On the analytic two-loop corrections to double Higgs production in the SM

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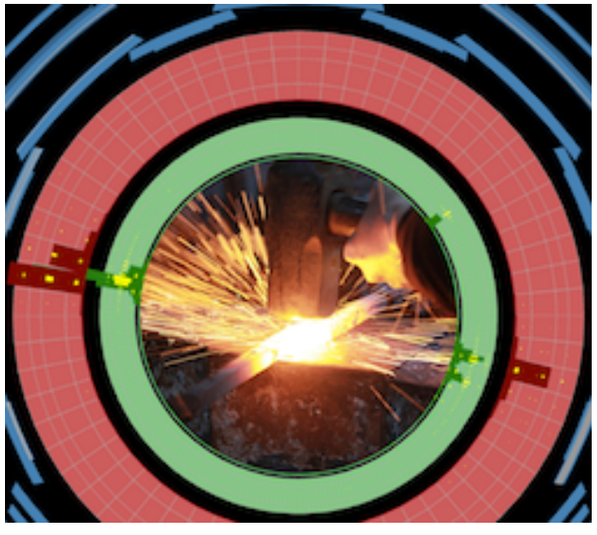

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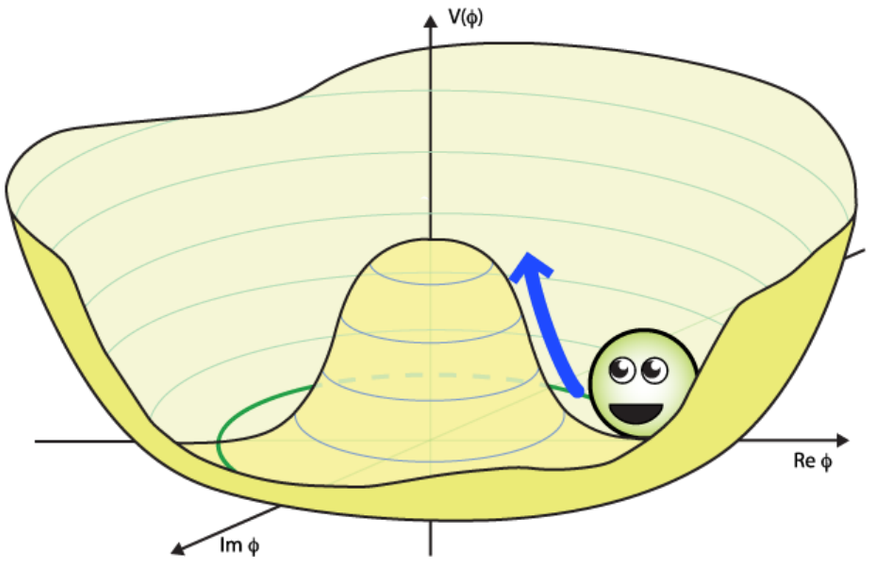
Partially based on arXiv:1603.00385, G. Degrassi, P.P.G., R. Gröber

Framework



quantumdiaries.com

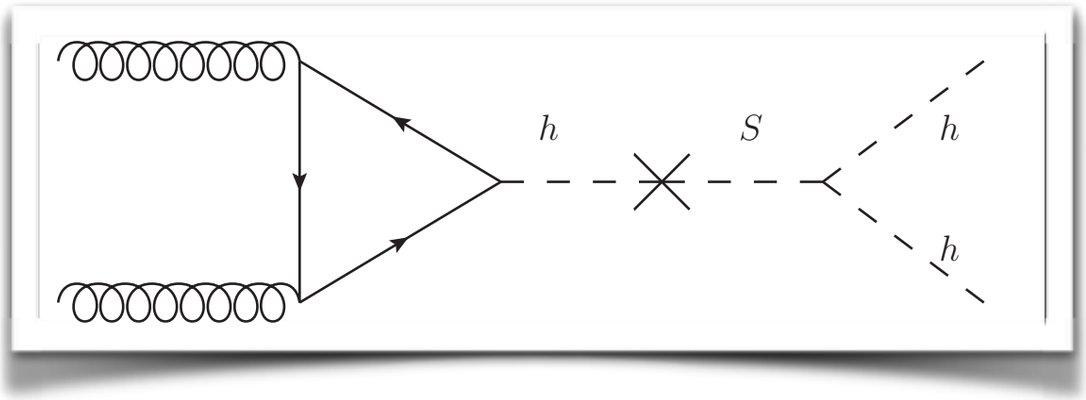
$$V(\phi) = -\mu^2 \phi^\dagger \phi + \lambda (\phi^\dagger \phi)^2$$

$$V(h) = \frac{1}{2} M_h^2 h^2 + \frac{M_h^2}{2v} h^3 + \frac{M_h^2}{8v^2} h^4$$

- In the SM the self coupling is fixed once the h-mass and the vev are known.
- Trilinear coupling *could* be measured at LHC from Higgs Pair Production.
- The quartic coupling will not be measured at LHC nor at ILC/CLIC.

New Physics

In general new physics affects the trilinear Higgs coupling:



- New Higgs bosons (e.g. 2HDM).
- New Particles in Loops (e.g. Susy).
- Modified couplings (e.g. Composite).

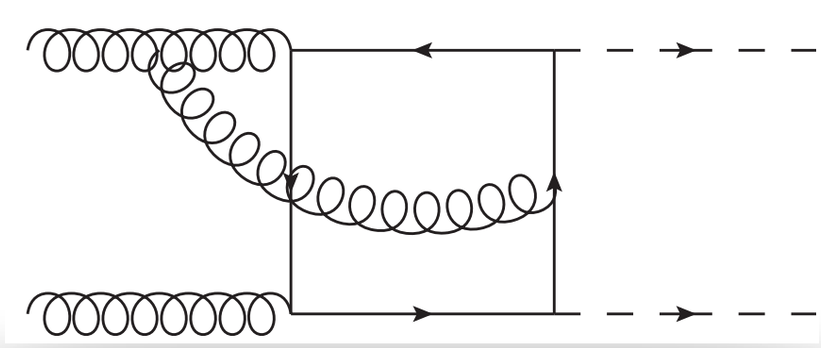
Adding a single scalar also would do the job.

$$V(\phi, S) = -\mu^2(\phi^\dagger\phi) + \lambda(\phi^\dagger\phi)^2$$
$$-m^2 S^2 + k_S(\phi^\dagger\phi)S^2 + \lambda_S S^4$$

NLO

- From $gg \to hh$ we can obtain information on NP.
- We need a calculation of the NLO corrections.
- NLO corrections are “large”.

- Large number of Amplitudes!
- Very complicated Integrals!



Programs like FIRE or REDUZE can solve the first problem.

Numerical approach

Borowka, Greiner, Heinrich, Jones, Kerner, Schlenk,
Schubert and Zirke, arXiv: 1604.06447

$$\sigma^{NLO} = 32.80^{+13\%}_{-12\%}\text{fb} \pm 0.4\%(\text{stat.}) \pm 0.1\%\text{int.}$$

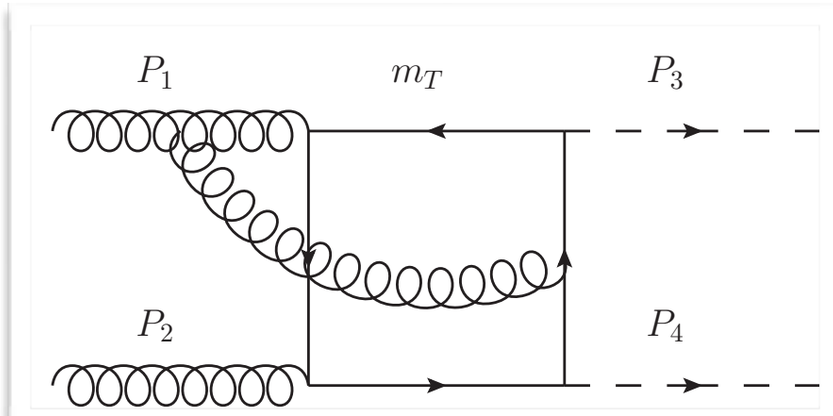
- Total cross section including the full top-quark dependence.
- 16 dual NVIDIA Tesla K20X GPGPU nodes.
- 4680 GPGPU hours.
- 665 phase space points.

Analytical approach

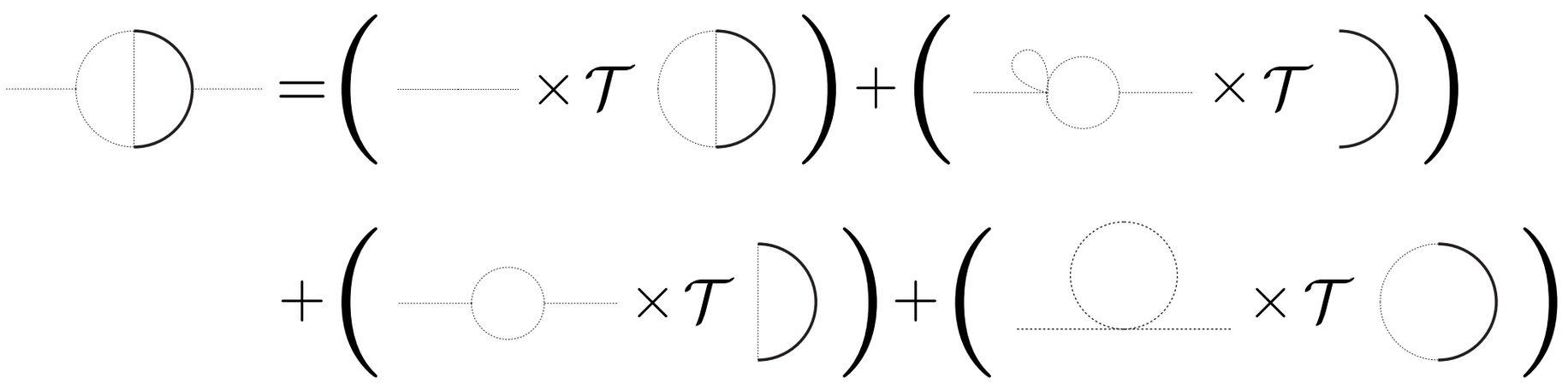
- Too many scales involved!

$$P_1^2 = P_2^2 = 0 \quad P_3^2 = P_4^2 = M_h^2$$

$$s_c = (P_1 + P_2)^2 \quad p_t^2 = \frac{(P_1 \cdot P_3)(P_2 \cdot P_3)}{s_c} - M_h^2$$



- Taylor expansion doesn't work: IR divergences.
- Asymptotic expansion for "large" parameters!



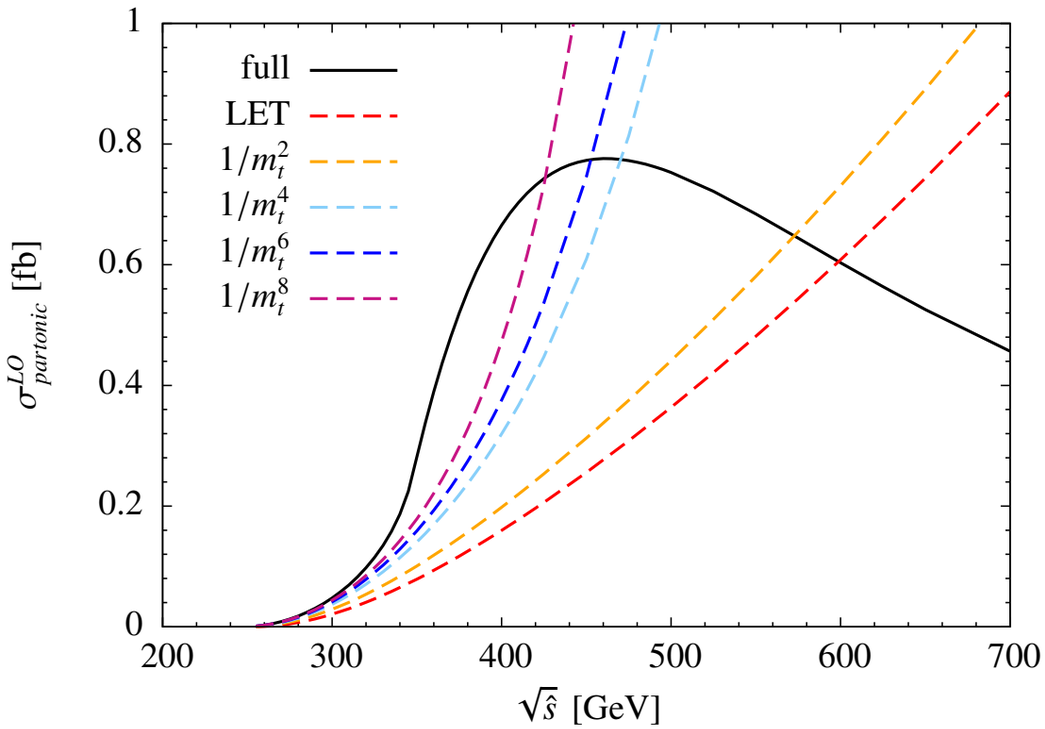
Berends, Davydychev, Smirnov, Tausk '95; Berends, Davydychev, Smirnov, '96; V.A. Smirnov's books.

Large Top Mass

- Grigo, Hoff, Melnikov, and Steinhauser, arXiv:1305.7340
- Grigo, Melnikov, and Steinhauser, arXiv:1408.2422
- Grigo, Hoff, and Steinhauser, arXiv:1508.00909
- G. Degrassi, PPG, R Gröber, arXiv:1603.00385

- Very good approximation in the region of validity.
- Simple formulas for MC.

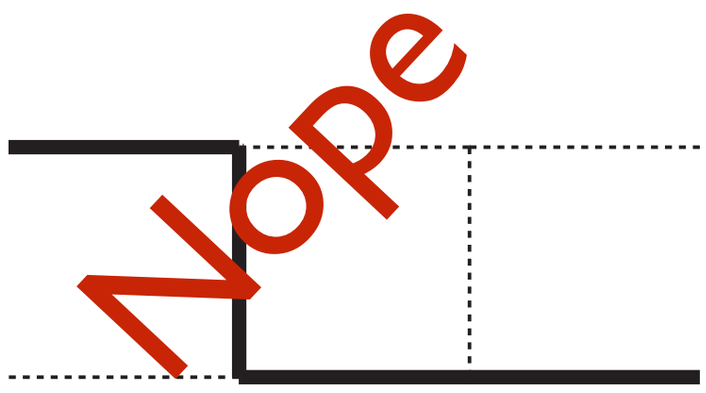
The expansion works well only in the region where m_t^2 is larger than the other parameters…



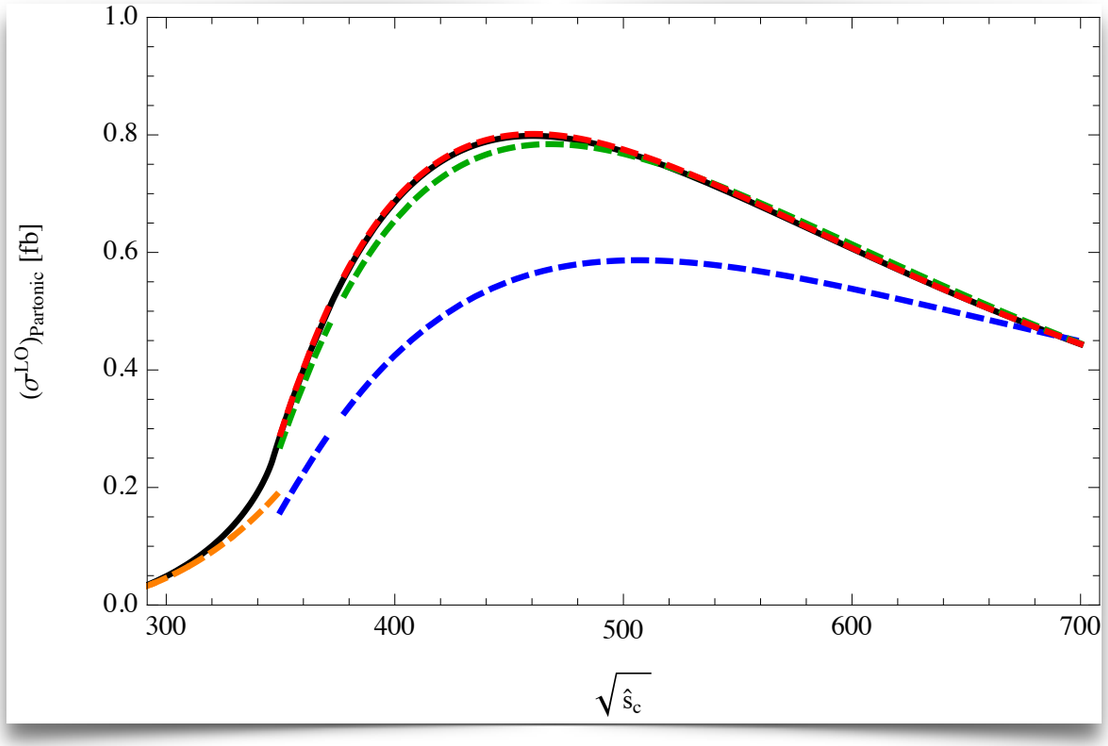
We need something else for the other region!

Large s

- No nice graph representation for this one.
- Rampant Collinear divergences!
- Expansion by "Regions".



$$\frac{1}{(k+P_1)^2 - m_t^2} \sim \frac{1}{2k \cdot P_1}$$



- However it seems to work pretty well for the LO already already for $1/s_c^2$.
- This seems to be the right way to follow!

Conclusions

- The double Higgs production can be useful in investigating NP.
- The NLO corrections will be necessary to this end.
- The numerical calculation is impressive but hardly flexible.
- For now, the analytic computations are done only for a very large top mass!
- More work is needed!