Higgs boson production via gluon fusion in the POWHEG approach in the SM and in the MSSM

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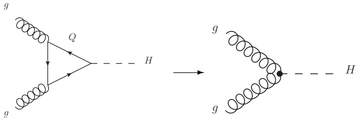
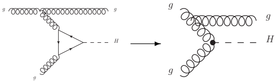
Talk structure

Gluon fusion: current results

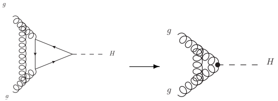
Most of the currently available codes use the effective theory in the $m_{\text{top}} \to \infty$ limit (HEFT).



(a) LO



(b) Real emission



(c) Virtual correction

Most important programs

- HqT - (NNLO+NNLL)-QCD (HEFT, no PS matching)
- HNNLO - NNLO parton level MC (HEFT, no PS matching)
- HRes NLO full, NNLO+NNLO-QCD HEFT (no PS matching)
- HIGLU, Fehip - NLO full theory (but no PS matching)
- iHixs - NLO full/ NNLO HEFT (but no PS matching)
- Pythia/Herwig - PS LO (HEFT)
- MC@NLO/POWHEG - MC NLO + PS (HEFT)

The predictions of the HEFT are accurate enough?

Aims of our work

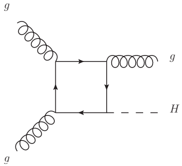
Implementation in the POWHEG framework of the gluon fusion process.
NLO-(QCD+EW) accuracy with exact masses dependence provided by already existing matrix elements:
SM (Aglietti et al, Bonciani et al)
MSSM (Bonciani et al, Degrassi e Slavich)

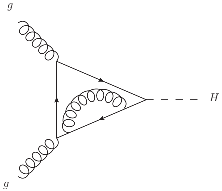
- *Determination of the total cross section with the possibility of imposing realistic acceptance cuts.*
- *Study of the impact of mass effect on the distributions.*
- *Individuation and study of observables which allow to distinguish between SM and MSSM.*

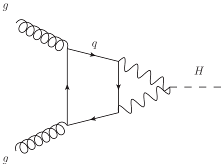
SM

Features

- Matrix elements expressed in terms of Harmonic PolyLogarithm (HPL).
- Full dependence from quarks mass, both for virtual and real contributions.
- Both NLO-QCD and NLO-EW corrections.



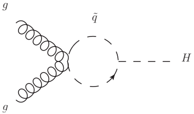


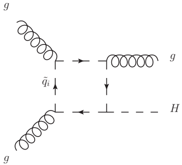


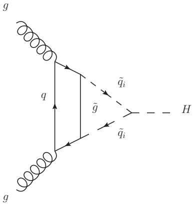
MSSM

Features

- Full dependence from quarks and squarks mass for the real emission diagrams.
- Virtual contributions from diagrams with quarks and gluons with full mass dependence.
- Virtual contributions from diagrams with quarks-squarks-gluinos in the light Higgs limit.





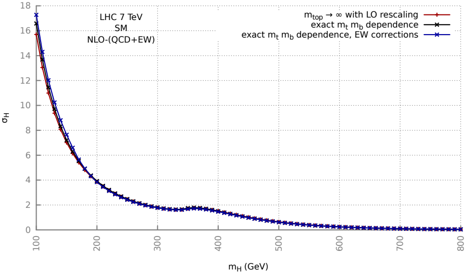


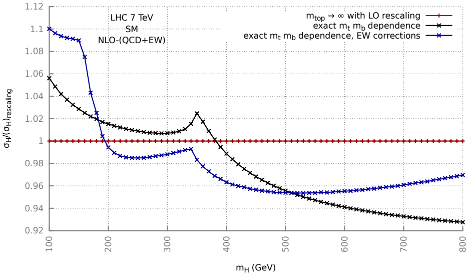
Consistency checks

- Agreement with the previous implementation in POWHEG in the $m_{\text{top}} \to \infty$ limit.
- Comparison with other programs for mutually calculable quantities with on-shell Higgs.
- SM: Total cross-section in agreement with hgvr (*Vicini et al*).
- SM: p_T distributions in agreement with Fehipro.
- MSSM: Total cross section in agreement with Degrassi&Slavich code.

Results - σ_H in the SM

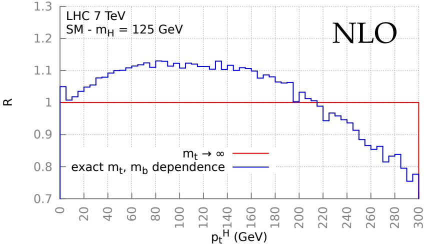
Total inclusive cross-section.



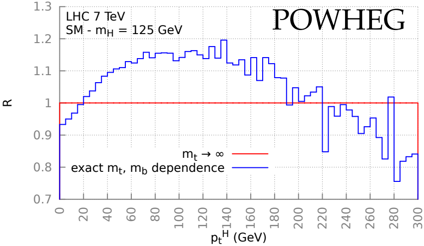


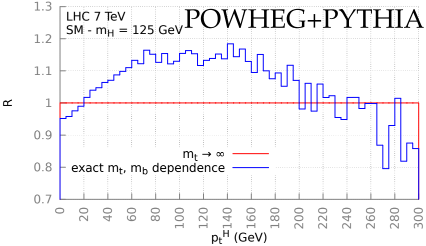
Cross-section normalized to the one in the $m_{\text{top}} \to \infty$ limit.

Results - $d\sigma / dp_T^H$ in the SM for $m_H = 125$ GeV

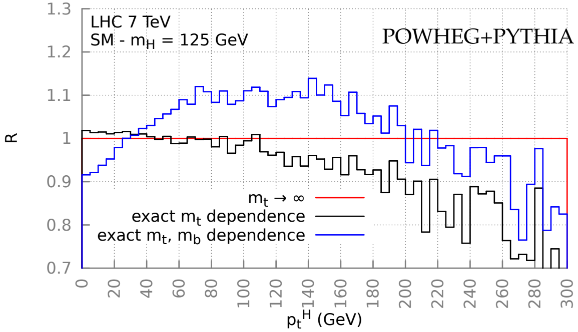


- Quarks mass effect $\mathcal{O}(15\%)$.
- Suppression at low p_T due to the POWHEG Sudakov form factor.



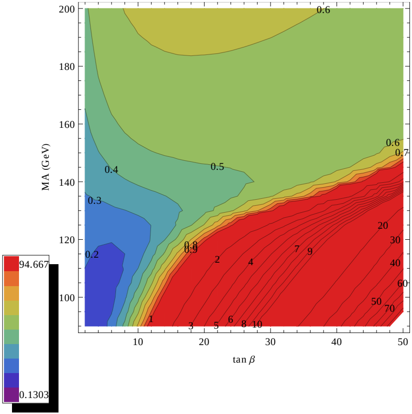


SM: bottom quark role



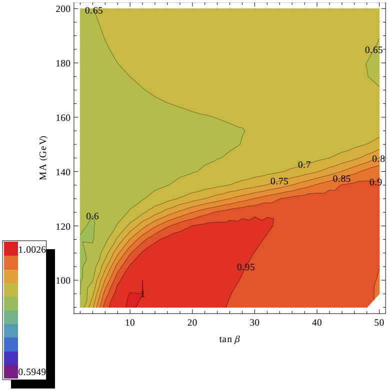
- The distribution with only the Top quark (exact) has a low p_T a similar behavior to the one in the $m_{\text{top}} \to \infty$.
- Import bottom quark correction and suppression for small p_T.
- Effect of the same order of the NNLO-NNLL uncertainty band (most accurate evaluation available).

MSSM - Total cross section σ_h - Light Higgs

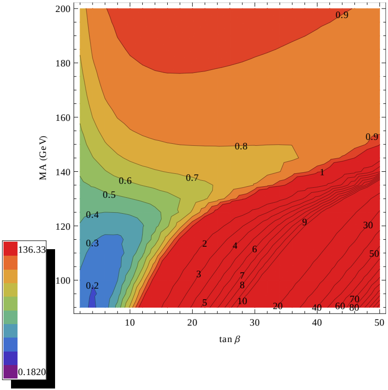


- Ratio of the total cross section in the MSSM and in the SM, for equal m_h.
- m_h^{max} scenario
- $\tan\beta$-m_A. plane scan.
- The ratio varies between 0.2 and 70.
- *What is the role of the scalars?*
- *In the event of equal MSSM and SM cross-section, how can we distinguish the two models?*

Role of the scalars in the MSSM

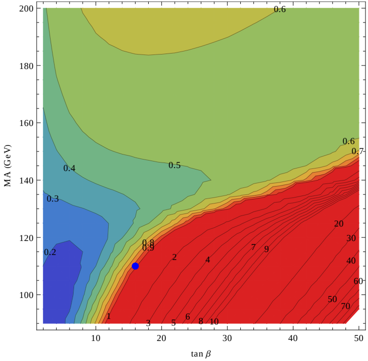


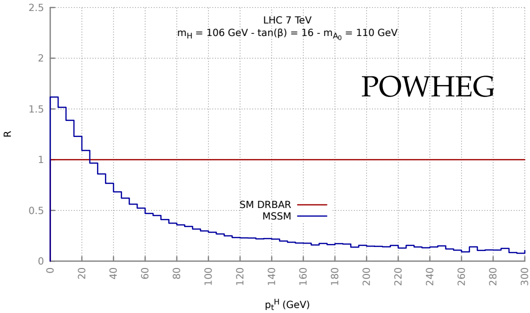
Ratio of the MSSM to the MSSM with only quarks cross-section.



Ratio of the MSSM only quarks to the SM cross-section.

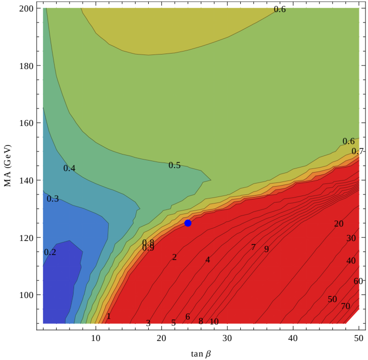
Study of the curve with equal cross-section

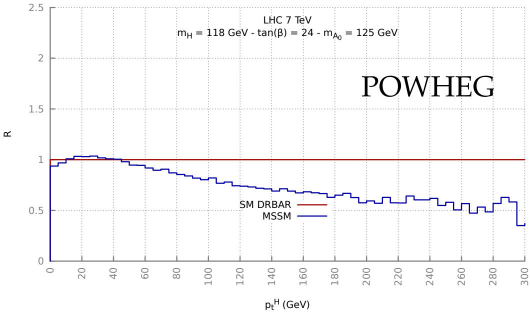




Ratio of the p_T^h distribution in the MSSM and the on in the SM for equal Higgs mass.

Study of the curve with equal cross-section





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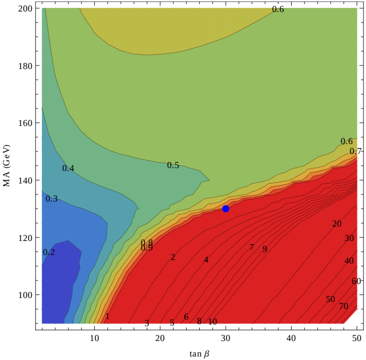
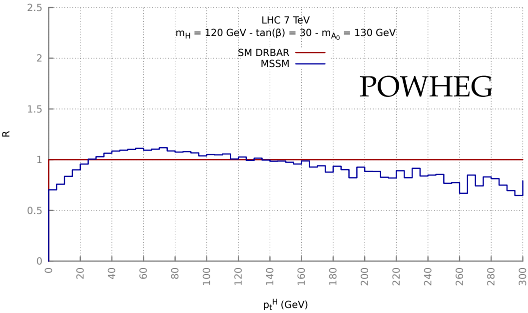
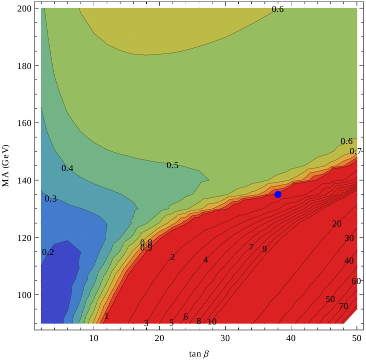
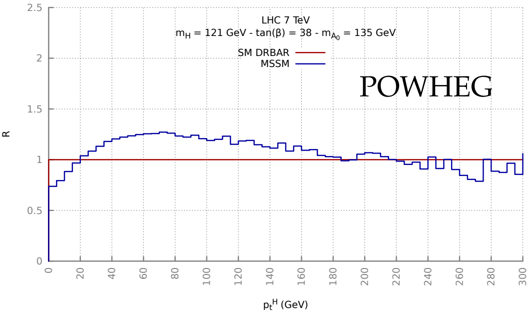




Ratio of the p_T^h distribution in the MSSM and the on in the SM for equal Higgs mass.

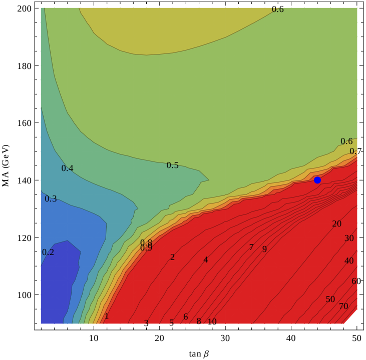
Study of the curve with equal cross-section

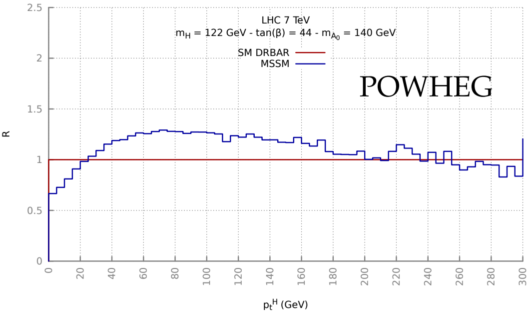




Ratio of the p_T^h distribution in the MSSM and the on in the SM for equal Higgs mass.

Study of the curve with equal cross-section





Ratio of the p_T^h distribution in the MSSM and the on in the SM for equal Higgs mass.

Conclusions

- New implementation of the gluon fusion process in POWHEG: NLO-(QCD+EW) accuracy and full mass dependence for quarks and squarks.
- Bottom quark mass effect are not negligible.
- MSSM: non trivial role of quarks and squarks for total and differential cross-sections.

Future developments

Improvements

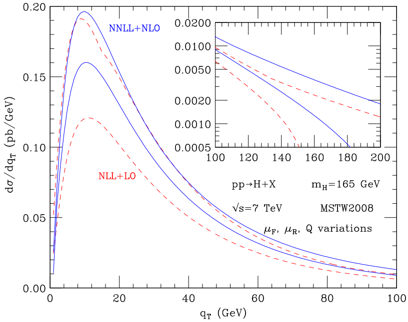
- Higgs decay.
- Phenomenological study in the SM/MSSM of the various decay channels in presence of acceptance cuts.
- MSSM: $gg \to H$
- MSSM: $gg \to A$.
- MSSM: $b\bar{b} \to h$

Theoretical studies

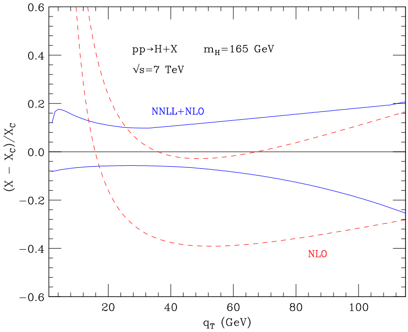
- Analytical study of the specific behaviors observed in the numerical simulations.

Backup slides

Theoretical uncertainty of the cross section in $gg \to H$



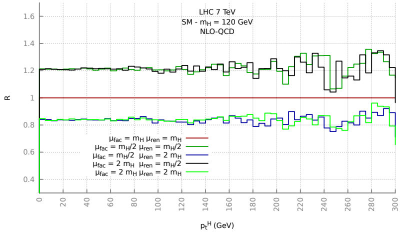
p_T^h spectrum with theoretical uncertainty bands.



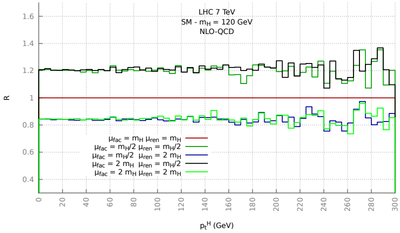
Theoretical uncertainty bands relative to the central NNLO+NNLL value.

Results from *Grazzini et al.*

Mass effects and scale variation



p_T^h spectrum with theoretical uncertainty bands in the new POWHEG implementation

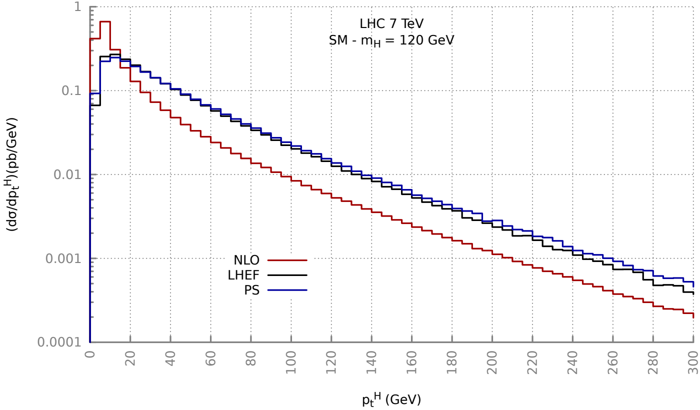


p_T^h spectrum with theoretical uncertainty bands in the old POWHEG implementation.

As expected the results are almost the same.

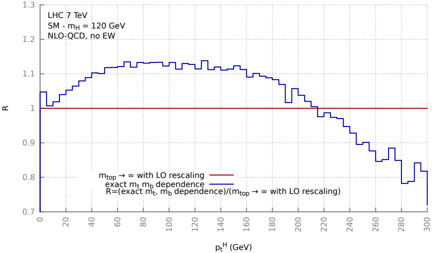
p_T^H distribution - NLO vs NLO+PS

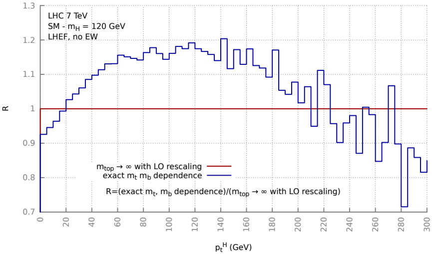
Different behavior for small p_T.
The fixed order calculation is divergent while the NLO+PS result goes to zero.

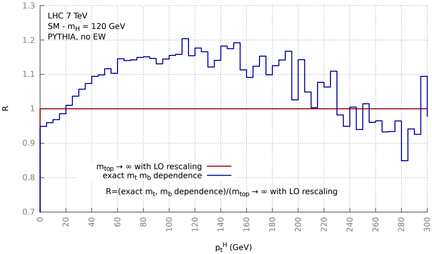


Results - $d\sigma/dp_T^H$ in the SM for $m_H = 120$ GeV

Positive mass correction.







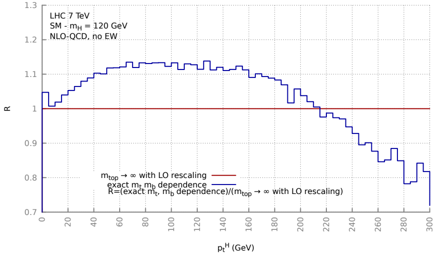
Results - $d\sigma/dp_T^H$ in the SM for $m_H = 120$ GeV

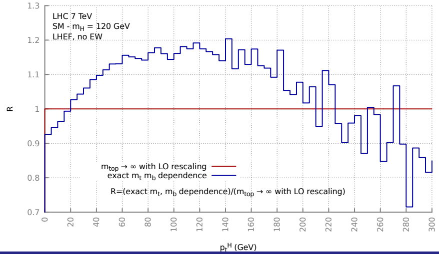
We have that:

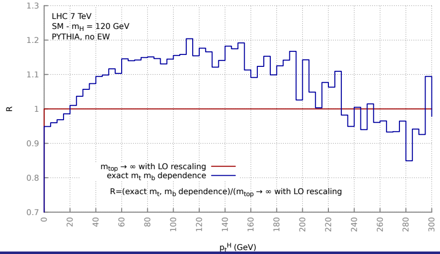
$$\frac{R(\text{t,b,exact})}{B(\text{t,b,exact})} > \frac{R(\text{t},\infty)}{B(\text{t},\infty)}$$

from where:

$$\Delta(\text{t,b,exact}) < \Delta(\text{t},\infty)$$

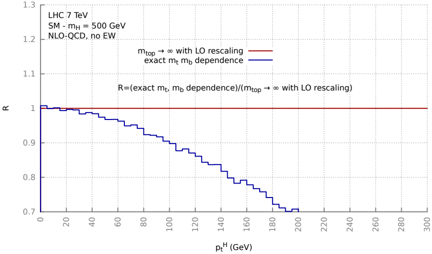


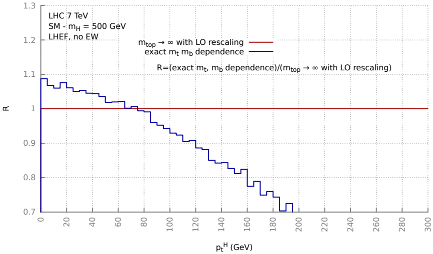


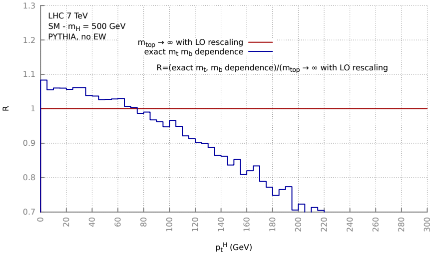


Results - $d\sigma/dp_T^H$ in the SM for $m_H = 500$ GeV

Negative mass correction.







Results - $d\sigma/dp_T^H$ in the SM for $m_H = 500$ GeV

We have that:

$$\frac{R(\mathrm{t,b,exact})}{B(\mathrm{t,b,exact})} < \frac{R(\mathrm{t},\infty)}{B(\mathrm{t},\infty)}$$

from where:

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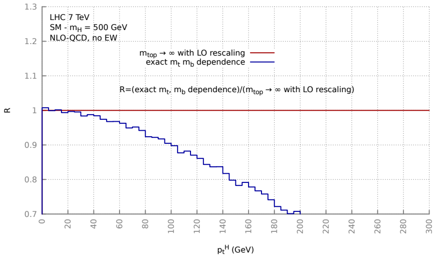
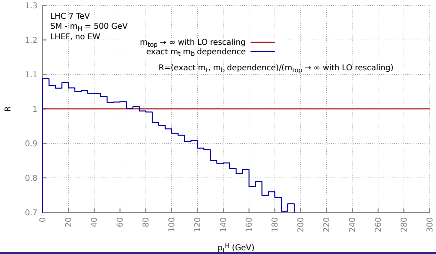
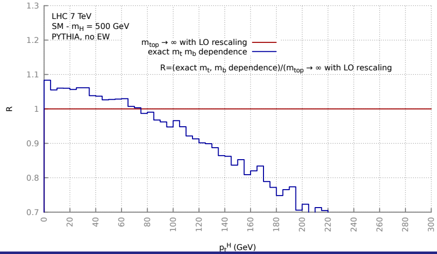
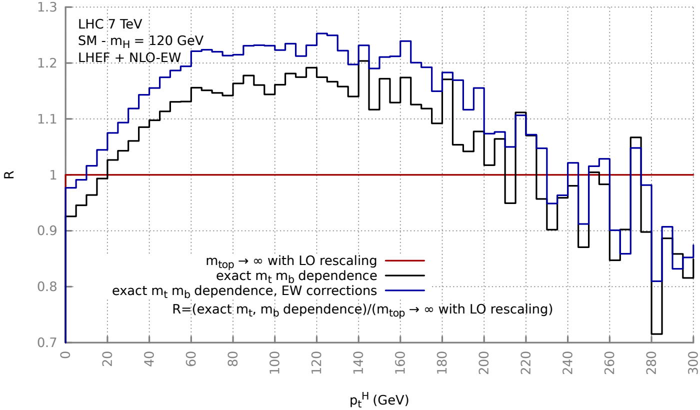




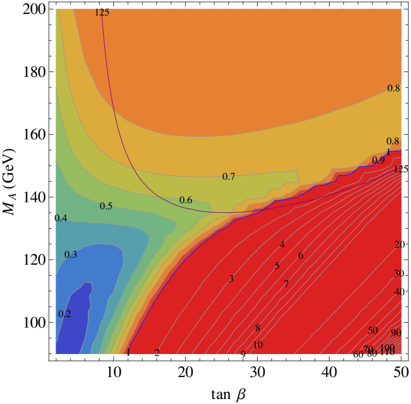


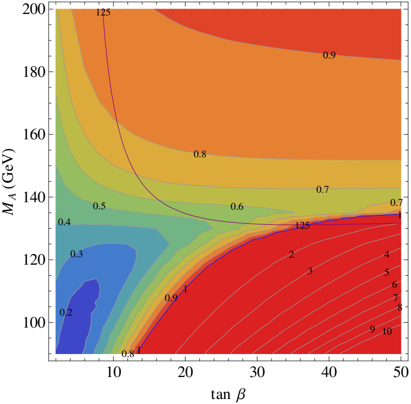
EW corrections for $m_h = 120$ GeV



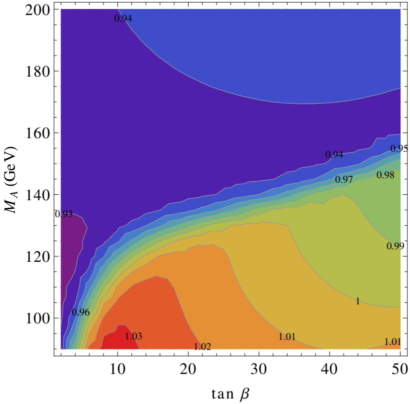
Comparison between the $m_{\text{top}} \to \infty$ distribution and the one with full mass dependence and EW corrections.

New results





New results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M_A (GeV)
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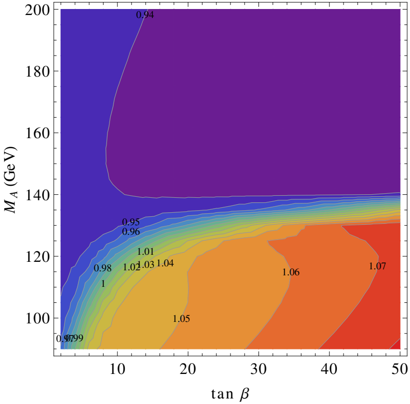
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1
1.01
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1.03
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1.05
1.06
1.07

POWHEG

P.O.W.H.E.G = POsitive Weight Hardest Emission Generator

The problem

- Matching of a NLO-QCD Monte Carlo (MC) event generator and Parton showers (PS) to achieve a better description of experimental data.
- Since a PS includes the Leading Log (LL) terms, it is necessary to develop a strategy to avoid double counting.

The solution

- POWHEG generates the hardest emission.
- The interface with the PS requires a p_T ordered (or a p_T vetoed shower).
- Independent from the specific PS implementation.
- Generates events with positive weight.

POWHEG: the generation of the events

- The POWHEG formula for the generation of the event is:

$$d\sigma = \bar{B}(\bar{\mathbf{\Phi}}_1)d\bar{\mathbf{\Phi}}_1 \left\{ \Delta(\bar{\mathbf{\Phi}}_1, p_T^{\text{min}}) + \Delta(\bar{\mathbf{\Phi}}_1, p_T) \frac{R(\bar{\mathbf{\Phi}}_1, \Phi_{\text{rad}})}{B(\bar{\mathbf{\Phi}}_1)} d\Phi_{\text{rad}} \right\} + \sum_q R_{q\bar{q}}(\bar{\mathbf{\Phi}}_1, \Phi_{\text{rad}}) d\Phi_{\text{rad}} d\bar{\mathbf{\Phi}}_1$$

$$\bar{B}(\bar{\mathbf{\Phi}}_1) = B_{gg}(\bar{\mathbf{\Phi}}_1) + V_{gg}(\bar{\mathbf{\Phi}}_1) + \int d\Phi_{\text{rad}} \left\{ \hat{R}_{gg}(\bar{\mathbf{\Phi}}_1, \Phi_{\text{rad}}) + \sum_q \hat{R}_{qg}(\bar{\mathbf{\Phi}}_1, \Phi_{\text{rad}}) + \sum_q \hat{R}_{gq}(\bar{\mathbf{\Phi}}_1, \Phi_{\text{rad}}) \right\} + c.r.$$

$$\Delta(\bar{\mathbf{\Phi}}_1, p_T) = \exp\left\{ -\int d\Phi_{\text{rad}} \frac{R(\bar{\mathbf{\Phi}}_1, \Phi_{\text{rad}})}{B(\mathbf{\Phi}_1)} \theta(k_T - p_T) \right\}$$

- NLO normalization.
- Sudakov form factor with full matrix elements.

POWHEG: the generation of the events

- The POWHEG formula for the generation of the event is:

$$d\sigma = \bar{B}(\bar{\mathbf{\Phi}}_1)d\bar{\mathbf{\Phi}}_1 \left\{ \Delta(\bar{\mathbf{\Phi}}_1, p_T^{\text{min}}) + \Delta(\bar{\mathbf{\Phi}}_1, p_T) \frac{R(\bar{\mathbf{\Phi}}_1, \Phi_{\text{rad}})}{B(\bar{\mathbf{\Phi}}_1)} d\Phi_{\text{rad}} \right\} + \sum_q R_{q\bar{q}}(\bar{\mathbf{\Phi}}_1, \Phi_{\text{rad}}) d\Phi_{\text{rad}} d\bar{\mathbf{\Phi}}_1$$

$$\bar{B}(\bar{\mathbf{\Phi}}_1) = B_{gg}(\bar{\mathbf{\Phi}}_1) + V_{gg}(\bar{\mathbf{\Phi}}_1) + \int d\Phi_{\text{rad}} \left\{ \hat{R}_{gg}(\bar{\mathbf{\Phi}}_1, \Phi_{\text{rad}}) + \sum_q \hat{R}_{qg}(\bar{\mathbf{\Phi}}_1, \Phi_{\text{rad}}) + \sum_q \hat{R}_{gq}(\bar{\mathbf{\Phi}}_1, \Phi_{\text{rad}}) \right\} + c.r.$$

$$\Delta(\bar{\mathbf{\Phi}}_1, p_T) = \exp\left\{ -\int d\Phi_{\text{rad}} \frac{R(\bar{\mathbf{\Phi}}_1, \Phi_{\text{rad}})}{B(\mathbf{\Phi}_1)} \theta(k_T - p_T) \right\}$$

- NLO normalization.
- Sudakov form factor with full matrix elements.

POWHEG: the generation of the events

- The POWHEG formula for the generation of the event is:

$$d\sigma = \bar{B}(\bar{\mathbf{\Phi}}_1) d\bar{\mathbf{\Phi}}_1 \left\{ \Delta(\bar{\mathbf{\Phi}}_1, p_T^{\min}) + \Delta(\bar{\mathbf{\Phi}}_1, p_T) \frac{R(\bar{\mathbf{\Phi}}_1, \Phi_{\text{rad}})}{B(\bar{\mathbf{\Phi}}_1)} d\Phi_{\text{rad}} \right\} + \sum_q R_{q\bar{q}}(\bar{\mathbf{\Phi}}_1, \Phi_{\text{rad}}) d\Phi_{\text{rad}} d\bar{\mathbf{\Phi}}_1$$

$$\bar{B}(\bar{\mathbf{\Phi}}_1) = B_{gg}(\bar{\mathbf{\Phi}}_1) + V_{gg}(\bar{\mathbf{\Phi}}_1) + \int d\Phi_{\text{rad}} \left\{ \hat{R}_{gg}(\bar{\mathbf{\Phi}}_1, \Phi_{\text{rad}}) + \sum_q \hat{R}_{qg}(\bar{\mathbf{\Phi}}_1, \Phi_{\text{rad}}) + \sum_q \hat{R}_{gq}(\bar{\mathbf{\Phi}}_1, \Phi_{\text{rad}}) \right\} + c.r.$$

$$\Delta(\bar{\mathbf{\Phi}}_1, p_T) = \exp\left\{ -\int d\Phi_{\text{rad}} \frac{R(\bar{\mathbf{\Phi}}_1, \Phi_{\text{rad}})}{B(\mathbf{\Phi}_1)} \theta(k_T - p_T) \right\}$$

- NLO normalization.
- Sudakov form factor with full matrix elements.