Higgs Properties in the Fourth Generation MSSM: Boosted Signals Over the 3G Plan

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Why SUSY? The Usual Reasons...

Gauge hierarchy stabilization, dark matter, unification...

A Fourth Family? Curiosity Mostly...

Why 3? Why not more?

Can be *consistent* with precision electroweak, direct searches, etc.
(e.g., Kribs *etal.*, 0706.3718)

Also: Improved flavor fits, Enough CP Violation for EW baryogenesis...
(e.g., Lunghi & Soni, 1104.2117) (e.g., Hou, 0803.1234)

A Four-Generation MSSM (4GMSSM)

(Fok & Kribs, 0803.4207)

Good baryogenesis, viable parameter space, novel collider phenomenology, generally constrained to be testable ~~soon~~ NOW!!

The 4GMSSM Is:

4GMSSM= (the usual MSSM superpotential) +

$$W_4 = \lambda_{t'} \hat{Q}_4 \hat{H}_2 (\hat{t}')^c + \lambda_{b'} \hat{Q}_4 \hat{H}_1 (\hat{b}')^c + \lambda_{e'} \hat{L}_4 \hat{H}_1 (\hat{e}')^c + \lambda_{\nu'} \hat{L}_4 \hat{H}_2 (\hat{\nu}')^c$$

In addition to 3GMSSM, have:

4th gen. fermions:				4th gen. sfermions:			
$\begin{pmatrix} t' \\ b' \end{pmatrix}_L$		$\begin{pmatrix} \nu' \\ e' \end{pmatrix}_L$		$\begin{pmatrix} \tilde{t}' \\ \tilde{b}' \end{pmatrix}_L$		$\begin{pmatrix} \tilde{\nu}' \\ \tilde{e}' \end{pmatrix}_L$	
$(t'_R)^c$	$(b'_R)^c$	$(\nu'_R)^c$	$(e'_R)^c$	$\tilde{t}'_R$	$\tilde{b}'_R$	$\tilde{\nu}'_R$	$\tilde{e}'_R$

Many subtleties in principle, but the key features here are just:

i) the 4th generation fermions and

ii) the SUSY 2HDM

In particular we take heavy (1 TeV) 4th generation sfermions and assume no sfermion mixing ($\mu = A^i_4 = 0$).

In This Talk...

We Discuss the Higgs Sector...

Spectrum: Light A^0, everything else heavy

Signals: Huge di-photon rates (gg --> A^0 --> $\gamma\gamma$)

We Discuss 4th Generation Fermions...

Highly constrained by scattering unitarity, precision electroweak data and collider direct searches. These fermions should be discovered or ruled out very soon.

Highly Constrained Tanβ…

The 4G Yukawas: $y_{t',\nu'} = \frac{m_{t',\nu'}\sqrt{2}}{v \sin\beta}$ $\quad y_{b',e'} = \frac{m_{b',e'}\sqrt{2}}{v \cos\beta}$

With q' >400 GeV, *weak-scale* perturbativity implies:

$y_i^2 < 4\pi$: $\tan\beta < \sqrt{2\pi\left(\frac{v}{m_{b'}}\right)^2 - 1}, \quad \cot\beta < \sqrt{2\pi\left(\frac{v}{m_{t'}}\right)^2 - 1}$

---

i.e., $0.65 \lesssim \tan\beta \lesssim 1.5$

tanβ is tightly constrained AND can be <1.0 !!

These Yukawas are *not* perturbative up to the GUT scale. Landau poles appear at 10-1000 TeV (Godbole *etal.* 0911.1882)

Higgs Sector...

Higgs Masses in the 4GMSSM...

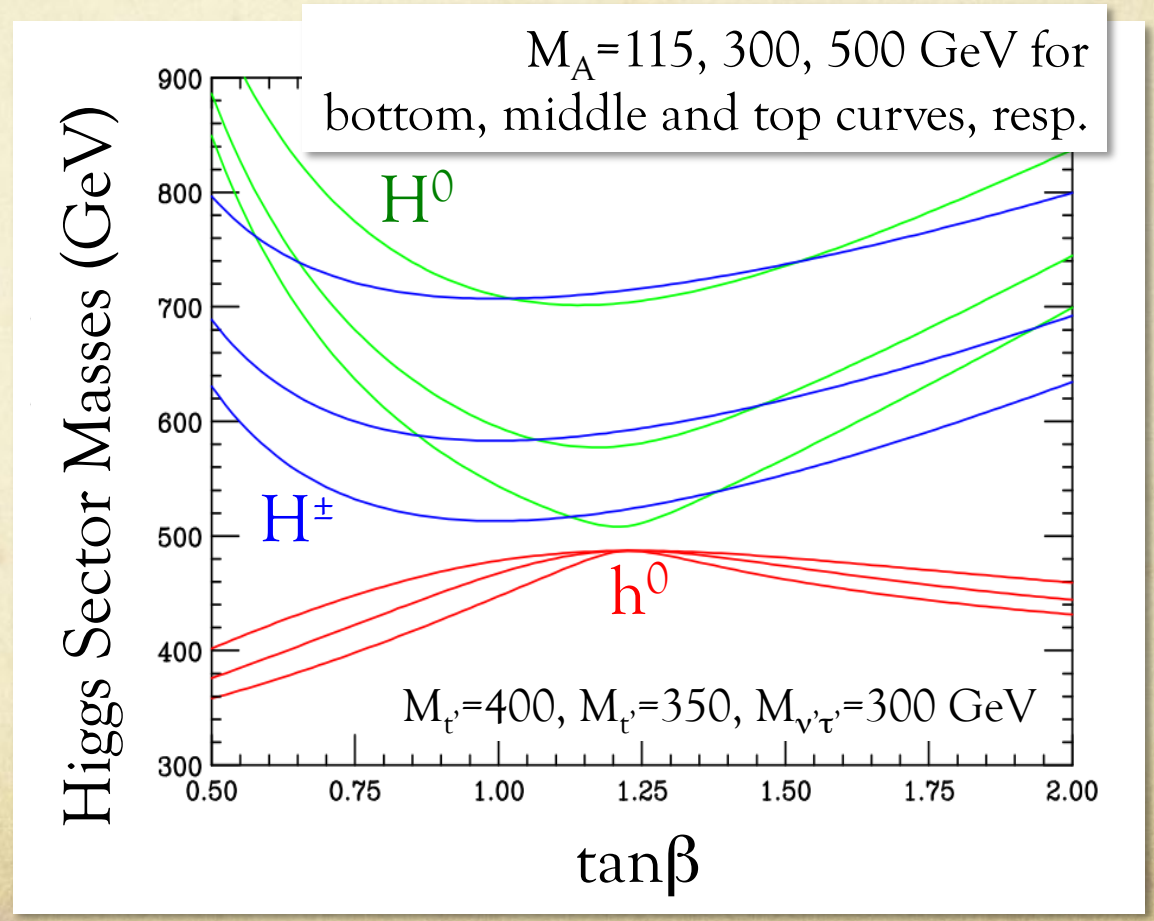
LARGE 4th Gen. contributions to higgs (mass)^2 matrices:

$$\sim \frac{g^2}{16\pi^2 M_W^2} \sum_{u=t,t',\nu'} \frac{m_u^4}{\sin^2\beta} \ln\left(\frac{\tilde{m}_{u1}^2 \tilde{m}_{u2}^2}{m_u^4}\right) + (u \leftrightarrow d)$$

h^0, H^0 and $H^\pm$ generally heavy: ~ 400 GeV-1 TeV

While A^0 can be light: ~ 100-300 GeV

Can be *consistent* with STU (0706.3718, 1009.1099)



A^0 Phenomenology in the 4GMSSM...

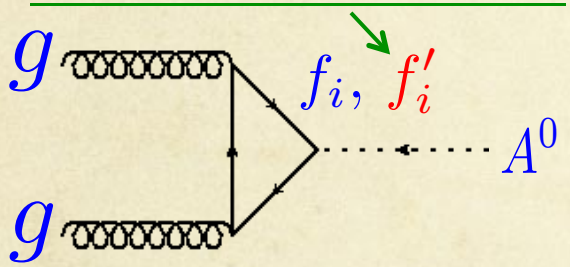
1.) Light A^0, ~100-300 GeV, 2.) $\tan\beta \sim 1$,

3.) 4th Gen. Fermions important in loops,

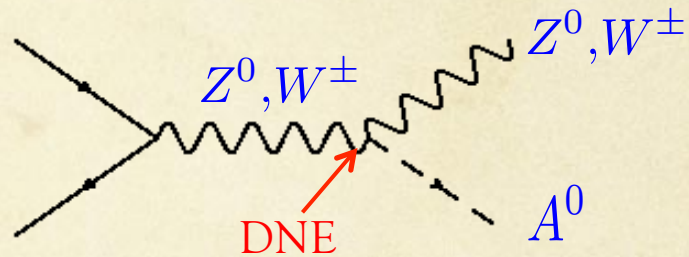
4.) Other Higgses heavy (evades HA and charged Higgs constraints)

5.) Tree-level WWA^0 or ZZA^0 couplings do not exist (DNE):

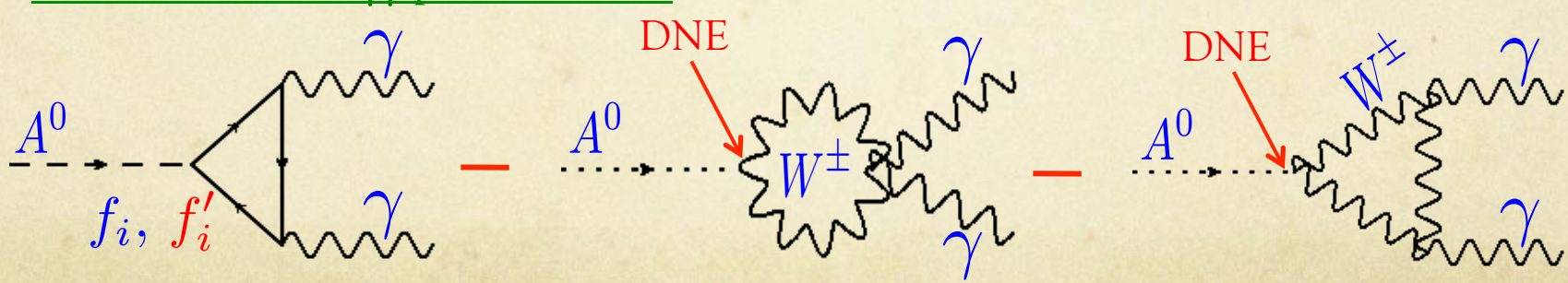
Enhanced A^0 Production:



No Higgs-strahlung Constraints on A^0:



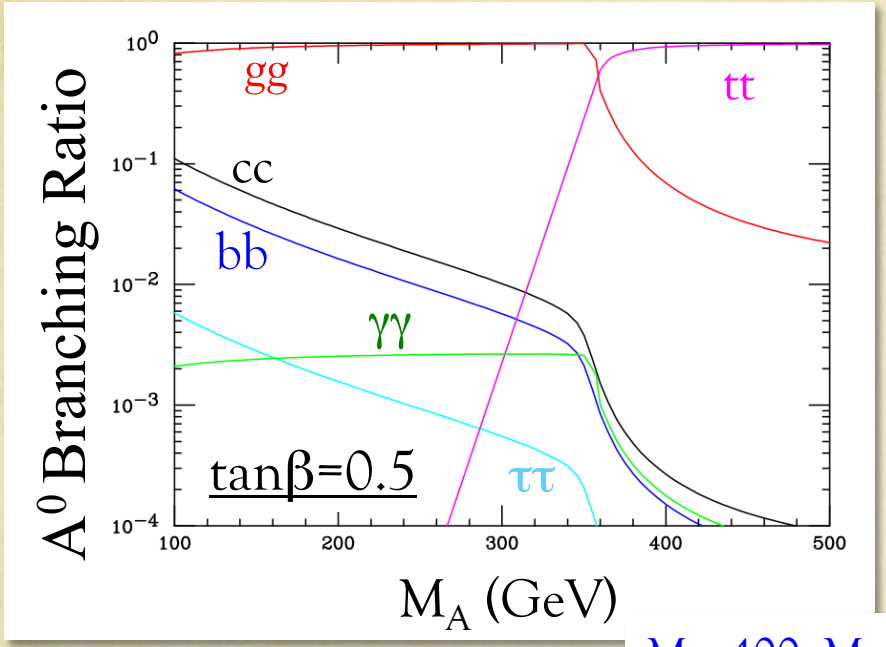
Enhanced A^0 --> $\gamma\gamma$ partial width:

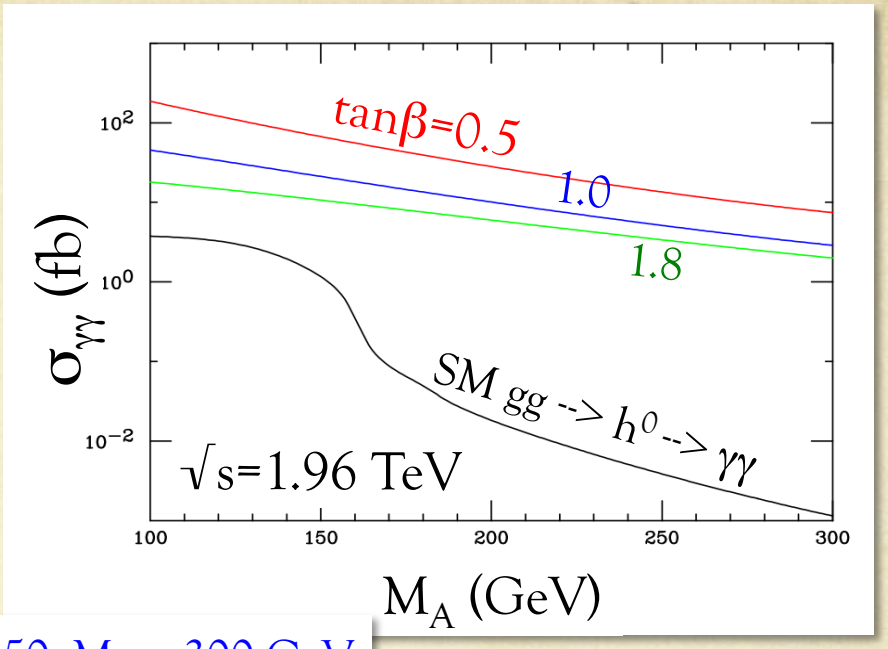


Di-Photons are perhaps most important signal!

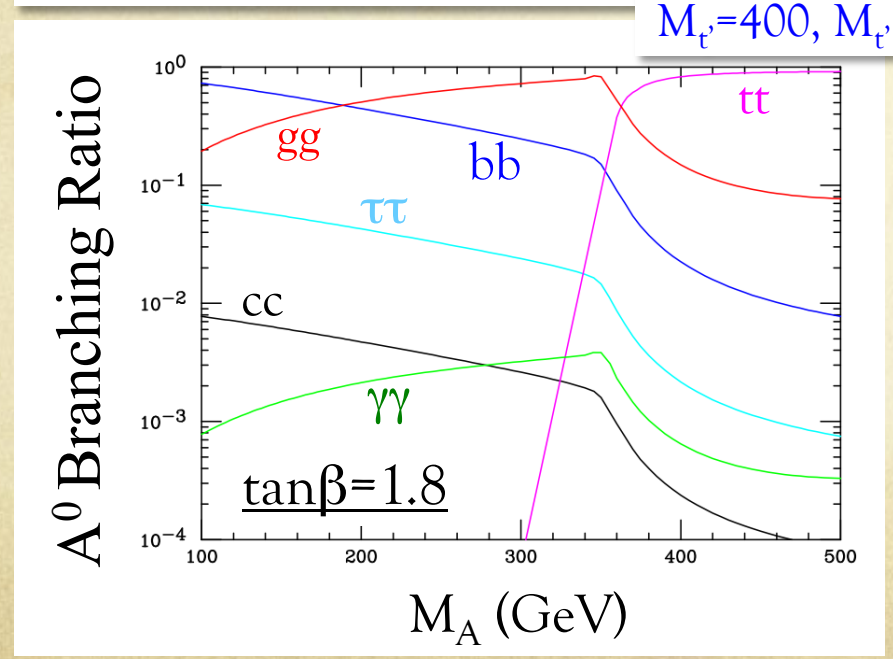
A^0 Branching Fractions…

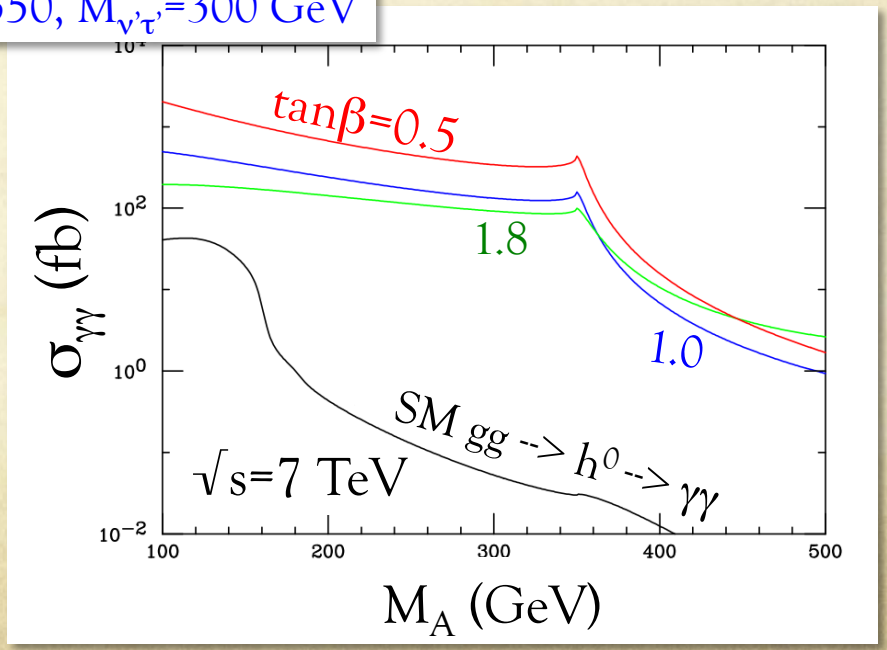
gg -->A^0 --> γγ Compared to SM h^0…





$M_{t'}$=400, $M_{t'}$=350, $M_{\nu'\tau'}$=300 GeV





I wrote this slide a few months ago...

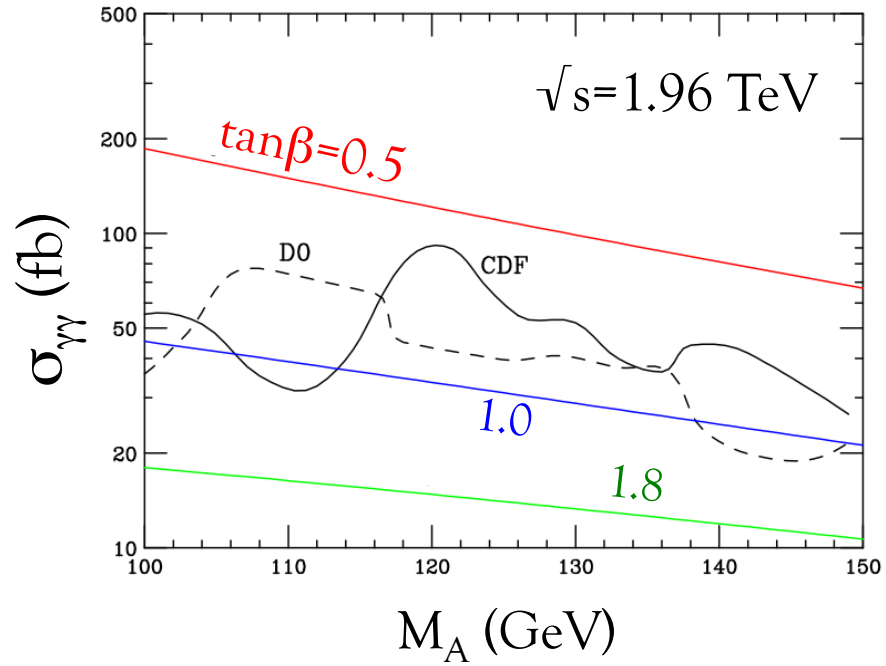
4GMSSM: gg -->A^0 --> γγ enhanced to level of current collider sensitivities!

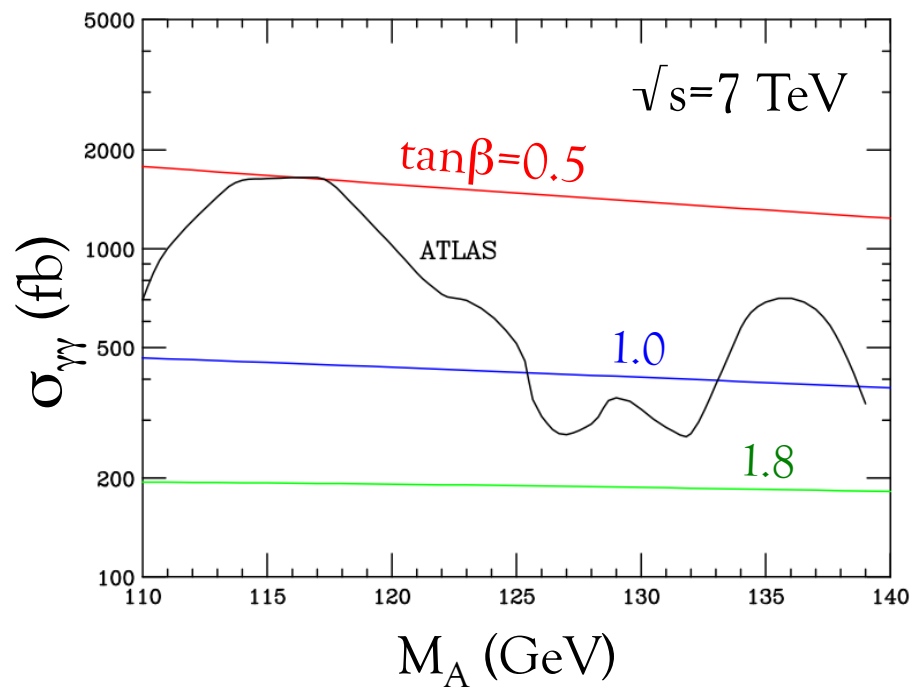
CDF/D0 have published limits.

ATLAS/CMS will soon be sensitive to the entire allowed region!

CDF/PUB/EXOTIC/PUBLIC/10485 (7.0 fb^{-1})
DØ Note 6177-CONF (8.2 fb^{-1})
ATLAS-CONF-2011-025 (38 pb^{-1})

!!!

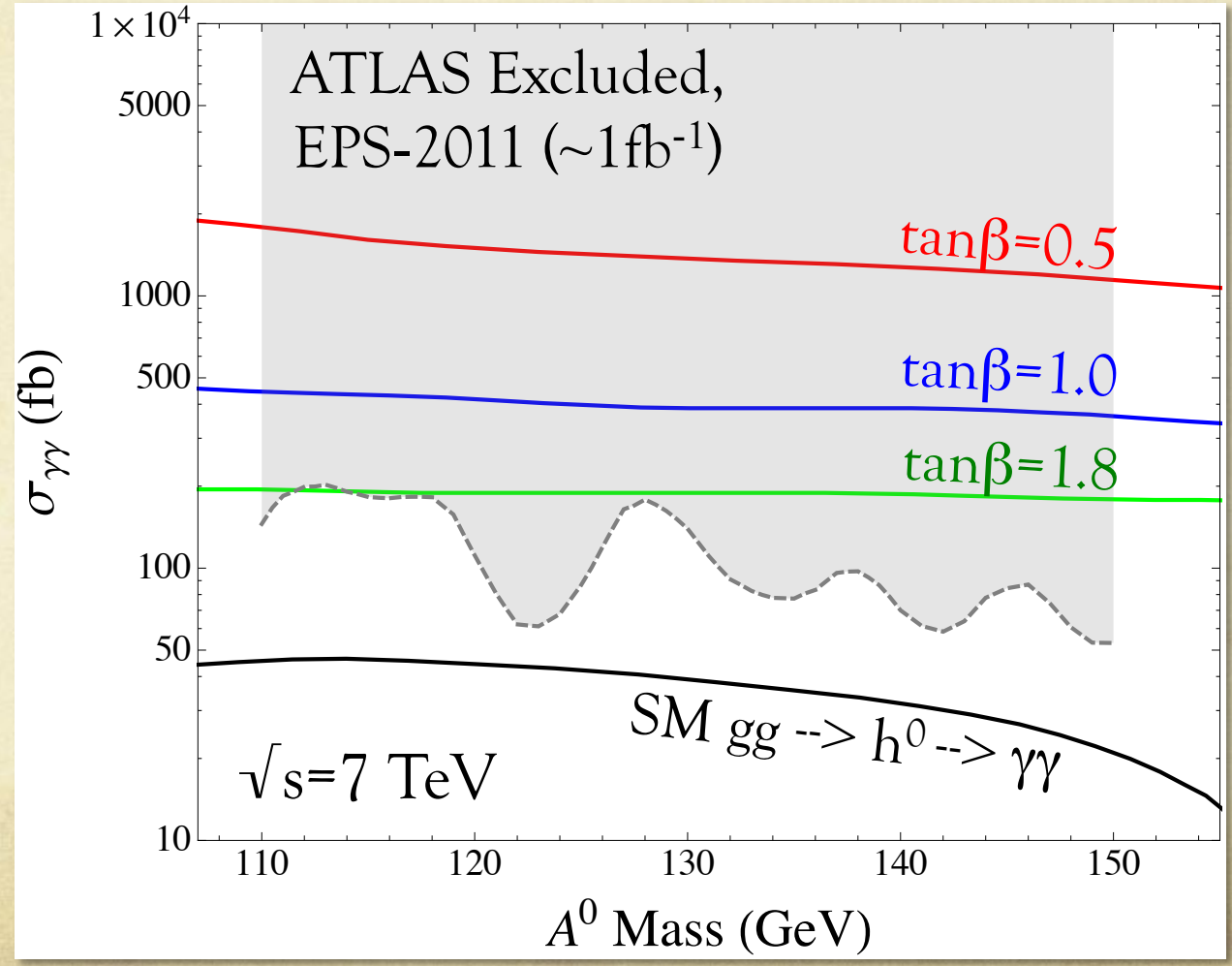




LHC Di-Photons @ 1fb^{-1} ...

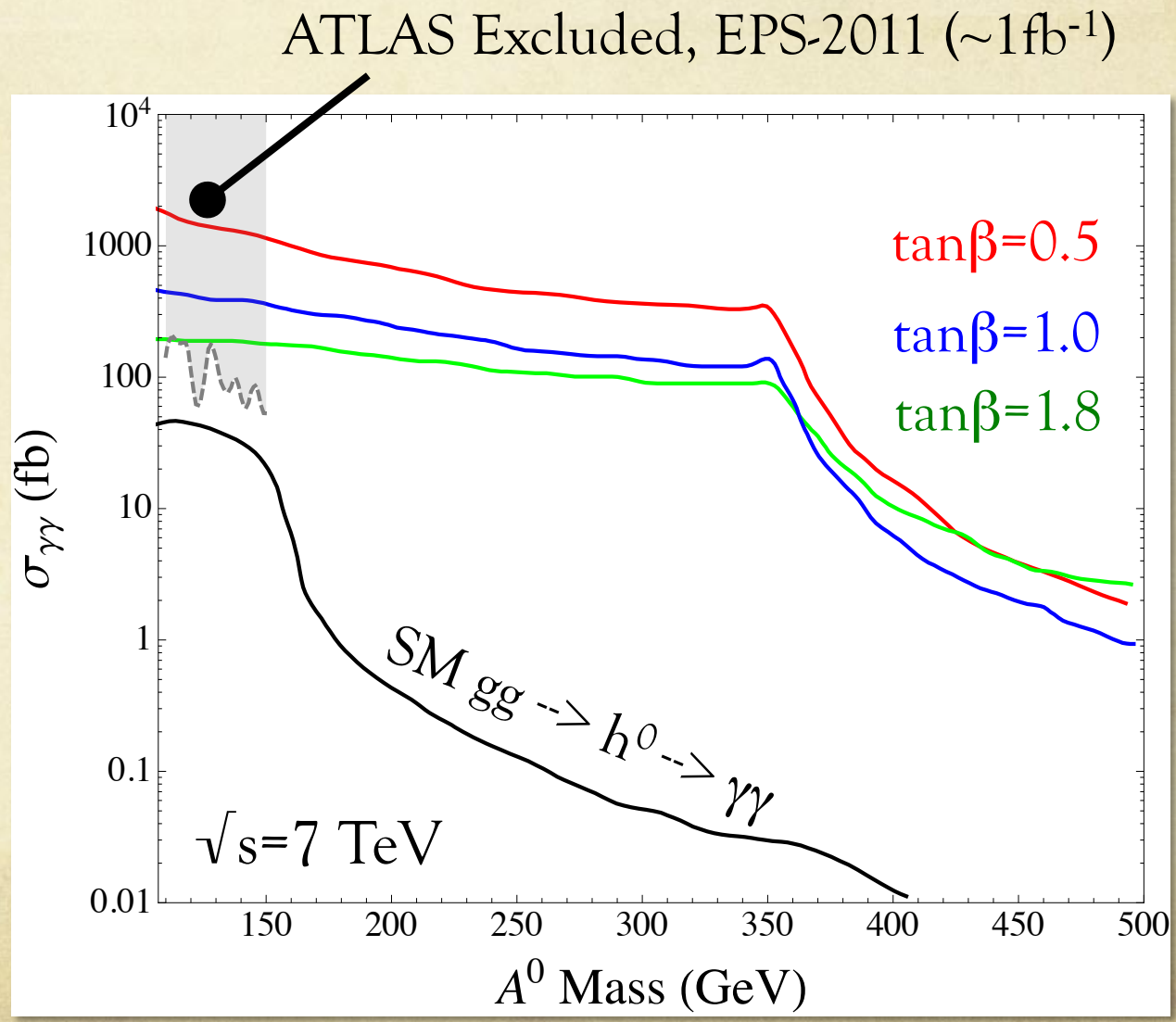
The 4GMSSM is essentially ruled out by this search for all viable tanβ:

... in the window ~100GeV-160GeV!



LHC Di-Photons @ 1fb^{-1} ...

For now we can get away with heavy enough (or light enough) M_A:



4th Generation Fermions...

4th Generation Fermion Masses

Constrained Via:

- 4G Fermion Scattering Unitary

  e.g., $\bar{f}_m' f_m' \to \bar{f}_n' f_n'$ (as in Chanowitz, Furman & Hinchliffe 1979).
  Already calculated for 4GMSSM in Dawson & Jaiswal 2010.

- Direct Searches @ LEP/~~Tevatron~~/LHC

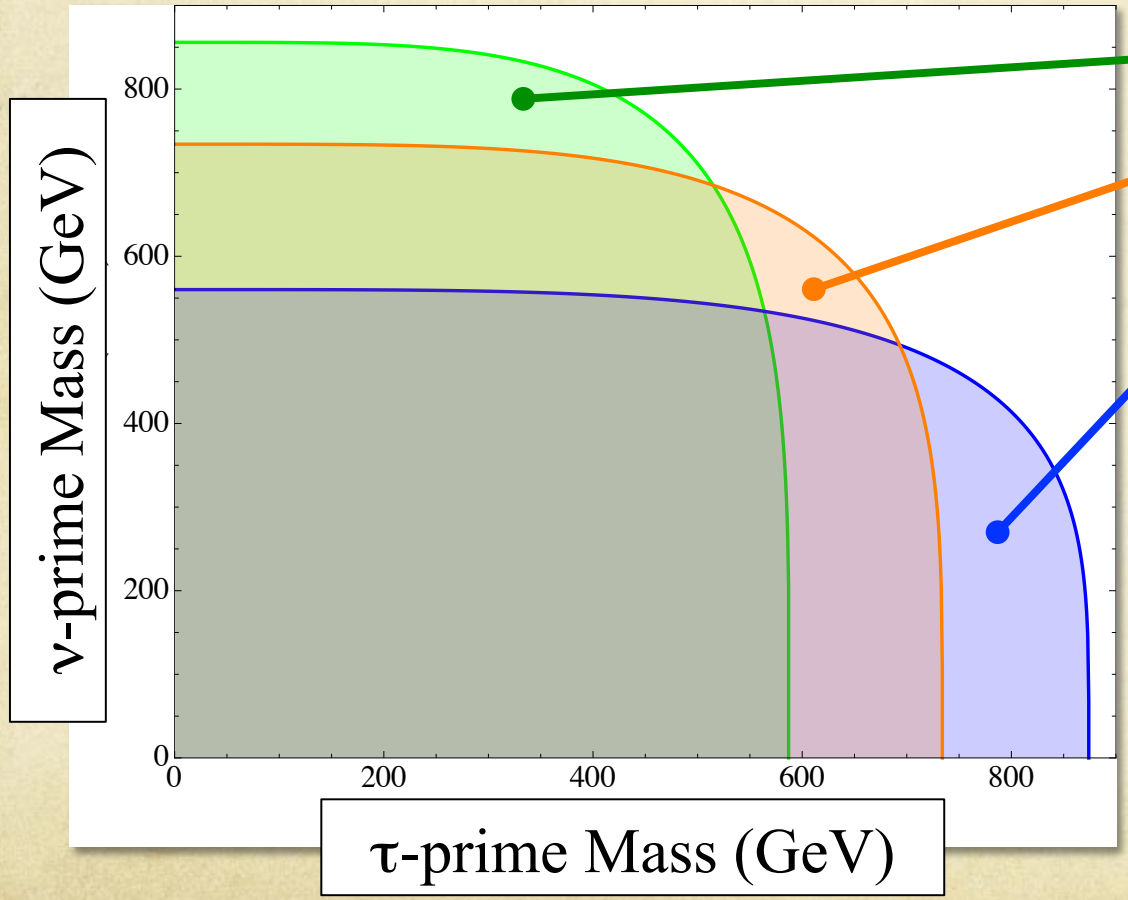
  Flacco *etal.* 1005.1077,
  Atwood *etal.* 1104.3874,
  Carpenter *etal.* 1010.1011

  Many assumptions (4th gen splittings, 3-4 mixing),
  e.g., t' -> Wb, b' -> Wt. Really: model-*dependent* topologies:
  e.g., t' -> Wq ("q"-light quark) or t' -> Wb' -> WWt-> WWWb, etc.

- Precision Electroweak Data

  STU description valid. Fermions and 2HDM important,
  sfermions decouple. 4G splittings *highly* constrained.

4th Generation Lepton Masses



Scattering unitarity regions *allowed* for:

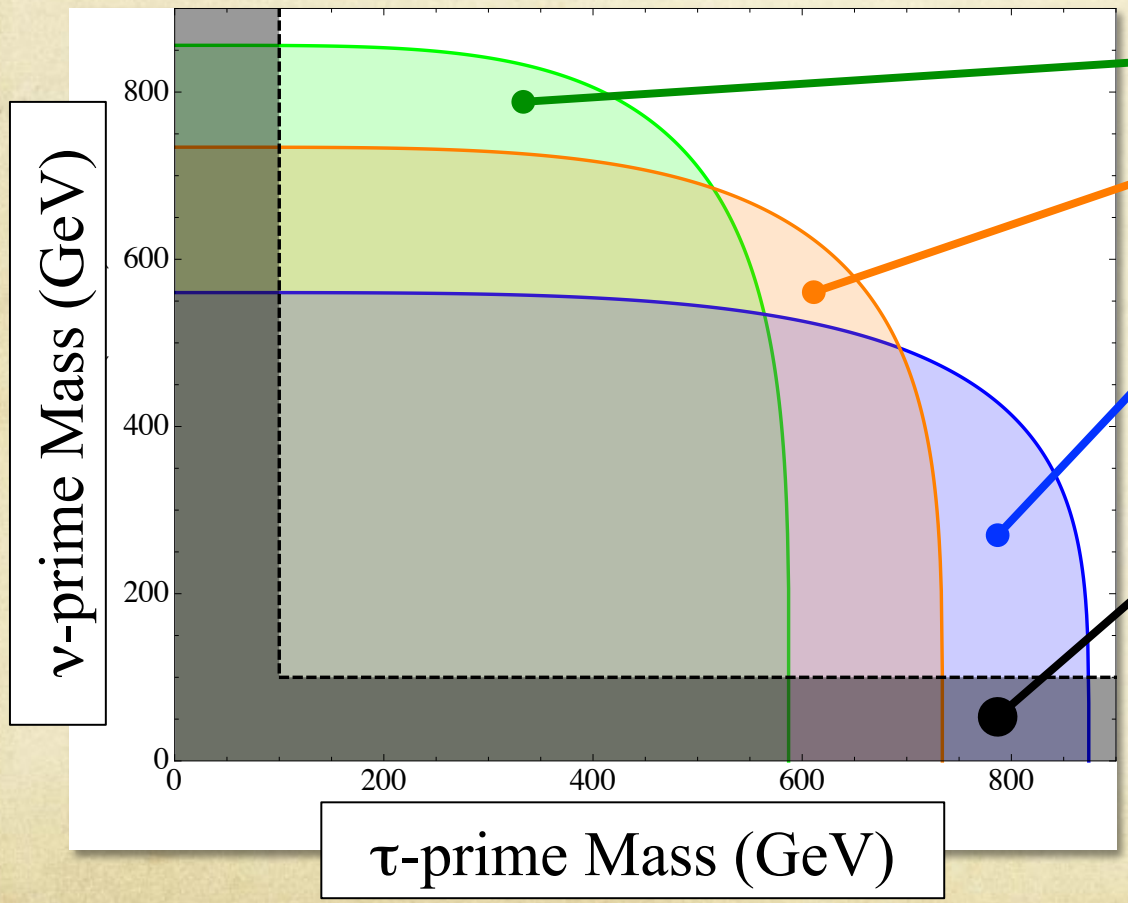
tanβ ~ 1.5,

tanβ ~ 1.0,

tanβ ~ 0.6.

Using Dawson & Jaiswal 1009.1099

4th Generation Lepton Masses



Scattering unitarity regions *allowed* for:

$\tan\beta \sim 1.5$,

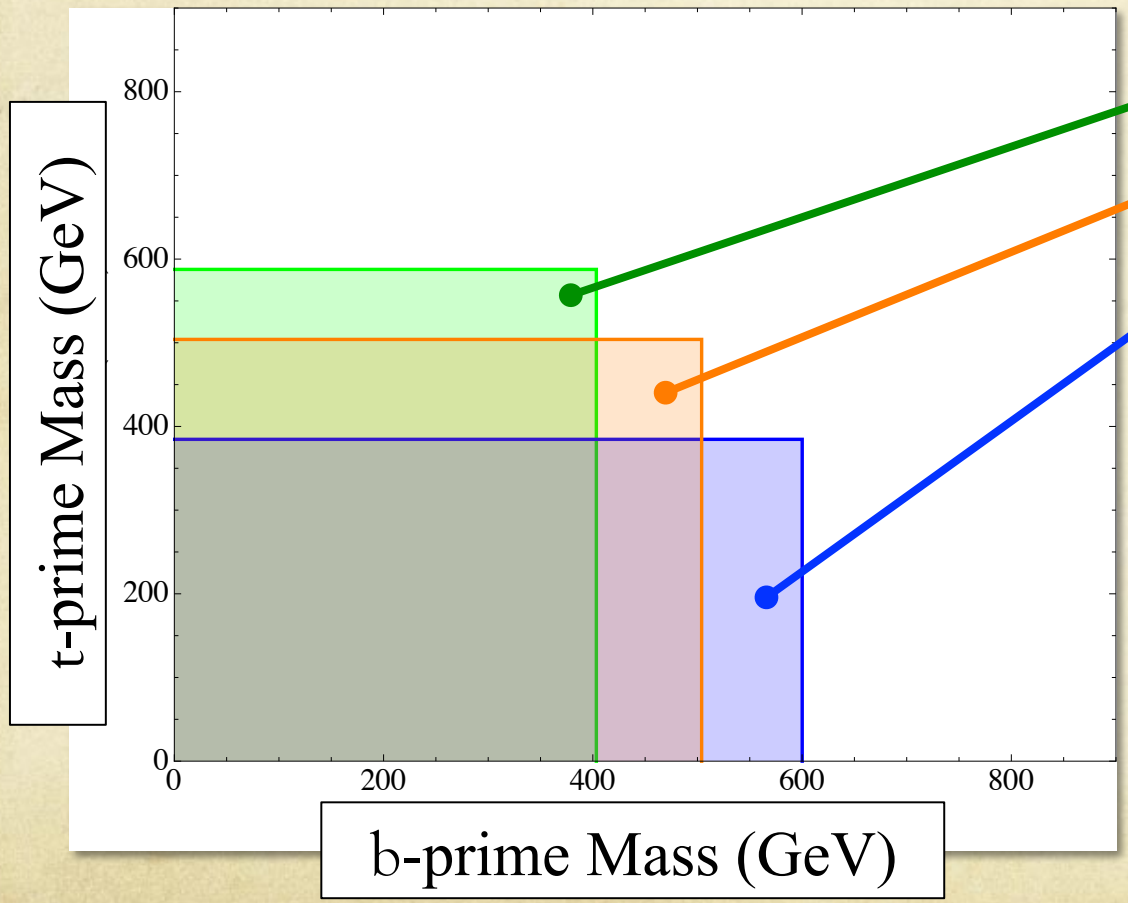
$\tan\beta \sim 1.0$,

$\tan\beta \sim 0.6$.

Excluded, LEP

Limits ~100GeV assuming unstable 4th gen. particles though model-dependent (see Carpenter 1010.5502, Carpenter & Rajaraman 1005.0628)

4th Generation Quark Masses



Scattering unitarity regions *allowed* for:

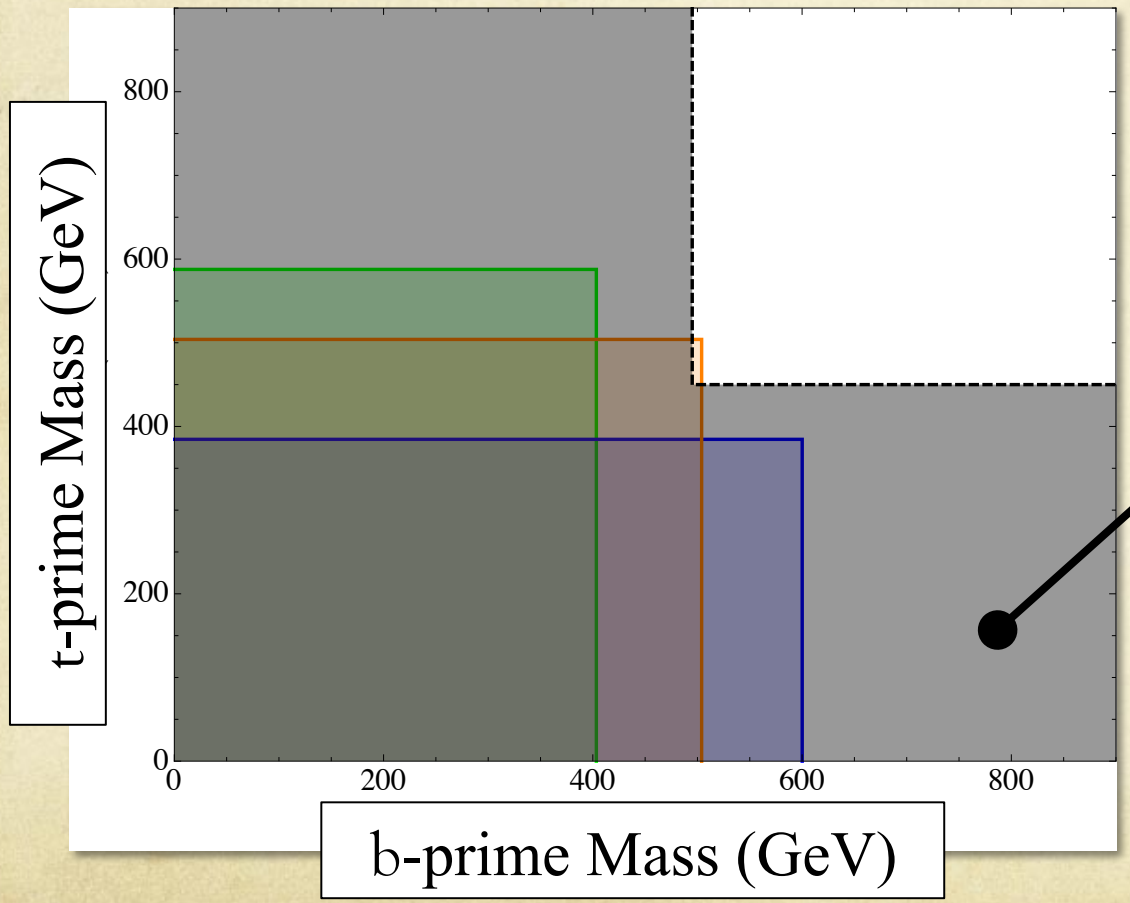
$\tan\beta \sim 1.5$,

$\tan\beta \sim 1.0$,

$\tan\beta \sim 0.6$.

Using
Dawson & Jaiswal
1009.1099

4th Generation Quark Masses



Scattering unitarity regions *allowed* for:

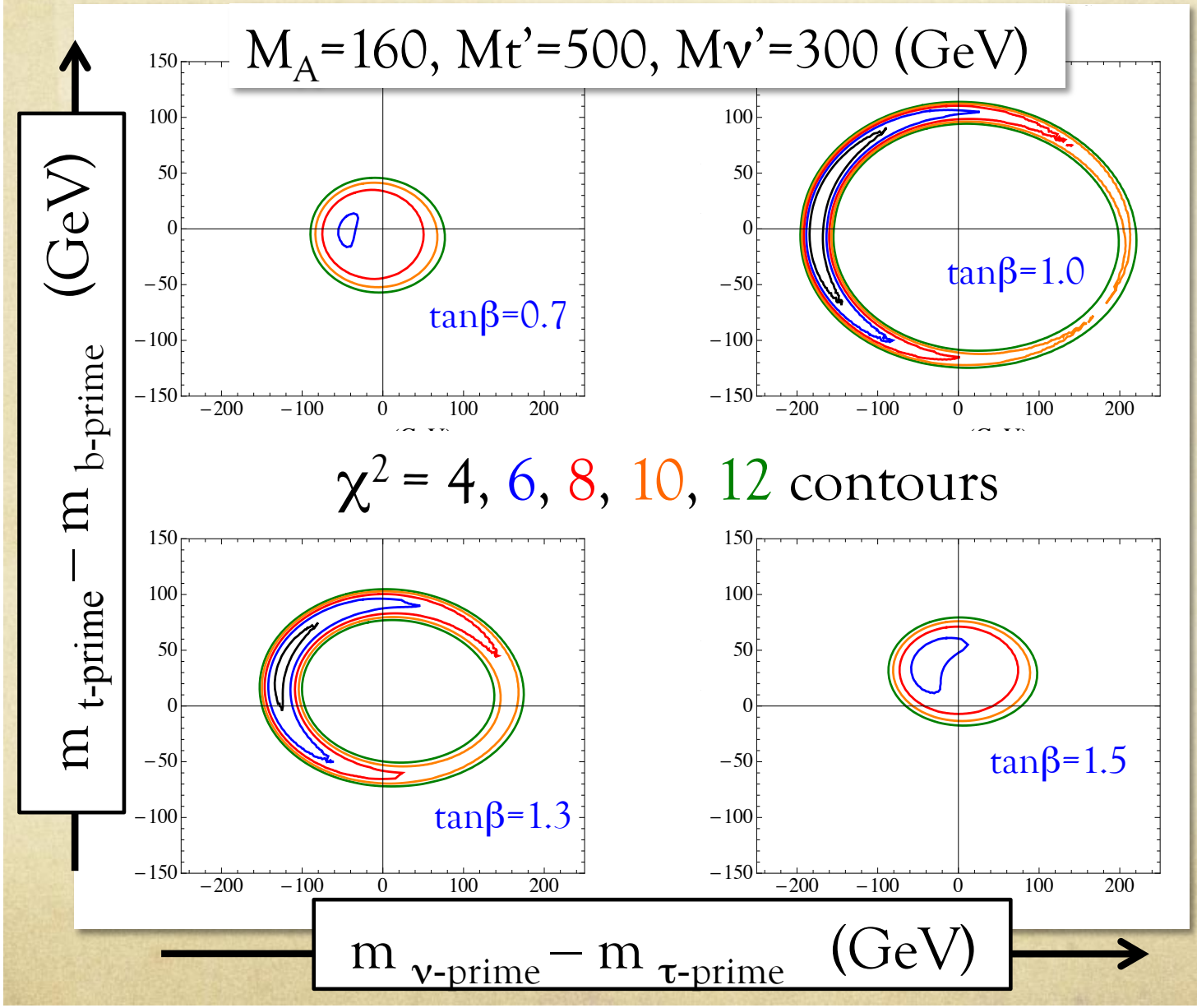
tanβ ~ 1.5,

tanβ ~ 1.0,

tanβ ~ 0.6.

Excluded, LHC (Assuming: t' -> Wb, b' -> Wt. Lepton-Photon 2011)

Precision Electroweak Fits



STU sensitive to 2HDM states and especially to the 4G fermions

Good fits to data with precisely tuned 4G mass splittings

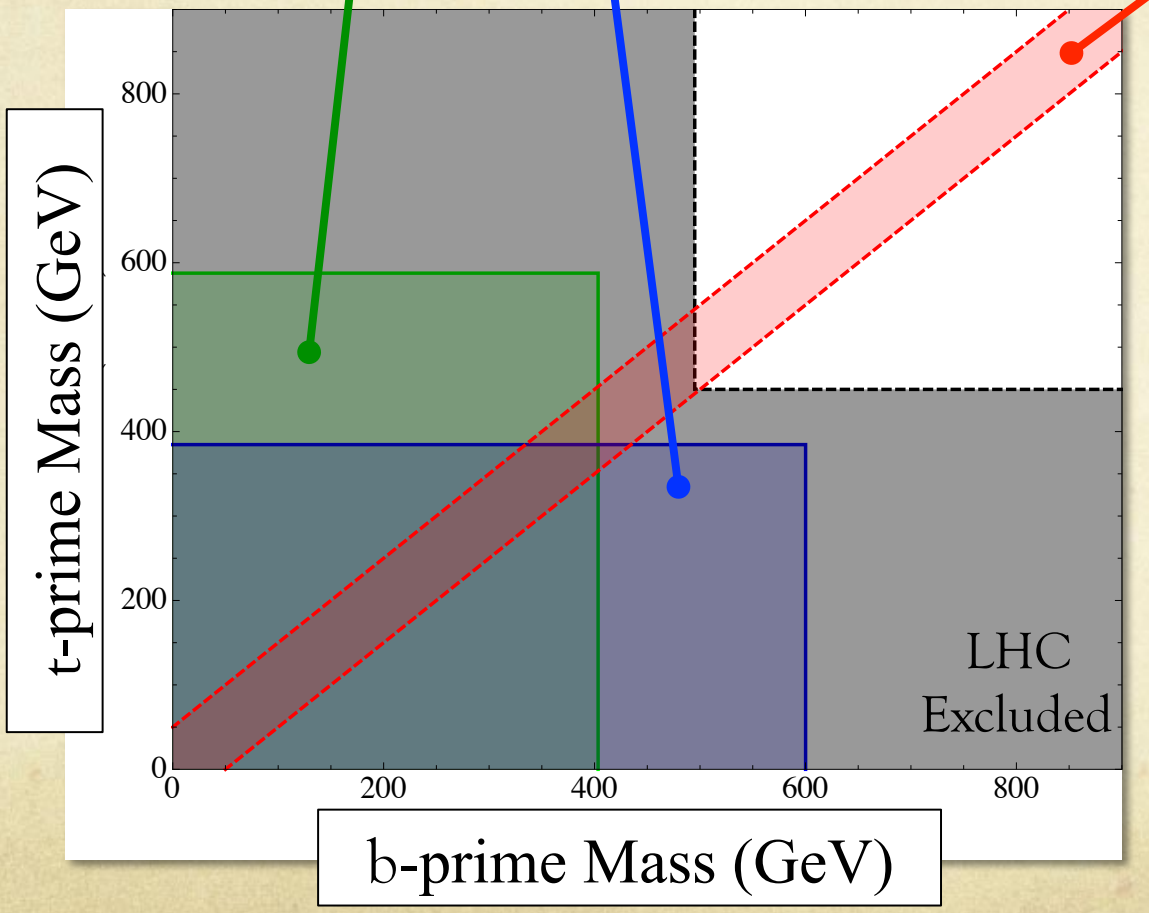
tanβ dependence due to splitting in the 2HDM

See also:
Dawson & Jaiswal 1009.1099,
He, Polonsky & Su hep-ph/0102144

4th Generation Quark Masses

Scattering unitarity regions *allowed* for:

tanβ ~ 1.5, tanβ ~ 0.6.



STU allowed Region

Small splittings required (STU) for extremal values of tanβ

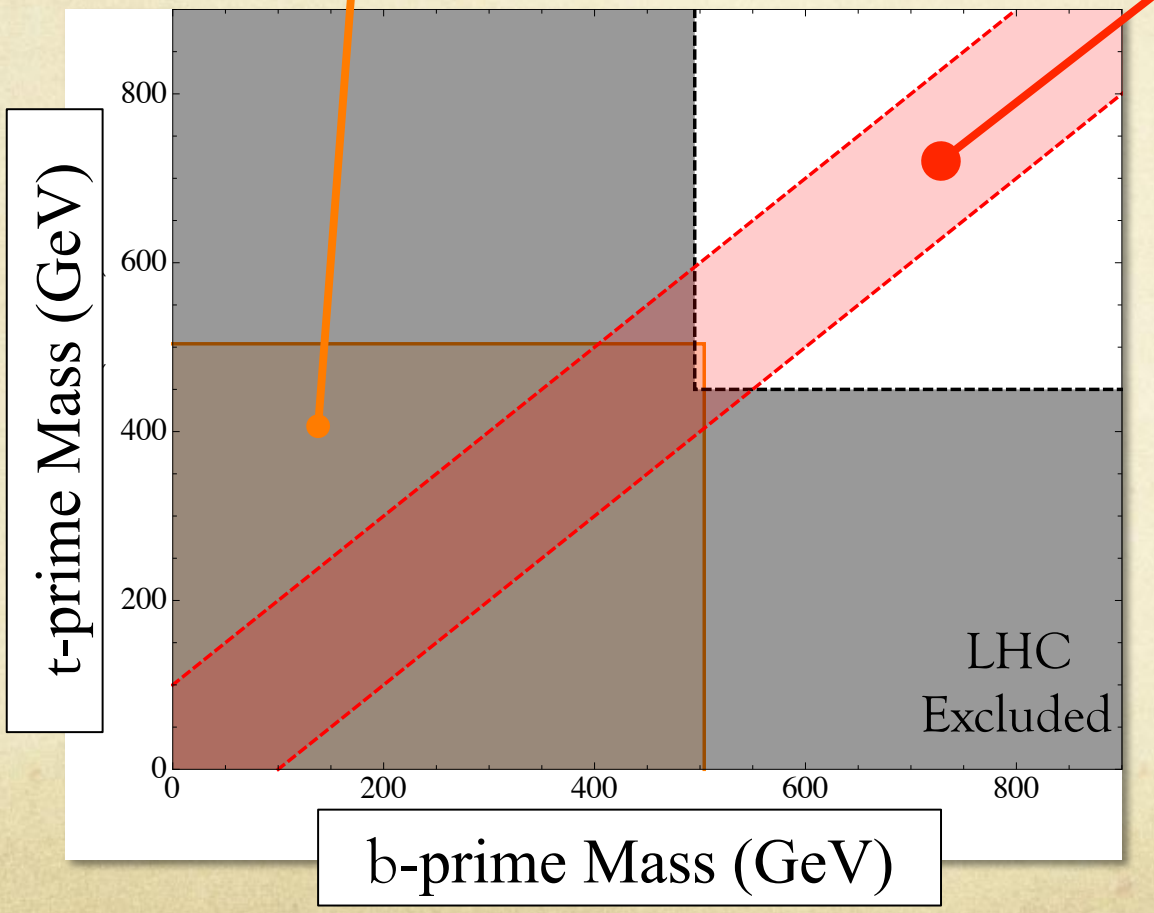
t',b'<400GeV for Unitarity+PEW consistency

4th Generation Quark Masses

Scattering unitarity regions *allowed* for:

$\tan\beta \sim 1.0$

STU allowed Region



Unitarity, PEW and LHC bounds can be simultaneously satisfied in a small region:

i) Nearly degenerate t'-b' mass ~500 GeV.

ii.) ν'-τ' splitting ~150-200 GeV

Summary...

The 4GMSSM enjoys a highly constrained, but non-zero parameter space that is consistent with observations.

4GMSSM phenomenology differs from that of the 3GMSSM not only in searches for heavy fermions, but also in the Higgs sector.

Outlook...

The LHC is currently sensitive to both the $A^0 \rightarrow \gamma\gamma$ signal and to the 4th Gen. fermions but...

The A^0 search region should be extended to higher masses and the 4G fermion searches should be generalized to suit the model dependence of the signal topologies.