Development of laser spectroscopic method using superfluid helium for the study of low-yield nuclei

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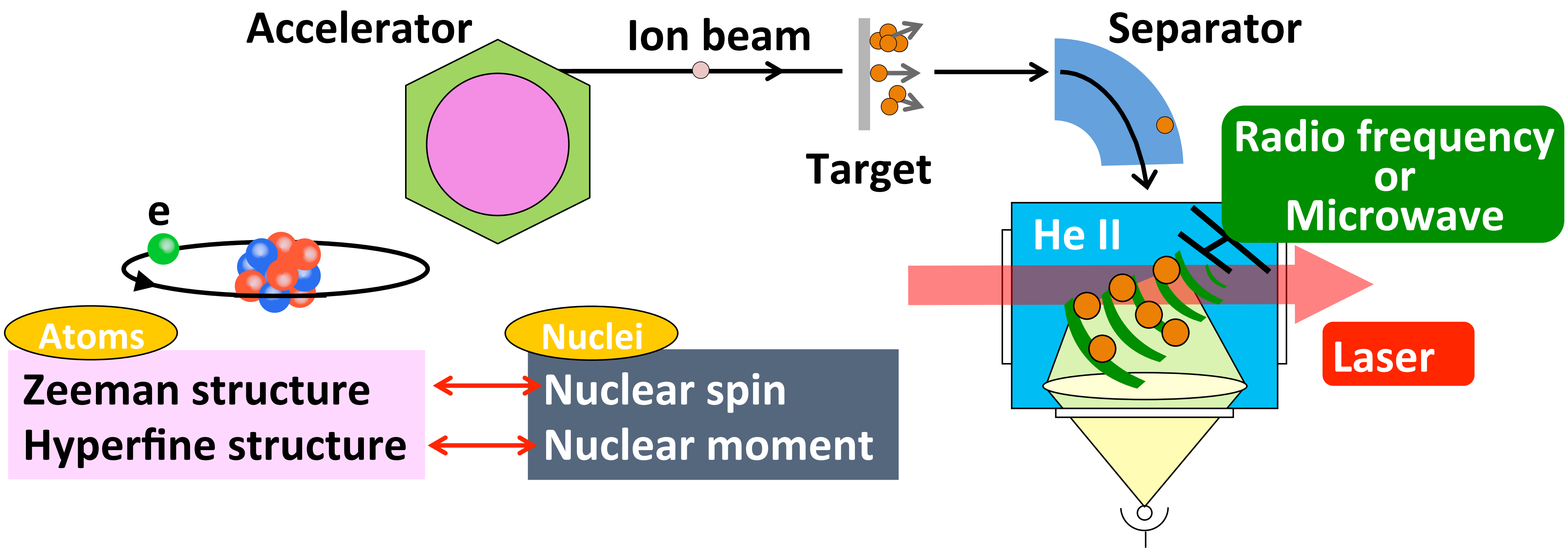
Laser spectroscopy of atoms using superfluid helium

- Measurement of Nuclear spin *I* , moment μ_I

Powerful tool: Laser spectroscopy ⇨ **Problem: Low efficiency**

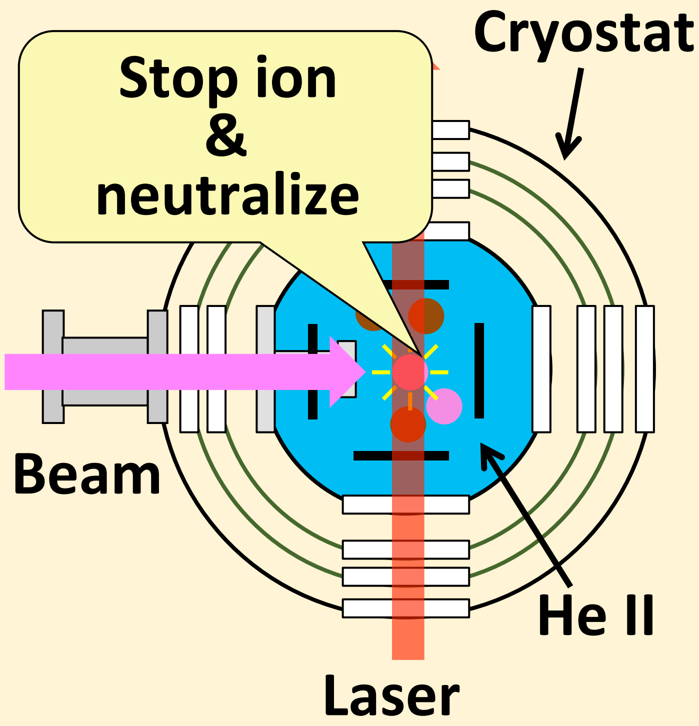
"OROCHI"

(Optical RI-atom Observation in Condensed Helium as Ion-catcher)

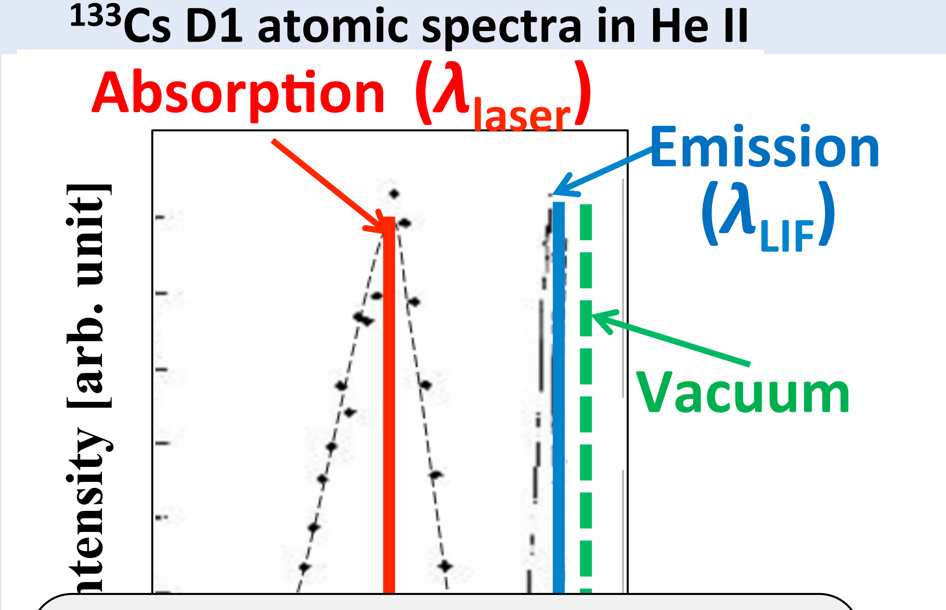


Advantage of superfluid helium

High trapping efficiency



Extremely low background



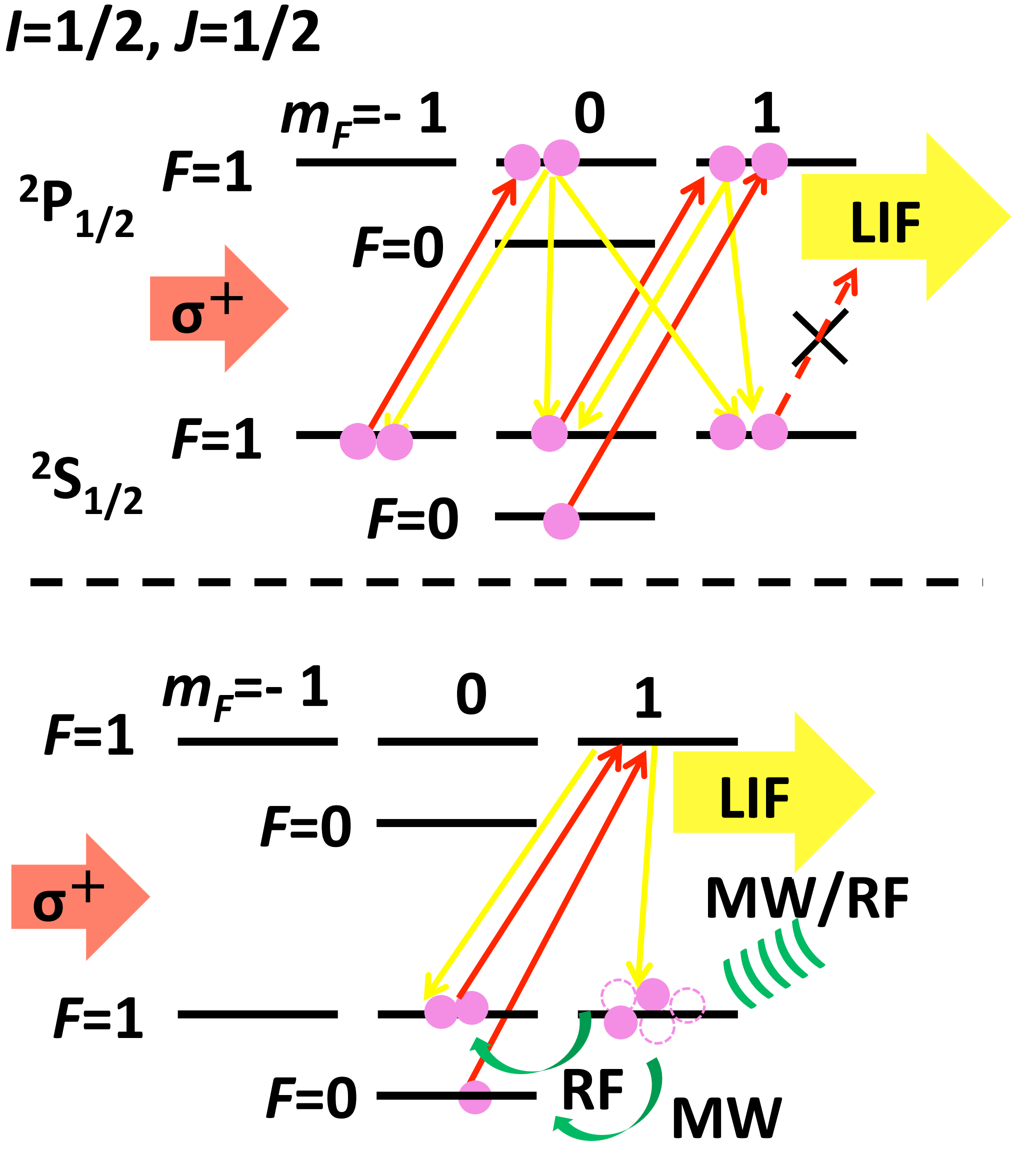
$\lambda_{laser} \neq \lambda_{LIF}$

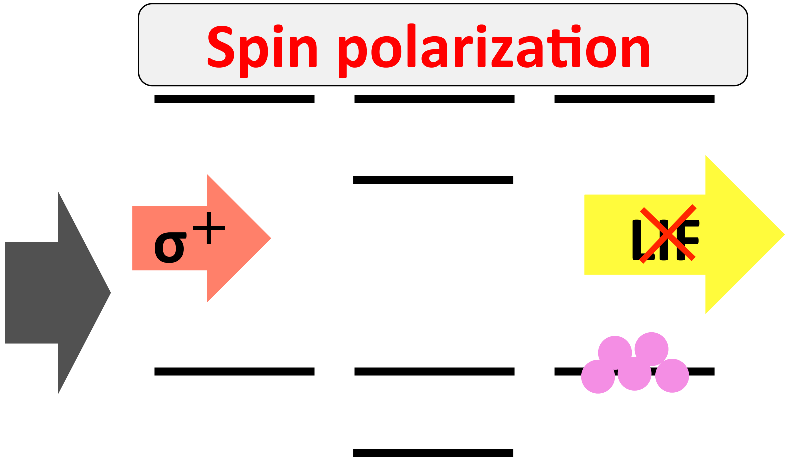
LIF: Laser induced fluorescence

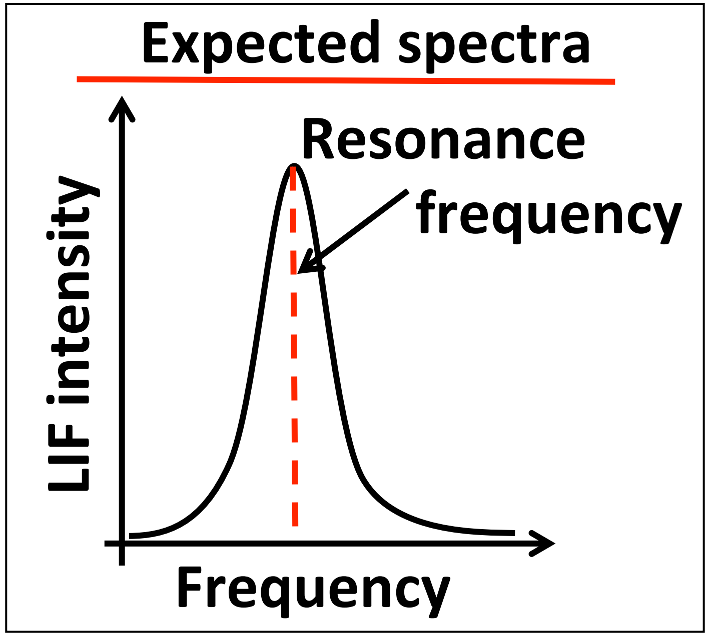
λ:Wavelength

"Suitable for studying low-yield exotic nuclei"

Optical pumping and double resonance method





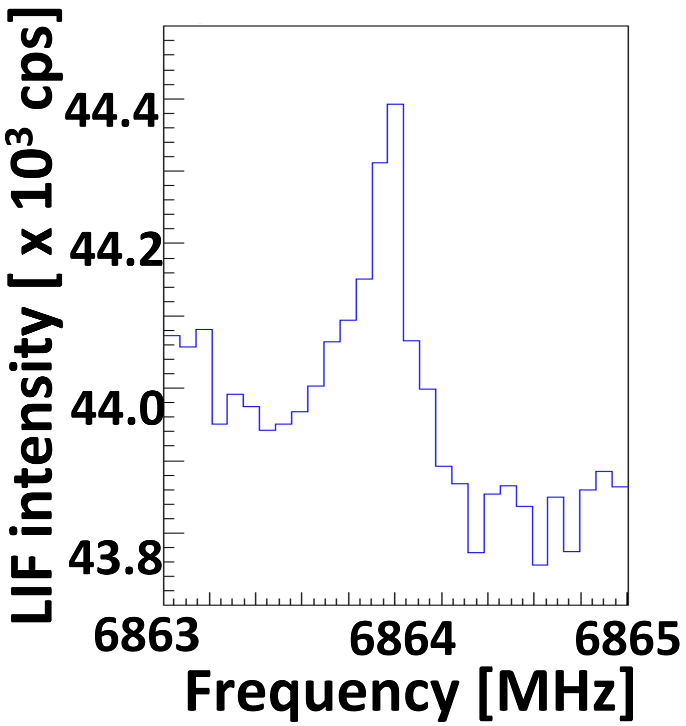


Result of experiment using RIPS at RIKEN and identified difficulties

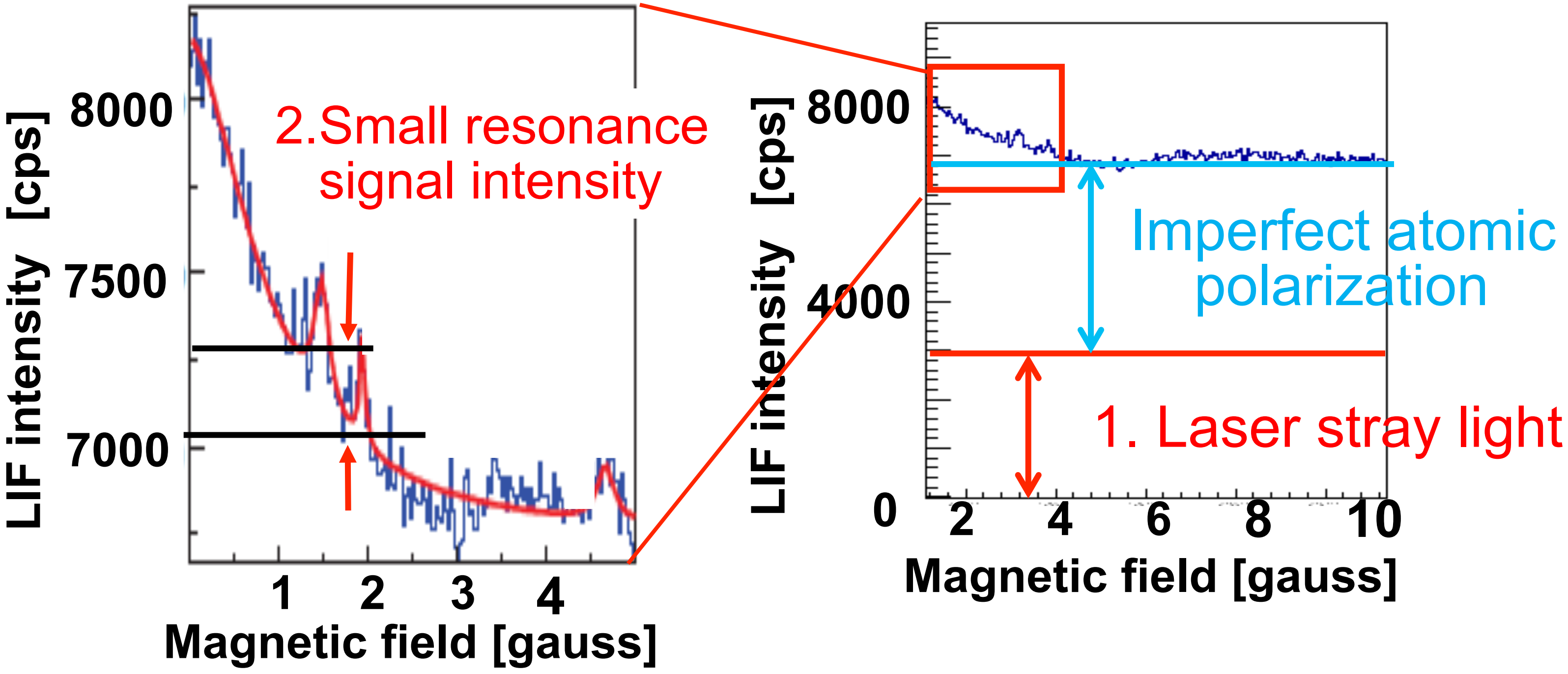
Successful observation of HFS/Zeeman resonance

Beam intensity: - 10^4, Mes. time: 40 min.

HFS resonance of ^{87}Rb



Zeeman resonance using $^{84-85}$Rb



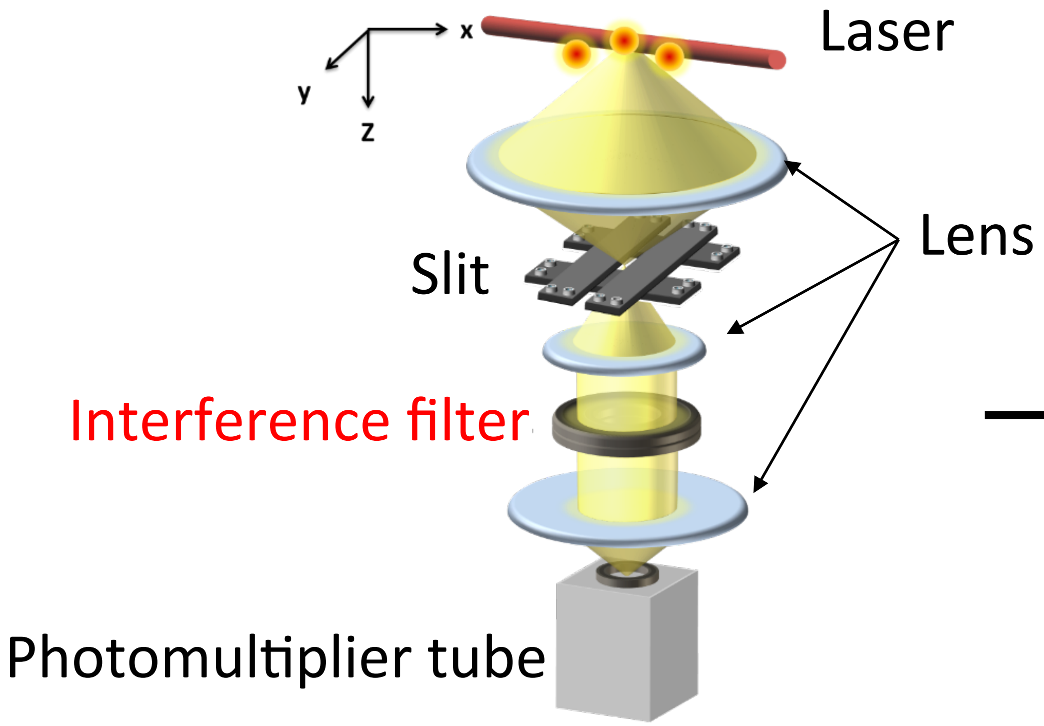
X. F. Yang *et al.*, PRA **96,** 030115 (2013)

Improvement of S/N ratio ← Lower yield nuclei (< 100 pps)

1.Laser stray light -How to reduce ?-

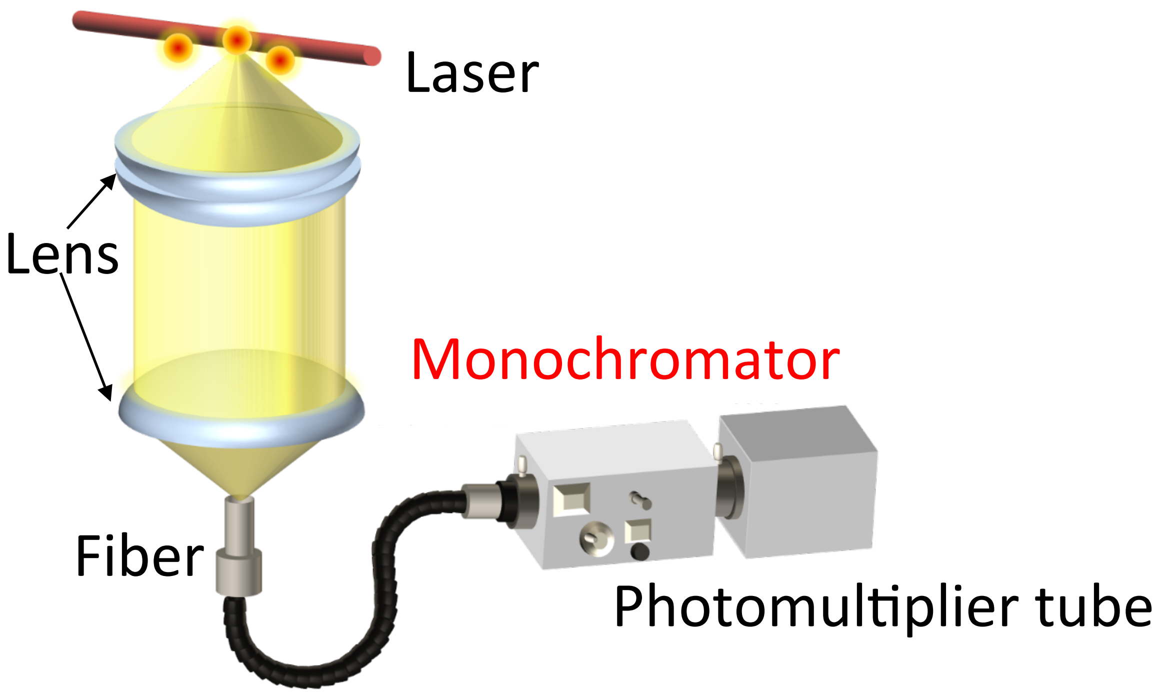
→ Change the system for the wavelength separation

Cf: Previous florescence detection system



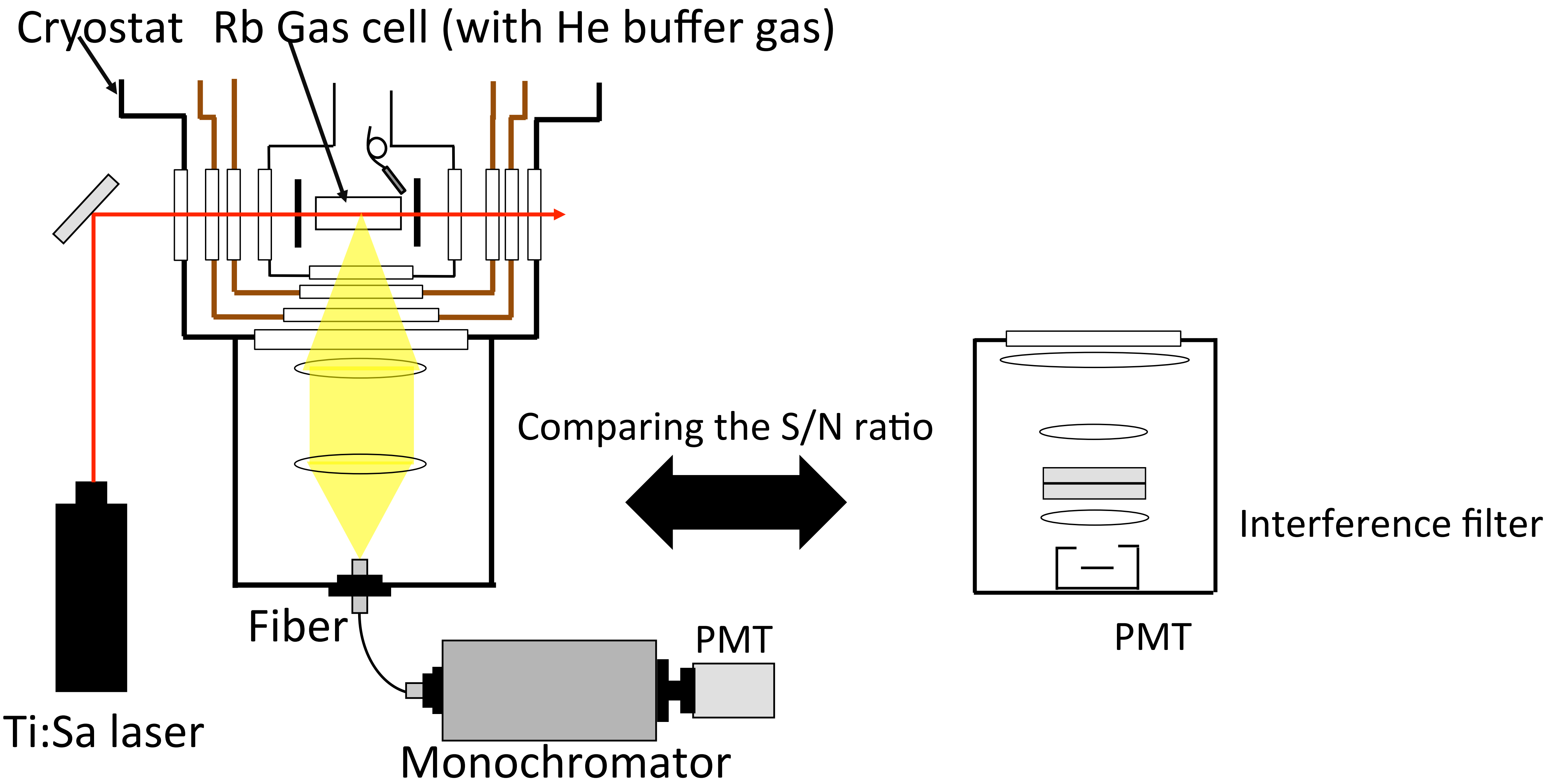
→

New one



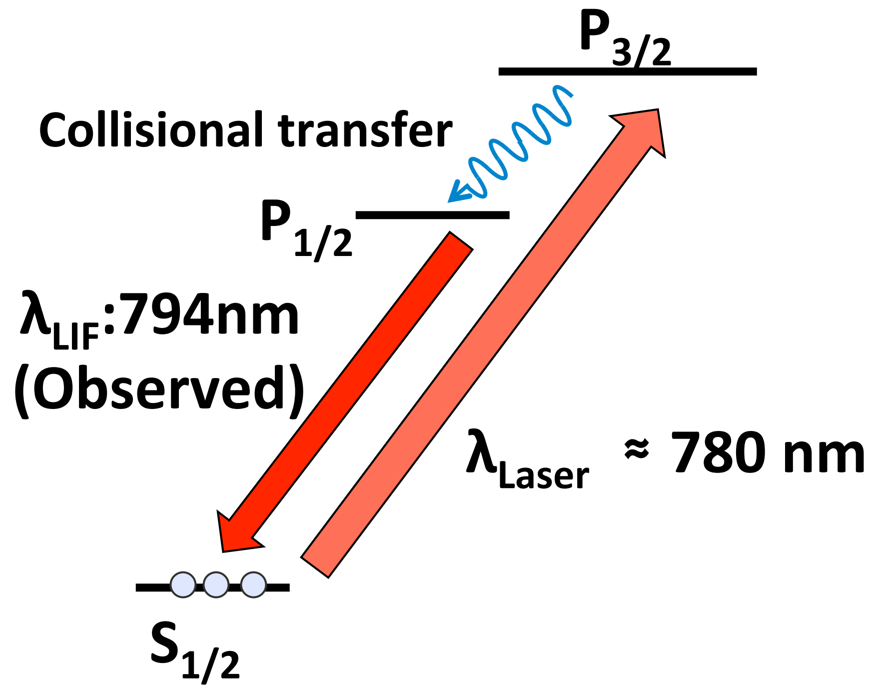
Reduction of noise due to laser stray light

1.Laser stray light -Performance evaluation-



1.Laser stray light -Result of experiment-

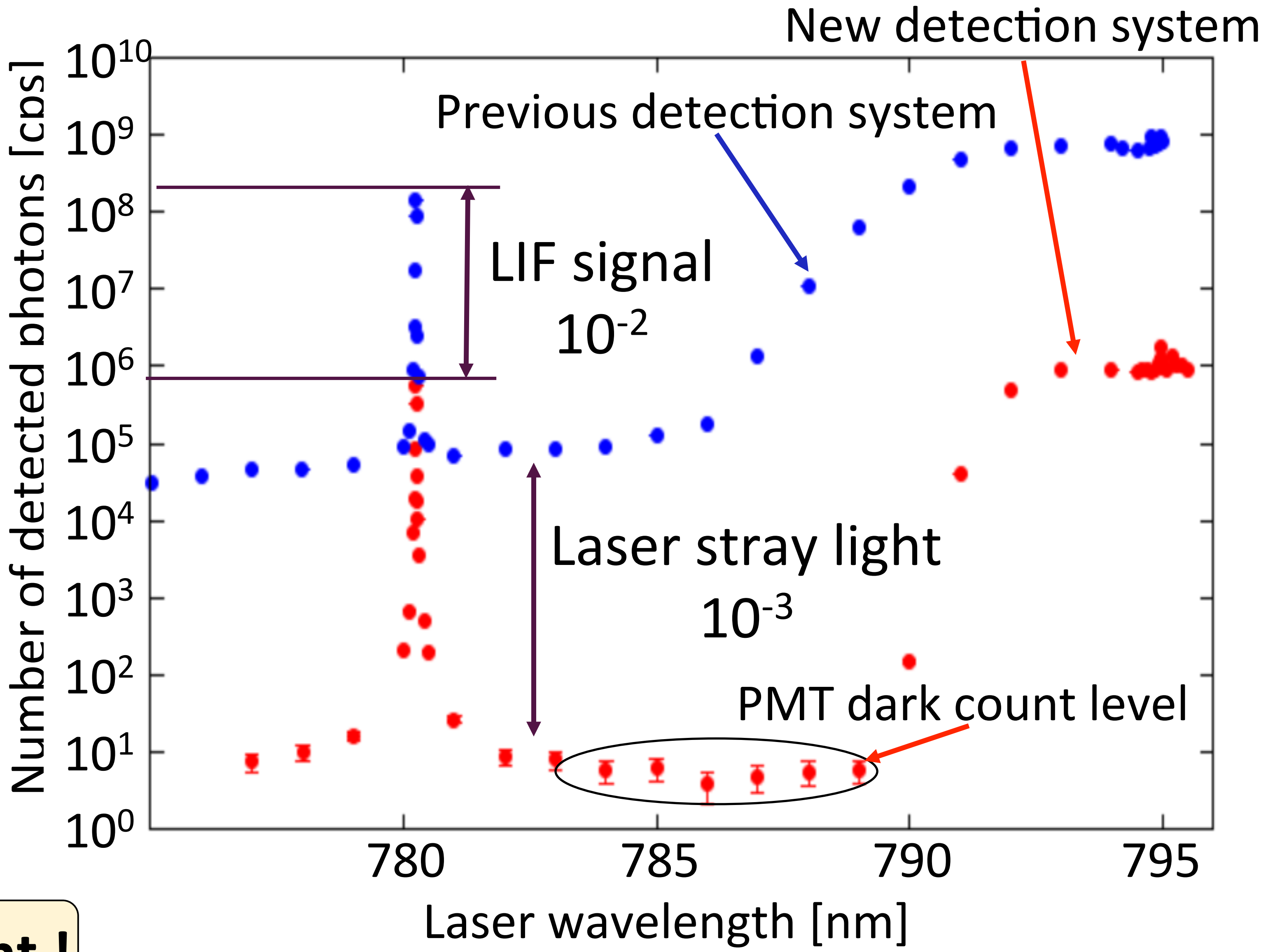
Laser wavelength: 775-795 nm



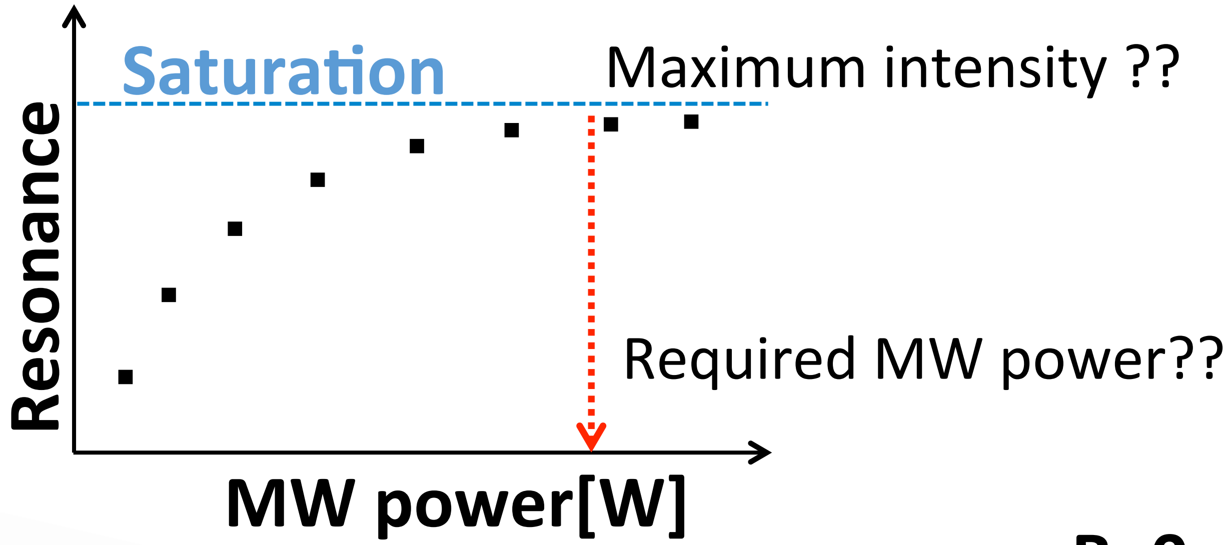
Previous system : S/N1.5×10^3

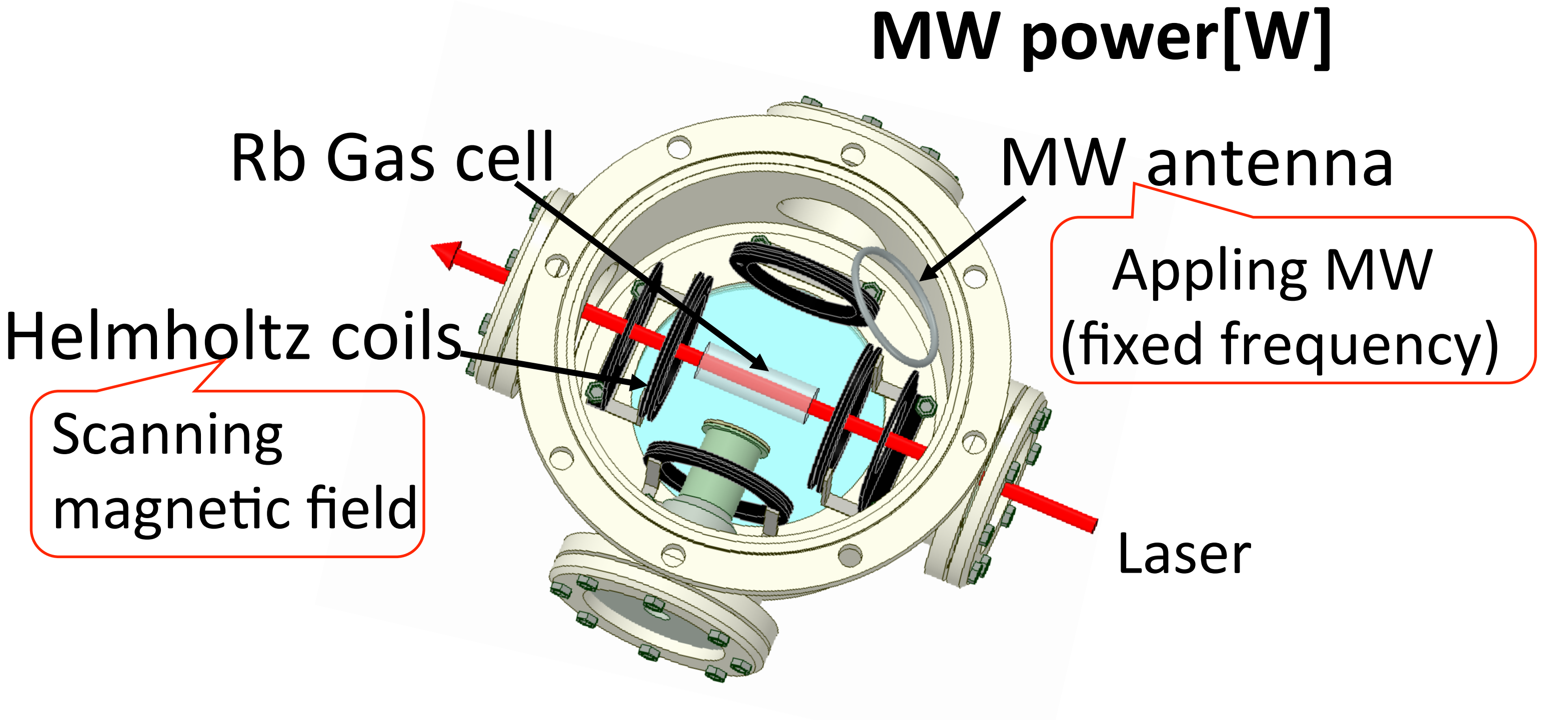
New system : S/N=1.4×10^4

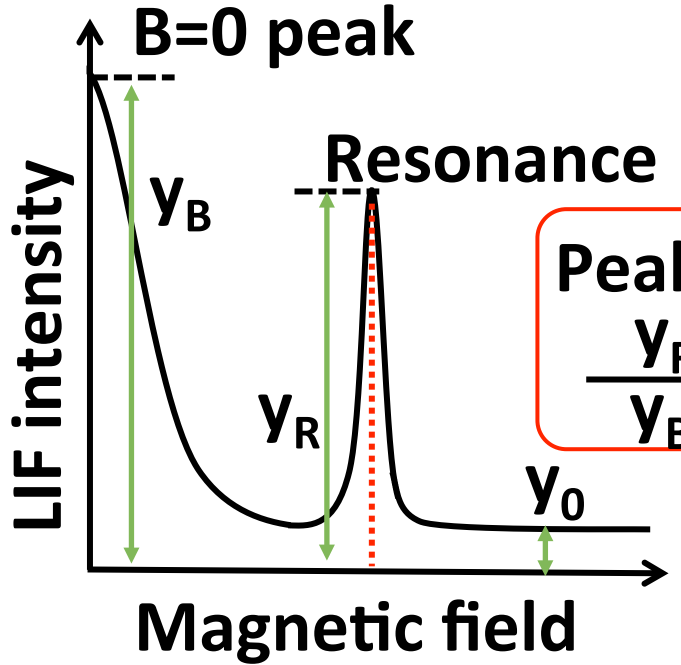
At least 10 times improvement !



2.Small resonance signal intensity -Was MW power enough?-





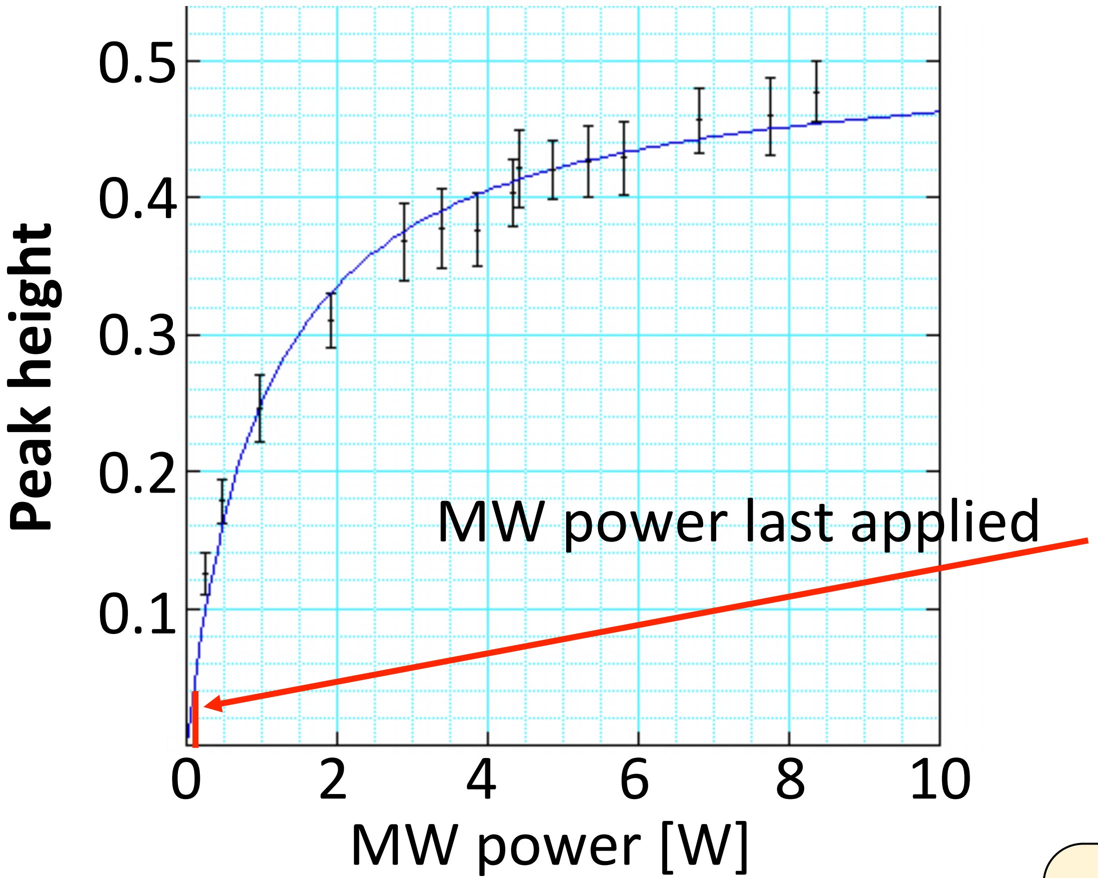


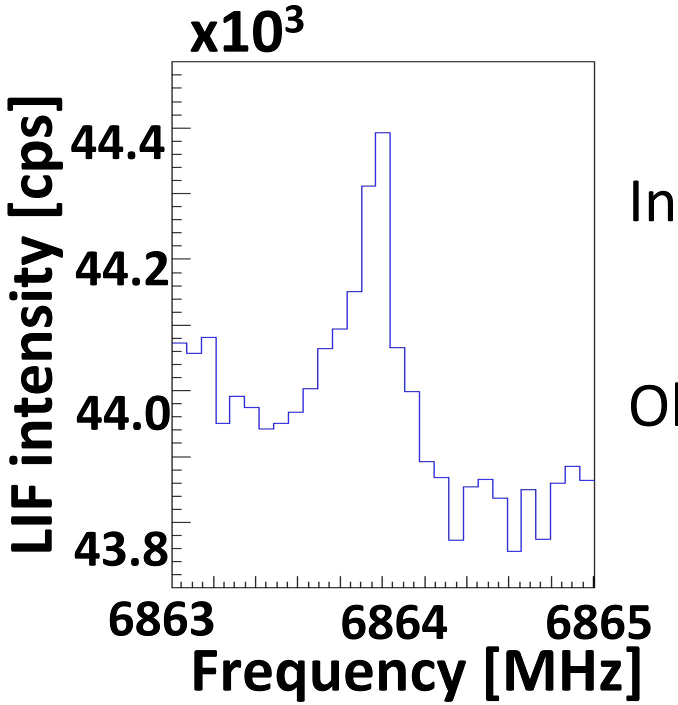
Peak height

$$\frac{y_R - y_0}{y_B - y_0}$$

2.Small resonance signal intensity –Result and discussion-

Saturation MW power : 5.5 W





Increasing MW power

Obtaining 15 times higher peak height

Laser：794.977 ～ 794.978 nm

Laser power: 0.7～0.8 mW, ϕ=1 mm

MW frequency:3.057 GHz

Total improvement of S/N ration

10 (New detection system) x 15 (increasing MW power) = 150 times !

Summary and outlook

*Developing a nuclear laser spectroscopy technique OROCHI for the study of low-yield exotic nuclei

*In the online experiment, we successfully observed HFS/Zeeman resonance spectra. However, we required the beam intensity of 10^4 pps at minimum.

* Towards lower-yield nuclei (< 100pps)
Developing the new florescence detection system
Evaluating MW power dependence of resonance signal intensity.

*As a result of development , we expect S/N ratio approximately 150 times higher.

*In Dec. 2016, we will perform a beam experiment to evaluate minimum beam intensity to observe the double resonance spectra using the system.

Collaborators

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Makoto Sanjo, Yukari Matsuo

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Tokyo Metropolitan University : Takeshi Furukawa

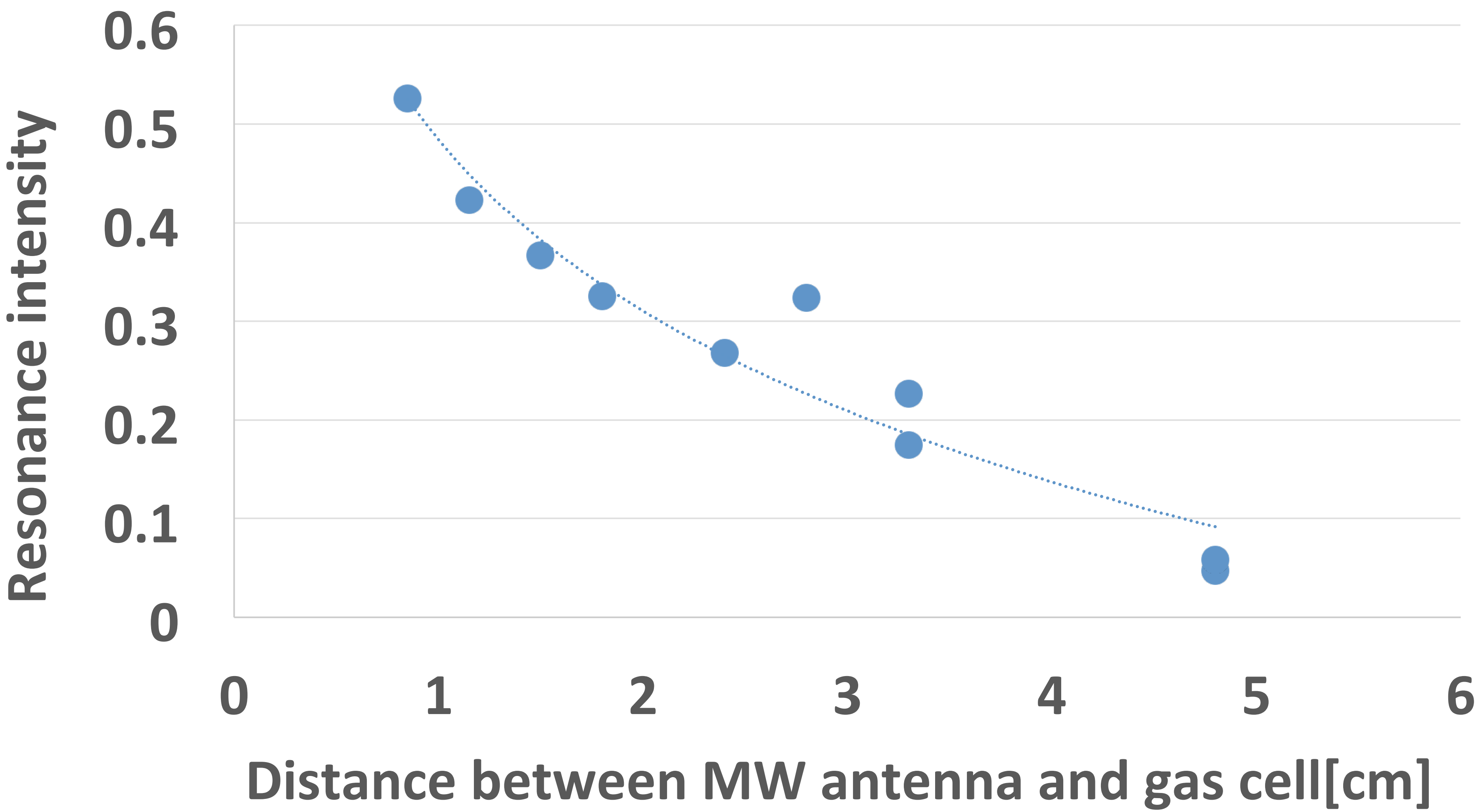
NIRS: Takashi Wakui

Meiji Univ.: Yutaro Nakamura, Hitoshi Odashiima

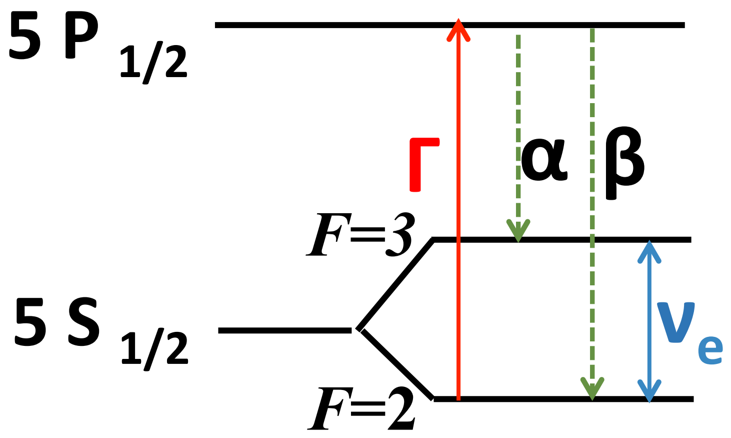
Thank you for your attention !!

Backup slide

Resonance intensity vs MW antenna position



Signal intensity of double resonance spectra



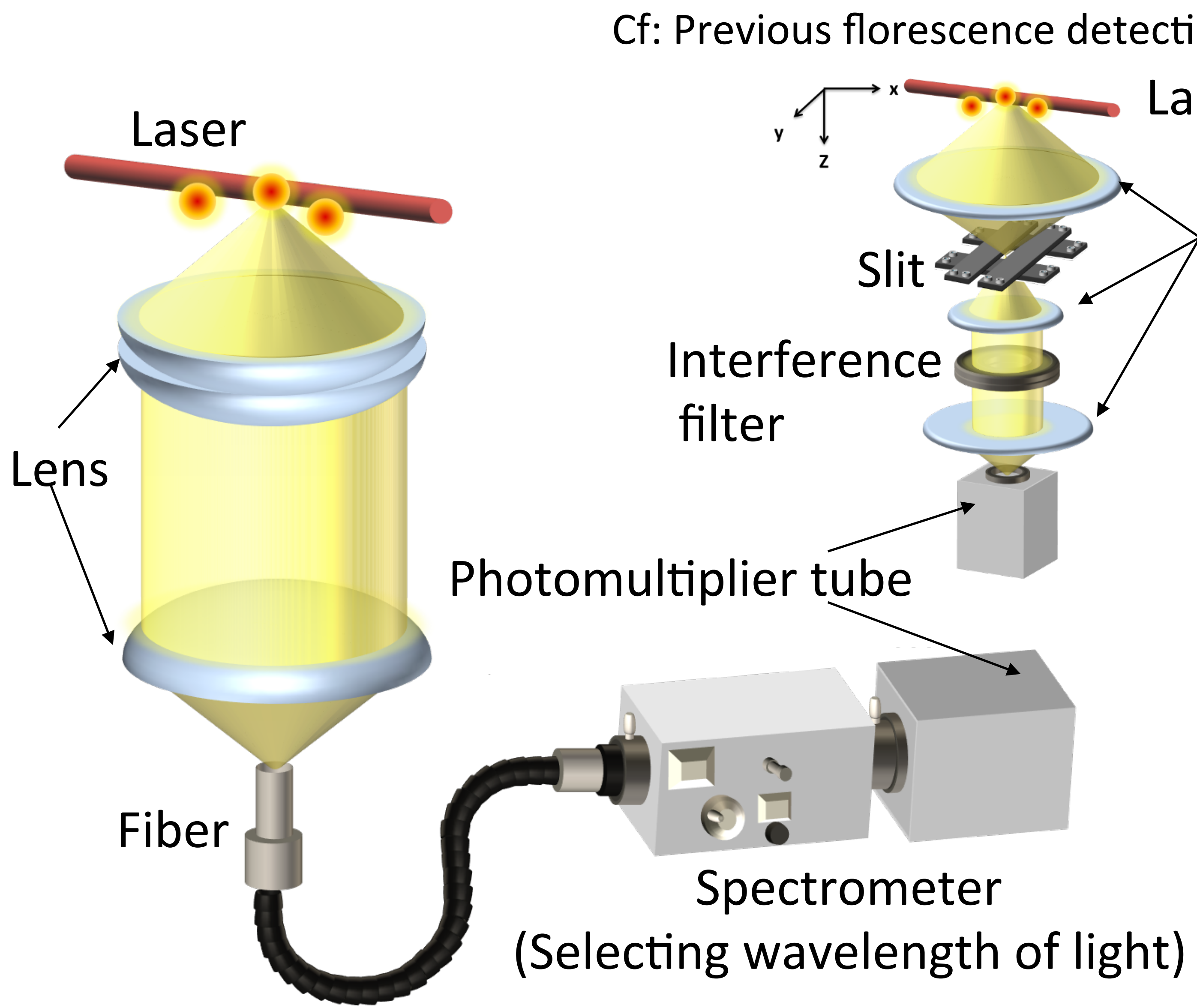
ν_e :MW resonance rate

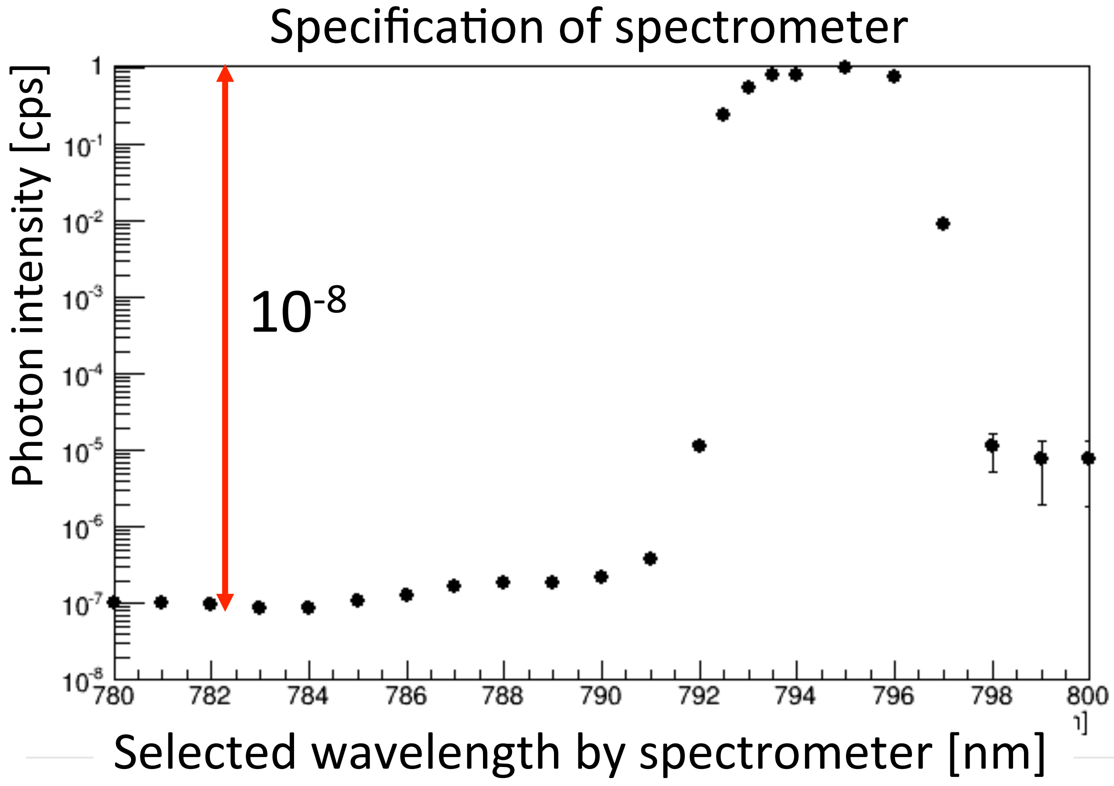
Γ :pumping rate

α , β : Spontaneous emission

$$\text{LIF intensity} = \frac{\Gamma(\alpha+\beta)}{3\Gamma + 2(\alpha+\beta) + \beta \cdot \Gamma/\nu_e}$$

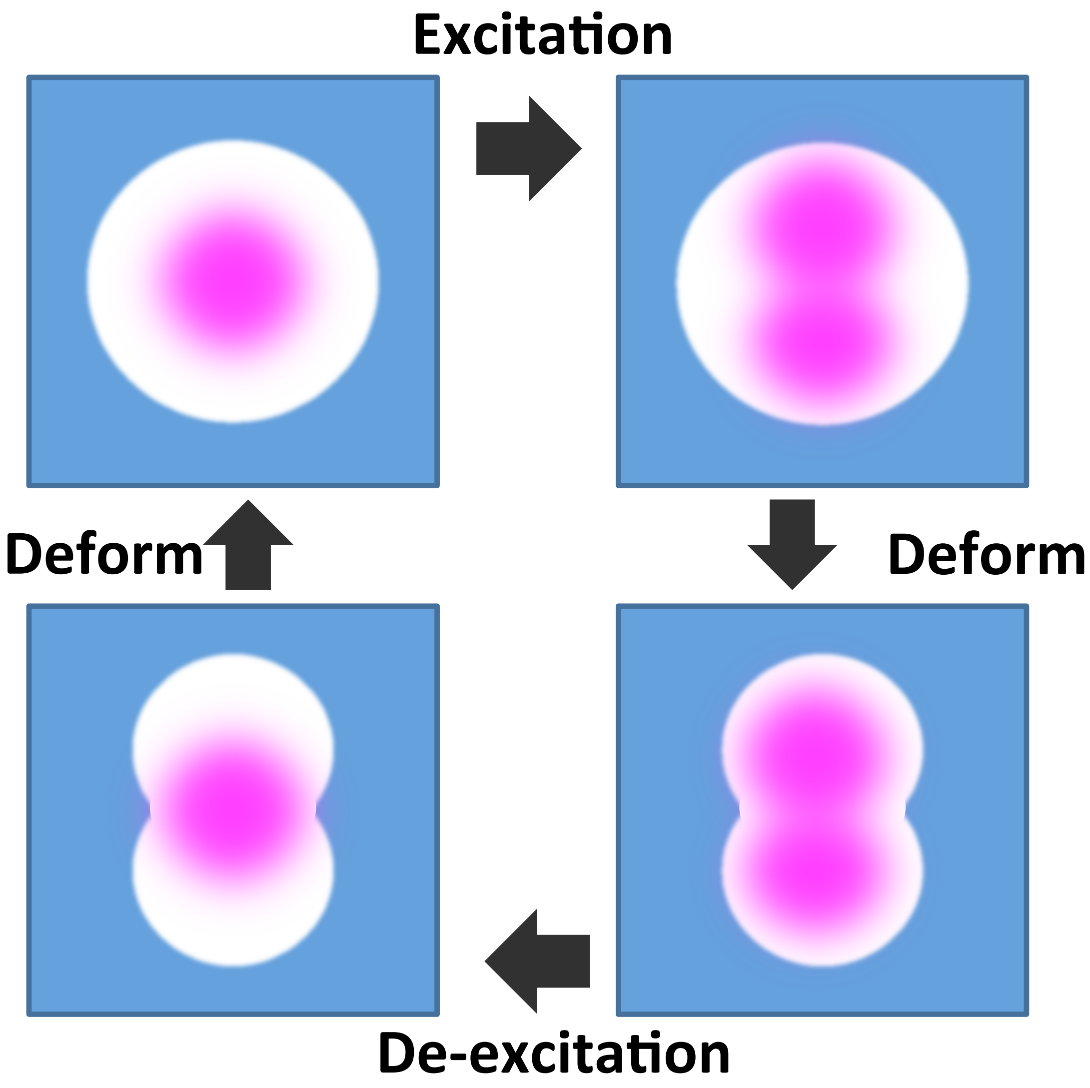
Comparison of new and old fluorescence system



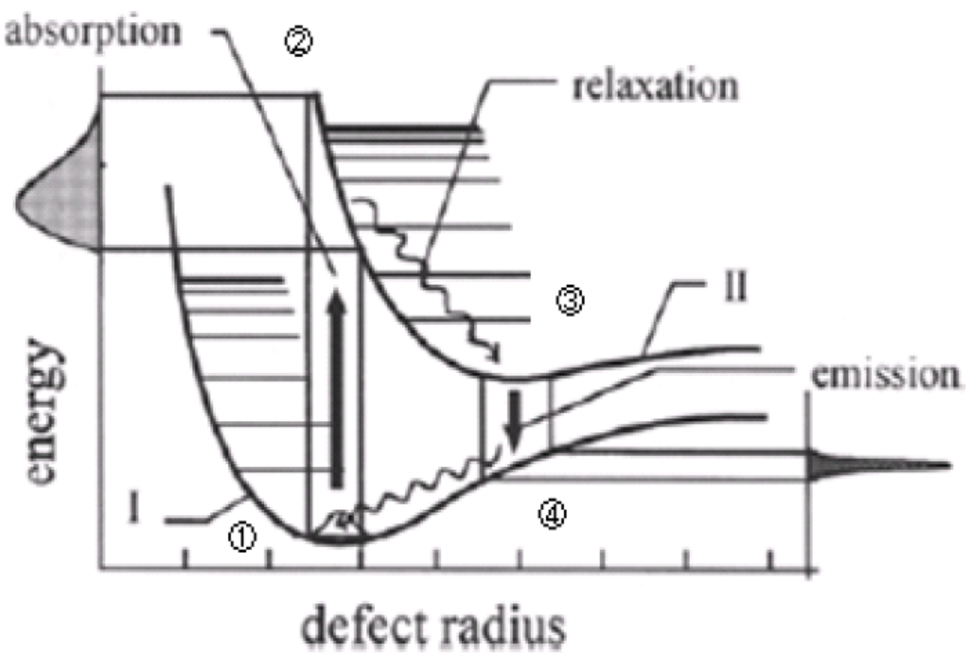


Laser stray light can be decreased by 10^{-8}

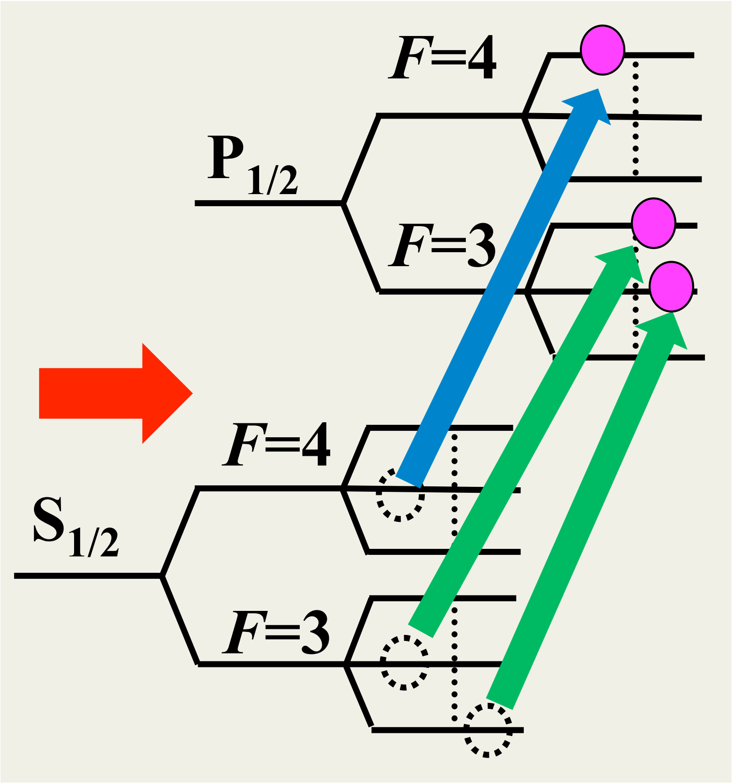
Atomic bubble model in superfluid helium

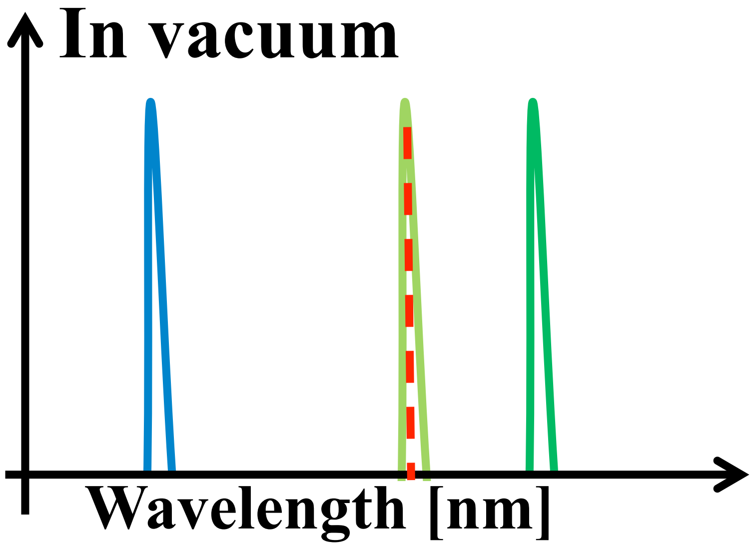


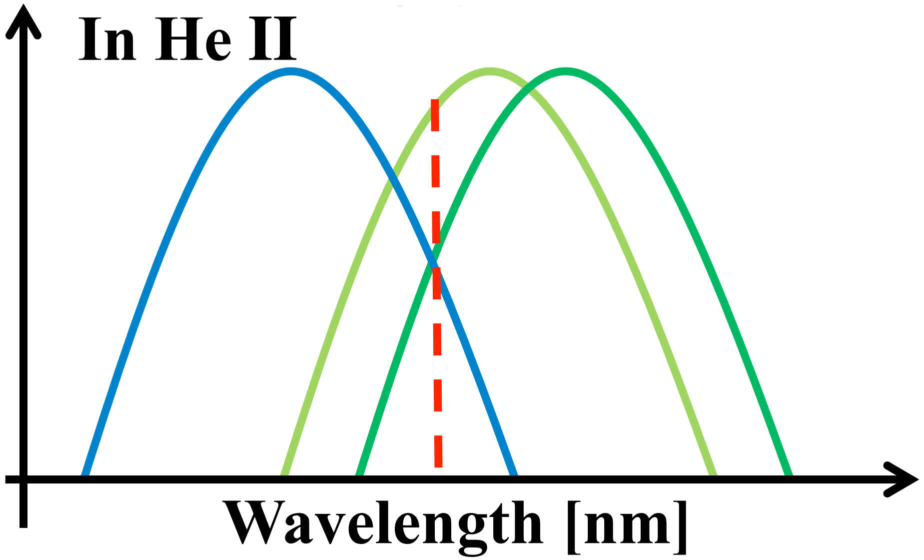
- Need more energy → blue shifted abs. spectrum
- Different atom-He distance → broadened spectra



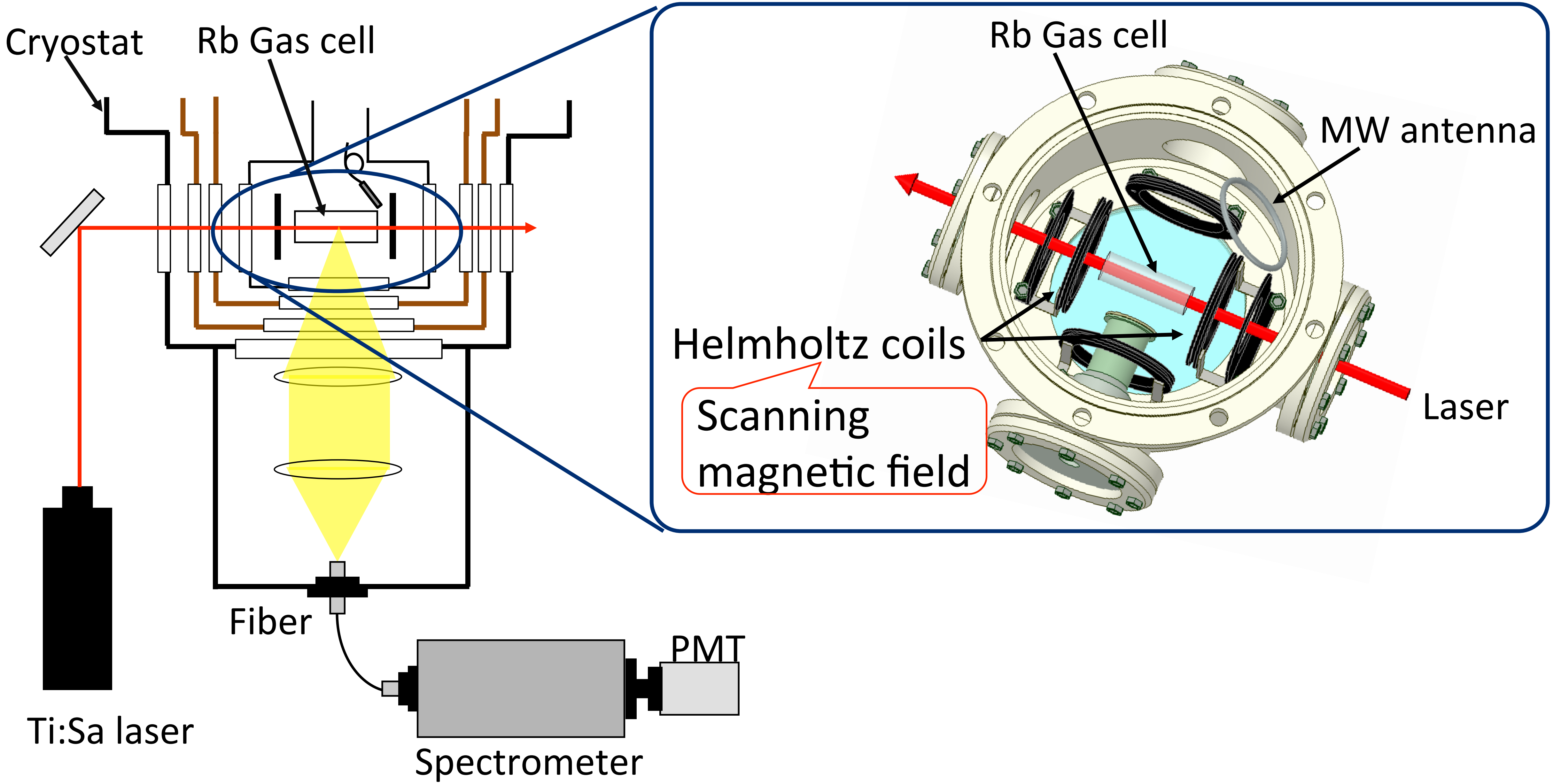
Optical pumping of atoms in superfluid helium







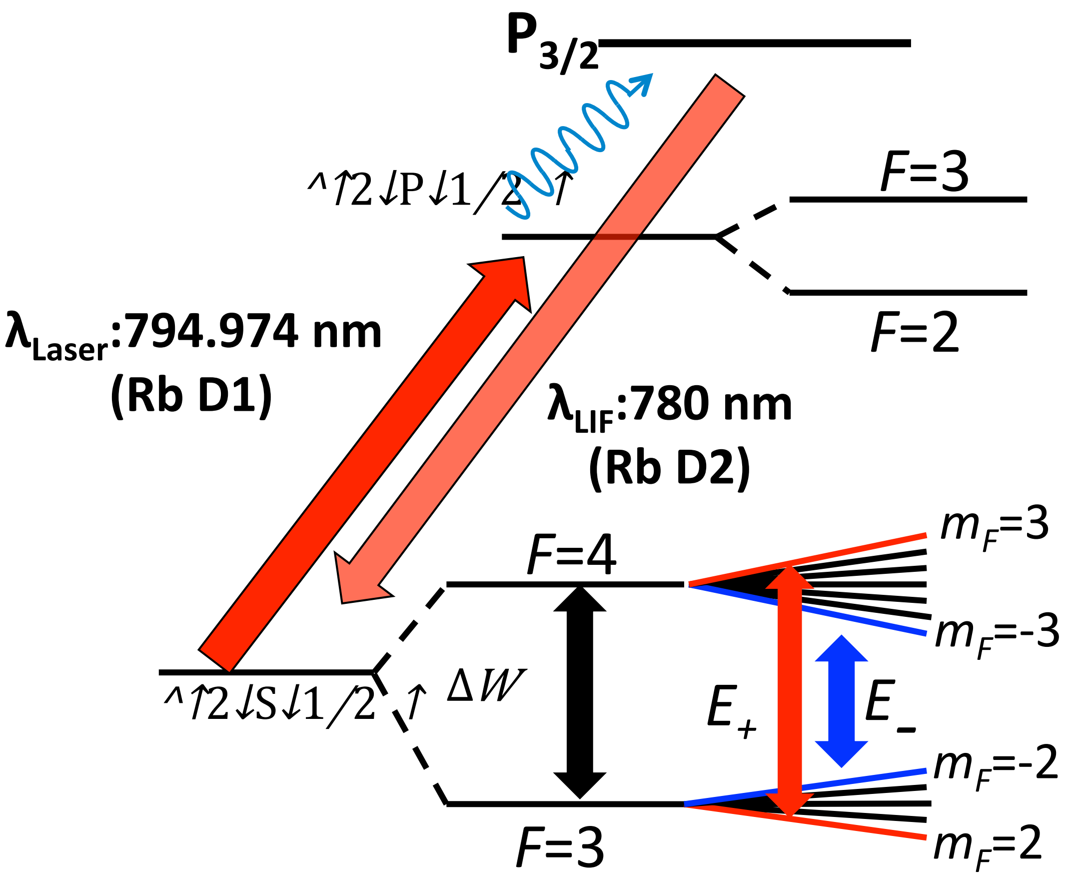
2.Small resonance signal intensity -Experimental setup-



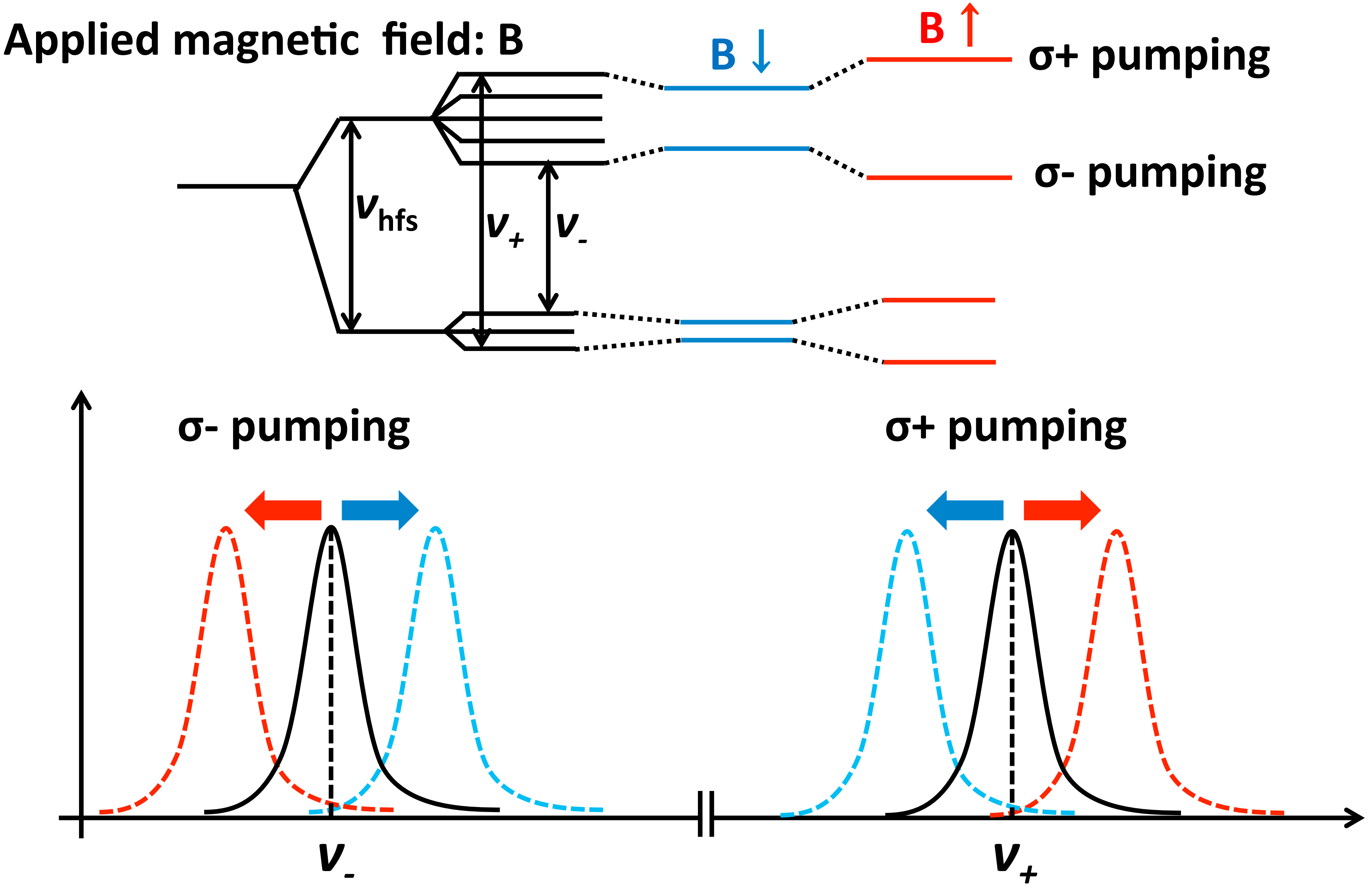
Hyperfine structure in magnetic field

$$W(F, m_F) = -\Delta W/2(2I+1) - \mu_I m_F B/I \pm (\Delta W/2)\cdot[1 + \{4m_F/(2I+1)\}\cdot(1+\varepsilon)x + (1+\varepsilon)^2x^2]$$

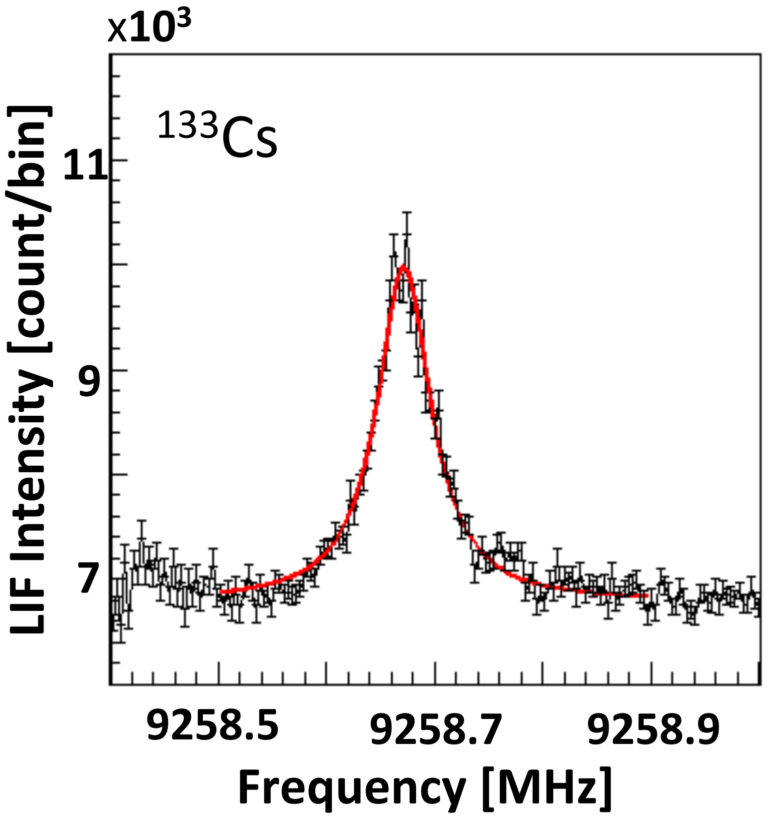
ΔW : hyperfine splitting $\quad x = g_J\mu_B$**B**$/\Delta W \quad \varepsilon = g_N\mu_N/g_J\mu_B$



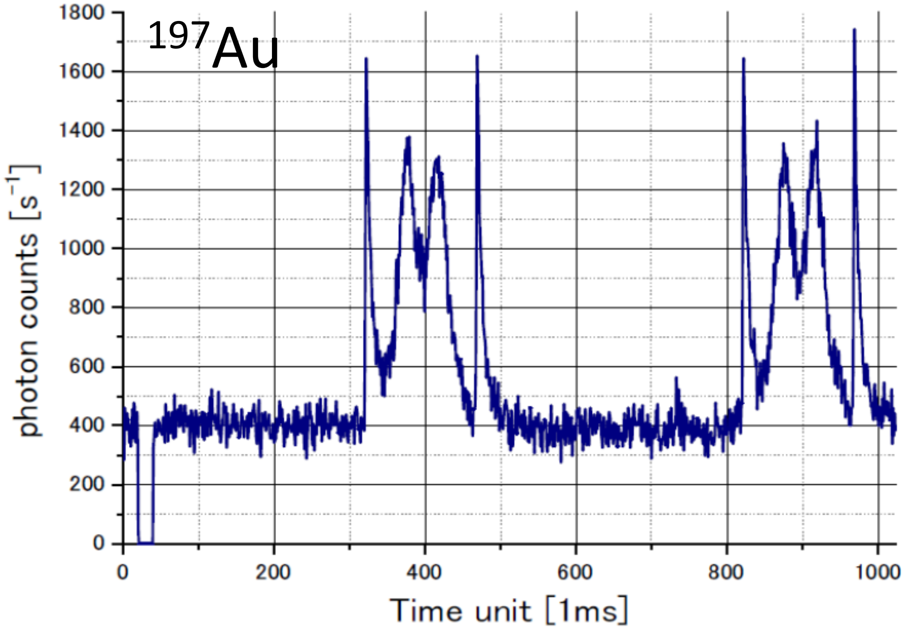
Frequency sift due to applied magnetic field



Double resonance spectra in He II



K. Imamura *et al.*, Hyperfine Interact., **230**, 73 (2014)



Y. Matsuura, Master Thesis, Meiji University(2010)

Cryostat for online experiment