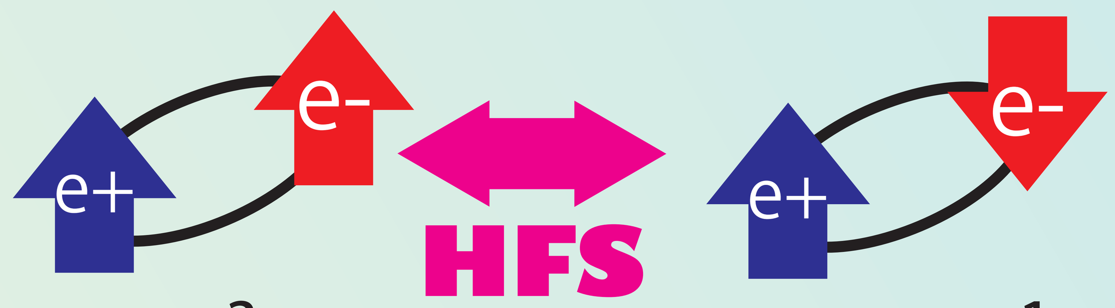
The First Direct Measurement of the Hyperfine Splitting of Positronium



o-Ps (1^3S_1) p-Ps (1^1S_0)

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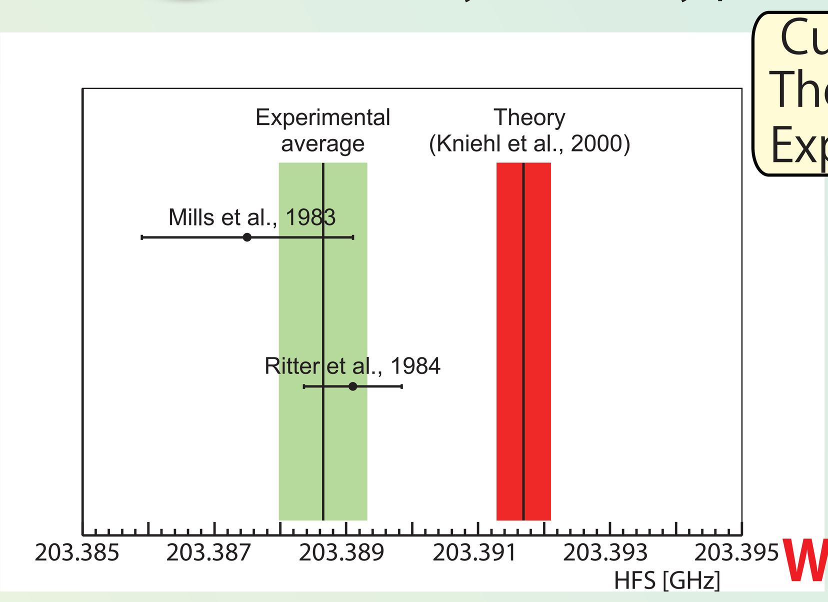
The HFS problem in Positronium

Positronium HFS is an identical target for precise measurements probing new physics.

- Frequency measurement: very precise measurement possible.
- Pure QED system: very precise theoretical calculation possible.



Theory vs Experiment on Ps-HFS

Current best numbers:
Theory: 203.**39169 (41)** GHz (2.0 ppm)
Experiment: 203.**38865 (67)** GHz (3.3 ppm)

3.9 σ Discrepancy between calculation and measurement was found!

We will investigate the discrepancy by a new experiment!

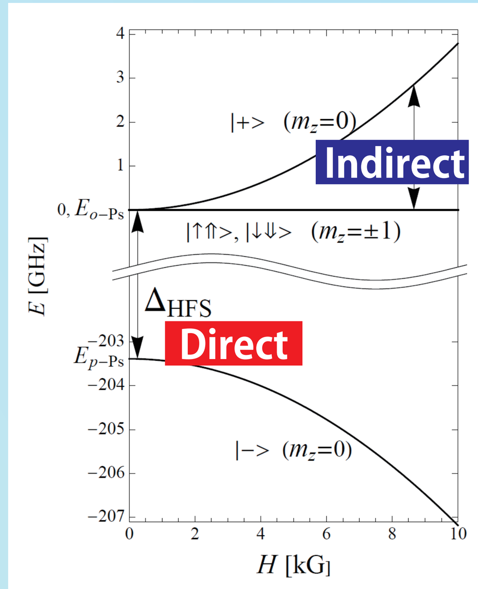
Measuring the HFS

Direct method — This presentation!

Applying **203 GHz electromagnetic radiation** to cause the o-Ps↔p-Ps direct transition.

New technology (sub-THz)
No measurement yet.

Indirect method — Formerly used



Energy level of Ps under B-field

Measuring Zeeman splitting of o-Ps (a few GHz) under static magnetic field (~ 1 Tesla).
The Zeeman split can be translated to HFS by a theoretical calculation.
Used in all previous measurements.
Non-uniformity of the magnetic field is a serious systematic error source.

Key developments to observe direct HFS transition

HFS transition is a rare process (τ ~3×10^8 sec): high radiation intensity is essential for the HFS observation.

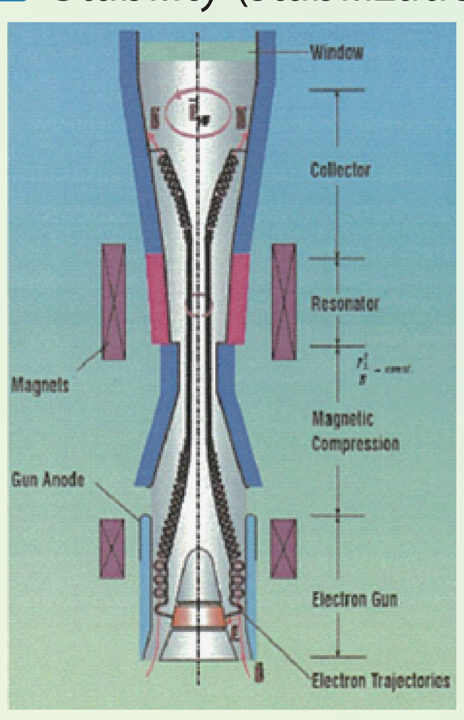
High power radiation source at 203 GHz (λ=1.475 mm)

High power, **stable**, **frequency-tunable** and **coherent sub-THz** radiation source is essential for the HFS observation.

We are developing a 203 GHz gyrotron: a novel radiation source for sub-THz range.

- High power (up to 200 W)
- Monochromatic (line width : ~ 10 kHz)
- Tunable frequency (~ a few GHz)
- Stability (stabilization possible)

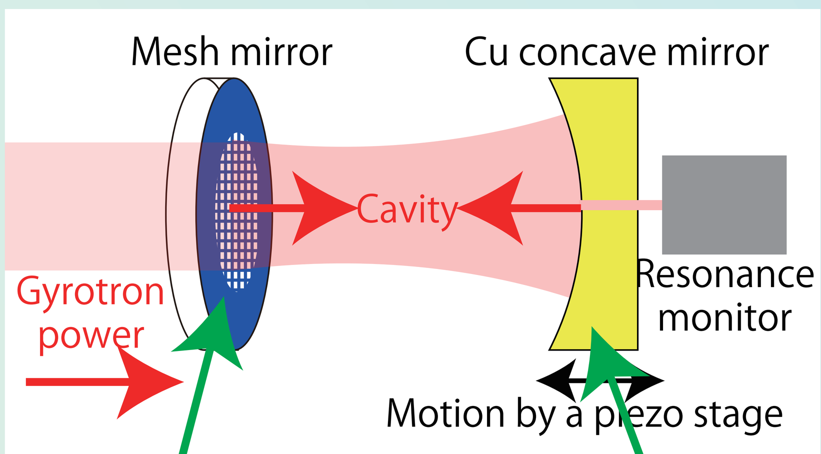

Gyrotron FU CW V, developed for the HFS measurement.



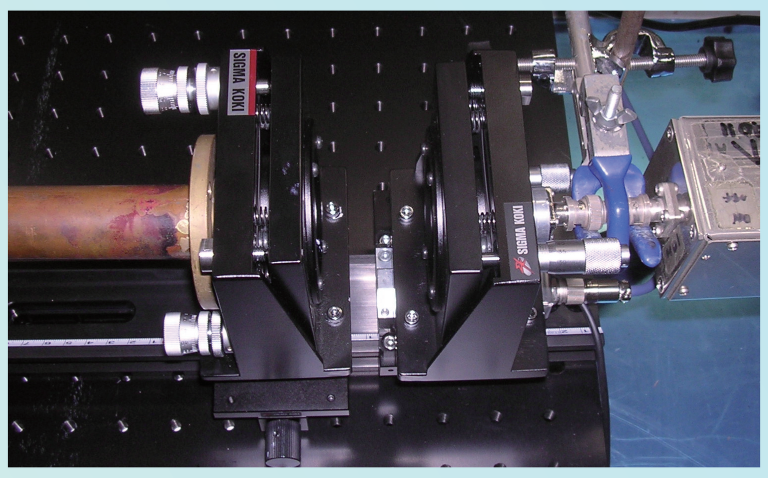
Schematic of gyrotrons.

Fabry-Perot resonator to accumulate photons

Using resonance to increase photon density up to 100 times.

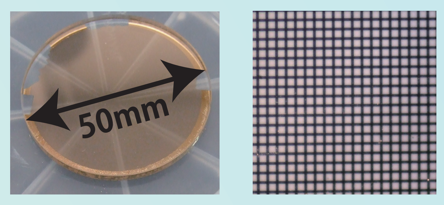


Schematic drawing of the planned cavity.


Picture of a cavity test.

Metal mesh mirror: suitable for input coupling.
High reflectivity (~99%)
Efficient coupling
Low loss (<10%)

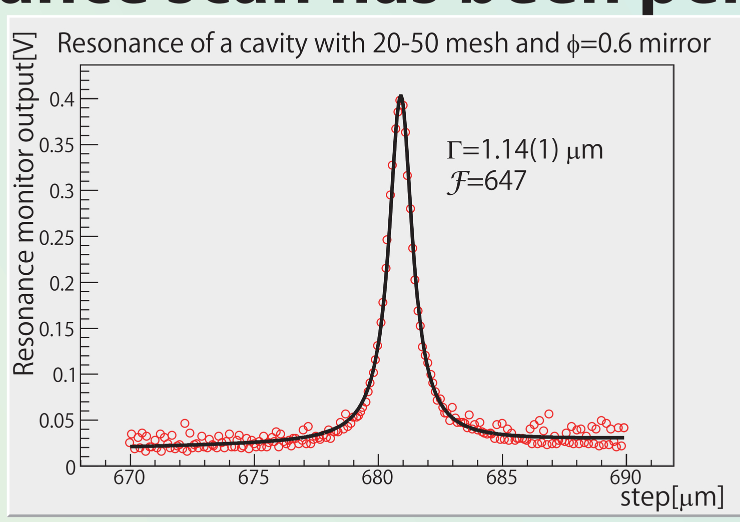
Cu concave mirror: to improve Finesse (resonance factor)
Focusing effect to confine radiation



Au mesh plate (20 μm width, 50 μm spacing)

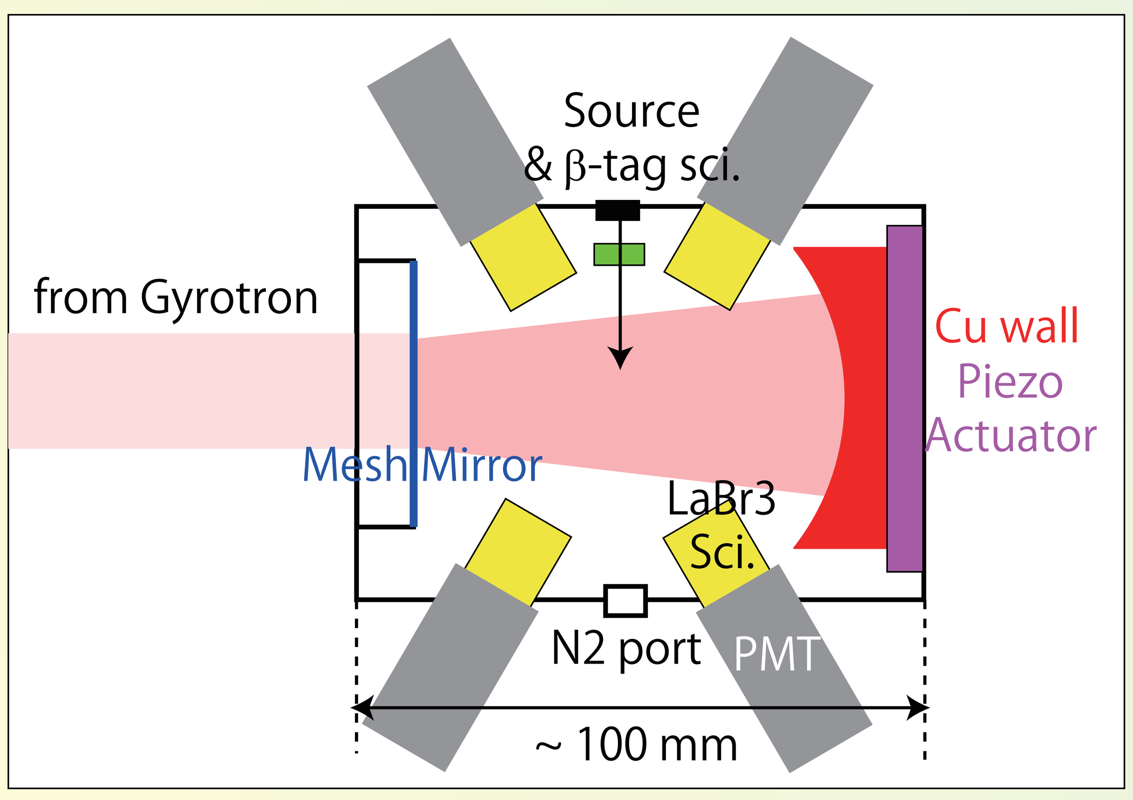

Cu mirror

Resonance scan has been performed to obtain cavity parameters



- **ℱ > 630 is obtained.** Round-trip reflectivity > 99% - OK.
- **Now performing detailed optimization of the cavity.** Increase input coupling. less ohmic/diffraction loss.

Experimental Setup



Schematic for the Ps-HFS detection setup.

Detection strategy:

- o-Ps decays into 3γ, slow (τ=138ns).
- p-Ps and annihilation (non-Ps) decays into 2γ, immediate.
- HFS transition (o-Ps to p-Ps) decays into 2γ, slow.

Energy + timing measurement can efficiently identify HFS events.

Source & detectors:

- 1MBq ^{22}Na source (545 keV max β+) β+ is tagged by a plastic scintillator
- Four LaBr3 crystal scintillator (~3% energy resolution at 511 keV) for 2γ/3γ separation.

Summary and plan

- **A new direct method of Ps-HFS measurement is under development.**
- **A high power gyrotron with 203 GHz resonant frequency was developed.**
- **Fabry-Perot cavity will be utilized to obtain high photon density.**
- **The first observation of direct HFS transition will be in this fall, leading to precise HFS measurements (comparable level to indirect method).**