



# Accurate predictions for (heavy) charged Higgs production

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# Motivation

- Discovery of a charged Higgs boson would be a clear sign of BSM physics
- Experimentalists push for having accurate fully differential predictions
- Testing ground for the MG5\_aMC@NLO + NLOCT machinery
- 4FS and 5FS description possible: nice QCD exercise
- First NLO+PS computation of charged Higgs production in the 4FS

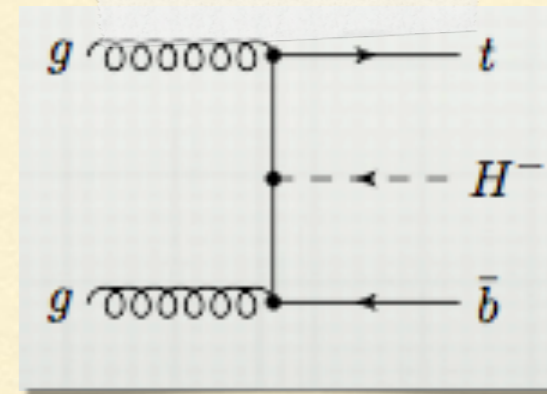
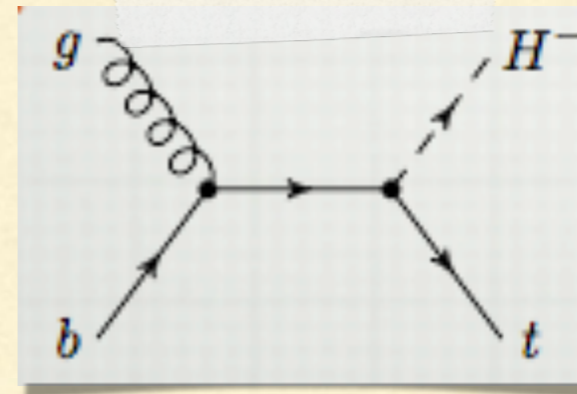
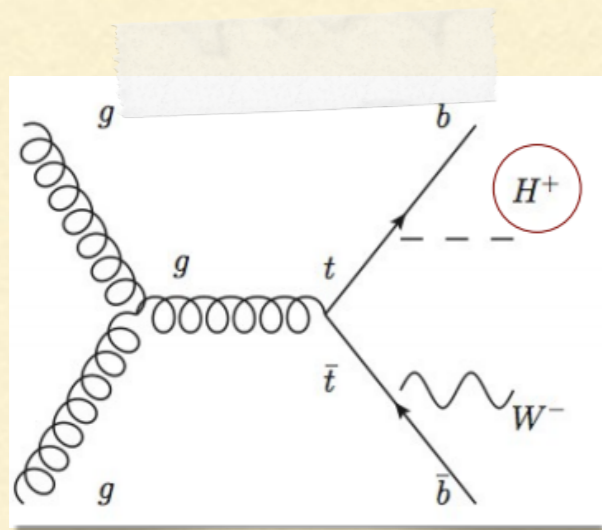
# 2HDMs

## CHARGED HIGGS PRODUCTION AT COLLIDERS

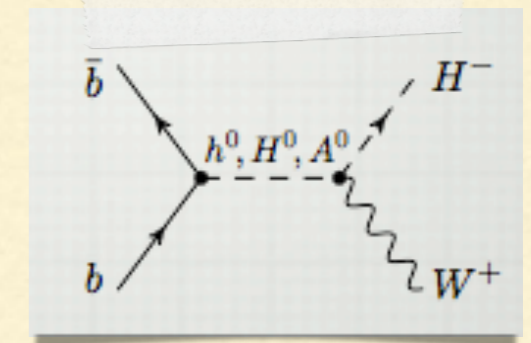
**LIGHT HIGGS**

**INTERMEDIATE REGION**

**HEAVY HIGGS**

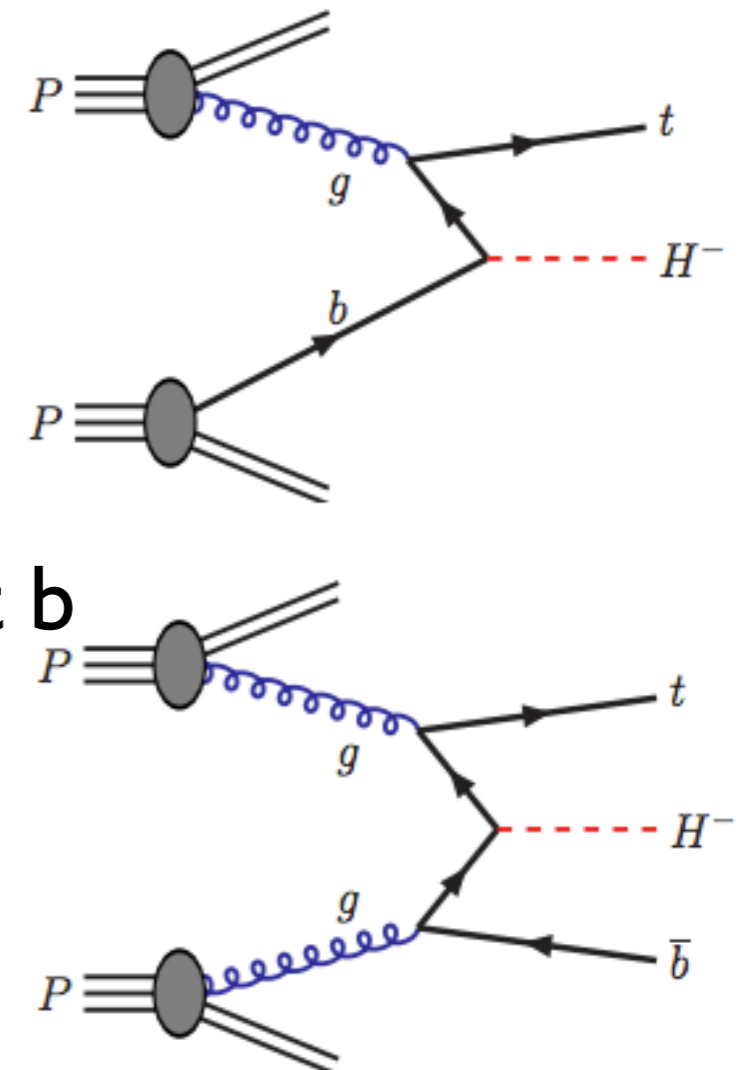


+ suppressed production channels



# 4FS and 5FS description

- Study the charged Higgs production in the 2HDM, for a heavy ( $m_H > 200$  GeV) Higgs boson  $pp \rightarrow H^- t + X$
- Two possible schemes:
  - 5F (include b in proton,  $m_b = 0$ ):  $gb \rightarrow H^- t$ 
    - Simpler process (lesser multiplicity)
    - No b mass effects
    - Worse description of b-related observables
    - Resum  $\log(m_b/Q)$
  - 4F (keep  $m_b \neq 0$ , no b in proton):  $q\bar{q}/gg \rightarrow H^- t b$ 
    - b mass effects included in the matrix-element
    - Can be spoiled by large  $\log(m_b/Q)$
    - Better description of b-related observables



# Cross-section

- Structure of the  $H^-tb$  vertex:

$$V_{t\bar{b}H^-} = -i (y_t P_R \cot \beta + y_b P_L \tan \beta)$$

- Cross-section will receive 3 contributions:

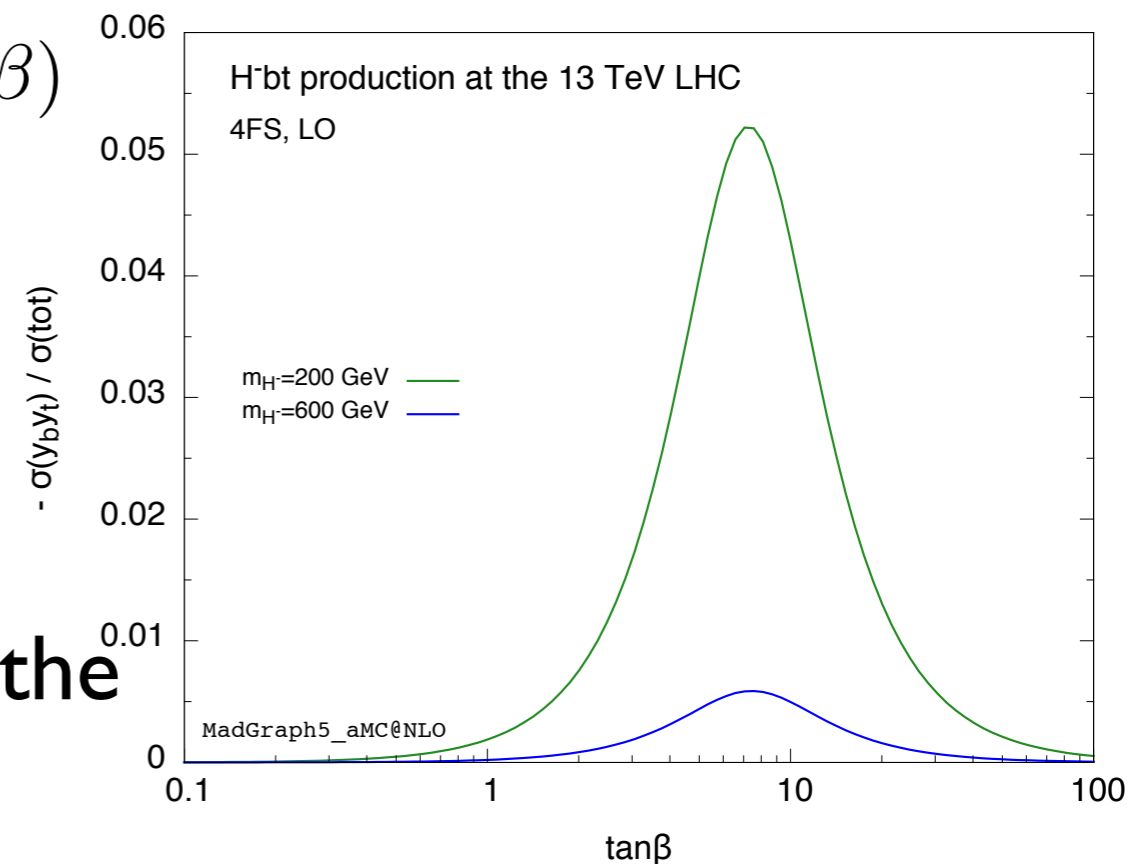
- $y_t^2 \sim 1/\tan^2 \beta$

- $y_b^2 \sim \tan^2 \beta$

- $y_t y_b$ , independent on  $\beta$ , vanishes in the 5FS

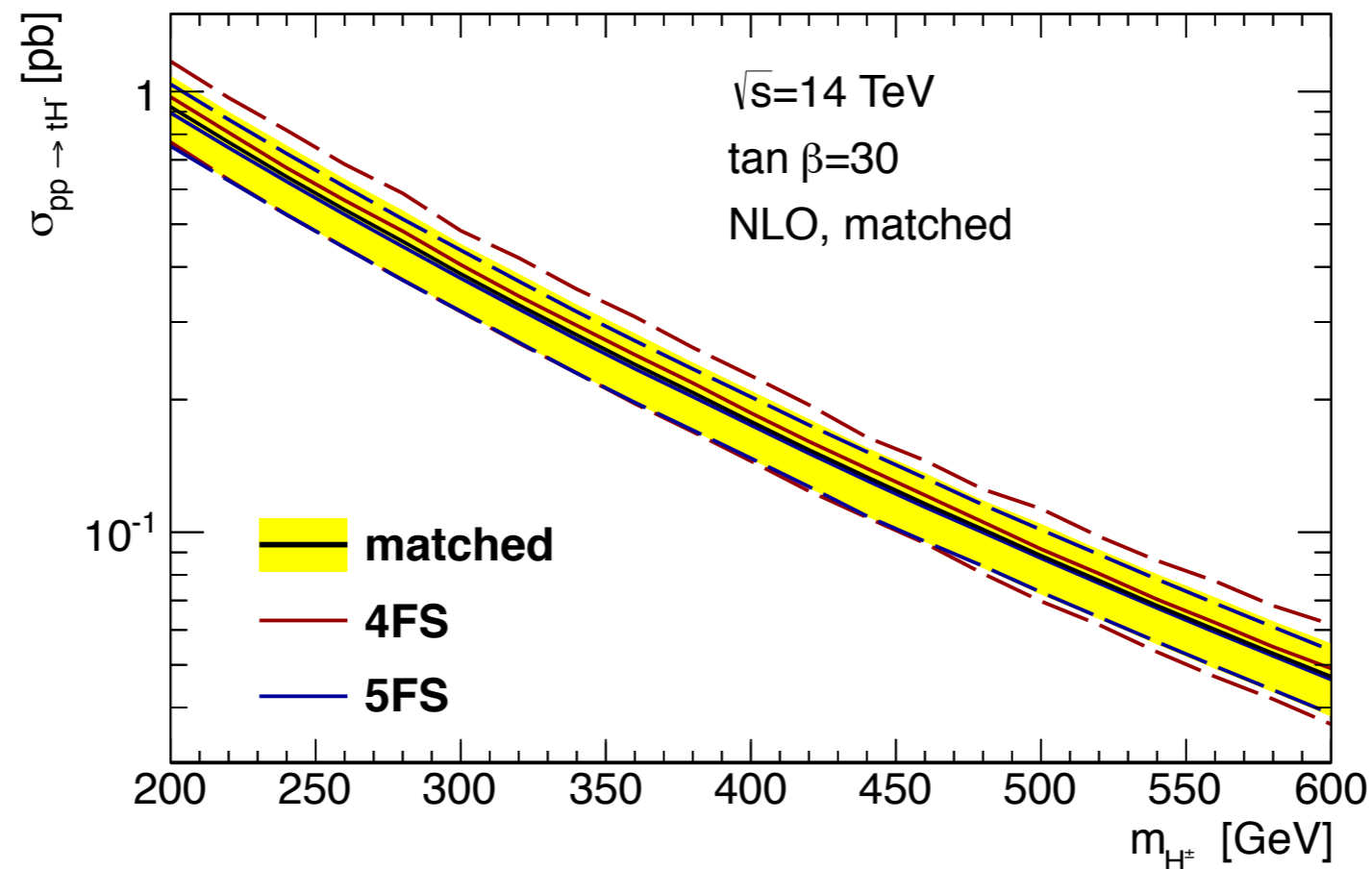
- $y_t y_b$  term has maximum impact at  $\tan \beta \sim 7-8$  (5% of total xsect for  $m_H=200$ , <1% for  $m_H=600$ )

- In practice, it can be neglected





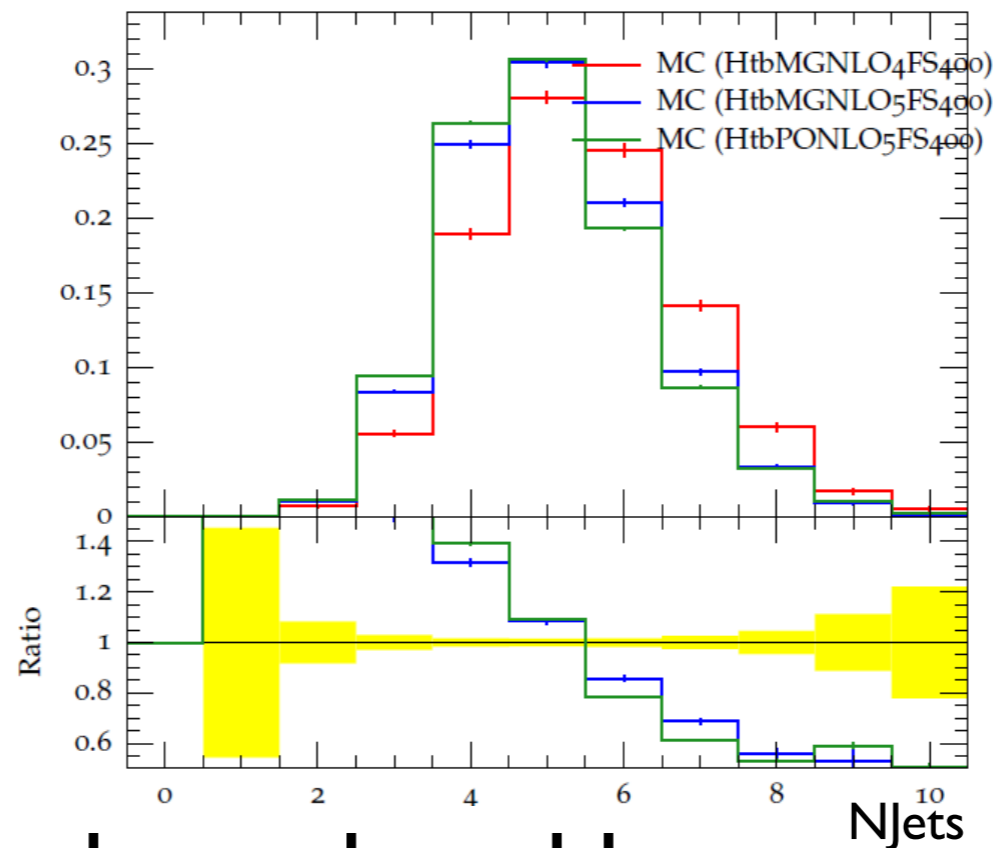
# Total cross-section agreement 4FS vs 5FS



- Nice agreement obtained at total xsect level, thanks to:  
[Flechl, Klees, Kramer, Spira, Ubiali arXiv:1409.5615](#)
  - Modern 4F/5F PDFs
  - Using  $\overline{\text{MS}}$  bottom Yukawa: resum  $\log(m_H/m_b)$
  - Suitable (low) value for  $\mu_{R/F}$  [Maltoni, Ridolfi, Ubiali arXiv:1203.6393](#)

# Out of the box results for distributions

- Large discrepancies observed by ATLAS between the two schemes



Plot by Liron Barak ~mid 2014

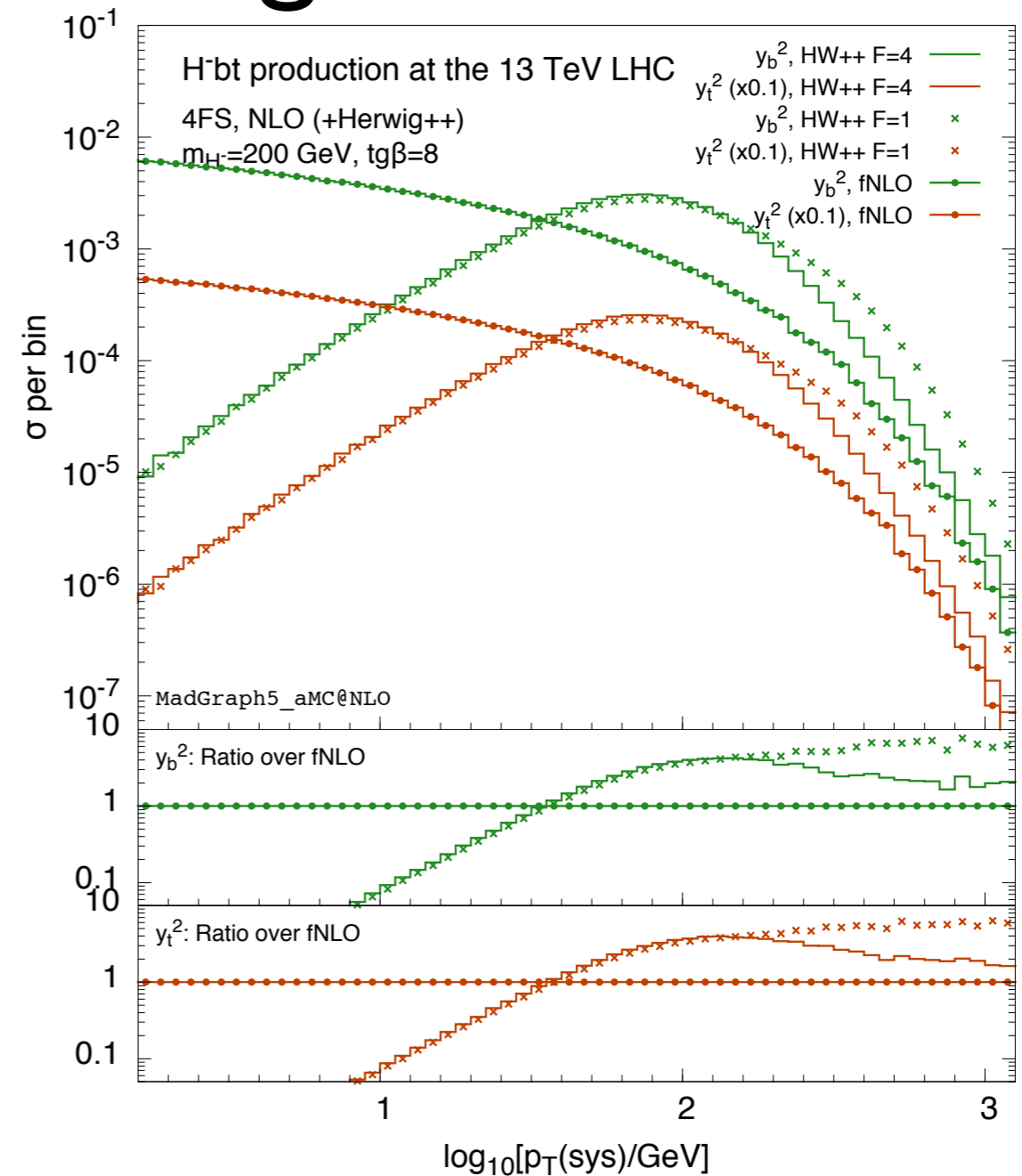
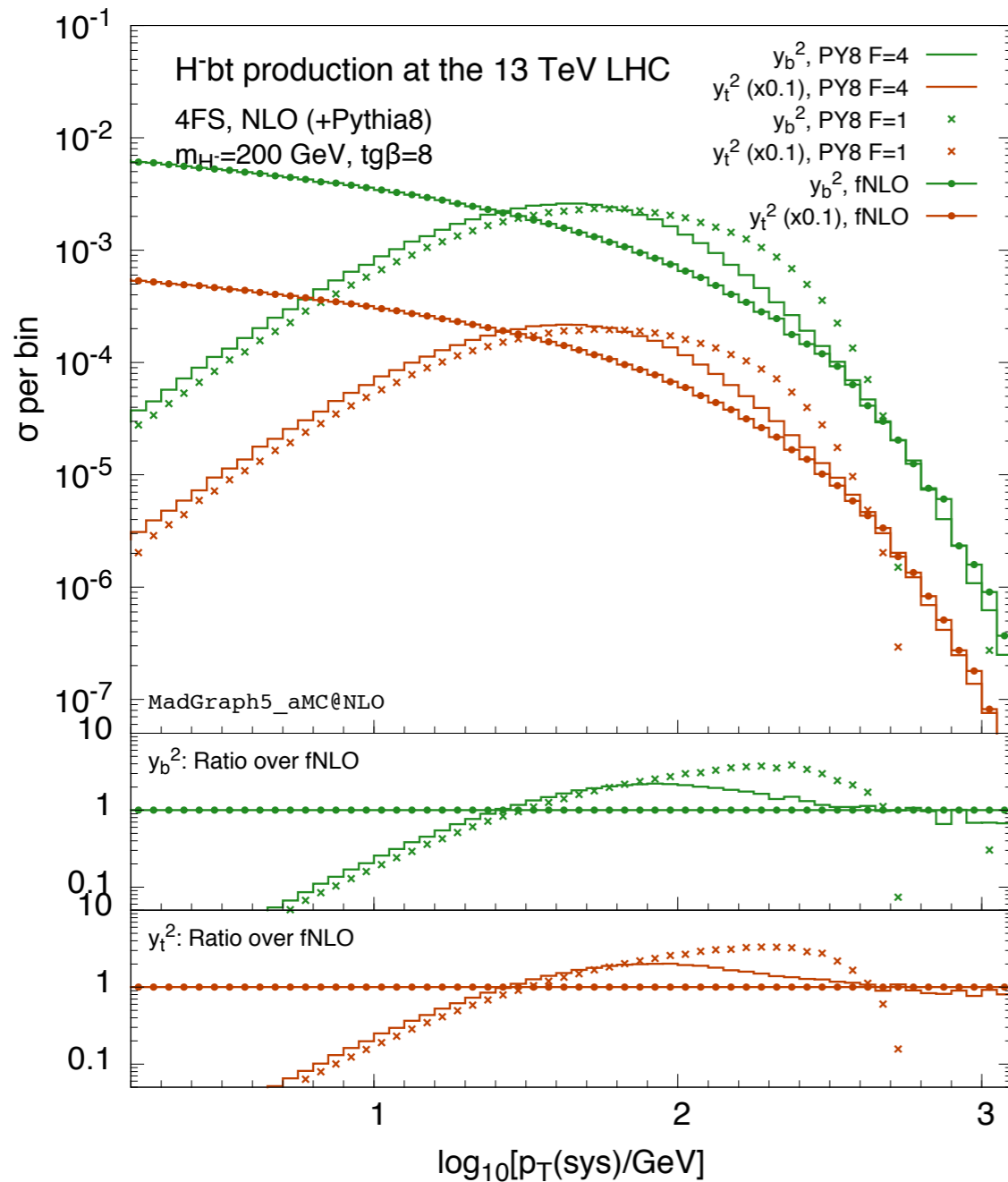
- Discrepancies can be reduced by
  - Using  $\overline{\text{MS}}$  bottom Yukawa: resum  $\log(m_H/m_b)$
  - $\mu_{F/R}$  choice:  $H_T/3$
  - Choose a reduced shower scale (factor  $F$  in the plots)

# Settings for the calculation

- Type II 2HDM @NLO generated with NLOCT  
Degrande, arXiv:1406.3030
- LHC Run II, 13TeV
- NNPDF2.3(3.0) 4FS/5FS at NLO(LO)
- $\mu_{F/R} = H_T/3$
- $m_H = 200, 600 \text{ GeV}; \quad m_t = 172.5 \text{ GeV};$
- $m_b^{\text{pole}} = 4.75 \text{ GeV}; \quad m_b(m_b) = 4.33 \text{ GeV}$
- Jets clustering: anti- $k_T$ ,  $R=0.4$ ,  $p_T > 25 \text{ GeV}$ ,  $|\eta| < 2.5$
- Higgs stable; leptonic top decay
  - 1 b-jet from top + 1 from matrix-element (shower)
- Default shower scale ( $F=1$ ) and shower scale reduced by  $F=4$

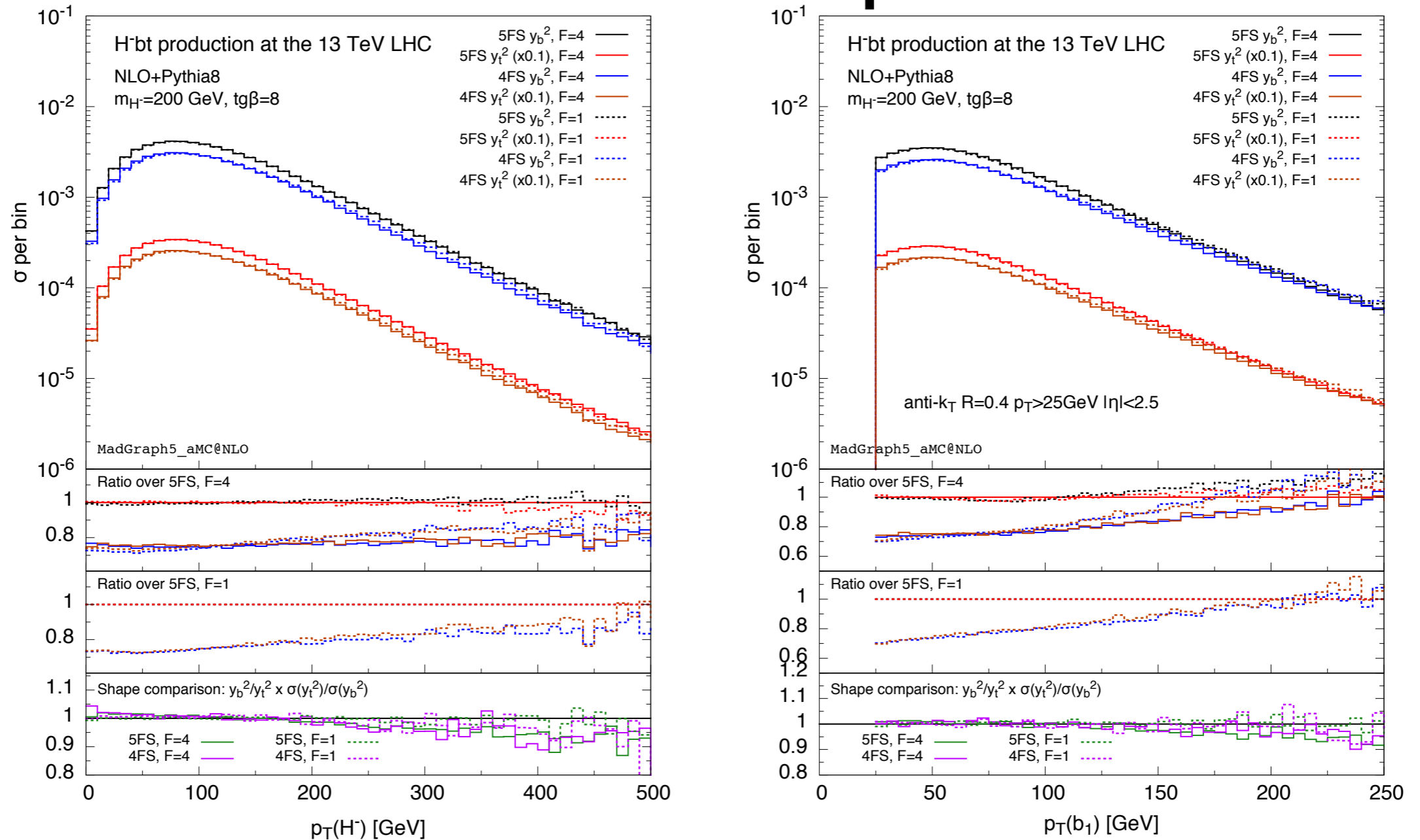


# Shower scale effects in the matching



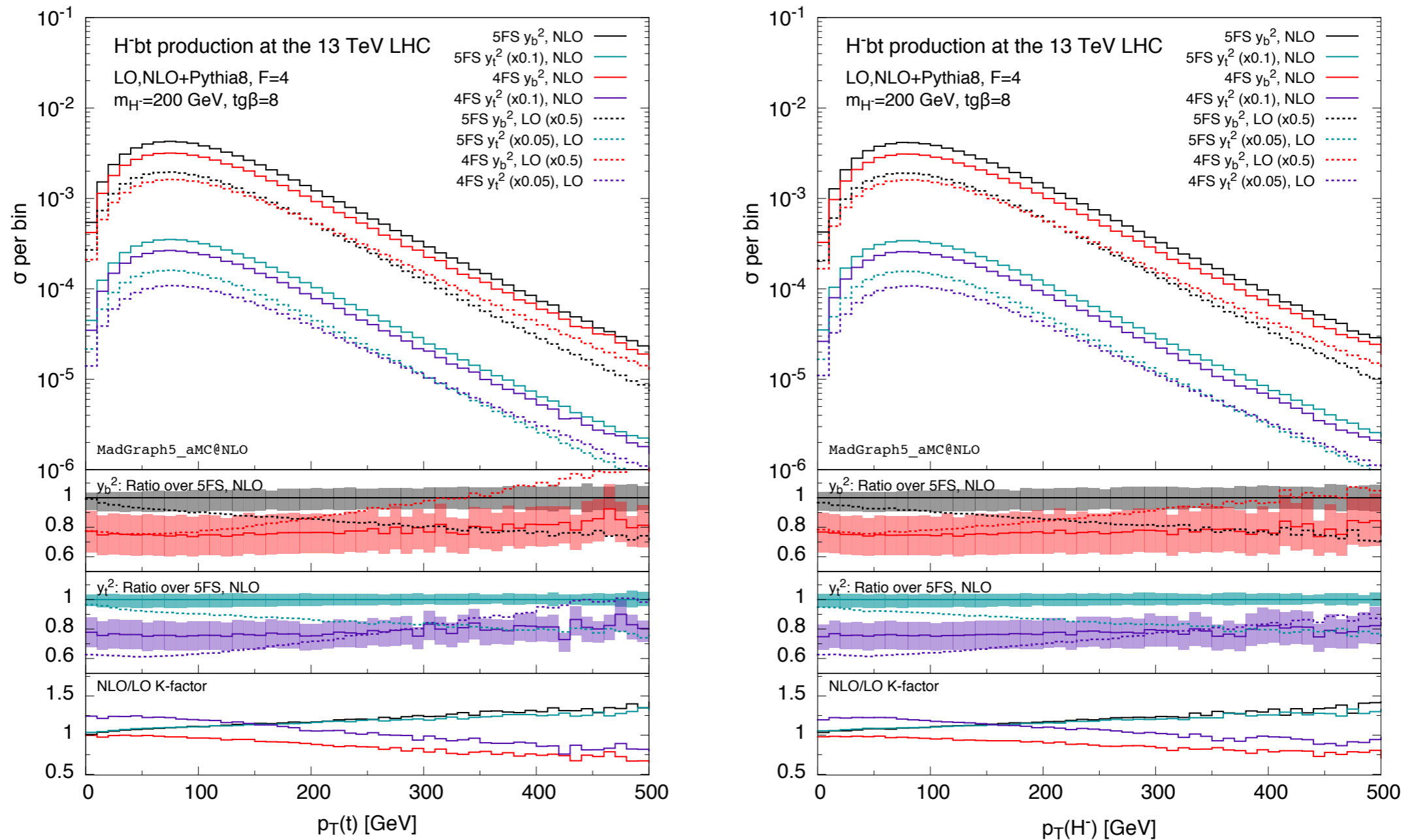
- Matching at high  $p_T$  much improved for F=4

# Shower scale effects and 5F vs 4F comparison



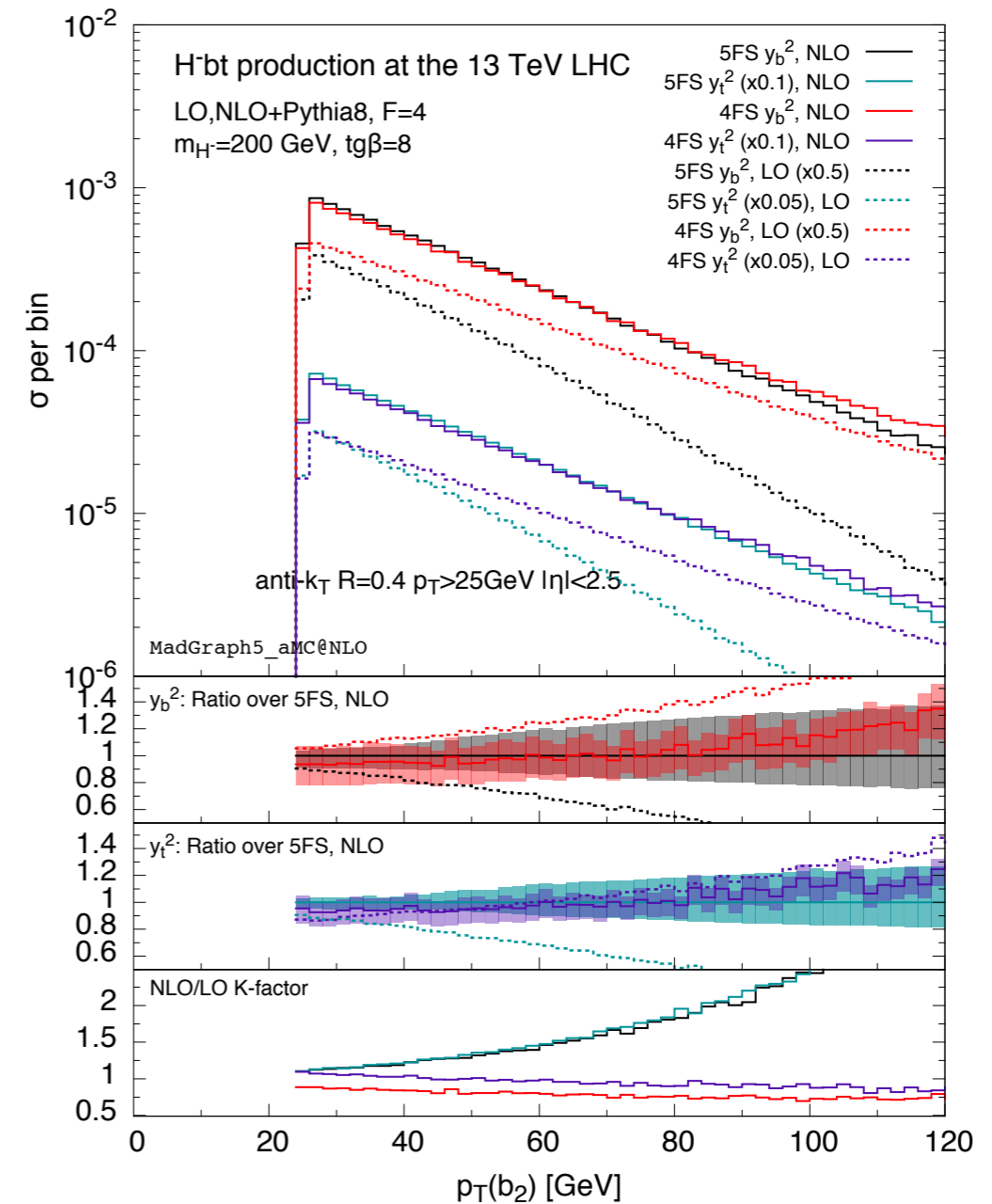
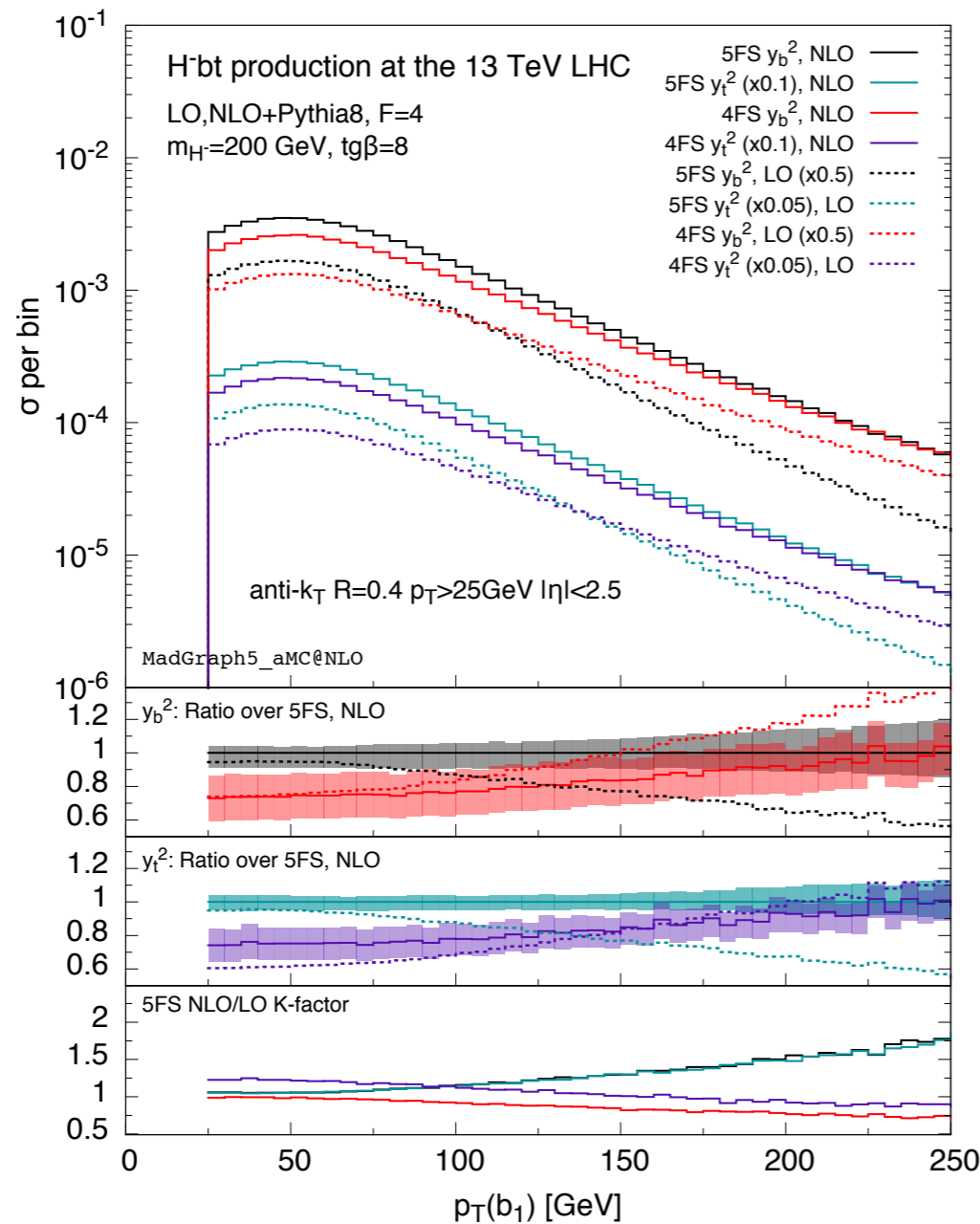
- Reduced shower scale (F=4) improves shape agreement between 4FS and 5FS

# 5FS and 4FS comparison: NLO effects



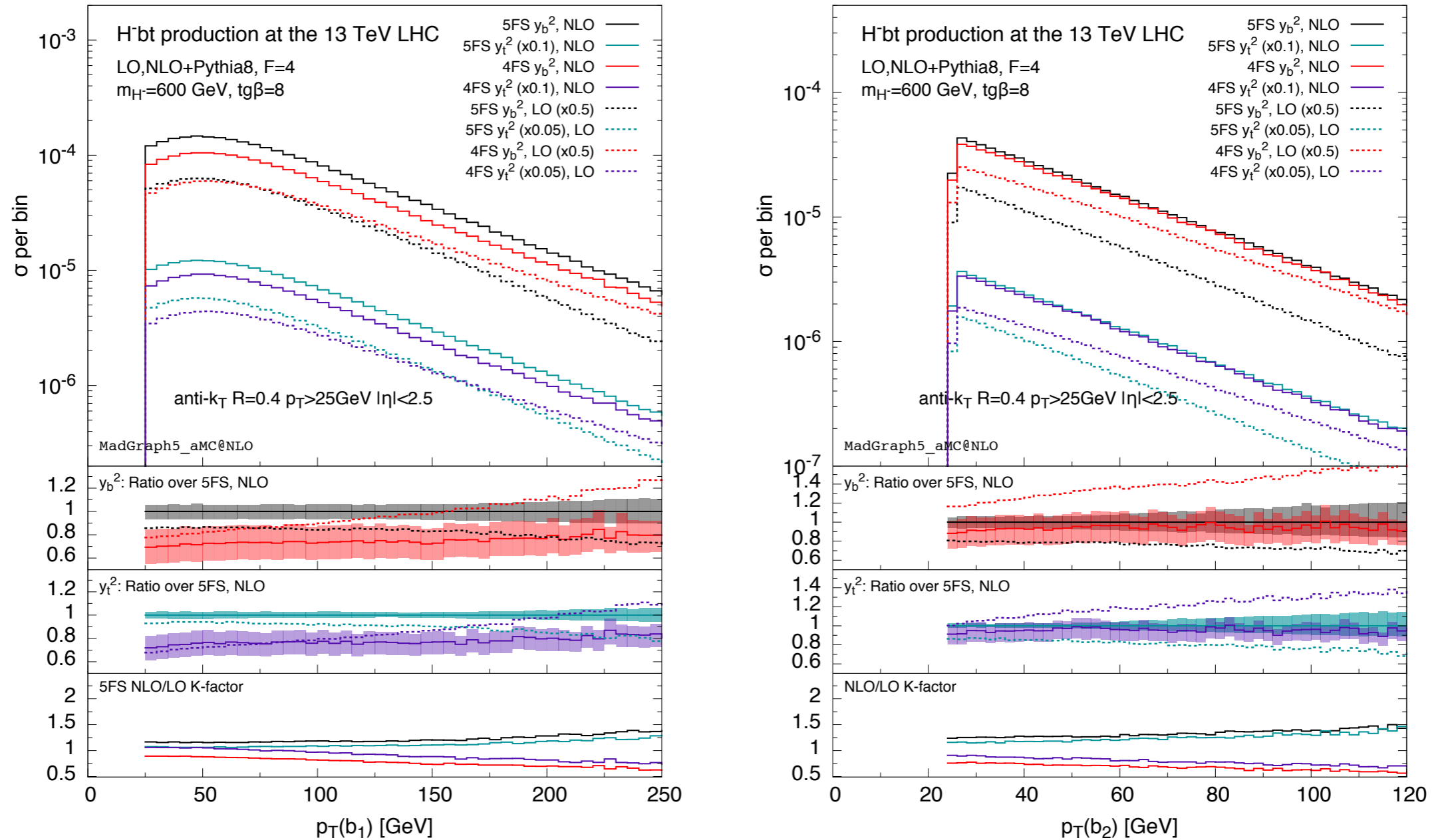
- NLO corrections crucial for shape agreement
- Residual  $\sim 20\%$  normalisation difference

# 5FS and 4FS comparison: NLO effects



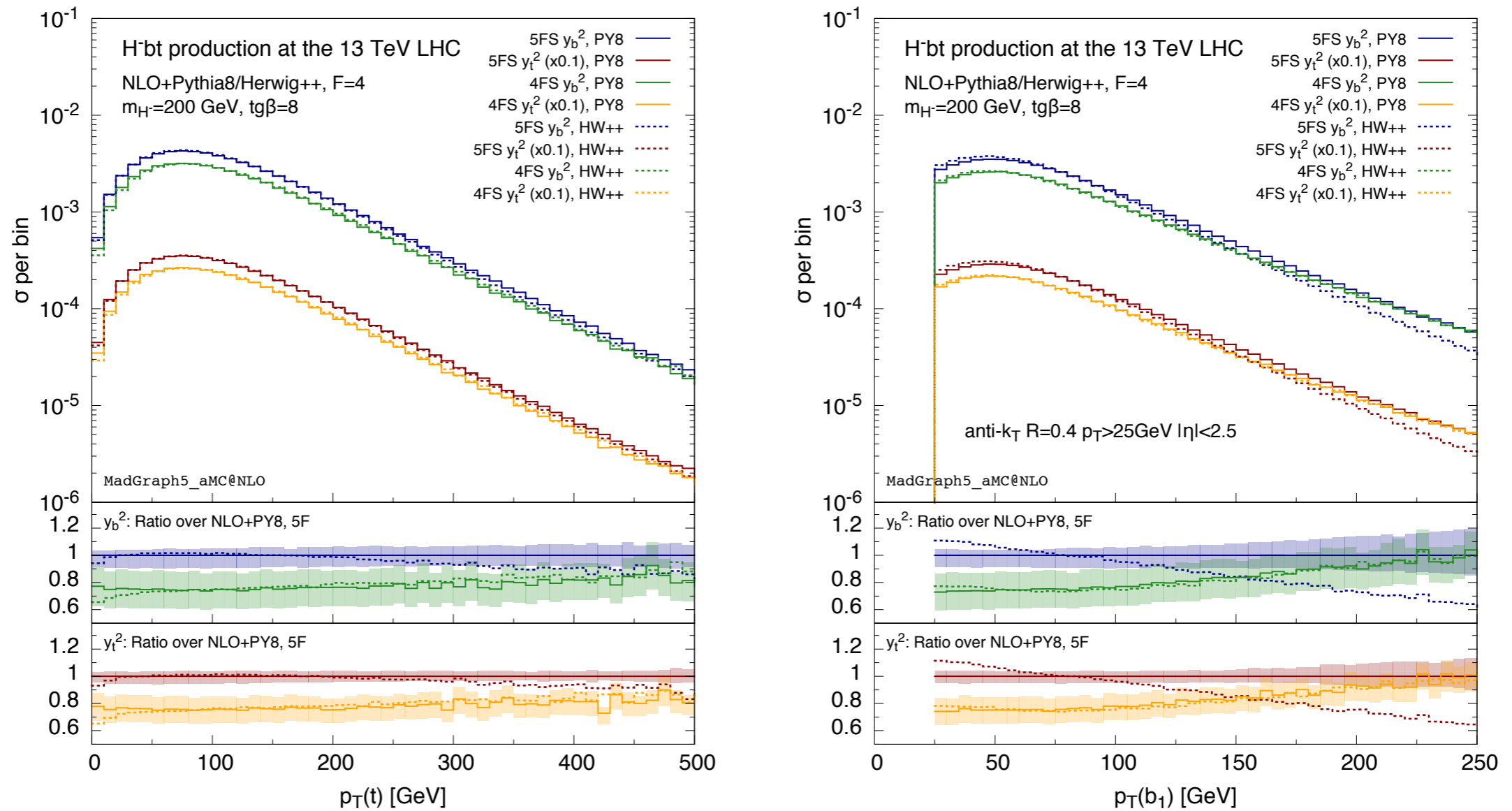
- Larger K-factors in 5FS for b-jets
- Still, remarkable agreement between 5FS, 4FS

# 5FS and 4FS comparison: NLO effects



- A heavier Higgs seems to stabilise jet K-factors
- Smaller phase-space for radiation, shower approx. ~OK

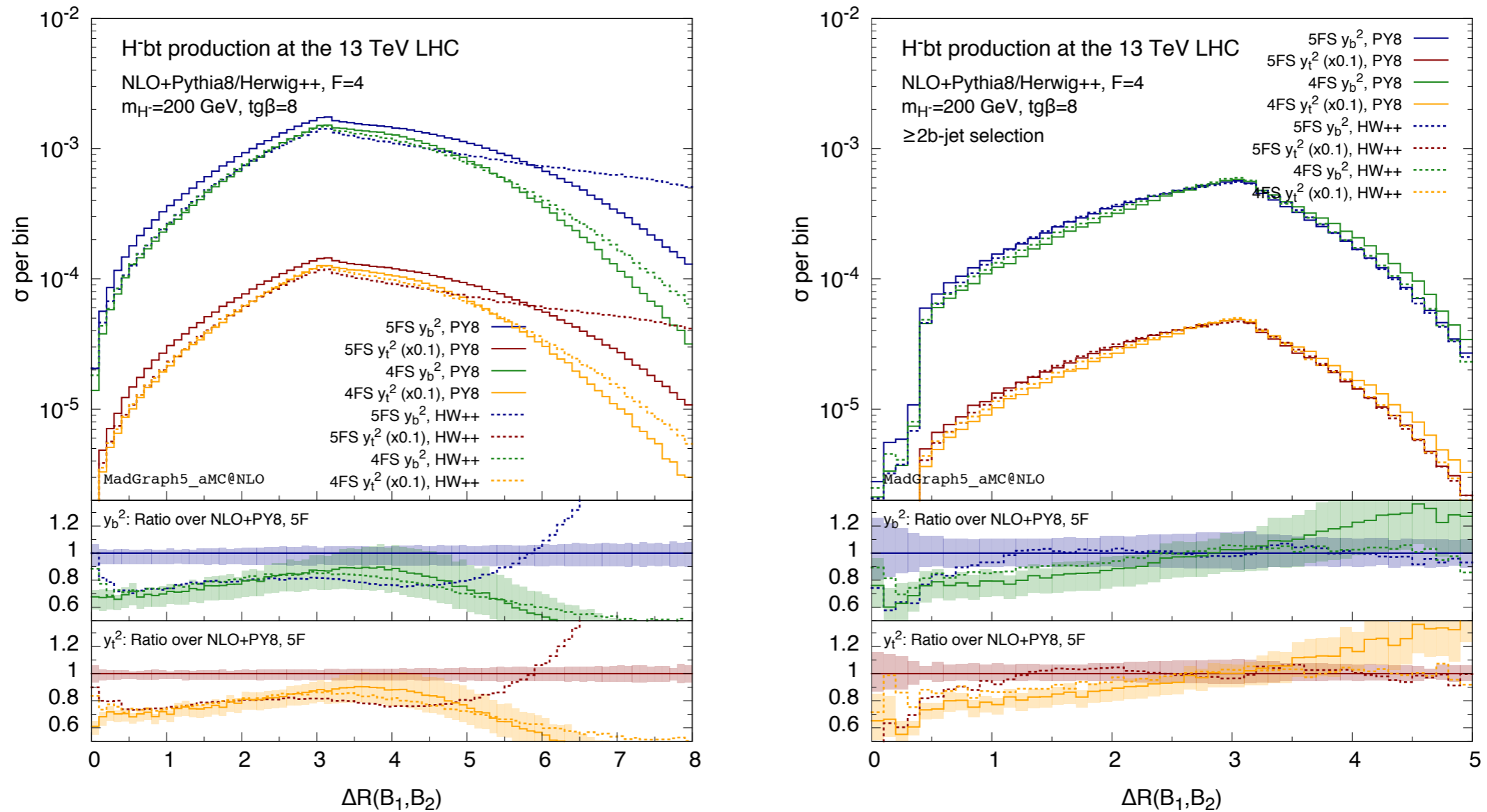
# MC comparison



- 4FS stabilizes MC predictions
- Very different shapes in 5FS for HW++ and PY8

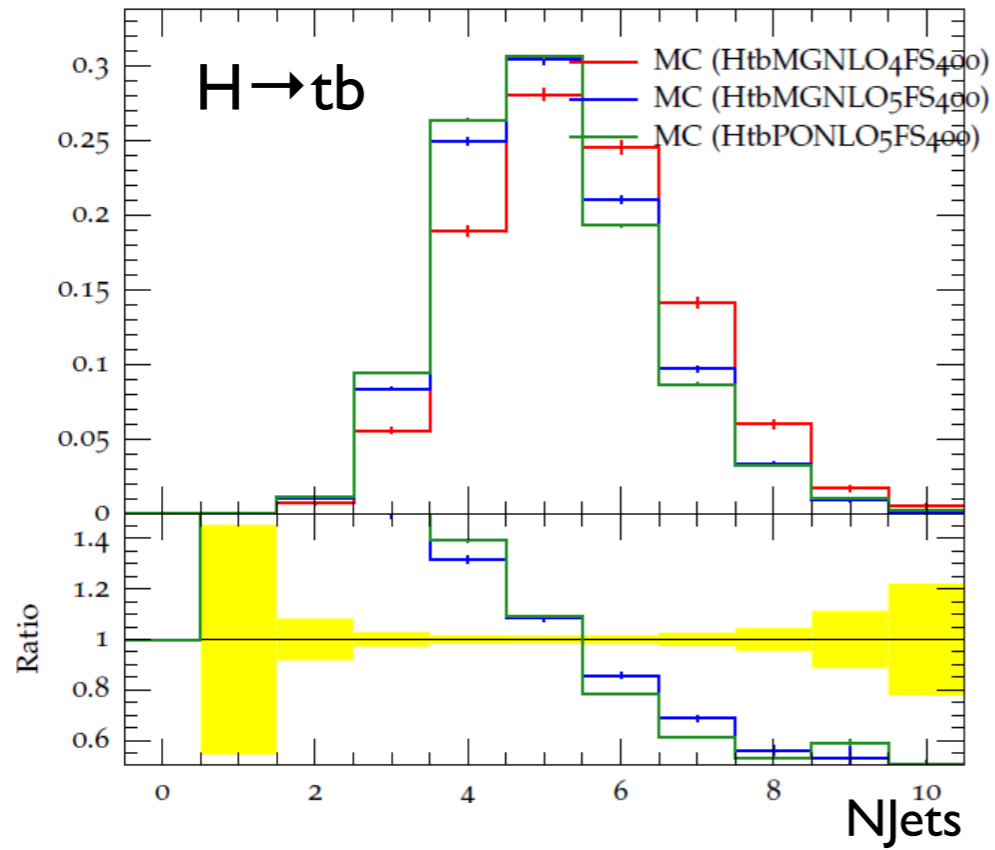


# MC comparison

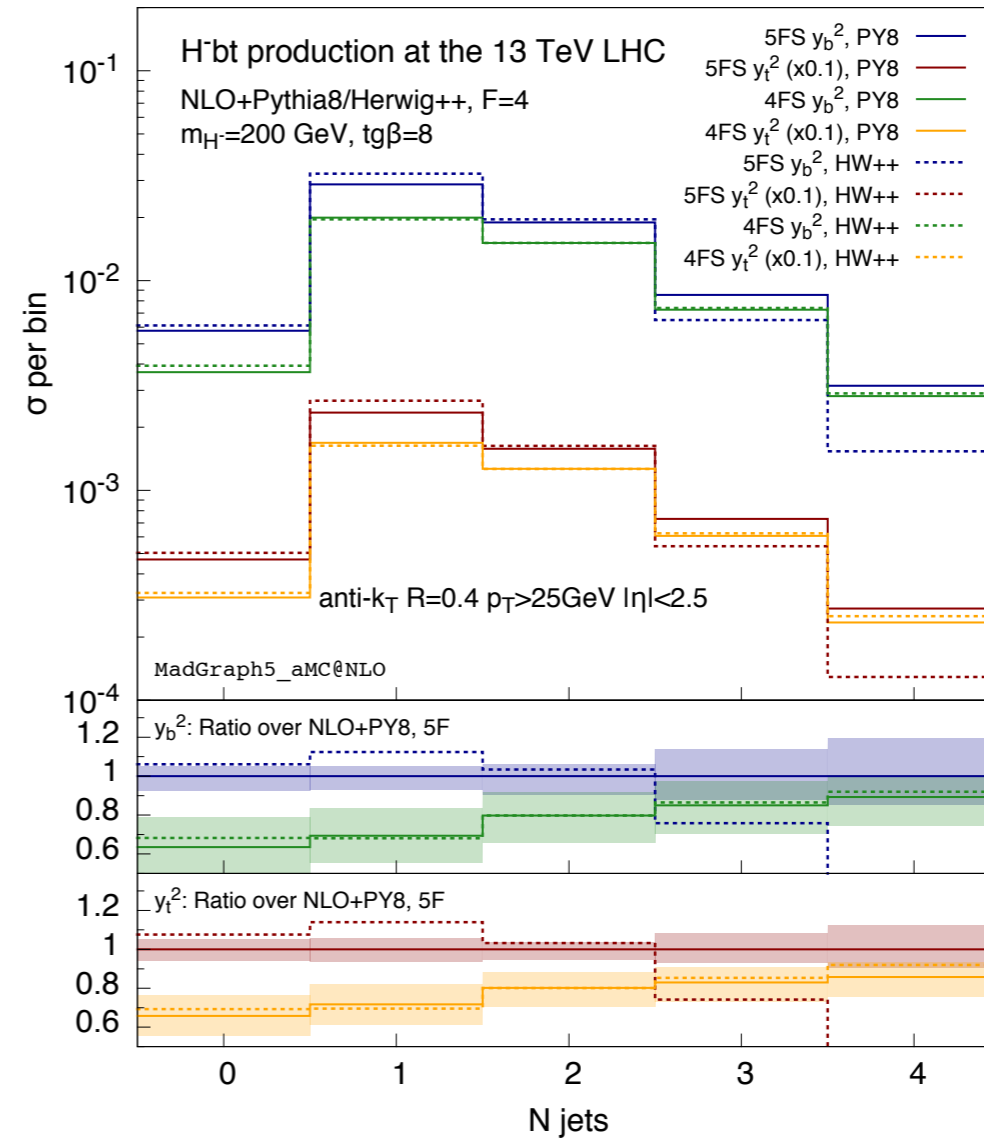


- HW++ produces many B's close to the beam line
- Effect mitigated when 2 b-jets are required; still some differences at large  $\Delta R$  in 4FS

# Past vs present



Plot by Liron Barak ~mid 2014



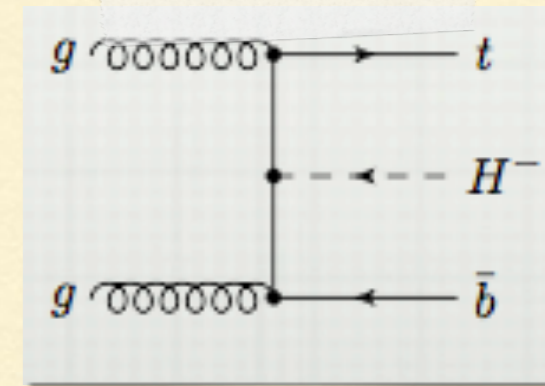
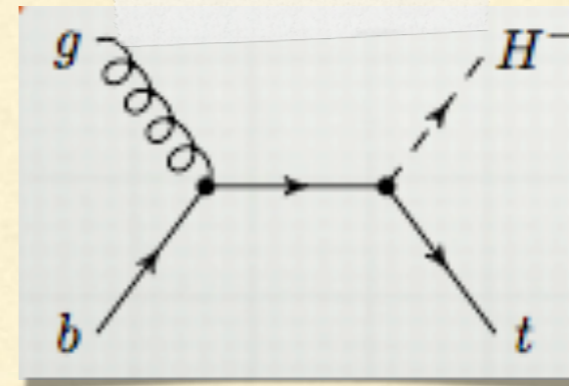
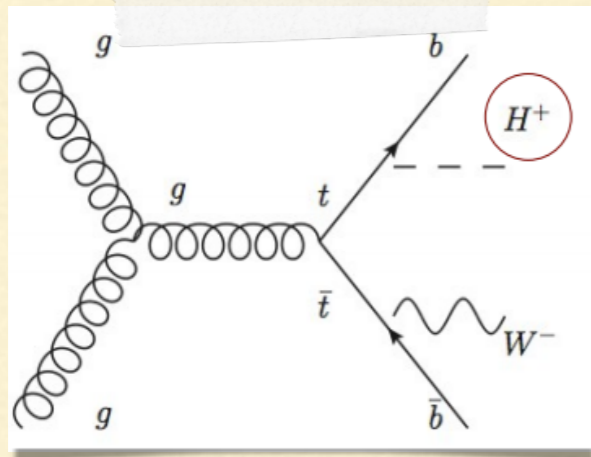
- Quite better agreement found (still, not really 🍏 to 🍏)

# Next: no man's land

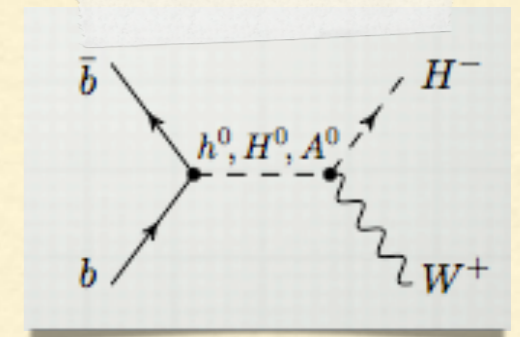
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## Next: no man's land

- No NLO prediction available (not even for total xsect) in the intermediate region
- The full  $pp \rightarrow WbHb$  computation is needed
- Technical difficulties:
  - High multiplicity process
  - Non trivial phase space (waiting for new PS parameterization at NLO to account for radiation off resonances)
  - $y_b y_t$  term might be non-negligible here

# Conclusions & Outlook

- Predictions for heavy charged Higgs have been presented for the first time at NLO+PS in the 4FS
- Scale tuning gives better agreement between 5 and 4FS
- 4FS gives better description of differential distributions, in particular related to b-kinematics
- 4FS reduces systematics due to MCs
- Gearing up for the intermediate region...