Higgs (N)NLO MC and tools workshop for LHC Run II
17-19 December 2014, CERN

CHARGED HIGGS PRODUCTION: 4FS VERSUS 5FS

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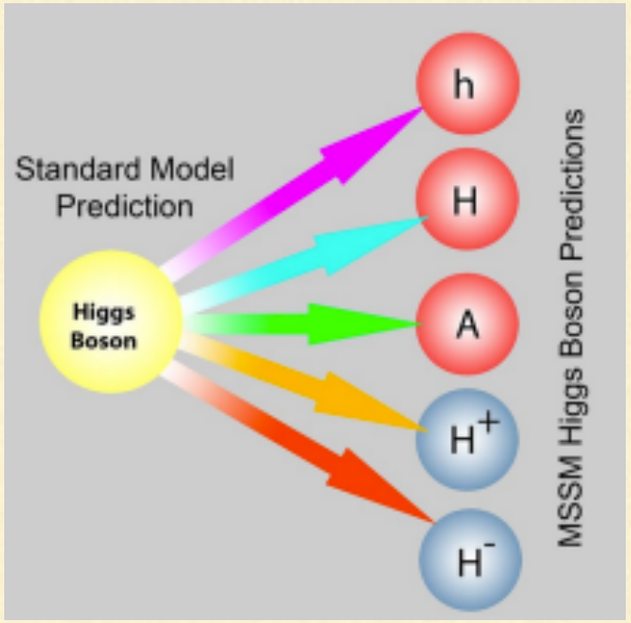
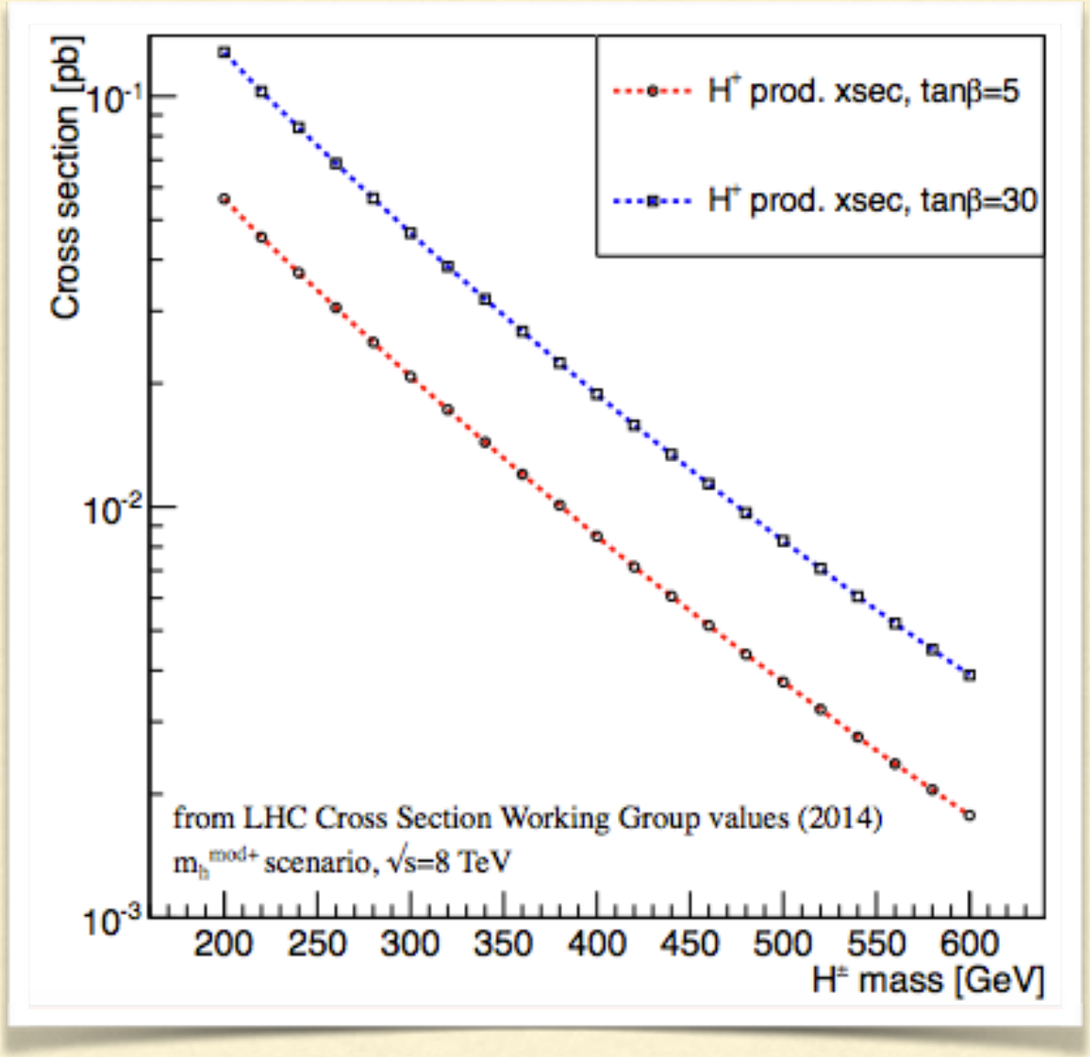
work in collaboration with C. Degrande, F. Maltoni, M. Wiesemann and M. Zaro

MOTIVATION

The discovery of a **charged Higgs** boson would be a clear evidence of an extended Higgs sector beyond the SM





* While the situation seems clear concerning normalisation **(new result),** things are not so clear when looking at differential distributions in the 4F and 5F schemes
* Charged Higgs good case study for QCD

CMS-PAS-HIG-12-052

M. Ubiali, "Charged Higgs production 4FS versus 5FS"

MOTIVATION

Nominal signal POWHEG 5F
PYTHIA8
$H^+ > t\,b$, m_{H+}: [180,600] GeV

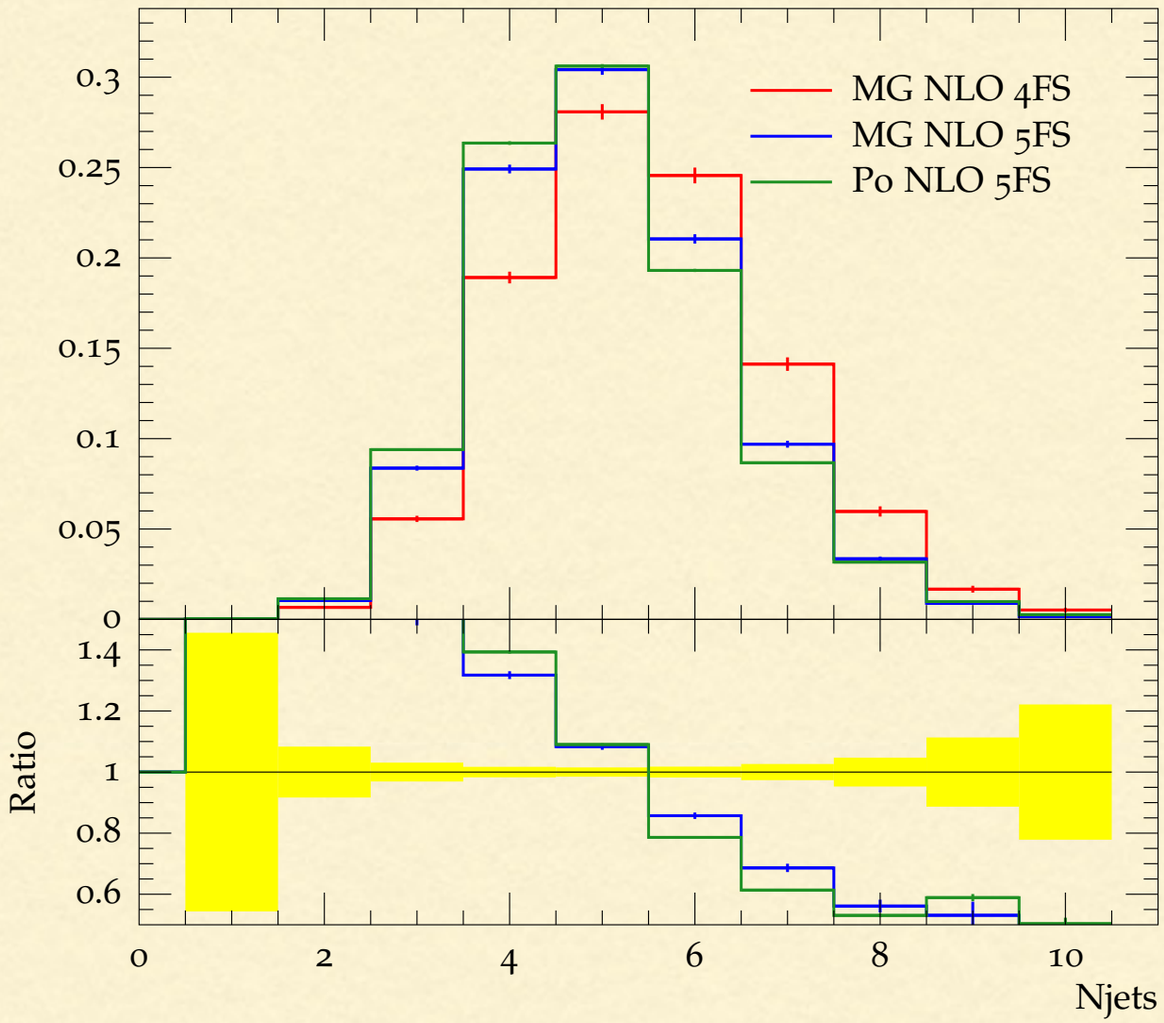
Model systematics:

- Scale variation
- Generator and parton shower: differences with respect to aMC@NLO 5F and HERWIG++
- 4F versus 5F scheme - MG5 LO

Large effect ~20% already evident in the inclusive signal region
$N_{jet} \geq 5$
$N_{bjet} \geq 3$

M. Ubiali, "Charged Higgs production 4FS versus 5FS"

MOTIVATION



courtesy of Liron Barak

- 4F versus 5F scheme - MG5_aMCatNLO

Where does large 4FS/5FS discrepancy in jet multiplicity come from? How to translate it in model uncertainty?

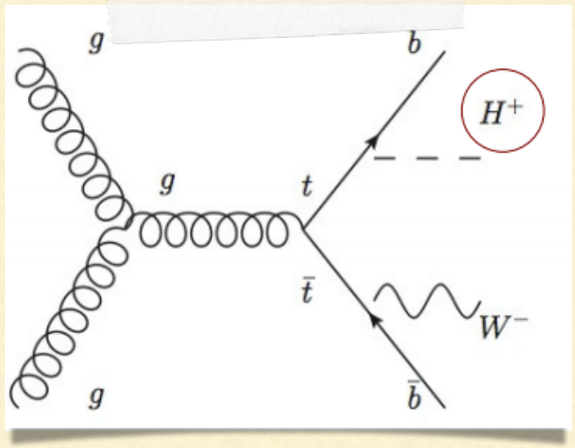
OUTLINE

- Charged Higgs production in 2HDM
- The total cross section (heavy Higgs scenario)
- Going differential: tools and implementation in MG5_aMCatNLO
- (Preliminary) results
- Conclusions and outlook

2HDMs

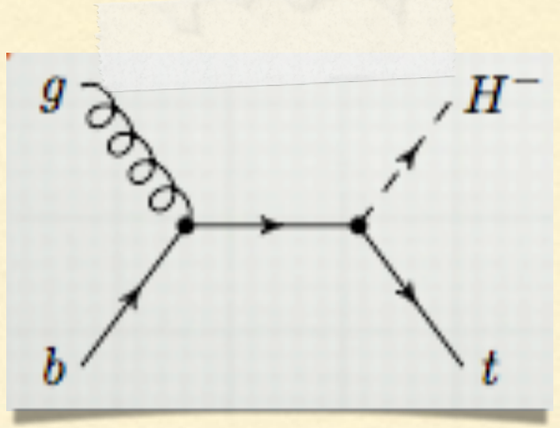
CHARGED HIGGS PRODUCTION AT COLLIDERS

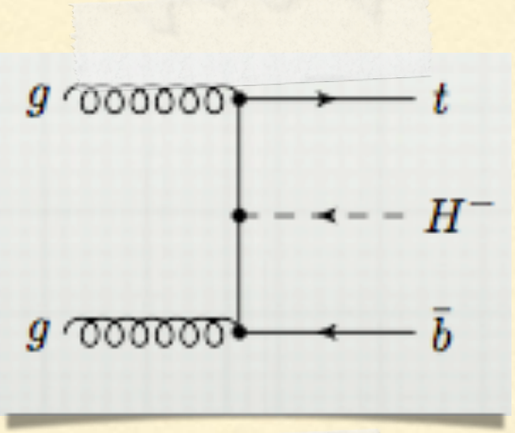
LIGHT HIGGS



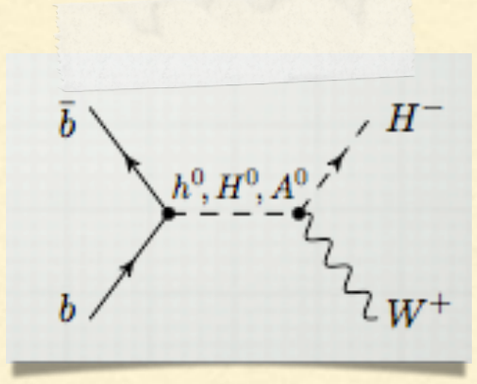
INTERMEDIATE REGION

HEAVY HIGGS





+ suppressed productions channels

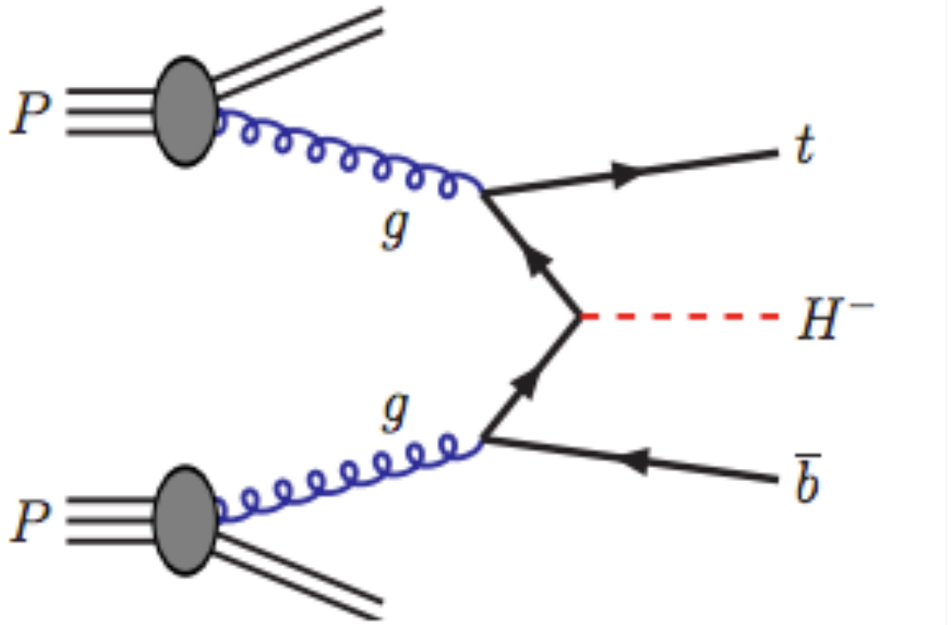


M. Ubiali, "Charged Higgs production 4FS versus 5FS"

4F VERSUS 5F

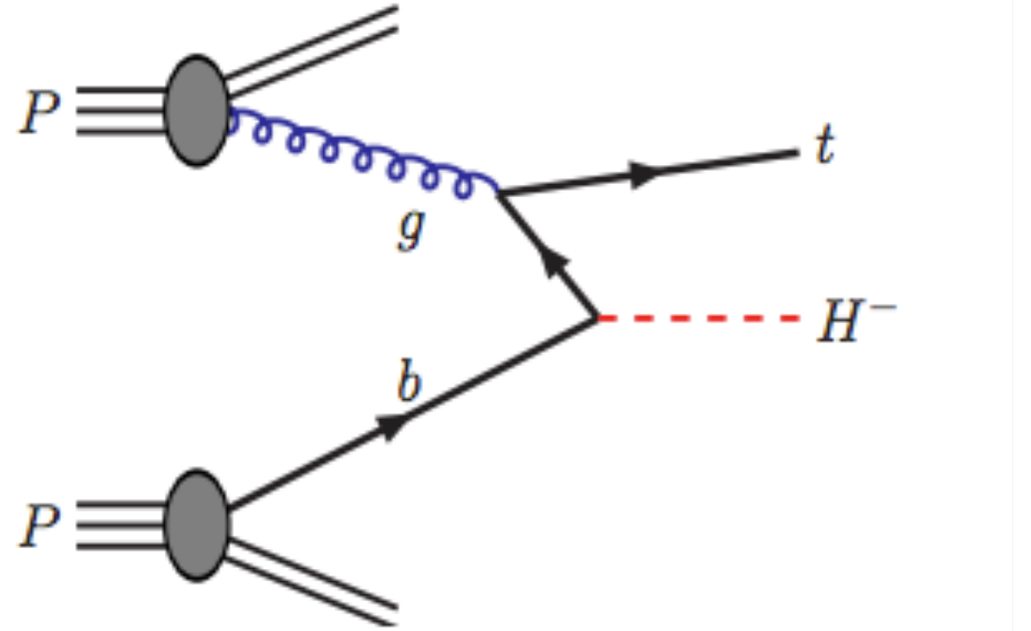
HEAVY $H^{\pm}$ PRODUCTION:TOTAL CROSS SECTION

4F



✘ It does not resum possibly large logs, yet it has them explicitly
✘ Computing higher orders is more difficult
✔ Mass effects are there at any order
✔ Straightforward implementation in MC event generators at LO and NLO

5F

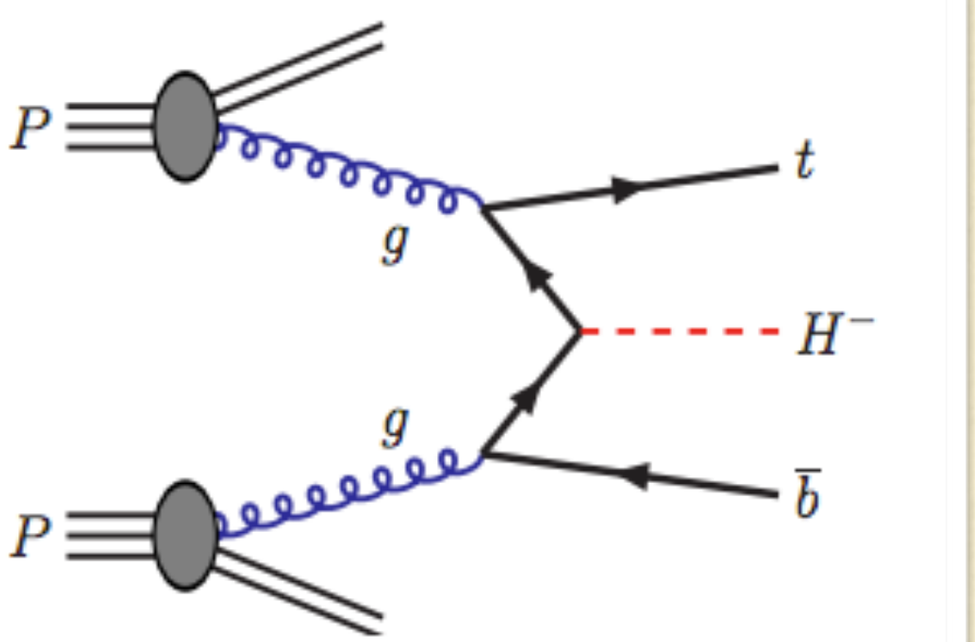


✔ It resums initial state large logs into b-PDFs leading to more stable predictions
✔ Computing higher orders is easier
✘ pT of bottom enters at higher orders
✘ Implementation in MC depends on the gluon splitting model in the PS

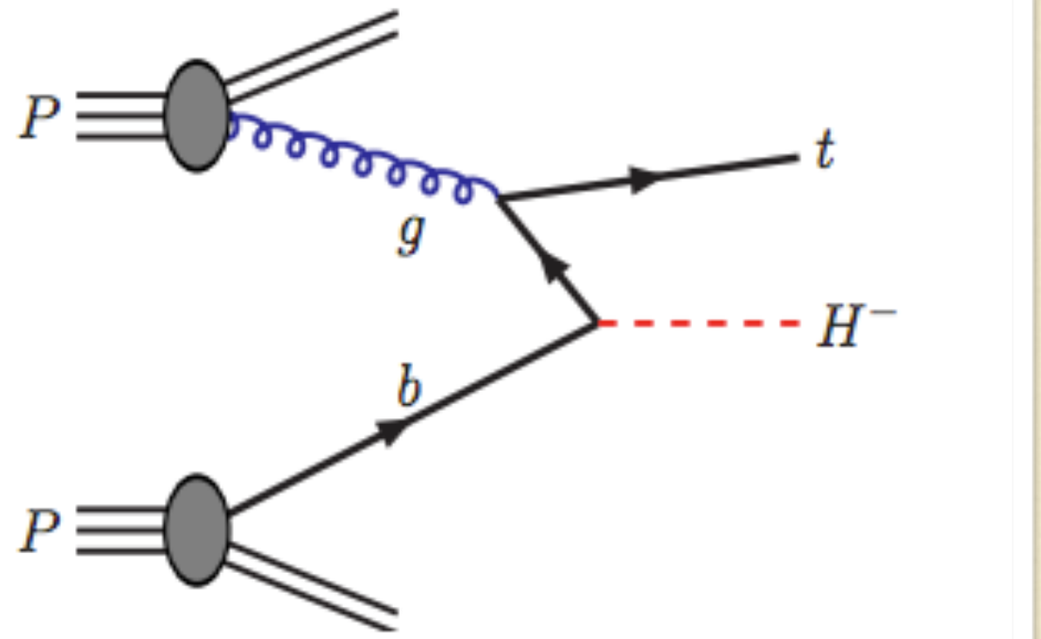
4F VERSUS 5F

HEAVY $H^{\pm}$ PRODUCTION:TOTAL CROSS SECTION

4F



5F



- Fixed order NLO calculation (+ SUSY corrections)

  Dittmaier et al., Phys. Rev. D83:055005 (2011)

- EW corrections

  Nhung et al., Phys. Rev. D87:113006 (2013)

- Threshold resummation up to NNLL

T. Plehn, Phys. Rev. D67:014018 (2003)
S. Zhu , Phys. Rev. D67:075006 (2003)
Berger et al, Phys. Rev. D71:115012 (2005)

Beccaria et al., Phys. Rev. D80:053011 (2009)

Kidonakis, Phys. Rev. D82:054018 (2010)

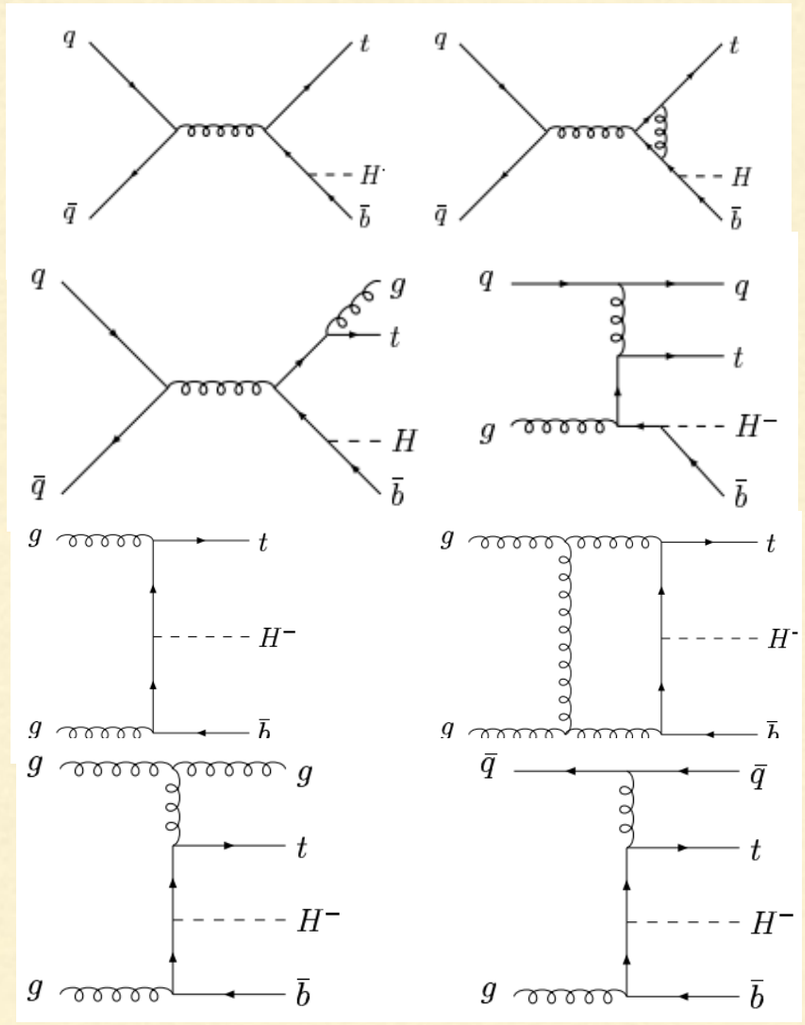
4F VERSUS 5F

HEAVY $H^{\pm}$ PRODUCTION: TOTAL CROSS SECTION

NLO

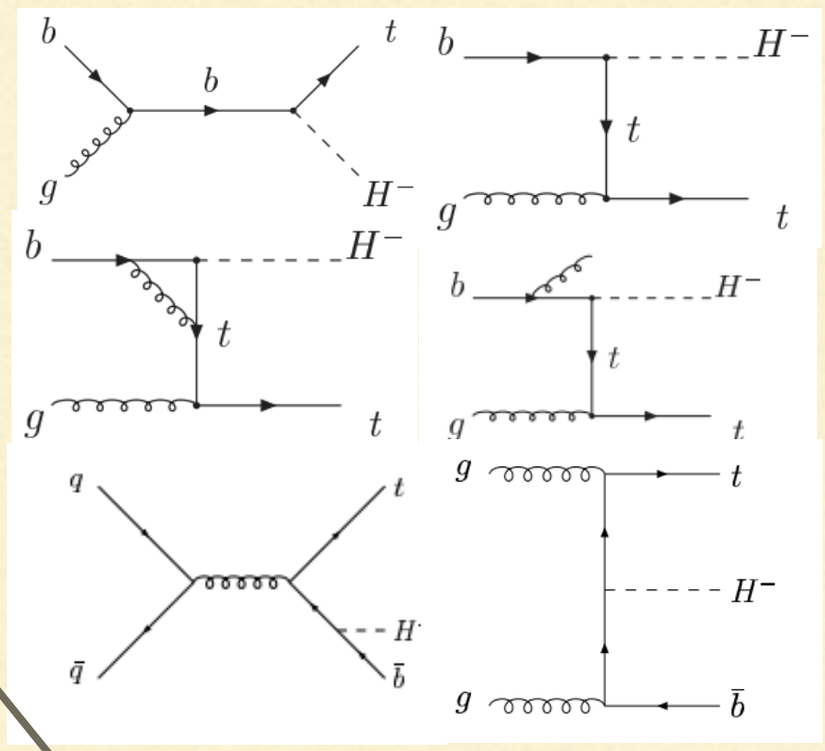
$$g_{t\bar{b}H^-} = \frac{\sqrt{2}}{v}\left(\underbrace{\frac{m_t}{\tan\beta}}_{y_t} P_R + \underbrace{m_b \tan\beta}_{y_b} P_L\right)$$

4F



$$\left(|y_t|^2, |y_b|^2, |y_b^* y_t|\right)$$

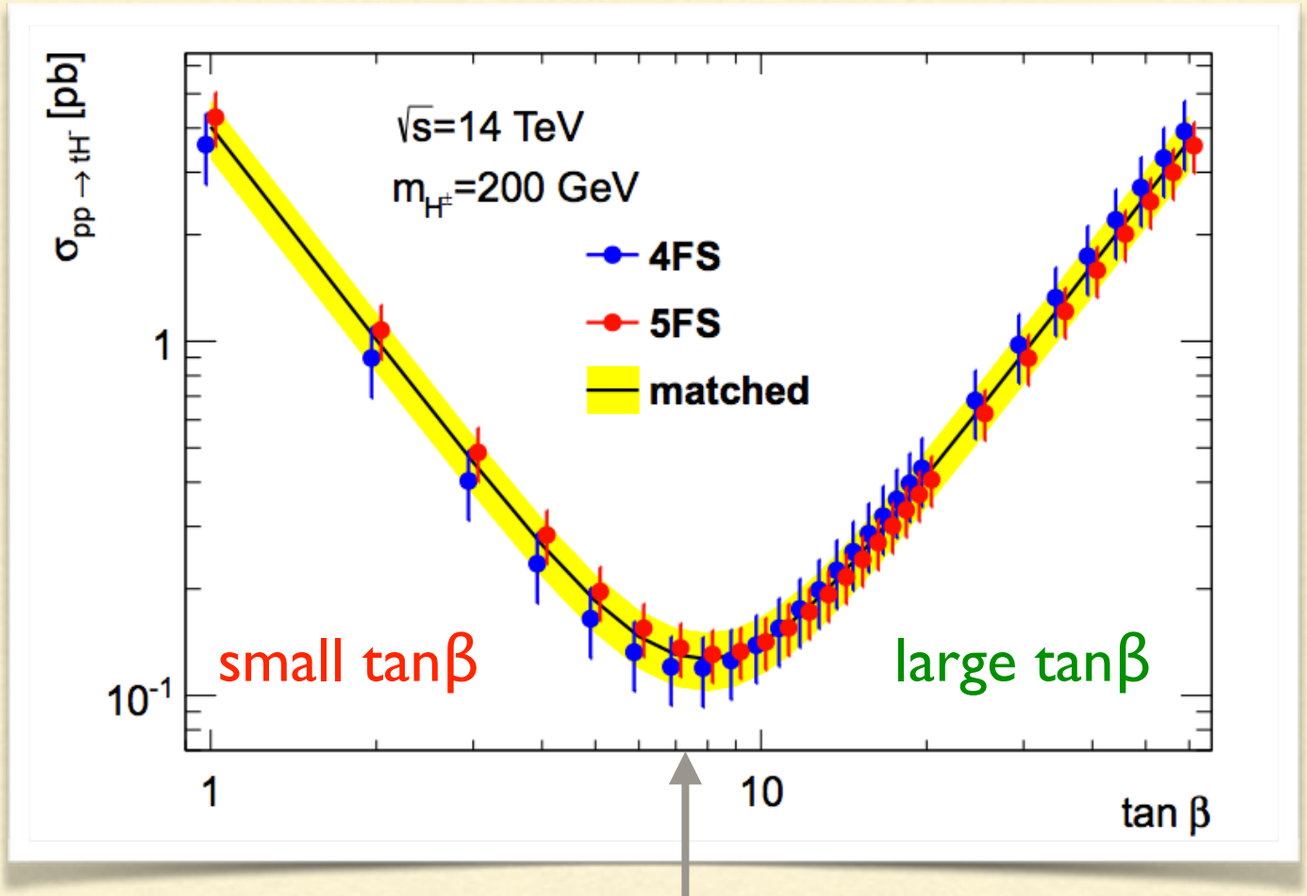
5F



$$\left(|y_t|^2, |y_b|^2\right)$$

4F VERSUS 5F

HEAVY $H^{\pm}$ PRODUCTION: TOTAL CROSS SECTION



$$g_{t\bar{b}H^-} = \frac{\sqrt{2}}{v}\left(\underbrace{\frac{m_t}{\tan\beta}}_{y_t} P_R + \underbrace{m_b \tan\beta}_{y_b} P_L\right)$$

Maximum effect of interference term is ~5% upward shift!

interference term independent of tanβ, max effect at tanβ ~ 8

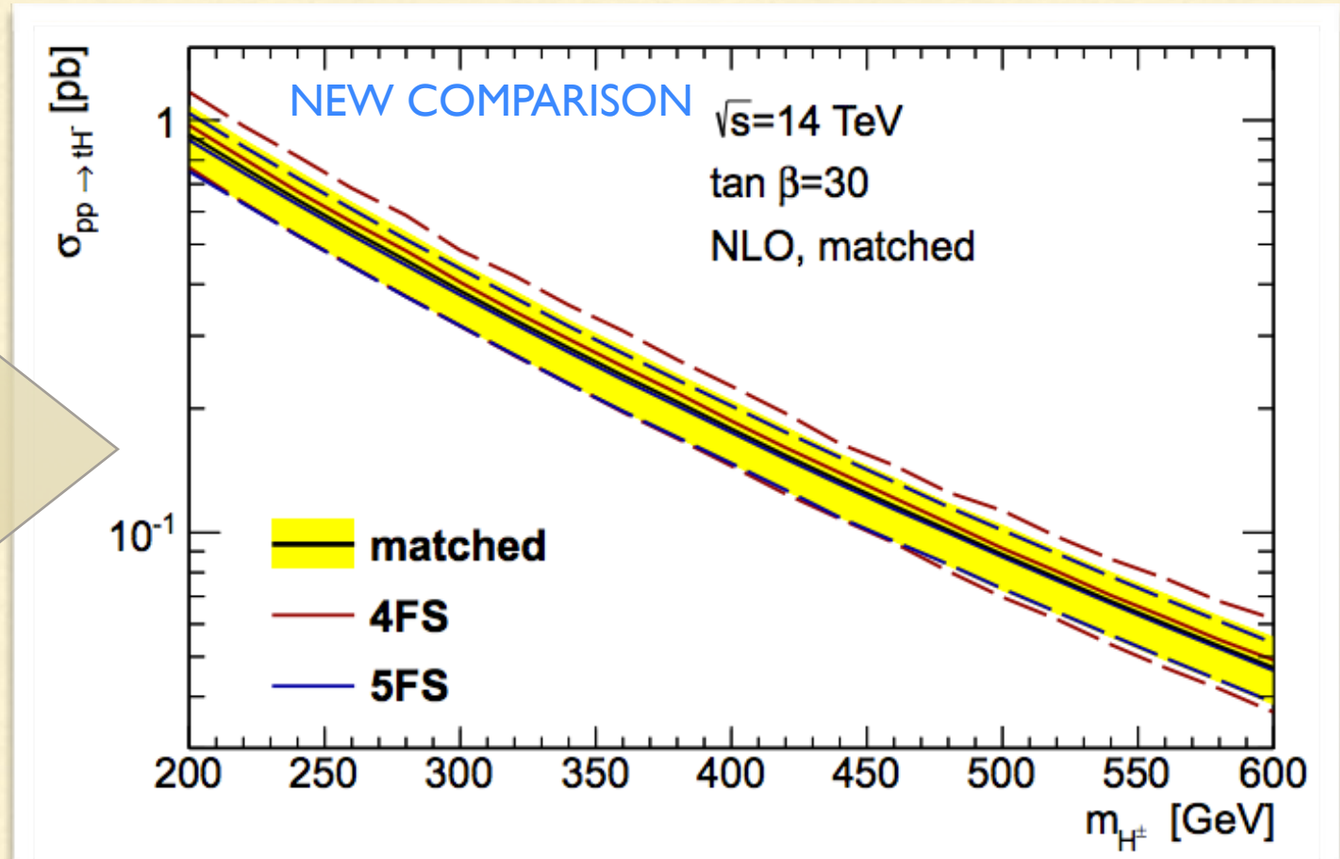
$$\left(|y_t|^2, |y_b|^2, |y_b^* y_t|\right) \qquad \left(|y_t|^2, |y_b|^2\right)$$

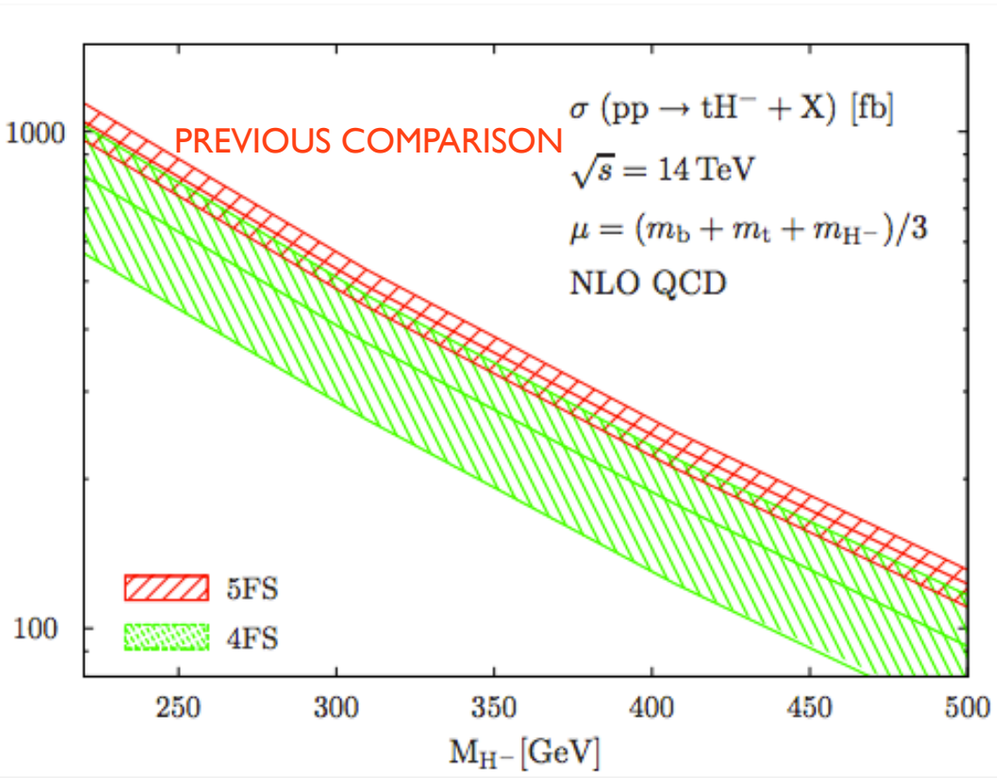
4F VERSUS 5F

HEAVY $H^{\pm}$ PRODUCTION: TOTAL CROSS SECTION

Flechl, Klees, Kramer, Spira, MU arXiv:1410.8849

- Substantial agreement between predictions and consequent reduced theoretical uncertainty for the combined prediction





S. Dittmaier, et al., PRD 83, 055005 (2011)

For inclusive scenarios

In regions of the phase space where resummation and mass effects are not dominant, 4FS and 5FS give similar results, if judicious scales are chosen
[Maltoni, Ridolfi, MU JHEP 1207 (2012) 022]

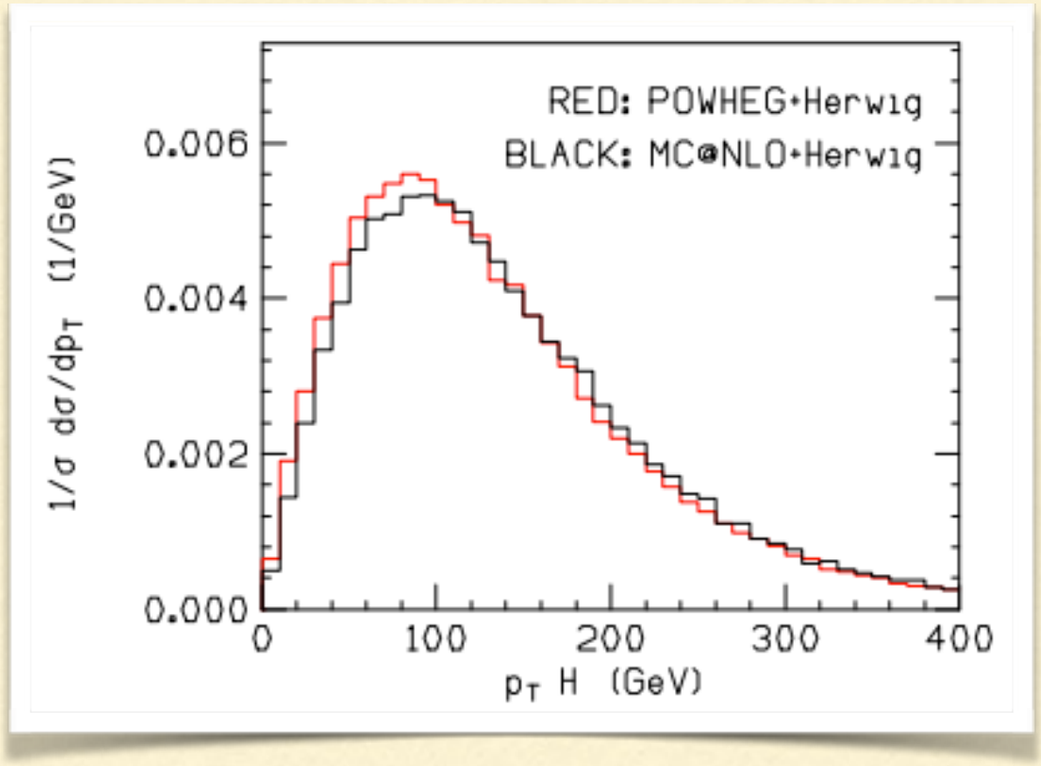
4F VERSUS 5F

HEAVY $H^{\pm}$ PRODUCTION: DIFFERENTIAL DISTR.

5FS: NLO + PS implemented in

- aMC@NLO **[Weydert et al. Eur.Phys.J. C67 (2010) 617]**
- POWHEG **[Klasen et al. Eur.Phys.J. C72 (2012) 2088]**

4FS: NLO + PS presented here for the first time in a consistent scheme to make comparison with previous NLO results and with 5FS NLO+PS distributions



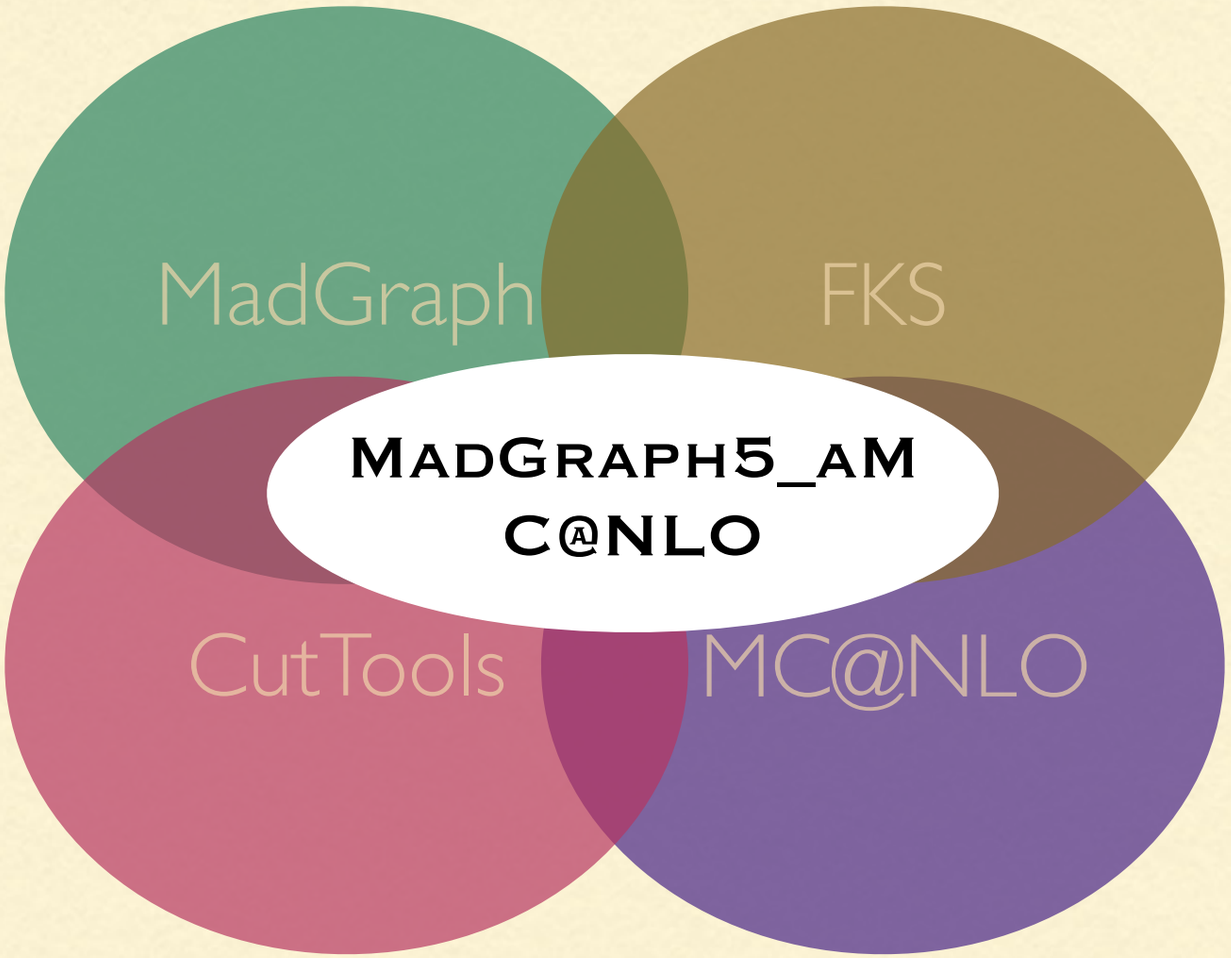
For more exclusive scenarios

- Whether missing higher order logs or power-suppressed terms are more important, it is observable-dependent
- NLO picture is modified (and improved) by matching with PS
- In 5FS backward evolution of initial-state b will generate B hadrons even at $O(\alpha_s^0)$
- In 4FS some of the possibly large logs are resummed by PS

4F VERSUS 5F
IMPLEMENTATION IN MG5_aMCatNLO

NEW: implementation of 2HDM and charged Higgs production in the 4F and 5F schemes in the automatic framework provided by MadGraph5_aMC@NLO

see S. Frixione talk on Wednesday



- NLO results: FKS method for IR subtraction and OPP integral-reduction procedure for one-loop matrix elements
- NLO+PS: MC@NLO method
- Scale and PDF uncertainties obtained 'on the fly', without the need of extra runs
- Models resulting into a set of rules (UFO) are now generated automatically [**C.Degrande 1406.3030**]
- R2 and UV counter-terms automatically generated. We are testing and validating them in the 2HDM case

Alwall, Frederix, Frixione, Maltoni, Mattelaer, Shao, Stelzer, Torrielli, Hirschi, Zaro arXiv:1405.0301

RESULTS
SETTINGS

- $\overline{\text{MS}}$ renormalised Yukawa coupling (not implemented in standard public code, with on-shell renormalisation) to compare with existing calculation and to resum large logarithms of (μ_R/m_b)

$$\bar{m}_b(\bar{m}_b) = 4.34\,\text{GeV}$$
$$M_b = 4.75\,\text{GeV}$$

- Change in renormalization scheme is dealt with at the level of UFO
- Added $m_b(\mu_R)$ dependence via reweighting **[Wiesemann et al, arXiv: 1409.5301]**
- Masses and parameters

$$\sqrt{S} = 13\,\text{TeV}$$
$$m_{H^-} = 200\,\text{GeV} \qquad \tan\beta = 8$$
$$m_t = 172.5\,\text{GeV}$$

Distribution shapes do not depend on value of tan(β)!

- PDF: NNPDF23 NLO 4F and 5F scheme with their corresponding α_S evolution
- This analysis: no cuts on number of b jets (>1bjet >2bjet will also be considered)

RESULTS
SETTINGS

- Scales

$$\mu_R = \mu_F = \mu_B = \frac{H_T}{6} = \frac{1}{6}\sum_i \sqrt{m_i^2 + p_{T,i}^2} \qquad \text{5F}$$

$$\mu_R = \mu_F = \mu_B = \frac{H_T}{3} = \frac{1}{3}\sum_i \sqrt{m_i^2 + p_{T,i}^2} \qquad \text{4F}$$

- At zero $p_{T,i}$ they reproduce scales of the total cross section comparison

- We do not let decay the charged Higgs and decay W from top leptonically
  ⇒ one b-jet from top and one from matrix element, all light jets generated from PS or real emission

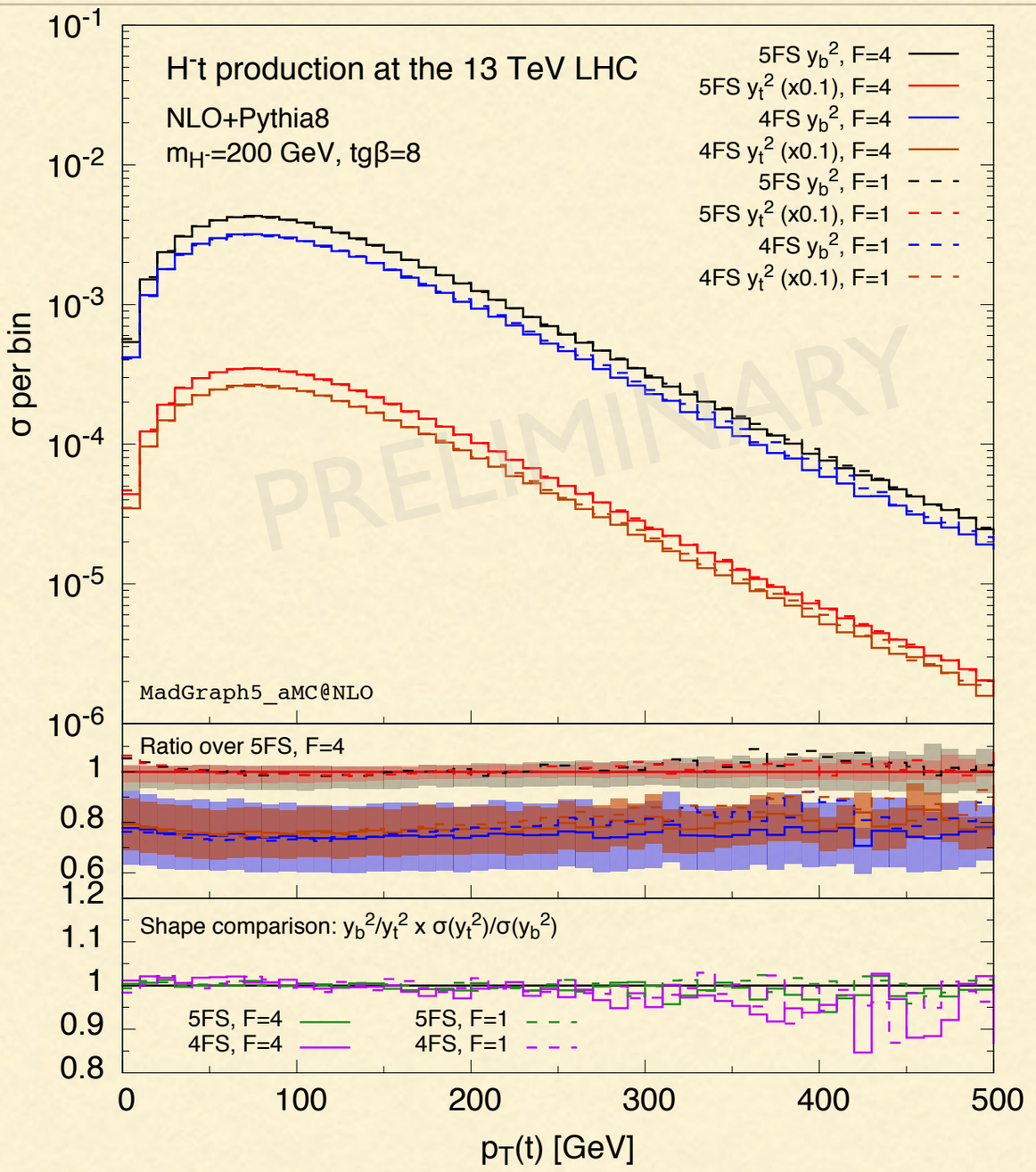
- Explore the dependence of distributions on Q_{sh} (the largest hardness accessible to showers): processes with b quarks have a too large default Q_{sh}: **[see M. Wiesemann talk]** we divide the default scale by 4.

RESULTS

$P_T(t)$

Curves with absolute NLO normalisation are displayed

- For inclusive quantities in the final b kinematics, ratio 5F/4F constant 0.8
- No significant differences in shapes
- Difference in normalisation due to scale choice? Larger effective scale?
- Reduction of the shower scale Q_{sh} slightly improves comparison to a perfect degree
- Y_t^2 and Y_b^2 have similar shapes
- Small effect of MS scheme for Y_b at the level of shapes
- Larger scale uncertainty for Y_b^2



M. Ubiali, "Charged Higgs production 4FS versus 5FS"

RESULTS

$P_T(H^-)$

Curves with absolute NLO normalisation are displayed

- For inclusive quantities in the final b kinematics, ratio 5F/4F constant 0.8
- No significant differences in shapes
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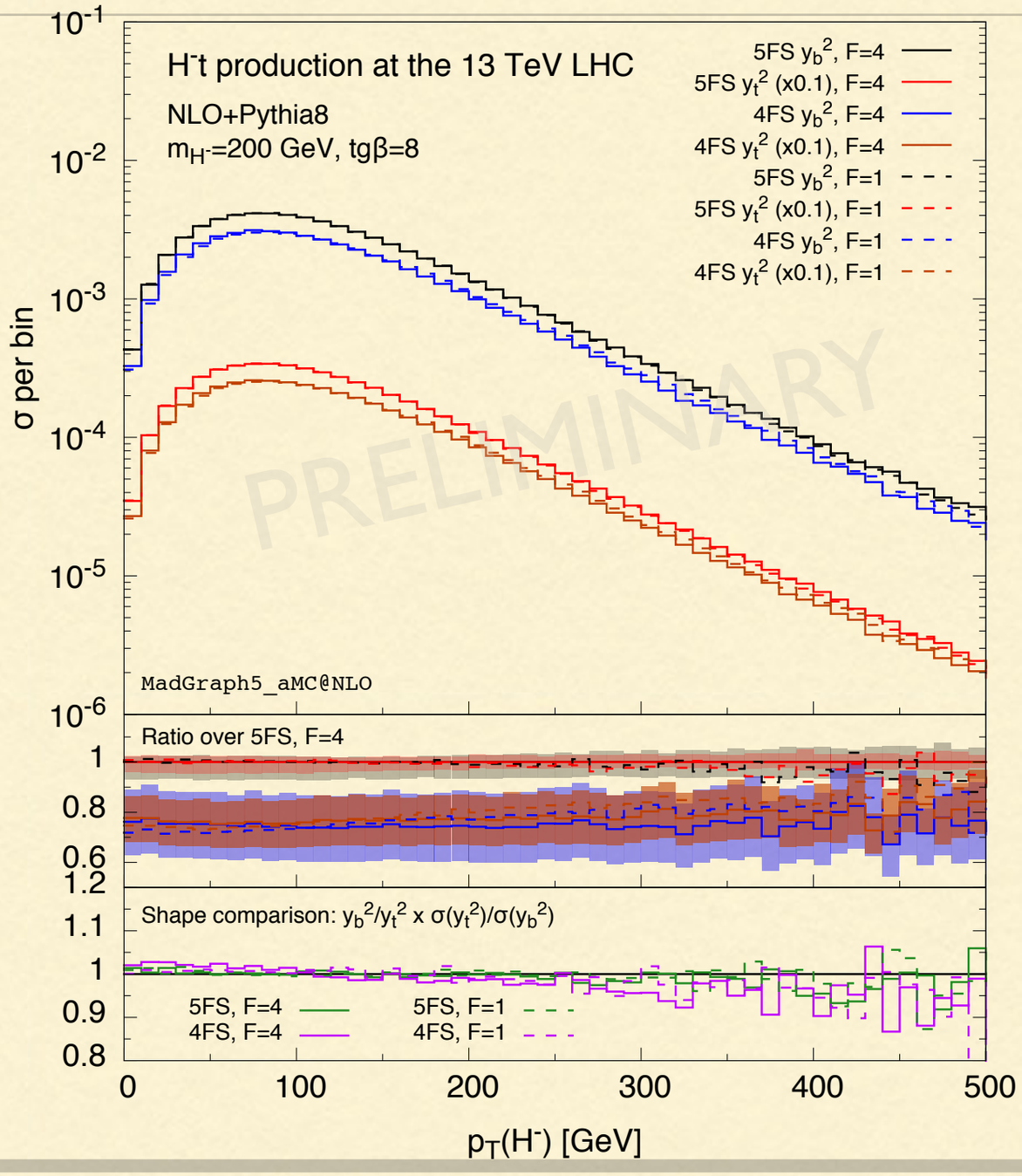
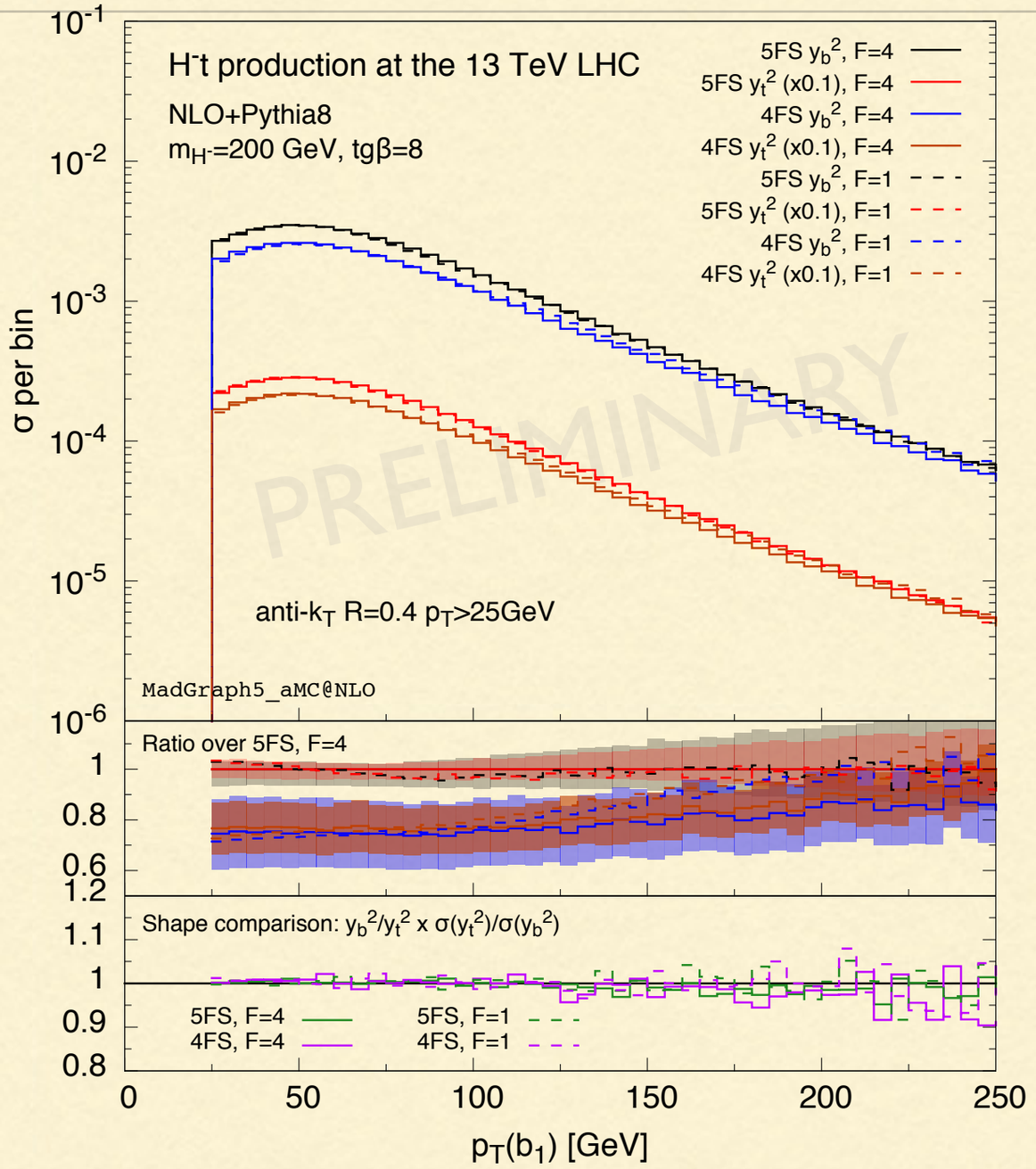


RESULTS

$P_T(b_1)$

Hardest b jet

- 4FS tends to be harder
- In 5FS scale uncertainty increases sizeably at p_T increases
- Scale uncertainty stable for 4FS
- Compatible with p_{Tb} distribution in 5FS been computed at a lower perturbative order
- Reduction of the shower scale softens the b-jet and greatly improves the agreement between 4FS and 5FS



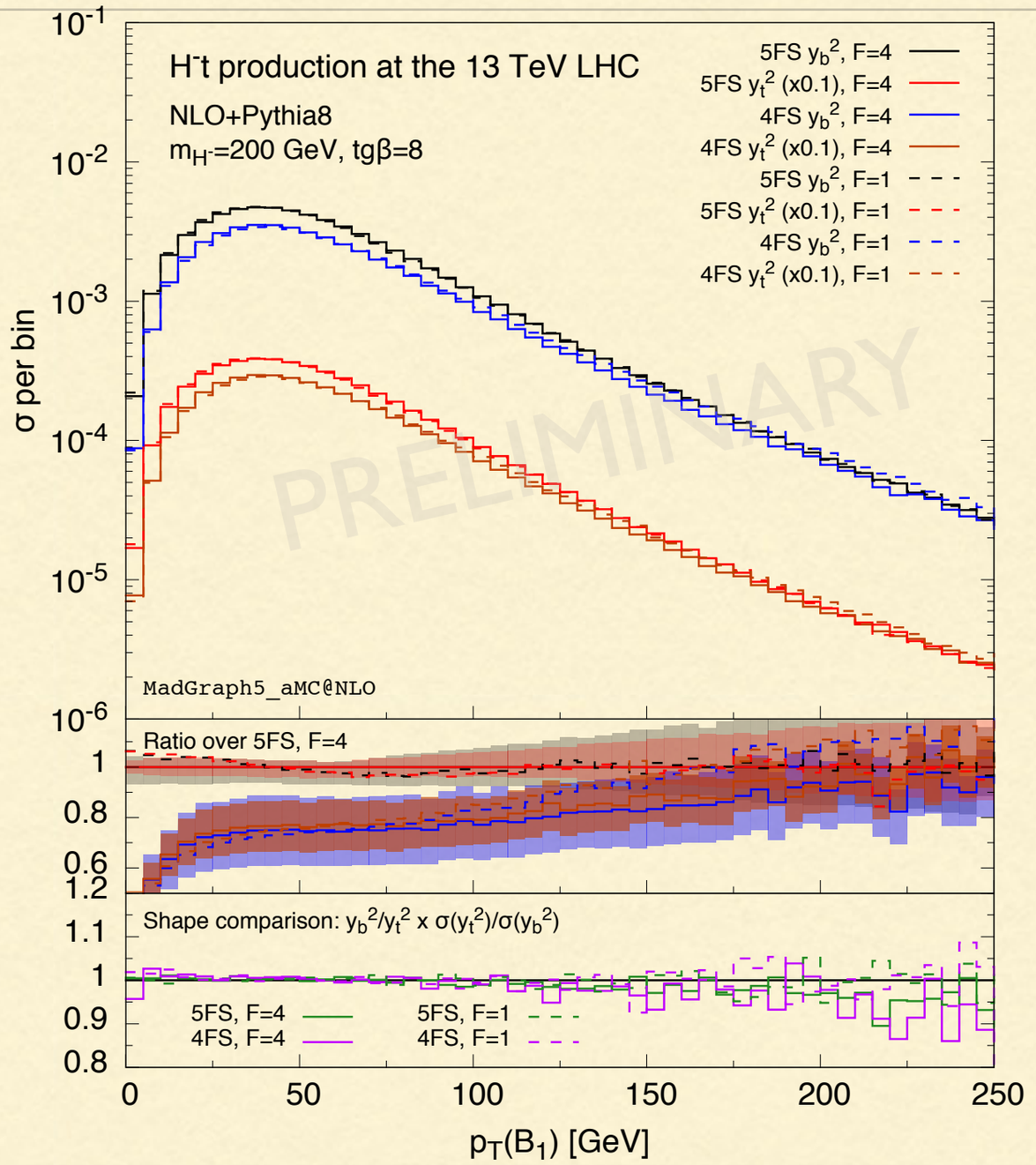
M. Ubiali, "Charged Higgs production 4FS versus 5FS"

RESULTS

$P_T(B_1)$

Hardest B hadron

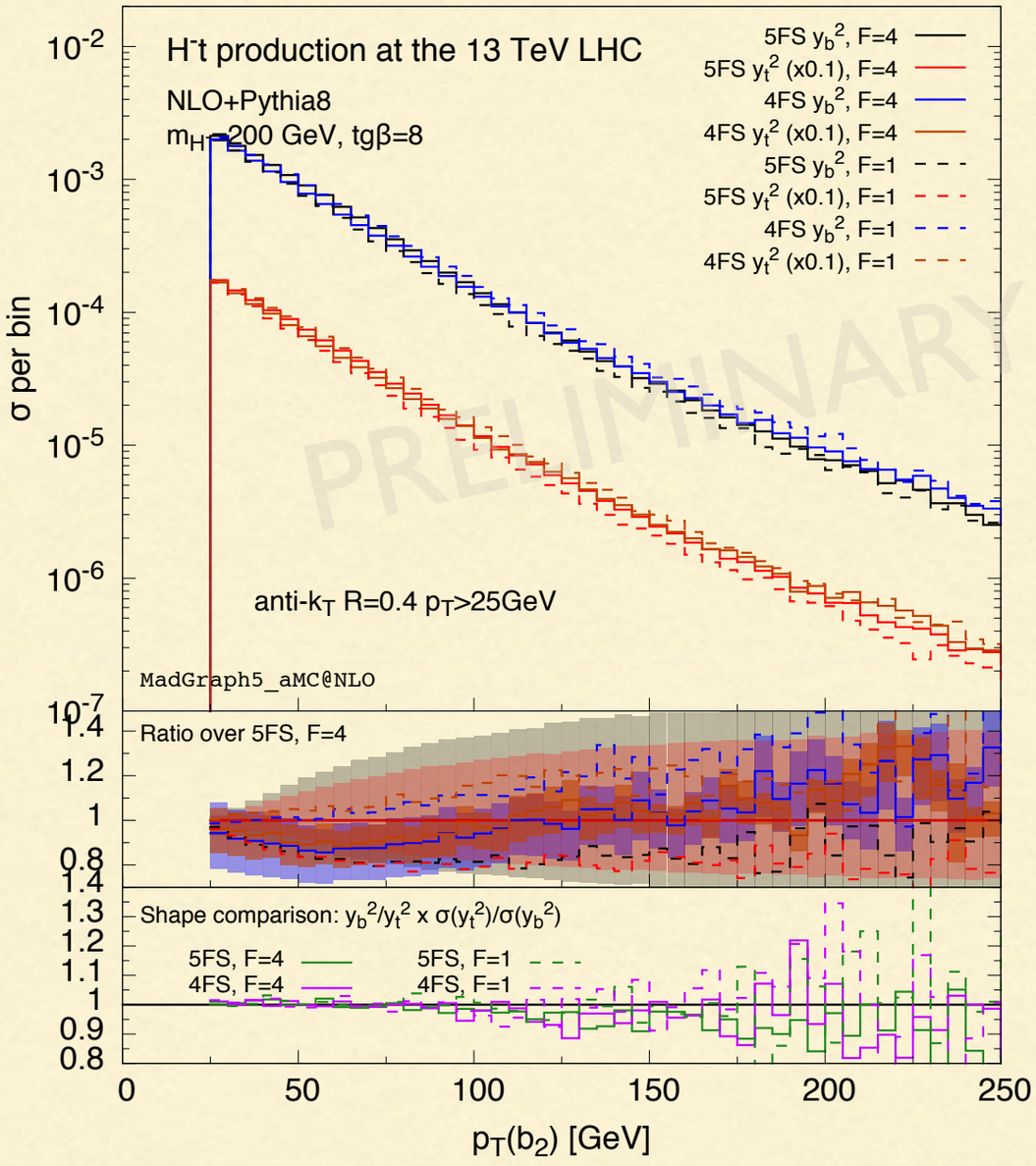
- 4FS tends to be harder
- In 5FS scale uncertainty increases sizeably at p_T increases
- Scale uncertainty stable for 4FS
- Compatible with p_{Tb} distribution in 5FS been computed at a lower perturbative order
- Reduction of the shower scale softens the b-jet and greatly improves the agreement between 4FS and 5FS
- At small pT large differences and expect strong dependence of 5FS curve on the Monte Carlo

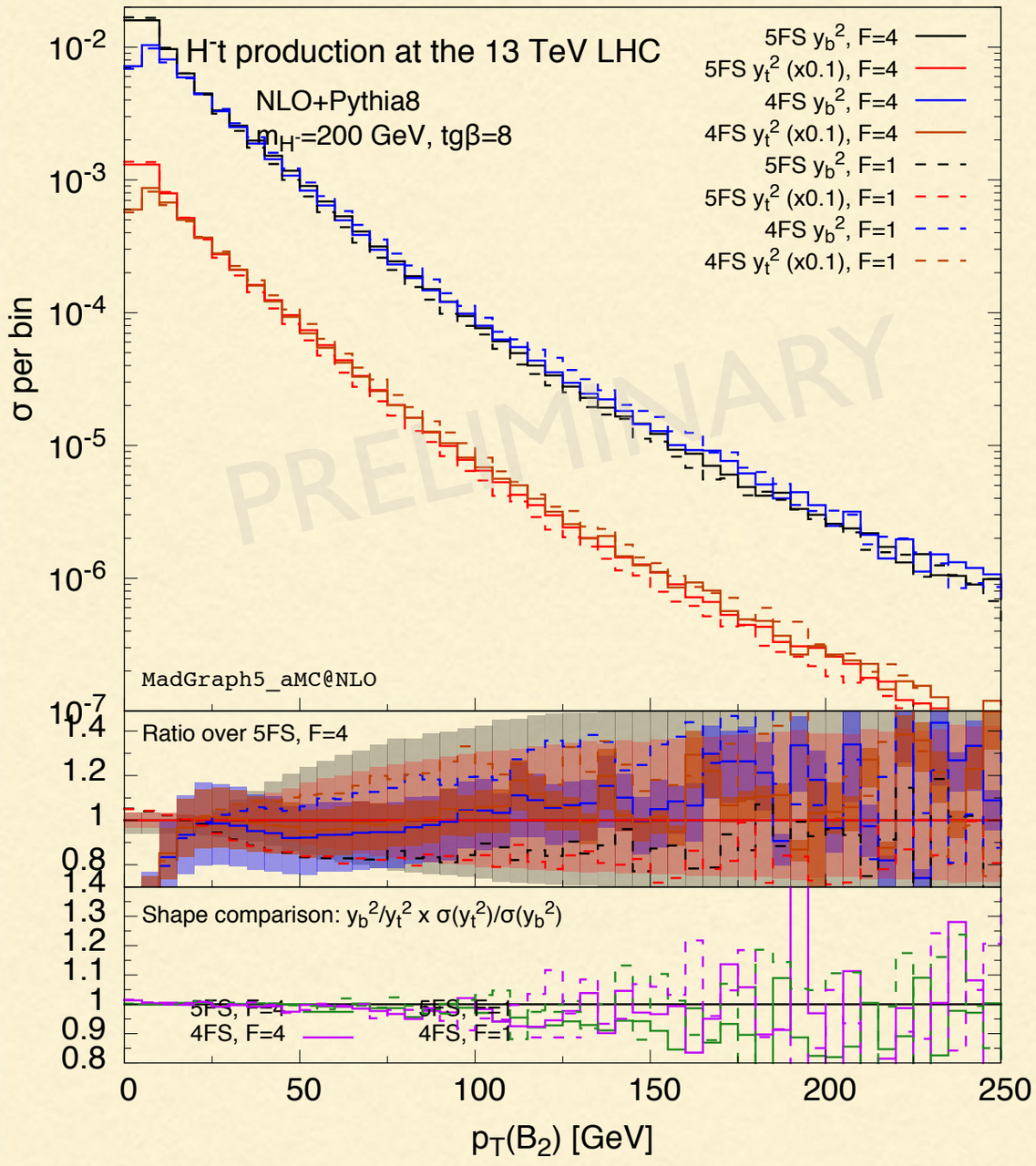


RESULTS

$P_T(b_2)$ & $P_T(B_2)$

Second hardest b jet and B hadron

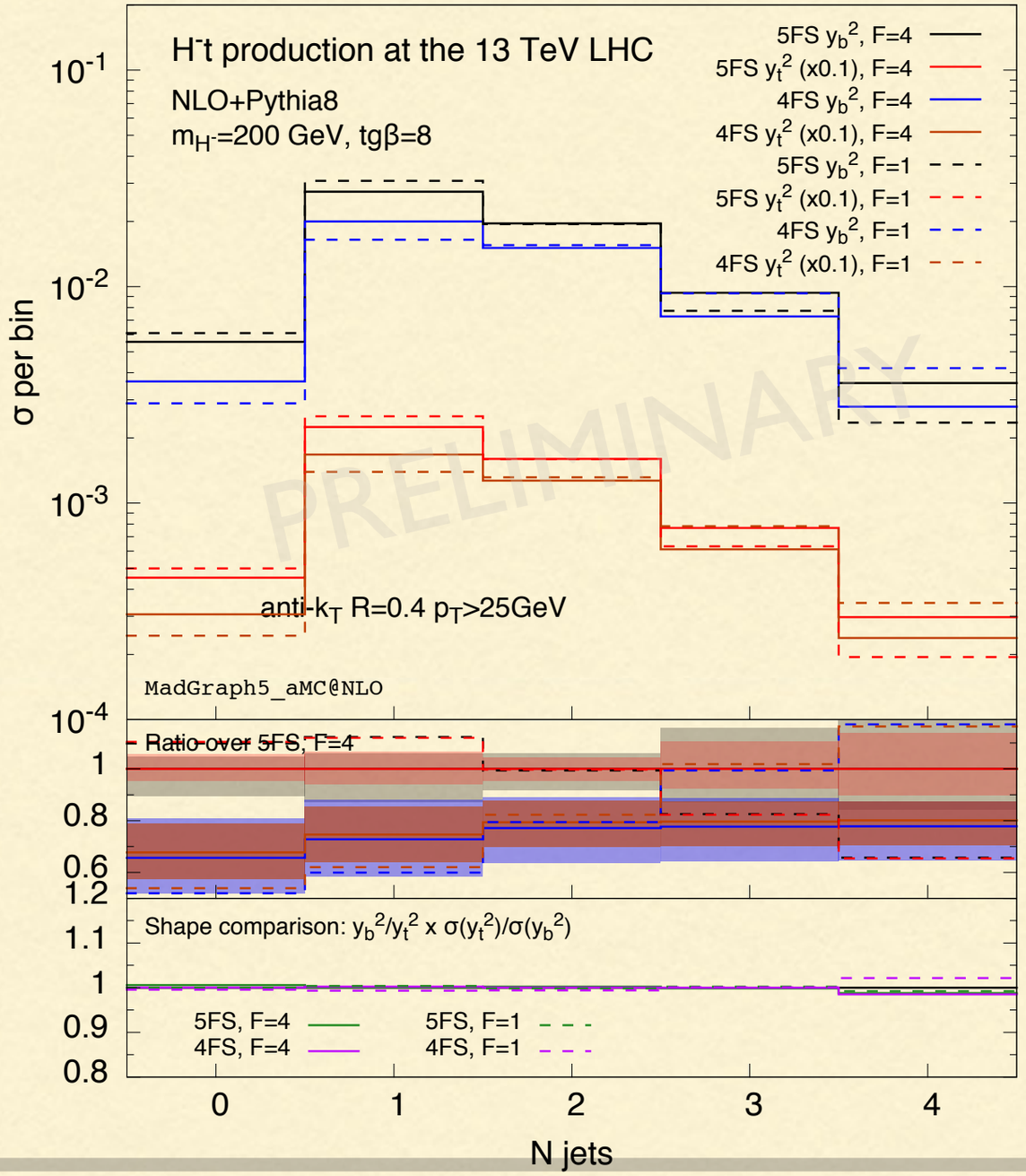


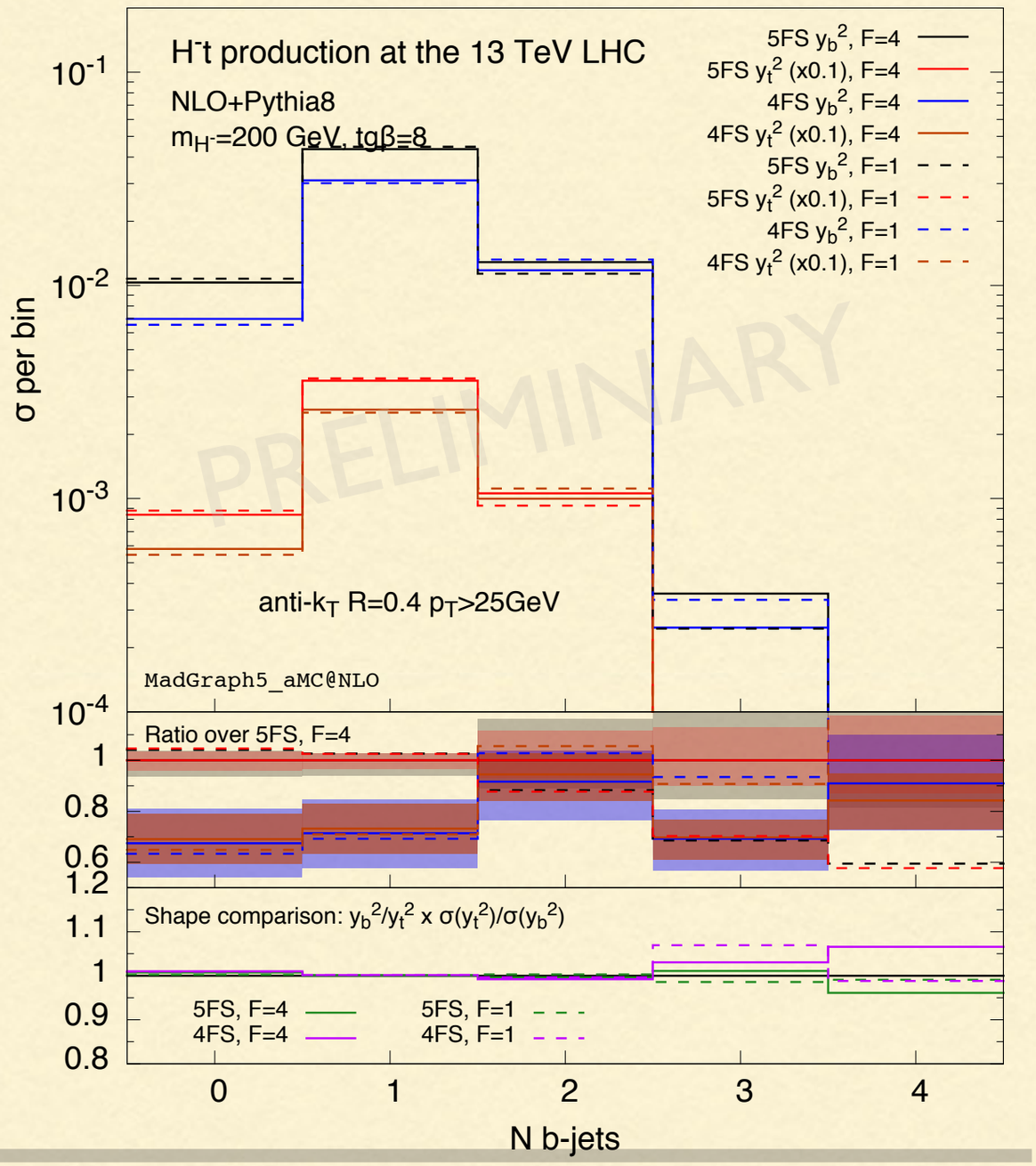


M. Ubiali, "Charged Higgs production 4FS versus 5FS"

RESULTS

NJETS & NBJETS





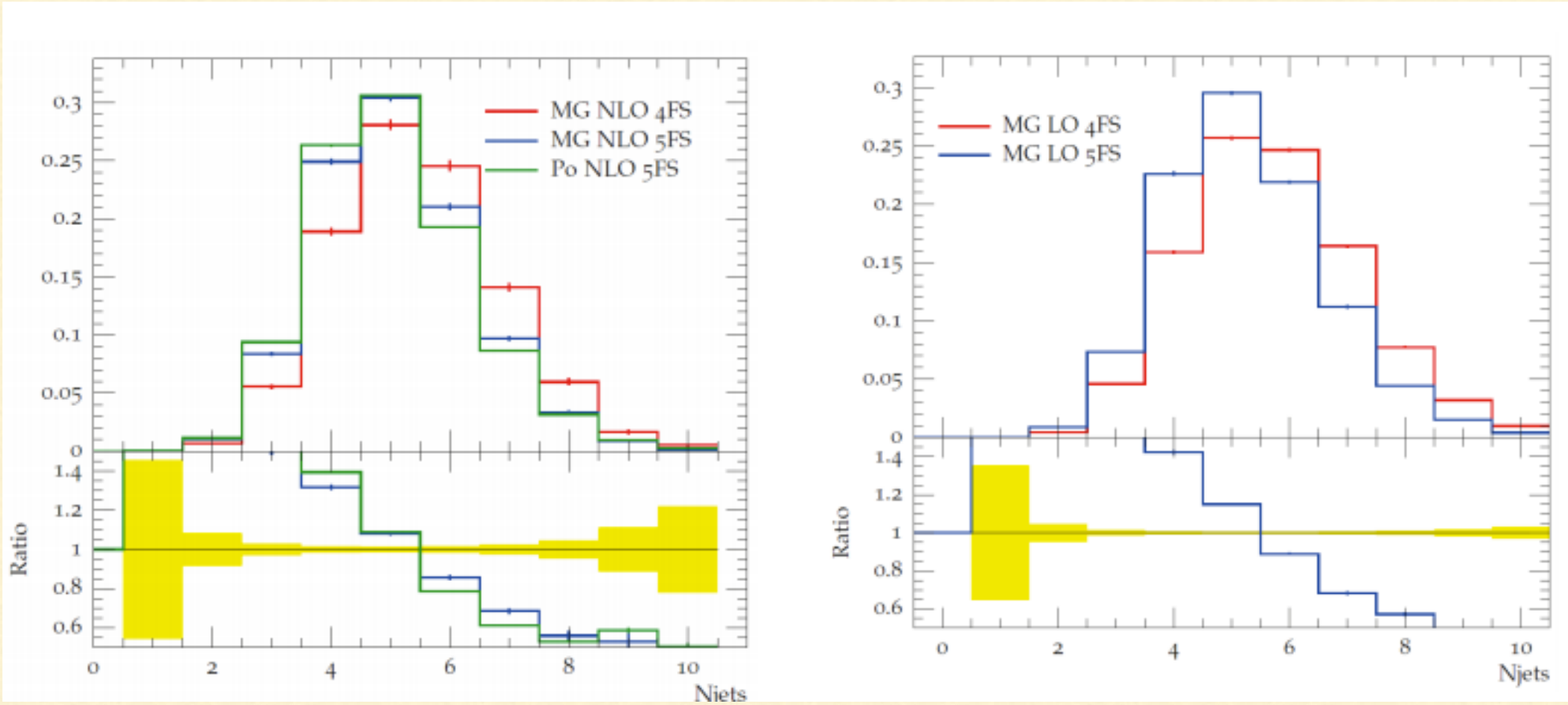
M. Ubiali, "Charged Higgs production 4FS versus 5FS"

CONCLUSIONS

- First NLO+PS differential distributions in the 4FS have been presented
- Consistent picture for 4F versus 5F comparison is emerging
  - For inclusive cross sections and differential distributions inclusive in the b quark where resummation nor b mass effects are essential 4F and 5F pictures are very close
  - For differential distributions sensitive to the b quarks kinematics the choice of shower scale becomes relevant [see M. Wiesemann talk]
- Differential distributions do not change with tanB
- A lot of work in progress
  - LO+PS, NLO, heavier charged Higgs
  - Look at the decayed Higgs to top - bottom
  - Look at intermediate region and interference with tt resonant

BACKUP SLIDES

MOTIVATION



courtesy of Liron Barak

2HDMs
A SHORT OVERVIEW

- Many new physics models require two Higgs doublets, leading to five physical scalar Higgs bosons, among which mass degenerate $H^{\pm}$

$$\Phi_1 = \begin{pmatrix} \Phi_1^+ \\ \Phi_1^0 \end{pmatrix} \qquad \Phi_2 = \begin{pmatrix} \Phi_2^+ \\ \Phi_2^0 \end{pmatrix}$$

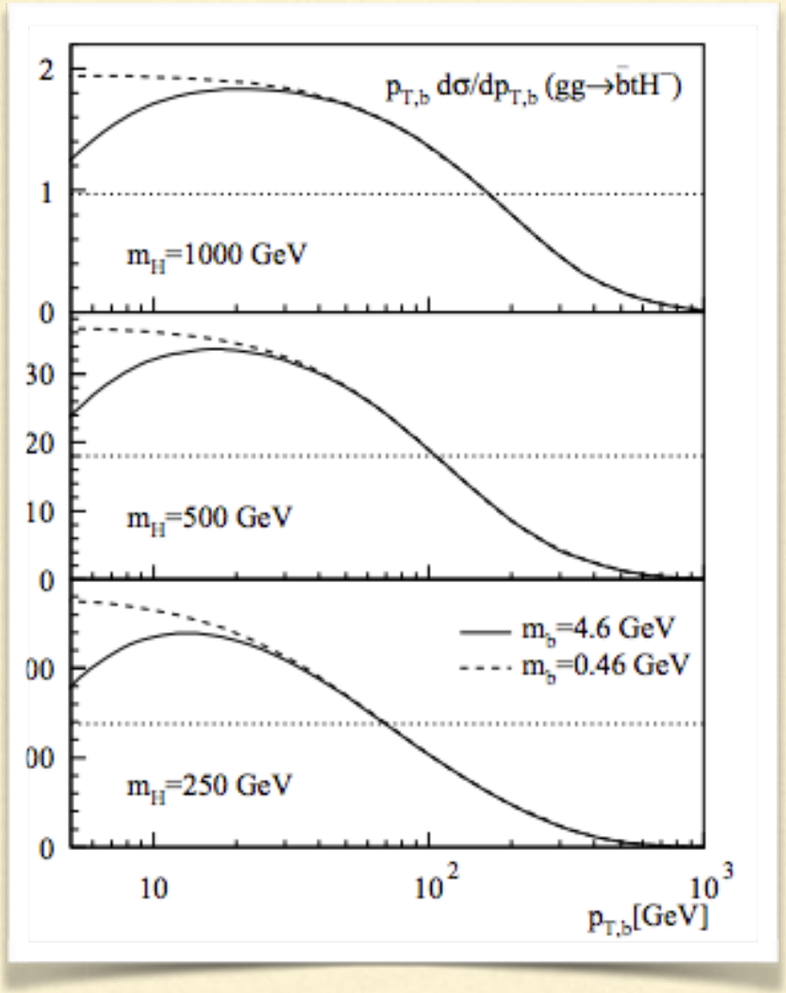
- **2HDMs** represent the simplest extension of the SM Higgs sector

- Imposing natural flavour conservation there are four different ways to couple the SM fermions to the two Higgs doublets. Each gives rise to a different phenomenology (Type-I, Type-II, Type-III or Flipped, Type-IV or II' or Lepton Specific)

- **Type-II:** one doublet generates the mass of the up-type quarks and the other the mass of down-type quarks and charged leptons. At tree level MSSM is a type-II 2HDM but the latter does not contain SUSY particle in the loop

4F VERSUS 5F
INCLUSIVE CROSS SECTION COMPARISON

- Recent comparison: modern sets of PDFs, all sources of uncertainties included, new scale prescription for the 5F factorisation scale **[M. Flechl et al, arXiv:1410.8849]**



T. Plehn, Phys. Rev. D67:014018 (2003)

	8 TeV		14 TeV	
$M_{H^\pm}$ [GeV]	$\tilde{\mu}$ [GeV]	$(m_t + M_{H^\pm})/\tilde{\mu}$	$\tilde{\mu}$ [GeV]	$(m_t + M_{H^\pm})/\tilde{\mu}$
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

Findings close to the ones of studies based on pTb distribution

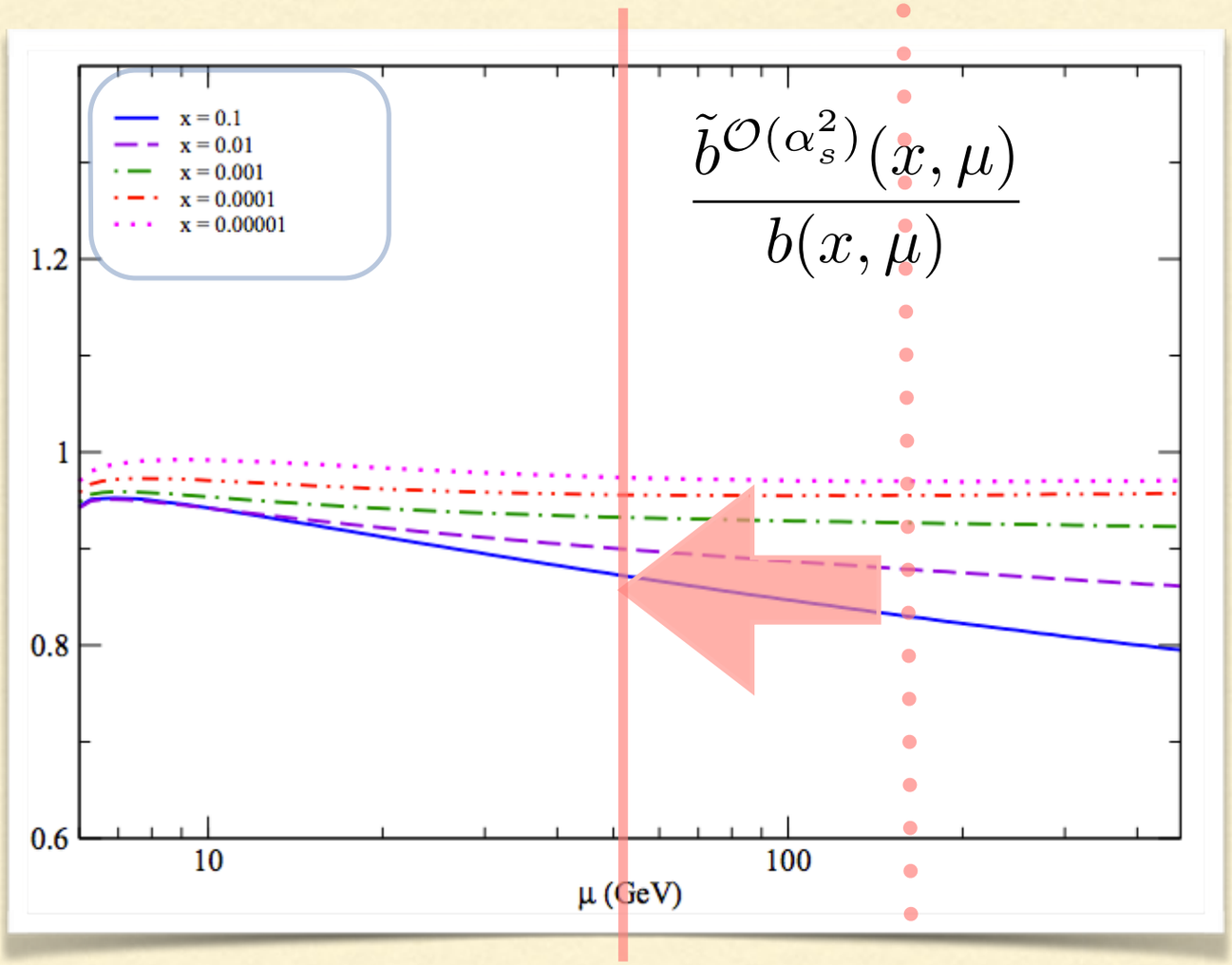
$$\log \frac{\tilde{\mu}^2}{m_b^2} = \frac{\int_\tau^1 \frac{dz}{z} \mathcal{L}_{gg}\left(\frac{\tau}{z}\right) P_{qg}(z) \log\left[\frac{(M_H+m_t)^2}{m_b^2}\frac{(1-z)^2}{z}\right]}{\int_\tau^1 \frac{dz}{z} \mathcal{L}_{gg}\left(\frac{\tau}{z}\right) P_{qg}(z)}$$

F. Maltoni et al, JHEP 1207 (2012) 022

4F VERSUS 5F

HEAVY $H^{\pm}$ PRODUCTION: TOTAL CROSS SECTION

☑ For process in regions of the phase space where the resummation and mass effects are not dominant, the two schemes are expected to give similar results, if judicious scales are chosen



[Maltoni, Ridolfi, MU JHEP 1207 (2012) 022]

For inclusive scenarios

- The resummation effects of the initial state logs are important only at large-x
- The possibly large ratios (M2/m2) are always accompanies by universal phase space factors that (at LHC) suppress the logarithms