THE DESIGN OF AN EXPERIMENT TO DETECT LOW ENERGY ANTIPROTONS

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ABSTRACT

The techniques to be used in a balloon-borne experiment
("APEX") to detect < 220 MeV antiprotons are described,
paying particular attention to potential sources of
background. Event time history is shown to be very
effective in eliminating this background. Results of
laboratory tests on the timing resolution which may be
achieved are presented. The limiting experimental
sensitivity of this experiment is $\bar{p}/p < 10^{-5}$.

1. __Introduction.__ The conceptual design of a balloon-borne experiment
to detect low energy antiprotons in the cosmic ray flux has been
described by Balasubrahmanyan et al [1]. The serious revision of ideas
concerning the origin and transport of galactic cosmic ray protons
seemingly required by the high $\bar{p}$ flux reported by Buffington et al [2]
makes such an independent measurement at solar minimum an urgent
requirement.
Referring to Figure 1, the trigger criterion of:
S1(> 1.6 min.)* S2(> 1.6 min.)* $\overline{C1}$ (prompt)* C2 permits the
unambiguous identification of antiprotons if (a) $\bar{p}/p > 10^{-5}$ and (b)
event time history in OS ('outershield') can be measured to 0.5ns. We
have previously considered [1] the importance of vetoing protons > 220
MeV because of the rapid rise in the π° production cross section above
this energy [3]
Here we consider other backgrounds in detail (Section 2), and show
how the timing history is effective in eliminating all but the neutral
high energy background. Schemes to achieve the timing resolution are
discussed in Section 3, and the results of laboratory tests reported in
Section 4.

2. __Background Elimination.__ The flux, coincidence rate, and method of
elimination for each type of background are summarized in Table 1.
These are:
(a) π° production by protons > 220 MeV--the elimination of this
background has been discussed in reference [1].
(b) An out-of-geometry relativistic charged particle
interacting in the Pb glass calorimeter (C2) and depositing an energy ≃
annihilation energy in time coincidence with a slow (< 220 MeV) proton
within the geometry. This is the most serious background, amounting to
~ 75% of the $\bar{p}/p$ ratio at 2 x 10^{-4}. The time history (OS precedes C2 by
3ns) is to be compared to that for a genuine $\bar{p}$ event (C2 precedes OS by
3ns) so that this background can be eliminated (to $\bar{p}/p < 10^{-5}$) if (1)

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minimum ionizing particle detection efficiency is > 99% and (2) the
relative times in S1, C2, and OS can be measured to $\sigma(\Delta t) \simeq 0.5$ ns.
Such timing resolution (nominally a '12σ' rejection factor) is
deliberately conservative in recognition of the existence of non-
Gaussian tails in scintillator timing distributions.

    (c) OS is ineffective if the out-of-geometry particle in (b) is
an atmospheric neutron. Calculations have been performed including the
measured neutron flux [4], the expected directional distribution at
2-5 gm cm^{-2} of residual atmosphere, the interaction cross section, and
experimental geometry factor. We determine that the spurious $\bar{p}$ events
induced by atmospheric neutrons correspond to a $\bar{p}/p$ ratio $< 2 \times 10^{-6}$.
Since this background cannot readily be eliminated, it determines
the $\bar{p}/p$ sensitivity of a calorimetric balloon-borne detector in this
energy range.

Table 1.   Summary of APEX Backgrounds

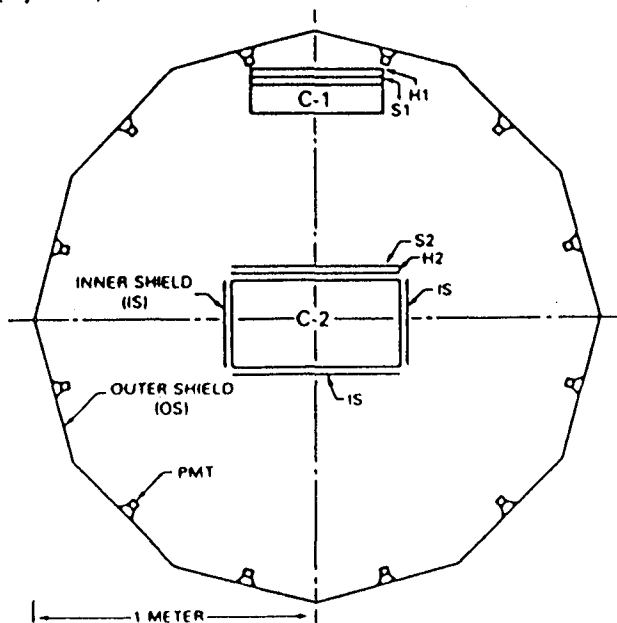| Text Ref.	Particle	Flux/cm^{2}sr.s.		Ref.	Background s^{-1}	Elimination
(a)	L.E. p	0.2-0.3 GeV:	< 2×10^{-2}	[8]	<30	S1.S2.$\overline{C1}$
(b)	H.E. p	> 6 GeV:	< 6×10^{-2}	[9]	2×10^{-3}	Timing
(c)	n	> 2GeV:	< 3×10^{-3}	[4]	8×10^{-6}	--
		> 1GeV:	~ 5×10^{-3}	[4]	2×10^{-5}	--
(d)	e$^-$	> 0.1 GeV:	1×10^{-2}	[10]	3×10^{-4}	Timing
(e)	γ	> 0.1 GeV:	< 6×10^{-5}	[10]	2×10^{-6}	--
(f)	μ+e	< 50MeV:	< 10^4	[11]	< 4×10^{-4}	C2 Threshold

Figure 1. (left) APEX
Design. C1, C2: Crown
Glass, Lead Glass Cherenkov
Detectors. H1, H2:
Hodoscopes. S1, S2, IS,
OS: Scintillator

    (d) Out-of-geometry
electrons > 100 MeV, again
in time coincidence, result
in a cascade in C2 which
could simulate an anni-
hilation. This background
is eliminated by timing as
efficiently as (b)

    (e) Atmospheric
γ-rays (> 100 MeV) cannot
be rejected efficiently
by OS, and can simulate an
annihilation as in (d). Fortunately, the flux of atmospheric γ-rays is
low, resulting in a < 2% contribution to $\bar{p}/p$ at 10^{-5}.

    (f) A low energy (< 50 MeV) atmospheric muon (satisfying the
within-geometry criteria) can decay in C2. although the rate is high,
the resulting cascade is low energy. Simulations have shown that ~ 95%

of the resulting C2 signals are below 98% of the $\bar{p}$ signals, so a suitable C2 threshold can effectively eliminate this background.

Summarizing, the time history eliminates all but the neutral backgrounds, resulting in a sensitivity of $\bar{p}/p \simeq 10^{-5}$. An experiment above the atmosphere would achieve much better sensitivity because of the virtual absence of the atmospheric n, γ background.

3. <u>Timing Resolution</u>. To achieve the high detection efficiency and good timing resolution, we consider using a 1 cm thick segmented scintillator sphere of 1.2m radius completely surrounding C2. Two possibilities are considered.

(1) Approximately 250 x 2" PMT's in optical contact with the scintillator. A large number is required to satisfy the conflicting requirements of redundancy (each signal seen by > 2 PMT's) and a high order of scintillator segmentation. For a background event, the signal in some of the OS PMT's consists of that of the interaction progenitor followed (in a barely resolvable time) by that of the interaction products. Positional information is therefore difficult to extract. The segmentation area (each PMT viewing ~ 0.1 m^2) is thus dictated by the acceptable time dispersion due to light propagation (at C/2) across the whole scintillator segment.

(2) Segmentation can be relaxed by viewing the scintillator face-on. Simulations have shown that a sphere of ~ 50 x 5" PMT's, looking in towards OS provide sufficient redundancy, photoelectron efficiency (> 10 p.e.) and minimum time dispersion. This sphere is located ~ 40 cm outside OS so that direct Cherenkov emission in any one PMT does not provide a false veto, which would reduce the genuine $\bar{p}$ detection efficiency.

Design (2) is to be preferred on the basis of cost-effectiveness, if 5" PMT's can be demonstrated to have the required timing stability.

4. <u>Timing Results</u>. Preliminary tests on RCA 8575 (2") and 4522 (5") have been performed with a small (5cm x 5cm x 0.5cm) scintillator and Sr^{90} source. The resulting signal distribution is not dissimilar in amplitude (threshold of ~ 10 p.e.) or, more importantly, dynamic range (~ 100:1) to that expected in practice. The standard start-stop, low-high technique has been employed with two PMT's viewing the scintillator. Application of an unconventional timing technique [5] allows the measurement of both time and amplitude in a single commercial ADC module (LeCroy 2249A). Excellent resolution ($\sigma(\Delta t) < 30$ ps) and linearity (integral non-linearity over a dynamic range of 50:1 of < 0.5% full scale) for the recording electronics is in agreement with the findings of Venema [5].

Figure 2 shows a comparison of the timing resolution achieved ($\sigma(\Delta t) \simeq \sqrt{2} \times \sigma(t_i)$) for the 2" and 5" PMT's, for leading edge and constant fraction discriminators (Ortec 453) as a function of the fraction of the low to high discrimination levels. The leading edge resolution is inadequate without time-walk corrections. In agreement with D'Agostini et al. [6], we find that an individual time correction to each PMT of the form $\Delta t_i = K_i/(amplitude)^{1/2}$ minimizes the time dispersion, and that the corrected resolution is comparable to that of the constant fraction discriminator.
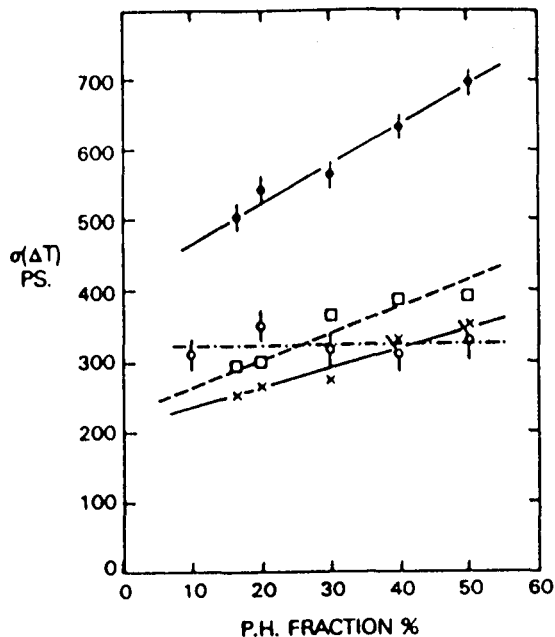
Figure 2. (left) Time Resolution for leading edge discrimination without walk correction (● 2" PMT); with walk correction (x 2" PMT,□ 5" PMT); and constant fraction (o 2" PMT).

The resolution achieved for the 2" PMT does not rival other reports (in particular, reference [6]) but, for both 2" and 5" PMT's, it is sufficient for the purposes outlined in Section 3.

5. Conclusions. The background limitations for APEX have been described. Severe demands are made on the time resolution of a large area scintillator shield in order to eliminate this background. Preliminary tests on small scintillators show that this resolution can be achieved with 2" or 5" PMT's. We are currently investigating much larger area scintillators. As an alternative, we are also investigating the possibility of using large area PSC's [7] as shields. These detectors have unprecedented time resolution (< 50 ps), offer the possibility of particle track identification, and (because of the localization of discharge) are sensitive multihit devices.

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References
1. Balasubrahmanyan, V. K., et al. (1983), 18th ICRC, Bangalore, Special Session on "p̄ and other antiparticles".
2. Buffington, A., et al. (1981), Ap. J. 248, 1179.
3. Stephens, S. A., (1981), 17th ICRC, Paris, 9, 60.
4. Hess, W. N. et al. (1961), J. Geo. Research, 66, 665.
5. Venema, W. Z., (1984), NIM, 219, 257.
6. D'Agostini, G., et al. (1981), NIM, 185, 49.
7. Atwood, W. B., et al. (1983), NIM, 206, 99.
8. Balasubrahmanyan, V. K., et al. (1966), J. Geophys. Res, 71, 1771.
9. Ginzburg, V. L. and Syrovatskii, S. I. (1964), "The Origin of Cosmic Rays" (McMillan).
10. Daniel R. R., Stephens, S. A.(1974), Revs. Geophys. Space Phys., 12, 233.
11. Stephens, S. A. (1981), 17th ICRC, Paris, 4, 282.