

Single top + Higgs production in the 2HDM

UCLouvain, CP3
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Work in progress

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Outline

- Constraints - Benchmarks
- 2HDM features in $t\Phi$ production
- Production cross sections
- Kinematical distributions
- Conclusion

Parameters restrictions

- 7 parameters in 2HDM CP conserving case:
 - $m_h, m_H, m_A, m_{h\pm}, \sin(\beta-\alpha), \tan \beta, m_{12}^2$
 - We fix $m_h = 125 \text{ GeV}$
- Constraints from:
 - HiggsBounds, HiggsSignals, SuperIso, 2HDMC, ...
 - Stability, perturbativity, unitarity, EWPO, flavour physics, LHC signal strengths, ...
- Strongest constraints:
 - $m_A \sim m_{h\pm}$ or $m_H \sim m_{h\pm}$
 - $\sin(\beta-\alpha) \sim 1$
 - $\tan \beta < 20$

Benchmarks

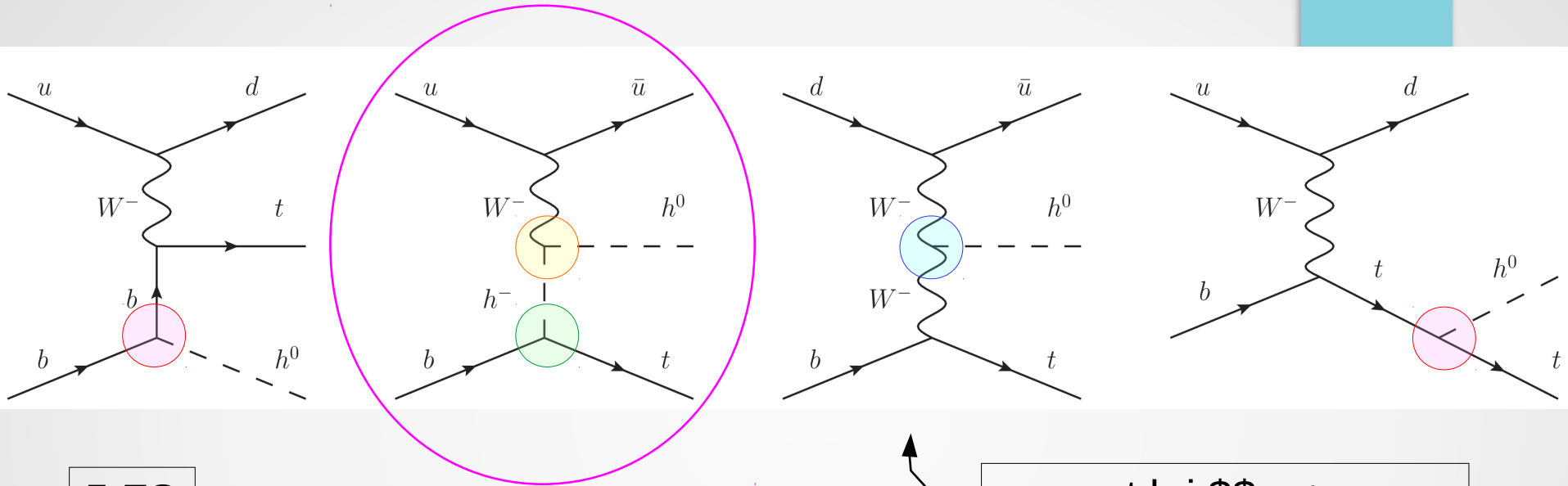
	Type	$\tan \beta$	$\sin(\beta-\alpha)$	m_H	M_A	$M_{h\pm}$	m^2_{12}
B1	II	1.75	0.9976	300	441	442	38300
B2	II	1.5	0.9958	700	701	670	180000
B3	II	2.22	0.9998	200	350	350	12000
B4	I	1.20	0.9899	200	500	500	-60000
B5	I	20.0	0.9987	200	500	500	2000
B6	II	10.0	0.9998	500	500	500	24746
B7	II	10.0	0.9798	500	500	500	24746

~ 1

Modified Yukawa couplings

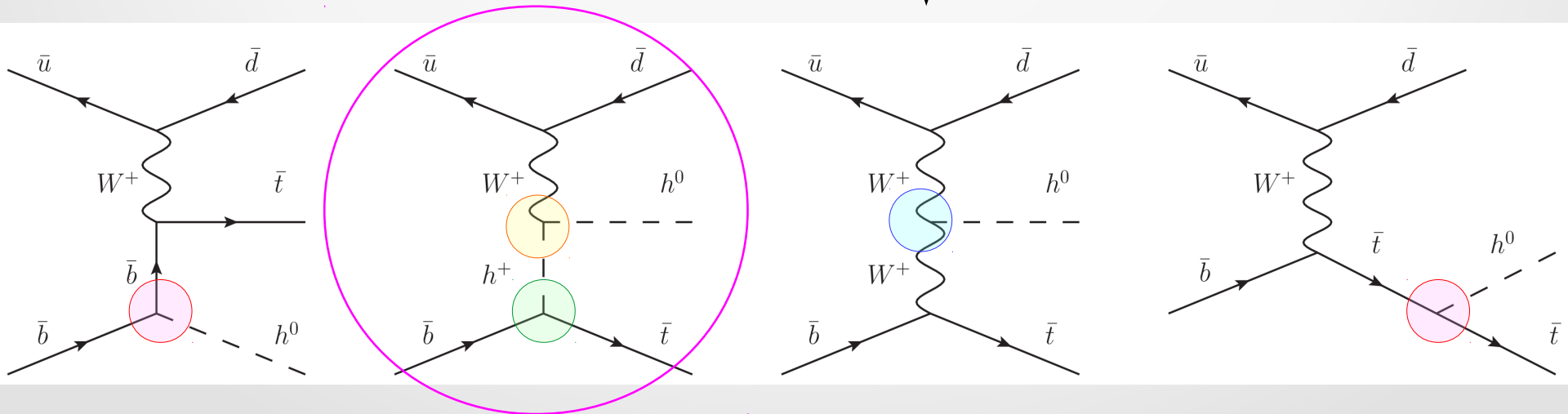
	h^0_{tt}	h^0_{bb}	H^0_{tt}	H^0_{bb}	A^0_{tt}	A^0_{bb}
B1	0.958	1.118	- 0.639	1.677	0.5714	1.75
B2	0.935	1.132	- 0.755	1.403	0.6667	1.50
B3	0.993	1.035	- 0.466	2.204	0.4504	2.22
B4	1.108	1.108	- 0.684	- 0.684	0.8333	-0.8333
B5	1.001	1.001	0	0	0.05	-0.05
B6	0.998	1.203	- 0.12	9.978	0.1	10.0
B7	0.999	- 1.018	+ 0.102	9.998	0.1	10.0
	~ 1	~ 1	$ < 1$	$ > 1$ Type II	< 1	> 1 Type II

Couplings – th^0 production

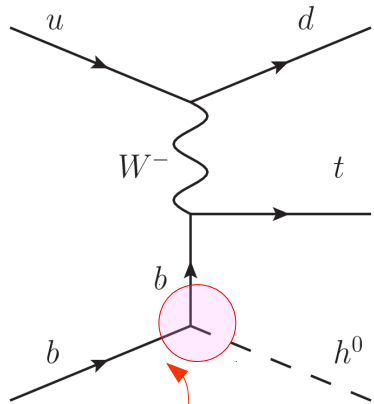


NEW!

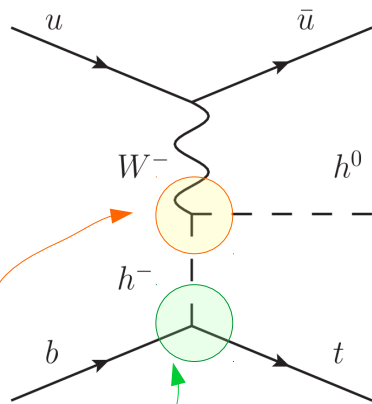
$pp \rightarrow thj \$\$ w^+ w^-$
 $pp \rightarrow t\bar{h}j \$\$ w^+ w^-$



Couplings – th^0 production

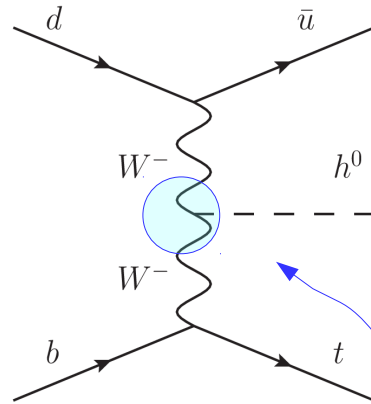


$\cos \alpha / \cos \beta \rightarrow \text{type I}$
 $-\sin \alpha / \cos \beta \rightarrow \text{type II}$

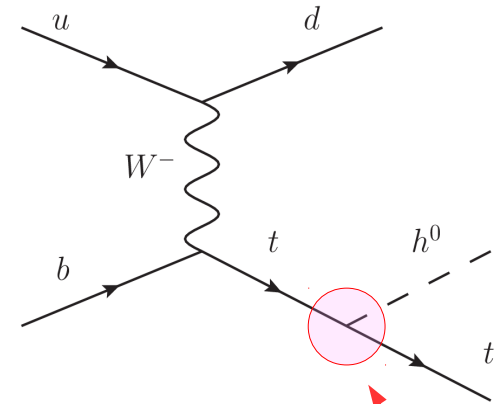


$-\cot \beta \rightarrow \text{type I}$
 $\cot \beta \rightarrow \text{type II}$

$\cos(\beta - \alpha)$



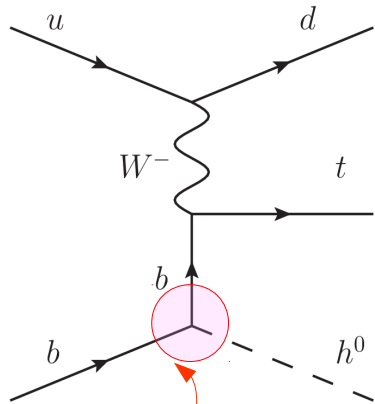
$\sin(\beta - \alpha)$



$\cos \alpha / \sin \beta$

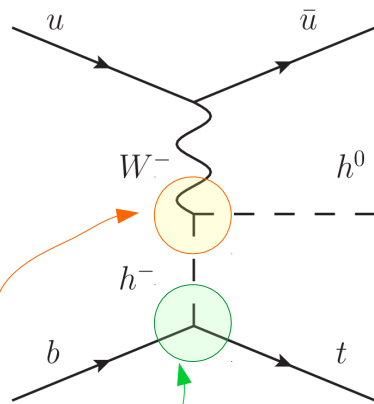
Couplings – th^0 production

Small



$\cos \alpha / \cos \beta \rightarrow \text{type I}$
 $-\sin \alpha / \cos \beta \rightarrow \text{type II}$

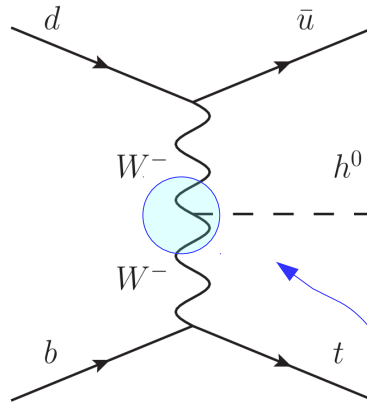
suppressed



$-\cot \beta \rightarrow \text{type I}$
 $\cot \beta \rightarrow \text{type II}$

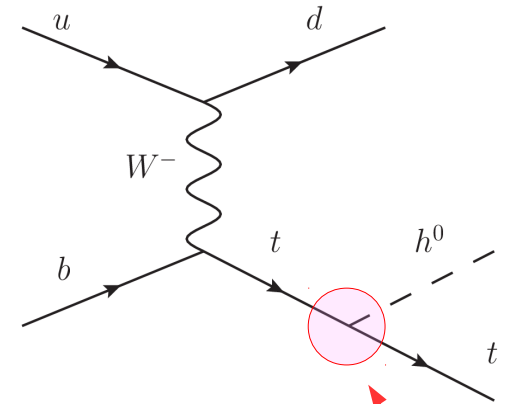
$\cos(\beta - \alpha)$

Big



$\sin(\beta - \alpha)$

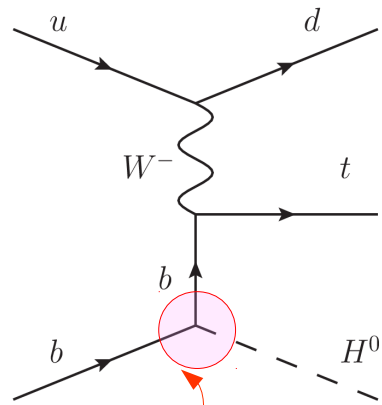
Big



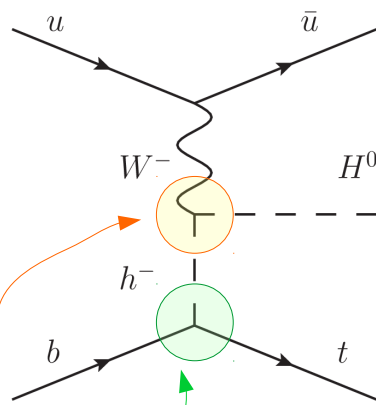
$\cos \alpha / \sin \beta$

Destructive interference between 1,4 $\leftrightarrow$ 3

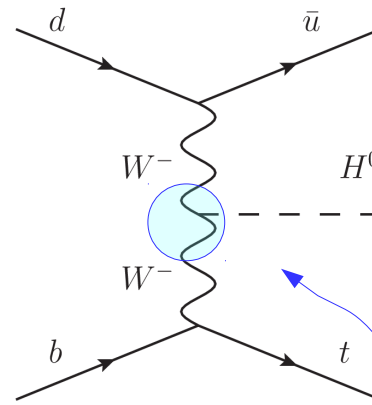
Couplings – tH^0 production



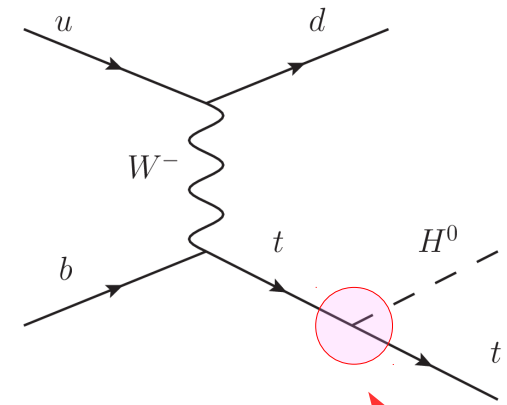
$\sin \alpha / \sin \beta \rightarrow \text{type I}$
 $\cos \alpha / \cos \beta \rightarrow \text{type II}$



$-\cot \beta \rightarrow \text{type I}$
 $\cot \beta \rightarrow \text{type II}$



$\cos(\beta - \alpha)$

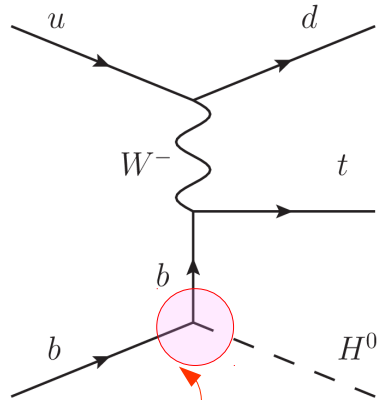


$\sin \alpha / \sin \beta$

$\sin(\beta - \alpha)$

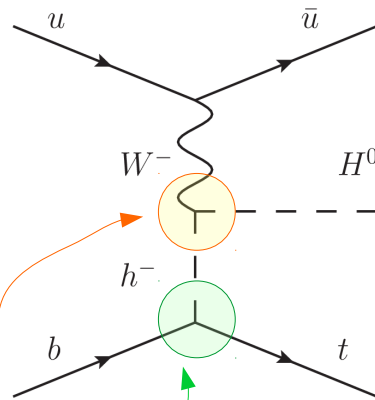
Couplings – tH^0 production

Enhanced



$\sin \alpha / \sin \beta \rightarrow \text{type I}$
 $\cos \alpha / \cos \beta \rightarrow \text{type II}$

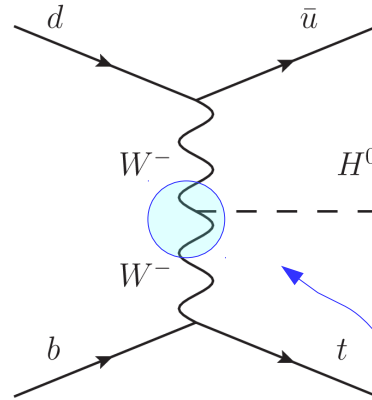
Small



$-\cot \beta \rightarrow \text{type I}$
 $\cot \beta \rightarrow \text{type II}$

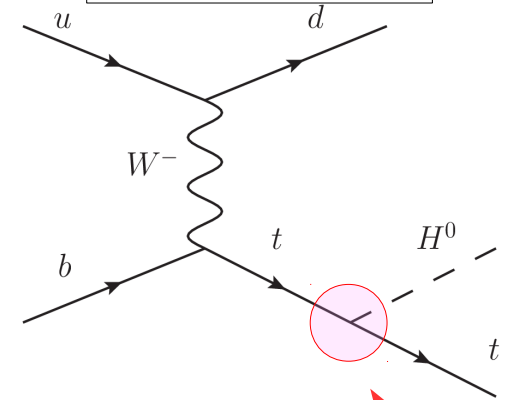
$\sin(\beta-\alpha)$

Suppressed



$\cos(\beta-\alpha)$

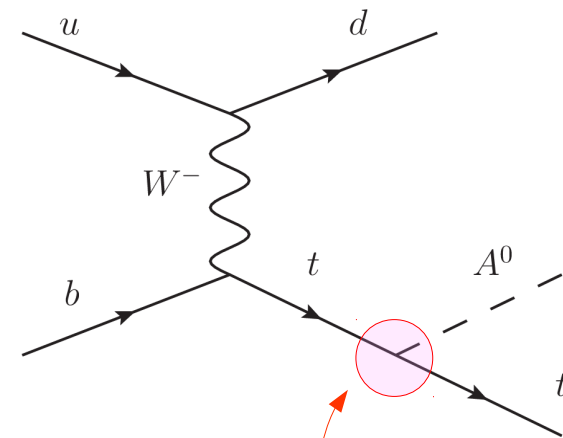
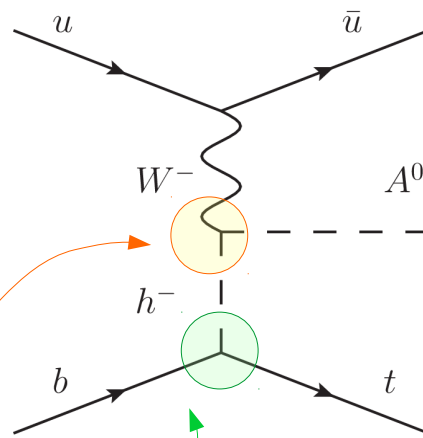
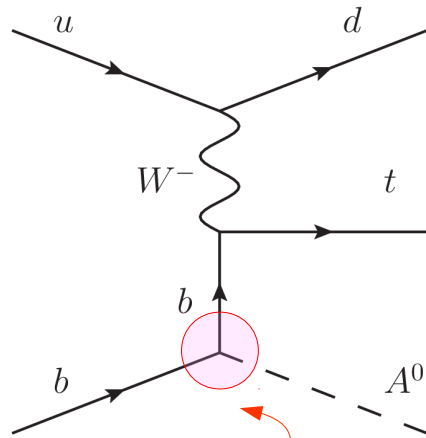
Reduced



$\sin \alpha / \sin \beta$

Destructive interference between 1,4 $\leftrightarrow$ 3

Couplings – tA^0 production



$-\cot \beta \rightarrow \text{type I}$
 $\tan \beta \rightarrow \text{type II}$

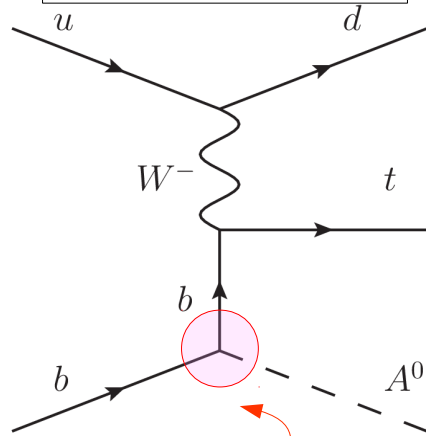
Independent of α, β

$-\cot \beta \rightarrow \text{type I}$
 $\cot \beta \rightarrow \text{type II}$

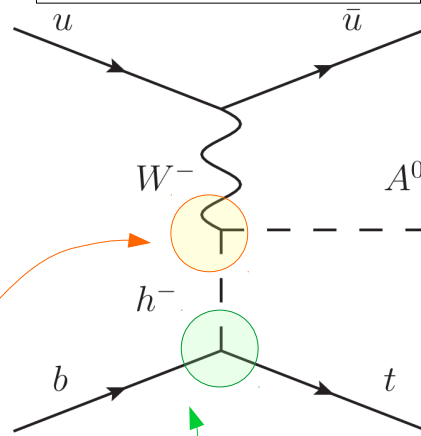
$\cot \beta$

Couplings – tA^0 production

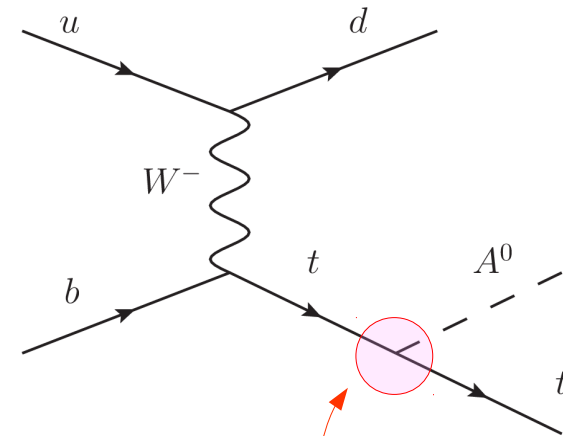
Enhanced



Suppressed



Suppressed



$-\cot \beta \rightarrow \text{type I}$
 $\tan \beta \rightarrow \text{type II}$

$-\cot \beta \rightarrow \text{type I}$
 $\cot \beta \rightarrow \text{type II}$

Independent of α, β

$\cot \beta$

Destructive interference between 1,2 $\leftrightarrow$ 3

MadGraph_aMC@NLO setup

- Run parameters:

- MSTW2008(n)lo68cl,
- dynamical scale $\mu_R=\mu_F= \Sigma_i m_{T_i}/6$, $m_T = (m^2+p_T^2)^{1/2}$
- 14 TeV, $p_{T^j} > 10$ GeV

- Model:

- provided by Céline Degrande, from NLOCT package
- Allows 5F scheme at NLO ($m_b = 0$ but $y_b \neq 0$)

- Plots:

- LO+PY8

Cross section for th^0 production (14 TeV)

	B1	B2	B3	B4	B5	B6	B7	Scale unc.
σ_{2HDM}^{LO}	67.2	66.7	68.0	71.16	68.24	68.38	66.07	+6.4% -10.5%
σ_{SM}^{LO}	68.33							+6.3% -10.6%
σ_{2HDM}^{NLO}	83.68	83.7	84.56	85.46	83.45	83.44	80.75	+6.1% -2.0%
σ_{SM}^{NLO}	83.94							+6.0% -1.7%
K factor	1.25	1.26	1.24	1.20	1.22	1.22	1.22	

No big deviation from the SM

B4 gives a 1.8 % enhancement

B7 gives a 3.8 % decrease

→ Inside the uncertainties

Cross section for tH^0 / tA^0 production (14 TeV)

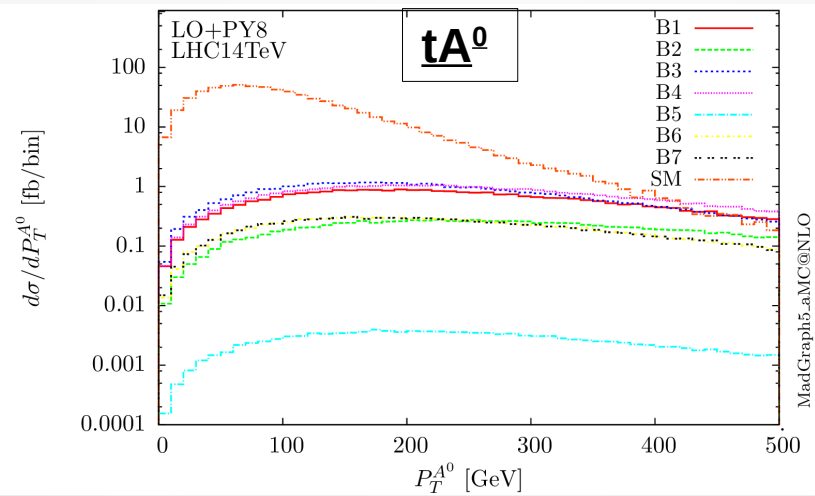
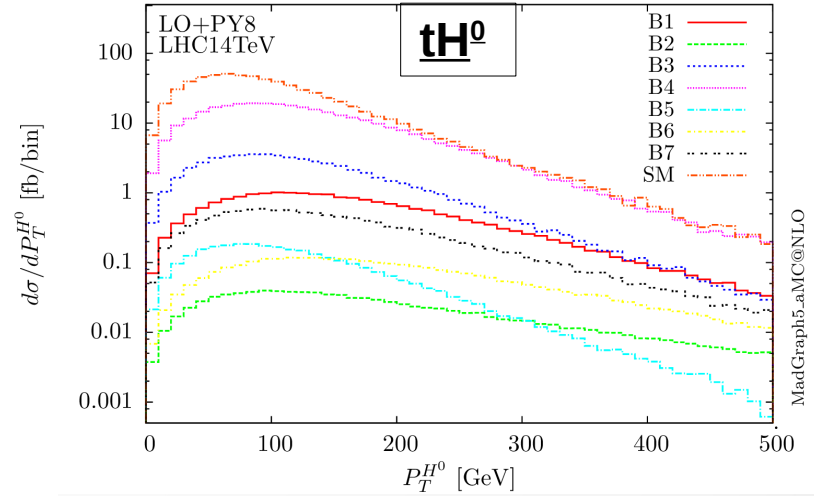
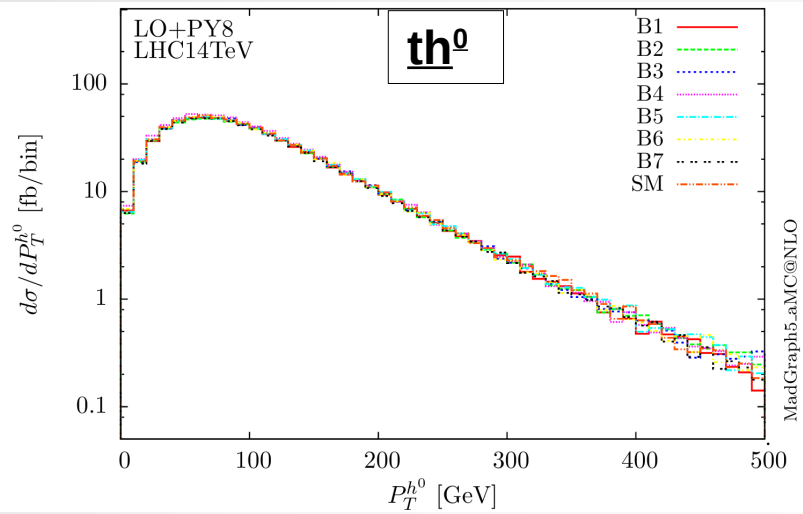
tH^0	B1	B2	B3	B4	B5	B6	B7	Scale
LO	2.211	0.106	6.105	33.69	0.2932	0.31391	1.2	+3.6% -2.9%
NLO	2.17	0.187	5.799	33.98	0.3293	0.3419	1.292	+2.6% -0.6%
K factor	0.98	1.77	0.95	1.01	1.12	1.09	1.08	

Very small production rates
Except for B4 $\rightarrow$ ~40% of the SM

tA^0	B1	B2	B3	B4	B5	B6	B7	Scale
LO	3.442	1.30	4.03	4.3	0.055	1.165	1.161	+0.0% -2.3%
NLO	In progress							
K factor								

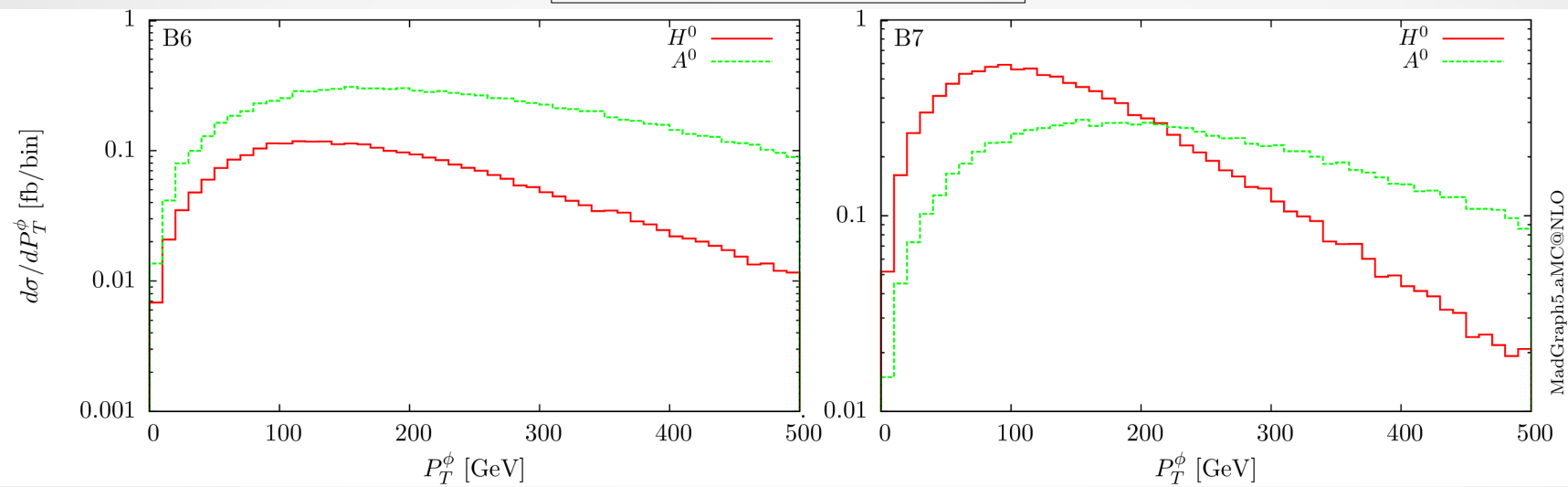
Very small production rates
 B1, B2, B6: bigger than tH^0 production
 B4 biggest

P_T^h distribution

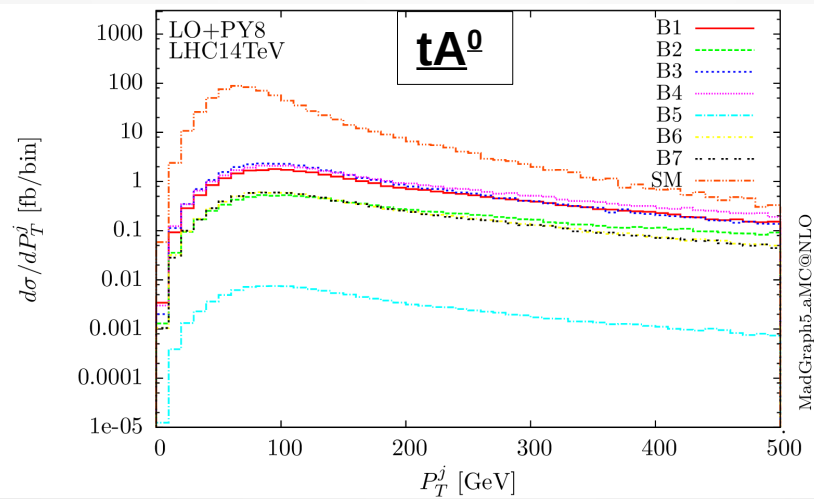
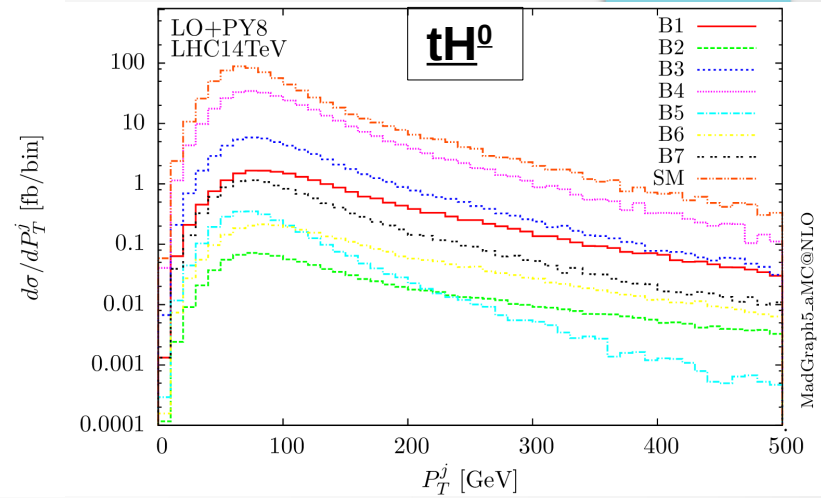
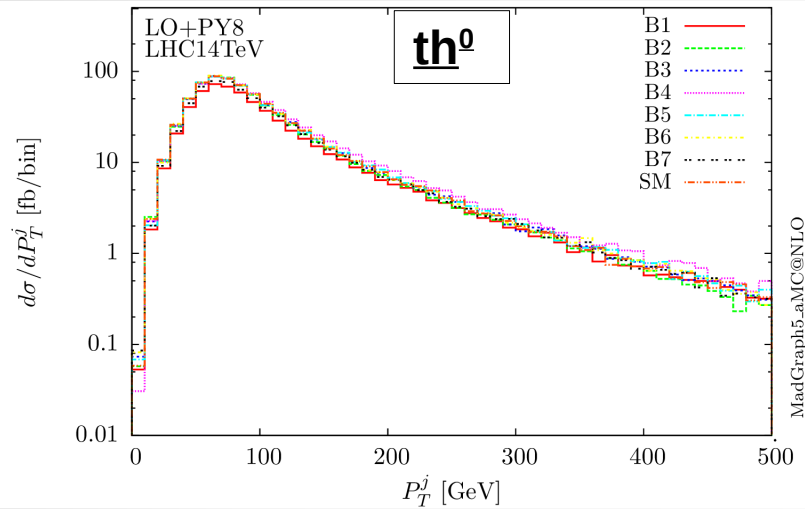


P_T^h distribution

$M_H = M_A = 500 \text{ GeV}$
 $\tan \beta = 10$

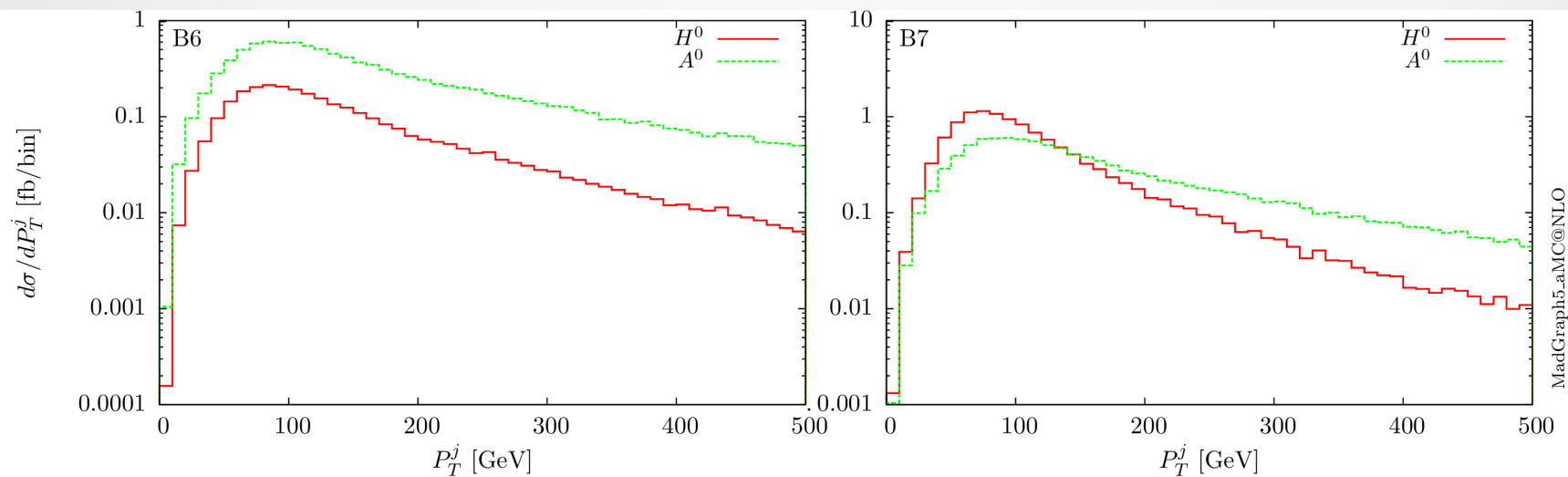


P_T^j distribution

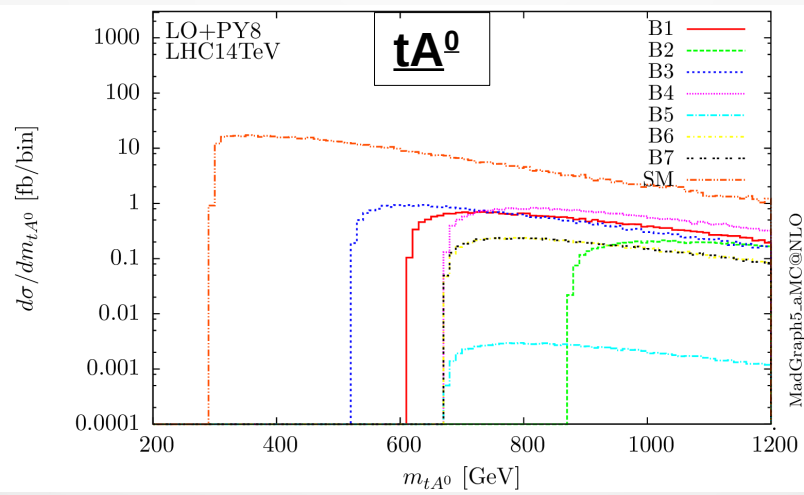
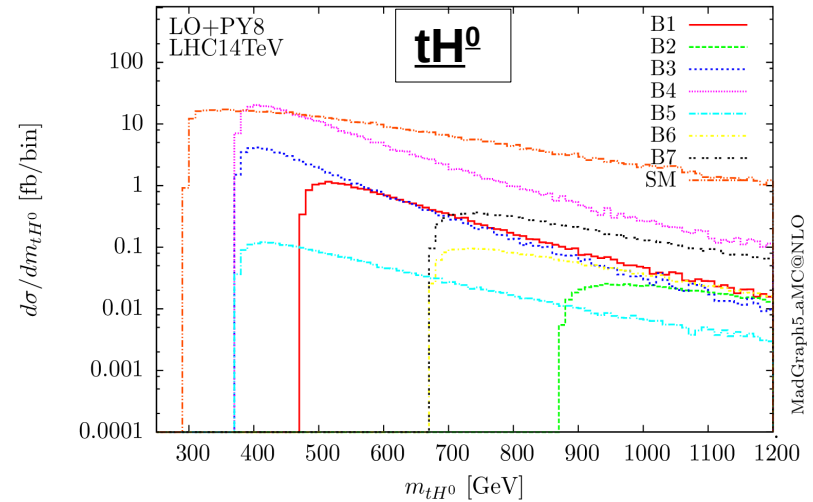
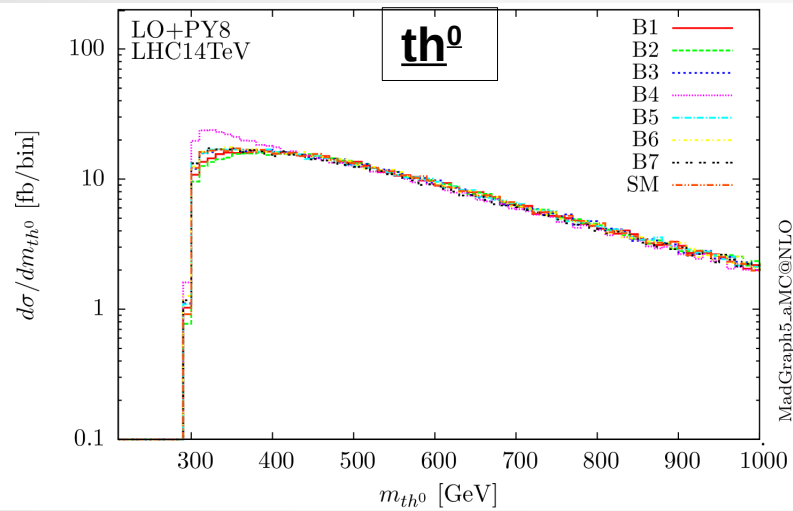


P_T^j distribution

$M_H = M_A = 500 \text{ GeV}$
 $\tan \beta = 10$

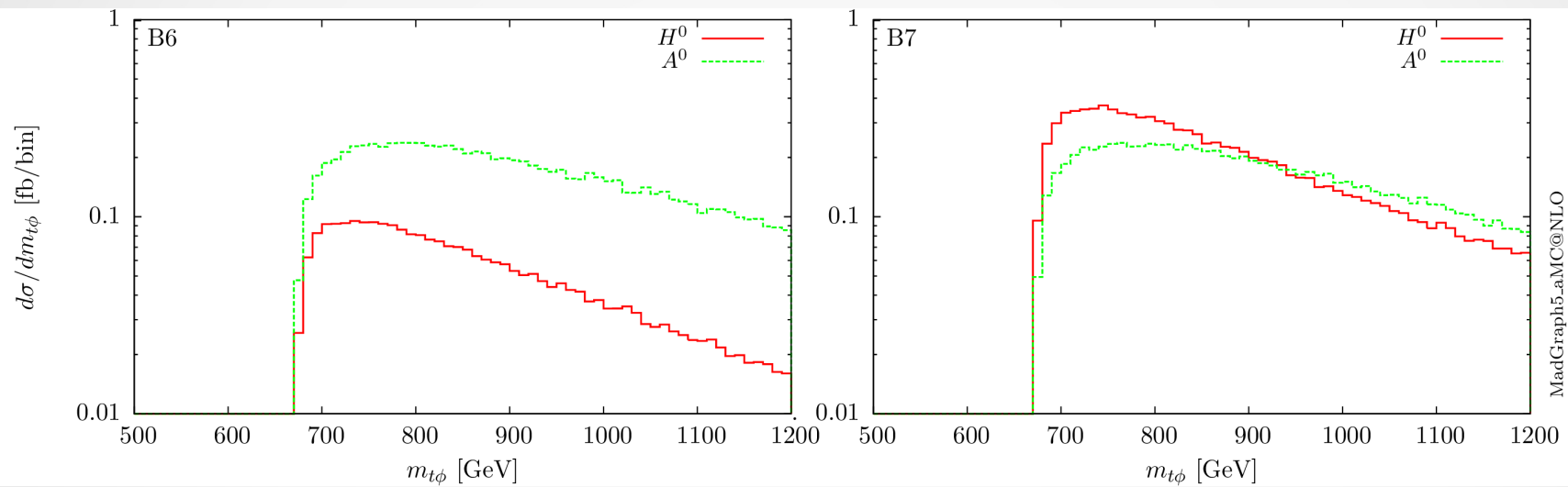


M_{th} distribution

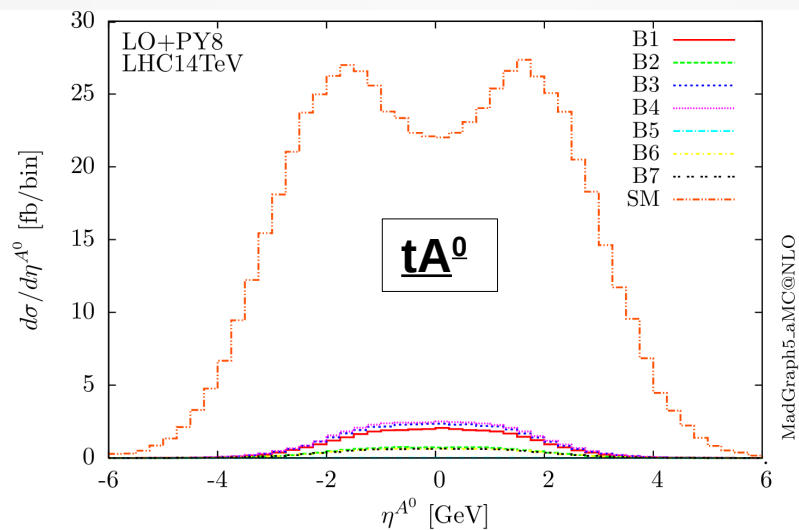
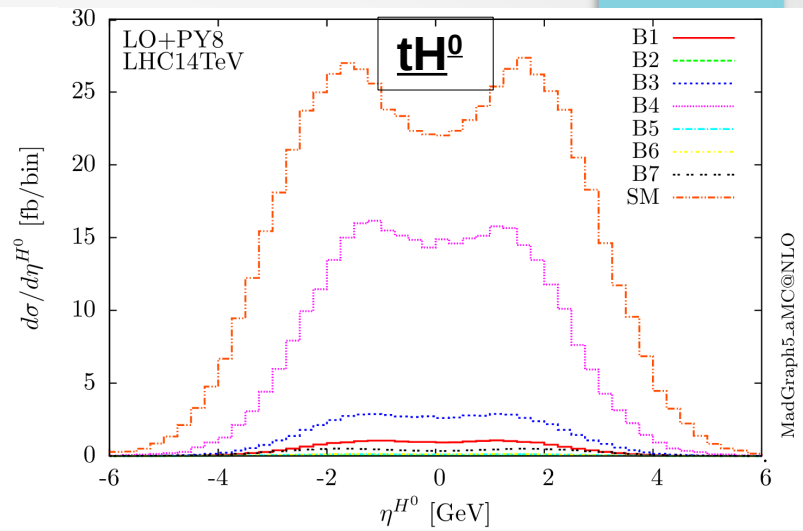
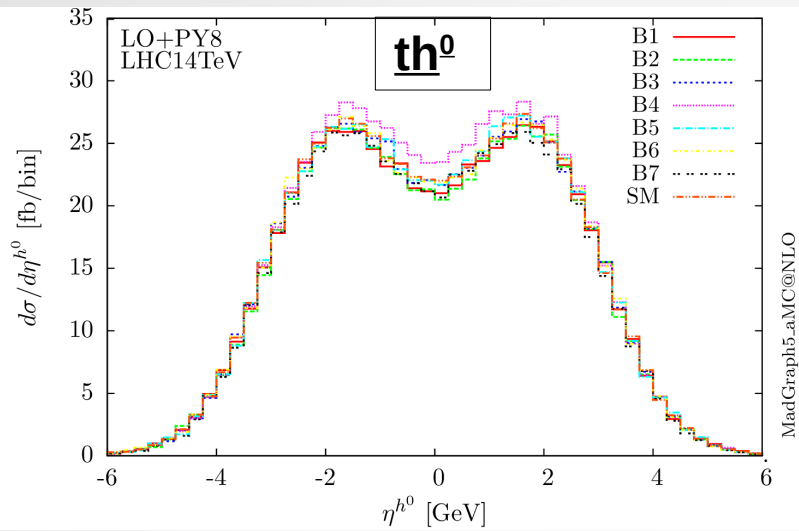


M_{th} distribution

$$M_H = M_A = 500 \text{ GeV}$$
$$\tan \beta = 10$$

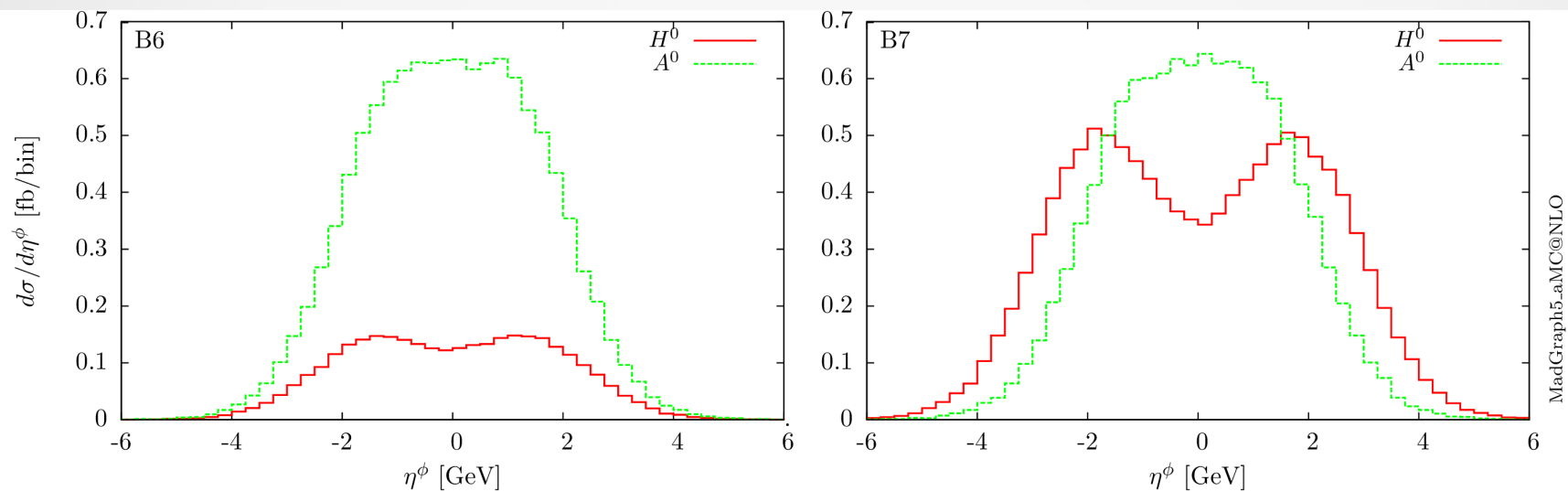


η_h distribution



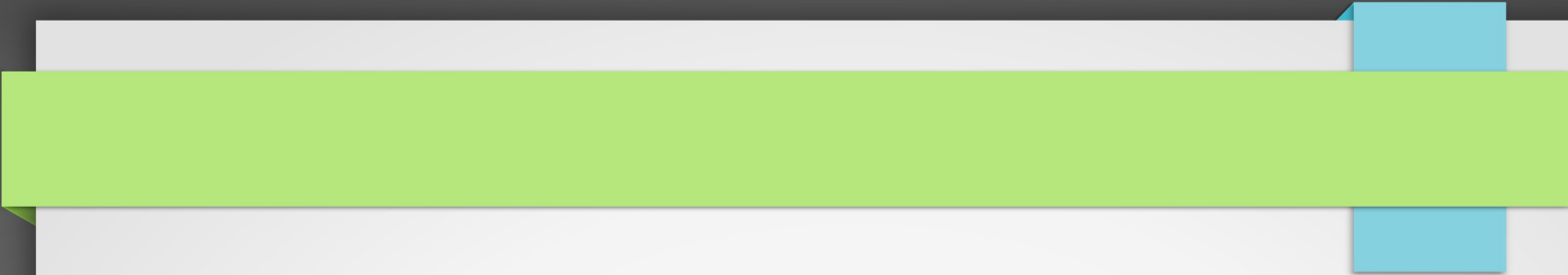
η_h distribution

$M_H = M_A = 500 \text{ GeV}$
 $\tan \beta = 10$



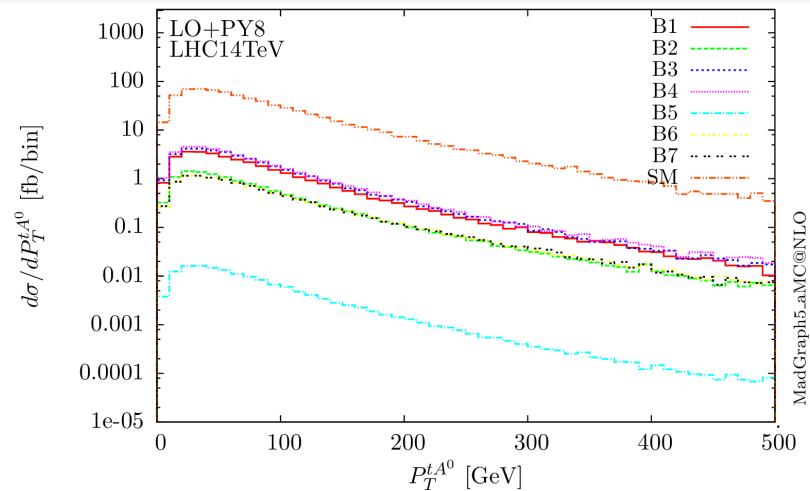
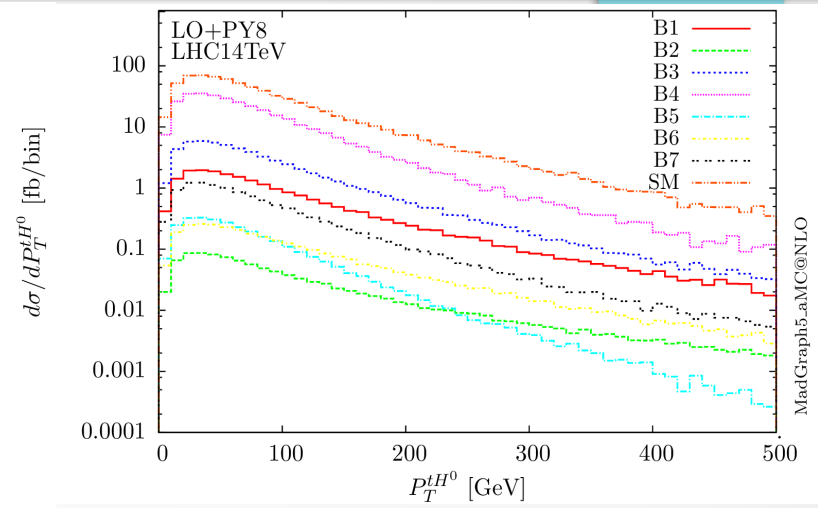
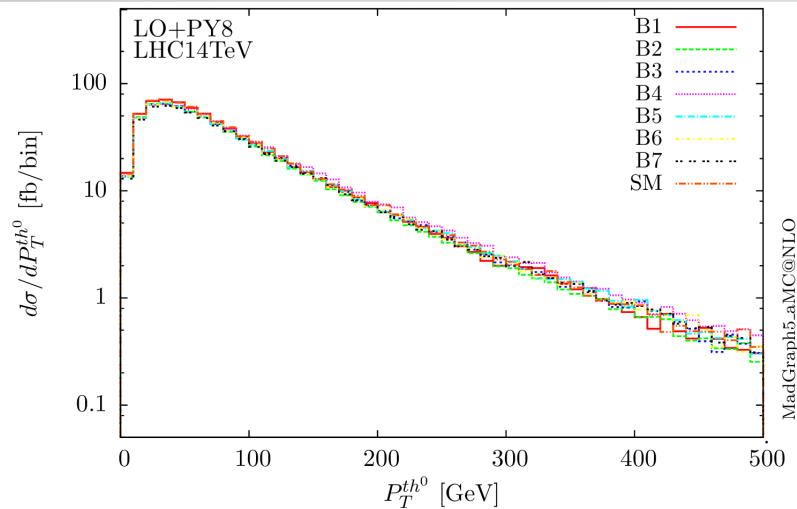
Conclusion

- t h^0 : very similar to the SM rates. Enhancement linked to top Yukawa shifts
- t H^0 : small rates
 - WWH^0 coupling suppressed by $\cos(\beta-\alpha)$
 - top Yukawa reduced
- t A^0 : very small rates
 - Absence of WWA^0 vertex
 - top Yukawa $\sim 1 / \tan \beta \rightarrow$ suppressed

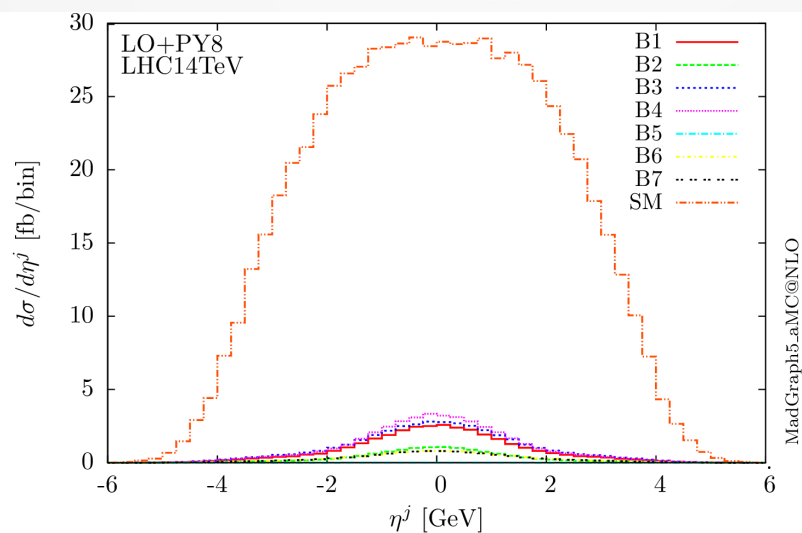
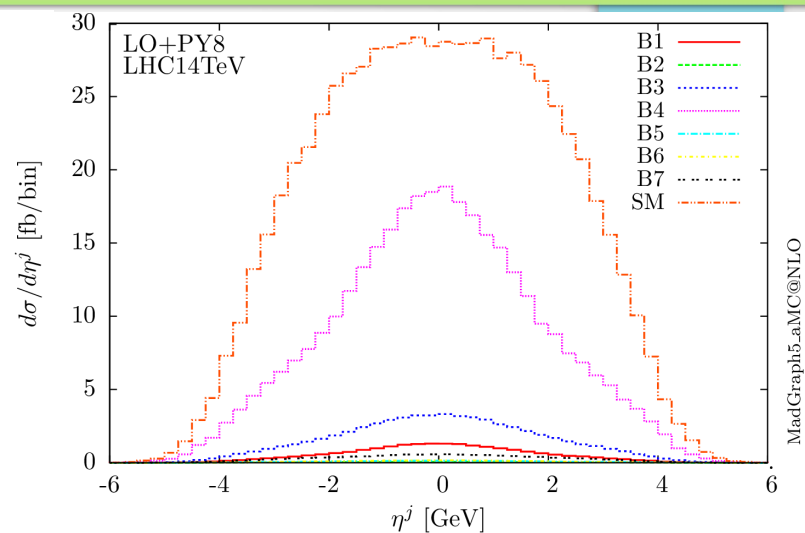
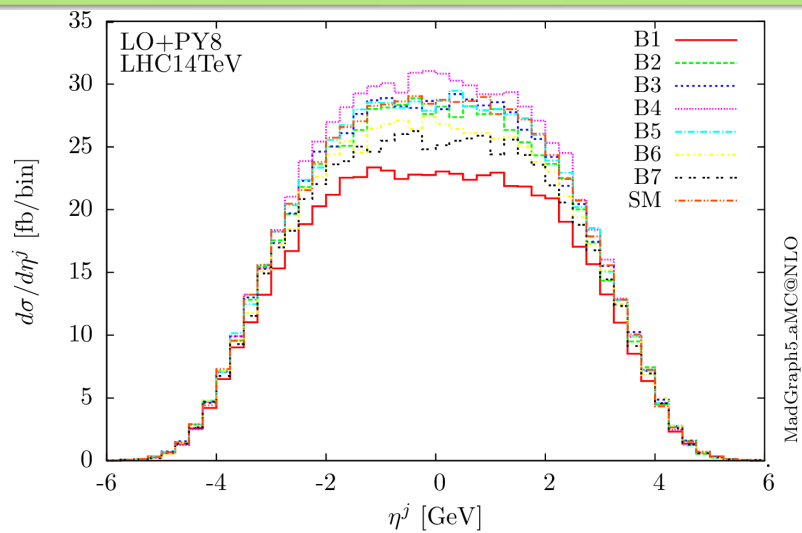


Additional plots

P_T^{ht} distribution



η_j distribution



Benchmark points

7 Benchmarks from our previous HH paper (arxiv:1408.6542)

- **B1** = Type II: Moderate mass hierarchy
- **B2** = Type II: Large mass hierarchy $\rightarrow$ decoupling
- **B3** = Type II: Small mass hierarchy $\rightarrow$ no $H^0 \rightarrow h^0 h^0$
- **B4** = Type I: htt and hbb slightly enhanced
- **B5** = Type I: Fermiophobic heavy Higgs
- **B6** = Type II: Enhanced bottom Yukawa
- **B7** = Type II: Enhanced and flipped bottom Yukawa