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FOR THE DETECTION OF BARYONIUM STATES

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In recent years theory¹ has predicted, within the framework of QCD, the existence of a new class of mesons. Calculable approximations to QCD predict that colour singlet, multiquark, and even multigluon systems should exist but are likely to be more elusive. All experimental effort^{2,3} to date has shown that these states, if narrow, are really very elusive, their yield being of the order of few per mille per antiproton interaction.

However, there is experimental evidence^{4,5} that the nucleon-antinucleon system possesses bound states, which may belong to such exotic objects. Such states are directly detectable by measuring the transitions between the atomic and the baryonium states via emission of a photon. The difficulties encountered in the realization of such experiments arise from the very small yield of these states and the high background produced by neutral pions of the ordinary annihilation. Clearly the visibility of narrow enhancements is increased by improving the detection resolution, thus reducing the π^0 background under a narrow monoenergetic gamma-ray. Still, from the π^0 spectrum from low-energy $\bar{p}p$ annihilations⁴, a 1 MeV bin at 100 (500) MeV will typically give a signal-to-background ratio of 1:140 (1:8) for a narrow gamma-line produced at 100 (500) MeV, which shows up with a branching fraction 10^{-4} of all annihilations.

It is our intention to attempt the suppression of the background in order to facilitate the detection of such exotic states. In contrast to a previously proposed approach⁶, we here propose a reaction mechanism which can be utilized without any great effort and which may be more sensitive to a four-quark state. This process is the internal lepton pair production:

$$(\bar{p}p) \text{ at rest} \rightarrow \gamma^* B \rightarrow \begin{matrix} e^+ e^- B \\ \mu^+ \mu^- B \end{matrix}$$

where B and γ^* stand for the baryonium state and the off-shell photon, respectively. The existence of a baryonium meson consisting of two quarks and two antiquarks would reflect in a monoenergetic peak in the (e^+e^-) missing-mass spectrum at the mass of the baryonium meson.

The conversion coefficient or the probability of an internal pair production, i.e. the ratio of the yields $Y(\bar{p}p \rightarrow e^+e^-B)/Y(\bar{p}p \rightarrow \gamma B)$, is given⁷ by:

$$\rho = \frac{\alpha}{4\pi} \int_{2m}^E dx \int_{-\eta}^{\eta} dy \left(\frac{k'}{k} \right) \frac{(E+M)^2 + M^2 - x^2}{(E+M)^2 + M^2} \times \\ \times \left[\left(\frac{1+y^2}{x} + \frac{4m^2}{x^3} \right) R_T(x) + (1-y^2) \frac{4(E+M)^2 x}{(2EM+E^2+x^2)^2} R_L(x) \right],$$

with

$$\eta = \left[1 - \left(\frac{2m}{x} \right)^2 \right]^{\frac{1}{2}}$$

$$\left(\frac{k'}{k} \right)^2 = \frac{(2EM+E^2)^2 - 2x^2(2M^2+2EM+E^2) + x^4}{(2EM+E^2)^2}$$

$$y = (E_+ - E_-) / (|\vec{p}_+ + \vec{p}_-|),$$

where E_+ , p_+ , and E_- , p_- are the energies and momenta of the positron and the electron, respectively; x is the lepton pair invariant mass; M is the baryonium mass; E is the energy difference between the initial and final state, m is the lepton mass; and $R_T(x)$, $R_L(x)$ are the transverse and the longitudinal conversion coefficient, respectively. Although these coefficients depend on the initial and final states, the coefficient of R_T is strongly peaked at small values of x and always exceeds that of $R_L(x)$. We have taken the approximation $R_T(x) = R_T(0) = 1$ and $R_L(x) = R_L(0) = 0$.

The physical backgrounds in a measurement of the inclusive lepton pairs consist of the following components:

- a) Dalitz pairs from the π^0 decay, $\pi^0 \rightarrow \gamma e^+ e^-$, with an invariant mass of the leptons spanning from 1 to 140 MeV. Thus by accepting only pairs with invariant masses larger than the π^0 mass, we would completely eliminate the background originating from the π^0 decays.

- b) Conversion of gammas on the surrounding materials. This source of background would be eliminated by the same cut on the lepton pair invariant mass as the background of the π^0 decays, because the invariant mass of the converted gamma-ray usually extends to approximately 5 MeV.
- c) Lepton pairs from the decays of vector mesons would give peaks in the invariant mass spectrum at the masses of the vector mesons. Thus by excluding these regions from the data, this kind of background could also be eliminated from the (e^+e^-) missing-mass spectrum.
- d) Dalitz pairs of pseudoscalar mesons with invariant masses of the lepton pair extended up to the mass of the pseudoscalar meson. This background can be calculated according to the formula⁸

$$\frac{d\Gamma_{\gamma ee}}{dx} = \Gamma_{\gamma\gamma} \left(\frac{2\alpha}{3\pi} \right) \frac{1}{x} \left(1 - \frac{4}{x} \frac{m_e^2}{m_{ps}^2} \right)^{\frac{1}{2}} \left(1 + \frac{2}{x} \frac{m_e^2}{m_{ps}^2} \right) (1-x^2)^3 |F(x)|^2,$$

where m_e = electron mass, m_{ps} = mass of the pseudoscalar meson, $x = m_{ee}^2/m_{ps}^2$, m_{ee} = the invariant mass of the lepton pair, $F(x)$ is the electromagnetic form factor of the pseudoscalar meson, and $\Gamma_{\gamma\gamma}$ is the width of $ps \rightarrow \gamma\gamma$. Monte Carlo calculations taking into account the known frequencies of occurrence of the η and η' mesons have shown that the remaining background after the invariant mass cut, for masses larger than the π^0 mass contributes only 2×10^{-5} and 10^{-6} per antiproton interaction for the η and η' mesons, respectively.

The constraint that the lepton pairs should have an invariant mass larger than the π^0 mass will reject also some events from the reaction $\bar{p}p \rightarrow e^+e^-B$. However, we expect very encouraging rates (Table 1) per running day at LEAR.

Table 1. Events per running day at LEAR from the reaction $\bar{p}p \rightarrow e^+e^-B$ for different baryonium masses, assuming a 4π detector and a baryonium yield corresponding to a yield of 10^{-4} for the reaction $\bar{p}p \rightarrow \gamma B$.

M_B (MeV)	Events per day with $10^6 \bar{p}/s$ and $m_{ee} > 130$ MeV
1300	1.1×10^4
1500	7.8×10^3
1700	1.4×10^3

Fig. 1. Missing mass spectrum of the reaction $\bar{p}p \rightarrow (e^+e^-) + \text{anything}$ for 10^{10} stopped antiprotons. The peak would correspond to a baryonium state of 1500 MeV mass with a yield equivalent to a yield of 10^{-4} for the reaction $\bar{p}p \rightarrow \gamma B$.

According to Monte Carlo calculations with reasonable resolutions, we expect in the (e^+e^-) missing mass spectrum (Fig. 1) in the most unfavourable case a peak-to-background ratio of 1:4 for a baryonium mass of 1500 MeV and for a yield which would correspond to 10^{-4} per antiprotons stopped for the reaction $\bar{p}p \rightarrow \gamma B$. Thus the detection of the internal conversion would greatly facilitate the search for exotic states, because it will eliminate the main source of background and thus improve the visibility of the signal.

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