Precise measurement of HFS of positronium

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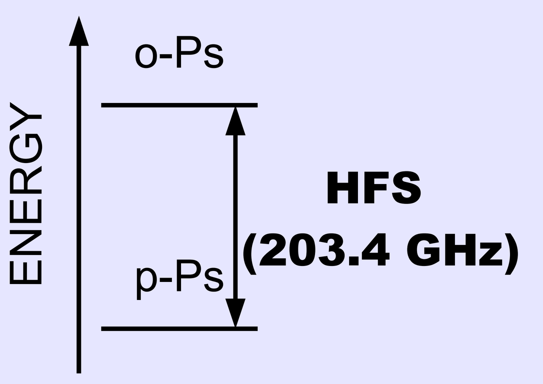
Positronium and its hyperfine structure (HFS)

Positronium (Ps)

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

$$\begin{cases} \text{orthopositronium}(\text{o-Ps}) & \cdots \quad 1^3S_1 \quad \text{mostly } 3\gamma \text{ decay} \\ \text{parapositronium}(\text{p-Ps}) & \cdots \quad 1^1S_0 \quad \text{mostly } 2\gamma \text{ decay} \end{cases}$$



Hyperfine structure (HFS)

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

Experimental average

203.388 65(67) GHz (3.3 ppm)

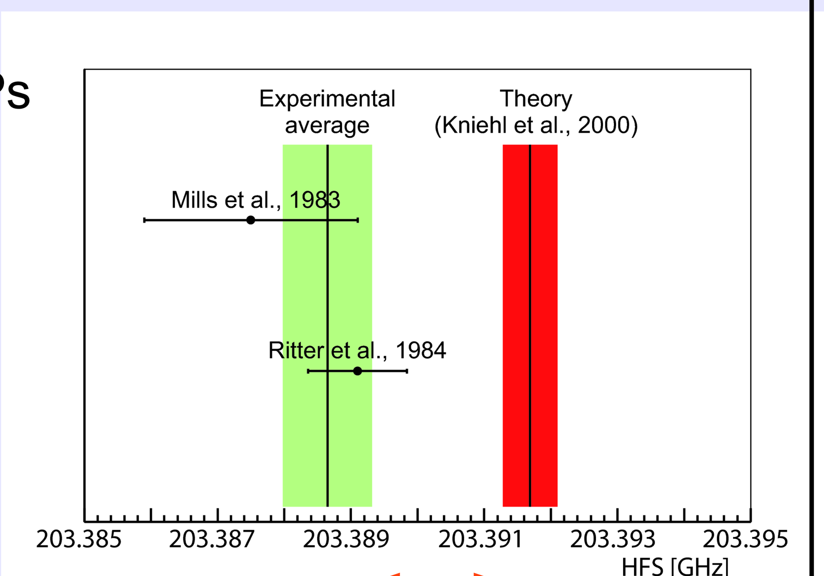
PRA **27**, 262 (1983)
PRA **30**, 1331 (1984)

Theory

203.391 69(41) GHz (2.0 ppm)

PRL **85**, 5094 (2000)

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



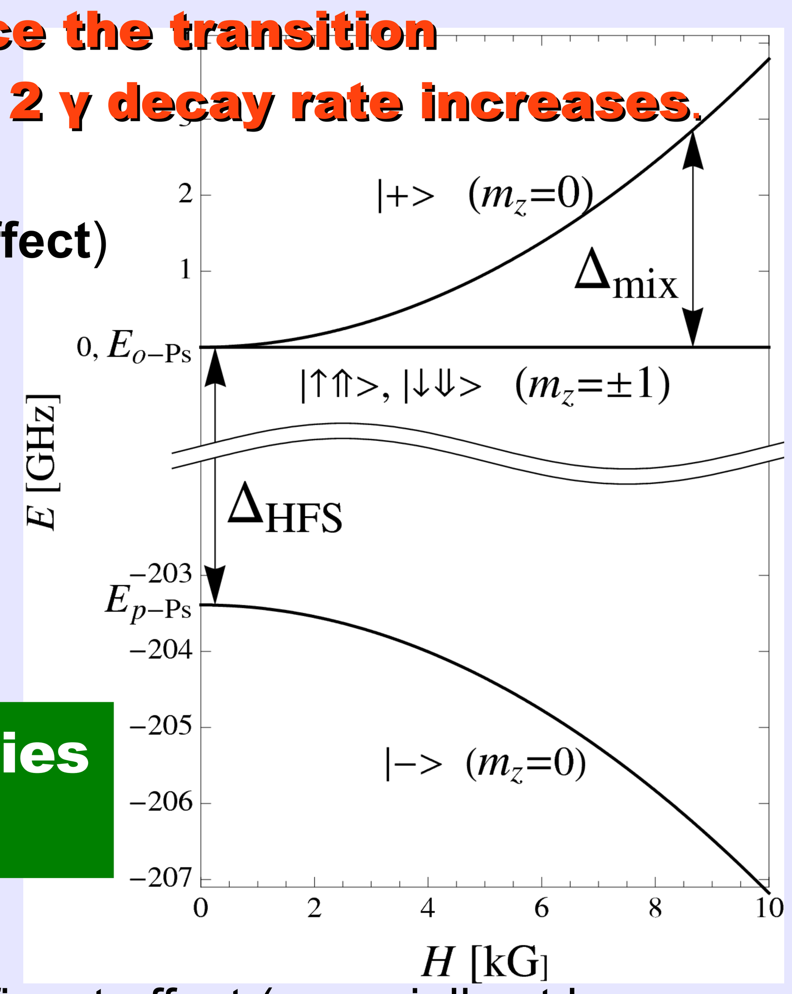
15 ppm (3.9 σ) discrepancy

Measurement using the Zeeman effect

How to measure the HFS?

- In a static magnetic field, energy levels of o-Ps split between $m_z=0$ and $m_z=\pm1$ states. (**Zeeman Effect**)
- At about ***9 kG***, Δ_{mix} is about ***3 GHz (microwave)***.
- The HFS value is **calculated from** Δ_{mix}. (***indirect measurement***)
- What about direct measurement?
  → *See T. Suehara's poster (Mo195)*

Induce the transition
→ 2 γ decay rate increases



Common systematic uncertainties in the previous experiments

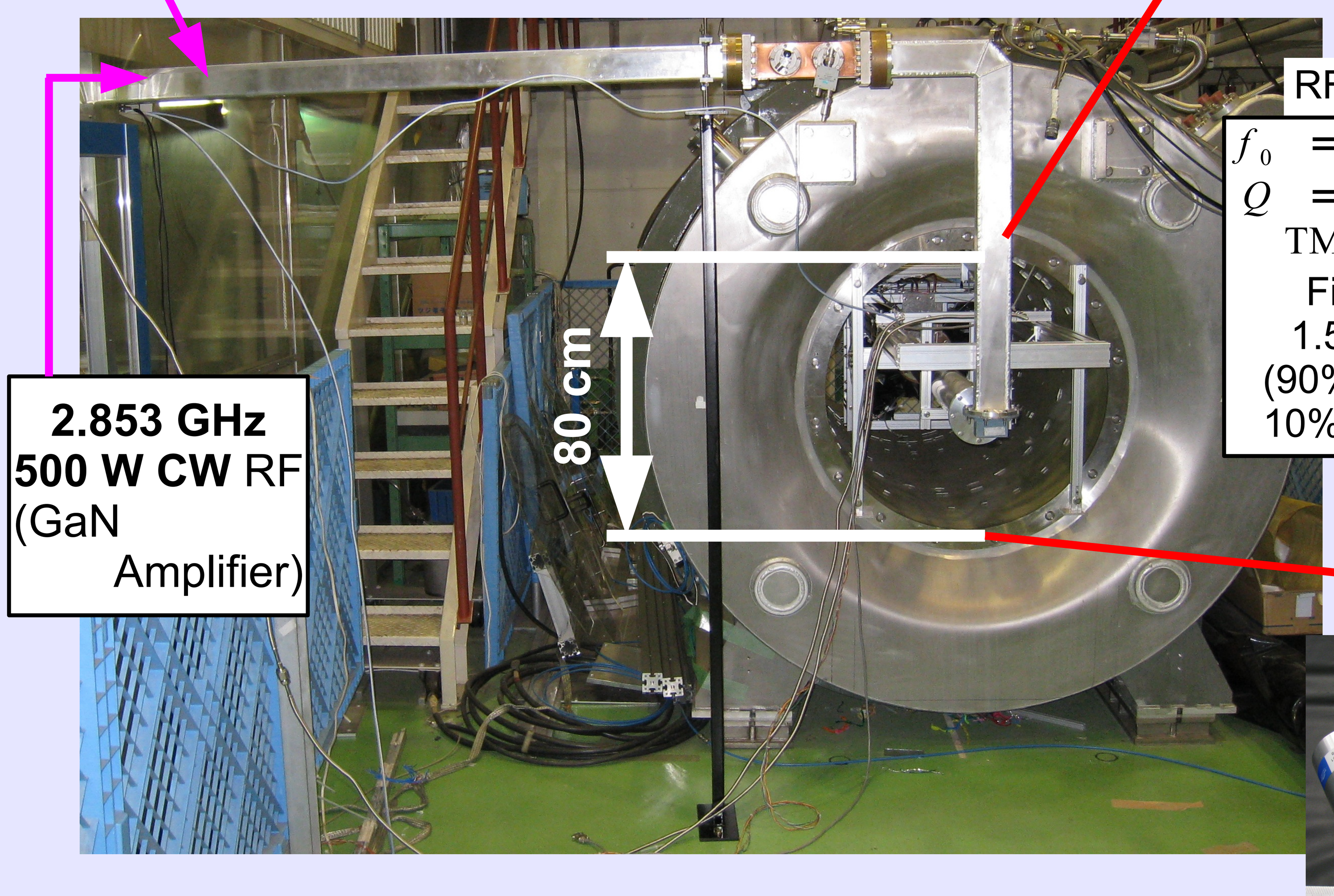
1. ***Underestimation of material effects***
   - Unthermalized o-Ps can have a significant effect (especially at low material density). ← o-Ps lifetime puzzle (1990's)
2. ***Non-uniformity of the magnetic field***
   - It is quite difficult to get ppm level uniform field in a large Ps creation volume

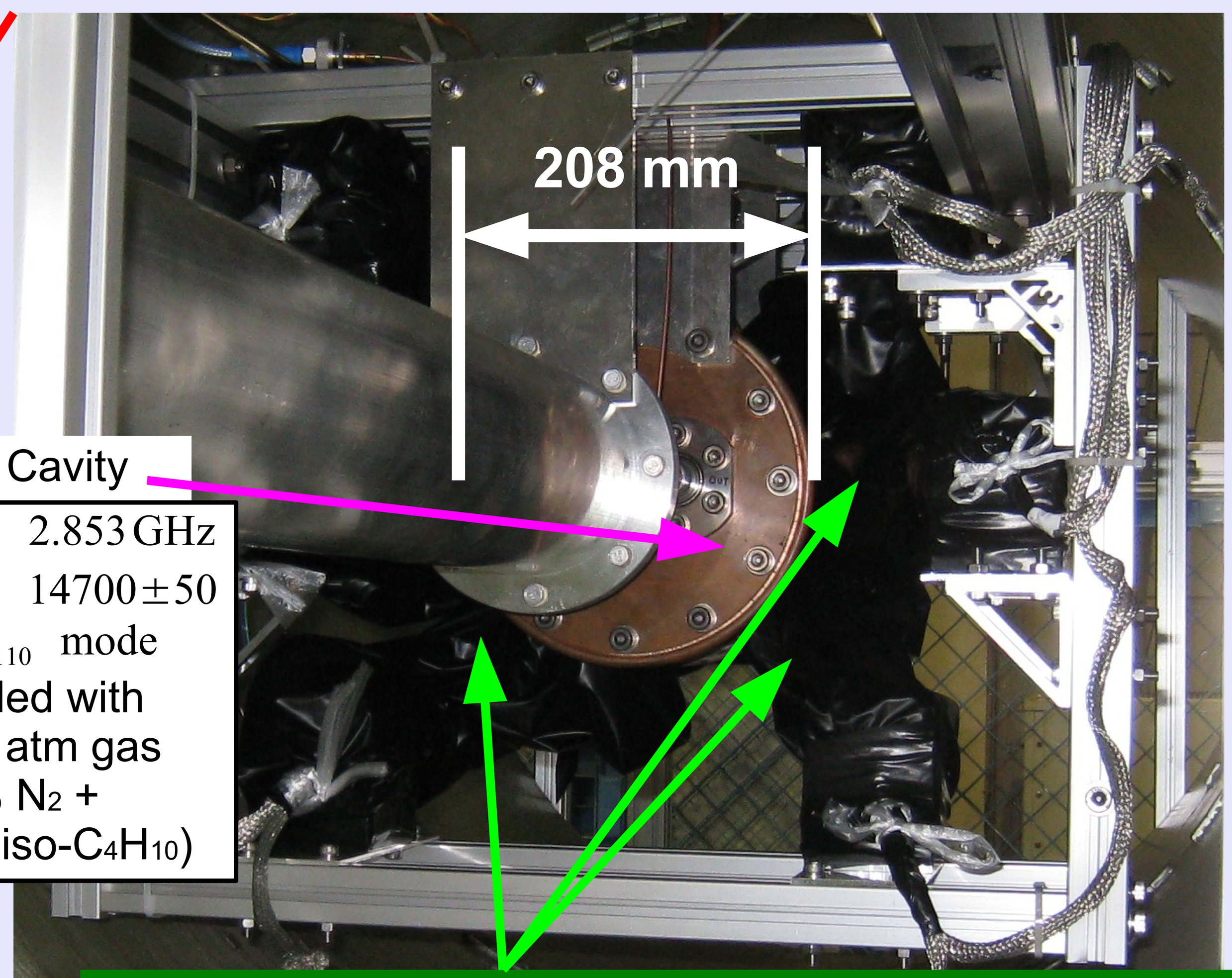
Experimental setup

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.

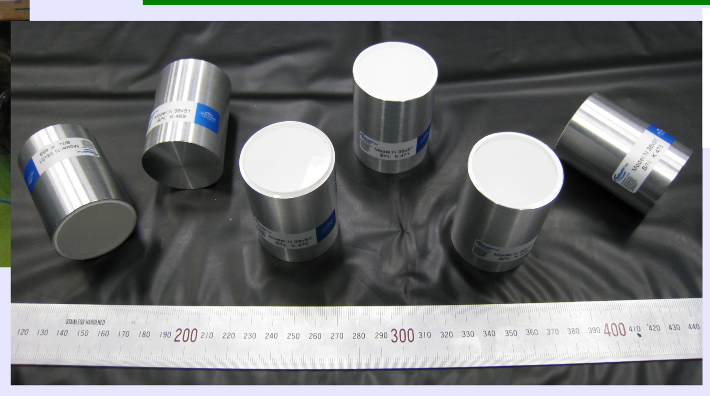




RF Cavity

f_0 = 2.853 GHz
Q = 14700±50
TM_{110} mode
Filled with 1.5 atm gas (90% N_2 + 10% iso-C_4H_{10})

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

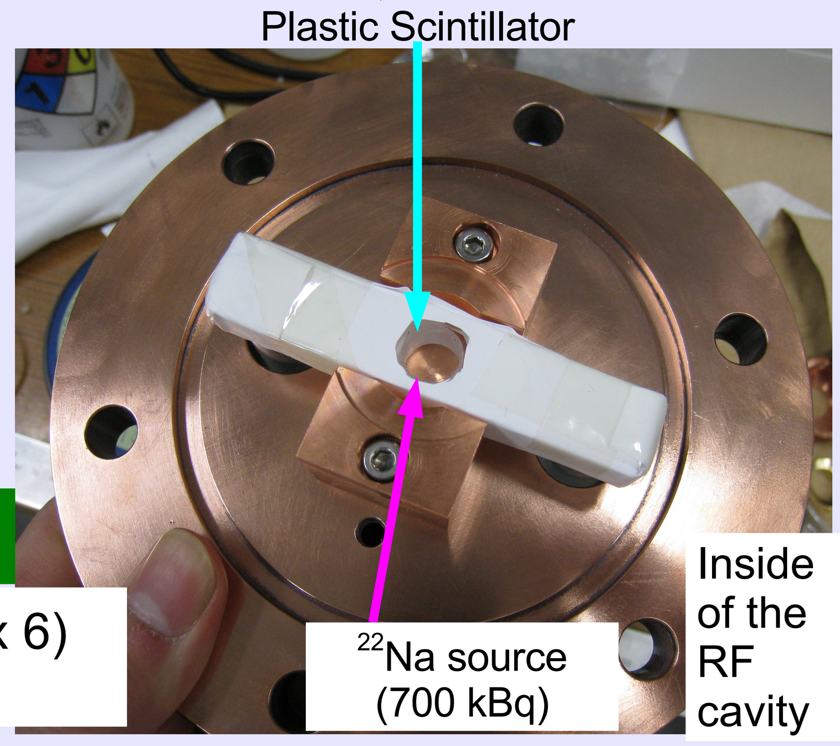
Time information

- **Plastic scintillator** is used to ***tag emitted*** β^+.
- 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

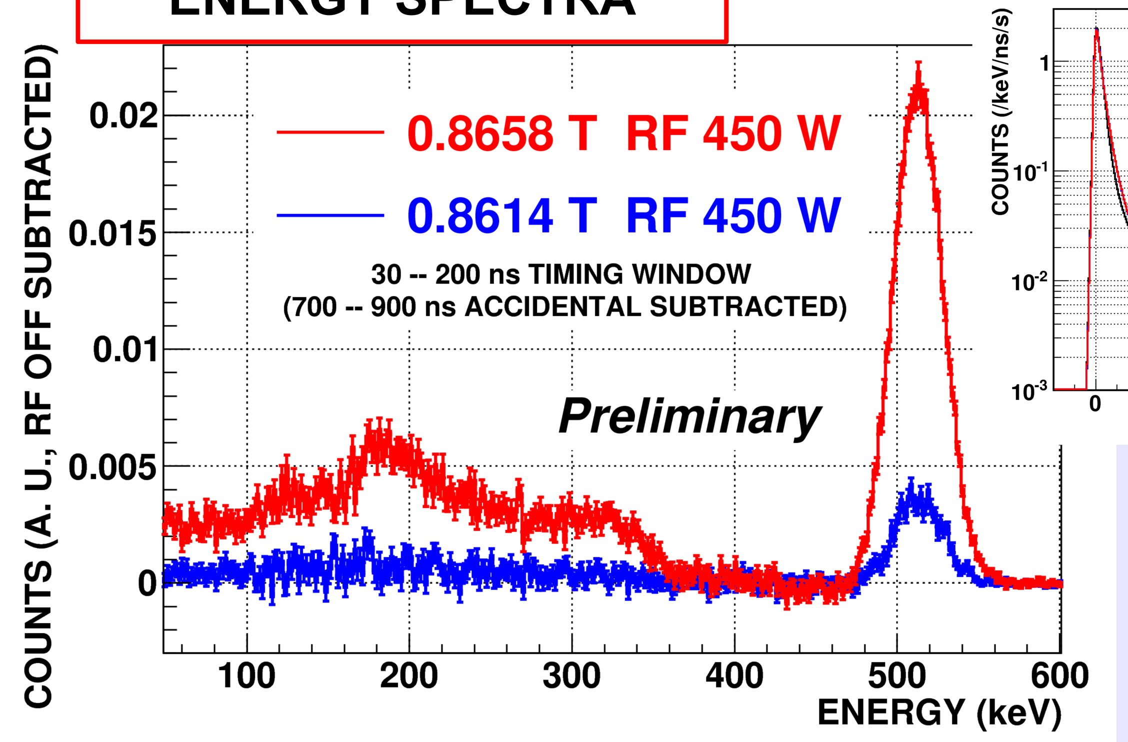


Current status

We are presently taking more data....

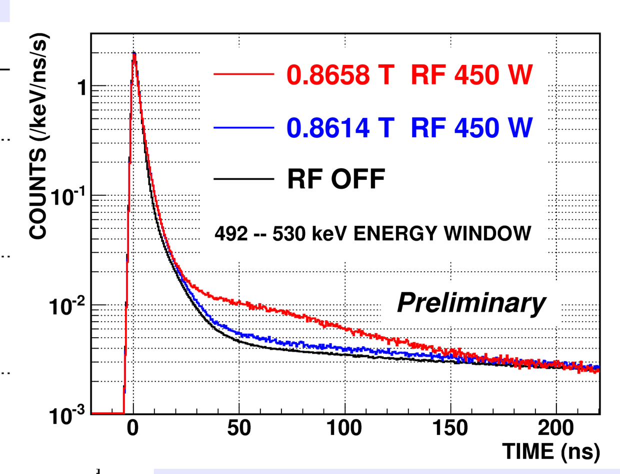
Preliminary plots

ENERGY SPECTRA

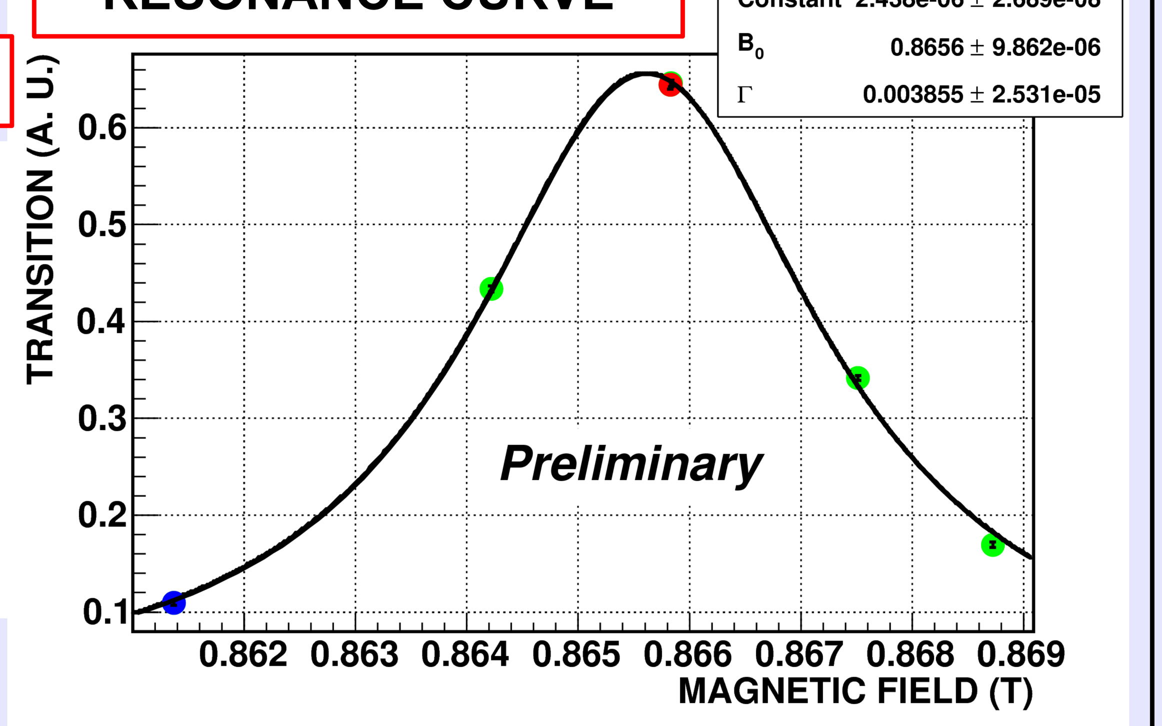


2 γ decay rate increases because of the transition between o-Ps' $m_z=0$ and $m_z=\pm1$ states.

TIMING SPECTRA



RESONANCE CURVE



Converted HFS value (from an <u>only 2 weeks run</u>) is

203.399
± 0.005 (23 ppm, stat.)
± 0.029 (140 ppm, sys.) GHz *(Preliminary)*

(consistent with the previous experiments)

The systematic error mainly comes from the non-uniformity of the magnetic field.

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.