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M.A.S.S.: "MATTER ANTIMATTER SPACE SPECTROMETER". A SPACE EXPERIMENT FOR THE MEASUREMENT OF THE FLUX OF COSMIC RAY ANTIMATTER.

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1.- MOTIVATIONS

The symmetry between matter and antimatter is nearly exact in experimental elementary particle physics. Only a small deviation in CP violating decay of kaons is observed.

Hot Big Bang cosmology would lead to the conclusion that this symmetry should also be observed in the Universe unless the baryon-antibaryon symmetry is broken during the early evolution of the Universe(1).

Astronomical observations can establish the antibaryonic fraction to be $\sim 10^{-10}$ in the local group of Galaxies (a region of the Universe of dimensions ~ 1 Mpc), but is unable to give an answer to the large scale baryon-antibaryon ratio(2).

Recent measurements of antiprotons in cosmic rays have given an indication that the ratio of antiprotons to protons in cosmic rays would be much larger ($\sim 10^{-4}$) than the limit to antimatter fraction in the local group.

This first indication could support the idea that $\bar{p}$s in the cosmic rays might have extragalactic origin. In this case the $\bar{p}/p$ ratio could indicate that $\bar{p}$s are radiated by antimatter Galaxies and the Universe could be symmetric in matter-antimatter concentration.

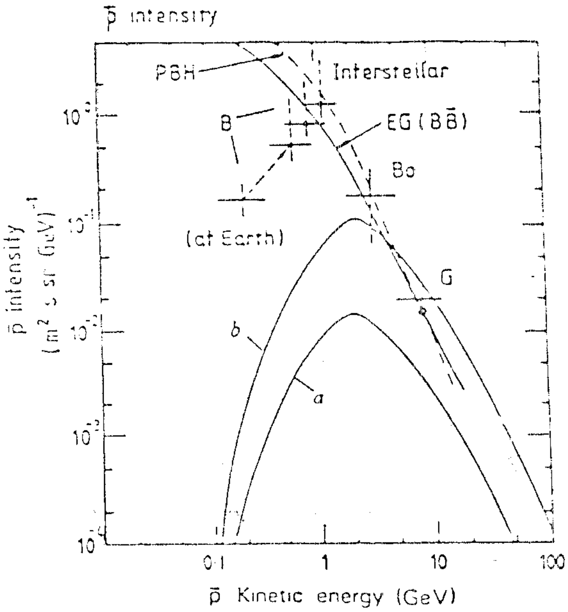
By now, three experiments have been performed to measure the $\bar{p}$ flux, collecting a total number of some 20 antiprotons$^{(2,3,4)}$. The three experiments cover an energy range from 130 MeV to 10 GeV and the results agree in showing a larger flux than expected. In particular, the low energy point$^{(4)}$, when appropriately corrected for solar wind modulation, does not show any sign of the kinematical decrease expected in secondary production, being, on the contrary, compatible with a constant $\bar{p}/p$ ratio $\approx 3\times10^{-4}$ (Fig.1, taken from ref.(7)).

Slight modifications of the standard scheme of cosmic ray propagation fail to reproduce the observed flux, in particular at low energy. As a consequence, more radical alternatives have been proposed, none of them really satisfactory$^{(5)}$:

a) Neutron oscillations.

If $\bar{n}$-n oscillations are allowed, the subsequent $\bar{n}$ decay into $\bar{p}$ could in principle explain the observed flux$^{(6)}$. The experimental limit on the oscillations requires however some special circumstances.

FIG. 1 - Secondary antiproton flux predictions. a, Leaky box model with λ=5 g cm^{-2}, b, closed Galaxy model. The displacement of the Buffington et al. point$^{(4)}$ (marked B) is to allow for solar modulation. The points correspond to mean adiabatic energy losses of 400, 600 and 900 MeV. The horizontal error bars represent the energy intervals from which $\sim$70% of the measured flux at Earth is expected. The highest value (900 MeV) would be unreasonably high for protons or for primary $\bar{p}$s with a power-law spectral shape, but is quite possible for the peaked spectra of secondary $\bar{p}$s. The dashed vertical bars represent plausible deviations from Liouville's theorem. Bo denotes Bogolomov et al.$^{(3)}$; G denotes Golden et al.$^{(2)}$; EG($B\bar{B}$) denotes the prediction for extragalactic $\bar{p}$s generated in antigalaxies in a baryon-antibaryon symmetric universe normalized at 9 GeV. If there is a significant galactic wind the $\bar{p}$ intensities will fall off with falling energy (< 1 GeV). PBH denotes the prediction for the exploding primaeval black hole model (quark version) normalized as above. The remarks about the influence of a galactic wind made in the last paragraph apply here too if, as is likely, many of the BHs are in the galactic halo.



b) Evaporation of primordial black holes (PBH) (Hawking effect).
This is a source of equal numbers of particles and antiparticles(7,8).

c) Relic massive photinos(9) with mass >1 GeV could be a dominating component of dark matter in the halo of our Galaxy. Hence the $\overline{p}$ excess in cosmic rays could be a result of photinos pair annihilation.

2.- EXPERIMENTAL APPARATUS

The cosmic antiproton differential flux from 130 to 320 MeV is expected to be $1.7\pm0.5\times10^{-4}\ m^{-2}sr^{-1}s^{-1}MeV^{-1}$ and the ratio to protons $2.2\pm0.6\times10^{-4}$(4).

Hence the expected number of antiproton interactions that could be recorded in a space experiment with an acceptance of 1 m^2 x sr over a range of 100-500 MeV is of the order of 200 per hour, while the same experiment would be invested in the same time by $\approx 10^6$ protons in the same energy range.

In a simple calorimetric experiment in which the signature would be a total released energy of 2 GeV, a possible contamination could be originated by more energetic protons, interacting in the calorimeter; thus a very rough estimate of the rate of such events could be:

$$r = \eta \times \Phi(E > 2\ \mathrm{GeV}) \times \pi A ,$$

where η is the probability of releasing $\gg 2$ GeV in the calorimeter, Φ is the integral flux of protons and A is the calorimeter area. Assuming the conservatively $\eta \gtrsim 1/3$ and a spectral index for the cosmic ray protons ≈ 2.7, we might expect that the number of proton interactions to be recorded in a simple calorimetric experiment would be of the order of 1000 per hour.

Therefore we propose an experimental apparatus composed of a magnetic spectrometer equipped with track chambers and scintillation counters in order to measure the momentum and, respectively, to give the time of flight (Fig. 2).

Choosing a toroidal magnetic lens the negative particles could be focused in a relatively small calorimeter area (i.e. less than 1 m^2), while the positive charged particles would be deflected outside.

The definition of the mass of the particle could be obtained measuring its time of flight, a procedure required also to avoid possible contaminations from albedo antiprotons and π^- produced by showering protons.

For a good containement of the annihilation event, the calorimeter should have high density and a high as possible ratio between radiation and interaction lenghts ($\lambda_{rad}/\lambda_{int}$). This ratio is remarkably good for copper ($\lambda_{rad}/\lambda_{int} \approx 0.1$). Furthermore, tracking calorimeters(10) made of copper streamer tubes(11) make it possible to reach densities of ≈ 5 gr/cm^2 with high granularity ($\approx 5x5x5$ mm^3).

The toroidal lens does not require an extremely high magnetic field because of the low momentum of the incoming antiprotons and antinuclei.

In order to evaluate the acceptance of the spectrometer for different particles, a Montecarlo simulation has been worked out.

The behaviour of the acceptances as function of the magnetic field ($|B|$ is the value of the magnetic field at 40 cm from the axis)(Fig. 3) shows that already at 4 kgauss more than 5% of the antiprotons crossing the first TOF counter (and only 1% of the protons) can reach the calorimeter.

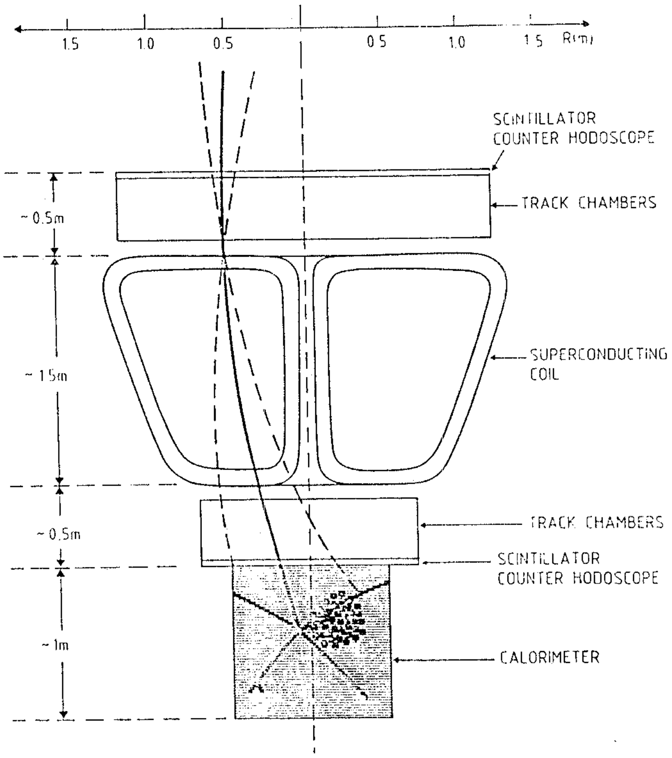


FIG. 2 - Schematic view of the spectrometer.

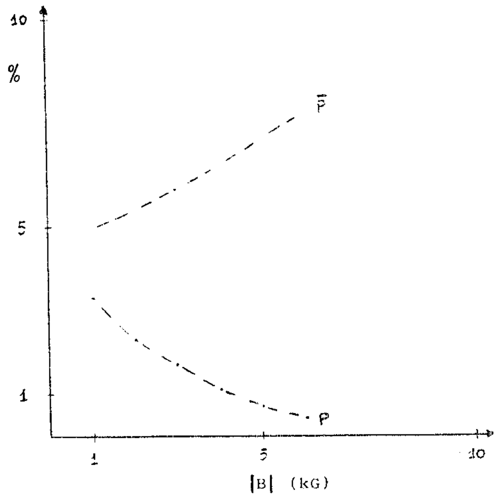


FIG. 3 - Percentage of particles (500 MeV/c) that reach the calorimeter for a magnetic field at 40 cm from the axis. The lenght of the magnetic field is 130 cm.

In such a field, a path of ≈ 1.5 m gives an avarage error of 5% on momentum determination due to the multiple scattering occuring in the interposed materials (e.g. about 10 mm alluminium equivalent). This error must be combined with the measurement error which, assuming 10 mrad determination of the deflection angle, is of the order of 10%·p. The result is given by the formula

$$\Delta p/p = a + b\cdot p , \qquad p \ (\mathrm{GeV}/c)$$

where, in our case, a = 0.05 and b = 0.1.

3.- IN FLIGHT CONFIGURATION

The experiment is intended for the use on the pallet of the Spacelab to be runned to collect data for a standard Shuttle space mission (7 days long) and/or for a balloon launch (Fig. 4) at latitudes with low geomagnetic cut-off.

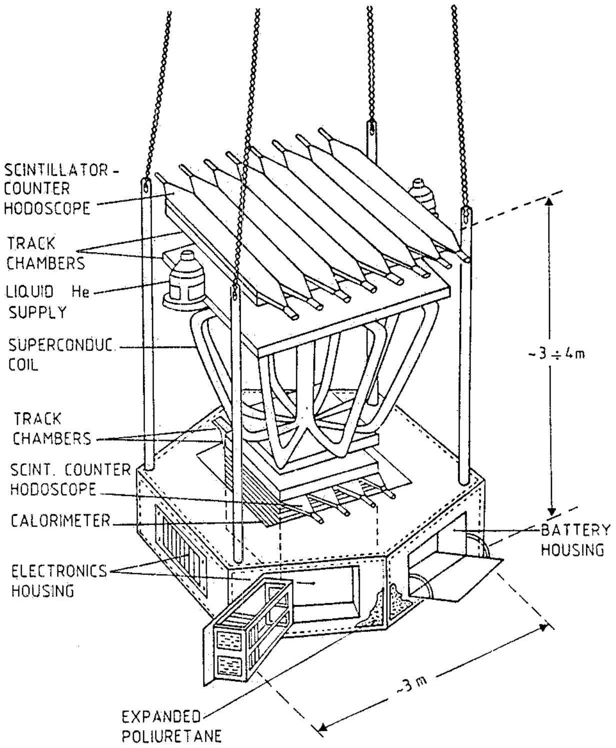


FIG. 4 - Comprehensive view of the apparatus for a balloon launch.

The experiment will be designed in order to be compatible with the accomodation requirements on two Spacelab pallets. According to this philosophy, a test flight on a balloon could be considered as the first phase of an experiment with the Shuttle. During the test flight the experiment could collect valuable scientific data and also obtain important results on the astrophysical and cosmological problems that motivate this kind of research.

Possible launching sites in the northern emisphere with logistic support for the campaign, exist in the Andoya Range, Norway (Geomagnetic lat. 67 deg.) and in the Esrange, Sweden (lat. 68 deg.)(12). Other opportunities (e.g. North-America) likely exist and will be investigated.

Moreover, the CNES (Centre National d'Etudes Spatiales, France) could perform launching operations of balloons which could carry up to 3 tons (i.e. 1 Mm^3 balloons) even in not well supported sites.

Hence the design goal of a total experiment weight less than 1-1.5 tons is to be considered.

Other constraints on the physical size of the experiment are to be investigated, both in the case of the Shuttle flight and of the balloon flight.

Power requirements are obviously more stringent in the case of the balloon flight, where power is to be supplied by batteries. A typical figure for organic high efficiency batteries is 10 Ah at 1.5 V per element, with a weight of 80 gr.

Thermal shielding of the apparatus is required with panels of polystirene foam. A totally passive thermal control is usually assured by the internal power dissipation of the electronics, if the external surface of the shielding is covered with white radiator foils, which limits the heat exchange with the Sun.

The superconducting magnetic lens is a passive device in which the magnetic field is stored and the energy for its maintenance is given by the cryogenic fluid storage. Tentative preliminary evaluations indicate that a reserve of about 120 liters of liquid He(13) can assure a maintenance of the magnetic field for a 100 hours flight duration. For safety of operation external dissipation of the current at the end of the flight must be provided.

4.- CONCLUSIONS

The described apparatus with a configuration not heavier than 1.5 tons, but really complete and flexible enough for both envisaged employements (balloon and Shuttle), will be a very good tool to investigate the origin of cosmic ray antimatter.

In our mind, the great variety of phenomena connected with the presence of antimatter in the Universe, the necessity, claimed by cosmologists, to have better statistics on $\bar{p}$ flux (and, thus more refined equipments) in order to check the various cosmological models, and, last but not least, the high technological interest in studying problems related to superconductivity and cryogeny under the conditions of this experiment, completely justify the opportunity in going on in this kind of physics.

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