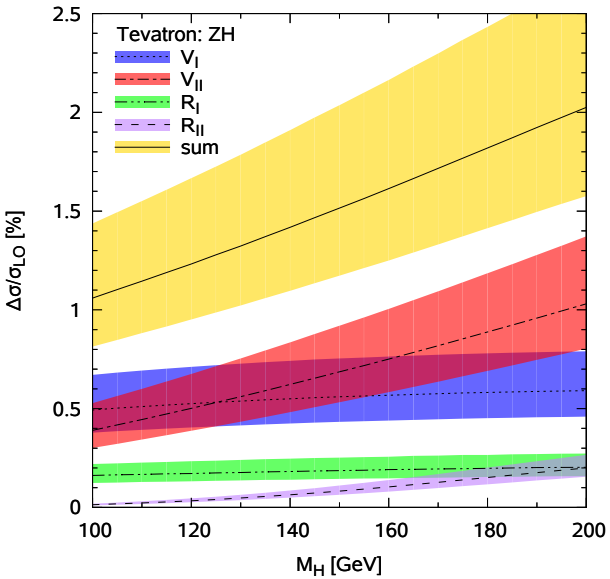



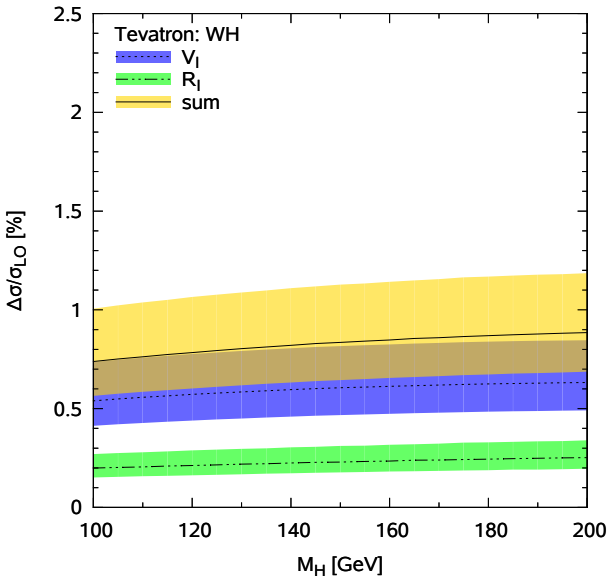



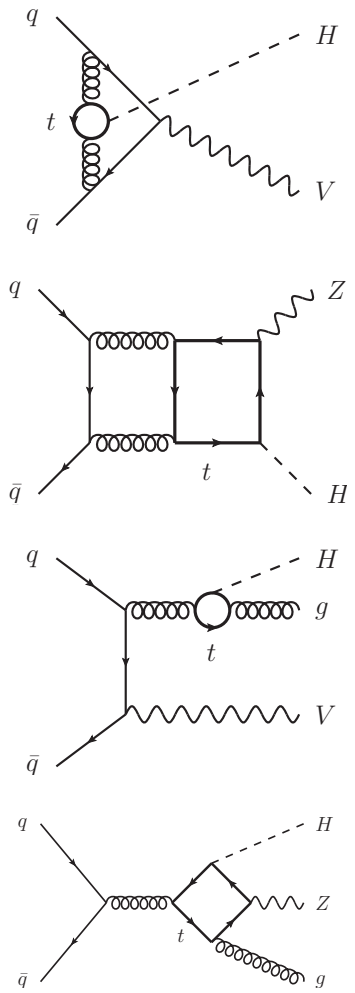

- Uncertainties as before from $\mu_R$ and $\mu_F$ variation.
- Largest contribution form $R_I$, especially $qg \to VHg$ channel.

# Numerical Results: Tevatron

Contribution to cross section at the Tevatron ($p\bar{p}@1.96$ TeV):



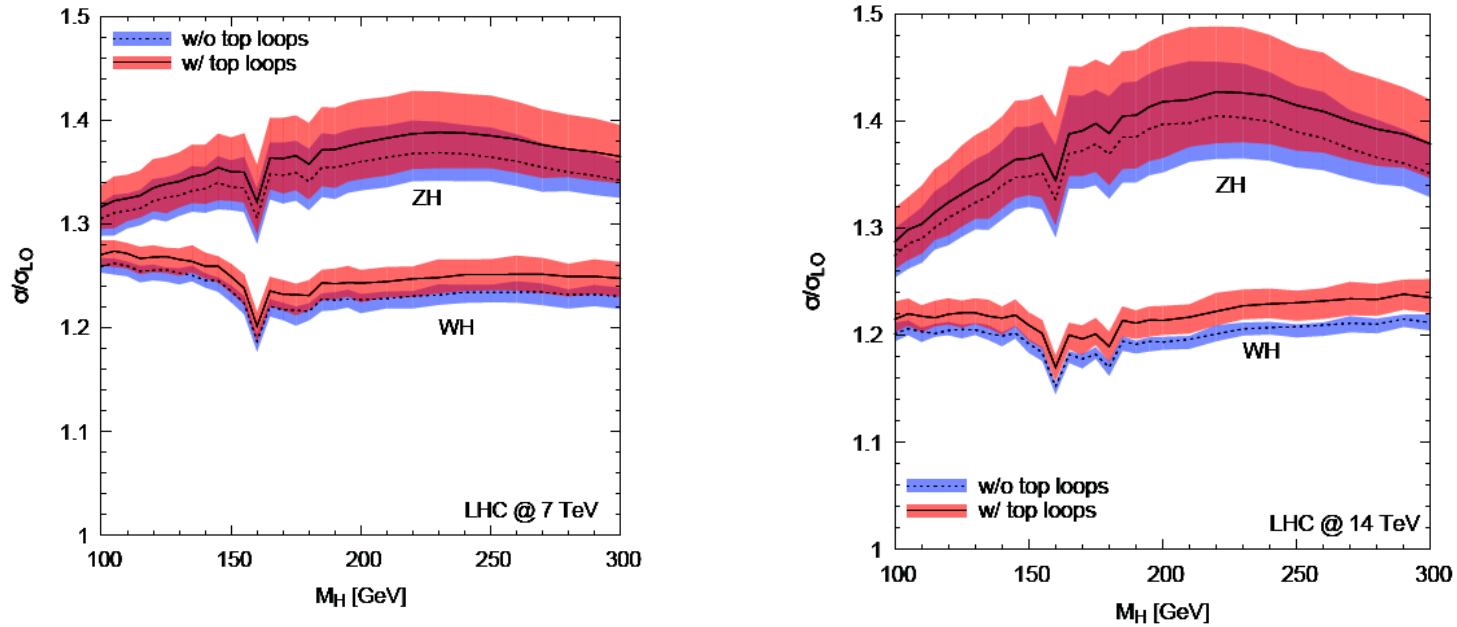




- Uncertainties again from $\mu_R$ and $\mu_F$ variation
- Largest contribution from $V_I$ and $V_{II}$

# K factors for the LHC

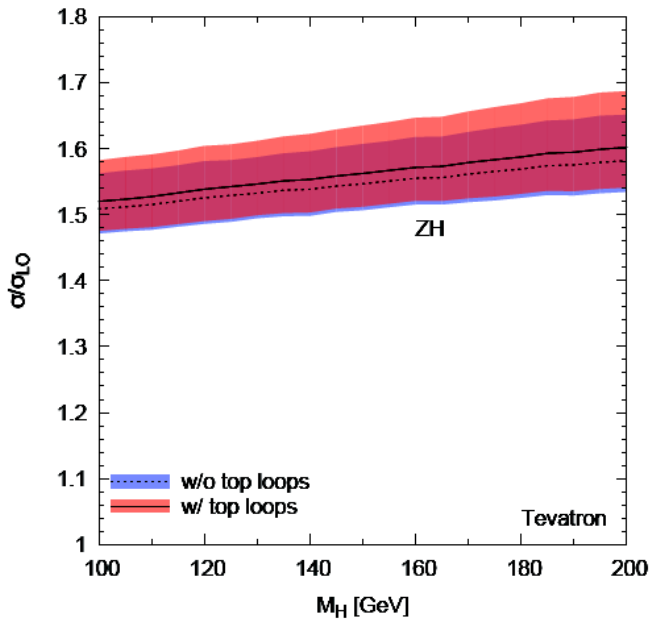
NNLO QCD K-factor including electroweak corrections from (Ciccolini, Dittmaier, Krämer (2003)):

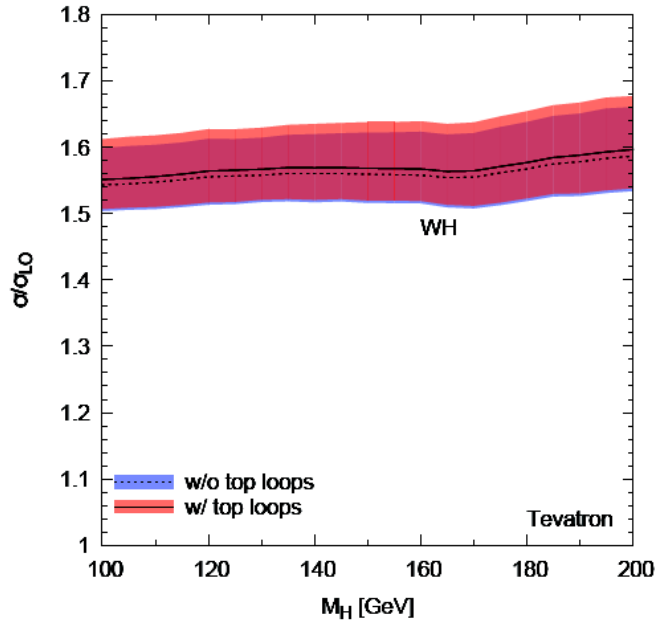



- "Theory error" consisting of PDF and $\alpha_S$ uncertainties, scale variation and uncertainty from $\frac{1}{M_t}$ expansion.
- Clearly visible shift though mostly smaller than uncertainty band.

# K factor for the Tevatron

NNLO QCD K-factor including electroweak corrections from (Ciccolini, Dittmaier, Krämer (2003)):




- Anagolous “Theory Error” as for LHC.
- Less impact than in case of LHC.

# Summary

- New contributions to $pp \to VH$ with Higgs radiated off a top loop have been considerd.
- Virtual corrections evaluated in the limit $M_t \to \infty$.
- For real corrections maintain full $M_t$ dependence
  $\Rightarrow$ comparison to $M_t \to \infty$ result possible.
- Overall correction at the % level, currently at the order of / less than uncertainty of total cross section for LHC / Tevatron.
- At the latest when PDFs and $\alpha_S$ are known more precisely, the new contribution will be numerically important.