SM Predictions for HH Production

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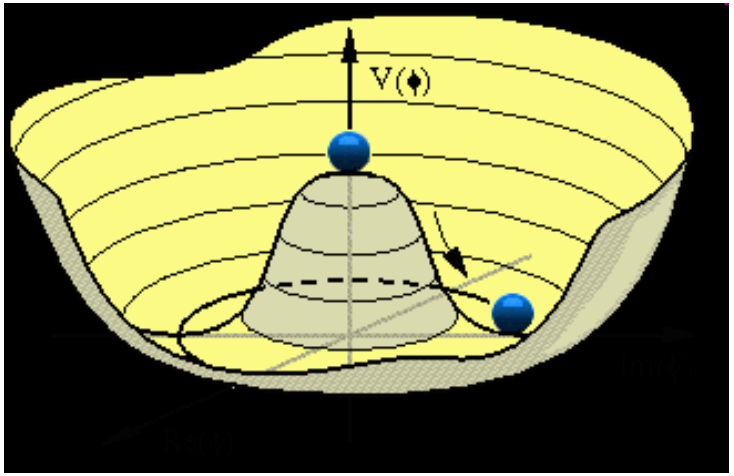
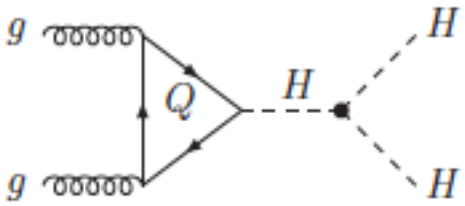
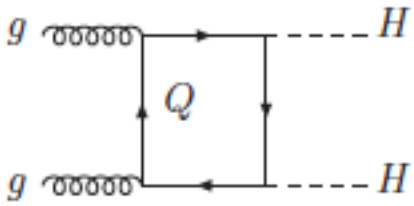


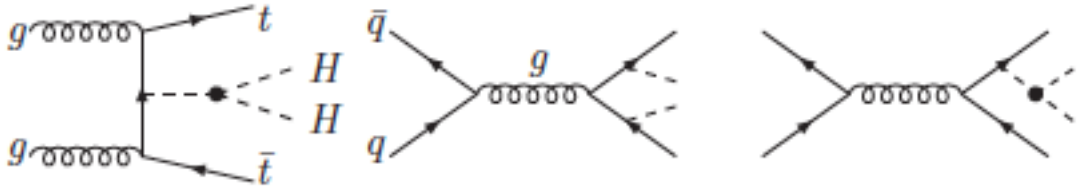
General Assembly Meeting
of LHCXSWG

Production of HH

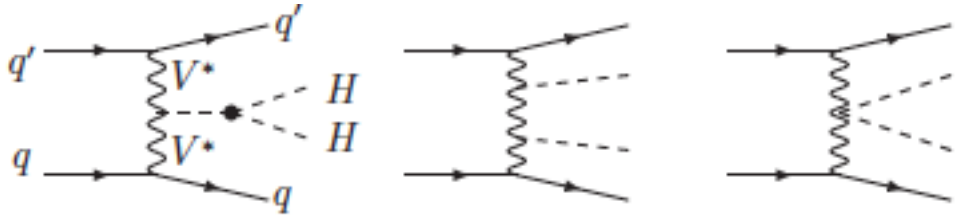




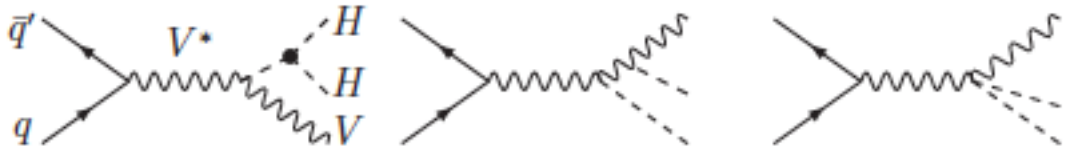
Sensitive to heavy colored particles (eg stops or top partners)



Sensitive to anomalous top-Higgs couplings



Sensitive to anomalous VVHH couplings



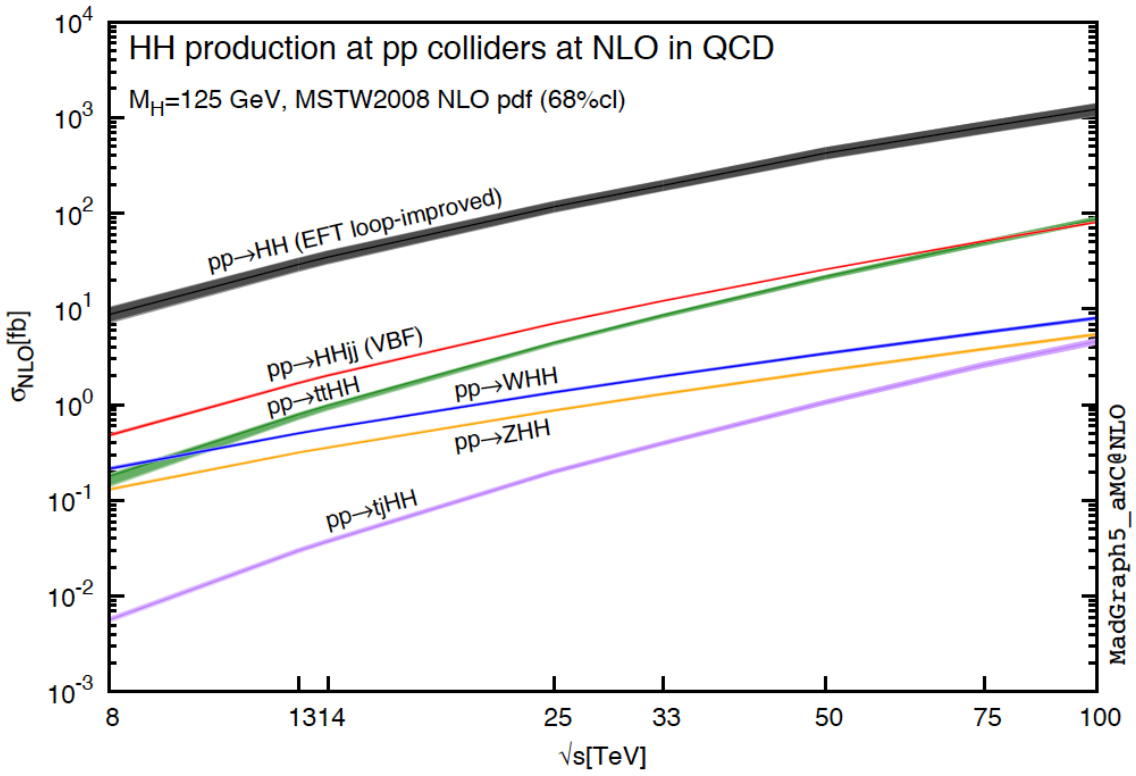
HH Production Probes Scalar Potential

$$V = -\frac{M_H^2}{2} H^2 + \lambda_3 H^3 + \lambda_4 H^4$$

- HHH and HHHH couplings prediction of theory
- They are perturbative $\lambda_3 = \frac{M_H^2}{2v} \sim .13v$ $\lambda_4 = \frac{M_H^2}{8v^2}$
- Calculations sensible
- In general EFT: $V = \Sigma_n \frac{c_n}{\Lambda^{2n}} \left(\Phi^\dagger \Phi - \frac{v^2}{2} \right)^{2+n}$

Corrections to relationship between λ_3 and λ_4 of $O(1/\Lambda^2)$ (assuming no new light particles)

Small Rates



[Frederix et al, arXiv:1401.7440, Baglio et al, arXiv:1215.5581]

Double Higgs Production from Gluon Fusion

- Sensitive to HHH coupling, $\lambda_3 = 3\ M_H^2/M_Z^2$
- Sensitive to new physics in loops
- New tensor structure compared to single Higgs production

$$A^{\mu\nu} = g^{\mu\nu} - \frac{p_1^\nu p_2^\mu}{p_1 \cdot p_2}$$

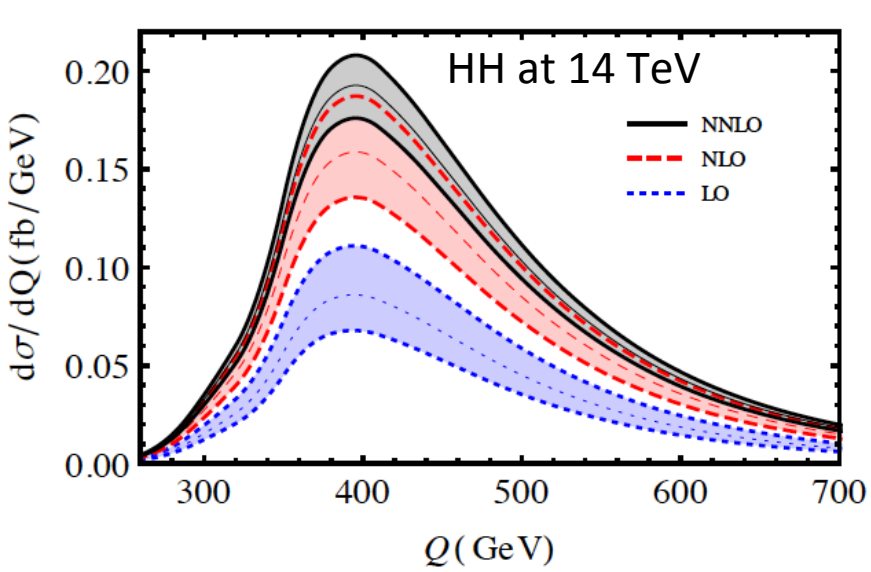
$$B^{\mu\nu} = g^{\mu\nu} + \frac{2}{p_T^2 s}\left(M_H^2 p_1^\nu p_2^\mu - 2p_1 \cdot p_2 p_2^\mu p_3^\nu - 2p_3 \cdot p_2 p_3^\mu p_1^\nu + 2p_1 \cdot p_2 p_3^\mu p_3^\nu\right)$$

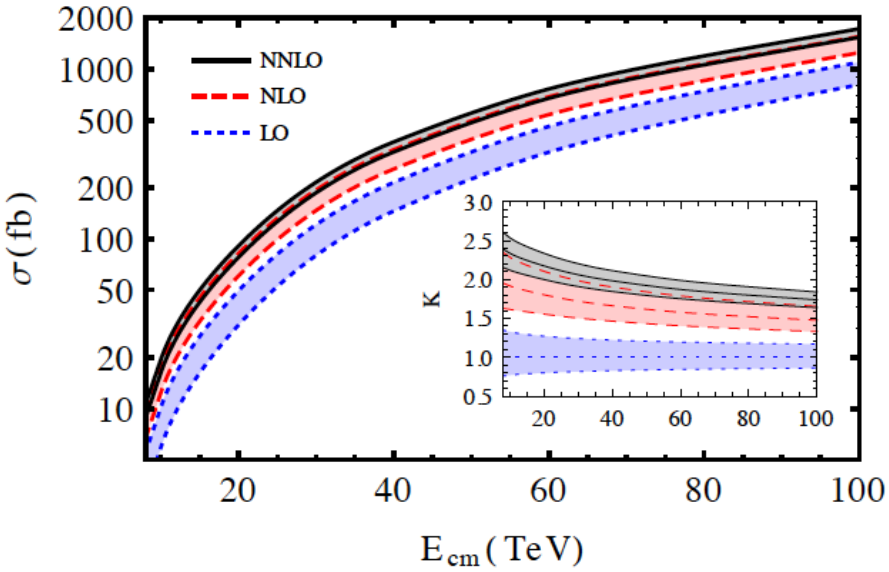
Destructive interference

Very Small Rate

- QCD corrections known to NLO and NNLO
  - NLO increases rate by factor of ~2
  - NNLO increases rate another 20%

BIG ASSUMPTION: Compute K factor in $m_t \rightarrow \infty$ limit, then rescale exact LO cross section by K factor



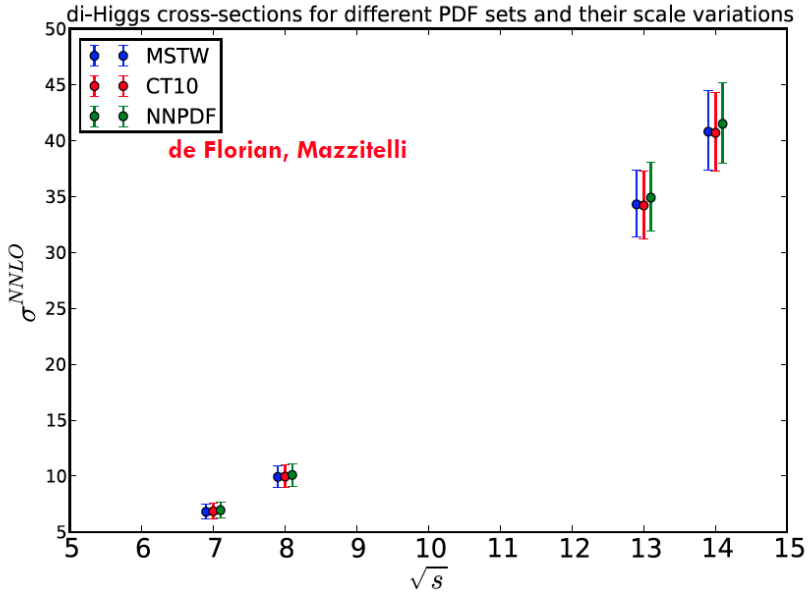


NNLO: deFlorian, Mazzitelli, arXiv:1309.6594

NLO: Dawson, Dittmaier, Spira, hep-ph/9805244

Preliminary Recommendations on total rate

- Compute NNLO K factor for total rate in $m_t \rightarrow \infty$ limit
- Scale by exact LO Results
- Central value is CTEQ 10 with dynamic scale=m_{HH}
- For now: PDF uncertainty is envelope of PDF sets and is ±2%
- For now: top mass effect uncertainty ±10%



Preliminary Recommendations for gg→ HH

NNLO σ in fb with CTEQ10

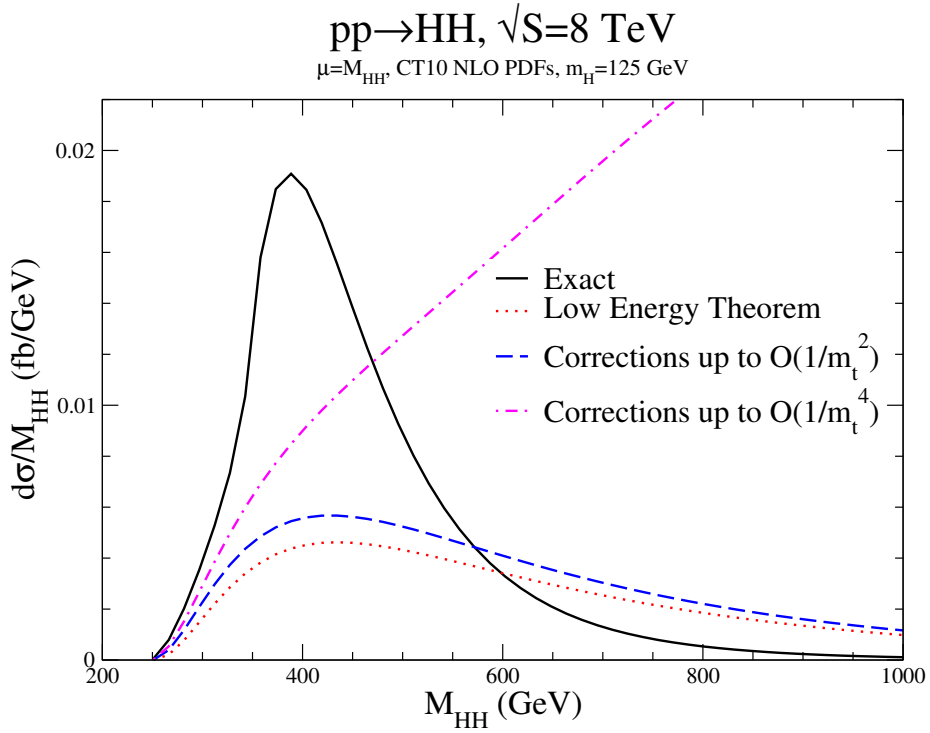
Scale	$\sqrt{s}$			
	7	8	13	14
$\mu = m_{HH}/2$	7.52	10.9	37.2	44.1
$\mu = m_{HH}$	**6.85**	**9.96**	**34.3**	**40.7**
$\mu = 2m_{HH}$	6.12	8.94	31.1	37.1
"+" [%]	**10%**	**9%**	**8%**	**8%**
"-" [%]	**11%**	**10%**	**9%**	**9%**

Scale uncertainty

Thanks to Mazzitelli and Grazzini for numbers

Distributions not well described by $1/m_t^2$ expansion

- Adding more terms doesn't improve convergence
- LO:



In a 2➔ 2 process, there are terms which grow like s/m_t^2, etc.

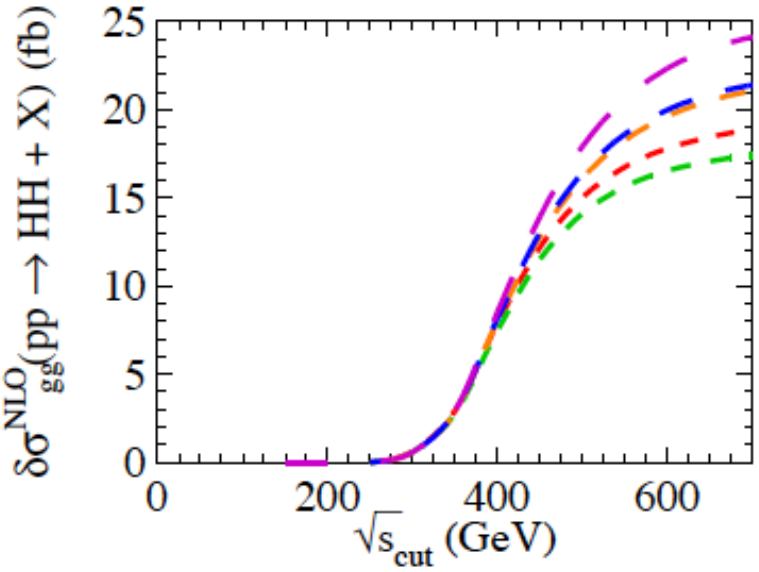
Advances/Improvements

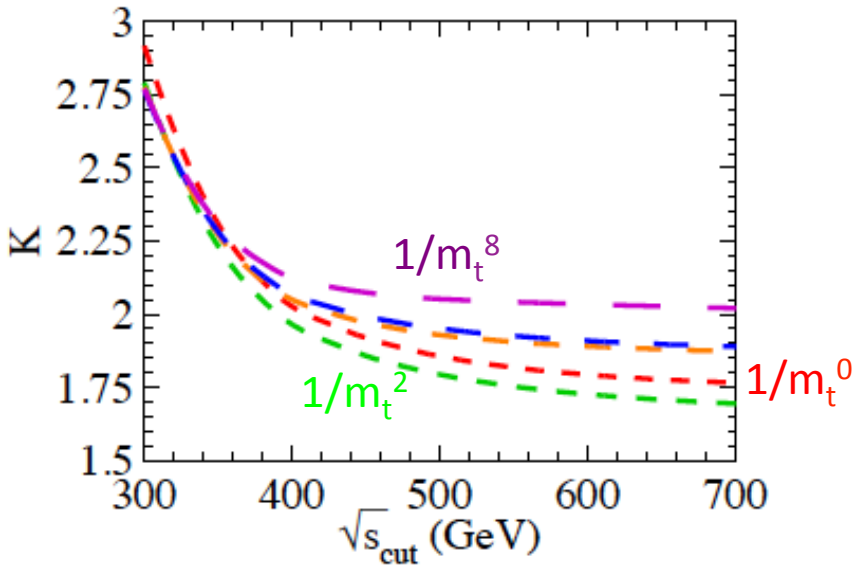
- HOW BIG ARE $1/m_t^2$ CORRECTIONS?
- Compute NLO with virtual corrections in $m_t \rightarrow \infty$ limit and real corrections with exact m_t dependence (improved HEFT)
- Compute $1/m_t^2$ corrections to NLO and normalize to exact LO
- Different results from 2 approaches

$1/m_t^2$ corrections at NLO: Grigo,Hoff, Melnikov, Steinhauser, arXiv:1305.7340
HEFT: Maltoni, Vryonidou, Zaro, arXiv: 1408.6542; Frederix et al, arXiv:1401.7340

NLO with $1/m_t^2$ corrections

- Poor convergence of $1/m_t^2$ expansion
- Impose cut on partonic energy, $\sqrt{s}_{cut}$ ($=m_{HH}$ at LO)





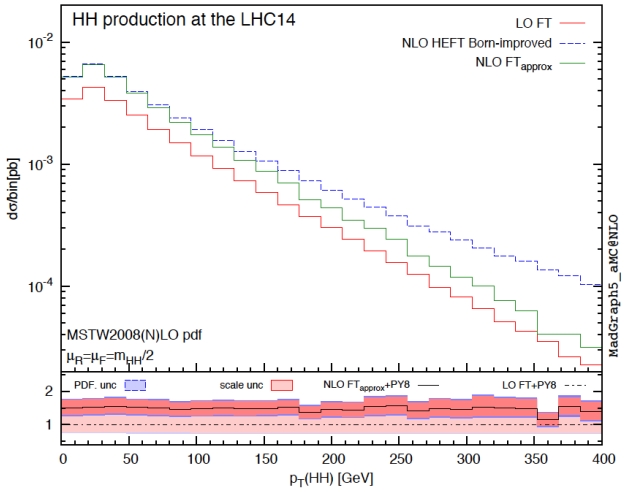
Mass corrections give O(10%) increase to NLO rate

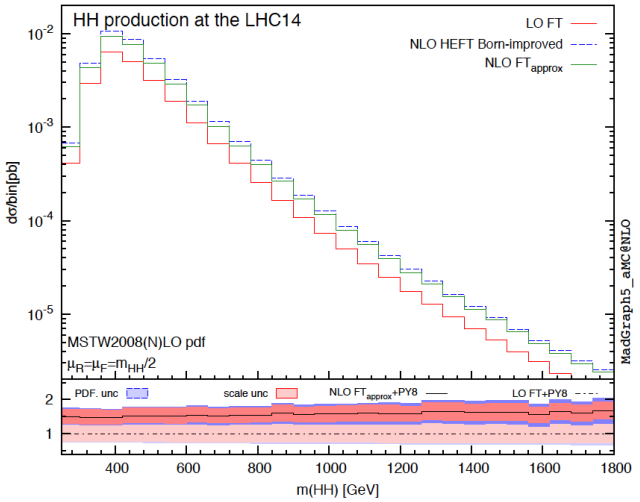
$1/m_t^2$ corrections at NLO: Grigo,Hoff, Melnikov, Steinhauser, arXiv:1305.7340

NLO FT_{approx}

- Include m_t in Born and in real contributions at NLO
- Only approximation is in 2-loop virtual contributions

11% decrease from result obtained rescaling mt➔∞ NLO K factor by exact LO





[Maltoni, Vryonidou, Zaro, arXiv: 1408.6542]

SM HH Theory Jobs

- Update PDF uncertainties with PDF4LHC recommendation
- Better understanding of $1/m_t$ effects?
  - May not be possible without full 2-loop calculation
- Characterize differential cross section
  - What is best way to extract information on EFTs?
- Are processes besides gluon fusion useful?