bbH group report for the LHCHXSWG meeting July 2017

Conveners:

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Layout

- Updated group twiki
- Inclusive cross-sections and recommendations
- Available tool for exclusive calculations
  - bbH NLO MC generators
- bbH generation in ATLAS and CMS MSSM $H \rightarrow \tau\tau$ analyses
- Recommendation for bbH acceptance uncertainty
  - why to use more than one NLO bbH generator
- bbZ proposal

Updated bbH group twiki

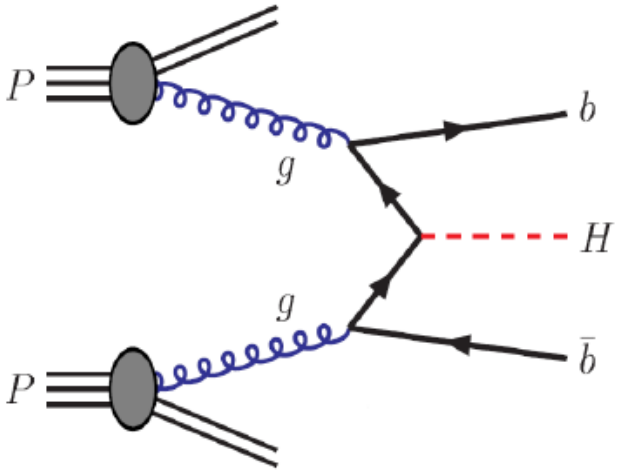
https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHXSWGBBH

bbH/bH Associated Production Process

Inclusive cross-sections and recommendations

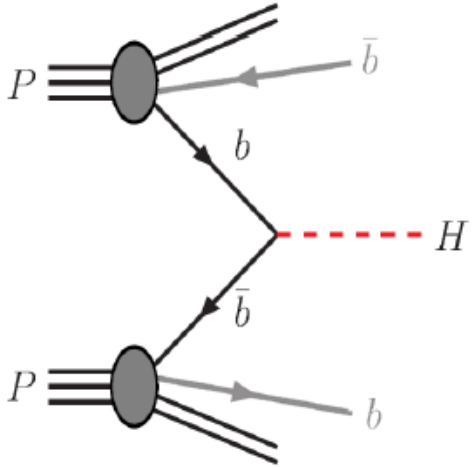
Associated $H(b\bar{b})$ production

4-flavour scheme



- massive b's
- potentially large logs $\ln(m_b/Q)$
- power terms $(m_b/Q)^n$
- involved $2 \to 3$ at LO
- 2 exclusive b's at LO
- b(-tag) well defined

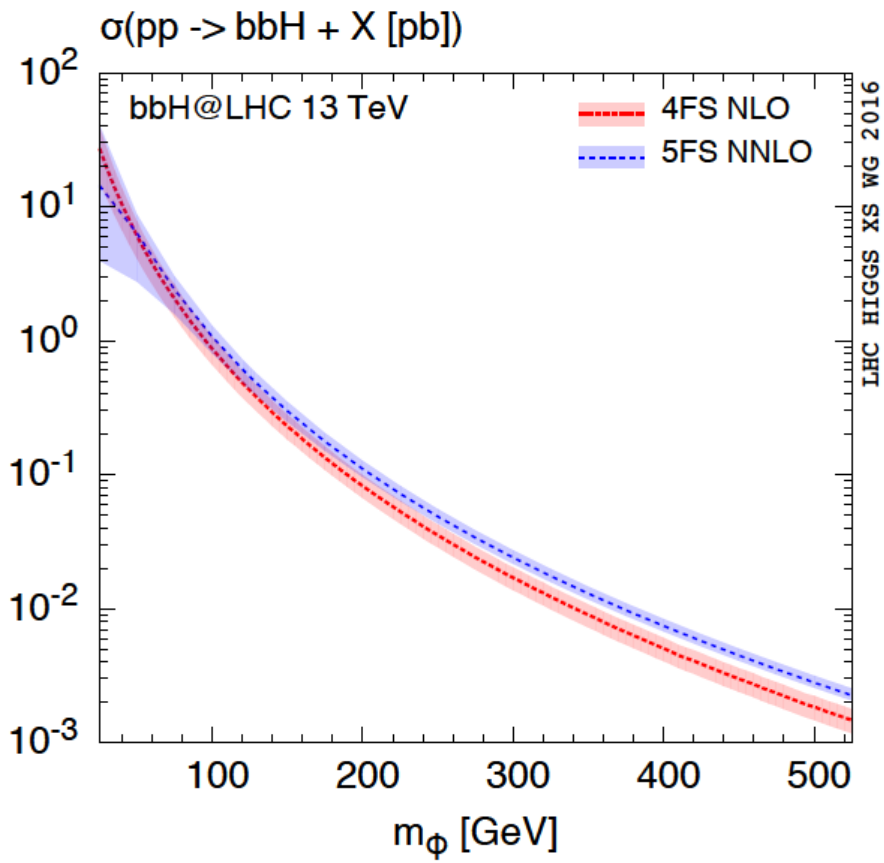
5-flavour scheme



- massless b's
- resummation into b-PDFs
- —
- simple $2 \to 1$ at LO
- exclusive b's at higher orders
- b part of light jets

”Santander” matched cross-sections used in the Run II 2016 data analyses

4FS vs. 5FS: Total cross section



Santander matching

[Harlander, Krämer, Schumacher '11]

4FS NLO:

[Dittmaier, Krämer, Spira '04]

[Dawson, Jackson, Reina, Wackeroth '04]

[MW, Frederix, Frixione, et al. '14]

new grids $m_\phi = 25 - 2025$ GeV for y_b^2 and $y_b\, y_t$ with MG5_aMC

5FS NNLO:

[Harlander, Kilgore '03]

[Harlander, Liebler, Mantler '13]

new grids $m_\phi = 25 - 2025$ GeV for y_b^2 produced with SusHi

MSSM: Δ_b approximation and resummation through y_b-reweighting (captures dominant effects) [Dawson, Jackson, Reina, Wackeroth '05], [Dittmaier, Häfliger, Krämer, Spira, Walser '14]

Santander matched cross-section values vs mH

Post "Santander" matchings described in YR4

- **FONLL-B matching**
  - **S. Forte, D. Napoletano and M. Ubiali**
    - arXiv:1508.01529, arXiv:1607.00389
- **NLO+NNLLpart+ybyt matching**
  - **M. Bonvini, A. S. Papanastasiou and F. J. Tackmann**
    - arXiv:1508.03288, arXiv:1605.01733
- **Recommendations for Run II 2017-18 data analyses:**
  - **use the numbers from NLO+NNLLpart+ybyt matching, by mentioning that the latter have been cross-checked against the FONLL ones and citing both works**

Comparison of matched approaches

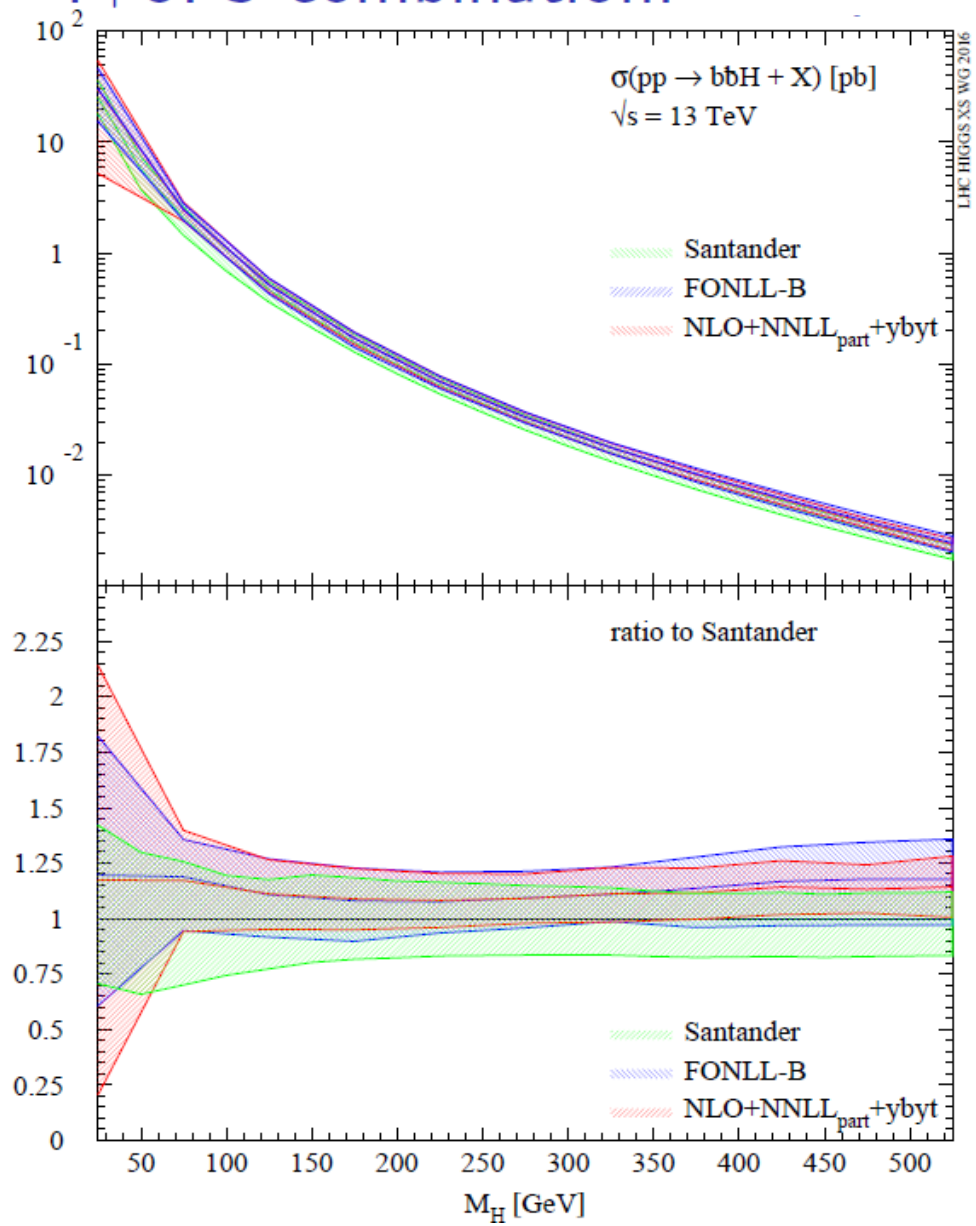
- $y_b\, y_t$ included in all predictions
- all predictions in agreement

consistently matched approaches:

(FONLL-B and NLO+NNLL$_{\text{partial}}$)

- perfect agreement among them
- decent agreement with Santander
- large m_H: tendency towards 5FS
- small m_H: no breakdown, closer to 4FS
- Santander now empirical

4+5FS combination:



- **Tar file (ascii) with cross-sections from NLO+NNLLpart+ybyt matching is available (link)**
  - **scan between 50 and 3000 GeV (13 TeV):**

```
Ecm = 13000 GeV. Cross-sections and uncertainties (pb)
muFcentral = (mH+2mb)/4,   muRcentral = mH/2
      mH       muF                descr            xs   muR_muF_unc       mub_unc        mb_unc   deltaPDF_up deltaPDF_
down   delta_as_up delta_as_down
      50         0    NLO+NNLLpart+ybyt     7.065e+00      1.44e+00      5.00e-01      2.30e-01      1.10e-01     -2.69
e-01     -4.39e-02      1.37e-01


    3000         0    NLO+NNLLpart+ybyt     4.133e-08      1.08e-08      9.73e-09      2.30e-10      1.12e-08     -1.66
e-08      5.21e-09     -3.64e-09
```

- **Need to convert it to the appropriate format to be used by WG3 for BSM rescaling**

Tools for exclusive $b\bar{b}H$ cross section and distributions

- Higgs distributions (inclusive over b's)
  - 5FS y^H at NNLO: private code

    [Bühler, Herzog, Lazopoulos, Müller '12]
  - 5FS $p_T(H)$ at NNLO+NNLL: private code by M. Wiesemann

    [Harlander, Tripathi, MW '14]
- MCs for bbH signal simulation
  - MG5_aMC with $y_b^{\overline{MS}}$ at NLO+PS in 4FS

    https://cp3.irmp.ucl.ac.be/projects/madgraph/wiki/bbH

    [MW, Frederix, Frixione, Hirschi, Maltoni, Torielli '14]
  - POWHEG at NLO+PS in 4FS

    [Jäger, Reina, Wackeroth, '15]
  - Sherpa at NLO+PS in 4FS

    [Krauss, Napoletano, Schumann. `16]
  - Sherpa merged 0,1,2 at NLO and 3-jet at LO in 5FS

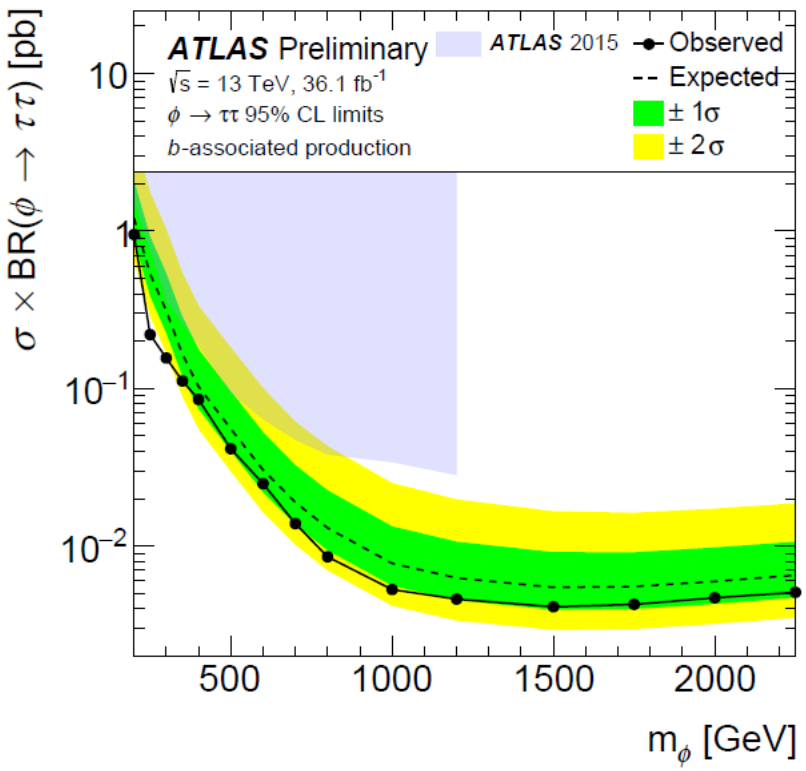
    [Krauss, Napoletano, Schumann. `16]

bbH in ATLAS and CMS analyses (I)

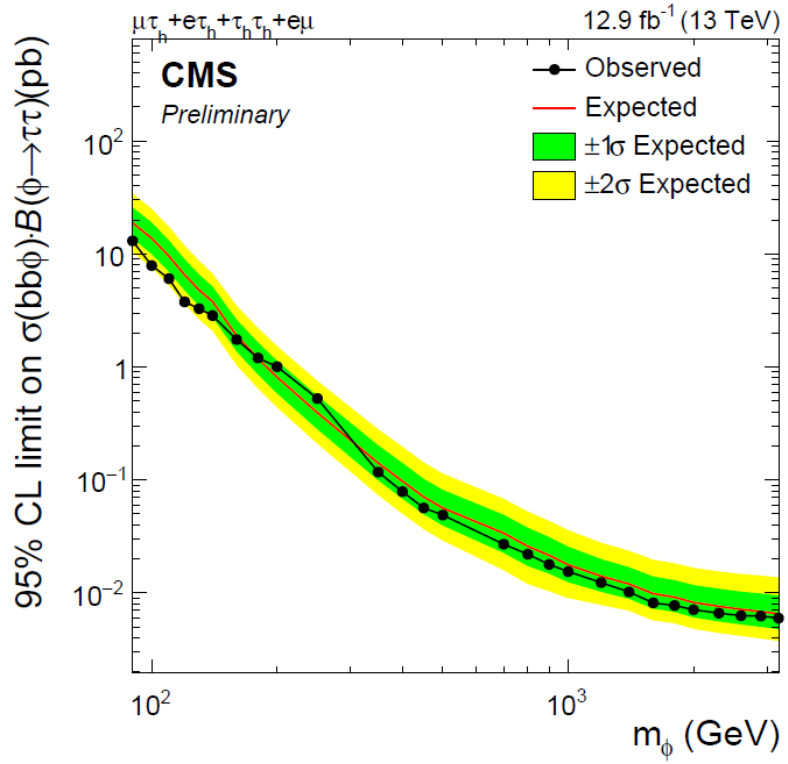
- ATLAS, 36.1 fb^{-1}, 13 TeV
- Signal modeling with MG5_aMC@NLO
  - signal acceptance uncertainty due to scale and PDFs are taken into account
  - not yet uncertainty due to shower scale

- CMS, 12.9 fb^{-1}, 13 TeV
- Signal modeling with PY8
  - moving to MG5_aMC@NLO for the 36fb^{-1} analysis (under preparation)

ATLAS-CONF-2017-050

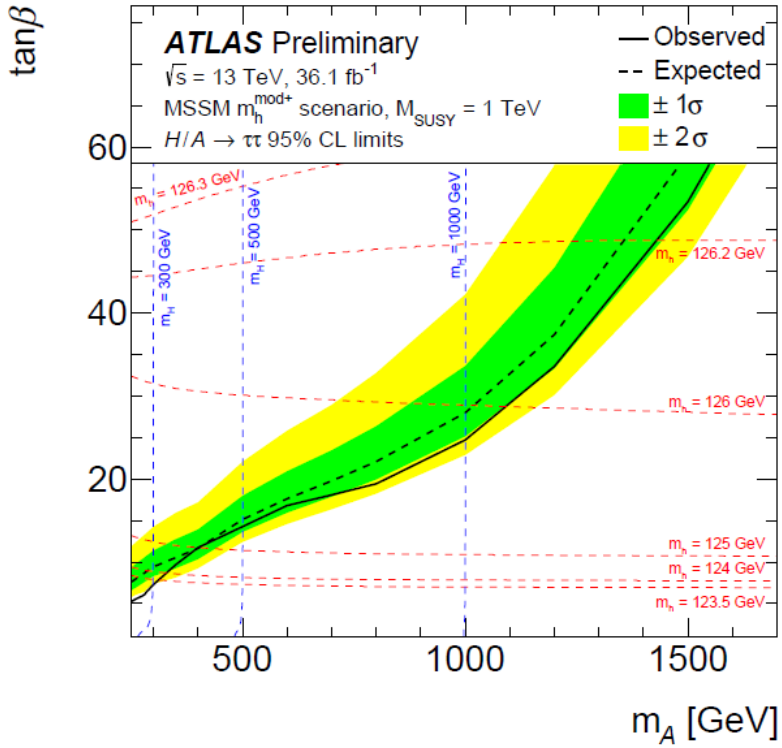


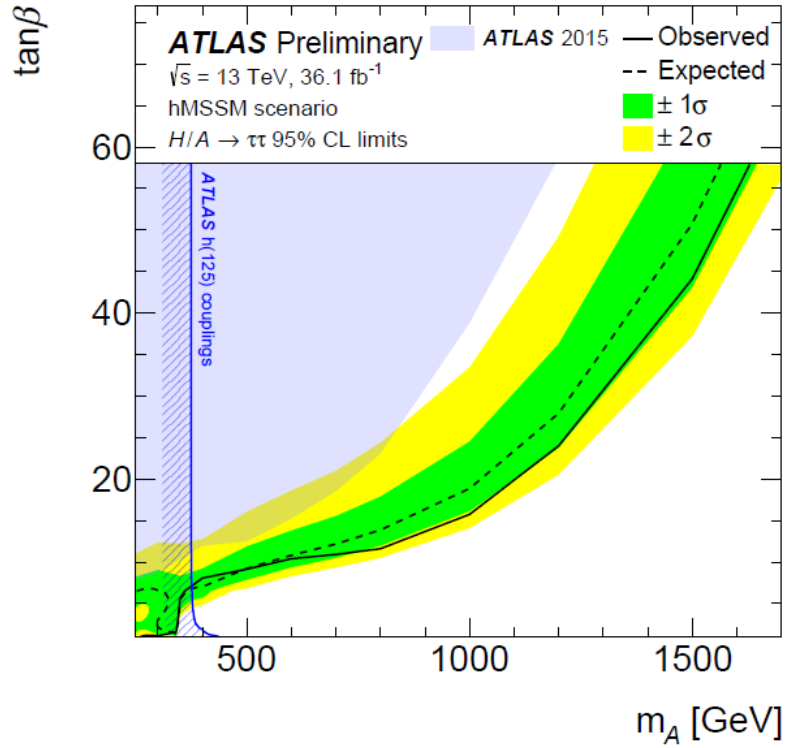
CMS-PAS-HIG-16-037



bbH in ATLAS and CMS analyses (II)

- **From cross-section limits to model interpretation limits in MSSM m_A-tanβ plane**
  - **input from WG3: bbH, ggH MSSM cross-sections**





bbH in ATLAS and CMS analyses (III)

- **CMS is moving from PY8 bbH simulation to NLO simulation (with MG5_aMC@NLO presently) for the next iteration of $H \rightarrow \tau\tau$ analysis with 36 fb^{-1}**
  - **testing also POWHEG bbH implementation (with help of authors)**

- **Large difference in acceptance between PY8 and aMC@NLO bbH**
- **Selections for CMS 2016 public analysis, $\tau_h\tau_h$:**
  - **$p_T^{\tau h} > 40$ GeV, $|\eta|<2.1$**
  - **at least one b-jet of $p_T > 20$ GeV, $|\eta|<2.4$**
  - **no more than one jet of $p_T > 30$ GeV, $|\eta|<4.7$**

	Efficiency at particle level	
m_A=700 GeV selections	PYTHIA8	aM5_aC@NLO+PY8
$p_T^{\tau h} > 40$ GeV, $|\eta|<2.1$	0.764	0.791
at least one b-jet of $p_T > 20$ GeV, $|\eta|<2.4$	0.426	0.589
no more than one jet of $p_T > 30$ GeV, $|\eta|<4.7$	0.741	0.260

Recommendations for a signal acceptance uncertainty due to TH

Recommendations for the acceptance uncertainty calculations in the experimantal analysis (Preliminary)

- Use one of the recommended NLO generators above for the signal modelling in your analysis
  - set the central values of QCD scales and shower scale (Q_sh for aMC@NLO, hdamp for POWHEG and mu_Q for Sherpa) as described in the bbH Section of YR4
  - use pdf set, PDF4LHC15_nlo_nf4_30 (92000) if you generate in 4FS, which is the case for aMC@NLO and POWHEG; Sherpa has both 4FS and 5FS implementations
  - Evaluate the acceptance uncertainies of the used generator varying the factorization, renormalization and shower scales as described in the bbH Section of YR4 and add them linearly
  - add PDF uncertainty of the acceptance from the used generator to above uncertainties
  - To account for the difference in acceptance given by the different generators, evaluate (at least at particle level and at least for a few Higgs mass points) the acceptance with aMC@NLO, POWHEG and Sherpa and add it linearly to the acceptance uncertainty due to QCD and shower scales and PDFs.

- **with a chosen generator evaluate uncertainty due to**
  - **renormalization and factorizations scales**
  - **PDFs**
  - **shower scale**
- **add uncertainty due to difference in acceptance given by different generators**
  - **why this (hopefully temporary) recommendations ? Next slides.**

Large difference in acceptance between generators

From YR4, bbh(125)

		$\geq 1 j_b$	$\geq 2 j_b$
acceptance	MG5_AMC	0.342	0.0432
	POWHEG	0.251	0.0203
	SHERPA 4FS	0.283	0.0258
	SHERPA 5FS	0.277	0.0132

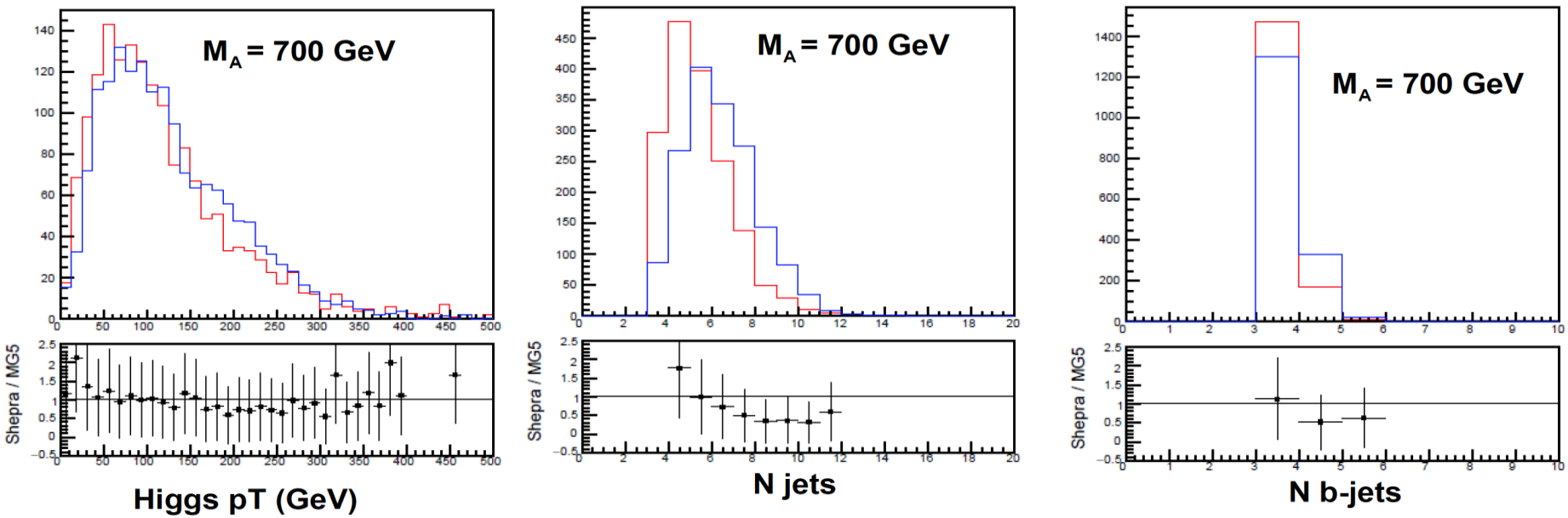
- **≈30 % difference in efficiency of ≥ 1b jet selection in 4FS generation**
- **≈50 % difference in efficiency of ≥2b jet selection between 4FS and 5FS generation (in Sherpa)**

Comparison of kinematic distributions from different bbH NLO generators for heavy Higgs

done so far in ATLAS and CMS

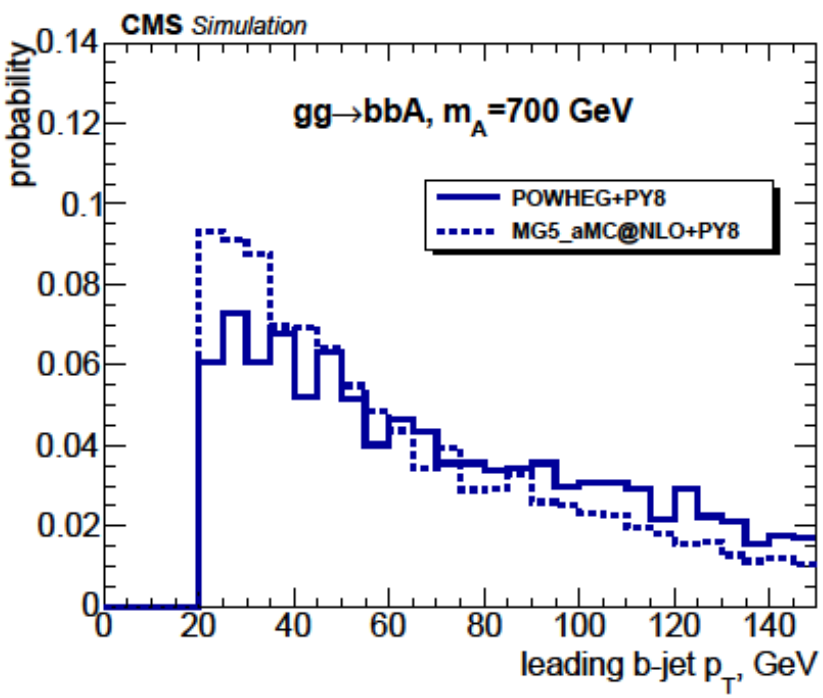
Sherpa2.2 5FS vs MG5_aMC@NLO

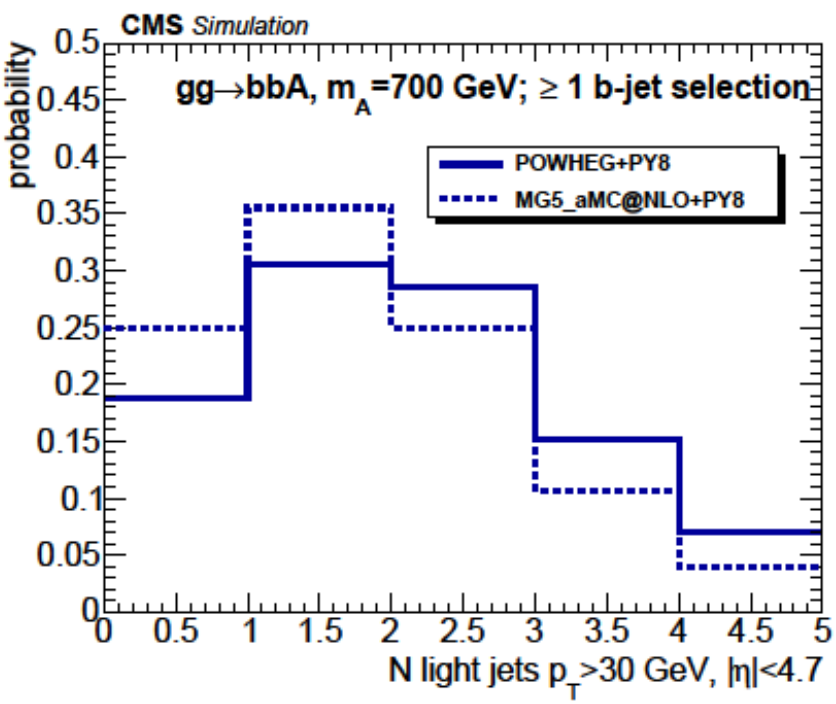
- **ATLAS particle level simulation**
  - **blue: MG5_aMC@NLO, red: Sherpa**
  - **p_T^j > 20 GeV**



MG5_aMC@NLO vs POWHEG

- **CMS particle level simulation**
  - ***preliminary***



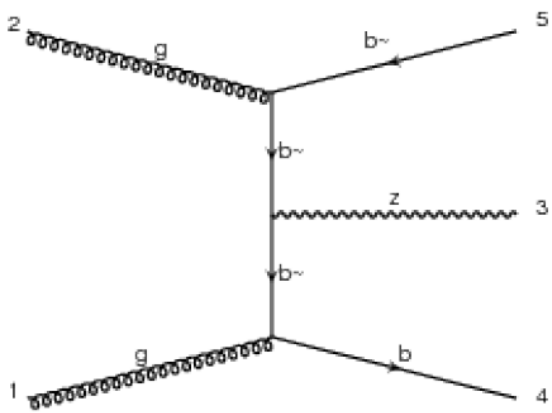


Proposal:
use bbZ data as a benchmark for bbH MC generators

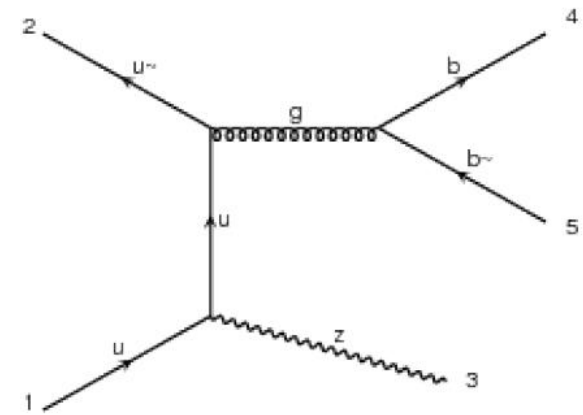
Thanks to S. Frixione, F. Krauss, D. Napoletano and M. Zaro for discussions and help

bbZ(H): LO production in 4FS

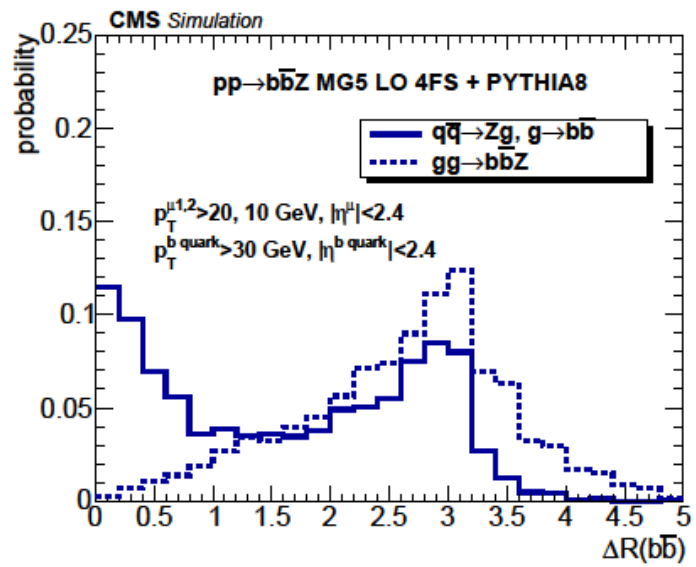
common for bbZ and bbH



bbZ only



Cross sections at LO (pb), MG5_aMC@NLO			
LHC √s	7 TeV	8 TeV	13 TeV
gg→bbZ	280	360	890
qq~→bbZ	55	65	120
Ratio: σ(qq~→bbZ)/σ(pp->bbZ)			
	0.16	0.15	0.12



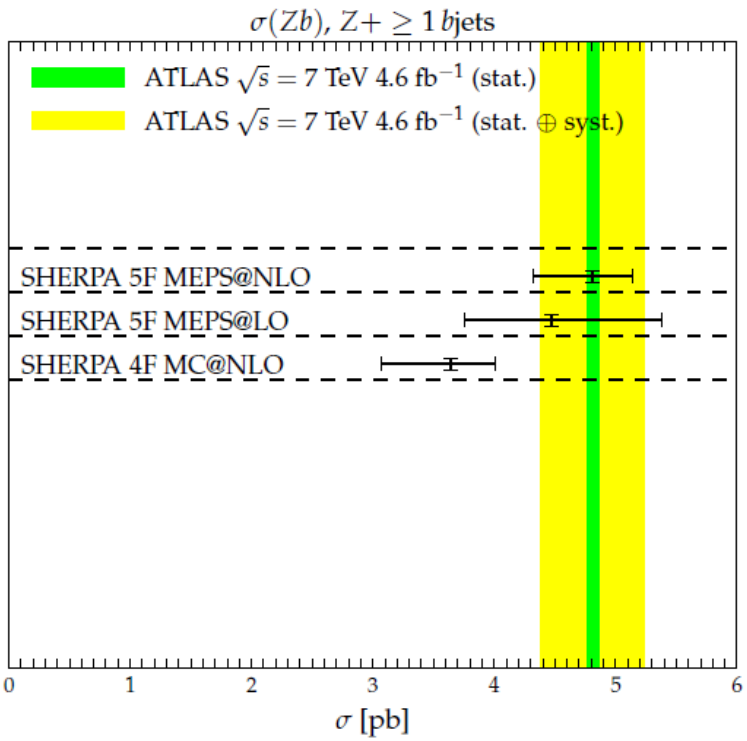
bbZ measurements at LHC so far

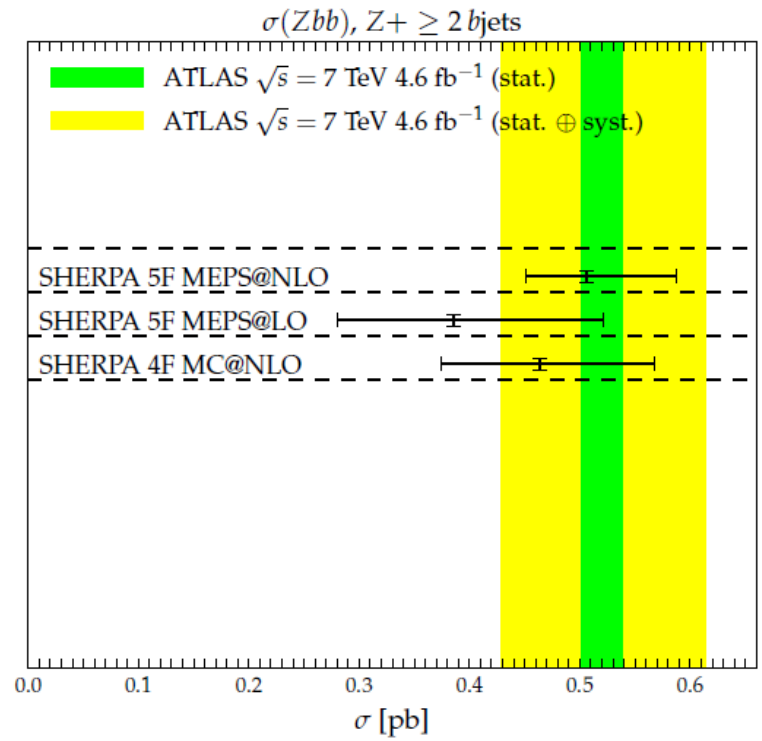
- 7 TeV
  - ATLAS, JHEP10(2014)141
  - CMS, JHEP 06 (2012) 126
  - CMS, JHEP 12 (2013) 039.
    - with reconstructed B-hadrons ! allows to test small ΔR_{bb}
  - CMS, JHEP 06 (2014) 120
- 8 TeV
  - CMS, arXiv:1611.06507

Recent nice TH review of V+b(b) processes:
F. Febres Cordero, L. Reina
Electroweak Gauge-Boson Production in Association with b Jets at Hadron Colliders
J. Mod. Phys. A Vol. 30 (2015) 1530042, arXiv:1504.07177

Comparison with theory so far: *cross-sections* (I)

F. Krauss, D. Napoletano, S. Schumann Phys. Rev. D 95, 036012 (2017)





7 TeV, ≥ 1b jet: σ(4FS) Sherpa is smaller than data

7 TeV, ≥1b jet and ≥2b jet: σ(5FS) Sherpa agrees with data

Comparison with theory so far: *cross-sections* (II)

arXiv:1611.06507

Measurements of the associated production of a Z boson and b jets in pp collisions at $\sqrt{s} = 8$ TeV

The CMS Collaboration*

	TH MG5_aMC@NLO
$\sigma_{\text{fid}}(\text{pp} \to \text{Z} + (\geq 1\text{b})) = 3.55 \pm 0.12\,(\text{stat}) \pm 0.21\,(\text{syst})\,\text{pb},$	$4.23^{+0.27}_{-0.37}$ pb
$\sigma_{\text{fid}}(\text{pp} \to \text{Z} + (\geq 2\text{b})) = 0.331 \pm 0.011\,(\text{stat}) \pm 0.035\,(\text{syst})\,\text{pb}.$	$0.36^{+0.03}_{-0.03}$ pb

These measured values can be compared with the corresponding predictions of MADGRAPH5_aMC@NLO interfaced with PYTHIA8, $4.23^{+0.27}_{-0.37}$ pb for Z(1b) and $0.356^{+0.030}_{-0.031}$ pb for Z(2b), where the theoretical uncertainties are dominated by the scale variations. The prediction underesti-

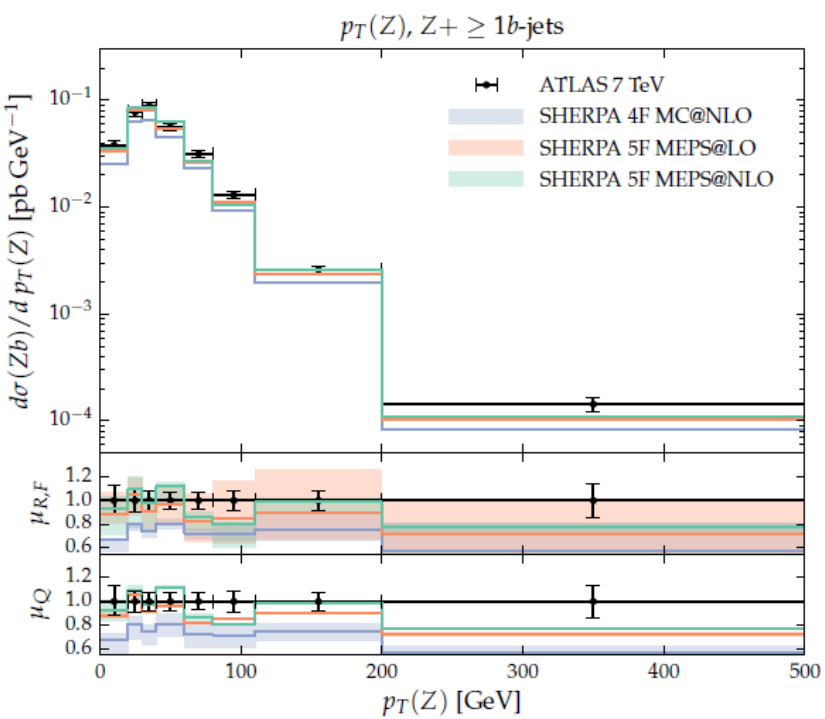
8 TeV, ≥ 1b jet: σ(4FS) MG5_aMC@NLO is larger than data

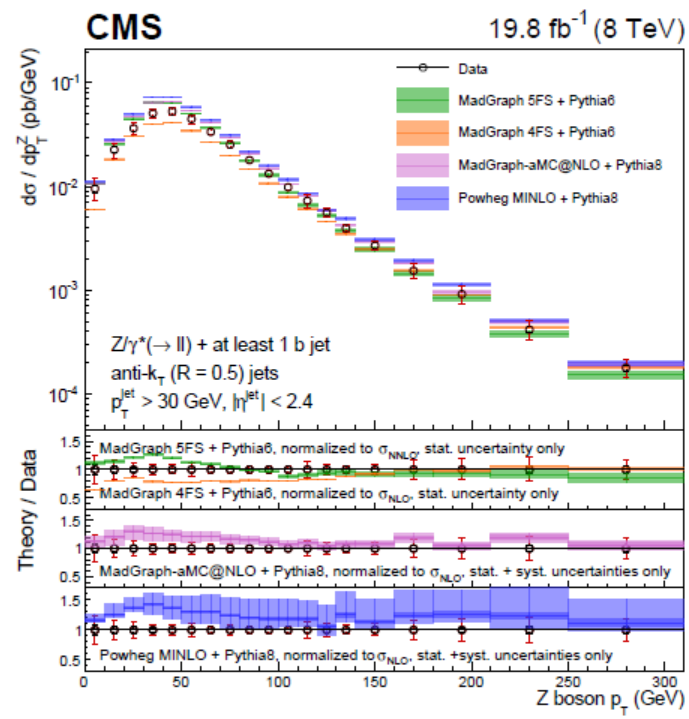
8 TeV, ≥1b jet and ≥2b jet: σ(4FS) agrees with data

Comparison with theory so far: *distributions* (p_T^Z)

- **7 TeV vs Sherpa (≥ 1b jet)**
  - **within the uncertainty shape is well modelled by both 4FS and 5FS**

- **8 TeV vs MG5_aMC@NLO (≥ 1b jet)**
  - **somewhat different shapes in data and MC; shower scale ?**



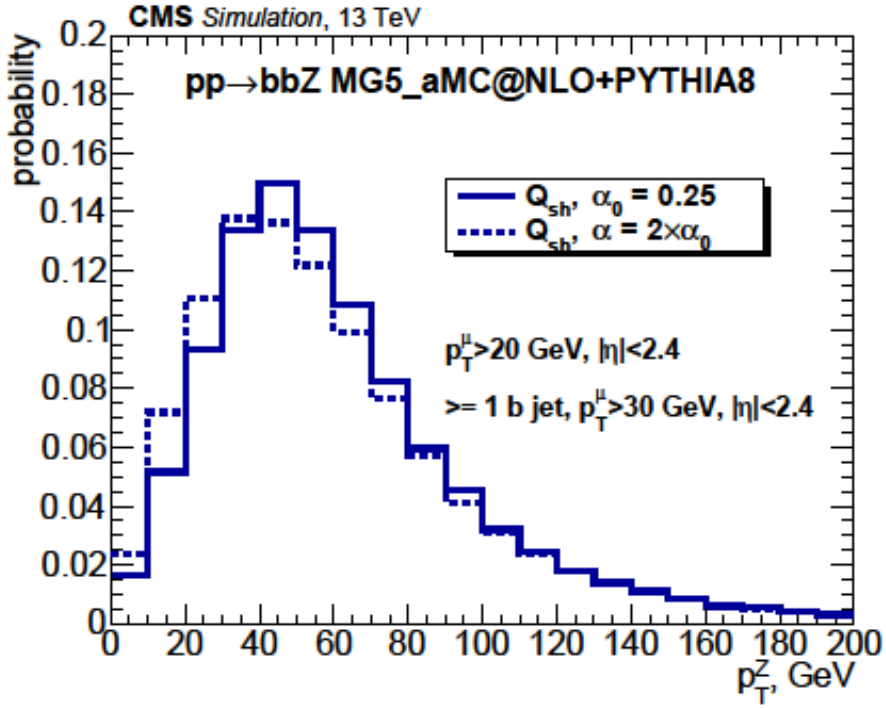


$p_T^{Z(H)}$ vs shower scale in bbZ(H) production

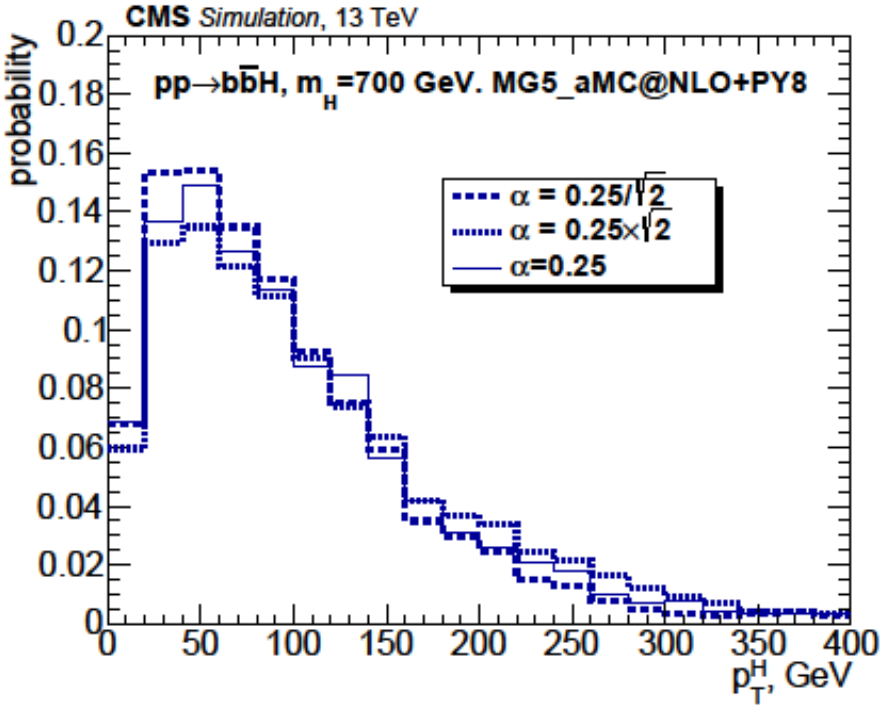
- **Can it be tuned from data ?**

MG5_aMC@NLO+PY8

bbZ



bbH, m_H=700 GeV



- **Not very clear picture so far (at least for an experimentalist) what MC generator and what scheme (4F or 5F) better describe available bbZ data**
  - **need to repeat bbZ analysis with 13 TeV and have a consistent comparison with Sherpa, MG5_aMC@NLO and POWHEG as it was done for SM h(125 GeV) in YR4 bbH Section**
  - **need to have inclusive bbZ cross-sections with new matching schemes used for bbH in YR4**
- **Next question is**
  - **suppose we have drown some conclusion from comparison of bbZ data with available NLO generators. Can it be propagated to the heavy Higgs bbH production, say for m_H=700 GeV ? Next slide**

bbH Sherpa, m_H=125 vs 700 GeV

- **Thanks to Davide Napoletano and Frank Krauss for this table !**

Cut flow is as in ArXiv:1612.04640.
QCD jets are defined through the anti-k_t algorithm using a radius parameter of $R = 0.4$, a minimal transverse momentum $p_{T,j} > 25$ GeV, and a rapidity cut of $|y_j| < 2.5$.
Numbers however are slightly different from YR and paper as I did not use the YR-like, 3-loop running of m_b nor the PDF4LHC pdf set.

Instead I use: $m_b^{\text{Pole}} = 4.72$ GeV to be consistent with the NNPDF30_nnlo_as_0118_nf_4 set, in the 4FS. In the 5FS instead I use the NNPDF30_nnlo_as_0118 pdf set, with $y_b = m_b^{\text{Pole}}$, run at LO at the scale m_H.

Note however, that all the numbers are consistent within themselves.

	Eff $\geq 1b$	Eff $\geq 2b$	$\sigma \geq 1b$ (pb)	$\sigma \geq 2b$ (pb)
4F $m_H = 125$ GeV	0.3130	0.0763	0.038	0.004
5F $m_H = 125$ GeV	0.3494	0.0303	0.069	0.005
4F $m_H = 700$ GeV	0.4560	0.1679	5×10^{-5}	1×10^{-5}
5F $m_H = 700$ GeV	0.3178	0.0496	7×10^{-5}	1×10^{-5}

- **≥1 bjet: no difference in acceptance between 4FS and 5FS for m_H=125 GeV while a large difference for m_H=700 GeV**
- **≥2b jets: difference in acceptance between 4Fs and 5FS is large and increased with Higgs mass**

Conclusions

- **Inclusive cross-section grid from new matching approaches was produced to be used for LHC 2017-18 data analyses**
- **ATLAS and CMS start using available bbH NLO generators in Run II analyses**
- **bbZ project can help to understand the large difference in acceptance from available NLO generators**