PAUL SCHERRER INSTITUT

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Physik-Institut

NLO QCD corrections to Higgs boson pair production via gluon fusion

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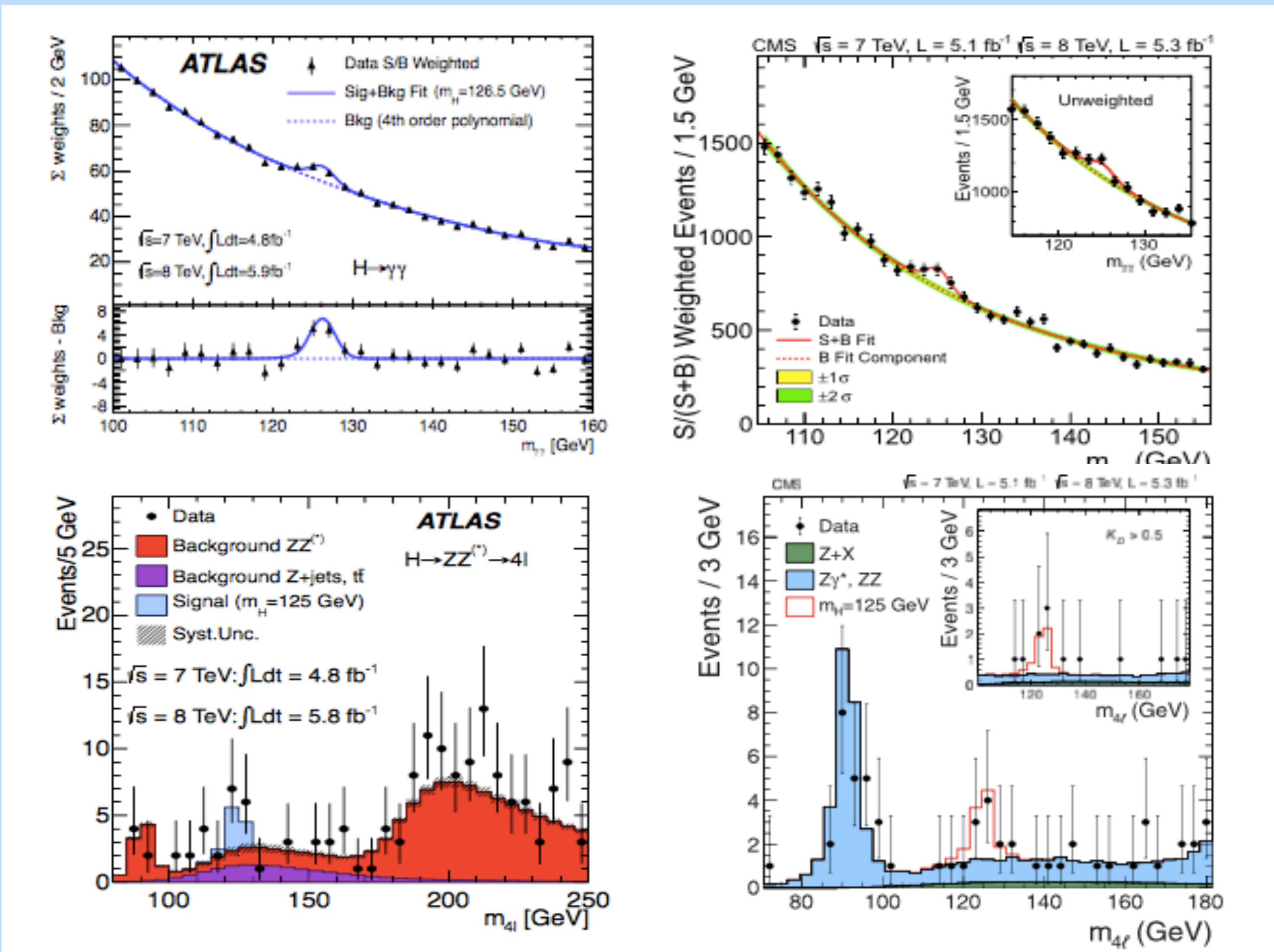
Outline

- Motivation
- Objective
- Previous work
- Project strategy
- Status / Outlook

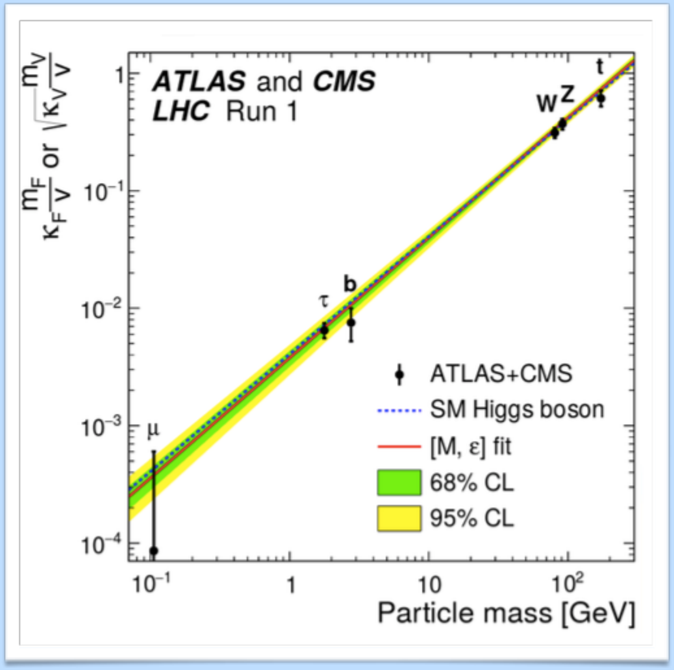
Motivation

Detection of a Higgs boson with a mass ~ 125 GeV



Motivation

- Further investigations of the properties of the detected particle for a unique association to a model
- Higgs mass, coupling strengths, spin and CP already determined
- self-coupling strength still unknown



$$V = \frac{\lambda}{2}\left(\phi^\dagger\phi - \frac{v^2}{2}\right)^2$$

$$\lambda = \frac{M_H^2}{2v^2}$$

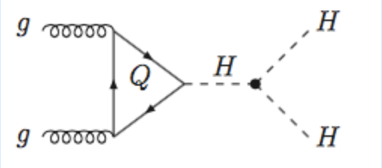
$$\lambda_{H^3} = 3\frac{M_H^2}{v}$$

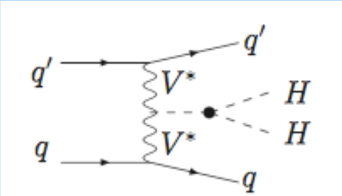
$$\lambda_{H^4} = 3\frac{M_H^2}{v^2}$$

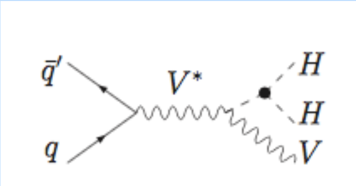
Motivation

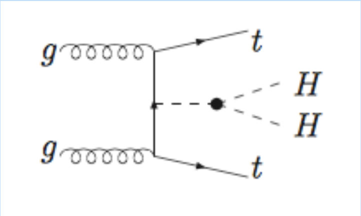
Higgs boson pair production

Production channel

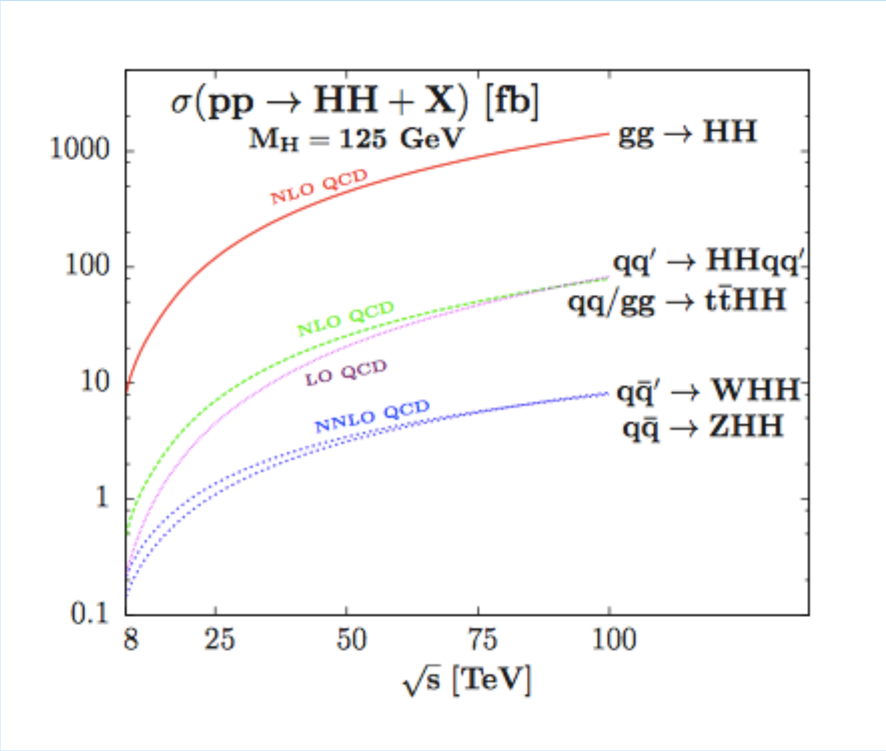








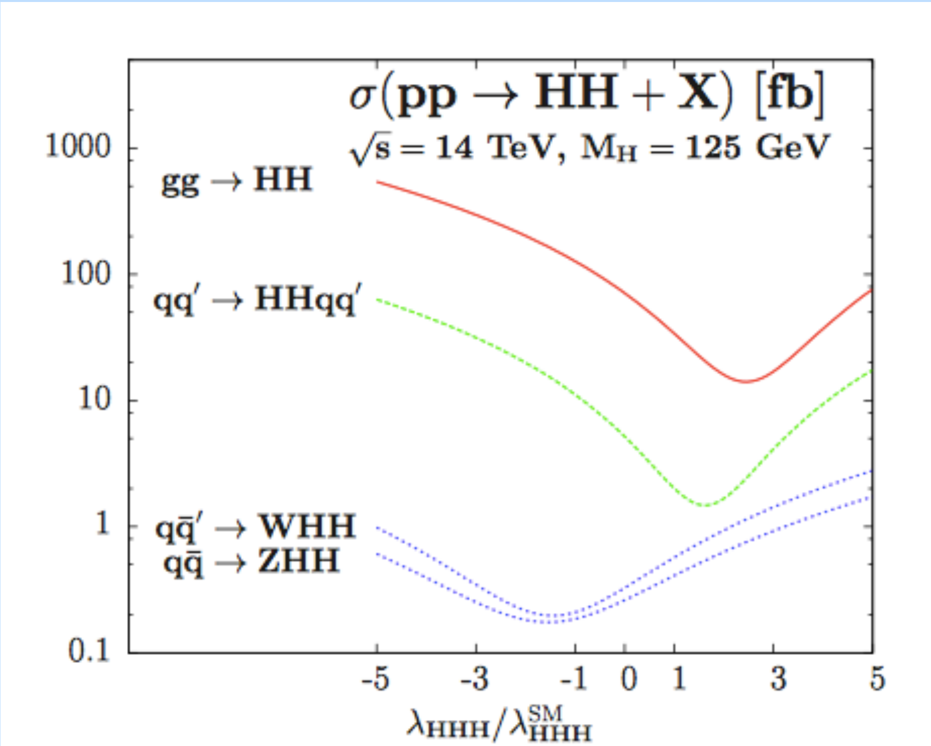
Cross section



Baglio, Djouadi, Gröber, Mühlleitner, Quevillon, Spira

Motivation

Uncertainties:



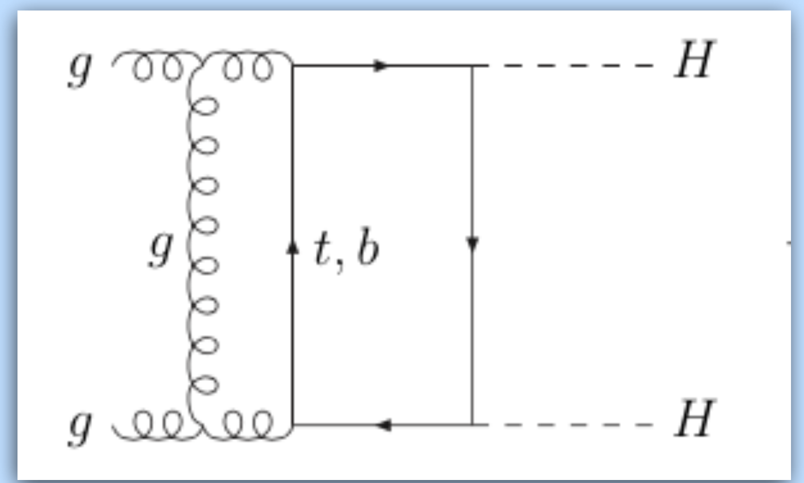
$$gg \to HH : \frac{\Delta\sigma}{\sigma} \sim -\frac{\Delta\lambda}{\lambda}$$

Baglio, Djouadi, Gröber,
Mühlleitner, Quevillon, Spira

Objective

Gluon fusion gg → HH: loop induced

Complete calculation of the NLO QCD corrections (2-loop) considering the top- und bottom mass dependences in the context of the Standard Model.



Previous work

- Virtual & real NLO QCD corrections in heavy top mass limit: ~100%

Dawson,Dittmaier,Spira
de Florian,Mazzitelli
Grigo,Melnikov,Steinhauser

- Heavy top mass expansion: ~ ±10%

$$\sigma = \sigma_0 + \frac{\sigma_1}{m_t^2} + \cdots + \frac{\sigma_4}{m_t^8}$$

Grigo, Hoff, Melnikov, Steinhauser

- NLO mass effects of the real NLO correction

  ~ -10 % mass effects

Frederix, Frixione, Hirschi, Maltoni, Mattelaer, Torrielli, Vryonidou, Zaro

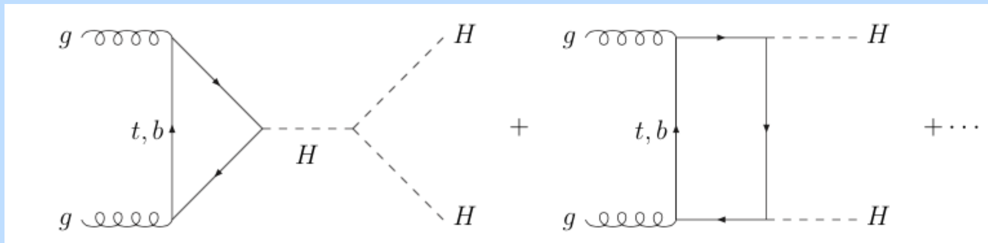
- NLO QCD corrections including the full top mass dependence

Borowka, Greiner, Heinrich, Jones, Kerner, Schlenk, Schubert, Zirke

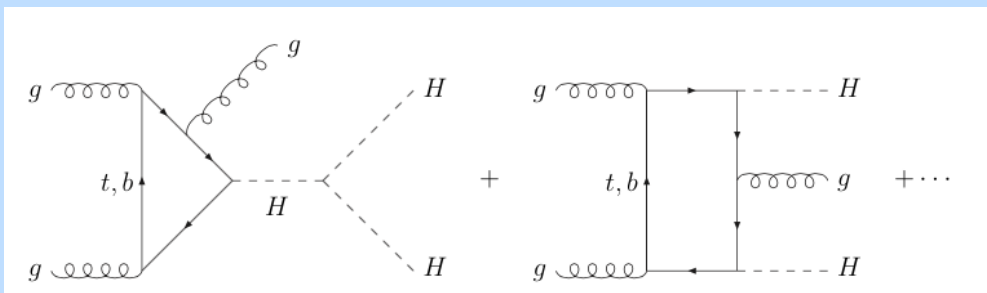
Project strategy

$$\sigma_{\rm NLO}(pp \to HH + X) = \sigma_{\rm LO} + \Delta\sigma_{\rm virt} + \Delta\sigma_{gg} + \Delta\sigma_{gq} + \Delta\sigma_{q\bar{q}},$$

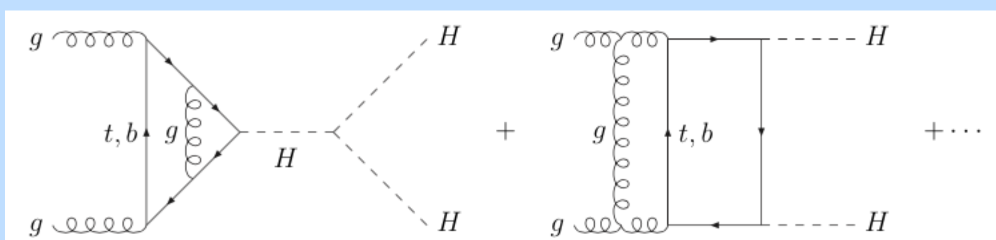
σ_{LO}:



$\Delta\sigma_{ij}$:



$\Delta\sigma_{virt}$:



Project strategy

$$\sigma_{\rm NLO}(pp \to HH + X) = \sigma_{\rm LO} + \Delta\sigma_{\rm virt} + \Delta\sigma_{gg} + \Delta\sigma_{gq} + \Delta\sigma_{q\bar{q}},$$

$$\sigma_{\rm LO} = \int_{\tau_0}^1 d\tau \, \frac{d\mathcal{L}^{gg}}{d\tau} \, \hat{\sigma}_{\rm LO}(Q^2 = \tau s)$$

$$\Delta\sigma_{\rm virt} = \frac{\alpha_s(\mu)}{\pi} \int_{\tau_0}^1 d\tau \, \frac{d\mathcal{L}^{gg}}{d\tau} \, \hat{\sigma}_{\rm LO}(Q^2 = \tau s) \; C$$

$$\Delta\sigma_{gg} = \frac{\alpha_s(\mu)}{\pi} \int_{\tau_0}^1 d\tau \, \frac{d\mathcal{L}^{gg}}{d\tau} \int_{\tau_0/\tau}^1 \frac{dz}{z} \, \hat{\sigma}_{\rm LO}(Q^2 = z\tau s) \left\{ -zP_{gg}(z) \log \frac{M^2}{\tau s} + d_{gg}(z) + 6[1 + z^4 + (1-z)^4] \left(\frac{\log(1-z)}{1-z} \right)_+ \right\}$$

$$\Delta\sigma_{gq} = \frac{\alpha_s(\mu)}{\pi} \int_{\tau_0}^1 d\tau \sum_{q,\bar{q}} \frac{d\mathcal{L}^{gq}}{d\tau} \int_{\tau_0/\tau}^1 \frac{dz}{z} \, \hat{\sigma}_{\rm LO}(Q^2 = z\tau s) \left\{ -\frac{z}{2} P_{gq}(z) \log \frac{M^2}{\tau s (1-z)^2} + d_{gq}(z) \right\}$$

$$\Delta\sigma_{q\bar{q}} = \frac{\alpha_s(\mu)}{\pi} \int_{\tau_0}^1 d\tau \sum_{q} \frac{d\mathcal{L}^{q\bar{q}}}{d\tau} \int_{\tau_0/\tau}^1 \frac{dz}{z} \, \hat{\sigma}_{\rm LO}(Q^2 = z\tau s) \; d_{q\bar{q}}(z)$$

$$C \to \pi^2 + \frac{11}{2} + C_{\triangle\triangle}, \qquad d_{gg} \to -\frac{11}{2}(1-z)^3, \qquad d_{gq} \to \frac{2}{3}z^2 - (1-z)^2, \qquad d_{q\bar{q}} \to \frac{32}{27}(1-z)^3$$

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Project strategy

- Associate the 47 double-box diagrams to similar topologies
- Produce matrix elements for all possible diagrams
- Use dimensionale regularisation: n = 4 – 2ε
- Perform Feynman parametrisation: 6-dimensional integrals

$$\frac{1}{A_1^{\alpha_1}\cdots A_n^{\alpha_n}} = \frac{\Gamma(\alpha_1+\ldots+\alpha_n)}{\Gamma(\alpha_1)\cdots\Gamma(\alpha_n)}\int_0^1 du_1 \int_0^{1-u_1} du_2 \cdots \int_0^{1-u_1-\ldots-u_{n-2}} du_{n-1} \frac{u_1^{\alpha_1-1}\cdots u_{n-1}^{\alpha_n-1}(1-u_1-\ldots-u_{n-1})^{\alpha_n-1}}{[u_1A_1+\ldots+u_{n-1}A_{n-1}+(1-u_1-\ldots-u_{n-1})A_n]^{\alpha_1+\ldots+\alpha_n}},$$

- Extraction of the ultraviolet divergences of the matrix element using endpoint subtraction of the 6-dimensional Feynman integrals

$$\int_0^1 dx\,\frac{f(x)}{(1-x)^{1-\epsilon}} = \int_0^1 dx\,\frac{f(1)}{(1-x)^{1-\epsilon}} + \int_0^1 dx\,\frac{f(x)-f(1)}{(1-x)^{1-\epsilon}}$$

$$= \frac{f(1)}{\epsilon} + \int_0^1 dx\,\frac{f(x)-f(1)}{1-x} + \mathcal{O}(\epsilon)$$

- Extraction of the infrared and collinear divergences using a proper subtraction of the integrand → followed by a semi-analytic integration of the singularities

Project strategy

- Integration by parts due to numerical instabilities at the threshold $M_{HH}^2 > 4m_Q^2 \Rightarrow m_Q^2 \rightarrow m_Q^2(1 - i\bar{\epsilon})\ mit\ \bar{\epsilon} << 1$

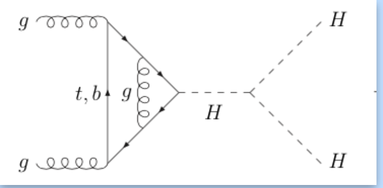
$$\int_0^1 dx \frac{f(x)}{(a+bx)^3} = \frac{f(0)}{2a^2} - \frac{f(1)}{2(a+b)^2} + \int_0^1 dx \frac{f'(x)}{2(a+bx)^2}$$

- Renormalisation of α_s ($\overline{MS}$, N_F=5) and m_t (on-shell)

$$\delta\sigma = \delta\alpha_s \frac{\delta\sigma_{LO}}{\delta\alpha_s} + \delta m_t \frac{\delta\sigma_{LO}}{\delta m_t}$$

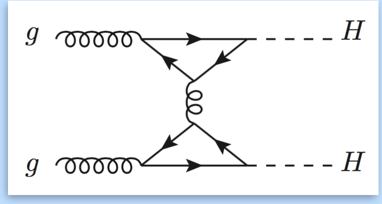
- Triangular diagrams

  ⟵ single Higgs case



- One-particle reducible diagrams

  ⟵ analytical results



- Real corrections: gg,qq ➞ HHg; gq ➞ HHq

  ⟵ in progress

Status / Outlook

- Numerical analysis
  → Production of differential cross section $\frac{d\sigma}{dQ^2}, \; (Q^2 = m_{HH}^2)$
  (results expected soon)

- Future: Extension of the calculation to BSM-Higgs scenarios (dim 6, 2HDM)

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