Two-loop electroweak corrections to Higgs production and decay at LHC

Christian Sturm
Brookhaven National Laboratory
Physics Department,
High Energy Theory Group
Upton, NY

I. Introduction & Motivation
II. Calculation & Techniques
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IV. Summary & Conclusion

In collaboration with: S. Actis, G. Passarino, S. Uccirati

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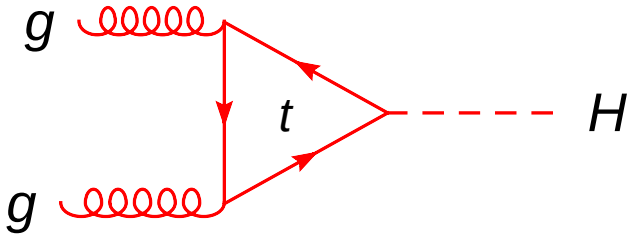
Phys. Lett. B669, 62, 2008, Phys. Lett. B655, 298, 2007.

Introduction & Motivation

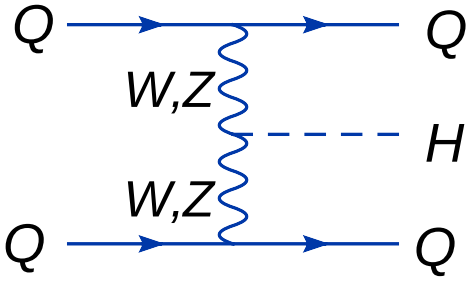
Higgs production

- Main production mechanisms:

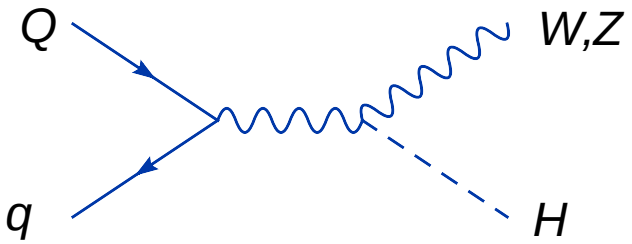
Gluon fusion:

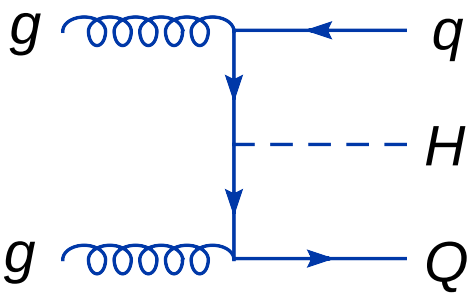


Vector boson fusion:



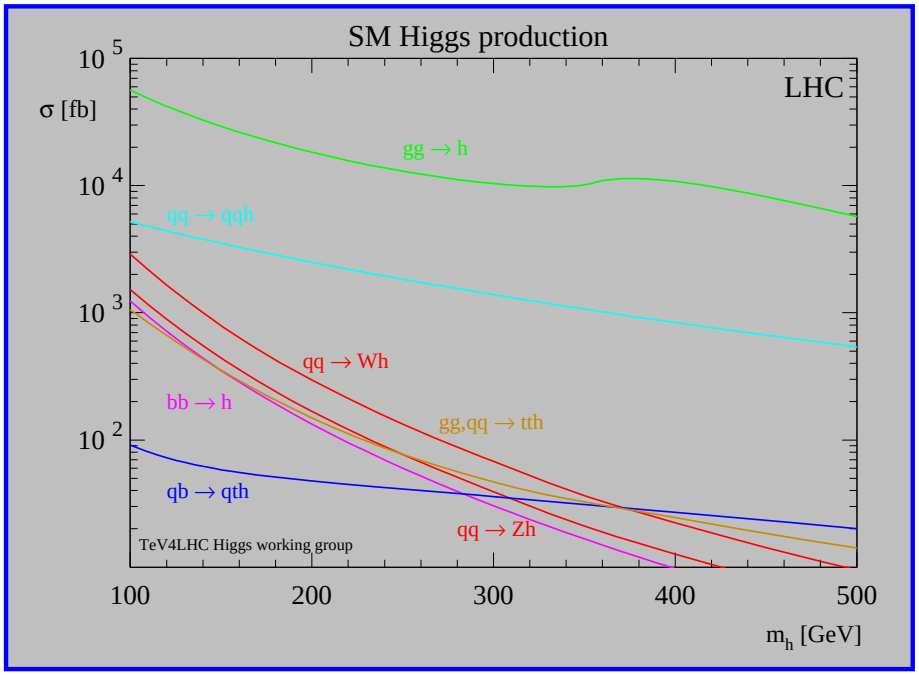
Associated production:





Introduction & Motivation

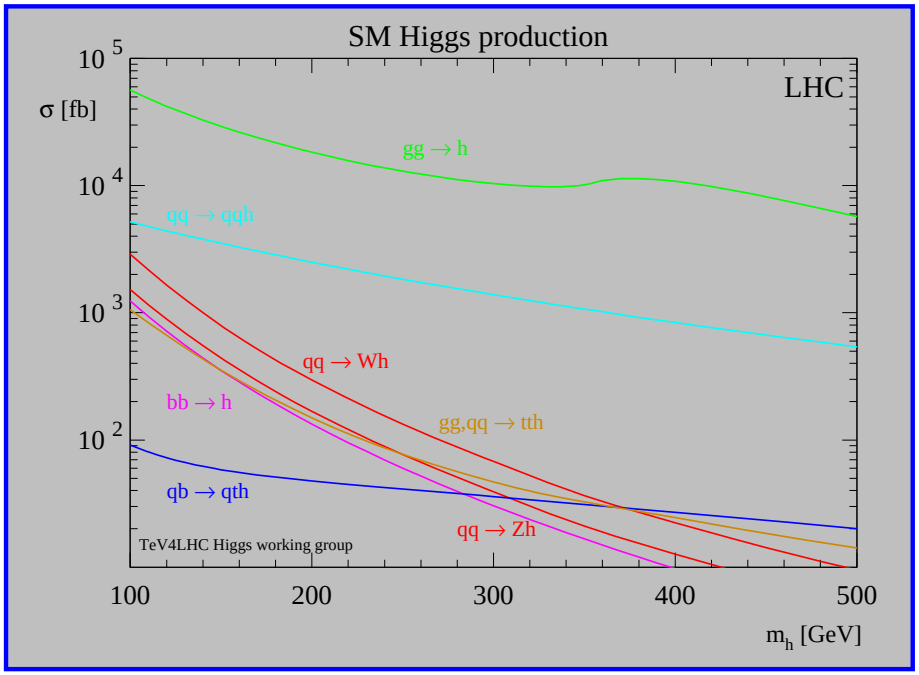
Higgs production



- Dominant production mechanism: Gluon fusion

Introduction & Motivation

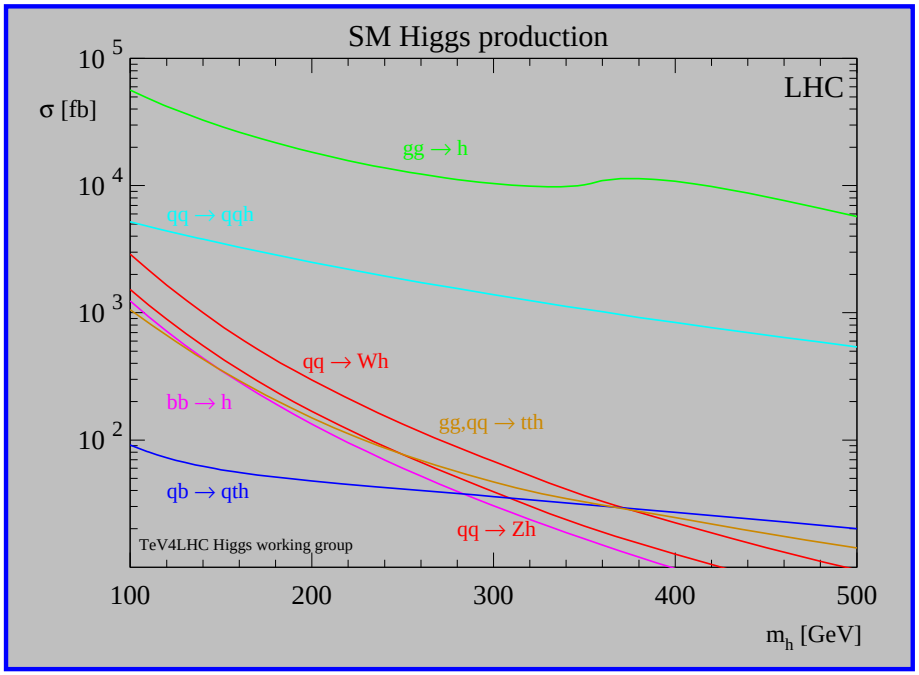
Higgs production



- Dominant production mechanism: Gluon fusion
- NLO QCD
  - Heavy top-quark limit:
    Dawson; Djouadi, Spira, Zerwas
  - Entire Higgs-mass range:
    Djouadi, Graudenz, Spira, Zerwas; Harlander, Kant; Anastasiou, Beerli, Bucherer, Daleo, Kunszt; Aglietti, Bonciani, Degrassi, Vincini
- NNLO QCD
  Harlander; Catani, Florian, Grazzini; Harlander, Kilgore; Anastasiou, Melnikov; Ravindran, Smith, Neerven; Anastasiou, Melnikov, Petriello; Catani, Grazzini

Introduction & Motivation

Higgs production

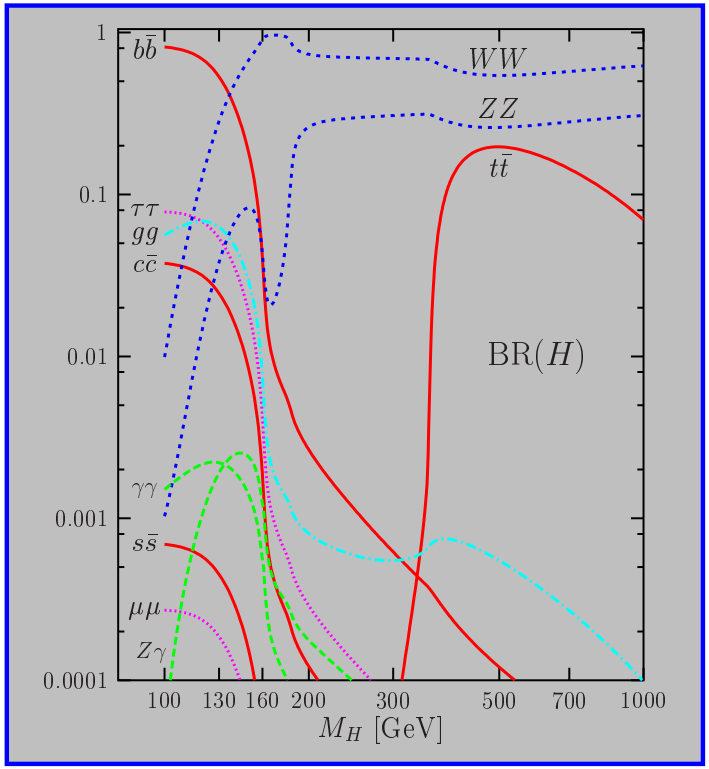


- Dominant production mechanism: Gluon fusion
- NLO EW
  - Exact light-fermion contribution
    Aglietti, Bonciani, Degrassi, Vincini
  - Contributions involving top-quark in terms of expansions
    Degrassi, Maltoni; Djouadi, Gambino, Kniehl

  ↪ full EW corrections: in this talk with complete dependence on heavy particles M_H, M_W, M_Z, M_t
  S. Actis, G. Passarino, C.S., S. Uccirati

Introduction & Motivation

Higgs decay

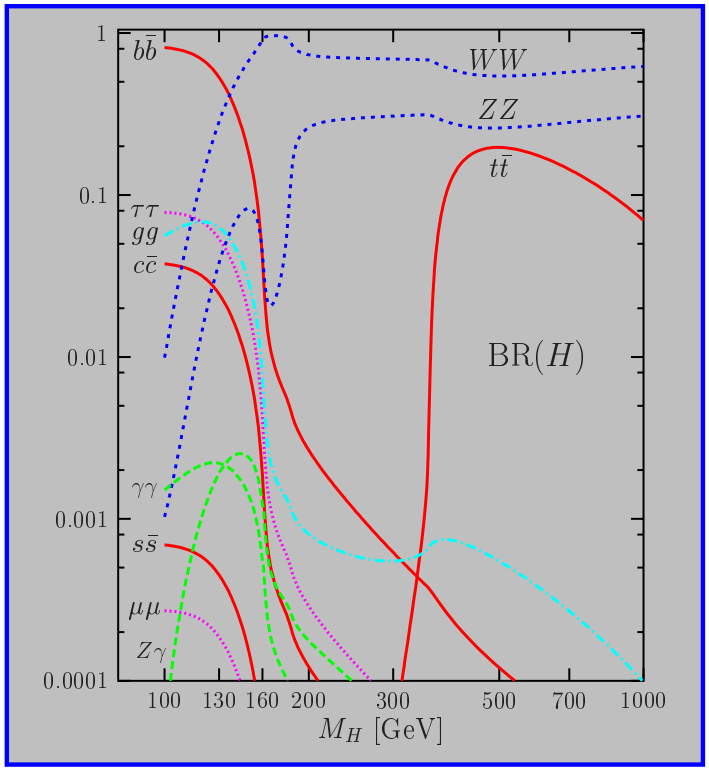


Djouadi, Graudenz, Spira, Zerwas

- $H \to WW, ZZ$ dominant process for heavy Higgs boson
- $H \to b\bar{b}$ dominant process for light Higgs, but huge QCD background.
- $H \to \gamma\gamma$ rare process Br$\sim 10^{-3}$, but experimentally clean

Introduction & Motivation

Higgs decay



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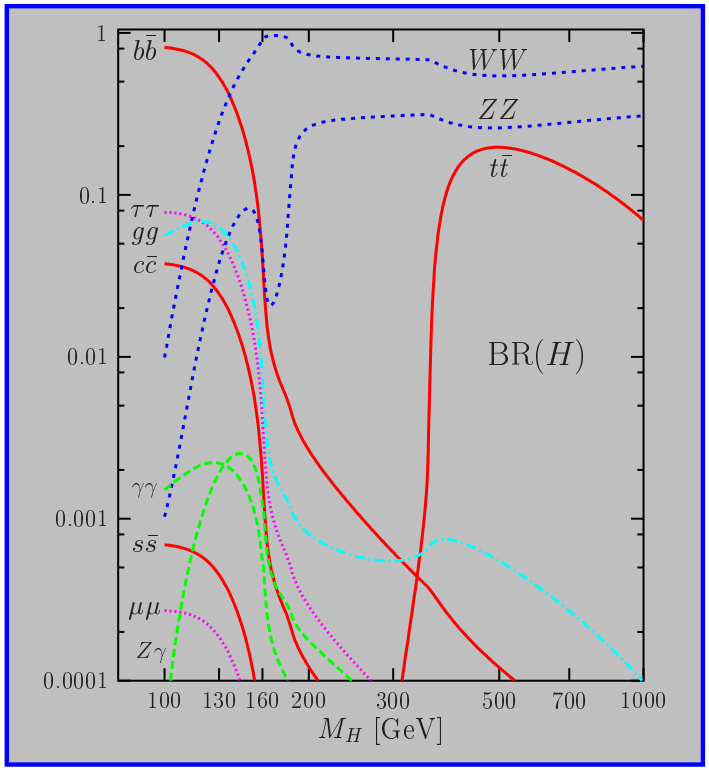
- NLO QCD
  - Expansions below/above threshold
    Zheng, Wu; Djouadi, Spira, van der Bji, Zerwas; Dawson, Kauffman
    Djouadi, Spira, Zerwas; Melnikov, Yakovlev; Inoue, Najima, Oka, Saito
  - Analytical results
    Fleischer, Tarasov, Tarasov; Harlander, Kant; Anastasiou, Beerli, Bucherer, Daleo, Kunszt; Aglietti, Bonciani, Degrassi, Vicini

Introduction & Motivation

Higgs decay



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- $H \to \gamma\gamma$ rare process Br$\sim 10^{-3}$, but experimentally clean
- NLO EW
  - corrections of $\mathcal{O}(G_f\, m_t^2)$
    Liao,Li; Fugel, Kniehl, Steinhauser
  - corrections of $\mathcal{O}(G_f\, m_h^2)$
    Korner, Melnikov, Yakovlev
  - exact light-fermion contribution
    Aglietti, Bonciani, Degrassi, Vincini
  - Contributions involving top-quark and weak bosons exp. in $M_h^2/(4M_w^2)$
    Degrassi, Maltoni

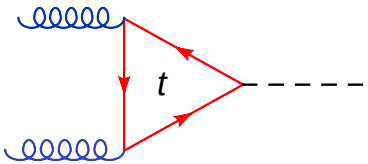
  $\hookrightarrow$ full EW corrections: in this talk
  Actis, Passarino, C.S., Uccirati

Calculation & Techniques

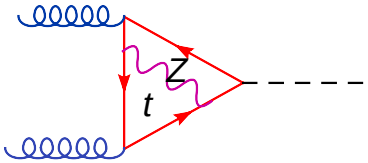
...some diagrams contributing to the EW 2-loop corrections

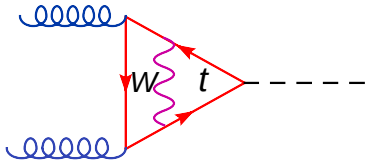
- $gg \to H$:

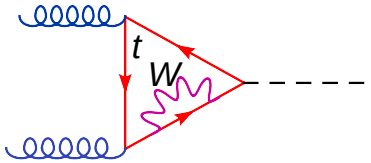
LO



NLO







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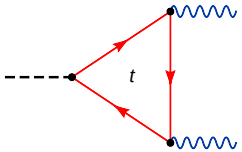
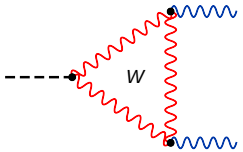
- $H \to \gamma\gamma$:

LO



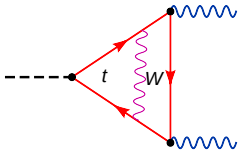
fermionic

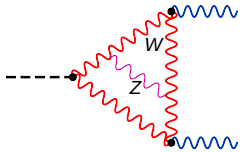


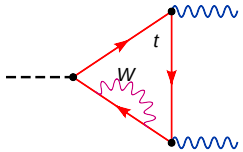
bosonic

, . . .

NLO







, . . .

Calculation & Techniques

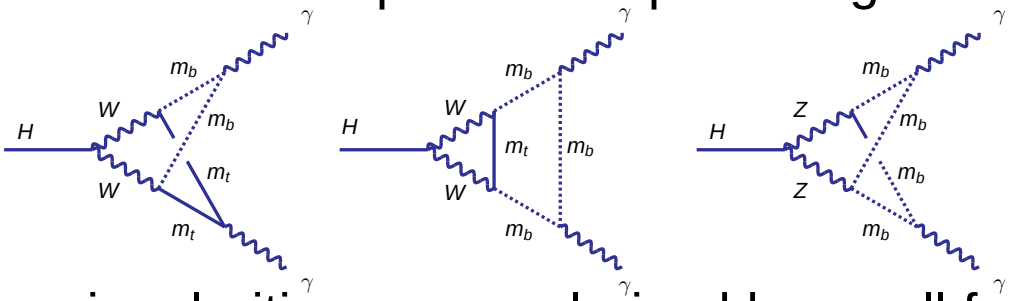
2-loop contributions are computed numerically:

- Diagrams: *GraphShot*
  S. Actis, A. Ferroglia, G. Passarino, M. Passera, C.S., S. Uccirati
  Form3 based package for automatic generation and manipulation of 1- and 2-loop Feynman diagrams:
  insert Feynman-rules, perform traces, remove reducible scalar products, symmetrize integrals, reduction, counter terms, renormalization,...
- $\rightsquigarrow$ UV-finite integrals classified into:
  scalar, vector and tensor type integrals
  $\rightsquigarrow$ mapped on form factors
- Form factors are evaluated numerically in parametric space
- Before num. integration: Cancel collinear sing. + Study threshold

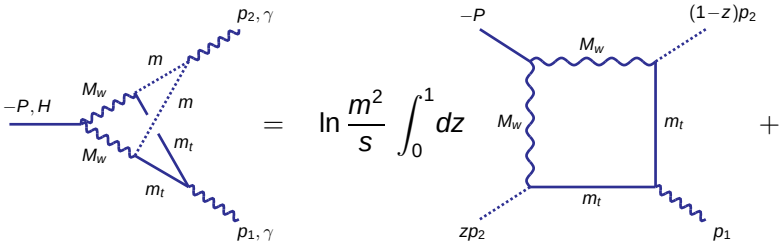
  For a moment consider $H \to \gamma\gamma$ without loss of generality

Collinear singularities

- Appear when external photon couples to light fermions, e.g.:



- Collinear singularities are regularized by small fermion mass
  $\rightsquigarrow$ singularities become manifest in $\log(m)$
- Verification of their cancellation:
  Requires universal representation of the coefficient
- Introduce integrals of one-loop functions:

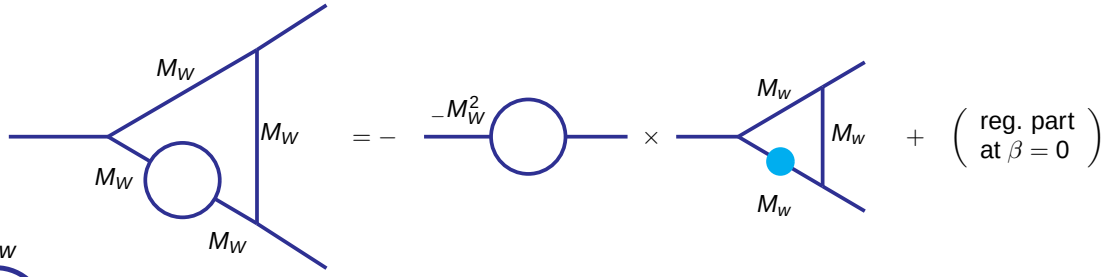


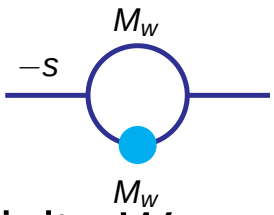
$\longrightarrow$ use their well-known properties to make cancellation explicit

Behavior at WW-threshold ($H \to \gamma\gamma$)

Amplitude develops threshold singularities in $\beta_W = \sqrt{1 - 4M_W^2/s}$, when $s = M_h^2 \sim 4M_W^2$, possible sources:

I) Square-root singularities:



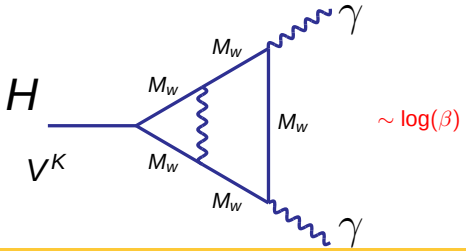


$$= \dot{B}_0(-s, M_W, M_W) = -\frac{1}{\beta} \ln \frac{\beta+1}{\beta-1} \quad \Longleftarrow \quad \textbf{singular for } M_h = 2M_W$$

II) Finite W-mass renormalization (derivative of C-function),

III) Higgs wave function factor (derivative of B-function)

IV) Logarithmic singularities:



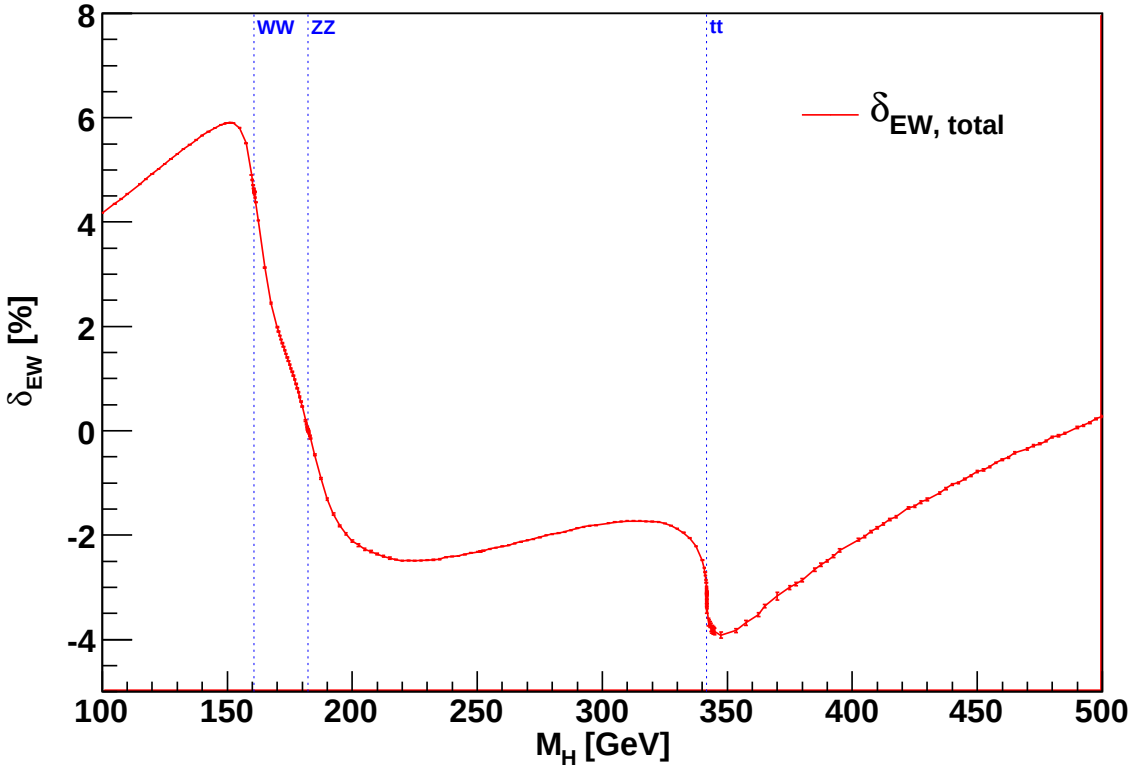
I) and II) cancel, III) and IV) survive

$\Rightarrow$regularize thr. singularity by complex mass scheme:

$M_{W,Z}^2 \to M_{W,Z}^2 - i\Gamma_W M_{W,Z}$

Result:

The partonic process $gg \to H$



Maximum around *WW*-threshold, minimum around *tt*-threshold

$\to$ The percentage correction varies between +6% and -4%

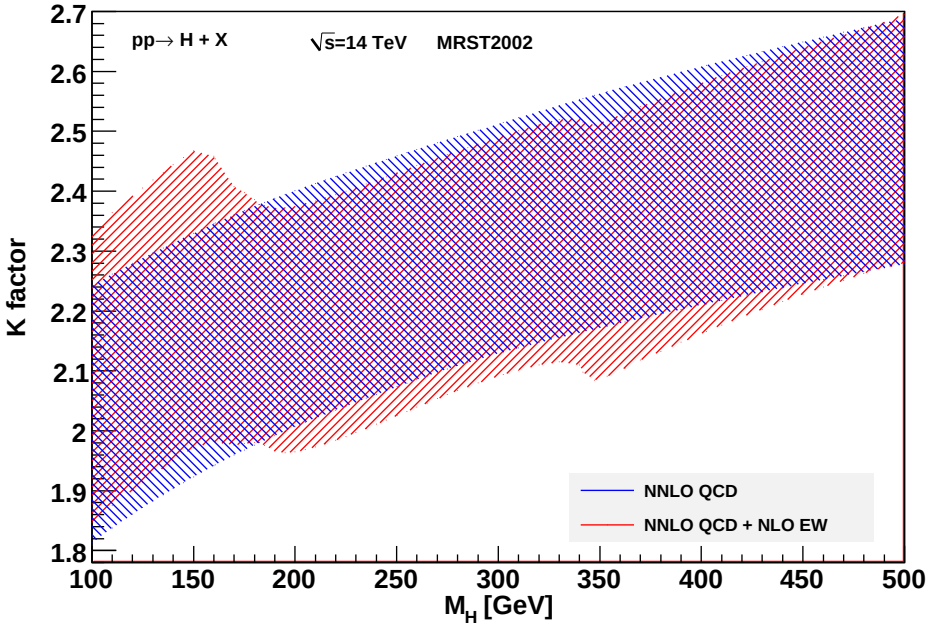
Result:

The hadronic process $pp \to H + X$

- Hadronic process:
  $\sigma\left(s, M_H^2\right) = \sum_{i,j} \int_0^1 dx_1 \int_0^1 dx_2 \; f_{i/h_1}\left(x_1, \mu_F^2\right) f_{j/h_2}\left(x_2, \mu_F^2\right) \times$
  $\int_0^1 dz \; \delta(z - \frac{M_H^2}{s\, x_1 x_2})\, z\, \sigma^{(0)}\, G_{ij}\left(z; \alpha_S(\mu_R^2), M_H^2/\mu_R^2; M_H^2/\mu_F^2\right),$
  Parton densities: $f_{i/h_1}, f_{j/h_1}, \; i,j \in \{g, q, \bar{q}\}$
  QCD corrections: $G_{ij} = \alpha_s^2(\mu_R)\delta_{ig}\delta_{jg}\delta(1-z) + \alpha_s^3(\mu_R) G_{ij}^{(1)} + \ldots$
- Complete factorization(CF): $\sigma^{(0)}\, G_{ij} \to \sigma^{(0)}\, (1 + \delta_{\mathrm{EW}})\, G_{ij}$
  amounts to an overall re-scaling of QCD result,
  consider electroweak correction point like
- Partial factorization(PF): $\sigma^{(0)}\, G_{ij} \to \sigma^{(0)} \left[G_{ij} + \alpha_s^2(\mu_R^2)\delta_{\mathrm{EW}}\, G_{ij}^{(0)}\right]$
  equivalent to add electroweak corrections to QCD ones

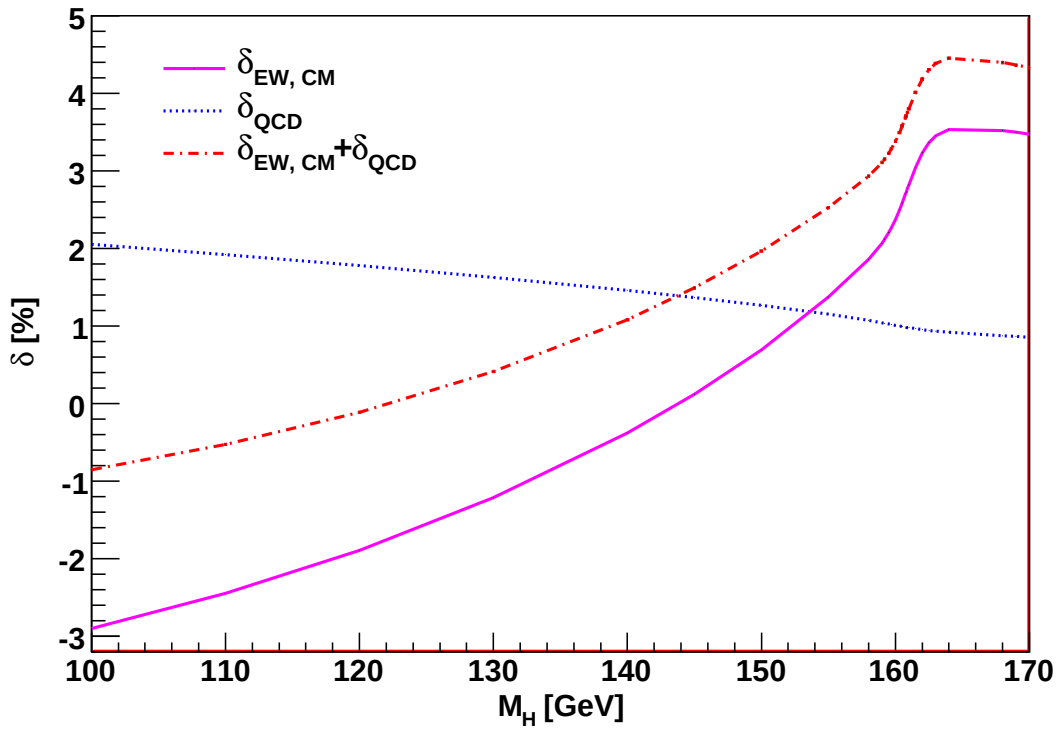
Result:
The hadronic process $pp \to H + X$

- Use Fortran program HiggsNNLO by M. Grazzini
- K-factor: Ratio cross section with higher orders over LO result



- Uncertainty band: Variation of μ_R, μ_F, PF, CF
- Central value for cross section is shifted by 2-5% ($M_H = 120$ GeV)

Result:
The decay $H \to \gamma\gamma$



- Cancellation between δ_{QCD} and δ_{EW} below threshold
- Around the threshold both positive leading to a sizable total correction of about 4.5%

Summary & Conclusion

- Gluon fusion ($gg \to H$) is the dominant production process for the Higgs boson at LHC
- The decay $H \to \gamma\gamma$ provides a clean environment for its discovery
- The two-loop electroweak corrections with complete dependence of all heavy particles(M_H, M_W, M_Z, M_t) have been computed:
- For $gg \to H$ the partonic cross section varies between

  $\delta \sim$-4% – 6% ($M_H = 100 - 500$ GeV)

  The had. cross section is shifted by +2%–5% ($M_H = 120$ GeV)
- For $H \to \gamma\gamma$ the relative corrections to the decay width are

  $\delta \sim$ -1% – 4.5% ($M_H = 100 - 170$ GeV)