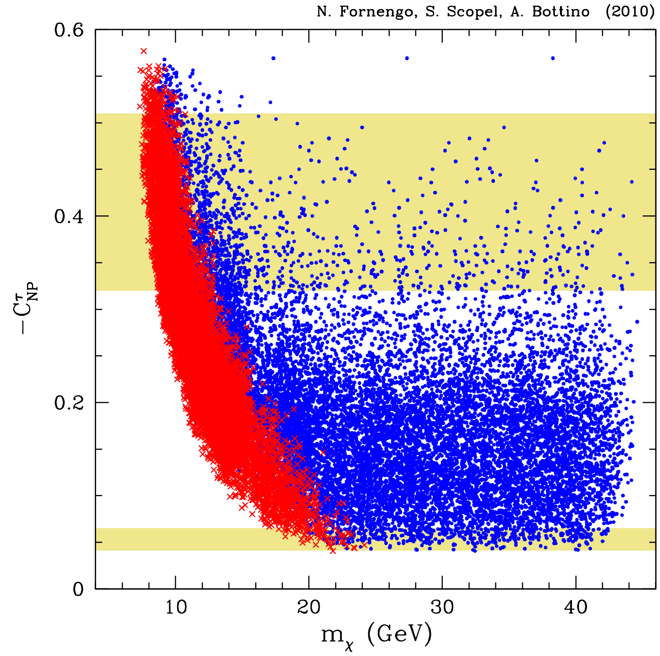

FIG. 21 (color online). Scatter plot of C^{τ}_{NP} as a function of the neutralino mass m_χ for the LNM-$\mathcal{A}$ scan. The two horizontal bands in yellow denote the ranges of C^{τ}_{NP} where the experimental intervals of $R_{B\tau\nu}$ and $R(D)$ have a common solution. Blue points stand for cosmologically subdominant neutralinos (i.e., $\Omega_\chi h^2 < 0.098$), while the red crosses refer to dominant configurations (i.e., $0.098 \leq \Omega_\chi h^2 \leq 0.122$).

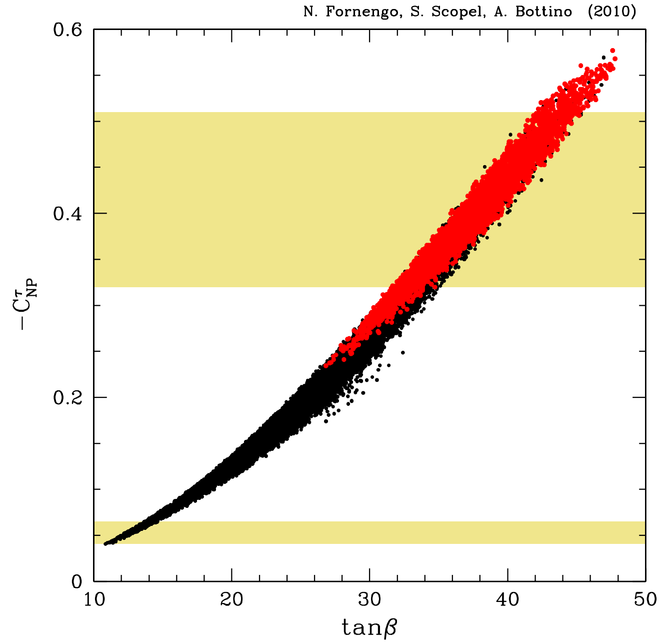

FIG. 22 (color online). Scatter plot of C^{τ}_{NP} as a function of tanβ for the LNM-$\mathcal{A}$ scan. The two horizontal bands in yellow denote the ranges of C^{τ}_{NP} where the experimental intervals of $R_{B\tau\nu}$ and $R(D)$ have a common solution. Black points stand for $m_\chi > 10$ GeV, while the red circles for $m_\chi \leq 10$ GeV.

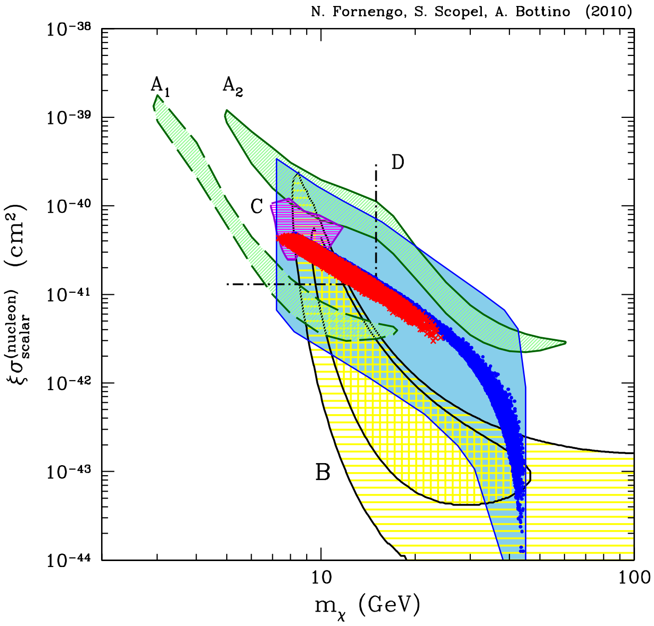

FIG. 23 (color online). $\xi\sigma^{(\mathrm{nucleon})}_{\mathrm{scalar}}$ as a function of the neutralino mass for the LNM-$\mathcal{A}$ scan and for $g_{d,\mathrm{ref}} = 290$ MeV (constraint from $R_{B\tau\nu}$ not included). The (red) crosses denote configurations with a neutralino relic abundance which matches the WMAP cold dark matter amount ($0.098 \leq \Omega_\chi h^2 \leq 0.122$), while the (blue) dots refer to configurations where the neutralino is subdominant ($\Omega_\chi h^2 < 0.098$). The blue-band flag-like region denotes the extension of the scatter plot upwards and downwards, when the hadronic uncertainties are included. The green shaded regions denote the DAMA/LIBRA annual modulation regions [81]; the region delimited by the dashed (solid) line refers to the case where the channeling effect is (is not) included. The two regions are denoted by letters A_1 and A_2, respectively. The yellow hatched regions denoted by letter B display the regions (at 68% and 85% C.L.) related to the two CDMS candidates [12]. The pink small (horizontally shaded) region denoted by letter C refers to the CoGeNT excess of events [2], whereas the black straight dot-dashed lines denoted by letter D show schematically a region linked to the excess reported by CRESST [3].

section $\sigma^{(\mathrm{nucleon})}_{\mathrm{scalar}}$ is calculated with its complete expression given in Ref. [52] at a fixed reference set of values for the hadronic quantities involved in the neutralino-nucleon cross sections [9] (the dominant coupling g_d is put at the value $g_{d,\mathrm{ref}} = 290$ MeV mentioned in Sec. V). The (red) crosses denote configurations with a neutralino relic abundance which matches the WMAP cold dark matter amount ($0.098 \leq \Omega_\chi h^2 \leq 0.122$), while the (blue) dots refer to configurations where the neutralino is subdominant ($\Omega_\chi h^2 < 0.098$). The region covered by a (blue) slant hatching denotes the extension of the scatter plot upwards and downwards, when the hadronic uncertainties extensively discussed in Ref. [51] are included.

Notice that the values displayed by the scatter plot validate the approximate expression in Eq. (28). They differ significantly from the estimates given elsewhere [15,16] for the reasons discussed in the previous section.

To report in Fig. 23 also the results of present experiments searching for direct detection of DM particles, we have to assume a specific model for the distribution function (DF) of the WIMPs (i.e., the neutralinos, in our case) in the galactic halo. Among the various possible DFs [80], we employ here as reference DF the one described by the density profile of the cored-isothermal sphere (denoted as Evans logarithmic model, or A1 model, in Ref. [80]) which is given by

$$\rho(r) = \frac{v_0^2}{4\pi G} \frac{3R_c^2 + r^2}{(R_c^2 + r^2)^2}, \tag{43}$$

where G is the Newton's constant, v_0 is the local value of the rotational velocity and R_c is the core radius. For R_c we use the value $R_c = 5$ kpc. For the parameter v_0, we take the value $v_0 = 220\ \mathrm{km\,sec^{-1}}$ and for the escape velocity the value $v_{\rm esc} = 650\ \mathrm{km\,sec^{-1}}$. We set $\rho = 0.34\ \mathrm{GeV\,cm^{-3}}$ for the total local DM density.

The green shaded regions denote the DAMA/LIBRA annual modulation regions, under the hypothesis that the effect is due to a WIMP with a coherent interaction with nuclei; the region delimited by the solid line refers to the case where the channeling effect is not included, the one with a dashed contour to the case where the channeling effect is included [25]. These regions represent the domains where the likelihood-function values differ more than 7.5σ from the null hypothesis (absence of modulation); they are derived by the DAMA Collaboration [81] from their data referring to an exposure of 1.17 ton × year, with an evidence for an annual modulation effect at 8.9σ C.L. [4].

As mentioned in the Introduction, recently a number of experimental collaborations have reported new data consisting of excesses of events (over the expected backgrounds) which might represent hints for very light DM candidates: CDMS [1], CoGeNT [2], CRESST [3]. Other experimental investigations (the XENON10 [82] and XENON100 [83] experiments and the CDMS reanalyses of previously collected data [84]) have led these groups to present upper bounds on $\xi\sigma^{(\rm nucleon)}_{\rm scalar}$ in the same range of WIMP masses (around 10 GeV). It is worth noting that none of these experiments is sensitive to a specific signature of DM particles such as the annual modulation or the directionality. Thus, their detection technique and data analysis is based on rather intricate discrimination criteria and sizable subtractions, which become more and more critical as the analyses of data are extrapolated into the range of very low recoil energies. This calls for a very cautious attitude both towards a claim of a possible signature, in case of excesses of events over expected backgrounds, as well as in implementing upper bounds rather fragile at the present stage. It is worth stressing that a major critical point consists in a reliable determination of the actual experimental efficiencies at very low recoil energies, a problem which is the subject of much debate [18,85–87]. It is beyond the purpose of the present paper to enter into these experimental points. We recall that an upper bound on $\xi\sigma^{(\rm nucleon)}_{\rm scalar}$ concerning somewhat heavier WIMPs (mass $\gtrsim 20$ GeV) was also presented by the KIMS Collaboration [88].

In Fig. 23 we also illustrate where the regions of the possible hints for DM discussed in Refs. [1–3] are located. The yellow hatched regions are related to the two CDMS candidate events [1], as derived in [12] under the hypothesis that these events might be due to DM. Also displayed in Fig. 23 are the CoGeNT region singled out by this Collaboration as due to an excess of bulk-like events [2] and a CRESST region which we denote with two black dot-dashed straight lines; this region is meant to represent approximately the data reported in Ref. [3] about 32 signals versus a background estimate of 8.7 ± 1.4, compatible with WIMPS with a mass $\gtrsim 15$ GeV and a WIMP-nucleon cross section of a few $\times\ 10^{-41}\ \mathrm{cm}^2$.

In Fig. 24 we display the scatter plot of the neutralino configurations, when the constraint of Eq. (41) on $R_{B\tau\nu}$ is included. We see that adding this constraint would have some impact in depriving the scatter plot of some neutralino configurations of significant relic abundance in the range 13 GeV $\lesssim m_\chi \lesssim$ 18 GeV and for $m_\chi \gtrsim$ 25 GeV. We remind that in Fig. 23 and 24 only neutralino configurations of the special scan LNM $\mathcal{A}$ are displayed.

Finally, in Fig. 25 we show the same scatter plot of Fig. 23, where now the MSSM parameter space is scanned

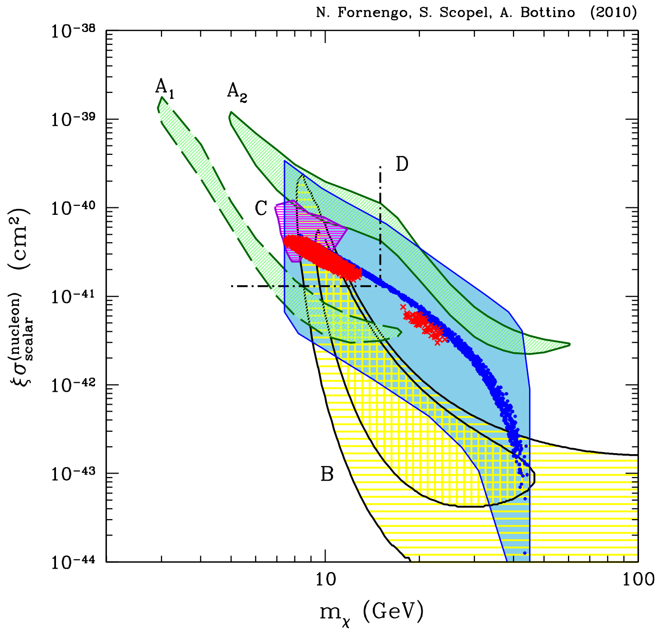

FIG. 24 (color online). The same as in Fig. 23 except that here the constraint from $R_{B\tau\nu}$ is included.

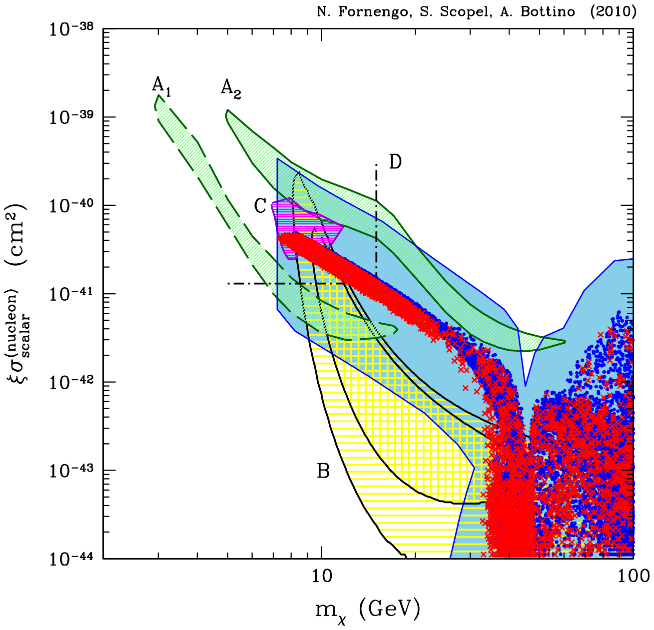

FIG. 25 (color online). The same as in Fig. 23 except that here the MSSM parameter space is scanned beyond the LNM-$\mathcal{A}$ intervals, as specified in Sec. IV, in order to include neutralino configurations of higher mass.

beyond the LNM-$\mathcal{A}$ intervals, as specified in Sec. IV, in order to include neutralino configurations of higher mass.

In conclusion, from the features displayed in Figs. 23–25 we derive that

(i) the light-neutralino population agrees with the DAMA/LIBRA annual modulation data over a wide range of light neutralinos 7–8 GeV $\lesssim m_\chi \lesssim$ 50 GeV.

(ii) This population is also in agreement with the data of CDMS, CoGeNT, and CRESST, should these results be significant of real DM signals; under these circumstances the range of the neutralino mass would be more restricted: 7–8 GeV $\lesssim m_\chi \lesssim$ (10–15) GeV.

(iii) Our results contradict the argument, sometimes put forward (see for instance Refs. [21,23]), according to which the results of Ref. [15], which are obtained in the context of a SUGRA scenario, imply that the $BR(B_s \to \mu^+\mu^-)$ constraint prevents $\sigma^{(\text{nucleon})}_{\text{scalar}}$ from reaching the size required to interpret current direct-detection data in terms of light neutralinos within the MSSM.

VIII. LINKS TO INDIRECT SEARCHES FOR DARK MATTER PARTICLES

Though indirect searches for relic particles is out of the scope of the present paper, some considerations referring to indirect effects due to light relic neutralinos are in order here. Rather than trying to be complete on these topics, we just recall briefly some of the most interesting aspects.

It is known that light relic particles, through their self-annihilation processes, can produce a flux of cosmic antiprotons in excess of the measured one. Indeed, the experimental antiproton spectrum is fitted well by the secondary component from cosmic rays spallation, calculated with the set of the diffusion parameters which is derived from the analysis of the boron-to-carbon ratio (B/C) component of cosmic rays [89], with an estimated uncertainty of about 20%. This feature makes the cosmic antiproton flux a potential stringent constraint for any exotic astrophysical source of primary antiprotons.

In Ref. [9] the low-mass neutralino populations extracted from the DAMA/LIBRA data (depending of the size of the channeling effect and on the parameters of the halo distribution function) were analyzed in terms of the expected effects on the cosmic antiprotons. It was concluded that many of these populations are fully compatible with the current bounds on cosmic antiprotons, especially for values of the local dark matter density ρ_0 and local rotational velocity v_0 in the low side of their physical ranges, and for values of the diffusion parameters of the two-zone propagation model not too close to the values of their maximal set [90]. A similar analysis in the case of the CoGeNT data has been performed in Ref. [91] in the phenomenological framework of effective DM-quark interactions.

At variance with cosmic antiprotons, where primary and secondary fluxes have very similar behaviors at low energies, and can then hardly be disentangled from each other, measurements of cosmic antideuterons could provide evidence of light DM particles [92–94]. In Ref. [9] it was shown that a sizable number of neutralino configurations compatible with the annual modulation data can generate signals accessible to antideuteron searches planned for the next years.

Also the possibility of investigating light WIMPs at neutrino telescopes has been the subject of specific investigations [95–99]. In Ref. [99] a detailed analysis of the neutrino-induced muon signal coming from light-neutralino pair-annihilations inside the Sun and the Earth is performed and it is shown that, under favorable conditions, a combination of the WIMP direct detection data and the measurements at neutrino telescopes with a low threshold energy could help in pinning down the features of the DM particles.

Other possible signals due to relic light neutralinos are mentioned in Ref. [9].

IX. CONCLUSIONS

In this paper we have analyzed the properties of a population of light neutralinos in an effective MSSM at the electroweak scale, already discussed in the past [5,9], in light of new measurements at the Tevatron and B factories which could potentially provide significant constraints in some relevant supersymmetric parameters.

Particular attention is devoted to the branching ratio of the process $B_s \to \mu^+ + \mu^-$ whose experimental upper bound entails rather strict constraints on SUGRA models. In the present analysis it is shown analytically and numerically why this experimental limit has only a mild effect on our light-neutralino model.

The light-neutralino population, while satisfying the cosmological upper bound on cold dark matter, entails also a neutralino-nucleon cross section of the correct size to interpret the current experimental results of experiments for direct detection of dark matter particles in terms of MSSM neutralinos. This population, while fitting quite well the DAMA/LIBRA annual modulation data, would also agree with the preliminary results of CDMS, CoGeNT, and CRESST, should these data, which are at present only hints or excesses of events over the expected backgrounds, be interpreted as authentic signals of DM. For the neutralino mass we find a lower bound of 7–8 GeV. We have also discussed in detail by how much this lower limit would be affected, as more refined and solid constraints from the searches on Higgs bosons and rare B decays at the Tevatron and B factories might be derived. It is obvious that great expectations are on the outcomes that hopefully will come out from the Large Hadron Collider at CERN to bring light to properties related to supersymmetry (in Ref. [43] the perspectives of searching for light neutralino of cosmological interest at LHC are investigated).

Our results differ from some recent conclusions by other authors; in the course of the presentation of our results we have tried to single out and elucidate the main points at the origin of these variances.

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