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DARK MATTER SEARCH WITH GAMMA RAYS: THE EXPERIMENTS EGRET AND GLAST

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The direct detection of annihilation products in cosmic rays offers an alternative way to search for supersymmetric dark matter particles candidates. The study of the spectrum of gamma-rays, antiprotons and positrons offers good possibilities to perform this search in a significant portion of the Minimal Supersymmetric Standard Model parameters space. In particular the EGRET team have seen a convincing signal for a strong excess of emission from the galactic center that have not easily explanation with standard processes. We will review the achievable limits with the experiment GLAST taking into accounts the LEP results and we will compare this method with th antiproton and positrons experiments, the direct underground detection and with future experiments at LHC.

Keywords: gamma-rays; dark matter; supersymmetry

1. the EGRET data

The EGRET team [1] have seen a convincing signal for a strong excess of emission from the galactic center, with I(E) x E^2 peaking at 2 GeV, and in an error circle of 0.2 degree radius including the position l = 0° and b = 0°. In figure 1 is shown the map towards the galactic center.

This is a particular aspect of a more general problem of the diffuse Galactic gamma-ray emission [2] that also outside the galactic center reveal a spectrum which is harder than expected. As can be seen in figure 2, the spectrum observed with EGRET below 1 GeV is in accord with the assumption that the cosmic ray spectra and the electron-to-proton ratio observed locally are uniform, however, the spectrum above 1 GeV, where the emission is supposedly dominated by π°-decay, is harder than that derived from the local cosmic ray proton spectrum [3]. Many differen approach are trying to solve the problem, as the realiving of the assumption that the local cosmic ray electron spectra is not representative for the Galaxy and it is in average harder than that measured locally, or dispersion in the cosmic ray

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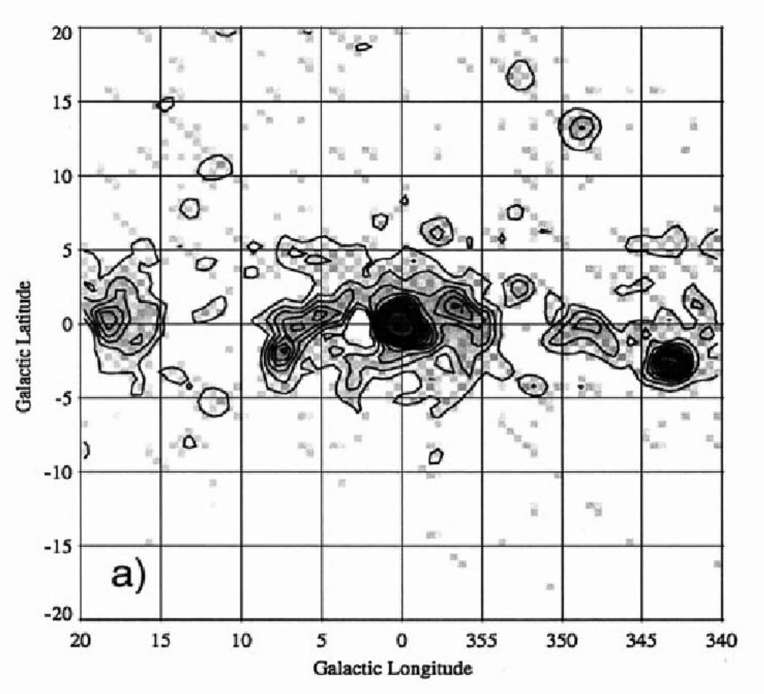

Fig. 1. *Residual smoothed profiles owards the galactic center after subtraction of the model-predicted diffuse emission background for $E > 1$ GeV*

source spectra such that the SNR would produce power-law spectra with varying indices (for a discussion see [4]). Here we will connect the problem of the GeV excess with the problem of the missing dark matter in the Universe and we will examine the possibility to disantangle this effect with the future space γ-ray and cosmic ray experiments.

Over the last years our knowledge of the inventory of matter and energy in the universe has improved dramatically. Astrophysical measurements from disparate experiments are now converging and a standard cosmological model is emerging. The most significant new data come from recent measurements of the cosmic microwave background radiation (CMBR)[5] and measurements of the Hubble flow using distant supernovae[6].

The evidence currently favors (see for example [7]) a flat universe with a cosmological constant $\Omega_\Lambda = 1 - \Omega_m$ and a total matter density of about 40%±10% of the critical density of the Universe, with a contribution of the baryonic dark matter less then 5% and a contribution from neutrinos that cannot be greater then 10%. The remaining matter should be composed of yet-undiscovered Weakly Interacting Massive Particles (WIMP) , and a good candidate for WIMP's is the Lightest Supersymmetric Particle (LSP) in R-parity conserving supersymmetric models.

The motivation for supersymmetry at an accessible energy is provided by the

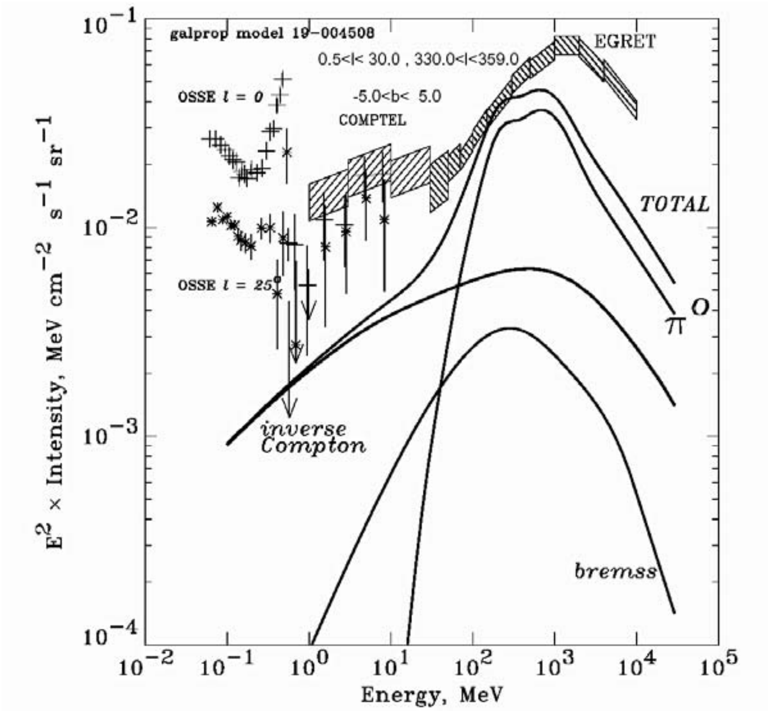

Fig. 2. *Gamma-ray energy spectrum of the inner galaxy (*$300^\circ \geq l \leq 30^\circ$*) compared with what is expected for standard propagation models* [3].

gauge hierarchy problem [8], namely that of understanding why $m_W \ll m_P$, the only candidate for a fundamental mass scale in physics. This difference introduce problems because one must fine-tune the bare mass parameter so that is almost exactly cancelled by the quantum correction in order to obtain a small physical value of m_W. This seems unnatural, and the alternative is to introduce new physics at the TeV scale and to postulate approximate supersymmetry[9], whose pairs of boson and fermions produce naturally cancelling quantum corrections that are naturally small if

$$|m_B^2 - m_F^2| \leq 1TeV$$

This is also the reason to expect that, if supersymmetry is real, it might be accessible to the current generation of accelerators and in the range expected for a cold dark matter particle.

The minimal supersymmetric extension of the Standard Model (MSSM) [10] has the same gauge interactions as the Standard Model and has the advantage that all the phenomenology can be parametrized by five parameters: the higgs mixing parameters μ that appears in the neutralino and chargino mass matrices, the common mass for scalar fermions at the GUT scale m_0, the gaugino mass parameter $M_{1/2}$, the trilinear scalar coupling parameter A and the ratio between the two vacuum expectation values of the Higgs fields defined as $\tan\beta = v_2/v_1 =< H_2 > / < H_1 >$.

The LSP is expected to be stable in the MSSM, and hence should be present in the Universe today as a cosmological relic from the Big Bang [11]. This is a consequence of a multiplicatively-conserved quantum number called R-parity, which is related to baryon number, lepton number and spin:

$$R = (-1)^{3B+L+2S}$$

It is easy to check that R=+1 for all Standard Model particles and R=-1 for all their supersymmetric partners. There are three important consequences of R conservation: (i) sparticle are always produces in pairs; (ii) heavier sparticles decay into lighter sparticles and (iii) the LSP is stable because it has no legal decay mode.

The LSP is expected also to be neutral, because with an electric charge or strong interaction, it would have condensed along with ordinary baryonic matter during the formation of astrophysical structures, and should be present in the Universe today in anomalous heavy isotopes [12]. This leaves as candidates a sneutrino with spin 0 , the gravitino with spin 2/3 and the neutralino χ that is a combination of the partners of the γ, Z and the neutral Higgs particles (spin 1/2).

The sneutrino seems to be ruled out by searches for the interactions of relic particles with nuclei that require a sneutralino mass greater then few TeV [13] while the gravitino could constitute warm dark matter with a mass around 1 keV. So the best candidate for cold dark matter appears to be the neutralino χ. The experimental LEP lower limit on m_χ is [14]

$$m_\chi \geq 50\ GeV$$

As m_χ increases, the LSP annihilation cross section decreases, but, as we will show below, up to $\sim 400\ GeV$ a possible signature of the existence of the LSP is a bump in the spectrum of the diffuse gamma ray background around the neutralino mass due to neutralino annihilation in the halo [15]. The bump arise because if neutralinos make up the dark matter of our galaxy, they would have non-relativistic velocities.

How can be see this kind of signal ? In the next session we present one possibility, i.e. the experiment GLAST.

2. The Gamma-ray Large Area Telescope GLAST

The standard techniques for the detection of gamma-rays in the pair production regime energy range are very different from the X-ray detection. For X-rays detection focusing is possible and this permits large effective area, excellent energy resolution, very low background. For gamma-rays no focusing is possible and this means limited effective area, moderate energy resolution, high background but a wide field of view. This possibility to have a wide field of view is enhanced now, in respect to EGRET, with the use of silicon detectors, that allow a further increase of the ratio between height and width, essentially for two reasons: a) an increase of the position resolution that allow a decrease of the distance between the planes

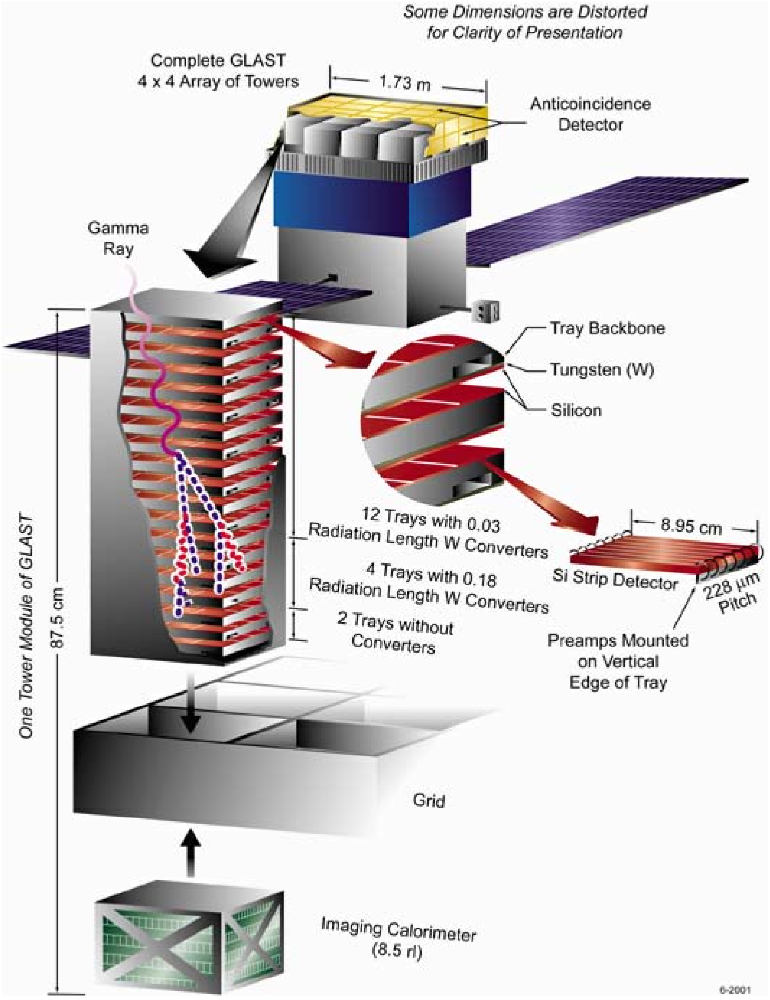

Fig. 3. *The GLAST instrument, exploded to show the detector layers in a tower, the stacking of the CsI logs in the calorimeter, and the integration of the subsystems.*

of the tracker without affect the angular resolution, b) the possibility to use the silicon detectors themselves for the trigger of an events, with the elimination of the Time of Flight system, that require some height.

The Gamma-ray Large Area Space Telescope (GLAST)[16], has been selected by NASA as a mission involving an international collaboration of particle physics and astrophysics communities from the United States, Italy, Japan, France and Germany for a launch in the first half of 2006. The main scientific objects are the study of all gamma ray sources such as blazars, gamma-ray bursts, supernova remnants, pulsars, diffuse radiation, and unidentified high-energy sources. Many years of refinement has led to the configuration of the apparatus shown in figure 3, where

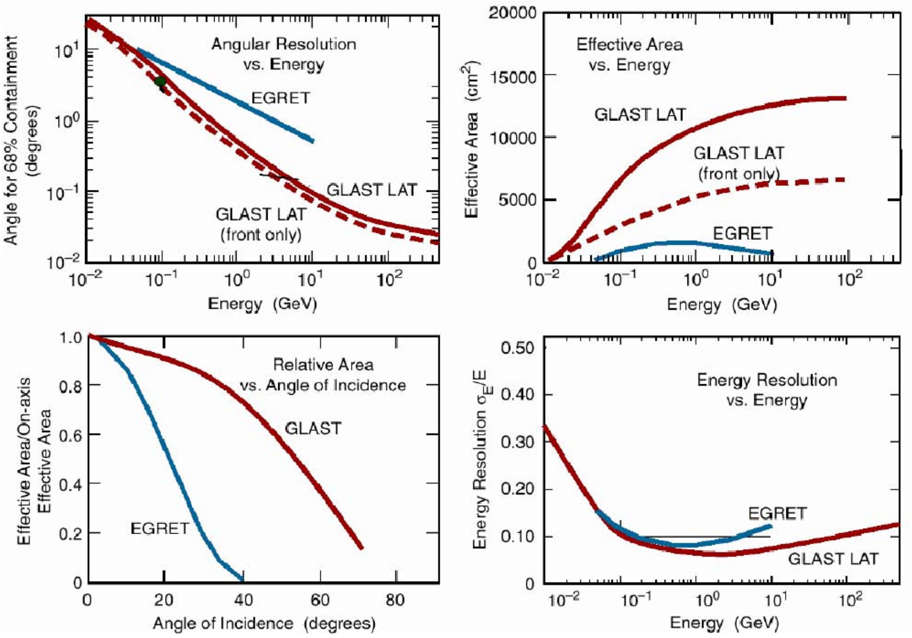

Fig. 4. *Instrument performance, including all background and track quality cuts.*

one can see the 4x4 array of identical towers each formed by: • Si-strip Tracker Detectors and converters arranged in 18 XY tracking planes for the measurement of the photon direction. • Segmented array of CsI(Tl) crystals for the measurement the photon energy. • Segmented Anticoincidence Detector (ACD). The main characteristics, shown in figure 4, are an energy range between 20 MeV and 300 GeV, a field of view of $\sim$ 3 sr, an energy resolution of $\sim$ 5% at 1 GeV, a point source sensitivity of 2x10^{-9} (ph cm^{-2} s^{-1}) at 0.1 GeV, an event deadtime of 20 μs and a peak effective area of 10000 cm^2, for a required power of 600 W and a payload weight of 3000 Kg.

The list of the people and the Institution involved in the collaboration together with the on-line status of the project is available at *http://www-glast.stanford.edu*. A description of the apparatus can be found in [17] and a description of the main physic items can be found in [18].

GLAST is particularly interesting for the supersymmetric particle search because, if neutralinos make up the dark matter of our galaxy, they would have non-relativistic velocities, hence the neutralino annihilation into the gamma gamma and gamma Z final states can give rise to gamma rays with unique energies $E_\gamma = M_\chi$ and $E'_\gamma = \ M_\chi \ (1 - m_z^2/4M_\chi^2)$.

In figure 5 is shown how strong can be the signal[19] in the case of a cuspy dark matter halo profiles distribution[20]. Figure 6 shows the GLAST capability to probe the supersymmetric dark matter hypothesis[19]. The various zone sample the MSSM

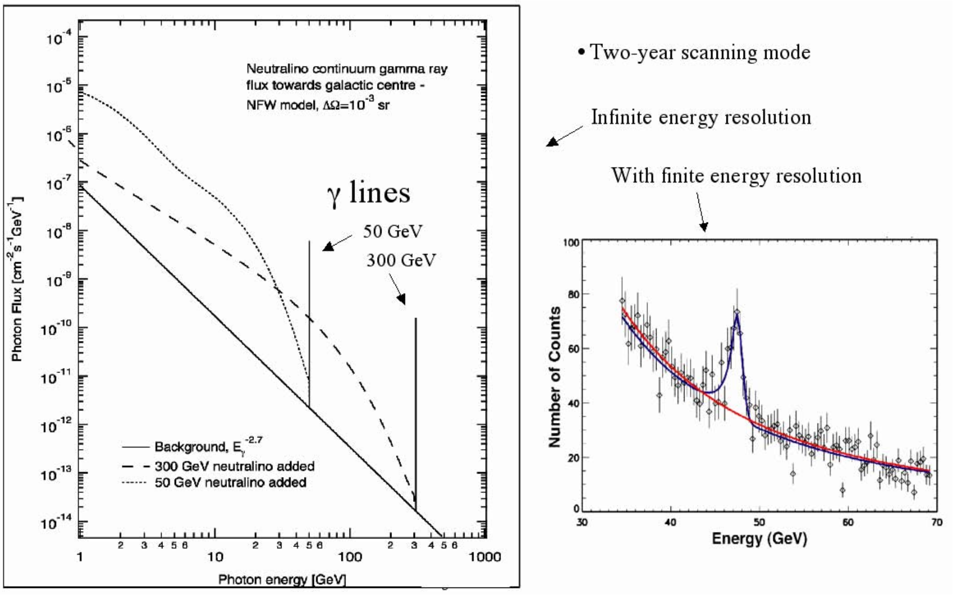

Fig. 5. *Total photon spectrum from the galactic center from $\chi\chi$ annihilation (on the left), and number of photons expected in GLAST for $\chi\chi \rightarrow \gamma\gamma$ from a 1-sr cone near the galactic center with a 1.5 % energy resolution (on the right)*

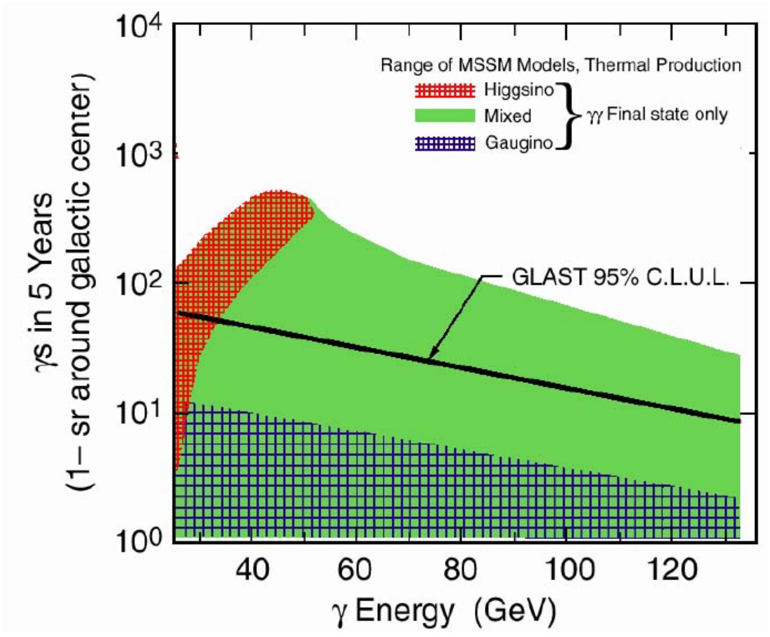

Fig. 6. *Number of photons expected in GLAST for $\chi\chi \rightarrow \gamma\gamma$ from a 1-sr cone near the galactic center as a function of the possible neutralino mass. The solid line shows the number of events needed to obtain a five sigma signal detection over the galactic diffuse gamma-ray background as estimated by EGRET data.*

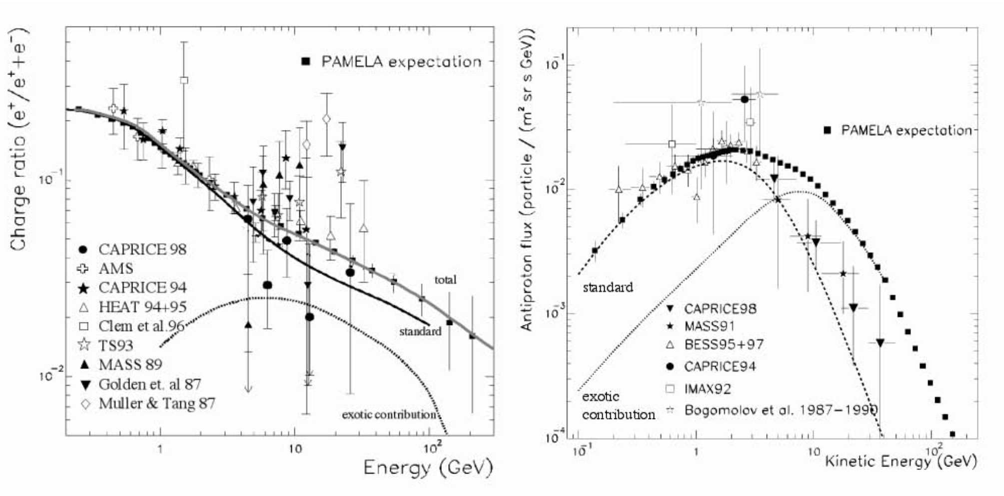

Fig. 7. *Distortion of the secondary positron fraction (on the left) and secondary antiproton flux (on the right) induced by a signal from a heavy neutralino. The PAMELA expectation in the case of exotic contributions are shown by black squares*

with different values of the parameters space for three classes of neutralinos. The previous galaxy dark matter halo profile[20] that gives the maximal flux has been assumed. The solid line shows the number of events needed to obtain a 5 σ detection over the galactic diffuse γ-ray background as estimated from EGRET data. As the figures show, a significant portion of the MSSM phase space is explored, particularly for the higgsino-like neutralino case.

This effort will be complementary to a similar search for neutralinos looking with cosmic-ray experiments like the next space experiments PAMELA[21] and AMS[22] at the distortion of the secondary positron fraction and secondary antiproton flux induced by a signal from a heavy neutralino.

The launch of PAMELA will take place from the cosmodrome of Baikonur, in Kazakhstan, at the beginning of 2003. In figure 7 (on the left) there are the experimental data[23] for the positron fraction together with the distortion of the secondary positron fraction (solid line) due to one possible contribution from neutralino annihilation (dotted line, from[24]). The expected data from the experiment PAMELA in the annihilation scenario for one year of operation are shown by black squares[25].

In the same figure (on the right) there are the experimental data for the antiproton flux[26] together with the distortion on the antiproton flux (dashed line) due to one possible contribution from neutralino annihilation (dotted line, from[27]). The antiproton data that PAMELA would obtain in a single year of observation for one of the Higgsino annihilation models are shown by black squares.

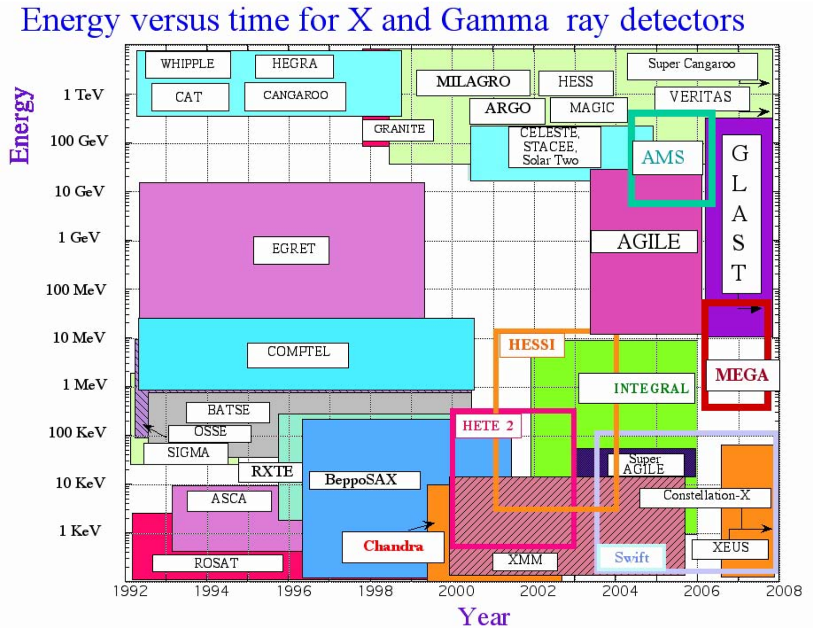

Fig. 8. *Timeline schedule versus the energy range covered by present and future detectors in X and gamma-ray astrophysics.*

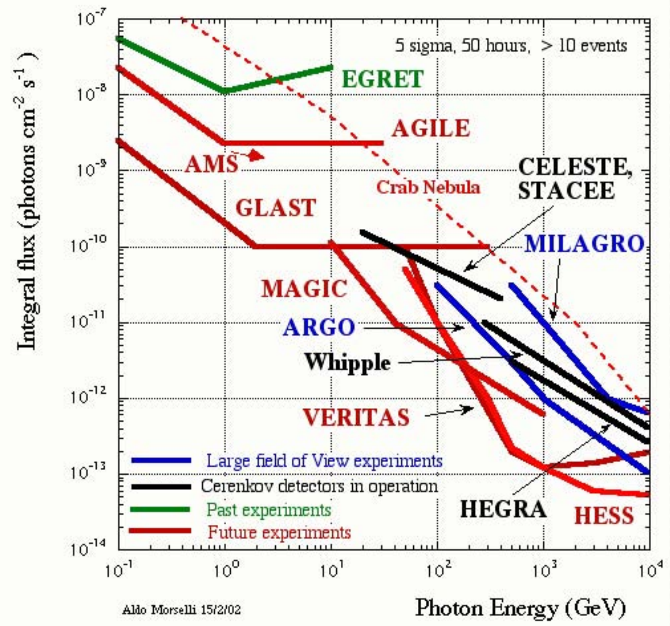

Fig. 9. *Sensitivity of present and future detectors in the gamma-ray astrophysics.*

3. Conclusion

The gamma-ray space experiment GLAST is under construction. Its time of operation and energy range is shown together with the other space X-ray satellite and gamma-ray experiments in figure 8. Note that it will cover an interval not covered by any other experiments. Note also the number of other experiments in other frequencies that will allow extensive multifrequency studies. In the last decade, ground-based instruments have made great progress, both in technical and scientific terms. High-energy gamma rays can be observed from the ground by experiments that detect the air showers produced in the upper atmosphere. In figure 9 the GLAST sensitivity is compared with the others present and future detectors in the gamma-ray astrophysics range is shown. The predicted sensitivity of a number of operational and proposed Ground based Cherenkov telescopes, CELESTE, STACEE, VERITAS, Whipple is for a 50 hour exposure on a single source. EGRET, GLAST, MILAGRO, ARGO and AGILE sensitivity is shown for one year of all sky survey. The diffuse background assumed is $2 \cdot 10^{-5}$ $photons\ cm^{-2} s^{-1} sr^{-1} (100\ MeV/E)^{1.1}$, typical of the background seen by EGRET at high galactic latitudes. The source differential photon number spectrum is assumed to have a power law index of -2, typical of many of the sources observed by EGRET and the sensitivity is based on the requirement that the number of source photons detected is at least 5 sigma above the background. Note that on ground only MILAGRO and ARGO will observe more than one source simultaneously. The Home Pages of the various instruments are at *http://www-hfm.mpi-hd.mpg.de/CosmicRay/CosmicRaySites.html*. The arrow for AMS indicates that a published estimate does not exist but flux sensitivity should be of the order of $2 \cdot 10^{-8}$ $photons\ cm^{-2} s^{-1}$ above few Gev [28].

A wide variety of experiments provide interesting probes for the search of supersymmetric dark matter. Indirect dark matter searches and traditional particle searches are highly complementary. In the next five years, an array of experiments will be sensitive to the various potential neutralino annihilation products. These include under-ice and underwater neutrino telescopes, atmospheric Cerenkov telescopes and the already described space detectors GLAST and PAMELA together with AMS. In many cases, these experiments will improve current sensitivities by several orders of magnitude.

Direct dark matter probes share features with both traditional and indirect searches, and have sensitivity in both regions. In the cosmologically preferred regions of parameter space with $0.1 < \Omega_\chi h^2 < 0.3$, all models with charginos or sleptons lighter than 300 GeV will produce observable signals in at least one experiment. An example[29] is shown in figure 10 in the framework of minimal supergravity, which is fully specified by the five parameters $m_0, M_{1/2}, A_0, \tan\beta, \mathrm{sgn}(\mu)$ defined in section 1. The figure shows the limits that can be obtained in the $m_0, M_{1/2}$ plane for $\tan\beta = 10,\ A_0 = 0,\ \mu > 0$. Higher values ($\sim 50$) of $\tan\beta$ requires significant fine-tuning of the electroweak scale. The limit from gamma-ray assumes a moderate halo profile. The curve $B \to X_s \gamma$ refers to the improvement expected for the same

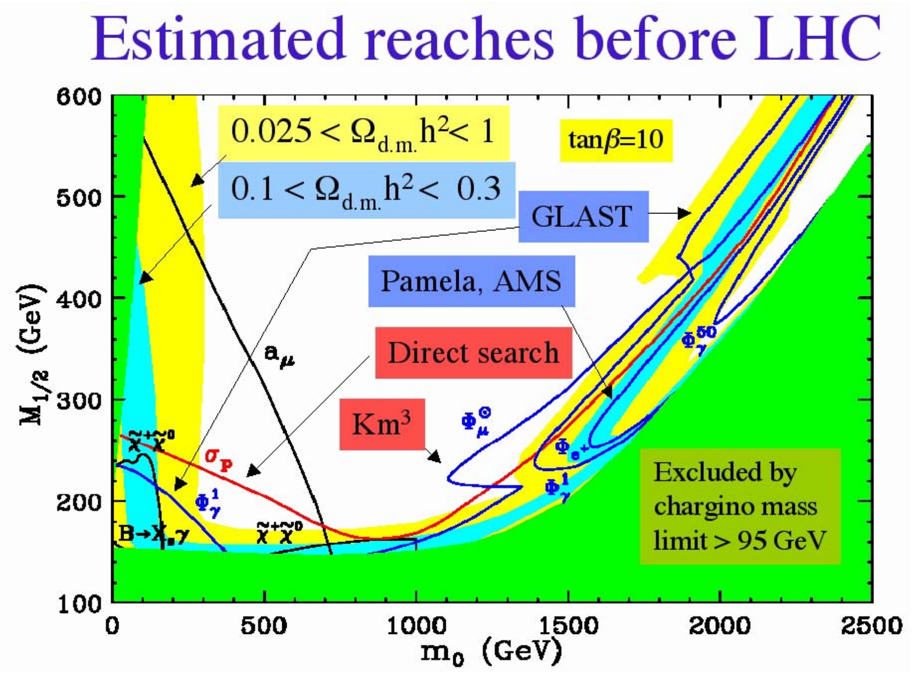

Fig. 10. *Example of estimated reaches of various searches before the LHC begins operation. Note the complementarity between the different techniques. For moderate values of* $\tan\beta$ *all the cosmological interesting region will be covered (see text for details).*

date from BaBar, BELLE and B factories in respect to the CLEO and ALEPH results[30]. The curve $\Phi_\mu^\odot$ refers to the indirect DM search with underwater ν experiments like AMANDA, NESTOR and ANTARES[31] and the curve σ_p refers to the direct DM search with underground experiments like DAMA, CDMS, CRESST and GENIUS[32]

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