

SPIN2021

18–22 Oct 2021, Matsue, Shimane Pref., Japan

Status of Lamb-shift polarized ion source at 6 MV tandem accelerator in UTTAC and its application to nuclear physics

T. Moriguchi^A,

A. Ozawa^A, Y. Yamato^A, M. Hayashi^A, R. Kagesawa^A,
N. Kaname^A, M. Mukai^B, K. Tomita^A, A. Yano^A

A University of Tsukuba, Japan

B RIKEN, Nishina Center, Japan

Outline

Status of polarized ion source

1. University of Tsukuba Tandem Accelerator Complex (UTTAC) and Lamb-shift Polarized Ion Source (PIS)
2. Operation of the PIS

Application to nuclear physics

3. Measurement of nuclear magnetic resonance (NMR) of unstable nuclei
4. Summary

Outline

Status of polarized ion source

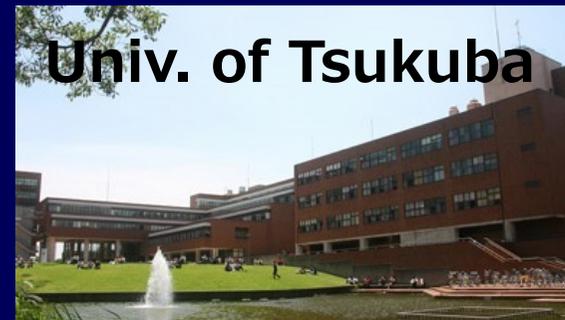
- 1. University of Tsukuba Tandem Accelerator Complex (UTTAC) and Lamb-shift Polarized Ion Source (PIS)**
2. Operation of the PIS

Application to nuclear physics

3. Measurement of nuclear magnetic resonance (NMR) of unstable nuclei
4. Summary

Tsukuba

- About 50 km away from Tokyo
 - Known as the Tsukuba science city
 - ◆ University of Tsukuba
 - ◆ Japan Aerospace Exploration Agency (JAXA)
 - ◆ High Energy Accelerator Research Organization (KEK)
- and more



<http://www.jaxa.jp/projects/pr/brochure/files/centers01.pdf>

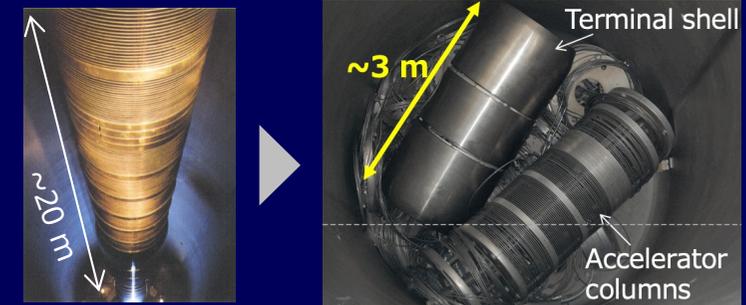
https://www.kek.jp/ja/PublicRelations/DigitalLibrary/2017_youran.pdf

University of Tsukuba Tandem Accelerator Complex (UTTAC)

Scientific studies with ion beams since 1975

<http://www.tac.tsukuba.ac.jp/uttac/>

- Nuclear physics
- Accelerator mass spectroscopy (AMS)
- Ion beam analysis and more..

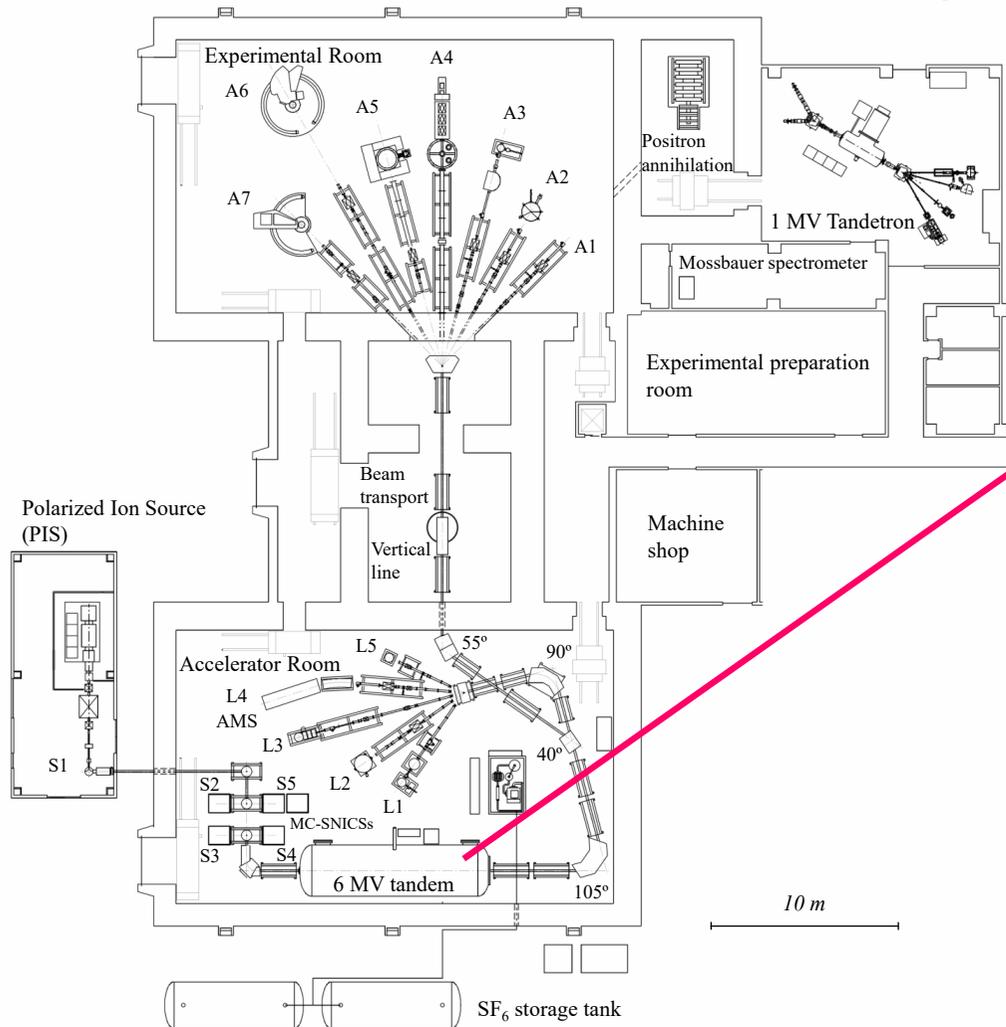


The original main tandem accelerator (1975-2011) was shut down because of the critical damage due to the giant earthquake occurred 10 years ago.

6MV Pelletron tandem accelerator

6/23

1st floor of the accelerator building



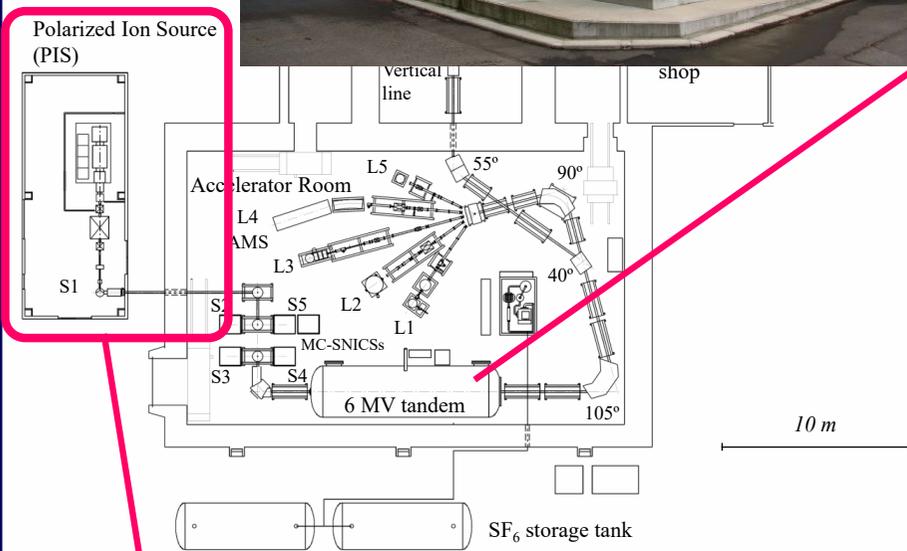
since 2016

- Model: 6 MV Pelletron Tandem (18SDH-2, National Electrostaics Corp., USA)
- Accelerator Tank Size: Length: 10.5 m
Diameter: 2.74 m
Line Height: 1.78 m
Weight: 20,865 kg
- Terminal Voltage: 1.0 – 6.5 MV
- Voltage Ripple: ≤ 750 V p-p at 6.0 MV
- Voltage Control: GVM & Slit Current Feedback System
- Maximum Beam Current: H : 3 μ A
Heavy ions: ~ 50 μ A
- Terminal Stripper: Gas (Ar or N₂)
Foil Unit (80 Foil Holders)

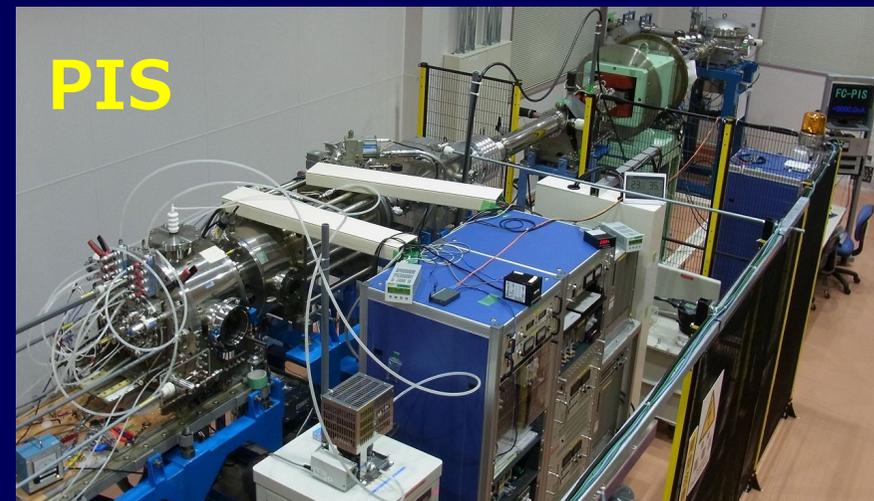
6MV Pelletron tandem accelerator

7/23

1st floor of the accelerator building



Lamb-shift polarized ion source (PIS)



PIS was also reconstructed from the damage due to the giant earthquake.

Outline

Status of polarized ion source

1. University of Tsukuba Tandem Accelerator Complex (UTTAC) and Lamb-shift Polarized Ion Source (PIS)

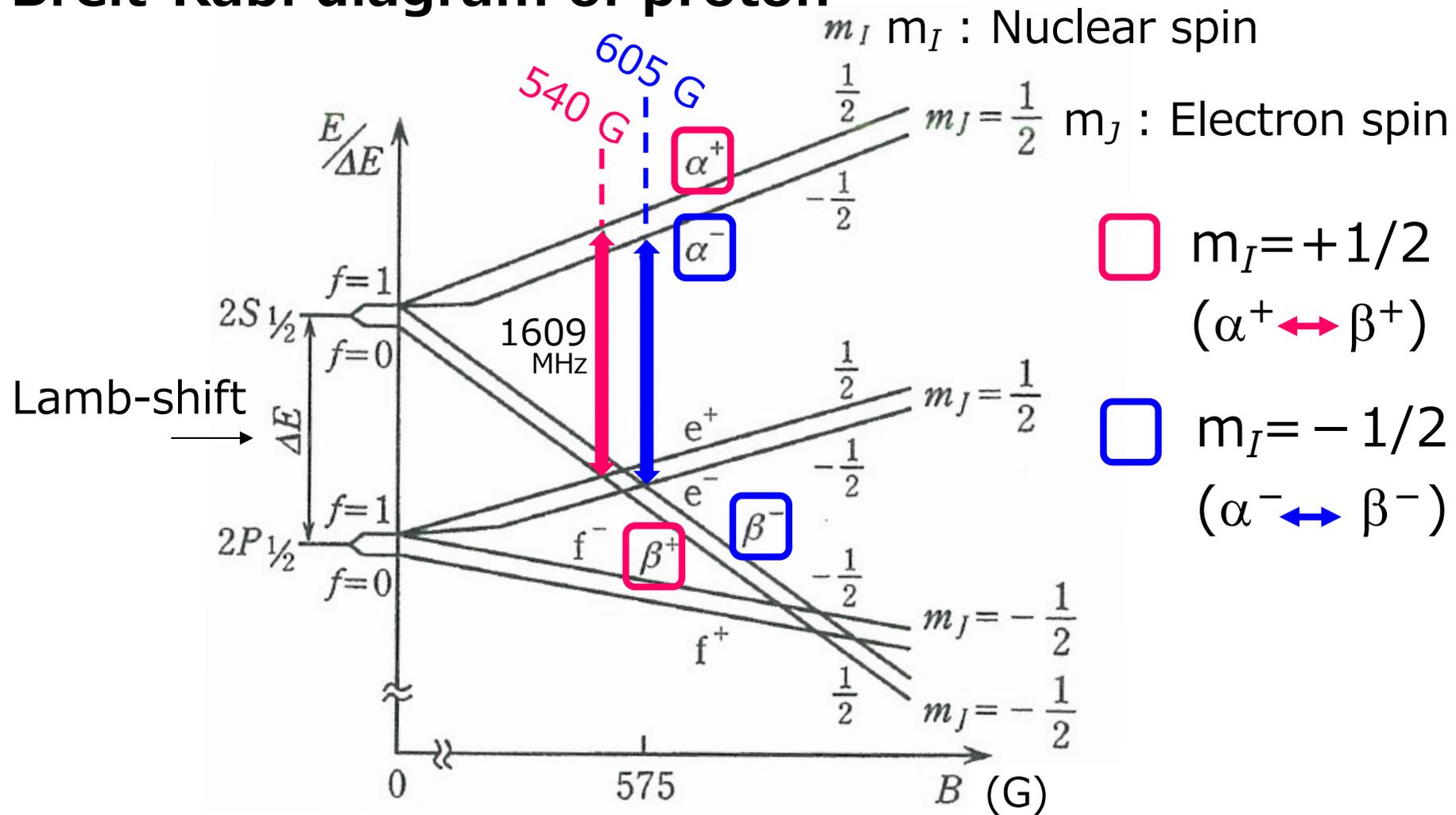
2. Operation of the PIS

Application to nuclear physics

3. Measurement of nuclear magnetic resonance (NMR) of unstable nuclei

4. Summary

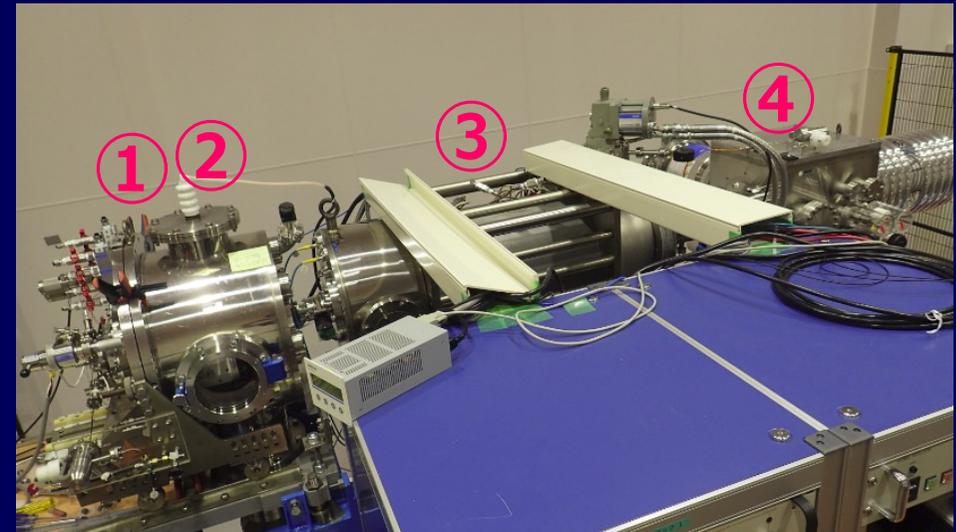
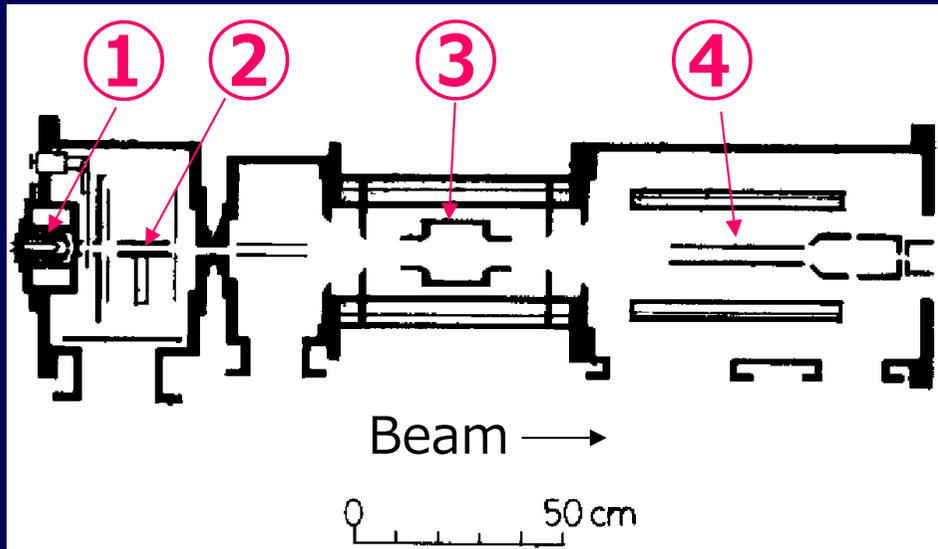
Breit-Rabi diagram of proton



- By adjusting magnetic and electric fields appropriately, state of $m_I = +1/2$ or $m_I = -1/2$ (polarized beam) is obtained.

It is possible to supply polarized proton and deuteron beams with highly polarization.

Schematic cross section of the PIS



Y. Tagishi et al., NIM164(79)411

①

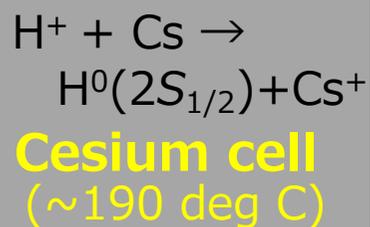
Production of positive ion

Duoplas-
matoron



②

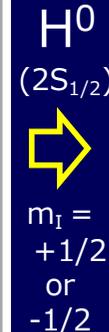
Selection of $\text{H}^0(2S_{1/2})$



③

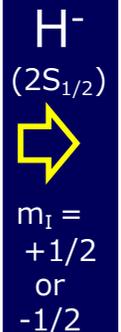
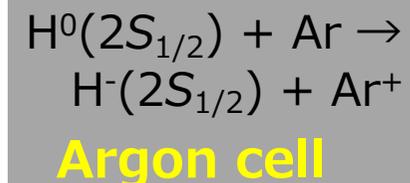
Selection of spin state
"Spin filter"

RF-cavity inside
solenoid coil

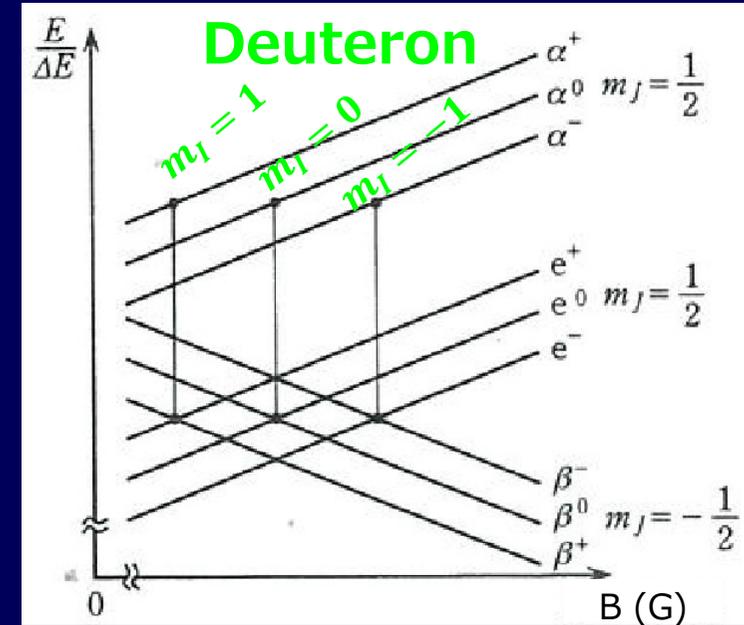
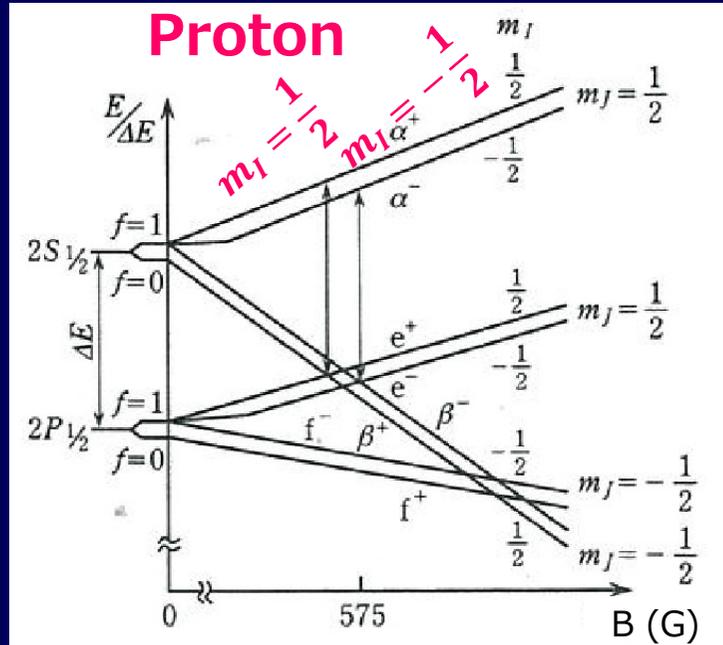


④

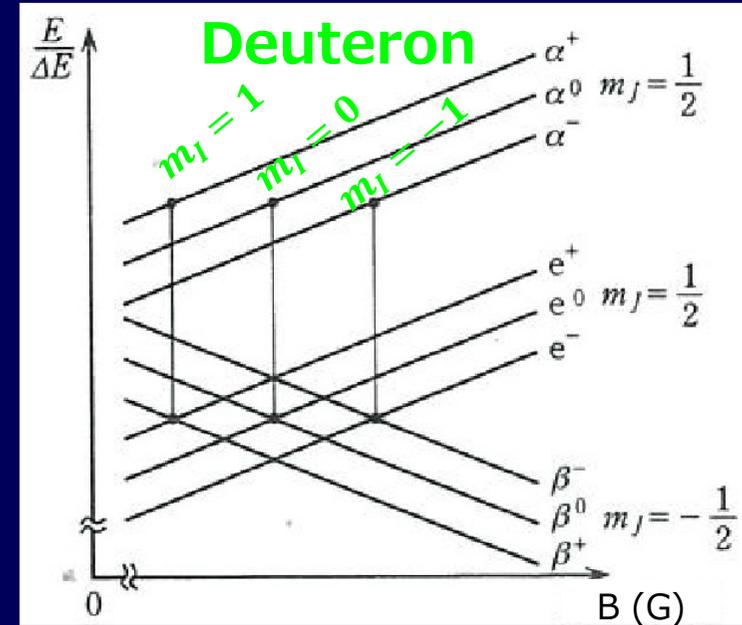
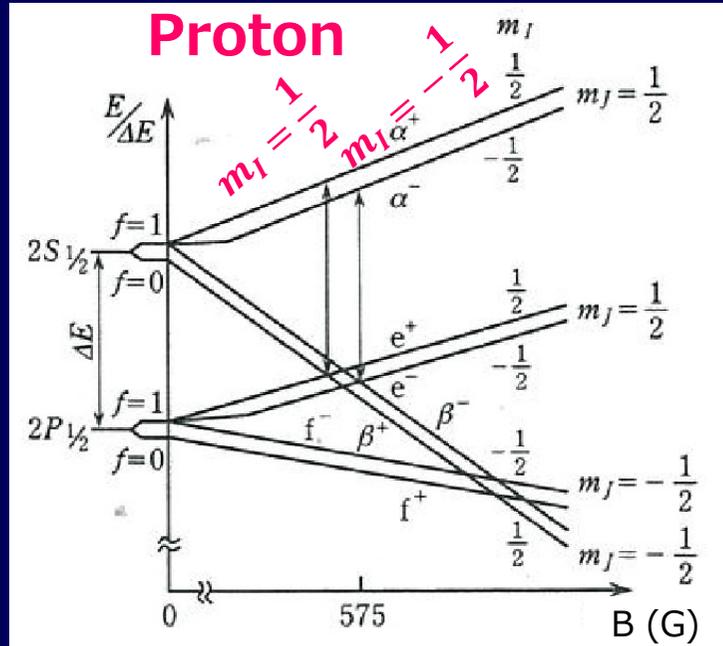
Ionization of $2S_{1/2}$ selectively



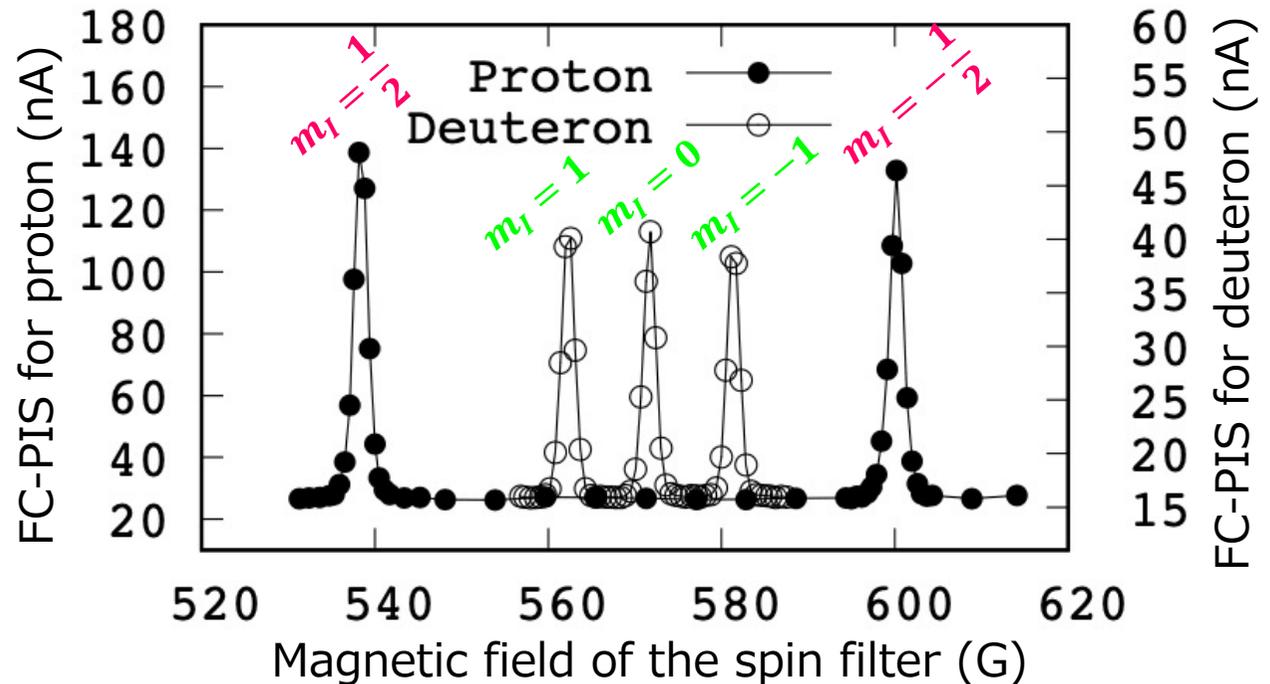
Checking polarized beams @ the PIS building



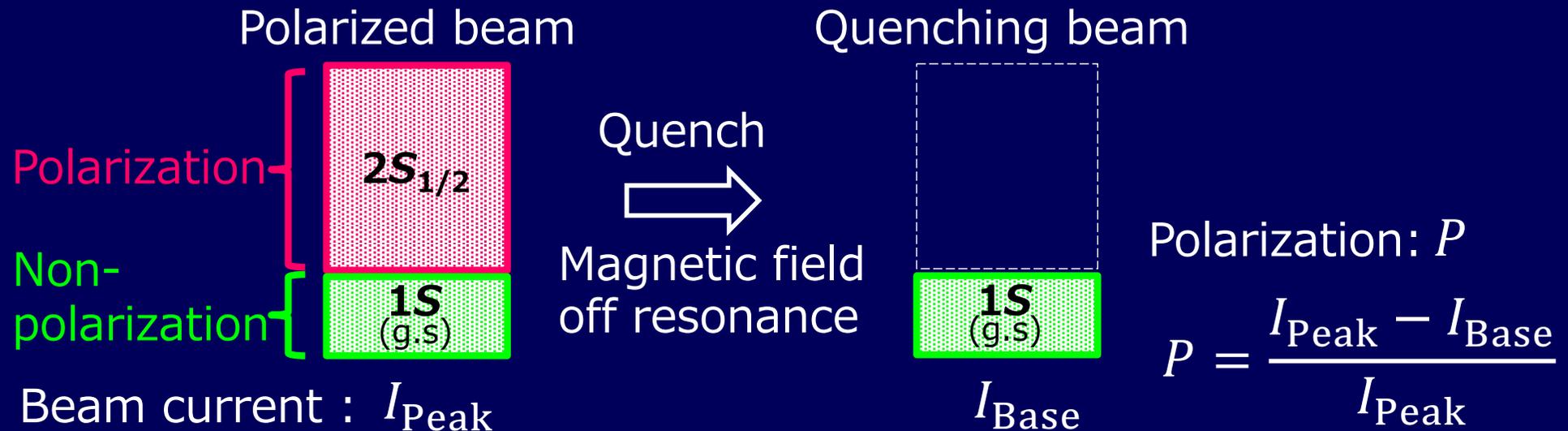
Checking polarized beams @ the PIS building



Beam current measured by a faraday cup @ PIS



Quenching method for the measurement of the polarization



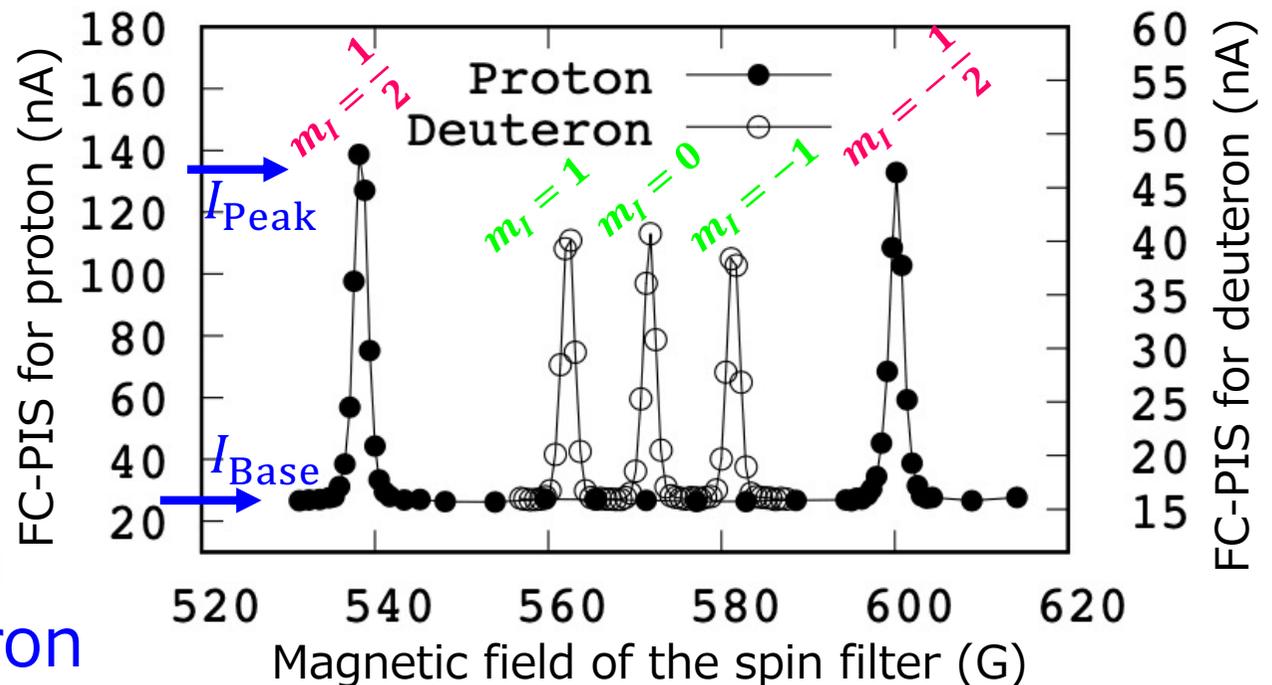
Beam current measured by a faraday cup @ PIS

Polarization

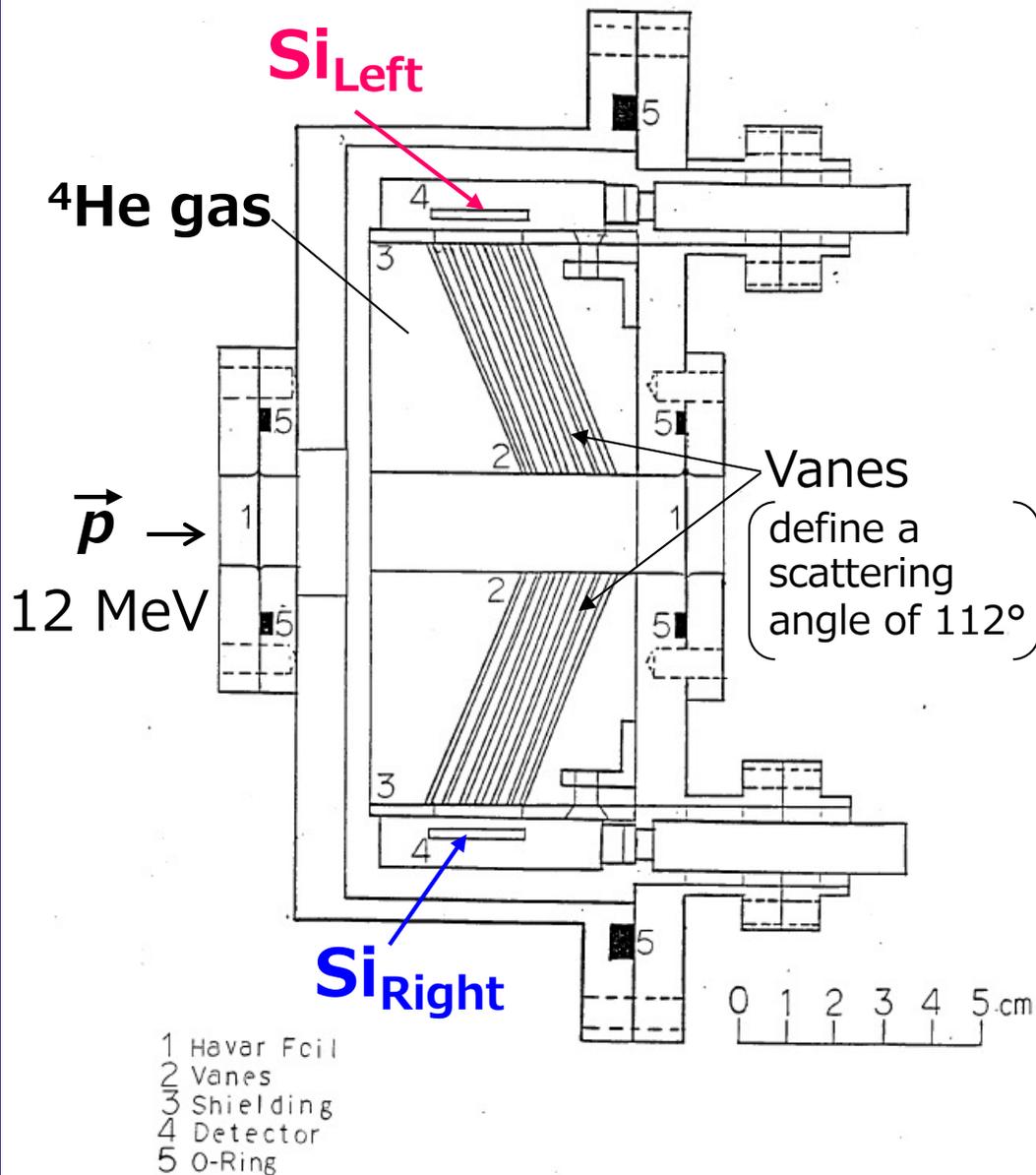
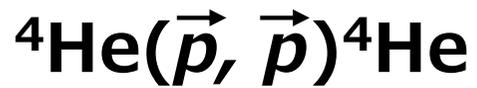
$$P = \frac{I_{\text{Peak}} - I_{\text{Base}}}{I_{\text{Peak}}}$$

$\approx 80\%$ for proton

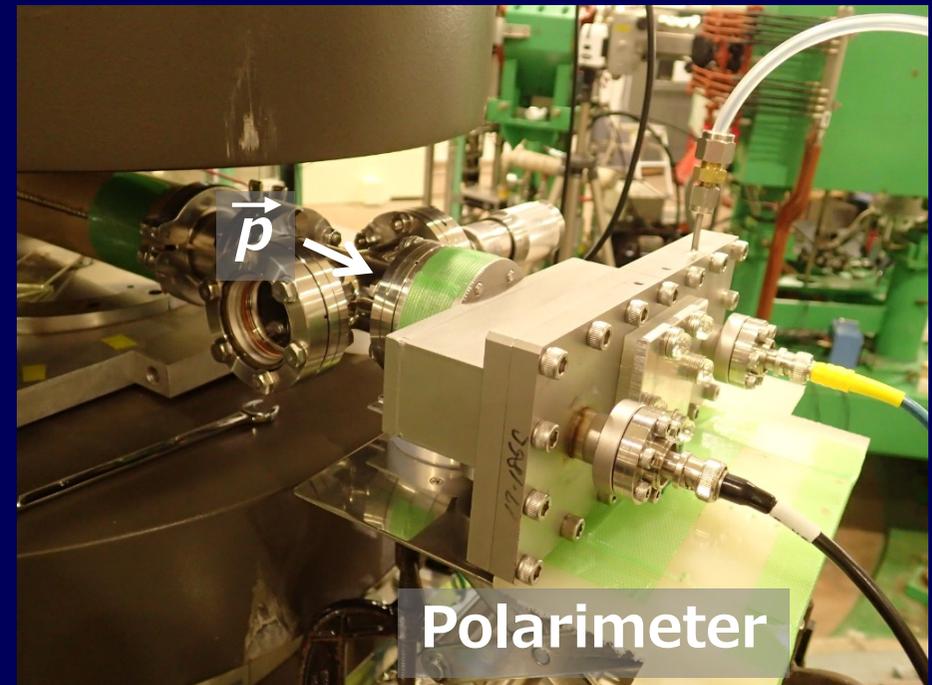
$\approx 60\%$ for deuteron



Polarization of \vec{p} after acceleration



This polarimeter is based on the p - ${}^4\text{He}$ elastic scattering.



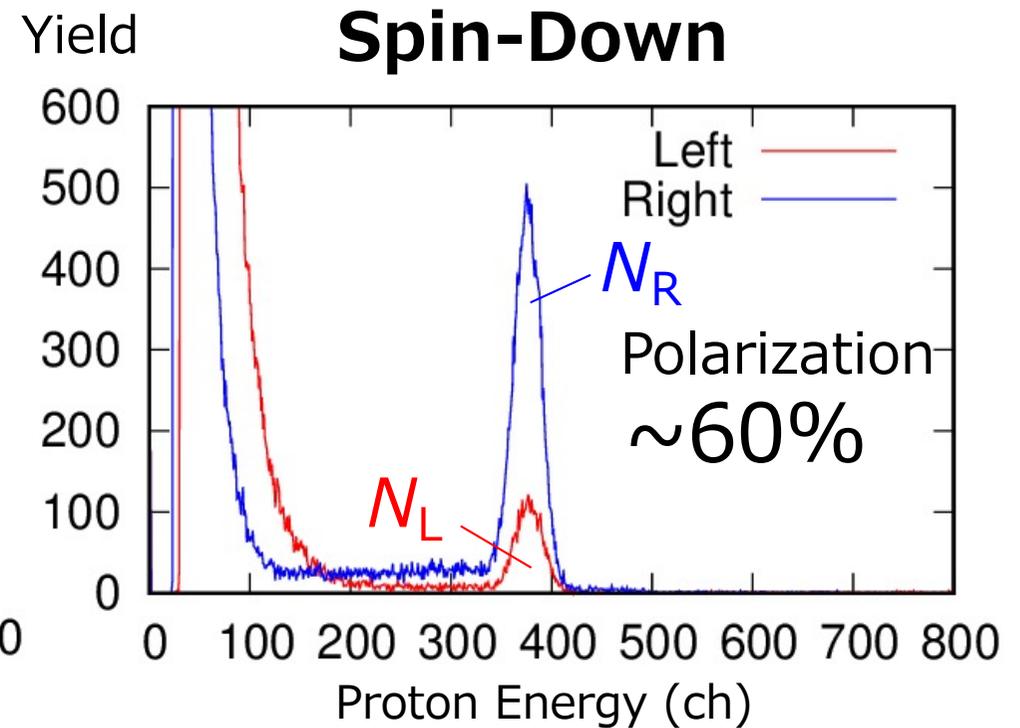
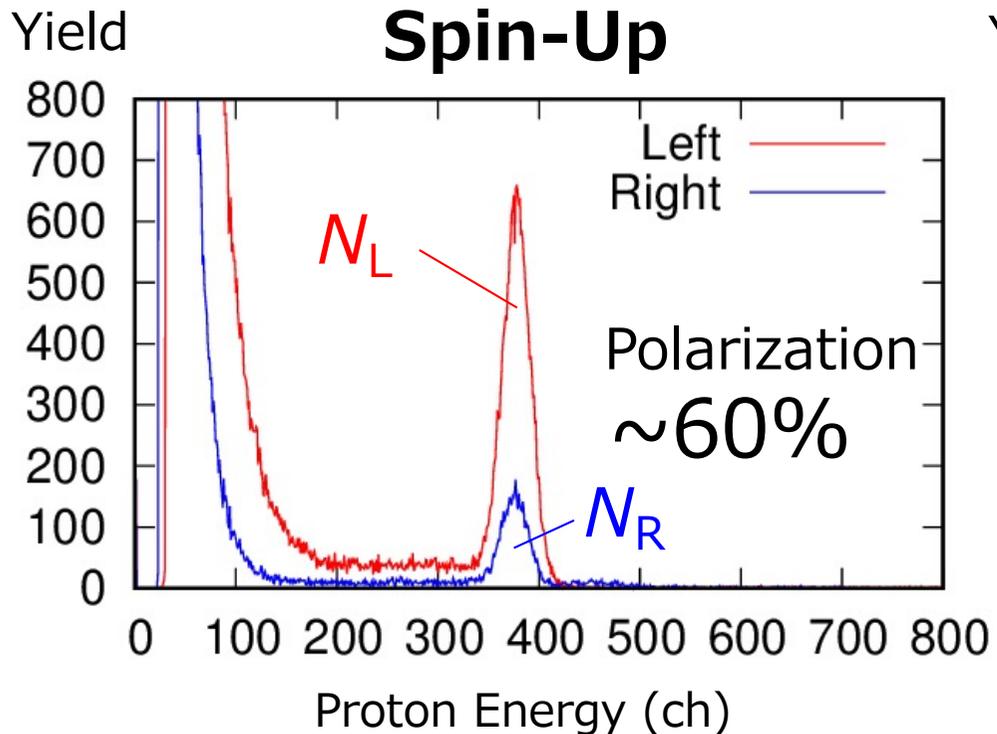
Polarization of \vec{p} after acceleration

$$A \cdot P = \frac{N_L - N_R}{N_L + N_R}$$

A : Analyzing power
 $A \approx 1$ (12 MeV proton)

P : Polarization

N_L (N_R): The number of elastically scattered proton detected by Si_{Left} (Si_{Right})



The depolarization is found during the transport from PIS to the experimental course.

Outline

Status of polarized ion source

1. University of Tsukuba Tandem Accelerator Complex (UTTAC) and Lamb-shift Polarized Ion Source (PIS)
2. Operation of the PIS

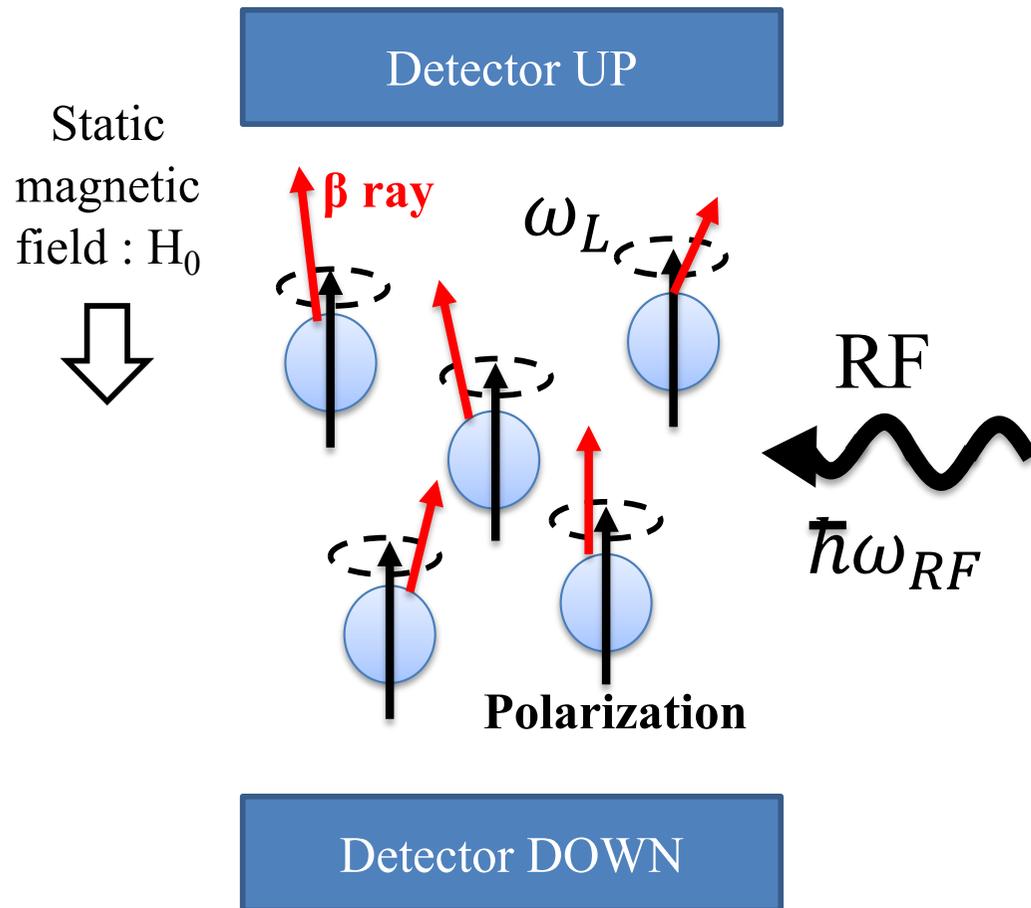
Application to nuclear physics

3. Measurement of nuclear magnetic resonance (NMR) of unstable nuclei
4. Summary

β -NMR (Nuclear Magnetic Resonance)

17/23

An effective method to detect a nuclear magnetic resonance (NMR) using asymmetry of emitted β rays.



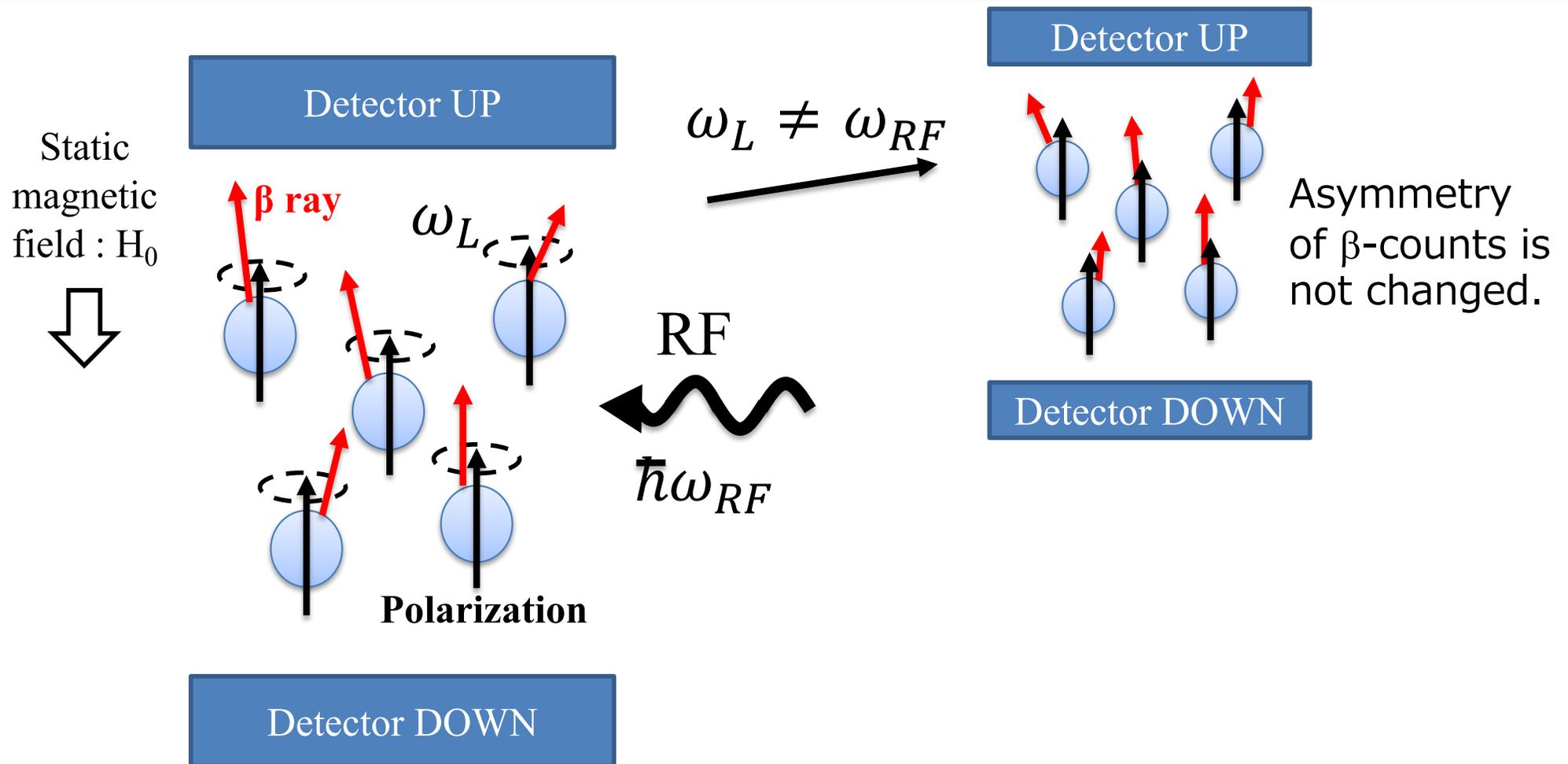
$$\omega_L = g\mu_N H_0 / \hbar$$

($\mu = g\mu_N I$)

ω_L : Larmor frequency
 g : g factor
 μ_N : Nuclear magneton
 μ : Nuclear magnetic moment
 I : Nuclear spin

β -NMR (Nuclear Magnetic Resonance)

An effective method to detect a nuclear magnetic resonance (NMR) using asymmetry of emitted β rays.



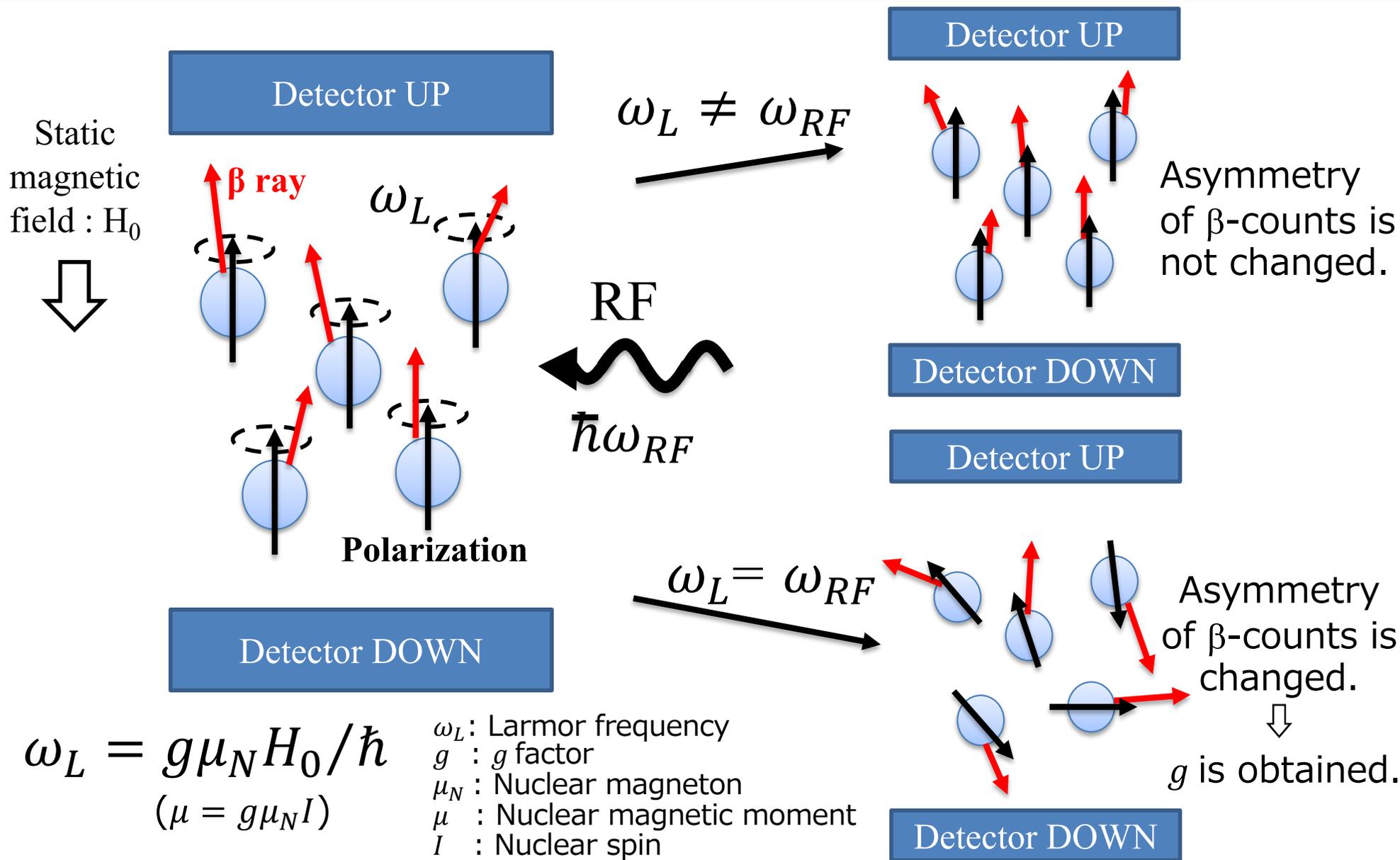
$$\omega_L = g\mu_N H_0 / \hbar$$

$$(\mu = g\mu_N I)$$

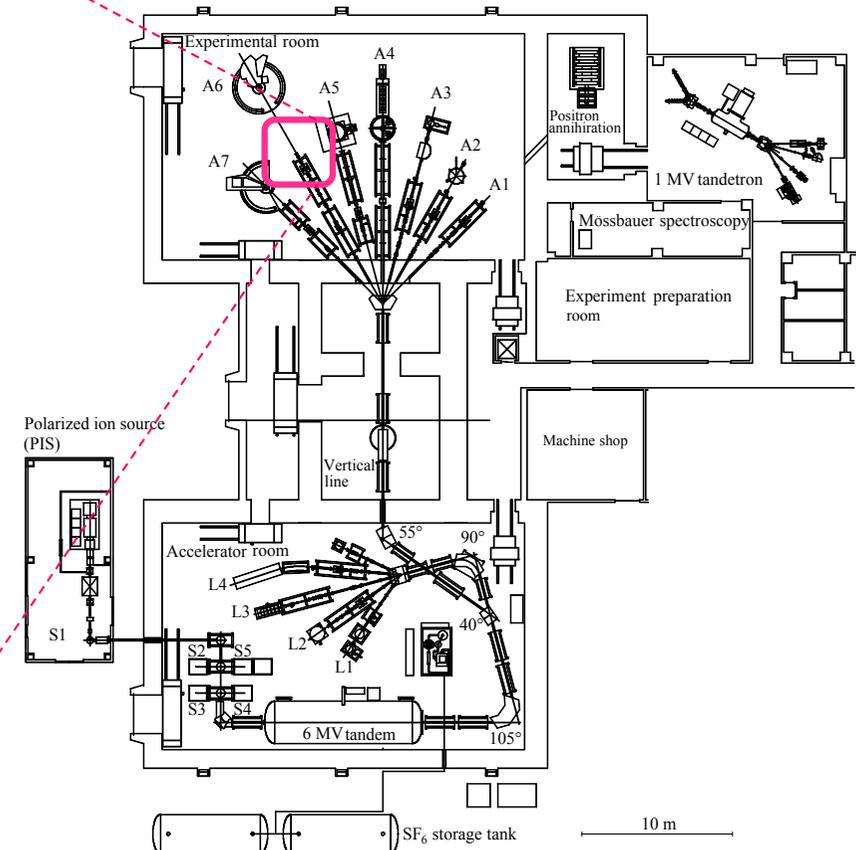
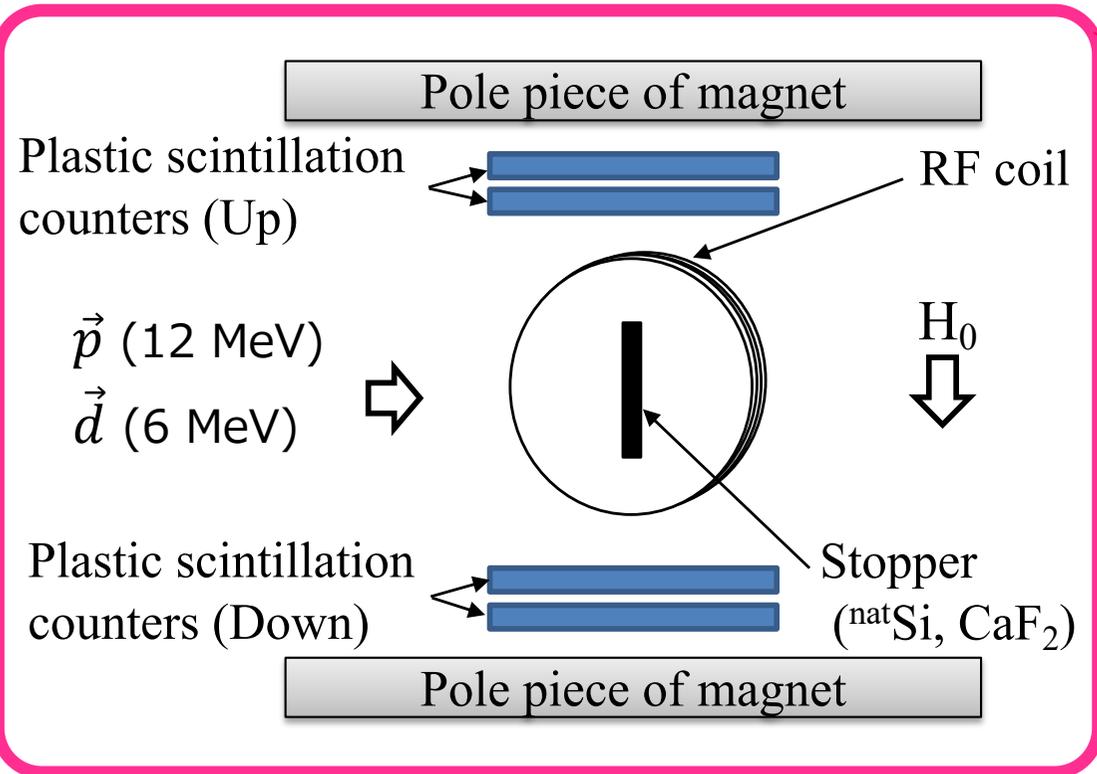
ω_L : Larmor frequency
 g : g factor
 μ_N : Nuclear magneton
 μ : Nuclear magnetic moment
 I : Nuclear spin

β -NMR (Nuclear Magnetic Resonance)

An effective method to detect a nuclear magnetic resonance (NMR) using asymmetry of emitted β rays.



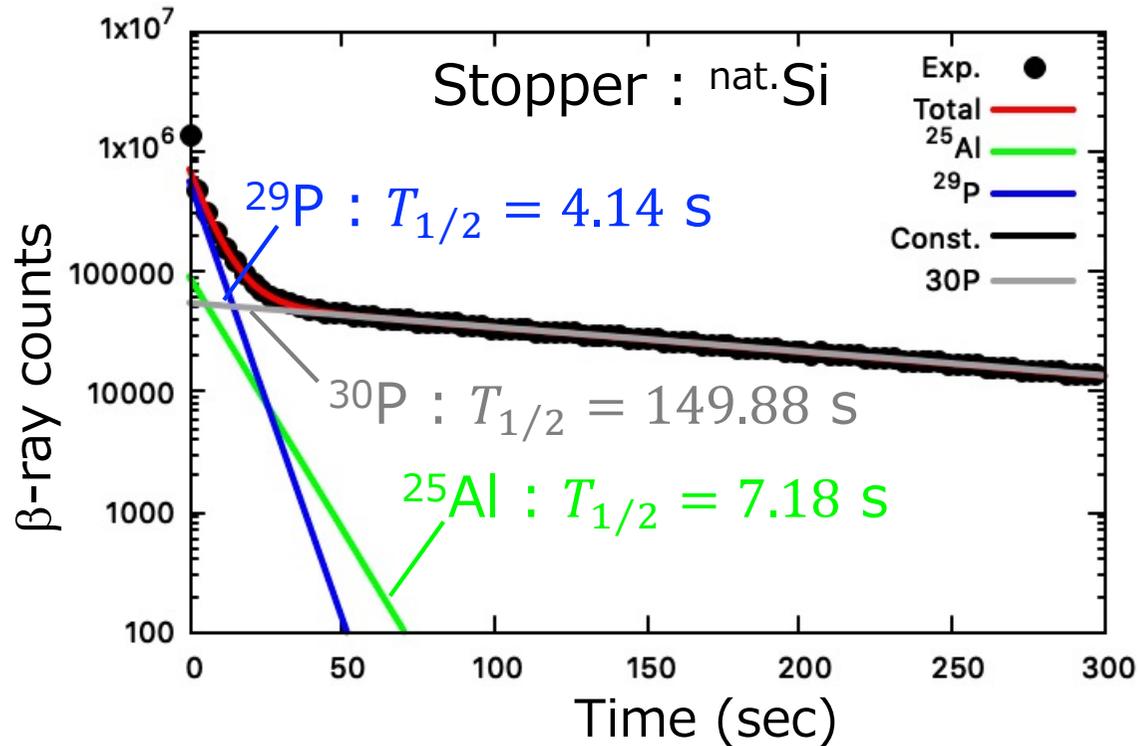
Experimental setup for β -NMR



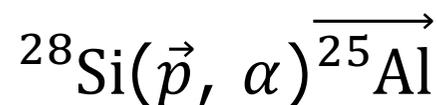
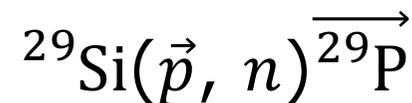
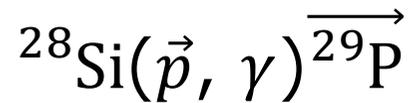
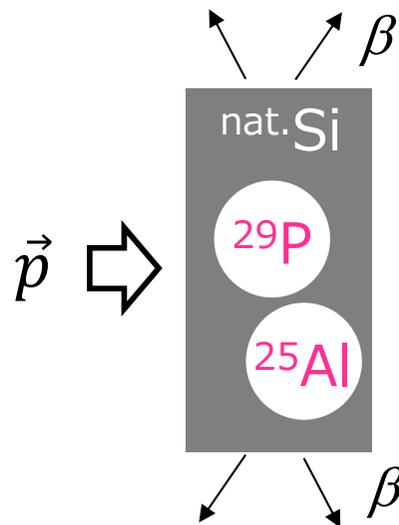
- Polarized unstable nuclei were produced in the stopper via the polarization-transfer reaction with \vec{p} and \vec{d} beams.
- The number of β -ray from unstable nuclei were counted by up and down plastic counters.

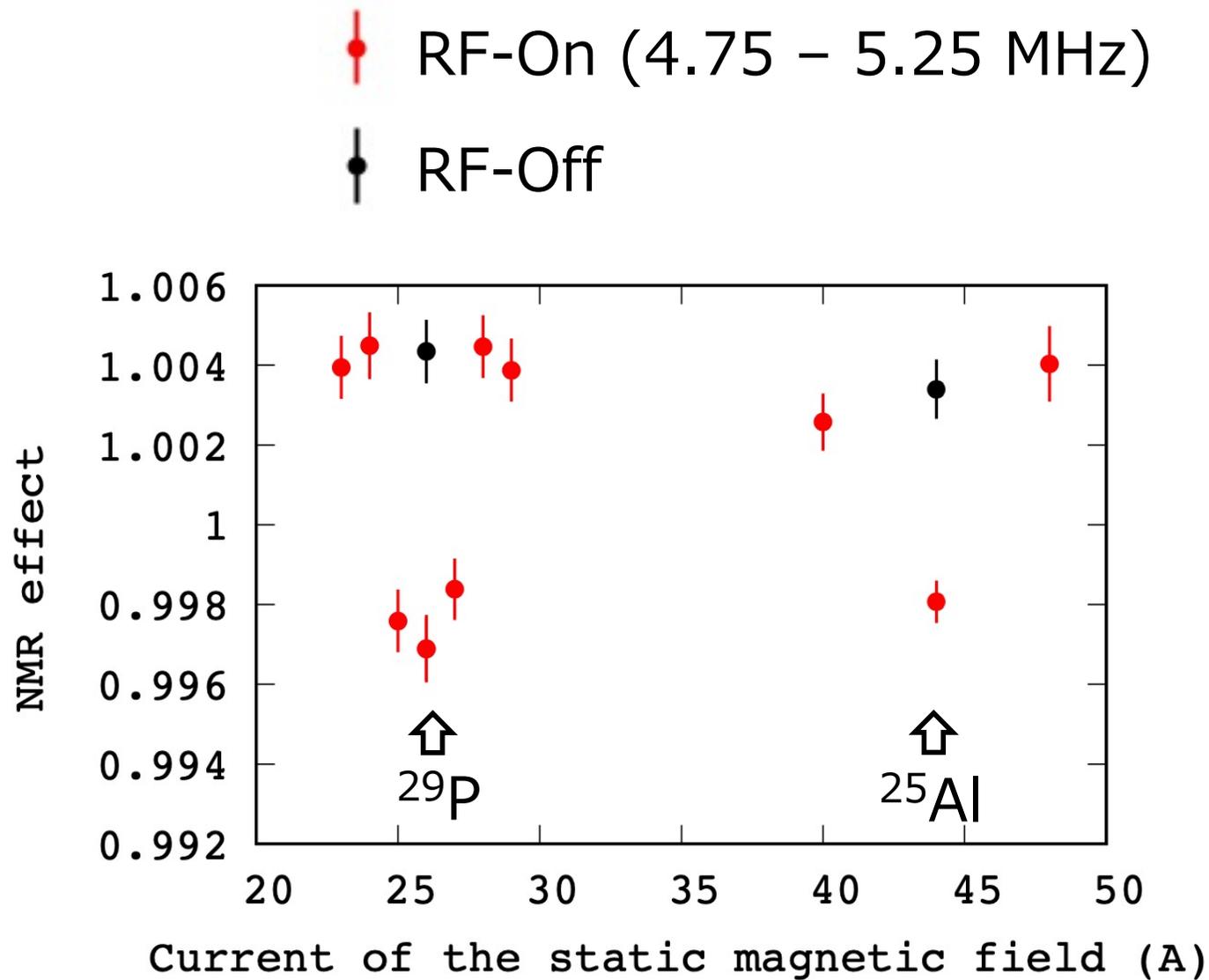
β -ray time spectrum

^{29}P , ^{30}P , ^{25}Al



Production of unstable nuclei (^{29}P , ^{30}P , ^{25}Al) in the beam stopper is confirmed.





We observed the NMR of ^{29}P and ^{25}Al .

Summary and prospect

- In the University of Tsukuba Tandem Accelerator Complex (UTTAC), the Lamb-shift polarized ion source (PIS) is used as one of the injections for the 6 MV Pelletron tandem accelerator.
- Lamb-shift polarized ion source can supply polarized proton and deuteron beams with highly polarization.

Polarization : ~80% for proton
~60% for deuteron

- Using polarized beams from PIS, we confirmed the production of unstable nuclei ($^{29,30}\text{P}$, ^{25}Al) via the polarization-transfer reaction, and observed the nuclear magnetic resonance (NMR) with the β -NMR method.
- We will measure the nuclear moments of unstable nuclei with polarized proton and deuteron beams.