Search for supersymmetric Dark Matter with the space experiments GLAST and PAMELA.

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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. We will review the achievable limits with the experiments GLAST and PAMELA taking into accounts the LEP results and we will compare this method with the direct underground detection and with future experiments beafore LHC .

1. GLAST

The Gamma-ray Large Area Space Telescope [1] 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 1, where 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 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 online status of the project is available in [2].

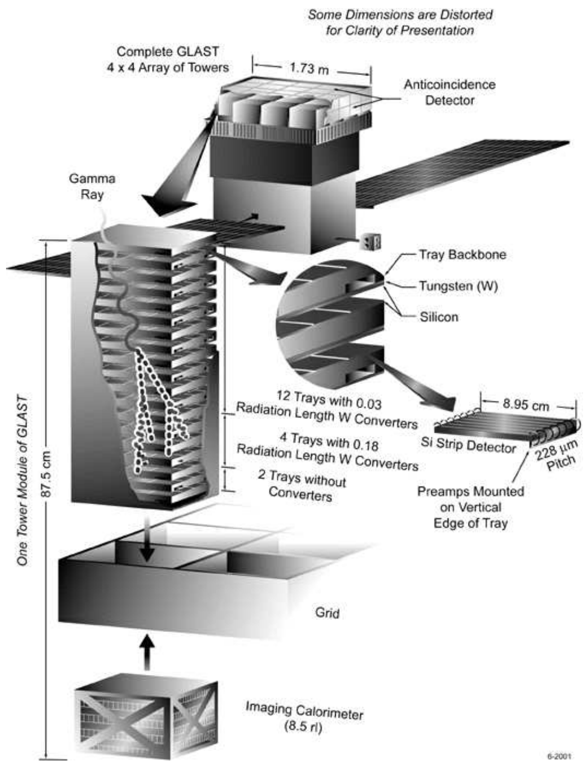

Figure 1. *The GLAST instrument, exploded to show the detector layers in a tower, the stacking of the CsI logs in the calorimeter, and the integration of the subsystems.*

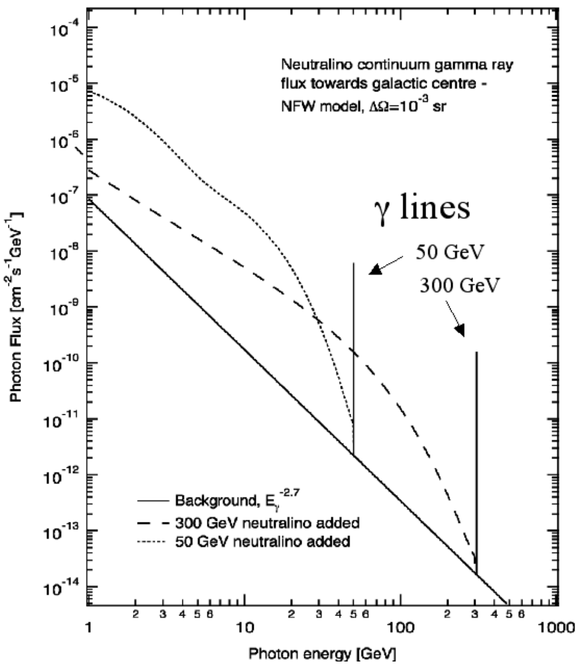

Figure 2. *Total photon spectrum from the galactic center from $\chi\chi$ annihilation from a 1-sr cone near the galactic center*

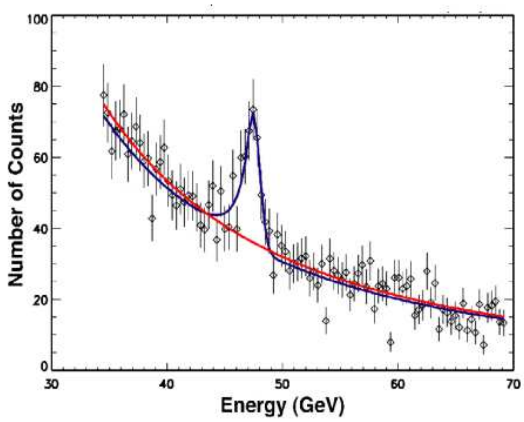

Figure 3. *Number of photons expected in GLAST for the flux shown in figure2 with a 1.5 % energy resolution*

1.1. Search for dark matter

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 2 is shown how strong can be the signal [3] in the case of a cuspy dark matter halo profiles distribution [4].

Figure 4 shows the GLAST capability to probe the supersymmetric dark matter hypothesis [3]. The various zone sample the MSSM with different values of the parameters space for three classes of neutralinos. The previous galaxy dark matter halo profile [4] 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 LSP looking with cosmic-ray experiments at the distortion of the secondary positron fraction and secondary antiproton flux induced by a signal from a heavy neutralino.

In figure 5 there are the experimental data [5] for the positron fraction together with the distortion of the secondary positron fraction (dashed line) due to one possible contribution from neutralino annihilation (dotted line, from [6]).

The expected data from the experiment PAMELA in the annihilation scenario for one year of operation are shown by grey circles [7].

In figure 6 there are the experimental data for the antiproton flux [10] together with the distortion on the antiproton flux (dashed line) due to one possible contribution from neutralino annihilation (dotted line, from [11]). Total expected flux is shown by solid line. The antiproton data that PAMELA would obtain in a single year of observation for one of the Higgsino annihilation models are shown by grey circles.

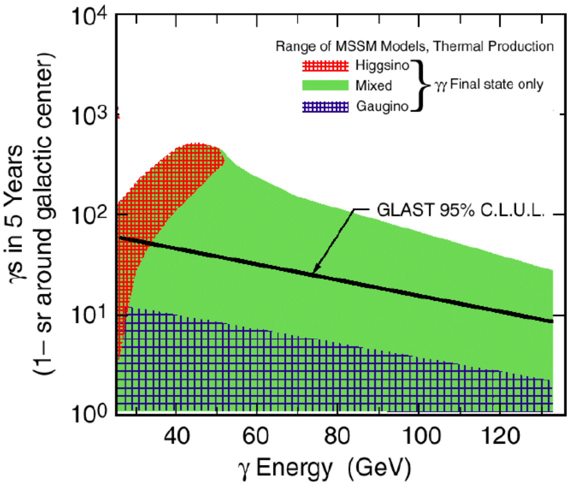

Figure 4. *Number of photons expected in GLAST for $\chi\chi \rightarrow \gamma\gamma$ from a 1-sr cone near the galactic center as a function of the possible neutralino mass. The solid line shows the number of events needed to obtain a five sigma signal detection over the galactic diffuse gamma-ray background as estimated by EGRET data.*

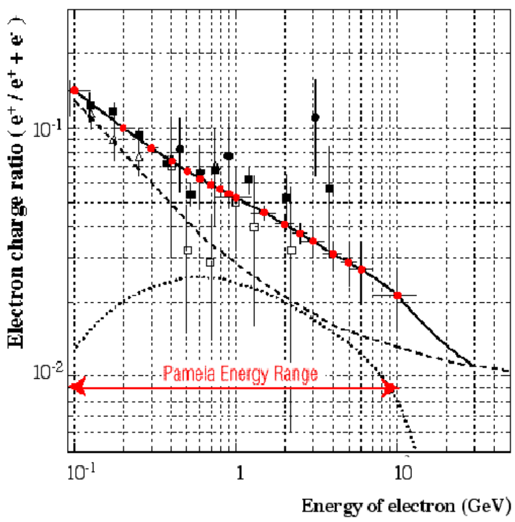

Figure 5. *Distortion of the secondary positron fraction induced by a signal from a heavy neutralino together with up to now experimental data and the statistical precision expected with PAMELA (grey cicles)*

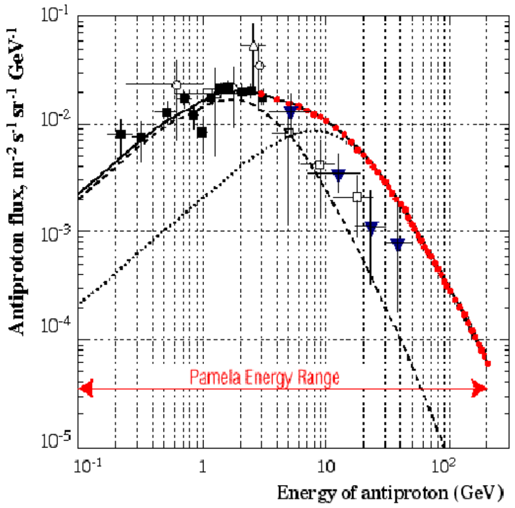

Figure 6. *Distortion of the secondary antiproton flux induced by a signal from a heavy neutralino together with up to now experimental data and the statistical precision expected with PAMELA (grey cicles)*

2. the PAMELA apparatus

PAMELA is a satellite-borne magnet spectrometer built by the WiZard-PAMELA collaboration [8]. It will be installed on-board of the RESURS-5 ARTIKA satellite to be launched in the 2003 for a mission at least three years long. The satellite orbit is polar, sun-synchronous and 700 km high.

The list of the people and the Institution involved in the collaboration together with the online status of the project is available in [9].

The Pamela telescope, shown in figure 7, consists of the following elements: a magnet + tracker system, an imaging calorimeter, a Transition-Radiation-Counter (TRD), scintillation counter hodoscopes for Time-of-Flight and Trigger, an anticoincidence scintillation counter. The magnet + tracker system consists of 5 permanent magnets, each 8 cm high, interleaving 6 detection planes of the silicon microstrip tracker. The whole closed

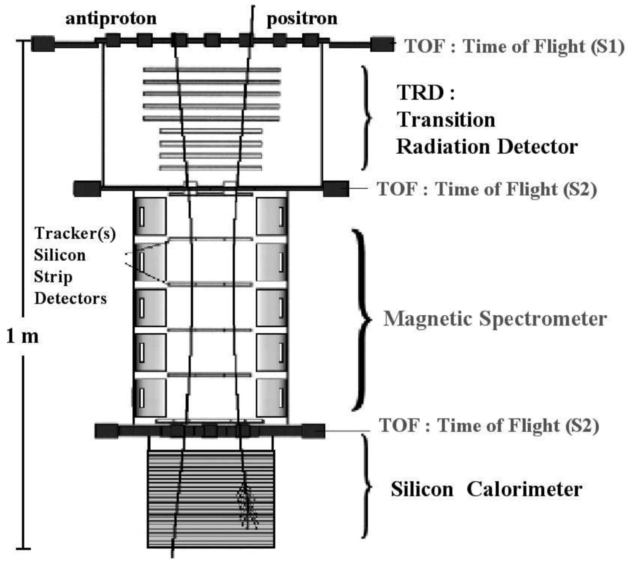

Figure 7. *Schematic of the PAMELA baseline instrument.*

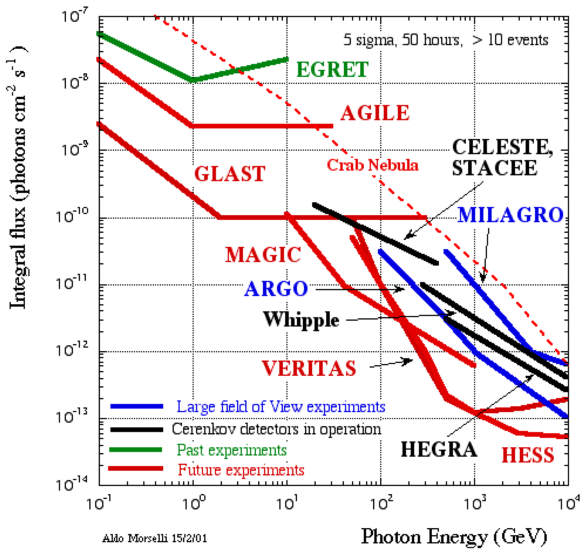

Figure 8. *Sensitivity of present and future detectors in the gamma-ray astrophysics.*

in a ferromagnetic screen and surrounded on its sides by a system of anticoincidence scintillation counters. The resolution of the tracking system is about 4 μm. The magnetic field inside the magnet will be ~ 0.4 T, so the Maximum Detectable Rigidity (MDR) will be around 800 GV/c.

The observational objectives of the PAMELA instrument are the measurement of the spectra of antiprotons, positrons and nuclei in a wide range of energies, the search for primordial antimatter and the study the cosmic ray fluxes over half a solar cycle. Data gathered with the PAMELA instrument will deal with a wide range of fundamental issues. These include:

• the role of Grand Unified Theories in Cosmology in relation to antimatter and dark matter.
• the understanding of the acceleration and propagation of cosmic rays.
• the role of solar, terrestrial and heliosperic relationships to energetic particle propagation in the heliosphere.

The PAMELA observations will extend the results of balloon-borne experiments over an unexplored range of energies with unprecedented statistics and will complement information gathered from Great Space Observatories. These observational objectives can be schematically listed in the following points:

• Measurement of the energy antiproton spectrum in a large energy range: from 100 MeV up to 150 GeV (present limits 0.4 - 20 GeV);
• Measurement of the energy positron spectrum in a large energy range: from 100 MeV up to 200 GeV (present limits 0.7 - 30 GeV);
• Search for anti-nuclei with a sensitivity of 6 10^{-8} in the anti-helium/helium ratio (present limit about 10^{-5});
• Measurement of the electron energy spectrum up to 1000 GeV;
• Continuous monitoring of the cosmic rays solar modulation during and after the 23rd maximum of solar activity;
• Studies of the time and energy distributions of the energetic particles emitted in solar flares.

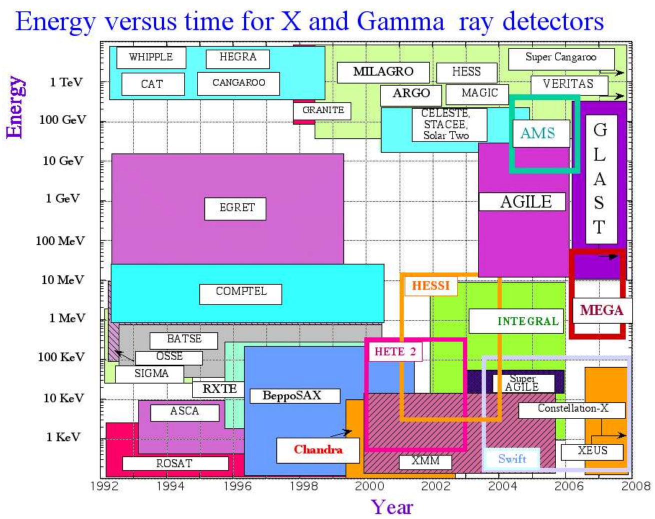

Figure 9. *Timeline schedule versus the energy range covered by present and future detectors in X and gamma-ray astrophysics.*

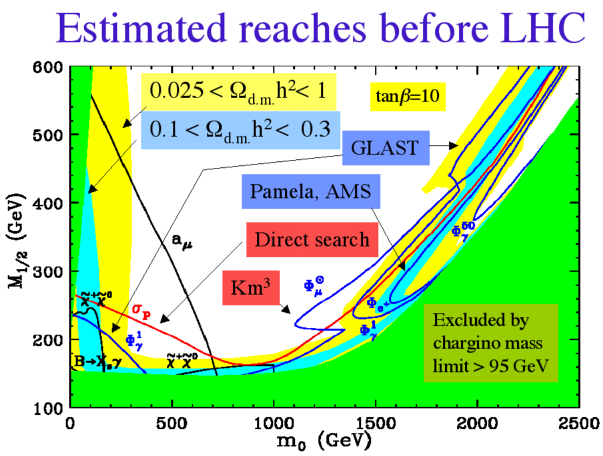

Figure 10. *Example of estimated reaches of various searches before the LHC begins operation. Note the complementarity between the different techniques. For moderate values of* $\tan\beta$ *all the cosmological interesting region will be covered (see text for details).*

The low energy antiproton and positron measurements and the last two objectives are peculiar of the PAMELA experiment because the satellite travels in a polar orbit. It spends a large fraction of its time in the high latitude and Polar Regions, where the cut-off due to the terrestrial magnetic field is negligible.

The scientific relevance of these objectives is enhanced by the length of the mission, that is planned to last not less than three years, but could be prolonged for many other years because of the orbit altitude and the maximization of the electric power due to its sun-synchronism.

3. Comparison with other searches

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 as it can be seen in figure 8 where the GLAST sensitivity is compared with the others present and future detectors in the gamma-ray astrophysics range. The predicted sensitivity of CELESTE, STACEE, VERITAS and Whipple is for a 50 hour exposure on a single source. ARGO, MILAGRO, EGRET, GLAST and AGILE sensitivity is shown for one year of all sky survey (the operation time and energy range is shown in figure 9). Note that on ground only MILAGRO and ARGO will observe more than one source simultaneously. The Home Pages of the various instruments are in [12].

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 ([13]) is shown in figure 10 in the framework of minimal supergravity, which is fully specified by the five parameters (four continuous, one binary)

$$m_0, M_{1/2}, A_0, \tan\beta, \mathrm{sgn}(\mu) \quad (1)$$

Here, m_0, $M_{1/2}$, and A_0 are the universal scalar mass, gaugino mass, and trilinear scalar coupling ([13]). 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 of $\tan\beta$ (~ 50) requires significant fine-tuning of the electroweak scale. The limit from gamma-ray assumes a moderate halo profile.

The a_μ curve refers to the expected region that will be probed before 2006 by the measurements of the muon magnetic dipole moment [14]. The curve $B \to X_s\gamma$ refers to the improvement expected for the same date from BaBar, BELLE and B factories in respect to the CLEO and ALEPH results [15]. The curve $\Phi_\mu^\odot$ refers to the indirect DM search with underwater ν experiments like AMANDA, NESTOR and ANTARES [16] and the curve σ_p refers to the direct DM search with underground experiments like DAMA, CDMS, CRESST and GENIUS [17]

4. Conclusion

We have presented two space experiments, PAMELA and GLAST, that will be launched respectively at the end of 2002 and in March 2006. These experiments have their own very important physics items that justify completely their construction, but in addition they can give some contribution in the search of signals from supersymmetry, if a substantial part of the dark matter component of the Universe is made by the lightest supersymmetric particle. Their searches will be complementary to all the other experiments that are looking for signal from supersimmetry theories under-ice, underwater, under-mountains and at accelerators. It will be only by combining all of these experiments that the preferred regions of supersymmetric parameter space may be completely explored.

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