Proton polarization in photo-excited aromatic molecule at room temperature

Satoshi Sakaguchi
Kyushu University

XVIth Internathonal Conference on Electromagnetic Isotope Separators and Techniques Related to their Applications (EMIS2012)

2012 / 12 / 7

Collaborators

<u>RIKEN</u>

T. Uesaka (Nishina Center)

S. Wada, Y. Urata, T. Ogawa (Advanced Science Institute)

<u>Kyushu Univ.</u>

T. Teranishi

<u>CYRIC, Tohoku Univ.</u>

T. Wakui

<u>Toho Univ.</u>

T. Kawahara

<u>CNS, Univ. of Tokyo</u>

T. L. Tang

Outline

- Study of unstable nuclei with polarized proton
- Application to low-energy RI beam experiment
- Proton polarization @room temperature
  - Increase of laser power
  - Optimization of laser pulse structure

Polarization study of unstable nuclei

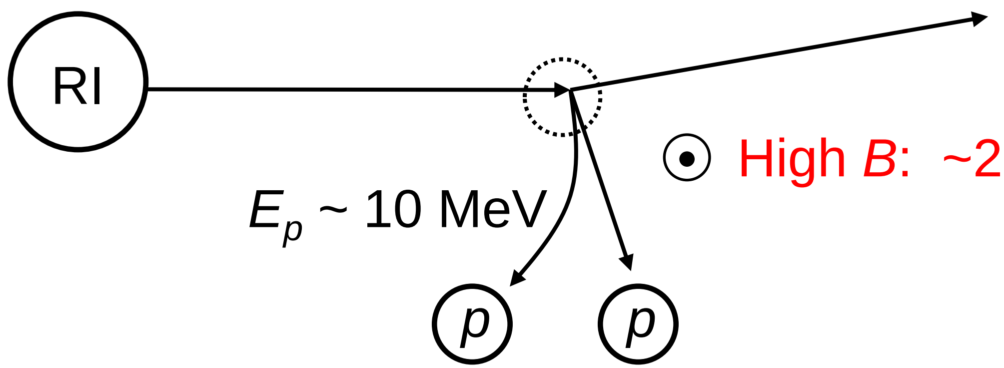
- Direct reactions induced by polarized light ions
  - Powerful probe for studying manifestation of spin-dependent interactions in nuclei
  - Reactions
    - $(\vec{p},p')$, $(\vec{p},n)$ spin-isospin response
    - $(\vec{p},d)$, $(\vec{d},p)$, $(\vec{p},p\mathrm{N})$ spin-parity of single particle/hole states
    - $(\vec{p},p)$, $(\vec{d},d)$ spin-orbit potential
  - Method

    Radioactive ion beam + polarized target ***(key element)***

Physics of unstable nuclei × Reaction of polarized light ion

Polarized proton target for RI-beam exp.

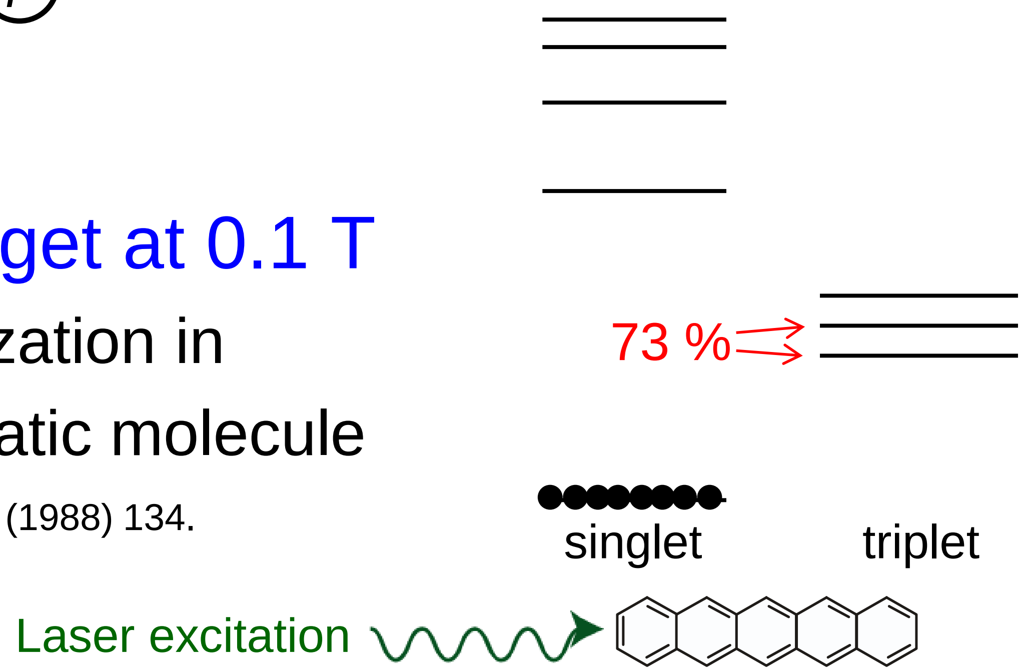
- Inverse kinematics



⊙ High B: ~2.5T (Conventional target)

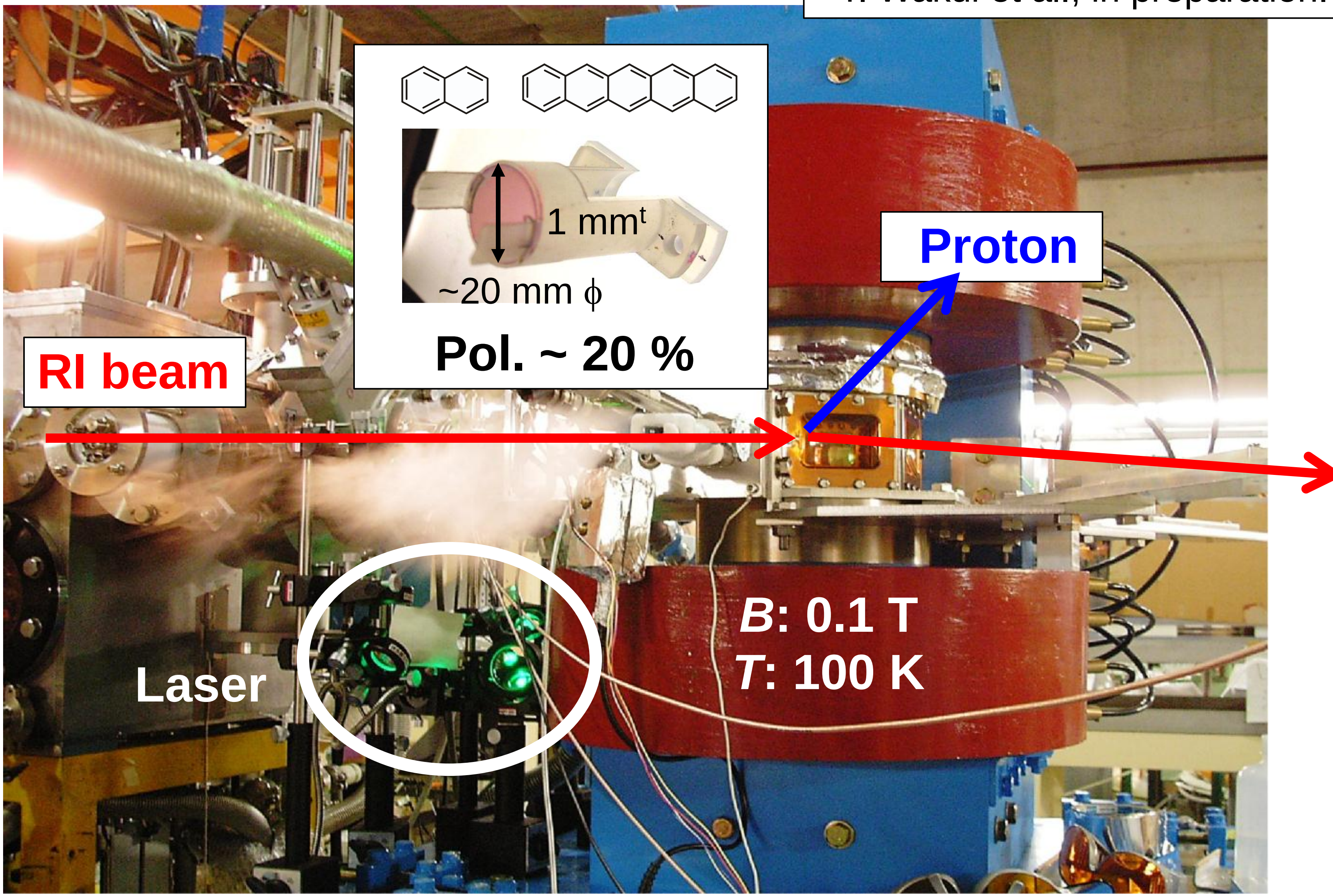
- Solid pol. proton target at 0.1 T
  - High electron polarization in photo-excited aromatic molecule

A. Henstra et al. Phys. Lett. A 134 (1988) 134.



Solid polarized proton target @CNS/RIKEN

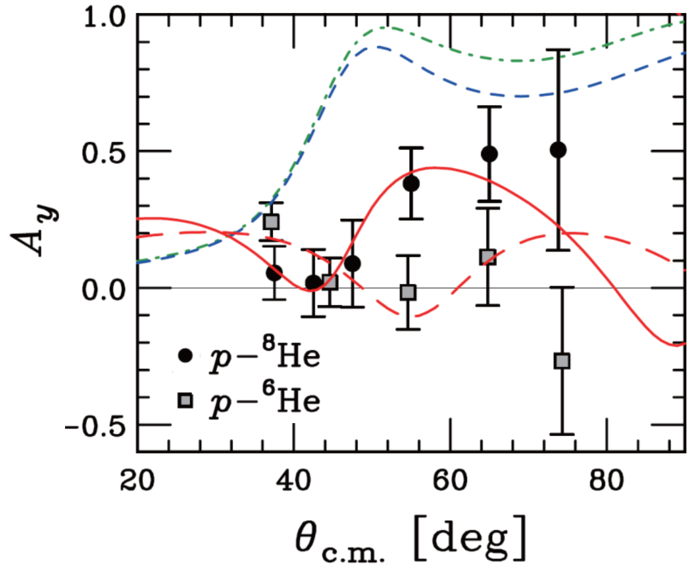
T. Wakui et al., in preparation.



Effectiveness of polarized target

- Elastic scattering
  - $\vec{p}$-^{6}He, ^{8}He at 71, 200 MeV/u

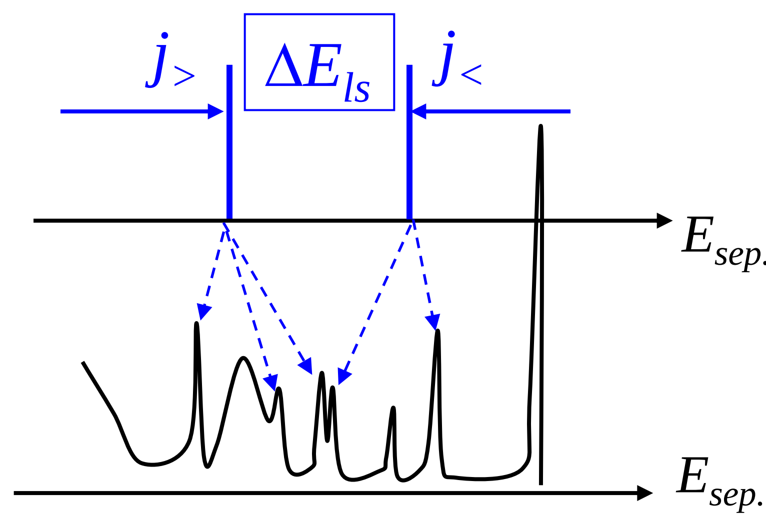
T.Uesaka, S.S. et al., PRC 82 (2010) 021602(R).
S.S., Y. Iseri et al., PRC 84 (2011) 024604.



  - Shallow and diffuse spin-orbit potential

- Knock-out reaction
  - $^{14, 22, 24}$O ($\vec{p}$,2p), ($\vec{p}$,pn) at 250 MeV/u

S. Kawase, T. Uesaka et al.,
Experiment carried out in 2012



  - Change of spin-orbit splitting ΔE_{ls}

Outline

- Study of unstable nuclei with polarized proton
- Application to low-energy RI beam experiment
- Proton polarization @room temperature
  - Increase of laser power
  - Optimization of laser pulse structure

New possibilities with low energy RI-beam

- Resonant proton scattering
  - Low-lying single-particle resonances in *p*-rich nuclei
  - Information by spin-asymmetry measurement

- Transfer reaction
  - Spectroscopy with $(\vec{p},d)$ reaction
  - Unambiguous J^{π} assignment

- Polarization transfer to stopped RI
  - Cross-polarization technique: applicable to any nucleus
  - Magnetic moment measurement by β-NMR method

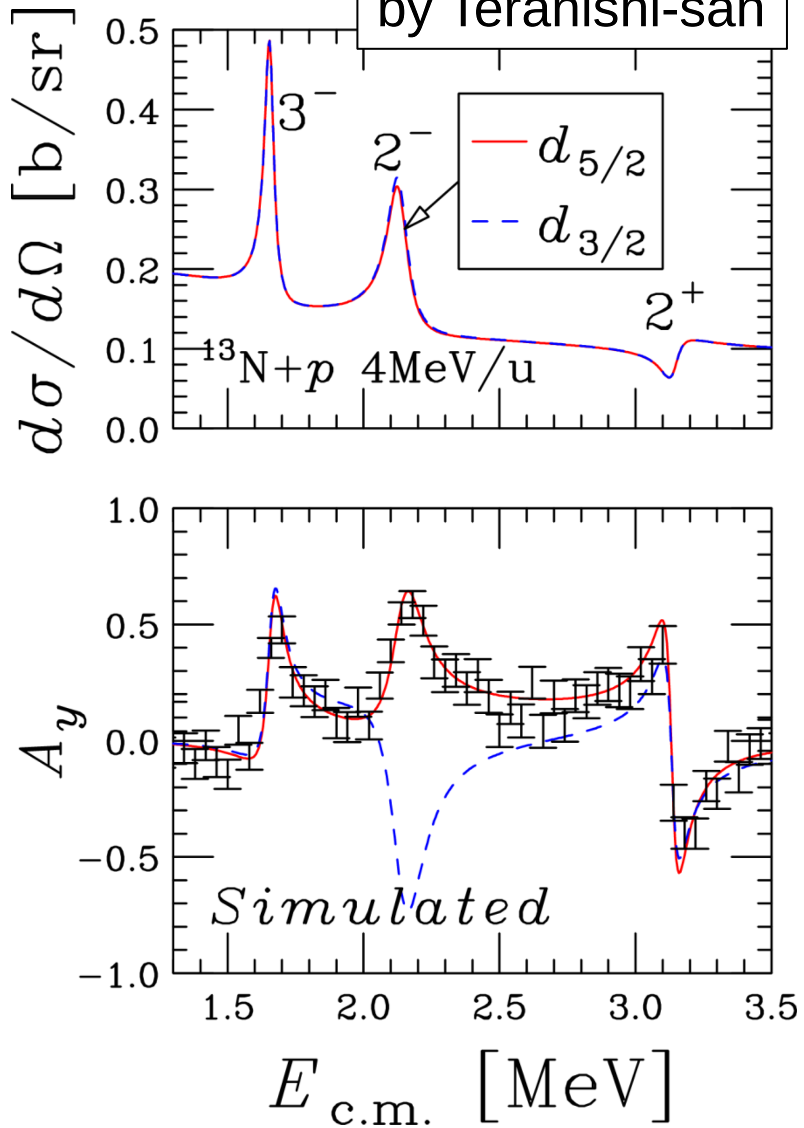
Resonant proton scattering

- Roles of spin asymmetry
  - J^{π} determination
    - Projectile w/ non-zero spin
    - Sensitive to configuration mixing
  - Information for extremely wide resonances
- Feasibility demonstration
  - ^{13}N+$\vec{p}$ scattering
  - Monte-Carlo simulation

    $P_p = 20\%$, 10 mg/cm^2,

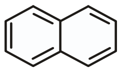
    10^5 pps × 3 days

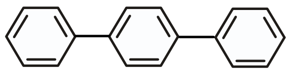
by Teranishi-san



Toward low-*E* exp. with polarized protons

- Requirement for target
  - Vacuum environment

 sublimates ×

 @300K ○

Applications:
- Hyper-resolution MRI
- Quantum computing

Challenge: High proton polarization at room temperature

- Current status of room-temp. polarization
  - Not easy to produce
    - 1.3% (2005, Kyoto Gr.) M. Iinuma et al., Jour. Mag. Res. 175 (2005) 235.
    - 5.7% (2009, Osaka Gr.) A. Kagawa et al., Jour. Mag. Res. 197 (2009) 9.

⇔ Insufficient for target use

Outline

- Study of unstable nuclei with polarized proton
- Application to low-energy RI beam experiment
- Proton polarization @room temperature
  - Increase of laser power
  - Optimization of laser pulse structure

For higher polarization

- Proton polarization P_p

$$P_p = \frac{A\,P_e}{A + \Gamma_i + \Gamma_t}$$

P_e: Electron polarization

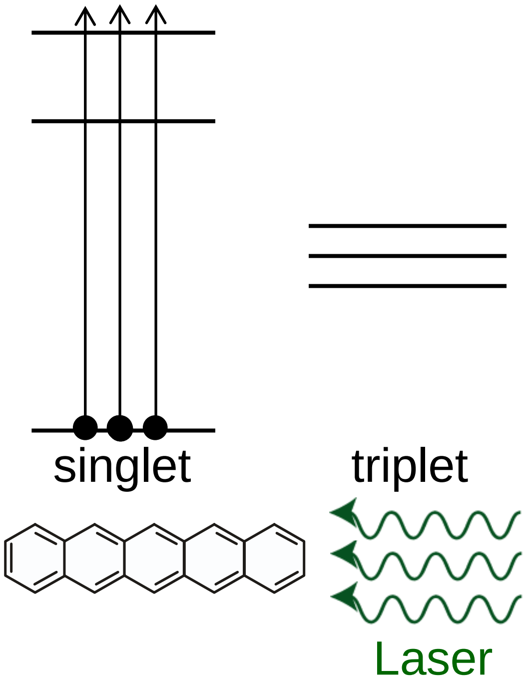
A : Build-up rate

Γ: Relaxation rate

- For higher build-up rate
  - Laser power should be increased

⇔ Not successful in previous studies

(ex.) M. Iinuma et al., Jour. Mag. Res. 175 (2005) 235.

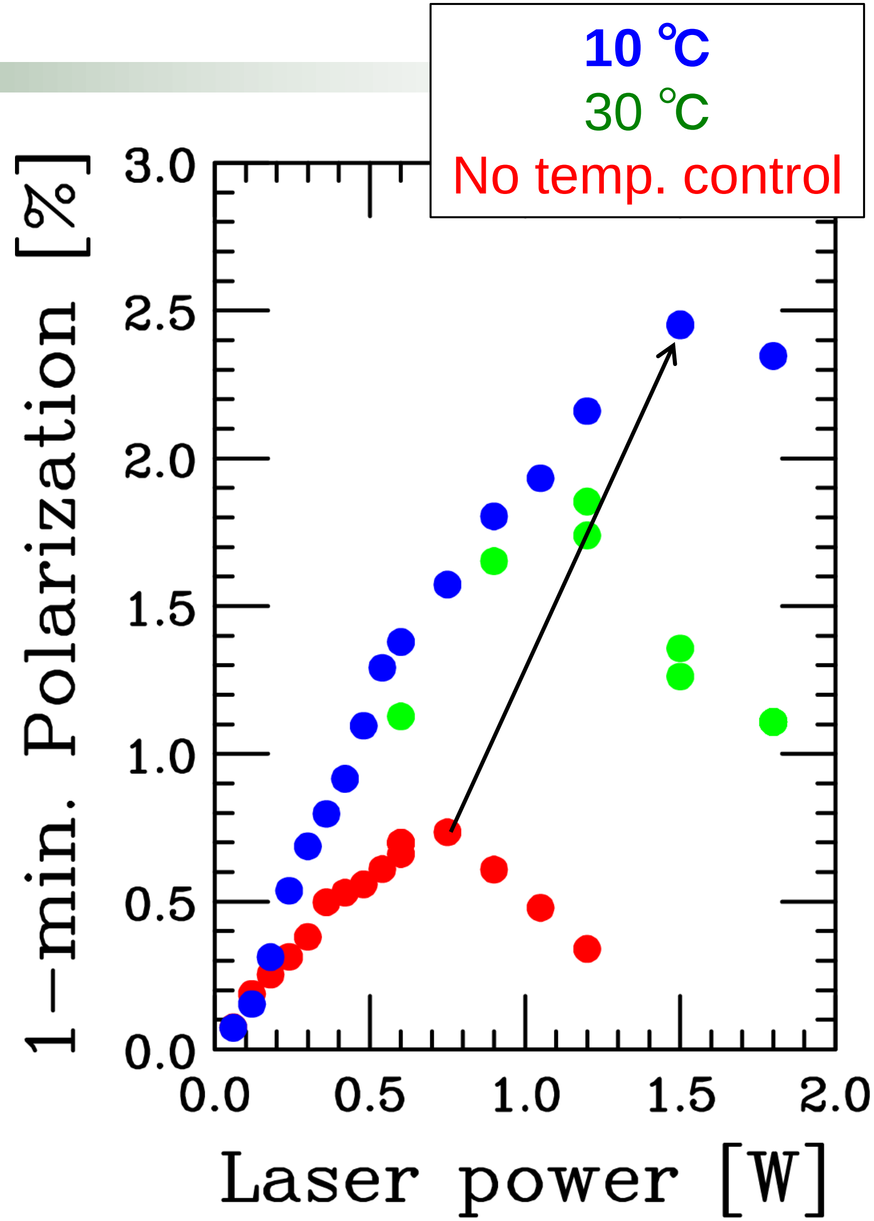


Higher laser power

- What is the problem?
  - High power
    ⇒ High temperature
    ⇒ Fast relaxation?

- Temperature control
  - Keep constant temp. by cooling gas

Build-up rate *A* was
enhanced by a factor of 3.



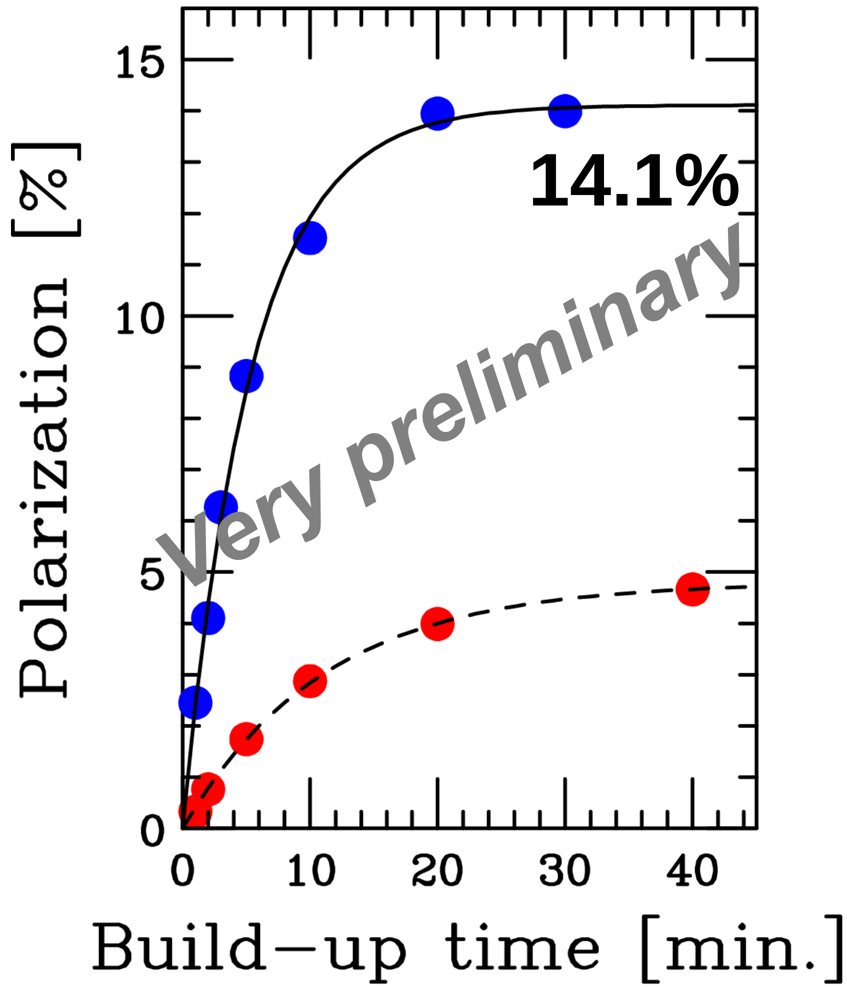
Polarization achieved

- Previous work (2004)
  - Polarization： 4.8%
  - Laser： 80 mW
  - No temp. control

- Present work (2012)

World-record **polarization of 14.1% at room temp.** by **high power laser (1.5 W)** and **temp. control (10 ℃)**.

(> **10^{5}** × thermal pol.)

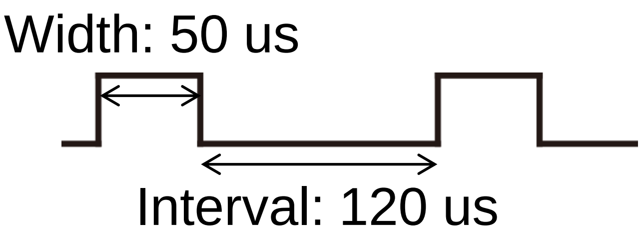


Outline

- Study of unstable nuclei with polarized proton
- Application to low-energy RI beam experiment
- Proton polarization @room temperature
  - Increase of laser power
  - Optimization of laser pulse structure

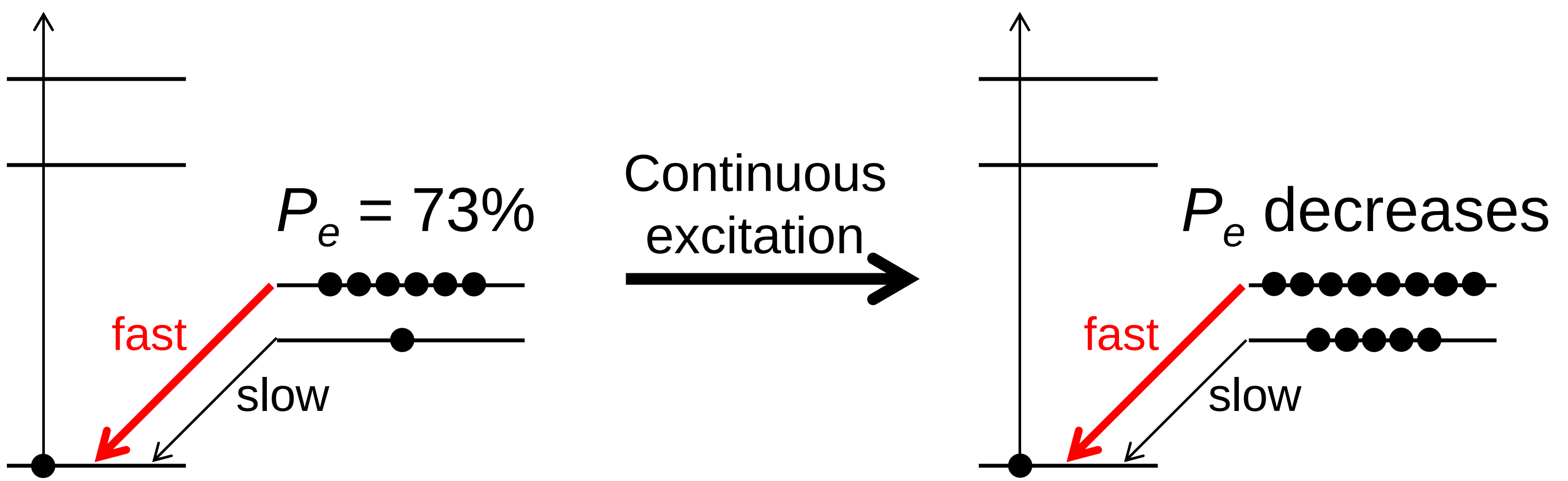
Use of pulse laser

- Time structure of pulse



⇔ Continuous-wave laser?

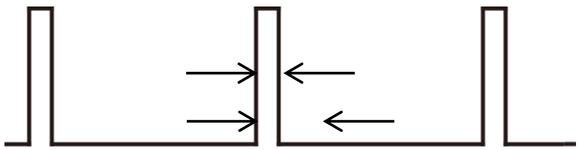
- Evolution of electron polarization



⇒ Width of laser pulse should be shorter (if power = const.).

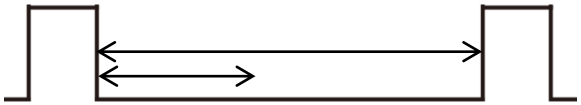
Enhancement of figure-of-merit ($A \times P_e$)

- Shortening of pulse width



$\Rightarrow AP_e$: $\times$ 2.4

- Extending pulse interval



$\Rightarrow AP_e$: $\times$1.3

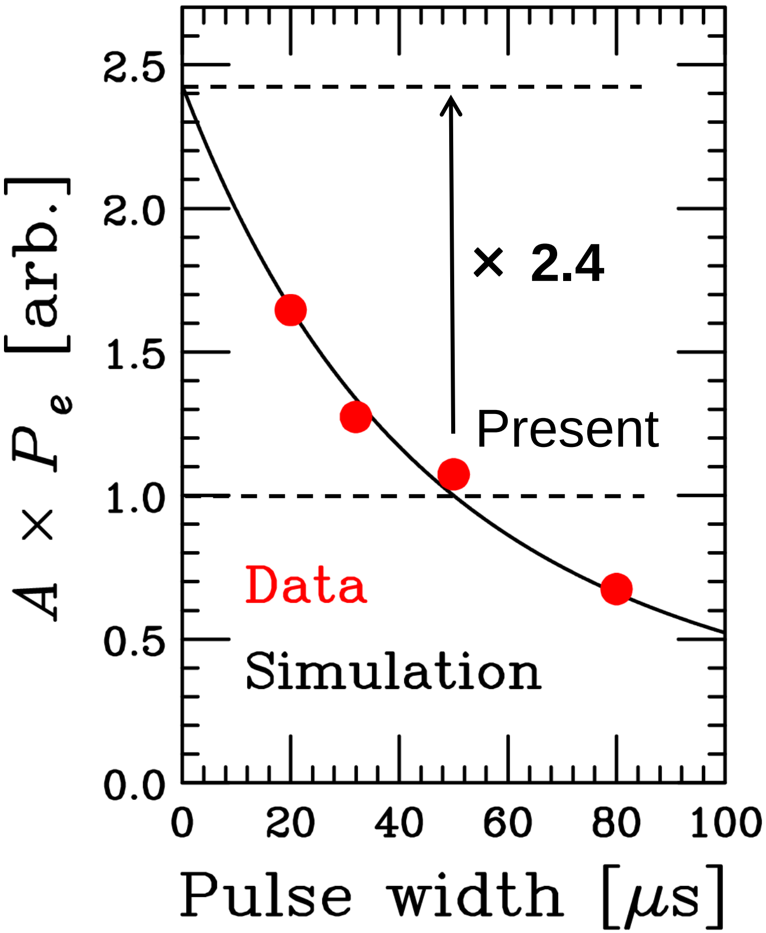


Figure of merit AP_e can be enhanced by a factor of > 3.

How far can we go?

- **Pulse structure**
  - Short pulse width
    (50 → 1 us)
  - Long pulse interval
    (120 → 1000 us)
- **High power**
  (1.5 → 10 W)

⇑

New laser
@RIKEN ASI, (~2013)
S. Wada *et al.*

⇒

- Expected polarization

$$P_p = \frac{\overset{\times 7}{A}\, P_e}{\underset{\times 7}{A} + \Gamma_i + \underset{\times 7}{\Gamma_t}} = 14\%$$

⇒ **35%** (pulse structure optimization)

⇒ **50%** (+ high power & temp. control)

Room-temp. polarization of > 30% is within sight !!

Summary

- Proton polarization at room temperature will open up new possibilities: studies of unstable nuclei with polarized protons at low incident energies.

- ***World-record* polarization of 14.1%** was achieved with high power laser and temp. control.

- Optimization of laser pulse structure will enable us to obtain **> 30% polarization**.