Automated BSM at NLO

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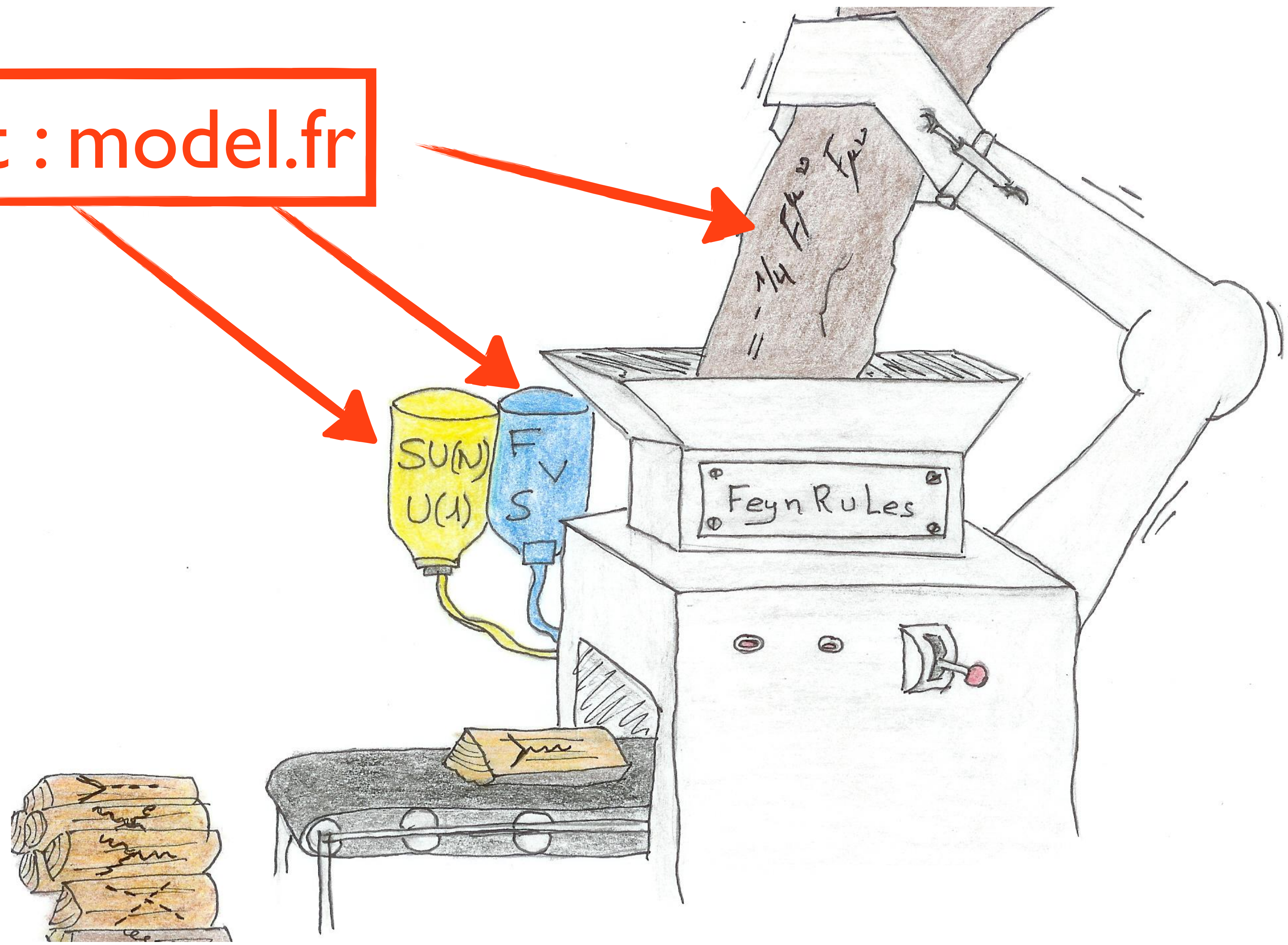
MC4BSM 2016
Beijing

Plan

- FeynRules in a nutshell
- BSM@NLO
  - Ingredients
  - How does it work?
- Examples :
  - Charged Higgs production
  - SUSY QCD
  - …

FeynRules

Input : model.fr



Output : vertices

A. Alloul, N. D. Christensen, CD, C. Duhr and B. Fuks, CPC185 (2014) 2250

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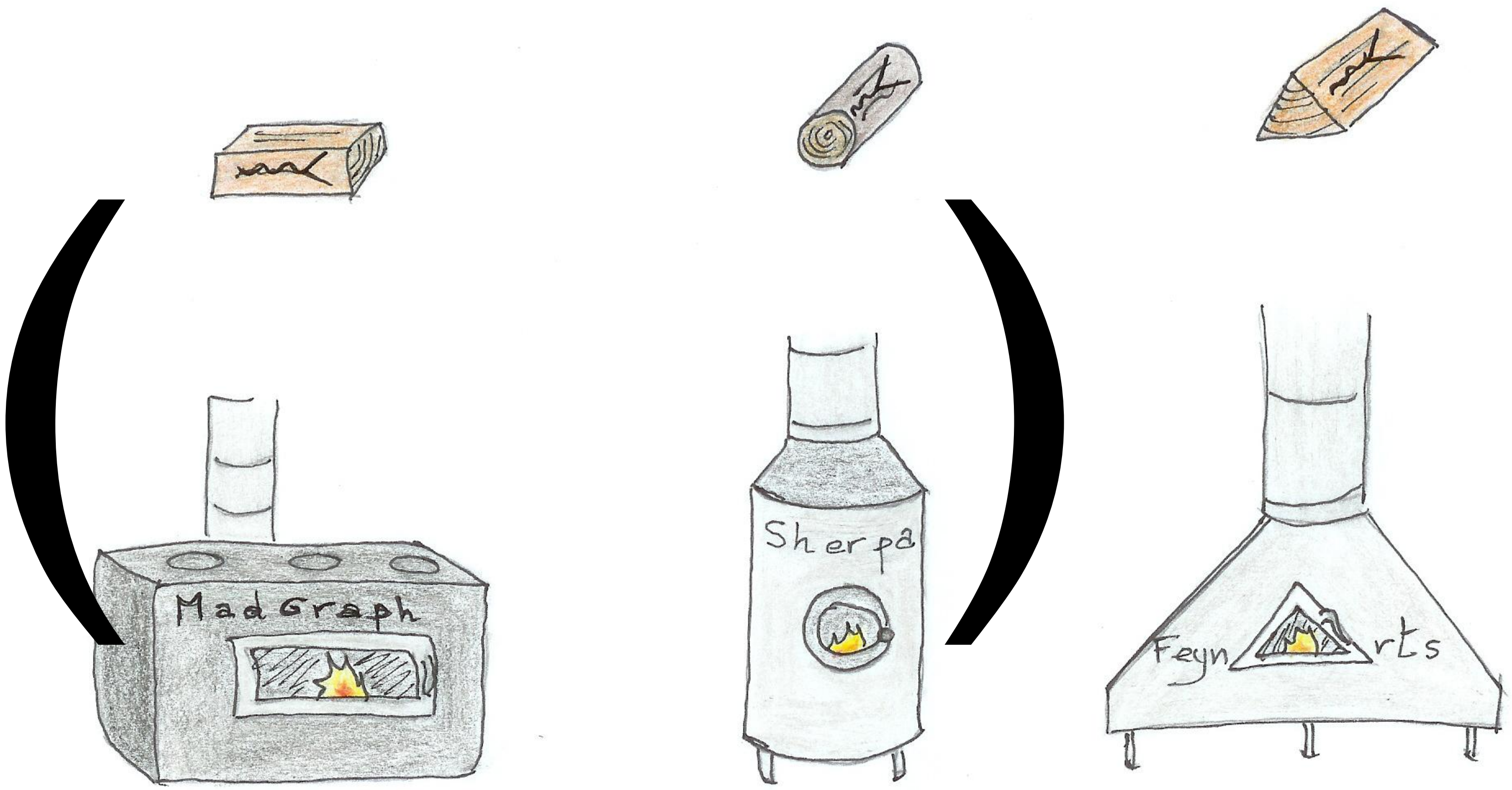
FeynRules outputs



FeynRules outputs can be used directly by event generators

UFO : output with the full information used by several generators

CD, C. Duhr, B. Fuks, D. Grellscheid, O. Mattelaer and T. Reiter, CPC 183 (2012) 1201

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UFO

- Generator independent output with full model information
- Contains the list of particles, parameters, vertices, decays (1 to 2), coupling orders
- vertices are split into Lorentz structures, colours and couplings and all are included in the model!

$$-ig_s \quad T^a_{ij} \quad \gamma_\mu$$

- Used in MG5, Herwig, Gosam, Sherpa

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Why NLO/Loop BSM?

- Discovery :
  - Loop-induced production/decay
  - NLO : Refine search strategies
- Measurement of properties/couplings : NLO corrections
  - QCD corrections are large at the LHC
- Quantification of the constraints NP should not be limited by the th. error on EFT

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Madgraph5_aMC@NLO

Wide BSM support
+
Automated NLO computation

- Computation of the born → MG5
- Computation of the real → MadFKS (IR)
- Computation of the loop → MadLoop
- Matching with parton shower 'à la' MC@NLO

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MadLoop

$$\mathcal{A}^{1-loop} = \sum_i d_i \ \text{Box}_i + \sum_i c_i \ \text{Triangle}_i + \sum_i b_i \ \text{Bubble}_i + \sum_i a_i \ \text{Tadpole}_i + R$$

- Box, Triangle, Bubble and Tadpole are known scalar integrals
- Loop computation = find the coefficients
  - Tensor reduction (OPP)
- R : rational terms should be partially provided
- UV counterterm vertices have to be provided

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To be provided : R_2

$$\bar{A}(\bar{q}) = \frac{1}{(2\pi)^4}\int d^d\bar{q}\,\frac{\bar{N}(\bar{q})}{\bar{D}_0\bar{D}_1\ldots\bar{D}_{m-1}}, \qquad \bar{D}_i = (\bar{q}+p_i)^2 - m_i^2$$

$$\bar{N}(\bar{q}) = N(q) + \tilde{N}(\tilde{q}, q, \epsilon)$$

d 4 ε

$$R_2 \equiv \lim_{\epsilon\to 0}\frac{1}{(2\pi)^4}\int d^d\bar{q}\,\frac{\tilde{N}(\tilde{q}, q, \epsilon)}{\bar{D}_0\bar{D}_1\ldots\bar{D}_{m-1}}$$

Finite set of vertices that can be computed once for all

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Computed in MadLoop :R_1

Due to the ε dimensional parts of the denominators

Like for the 4 dimensional part but with a different set of integrals

$$\int d^n\bar{q}\frac{\tilde{q}^2}{\bar{D}_i\bar{D}_j} = -\frac{i\pi^2}{2}\left[m_i^2+m_j^2-\frac{(p_i-p_j)^2}{3}\right]+\mathcal{O}(\epsilon)\,,$$

$$\int d^n\bar{q}\frac{\tilde{q}^2}{\bar{D}_i\bar{D}_j\bar{D}_k} = -\frac{i\pi^2}{2}+\mathcal{O}(\epsilon)\,,$$

$$\int d^n\bar{q}\frac{\tilde{q}^4}{\bar{D}_i\bar{D}_j\bar{D}_k\bar{D}_l} = -\frac{i\pi^2}{6}+\mathcal{O}(\epsilon)\,.$$

Only $R = R_1+R_2$ is gauge invariant ⇒ Check

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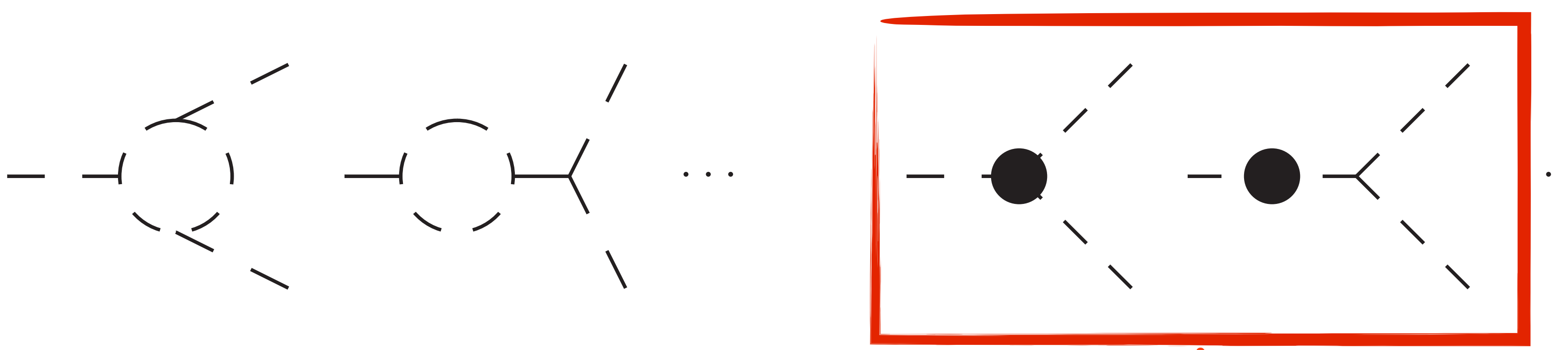
UV

$$\bar{A}(\bar{q}) = \frac{1}{(2\pi)^4} \int d^d \bar{q} \frac{\bar{N}(\bar{q})}{\bar{D}_0 \bar{D}_1 \ldots \bar{D}_{m-1}} = K \frac{1}{\epsilon} + \mathcal{O}\left(\epsilon^0\right)$$



$$= 0 \frac{1}{\epsilon} + \mathcal{O}\left(\epsilon^0\right)$$

Relations fixed by the Lagrangian (finite part)

Finite set of vertices that can be computed once for all

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Renormalization

External parameters

$$
\begin{aligned}
x_0 &\rightarrow x + \delta x, \\
\phi_0 &\rightarrow (1 + \frac{1}{2}\delta Z_{\phi\phi})\phi + \sum_{\chi} \frac{1}{2}\delta Z_{\phi\chi}\chi;
\end{aligned}
$$

Same for the conjugate field

Internal parameters are renormalised by replacing the external parameters in their expressions

$$
\begin{aligned}
gg &\quad (1 + \delta Z_{gg})\, TL \\
ggg &\quad \left(1 + \tfrac{1}{2}\delta\alpha_s + \tfrac{3}{2}\delta Z_{gg}\right) TL \\
gggg &\quad (1 + \delta\alpha_s + 2\delta Z_{gg})\, TL
\end{aligned}
$$

Fixed by

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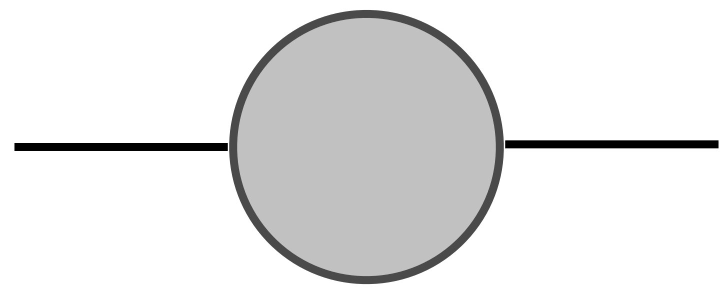
Renormalization conditions

On-shell scheme (or complex mass scheme):

Renormalized mass = Physical mass

Two-point function vanishes on-shell (No external bubbles)



$$i\delta_{ij}\left(\not p - m_i\right) + i\left[f^L_{ij}\left(p^2\right)\not p\gamma_- + f^R_{ij}\left(p^2\right)\not p\gamma_+ + f^{SL}_{ij}\left(p^2\right)\gamma_- + f^{SR}_{ij}\left(p^2\right)\gamma_+\right]$$

$$\begin{aligned}
\cancel{\widetilde{\Re}}\left[f^L_{ij}\left(p^2\right)m_i + f^{SR}_{ij}\left(p^2\right)\right]\Big|_{p^2=m_i^2} &= 0\\
\cancel{\widetilde{\Re}}\left[f^R_{ij}\left(p^2\right)m_i + f^{SL}_{ij}\left(p^2\right)\right]\Big|_{p^2=m_i^2} &= 0\\
\cancel{\widetilde{\Re}}\left[2m_i\frac{\partial}{\partial p^2}\left[\left(f^L_{ii}\left(p^2\right)+f^R_{ii}\left(p^2\right)\right)m_i + f^{SL}_{ii}\left(p^2\right)+f^{SR}_{ii}\left(p^2\right)\right] + f^L_{ii}\left(p^2\right)+f^R_{ii}\left(p^2\right)\right]\Big|_{p^2=m_i^2} &= 0
\end{aligned}$$

Similar for the vectors and scalars

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How does it work?

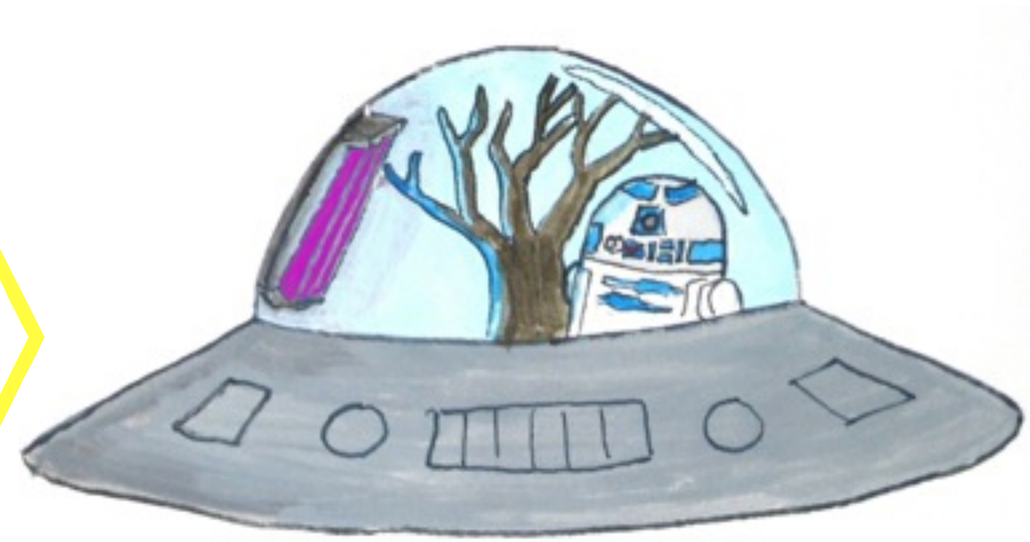
FeynRules
Renormalize the Lagrangian

model.mod
model.gen

FeynArts
Write the amplitudes

NLOCT.m
Compute the NLO vertices

model.nlo



CD, CPC 197 (2015) 239

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Restrictions/Assumptions

- Renormalizable Lagrangian, maximum dimension of the operators is 4
- Feynman Gauge
- $\{\gamma_\mu, \gamma_5\} = 0$
- ‘t Hooft-Veltman scheme
- On-shell scheme for the masses and wave functions
- $\overline{\text{MS}}$ by default for everything else (zero-momentum possible for fermion gauge boson interaction)

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R2 :Validation

- tested* on the SM (QCD:P. Draggiotis et al. +QED:M.V. Garzelli et al)
- tested* on MSSM (QCD:H.-S. Shao, Y.-J. Zhang) : test the Majorana

*Analytic comparison of the expressions

UV Validation

- SM QCD : tested* (W. Beenakker, S. Dittmaier, M. Kramer, B. Plumper)
- SM EW : tested* (expressions given by H.-S. Shao from A. Denner)

*Analytic comparison of the expressions

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Tests in event generators

- aMC@NLO
- The SM QCD has been tested by V. Hirschi (Comparison with the built-in version)
- SM EW (MZ scheme): comparison to published results for ME by H.-S. Shao and V. Hirschi
- Various BSM
    - gauge invariance
    - pole cancelation

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Test EW

```
== a a > t t~ ['QED'] ==
== a a > t t~ a ['QED'] ==
== a a > w+ w- ['QED'] ==
== a b > t w- ['QED'] ==
== d~ d > w+ w- ['QCD'] ==
== d~ d > w+ w- ['QED'] ==
== d~ d > z z ['QCD'] ==
== d~ d > z z ['QED'] ==
== e+ e- > t t~ a ['QED'] ==
== e+ e- > t t~ g ['QED'] ==
== g b > t w- ['QED'] ==
== g g > h h ['QCD'] ==
== g g > t t~ ['QED'] ==
== g g > t t~ g ['QED'] ==
== g g > t t~ h ['QCD'] ==
== g g > t t~ h ['QED'] ==
== h h > h h ['QED'] ==
== h h > h h h ['QED'] ==
== t t~ > w+ w- ['QED'] ==
```

```
== u b > t d ['QED'] ==
== u d~ > t b~ ['QED'] ==
== u g > t d b~ ['QED'] ==
== u u~ > a a ['QED'] ==
== u u~ > e+ e- ['QED'] ==
== u u~ > g a ['QCD QED'] ==
== u u~ > u u~ ['QCD QED'] ==
== u u~ > u u~ a ['QCD QED'] ==
== u u~ > u u~ g ['QCD QED'] ==
== u u~ > w+ w- ['QED'] ==
== u u~ > z a ['QED'] ==
== u u~ > z z ['QED'] ==
== u~ d > w- z ['QCD'] ==
== u~ d > w- z ['QED'] ==
== u~ u > w+ w- ['QCD'] ==
== u~ u > w+ w- ['QED'] ==
== u~ u > z z ['QCD'] ==
== u~ u > z z ['QED'] ==
== ve ve~ > e+ e- ['QED'] ==
== w+ w- > h h ['QED'] ==
```

Massive and massless b

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Future development

- EFT : done but 4F operators (in progress)
  - any gauge
- UFO@NLO in Gosam (N. Greiner)
- DRED (asked by Gosam)
- UFO 2.0

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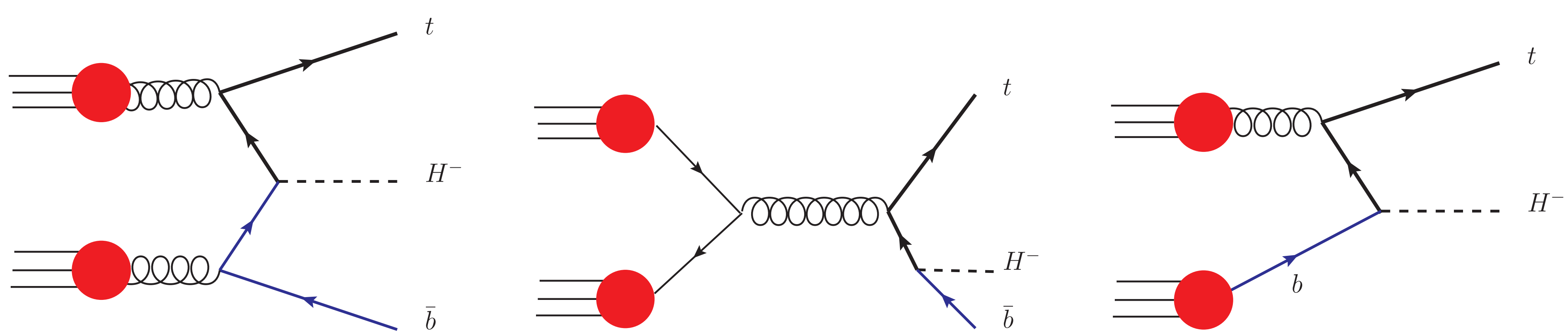
Example 1: Charged Higgs production

- Motivations :
  - needed for the LHC current and future runs
  - First searches in the high mass region
  - First searches in the threshold region
- 4F NLO fully differential matched with parton shower



- Shape comparison with the 5F

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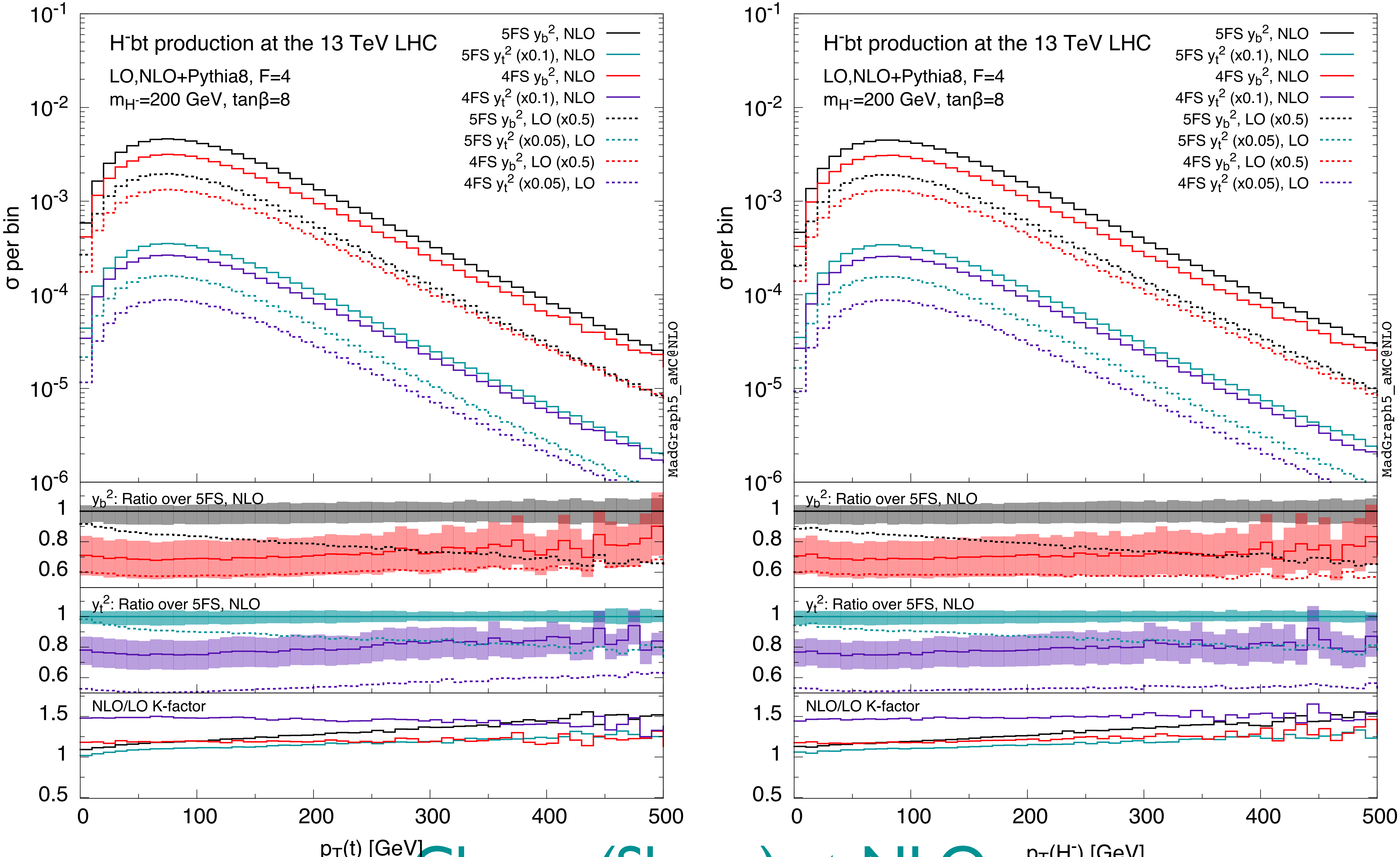
H^+ production : 4F vs 5F

C. D., M.Ubiali, M.Wiesemann and M.Zaro, JHEP 1510 (2015) 145



Closer (Shape) at NLO

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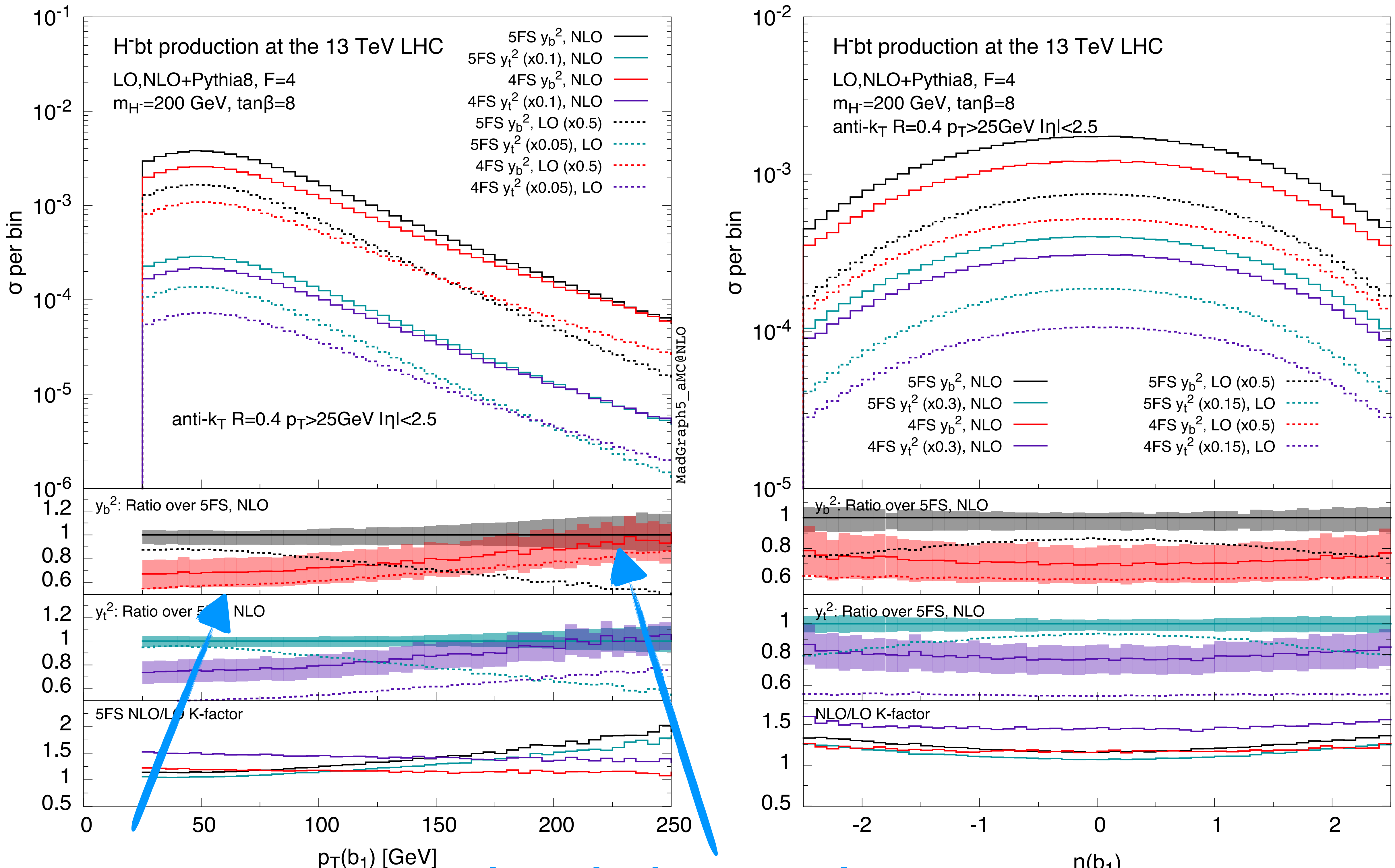
H^+ production : 4F vs 5F



Top decay

hard gluon splitting

more exclusive in b more different

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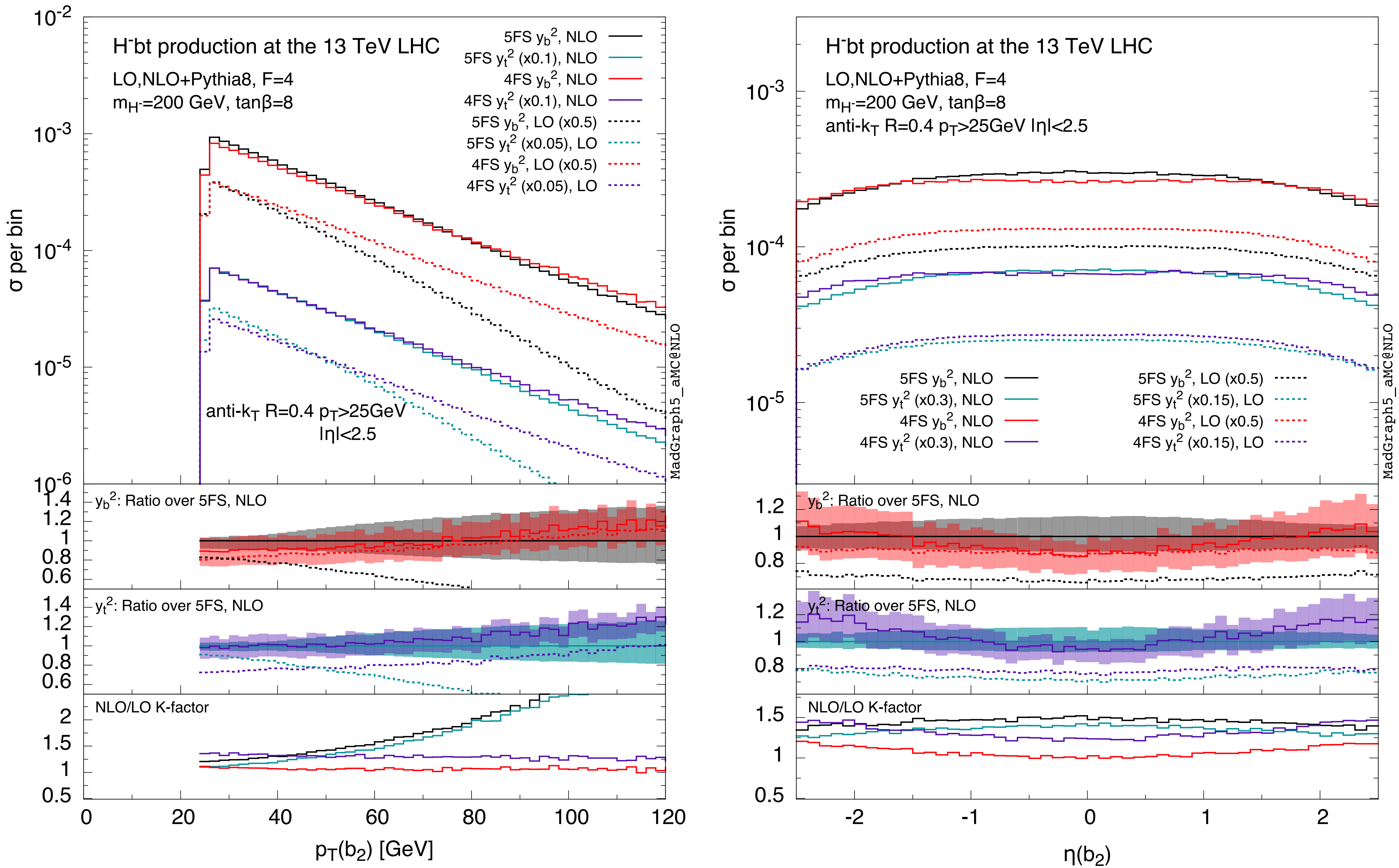
H^+ production : 4F vs 5F



Only LO in 5F

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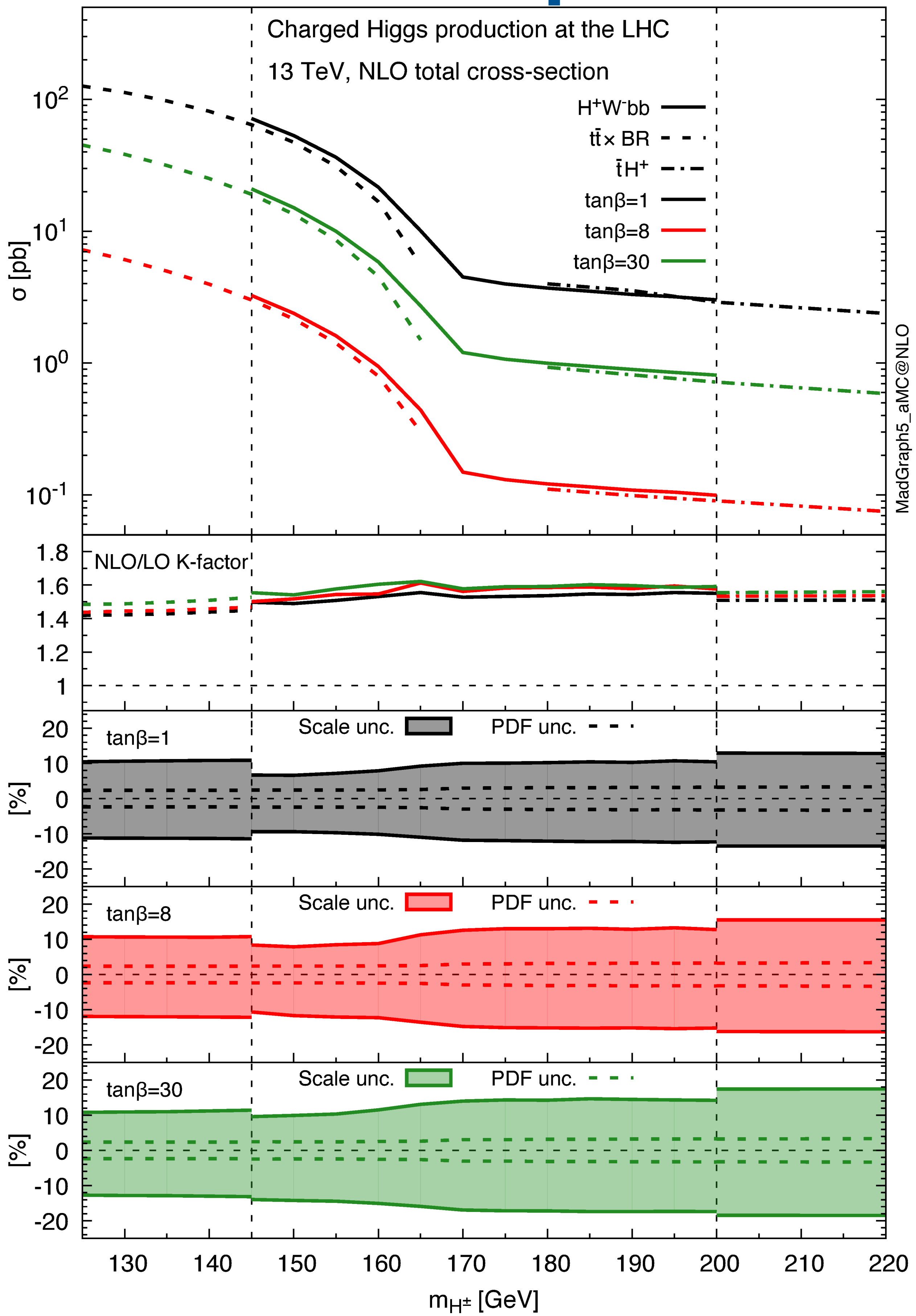
H^+ production : $m_H \sim m_t$



1607.05291 : C. D., R. Frederix ,V. Hirschi, M.Ubiali, M.Wiesemann and M.Zaro

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Example II: Gluino pair production

CD, B. Fuks, V. Hirschi, J. Proudom and H. S. Shao, PLB 755, 82 (2016)

12 scalar triplets
no mixing

1 Majorana octet

$$\mathcal{L}_{\rm SQCD} = D_\mu \tilde{q}_L^\dagger D^\mu \tilde{q}_L + D_\mu \tilde{q}_R^\dagger D^\mu \tilde{q}_R + \frac{i}{2}\bar{\tilde{g}} \not{D} \tilde{g}$$
$$- m^2_{\tilde{q}_L} \tilde{q}_L^\dagger \tilde{q}_L - m^2_{\tilde{q}_R} \tilde{q}_R^\dagger \tilde{q}_R - \frac{1}{2} m_{\tilde{g}} \bar{\tilde{g}} \tilde{g}$$
$$+ \sqrt{2} g_s \Big[- \tilde{q}_L^\dagger T \big(\bar{\tilde{g}} P_L q\big) + \big(\bar{q} P_L \tilde{g}\big) T \tilde{q}_R + \text{h.c.}\Big]$$
$$- \frac{g_s^2}{2} \Big[\tilde{q}_R^\dagger T \tilde{q}_R - \tilde{q}_L^\dagger T \tilde{q}_L\Big] \Big[\tilde{q}_R^\dagger T \tilde{q}_R - \tilde{q}_L^\dagger T \tilde{q}_L\Big] ,$$

Full QCD sector of the MSSM

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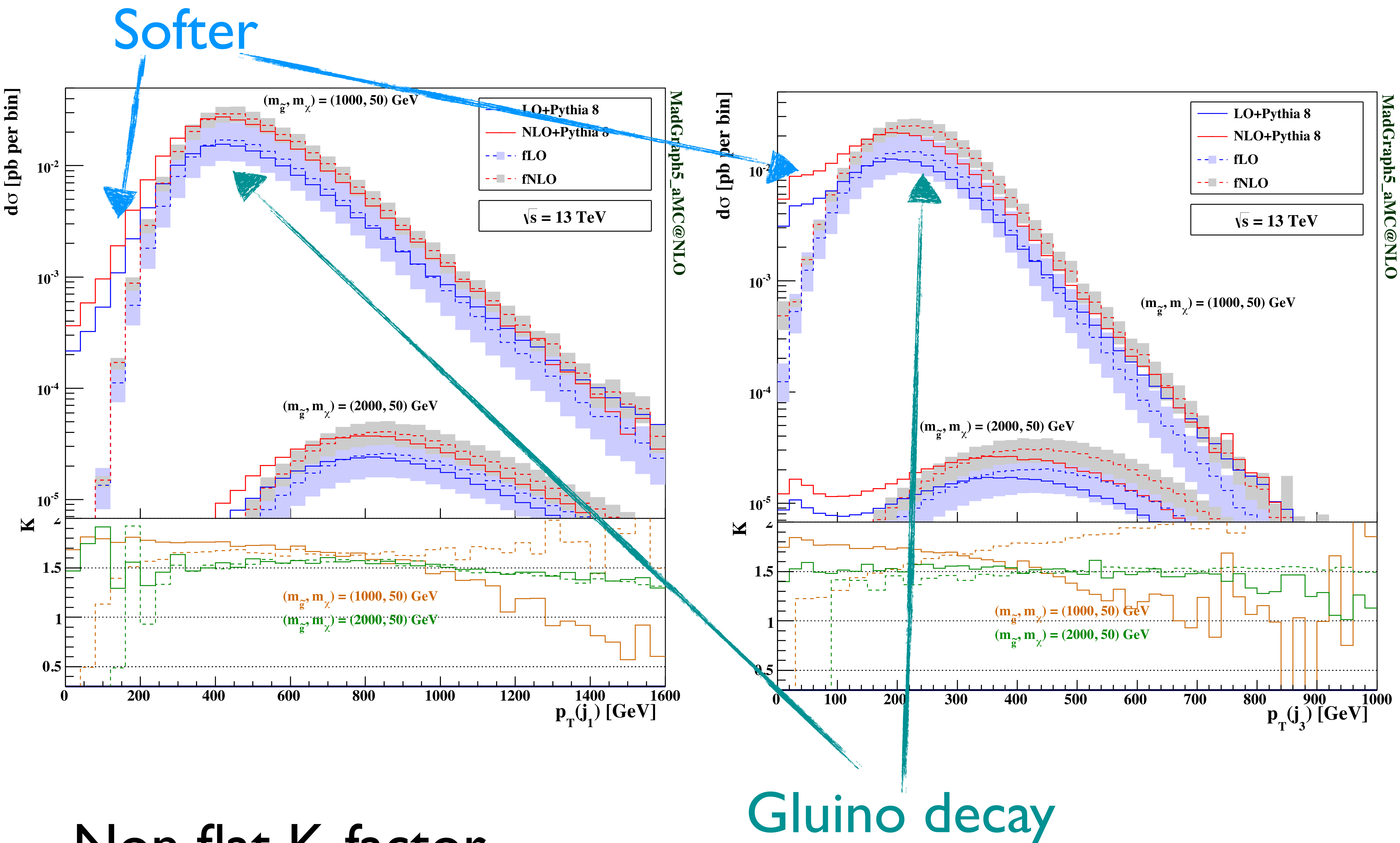
Example II: Gluino pair production



Non flat K-factor

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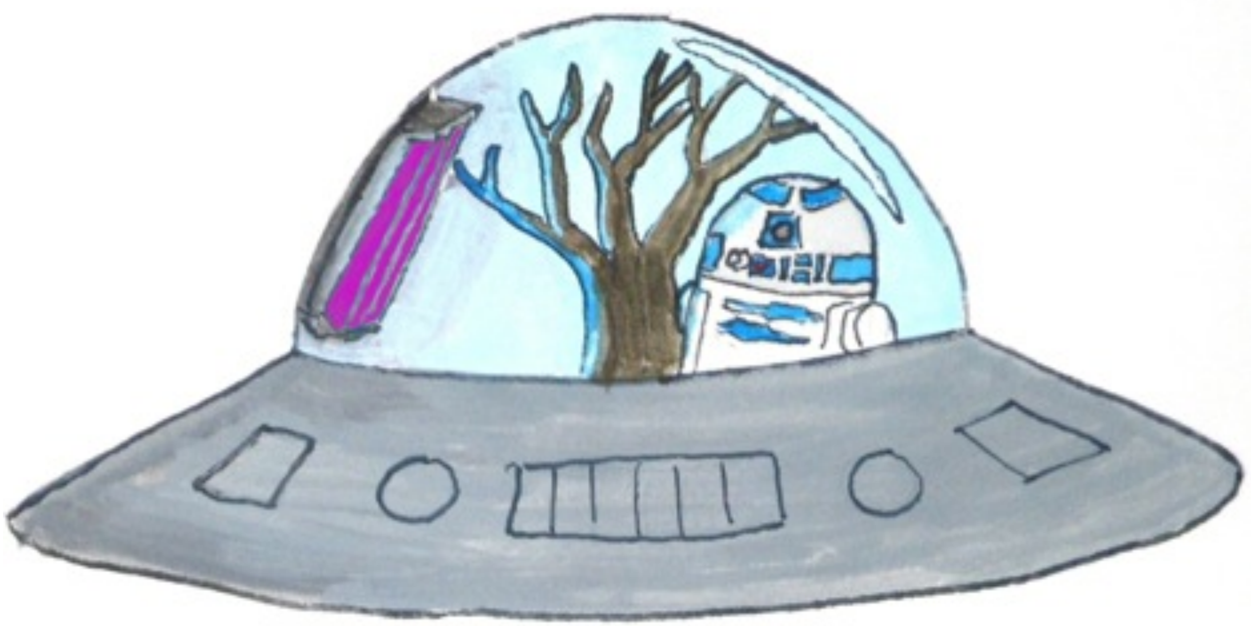
More examples

- Squark and sgluon production [CD, B. Fuks, V. Hirschi, J. Proudom and H. S. Shao, PRD 91 (2015) no.9, 094005]
- GM [CD, K. Hartling, H. E. Logan, A. D. Peterson and M. Zaro, PRD 93 (2016) no.3, 035004]
- Heavy neutrino [CD, O. Mattelaer, R. Ruiz and J. Turner, arXiv:1602.06957]
- Spin-2 (dim-5 operators) [G. Das, CD, V. Hirschi, F. Maltoni and H. S. Shao, arXiv:1605.09359]
- Top dim-6
  - FCNC [CD F. Maltoni, J. Wang and C. Zhang, PRD 91 (2015) 034024]
  - Pair prodution [D. Buarque Franzosi and C.Zhang, PRD 91 (2015) no. 11, 114010]
  - tth [F. Maltoni, E. Vryonidou and C. Zhang, arXiv:1607.05330]
- …

Final remarks

- Automatic BSM@NLO
  - Renormalizable (Public)
- Pheno
  - Spin 2
  - Charged Higgs threshold
  - Top EFT
  - …
- Jointly by FeynRules and Madgraph_aMC@NLO teams



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Back-up

Example 1: Charged Higgs production

$m_{H^\pm} = 200\,\text{GeV}$ **and** $m_{H^\pm} = 600\,\text{GeV}$

$\tan\beta = 8$ **but** $y_b^2,\ y_t^2$ and $y_b y_t$

NNPDF2.3 at NLO/ NNPDF3.0 at LO with 4/5F

$\alpha_s(M_Z) = 0.118$ (5F) $\alpha_s(M_Z) = 0.1226$ (4F)

$m_b^{\text{pole}} = 4.75\,\text{GeV}$ $m_t^{\text{pole}} = 172.5\,\text{GeV}$

$\bar{m}_b(\bar{m}_b) = 4.3377\,\text{GeV}$

$$\mu_{R,F} = H_T/3 \equiv \frac{1}{3}\sum_i \sqrt{m(i)^2 + p_T(i)^2}$$

Anti-k_T $\Delta R = 0.4$ $p_T(j) \geq 25\,\text{GeV},$ $|\eta(j)| \leq 2.5.$

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Renormalization conditions

Zero momentum scheme available for the gauge couplings

$$\Gamma^{\mu}_{FFV}(p_1,p_2) = igT^a\delta_{f_1,f_2}\left[\gamma^\mu\left(\frac{\delta g}{g}+\frac{1}{2}\delta Z_{VV}+\frac{1}{2}\delta Z^R_{FF}+\frac{1}{2}\delta Z^L_{FF}+\frac{g'_V}{2g}\delta Z_{V'V}\right)\right.$$
$$+\gamma^\mu\gamma_5\left(\frac{1}{2}\delta Z^R_{FF}-\frac{1}{2}\delta Z^L_{FF}+\frac{g'_A}{2g}\delta Z_{V'V}\right)$$
$$\left.+\left(\gamma^\mu h^V(k^2)+\gamma^\mu\gamma_5 h^A(k^2)+\frac{(p_1-p_2)^\mu}{2m}h^S(k^2)+\frac{k_\mu}{2m}h^P(k^2)\right)\right]$$

$$\frac{\delta g}{g}+\frac{1}{2}\delta Z_{VV}+\frac{1}{2}\delta Z^R_{FF}+\frac{1}{2}\delta Z^L_{FF}+\frac{g'_V}{2g}\delta Z_{V'V}+h^V(0)+h^S(0) = 0$$
$$\frac{1}{2}\delta Z^R_{FF}-\frac{1}{2}\delta Z^L_{FF}+\frac{g'_A}{2g}\delta Z_{V'V}+h^A(0) = 0.$$

By gauge invariance

$$\frac{\delta g}{g}+\frac{1}{2}\delta Z_{VV}+\frac{g'_V}{2g}\delta Z_{V'V}+\frac{g'_A}{2g}\delta Z_{V'V}=0$$

Only from two-point functions

$\overline{\text{MS}}$ scheme for everything else (option for all)

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How does it work?

FeynRules :

...

```
Lren = OnShellRenormalization[ LSM , QCDOnly ->True];
WriteFeynArtsOutput[ Lren , Output -> "SMrenoL",
GenericFile -> False]
```

FeynArts / NLOCT :

```
WriteCT[ "SMrenoL/SMrenoL" , "Lorentz", Output->
"SMQCDreno", QCDonly -> True]
```

FeynRules :

...

```
Get["SMQCDreno.nlo"];
WriteUFO[ LSM , UVCounterterms -> UV$vertlist ,
 R2Vertices -> R2$vertlist]
```

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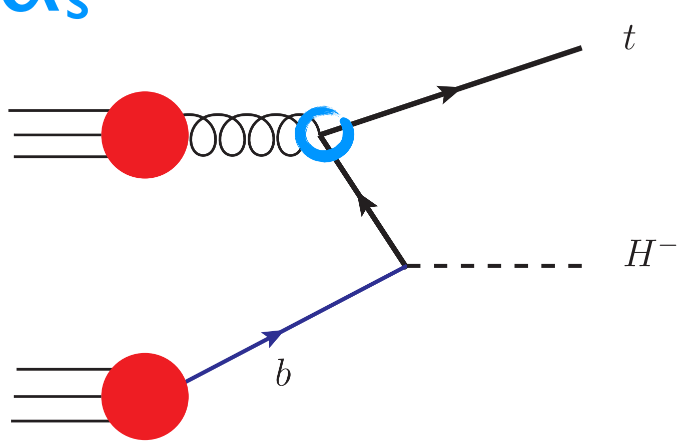
Example 1: Charged Higgs production

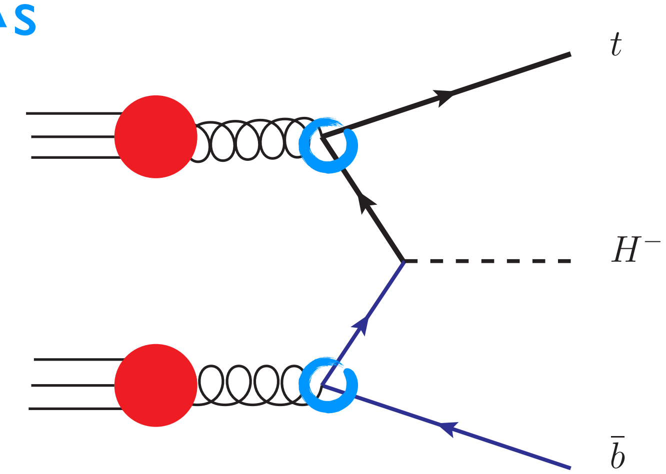
5 Flavours

- $m_b=0$ (but $m_b^y>0$)
- In the PDF
- In the running of α_s
- Handle collinear logarithms
- α_s



4 Flavours

- $m_b>0$
- Not in the PDF
- Not in the running of α_s
- Contribution to b observable at LO
- α_s^2



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Example 1: Charged Higgs production

Type-II 2HDM

$$V_{t\bar{b}H^-} = -i\left(y_t P_R \frac{1}{\tan\beta} + y_b P_L \tan\beta\right)$$

$$P_{R/L} = (1 \pm \gamma_5)/2$$

$$y_{t/b} \equiv \sqrt{2}\frac{m^y_{t/b}}{v}$$

$$\delta y_{t/b} = \sqrt{2}\frac{\delta m_{t/b}}{v}$$

On-shell sc.

$$\delta m_{t/b} = -\frac{g_s^2}{12\pi^2} m_{t/b}\left(\frac{3}{\bar{\epsilon}} + 4 - 6\log\frac{m_{t/b}}{\mu_R}\right)$$

$\overline{\text{MS}}$ sc.

$$\delta y_b = -\frac{\sqrt{2}}{v}\frac{g_s^2 m_b^y}{4\pi^2\bar{\epsilon}}$$

Input : -FR model

-running of the b yukawa mass

Validation : -Comparison with S. Dittmaier, M. Kramer, M. Spira and M. Walser, PRD 83 (2011) 055005

-Recover ttH

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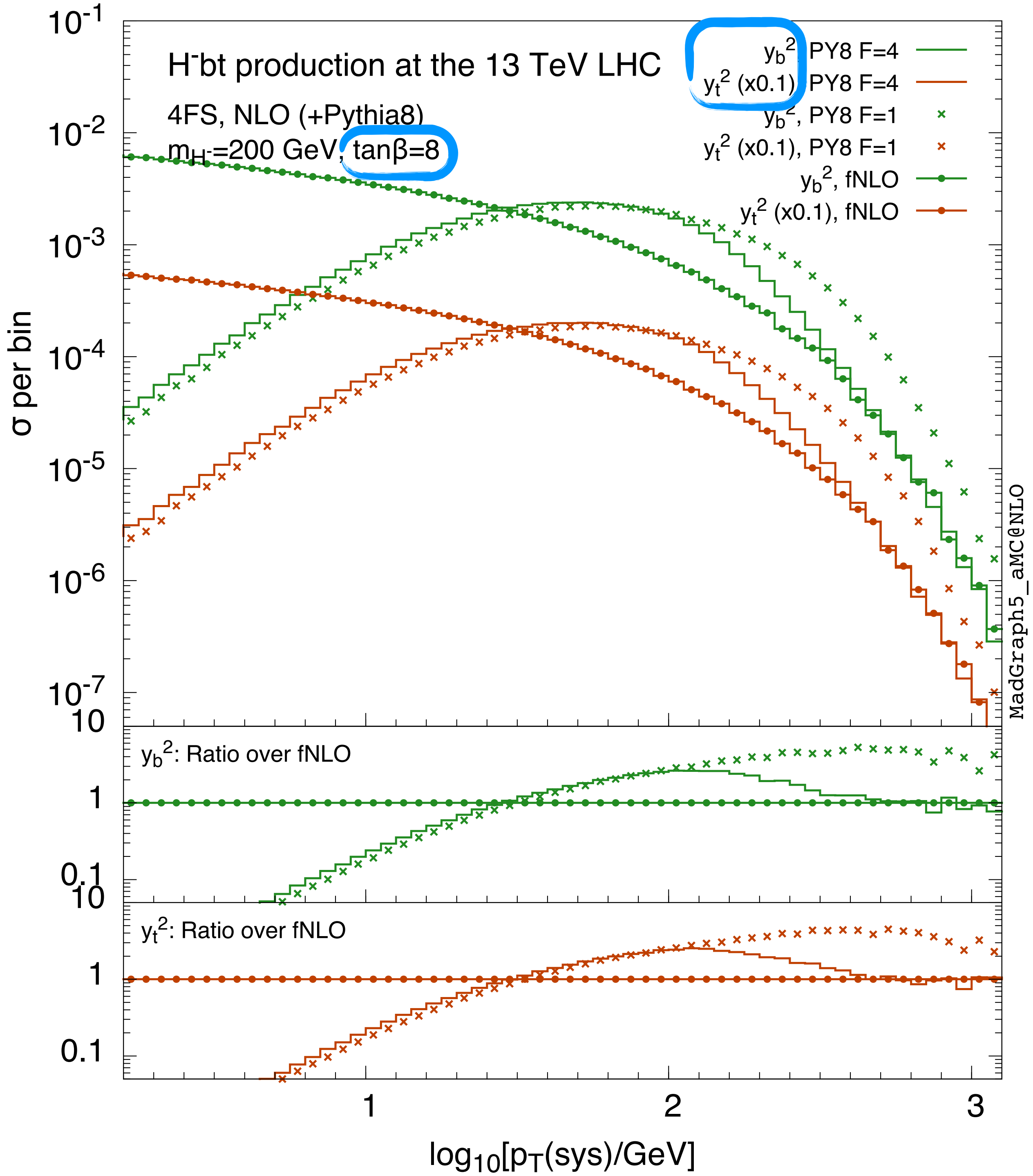
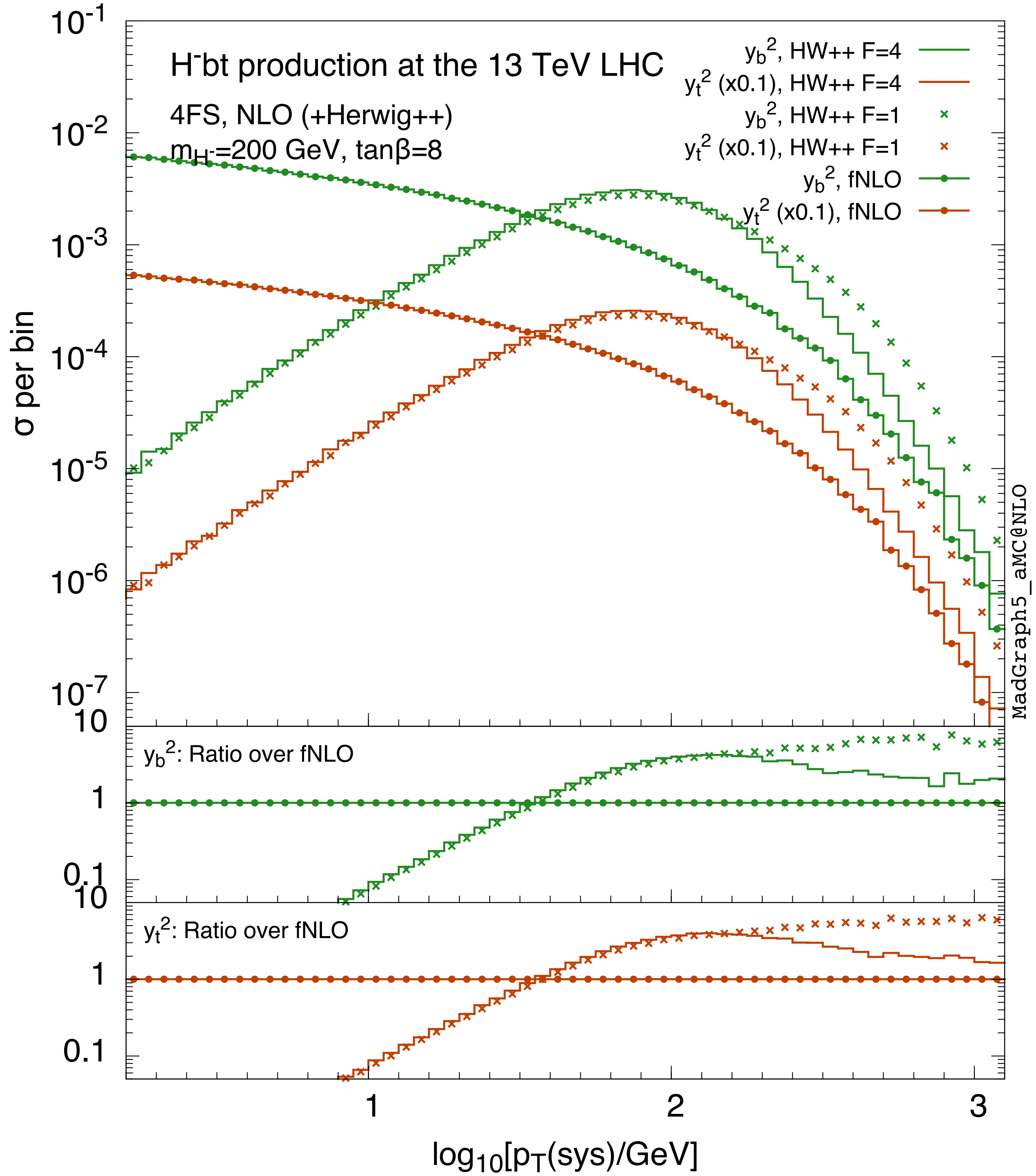
Example 1: Charged Higgs production





$$\mu_{R,F} = H_T/3 \equiv \frac{1}{3}\sum_i \sqrt{m(i)^2 + p_T(i)^2}$$

$$\frac{0.1}{F}\hat{s} \leq \mu_{\rm sh} \leq \frac{1}{F}\hat{s}$$

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Example 1: Charged Higgs production

$\sigma(m_{H^-} = 200\,\text{GeV})$ [fb]		NLO y_b^2	NLO y_t^2	LO y_b^2	LO y_t^2
	Inclusive	$50.40^{+17.8\%}_{-18.6\%}$	$42.43^{+12.4\%}_{-13.1\%}$	$42.12^{+52.2\%}_{-31.9\%}$	$28.68^{+36.3\%}_{-24.7\%}$
$\geq 1 j_b$	F.O.	$45.47^{+17.5\%}_{-18.4\%}$	$38.31^{+12.2\%}_{-13.0\%}$	$38.26^{+51.9\%}_{-31.8\%}$	$26.09^{+36.1\%}_{-24.6\%}$
	Pythia8	$43.44^{+17.4\%}_{-18.4\%}$	$36.67^{+12.0\%}_{-13.0\%}$	$36.81^{+52.0\%}_{-31.8\%}$	$25.09^{+36.1\%}_{-24.7\%}$
	Herwig++	42.64	36.04	36.08	24.61
$\geq 2 j_b$	F.O.	$11.55^{+10.9\%}_{-15.4\%}$	$9.76^{+6.5\%}_{-10.0\%}$	$11.22^{+50.4\%}_{-31.2\%}$	$7.79^{+35.0\%}_{-24.1\%}$
	Pythia8	$12.55^{+15.3\%}_{-17.4\%}$	$10.67^{+10.4\%}_{-12.1\%}$	$11.73^{+51.2\%}_{-31.5\%}$	$8.12^{+35.6\%}_{-24.4\%}$
	Herwig++	11.03	9.33	10.09	7.00

$\tan\beta = 8$

$\sigma(m_{H^-} = 600\,\text{GeV})$ [fb]		NLO y_b^2	NLO y_t^2	LO y_b^2	LO y_t^2
	Inclusive	$2.400^{+20.3\%}_{-20.1\%}$	$2.117^{+13.1\%}_{-14.2\%}$	$1.794^{+54.9\%}_{-33.0\%}$	$1.339^{+40.1\%}_{-26.5\%}$
$\geq 1 j_b$	F.O.	$2.187^{+19.9\%}_{-19.9\%}$	$1.925^{+12.6\%}_{-14.0\%}$	$1.649^{+54.7\%}_{-32.9\%}$	$1.232^{+39.9\%}_{-26.5\%}$
	PYTHIA8	$2.115^{+19.9\%}_{-19.9\%}$	$1.865^{+12.5\%}_{-14.0\%}$	$1.601^{+54.8\%}_{-32.9\%}$	$1.197^{+40.0\%}_{-26.5\%}$
	HERWIG++	2.077	1.836	1.570	1.175
$\geq 2 j_b$	F.O.	$0.630^{+12.6\%}_{-17.0\%}$	$0.548^{+5.9\%}_{-10.8\%}$	$0.548^{+53.8\%}_{-32.6\%}$	$0.413^{+39.2\%}_{-26.2\%}$
	PYTHIA8	$0.697^{+16.7\%}_{-18.6\%}$	$0.611^{+9.6\%}_{-12.6\%}$	$0.588^{+54.3\%}_{-32.8\%}$	$0.443^{+39.6\%}_{-26.3\%}$
	HERWIG++	0.602	0.532	0.498	0.376

Reduced

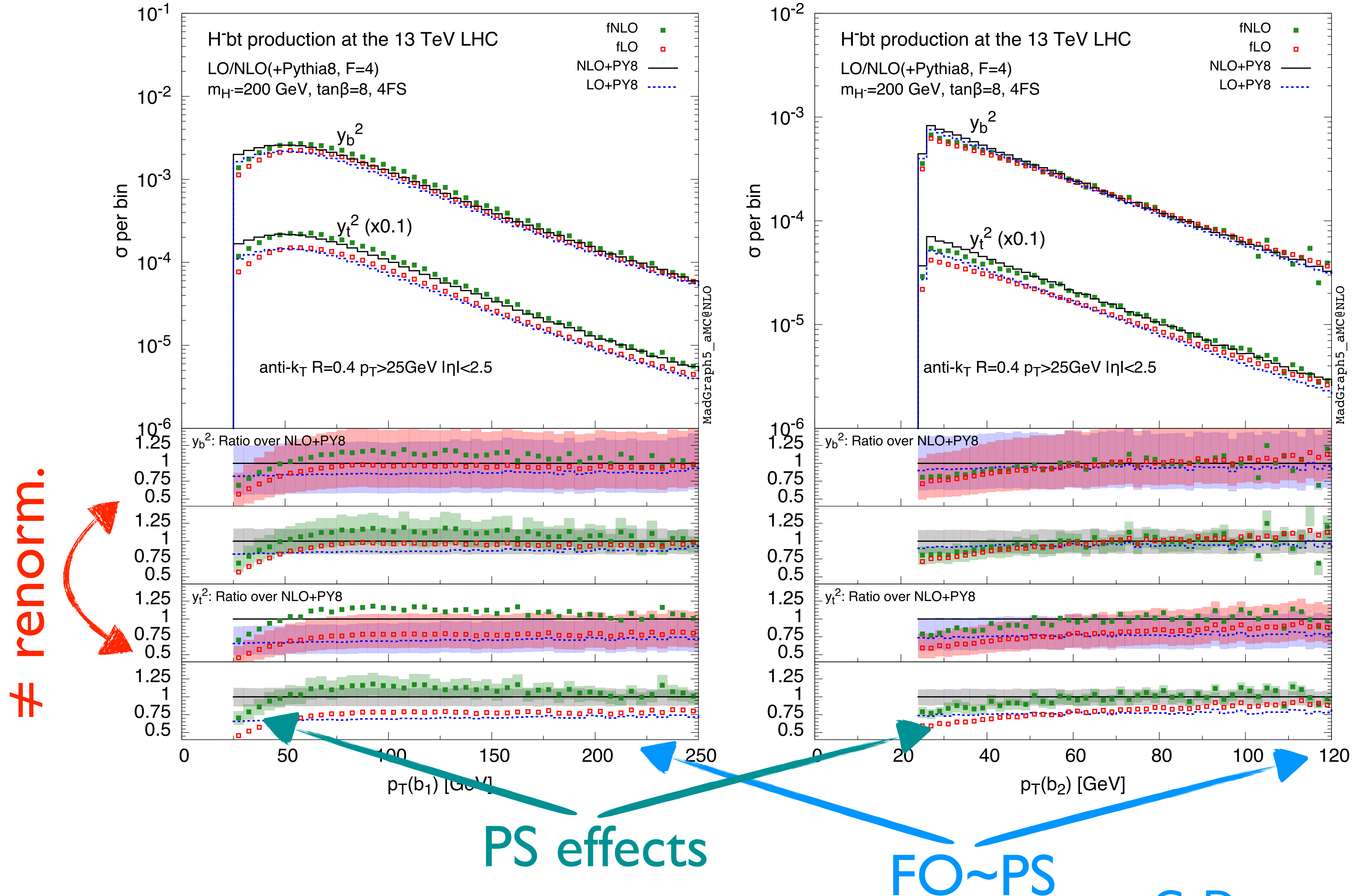
Top leptonic decay

$\simeq$

$\neq$ K-factor

C. Degrande

Example 1: Charged Higgs production



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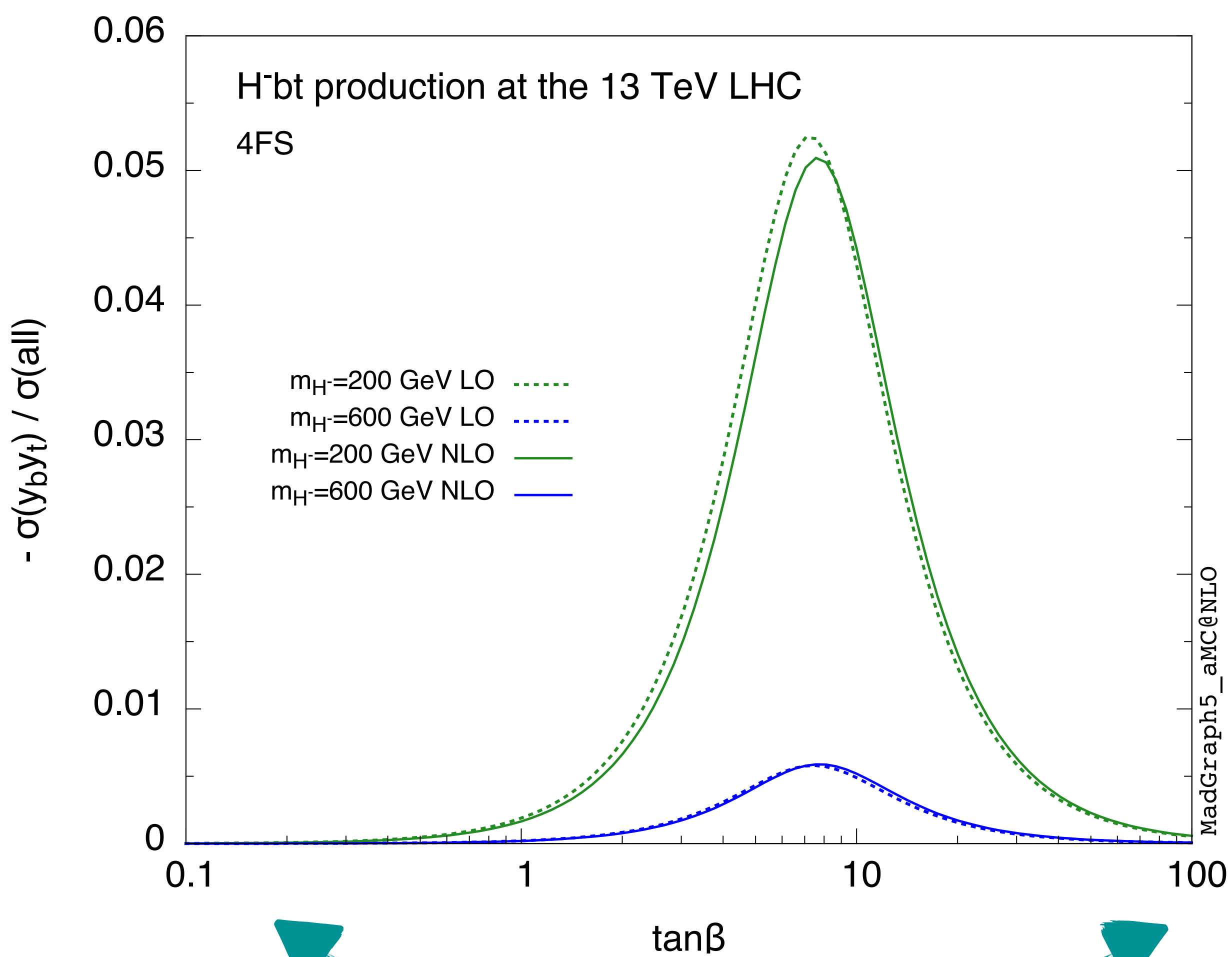
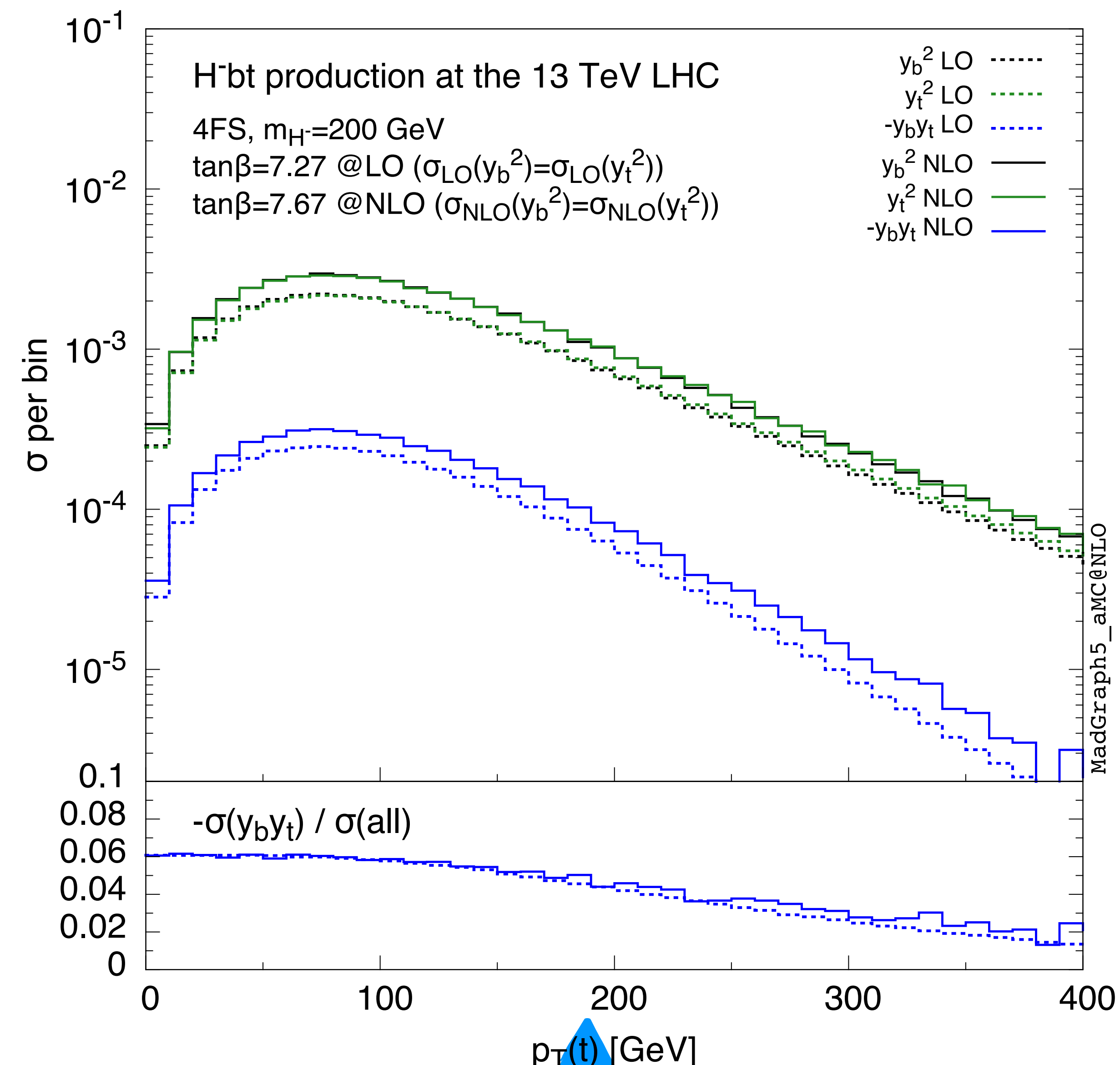
Example 1: Charged Higgs production

Interference : $\propto m_b$





Other terms are enhanced

More important at low energy

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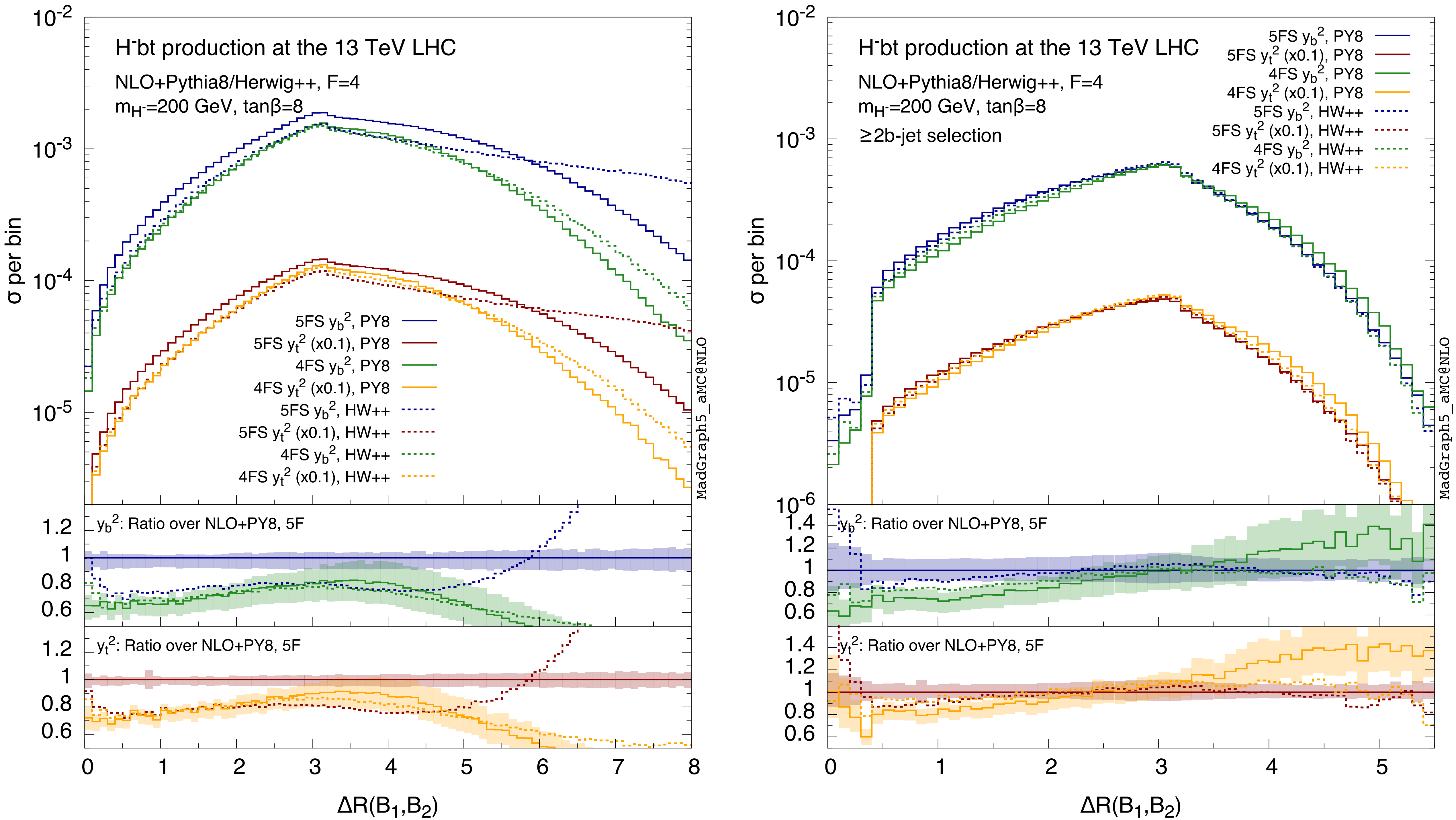
Example 1: Charged Higgs production



Shower dependent in 5F

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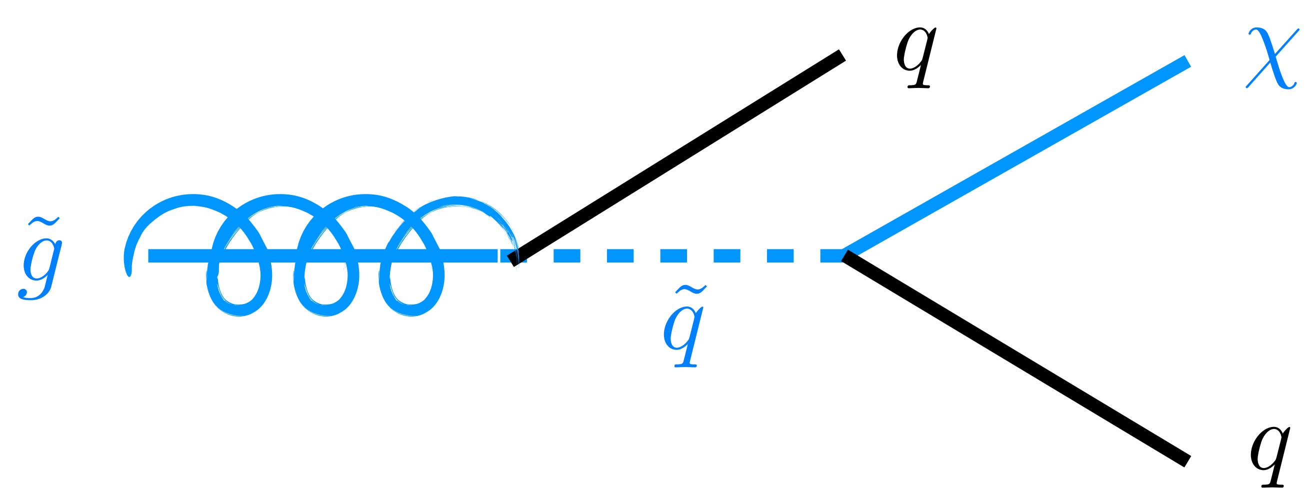
Example II: Gluino pair production

1 Majorana gauge singlet (bino-like)

$$\mathcal{L}_{\text{decay}} = \frac{i}{2}\bar{\chi}\partial\!\!\!/\chi - \frac{1}{2}m_\chi\bar{\chi}\chi$$
$$+ \sqrt{2}g'\Big[- \tilde{q}_L^\dagger Y_q \big(\bar{\chi}P_L q\big) + \big(\bar{q}P_L\chi\big)Y_q\tilde{q}_R + \text{h.c.}\Big]$$



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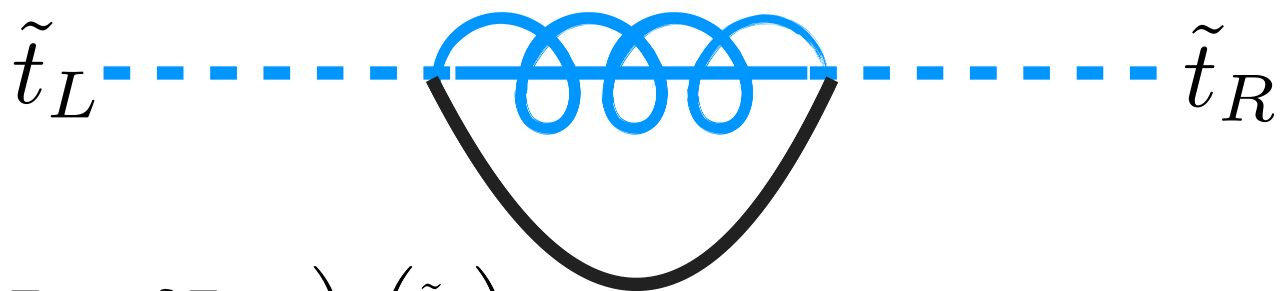
Example II: Gluino pair production



$$\begin{pmatrix} \tilde{t}_L \\ \tilde{t}_R \end{pmatrix} \to \begin{pmatrix} \tilde{t}_L \\ \tilde{t}_R \end{pmatrix} + \frac{1}{2} \begin{pmatrix} \delta Z_{\tilde{t}_L} & \delta Z_{\tilde{t},\mathrm{LR}} \\ \delta Z_{\tilde{t},\mathrm{RL}} & \delta Z_{\tilde{t}_R} \end{pmatrix} \begin{pmatrix} \tilde{t}_L \\ \tilde{t}_R \end{pmatrix}$$

$$\delta \mathcal{L}_{\mathrm{off}} = -\delta m^2_{\tilde{t},\mathrm{LR}} (\tilde{t}^\dagger_L \tilde{t}_R + \tilde{t}^\dagger_R \tilde{t}_L)$$

Zero-momentum for the massive d.o.f.

$$\frac{\delta \alpha_s}{\alpha_s} = \frac{\alpha_s}{2\pi\bar{\epsilon}} \left[\frac{n_f}{3} - \frac{11 n_c}{6} \right] + \frac{\alpha_s}{6\pi} \left[\frac{1}{\bar{\epsilon}} - \log \frac{m_t^2}{\mu_R^2} \right] + \frac{\alpha_s n_c}{6\pi} \left[\frac{1}{\bar{\epsilon}} - \log \frac{m_{\tilde{g}}^2}{\mu_R^2} \right] + \frac{\alpha_s}{24\pi} \sum_{\tilde{q}} \left[\frac{1}{\bar{\epsilon}} - \log \frac{m_{\tilde{q}}^2}{\mu_R^2} \right]$$

Finite CT to remove SUSY artificial breaking

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Example II: Gluino pair production

Validation : Comparison with Prospino (degenerate spectrum)

$$m_{\tilde{t}_R} = 17\text{TeV}, \quad m_{\tilde{t}_L} = 16\text{TeV}, \quad m_{\tilde{q}_{R/L}} = 15\text{TeV}$$

No resonant squark

$m_{\tilde{g}}$ [GeV]	$\sigma^{\rm LO}$ [pb]	$\sigma^{\rm NLO}$ [pb]
200	$2104^{+30.3\%+14.0\%}_{-21.9\%-14.0\%}$	$3183^{+10.8\%+1.8\%}_{-11.6\%-1.8\%}$
500	$15.46^{+34.7\%+19.5\%}_{-24.1\%-19.5\%}$	$24.90^{+12.5\%+3.7\%}_{-13.4\%-3.7\%}$
750	$1.206^{+35.9\%+23.5\%}_{-24.6\%-23.5\%}$	$2.009^{+13.5\%+5.5\%}_{-14.1\%-5.5\%}$
1000	$1.608 \cdot 10^{-1}{}^{+36.3\%+26.4\%}_{-24.8\%-26.4\%}$	$2.743 \cdot 10^{-1}{}^{+14.4\%+7.3\%}_{-14.8\%-7.3\%}$
1500	$6.264 \cdot 10^{-3}{}^{+36.2\%+29.4\%}_{-24.7\%-29.4\%}$	$1.056 \cdot 10^{-2}{}^{+16.1\%+11.3\%}_{-15.8\%-11.3\%}$
2000	$4.217 \cdot 10^{-4}{}^{+35.6\%+29.8\%}_{-24.5\%-29.8\%}$	$6.327 \cdot 10^{-4}{}^{+17.7\%+17.8\%}_{-16.6\%-17.8\%}$

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