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Experiments aiming at direct detection of dark matter

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Abstract. We present a review of existing and planned dark matter direct detection experiments. The emphasis is on principle limitations for this detection technique and resulting consequences for future projects. We argue that the near future experiments, CDMS and HDMS, will give such stringent limits on WIMP–nucleon elastic cross sections that the next round of experiments will have to be either massive direction–sensitive detectors or massive ton–scale detectors with almost zero background. Candidate experiments with these requirements are shortly introduced like the newly announced GENIUS proposal. We also shortly discuss the implications of WIMP search results for accelerator experiments and vice versa.

PACS. 95.35.+d Dark matter

1 Introduction

The direct detection of dark matter in the form of WIMPs (weakly interacting massive particles), has evolved into an intensive field of research with about 20 experiments running or starting in the near future (compare Tab. 1, for reviews see [1–3]). The hints from astrophysics for the existence of non–baryonic dark matter in the universe are summarised in [1,4] and references therein.

The direct detection technique is defined by the observation of WIMP–nucleus elastic scattering events. These events deposit energy in the detector by the recoiling nucleus. The main uncertainties entering this technique stem from the astrophysical input data like the local WIMP halo–density, 0.3 – 0.7 GeV/cm^3 [5,6] (note that the WIMP rates are directly proportional to this parameter) and the WIMP velocity distribution. The mean WIMP velocity is of the order 10^{-3}c. Combined with expected masses above a few GeV/c^2, the interesting energy region for experiments results from kinematics as below $\sim$ 100 keV. The main challenge for all kinds of direct detection experiments is to reduce their background, induced for instance by radioactive impurities or neutrons.

Results of existing experiments give upper limits on the allowed WIMP–nucleon elastic scattering cross section as function of the WIMP mass. The conservative assumption underlying these limits is that the measured energy spectrum (usually in the units cpd/kg/keV [1]) in the interesting energy region consists of WIMP events. Without any further information a given energy spectrum produces a time independent exclusion curve in the cross section–mass plane (all limits in this article have a 90% confidence level).

The next step would be to use signatures of WIMP events and nuclear recoil–specific observables to suppress background. There exists for some detectors (*e.g.* NaI scintillators) the possibility to discriminate between nuclear recoil induced events and others due to differences in pulse shapes [14,11]. Another special observable, already used in cryogenic detectors [21], is the partition of deposited energy by nuclear recoils into a phonon signal and an ionization signal.

Further, there are time–dependent WIMP signatures due to the movement of the sun through the galactic halo [31] inducing a diurnal modulation of WIMP events for direction–sensitive detectors and an annual modulation due to the rotation of the earth around the sun [32] (compare Fig. 1). A time–independent signature comes from the detector–material dependence of WIMP events. All these signatures and observables, if handled with care, can in principle be used to either suppress background and thereby improve the limits considerably or even to 'prove' the detection of WIMPs (material dependence and modulation signatures could 'prove' WIMP detection).

Besides the fascinating chance to discover WIMP dark matter in the Universe or at least in our galaxy there also exists the possibility to test the idea of supersymmetry (SUSY) since the minimal supersymmetric standard model (MSSM, with R–Parity conservation) provides a dark matter candidate, the lightest supersymmetric particle (LSP). The expectations for WIMP direct detection rates are at best of the order 1 cpd/kg but can be sup-

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[1] (cpd: counts per day)

Table 1. List of existing and planned direct detection experiments (updating [7])

WIMP SEARCHES			
Experiment in progress	**Location**	**Detector Type**	**Ref.**
Baksan	Prielbrusye, Russia	Ge ionization	[8]
Canfranc-NaI	Canfranc, Spain	NaI scintillator	[9]
COSME	Canfranc, Spain	Ge ionization	[10]
DAMA	Gran Sasso, Italy	NaI scintillator, liquid Xe scintillator, CaF_2 scintillator	[11]
DEMOS	Sierra Grande, Argentina	Ge ionization	[12]
Milan	Gran Sasso, Italy	Cryogenic TeO_2 bolometer	[13]
UKDMC	Boulby mine, U.K.	NaI scintillator	[14]
Under construction			
HDMS	Heidelberg, Germany	Ge ionization	[18]
CDMS	Stanford, U.S.	Cryogenic Ge/Si bolometer with ionization	[21]
CRESST	Gran Sasso, Italy	Cryogenic sapphire bolometer	[24]
EDELWEISS	Fréjus, France	Cryogenic Ge bolometer with ionization	[15]
ELEGANT VI	Oto cosmo obs, Japan	CaF_2 scintillator	[16]
Tokyo	Nokogiri-yama, Japan	Cryogenic LiF bolometer	[17]
LP–TPC	San Diego, USA	Direction–sensitive low–pressure TPC	[30]
Future			
PICASSO	Montreal, Canada	Superheated Freon droplets	[19]
ORPHEUS	Bern, Switzerland	Superconducting transition in tin granules	[20]
ROSEBUD	Canfranc, Spain	Cryogenic sapphire bolometer	[25]
SALOPARD	Canfranc, Spain	Superconducting transition in tin granules	[26]
SIMPLE	Paris, France	Superheated Freon droplets	[27]
UKDMC	Boulby mine, U.K.	Liquid Xe scintillator	[28]
CASPAR	Boulby mine, U.K.	CaF_2+L-scintillator gel	[29]
GENIUS	Heidelberg, Germany	Ge ionization in liquid nitrogen	[46,47]

pressed by many orders of magnitude depending on the candidate (for the neutralino as the LSP and expected rates, see [33–40]). In order to compare theoretical expectations for WIMP-rates and experimental exclusion curves from different experiments (using different target materials) one has to be careful. First of all, a common set of astrophysical input data has to be used. Second, to compare exclusion curves obtained with different target materials one has to separate nuclear properties due to the material from WIMP properties (both entering into the elastic scattering cross section) [1,2,35]. This is the reason why in recent works usually exclusion curves are given for WIMP–nucleon scattering, differentiating between the two cases of spin–independent WIMP–nucleon interactions σ^{W-N}_{scalar} and spin–dependent interactions σ^{W-N}_{axial}. Only experiments using the same target material can directly compare their results in a Rate–WIMP-mass diagram, since the schematic rate equation is

$$R = \frac{N_0}{A}\, n_0\, \sigma\, \langle v \rangle \ , \tag{1}$$

where R is the countrate in cpd/kg, N_0/A gives the number of target nuclei, n_0 the local number density of WIMPs in the halo, $\langle v \rangle$ the average WIMP velocity in the halo and σ is the elastic scattering cross section including the nuclear form factor. Disentangling the cross section σ^{W-N} from nuclear properties in the form factor therefore is necessary in order to compare different experiments using different target material.

The Figs. 5 and 6 are examples for this procedure: Fig. 5 compares detectors using different target materials and expectations together in one picture for spin–

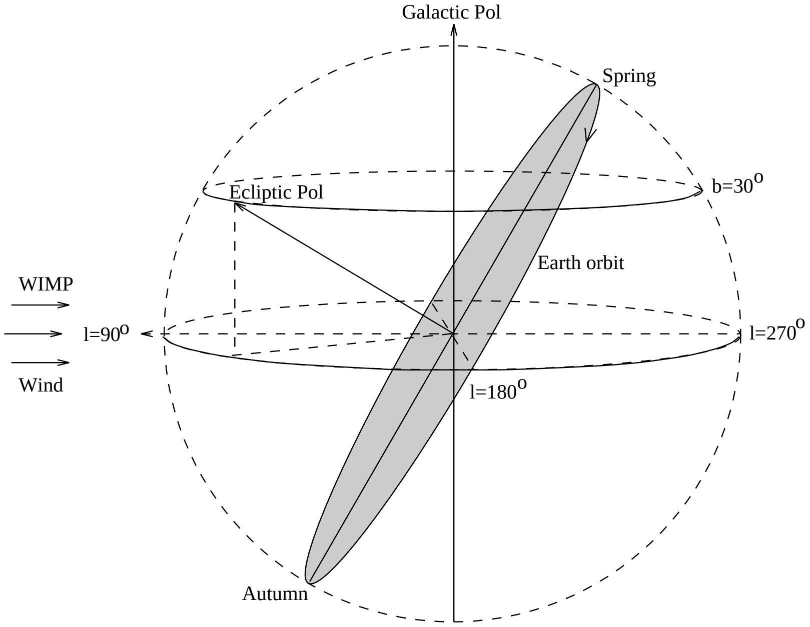

Fig. 1. Schematic picture of the earth orbit (shaded region) in galactic coordinates, showing the 60 degree tilt relative to the velocity vector of the sun rotating around the galactic center. This rotation induces a wimp–wind indicated by arrows from the left. In June the velocity vector of the earth is antiparallel, adding an extra–velocity of 15 km/s. This modulation of WIMP-kinetic energies is an annual WIMP-signature [32]

independent interactions using the σ^{W-N}_{scalar}–scale in picobarn. Fig.6 compares bounds from Germanium experiments where we for simplicity assumed that these experiments use ^{76}Ge (which HDMS and CDMS won't use) in order to compare them consistently to excluded rates from the HEIDELBERG–MOSCOW–EXPERIMENT [41], [55]. The reason to show Fig. 6 is to ease the comparison to theoretical expectations usually given in rates rather then cross sections.

2 Present experiments

According to the philosophy of using raw data, *i.e.* the measured energy spectrum without subtraction of events (with the exception of obvious microphonic noise), to obtain a WIMP–nucleon cross section upper limit, the HEIDELBERG–MOSCOW–EXPERIMENT still gives the best limit for heavy WIMPs [41]. Combined with other Germanium ionization detectors like COSME, Baksan and DEMOS, the limits from Germanium detectors are the most sensitive ones for spin–independent interactions using raw data. Limits for spin–dependent interactions are dominated by raw data NaI scintillator experiments like DAMA and UKDMC.

The interesting experimental number which mainly determines obtainable WIMP–nucleon cross section limits is the background index near the detector threshold, typically at or below 10 keV. Background of the order 1 cpd/(kg keV) or below (HEIDELBERG–MOSCOW–EXPERIMENT: 0.1 cpd/(kg keV) between 12 keV – 30 keV) has already been reached for raw data. Decrease of detector thresholds improves the sensitivity for low mass WIMPs (<tens of GeV), whereas lowering the background index improves the whole WIMP exclusion curve.

Recently, two new limits (for spin–dependent as well as spin–independent interactions) from the UKDMC and DAMA experiments have been published [14,11]. These limits do not result from raw data but from a reduction of background due to the application of a highly elaborate pulse shape analysis. In NaI scintillators pulses induced by nuclear recoil events can be selected with an experiment–specific efficiency. As obvious, these efficiencies and their dependence on all detector parameters must be well known. With the ability to use this scintillator–specific WIMP signature both groups reduced their background considerably and the DAMA experiment [11] now gives the best limits for both kinds of possible interactions (for spin–independent interactions the UKDMC [14] gives a comparable limit to the 'old' limit of the HEIDELBERG–MOSCOW–EXPERIMENT [41]; the DAMA [11] result improves that limit by roughly a factor four). A new limit from the HEIDELBERG–MOSCOW experiment [55] is practically identical to this DAMA limit.

The first cryogenic experiment using information from the phonon and the ionization signal, the CDMS experiment, just started data taking and reported their first results [22,21,23]). Again, a signature of nuclear recoils is used to suppress background. Nuclear recoils in Germanium crystals deposit about 2/3 of their energy in lattice vibrations; 1/3 in ionization ([1,42] and references therein). Discrimination efficiencies for nuclear recoils against electron recoils are quoted as $\sim 99\%$ or even higher. This cryogenic–detector–specific signature is energy dependent. Their nuclear recoil separation abilities increase at higher energies and so far work well for energies above about 15 keV. The background has been determined to be up to now – *after* rejection of electron and γ events – not better than that of the HEIDELBERG–MOSCOW–EXPERIMENT. As emphasised by the CDMS collaboration, the rejection mechanism for their Germanium crystal is bounded below about 8 keV due to electron induced events at the surface dead layer. To conclude, they

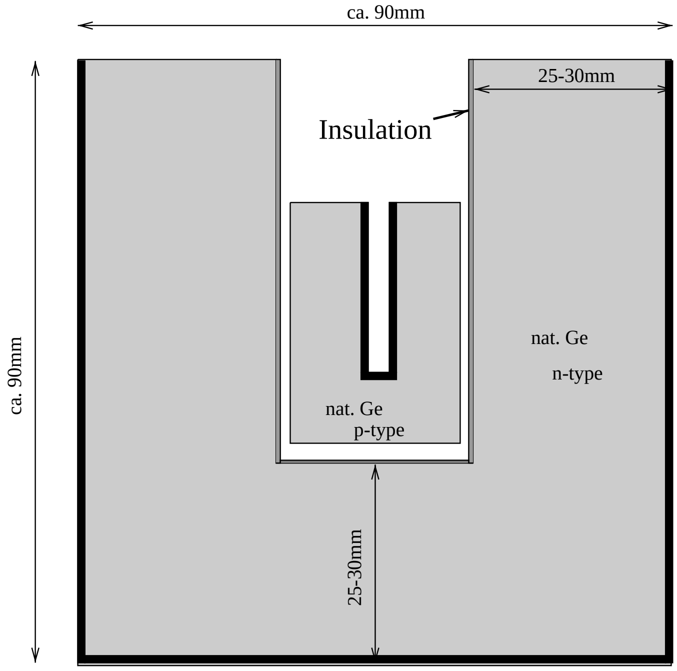

Fig. 2. Schematic geometry of the new HDMS (Heidelberg Dark Matter Search) anti–coincidence detector design. The well-type Ge crystal will be a n–type semiconductor, the small measurement Ge crystal a p–type. The approximate diameter of the well–type will be 90mm, the height 90mm; the small measurement crystal will have about 30mm diameter and a height of 40mm (from [18])

showed their ability to reach a 99% relative background rejection, at least for a threshold above 15 keV which will probably improve in the future. Now they have to reach a comparable absolute background level like, for example, the HEIDELBERG–MOSCOW–EXPERIMENT for raw data in order to improve WIMP limits to the order of 0.1 cpd/kg. The problem is much more serious for the CRESST experiment [24] and for the new CUORE proposal [54], whose backgrounds could be *at best* that of the HEIDELBERG–MOSCOW–EXPERIMENT, but *without* the possibility of CDMS, to improve this by some kind of discrimination.

3 Future projects

In the near future (1998) a rather unusual prototype experiment will start, the Heidelberg Dark Matter Search (HDMS) Experiment [18]. It is unusual in the sense that it will be a raw data experiment using the 'old–fashioned' (compare Tab. 1) Germanium ionization technique. The idea is to plug a small Ge crystal into the hole of a huge well-type Ge crystal with just a thin electric insulation plastic between the crystals (compare Fig .2).

We expect two effects to reduce the background: First, the outer well–type will act as an anticoincidence shield for the inner detector, thereby reducing Compton background from multiple scattered photons. A relative background reduction of the order of 10 by this anticoincidence has been estimated. Second, the overall background level is expected to be reduced relative to usual Ge ionization detectors since in the immediate vicinity of the measurement crystal there is one of the radiopurest materials which we know, *i.e.* a second Ge crystal. This effect on the background level is so far undetermined and remains open until the experiment will be tested in its final location, the Gran Sasso underground laboratory. To conclude, we expect to give WIMP limits comparable to planned or started cryogenic experiments just by using raw data (microphonics subtracted).

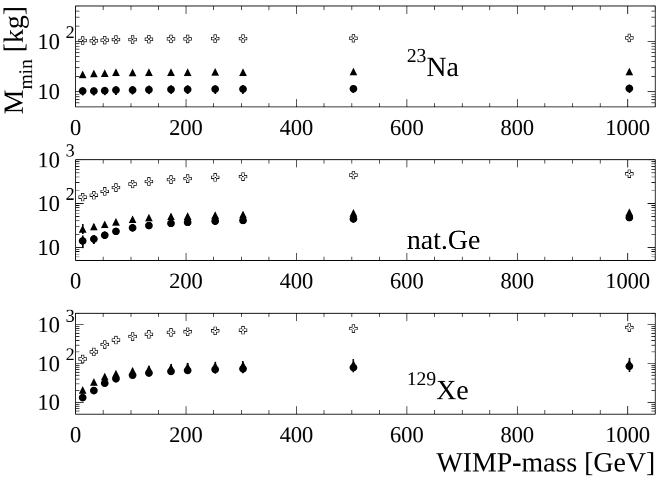

Fig. 3. Minimum target mass needed for a direct detection experiment to detect modulations as the WIMP signature as function of the WIMP mass in GeV (dots). The assumptions in this picture are a zero background rate $\langle B \rangle = 0$ and an optimistic WIMP candidate rate of $R_{\rm expect} = 1$ cpd/kg ($N\,P = 365$ days; 97.5% C.L.). Changes due to a 10^3 cpd (integral) background (triangles) and due to an expected rate of 0.1 cpd/kg (zero background) (crosses) are also shown (from [43])

Notable exceptions of upcoming direct detection experiments are the so called background–blind experiments using superheated freon droplets: PICASSO [19] and SIMPLE [27]. Like Germanium ionization detectors they will have to use raw data with the advantage of being insensitive to β– and γ–radiation. Since this detector principle can not measure an energy spectrum (it could by tediously raising the threshold stepwise) but is a pure counting detector, they are forced to search for the time dependent signature of WIMP events, *i.e.* the annual signal modulation.

In principle every kind of experiment could use this annual signature to improve its limit or even to find the modulation, but as can be shown [43] this procedure only makes sense for high–mass experiments. Note that the diurnal modulation mentioned in the introduction requires nuclear recoil direction–sensitive detectors as the low pressure drift chamber from [30], which is the only direction–sensitive experiment up to now (see Tab. 1).

The reason for the restriction to high detector masses to exploit the annual modulation signature is purely statis-

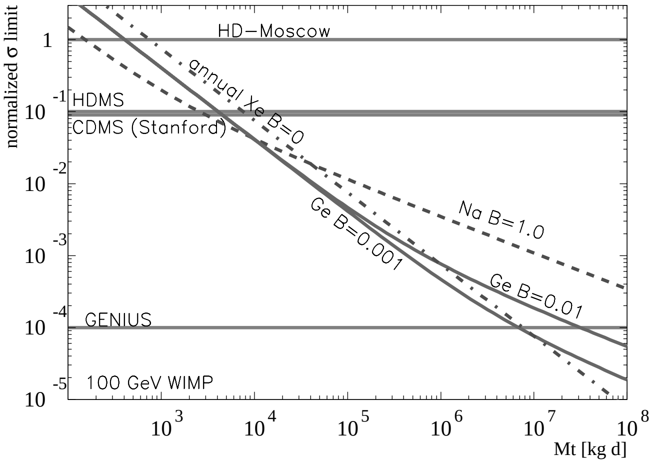

Fig. 4. Comparison of WIMP–nucleon cross section limits for time–independent as well as time–dependent limits as function of the significance in units of kg days (here for a 100 GeV WIMP; B: background in cpd/kg, 90% C.L.). Results and perspectives are normalised to the HEIDELBERG–MOSCOW–EXPERIMENT result. Using the annual WIMP signature gives the time–dependent limits. In order to use the annual modulation in a reasonable time, a high–mass experiment is needed. The influence of upcoming CDMS and HDMS limits on future experiments using the absence of any annual modulation to obtain limits is obvious in this picture. The time–dependent limit for Germanium (assuming the almost zero background for GENIUS of B= 0.001 cpd/kg, solid line) would improve the time–independent limit for GENIUS only after 7×10^6 kg days (about 20 years for a one ton experiment). A more conservative background expectation however (say, factor ten higher), would result in a 0.01 cpd/kg limit for the time–independent as well as for the time–dependent experiment after 10^6 kg days (below 3 years for a one ton experiment). The two GENIUS curves show the relatively weak dependence of time–dependent limits on the background. The dashed line is for Sodium, assuming the a raw data background of 1 cpd/kg, the dot–dashed line is for Xenon assuming $B = 0$ cpd/kg

tical. There exist statistical limitations for the detection of a superimposed structure like a modulation of the energy spectrum [43]. These give stringent minimum detector–mass bounds for experiments trying to detect the modulations (see Fig. 3). Going to more realistic, lower WIMP limits below 1 cpd/kg would result in even stronger lower bounds due to the $(\text{rate})^{-1}$–dependence of required detector masses (for a relation to scale the bounds from Fig. 3 for non–vanishing background, different expected rates, measurement times and confidence level, see [43]). Thus, for improvements of WIMP limits with the help of this signature, even ideal (zero background) experiments will need high masses (see Fig. 4). This conclusion will be strengthened by the expected stringent WIMP limits from near future experiments like CDMS and HDMS. The time–dependent limits due to the non–observation of any annual modulation in the data (shown in Fig. 4 for a Sodium, Germanium and Xenon target and different assumed background B) will improve the time–independent limits after acquiring a significance (mass×time) of some 10^4 kgd (90% C.L.).

Thus, experiments like CDMS and HDMS set the stage for other future direct detection experiments which would rather have the task to detect a WIMP signature than to improve limits further.

The inspection of Tab. 1 shows three candidates for an experiment fulfilling the requirements of a high detector mass and low background: The DAMA experiment already runs about 90 kg NaI scintillators and proposes a ton mass–scale experiment [44], PICASSO and SIMPLE could built up similar masses due to the relatively low cost of their detectors and they expect a background of the order 10^{-3} cpd/kg [19]. The liquid Xenon proposal by the UKDMC is another high–mass candidate, promising an almost zero background [28]. All of these experiments (except perhaps the NaI epxeriment) will be experiments of a rather far future.

The optically imaged parallel plate avalanche chamber from [30] is another interesting project since it is a direction–sensitive detector. Although this experiment is too small (3.3 g carbon targets for 20 torr CH_4-TEA; 6.7 g argon targets for 20 torr Ar-CH_4-TEA [30]) at the moment, it could show the way for a far future experiment of the second category: massive direction–sensitive detectors. For example, a nuclear recoil direction sensitive detector, using the diurnal modulation mechanism with a relative amplitude of 3.3 (modulation amplitude over constant signal for orthogonal directions of recoils [45]), would even for a B= 1.0 cpd/kg background improve the CDMS limit from Fig. 4 after only 20 kg days (all limits for a 100 GeV WIMP, see [43]). For a reduction of background to zero even 7 kg days would be enough. Since the method of obtaining a WIMP limit from the non–observation of a modulation signature is strongly dependent on the modulation amplitude, a forward–backward sensitive experiment, giving relative amplitudes of the order of 8 [45], would improve WIMP limits very fast. For such high expected amplitudes (taking 8.5) the CDMS limit would be improved only after 3 kg days (B= 1.0 cpd/kg) or 1 kg day (B= 0 cpd/kg). This is a good reason to proceed with research for these detector types.

A very recent proposal, called GENIUS (Germanium Nitrogen Underground Setup) [46], [47], also belongs to the category future direct detection dark matter experiment and to the most promising ones. Although it is designed originally to search for the neutrinoless double beta decay in enriched ^{76}Ge, simply due to the mass scale of a ton, combined with an expected background reduction of a factor 10^4 relative to the HEIDELBERG–MOSCOW–EXPERIMENT, GENIUS would automatically give a strong WIMP limit of the order 0.001 cpd/kg from raw data (see Fig. 4,5). Even with a more conservative expectation for the low–energy background, GENIUS would give an 0.01 cpd/kg WIMP limit (WIMP–mass dependent) due to the absence of the annual modulation signature after one year (compare Fig. 4). As can be seen in Fig. 4, it would take about 20 years for GENIUS to improve its time–independent limit assuming the background reduction of a factor of 10^4 compared to the HEIDELBERG–MOSCOW–EXPERIMENT. The time-dependent limits

Table 2. Time-schedule for obtaining WIMP–limits from GENIUS after starting the measurement and assuming the indicated background suppression factors relative to the 1994 HEIDELBERG–MOSCOW–EXPERIMENT background. Time–independent limits are determined from the requirement to collect enough statistics for an evaluation, measurement times for time–dependent limits come from Fig. 4 and the requirement to improve the time–independent limits

	time–independent		time–dependent	
GENIUS mass	10^{-4} suppr.	10^{-3} suppr.	10^{-4} suppr.	10^{-3} suppr.
100 kg	~ 3 years	< 1 year	> 25 years	> 25 years
1 ton	< 1 year	< 40 days	$\sim$20 years	< 3 years

become interesting for more conservative background expectations since they are less background dependent (see in Fig. 4 the two curves for Germanium, and the curves for Sodium and Xenon and their different shapes due to their background). The time–scale for this experiment is so far undetermined but it has the advantage of using a well known detector technology, basically HPGe detectors but immersed in liquid nitrogen as outer shielding [46,47]. A very important point for the realization of GENIUS as a dark matter experiment is, that already 100 kg of *natural* Ge detectors are sufficient to perform the experiment in its full sensitivity (see Table 2).

4 On the relationship neutralino dark matter ↔ collider experiments

With the assumption that WIMP dark matter consists of neutralinos as the LSP one can compare the impact of direct detection experiments on accelerator experiments looking for SUSY particles and vice versa. Since this comparison deals with regions of the MSSM parameter space one first has to specify the MSSM scheme which determines the parameter space. Well known for predictions and also comparison of dark matter experiments and accelerators is the minimal supergravity (mSUGRA) scheme for which highly developed tools exist like ISAJET (see [33,48] and references therein). The mSUGRA scheme has a five dimensional parameter space (four numbers and the sign of the μ parameter are sufficient to fix a complete MSSM model, see for example [49]).

Unfortunately, predictions for direct detection rates are rather low (order 0.1 cpd/kg and below) [33,34]. As soon as the unification conditions of the mSUGRA scheme are relaxed (nonuniversal scalar unification, nonuniversal gaugino mass scheme, etc.) the dimension of the SUSY parameter space grows (six or seven dimensions) and predictions for neutralino rates increase (sometimes up to already excluded rates, see Fig. 5 for a nonuniversal scalar mass unification scenario) [36–40]. With this MSSM scheme dependence in mind one can state that current WIMP limits just start to cut into the SUSY parameter space.

The next–generation accelerator LHC will be able to cover the whole SUSY parameter space allowed by the cosmological constraint (neutralinos, if stable, should not overclose the universe) [33,50,51]. On the other hand, even for relaxed GUT conditions [40] phenomenologists

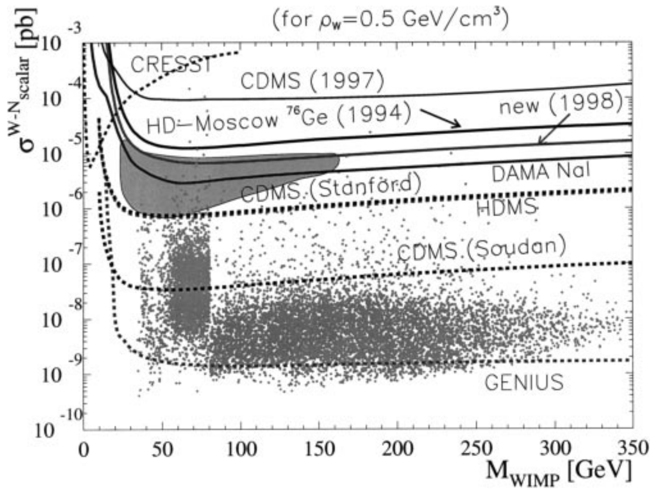

Fig. 5. Comparison of already achieved WIMP–nucleon scalar cross section limits (solid lines): the Heidelberg–Moscow ^{76}Ge [41](second top line the 1994 limit, below the new 1998 limits [55]); the UKDMC NaI experiment [14] is similar to the 1994 Heidelberg–Moscow limit), the 1997 CDMS nat. Ge [23] and the new DAMA NaI result [11] in pb for scalar interactions as function of the WIMP–mass in GeV and of possible results from upcoming experiments (dashed lines for HDMS, CDMS (at different locations; note that we changed their threshold expectations according to the already achieved 15 keV) CRESST, and GENIUS [46,47]). These experimental limits are also compared to expectations (scatter plot) for WIMP–neutralinos calculated in the MSSM framework with non–universal scalar mass unification [36]

find lower limits on allowed cross sections for dark matter detection rates under reasonable assumptions. As indicated in Fig. 5 the scatter plot of expected cross section is bounded at low cross sections and therefore it might be possible for a direct detection experiment to fully cover the range of cross sections. For example, the largest part of the allowed range could be probed by the future project GENIUS.

As Baer and Brhlik [33] discuss for the mSUGRA scheme, there is a clear complementarity between parameter regions testable by future dark matter and collider experiments. The dark matter experiments should be sensitive to rates of the order 0.01 cpd/kg like GENIUS (Fig. 6) to test SUSY parameter regions inaccessible to LEP2 or the upgraded Tevatron collider. A dark matter detector will be particularly sensitive in regions of large tan β in

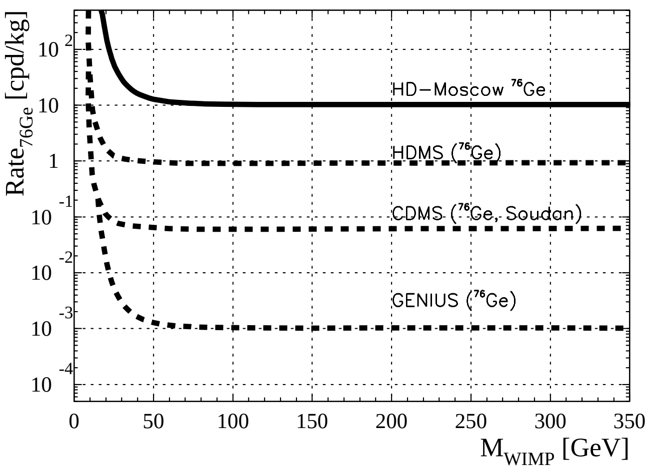

Fig. 6. Comparison of rate–limits obtained (solid) or obtainable (dashed) as function of the WIMP–mass for Germanium experiments. In order to draw the picture consistently, we had to assume that HDMS and CDMS would use the same isotope as the HEIDELBERG–MOSCOW–EXPERIMENT: ^{76}Ge. These possible rate–limits can roughly be compared to the expected rates from [33] since these are for ^{73}Ge (as long as spin–dependent interactions do not contribute significantly to the expectations, since ^{73}Ge would be sensitive for these but not ^{76}Ge). Note that the dashed lines only give approximate limits but they already show that the future experiments could indeed give strong constraints for the SUSY parameter space in the mSUGRA scheme, as discussed in [33]

the mSUGRA parameter space, where many conventional signals for supersymmetry in collider experiments are difficult to detect. Thus, if the parameter $\tan\beta$ is large, there is a significant probability that the first direct evidence for supersymmetry could come from direct dark matter detection experiments, rather than from collider searches for sparticles [33] (see also the discussion in [3]).

The detection of the neutralino at LHC would naturally have a big effect for WIMP experiments. Suddenly, one would know the kind of particle to look for but it would still be a fascinating question whether that candidate particle really constitutes the main ingredient of the universe. To answer that question directly, one needs direct detection dark matter experiments. More interesting from the point of view of a WIMP searcher is of course the case of detection of a WIMP before LHC has started. Such a scenario would have the disadvantage that one direct detection experiment can not determine the nature of the WIMP but measure its mass and the product of the local WIMP–halo density with the elastic scattering cross section, $n_W\,\sigma_{el}$. So the question to colliders in this case would be to check whether there is a neutralino or some other particle with corresponding mass and couplings to explain the WIMP search result. The maximum information about WIMPs from non–accelerator experiments can be obtained using different target nuclei [35,52] for direct detection, find a WIMP signal in an indirect detection experiment (a neutrino telescope) [53] and combine the results.

5 Conclusion

As soon as the upcoming experiments, CDMS and HDMS, improve the elastic WIMP–nucleon cross section limit, the future direct detection experiments will have to be high–mass experiments with an almost ideal, zero background in order to either proof possible hints for WIMP detection from CDMS or HDMS or to probe new regions of sensitivity. Candidate experiments for this purpose are planned for the future (some years from now): The Heidelberg GENIUS detector, the freon droplet detectors, the liquid Xenon project from the UKDM Collaboration or the ton mass scale project of the DAMA Collaboration.

Direction–sensitive detectors would be an alternative way having the disadvantage that research in this field has just started and so far no realistic massive detector of this kind is in sight.

The GENIUS proposal from the Heidelberg group would be an outstanding future dark matter detector in the sense that it combines a high mass, ultra–low background even for raw data and a well–known detector technology with HPGe detectors. As has been shown, either an extremely low background level or the mass–scale of a ton of target material provide two different ways to improve the WIMP–sensitivity of future detectors considerably. A detector combining both possibilities, like GENIUS, would be favoured as a future dark matter detector and able to face the challenge of WIMP detection, in combination with future collider experiments.

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