New precision measurement of Hyperfine Splitting of Positronium


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Positronium and its hyperfine structure (HFS)
- The bound state of an electron (e-) and a positron (e+)

Hyperfine splitting (HFS)
- The energy splitting between o-Ps and p-Ps
- The value of HFS

Experimental average
203.388 65(67) GHz (3.3 ppm)

How to measure the HFS?
In a static magnetic field, the p-Ps state mixes with the m=0 state of o-Ps (Annihilate into 2 γ-rays).
Precisely measure the \( \Delta_{\text{mix}} \) and calculate \( \Delta_{\text{meas}} \) by the equation,
\[
\Delta_{\text{meas}} = \frac{1}{2} \Delta_{\text{mix}} \sqrt{1 + 4x^2} - 1
\]

Transition → 2 γ decay rate increases.

Possible systematic uncertainties in the previous experiments
1. Underestimation of the material effect
   - Unthermalized o-Ps affect seriously (especially at low material density).
2. Non-uniformity of the magnetic field
   - It’s quite difficult to get ppm level uniform field in a large Ps creation volume

Experimental setup
To reduce possible systematic uncertainties, we use the following new methods.

Large bore superconducting magnet
- Get uniform magnetic field (~0.886 T) in a large volume.
- 1.5 ppm RMS uniformity with compensation coils

High performance gamma-ray detectors
- LaBr₃ (Ce) scintillators (x 6)
  1.5” in diameter & 2.0” long
  - High energy and timing resolutions enable high statistical counting

Current status
Timing spectra
- Suppress Prompt and Accidental backgrounds with a Timing window of 35 ns – 155 ns
  → 20 times higher S/N
- Unthermalized o-Ps even more are also suppressed.

Energy spectra
- Accidental is subtracted using PoI of 950 – 1350 ns
  - 2γ decay rate increases because of the Zeeman transition. Zeeman transition probability is calculated from the difference between RF-ON and RF-OFF.

Ps thermalization
Ps thermalization function is measured using a Ge detector to estimate the non-thermalized Ps effect.

Result coming soon
HFS is measured at many gas densities to correct the material effect.
Now we are checking our data finally.
We will fix the final result very soon.