Modelling Higgs p_T distributions for heavy Higgs bosons

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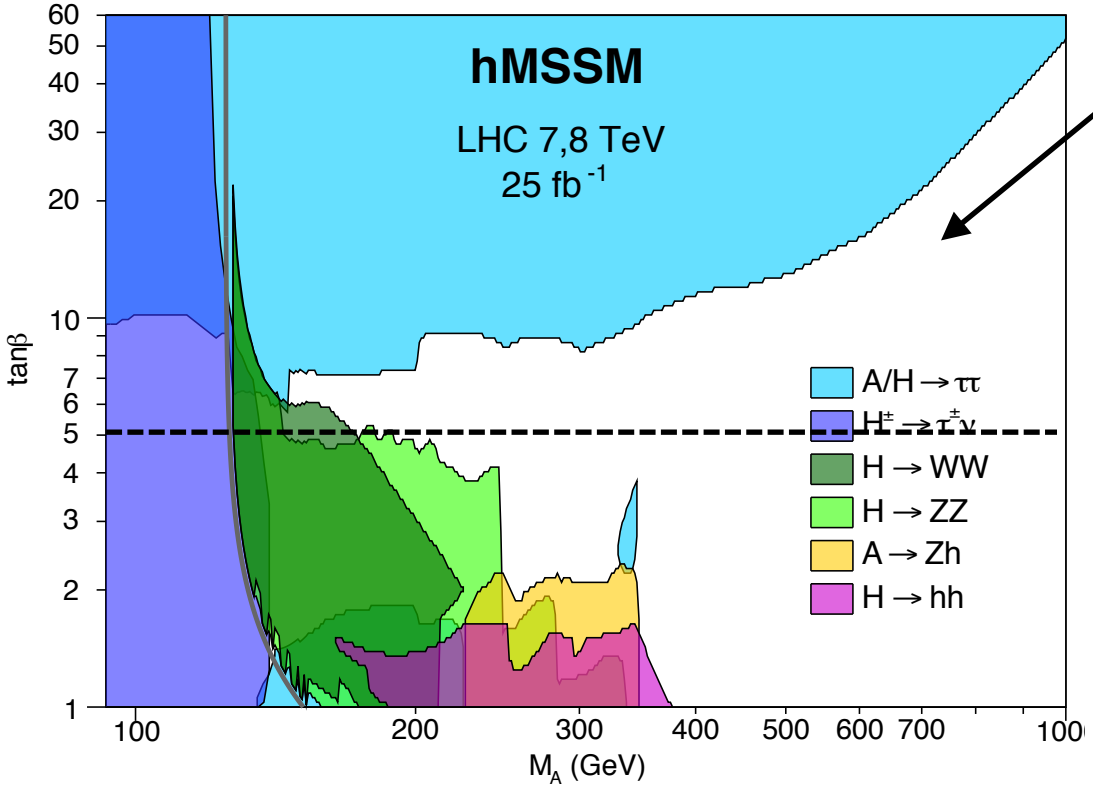
Special thanks : Emanuele, Stefan (DESY theory group)

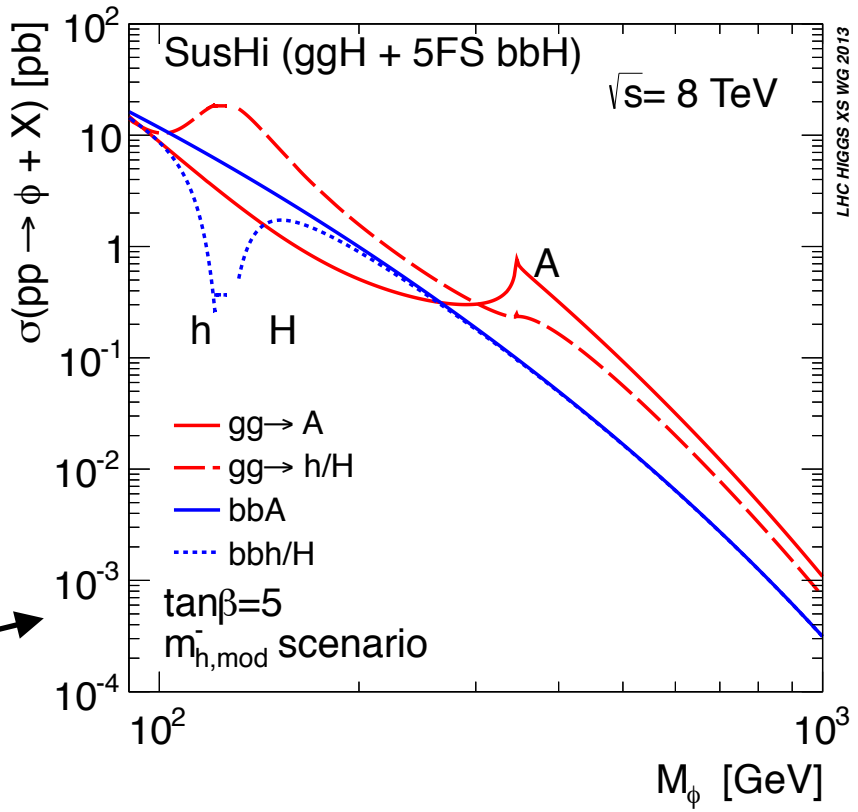
gg → ϕ(h/H/A) is important

A. Djouadi et al, arxiv:1502.05653



Large boost in sensitivity at 13TeV

arXiv:1307.1347

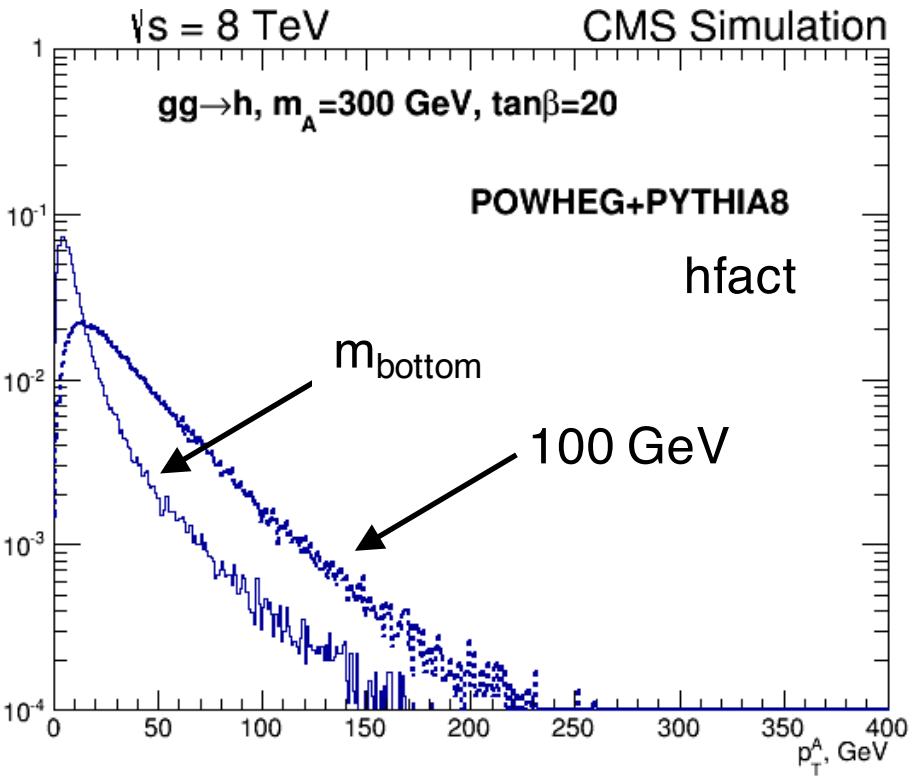


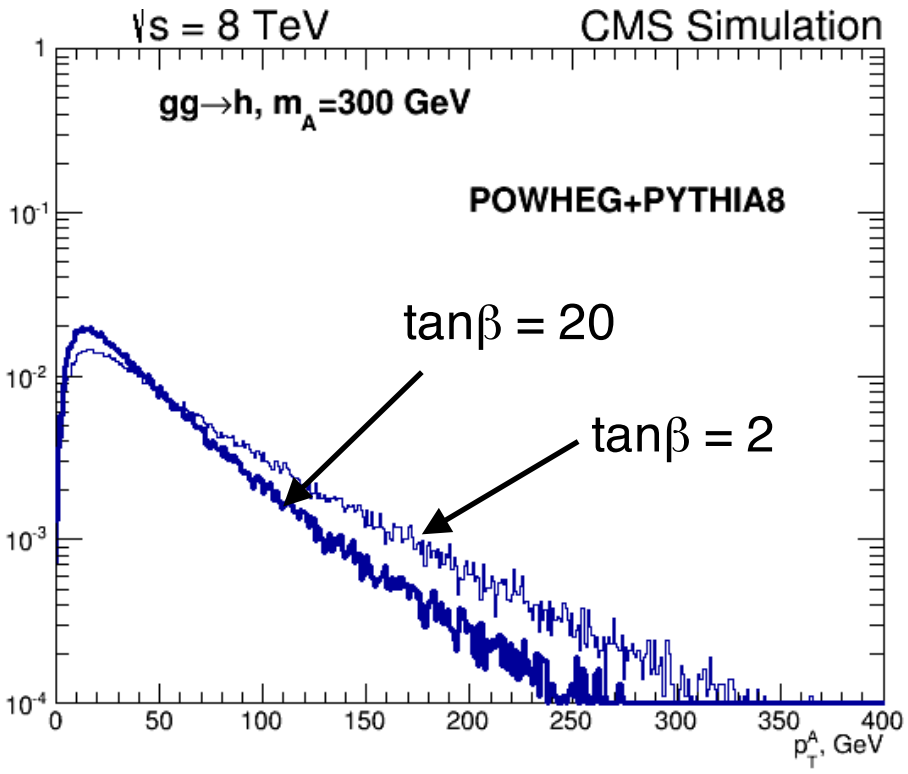
ggH dominates @ low tanβ

Difficulties : Signal generation

Event kinematics is different at each (mϕ, tanβ)

Sasha

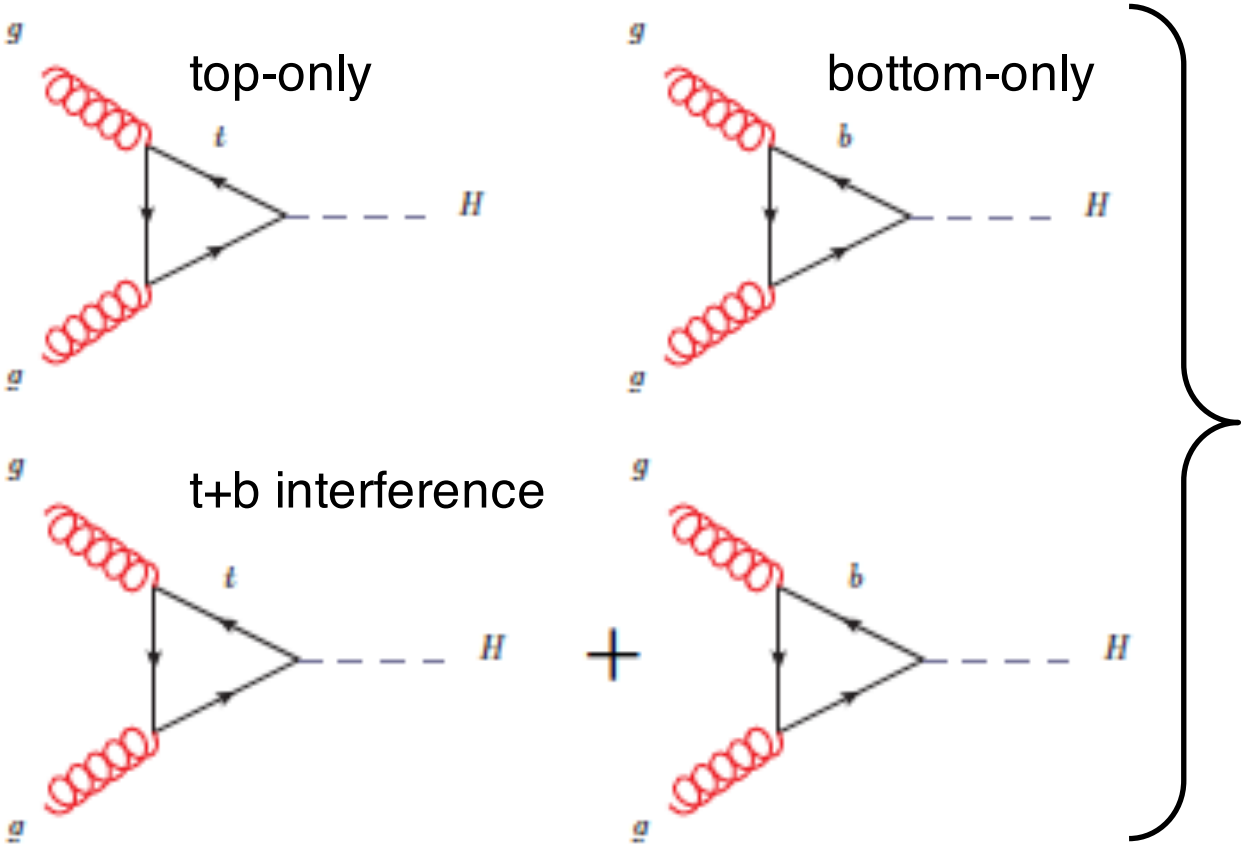




- We don't want to generate NLO signal samples for all (mϕ, tanβ) grid
- How to get correct kinematics w/o too much computation ?

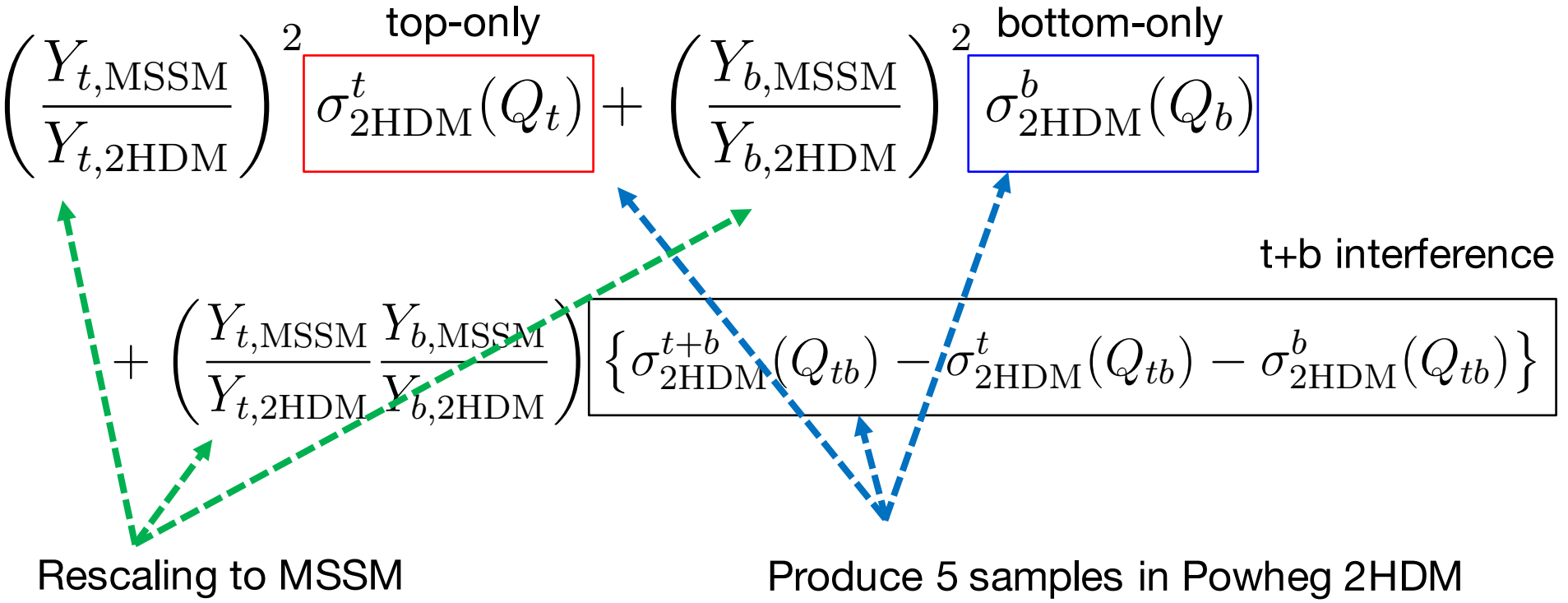
Idea (Simplified picture)

- For the given mass point, we can disentangle the distribution into t-only, b-only and t+b interference part



- Once we generate 3 terms for given mϕ, we can derive full spectrum for arbitrary tanβ, by simple reweighting

Full Formula

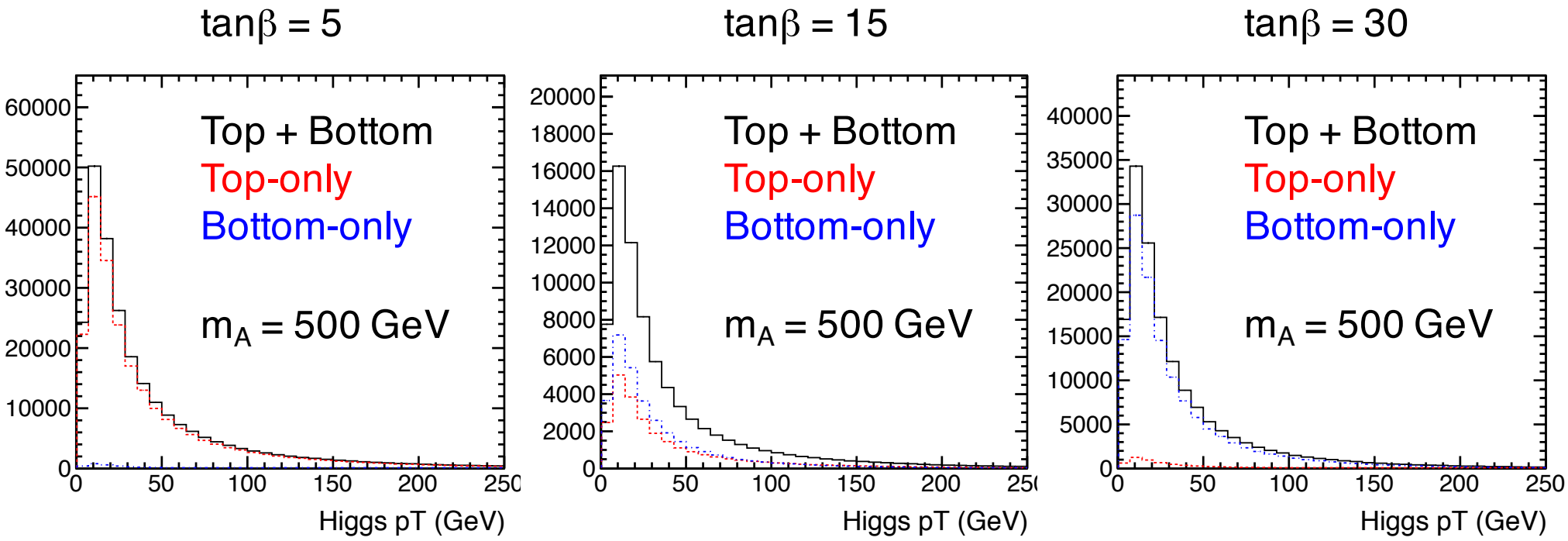


$$\left(\frac{Y_{t,\mathrm{MSSM}}}{Y_{t,2\mathrm{HDM}}}\right)^2 \sigma^{t}_{2\mathrm{HDM}}(Q_t) + \left(\frac{Y_{b,\mathrm{MSSM}}}{Y_{b,2\mathrm{HDM}}}\right)^2 \sigma^{b}_{2\mathrm{HDM}}(Q_b)$$

$$+ \left(\frac{Y_{t,\mathrm{MSSM}}}{Y_{t,2\mathrm{HDM}}}\frac{Y_{b,\mathrm{MSSM}}}{Y_{b,2\mathrm{HDM}}}\right)\left\{\sigma^{t+b}_{2\mathrm{HDM}}(Q_{tb}) - \sigma^{t}_{2\mathrm{HDM}}(Q_{tb}) - \sigma^{b}_{2\mathrm{HDM}}(Q_{tb})\right\}$$

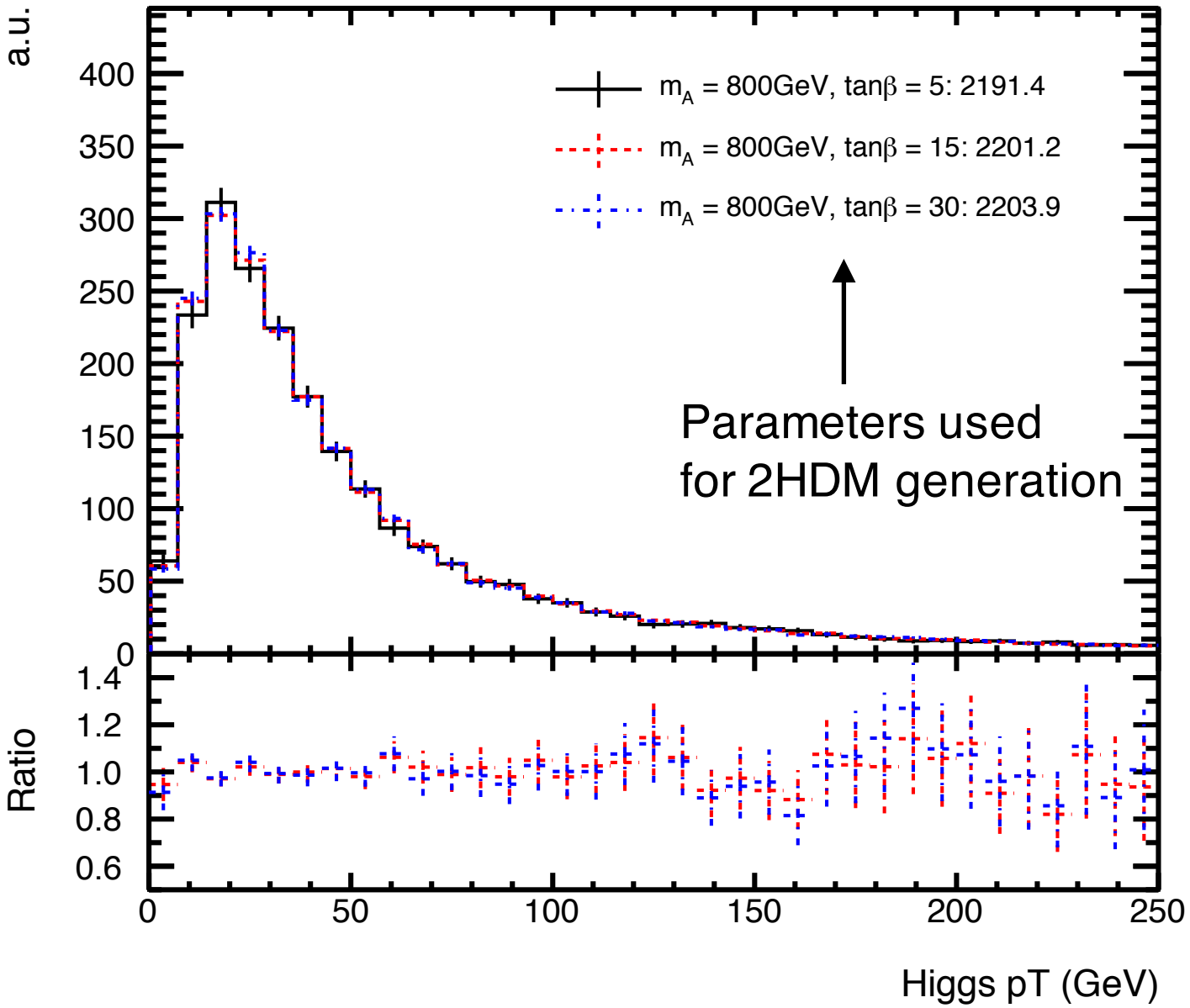
- Rely on 2HDM generation to avoid unnecessary dependence of tanβ to the kinematic distributions
  - Top and bottom-only part clearly not affected
- Crucial point to check : tanβ for the 2HDM generation does not affect interference distribution

3 distributions for interference term in 2HDM (Pseudo-scalar)



- Top-only & bottom-only : Yield depends on tanβ
- Top + bottom : both yield and shape depends on tanβ
- But as a whole, interference term should not depend on tanβ

Interference term @ $m_A = 800$

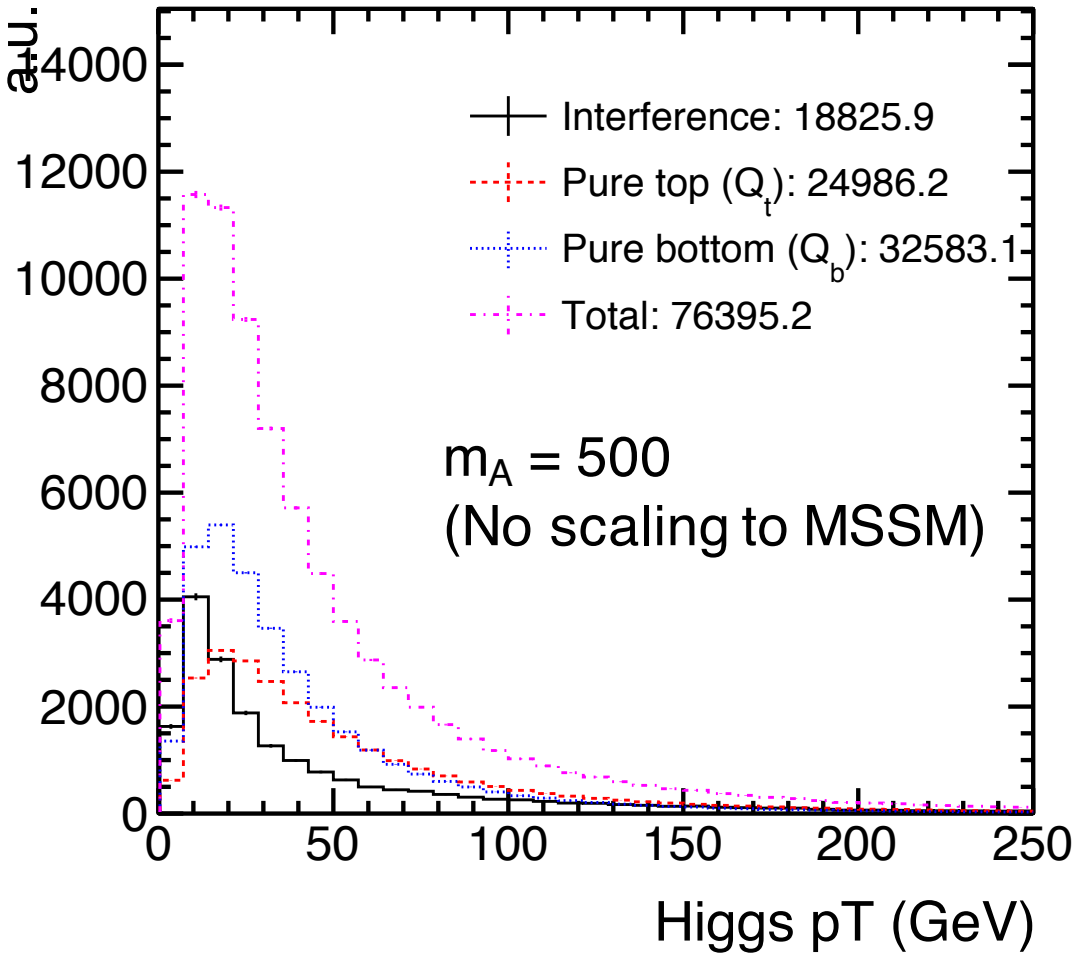


- Indeed, interference term does not depend on tanβ !

Combined distribution (2HDM)

$$\left(\frac{Y_{t,\mathrm{MSSM}}}{Y_{t,2\mathrm{HDM}}}\right)^2 \sigma^t_{2\mathrm{HDM}}(Q_t) + \left(\frac{Y_{b,\mathrm{MSSM}}}{Y_{b,2\mathrm{HDM}}}\right)^2 \sigma^b_{2\mathrm{HDM}}(Q_b)$$

$$+ \left(\frac{Y_{t,\mathrm{MSSM}}}{Y_{t,2\mathrm{HDM}}}\frac{Y_{b,\mathrm{MSSM}}}{Y_{b,2\mathrm{HDM}}}\right)\left\{\sigma^{t+b}_{2\mathrm{HDM}}(Q_{tb}) - \sigma^t_{2\mathrm{HDM}}(Q_{tb}) - \sigma^b_{2\mathrm{HDM}}(Q_{tb})\right\}$$



- Before rescaling to MSSM
- top-only distribution is harder than b-only (as expected)
- The interference term is even softer than b-only and sizable contribution

(tanβ = 15 is used for 2HDM generation)

Rescaling : 2HDM → MSSM

- Let's derive MSSM spectrum for $m_A = 500$, $\tan\beta = 15$ using 2HDM dist. generated with $m_A = 500$, $\tan\beta = 15$
  - $Y_t(\text{2HDM}) = 1/\tan\beta = 1/15$
  - $Y_b(\text{2HDM}) = 1/Y_t(\text{2HDM}) = \tan\beta = 15$
  - $Y_t(\text{MSSM}) = Y_t(\text{2HDM}) = 1/15$
  - $Y_b(\text{MSSM}) = 14.3$, different from 15 due to Δb correction(*)

$$\left(\frac{Y_{t,\text{MSSM}}}{Y_{t,\text{2HDM}}}\right)^2 \sigma^t_{\text{2HDM}}(Q_t) + \left(\frac{Y_{b,\text{MSSM}}}{Y_{b,\text{2HDM}}}\right)^2 \sigma^b_{\text{2HDM}}(Q_b)$$

$$+ \left(\frac{Y_{t,\text{MSSM}}}{Y_{t,\text{2HDM}}}\frac{Y_{b,\text{MSSM}}}{Y_{b,\text{2HDM}}}\right)\left\{\sigma^{t+b}_{\text{2HDM}}(Q_{tb}) - \sigma^t_{\text{2HDM}}(Q_{tb}) - \sigma^b_{\text{2HDM}}(Q_{tb})\right\}$$

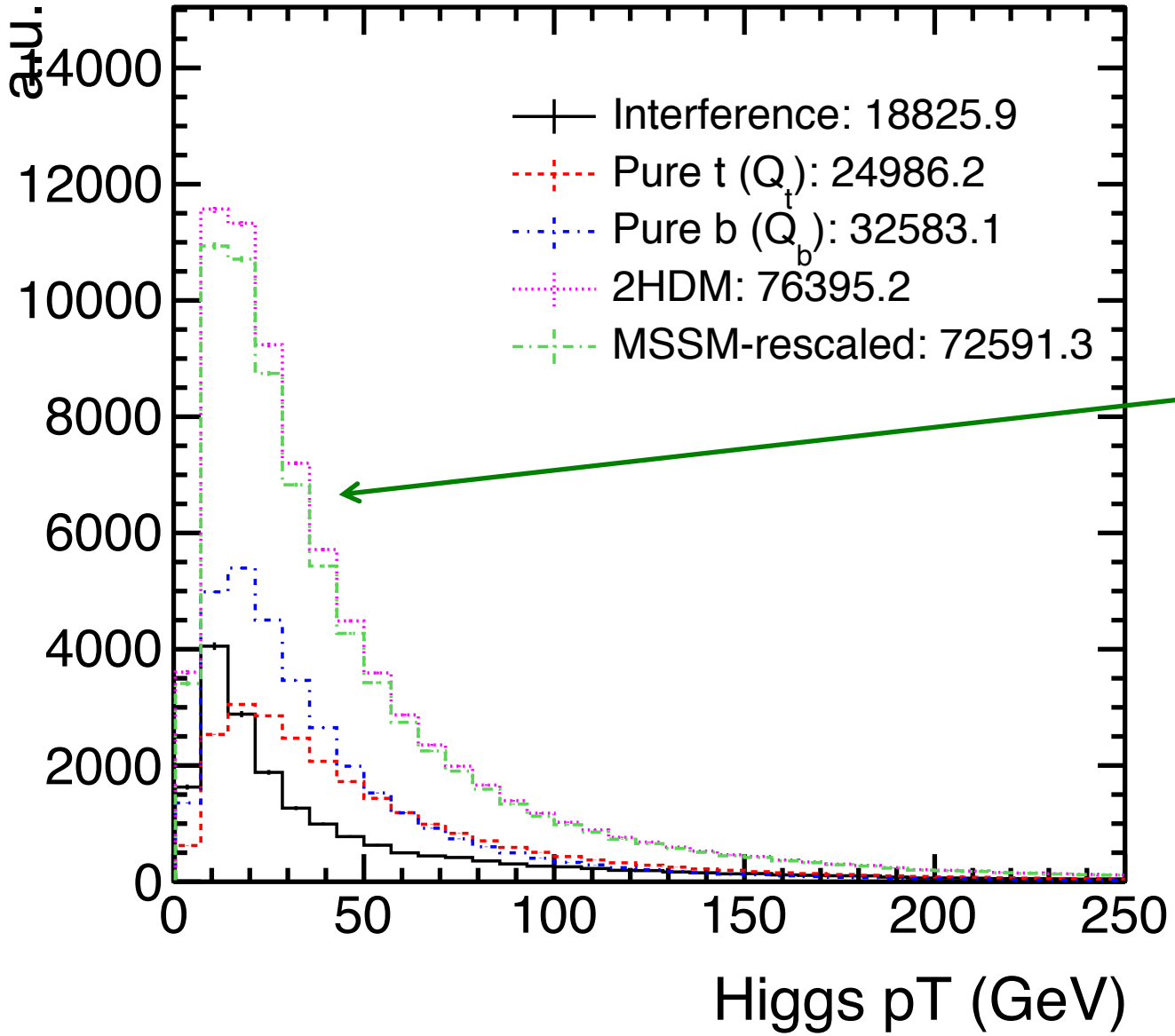
1

$(14.308\ldots/15)^2 \sim 0.9$

1 x $(14.308\ldots/15) \sim 0.95$

(*) http://www.desy.de/~sliebler/LHCHXSWG/

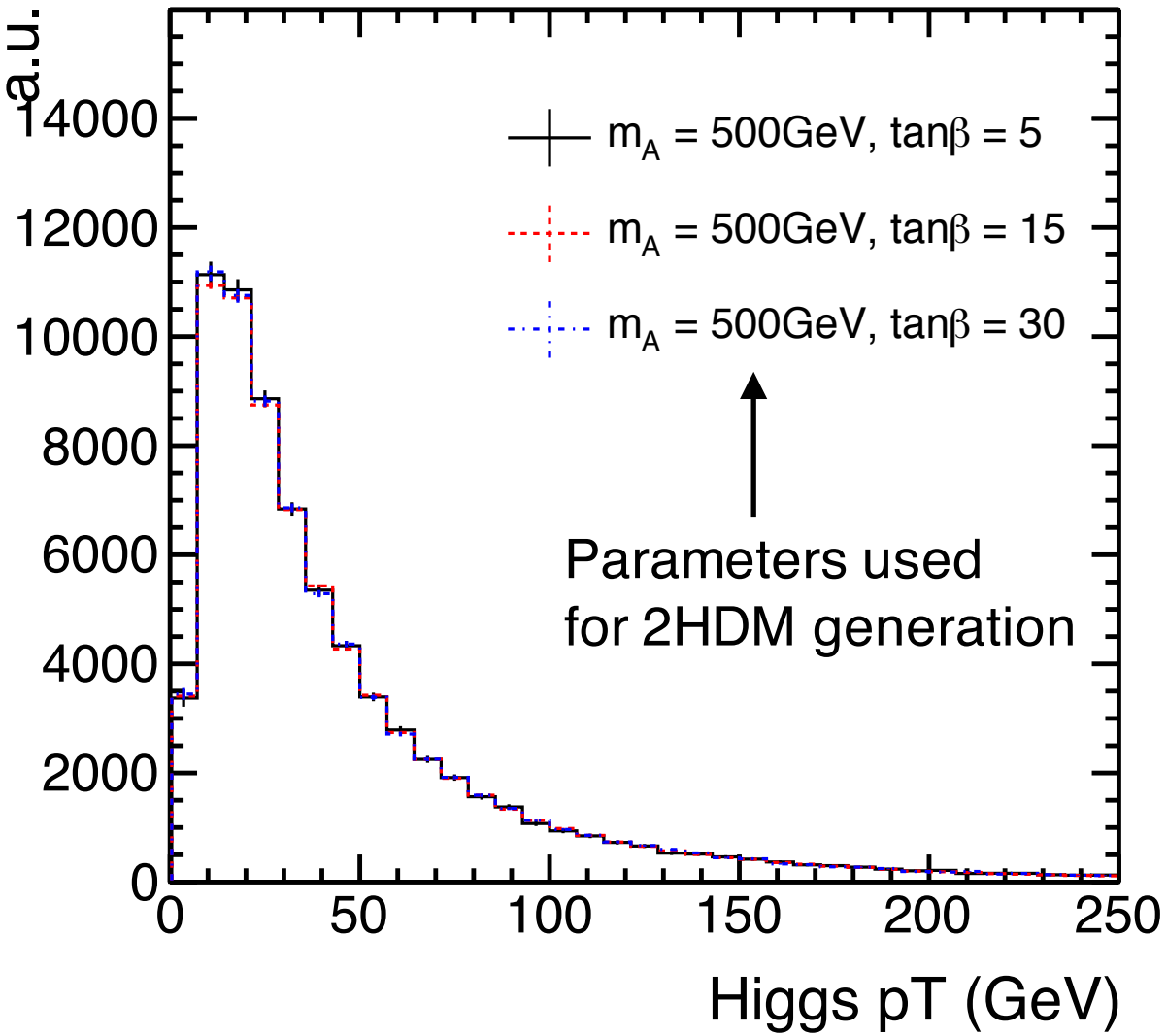
Rescaled dist. for MSSM



- Due to the down-scaling of bottom and interference contribution, the resulting MSSM distribution becomes slightly harder than 2HDM case

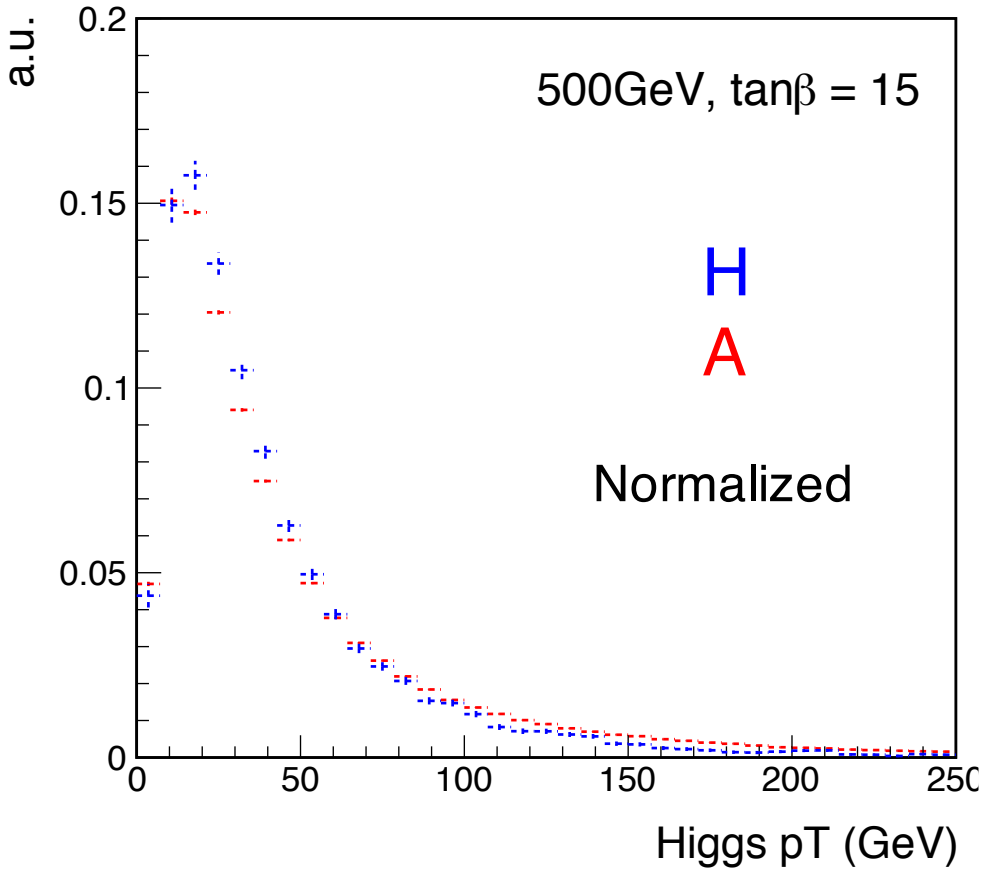
Comparison of full MSSM spectrum : Pseudo-scalar

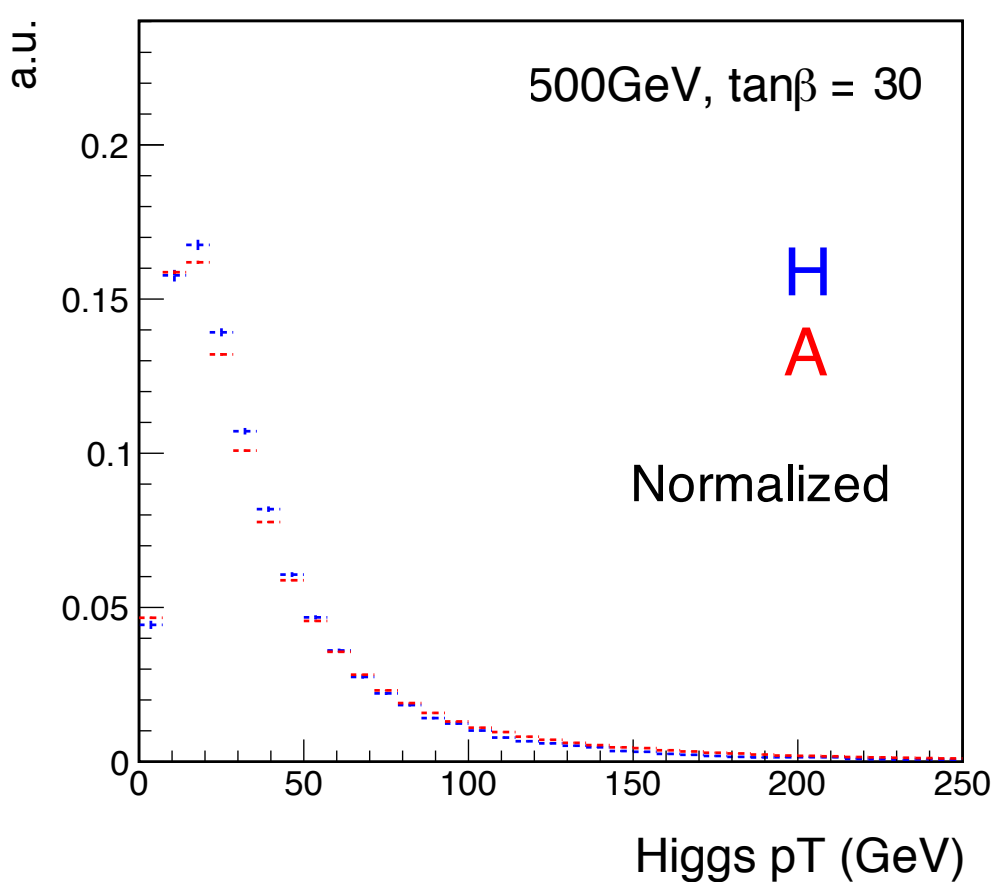
Rescaling to :
m_A = 500 GeV, tanβ = 15
(for MSSM)



- All consistent
- The results does not depend on tanβ used for 2HDM generation

Comparison between H and A





- In general, H and A does not have same distribution
  - Pseudo-scalar has additional γ^5 in the loop !
  - Pseudo-scalar seems to be slightly harder than Heavy scalar
- Need separate generation for pseudo and scalar Higgs

Conclusion

- We could setup the machinery to generate Higgs p_T spectrum for desired $m\phi$ and $\tan\beta$ point
  - Once we generate 5 samples for the given mass point, one can derive full Higgs p_T spectrum for desired $\tan\beta$
  - Interference term is not affected by the $\tan\beta$ choice, used for the 2HDM generation

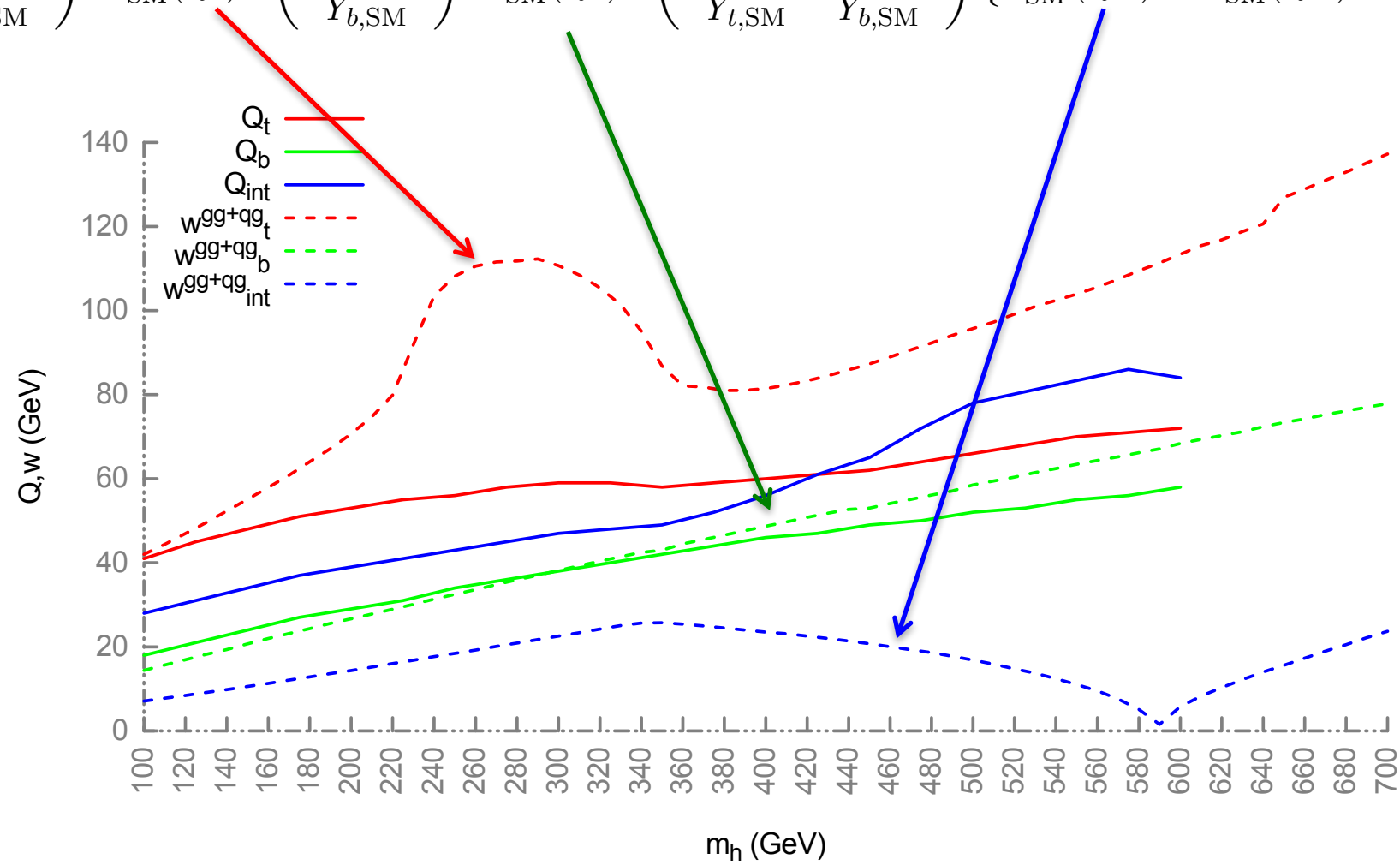
- The machinery works for both pseudo-scalar and Heavy Higgs signal
  - The shape is different → need separate generation

- Reweighting tool is ready
  - https://github.com/CMS-HTT/NLOReweightingTool

- Analysis Note (AN-16-142) is ready

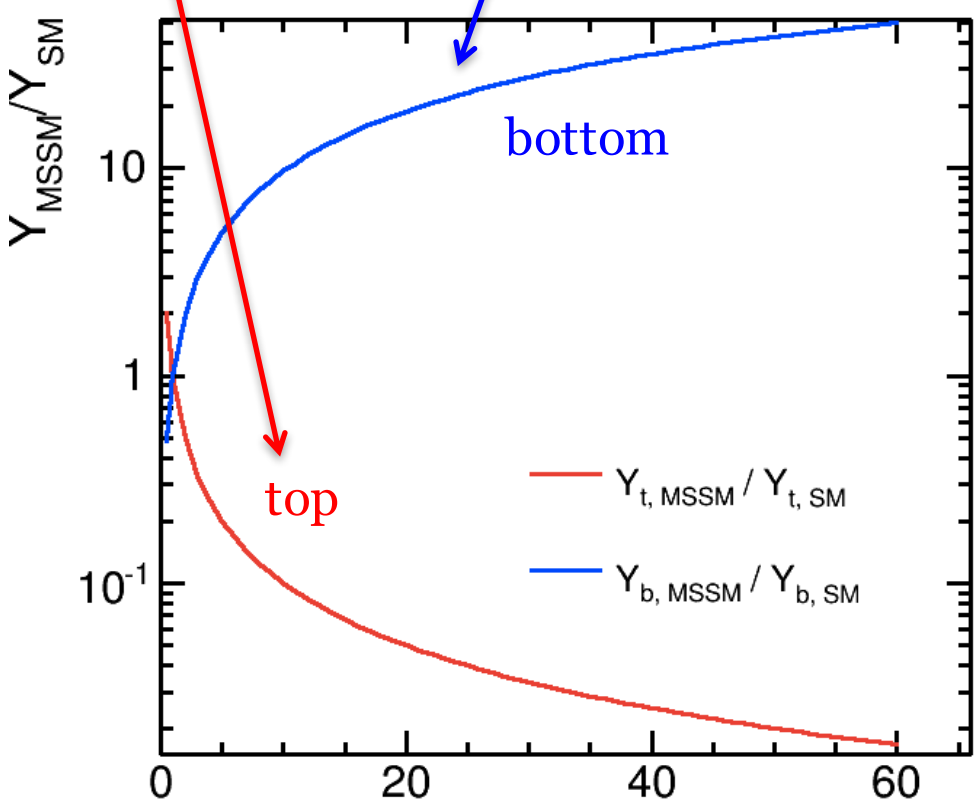
Resummation scale vs mϕ

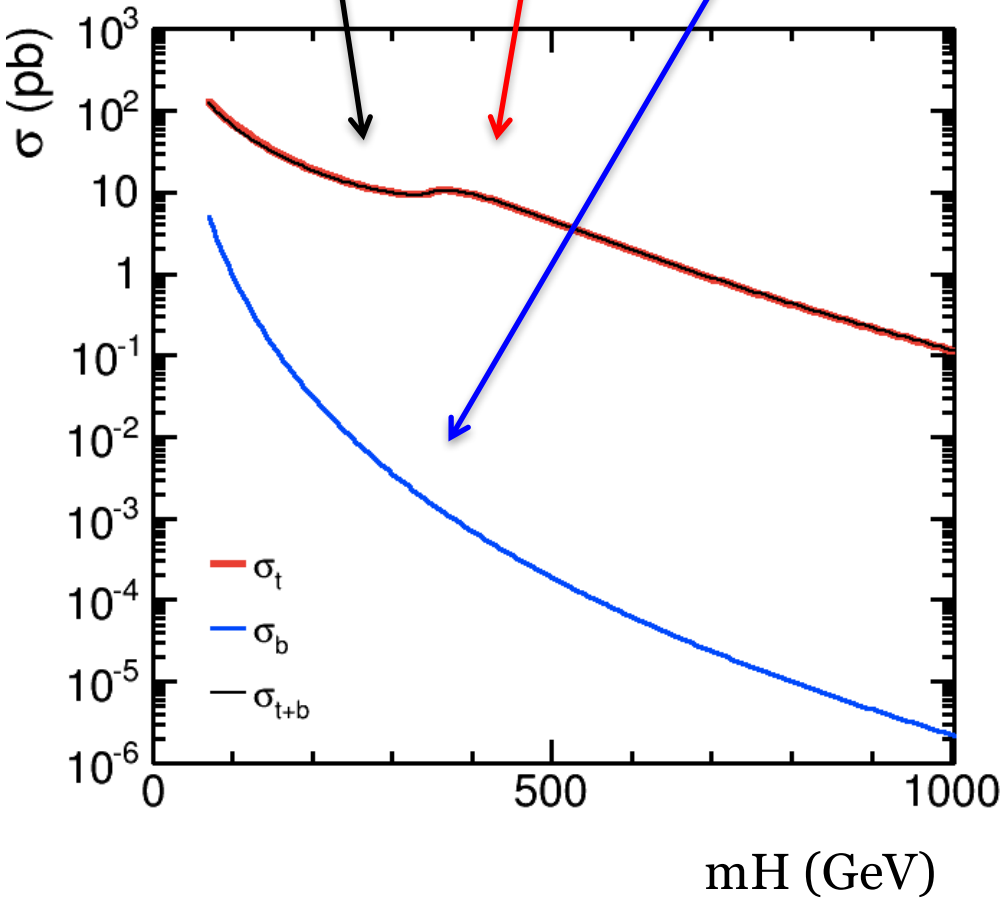
$$\left(\frac{Y_{t,\mathrm{MSSM}}}{Y_{t,\mathrm{SM}}}\right)^2 \sigma^t_{\mathrm{SM}}(Q_t) + \left(\frac{Y_{b,\mathrm{MSSM}}}{Y_{b,\mathrm{SM}}}\right)^2 \sigma^b_{\mathrm{SM}}(Q_b) + \left(\frac{Y_{t,\mathrm{MSSM}}}{Y_{t,\mathrm{SM}}}\frac{Y_{b,\mathrm{MSSM}}}{Y_{b,\mathrm{SM}}}\right) \left\{\sigma^{t+b}_{\mathrm{SM}}(Q_{tb}) - \sigma^t_{\mathrm{SM}}(Q_{tb}) - \sigma^b_{\mathrm{SM}}(Q_{tb})\right\}$$



Emanuele Bagnaschi, Alessandro Vicini, arXiv:1505.00735
R. V. Harlander, H. Mantler, Marius Wiesemann, arXiv:1409.0531

$$\left(\frac{Y_{t,\mathrm{MSSM}}}{Y_{t,\mathrm{SM}}}\right)^2 \sigma^t_{\mathrm{SM}}(Q_t) + \left(\frac{Y_{b,\mathrm{MSSM}}}{Y_{b,\mathrm{SM}}}\right)^2 \sigma^b_{\mathrm{SM}}(Q_b) + \left(\frac{Y_{t,\mathrm{MSSM}}}{Y_{t,\mathrm{SM}}}\frac{Y_{b,\mathrm{MSSM}}}{Y_{b,\mathrm{SM}}}\right) \left\{\sigma^{t+b}_{\mathrm{SM}}(Q_{tb}) - \sigma^t_{\mathrm{SM}}(Q_{tb}) - \sigma^b_{\mathrm{SM}}(Q_{tb})\right\}$$



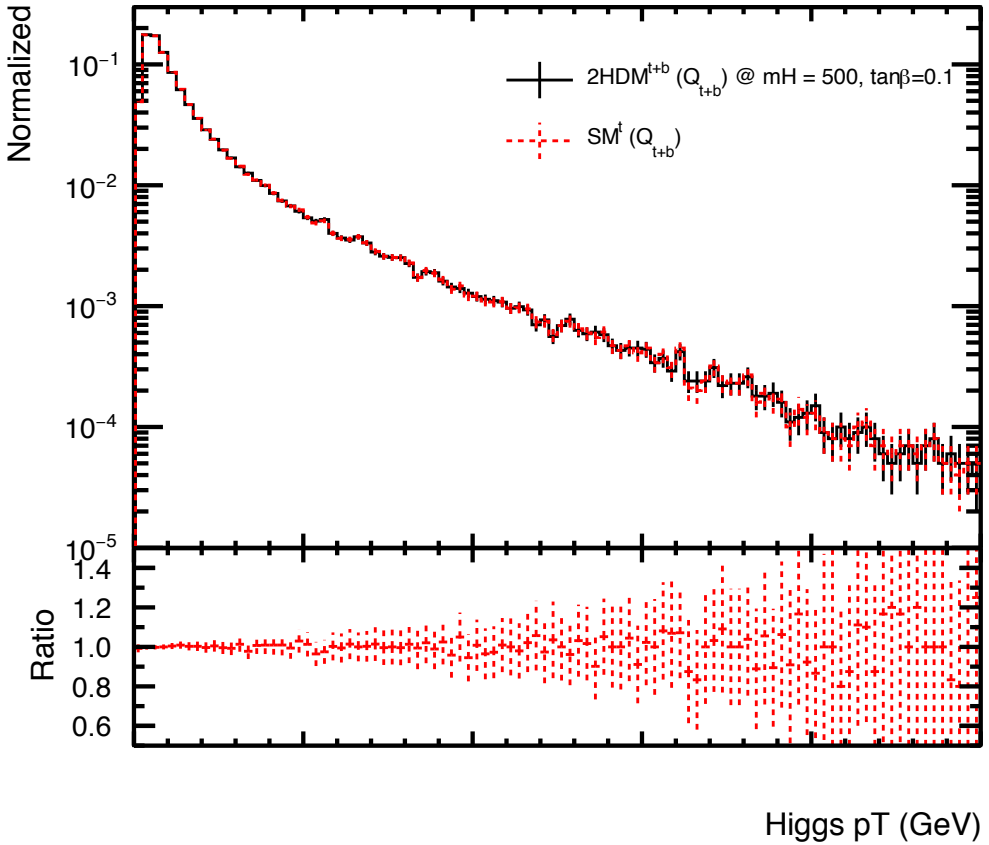


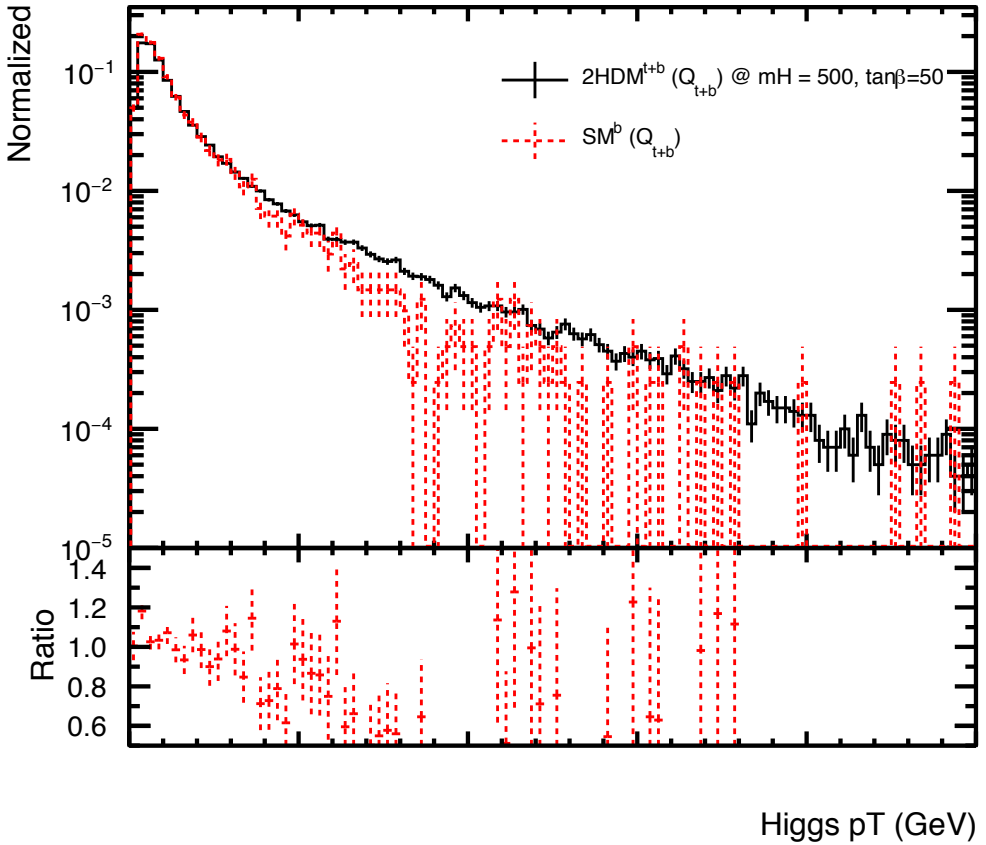
Based on *SuShi*, linked to FeynHiggs for MSSM Yukawa coupling evaluation

Stefan Liebler
http://www.desy.de/~sliebler/LHCHXSWG

Backup

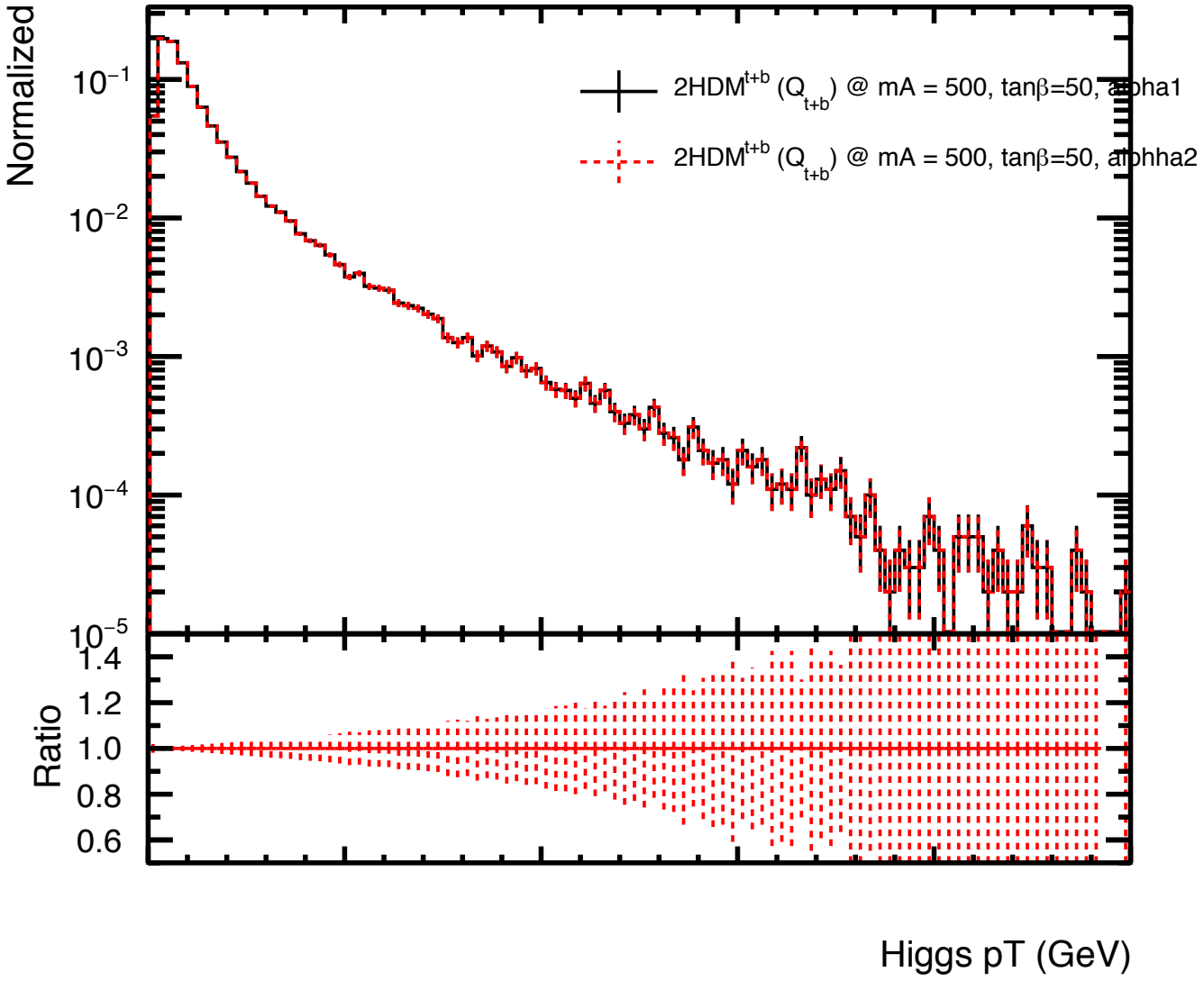
- Decoupling limit cos(alpha - beta) = 0





CHANGE !

Dependence on alpha



Pseudo-scalaar
Does not depend on
Alpha, as expected

Powheg settings

Important parameters to be set in “gg_H_2HDM”

```
(example : mA = 500, tan(beta) = 10, resum. scale = Qtb)

hfact    17d0   (depends on resummation scale)
…

hmass  500              ! Higgs boson mass
topmass 172.5           ! top quark mass
bottommass 4.75d0       ! bottom quark mass

hdecaywidth 0           ! If equals to 1 read total decay width
from HDECAY

higgstype 3 (pseudo-scalar.  1 : h, 2 : heavy Higgs, H)
2HDMtype 2
tanb 10d0 (the value you want)
notop 1 (in case bottom-only)
nobot 1 (in case top-only)
```

tanβ choice ?

- Which tan(beta) value is appropriate for the interference calculation ?

Numbers in the table : weighted sum of events

m_A = 500	Top + bottom	Top-only	Bottom-only	Interference
tanβ = 5	247709	224860	3621	19227 ± 489
tanβ = 15	76442	25007	32558	19260 ± 126
tanβ = 30	155866	6251	130354	19260 ± 320

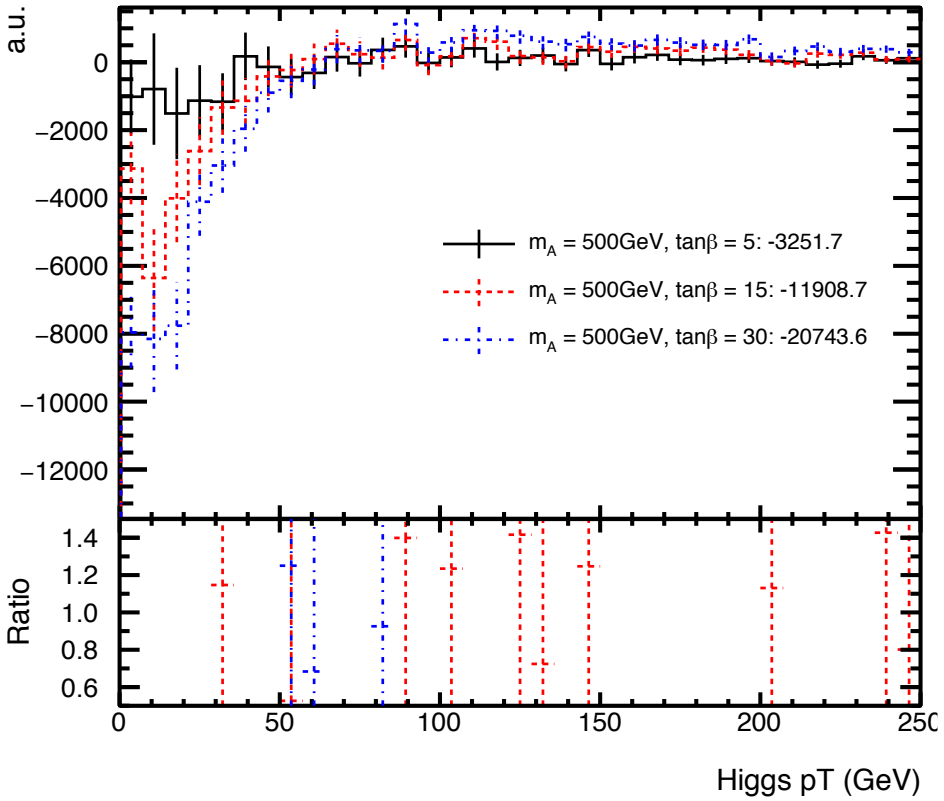
m_A = 800	Top + bottom	Top-only	Bottom-only	Interference
tanβ = 5	17815	15436	188	2191 ± 27
tanβ = 15	5607	1715	1691	2201 ± 7
tanβ = 30	9397	429	6764	2204 ± 14

- Intermediate tan(beta), where neither top nor bottom dominate the spectrum, seems to be the best choice

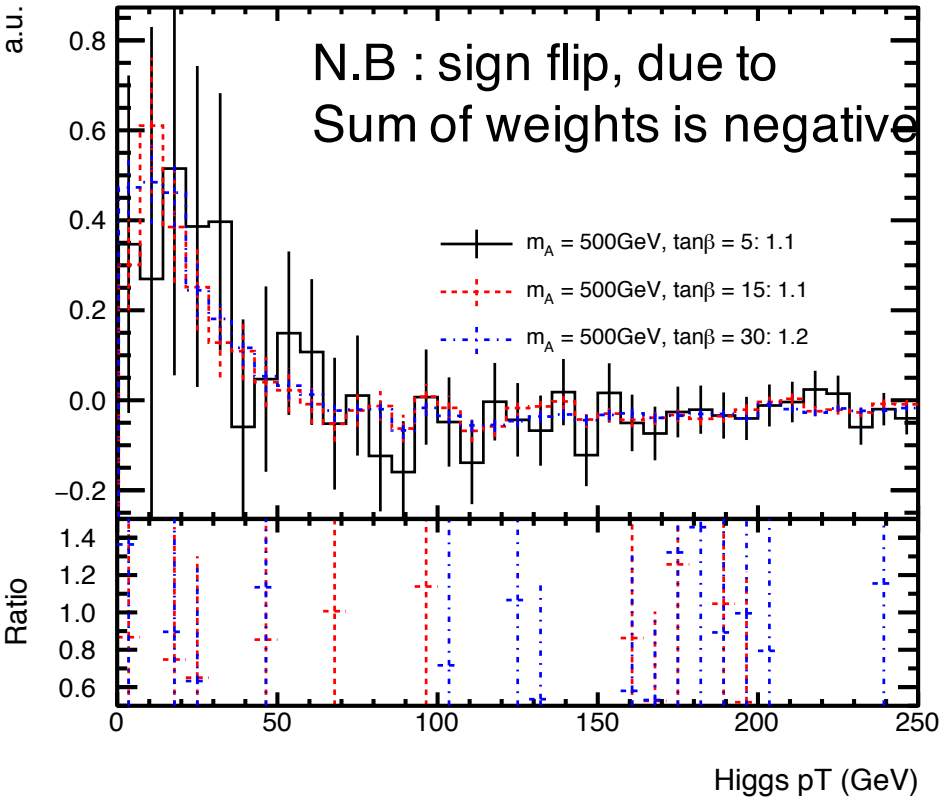
Heavy Higgs ?

- Repeat the same game, this time, for Heavy Higgs
  - mixing angle alpha (between h and H) is set to be $\alpha = \pi/4$

Absolute comparison



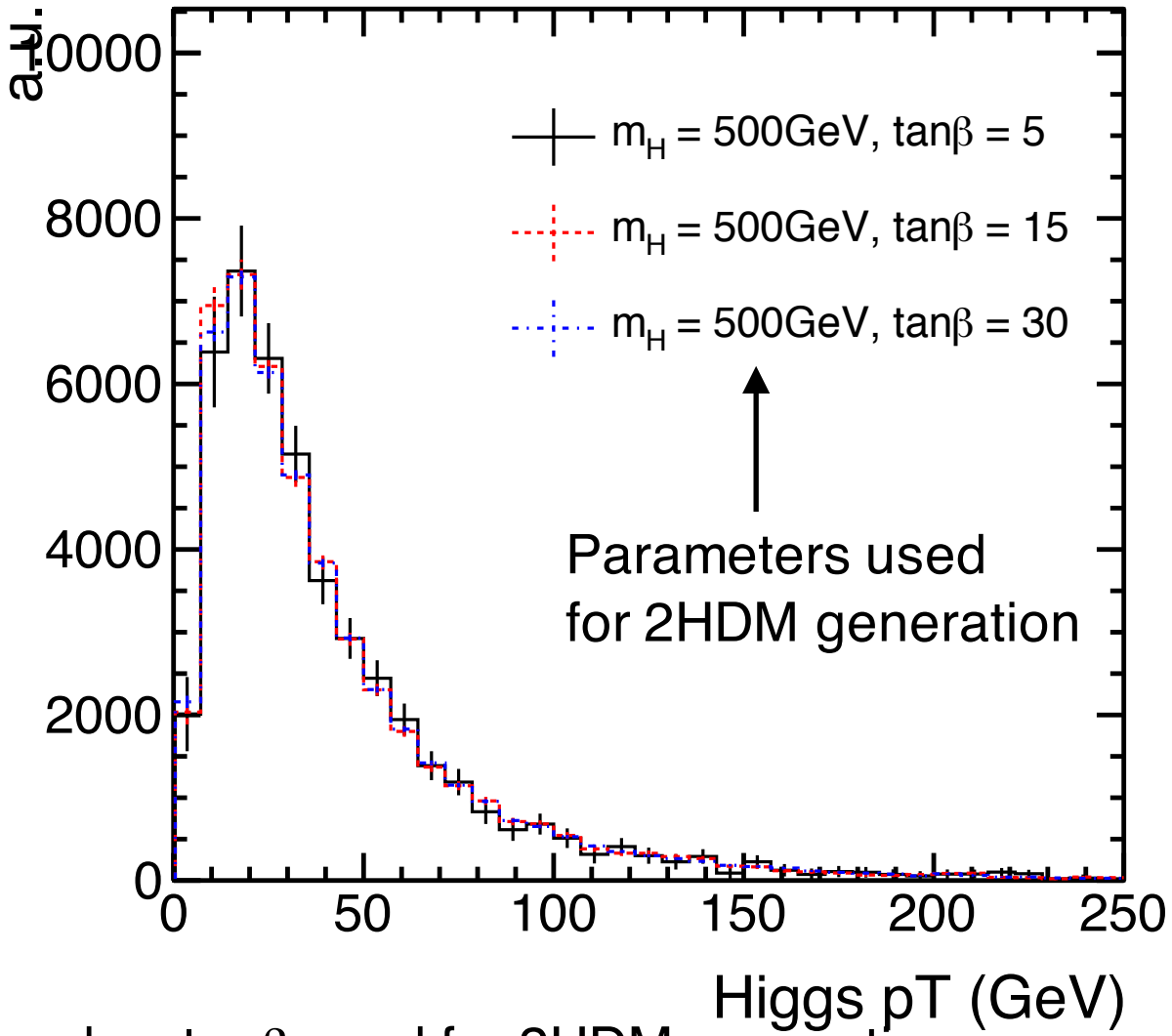
Shape comparison



- Interference term depends on tanβ (but shape doesn't)
- Doesn't this need to be taken into account by coefficient ?

Comparison of full MSSM spectrum : Heavy Higgs

Rescaling to :
m_A = 500 GeV, tanβ = 15
(for MSSM)



- All consistent.
- The results does not depend on tanβ used for 2HDM generation

Problem : interference term

Does the interference term really not depend on tanβ ?

$$\sigma^{t+b}_{\mathrm{MSSM}}(Q_{tb}) - \left(\frac{Y_{t,\mathrm{MSSM}}}{Y_{t,\mathrm{SM}}}\right)^2 \sigma^{t}_{\mathrm{SM}}(Q_{tb}) - \left(\frac{Y_{b,\mathrm{MSSM}}}{Y_{b,\mathrm{SM}}}\right)^2 \sigma^{b}_{\mathrm{SM}}(Q_{tb})$$

Powheg (MSSM):
Pure top + pure bottom
Top + bottom interference

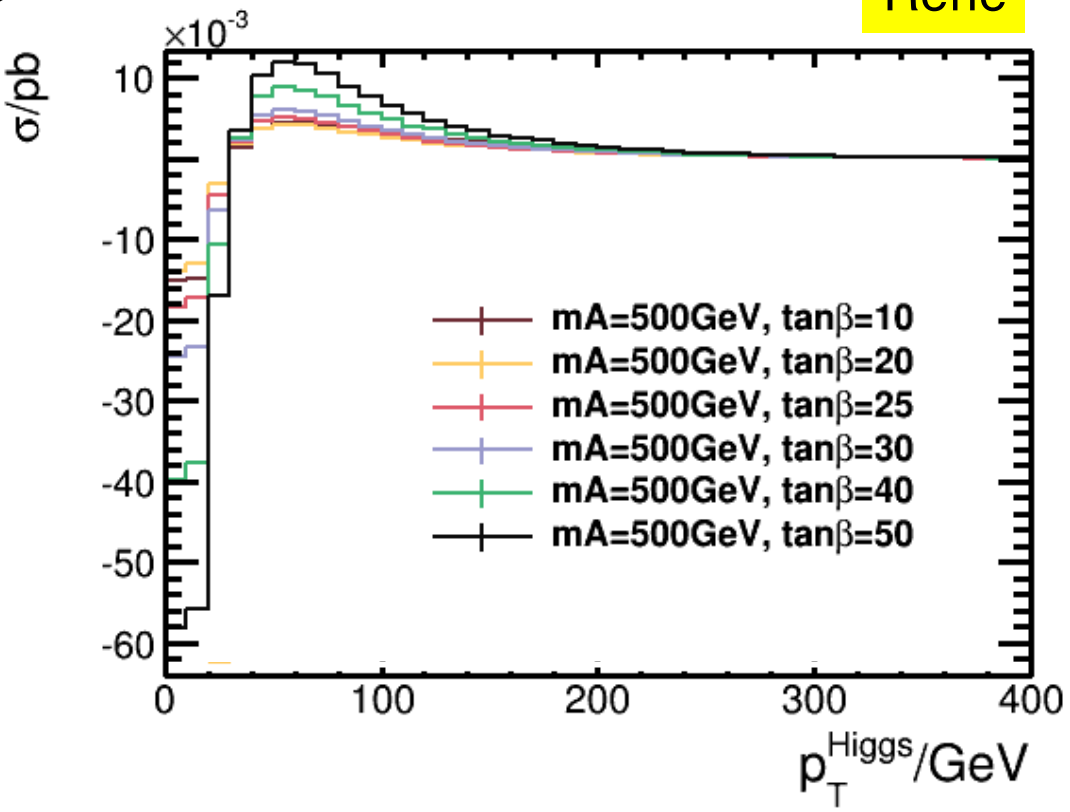
Pure top

Pure bottom

Powheg (SM)

Simple rescaling to
account for SM → MSSM

Rene

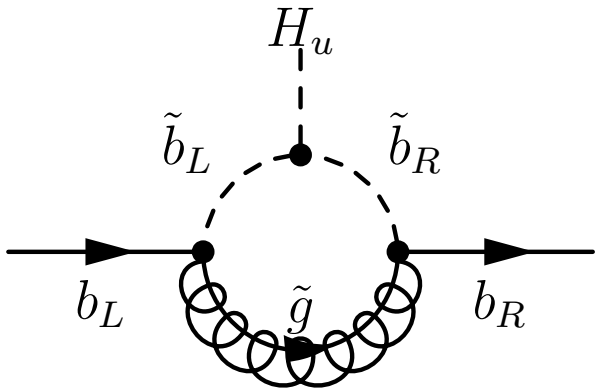


It doesn't work !

New approach

- Extensive discussion with theorist and found the problem

$$\sigma^{t+b}_{\mathrm{MSSM}}(Q_{tb}) - \left(\frac{Y_{t,\mathrm{MSSM}}}{Y_{t,\mathrm{SM}}}\right)^2 \sigma^{t}_{\mathrm{SM}}(Q_{tb}) - \left(\frac{Y_{b,\mathrm{MSSM}}}{Y_{b,\mathrm{SM}}}\right)^2 \sigma^{b}_{\mathrm{SM}}(Q_{tb})$$



The MSSM unavoidably includes contributions from sbottom loop, and modify its shape, as a function of tanβ :

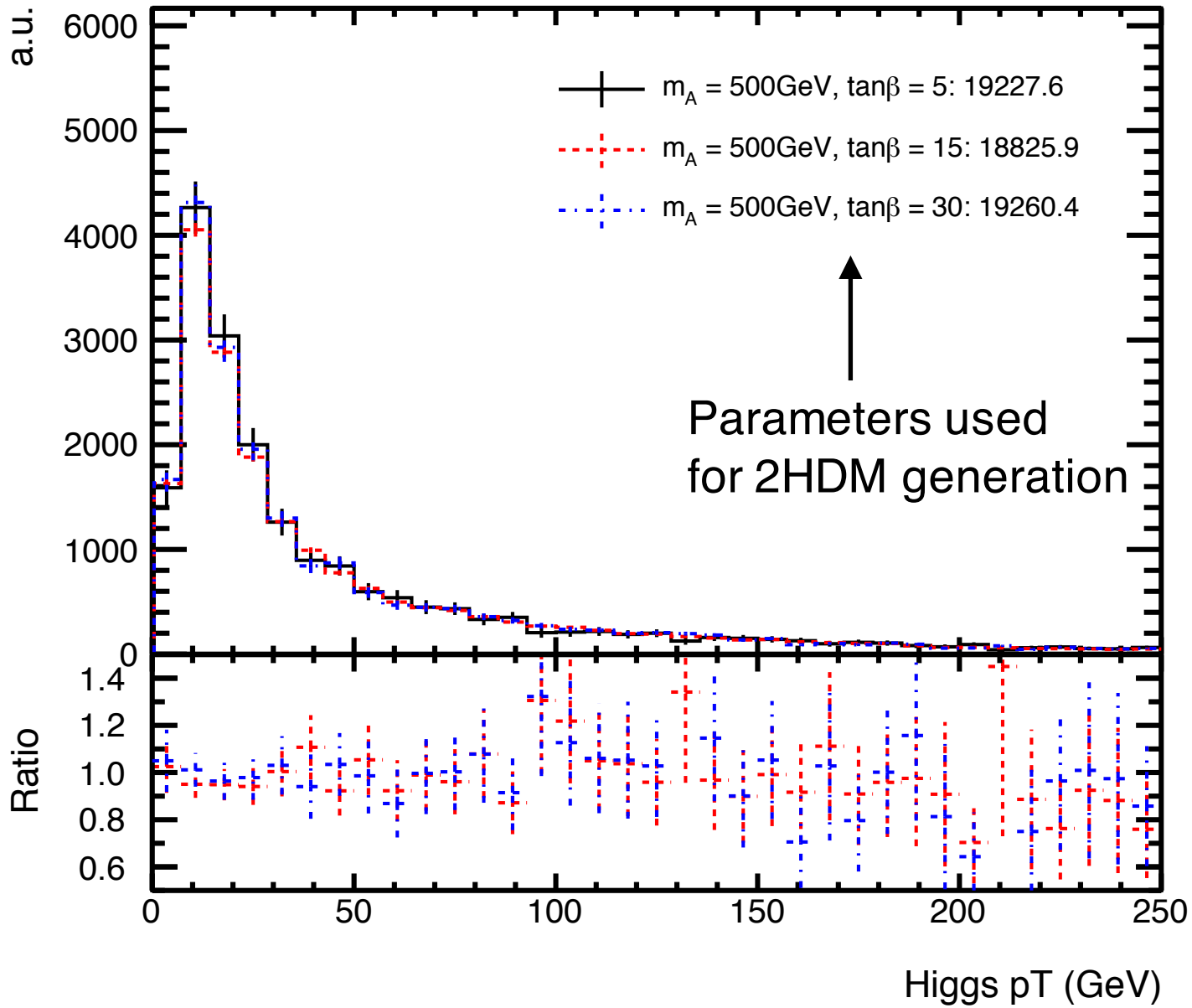
$$Y_b^{\phi} = \sqrt{2} m_b^{Y,\phi} g_f^{\phi} / v$$

$$m_b^{Y,A} = \frac{m_b^{\mathrm{OS}}}{1+\Delta_b}\left(1 - \Delta_b \frac{1}{\tan^2\beta}\right)$$

- New approach : use 2HDM model (i.e. no SUSY extension) for all 3 terms and rescale it to MSSM

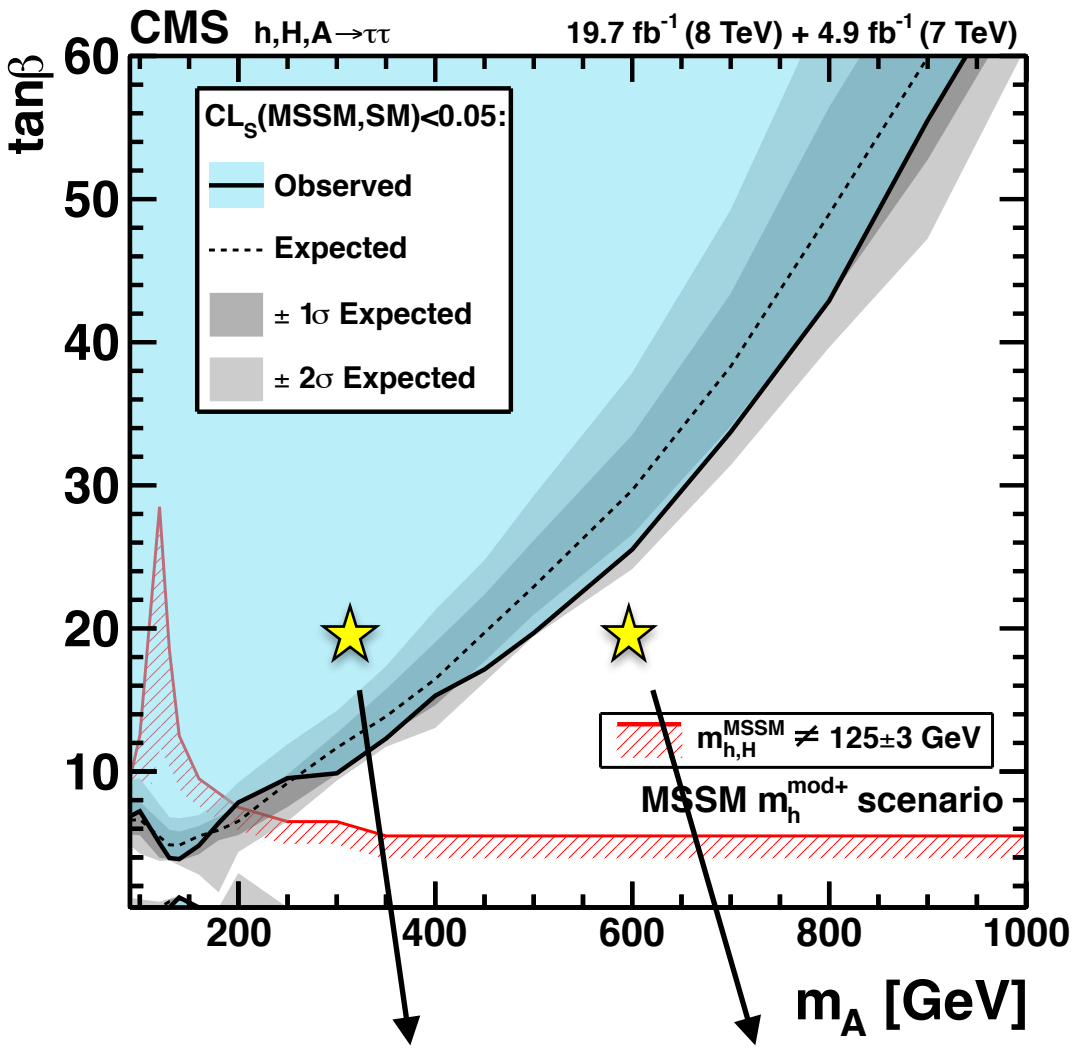
$$\left(\frac{Y_{t,\mathrm{MSSM}}}{Y_{t,\mathrm{2HDM}}}\frac{Y_{b,\mathrm{MSSM}}}{Y_{b,\mathrm{2HDM}}}\right)\left\{\sigma^{t+b}_{\mathrm{2HDM}}(Q_{tb}) - \sigma^{t}_{\mathrm{2HDM}}(Q_{tb}) - \sigma^{b}_{\mathrm{2HDM}}(Q_{tb})\right\}$$

Interference term @ $m_A = 500$



- Indeed, interference term does not depend on tanβ !

gg → ϕ is also important at high tanβ



Sasha

Cross-section ratio @ tanβ = 20	m_A = 300 GeV	m_A = 600 GeV
$\sigma(gg \to \phi) / \sigma(bb \to \phi)$	0.16	0.08
$\sigma(gg \to \phi) / \sigma(bb \to \phi) \times (\varepsilon_{gg \to H} / \varepsilon_{bb \to H})^{exp}$	0.20	0.27