Precise measurement of HFS of positronium


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Positronium (Ps)

The bound state of an electron (e−) and a positron (e+):
- orthopositronium (o–Ps) → 1S1, mostly 3y decay
- parapositronium (p–Ps) → 1S0, mostly 2y decay

Hyperfine structure (HFS)

- The energy splitting between o–Ps and p–Ps
- The value of the HFS

Energy splitting between o–Ps and p–Ps

The energy splitting between o–Ps and p–Ps is calculated to be 203.399 ± 0.029 (140 ppm, sys.) GHz (Preliminary). (1)

Conversion of HFS value

The measured value of the HFS value is 203.399 ± 0.029 (140 ppm, sys.) GHz (Preliminary) (from an indirect measurement).

Measurement using the Zeeman effect

How to measure the HFS?

- In a static magnetic field, energy levels of o–Ps split between m_i=0 and m_i=±1 states. (Zeeman Effect)
- At about 5 kG, Δm=1 is about 3 GHz (microwave).
- The HFS value is calculated from Δm=1. (Indirect measurement)
- What about direct measurement?
  → See T. Suehara’s poster (Mo195)

Common systematic uncertainties in the previous experiments

1. Underestimation of material effects
   - Unthermalized o–Ps can have a significant effect (especially at low material density). → o–Ps lifetime puzzle (1990’s)
2. Non-uniformity of the magnetic field
   - It is quite difficult to get ppm level uniform field in a large Ps creation volume

Experimental setup

To reduce these systematic uncertainties, we use the following new methods.

Large bore superconducting magnet

- Operated in Persistent Current mode (stable).
- 70 ppm magnetic field uniformity without any compensations.

High performance gamma-ray detectors

LaBr3 (Ce) scintillators (x 6)

1.5” in diameter & 2.0” long

High energy and timing resolutions. short decay constant

Current status

Preliminary plots

We are presently taking more data....

CONTOURS [A, U, RF OFF SUBTRACTED]

ENERGY SPECTRA

0.8658 T RF 450 W
0.8614 T RF 450 W
32 – 300 keV TIMING WINDOW
(98% NaI) (ACCIDENTAL SUBTRACTED)

Preliminary

ENERGY (keV)

PRELIMINARY

2 y decay rate increases because of the transition between o–Ps’ m_i=0 and m_i=±1 states.

Time information

- Plastic scintillator is used to tag emitted γ. → Get the time information between o–Ps creation (t=0) and decay.

(1) We can measure the thermalization.

(2) Prompt suppression

0.2 mm thick, 15 mm x 15 mm Plastic Scintillator

High energy and timing resolutions. short decay constant

Our goal

O (1) ppm accuracy in a year

1. Develop compensation coils
   → Get O(1) ppm B - uniformity
2. Precisely measure the thermalization function.
3. Derive the HFS value at O (1) ppm accuracy.
   → Solve or Confirm the discrepancy between the experimental values and the theoretical value.