On importance of dark matter for LHC physics[1]

V.A. Bednyakov

Laboratory of Nuclear Problems, Joint Institute for Nuclear Research, Moscow region, 141980 Dubna, Russia; E-mail: bedny@nusun.jinr.ru

Abstract

I would like to attract attention of the LHC high-energy physics community to non-accelerator, low-energy experiments, that are also very sensitive to new physics. My example concerns search for supersymmetric dark matter particles. It is shown that non-observation of the SUSY dark matter candidates with a high-accuracy detector can exclude large domains of the MSSM parameter space and, in particular, can make especially desirable collider search for light SUSY charged Higgs boson.

A direct dark matter search for neutralinos, lightest SUSY particles (LSP), is complementary to high energy searches for SUSY with colliders [1]–[4]. For example, colliders unable to prove that the LSP is a stable particle. Such dark matter searches offer interesting prospects for beating accelerators in discovery of SUSY, particularly during the coming years before the LHC enters into operation [5].

By definition, Galactic Dark Matter (DM) does not emit detectable amounts of electromagnetic radiation and (only) gravitationally affects other, visible, celestial bodies. The best evidence of this kind comes from the study of galactic rotation curves, when one measures the velocity with which globular stellar clusters, gas clouds, or dwarf galaxies orbit around their centers. If the mass of these galaxies were concentrated in their visible parts, the orbital velocity at large radii r should decrease as $1/\sqrt{r}$ (fig. 1). Instead, it remains approximately constant to the largest

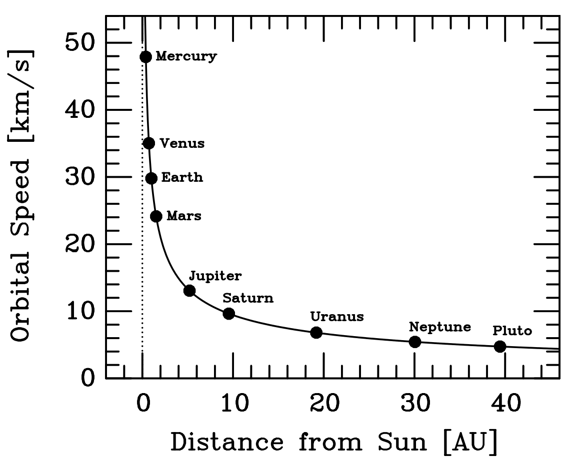

Figure 1: Rotation curve of the solar system which falls off as $v = \sqrt{G_{\rm N}M/r}$ in accordance with Kepler's law. AU is the Earth-Sun distance of 1.5×10^{13} cm

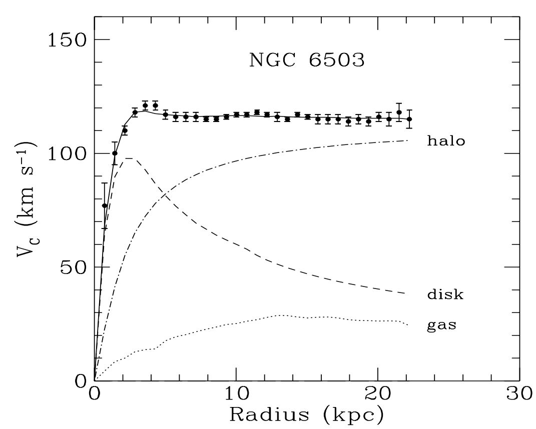

Figure 2: Rotation curve of the spiral galaxy NGC 6503 as established from radio observations of hydrogen gas in the disk

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radius where it can be measured. This implies that the total mass $M(r)$ felt by an object at a radius r must increase linearly with r (fig. 2). Studies of this type imply that 90% or more of the mass of large galaxies is dark [6].

The mass density averaged over the entire Universe is usually expressed in units of critical density $\rho_c \approx 10^{-29}$g/cm^3, the dimensionless ratio $\Omega \equiv \rho/\rho_c = 1$ corresponds to a flat Universe. Analyses of galactic rotation curves imply $\Omega \geq 0.1$. Studies of clusters and superclusters of galaxies through gravitational lensing or through measurements of their X-ray temperature, as well as studies of the large-scale streaming of galaxies favor larger values of the total mass density of the Universe $\Omega \geq 0.3$. Finally, naturalness arguments and inflationary models prefer $\Omega = 1.0$ to a high accuracy. The requirement that the Universe be at least 10 billion years old implies $\Omega h^2 \leq 1$, where $h = 0.65 \pm 0.15$ is the present Hubble parameter in units of 100 km/(sec·Mpc). The total density of luminous matter only amounts to less than 1% of the critical density. Analyses of Big Bang nucleosynthesis determine the total baryonic density to lie in the range $0.01 \leq \Omega_{\rm baryon} h^2 \leq 0.015$. The upper bound implies $\Omega_{\rm baryon} \leq 0.06$, in obvious conflict with the lower bound $\Omega \geq 0.3$. Most Dark Matter must therefore be non–baryonic (fig. 3).

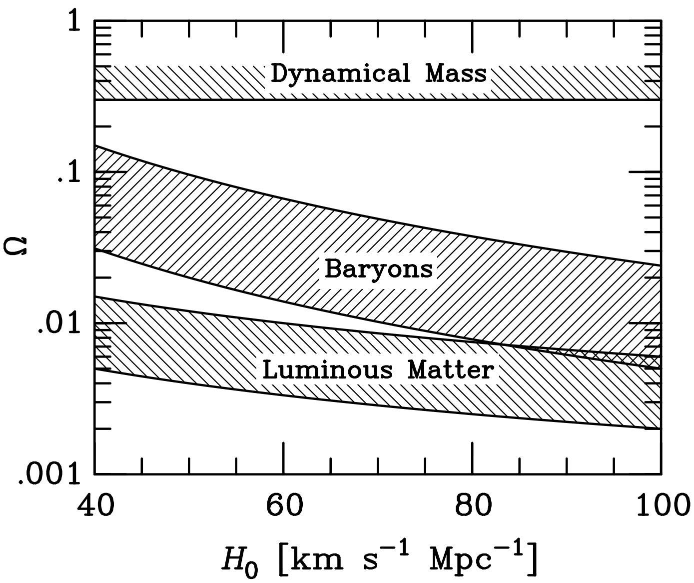

Figure 3: Most Dark Matter must be non–baryonic: $\Omega = \Omega_{\rm baryon} + \Omega_{\rm non\text{-}baryon} \geq 0.3$, with $\Omega_{\rm baryon} \leq 0.06$

Some sort of "new physics" seems to be required to describe this exotic matter, beyond the particles described by the Standard Model of particle physics [6]. According to the best estimate, the local density of this invisible matter amounts to about

$$\rho^{\rm DM}_{\rm local} \simeq 0.3 \text{ GeV/cm}^3 \simeq 5 \cdot 10^{-25} \text{g/cm}^3.$$

It is assumed to have a Maxwellian velocity distribution with mean $\bar{v} \simeq 300$ km/sec. The local flux of DM particles χ is thus

$$\Phi^{\rm DM}_{\rm local} \simeq \frac{100 \text{ GeV}}{m_\chi} \cdot 10^5 \text{ cm}^{-2}\text{s}^{-1}.$$

This not-small-enough value is considered as a basis for direct search for dark matter particles.

A dark matter event is elastic scattering of a relic DM neutralino from a target nucleus producing a nuclear recoil which can be detected by a suitable detector [3, 7, 8]. The differential event rate (per unit mass of the target nucleus) in respect to the recoil energy is the subject of experimental measurements:

$$\frac{dR}{dE_r} = \left[N\frac{\rho_\chi}{m_\chi}\right]\int_{v_{\rm min}}^{v_{\rm esc}} dv f(v) v \frac{d\sigma}{dq^2}(v, E_r),$$

where $q^2 = 2M_A E_r$, $v_{\rm esc} \approx 600$ km/s, $\rho_\chi \approx 0.3$ GeV/cm^3, $v_{\rm min} = \left(M_A E_r / 2M_{\rm red}^2\right)^{1/2}$, M_A is the mass of the target nucleus, and $M_{\rm red}$ is the reduced mass. A typical nuclear recoil energy is $E_r \approx 10^{-6} m_\chi$. The rate depends on the distribution of the DM neutralinos in the solar vicinity $f(v)$ and the cross section of neutralino-nucleus elastic scattering:

$$v^2\frac{d\sigma}{dq^2}(v,q^2) \;\propto\; \Bigg[\underbrace{c_0^2(\mathcal{C}_q, f_q)}_{\rm SUSY}\underbrace{A^2\ \mathcal{F}_{\rm S}^2(q^2)}_{\rm scalar}$$

$$+\ \underbrace{a_0^2(\mathcal{A}_q,\Delta q)}_{\rm SUSY}\underbrace{\mathcal{F}_{00}^2(q^2)}_{\rm spin} + a_0 a_1\underbrace{\mathcal{F}_{10}^2(q^2)}_{\rm spin} + \underbrace{a_1^2(\mathcal{A}_q,\Delta q)}_{\rm SUSY}\underbrace{\mathcal{F}_{11}^2(q^2)}_{\rm spin}\Bigg].$$

Here $a_{0,1} = \sum_q^p \mathcal{A}_q\Delta q \pm \sum_q^n \mathcal{A}_q \Delta q$, and $c_0 = \sum_q^{p,n} \mathcal{C}_q f_q$. The first term in brackets, which has A^2 enhancement, corresponds to the so-called spin-independent or scalar interaction, the other terms give parametrization of the so-called spin-dependent interaction. The nuclear structure presented by the scalar $\mathcal{F}_{\rm S}^2(q^2)$ and spin $\mathcal{F}_{ij}^2(q^2)$ form factors is factorized out of the nucleon structure (given via quark contributions to the spin Δq and to the mass f_q of the nucleon) and the SUSY contribution ($\mathcal{C}_q$ and $\mathcal{A}_q$), which enters into the calculations at the level of neutralino-quark effective low-energy interaction via the Lagrangian:

$$L_{\rm eff} = \mathcal{A}_q \cdot \bar\chi\gamma_\mu\gamma_5\chi\cdot\bar q\gamma^\mu\gamma_5 q + \frac{m_q}{M_W}\cdot\mathcal{C}_q\cdot\bar\chi\chi\cdot\bar q q\ + ...$$

where the terms with vector and pseudoscalar quark currents are omitted being negligible in the case of non-relativistic DM neutralinos with typical velocities $v_\chi \approx 10^{-3}c$;

$$\begin{aligned}
\mathcal{A}_q = & -\frac{g^2}{4M_W^2}\Bigg[\frac{\mathcal{N}_{14}^2-\mathcal{N}_{13}^2}{2}T_3 - \frac{M_W^2(\cos^2\theta_q\phi_{qL}^2+\sin^2\theta_q\phi_{qR}^2)}{m_{\tilde q1}^2-(m_\chi+m_q)^2}\\
& - \frac{M_W^2(\sin^2\theta_q\phi_{qL}^2+\cos^2\theta_q\phi_{qR}^2)}{m_{\tilde q2}^2-(m_\chi+m_q)^2}\\
& - \frac{m_q^2}{4}P_q^2\left(\frac{1}{m_{\tilde q1}^2-(m_\chi+m_q)^2}+\frac{1}{m_{\tilde q2}^2-(m_\chi+m_q)^2}\right)\\
& - \frac{m_q}{2}\ M_W\ P_q\ \sin 2\theta_q\ T_3(\mathcal{N}_{12}-\tan\theta_W\mathcal{N}_{11})\\
& \times\left(\frac{1}{m_{\tilde q1}^2-(m_\chi+m_q)^2}-\frac{1}{m_{\tilde q2}^2-(m_\chi+m_q)^2}\right)\Bigg];\\
\mathcal{C}_q = & -\frac{g^2}{4}\Bigg[\frac{F_h}{m_h^2}h_q+\frac{F_H}{m_H^2}H_q+\left(\frac{m_q}{4M_W}P_q^2-\frac{M_W}{m_q}\phi_{qL}\ \phi_{qR}\right)
\end{aligned}$$

$$\times \quad \left(\frac{\sin 2\theta_q}{m^2_{\tilde{q}1}-(m_\chi+m_q)^2}-\frac{\sin 2\theta_q}{m^2_{\tilde{q}2}-(m_\chi+m_q)^2}\right)$$
$$+ \quad P_q\left(\frac{\cos^2\theta_q\ \phi_{qL}-\sin^2\theta_q\ \phi_{qR}}{m^2_{\tilde{q}1}-(m_\chi+m_q)^2}-\frac{\cos^2\theta_q\ \phi_{qR}-\sin^2\theta_q\ \phi_{qL}}{m^2_{\tilde{q}2}-(m_\chi+m_q)^2}\right)\Bigg].$$

$$\begin{aligned}
F_h &= (\mathcal{N}_{12}-\mathcal{N}_{11}\tan\theta_W)(\mathcal{N}_{14}\cos\alpha_H+\mathcal{N}_{13}\sin\alpha_H),\\
F_H &= (\mathcal{N}_{12}-\mathcal{N}_{11}\tan\theta_W)(\mathcal{N}_{14}\sin\alpha_H-\mathcal{N}_{13}\cos\alpha_H),\\
h_q &= (\frac{1}{2}+T_3)\frac{\cos\alpha_H}{\sin\beta}-(\frac{1}{2}-T_3)\frac{\sin\alpha_H}{\cos\beta},\\
H_q &= (\frac{1}{2}+T_3)\frac{\sin\alpha_H}{\sin\beta}+(\frac{1}{2}-T_3)\frac{\cos\alpha_H}{\cos\beta},\\
\phi_{qL} &= \mathcal{N}_{12}T_3+\mathcal{N}_{11}(Q-T_3)\tan\theta_W, \qquad \phi_{qR}=\tan\theta_W\ Q\ \mathcal{N}_{11},\\
P_q &= (\frac{1}{2}+T_3)\frac{\mathcal{N}_{14}}{\sin\beta}+(\frac{1}{2}-T_3)\frac{\mathcal{N}_{13}}{\cos\beta}.
\end{aligned}$$

In this paper the MSSM parameter space is explored at the weak scale, when any constraints following from the unification assumptions are completely relaxed. On the other side, restrictions from the age of the Universe, accelerator SUSY searches, rare FCNC $b\to s\gamma$ decay, etc are respected [9]–[12]. Therefore, the MSSM parameter space is determined by entries of the mass matrices of neutralinos, charginos, Higgs bosons, sleptons and squarks. All relevant mass matrices are given below. The one-generation squark and slepton mass matrices have the form [13]:

$$\begin{aligned}
M^2_{\tilde{t}} &= \begin{bmatrix} M^2_{\tilde{Q}}+m_t^2+m_Z^2(\frac{1}{2}-\frac{2}{3}s_W^2)\cos 2\beta & m_t(A_t-\mu\cot\beta)\\ m_t(A_t-\mu\cot\beta) & M^2_{\tilde{U}}+m_t^2+m_Z^2\frac{2}{3}s_W^2\cos 2\beta\end{bmatrix},\\
M^2_{\tilde{b}} &= \begin{bmatrix} M^2_{\tilde{Q}}+m_b^2-m_Z^2(\frac{1}{2}-\frac{1}{3}s_W^2)\cos 2\beta & m_b(A_b-\mu\tan\beta)\\ m_b(A_b-\mu\tan\beta) & M^2_{\tilde{D}}+m_b^2-m_Z^2\frac{1}{3}s_W^2\cos 2\beta\end{bmatrix},\\
M^2_{\tilde{\nu}} &= M^2_{\tilde{L}}+\frac{1}{2}m_Z^2\cos 2\beta,\\
M^2_{\tilde{\tau}} &= \begin{bmatrix} M^2_{\tilde{L}}+m_\tau^2-m_Z^2(\frac{1}{2}-s_W^2)\cos 2\beta & m_\tau(A_\tau-\mu\tan\beta)\\ m_\tau(A_\tau-\mu\tan\beta) & M^2_{\tilde{E}}+m_\tau^2-m_Z^2 s_W^2\cos 2\beta\end{bmatrix}
\end{aligned}$$

where $s_W^2\equiv\sin^2\theta_W$ and $\tan\beta\equiv\langle H_2^0\rangle/\langle H_1^0\rangle$. In the $\widetilde{W}^+$–$\widetilde{H}^+$ basis, the chargino mass matrix is

$$X=\begin{pmatrix} M_2 & \sqrt{2}m_W\sin\beta\\ \sqrt{2}m_W\cos\beta & \mu\end{pmatrix}.$$

Two unitary 2×2 matrices U and V are required to diagonalize the chargino mass-squared matrix $\mathcal{M}^2_{\widetilde{\chi}^+}=VX^\dagger XV^{-1}=U^*XX^\dagger(U^*)^{-1}$. The two mass eigenstates are denoted by $\widetilde{\chi}_1^+$ and $\widetilde{\chi}_2^+$. In the $\widetilde{B}$–$\widetilde{W}^3$–$\widetilde{H}_1^0$–$\widetilde{H}_2^0$ basis, the neutralino Majorana mass matrix is

$$Y=\begin{pmatrix} M_1 & 0 & -m_Zc_\beta s_W & m_Zs_\beta s_W\\ 0 & M_2 & m_Zc_\beta c_W & -m_Zs_\beta c_W\\ -m_Zc_\beta s_W & m_Zc_\beta c_W & 0 & -\mu\\ m_Zs_\beta s_W & -m_Zs_\beta c_W & -\mu & 0\end{pmatrix},$$

where $s_\beta = \sin\beta$, $c_\beta = \cos\beta$, etc. A 4×4 unitary matrix $\mathcal{N}$ is required to diagonalize the neutralino mass matrix $\mathcal{M}_{\widetilde{\chi}^0} = \mathcal{N}^* Y \mathcal{N}^{-1}$ where the diagonal elements of $\mathcal{M}_{\widetilde{\chi}^0}$ can be either positive or negative. The CP-even Higgs mass matrix has the form [14]

$$\begin{aligned}\begin{pmatrix} H_{11} & H_{12} \\ H_{12} & H_{22}\end{pmatrix} &= \frac{1}{2}\begin{pmatrix} \tan\beta & -1 \\ -1 & \cot\beta\end{pmatrix} M_A^2 \sin 2\beta \\ &+ \frac{1}{2}\begin{pmatrix} \cot\beta & -1 \\ -1 & \tan\beta\end{pmatrix} m_Z^2 \sin 2\beta + \frac{3g_2^2}{16\pi^2 m_W^2}\begin{pmatrix} \Delta_{11} & \Delta_{12} \\ \Delta_{12} & \Delta_{22}\end{pmatrix};\end{aligned}$$

$$\begin{aligned}\Delta_{11} &= \frac{m_b^4}{c_\beta^2}\Big(\ln\frac{m_{\tilde{b}_1}^2 m_{\tilde{b}_2}^2}{m_b^4} + \frac{2A_b(A_b-\mu\tan\beta)}{m_{\tilde{b}_1}^2 - m_{\tilde{b}_2}^2}\ln\frac{m_{\tilde{b}_1}^2}{m_{\tilde{b}_2}^2}\Big) \\ &+ \frac{m_b^4}{c_\beta^2}\Big(\frac{A_b(A_b-\mu\tan\beta)}{m_{\tilde{b}_1}^2 - m_{\tilde{b}_2}^2}\Big)^2 g(m_{\tilde{b}_1}^2, m_{\tilde{b}_2}^2) + \frac{m_t^4}{s_\beta^2}\Big(\frac{\mu(A_t - \frac{\mu}{\tan\beta})}{m_{\tilde{t}_1}^2 - m_{\tilde{t}_2}^2}\Big)^2 g(m_{\tilde{t}_1}^2, m_{\tilde{t}_2}^2). \\ \Delta_{22} &= \frac{m_t^4}{s_\beta^2}\Big(\ln\frac{m_{\tilde{t}_1}^2 m_{\tilde{t}_2}^2}{m_t^4} + \frac{2A_t(A_t - \frac{\mu}{\tan\beta})}{m_{\tilde{t}_1}^2 - m_{\tilde{t}_2}^2}\ln\frac{m_{\tilde{t}_1}^2}{m_{\tilde{t}_2}^2}\Big) \\ &+ \frac{m_t^4}{s_\beta^2}\Big(\frac{A_t(A_t - \frac{\mu}{\tan\beta})}{m_{\tilde{t}_1}^2 - m_{\tilde{t}_2}^2}\Big)^2 g(m_{\tilde{t}_1}^2, m_{\tilde{t}_2}^2) + \frac{m_b^4}{c_\beta^2}\Big(\frac{\mu(A_b-\mu\tan\beta)}{m_{\tilde{b}_1}^2 - m_{\tilde{b}_2}^2}\Big)^2 g(m_{\tilde{b}_1}^2, m_{\tilde{b}_2}^2). \\ \Delta_{12} &= \Delta_{21} = \frac{m_t^4}{s_\beta^2}\frac{\mu(A_t - \frac{\mu}{\tan\beta})}{m_{\tilde{t}_1}^2 - m_{\tilde{t}_2}^2}\Big(\ln\frac{m_{\tilde{t}_1}^2}{m_{\tilde{t}_2}^2} + \frac{A_t(A_t - \frac{\mu}{\tan\beta})}{m_{\tilde{t}_1}^2 - m_{\tilde{t}_2}^2} g(m_{\tilde{t}_1}^2, m_{\tilde{t}_2}^2)\Big) \\ &+ \frac{m_b^4}{c_\beta^2}\frac{\mu(A_b-\mu\tan\beta)}{m_{\tilde{b}_1}^2 - m_{\tilde{b}_2}^2}\Big(\ln\frac{m_{\tilde{b}_1}^2}{m_{\tilde{b}_2}^2} + \frac{A_b(A_b-\mu\tan\beta)}{m_{\tilde{b}_1}^2 - m_{\tilde{b}_2}^2} g(m_{\tilde{b}_1}^2, m_{\tilde{b}_2}^2)\Big).\end{aligned}$$

Here $c_\beta^2 = \cos^2\beta$, $s_\beta^2 = \sin^2\beta$ and $g(m_1^2, m_2^2) = 2 - \frac{m_1^2 + m_2^2}{m_1^2 - m_2^2}\ln\frac{m_1^2}{m_2^2}$. Neutral CP-even Higgs eigenvalues are

$$m_{H,h}^2 = \frac{1}{2}\Big\{H_{11} + H_{22} \pm \sqrt{(H_{11}+H_{22})^2 - 4(H_{11}H_{22} - H_{12}^2)}\Big\},$$

The mixing angle α_H is obtained from

$$\sin 2\alpha_H = \frac{2H_{12}^2}{m_{H_1^0}^2 - m_{H_2^0}^2}, \qquad \cos 2\alpha_H = \frac{H_{11}^2 - H_{22}^2}{m_{H_1^0}^2 - m_{H_2^0}^2}.$$

The mass of the charged Higgs boson is given by $m_{\rm CH}^2 = m_W^2 + M_A^2 + \frac{3g_2^2}{16\pi^2 m_W^2}\Delta_{\rm ch}$ [14].

Therefore free parameters are $\tan\beta$, the ratio of neutral Higgs boson vacuum expectation values; μ, the bilinear Higgs parameter of the superpotential; M_1 and M_2, soft gaugino masses; M_A, the CP-odd Higgs mass; $m_{\widetilde{Q}}^2$, $m_{\widetilde{U}}^2$ and $m_{\widetilde{D}}^2$, squark mass parameters squared for the 1st and 2nd generation; $m_{\widetilde{L}}^2$ and $m_{\widetilde{E}}^2$, slepton mass parameters squared for the 1st and 2nd generation; $m_{\widetilde{Q}_3}^2$, $m_{\widetilde{T}}^2$ and $m_{\widetilde{B}}^2$, 3rd generation squark mass parameters squared; $m_{\widetilde{L}_3}^2$ and $m_{\widetilde{\tau}}^2$, 3rd generation slepton mass parameters squared; A_t, A_b and A_τ, soft trilinear couplings for the 3rd generation. With these parameters one completely determines the MSSM spectrum and the coupling constants. Following [15]–[17] we assume that squarks are degenerate. Bounds on flavor-changing neutral currents imply that squarks with equal gauge quantum numbers must be close in mass. Therefore, for the sfermion mass parameters we used the relations $m^2_{\widetilde{U}} = m^2_{\widetilde{D}} = m^2_{\widetilde{Q}}$, $m^2_{\widetilde{E}} = m^2_{L}$, $m^2_{\widetilde{T}} = m^2_{\widetilde{B}} = m^2_{Q_3}$, $m^2_{\widetilde{E}_3} = m^2_{L_3}$. The parameters A_b and A_τ are fixed to be zero.

The present lifetime of the Universe implies an upper limit on the expansion rate and correspondingly on the total relic abundance. Assuming that the neutralinos form a dominant part of the dark matter in the Universe [1, 8, 10] one obtains a lower limit on the neutralino relic density. In this analysis the cosmological constraint $0.025 < \Omega_\chi h_0^2 < 1$ was implemented[2]. The neutralino mass density parameter $\Omega_\chi h_0^2$ was calculated by the standard procedure on the basis of the approximate formula [20]. All channels of the $\chi - \chi$ annihilation are included. Since neutralinos are mixtures of gauginos and higgsinos, annihilation can occur both via s-channel exchange of the Z^0 and Higgs bosons and t-channel exchange of a scalar particle [12, 20, 21]. Another stringent constraint is imposed by the branching ratio of the $b \to s\gamma$ decay, measured by the CLEO collaboration to be $1.0 \times 10^{-4} < \mathrm{B}(b \to s\gamma) < 4.2 \times 10^{-4}$. In the MSSM this flavor-changing neutral-current process receives contributions from $H^\pm$–t, $\tilde{\chi}^\pm$–$\tilde{t}$ and $\tilde{g}$–$\tilde{q}$ loops in addition to the standard model W–t loop. These also strongly restrict the parameter space [22].

The masses of the supersymmetric particles are constrained by the results from the high energy colliders. This imposes constraints on the parameter space of the MSSM. The following experimental restrictions are used [23]: $M_{\tilde{\chi}^+_2} \geq 65$ GeV for the light chargino, $M_{\tilde{\chi}^+_1} \geq 99$ GeV for the heavy chargino, $M_{\tilde{\chi}^0_{1,2,3}} \geq 45, 76, 127$ GeV for non-LSP neutralinos, $M_{\tilde{\nu}} \geq 43$ GeV for sneutrinos, $M_{\tilde{e}_R} \geq 70$ GeV for selectrons, $M_{\tilde{q}} \geq 210$ GeV for squarks, $M_{\tilde{t}_1} \geq 85$ GeV for light top-squark, $M_{H^0} \geq 79$ GeV for neutral Higgs bosons, $M_{\mathrm{CH}} \geq 70$ GeV for charged Higgs boson.

In the numerical analysis a trial set of MSSM parameters is picked up randomly from the following intervals:

$$\begin{gathered} -1\ \mathrm{TeV} < M_1 < 1\ \mathrm{TeV}, \quad -2\ \mathrm{TeV} < M_2, \mu, A_t < 2\ \mathrm{TeV}, \\ 1 < \tan\beta < 50, \quad 60\ \mathrm{GeV} < M_A < 1000\ \mathrm{GeV}, \\ 10\ \mathrm{GeV}^2 < m^2_Q, m^2_L, m^2_{Q_3}, m^2_{L_3} < 10^6\ \mathrm{GeV}^2. \end{gathered}$$

For each trial set the MSSM particle masses and other observables are evaluated and compared with the restrictions and constraints discussed above. If all constraints are successfully passed, the so-called total event rate R integrated over recoil energies is calculated [7].

The results of the scanning procedure are presented in fig. 4 as scatter plots. The main feature is a lower bound for the total event rate R. An absolute minimum value of about 10^{-6} events/day/kg in a ^{73}Ge detector is obtained in the above-mentioned domain of the MSSM parameter space. There is a clear increase (up to one order of magnitude) in the lower bound only with $\tan\beta$. In all other cases there is a decrease in the lower bound; the decrease is the sharpest with $|\mu|$, M_A (about 5 orders of magnitude) and M^2_Q and with the squark mass $M_{\widetilde{q}}$, heavy chargino mass $M_{\tilde{\chi}^+_1}$ and charged Higgs boson mass M_{CH}.

[2]Recently exciting evidence for a flat and accelerating universe has been obtained [18, 19], which results in a more stringent cosmological constraint $0.1 < \Omega_\chi h_0^2 < 0.3$. This new constraint does not affect the main result of the paper.

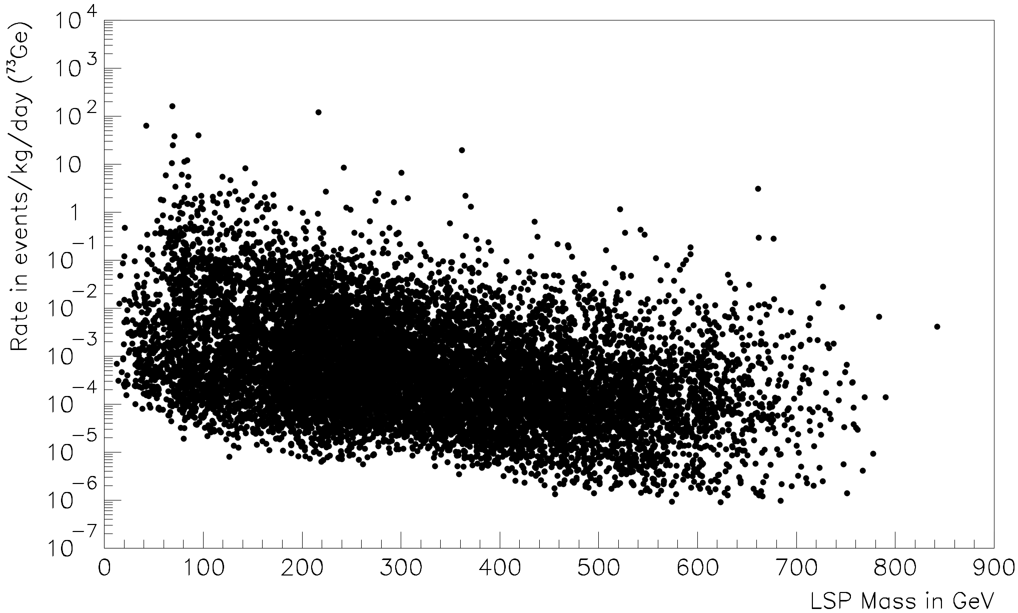

Figure 4: Total event rate in ^{73}Ge versus the mass of LSP. The lower bound decreases with increasing the mass of the LSP and reaches the absolute minimum of about 10^{-6} events/day/kg

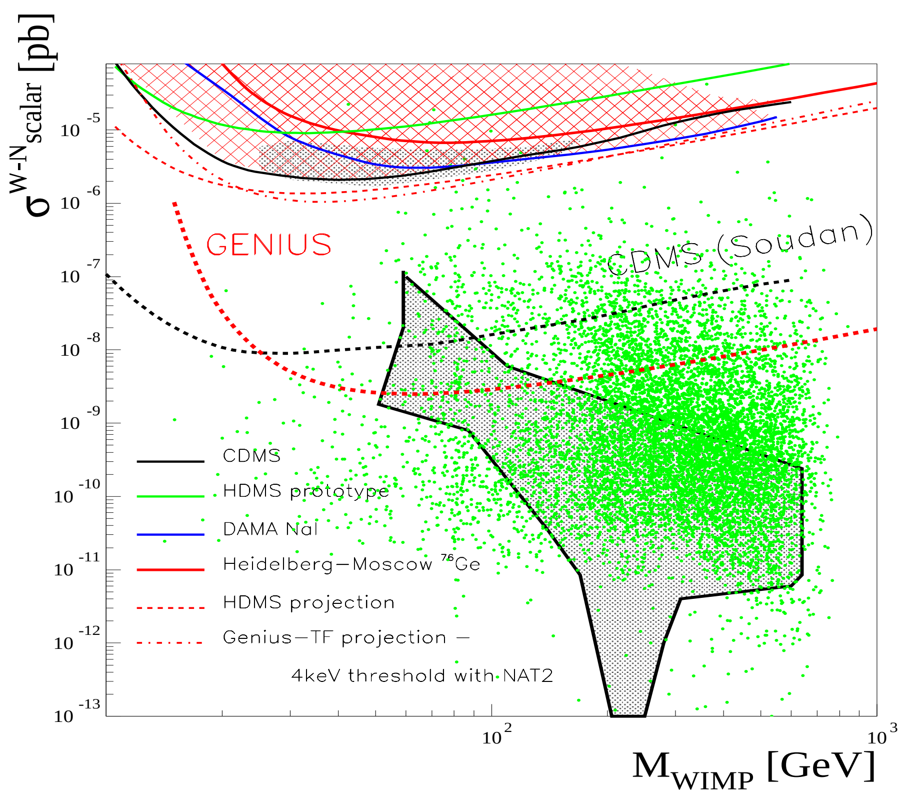

Figure 5: WIMP-nucleon cross section limits for scalar interactions as a function of the WIMP mass. Points are calculated without extra constraints. The filled area is obtained in [5]. Some experimental results and expectations are also given [24, 25, 26]

For comparison of the results obtained with sensitivities of different dark matter experiments the total cross section for relic neutralino scalar elastic scattering on the nucleon was also calculated and presented in fig. 5.

The variation of the lower bound for the event rate with the MSSM parameters and SUSY particle masses allows one to consider prospects for dark matter search under specific assumptions concerning these parameters and masses. To this end a number of extra scans with extra limitations on the single squark mass ($M_{sq} < 250,\ 230$ GeV), light neutral CP-even Higgs boson mass ($M_{Hl} < 80,\ 100,\ 120$ GeV), charged Higgs boson mass ($M_{CH} < 150,\ 200$ GeV) and heavy chargino mass ($M_{ch-os} < 250$ GeV) were performed. The case with light masses of all superpartners (less than 300–400 GeV) was also considered. All corresponding curves together with the absolute lower bound from the unconstrained scan are depicted in Fig. 6. A restriction that the

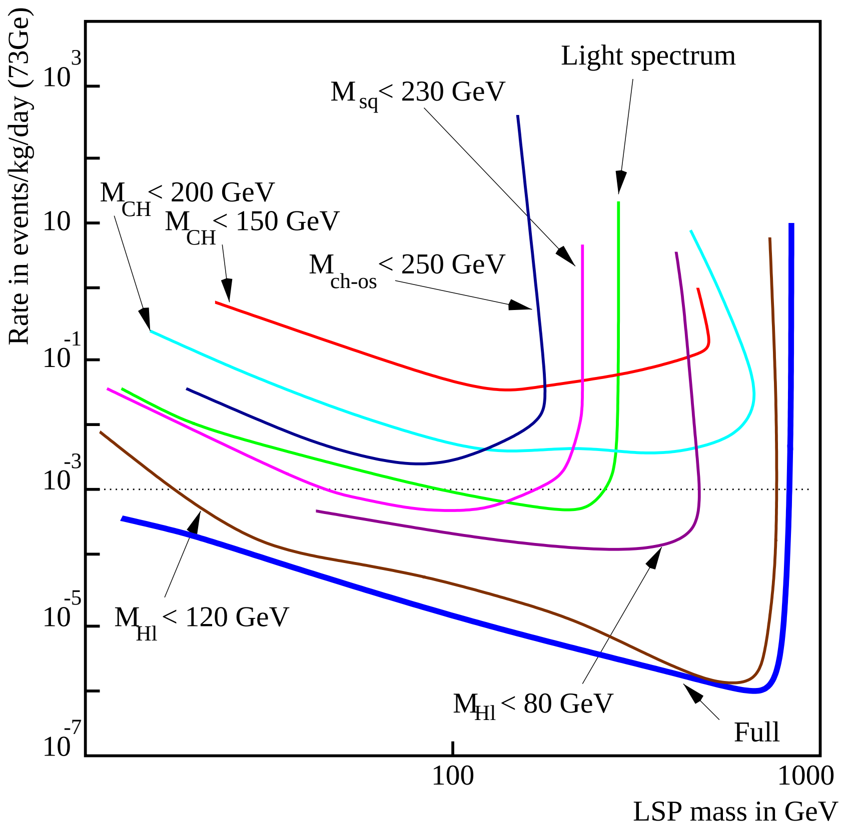

Figure 6: Different lower bounds for the total event rate in ^{73}Ge (events/day/kg) versus the LSP mass (GeV). Here $M_{sq,\ CH,\ Hl}$ denote masses of the squark, the charged Higgs boson and the light neutral CP-even Higgs boson respectively. The heavy chargino mass is denoted as M_{ch-os}. "Full" corresponds to the lower bound obtained from the main (unconstrained) scan, and "Light spectrum" denotes the lower bound for R obtained with all sfermion masses lighter than about 300 GeV. The horizontal dotted line represents the expected sensitivity for direct dark matter detection with GENIUS [24, 25]

single (light) squark mass is small ($M_{sq} < 230$ GeV) as well as another assumption that all sferminos masses do not exceed 300–400 GeV put upper limits on the mass of the LSP and do not permit R to drop very deeply as the mass of the LSP increases. In both cases the lower bound for the rate is established for all allowed masses of the LSP at a level of 10^{-3} events/kg/day. This value for the event rate is considered as an optimistic sensitivity expectation for future high-accuracy detectors of dark matter like GENIUS (Fig. 7). The same lower bound is obtained under the assumption that both charginos are light ($M_{ch-os} < 250$ GeV).

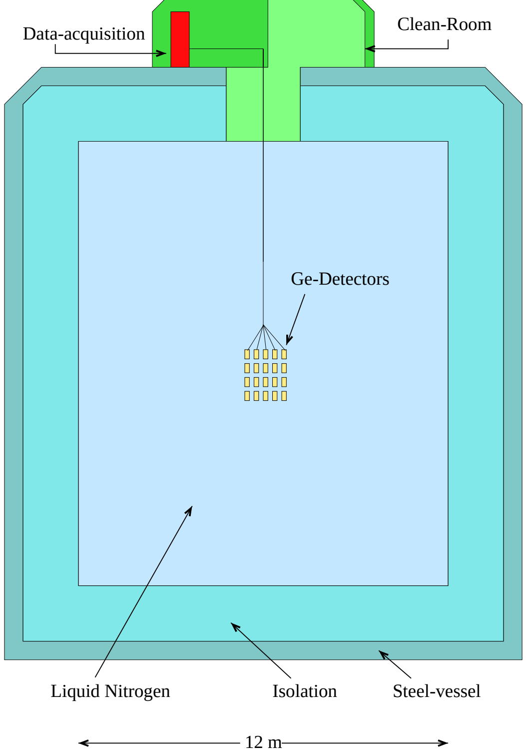

Figure 7: Schematic view of the GENIUS experiment: there are 300 enriched ^{76}Ge detectors (1 ton) in a liquid nitrogen shielding [24]

It is seen that the mass of the light neutral CP-even Higgs boson M_{Hl} has unfortunately a very poor restrictive potential (see, for example, the curve with $M_{Hl} <$ 120 GeV, the curve with $M_{Hl} <$ 80 GeV is already excluded). The situation looks most promising with the mass of the charged Higgs boson. When the charged Higgs boson mass is (relatively) small the other masses of CP-even and CP-odd Higgs bosons are also restricted from above. Therefore, couplings of the scalar neutralino-quark interaction, which contain $m^{-2}_{H,h}$-terms, are not suppressed enough and the rate cannot decrease significantly. The lower bound of the rate increases when the mass M_{CH} decreases and for $M_{CH} < 200\,$GeV (150 GeV) reaches the values of about 10^{-2} (10^{-1}) events/kg/day practically for all allowed masses of the LSP. As can be seen from Fig. 8, these values can be reached not only with GENIUS, but also with some other near-future direct dark matter detectors [26]. Filled circles in Fig. 8 give the scalar cross sections calculated under the assumption that the SUSY spectrum is light. Filled triangles give the cross section obtained with the charged Higgs boson mass restriction $M_{CH} <$ 200 GeV. If it happens, for instance, that either the SUSY spectrum is light indeed or the charged Higgs boson mass really does not exceed 200 GeV, in both cases at least the GENIUS experiment should detect a dark matter signal. If one considers a more complicated condition and assumes that the SUSY spectrum is light and simultaneously that $\tan\beta$ is quite large, then not only GENIUS, but also CDMS and HDMS [25, 26] will have very good prospects for detecting a dark matter signal. This situation is illustrated in Fig. 9, where, besides cross section limits for the WIMP-nucleon scalar interactions for different experiments, calculations for the case of a light SUSY spectrum with extra assumptions of $\tan\beta > 20$ (filled circles) and $\tan\beta > 40$ (filled triangles) are given.

Therefore, the correlations between the lower limit for the event rate R and some masses of SUSY particles allow good prospects for direct dark matter detection with next-generation detectors. The prospects could be brighter if collider searches would be able to restrict the mass of the charged Higgs boson at a level of about 200

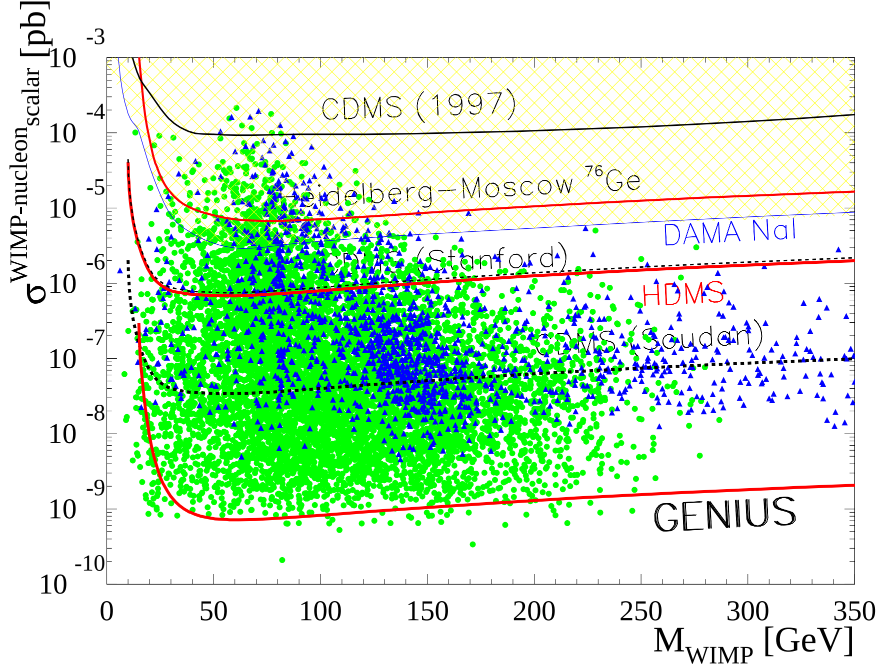

Figure 8: WIMP-nucleon cross section limits for scalar interactions as a function of the WIMP mass. Filled circles present calculations with the light SUSY spectrum. Filled triangles give the cross section on the assumption that $M_{CH} < 200$ GeV

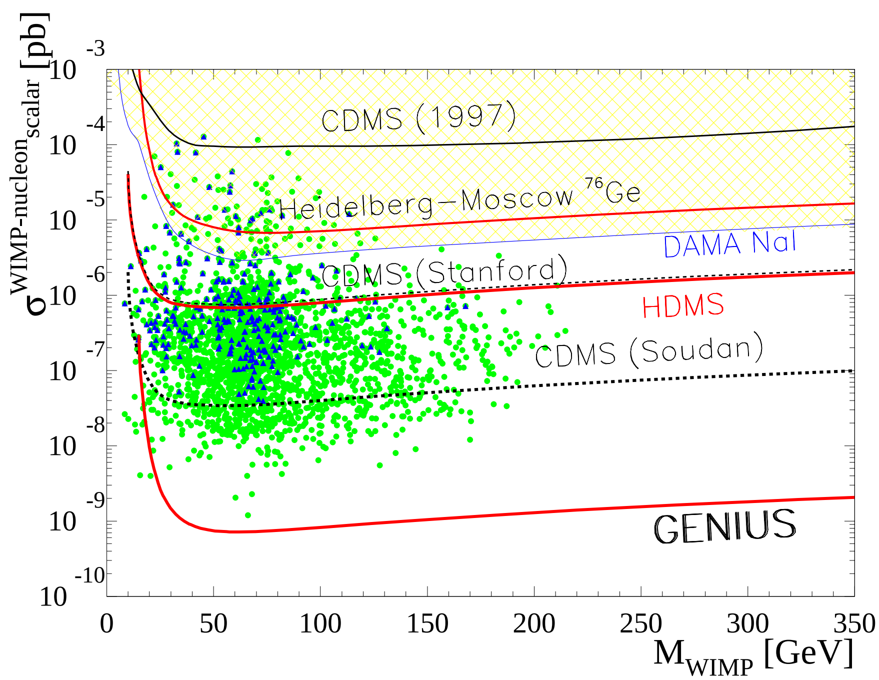

Figure 9: WIMP-nucleon cross section limits for scalar interactions as a function of the WIMP mass. Filled circles present our calculations with the light SUSY spectrum and $\tan\beta > 20$. Filled triangles give the same, but for $\tan\beta > 40$

GeV (light Higgs sector). The observation, due to its importance for dark matter detection, could serve as a stimulus for extra efforts to search for charged Higgs boson with colliders. Considered together, both these experiments, collider search for charged Higgs boson and dark matter search for SUSY LSP, become very decisive for a verification of SUSY models.

On the contrary, non-observation of any dark matter signal with very sensitive dark matter detectors, in accordance with Fig. 6–9, would exclude, for example, a SUSY spectrum with masses lighter than 300–400 GeV as well as a light SUSY spectrum with large $\tan\beta$ (Fig. 9), charginos with masses smaller than 250 GeV (Fig. 6), charged Higgs boson with $M_{CH} < 200$ GeV, and therefore the entire light Higgs sector in the MSSM (Fig. 8).

The latter case is in particular interesting, because if the light charged Higgs boson is excluded by GENIUS, then either it will be rather unpromising to search for it with colliders, or any positive result of a collider search brings strong contradictions in the MSSM approach to dark matter detections and/or collider SUSY searches.

These results may be considered as a good example of the complementarity of modern accelerator and non-accelerator experiments looking for SUSY and other new physical phenomena.

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