THE 4TH FILM BY QUENTIN TARANTINO

KILL BBH

VOLUME 1

Deutschmann, Maltoni, Wiesemann, MZ, arXiv:1808.01660

VOLUME 2

Pagani, Shao, MZ, arXiv:2005.10277

Or why not to use $b\bar{b}H$ as a probe of the bottom Yukawa

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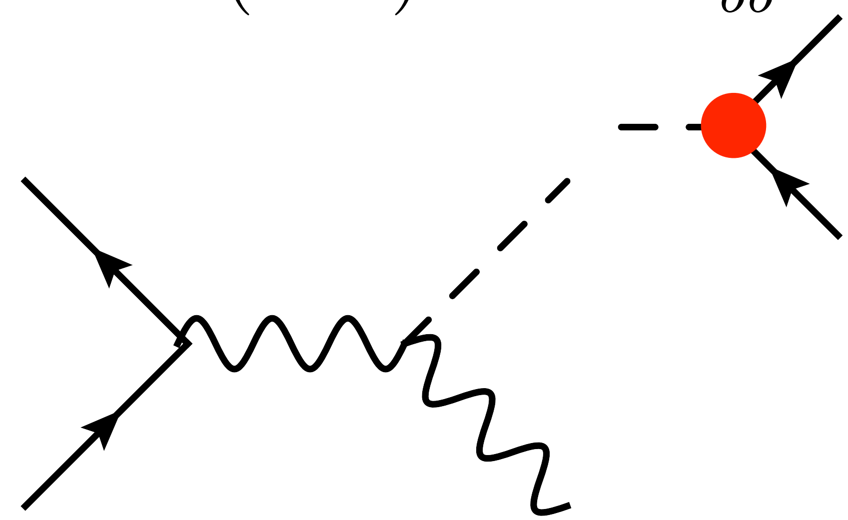
Sezione di Milano

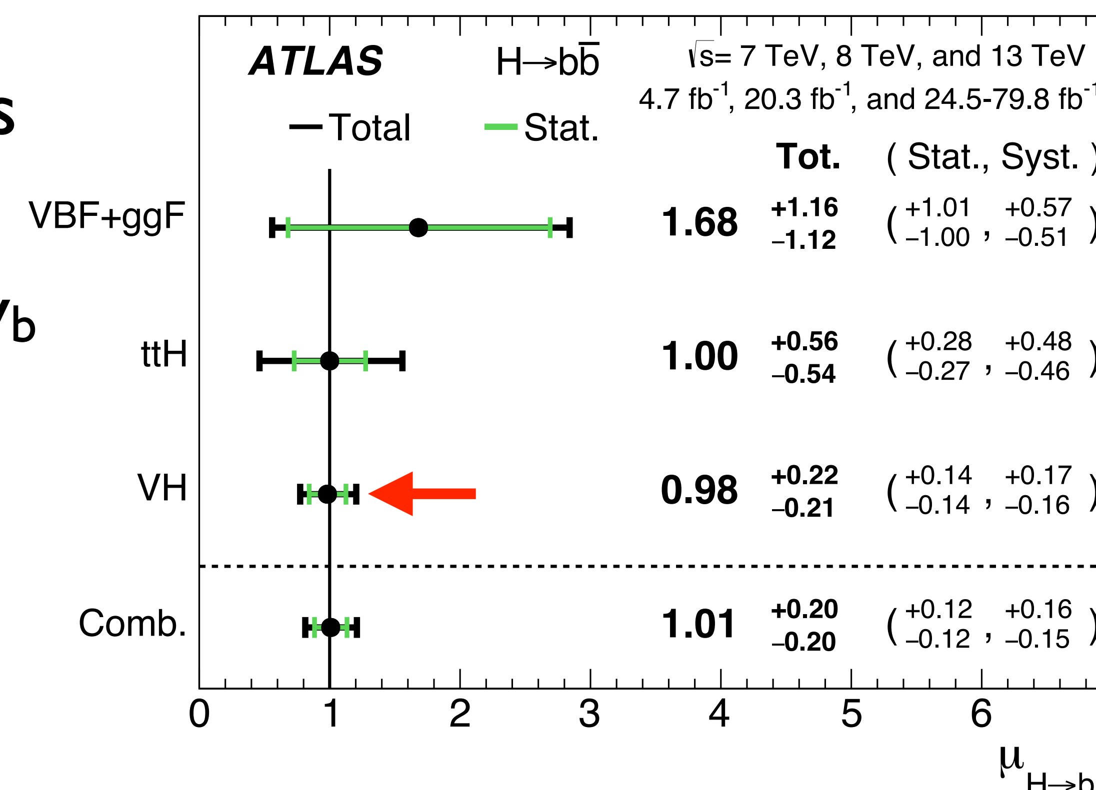
Probing y_b

$$\sigma(VH) \times \mathrm{BR}_{b\bar{b}}$$



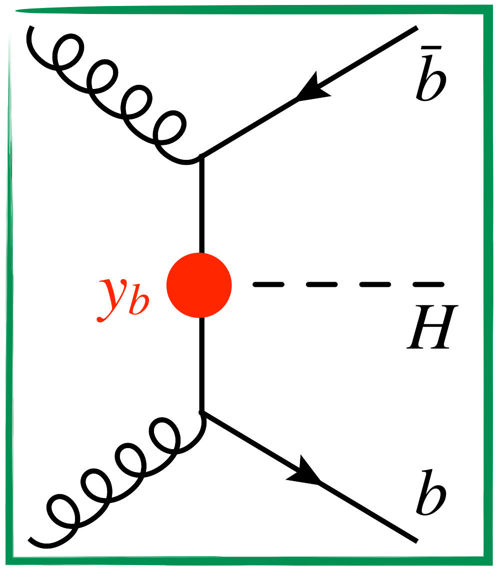
$$\mathrm{BR}_{b\bar{b}} = \frac{\Gamma_{b\bar{b}}}{\Gamma_{b\bar{b}} + \Gamma_{\mathrm{oth.}}}$$

- The main current source of sensitivity for y_b is via the $H\rightarrow b\bar{b}$ decay mode
- ATLAS and CMS measurements are compatible with SM, with ~15% uncertainty
- The $H\rightarrow b\bar{b}$ branching fraction may be affected by other unconstrained channels ($H\rightarrow gg$ and $H\rightarrow$inv.)
- Can we use $b\bar{b}H$ production to extract y_b (as $t\bar{t}H$ for y_t)?



What couplings are probed by $b\bar{b}H$?

- $b\bar{b}H$ has been thought as a clean access to y_b. Is it really the case?
- Can other channel pollute the extraction of y_b?
- Consider the $b\bar{b}H$ final state. Which processes can contribute?



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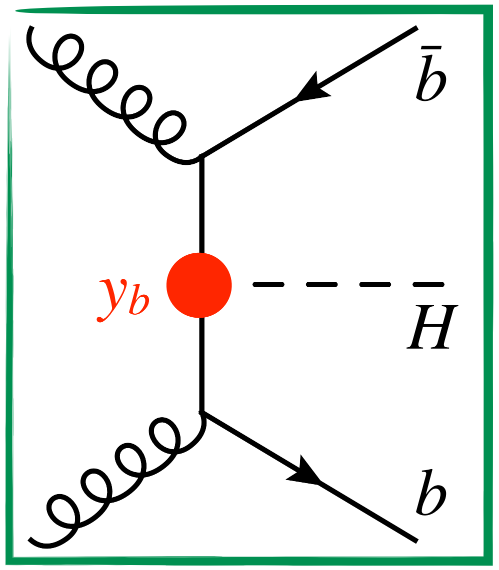

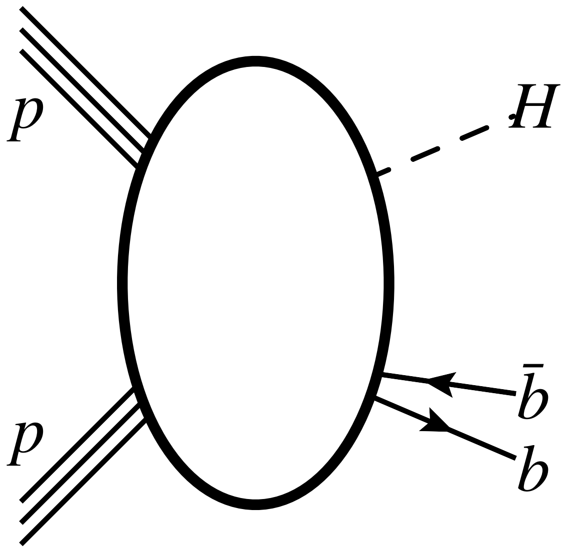

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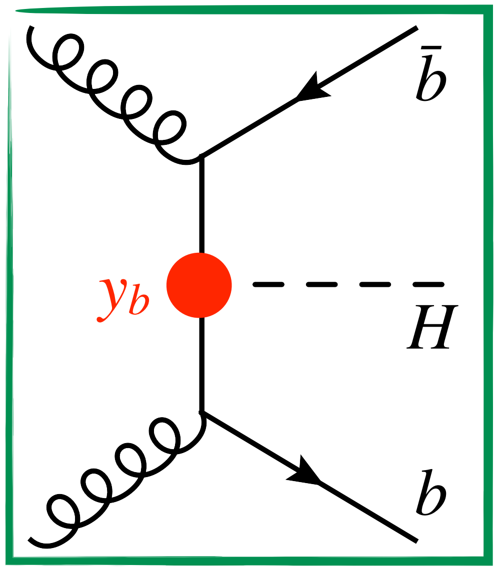

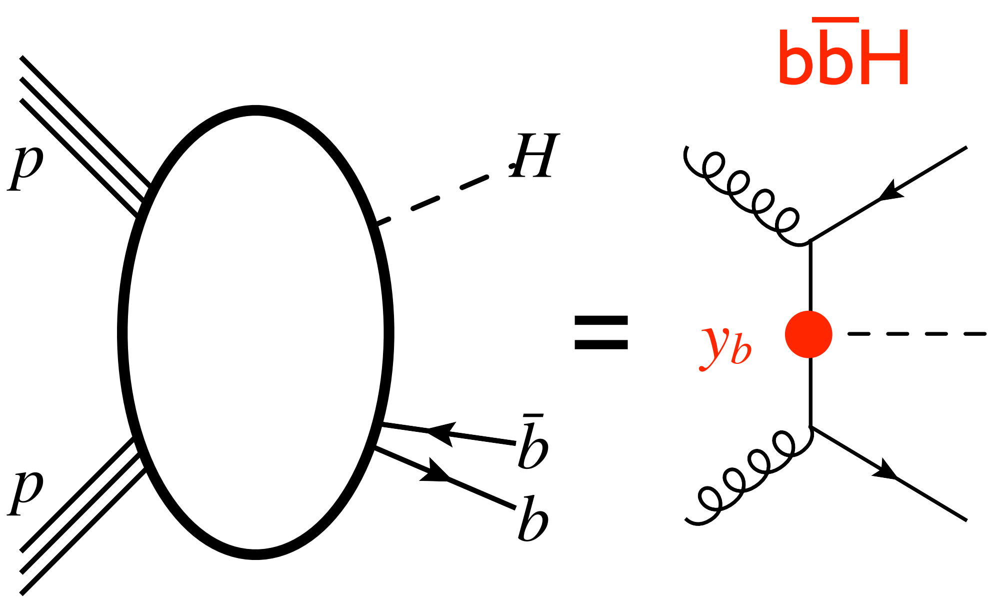

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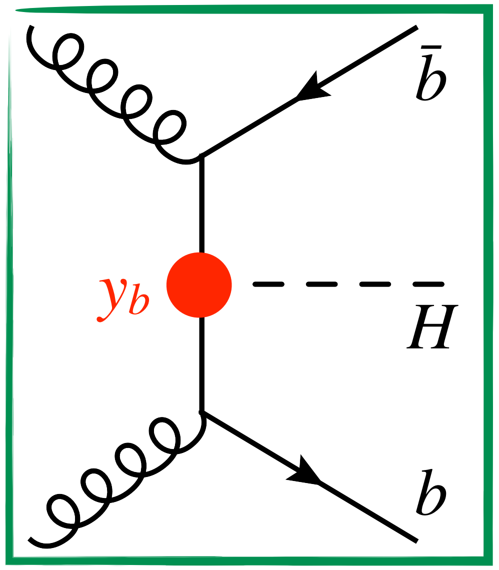

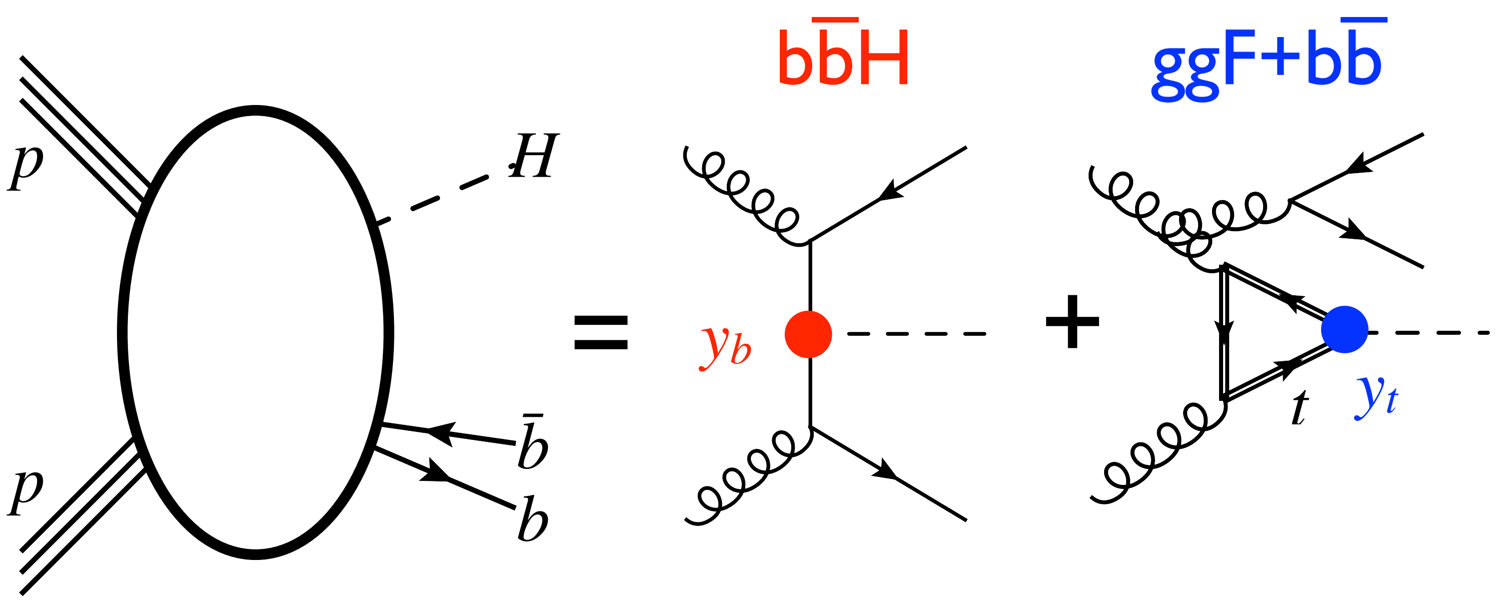

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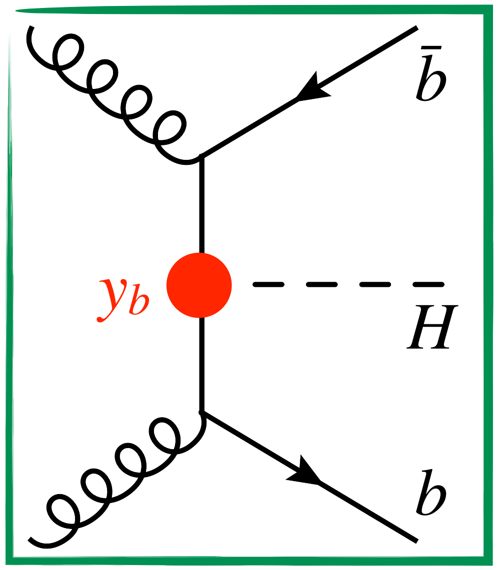

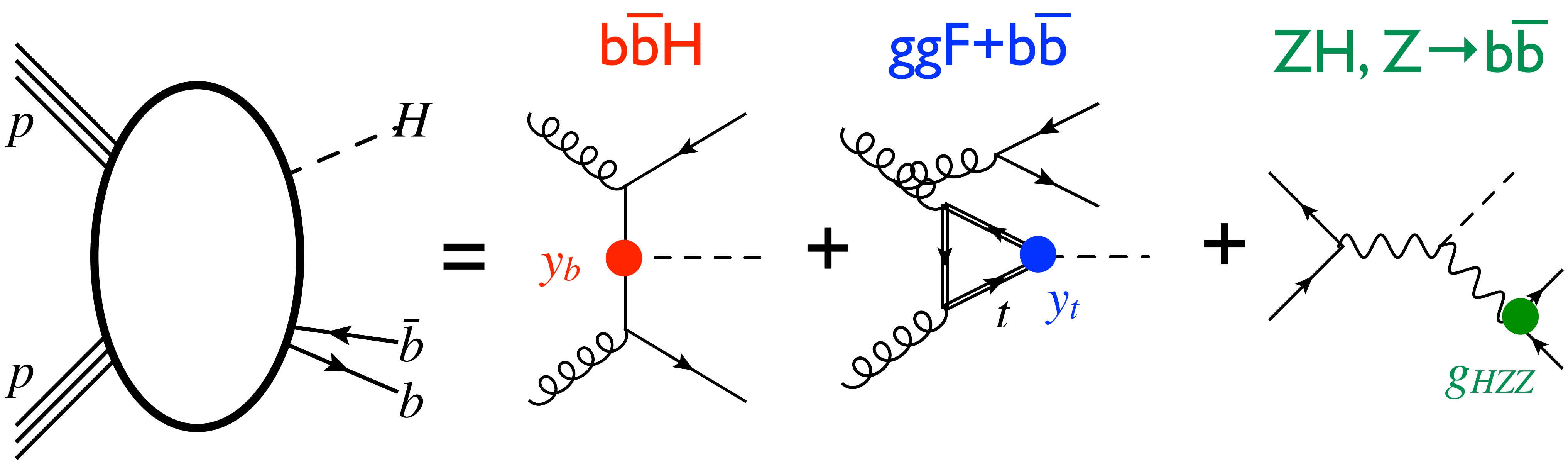

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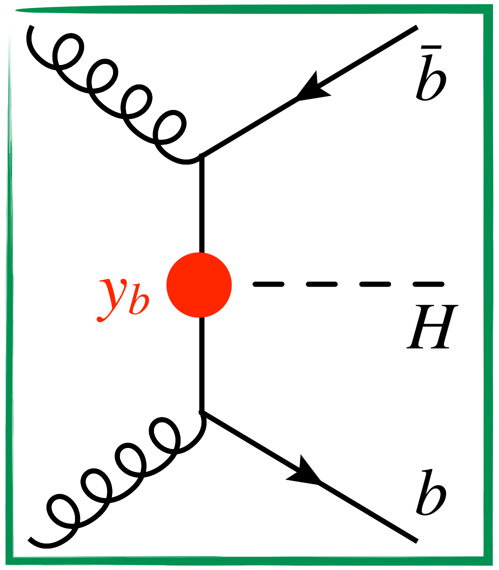

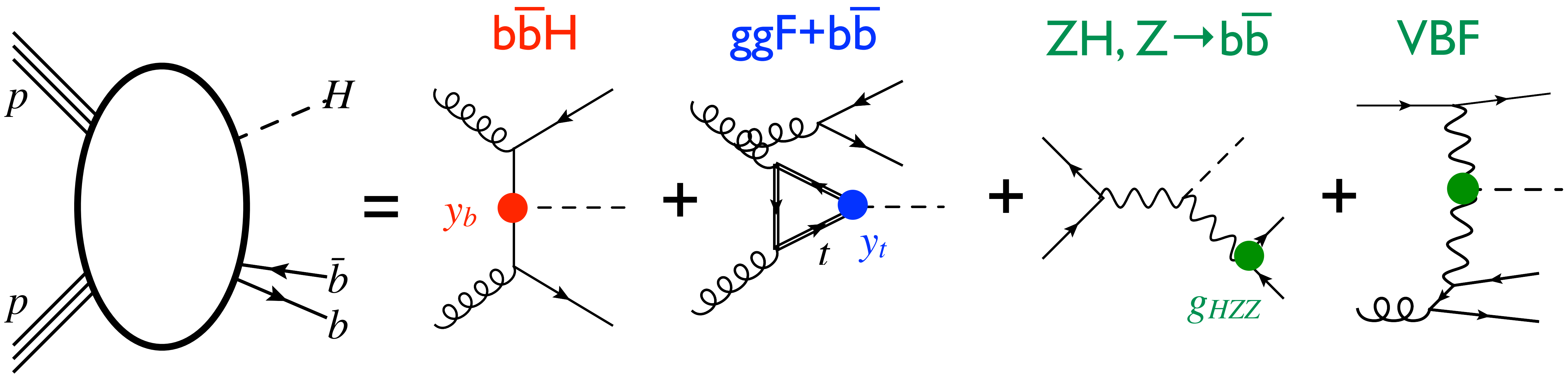

Remember: Higgs couplings ~ mass

VOLUME 1

y_t-induced $b\bar{b}H$

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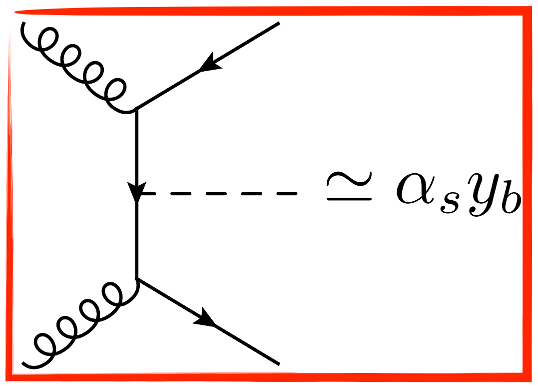

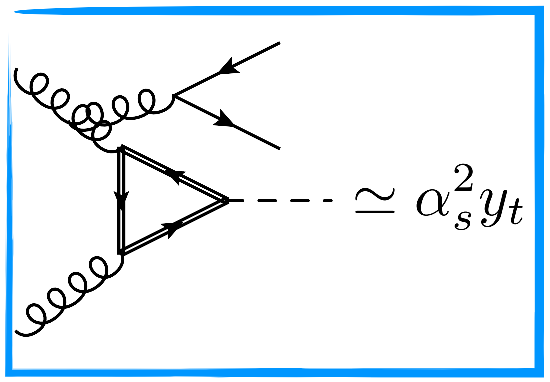

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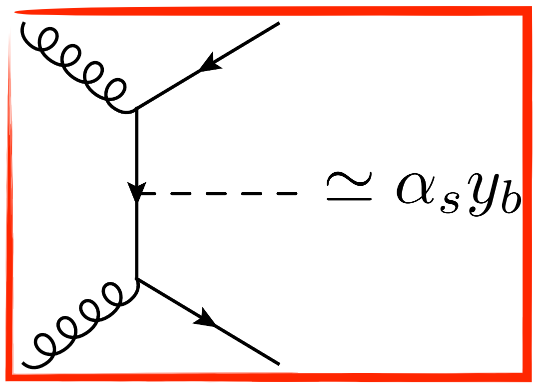

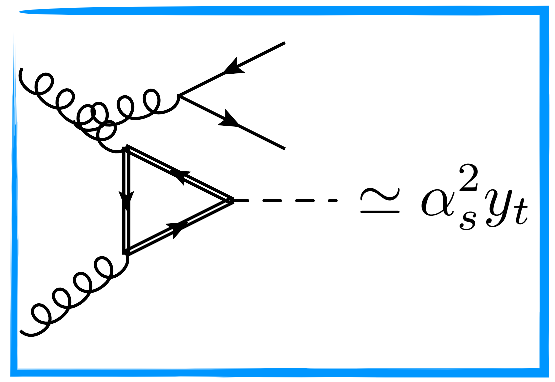

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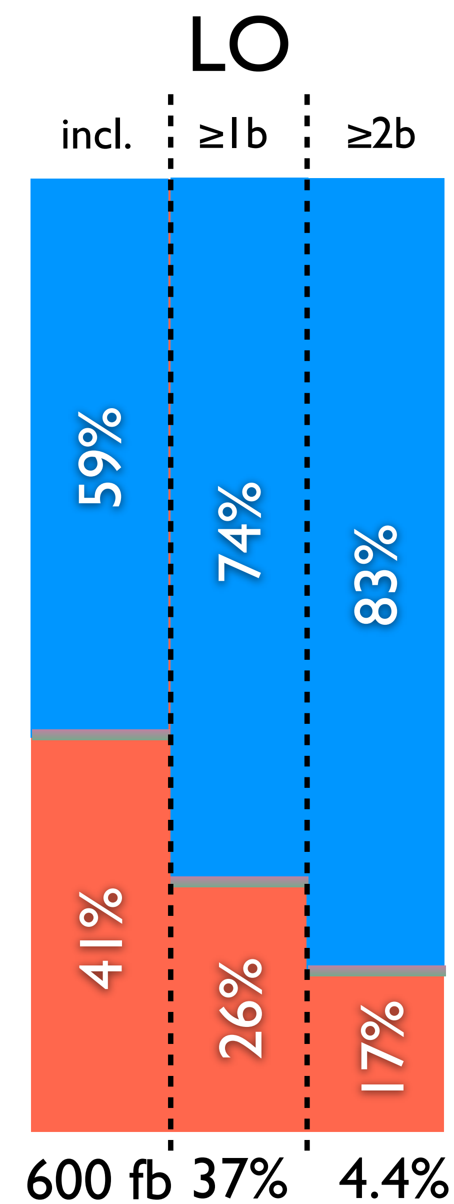

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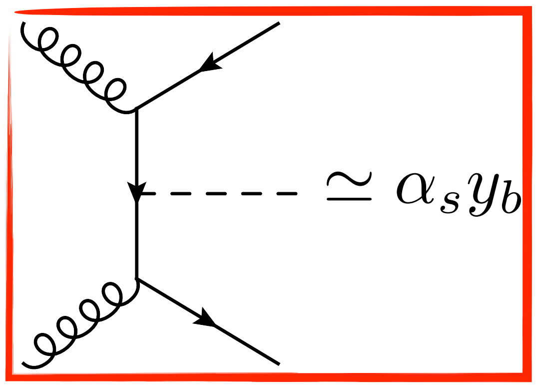

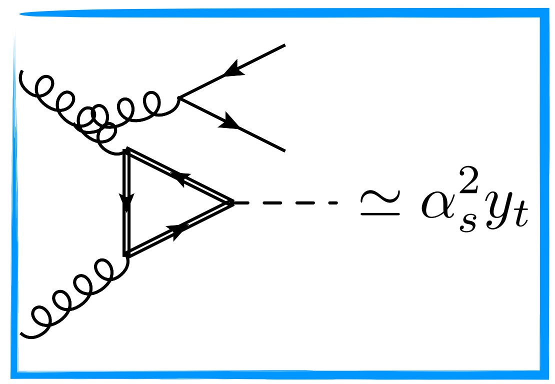

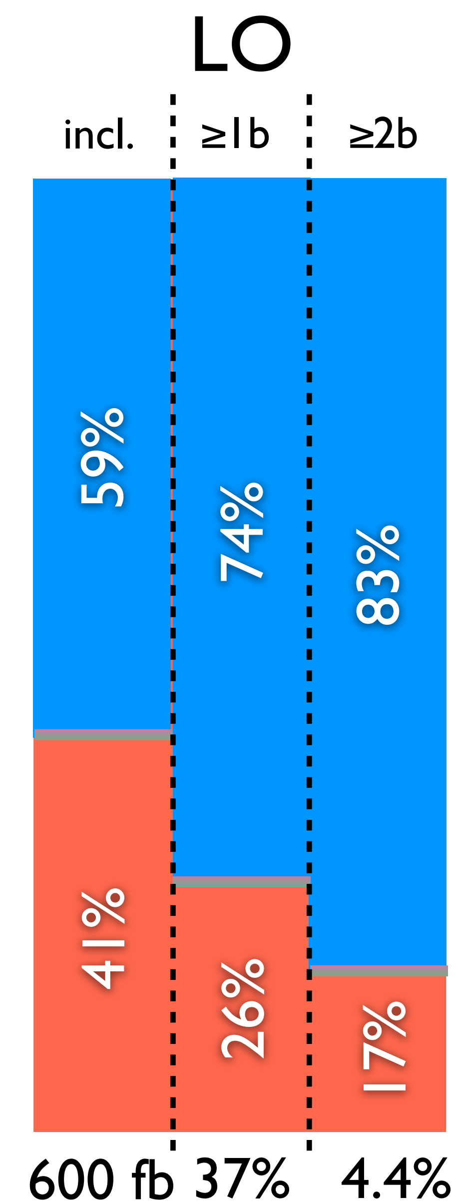

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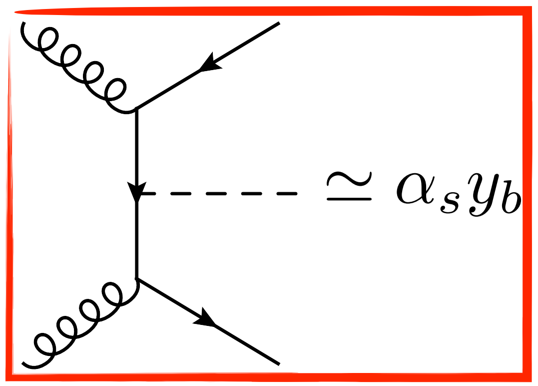

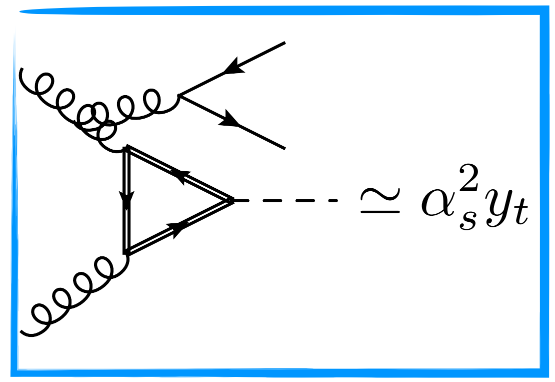

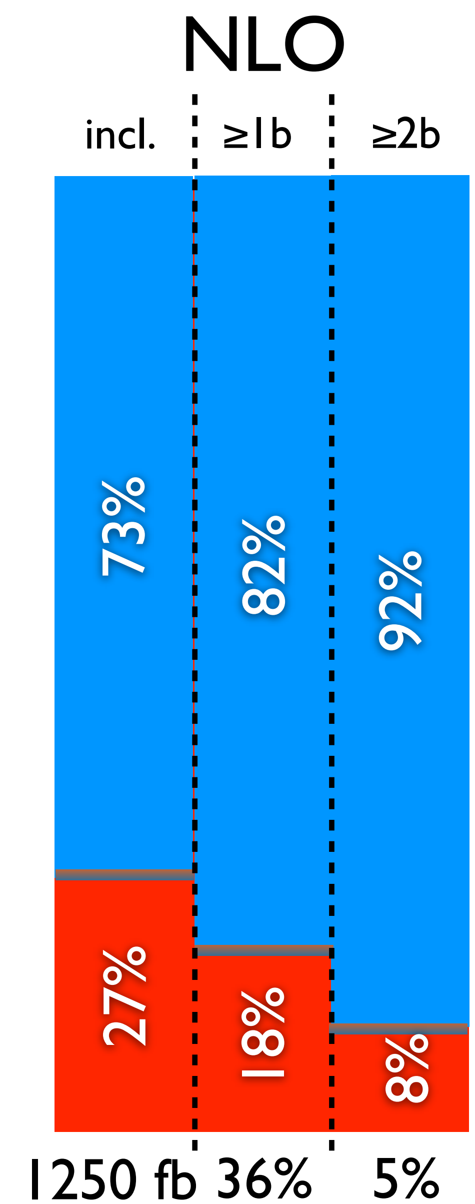

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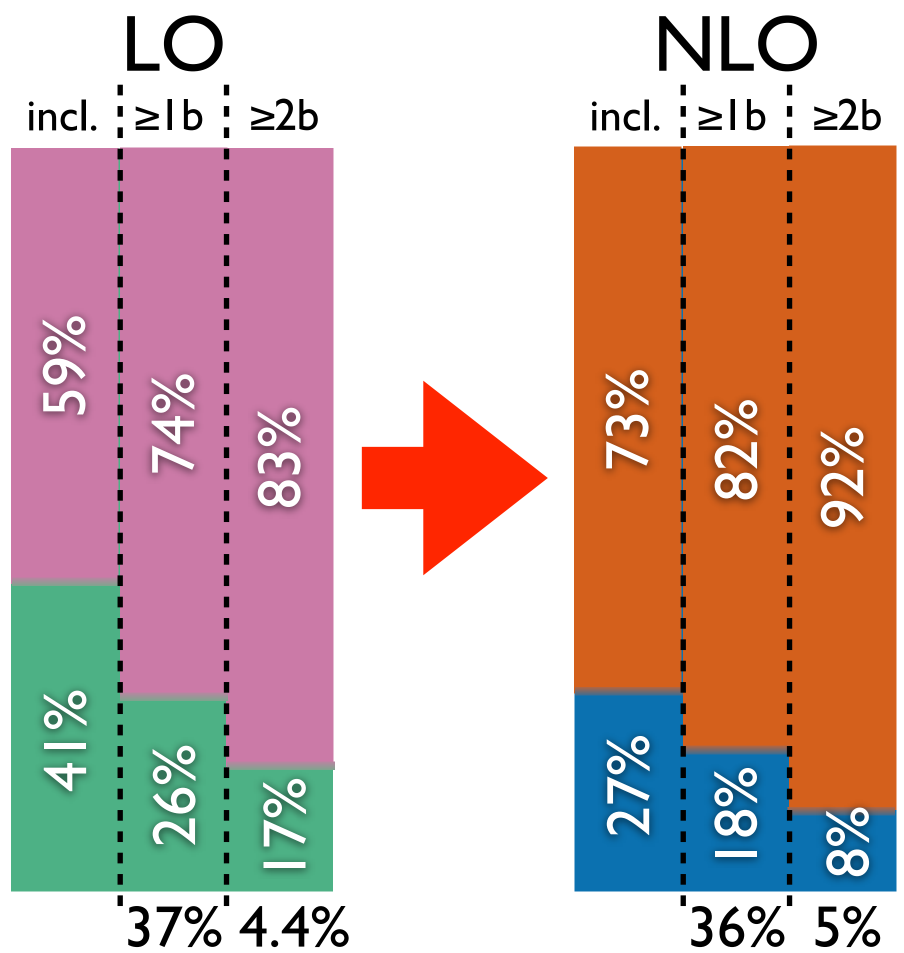
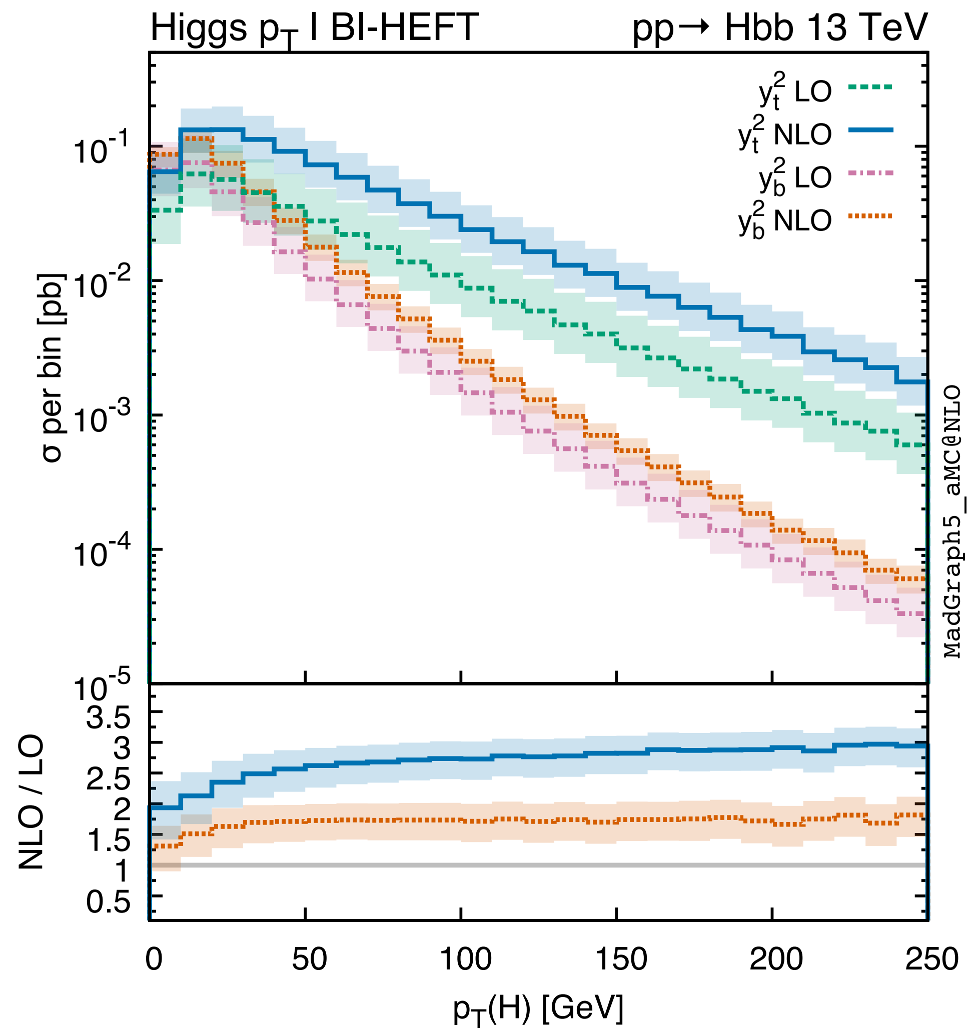
- But y_t^2 contributes to almost 3 times the y_b^2 when both are evaluated at their lowest order
- NLO corrections to both terms (and to the interference) are computed with `MG5_aMC` in the Born-improved HEFT
- At NLO (including terms ~y_t^2 formally N^{3}LO for the y_b^2 piece), the situation gets even worse

$b\bar{b}H$ at NLO

- The y_t^2 contribution has very large NLO corrections: inclusively, K=2.5! For y_b^2 K=1.5. The y_b^2 contribution to $b\bar{b}H$ is further suppressed
- Both K factors grow with the Higgs p_T, with y_t^2 showing a much harder spectrum





VOLUME 2

g_{HZZ}-induced $b\bar{b}H$

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LO: ❶ $\alpha\alpha_s^2$ ❷ $\alpha^2\alpha_s$ ❸ α^3

QCD / EW

NLO: ❶ $\alpha\alpha_s^3$ ❷ $\alpha^2\alpha_s^2$ ❸ $\alpha^3\alpha_s$ ❹ α^4

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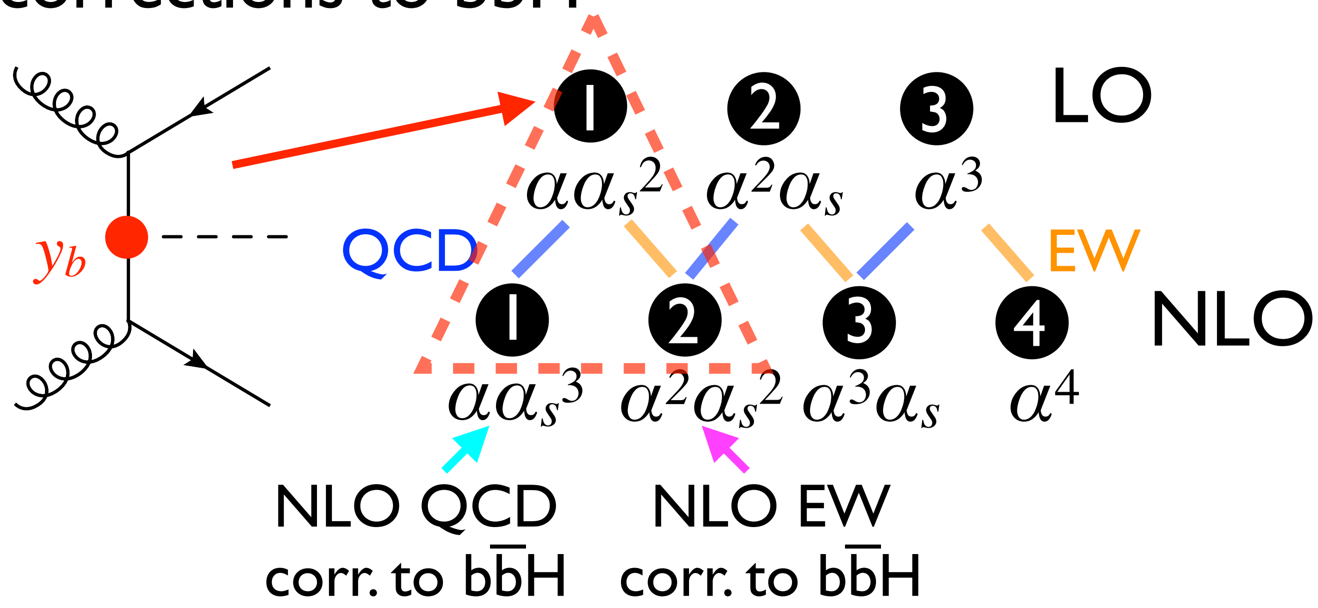

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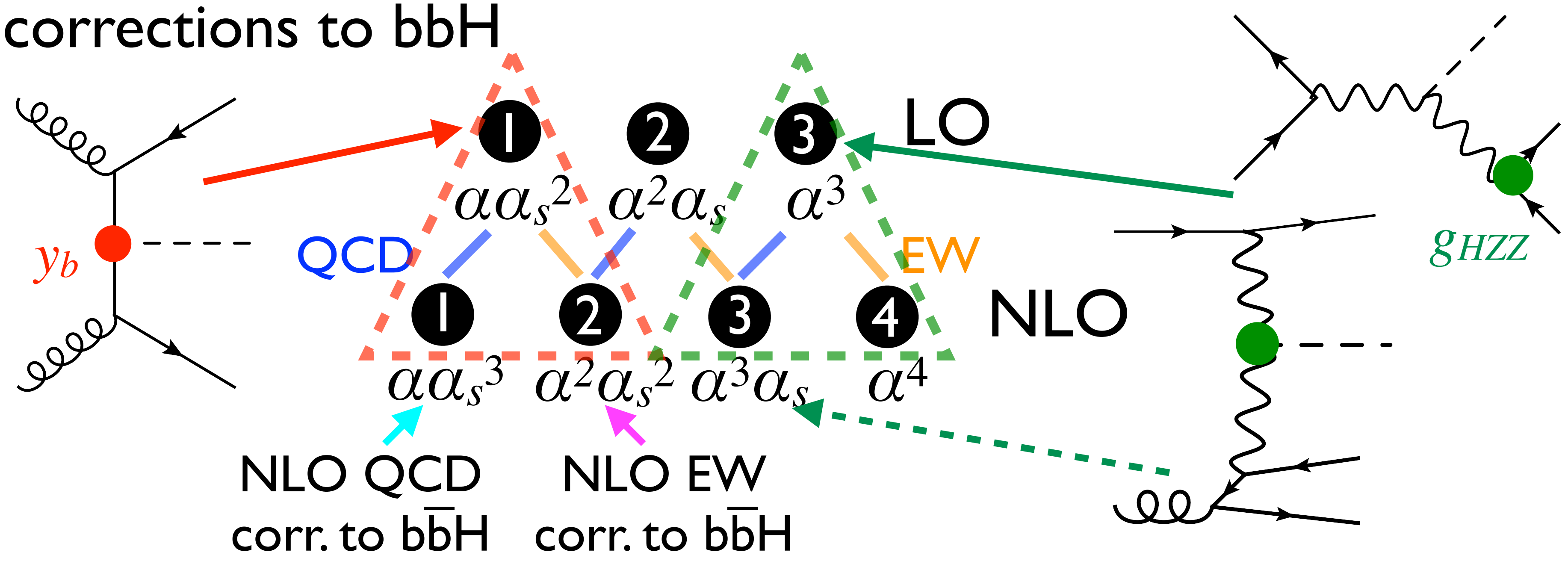

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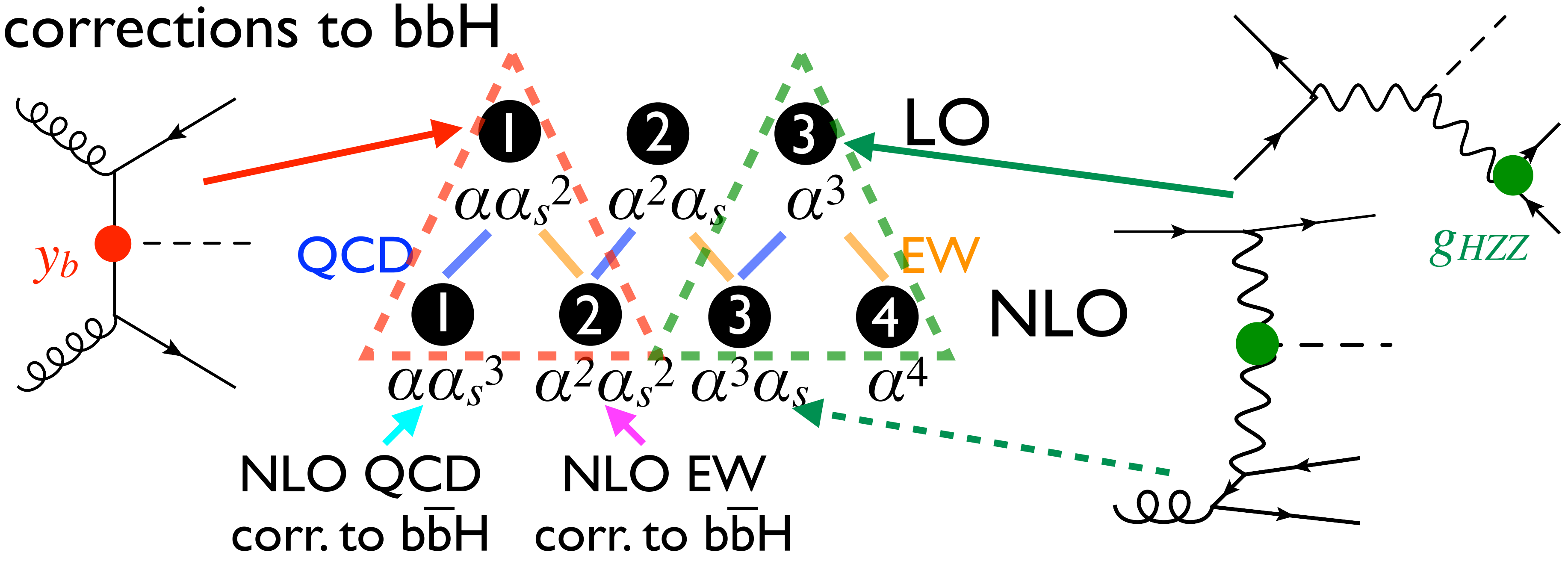

- Complete-NLO corrections computed with `MG5_aMC`, first process in the 4FS

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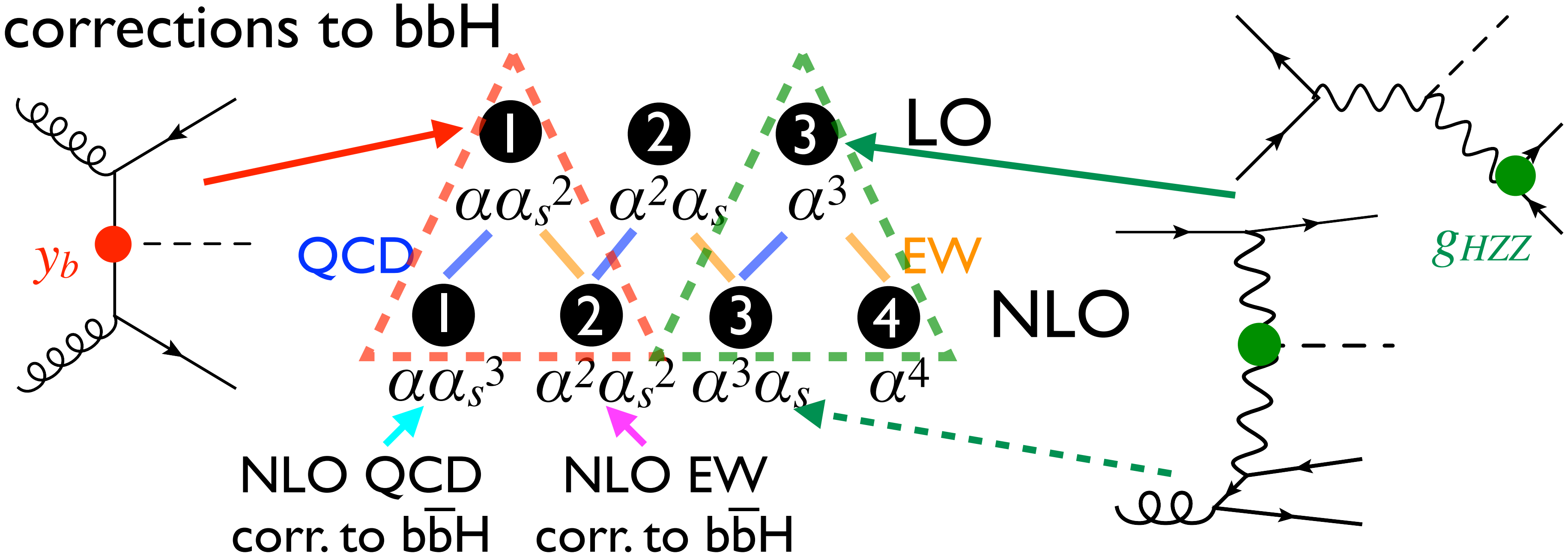

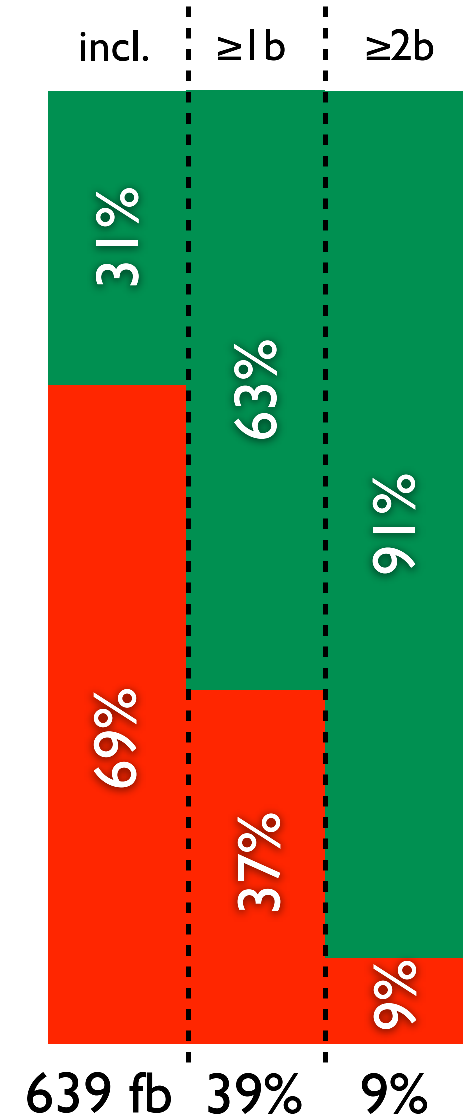

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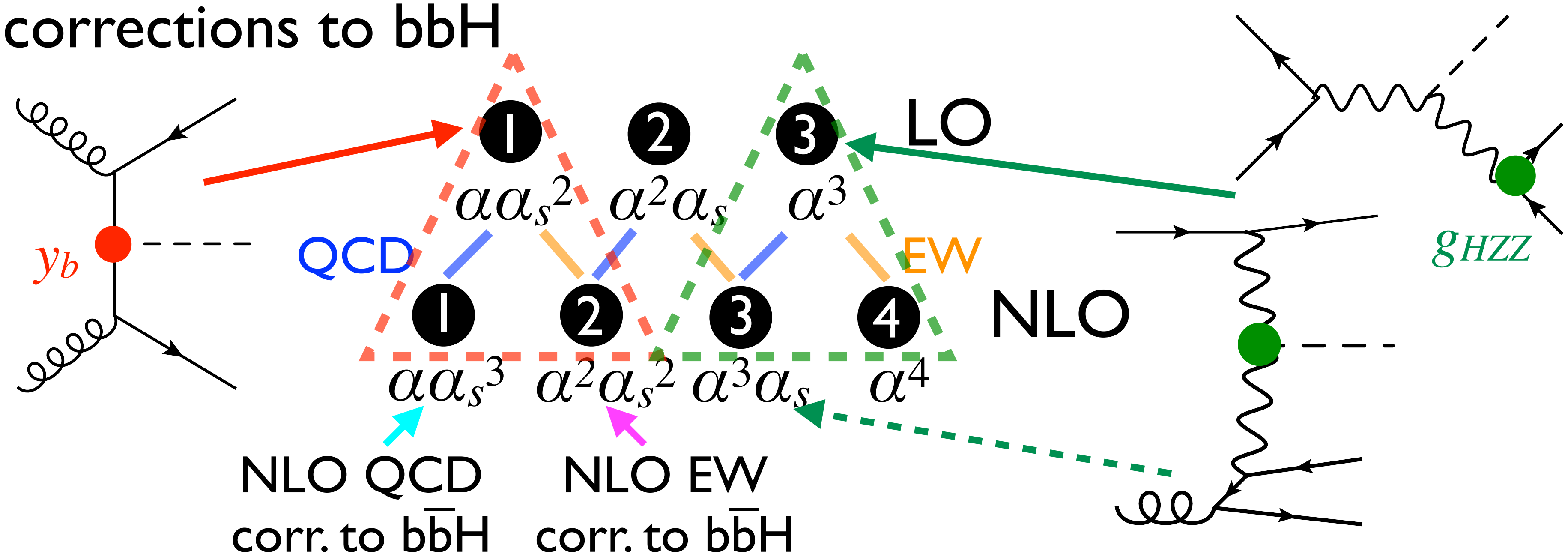
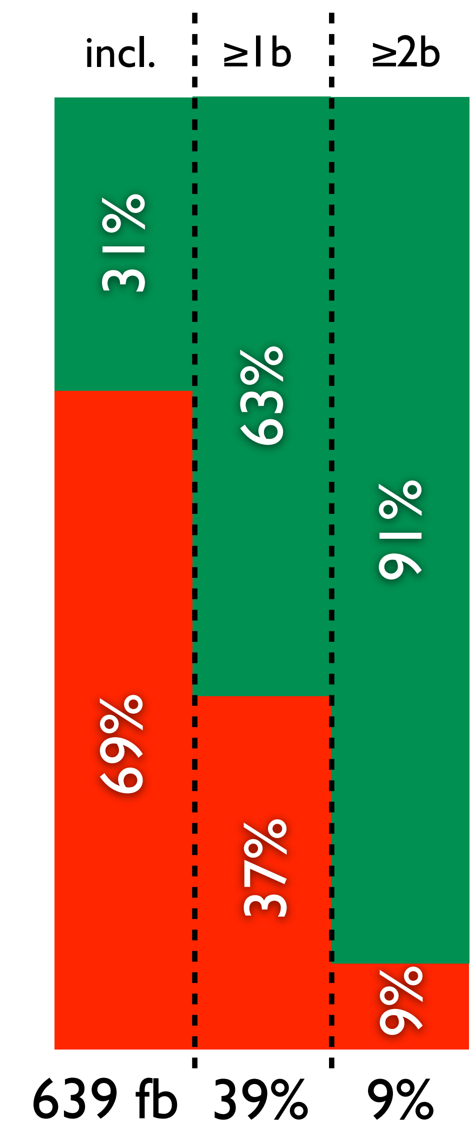
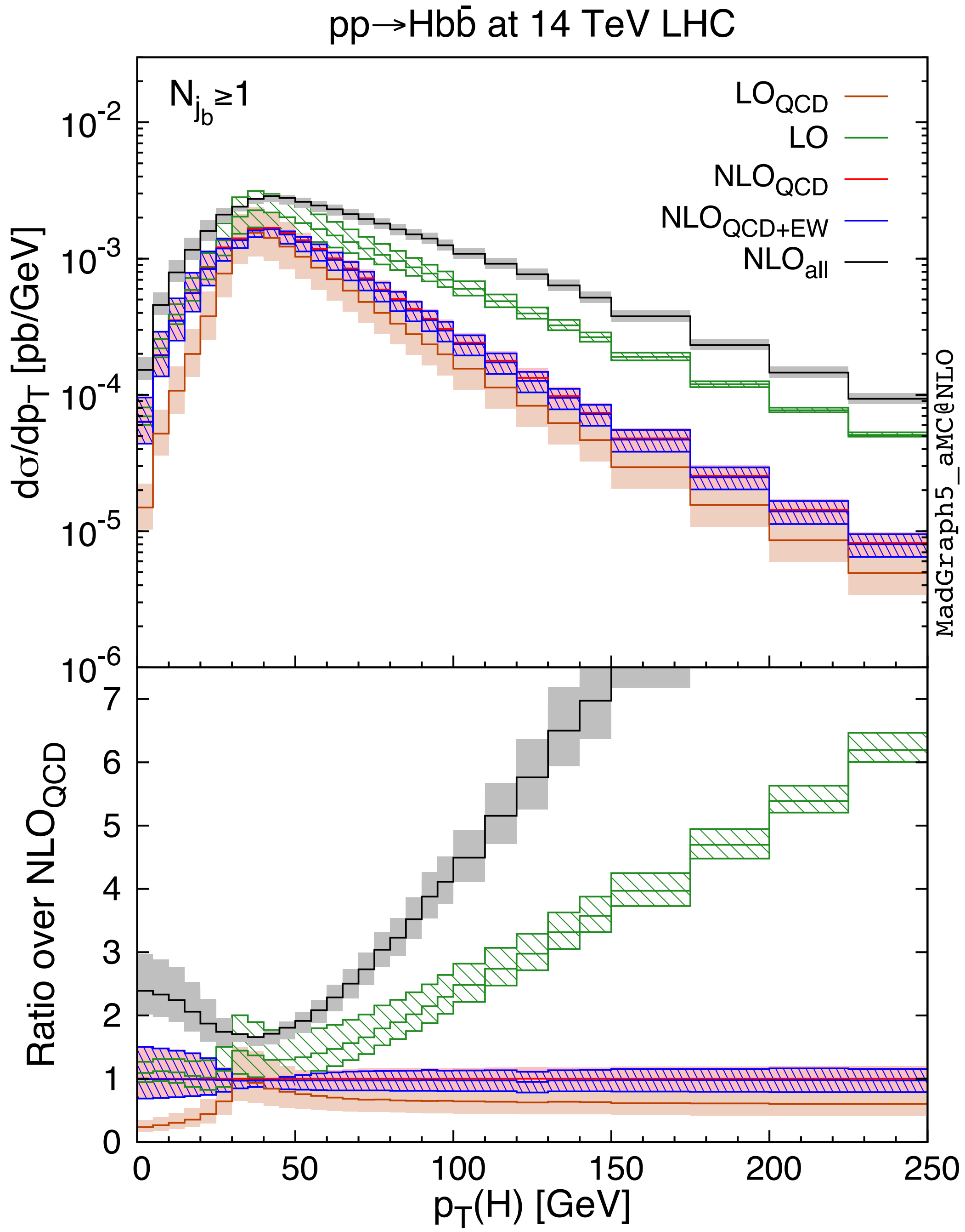


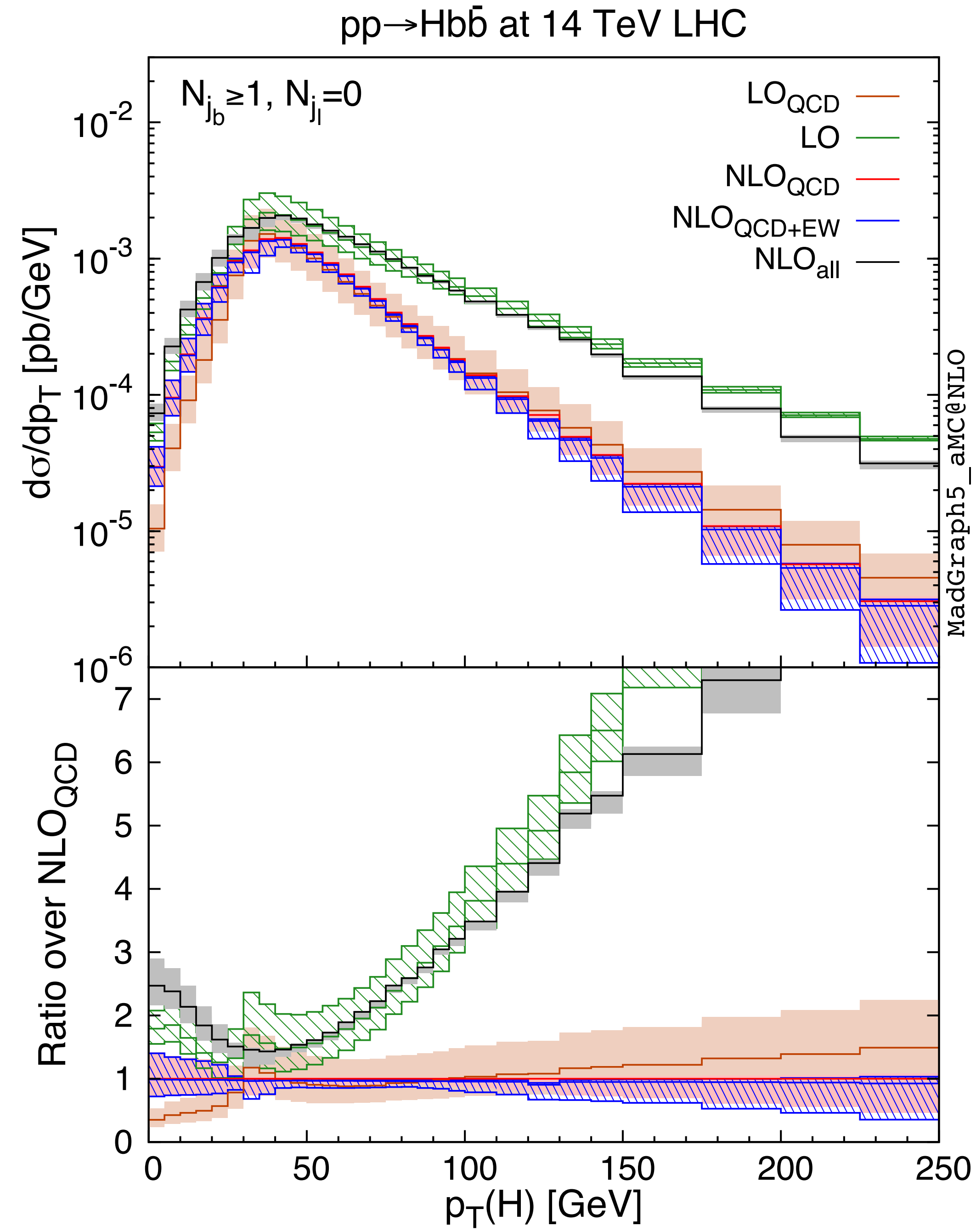
- Complete-NLO corrections computed with `MG5_aMC`, first process in the 4FS
- The α/α_s suppression is compensated by g_{HZZ}/y_b
- If (at least) 1 b-jet is required, almost 2/3 of the cross-section is not sensitive to y_b



Differential distributions
$N_b \geq 1$

light jet veto

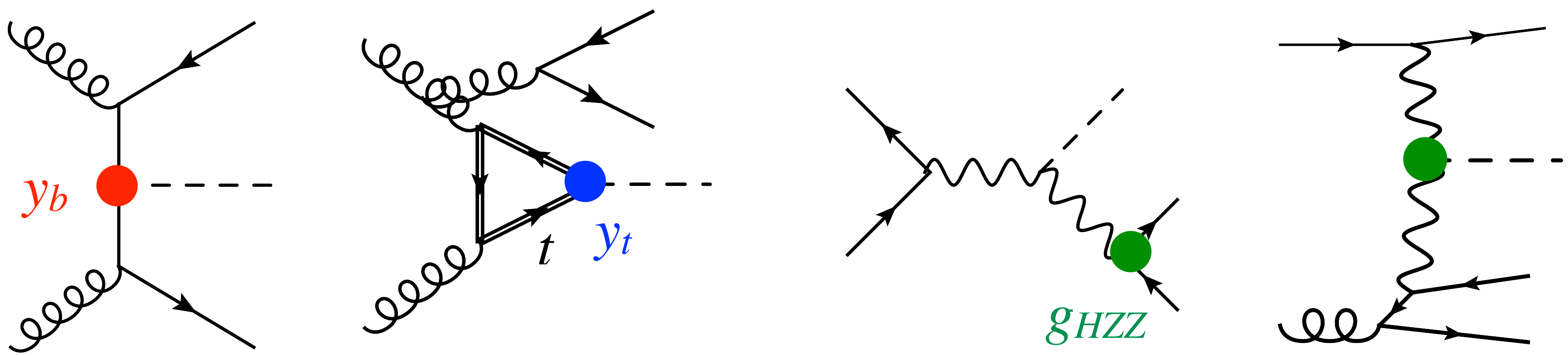


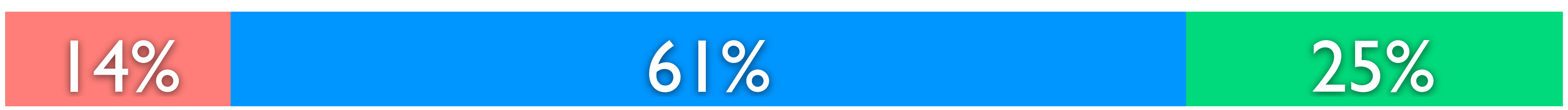


Goodbye y_b…

- Putting all together, asking for 1 b jet (ak$_T$, R=0.4, p_T>30 GeV, $|\eta|$<2.5)

$b\bar{b}H$ ggF+$b\bar{b}$ ZH, $Z\to b\bar{b}$ VBF+b





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$b\bar{b}H$ final state is only marginally sensitive to y_b

This holds true in the SM, and BSM for O(1) effects on y_b

For extra Higgs bosons (≠125 GeV), estimates of sensitivity should account for all the backgrounds

Higgs decay remains the most effective way to constrain y_b

Conclusion

- $Hb\bar{b}$ final state receives large contributions not proportional to y_b
- Relevant whenever H+b's is a signal or background (HH, …)
- Looking at differential observables (jet veto, small/large p_T, …) does not improve the picture (more in backup)
- Allowed range for y_b in current global fits unlikely to alter this (sad) picture

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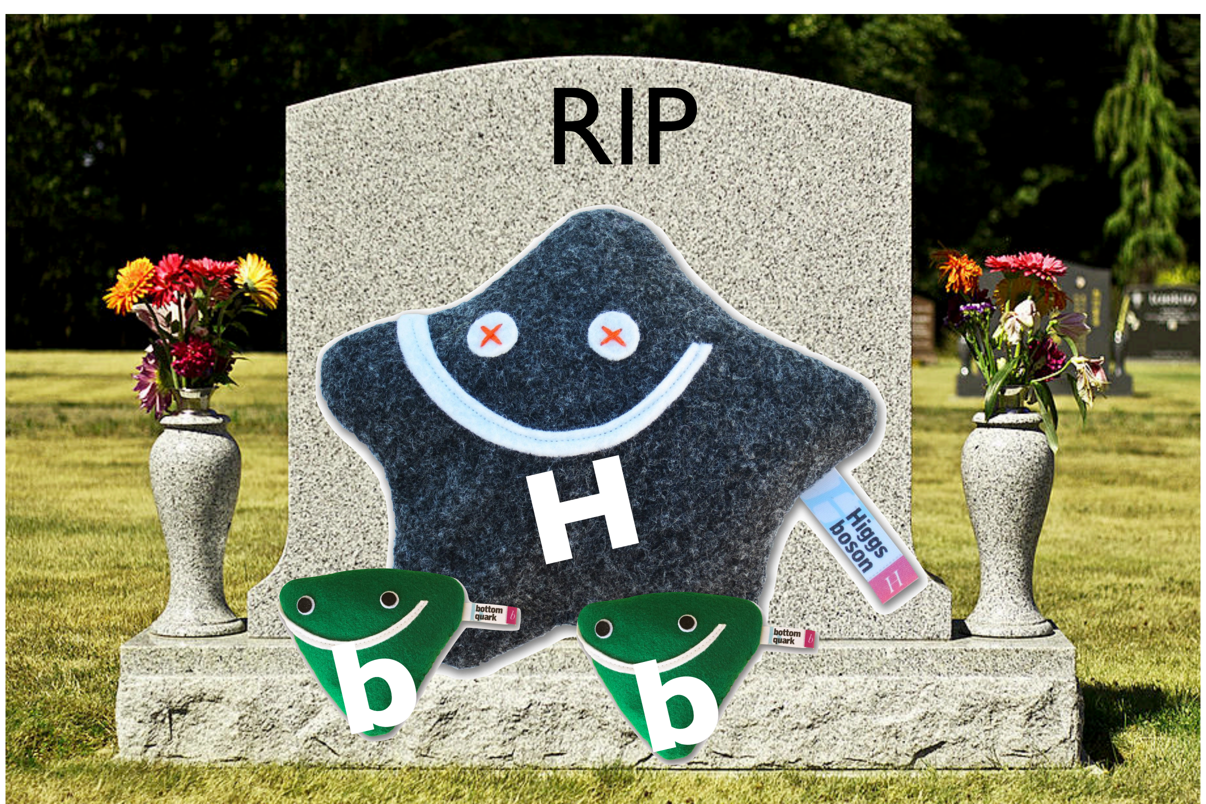

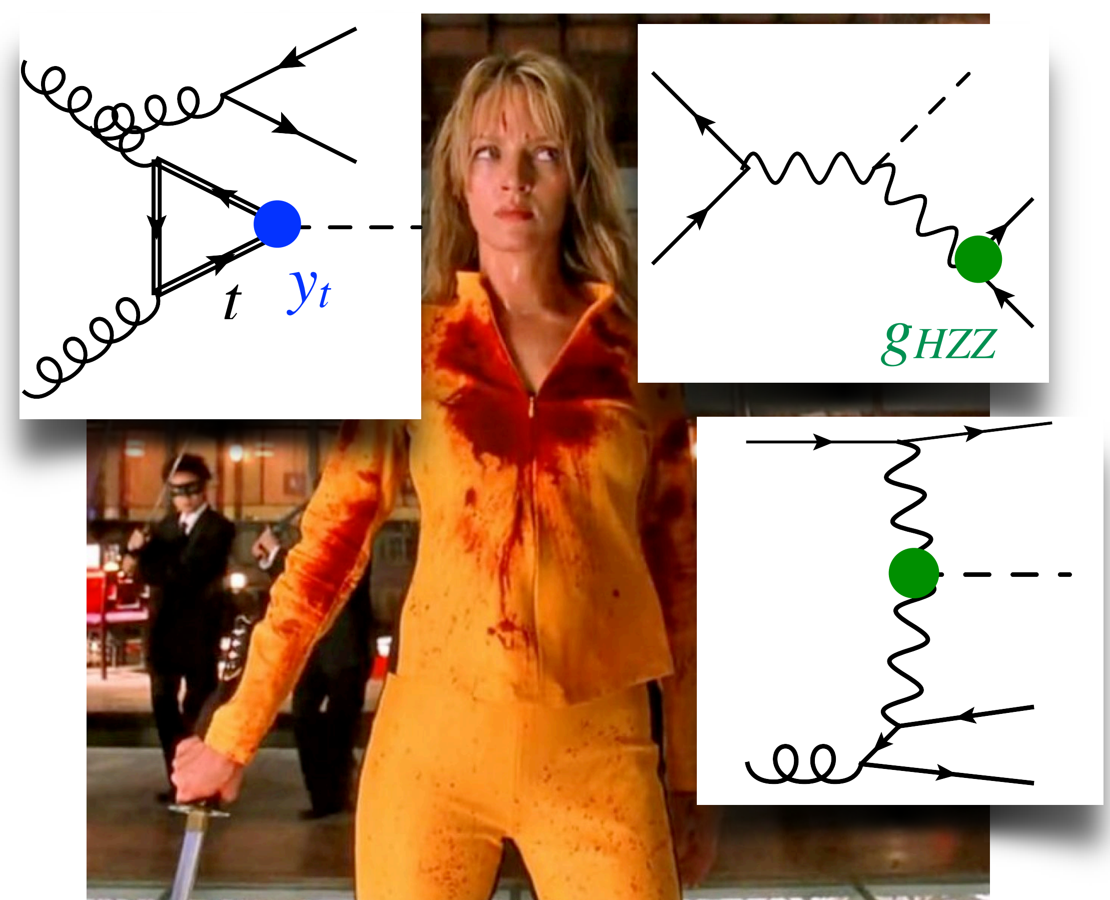

…or maybe not?

Resurrecting $b\bar{b}h$ with kinematic shapes

arXiv:2011.13945, see talk by Zhuoni Qian

Christophe Grojean,[a,b] Ayan Paul,[a,b] and Zhuoni Qian[a,c]

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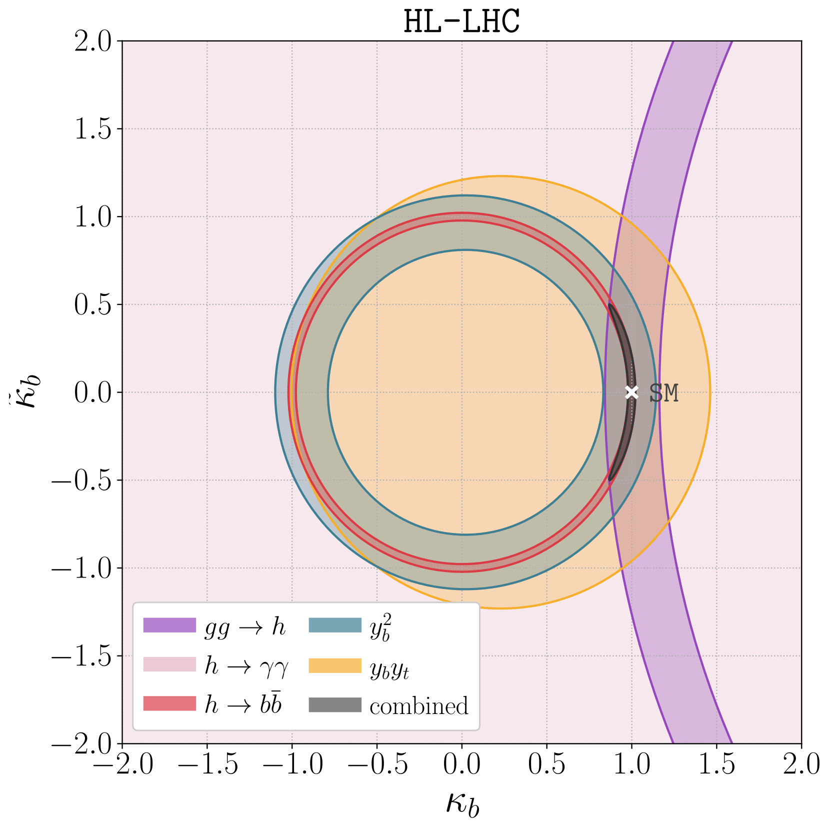
[b] *Institut für Physik, Humboldt-Universität zu Berlin, D-12489 Berlin, Germany*
[c] *Department of Physics, Shandong University, Jinan, Shandong 250100, China*

E-mail: christophe.grojean@desy.de, ayan.paul@desy.de, zhuoni.qian@desy.de



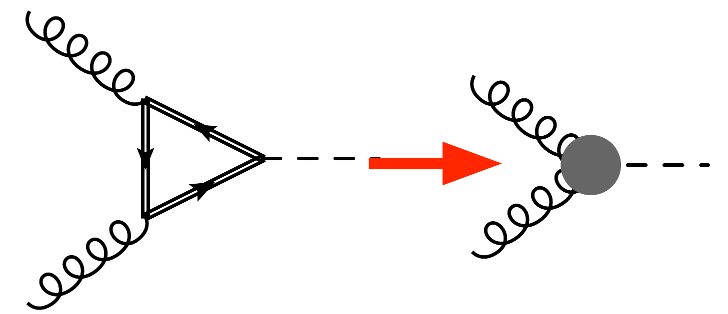
- New analysis based on modern AI techniques and game theory
- Authors claim to be able to reduce the ggF and VH bkgds, getting O(20%) constraints on y_b from bbH
- VBF is not considered in the analysis
- Eager to see how the movie ends…

Backup

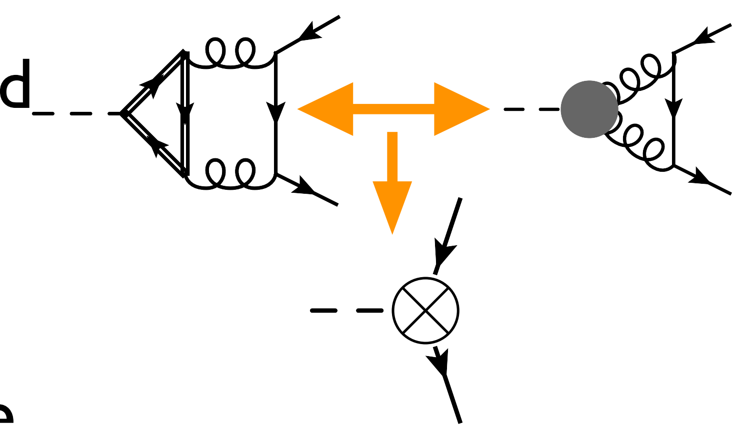
VOLUME 1

Computing NLO corrections to $b\bar{b}H$

- NLO corrections to y_b-induced $b\bar{b}H$ known for long time
  5FS NLO: Dicus, hep-ph/9811492, Balazs, hep-ph/9812263; 5FS NNLO: Harlander, hep-ph/0304035 4FS NLO: Dittmaier, hep-ph/0309204, Dawson, hep-ph/0508293; 4FS NLOPS: Wiesemann, arXiv:1409.5301, Jager, arXiv:1509.05843, Krauss, arXiv:1612.04640



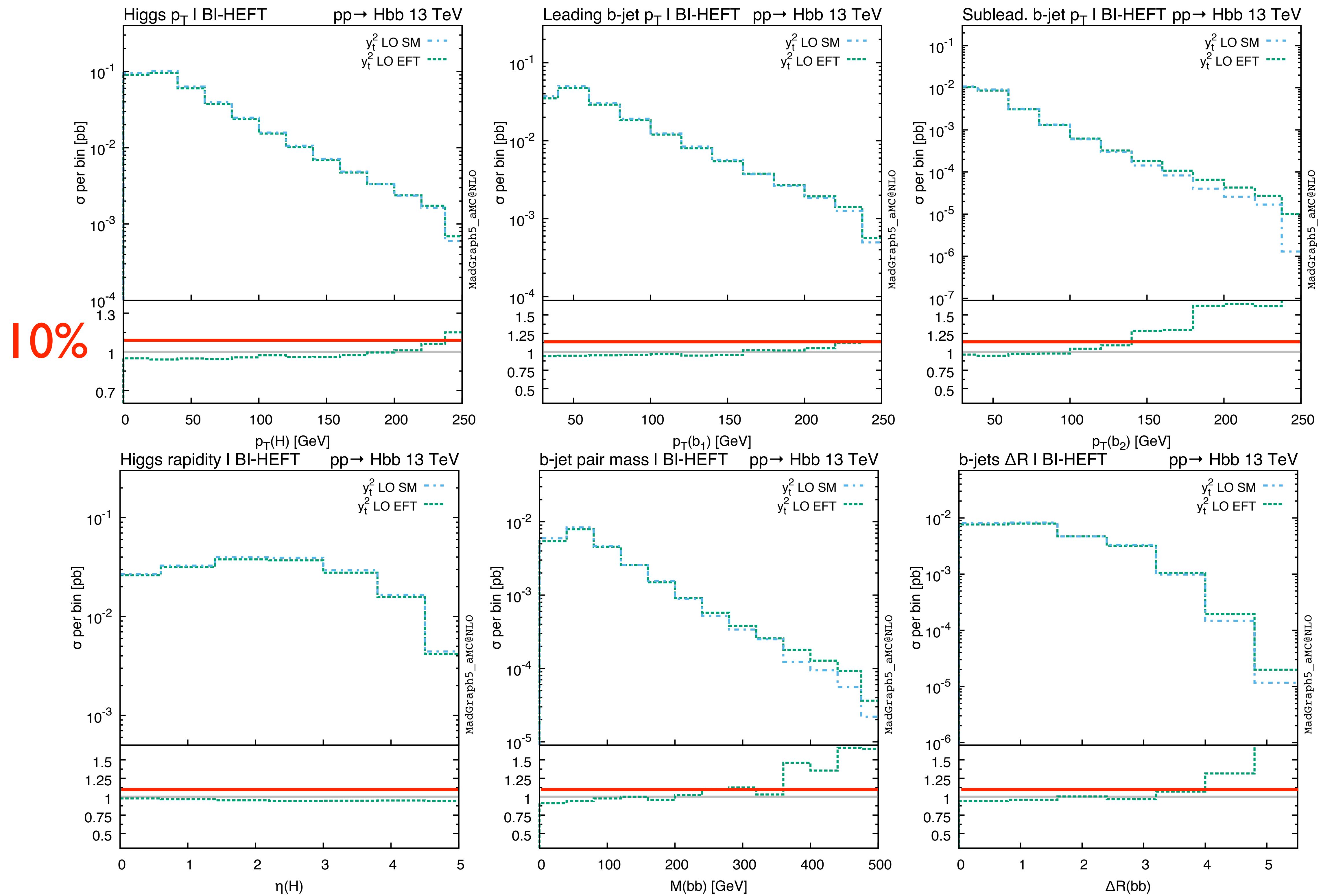
- y_t-induced contribution missing, mostly for two reasons
  - Loop-induced at LO→ 2 loops at NLO with 3 particles in the final state. Beyond current 2-loop technology
    Solution: Use an HEFT to shrink the top loop into a pointlike interaction
  - If mb≠0, in the HEFT y_b receives a correction ~y_t. Obtained by matching HEFT with 2-loop SM.
    Reproduced results by Chetyrkin et al, PRL 1997, NPB 1997, hep-ph/9708255



- This made it possible to use modern automatic codes (`MadGraph5_aMC@NLO`) to compute simultaneously the y_t^2, y_b^2 and $y_t y_b$ terms at NLO QCD
- We use m_H=125 GeV, m_b^{pole}=4.92 GeV, m_t=172.5 GeV, NNPDF3.1 (n_f=4), y_b renorm. in MSbar, $\mu_{R/F}=H_T/4$

$$\delta y_b = y_t \left(\frac{\alpha_s}{2\pi}\right)^2 \left(\frac{m_b}{m_t}\right) \left[\frac{C_F}{2\epsilon} - \frac{C_F}{24}\left(5 - 6\log\left(\frac{\mu_R^2}{m_t^2}\right)\right)\right]$$

EFT and $b\bar{b}H$



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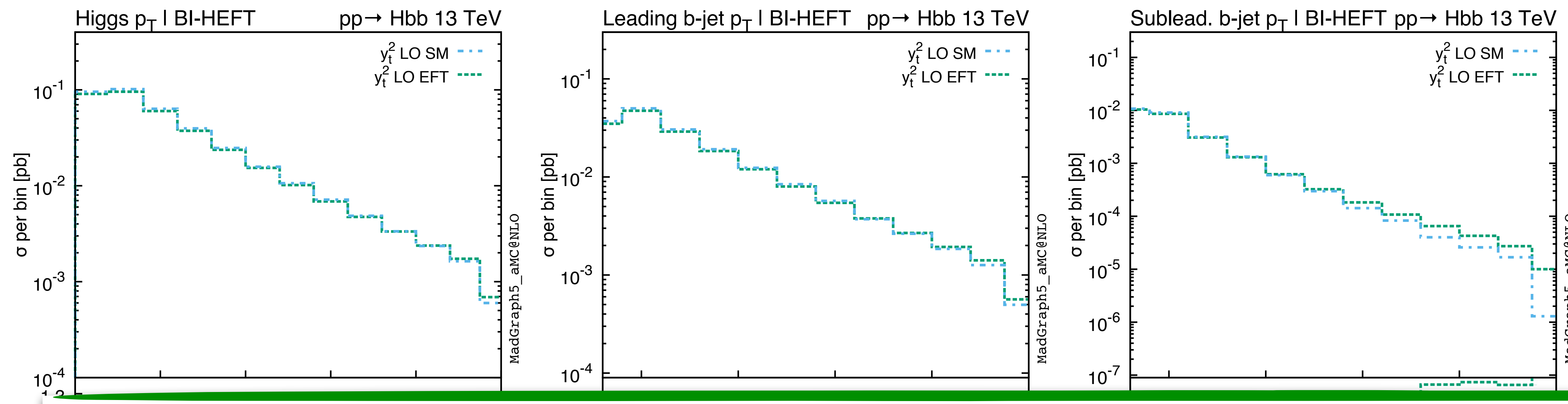
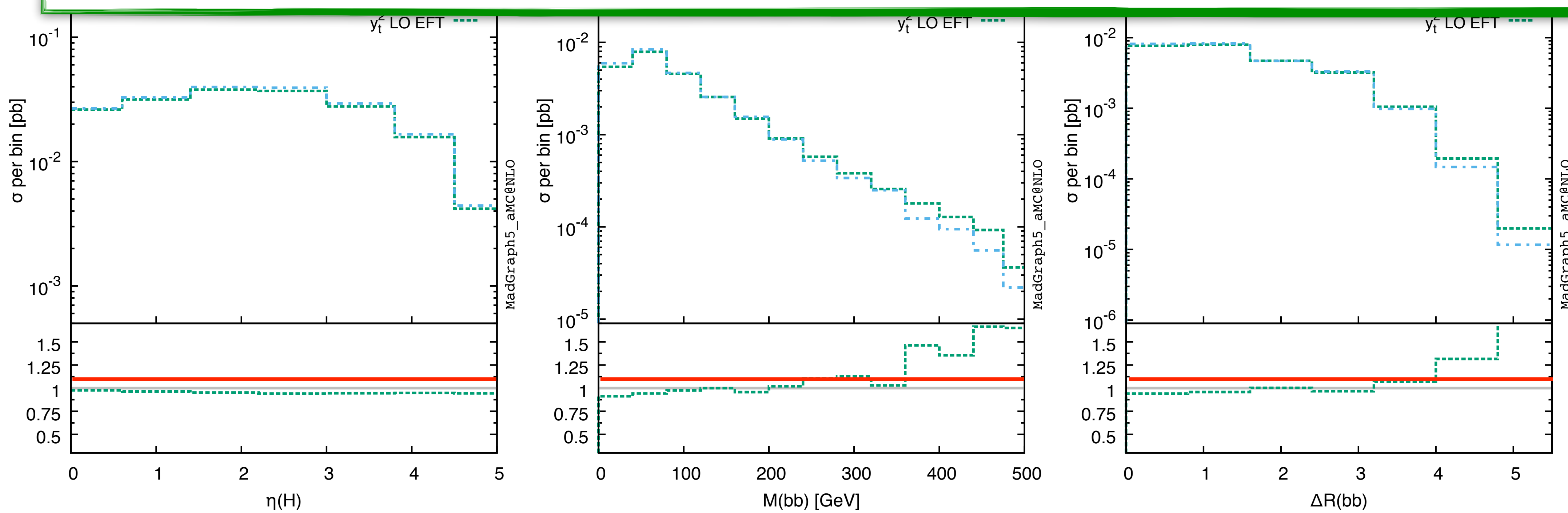


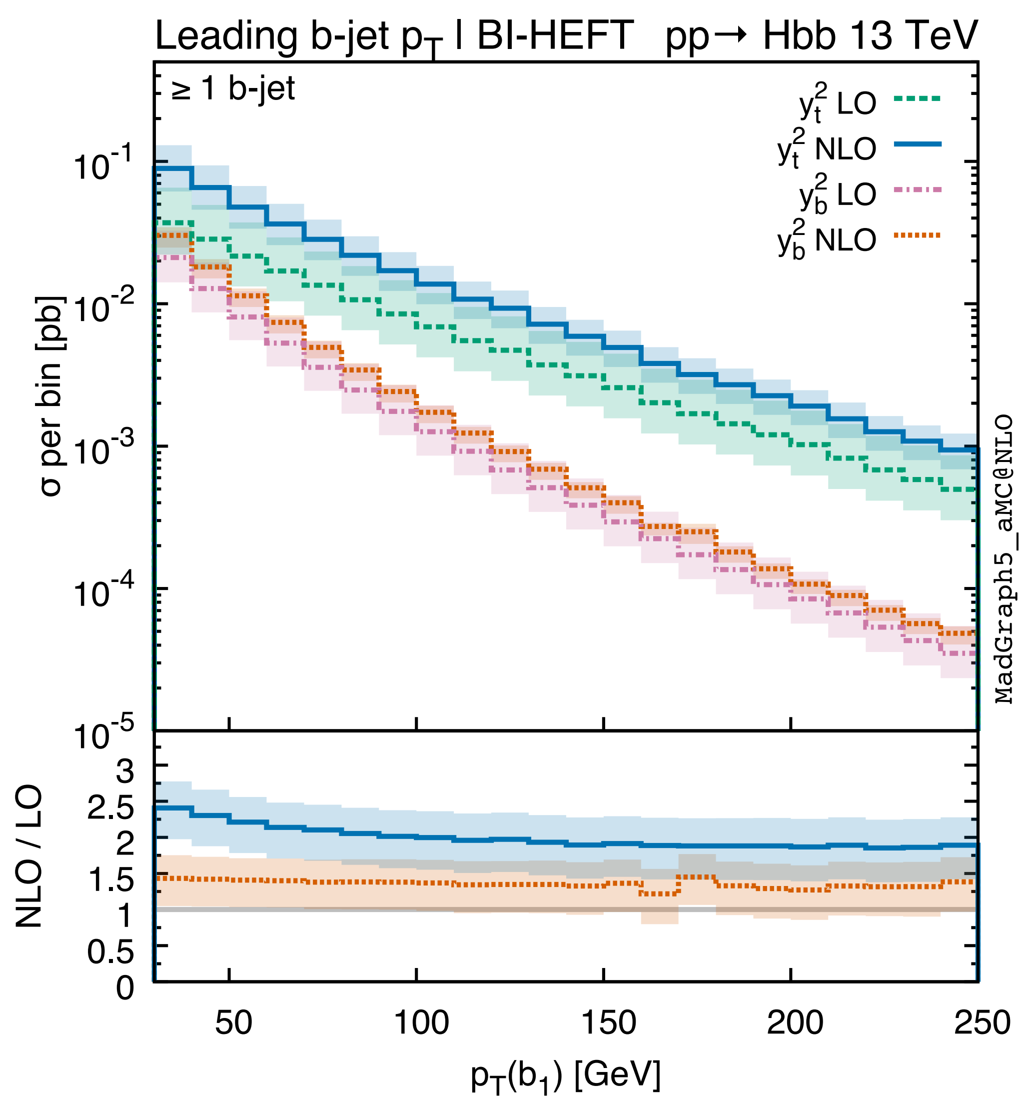
10%

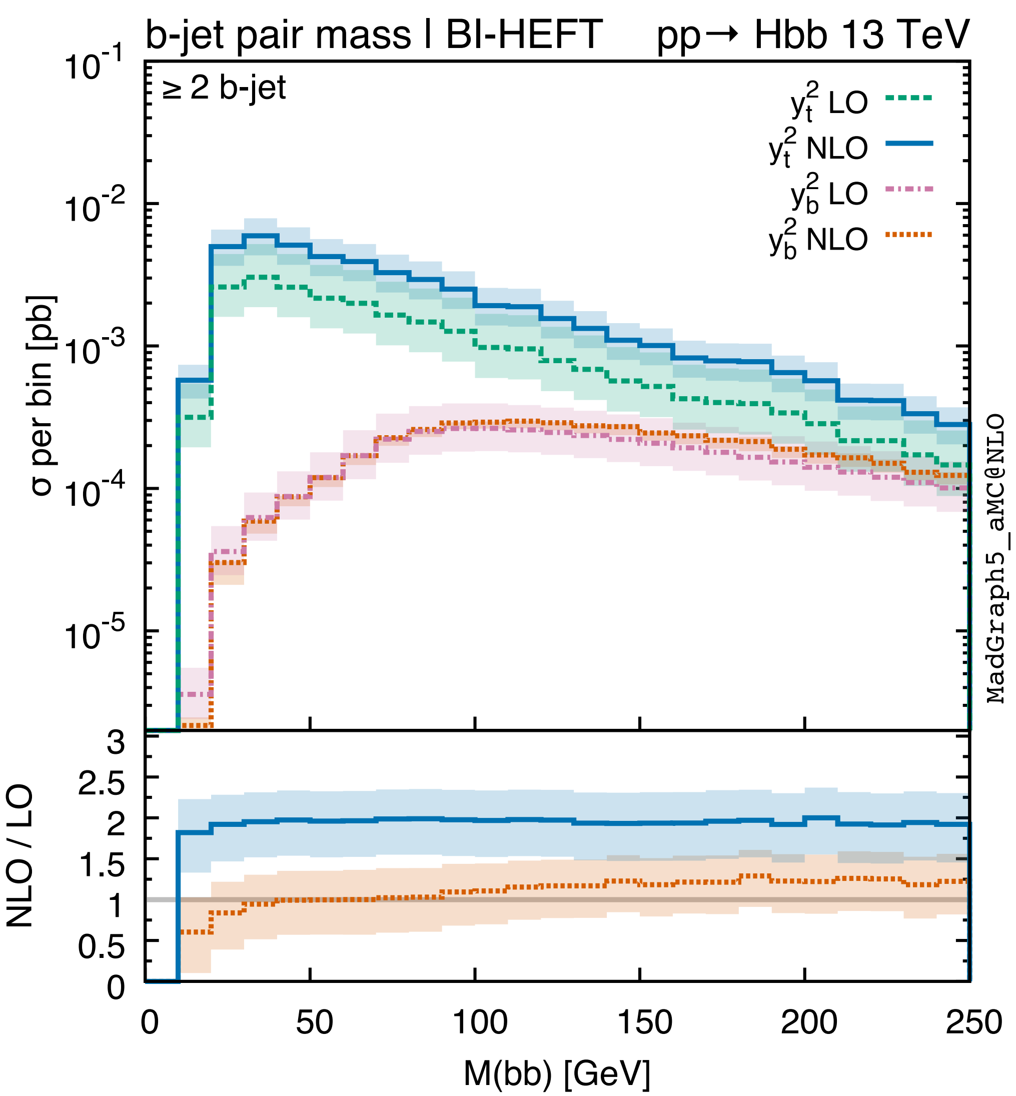
EFT is valid up to $p_T(H)$, $p_T(b_1)$~200 GeV
NLO differential distributions can be improved by including the LO SM/EFT K-factor



Other distributions

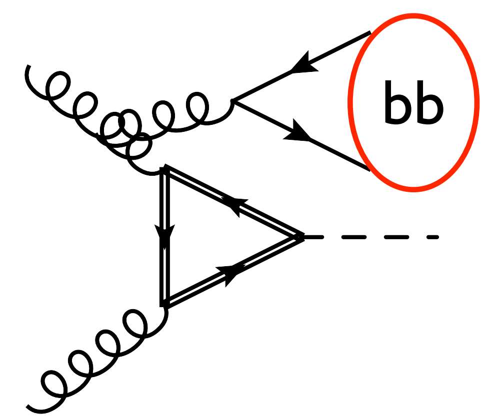
- The b-jet p_T distribution has a similar behaviour w.r.t. $p_T(H)$
- If two b-jets are present, M(bb) peaks at lower value for the y_t^2 contribution than for the y_b^2

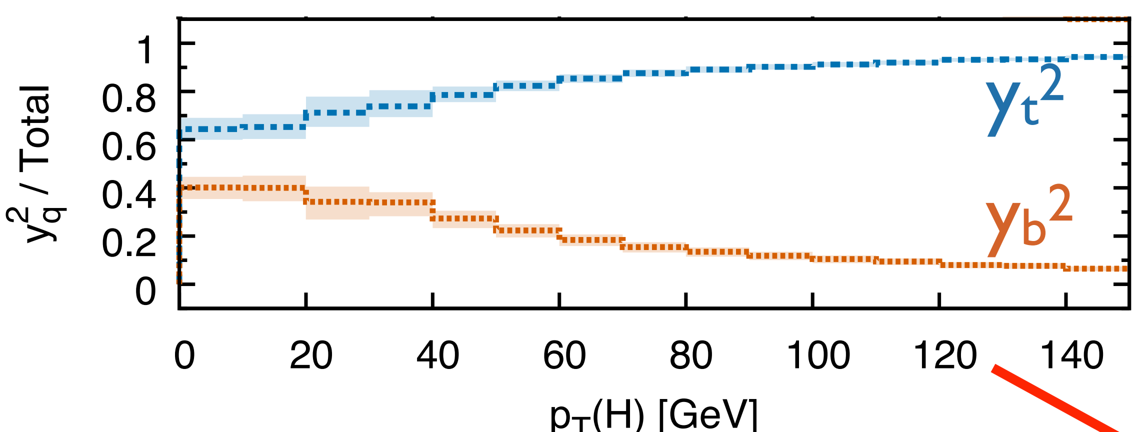




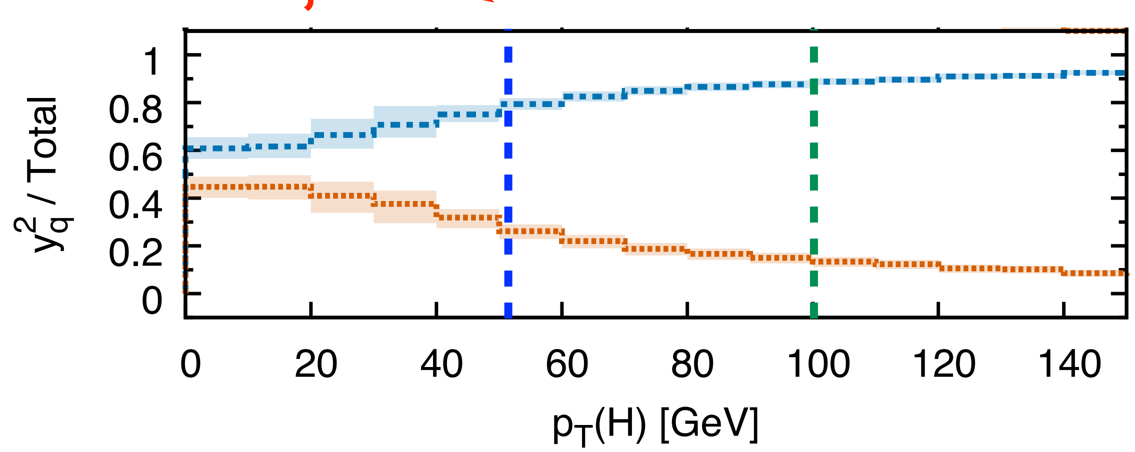
How to improve the sensitivity on y_b?

- One can try to enhance the y_b^2 component by exploiting the different kinematics of the y_t^2 and y_b^2 contribution. We will focus in the 1b jet bin
  - y_t^2 is more likely to produce b jets with two b quarks in it (bb jets). This happens ~25% of the times one has a b jet.
    → Veto bb jets
  - y_t^2 has a harder Higgs p_T spectrum. Stay at low $p_T(H)$





veto bb jet



	y_b^2 / total	effic. / y_b^2, ≥1b
≥1b	18 %	100 %
≥1b, no bb	23 %	99.9 %
≥1b, no bb p_T<100	27 %	90 %
≥1b, no bb p_T<50	36 %	50 %

VOLUME 2

Setup

- Complex-mass scheme, with

$$m_Z = 91.15348\ \text{GeV}\,, \qquad \Gamma_Z = 2.4946\ \text{GeV}\,, \qquad m_W = 80.35797\ \text{GeV}\,, \qquad \Gamma_W = 2.08899\ \text{GeV}\,, \tag{10}$$

$$m_H = 125.0\ \text{GeV}\,, \qquad \Gamma_H = 0\,, \qquad m_t = 173.34\ \text{GeV}\,, \qquad \Gamma_t = 1.3692\ \text{GeV}\,, \tag{11}$$

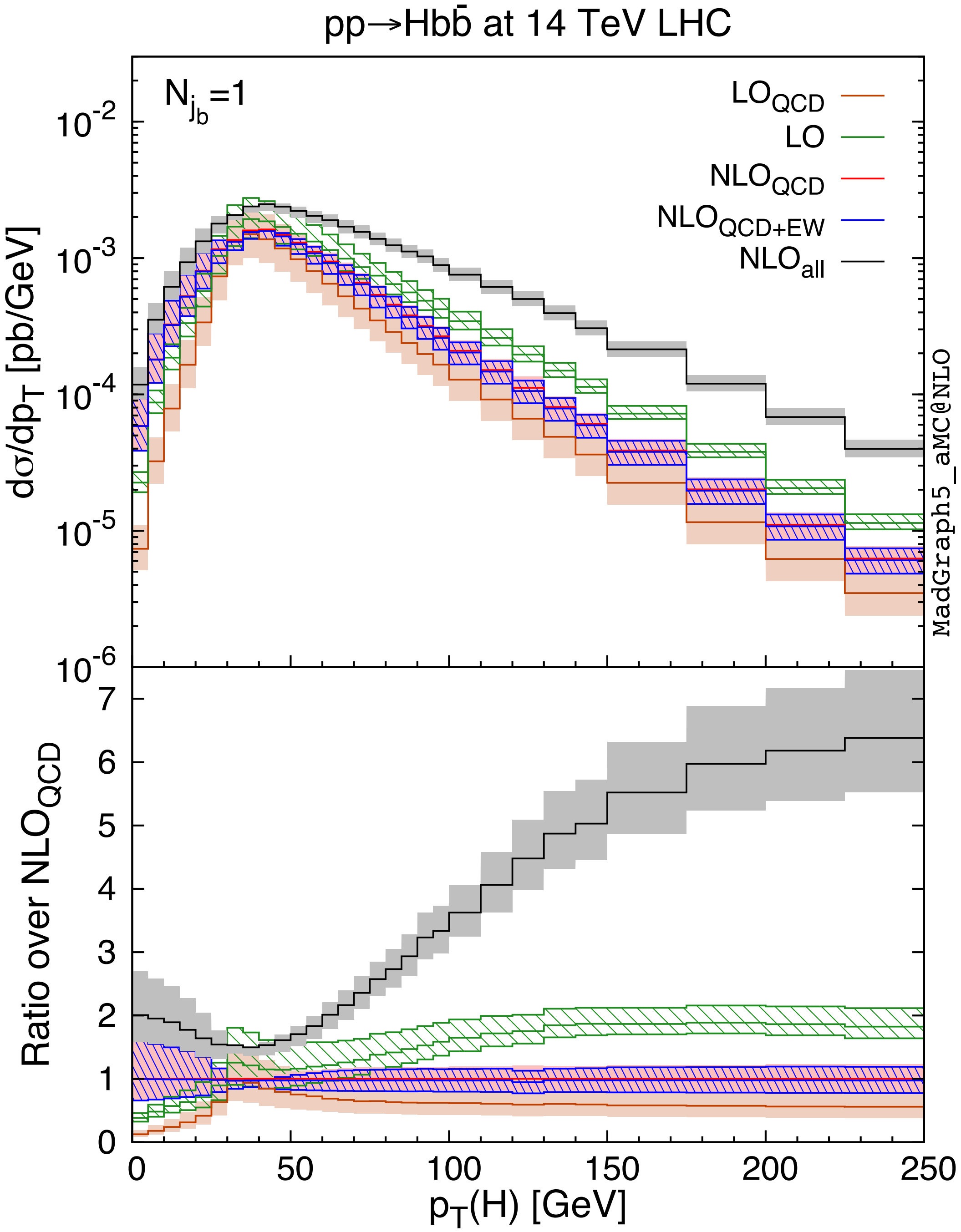
- m_b^{pole}=4.58 GeV, y_b renorm. in MSbar
  $\mu_{R/F}=H_T/4$, NNPDF3.1 NNLO evol, (n_f=4)
- EW renormalisation in the G_μ scheme,
- Jets are clustered with anti-k_T, p_T>30 GeV, R=0.4 and $|\eta|<4.5$.
  B-tagging up to $|\eta|<2.5$

Results

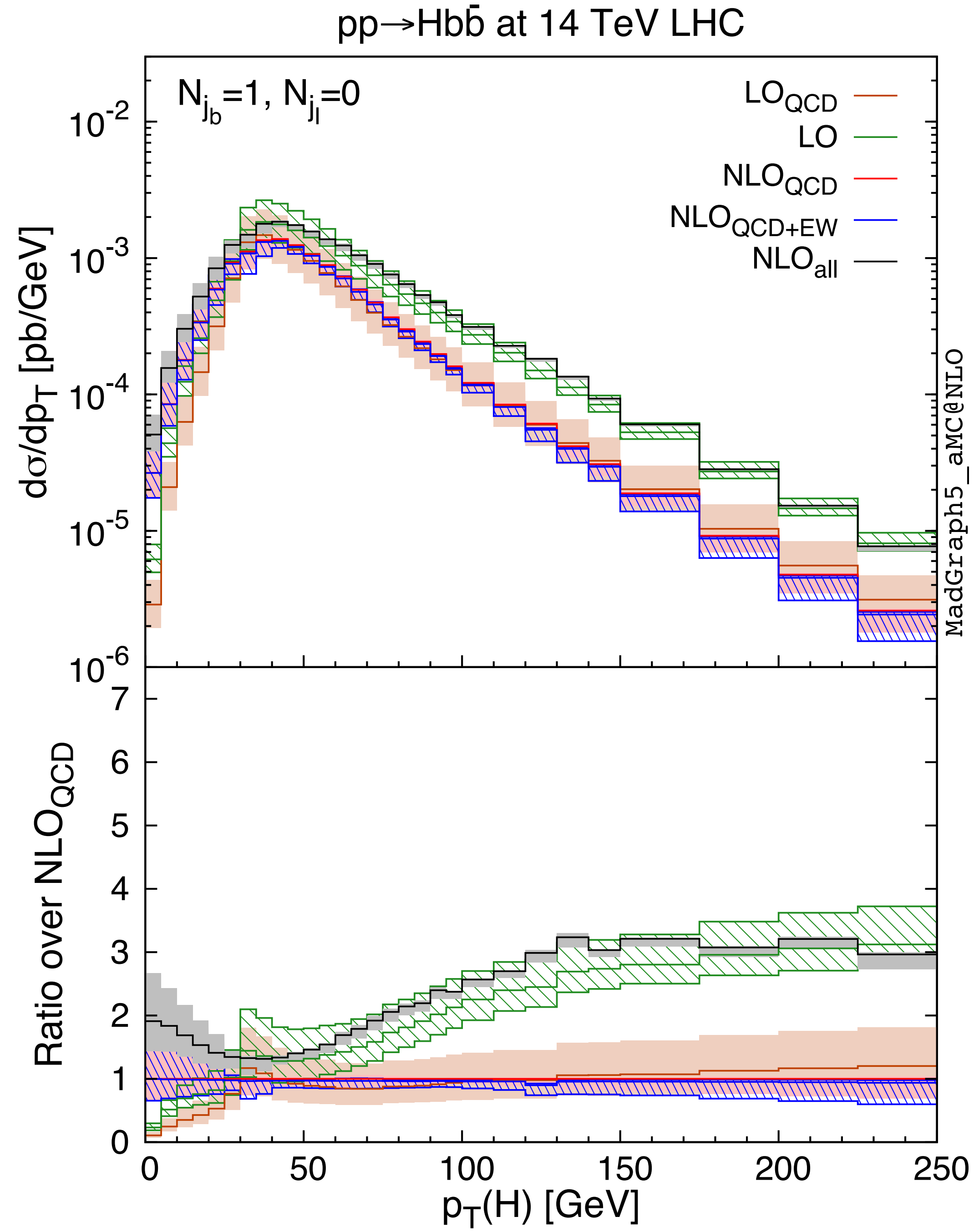
accuracy (i)	σ_i [fb]	$\sigma_i/\sigma_{\mathrm{LO_{QCD}}}$	cuts
$\mathrm{LO_{QCD}}$	$297^{+55.9\%}_{-34.1\%}$	1.00	NO CUT
LO	$399^{+42.9\%}_{-26.9\%}$	1.34	
$\mathrm{NLO_{QCD}}$	$450^{+19.2\%}_{-20.7\%}$	1.51	
$\mathrm{NLO_{QCD+EW}}$	$442^{+18.5\%}_{-20.4\%}$	1.49	
$\mathrm{NLO_{all}}$	$639^{+14.3\%}_{-15.6\%}$	2.15	
$\mathrm{LO_{QCD}}$	$67.2^{+49.1\%}_{-30.8\%}$ $(64.6^{+49.5\%}_{-31.1\%})$	1.00 (1.00)	$N_{j_b} \geq 1$
LO	$154^{+24.2\%}_{-16.9\%}$ $(142^{+25.2\%}_{-17.5\%})$	2.29 (2.19)	
$\mathrm{NLO_{QCD}}$	$94.4^{+12.3\%}_{-16.2\%}$ $(69.6^{+2.3\%}_{-11.3\%})$	1.40 (1.08)	
$\mathrm{NLO_{QCD+EW}}$	$92.0^{+11.4\%}_{-15.8\%}$ $(67.3^{+2.4\%}_{-10.6\%})$	1.37 (1.04)	
$\mathrm{NLO_{all}}$	$247^{+8.9\%}_{-8.9\%}$ $(139^{+0.9\%}_{-5.3\%})$	3.67 (2.15)	
$\mathrm{LO_{QCD}}$	$61.7^{+49.6\%}_{-31.1\%}$ $(59.0^{+50.0\%}_{-31.3\%})$	1.00 (1.00)	$N_{j_b} = 1$
LO	$105^{+31.1\%}_{-20.8\%}$ $(93.3^{+33.7\%}_{-22.3\%})$	1.71 (1.58)	
$\mathrm{NLO_{QCD}}$	$87.9^{+13.1\%}_{-16.6\%}$ $(66.0^{+2.2\%}_{-12.3\%})$	1.43 (1.12)	
$\mathrm{NLO_{QCD+EW}}$	$85.7^{+12.2\%}_{-16.3\%}$ $(63.9^{+2.3\%}_{-11.7\%})$	1.39 (1.08)	
$\mathrm{NLO_{all}}$	$187^{+10.4\%}_{-10.6\%}$ $(107^{+1.3\%}_{-8.4\%})$	3.03 (1.82)	
$\mathrm{LO_{QCD}}$	$5.57^{+45.4\%}_{-29.0\%}$	1.00	$N_{j_b} \geq 2$
LO	$48.4^{+9.0\%}_{-8.2\%}$	8.70	
$\mathrm{NLO_{QCD}}$	$6.53^{+1.8\%}_{-10.8\%}$	1.17	
$\mathrm{NLO_{QCD+EW}}$	$6.30^{+1.0\%}_{-10.2\%}$	1.13	
$\mathrm{NLO_{all}}$	$59.8^{+4.0\%}_{-3.7\%}$	10.75	

() $\Leftrightarrow$ light jet veto

Differential distributions
$N_b=1$



light jet veto



Differential distributions
N_b=2

light jet veto