Accurate predictions for tH signal at LHC

Federico Demartin
UCLouvain (CP3)

In collaboration with
F. Maltoni, K. Mawatari, M. Zaro

26.01.2015

So far

Experimental searches

ATLAS (in progress)
CMS coll. CMS-PAS-HIG-14-015

Limits on tH cross section (optimized for $-y_t$)

Pheno studies at the LHC

Maltoni, *Paul*, *Stelzer*, *Willenbrock* [arXiv:hep-ph/0106293] (LO, sig+bkg)
Biswas, *Gabrielli*, *Mele* [arXiv:1211.0499] (LO, $H \to \gamma\gamma$ sig+bkg)
Farina, *Grojean*, *Maltoni*, *Salvioni*, *Thamm* [arXiv:1211.3736]
(NLO xsect 5F, LO distr, $H \to b\bar{b}$ sig+bkg, $\pm y_t$)
Ellis, *Hwang*, *Sakurai*, *Takeuchi* [arXiv:1312.5736] (LO, sign/phase of y_t)
Chang, *Cheung*, *Lee*, *Lu* [arXiv:1403.2053]
(LO distr, $H \to b\bar{b}, \gamma\gamma, 4\ell, \tau^+\tau^-$ sig+bkg, detector simulation, $\pm y_t$)

Aims of our work: outline

(1) Provide recommendations for tH cross section at NLO-QCD

Compare & combine flavour schemes (4F vs 5F)

Uncertainties: scale, PDF, $\alpha_s(m_Z)$, m_b

(2) Study distributions at NLO-QCD + parton shower

MG5_aMC@NLO + Pythia8 with 4F and 5F

Dependence on $\mu_{R,F}$ and scale of the shower

(3) Possibility to study sign/phase of y_t

Setup

Madgraph5_aMC@NLO

NLO-QCD predictions + parton shower (PY6, PY8, HW6, HW++)

Maltoni, *Zaro et al*. [arXiv:1405.0301]
https://launchpad.net/mg5amcnlo

HC_NLO_X0 (FeynRules UFO model)

All SM single-Higgs interaction at NLO-QCD (and BSM up to dim-6)
Accurate & precise characterisation of H couplings and properties

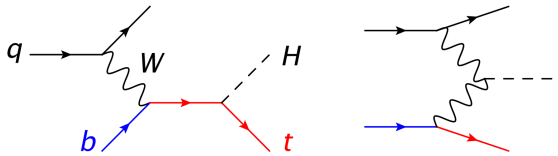
FD, *Maltoni*, *Mawatari*, *Zaro et al*. [arXiv:1306.6464, 1311.1829, 1407.5089]
https://feynrules.irmp.ucl.ac.be/wiki/HiggsCharacterisation

$$\mathcal{L}_0^t = -\frac{m_t}{v}\,\bar{\psi}_t\left(\cos\alpha\,\kappa_{Htt} + i\sin\alpha\,\kappa_{Att}\,\gamma_5\right)\psi_t\,X_0$$

(y_t is on-shell)

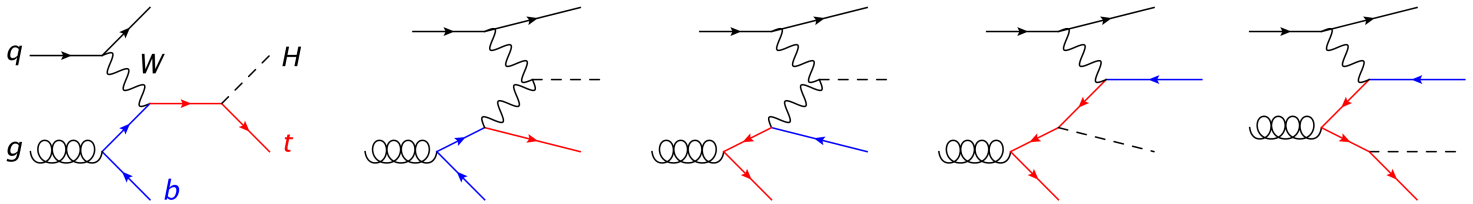
Definitions of tH (a multiscale process)

5F ($2 \to 3$ at LO)



all large logs $\ln(m_b/Q)$ resummed in the b's PDF

4F ($2 \to 4$ at LO)

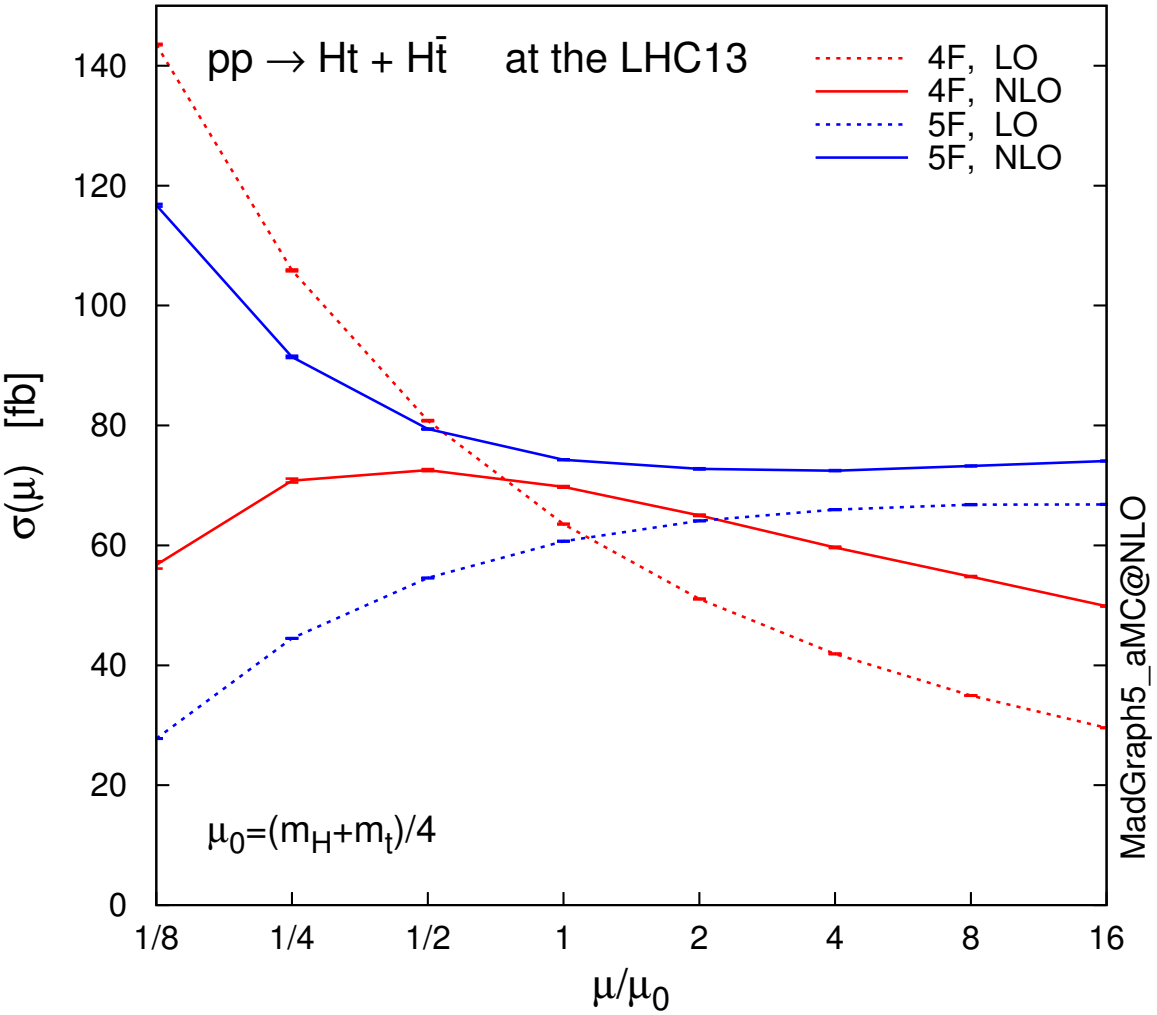


correct kinematics of all b's

They differ in the missing higher-order contributions ($\Rightarrow$ go to NLO)

see also *Maltoni*, *Ridolfi*, *Ubiali* [arXiv:1203.6393]

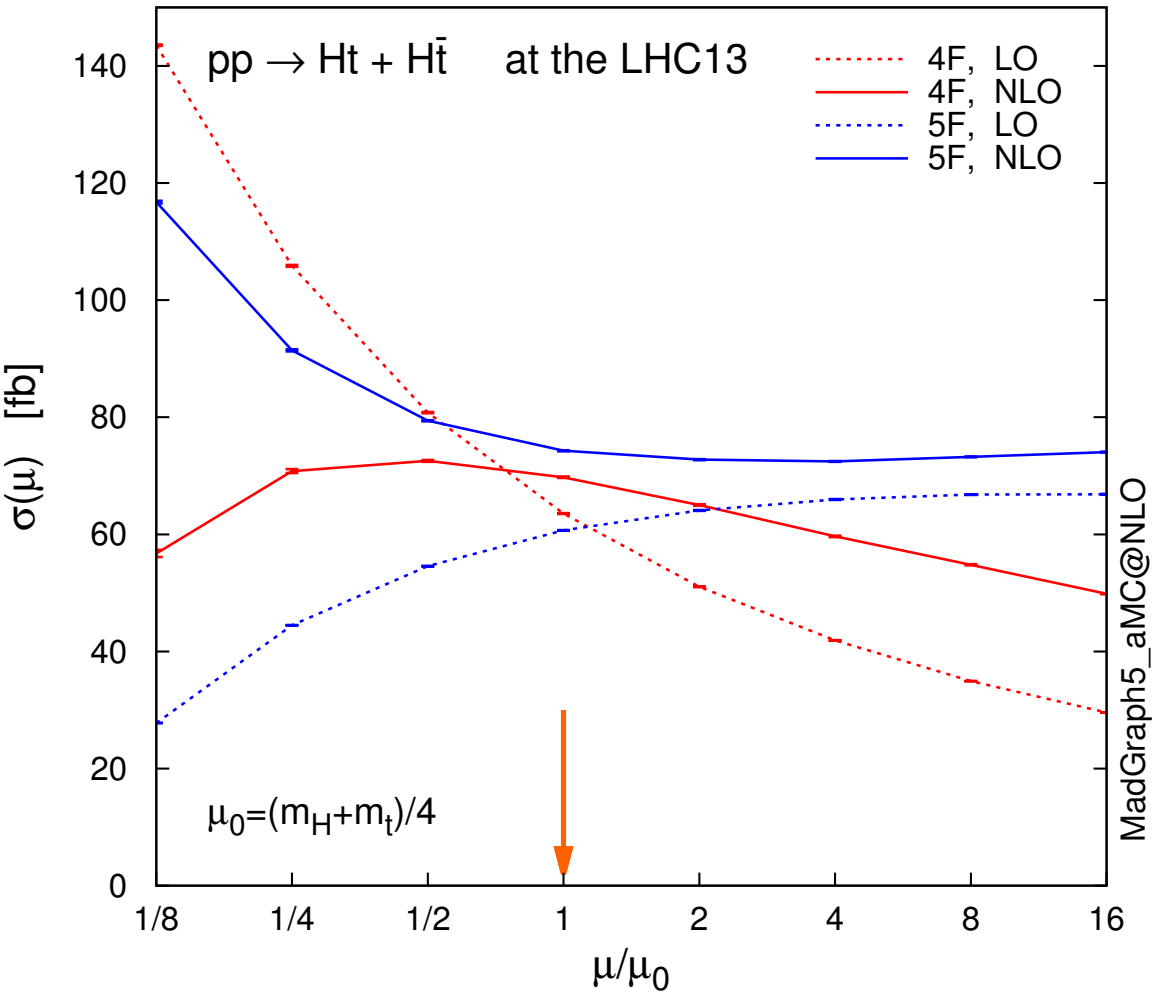
Cross-section:
flavour scheme and scale dependence



$$\mu_R = \mu_F \equiv \mu$$

FS and μ dependences are correlated

Cross-section:
flavour scheme and scale dependence



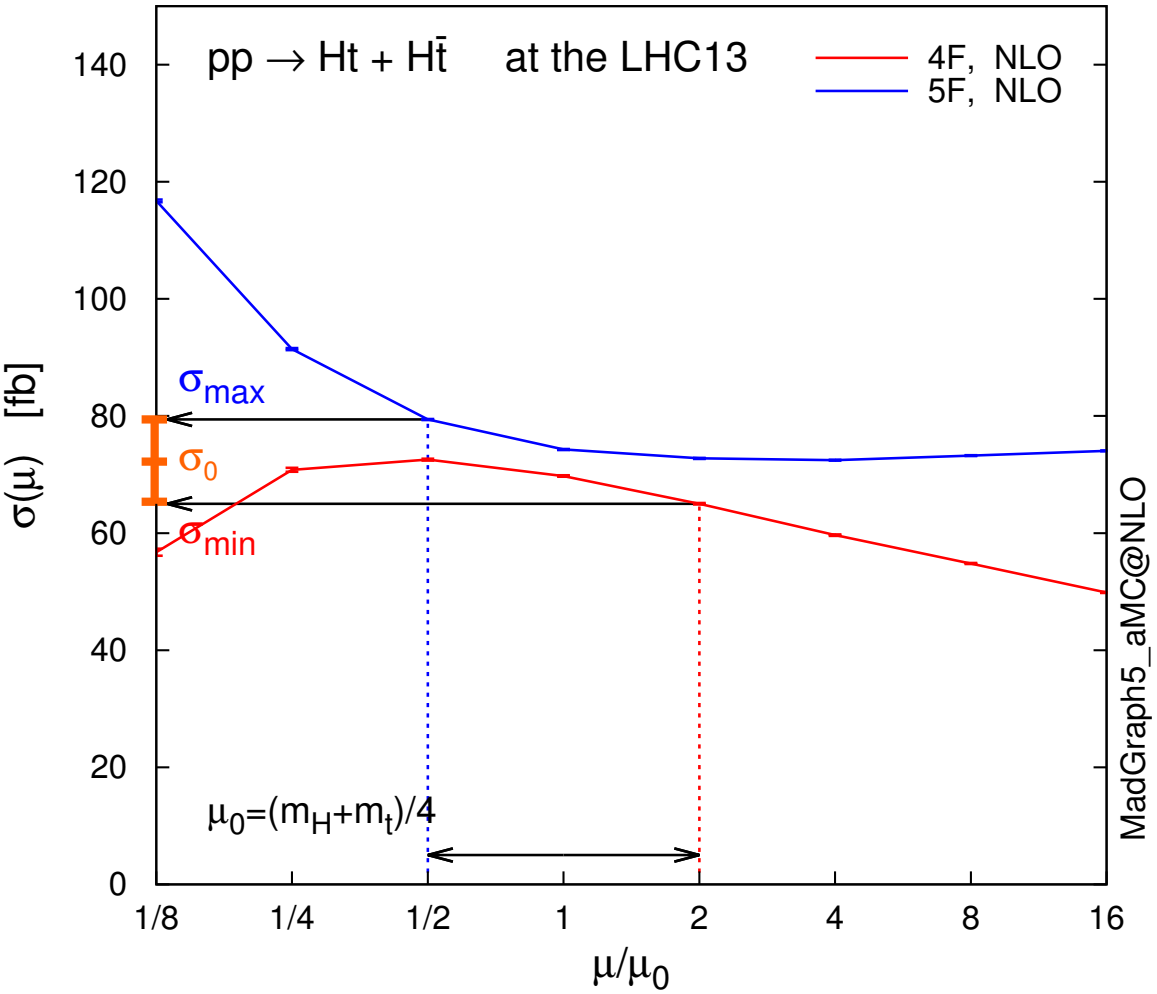
Choose reference μ that minimizes FS dependence

$g \to b\bar{b}$ splitting reduces the effective scale of the process from the "natural" choice $m_H + m_t$

NLO significantly reduces μ dependence

analogous to single-top *Campbell*, *Frederix*, *Maltoni*, *Tramontano* [arXiv:0903.0005]

Cross-section:
flavour scheme (FS) and scale μ dependence



Vary μ by 2 and take the envelope:

$$\sigma_0 = (\sigma_{\max} + \sigma_{\min})/2$$

$$\delta_{FS+\mu} = (\sigma_{\max} - \sigma_{\min})/2$$

$$\sigma_{NLO} = \sigma_0 \pm \delta_{FS+\mu}$$

Cross-section:
PDF, $\alpha_s(m_Z)$ and m_b uncertainty

Global PDF fits via LHAPDF: `NNPDF2.3`, `MSTW2008`, `CT10`

each group provides error sets to compute δ_{PDF} (data fit uncertainty)

Reference value for the strong coupling: $\alpha_s(m_Z) = 0.1190 \pm 0.0012$

Uncertainty as recommended by PDF4LHC

Encompasses preferred α_s values of each group and PDG global average

Reference value for bottom mass (pole): $m_b = 4.75 \pm 0.25$ GeV

4F: enters the hard scattering amplitude and the phase space

5F: defines threshold for $g \to b\bar{b}$ splitting in the PDFs

---

$\alpha_s^{\rm CT} = 0.1180$, $\alpha_s^{\rm NNPDF} = 0.1191$, $\alpha_s^{\rm MSTW} = 0.1202$, $\alpha_s^{\rm PDG2014} = 0.1185$

Martin et al. [arXiv:0905.3531], *Lai et al*. [arXiv:1004.4624], *Lionetti et al*.[arXiv:1103.2369] , *PDF4LHC* [arXiv:1101.0536, 1101.0538] , *Martin et al*. [arXiv:1007.2624], *Ball et al*. [arXiv:1101.1300]

Cross-section:
PDF, $\alpha_s(m_Z)$ and m_b uncertainty

Tiny correlations between the fractional uncertainties
$\Rightarrow$ can be neglected

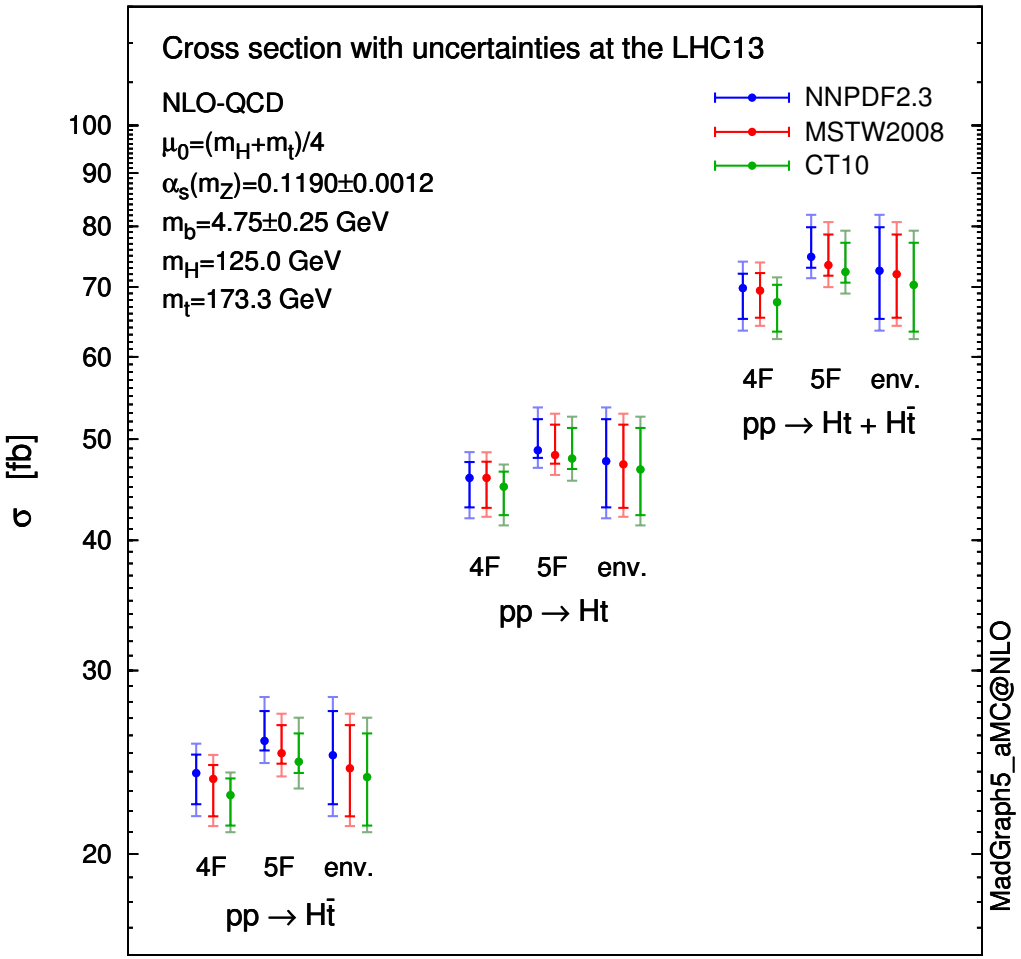
$$\delta^{\pm}_{PDF+\alpha_s+m_b} = \sqrt{(\delta^{\pm}_{PDF})^2 + (\delta^{\pm}_{\alpha_s})^2 + (\delta^{\pm}_{m_b})^2}$$

Compute reference XS values with common m_b and α_s
(when possible).

Then add fractional uncertainties computed
using each group's dedicated PDF set
(when available).

Checked explicitly for PDF+α_s; see also *Martin et al.* [arXiv:1007.2624] and joint PDF study *Ball et al.* [arXiv:1211.5142]

Cross-section: total uncertainty



scheme	$\sigma_{\rm NLO}$ [fb]	$\delta^{\%}_{\mu}$	$\delta^{\%}_{\rm PDF}$	$\delta^{\%}_{\alpha_s}$	$\delta^{\%}_{m_b}$
5F $Ht + H\bar{t}$	74.80(9)	$^{+6.8}_{-2.4}$	$^{+1.0}_{-1.0}$	$^{+1.5}_{-1.1}$	$^{+2.4}_{-1.9}$
4F $Ht + H\bar{t}$	69.81(11)	$^{+3.2}_{-6.6}$	$^{+0.9}_{-0.9}$	$^{+1.6}_{-1.7}$	$^{+2.1}_{-1.6}$

$$\delta_{\rm tot} = \delta^{\pm}_{FS+\mu} + \delta^{\pm}_{PDF+\alpha_s+m_b}$$

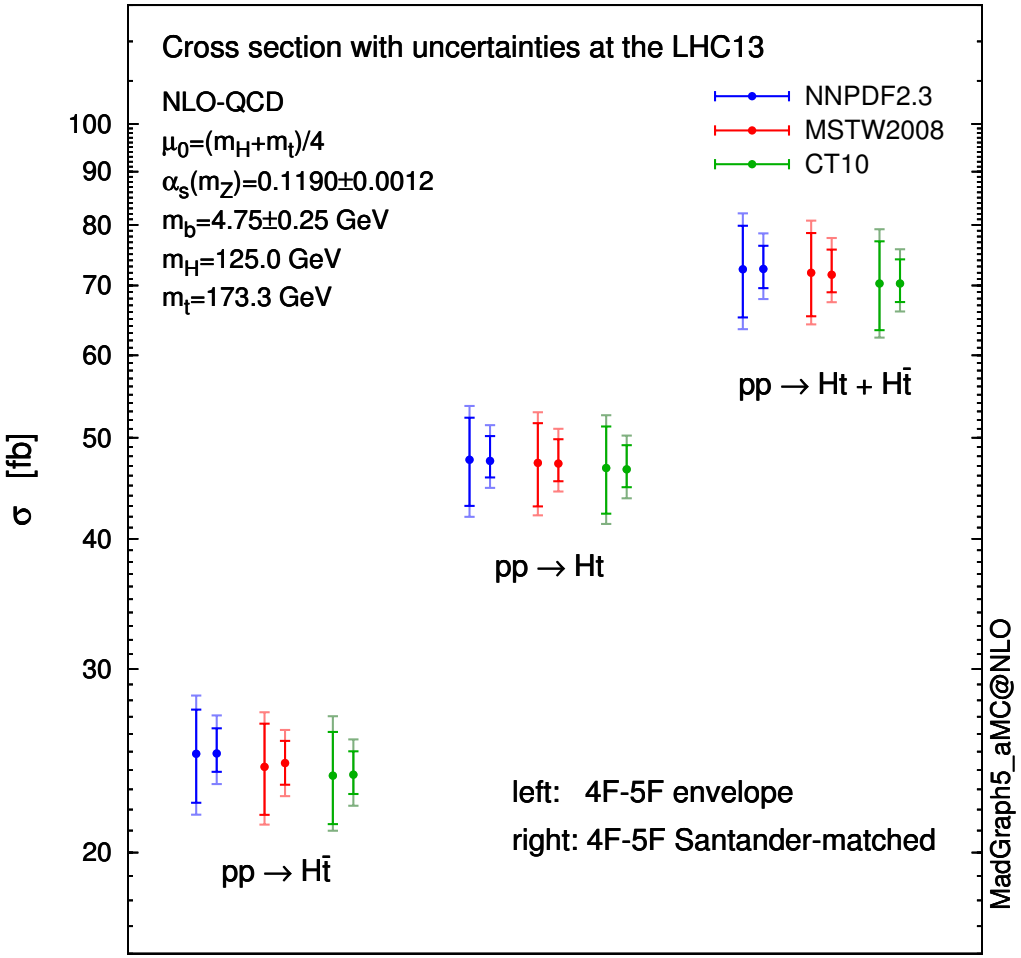
(inner + outer tics)

e.g: NNPDF results

$$\Rightarrow \quad \sigma_{\rm NLO} = 72.54 \text{ pb } \pm 10.1\% \; ^{+3.0\%}_{-2.5\%}$$

Cross-section: total uncertainty

Comparison of envelope vs "Santander" matching



$$\sigma_{\text{matched}} = \frac{\sigma_{4F} + w\sigma_{5F}}{1+w}$$

$$\delta^{\pm}_{\text{matched}} = \frac{\delta^{\pm}_{4F} + w\delta^{\pm}_{5F}}{1+w}$$

$$w = \ln\left(\frac{m_H}{m_b}\right) - 2 \simeq 1,27$$

Let's discuss this!

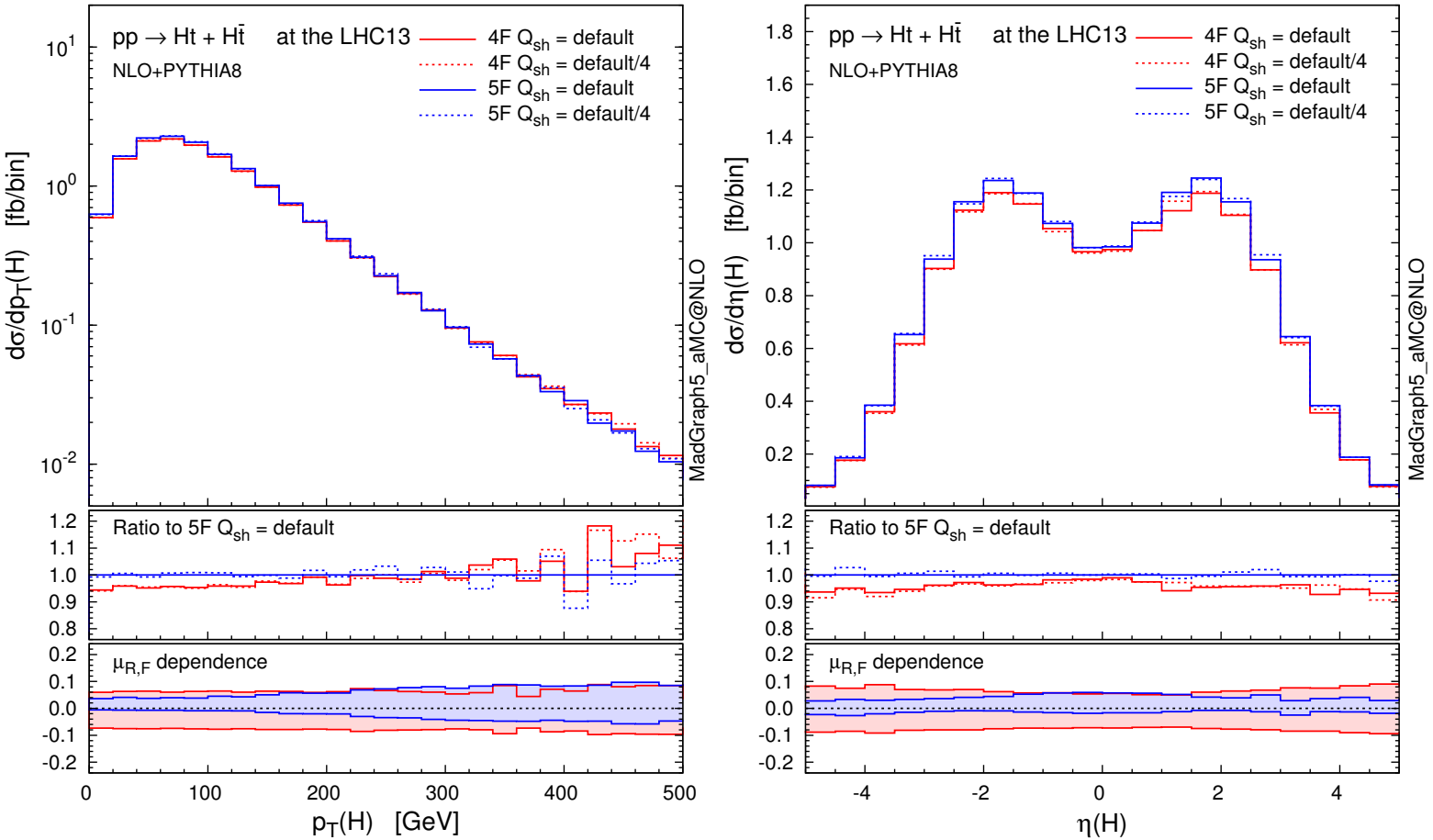
Harlander, *Kramer*, *Schumacher* [arXiv:1112.3478]

Yukawa of the bottom is completely negligible!

	4F $\sigma_{\rm NLO}$ [fb]	5F $\sigma_{\rm NLO}$ [fb]
y_b off	69.92(15)	74.65(9)
y_b on	69.76(15)	74.53(8)

Less than integration accuracy (0.1-0.2%).

Distributions: Higgs (no decay)

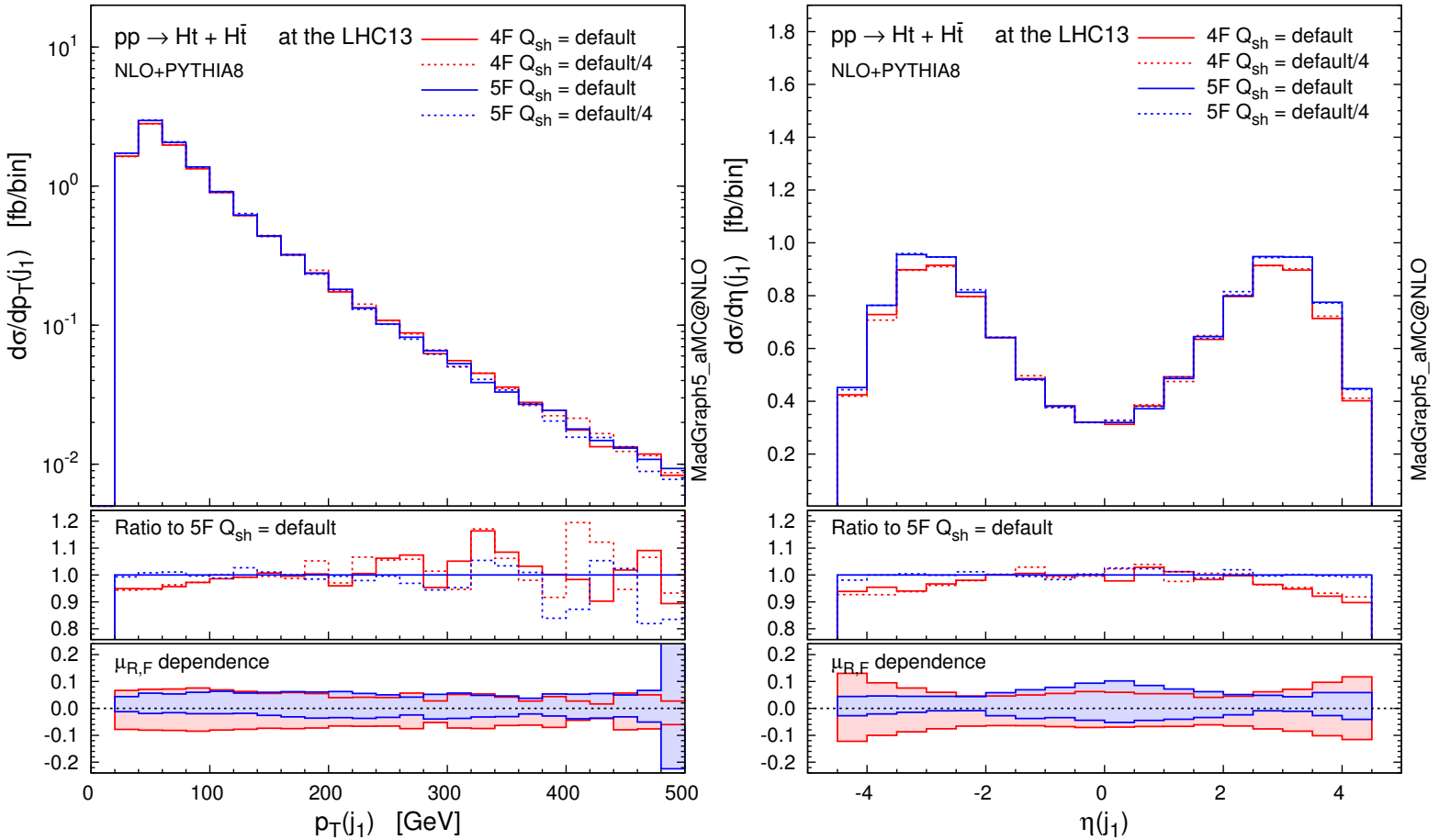


Reasonable agreement for 4F/5F shapes within scale uncertainty

Same for the top quark

Shower scale dependence is very small

Distributions: light jet

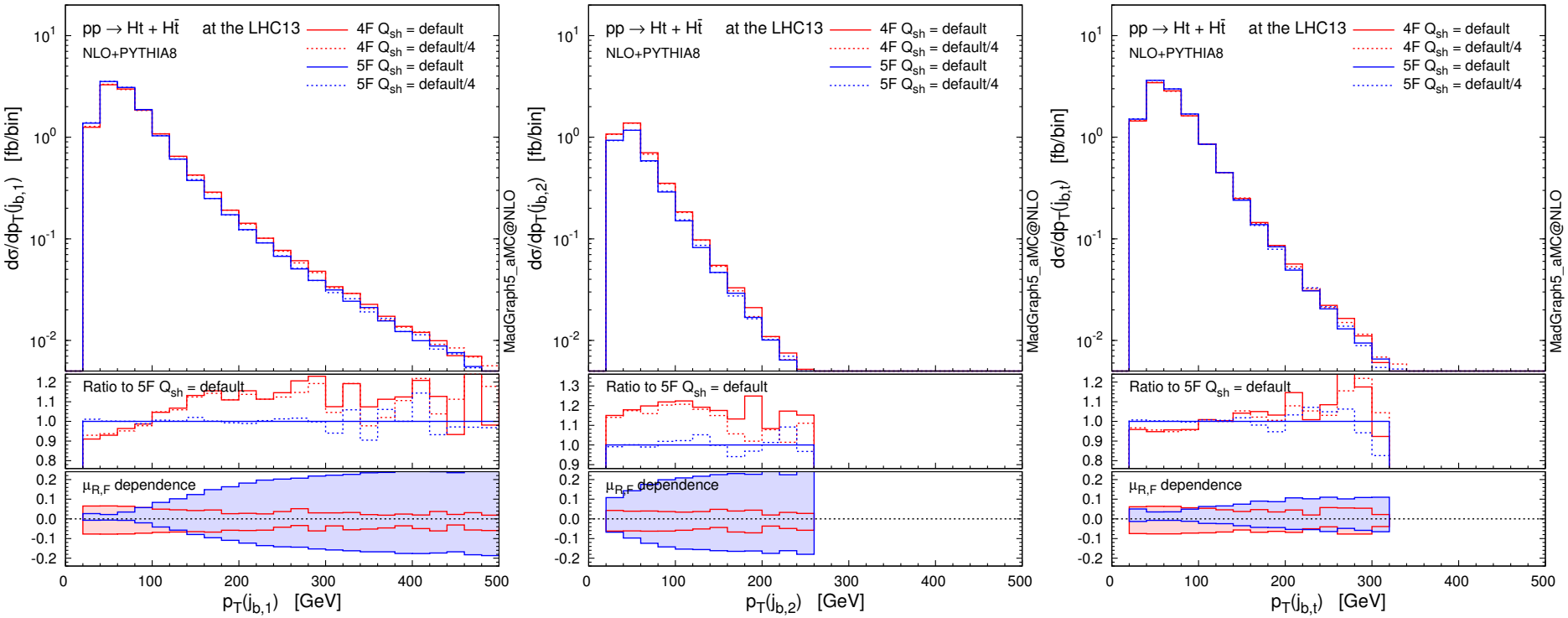


anti-k_T $p_T > 30$ GeV $R = 0.4$ $|\eta| < 4.5$

Highest-p_T light jet is forward (similar to VBF)

Again reasonable agreement between 4F and 5F

Distributions: b-jets



anti-k_T $p_T > 30$ GeV $R = 0.4$ $|\eta| < 2.5$ no H decay, $t \to b\ell^+\nu_\ell$

Significant discrepancy between 4F and 5F, especially for 2nd b-jet

5F has large scale dependence

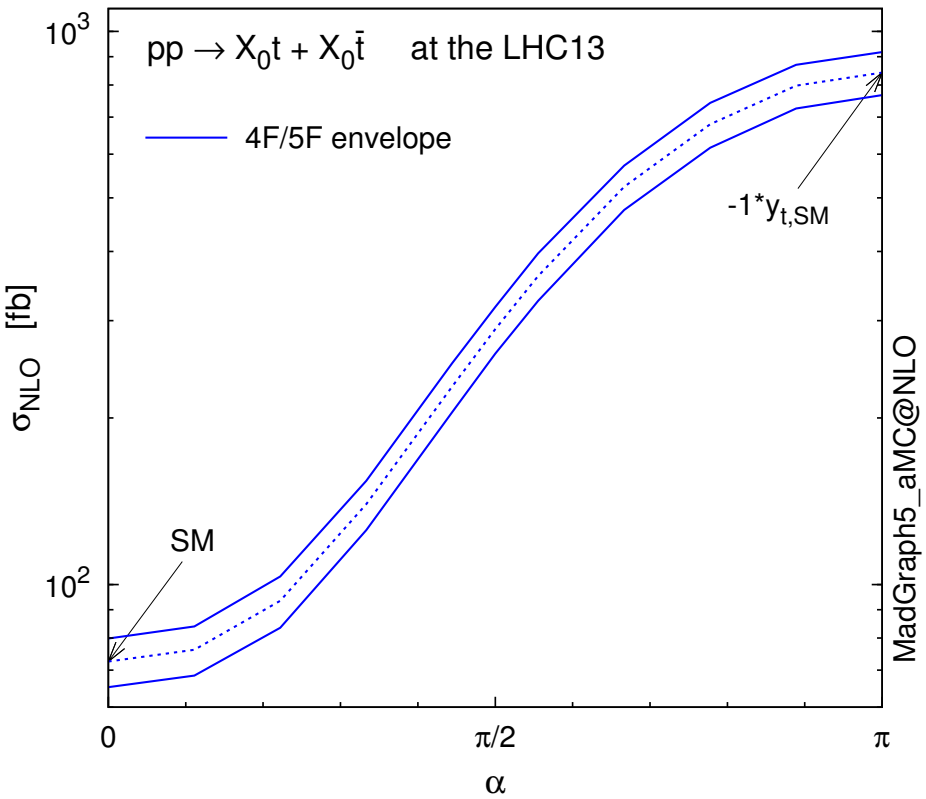
1st b-jet comes from top at low-p_T, frm hard scattering at high-p_T

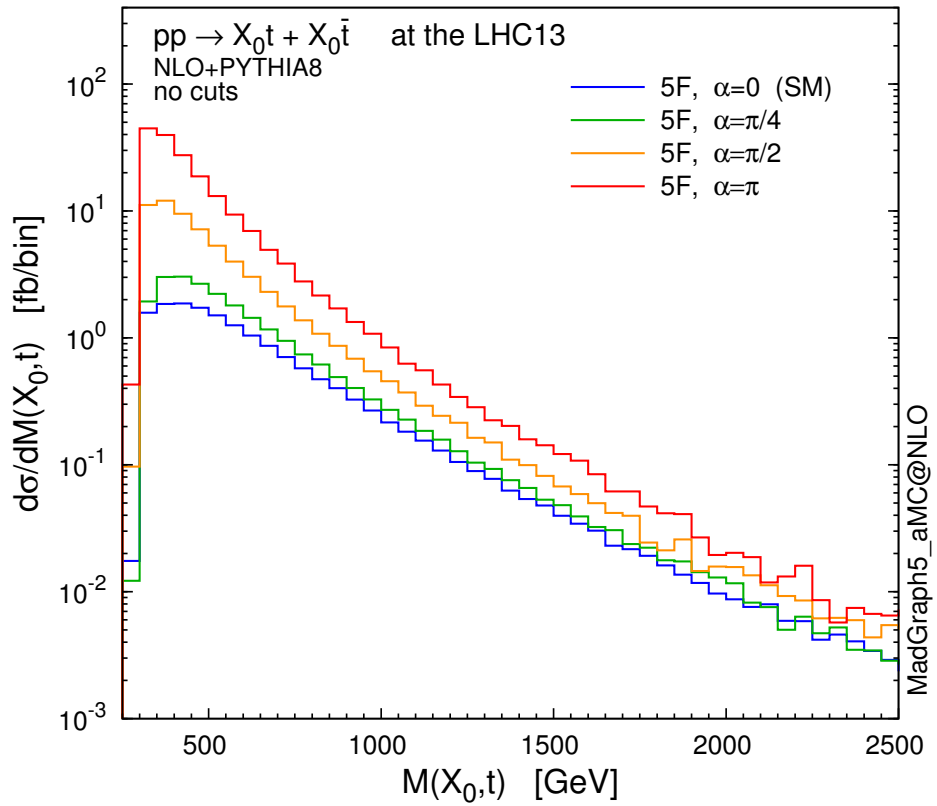
Yukawa of the top

$$\mathcal{L}_0^t = -\frac{m_t}{v}\,\bar{\psi}_t\left(\cos\alpha\,\kappa_{Htt} + i\,\sin\alpha\,\kappa_{Att}\,\gamma_5\right)\psi_t\,X_0$$

$\kappa_{Att} = 2/3$ in order to keep SM σ_{GF}

SM coupling to W





Interpolation of cross section between $\pm y_{t,SM}$

Threshold enhancement for a complex phase (no unitarity violation)

Summary of the results

0) ALL RESULTS ARE PRELIMINARY
a paper will appear soon

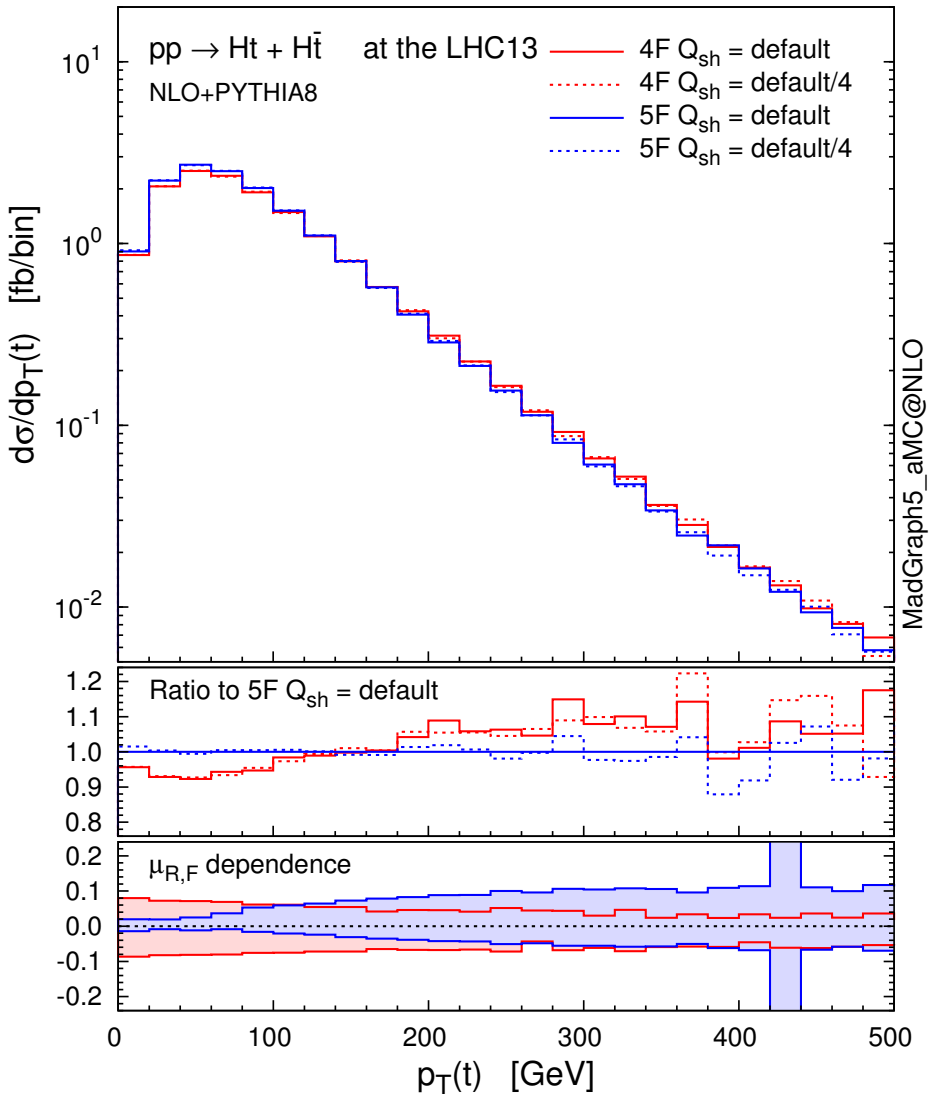
1) NLO-QCD cross section with uncertainties at 13 Tev, including 5F/4F combination: $\sigma_{NLO} \sim 72$ pb $\pm 13\%$

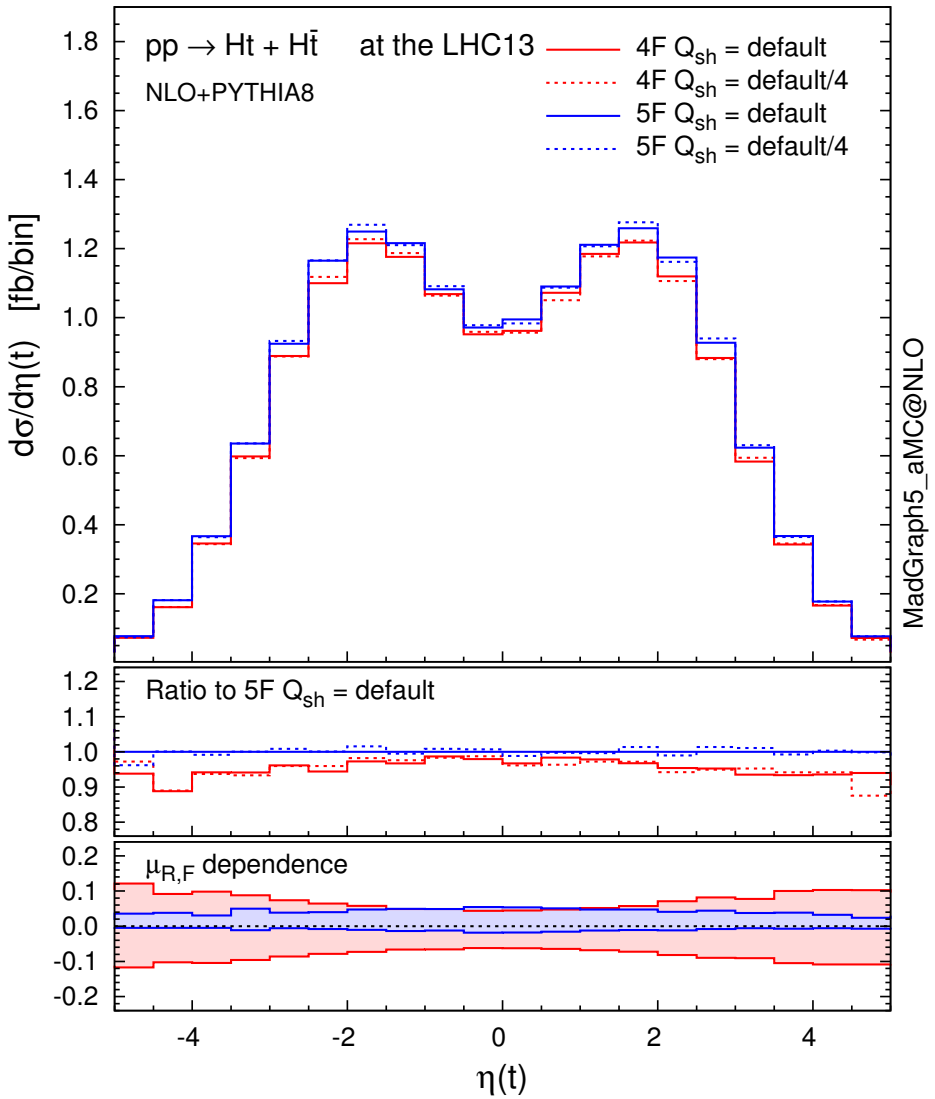
2) NLO+PS event generation in MG5_aMC, 4F and 5F.
Differential uncertainties show good agreement where expected;
4F possibly give better description of b-jets and extra radiation

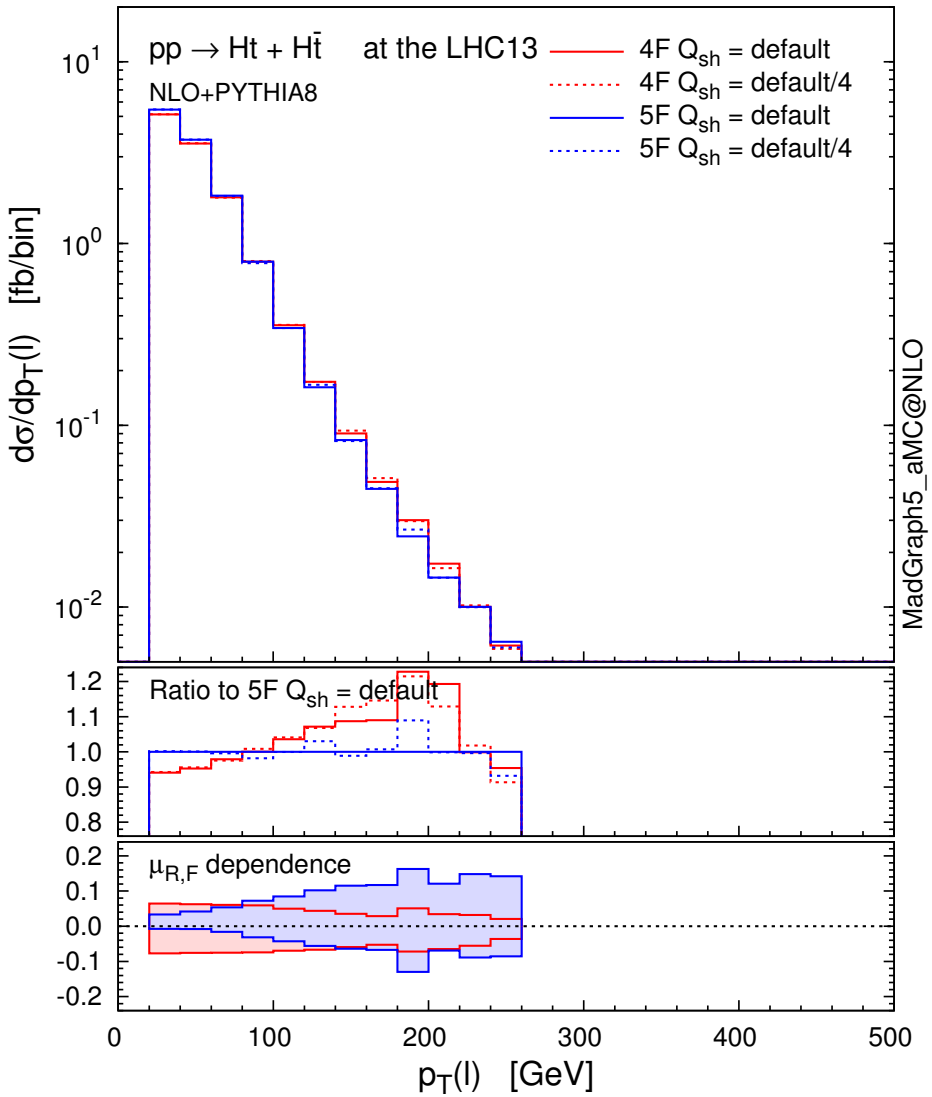
3) Possibility of changing the phase of the top Yukawa to study Higgs' properties

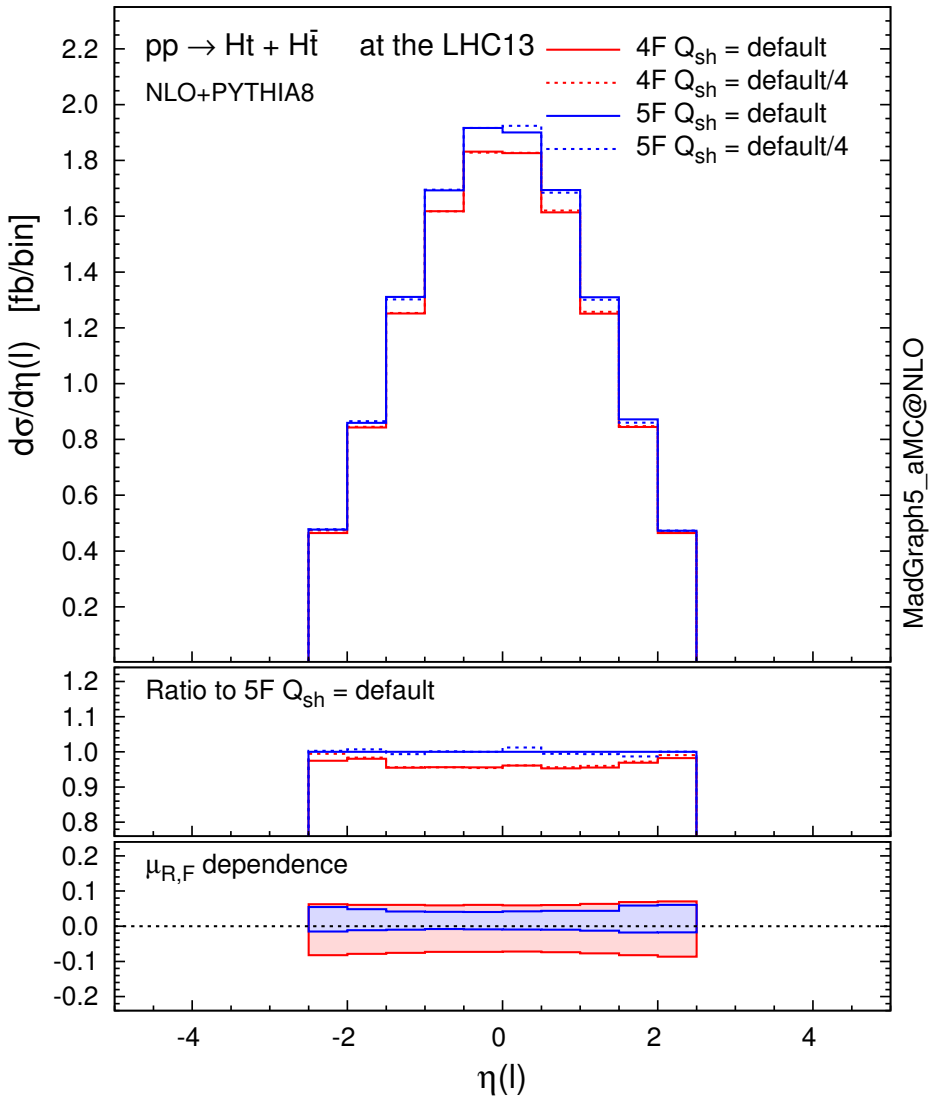
Thanks for your attention!

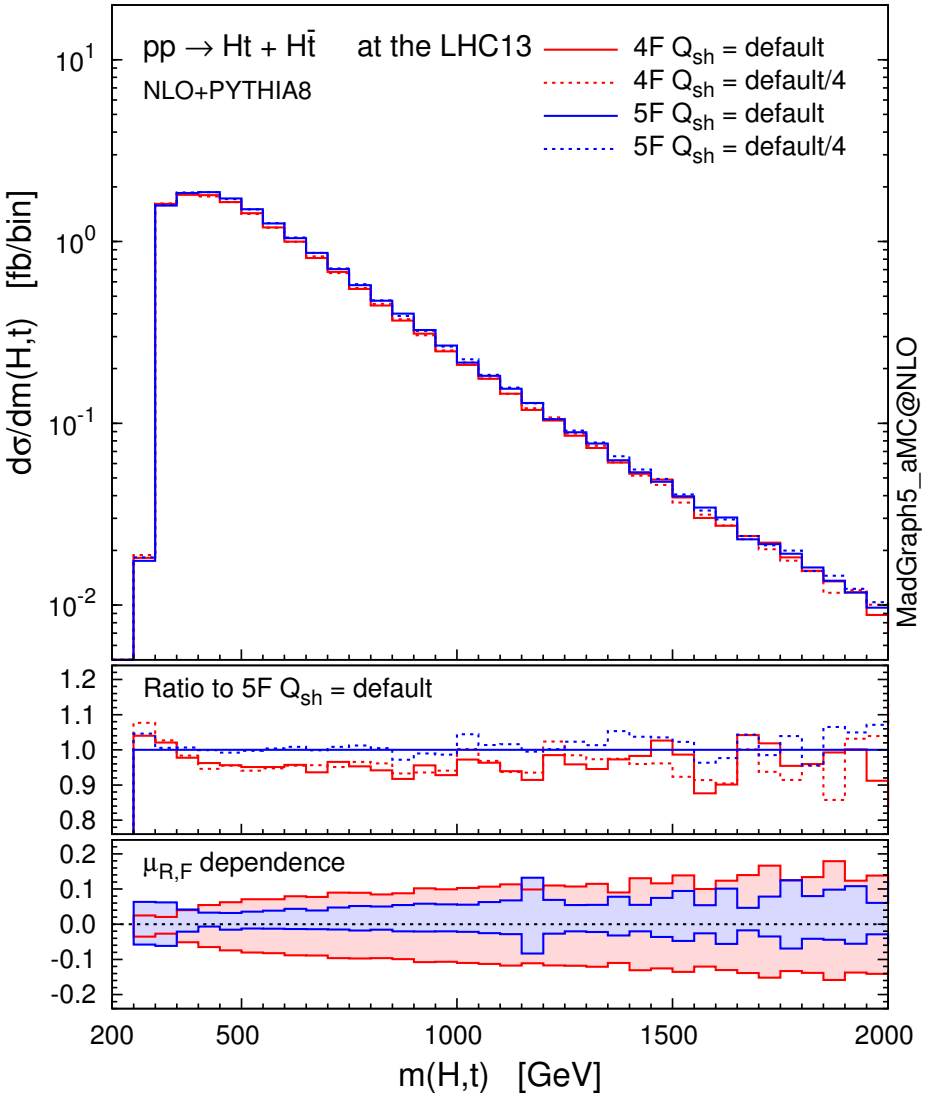
backup slides

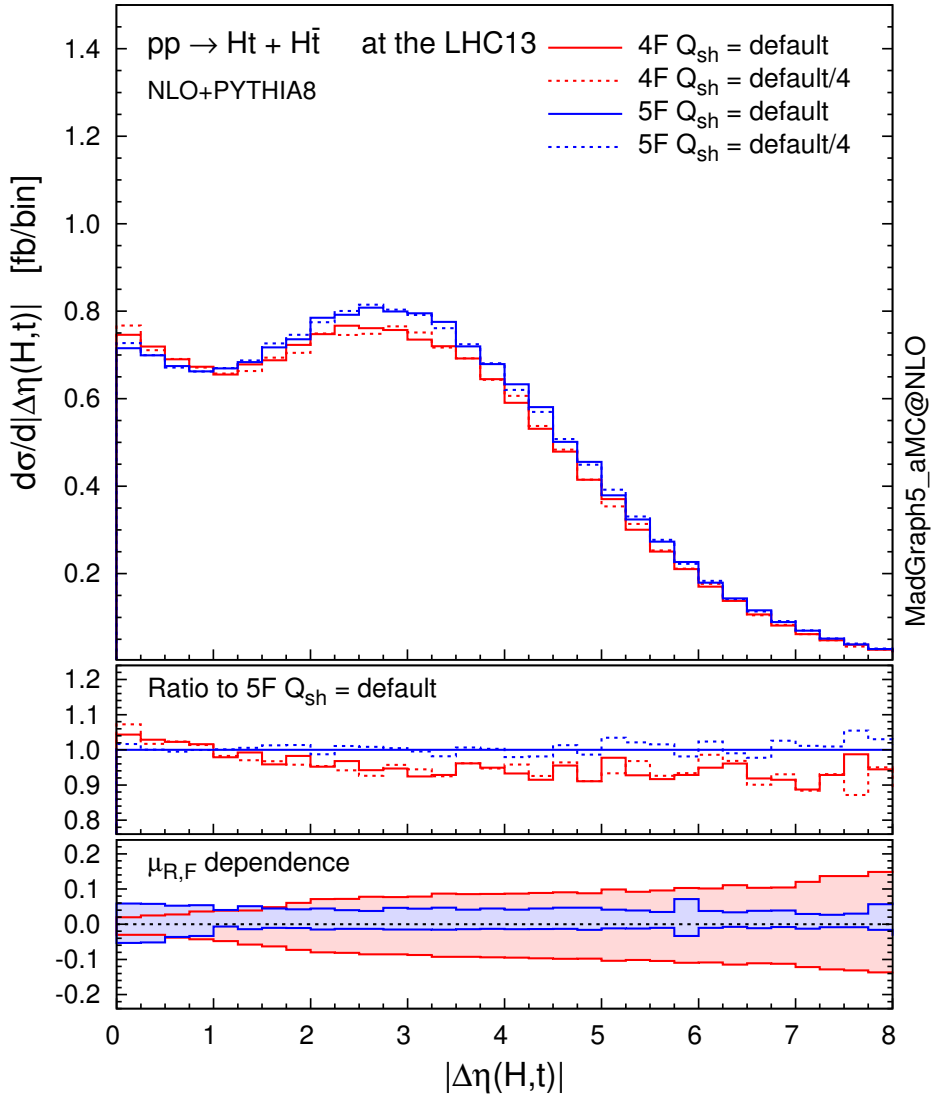

pp → Ht + Ht̄ at the LHC13
NLO+PYTHIA8
4F Q_sh = default
4F Q_sh = default/4
5F Q_sh = default
5F Q_sh = default/4
dσ/dp_T(t) [fb/bin]
MadGraph5_aMC@NLO
Ratio to 5F Q_sh = default
μ_R,F dependence
p_T(t) [GeV]

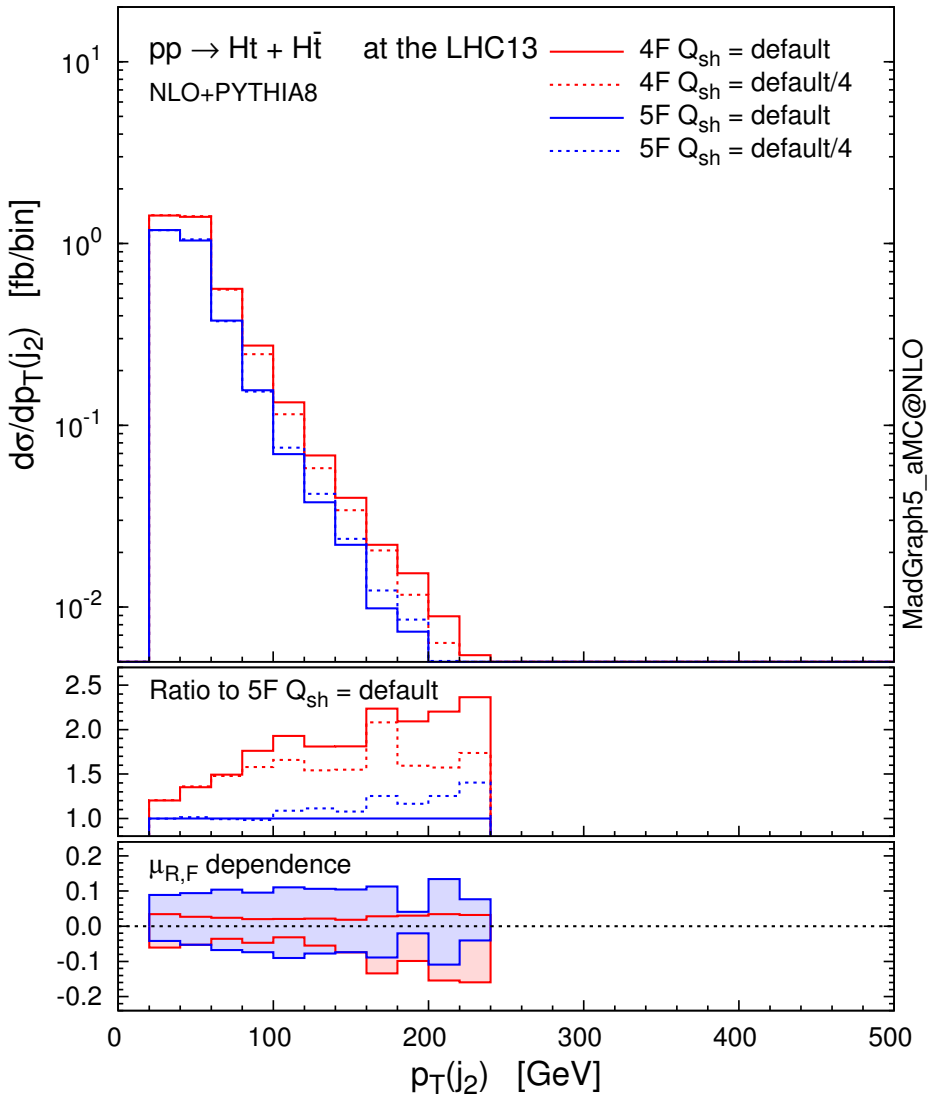

pp → Ht + Ht̄ at the LHC13
NLO+PYTHIA8
4F Q_sh = default
4F Q_sh = default/4
5F Q_sh = default
5F Q_sh = default/4
dσ/dη(t) [fb/bin]
MadGraph5_aMC@NLO
Ratio to 5F Q_sh = default
μ_R,F dependence
η(t)

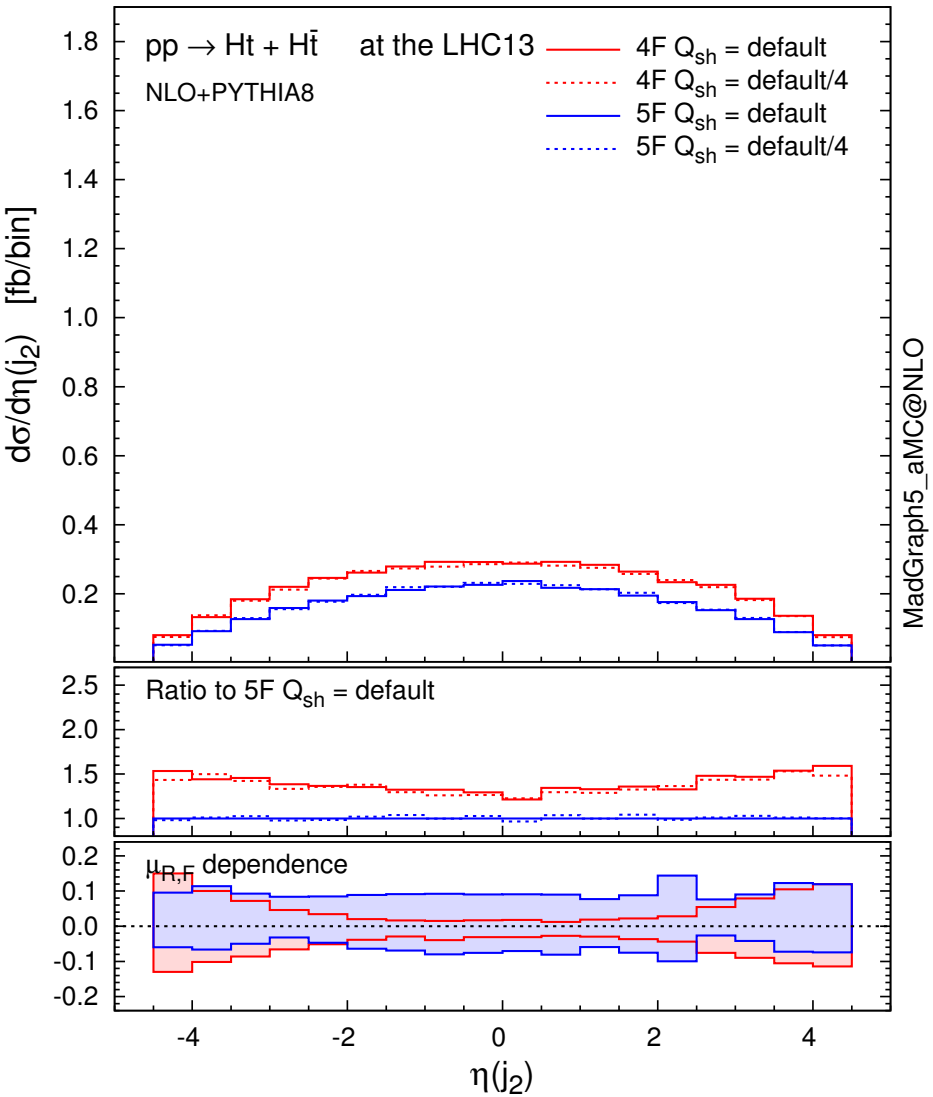

pp → Ht + Ht̄ at the LHC13
NLO+PYTHIA8
4F Q_sh = default
4F Q_sh = default/4
5F Q_sh = default
5F Q_sh = default/4
dσ/dp_T(l) [fb/bin]
MadGraph5_aMC@NLO
Ratio to 5F Q_sh = default
μ_R,F dependence
p_T(l) [GeV]

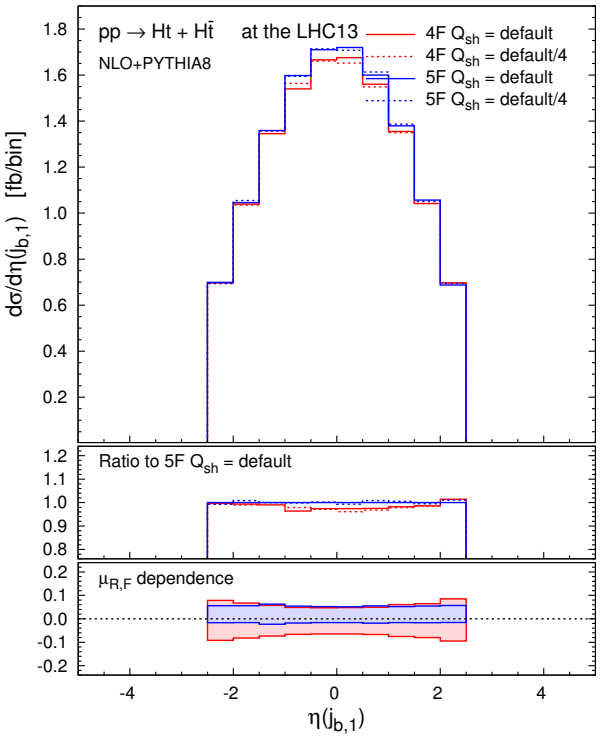

pp → Ht + Ht̄ at the LHC13
NLO+PYTHIA8
4F Q_sh = default
4F Q_sh = default/4
5F Q_sh = default
5F Q_sh = default/4
dσ/dη(l) [fb/bin]
MadGraph5_aMC@NLO
Ratio to 5F Q_sh = default
μ_R,F dependence
η(l)

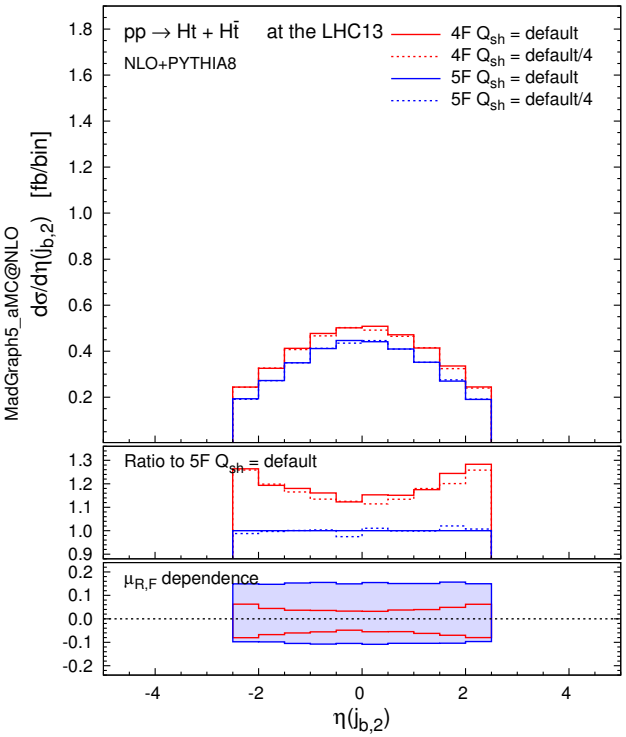

pp → Ht + Ht̄ at the LHC13
NLO+PYTHIA8
4F Q_sh = default
4F Q_sh = default/4
5F Q_sh = default
5F Q_sh = default/4
dσ/dm(H,t) [fb/bin]
MadGraph5_aMC@NLO
Ratio to 5F Q_sh = default
μ_R,F dependence
m(H,t) [GeV]

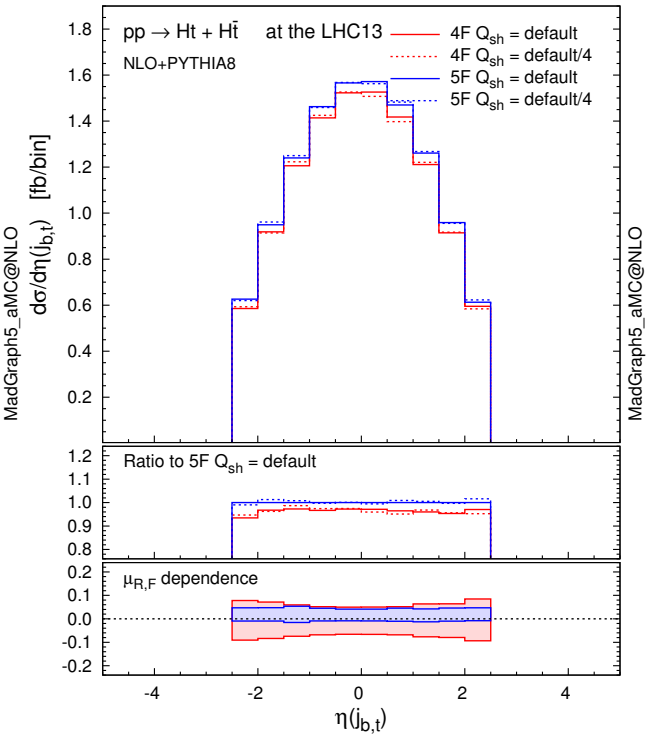

pp → Ht + Ht̄ at the LHC13
NLO+PYTHIA8
4F Q_sh = default
4F Q_sh = default/4
5F Q_sh = default
5F Q_sh = default/4
dσ/d|Δη(H,t)| [fb/bin]
MadGraph5_aMC@NLO
Ratio to 5F Q_sh = default
μ_R,F dependence
|Δη(H,t)|


pp → Ht + Ht̄ at the LHC13
NLO+PYTHIA8
4F Q_sh = default
4F Q_sh = default/4
5F Q_sh = default
5F Q_sh = default/4
dσ/dp_T(j_2) [fb/bin]
MadGraph5_aMC@NLO
Ratio to 5F Q_sh = default
μ_R,F dependence
p_T(j_2) [GeV]


pp → Ht + Ht̄ at the LHC13
NLO+PYTHIA8
4F Q_sh = default
4F Q_sh = default/4
5F Q_sh = default
5F Q_sh = default/4
dσ/dη(j_2) [fb/bin]
MadGraph5_aMC@NLO
Ratio to 5F Q_sh = default
μ_R,F dependence
η(j_2)


pp → Ht + Ht̄ at the LHC13
NLO+PYTHIA8
4F Q_sh = default
4F Q_sh = default/4
5F Q_sh = default
5F Q_sh = default/4
dσ/dη(j_b,1) [fb/bin]
MadGraph5_aMC@NLO
Ratio to 5F Q_sh = default
μ_R,F dependence
η(j_b,1)


pp → Ht + Ht̄ at the LHC13
NLO+PYTHIA8
4F Q_sh = default
4F Q_sh = default/4
5F Q_sh = default
5F Q_sh = default/4
dσ/dη(j_b,2) [fb/bin]
MadGraph5_aMC@NLO
Ratio to 5F Q_sh = default
μ_R,F dependence
η(j_b,2)


pp → Ht + Ht̄ at the LHC13
NLO+PYTHIA8
4F Q_sh = default
4F Q_sh = default/4
5F Q_sh = default
5F Q_sh = default/4
dσ/dη(j_b,t) [fb/bin]
MadGraph5_aMC@NLO
Ratio to 5F Q_sh = default
μ_R,F dependence
η(j_b,t)