LHC constraints on light neutralino dark matter in the MSSM

Béranger Dumont
(LPSC Grenoble)

based on work with
G. Bélanger, G. Drieu La Rochelle, R. M. Godbole, S. Kraml and S. Kulkarni,
[arXiv:1306.2941, to appear in PLB]

GDR Terascale @ Annecy

October 29, 2013

light neutralino dark matter

In the MSSM: $(\widetilde{B}, \widetilde{W}^0, \widetilde{H}_d^0, \widetilde{H}_u^0) \xrightarrow{\text{EWSB}} (\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0)$

↳ LSP and dark matter candidate

light neutralino dark matter motivated by:

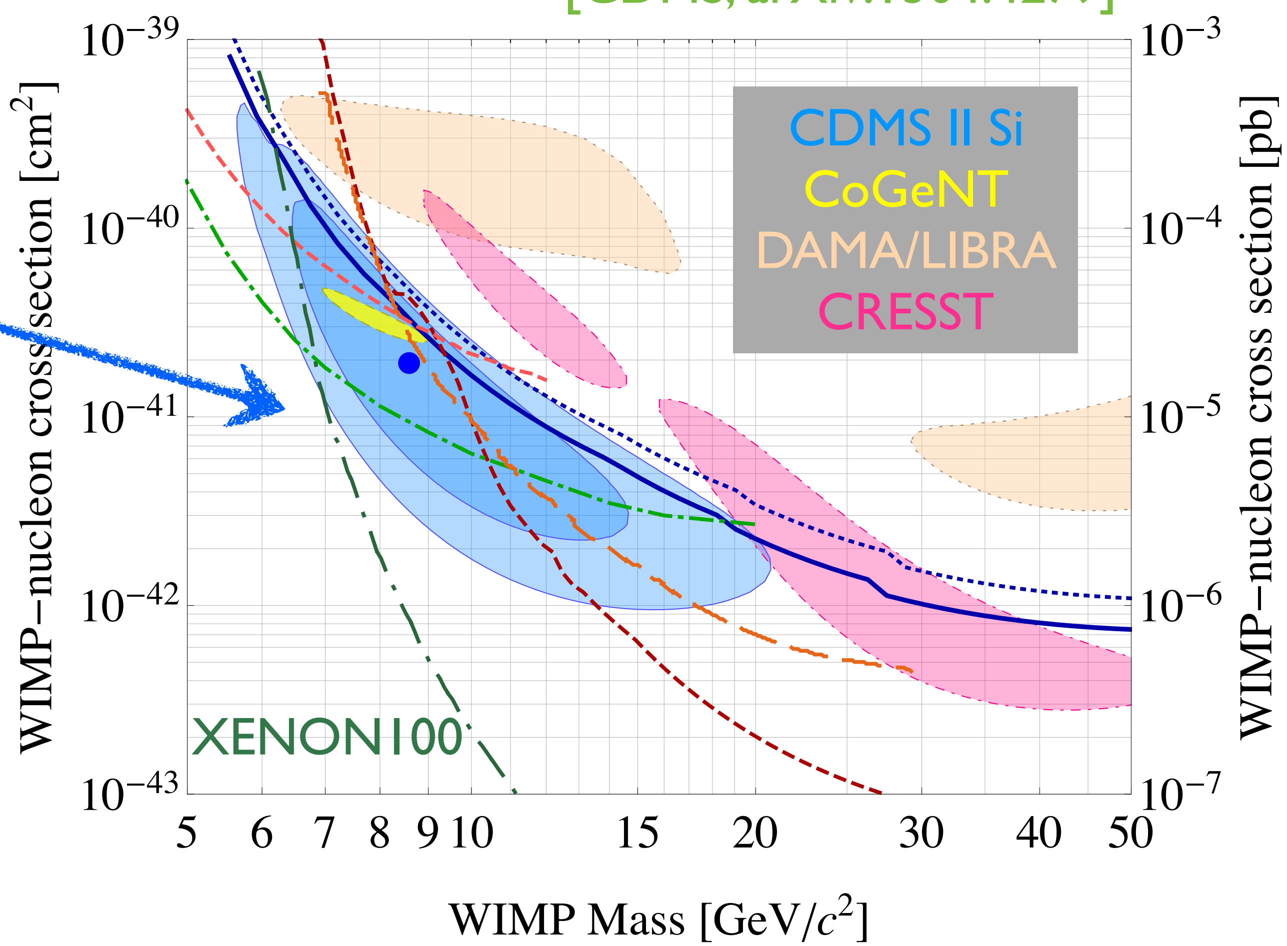
✦ having a light SUSY spectrum

✦ hints from direct detection ~ 10 GeV
(... and maybe from indirect detection)
[Hopper et al. claims]

✦ easy-to-exclude region
- no resonance under $M_Z/2$ = 45 GeV
- no co-annihilation under ~ 100 GeV

(counterexample: [arXiv:1308.2153]
see Alexandre Arbey's talk tomorrow)

[CDMS, arXiv:1304.4279]



viable light neutralino dark matter

nature of the lightest neutralino?

- pure wino or higgsino dark matter?
  → excluded by chargino searches at LEP
- pure bino dark matter?
  → the relic density is too large

$$\begin{array}{cccc} \widetilde{B} & \widetilde{W}^0 & \widetilde{H}_d^0 & \widetilde{H}_u^0 \end{array}$$

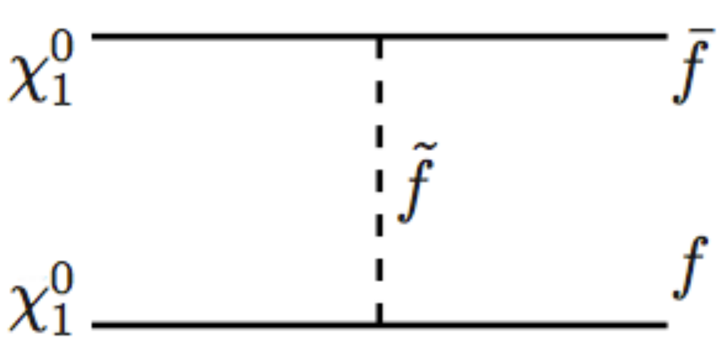
$$\begin{pmatrix} M_1 & 0 & -c_\beta\, s_W\, m_Z & s_\beta\, s_W\, m_Z \\ 0 & M_2 & c_\beta\, c_W\, m_Z & -s_\beta\, c_W\, m_Z \\ -c_\beta\, s_W\, m_Z & c_\beta\, c_W\, m_Z & 0 & -\mu \\ s_\beta\, s_W\, m_Z & -s_\beta\, c_W\, m_Z & -\mu & 0 \end{pmatrix}$$

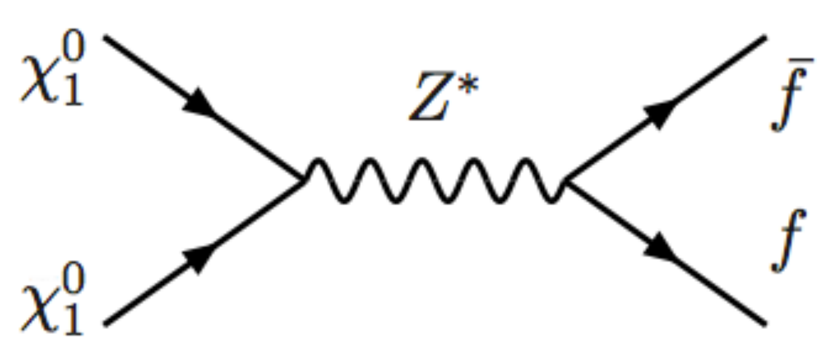
solution: mainly bino ($M_1 \ll M_2,\mu$) with some wino/higgsino admixture (μ and/or $M_2 \lesssim 200$ GeV)

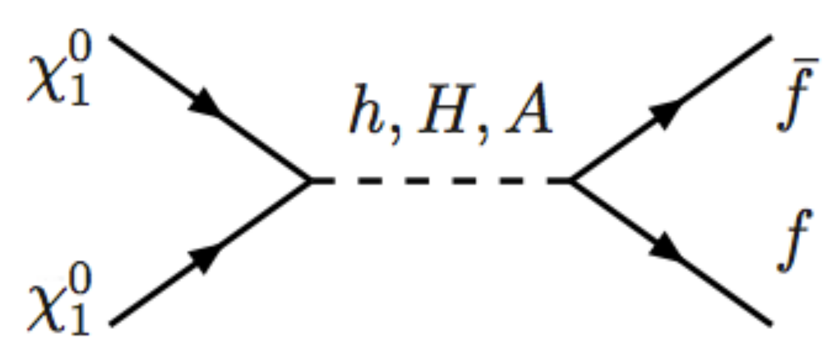
other SUSY particles?

- gluino and squarks: constrained by LEP and LHC searches to be heavy → no influence on DM
- other Higgses: little influence expected on DM (constraints on $A^0,H^0 \to \tau^+\tau^-$ at the LHC)
- sleptons: ~100 GeV is allowed, contributions from staus to DM annihilation can be large

light sleptons are required for light neutralino DM [Albornoz Vasquez, Belanger, Boehm '11]

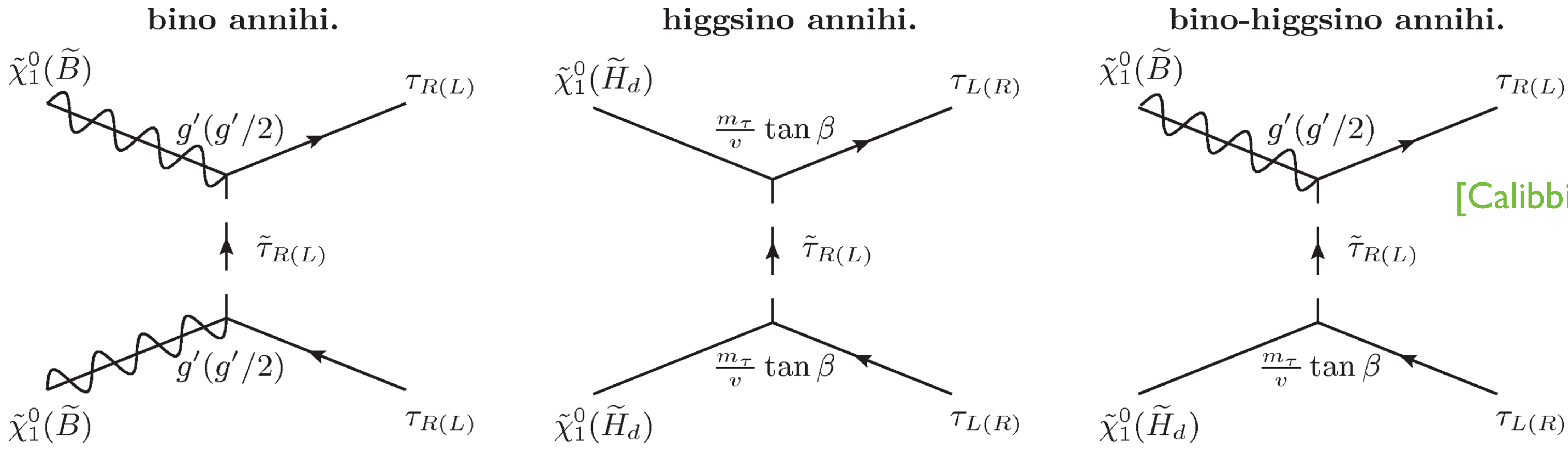






viable light neutralino dark matter

stau-mediated annihilation



[Calibbi et al. '13]

RH stau annihilation is much more efficient, also higgsino enhancement (low μ, high tan β)

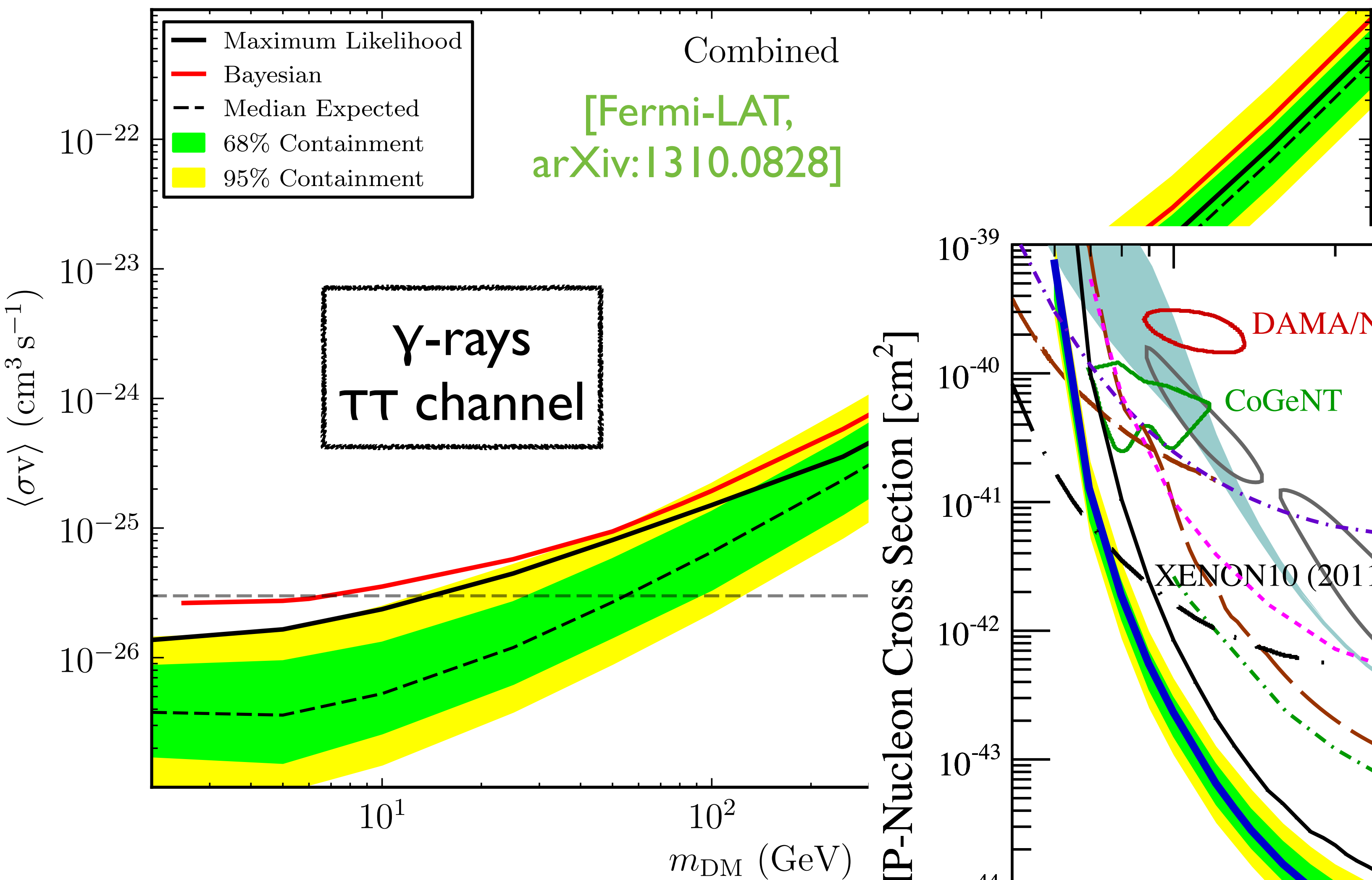
collider constraints on electroweakinos

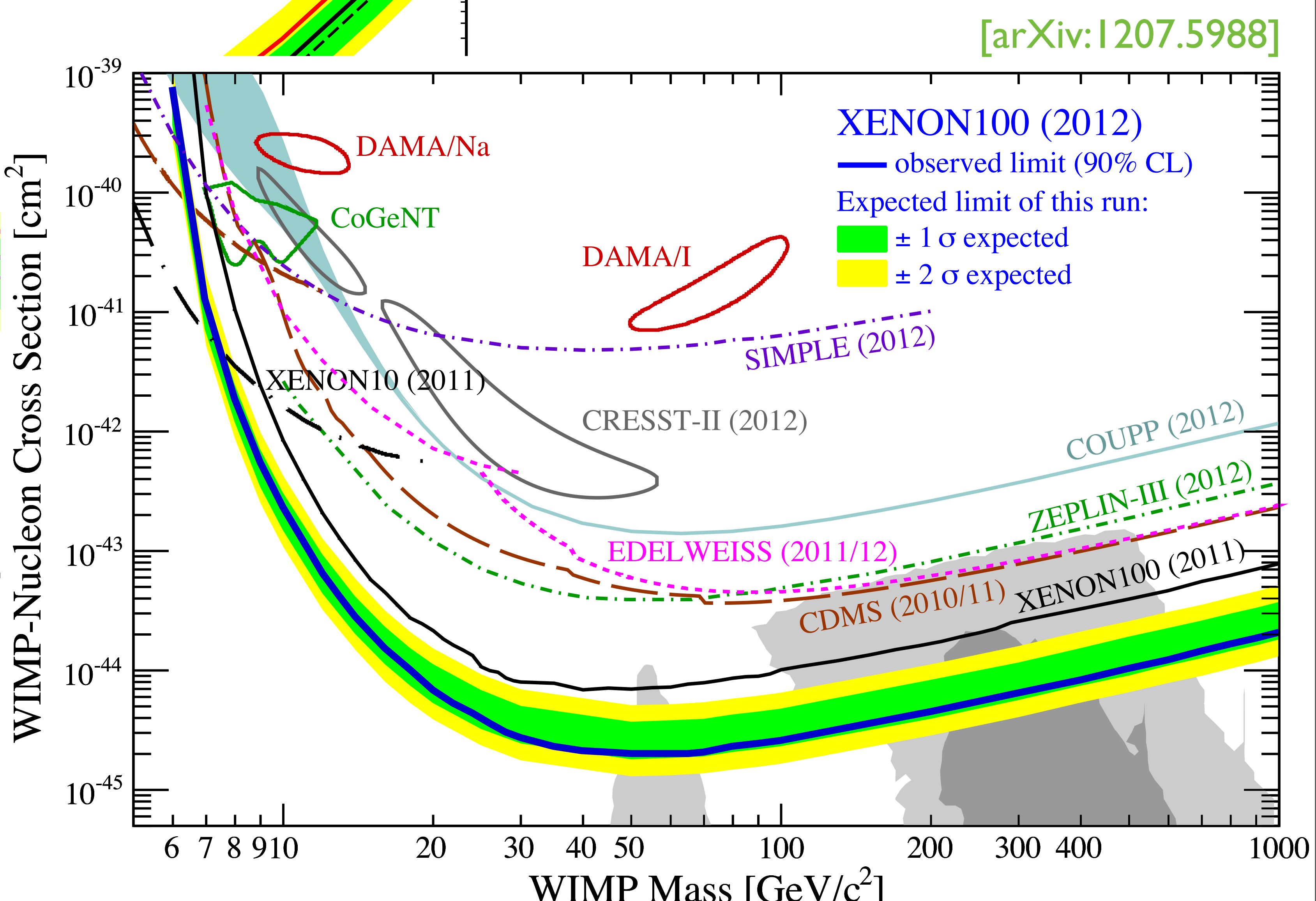
- rather light charginos: need to check the LEP and LHC constraints
- invisible Z decays, invisible Higgs decays (LEP and LHC limits, resp.)
- light neutralino 2 ➞ LEP limit on $\sigma(e^+e^- \to \tilde{\chi}_2^0\tilde{\chi}_1^0)$

sleptons and staus: direct searches at LEP and at the LHC

viable light neutralino dark matter

searches for dark matter





setup of the analysis

pMSSM framework

$M_3 = 1$ TeV
$M_{Q_3} = 750$ GeV
$M_{U_i} = M_{D_i} = M_{Q_1} = 2$ TeV
$A_b = 0$

→ heavy 1st and 2nd generation squarks
moderately heavy gluino, stop and sbottom

$\tan\beta$	$[5, 50]$	M_{L_3}	$[70, 500]$
M_A	$[100, 1000]$	M_{R_3}	$[70, 500]$
M_1	$[10, 70]$	A_τ	$[-1000, 1000]$
M_2	$[100, 1000]$	M_{L_1}	$[100, 500]$
μ	$[100, 1000]$	M_{R_1}	$[100, 500]$

(all masses in GeV)

variations in the
Higgs, electroweak and leptonic sectors

A_t tuned in order to have $m_h \approx 125.5$ GeV

we perform flat random scans within `micrOMEGAs 3.1`, using `SuSpect 2.4`

experimental constraints

we impose experimental constraints in the following order:

LEP limits	$m_{\tilde{\chi}_1^\pm} > 100$ GeV $m_{\tilde{\tau}_1} > 84 - 88$ GeV (depending on $m_{\tilde{\chi}_1^0}$) $\sigma(e^+e^- \to \tilde{\chi}_{2,3}^0\tilde{\chi}_1^0 \to Z^{(*)}(\to q\bar{q})\tilde{\chi}_1^0) \lesssim 0.05$ pb
invisible Z decay	$\Gamma_{Z\to\tilde{\chi}_1^0\tilde{\chi}_1^0} < 3$ MeV
μ magnetic moment	$\Delta a_\mu < 4.5 \times 10^{-9}$
flavor constraints	$\mathrm{BR}(b \to s\gamma) \in [3.03, 4.07] \times 10^{-4}$ $\mathrm{BR}(B_s \to \mu^+\mu^-) \in [1.5, 4.3] \times 10^{-9}$
Higgs mass	$m_{h^0} \in [122.5, 128.5]$ GeV
$A^0, H^0 \to \tau^+\tau^-$	CMS results for $\mathcal{L} = 17$ fb^{-1}, $m_h^{\max}$ scenario
Higgs couplings	ATLAS, CMS and Tevatron global fit
relic density	$\Omega h^2 < 0.131$ or $\Omega h^2 \in [0.107, 0.131]$
direct detection	XENON100 upper limit
indirect detection	Fermi-LAT bound on gamma rays from dSphs
$pp \to \tilde{\chi}_2^0\tilde{\chi}_1^\pm$ $pp \to \tilde{\ell}^+\tilde{\ell}^-$	Simplified Models Spectra approach

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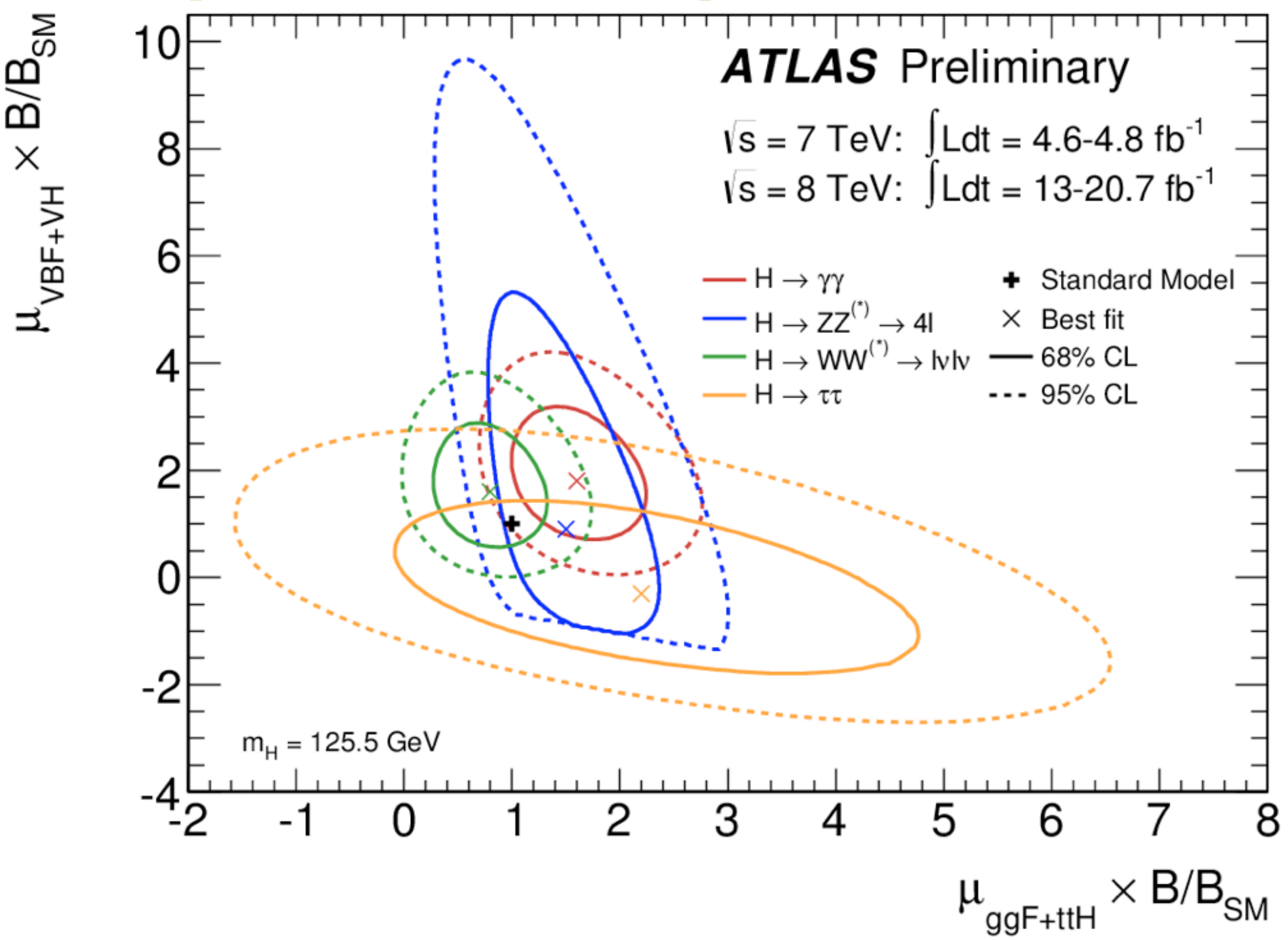
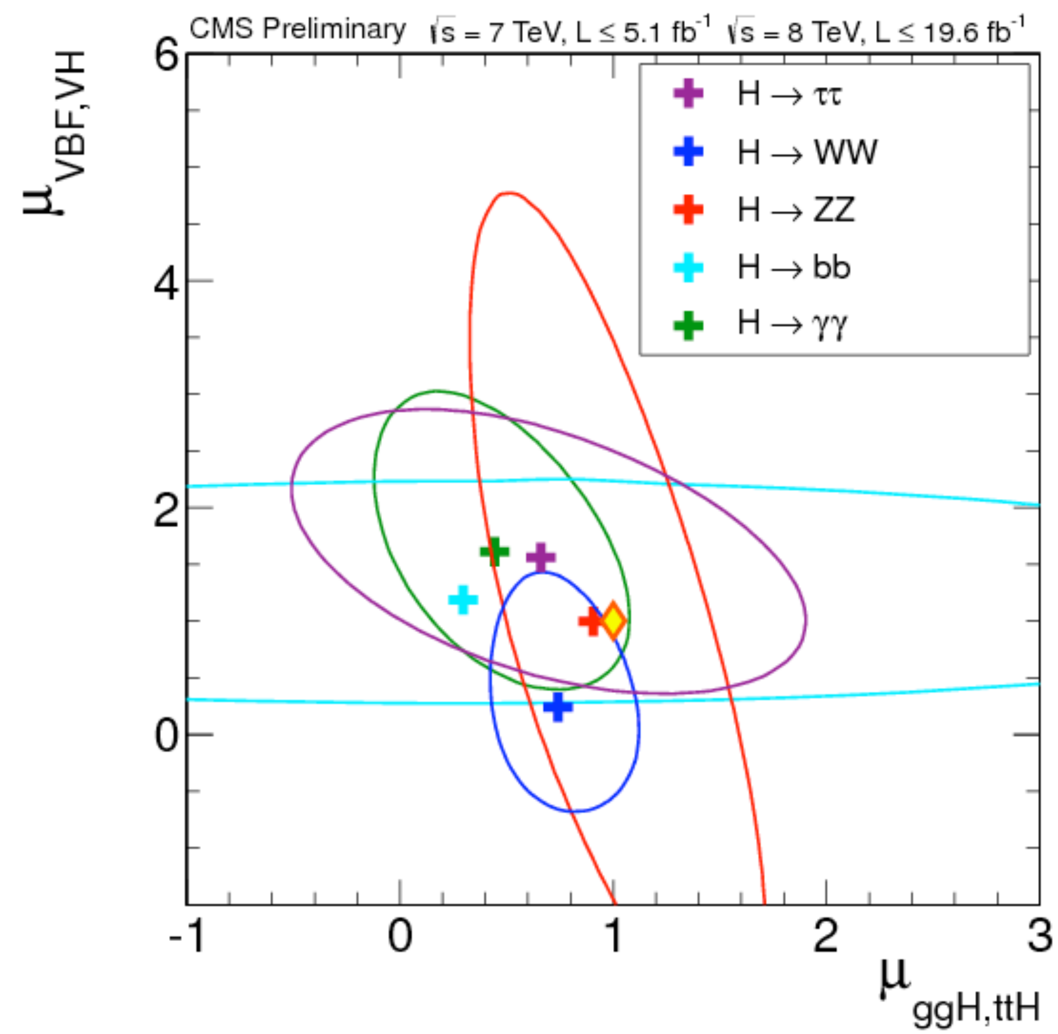
Higgs signal strengths

[ATLAS-CONF-2013-034]



[CMS-PAS-HIG-13-005]

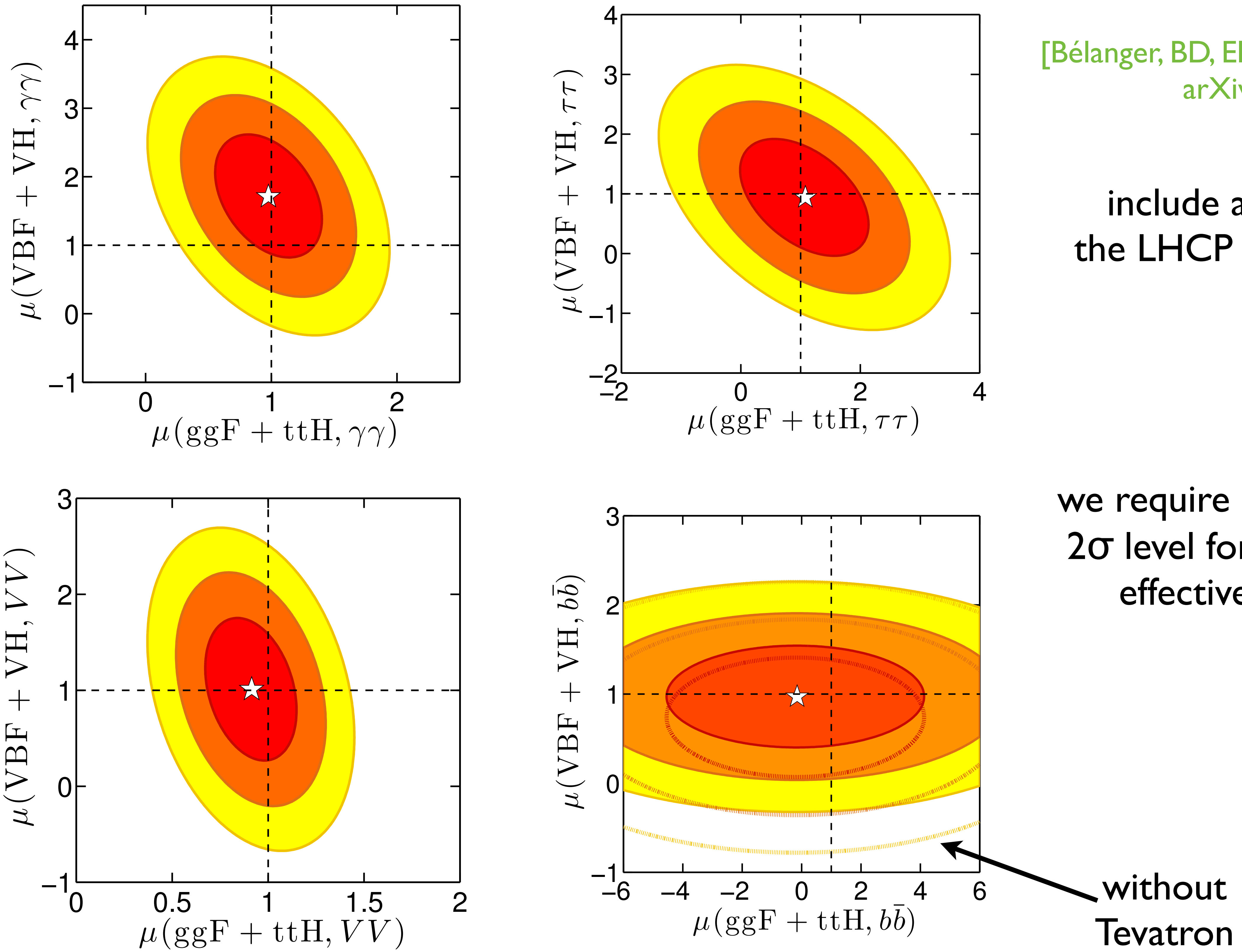


in order to construct a likelihood, one can:

i) fit a 2D Gaussian using the 68% CL contour for each final state

ii) combine the measurements from ATLAS and CMS final state by final state

combined 2D μ plots



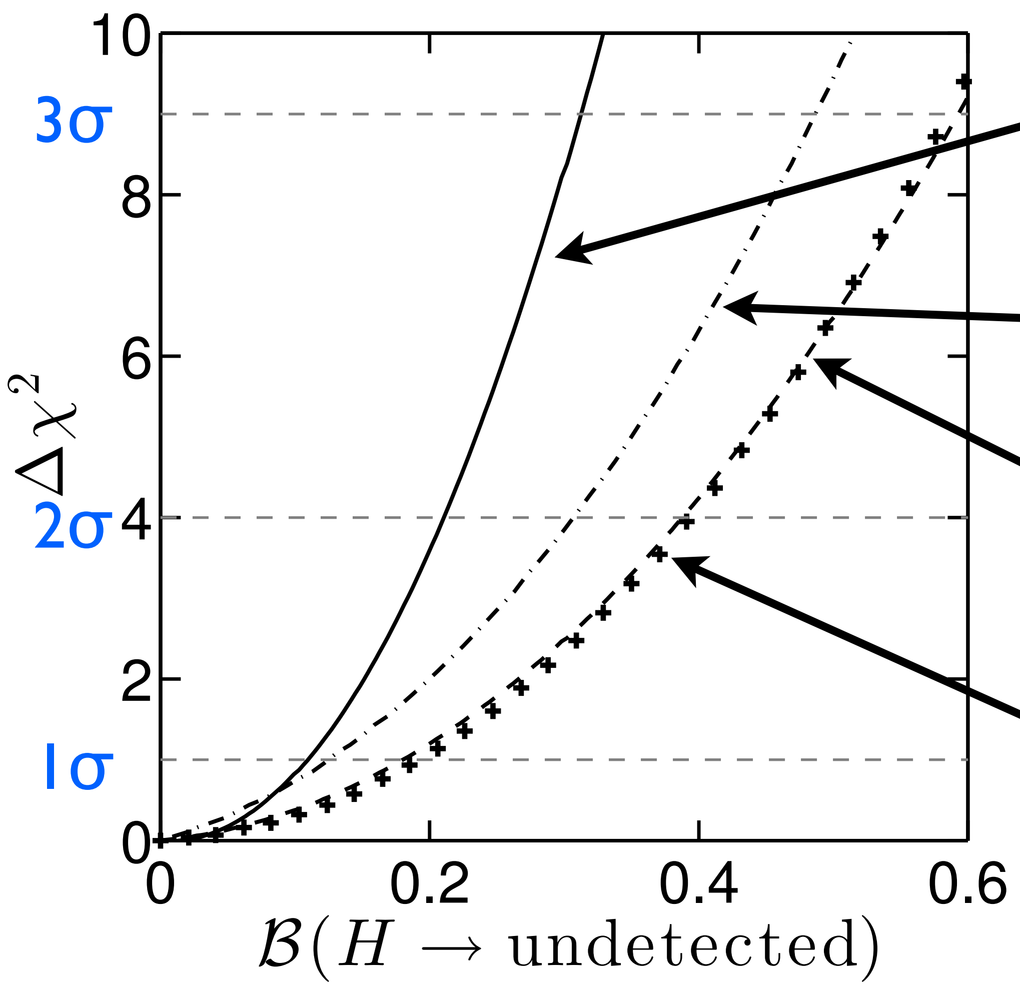
[Bélanger, BD, Ellwanger, Gunion, Kraml, arXiv:1306.2941]

include all results up to the LHCP 2013 conference

we require consistency at the 2σ level for each of the four effective decay modes

invisible decays of the Higgs boson

[Belanger, BD, Ellwanger, Gunion,Kraml, arXiv:1306.2941]



SM+invisible
$\mathcal{B}(H \to \text{inv.}) < 0.21$ at 95% CL

SM+C_U+C_D+($C_V \leq 1$)+invisible
$\mathcal{B}(H \to \text{inv.}) < 0.31$ at 95% CL

SM+ΔC_g+ΔC_γ+invisible
$\mathcal{B}(H \to \text{inv.}) < 0.39$ at 95% CL

SM+C_U+C_D+($C_V \leq 1$)+ΔC_g+ΔC_γ+invisible
$\mathcal{B}(H \to \text{inv.}) < 0.39$ at 95% CL

global fit to the Higgs properties: indirect constraint on H→invisible
(more constraining than direct searches for invisible decays at the moment)

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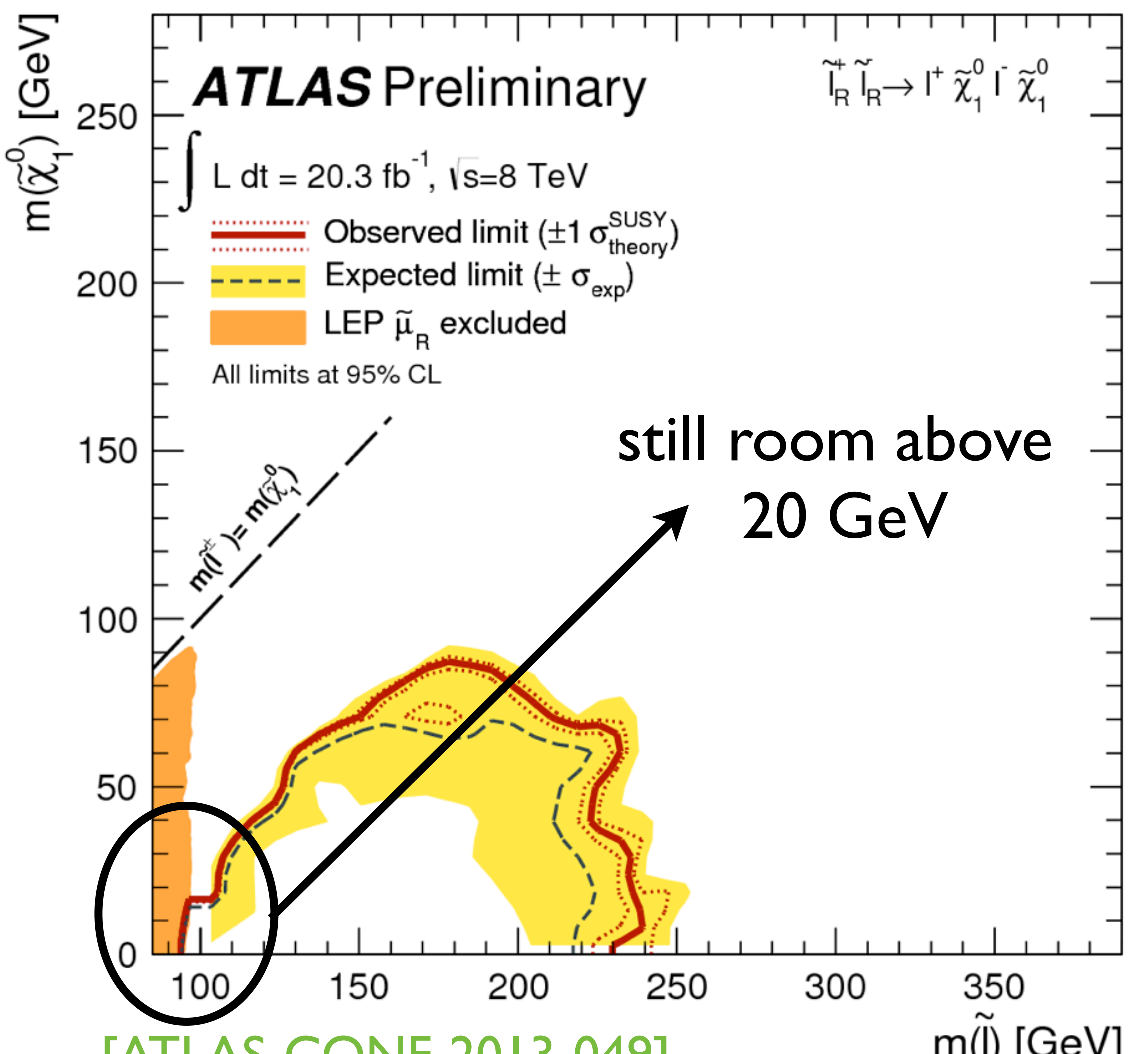
LHC searches — implementation

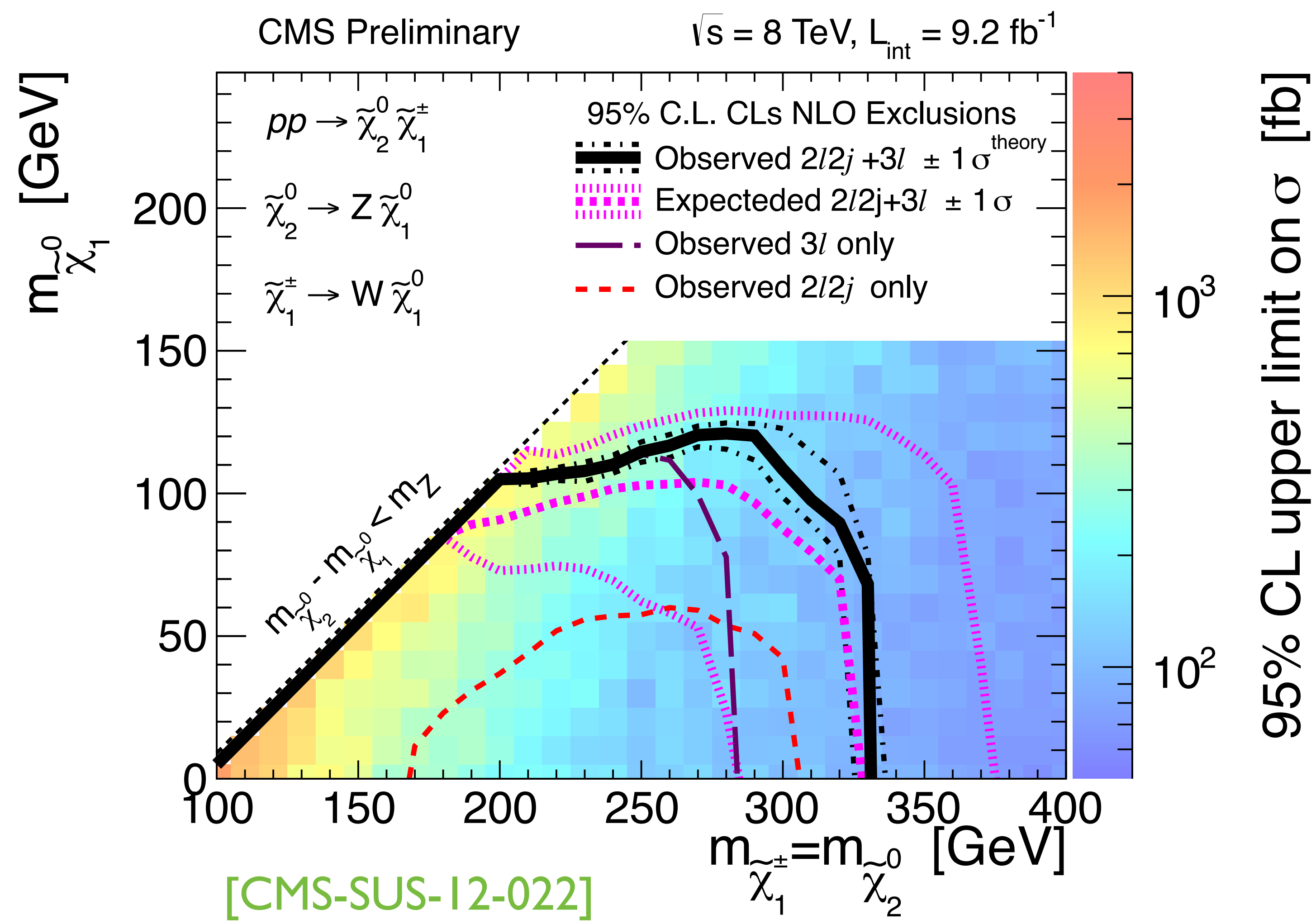
decomposition of a pMSSM point into simplified models, then compare to the limits on (σ×BR)
→ see Suchita Kulkarni's talk on SmodelS earlier today

direct RH selectron/smuon production



[ATLAS-CONF-2013-049]

chargino-neutralino → WZ + MET

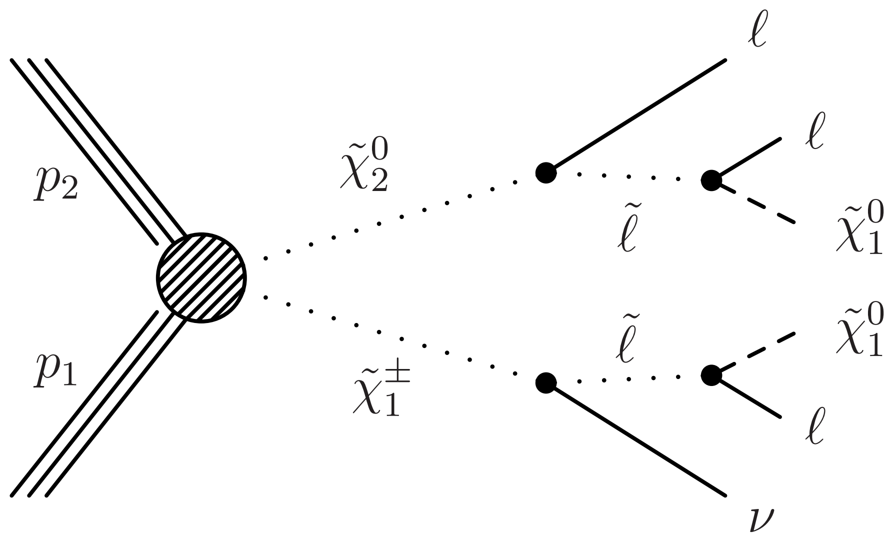


[CMS-SUS-12-022]

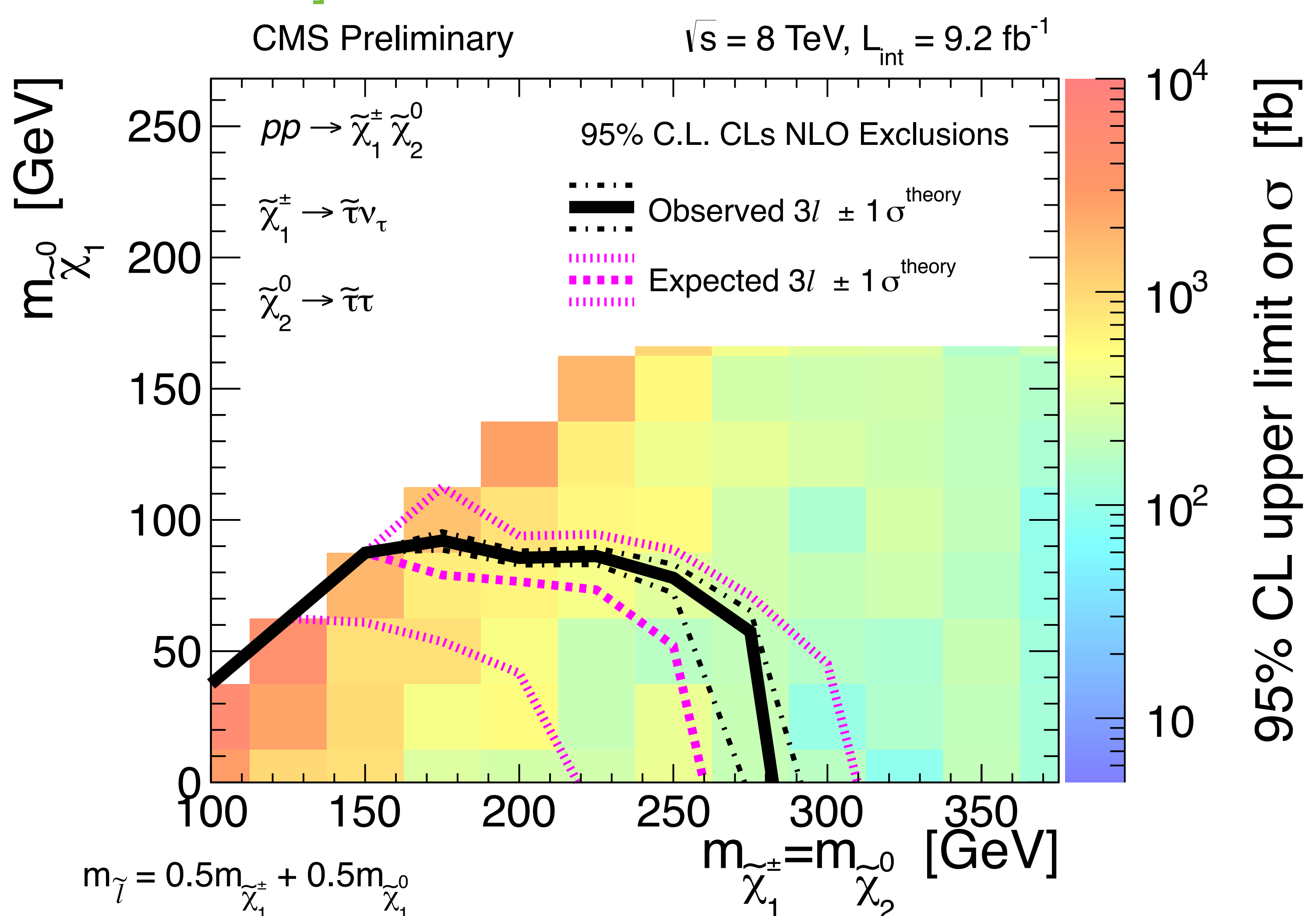
black line overestimates the limit
"hidden" assumption: $\tilde{\chi}^0_2, \tilde{\chi}^{\pm}_1$ wino-like

LHC searches — implementation

there are no limits on direct stau production at the LHC
but one has to consider intermediate stau decays from EWinos



[CMS-SUS-12-022]

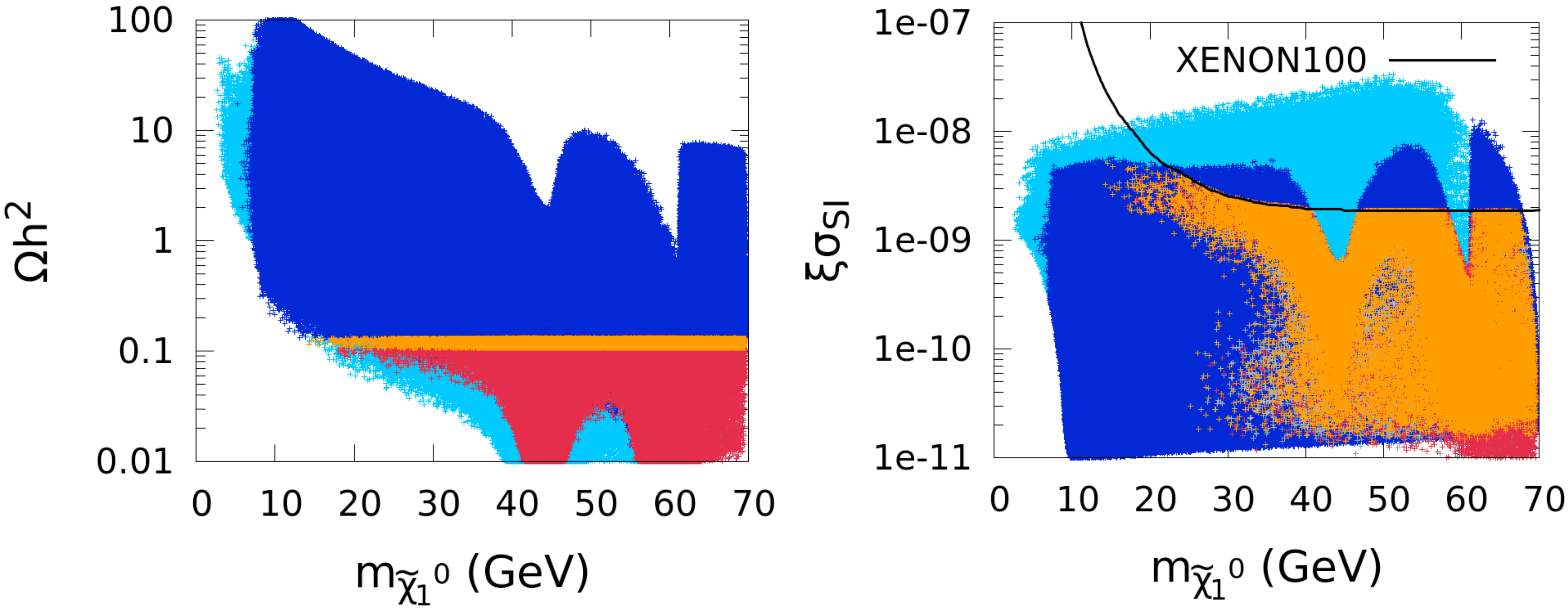


also ATLAS results on 2τ+MET but the only interpretation available is for LH staus

↳ this assumption is problematic — we would need other values of the stau mass
we extrapolate the limit for other stau masses from a similar measurement

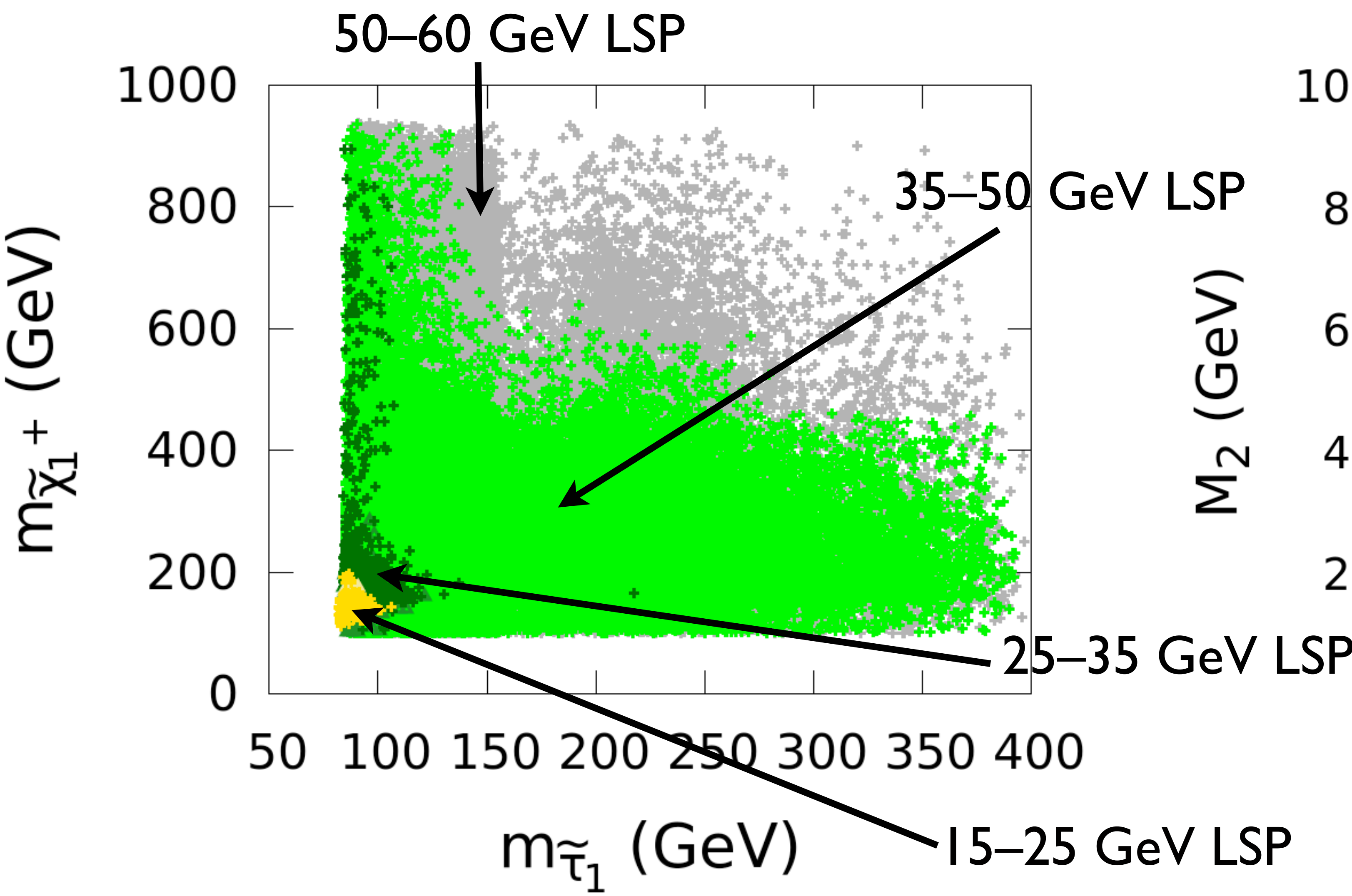
results

relic density and direct detection



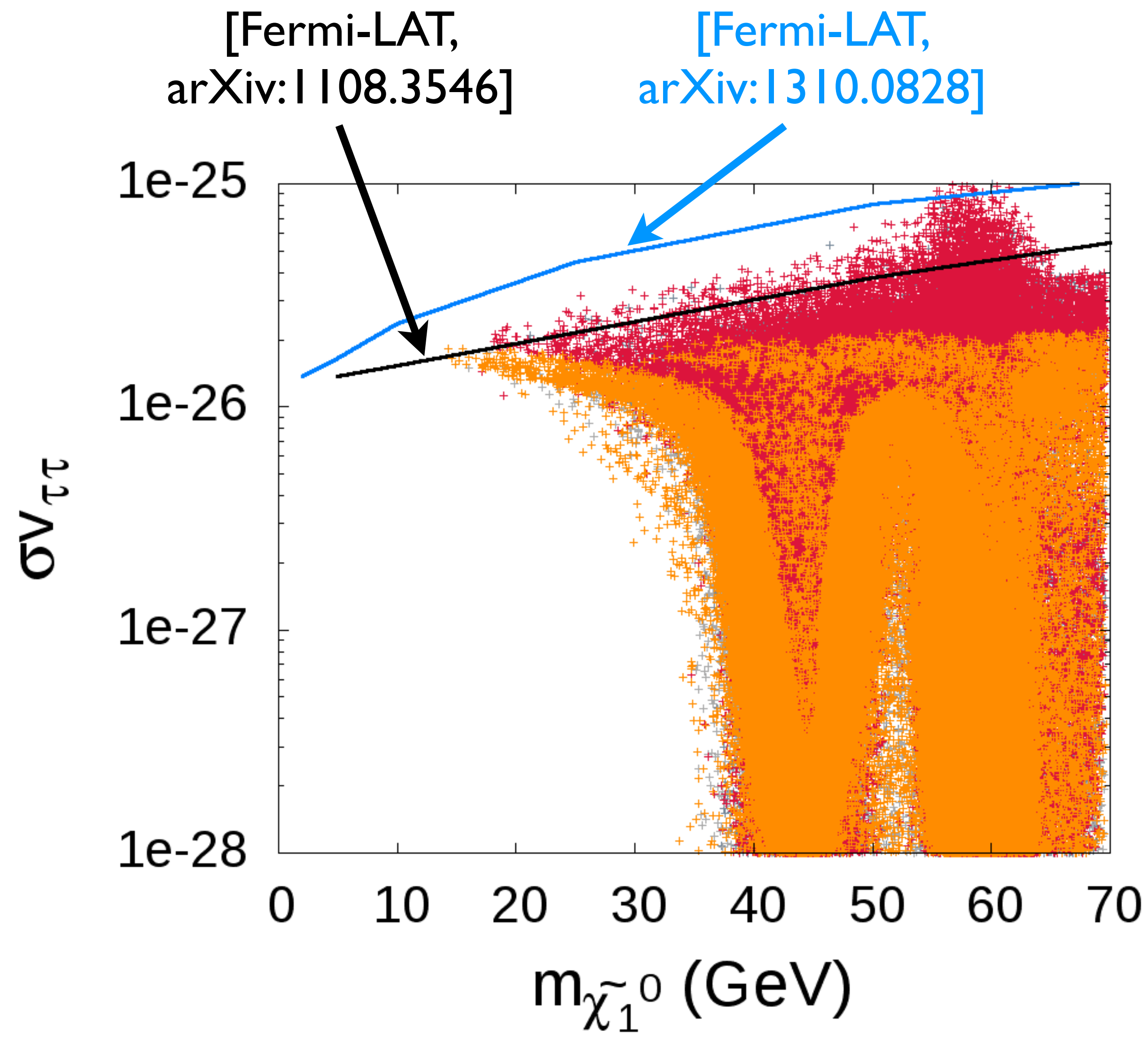
- upper bound on the relic density → lower bound on the neutralino mass of ~15 GeV
  not possible to have 8–10 GeV dark matter in this context
- direct detection could soon tell us more on the low mass region (LUX results tomorrow?)

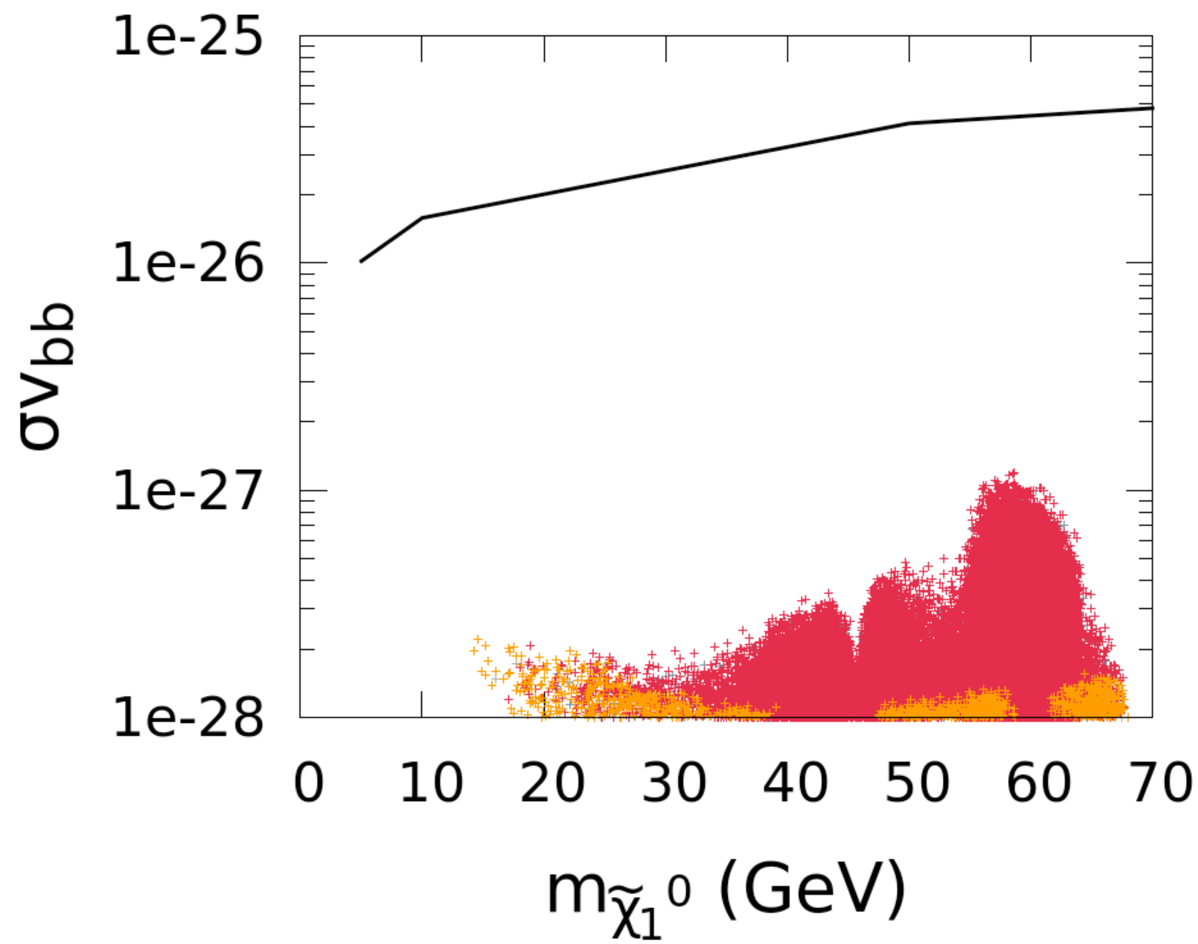
charginos and staus



- light region only possible for very light charginos (≲ 200 GeV) and staus (≲ 100 GeV)
  this is relaxed for higher masses, especially above 35 GeV (Z resonance)
- lightest chargino and neutralino 2 are mostly higgsino-like (and not excluded by direct searches)

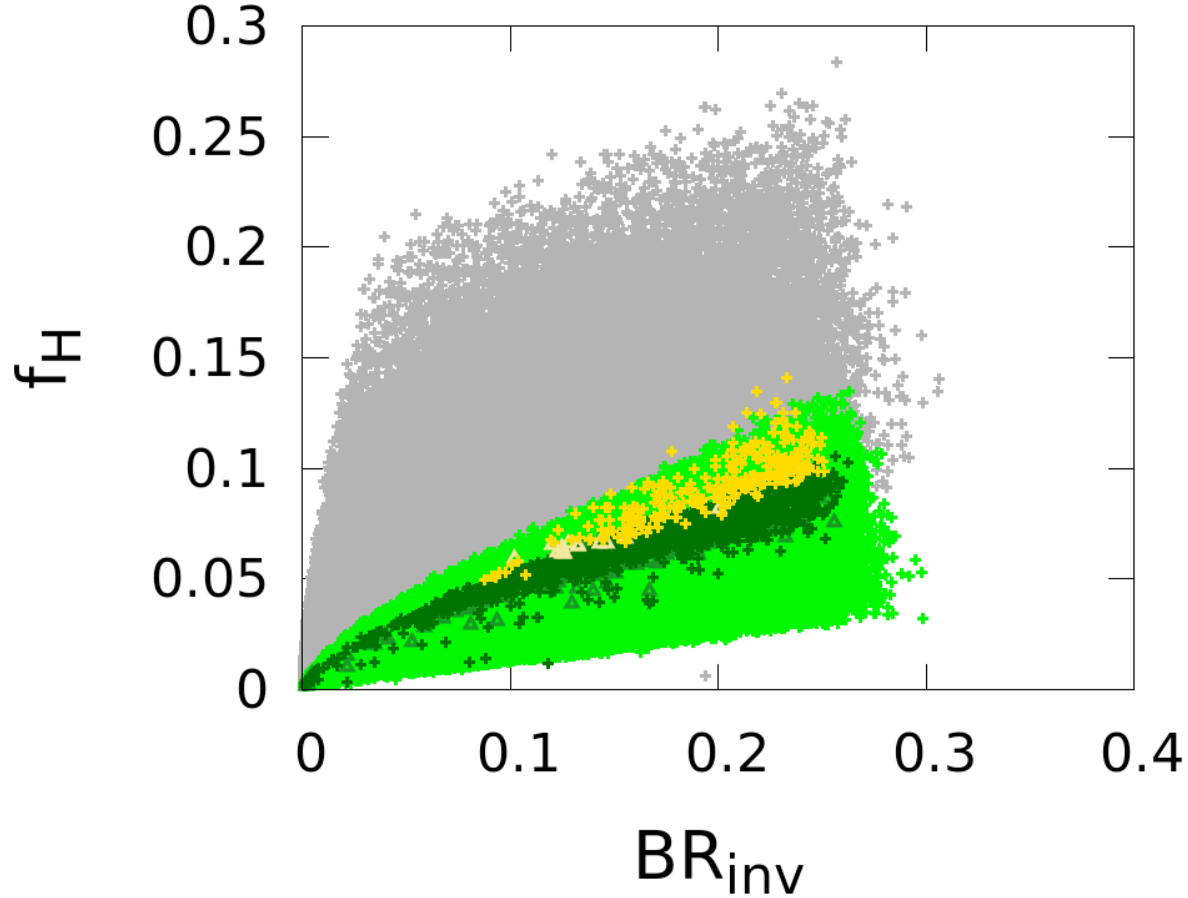
indirect detection

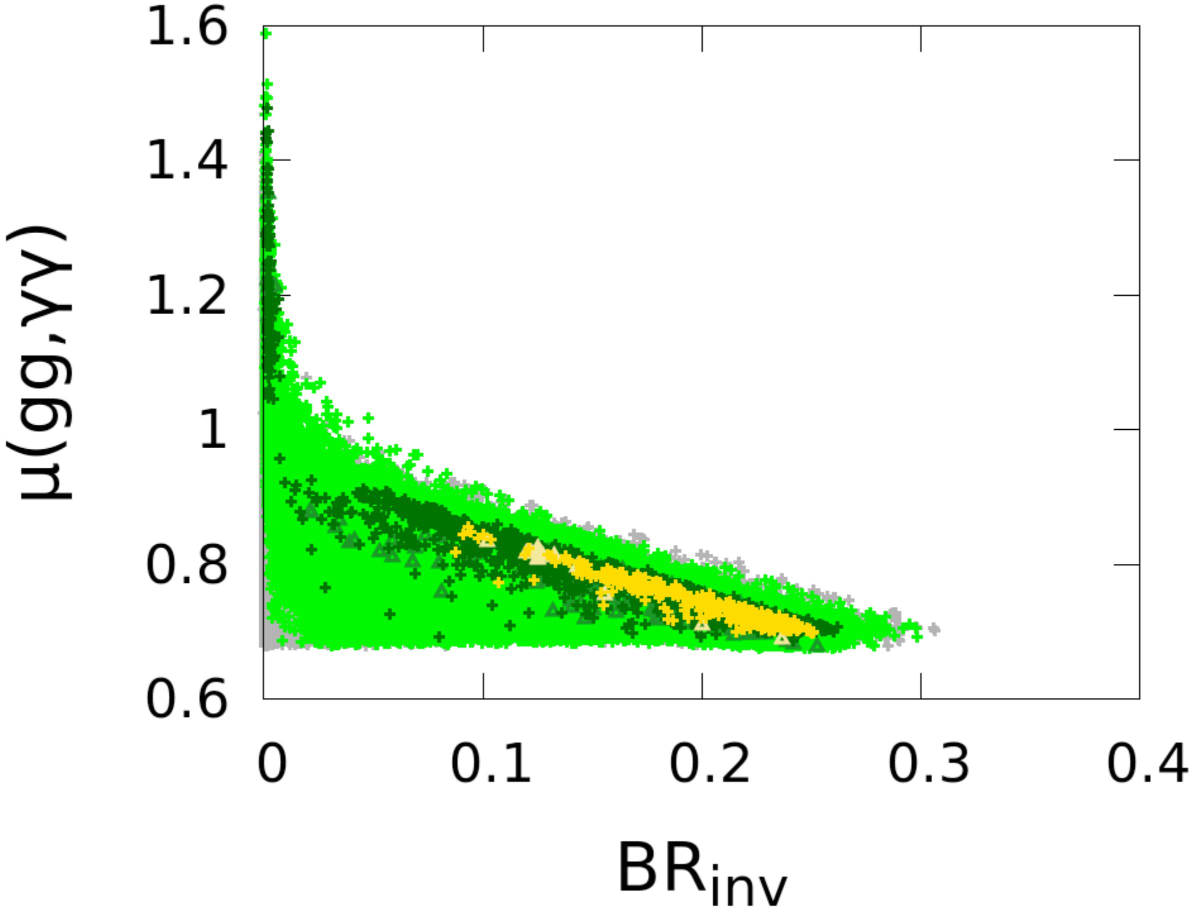




- update of the Fermi-LAT analysis on dwarf spheroidal galaxies: weaker limit (excess mainly driven by ultra-faint dwarf galaxies)
  → no tension with indirect detection in the low-mass region
- in the bb channel the prediction is still two orders of magnitude below the experimental limit

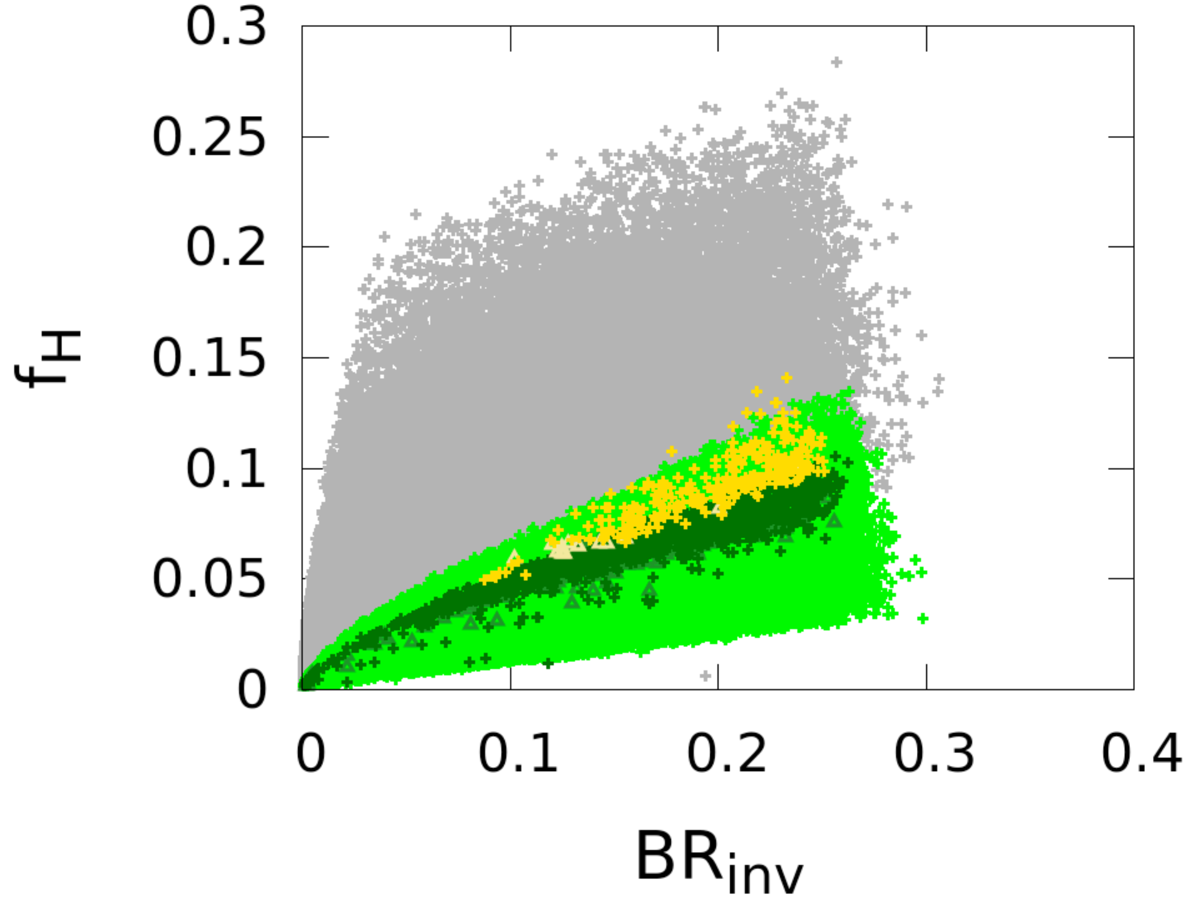
invisible Higgs decays

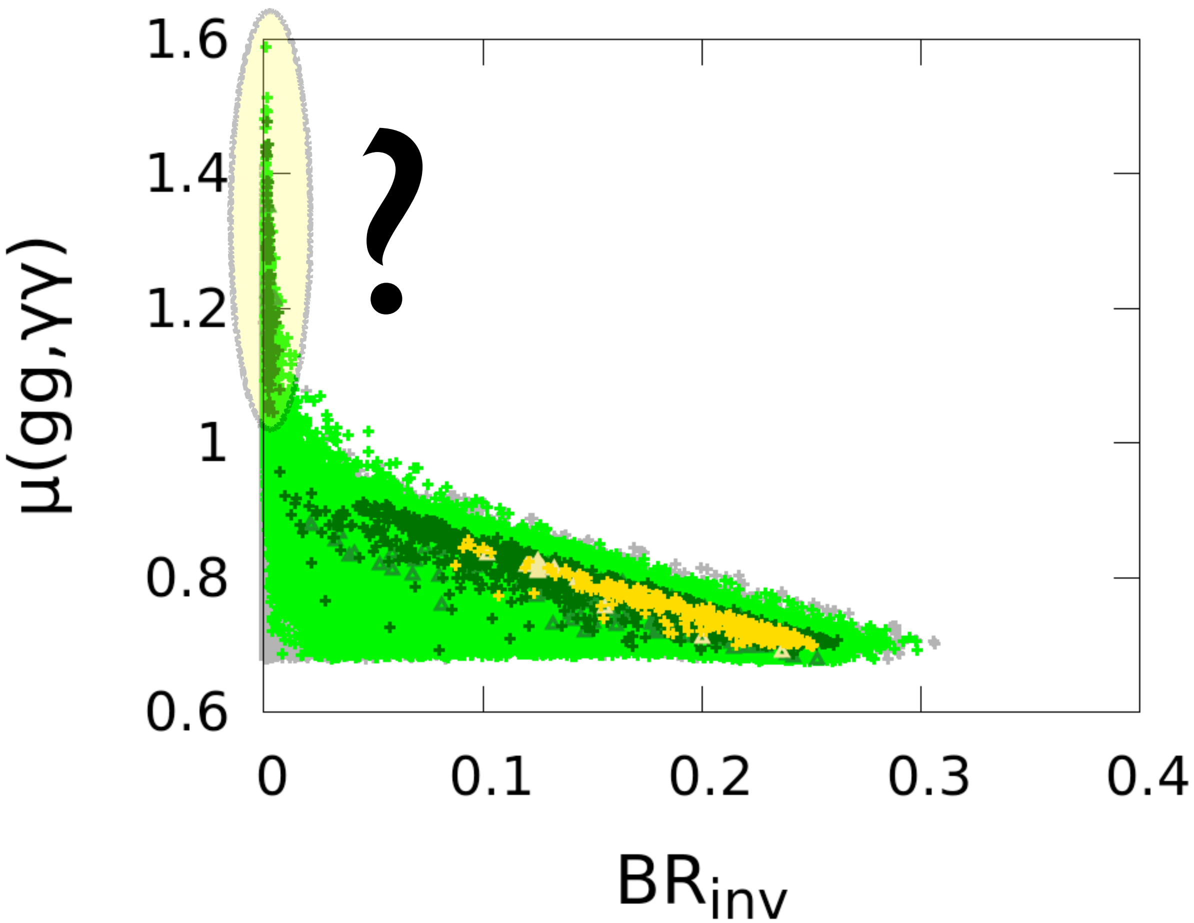




- the Higgs boson couples to a mixture of higgsino and gaugino
  → limit on the higgsino fraction f_H from Higgs measurements
- as expected, anticorrelation between $\mu(gg \to h \to \gamma\gamma)$ and BR_{inv}

invisible Higgs decays





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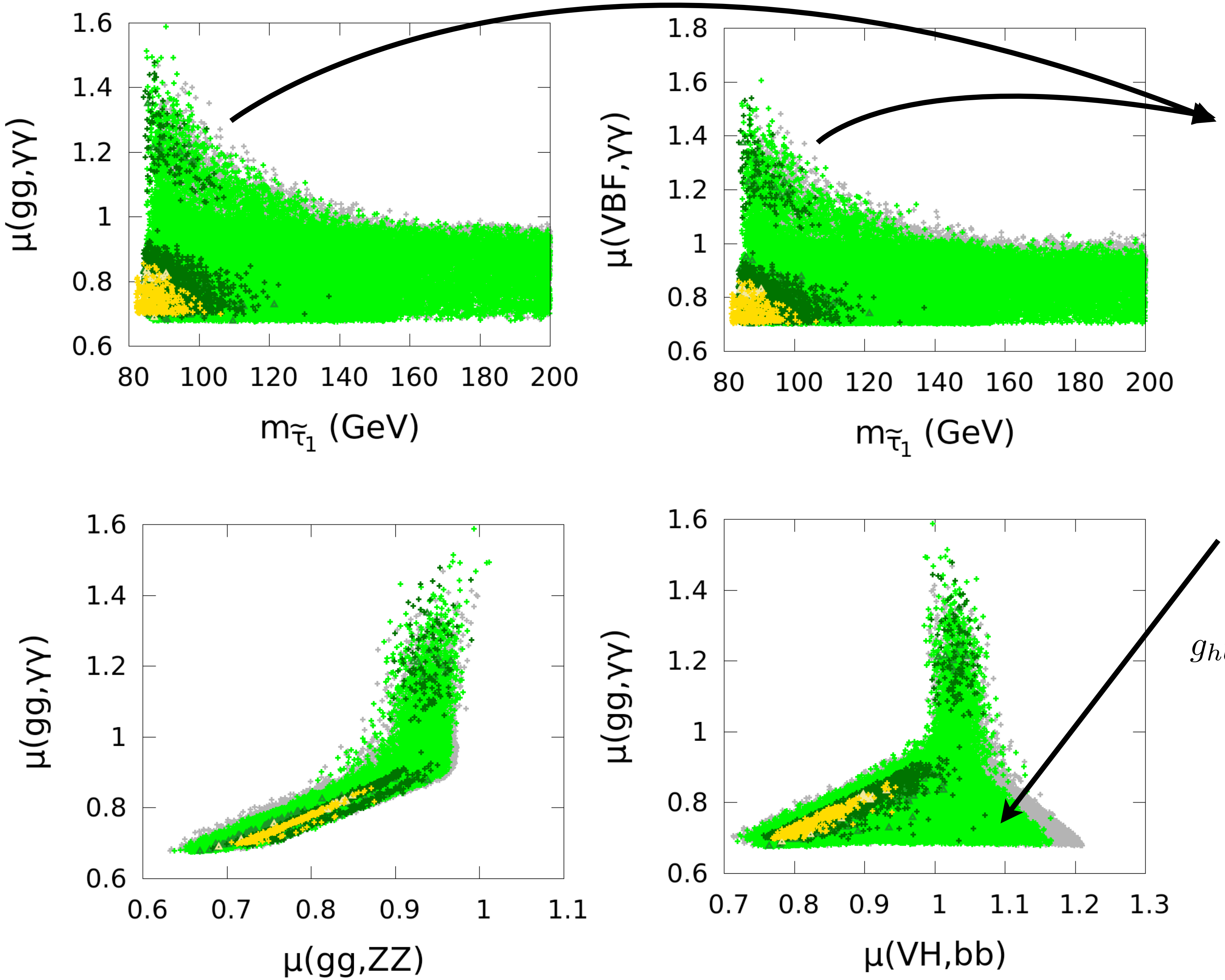
Higgs signal strengths



light, maximally mixed staus

(see [Carena et al, arXiv:1205.5842])

in this case $\mu \gtrsim 400$ GeV

and light selectrons/smuons

high μ (no BR_{inv})
and low M_A, high tan β

$$g_{hbb} = \sin(\beta - \alpha) - \tan\beta \cos(\beta - \alpha)$$

→ promising way to probe light neutralino scenarios

conclusion

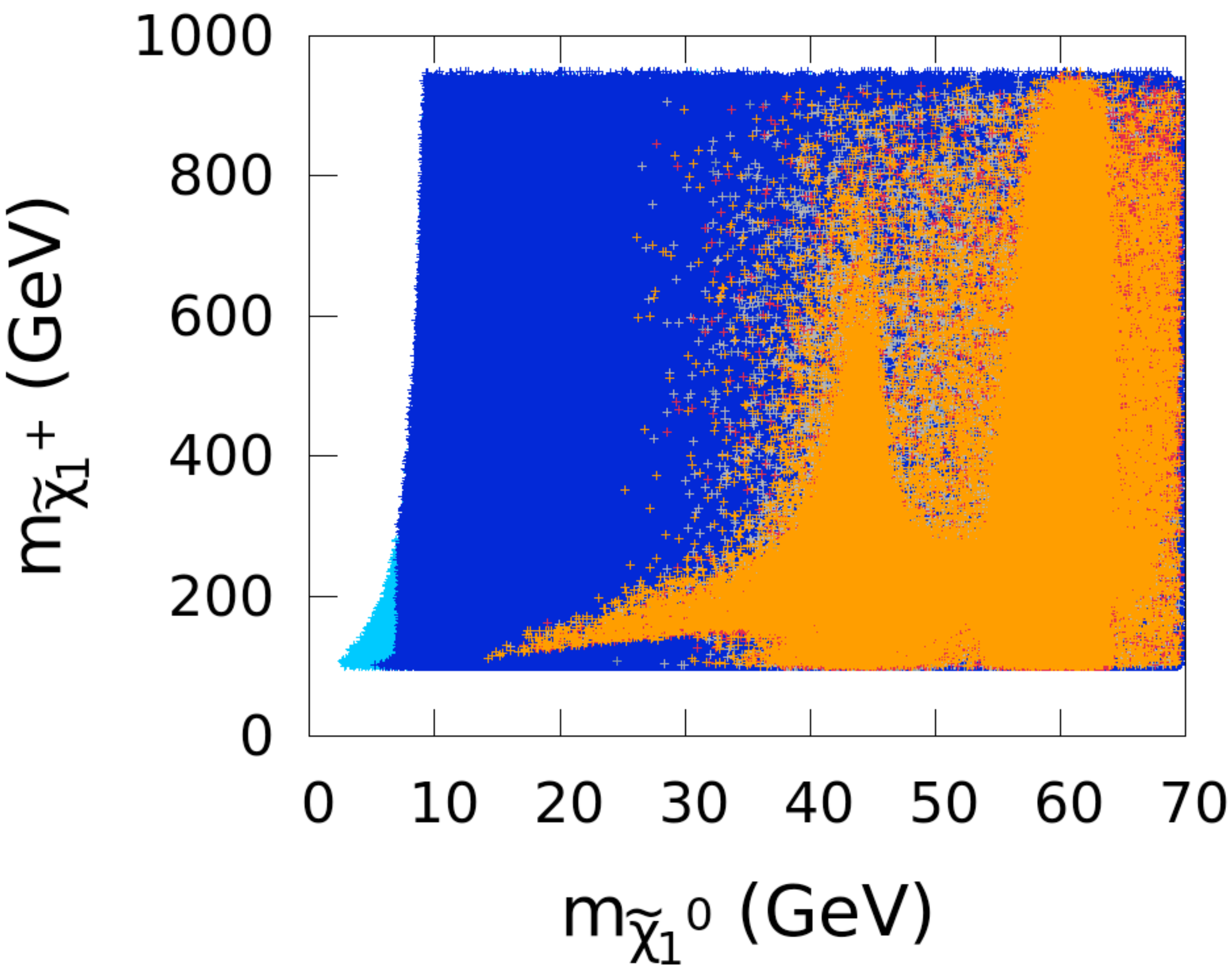
- ✦ no efficient annihilation mechanism for 8–10 GeV neutralino dark matter
  → difficult to accommodate with direct detection hints at low mass
  (but experimental situation unclear: stay tuned)

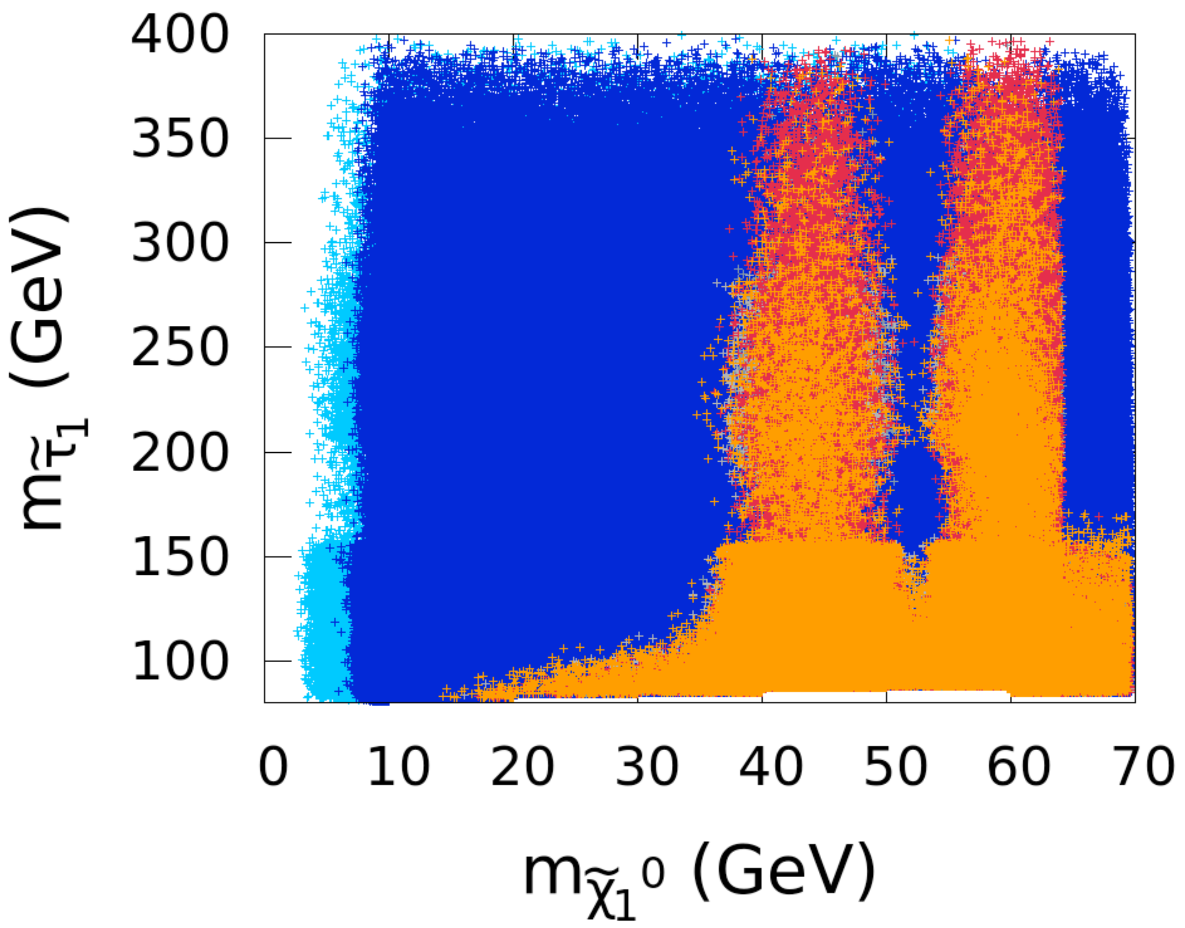
- ✦ low-mass neutralino (~ 15–35 GeV) can be accommodated with light staus and/or charginos
  this is under pressure by the LHC SUSY searches but still allowed

- ✦ significant deviations in the couplings of the Higgs → promising way to probe such scenarios

Backup slides

charginos and staus again

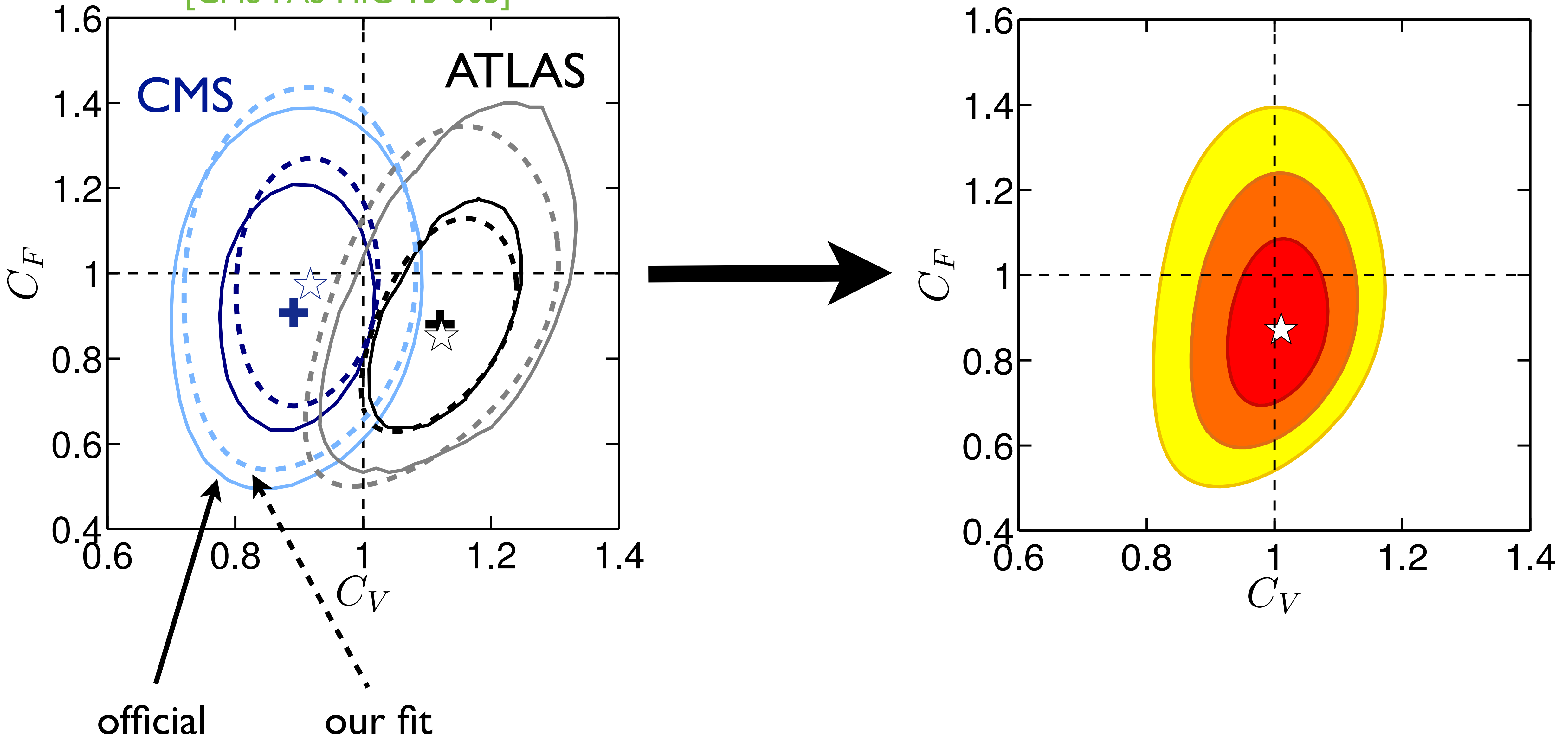




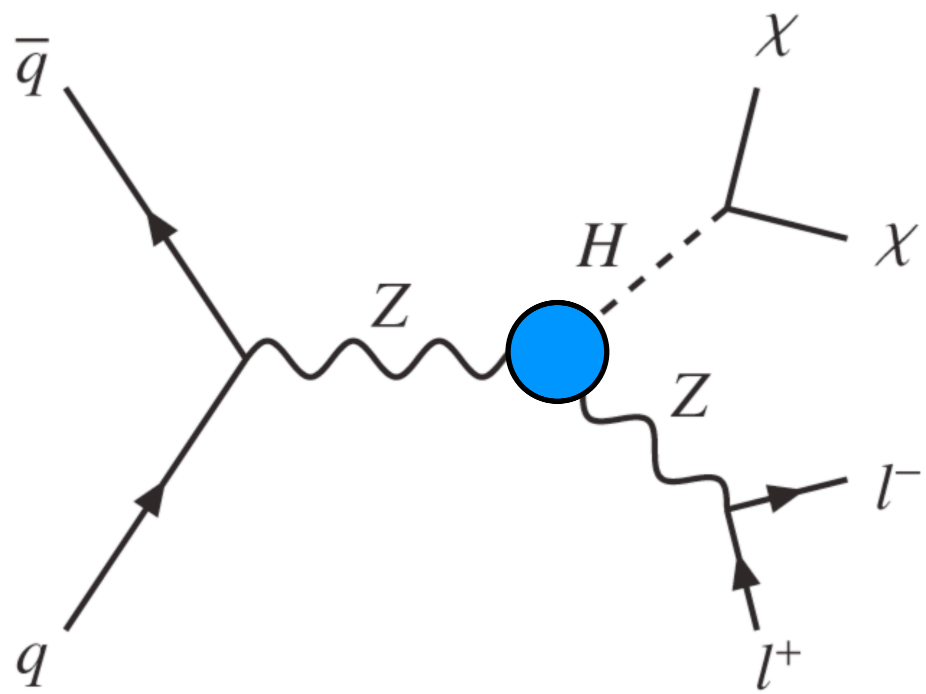
validation with ATLAS and CMS

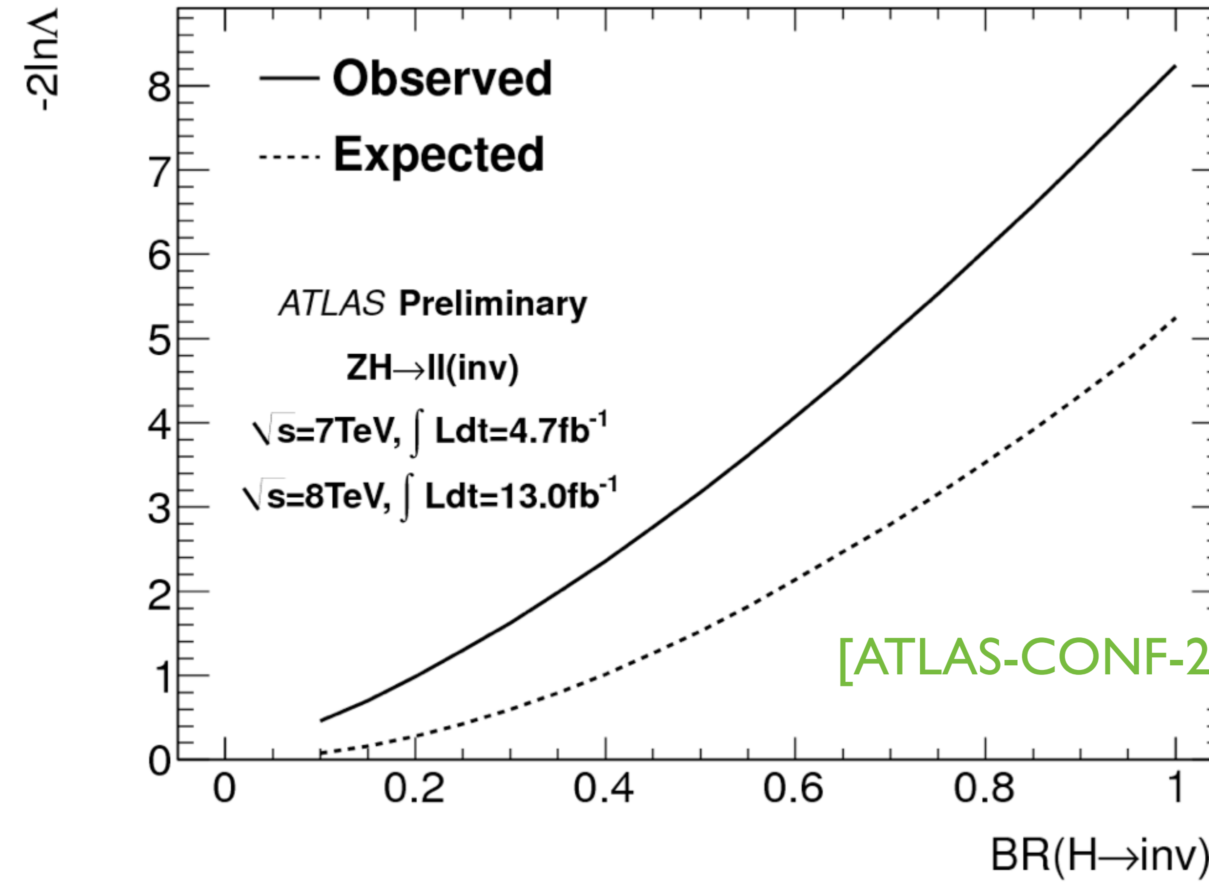
validation with benchmark scenarios of the ATLAS and CMS couplings fits

[ATLAS-CONF-2013-034]
[CMS-PAS-HIG-13-005]



invisible decays of the Higgs boson





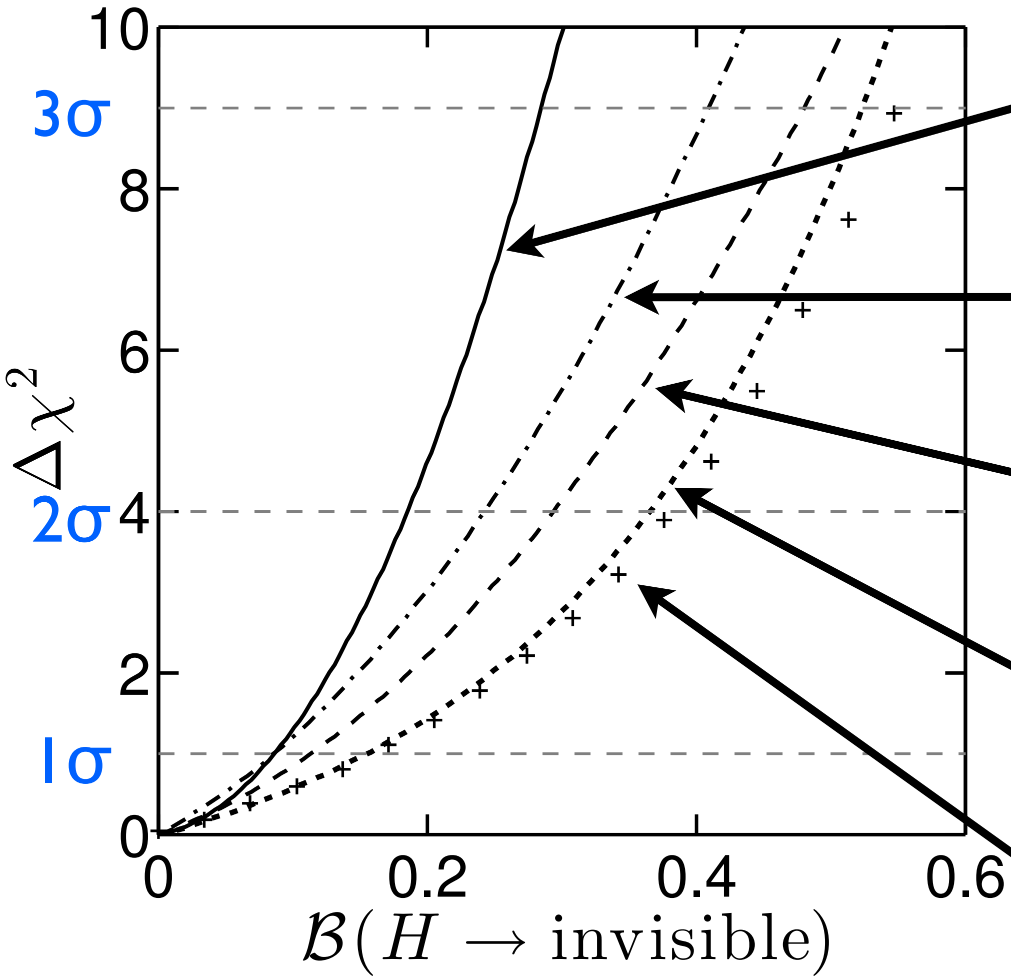
[ATLAS-CONF-2013-011]

$C_V^2 \mathcal{B}\ H \to \quad . < \ .$

see also CMS limit on ZH→ll+invisible [HIG-13-018]
and on VBF→invisible [HIG-13-013]

invisible decays of the Higgs boson

[arXiv:1302.5694, arXiv:1306.2941]



SM+invisible
$\mathcal{B}(H \to \text{inv.}) < 0.19$ at 95% CL

SM+C_U+C_D+($C_V \leq 1$)+invisible
$\mathcal{B}(H \to \text{inv.}) < 0.24$ at 95% CL

SM+ΔC_g+ΔC_γ+invisible
$\mathcal{B}(H \to \text{inv.}) < 0.29$ at 95% CL

SM+C_U+C_D+C_V+invisible
$\mathcal{B}(H \to \text{inv.}) < 0.36$ at 95% CL

SM+C_U+C_D+C_V+ΔC_g+ΔC_γ+invisible
$\mathcal{B}(H \to \text{inv.}) < 0.38$ at 95% CL

mainly from global μ fit

mainly from searches for invisible