Four Photon Decay of Positronium in GAMMASPHERE

P.A. Vetter, B.K. Fujikawa, S.J. Freedman, Lawrence Berkeley National Laboratory

Positronium (Ps) is an eigenstate of the charge conjugation operator (C), and C symmetry can be tested in the decay of Ps. The physics of Ps decay is governed by Quantum Electrodynamics (QED), and QED can also be tested at high radiative orders in α.

Ps atoms from a source are formed in two states, para-Ps, or ortho-Ps, with C eigenvalues of +1 and –1. Since the photon has an intrinsic C eigenvalue of –1, para-Ps is constrained by C symmetry to decay to an even number of photons while ortho-Ps decays to an odd number. Detecting O-Ps decaying to 4 photons would be a C violating signal. The QED allowed branching ratio for P-Ps to decay to 4 photons has been calculated to be 1.48×10^{-6}, and this has been measured with an uncertainty of 8%[1]. The best limit for a C violating decay of O-Ps to 4 γ is a branching ratio of $< 2.6 \times 10^{-6}$ [2]. These measurements required dedicated apparatus and acquisition times longer than five months.

We have performed an experiment to measure four-photon decay of Ps in Gammasphere (GS). We acquired 15 days of data using a Ps source consisting of 10 μCi of 68Ge encapsulated in a plastic scintillator beta detector, surrounded by SiO2 aerogel as a Ps-forming moderator. The 68Ge and beta detector gave a 10-fold increase in detection efficiency for Ps decay events in GS versus the 22Na source used during a test run in 2000. We collected ~10^10 events on tape. After an initial sort of the data, about 4x10^9 events of fully reconstructed positronium decays remain.

The beta detector was triggered by the e+ from the 68Ge decay. This acted as a start signal for a TAC, which was stopped by the decay gammas detected by GS. This allows discrimination between long-lived o-Ps and short-lived p-Ps.

To count 2, 3, and 4γ Ps decay events, several cuts on the data reject scattered, accicental, and background events:

1. Sum energy within 83 keV of 1022 keV
2. γ's must arrive within a 30 ns window of the average decay time
3. momentum sum of γ's < 150keV/c
4. 2γ events must be colinear, but 3 and 4γ events must have no colinear photons
5. 3γ events must be coplanar with the source, but 4 γ events must have no coplanar γ's.

With these cuts, we observed 3.736x10^9 2γ, 5.080x10^7 3γ, and 43 4γ events. The time spectrum of these events is shown in Fig. 1. C violating candidate 4γ events occur after the initial decay of P-Ps, while allowed 4γ events are simultaneous with this peak.

To measure branching ratios of P-Ps and O-Ps to 4γ, simulations are necessary to determine the detection efficiency of GS for Ps decays. Using a GEANT based simulation of GS, and random event generators for decay photons based on the Ps decay kinematics, we determined the detection efficiency of GS for 2, 3, and 4 photon decays. We are now calculating expected background rates for several different event types to interpret the observed 4γ events.

References

1. S. Adachi, et al., Phys. Rev. Lett. **65**, 2634 (1990).
2. J. Yang, et al., Phys. Rev. A **54**, 1952 (1996).

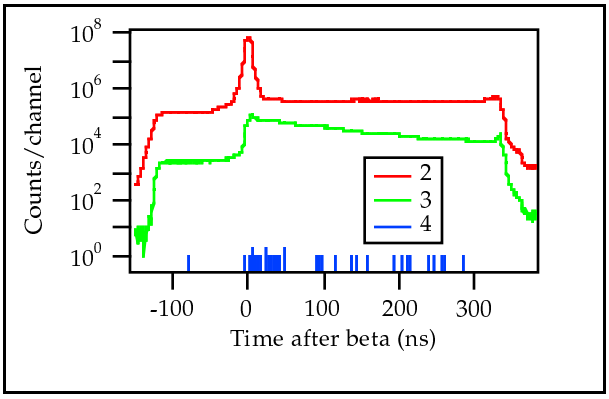

Fig. 1. Time spectrum of Ps annihilation photons in Gammasphere for April, 2001 run data.