SPLIT SUPERSYMMETRY

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- Motivazioni per Split Supersymmetry
- Conseguenze osservative di Split Supersymmetry

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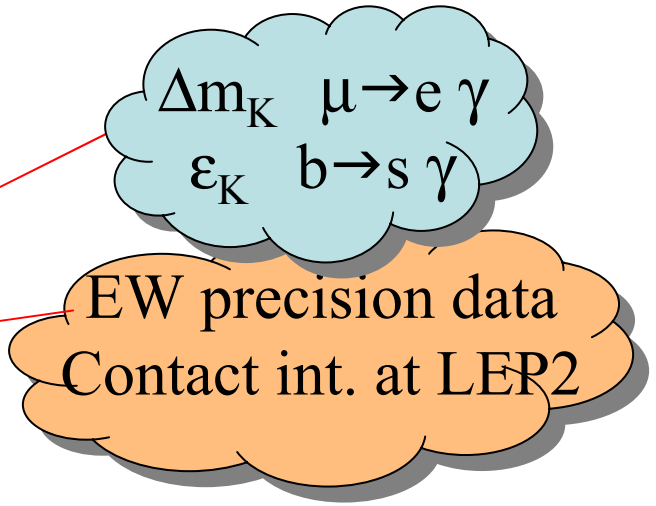
$M_W << M_{Pl}$ ⇨ nuova fisica a $\Lambda \sim$ TeV

Problema del sapore ⇨ $\Lambda > 10^{3-4}$ TeV

Piccola gerarchia ⇨ $\Lambda > 5–10$ TeV

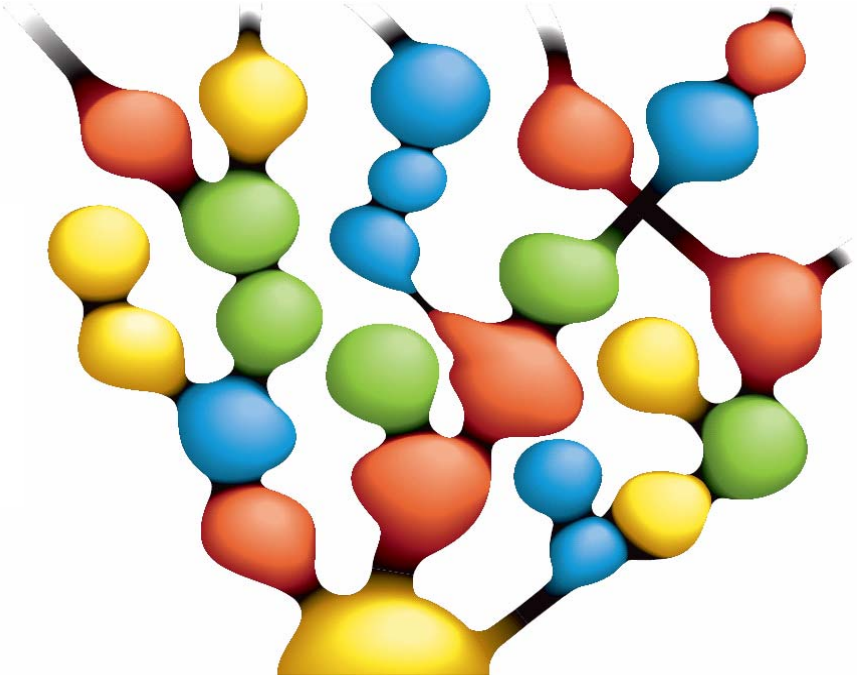


$\Lambda_{CC} << M_{Pl}$ ⇨ nuova fisica a $\Lambda \sim 10^{-3}$ eV

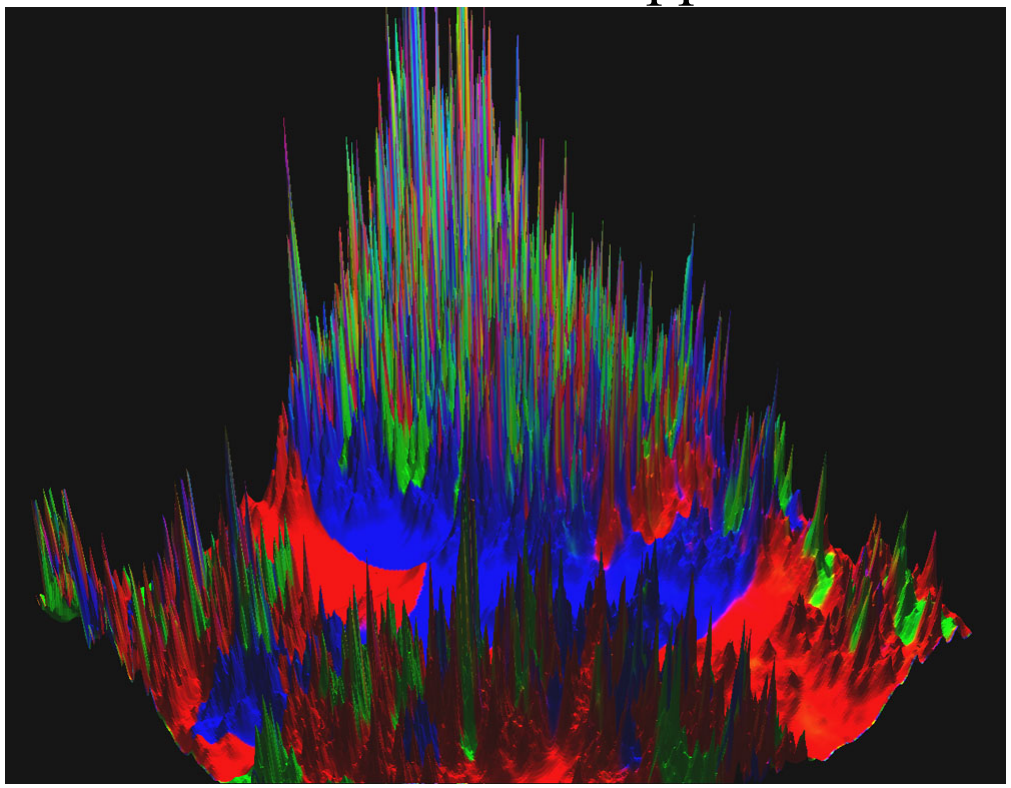
Gravità modificata a questa scala oppure
fallimento del criterio di naturalezza

Riconsideriamo il problema della gerarchia:
la scala elettrodebole è determinata dalla
dinamica o dalla statistica ?

Idea del multiverso emerge dalla teoria dell'inflazione



Landscape delle teorie di stringa: 10^{100} vuoti che corrispondono a diverse costanti di accoppiamento



Come la vita si è sviluppata su un pianeta con acqua liquida, con massa tale da trattenere l'atmosfera, con campo magnetico tale da proteggere dal vento solare, in un'orbita galattica con limitato impatto di comete, …così il nostro universo si è sviluppato in un vuoto con $\Lambda_{CC} \sim 10^{-3}$ eV , $v \sim 10^{2}$ GeV

Abandon hierarchy problem (speculations on probability distributions of theories) and use only observational hints

Gauge-coupling unification: motivated by theory that addresses fundamental structure of SM and by measurements on α_i

Dark matter: connection between weak scale and new particle masses

$$\Omega_{\rm rel} h^2 \approx \frac{0.1\,{\rm pb}}{\langle \sigma v \rangle}$$

Proposal of SPLIT SUPERSYMMETRY: retain at the weak scale only gauginos, higgsinos and one Higgs boson (squarks, sleptons and extra Higgs at the scale $\tilde{m}$)

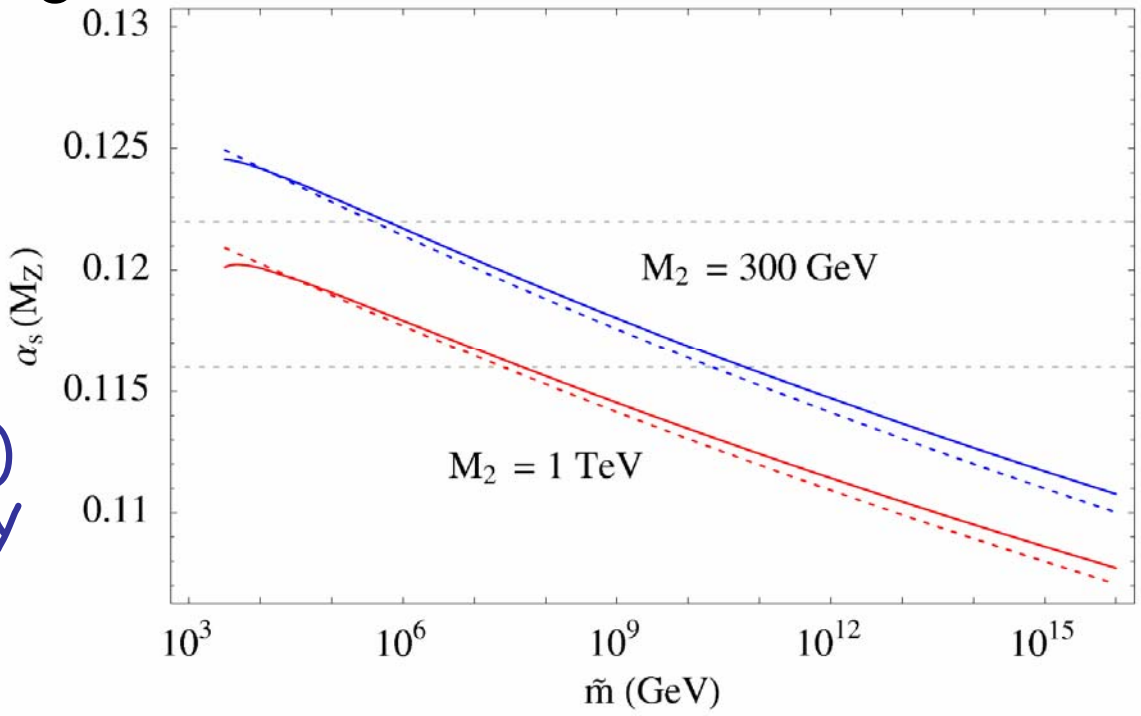
Eliminate :

- Excessive flavour and CP violation
- Fast dim-5 proton decay
- Tight constraints on the Higgs mass

Retain :

- DM & gauge-coupling unification

Gauge-coupling unification as successful (or better) than in ordinary SUSY



Not unique solution, however…

• Minimality: search for unification with single threshold, only fermions in real reps, and 10^{15} GeV < M_{GUT} < 10^{19} GeV ⇨ SpS has the minimal field content consistent with gauge-coupling unification and DM

• Splitting of GUT irreps: in SpS no need for new split reps either than SM gauge and Higgs

• Light particles: R-symmetry protects fermion masses

• Existence and stability of DM: R-parity makes χ stable

• Instability of coloured particles: coloured particles are necessary, but they decay either by mixing with quarks (FCNC!) or by interactions with scale < 10^{13} GeV

SpS not unique, but it has all the necessary features built in

Why Supersymmetry?

$$X = 1 + \theta^2 \tilde{m}$$

$$\int d^4\theta\, X^* X\, Q^* Q \to \tilde{m}_Q^2 = \tilde{m}^2 \qquad \int d^2\theta\, X\, W_\alpha W_\alpha \to M_{\tilde{g}} = \tilde{m}$$

$$\int d^4\theta\, X^* X\, H_1 H_2 \to B_\mu = \tilde{m}^2 \qquad \int d^2\theta\, X\, Q^3 \to A = \tilde{m}$$

$$\int d^4\theta\, X^*\, H_1 H_2 \to \mu = \tilde{m}$$

R - invariant soft terms (choose $\mathrm{R}[H_1 H_2] = 0$ so that $\int d^2\theta\, H_1 H_2$ forbidden)

R - violating soft terms ($\mathrm{R}[X] = 0$, R - symmetry broken by F_X)

- R-symmetry "splits" the spectrum ($M_{\tilde{g}}$ and μ mix through renorm.)
- R-invariant ⇨ dim = 2 R-violating ⇨ dim = 3

Split Supersymmetry determined by susy-breaking pattern

$$\text{D-breaking} \qquad Y = 1 + \theta^4 \tilde{m}^2$$

$$\int d^4\theta\, Y Q^* Q \to \tilde{m}_Q^2 = \tilde{m}^2 \qquad \int d^4\theta\, Y H_1 H_2 \to B_\mu = \tilde{m}^2$$

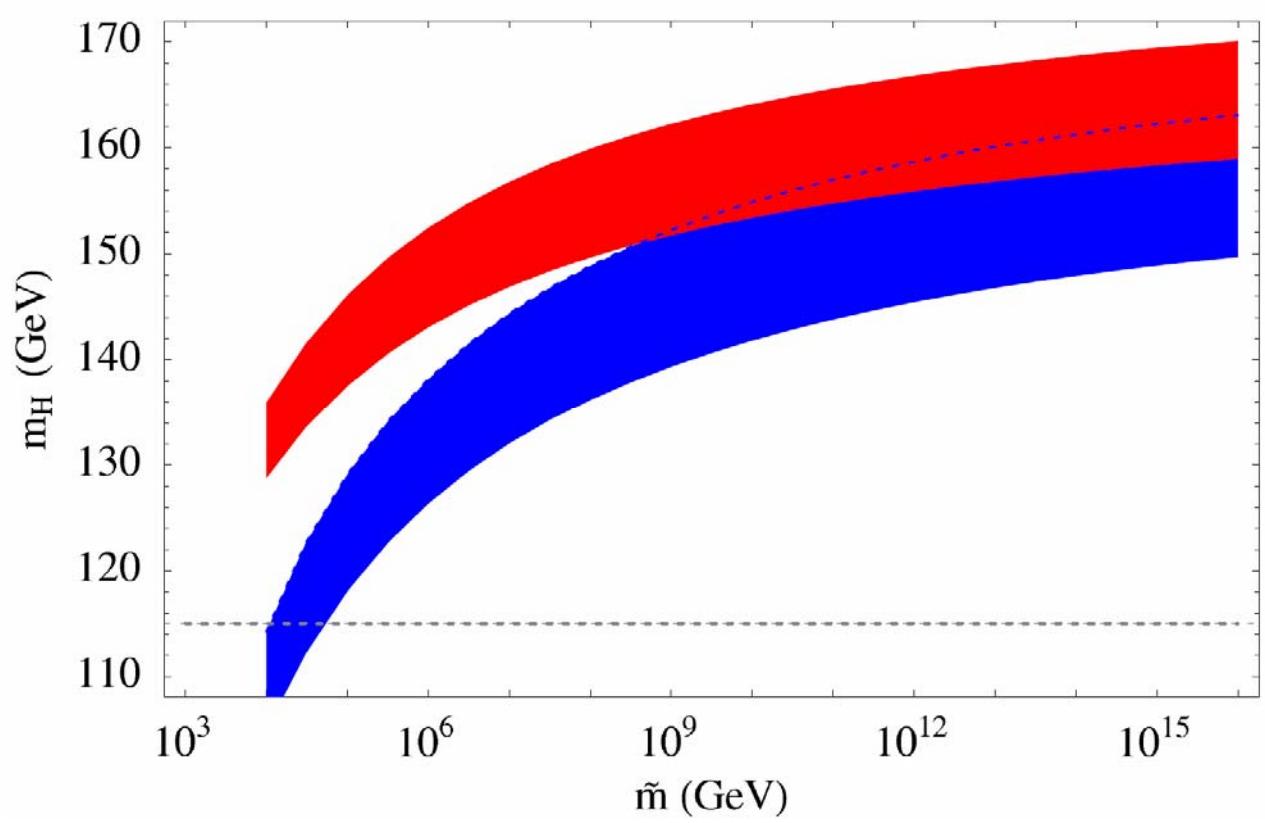
$$\text{Non renorm. operators} \qquad \frac{1}{M_*}\int d^4\theta\, Y W_\alpha W_\alpha \to M_{\tilde{g}} = \frac{\tilde{m}^2}{M_*}$$

$$\frac{1}{M_*}\int d^4\theta\, Y Q^3 \to A = \frac{\tilde{m}^2}{M_*} \qquad \frac{1}{M_*}\int d^4\theta\, Y D^2 (H_1 H_2) \to \mu = \frac{\tilde{m}^2}{M_*}$$

- Analogy: in SM, L not imposed but accidental. m_ν small, although L-breaking is O(1) in underlying theory
- In supergravity, μ not generated at $O(M_{Pl})$ but only $O(M_S^2/M_{Pl})$
- Here, $M_{\tilde{g}}$ and μ not generated at $O(\tilde{m})$ but only $O(\tilde{m}^2/M_*)$

OBSERVATIONAL CONSEQUENCES OF SPLIT SUPERSYMMETRY

- Only one Higgs boson with SM properties
- With respect to MSSM, larger log corrections to $\lambda = g^2$



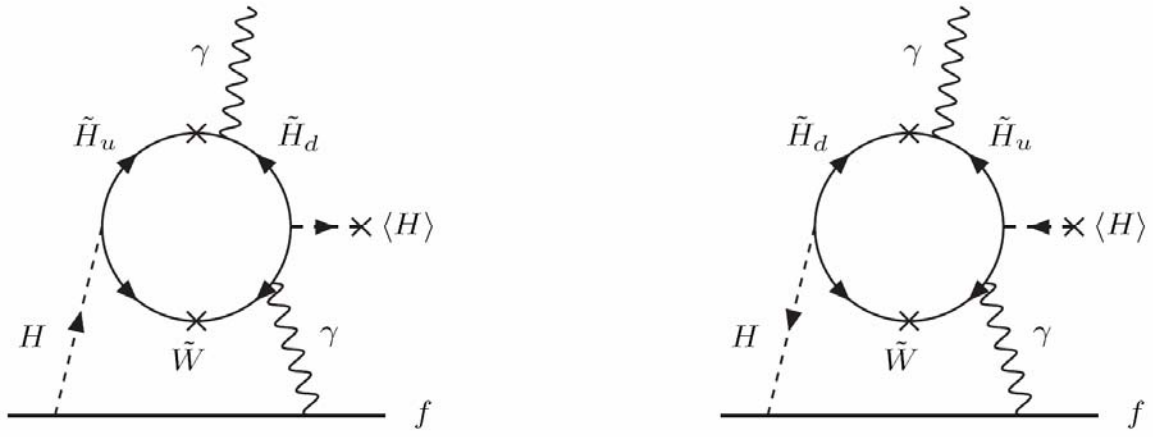
Heavy squarks and sleptons suppress flavour & CP violation, dim-5 proton decay

New source of flavour-diagonal CP violation remains

$$\mathcal{L} = \frac{M}{2}\tilde{W}\tilde{W} + \mu H_u H_d + \frac{\tilde{g}_u}{\sqrt{2}} H^* \tilde{W}\tilde{H}_u + \frac{\tilde{g}_d}{\sqrt{2}} H \tilde{W}\tilde{H}_d + \text{h.c.}$$

CP violation in $\mathrm{Im}\left(\tilde{g}_u^* \tilde{g}_d^* M\mu\right)$

Effects on SM matter at two loops: **EDM**

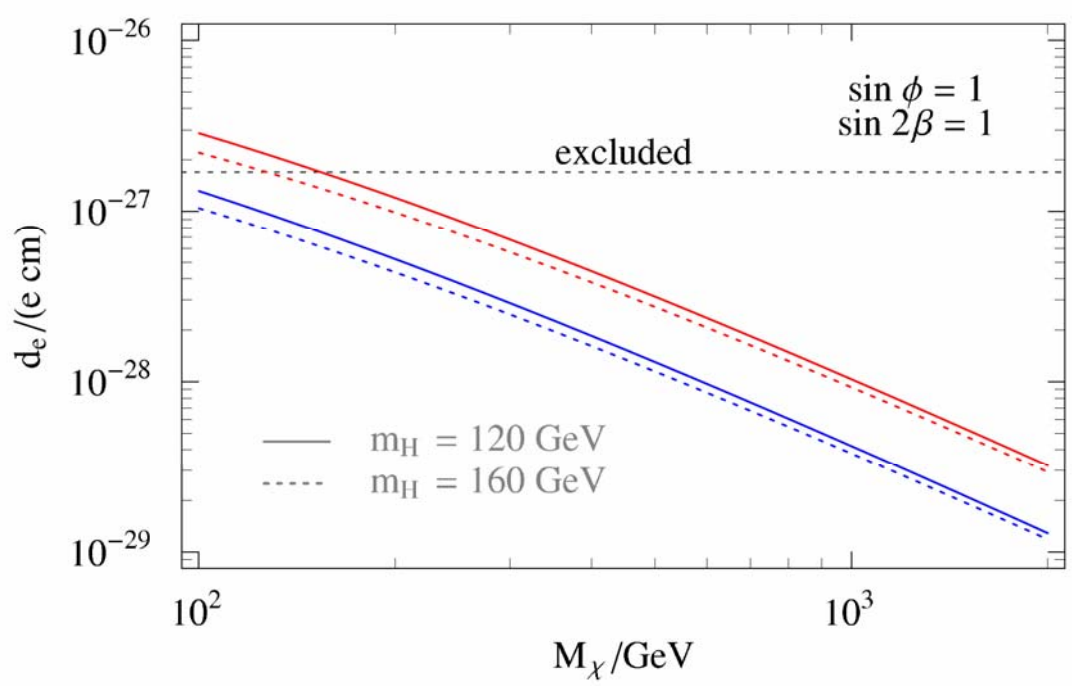


Eliminate phases in chargino mass matrix ⇨

$$\frac{e^2}{32\pi^2}\arg\left(\det \mathcal{M}_{\chi^+}\right) F_{\mu\nu}\tilde{F}^{\mu\nu} \qquad \mathcal{M}_{\chi^+} = \begin{pmatrix} M & \sqrt{2}M_W \tilde{g}_u/g \\ \sqrt{2}M_W \tilde{g}_d/g & \mu \end{pmatrix}$$

$$O_H = H^* H \; F_{\mu\nu}\tilde{F}^{\mu\nu}$$ mixes with EDM operator

$$\frac{d_f}{e} = -\frac{Q_f m_f \alpha}{16\pi^3}\,\mathrm{Im}\left(\frac{\tilde{g}_u \tilde{g}_d}{M\mu}\right)\log\frac{|M\mu|}{m_H^2}$$



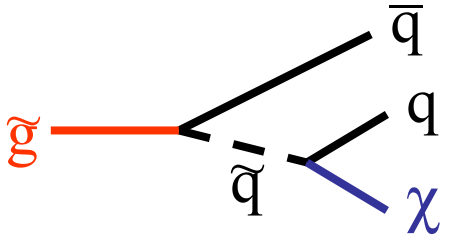
Present limit: $d_e < 1.7 \times 10^{-27}$ *e*cm at 95% CL (DeMille et al.)

Future: DeMille et al. (Yale) 10^{-29} *e*cm in 3 years and 10^{-31} *e*cm in 5 years.

Lamoreaux et al. (Los Alamos): 10^{-31} *e*cm and eventually 10^{-35} *e*cm.

Results from Hinds et al. (Sussex) and Semertzidis et al. (Brookhaven) plans to improve by 10^5 sensitivity on μ EDM

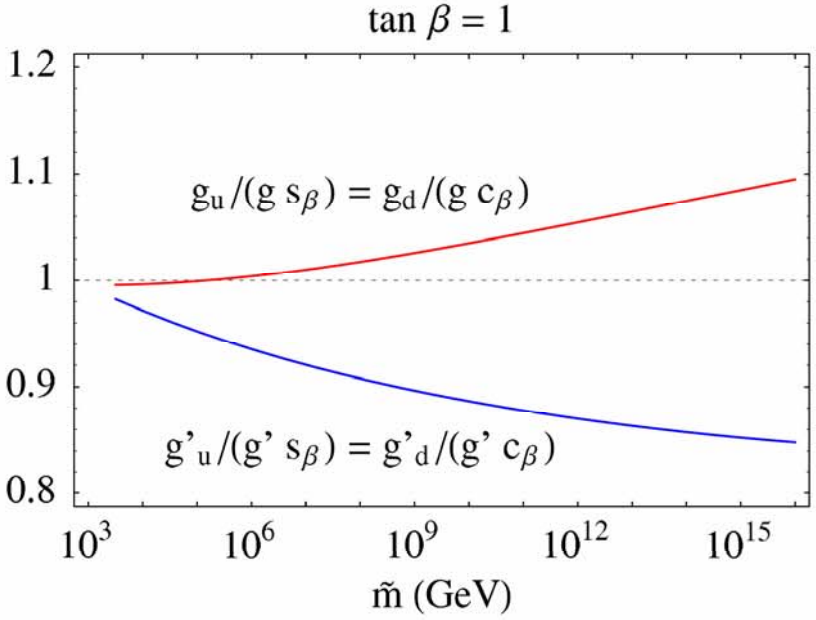
GLUINO: decays through intermediate heavy scalars

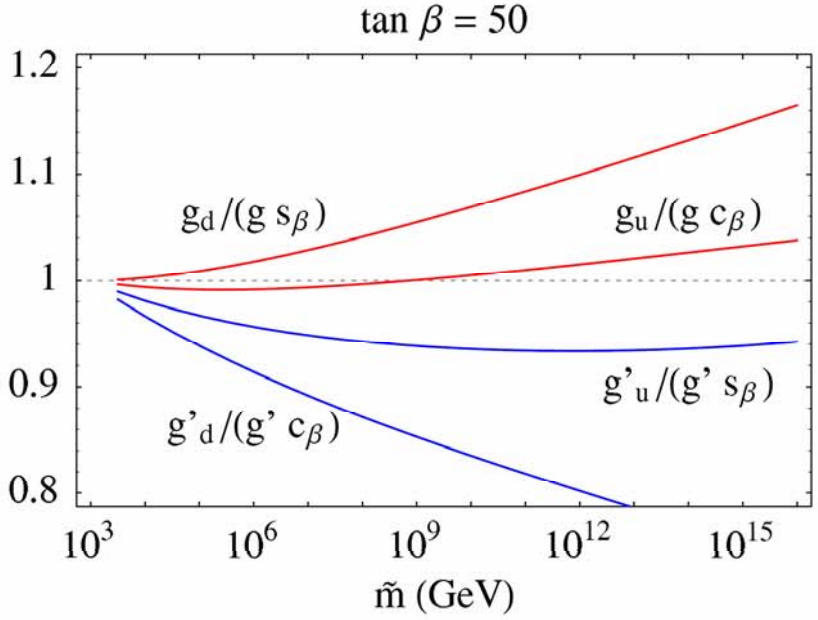


$$\tau_{\tilde{g}} \approx \left(\frac{\text{TeV}}{M_{\tilde{g}}}\right)^5 \left(\frac{\tilde{m}}{10^{13}\,\text{GeV}}\right)^4 0.4\,\text{Gyr}$$

CHARGINOS AND NEUTRALINOS:

- μ not determined by EWSB
- at LHC produced in DY, not in cascades
- decay chains with Higgs bosons
- couplings violate susy relations

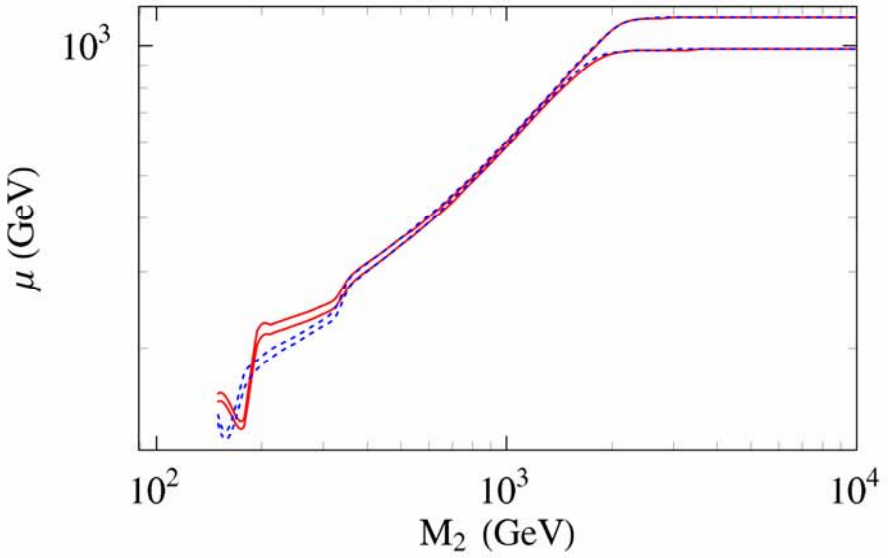


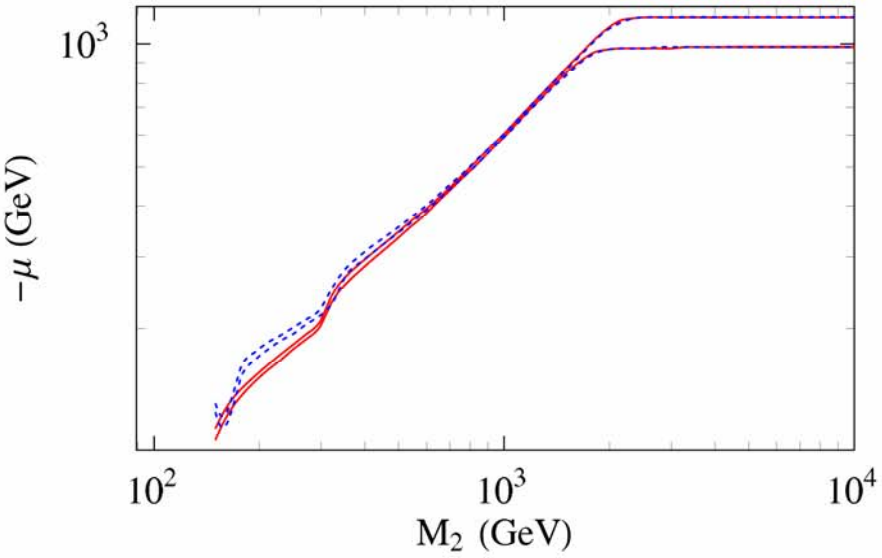


DARK MATTER IN SPLIT SUPERSYMMETRY

With respect to ordinary susy
- μ not determined by EWSB
- $\widetilde{B}$ only interacts with Higgs-Higgsino

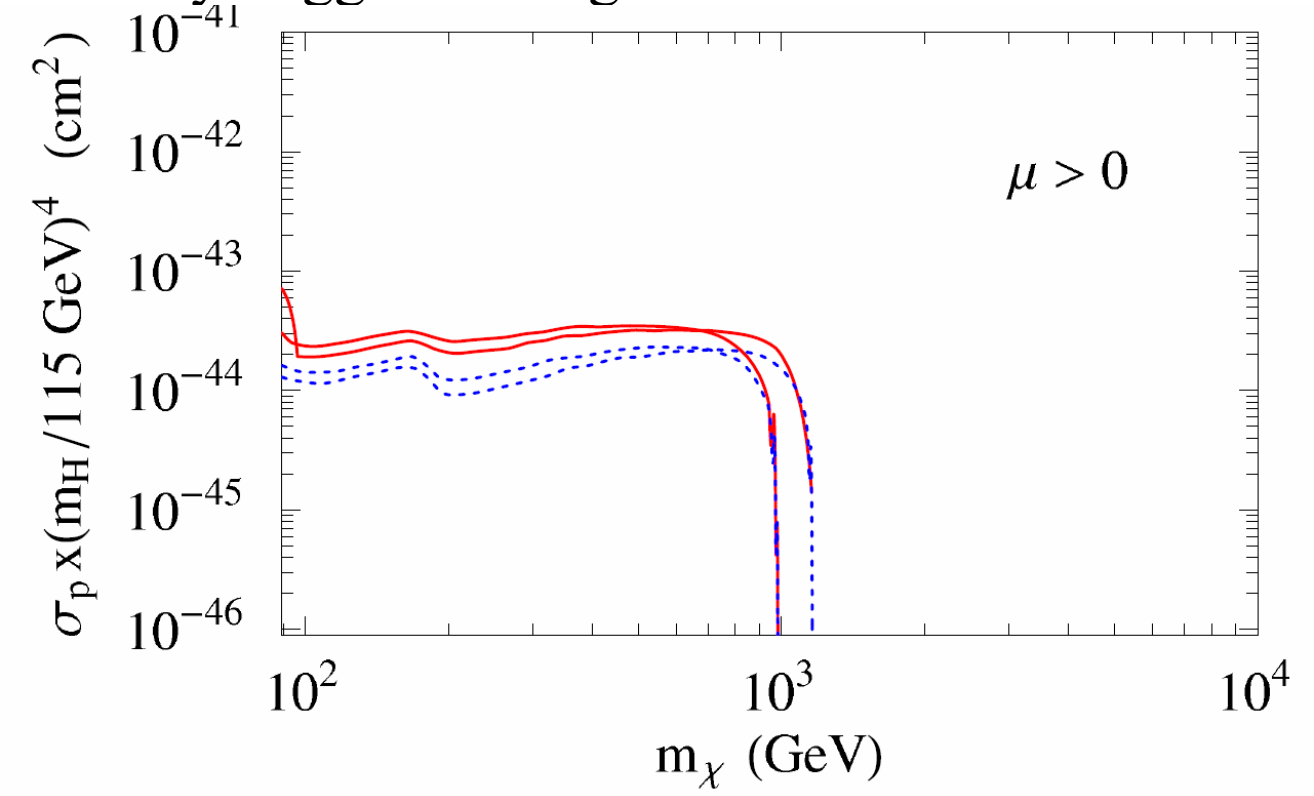
- χ mixed state $\Omega_\chi h^2 \approx 0.1\,\mu^2\left(M_1^2+\mu^2\right)^2/\left(m_\chi\ \mathrm{TeV}\right)^4$
- χ Higgsino $\Omega_\chi h^2 \approx 0.09\left(\mu/\mathrm{TeV}\right)^2$ DM for $\mu = 1.0-1.2\ \mathrm{TeV}$
- χ Wino $\Omega_\chi h^2 \approx 0.02\left(M_2/\mathrm{TeV}\right)^2$ DM for $M_2 = 2.0-2.5\ \mathrm{TeV}$





Upper bound on m_χ from thermal relic abundance retained also when gravitino decay contributes to DM

Spin-independent χ scattering cross section off protons is mediated by Higgs exchange



Present: CDMS & EDELWEISS: 10^{-42}–10^{-41} cm^2

Future:CDMS II: 10^{-44}–10^{-43} cm^2;

ZEPLIN, XENON, GENIUS: 10^{-46}–10^{-44} cm^2

CONCLUSIONS

- Failure of naturalness argument for CC casts doubts on the existence of a physical threshold at the weak scale
- Split Supersymmetry abandons hierarchy problem, but retains gauge-coupling unification and dark matter
- Not unique solution but, under certain assumption, it is the simplest option
- Certain patterns of susy breaking automatically lead to the spectrum of Split Supersymmetry
- Observational consequences for collider searches, EDM, dark matter and gravitino cosmology