$b\bar{b}H$: introduction and theoretical status

Marius Wiesemann

University of Zürich

bbH cross-group kick off meeting, CERN (Switzerland)

November 28, 2014

Structure of the group

$b\bar{b}H$ sub-group acts as a cross-group of WG1 (SM Higgs XS&BR) and WG3 (BSM Higgs)

Theory conveners:

Michael Spira, Marius Wiesemann

Experimental conveners:

Matthew Beckingham (ATLAS), Alexandre Nikitenko (CMS)

Tasks of the group:

- inclusive $b\bar{b}H$ cross sections
- exclusive Higgs cross sections with b-tagging
- differential observables
- acceptance for experimental searches
- predictions for both SM and 2HDM/MSSM

outline of the meeting

bbH cross-group kick off meeting

Friday, 28 November 2014 from **14:00** to **16:00** (Europe/Zurich)
at **CERN**

Video Services Vidyo public room : bbH_cross-group_kick_off_meeting More Info | **Join Now!**

Friday, 28 November 2014

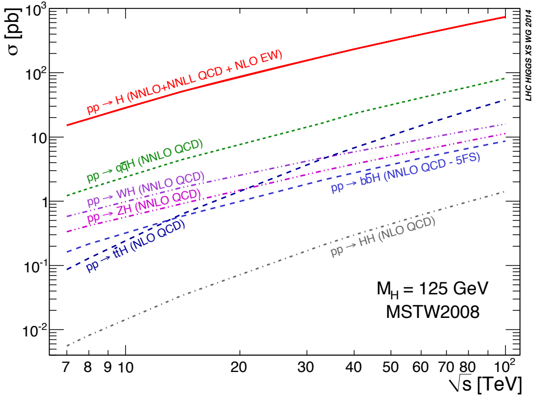
14:00 - 14:20 Introduction and theoretical status *20′*
Speaker: Marius Wiesemann (Universitaet Zuerich (CH))

14:20 - 14:40 Resummation of b-quark mass effects in bbH-induced Higgs production *20′*
Speaker: Andrew Sofronis Papanastasiou (Deutsches Elektronen-Synchrotron (DE))

14:40 - 15:00 bbH generation in ATLAS: status and plan *20′*
Speaker: Matthew Beckingham (University of Warwick (GB))

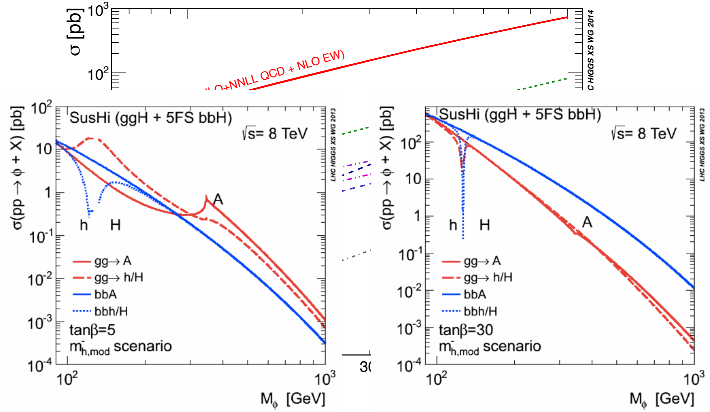
15:00 - 15:20 bbH generation in CMS, status and plan *20′*
Speaker: Alexandre Nikitenko (Imperial College Sci., Tech. & Med. (GB))

SM vs. MSSM Higgs production



- SM:
  - gluon fusion by far dominant
  - $b\bar{b}H$ sizeable only with b-tagging

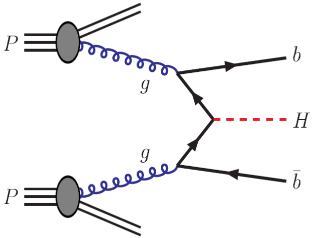
SM vs. MSSM Higgs production



- SM:
  - gluon fusion by far dominant
  - $b\bar{b}H$ sizeable only with b-tagging
- MSSM/2HDM:
  - 3 neutral Higgs: h, H and A
  - y_b/y_t enhanced by $\tan\beta$
  - h: constrained to be SM-like
  - $b\bar{b}H/A$ dominant for large $\tan\beta$

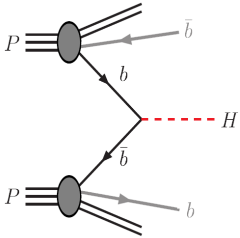
Associated $H(b\bar{b})$ production

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

4-flavour scheme

- inclusive (exclusive) up to NLO

  [Dittmaier, Krämer, Spira '04]

  [Dawson, Jackson, Reina, Wackeroth '04]

- exclusive NLO+PS

  [MW, Frederix, Frixione, Hirschi, Maltoni, Torrielli '14]

5-flavour scheme

- inclusive up to NNLO

  [Harlander, Kilgore '03]

- exclusive H+b at NLO

  [Campbell, Ellis, Maltoni, Willenbrock '03]

- exclusive H+n-jet ($n = 0/1/2$)

  [Harlander, Ozeren, MW '10]

  [Harlander, MW '11]

- exclusive up to NNLO

  [Buehler, Herzog, Lazopoulos, Mueller '12]

- NLO+NLL p_T resummation

  [Belyaev, Nadolsky, Yuan '06]

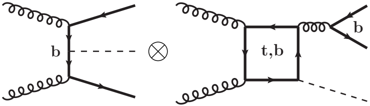
- NNLO+NNLL p_T resummation

  [Harlander, Tripathi, MW '14]

- exclusive NLO+PS

  [MW, Frederix, Frixione, Hirschi, Maltoni, Torrielli '14]

The $b\bar{b}H$ cross section



y_b^2-term at NLO

$y_b\, y_t$-term at NLO

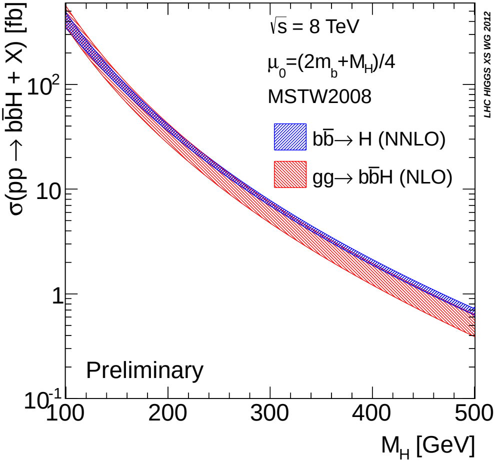
y_t^2-term at NNLO

$$\sigma_{b\bar{b}H}^{4FS} = \alpha_s^2\, y_b^2\, \Delta_{y_b^2}^{(0)} + \alpha_s^3 \left(y_b^2\, \Delta_{y_b^2}^{(1)} + y_b\, y_t\, \Delta_{y_b y_t}^{(1)} \right) + \alpha_s^4 \left(y_b^2\, \Delta_{y_b^2}^{(2)} + y_b\, y_t\, \Delta_{y_b y_t}^{(2)} + y_t^2\, \Delta_{y_t^2}^{(2)} \right) + \mathcal{O}(\alpha_s^5)$$

$$\sigma_{b\bar{b}H}^{5FS} = y_b^2\, \Delta_{y_b^2}^{(0)} + \alpha_s\, y_b^2\, \Delta_{y_b^2}^{(1)} + \alpha_s^2 \left(y_b^2\, \Delta_{y_b^2}^{(2)} + y_t^2\, \Delta_{y_t^2}^{(2)} \right) + \mathcal{O}(\alpha_s^3)$$

- $y_b\, y_t$-term enters at NLO:
  - interference with (contamination from) gluon fusion
  - no double counting with gluon fusion cross section!
- y_t^2-term enters at NNLO:
  - part of gluon fusion cross section
  - sizable in SM $\sim 40\%$ (LO – large uncertainties)
  - e.g., with MG5@LO in 4FS HEFT; agreement with full theory

4FS vs. 5FS: Inclusive cross section



4FS NLO:

[Dittmaier, Krämer, Spira '04]

[Dawson, Jackson, Reina, Wackeroth '04]

grids $m_\phi = 80 - 1000$ GeV for y_b^2 and $y_b\, y_t$ produced by M. Spira

5FS NNLO:

[Harlander, Kilgore '03]

grids $m_\phi = 80 - 1000$ GeV for y_b^2 and produced with SusHi

[Harlander, Liebler, Mantler '13]

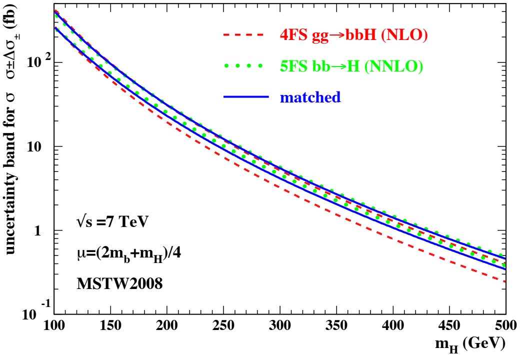
MSSM: $\frac{1}{1-\Delta_b}$ (tan β-resummation) y_b-reweighting approach (captures dominant effects) [Dawson, Jackson, Reina, Wackeroth '05],

[Dittmaier, Häfliger, Krämer, Spira, Walser '14]

4FS vs. 5FS: Santander matching

$$\sigma = \frac{\sigma^{4FS} + w\,\sigma^{4FS}}{1+w}, \quad w = ln(m_\phi/m_b) - 2$$

[Harlander, Krämer, Schumacher '11]



combined grids available on:
http:\\twiki.cern.ch/twiki/bin/view/LHCPhysics/CERNYellowReportPageAt8TeV

– **now:** $y_b\, y_t$ included (crucial for large-y_t scenarios)
– e.g, SM: $y_b\, y_t \sim -10\%$
– y_t^2 simply from gluon fusion

Alternative matching scheme: **next talk by Andrew Papanastasiou...**

Exclusive $b\bar{b}H$ cross section and distributions

4FS:

- NLO+PS: MG5_aMC with $y_b^{\overline{MS}}$ (both y_b^2 and $y_b\, y_t$)

  [MW, Frederix, Frixione, Hirschi, Maltoni, Torielli '14]

  process folder publicly available on:

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

- preferred shower scale significantly smaller than m_ϕ (similar to $\mu_F \sim m_\phi/4$)

5FS:

- NNLO fully differential

  [Bühler, Herzog, Lazopoulos, Müller '12]

- resummed NNLO+NNLL p_T cross section

  [Harlander, Tripathi, MW '14]

- NLO+PS: MG5_aMC with $y_b^{\overline{MS}}$

  [MW, Frederix, Frixione, Hirschi, Maltoni, Torielli '14]

Exclusive $b\bar{b}H$ cross section

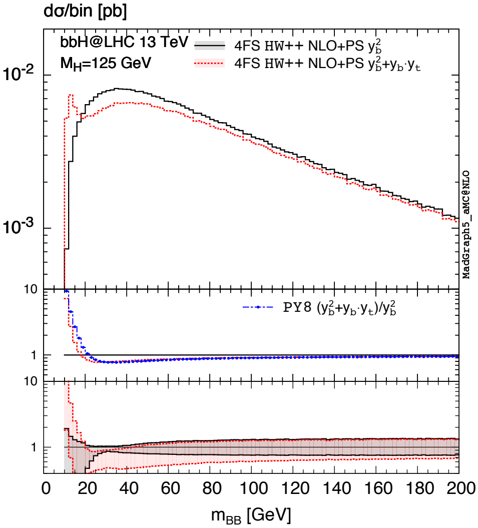
SM NLO+PS with `Pythia 8`; $\mu_F = \mu_R = H_T/4$;
shower scale according to [MW, Frederix, Frixione, Hirschi, Maltoni, Torielli '14]

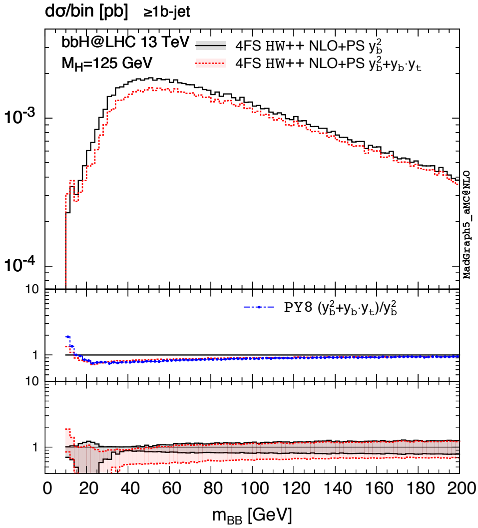
- significantly reduced residual uncertainty at NLO
- $y_b\, y_t$ always $\sim -10\%$ with large uncertainty (effectively LO)
- b-tag reduces cross section by factor of 3 – 4
- second b-tag by additional factor of 10

	NLO			LO
σ[pb]	y_b^2	$y_b\, y_t$	$y_b^2 + y_b\, y_t$	y_b^2
inclusive	$0.448^{+19.8\%}_{-20.8\%}$	$-0.0365^{+35.5\%}_{-62.8\%}$	$0.411^{+24.6\%}_{-28.4\%}$	$0.478^{+59.0\%}_{-34.6\%}$
$\geq 1j_b$	$0.133^{+16.7\%}_{-17.3\%}$	$-0.0148^{+35.0\%}_{-60.1\%}$	$0.118^{+23.5\%}_{-26.8\%}$	$0.150^{+55.9\%}_{-32.8\%}$
$\geq 2j_b$	$0.0133^{+13.7\%}_{-16.0\%}$	$-0.00147^{+34.3\%}_{-58.8\%}$	$0.0118^{+20.0\%}_{-25.1\%}$	$0.0168^{+54.4\%}_{-32.7\%}$

m_{BB}: y_b^2 vs. $y_b\, y_t$ (4FS)

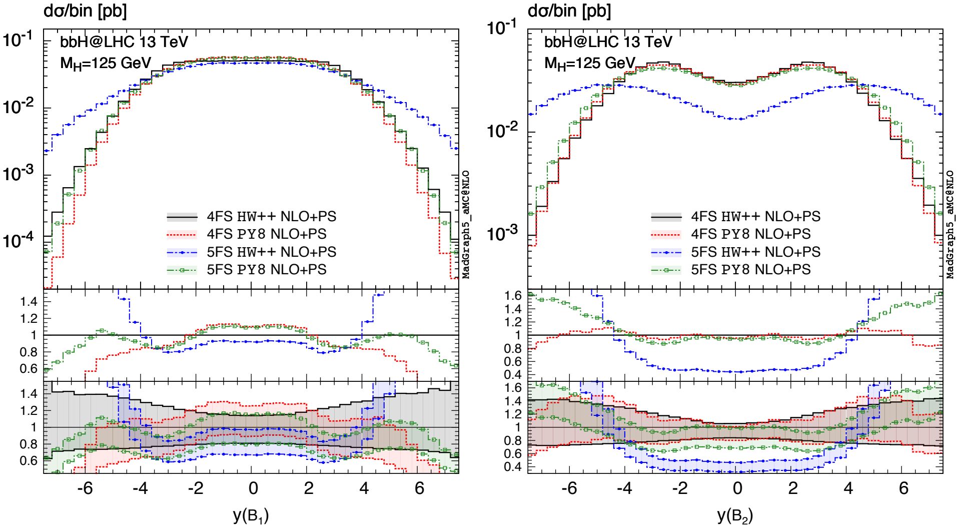
[MW, Frederix, Frixione, Hirschi, Maltoni, Torielli ’14]





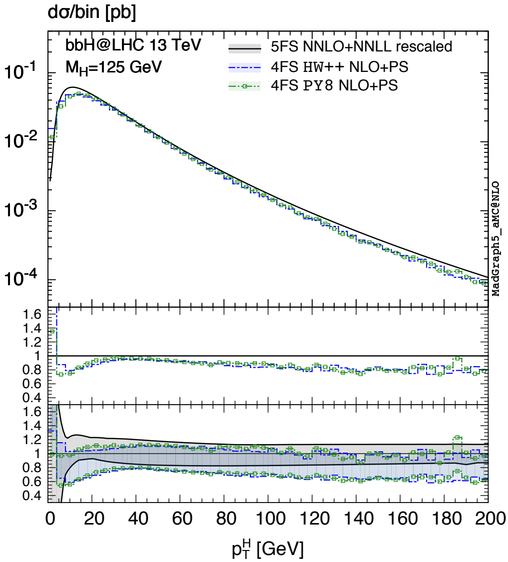
y_B: 4FS vs. 5FS

[MW, Frederix, Frixione, Hirschi, Maltoni, Torielli '14]



p_T^H: 4FS vs. 5FS NNLO+NNLL

[MW, Frederix, Frixione, Hirschi, Maltoni, Torielli '14]



analytic resummation:
$\mu_F = \mu_R = m_T/4$

NLO+PS:
$\mu_F = \mu_R = H_T/4$

Summary: Recommended tools for $b\bar{b}H$

- inclusive cross section
  - 4FS at NLO: private code by M. Spira, MG5_aMC with $y_b^{\overline{MS}}$
  - 5FS at NNLO: SusHi (bbh@nnlo)
- 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
  - 4FS at NLO: private code by M. Spira [Dittmaier, Krämer, Spira '04]
  - 4FS at NLO+PS: MG5_aMC with $y_b^{\overline{MS}}$
- exclusive cross section with b-tagging
  - 4FS at NLO+PS: MG5_aMC with $y_b^{\overline{MS}}$

Outlook

more things to do...

- contribution from ggF to exclusive $b\bar{b}H$ (y_t^2 terms)
- combination with ggF for inclusive Higgs observables
- relative importance of ggF and $b\bar{b}H$ in various 2HDM/MSSM scenarios (done for inclusive cross section)

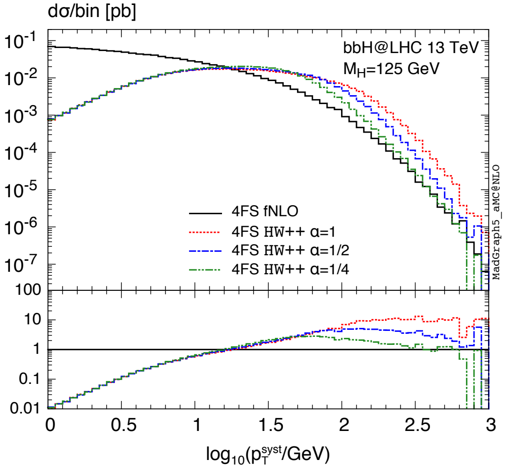
  [Bagnaschi, Harlander, Liebler, Mantler, Vicini '14]
- careful estimation of uncertainties from various sources
- extend comparison of 4FS and 5FS to higher Higgsmasses

Some cross-talk with MSSM and ggF sub-groups will be crucial!

BackUp

4FS: choosing the shower scale

[MW, Frederix, Frixione, Hirschi, Maltoni, Torielli '14]



$\alpha = 1 \quad \hat{=}\ Q_{\text{peak}} \sim 180\text{GeV}$

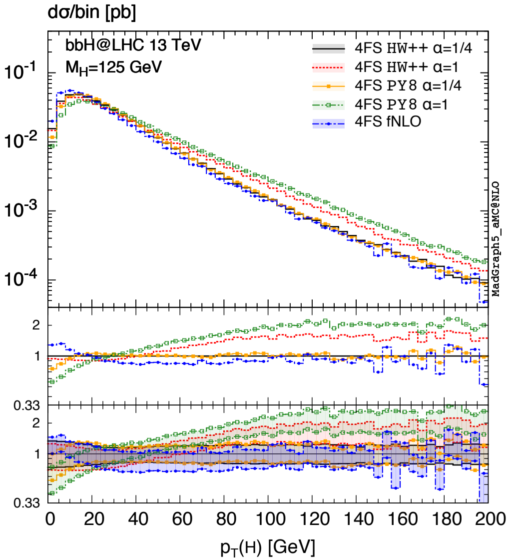
$\alpha = 1/2\ \hat{=}\ Q_{\text{peak}} \sim 90\text{GeV}$

$\alpha = 1/4\ \hat{=}\ Q_{\text{peak}} \sim 45\text{GeV}$

Q event-wise from a distribution peaked at $Q_{\text{peak}} \sim \alpha(f_1 + f_2)\sqrt{\langle s_0 \rangle}/2$
in an interval: $\alpha f_1 \sqrt{s_0} \leq Q \leq \alpha f_2 \sqrt{s_0}$, $\quad f_1 = 0.1,\ f_2 = 1,\ s_0$: LO c.m.e.

4FS: choosing the shower scale

[MW, Frederix, Frixione, Hirschi, Maltoni, Torielli '14]



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