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G. Basini, P. Spillantini:

SEARCH FOR ANTIMATTER. GOALS AND TECHNIQUES

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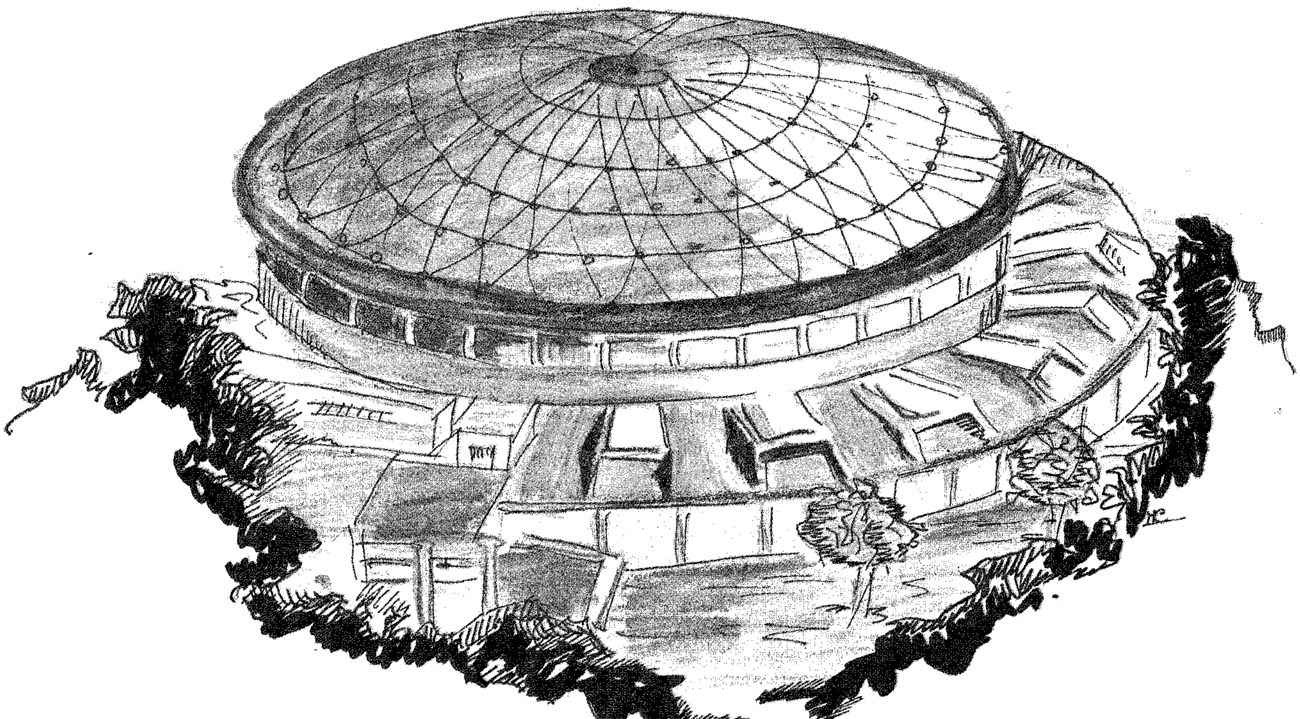

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SEARCH FOR ANTIMATTER. GOALS AND TECHNIQUES

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1. Introduction

The common field between particle physics and astrophysics shows today the greatest interest in research.

New basis on theory for the unification of the fundamental laws give us a framework for a better comprehension of nature stimulating new experimental work.

In recent years the progress on technologies in space transportation systems and in small dimension particle detectors (e.g. transition radiation detectors, superconducting magnets, compact calorimeters, high resolution T.O.F.) have made possible to start with a systematic search for antiparticles in cosmic rays with space based apparata. This search was for a long time forbidden because of the impossibility for heart-based apparata to detect antimatter particles which don't survive the interaction with the atmosphere.

So it becomes now possible to verify several theories and hypothesis that cannot be tested otherwise because of the impossibility for an e.m. signal to discriminate between a source of matter or antimatter.

A fundamental question in astrophysics and cosmology is to what degree the universe exhibits matter-antimatter symmetry. Cosmic rays can give indication on that. It is clear that cosmic rays contain a measurable flux of "secondary" antiprotons (as well as positrons) produced in high-energy collision of cosmic rays with the interstellar gas, but at the same time more exotic sources of antiprotons have also been proposed that might add to and modify the spectrum of antiprotons in predictable ways.Among them there is also a possibility for a dark matter signature (fig.1).

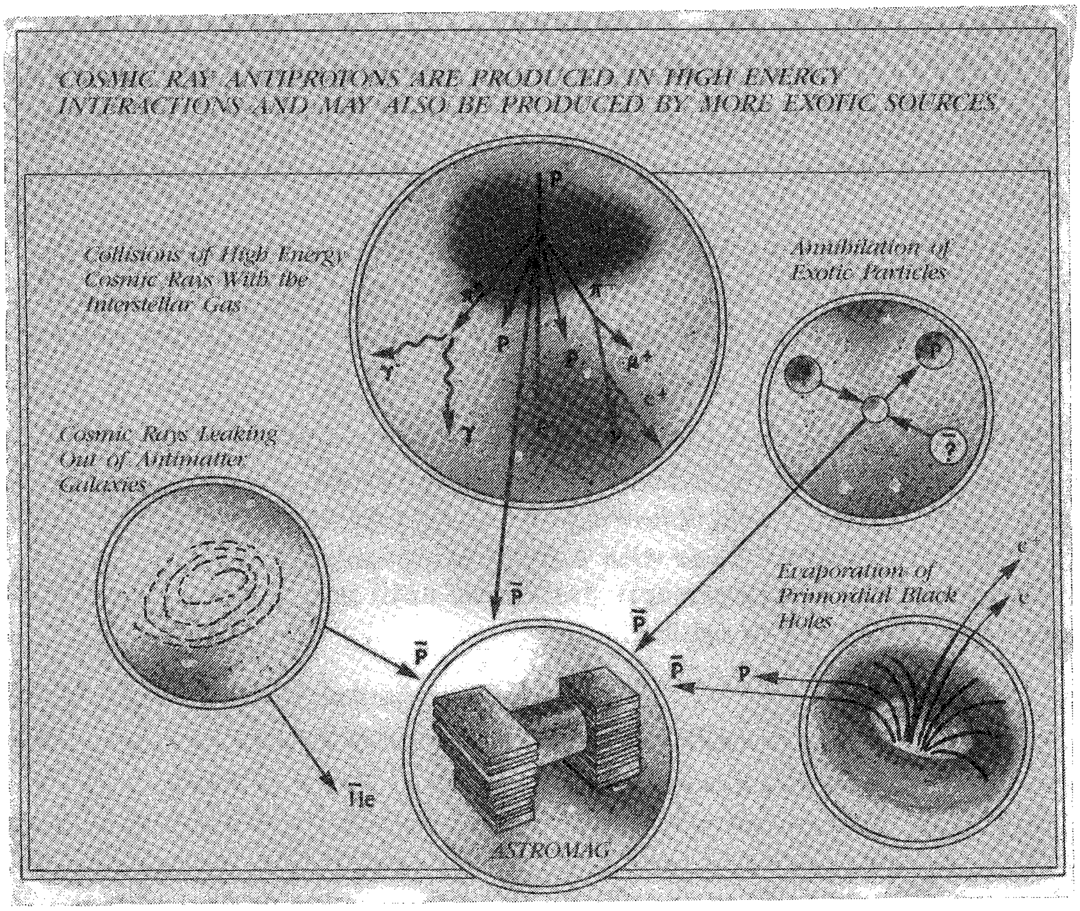

fig.1.

2. Standard models and experimental situation

It seems that there are evidences [ref. 1,2,3] of an excess of antiprotons in cosmic rays that cannot be explained by secondary production via $p + p \rightarrow \bar{p}$+anything, applied to the standard scheme of cosmic rays propagation models [ref.4] which computes expected $\bar{p}$ flux starting from proton flux, antiproton production cross section, and quantity of trasversed matter.

In fact starting from that reaction the differential cross section is given by

$$dN_{\bar{p}}/dE \sim (2 < y > /m_p) \int_E^{\infty} (d^3\sigma_{\bar{p}}/dE)(E, E')(dN_o/dE')dE'$$

where $< y >$ means the path free length (g/cm^2), m_p is the proton mass (in g), dN_o/dE' is the proton flux, $(d^3\sigma_{\bar{p}}/dE)(E, E')$ the $\bar{p}$ production cross section. Following Gaisser and Maurer [ref.4], using parametrization obtained by accelerator data and extrapolating beyond ISR data, it comes out an asymptotic value

$$\lim_{E\to\infty} \bar{p}/p \sim 4.6 \cdot 10^{-4}$$

with an expectation of values raising from 10^{-6} to 10^{-5} in the range 0.2-5 GeV, inconsistent with the [1,2,3] experimental data, showing the necessity of different models.

Contraryly to that, recent data, unpublished at the date of the Erice school of astrophysics (May 88) due to S.Ahlen et al. and again by R.L.Golden et al., collected in the 1987 campaign of flight, shows no evidence of low energy antiproton.

It is difficult to discriminate between these results and the previous one, because of the poor statistics and because no-one apparatus was significantly better than the other, beeing them, following the case, without magnetic signature or without tracking calorimeter, or with a small acceptance.

A summary of the experiments performed until now (including older measuraments) is presented in table I.

The experimental situation and the best fits are shown in fig.2. The fits correspond to the various models trying to explain the discrepancy from the standard leaky box model (curve labeled 7 g/cm^2). The models differ in the amount of the traversed material by cosmic rays protons.

The curve labeled "21 g/cm^2" arbitrarily scales the proton pathlength by a factor of 3, in order to match the antiproton experimental values. Another proposed possibility is the so called "closed (or lossless) galaxy model" (fig.2), in which there are two cosmic rays components, one of which is "old" and has traversed a great amount of matter.

Finally a model proposes that a portion of cosmic rays originates in sources surrounded by a thick shell (e.g. about 50 g/cm^2) of matter, perhaps supernovae explosion in dense clouds. The calculated slope of the antiproton spectrum from such model depends on the detailed assumptions of the model. For example, the slope is predicted to be proportional to $E^{-2.7}$ if antiprotons are further accelerated after production at the source (collisional injection in fig.2). All these models try to explain the high energy data, but they are ineffective at low energy, because, unless there are mechanisms that significantly decelerate particles after their production, antiproton spectra resulting from high-energy interactions would be expected to exhibit a "kinematic cutoff" below ~ 1 GeV.

. I

COSMIC RAY ANTIMATTER SEARCHES

	Rigidity (GV/c)	$\bar{N}/N$	Reference	Technique
Antiproton	.5 to 1	$2.2 \pm 0.6 \times 10^{-4}$	Buffington et al. 1981	AnnihilationTopology--Counter
	< 0.6	$< 9 \times 10^{-4}$	Apparao, 1967	Annihilation--Emulsion
	< 1.3	$< 3 \times 10^{-3}$	Aizu et al., 1961	Annihilation--Emulsion
	3-6	$< 1 \times 10^{-2}$	Bogomolov et al., 1971	Permanent Magnet
	5.6 to 12.5	$5.2 \pm 1.5 \times 10^{-4}$	Golden et al., 1979, 1984	Superconducting Magnet
	> 16	< 0.13	Durgaprasad and Kunte, 1971	Geomagnetic--Counters
	< 1	$< 3.5 \times 10^{-5}$	Golden et al., 1987	Superconducting Magnet
	< 1	$< 4.6 \times 10^{-5}$	S.Ahlen et al. , 1987	AnnihilationTopology-Magnet
Antihelium	0.25 to 0.5	$< 2.2 \times 10^{-5}$	Buffington et al., 1981	Annihilation Topology--Counter
	1-10	$< 1 \times 10^{-3}$	Evenson, 1972	Permanent Magnet--Spark Chamb.
	10-25	$< 8 \times 10^{-3}$	Evenson, 1972	Permanent Magnet--Spark Chamb.
	4-33	$< 5 \times 10^{-4}$	Smoot, Buffington, and Orth, 1975	Superconducting Magnets
	33-100	$< 2 \times 10^{-2}$	Smoot, Buffington, and Orth, 1975	Superconducting Magnets
	< 2.7	$< 7 \times 10^{-3}$	Aizu et al., 1961	Annihilation Emulsion
	< 100	$< 7 \times 10^{-3}$	Damle et al., 1973	Permanent Magnet--Emulsion

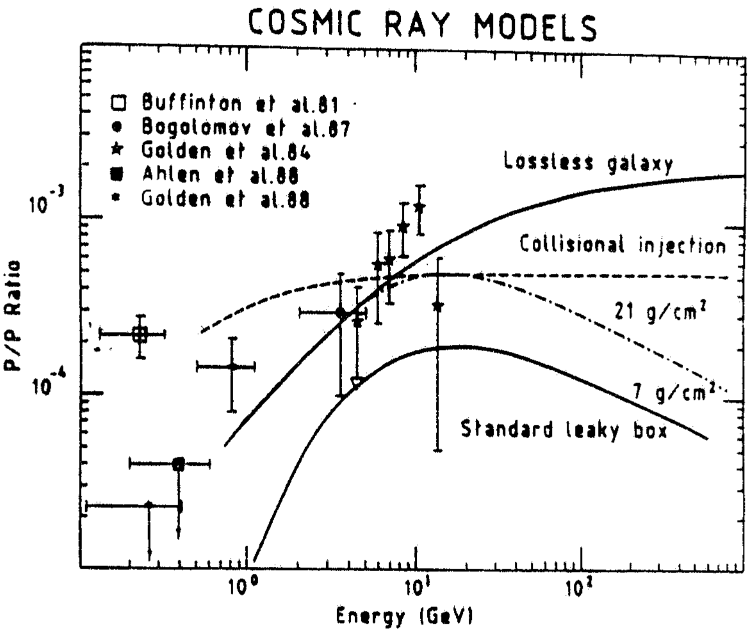

Figure 2

3. Exotic models and experimental situation

Despite the attempts, the proposed changement of the standard model of secondary production, seems do not fit the existing data, showing that simple modifications of that models are unable to explain the observed points.

New and more exotic solutions have been investigated, among which neutron oscillation (n-$\bar{n}$ oscillation, if existent, could in principle explain the $\bar{p}$ excess because of the subsequent $\bar{n}$ decay into $\bar{p}$. ref.5), evaporation of primordial black holes (ref.6,7), photino pair annihilation (ref.8,9) and the generation of extragalactic antiprotons in antigalaxies in a baryon-antibaryon symmetric universe (ref.6,10,11).

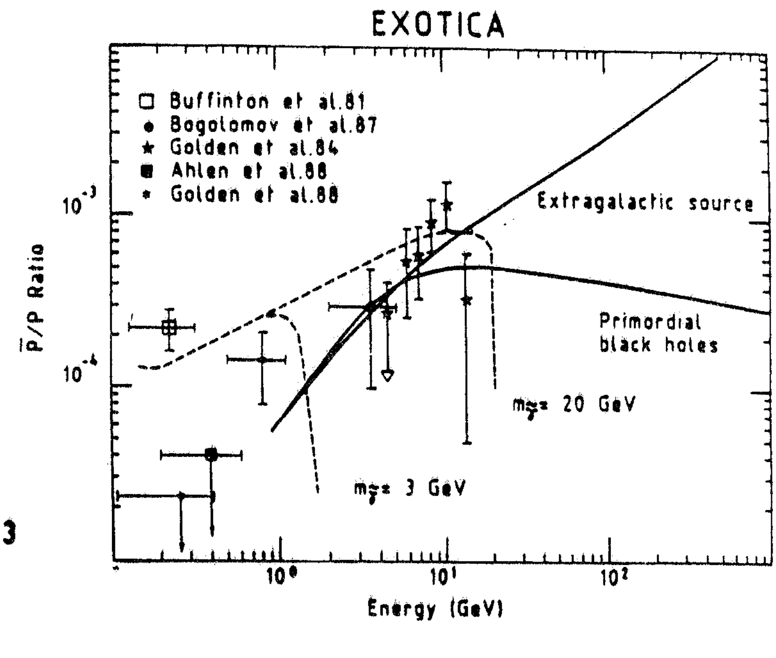

Figure 3

It is very important to get the higher possible statistics on antiproton research, because of the interest of the exotic mechanism suggested (fig.3,4). In fact, looking at the picture, the contradictory experimental results lead to completely different conclusions.

The Buffington point, for instance, is completely consistent with a photino annihilation with a mass of more than 15 *GeV* (see next paragraph), in contradiction with the new limits of Golden and Ahlen, which are compatible with the existence of extragalactic antimatter sources or with primordial black hole evaporation (Hawking effect).

4. Antiproton and dark matter

A very interesting hypotesis comes out from the supersymmetric theories, that attempt to explain the very early universe and to unify the four foundamental forces of the nature.

The photino, the supersymmetric partner of the photon has been proposed as a candidate for the invisible part in the universe and the observed flux of cosmic rays antiprotons may result from the annihilation of photinos and antiphotinos.

As indicated in fig.4, photino annihilation results in antiproton spectra that cut-off at an energy corresponding to the photino mass; it is interesting to notice that the existing data are consistent with a photino mass of 15 GeV or greater. If more precise measuraments show a sharp cut-off in the antiproton spectrum, it would be a strong evidence for the existence of photinos or other Majorana fermions in the Galaxy. Gamma ray lines may also be a signatere of these particles.

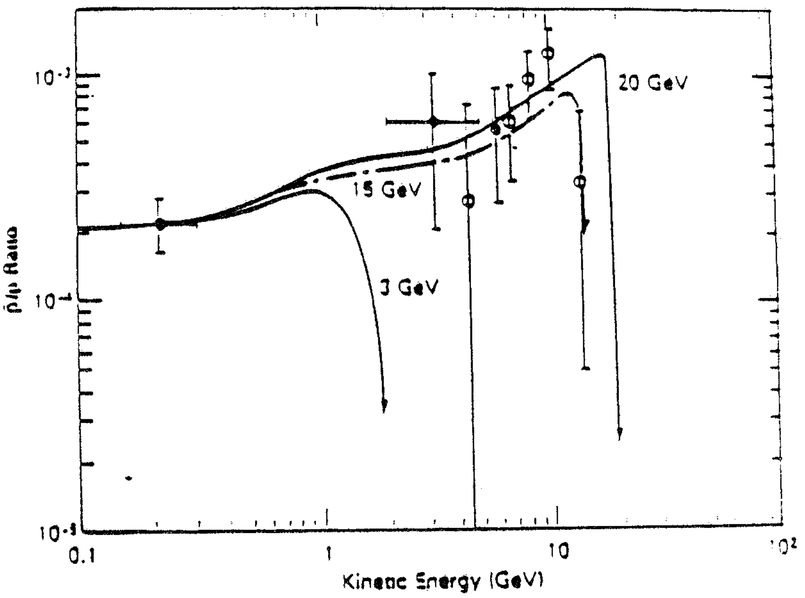

Figure 4

5. Future programs. The MASS experiment

The Mass (Matter Antimatter Space spectrometer) apparatus shows itself as a second generation detector, able in principle to solve the problem of the presence of low energy ($\leq 1\ GeV/c$) antiprotons, wich is still open because of the contraddiction between the existent experimental data, as we have seen previously.

The apparatus (fig.5) is composed by track detection chambers, time of flight, superconducting magnet, Čerenkov, and is basically the same apparatus used by R.L. Golden to collect data already presented, but with an important upgrading: a fifty planes tracking calorimeter, made by 3200 brass streamer tubes coupled with an equal number of strips for the induced signals, that seems the best device to work in connection with a magnetic spectrometer, in order to detect cosmic antiprotons. In fact it will be possible to get the topology of the annihilation with the reconstruction of the vertex, improving the capability to recognize a $\bar{p}$ signature.

The full apparatus is designed to work transported by a flying baloon at an altitude of about 45 Kilometers, in a canadian area closest as possible to the magnetic north-pole to minimize the geomagnetic cut-off due to the terrestrial field.

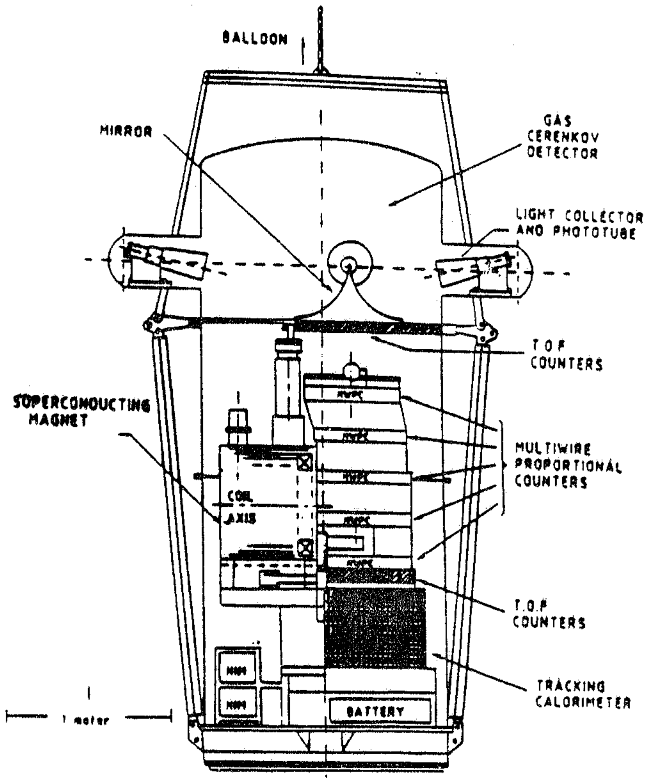

Figure 5

6. Future programs. Astromag on Space Station

Placed on a 28^0 degree orbit at an altitude of about 500 kilometers, the space station (fig.6) will make possible the installation of the Astromag facility.

The Astromag facility (essentially a superconducting magnet) will be the core of two experiment: MAS (Matter Antimatter Spectrometer) reviewed in this talk, and CRIS (Cosmic Rays isotope spectrometer), placed on the other side of the magnet (fig.7).

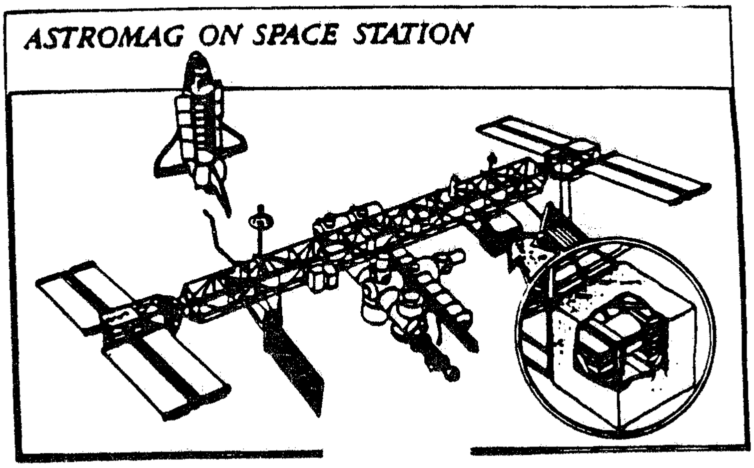

FIG. 6 - Location of ASTROMAG on the SS-phase 1 aside one of the 5 meter cubes constituting the basic SS structure and protective netting around it.

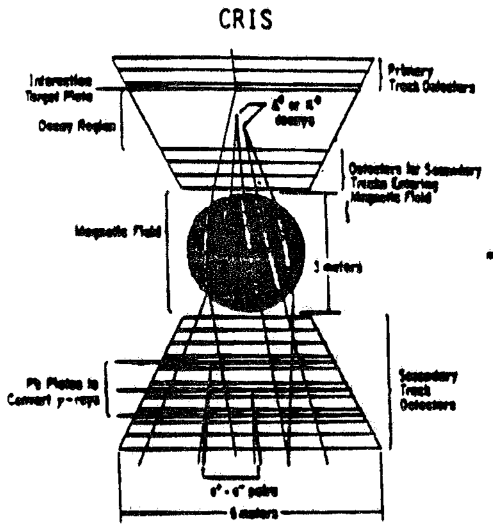

FIG. 7-A Cross-section of a detector system designed to search for strange-quark matter and other exotic particles and to study nuclear interactions. A hypotetical event with two strange particle decays ($\Lambda^0 \rightarrow p + \pi^-$ and $K^0 \rightarrow \pi^+ + \pi^-$) and two gamma rays is shown.

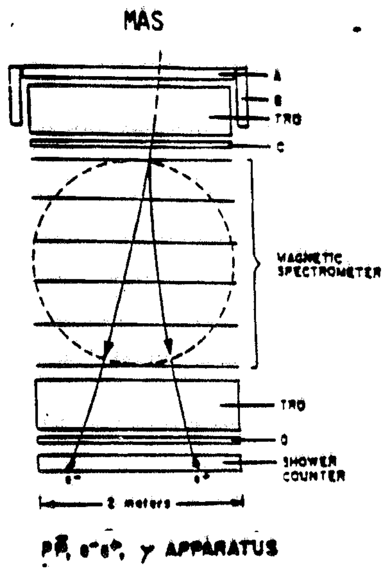

FIG. 7-B An apparatus for p, $\bar{p}$, e^-, e^+, gammas, $\overline{He}$.

Goals of the Astromag-Mas apparatus will be to try to answer to the question of the degree to which the universe contains antimatter.

Experimentally this is the Astromag-Mas program:

1) Search for antinuclei (galactic or extragalactic) with a never achieved before sensitivity.

2) Confirm and search for the origin of the overabundances of antiprotons in cosmic rays.

3) Search of possible confirmation to the hypotesis related to the dark matter, like photino annihilation, studying the antiproton spectrum.

4) Search of possible confirmation of exotic process like the decay of primordial black holes or the antigalaxies contribution studying the antiproton and positron spectrum.

5) Search for production mechanism of positrons and antiprotons in nucleon interaction taking place in interstellar medium and in cosmic ray sources

7. Future program: a polar detector ?

Astromag will be a very performant multi-purpouse apparatus and a fundamental step in antimatter search mainly because of its capability to take data for years instead days as in balloon borne experiments, but Astromag still is not the best that can be done for specific antimatter research because of the orbit. In fact, because of the 28^0 inclination of the space station, the geomagnetic cut-off due to the magnetic terrestrial field (fig.8) makes impossible the study of the low energy zone of the spectrum ($< 3-4\ GeV/nucleon$) for antiproton and antihelium. Now there are reasons to prefer to search for antimatter at low energy because of both physics and technology. The physical reasons are related to the $\bar{p}$ production mechanism and to the $\bar{H}e$ aboundancy. There should not be secondary antiprotons produced by colliding protons below $\sim 1.1 GeV/c$ for kinematics, so that low energy $\bar{p}$ would be clearly produced by one or more of the exotic mechanism presented before. For the hypotetic $\bar{H}e$ (that can be only primary) their rarity suggests to extend the research in the low energy region under the hypotesis that the $\bar{H}e$ flux decreases with the increasing energy. The technological reason is also very important being related to the necessity of detecting an eventual $\bar{H}e$ with no ambiguity at all because their rarity makes impossible to get a significant statistics. Now a low energy antihelium is more easily detectable in comparison with a more energetic-one i) because the annihilation star can be fully contained in a tracking calorimeter showing its clear signature and ii) because it's easier to make a significant comparison between the low momentum detected by a magnetic spectrometer and the much higer energy released in the calorimeter (because of the contribution of the annihilation). Thus, the full containament (possible only at low energy) make the experimenters sure of the signature even for the cosmological implication if very few $\bar{H}e$ are detected (in fact even the detection of a single $\bar{H}e$ would be a major result). From these considerations it comes out that an apparatus able to cover a big energy range from 1 to 500 Gev using Astromag-like detectors (T.R.D., dE/dx, magnetic field) for more energetic particles and a tracking silicon calorimeter for the less energetic-ones, placed in a polar orbit reducing the cut-off would be the best for systematic antimatter research.

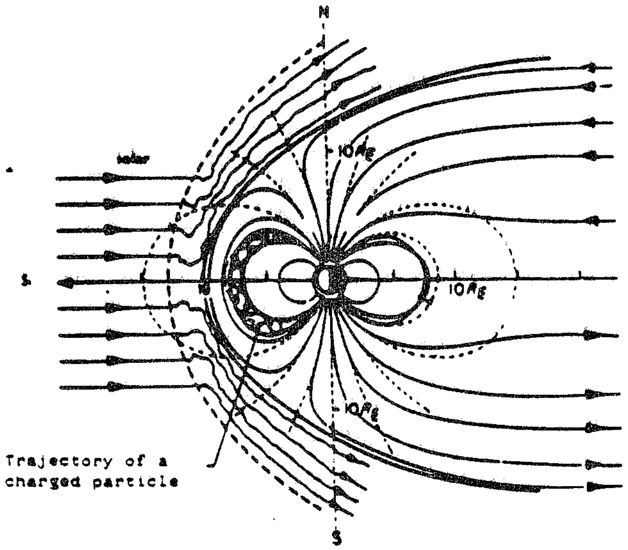

Figure 8

Another possibility (depending on launch availability) could be an apparatus placed in a very high orbit, away from the strong influence of the terrestrial magnetic field, getting even more advantages than a polar orbit in eliminating the geomagnetic cut-off.

Considering the U.S. strong engagement in the Space Station Program, maybe a polar antimatter detector would be an excellent task for Europe (European Space Agency and National Space Agencies like the Italian ASI) to deal with, gettin the goal to use european launchers and satellites to achieve very significant results, eventually in close cooperation with American partners.

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