Heavy Higgs Bosons at LHC

Ying-Ying Li

arXiv:1504.07617 J. Hajer, T. Liu and J.F.H. Shiu

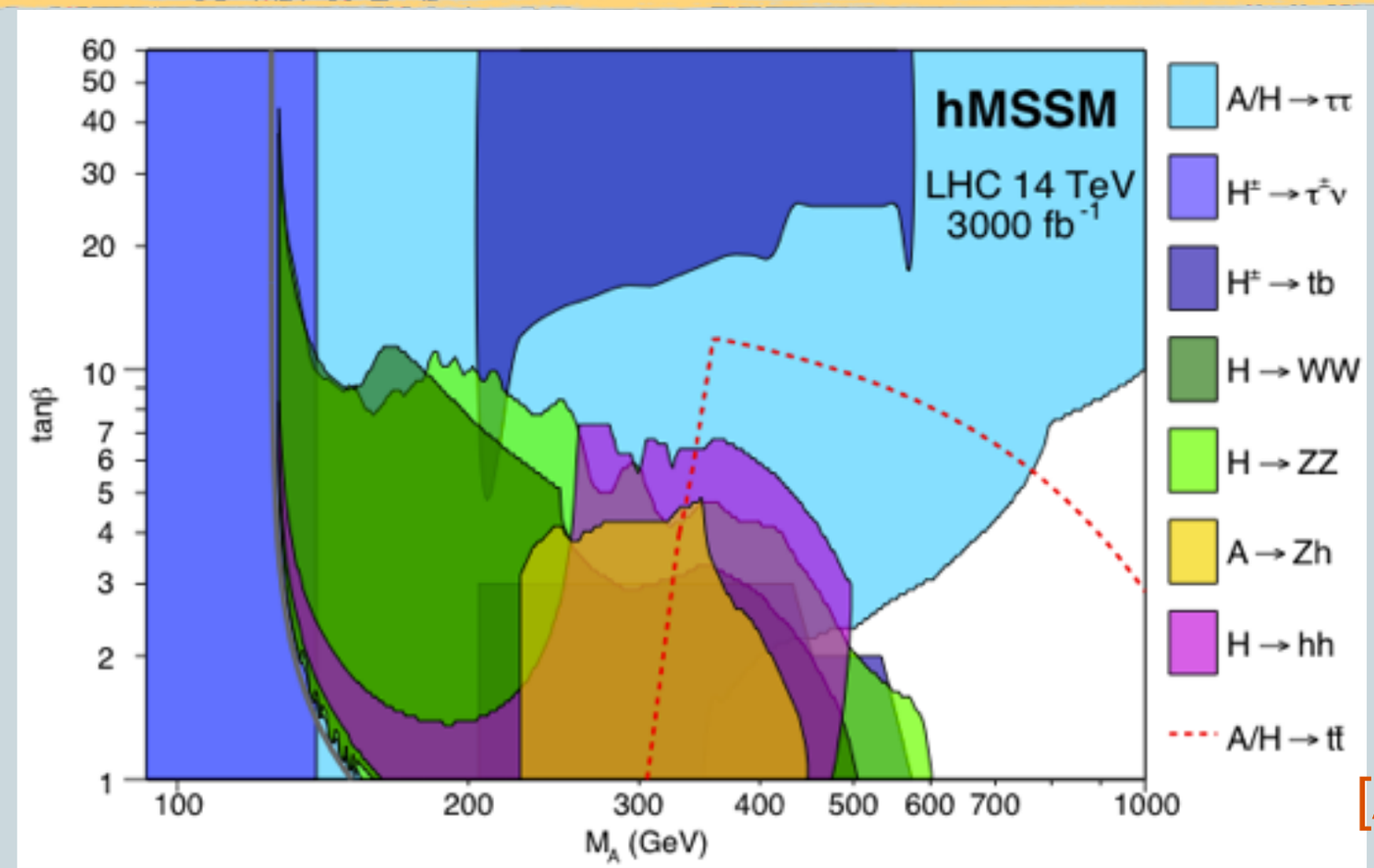
arXiv:1605.08744 N. Craig, J.Hajer, T.Liu and H. Zhang

Hong Kong Univ of Science and Technology

BSM Higgs Bosons

- An extended Higgs sector extensively exists in NP
- We focus on the MSSM Higgs bosons (no CP-violation): H, A, Hc
  - Higgs mass spectrum and couplings only depend on two parameters (in additional to the SM ones) at tree-level: tan_beta, mA/mHc
  - So in principle we can make a sensitivity projection on a plane expanded by these two parameters: mA/mHc - tan_beta
- It is straightforward to generalise the analyses to many other models, such as 2HDM, NMSSM, etc.

MSSM Higgs Bosons at 14 TeV



[A. Djouadi et. al.'15]

- A sensitivity projected at the LHC, by rescaling the 7 and 8 TeV results to 14 TeV
- Neutral Higgs: excluded up to ~ O(1) TeV, except an expected wedge region
- Charged Higgs: excluded up to ~600 GeV, via pp -> tb Hc -> tbtb

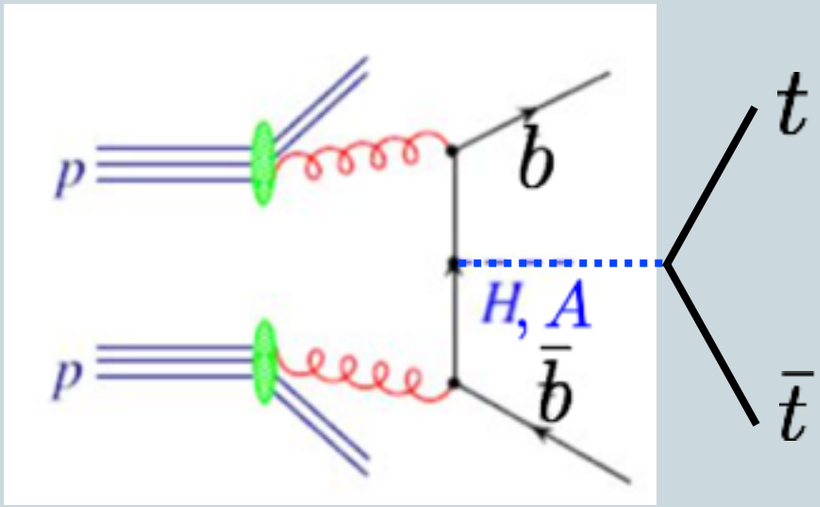
Questions to Address

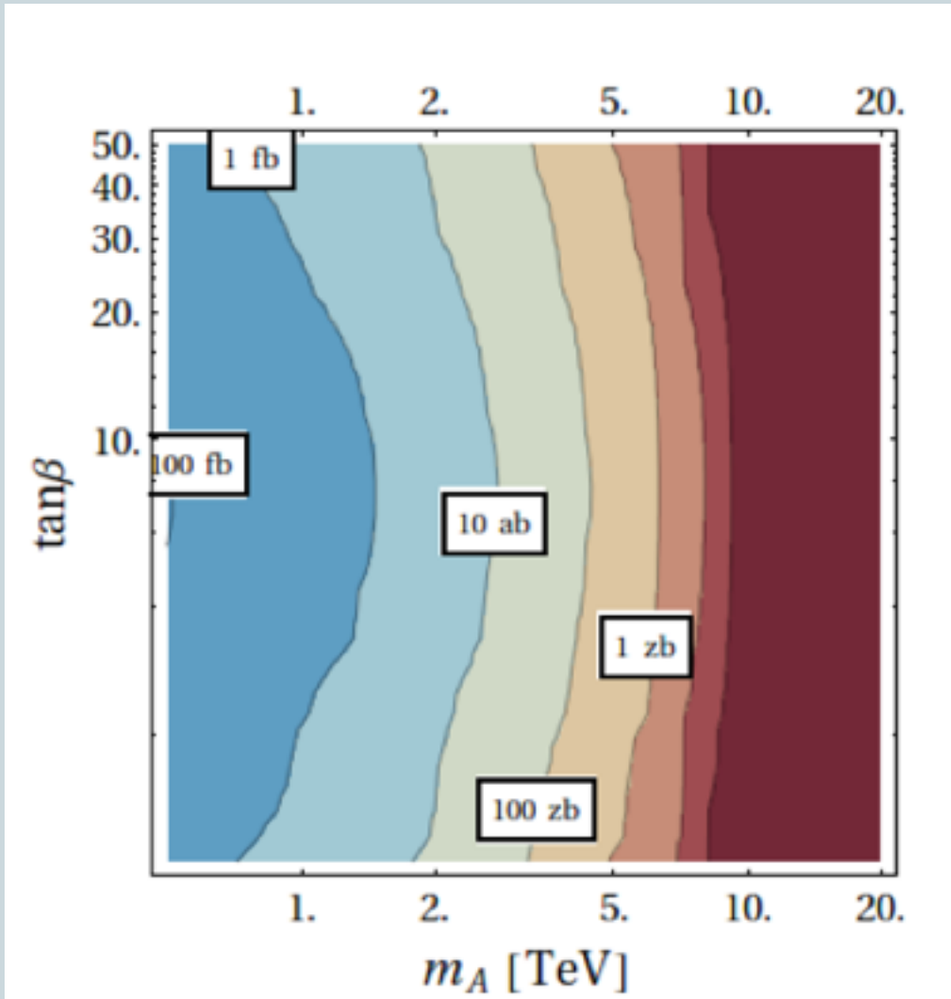
- For neutral Higgs search, how to probe the uncovered wedge region?
- What is wrong with the red dotted line?

$$g_{HVV} = g_{hZA} = g_{hW^{\mp}H^{\pm}} \propto \cos(\beta - \alpha) \to 0$$

	Couplings	MSSM
H	g_{HVV}	$\cos(\beta-\alpha)$
	$g_{Ht\bar{t}}$	$\sin\alpha/\sin\beta$
	$g_{Hb\bar{b}}$	$\cos\alpha/\cos\beta$
	$g_{H\tau\bar{\tau}}$	$\cos\alpha/\cos\beta$
A	g_{AVV}	0
	$g_{At\bar{t}}$	$\cot\beta$
	$g_{Ab\bar{b}}$	$\tan\beta$
	$g_{A\tau\bar{\tau}}$	$\tan\beta$
$H^{\pm}$	$g_{H^+\bar{u}d}$	$\frac{1}{\sqrt{2}v}V_{ud}^*[m_d\tan\beta(1+\gamma_5)+m_u\cot\beta(1-\gamma_5)]$
	$g_{H^-u\bar{d}}$	$\frac{1}{\sqrt{2}v}V_{ud}[m_d\tan\beta(1-\gamma_5)+m_u\cot\beta(1+\gamma_5)]$
	$g_{H^+\bar{\nu}l}$	$\frac{1}{\sqrt{2}v}m_l\tan\beta(1+\gamma_5)$
	$g_{H^-\nu\bar{l}}$	$\frac{1}{\sqrt{2}v}m_l\tan\beta(1-\gamma_5)$

Neutral Higgs-14TeV



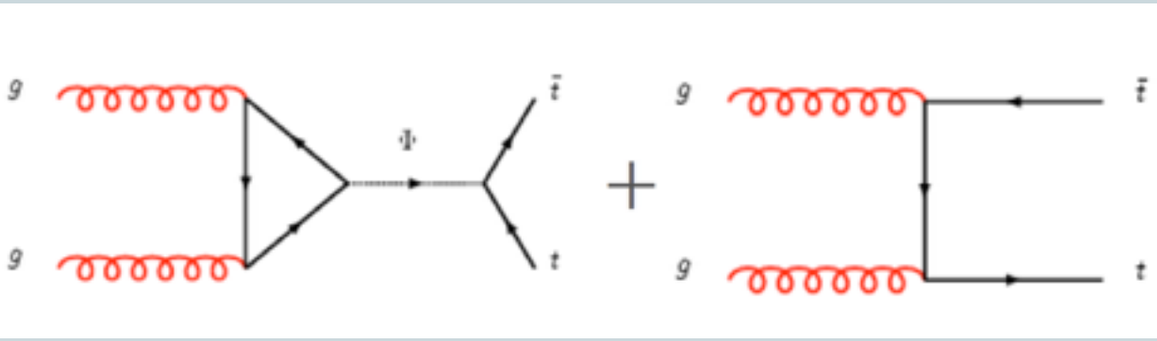


$$\sigma(pp \to b\bar{b}H/A)\mathrm{Br}(H/A \to t\bar{t})$$

- moderate tan_beta enhanced !
- expected to yield a larger sensitivity for probing moderate tan_beta => the wedge region might be covered !

$$g_{HVV} = g_{hZA} = g_{hW^{\mp}H^{\pm}} \propto \cos(\beta - \alpha) \to 0$$

Neutral Higgs-14TeV

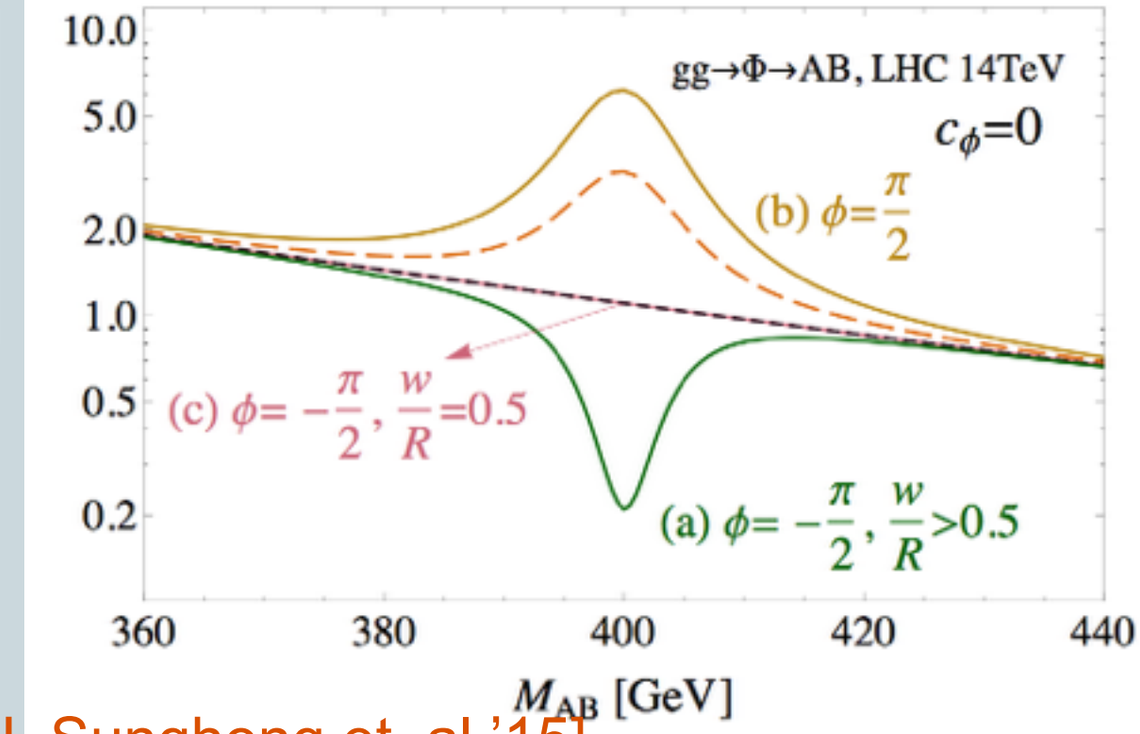


$$\hat{\sigma} = \hat{\sigma}_{\rm bg} + \frac{M^4}{(\hat{s}-M^2)^2 + M^4 w^2} \times \left[\frac{2(\hat{s}-M^2)}{M^2}\,\hat{\sigma}_{\rm int} c_\phi + \hat{\sigma}_{\rm res}\left(1 + \frac{2w}{R} s_\phi\right)\right]$$

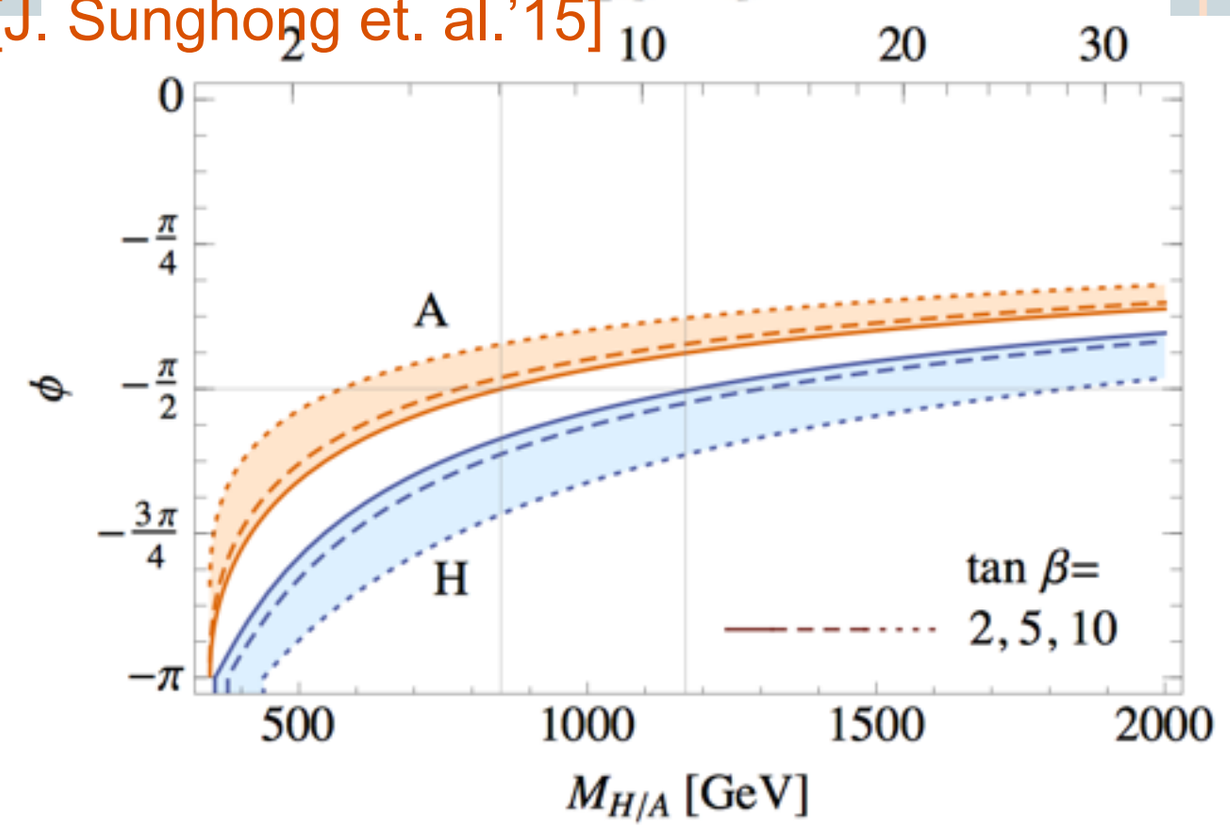
$$\hat{\sigma}_{\rm bg,res} = \frac{1}{32\pi\hat{s}} \int dz \sum \mathcal{A}^2_{\rm bg,res},$$

$$\hat{\sigma}_{\rm int} e^{i\phi} = \frac{1}{32\pi\hat{s}} \int dz \sum \mathcal{A}_{\rm bg}\mathcal{A}_{\rm res} e^{i(\phi_{\rm res}-\phi_{\rm bg})}$$

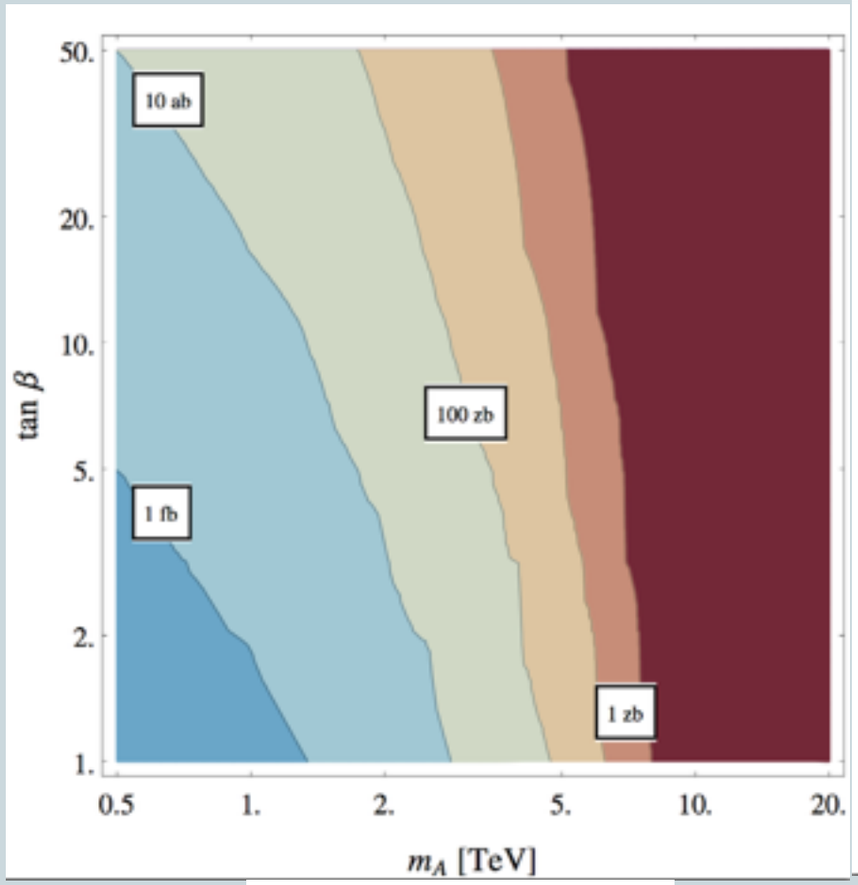
$$R = \frac{\hat{\sigma}_{\rm res}}{\hat{\sigma}_{\rm int}}\,, \quad w \equiv \frac{\Gamma}{M}.$$



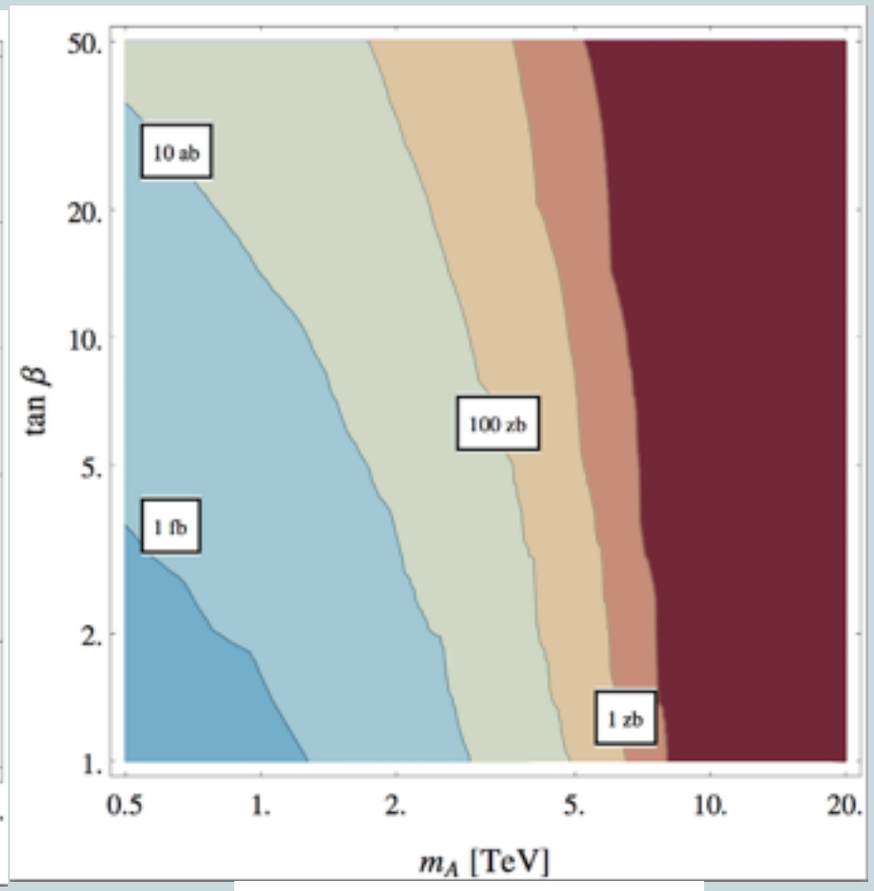
[J. Sunghong et. al.'15]



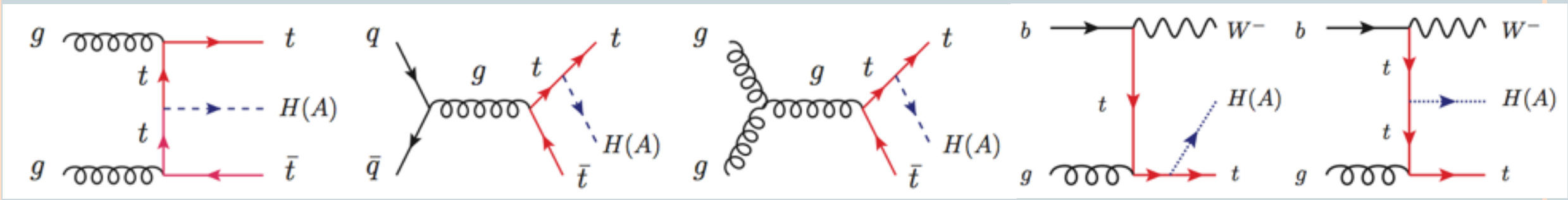
Neutral Higgs-14TeV



$\sigma(pp \to H/Att)$



$\sigma(pp \to H/AtW)$



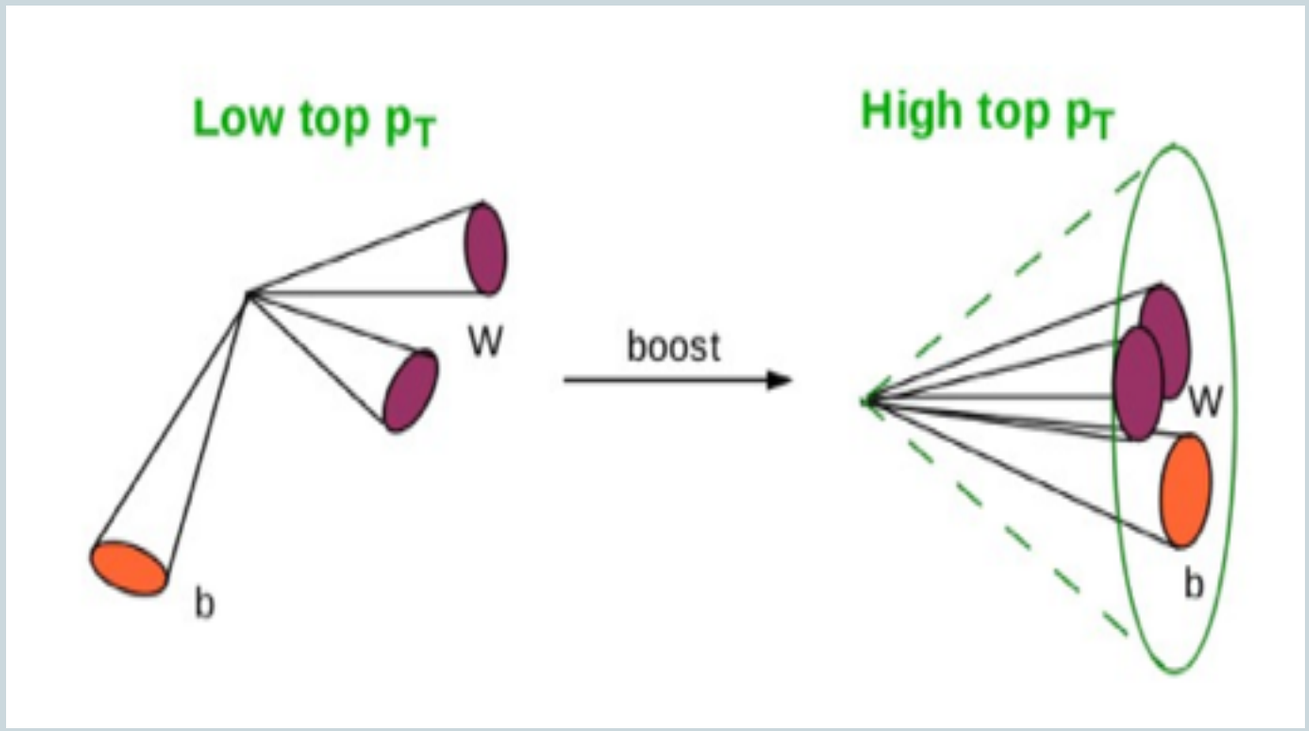
Kinematics

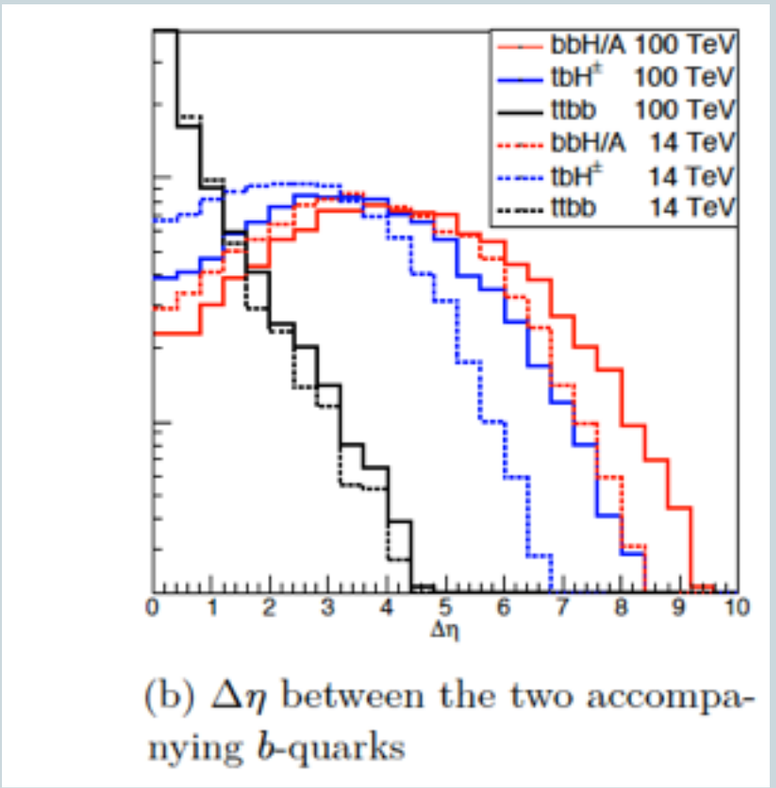
- Heavy Higgs resonance

  related to the heaviness of Higgs bosons in the decoupling limits.

- Forwardness/Backwardness of accompanying particles

  the accompanying particles are less boosted, but tend to have a large rapidity.





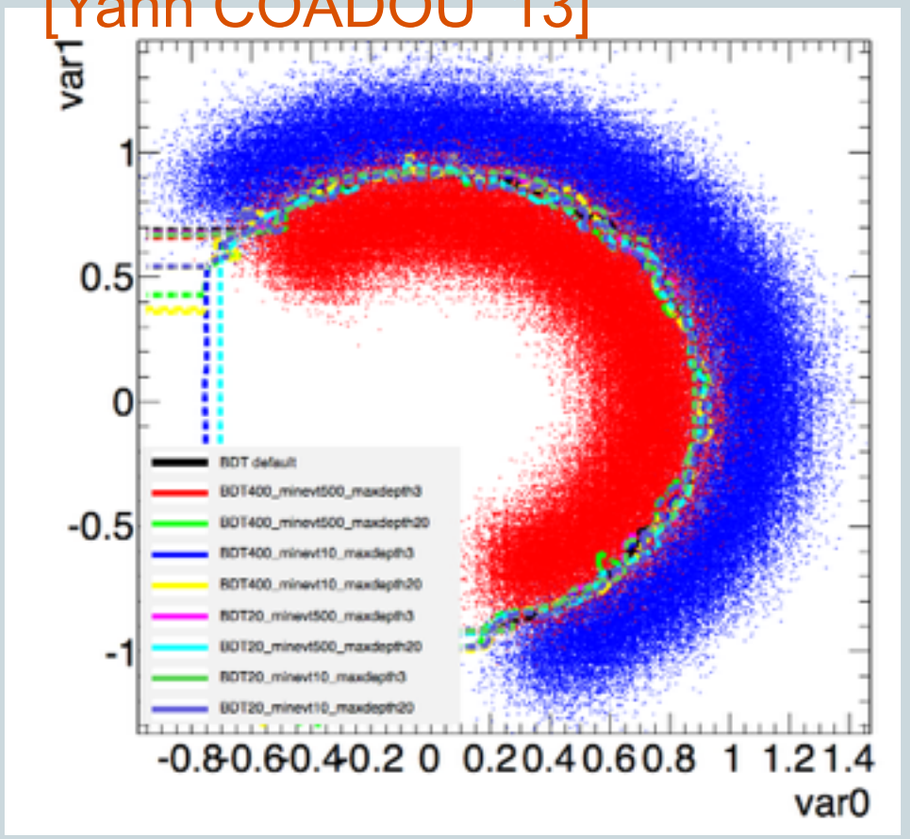
(b) $\Delta\eta$ between the two accompanying b-quarks

BDT

BDT: Non-linear combination of variables.

optimise the analysis.

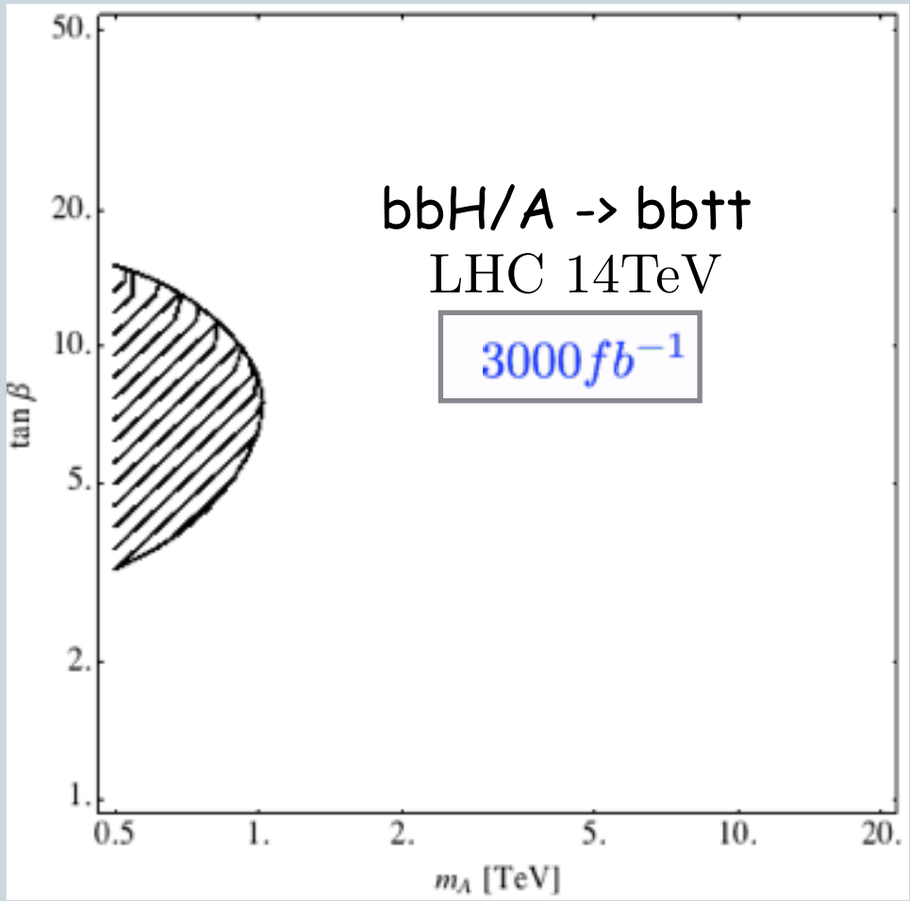
[Yann COADOU '13]



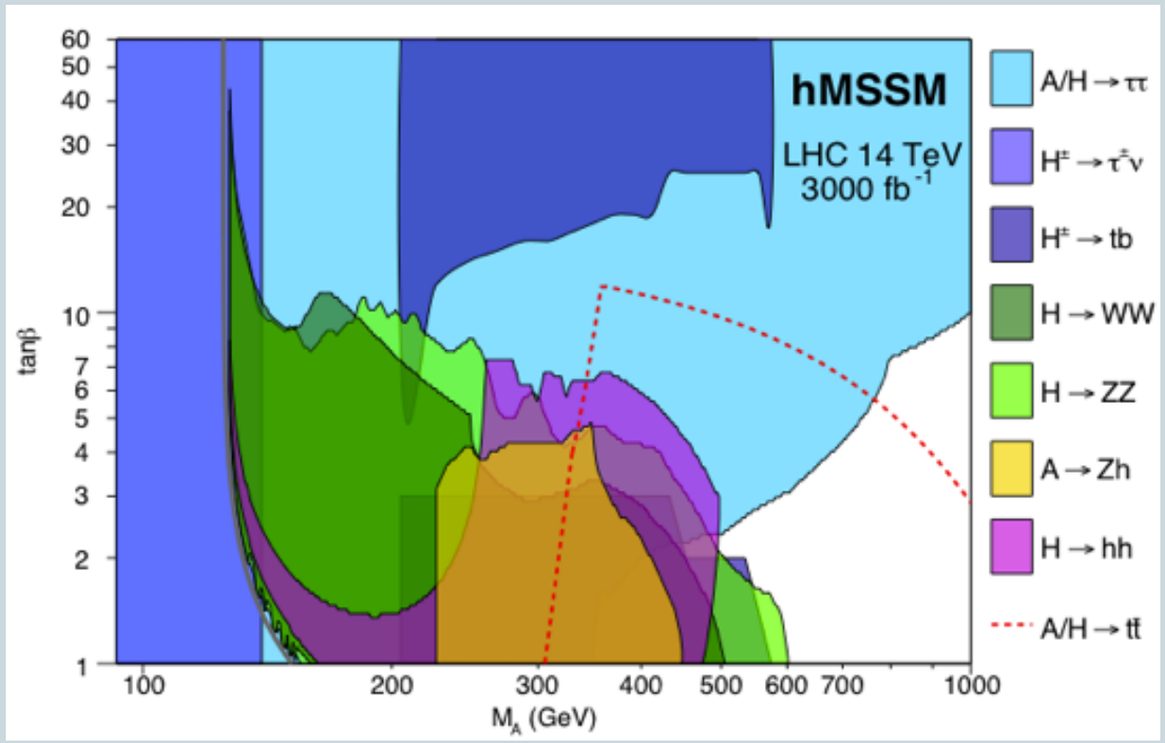
(a) Circular correlation example

- Construct top BDT: one is hadronic, another one is leptonic.
- Construct Bottom Fusion BDT: demand two b-like jets with large delta eta

Neutral Higgs Exclusion Limit-14TeV



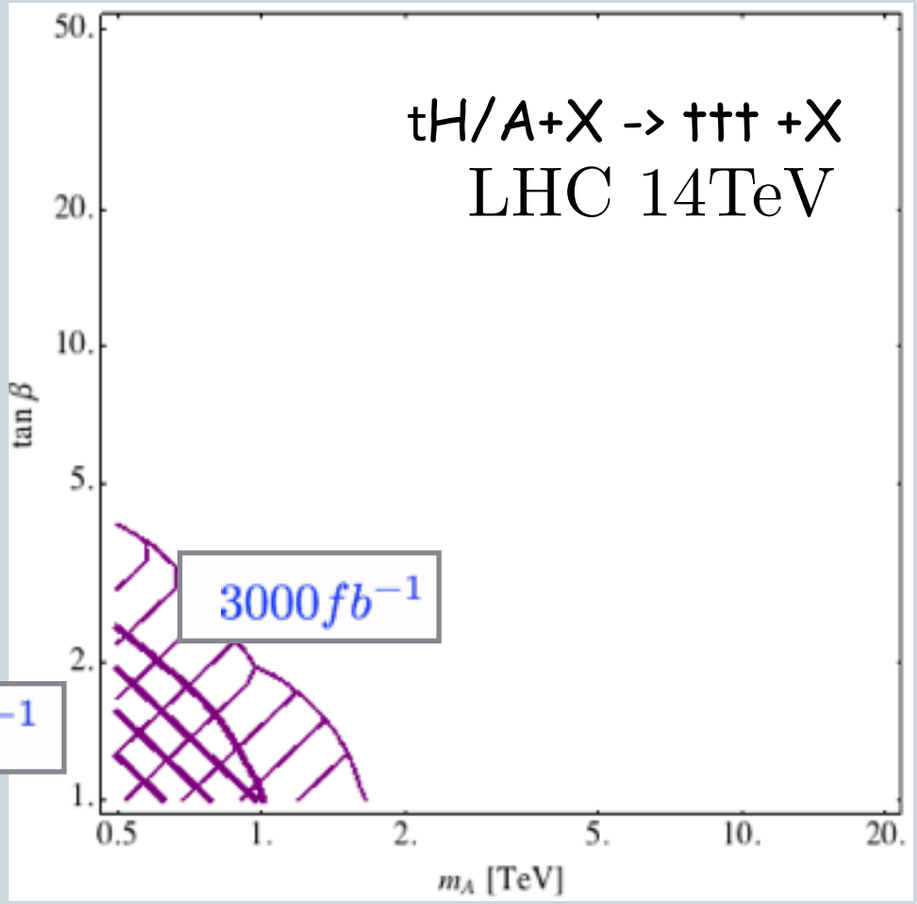
(a) Exclusion limit



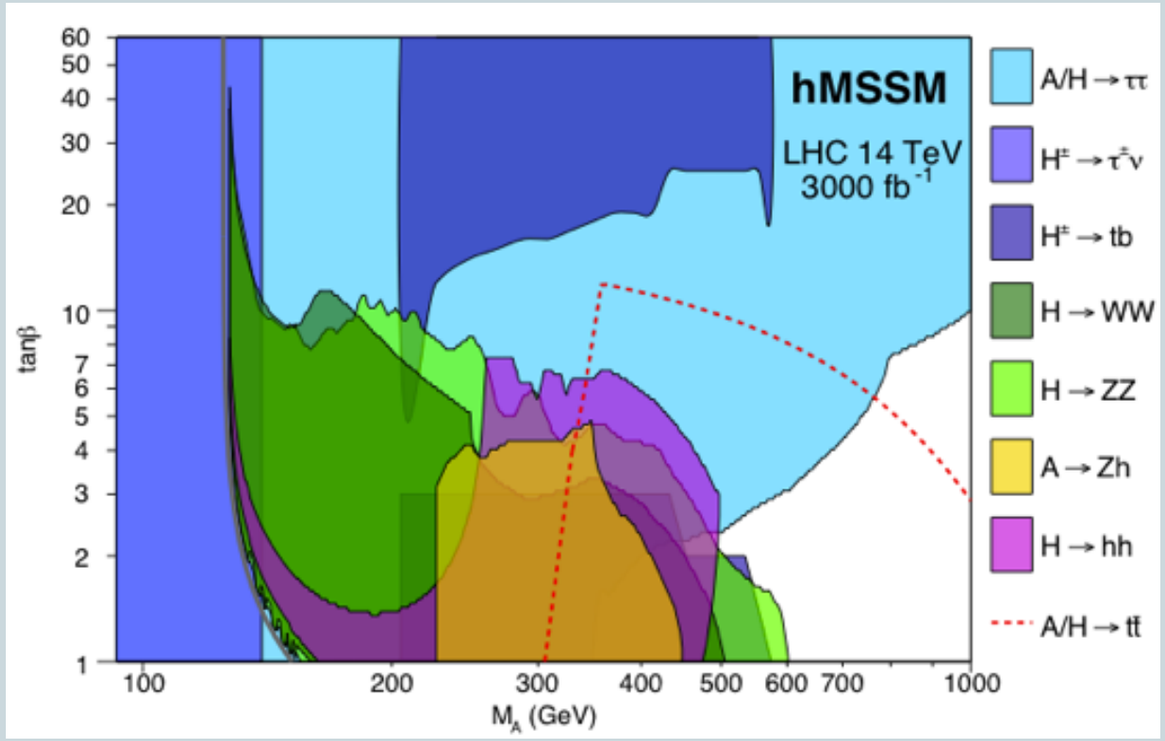
[A. Djouadi et. al.'15]

- The wedge region centered on moderate tan_beta is covered(3/ab).
- A potential to exclude mA/mH up to 1 TeV via bbH/A -> bbtt, with tt decaying semi-leptonically.

Neutral Higgs Exclusion Limit-14TeV



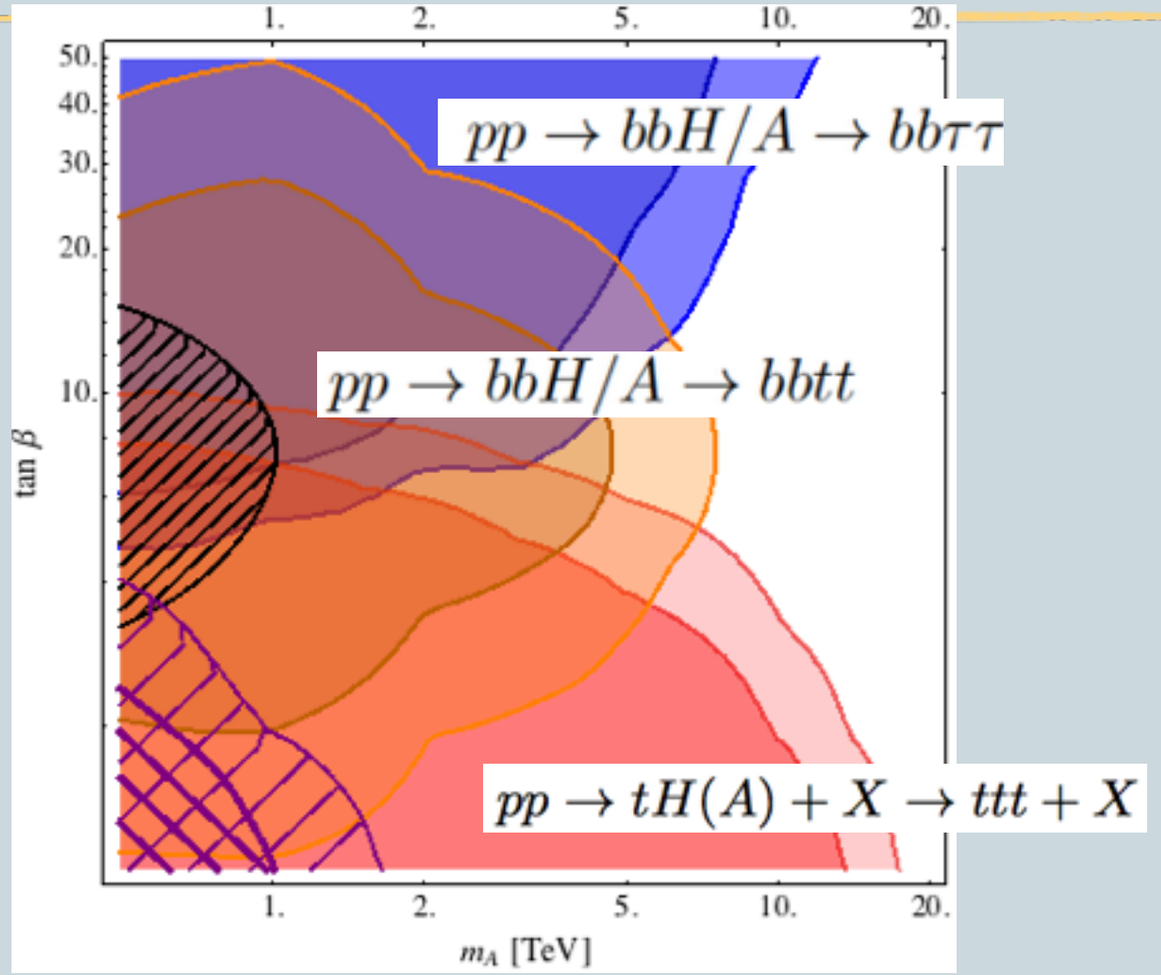
(a) Exclusion limit



[A. Djouadi et. al.'15]

- The red dotted line for low tan_beta region is covered to ~1 TeV for (0.3/ab) and to ~1.5TeV for (3/ab).
- Associated production help to probe the low tan_beta region.

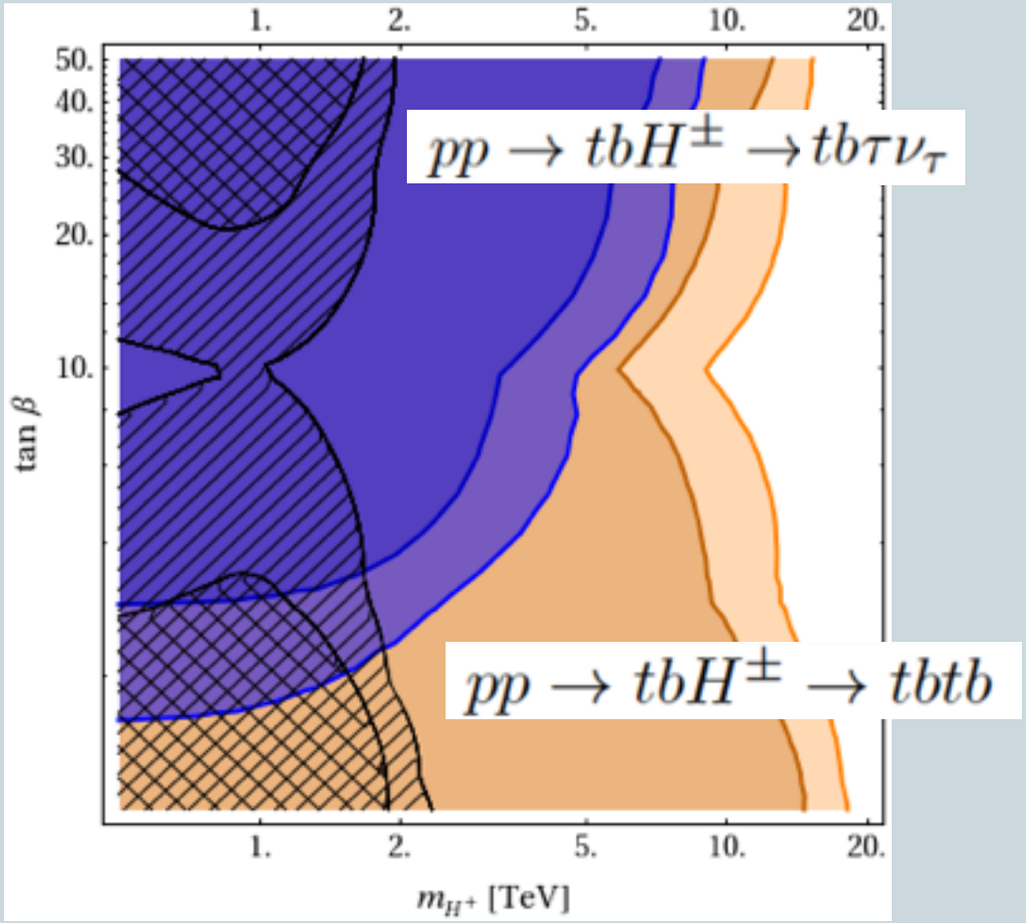
Conclusion-Neutral Higgs at 100 TeV



(a) Exclusion limit

- Different transy represents different luminosity, 30/ab and 3/ab.
- Large tan_beta: bbH -> bbtautau continues to play a significant role.
- A potential to exclude mA/mH up to 10TeV via bbH/A -> bbtt (30/ab), with tt decaying semi-leptonically, except for low tan_beta region.

Conclusion-Charged Higgs at 100 TeV

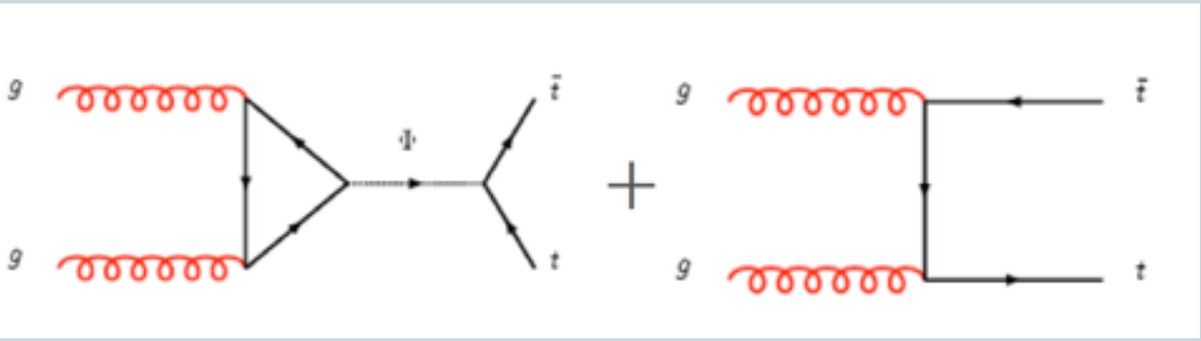


(a) Exclusion limit

- Different transparency represents different luminosity, 30/ab and 3/ab.
- A potential to exclude mHc up to 10 TeV via tbHc ->tbtb (30/ab) for the whole tan_beta region, with tt decaying semi-leptonically
- Cover up to 20TeV (30/ab) for both high and low tan_beta region.


Thank you

Neutral Higgs-14TeV

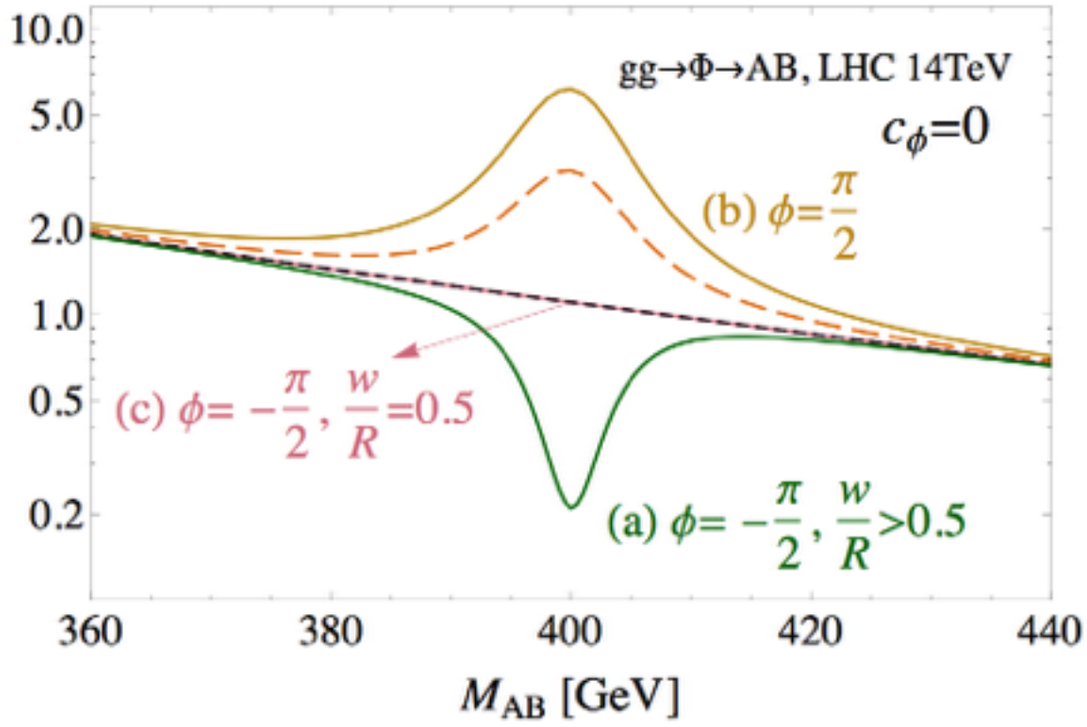


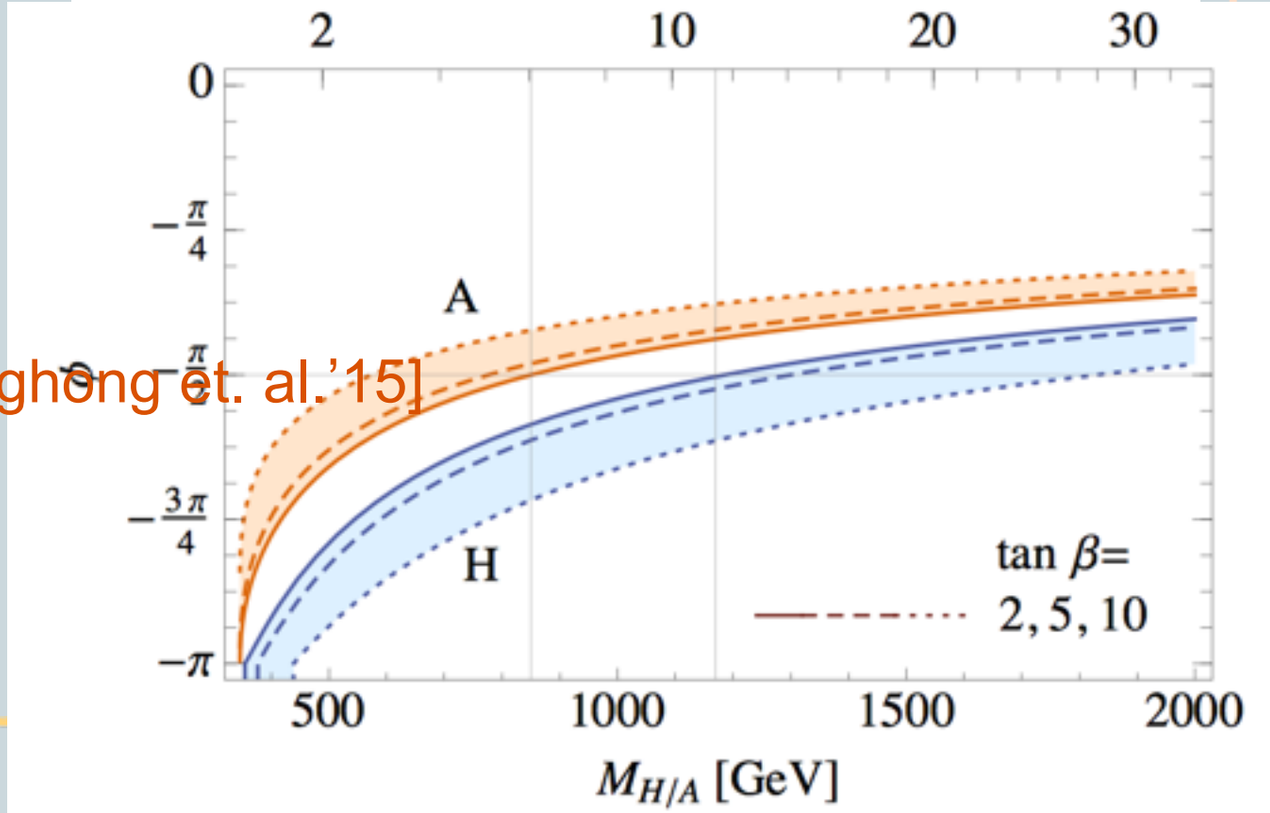
$$\hat{\sigma} = \hat{\sigma}_{\rm bg} + \frac{M^4}{(\hat{s}-M^2)^2 + M^4 w^2} \times \left[\frac{2(\hat{s}-M^2)}{M^2}\,\hat{\sigma}_{\rm int} c_\phi + \hat{\sigma}_{\rm res}\left(1 + \frac{2w}{R} s_\phi\right)\right]$$

$$\hat{\sigma}_{\rm bg,res} = \frac{1}{32\pi\hat{s}} \int dz \sum \mathcal{A}^2_{\rm bg,res},$$

$$\hat{\sigma}_{\rm int} e^{i\phi} = \frac{1}{32\pi\hat{s}} \int dz \sum \mathcal{A}_{\rm bg}\mathcal{A}_{\rm res} e^{i(\phi_{\rm res}-\phi_{\rm bg})}$$

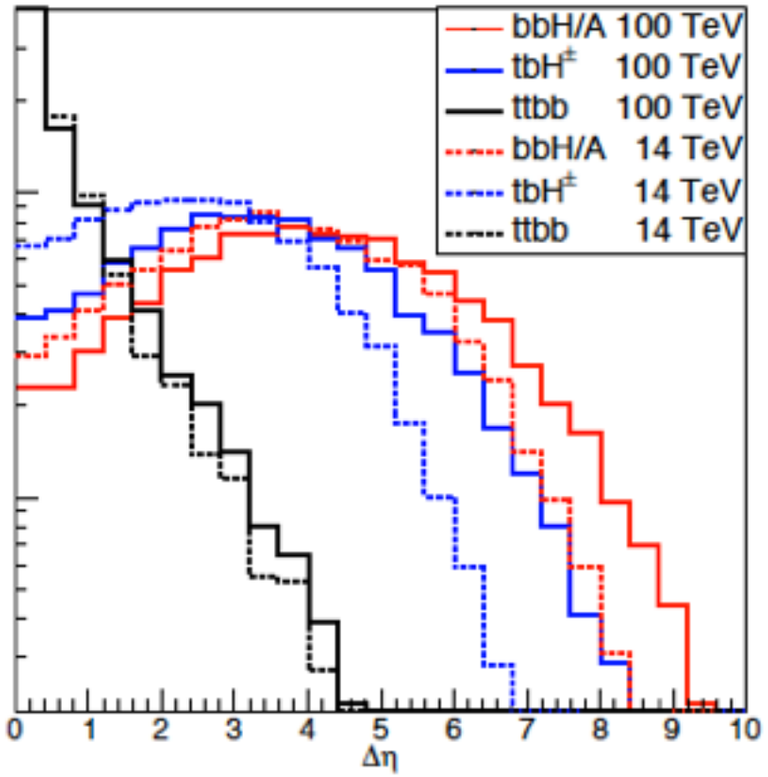
$$R = \frac{\hat{\sigma}_{\rm res}}{\hat{\sigma}_{\rm int}}\,, \quad w \equiv \frac{\Gamma}{M}.$$



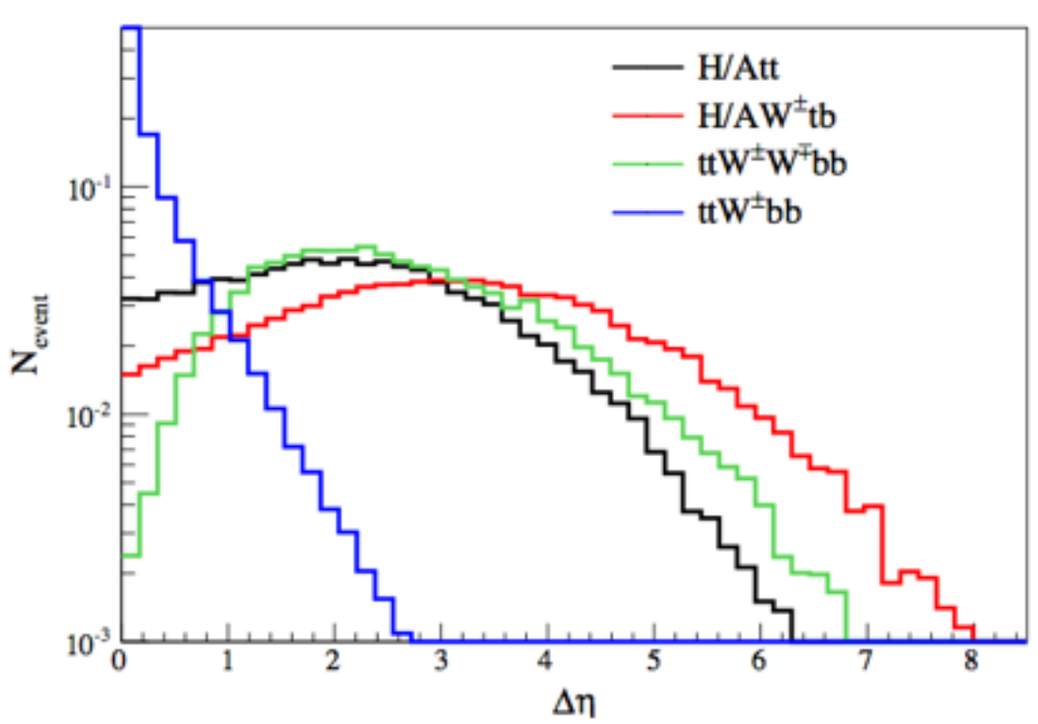


[J. Sunghong et. al.'15]

Kinematics - Particles Accompanying Higgs Production

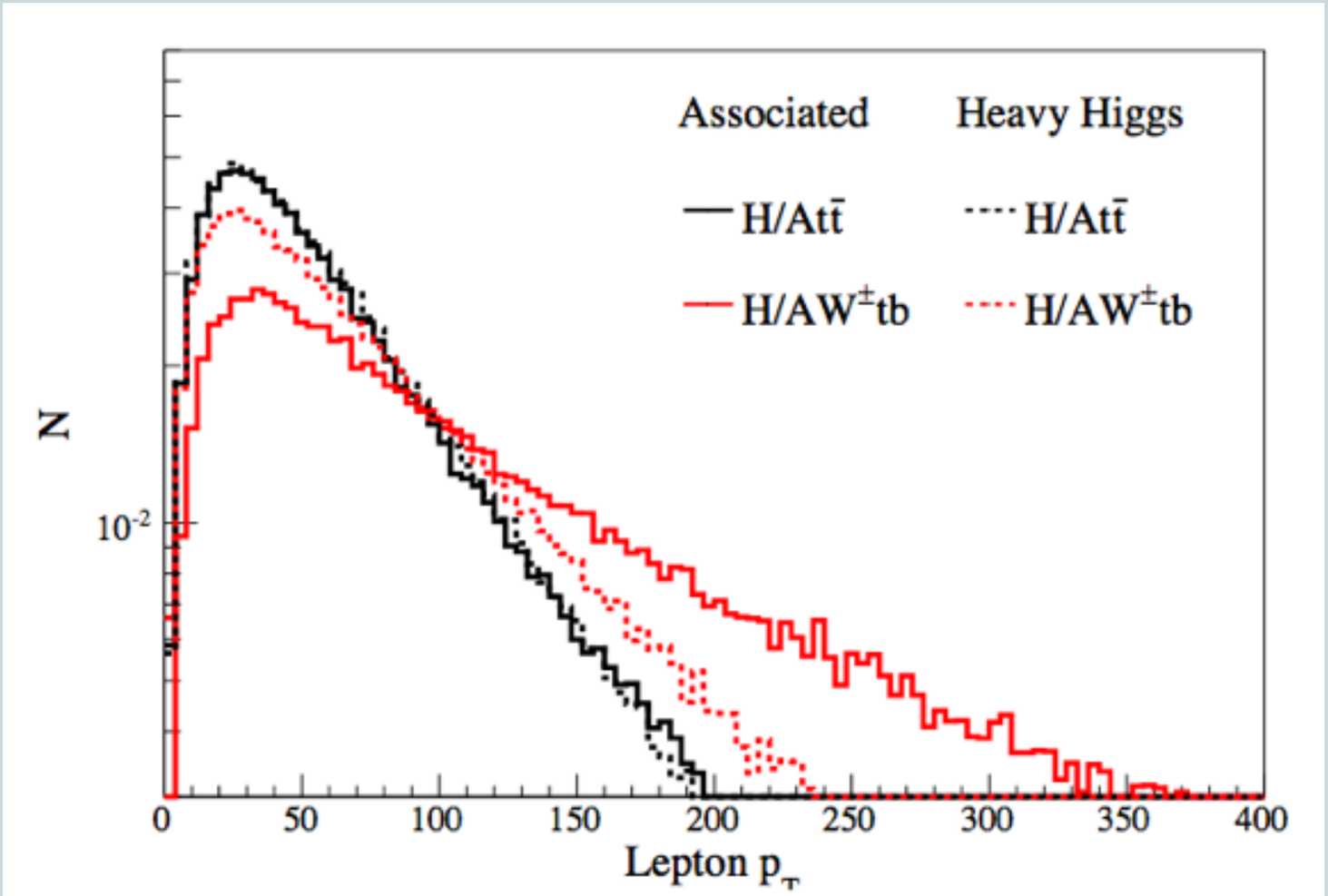


$\Delta\eta$ between the two accompanying b-quarks

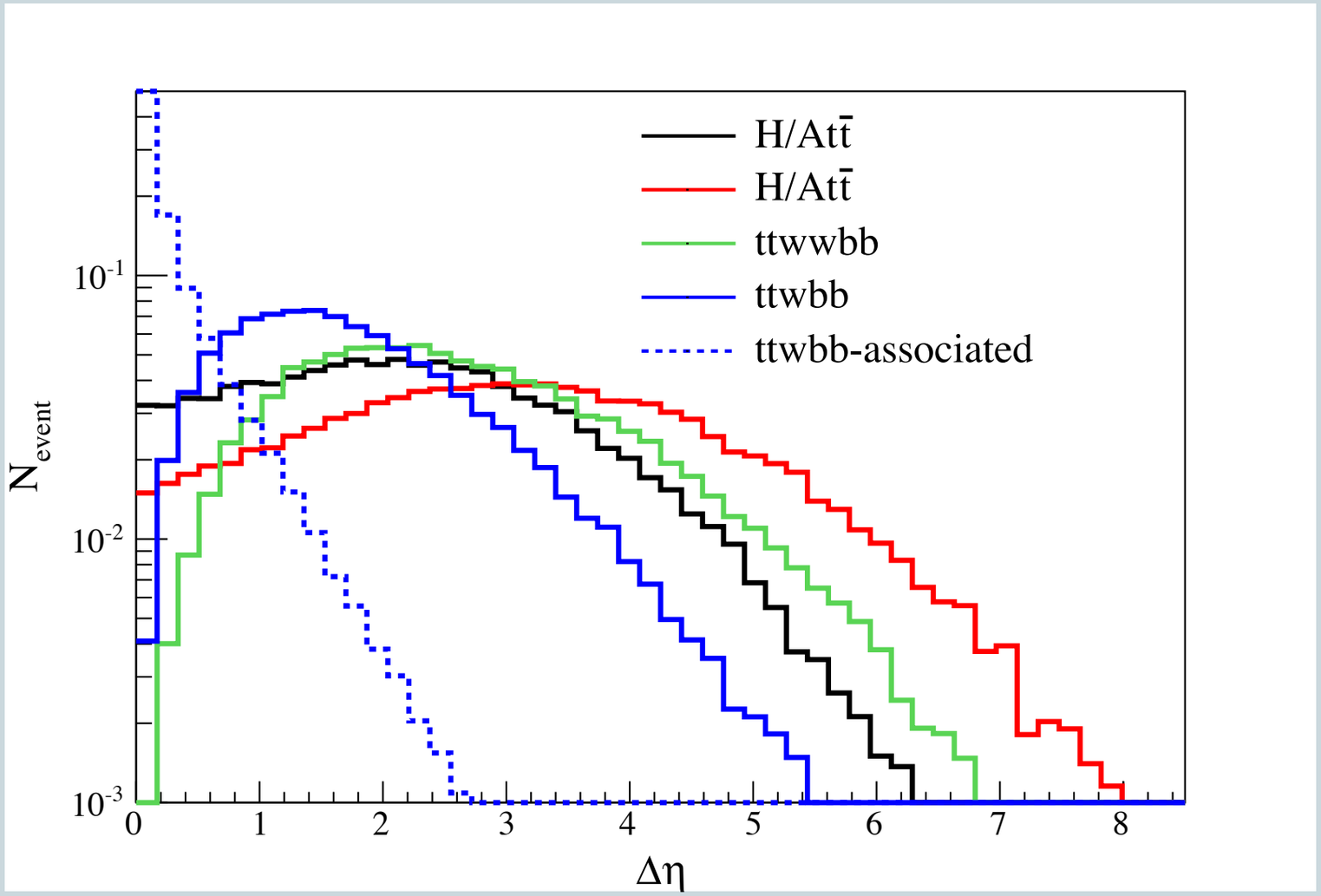


$\Delta\eta$ between two accompanying b-quarks

- All b quarks are required to have pt > 40 GeV for 100TeV, and pt > 20GeV for 14TeV.
- The b-quarks accompanying Higgs production tend to be forward and backward => large delta eta


Associated
Heavy Higgs
H/Attt̄
H/Attt̄
H/AW±tb
H/AW±tb
N
10-2
0
50
100
150
200
250
300
350
400
Lepton pT

(b) Lepton p_T


H/Att̄
H/Att̄
ttwwbb
ttwbb
ttwbb-associated
10^{-1}
10^{-2}
10^{-3}
N_{event}
0
1
2
3
4
5
6
7
8
Δη