SEARCH FOR SUSY

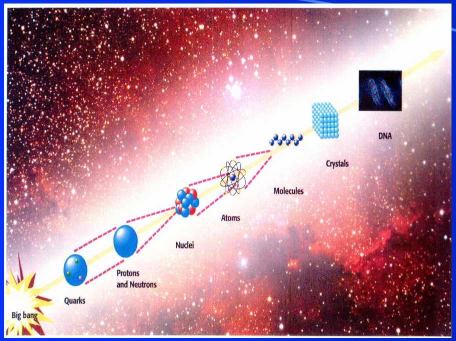
Status of the MSSM and hints for Astrophysics

Dmitri Kazakov

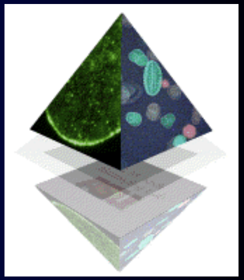
Bogoliubov Laboratory of Theoretical Physics

In collaboration with W. de Boer, C. Sander, V. Zhukov (Uni Karlsruhe) and A. Gladyshev (JINR, Dubna)

"Problems of Theoretical and Mathematical Physics", Dubna, 03.09.2004



What is SUSY



- **Supersymmetry** is a boson-fermion symmetry that is aimed to unify all forces in Nature including gravity within a singe framework

$$Q\,|\,boson>=|\,fermion> \qquad Q\,|\,fermion>=|\,boson>$$

$$[b,b]=0, \quad \{f,f\}=0 \;\Rightarrow \qquad \{Q^i_\alpha, \overline{Q}^j_{\dot\beta}\} = 2\delta^{ij}(\sigma^\mu)_{\alpha\dot\beta}P_\mu$$

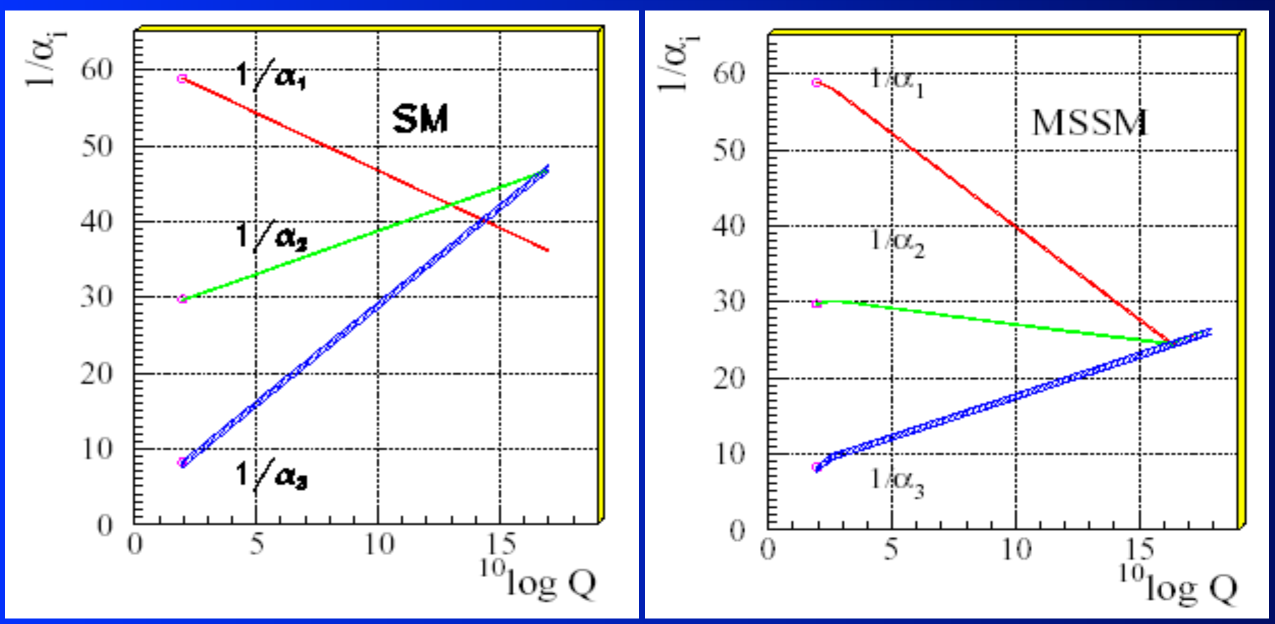
- Modern views on supersymmetry in particle physics are based on string paradigm, though low energy manifestations of SUSY can be found (?) at modern colliders and in non-accelerator experiments

Motivation of SUSY in Particle Physics

- Unification with Gravity
- Unification of gauge couplings
- Solution of the hierarchy problem
- Dark matter in the Universe
- Superstrings

Local translation = general relativity !

$\mathit{spin}\ 2 \rightarrow \mathit{spin}\ 3/2 \rightarrow \mathit{spin}\ 1 \rightarrow \mathit{spin}\ 1/2 \rightarrow \mathit{spin}\ 0$



SUSY yields unification!

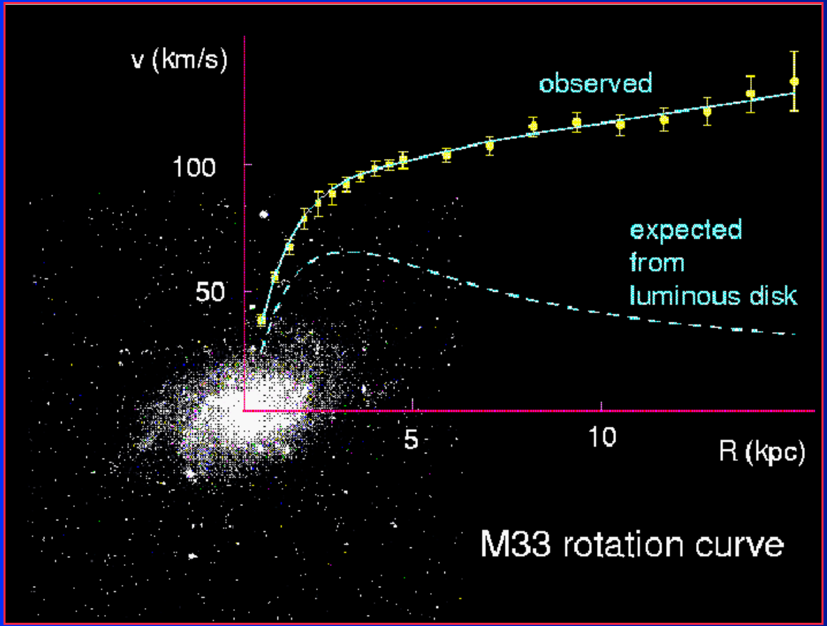
$$M_{SUSY} = 10^{3.4\pm0.9\pm0.4}\ \mathrm{GeV}$$

$$M_{GUT} = 10^{15.8\pm0.3\pm0.1}\ \mathrm{GeV}$$

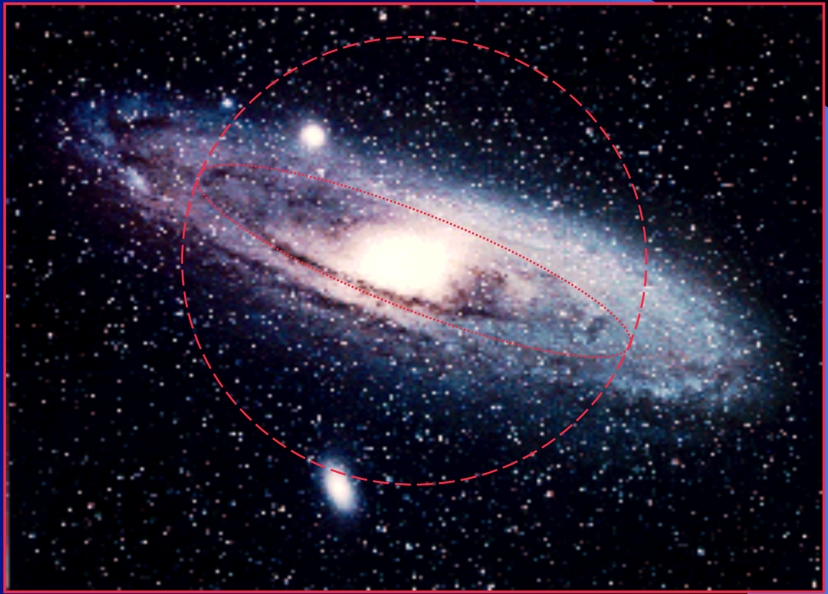
$$\alpha_{\mathrm{GUT}}^{-1} = 26.3\pm1.9\pm1.0$$

Motivation of SUSY

- Dark Matter in the Universe



The flat rotation curves of spiral galaxies provide the most direct evidence for the existence of large amount of the dark matter.



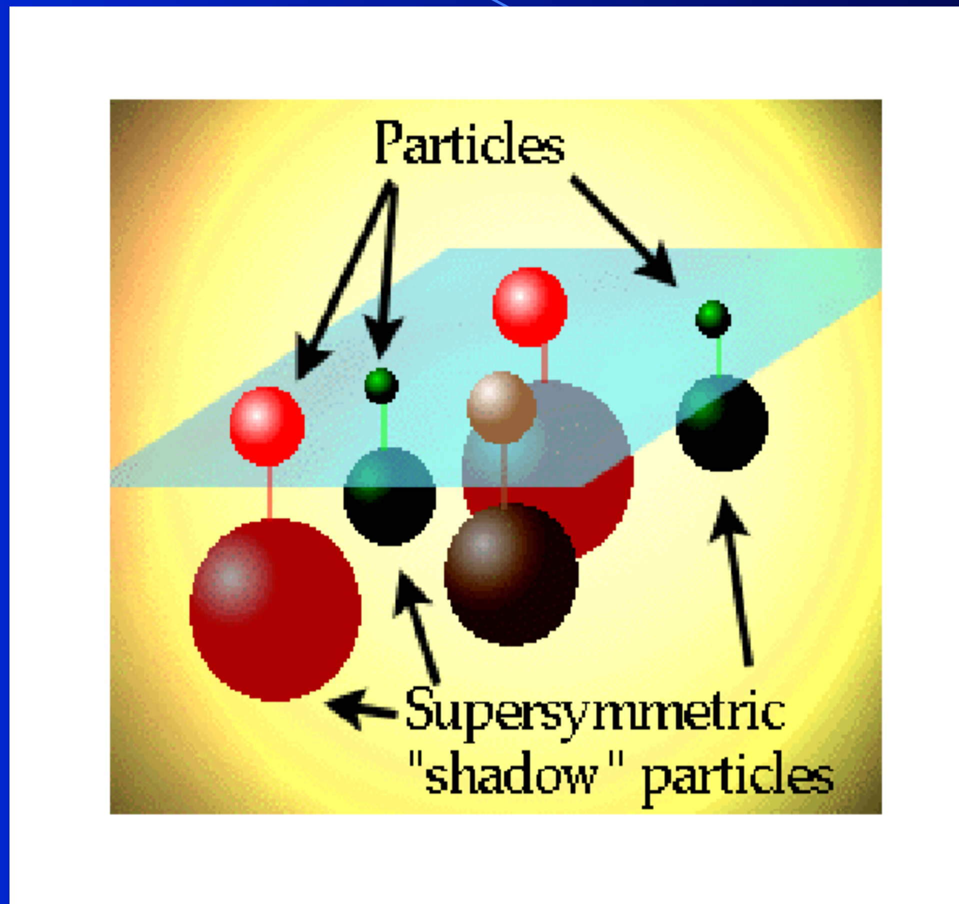
Spiral galaxies consist of a central bulge and a very thin disc, and surrounded by an approximately spherical halo of dark matter

SUSY provides a candidate for the Dark matter – a stable neutral particle

Particle Content of the MSSM

Superfield	*Bosons*	*Fermions*	$SU_c(3)$	$SU_L(2)$	$U_Y(1)$
Gauge					
G^a	*gluon* g^a	*gluino* $\tilde{\mathrm{g}}^a$	8	0	0
V^k	*Weak* $\mathrm{W}^k(W^\pm, Z)$	*wino, zino* $\tilde{w}^k(\tilde{w}^\pm, \tilde{z})$	1	3	0
V'	*Hypercharge* $\mathrm{B}(\gamma)$	*bino* $\tilde{b}(\tilde{\gamma})$	1	1	0
Matter					
L_i	sleptons $\tilde{L}_i = (\tilde{\nu}, \tilde{e})_L$	leptons $L_i = (\nu, e)_L$	1	2	-1
E_i	sleptons $\tilde{E}_i = \tilde{e}_R$	leptons $E_i = e_R$	1	1	2
Q_i	squarks $\tilde{Q}_i = (\tilde{u}, \tilde{d})_L$	quarks $Q_i = (u, d)_L$	3	2	$1/3$
U_i	squarks $\tilde{U}_i = \tilde{u}_R$	quarks $U_i = u_R^c$	3^*	1	$-4/3$
D_i	squarks $\tilde{D}_i = \tilde{d}_R$	quarks $D_i = d_R^c$	3^*	1	$2/3$
Higgs					
H_1	Higgses H_1	higgsinos $\tilde{H}_1$	1	2	-1
H_2	Higgses H_2	higgsinos $\tilde{H}_2$	1	2	1

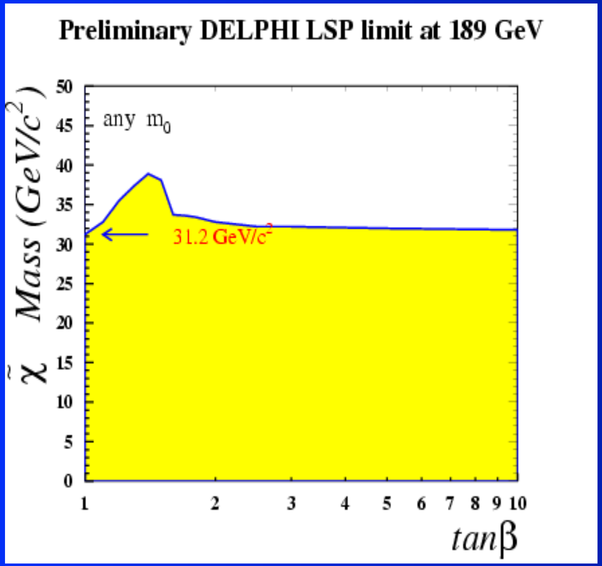
SUSY Shadow World



One half is observed!

One half is NOT observed!

SUSY Searches at LEP

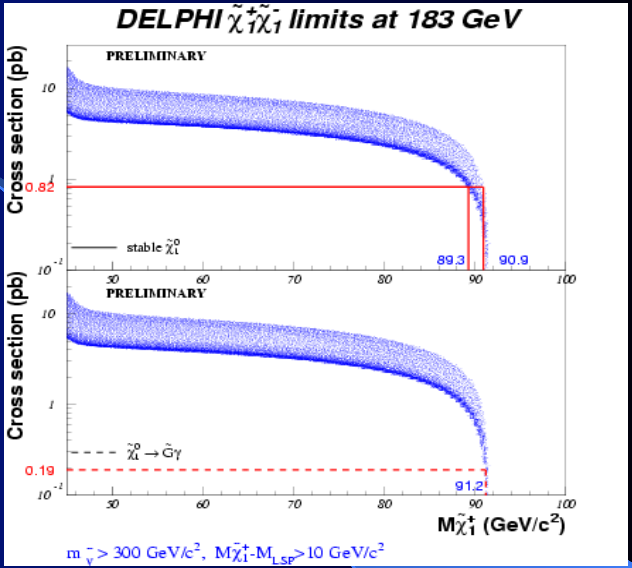


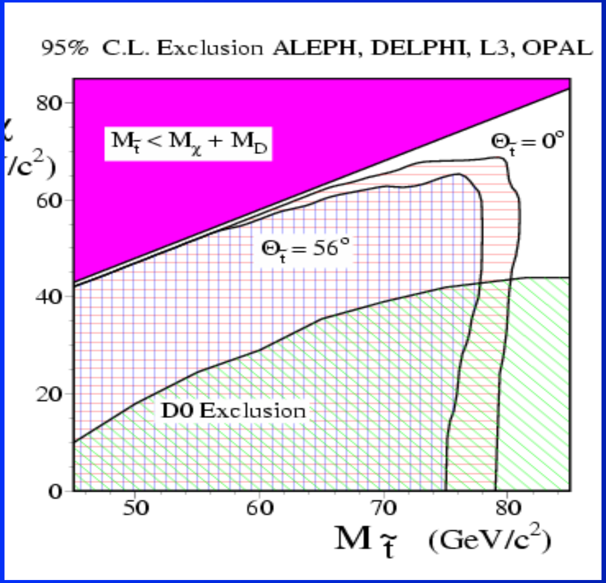
neutralinos

$\tilde{M}\chi 0 \geq$ 40 GeV

charginos

$\tilde{m}\chi+ \geq$ 100 GeV

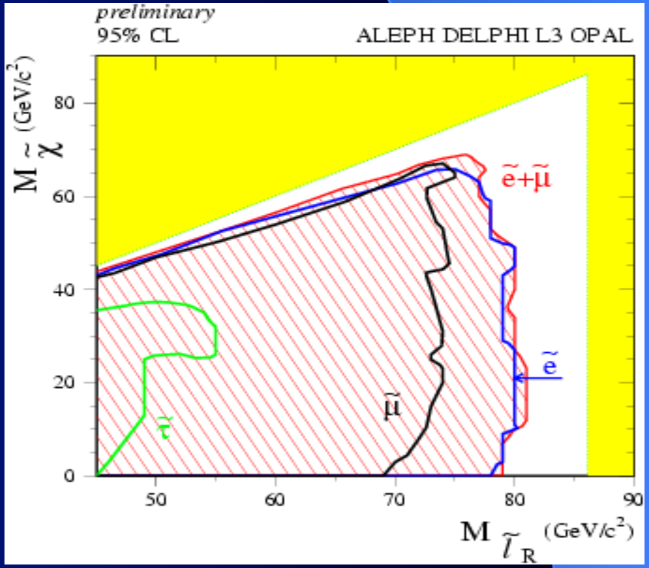




squarks

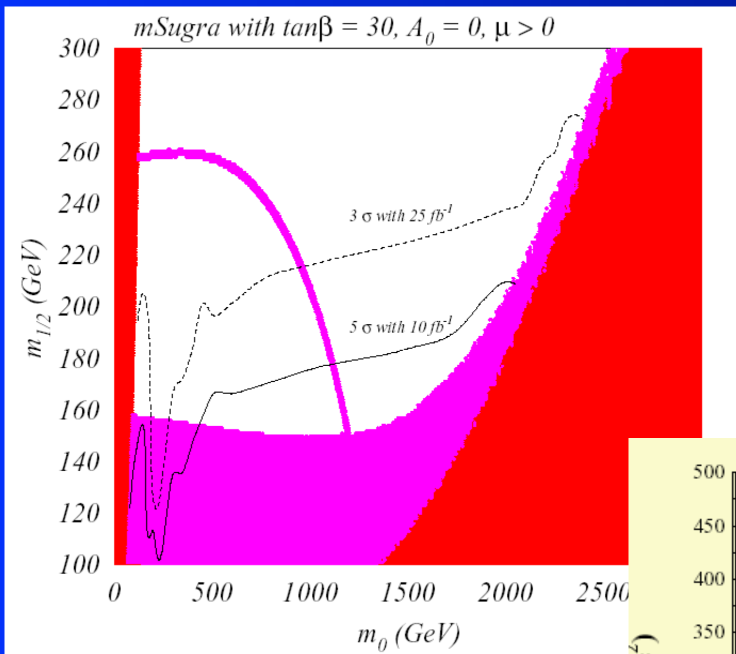
sleptons

$\tilde{m}_l \geq$ 100 GeV



SUSY Searches at Tevatron

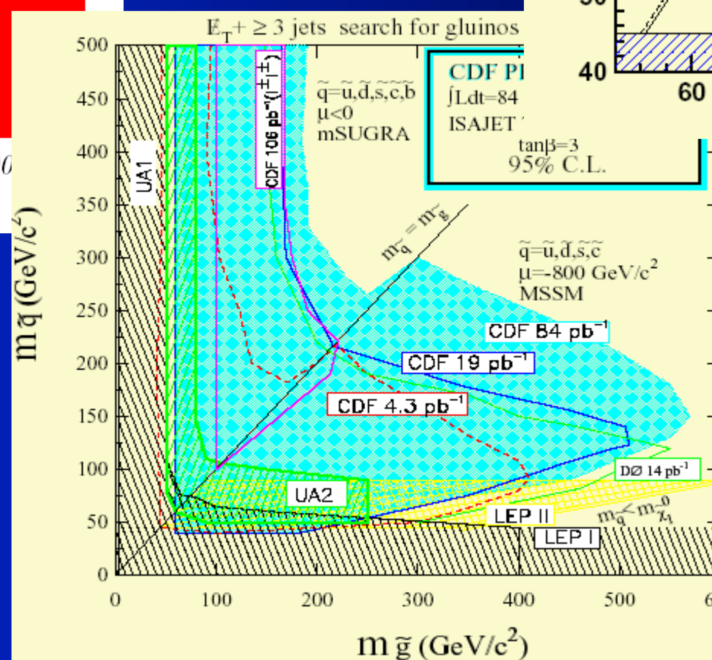
The reach of Tevatron in $m_0 / m_{1/2}$ plane

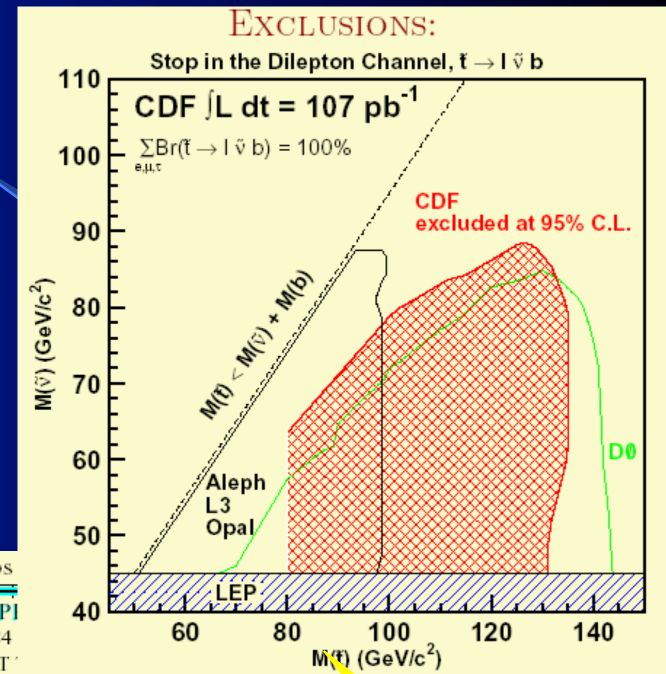


Exclusion:
World's Best Limits

$M\tilde{q} \geq$ 300 GeV

$m\tilde{g} \geq$ 195 GeV

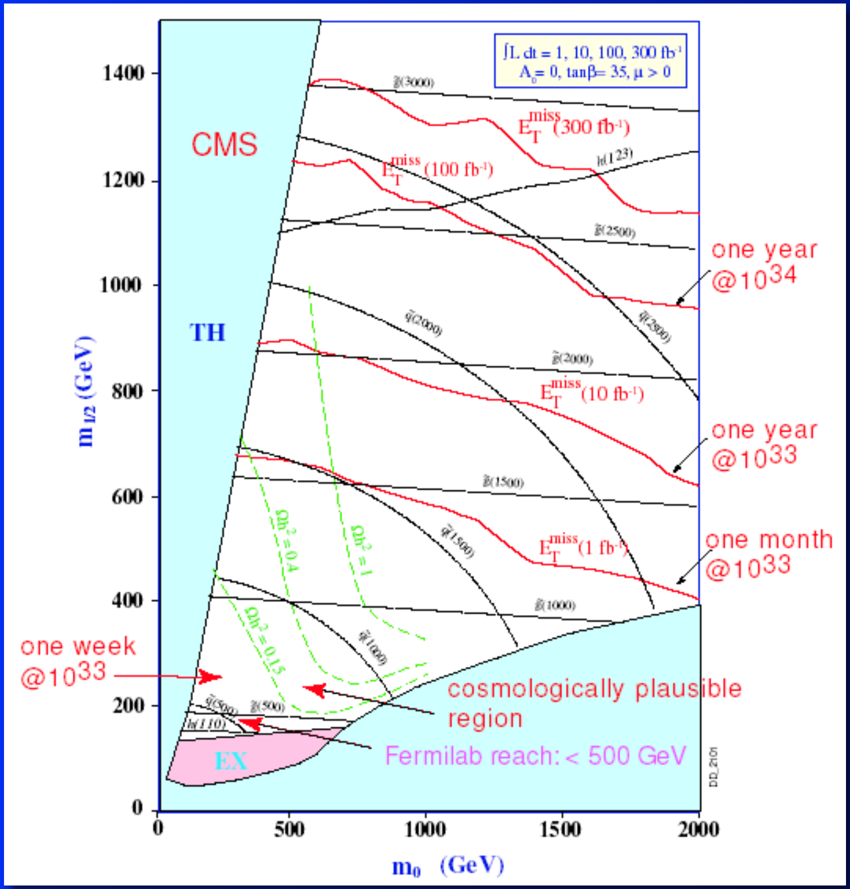




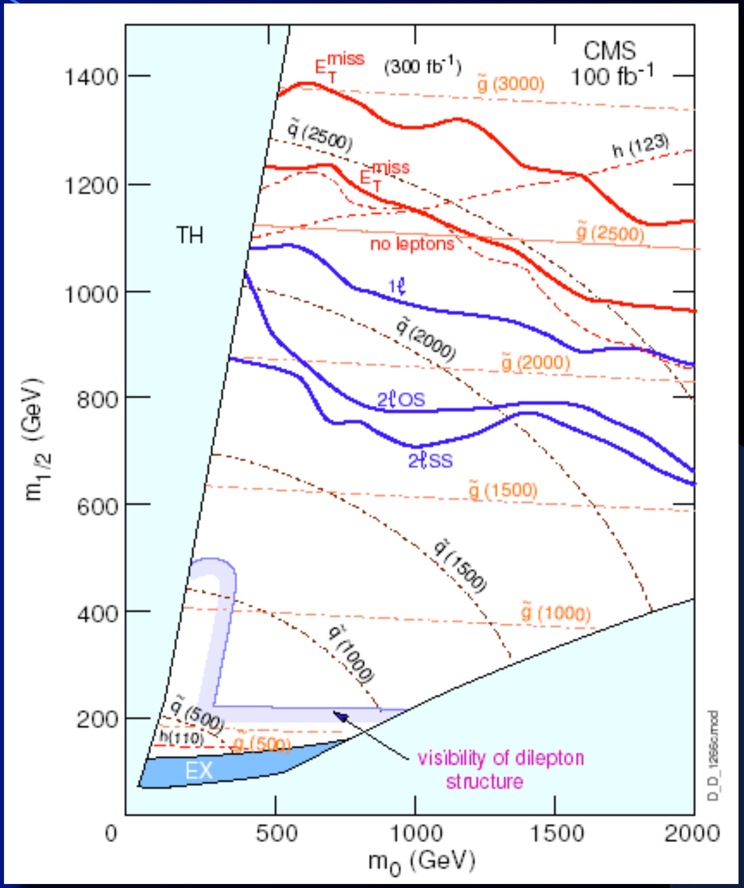
Dilepton Channel

3 jet channel

SUSY Searches at LHC

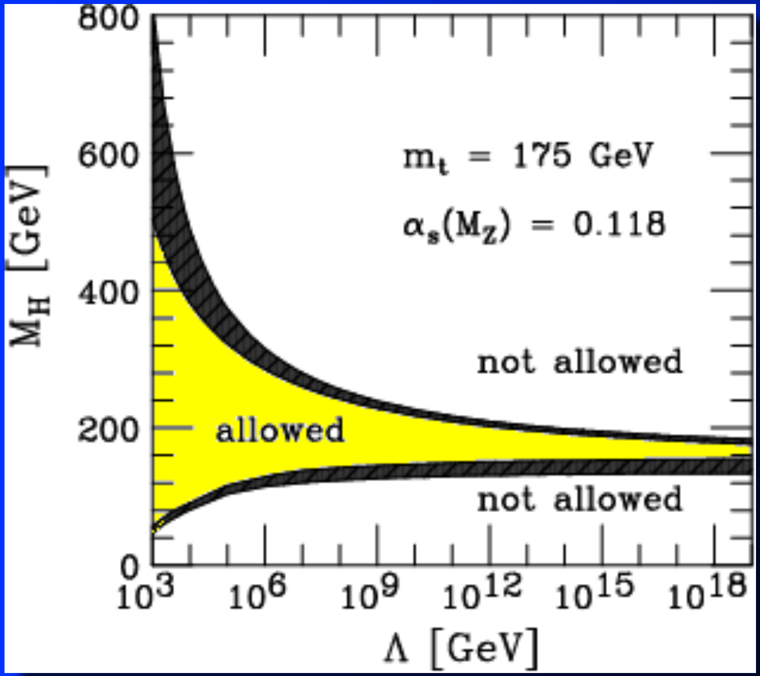


5 σ reach in jets + $\not{E}_T$ channel



Reach limits for various channels at 100 fb^{-1}

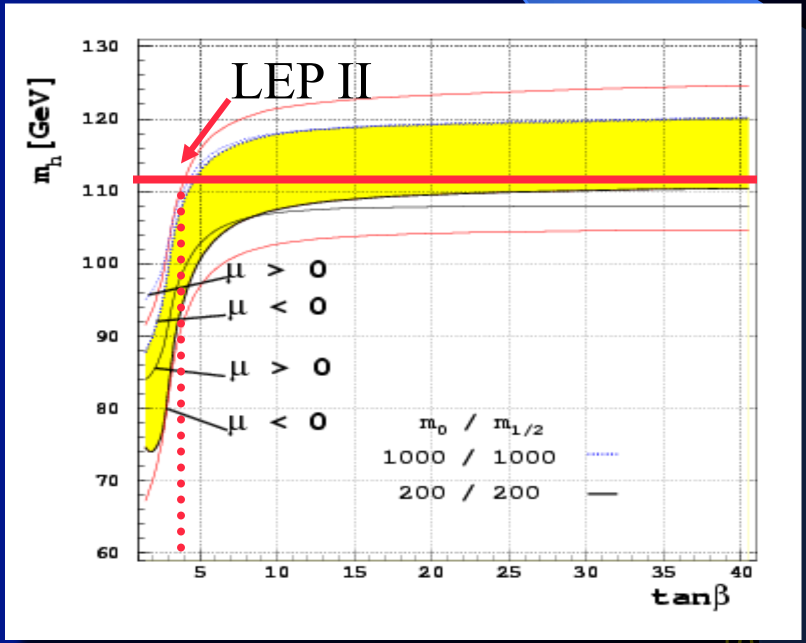
The Higgs Mass Limit



- The SM Higgs

Theory: $m_H \geq 134$ GeV

Exp: $113 < m_H < 200$ GeV



SUSY Higgs

$m_H \leq 130$ GeV

Constrained MSSM

Requirements:

- Unification of the gauge couplings
- Radiative EW Symmetry Breaking
- Heavy quark and lepton masses
- Rare decays (b -> sγ)
- Anomalous magnetic moment of muon
- LSP is neutral
- Amount of the Dark Matter
- Experimental limits from direct search

Allowed region in the parameter space of the MSSM

$$A_0, m_0, M_{1/2}, \mu, \tan\beta$$

Parameter space:

$$100\ Gev < m_0, M_{1/2}, \mu < 2\ Tev$$
$$-3m_0 < A_0 < 3m_0,\ 1 < \tan\beta < 70$$

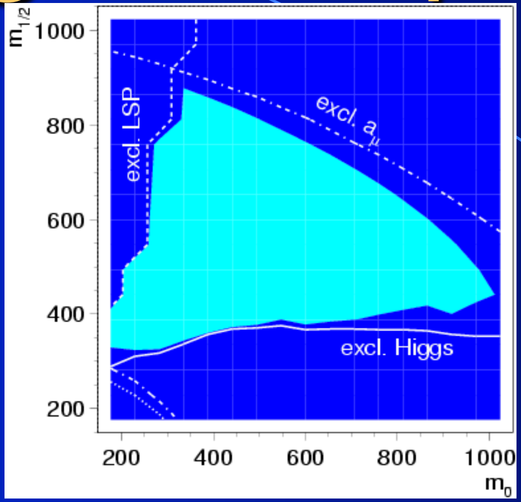
Allowed regions of parameter space

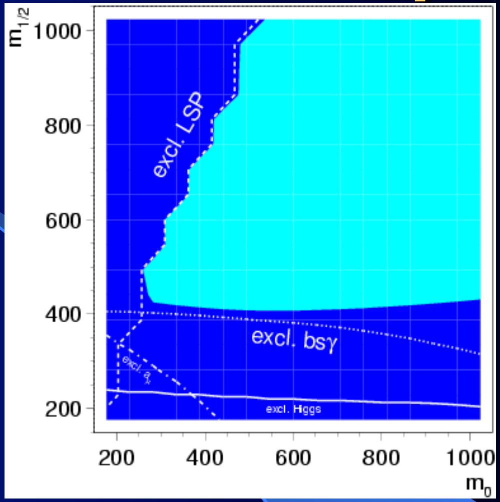
- $\tan\beta > 4$

From the Higgs searches

- $\mu > 0$

From a_μ measurement

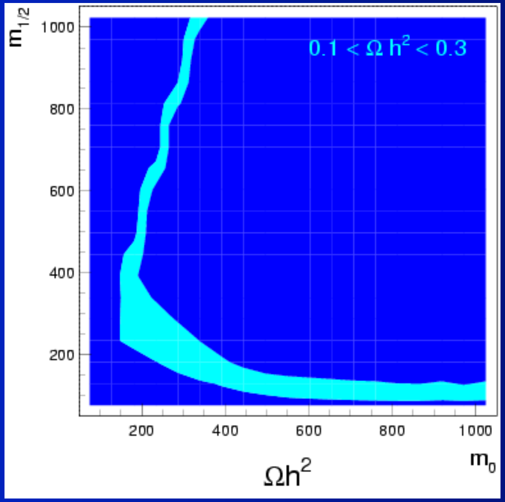


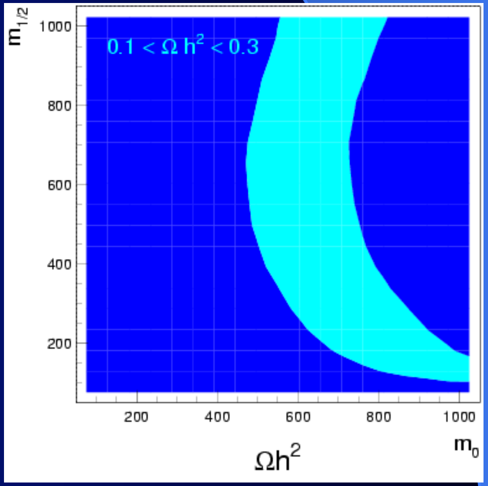


Fit to all constraints (without astrophysics)

In allowed region one fulfills all the constraints simultaneously and has the suitable amount of the dark matter

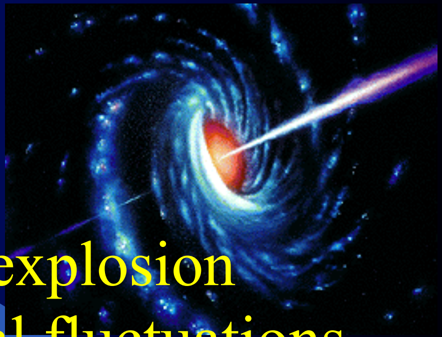
Before WMAP





$\tan\beta = 35$ Fit to Dark Matter constraint $\tan\beta = 50$

Cosmological Constraints



New precise cosmological data

$$\Omega h^2 = 1 \quad \longleftrightarrow \quad \rho = \rho_{crit}$$

$$\Omega_{vacuum} \approx 73\%$$

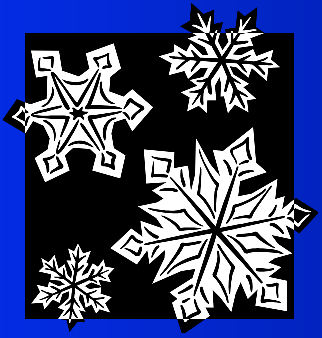
$$\Omega_{DarkMatter} \approx 23 \pm 4\%$$

$$\Omega_{Baryon} \approx 4\%$$

- Supernova Ia explosion
- CMBR thermal fluctuations

(news from WMAP)

Dark Matter in the Universe:



→ Hot DM (not favoured by galaxy formation)

→ Cold DM (rotation curves of Galaxies) ← SUSY

The Lightest Superparticle

		property	signature
• Gravity mediation	$LSP = \tilde{\chi}_1^0$	stable	jets/leptons $+ \not{E}_T$
• Gauge mediation	$LSP = \tilde{G}$	stable	$\not{E}_T$
	$NLSP = \tilde{\chi}_1^0$	$\tilde{\chi}_1^0 \to \gamma\tilde{G}, h\tilde{G}, Z\tilde{G}$	photons/jets $+ \not{E}_T$
	$NLSP = \tilde{l}_R$	$\tilde{l}_R \to \tau\tilde{G}$	lepton $+ \not{E}_T$
• Anomaly mediation	$LSP = \tilde{\chi}_1^0$	stable	lepton $+ \not{E}_T$
	$LSP = \tilde{\nu}_L$	stable	

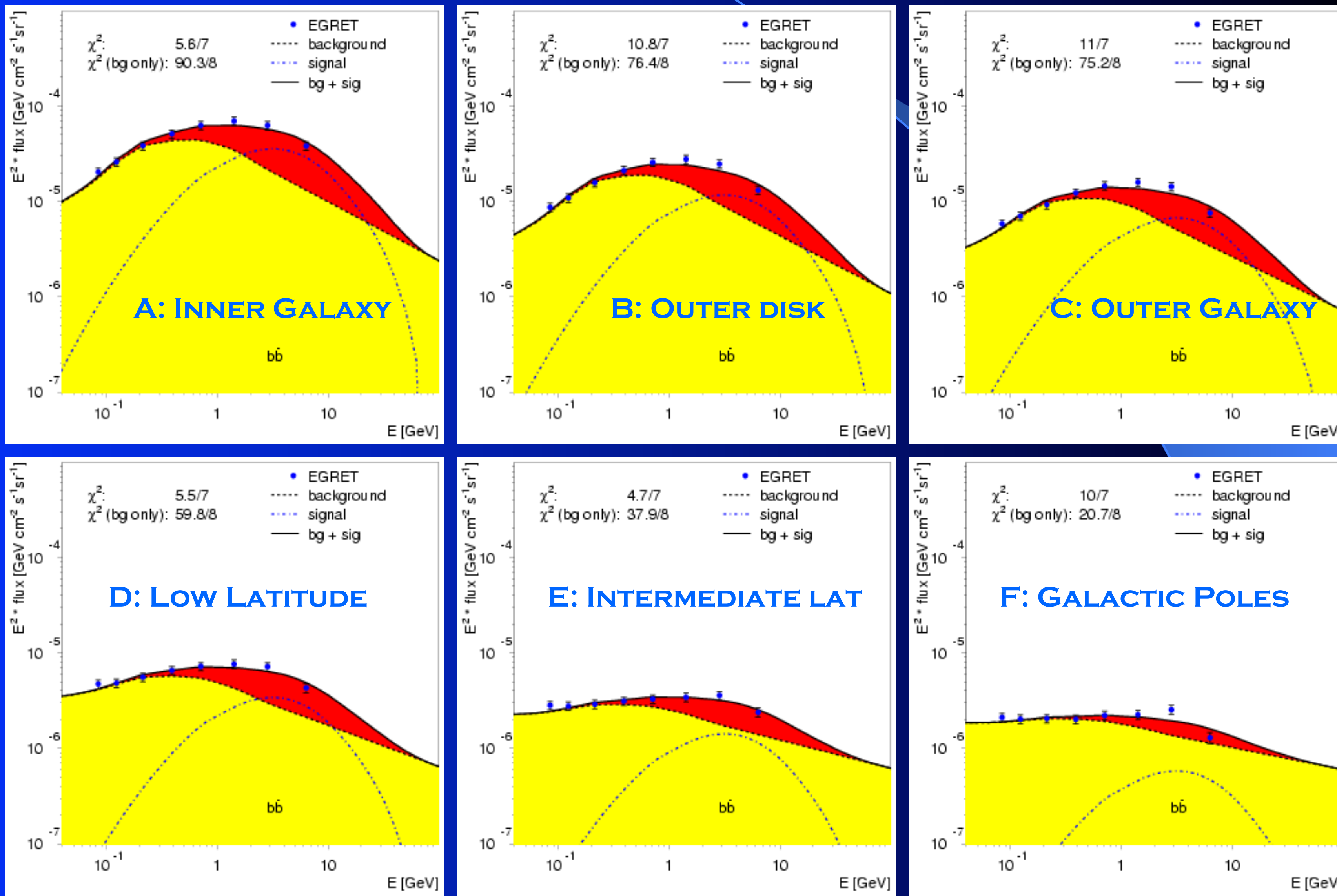
• R-parity violation — LSP is unstable ➔ SM particles

Rare decays
Neutrinoless double β decay

• Modern limit

$$M_{LSP} \geq 40\ \text{GeV}$$

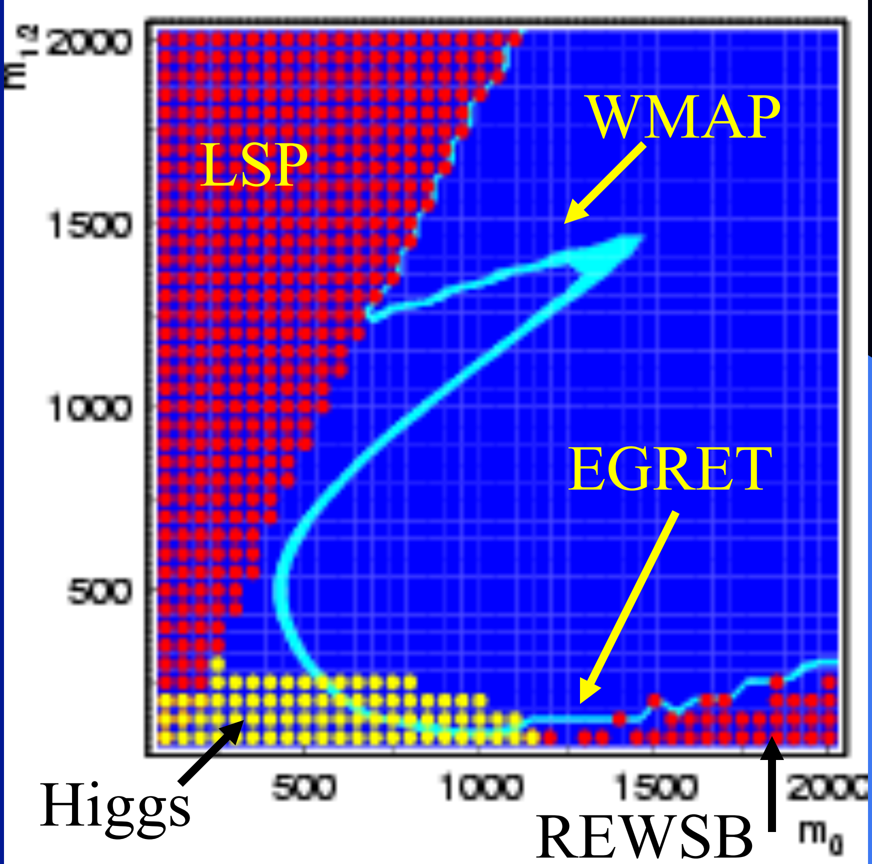
Excess of the Gammas versus Energy for various regions



Allowed regions of parameter space (after WMAP)

Constraint from the WMAP data on the amount of the Dark matter leaves a very narrow band in parameter space.

SUSY interpretation of the cosmic ray spectrum (diffuse gamma - rays) suggests very light gauginos and heavy squarks and sleptons to be discovered at LHC



$\tan\beta = 50$

SUMMARY

- The MSSM (low-energy SUSY model) is a viable model which fulfills all constraints simultaneously!
- The light Higgs boson is a generic feature of the MSSM.
- SUSY predicts the Dark Matter in the Universe in agreement with the CMB data.
- Combined fit to all data suggests light gaugino spectrum and heavy squarks and sleptons
- If low-energy SUSY is realized in Nature it has to be discovered at LHC or … abandoned