Higgs coupling measurements and impact on the MSSM

Béranger Dumont
(LPSC Grenoble)

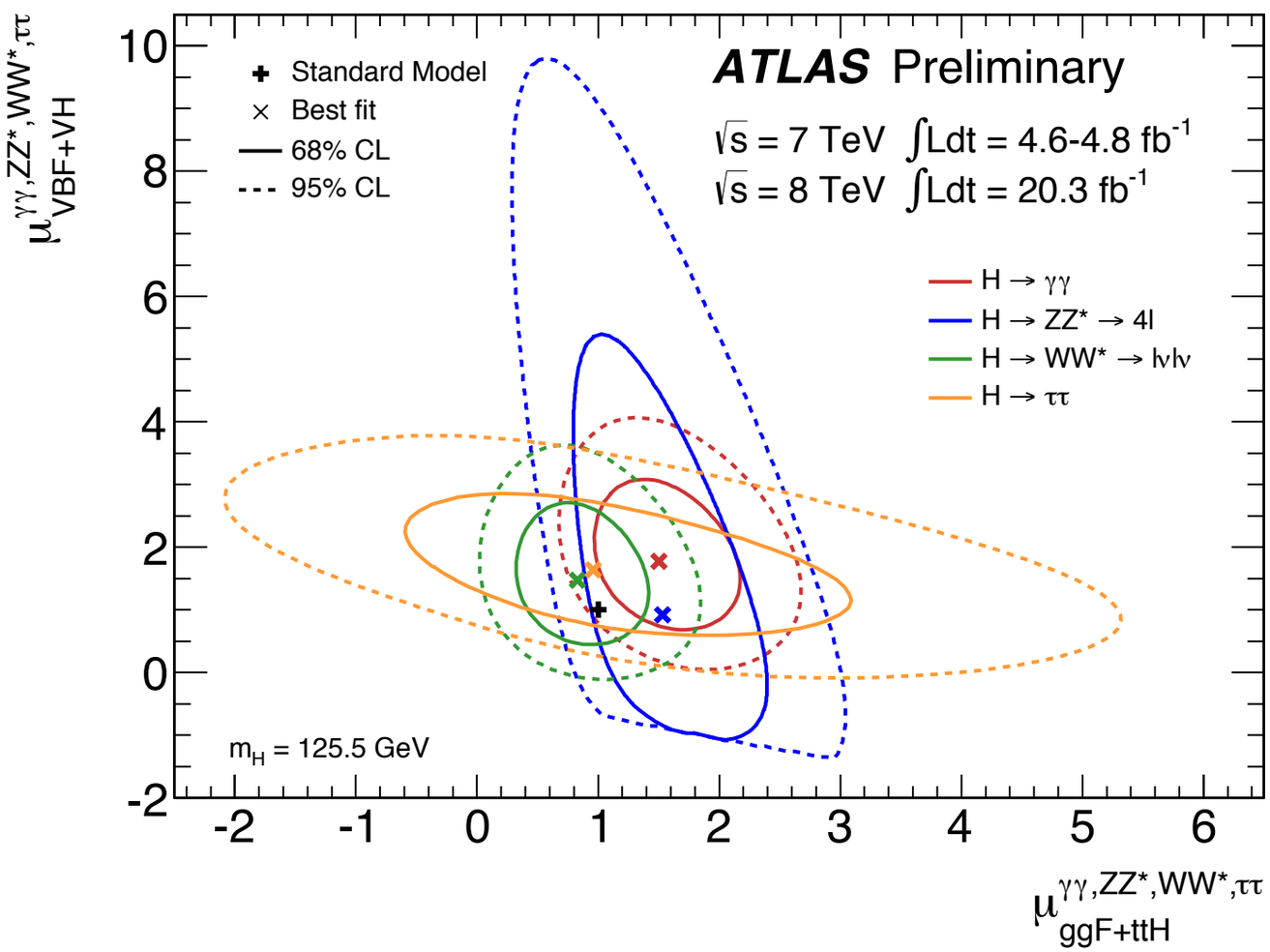
based on work with
G. Bélanger, G. Drieu La Rochelle, U. Ellwanger, R. M. Godbole, J.F. Gunion, S. Kraml, S. Kulkarni and S. Sekmen
[arXiv:1306.2941, arXiv:1308.3735, arXiv:1312.7027]

DIS 2014 @ Warsaw

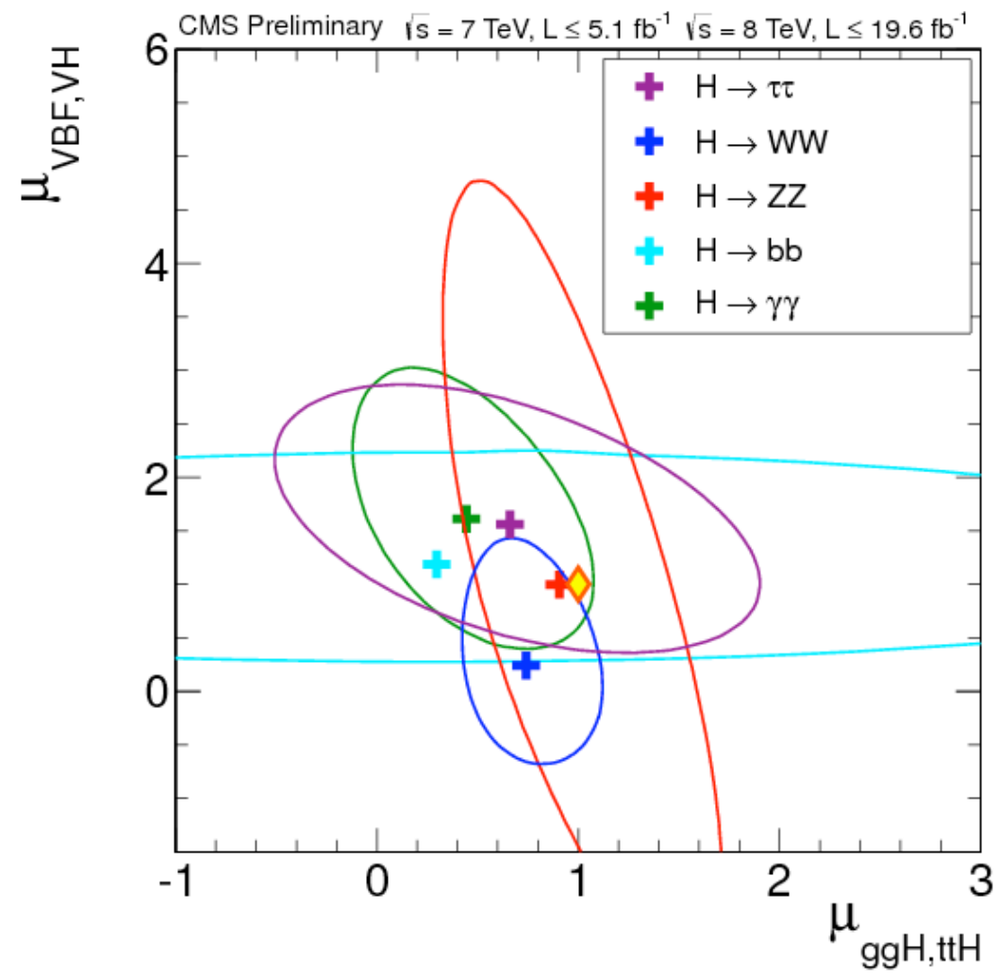
April 30, 2014

Higgs signal strengths

[ATLAS-CONF-2014-009]



[CMS-PAS-HIG-13-005]

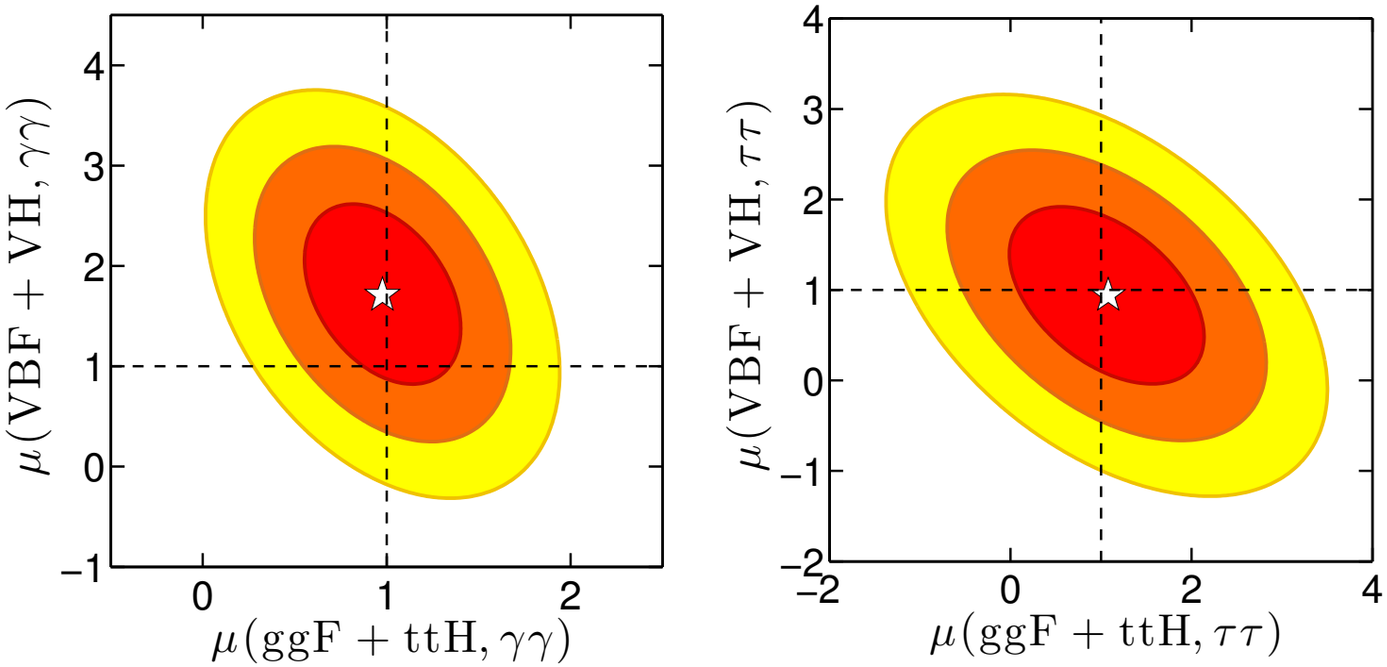


in order to construct an approximation to the Higgs likelihood, one can:

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

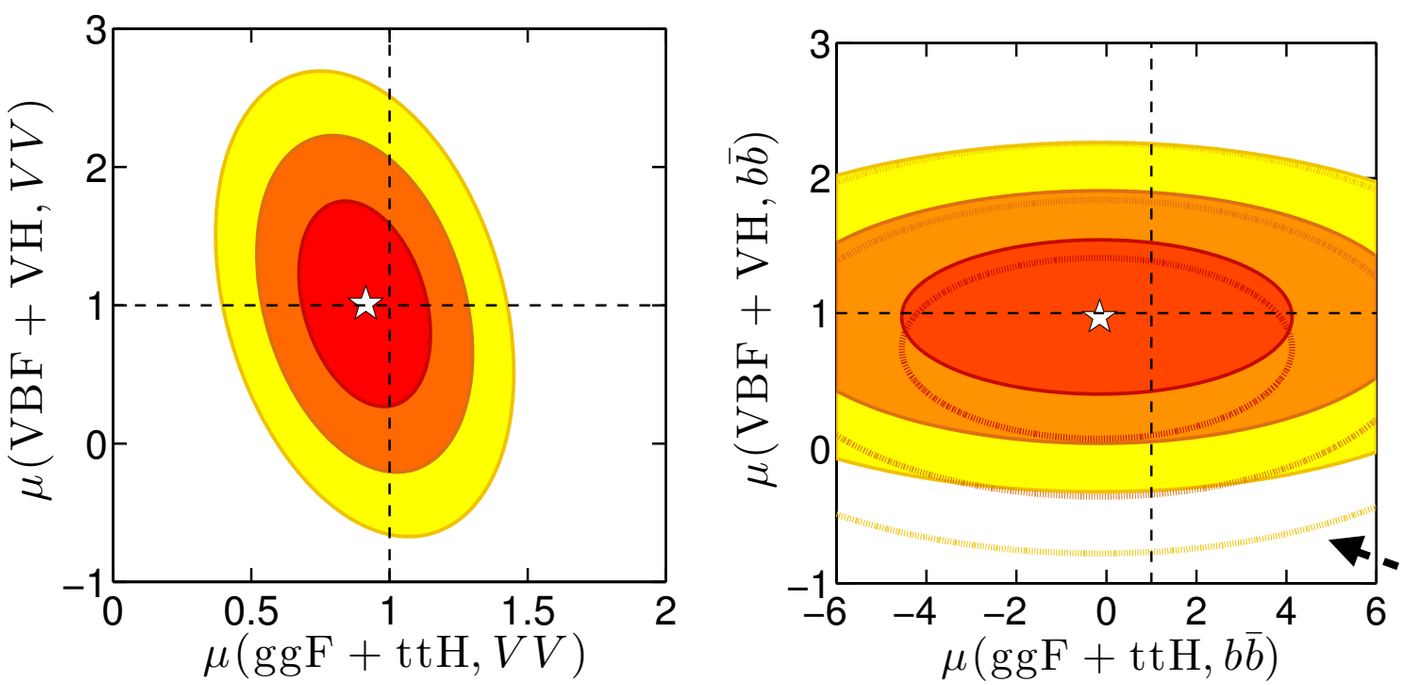
combined 2D μ plots



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

include all results up to the LHCP 2013 conference

$$\chi_i^2 = a_i(\mu_{\mathrm{ggF},i} - \hat{\mu}_{\mathrm{ggF},i})^2 + 2b_i(\mu_{\mathrm{ggF},i} - \hat{\mu}_{\mathrm{ggF},i})(\mu_{\mathrm{VBF},i} - \hat{\mu}_{\mathrm{VBF},i}) + c_i(\mu_{\mathrm{VBF},i} - \hat{\mu}_{\mathrm{VBF},i})^2$$



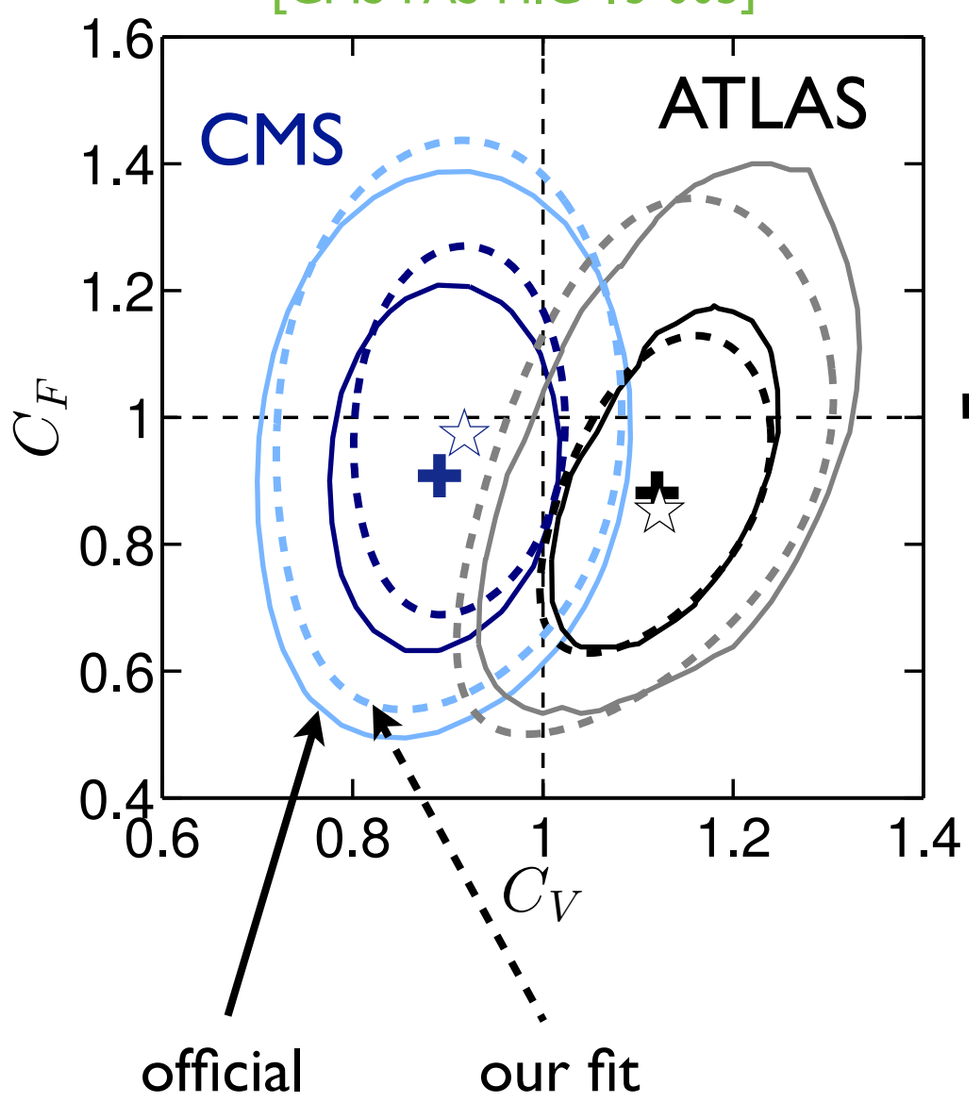
	$\hat{\mu}_{\mathrm{ggF}}$	$\hat{\mu}_{\mathrm{VBF}}$	a	b	c
$\gamma\gamma$	0.98	1.72	14.94	2.69	3.34
VV	0.91	1.01	44.59	4.24	4.58
$b\bar{b}/\tau\tau$	0.98	0.97	2.67	1.31	10.12
$b\bar{b}$	−0.23	0.97	0.12	0	7.06
$\tau\tau$	1.07	0.94	2.55	1.31	3.07

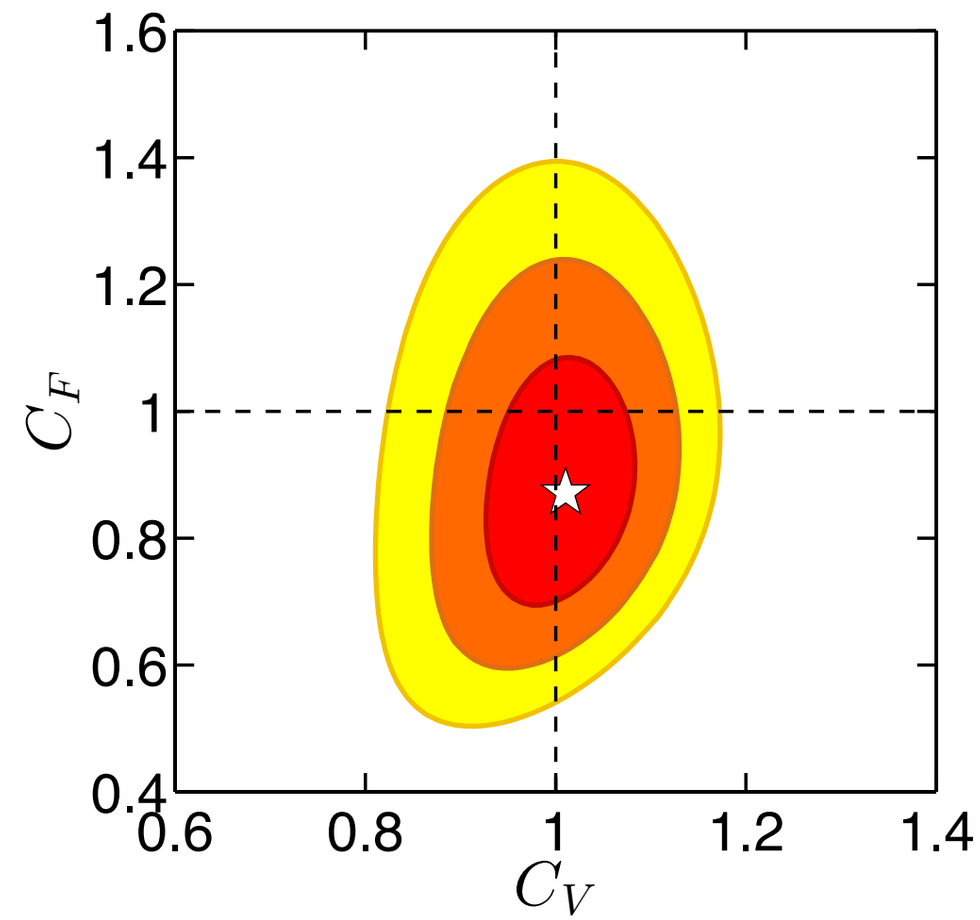
without Tevatron

validation with ATLAS and CMS

validation with benchmark scenarios of the ATLAS and CMS couplings fits

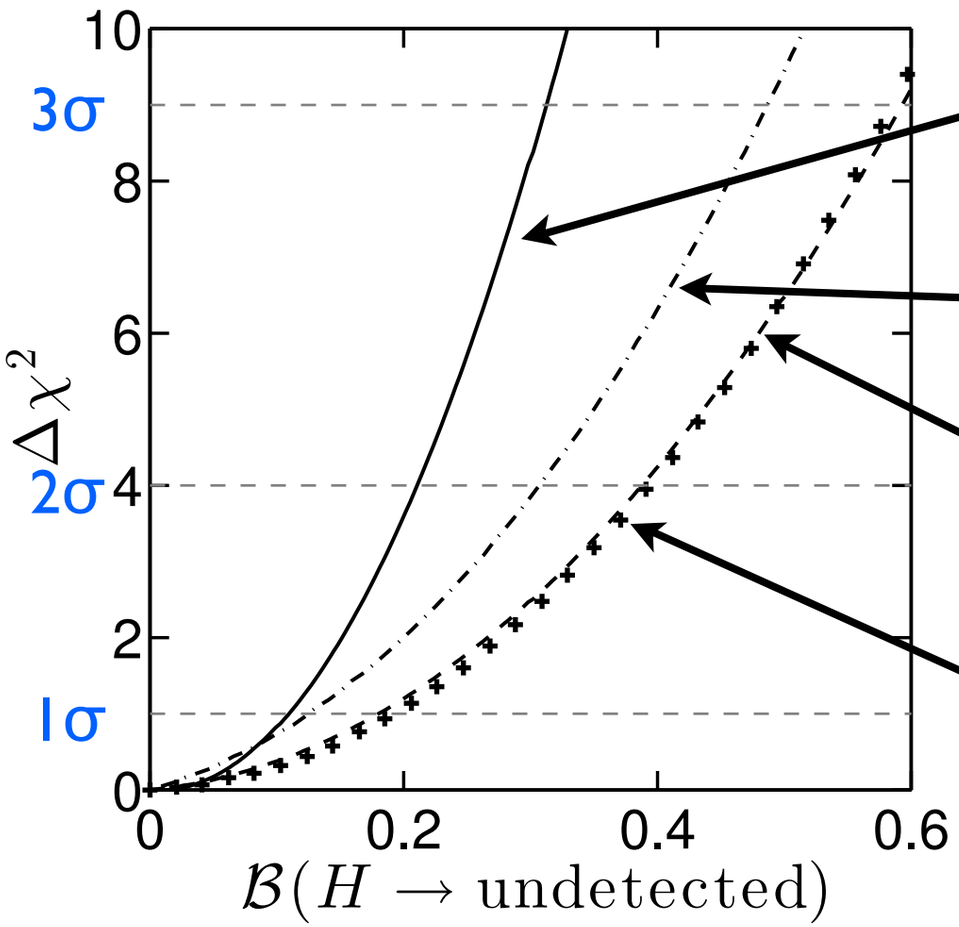
[ATLAS-CONF-2013-034]
[CMS-PAS-HIG-13-005]





invisible decays of the Higgs boson

includes ATLAS results for ZH→ll+invisible



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)

the p(henomenological) MSSM

19-parameter realization of general MSSM
parameters defined at the weak scale, no SUSY breaking prejudices

minimal assumptions:
flavor-diagonal mass matrices, 1st and 2nd gen. degenerate, no new CP phases,
R-parity & neutralino LSP

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

LSP and dark matter candidate

we scan over:
(flat prior)

[BD, Gunion, Kraml, arXiv:1312.7027]

$$-3\,\text{TeV} \leq M_1,\, M_2,\, \mu \leq 3\,\text{TeV}\,;$$
$$0 \leq M_3, m_{\tilde{F}}, m_A \leq 3\,\text{TeV}\,;$$
$$-7\,\text{TeV} \leq A_t, A_b, A_\tau \leq 7\,\text{TeV}\,;$$
$$2 \leq \tan\beta \leq 60\,.$$

Bayesian analysis using
Markov Chain Monte Carlo
(MCMC) methods

$$p(\theta|D) \sim L(D|\theta)\, p_0(\theta)$$

experimental constraints

"preLHC":

Observable $\mu_j(\theta)$	Constraint D_j^{preHiggs}	Likelihood function $L(D_j^{\text{preHiggs}}\|\mu_j(\theta))$
$\text{BR}(b \to s\gamma)$	$(3.43 \pm 0.21^{\text{stat}} \pm 0.23^{\text{th}} \pm 0.07^{\text{sys}}) \times 10^{-4}$	Gaussian
$\text{BR}(B_s \to \mu\mu)$	$(2.9 \pm 0.7 \pm 0.29^{\text{th}}) \times 10^{-9}$	Gaussian
$R(B_u \to \tau\nu)$	1.04 ± 0.34	Gaussian
Δa_μ	$(26.1 \pm 8.0^{\text{exp}} \pm 10.0^{\text{th}}) \times 10^{-10}$	Gaussian
m_t	173.20 ± 0.87 GeV	Gaussian
$m_b(m_b)$	$4.19^{+0.18}_{-0.06}$ GeV	Two-sided Gaussian
$\alpha_s(M_Z)$	0.1184 ± 0.0007	Gaussian
sparticle masses	LEP (via micrOMEGAs)	1 if allowed 0 if excluded

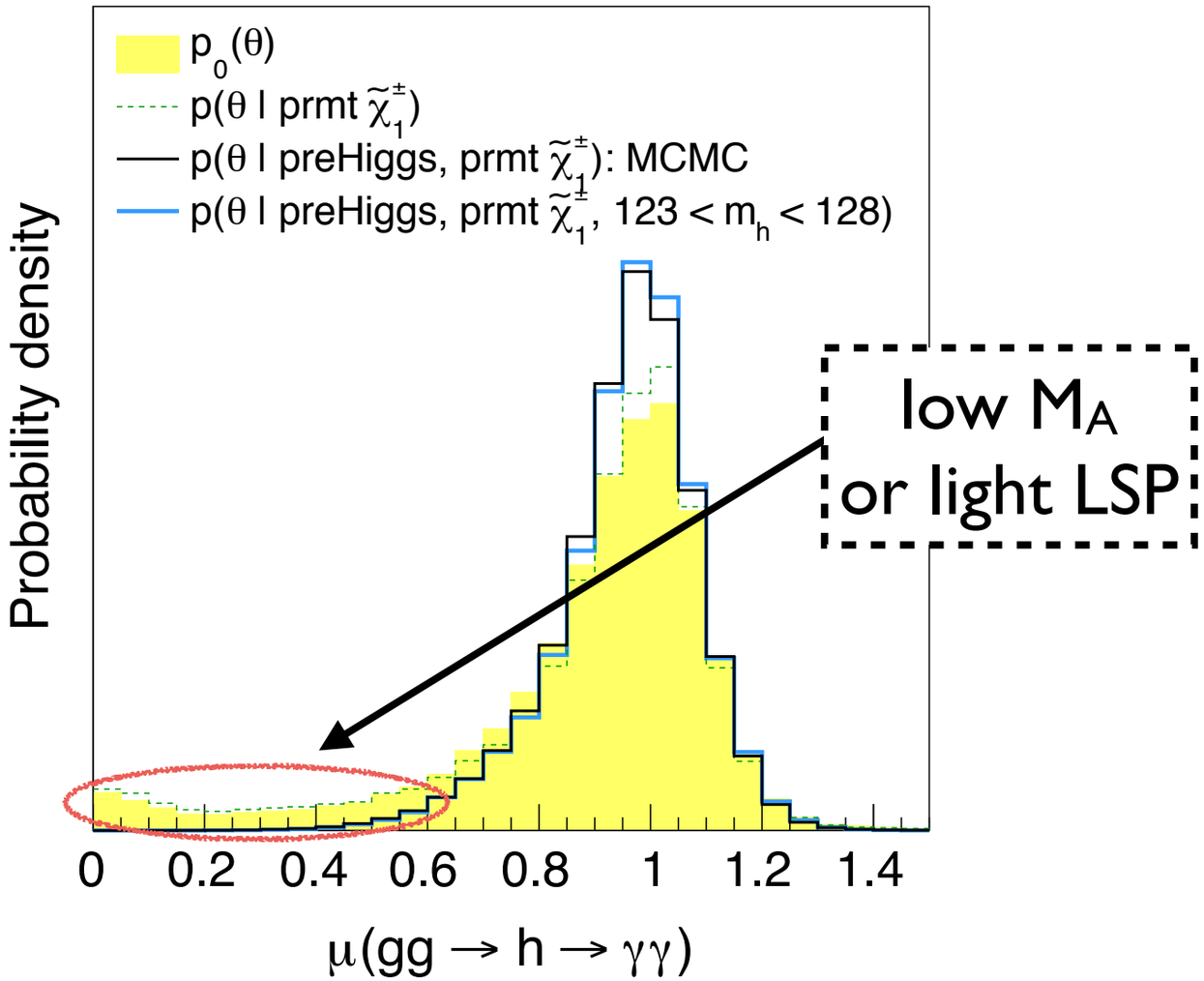
+ prompt chargino decay ($c\tau$ < 10 mm)

+ "hsig": 125 GeV Higgs likelihood + CMS $A^0,H^0 \to \tau^+\tau^-$ constraint [CMS-PAS-HIG-13-021]

+ "DMup": $\Omega_{\text{DM}}h^2 \lesssim 0.119$ and 90% CL LUX limit

orthogonal to the CMS pMSSM studies (that incl. results from SUSY searches)
[CMS-PAS-SUS-12-030, CMS-PAS-SUS-13-020]

results: gg→h→γγ



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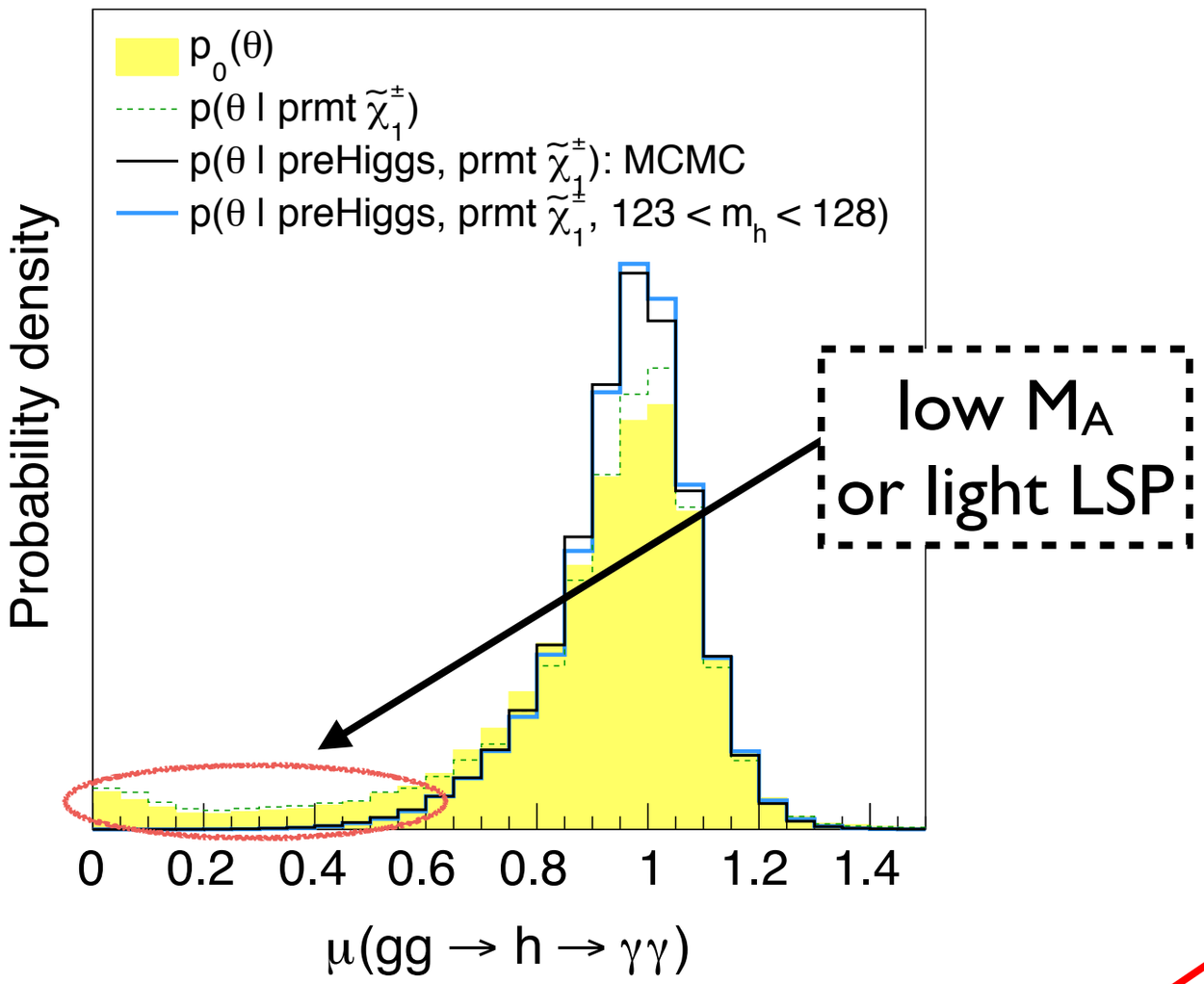
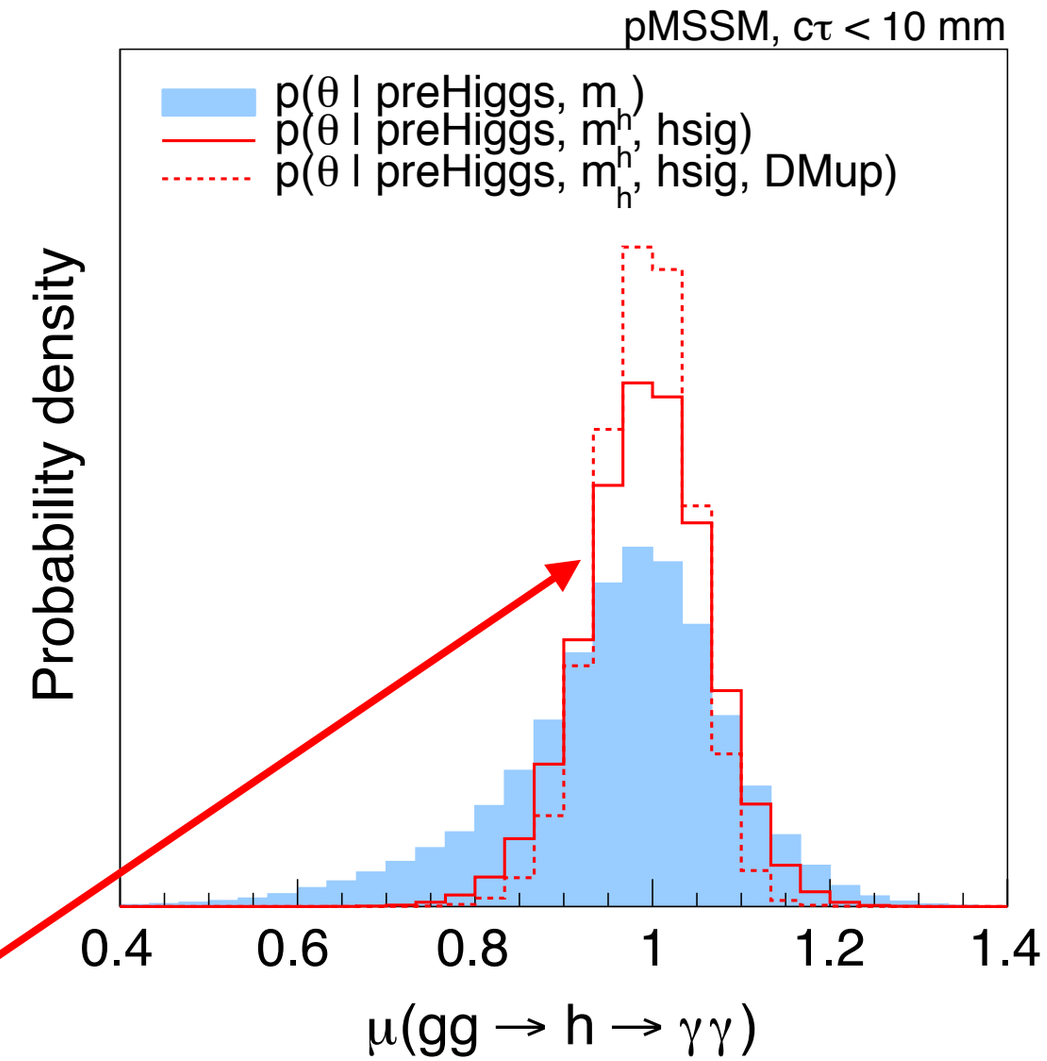




$\mu \approx 1 \pm 0.15$

SUSY partners are typically too heavy to modify the Higgs properties
…so where are the deviations from a SM-like Higgs coming from?

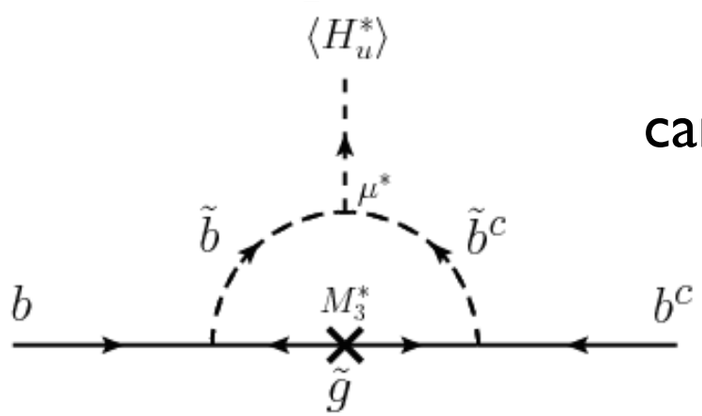
why is μ ≠ 1

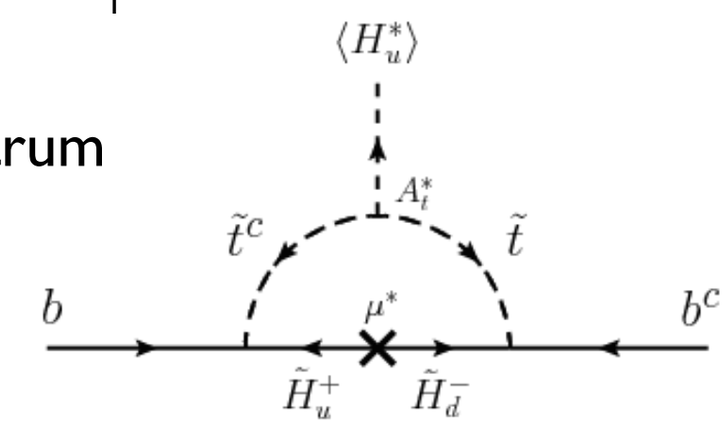
the SM Higgs width is dominated by h→bb (BR=57%)
SUSY correction to the bottom Yukawa coupling:

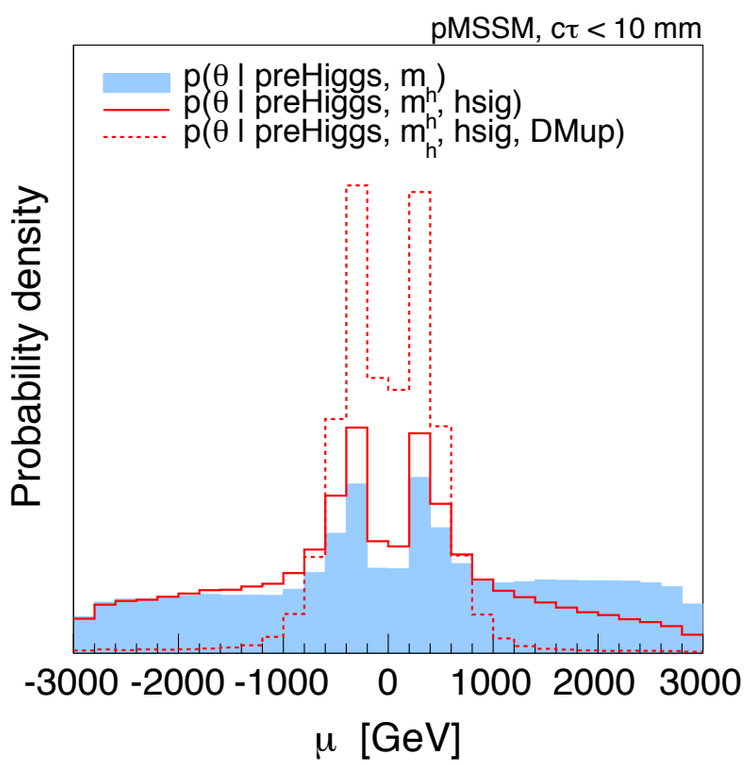
[Carena et al. '99]
[Eberl et al. '99]

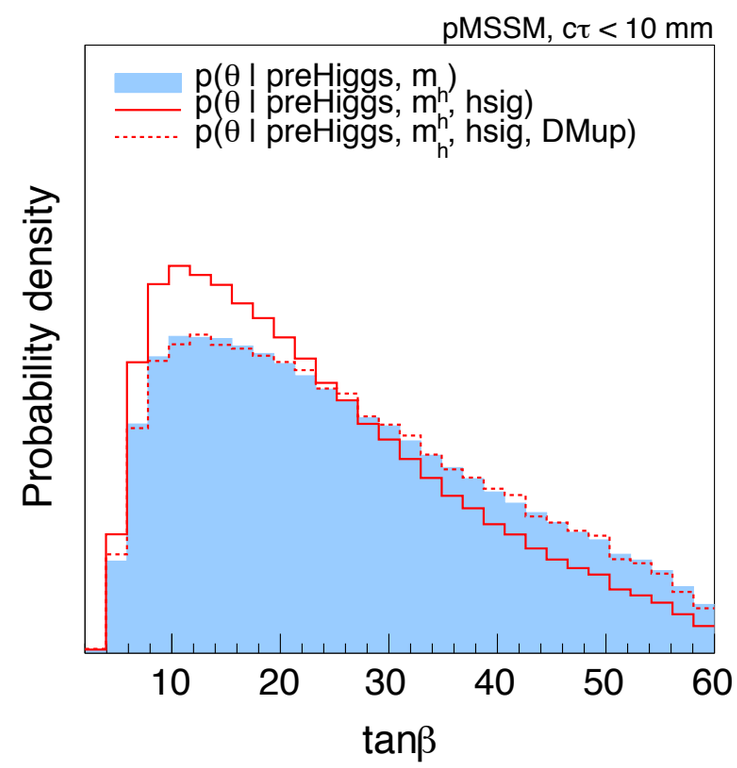
$$\Delta_b \equiv \frac{\Delta m_b}{m_b} \simeq \left[\frac{2\alpha_s}{3\pi}\mu m_{\tilde{g}}\, I(m^2_{\tilde{g}}, m^2_{\tilde{b}_1}, m^2_{\tilde{b}_2}) + \frac{\lambda_t^2}{16\pi^2} A_t \mu\, I(\mu^2, m^2_{\tilde{t}_1}, m^2_{\tilde{t}_2})\right] \tan\beta$$

can be large for a heavy SUSY spectrum









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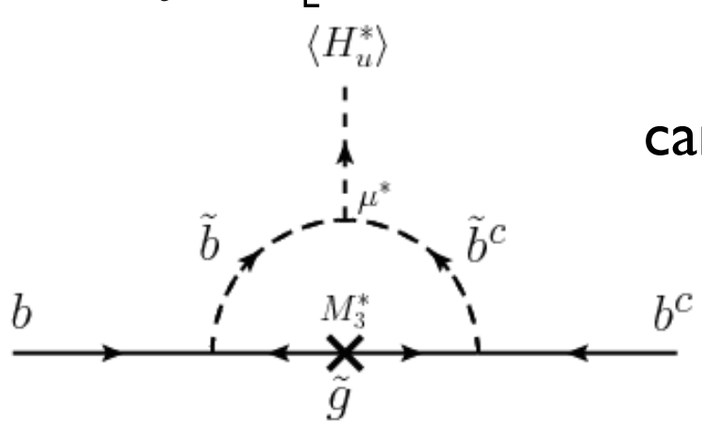
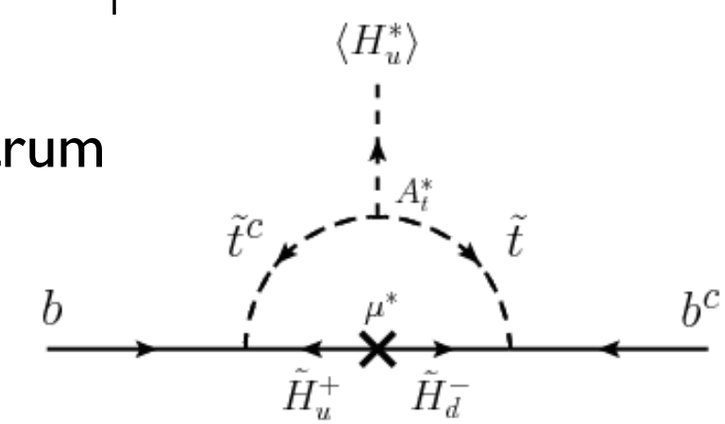
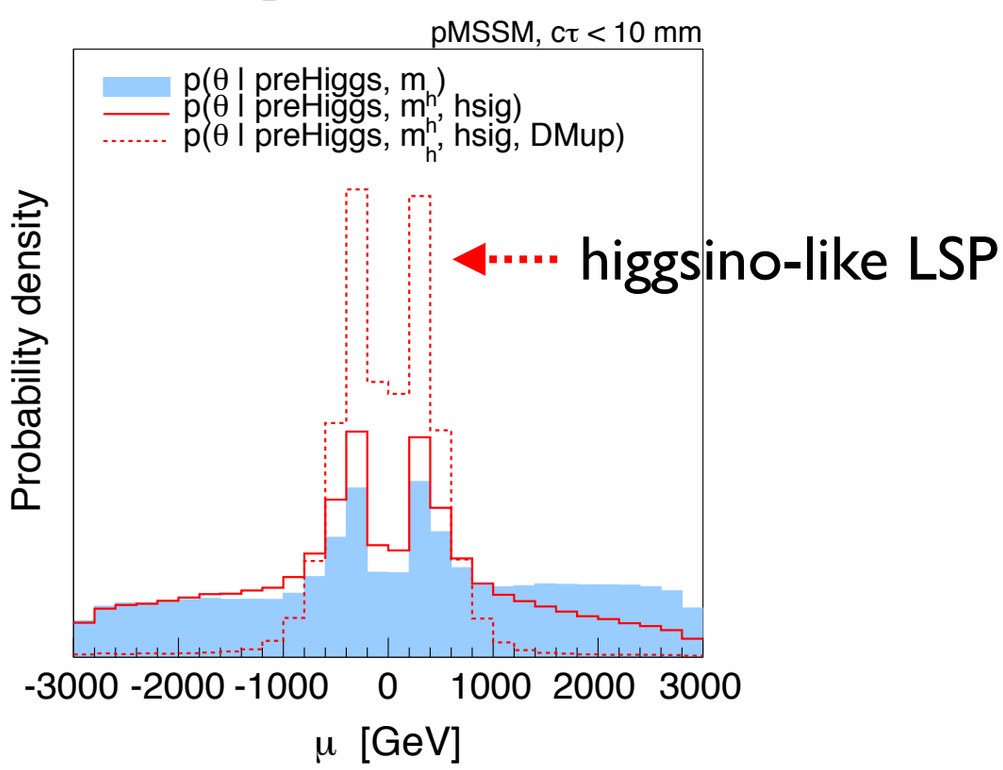
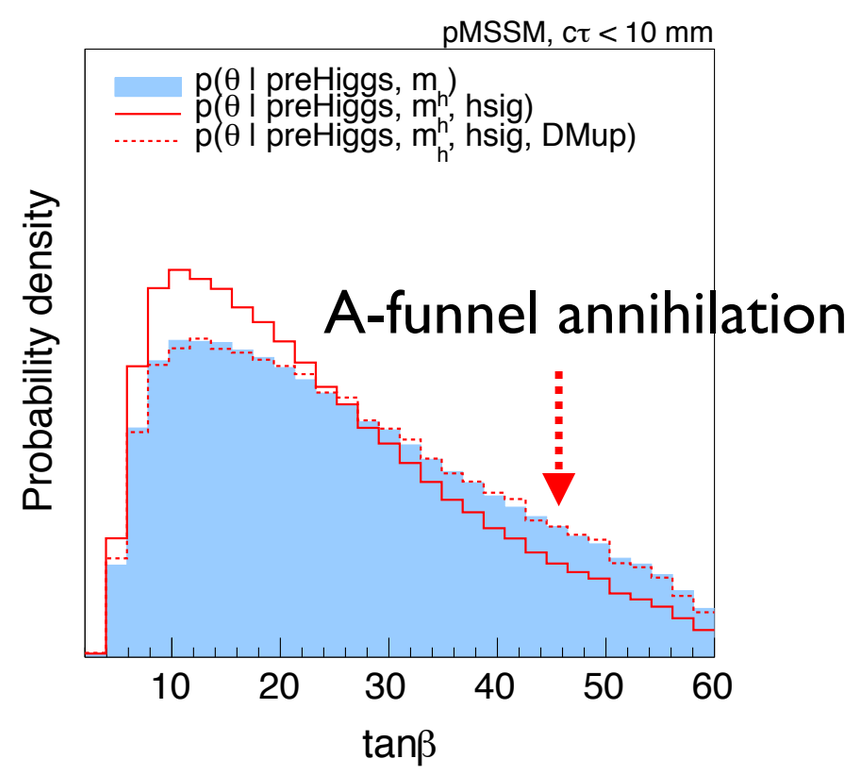
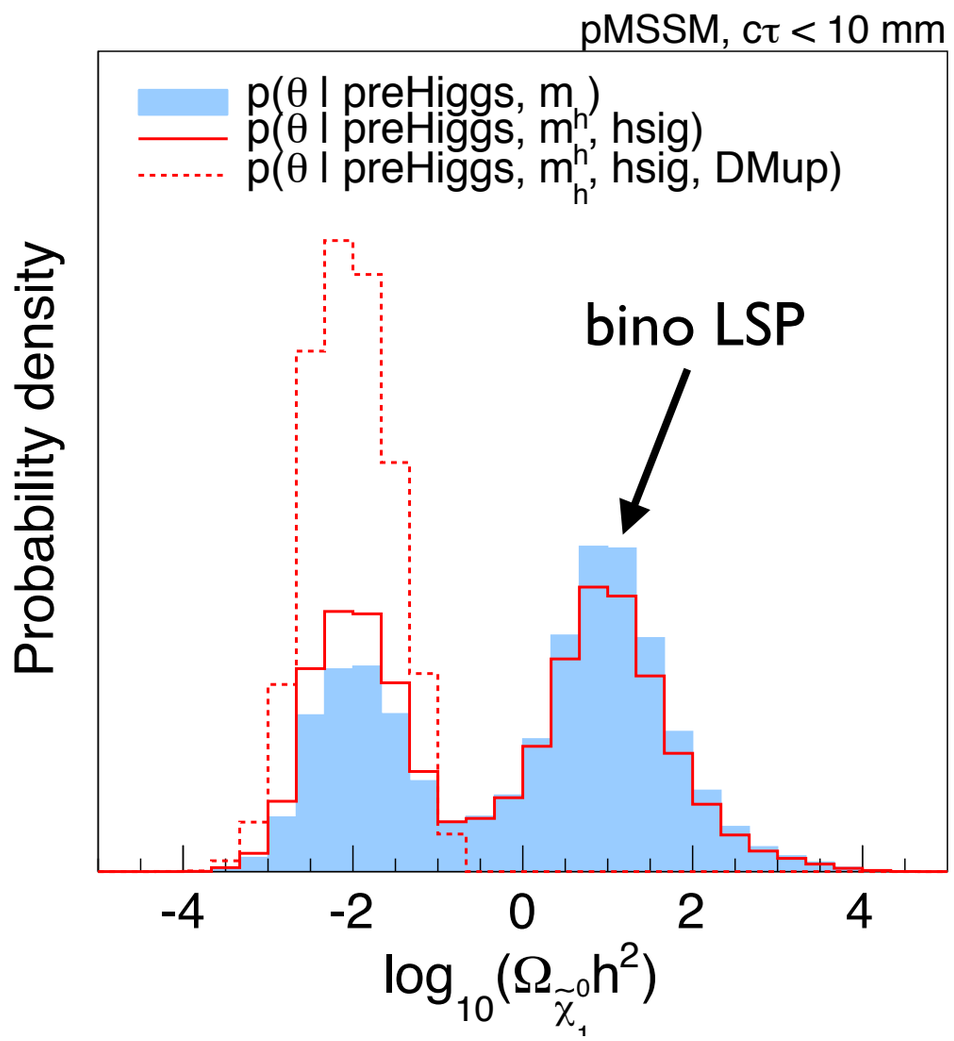


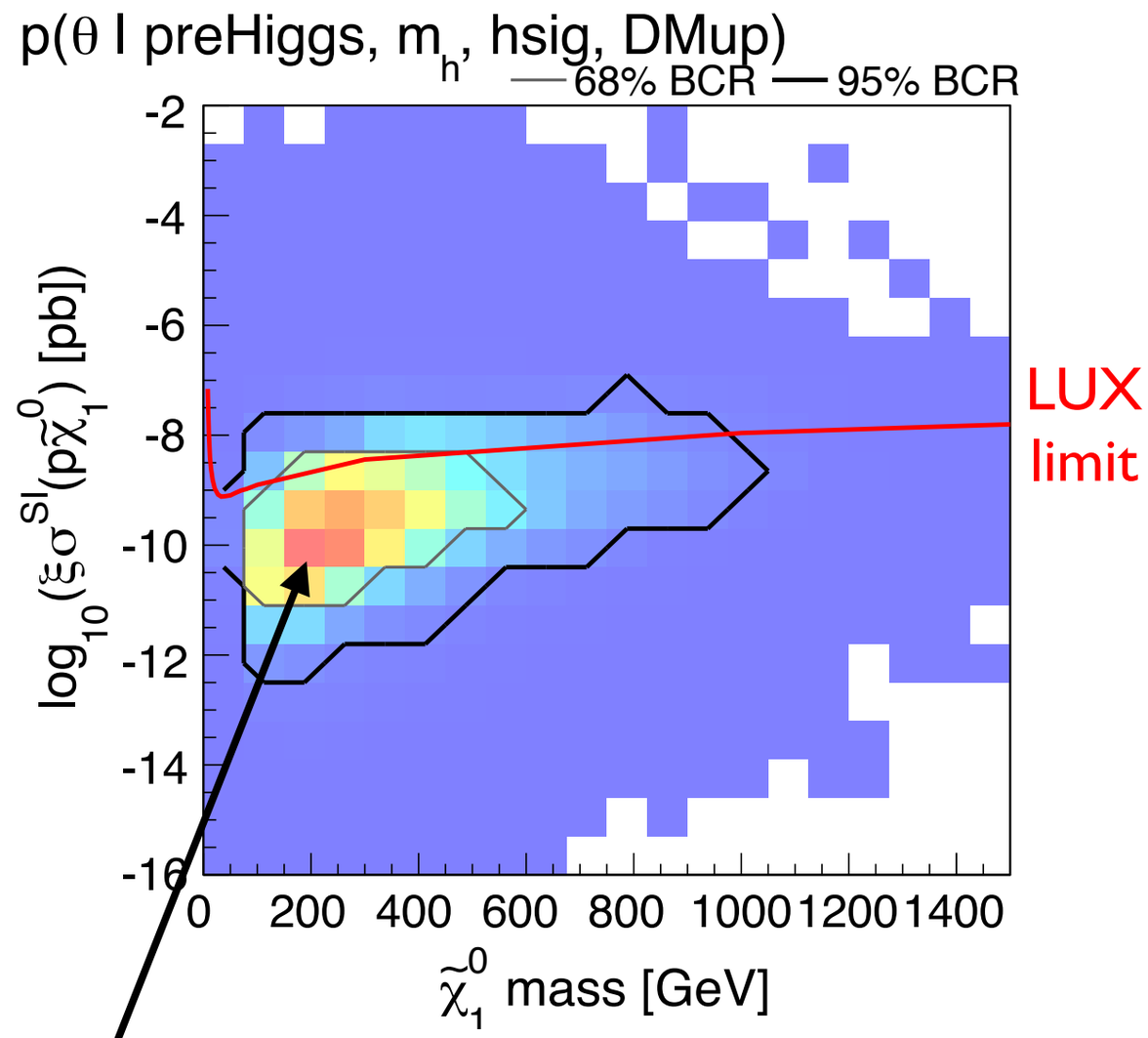






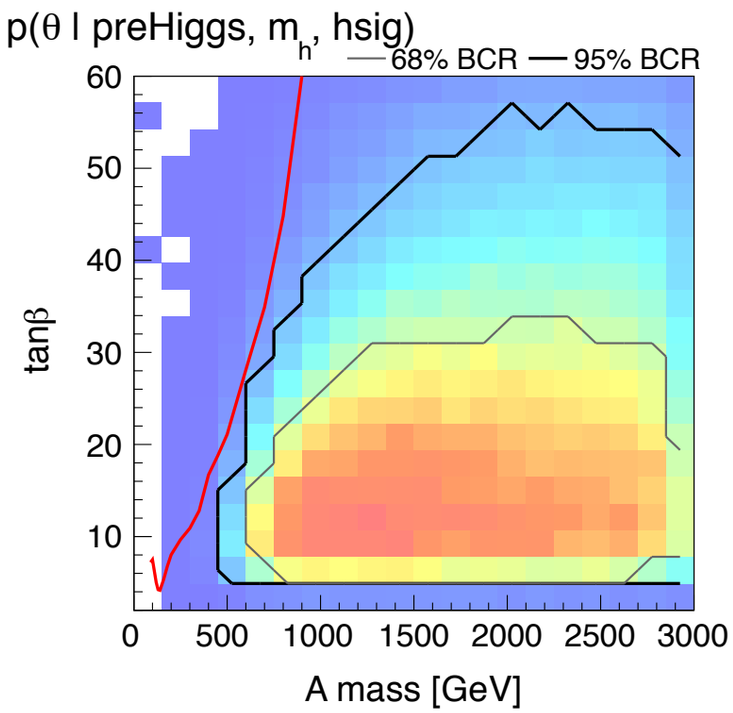
implications for dark matter

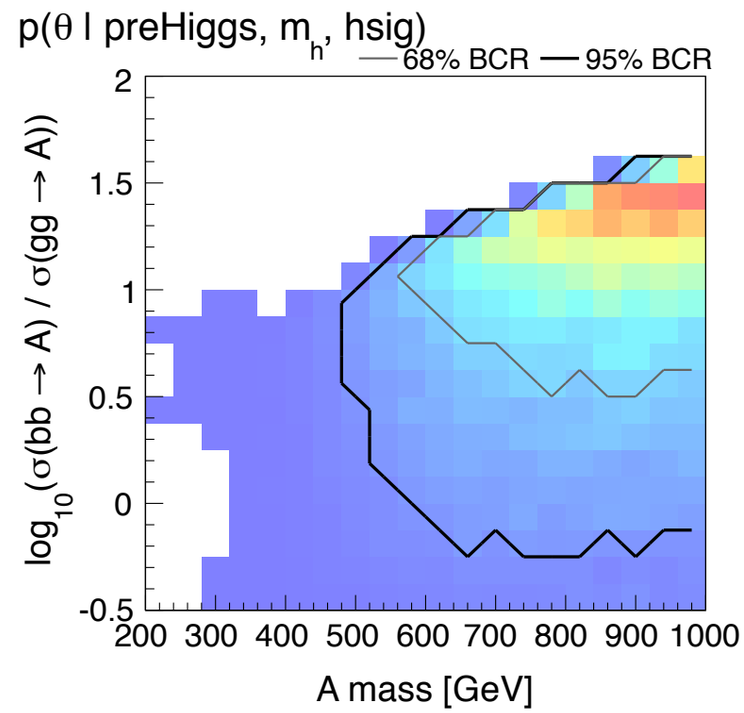


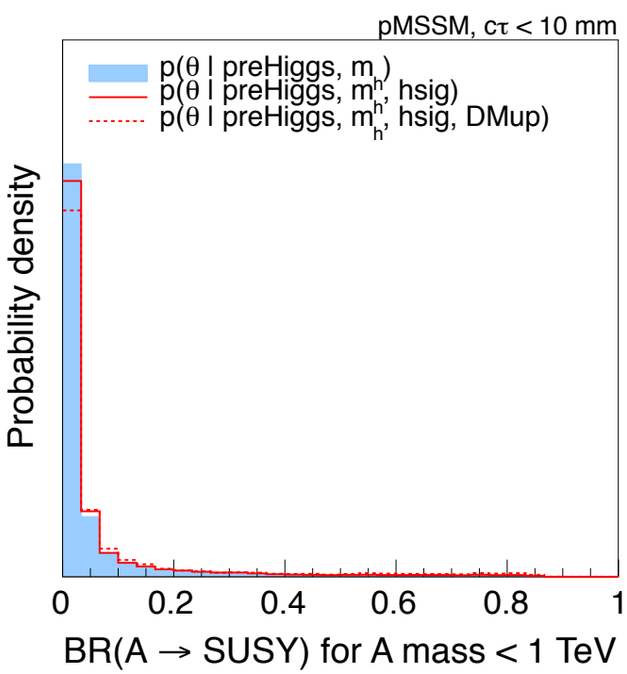


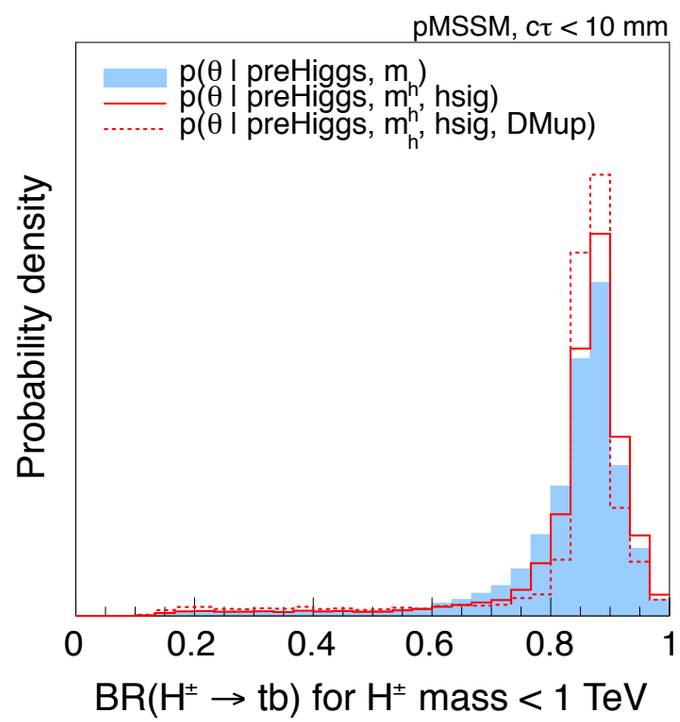
the LSP constitute only a fraction
of the observed relic density

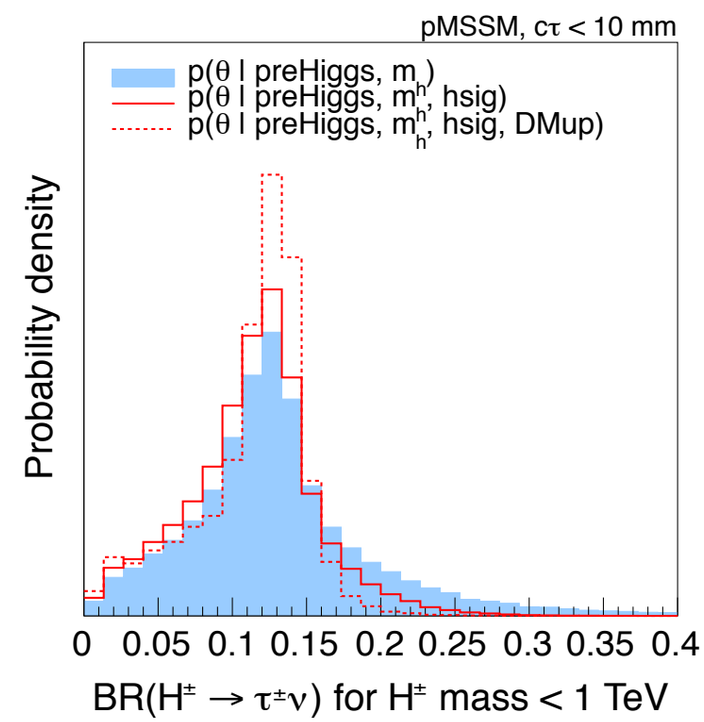
implications for heavier Higgses











light neutralino dark matter

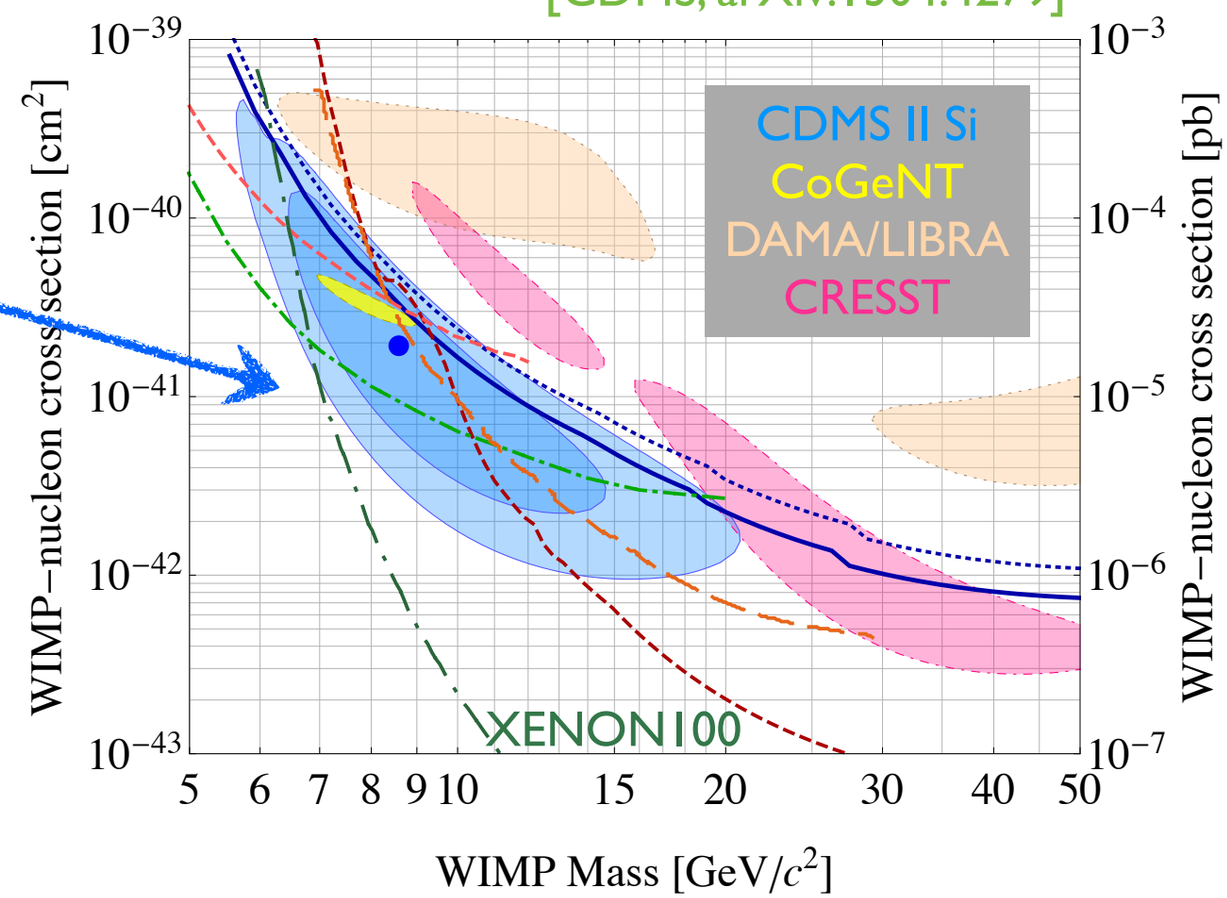
[Bélanger, Drieu La Rochelle, BD, Goldbole, Kraml, Kulkarni, arXiv:1308.3735]

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: [Arbey et al., arXiv:1308.2153])

[CDMS, arXiv:1304.4279]



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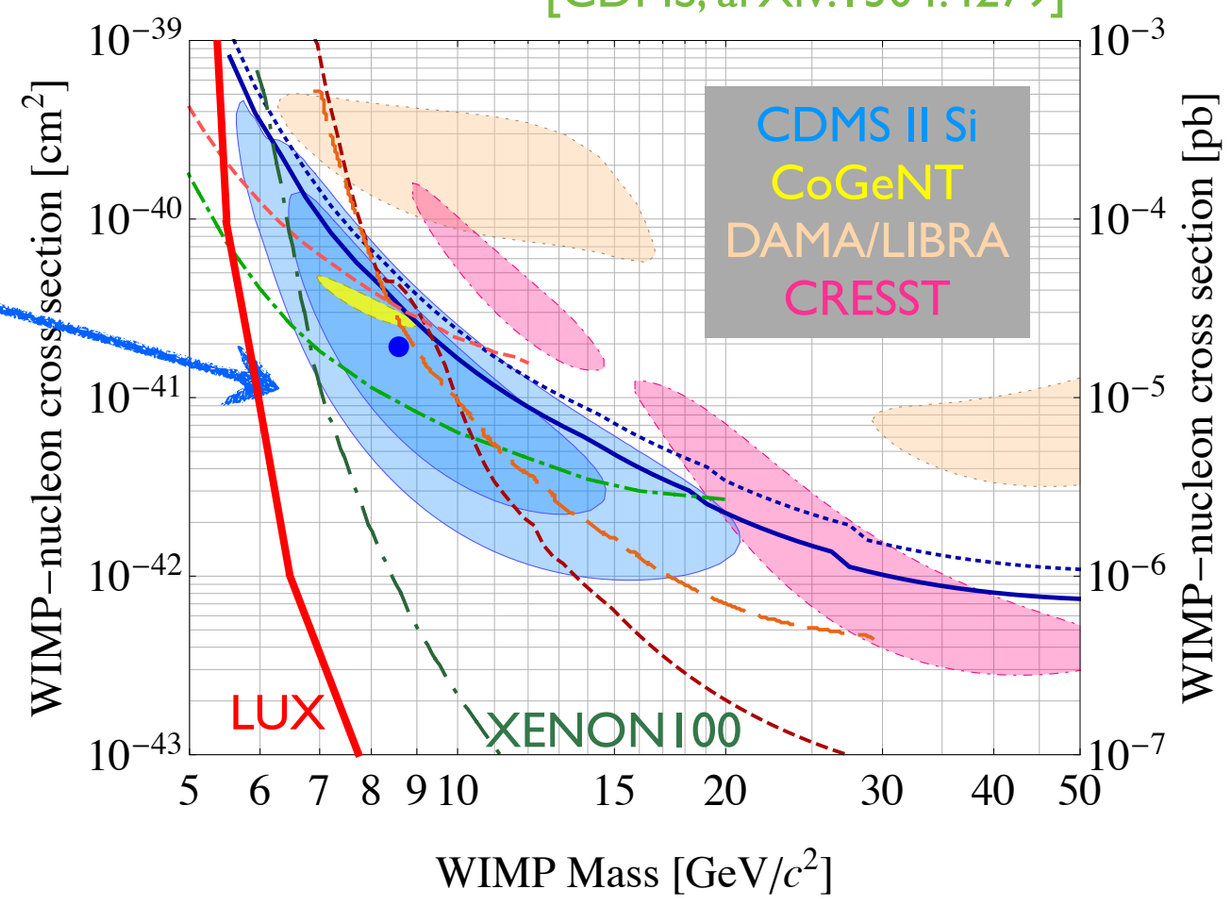


viable light neutralino dark matter

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

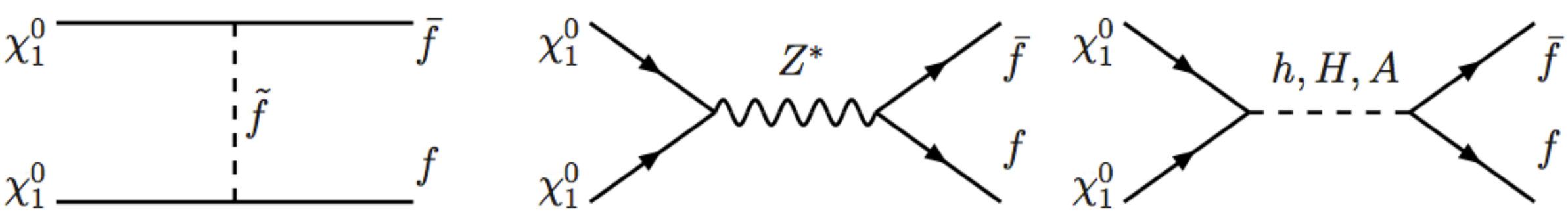
$$\begin{array}{cccc} \widetilde{B} & \widetilde{W}^0 & \widetilde{H}_d^0 & \widetilde{H}_u^0 \end{array}$$
$$\begin{pmatrix} M_1 & 0 & -c_\beta\, s_W\, m_Z & s_\beta\, s_W\, m_Z \\ 0 & M_2 & c_\beta\, c_W\, m_Z & -s_\beta\, c_W\, m_Z \\ -c_\beta\, s_W\, m_Z & c_\beta\, c_W\, m_Z & 0 & -\mu \\ s_\beta\, s_W\, m_Z & -s_\beta\, c_W\, m_Z & -\mu & 0 \end{pmatrix}$$

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?

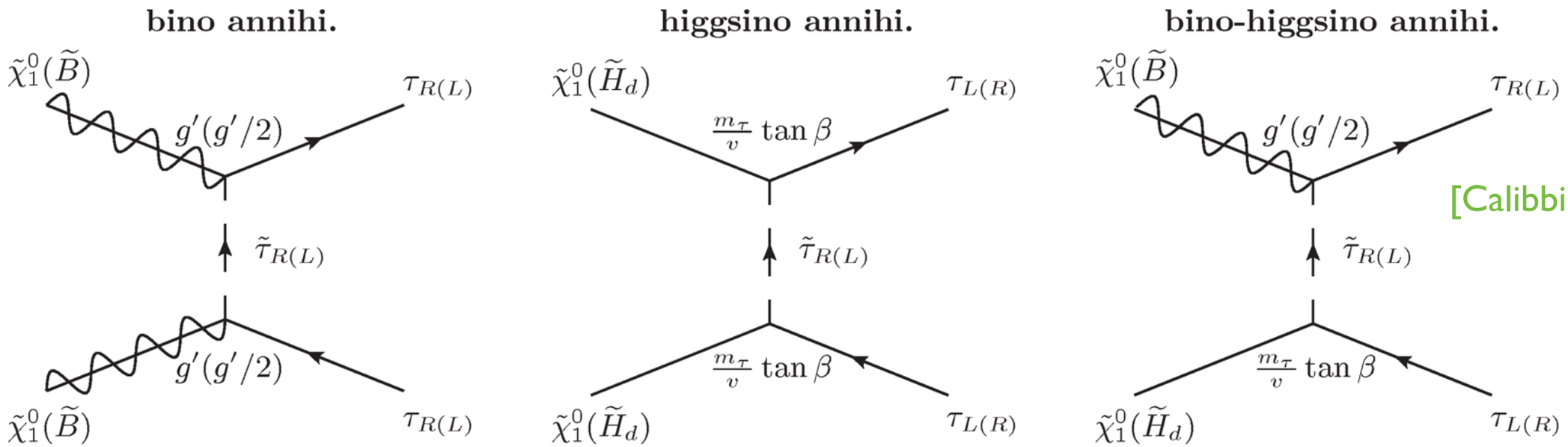
- gluino and squarks: constrained by LEP and LHC searches to be heavy → no influence on DM
- other Higgses: little influence expected on DM (constraints on $A^0, H^0 \to \tau^+\tau^-$ at the LHC)
- sleptons: ~100 GeV is allowed, contributions from staus to DM annihilation can be large

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

setup of the analysis

pMSSM framework again

$M_3 = 1$ 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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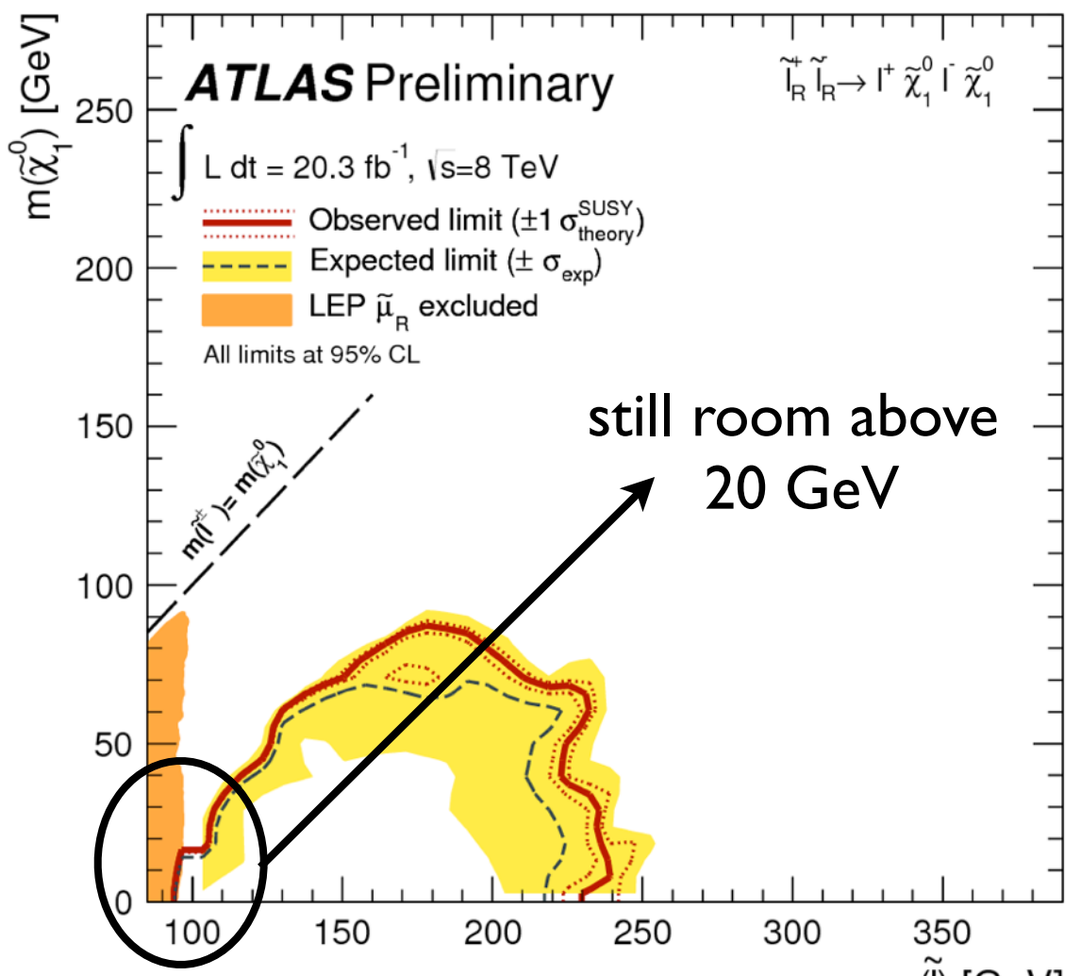
LHC searches — implementation

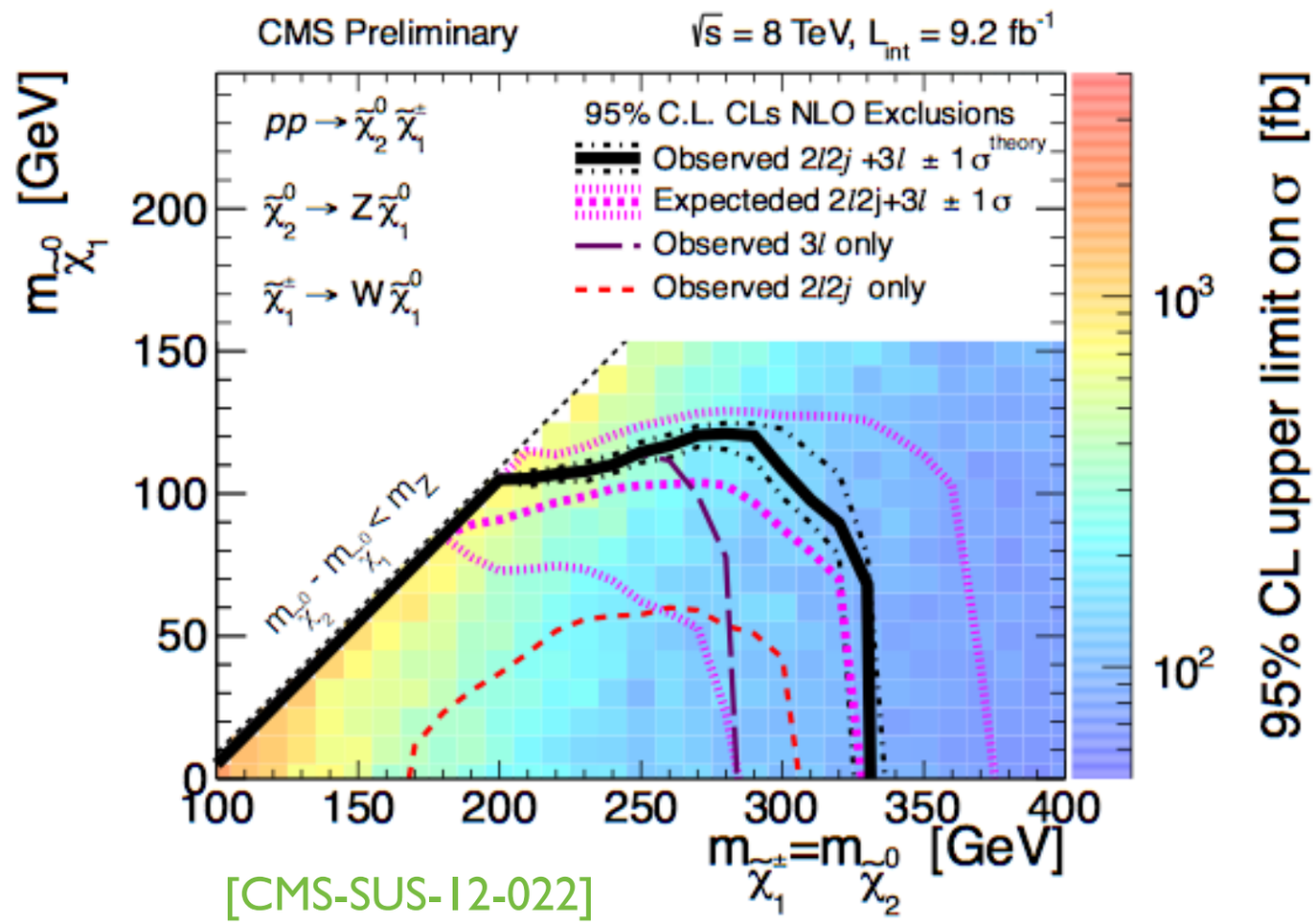
decomposition of a pMSSM point into simplified models, then compare to the limits on (σ×BR) using SmodelS [Kraml et al., arXiv:1312.4175]

direct RH selectron/smuon production



[ATLAS-CONF-2013-049]

chargino-neutralino → WZ + MET

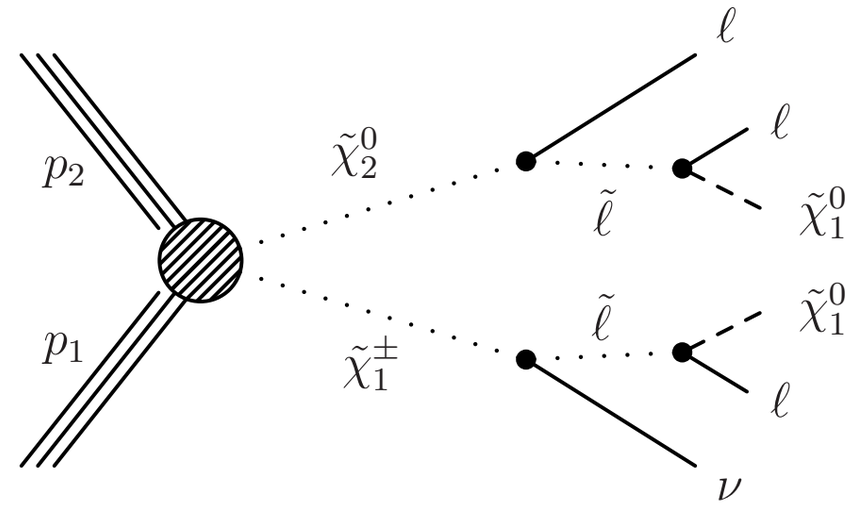


[CMS-SUS-12-022]

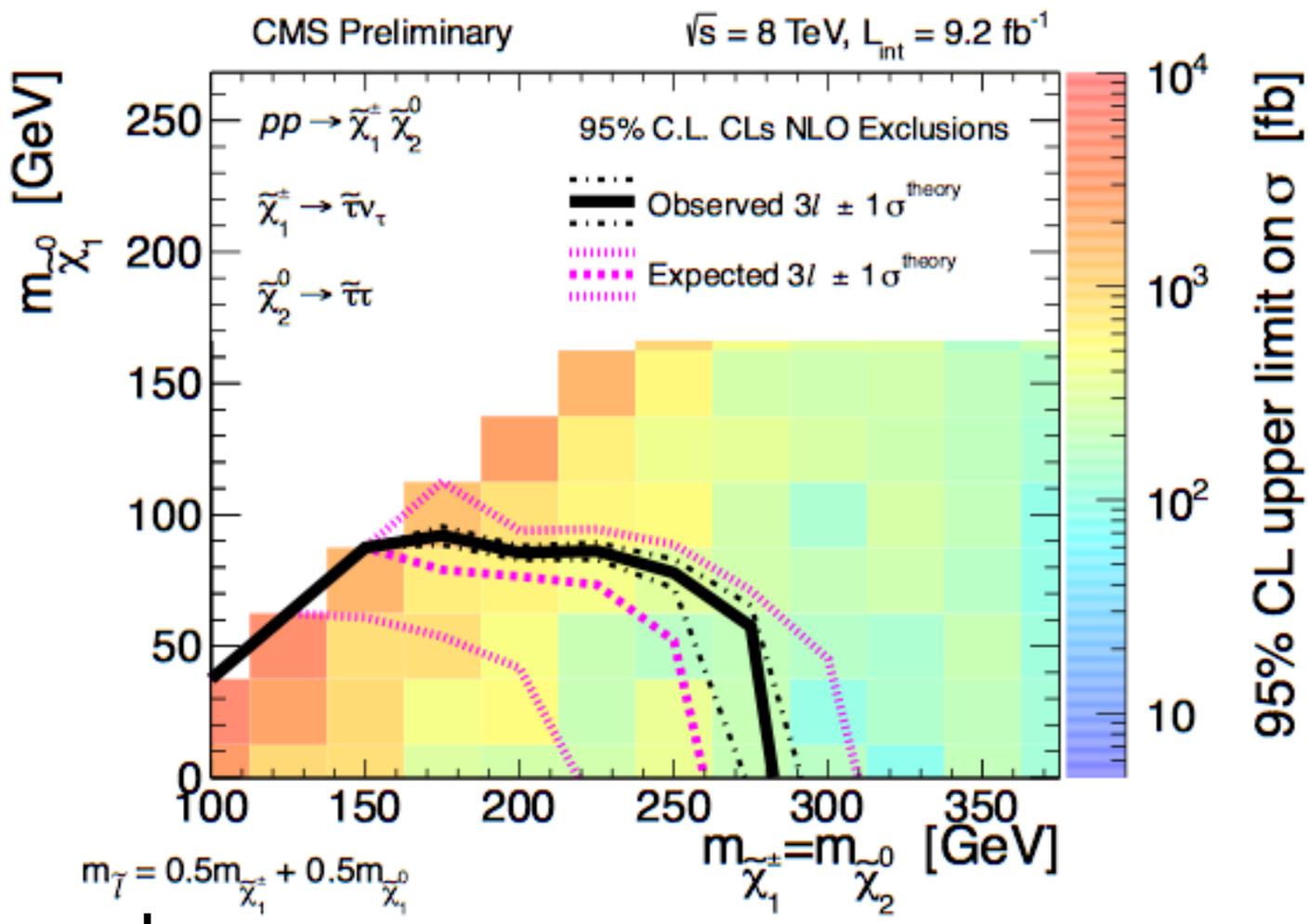
black line overestimates the limit
"hidden" assumption: $\tilde{\chi}_2^0, \tilde{\chi}_1^\pm$ wino-like

LHC searches — implementation

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



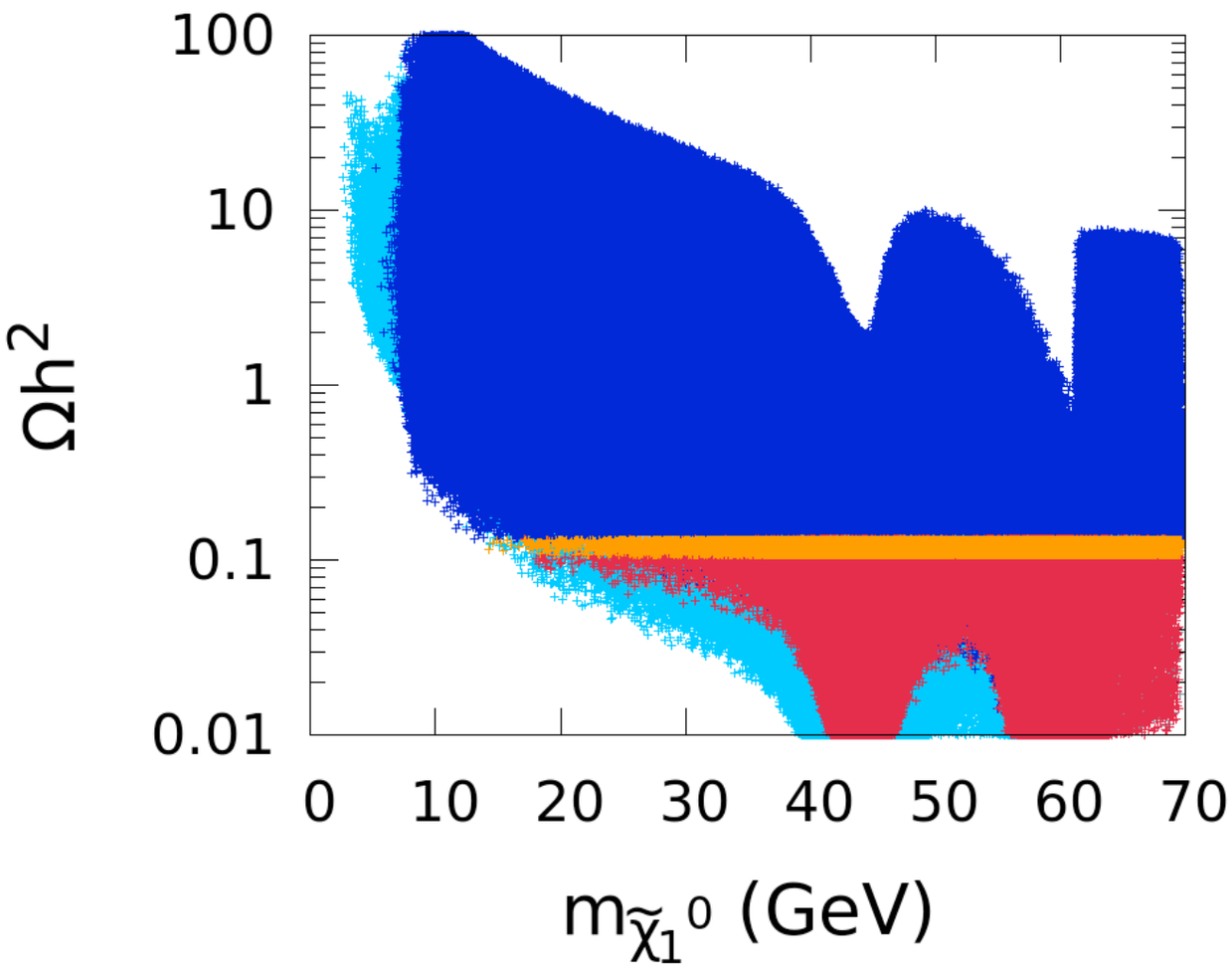
[CMS-SUS-12-022]

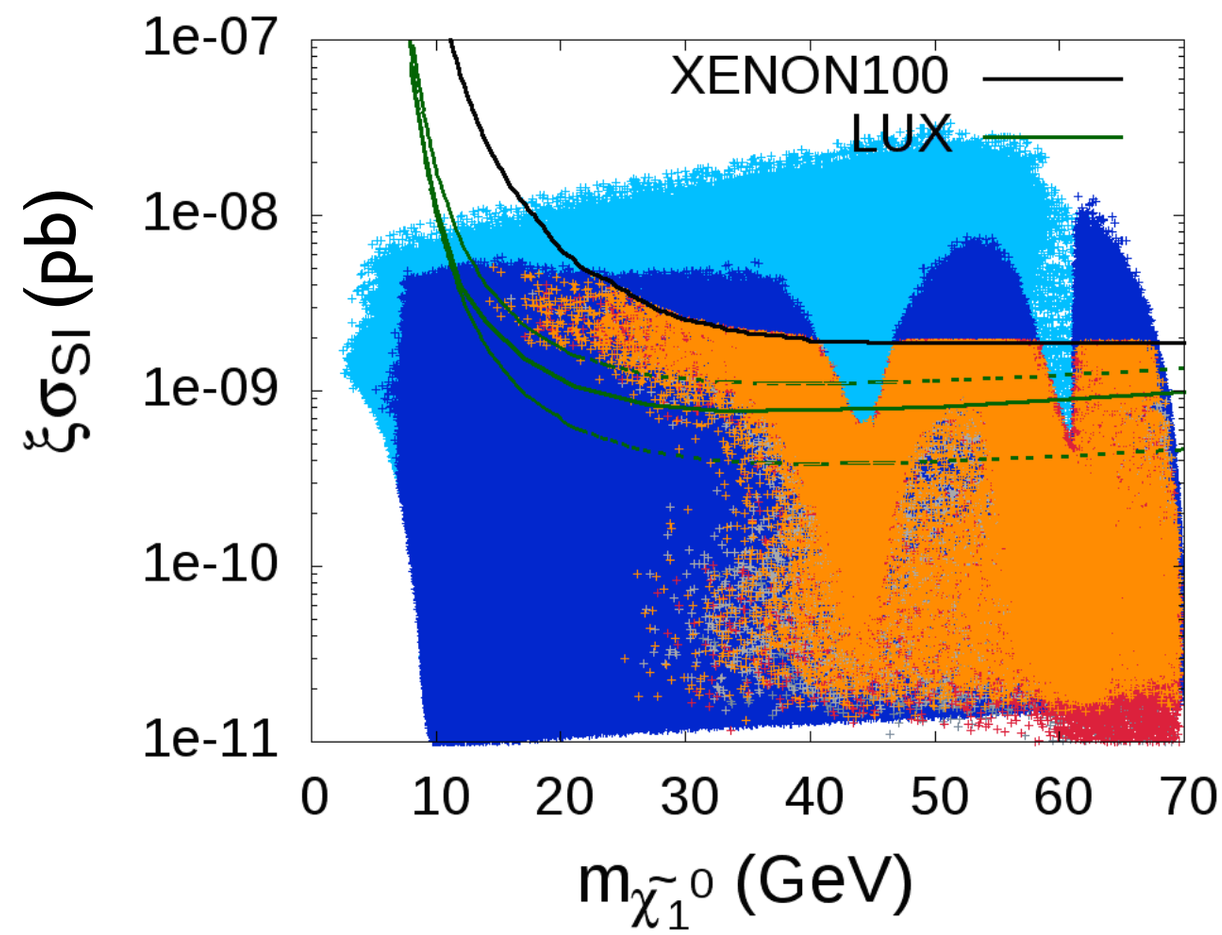


also ATLAS results on 2τ+MET
but the only interpretation
available is for LH staus

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

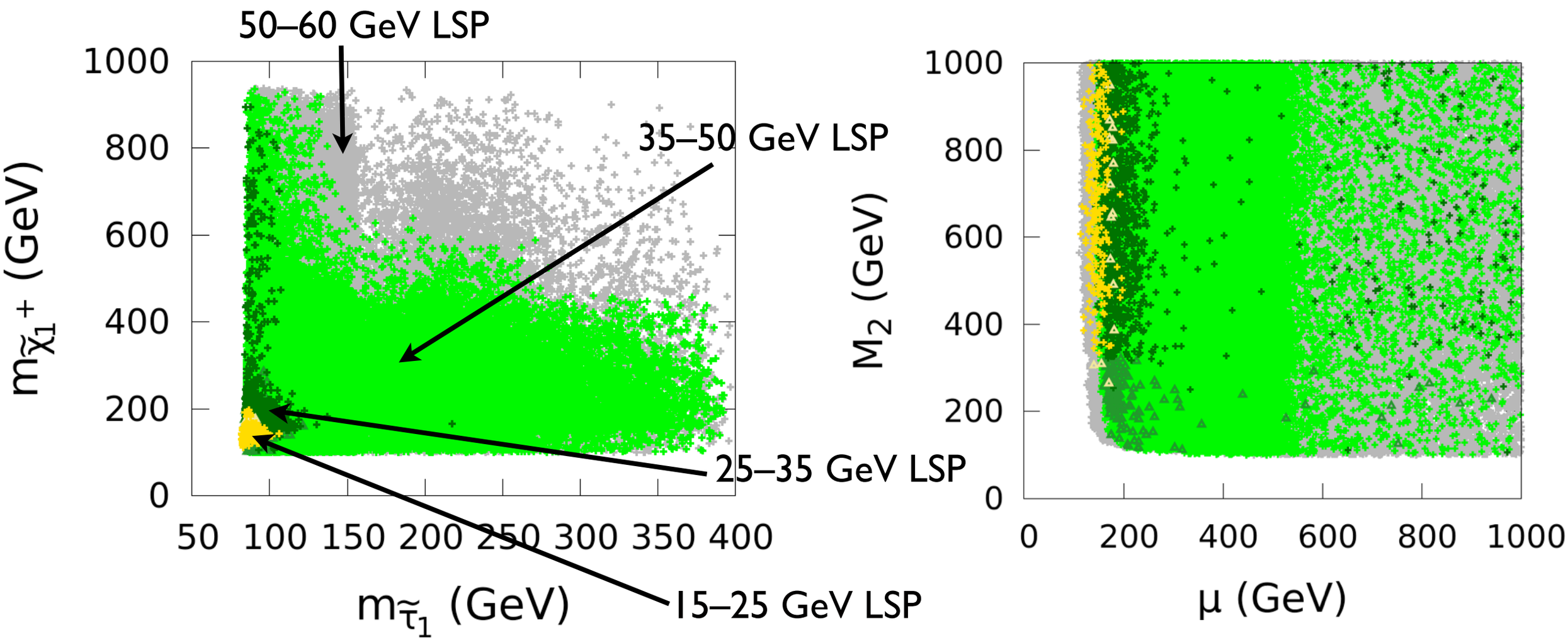
relic density and direct detection





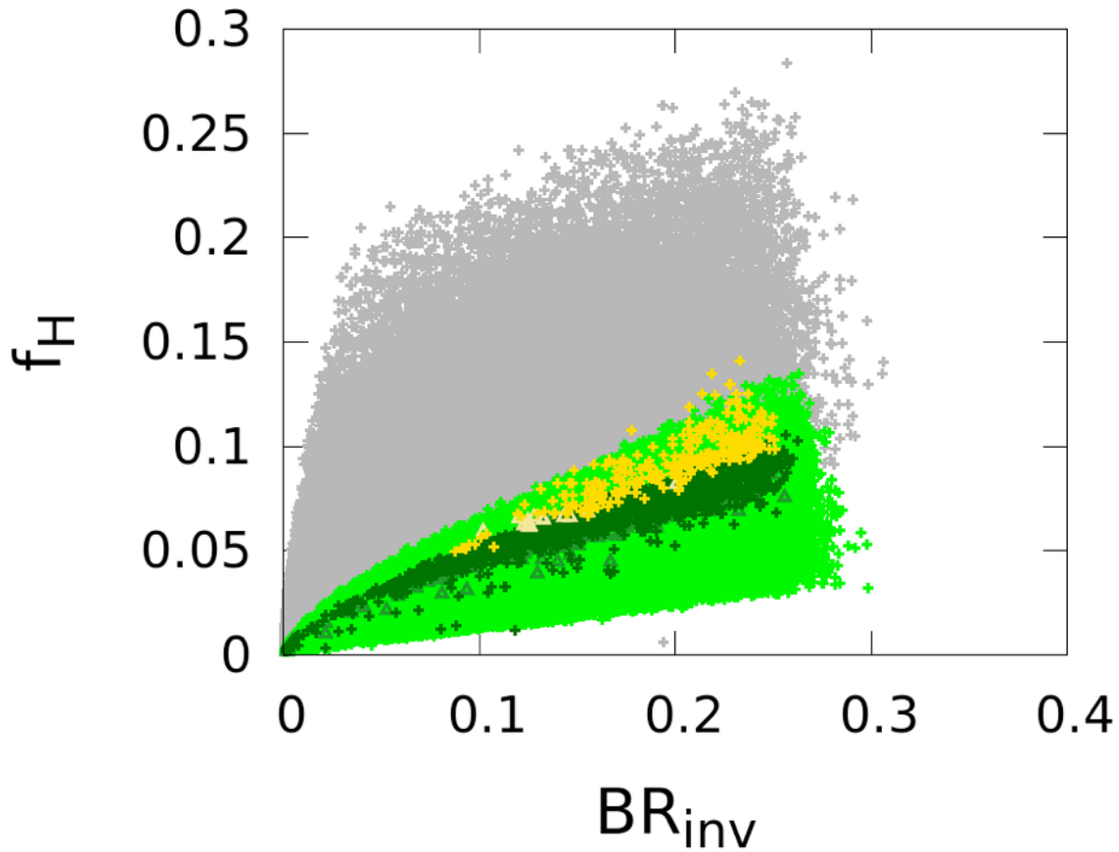
- upper bound on the relic density → lower bound on the neutralino mass of ~15 GeV
  not possible to have 8–10 GeV dark matter in this context
- direct detection could soon exclude completely the low-mass region (up to 25 GeV)

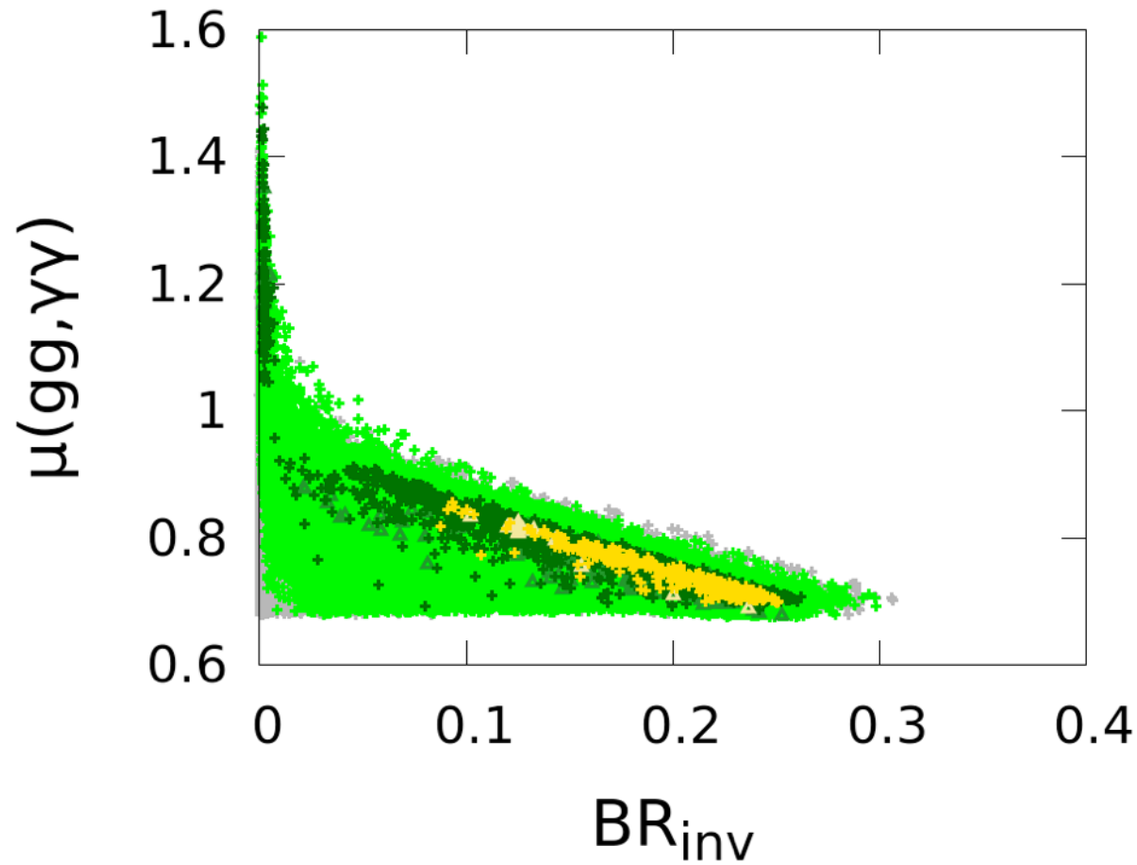
charginos and staus



- 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)

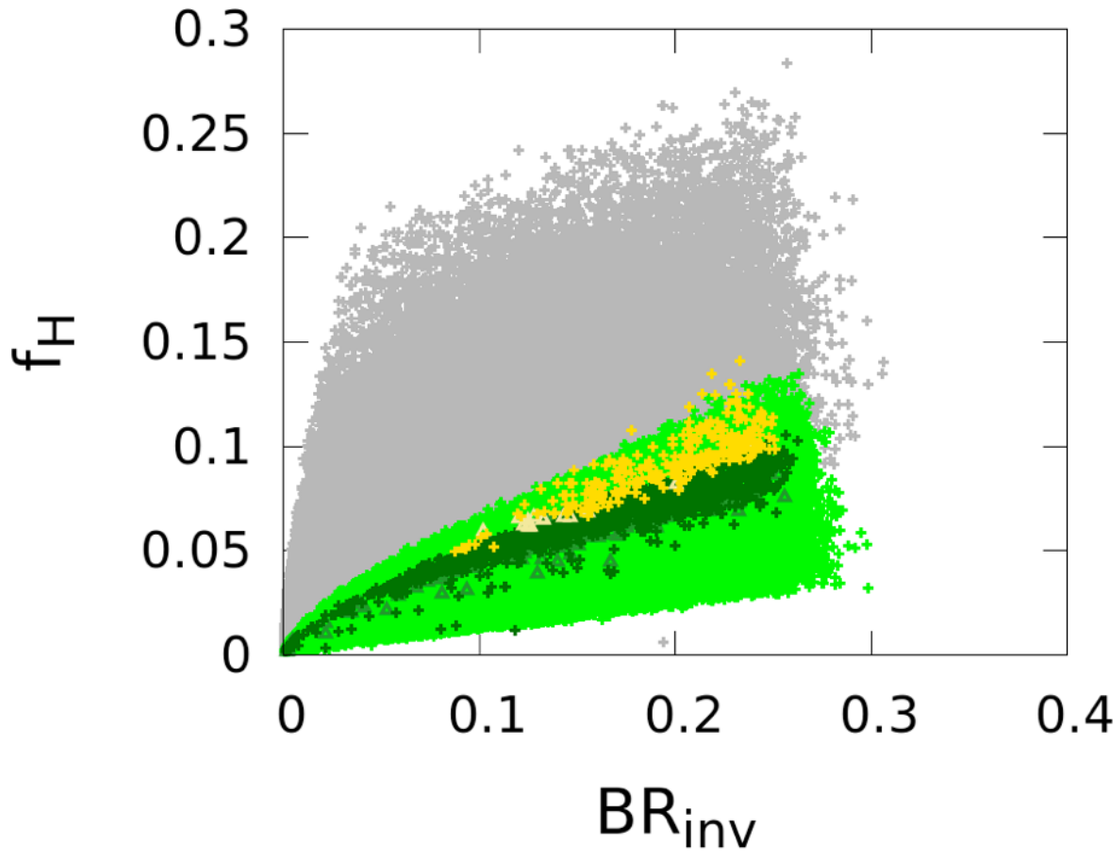
invisible Higgs decays

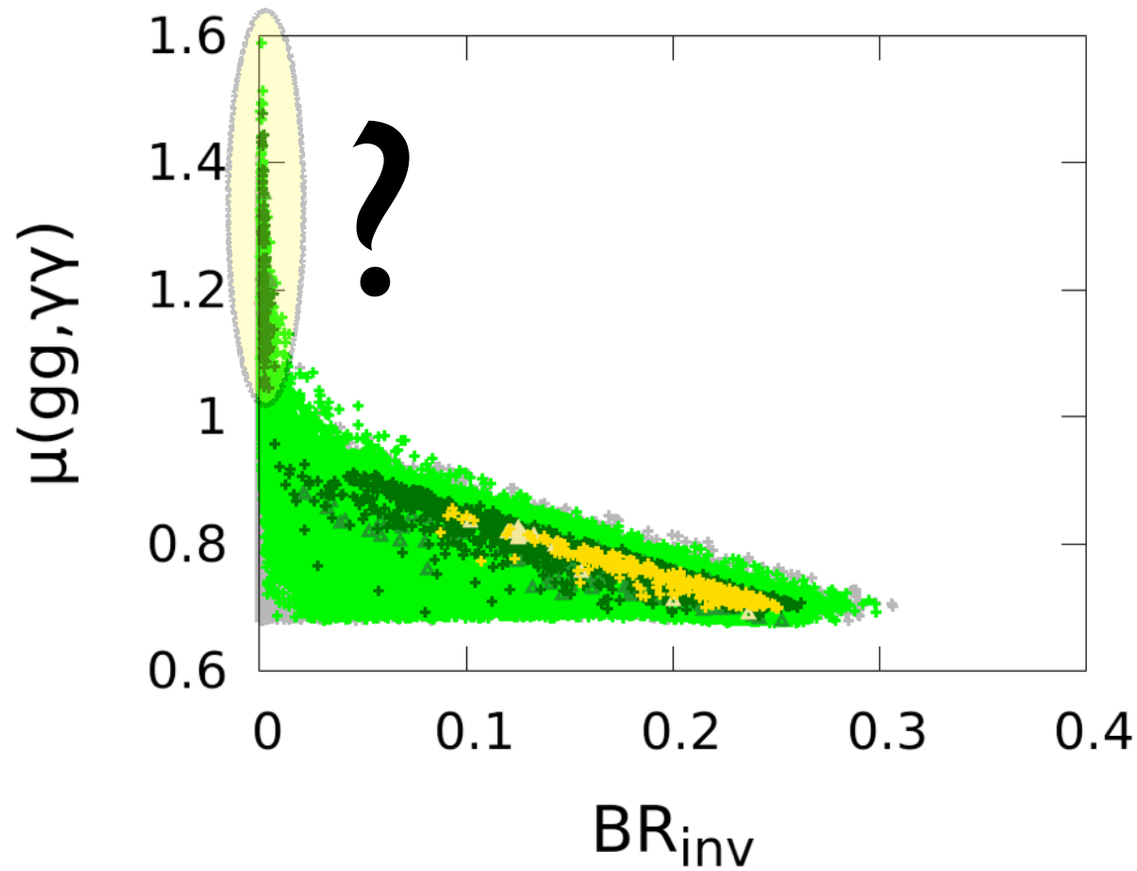




- the Higgs boson couples to a mixture of higgsino and gaugino
  → limit on the higgsino fraction f_H from Higgs measurements
- as expected, anticorrelation between $\mu(gg \to h \to \gamma\gamma)$ and BR_{inv}

invisible Higgs decays





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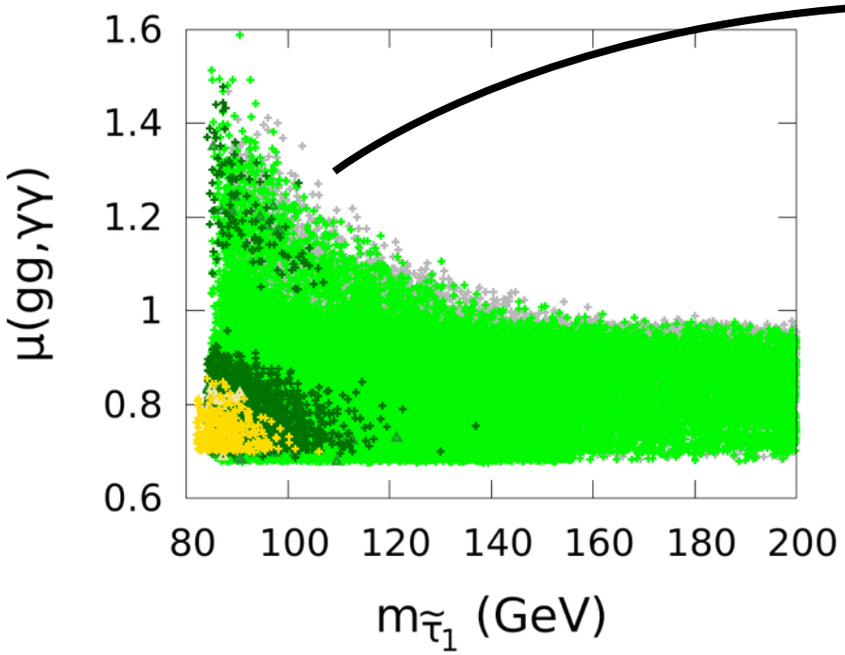
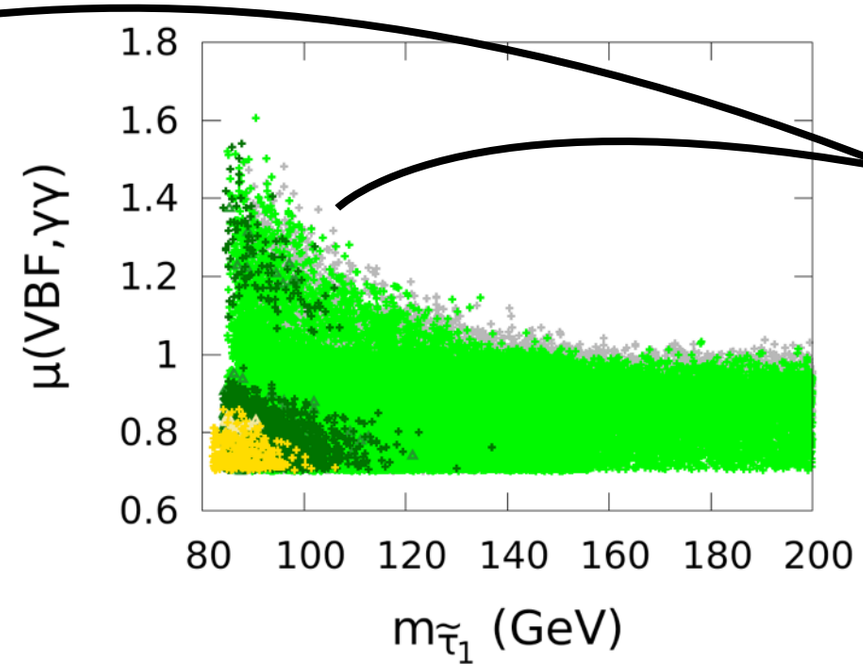
Higgs signal strengths



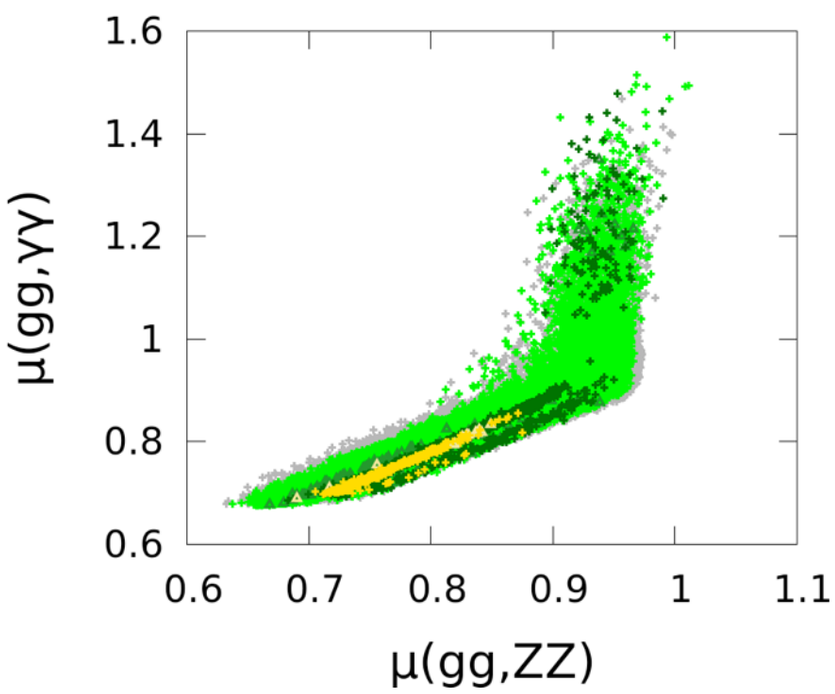


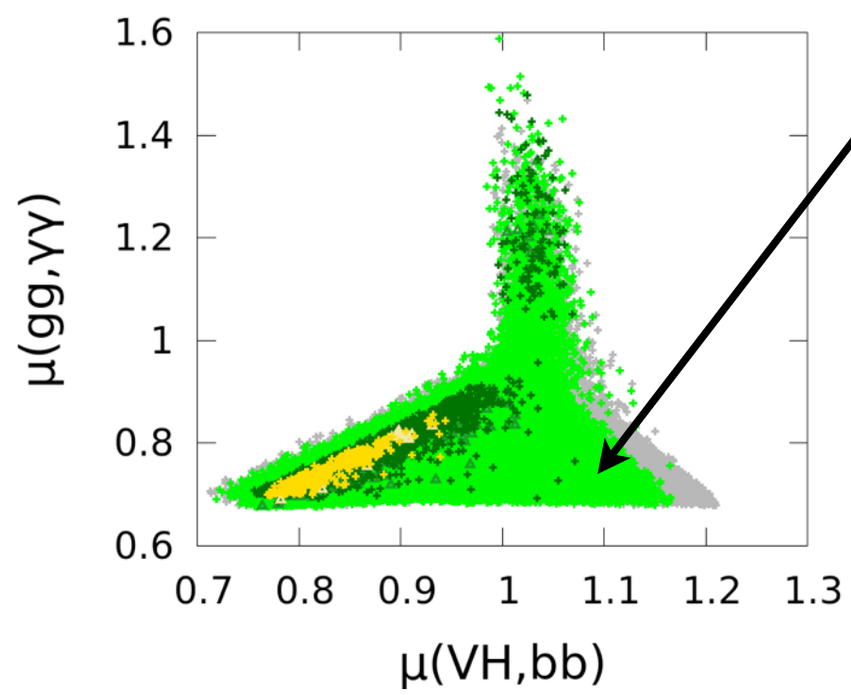
light, maximally mixed staus

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

in this case μ ≳ 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

✦ in the pMSSM, significant deviations of the Higgs couplings are possible and are already constrained by the LHC results

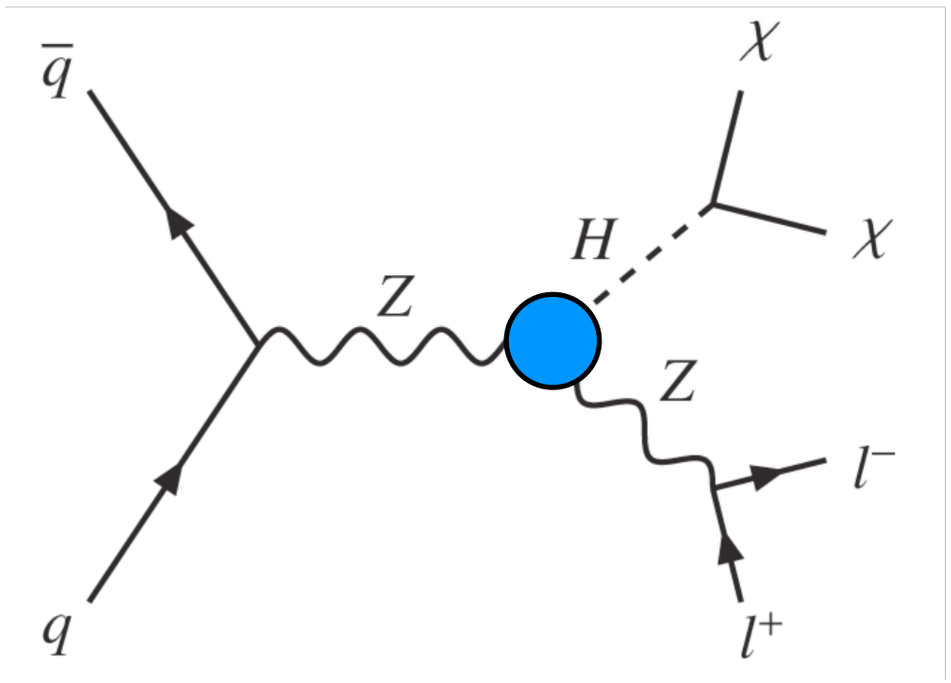
✦ low-mass neutralino (~ 15–35 GeV) can be accommodated with light staus and/or charginos but is under pressure by direct detection and the LHC SUSY searches

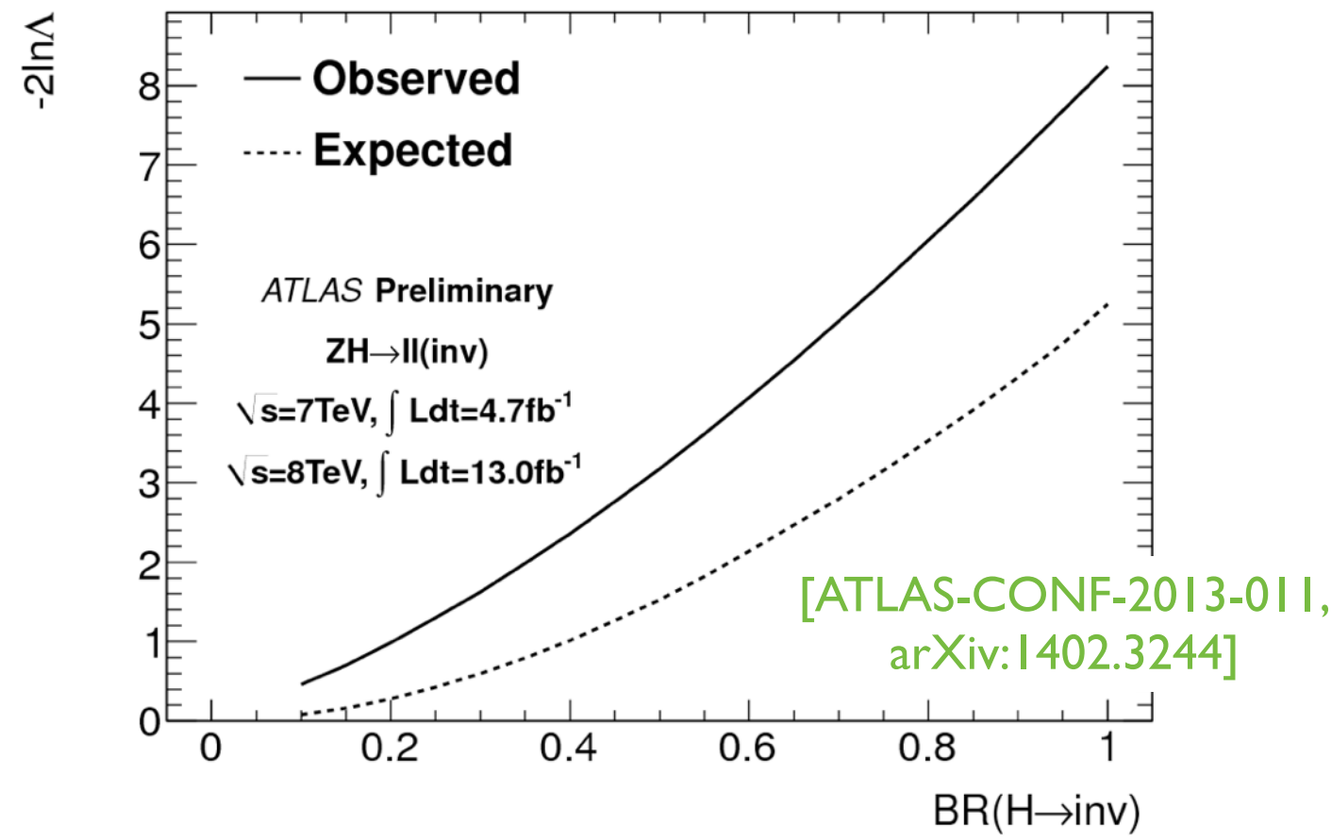
✦ possible to go beyond the Gaussian approximation for Higgs results: full likelihood in the ($\mu_{ggF+ttH}$, μ_{VBF+VH}) plane is given in several final states by ATLAS and CMS

✦ this is taken into account in **Lilith**: a new, friendly-user tool for constraining BSM scenarios from Higgs measurements—stay tuned! [Jérémy Bernon and BD, in preparation]

backup slides

invisible decays of the Higgs boson





[ATLAS-CONF-2013-011, arXiv:1402.3244]

$$C_V^2 \mathcal{B}(H \to \text{inv.}) < 0.65 \text{ at } 95\% \text{ CL}$$

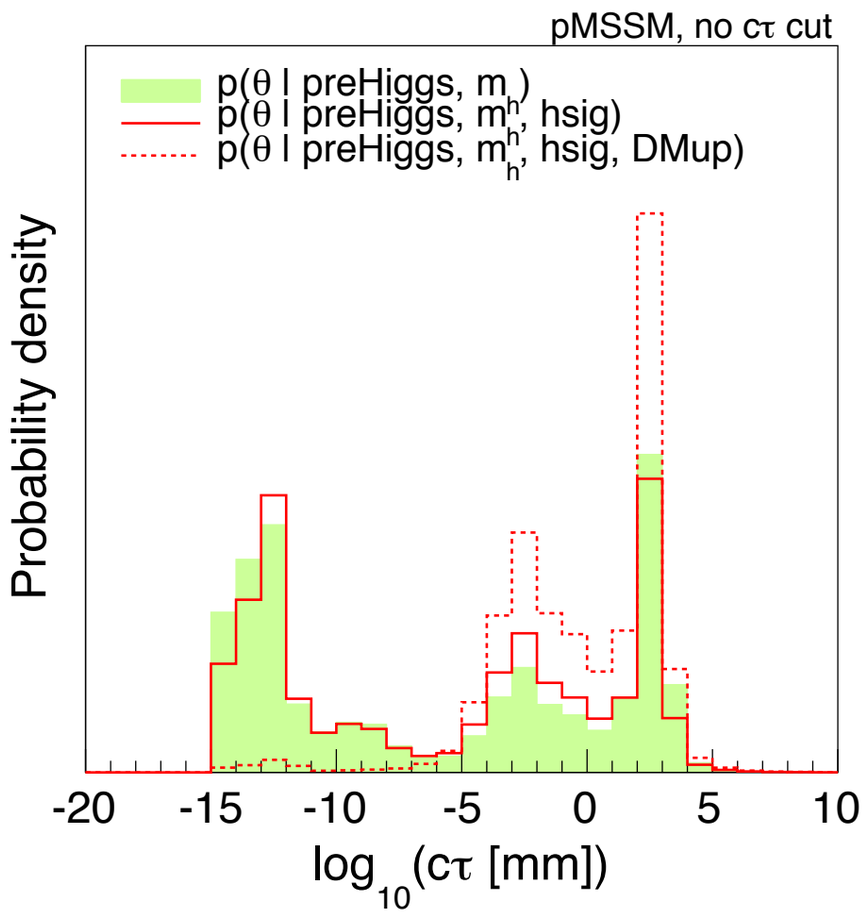
see also CMS limit on ZH→ll/bb+invisible [CMS-PAS-HIG-018/028]
and on VBF→invisible [CMS-PAS-HIG-013]
and the combination [arXiv:1404.1344]

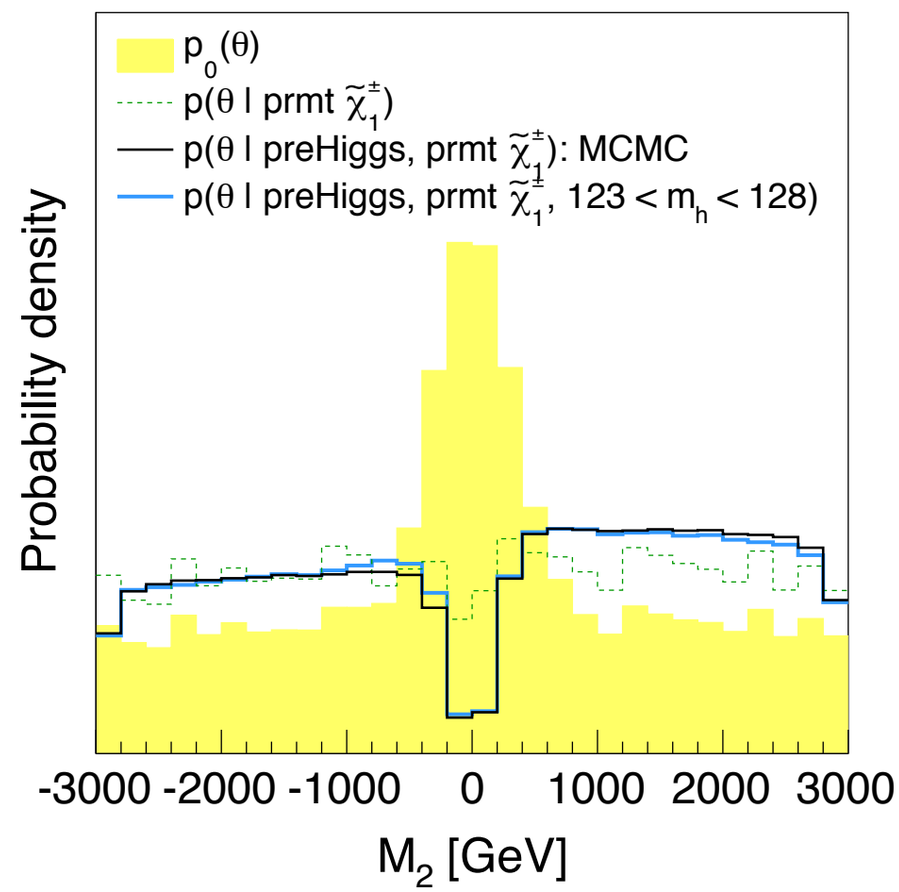
prompt chargino decay

prompt chargino decay ($c\tau$ < 10 mm):

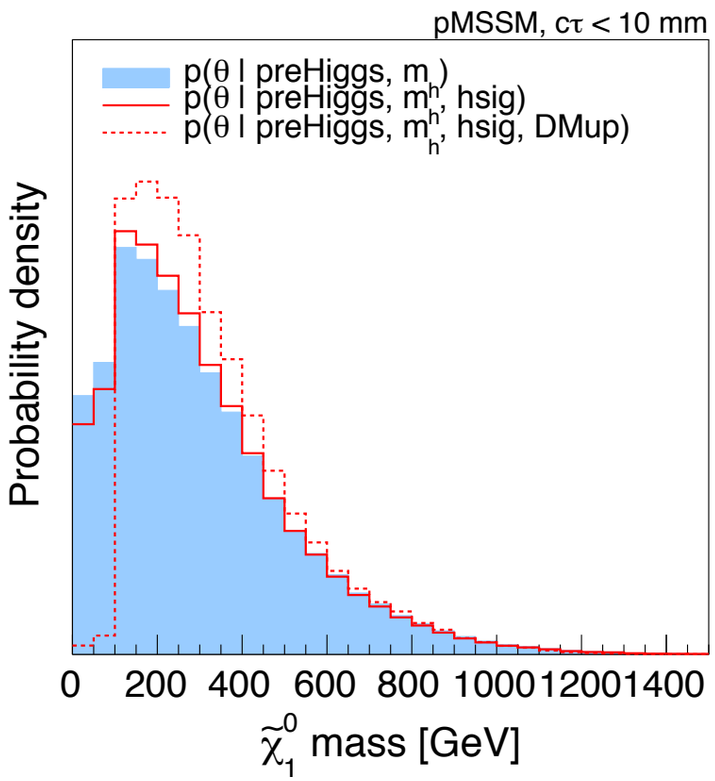
strong impact on M_2

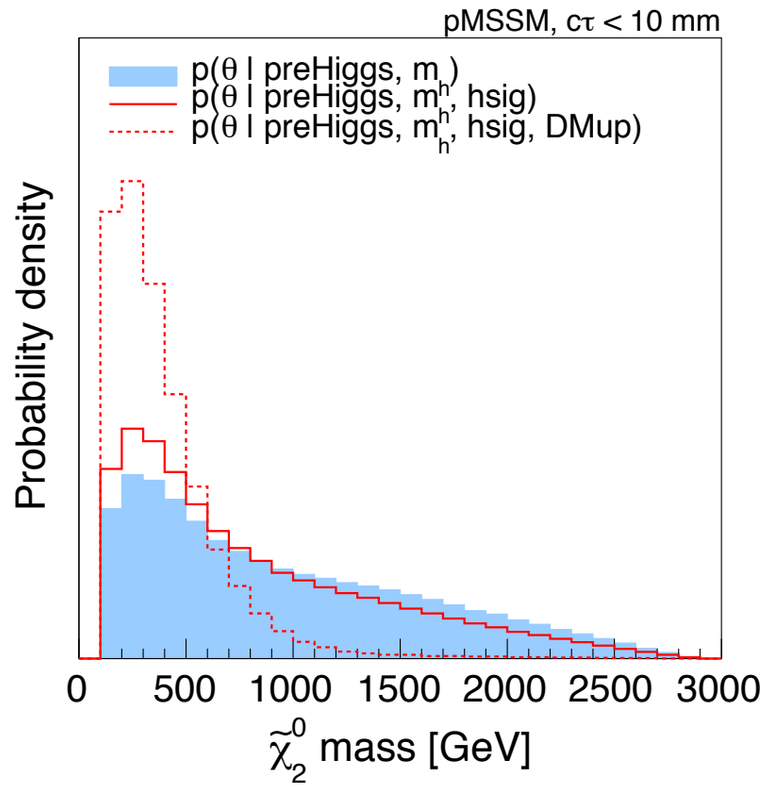
do not change main conclusions

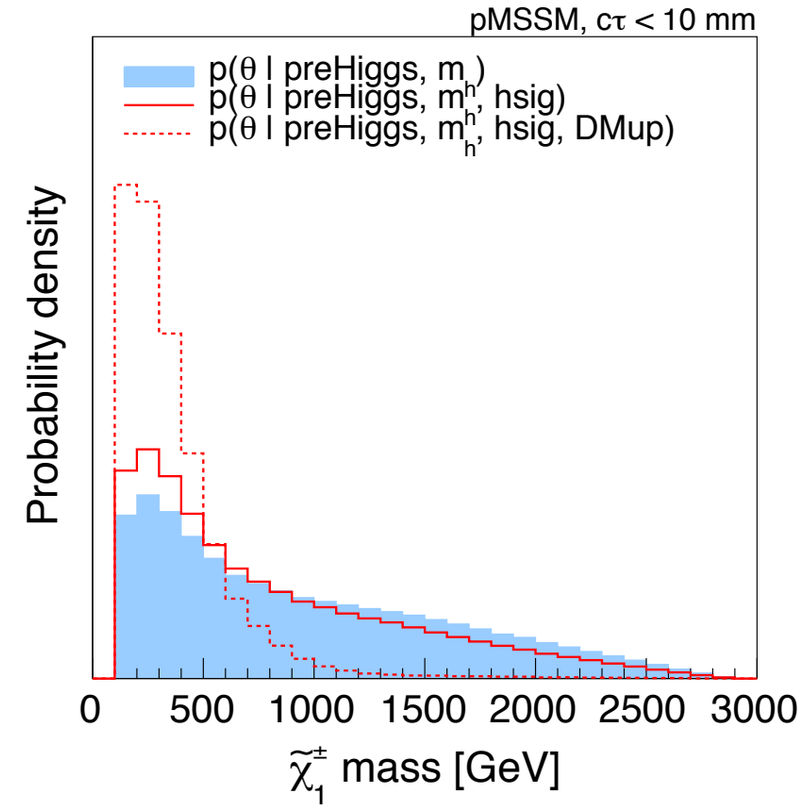


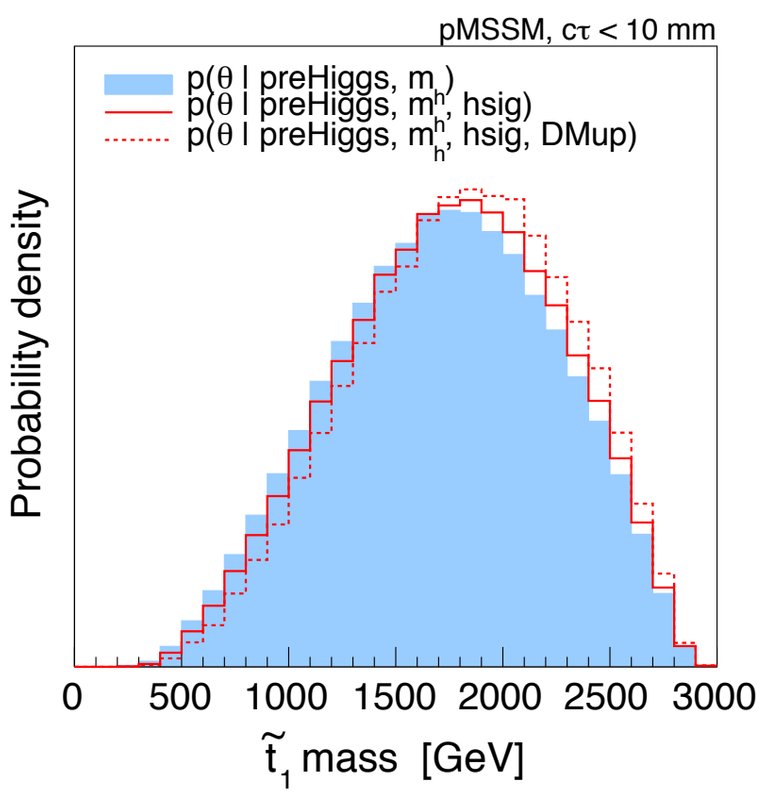


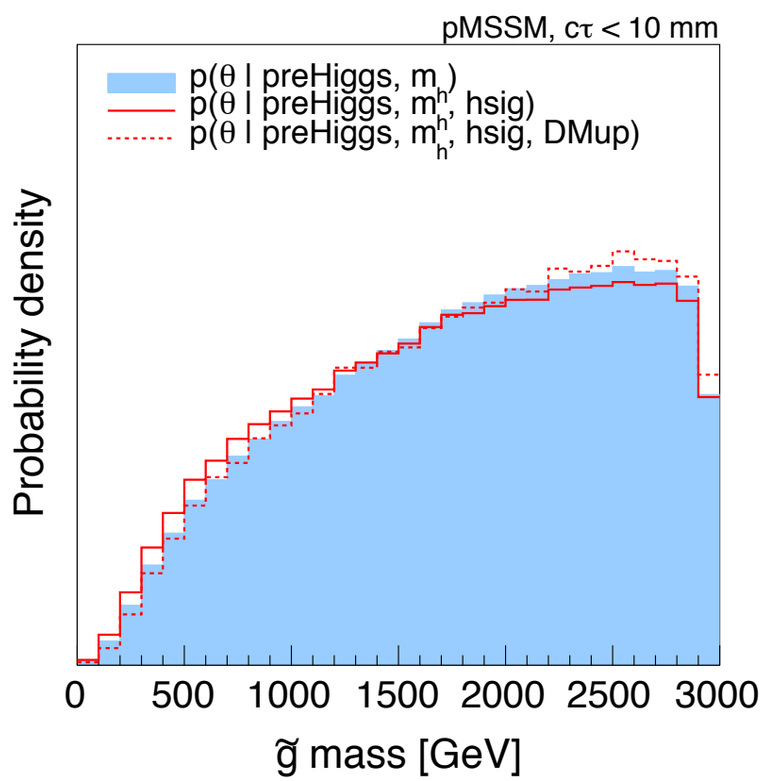
masses of the SUSY partners

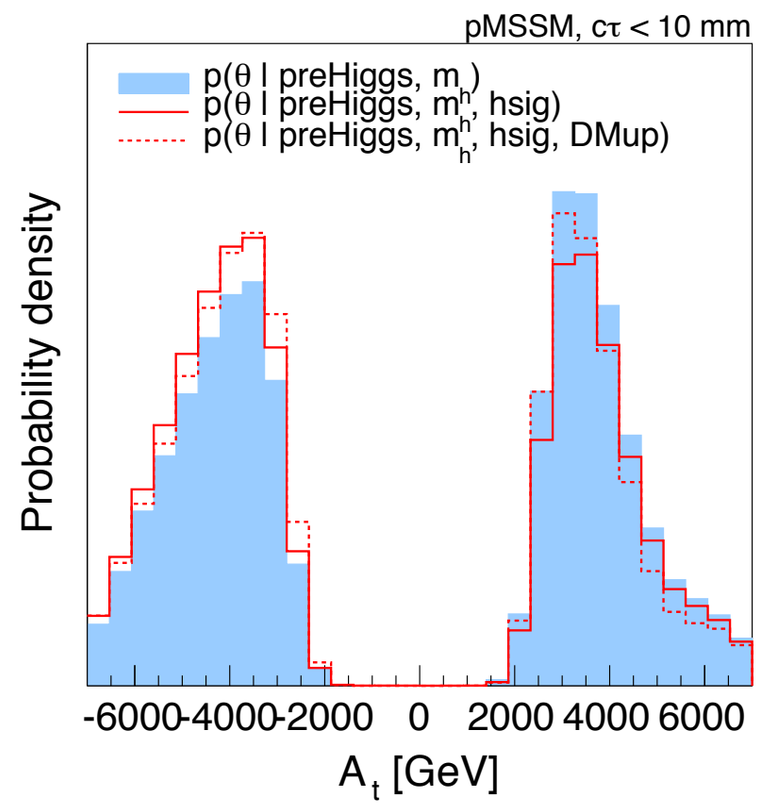




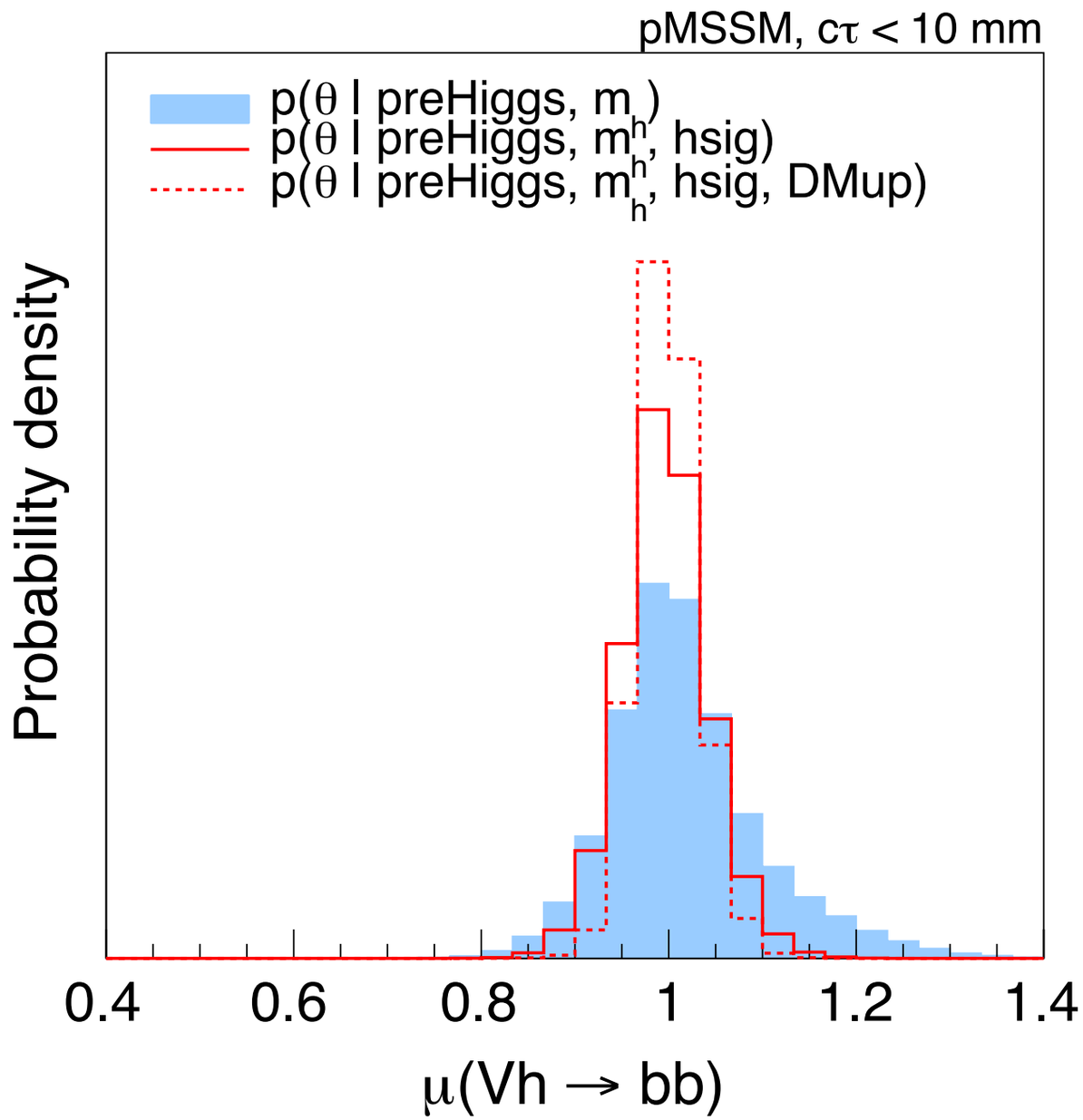




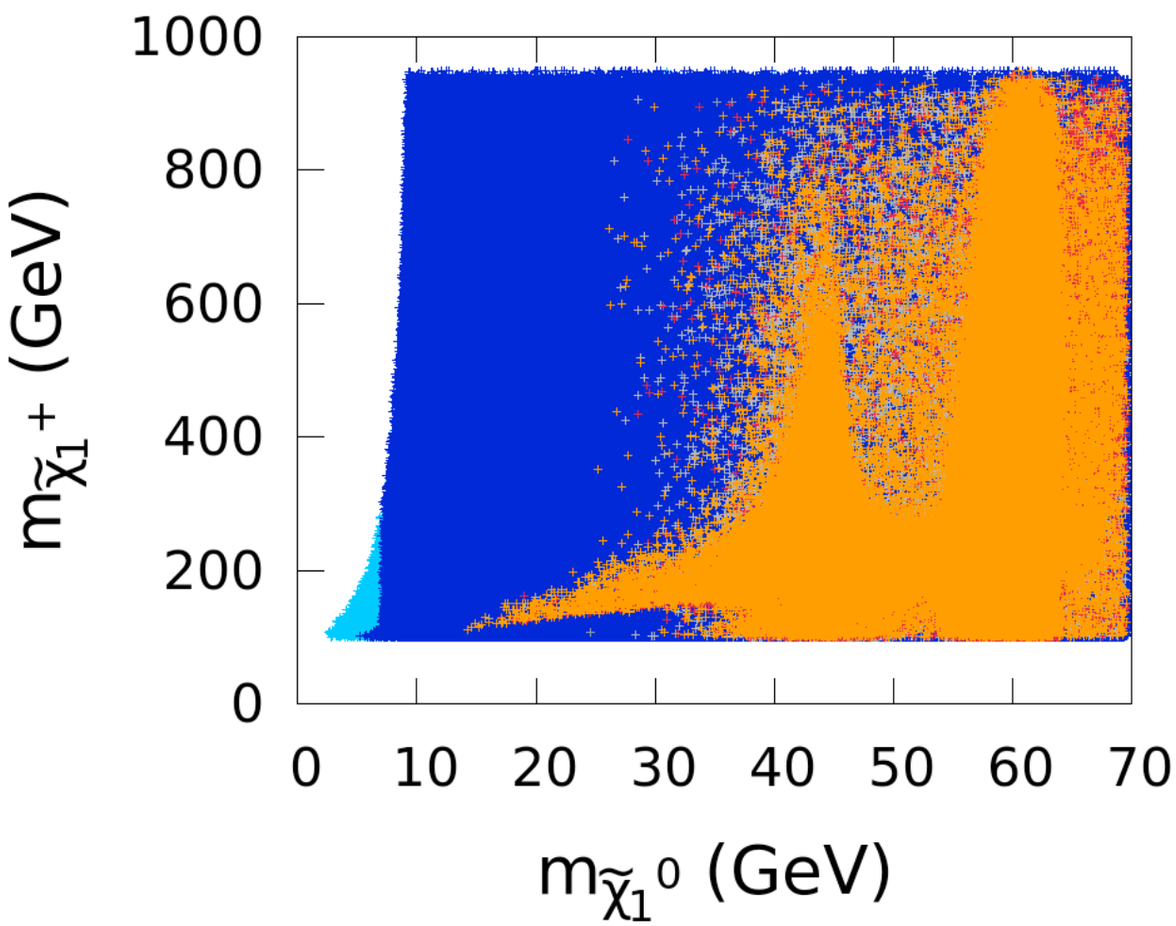


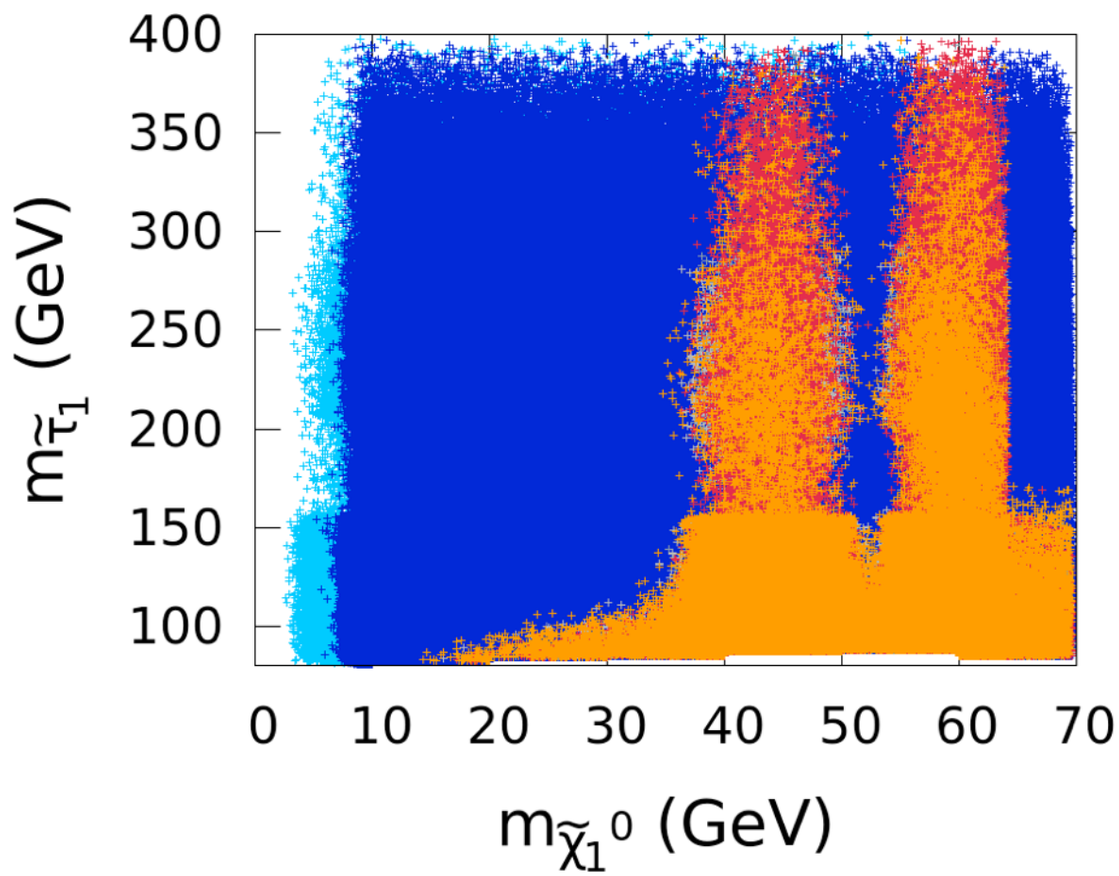


μ(Vh→bb)


pMSSM, cτ < 10 mm
p(θ | preHiggs, m_h)
p(θ | preHiggs, m_h, hsig)
p(θ | preHiggs, m_h, hsig, DMup)
Probability density
0.4
0.6
0.8
1
1.2
1.4
μ(Vh → bb)

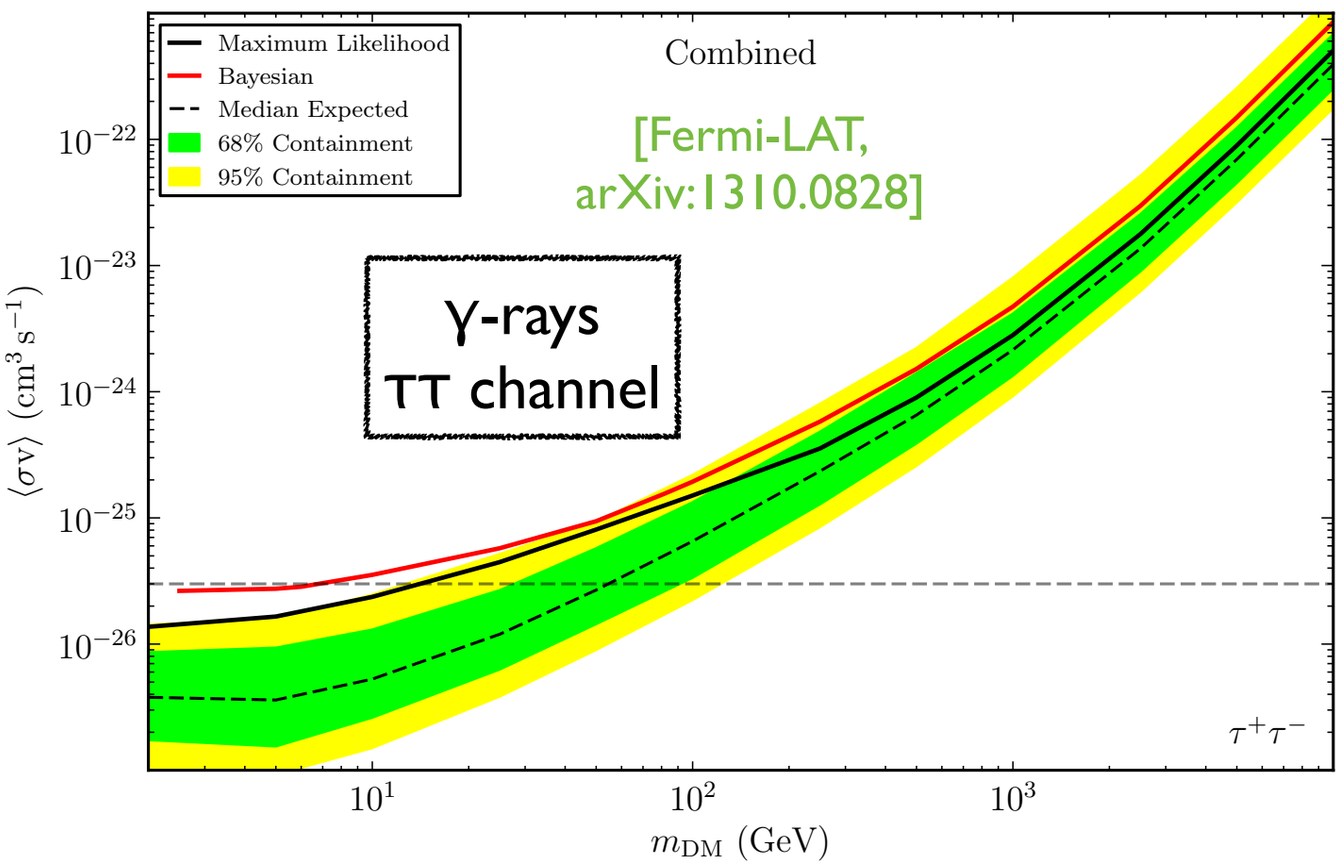
charginos and staus again

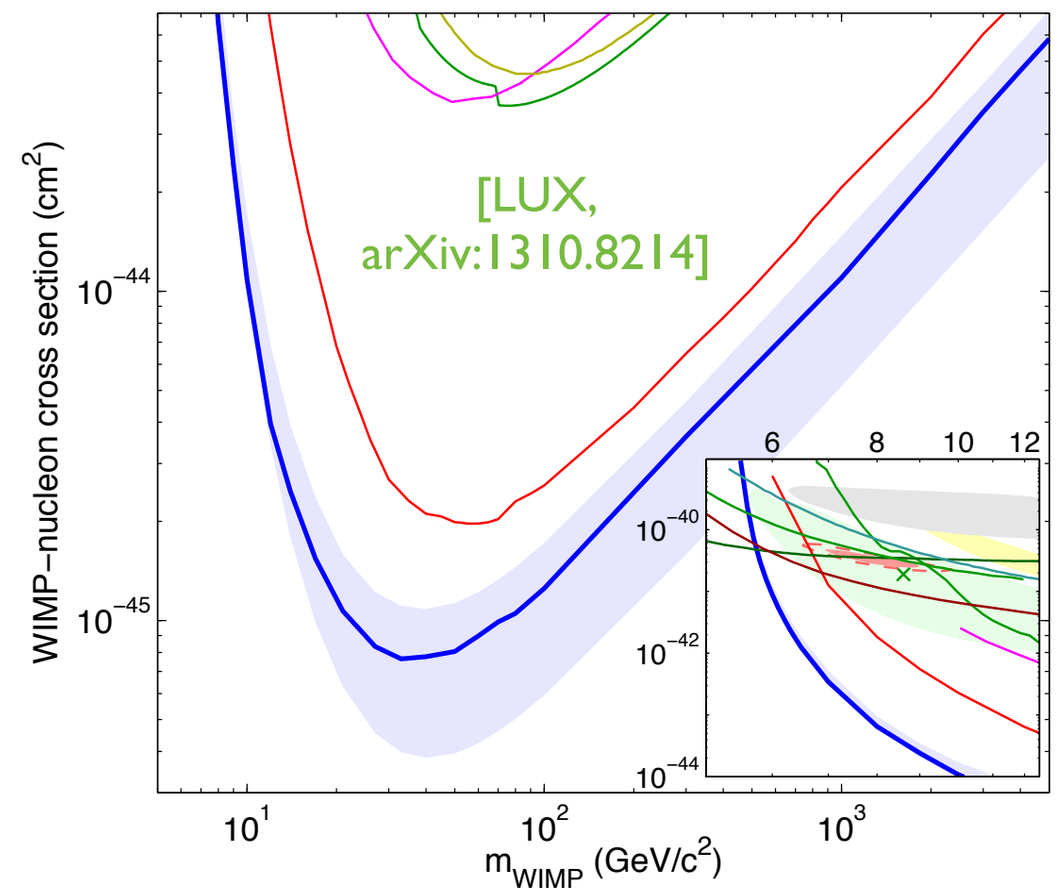




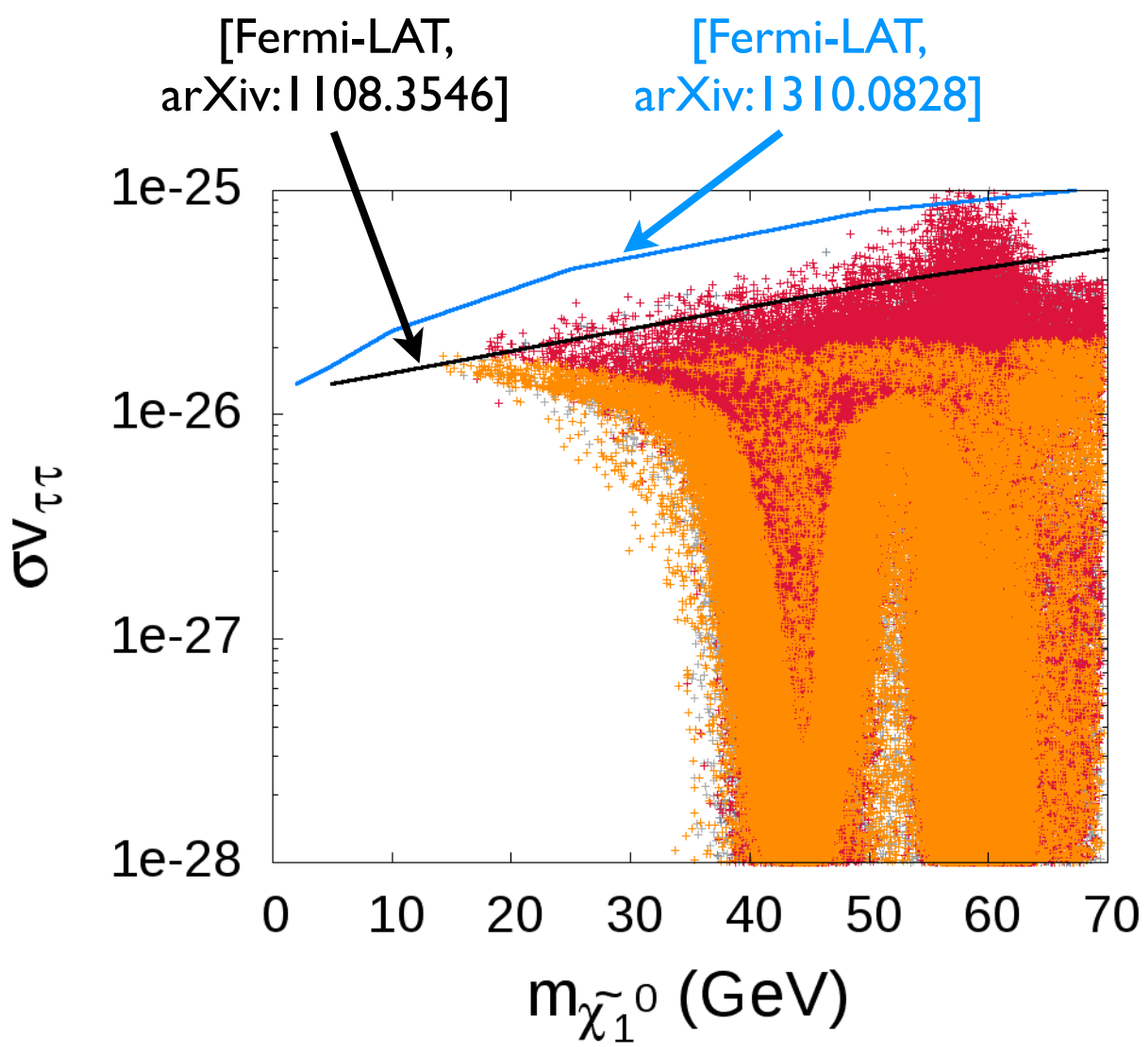
viable light neutralino dark matter

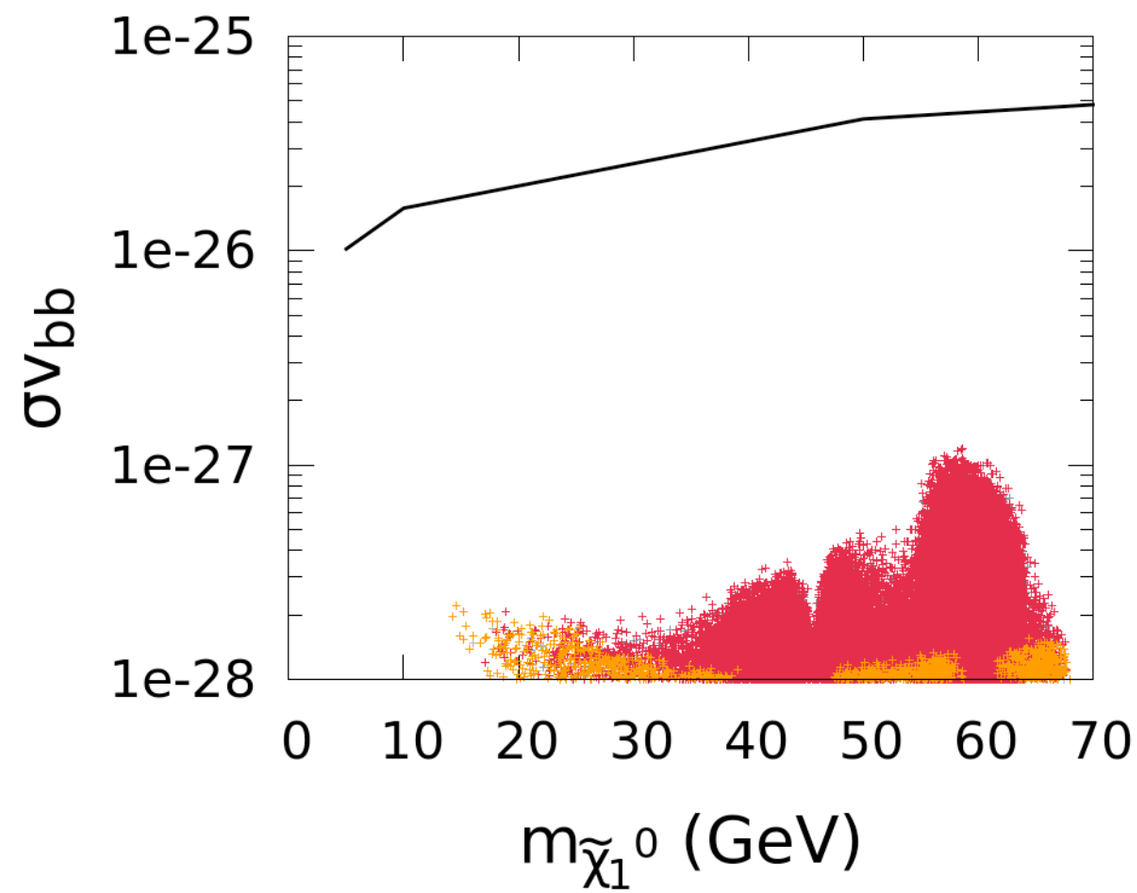
searches for dark matter





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