New precision measurement of Hyperfine Splitting of Positronium

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Positronium and its hyperfine structure (HFS)

Positronium (Ps)

- The bound state of an electron (e-) and a positron (e+)

Hyperfine splitting (HFS)

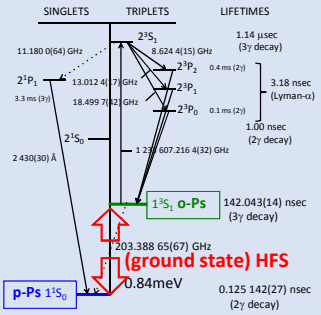
- The energy splitting between o-Ps and p-Ps
- The value of HFS

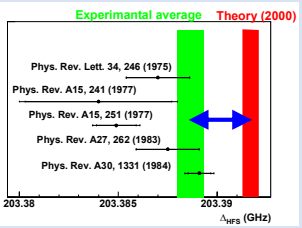
Experimental average
203.3**88 65**(67) GHz (3.3 ppm)

Theory
203.3**91 69**(41) GHz (2.0 ppm)

- The measured values are **consistent with each other** and **lower than the theoretical Calculations**

15 ppm (3.9 σ) significant discrepancy





Measurement using the Zeeman effect

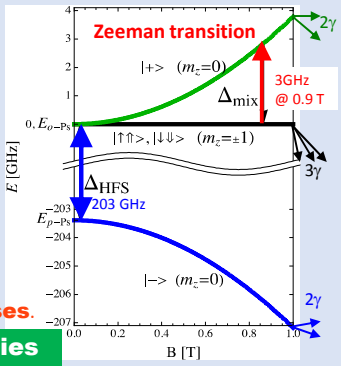
How to measure the HFS?

In a static magnetic field, the **p-Ps** state mixes with the **m_z=0 state of o-Ps** (Annihilate into 2 γ-rays).

Precisely measure the Δ_{mix} and calculate Δ_{HFS} by the equation,

$$\Delta_{mix} = \frac{1}{2}\Delta_{HFS}\left(\sqrt{1+4x^2}-1\right),$$

$$x = \frac{g'\mu_B B}{\Delta_{HFS}}.$$



Transition → 2 γ decay rate increases.

Possible systematic uncertainties in the previous experiments

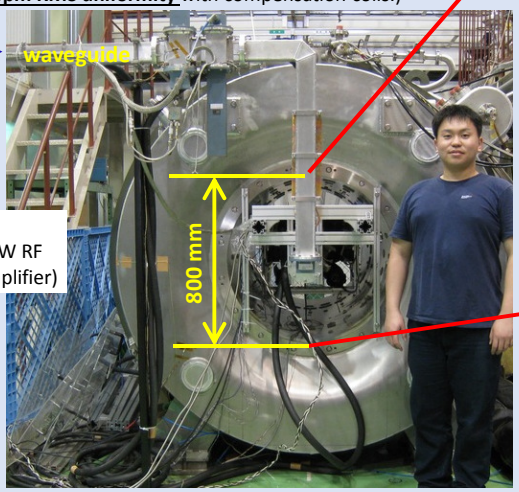
1. ***Underestimation of the material effect***
   - Unthermalized o-Ps affect seriously (especially at low material density). ← o-Ps lifetime puzzle (1990's)
2. ***Non-uniformity of the magnetic field***
   - It's quite difficult to get ppm level uniform field in a large Ps creation volume

Experimental setup

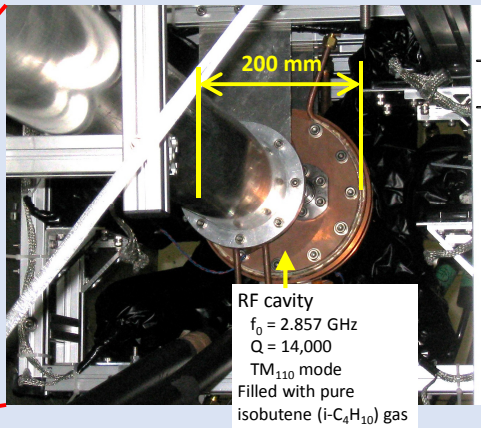
To **reduce possible systematic uncertainties**, we use the following **new methods**.

Large bore superconducting magnet

- Get uniform magnetic field (~0.866 T) in a large volume. (**1.5 ppm RMS uniformity** with compensation coils.)

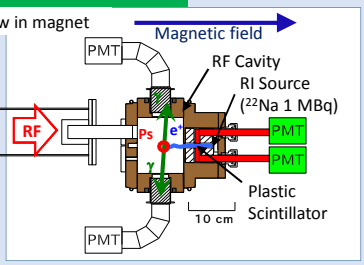


2.9 GHz
500 W CW RF
(GaN amplifier)



RF cavity
f_0 = 2.857 GHz
Q = 14,000
TM_{110} mode
Filled with pure isobutene ($i\text{-}C_4H_{10}$) gas

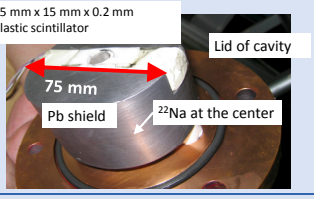
β - tagging system



- Time spectrum between positron emission and γ-detection is measured.
  (1) Only well thermalized Ps are selected, **reducing the unthermalized o-Ps contribution** by imposing a time selection.
  (2) S/N of the measurement is significantly improved **by factor 20**.

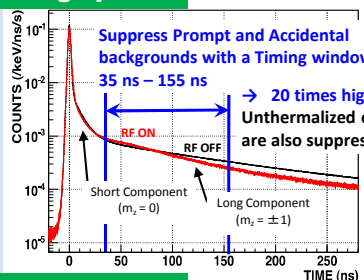
High performance gamma-ray detectors

- **LaBr3 (Ce) scintillators** (x 6)
  1.5" in diameter & 2.0" long
- **High energy and timing resolutions**, and **short decay constant** enable **high statistical counting**.



Current status

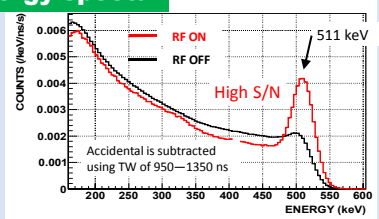
Timing specta



Suppress Prompt and Accidental backgrounds with a Timing window of 35 ns – 155 ns

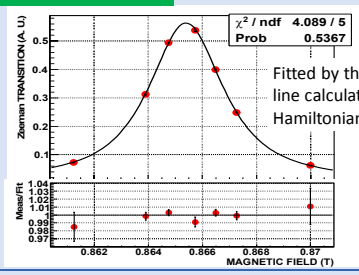
→ **20 times higher S/N**
Unthermalized o-Ps events are also suppressed.

Energy specta



2γ decay rate increases because of the Zeeman transition. Zeeman transition probability is calculated from the difference between RF-ON and RF-OFF.

Resonance line

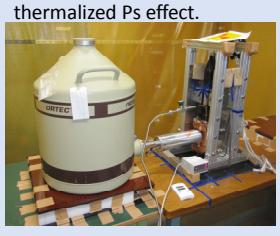


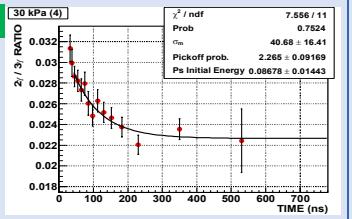
Fitted by theoretical line calculated from Hamiltonian

Measurements are performed from July 2010 to March 2013.

Ps thermalization

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





pick-off probability ($\propto v^{3/5}$ in isobutene)) is measured as a function of time.

$\sigma_m = 61\ ^{+7}_{-9}$ Å, $E_0 = 0.20\ ^{+0.09}_{-0.07}$ eV are obtained preliminary.

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.