Dark Matter motivated SUSY scenarios with heavy scalars at CLIC

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– Motivations for SUSY with heavy scalars

– General scenarios with heavy scalars

– Benchmark scenarios for SUSY with heavy scalars

– Observables at CLIC and reconstruction of parameters

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Ongoing work in collaboration with N. Bernal (and earlier with P. Slavich)

Motivations for SUSY with heavy scalars

The usual motivations for low–energy Supersymmetry are threefold:

- The Standard Model gauge coupling unification at the GUT scale.
- Existence of a WIMP that is a very good candidate for Dark Matter.
- Solves the hierarchy problem: no quadrqtic divergences to $\mathrm{M_H^2}$.

For the last argument, superparticles must be light otherwise fine-tuning.

However, experimentally $\mathrm{M_S} \gtrsim$ a few 100 GeV $\Rightarrow$ a few % fine-tuning.

But heavy scalars interesting as they might cure some problems: a too light Higgs, FCNC, too much CP violation, fast proton decay, etc...

A solution is Split SUSY or SUSY with heavy scalars:

we accept a fine-tuning (no or bad solution to the hierarchy problem) but we retain the two other good features $\mathrm{g_i}$ unif. and DM solution.

In fact, $\mathrm{M_S} \gtrsim$ few TeV is enough, giving one permille fine-tuning (only...)

Consequence: only gauginos and SM–like H are acceesible at colliders (in fact even gauginos will be hard to access at LHC if $\mathrm{m_{\tilde{g}}} \gtrsim$ 1 TeV).

General scenarios with heavy scalars

The model in the limit $\mathrm{M_S} \gg \mathrm{M_Z}$ is simple:

- **one Higgs coupling λ giving $\mathrm{M_H} = 2\lambda \mathbf{v^2} +$ radiative corrections,**
- **one scalar parameter $\mathrm{M_S}$ and no trilinear A couplings ($\mathrm{A} \ll \mathrm{M_S}$),**
- **three gaugino masses $\mathrm{M_1}, \mathrm{M_2}, \mathrm{M_3}$ (allow for non-universality),**
- **a higgsino μ parameter (put by hand as there is no radiative EWSB).**

tanβ is not a model parameter but enters the boundary conditions at $\mathrm{M_S}$

$$\tilde{\mathbf{g}}_{\mathbf{u}} = \mathbf{g}\sin\beta,\ \tilde{\mathbf{g}}_{\mathbf{d}} = \mathbf{g}\cos\beta,\ \tilde{\mathbf{g}}'_{\mathbf{u}} = \mathbf{g}'\sin\beta,\ \tilde{\mathbf{g}}'_{\mathbf{d}} = \mathbf{g}'\cos\beta$$

Gaugino masses (at tree–level):

$$\mathcal{M}_{\mathbf{C}} = \begin{pmatrix} M_2 & \tilde{g}_u v \\ \tilde{g}_d v & \mu \end{pmatrix},\ \mathcal{M}_{\mathbf{N}} = \begin{pmatrix} M_1 & 0 & -\frac{\tilde{g}'_d v}{\sqrt{2}} & \frac{\tilde{g}'_u v}{\sqrt{2}} \\ 0 & M_2 & \frac{\tilde{g}_d v}{\sqrt{2}} & -\frac{\tilde{g}_u v}{\sqrt{2}} \\ -\frac{\tilde{g}'_d v}{\sqrt{2}} & \frac{\tilde{g}_d v}{\sqrt{2}} & 0 & -\mu \\ \frac{\tilde{g}'_u v}{\sqrt{2}} & -\frac{\tilde{g}_u v}{\sqrt{2}} & -\mu & 0 \end{pmatrix}.$$

$$m_{\tilde{g}} = M_3$$

Determination of viable spetra

- **First of all, one needs calculation of mass spectra: diagonalisation, include RC, resum large $(\mathrm{M_S})$ logs, RG evolution from $\mathrm{M_{GUT}}$, etc..**

  $\Rightarrow$ all implemented in the program Suspect.

- **Impose all theoretical constraints: no tachyons, neutralino LSP, non stable–like gluino, check gauge coupling unification, ...**

- **Impose constraints from high–energy colliders: LEP1, LEP2 and Tevatron direct searches (almost no bound from precision data).**

- **Impose the dark matter (3σ) constraint: $0.09 \lesssim \Omega_{\rm DM}h^2 \lesssim 0.13$; in this case, only a few (co)annihilation channels of the χ LSP survive:**

  – the s-channel pole: $\chi\chi \to \mathrm{H} \to \mathrm{b\bar{b}}, \mathrm{Wf\bar{f}}$; also $\chi\chi \to \mathrm{Z} \to \mathrm{f\bar{f}}$,

  – the mixed higgsino–gaugino region, $\chi\chi \to \mathrm{WW}, \mathrm{ZZ}, \mathrm{ZH}$,

  – the co–annihilation region with charginos (and also with gluinos).

  $\Rightarrow$ all implemented in the program Micromegas.

Non universal gaugino mass scenarios

All in scenarios with non–universal gaugino masses for generality...

Example of non-universality in gravity mediated SU/SY in SU(5) GUT

masses given by a field which is singlet, but it can be of higher rep.

Example: $(\mathbf{24} \otimes \mathbf{24})_{\rm symmetric} = \mathbf{1} \oplus \mathbf{24} \oplus \mathbf{75} \oplus \mathbf{200}$

	$Q = M_{\rm GUT}$	$Q = M_Z$ $[M_S = 10^4\,{\rm GeV}]$
1	$1 : 1 : 1$	$1.0 : 2.0 : 7.8$
24	$1 : 3 : -2$	$1.0 : 6.3 : -15.2$
75	$5 : -3 : -1$	$1.0 : -1.2 : -1.5$
200	$10 : 2 : 1$	$2.4 : 1.0 : 1.9$

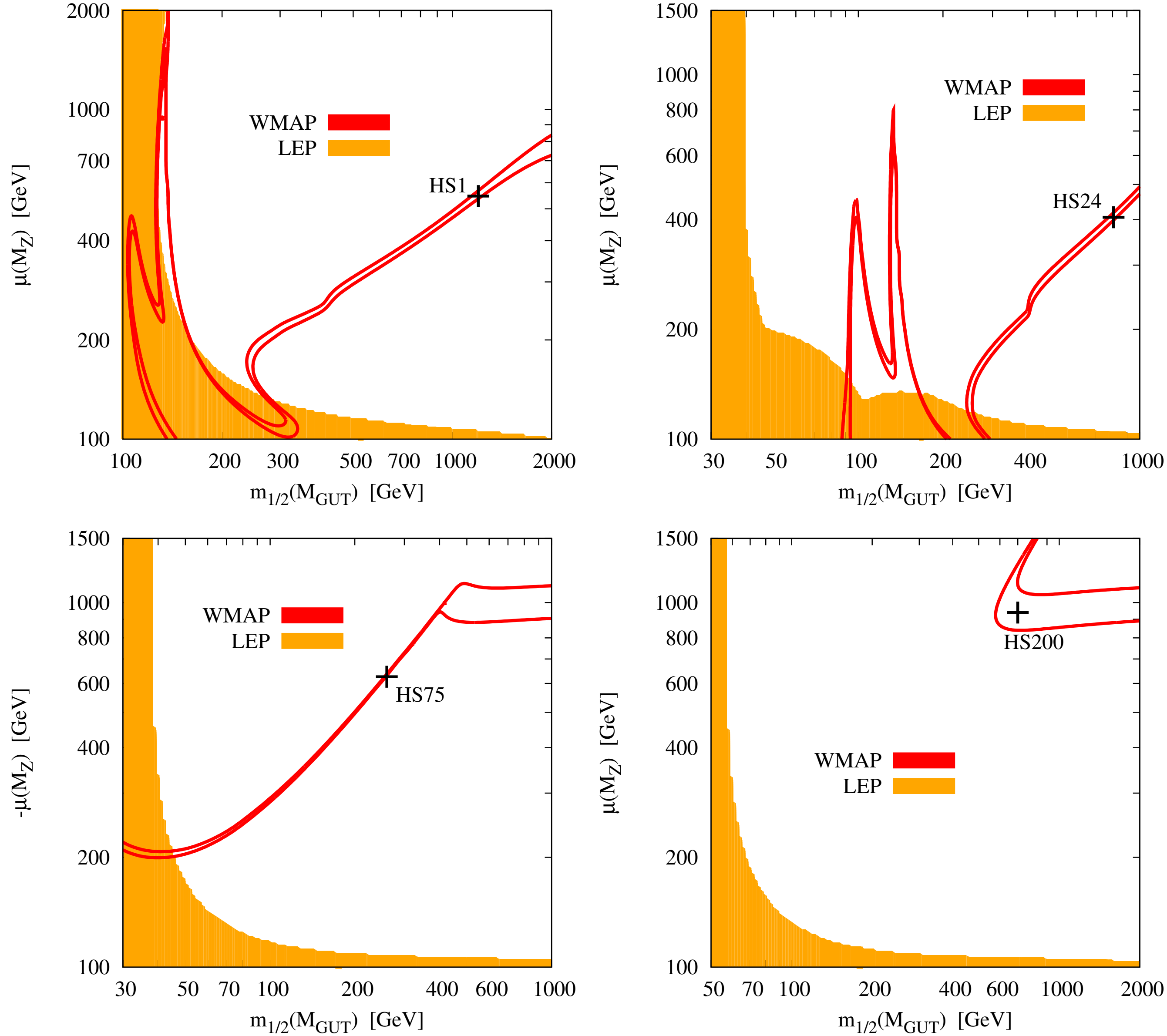
$$\mathbf{HS1} : \mu(\mathbf{M_Z}) = \mathbf{550\,GeV}\,,\ \mathbf{m_{1/2}} = \mathbf{1200\,GeV}\,,\ \tan\beta = \mathbf{3}$$

$$\mathbf{HS24} : \mu(\mathbf{M_Z}) = \mathbf{405\,GeV}\,,\ \mathbf{m_{1/2}} = \mathbf{800\,GeV}\,,\ \tan\beta = \mathbf{10}$$

$$\mathbf{HS75} : \mu(\mathbf{M_Z}) = \mathbf{-610\,GeV}\,,\ \mathbf{m_{1/2}} = \mathbf{250\,GeV}\,,\ \tan\beta = \mathbf{5}$$

$$\mathbf{HS200} : \mu(\mathbf{M_Z}) = \mathbf{950\,GeV}\,,\ \mathbf{m_{1/2}} = \mathbf{700\,GeV}\,,\ \tan\beta = \mathbf{20}$$

Benchmark scenarios for SUSY with heavy scalars



Benchmark scenarios for SUSY with heavy scalars

Inputs

Point	$m_{1/2}(M_{\rm gut})$	$M_1(M_Z)$	$M_2(M_Z)$	$M_3(M_Z)$	$\mu(M_Z)$	tan
HS1	1200	573	1108	3248	550	3
HS24	800	385	2214	−4212	405	10
HS75	250	597	−695	−725	−610	5
HS200	700	3364	1285	1850	950	20

Masses

	H	$\tilde{\chi}_1^0$	$\tilde{\chi}_2^0$	$\tilde{\chi}_3^0$	$\tilde{\chi}_4^0$	$\tilde{\chi}_1^\pm$	$\tilde{\chi}_2^\pm$	$\tilde{g}$
HS1	119.3	515.0	550.3	598.1	1122	541.8	1122	301
HS24	127.0	360.1	408.9	430.3	2203	406.3	2203	388
HS75	124.3	572.5	577.0	625.6	735.1	573.0	735.4	781.
HS200	127.3	926.4	937.1	1309	3365	928.3	1309	189

Decays, cross setions and asymmetries at CLIC

BR	1	24	75	200
$\chi_1^\pm \to \chi_1^0 W$	100	100	100	100
$\chi_2^\pm \to \chi_1^\pm Z$	25	25	31	25
$\chi_2^\pm \to \chi_1^0 W$	16	9	35	25
$\chi_2^\pm \to \chi_2^0 W$	24	24	17	24
$\chi_2^\pm \to \chi_3^0 W$	9	15	3	-
$\chi_2^\pm \to \chi_1^\pm H$	24	25	12	24
$\chi_2^0 \to \chi_1^0 Z$	98	99	15	38
$\chi_2^0 \to \chi_1^\pm W$	0.5	-	35	47
$\chi_2^0 \to \chi_1^0 \gamma$	1.4	0.1	49	14
$\chi_3^0 \to \chi_2^0 Z$	12	17	-	23
$\chi_3^0 \to \chi_1^\pm W$	87	76	72	51
$\chi_3^0 \to \chi_1^0 H$	-	-	-	23
$\chi_4^0 \to \chi_2^0 Z$	24	19	15	19
$\chi_4^0 \to \chi_1^\pm W$	49	49	72	46
$\chi_4^0 \to \chi_1^0 H$	15	7	12	19

σ(fb)	1	24	75	200
$\chi_1^+\chi_1^-$	13	13	15	13
$\chi_1^0\chi_2^0$	4	2.5	2.1	5
$\chi_1^0\chi_3^0$	—	$\cdot 10^{-4}$	2.4	$\cdot 10^{-}$
$\chi_2^0\chi_3^0$	1.59	3.4	—	0.1
$\chi_2^0\chi_4^0$	$\cdot 10^{-1}$	$\cdot 10^{-3}$	0.5	—
$\chi_3^0\chi_4^0$	$\cdot 10^{-4}$	10^{-4}	0.6	—
$\chi_1^+\chi_2^-$	$\cdot 10^{-1}$	$\cdot 10^{-3}$	0.9	0.1
$\chi_2^+\chi_2^-$	23	—	23	18

- A(%)	1	24	75	200
$A_{LR}^{\chi_1^+\chi_1^-}$	68	67	81	69
$A_{FB}^{\chi_1^+\chi_1^-}$	0.4	0.1	2	0.5
$A_{LR}^{\chi_1^+\chi_2^-}$	21	21	21	21
$A_{FB}^{\chi_1^+\chi_2^-}$	4	7.4	1.3	2.5
$A_{LR}^{\chi_2^+\chi_2^-}$	99	—	99	99

Reconstruction of basic parameters

In the chargino case, we need to determine 4 parameters from data:

Defining the combinations of masses and mixing angles,

$$\alpha = m^2_{\chi_1^\pm} + m^2_{\chi_2^\pm},\ \beta/\gamma = \frac{1}{2}(\cos 2\phi_R \mp \cos 2\phi_R)(m^2_{\chi_2^\pm} - m^2_{\chi_1^\pm}),\ \delta = m^2_{\chi_1^\pm} m$$

$$x = \frac{\alpha^2+\beta^2-\gamma^2-4\delta^2 \pm \sqrt{(\alpha^2+\beta^2-\gamma^2-4\delta^2)^2 - 4(\alpha^2-4\delta^2)\beta^2}}{2(\alpha-2\delta)}$$

One obtains for the four basic chargino parameters:

$$M_2^2 = \frac{(\beta+x)^2}{4x},\ \mu^2 = \frac{(\beta+x)^2}{4x} - \beta,\ \tilde{g}_d^2/\tilde{g}_u^2 = \frac{1}{2v^2}(\alpha+\beta\pm\gamma) - \frac{(\beta+x)^2}{4\,x\,v^2}$$

In the neutralino case, 3 more parameters need to be determined:

– more complicated to do analytically as we have a 4x4 matrix,

– inversion possible with 3 masses or 2 masses + 1 cross section,

– discrete ambiguities are nevertheless remaining (under study...).

If the gluino is observed at LHC $\Rightarrow$ gluino mass parameter M_3

Detailed/realistic study needed to assess what you can reconstruct

(need to produce as many states as possible and thus CLIC needed)

$\Rightarrow$ under way by M. Battaglia et al.