Implications of Higgs Searches and Discovery

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Outline

- Is it a Higgs or an impostor? Does it participate in EWSB?
- If it is an Higgs, is it fundamental or composite?
- Implications for specific models?
- ...

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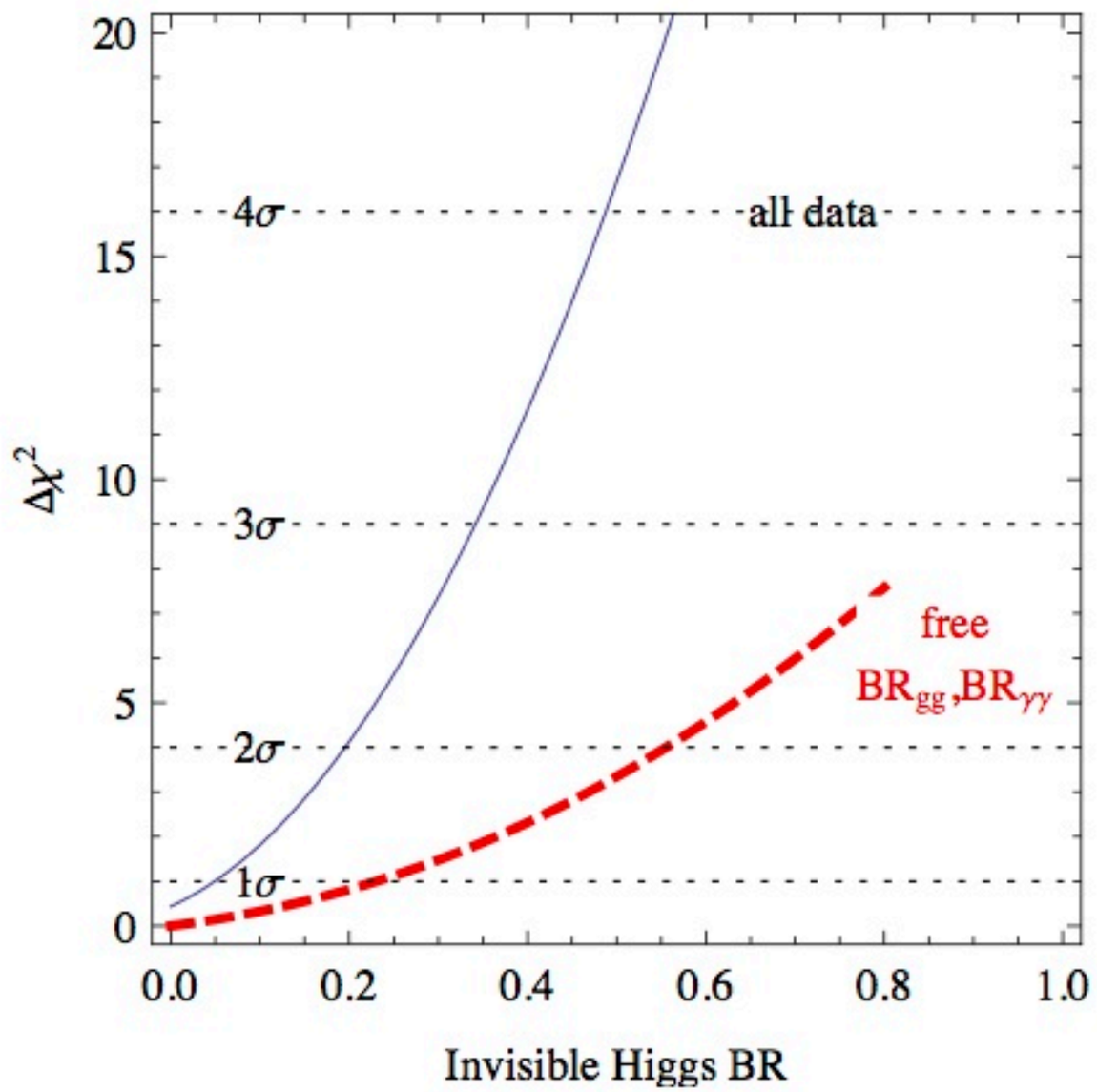
Today

Invisible Higgs width

Invisible Width

- Testing invisible Higgs decays is notoriously hard
- total width of the Higgs is too small to be measured
- Under assumptions of narrow width (and neglecting light quark contrib'), absolute $\Gamma_{h\to gg}$ can be extracted
- Indirect constrain on BR(H→inv)

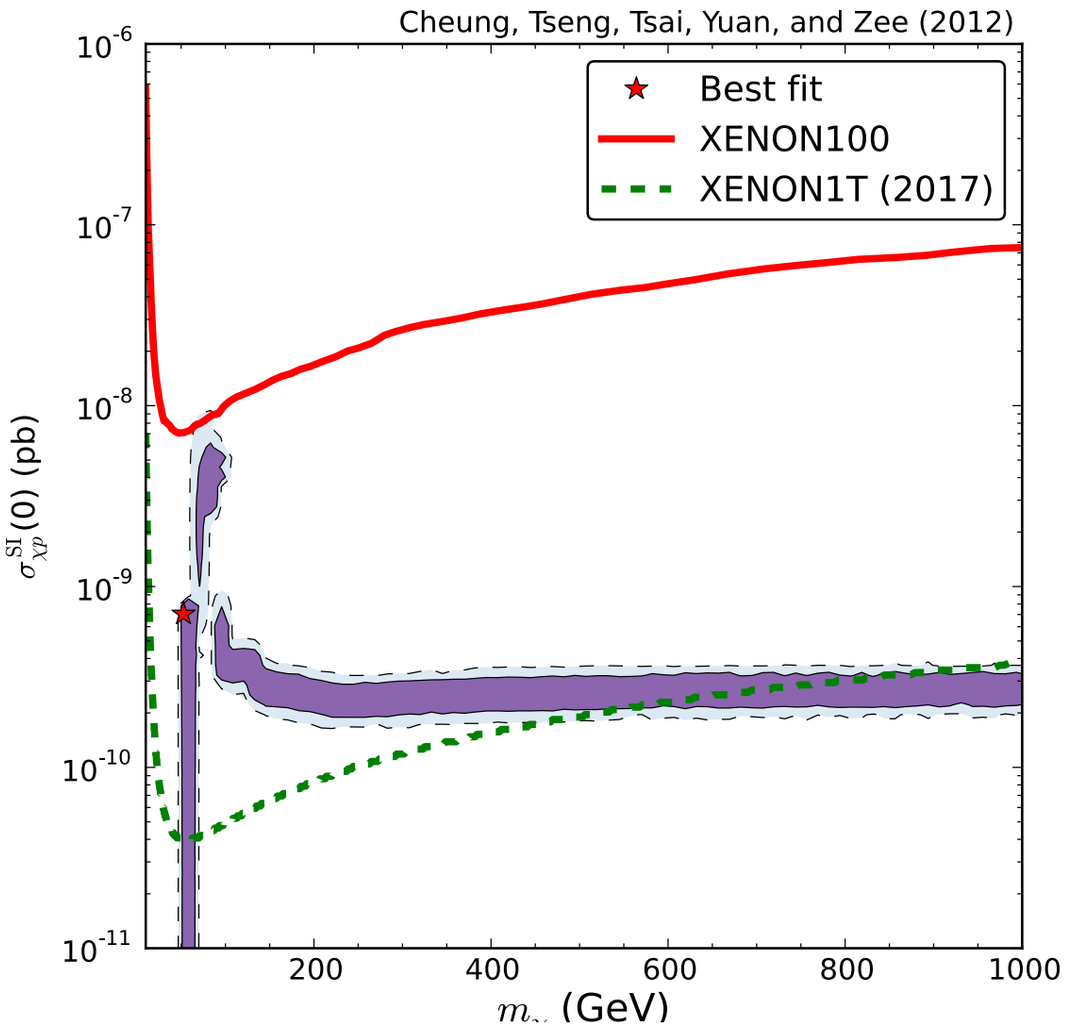
Giardino, Kannike, Raidal, Strumia arXiv:1207.1347



BR(inv.) < 0.2 - 0.6

Invisible Width

- Relevant for "Higgs portal" models (i.e. new physics coupled to $|H|^2$)
- models of Dark Matter coupled thru Higgs portal predicts large Higgs-DM-DM couplings
- if $m_{DM}<m_H/2$ large invisible width → BR can be O(50%)



- new Higgs data currently mild constrain, will improve in the future

Effects of new particles

Simplified Models for top & W partners

Carmi, Falkowski, Kuflik,
Volansky, Zupan arXiv:1207.1718

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c's parameterize the amount of mass coming from EWSB

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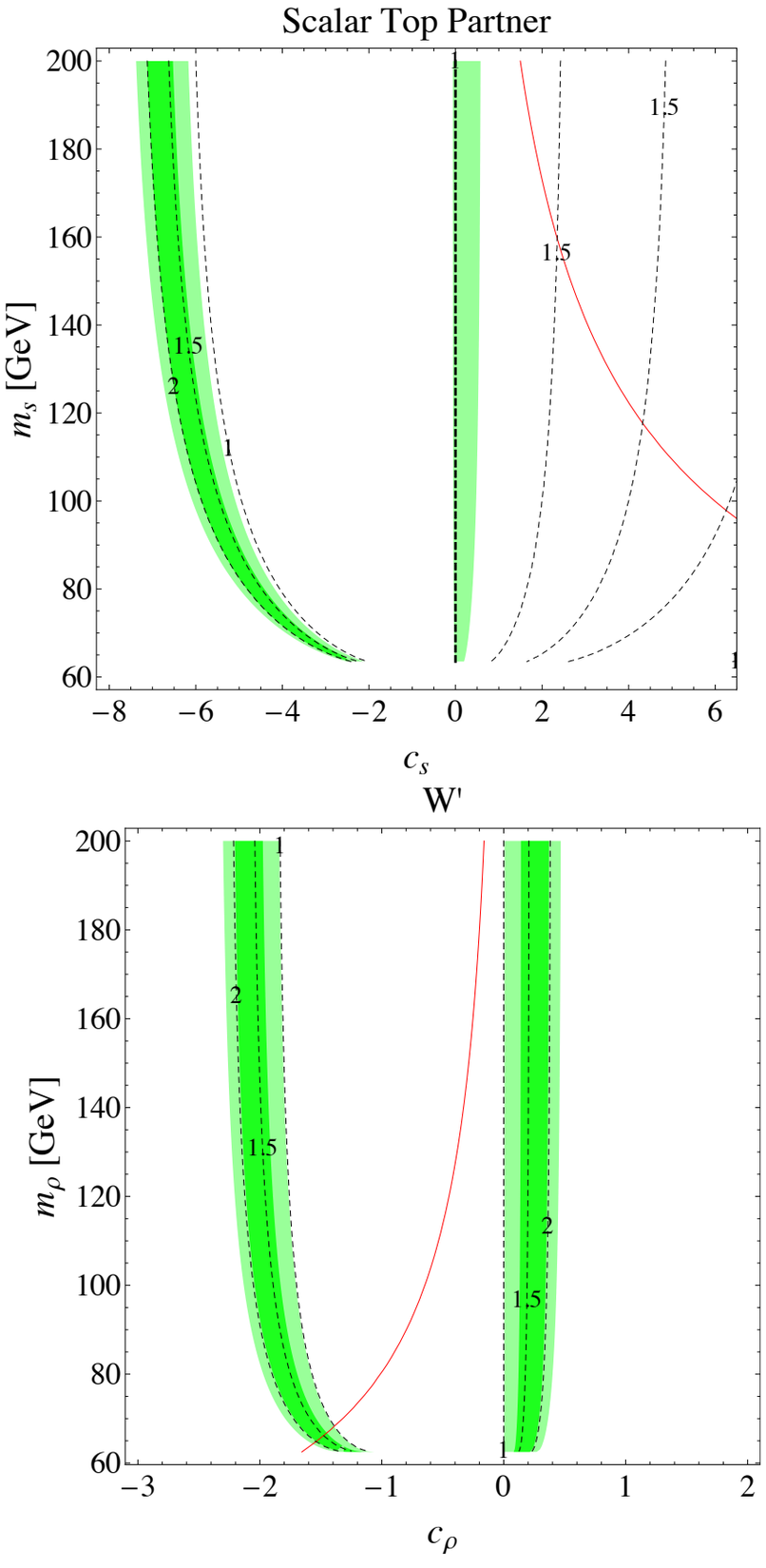

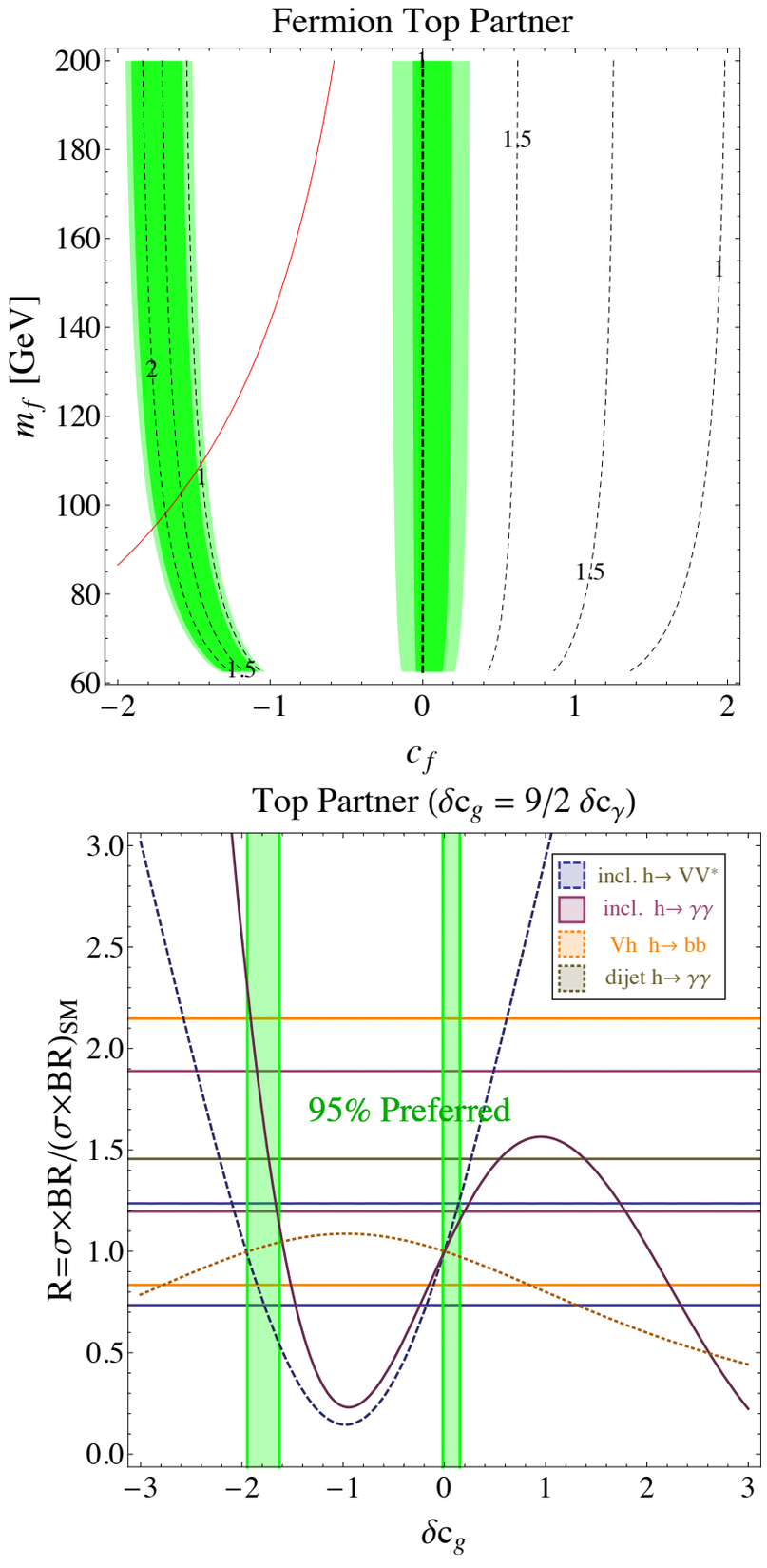

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top and W partners can accommodate increased h→γγ

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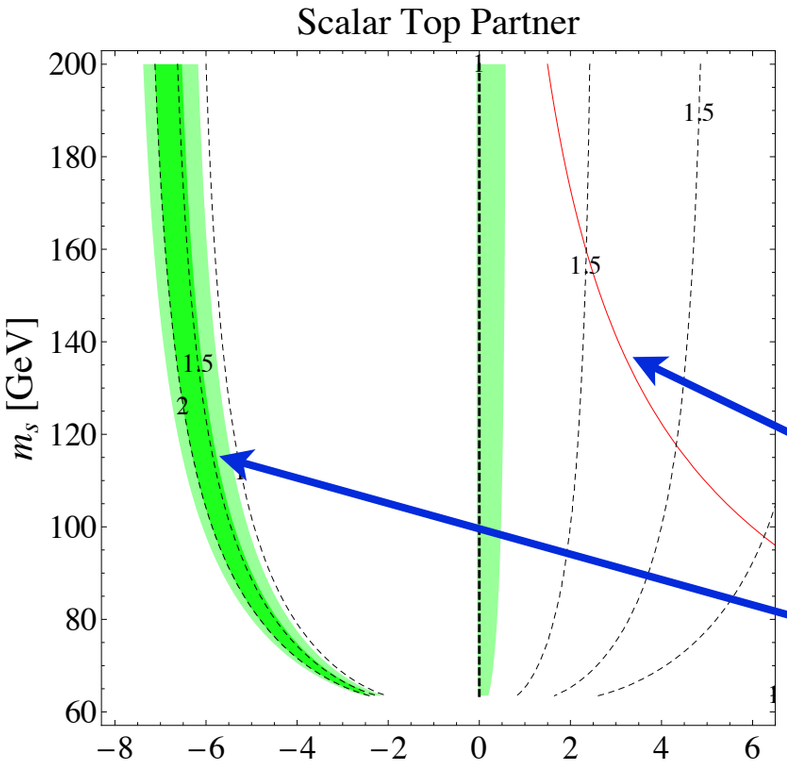
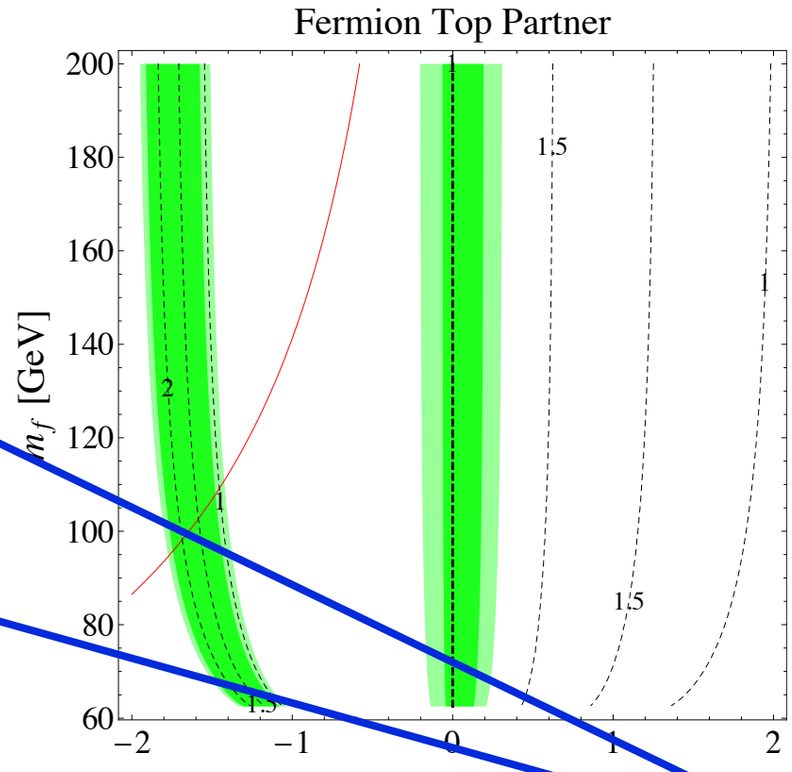
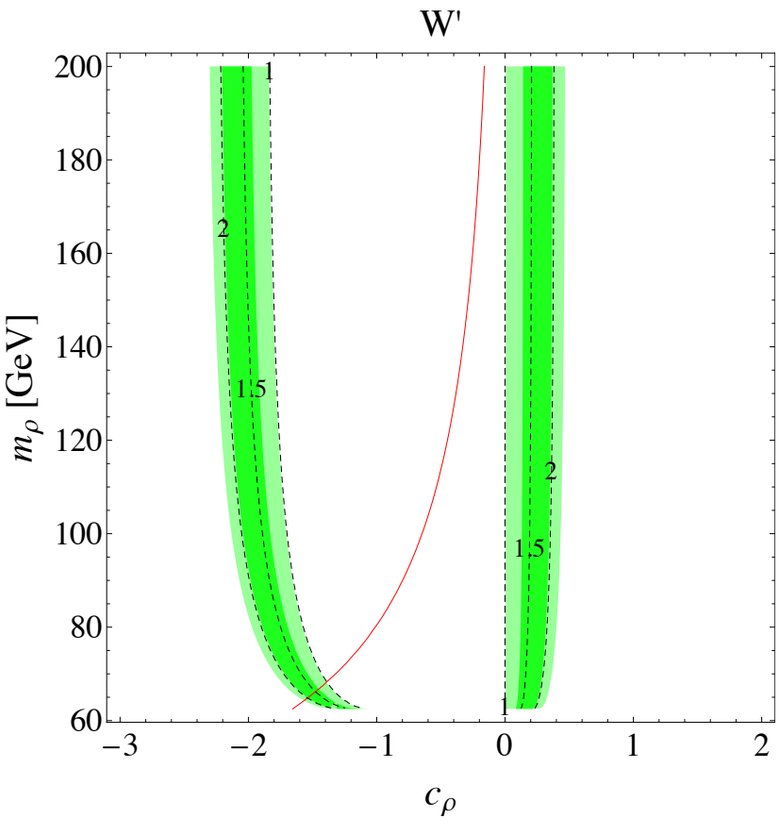
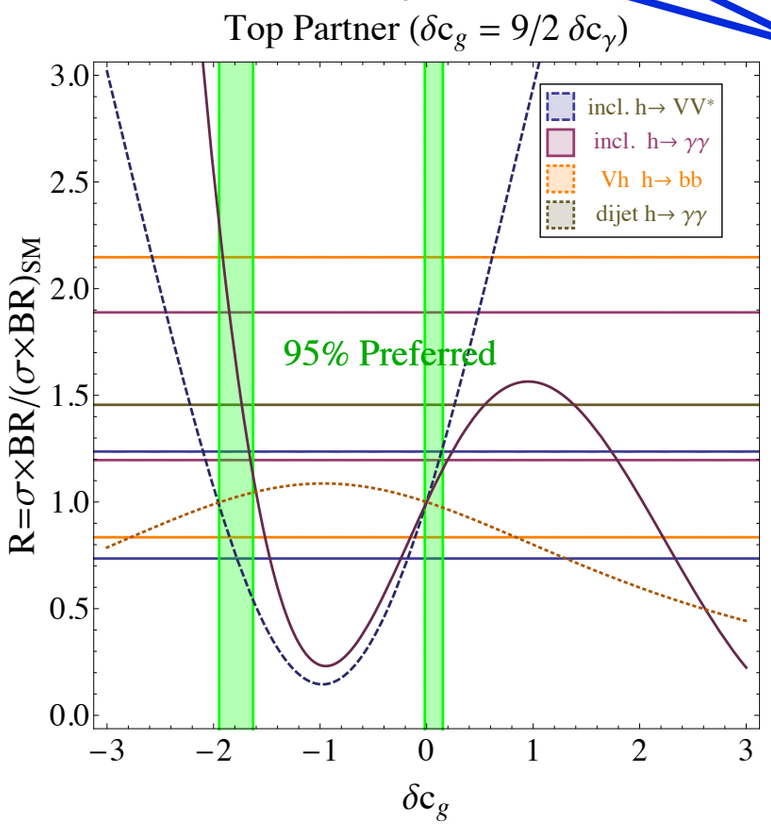




top and W partners can accommodate increased $h \to \gamma\gamma$





scalar top (1stop only) either fix naturalness or fix the BR's

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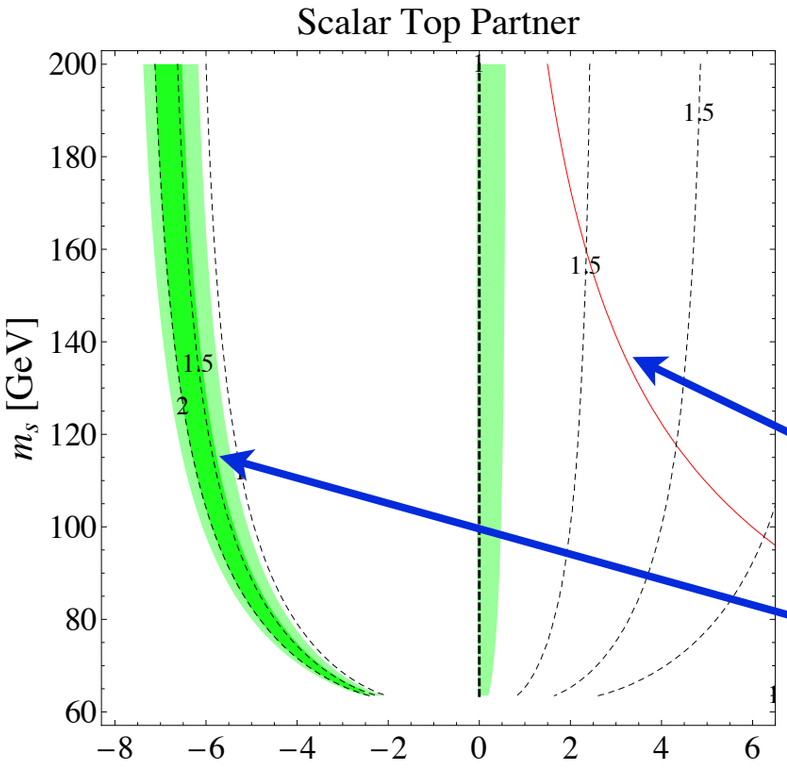
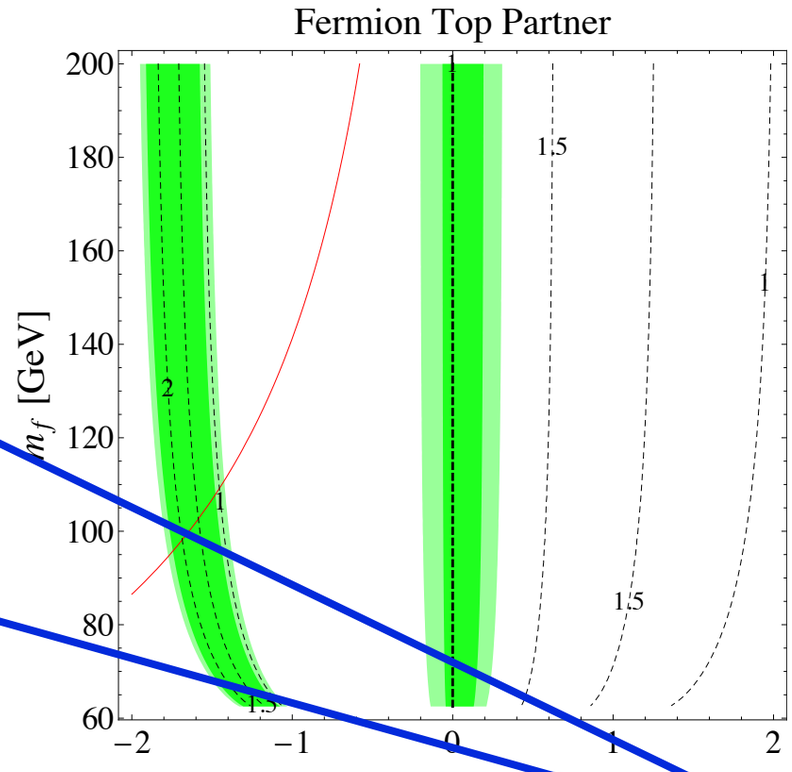
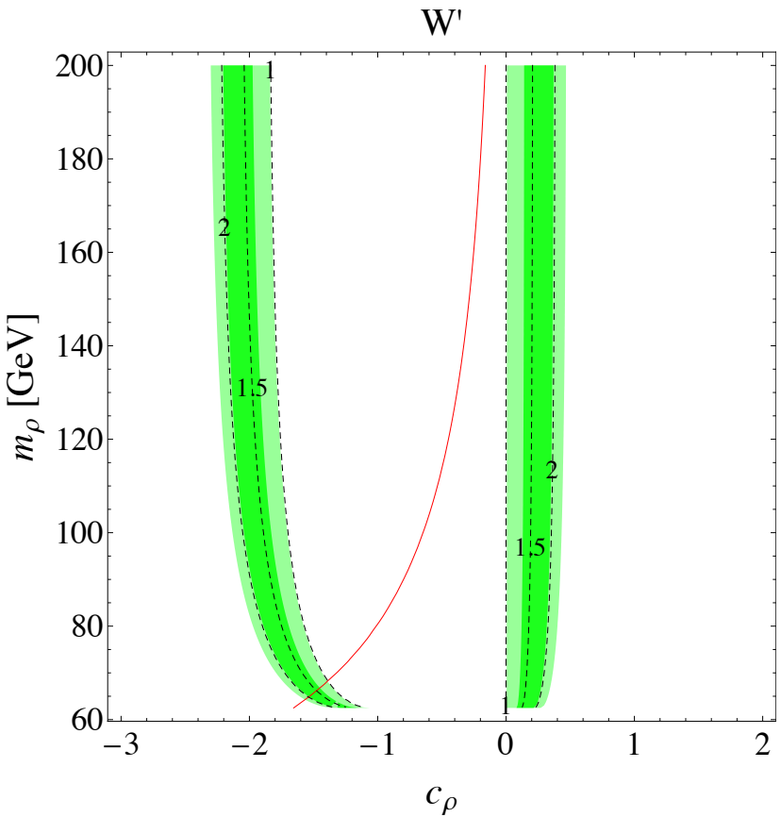
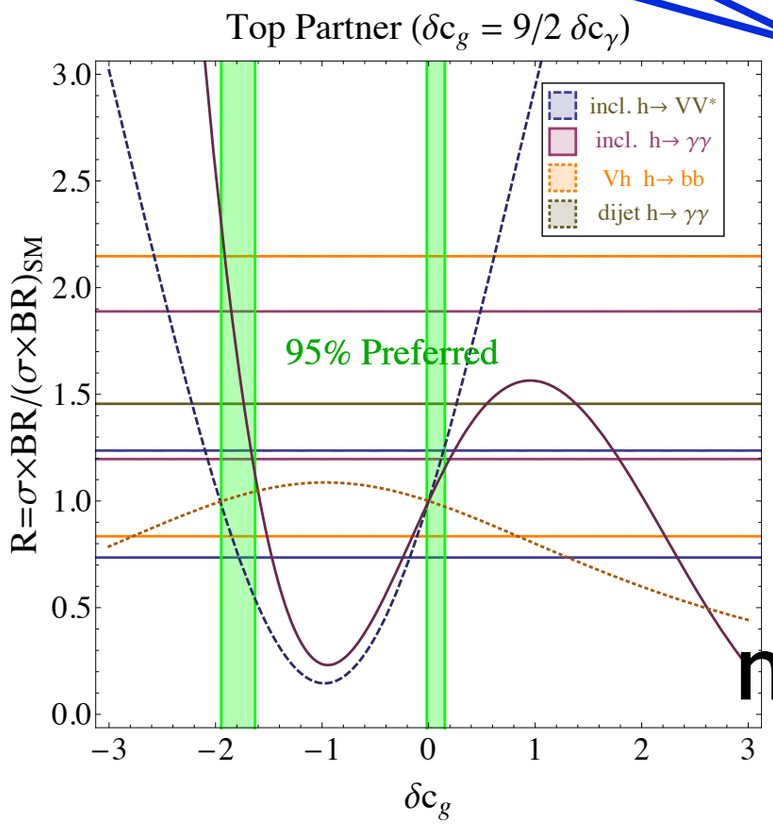








top and W partners can accommodate increased h→γγ

scalar top (1stop only) either fix naturalness or fix the BR's

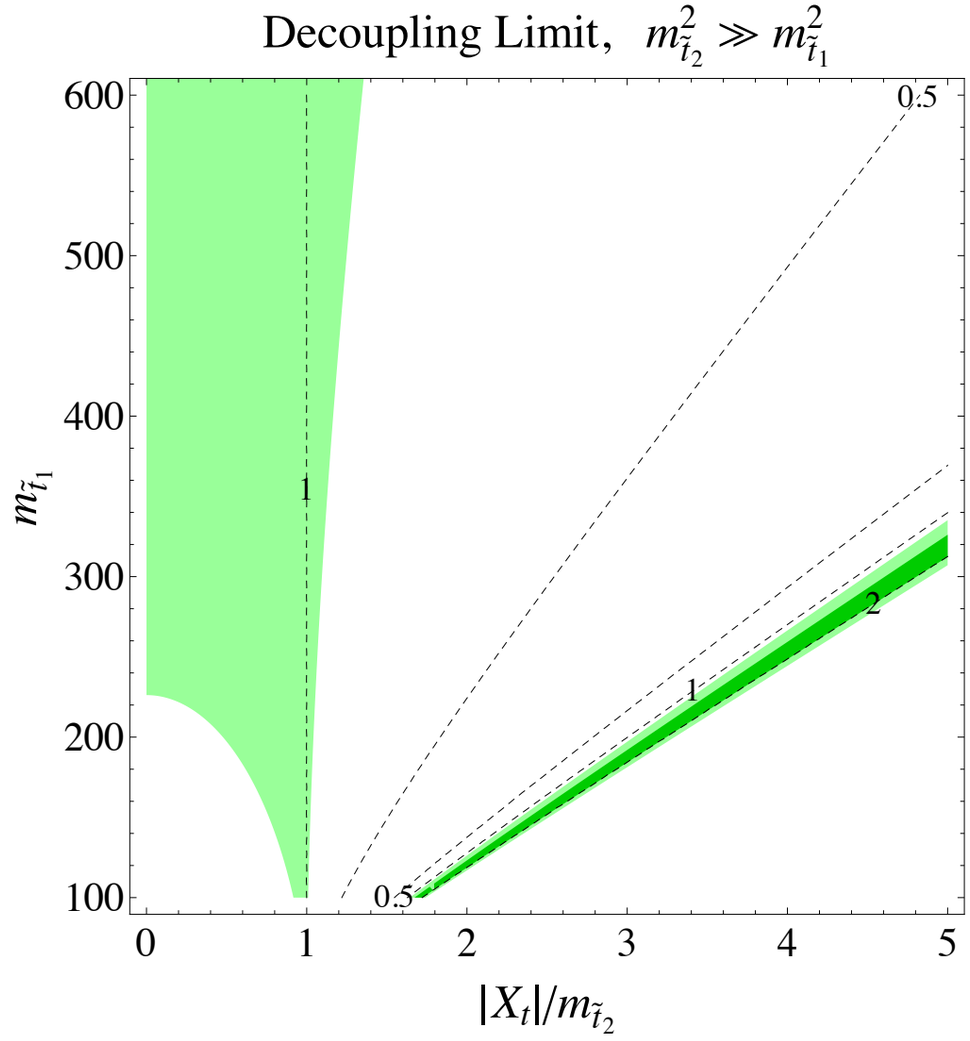
need 2 stops (SUSY)

SUSY (again…)

Stops in SUSY may be able to fix Higgs BR's, even at relatively light masses

from M.Carena's talk:
stops fail to fix the BR's
AND raise the Higgs mass

light stops are interesting for naturalness, so have a look at a more general scenario...



SUSY & the weak scale

- SUSY provides a nice framework for stabilizing the ElectroWeak scale

$$\frac{m^2_{Higgs}}{2} = -|\mu|^2 + \ldots + \delta m^2_H$$

$$\delta m^2_H|_{stop} = -\frac{3}{8\pi^2} y_t^2 \left(m^2_{U_3} + m^2_{Q_3} + |A_t|^2 \right) \log\left(\frac{\Lambda}{\mathrm{TeV}} \right)$$

$$\delta m^2_H|_{gluino} = -\frac{2}{\pi^2} y_t^2 \left(\frac{\alpha_s}{\pi} \right) |M_3|^2 \log^2\left(\frac{\Lambda}{\mathrm{TeV}} \right)$$

- more general than the MSSM
- amount of cancelation has not been directly probed yet! (experimental question)
- interesting to look first for those cases where this cancelation is not strong (naturalness)

- What are the minimal requirements for a "natural" weak-scale SUSY?
  - (some of the) superpartners have to be light enough:
    - 2 light stops
      - 1 light "left-handed" sbottom (required to be near the stops by weak isospin)
    - light higgsinos, i.e. 2 neutralinos and 1 chargino
    - a not-too-heavy gluino

Model dep':

- if low scale mediation, a light gravitino
- if WIMP DM, another neutralino (bino?)

Rest could be decoupled...

What about numbers?

difficult to make sharp quantitative statements (just a guidance):
what is "natural"? 10-9=1? 100-99=1? 1000-999=1? 1 part in 10^4? …

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$$\sqrt{m_{\tilde{t}_1}^2 + m_{\tilde{t}_2}^2} \lesssim 600\,\mathrm{GeV}\,\frac{\sin\beta}{(1+x_t^2)^{1/2}}\left(\frac{\log\left(\Lambda/\,\mathrm{TeV}\right)}{3}\right)^{-1/2}\left(\frac{m_h}{120\,\mathrm{GeV}}\right)\left(\frac{\Delta^{-1}}{20\%}\right)^{-1/2}$$

(e.g. Kitano & Nomura 2006)

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(bino, wino)

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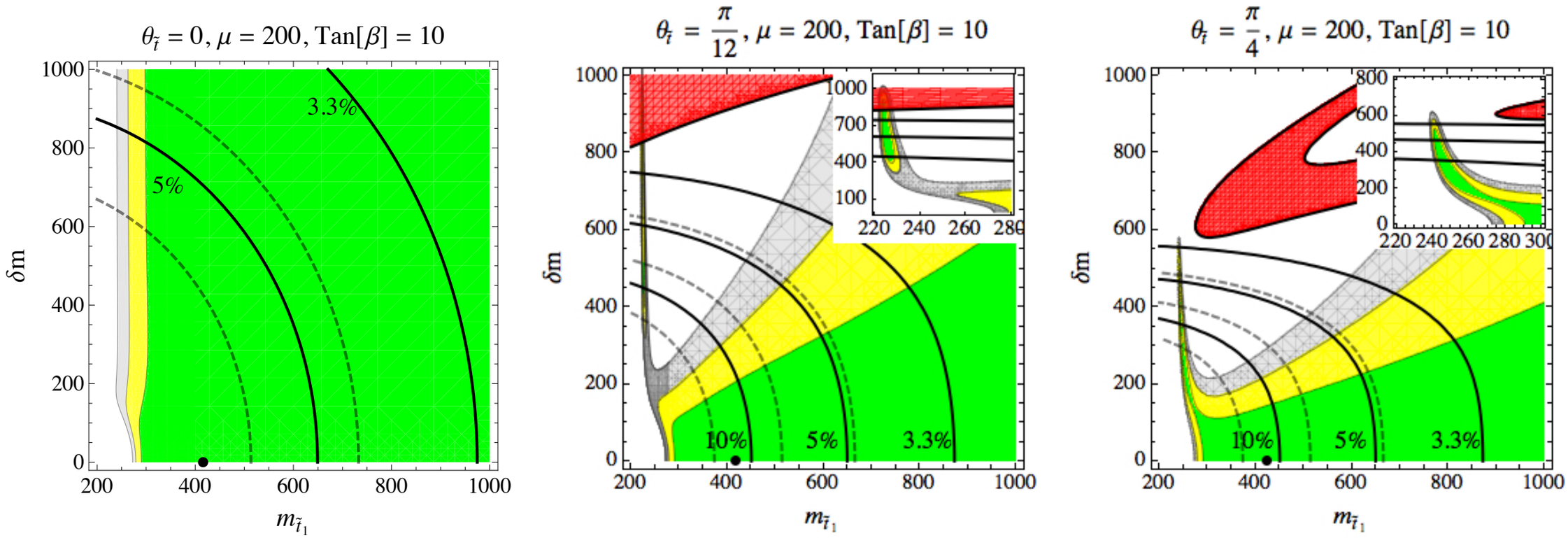
1st-2nd gen' squarks not very constrained

Natural SUSY



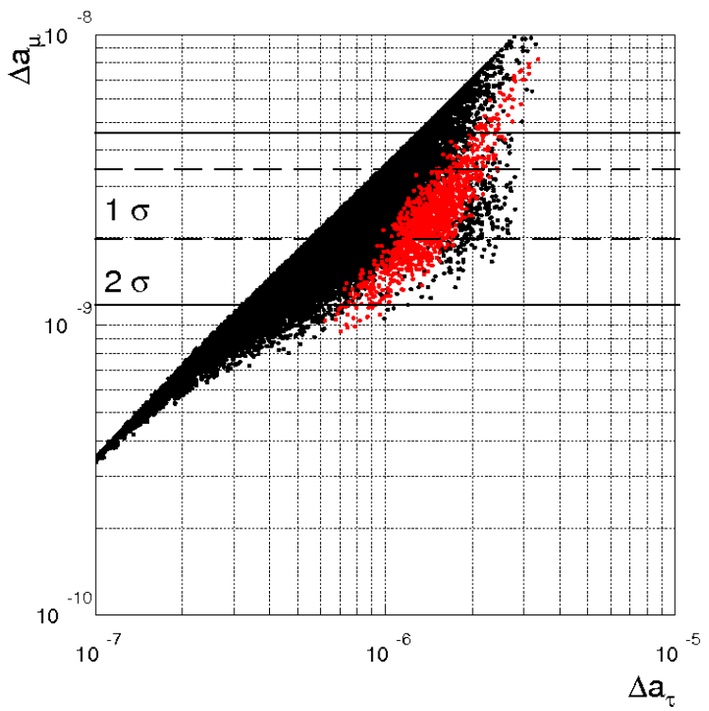
Espinosa, Grojean, Sanz, Trott
arXiv:1207.7355

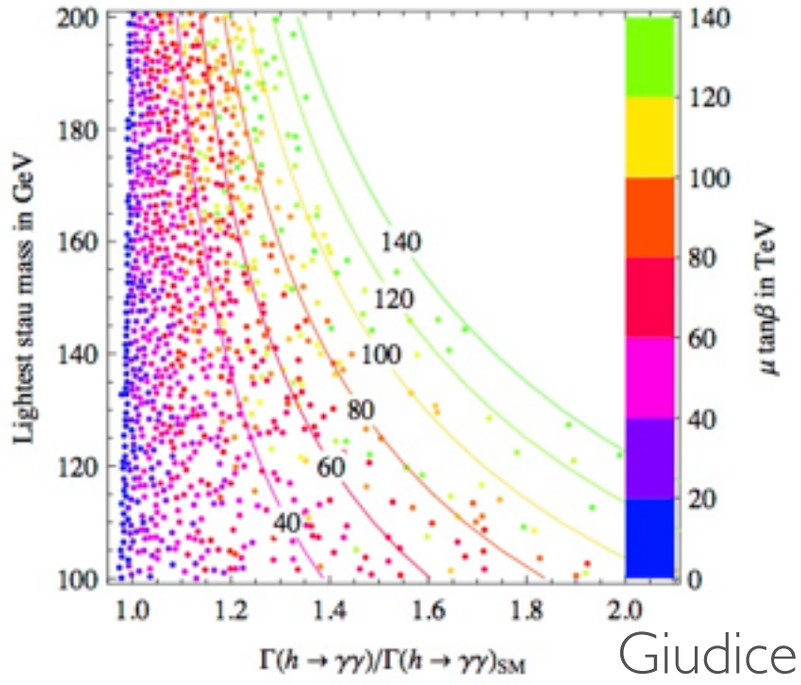
- constraints from Higgs measurements, b→sγ, direct searches
- assumes other source for Higgs mass (red region would be required in MSSM), decoupling limit and that addtl source for the Higgs mass does not modify the BR's

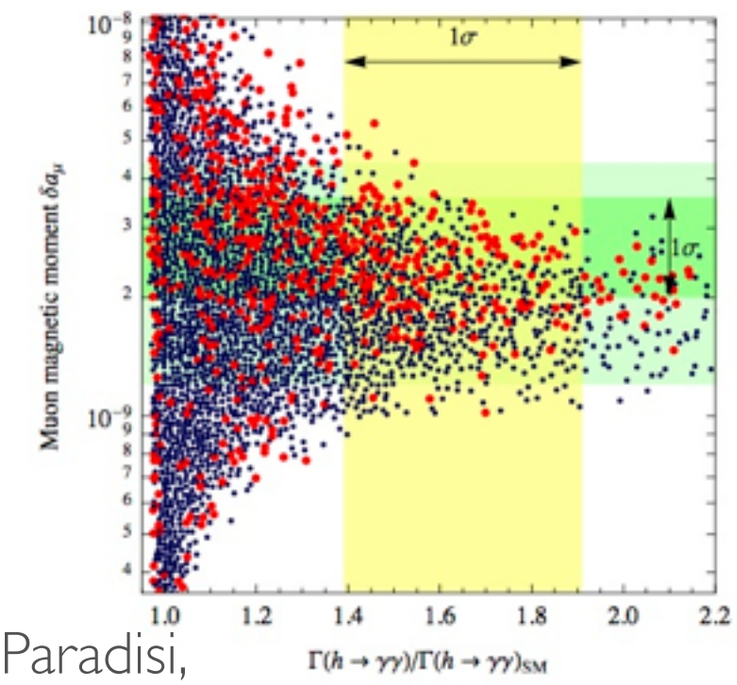
Correlations with other anomalies

Higgs & g_μ-2

- Enhanced $\gamma\gamma$ rate in the MSSM can be achieved with light mixed staus (see M.Carena's talk)
- staus also contribute to g_μ-2 of the muon
- contribution is in the right direction and of the right size → correlation between the two effects



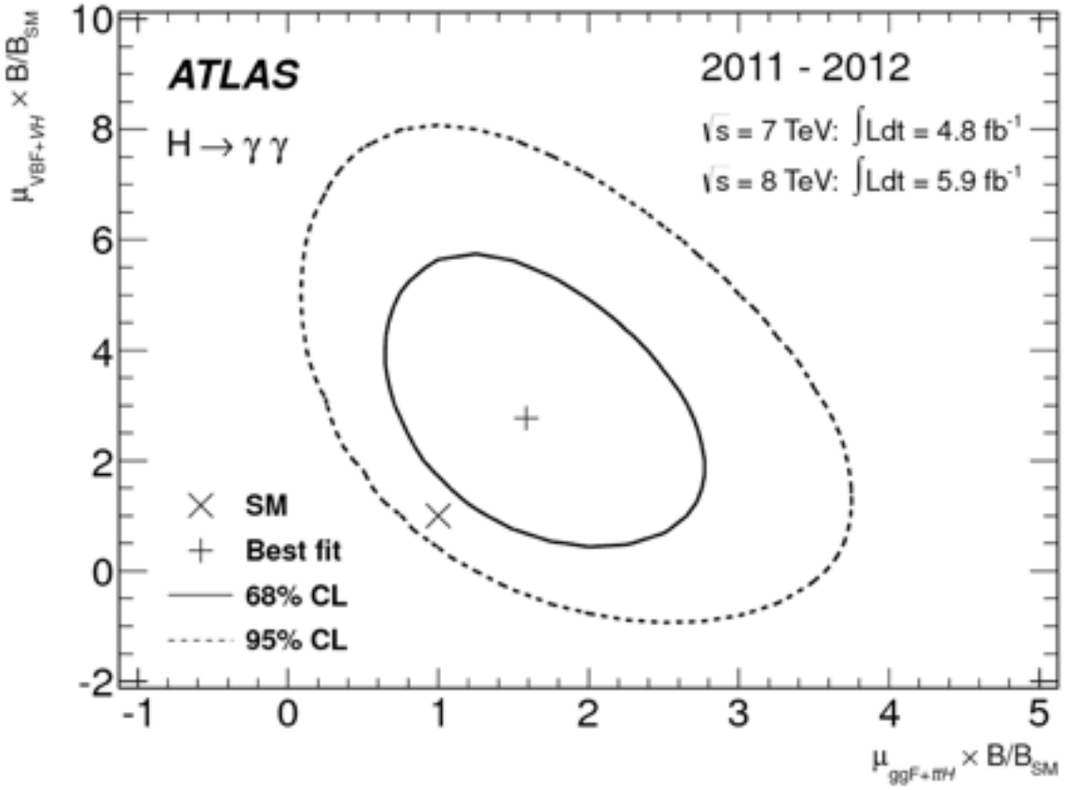


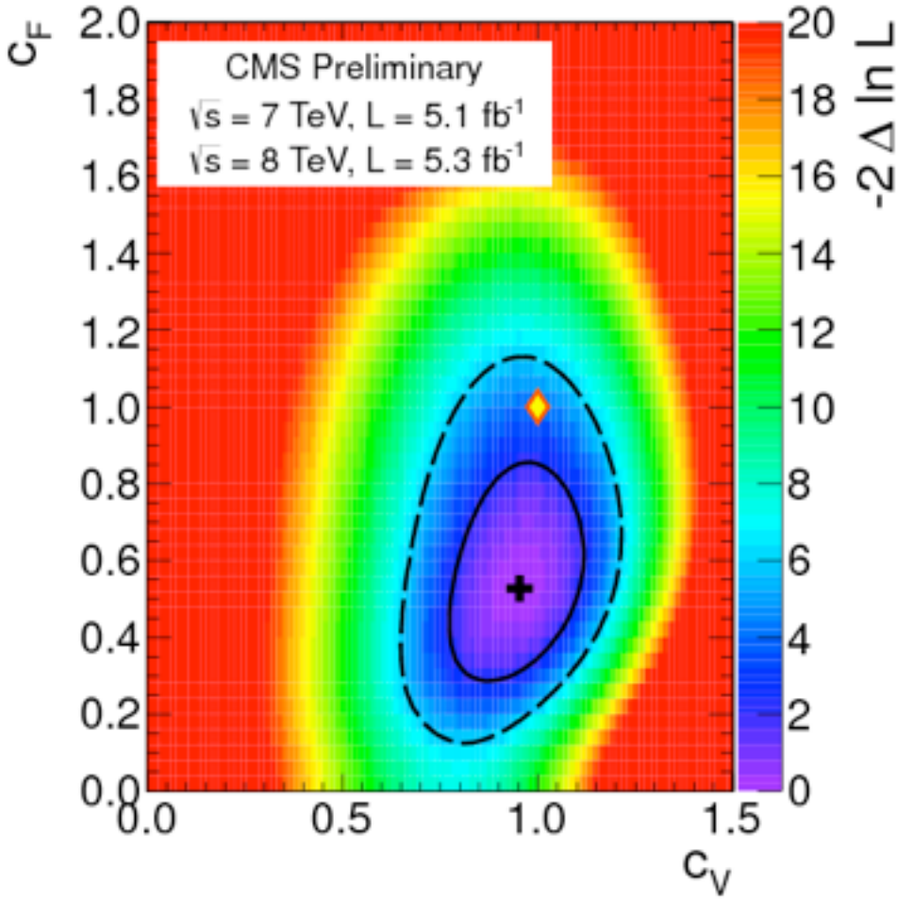


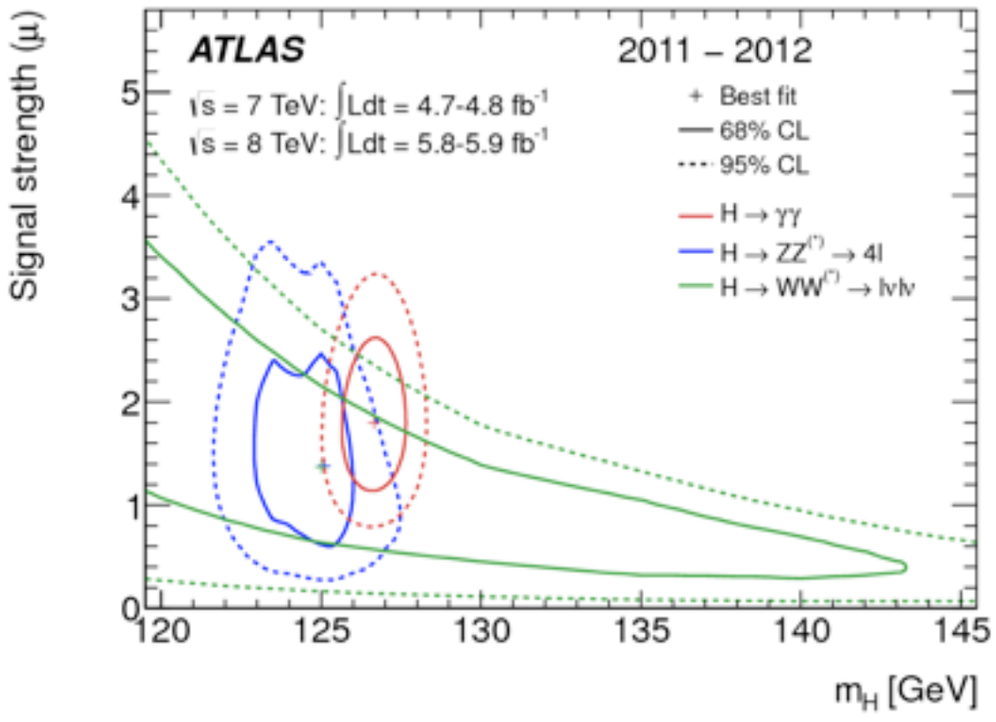
Giudice, Paradisi, Strumia 1207.6393

Model building enhanced rates

Enhanced h→VV?







What if with more data g_{VVh} remain larger than the SM?

Enhanced h→VV?

- How can you enhance a?

$$\mathcal{L}_{hVV} = a\,\frac{h}{v}\left(2m_W^2 W_\mu^+ W_\mu^- + m_Z^2 Z_\mu Z_\mu\right)$$

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More stringent sum rule: Falkowski, Rychkov, Urbano 1202.1532

$$1 - a^2 = \frac{v^2}{6\pi}\int_0^\infty \frac{ds}{s}\left(2\sigma_{I=0}^{\rm tot}(s) + 3\sigma_{I=1}^{\rm tot}(s) - 5\sigma_{I=2}^{\rm tot}(s)\right).$$

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I=2 contrib in WW scattering necessary. Models?

Enhanced h→VV?

- Simplest model: Machacek & Georgi (1985):
  - $H_{2,1/2} + T^0_{3,0} + T^1_{3,1}$
- both doublets and triples participate in EWSB but custodial symmetry is preserved
- 2singlets+ 1 triplet+ 1 quintuplet of custodial isospin
- 4 neutral + 2 charged + 1 doubly charged scalars
- a depends on mixing angles and $a^2<8/3$ (can be larger than 1)

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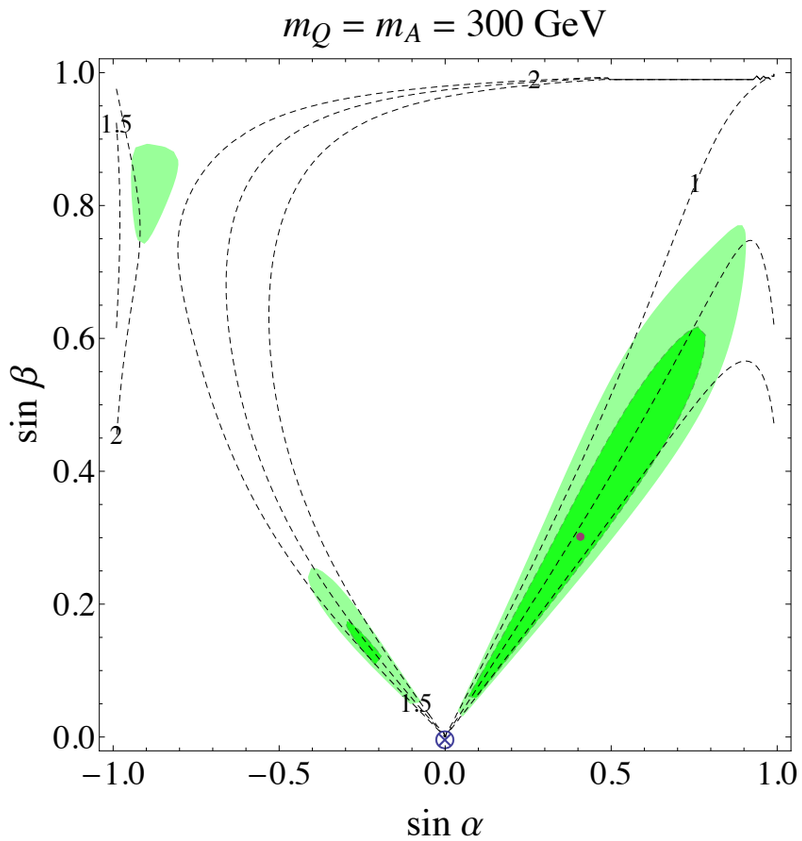
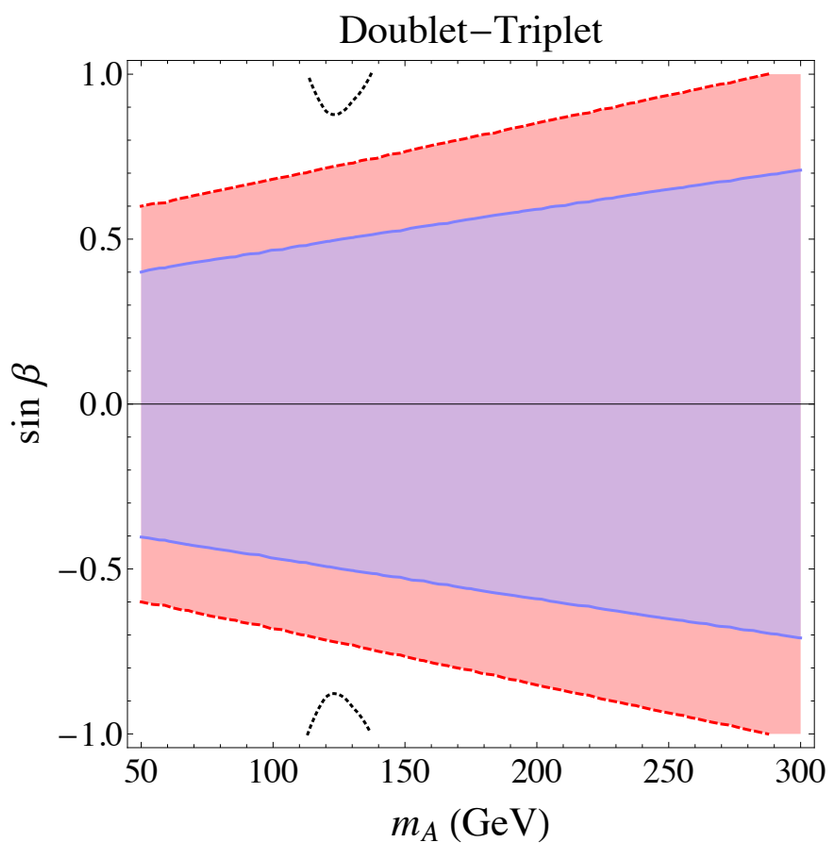
Carmi, Falkowski, Kuflik,
Volansky, Zupan arXiv:1207.1718





viable in large region of parameter space

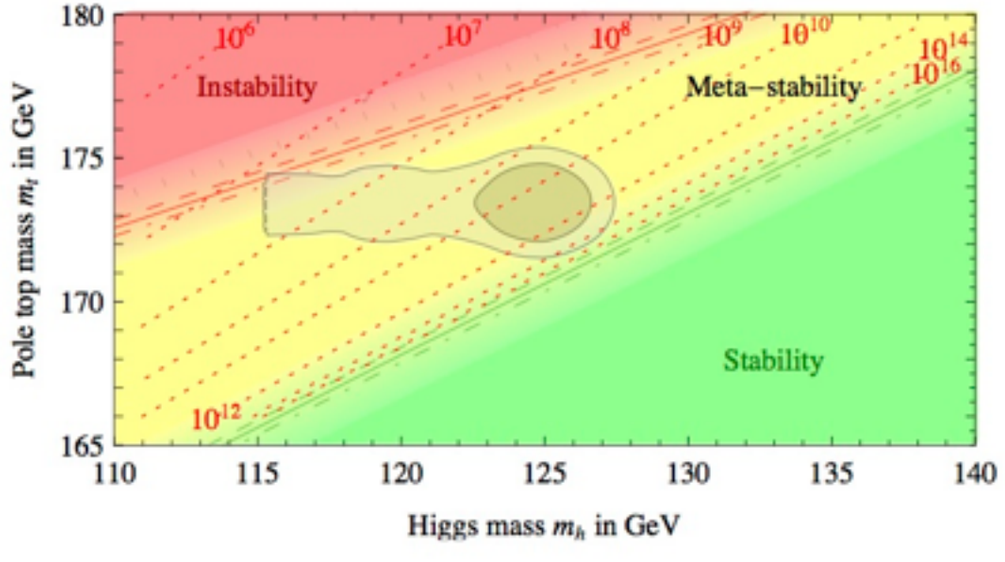
best fit: c~1, a>1 (enhance γγ)

direct and indirect constraints easily satisfied

Unnatural SM + ??

(split susy, supersplit susy and all that…)

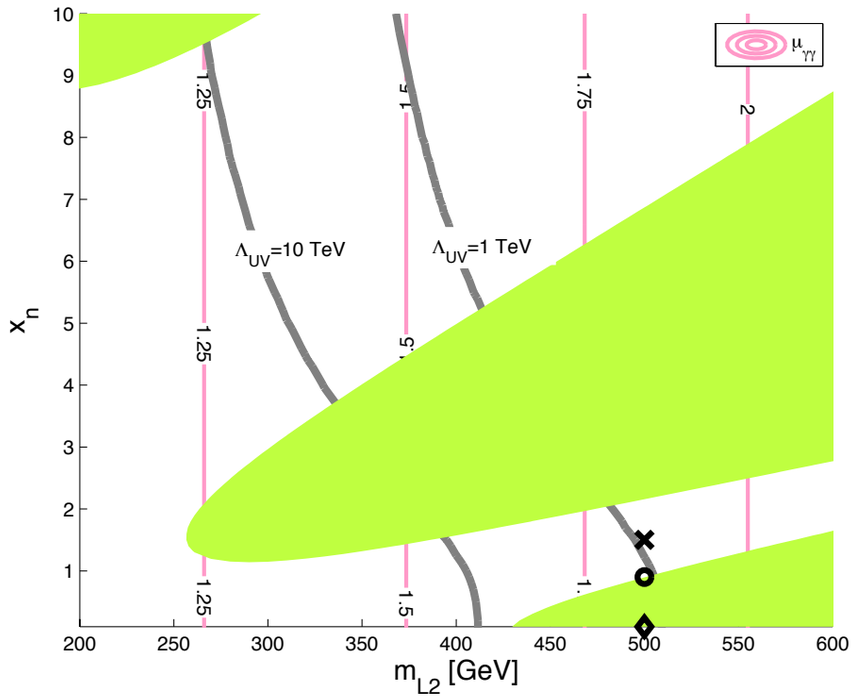
Unnatural SM

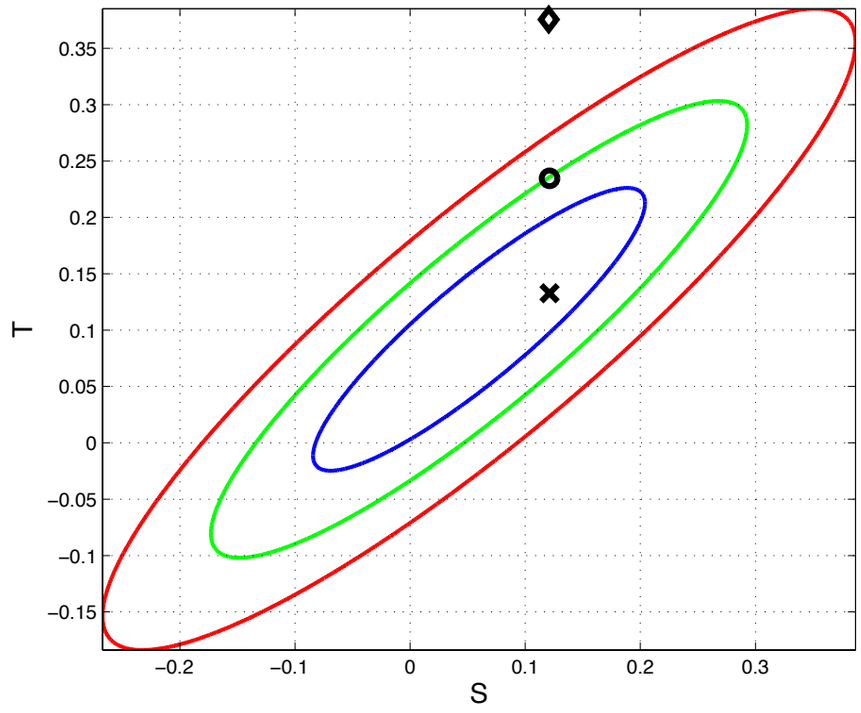


- In H.Haber lecture: 125GeV Higgs imply that if the SM is valid up to the Planck scale, the EW vacuum is metastable (and the potential is very flat at that scale)
- Requires that hierachy problem is of "environmental" origin
  - maybe only scalar finetuned is the Higgs b/c $v<<M_P$
  - but if $h \to \gamma\gamma$ stays enhanced new physics at the EW scale is needed...

Unnatural SM+...

- enhance $h \to \gamma\gamma$ with scalars would introduce new hierarchy problems
- using fermions destabilize Higgs potential: $\Lambda_{SM} << M_P$





Arkani-Hamed, Blum, d'Agnolo, Fan arXiv:1207.4482

if $h \to \gamma\gamma$ stays high at 1.5x SM either new fermions in LHC reach or low cutoff → NP around the corner

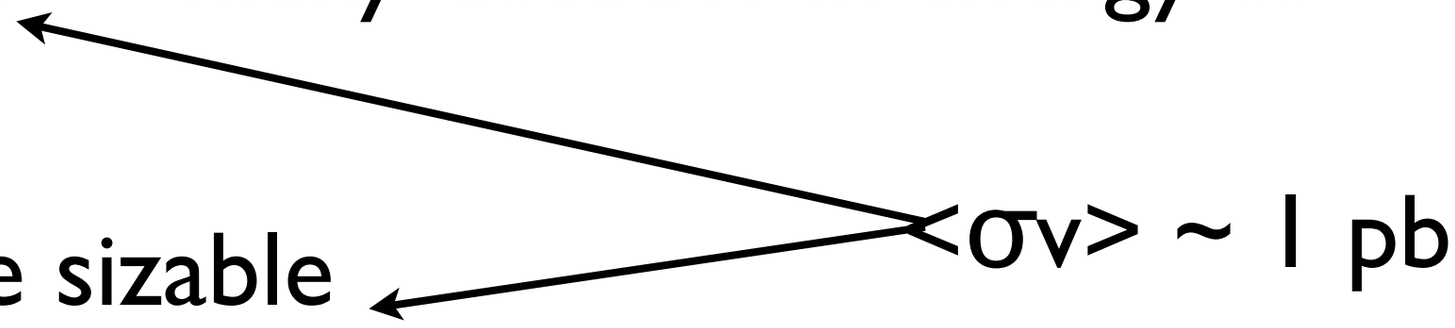
Unnatural SM+??

- We know there is physics beyond the standard model that requires new dynamics
  - neutrino masses
  - dark matter
  - baryonic asymmetry
- Some of the models presented to address these questions require new interactions with the Higgs
- minimally including these new ingredients may change the Higgs stability picture → different cutoff

SM+WIMP DM

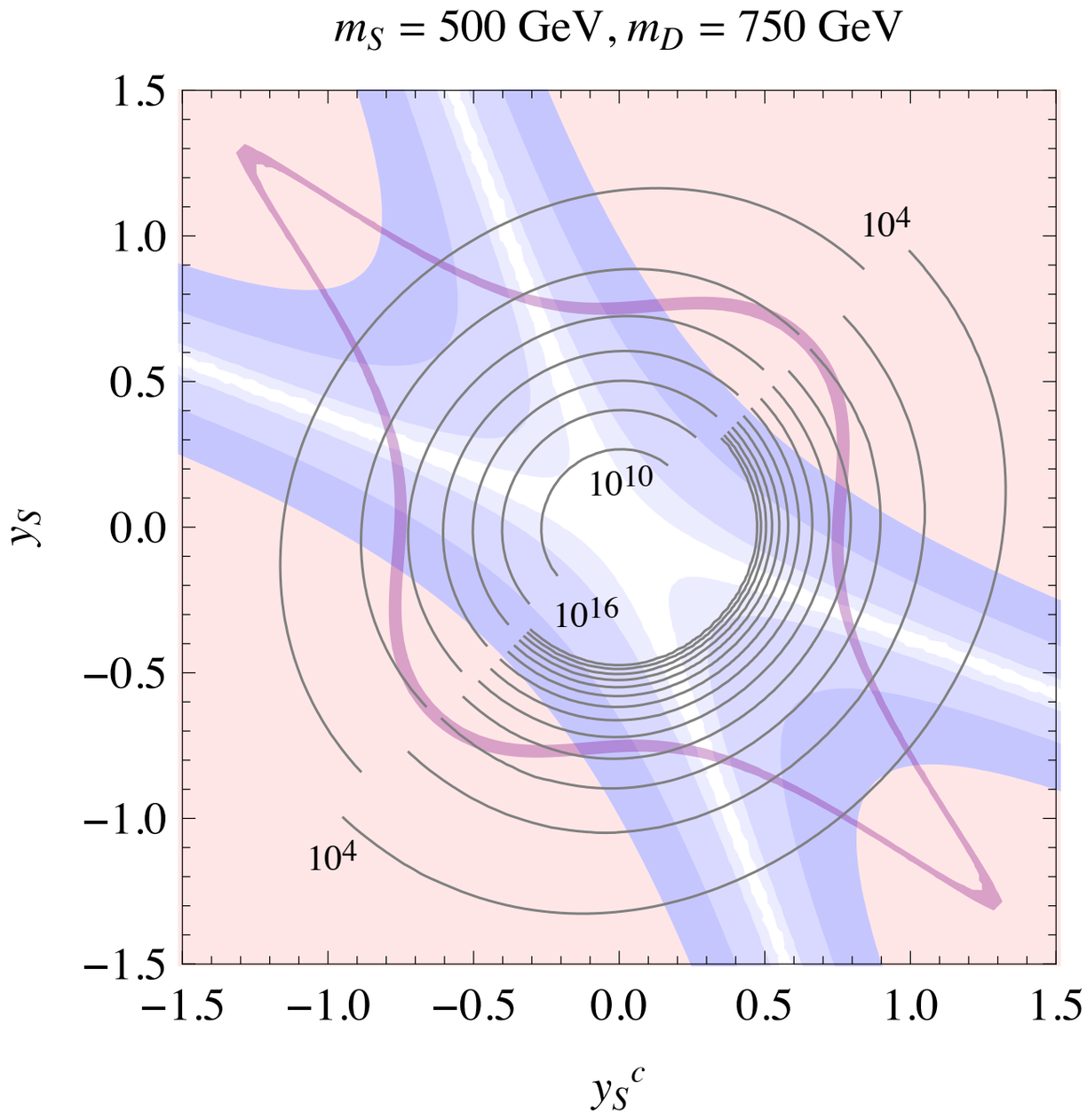
Cheung, M.P., Zurek arXiv:1203.5106

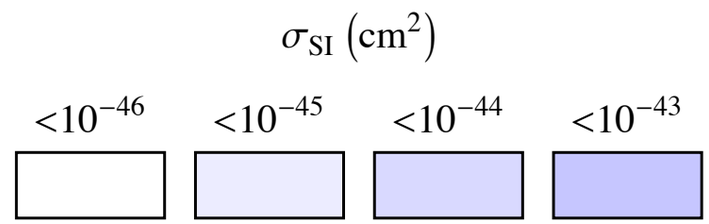
- WIMP Dark matter is "unique":
  - weak scale mass → many decades in energy to affect Higgs
  - couplings can be sizable
  - indipendent constraints → correlations with Direct Detection measurements



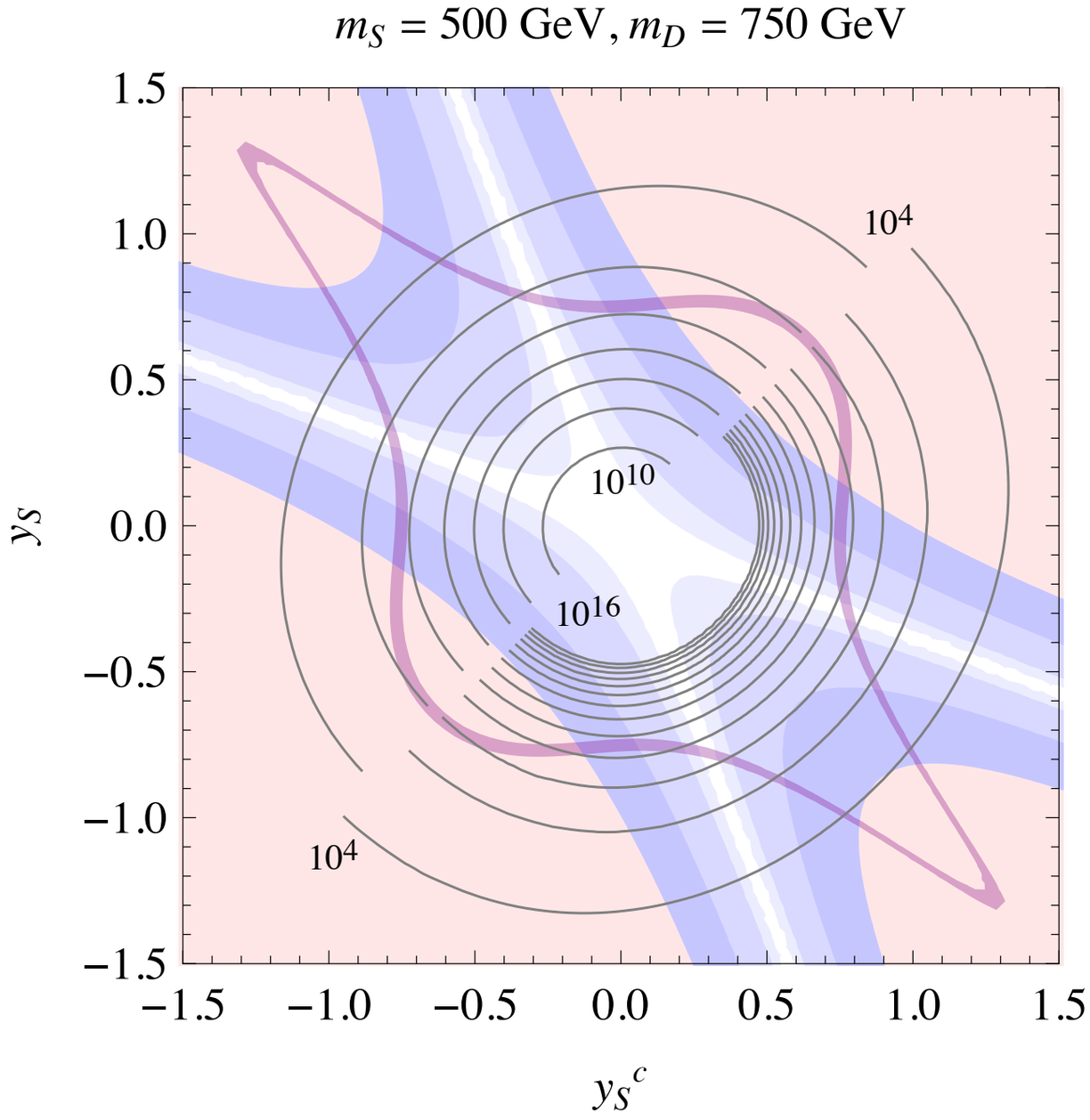
Higgs stability of SM+WIMP DM?

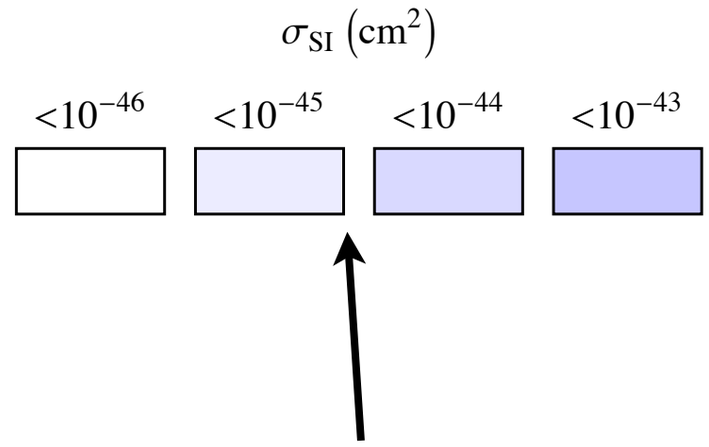
Full picture: Fermionic DM





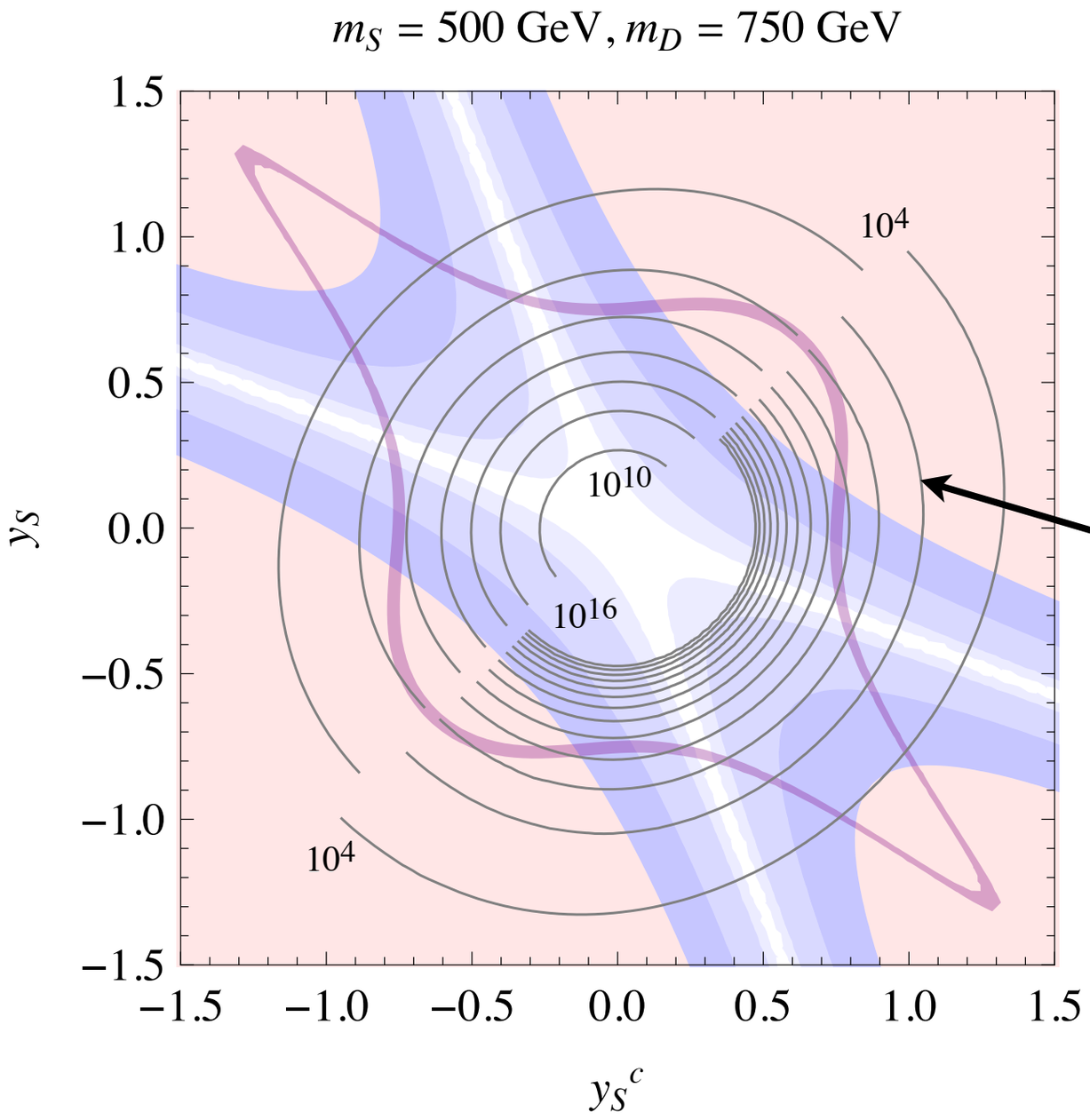
Full picture: Fermionic DM

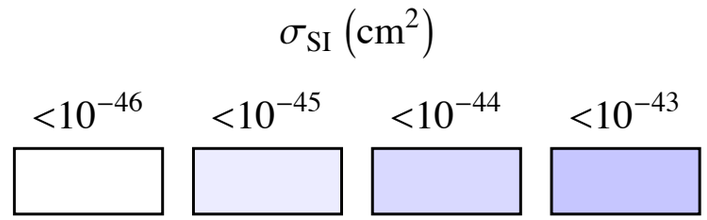




Direct Det' xsec

Full picture: Fermionic DM

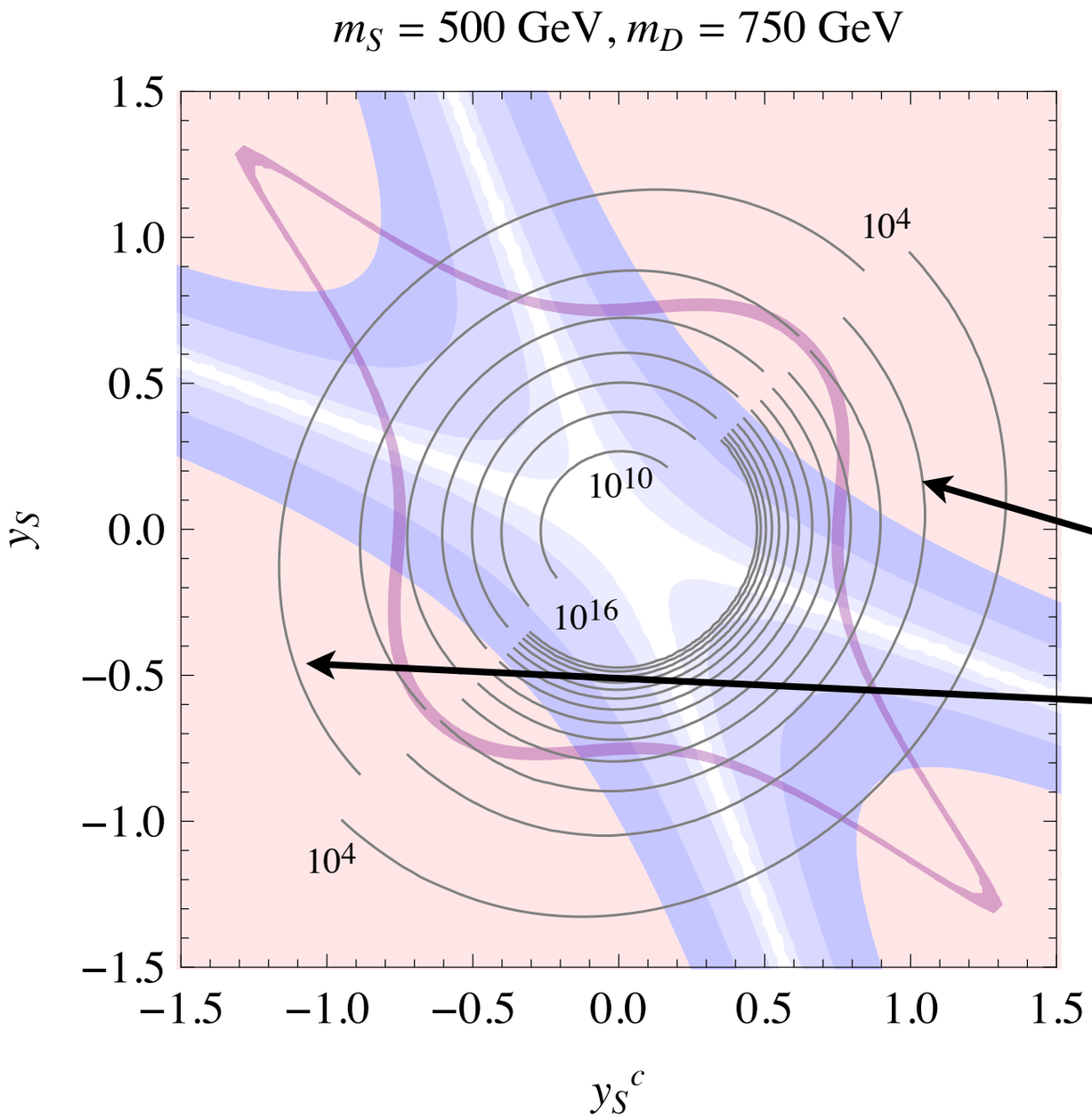


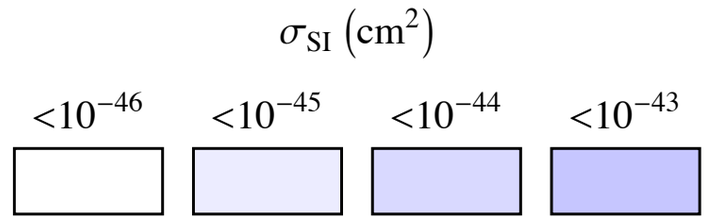


Direct Det' xsec

Stability limits

Full picture: Fermionic DM



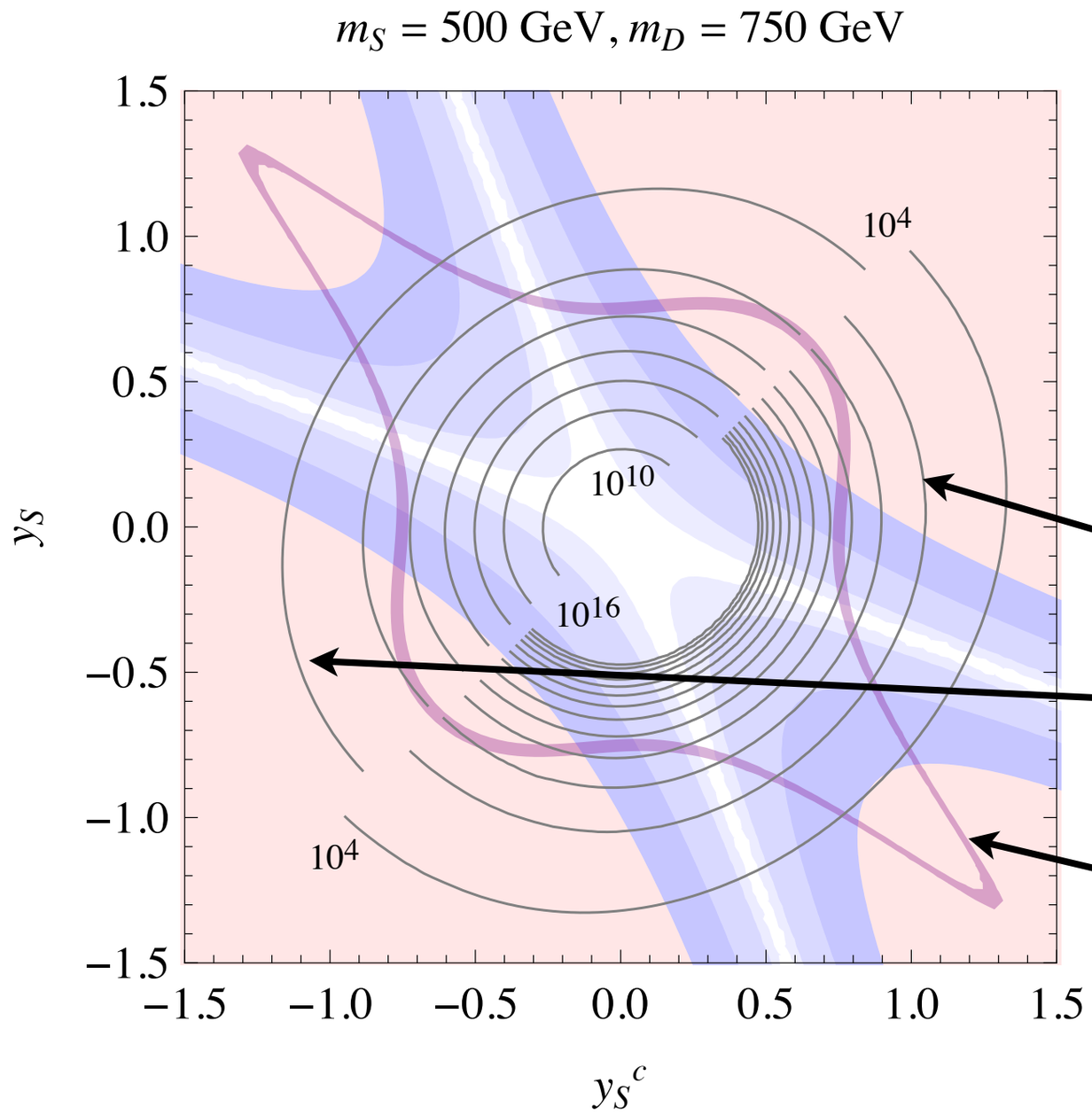


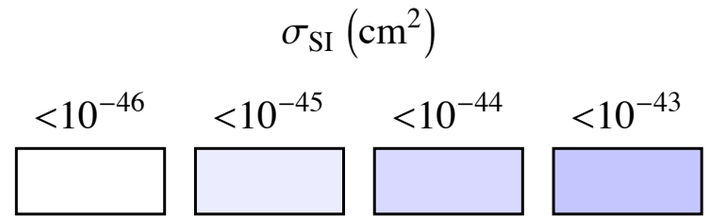
Direct Det' xsec

Stability limits

Metastability limits

Full picture: Fermionic DM





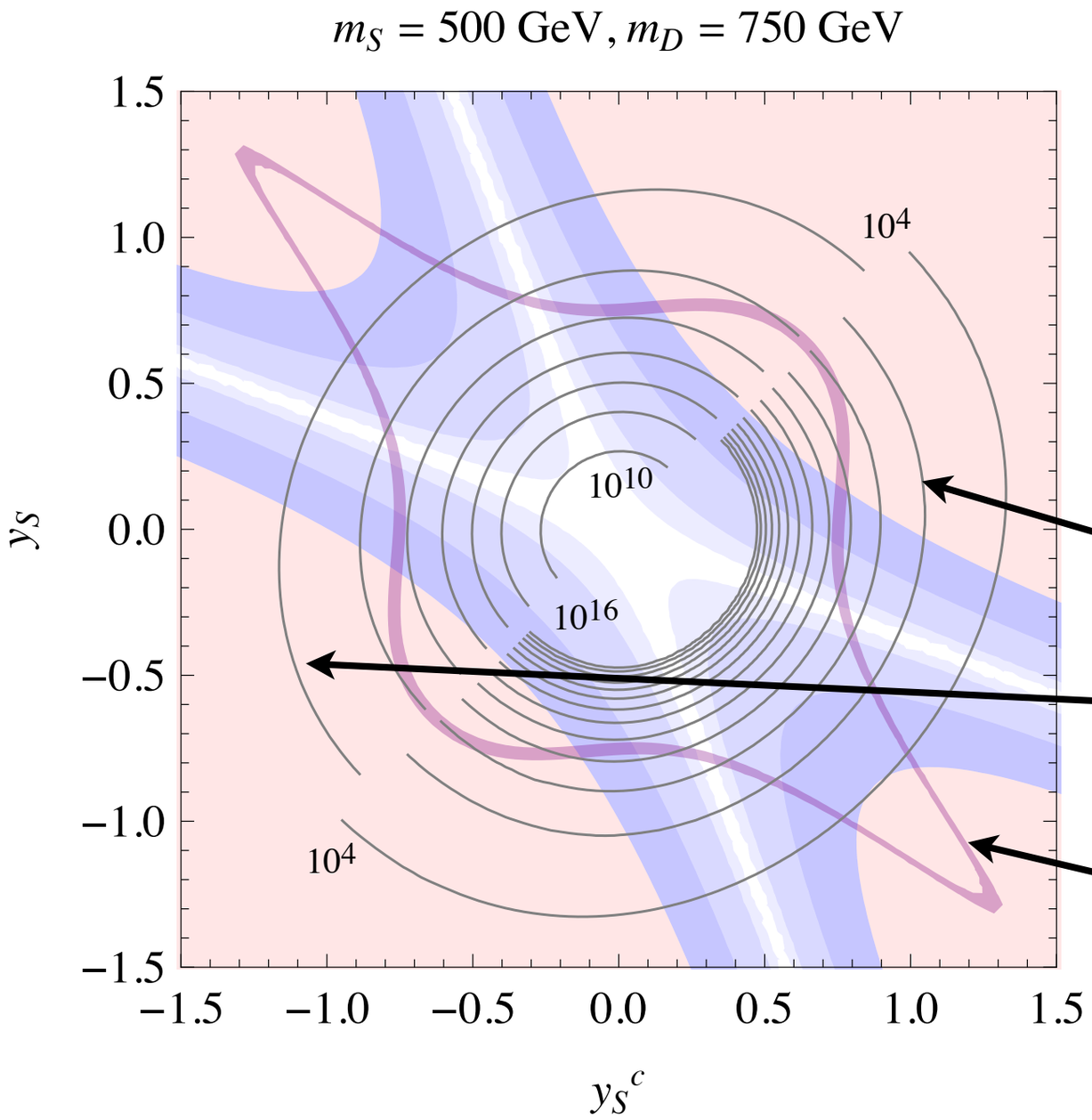
Direct Det' xsec

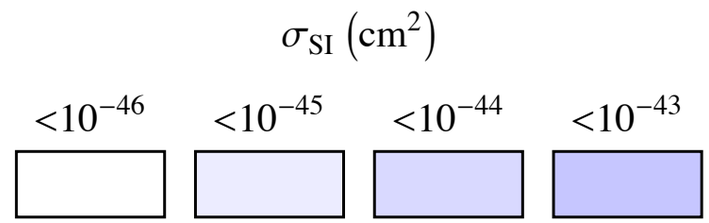
Stability limits

Metastability limits

Relic abundance

Full picture: Fermionic DM





Direct Det' xsec

Stability limits

Metastability limits

Relic abundance

- Requirements of relic abundance limit the desert

What's next?

- The "sketch of the Higgs face" will become more detailed: smaller errors, new info on bb,ττ modes, maybe even some "exotic" modes like h→aa→bbττ or jjμμ, etc.
- If something non-standard remains in the BR's (or appears) the hunt for the responsible particles will be open
- Testing the role of the 125GeV particle in the (composite nature, role in WW scattering, …) will take a long time
- In the meantime it will bring us a lot of fun. Happy Higgs to all of you!!