

Combined signatures of heavy Higgses and vector- like quarks

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TRIUMF

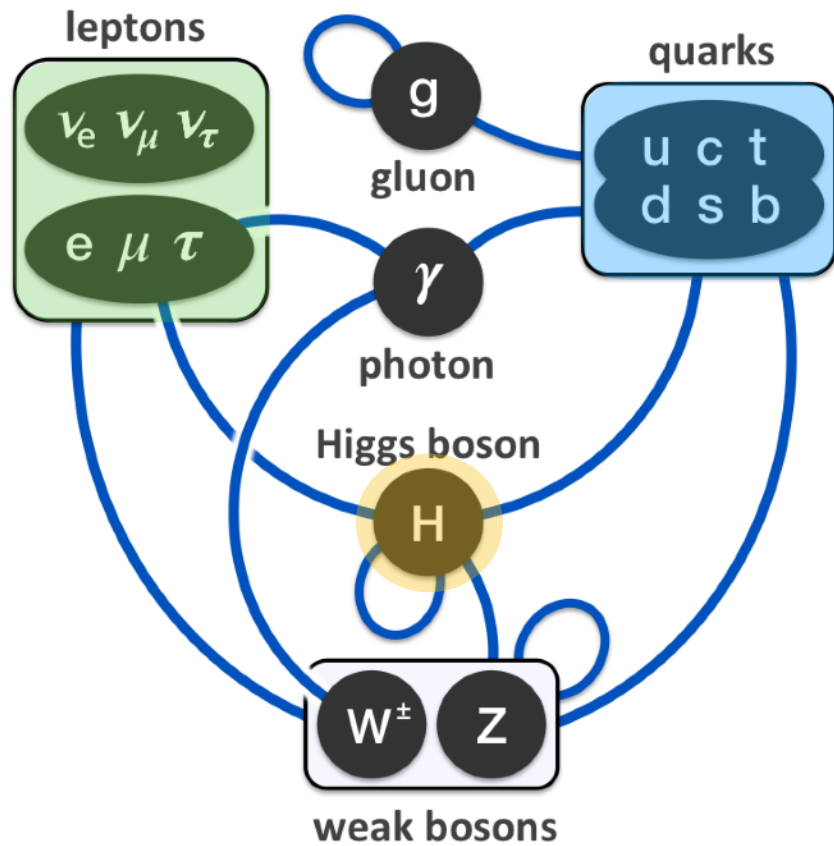
Based on collaboration with
Radovan Dermisek, Enrico
Lunghi, & Seodong Shin

LHC Higgs Working Group WG3 (BSM) -- Extended Higgs
Sector subgroup meeting - Nov 5, 2021



Motivation

Standard Model



What else?



Extended matter sectors

$$Q_{L,R}, U_{L,R}, D_{L,R}$$

+

$$L_{L,R}, E_{L,R}, N_{L,R}$$

Extended Higgs sectors

$$H, A, H^\pm$$

For me: focus on 2HDM + vector-like fermions

Motivation

Connection to BSM scenarios:

- Composite Higgs
- Supersymmetry
- Z' models
- GUTs
- Etc.

Connection to Pheno:

- $(g - 2)_{e,\mu}$
- B-physics
- Cabibbo anomaly
- DM
- Etc.

Personal motivation: Understanding of couplings from IR fixed points in MSSM + 1VF: R. Dermisek, NM, [arXiv:1812.05240](https://arxiv.org/abs/1812.05240)

Direct searches for LHC (typically) focus on production of individual particles

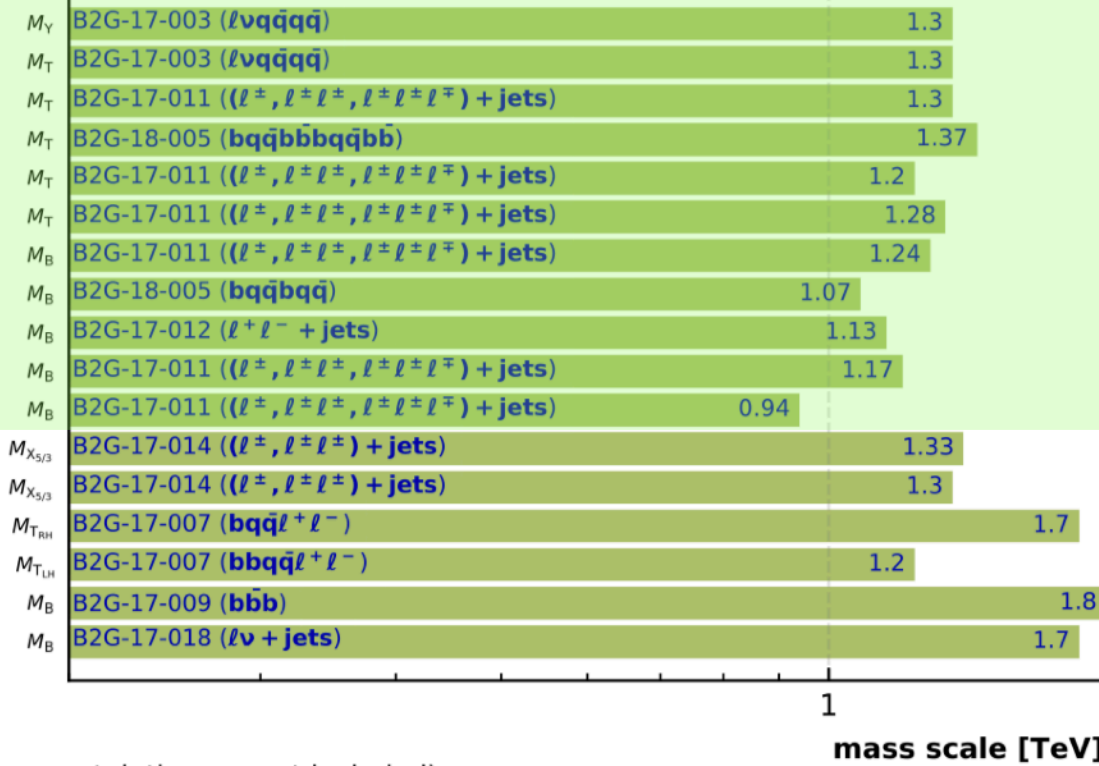
Lots of well motivated scenarios with extended Higgs AND matter sectors
Combined signatures, e.g. cascade decays, presents many new opportunities for searches
with many advantages over individual searches

VL Quarks + heavy Higgses

CMS Beyond-two-generations (B2G) Public Physics Results

Very Heavy Fermions

$YY \rightarrow bWbW \rightarrow \ell\nu q\bar{q}q\bar{q}$, $B(Y \rightarrow bW) = 100\%$
 $TT \rightarrow bWbW \rightarrow \ell\nu q\bar{q}q\bar{q}$, $B(T \rightarrow bW) = 100\%$
 $TT \rightarrow tZtZ \rightarrow (\ell^\pm, \ell^\pm\ell^\pm, \ell^\pm\ell^\pm\ell^\mp) + jets$, $B(T \rightarrow tZ) = 100\%$
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 $T_{RH} \rightarrow tZ \rightarrow bq\bar{q}\ell^+\ell^-$, narrow T
 $bT_{LH} \rightarrow btZ \rightarrow bbq\bar{q}\ell^+\ell^-$, narrow T
 $B \rightarrow bH \rightarrow b\bar{b}b$, narrow B
 $B \rightarrow tW \rightarrow \ell\nu + jets$, narrow B



Pair production of VLQ w/ SM charge assignments

Selection of observed exclusion limits at 95% CL (theory uncertainties are not included).

EPS-HEP 2019

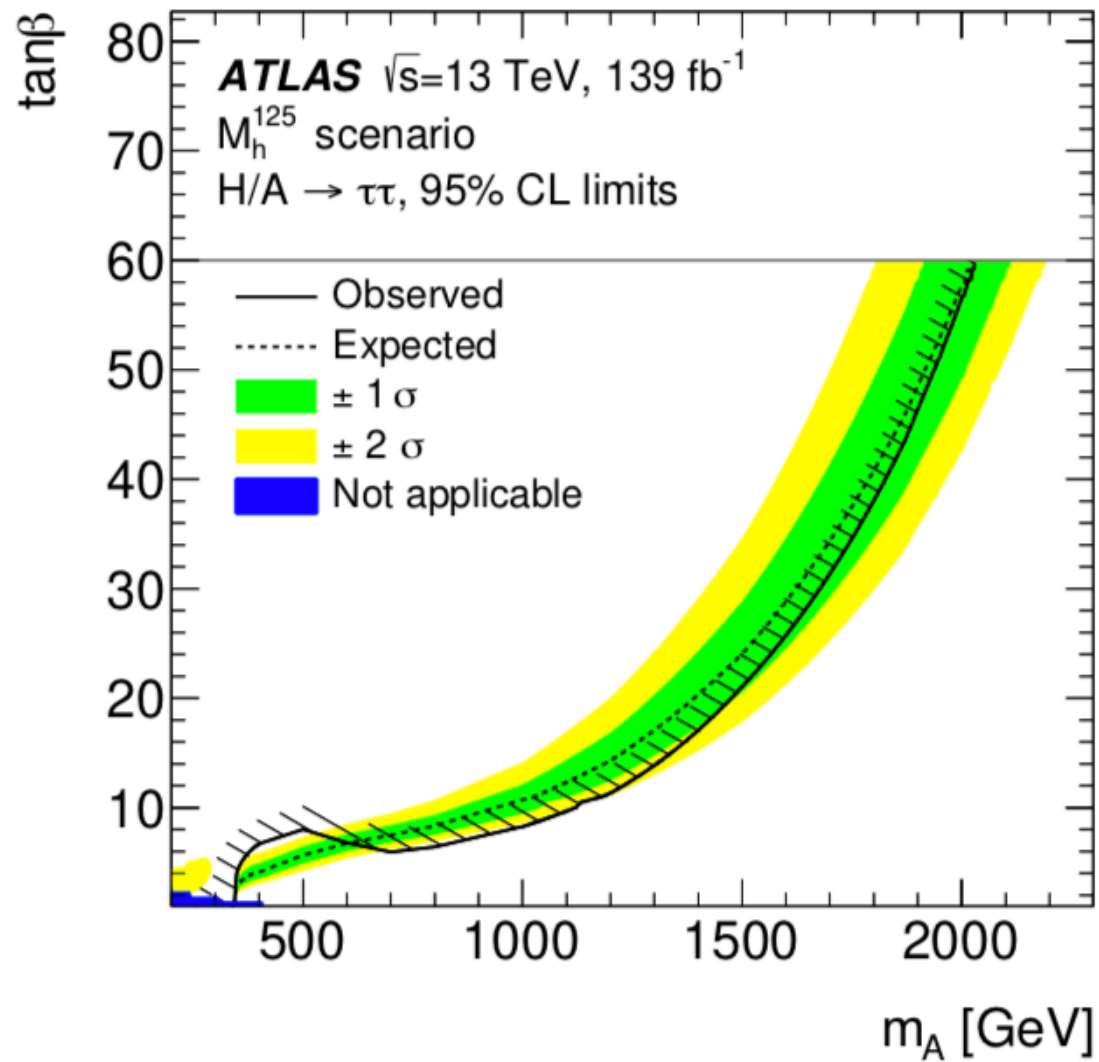
Exclusion of VLQ up to 1.2 ~ 1.4 TeV

IMPORTANT: Assumes 100% BRs to only SM states

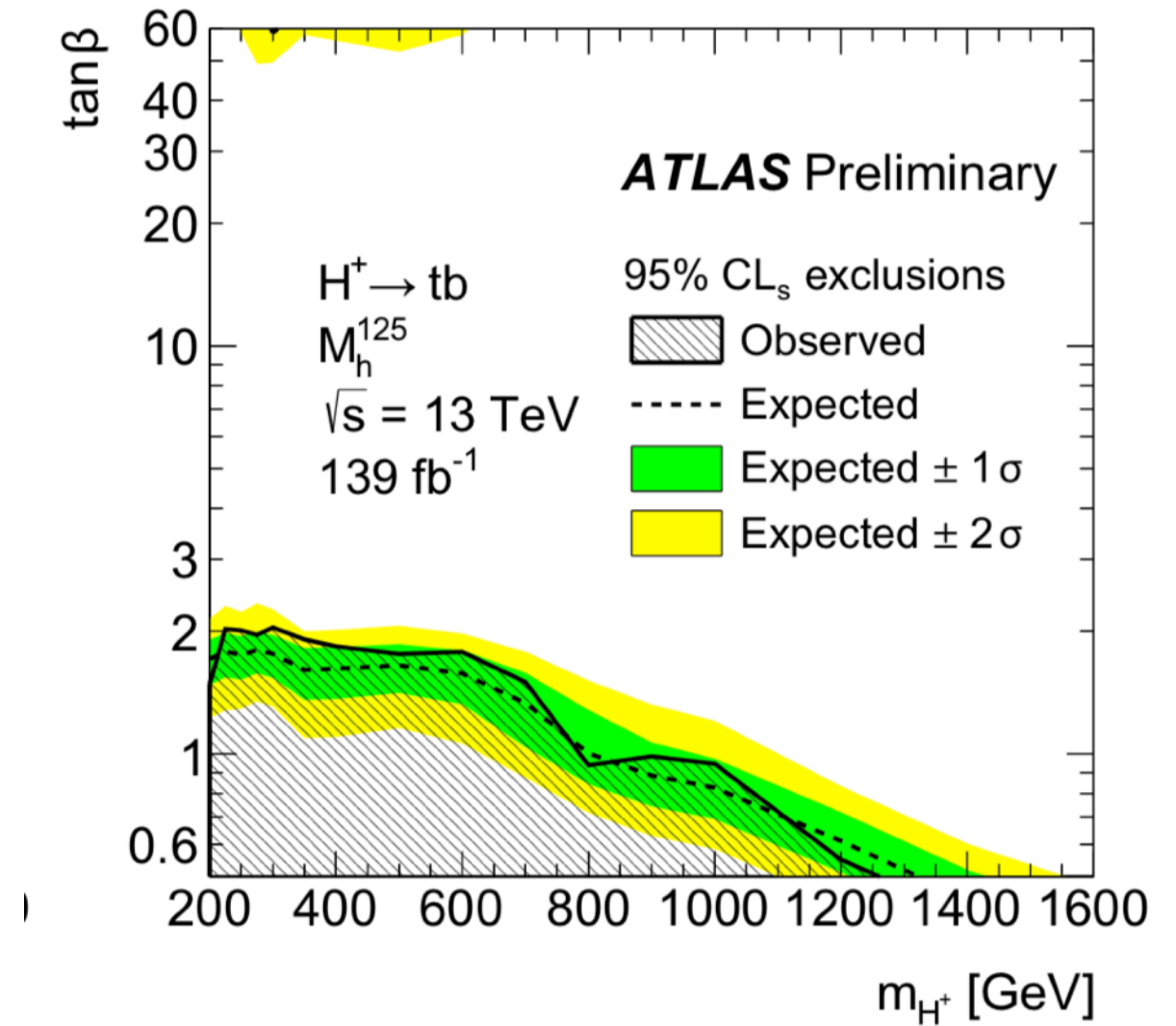
Similar results (and assumptions) from ATLAS: <http://cds.cern.ch/record/2718942?ln=en>

VL Quarks + heavy Higgses

CERN-EP-2020-014

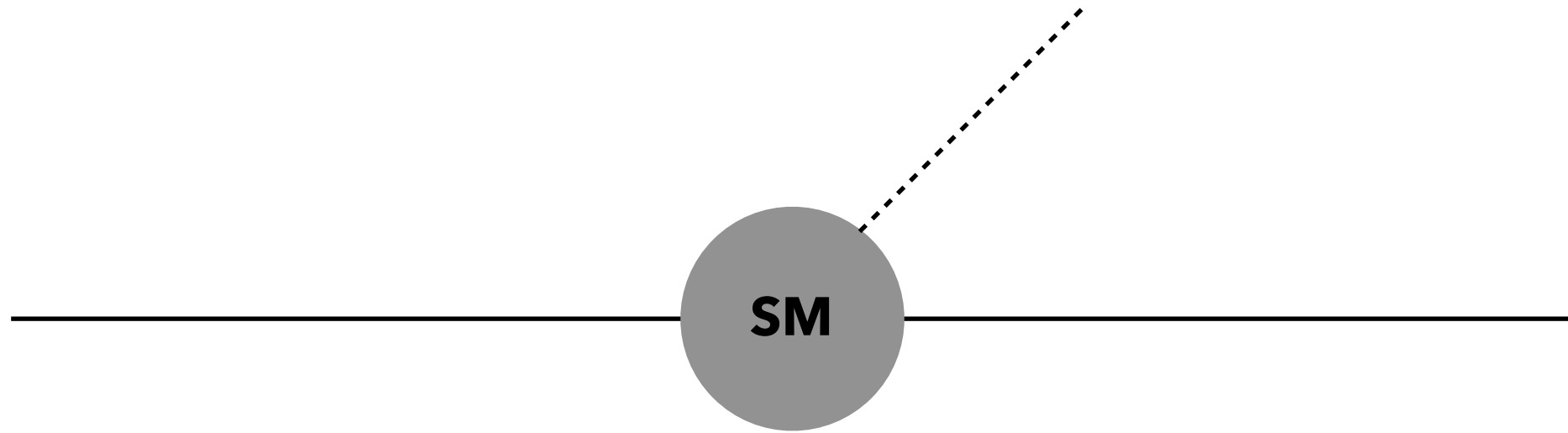


ATLAS-CONF-2020-039

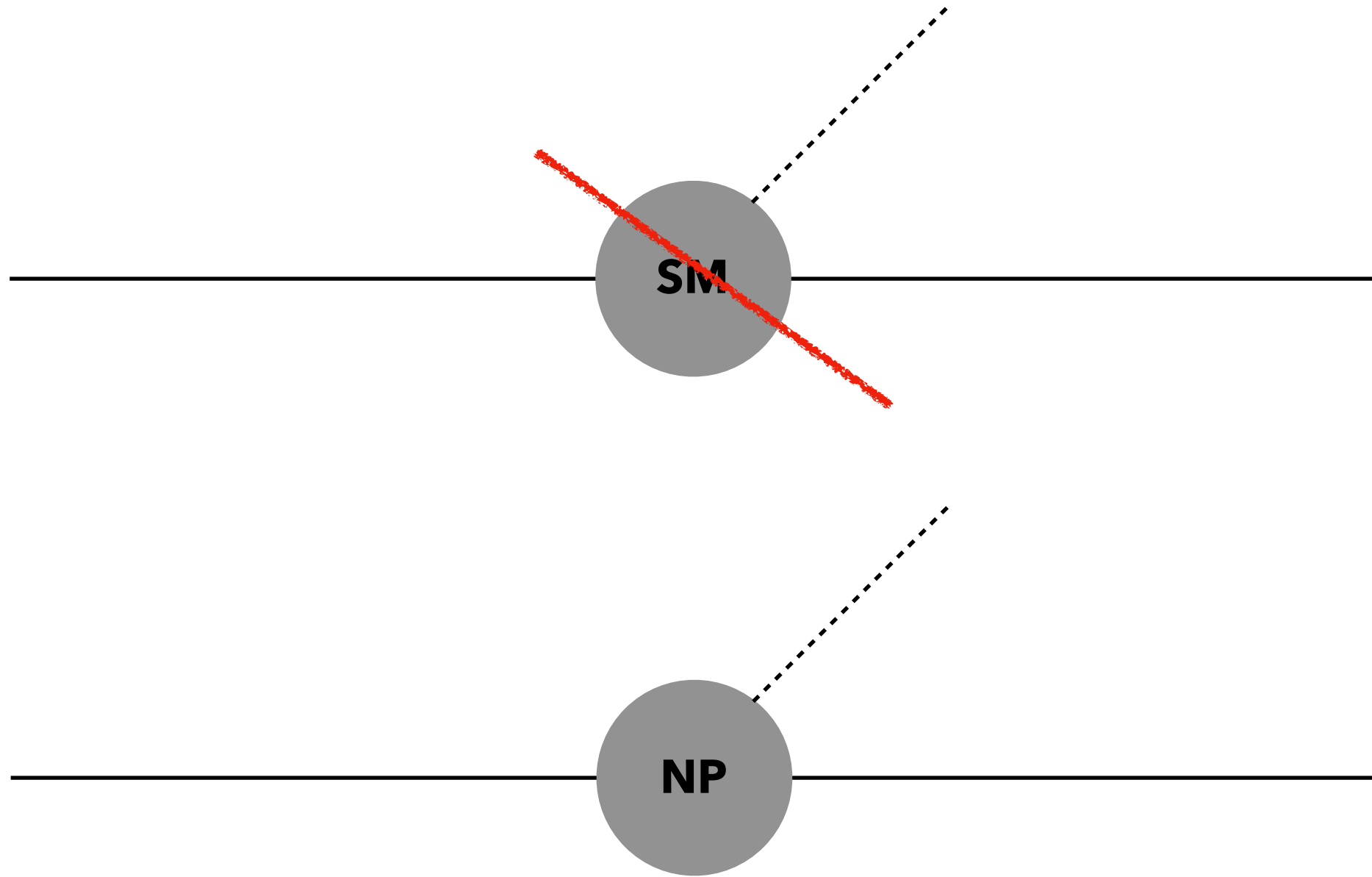


For me: focus on type-II 2HDM scenarios

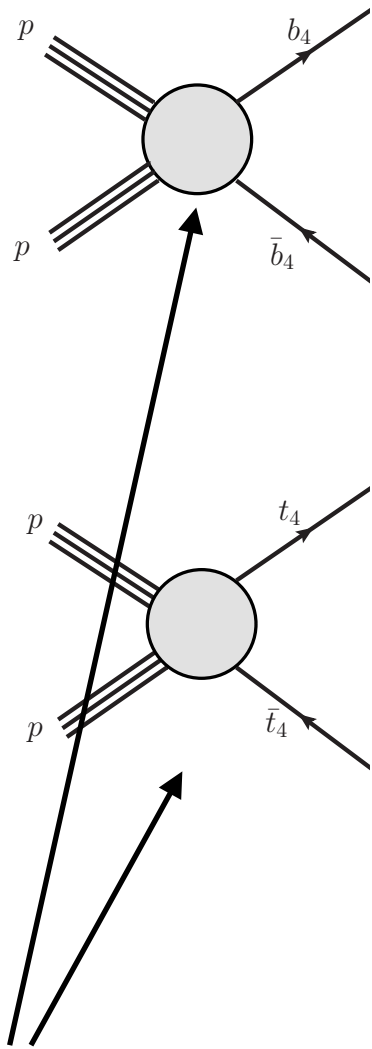
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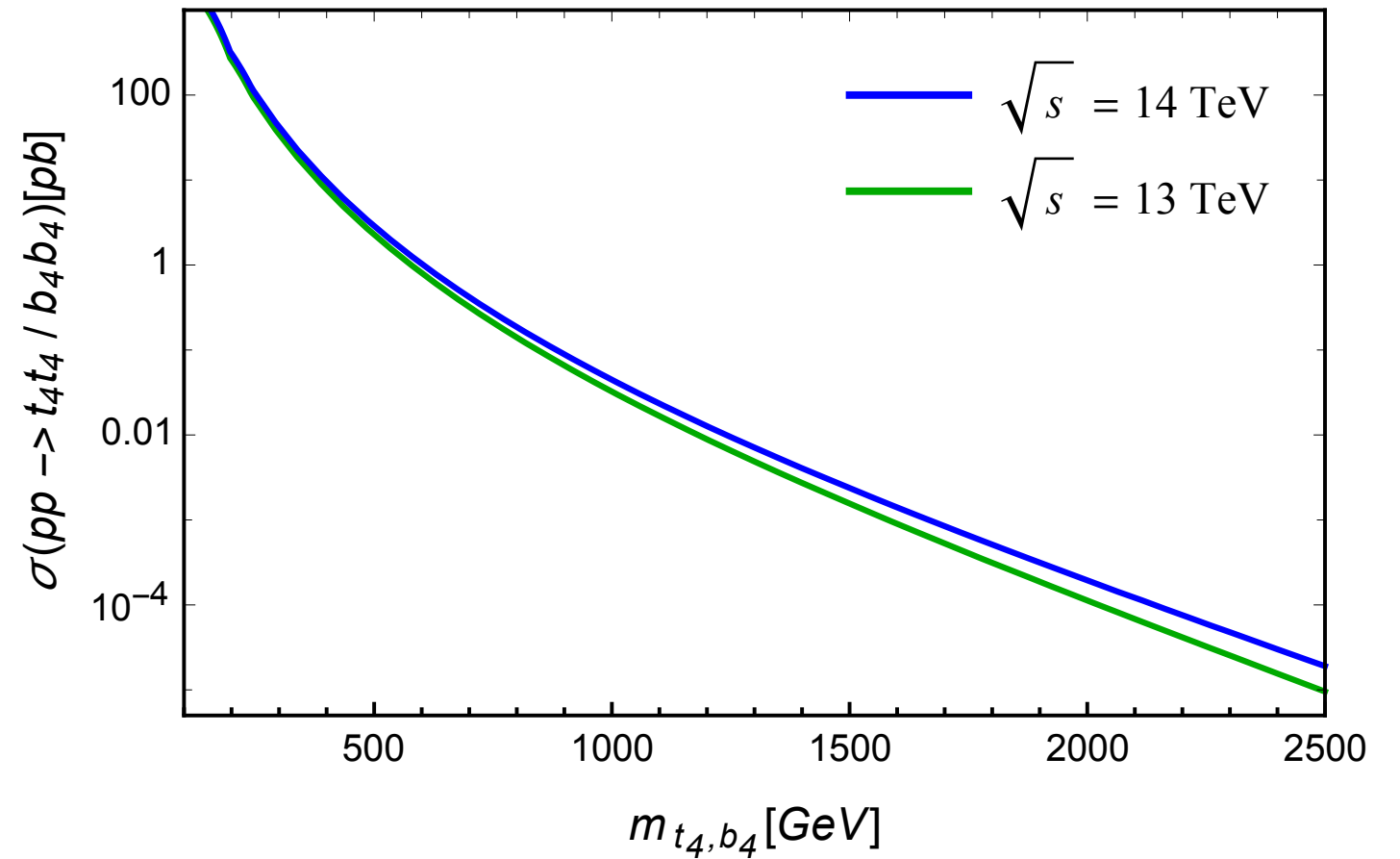
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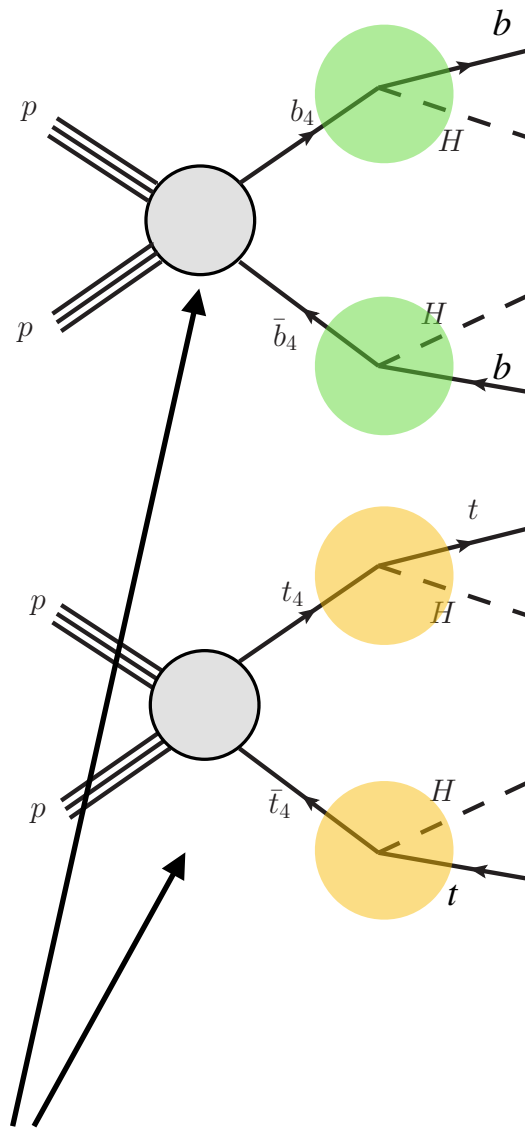


QCD cross section,
model independent,
 $\sigma(m_{t_4, b_4} = 1 \text{ TeV}) \simeq 50 \text{ fb}$



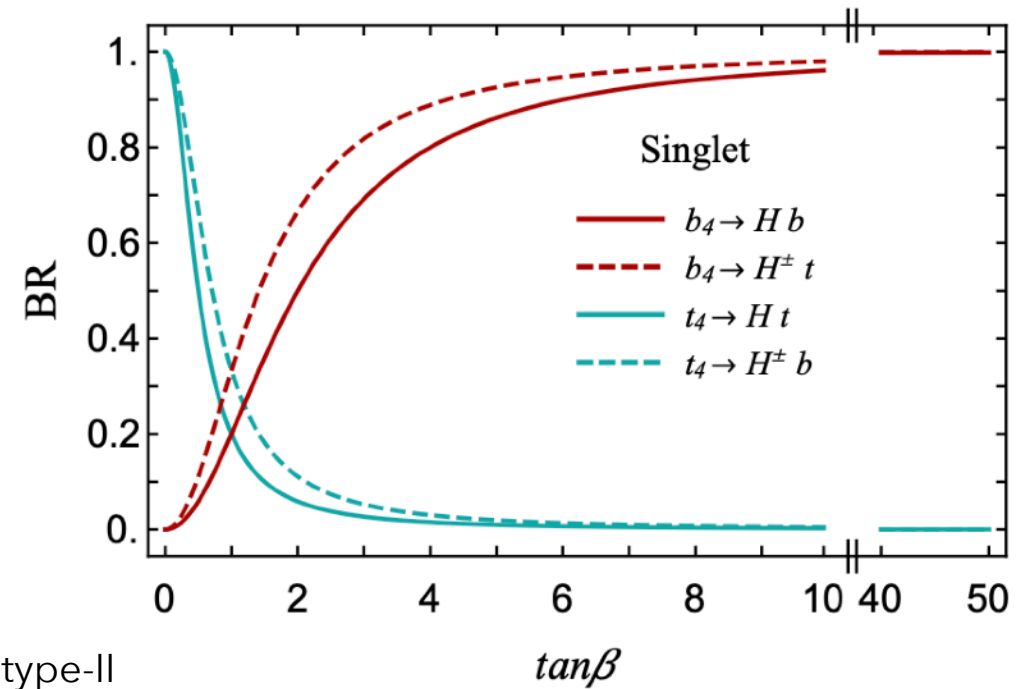
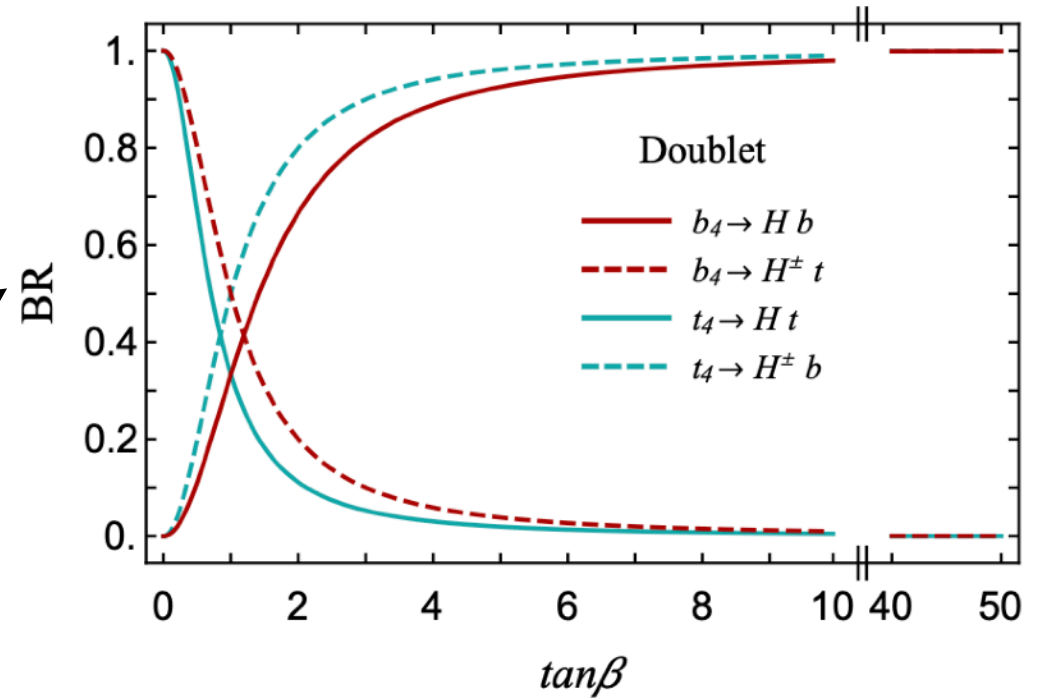
VL Quarks + heavy Higgses

VLQ + 2HDM



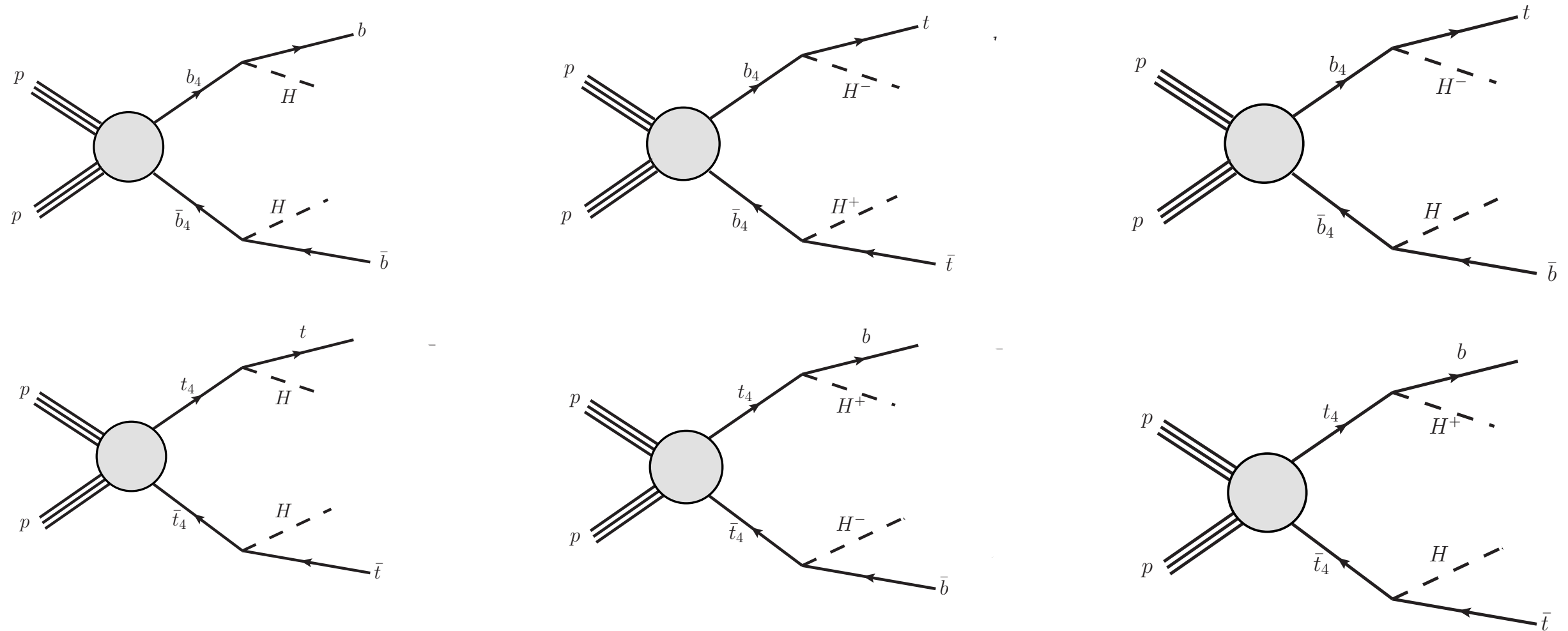
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Branching ratios
can be $\sim 100\%$ to
SM + HH



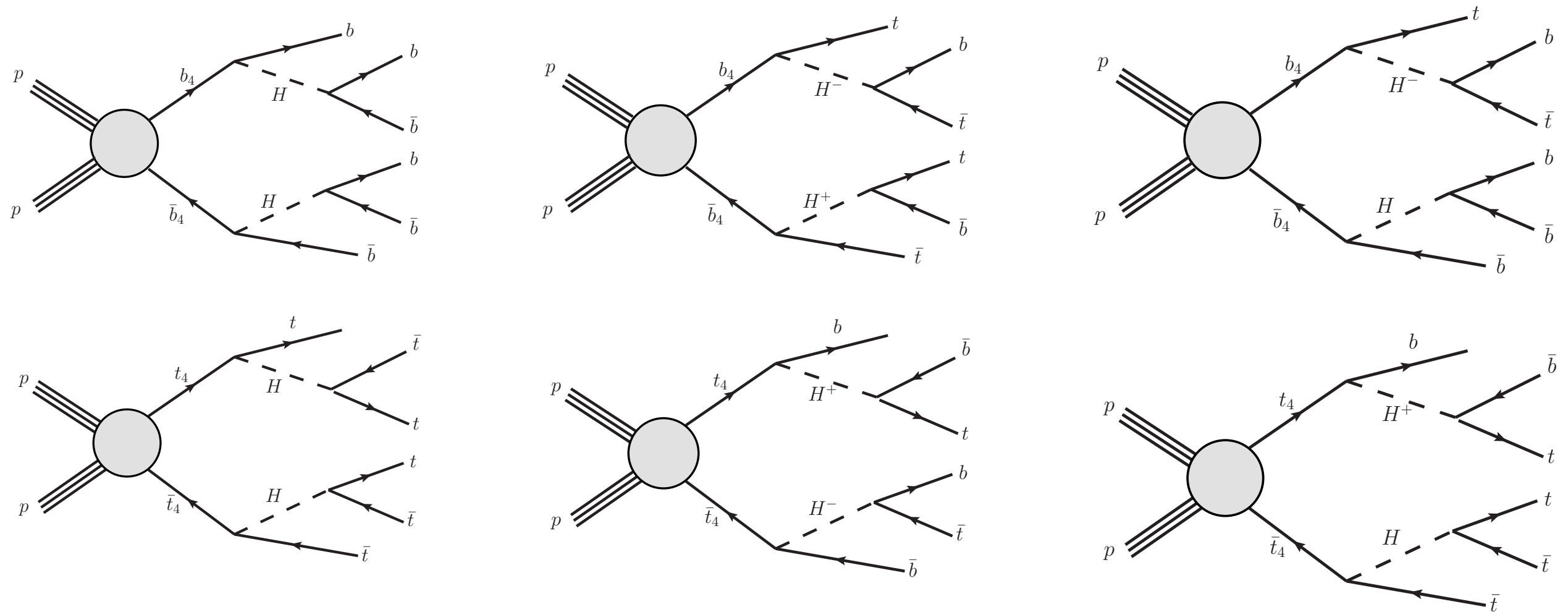
(Assuming couplings as in type-II
2HDM and single heavy Higgs decay channel open)

VL Quarks + heavy Higgses



- Including extended Higgs sector, as in 2HDM, opens many possible search channels
- Heavy Higgses produced with **QCD size cross sections**
- Note: can be used to interpret reach for similar models e.g. Z'/W'

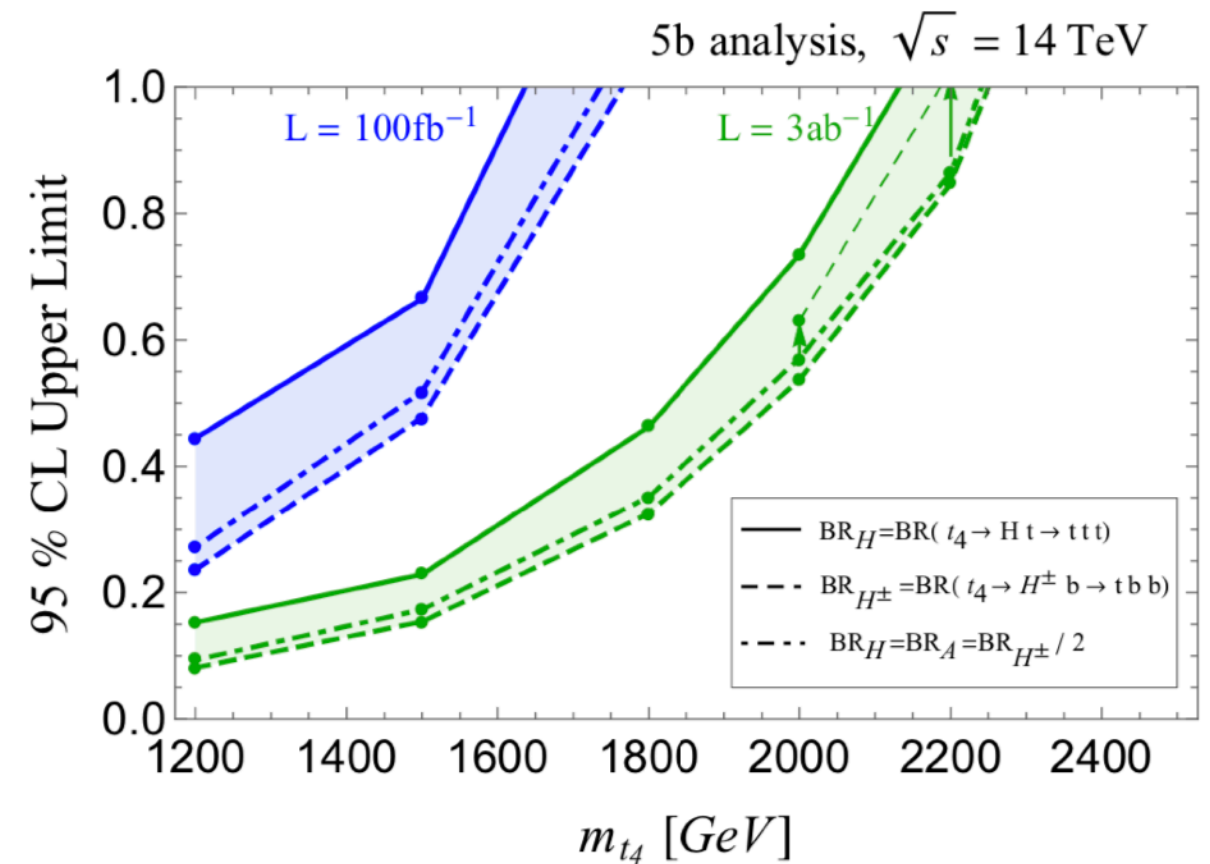
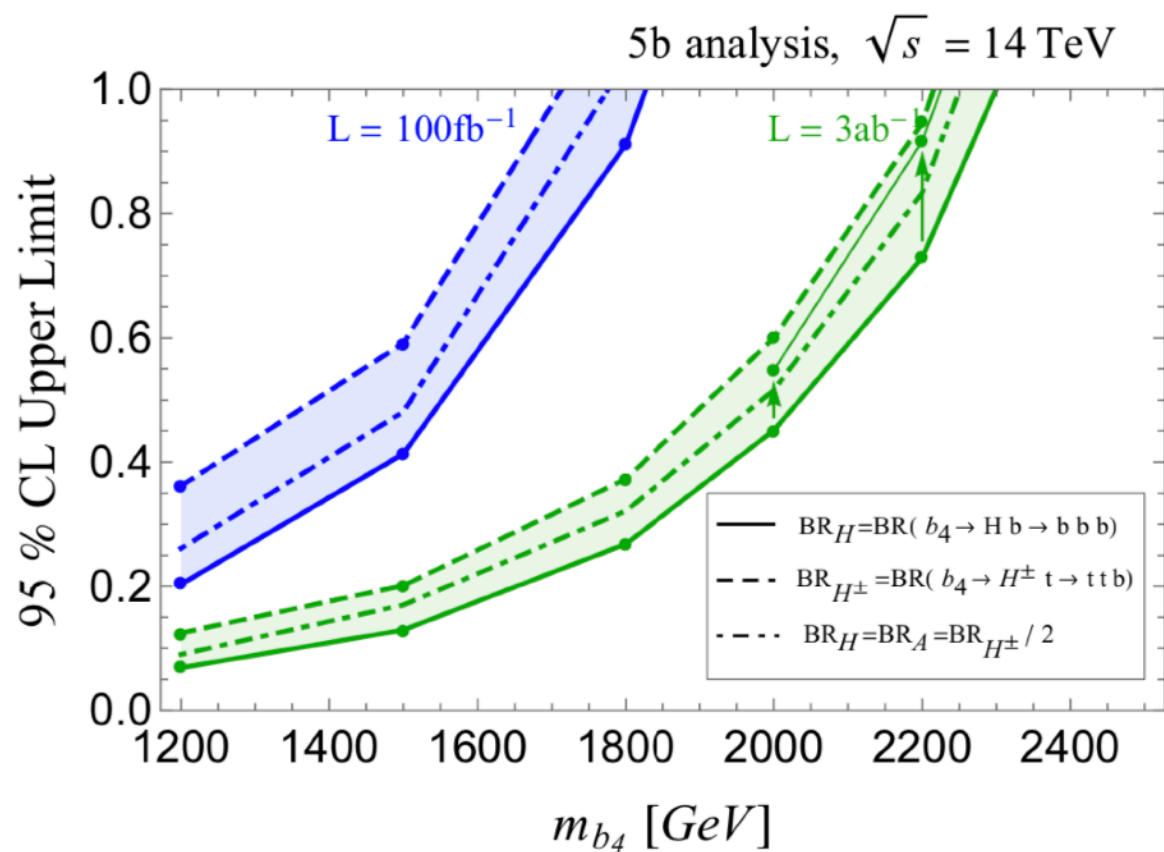
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VL Quarks + heavy Higgses

Reach for analysis based on 5 b-tagged jets:

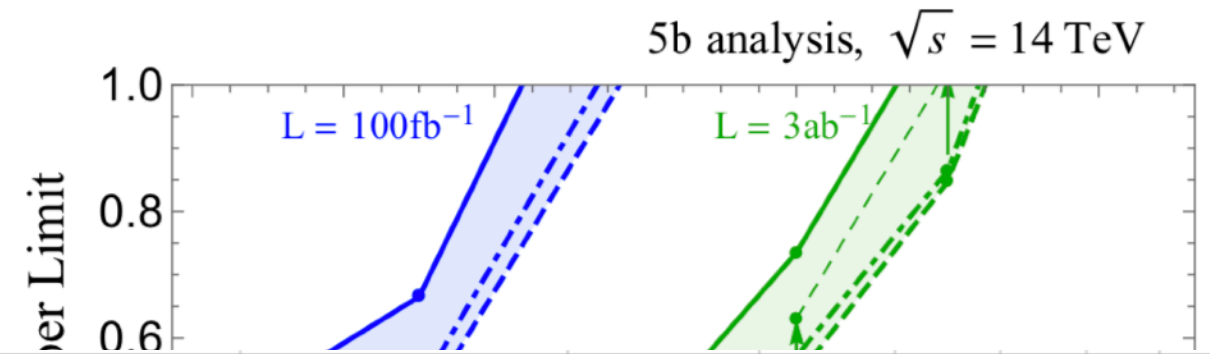
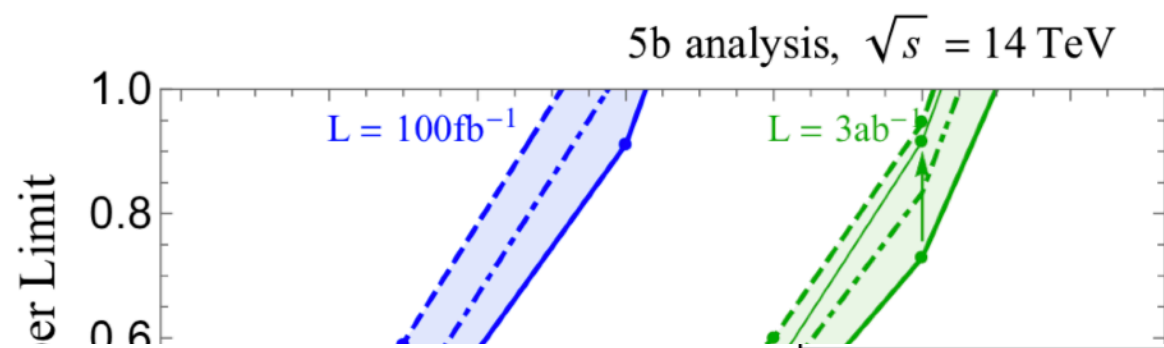


LHC @ 139 fb^{-1} sensitive to heavy Higgses ~ 1.6 TeV

HL-LHC sensitive to heavy Higgses ~ 2 TeV

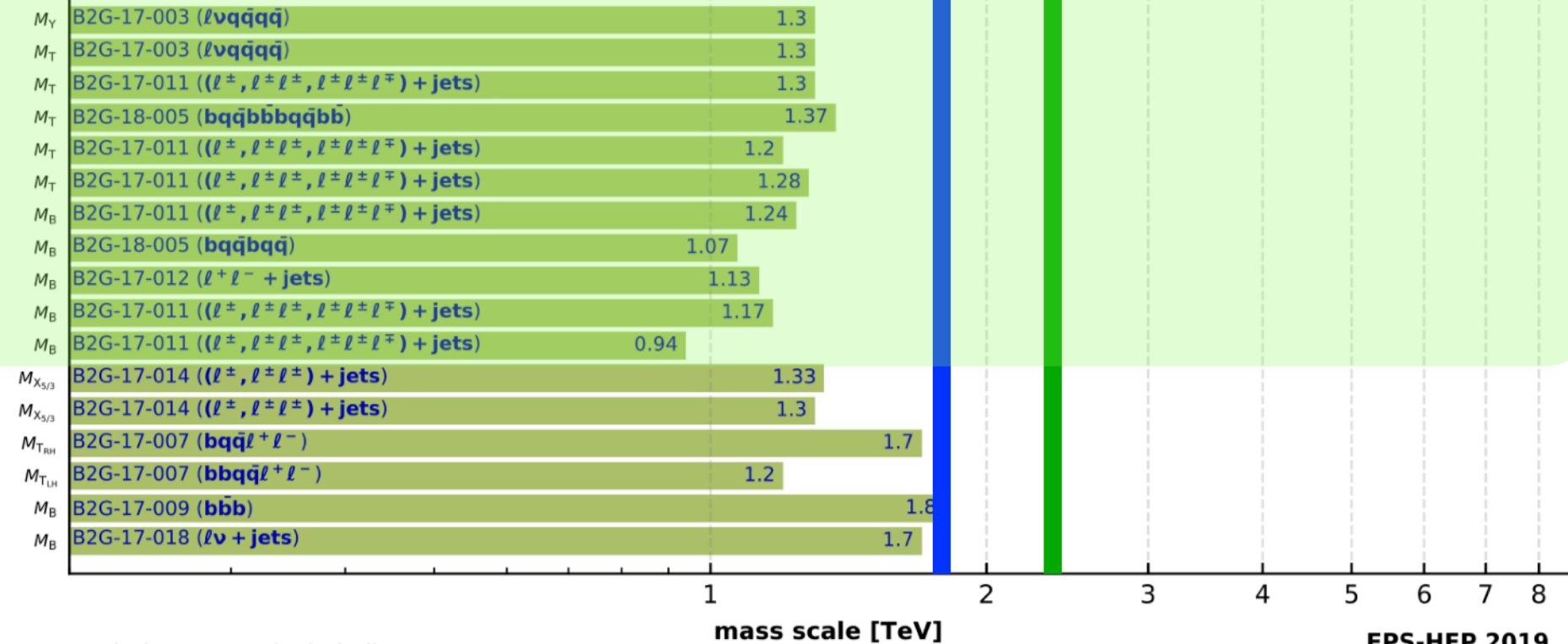
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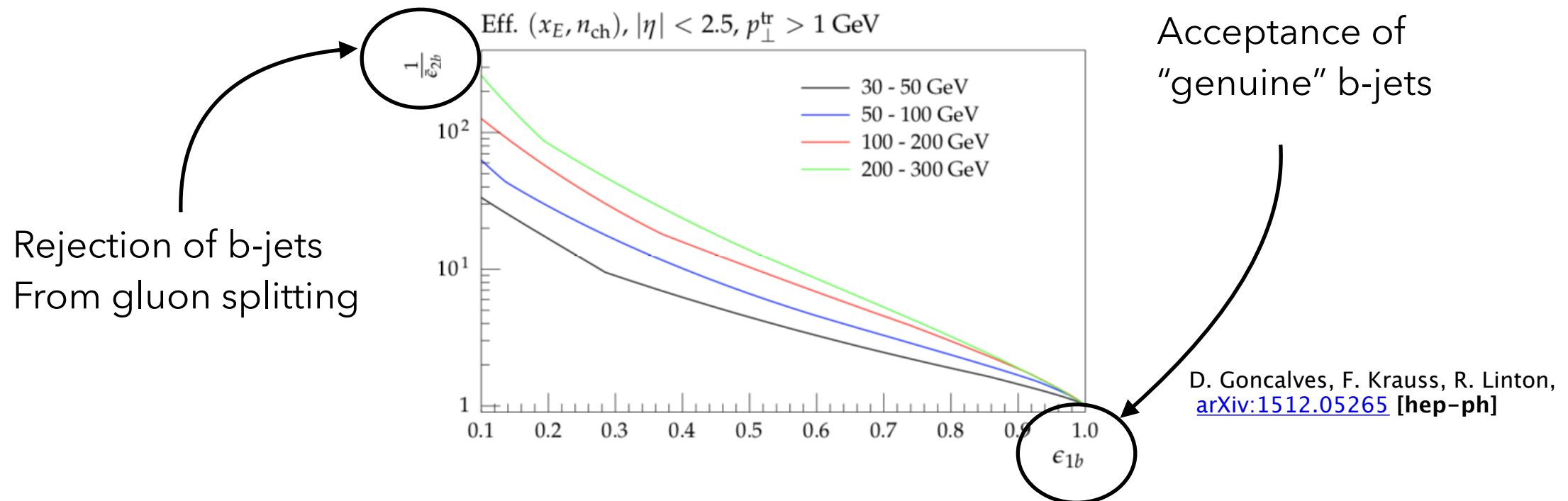
mass scale [TeV]

EPS-HEP 2019

Useful inputs going forward:

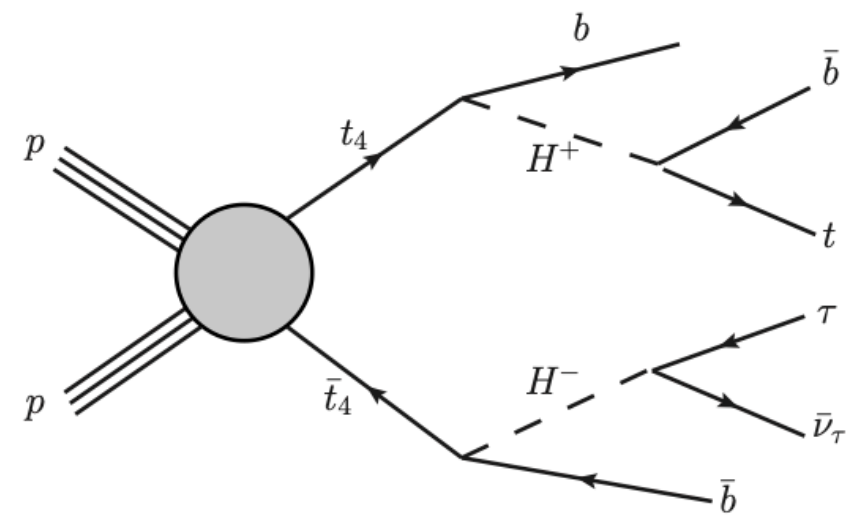
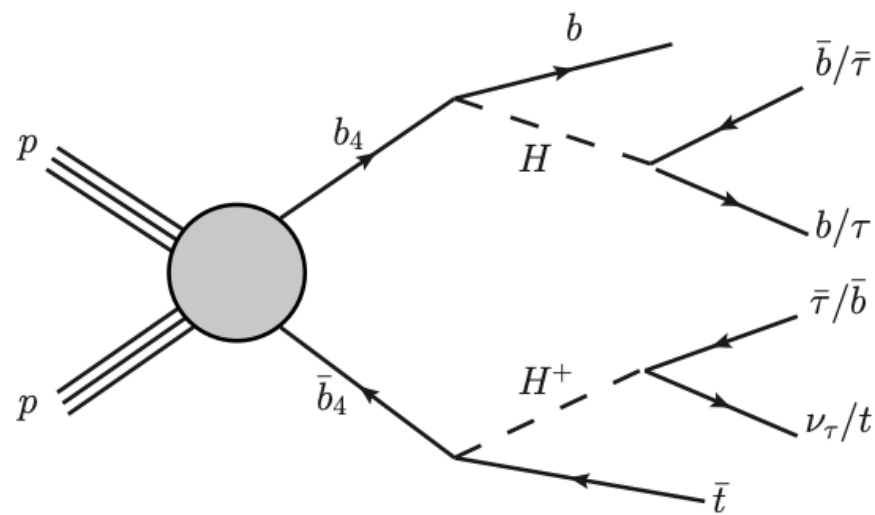
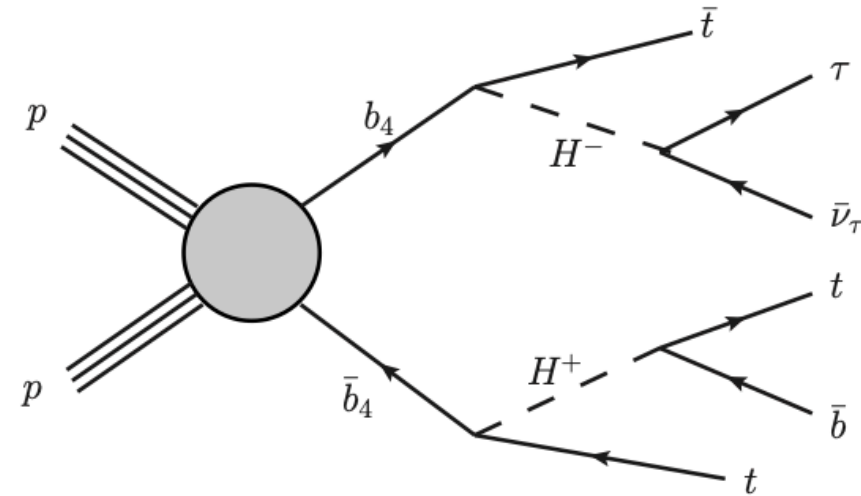
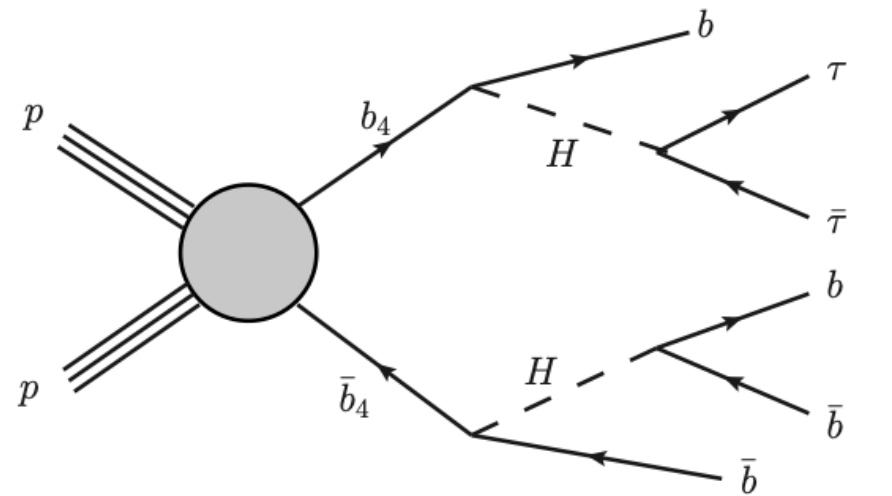
VLQ analysis with b-tagging:

- bottom rich environment
- Challenging to simulate backgrounds
 - $t \rightarrow W + b$ vs. $g \rightarrow bb$



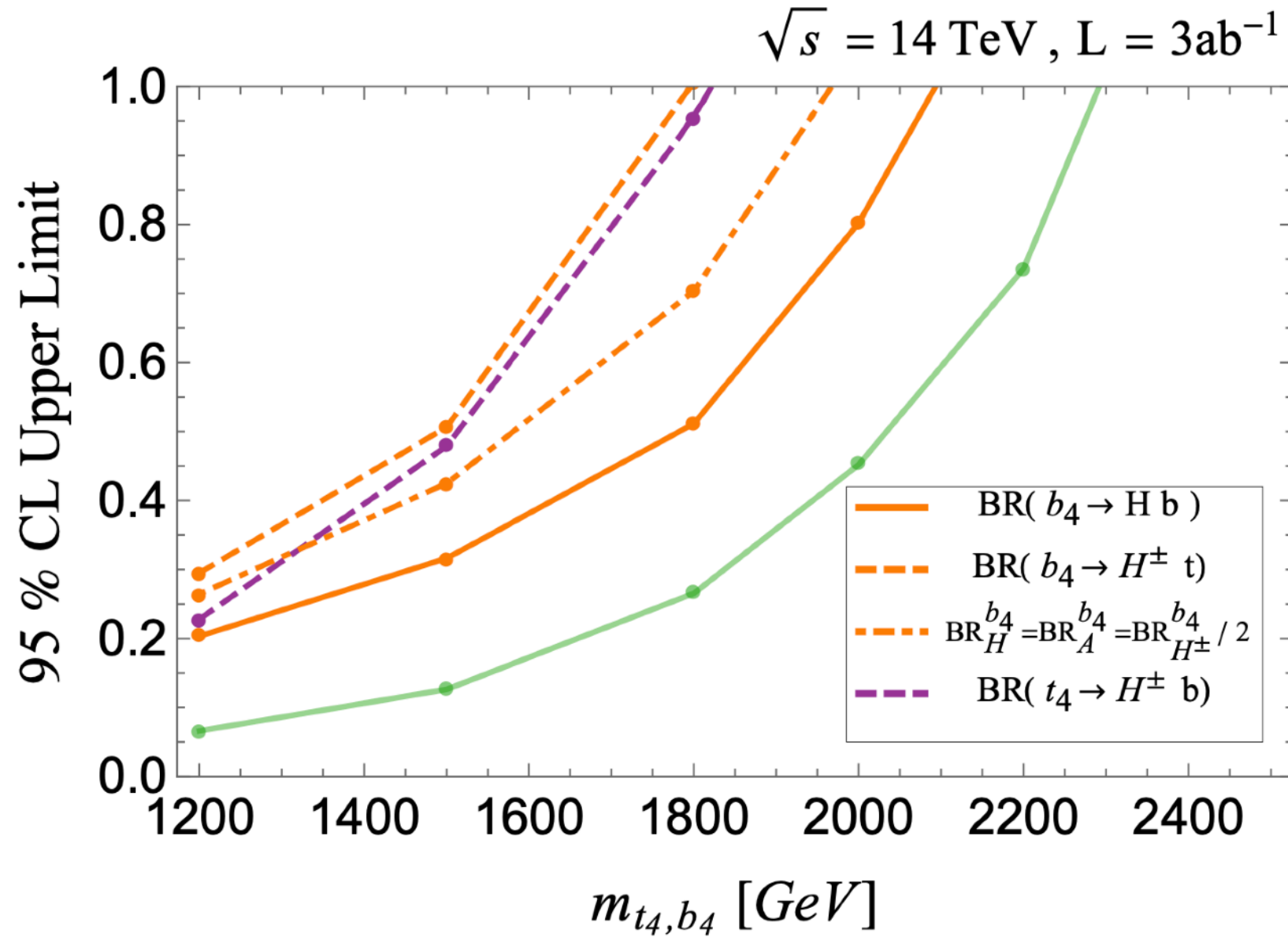
- Monte Carlo data for multi-jet/b may be useful input for many VLQ analyses

VL Quarks + heavy Higgses



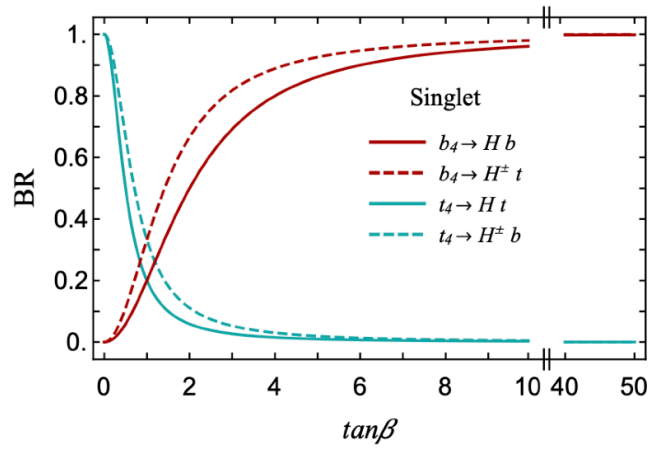
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VL Quarks + heavy Higgses

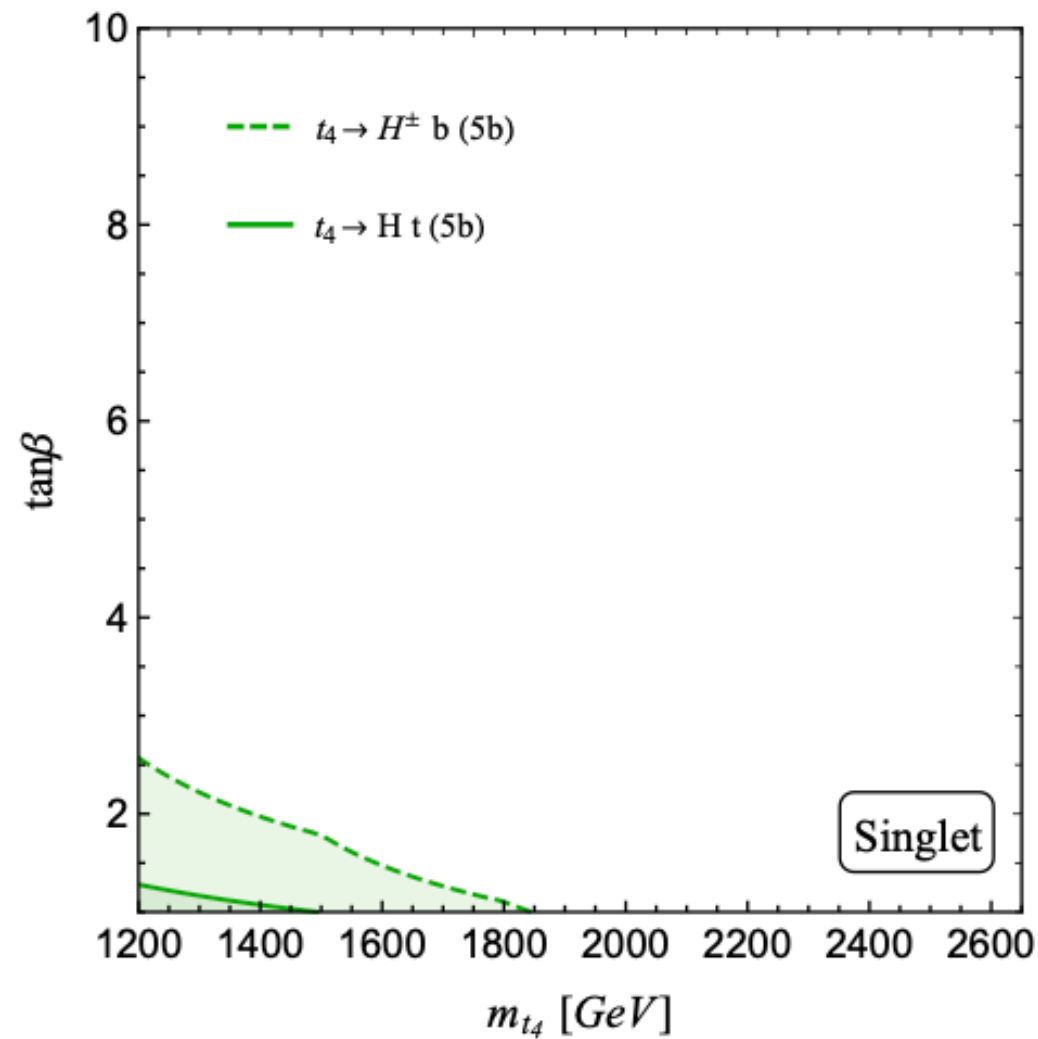


- Comparable reach despite small branching ratios

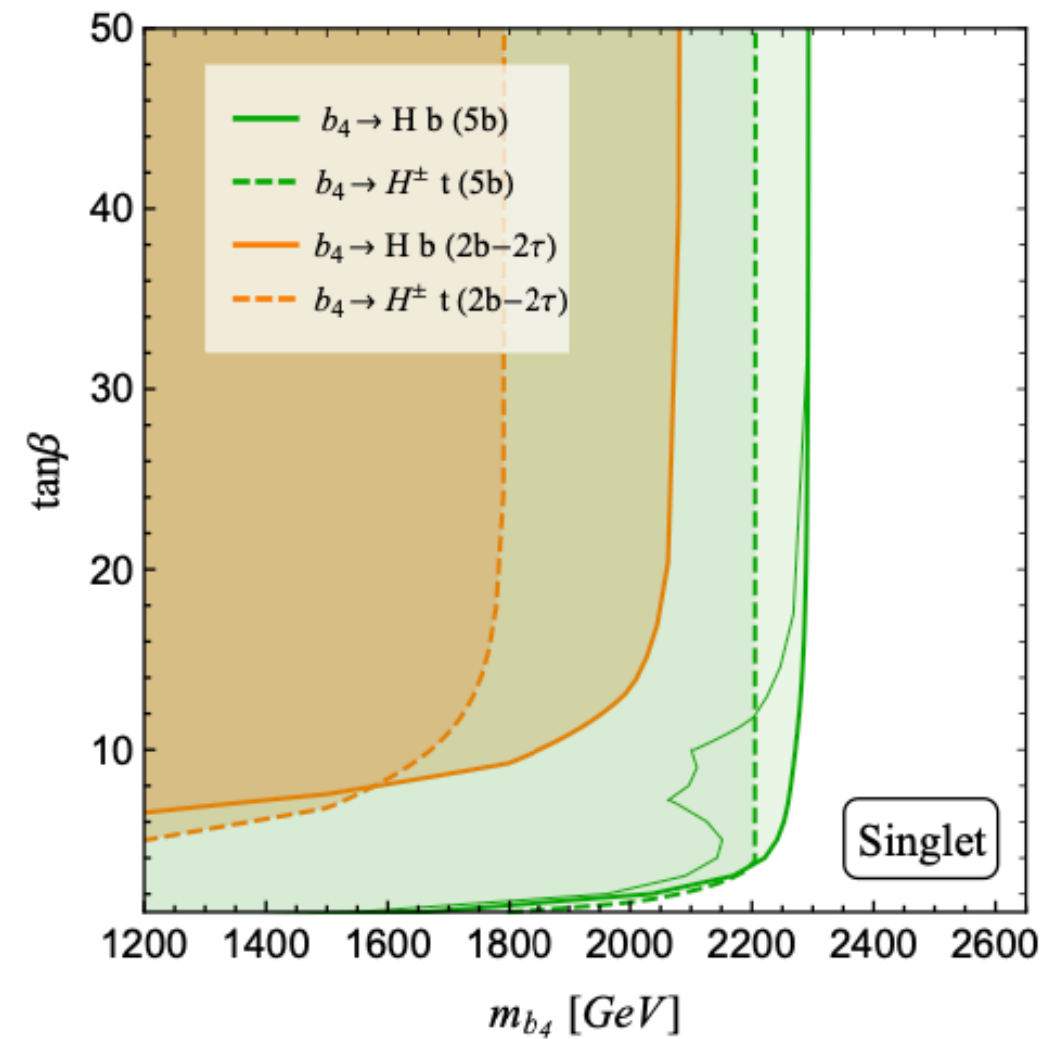
VL Quarks + heavy Higgses



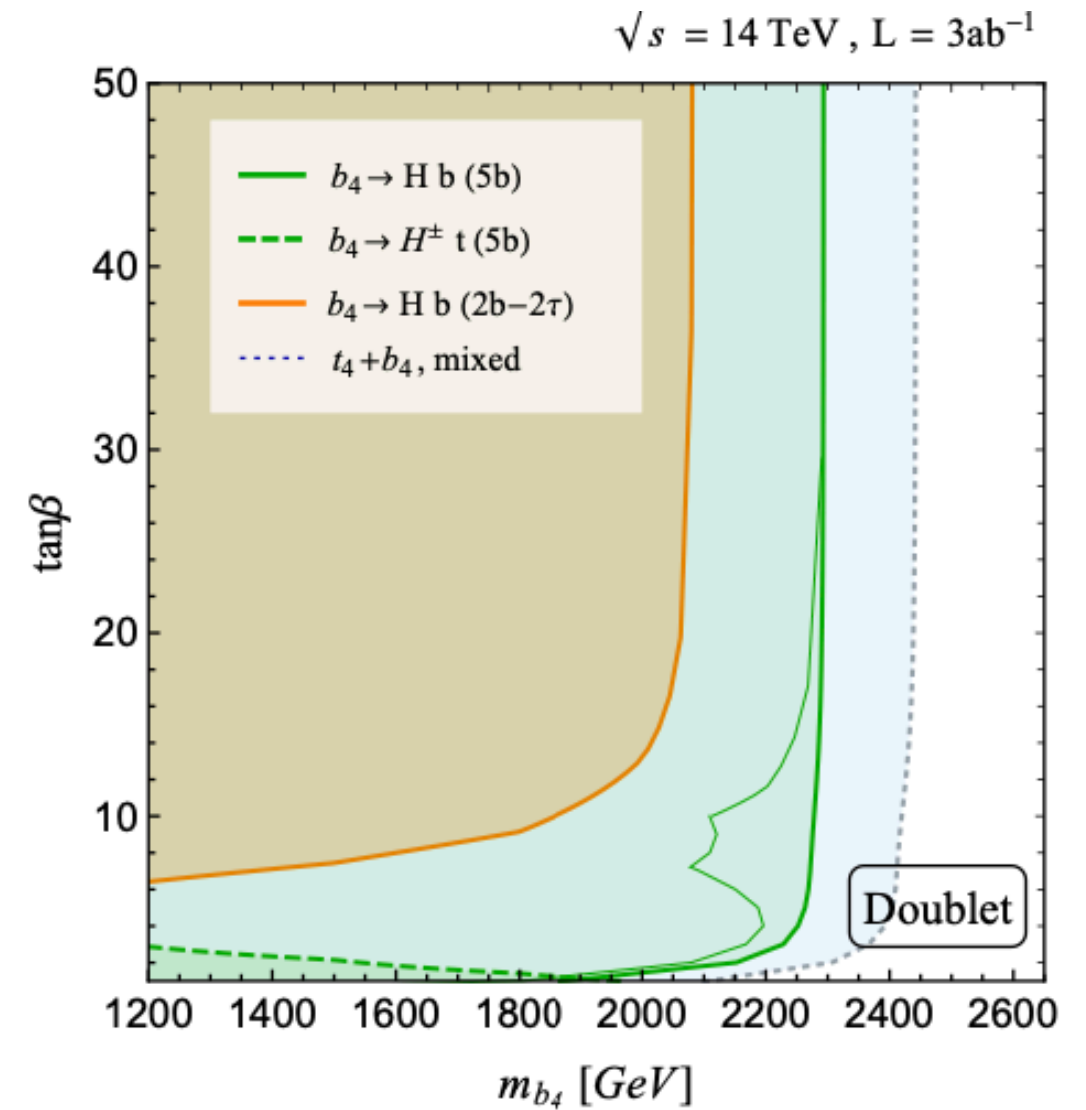
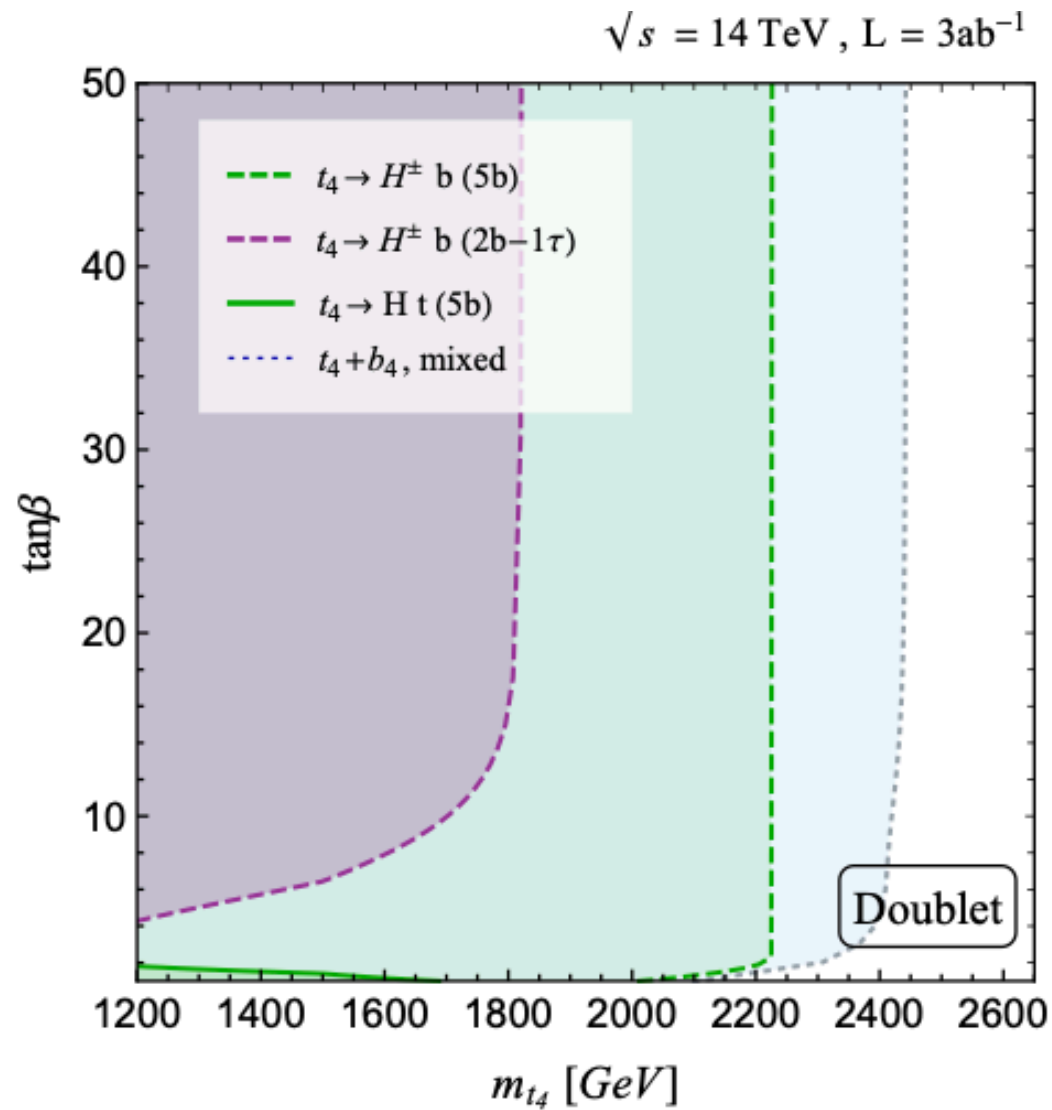
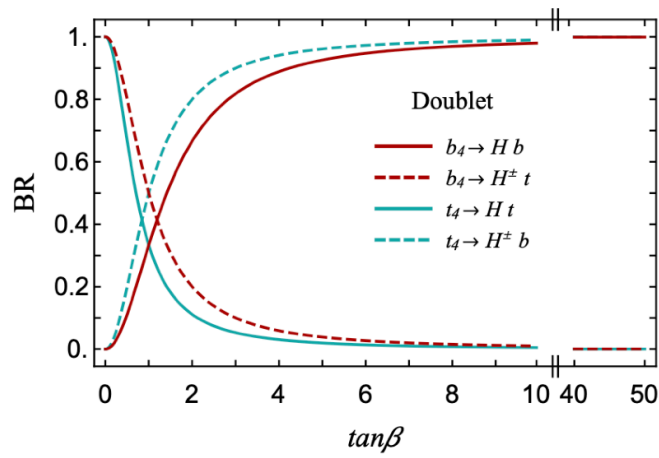
$\sqrt{s} = 14 \text{ TeV}, L = 3 \text{ ab}^{-1}$



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VL Quarks + heavy Higgses



Conclusions:

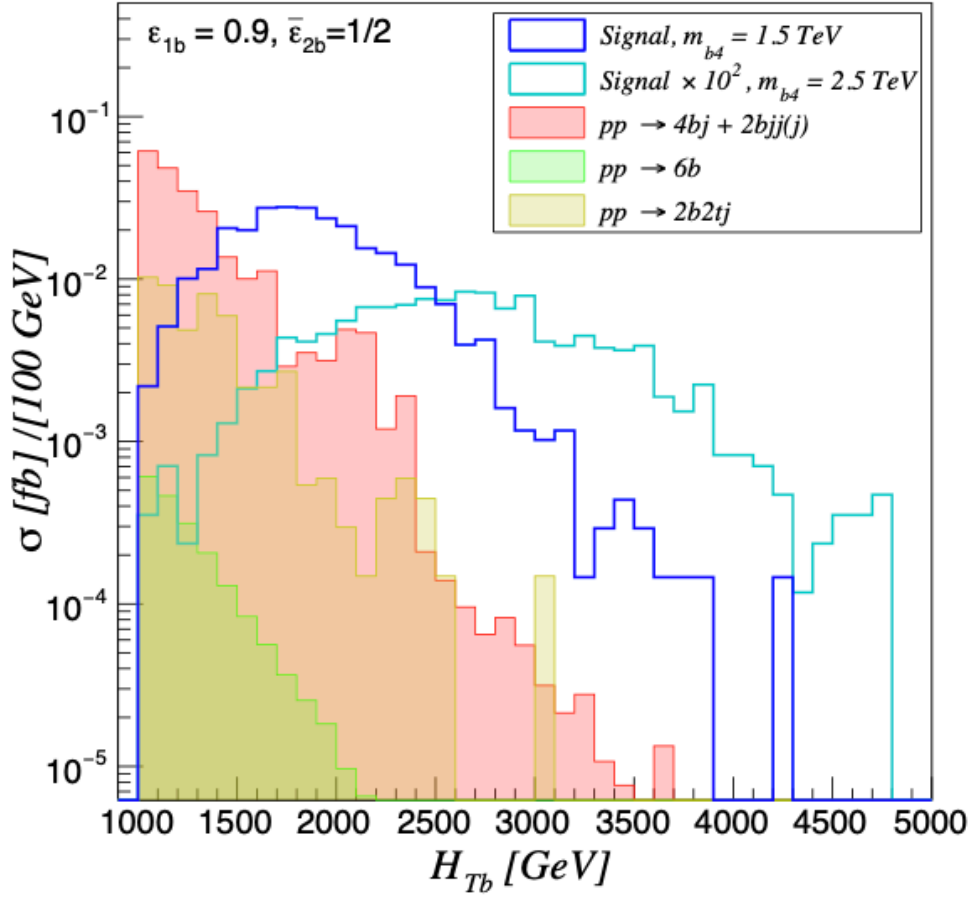
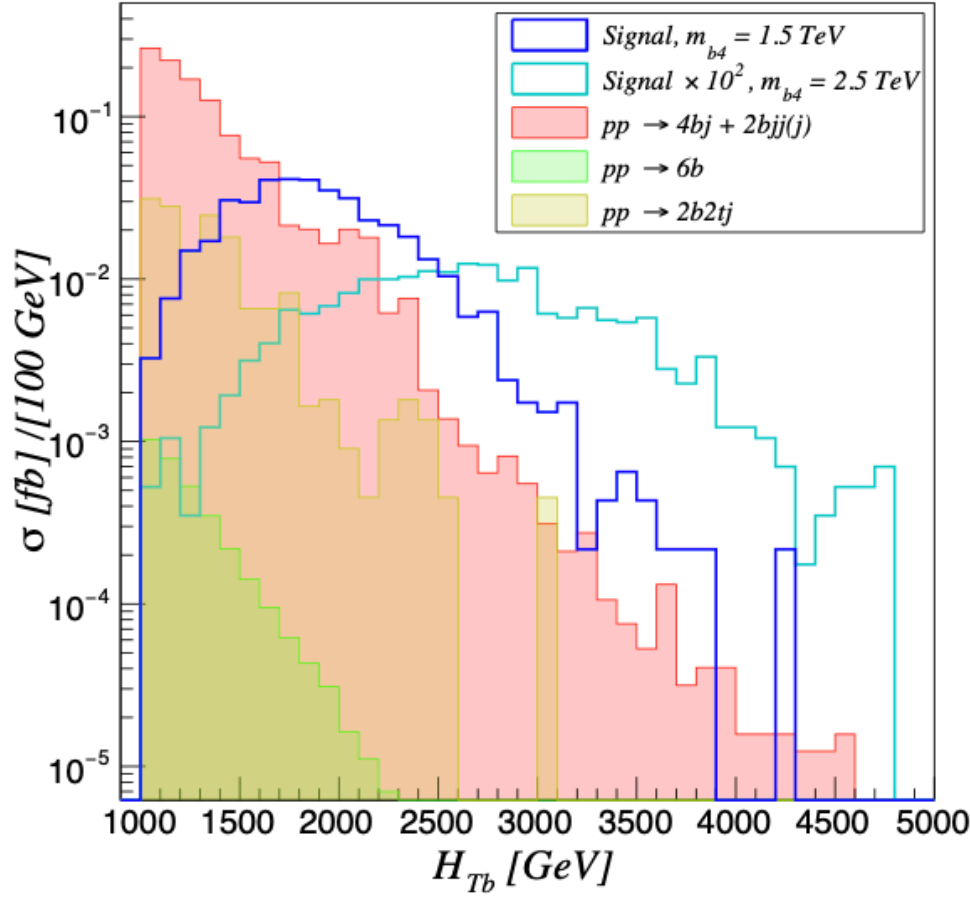
- Models with extended Higgs sectors and/or vector-like fermions are among the simplest extensions of the SM
- Pheno can connect to different types of UV completions (under various assumptions)
- Combined signatures of heavy Higgses + VLQ offers many opportunities for interesting search strategies
- Some plans:
 - Improved b-tagging procedures: kinematics, "2b" jets, etc.
 - Detailed analyses of Higgs cascade decay channels

Suggestions from ATLAS or CMS? What can we do that would be helpful for relevant searches?

Thanks!

Backup:

5b analysis



$$H_{Tb} \equiv \sum_{j \ni b} |p_T(j)|$$

Backup:

2b+2τ analysis

