Accurate predictions for charged Higgs boson production at the LHC

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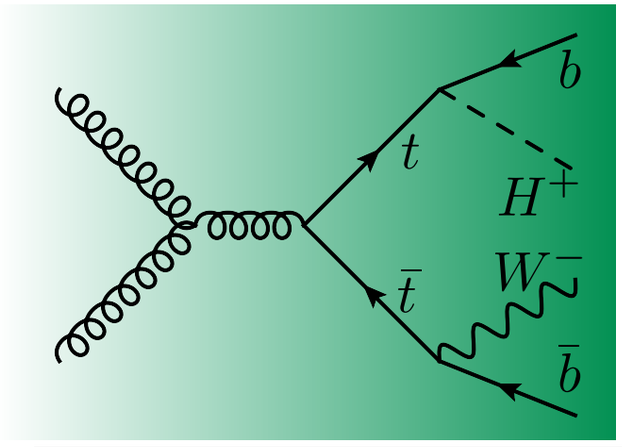
Annecy

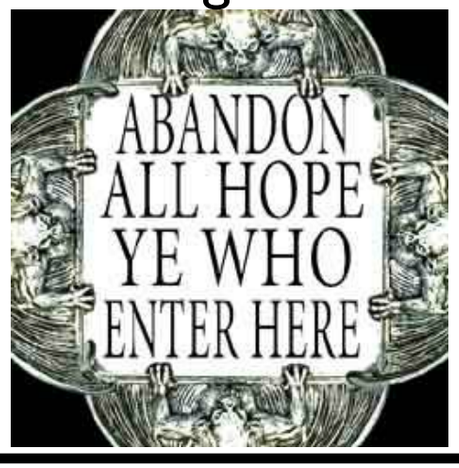
Charged Higgs production in the (type II) 2HDM

- In the 2HDM, the dominant production channel depends on the Charged Higgs mass

light Higgs



Intermediate region



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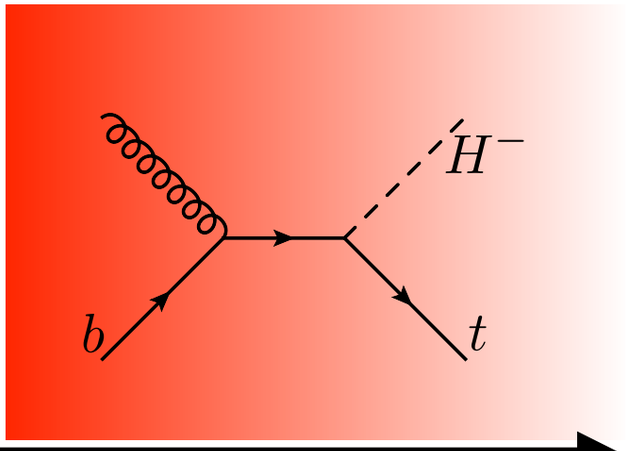


$M_{H+} < M_t$ $M_{H+} \simeq M_t$ $M_{H+} > M_t$

$H^\pm$ mostly produced in $t\bar{t}$ events. Depending on BR($t \to H^\pm b$) also $H^\pm t$ can become important. At NLO one has to subtract on-shell tops (see Plehn, hep-ph/0206121)

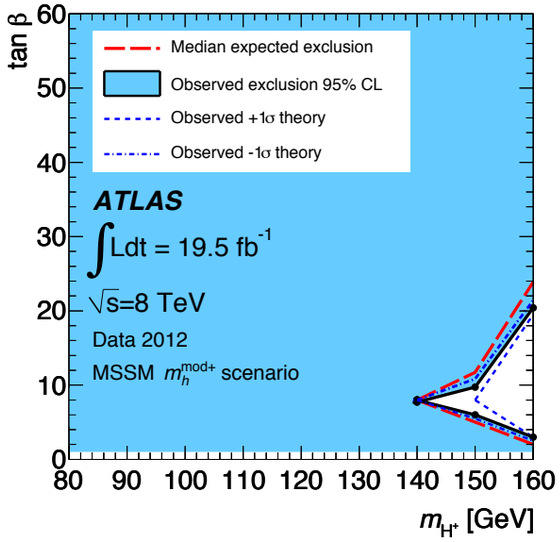
The full $pp \to H^\pm W^\mp b\bar{b}$ process has to be simulated. Computationally very demanding, but feasible

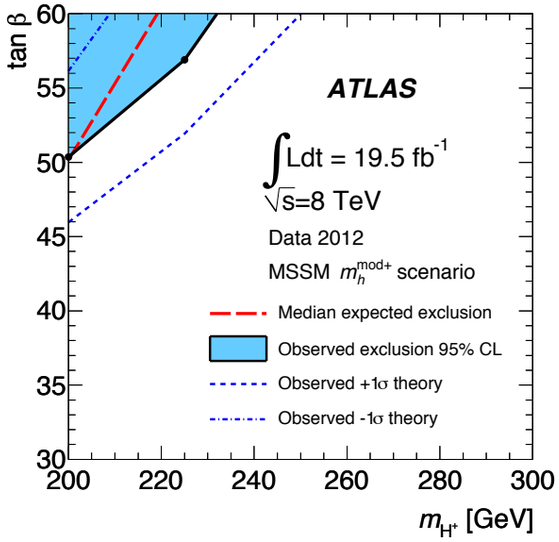
$H^\pm$ mostly produced in association with a top quark

Searches at the LHC

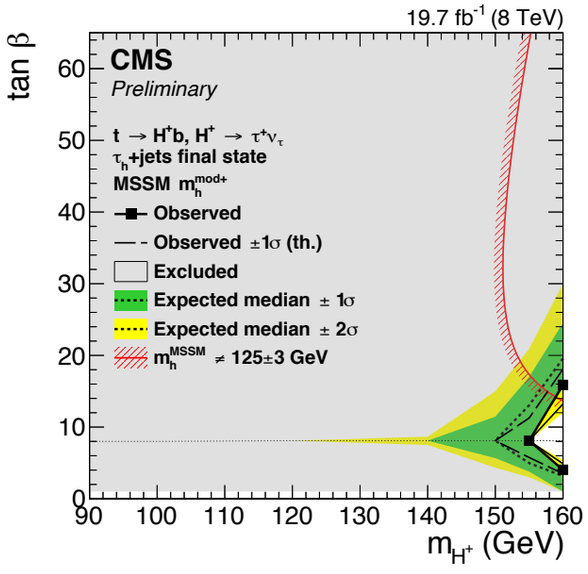
- LHC experiments tend to exclude a light charged Higgs
- For a heavy charged Higgs, only very large values of $\tan\beta$ are excluded
- Missing mass window due to non-existence of NLO predictions for the intermediate range

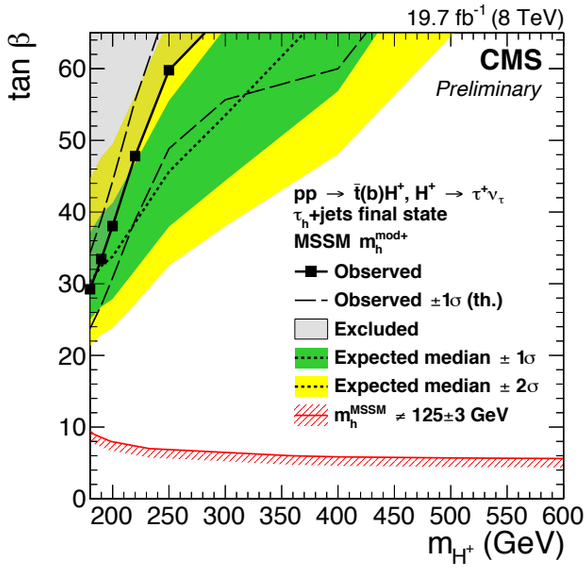
ATLAS, arXiv:1412.6663





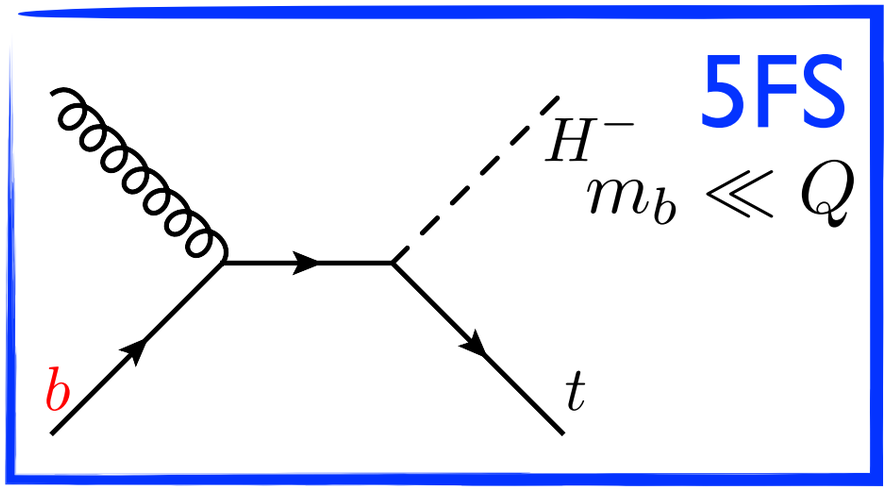
CMS, PAS HIG-14-020



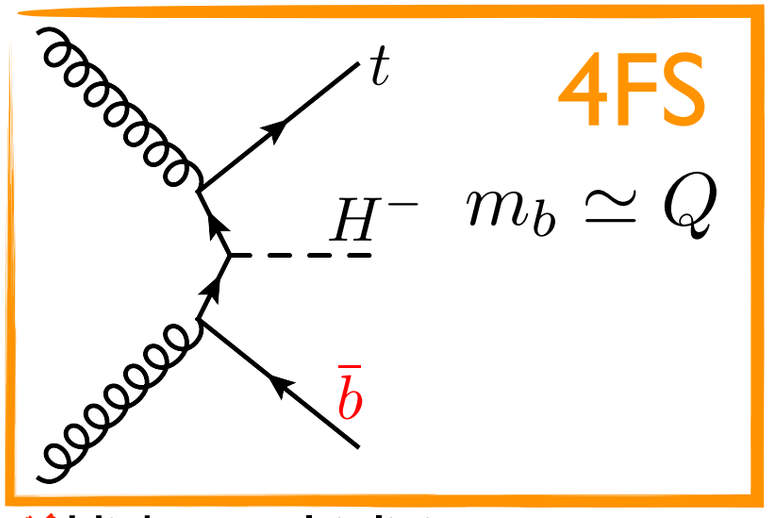


Heavy charged Higgs production

- Production mechanism features b quarks in the initial state: can be described either with 4- or 5-flavour scheme



✔Simpler process; computing HO is easier
✔b-PDF resums $\log(m_b/Q)$ at all orders
✘b-quark observables enter at higher orders
✘Matching to PS requires some care (gluon splitting, momentum reshuffling, …)



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✘Cross section can be affected by large $\log(m_b/Q)$
✔Accounts for b-mass effects and better descriptions of b-quark observables
✔Less ambiguities when matched to PS

Two schemes are equivalent if all orders were known
4FS believed to be superior for fully differential studies

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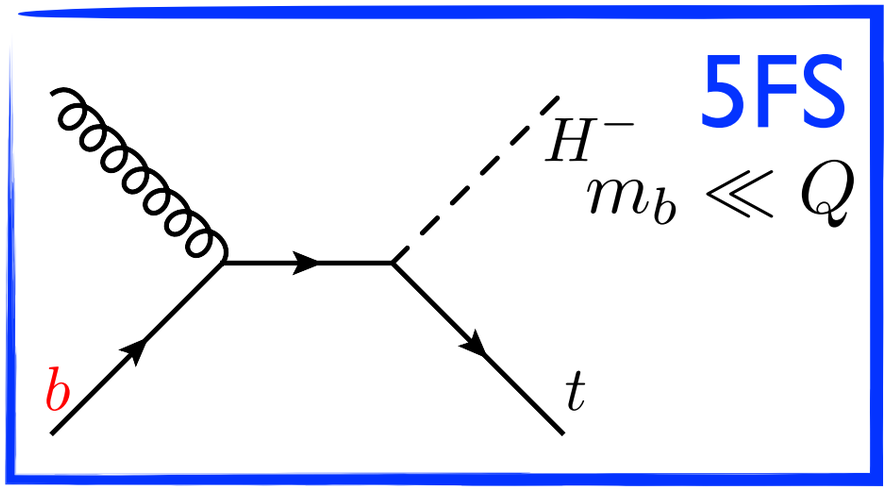

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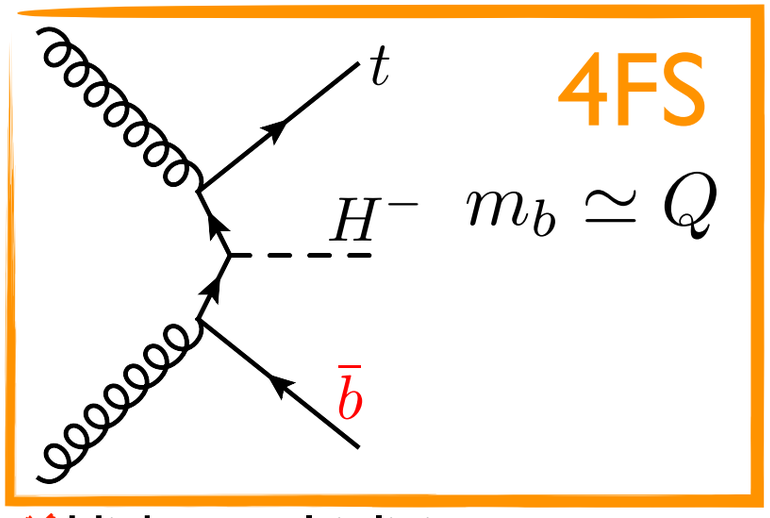

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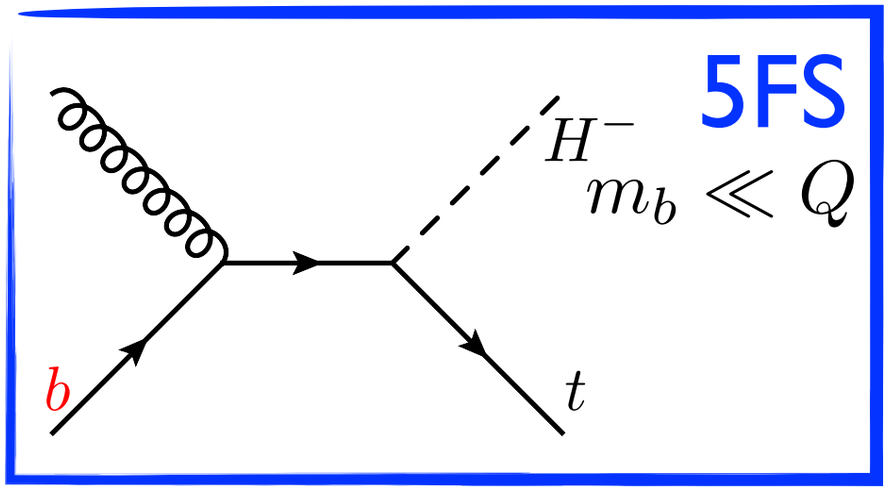

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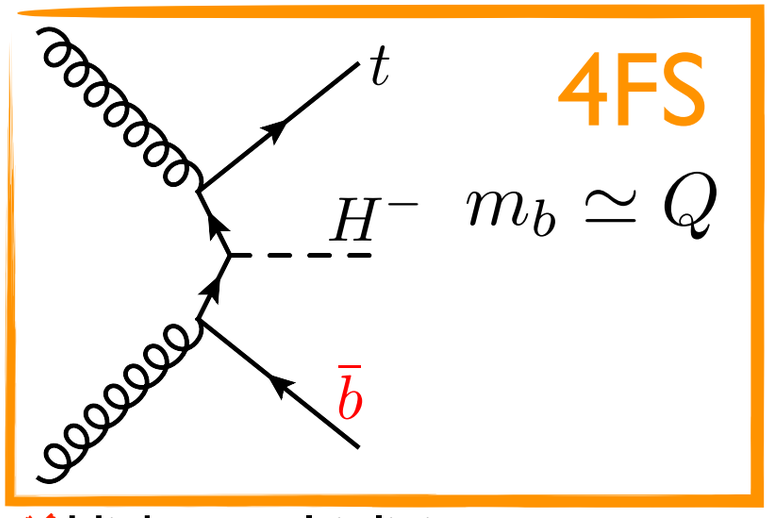

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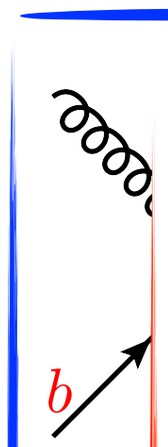

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✔b-PDF

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✘Matchin
splitting

Higher order results:

- NLO (SUSY-)QCD corrections
  Zhu, hep-ph/0112109, Plehn, hep-ph/0206121, Berger et al, hep-ph/0312286
  Dittmaier et al, arXiv:0906.2648
- EW corrections
  Beccaria et al, arXiv:0908.1332
  Nhung et al, arXiv:1210.4087
- Threshold resummation
  Kidonakis, arXiv:1005.4451
- Fully differential NLO+PS
  Weydert et al, arXiv:0912.3430, Klasen et al, arXiv:1203.1341
  Degrande, Ubiali, Wiesemann, MZ, arXiv:1507.02549;

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Fully differential comparison of 4 and 5FS

Degrande, Ubiali, Wiesemann, MZ, arXiv:1507.02549

- Use modern automated tool chains to generate the code, starting from the model Lagrangian
  - Generate UV/R_2 counterterms for the evaluation of loops with NLOCT Degrande arXiv:1406.3030
  - Use MadGraph5_aMC@NLO to generate the code for event generation Alwall et al. arXiv:1405.0301
- MSbar renormalisation to be preferred for y_b: logs of μ_R/m_b resummed. Add $m_b(\mu_R)$ dependence as in Wiesemann et al. arXiv:1409.5301
- b-initiated processes typically prefer scales lower than $\hat{s}$. This argument holds also for the shower scale
- Keep H^- stable, decay top quark leptonically
  →One b-jet from top and one from matrix element / shower

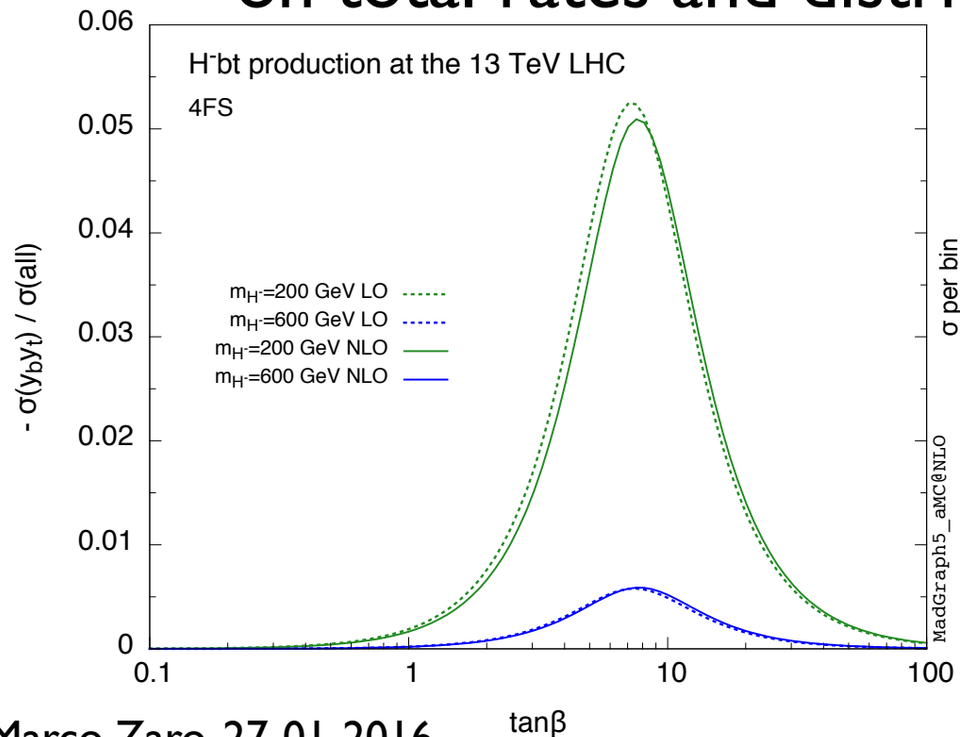
Setup and cross-section structure

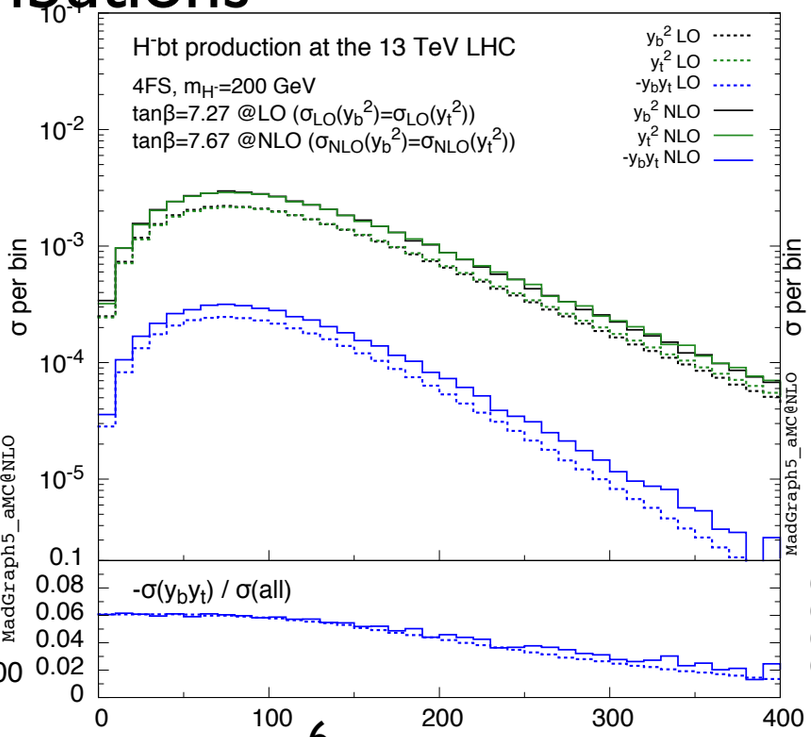
- The following parameters are used

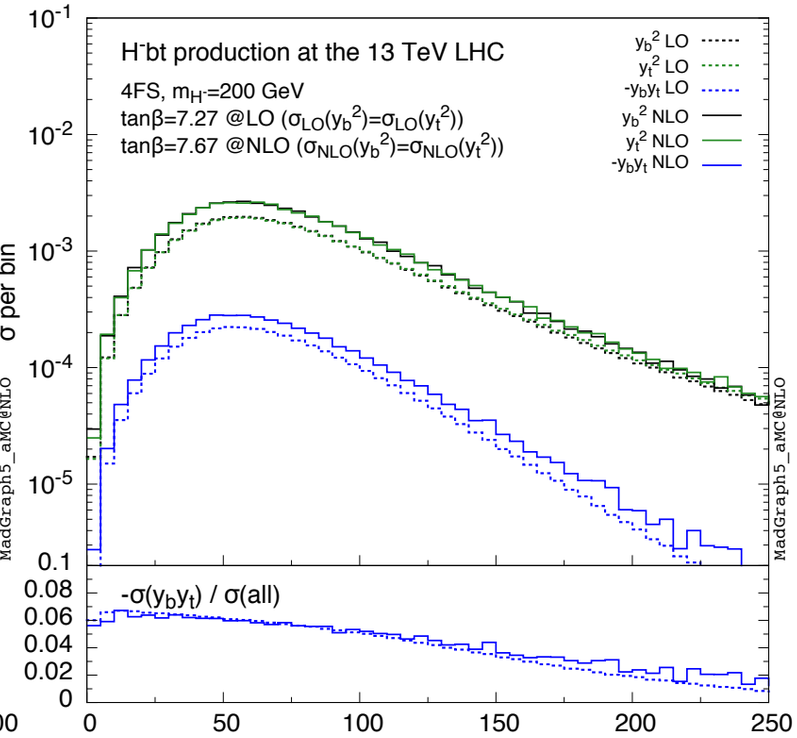
$$\sqrt{S} = 13\,\text{TeV} \qquad m_H = 200\,\text{GeV} \qquad \tan\beta = 8$$

$$\mu_R = \mu_F = \mu_B = H_T/3 = \sum \sqrt{p_T(i)^2 + m(i)^2}/3$$

- Owing to the structure of the H±tb coupling, the cross section will receive three contributions: $y_b{}^2$ (~tanβ^2), $y_t{}^2$ (~1/tanβ^2) and $y_b y_t$ (tanβ independent).
  - In the 5FS, the $y_b y_t$ term is null (helicity conservation)
  - In the 4FS, it is proportional to $m_b/\hat{s}$. Numerically it turns to be negligible on total rates and distributions

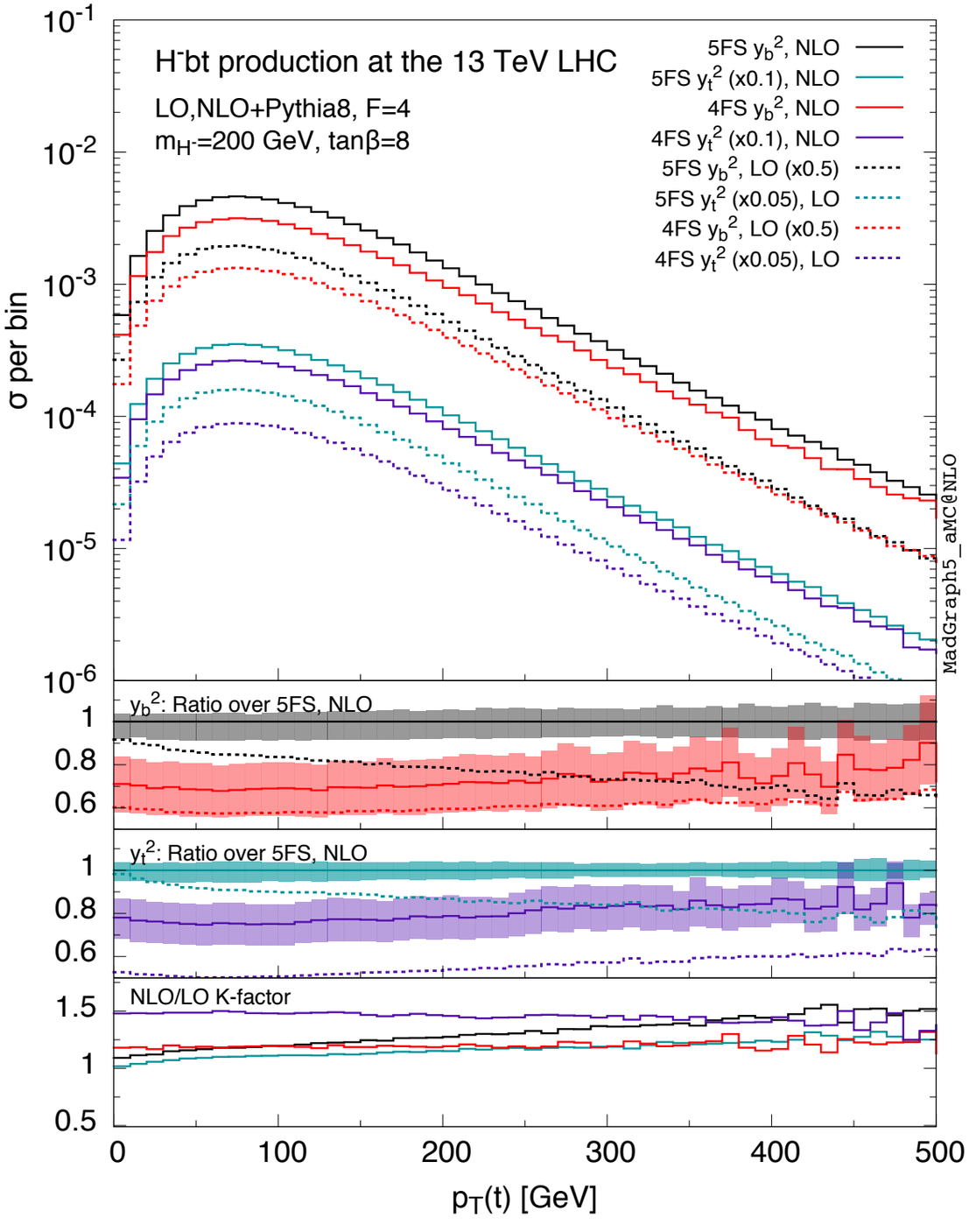






4FS vs 5FS

- NLO corrections improve the shape agreement between the two schemes
- Very good agreement for b-inclusive observables ($p_T(t), p_T(H)$)
- Agreement remains quite good for more exclusive observables ($p_T(b_2)$), despite the large K-factors and uncertainties for 5FS
- Very exclusive observables ($p_T(B_2)$) show larger discrepancies in regions where mass-effects are enhanced
- Bottom line: 4FS provides a better description of exclusive observables



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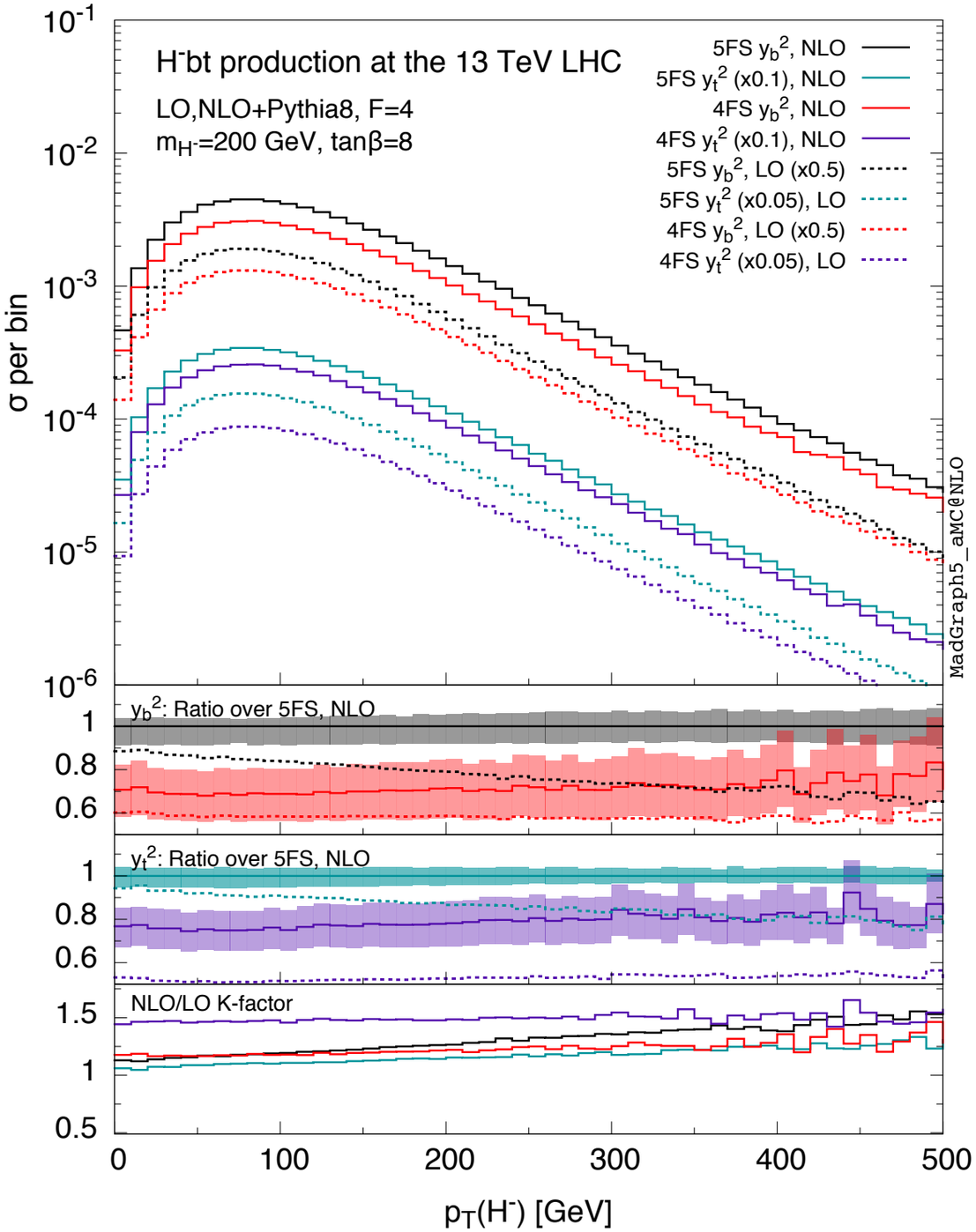

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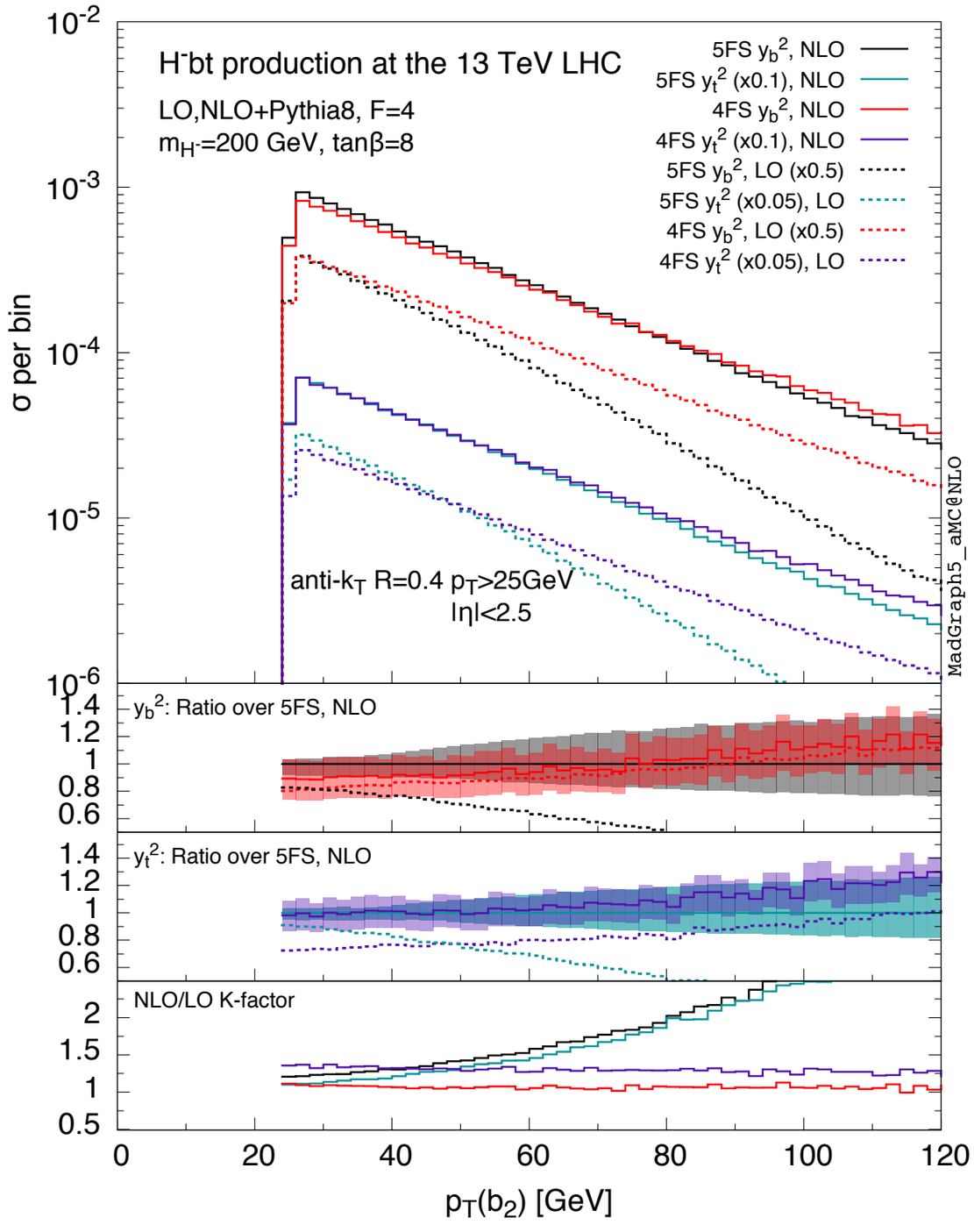

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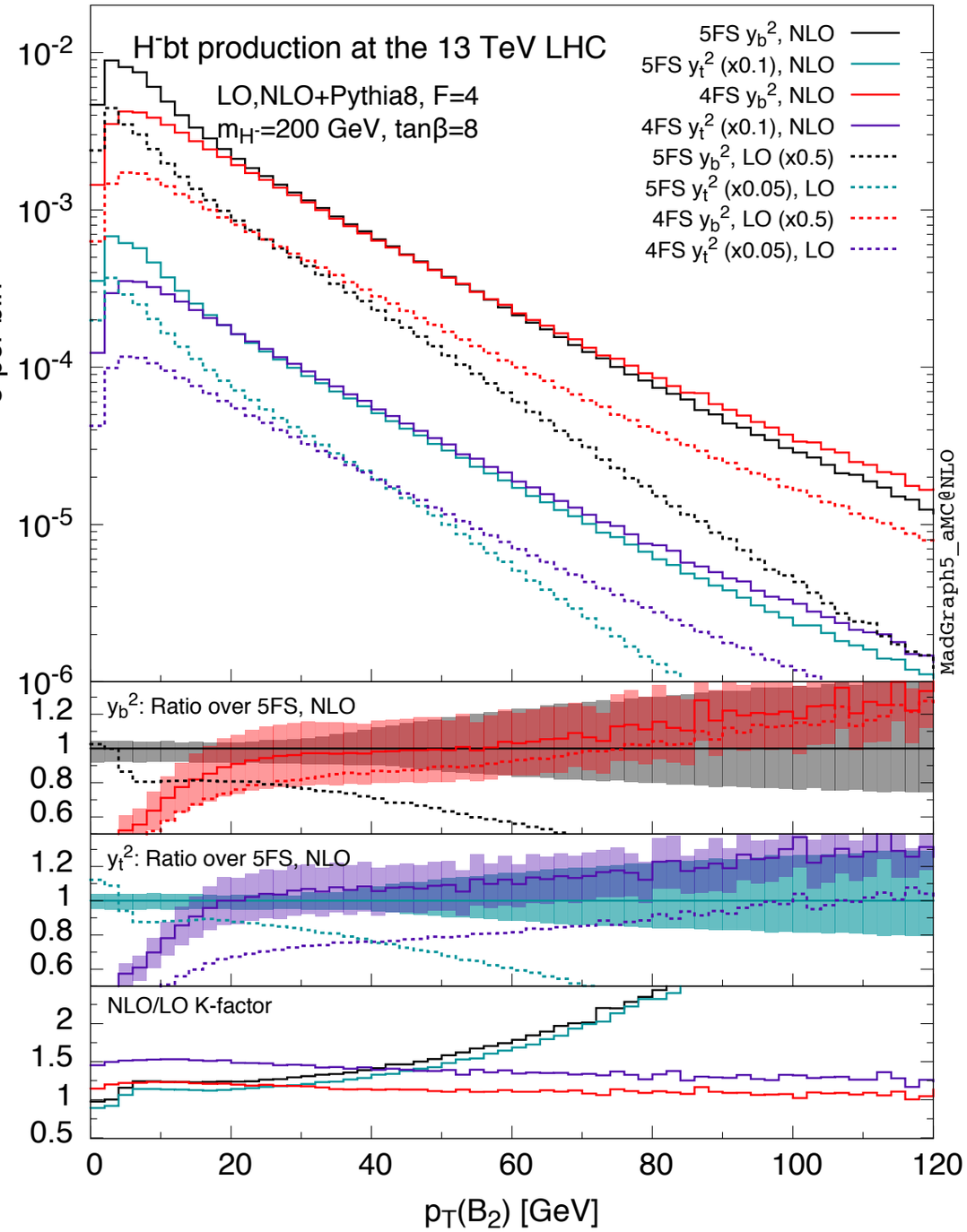

Conclusions

- The discovery of a charged Higgs boson at the LHC would be a clear sign of BSM physics
- Lot of recent and ongoing progress towards providing accurate predictions for cross section and realistic signal modelling
  - Fully differential predictions for charged Higgs production in the 2HDM available for the first time in the 4FS at NLO+PS
    - Better description of b-kinematics
    - Better matching to PS, less effects due to reshuffling
    - 4FS to become reference for signal simulations at the LHC

Thank you!

Bakup slides

Parton-shower dependence

- The inclusion of m_b effects at the matrix-element level should reduce possible systematics due to the PS used
- The largest effects should be visible on the most exclusive observables $(p_T(B_2), \eta(B_2))$
- Herwig++ in the 5FS produces b hadrons too close to the beam pipe; $\Delta R(B_1, B_2)$ is a quite spectacular case
- Effects are mitigated for less exclusive observables $(p_T(b_2), \eta(b_2))$, or when 2 bjets are required
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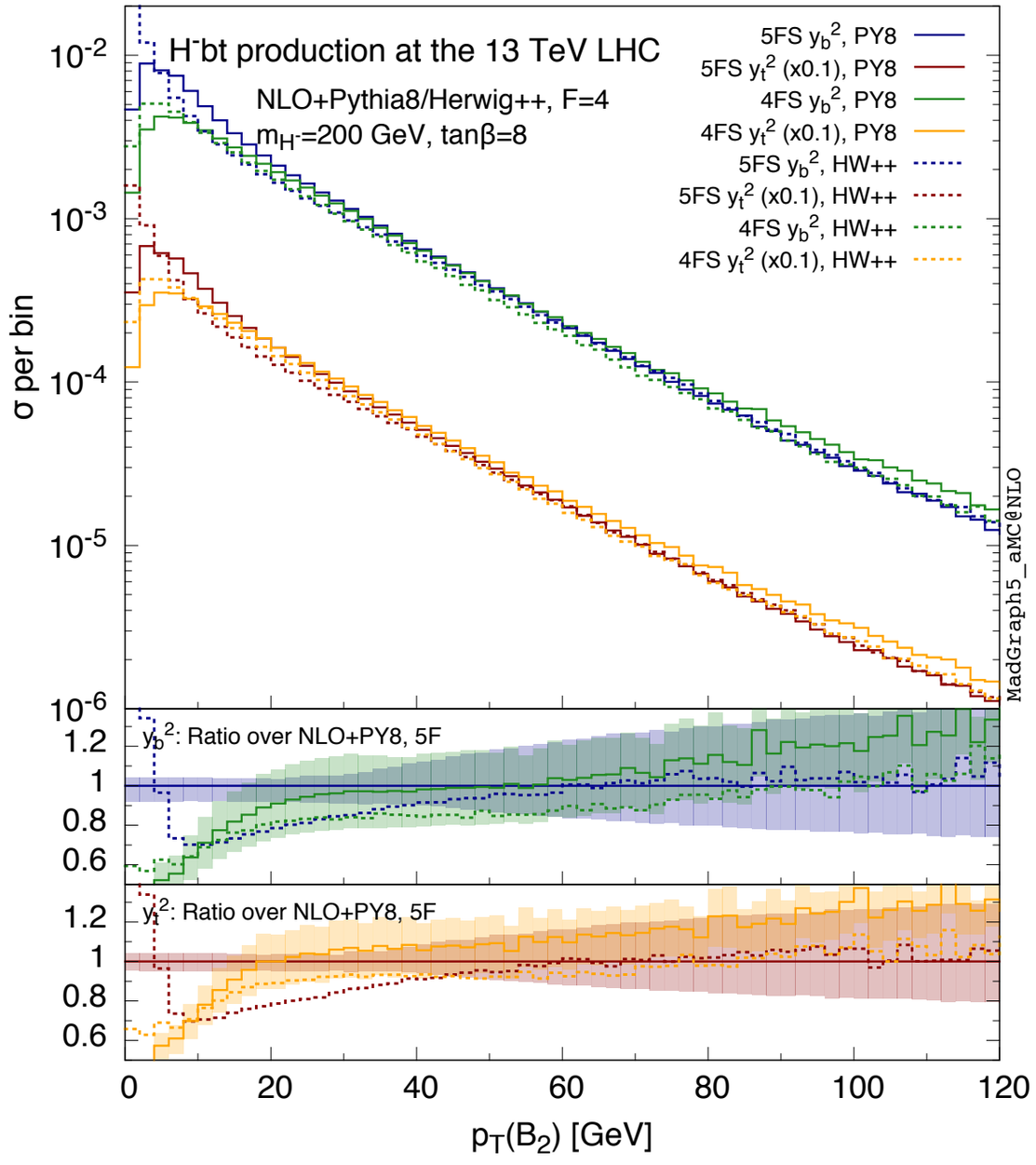

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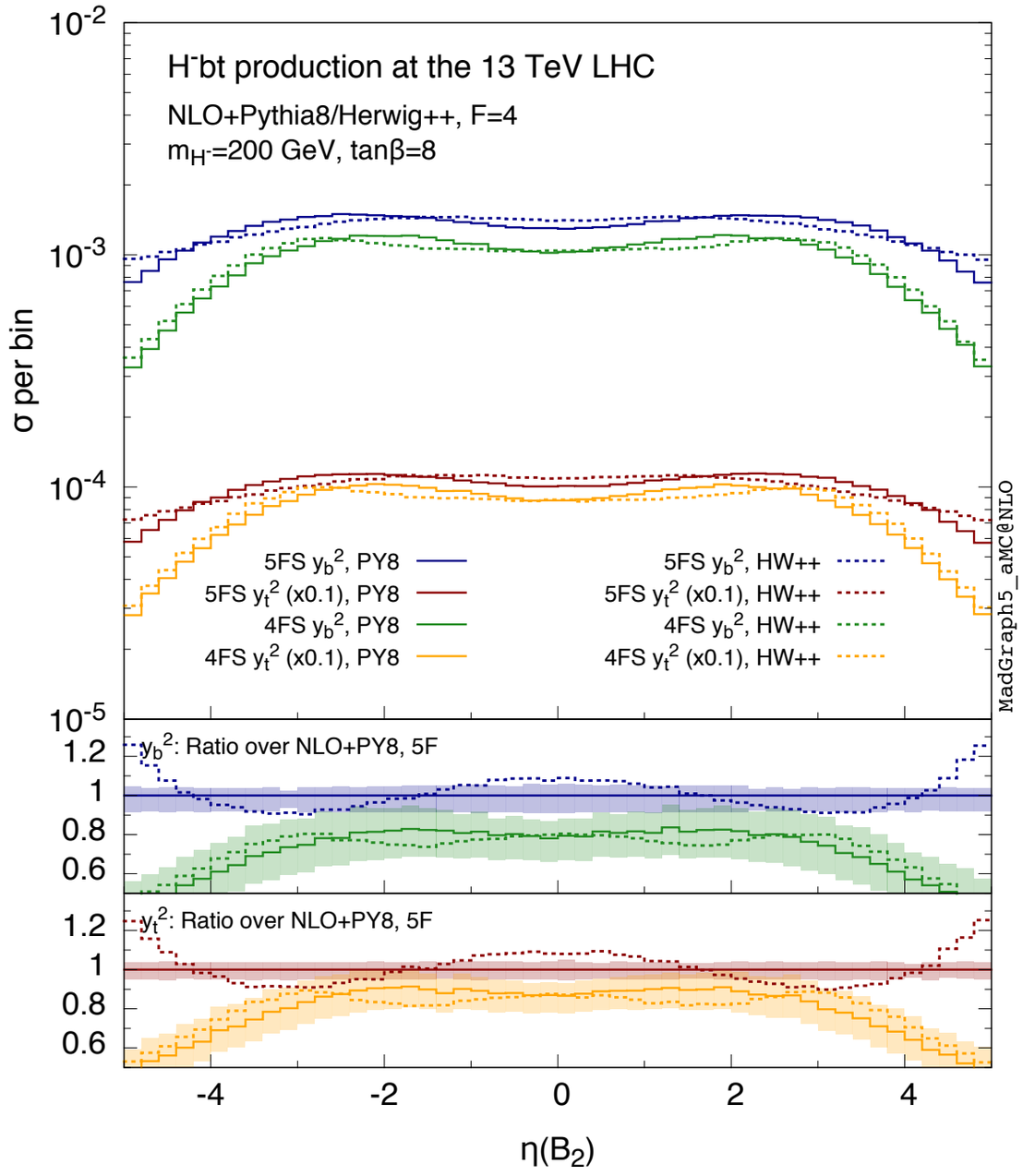

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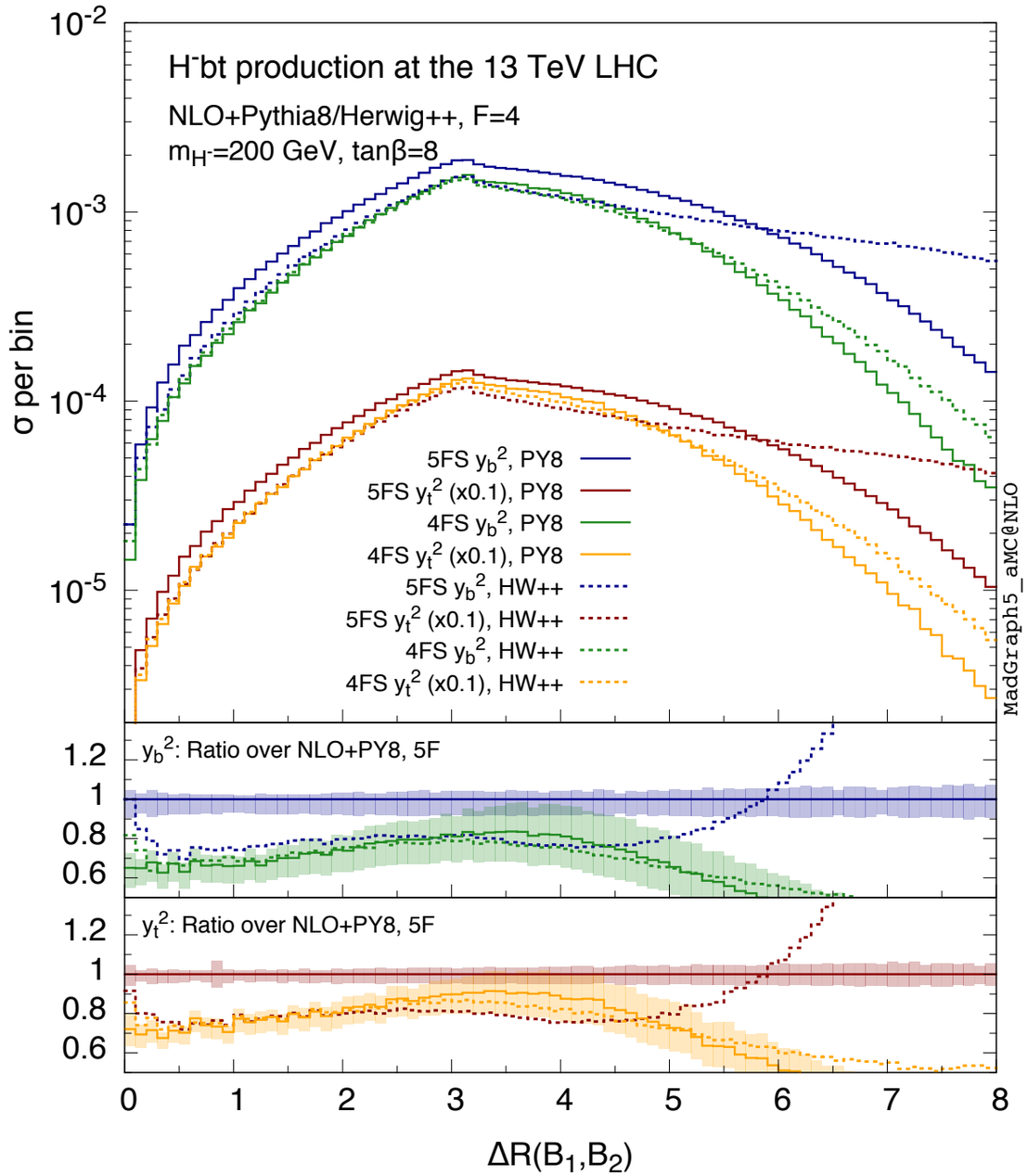

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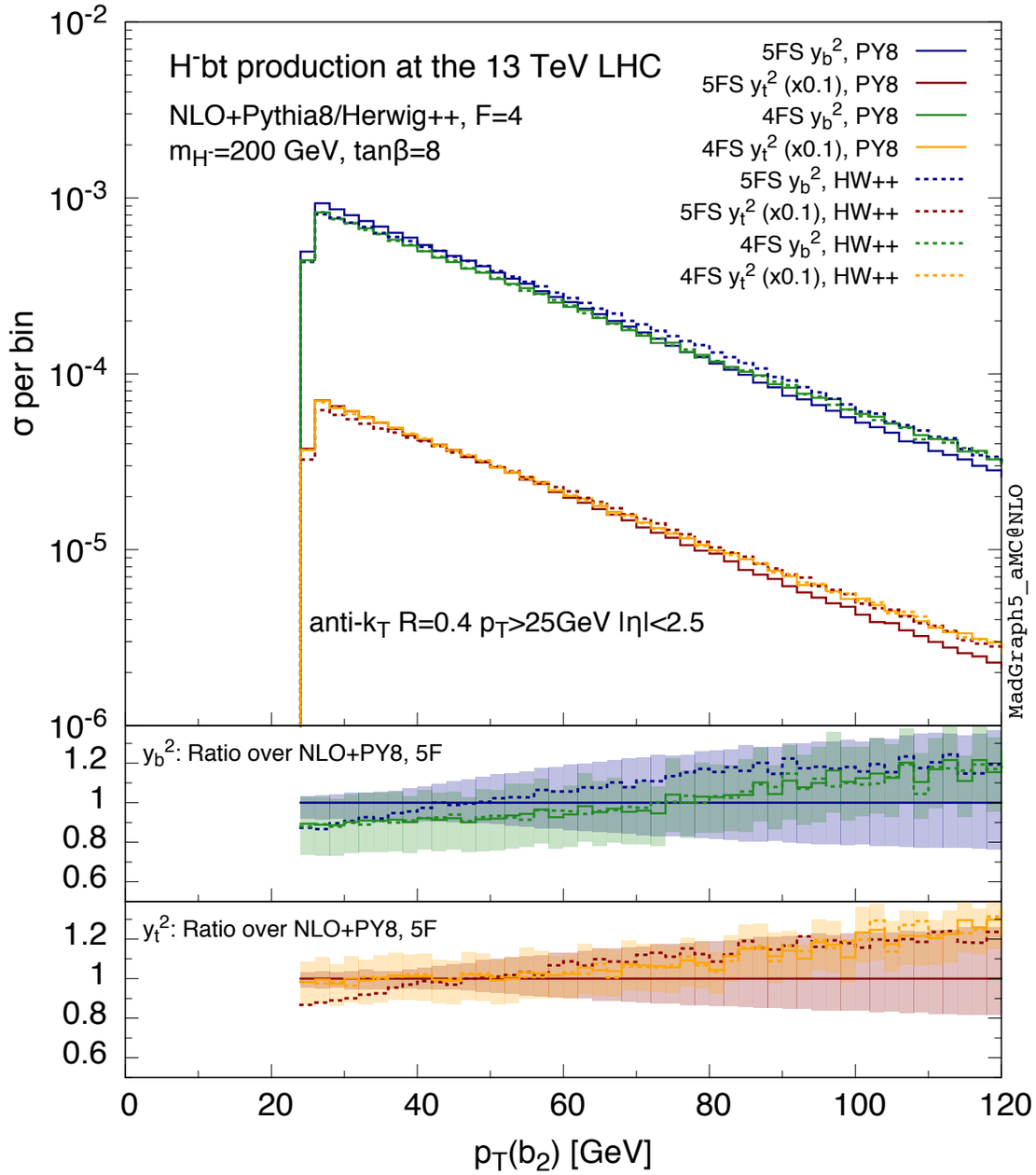

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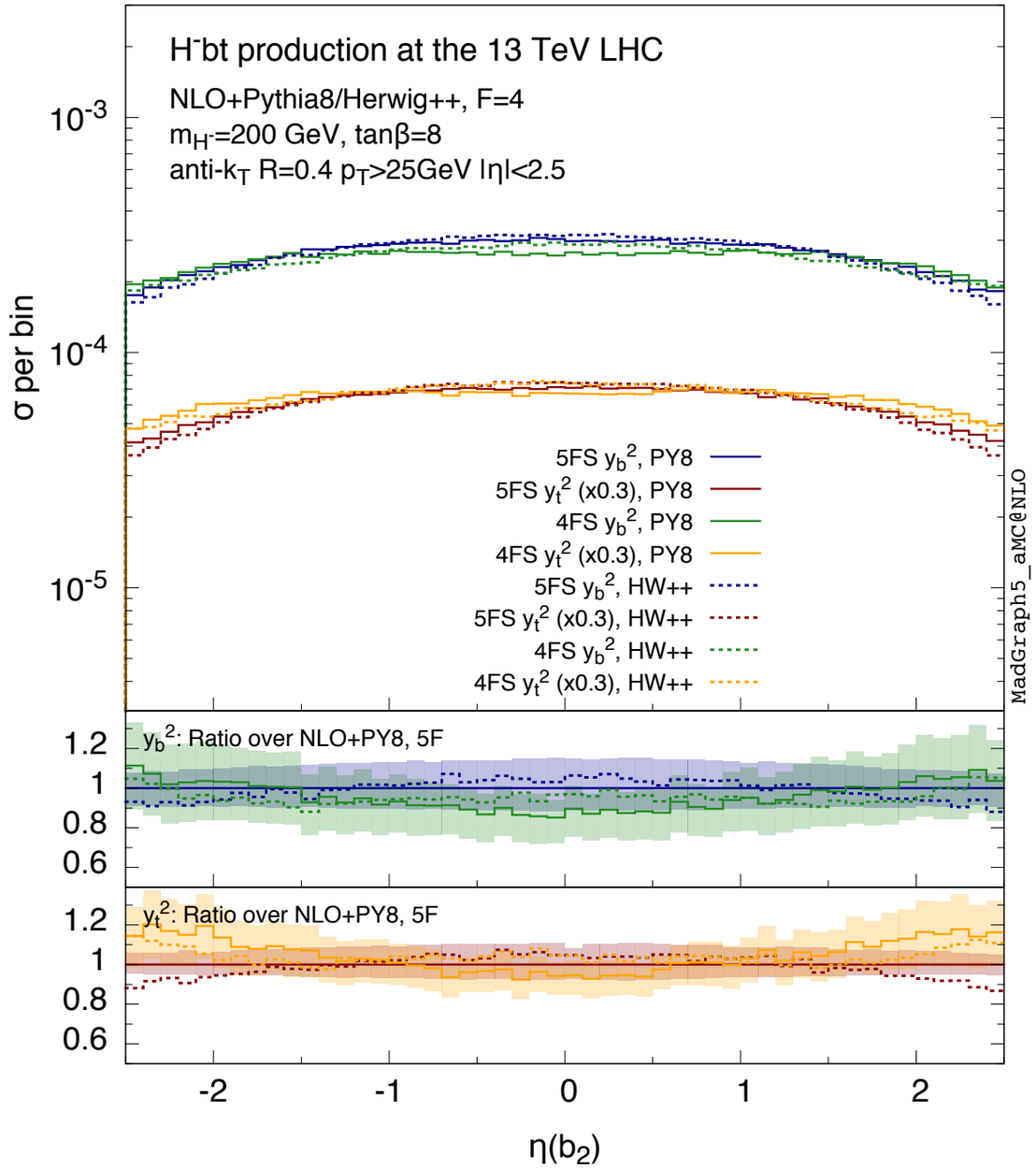

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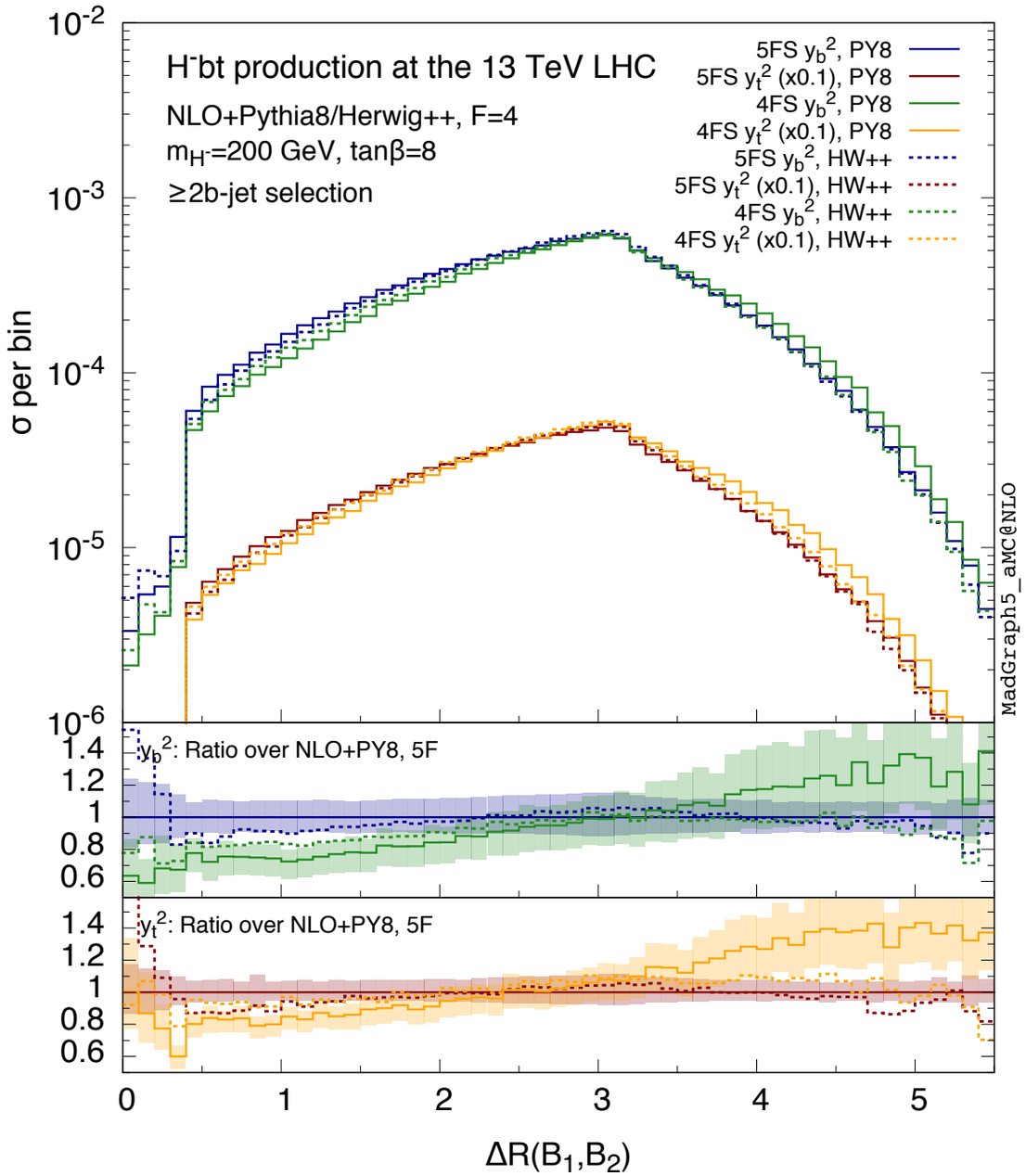


Matched predictions for the total cross-section

Flechl, Klees, Kramer, Spira, Ubiali, arXiv:1409.5615

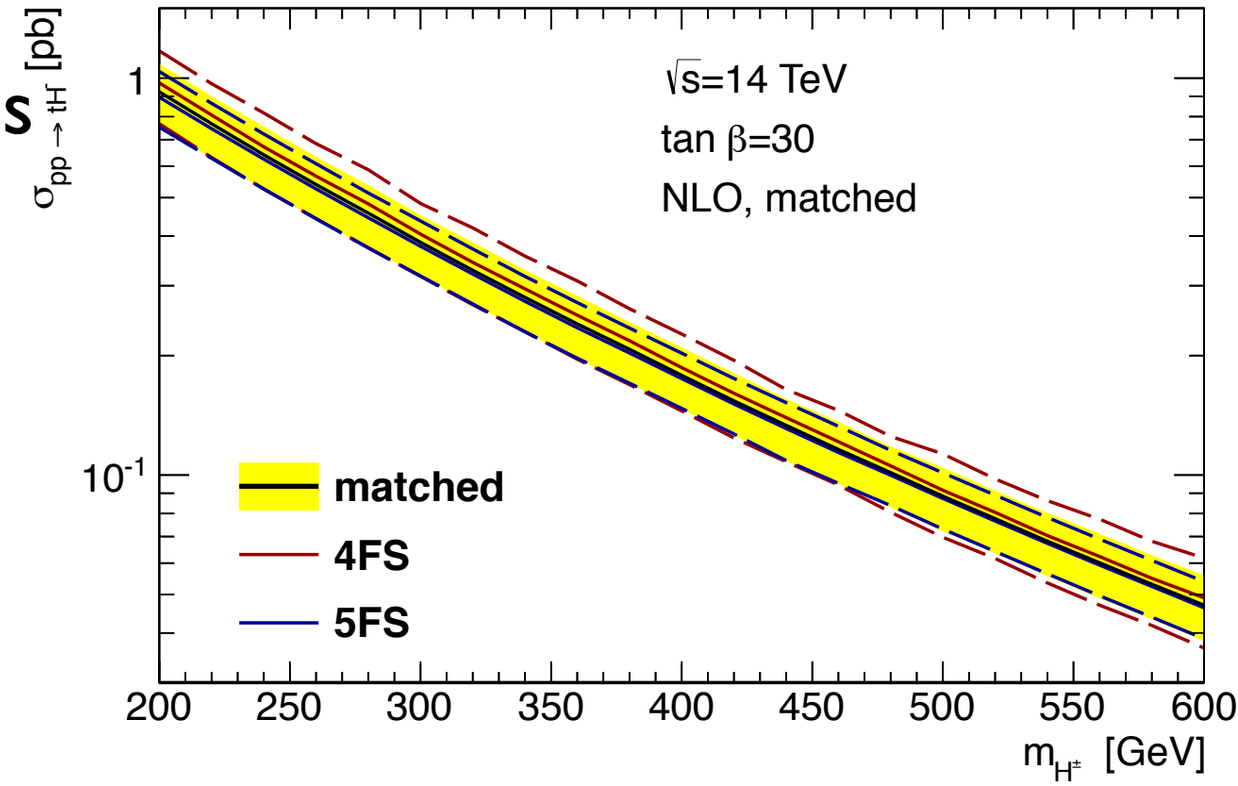
- The scale in the logs resumed in the 5FS is typically much smaller than the hard scale of the process (phase-space suppression) Maltoni, Ridolfi, Ubiali, arXiv:1203.6393

$$\mathcal{Q}^2_{tHb} = M^2 \frac{(1-z)^2}{z} \qquad z = \frac{M^2}{\hat{s}}$$

  - Set $\mu_F = \tilde{\mu}$ in the 5FS
- Include all sources of uncertainties
  - scale, PDF (PDF4LHC), m_b, α_s
- Compare 5FS, 4FS @NLO and Santander-matched prediction

$$\sigma_{\text{matched}} = \frac{\sigma_{4\text{F}} + w\sigma_{5\text{F}}}{1+w} \qquad w = \log\frac{m_{H^\pm}}{m_b} - 2$$

	8 TeV		14 TeV	
$M_{\text{H}^\pm}$ [GeV]	$\tilde{\mu}$ [GeV]	$(m_t + M_{\text{H}^\pm})/\tilde{\mu}$	$\tilde{\mu}$ [GeV]	$(m_t + M_{\text{H}^\pm})/\tilde{\mu}$
200	67.3	5.5	74.9	5.0
300	80.3	5.9	90.6	5.2
400	92.1	6.2	105.3	5.4
500	103.1	6.5	119.0	5.7



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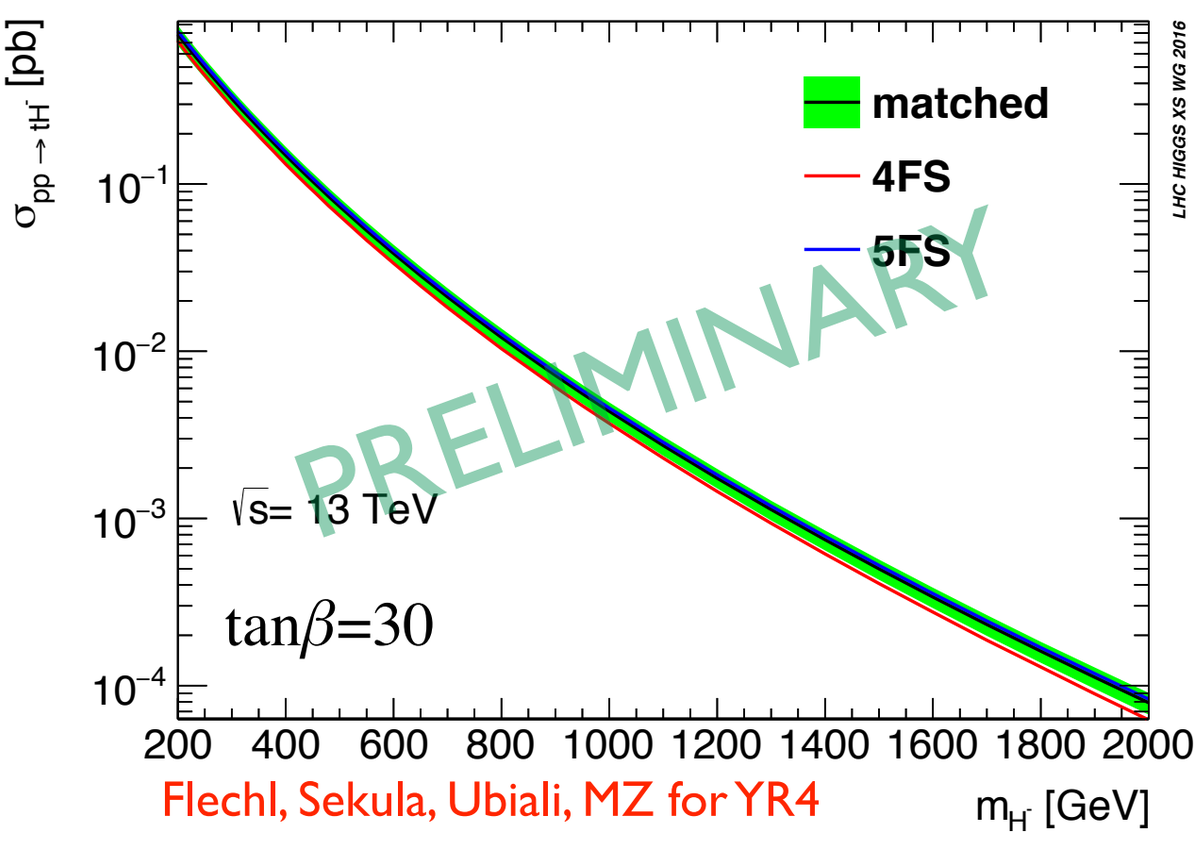
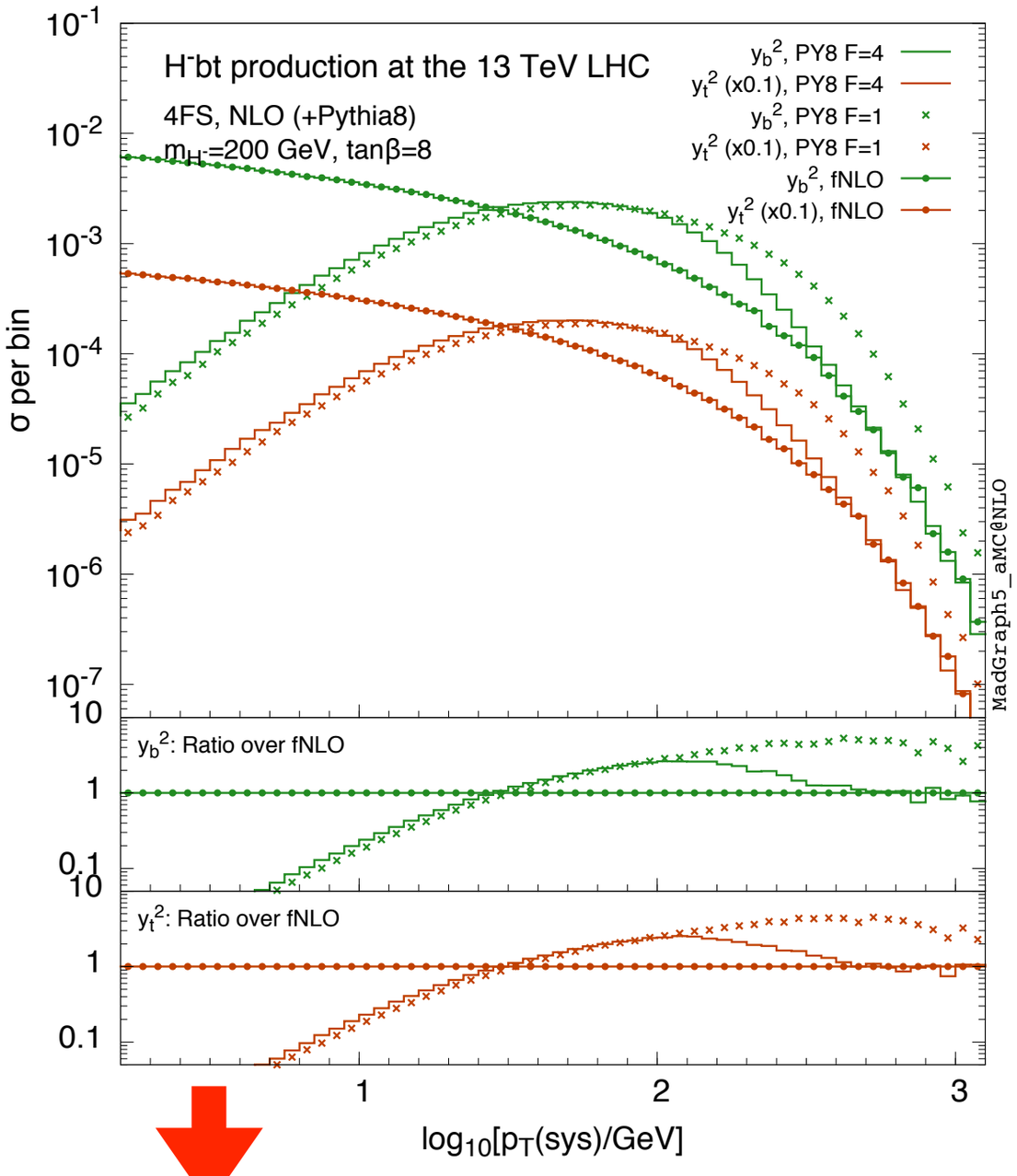
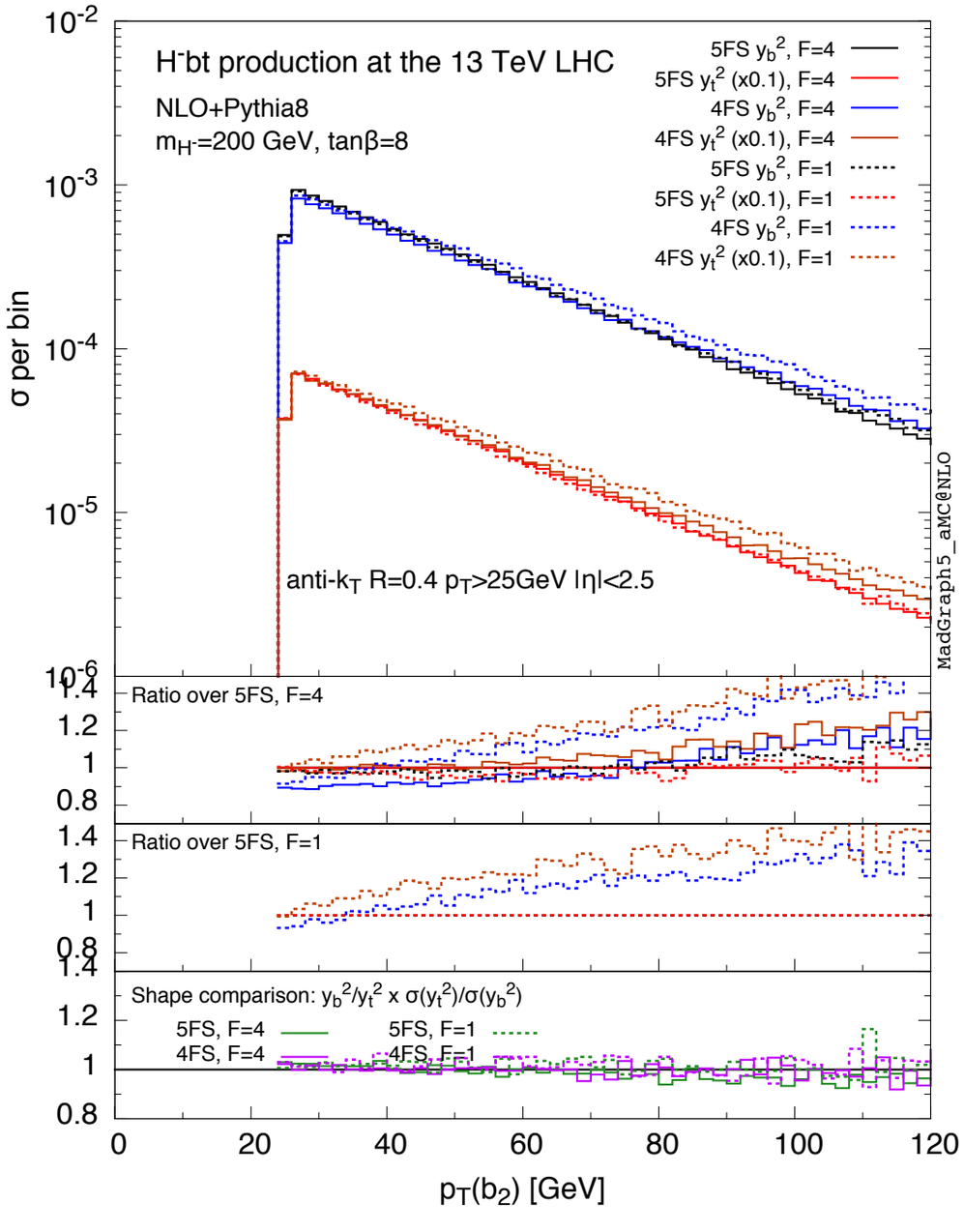


Flechl, Sekula, Ubiali, MZ for YR4

Choice of shower scale





Reduced shower scale to be preferred
improves NLO+PS/fNLO matching at high-p_T

Consequence:
better agreement at differential level
between the two schemes