Light dark matter and the Higgs

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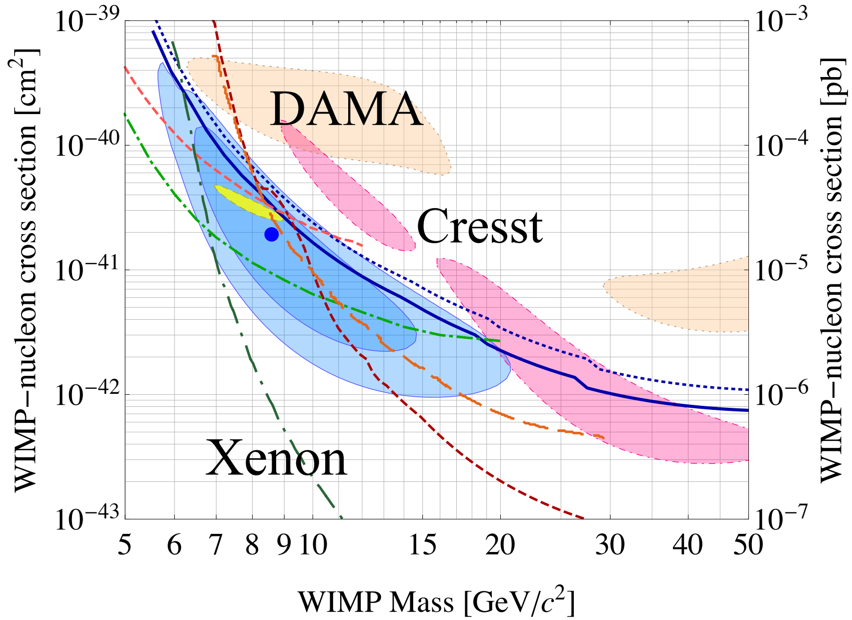
DMAstroLHC

- The 126 GeV Higgs is standard
  - Not so surprising - to the level of precision that its properties are measured. That was expected for most of the parameter space of SUSY models - even if large deviations are possible.
- No sign of new physics in B-observables
- No sign of BSM at LHC
- But we have strong evidence for dark matter
- What can we learn on DM from the Higgs?
  - How non-standard can the Higgs be?

Light dark matter

- $m_{DM} < m_h/2$ --> direct link with Higgs physics
- Hints in direct detection
- DAMA, CoGENT, CDMS-Si, CRESST all reported some signals compatible with light DM
- Exclusion by Xenon ...
- Hints indirect detection



CDMS, arXiv:1304.4279

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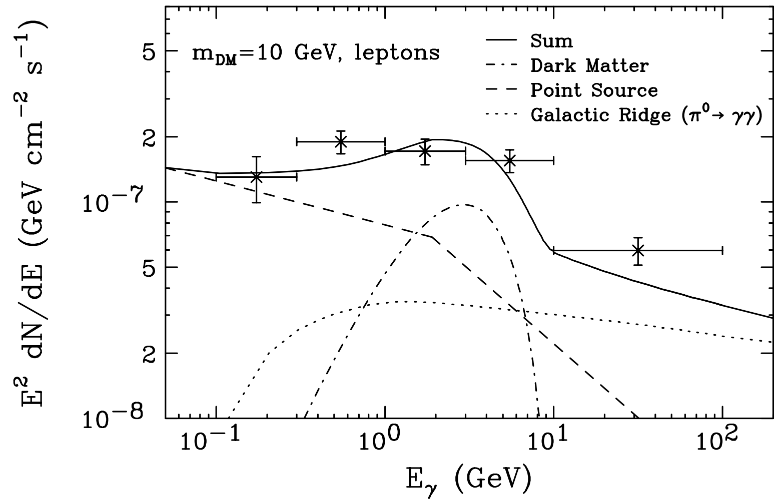


Gamma-rays from Galactic Center
Hooper, Linden 1110.0006

- No clear DM signal

Outline

- How standard is the Higgs and implications for dark matter
- The special case of the MSSM
- Conclusion

How standard is the Higgs?

- Carmi et al, 1202.3144, Azatov et al, 1202.3415, Espinosa et al, 1202.3697, Klute et al, 1205.2699, Azatov et al, 1206.1058, Low et al, 1207.1093, Corbett et al, 1207.1344, Giardino et al, 1207.1347, Ellis et al, 1207.1693, Montull et al 1207.1716, Espinosa et al, 1207.1717, Carmi et al, 1207.1718, Banerjee et al, 1207.3588, Bertolini et al, 1207.4209, Bonnet et al, 1207.4599, Plehn et al, 1207.6108, Elander et al, 1208.0546, Djouadi, 1208.3436, Dobrescu, Lykken, 1210.3342, Moreau, 1210.3977, Cacciapaglia et al 1210.8120, Corbett et al, 1211.4580, Masso, Sanz, 1211.1320, Azatov, Galloway, 1212.1380, GB et al, 1212.5244, Cheung et al, 1302.3794, Celis et al, 1302.4022, GB et al, 1302.5694, Falkowski et al, 1303.1812, Cao et al, 1303.2426, Giardino et al, 1303.3570, Ellis et al, 1303.3879, Djouadi et al, 1303.6591, Chang et al, 1303.7035, Dumont et al 1304.3369, Bechtle et al, 1305.1933 ....

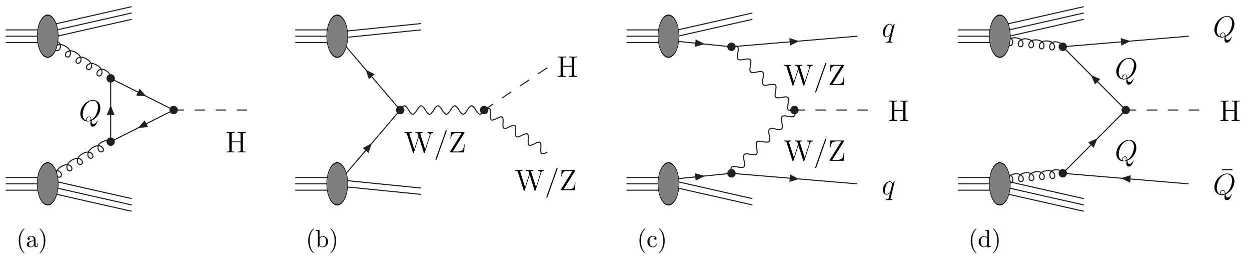
Generic Higgs couplings

- Scaling SM tree-level couplings

$$\mathcal{L} = g\left[C_V\left(m_W W_\mu W^\mu + \frac{m_Z}{\cos\theta_W} Z_\mu Z^\mu\right) - C_U \frac{m_t}{2m_W}\bar{t}t - C_D \frac{m_b}{2m_W}\bar{b}b - C_D \frac{m_\tau}{2m_W}\bar{\tau}\tau\right] H$$

- Assume custodial symmetry $C_W = C_Z = C_V$
- Assume family universality
- Loop-induced couplings: hgg, hγγ
  - modified if tree-level couplings are modified even if only SM particles in the loop
  - contributions from new particles
  - 5 free parameters $C_U, C_D, C_V, \Delta C_g, \Delta C_\gamma$

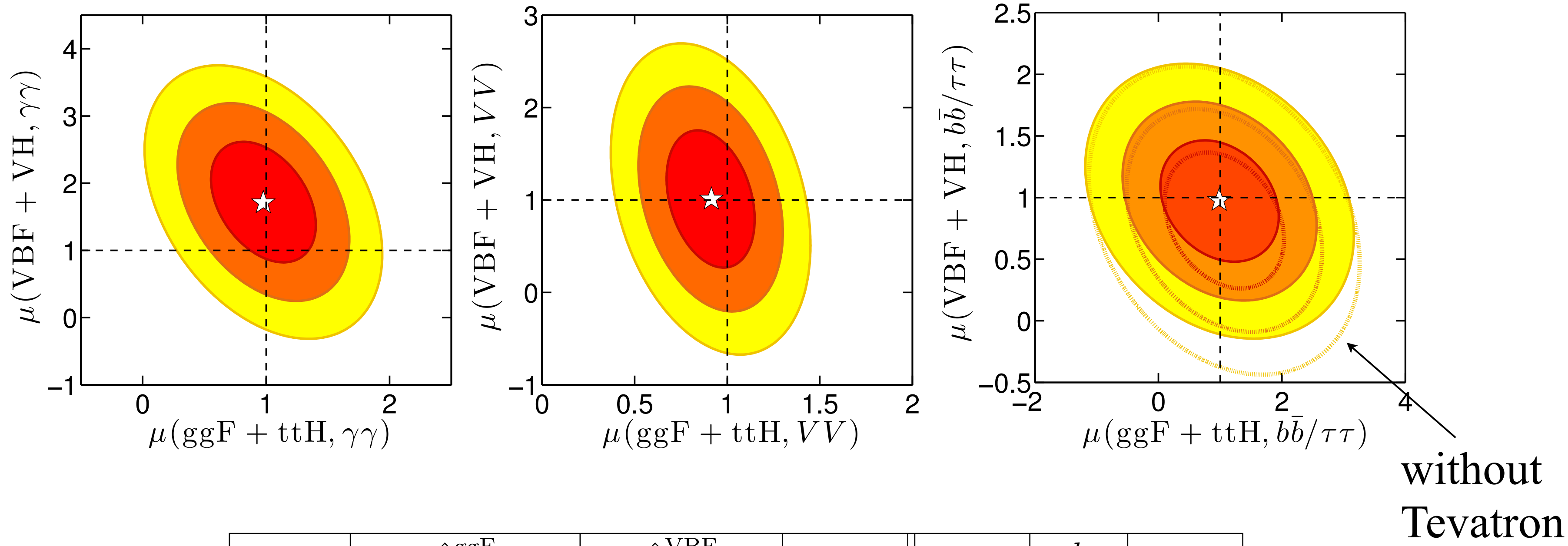
Production in pp



- two independent production modes VBF+VH, ggF+ttH
- Four independent final states: γγ,VV, bb,ττ
- Combine ATLAS, CMS and Tevatron results from Moriond and LHCP 2013 - include error correlations among production modes
- Combined likelihood in μ(ggF+ttH) - μ(VBF+VH) plane

$$\chi_i^2 = a_i(\mu_i^{\rm ggF} - \hat{\mu}_i^{\rm ggF})^2 + 2b_i(\mu_i^{\rm ggF} - \hat{\mu}_i^{\rm ggF})(\mu_i^{\rm VBF} - \hat{\mu}_i^{\rm VBF}) + c_i(\mu_i^{\rm VBF} - \hat{\mu}_i^{\rm VBF})^2\,,$$

Signal strength ellipses

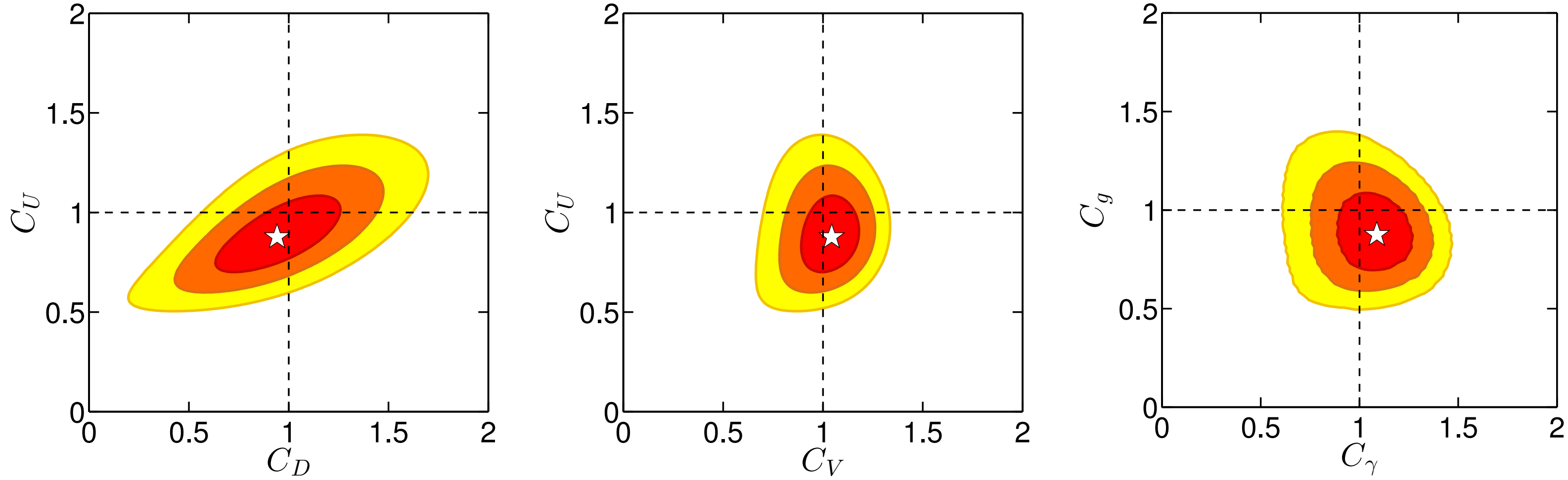


	$\hat{\mu}^{\rm ggF}$	$\hat{\mu}^{\rm VBF}$	ρ	a	b	c
$\gamma\gamma$	0.98 ± 0.28	1.72 ± 0.59	-0.38	14.94	2.69	3.34
VV	0.91 ± 0.16	1.01 ± 0.49	-0.30	44.59	4.24	4.58
$b\bar{b}/\tau\tau$	0.98 ± 0.63	0.97 ± 0.32	-0.25	2.67	1.31	10.12
$b\bar{b}$	-0.23 ± 2.86	0.97 ± 0.38	0	0.12	0	7.06
$\tau\tau$	1.07 ± 0.71	0.94 ± 0.65	-0.47	2.55	1.31	3.07

$$\chi_i^2 = a_i(\mu_i^{\rm ggF} - \hat{\mu}_i^{\rm ggF})^2 + 2b_i(\mu_i^{\rm ggF} - \hat{\mu}_i^{\rm ggF})(\mu_i^{\rm VBF} - \hat{\mu}_i^{\rm VBF}) + c_i(\mu_i^{\rm VBF} - \hat{\mu}_i^{\rm VBF})^2\,,$$

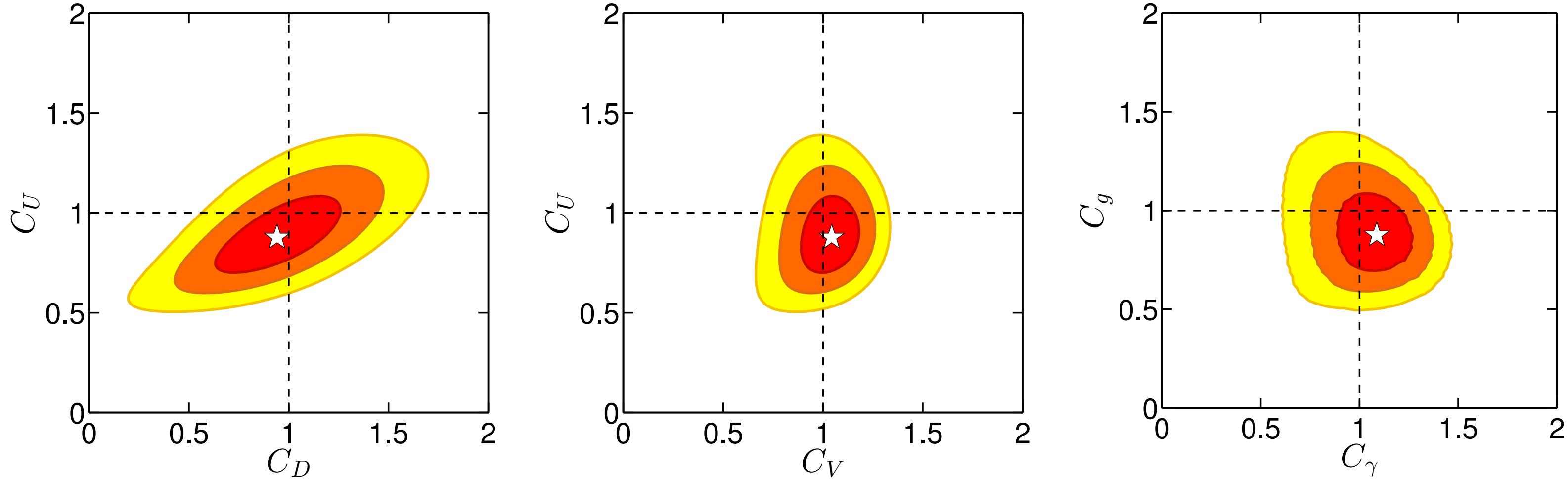
GB, Dumont, Ellwanger, Gunion, Kraml, 1306.2941

Reduced Higgs couplings

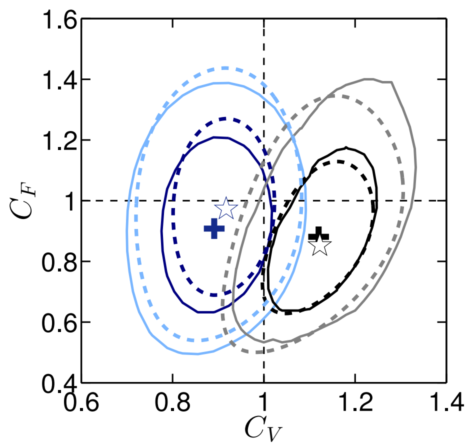


- Here $\Delta C_g, \Delta C_\gamma = 0$, no invisible decays

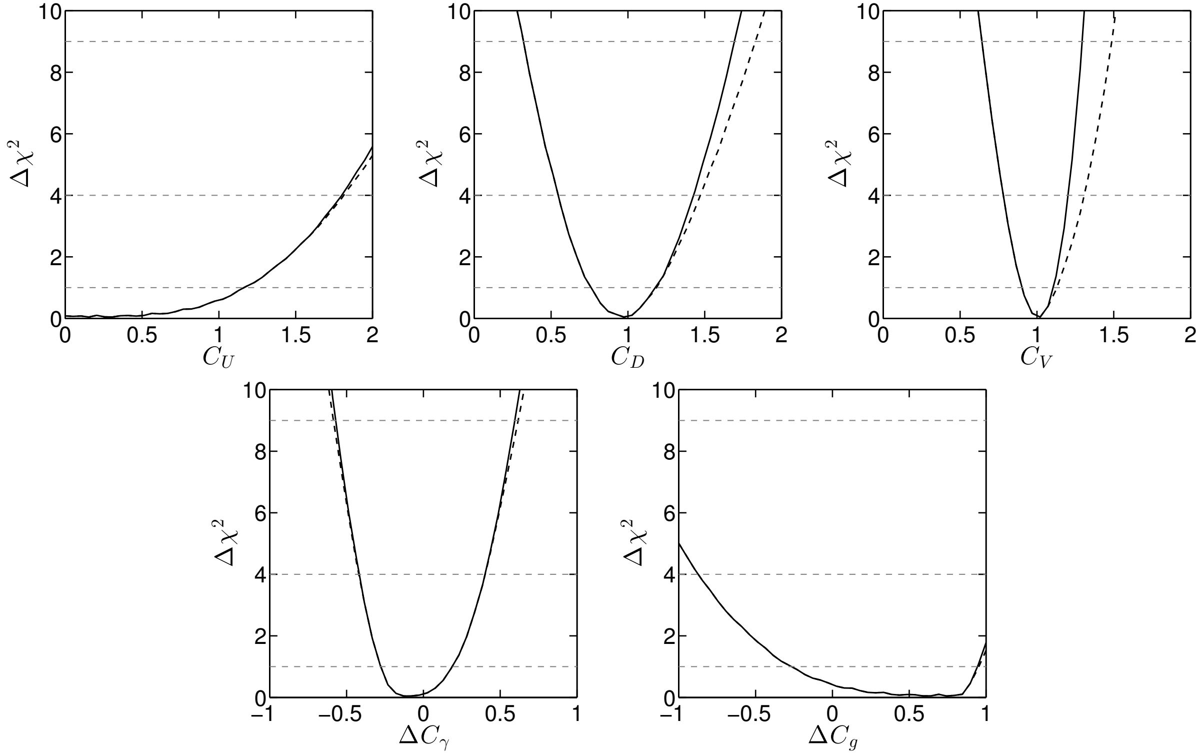
Reduced Higgs couplings



- Under the same assumptions - matches very well the contours of CMS and ATLAS individually

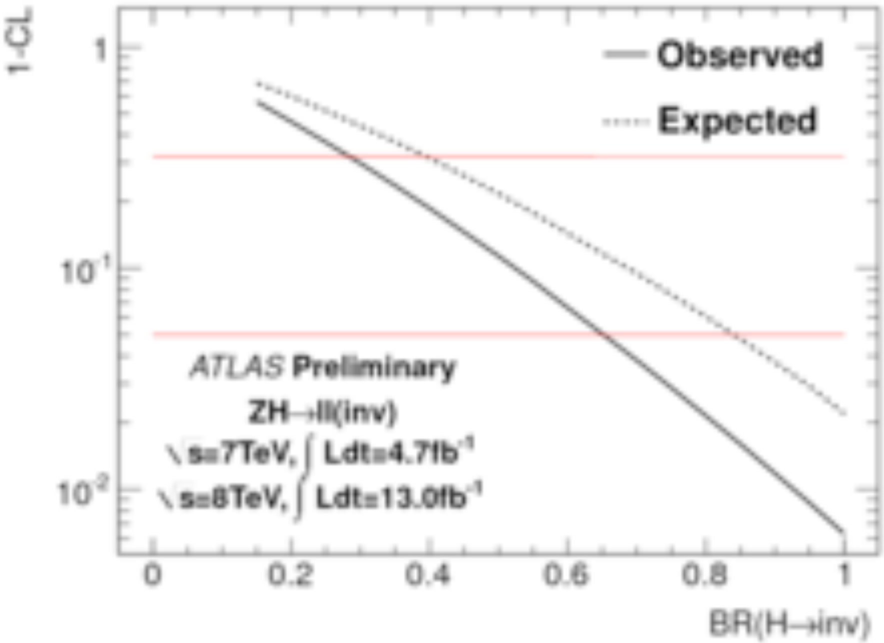


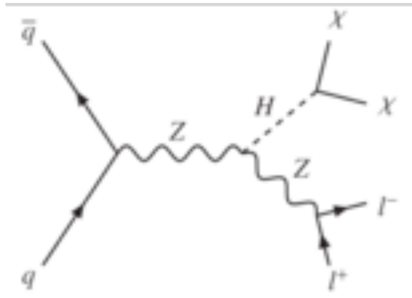
Reduced Higgs couplings



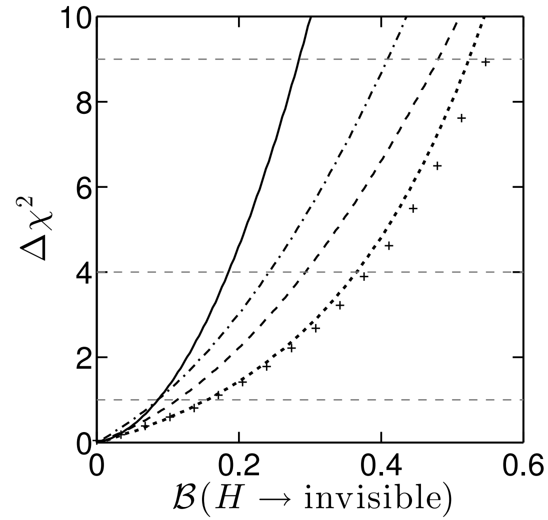
- All couplings free with/without invisible decays

Direct search for invisible Higgs



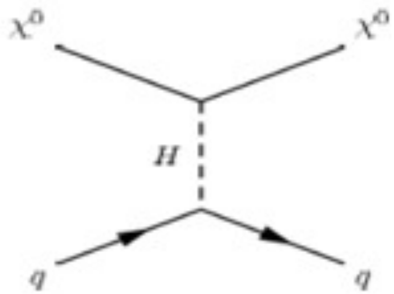


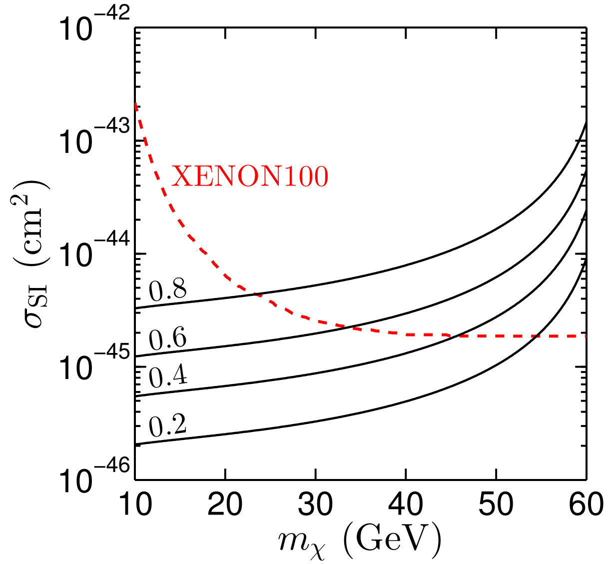
How much invisible Higgs?



- Best fit at 0 - the 95%CL allows B_{inv} up to 19% (only SM + invisible) or 38% ($C_U, C_D, C_V, \Delta C_g, \Delta C_\gamma$)
- Include both global fit + direct search for Z(l+l-)H(inv)
- There is still plenty of room for non standard Higgs decays

- What are the implications for dark matter?
- Both the invisible width and SI cross section (direct detection) depend on h coupling to DM





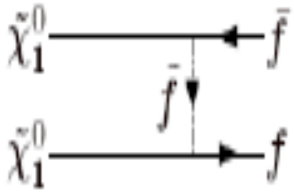
$$\sigma_{\rm SI} = \eta \mu_r^2 m_p^2 \frac{g^2}{M_W^2} \Gamma_{\rm inv} \left[C_U(f_u^N + f_c^N + f_t^N) + C_D(f_d^N + f_s^N + f_b^N) + \frac{\Delta C_g}{\widehat{C}_g} f_g^N \right]^2$$

Light neutralino in the MSSM

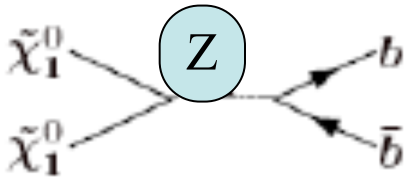
- Possibility of “light” neutralino (below LEP limit) explored by many groups
  - Bottino,Fornengo,Scopel,Donato,Plehn,GB,Boudjema,Godbole, Roszkowski, R. de Austri, Cumberlach, Dreiner, Heinemeyer, Kittel,AlbornozVasquez,Boehm,Calibbi,Ota,Takanishi, Gunion, Belikov, Arbey, Battaglia, Mahmoudi, Dev, Mazumdar, Pukartas, Han,Liu,Natarajan....
- In part motivated by hints in direct detection
- Possible only for non-universal gaugino mass (need M_1 small)
- Is it possible after LHC?
  - New constraints on B-physics
  - Constraints on Higgs couplings and invisible decays
  - Searches for SUSY particles

MSSM with light neutralino

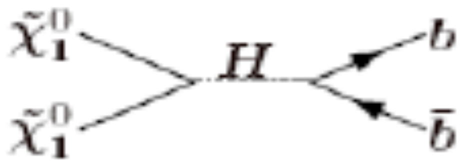
- Relaxing gaugino universality: few collider constraints
  - Z invisible (Γ_{inv}<2MeV), $e^+e^- \rightarrow \chi_1\, \chi_{i,}$ Hinvisible
- Cosmological constraints : need annihilation mechanism efficient enough (LSP dominantly bino)



Need light slepton (collider constraints)



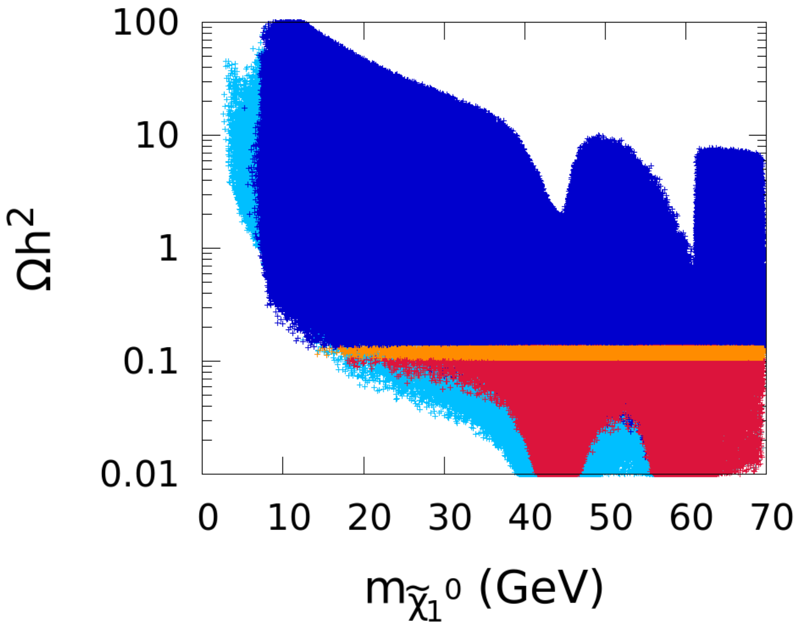
works well for M>35GeV

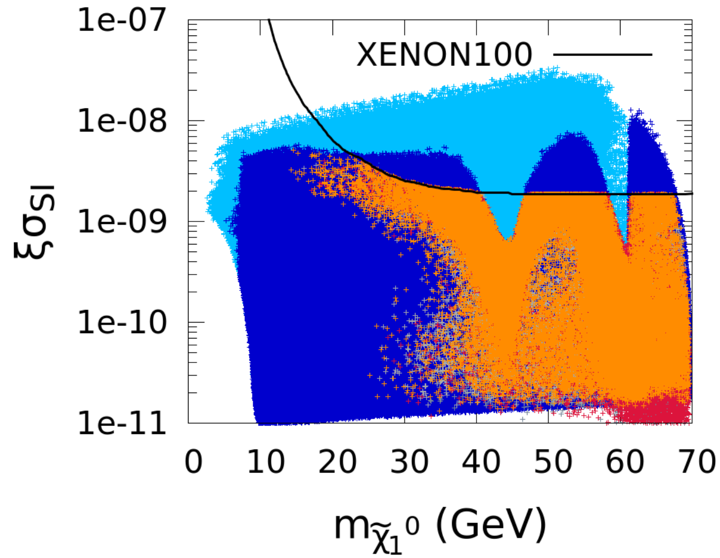


works well for m~m_h/2 otherwise need enhanced Higgs coupling (large tanβ) ruled out by LHC searches for heavy Higgses

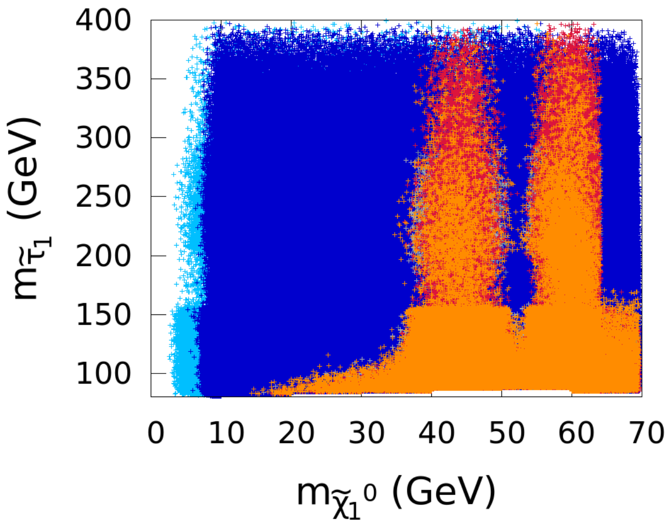
- light sbottom (Arbey et al, 1211.2795, 1308.2153)

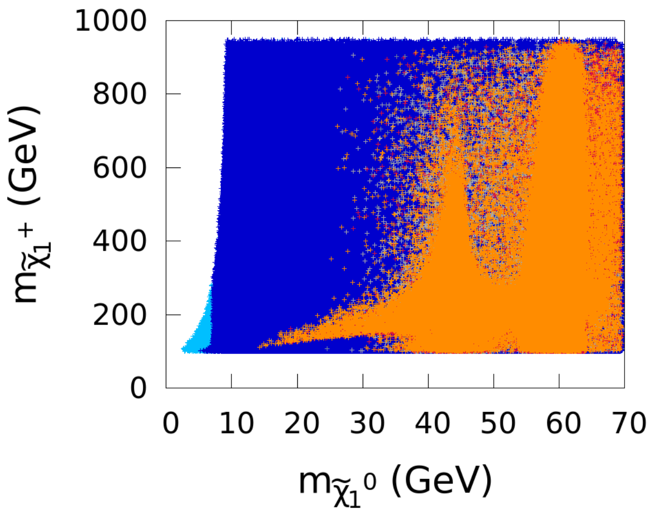
- pMSSM - scan over relevant parameters
  - M_1, M_2, μ, $\tan\beta$, M_A, A_t, M_{lL}, M_{lR}, M_{3L}, M_{3R}, A_τ
  - LEP limits, invisible Z, B-physics, Higgs mass +couplings, heavy Higgs@LHC, Xenon100





GB, G.Drieu La Rochelle, B.Dumont, R. Godbole, S. Kraml,S. Kulkarni, arXiv:1308.3735



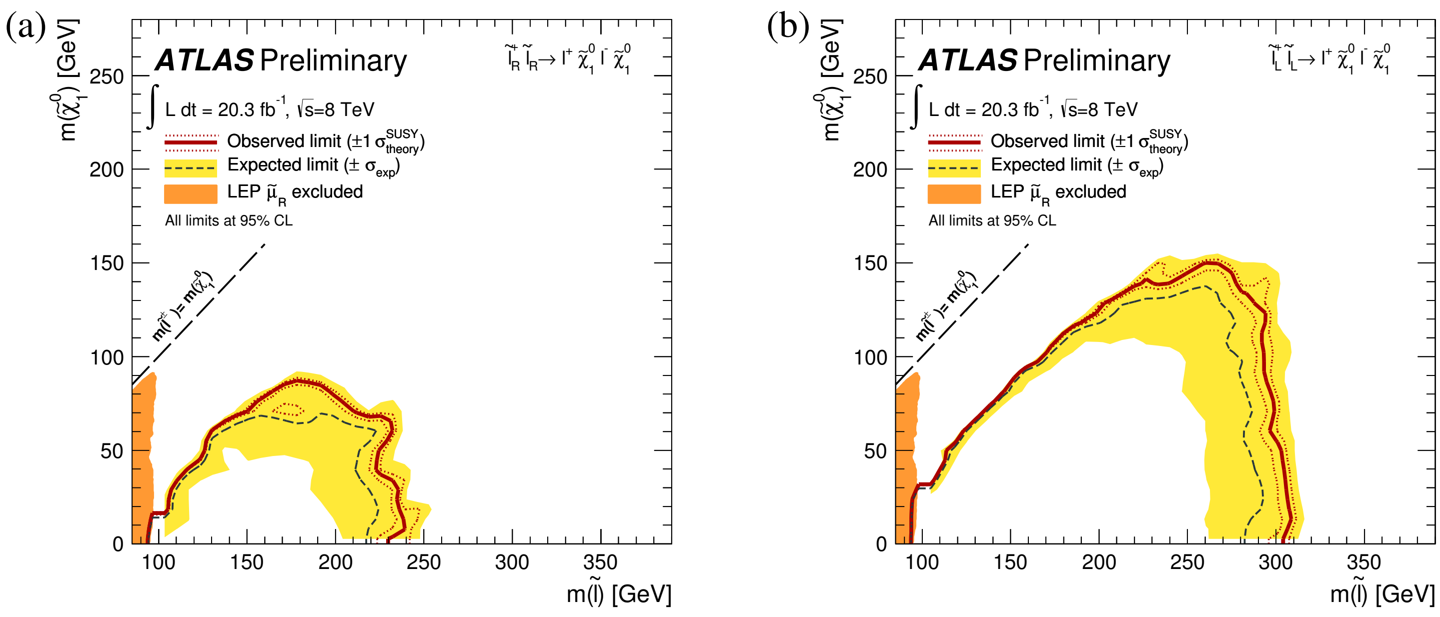


- DM < 35 GeV associated with light sparticles : light stau + light chargino
- ATLAS and CMS have started to probe electroweak-ino and sleptons
- Analysis based on SModelS (Kraml, Kulkarni, Laa, Lessa, Proschovsky-Spindler, Waltenberger, in progress)

LHC searches

- Each point decomposed in relevant SMS topologies and compared with experimental limits using SModelS
- sleptons :

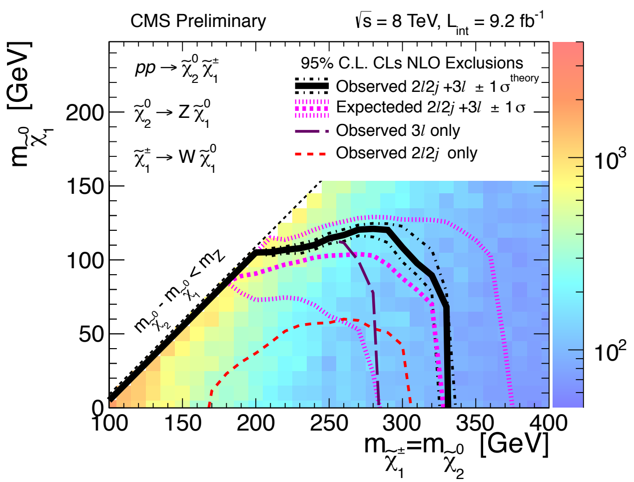
$$\tilde{\ell}_L^\pm \tilde{\ell}_L^\mp \to \ell^\pm \tilde{\chi}_1^0 \ell^\mp \tilde{\chi}_1^0 \; ; \; \tilde{\ell}_R^\pm \tilde{\ell}_R^\mp \to \ell^\pm \tilde{\chi}_1^0 \ell^\mp \tilde{\chi}_1^0 \; , \; \text{ATLAS-CONF-2013-049,CMS-PAS-SUS-12-022}$$

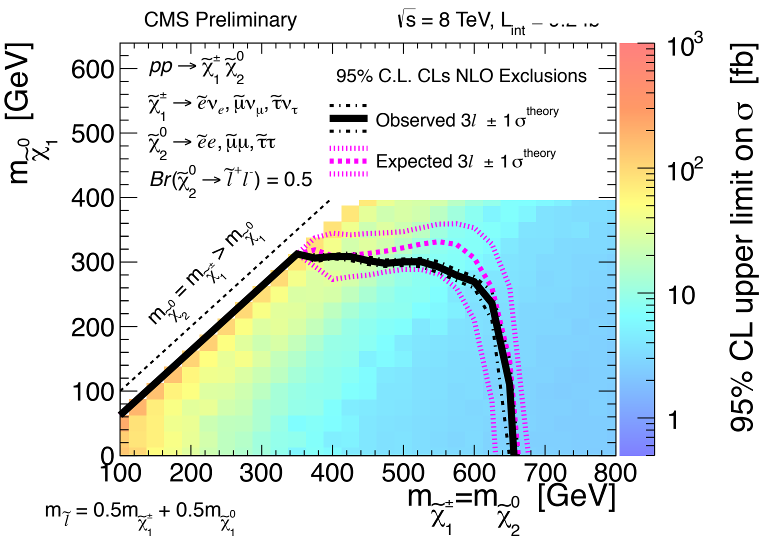


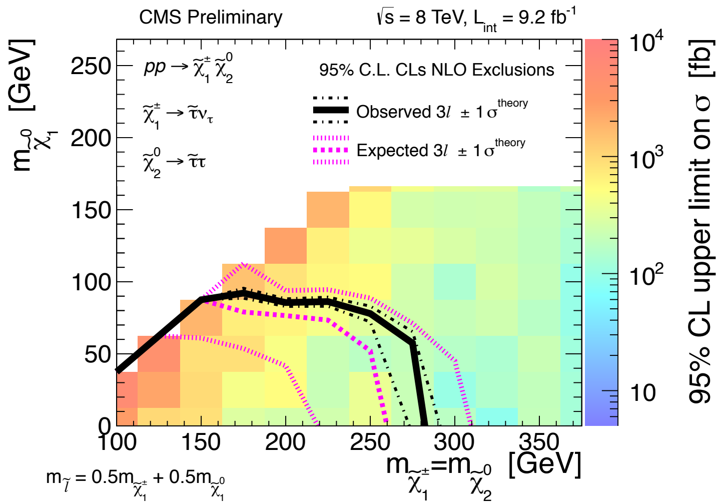
Charginos/neutralinos

$\tilde{\chi}_2^0\tilde{\chi}_1^\pm \to Z^{(*)}\tilde{\chi}_1^0 W^{(*)}\tilde{\chi}_1^0$, ATLAS-CONF-2013-035, CMS-PAS-SUS-12-022

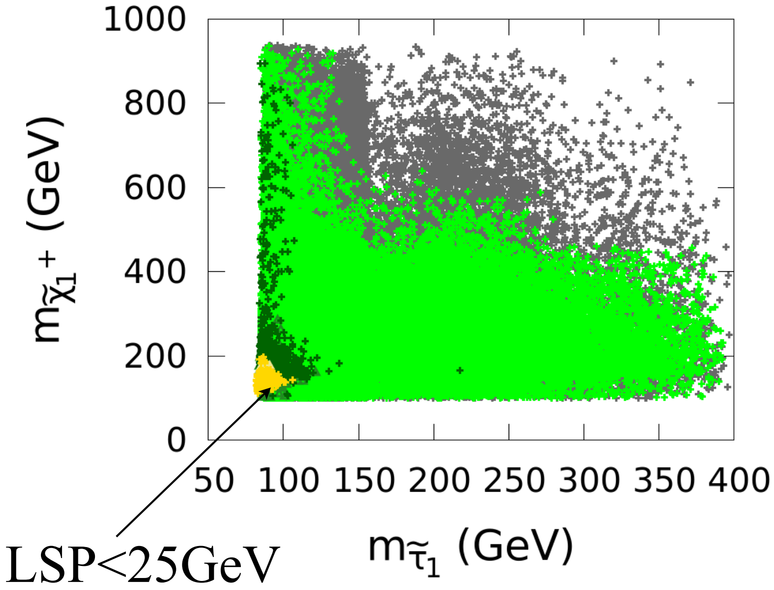
$\tilde{\chi}_2^0\tilde{\chi}_1^\pm \to \tilde{\ell}_R^\pm \nu \tilde{\ell}_R^\pm \ell^\mp \to \ell^\pm \tilde{\chi}_1^0 \nu \ell^\pm \tilde{\chi}_1^0 \ell^\mp$ CMS-PAS-SUS-12-022, $(l = e, \mu, \tau)$

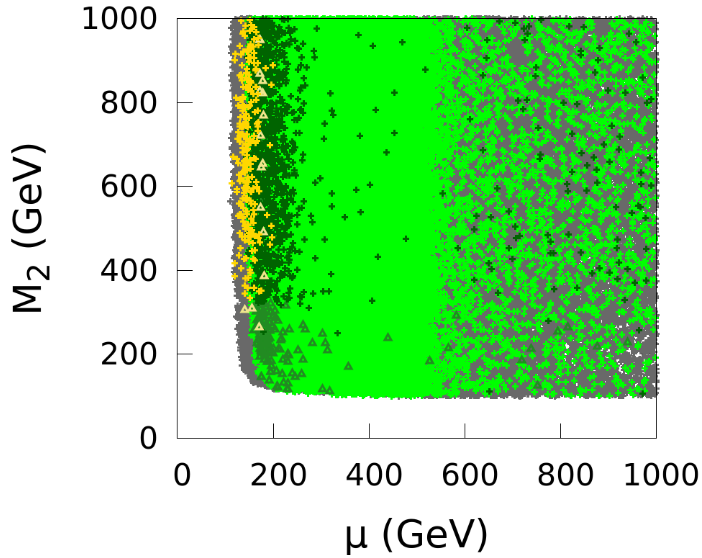






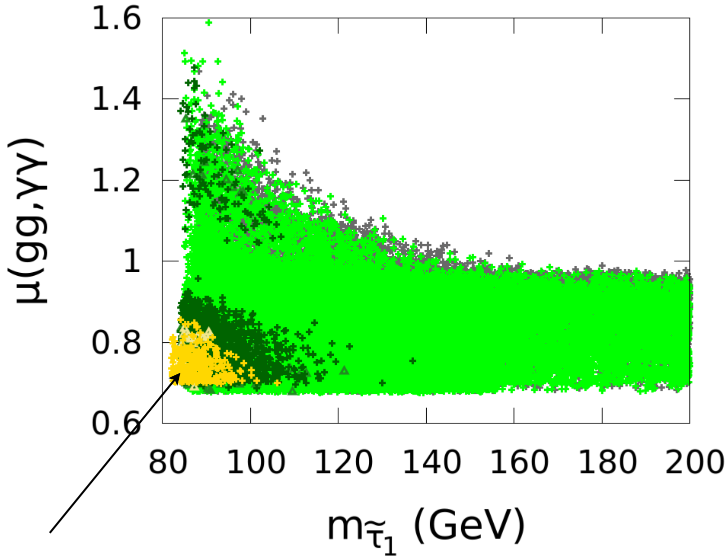
After LHC limits



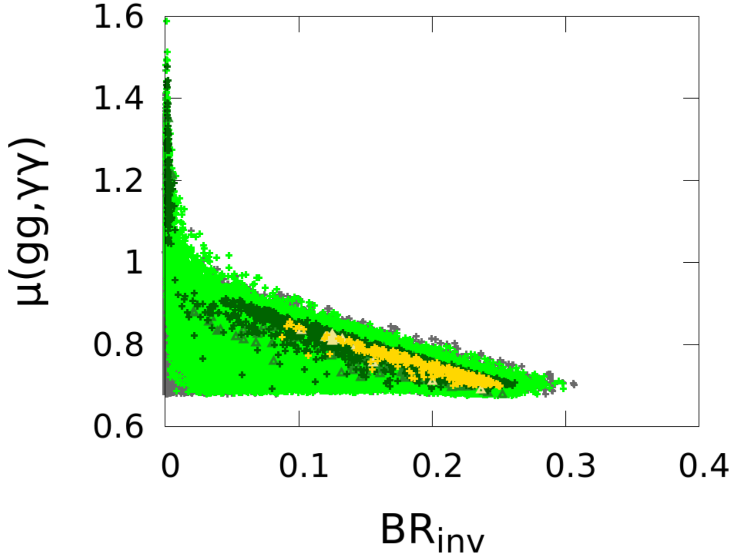


- LHC constrains many models but light neutralino still possible

Higgs



LSP<25GeV



- Lightest neutralinos associated with some invisible Higgs decays
- Further probe at LHC14TeV with ZH-> inv, expect Br<0.17 (Ghosh et al, 1211.7015)
- and improved global fits to Higgs couplings

Conclusion

- Some room for non-standard Higgs couplings - important to improve the precision on measurements

- Light dark matter still compatible with the Higgs

- Neutralinos ~15-20GeV allowed in MSSM further probed at LHC with searches for sleptons, electroweak-inos, Higgs properties and direct detection