Split Higgsino scenario: an origin and possible manifestations

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Outline

- Split SUSY scenarios
- Spectrum of scales from the RG evolution
- The Split Higgsino scenario: parameterization and possibilities
- Experimental manifestations: what can be seen at the LHC?
- Charge exchange process – a high-energy neutralino signal
- Resume

The SM: description of experiments up to ~ 100 GeV.

The scale of the SM breaking, M_{SM}, is not too large

↓

If not, mass of the Higgs boson should be fine-tuned (with an accuracy ~ M_W / M_{SM}) to realize the weak scale.

↓

It is the naturalness principle

↓

For the details of the MSSM formulation, mass spectrum, coupling unification and so on see a lot of reviews (D.Kazakov, for example)

The MSSM successes:

- RG evolution of gauge couplings is successful;
- high GUT scale provides the proton stability (except of dim.5 operators, with R-parity);
- the MSSM (stable) LSP can describe the (Cold) Dark Matter (with R-parity);
- "naturalness" holds out hope for the LHC experiment (the SUSY breaking scale $\sim M_0 \sim M_1 \sim M_2 \leq O(1\ \text{TeV})$);

Is the MSSM scale hierarchy unique?

Can be the SUSY spectrum splitted up?
The answer - “yes”

See, for example:

- N.Arkani-Hamed, S.Dimopoulos (2004), G.F.Giudice, A.Romanino (2004);
- N.Arkani-Hamed, S.Dimopoulos, G.F.Giudice, A.Romanino (2005);
- R.Mahbubani, L.Senatore (2006); M.Masip, I.Mastromatteo (2006);
- M.Drees (2005); A.Masiero, S.Profumo, P.Ullio (2004);
- K.Cheng, C.-W.Chiang, J.Song (2005, 2006);
- G.Vereshkov, V.Kuksa, V.Beylin, R.Pasechnik (2004, 2005, 2007)

An argumentation of the Split SUSY spectrum is based on:

- if there is the fine-tuning for the Cosmological Constant, it can be realized for the high SUSY breaking scale – unknown “statistical weights” of vacuum states allow to introduce the fine-tuning for the segregated light Higgs;
- modifications of Anthropic Principle also allow to understand (“explain”) why the fine-tuned Higgs can be light simultaneously with the high M_{SUSY};
- (some of) gaugino and higgsino can survive beneath the high M_{SUSY}, squarks and sleptons are far from the EW scale;
- gauge coupling unification takes place;
- a good candidate for the DM occurs in the scenario.

Basic idea: the gauge coupling unification drives the structure of scales

⇓

One-loop RG evolution in SUSY SU(5) allows to select some classes of hierarchies

- The states near M_{GUT} are involved into RG evolution
- The couplings unification is putted from the very beginning
- The RG equations are considered in a specific form
- Then, the GUT scale occurs as sufficiently high

One-loop RG analysis

- Start from Mz scale →

$$\alpha^{-1}(M_Z) = 127.922 \pm 0.027, \qquad \alpha_s(M_Z) = 0.1200 \pm 0.0028,$$
$$\sin^2\theta_W(M_Z) = 0.23113 \pm 0.00015.$$

- Include an SU(5) additional heavy states:

$$\alpha_1^{-1}(M_Z) = \frac{3}{5}\alpha^{-1}(M_Z)\cos^2\theta_W(M_Z)$$
$$\alpha_2^{-1}(M_Z) = \alpha^{-1}(M_Z)\sin^2\theta_W(M_Z)$$
$$\alpha_3^{-1}(M_Z) = \alpha_s^{-1}(M_Z)$$

- singlet fields from quintets;
- chiral fields from 24-plet;
- their masses and couplings are unknown, these contributions play a role of "threshold corrections" in the RG equations

One-loop RG analysis

$$\alpha_i^{-1}(Q_2) = \alpha_i^{-1}(Q_1) + \frac{b_i}{2\pi} \ln \frac{Q_2}{Q_1}, \qquad b_i = \sum_j b_{ij}.$$

In the sum all states with masses $M_j < Q_2/2$ at $Q_2 > Q_1$ are taken into account.

$$M_5 = (M_D, M_{\bar{D}}), \;\; M_{24} = (M_\Psi, M_{\bar{\Psi}}, M_\Phi, M_{\bar{\Phi}})$$

Some assumptions and notations:

- masses M_5, M_{24} are slightly lower M_{GUT};
- M_0 – a common scale of squarks and sleptons;
- M_H – a common scale of all (heavy) Higgs bosons except the lightest one – m_h is conserved near EW scale

In this form one-loop RG equations depend on separated mass scales

$$\underline{\alpha_1^{-1}(2M_{GUT})} = \alpha_1^{-1}(M_Z) - \frac{103}{60\pi}\ln 2 + \frac{1}{2\pi}\Bigg(-7\ln M_{GUT} + \frac{4}{15}\ln M_D + \frac{2}{15}\ln M_{\tilde D}$$

$$+\frac{11}{10}\ln M_{\tilde q} + \frac{9}{10}\ln M_{\tilde l} + \frac{2}{5}\ln \mu + \frac{1}{10}\ln M_H + \frac{17}{30}\ln M_t + \frac{53}{15}\ln M_Z\Bigg),$$

$$\underline{\alpha_2^{-1}(2M_{GUT})} = \alpha_2^{-1}(M_Z) - \frac{7}{4\pi}\ln 2 + \frac{1}{2\pi}\Bigg(-3\ln M_{GUT} + \frac{4}{3}\ln M_{\tilde\Phi} + \frac{2}{3}\ln M_{\Phi}$$

$$+\frac{3}{2}\ln M_{\tilde q} + \frac{1}{2}\ln M_{\tilde l} + \frac{4}{3}\ln M_{\tilde W} + \frac{2}{3}\ln \mu + \frac{1}{6}\ln M_H + \frac{1}{2}\ln M_t - \frac{11}{3}\ln M_Z\Bigg),$$

$$\underline{\alpha_3^{-1}(2M_{GUT})} = \alpha_3^{-1}(M_Z) + \frac{23}{6\pi}\ln 2 + \frac{1}{2\pi}\Big(-\ln M_{GUT} + 2\ln M_{\tilde\Psi} + \ln M_{\Psi}$$

$$+\frac{2}{3}\ln M_D + \frac{1}{3}\ln M_{\tilde D} + 2\ln M_{\tilde q} + 2\ln M_{\tilde g} + \frac{2}{3}\ln M_t - \frac{23}{3}\ln M_Z\Bigg).$$

Let's use an effective parameters as ratios of scales:

$$k_1 = K_{\tilde{q}\tilde{l}}^{-1/12} K_{GUT1}^{1/3} \equiv \left(\frac{M_{\tilde{l}}}{M_{\tilde{q}}}\right)^{1/12} \left(\frac{M_{GUT}}{M'_{GUT}}\right)^{1/3}$$

$$k_2 = K_{Ht}^{-1/4} K_{\tilde{q}\tilde{l}}^{1/4} K_{\tilde{g}\tilde{W}}^{5/2} K_{GUT2}^{-1} \equiv \left(\frac{M_{top}}{M_H}\right)^{1/4} \left(\frac{M_{\tilde{q}}}{M_{\tilde{l}}}\right)^{1/4} \left(\frac{M_{\tilde{g}}}{M_{\tilde{W}}}\right)^{5/2} \left(\frac{M''_{GUT}}{M_{GUT}}\right)$$

$$M'_{1/2} \equiv (M_{\tilde{W}} M_{\tilde{g}})^{1/2}, \qquad M'_{GUT} \equiv (M_{\tilde{\Psi}} M_{\tilde{\Phi}})^{1/3} (M_{\Psi} M_{\Phi})^{1/6} \leq M_{GUT}.$$

$$M''_{GUT} \equiv \frac{(M_{\tilde{\Psi}}^2 M_{\Psi})^{7/6} (M_{\tilde{D}}^2 M_{D})^{1/2}}{(M_{\tilde{\Phi}}^2 M_{\Phi})^{4/3}} \leq M_{GUT},$$

$$A = \exp\left(\frac{\pi}{18}(5\alpha_1^{-1}(M_Z) - 3\alpha_2^{-1}(M_Z) - 2\alpha_3^{-1}(M_Z)) - \frac{11}{18}\ln 2\right) = (1.57 \times^{1.09}_{0.92}) \cdot 10^{14},$$

$$B = \exp\left(\frac{\pi}{3}(5\alpha_1^{-1}(M_Z) - 12\alpha_2^{-1}(M_Z) + 7\alpha_3^{-1}(M_Z)) + \frac{157}{12}\ln 2\right) = (2.0 \times^{0.15}_{6.56}) \cdot 10^{3}.$$

Equaling coupling constants at M_{GUT}, with dimensionless parameters in a reasonable intervals, two functions occur

$$M'_{1/2}(M_{GUT}) = (Ak_1)^{9/2} M_Z^{11/2} \times M_{GUT}^{-9/2}, \qquad \mu(M_{GUT}) = \frac{Bk_2}{(Ak_1)^{3/2} M_Z^{1/2}} \times M_{GUT}^{3/2}.$$

K_{GUT1}, K_{GUT2} - are beyond the theoretical control, they can be taken from [1,10]

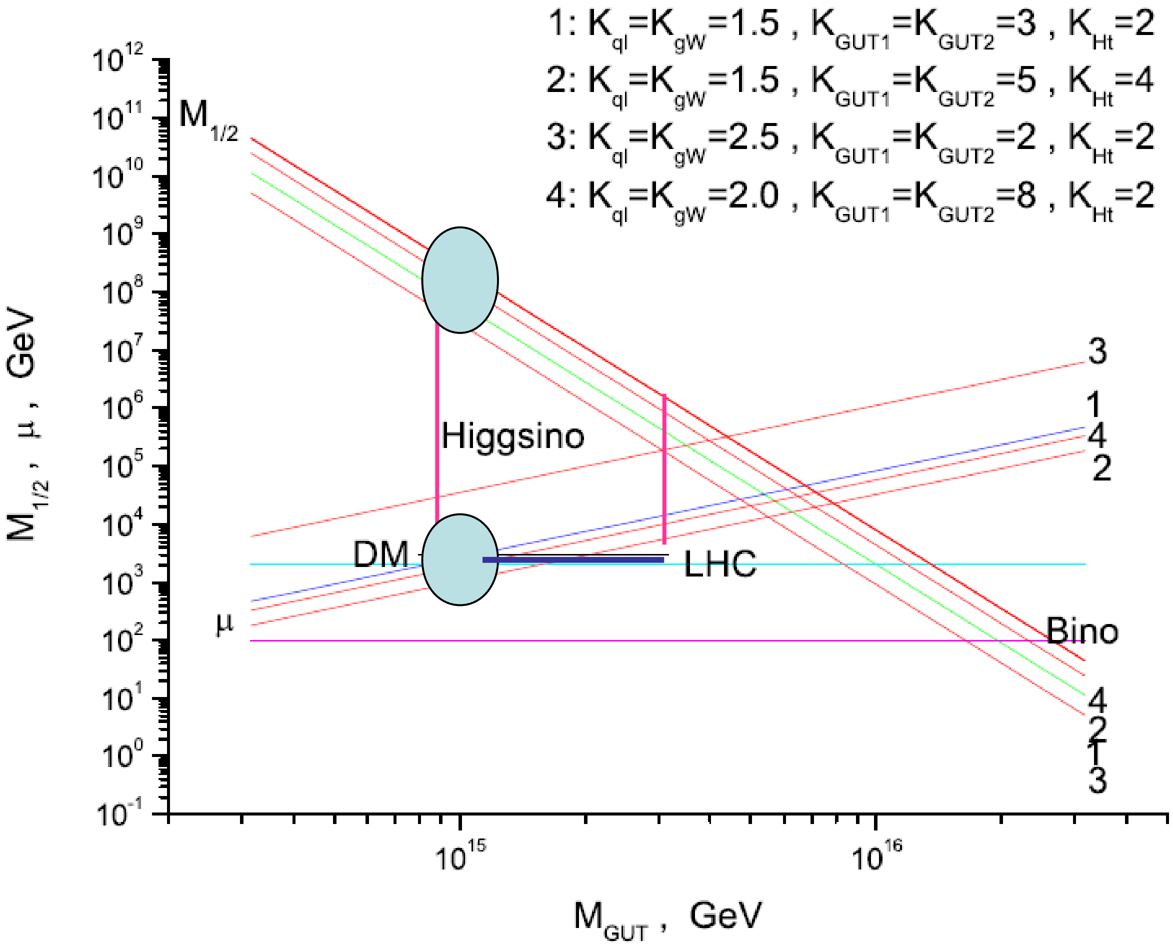
$2 \leq K_{Ht} \leq 10$ - it is supposed for the numerical analysis

$1.5 \leq K_{\tilde{q}\tilde{l}} \simeq K_{\tilde{g}\tilde{W}} \leq 2.5$ - it is used in numerical analysis, so we suppose **a heavy gluino** and **close scales for squarks and leptons**

From the system of RG equations we get two equations for the effective gaugino and μ scales; other characteristic scales arise as dimensionless ratios only.

J.Hisano, H.Murayama, T.Yanagida (1992)
J.Bagger,K.Matchev, D.Pierce (1995)
V.Beylin, G.Vereshkov, V.Kuksa (2001)

Graphically, these equations give the following picture for some values of parameters



- Assuming the ratio of $M_{squark}/M_{slepton}$ ~O(1-10), it doesn't change the hierarchy radically

Two possible classes of hierarchies

$$|\mu| \gg M_{1/2} \gtrsim M_{EW}$$

$$M_{1/2} \gg |\mu| > M_{EW}$$

"High μ"- subscenarios

$$(a) \quad M_0 \gg |\mu| \gg M_{1/2} \gtrsim M_{EW},$$
$$(b) \quad M_0 \sim |\mu| \gg M_{1/2} \gtrsim M_{EW},$$
$$(c) \quad |\mu| \gg M_0 \gg M_{1/2} \gtrsim M_{EW},$$
$$(d) \quad |\mu| \gg M_0 \sim M_{1/2} \gtrsim M_{EW}.$$

"Low μ"-subscenarios

$$(e) \quad M_0 \gtrsim M_{1/2} \gg |\mu| > M_{EW},$$
$$(f) \quad M_{1/2} \gg M_0 \sim |\mu| > M_{EW},$$
$$(g) \quad M_{1/2} \gg M_0 \gg |\mu| > M_{EW},$$
$$(h) \quad M_{1/2} \gg |\mu| > M_0 \gtrsim M_{EW}.$$

Here we consider the "Split Higgsino scenario" only

$$M_0 \gtrsim M_{1/2} \gg |\mu| > M_{EW}$$

Parameters values which select the scenario

$$M_{GUT} = (1-2)\cdot 10^{15}\,\mathrm{GeV}$$

$$M_{1/2} \sim (0.1-2.5)\cdot 10^{8}\,\mathrm{GeV}$$

Higgsino masses, μ – in the region (1 – 10) TeV

$$K_{GUT1},\ K_{GUT2} \sim 5-8$$

Effect of threshold corrections (near GUT scales) is essentially important!

If $M_{24},\ M_5$ are equal to M_{GUT} ⟶ “ordinary” one-loop RG equations

Two lowest neutralino (Majorana Higgsino-like states) $\chi^0_{1,2}$

and the light chargino $\chi^\pm_1$ have masses near μ - scale;

in the pure Higgsino limit at the tree level

$$M_{\chi^0_1} \simeq \mu - \frac{M_Z^2(1+\sin 2\beta)}{2M_1M_2}(M_1\cos^2\theta_W + M_2\sin^2\theta_W),$$

$$M_{\chi^0_2} \simeq \mu + \frac{M_Z^2(1-\sin 2\beta)}{2M_1M_2}(M_1\cos^2\theta_W + M_2\sin^2\theta_W),$$

$$M_{\chi^\pm_1} \simeq \mu - \mu\frac{M_W^2}{M_2^2} - M_W\frac{M_W}{M_2}\sin 2\beta.$$

The lowest states are degenerated; other neutralino and chargino states are near

high SUSY breaking scale $M_{SUSY} \sim M_1 \sim M_2 \sim (0.1 - 2.5)\cdot 10^8$ GeV

Does the Split Higgsino scenario describe the DM physics? What about relic abundance?

Annihilation and coannihilation channels, α,β=1,2 – the LSP and NLSP states, index "c" - chargino

$$\chi_\alpha \bar{\chi}_\beta \to ZZ, \quad W^+W^-$$
$$\chi_c \bar{\chi}_c \to ZZ, \quad W^+W^-, \quad f\bar{f}, \quad \gamma\gamma, \quad Zh$$
$$\chi_\alpha \bar{\chi}_c \to ZW, \quad l\nu_l, \quad q_i\bar{q}_j, \quad \gamma W, \quad Wh,$$

Effective cross-section

$$< (\sigma v)_{ann} >= \frac{g_2^4}{128\,\pi M_\chi^2} \cdot \left\{ 27 + 4(3+5t_W^4)(c_W^4+s_W^4) - kc_W^2 + \frac{k^2}{4}(c_W^4+s_W^4) + \frac{1}{2\,c_W^4}\left[1+\frac{1}{8}(c_W^4+s_W^4)+(c_W^2-s_W^2)^4\right] + \frac{1}{2\,c_W^2}\left[s_W^4\left(10-\frac{1}{k}\right)+2kc_W^2\right]\right\},$$

$t_W = \tan\Theta_W$, $s_W = \sin\Theta_W$, $c_W = \cos\Theta_W$ and $k = M_Z^2/M_W^2$

From the estimation $x_f = M_X / T_f \approx 20 - 25$

and via the standard procedure of relic calculations

See: J.Ellis, J.C.Hagelin, D.V.Nanopoulos, K.Olive, M.Srednicki (1989)
K.Griest, M.Kamionkowski, M.C.Turner (1990)
K.Griest, D.Seckel (1991)
G.Jungman, M.kamionkowski, K.Griest (1996)
J.Edsjo, P.Gondolo (1990)
See also: V.A.Bednyakov, H.V.Klapdor-Kleingrothaus, E.Zaiti (2002)

From the comparison with the relic data

M_X = 1.2 – 1.6 TeV

In agreement with results of

N.Arkani-Hamed, S.Dimopoulos (2004,2005)
N.Arkani-Hamed, A.Delgado, G.F.Giudice (2006)
K.Cheng, J.Song (2005)

Split SUSY scenarios can explain the modern DM data, saving the SUSY ideas. At the same time, scenarios of such type can be nearly "invisible" at the LHC –

the SUSY can exist but it is hidden at the EW scale!

The only following direct signals can be detected at the collider:

- creation and decay of chargino
- creation and decay of the NLSP

Non-direct Split Higgsino signals:

- diffuse gamma-flux from the Galactic halo
- neutralino-nucleon scattering
- high-energy photons from neutralino annihilation

Experimental manifestations of the Split Higgsino scenario crucially depend on the mass splitting parameters

$$\delta m = M_{\chi_2} - M_{\chi_1} \text{ and } \delta m^- = M_{\tilde{H}} - M_{\chi_1}$$

Approximately, tree level mass splitting are

$$\delta m \approx M_Z^2/M, \quad \delta m \approx 2\delta m^-$$

Here

$$M \sim M_{1,2} \text{ and we suppose } \tan\beta \gg 1$$

Due to main one-loop contributions $\delta m^{-} \simeq$ 350 MeV

Note that this tree mass splitting is no more than 10 MeV

See:
G.Vereshkov, V.Kuksa, V.Beylin, R.Pasechnik (2004),
K.Cheng, C.-W.Chiang, J.Song (2005)

Despite the fact that all superscalars are heavy in the scenario, due to unknown structure of squark scales it occurs a dominant one-loop contribution

$$\delta m \simeq 2G_t^2 m_t \sin(2\theta_t) \cdot \ln(\frac{m_{\tilde{t}_1}^2}{m_{\tilde{t}_2}^2})$$

$$G_t = \sqrt{\frac{3G_F}{8\sqrt{2}\pi^2}} \frac{m_t}{\sin\beta}$$

See G.F.Giudice, A.Pomarol (1996),
C.H.Chen, M.Drees, J.F.Gunion (1997,1999) and others

So, it is possible to get for the LSP-NLSP splitting an estimation:

$$\delta m \simeq 5 \log(m^2_{\tilde{t}_1}/m^2_{\tilde{t}_2}) \ \mathrm{GeV}$$

Then, if the ratio

$m_{\tilde{t}_1}/m_{\tilde{t}_2}$ ~ 2-3

the mass splitting
(induced by one-loop corrections)
can be an order of (1-10)GeV!

We consider manifestations of the scenario only for the case

$$\delta m, \ \delta m^- \lesssim 1 - 2 \ \mathrm{GeV}.$$

At the LHC, this scenario can manifest itself by virtue of the chargino-neutralino pair production (it depends on the mass splittings)

For all possible combinations $(\chi_1\chi_2,\, \chi_1\tilde{H},\, \chi_2\tilde{H},\, \tilde{H}\bar{\tilde{H}})$

cross-sections were calculated in the analogous scenario (K.Cheng, C.-W.Chiang, J.Song (2005, 2006));

for μ = 0.8 – 1.4 TeV

cross sections are an order of

$10^{-3} - 10^{-5}$ pb

We consider chargino and the NLSP decay properties and possible signatures at the collider

Chargino decay modes:

$\tilde{H}^- \to \chi_1 l^- \bar{\nu}_l, \chi_1 \pi^-, \chi_1 \pi^- \pi^0$, where $l = e, \mu$ and χ_1 is LSP.

Three-pion decay mode is negligible for the small mass splitting $\delta m^- = M_{\tilde{H}} - M_{\chi_1}$

Semi-leptonic decay channel

$$\Gamma_l = \frac{G_F^2}{96\pi^3 M_{\tilde{H}}} \int_{M_l^2}^{(\delta m^-)^2} dq^2 \bar{\lambda}(q, M_{\chi_1}; M_{\tilde{H}}) \bar{\lambda}(0, M_l; q)[q^2 \bar{\lambda}^2(0, M_l; q)(M_{\tilde{H}}^2 + M_{\chi_1}^2 - 4M_{\tilde{H}} M_{\chi_1} - q^2) + (1 + \frac{M_l^2}{q^2} - 2\frac{M_l^4}{q^4})((M_{\tilde{H}}^2 - M_{\chi_1}^2)^2 - 2M_{\tilde{H}} M_{\chi_1} q^2 - q^4)],$$

For l=e
due to small electron mass

$$\Gamma_e \approx \frac{G_F^2}{192\pi^3} (\delta m^-)^5$$

One-pion decay channel

$$\Gamma_\pi \simeq \frac{G_F^2}{4\pi}|U_{ud}|^2 f_\pi^2 (\delta m^-)^2 M_{\tilde{H}} \sqrt{1 - 2\frac{M_\pi^2 + M_{\chi_1}^2}{M_{\tilde{H}}^2} + \frac{(M_\pi^2 - M_{\chi_1}^2)^2}{M_{\tilde{H}}^4}}$$

Two-pion decay channel

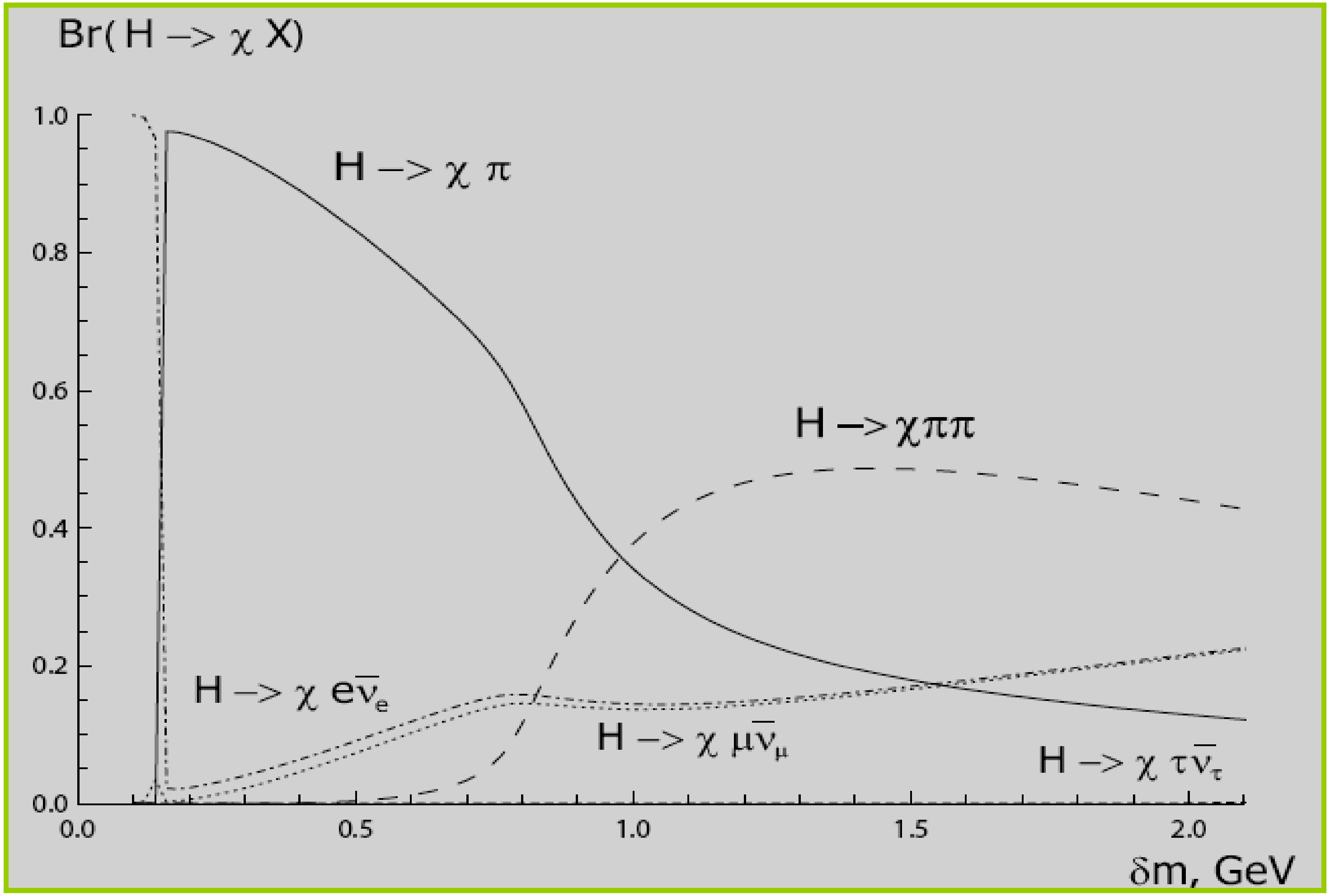
$$\Gamma_{2\pi} = \frac{G_F^2 |U_{ud}|^2}{64\pi^3 M_{\tilde{H}}} \int_{q_1^2}^{q_2^2} |F_\pi(q^2)|^2 \sqrt{1 - 4\frac{M_\pi^2}{q^2}} f(q^2) \lambda(M_{\chi_1}, q; M_{\tilde{H}})\, dq^2$$

Due to inequalities $M_\pi / M_{\tilde{H}} \ll 1,\ \delta m^- / M_{\tilde{H}} \ll 1,$

$$\Gamma_{2\pi} \simeq \frac{G_F^2 |U_{ud}|^2}{48\pi^3} \int_{q_1^2}^{q_2^2} |F_\pi(q^2)|^2 \left(1 - \frac{4M_\pi^2}{q^2}\right)^{3/2} ((\delta m^-)^2 - q^2)^{3/2}\, dq^2$$

Because of small mass splitting, hadronic decay modes work in a soft regime (final states with K are suppressed)

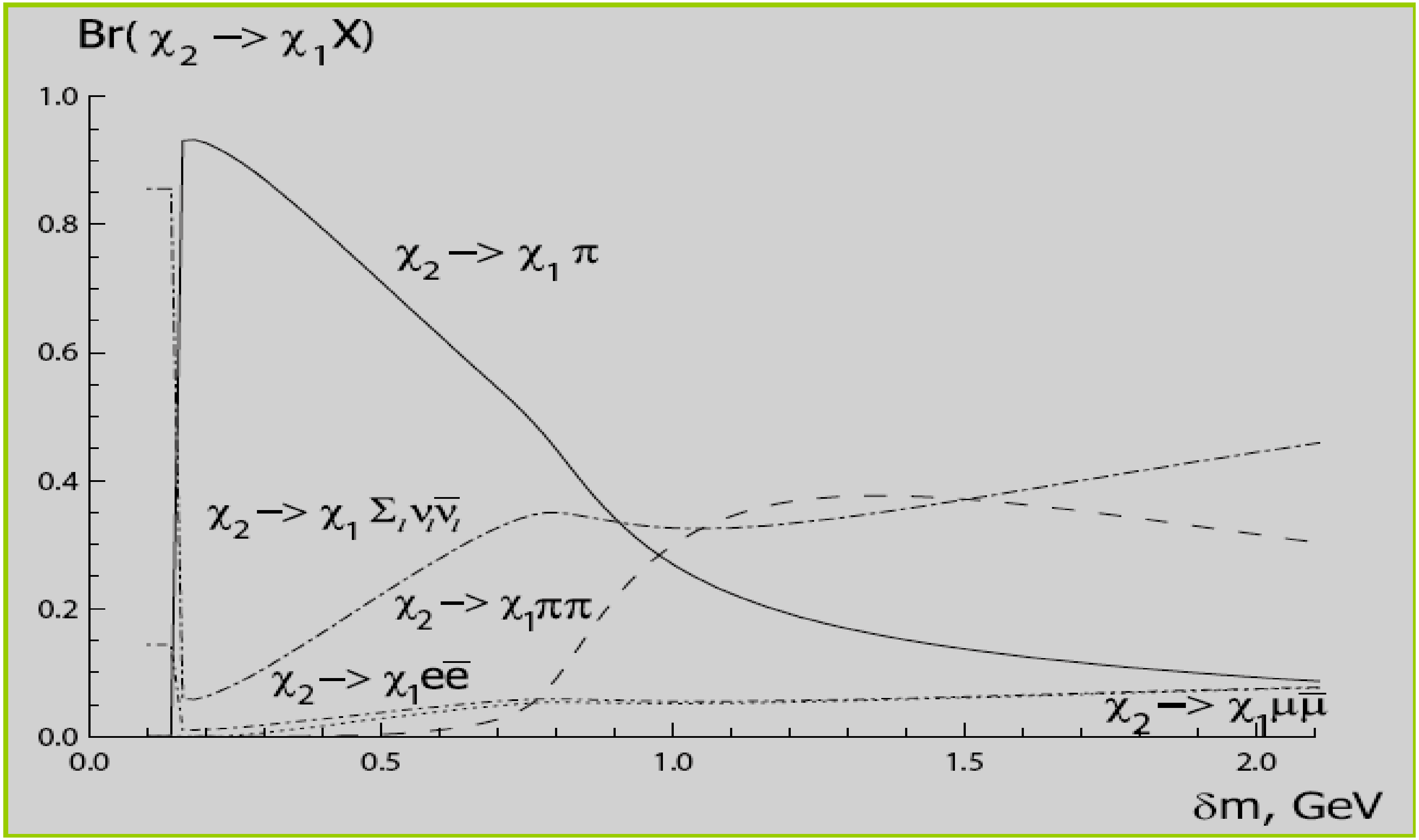
Neglecting other decay channels for this mass splitting



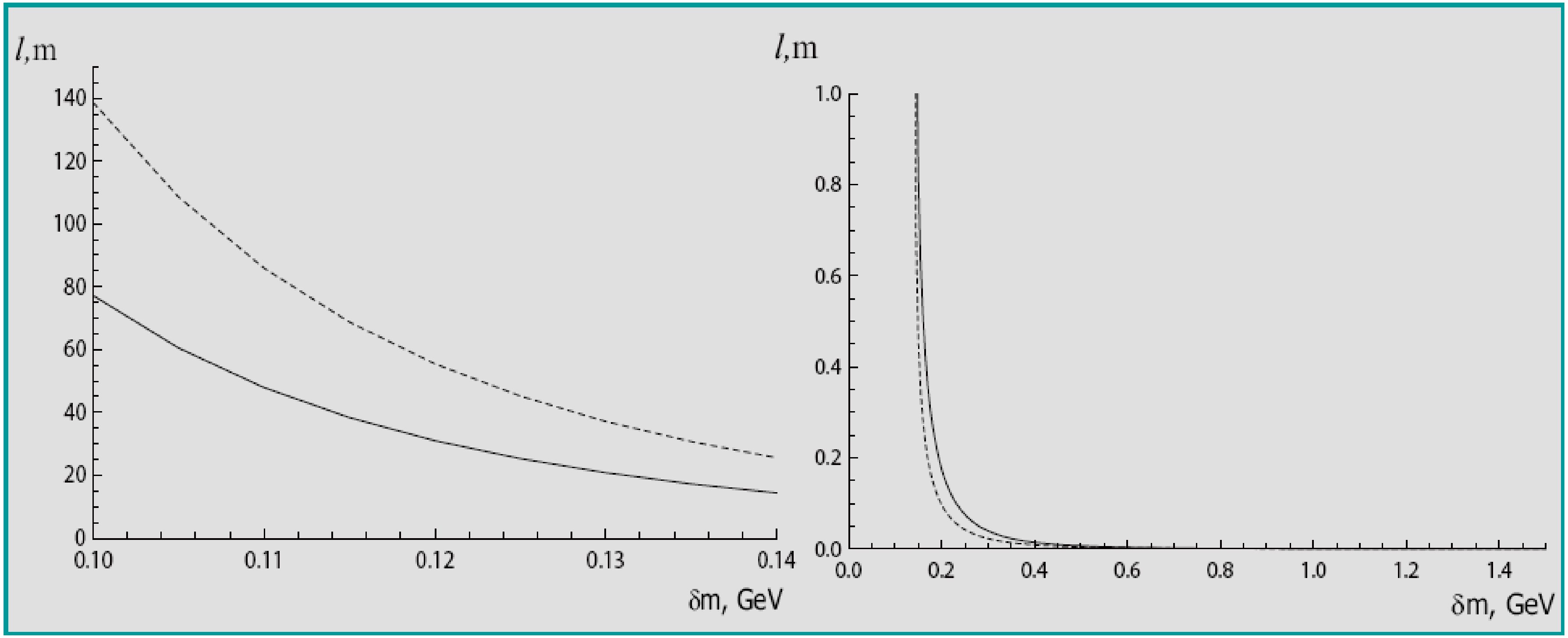
Branching ratios for chargino decays as the mass splitting functions

Neutralino (the NLSP) decay modes:

$\chi_2 \to \chi_1 f \bar{f},$ $f = e, \mu, \nu$ and $\chi_2 \to \chi_1 \pi^0$ $\chi_2 \to \chi_1 \pi^+ \pi^-$



Branching ratios for the NLSP decays as the mass splitting functions



The range of neutralino (solid line) and chargino (dashed line) as function of mass splitting.

Here l=cτ

For small mass splitting
chargino decays beyond the detector,
i.e. it can produce a visible track

For mass splittings ≥ 0.2 GeV chargino and neutralino decays
can be characterized by (appreciable) displaced vertices

This SUSY scenario is most simple, it produces a minimal number of experimental manifestations at the LHC – due to degenerated chargino and NLSP decays only.

Heavy gluino, squarks and sleptons elude detection at the LHC

1. If $\delta m^- \lesssim m_\pi$ there are no signals from $\tilde{H} \to l\nu\chi_1$

If tree relation $\delta m \approx 2\delta m^-$ takes place,

the NLSP decay products (leptons) are also too soft.

SUSY exists, but
it cannot be observed at the LHC scale

If for the case δm becomes larger than pion mass,
the channel with the soft pion is opened – but it is hardly detectable!

Even if δm ~ 1 GeV, lepton pair signals remain practically unobservable.

Here are a large fractions of neutrino and two-pion channels.

It is unlikely to have so large δm to mimic dilepton events induced by the gluino, $l^+l^- + \mathrm{jets} + \mathrm{E_T}$

2. If $m_\pi < \delta m^-, \delta m \lesssim 1\,\mathrm{GeV}$ chargino decays mainly

through one- and two-pion channels, semi-leptonic fraction comes up to 0.15

The second neutralino decays mainly

through one- and two-pion channels, leptonic fraction comes up to 0.4

(more than 0.3 – neutrino channel).

All final products are soft, their observation is problematic.

We don’t consider γ-modes and don’t assume large mass splittings (up to 10 GeV)

For mass splittings no more than 1-2 GeV, mostly pion modes and neutrino modes (with the missing energy) can be seen together with the chargino tracks.

Final leptons and “jets” are too soft for the detection.

Regime of observable jets and leptons is beyond the experiment limits

- Signals from (degenerate) neutralino and chargino decays were analyzed for masses ~ O(100 GeV)
- See:

J.F.Gunion, S.Mrenna (2000)

C.H.Chen, M.Drees, J.F.Gunion (1997)

See also K.Cheung, C.W.Chiang, J.Song (2006) – only heavy chargino decays

If $1-2 \text{ GeV} < \delta m^-, \delta m < 4-5 \text{ GeV}$

$\tilde{H}\tilde{H}$ channel:
two-lepton signal (from semi-leptonic mode)
jets+ missing energy
jets+missing energy

$\chi_1\tilde{H}$ channel:
jets+ missing energy
lepton+missing energy

$\chi_1\chi_2$ channel:
jets+ missing energy
neutrino (missing energy) mode

$\chi_2\tilde{H}$ channel:
jets+ missing energy
lepton+missing energy
“tri-lepton” signal

Neutralino-nucleon scattering

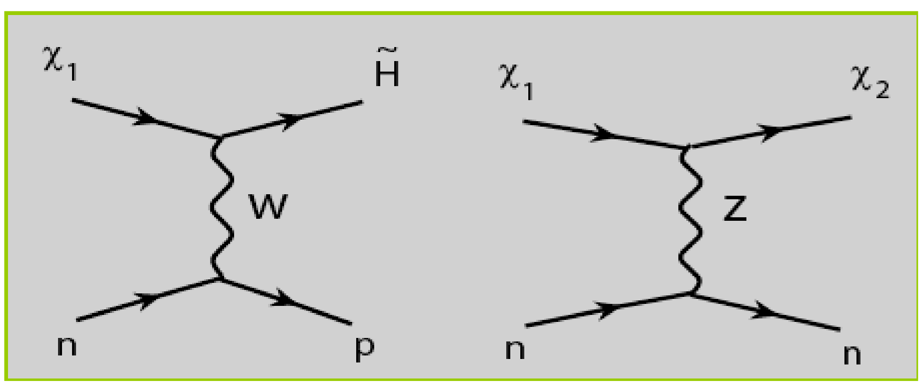
- Due to connection between mass sign, parity and neutralino-boson interaction

$Z_\mu \bar{\chi}_i \gamma^\mu \gamma_5 \chi_k$ is suppressed by the mixing with heavy neutralino states

$Z_\mu \bar{\chi}_2 \gamma^\mu \chi_1$ dominant contribution

For detail, see V.Beylin, V.Kuksa, G.Vereshkov, R.Pasechnik (EJPC, 2008)

Charge exchange process and the NLSP creation



Relic neutralino – cannot penetrate the threshold

High-energy neutralino – can be produced in cosmic rays or in decays of an exotic M_X particles

(see, for example, S.Bornhauser, M.Drees (2006))

The charge exchange process amplitude

$$M = \frac{g^2}{4\sqrt{2}M_W^2}\bar{\chi}_1\gamma^\mu \tilde{H} \cdot \bar{n}\gamma_\mu [c_V(Q^2) - c_A(Q^2)\gamma_5]p$$

For $Q^2 \lesssim 2\,\mathrm{GeV}$

$$c_V(Q^2) = c_V(0)(1+Q^2/m_V^2)^{-2}$$

Approximate cross-section for $\chi_1 n \to \tilde{H} p$

(the high-energy neutralino scattering)

$$\sigma(s) \approx \frac{G_F^2}{16\pi} f(s) \int_{-1}^{1} [c_V^2(Q^2) + c_A^2(Q^2)] F(x) dx,$$

where

$$f(s) = \frac{s(1 - M_{\tilde{H}}^2/s)}{[(1 - \frac{M_\chi^2}{s})^2 - 2\frac{M_N^2 M_\chi^2}{s^2}]^{1/2}}, \quad F(x,s) = b + \frac{1}{4}(a_1 + bx)(a_2 + bx) -$$

$$\frac{M_\chi M_{\tilde{H}}}{s} b(1-x); \quad Q^2 = \frac{s}{2} b(1-x), \quad a_{1,2} = 1 \pm \frac{M_\chi^2 - M_{\tilde{H}}^2}{s} - \frac{M_\chi^2 M_{\tilde{H}}^2}{s^2};$$

$$b = (1 - \frac{M_\chi^2}{s})(1 - \frac{M_{\tilde{H}}^2}{s}), \quad x = \cos\theta.$$

$\sigma \approx 2 - 3$ fb for δm^- = 0.1 – 1 GeV, $s \sim M_\chi^2$

The cross-section decreases when the mass splitting and/or E^{thr} increase

Analogously for the neutral process $\chi_1 N \to \chi_2 N'$

Resume

- Split Higgsino scenario is resulted from the one-loop RG evolution of gauge couplings;
- The scenario contains the LSP, which is suitable as the DM carrier;
- Features of the mass spectrum define the SUSY detection in the collider experiment;
- The scattering of high-energy LSP off nucleons can produce the nearest SUSY states;
- Results on the positron excess (from PAMELA, ATIC and others space detectors) can be explained in the scenario too (with a reasonable boost factor – cross-section of the LSP annihilation into WW or ZZ is not so large, but it is sufficient);
- The scenario can be useful to understand possible absence of obvious SUSY signals at the LHC (which are promised by the MSSM and the “natural” mass spectrum in the TeV region).

The SUSY can live far from the EW scale and it can be invisible at the LHC.

So, the scenarios of that type have a “HIDDEN SUSY” from the experiment point of view.