Light H^{+}iggs Searches

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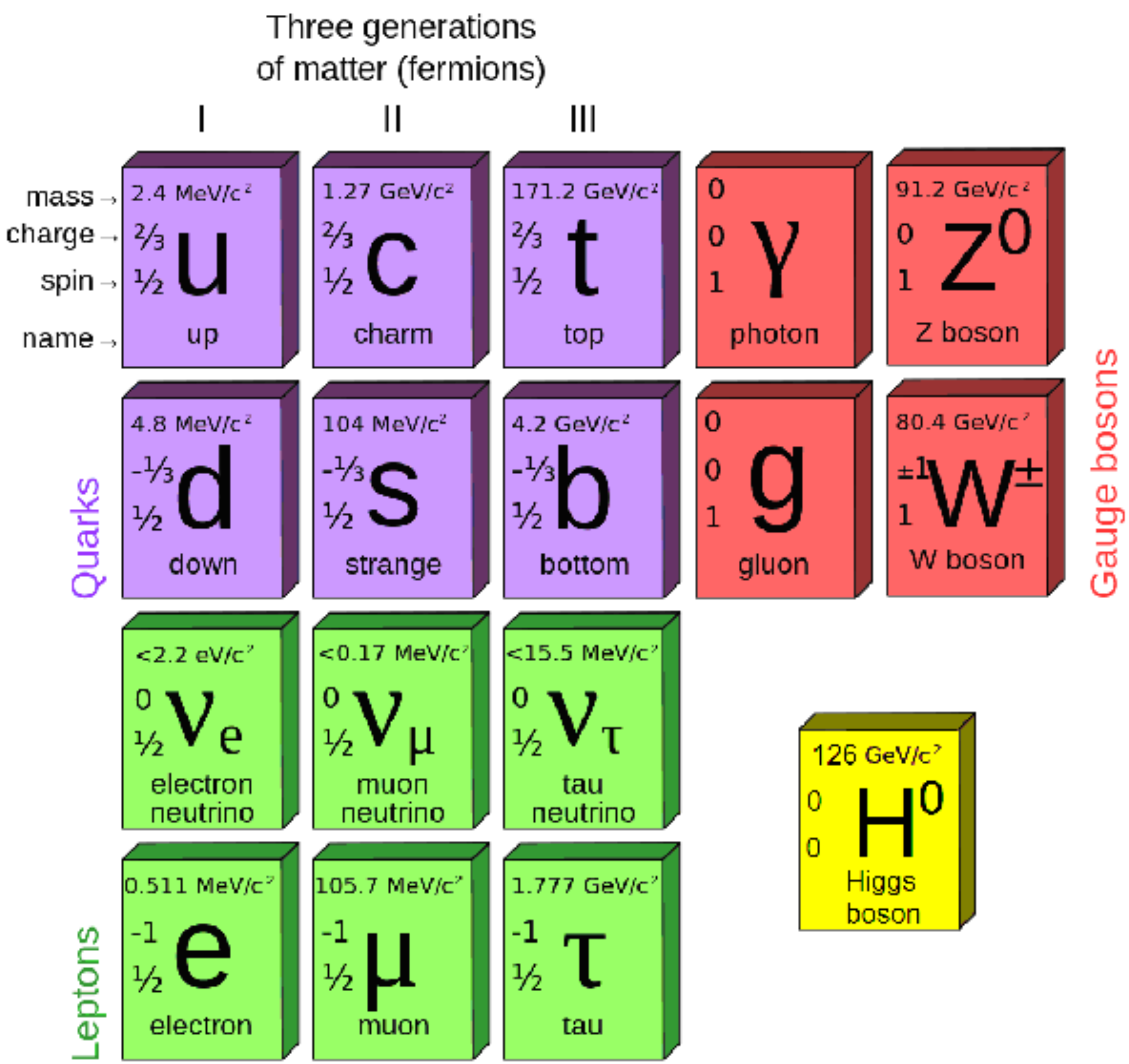
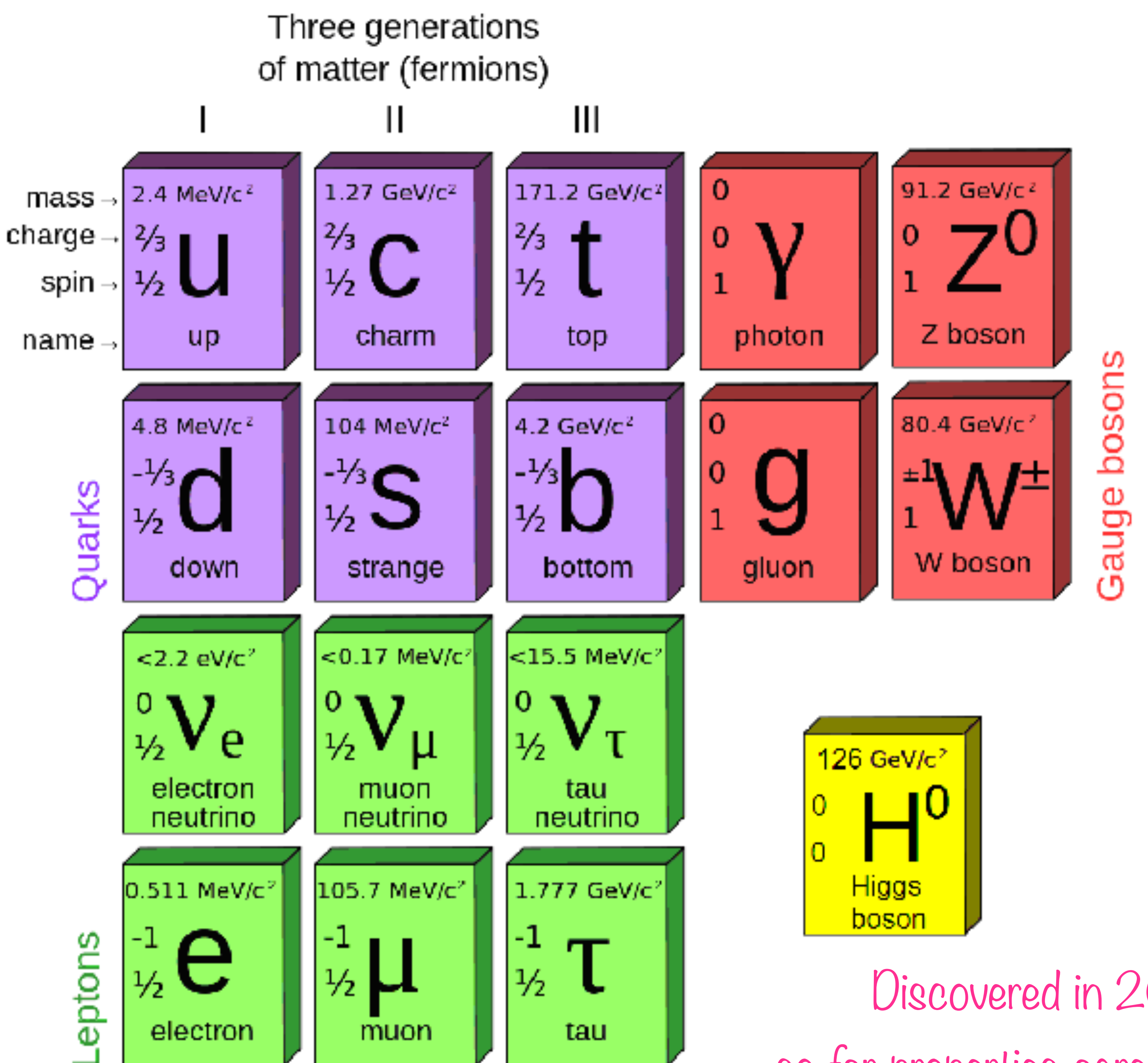
Outlook

- Introduction of H^+ & two Higgs doublet model
- Variety of H^+ Searches
- Search Strategy (light H^+ cases)
- Results
- Summary

Standard Model & particles



Standard Model & particles

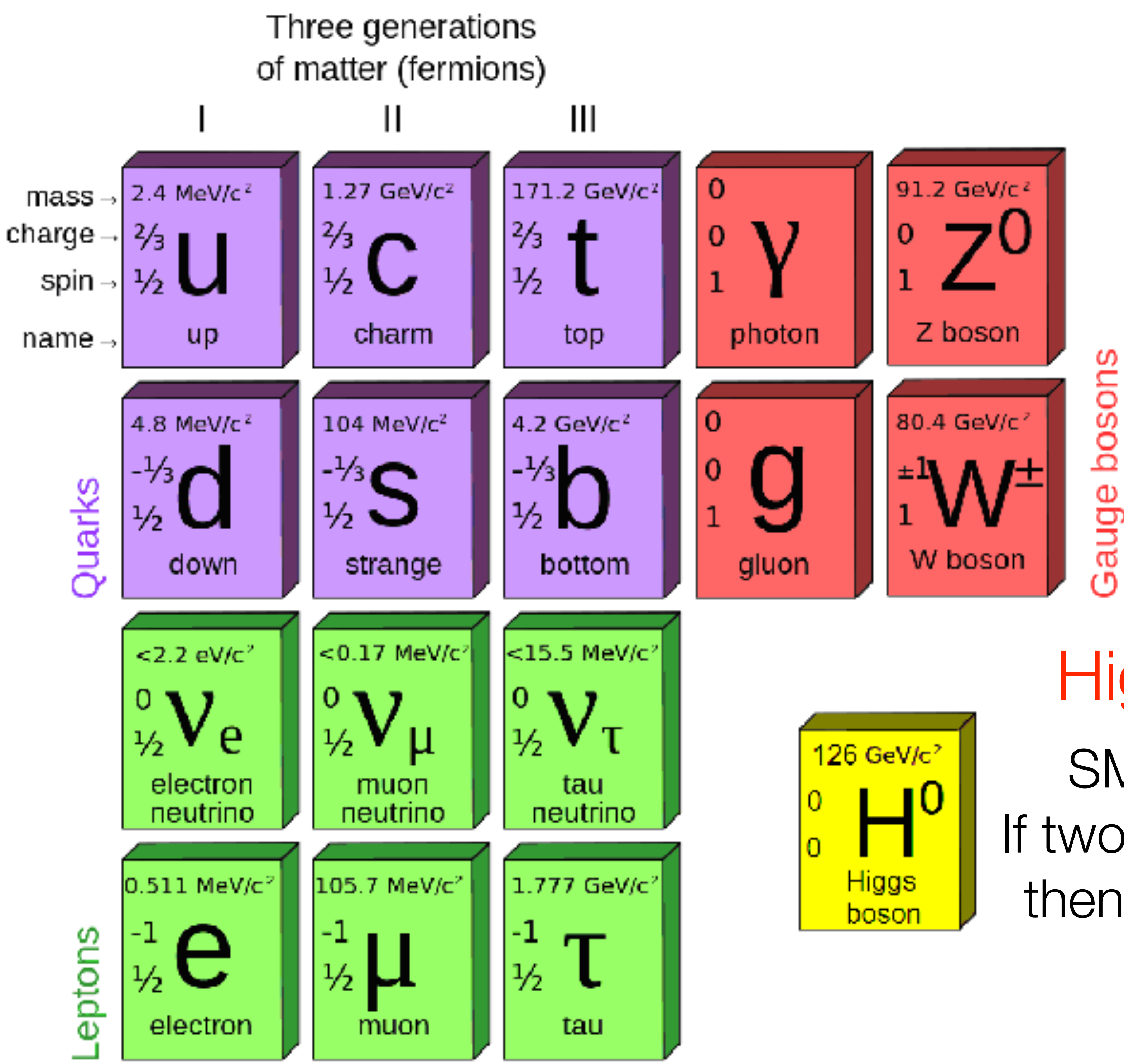


Complete list of particles in the model

Masses given to bosons & fermions by electro-weak symmetry breaking
→one Higgs boson

Discovered in 2012,
so far properties agree with SM

Standard "Model" & particles

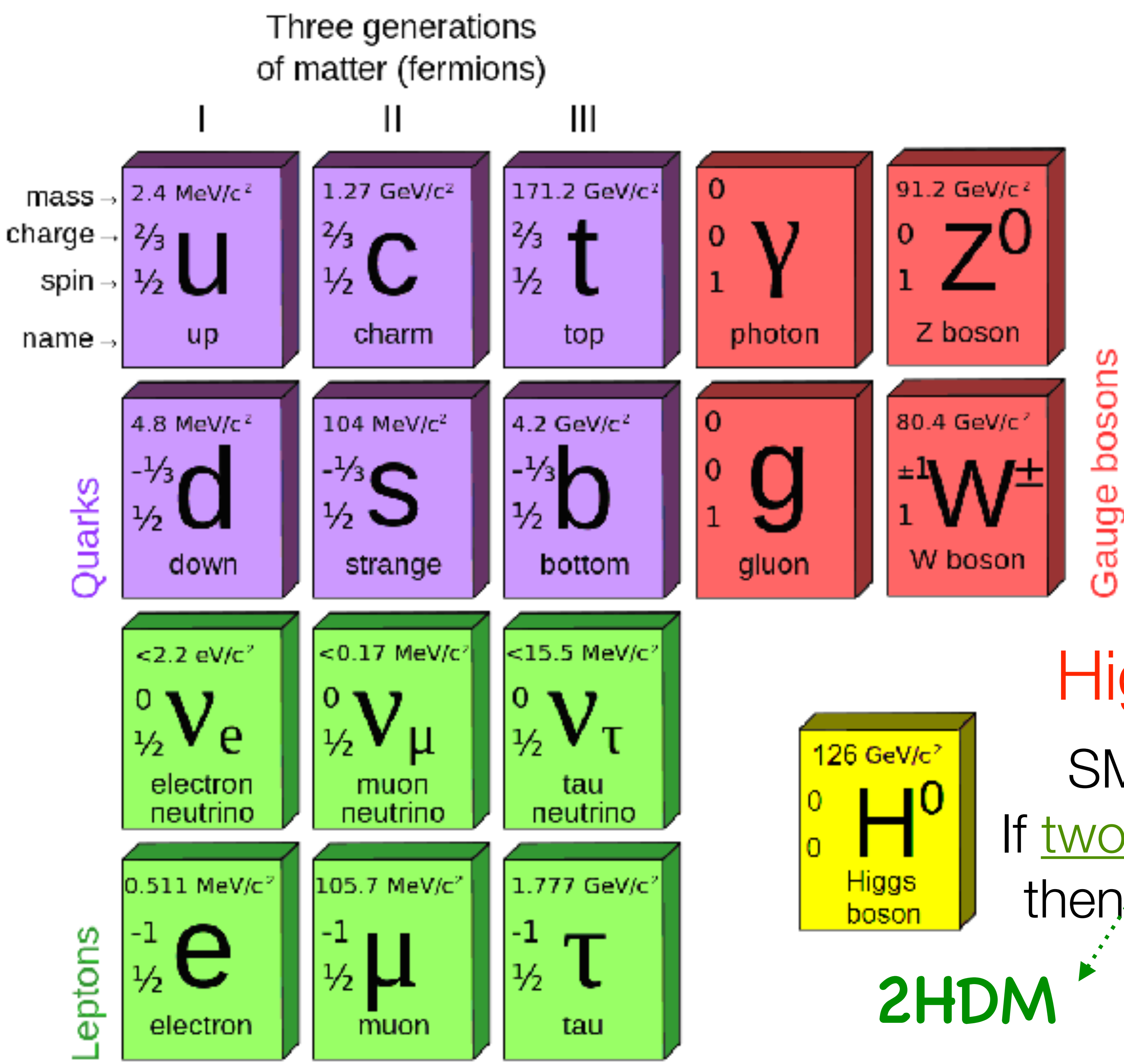


Questions still remain
-Dark energy/matter
-Neutrino oscillation
-….

Higgs, the one and only?

SM adopts minimal scalar field.
If two Higgs doublets come into play,
then we will see five Higgs bosons:
$h^0, H^0, A^0, H^{\pm}$

Standard "Model" & particles



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2HDM

Many beyond SM (BSM) theories employ 2HDM

Two Higgs Doublets Models (2HDM)

- Higgs potential: $$V^{\mathrm{THDM}} = m_1^2\Phi_1^\dagger\Phi_1 + m_2^2\Phi_2^\dagger\Phi_2 - m_3^2\left(\Phi_1^\dagger\Phi_2 + \Phi_2^\dagger\Phi_1\right) + \frac{\lambda_1}{2}(\Phi_1^\dagger\Phi_1)^2 + \frac{\lambda_2}{2}(\Phi_2^\dagger\Phi_2)^2 + \lambda_3(\Phi_1^\dagger\Phi_1)(\Phi_2^\dagger\Phi_2) + \lambda_4(\Phi_1^\dagger\Phi_2)(\Phi_2^\dagger\Phi_1) + \frac{\lambda_5}{2}\left[(\Phi_1^\dagger\Phi_2)^2 + (\Phi_2^\dagger\Phi_1)^2\right],$$

$$\langle\Phi_1\rangle = \begin{pmatrix} 0 \\ \frac{v_1}{\sqrt{2}} \end{pmatrix}, \qquad \langle\Phi_2\rangle = \begin{pmatrix} 0 \\ \frac{v_2}{\sqrt{2}} \end{pmatrix}$$

- Mass: $$M_{H^\pm}^2 = \mu^2 - \frac{v^2}{2}(\lambda_4 + \mathrm{Re}\,\lambda_5),$$

$$v = \sqrt{v_1^2 + v_2^2} \simeq 246\ \mathrm{GeV} \qquad \tan\beta = \frac{v_2}{v_1}.$$

- Coupling:

Model	d	u	ℓ
I	Φ_2	Φ_2	Φ_2
II	Φ_1	Φ_2	Φ_1
III	$\Phi_1\&\Phi_2$	$\Phi_1\&\Phi_2$	$\Phi_1\&\Phi_2$
X	Φ_2	Φ_2	Φ_1
Y	Φ_1	Φ_2	Φ_2

- Yukawa interactions (type-II):

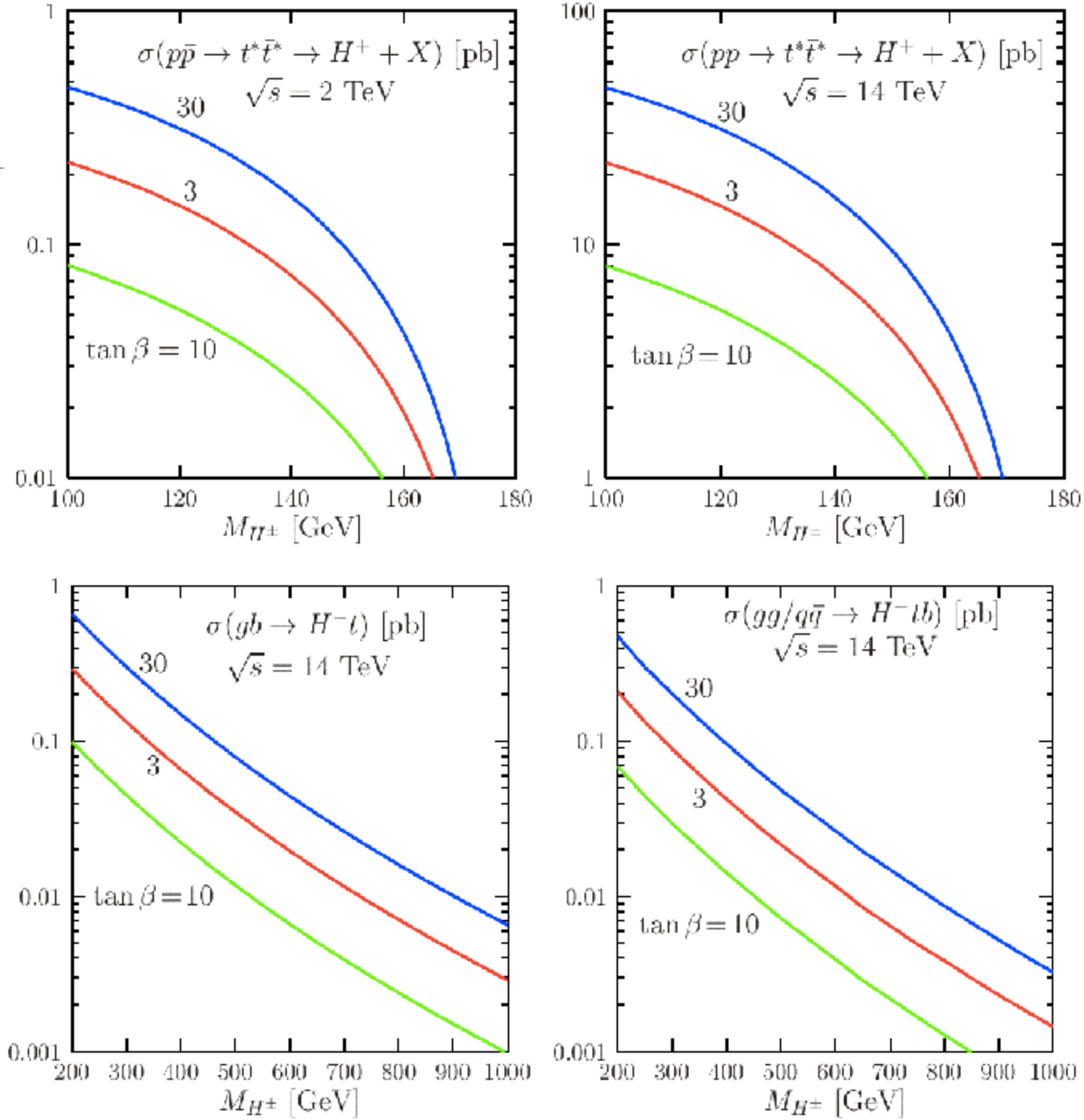
$$H^+ b\bar{t}: \qquad \frac{ig}{2\sqrt{2}\,m_W} V_{tb}[m_b(1+\gamma_5)\tan\beta + m_t(1-\gamma_5)\cot\beta],$$

$$H^- t\bar{b}: \qquad \frac{ig}{2\sqrt{2}\,m_W} V_{tb}^*[m_b(1-\gamma_5)\tan\beta + m_t(1+\gamma_5)\cot\beta].$$

H^+ production

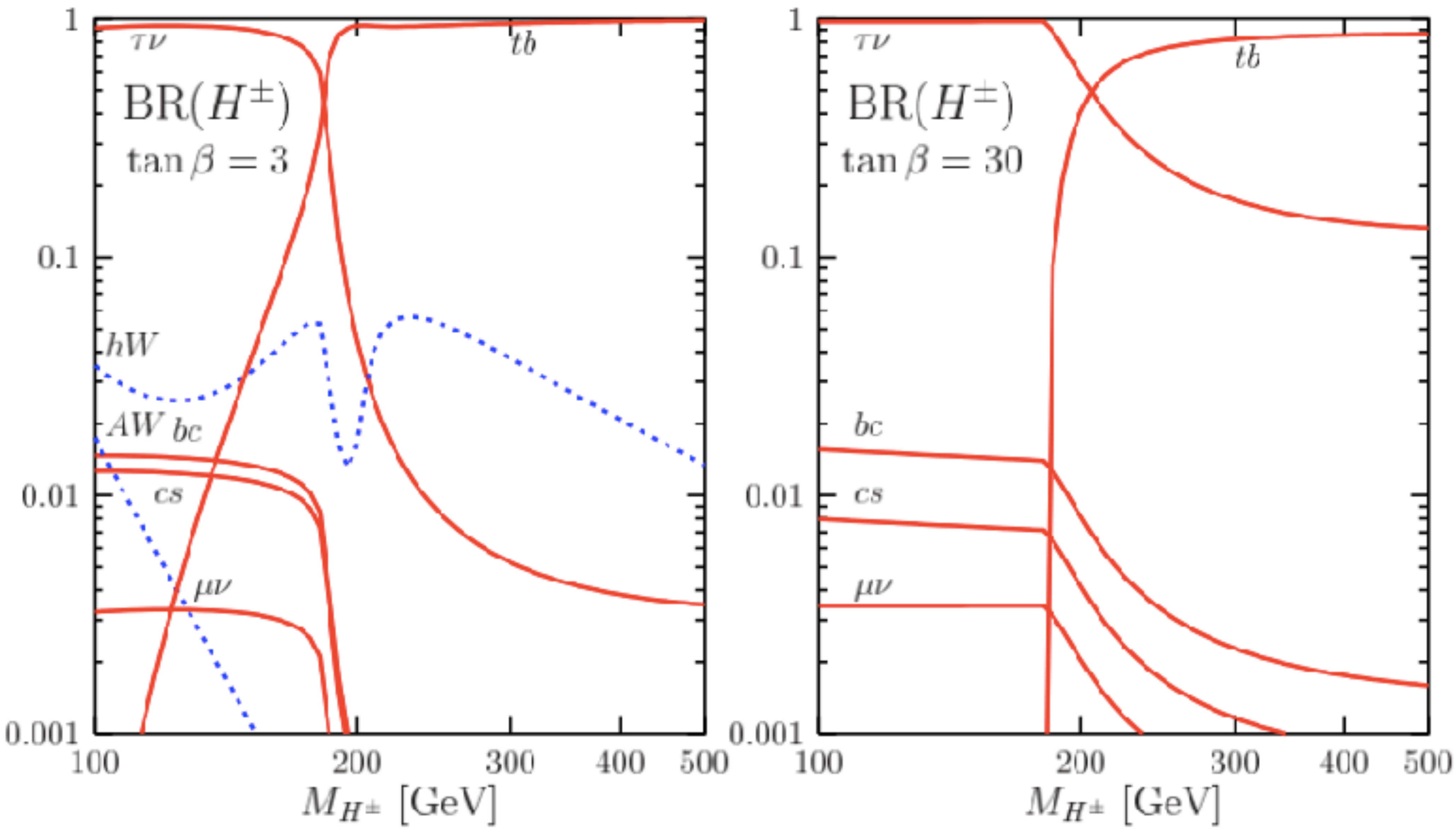
$m(H^+)<m(t)$

$m(H^+)>m(t)$



H^+ decays

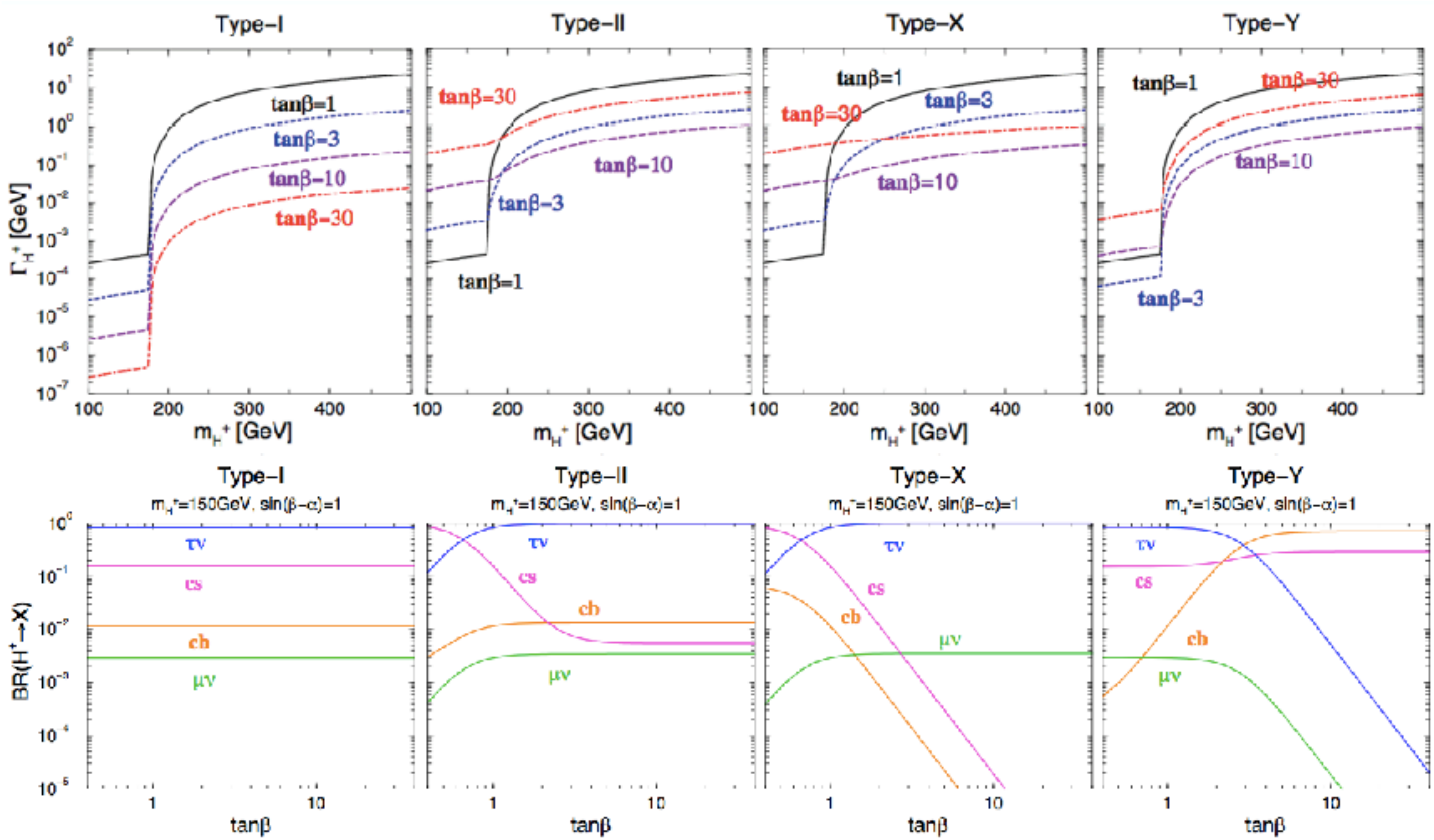
key parameters: tanβ, m(H^+)



Minimal Supersymmetric SM (MSSM), type-II 2HDM

Charged Higgs (H^+) Decays (depends on model)

key parameters: tanβ, m(H^+)

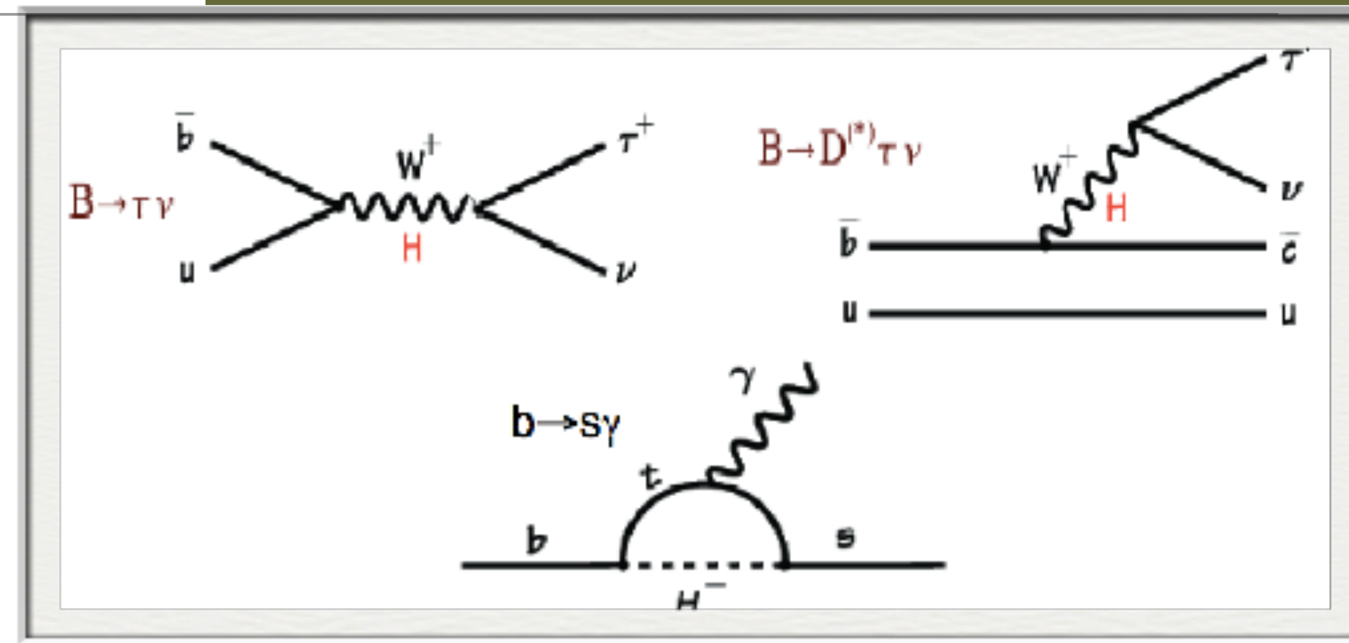


Kei Yagyu et al., Phys.Rev.D80:015017,2009

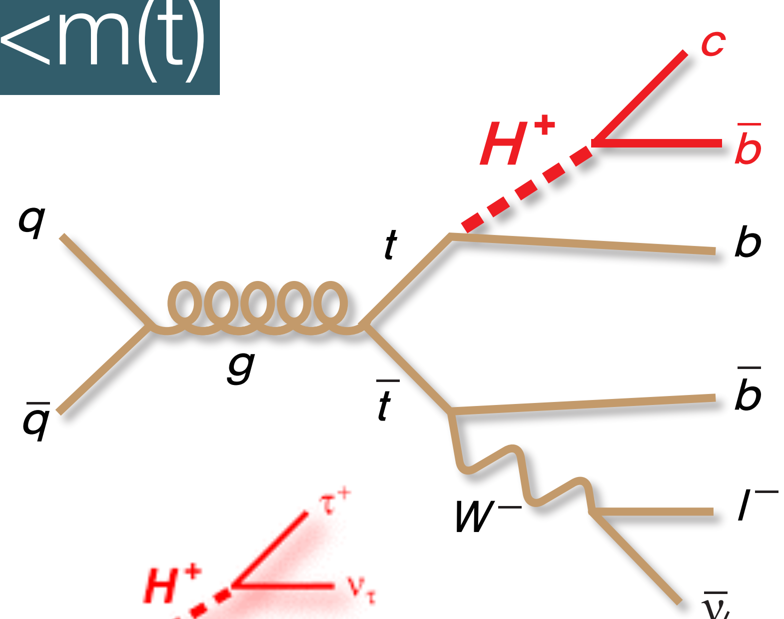
Charged Higgs (H^+) boson

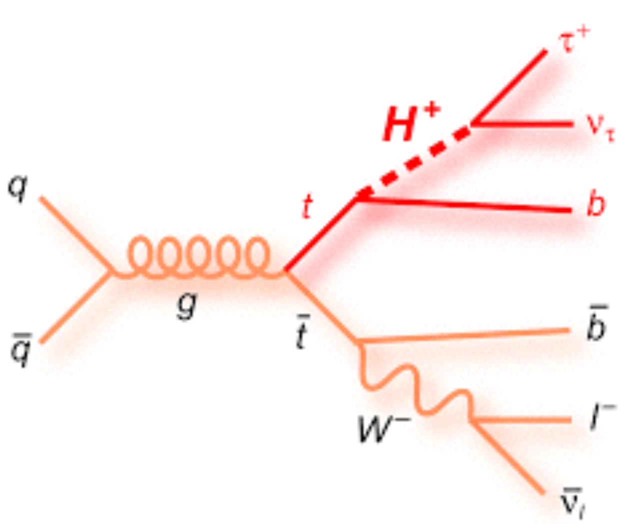
- Distinctive property: Charge!
- H^+ can appear in place of W boson

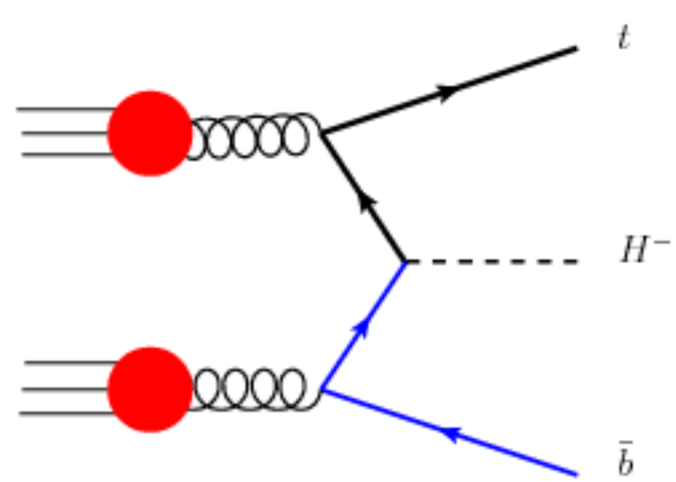
H^+ contribution @ B-factory

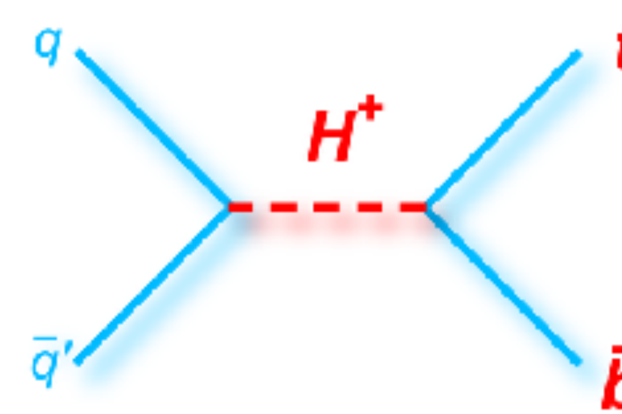


m(H+)<m(t)

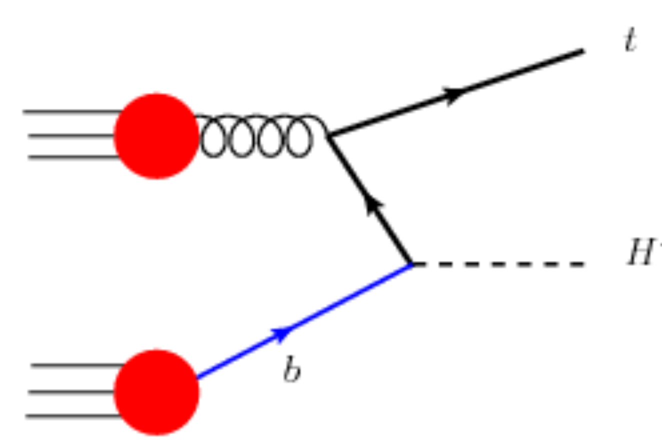








m(H+)>m(t)



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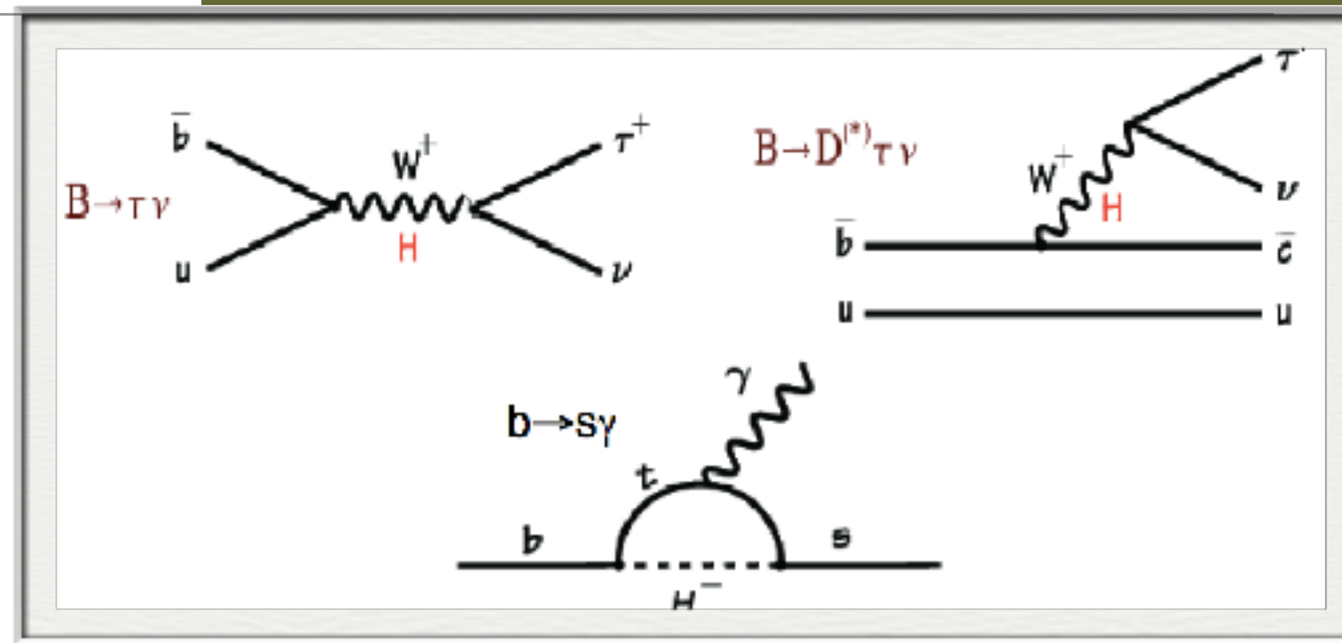
- H^+ can appear in place of W boson

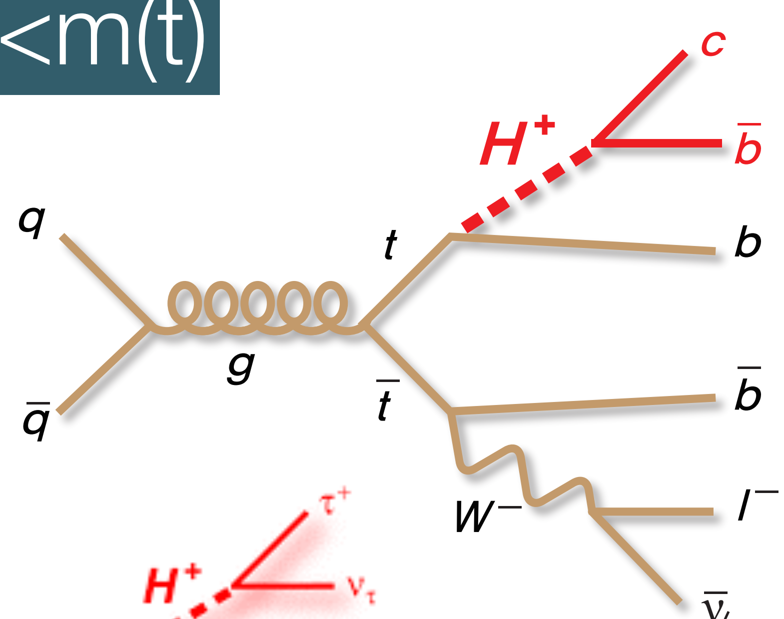
Indirect H^+ search

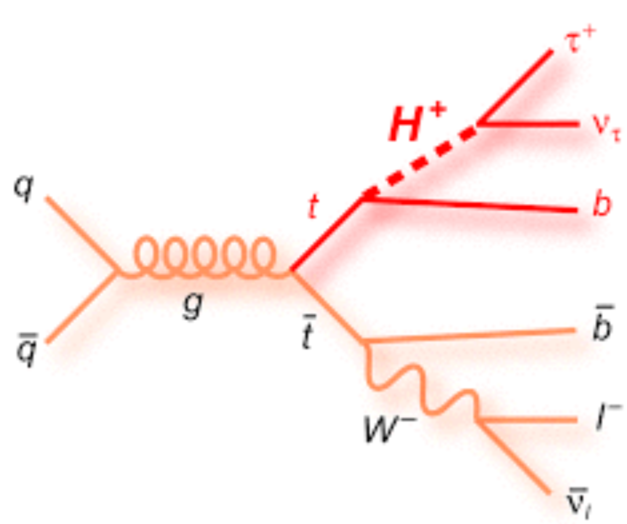
H^+ contribution @ B-factory



Light H^+ search

$m(H^+)<m(t)$





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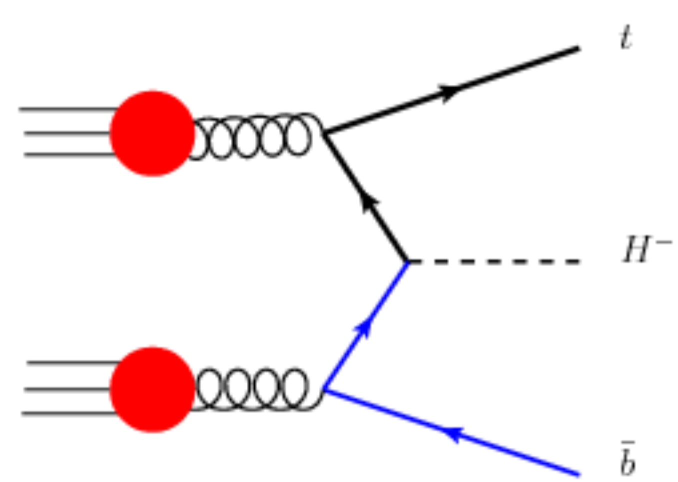
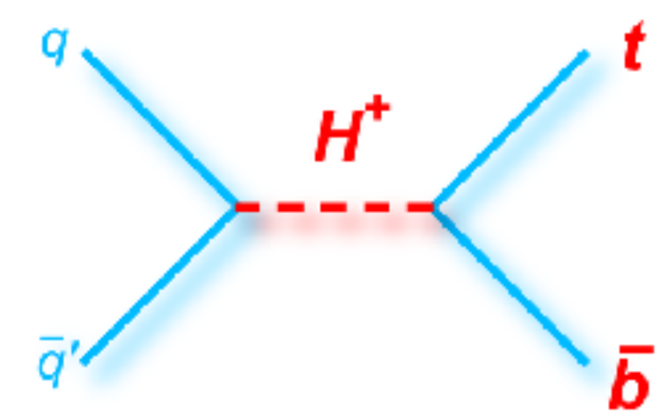
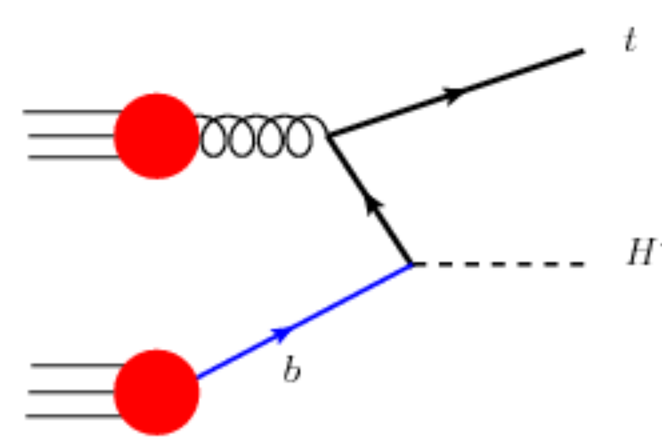
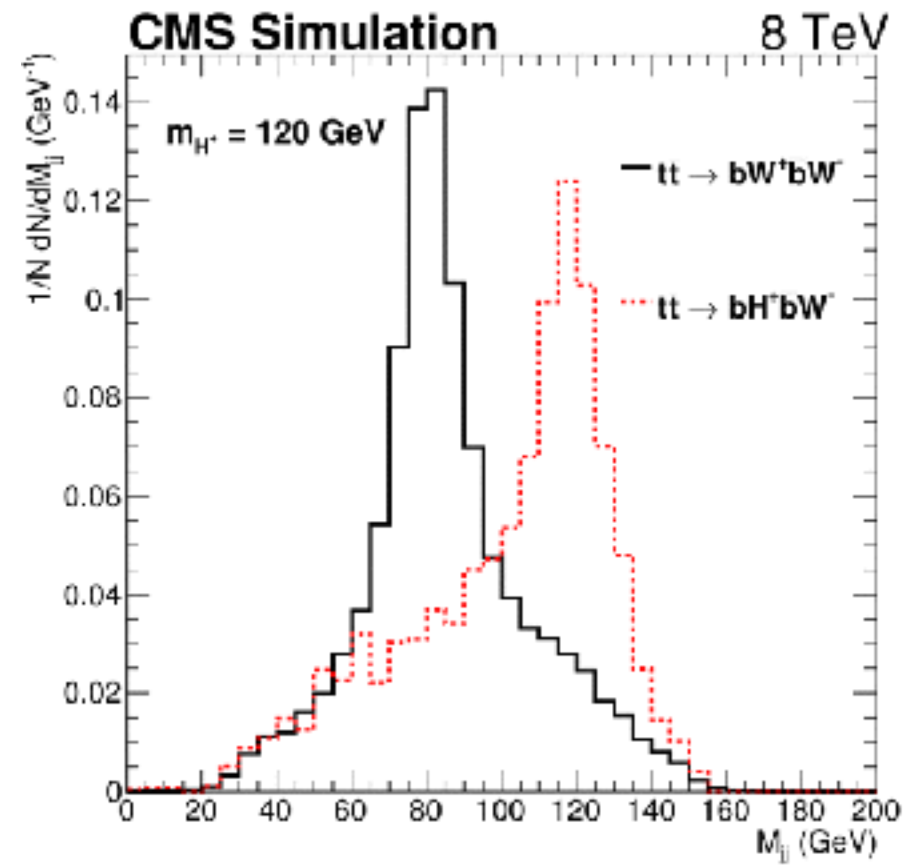






Heavy H^+ search

using mass separation
W vs H^+

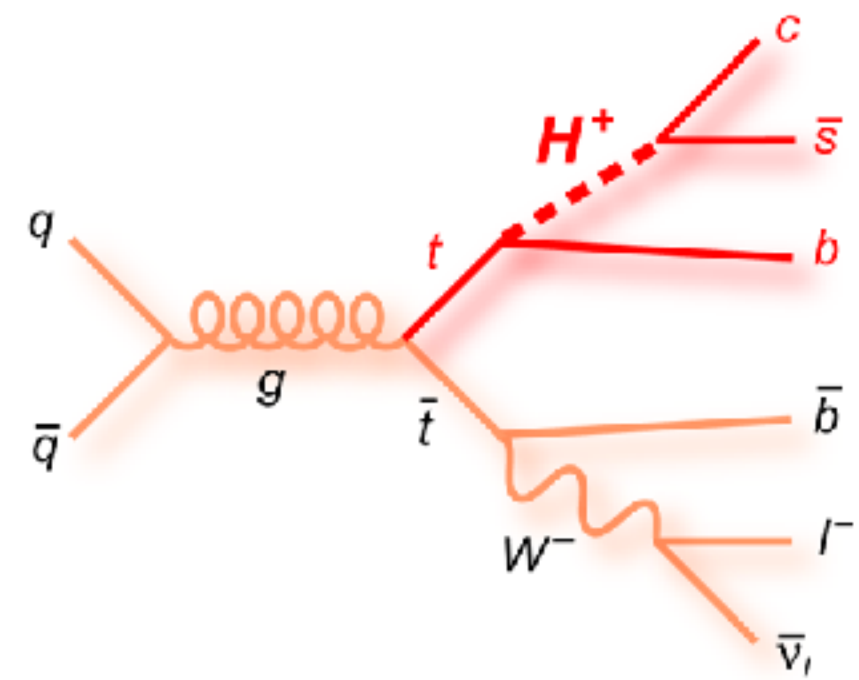


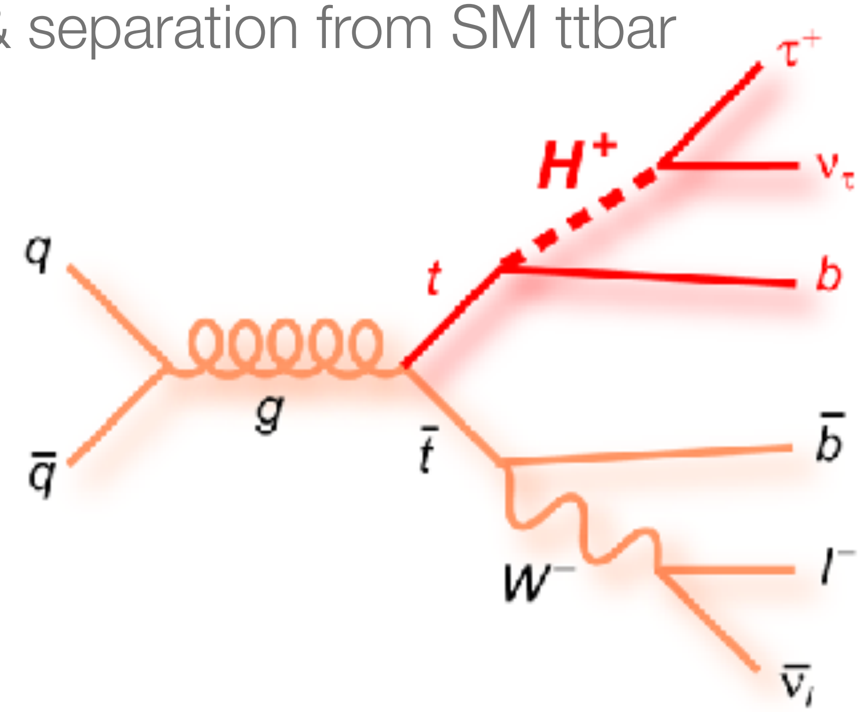
Search Strategy for light H^+ search

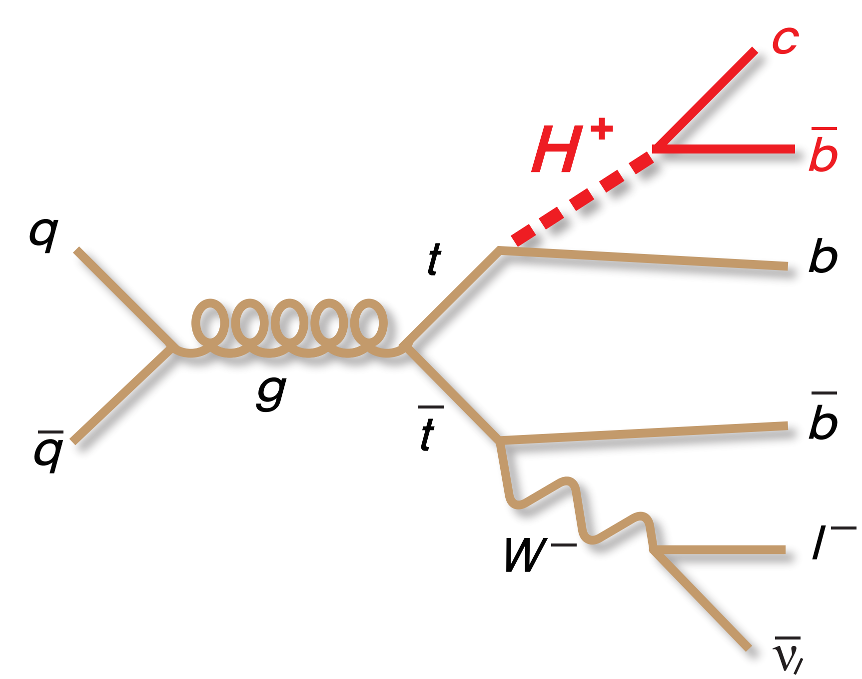
M(H^+): 90~160 GeV

What we search for?

- H^+ searched in top quark decays
  - Measure $B(t \to H^+ b)$ with sub-decays
- Dominant H^+ decay: τν
  - Difficulty in τ identification
- Dominant in low tanβ or type-Y model: $c\bar{s}$ $c\bar{b}$
  - Good identification & separation from SM ttbar







What we search for?

This talk focuses on hadronic decays

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  - Measure $B(t\to H^+ b)$ with sub-decays
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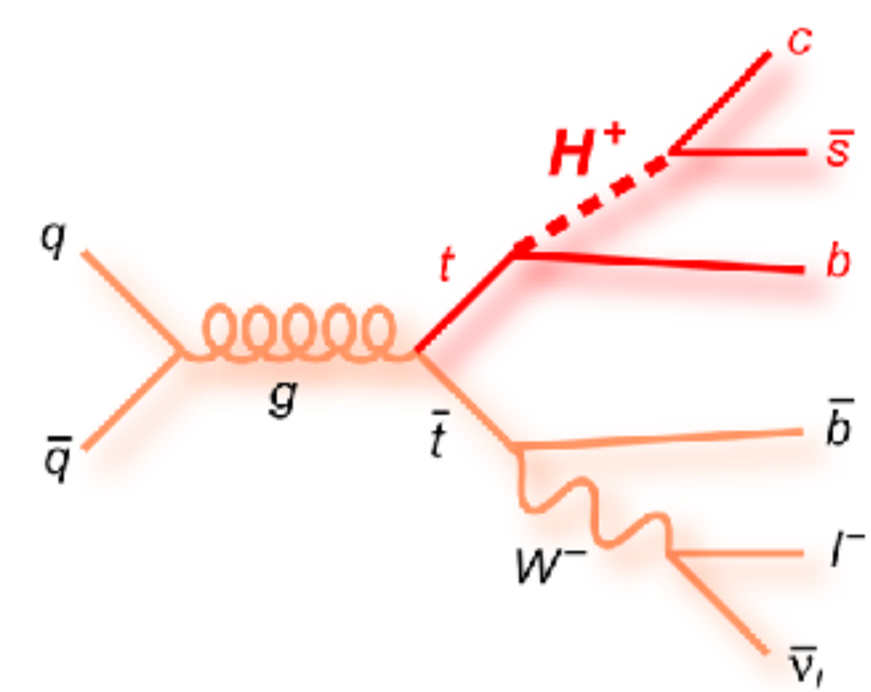
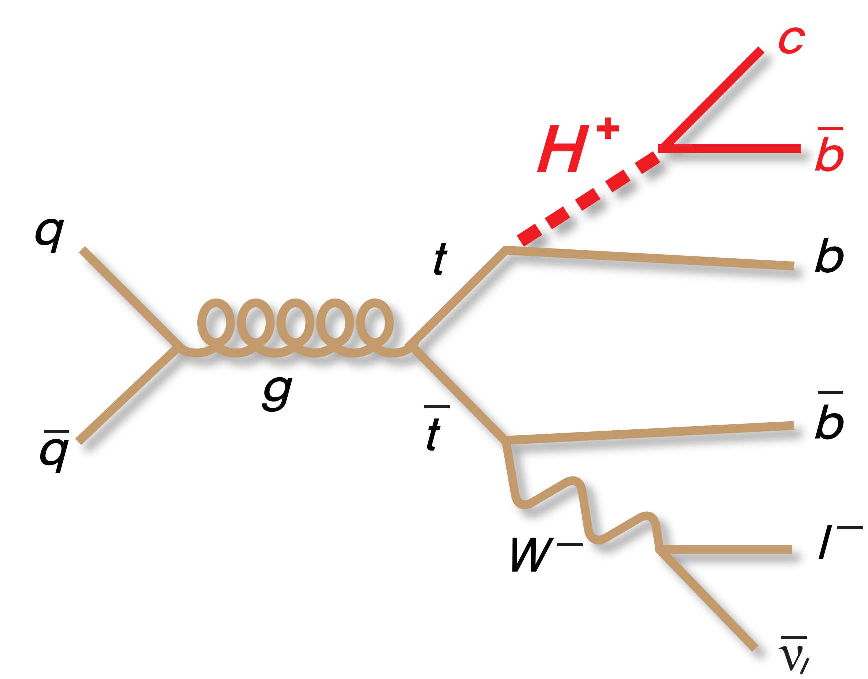
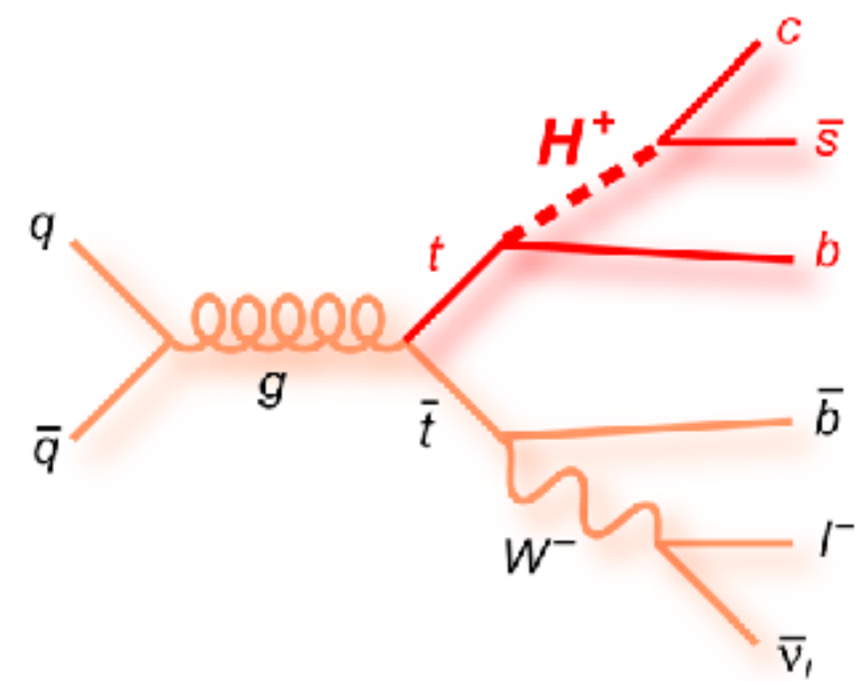


Background SM processes:
ttbar (~92%), single-top, tt+H/W/Z
Diboson, W/Z+jets, QCD multi jets

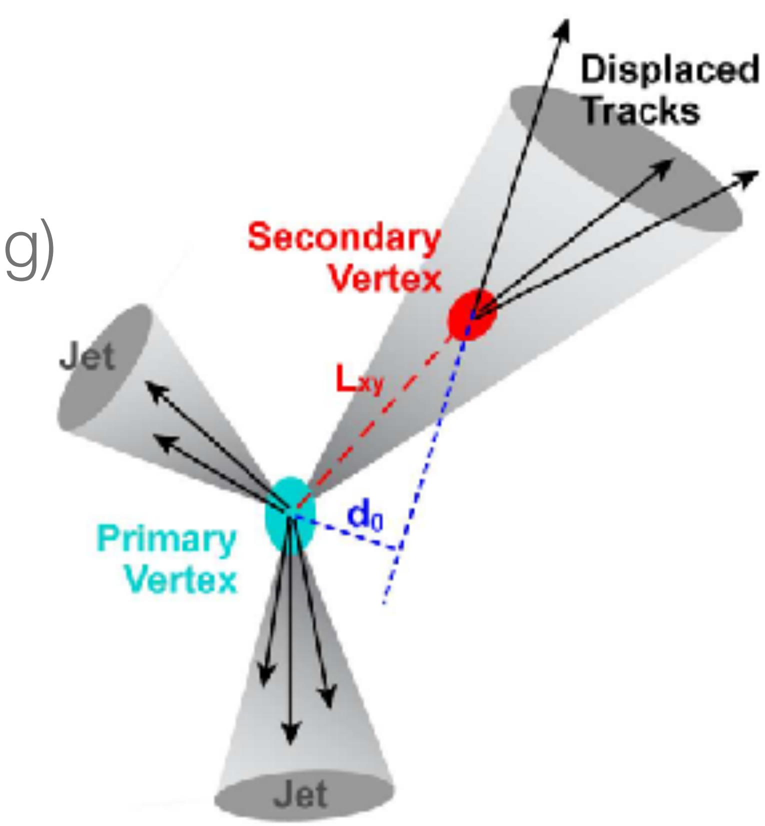


Event Selection

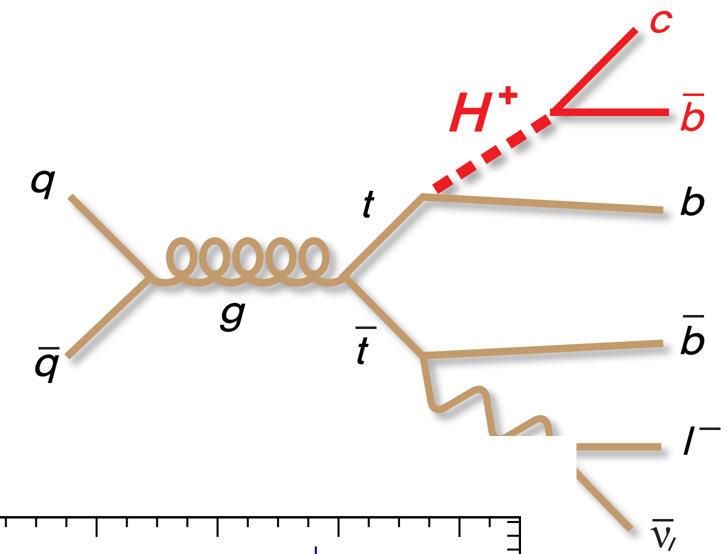
- Use golden ttbar channel
- Single lepton trigger
- Final state object:
  - == one well-identified, isolated lepton
  - ≥ 4 jets with p_T>25 GeV, $|\eta|$<2.4
  - ≥ 2 jets identified as having a secondary vertex (b-tagging)
  - MET ≥ 20 GeV
- Pileup contribution to jets and primary vertex are corrected
- Other loose leptons vetoed



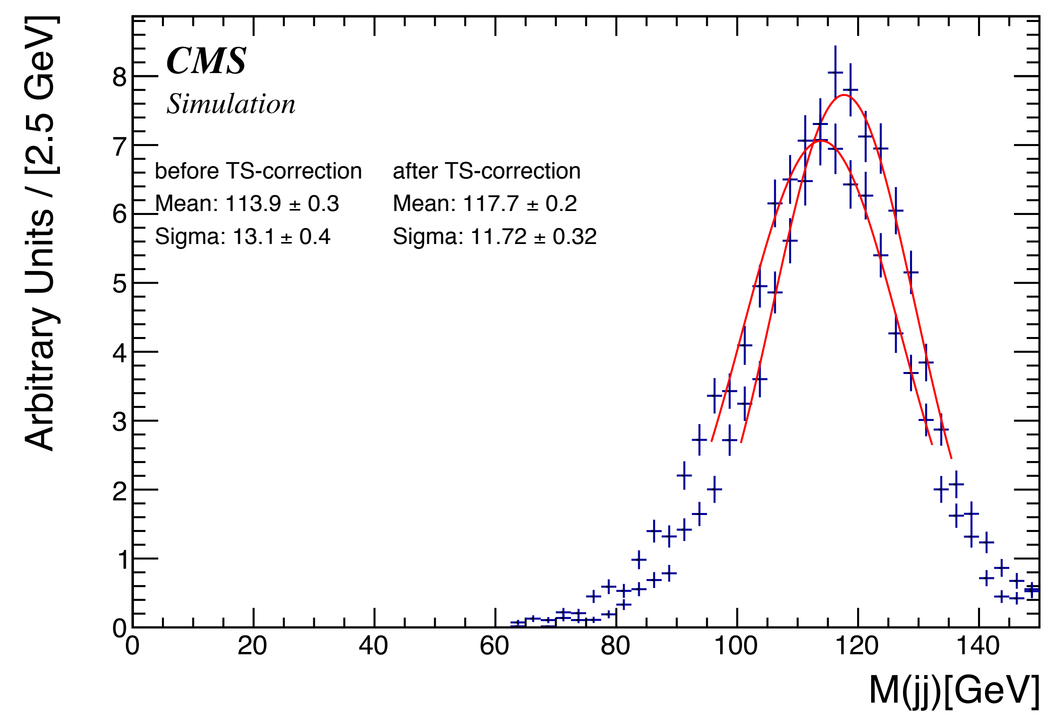
Full reconstruction of ttbar events by kinematic fitter

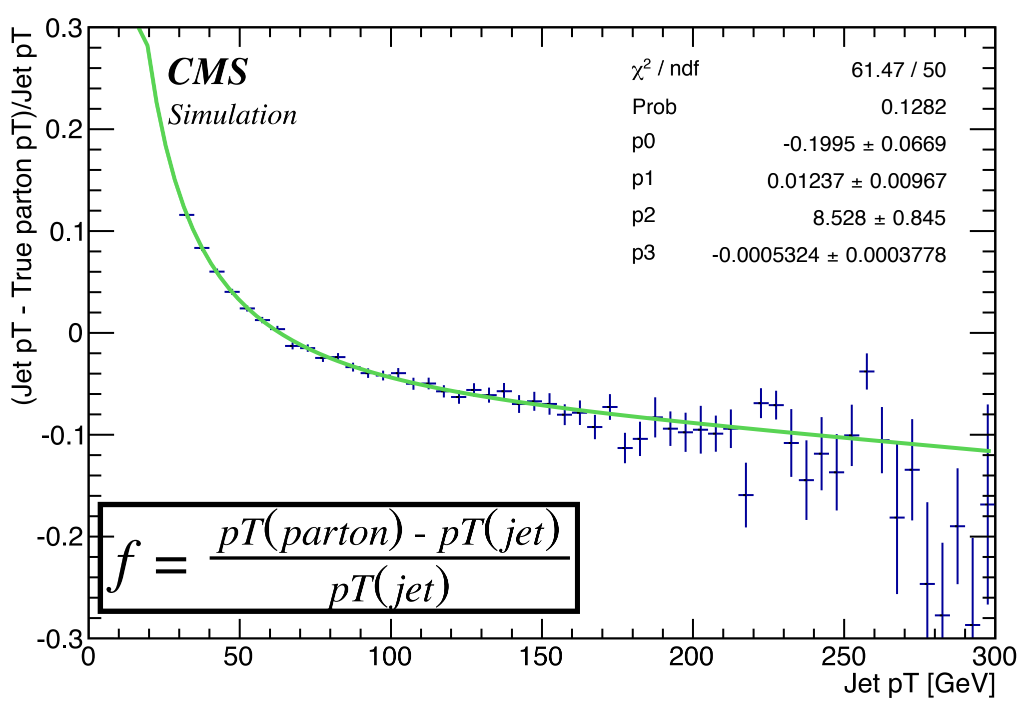


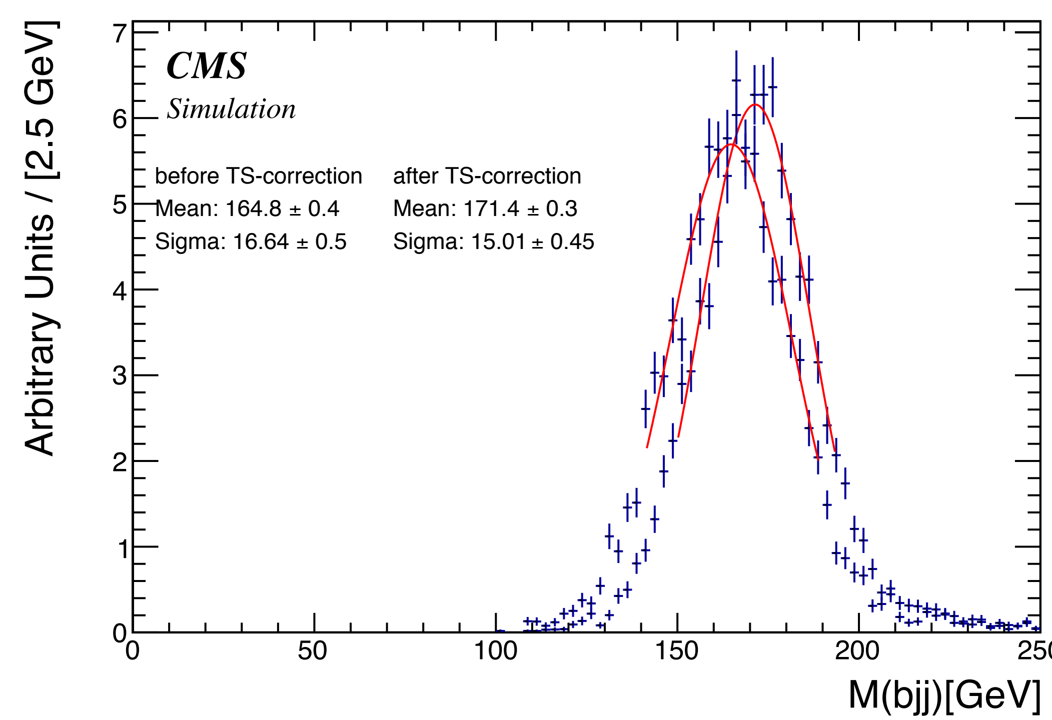
Top-specific corrections



- Flavor dependent correction of reco jets to partons
- With this correction reconstructed mass (W^+, H^+, top) gets closer to the true value and its resolution improved by 7~9% in SM ttbar and H^+ signal
- This correction is applied to leading four jets in both MC samples and data

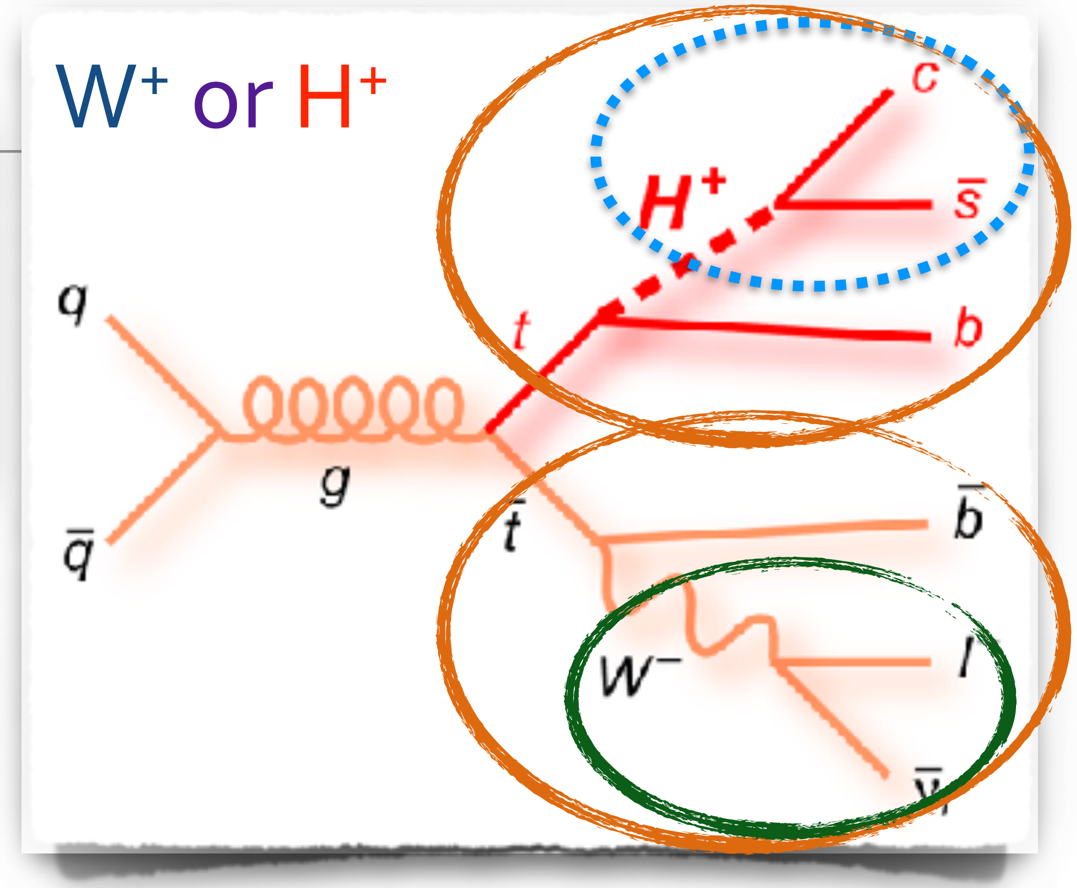


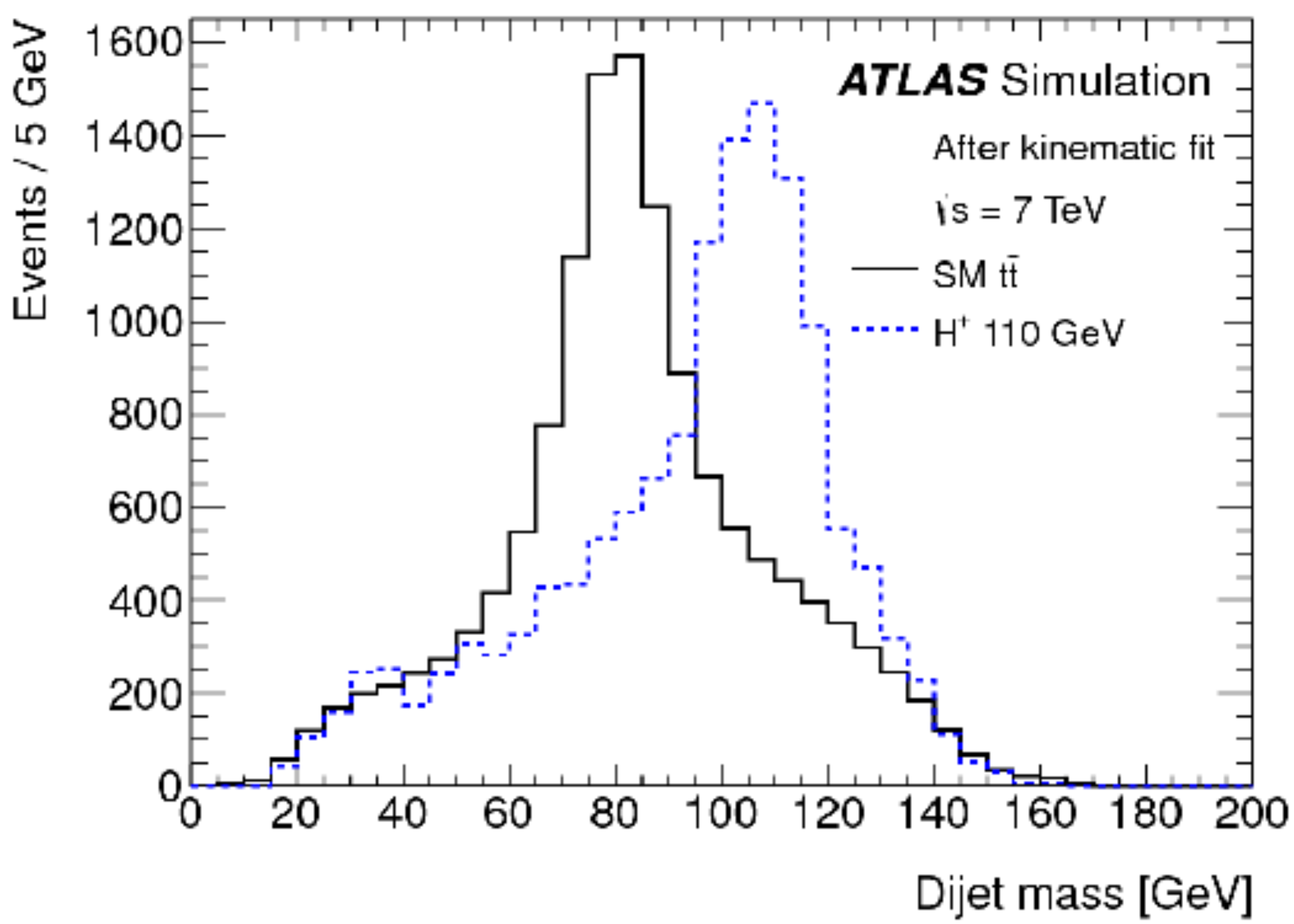




TTbar kinematic fitter

$$\chi^2 = \sum_{i=l,4\text{jets}} \frac{(p_T^{i,\text{fit}} - p_T^{i,\text{meas}})^2}{\sigma_i^2} + \sum_{j=x,y} \frac{(p_j^{\text{UE,fit}} - p_j^{\text{UE,meas}})^2}{\sigma_{\text{UE}}^2} + \frac{(M_{l\nu} - M_W)^2}{\Gamma_W^2} + \frac{(M_{bl\nu} - M_t)^2}{\Gamma_t^2} + \frac{(M_{bjj} - M_t)^2}{\Gamma_t^2},$$





- Assign leading four jets to four partons of ttbar
- TS corrections applied to the assigned jets
- Constrain masses but the hadronic boson

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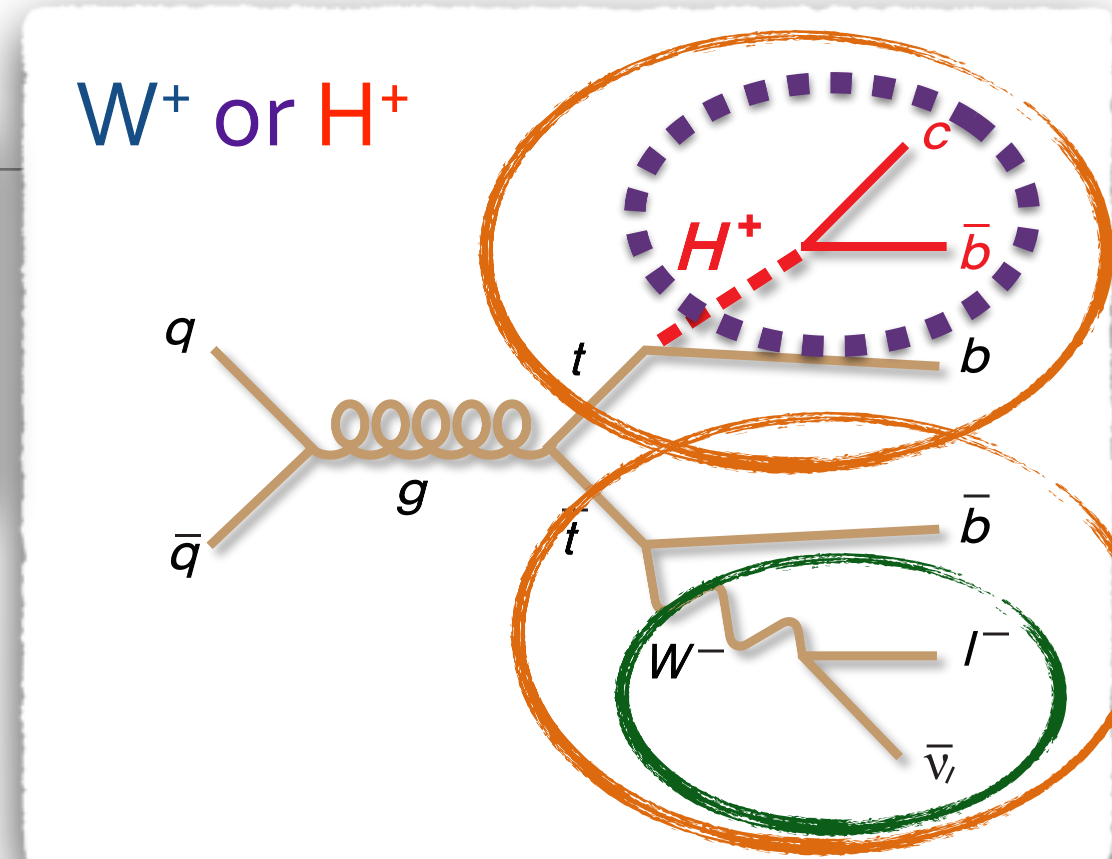
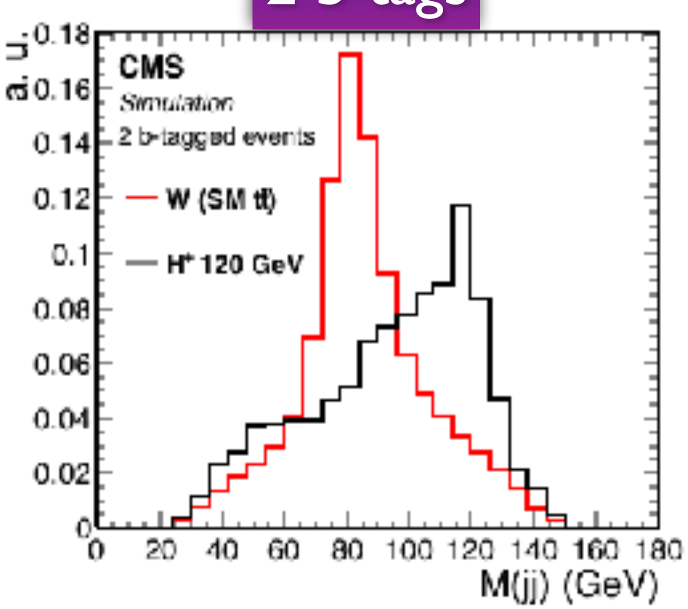
$H^+ \rightarrow$cbbar signal has 3 b-jets

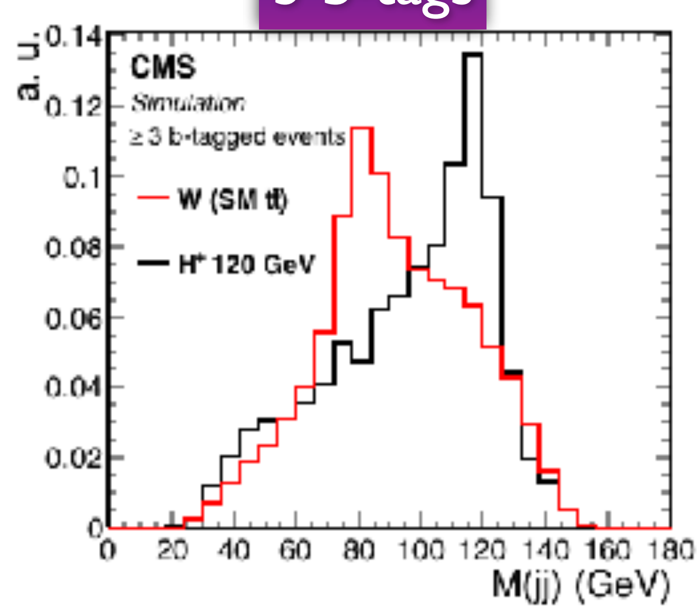


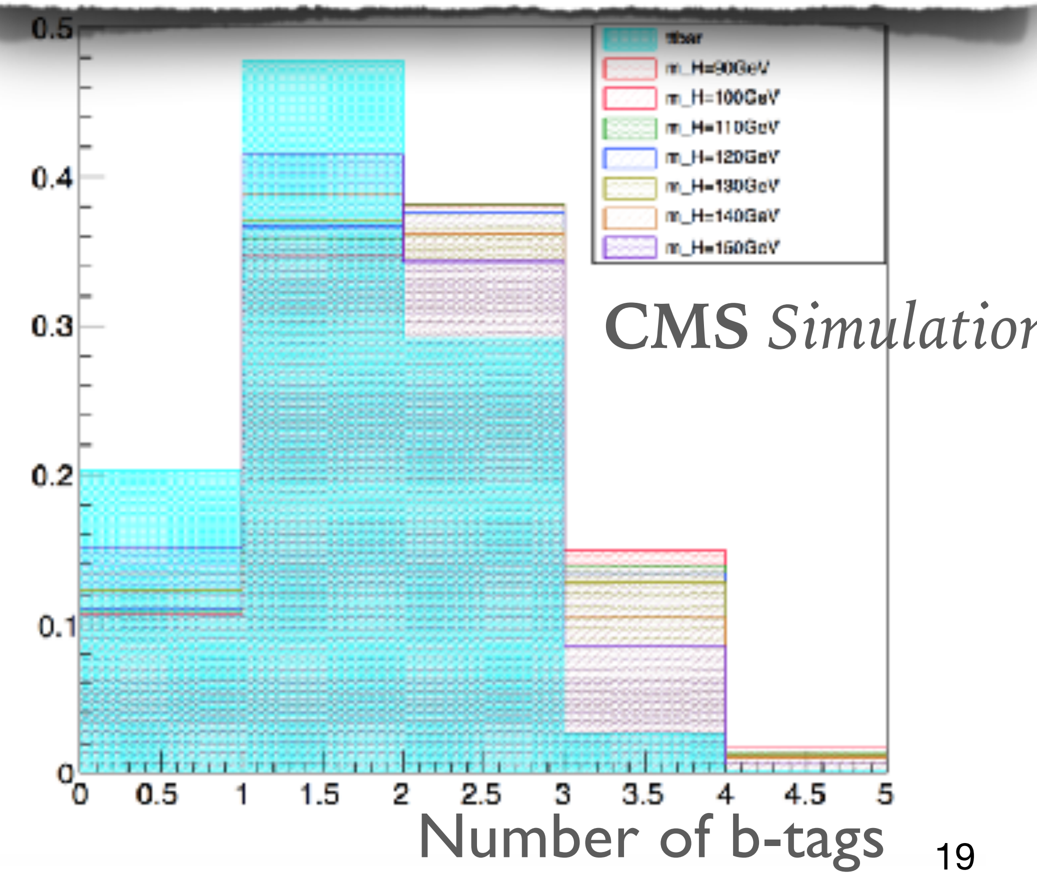
Di-jet mass in 2b/3b events prepared for template fit

2 b-tags



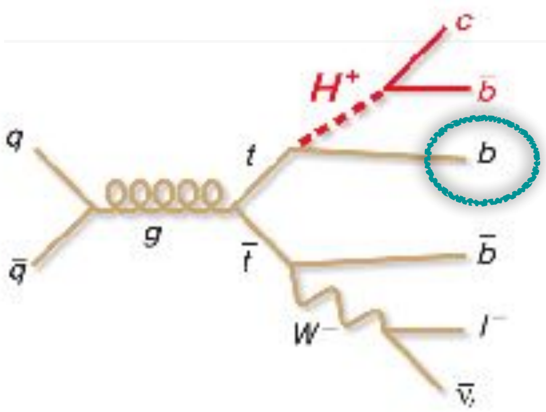
3 b-tags





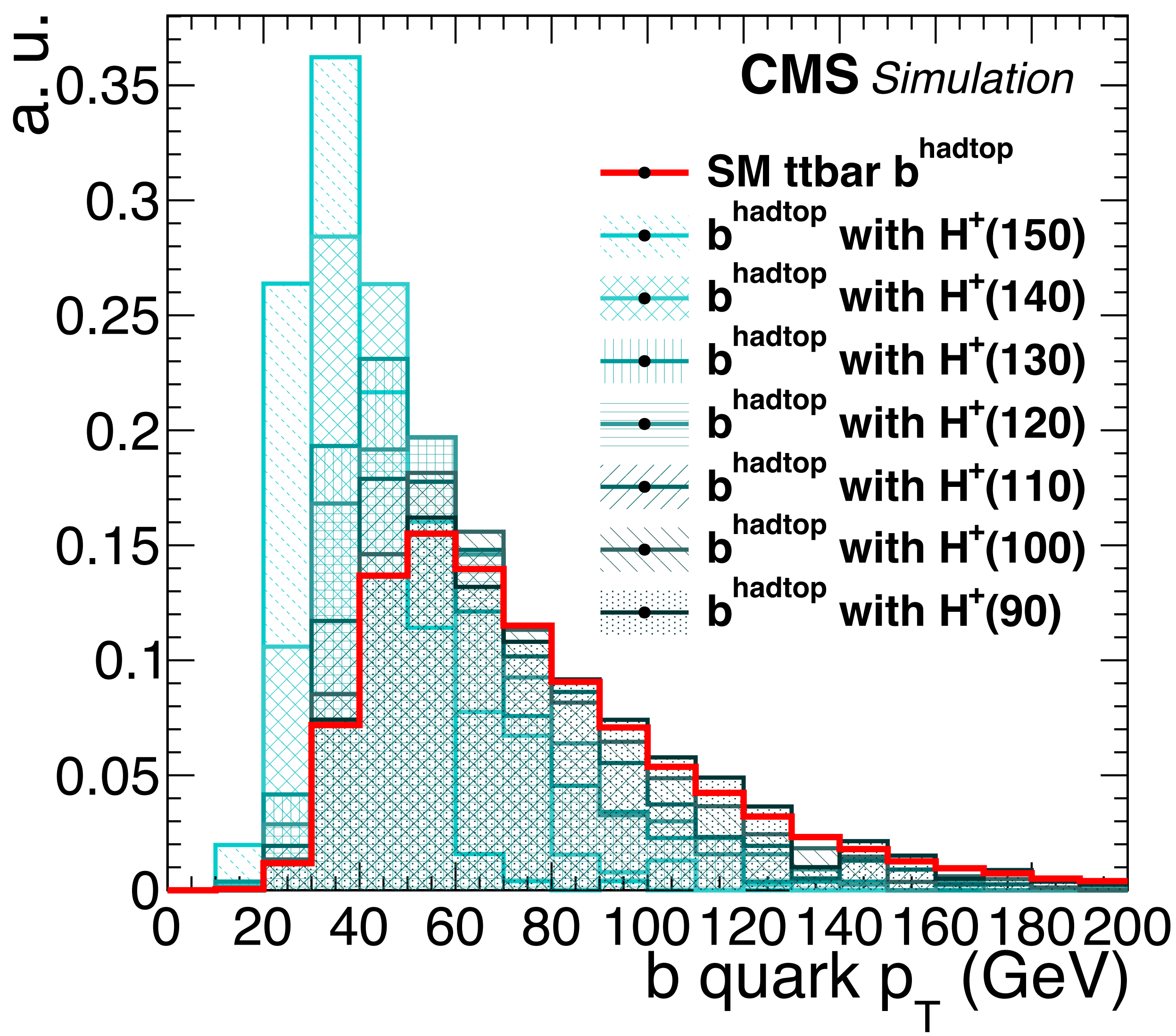
B-jet assignment (3b-jets)

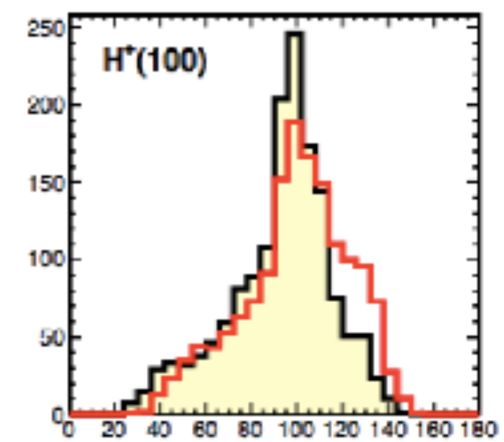
- In 2b-jets selection, both b-jets assigned to top-b-quarks only

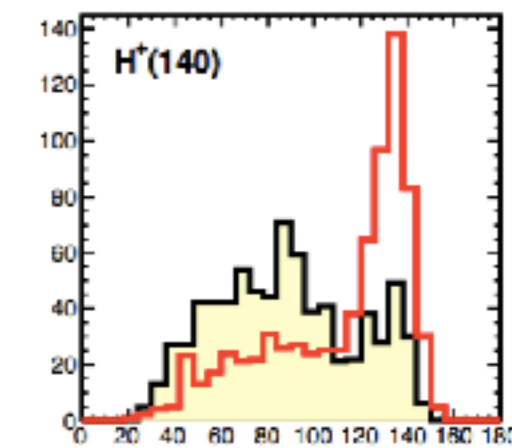


Gen. b-parton p_T distribution

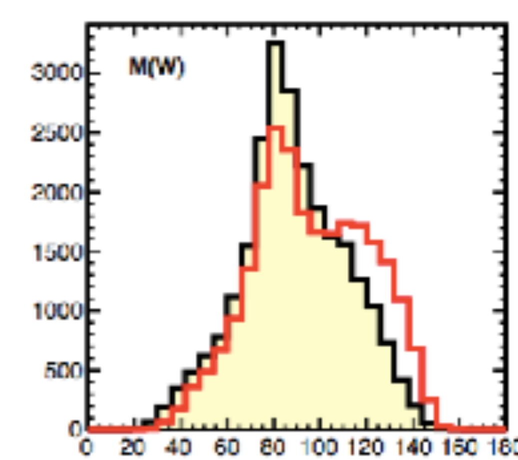
- Two b-tagged jets assigned to direct top-b-quark and H^+-b-quark
- Force lower p_T b-tagged jet to direct top-b-jet (for $M(H^+) \geq 130$GeV)





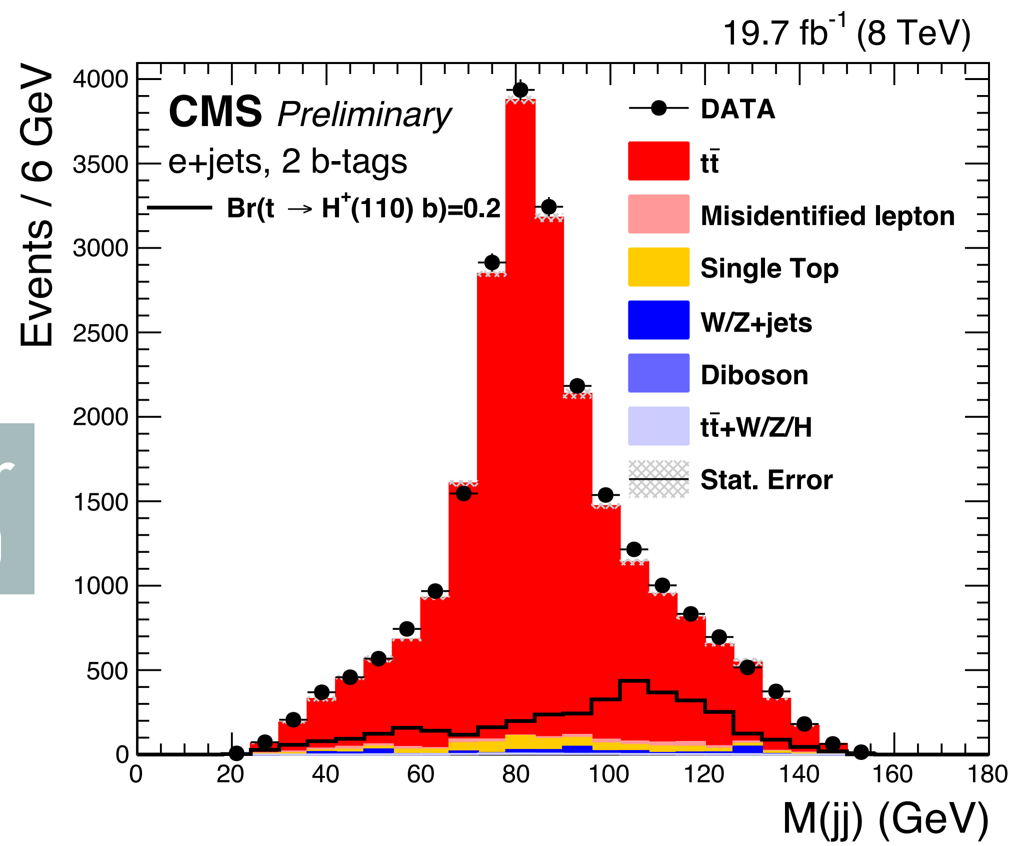


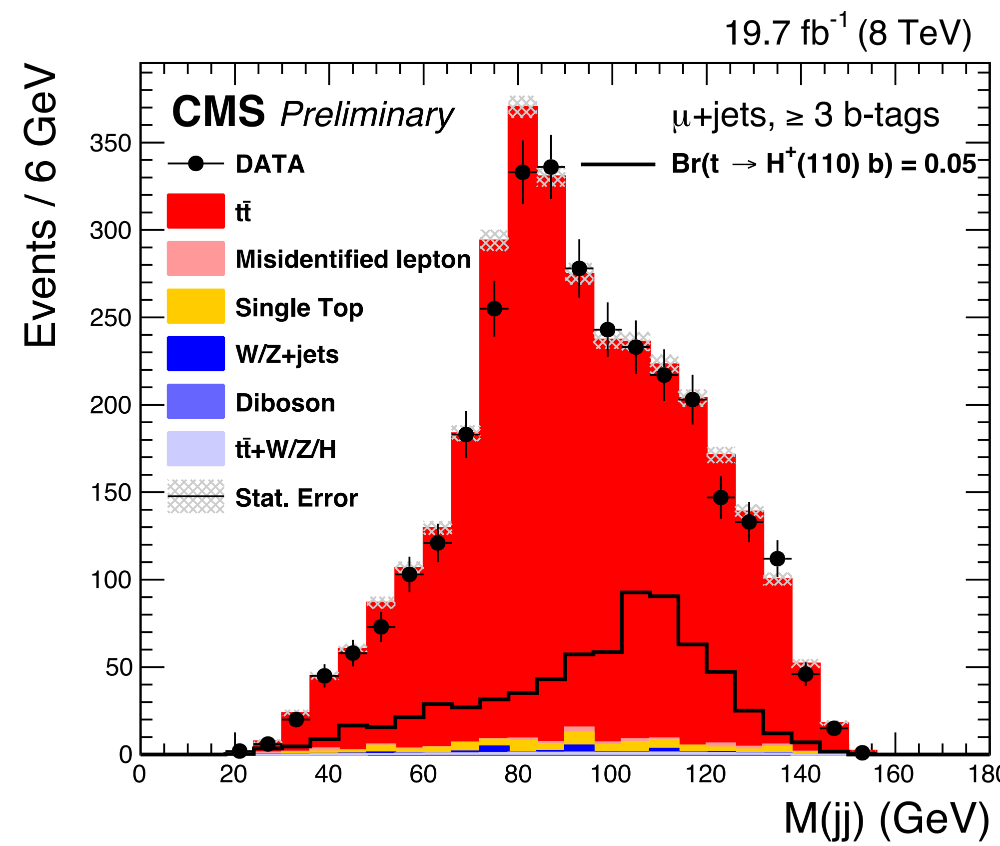
Low mass fitter
High mass fitter



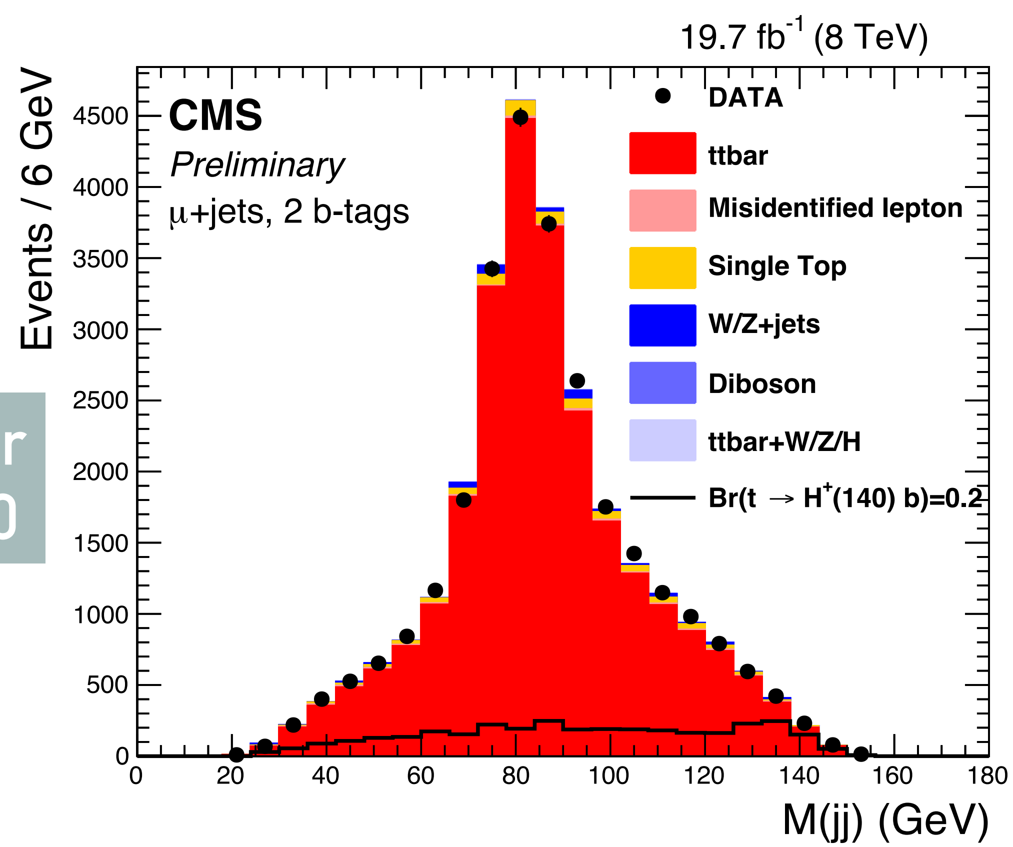
Dijet mass templates

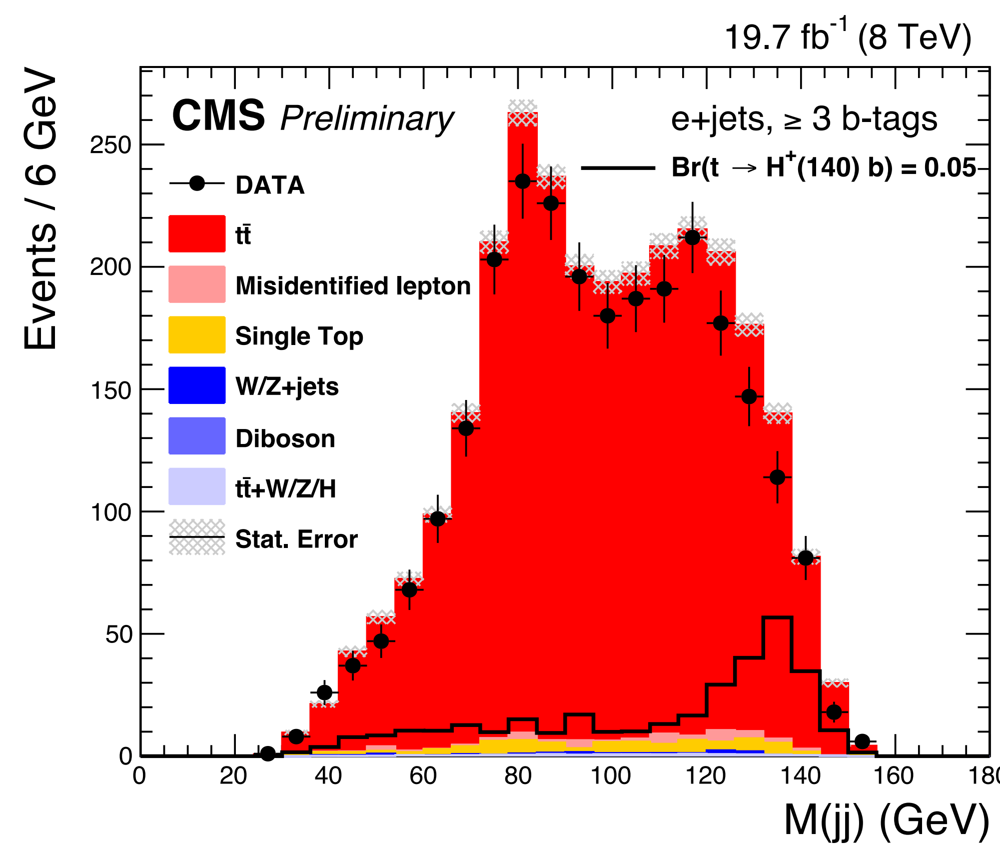
low mass fitter
m(H⁺)=90-120





high mass fitter
m(H⁺)=130-150





Systematic uncertainties

- All uncertainties are taken as shape systematics except
  - ttbar xsec, luminosity, pileup corrections to MC, scale factors (B-tagging,lepton)
- Jet-related uncertainty:
  - Jet energy correction&resolution/Flavour dependent uncertainty
- Top-related uncertainty:
  - TTbar p_T shape shift/NLO-vs-LO production/top quark mass shift
- MonteCarlo uncertainty:
  - MatrixElement event generation matching to Pythia hadronization/Factorization scale (Q^2)/Pythia-vs-Madgraph ttbar p_T difference

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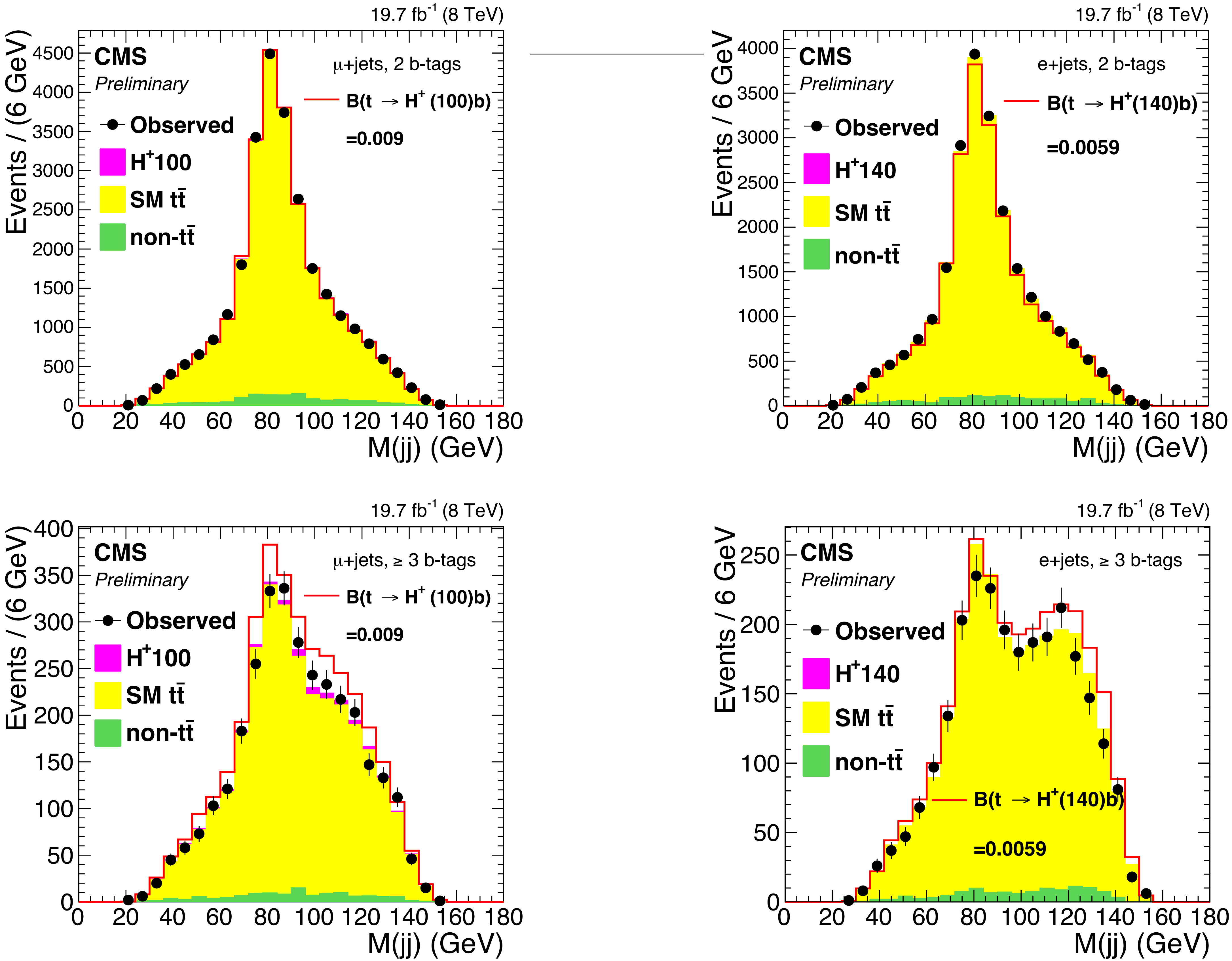
Major systematic effects

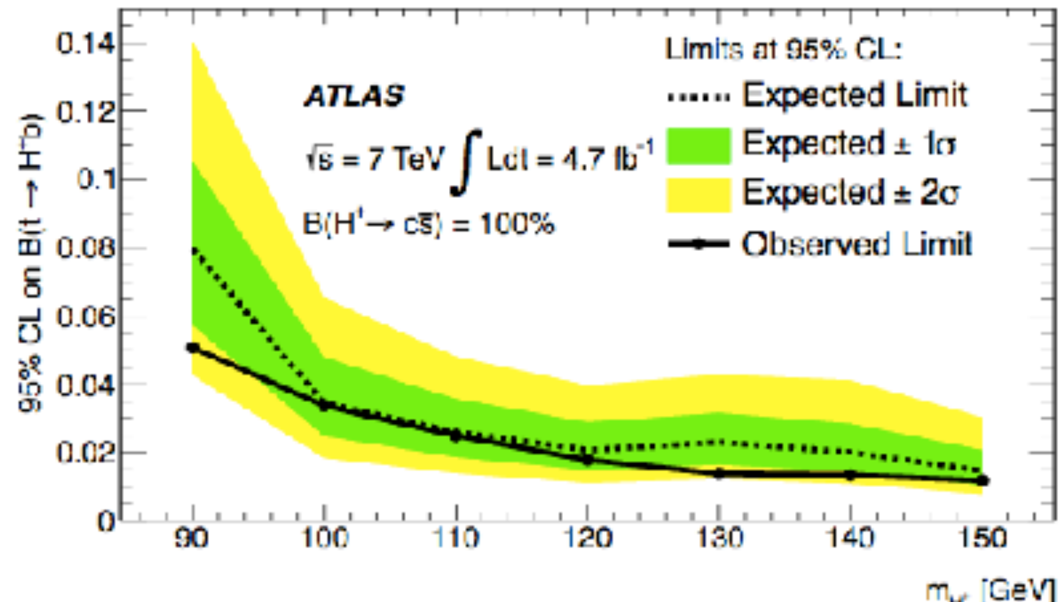
Maximum likelihood fit on dijet mass

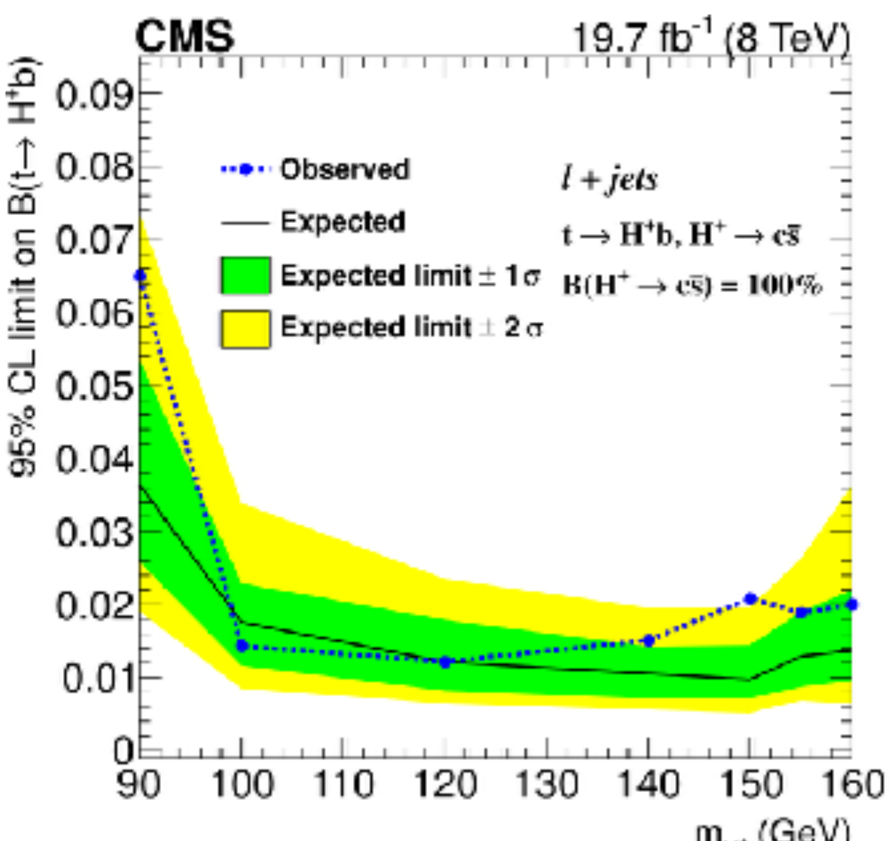


Light H+ searches (for non-τ decays)

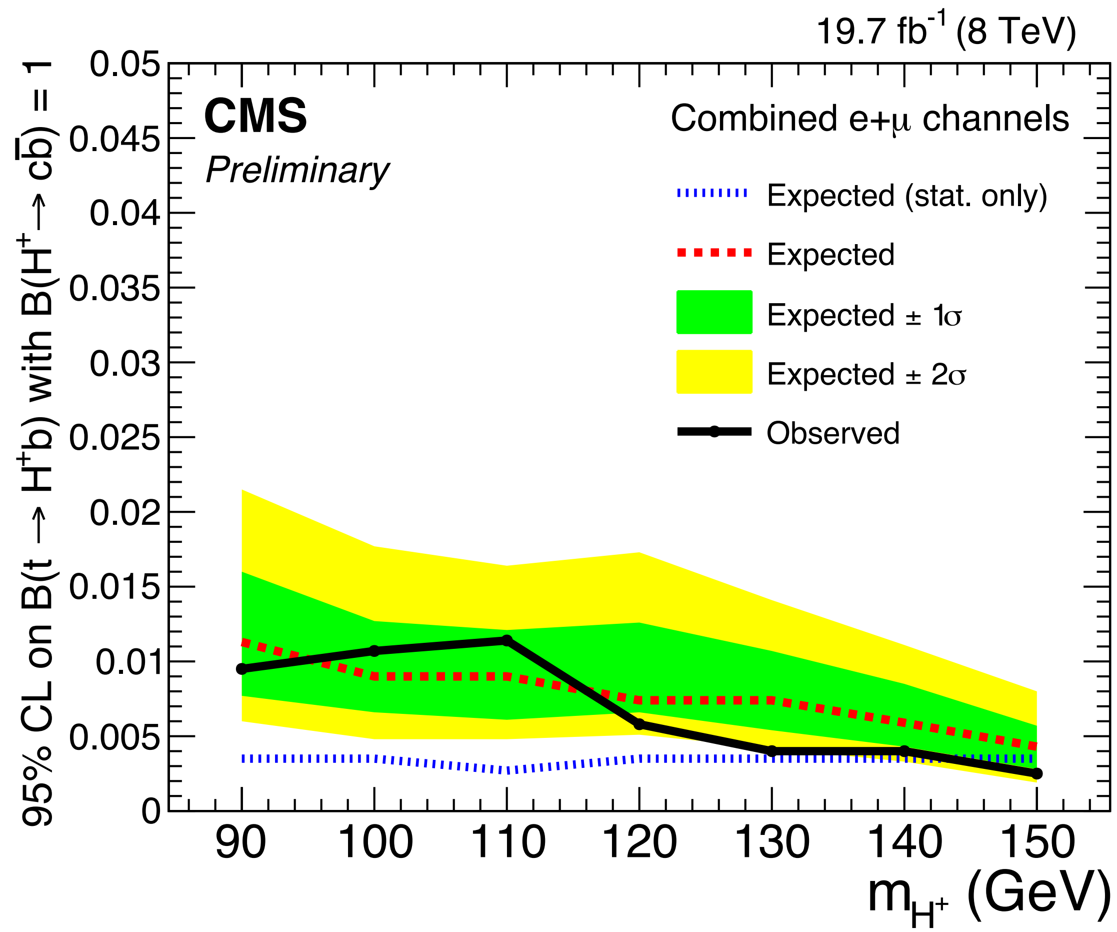
$t \rightarrow H^+b$, $H^+ \rightarrow cs$

Limits calculated using Asymptotic Method





$t \rightarrow H^+b$, $H^+ \rightarrow cb$



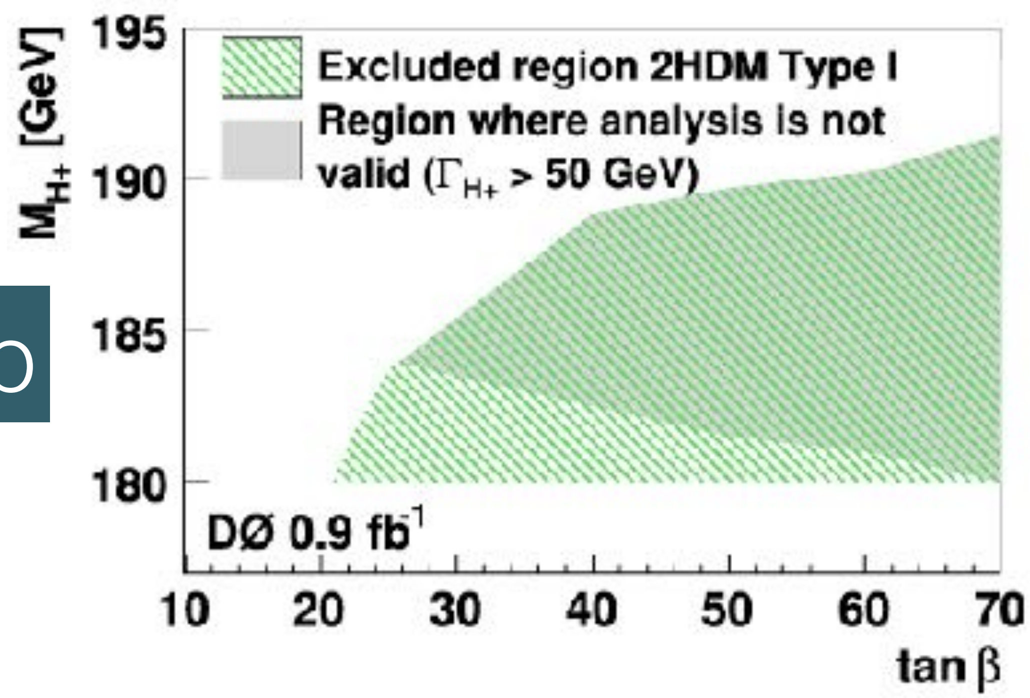
Analysis using 13TeV data in progress

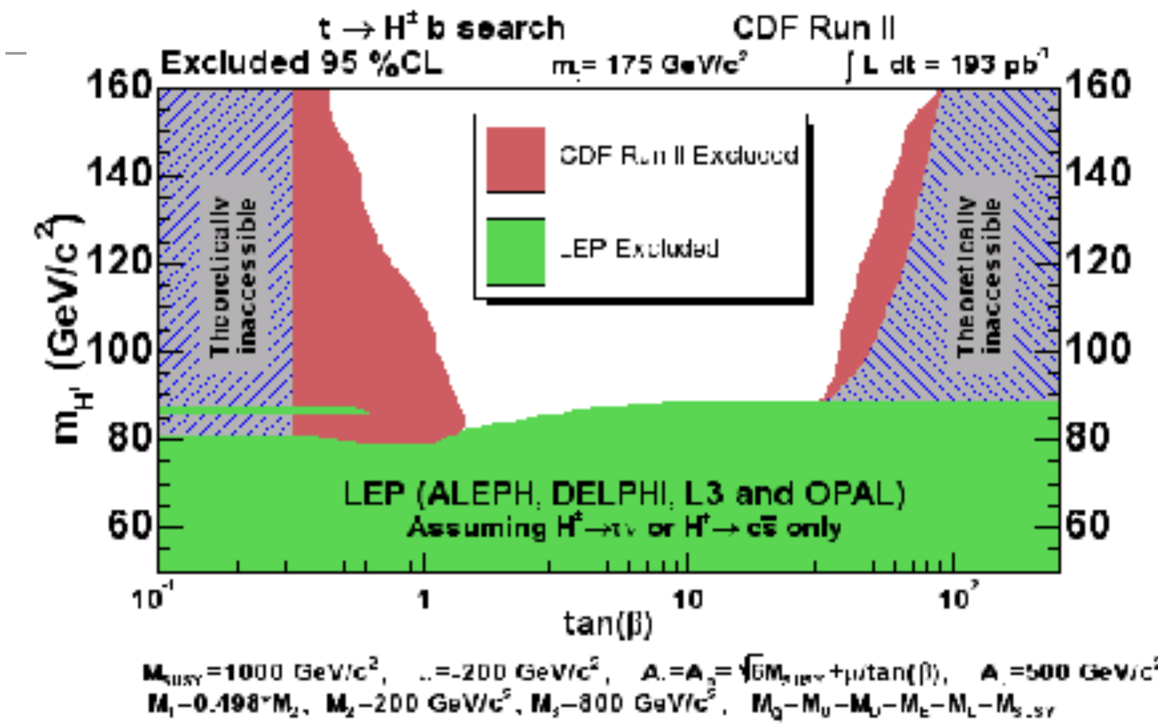
No excess over SM processes so far..
Search Result

Results in pre-LHC era

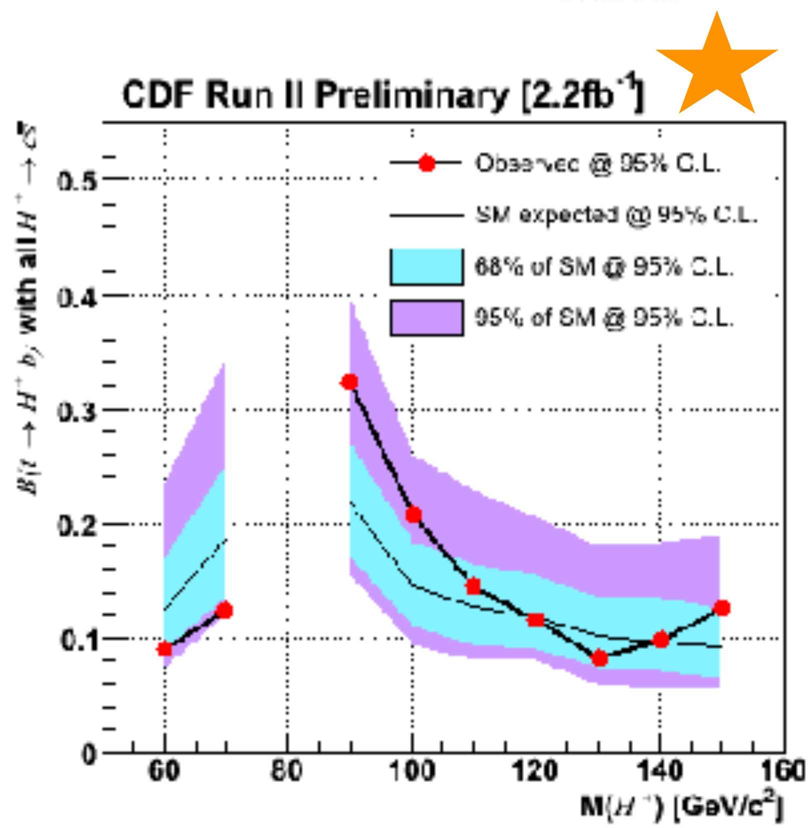
t→H⁺b, H⁺→τν

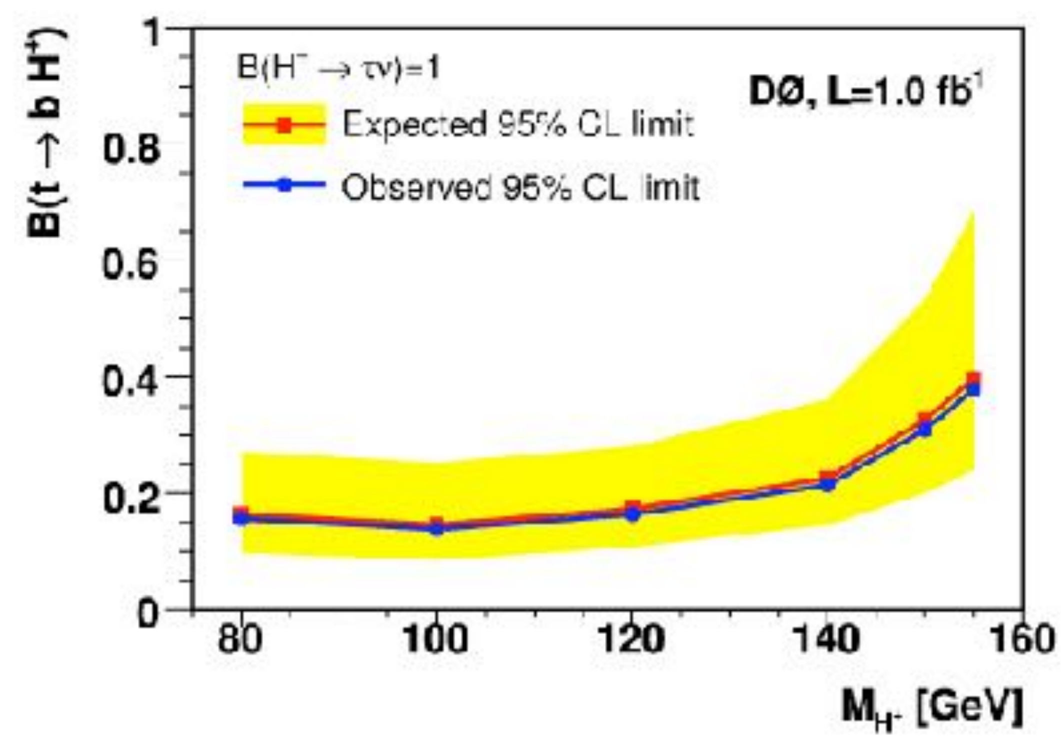
H⁺→tb





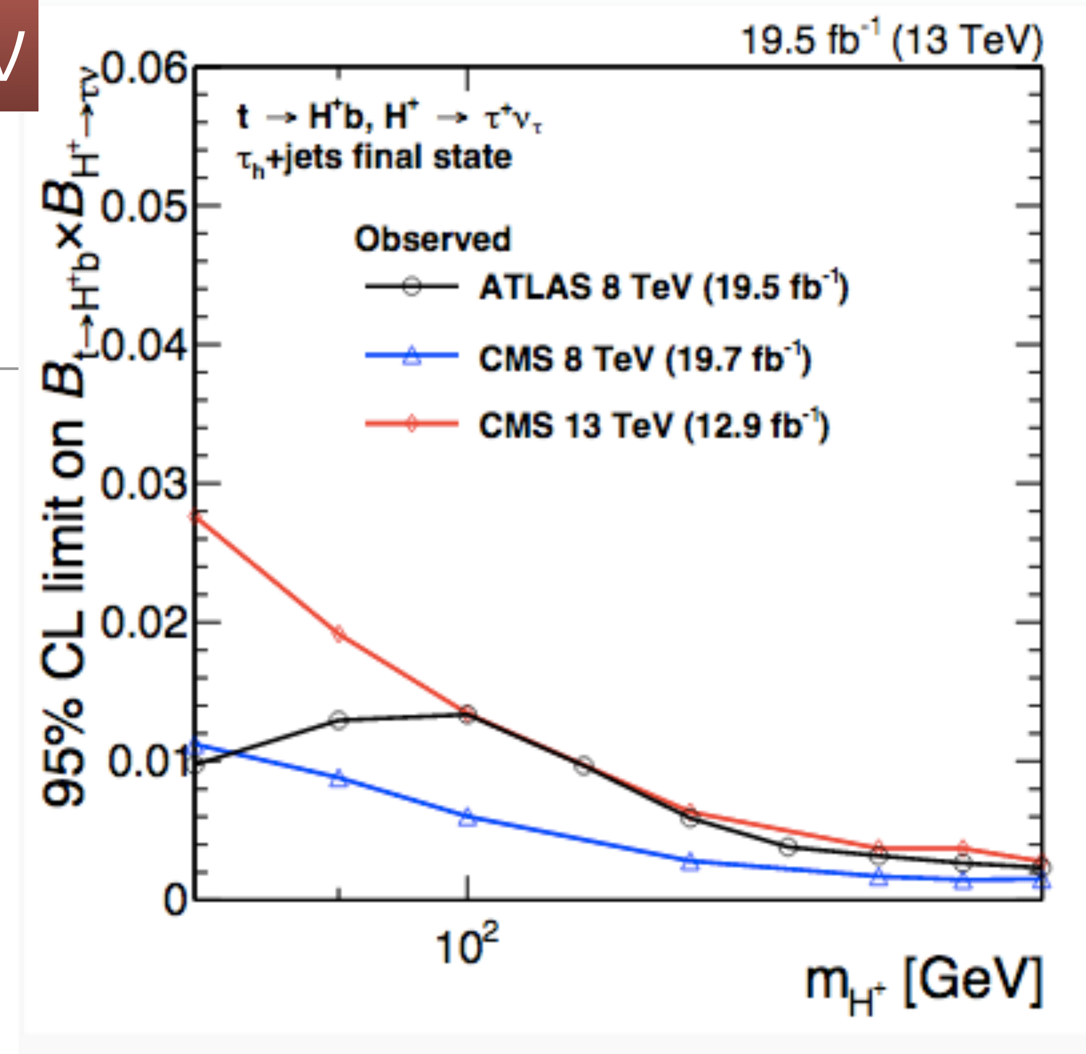
t→H⁺b, H⁺→cs



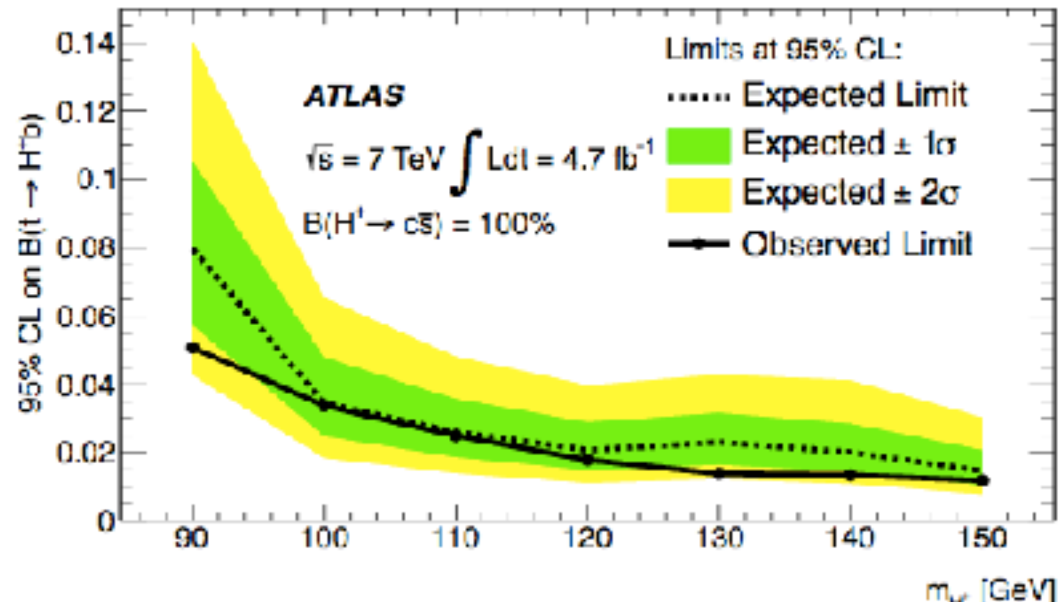


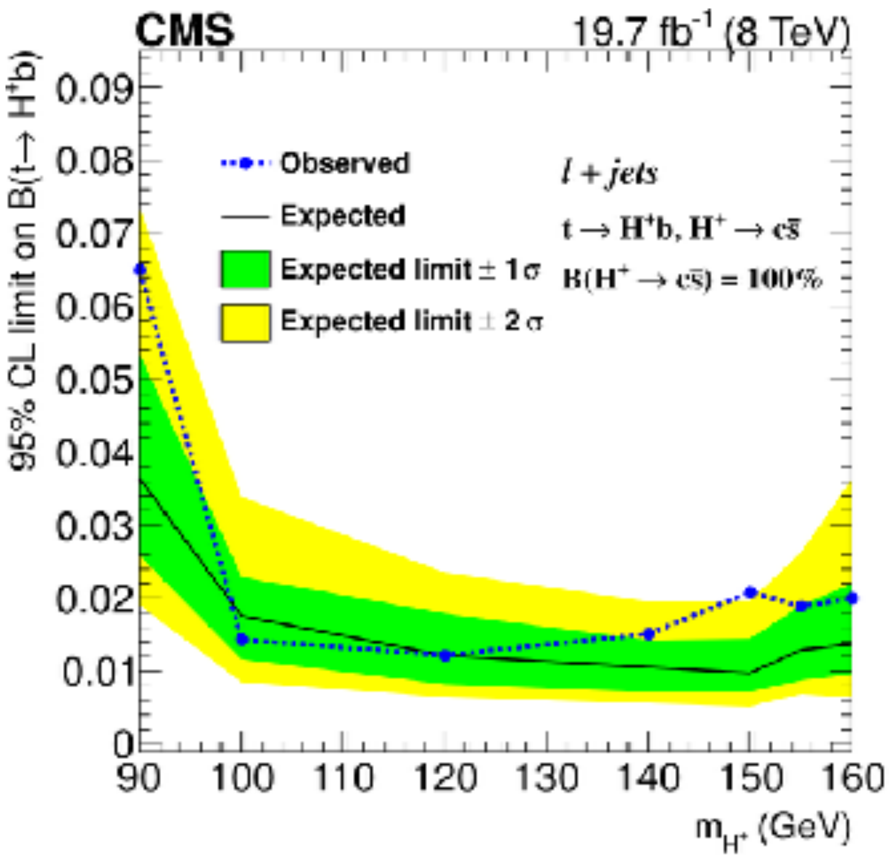
$t \to H^+b,\ H^+ \to \tau\nu$

Light H+ searches

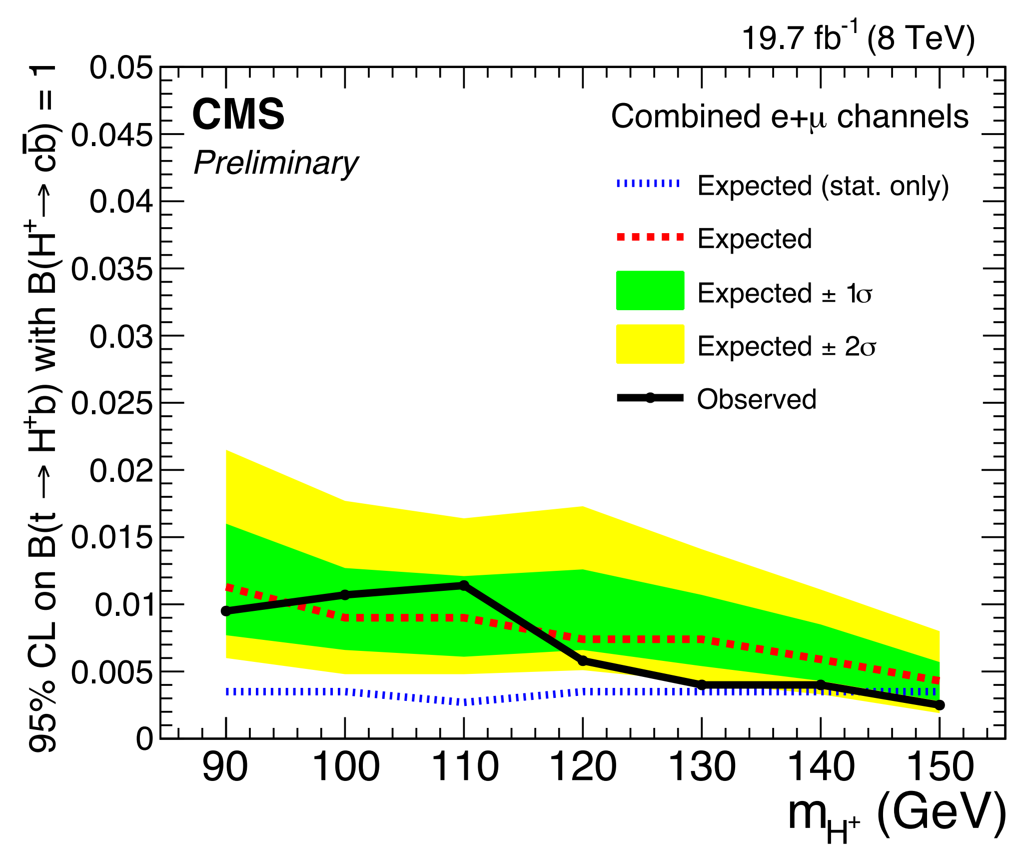


$t \to H^+b,\ H^+ \to cs$



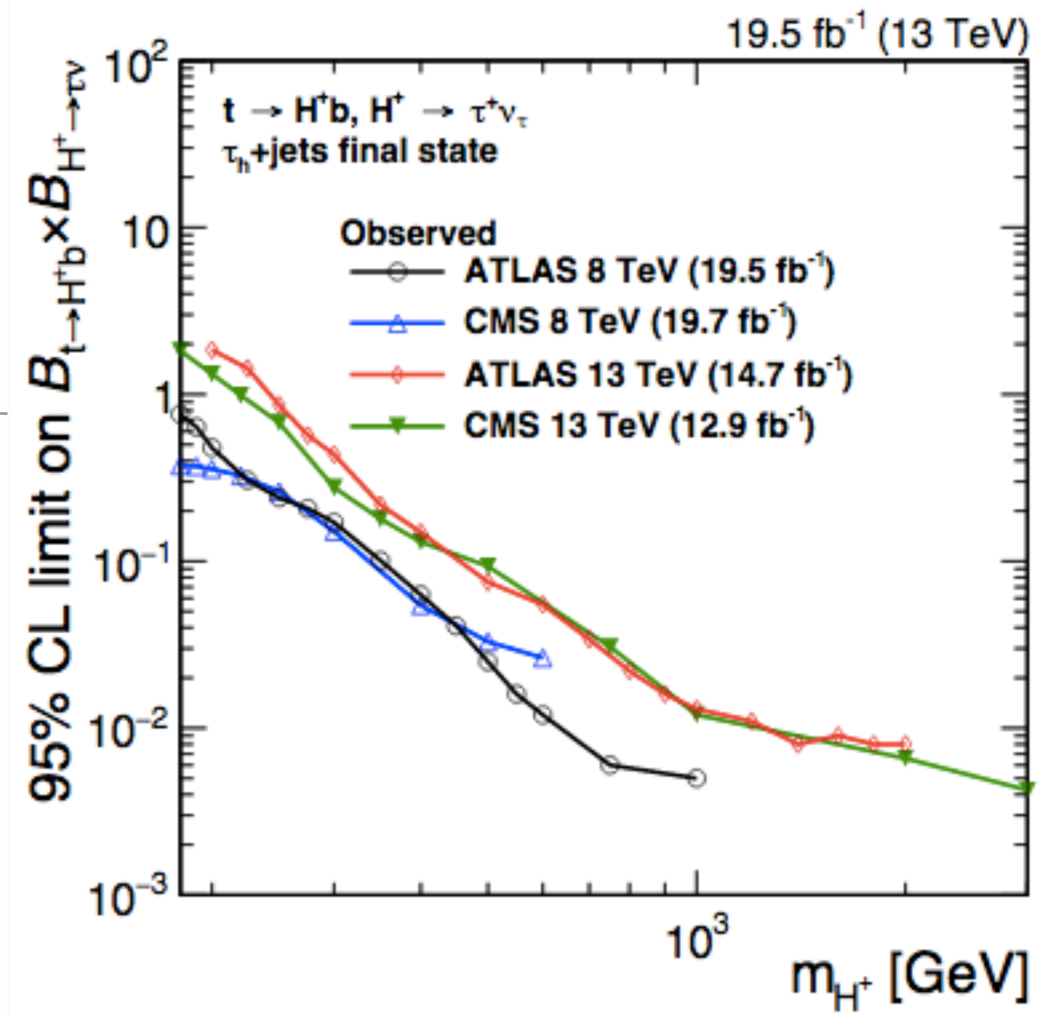


$t \to H^+b,$
$H^+ \to cb$

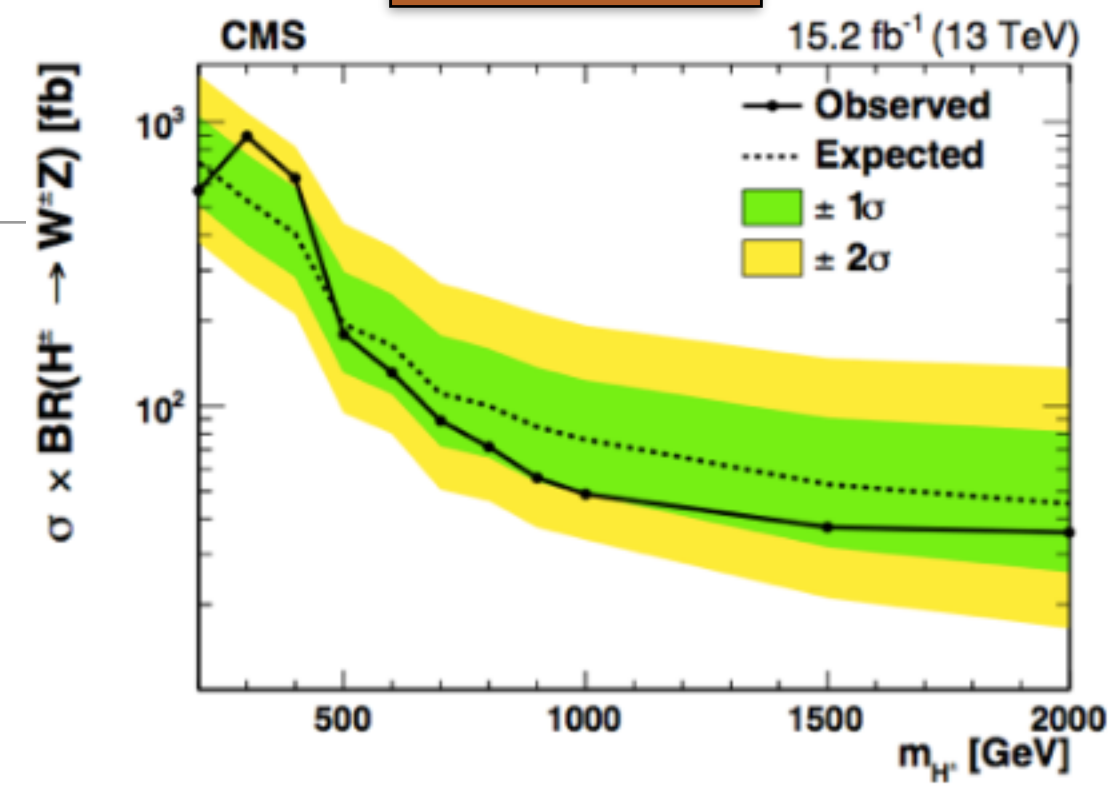


Heavy H+ searches

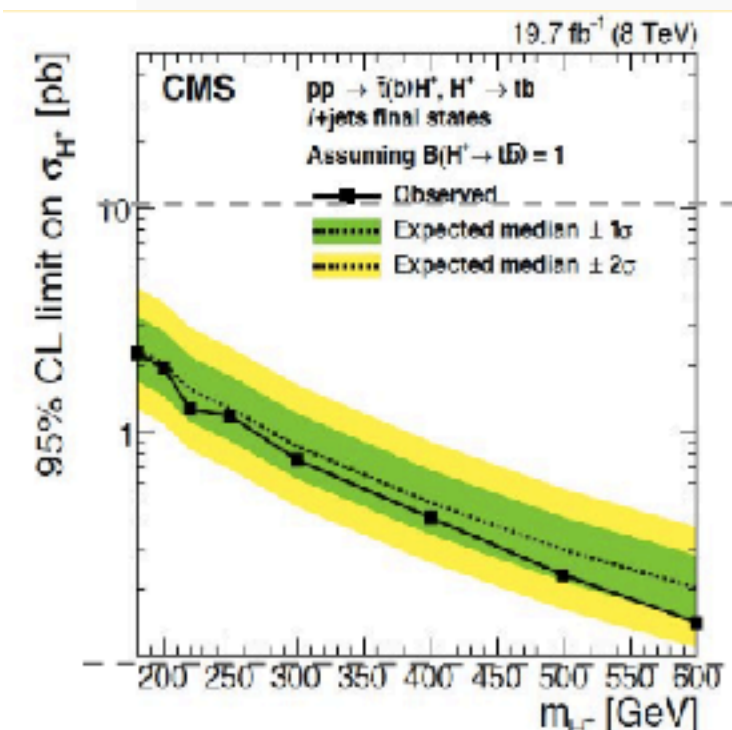
H+→τν

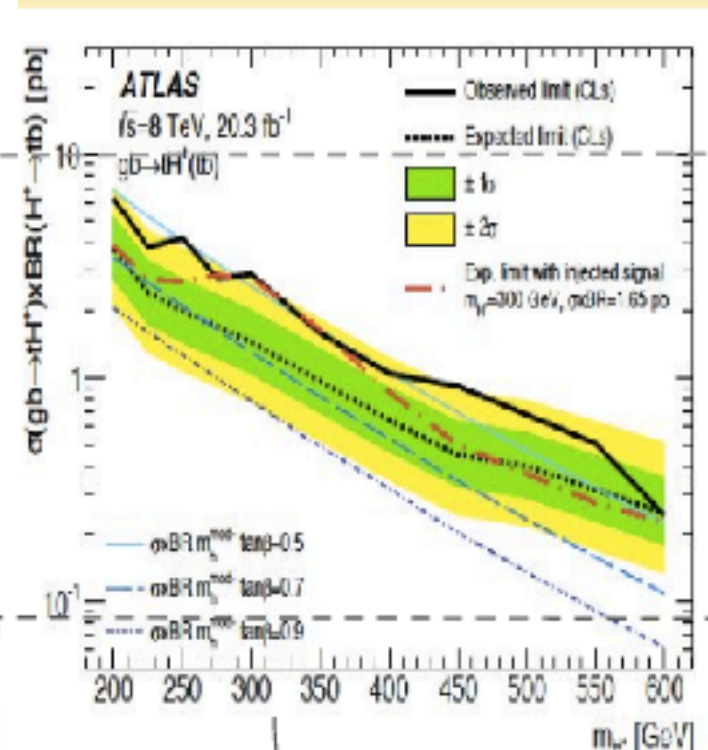


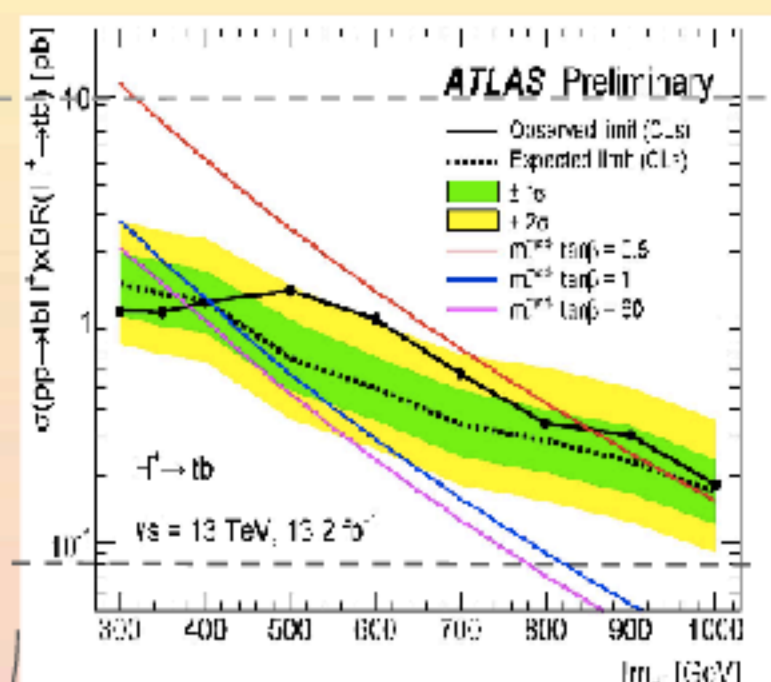
H+→WZ



H+→tb



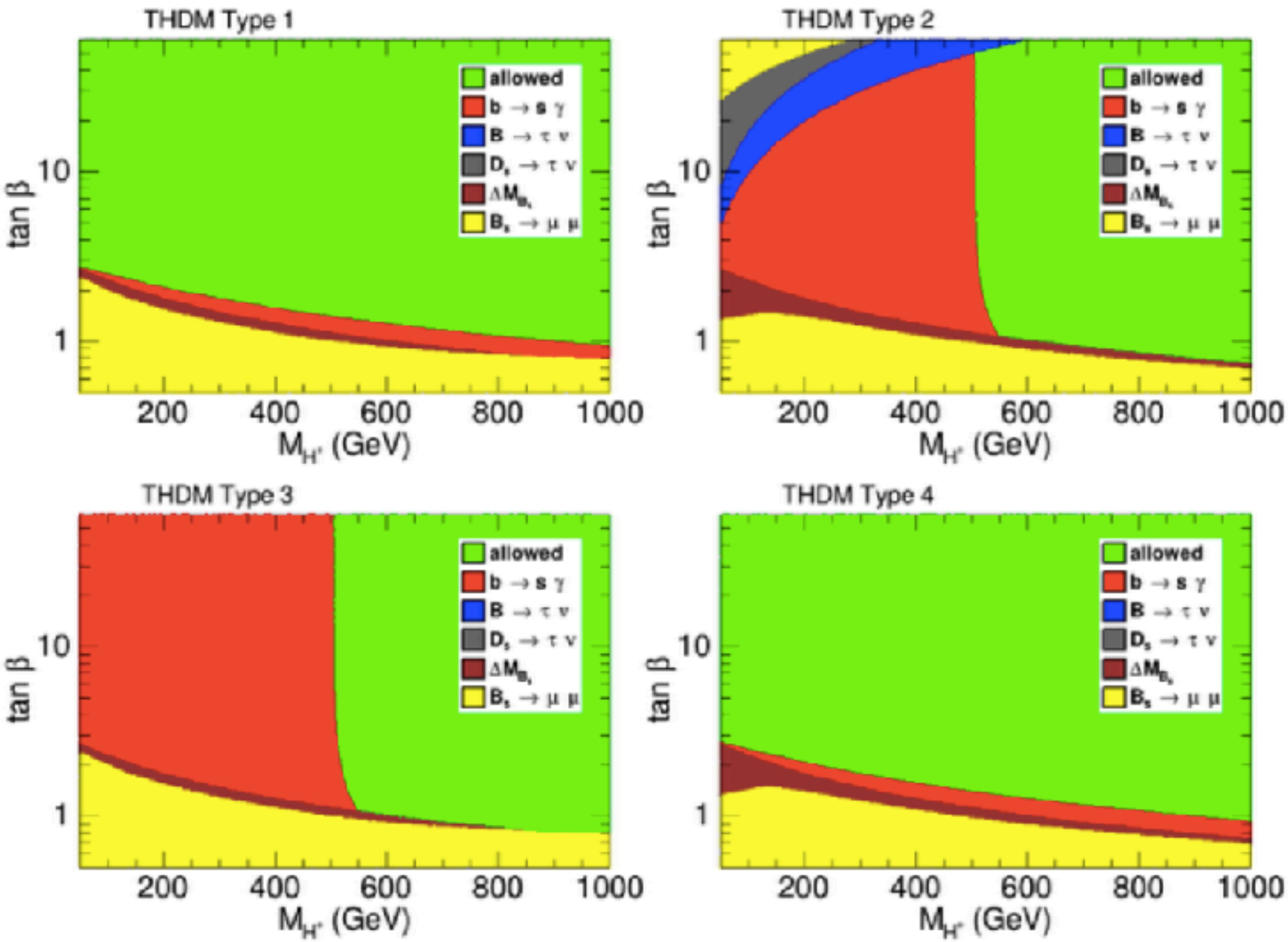




Generally the CMS limits looks better

Extended sensitvity to higher masses w/ 13 TeV dataset

Indirect limits from B-factories



Summary

- Charged Higgs has been searched directly and indirectly from collider experiments
- So far results amazingly agree with the SM
- Most MSSM phase space (type-II 2HDM) has been excluded from both direct & indirect searches
- Still many models are proposed beyond the SM
    - No need to give up!
    - Live discussions between phenomenologists and experimentalists
- In light charged Higgs searches, current upper limit with 95% C.L. on $B(t \to H^{+} b)$
    - $\tau\nu$: 1.2~0.2 for $m(H^{+})$ 80-160 GeV
    - cs-bar, cb-bar : 1.1~0.4 for $m(H^{+})$ 90-150 GeV
    - Limits can be used for anomalous boson decays from top quark: model-independent
- Stay tuned for more news from 13 TeV analysis!

Backup

Systematic uncertainties

Uncertainties in percentage	TTbar	non-TTbar	CH 120	Syst
Jet Energy Scale	3.4(3.3)	7.5-9.6(0.9-2.8)	4.6-5.3(5.0-5.9)	shape
Jet Energy Resolution	0.3(0.4)	1.1(1.5)	0.1-0.2(0.2-0.8)	shape
BtagSF (B/C)	3.6(5.7)	2.9-3.0(4.0-4.4)	1.2-2.1(5.6-5.8)	lnN
BtagSF (UDSG)	0.2(0.3-0.7)	0.7-1.3(0.3-0.4)	0.1-0.2(0.2-0.7)	lnN
L5 FlavorUncertainty(b)	0.1(9.0)	0.1-0.7(0.5-0.9)	0.3-0.4(0.2-0.6)	shape
L5 FlavorUncertainty(udscg)	1.0(9.0)	3.1-4.1(1.1-1.8)	0.9-1.2(0.4-0.6)	shape
TTbar XSEC	6.5(20)	-	6.5(20)	lnN
TTbar p_T Reweight	1	-	1	shape
NLO-vs-LO	8.3-8.5(8.0)	-	8.6-9.0(7.6-8.8)	shape
Top quark mass	5	-	5	shape
Normalization/Factorization scale	1.3-1.7(1.3-2.0)	-	4.0-4.2(6.8-7.2)	shape
ME-PS matching	0.6-0.8(0.8-1.4)	-	-	shape
Pythia-MG p_T(tt) difference	-	-	1	shape
Pileup Reweight		≈0.5		lnN
Lepton SF		2		lnN
Luminosity		2.6		lnN
multi jet (anti-iso region shift)	-	1	-	shape