PHENOMENOLOGY OF MODELS WITH ADDITIONAL LEPTON GENERATIONS

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with A. Joglekar, C. Wagner,
in progress

CHIRAL FOURTH GENERATION

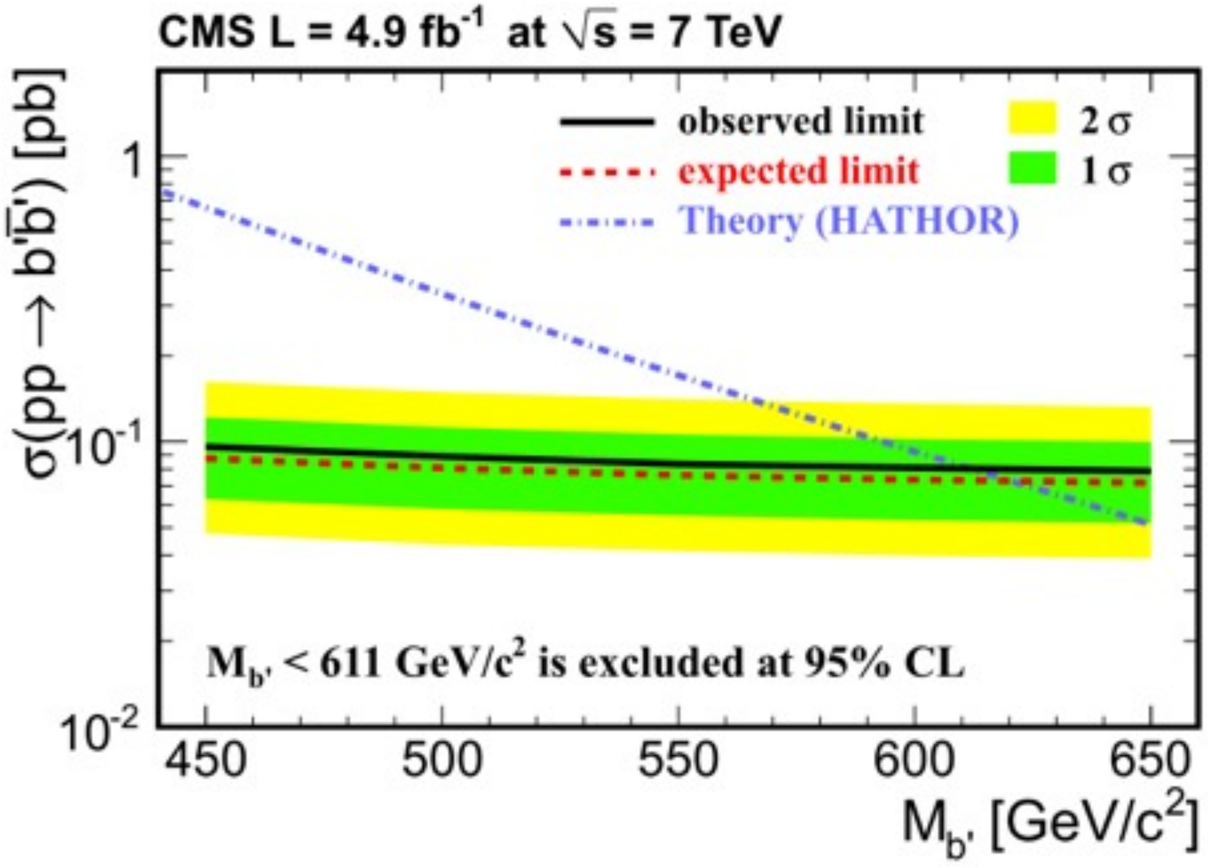
- 4G Quarks strongly constrained

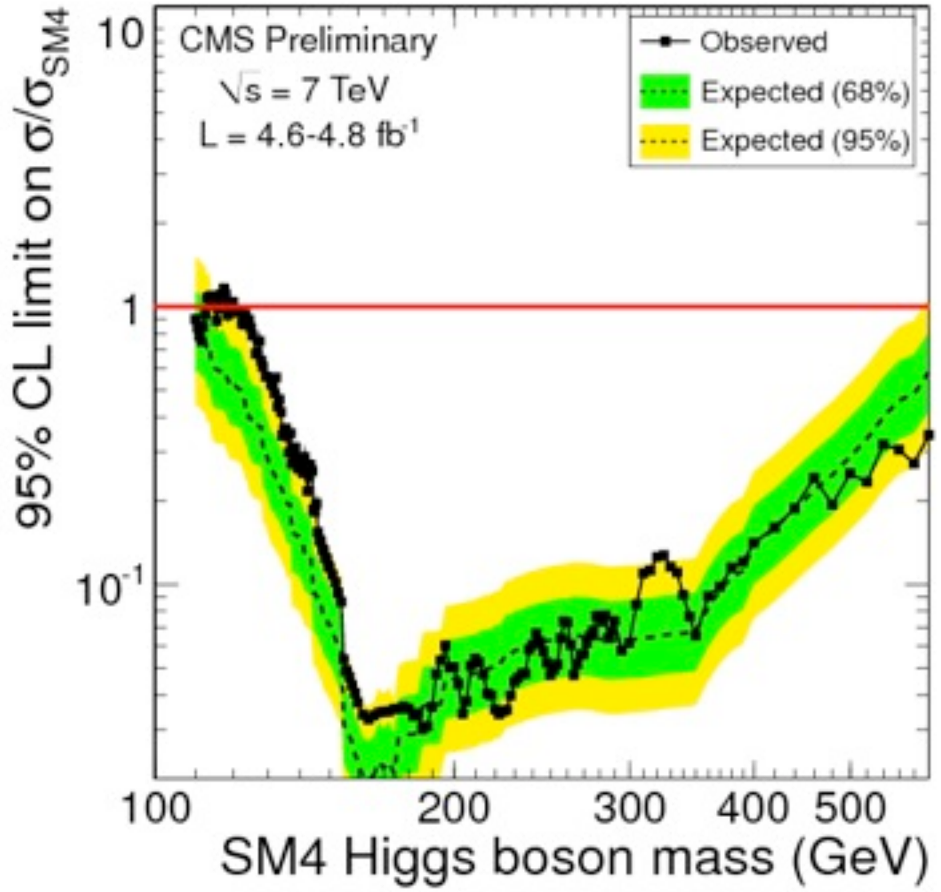
Direct searches:

$$M_{b',t'} \gtrsim 600 \text{ GeV}$$

Indirect Limits:

$$m_h > 600 \text{ GeV} \quad !$$





4G LEPTONS WITHOUT QUARKS

- Full family of quarks and lepton required for anomaly cancellation
- Instead: Introduce a set of mirror leptons with same quantum numbers but opposite chirality

$\ell'_{\rm L}$	$e'_{\rm R}$	$\nu'_{\rm R}$	$\ell''_{\rm R}$	$e''_{\rm L}$	$\nu''_{\rm L}$
(1,2,1/2)	(1,1,1)	(1,1,0)	(1,2,1/2)	(1,1,1)	(1,1,0)

4G Leptons

Mirror Leptons

LAGRANGIAN/PARAMETERS

- Yukawa couplings within one generation

$$Y_c'(\bar{\ell}_{\rm L}'H)e_{\rm R}' + Y_n'(\bar{\ell}_{\rm L}'\tau H^\dagger)\nu_{\rm R}' + Y_c''(\bar{\ell}_{\rm R}''H)e_{\rm L}'' + Y_n''(\bar{\ell}_{\rm R}''\tau H^\dagger)\nu_{\rm L}''$$

- Majorana masses for right handed neutrinos

$$\frac{1}{2}M'\nu'\nu' + \frac{1}{2}M''\nu''\nu''$$

- Dirac masses mix generations (mirror parity?)

$$m_\ell \bar{\ell}_{\rm L}'\ell_{\rm R}'' + m_e \bar{e}_{\rm L}''e_{\rm R}' + m_\nu \bar{\nu}_{\rm L}''\nu_{\rm R}'$$

WITH MIRROR PARITY

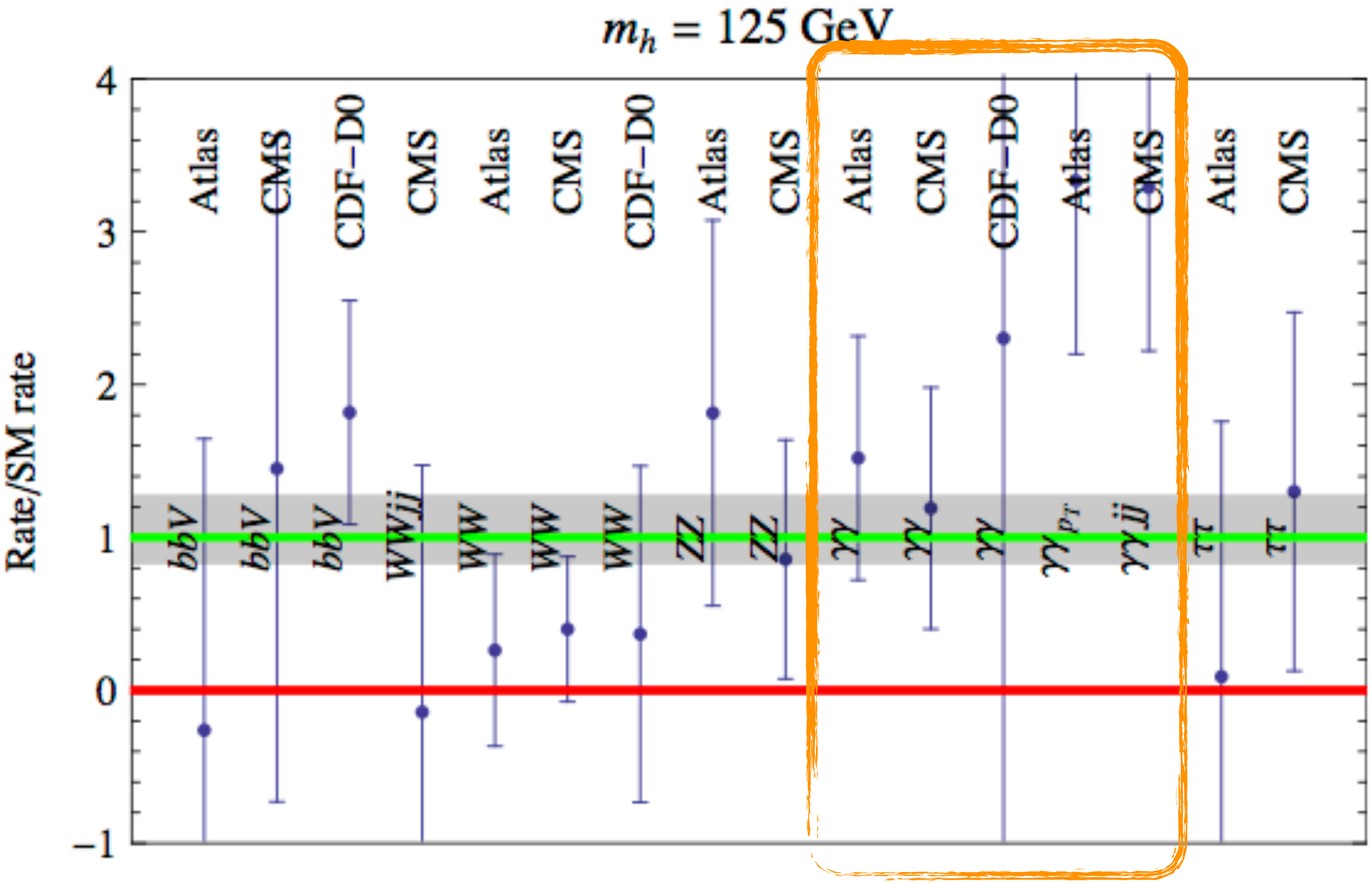
- Charged lepton masses purely from Yukawa couplings
- LEP limits $m_{\ell'} > 100\ \mathrm{GeV}$: sizable coupling to Higgs
- Higgs diphoton rate:

$$\Gamma_{h\to\gamma\gamma} \propto \left| \underbrace{A_1(\tau_w)}_{-8.3} + \frac{4}{3}A_{1/2}(\tau_t) + \frac{c_{h11}v}{m_1}A_{1/2}(\tau_{e_1}) + \frac{c_{h22}v}{m_2}A_{1/2}(\tau_{e_2}) \right|^2$$

$\mathcal{O}(1)$

- Large (70%) suppression

HIGGS "PROPERTIES"



Giardinoa, Kannikeb, Raidalc, Strumia, 2012

No discovery yet!
But: Suppression of di-photon rate probably a bad idea

HIGGS TO PHOTONS, WITH MIXING

- Charged lepton mass matrix

$$\mathcal{L} \supset \begin{pmatrix} \bar{e}'_{\mathrm{L}} & \bar{e}''_{\mathrm{L}} \end{pmatrix} \mathcal{M} \begin{pmatrix} e'_{\mathrm{R}} \\ e''_{\mathrm{R}} \end{pmatrix} + \mathrm{h.c.} \qquad \text{where} \qquad \mathcal{M} = \begin{pmatrix} Y'_c v & m_\ell \\ m_e & Y''_c v \end{pmatrix}$$

- Remember: $\Gamma_{h\to\gamma\gamma} \propto \left| A_1(\tau_w) + \frac{4}{3} A_{1/2}(\tau_t) + \frac{c_{h11} v}{m_1} A_{1/2}(\tau_{e_1}) + \frac{c_{h22} v}{m_2} A_{1/2}(\tau_{e_2}) \right|^2$

- Enhancement possible?

$$\sum_i \frac{c_{hii} v}{m_i} = v \frac{d}{dv} \log \det(\mathcal{M}) = \frac{2 Y'_c Y''_c v^2}{Y'_c Y''_c v^2 - m_\ell m_e}$$

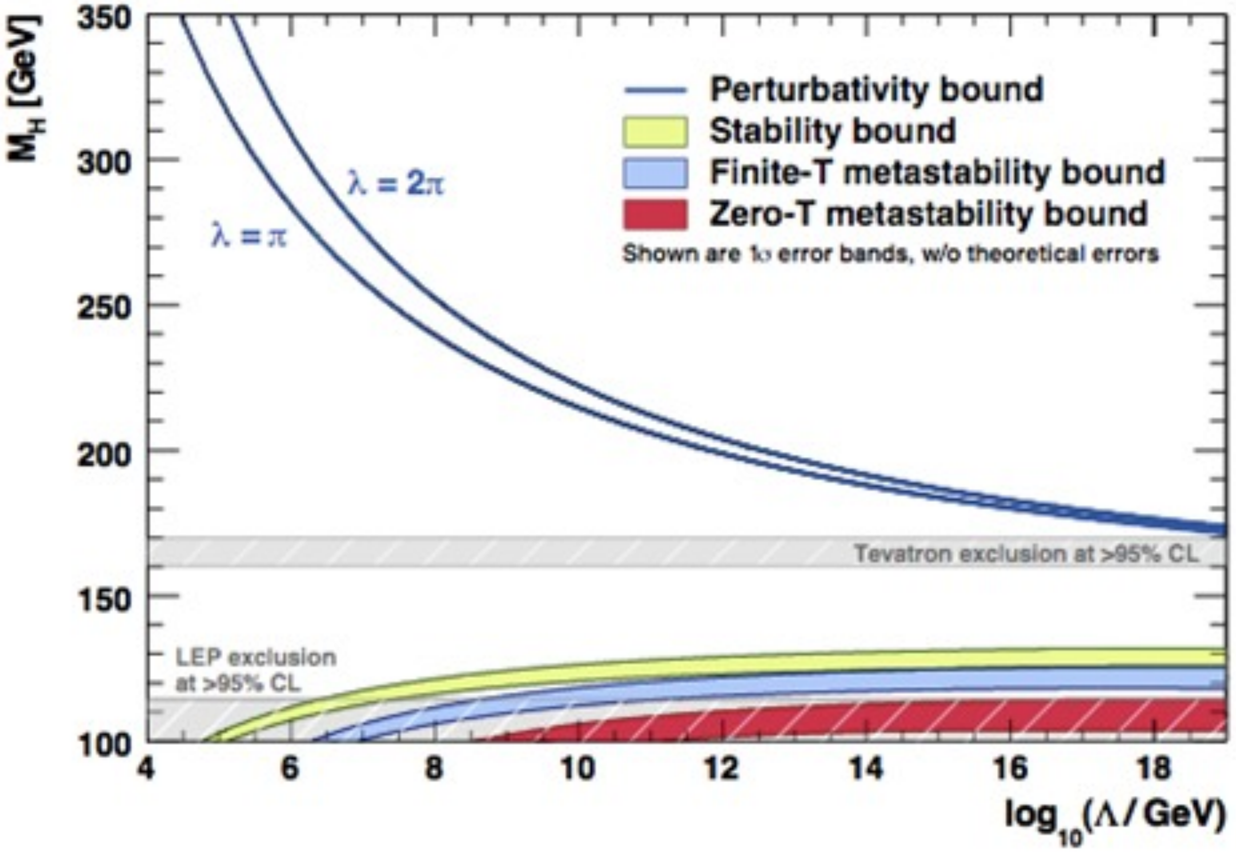
Falkowski, 2008

- Need: both Yukawas nonzero, finite lepton masses

STABILITY LIMITS

- Higgs stability/triviality, standard model:
- For low m_h, Higgs quartic gets negative at large scales: unstable

Ellis et al, arXiv:0906.0954



- We add more Yukawas - if the Higgs is at 125 GeV, stability will be an issue!

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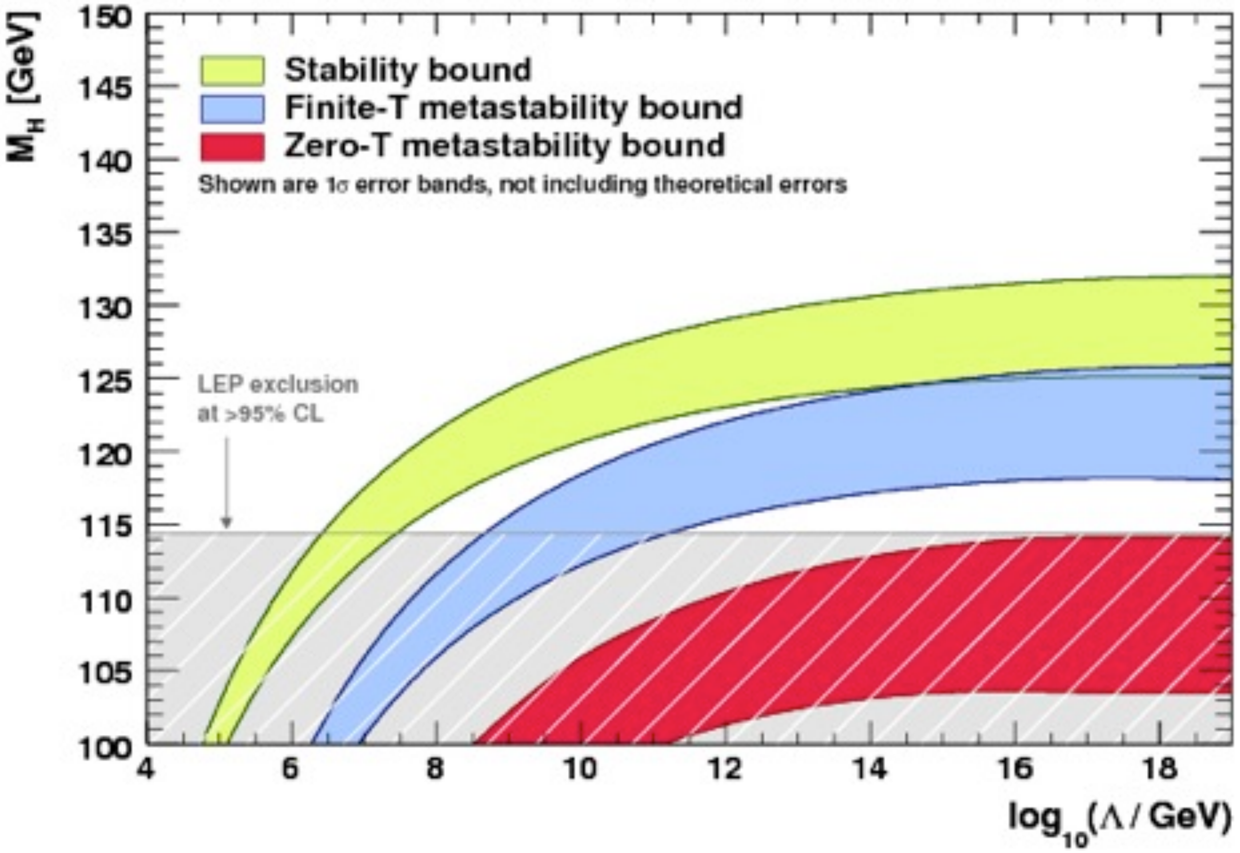

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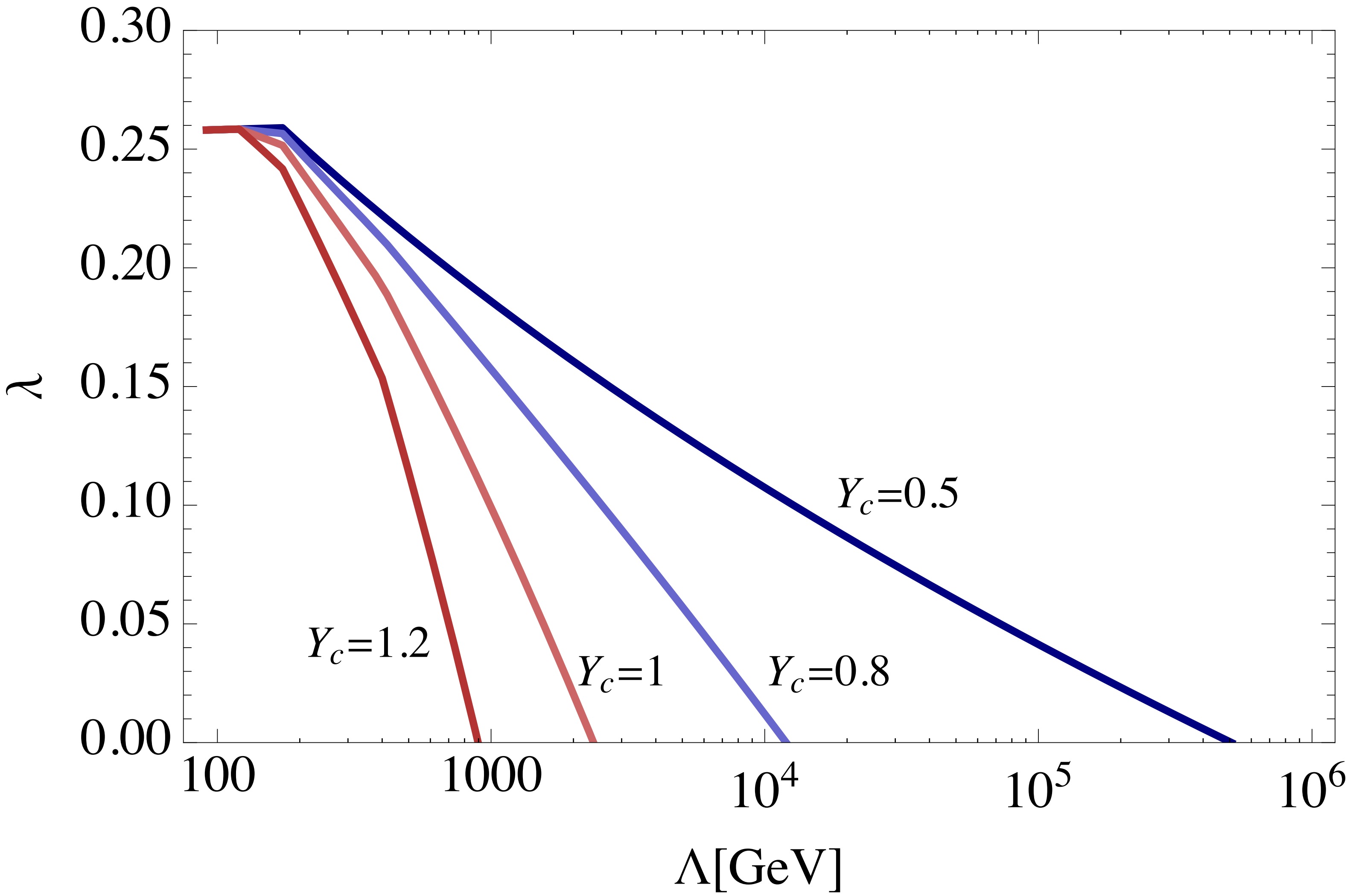
STABILITY LIMITS

- One loop RGE of Higgs quartic
- Vanishing neutral Yukawas
- $Y_c' \sim Y_c'' \lesssim 1$



- Or, add new physics at TeV scale to improve UV behavior

DI-PHOTON RATE

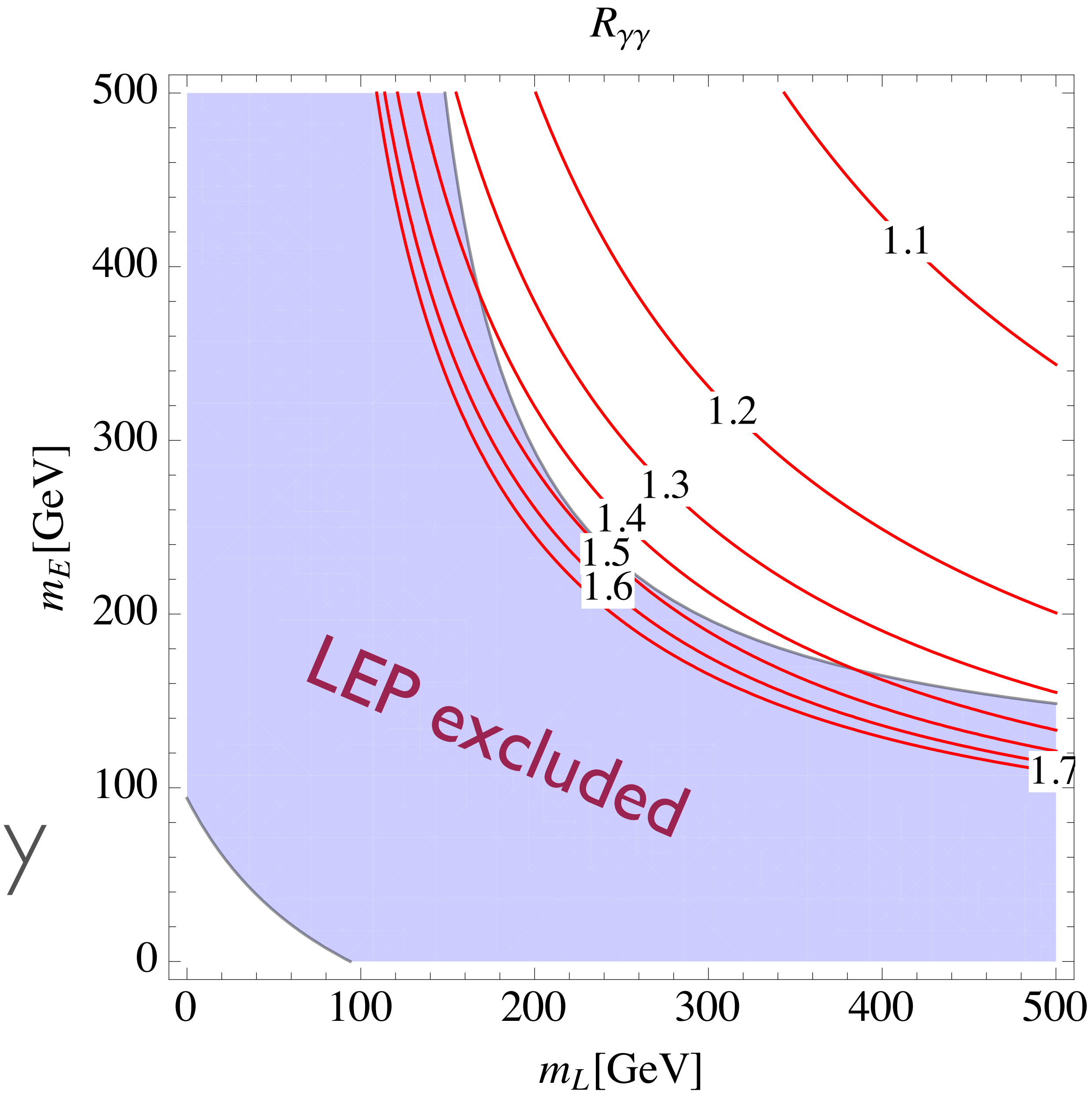
- Ratio

$$R_{\gamma\gamma} = \frac{\Gamma(h \to \gamma\gamma)}{\Gamma(h \to \gamma\gamma)_{\rm SM}}$$

- Yukawas

$$Y_c' = Y_c'' = 0.8$$

- 50% enhancement easy

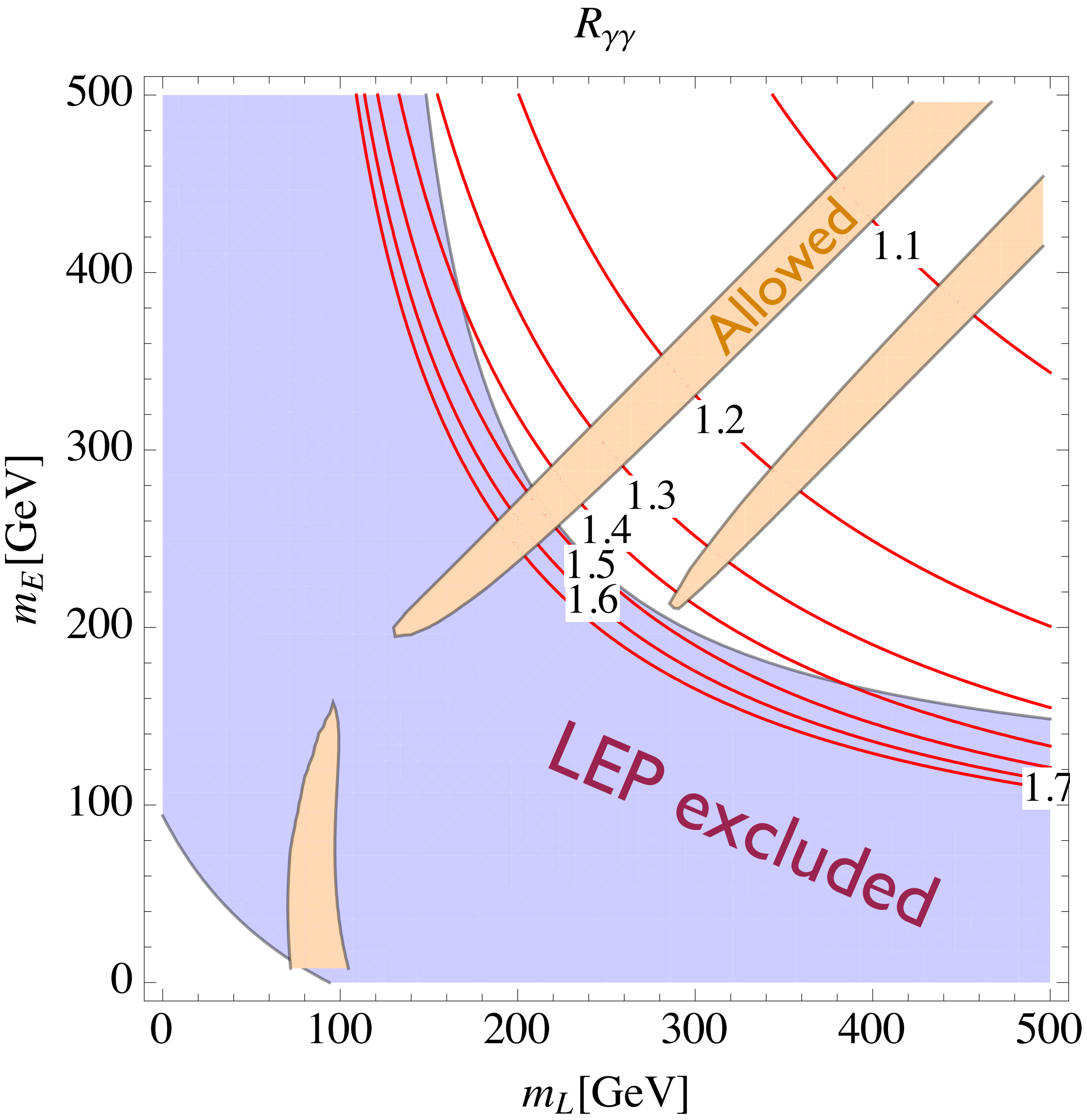


- More enhancement:

increase Yukawas, or have to evade LEP limit

PRECISION CONSTRAINTS

- Add electroweak constraints
- Orange: allowed by S & T parameters at 95% CL



OTHER PHENOMENOLOGY

- Assume no mixing with SM leptons
  - Lightest neutrino is dark matter candidate
  - Generic decays $e' \to W\nu'$ $\nu'' \to Z\nu'$
  - Simplified model for

$$pp \to WW + \not{E} \to 2\ell + \not{E}$$
$$pp \to WZ + \not{E} \to 3\ell + \not{E}$$
$$pp \to ZZ + \not{E} \to 4\ell + \not{E}$$

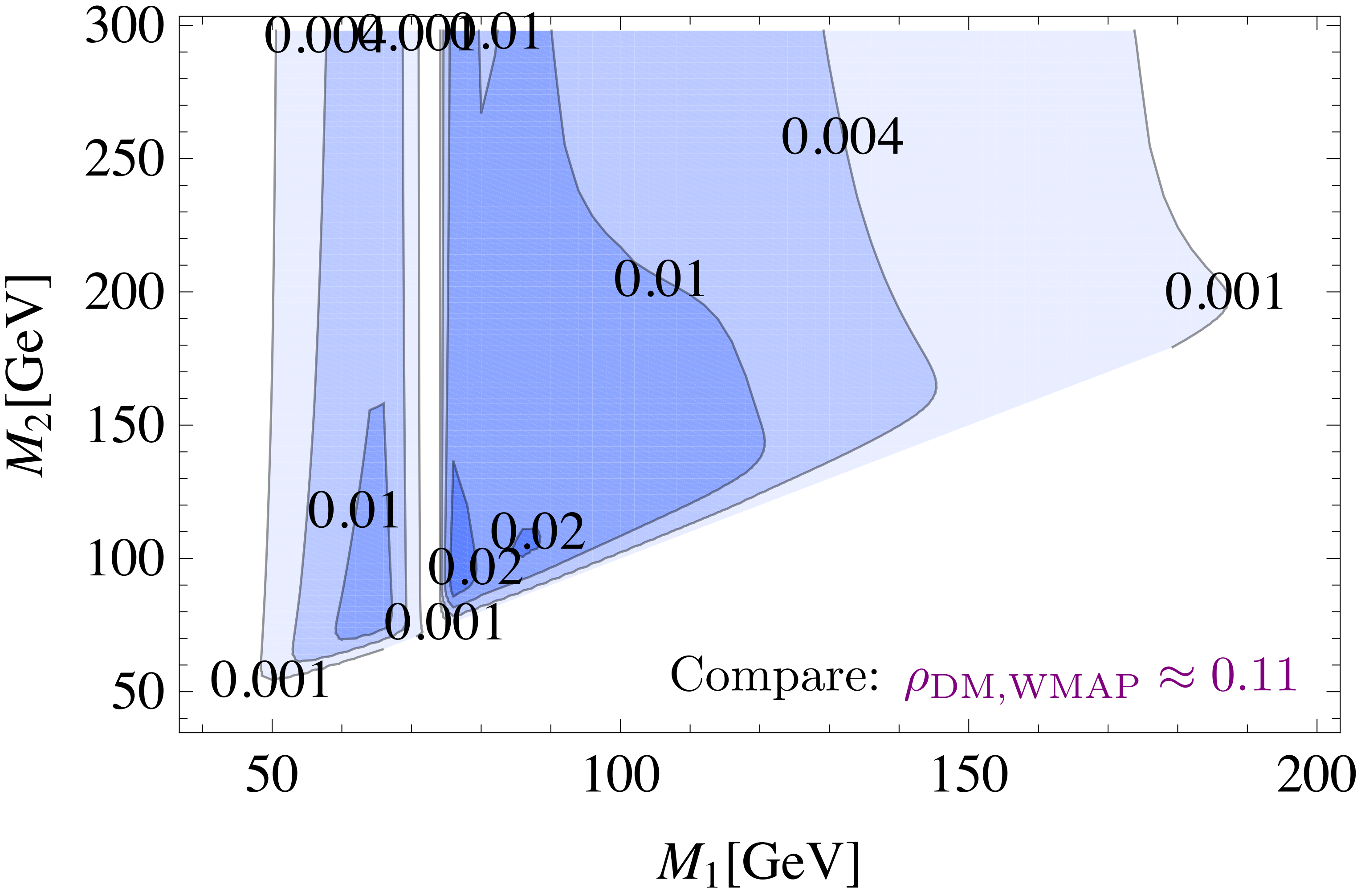
  - Weak production, LHC only starts being sensitive

CONCLUSIONS

- New leptons are interesting!
- Possible explanation for modified Higgs BRs, consistent with EWPT, stability
- Rich collider and dark matter phenomenology

THANK YOU!

RELIC DENSITY



- at most 20% of "observed" dark matter
- Higgs mass 150 GeV
- Co-annihilation near $M_2 = M_1$
- full density only with modified thermal history

e.g. Kainulainen et. al. 2007

DM: CONSTRAINTS

- Thermal relic density - annihilation rate

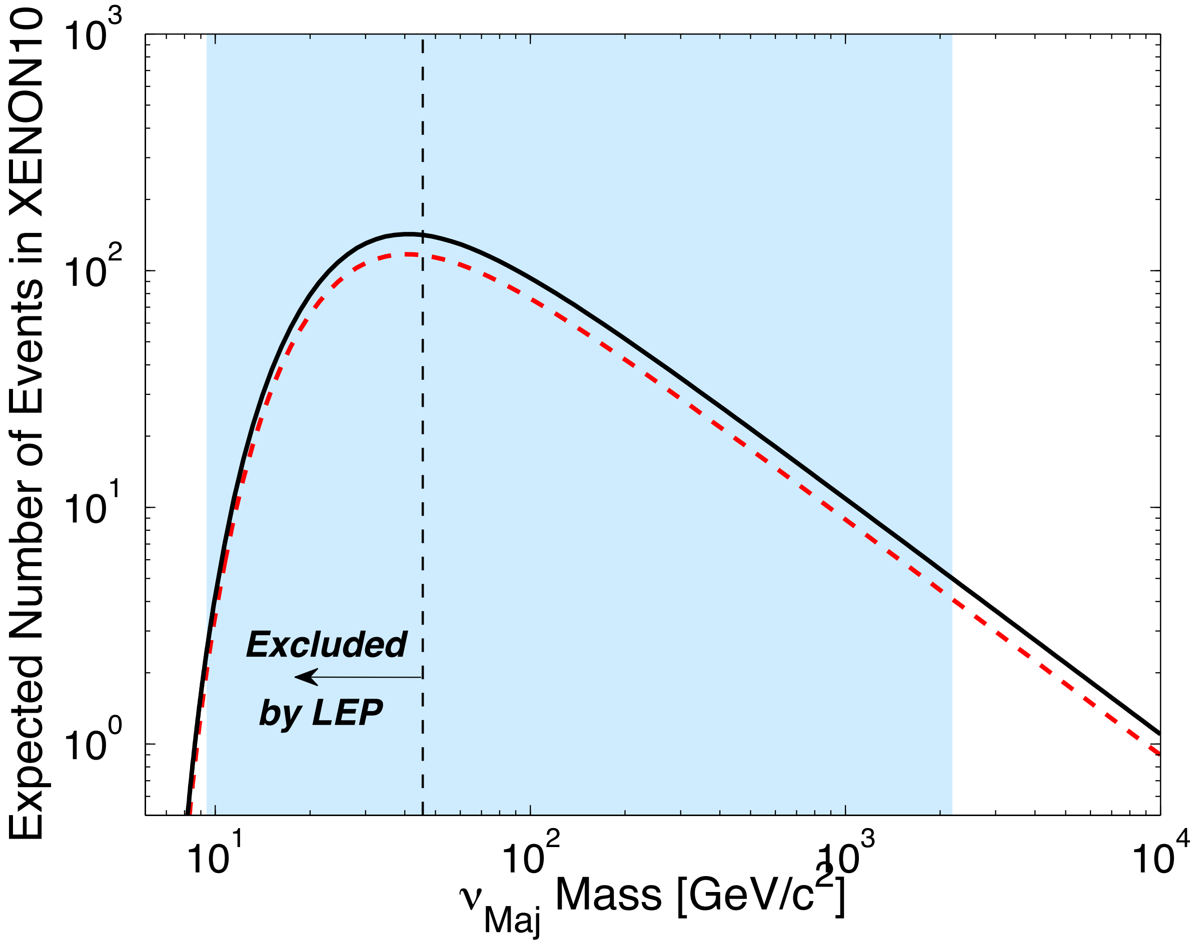
small, but non-negligible
for Majorana N_1

- Direct detection rates
  - Dirac: Spin-independent scattering unsuppressed excluded 20 years ago
  - Majorana: SI scattering suppressed by light quark masses. Consider both SI and SD scattering

DIRECT DETECTION: SD LIMITS

- Xenon 10: Exclude Majorana neutrino for

  $10\ \mathrm{GeV} < M_1 < 2\ \mathrm{TeV}$



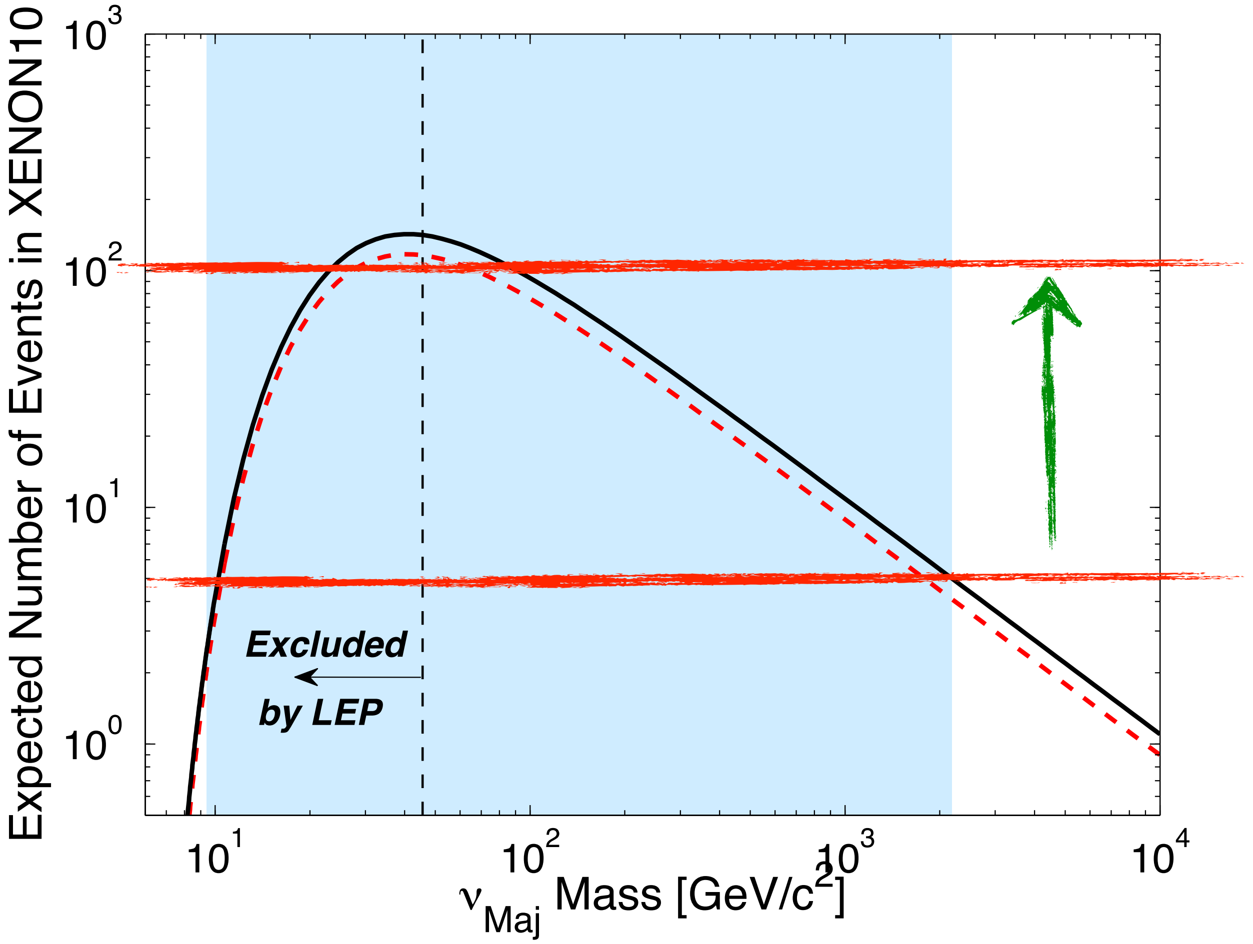
DIRECT DETECTION: SD LIMITS

- Xenon 10: Exclude Majorana neutrino for

  $$10\ \text{GeV} < M_1 < 2\ \text{TeV}$$

- Event rate scales with relic density

  $$\propto \rho_{N_1}/\rho_{\text{WMAP}}$$

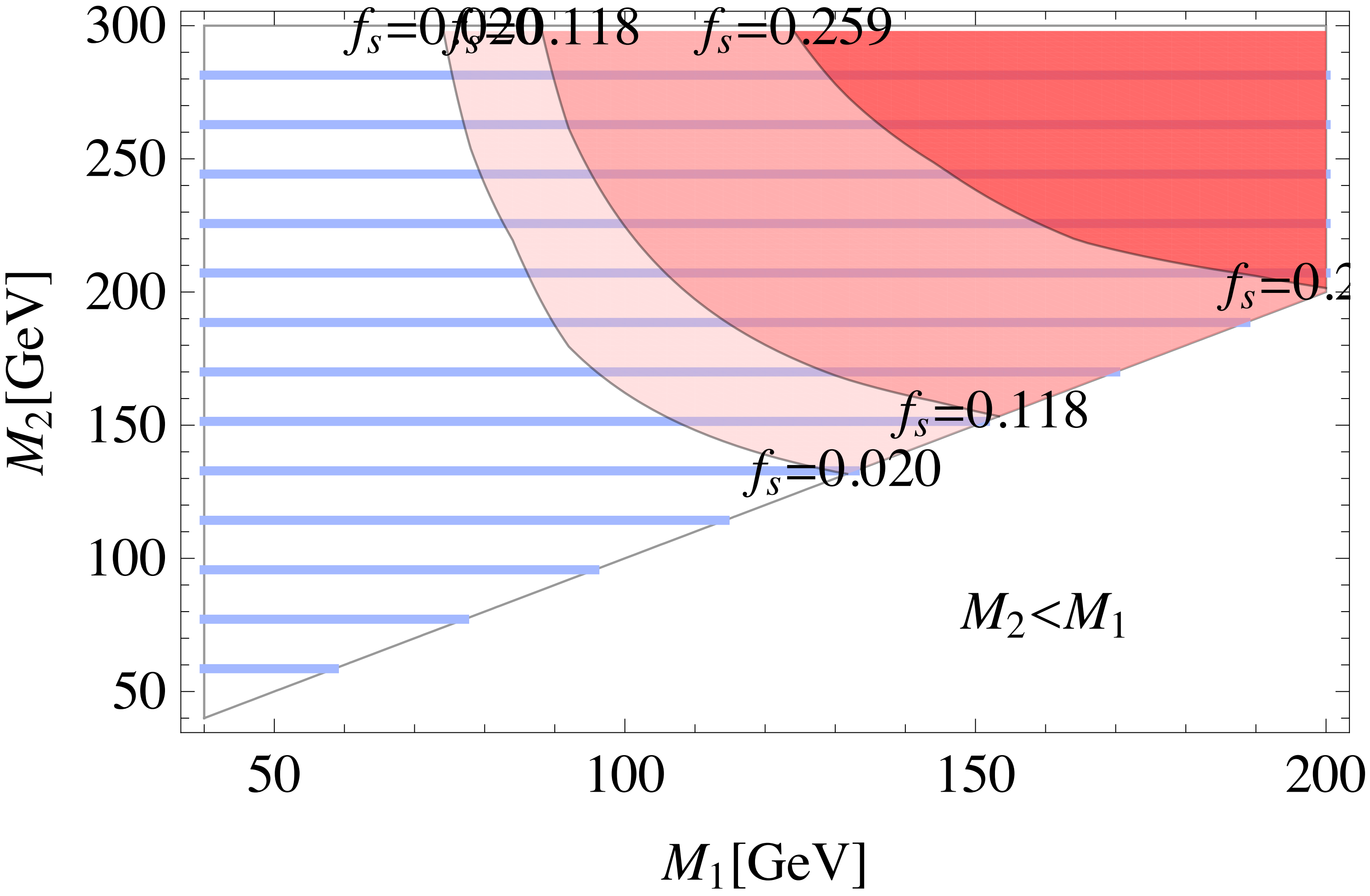


- Stable N_1 allowed if $\rho_{N_1}/\rho_{\text{WMAP}} < 5\%$

  this is what we expect for a thermal relic N_1

ADD IN SPIN INDEPENDENT LIMIT

- Red: Excluded by Xenon 100 2010 data
- Blue hatched: Excluded by Xenon 10



- Both limits assuming full relic density. No exclusion (yet) for thermal relic density

HOW TO GENERATE A BARYON ASYMMETRY?

Sakharovs conditions (1967):	SM:	
• Baryon number violation	☺	(B+L)!
• CP violation	😐	4G: New CP phases
• Departure from equilibrium	☹	4G: Low scale Leptogenesis

PREVENT (B+L) WASHOUT

Murayama et al, 2010

- Assume initial (B+L) asymmetry
- Problem: Erased by weak sphalerons
- Long lived 4G quarks/leptons: Additional, approximate quantum numbers $B_4, \quad L_4$
- Prevents complete washout:

Murayama et al, 2010