Search for CPT-Odd Decays of Positronium

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In the annihilation of polarized ortho-positronium (o-Ps), the quantity $\vec{s}\cdot\left(\vec{k_1}\times\vec{k_2}\right)$ (where $\vec{k_1}$ and $\vec{k_2}$ are the two largest photon momenta, and $\vec{s}$ is the o-Ps spin) is odd under time reversal, and under the combined symmetry operation CPT (charge, parity, and time). The cross produt $\vec{k_1}\times\vec{k_2}$ defines the decay plane of the three annihilation photons. If CPT is a conserved symmetry, polarized o-Ps would show no asymmetry in the orientation of the decay plane with respect to the initial spin direction. We searched for such an asymmetry using Gammasphere. Although the Standard Model respects CPT symmetry, some promising extensions to the Standard Model, such as string theory with extra spatial dimensions, predict tiny violations of Lorentz invariance and CPT symmetry, which could be as large as 10^{-5} in o-Ps.

Polarized positronium was produced in Gammasphere using 10 μCi sources of ^{68}Ge and ^{22}Na. Positrons from β decay are polarized along their momentum. The source was placed under a thin scintillator and a hemisphere of silicon dioxide aerogel. Only upward directed and polarized positrons trigger the data acquisition and form o-Ps. In a 36-day run in summer, 2002, we acquired 2.65×10^7 events (passing cuts) of o-Ps decay. For each event, we reconstructed the triple product $\vec{s}\cdot\left(\vec{k_1}\times\vec{k_2}\right)$. The source could be rotated in Gammasphere, and we used four different positions to search for any artificial asymmetry. The two sources have different net polariztions for the o-Ps they produce: ^{22}Na has $P = 0.43$ and ^{68}Ge has $P = 0.61$. A true asymmetry signal would scale differently for the two sources.

The experimental sensitivity to an asymmetry was determined using Monte-Carlo events from a GEANT simulation of Gammasphere. Events were generated with a false CPT-odd signal in the o-Ps decay photons. We generated the asymmetry in the data histogram of $\vec{s}\cdot\left(\vec{k_1}\times\vec{k_2}\right)$ (shown in Figure 2) (by calculating the odd part of the histogram about $\vec{s}\cdot\left(\vec{k_1}\times\vec{k_2}\right)=0$) and in the Monte-Carlo data. The amplitude of a CPT-odd signal in the data is the ratio of the up-down asymmetry in the data to the Monte-Carlo asymmetry. In Figure 1, we plot the CPT-odd signal for each of seven data sets. No CPT-odd asymmetry or geometric asymmetry is observed.

Averaging the data over both sources and all orientations, we find the CPT-odd decay amplitude $C = +0.0022(26)$. This gives a 90% confidence level limit of $C < 0.005$. This is a factor of ten improvement over previous searches for the CPT-odd decay asymmetry in [1] and [2]. This is mainly due to higher detection efficiency and faster data acquisition in Gammasphere. Gammasphere is a 4π detector which can detect events with any decay plane orientation with respect to the o-Ps spin. This experiment was therefore less susceptible to false geometric asymmetries, such as a source displacement when the o-Ps spin was reversed. Tests of large position and angle shifts of the source in the Monte-Carlo simulation gave no asymmetry larger than $C = 0.002$, consistent with our observations for different source orientations.

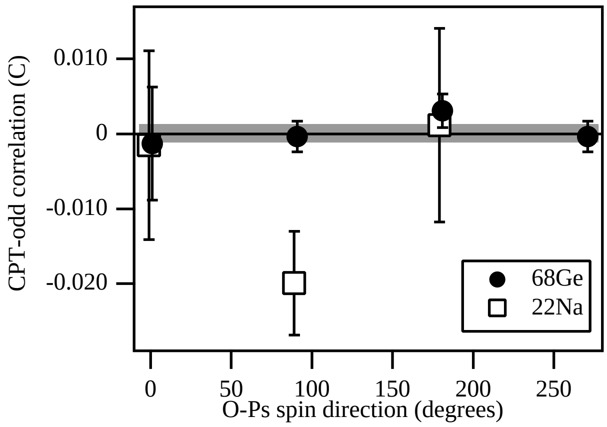

FIG. 1: Asymmetry averages for seven data sets.

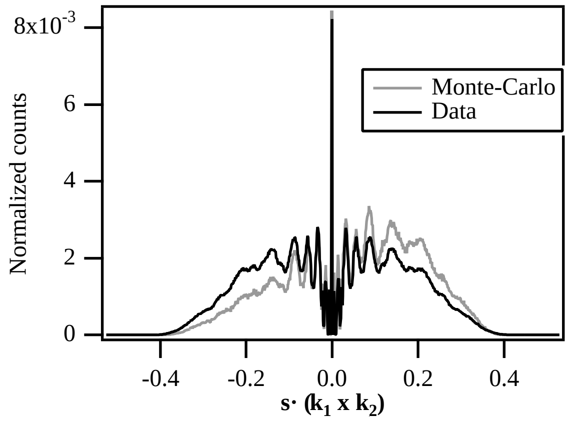

FIG. 2: Data histogram of $\vec{s}\cdot\left(\vec{k_1}\times\vec{k_2}\right)$ for one run compared to Monte-Carlo generated data which includes a CPT-odd correlation of amplitude $C = 1$. Peak features are caused by the placement of the Gammasphere detectors into a regular ring pattern.

[1] B.K. Arbic *et al.*, Phys. Rev. A **3**7, 3189 (1988).
[2] S.K. Andrukhovich *et al.*, Inst. and Exp. Tech. **4**3, 453 (2000).