DARK MATTER SEARCH BY SCINTILLATING FIBER GAMMA RAY SATELLITE

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Abstract

Cold dark matter is one of most promising solutions to astro-physics and fundamental particle physics. If the universe is dominantly occupied by majorana fermions such as super particles, they annihilate with their anti-particles via weak interaction and produce secondary hadrons in the same way as e^+e^- to hadrons. The excess of the intensity by those particle should be significant compared to that of ordinary cosmic rays. We propose a new gamma ray satellite which uses scintillating fiber in order to gain larger area and larger solid angle coverage. The satellite is sensitive to the cold dark matter with mass from a few GeV to 1 TeV.

Introduction

So far, dark matter problem has been discussed only in view of astrophysics, such as isotropy of 3^oK radiation, large structure of the universe, Ω problem, etc. Recently, however, it is thought to be necessary from a point of fundamental particle physics.

In the particle physics, most successful theory is electroweak theory by Weinberg (1967). In the same frame work, the unification including strong interaction is also possible (Langacker, 1981). Both theories require spontaneous symmetry breaking down, such as higgs particle of mass less than 1 TeV. Even though, in order to explain unification mass scale (10^{15} GeV), an "unnatural" assumption is necessary. To avoid this situation, theorists have introduced a new symmetry with a mass scale of TeV, namely, supersymmetry (Fayet, 1977).

Shortly after the big bang of the universe, the temperature was so high that all of forces were symmetric. Most of superpaticles had been annihilated into LSP's (lightest superparticles). If the mass of LSP is greater than a few GeV, the condition $\Omega<1$ can be satisfied (Lee, 1977). Especially when the mass is the order of a few 10 GeV, a significant amount of LSP ($\Omega\sim0.1$) is left as dark matter.

In the accelerator physics, for example SSC (SSC,1986), they are sensitive to the particle with mass less than 500 GeV. They look for the decay process of $\chi\rightarrow$matter+LSP, which does not show clean signature. Anyway, it is necessary to have a different type of approach.

If the dark halo of our galaxy is dominantly occupied by those majorana ferimions (~GeV/cc) which have low velocity, $\sim10^{-3}$c. Those annihilate with their antiparticle via Z^o to matter anti-matter in CMS frame. The s-wave annihilation is dominant so that the decay products may be c,b quarks or τ lepton. Hadronization of those fermions have been measured accurately by the e^+e^- experiment (Aihara,1984). The energy spectrum of those secondary particle is exponential which differs from that of cosmic-ray ($E^{-2.7}$) so that it is easy to discriminate. By applying scaling law, mass of LSP is also measurable. By this assumption, the antiproton flux in the cosmic rays are explained well (Fig.1). The data shows as if $M\chi$~15 GeV. ASTROMAG project (Ohmes,1988) are going to confirm this measurement.

However, it is very difficult to conclude this as an evidence for dark matter. Because charged cosmic-rays have ambiguities in transportation in the galactic B field, solar wind modulation and etc. Gamma rays are most powerful probe which have less ambiguities in above discussion.

SFAGO detector

We propose a gamma ray satellite using scintillation fiber calorimeter, SFAGO (Scintillation Fiber Astronomical Gamma-ray Observatory).The scintillating fiber calorimeter has following advantages.

1) Large area and large solid angle.

There is no reflection loss. The attenuation length is 3m (Takasaki, 1988) so that 1 m^2 detector can be made very easily. The total thickness is determined only by that of convertor to be a few ten cm. Solid angle of 3 sr is possible.

2) Reliability.

The technique has been developed 30 years ago (Reynolds, 1961). The material is only plastic scintillator.

3) Time resolution, light yield, energy resolution, angle resolution etc.

Time resolution is a few nsec. 7 photons / 1mmϕ are emitted by a charged track. By using appropriate sampling thickness, the energy resolution of $10\%/\sqrt{E}$ and angle resolution of less than 1 degree are obtained.

A schematic view of the satellite is shown in Fig.2. Main differences from the ordinary gamma ray satellite are following.

1) Large surface area ($S=10^4$ cm^2). Large solid angle ($\Omega=3$ sr).
2) Good energy resolution ($10\%/\sqrt{E}$) and angle resolution ($\Delta\theta \sim 0.1^{\circ}$).
3) Long life (essentially infinite).
4) Large energy range (100 MeV to 1 TeV).
5) Total weight ~ weight of convertor (20 rl. = 1 ton).

Especially for 1), $S \times \Omega$ is 30 time bigger than Gamma-Ray Observatory (GRO, 1981). GRO's life is 2 years so that SFAGO can catch up with it by only 3 weeks of data taking.

Sensitivity

The sensitivity of the SFAGO satellite is shown in Fig.3. It covers from 100 MeV to 1 TeV by 1 year of operation. This is significantly larger than that of GRO. By this, we can cover unsearched energy range between the ordinary satellite (<a few GeV) and ground based experiment (>TeV).

For dark matter search, we use the reaction

$$\chi\,\chi \rightarrow q \text{ anti-}q \rightarrow \gamma + X.$$

For the branching fraction of $q \rightarrow \gamma + X$, we used data from e^+e^- experiment (Aihara, 1985). Fig.4. are the expected gamma ray spectra for cases, M_χ=15 GeV, 50 GeV, 300 GeV and 500 GeV. We assumed halo density of 0.75 GeV/cc, velocity of 10^{-3} c and halo shape of $1/(r^2+(10\text{kpc})^2)$. The main background is diffuse gamma ray and it is considered to have energy spectrum of $E^{-2.7}$ which differs from the exponential shape of CMS quark anti-quark decay. The background subtracted signal is also shown in Fig.4 with error bar. If the mass of LSP is less than 100 GeV, only 1 month observation is enough.

For a case LSP is less than 10 GeV, we can use the reaction $\chi\,\chi \rightarrow J/\varphi + \gamma$ (Rudaz, 1986). In this case, a monochromatic gamma ray peak of a few GeV is a signature.

Summary

Dark matter is necessary not only by astro-physical argument but by fundamental particle physics. The effort to detect it is important in constructing TOE (Theory of Everything). We have shown a way to do it other than an accelerator experiment.

References

Aihara, H. et al., 1984, PRL 52,577.
Aihara, H. et al., 1985, Z. Phys. C27,187.
Bogomolov, E.A. et al., 1981, Proc. 17th Int. Cosmic Ray Conf. 9,146.
Buffington, A. et al., 1981, Ap. Lett. L105,247.
Fayet, P. et al., 1977, Phys. Rep. 32,249.
Goldberg, H., PRL 50,1419.
Golden, R.L. et al., 1984, Ap Lett. 24,75.
GRO, 1981, "The Gamma-Ray Observatory Science Plan".
Langacker, P., 1981, Phys.Rep. 72,185.
Lee, B.W. et al., 1977, PRL 39,165.
Ohmes, L. et al., 1988, "Report of ASTROMAG Definition Team"
Protheroe, R.J., 1982, Ap. J. 254,391.
Reynolds, G.T. et al., 1961, "Method of Experimental Physics", Vol 5., Academic Press.
Rudaz, S., 1986, PRL 56,2128.
Rudaz, S. et al., 1988, APJ 325,16.
SSC, 1986, "Proceeding of the 1986 Summer Study on the Physics of the Superconducting Supercollider", June 23-July 11, 1986.
Takasaki, F. et al., 1988, KEK-Preprint 88-69.
UA2 Collaboration, 1985, CERN-EP/85-203.
Weinberg, S., 1967, PRL 19,1264.

Figure captions

Fig.1:Copied from Rudaz et al. (1988). Intersteller cosmic-ray antiproton flux from Mχ=15GeV dark matter fermion annihilation (dashed line) and that spectrum modulated by the solar wind (solid line) compared with the observed fluxes as measured by Buffington et al. (1981)(Bu), Bogomolov et al. (1981)(Bo), and Golden et al. (1984)(G). Lower curves, marked CRS, show the predicted flux of antiprotons as cosmic-ray secondaries produced by cosmic-ray collisions in intersteller space (Protheroe 1981).

Fig.2:SFAGO (Scintillating Fiber Astronomical Gamma-ray Observatory) detector.

Fig.3:Sensitivity to the diffuse gamma ray sources.

Fig.4:Contribution of the reaction $\chi\chi \rightarrow q$ anti-q $\rightarrow \gamma X$ to the intensity of cosmic gamma rays. Solid line is the intensity of diffuse gamma ray. The background subtracted signals are also shown in the same plot (right scale).

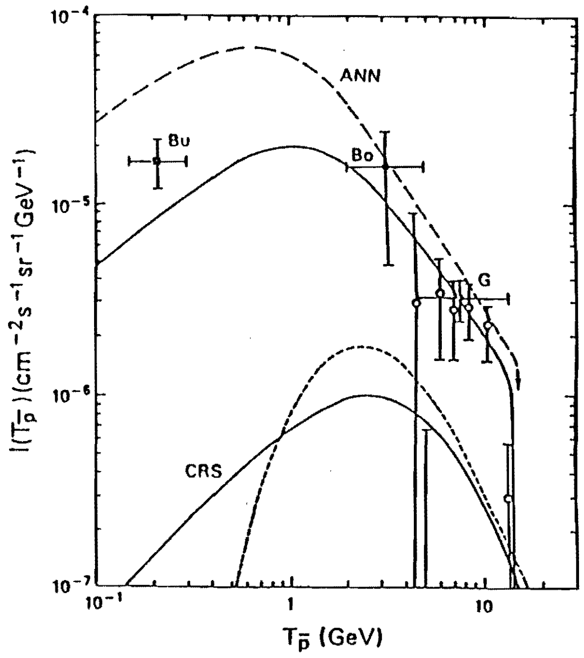


Fig.1

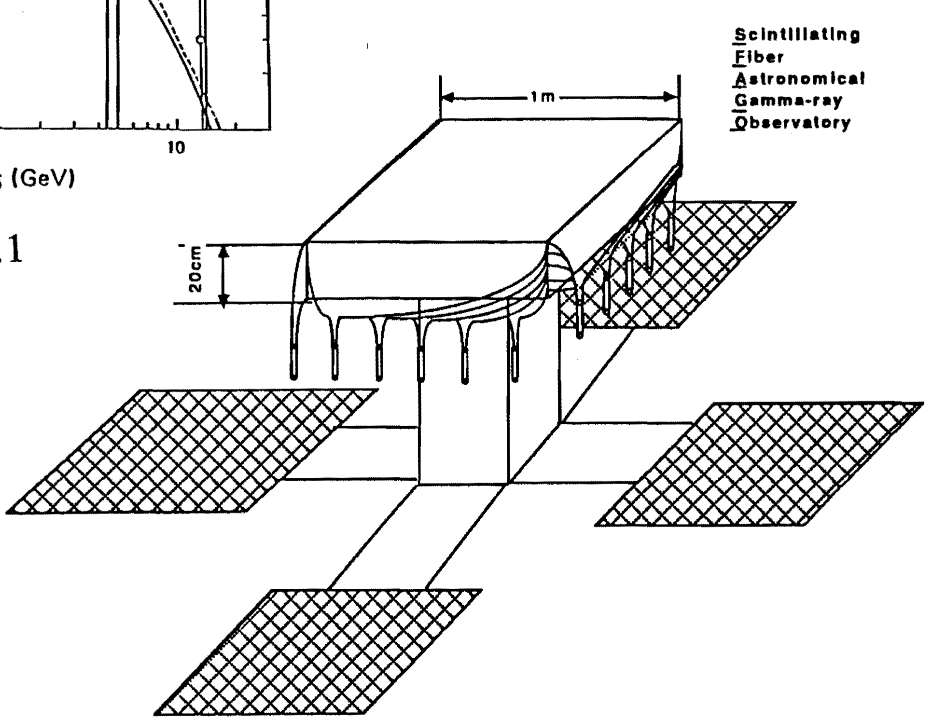
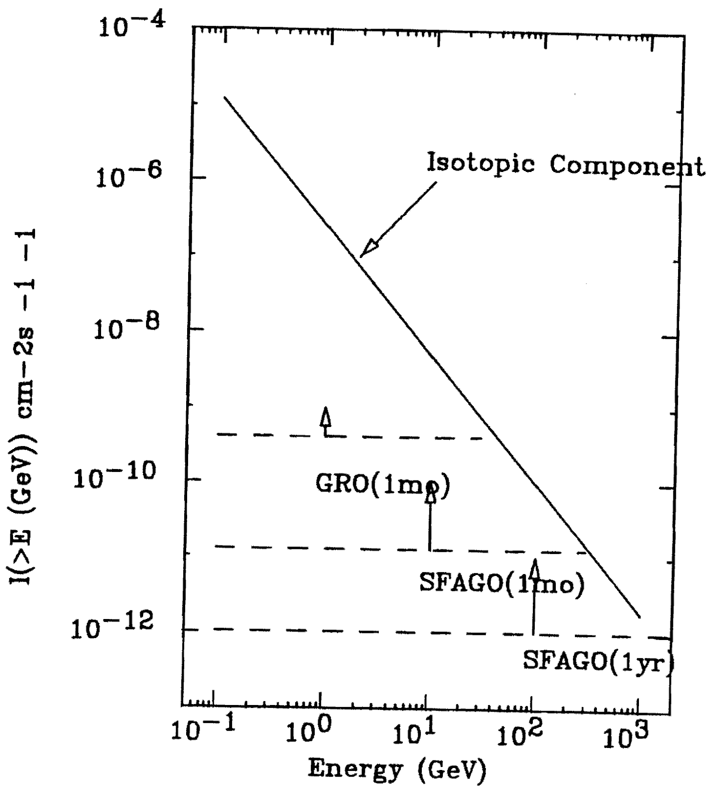
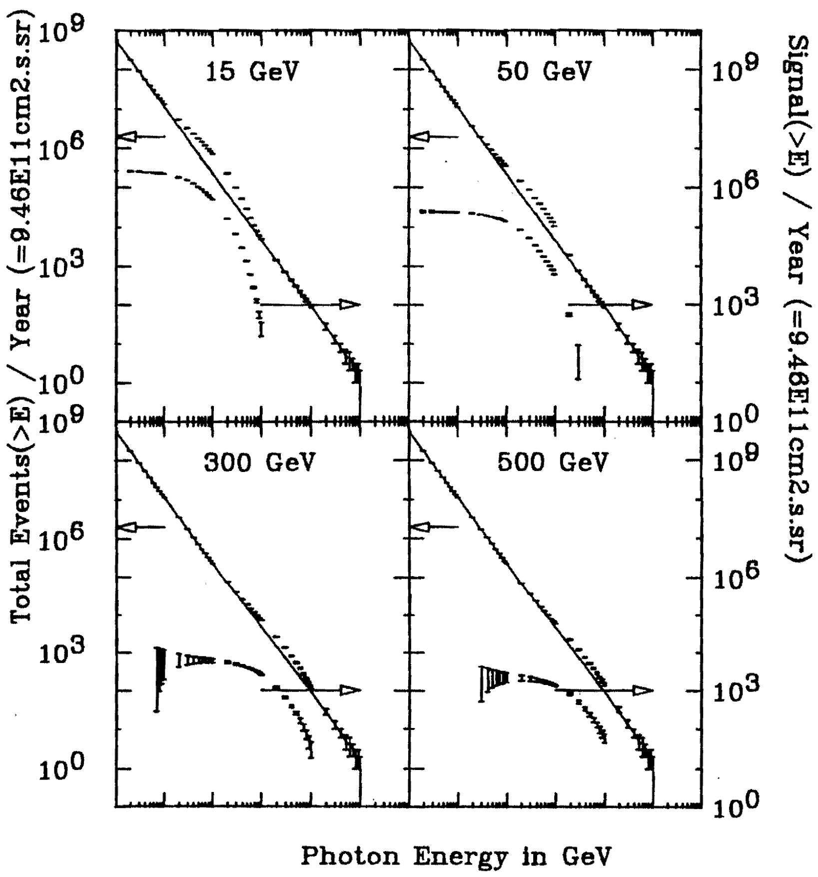


Fig.2



10^-4
10^-6
10^-8
10^-10
10^-12
I(>E (GeV)) cm-2s -1 -1
Isotopic Component
GRO(1mo)
SFAGO(1mo)
SFAGO(1yr)
10^-1
10^0
10^1
10^2
10^3
Energy (GeV)

Fig.3



Total Events(>E) / Year (=9.46E11cm2.s.sr)
Signal(>E) / Year (=9.46E11cm2.s.sr)
15 GeV
50 GeV
300 GeV
500 GeV
10^9
10^6
10^3
10^0
Photon Energy in GeV

Fig.4