y_t-induced $Hb\bar{b}$ as a background for HH searches

Marco Zaro

Heavy Flavours at High p_T workshop

based on

(Deutschmann, Maltoni, Wiesemann, MZ, arXiv:1808.01660; Pagani, Shao, MZ, arXiv:2005.10277)
Manzoni, Mazzeo, Mazzitelli, Wiesemann, MZ, arXiv:2307.09992

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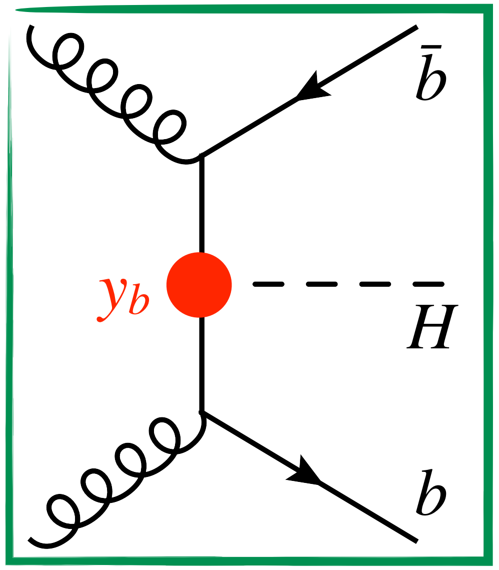
Sezione di Milano

Outline

- $Hb\bar{b}$ production in the SM and the *in*sensitivity to y_b
- y_t-induced $Hb\bar{b}$ @NLO+PS as a background to HH
- On a possible source of double counting in 5FS simulations

$Hb\bar{b}$ production in the SM and the insensitivity to y_b

- $Hb\bar{b}$ 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 $Hb\bar{b}$ final state. Which processes can contribute?



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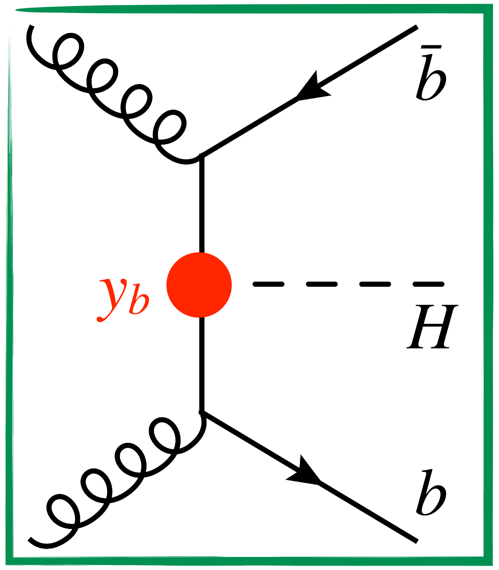

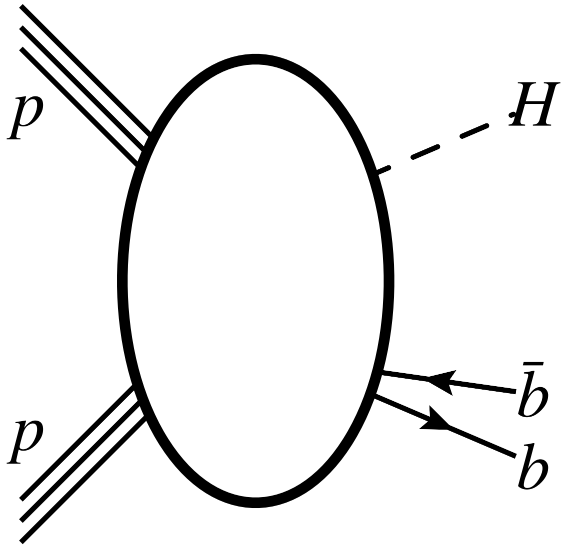

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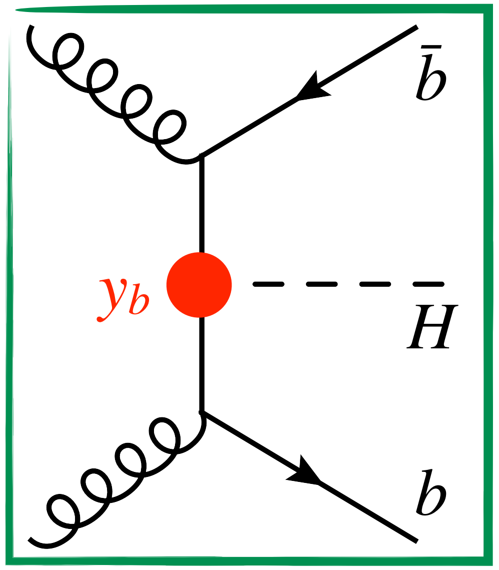

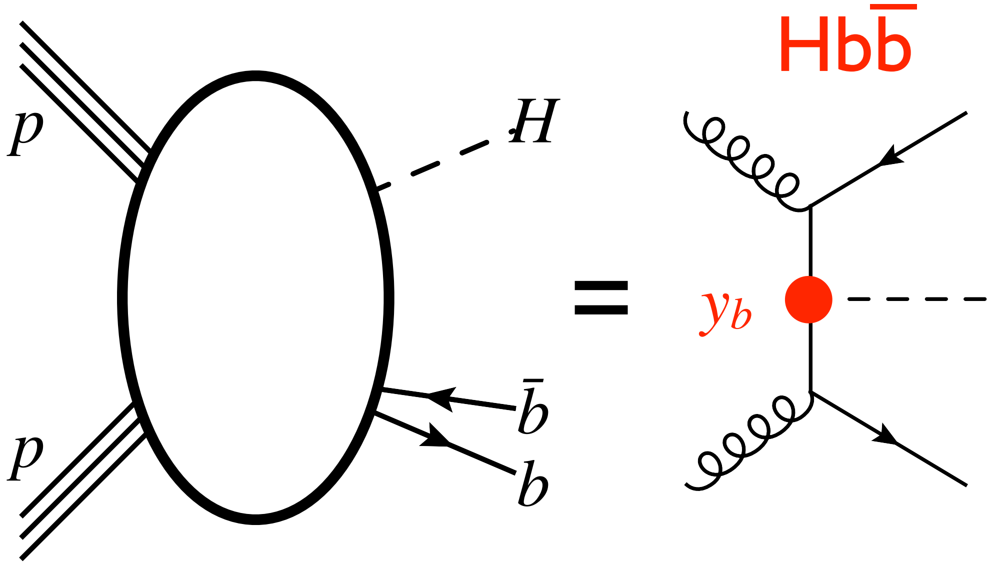

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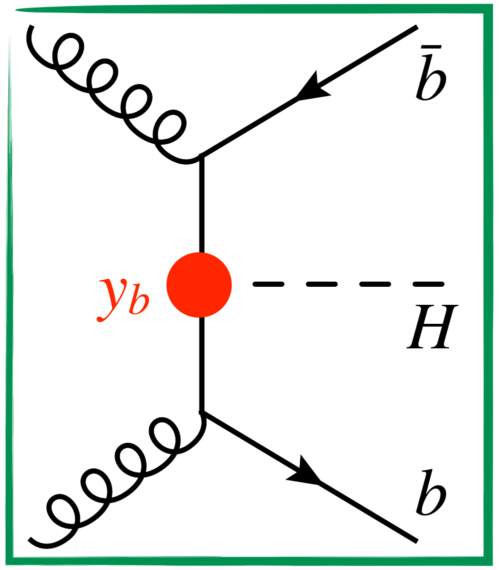

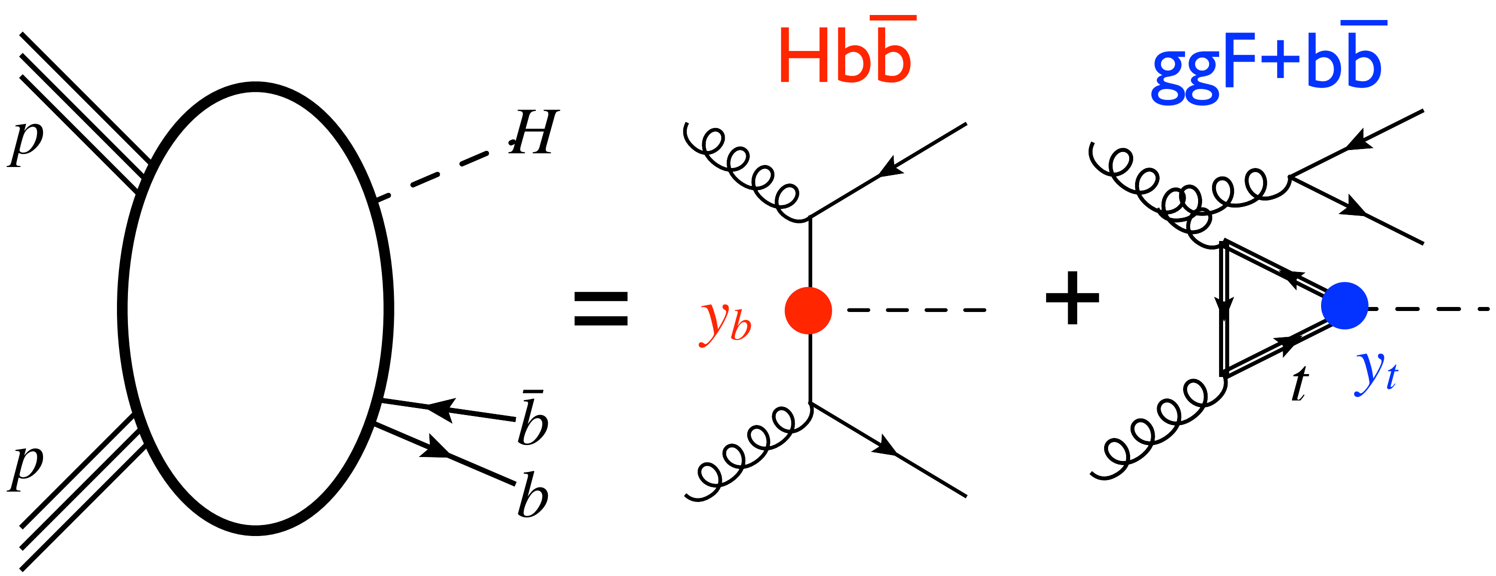

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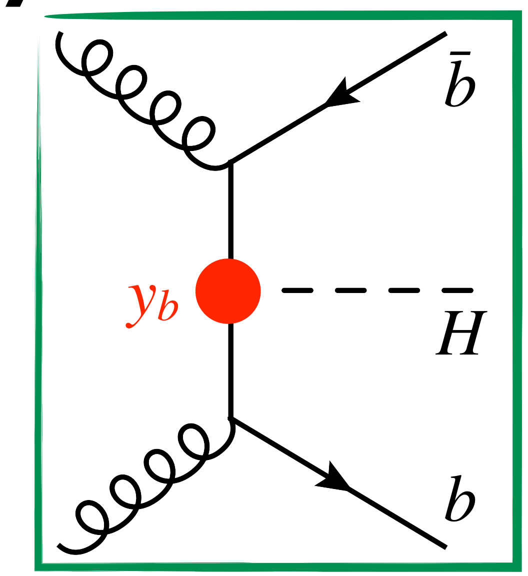

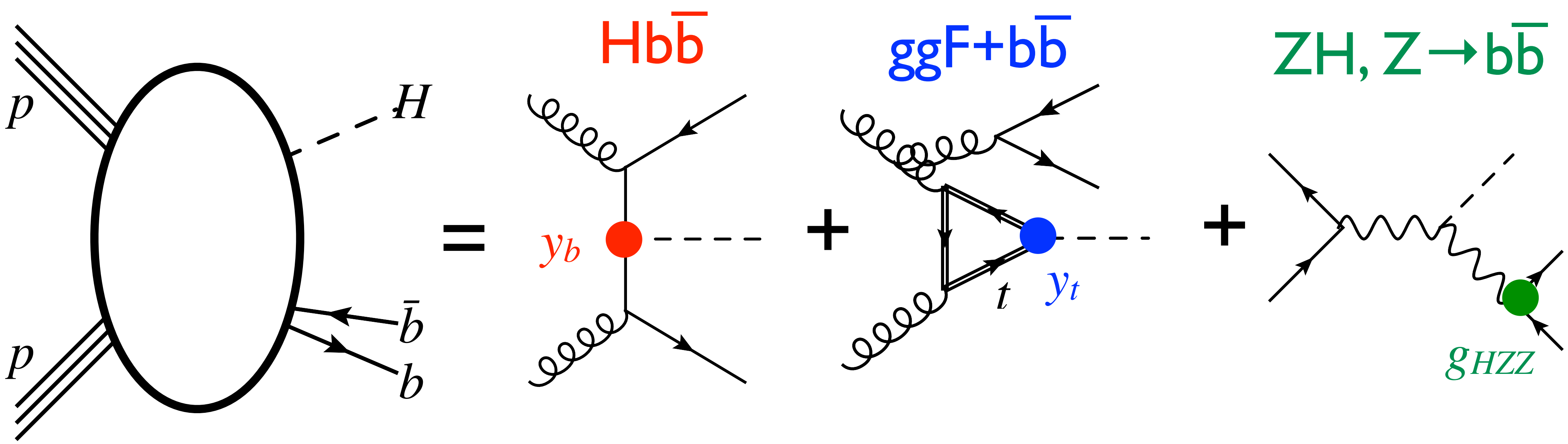

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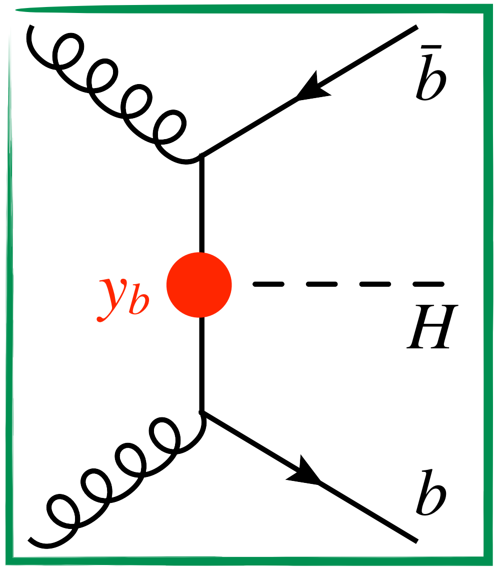

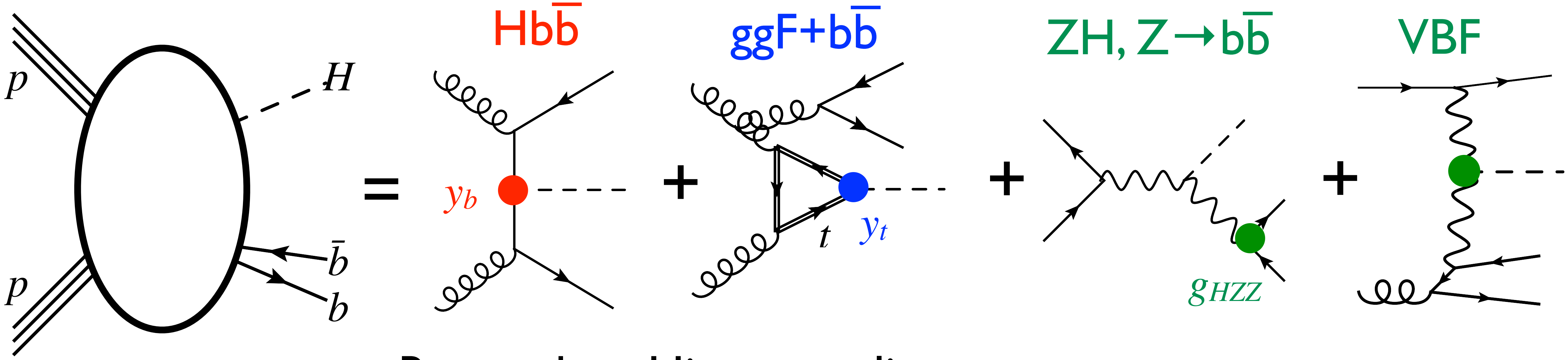

Remember: Higgs couplings ~ mass

y_b^2 contribution most studied: 35+ references in our paper

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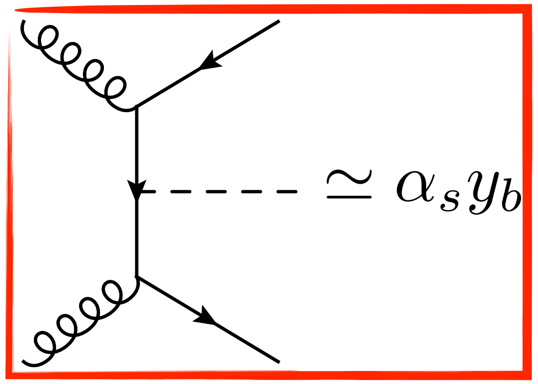

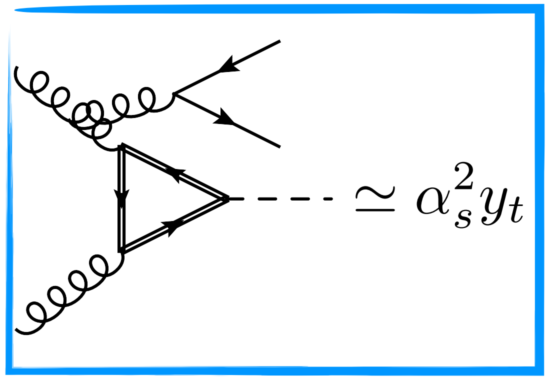

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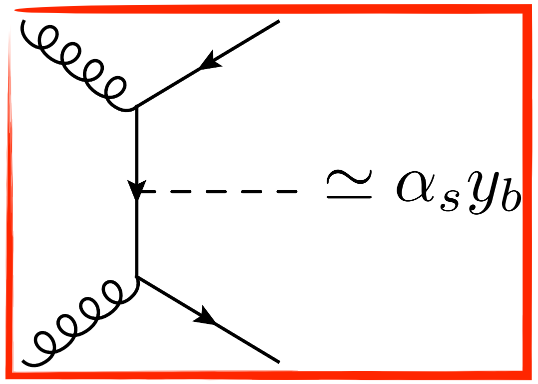

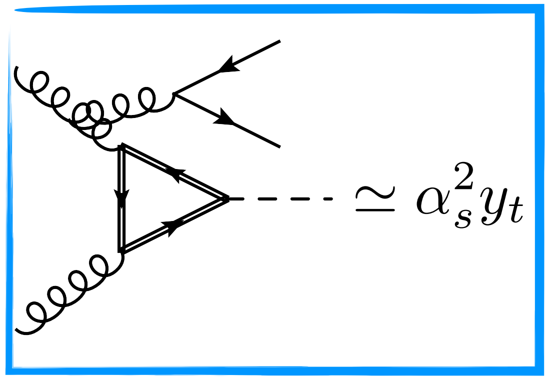

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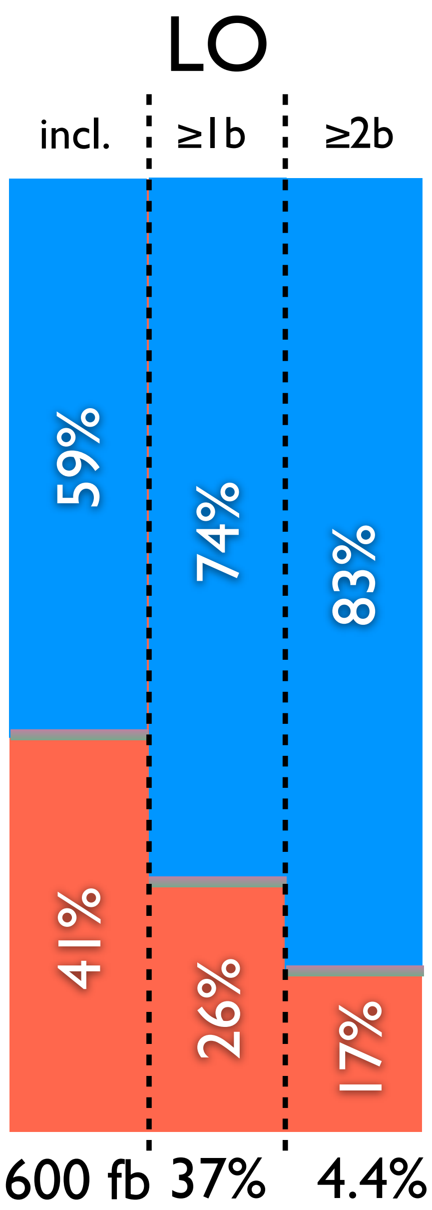

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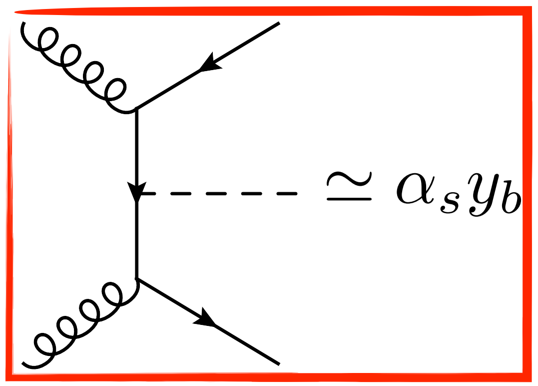

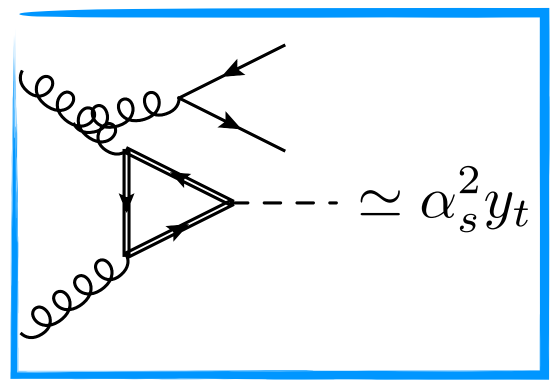

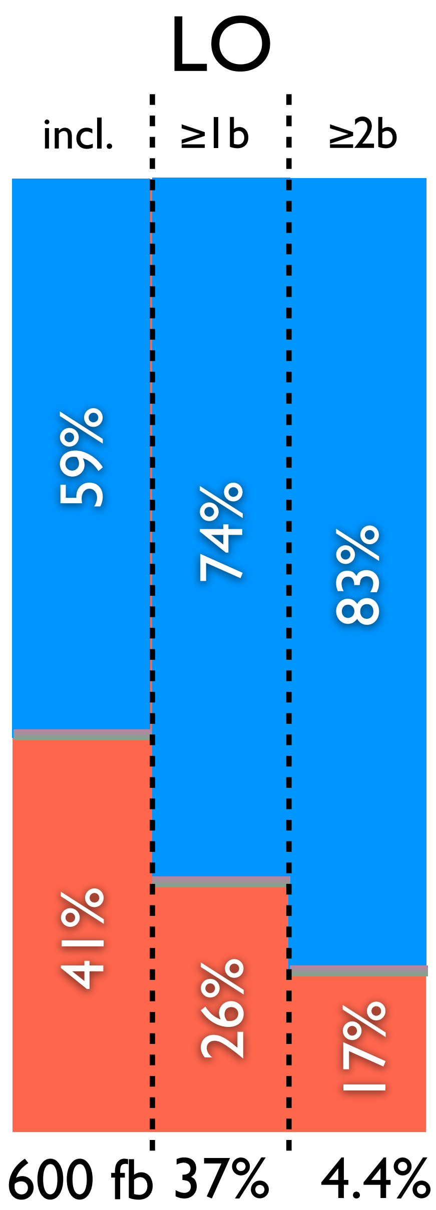

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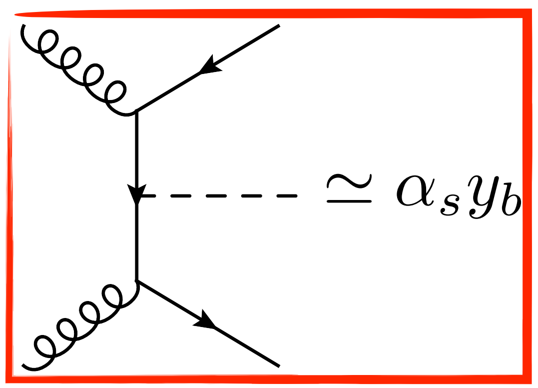

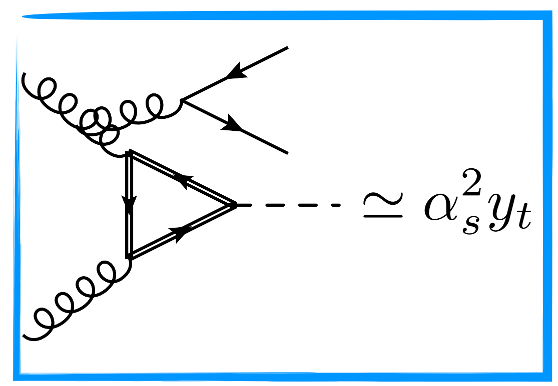

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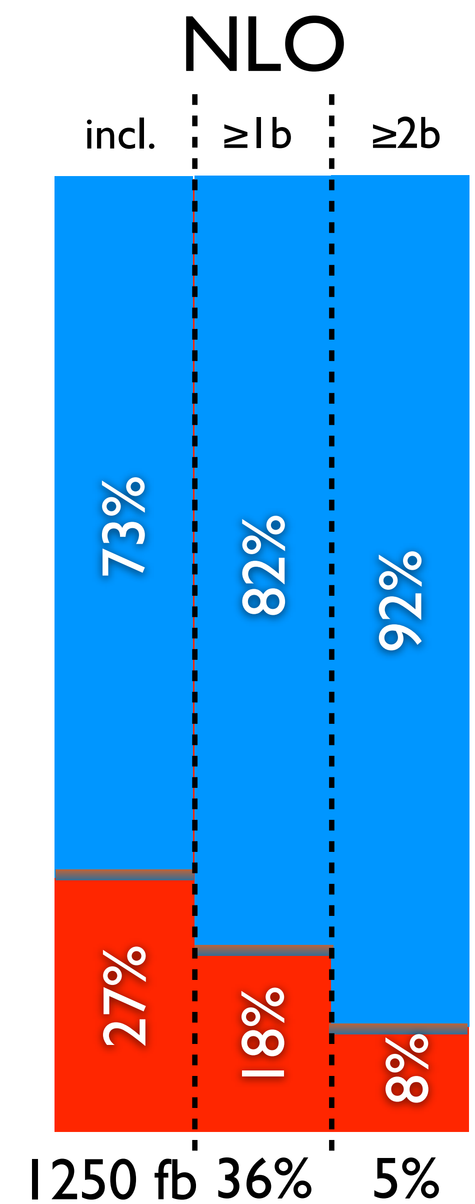
- y_t^2 contribution is actually larger than y_b^2
- NLO corrections to both terms (and to the interference, negligible) are computed with `MG5_aMC` in the Born-improved HEFT
- At NLO (including terms ~y_t^2 formally N^3LO for the y_b^2 piece), the situation gets even worse



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

Pagani, Shao, MZ, arXiv:2005.10277

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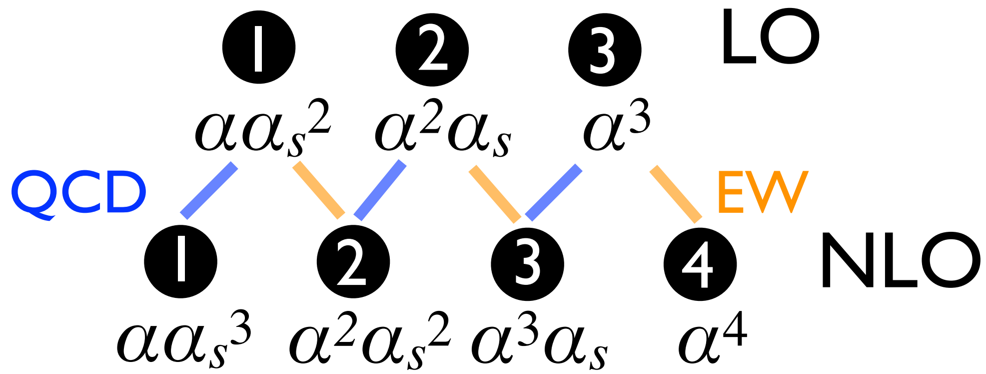

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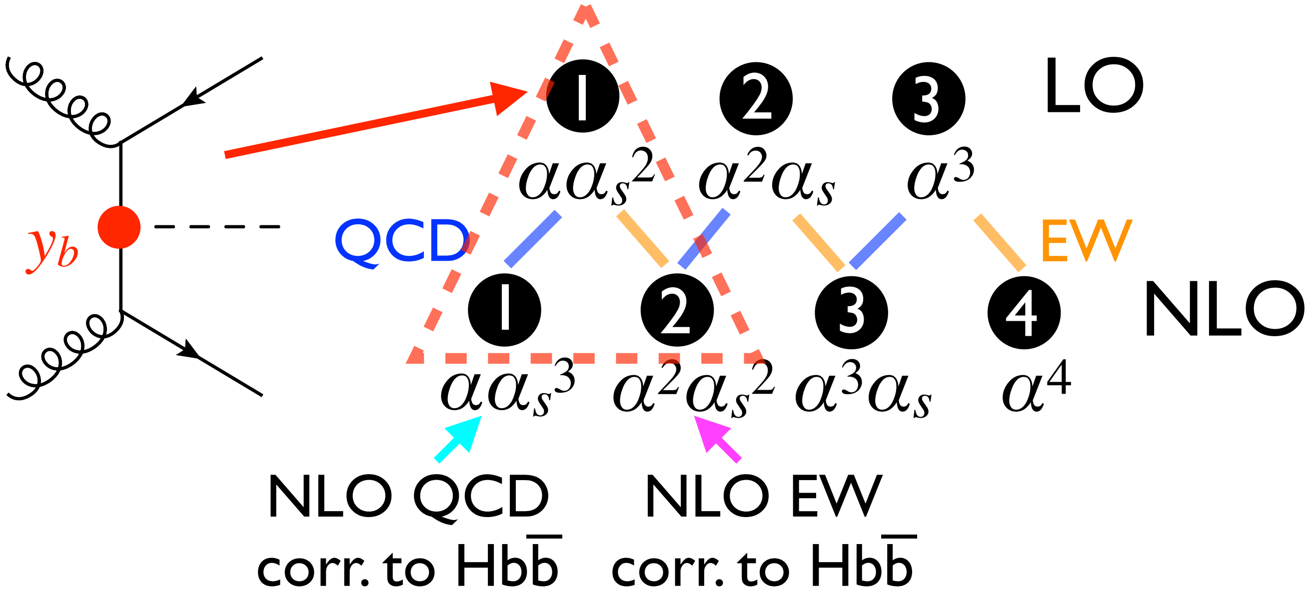

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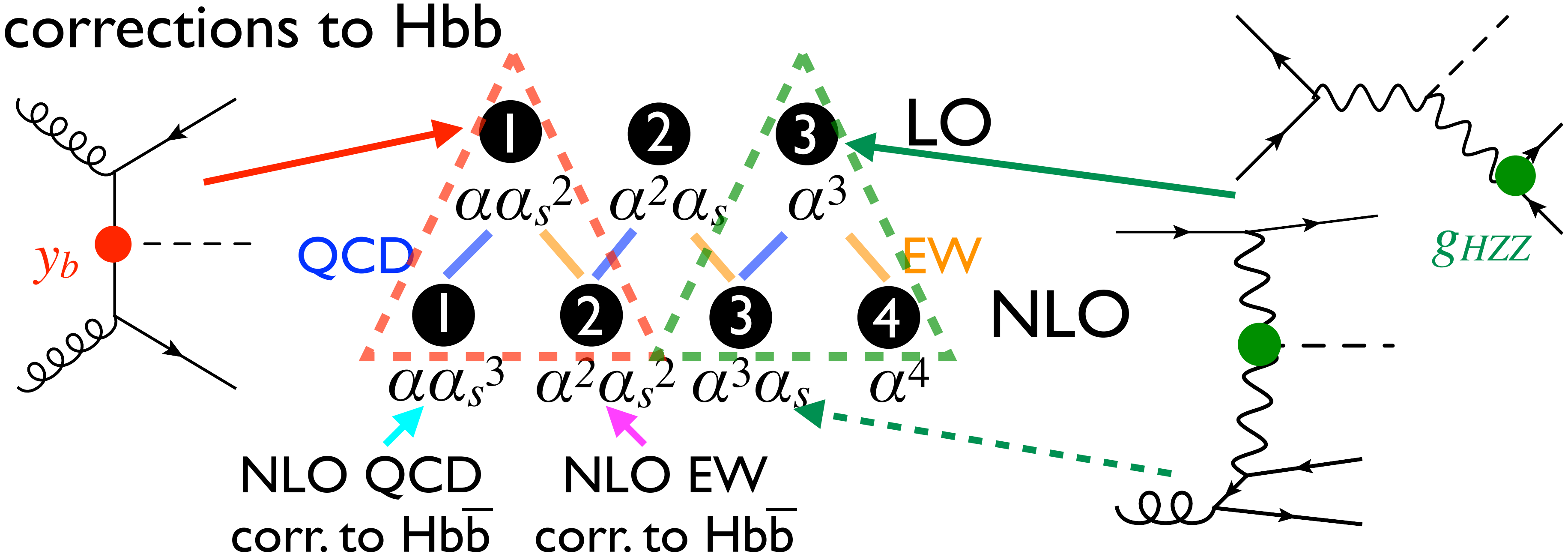

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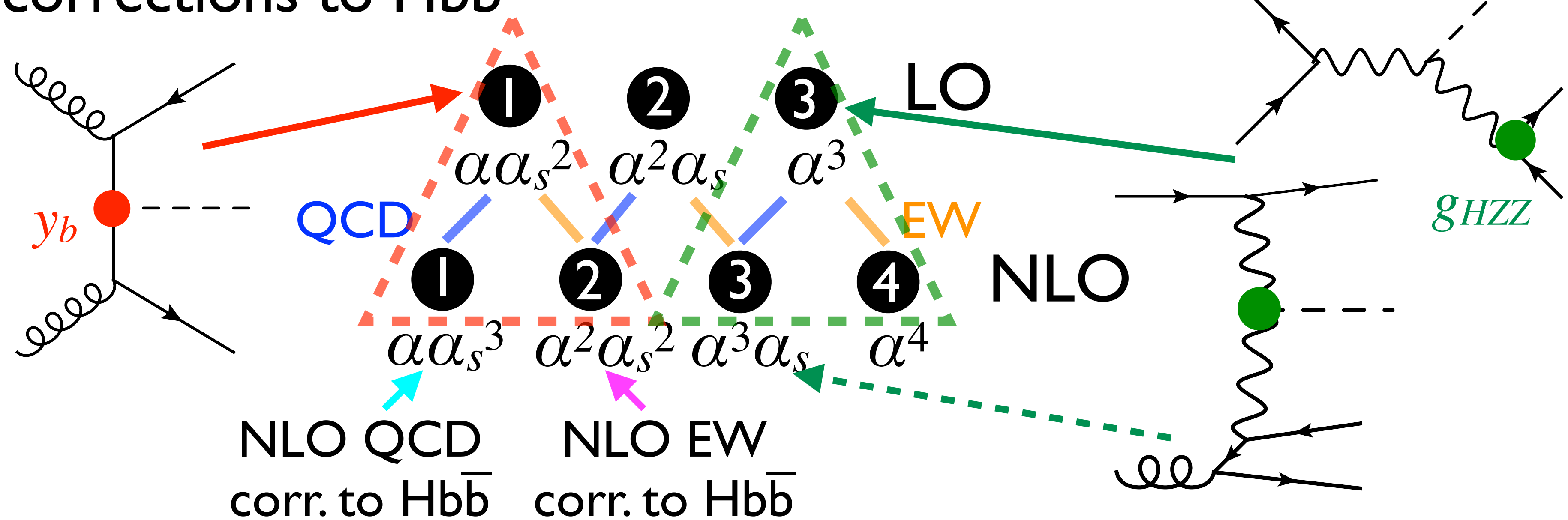

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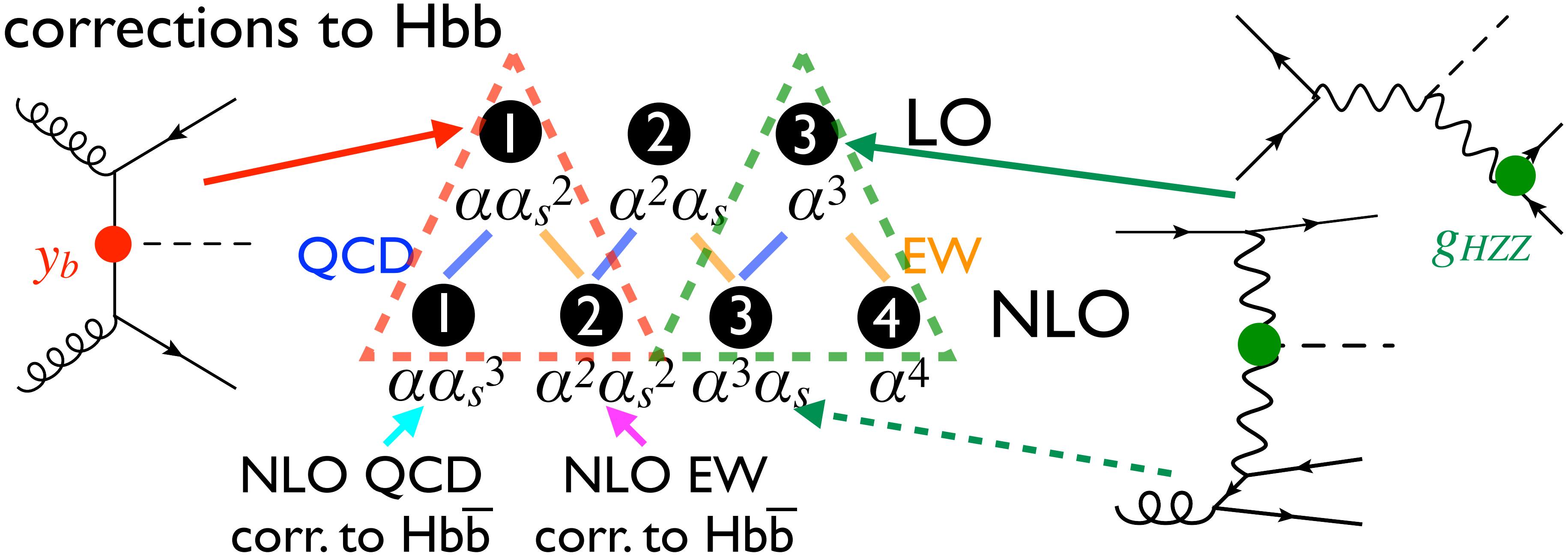

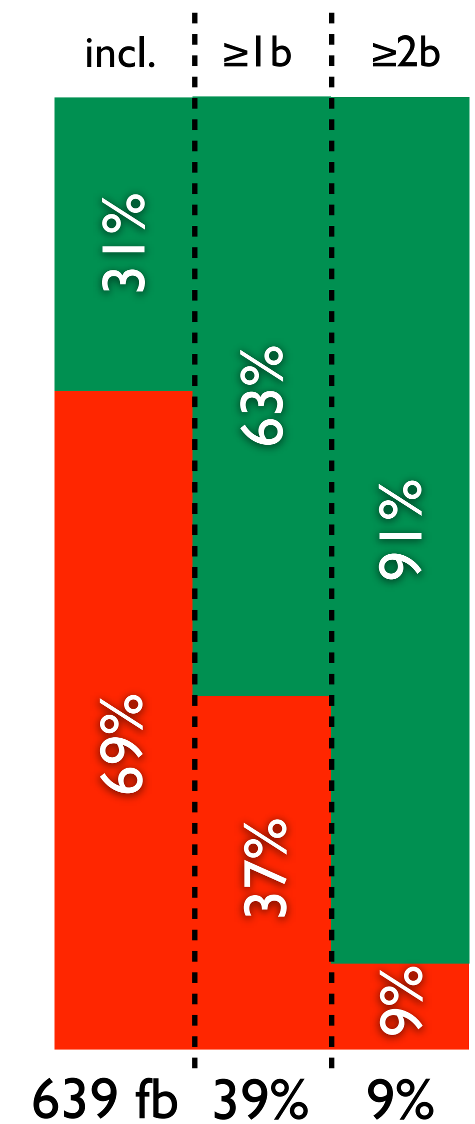

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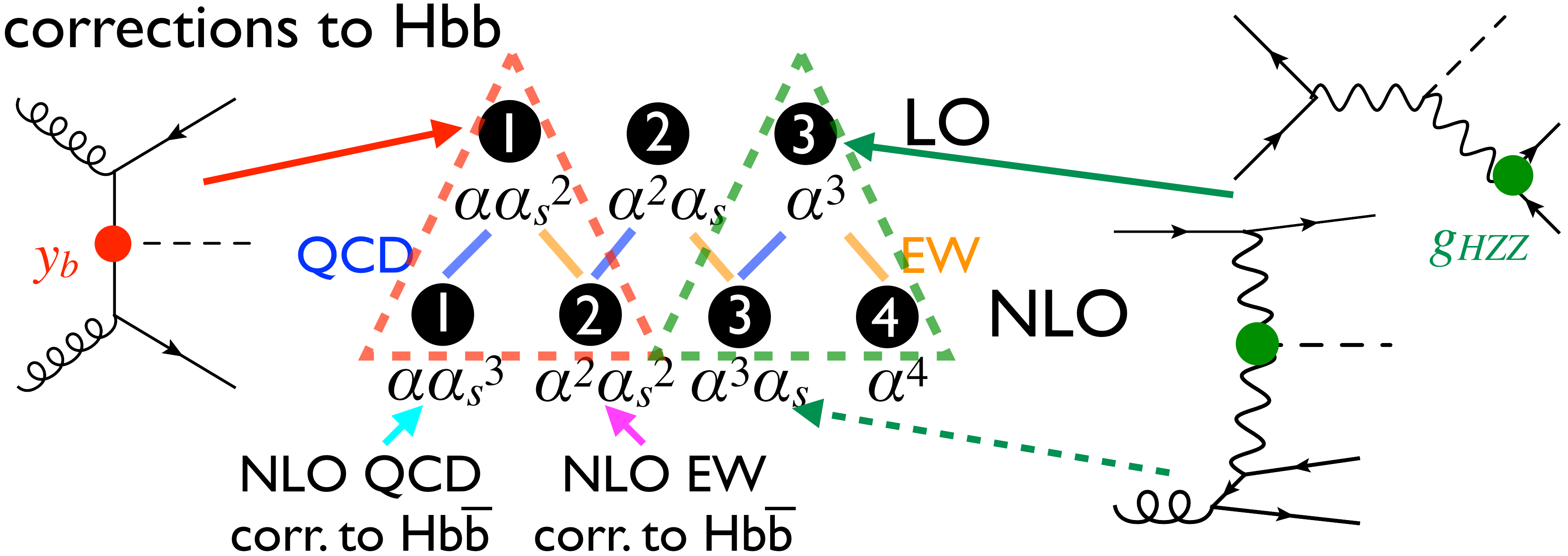
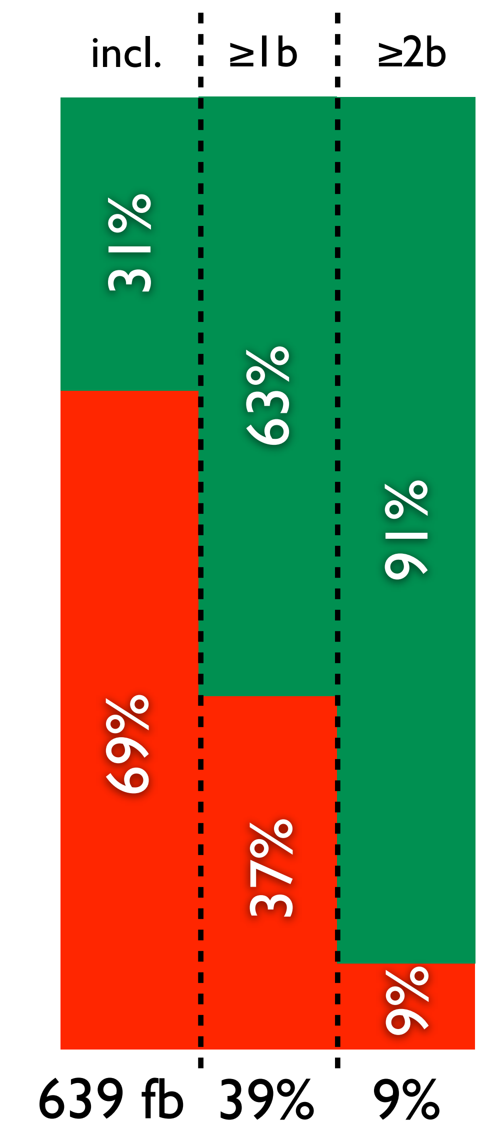
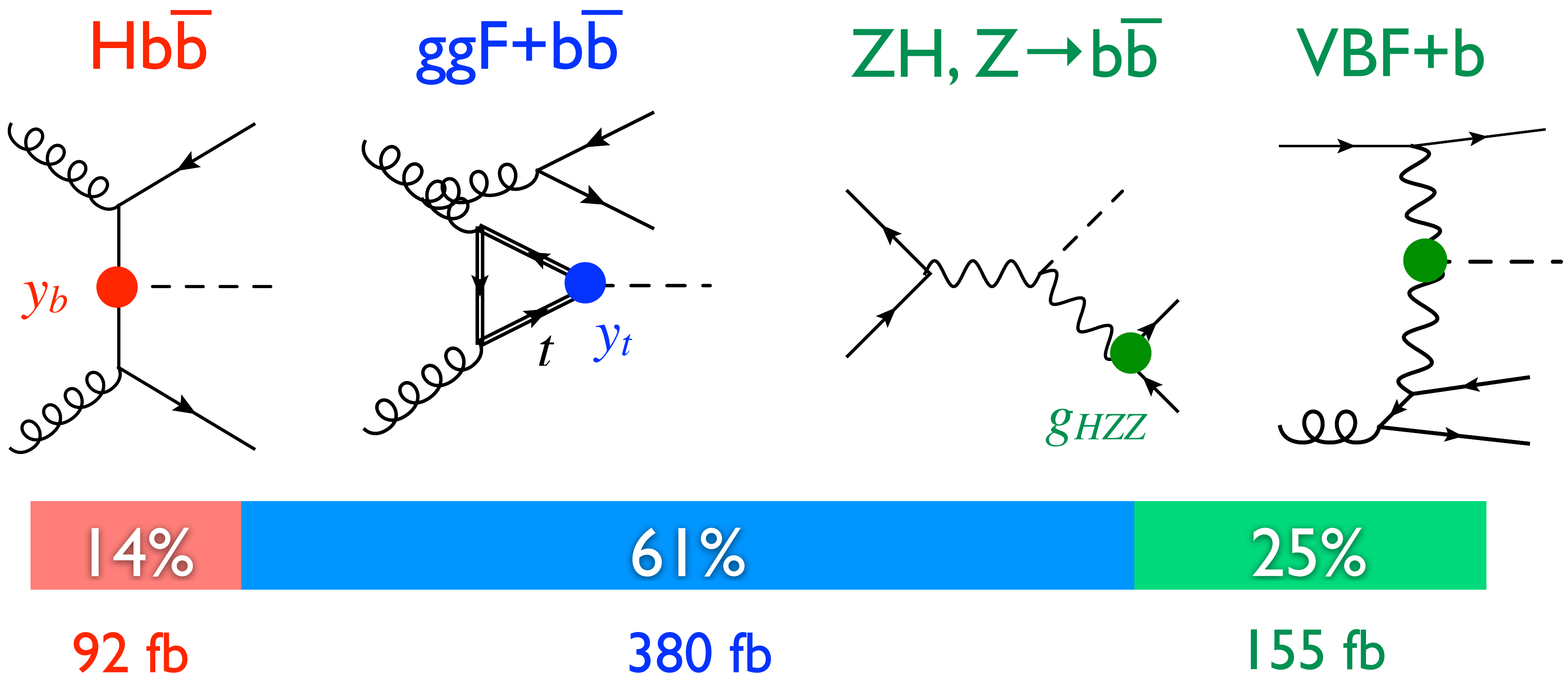




- Complete-NLO corrections computed with `MG5_aMC`, first process in the 4FS
- The α/α_s suppression is compensated by g_{HZZ}/y_b
- If (at least) 1 b-jet is required, the g_{HZZ} contribution is almost twice as large as y_b

Goodbye y_b…

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



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

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

If $Hb\bar{b}$ is a background, all the various channels should be taken into account

THE 4TH FILM BY QUENTIN TARANTINO

KILL BBH

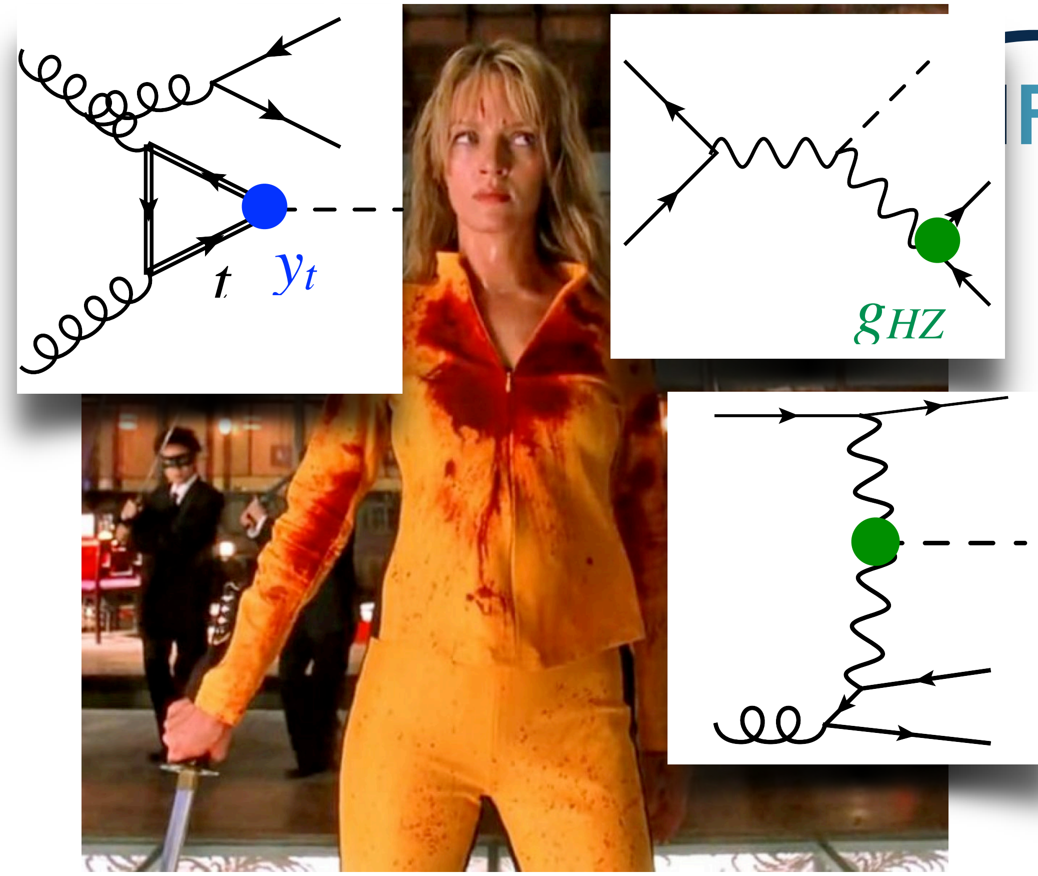
VOLUME 1

Deutschmann, Maltoni, Wiesemann, MZ, arXiv:1808.01660

VOLUME 2

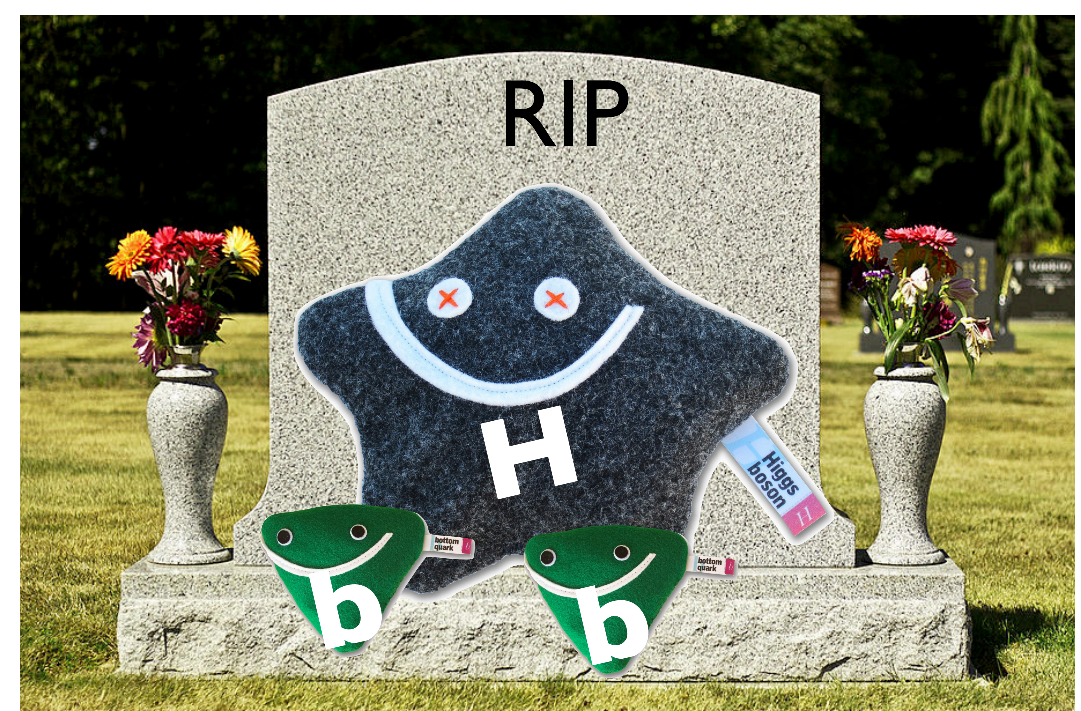
Pagani, Shao, MZ, arXiv:2005.10277

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



RIP $Hb\bar{b}$: how other Higgs production modes conspire to kill a rare signal at the LHC

Davide Pagani,[a] Hua-Sheng Shao[b] and Marco Zaro[c]

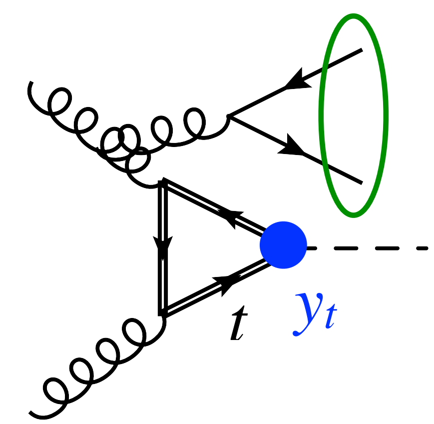


y_t-induced $Hb\bar{b}$ @NLO+PS as a background to HH

Manzoni, Mazzeo, Mazzitelli, Wiesemann, MZ, arXiv:2307.09992

Long-live H$b\bar{b}$! (as a background)

- ggF (y_t-induced) H$b\bar{b}$ has a very large share of H$b\bar{b}$ production
- As a background, usually simulated via inclusive/multi-jet merged ggH samples (NNLOPS in ATLAS), in the 5FS, with 100% uncertainty NNLOPS: Hamilton et al, 1501.04637
- This provided only LO-accurate predictions for H$b\bar{b}$ production
- We performed the first simulation of y_t-induced H$b\bar{b}$ at NLO+PS, using the 4FS
- `MG5_aMC` was employed for the event generation
- The HH→$b\bar{b}\gamma\gamma$ phase-space was considered



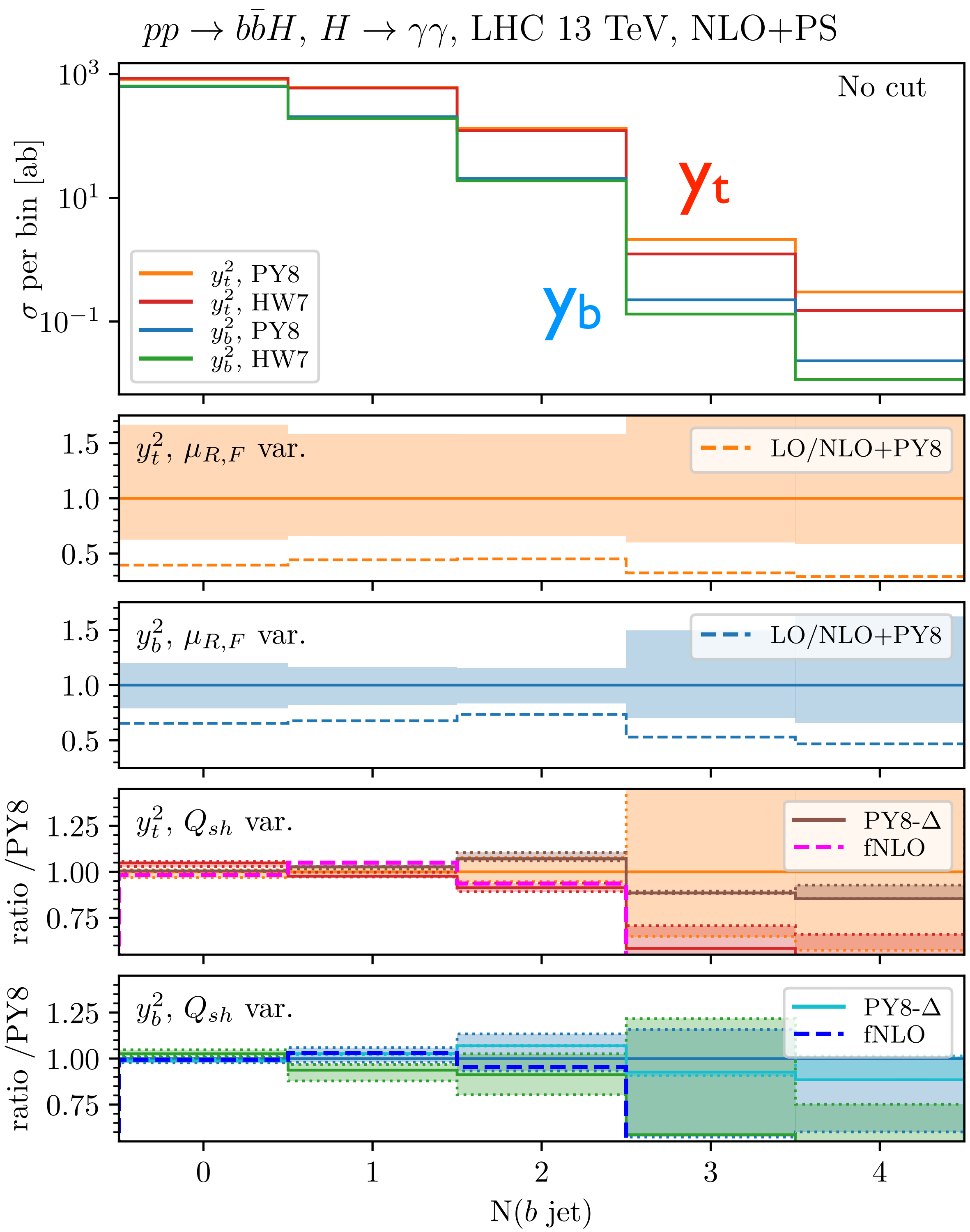
5FS: b's from ME or PS
4FS: b's (mostly) from ME

$$\text{anti-}k_T, \quad R = 0.4 \quad p_T(j) > 25\,\text{GeV} \quad |\eta(j)| < 2.5 \qquad 80\,\text{GeV} < m(b_1, b_2) < 140\,\text{GeV}$$

$$105\,\text{GeV} < m(\gamma_1, \gamma_2) < 160\,\text{GeV}, \quad |\eta(\gamma_i)| < 2.37, \quad \frac{p_T(\gamma_1)}{m(\gamma_1, \gamma_2)} > 0.35, \quad \frac{p_T(\gamma_2)}{m(\gamma_1, \gamma_2)} > 0.25$$

similar cuts as in ATLAS HH search, 2112.11876

Some results



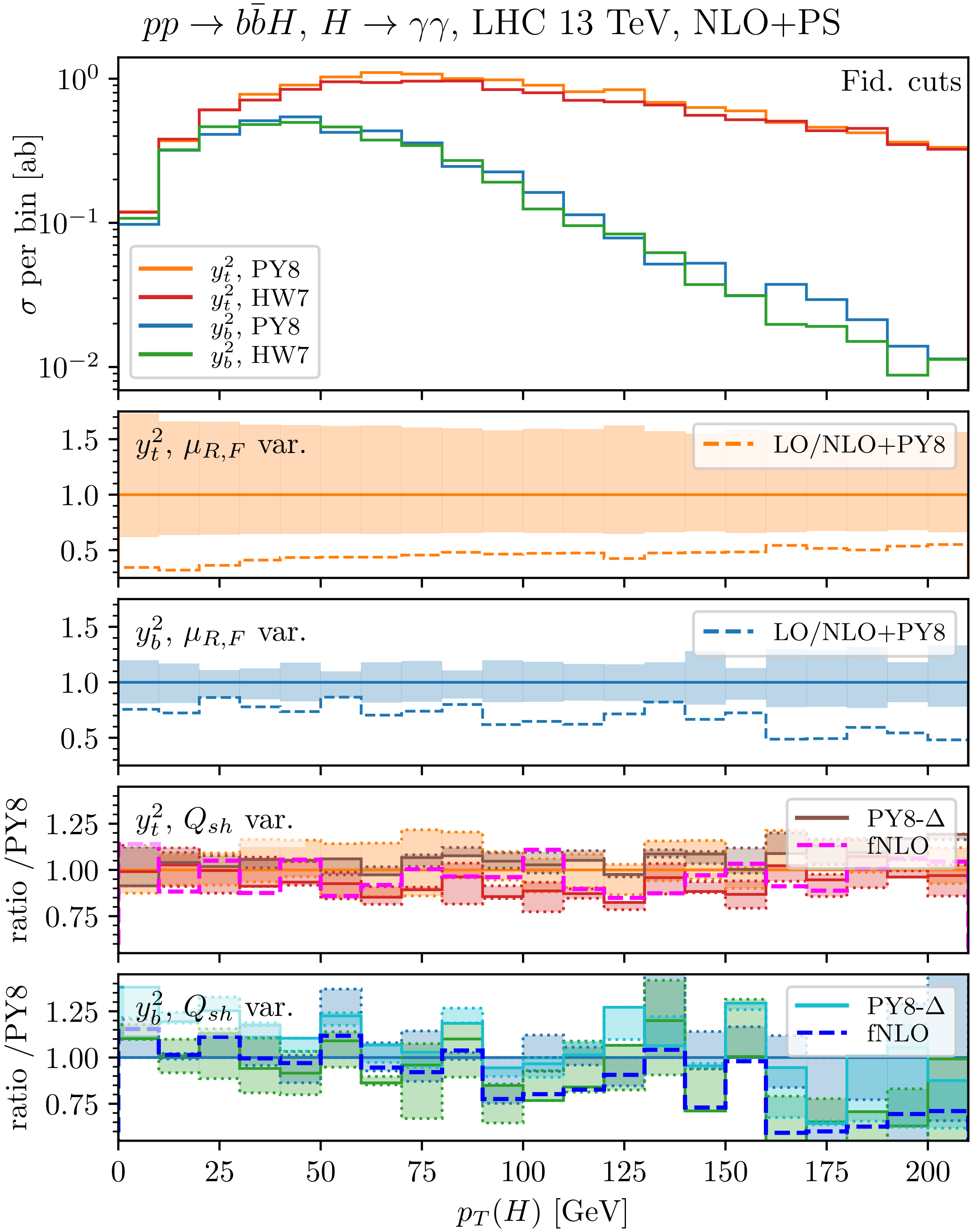
Total rates: dominated by y_t,
with exceptions at very low scales
y_t shows much harder spectra

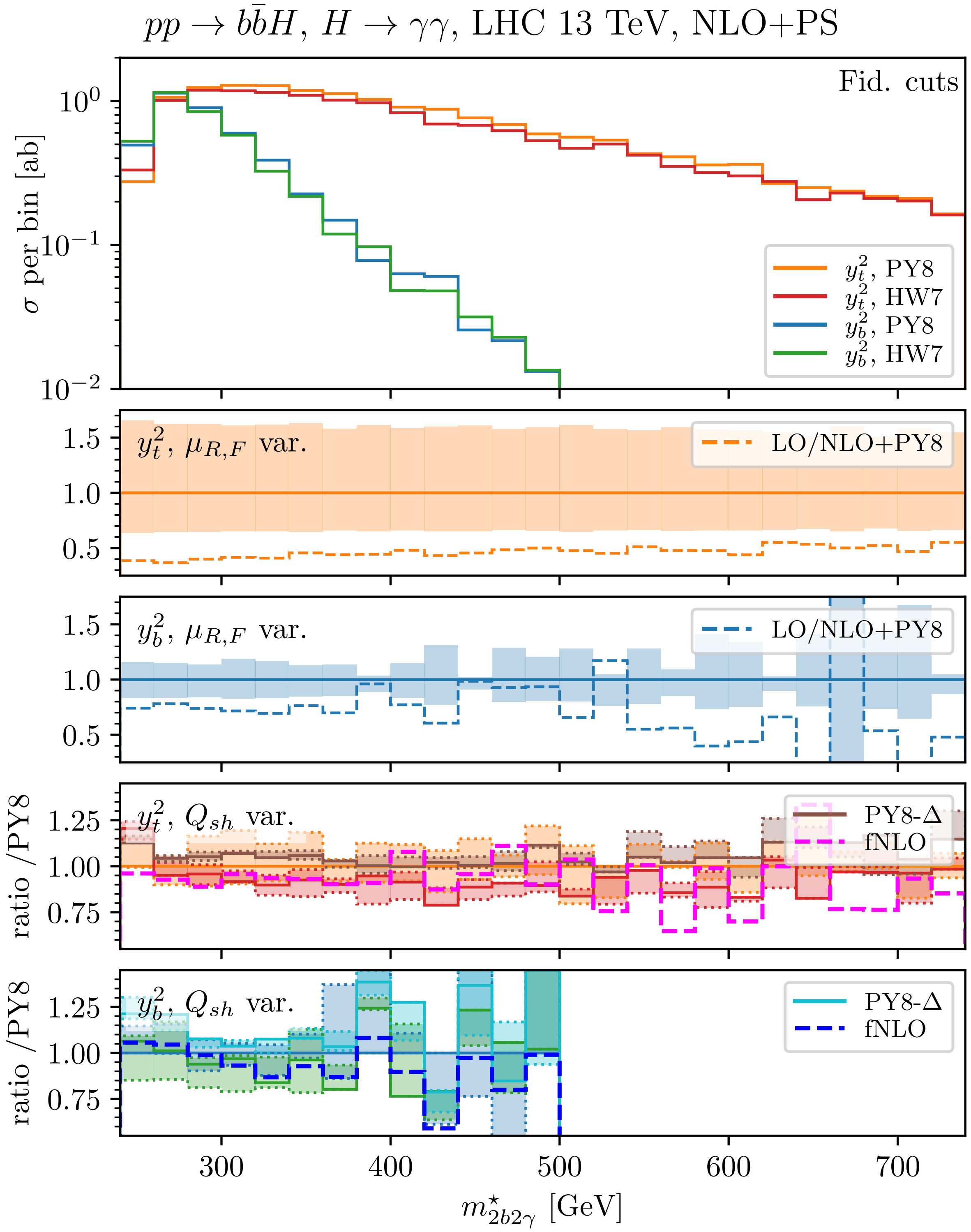
NLO corrections to y_t part:
>100% increase on top of LO
Still sizeable scale uncertainty (30-50%)

Rather small matching/shower uncertainties
O(10-20%) between different PS: HW7 vs PY8
and matching schemes:
standard MC@NLO vs MC@NLO-Δ*
Bands are due to shower-scale variations only

*Frederix et al, arXiv:2002.12716

More results



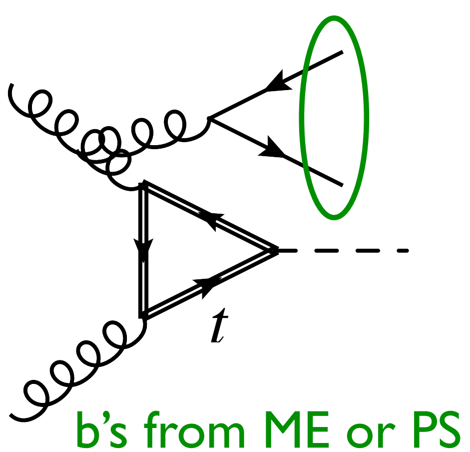


$$m^{\star}_{2b2\gamma} = m_{2b2\gamma} - m(b_1, b_2) - m(\gamma_1, \gamma_2) + 2m_H$$

On a possible source of double counting in 5FS simulations

Comparison with the 5FS

- In a 4FS simulation, two b-quarks are always present at the matrix-element level
- In a 5FS simulation stemming from an inclusive prediction (like NNLOPS, used by ATLAS) , b-quarks can either be generated by the PS or at the ME-level
  - Given the hierarchy between ggH (50 pb) and Hb$\bar{b}$ (0.5 pb), assuming O(1%) of events with b quarks from the PS, the two effects are of the same order

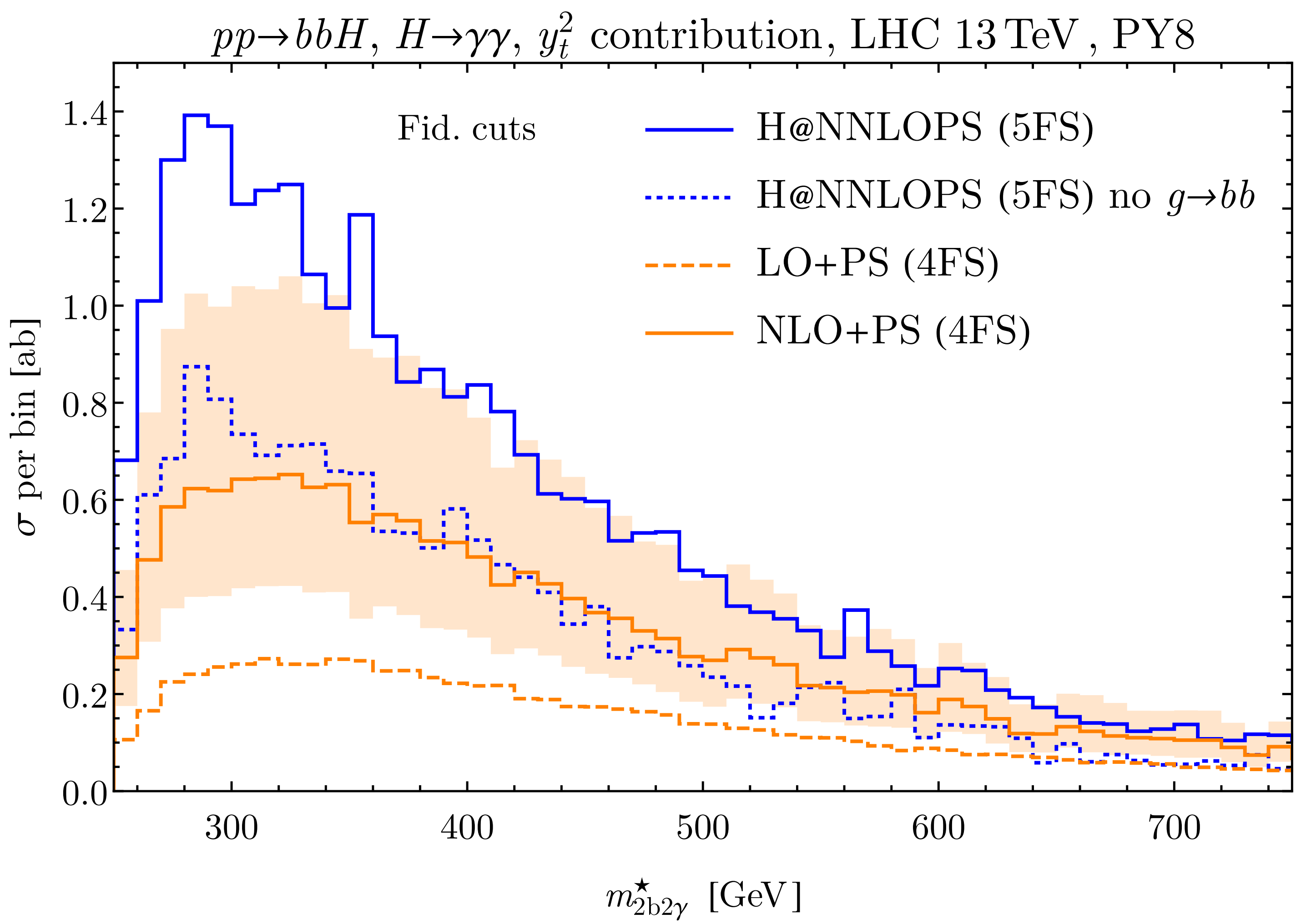


Cut	Contr.	Run	LO	NLO	$\delta\mu_{R,F}$	δQ_{sh}	NNLOPS (y_t^2 LO)	HH signal
Fid. cuts	y_b^2	PY8	3.15	4.22	$^{+15\%}_{-15\%}$	$^{+10\%}_{-4\%}$		
		PY8-Δ		4.75		$^{+0\%}_{-2\%}$		
		HW7	2.59	4.08		$^{+8\%}_{-12\%}$	29.9 ME+PS ~1.7*4FS	
	y_t^2	PY8	8.24	18.1	$^{+58\%}_{-34\%}$	$^{+10\%}_{-7\%}$		
		PY8-Δ		19.2		$^{+3\%}_{-1\%}$	~~$g \to b\bar{b}$~~:	22.7
		HW7	6.83	16.6		$^{+4\%}_{-5\%}$	17.2 ME only ~4FS	

  - Ideally, the two kinds should fill different regions of phase-space

Comparison with the 5FS

- At the level of cross sections and distributions, the following trend seems to hold: 4FS ~ 5FS (ME-only) ~0.5 5FS (ME+PS)



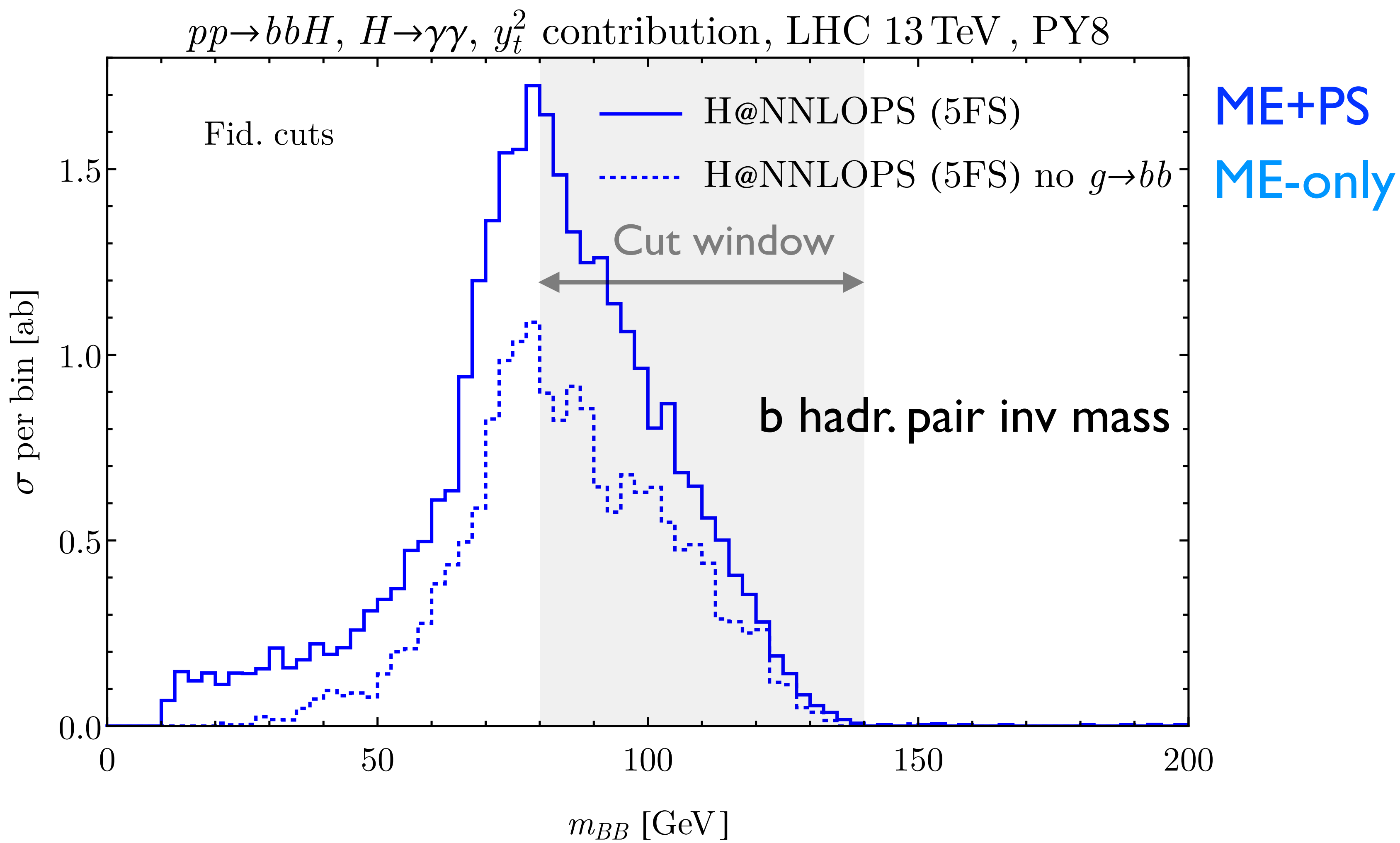
ME+PS

ME-only

-

(Non-)interplay between PS and ME

- The PS should fill soft/collinear regions, and leave the rest to the ME
- Are b quarks/hadrons from the PS soft/collinear?



- PS fills all over the mass range; it is not limited to soft-collinear

Comments/Thoughts

(see also Davide's talk yesterday)

- In the vast majority of events, there is only 1 bb pair
- The shower scale is typically $O(m_H)$. Is it a surprise that we see m(BB)~120 GeV?
- Keep in mind that b quarks are not generated in the first steps of the evolution, so they should naturally go at lower scales
- There may be non trivial interplay between different multiplicities described at different perturbative orders. What happens if also H+2jet is NLO-accurate?
- Also, the upper bound for $m(b_1 b_2)$ can have an effect
- Does the same happen for other processes with b quarks+X?

Conclusions

- $Hb\bar{b}$ production receives huge contributions insensitive to y_b in the SM
- They must be accounted for whenever $Hb\bar{b}$ is a background
- The y_t^2 contribution was never studied in the 4FS at NLO+PS
- At NLO+PS, dominant uncertainties from MHO. PS/matching uncertainties seem under control
- Such a description improves on the NNLOPS modelling previously used by experiments (with 100% uncertainty)
- Besides, the NNLOPS simulation seems affected by double counting, which are absent in a 4FS description
- It is possible (in principle) to improve the 4FS in the regions mostly sensitive to logs Hoeche et al, 1904.09382
- Studying b quarks looks easy at the beginning, but leads to many surprises