PAUL SCHERRER INSTITUT PSI

ISSUES IN SINGLE AND DOUBLE HIGGS PRODUCTION

Michael Spira (PSI)

I Introduction

II Single Higgs Boson Production

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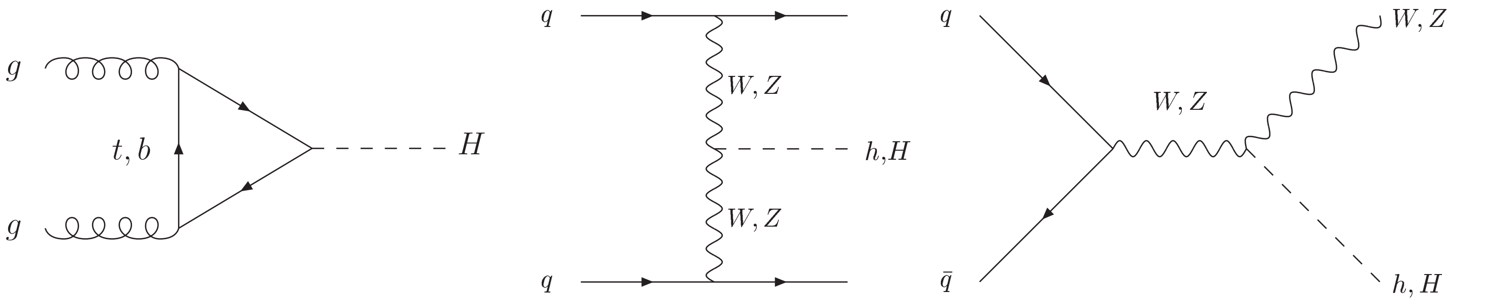
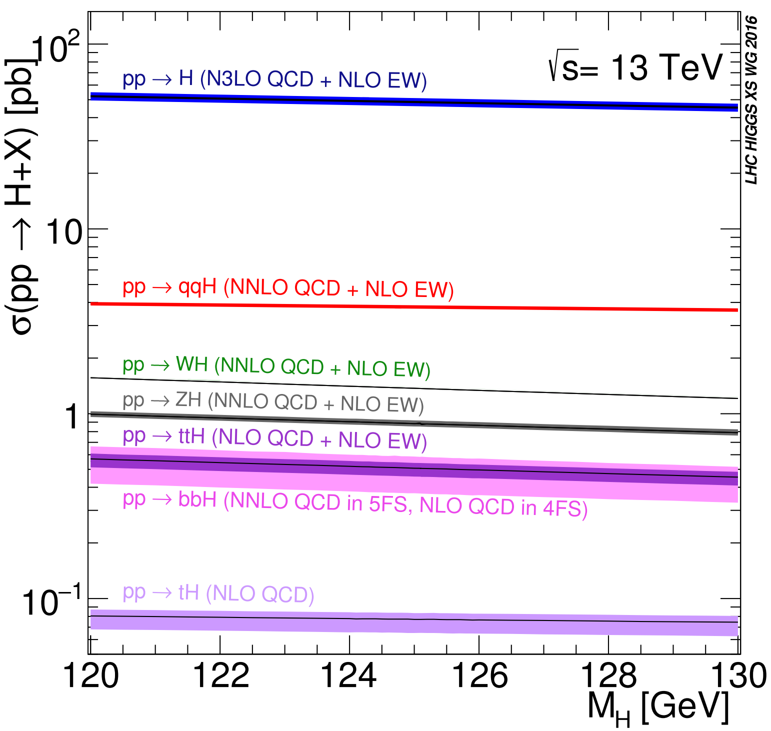
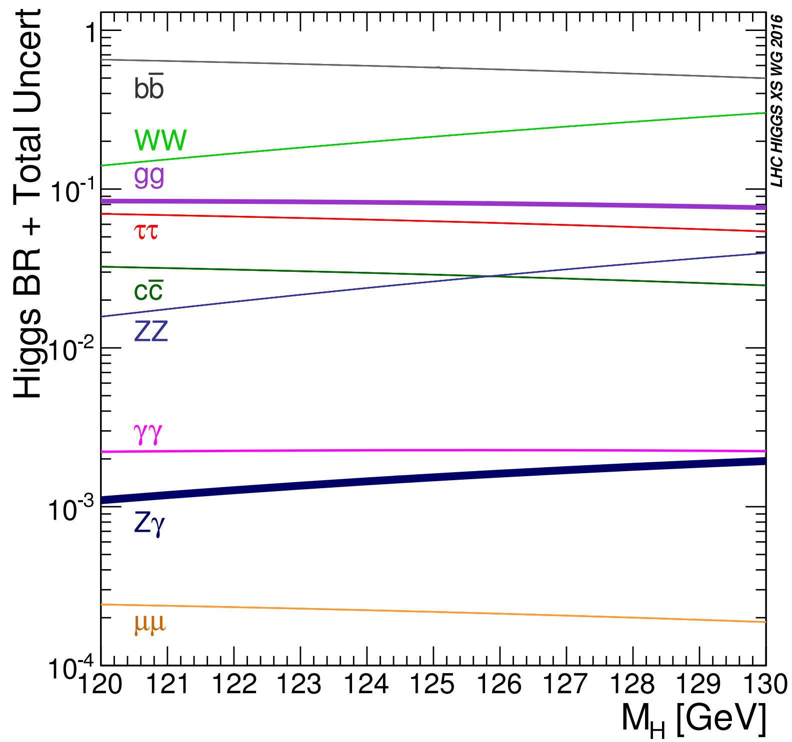
IV Conclusions

I INTRODUCTION

- Higgs Boson Production

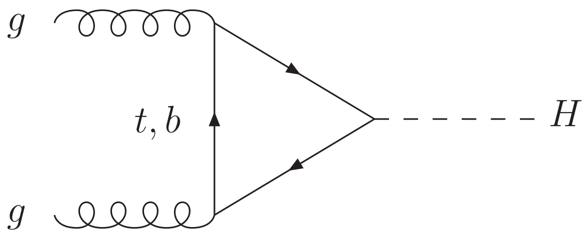






LHC Higgs XS WG

III SINGLE HIGGS BOSON PRODUCTION



Georgi,. . .

S., Djouadi, Graudenz, Zerwas
Dawson, Kauffman

- NLO QCD corrections: $\sim$ 100%

- NNLO calculated for $m_t \gg M_\phi \Rightarrow$ further increase by 20–30%
  [top mass effects small in SM]

Harlander, Kilgore
Anastasiou, Melnikov
Ravindran, Smith, van Neerven

Marzani, Ball, Del Duca, Forte, Vicini
Harlander, Ozeren
Pak, Rogal, Steinhauser
Czakon, Harlander, Klappert, Niggetied

- N^{3}LO for $m_t \gg M_\phi \quad \Rightarrow$ scale stabilization

scale dependence: $\Delta \lesssim 5\%$

Moch, Vogt
Ravindran
de Florian, Mazzitelli, Moch, Vogt
Anastasiou, Duhr, Dulat, Furlan, Gehrmann, Herzog, Mistlberger
Ball, Bonvini, Forte, Marzani, Ridolfi

- N^3LL soft gluon resummation: $\lesssim 1\%$

Catani, de Florian, Grazzini, Nason
Ravindran
Ahrens, Becher, Neubert, Yang
Ball, Bonvini, Forte, Marzani, Ridolfi
Bonvini, Marzani
Schmidt, S.

- impl. of $gg \to \phi$ in POWHEG including mass effects @ NLO (QCD also valid for 2HDM and other Higgs extensions)

Bagnaschi, Degrassi, Slavich, Vicini

- elw. corrections: $\sim 5\%$

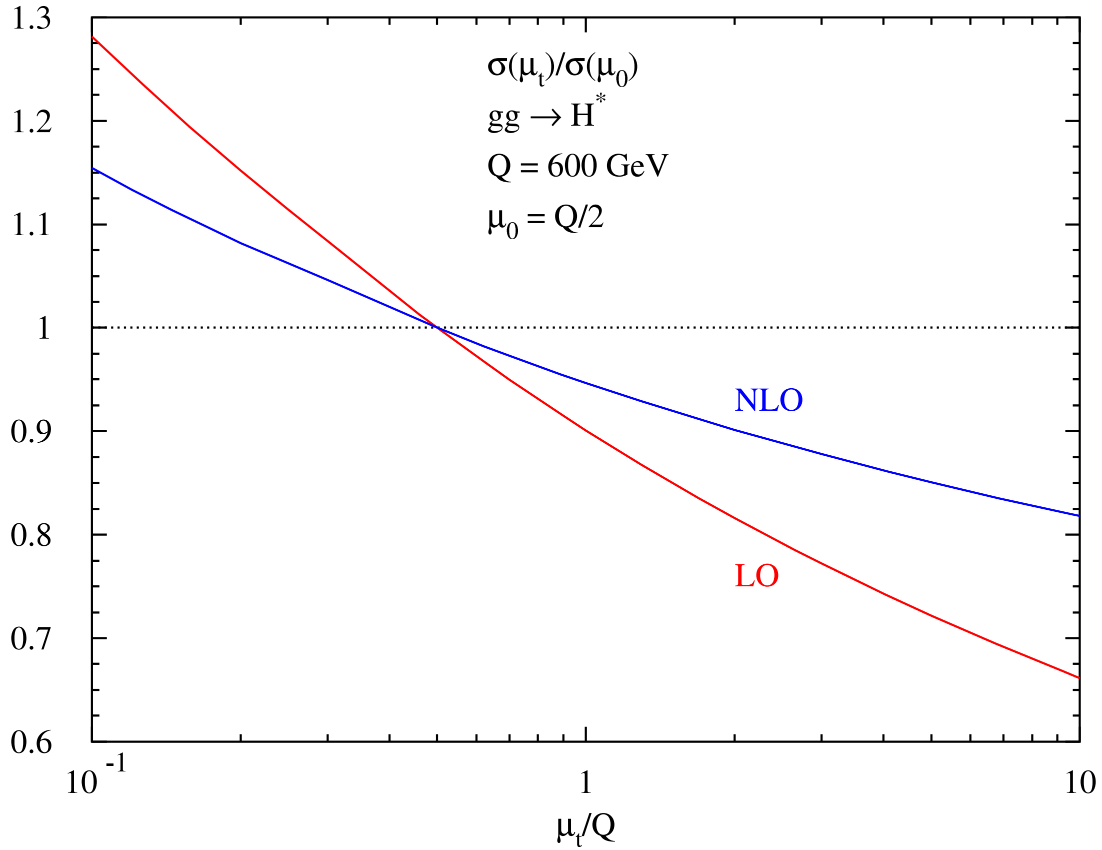
Aglietti,...
Degrassi, Maltoni
Actis, Passarino, Sturm, Uccirati

- $\sigma(gg \to H) = \left(54.72^{+4.3\%}_{-6.5\%}(TH) \pm 3.2\%(PDF, \alpha_s)\right)$ pb @ $\sqrt{s} = 14$ TeV

Anastasiou,...

- uncertainties: PDF+α_s, renormalization/factorization scale top/bottom masses: $\sim \pm 0.8\% \leftarrow$ scale/scheme dependence

$$\sigma(gg \to H)_{LO} = 18.43^{+0.8\%}_{-1.1\%}\ \text{pb} \qquad \sigma(gg \to H)^{QCD}_{NLO} = 42.17^{+0.4\%}_{-0.5\%}\ \text{pb}$$



Jones, S.

$$\sigma(gg \to H_{SM^*}) \equiv \sigma(gg \to H_{BSM})\Big|_{M_{H_{BSM}}=Q}$$

• m_t scheme/scale uncertainties only:

• LO:

$$\sigma(gg \to H^*)|_{Q=125\ \text{GeV}} = 18.43^{+0.8\%}_{-1.1\%}\ \text{pb}, \qquad \sigma(gg \to H^*)|_{Q=300\ \text{GeV}} = 4.88^{+23.1\%}_{-1.1\%}\ \text{pb}$$

$$\sigma(gg \to H^*)|_{Q=400\ \text{GeV}} = 4.94^{+1.2\%}_{-1.8\%}\ \text{pb}, \qquad \sigma(gg \to H^*)|_{Q=600\ \text{GeV}} = 1.13^{+0.0\%}_{-26.2\%}\ \text{pb}$$

$$\sigma(gg \to H^*)|_{Q=900\ \text{GeV}} = 0.139^{+0.0\%}_{-36.0\%}\ \text{pb}, \qquad \sigma(gg \to H^*)|_{Q=1200\ \text{GeV}} = 0.0249^{+0.0\%}_{-41.1\%}\ \text{pb}$$

• NLO QCD:

$$\sigma(gg \to H^*)|_{Q=125\ \text{GeV}} = 42.17^{+0.4\%}_{-0.5\%}\ \text{pb}, \qquad \sigma(gg \to H^*)|_{Q=300\ \text{GeV}} = 9.85^{+7.5\%}_{-0.3\%}\ \text{pb}$$

$$\sigma(gg \to H^*)|_{Q=400\ \text{GeV}} = 9.43^{+0.1\%}_{-0.9\%}\ \text{pb}, \qquad \sigma(gg \to H^*)|_{Q=600\ \text{GeV}} = 1.97^{+0.0\%}_{-15.9\%}\ \text{pb}$$

$$\sigma(gg \to H^*)|_{Q=900\ \text{GeV}} = 0.230^{+0.0\%}_{-22.3\%}\ \text{pb}, \qquad \sigma(gg \to H^*)|_{Q=1200\ \text{GeV}} = 0.0402^{+0.0\%}_{-26.0\%}\ \text{pb}$$

$\Rightarrow$ limited sensitivity to interference effects!

$$\sigma = \sigma_{H_1} + \Delta\sigma_{int} + \sigma_{H_2}$$

[BTW: very difficult to determine charm Yukawa coupl. from charm loops in p_{TH} distribution $(H + j)$]

Bishara, Haisch, Monni, Re

- different radiative corrections to top and bottom loops [pole masses]:

$$\begin{aligned}\sigma(gg \to H) &= \sigma_{tt} + \sigma_{tb} + \sigma_{bb} \\ K_{tt} &\sim 1.68 \\ K_{tb} &\sim 0.97 \\ K_{bb} &\sim 1.20\end{aligned}$$

$\Rightarrow$ up to $20-30\%$ differences in NLO cxn [m_b: scheme/scale dep.?]
$\Rightarrow$ not possible to use SM-like cxns in many BSM cases
for different weighting of top and bottom loops
[enhancement of bottom loops (e.g. 2HDM type II, MSSM,. . .)]

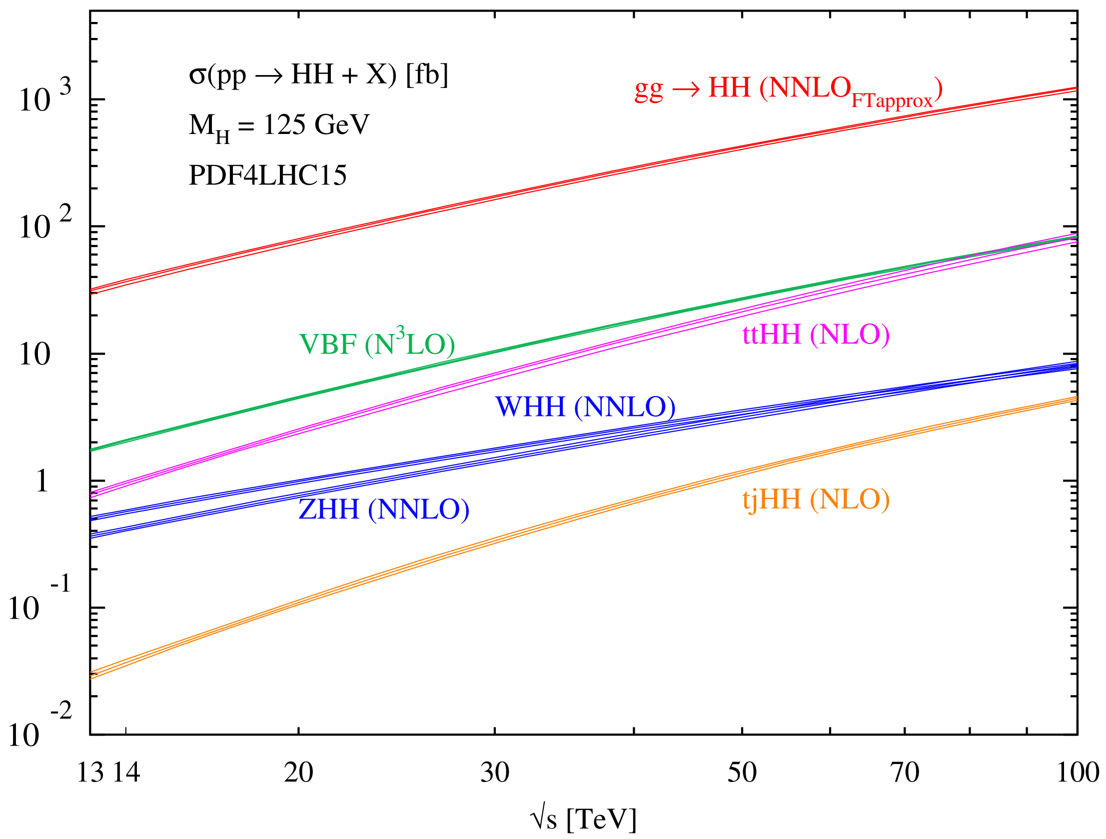
- bottom-loop dominance: full NLO 20% uncertainties $\leftarrow$ double logs

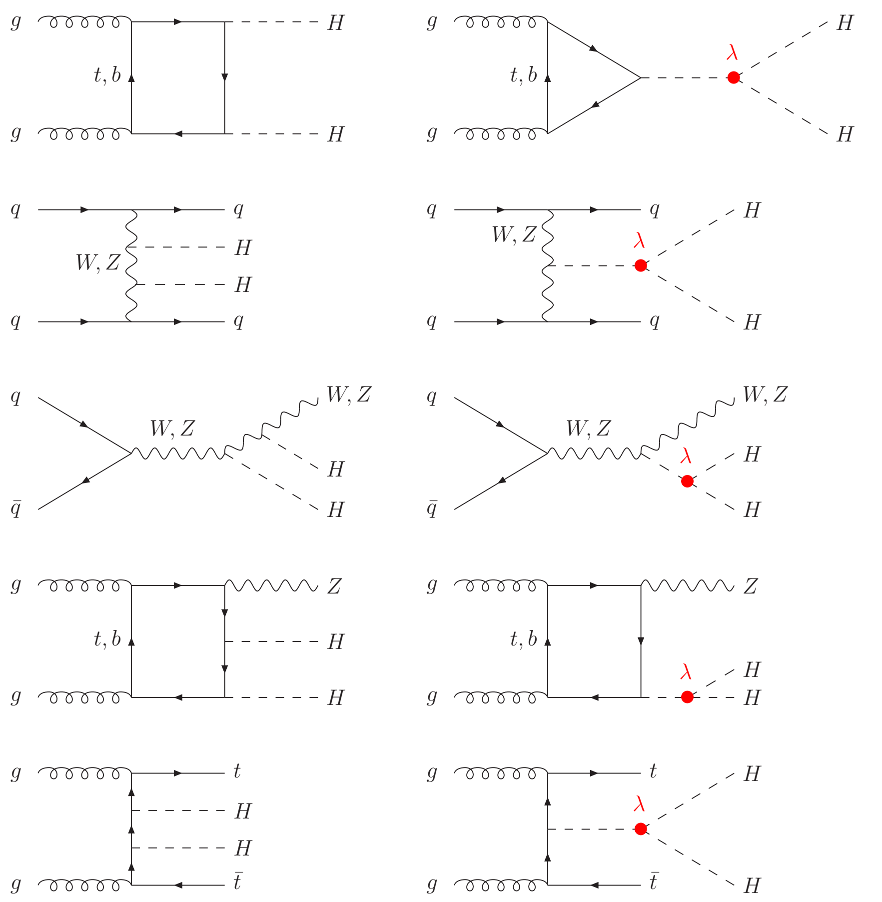
- can only use N^{3}LO results for σ_{tt}
$\Rightarrow$ individual grids [(pseudo)scalar] for $\sigma_{tt}, \sigma_{tb}, \sigma_{bb}$ [$\leftarrow \sigma_{BSM}$?]

- BSM heavy: eff. ggH coupl. c_g $\to$ interf. with full top/bottom loops!

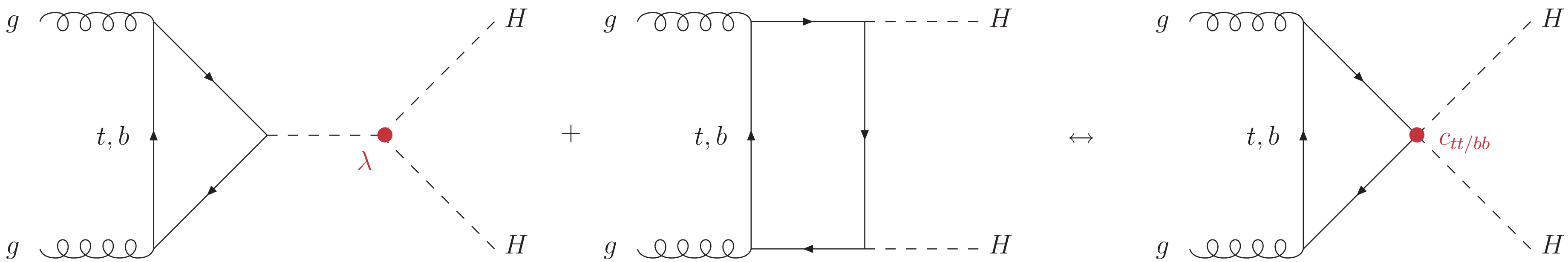
$$\sigma(gg \to H) = \underbrace{\sigma_{c_g c_g} + \sigma_{tt}}_{\sim N^3LO} \underbrace{+ \sigma_{tb} + \sigma_{bb}}_{NLO} \underbrace{+ \sigma_{c_g t}}_{\sim N^3LO} \underbrace{+ \sigma_{c_g b}}_{NLO} \qquad \left[\mathcal{L}_{BSM} = c_g \; G^{a\mu\nu} G^a_{\mu\nu} H\right]$$

III *DOUBLE HIGGS BOSON PRODUCTION*



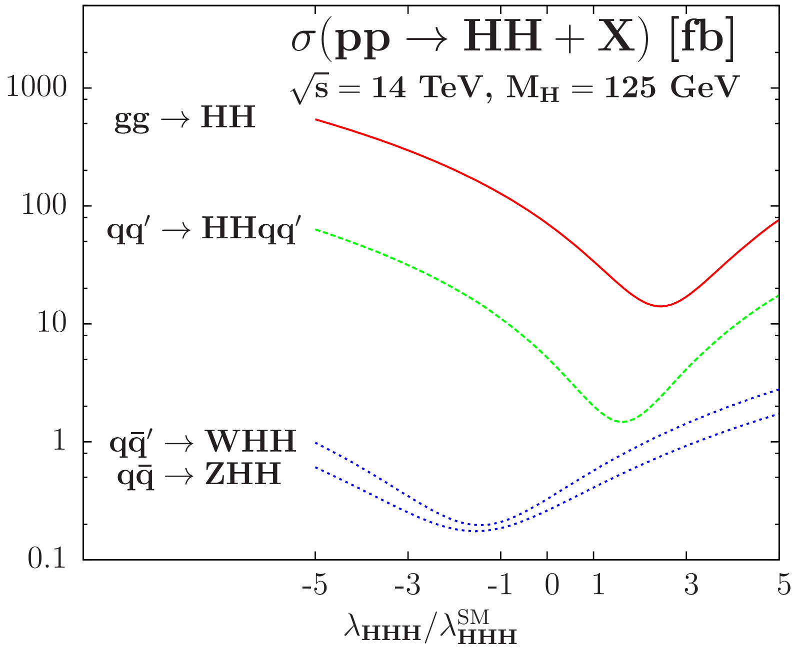


HH White Paper



- threshold region: sensitive to λ

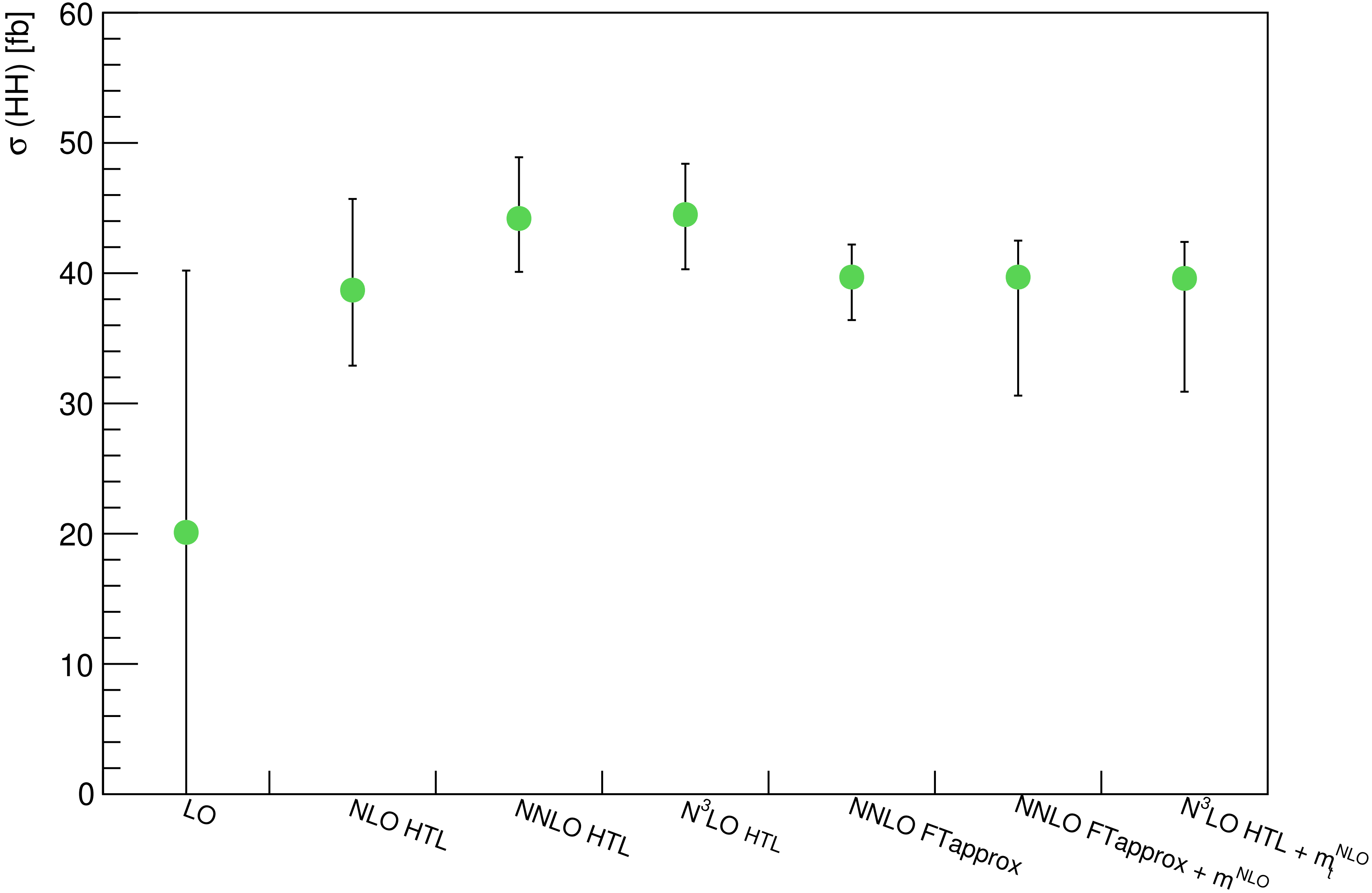
  large M_{HH}: sensitive to $c_{tt/bb}$ [e.g. boosted Higgs pairs]



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

[decreasing with M_{HH}^2]

Baglio, Djouadi, Gröber, Mühlleitner, Quevillon, S.



σ (HH) [fb]
60
50
40
30
20
10
0
LO
NLO HTL
NNLO HTL
N3LO HTL
NNLO FTapprox
NNLO FTapprox + mt NLO
N3LO HTL + mt NLO

uncertainties due to m_t

- use m_t, $\overline{m}_t(\overline{m}_t)$ and scan $Q/4 < \mu < Q$ $\rightarrow$ uncertainty = envelope:

$$\frac{d\sigma(gg \to HH)}{dQ}\Big|_{Q=300\text{ GeV}} = 0.02978(7)^{+6\%}_{-34\%}\text{ fb/GeV},$$

$$\frac{d\sigma(gg \to HH)}{dQ}\Big|_{Q=400\text{ GeV}} = 0.1609(4)^{+0\%}_{-13\%}\text{ fb/GeV},$$

$$\frac{d\sigma(gg \to HH)}{dQ}\Big|_{Q=600\text{ GeV}} = 0.03204(9)^{+0\%}_{-30\%}\text{ fb/GeV},$$

$$\frac{d\sigma(gg \to HH)}{dQ}\Big|_{Q=1200\text{ GeV}} = 0.000435(4)^{+0\%}_{-35\%}\text{ fb/GeV}$$

- bin-by-bin interpolation:

$$\sigma(gg \to HH) = 32.81^{+4\%}_{-18\%}\text{ fb}$$

Baglio, Campanario, Glaus, Mühlleitner, S., Streicher final combined ren./fac. scale and m_t scale/scheme unc. @ NNLO$_{FTapprox}$:

$$\sqrt{s} = 13 \text{ TeV}: \quad \sigma_{tot} = 31.05^{+6\%}_{-23\%} \text{ fb}$$

$$\sqrt{s} = 14 \text{ TeV}: \quad \sigma_{tot} = 36.69^{+6\%}_{-23\%} \text{ fb}$$

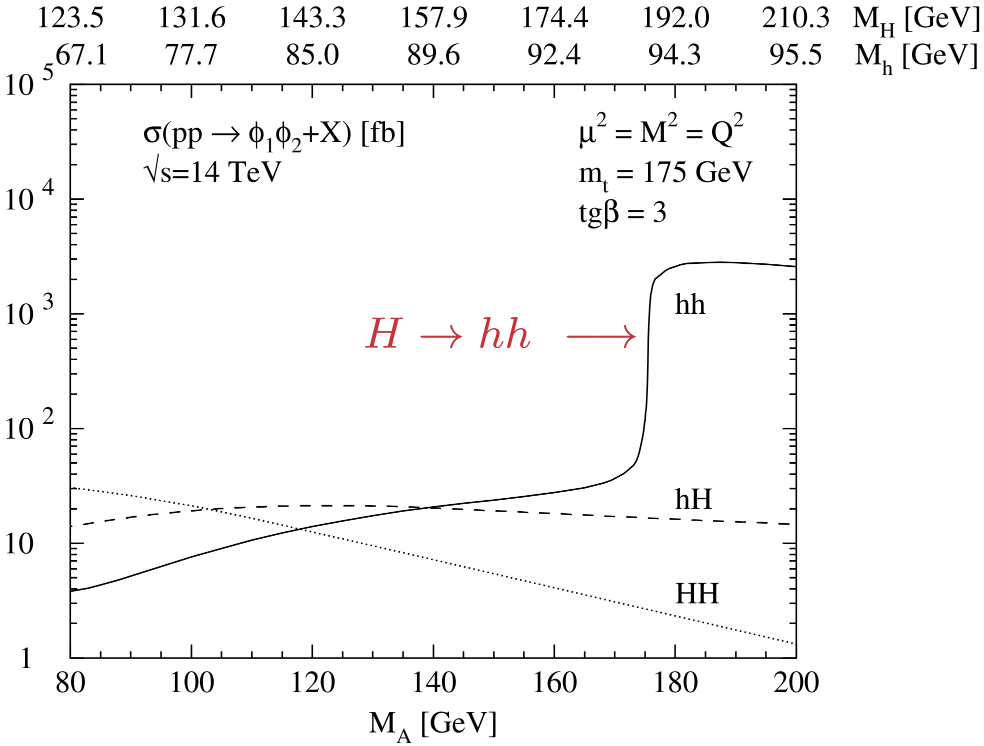
- similar uncertainties for other Higgs masses expected

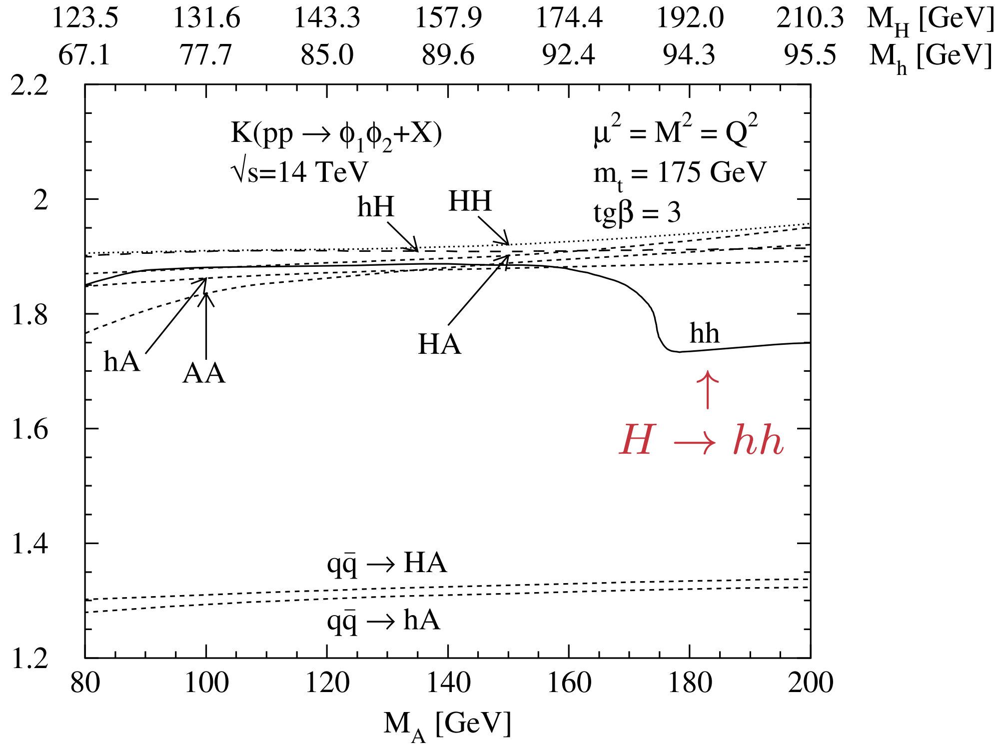
$$\begin{aligned} \sigma(gg \to HH) &= \sigma_{tt} + \sigma_{tb} + \sigma_{bb} \\ K_{tt} &\sim 1.7 \text{ (incl. } m_t \text{ effects, } \mu = Q/2) \\ K_{tb} &\sim ??? \\ K_{bb} &\sim ??? \end{aligned}$$

[grid in M_H?]

⇒ sizeable uncerts. that affect extraction of BSM/int. contributions

$$\sigma = \sigma_{h^{(*)} \to H_1 H_2} + \Delta\sigma_{int} + \sigma_{H^{(*)} \to H_1 H_2} + \sigma_{\Box\Box} + \sigma_{\triangle\Box} + \cdots$$





Dawson, Dittmaier, S. ('98)

IV CONCLUSIONS

• Higgs boson searches/studies at LHC belong to major endeavours

• scale and scheme uncertainties due to m_t relevant for large momenta ($M_H, M_{HH}, p_{TH}, \ldots$)

• significant uncertainties for single and double Higgs production

• different corrections and uncertainties for top- and bottom-loop contributions

$\Rightarrow$ difficult to extract BSM from SM effects and interference terms in pure BSM scenarios quantitatively

$\leftarrow$ more work needed. . .

BACKUP SLIDES