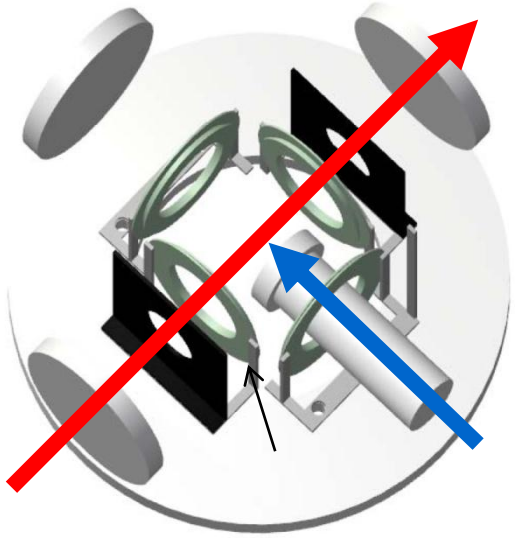
A Novel Nuclear Laser Spectroscopy Method using Superfluid Helium for the Measurement of Spins and Moments of Exotic Nuclei

"OROCHI"

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

Tokyo Metropolitan University

Takeshi Furukawa



Outline

- **Details of "OROCHI"**
  - Nuclear laser spectroscopy in superfluid helium
  - For the measurement of rare isotopes
  - Advantage by using He II
- **Development of "OROCHI"**
  - Off-line developments with Rb, Cs, Ag, and Au stable isotopes
  - On-line experiments with Rb beams
- **Future prospect of "OROCHI"**

What is "OROCHI" ?

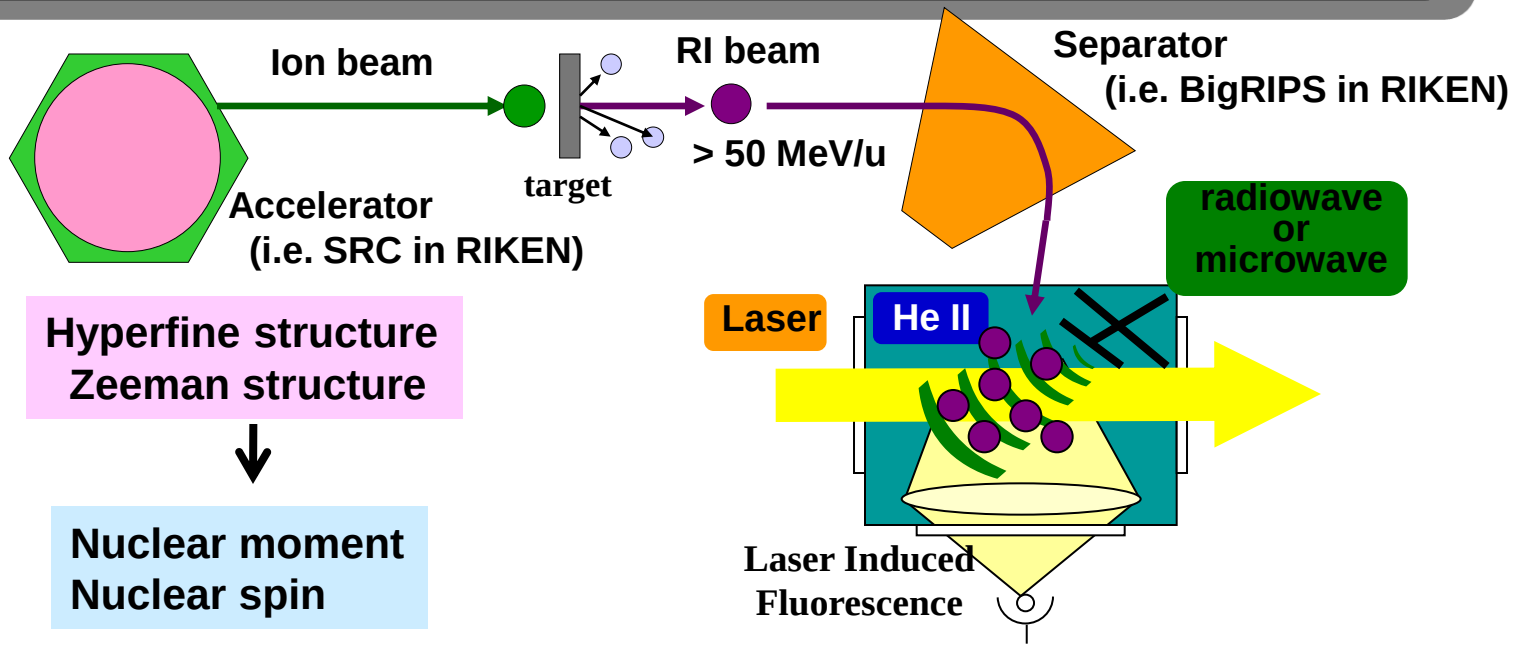
(Traditional) laser spectroscopy of rare and exotic nuclei…

- Tiny fluorescent signal
  - Low yield & low trapping efficiency/interaction time
- Huge background photons
  - Mostly due to strong stray laser light

Our solution : "Laser spectroscopy in superfluid helium (He II)"

"OROCHI"

Optical **R**I-atom **O**bservation in **C**ondensed **H**elium as **I**on-catcher

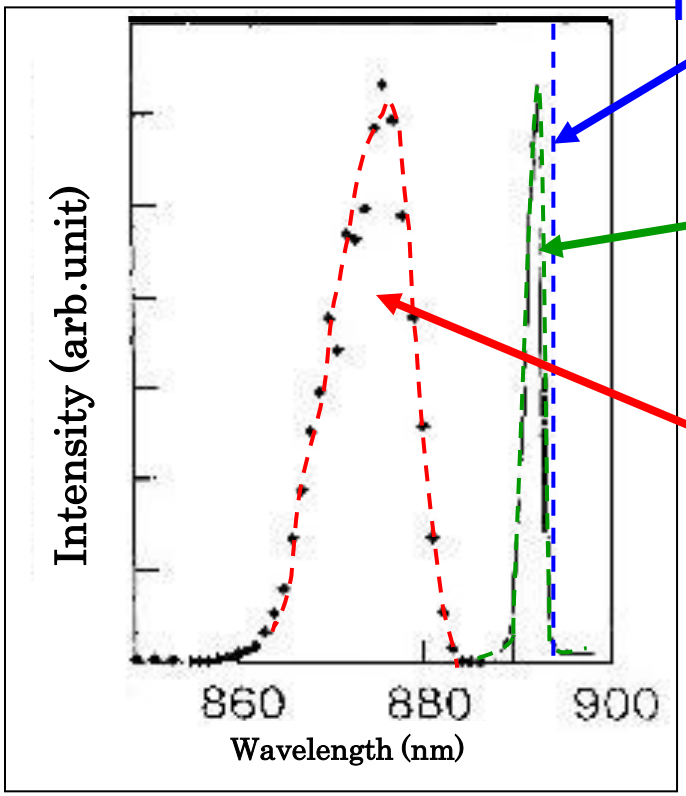


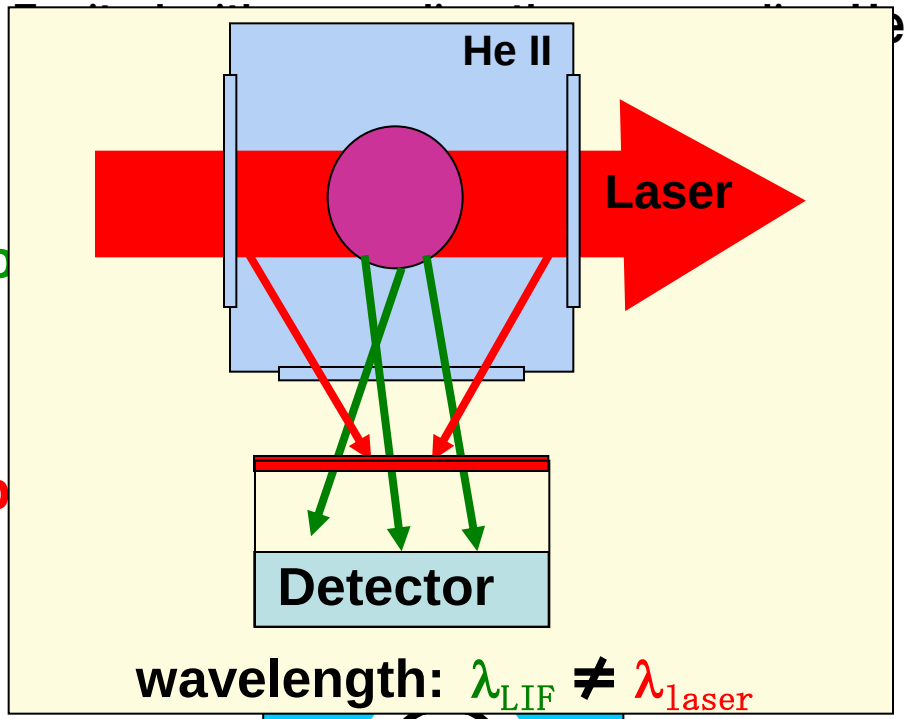
Advantage in He II

We use He II to trap the atoms efficiently, also to reduce the b.g. photons.

Atomic absorption spectra in He II (① largely blue-shifted ② widely broadened)

^{133}Cs atomic spectra in He II





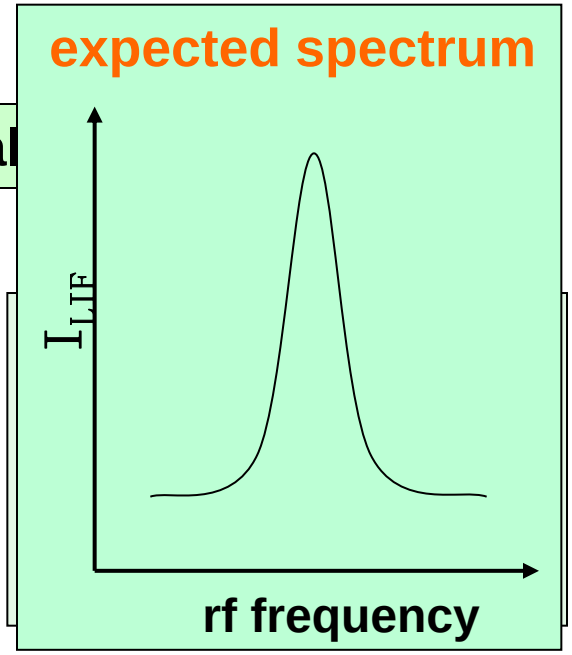
Suppress background count

Reduction: $10^{-10} \sim 10^{-13}$

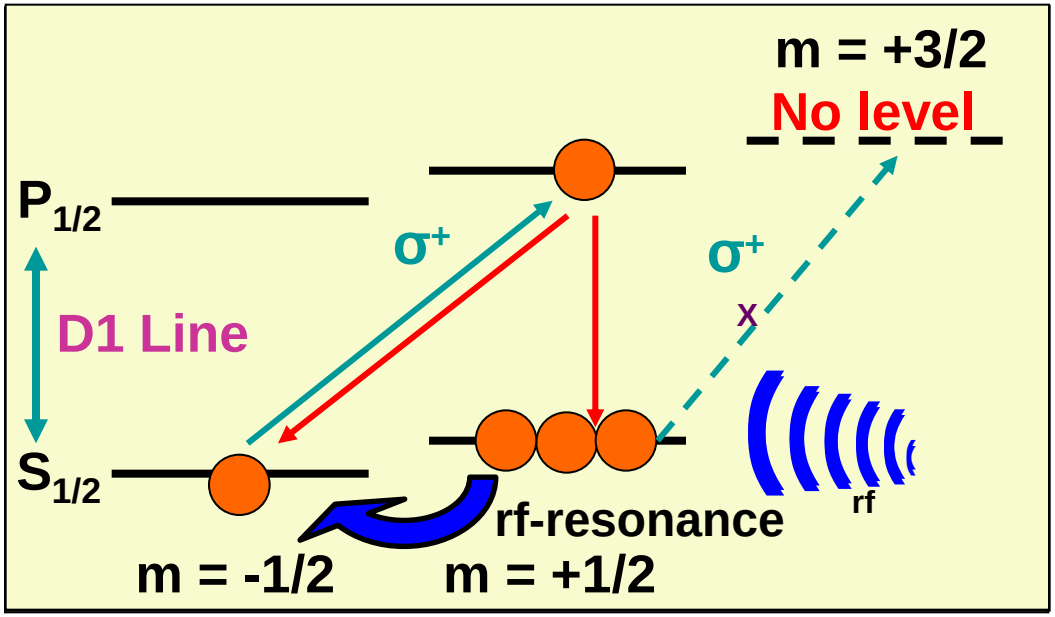
Double resonance spectroscopy

Measurement of atomic sublevel structure
: Double resonance spectroscopy

In the case of Zeeman splitting in al



2nd step: optical pumping



Emission photons in optical pumping
(Laser Induced Fluorescence, LIF)

decreased gradually

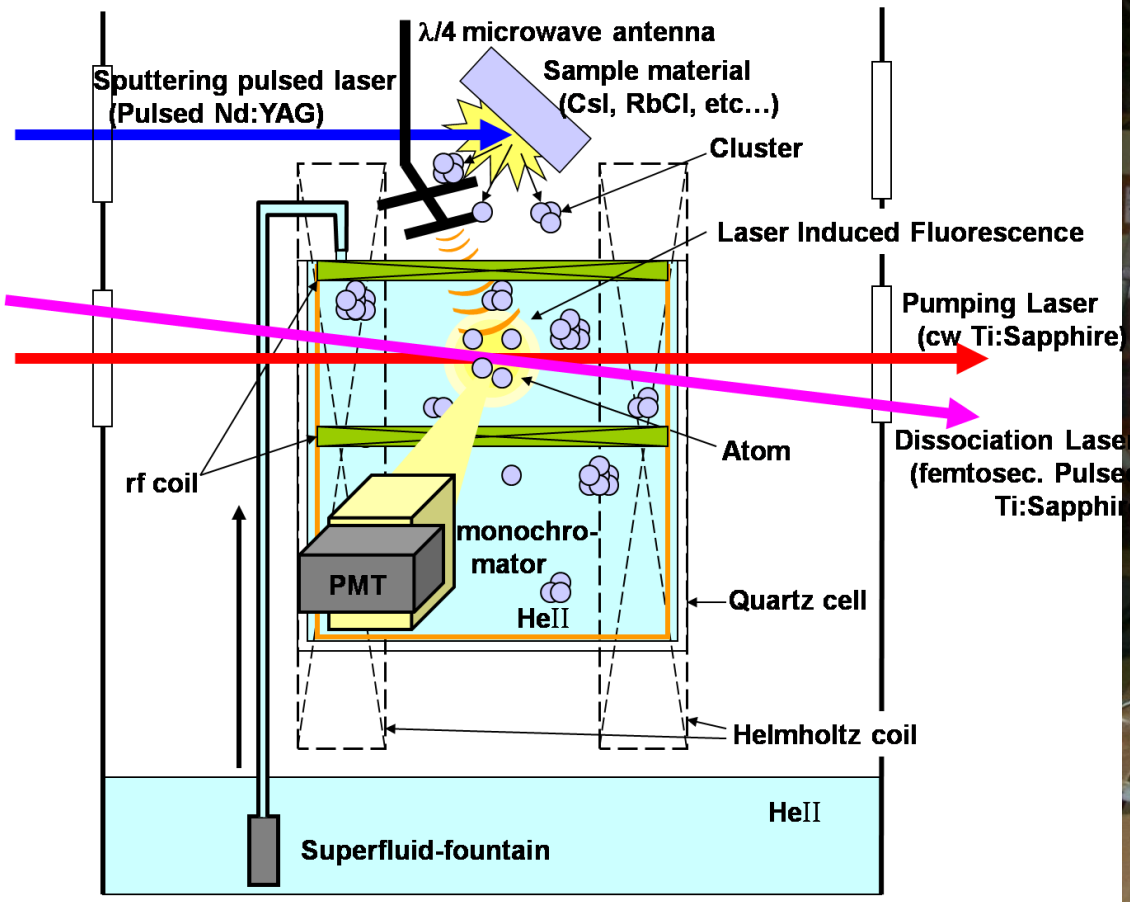
$[I_{LIF}] \propto 1 - P_z$

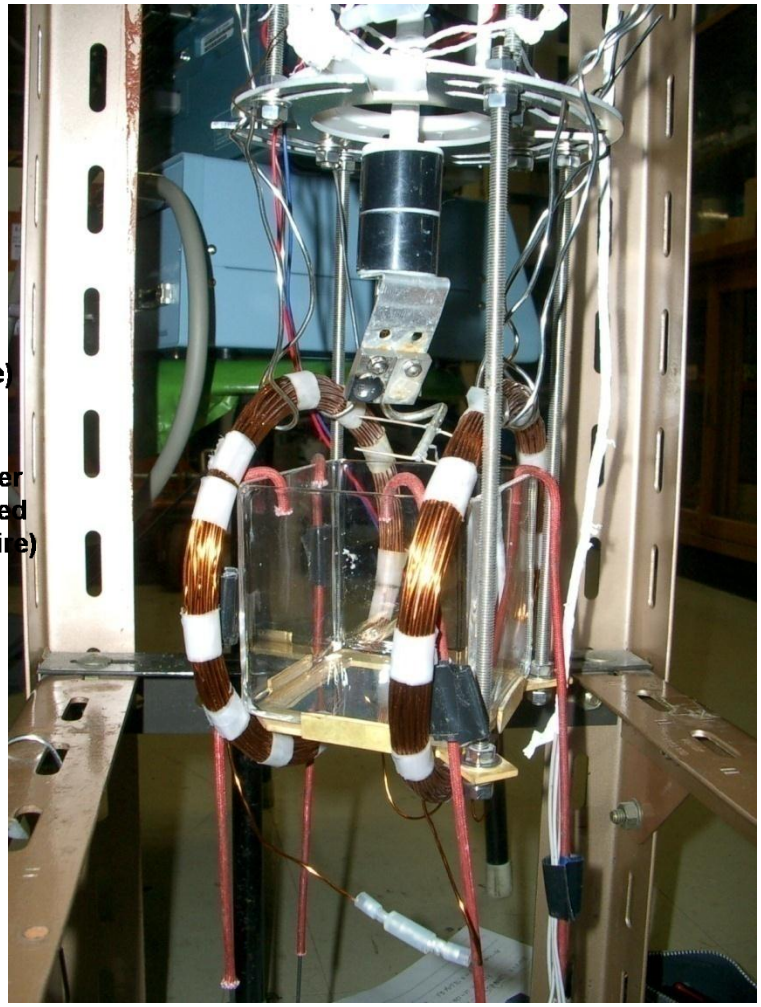
Off-Line Experiments

with stable isotope: Rb, Cs, Ag, Au, …

Experimental Setup

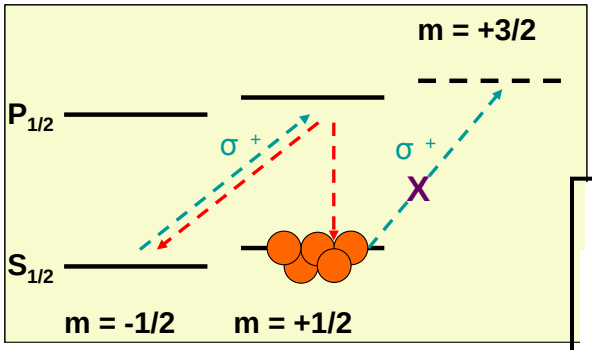
Atoms are introduced by laser sputtering technique.





Optical pumping in He II

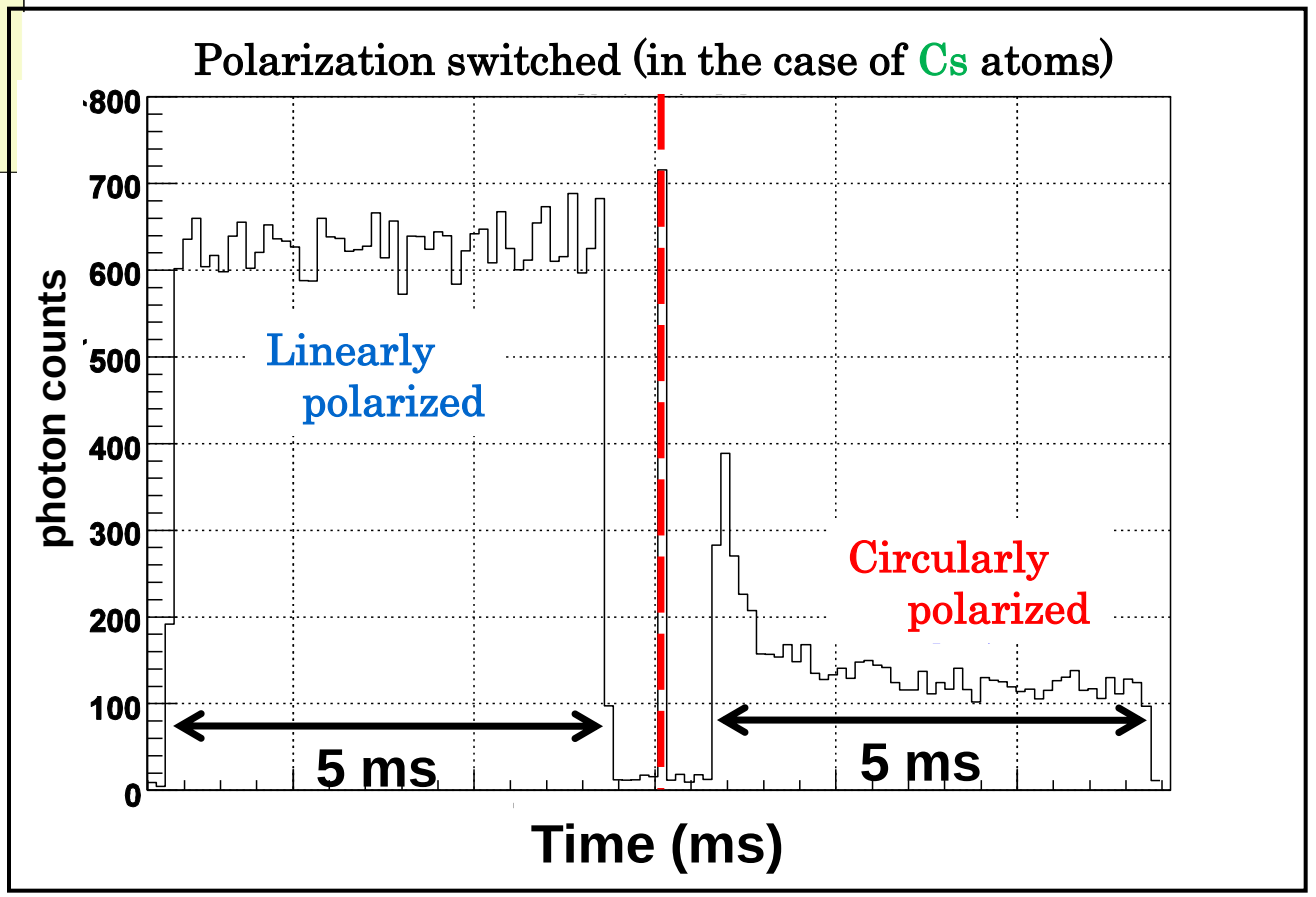
Produce the polarization on stable isotopes in He II



Polarization :~90 % (Cs), ~40 %(Rb)
~85 % (Ag and Au)

Polarization: increased

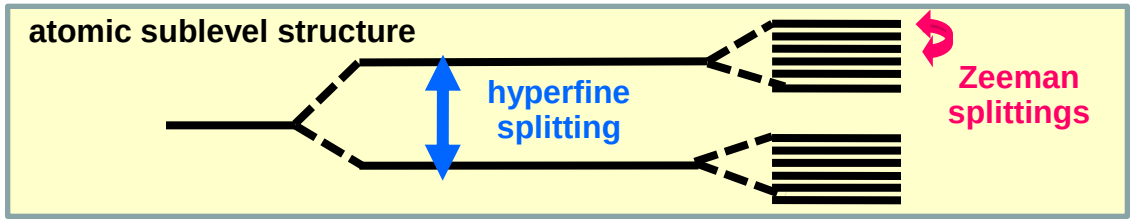
LIF intensity: decreased



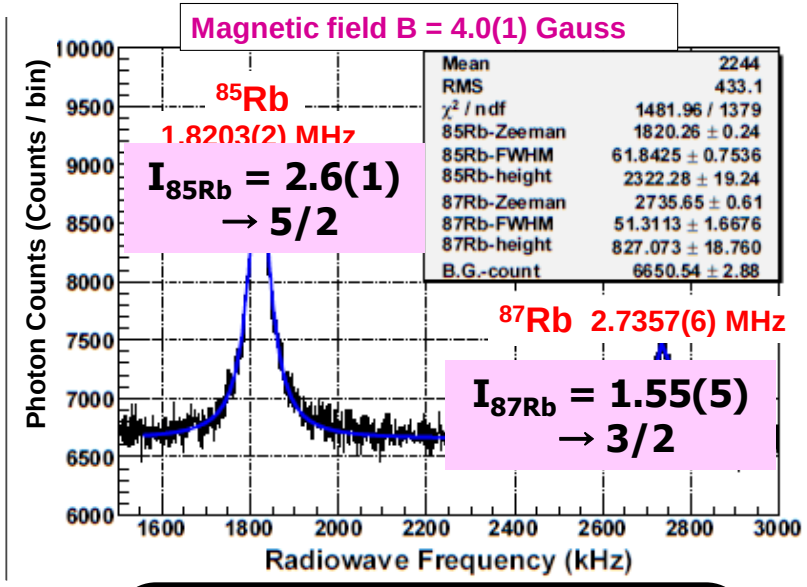
T. Furukawa *et al.*, Phys. Rev. Lett. 96, 095301 (2006)

T. Furukawa *et al.*, Physica E 43, 843 (2011)

Nuclear spin & moment determination



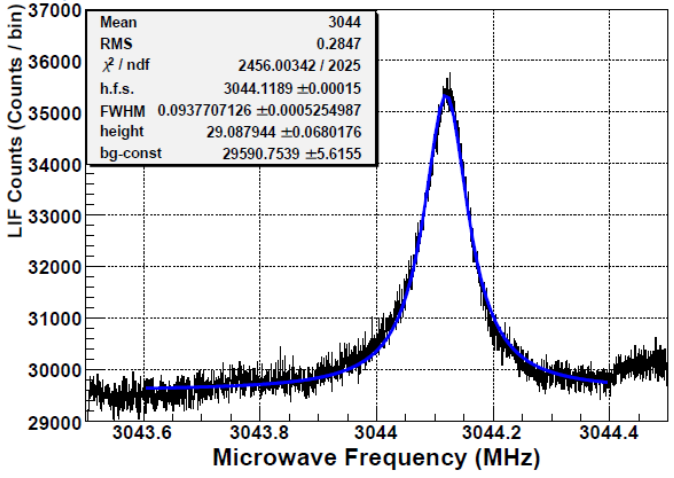
Zeeman resonance of Rb isotopes



$$\Delta\nu_{Zmn} = g_F m_B B / h = \frac{2.8(\mathrm{MHz}) \times B(\mathrm{Gauss})}{(2I+1)}$$

I: Nuclear spin

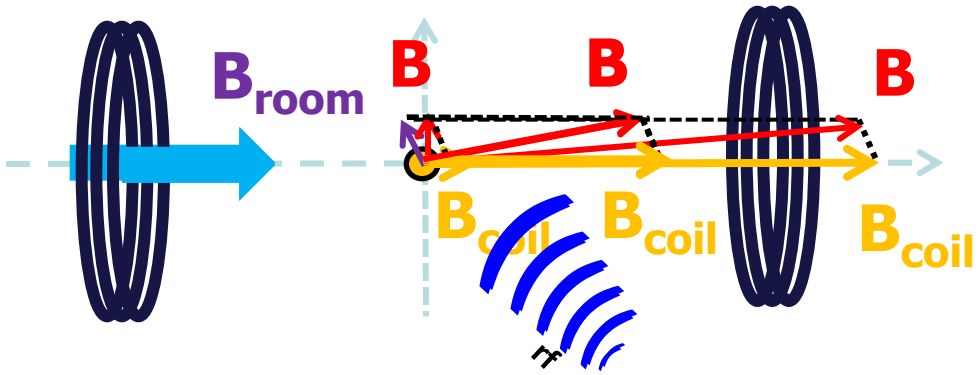
Hyperfine resonance of ^{85}Rb



	$\mu_I^{85\mathrm{Rb}}$ (μ_N)
This work (from A_{HeII})	1.357 83 (7) μ_N
evaluated (from A_{vacuum})	1.358 071(1) μ_N
literature value (NMR)	1.353 351 5 μ_N

T. Furukawa, Doctoral thesis, Osaka Univ. (2007)
T. Furukawa, *et.al.*, Proceedins on INPC07 (2008)

Optical-Detected Magnetic Resonance



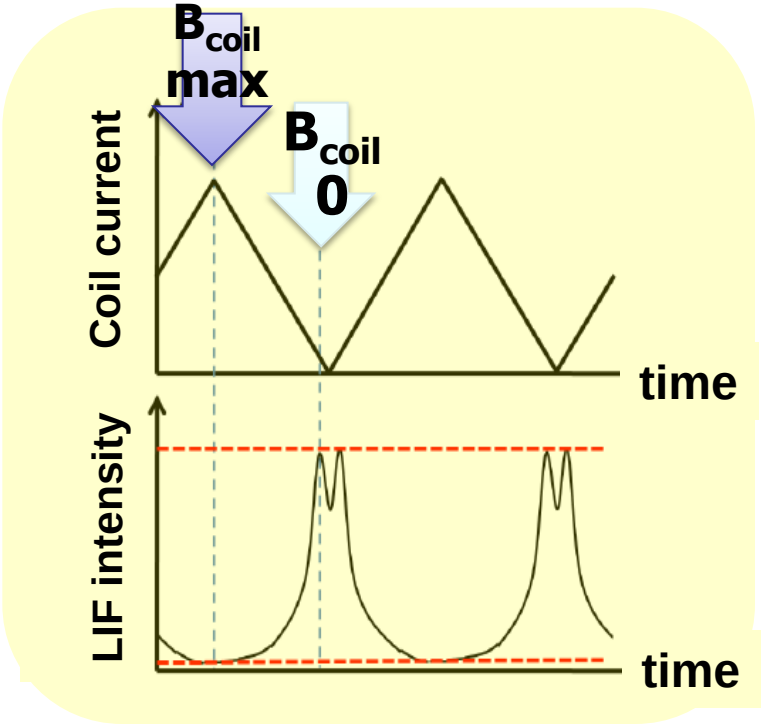
Sweeping magnetic field strength…

B_{coil}: Max = Large polarization

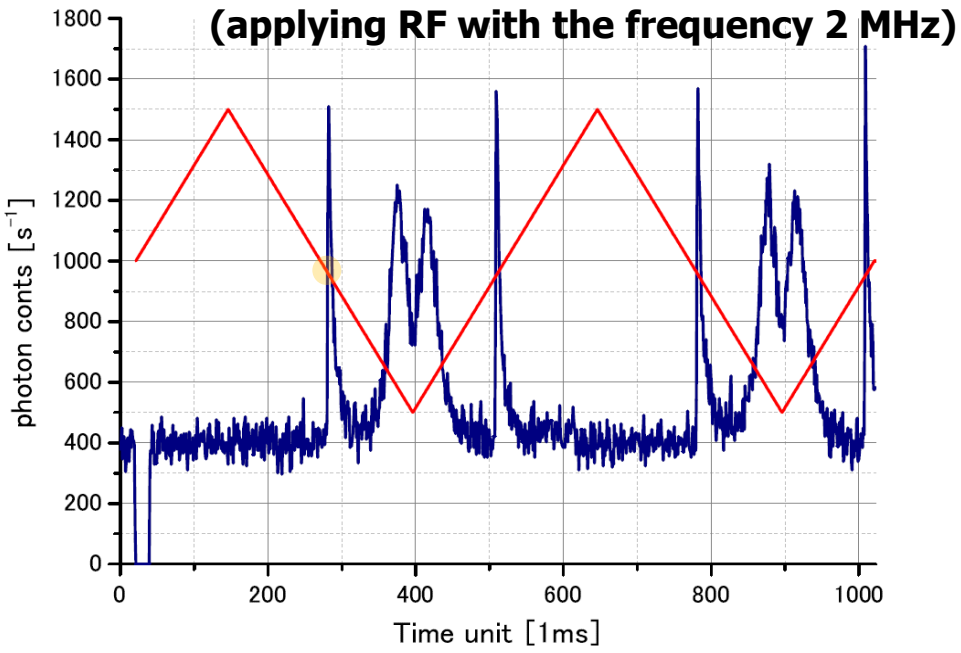
B_{coil}: 0 = Small polarization

With applying rf field …

B_{coil}: $h\nu_{rf}/g_F\mu_B$ = Resonance



In the case of stable Au atoms



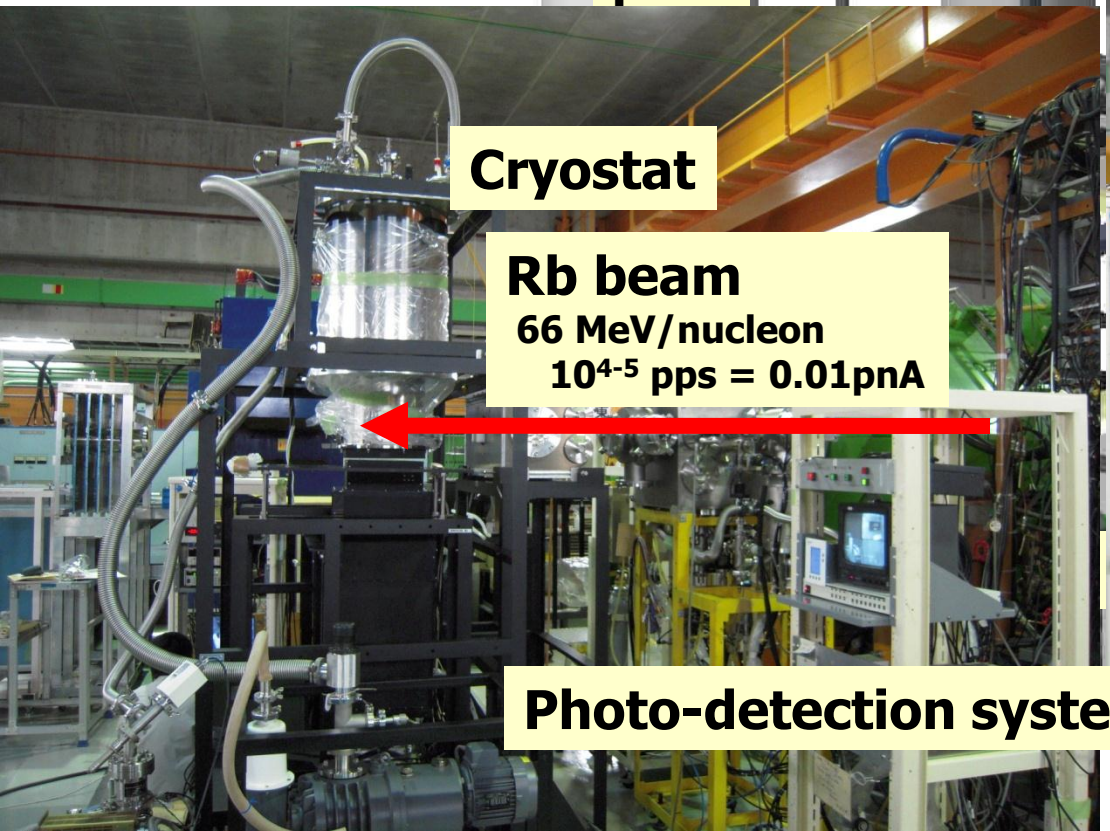
On-Line Experiments

with Rb isotope: $^{84, 85, 87}$Rb

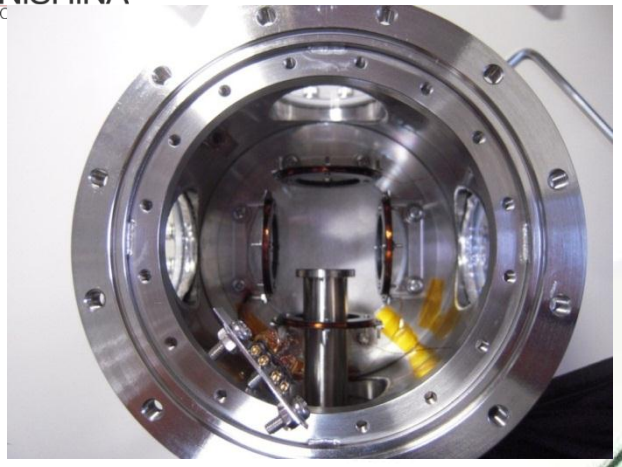
Energy: < 50 MeV/u

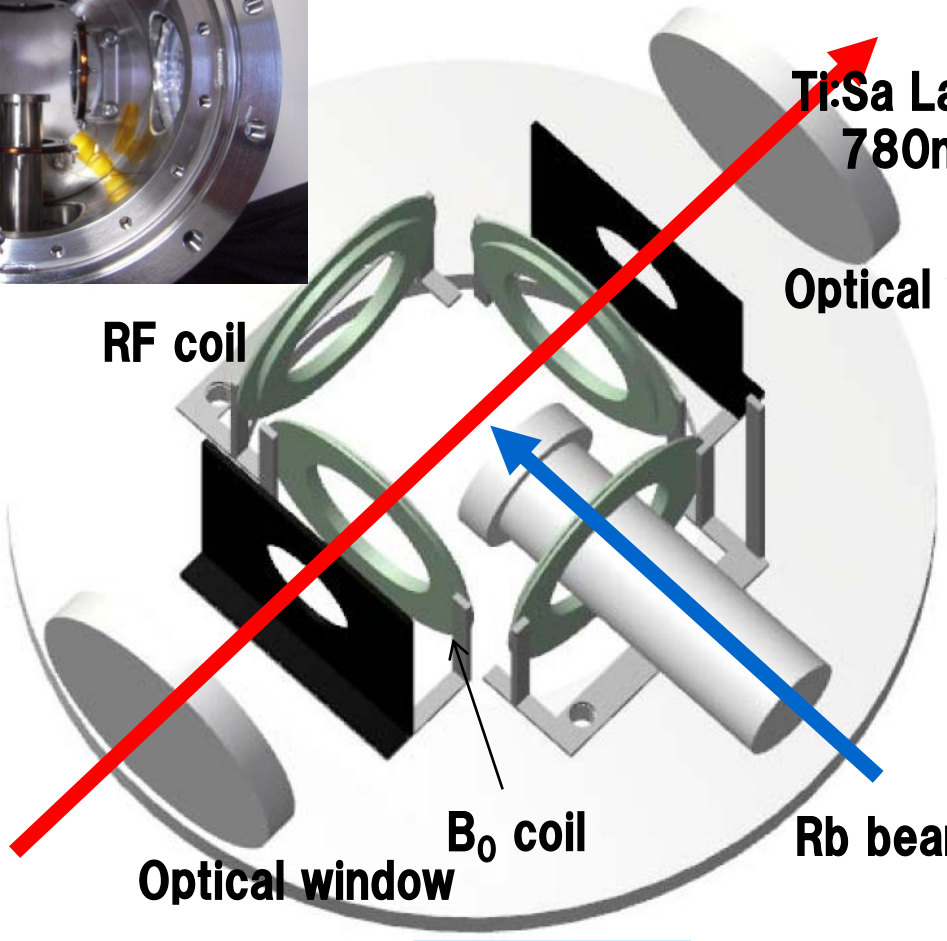
Setups : On-line experiment

All the devices were mounted on RIKEN RIPS beam line

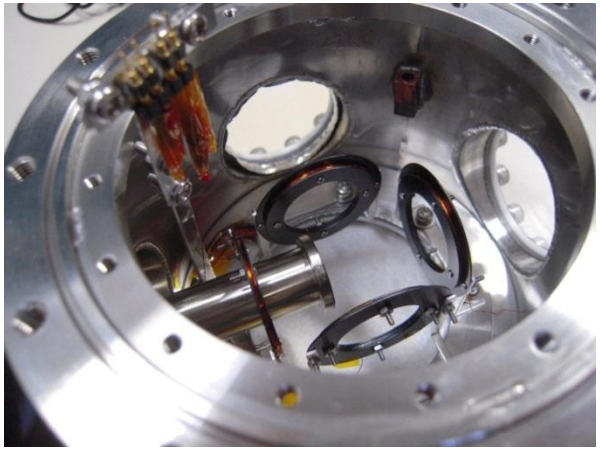


Inner Cryostat





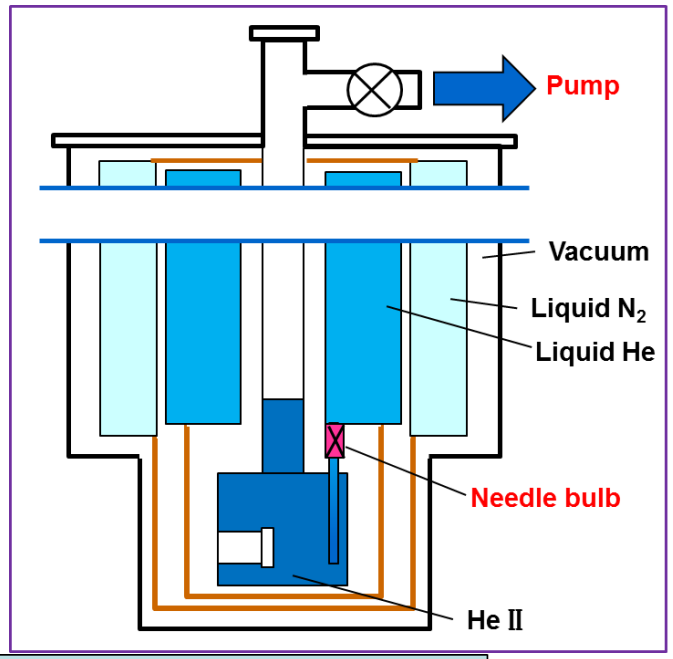
T_{He} = 1.8 K

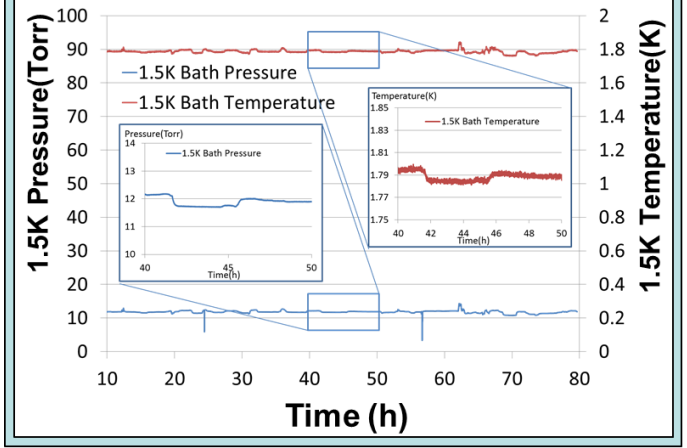


Control of experimental condition

Control of He II condition

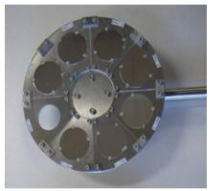
Poster 132 (K.Imamura) on Category : 9



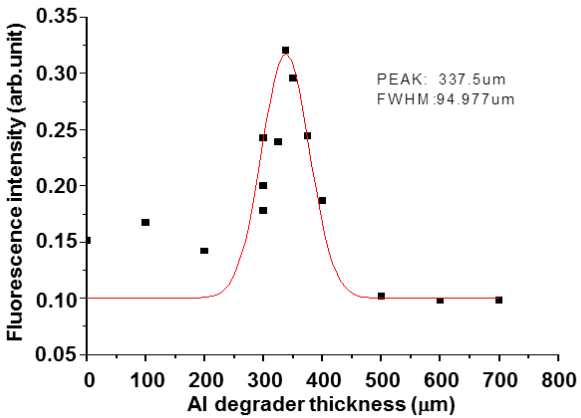


Control of beam stop position

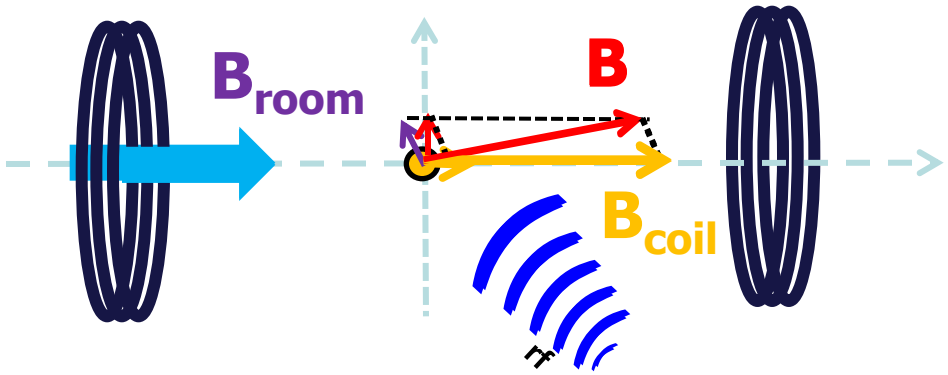
Poster 108 (X.F. Yang) on Category : 9



Energy degrader
(various thickness of Al foils, t: 12.5 μm step)



Highlight data of on-line experiment



Sweeping magnetic field strength…

B_{coil}: Max = Large polarization

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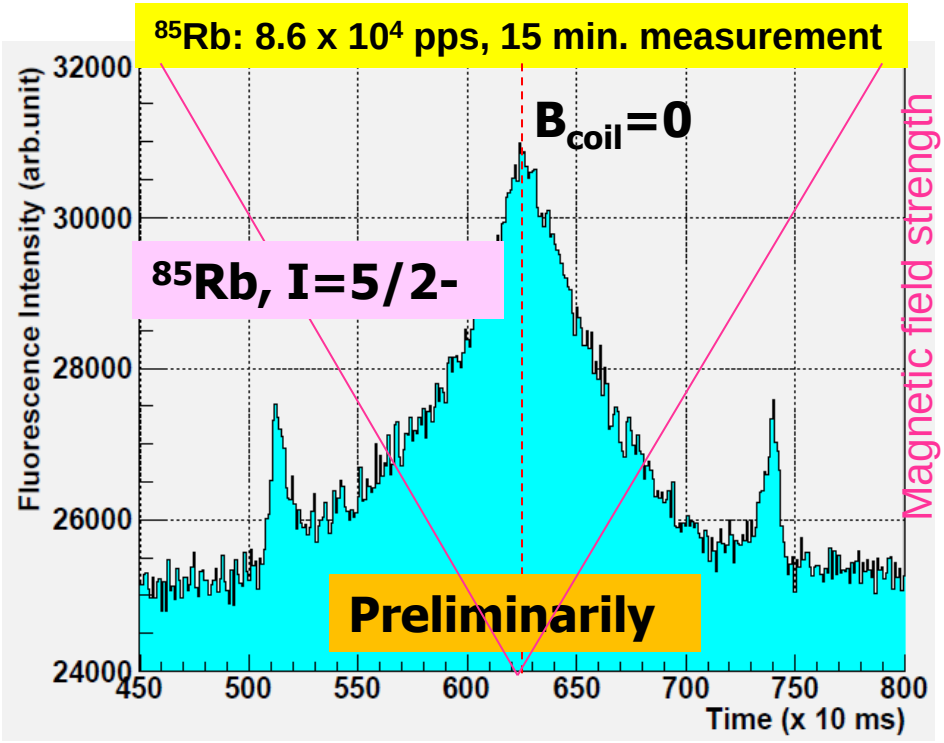
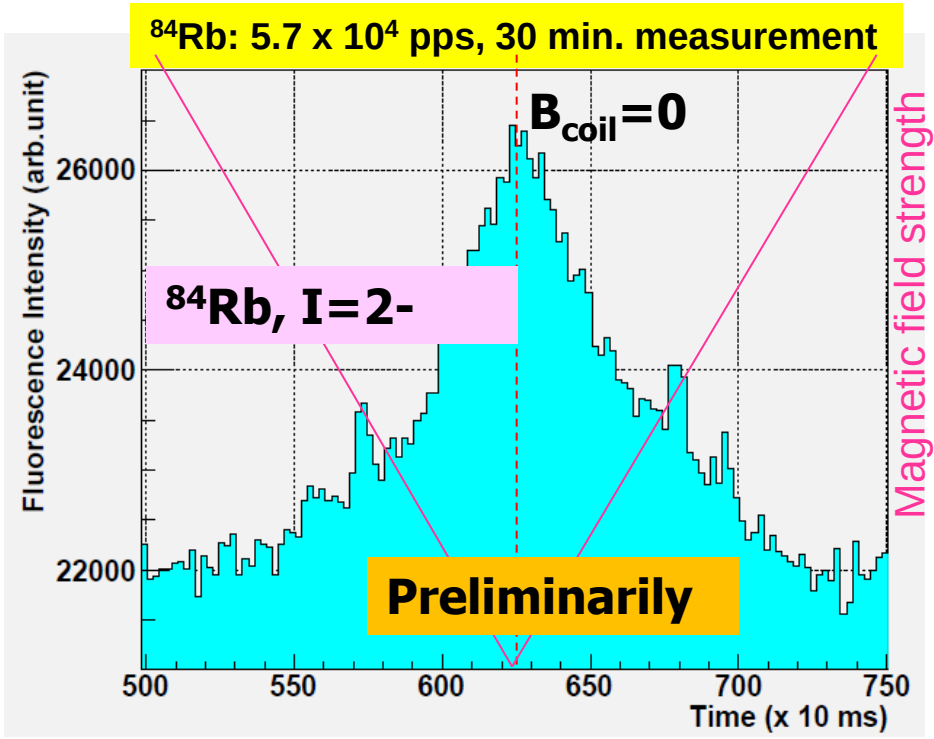
With applying rf field …

B_{coil}: $h\nu_{rf}/g_F\mu_B$ = Resonance





Summary & Future

"OROCHI"

Optical Radioisotope-atom Observation in Condensed Helium as Ion-catcher

- We developed the new laser spectroscopy method "OROCHI" for exotic RIs far from stability, by using superfluid helium (He II) as a stopper of RI beam and host matrix of laser spectroscopy.
- We have successfully demonstrated the off-line developments using stable Rb, Cs, Ag and Au isotopes for the measurement of nuclear spins and moments. The achieved polarization is mostly up to 90 %.
- We have also successfully demonstrated On-line experiment. We have observed Zeeman resonances from ^{84,85}Rb atoms in He II injected as ionic beam whose intensity as the order of 10^4 pps.
- We will upgrade some of our experimental setups and improve the overall efficiency. The required RI intensity is now typically up to 10^3 pps. We try to reduce that to less than 10 pps.
- Next, we will measure the hyperfine structure of radioisotope ^{84,86}Rb in He II in the next year. After that we will apply it to exotic RI of feasible elements, for example Ag, Au and Fr in near future, hopefully during 2 - 3 years.

Collaboration

Spokesperson:

Takeshi Furukawa (Tokyo Metropolitan University), **Yukari Matsuo** (RIKEN)

Email: takeshi@tmu.ac.jp

RIKEN:

X.Yang, H. Ueno, Y. Ishibashi, M. Wada, T. Sonoda, Y. Itou ,
T. Kobayashi, S. Nishimura, M, Nishimura, K. Yoneda

CYRIC, Tohoku Univ.:

T. Wakui, T. Shinozuka

Osaka Univ.:

T. Fujita, T. Shimoda

Meiji Univ.:

K. Imamura, Y. Yamaguchi,, Y. Mitsuya, S. Arai, M. Muraoka

Tokyo Gakugei Univ.:

H. Tetsuka, Y.Tsutsui, Y. Ebara, M. Hayasaka,

Tokyo institute of Technology:

Y. Ichikawa, K. Asahi, N. Yoshida, H. Shirai, Y. Kondo

Tokyo Univ. of Agriculture and Tech.:

A. Hatakeyama

CNS, Univ. Tokyo:

S. Kubono, Y. Oshiro

Thank you for your attention.