Higgs plus two jets via gluon fusion in the $m_t \longrightarrow \infty$ approximation

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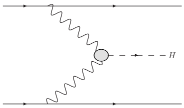
[1] In cooparation with Prof. Zeppenfeld

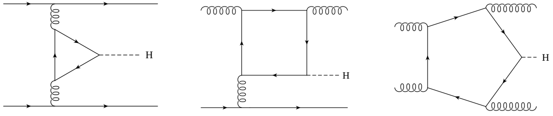
Outline

$pp \longrightarrow Hjj$

- The WBF process is known at NLO in α_s



- Background process: gluon fusion, only known at LO



(a) (b) (c)

- Large scale uncertainties (LO is $\mathcal{O}(\alpha_s^4)$)
- NLO calculation far away of being feasible

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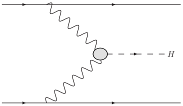

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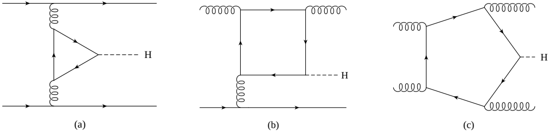

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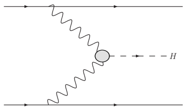

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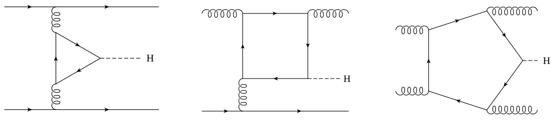

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Approximation: $m_t \to \infty$

- Calculation simplifies enormously for $m_t \gg m_H$
- Within this limes NLO calculation was performed

  Monte Carlo available (MCFM) [Campbell, Ellis, Zanderighi]
- To get a fast MC, MHV techniques were used for the real emission amplitudes [Dixon, Glover, Khoze, Badger]
- MHV amplitudes are compact expressions for the partial amplitude, given in terms of spinor products, e.g.

$$A_n(\Phi, 1^+, \ldots, p^-, \ldots, q^-, \ldots, n^+) = \frac{\langle pq \rangle^4}{\langle 12 \rangle \langle 23 \rangle \ldots \langle n1 \rangle}$$

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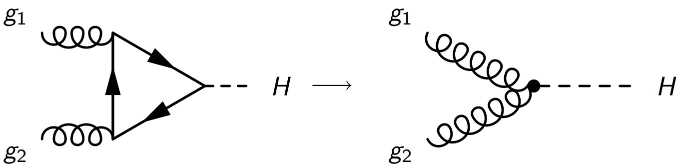
Upcoming questions discussed in the following:

- How well is this process described in the large top mass approximation?
- Can it be improved by considering the $1/m_{\text{top}}^2$ suppressed parts, described by dimension 7 (D7) operators?
- Are there MHV amplitudes for this D7 operators in order to perform a NLO calculation therewith?

Effective theory

In the large top mass approximation, *Hgg* coupling reduces to point interaction:



- Analytic expression can be expanded into a power series in $(1/m_t^2)$
- The effective Lagrangian corresponding to this expansion can be written as

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{D5}} + \frac{1}{m_t^2}\mathcal{L}_{\text{D7}} + \mathcal{O}\left(\frac{1}{m_t^4}\right)$$

Effective D5 Lagrangian

- The leading order of this expansion is given by the well known dimension 5 (D5) Lagrangian:

$$\mathcal{L}_{\text{D5}} = \frac{\alpha_s}{12\pi v} H \,\mathrm{Tr}(G_{\mu\nu} G^{\mu\nu})$$

Effective D7 Lagrangian

One choice for $\mathcal{L}_{\mathrm{D7}}$ is

$$\mathcal{L}_{\mathrm{D7}} = \frac{\alpha_s}{360\pi v}\Big[\frac{7}{4} m_H^2 H G^a_{\mu\nu} G^{a\,\mu\nu} - \frac{11}{2} H G^{a\,\mu}{}_{\mu\nu\rho} G^{a\,\nu\rho} + H G^{a\,\mu}{}_{\mu\rho} G^{a\,\nu}{}_{\nu}{}^{\rho} + 12 g\, H f^{abc} G^{a\,\alpha}{}_{\beta} G^{b\,\beta}{}_{\gamma} G^{c\,\gamma}{}_{\alpha}\Big]$$

where abbreviatory

$$G^a_{\mu\nu\rho} \equiv D^{ab}_\mu G^b_{\nu\rho}$$

a, b, c: color indices

$$G^a_{\mu\nu\rho\sigma} \equiv D^{ab}_\mu D^{bc}_\nu G^c_{\rho\sigma}$$

$$D^{ab}_\mu = \text{gauge covariant derivative}$$

$$G^a_{\mu\nu} = \text{gluonic field strength tensor}$$

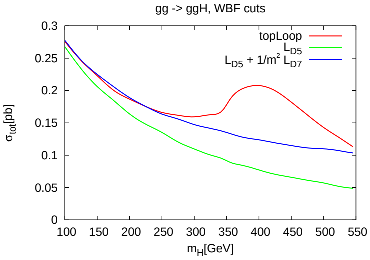
Effective theories vs. full calculation

- D7 operators were implemented into the parton level Monte Carlo program VBFNLO [Zeppenfeld et al.]
- Correction to the squared matrix element is taken to $\mathcal{O}\left(1/m_t^2\right)$:

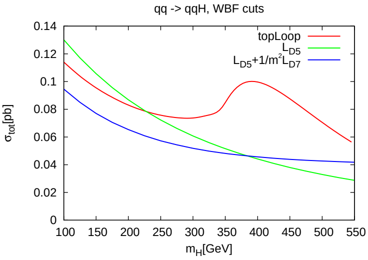
$$|M|^2 = |M_5 + M_7|^2 \overset{\mathcal{O}(\frac{1}{m_t^2})}{=} |M_5|^2 + 2\,\mathrm{Re}(M_5 \cdot M_7^*)$$

- The three subprocesses $gg \rightarrow ggH$, $qg \rightarrow qgH$ and $qq \rightarrow qqH$ have been examined separately

$gg \rightarrow ggH$



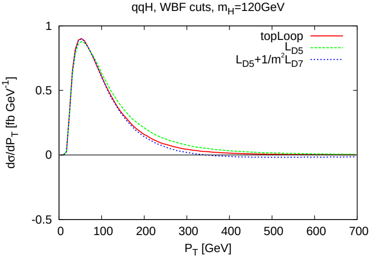
$qq \rightarrow qqH$

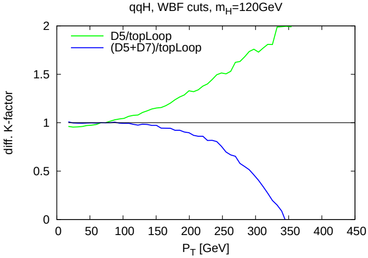


$$\text{Cuts: } R_{jj} > 0.6,\ p_{Tj} > 20\mathrm{GeV},\ |\eta_j| < 5$$
$$|\Delta y_{jj}| > 4,\ m_{jj} > 600\mathrm{GeV},\ y_{j_1} \cdot y_{j_2} < 0$$

- For the qgH and qqH subprocess, the effective theories get spoiled by high p_T regions.

differential p_T distribution of the hardest jet $qq \to qqH$





- K-factor suggests a cut $p_T < 200\mathrm{GeV}$

total deviation for all three subprocesses[2]

		$m_H = 120\mathrm{GeV}$	$m_H = 200\mathrm{GeV}$
D5 theory	minimal cuts	9.8%	11.4%
	WBF cuts	10.2%	15.9%
D5+D7, $p_{\mathrm{T,max}} < 200\mathrm{GeV}$	minimal cuts	3.1%	5.2%
	WBF cuts	3.7%	4.8%

[2]Deviation was calculated by summing over the deviation between effective theory and full calculation for each PS-point and dividing by σ_{tot}. (By just comparing total cross sections, the real deviation might be underestimated up to a factor 8)

D7 MHV amplitudes

- Conjecture for MHV amplitudes for the various D7 operators available, e.g.

$$A_n(\Phi, i^-, j^-, k^-) = \frac{\langle ij\rangle \langle jk\rangle \langle kl\rangle}{\langle 12\rangle \langle 23\rangle \ldots \langle n1\rangle}$$

  for the part $\propto H\,\mathrm{Tr}\left(G^3\right)$

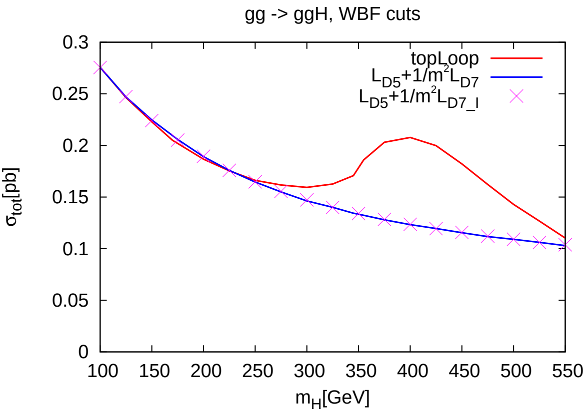
- Similar expressions available for (most of) the other parts of $\mathcal{L}_{D7}$

Conclusions

- The D5 effective theory produces large uncertainties.
- These can be reduced by a factor 3 by considering the $1/m_{top}^2$ suppressed parts (D7).
- Most likely NLO calculation suffers form the same uncertainties.
- MHV amplitudes for the different D7 operators exist, making NLO calculation feasible.

- S. J. Parke and T. R. Taylor, Phys. Rev. Lett. **56** (1986) 2459.
- E. Witten, Commun. Math. Phys. **252** (2004) 189 [arXiv:hep-th/0312171].
- F. Cachazo, P. Svrcek and E. Witten, JHEP **0409** (2004) 006 [arXiv:hep-th/0403047].
- L. J. Dixon, E. W. N. Glover and V. V. Khoze, JHEP **0412** (2004) 015 [arXiv:hep-th/0411092].
- S. D. Badger, E. W. N. Glover and V. V. Khoze, JHEP **0503** (2005) 023 [arXiv:hep-th/0412275].
- J. M. Campbell, R. K. Ellis and G. Zanderighi, JHEP **0610** (2006) 028 [arXiv:hep-ph/0608194].

$gg \to ggH$



$$\mathcal{L}_{D7} = \frac{\alpha_s}{360\pi v}\left[\frac{7}{4} m_H^2 H G^a_{\mu\nu} G^{a\,\mu\nu} - \frac{11}{2} H G^{a\,\mu}{}_{\mu\nu\rho} G^{a\,\nu\rho} + H G^{a\,\mu}{}_{\mu\rho} G^{a\,\nu}{}_{\nu}{}^{\rho} \right.$$

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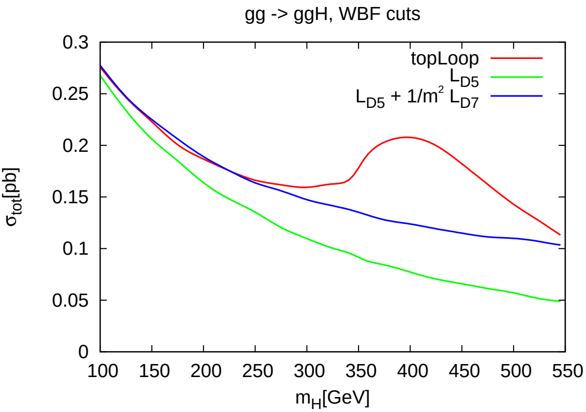

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For this subprocess everything looks fine...

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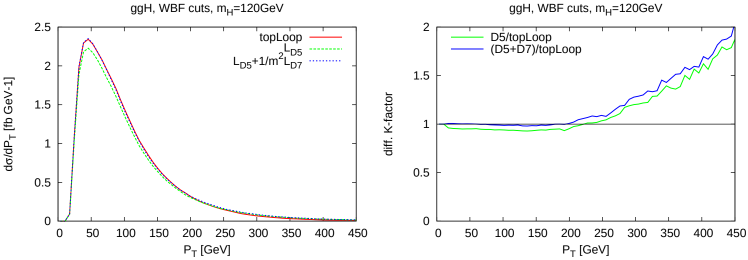
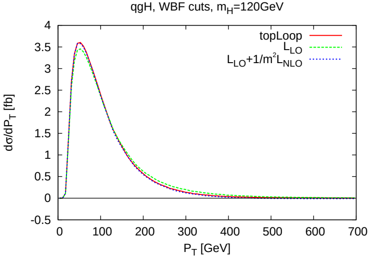


- Full theory and effective D5+D7 in perfect agreement up to $p_T \approx 200\mathrm{GeV}$

differential K-factor: $d\sigma/p_{TH}$:

$qg \longrightarrow qgH$



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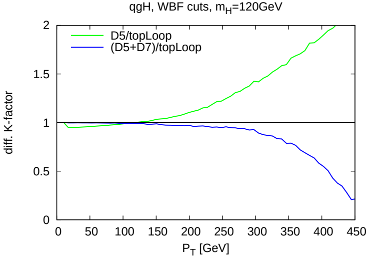

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Field Strength Tensors

One can now write down all Gauge and Lorentz invariant D7 operators, e.g.:

- $\partial^2 H \,\mathrm{Tr}\,(G_{\mu\nu} G^{\mu\nu})$
- $\partial_\mu H \,\mathrm{Tr}\,((D^\mu G^{\nu\rho}) G_{\nu\rho})$
- $H \,\mathrm{Tr}\,((D_\mu G_{\nu\rho})(D^\mu G^{\nu\rho}))$
- $H \,\mathrm{Tr}\,\left((D^\mu G_{\mu\nu})(D^\mu G_\mu{}^\nu)\right)$
- $H \,\mathrm{Tr}\,((D^\mu D_\mu G_{\nu\rho}) G^{\nu\rho})$
- $H \,\mathrm{Tr}\,\left(G_\mu{}^\nu G_\mu{}^\rho G_\rho{}^\mu\right)$

Most of these operators are related by partial integration.

Take independent set that forms a basis.