Inert doublet dark matter and mirror/extra families, implications after Xenon 100

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(1105.4611)

Extra chiral families

- Extra family is the simplest extension of SM.
- Yukawa perturbativity, not too heavy, accessible at the LHC.
- Fourth family is perfectly allowed by EWPT.

Maltoni, Novikov, Okun, Rosanov, Vysotski, 00'
He, Polonski, Su, 01'
Kribs, Plehn, Spannowsky, 07'

- How much room allowed for even more families?
- Mirror families: originally proposed by Lee and Yang in the parity non-conservation paper to restore parity symmetry.
  - Share the same SM gauge interaction.
  - RH fermion doublets, LH singlets.

Mirror families can naturally arise

- SO(10) unification: 16 (families), 16-bar (empty or mirror).

Gell-Mann, Ramond, Slansky, 79'
Bagger, Dimopoulos, 84'
Senjanovic, Wilczek, Zee, 84'

- Two ways of getting mass:
  - SO(4n+2) chiral, 16*16 is not singlet, couple to EW Higgs.
  - Otherwise, pair up 16 and 16-bar, same mass.
  - If have families, mirror families must lie not far above.
- Also Kaluza-Klein theories; N=2 supersymmetry; gauged B and L in low cutoff theories, like ADD.
- Still possible to have "small" vector like mass: m 16 16-bar. Small mixings useful: make mirror fermions decay.

Experimental and theoretical bounds

- Direct searches:
  - LEP: mE>102.6 (Long-lived: 100.8)GeV, mN> 90.3 (45) GeV.
  - CDF: mQ>356 GeV, CDF: mT'>338 GeV, CMS: mB'>361 GeV.
- Extra fermions not heavier than ~500 GeV.
- SM Higgs lighter than 600 GeV,
- SM Higgs heavier 300 GeV for two extra or 400 GeV for three extra families.

$$16\pi^2 \frac{d\lambda_1}{dLogQ} = 24\lambda_1^2 + 12y_t^2\lambda_1 - 6y_t^4 + \cdots$$

more negative contribution from heavy fermions

EW oblique parameters

- For nearly-degenerate & heavy fermion doublet:

$$S = -16\pi \frac{\Pi_{3Y}(M_Z^2) - \Pi_{3Y}(0)}{M_Z^2} \approx \frac{1}{6\pi}$$

$$T = 4\pi \frac{\Pi_{11}(0) - \Pi_{33}(0)}{s_W^2 c_W^2 M_Z^2} \approx \frac{1}{12\pi s_W^2 c_W^2} \frac{(\Delta m)^2}{M_Z^2}$$

$$U = 16\pi \frac{[\Pi_{11}(M_Z^2) - \Pi_{11}(0)] - [\Pi_{33}(M_Z^2) - \Pi_{33}(0)]}{M_Z^2} \approx \frac{2}{15\pi} \frac{(\Delta m)^2}{M_F^2}$$

- Fourth family: allows heavier SM Higgs, consistent with S, T.
- More extra families, U becomes crucial.
- In fact, for three extra families, the EWPT failed badly.
- $\chi^2 = 13.5$ taking into account of that SM Higgs must be heavier than 400 GeV due to vacuum stability.

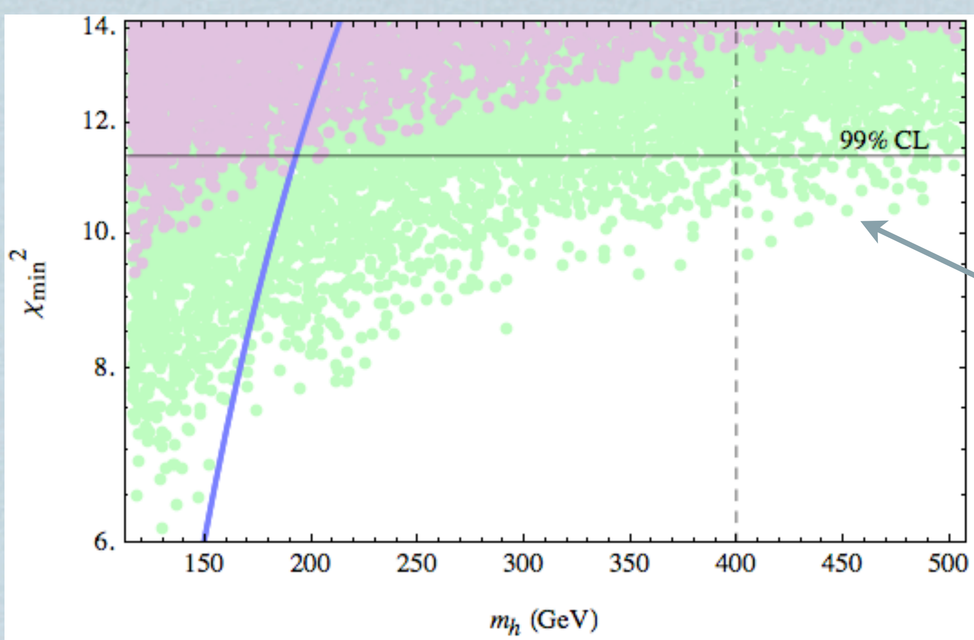
Saved by a second Higgs doublet

$$H' = \begin{pmatrix} C^+ \\ S + iA \end{pmatrix}$$

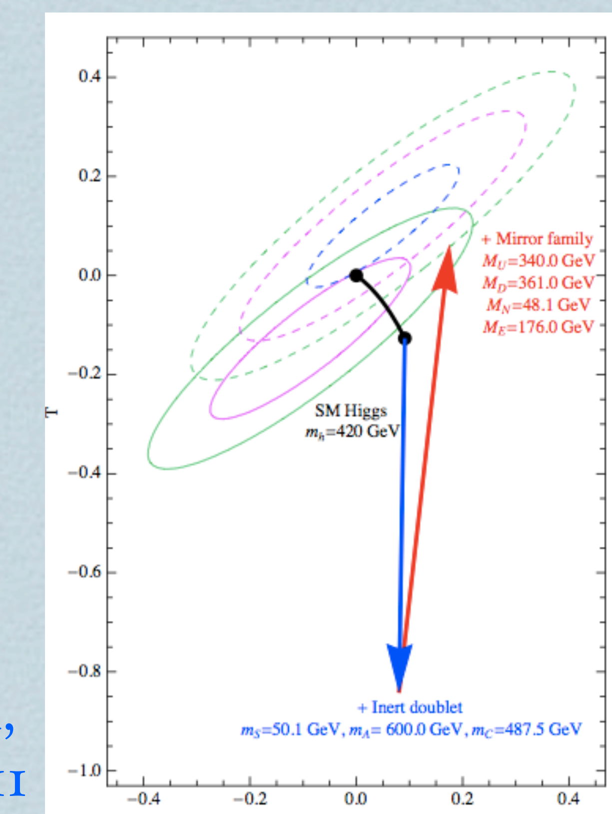
- Expt. bounds: LEP: mC>70 GeV, mS>50 GeV, mS+mA>MZ.
- Improve the fit to 99% CL ($\chi^2_{\rm best} \approx 9.5$).

Despande, Ma, 78'
Baribieri, Hall, Rychkov 06'

  - S: each heavy fermion doublet $\frac{1}{6\pi}$, make neutrino lighter than Z-boson gives negative contribution.
  - T: Splitting neutrino and charged lepton makes large contribution to the T parameter -- need second doublet.
  - U: cannot cancel completely at the same time.

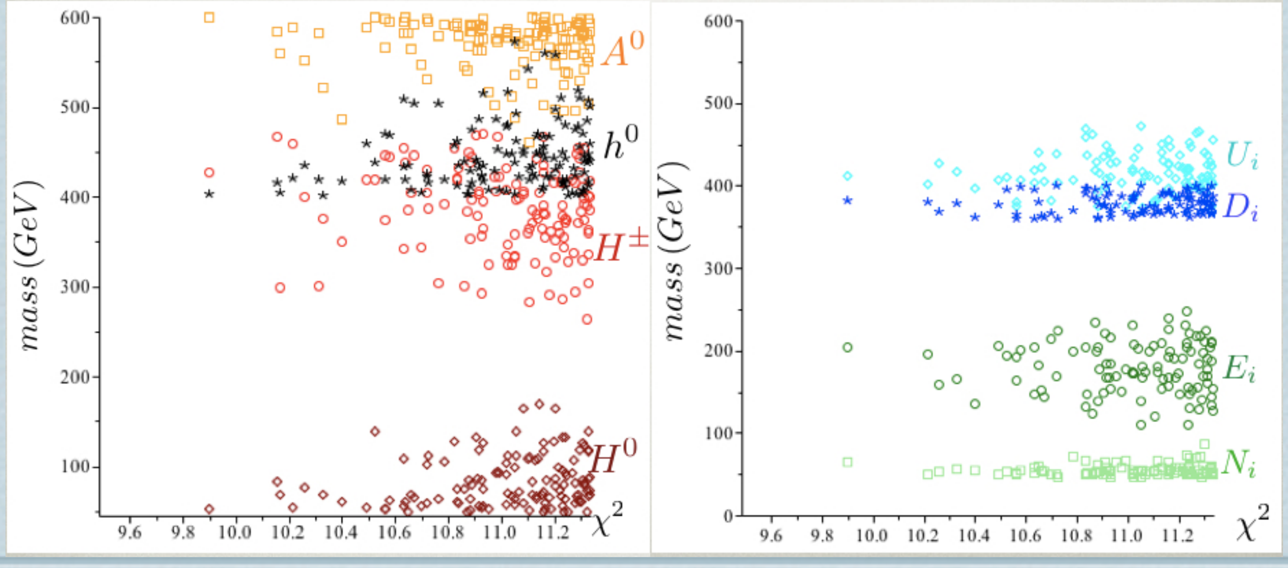


Melfo, Nemevsek, Nesti, Senjanovic, YZ, 1105.4611



Argument for inertness & Spectrum

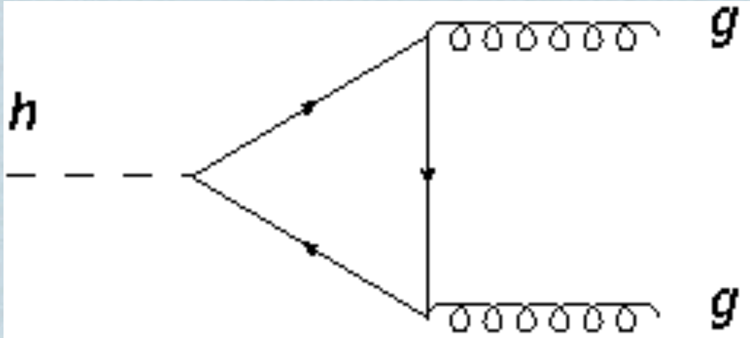
- Fit to 99%CL calls for: mS < 100 GeV & S should be a mass eigenstate has no VEV.
- LEP bound for Higgs-like scalar -- no large mixing with SM Higgs -- forbid Z2 breaking in Higgs potential (HH')(HH).
- Natural to further assume its stability by forbidding Z2 breaking Yukawa couplings of S -- DM candidate.
- Quite predictive in the mass spectra for fermions and scalars:



Martinez, Melfo, Nesti, Senjanovic, 1101.3796

Implications for phenomenology

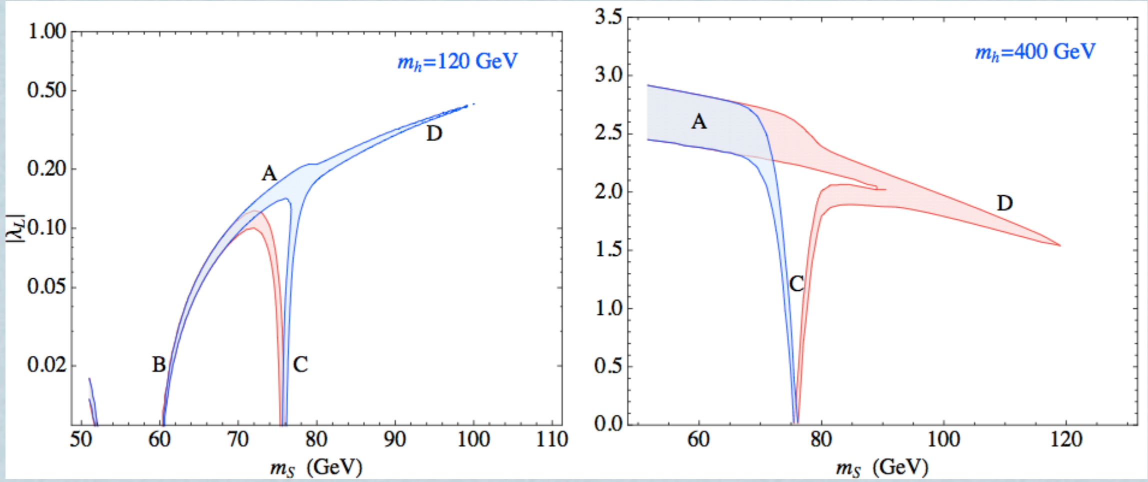
- Virtual heavy quarks enhances Higgs-gluon-gluon coupling
- Dark matter direct detection (Higgs mediated)
- Higgs boson direct searches at Tevatron and LHC



Shifman, Vainshtein, Zakharov, 78'
Melfo, Nemevsek, Nesti, Senjanovic, YZ, 1105.4611

The inert scalar S as dark matter

- Main interactions for relic density and detection SSWW and $\lambda_L SShh$.
- Heavy A, C: no inelastic partner, no co-annihilation.
- Annihilation channels: $SS \to h \to b\bar{b}$ $SS \to (h \to)WW$
- I will not consider extra neutrinos as DM; and assume they are heavier than S, otherwise SSh coupling too small.
- Four main regimes for correct relic density.
- Annihilation through virtual W* does not make much changes.



Enhanced cross section & Xenon

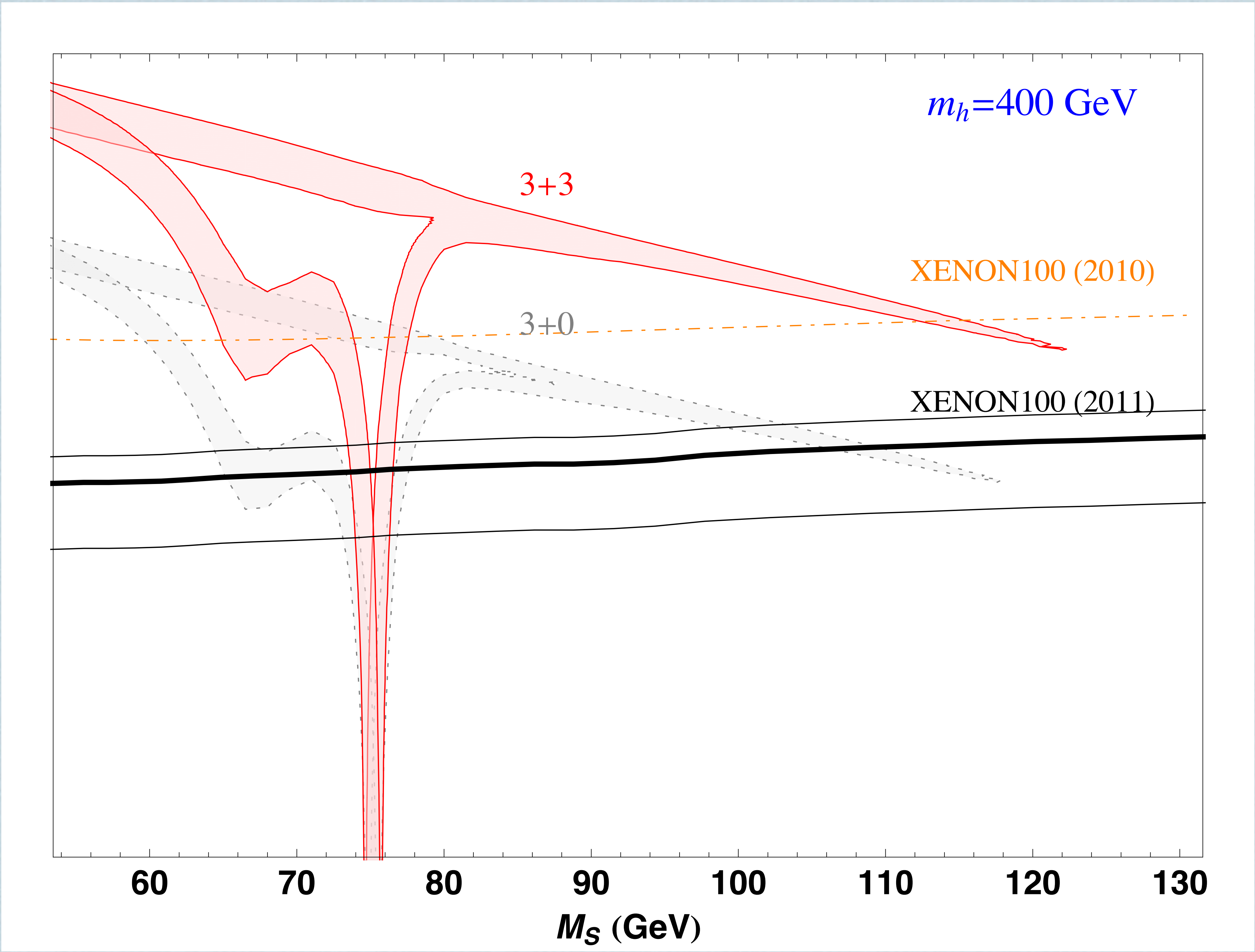
- Direct detection: SM Higgs mediated.
- uncertainty in effective Higgs-nucleon couplings.

f

$$\frac{1}{v}\langle N|\sum_q m_q\bar{q}q|N\rangle = \frac{m_N}{v}\left[\left(1+\frac{2n_h}{27}\right)(f_{T_u}^{(N)}+f_{T_d}^{(N)}+f_{T_s}^{(N)})+\frac{2n_h}{27}\right]$$

- I will take low f to be conservative, SM: f=0.375; mirror: f=0.875
- Xenon 100 implies:
  - DM mass: $m_S \approx 74 - 76\,\mathrm{GeV}$
  - Thermal freeze out dominated by SS toWW.
  - Annihilation at low energy: SS to bb.
- A robust predictions in spite of local DM density.

Constraints from Xenon 100



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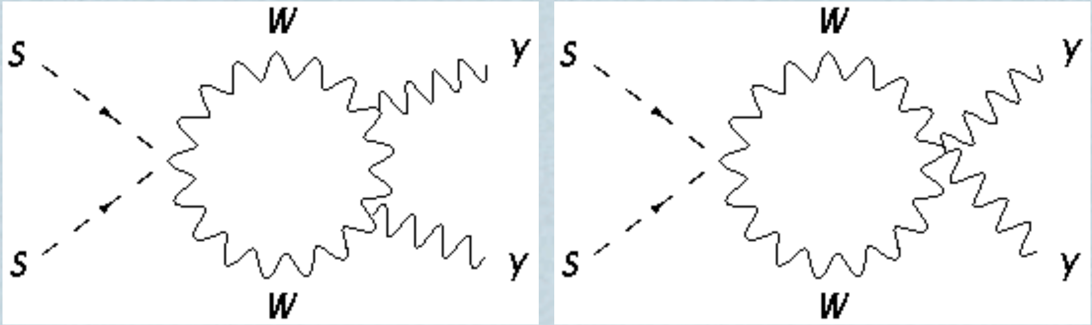
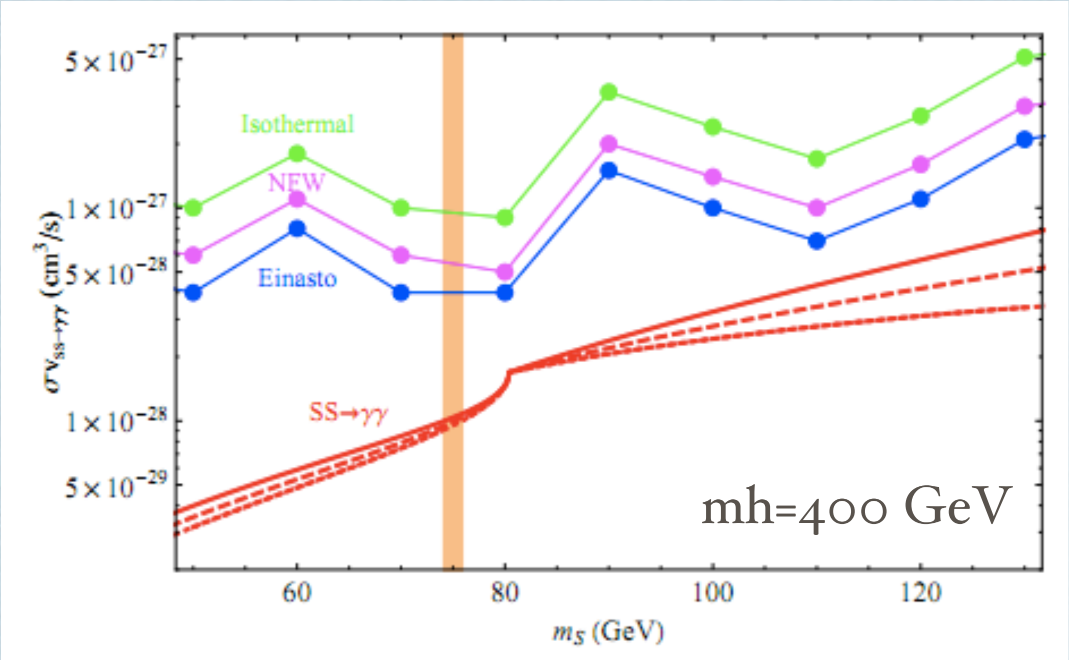
Indirect detection

- Mono-chromatic gamma ray from annihilation, calculable.
- The same loop function as Higgs to two photon, dominated by W-loop, fermion loop small.
- Xenon constraint SSh coupling, exclude possibility of cancellation.
- A lower limit on the annihilation rate in the galactic halo.



Also connect to the loop through SM Higgs, but suppressed according to Xenon.



Modify SM Higgs Search

- production cross section:
  - Below 200 GeV, enhancement $(2n+1)^2$ = 49.
  - Near top-pair threshold, smaller. Mirror case, decrease to 20.

Djouadi, 05'
Arik, Cakir, Cetin, Sultansoy, 02'

- Branching ratio (look for WW channel):
  - Enhance Higgs to 2 gluon.
  - Suppress 2 photon: cancellation between W and new fermions (most complete for 2 family case, similar for 1 and 3 family).
  - Decay into NN or SS could dominate for low Higgs mass.
  - WW starts to take over above ~200 GeV.

Higgs search at Tevatron

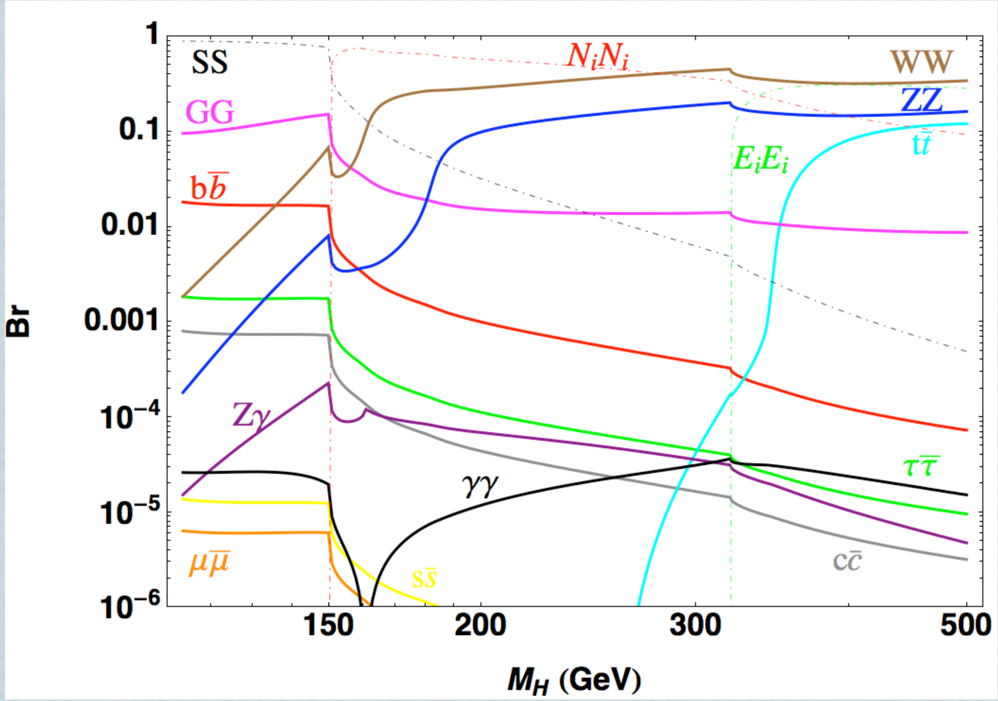
- Tevatron bound on Higgs mass for heavy 4th generation exclude

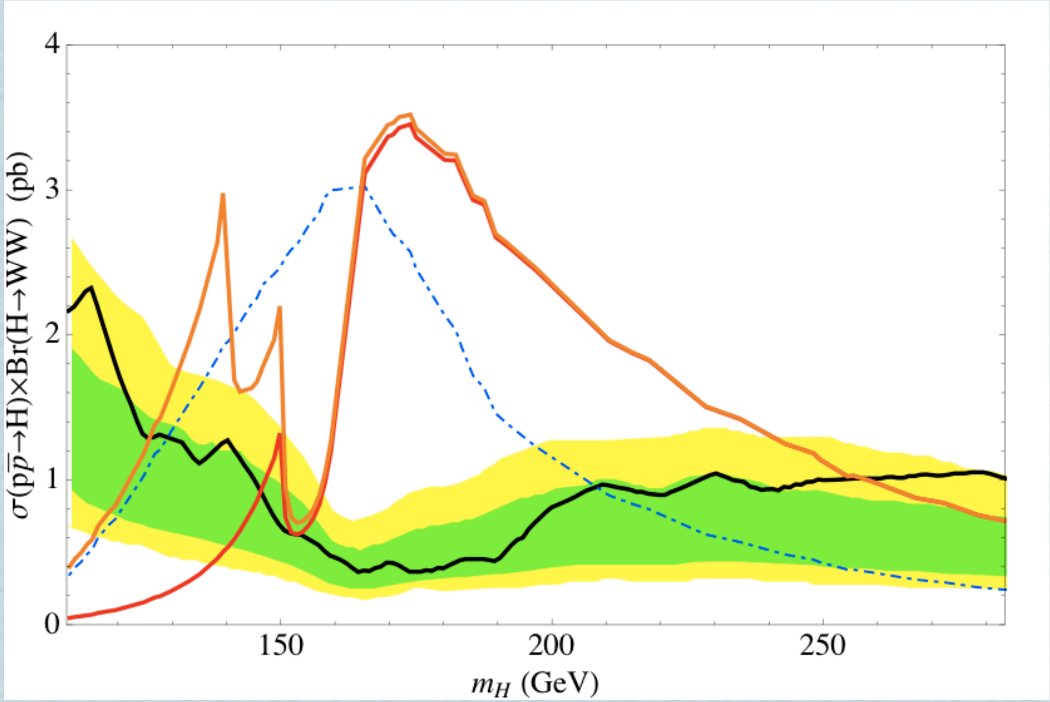
$$131\,\mathrm{GeV} < m_h < 204\,\mathrm{GeV}$$

CDF and D0, 1005.3216

- Depending on N or S masses: lower edge can change to 150 GeV.

- Mirror case $\quad 130 - 150\,\mathrm{GeV} < m_h < 250\,\mathrm{GeV}$





Conclusions

- Mirror families naturally exist in unifications, etc..
- EWPT favors the existence an inert doublet.
- Enhance Higgs mediated DM-nucleon interaction.
  - Xenon 100 new limit: predict the DM mass in a small window, constrain its annihilation in early universe and today.
  - A lower bound on gamma-ray line for indirect detection.
- Modify the SM Higgs search limits.
- Heavy extra quarks will soon be excluded or established at LHC.