SUSY analyses in MasterCode

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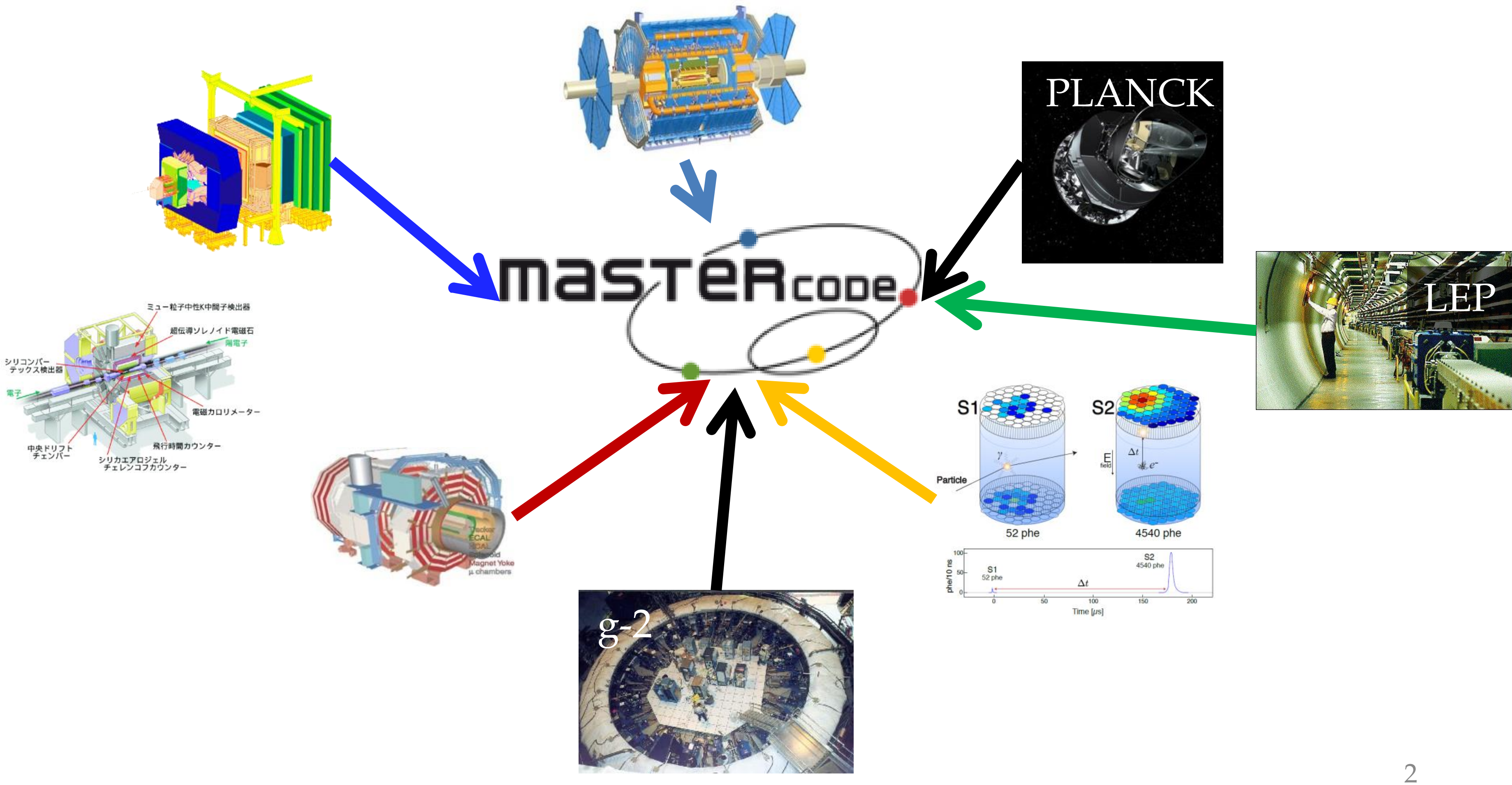
GAIN & USC

On behalf of the MasterCode collaboration

MasterCode

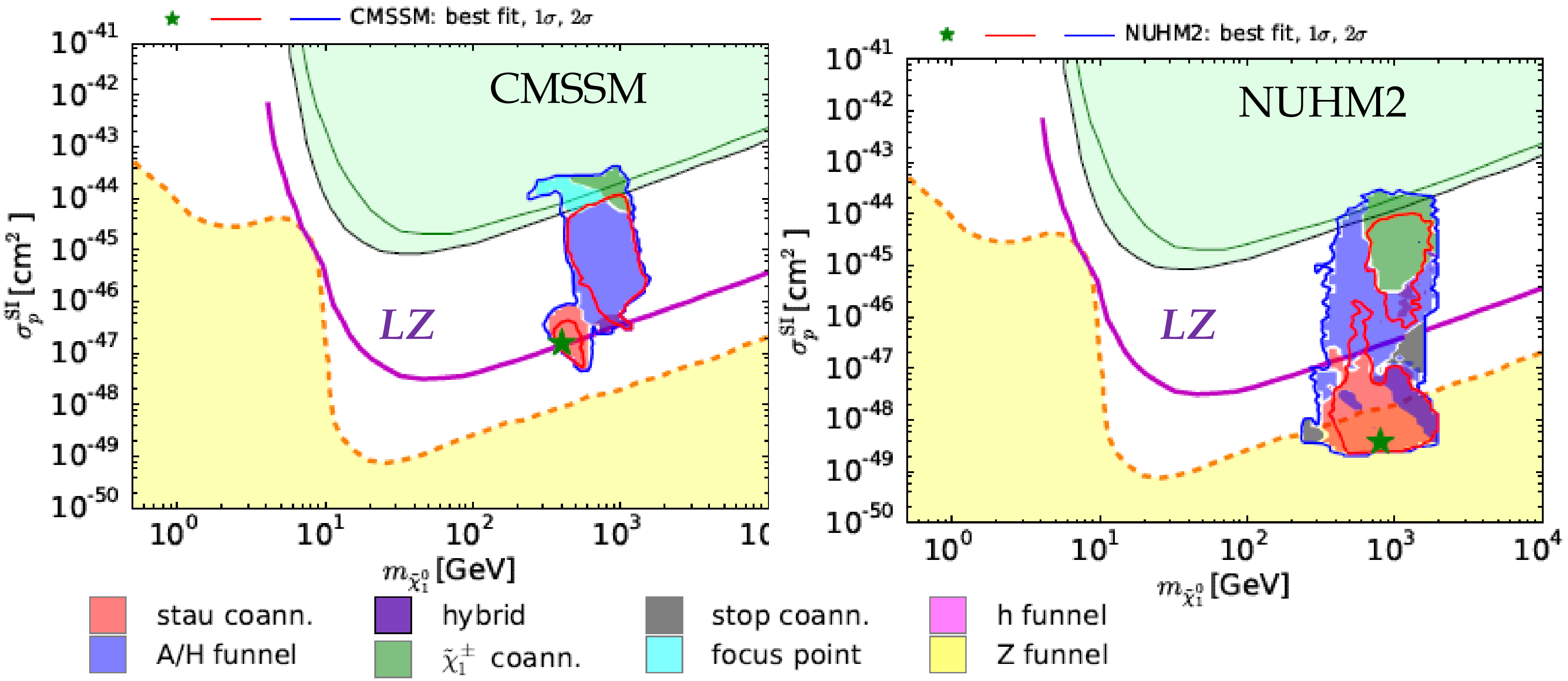
Global analyses of experimental data in constrained versions of the Minimal Supersymmetric Standard Model (MSSM)



CMSSM/NUHM

Eur.Phys.J. C75 (2015) 500
arXiv:1508.01173v1

- Universal conditions on scalar and sfermion masses @ GUT scale
  CMSSM: Universal scalar (m_0) sfermion ($m_{1/2}$), tβ, sign(μ), tril. coup. A_0.
  NUHM1(2): m_{Hu} = (□) m_{Hd} □ m_0
- DM: Bino /Higgsino



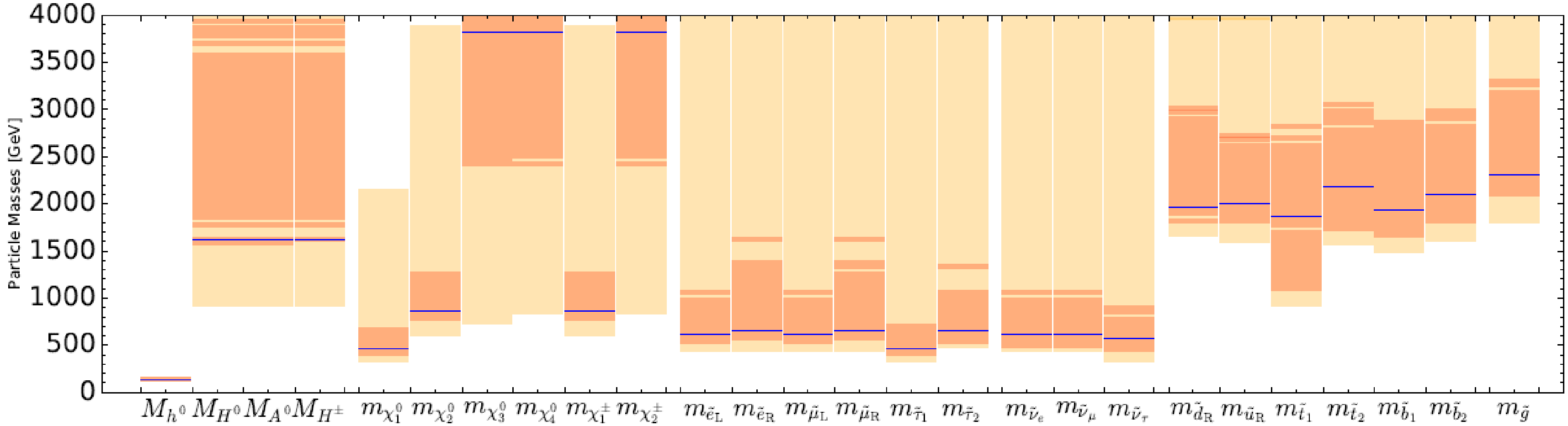
- Other related models we studied in the past and not discussed here: VCMSSM, mSUGRA: arXiv:1106.2529v1

SU(5) GUTs

Eur.Phys.J. C77 (2017) no.2, 104
arXiv:1610.10084

- Universal gaugino masses. Soft-Susy breaking masses for scalars **with same quantum numbers** also universal
- 1 parameter extension w.r.t NUHM2

mSUGRA □ CMSSM □ NUHM1 □ NUHM2 □ SU(5) GUT



- Lightest neutralino is bino-like (CHECK)
- Some region of parameter space within reach of HL-LHC, also for long-lived searches + ET miss
- Good fraction of the 68% CL contours (EW spectrum) within reach of ILC or CLIC

SU(5) GUTs

Eur.Phys.J. C77 (2017) no.2, 104
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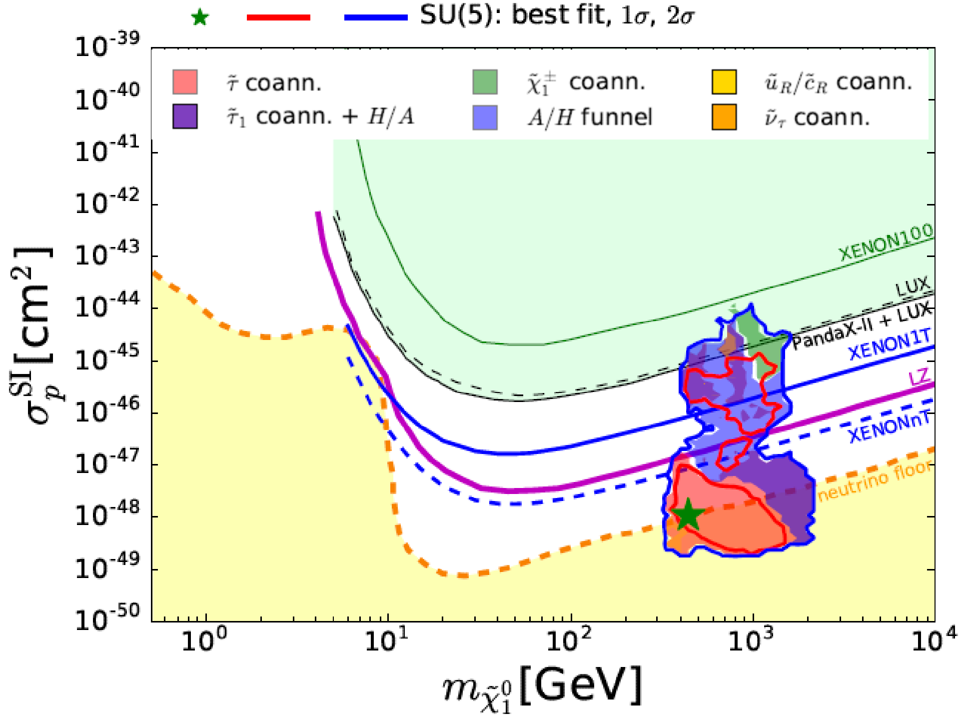
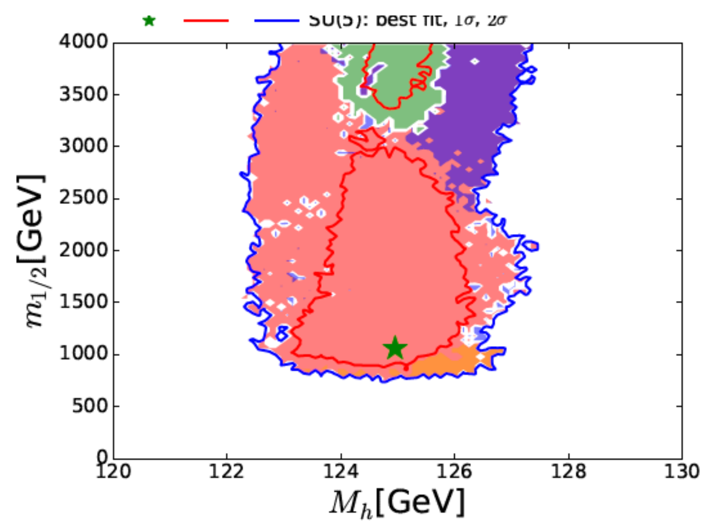


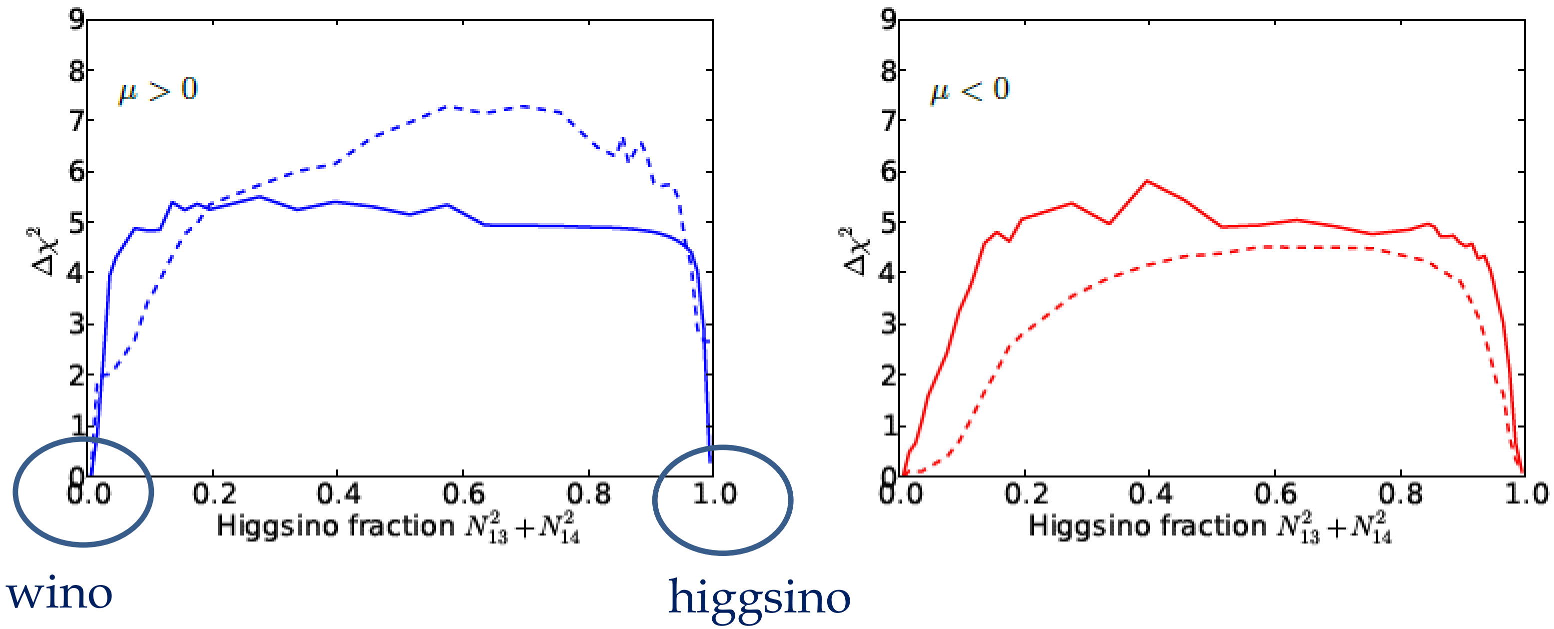


- Mixed prospects for direct DM detection:
    - Good in the chargino / neutralino co-annihilation regions
    - Not so good elsewhere
        - On the other hand, complementary to direct SUSY searches

mAMSB

Eur.Phys.J. C77 (2017) no.4, 268
arXiv:1612.05210

- Anomaly mediated SuperSymmetry breaking, + universal scalar mass term m_0
- Very reduced number of parameters (less than CMSSM): m_0, $m_{3/2}$,tβ, sign(μ)
- According to our analysis: Lightest neutralino is wino or higgsino, ~equally likely. Some level of admixture also allowed



mAMSB

Eur.Phys.J. C77 (2017) no.4, 268
arXiv:1612.05210

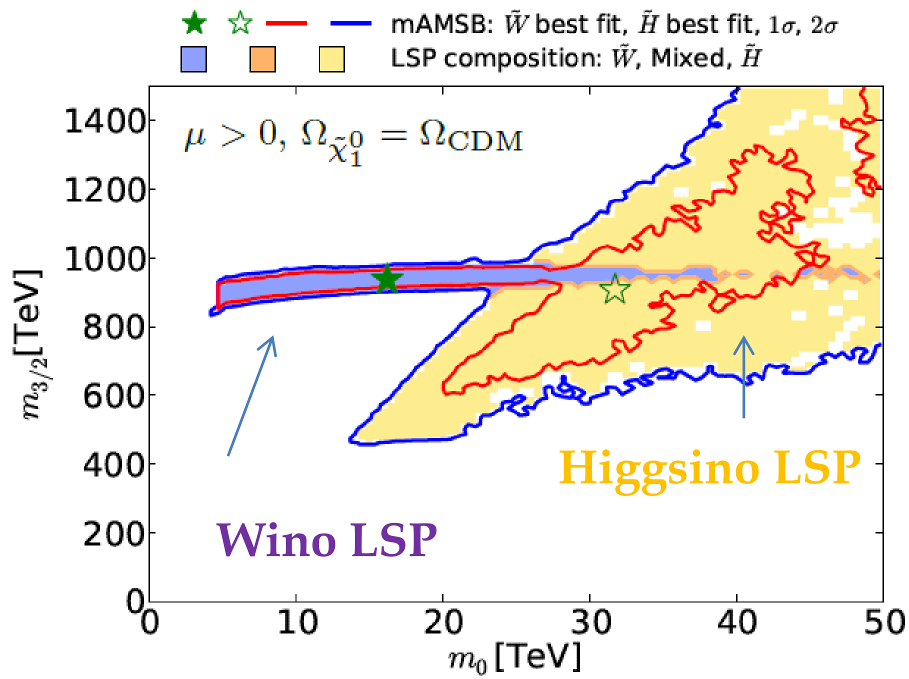
Wino DM , relic densisty → mLSP ~ 3 TeV in any MSSM

$$m_{wino-DM}^{mAMSB} = 2.9 \pm 0.1\ TeV$$

Most of the parameter space of mAMSB has **wino LSP**

Higgsino LSP equally likely, but only accessible in a narrow region

$$m_{Hgsino-DM}^{mAMSB} = 1.12 \pm 0.02\ TeV$$

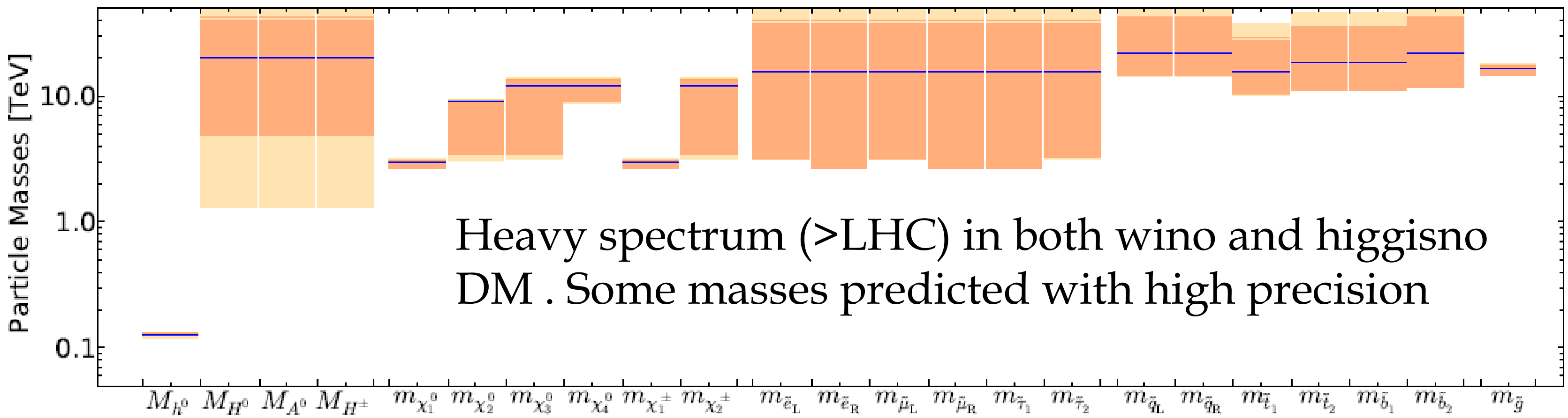


(Wino DM can be disfavoured by Fermi-LAT and HESS, but TH uncertainties on the DM profile near the galactic center still too large)

mAMSB

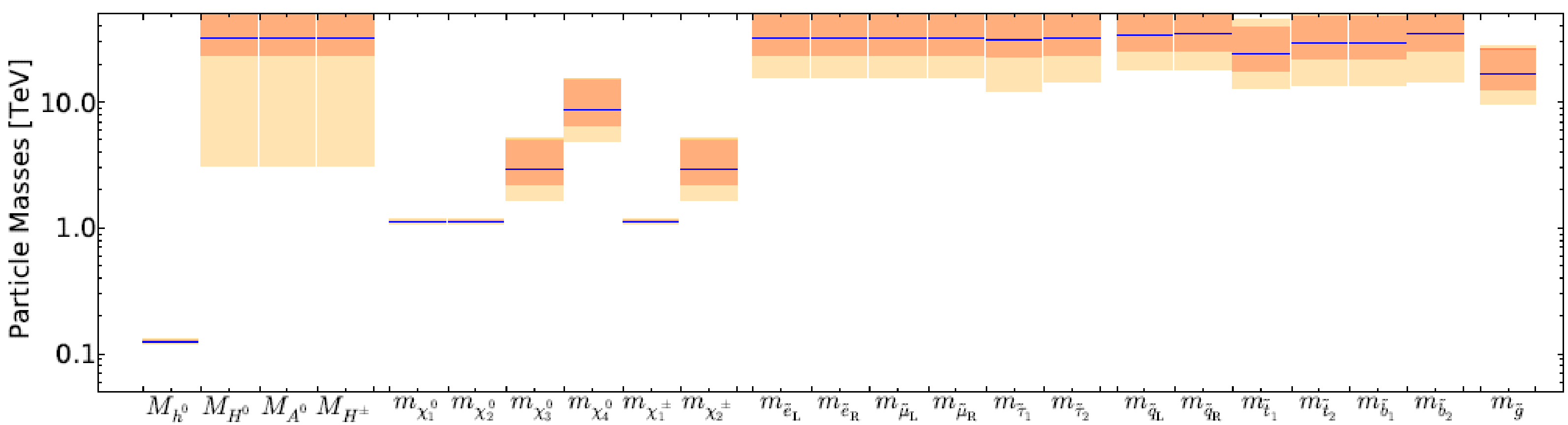
Eur.Phys.J. C77 (2017) no.4, 268
arXiv:1612.05210

$\tilde{W}$-LSP for $\mu > 0$, $\Omega_{\tilde{\chi}_1^0} = \Omega_{\mathrm{CDM}}$



Heavy spectrum (>LHC) in both wino and higgisno DM . Some masses predicted with high precision

$\tilde{H}$-LSP for $\mu > 0$, $\Omega_{\tilde{\chi}_1^0} = \Omega_{\mathrm{CDM}}$



mAMSB

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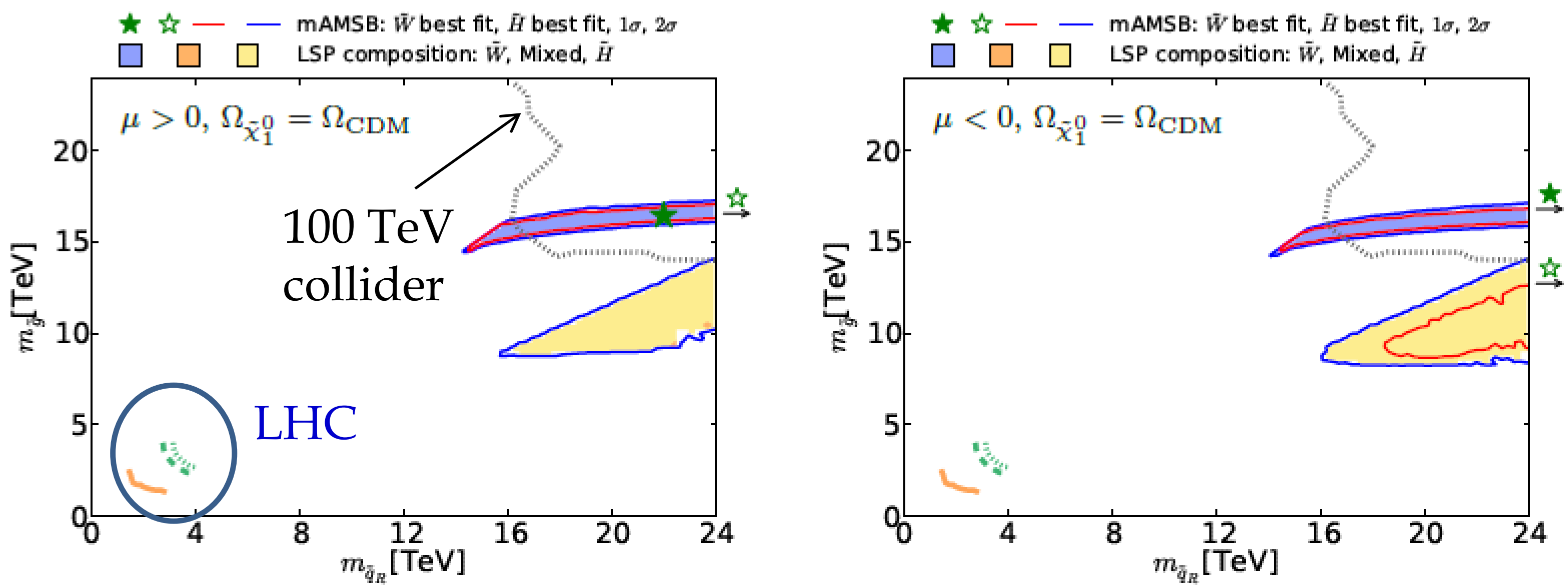


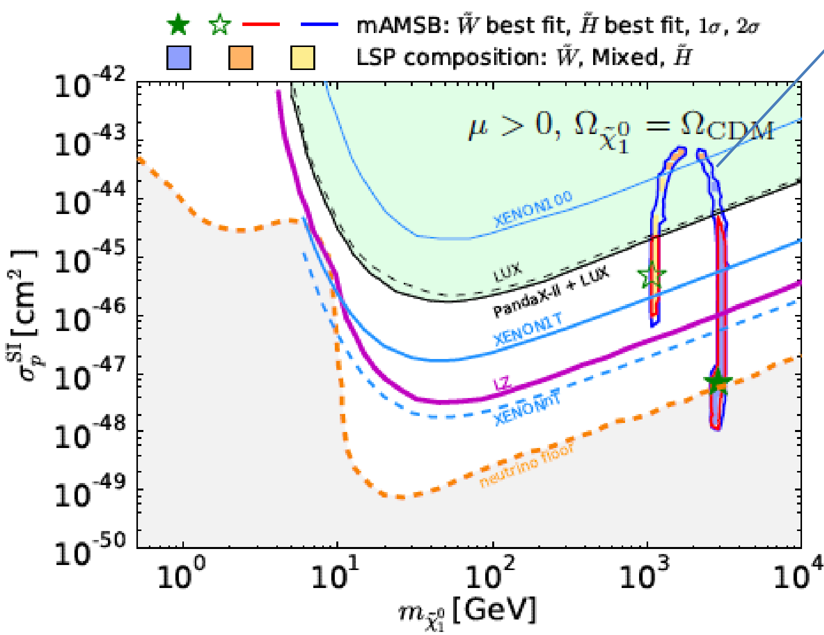
Part of the parameter space accessible @ 100 TeV pp collider

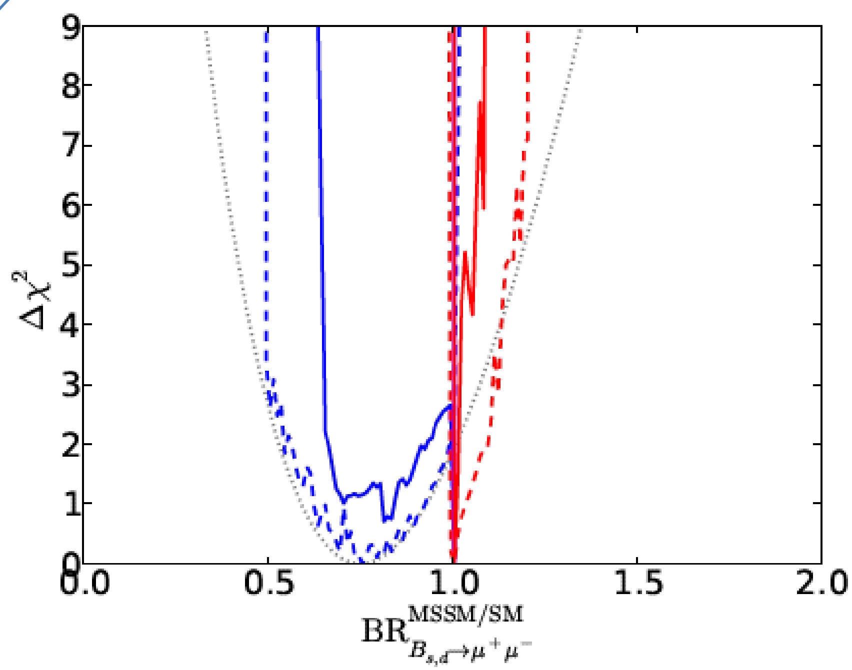
Accessible at LHC ~only if $\Omega_{SUSY} < \Omega_{CDM}$

mAMSB

Eur.Phys.J. C77 (2017) no.4, 268
arXiv:1612.05210

Large TH uncertainties





But nice prospects for direct DM detection, especially for Higgsino LSP, which could get completely excluded

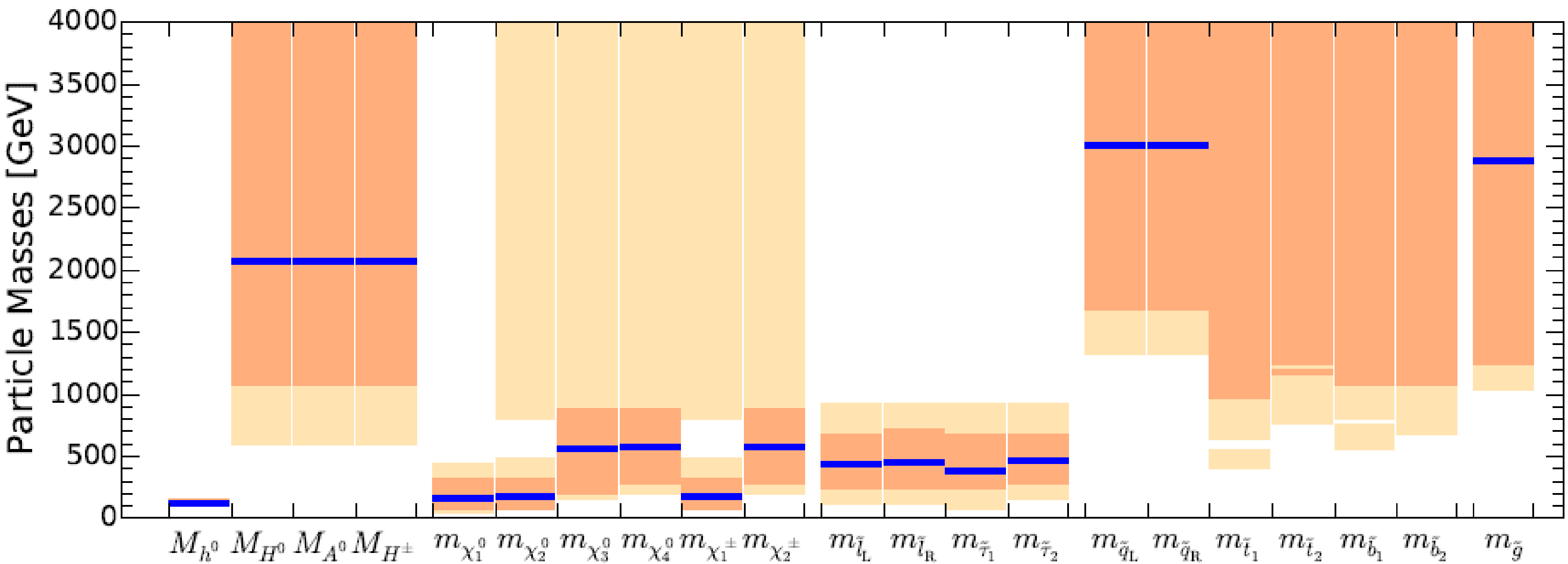
O(25%) effects in B→μμ allowed

pMSSM10

Eur.Phys.J. C75 (2015) no.9, 422
arXiv:1504.03260v1

Eur.Phys.J. C75 (2015) 500
arXiv:1508.01173v1

- Phenomenological approach: don't specify SUSY breaking, take MSSM and impose some conditions at EW scale to reduce # free parameters to 10
- DM : Bino/Higgsino



Good fraction of the parameter space within **LHC** reach, as well as **ILC**, **CLIC**

pMSSM10

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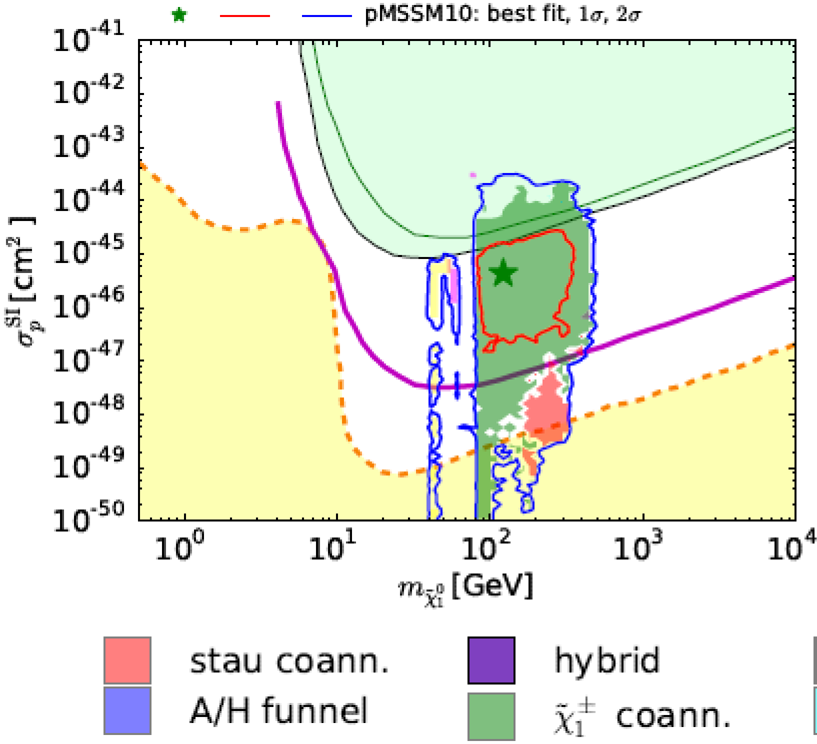
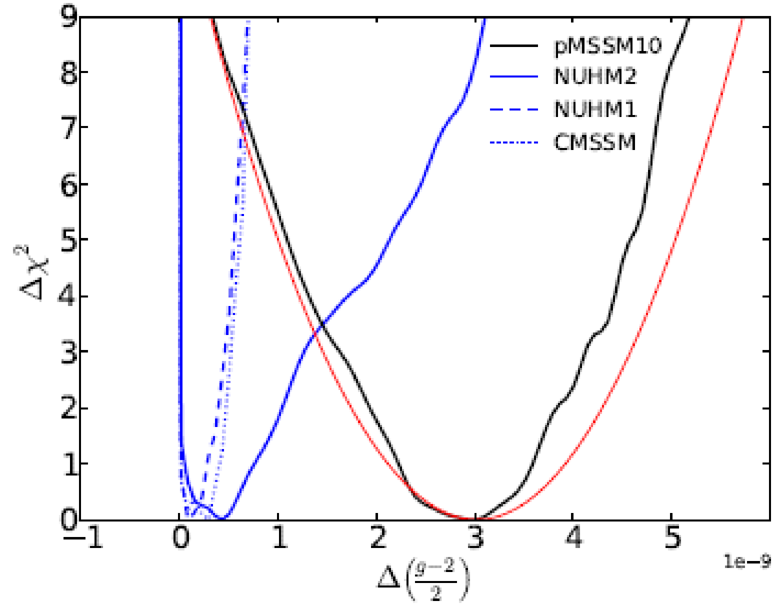


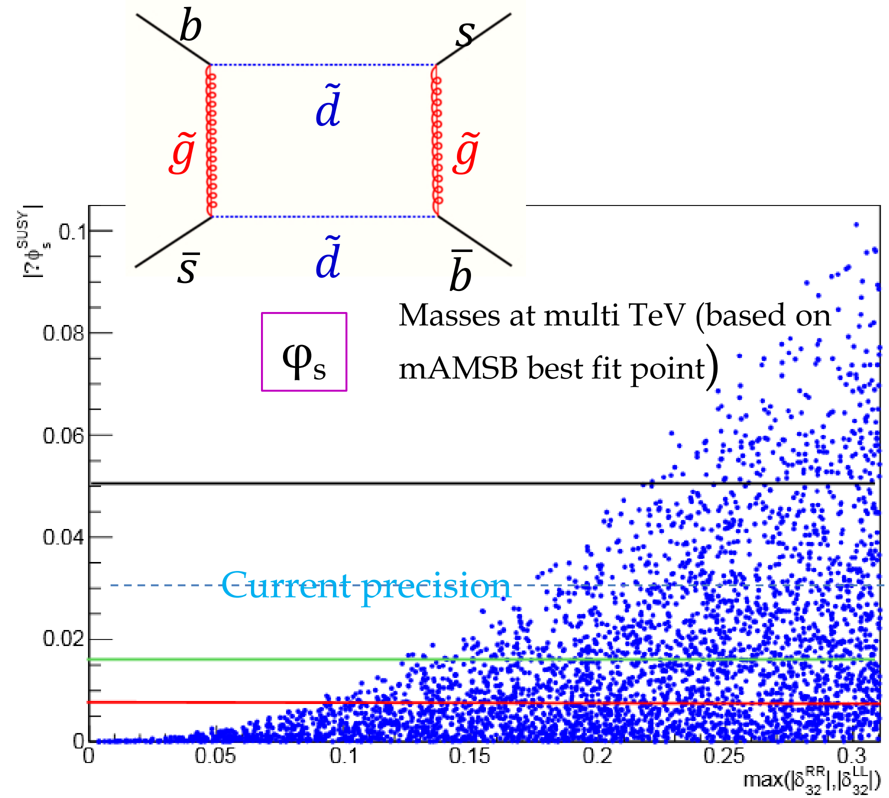


Good fraction of the parameter space accessible for direct detection

pMSSM10 can accommodate $(g\text{-}2)_\mu$

Heavy SUSY

- Multi TeV SUSY can also be accessed indirectly, if it contains new sources of Flavour Violation (FV) or CPV
  - Electric Dipole Moments
  - meson oscillations (Φs, ε_K) ,
  - rare decays of light particles ($K \rightarrow \pi\nu\nu$, $B \rightarrow \mu\mu$)
  - LFV
  - …



Conclusions, future plans

model	LHC direct	Fut. colliders	Direct DM det.	Low E
NUHM	✓ (orange)	✓ (green)	✓ (green)	✗ (*)
SU(5)	✓ (orange)	✓ (green)	✓ (green)	✗ (*)
pMSSM10	✓ (orange)	✓ (green)	✓ (green)	✓ (green) $(g\text{-}2)_\mu$
mAMSB	✗	✓ (orange) 100 TeV	✓ (green)	✓ (orange) $(B \rightarrow \mu\mu)$

(*) at least ignoring FV generated by CKM@RGE

- pMSSM11 ongoing
- Recast of LHC 13 TeV searches (see Isabel Suarez in the poster session)
- Other ideas in wish list: Long Lived Particles, FV generated by CKM&RGE @ EW scale, non SUSY (eg Z′ models)…

BACKUP

P-values?

- FAQ: Which is the p-value of those models?
  - Out of the fit, it's p~50%, mainly because most of DoF are from HiggsSignals, which are all in very good agreement with SM / MSSM
  - If you refit only with most sensitive observalbes, p-values can reduce to even 5%, because of g-2. Same happens for SM (dropping of course Dark Matter observables, which SM can't explain)
  - i.e, no tensions other than those already present in SM

Constraints

$\rightarrow\ \mathbf{m_t}$ [GeV]	[39]	$\mathbf{173.34 \pm 0.76}$
$\Delta\alpha^{(5)}_{\mathrm{had}}(M_Z)$	[40]	0.02771 ± 0.00011
M_Z [GeV]	[41, 42]	91.1875 ± 0.0021
Γ_Z [GeV]	[43] / [41, 42]	$2.4952 \pm 0.0023 \pm 0.001_{\mathrm{SUSY}}$
σ^0_{had} [nb]	[43] / [41, 42]	41.540 ± 0.037
R_l	[43] / [41, 42]	20.767 ± 0.025
$A_{\mathrm{FB}}(\ell)$	[43] / [41, 42]	0.01714 ± 0.00095
$A_\ell(P_\tau)$	[43] / [41, 42]	0.1465 ± 0.0032
R_{b}	[43] / [41, 42]	0.21629 ± 0.00066
R_{c}	[43] / [41, 42]	0.1721 ± 0.0030
$A_{\mathrm{FB}}(b)$	[43] / [41, 42]	0.0992 ± 0.0016
$A_{\mathrm{FB}}(c)$	[43] / [41, 42]	0.0707 ± 0.0035
A_b	[43] / [41, 42]	0.923 ± 0.020
A_c	[43] / [41, 42]	0.670 ± 0.027
A^e_{LR}	[43] / [41, 42]	0.1513 ± 0.0021
$\sin^2\theta^\ell_{\mathrm{w}}(Q_{\mathrm{fb}})$	[43] / [41, 42]	0.2324 ± 0.0012
M_W [GeV]	[43] / [41, 42]	$80.385 \pm 0.015 \pm 0.010_{\mathrm{SUSY}}$
$a_\mu^{\mathrm{EXP}} - a_\mu^{\mathrm{SM}}$	[44] / [45]	$(30.2 \pm 8.8 \pm 2.0_{\mathrm{SUSY}}) \times 10^{-10}$
$\rightarrow\ \mathbf{M_h}$ [GeV]	[46, 47] / [48]	$\mathbf{125.09 \pm 0.24 \pm 1.5_{\mathrm{SUSY}}}$

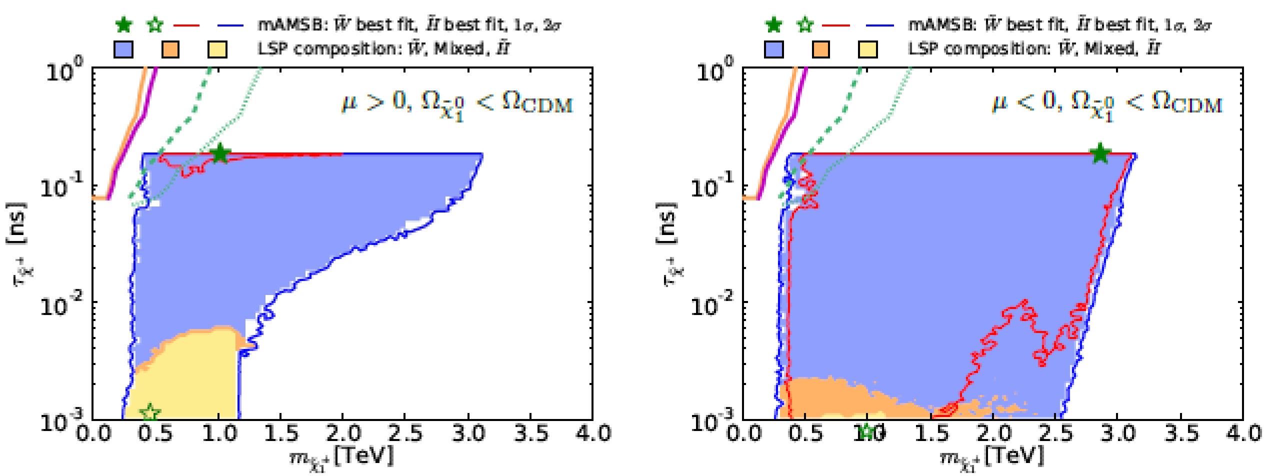
Constraints

$\rightarrow \quad \mathrm{BR}^{\mathrm{EXP/SM}}_{b\rightarrow s\gamma}$	[49]/ [50]	$\mathbf{1.021 \pm 0.066_{\mathrm{EXP}} \pm 0.070_{\mathrm{TH,SM}} \pm 0.050_{\mathrm{TH,SUSY}}}$
$\rightarrow \quad \mathrm{R}_{\mu\mu}$	[51]/ [37,38]	**2D likelihood, MFV**
$\rightarrow \quad \mathrm{BR}^{\mathrm{EXP/SM}}_{B\rightarrow\tau\nu}$	[50,52]	$\mathbf{1.02 \pm 0.19_{\mathrm{EXP}} \pm 0.13_{\mathrm{SM}}}$
$\rightarrow \quad \mathrm{BR}^{\mathrm{EXP/SM}}_{B\rightarrow X_s \ell\ell}$	[53]/ [50]	$\mathbf{0.99 \pm 0.29_{\mathrm{EXP}} \pm 0.06_{\mathrm{SM}}}$
$\rightarrow \quad \mathrm{BR}^{\mathrm{EXP/SM}}_{K\rightarrow\mu\nu}$	[54,55] / [40]	$\mathbf{0.9998 \pm 0.0017_{\mathrm{EXP}} \pm 0.0090_{\mathrm{TH}}}$
$\rightarrow \quad \mathrm{BR}^{\mathrm{EXP/SM}}_{K\rightarrow\pi\nu\bar{\nu}}$	[56]/ [57]	$\mathbf{2.2 \pm 1.39_{\mathrm{EXP}} \pm 0.20_{\mathrm{TH}}}$
$\rightarrow \quad \Delta\mathrm{M}^{\mathrm{EXP/SM}}_{B_s}$	[54,58] / [50]	$\mathbf{1.016 \pm 0.074_{\mathrm{SM}}}$
$\rightarrow \quad \frac{\Delta\mathrm{M}^{\mathrm{EXP/SM}}_{B_s}}{\Delta\mathrm{M}^{\mathrm{EXP/SM}}_{B_d}}$	[54,58] / [50]	$\mathbf{0.84 \pm 0.12_{\mathrm{SM}}}$
$\rightarrow \quad \Delta\epsilon^{\mathrm{EXP/SM}}_{K}$	[54,58] / [40]	$\mathbf{1.14 \pm 0.10_{\mathrm{EXP+TH}}}$
$\rightarrow \quad \Omega_{\mathrm{CDM}}\mathrm{h}^2$	[59,60]/ [28]	$\mathbf{0.1186 \pm 0.0020_{\mathrm{EXP}} \pm 0.0024_{\mathrm{TH}}}$
$\rightarrow \sigma^{\mathrm{SI}}_{\mathrm{p}}$	[31,32]	$(\mathrm{m}_{\tilde{\chi}^0_1}, \sigma^{\mathrm{SI}}_{\mathrm{p}})$ **plane**
$\rightarrow$ **Heavy stable charged particles**	[61]	**Fast simulation based on** [61,62]
$\rightarrow \quad \tilde{\mathrm{q}} \rightarrow \mathrm{q}\tilde{\chi}^0_1, \tilde{\mathrm{g}} \rightarrow \mathrm{f}\bar{\mathrm{f}}\tilde{\chi}^0_1$	[5]	$\sigma \cdot \mathrm{BR}$ **limits in the** $(\mathrm{m}_{\tilde{\mathrm{q}}}, \mathrm{m}_{\tilde{\chi}^0_1}), (\mathrm{m}_{\tilde{\mathrm{g}}}, \mathrm{m}_{\tilde{\chi}^0_1})$ **planes**
$\rightarrow \mathrm{H/A} \rightarrow \tau^+\tau^-$	[63–65]	**2D likelihood,** $\sigma \cdot \mathrm{BR}$ **limit**

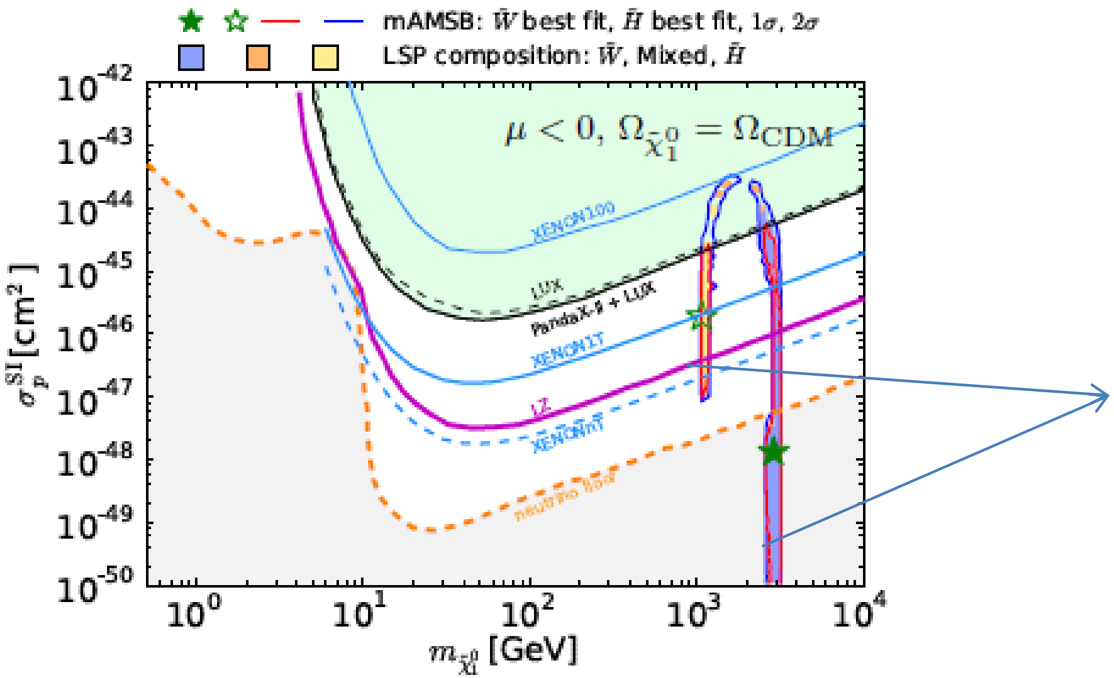
$$
\begin{aligned}
\tilde{\tau}_1 \text{ coann. (pink)}: &\quad \left(\frac{m_{\tilde{\tau}_1}}{m_{\tilde{\chi}_1^0}} - 1\right) < 0.15\,, \\
\tilde{\chi}_1^{\pm} \text{ coann. (green)}: &\quad \left(\frac{m_{\tilde{\chi}_1^{\pm}}}{m_{\tilde{\chi}_1^0}} - 1\right) < 0.1\,, \\
\tilde{t}_1 \text{ coann. (grey)}: &\quad \left(\frac{m_{\tilde{t}_1}}{m_{\tilde{\chi}_1^0}}\right) - 1 < 0.2\,, \\
A/H \text{ funnel (blue)}: &\quad \left|\frac{M_A}{m_{\tilde{\chi}_1^0}} - 2\right| < 0.4\,, \\
\text{focus point (cyan)}: &\quad \left(\frac{\mu}{m_{\tilde{\chi}_1^0}}\right) - 1 < 0.3\,. \qquad (1)
\end{aligned}
$$

mAMSB, disappearing tracks

* Constraints on disappearing track searches @ LHC are important for mAMSB if $\Omega_{SUSY} < \Omega_{DM}$



mAMSB, μ < 0



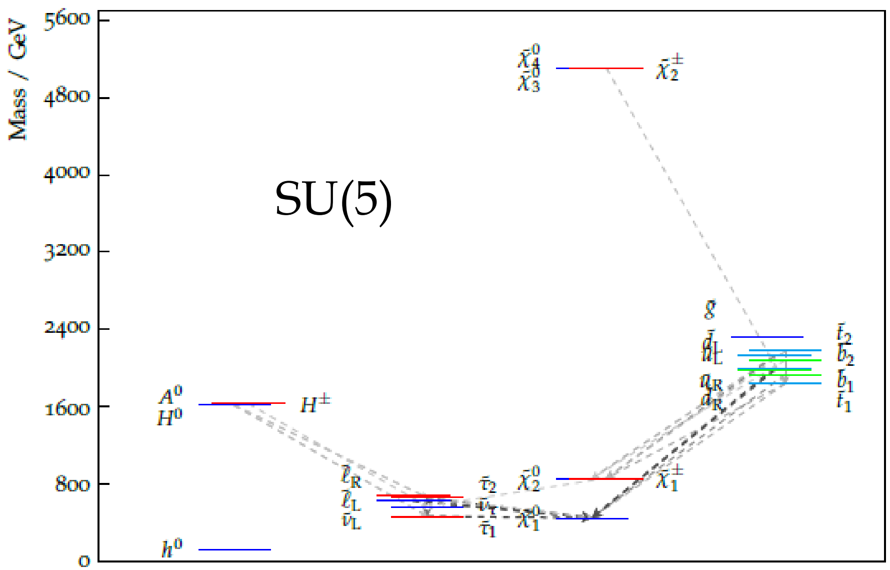
Cancelations in the scattering matrix element allow for lower σ than for μ > 0

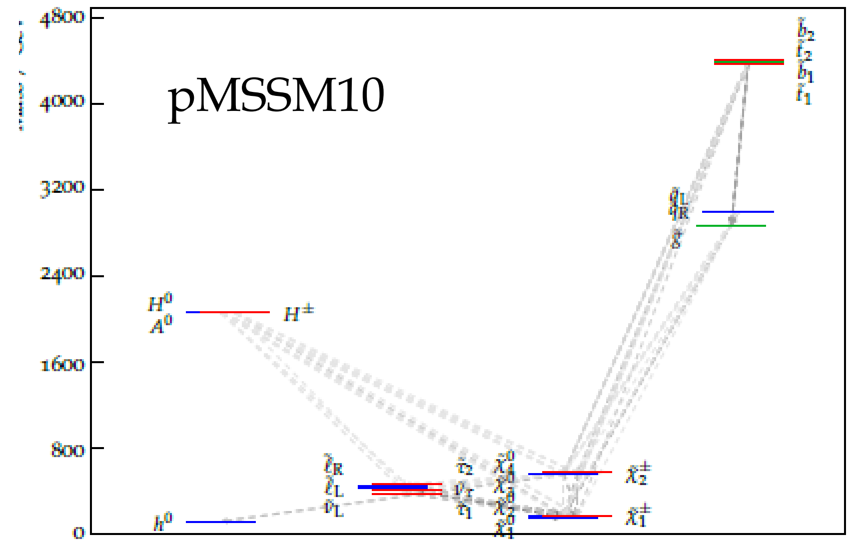
Parameter	Range	Number of segments
$m_{1/2}$	(0 , 4)	2
m_5	(- 2.6 , 8)	2
m_{10}	(- 1.3 , 4)	3
m_{H_u}	(-7 , 7)	3
m_{H_d}	(-7 , 7)	3
A_0	(-8 , 8)	1
$\tan\beta$	(2 , 68)	1
Total number of boxes		108

Parameter	Range	Generic Segments	Higgsino Segments
m_0	(0.1 , 50 TeV)	4	6
$m_{3/2}$	(10 , 1500 TeV)	3	3
$\tan\beta$	(1 , 50)	4	2
Total number of boxes		48	36

Parameter	Range	Number of segments
M_1	(-1 , 1) TeV	2
M_2	(0 , 4) TeV	2
M_3	(-4 , 4) TeV	4
$m_{\tilde{q}}$	(0 , 4) TeV	2
$m_{\tilde{q}_3}$	(0 , 4) TeV	2
$m_{\tilde{l}}$	(0 , 2) TeV	1
M_A	(0 , 4) TeV	2
A	(-5 , 5) TeV	1
μ	(-5 , 5) TeV	1
$\tan\beta$	(1 , 60)	1
Total number of boxes		128

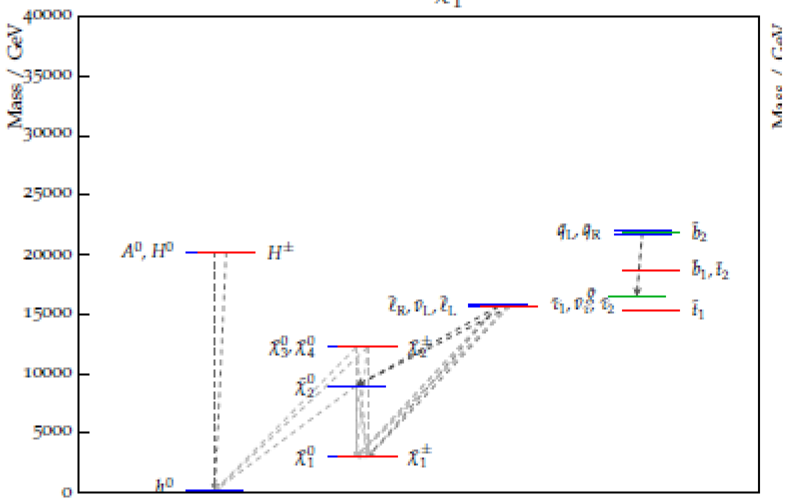
SU(5) GUTs


Mass / GeV
5600
4800
4000
3200
2400
1600
800
0
SU(5)

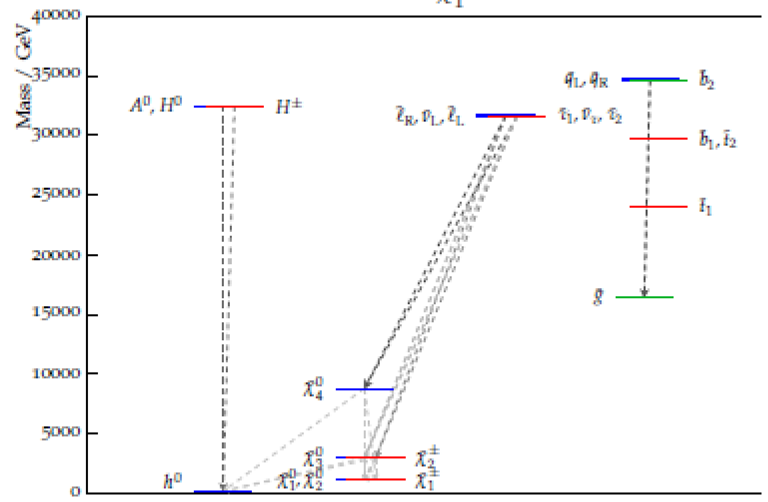

4800
4000
3200
2400
1600
800
0
pMSSM10

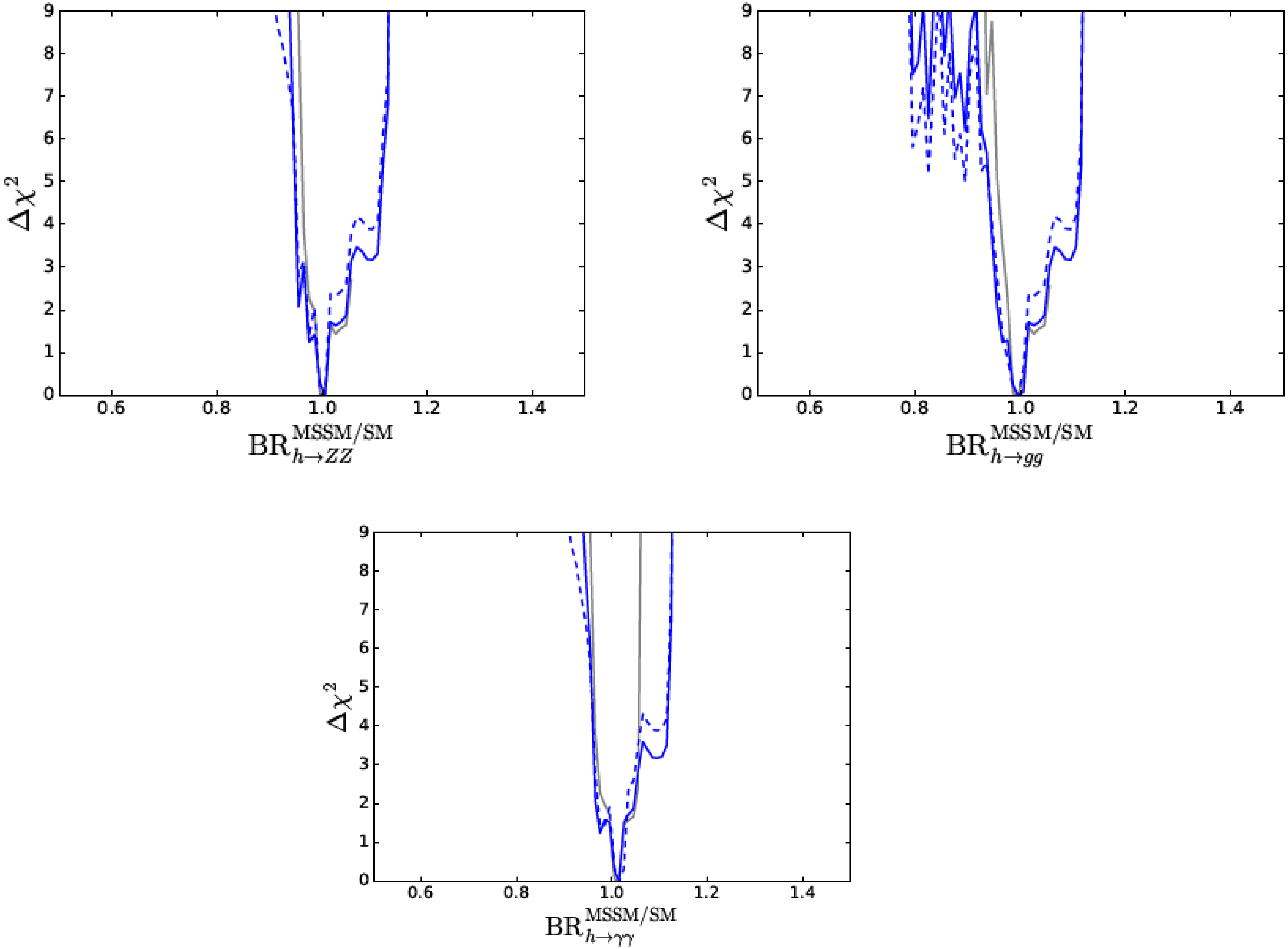
mAMSB

$\tilde{W}$-LSP for $\mu > 0$, $\Omega_{\tilde{\chi}_1^0} = \Omega_{CDM}$



$\tilde{H}$-LSP for $\mu > 0$, $\Omega_{\tilde{\chi}_1^0} = \Omega_{CDM}$





$\Delta\chi^2$
0 1 2 3 4 5 6 7 8 9
0.6 0.8 1.0 1.2 1.4
$\mathrm{BR}_{h\to ZZ}^{\mathrm{MSSM/SM}}$
$\Delta\chi^2$
0 1 2 3 4 5 6 7 8 9
0.6 0.8 1.0 1.2 1.4
$\mathrm{BR}_{h\to gg}^{\mathrm{MSSM/SM}}$
$\Delta\chi^2$
0 1 2 3 4 5 6 7 8 9
0.6 0.8 1.0 1.2 1.4
$\mathrm{BR}_{h\to\gamma\gamma}^{\mathrm{MSSM/SM}}$