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Capture in-flight of low-energy $\bar{p}$'s in polarized neutral beams; application to $\bar{p}p \rightarrow \pi^{\pm}$ annihilation

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Two technical developments are taking place which will allow high formation rates for capture-in-flight production of exotic (nuclear) polarized atomic systems. The decay of these systems will allow systematic study of threshold annihilation of the $\bar{p}p$ system and the $\bar{p}n$ system from polarized protonium, (exotic) polarized deuterium, etc.

First, high currents of cooled stored $\bar{p}$ beams at low energies will be shortly available at LEAR ($I = 10^{10}\,\bar{p}/s$, $\Delta p/p = 10^{-3}$ at $E_{\bar{p}} \gtrsim 5$ MeV). The energy of the $\bar{p}$ beam can even be further lowered either by a second storage ring or via an RFQ decelerator and the $\bar{p}$'s made available in an ion trap. Second, intense highly polarized beams of charged protons and deuterons from standard atomic sources[1] are available (at ETH, $I_{H^+} = 100$ μA with polarization (P) = 80% and $I_{D^+} = 100$ μA with P = 60%). By beam matching ($v_{\bar{p}} = v_{nucleon}$), that is, by sending the polarized neutral beam (H^0 or D^0 etc.) at a matched parallel $\bar{p}$ velocity through one leg of the $\bar{p}$ storage ring or into the ion trap, high capture cross sections result from Auger capture of the $\bar{p}$ with the polarized nucleus (i.e.$\sim 10^8 \times$ radiative capture cross sections). This allows observation of important exotic-atom annihilation decay channels at high counting rates. For example, the enormous Auger capture cross section[2] of $\sigma(\bar{p}p) \simeq 4\times10^{-14}\text{cm}^2$, results in a formation rate R of $\bar{p}p$ systems $R = 6\times10^5$/s under the beforementioned estimated source intensities (see ref.3 for further details).

To illustrate the type of information yielded by this experimental approach, the analysis of the polarization angular correlation in the following weak ($\sim$0.2%) annihilation branch

$$H^0\!\uparrow + \bar{p} \rightarrow \bar{p}p\!\uparrow \;\begin{matrix}\nearrow \\ \searrow\end{matrix}\; \begin{matrix} {}^3P_0 \rightarrow \pi^+ + \pi^- \\ {}^3P_2 \rightarrow \pi^+ + \pi^- \end{matrix} \tag{1}$$

is given. Specifically, one determines $W(\theta)$, the angular correlation between $\pi^{\pm}$ and the direction of the L x-ray with respect to a given proton polarization direction. (The L x-ray is emitted just before annihilation. 98% of the annihilation as measured by Asterix[4] occurs by P waves. An effective coincidence L x-ray-π solid angle of $\Omega = 0.1$, using the previously mentioned R, would yield a coincidence rate 10^2/s).

The role of the L x-ray is vital and its detection performs 3 independent functions. 1) It helps determine the annihilation vertices; 2) It tags the annihilation orbital angular momentum (P wave); 3) it aligns the P atomic state so that both angular correlation and polarization effects can be measured by in-flight $\bar{p}$ capture. With respect to point 3, unlike in scattering experiments, there is no alignment plane in a center-of-mass system. However, a quantization axis can be defined along the direction of emission of the x-ray by a coincidence condition. As $\Delta m = 0$ transitions are not permitted along this axis for E1 radiation, the net effect is to align the P atomic state and create an alignment plane.

For the L x-ray-π plane, the polarizational directional correlation $W(\theta)$ between the L x-ray and $\pi^{\pm}$ is[3]

$$W(\theta) = C_0[1 + C_1\cos^2\theta - (-1)^{\lambda+\frac{1}{2}}C_2\sin 2\theta] \tag{2}$$

where θ is the angle between the L x-ray and π direction, the C parameters (functions of the J = 0 and J = 2 partial wave amplitudes for the process $N\bar{N} \rightarrow \pi\pi$ extrapolated to threshold energies) are defined in ref.3 and $\lambda = \frac{1}{2}$ or $-\frac{1}{2}$ refers to opposite proton spin directions. The range of these values are shown in figure 1 plotted as a function of the P-state (m = 0) sublevel m_0 population. Under the assumptions, that the atomic D-state m sublevels are equally populated and that the functions a and b of the S and D annihilation partial waves (see definition in ref.3) can be extrapolated to values: $a = (1.7\pm1.0) - i(0.6\pm0.4)\ \text{GeV}^{-1}$, $b = (0.8\pm0.2) - i(0.6\pm1.0)\ \text{GeV}^{-4}$, our theoretical estimates yield a range of C parameter values: $-0.12 < C_1 < -0.5$ and $-.05 < C_2 < +.05$. The C_0, a normalization constant, is proportional to the partial decay rates.

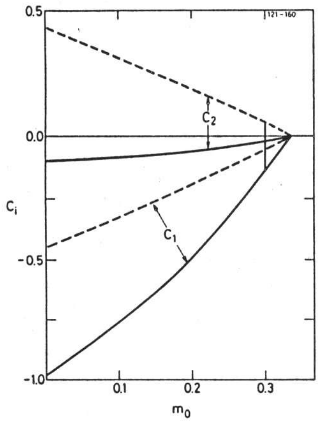

Fig.1. The coefficients C_1 and C_2 in the L x-ray - $\pi^{\pm}$ polarization angular distribution (eq.2) plotted as a function of m_0, the fractional population of the m = 0 magnetic substate of the atomic P-state. The solid curves represent the average values of the C coefficients whereas the dashed curves represent their values at maximum; all values are based on extrapolated annihilation partial waves (and errors) at threshold energies. The values of C_1 and C_2 at m_0 = 0.3 (the intersection of the curves with the vertical solid line) correspond to the values obtained under the assumption that the atomic D state magnetic sublevels are equally populated (no atomic D-state alignment). The coefficients vanish at m_0 = 1/3 (no atomic P-state alignment).

Except for an overall phase, the determination of all 3 coefficients by the proposed experiments yields the threshold partial wave amplitudes. The determination of the polarization parameter C_2 is not just the determination of an extra parameter; it is the determination of the necessary and sufficient parameter to complete the problem. An equivalent measurement with the $K\bar{K}$ branch would also completely determine the corresponding threshold partial wave amplitudes. Such information answers whether annihilation to $\pi^+\pi^-$ and K^+K^- are dynamically the same. Thus the data provide important tests for quark models of these annihilations. Yet the predictions are model independent. Note also that similar experiments with polarized $D^0\bar{p}$ yield the $\bar{p}n$ interaction parameters.

References

1) W.Grüebler: Workshop on polarized targets in storage rings, Argonne Nat.Lab.(1984)
2) L.Bracci, G.Fiorentini, and O.Pitzurra: Phys.Lett.85B (1979) 280
3) B.I.Deutch, A.S.Jensen, A.Miranda, G.C.Oades, and E.Uggerhøj: Proc.of the 3rd LEAR Workshop (Tignes) 1985, to be published
4) ASTERIX group: Ibid

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