# Sub-THz Spectroscopy of the Ground State Hyperfine Splitting of Positronium

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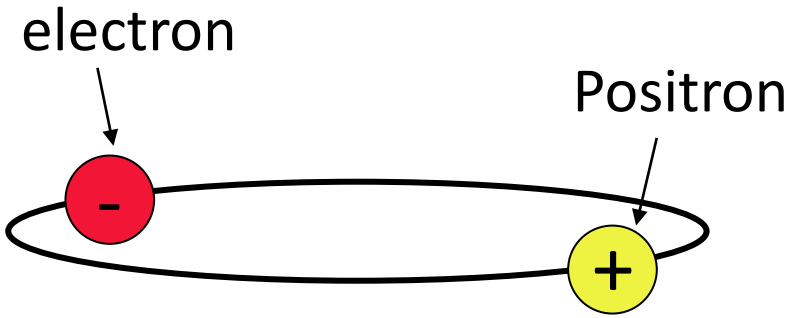
# Outline

- Introduction (Ps, Ps-HFS)
- Experimental Setup
  - ✓ Quasi-optical system
  - ✓ Ps assembly & transition measurement detectors
- Analysis & Current Status
- Summary

# Positronium (Ps)

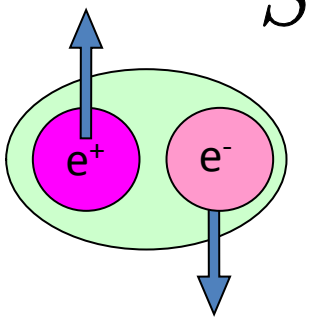



- Ps is the bound state of $e^-$ and $e^+$ ($e^+$ is the antiparticle of $e^-$)
  - The lightest hydrogen-like atom
  - Unstable, particle-antiparticle system
  - Simple, good target to study bound state QED (Quantum ElectroDynamics)

# Positronium (*o*-Ps, *p*-Ps)

- *Para*-positronium (*p*-Ps)

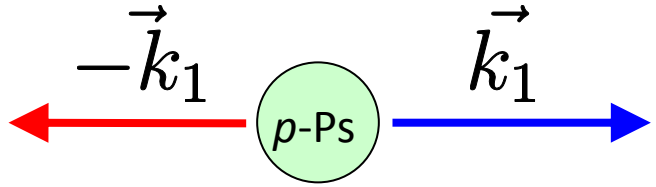
$S = 0$ Spin singlet




Short lifetime (0.125 nsec)

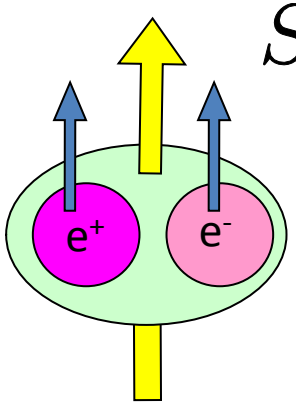
*p*-Ps → 2γ (, 4γ, …)

511 keV (= electron mass) γ rays




- *Ortho*-positronium (*o*-Ps)

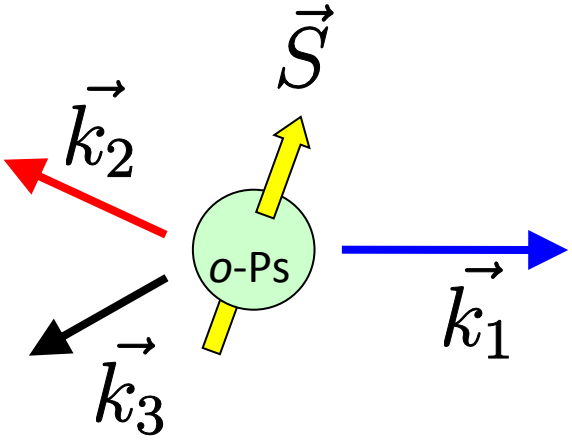
$S = 1$ Spin triplet



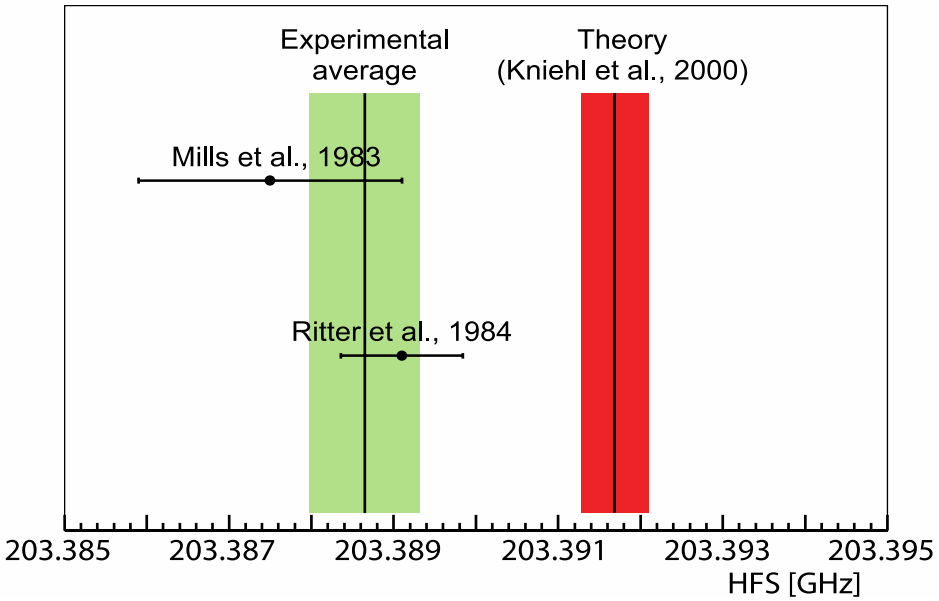

Long lifetime (142 nsec)

*o*-Ps → 3γ (, 5γ, …)

Continuous energy spectrum



# Hyperfine Structure of the Ground State of Positronium (Ps-HFS)




Exp.

203.388 65(67) GHz (3.3 ppm)

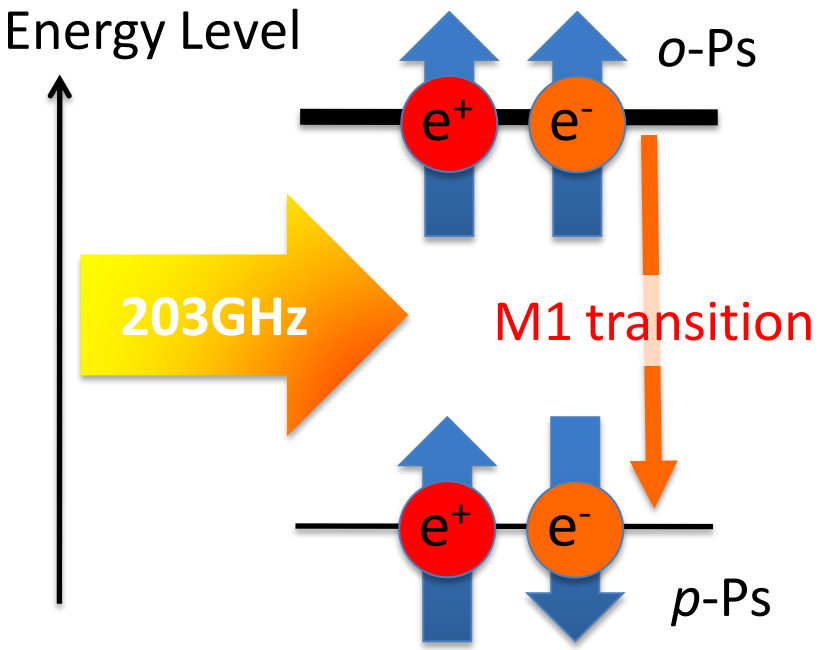
O($\alpha^3$) QED calc.

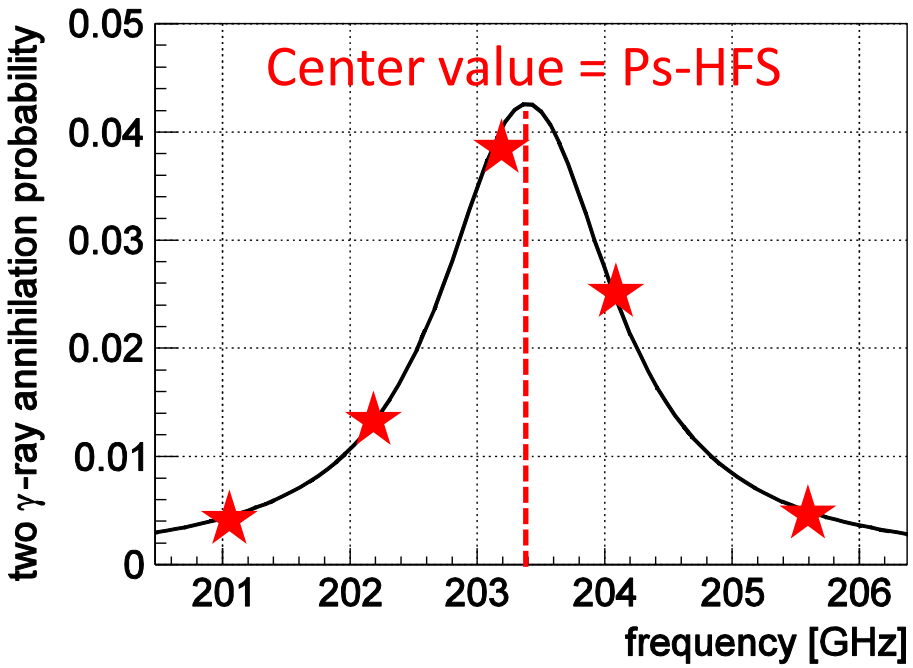
203.391 69(41) GHz (2.0 ppm)

- Energy difference between o-Ps and p-Ps, about 203 GHz.
- A large (3.9 σ, 15 ppm) discrepancy between the measured and the theoretical value.
- All of the previous measurements are indirect measurements using static magnetic field.

→We plan to "directly" measure Ps-HFS using high power sub-THz (203 GHz) radiation.

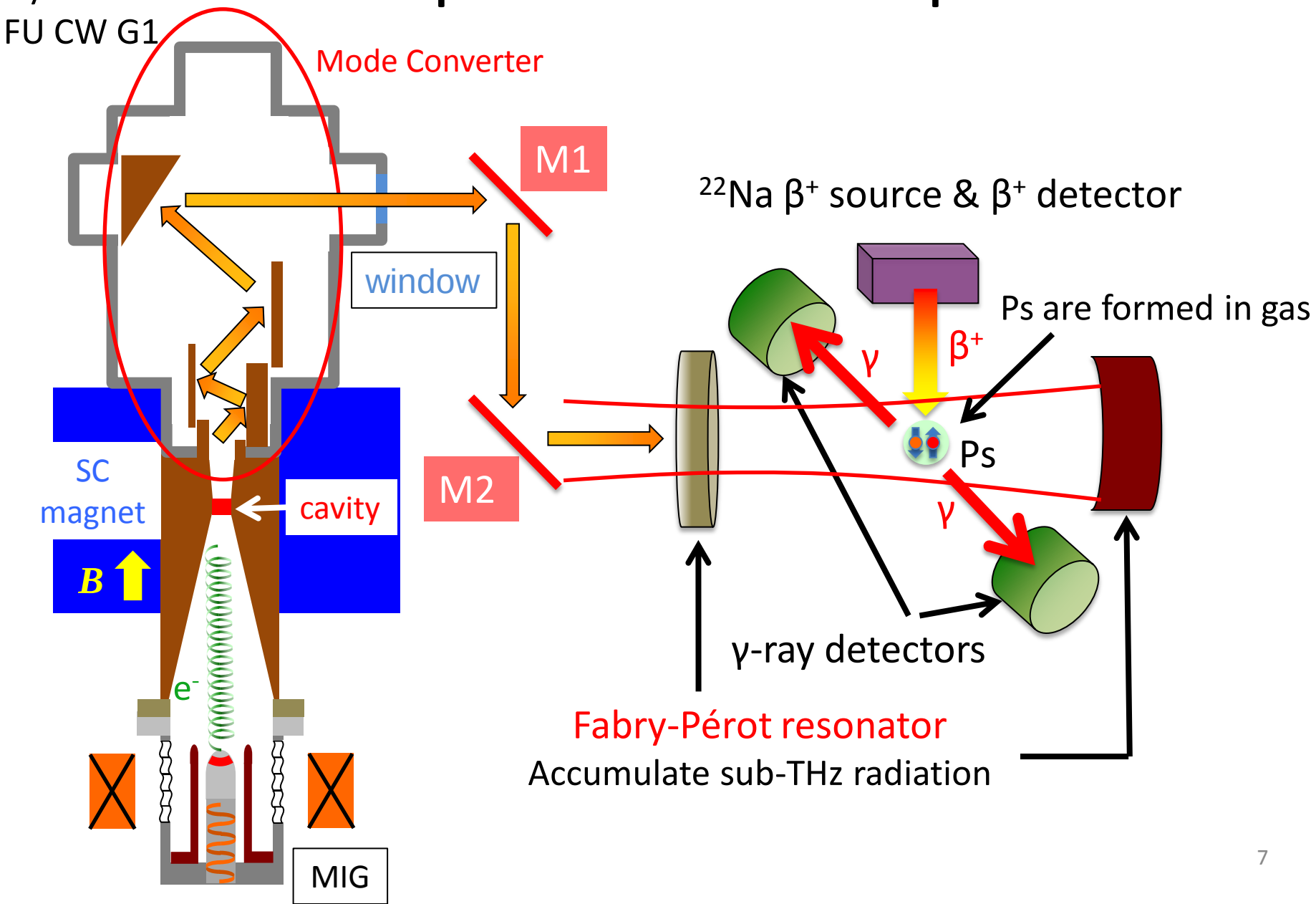
# First Direct Measurement of Ps-HFS with New Sub-THz Technique



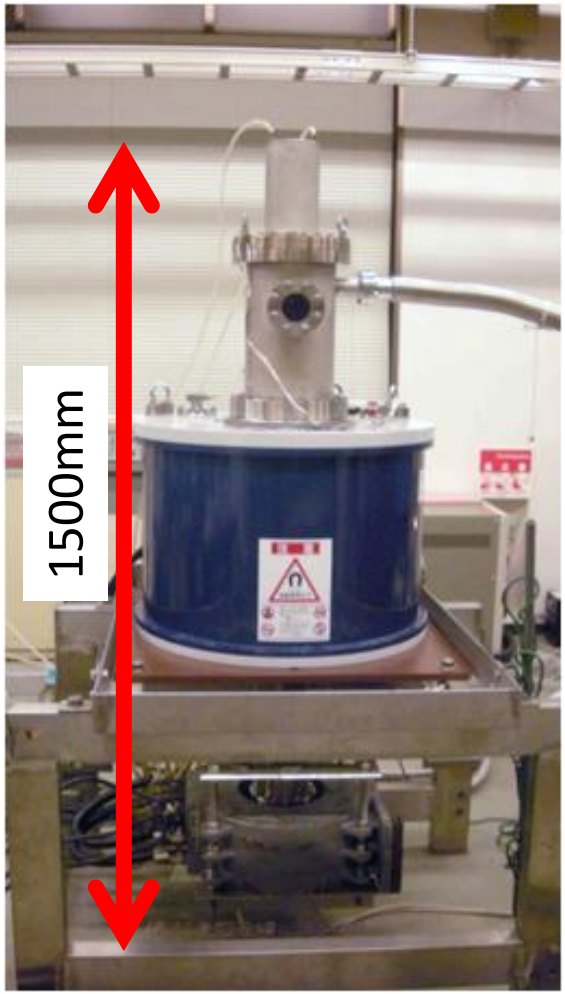

- Drive stimulated emission from *o*-Ps to *p*-Ps using 203 GHz radiation.
- Since *p*-Ps decays into 2γ promptly (125 ps), 2γ annihilation increases when Ps are exposed to 203 GHz radiation.
- The natural transition rate is $10^{14}$ times smaller than decay rate of *o*-Ps. High power (> 10kW) sub-THz radiation is necessary.
- Frequency has to be changed from 201 to 206 GHz in order to measure transition curve.

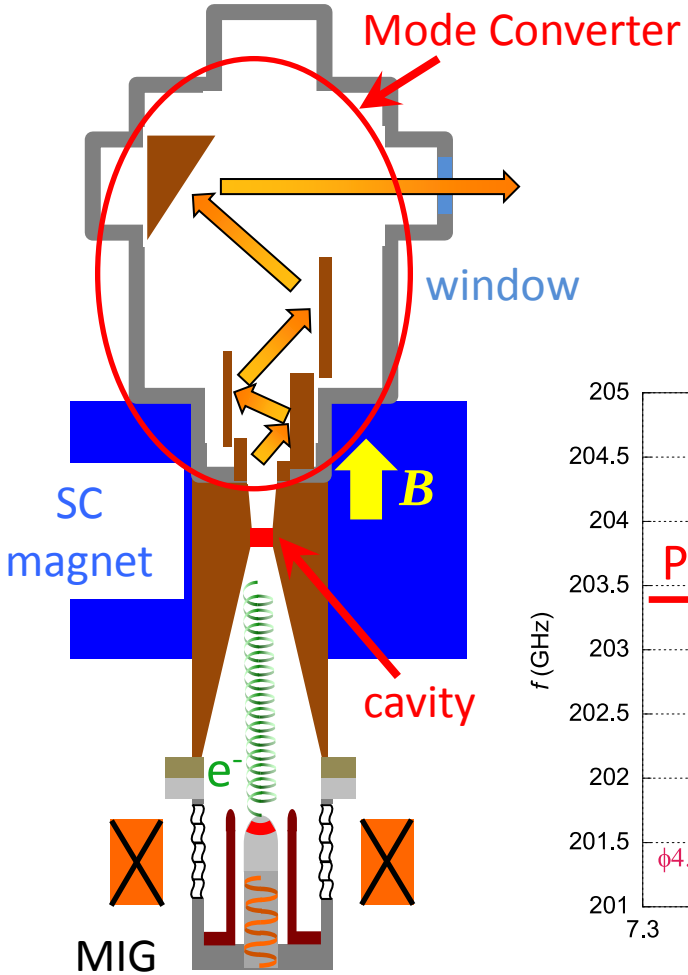
# Experimental Setup



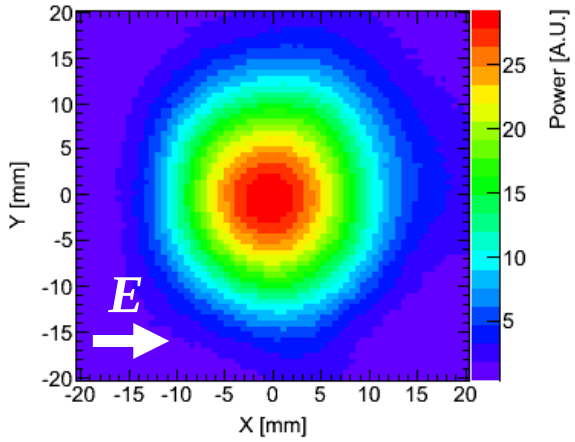
# Gyrotron “FU CW GI”

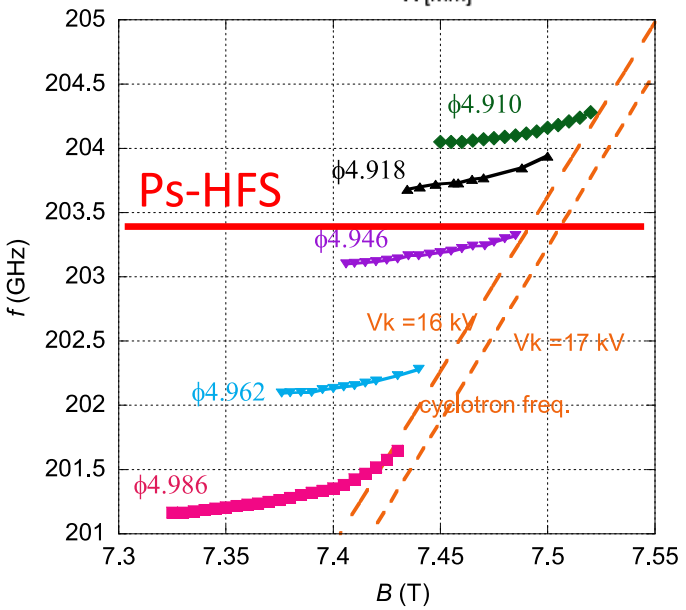
- Gaussian beam power ~ 350 W (5Hz, duty 30%)
- Replacing gyrotron cavities of different sizes to change frequency without breaking vacuum of the MIG.



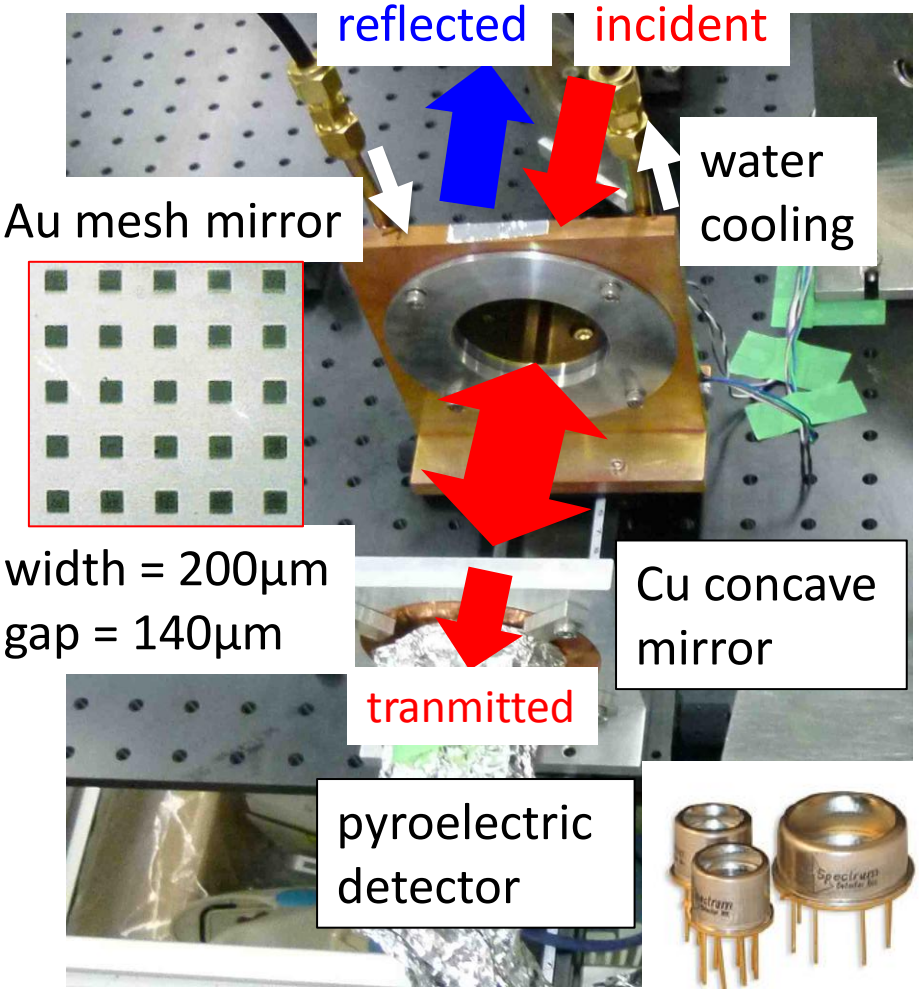



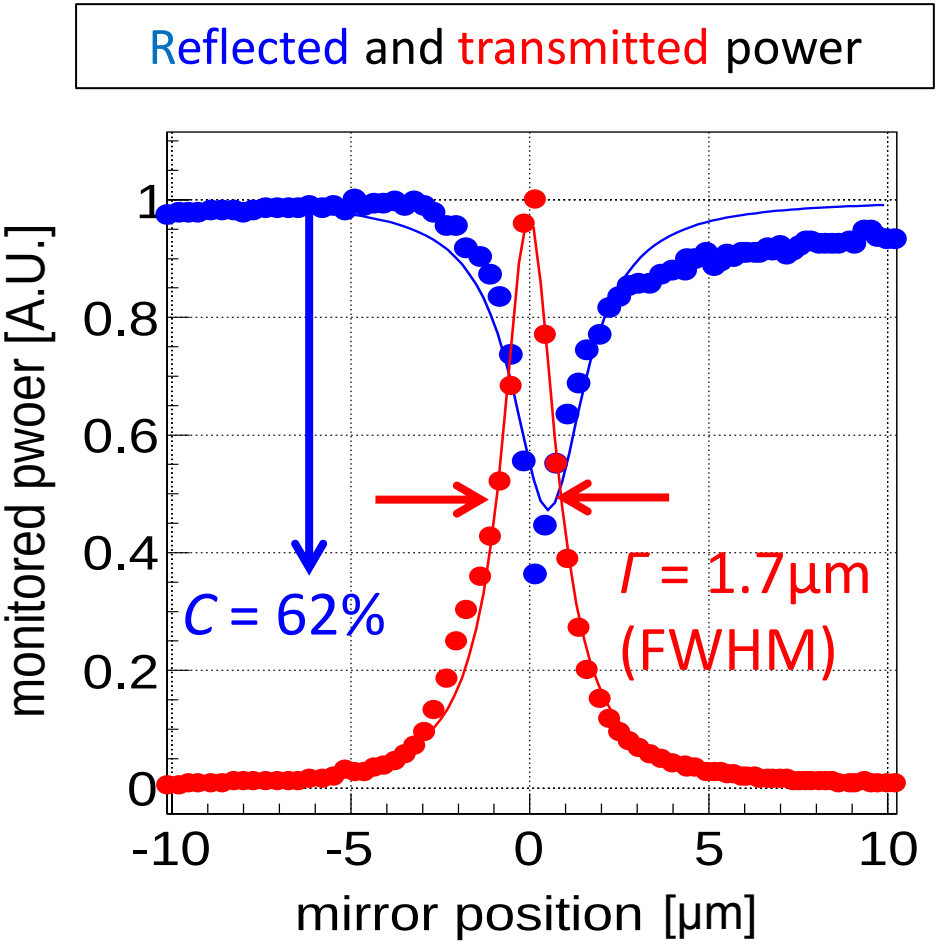

Beam Profile



# Fabry-Pérot Resonator

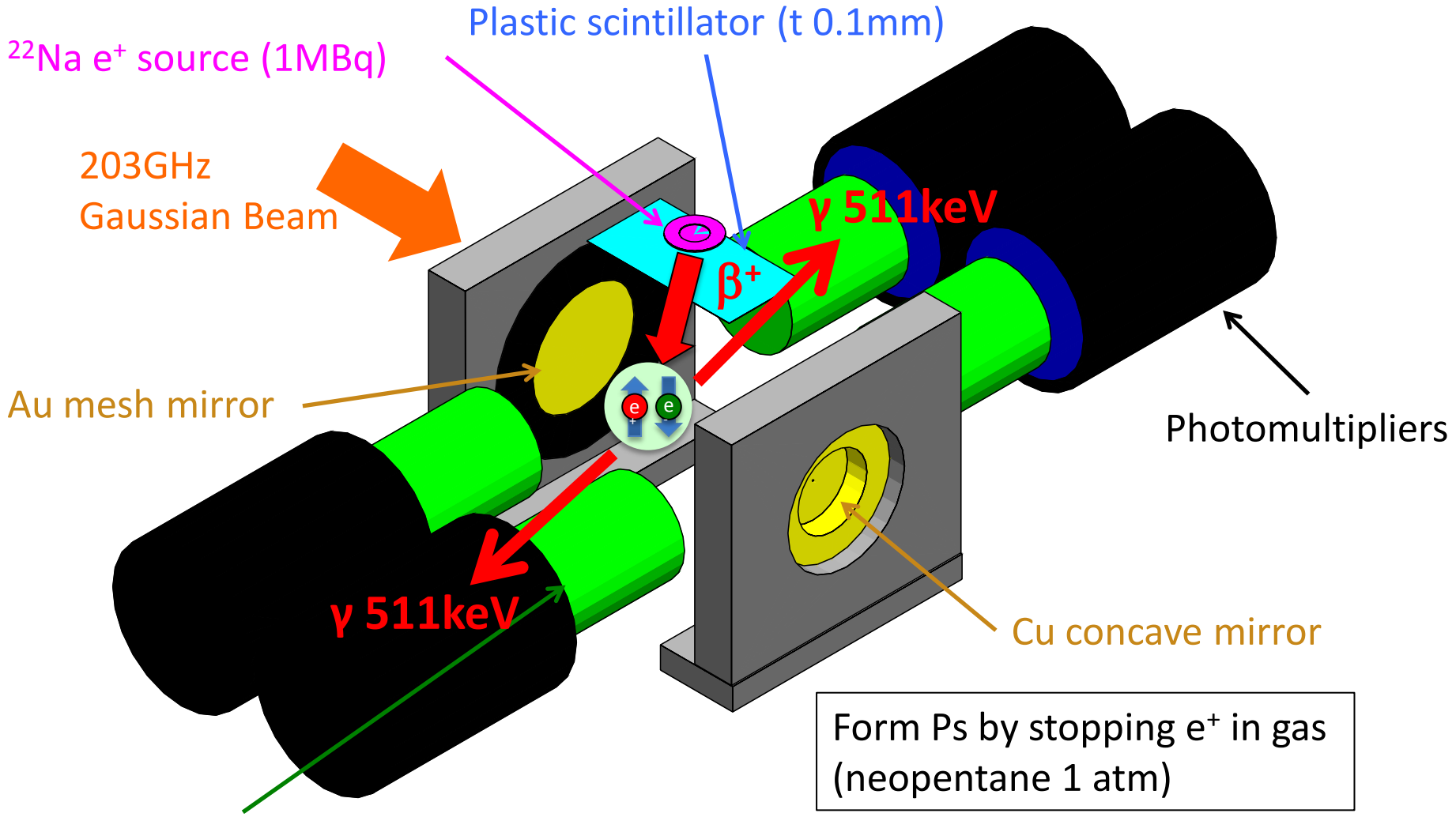



- Sharpness $\Gamma$ = 1.7µm (Finesse = 430), and coupling $C$ = 62%
  → Gain of the resonator is 85! (incident power ~ 350W)

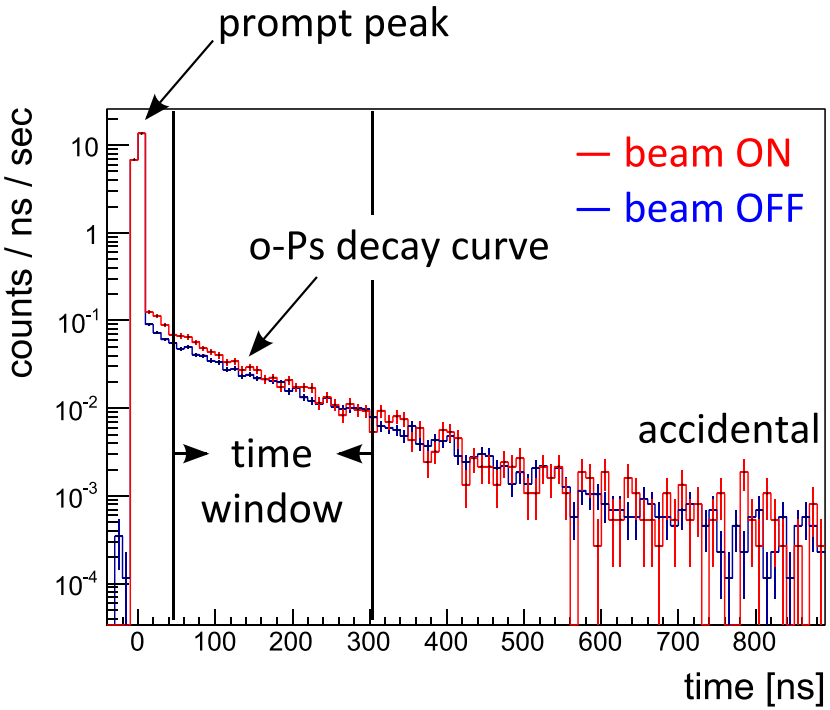
# Ps Assembly and γ-ray detectors

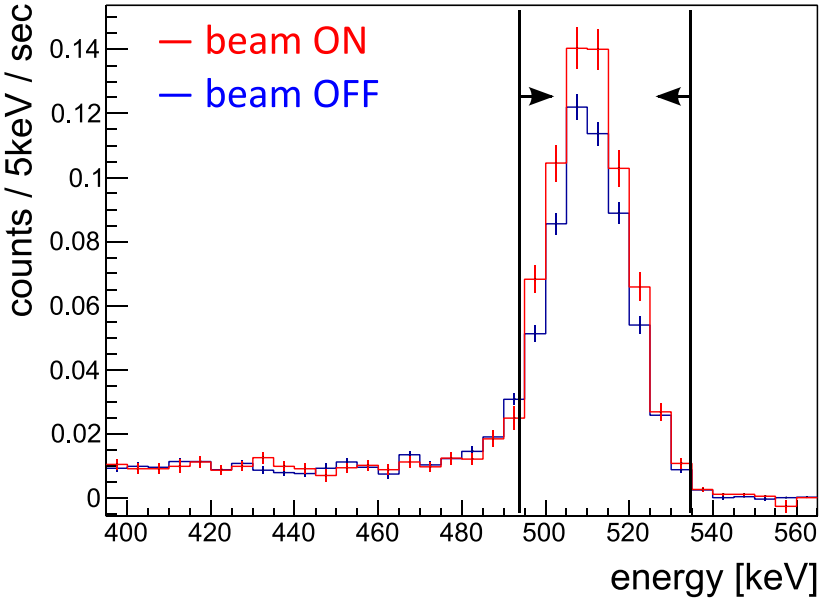
Signal = 2γ decay of *o*-Ps (monochromatic 511keV・back-to-back)



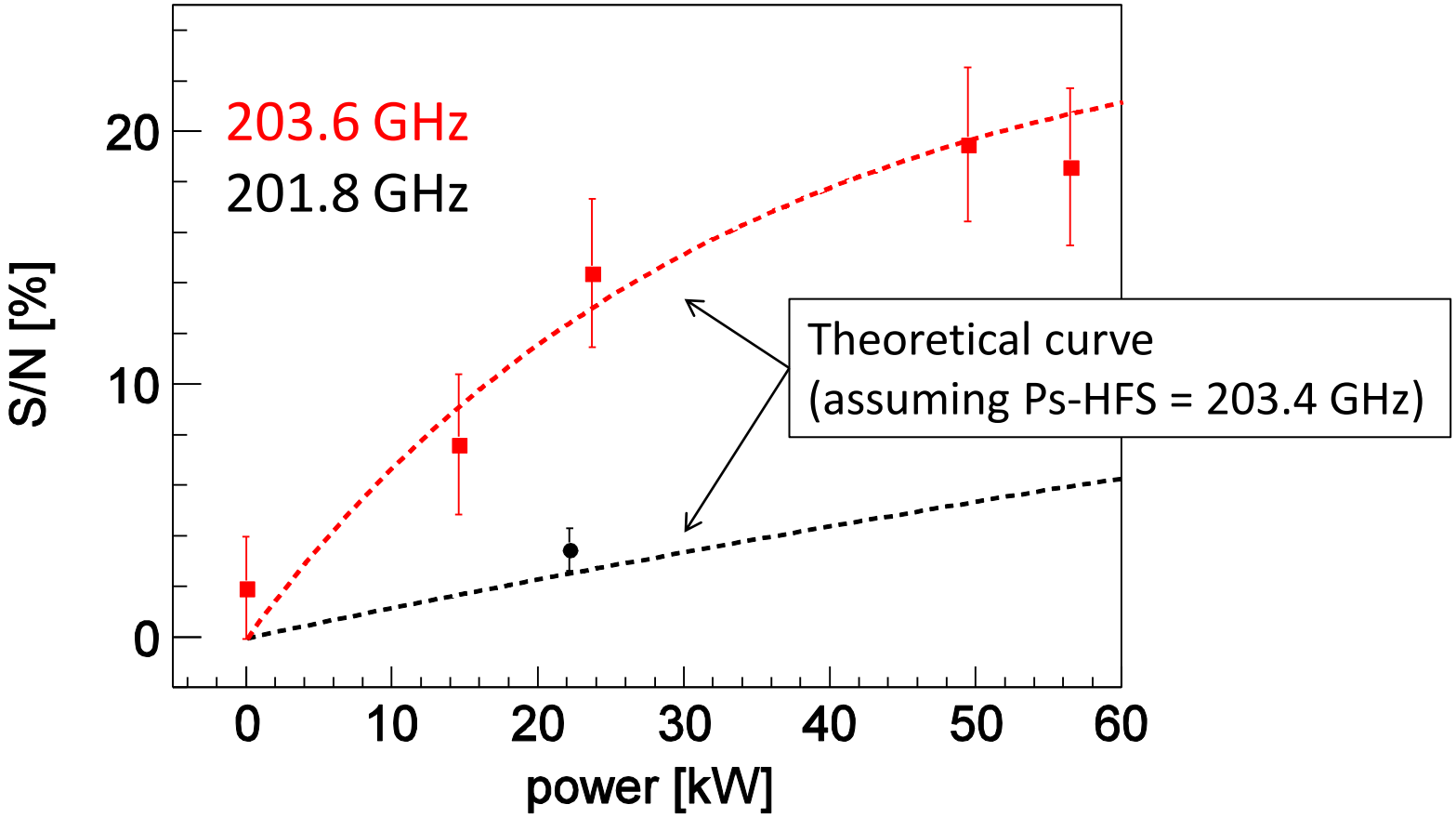
# Ps-HFS transition@203.6GHz, 52kW

- A measurement at a frequency point takes about 3 weeks (2 weeks for preparation, 1 weeks for data acquisition)
- When Ps are exposed to 203 GHz radiation, *o*-Ps→3γ (tail at the left of 511keV peak) decrease and *o*-Ps(→*p*-Ps)→2γ (511keV peak) increase. The 511keV peak during beam OFF is due to *o*-Ps+$e^-$→2γ+$e^-$ (pick off annihilation).



# Power & Frequency Dependence of Transition




- We have already measured transitions at 201.8 GHz, 203.6 GHz. The data points are consistent with the theoretical curve.
- We are going to measure at three more freuencies to estimate Ps-HFS within this year.

# Summary

- We plan to directly measure Ps-HFS (203.4 GHz) for the first time by developing new sub-THz technique.
- High power (>10 kW) and frequency tunability from 201 GHz to 206 GHz are necessary, so we use a demountable type gyrotron “FU CW GI” and a high finesse Fabry-Perot resonator with a gold mesh mirror.

- We have already measure transitions at two frequencies. In order to masure Ps-HFS, we will perform three more measurements at different frequencies within this year.