NLO+PS matching for $t\bar{t}b\bar{b}$ production with massive b-quarks

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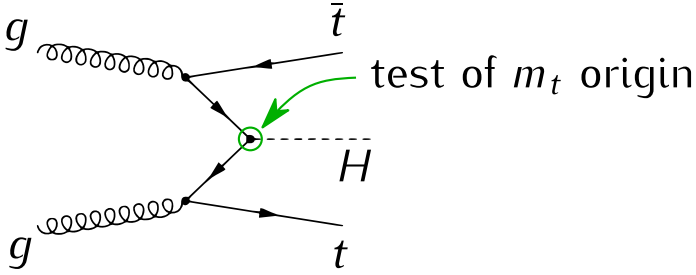
In collaboration with:
J. Lindert, N. Moretti and S. Pozzorini

Universität Zürich[UZH]

$t\bar{t}H$ @ LHC run 2

- Direct probe of top-quark Yukawa coupling



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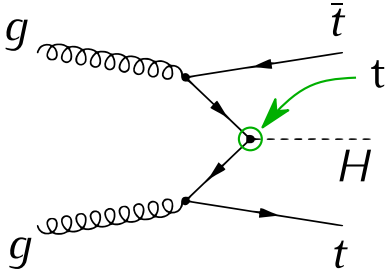
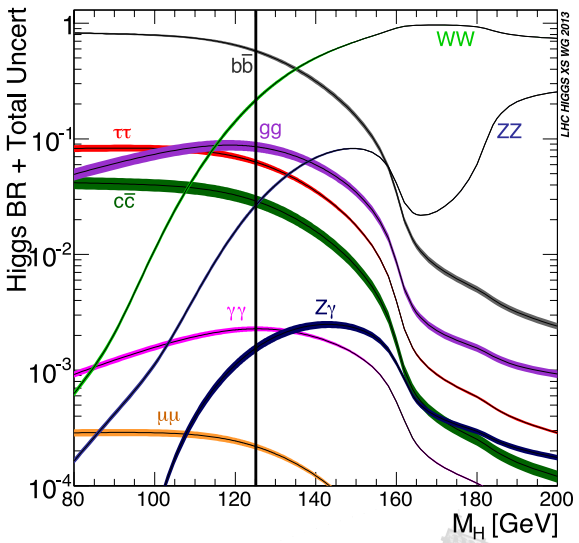


test of m_t origin



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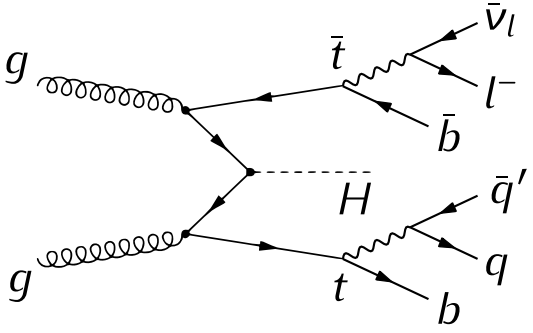

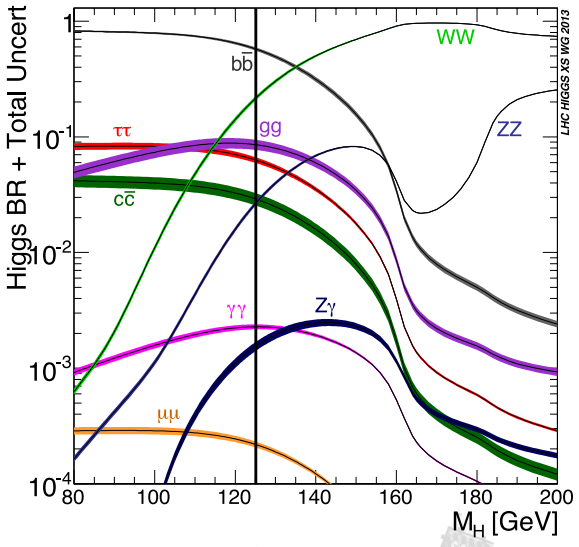

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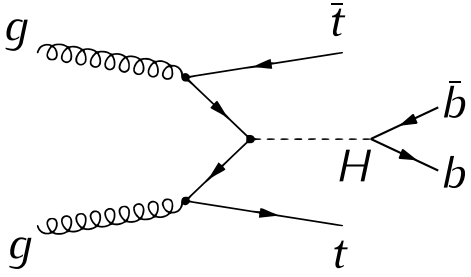

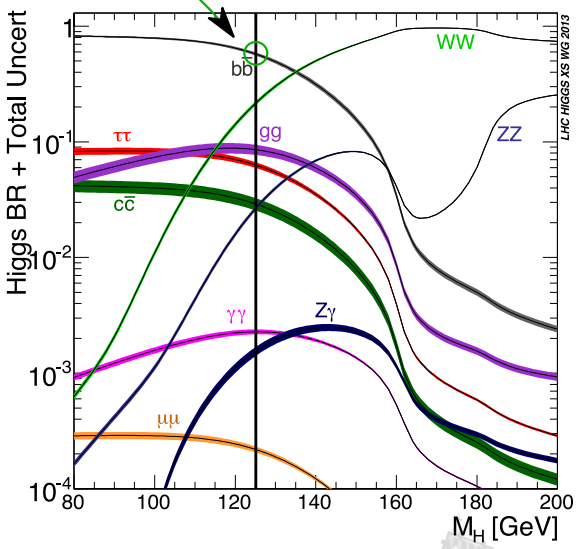

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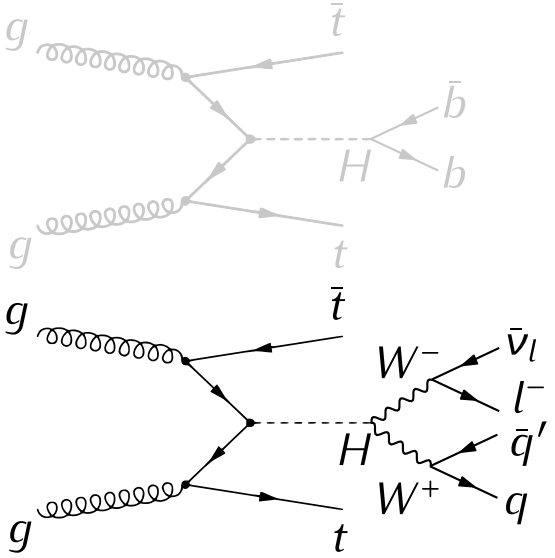

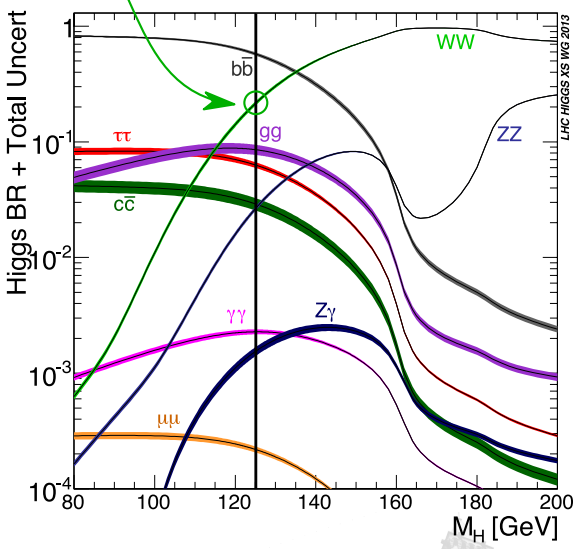

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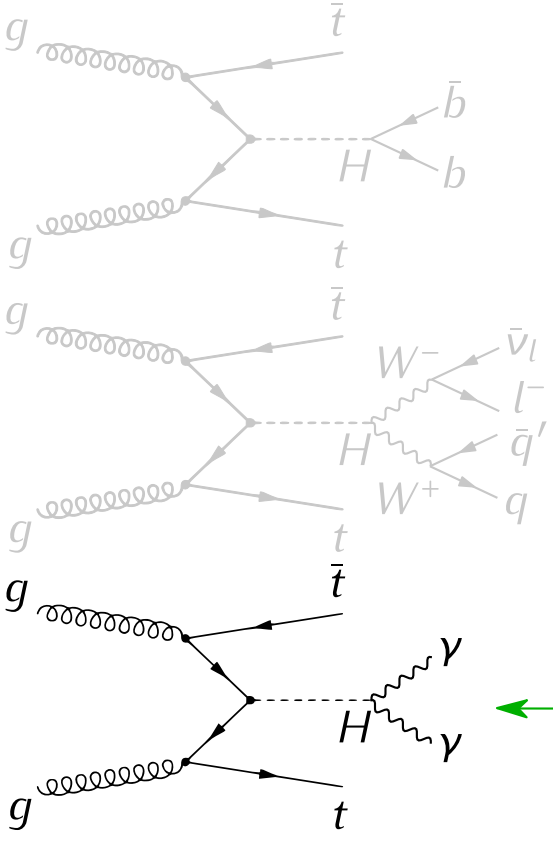

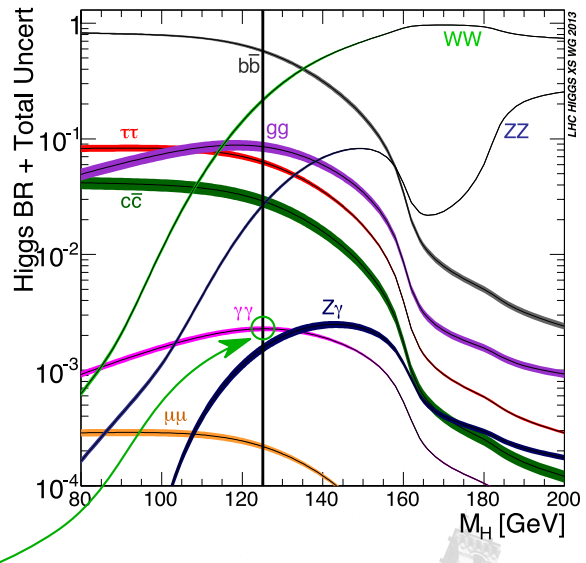

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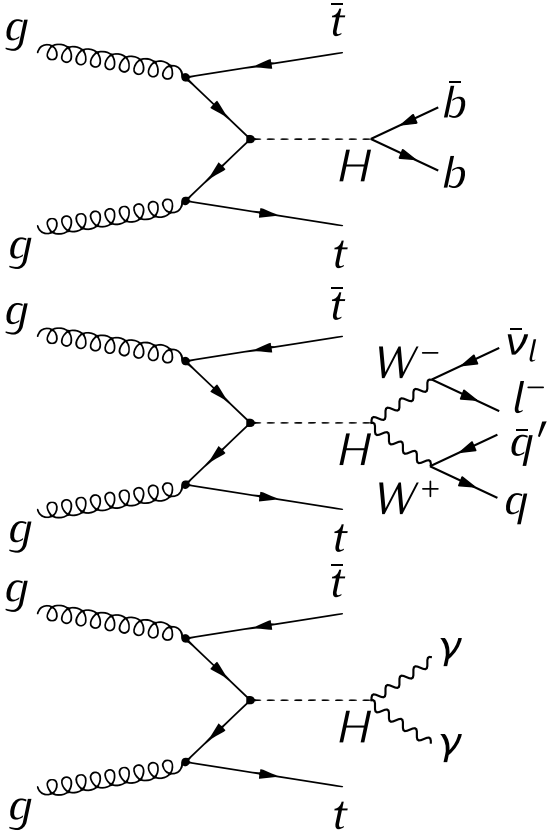

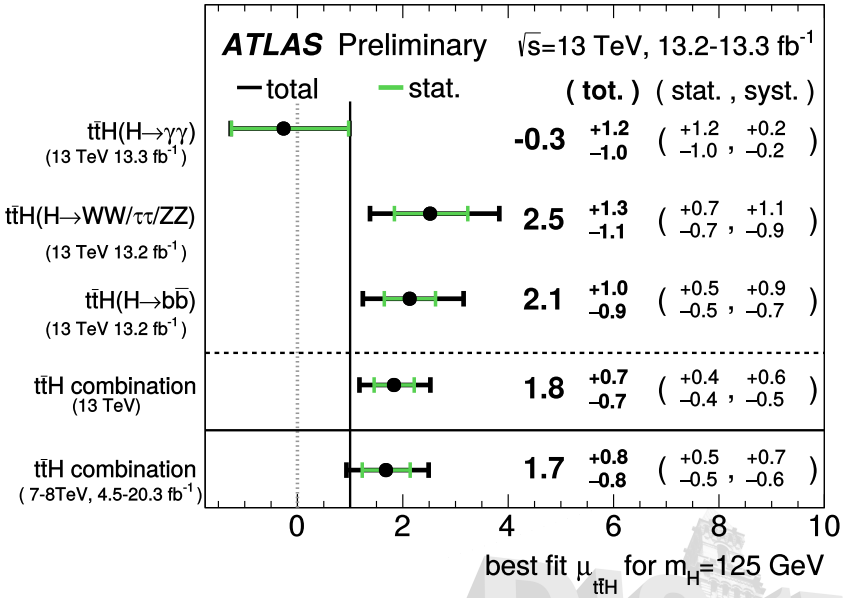

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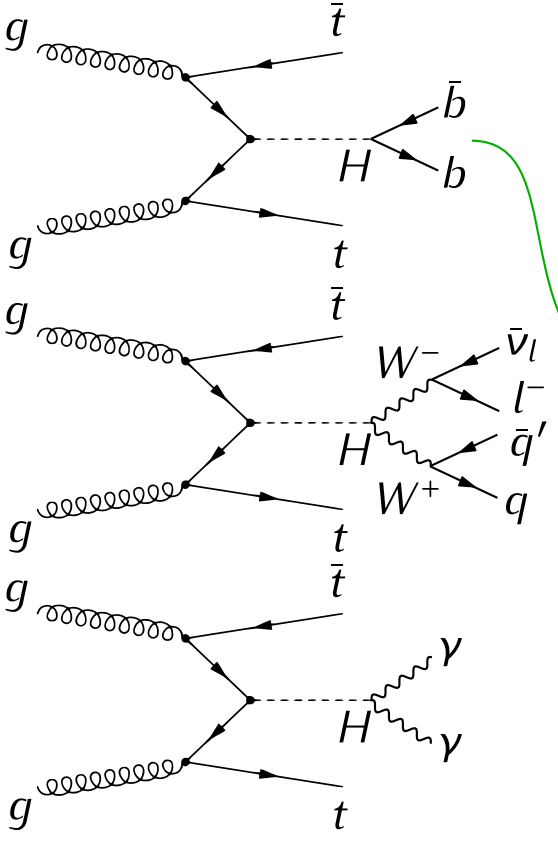

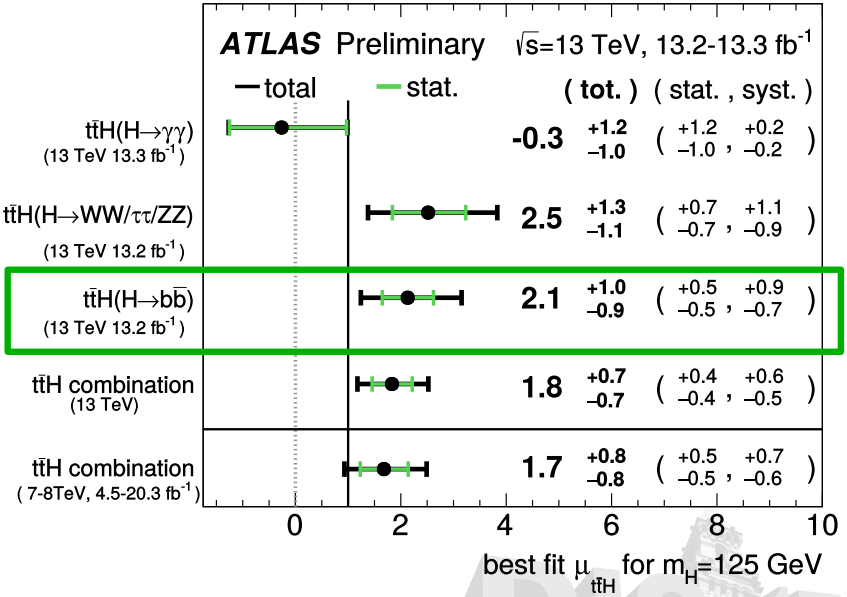

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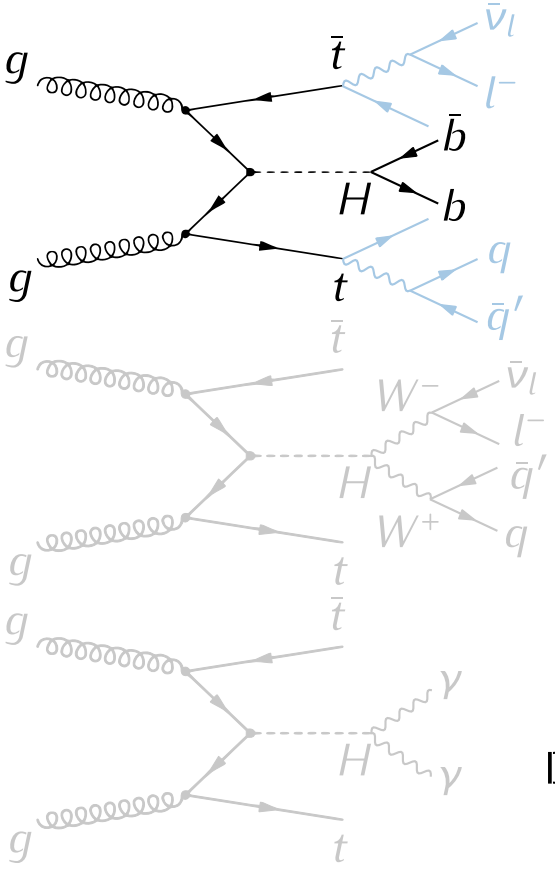

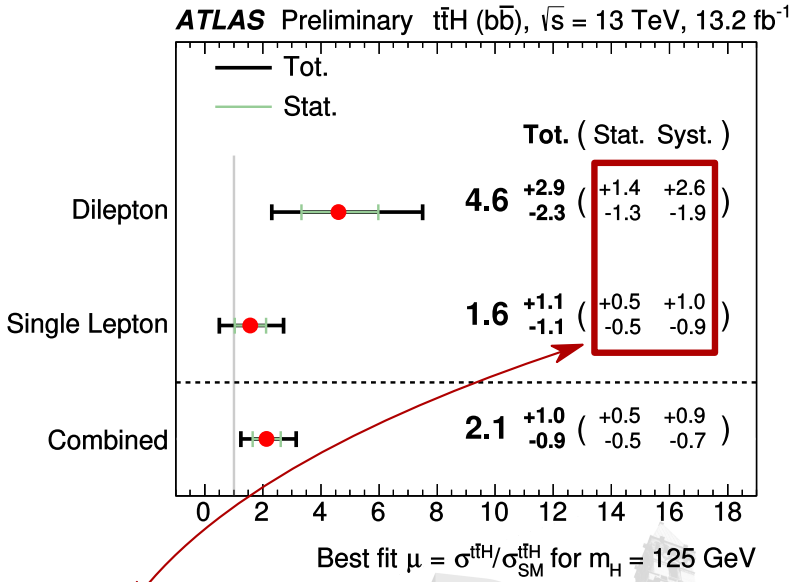

Dominated by systematics!

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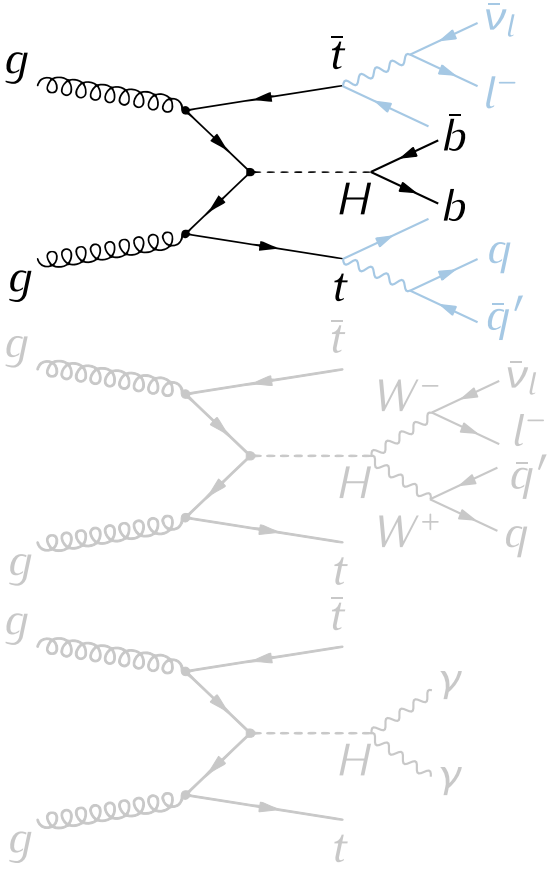

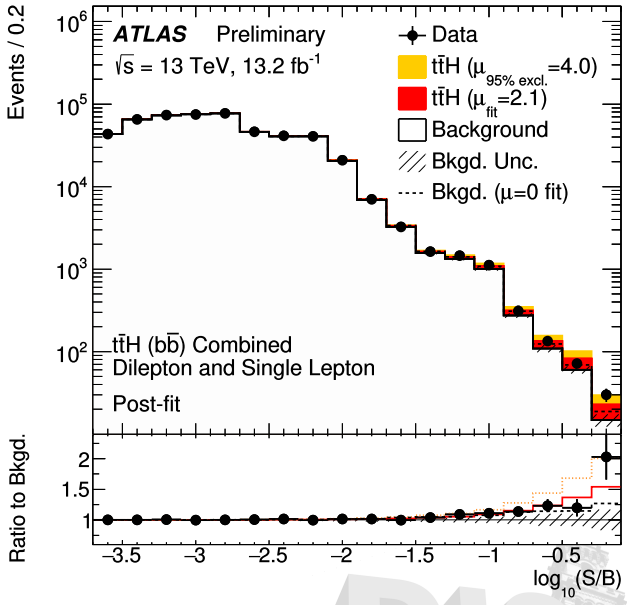

QCD production of $t\bar{t}b\bar{b}$

- Key features of $pp \to t\bar{t}b\bar{b}$:
  - Irreducible background to $t\bar{t}H(\to b\bar{b})$
  - 34 LO diagrams, multiple scales from 5 to 500 GeV
  - Dominated by topologies with $g \to bb$ splittings

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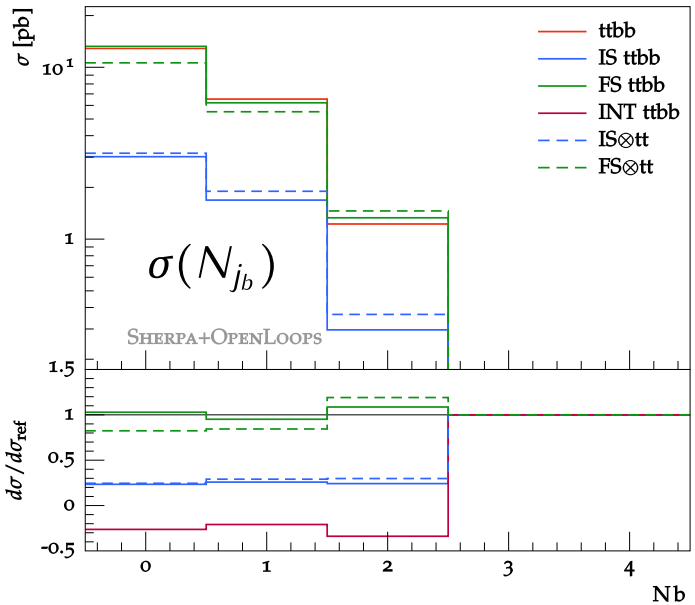

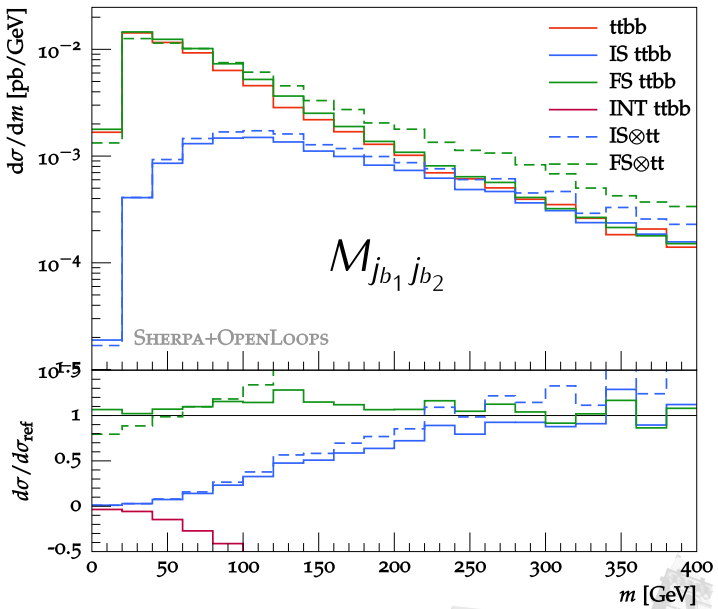

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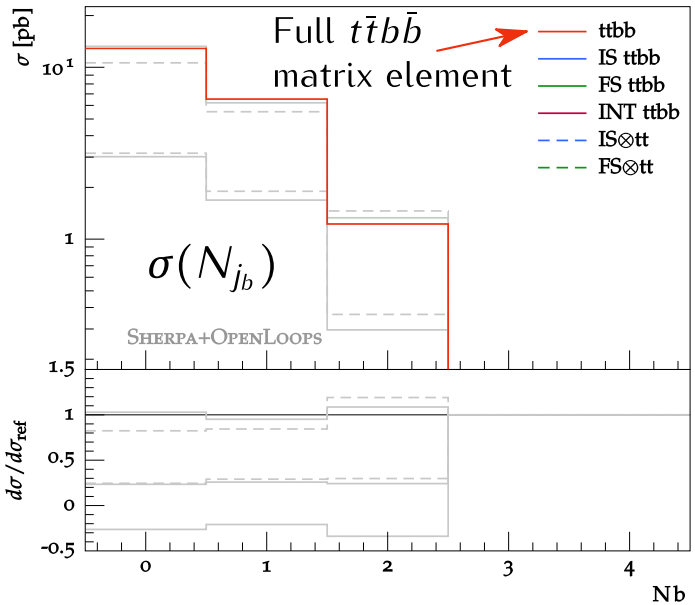

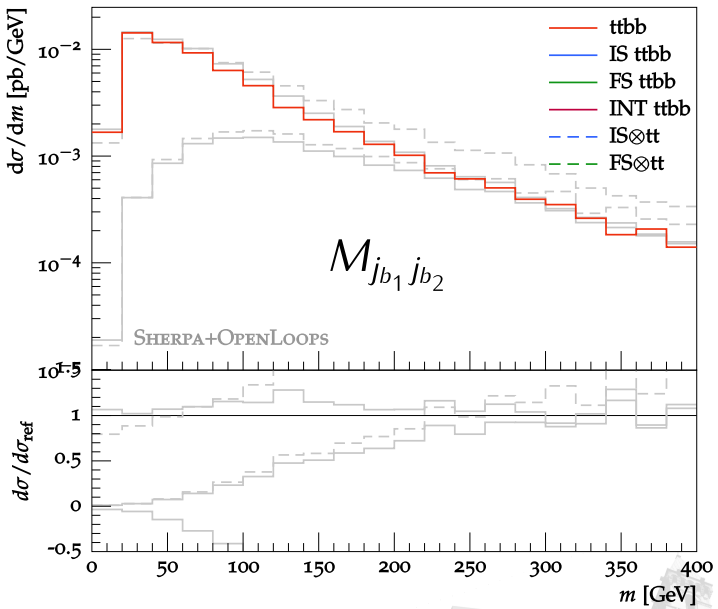

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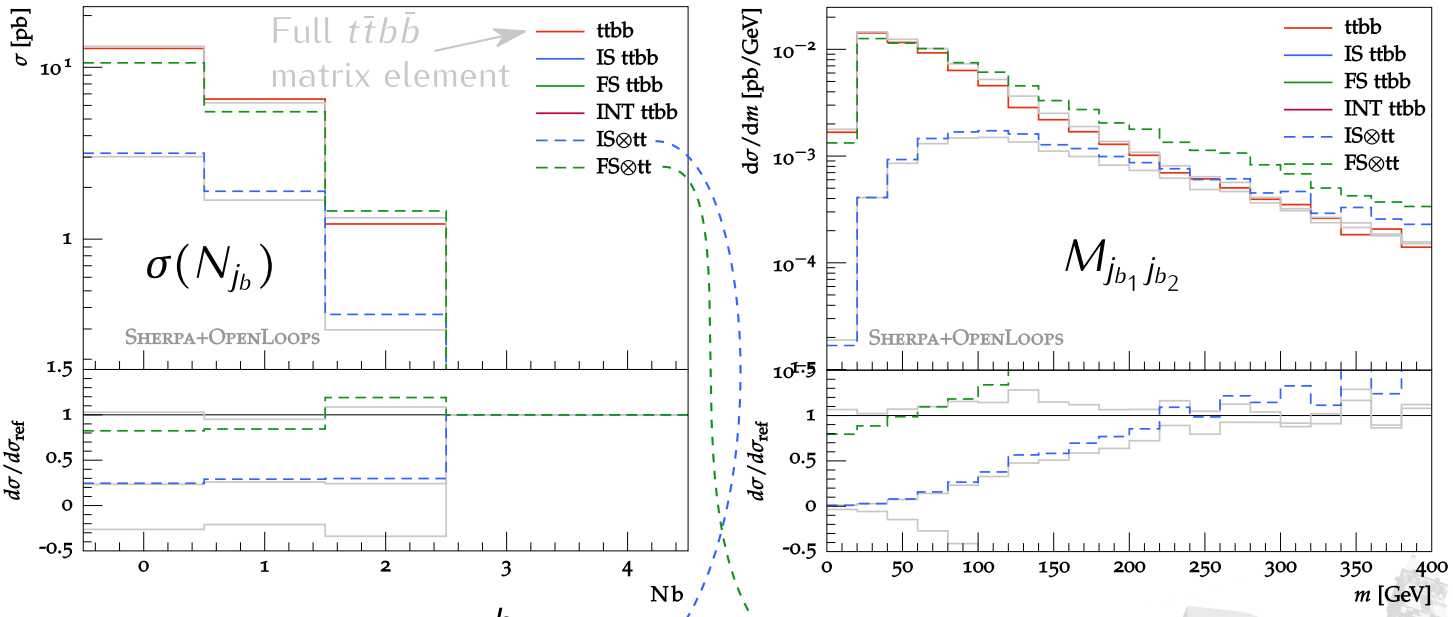
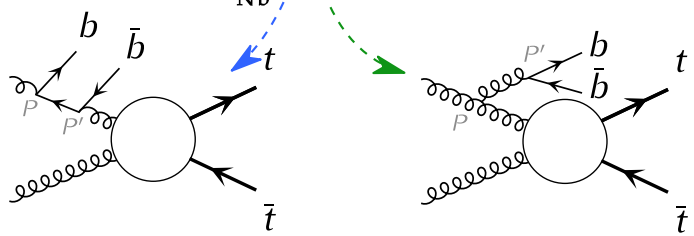


$M_{t\bar{t}} \times P \times P'$:



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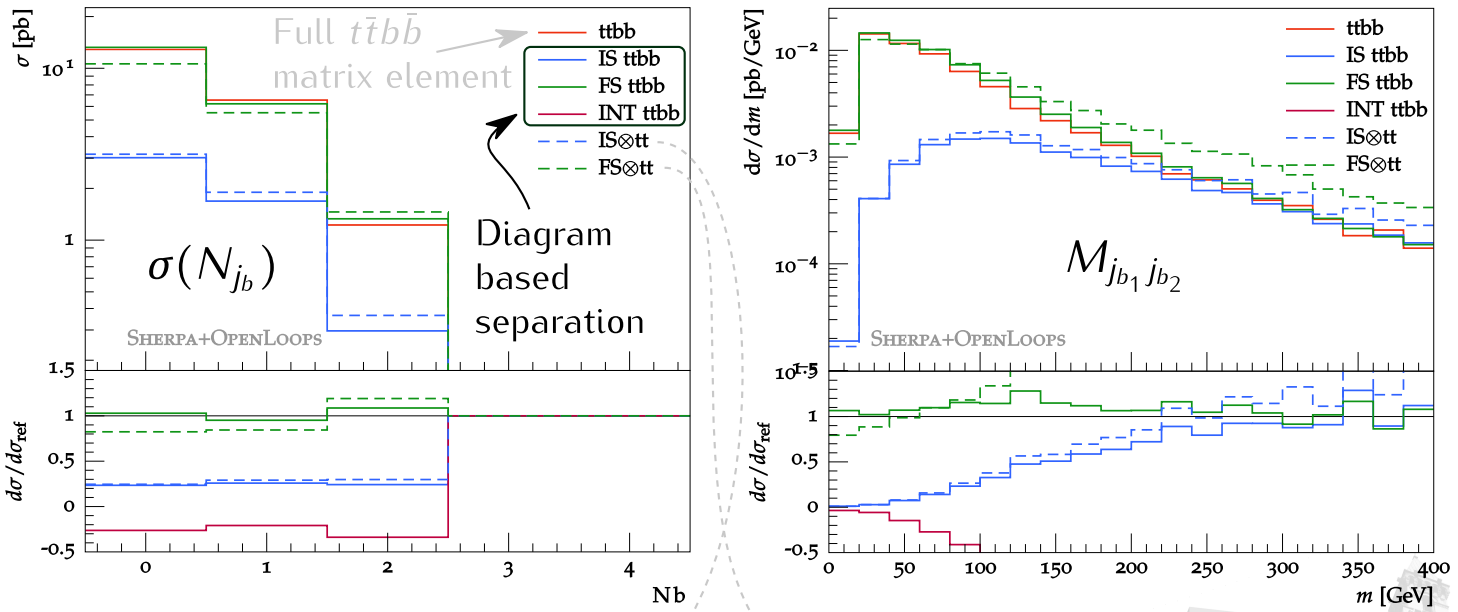

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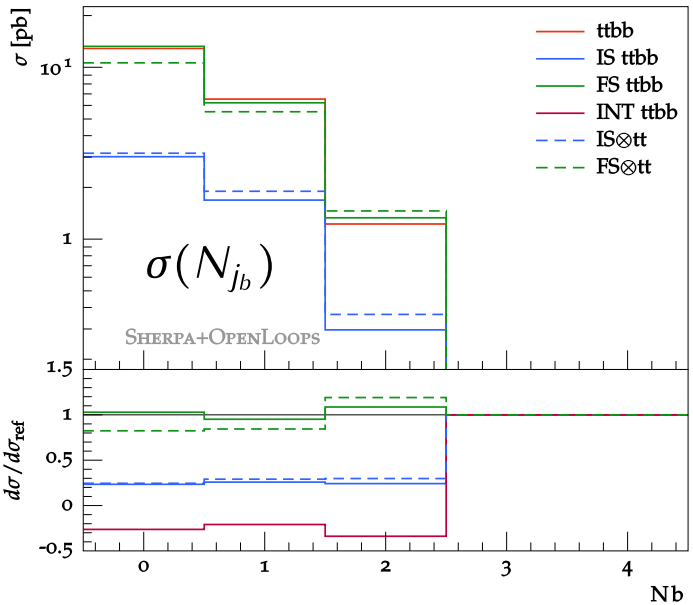
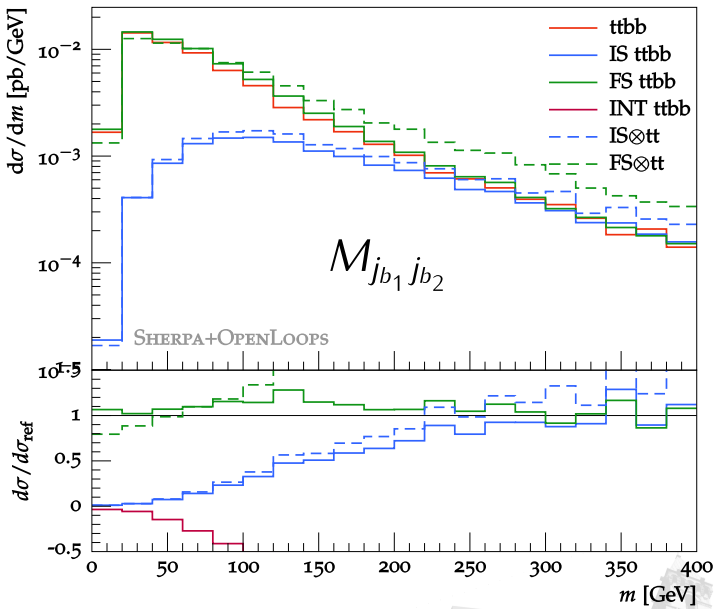
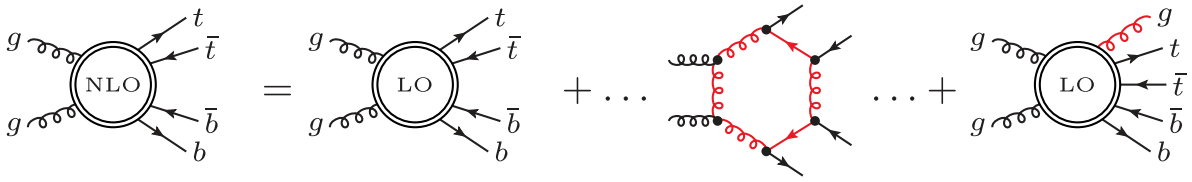




  - Collinear regions and the effects of m_b very important
    - 5FNS: IS contribution resummed, but excludes in $g \to b\bar{b}$
    - 4FNS: includes $g \to b\bar{b}$, m_b effects included

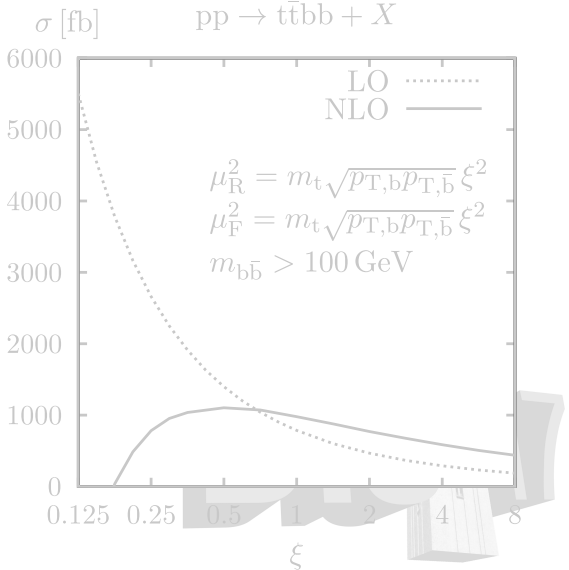
QCD production of $t\bar{t}b\bar{b}$ @NLO

- $t\bar{t}b\bar{b}$ @ NLO QCD:



  - 5FNS ($m_b = 0$): [Bredenstein et al. '09–'10; Bevilacqua et al. '10]
  - 4FNS ($m_b > 0$): [Cascioli et al. '13]

- $t\bar{t}b\bar{b}$ dominates $t\bar{t}H(b\bar{b})$ systematics
- $\sigma_{t\bar{t}b\bar{b}} \propto \alpha_S^4(\mu_R) \Rightarrow$ scale uncertainty:
  - $\sim 80\%$ @ LO
  - $20 - 30\%$ @ NLO
- NLO+PS predictions mandatory for realistic analysis



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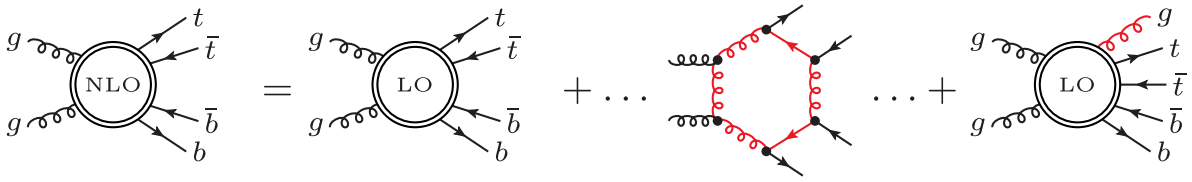

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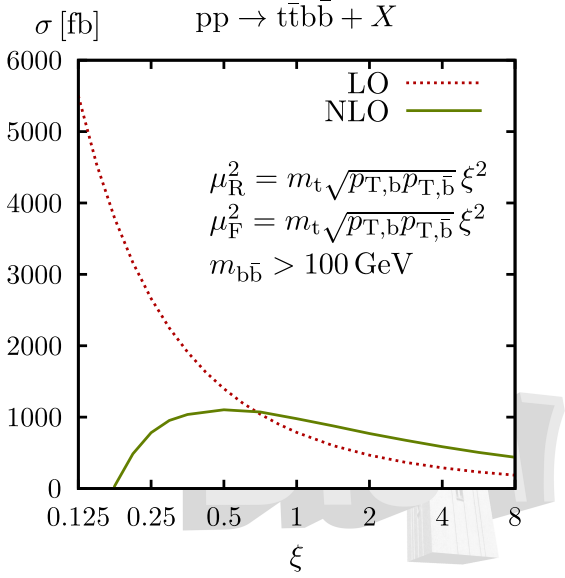

QCD production of $t\bar{t}b\bar{b}$ @NLO+PS

- Available $t\bar{t}b\bar{b}$ calculations @NLO+PS:
  - `Powhel` [Garzelli et al. '13/'14]
    - POWHEG matching
    - 5F scheme, $m_b = 0$
    - requires a generation cut
  - `Sherpa+OpenLoops` [Cascioli et al. '13]
    - S-MC@NLO matching
    - 4F scheme, $m_b > 0$
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MEs cannot describe collinear $g \to b\bar{b}$ splittings

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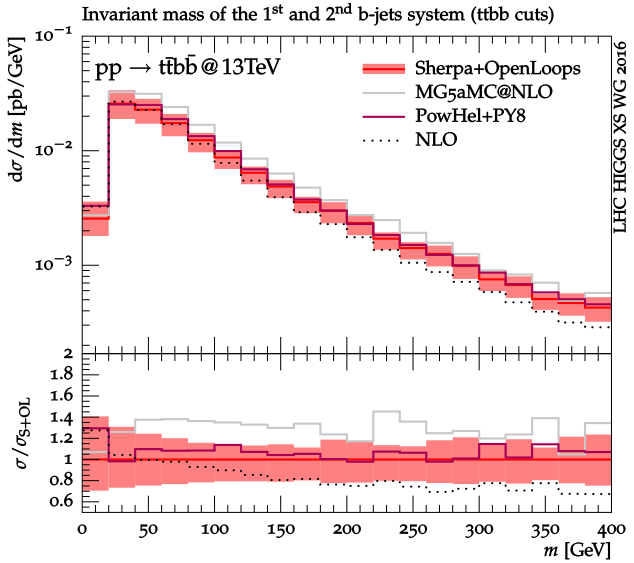
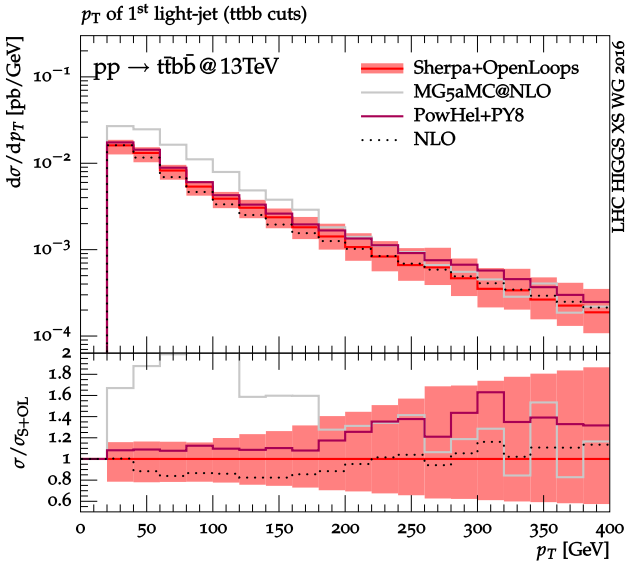
MEs cover full b-quark phase space

Why another $t\bar{t}b\bar{b}$ @NLO+PS?

- YR4 [arXiv:1610.07922]:





- `Sherpa+OpenLoops` vs. `PowHel+PY8`
  - Good agreement also in observables with large NLO+PS corrections
- `Sherpa+OpenLoops` vs. `MG5_aMC@NLO` [arXiv:1405.0301]
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  - Strong resummation-scale sensitivity of $t\bar{t}b\bar{b}$+jet in `MG5_aMC@NLO`

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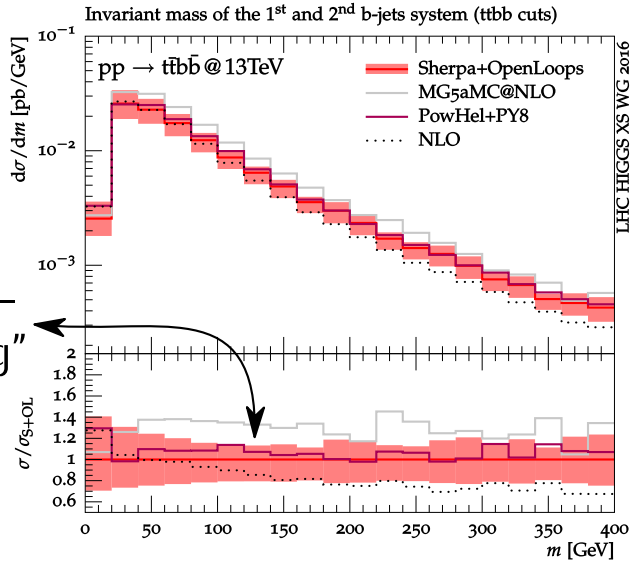
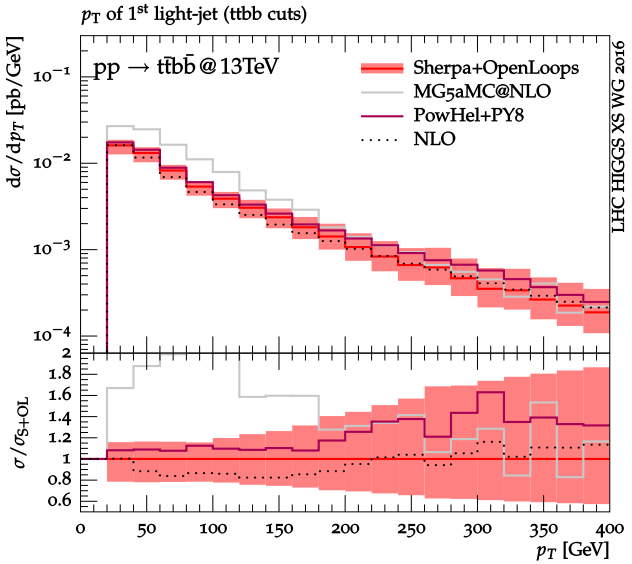


"double-splitting"



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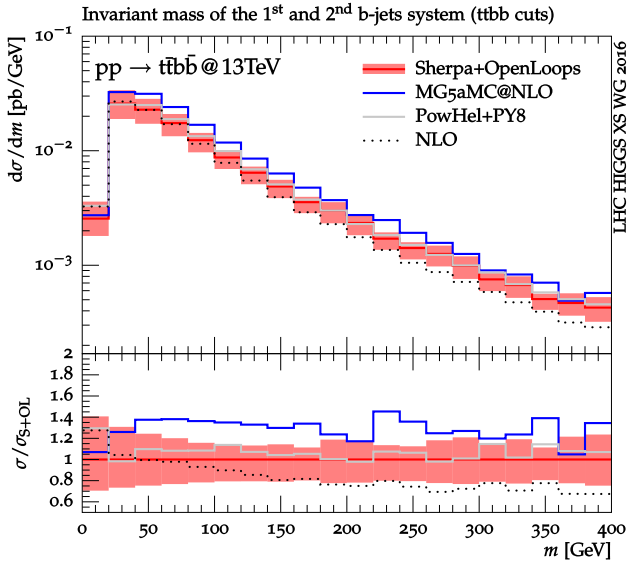

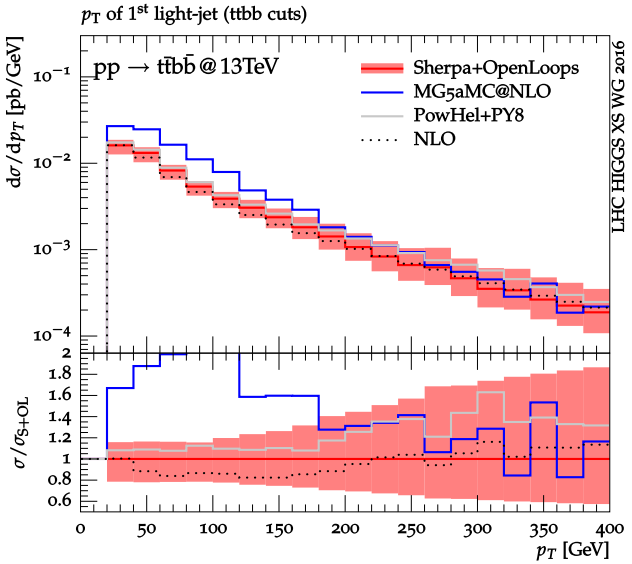

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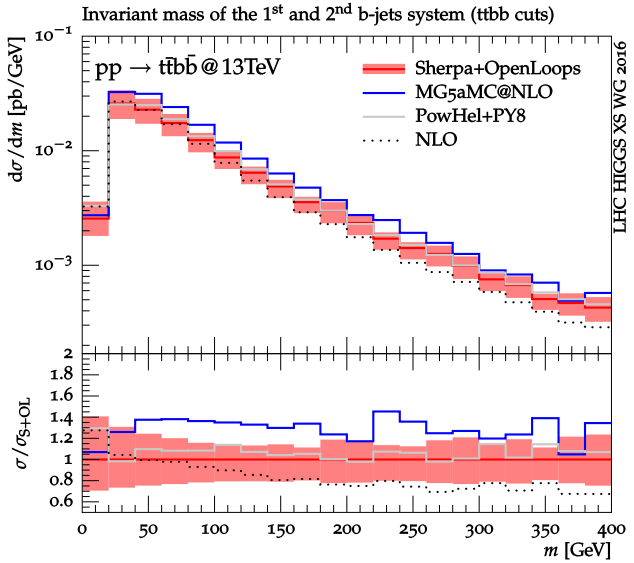

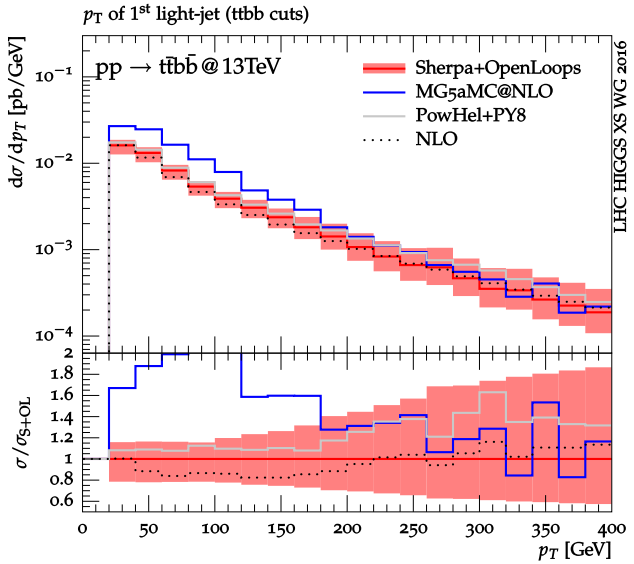

- What can `POWHEG-BOX+OpenLoops` bring?
  - MC@NLO: is matching of a multi-scale problem ($m_{tt} \sim 100 m_b$) with a single resummation scale straightforward?
  - POWHEG: resummation scale not a free parameter, does `hdamp` fullfill a similar role?

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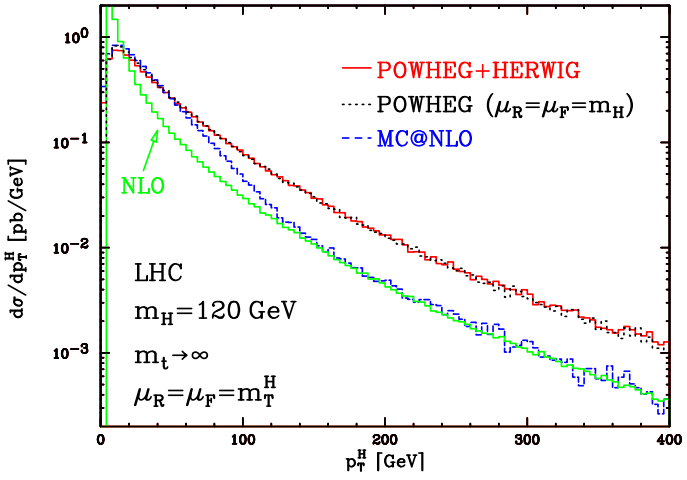
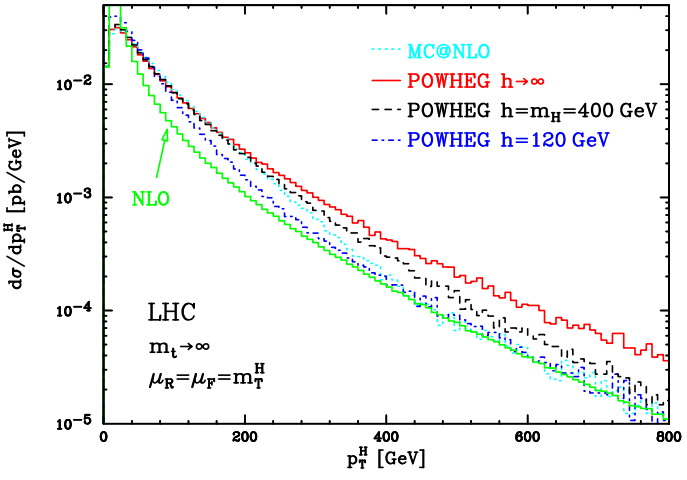
[arXiv:0812.0578]





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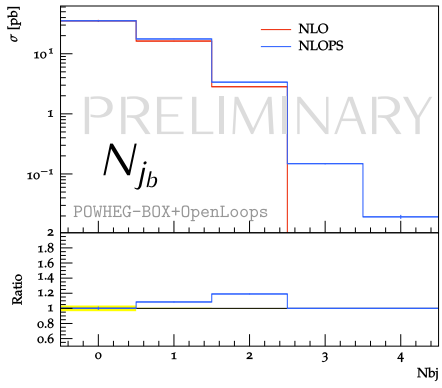
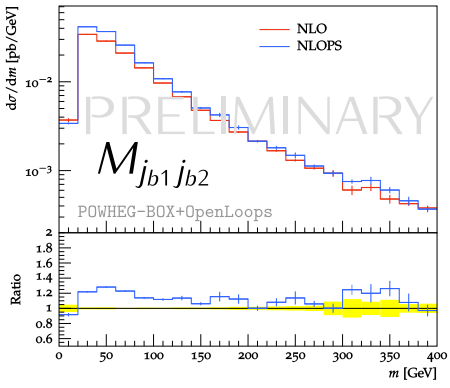
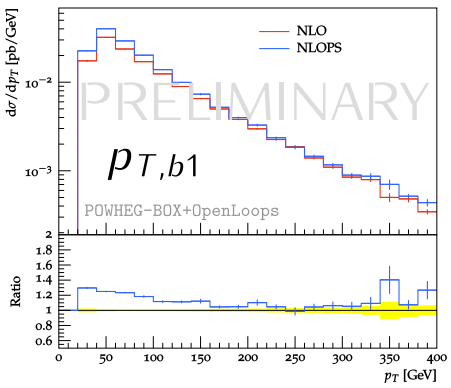
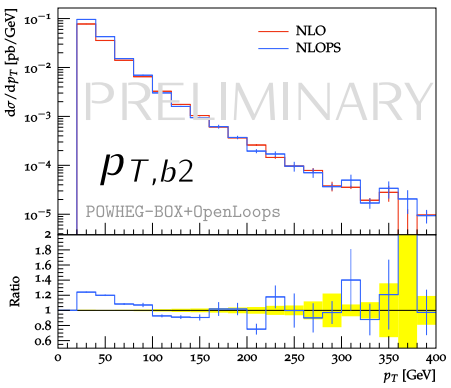
POWHEG BOX predictions

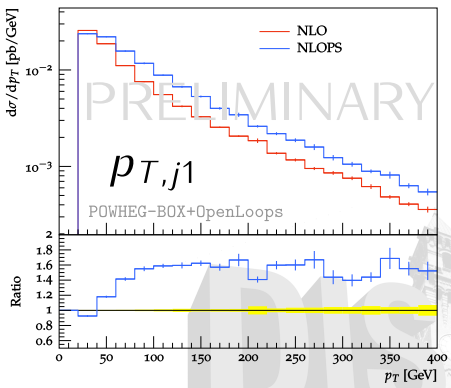
NLO vs. NLO+PS





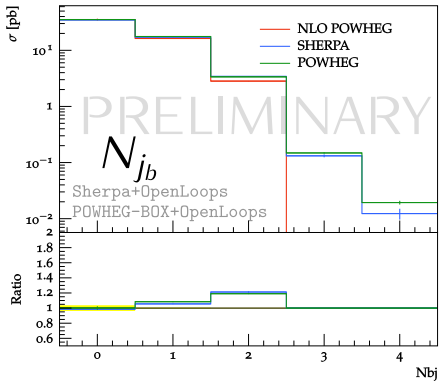


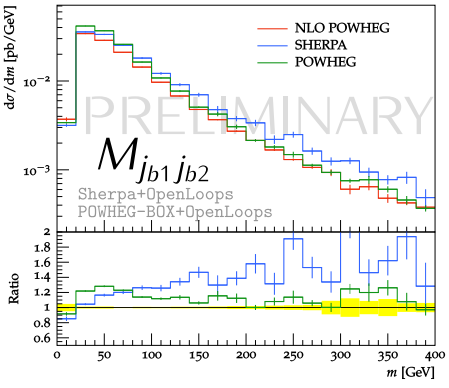


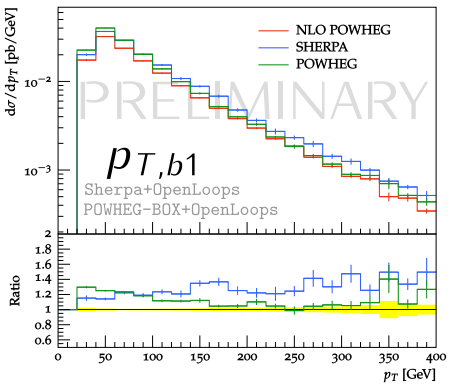


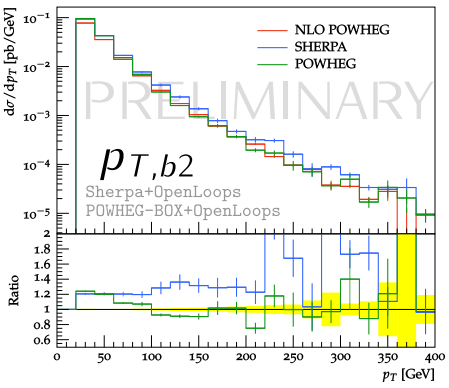
POWHEG BOX predictions

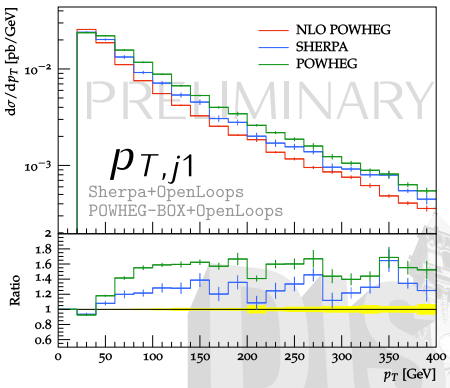
POWHEG-BOX vs. SHERPA





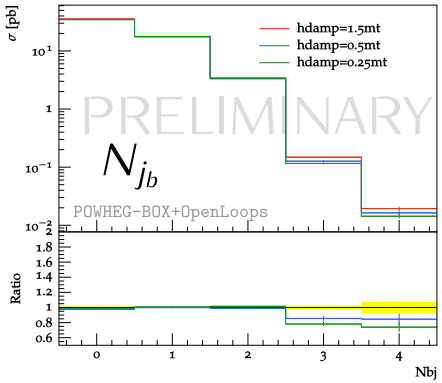


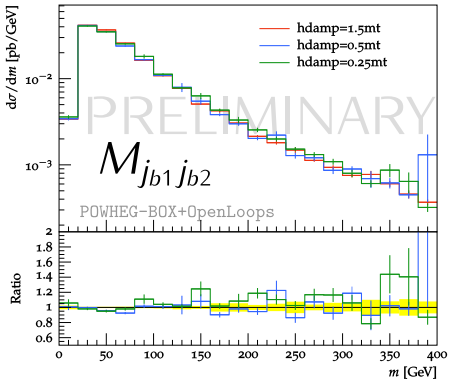


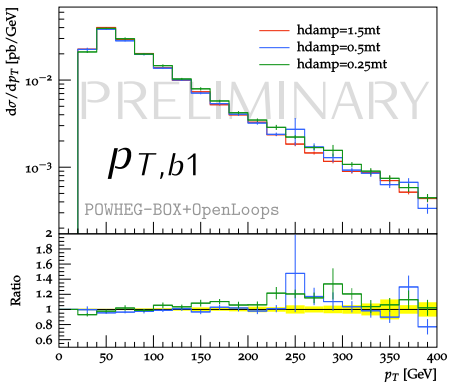


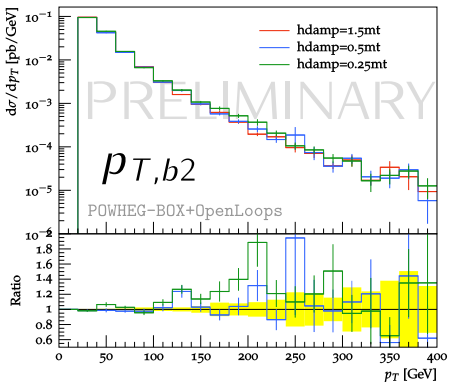
POWHEG BOX predictions

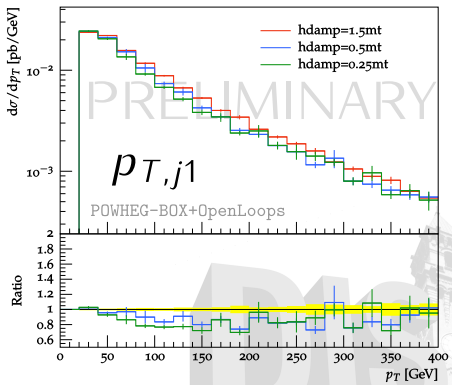
POWHEG-BOX hdamp dependence











Summary

- $t\bar{t}H$ is a direct probe of top Yukawa coupling
- QCD production of $t\bar{t}b\bar{b}$:
  - Irreducible background to $t\bar{t}H(b\bar{b})$
  - Dominates systematics in $t\bar{t}H(b\bar{b})$
  - Dominated by FS $g \to b\bar{b}$ splittings $\Rightarrow$ use of 4FNS important
- Available NLO+PS for $t\bar{t}b\bar{b}$ in MC@NLO framework in tension
  - Matching of a multi-scale problem with a single resummation scale straightforward?
- We implement $t\bar{t}b\bar{b}$ in `POWHEG-BOX+OpenLoops`
  - Good agreement with `Sherpa+OpenLoops`
  - Softer p_T spectra of both b-jets
  - Shower corrections to $M_{b\bar{b}}$ less significant
  - Predictions stable with respect to `hdamp`