The Theory of the Standard Model Higgs

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YETI

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Outline

Yesterday: Standard Model Higgs Theory

- Brief SM introduction
- Symmetry breaking: Masses and Goldstone modes
- The role of the Higgs boson
- The SM Higgs sector

Today: Higgs Phenomenology at the LHC

- Higgs decays
- Higgs production
- Higgs properties

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only about EW

Today: Higgs Phenomenology at the LHC

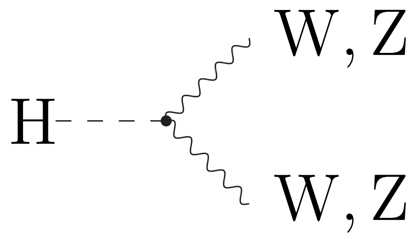
- Higgs decays
- Higgs production
- Higgs properties

mostly about QCD

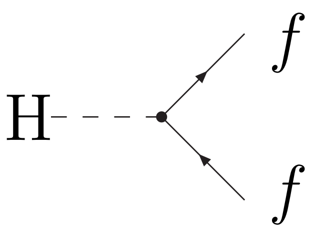
Important Couplings

Tree-level couplings:

- to gauge bosons and fermions



$\propto \frac{M^2_{\mathrm{W,Z}}}{M_{\mathrm{W}}}$



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$\Rightarrow$ all couplings proportional to mass

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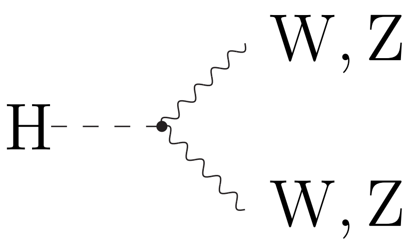

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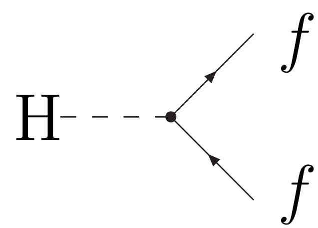

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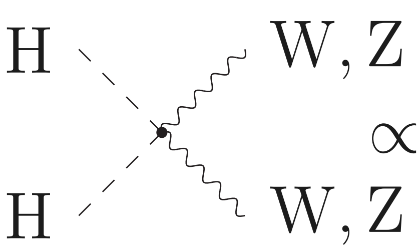
- with more than one Higgs



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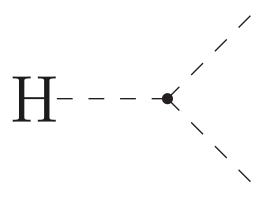
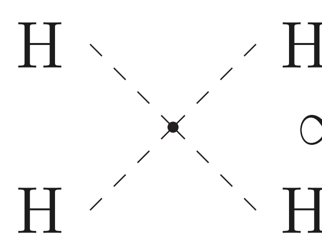


$\propto \frac{M^2_{\mathrm{H}}}{M_{\mathrm{W}}}$



$\propto \frac{M^2_{\mathrm{H}}}{M^2_{\mathrm{W}}}$

$\Rightarrow$ hard to access at the LHC

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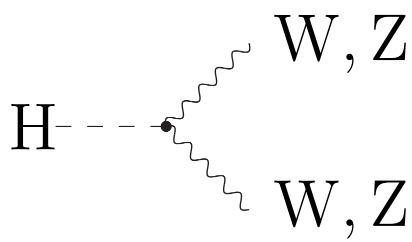

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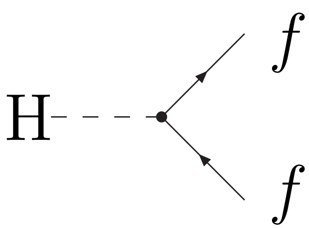

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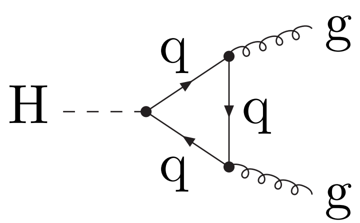
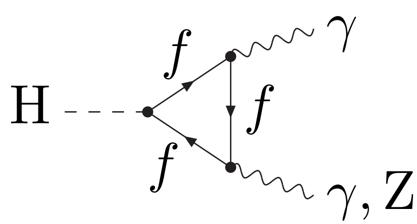
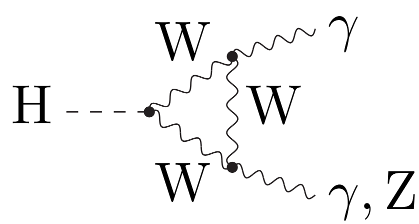
$\Rightarrow$ all couplings proportional to mass

Loop-induced couplings:

- to gluons and photons







from above: $\mathrm{q} = f =$ top most relevant in the SM
and extremely important at the LHC

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Theory Predictions

In the SM everyhing is calculable. . .

- precision predictions needed for all production and decay modes at the LHC
- as a function of M_{H}, now focussing at $M_{\mathrm{H}} = 125$ GeV

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Theory Predictions

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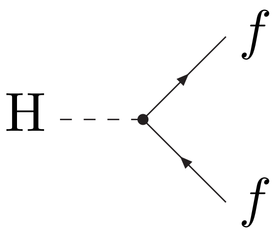
- as a function of M_{H}, now focussing at $M_{\mathrm{H}} = 125$ GeV
- higher-order corrections: NLO and NNLO QDC, NLO EW, resummation, NLO parton shower matching, etc.
- dedicated effort of theory and experiment:

  LHC Higgs Cross Section Working Group

  - https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections
  - Yellow reports: arXiv:1101.0593 and arXiv:1201.3084

Higgs Decays

Decay channels:



$\Rightarrow$ decay into heaviest accessible fermion ($M_{\mathrm{H}} > 2m_f$)

Higgs Decays

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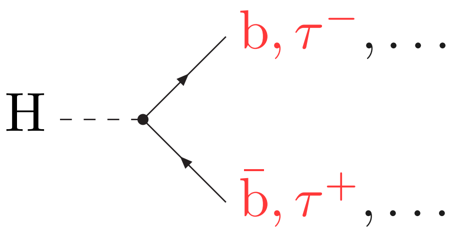

for $M_{\mathrm{H}} \sim 125$ GeV

Higgs Decays

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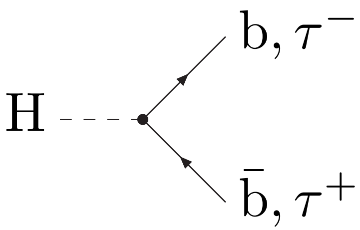

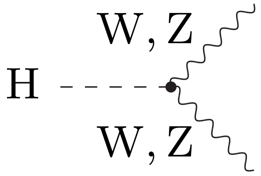

for $M_{\mathrm{H}} \sim 125$ GeV

at least one Z, W off-shell

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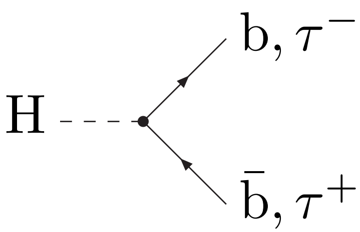
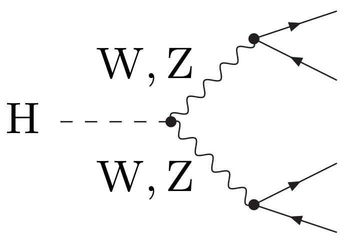
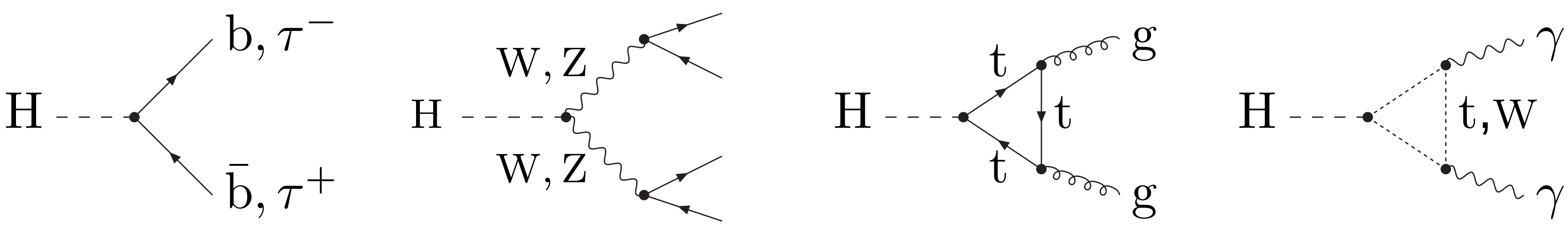




decay into 4 fermions

Higgs Decays

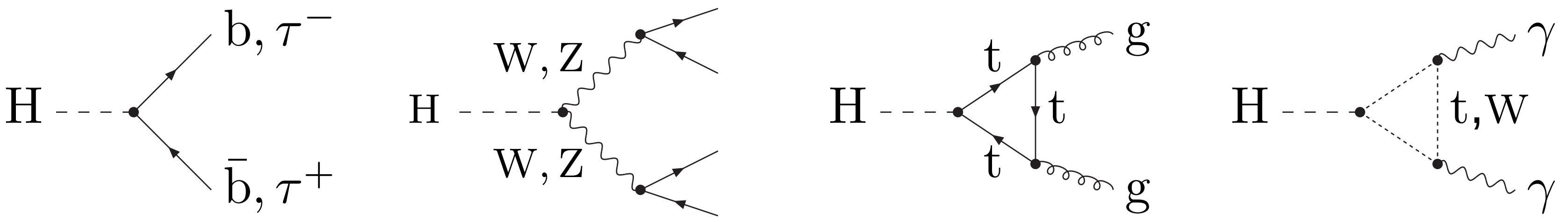
Decay channels:



loop-induced decays

Higgs Decays

Decay channels:

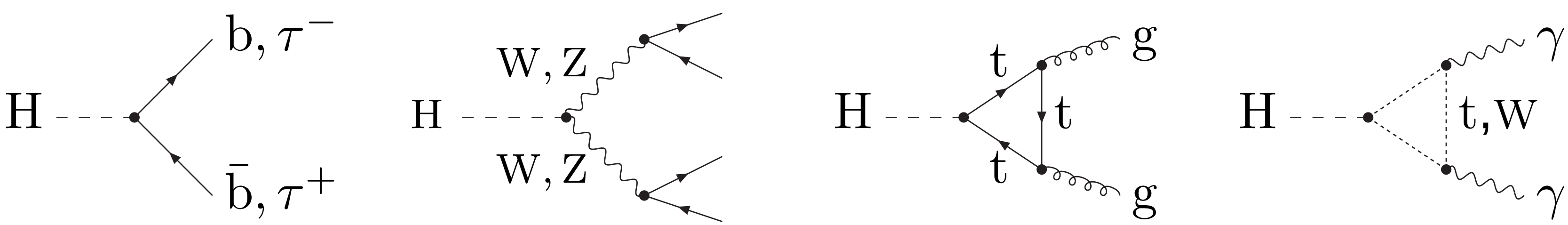


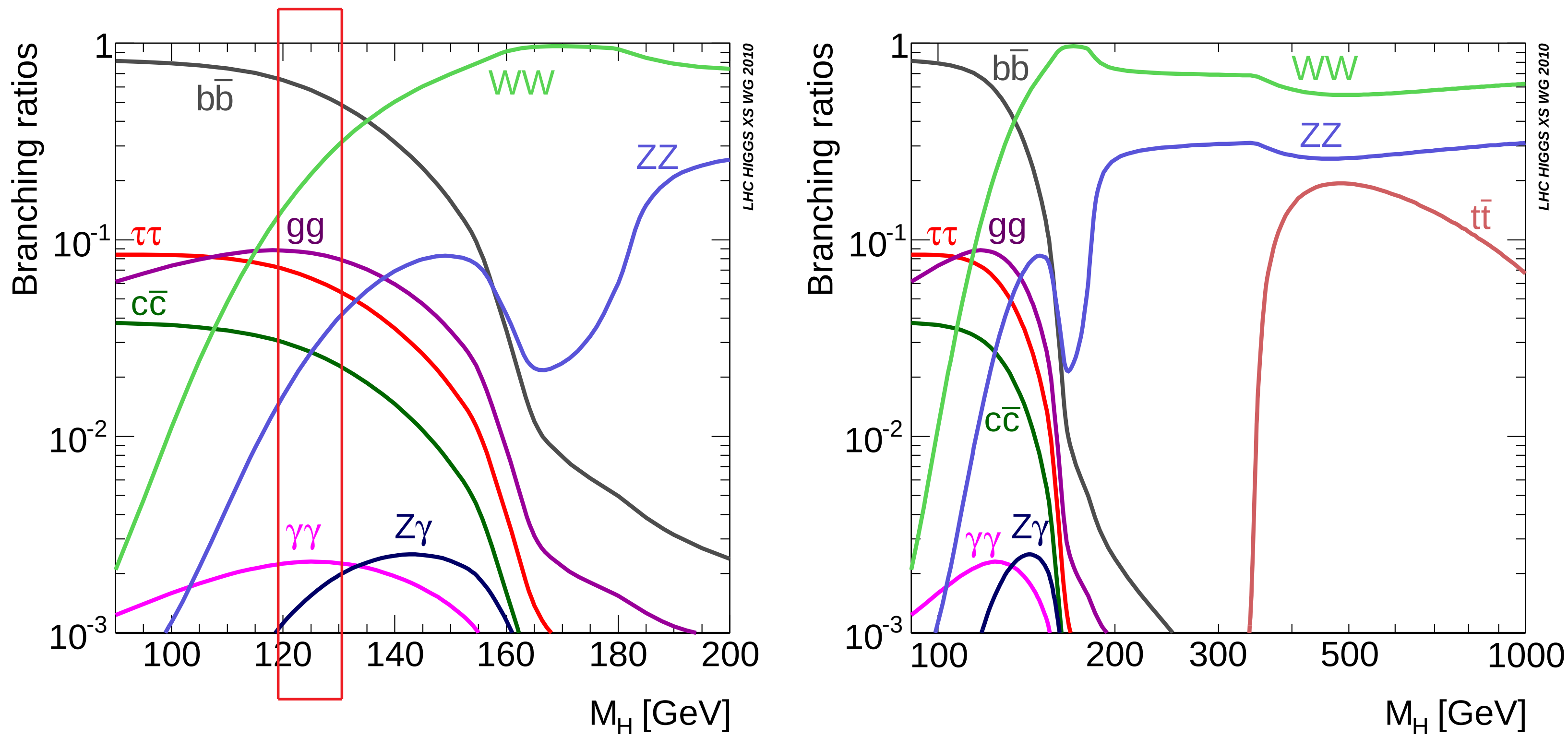
- calculate partial widths
- calculate resulting branching rations

(i.e. fraction of decays to a given final state)

Higgs Decays

Decay channels:





Higgs Decays

- many Higgs decays ($\Rightarrow$ couplings) accessible at $M_{\mathrm{H}} = 125$ GeV
- measurements depend strongly on production mode

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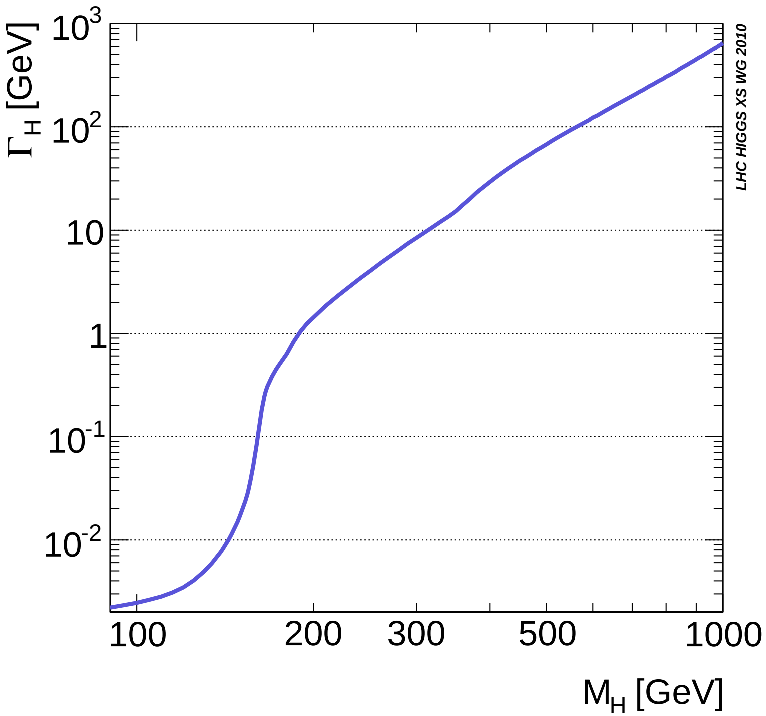
- measurements depend strongly on production mode
- extremely narrow resonance: $\Gamma_{\mathrm{H}} = 4$ MeV at 125 GeV



- way below experimental resolution
- narrow width approximation applicable
  (up to a little twist)

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Predicting branching ratios

Calculate

- partial widths for each decay: $\Gamma_i^{\mathrm{H}} = \Gamma(\mathrm{H} \to i)$
  using available tools:
  - HDecay for all decays but $\mathrm{H} \to \mathrm{WW}/\mathrm{ZZ}$ (all avail. corr.)
    Djouadi, Kalinowski, Mühlleitner, Spira
  - Prophecy4F for $\mathrm{H} \to \mathrm{WW}/\mathrm{ZZ} \to 4f$ (NLO EW and QCD)
    Bredenstein, Denner, Dittmaier, AM, Weber
- total width: $\Gamma^{\mathrm{H}} = \sum_i \Gamma_i^{\mathrm{H}}$ (from all (relevant) decay modes)
- branching ratio: $\mathrm{BR}(\mathrm{H} \to i) = \Gamma_i^{\mathrm{H}}/\Gamma^{\mathrm{H}}$
  - $\sum_i \mathrm{BR}(\mathrm{H} \to i) = 1$ induces correlations for BRs
  - uncertainties in any Γ_i^{H} affect all BRs

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Predicting branching ratios

Partial widths for 4f final states from Prophecy4f:

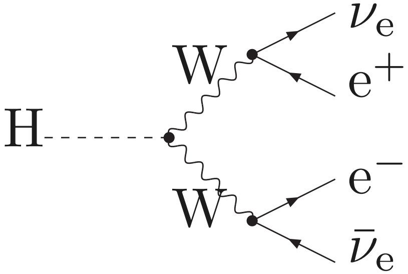
$$\Gamma_{4f}^{\mathrm{Proph.}} = \Gamma_{\mathrm{H}\to\mathrm{W}^*\mathrm{W}^*\to 4f} + \Gamma_{\mathrm{H}\to\mathrm{Z}^*\mathrm{Z}^*\to 4f} + \Gamma_{\mathrm{WW/ZZ-int.}}$$

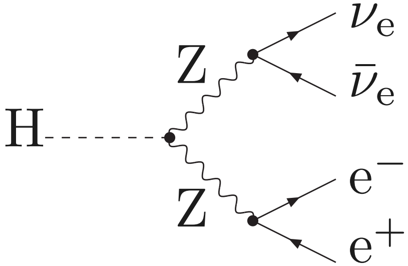
$$\Gamma_{\mathrm{H}\to\mathrm{W}^*\mathrm{W}^*\to 4f} = 9\cdot\Gamma_{\mathrm{H}\to\nu_\mathrm{e}\mathrm{e}^+\mu^-\bar{\nu}_\mu} + 12\cdot\Gamma_{\mathrm{H}\to\nu_\mathrm{e}\mathrm{e}^+\mathrm{d}\bar{\mathrm{u}}} + 4\cdot\Gamma_{\mathrm{H}\to\mathrm{u}\bar{\mathrm{d}}\mathrm{s}\bar{\mathrm{c}}}$$

$$\begin{aligned}\Gamma_{\mathrm{H}\to\mathrm{Z}^*\mathrm{Z}^*\to 4f} = {} & 3\cdot\Gamma_{\mathrm{H}\to\nu_\mathrm{e}\bar{\nu}_\mathrm{e}\nu_\mu\bar{\nu}_\mu} + 3\cdot\Gamma_{\mathrm{H}\to\mathrm{e}^-\mathrm{e}^+\mu^-\mu^+} + 9\cdot\Gamma_{\mathrm{H}\to\nu_\mathrm{e}\bar{\nu}_\mathrm{e}\mu^-\mu^+} \\ & + 3\cdot\Gamma_{\mathrm{H}\to\nu_\mathrm{e}\bar{\nu}_\mathrm{e}\nu_\mathrm{e}\bar{\nu}_\mathrm{e}} + 3\cdot\Gamma_{\mathrm{H}\to\mathrm{e}^-\mathrm{e}^+\mathrm{e}^-\mathrm{e}^+} \\ & + 6\cdot\Gamma_{\mathrm{H}\to\nu_\mathrm{e}\bar{\nu}_\mathrm{e}\mathrm{u}\bar{\mathrm{u}}} + 9\cdot\Gamma_{\mathrm{H}\to\nu_\mathrm{e}\bar{\nu}_\mathrm{e}\mathrm{d}\bar{\mathrm{d}}} + 6\cdot\Gamma_{\mathrm{H}\to\mathrm{u}\bar{\mathrm{u}}\mathrm{e}^-\mathrm{e}^+} + 9\cdot\Gamma_{\mathrm{H}\to\mathrm{d}\bar{\mathrm{d}}\mathrm{e}^-\mathrm{e}^+} \\ & + 1\cdot\Gamma_{\mathrm{H}\to\mathrm{u}\bar{\mathrm{u}}\mathrm{c}\bar{\mathrm{c}}} + 3\cdot\Gamma_{\mathrm{H}\to\mathrm{d}\bar{\mathrm{d}}\mathrm{s}\bar{\mathrm{s}}} + 6\cdot\Gamma_{\mathrm{H}\to\mathrm{u}\bar{\mathrm{u}}\mathrm{s}\bar{\mathrm{s}}} + 2\cdot\Gamma_{\mathrm{H}\to\mathrm{u}\bar{\mathrm{u}}\mathrm{u}\bar{\mathrm{u}}} \\ & + 3\cdot\Gamma_{\mathrm{H}\to\mathrm{d}\bar{\mathrm{d}}\mathrm{d}\bar{\mathrm{d}}}\end{aligned}$$

$$\begin{aligned}\Gamma_{\mathrm{WW/ZZ-int.}} = {} & 3\cdot\Gamma_{\mathrm{H}\to\nu_\mathrm{e}\mathrm{e}^+\mathrm{e}^-\bar{\nu}_\mathrm{e}} - 3\cdot\Gamma_{\mathrm{H}\to\nu_\mathrm{e}\bar{\nu}_\mathrm{e}\mu^-\mu^+} - 3\cdot\Gamma_{\mathrm{H}\to\nu_\mathrm{e}\mathrm{e}^+\mu^-\bar{\nu}_\mu} \\ & + 2\cdot\Gamma_{\mathrm{H}\to\mathrm{u}\bar{\mathrm{d}}\mathrm{d}\bar{\mathrm{u}}} - 2\cdot\Gamma_{\mathrm{H}\to\mathrm{u}\bar{\mathrm{u}}\mathrm{s}\bar{\mathrm{s}}} - 2\cdot\Gamma_{\mathrm{H}\to\mathrm{u}\bar{\mathrm{d}}\mathrm{s}\bar{\mathrm{c}}}\end{aligned}$$

- all off-shell effects included
- all interferences included





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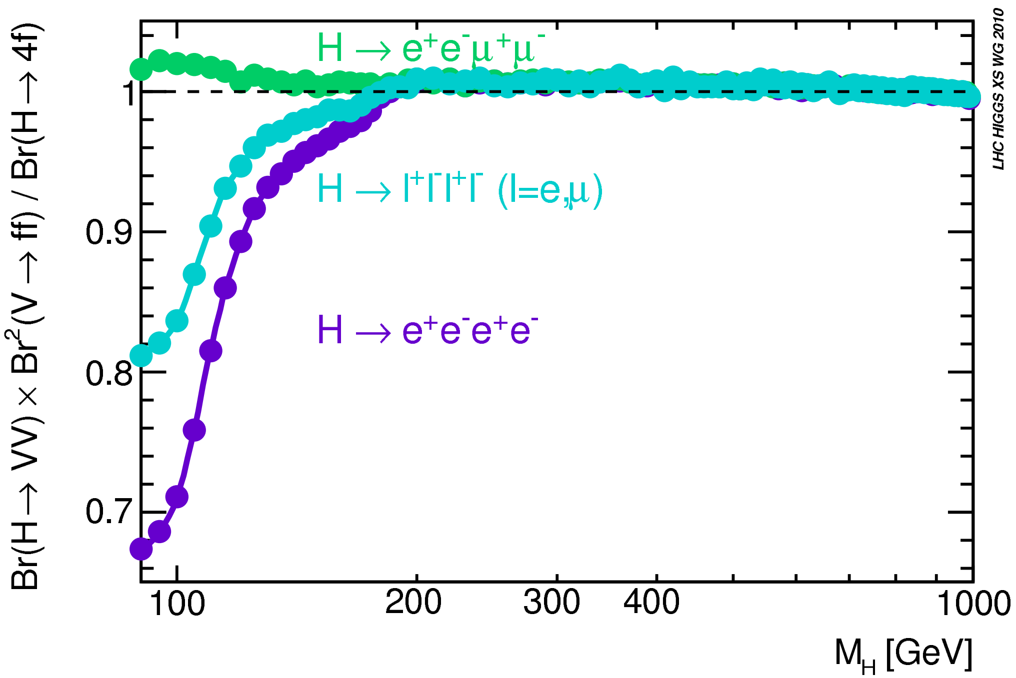

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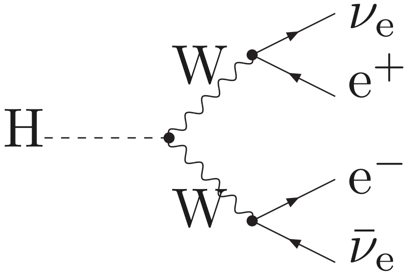

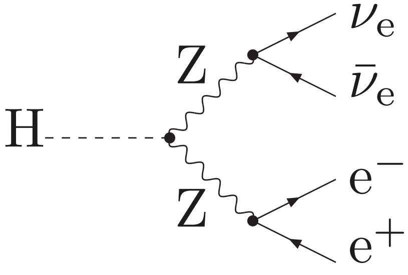

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Uncertainties

- unknown higher-order corrections: Theory Uncertainty

partial width	QCD	electroweak (EW)	total
$\mathrm{H} \to \mathrm{bb/cc}$	~ 0.1–0.2%	~ 1–2% for $M_\mathrm{H} \lesssim 135$ GeV	~ 1–2%
$\mathrm{H} \to \tau\tau$		~ 1–2% for $M_\mathrm{H} \lesssim 135$ GeV	~ 1–2%
$\mathrm{H} \to \mathrm{gg}$	$\sim 10\%$	$\sim 1\%$	$\sim 10\%$
$\mathrm{H} \to \gamma\gamma$	$< 1\%$	$< 1\%$	$\sim 1\%$
$\mathrm{H} \to 4f$		$\sim 0.5\%$ for $M_\mathrm{H} < 500$ GeV	$\sim 0.5\%$

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Uncertainties

- unknown higher-order corrections: Theory Uncertainty
- errors from input parameters: Parametric Uncertainties at the percent level

$$M_\mathrm{c} = 1.42 \pm 0.03 \text{ GeV}$$

$$M_\mathrm{b} = 4.49 \pm 0.06 \text{ GeV}$$

$$\Delta\alpha_\mathrm{s}(M_\mathrm{Z}) = 0.119 \pm 0.002$$

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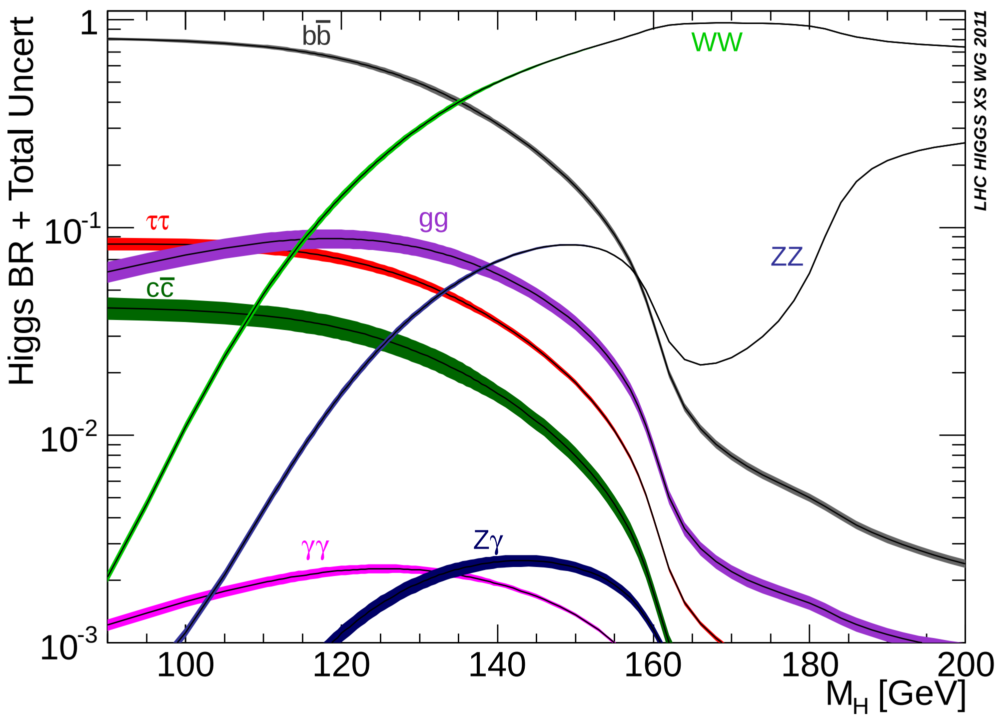
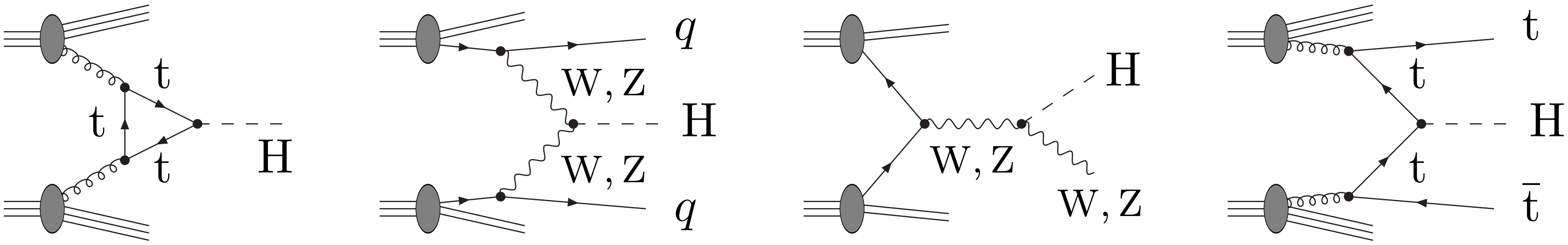


For $M_{\mathrm{H}} \sim 125$ GeV:

- $\mathrm{BR} = (\mathrm{H} \to \mathrm{b\bar{b}})$
  PU from M_{b}, α_{s}: 1% each
  TU: 1%, total uncertainty 3%
- $\mathrm{BR}(\mathrm{H} \to \mathrm{WW}, \mathrm{ZZ})$, $\mathrm{BR}(\mathrm{H} \to \gamma\gamma)$, $\mathrm{BR}(\mathrm{H} \to ll)$
  PU: 2.5%
  TU: $2-4\%$, total uncertainty $5-6\%$
  (indirectly via $\Gamma(\mathrm{H} \to \mathrm{b\bar{b}})$)
- $\mathrm{BR}(\mathrm{H} \to \mathrm{c\bar{c}})$:
  PU from M_{c}, α_{s}: 6% each
  TU: 4%, total uncertainty 12%

Higgs Production

Production processes at the LHC:



- gluon fusion
- vector-boson fusion (VBF)
- Higgs strahlung (WH/ZH)
- associated production with a top-quark

Higgs Production

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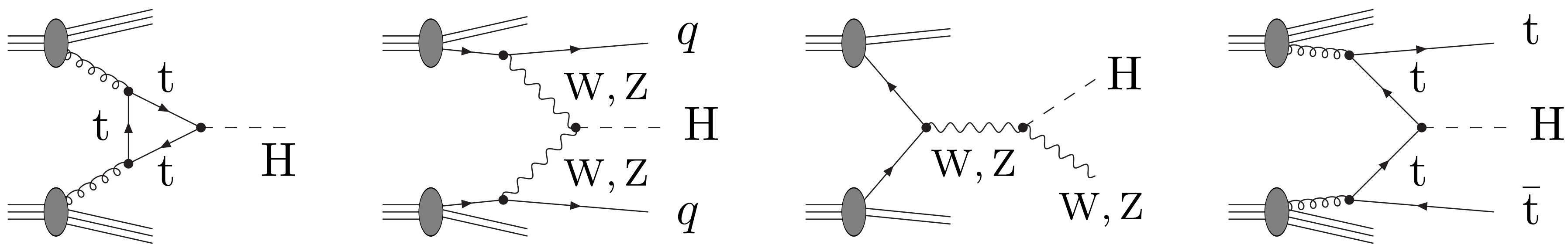
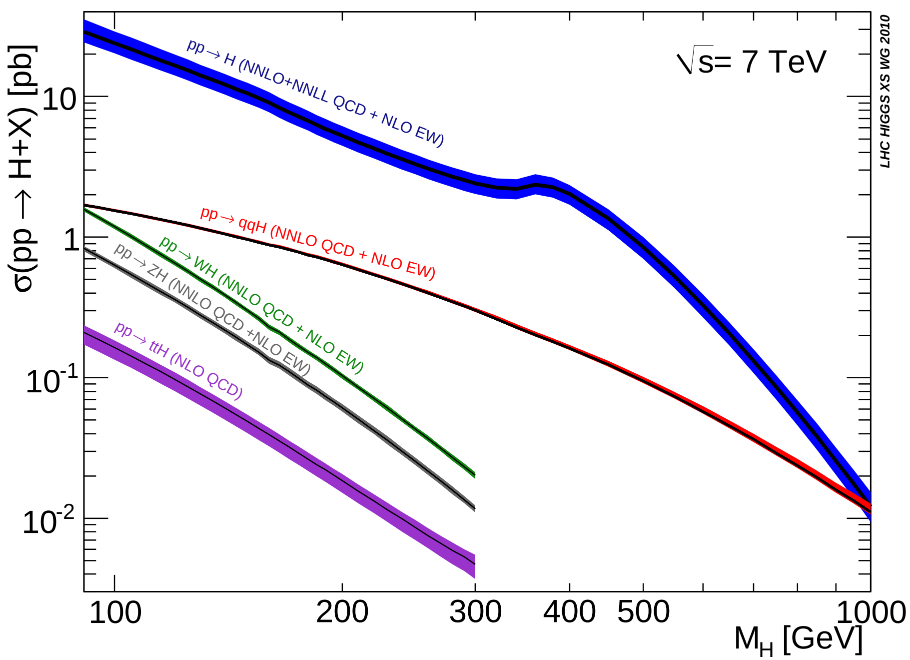
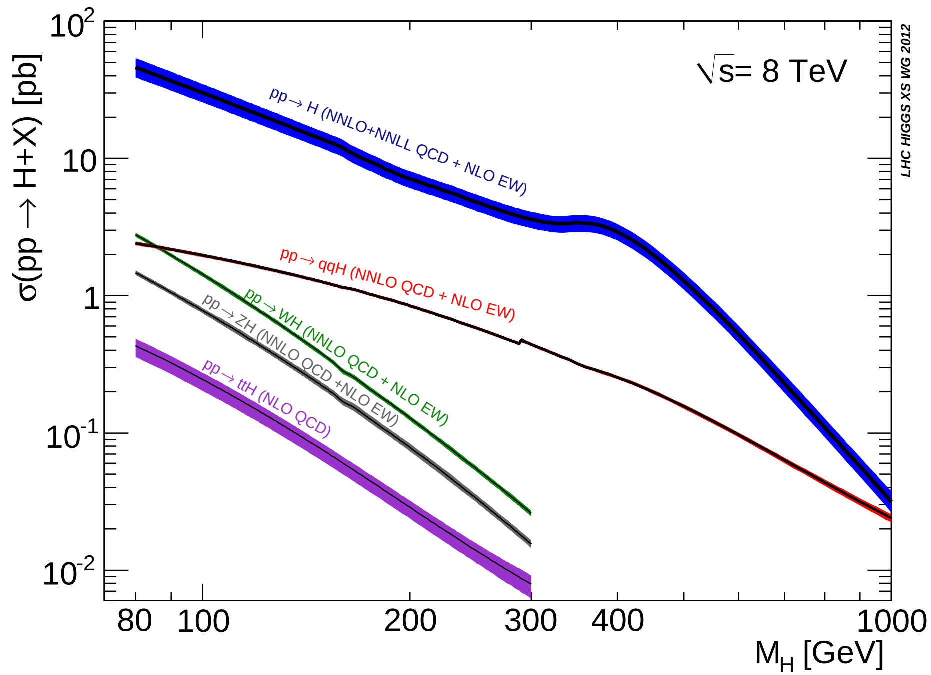
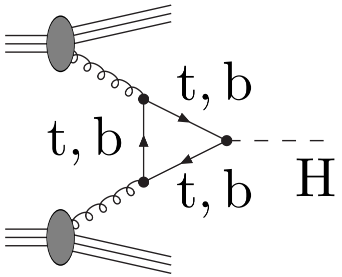






Gluon Fusion

- largest cross section (by factor 10)
  - ~ 20 pb at $\sqrt{s} = 8$ TeV ($M_{\mathrm{H}} = 125$ GeV)



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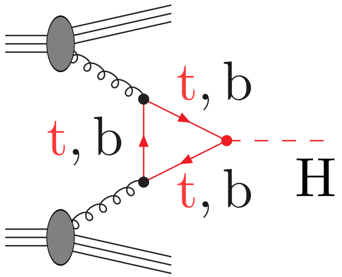
    (large top Yukawa-coupling)
    (small contribution from bottom loop)



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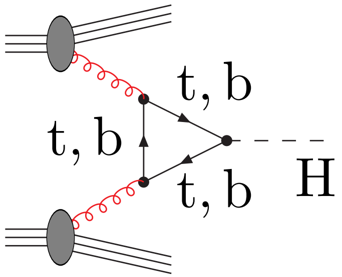

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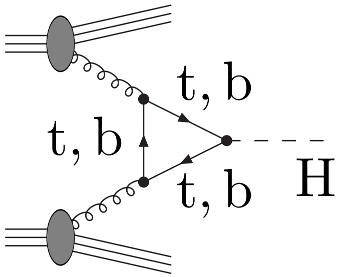

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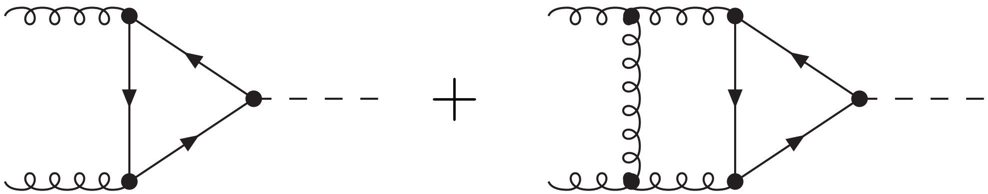
  - ~ 20 pb at $\sqrt{s} = 8$ TeV ($M_{\mathrm{H}} = 125$ GeV)
  - dominant top loop
    (large top Yukawa-coupling)
    (small contribution from bottom loop)
  - large gluon luminosity at the LHC
- only Higgs decay products to tag
  - $\mathrm{H} \to \mathrm{b\bar{b}}$ impossible
  - $\mathrm{H} \to \gamma\gamma$ (BR 2×10^{-3})
  - $\mathrm{H} \to \mathrm{WW/ZZ} \to 4$ leptons (small $V \to 2l$)
  - $\mathrm{H} \to \tau\tau$

Gluon Fusion

cross section is crucial input

- huge theoretical challenge
- LO already loop-induced
- large higher-order QCD corrections



  - $\mathcal{O}(100\%)$ correction at NLO
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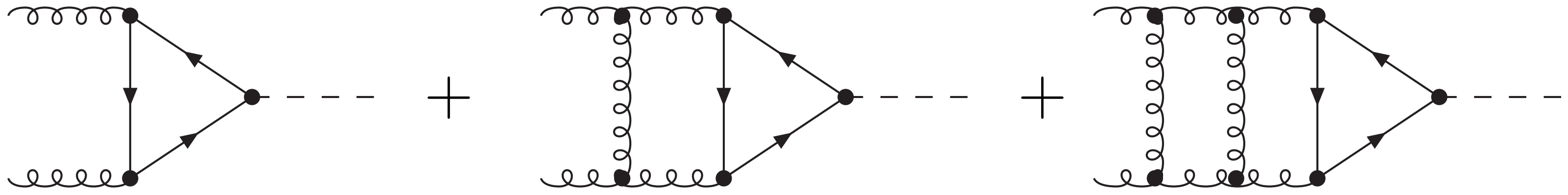
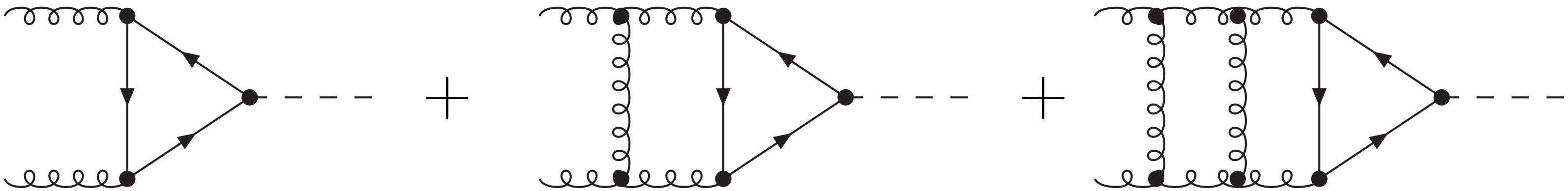


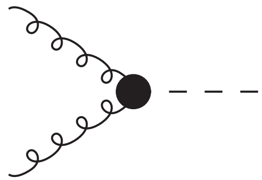
- $\mathcal{O}(100\%)$ correction at NLO
- still large scale variation at NLO
- full NNLO too difficult

Gluon Fusion

effective theory approach:



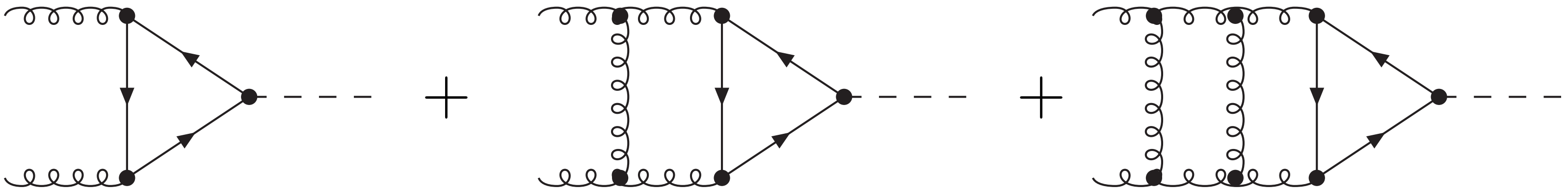
$m_t \to \infty \quad (m_t \gg M_H)$



- derive eff. interaction: $\mathcal{L}_{Hgg} = \frac{\alpha_s}{12\pi} F^a_{\mu\nu} F^{a,\mu\nu} \frac{H}{v}$

Gluon Fusion

effective theory approach:



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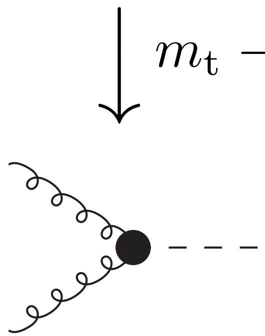
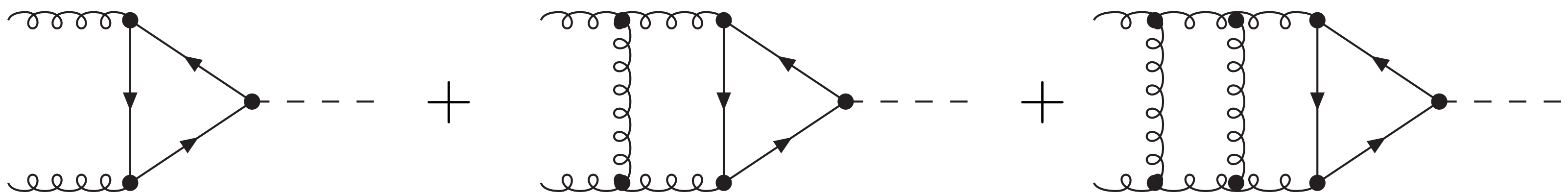


- derive eff. interaction: $\mathcal{L}_{\mathrm{Hgg}} = \frac{\alpha_s}{12\pi} F^a_{\mu\nu} F^{a,\mu\nu} \frac{H}{v} (1 + \frac{11\alpha_s}{4\pi} + \ldots)$

  (including higher order corrections)

Gluon Fusion

effective theory approach:



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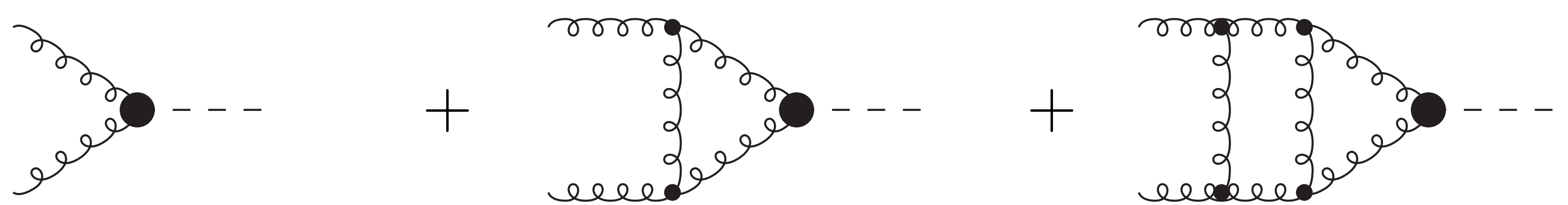

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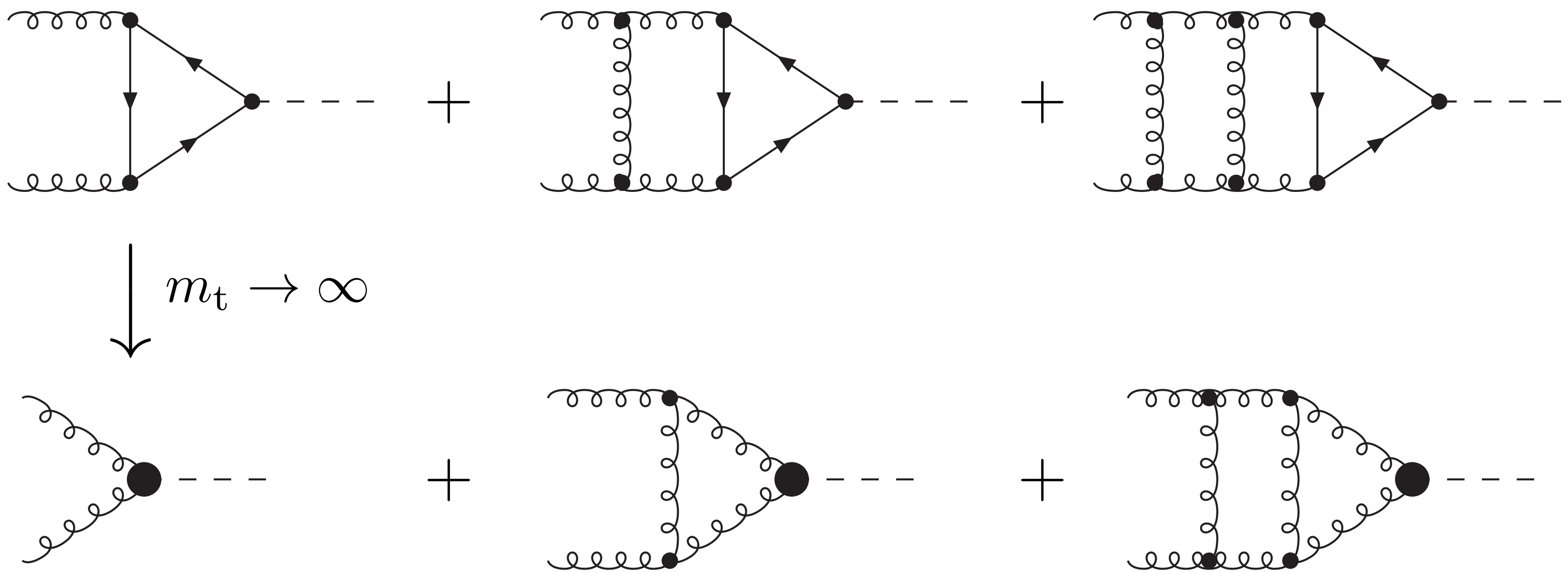
  (soft-collinear gluons do not resolve top-loop)

Gluon Fusion

effective theory approach:



- derive eff. interaction: $\mathcal{L}_\mathrm{Hgg} = \frac{\alpha_\mathrm{s}}{12\pi} F^a_{\mu\nu} F^{a,\mu\nu} \frac{H}{v} (1 + \frac{11\alpha_\mathrm{s}}{4\pi} + \ldots)$
- calculate K-factor in effective theory
  (soft-collinear gluons do not resolve top-loop)
- use full LO M_H dependence (small error for $M_\mathrm{H} \sim 125$ GeV)

Gluon Fusion

Higher-order QCD corrections:

- full NLO

  Graudenz, Spira, Zerwas '93
  Djouadi, Graudenz, Spira, Zerwas '95

- NNLO
  (as expansion for $M_{\mathrm{t}} \to \infty$)
  (matched with $\hat{s} \to \infty$)

  $$K = \frac{\sigma_{\mathrm{NNLO}}}{\sigma_{\mathrm{LO}}} \sim 2.0$$

  Harlander, Kilgore '01,'02
  Catani, de Florian, Grazzini '01
  Anastasiou, Melnikov '02
  Ravindran, Smith, van Neerven '03, '04
  Anastasiou, Melnikov, Petriello '04
  Catani, Grazzini '07
  Marzani et al. '08
  Harlander, Ozeren '09
  Pak, Rogal, Steinhauser '09

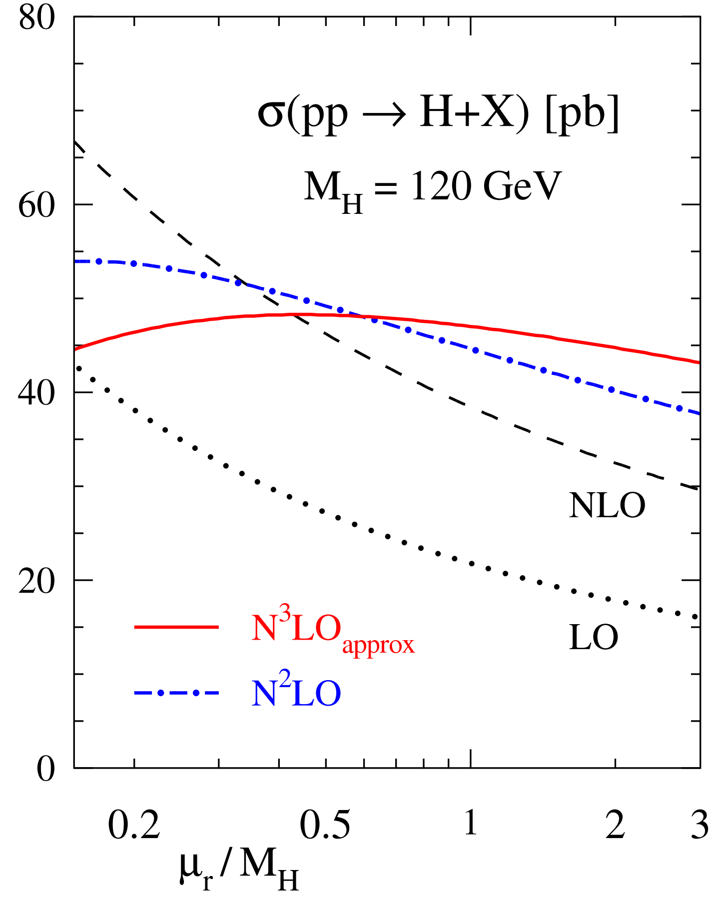
- soft-gluon resummation
  to NNLL: $6–9\%$

  leading soft contribution to
  NNNLO in limit $M_{\mathrm{t}} \to \infty$

  Catani et al. '03, Moch, Vogt '05
  Laenen, Magnea '05; Idilbi et al. '05
  Ravindran '05,'06;
  Ravindran, Smith, van Neerven '06
  Ahrens et al. '08

Gluon Fusion

Moch, Vogt '05



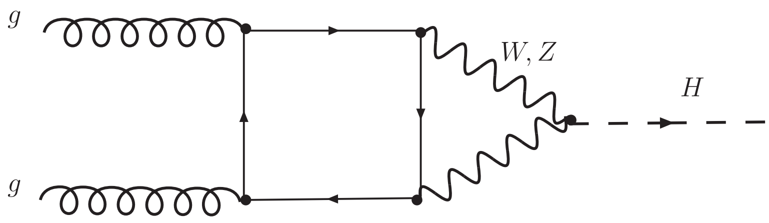
$\sqrt{s} = 14$ TeV

residual scale uncertainty: ~ 5–10%

Gluon-Fusion

EW corrections

- full NLO (2-loop) EW corrections



Actis, Passarino, Sturm, Uccirati ’09

Gluon-Fusion

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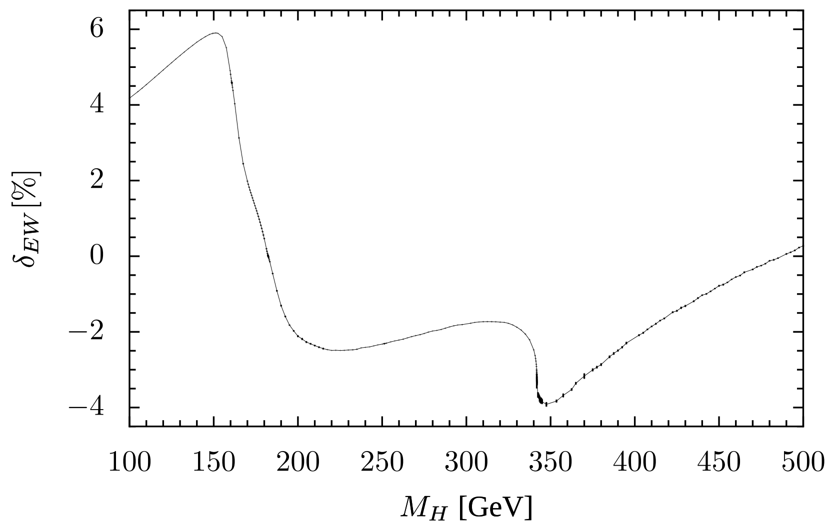
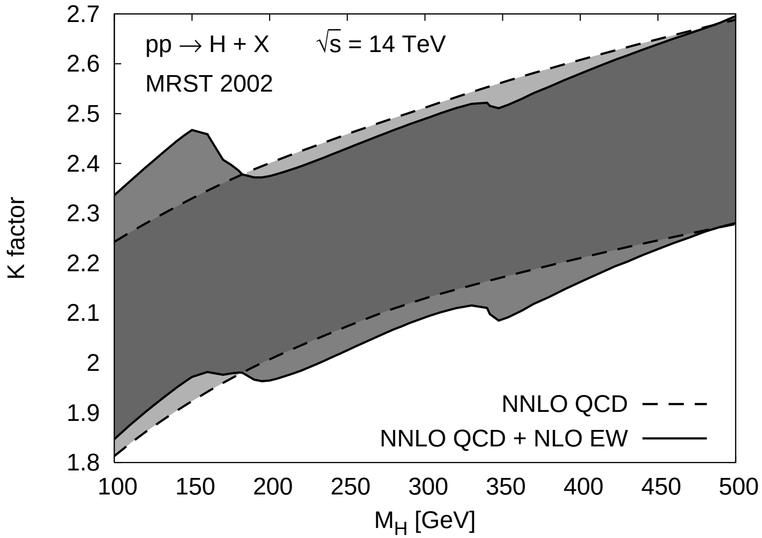




Actis, Passarino, Sturm, Uccirati '09

- non-trivial threshold behaviour inside loops (WW,ZZ,$t\bar{t}$)

  $\Rightarrow$ complex-mass scheme at two loops

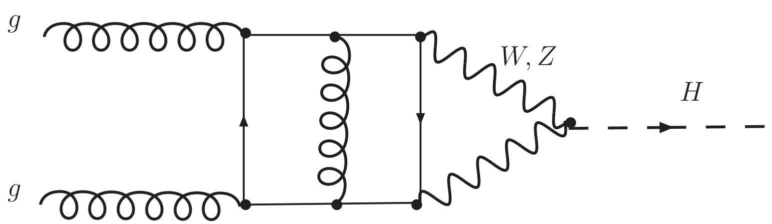
- $+5\%$ correction for $M_{\rm H} = 125$ GeV

Gluon-Fusion

EW corrections

- full NLO (2-loop) EW corrections
- mixed $\mathcal{O}(\alpha\alpha_s)$ corrections (light fermion loops)

Anastasiou, Boughezal, Petriello'11



$\Rightarrow$ effective theory approach

(corrections to Wilson coefficient
in effective ggH coupling)

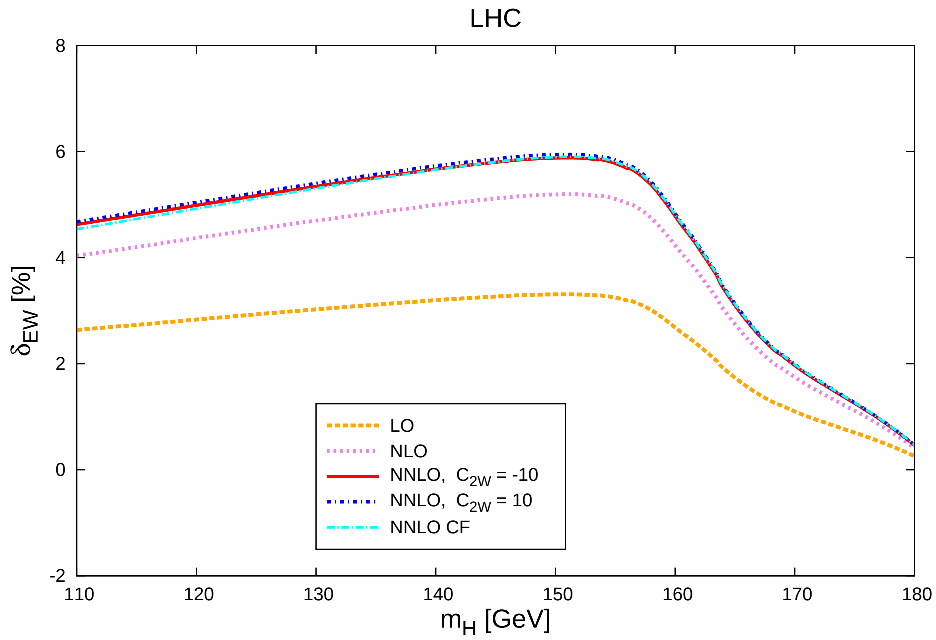
$\Rightarrow$ same philosophy like for QCD corrections

Gluon-Fusion

EW corrections

- full NLO (2-loop) EW corrections
- mixed $\mathcal{O}(\alpha\alpha_s)$ corrections (light fermion loops)

Anastasiou, Boughezal, Petriello'11



$\sim 5\%$ correction at $M_H = 125$ GeV

supports factorization of EW and QCD corrections

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Gluon Fusion

Error estimate by the LHC Higgs XS WG ('11)

- missing QCD corrections (scale uncertainty)
  $\sim 8\%$ for $M_\mathrm{H} = 125$ GeV
- PDF + α_s uncertainty (PDF4LHC recipe)
  $\sim 7\%$ for $M_\mathrm{H} \lesssim 300$ GeV

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- $M_{\mathrm{t}} \to \infty$ approximation for NNLO corrections
  $\sim 1\%$ for $M_{\mathrm{H}} \lesssim 300$ GeV
- missing EW corrections
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- input value for M_{b}:
  $\sim$1–2%

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$\Rightarrow$ $\sigma = 19.5$ pb at $\sqrt{s} = 8$ TeV with error $\pm 14.7\%$

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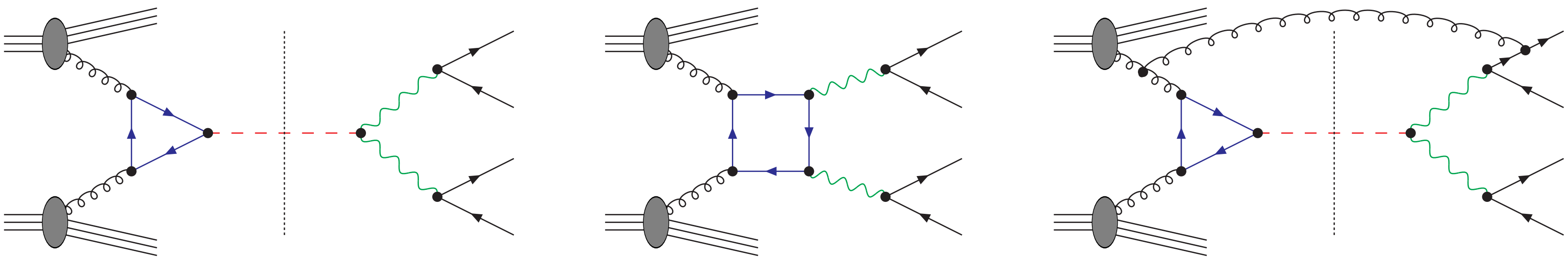
not mentioned here: efforts on differential predictions

Gluon Fusion

The complete picture:
combining production and decay, signal and background



- a crucial issue for a heavy SM Higgs ($\Rightarrow$ large width)

Gluon Fusion

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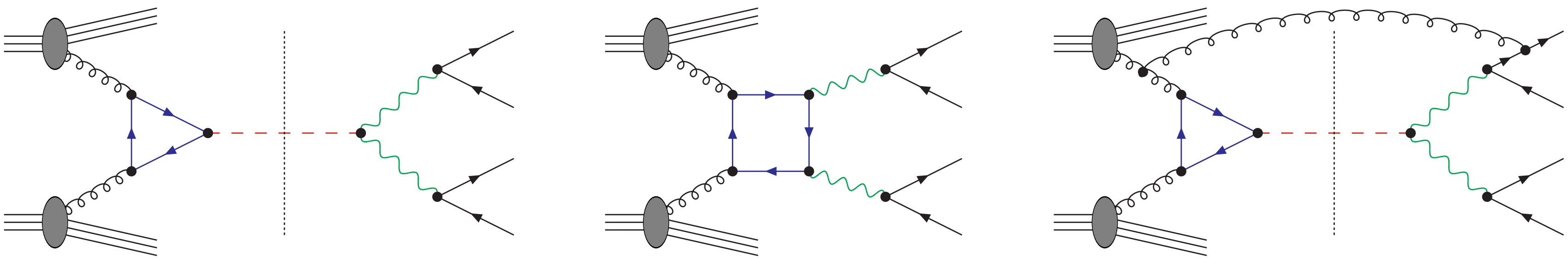
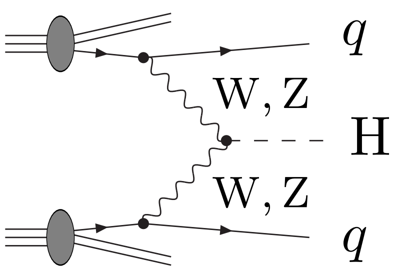


- a crucial issue for a heavy SM Higgs ($\Rightarrow$ large width)
- $M_{\rm H} = 125$ GeV makes live easier
- still sizeable amount of off-shell Higgs (and interference) in $\rm pp \to WW \to l\bar{\nu}_l l^+ \nu_l$ Kauer, Passarino '12

off-shell Higgs $\Leftrightarrow$ off-shell $\rm W$ ($M_{\rm T}$ cut helps)

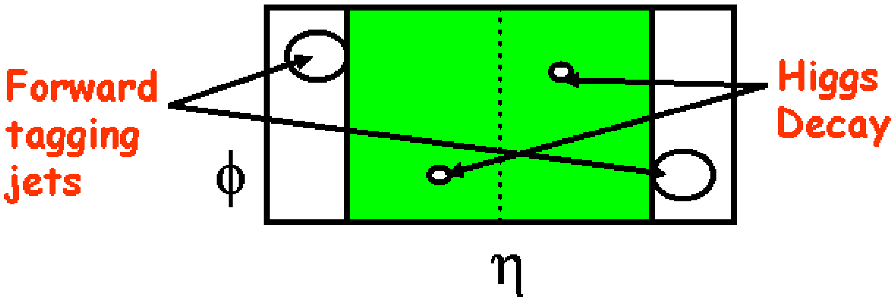
Vector-Boson Fusion

- sizeable fraction of inclusive Higgs production
  - ~ 1.5 pb at $\sqrt{s} = 8$ TeV ($M_\mathrm{H} = 125$ GeV)



- special kinematics:
  forward and backward tagging jets $\Rightarrow$ VBF signal
  - powerful cuts for background suppression

$\Delta y_{jj} > 4$, $y_{j1} \cdot y_{j2} < 0$ ($p_{\mathrm{T},j} > 20$ GeV, $|y_j| < 4.5$)



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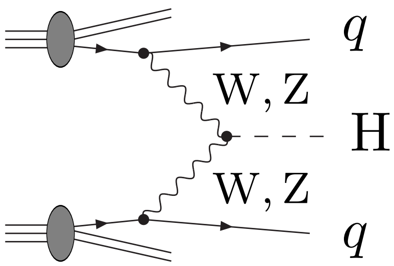

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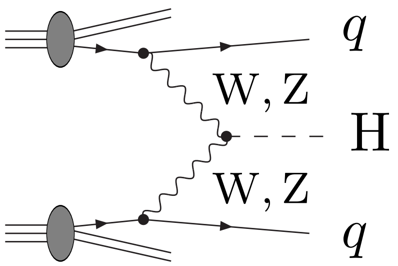
  - $\mathrm{H} \to \mathrm{b\bar{b}}$ still impossible
  - $\mathrm{H} \to \gamma\gamma,\ \tau\tau,\ \mathrm{WW}$

Vector-Boson Fusion



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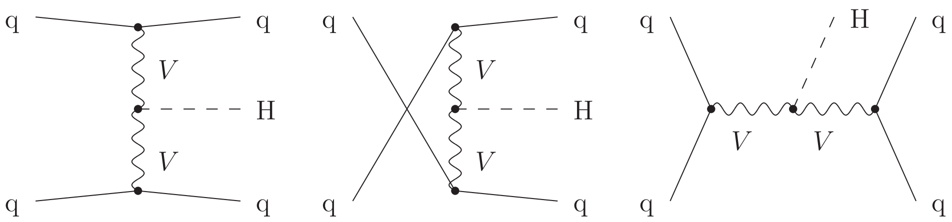
  - $\mathrm{H} \to \mathrm{b\bar{b}}$ still impossible
  - $\mathrm{H} \to \gamma\gamma,\ \tau\tau,\ \mathrm{WW}$
- measure HWW and HZZ couplings in production
- investigate non-standard couplings

Vector-Boson Fusion

$pp \to \mathrm{H}jj$

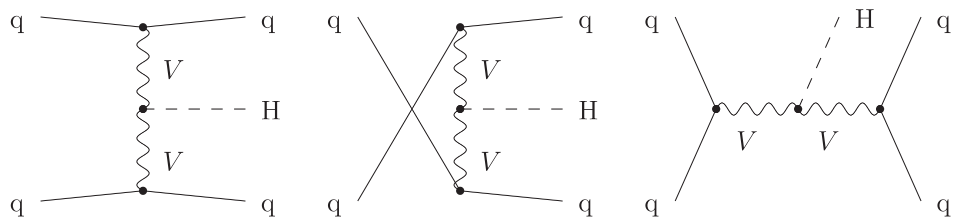


VBF cuts on jets:

- reduce background
- separate from $gg \to \mathrm{H}jj$ in gluon fusion (5% after cuts)
- s-channel and interferences negligible
  (DIS^2 like process)

Vector-Boson Fusion

$pp \to \mathrm{H}jj$



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- separate from $gg \to \mathrm{H}jj$ in gluon fusion (5% after cuts)
- s-channel and interferences negligible (DIS^2 like process)

Higher-order corrections:

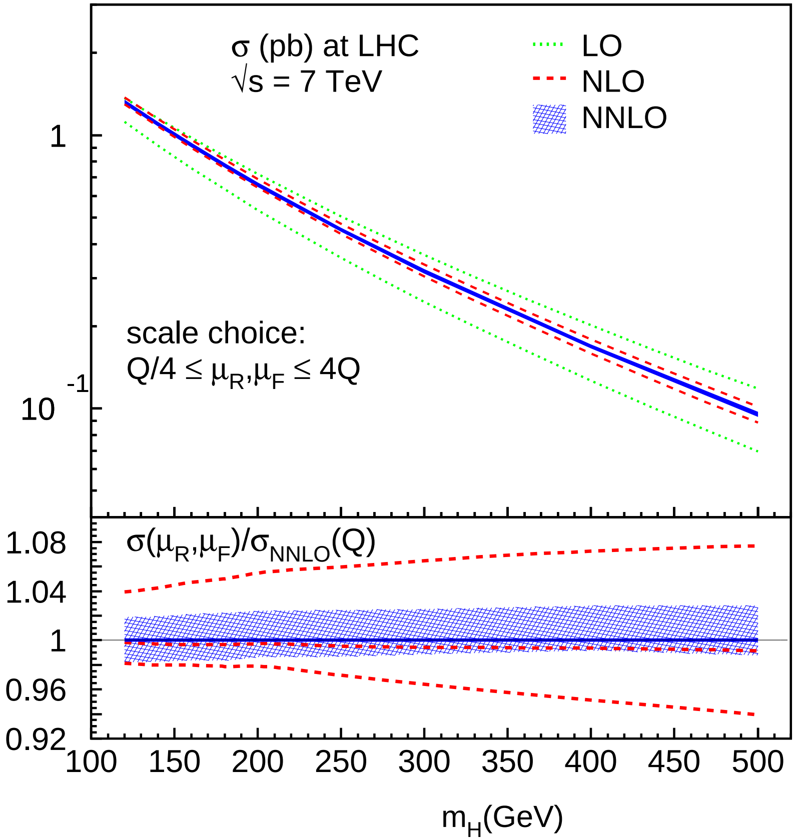
- QCD corrections small ($\Leftrightarrow$ DIS^2 like process)
- EW of the same size (5–10%)
- assume factorized corrections: $\sigma = \sigma_{\mathrm{NNLO}}(1 + \delta_{\mathrm{EW}})$
- PDF + α_{s} error dominant: $\pm 3\%$ ($M_{\mathrm{H}} = 125$ GeV)

Vector-Boson Fusion

- NNLO QCD corrections: VBF@NNLO

  Bolzoni,Maltoni,Moch,Zaro '10
  - for total cross section
  - QCD under excellent theoretical control at the 1% level

structure function approach ($\rightarrow$ DIS^2)



Vector-Boson Fusion

- NNLO QCD corrections: VBF@NNLO
  - for total cross section
  - QCD under excellent theoretical control at the 1% level
- differetial NLO QCD+ EW corrections
  - VBFNLO
    s-channel and interferences neglected
    EW corrections in the MSSM
    many additional features
  - HAWK
    no kinematic limitations (s-channel and interferences included)

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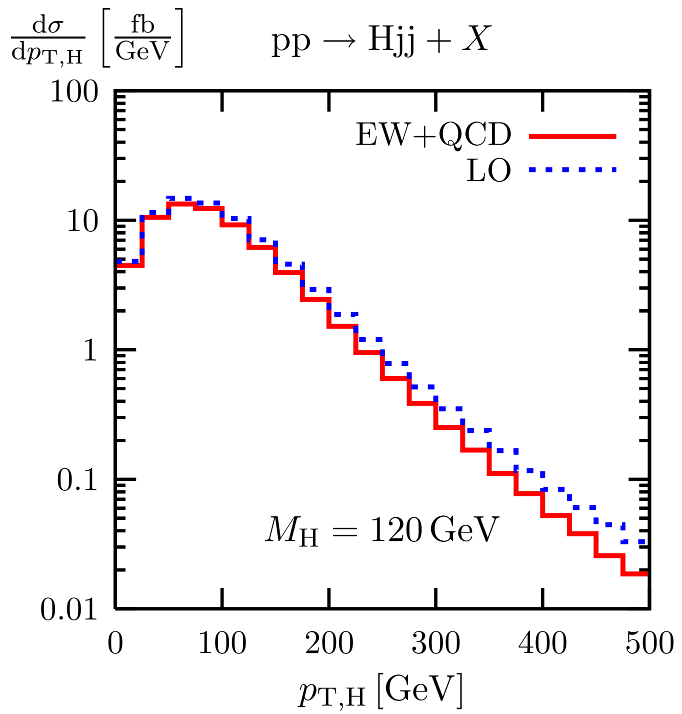
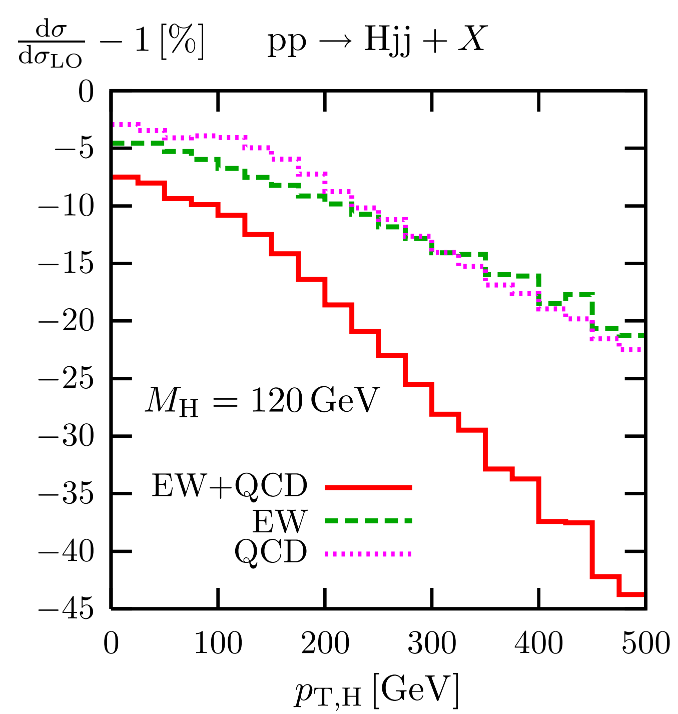
    many additional features
  - HAWK
    no kinematic limitations (s-channel and interferences included)
- Beyond fixed order
  - merging NLO QCD with PS: Powheg, MC@NLO

Vector-Boson Fusion

Transverse momentum of Higgs boson: (with VBF cuts)





Ciccolini, Denner, Dittmaier ’07 (Hawk)

- corrections distort shapes of distributions
- EW corrections -20% at $p_{T,H} = 500$ GeV from electroweak Sudakov logarithms

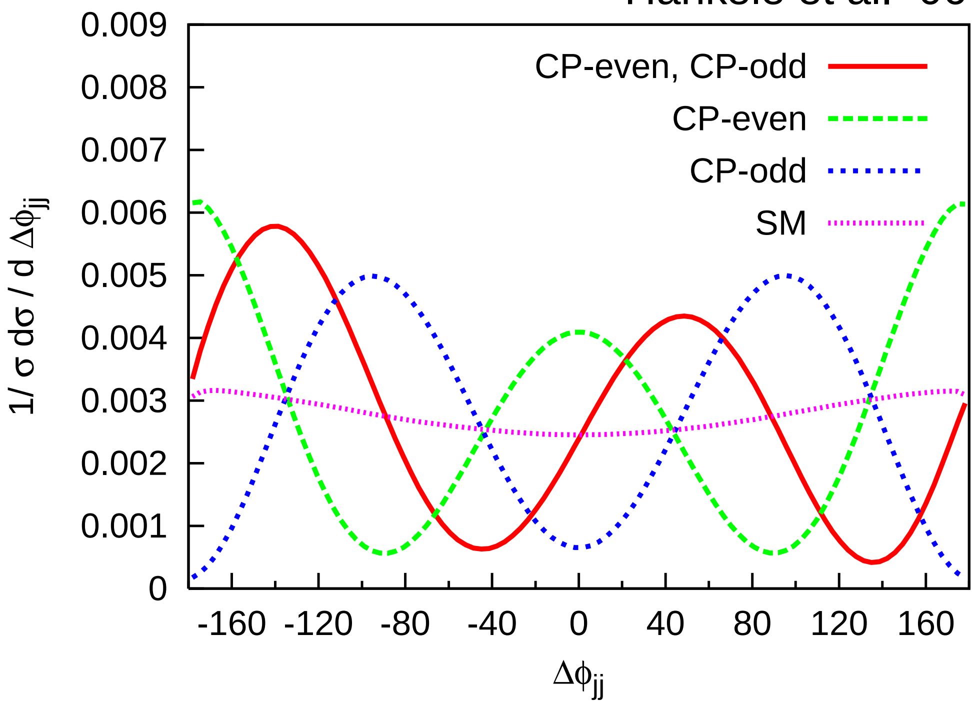
Vector-Boson Fusion

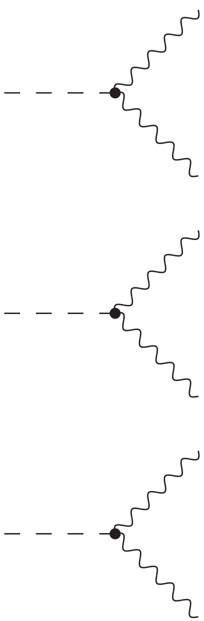
Higgs couplings from $\Delta\Phi_{jj}$ in VBF

- sensitivity to non-standard couplings

Hankele, Klämke, Zeppenfeld, Figy '06
Ruwiedel, Schumacher, Wermes '07

Hankele et al. '06





SM: $\propto g^{\mu\nu}$

CP-even: $\propto g^{\mu\nu} k_1 \cdot k_2 - k_1^\mu k_2^\nu$

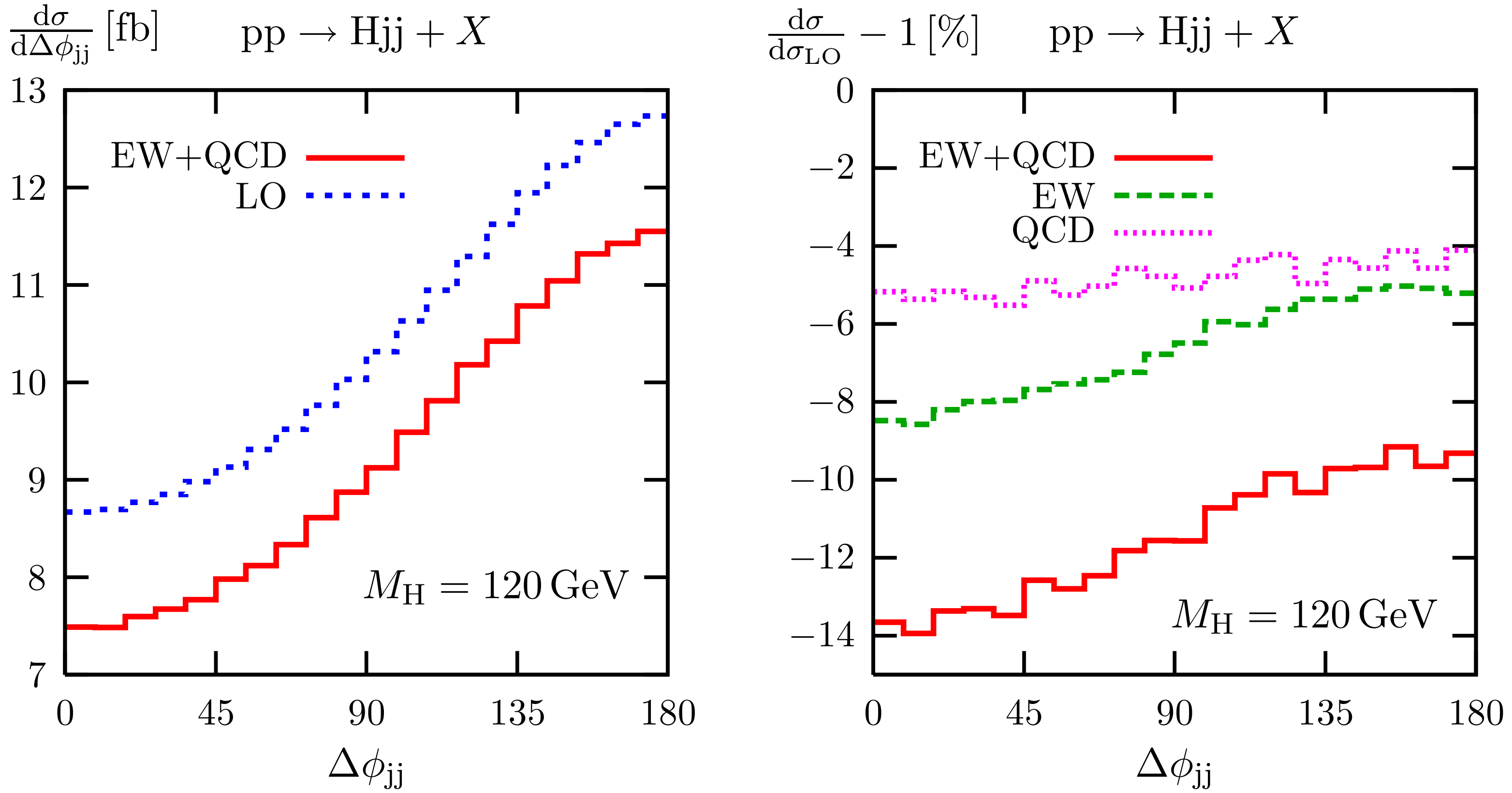
CP-odd: $\propto \epsilon^{\mu\nu\rho\sigma} k_{1\rho} k_{2\sigma}$

$k_{1,2}$: boson momenta

Vector-Boson Fusion

Corrections to $\Delta\Phi_{jj}$ (with VBF cuts)

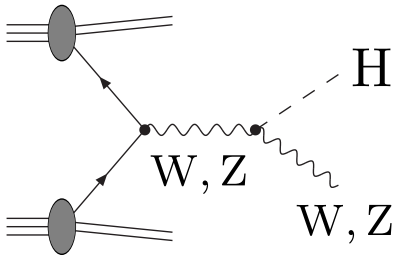
Ciccolini, Denner, Dittmaier '07 (HAWK)



EW corrections distort distribution by $\sim 4\%$

Higgs strahlung

- associated production:
  $pp \to W/Z + \mathrm{H}$



- σ a bit smaller than VBF
  - ~ 1.1 pb at $\sqrt{s} = 8$ TeV ($M_\mathrm{H} = 125$ GeV)
  - main channel at the Tevatron
- leptonic W/Z decay allows for additional tag
  $\Rightarrow$ punished by small leptonic $\mathrm{W/Z}$ BRs
- for a 125 GeV Higgs $H \to b\bar{b}$ should be accessible
  $\Rightarrow$ modern jet-techniques
- small signal to background ratio

  $\Rightarrow$ boosted Higgs: use high p_T Higgs bosons only

  b jets from "fat jet" substructure

Higgs strahlung

- QCD corrections
  - similar to Drell-Yan ($\longrightarrow$ relatively simple)
  - inclusive NNLO QCD corrections: VH@NNLO

Brein, Djouadi, Harlander '03

Higgs strahlung

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  - similar to Drell-Yan ($\to$ relatively simple)
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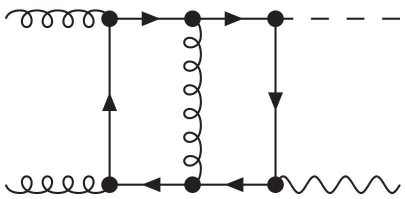
    Brein, Djouadi, Harlander '03
  - ZH gluon-fusion contribution at NLO ($\lesssim 10\%$)

    Altenkamp, Dittmaier, Harlander, Rzehak, Zirke '12



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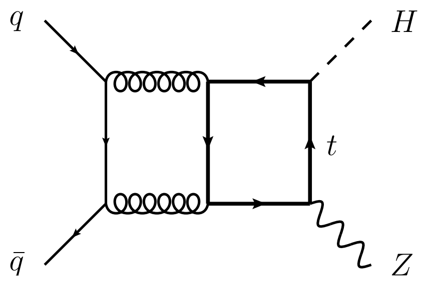

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  - fully differential Drell-Yan like NNLO for WH

    Ferrera, Grazzini, Tramontano '11

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  - fully differential Drell-Yan like NNLO for WH

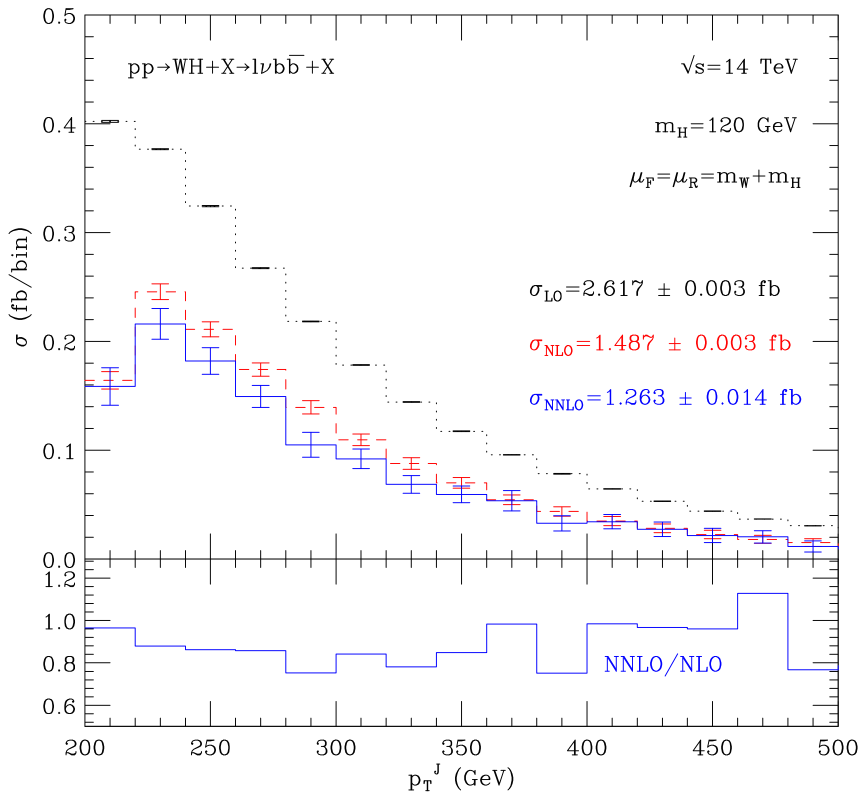
    Ferrera, Grazzini, Tramontano '11
- EW corrections
  - fully differential including decay in HAWK

    Denner, Dittmaier, Kallweit, Mück '11

Higgs strahlung

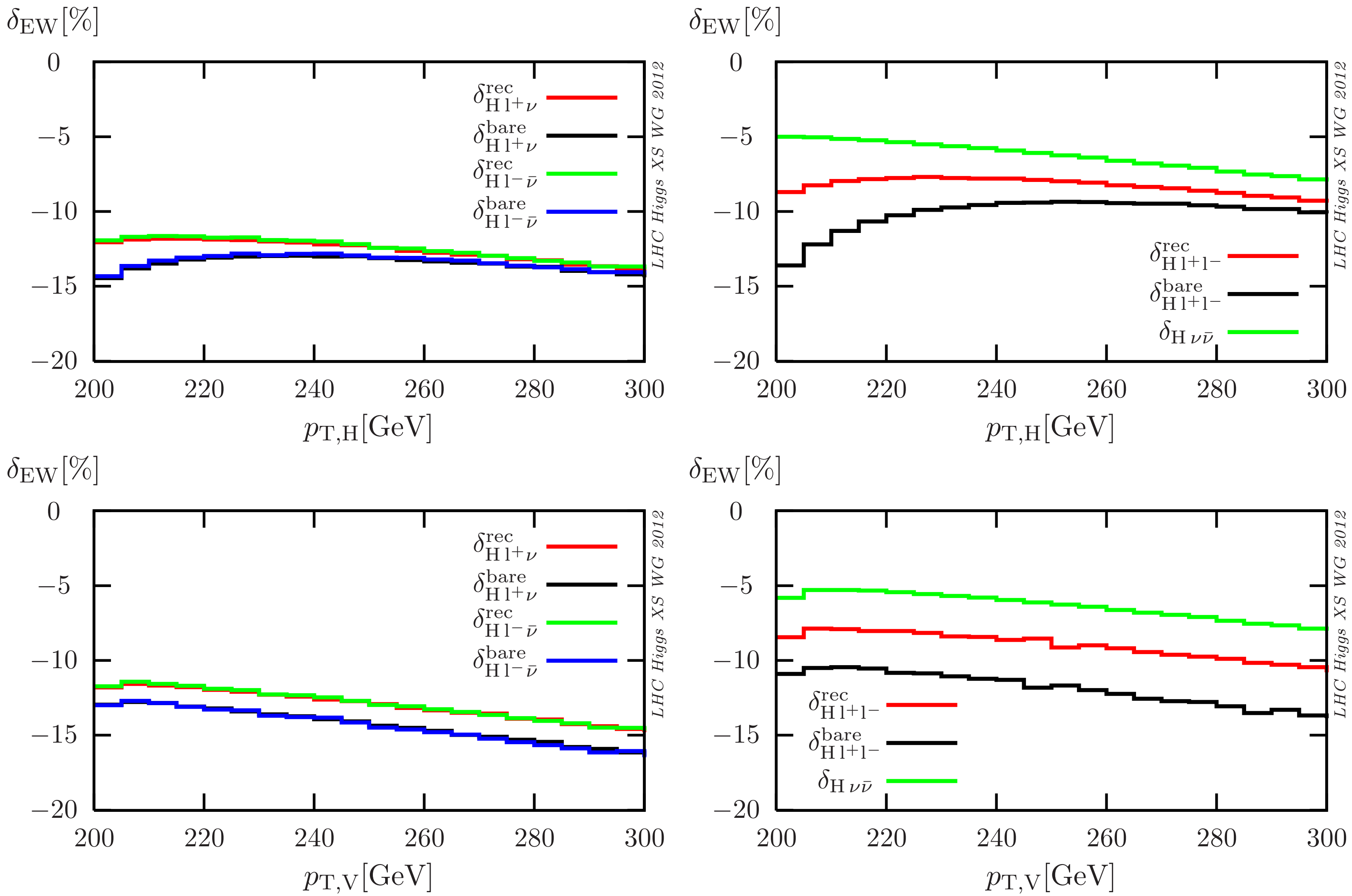
- Differential NNLO QCD for WH

Ferrera, Grazzini, Tramontano [arXiv:1107.1164]



(large negative correction due to strict jet veto)

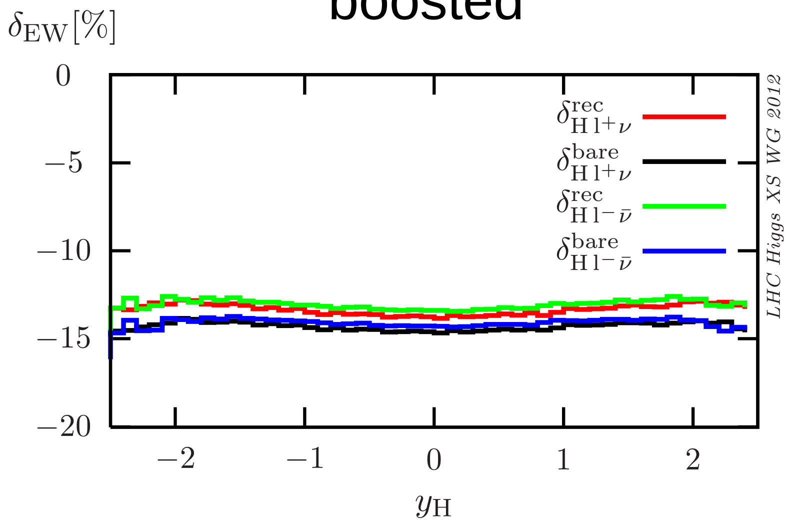
Higgs strahlung



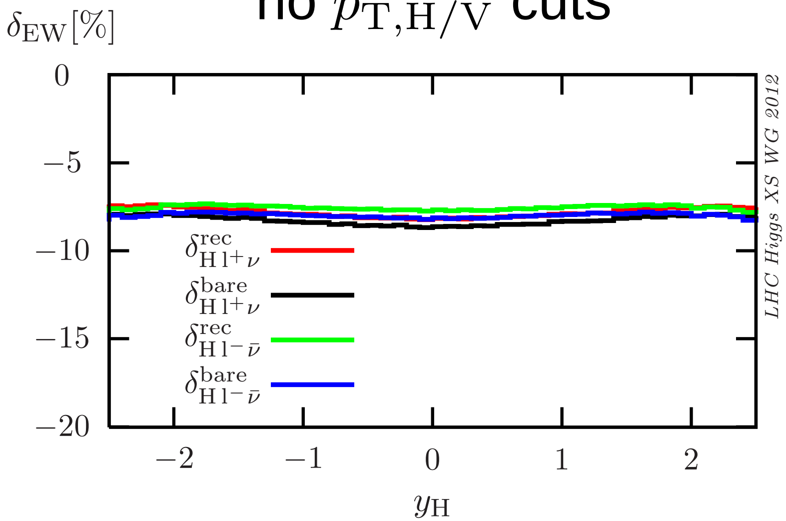
different lepton–photon recombination: rec for electrons
bare for muons

Higgs strahlung

boosted

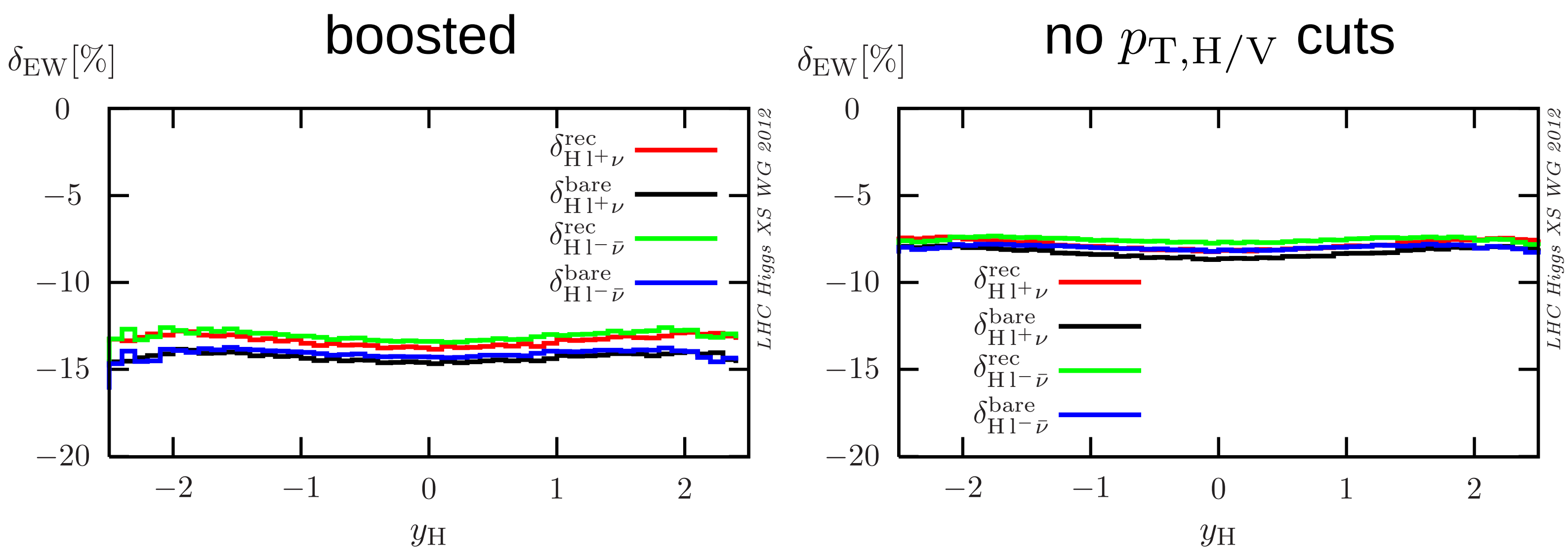


no $p_{\mathrm{T,H/V}}$ cuts



- larger EW corrections for boosted Higgs
- up to -15% for WH

Higgs strahlung



- larger EW corrections for boosted Higgs
- up to -15% for WH
- uncertainties (for differential analysis):
  - scale: 2%
  - PDF: 5%
  - missing higher orders (e.g. $gg \to VH$): 1% (7%) for WH (ZH)

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AACHEN
RWTH

Summary

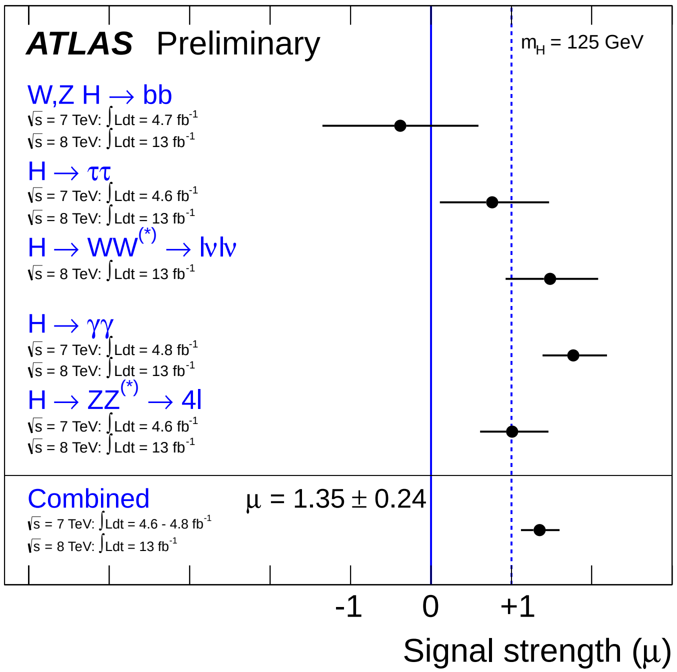
LHC Higgs phenomenology

- enormous theoretical efforts have been invested
- good control on SM predictions for
  - production cross-sections
  - branching ratios
- focus now on
  - differential predictions
  - Higgs properties
  - SM $\Leftrightarrow$ alternative models
- all data so far looks consistent with the SM ($H \to \gamma\gamma$?)

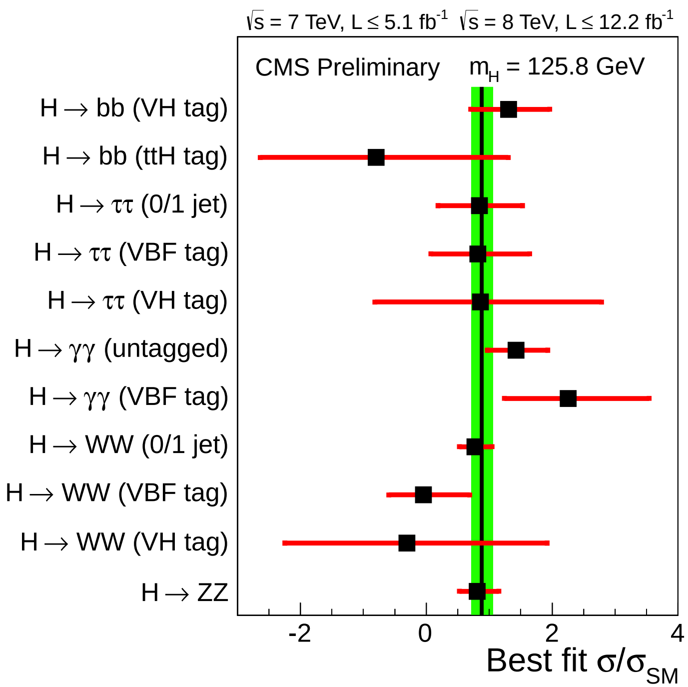
Summary

working on the most important question. . .

ATLAS-CONF-2012-170



CMS-HIG-12-045



Is it the SM Higgs boson?

⇒ only data can tell. . .