Type I 2HDM in Top Decays and the 13 TeV excess in $t\bar{t}H$ searches

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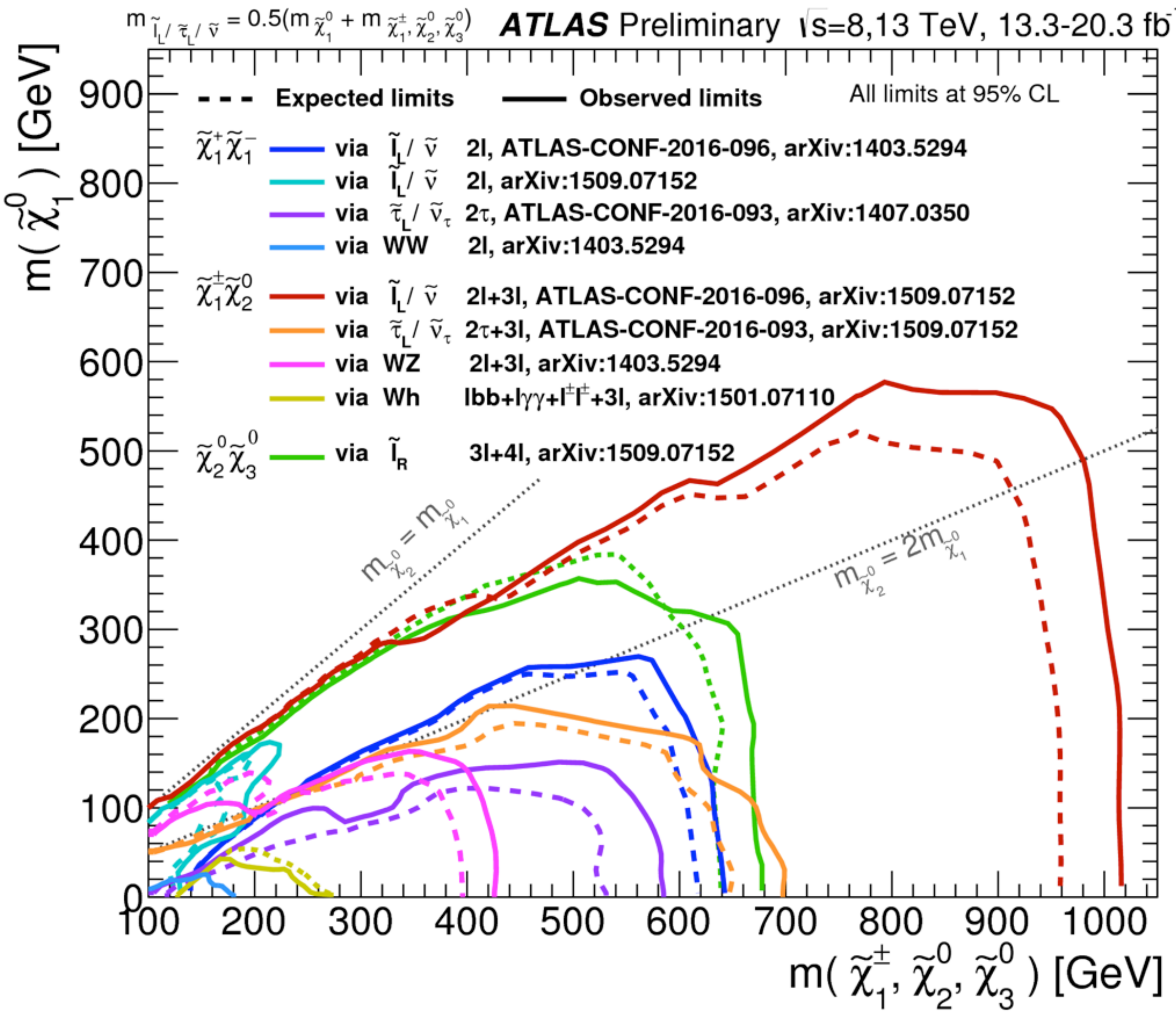
w/ El Hedri, Taki, Weiner (*in progress*)

LHC-TI fellows meeting, SLAC, 2017

LHC reach to new electroweak particles

In direct searches, reach is very model dependent



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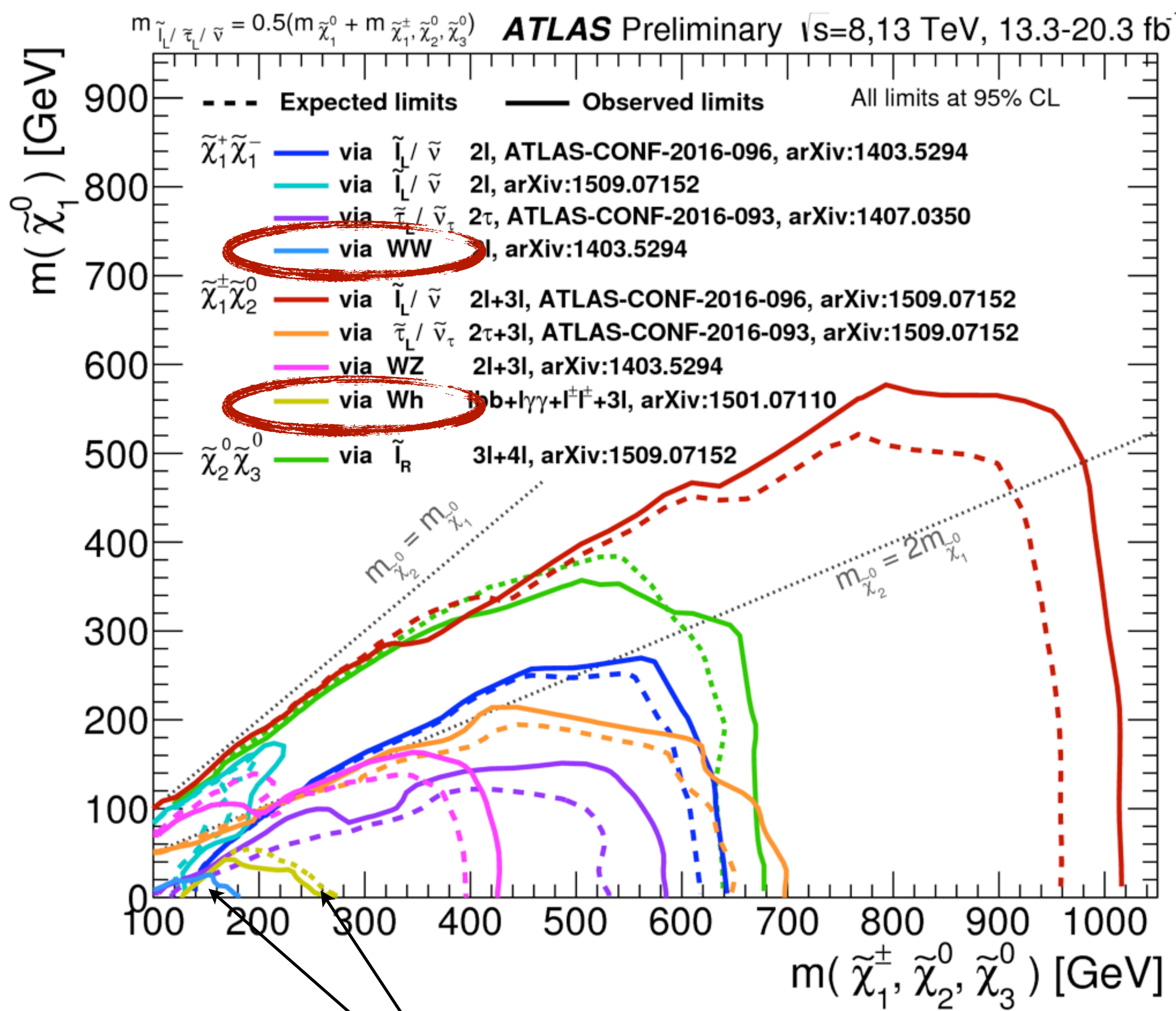


Some final states are very challenging

LHC reach to new electroweak particles

Important to consider alternatives
complementary to direct production

High Statistics Final States

E.g.,

> Differential Drell-Yan distribution

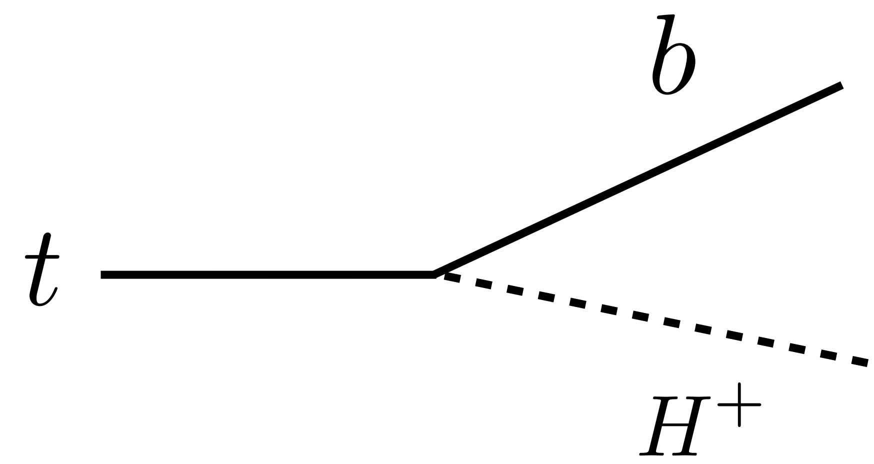
> running of EW couplings:
indirect probe of EW-charged states

> Rare decays of copiously produced SM particles

> rare top decays:
sensitive to additional scalars in Higgs sector

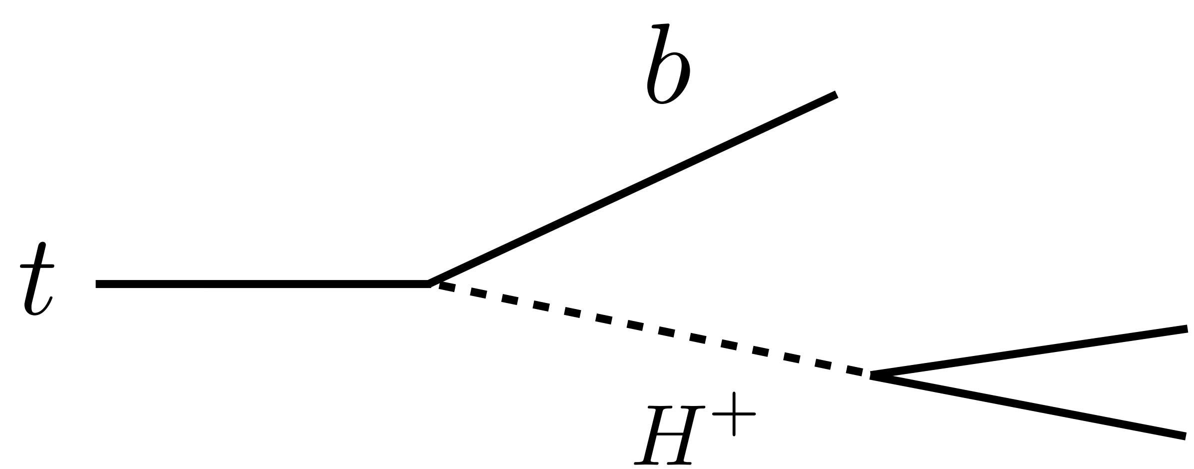
Rare Top Decays

In 2 Higgs Doublet Model, top can decay to charged Higgs



If type-II 2HDM:

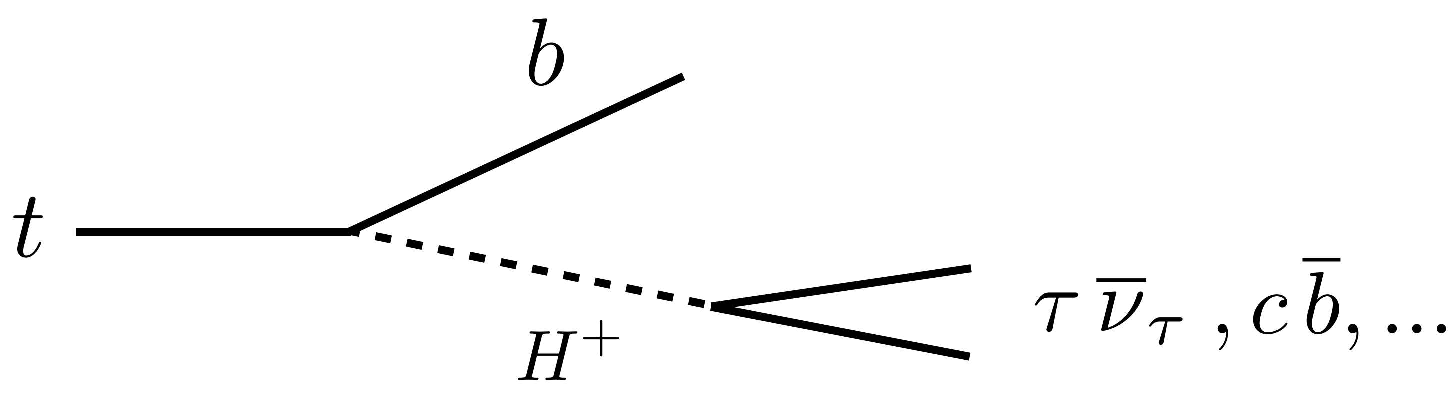
$$\mathrm{y}_u\, H_u Q\, u^c \;+\; \mathrm{y}_d\, H_d Q\, d^c \;+\; \mathrm{y}_\ell\, H_d Q\, \ell^c$$



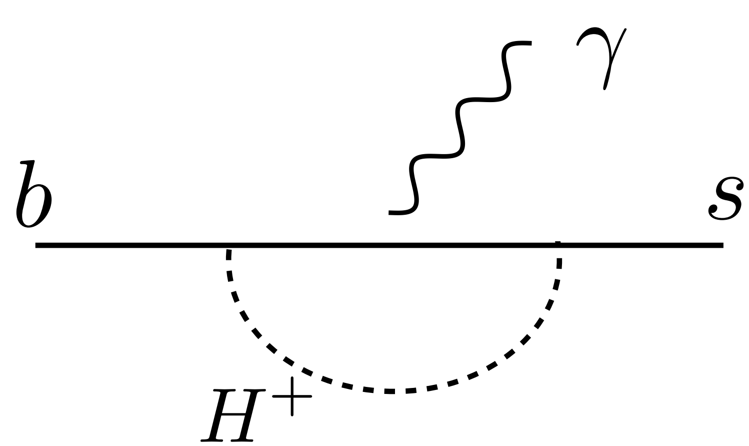
$\tau\,\overline{\nu}_\tau\;, c\,\overline{b}, \ldots$

Type-II 2 Higgs Doublet Model

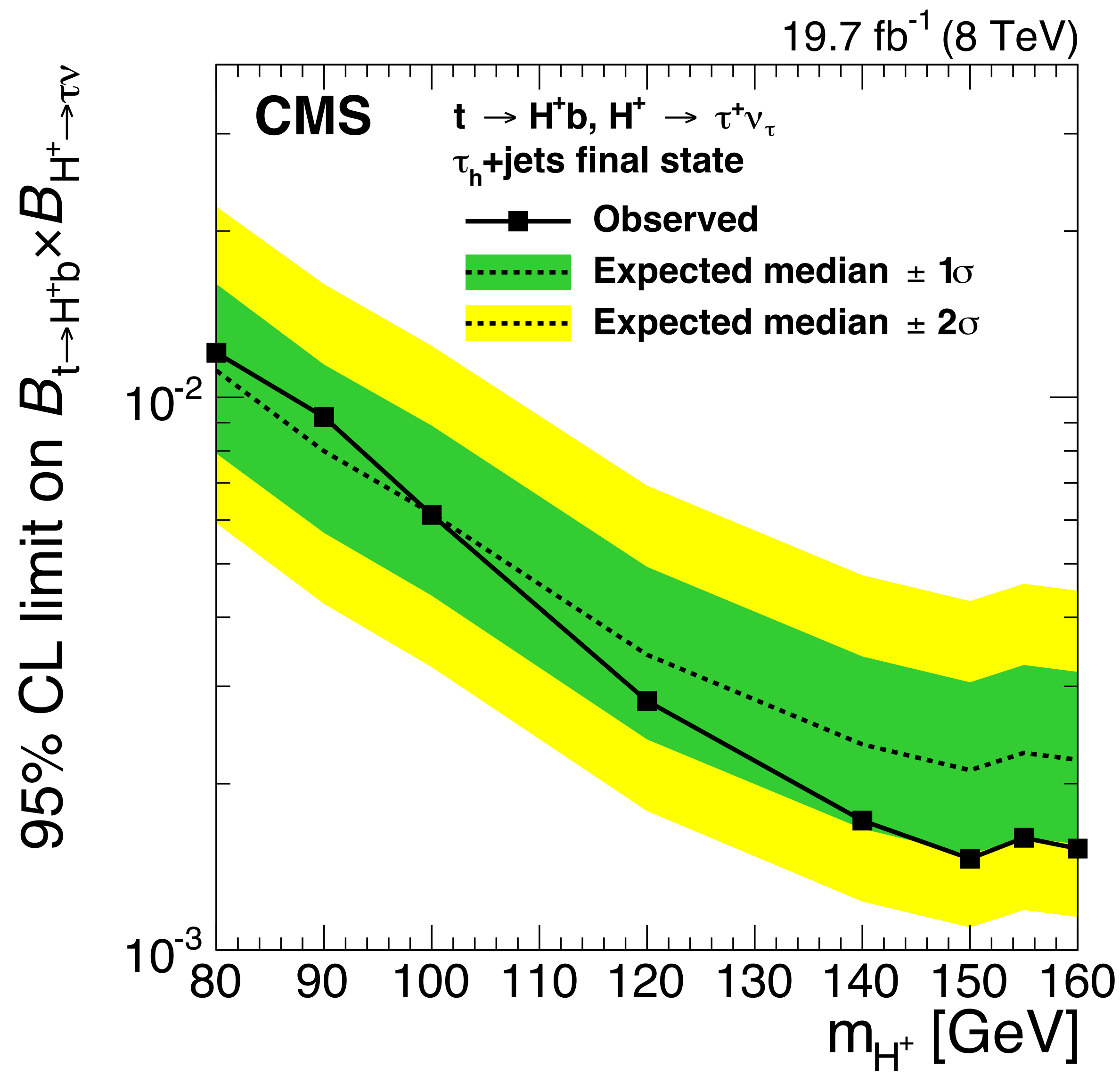
$$y_u\, H_u Q\, u^c \;+\; y_d\, H_d Q\, d^c \;+\; y_\ell\, H_d Q\, \ell^c \;+ V(H_u, H_d)$$



Already constrained by direct searches and rare b-decays:



$$m_{H^\pm} \gtrsim 480\,\mathrm{GeV}$$



Type-I 2 Higgs Doublet Model

Much less constrained (and explored):

$$\mathrm{y}_u\, H_1\, Q\, u^c \;+\; \mathrm{y}_d\, H_1\, Q\, d^c \;+\; \mathrm{y}_\ell\, H_1\, Q\, \ell^c \;+ V(H_1\,, H_2)$$

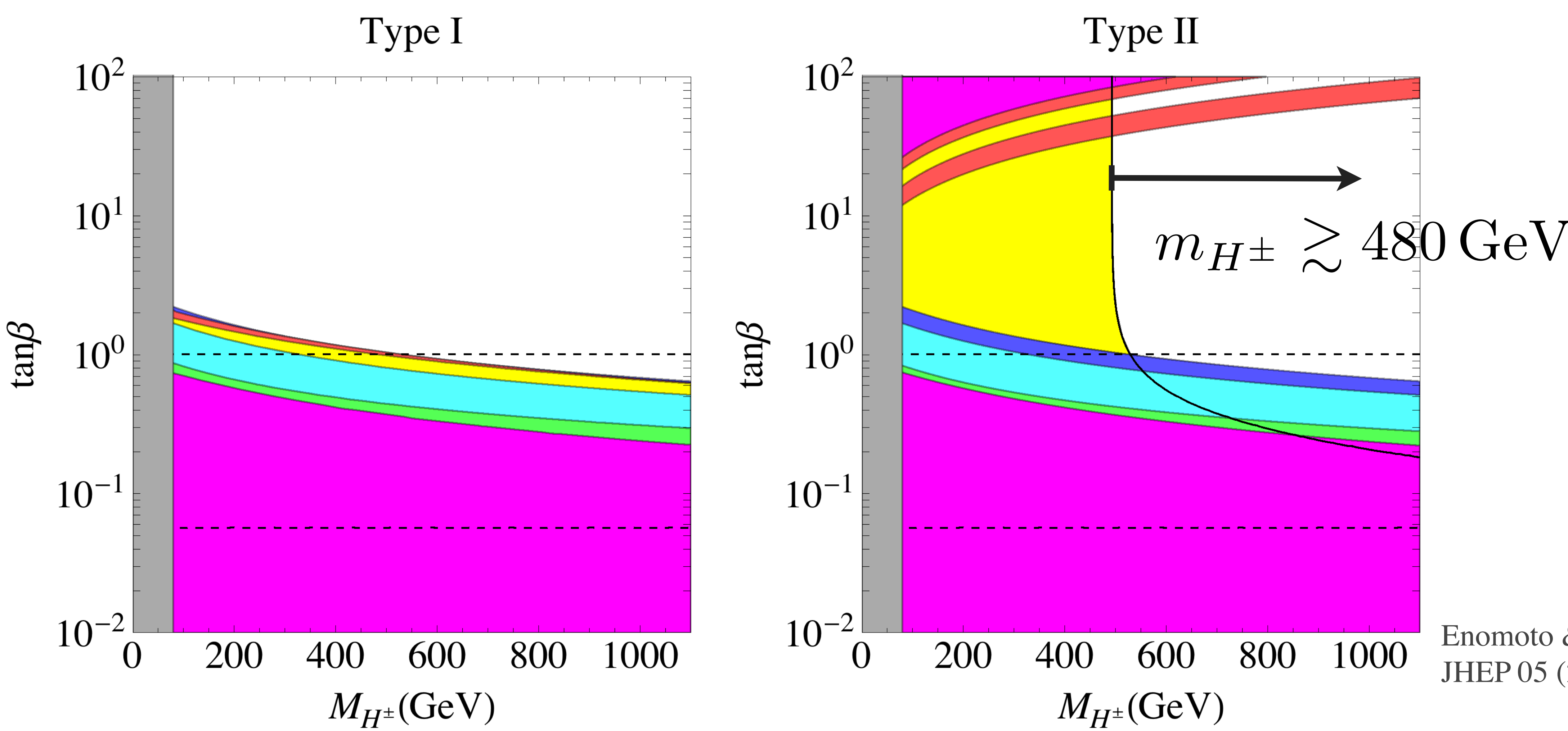
Type-I 2 Higgs Doublet Model

Much less constrained (and explored):

$$y_u H_1 Q u^c + y_d H_1 Q d^c + y_\ell H_1 Q \ell^c + V(H_1, H_2)$$

$b \to s\gamma$

$$\tan\beta \equiv \frac{\langle H_1 \rangle}{\langle H_2 \rangle} \gtrsim 2$$



Enomoto & Watanabe
JHEP 05 (2016)

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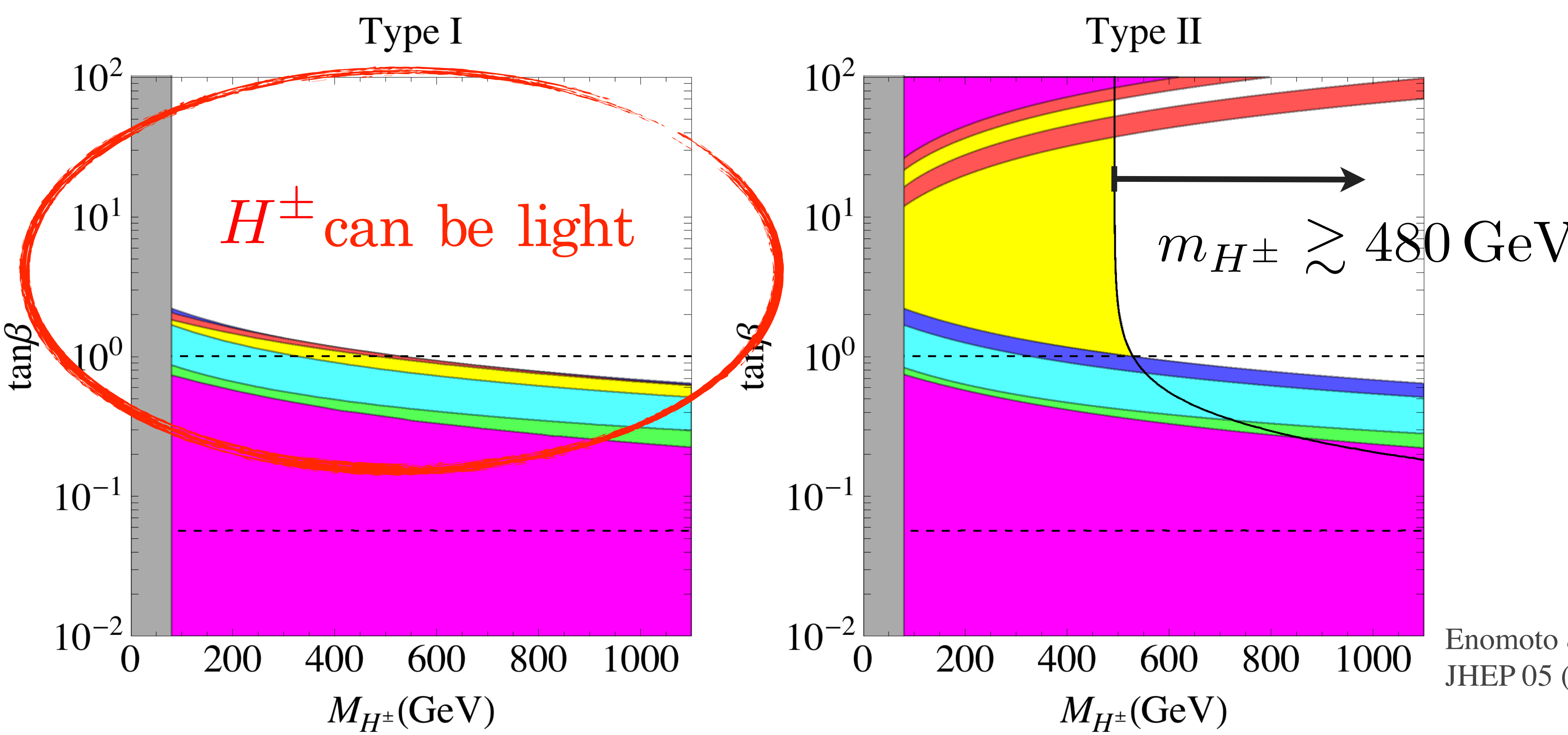

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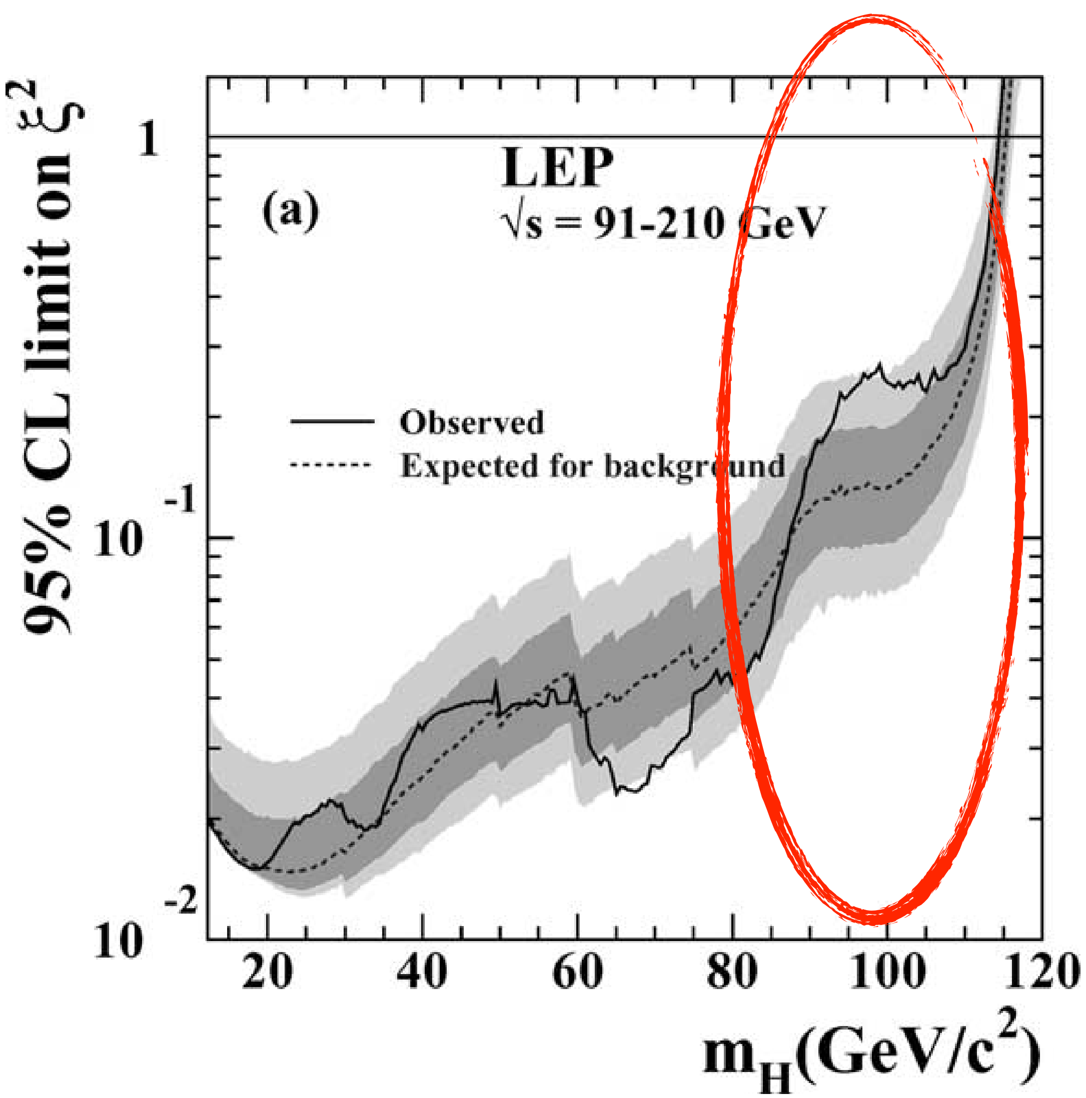
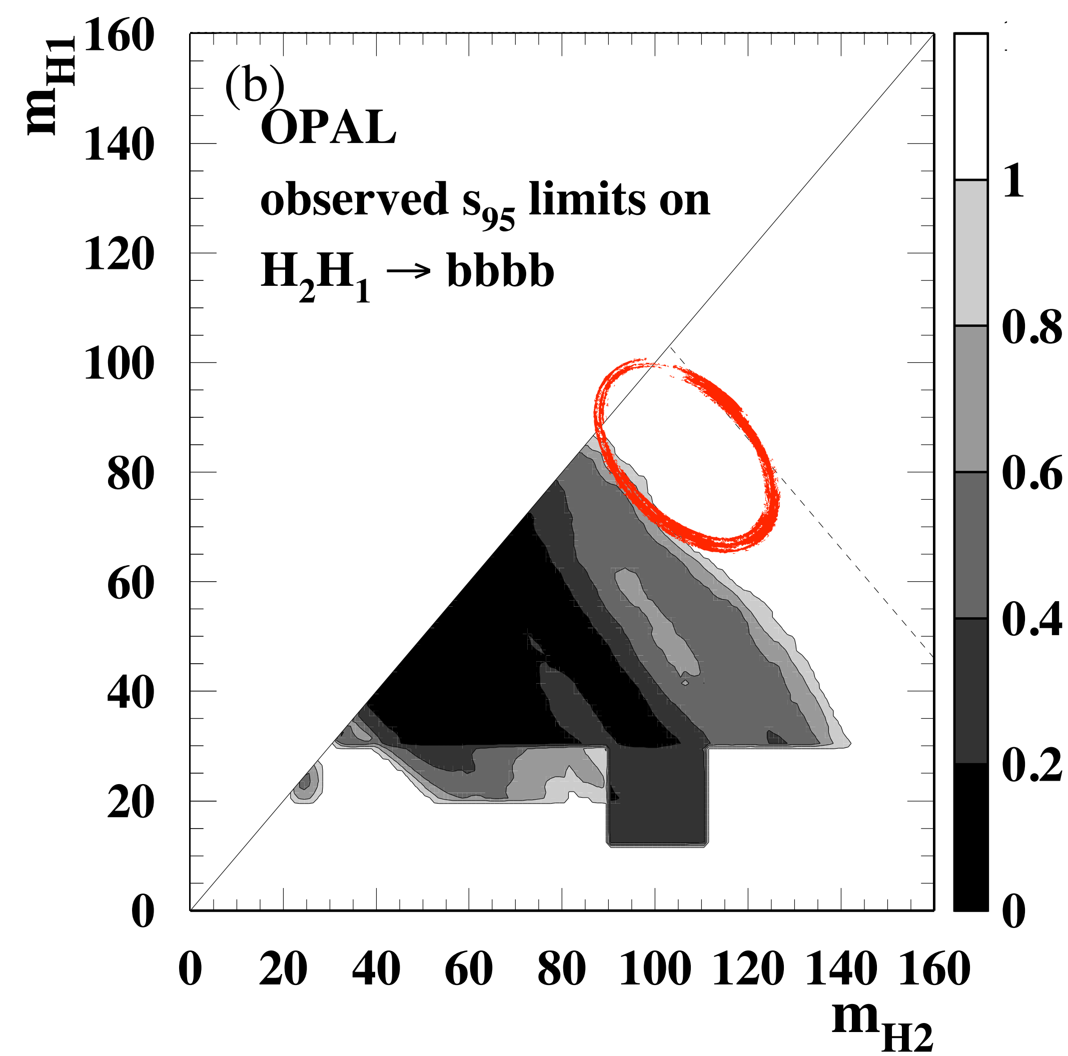
A^0, H^0 also can be light





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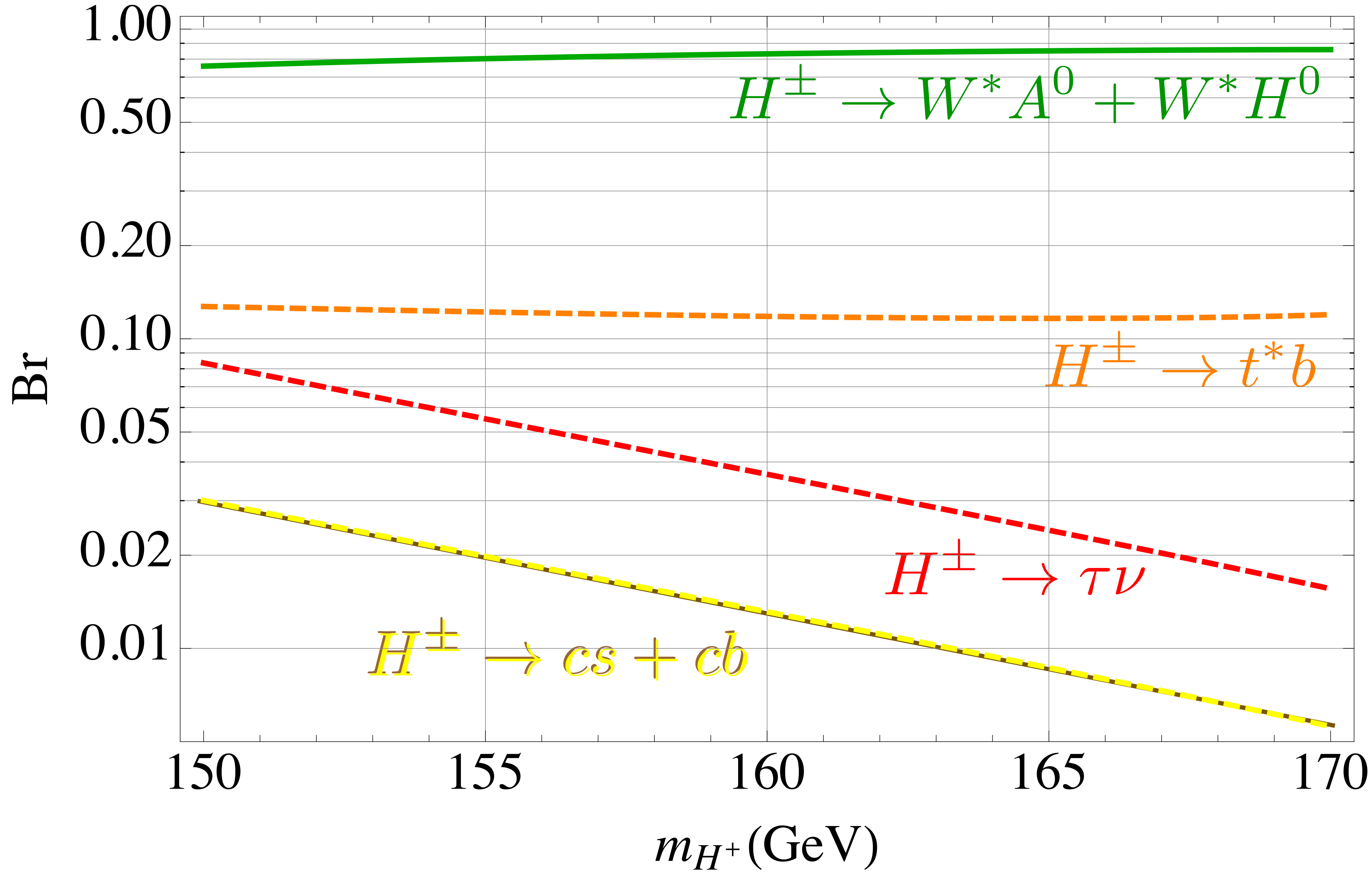
H^+ decays



$m_{A^0} = 100\,\text{GeV}$

$m_{H^0} = 100\,\text{GeV}$

$\tan\beta = 3$

Contrast between 2HDM spectra

MSSM inspired	In this talk
Type II $\mathrm{y}_u\, H_u Q\, u^c \;+\; \mathrm{y}_d\, H_d Q\, d^c \;+\; \mathrm{y}_\ell\, H_d Q\, \ell^c$	Type I $\mathrm{y}_u\, H_1 Q\, u^c \;+\; \mathrm{y}_d\, H_1 Q\, d^c \;+\; \mathrm{y}_\ell\, H_1 Q\, \ell^c$

Contrast between 2HDM spectra

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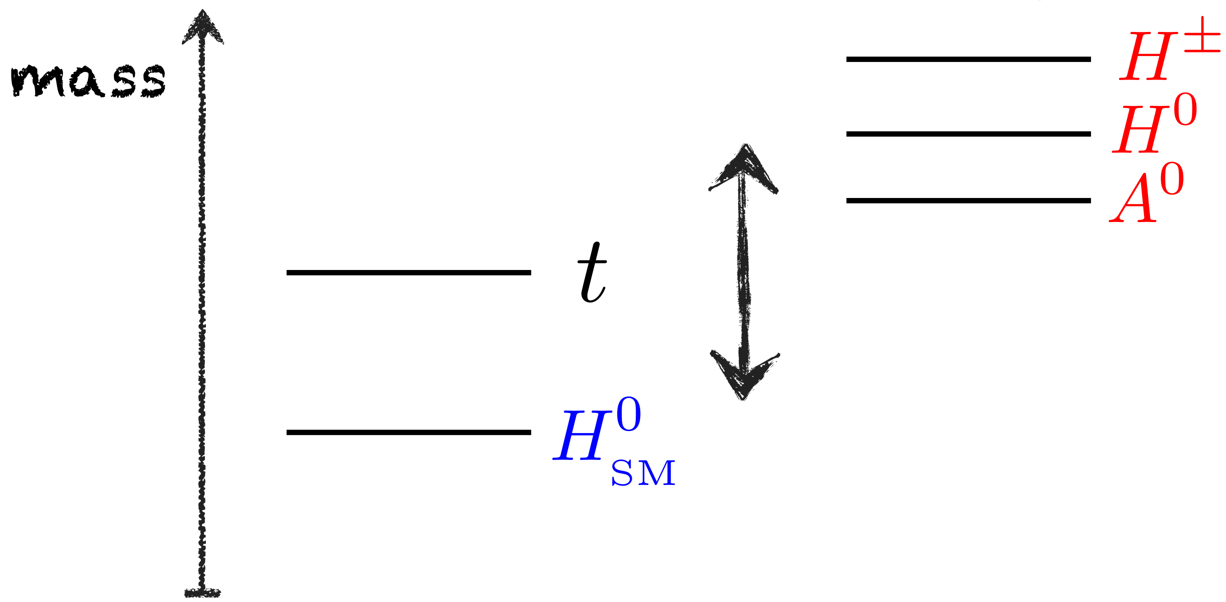

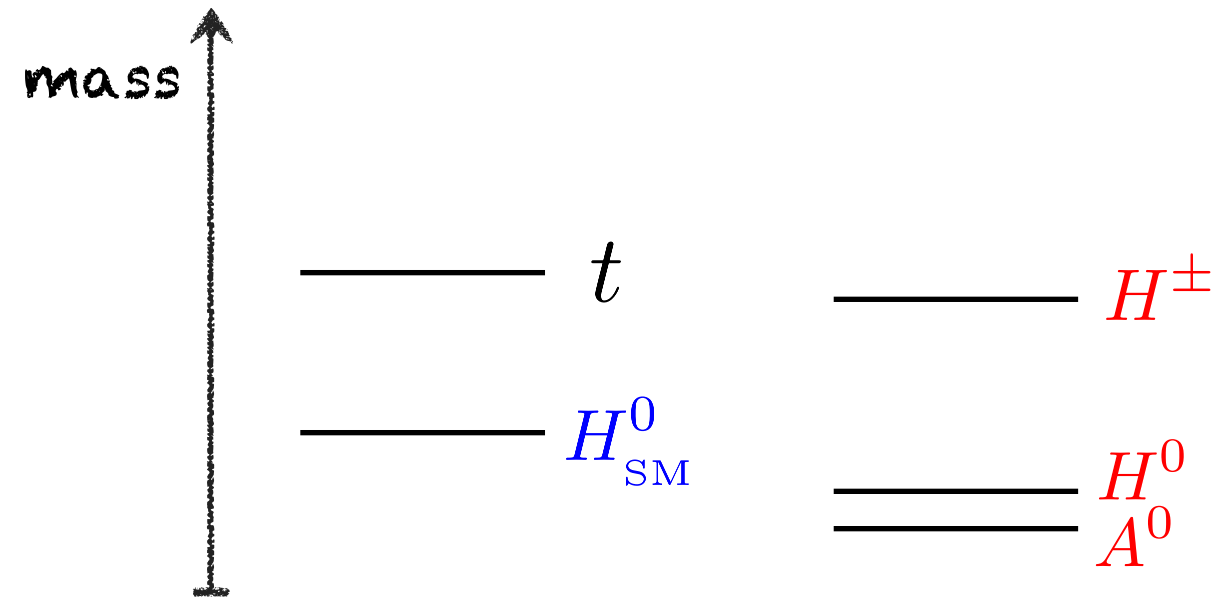

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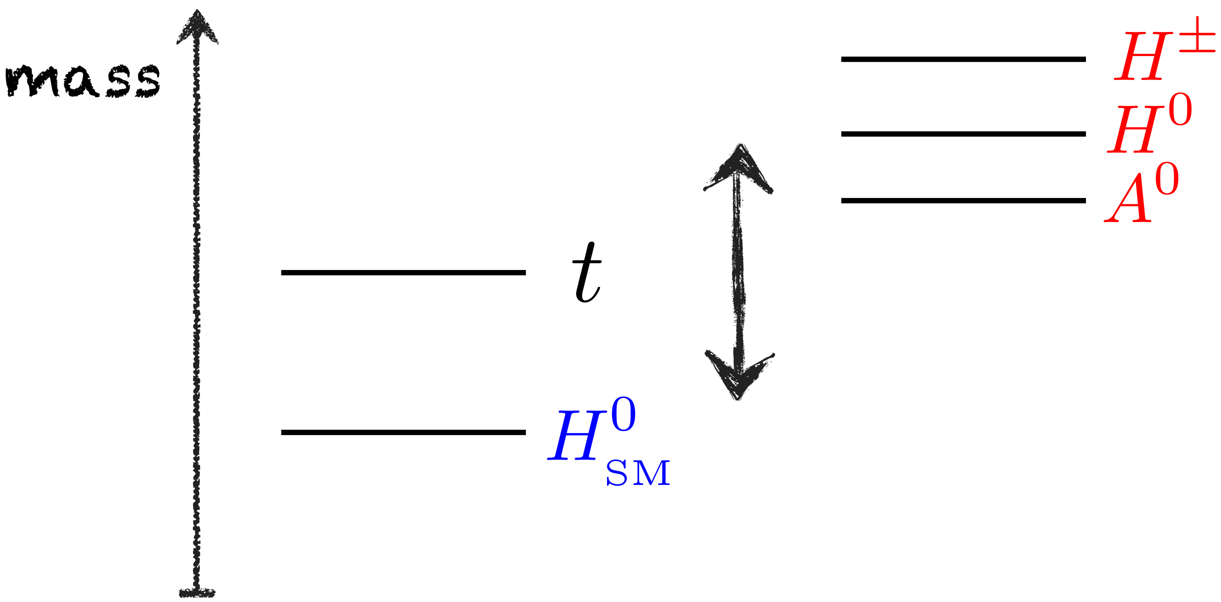
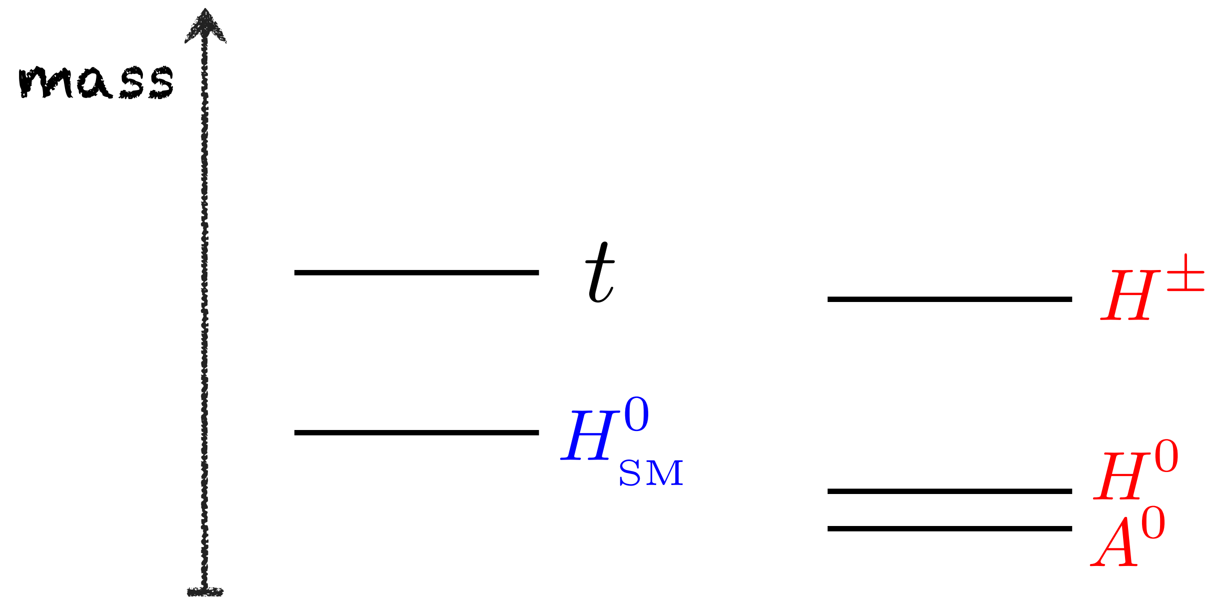
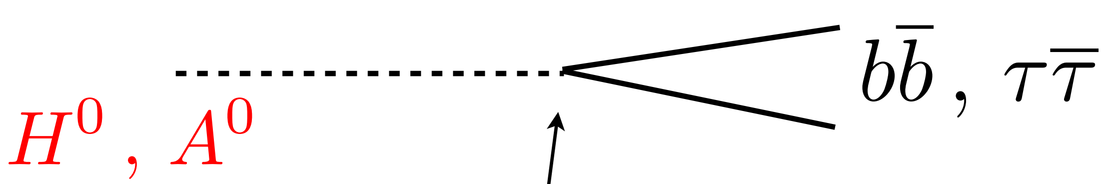
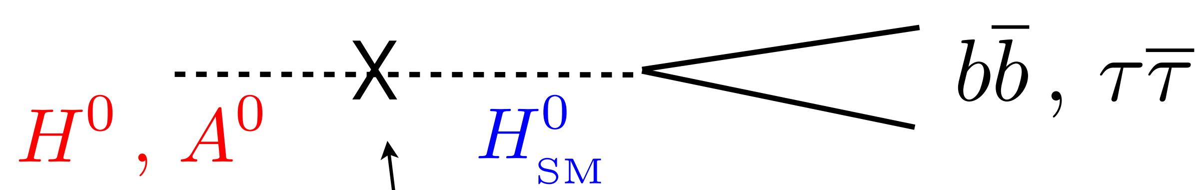






large yukawa



mixing with other doublet

Contrast between 2HDM spectra

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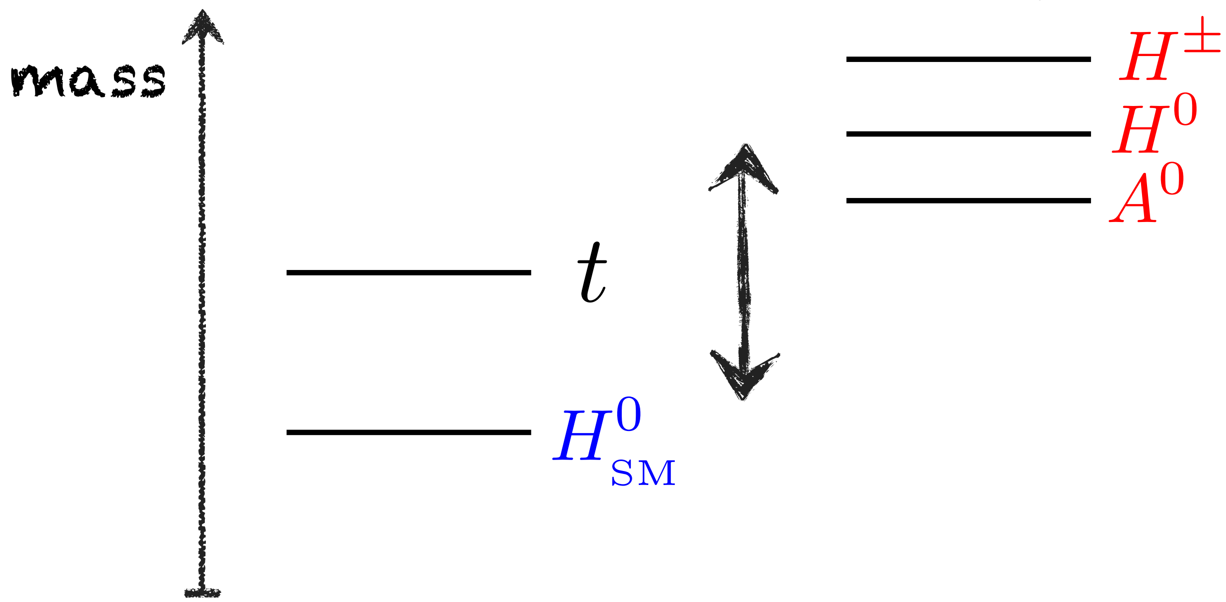
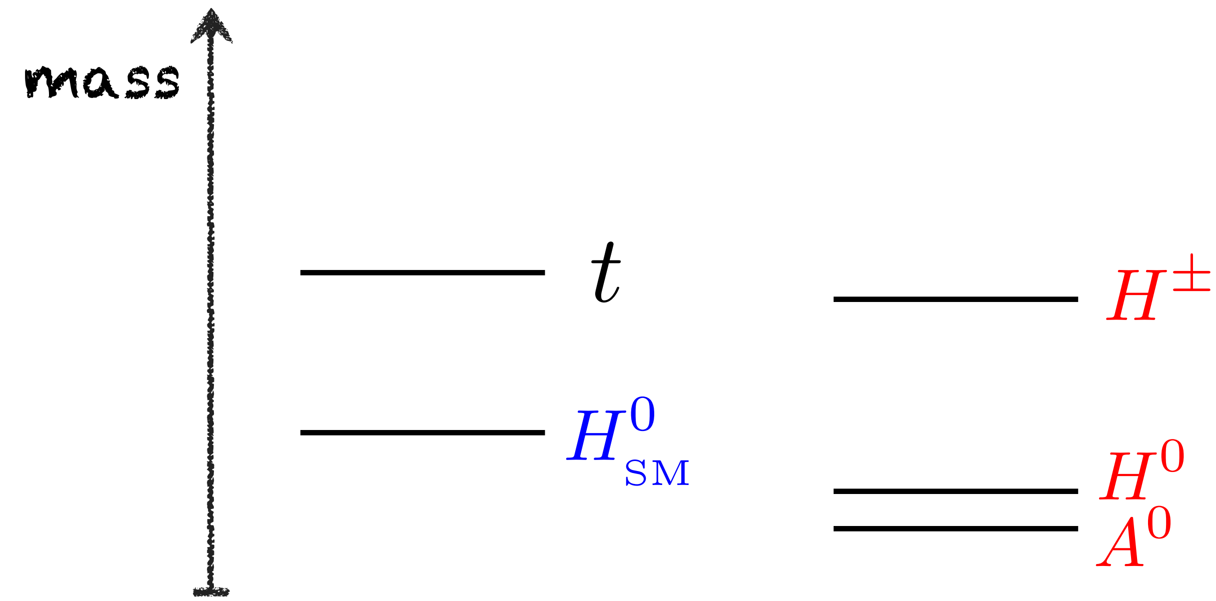
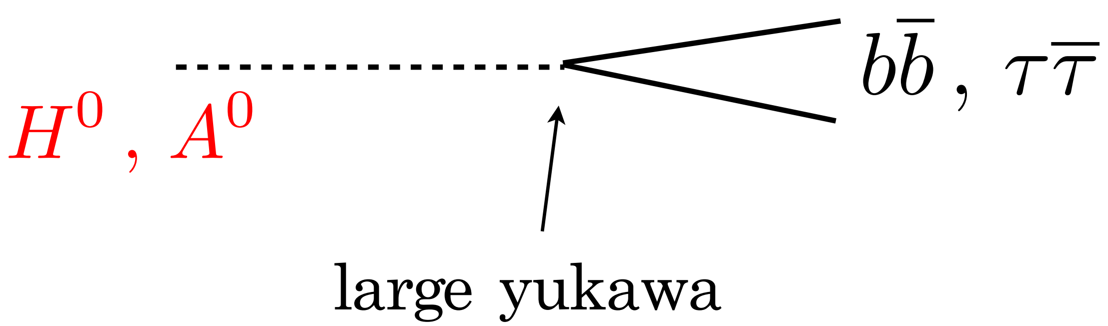
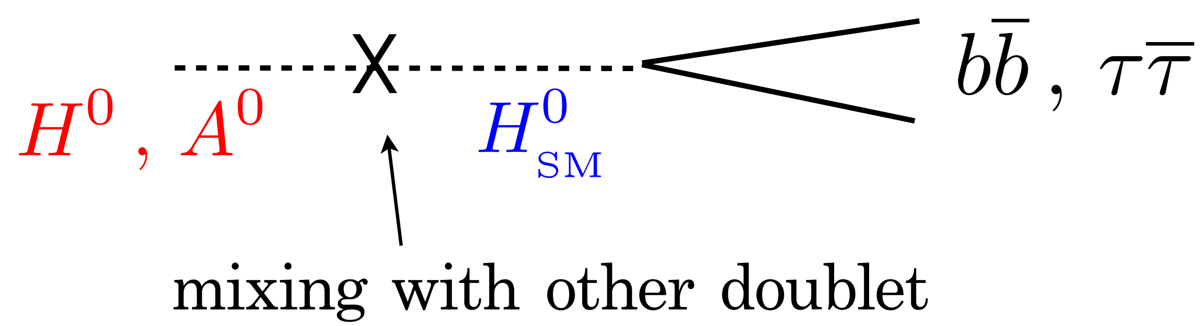
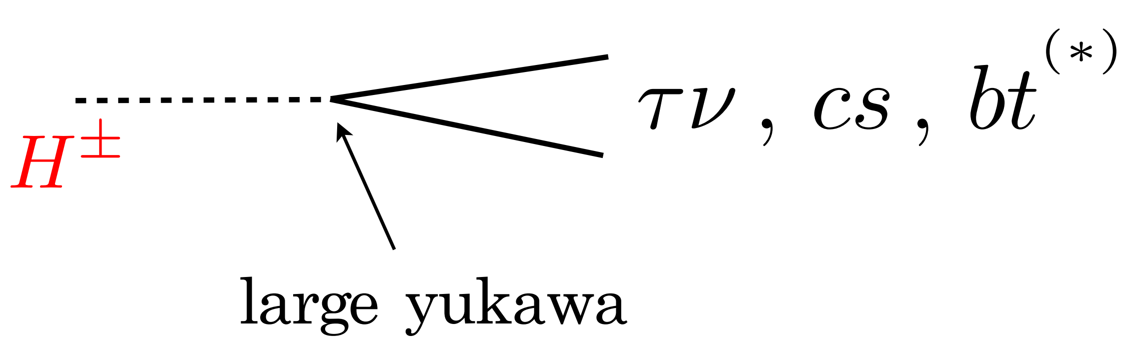
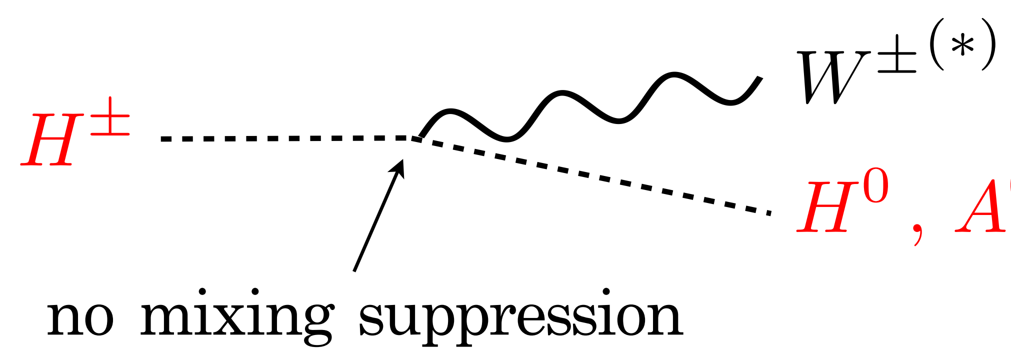






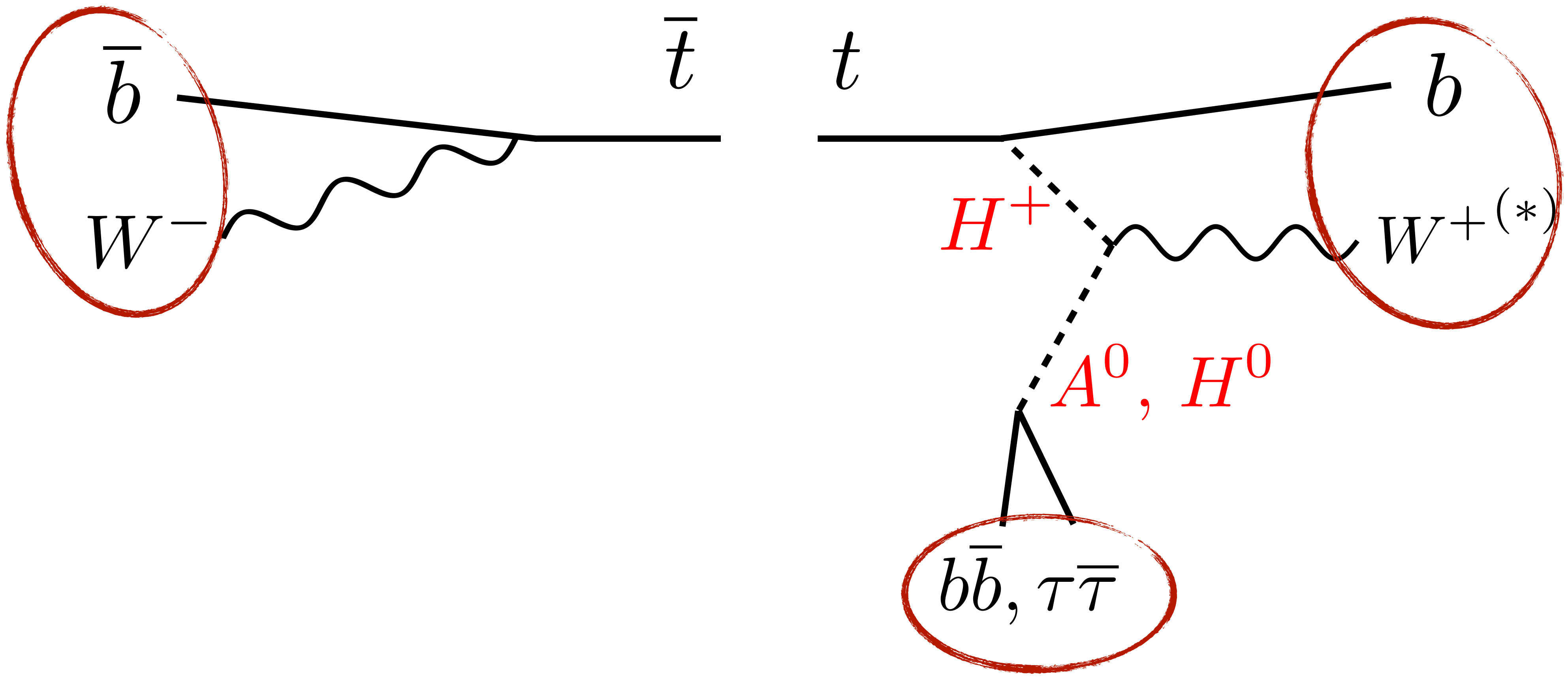






Rare Top Decays in Light Type-I 2HDM

Same final state as $t\bar{t}H$



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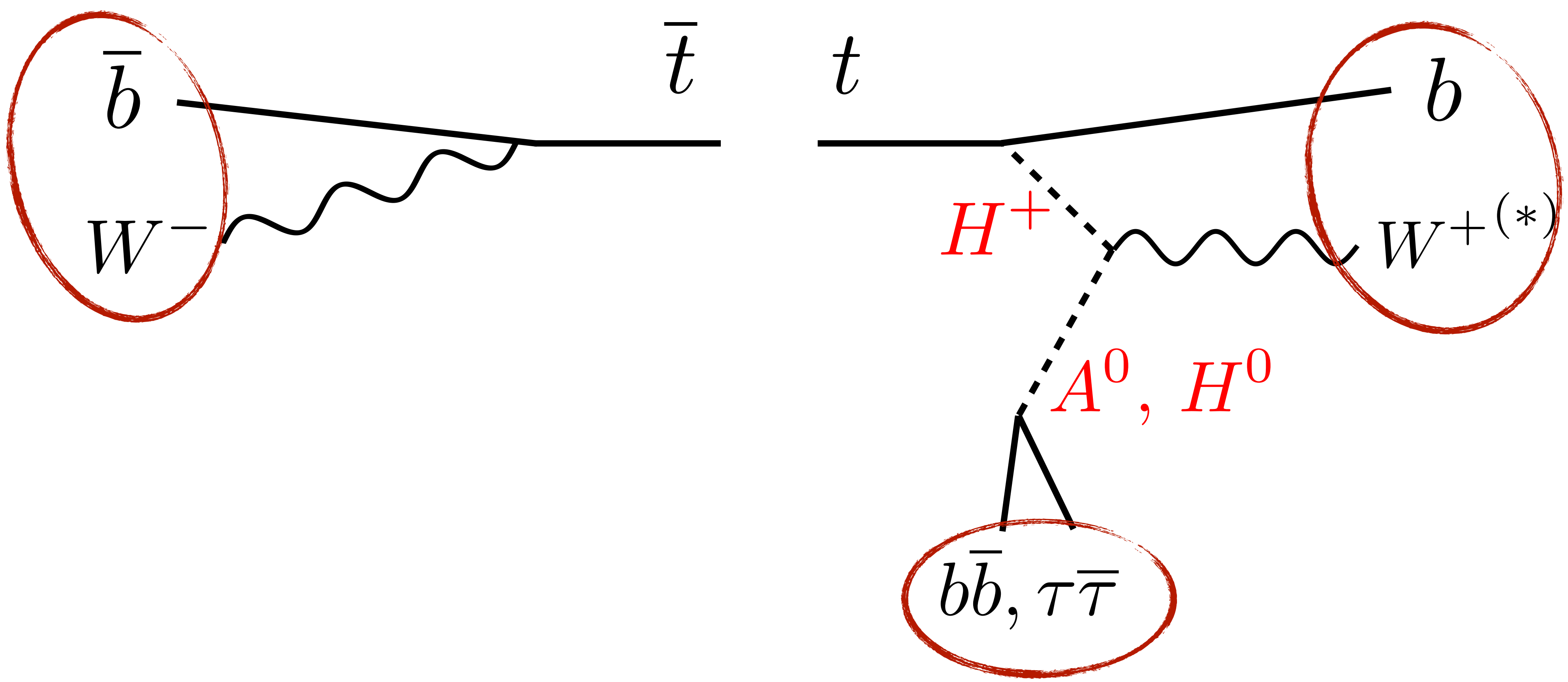

To avoid conflict with measurements of $\sigma_{t\bar{t}}$:

$$\mathrm{Br}(t \to bH^+) \lesssim \mathcal{O}(1\%)$$

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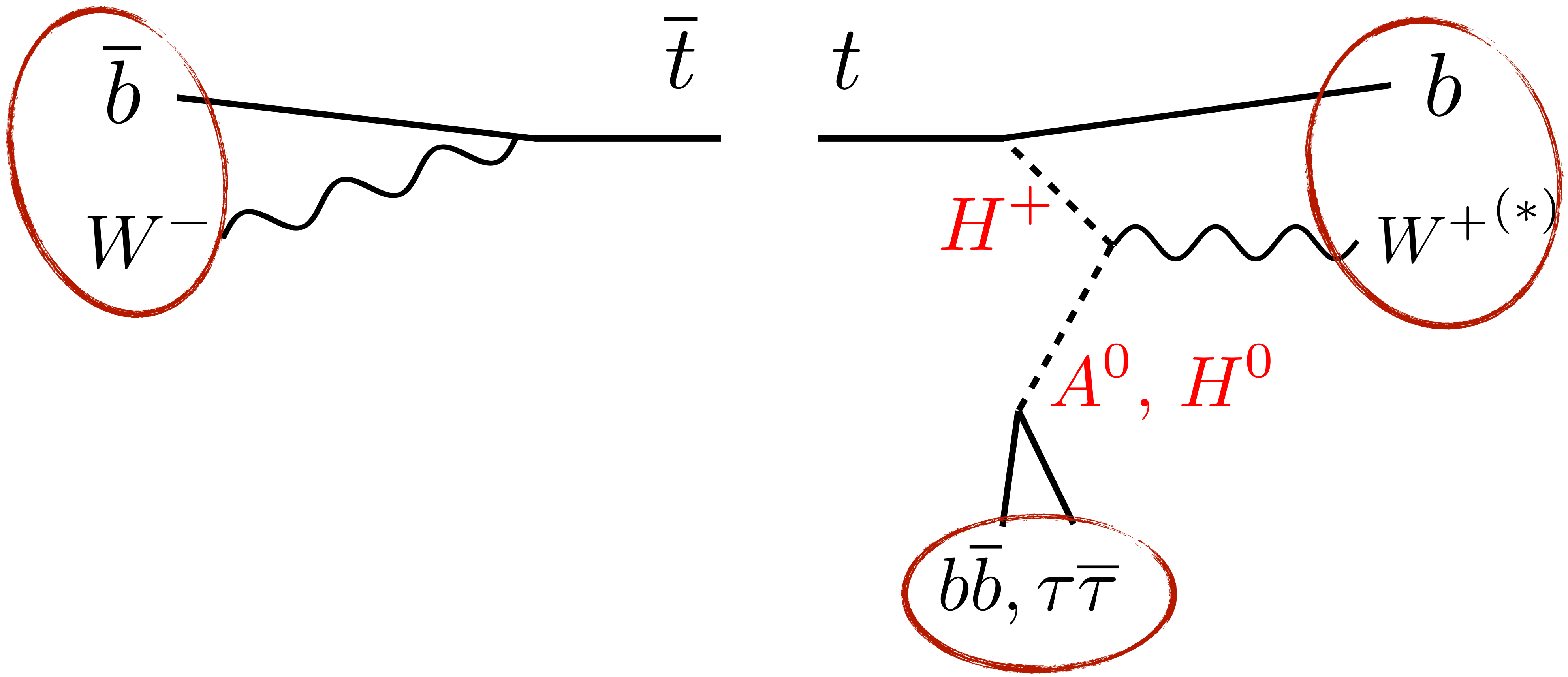

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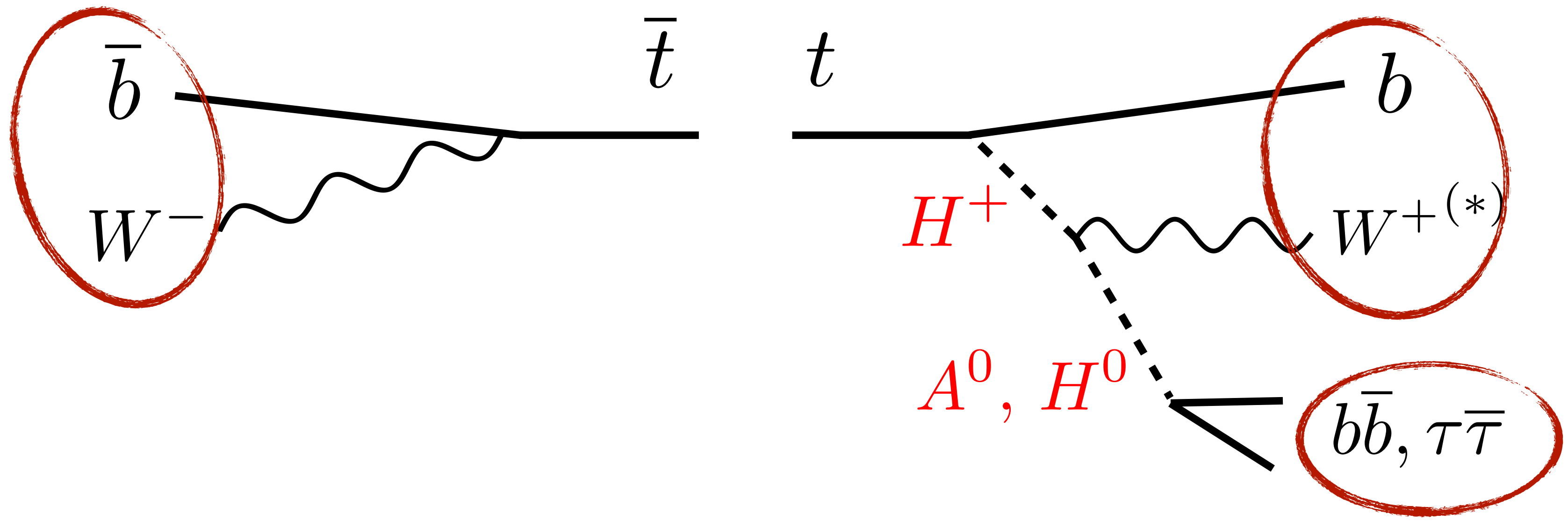
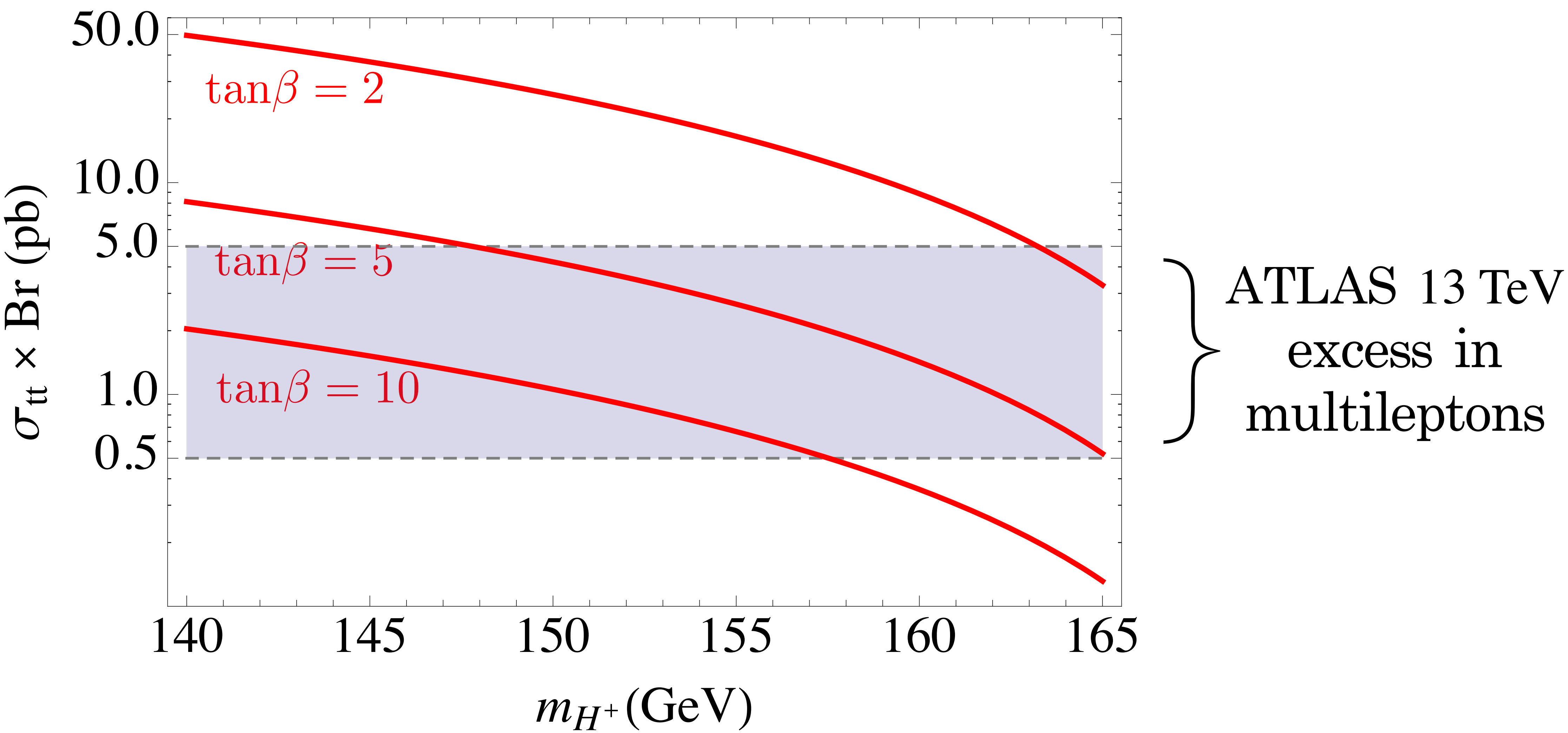
Right ballpark to explain recent ATLAS excess in $t\bar{t}H$

13 TeV ATLAS excess in $t\bar{t}H$





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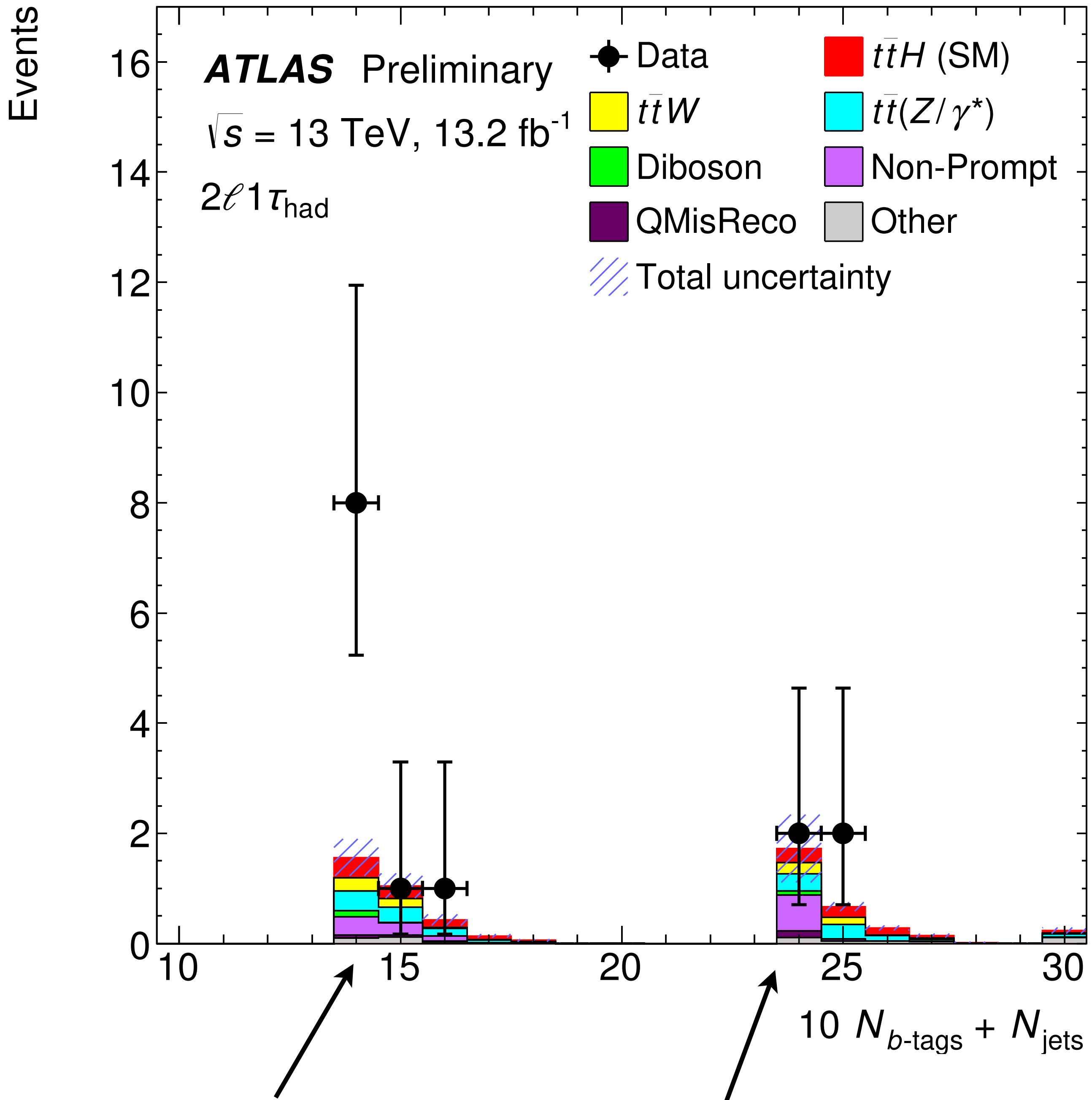


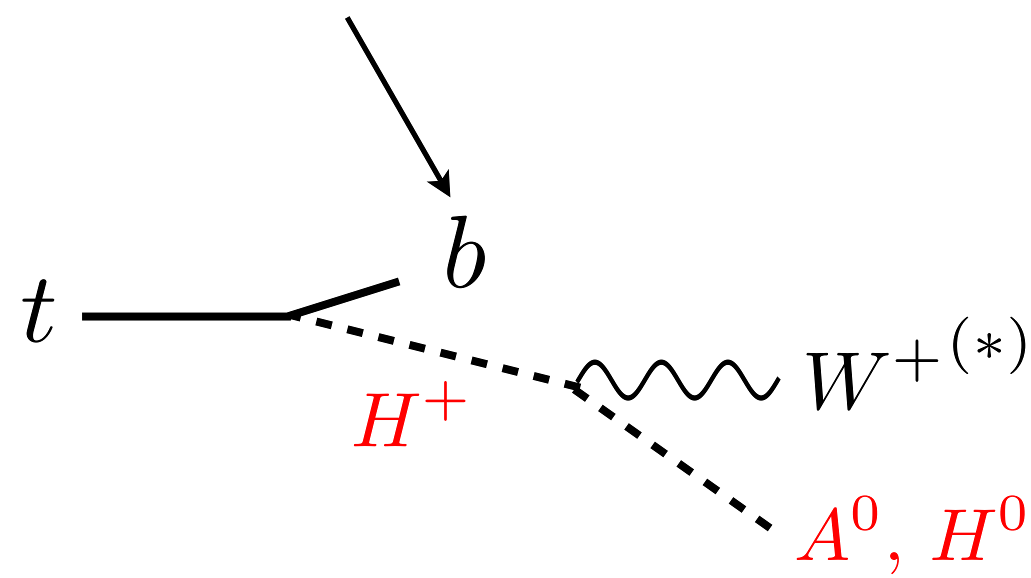
1 b-tag

2 b-tags

Excess appears exclusively on 1 b-tag channel

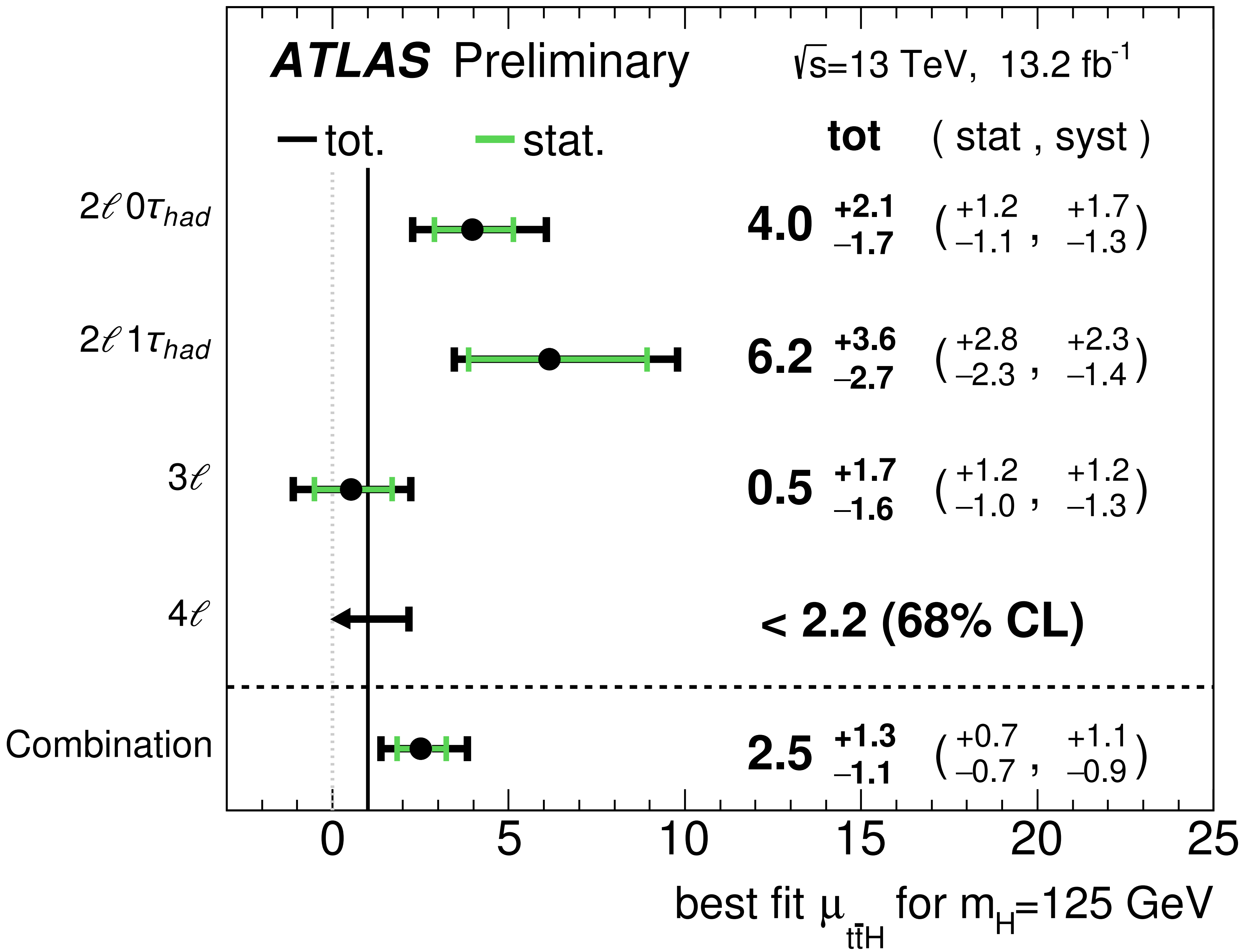
Easily explained by small mass splitting $m_t - m_{H^\pm}$

$\Rightarrow$ b is too soft to be tagged



13 TeV ATLAS excess in $t\bar{t}H$

relative excess strength varies across different leptonic channels



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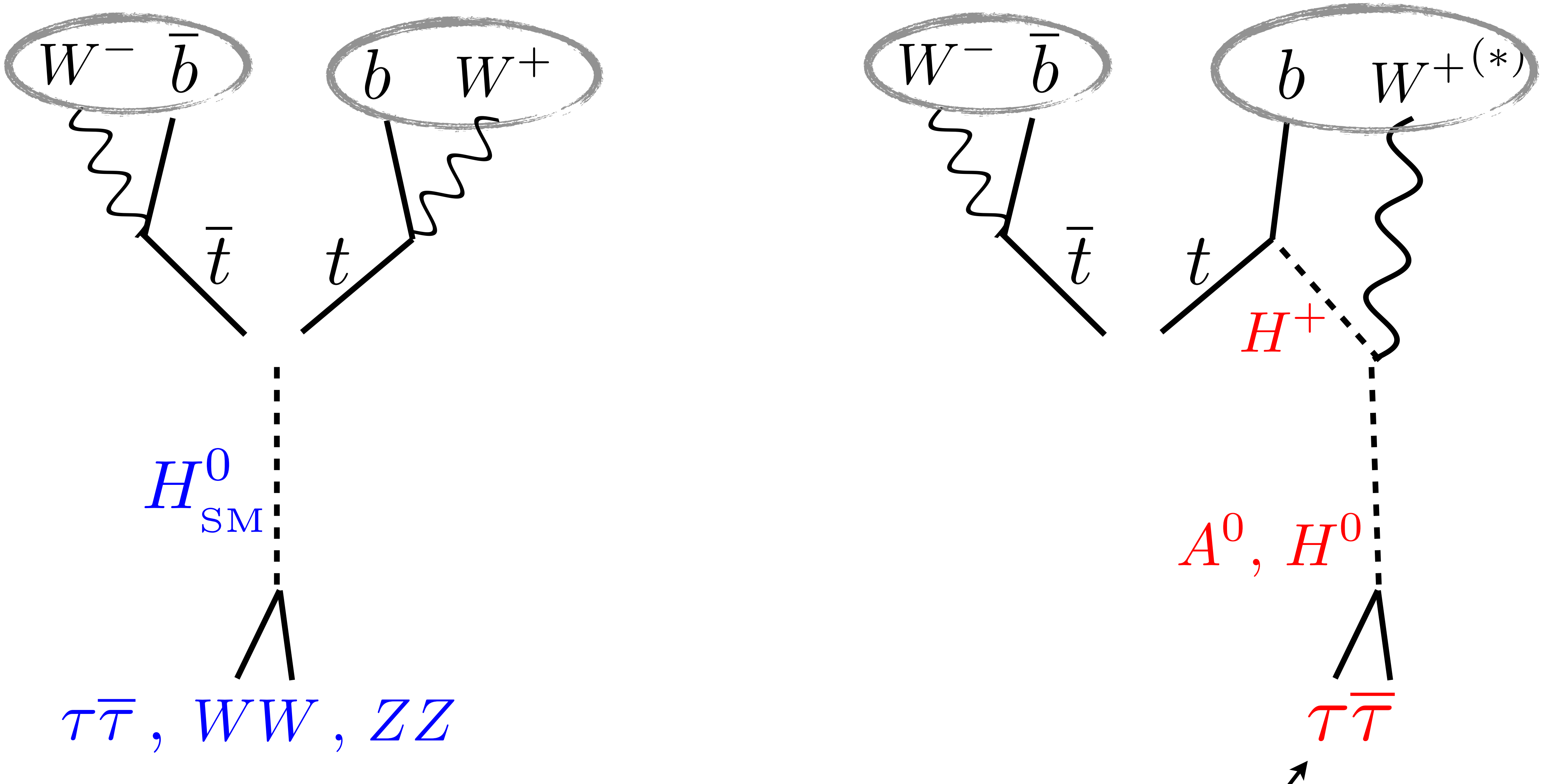


dominant "leptonic" decay if

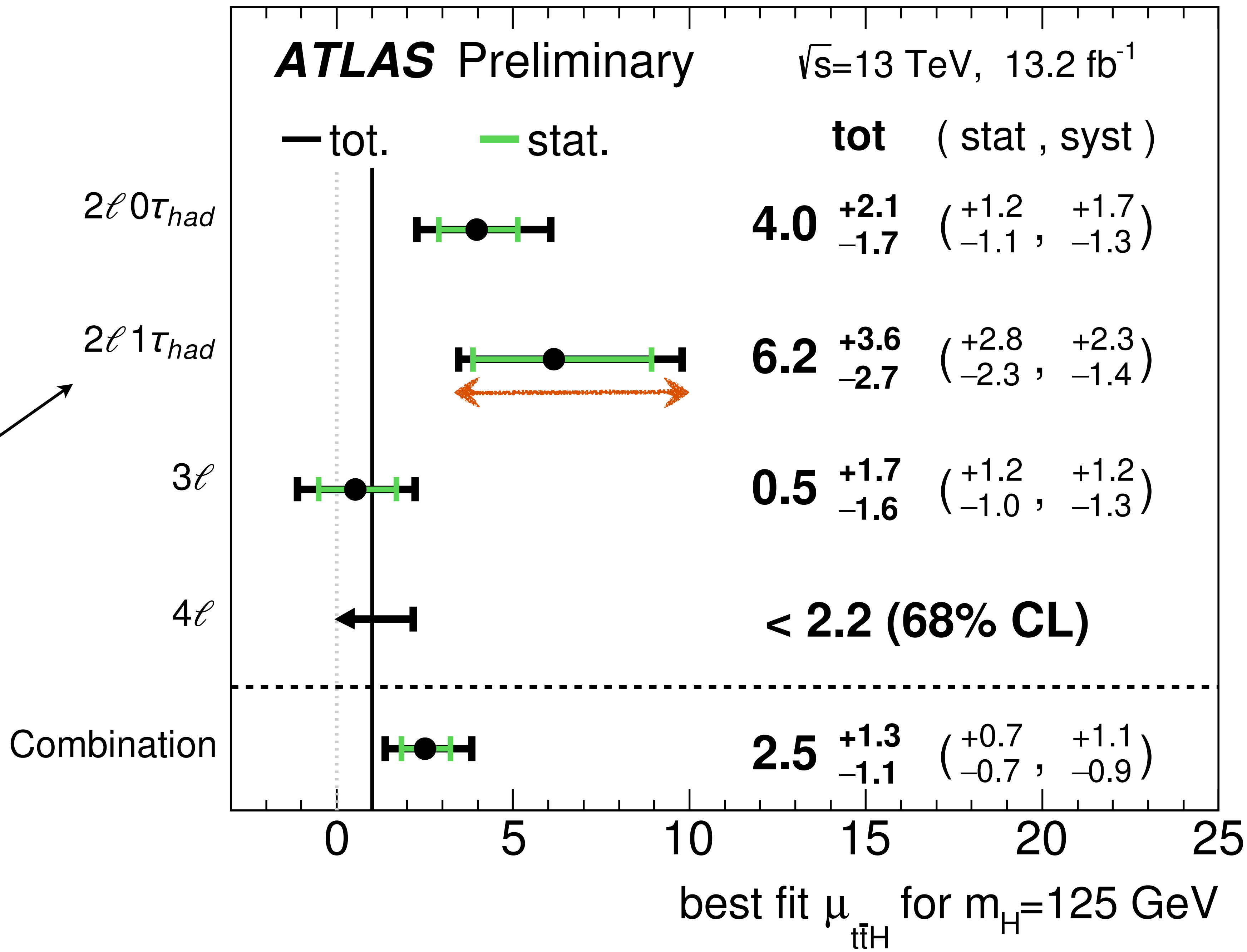
$m_{H^0_2} \sim 80 - 110\,\text{GeV}$

13 TeV ATLAS excess in $t\bar{t}H$

relative excess strength varies across different leptonic channels

PRELIMINARY

fit excess strength in this channel

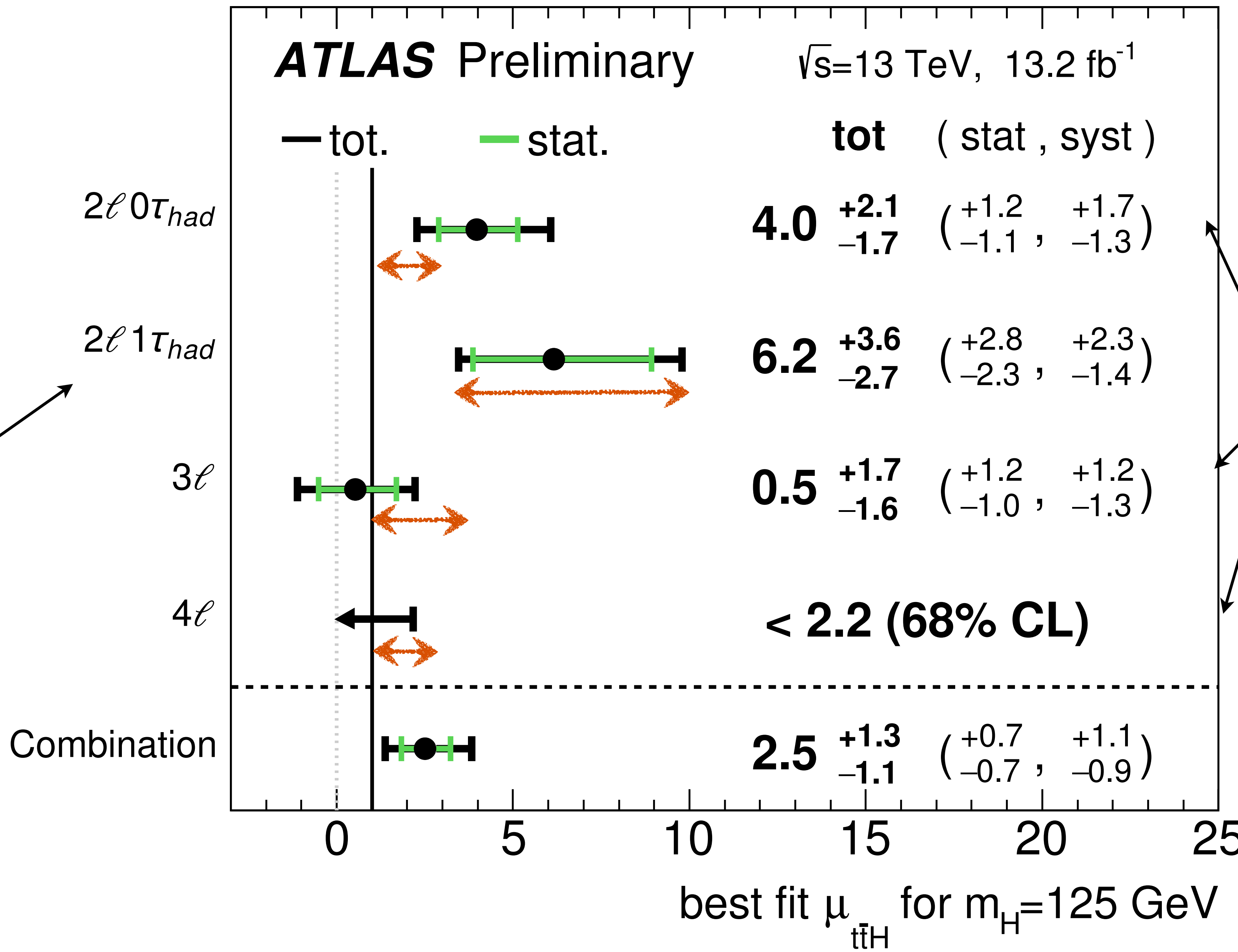


13 TeV ATLAS excess in $t\bar{t}H$

relative excess strength varies across different leptonic channels

PRELIMINARY

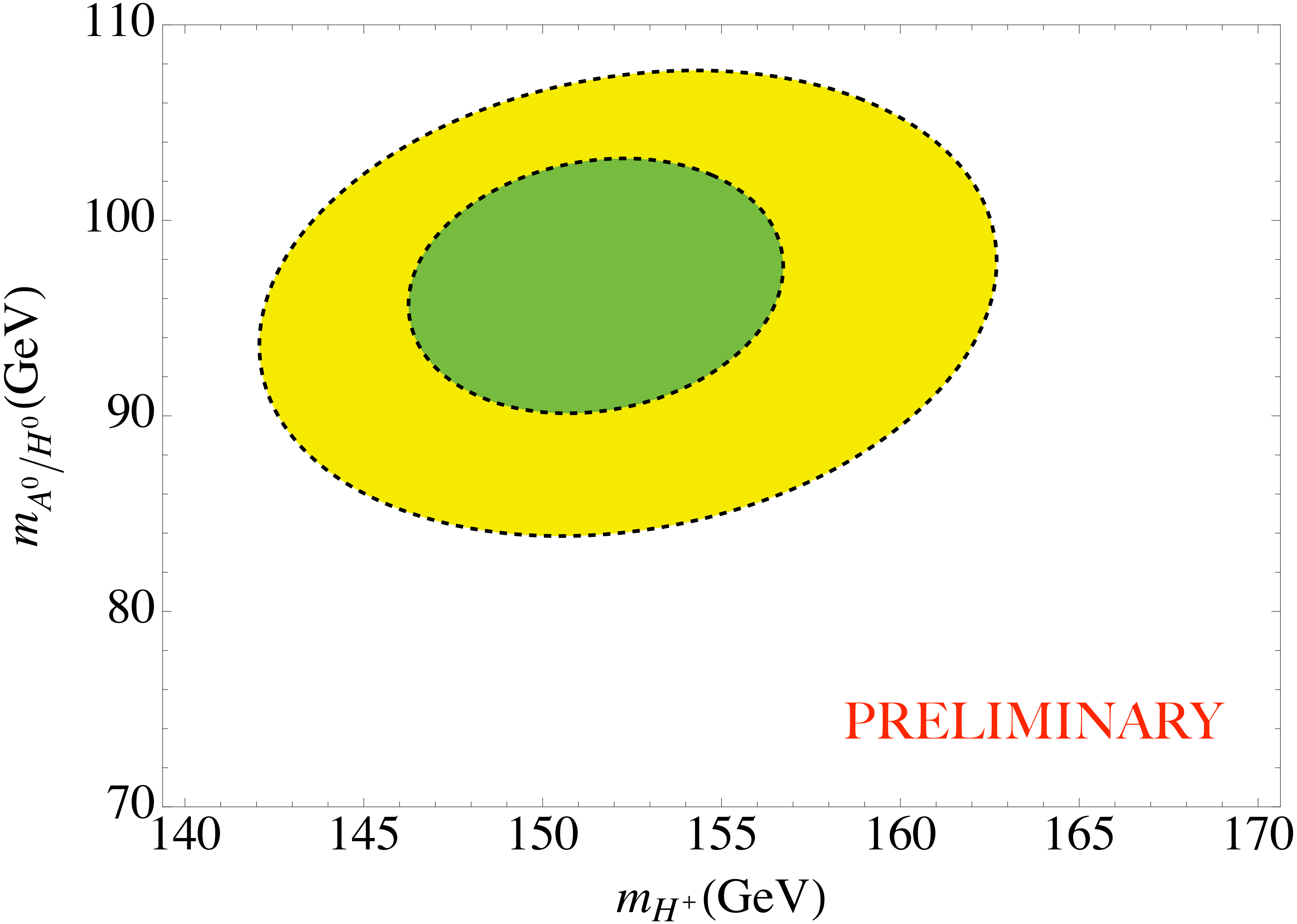
fit excess strength in this channel



predict excess strength in remaining channels

13 TeV ATLAS excess in $t\bar{t}H$

Fit of excess with rare top decay in light type-I 2HDM



Summary

Probing new EW physics @ LHC is challenging

Searches in direct production (low statistics)
can be complemented by high statistics channels

E.g., rare top decays

In type I 2HDM,

> new scalars can be light

> top can decay to charged higgs

> such decays can contaminate ttH searches

> could explain recent excess in
ATLAS ttH search in multileptons

Thank You