Measurement of deeply bound pionic states using the $(p, {}^2He)$ reaction at RCNP

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collaborators

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Deeply bound pionic atom

- Binding energy and width of pionic atom

→ **Partial restoration of chiral symmetry**

- s-wave pion-nucleus potential

$$U_s(r) = -\frac{2\pi}{\mu}\left[\varepsilon_1\{b_0\rho(r) + b_1[\rho_n(r) - \rho_p(r)]\} + \varepsilon_2 B_0 \rho^2(r)\right]$$

$\mu = m_\pi M/(m_\pi + M)$, $\varepsilon_1 = 1 + m_\pi/M$, $\varepsilon_2 = 1 + m_\pi/2M$

$\rho_n(r)$: neutron density, $\rho_p(r)$: proton density, $\rho(r) = \rho_n(r) + \rho_p(r)$

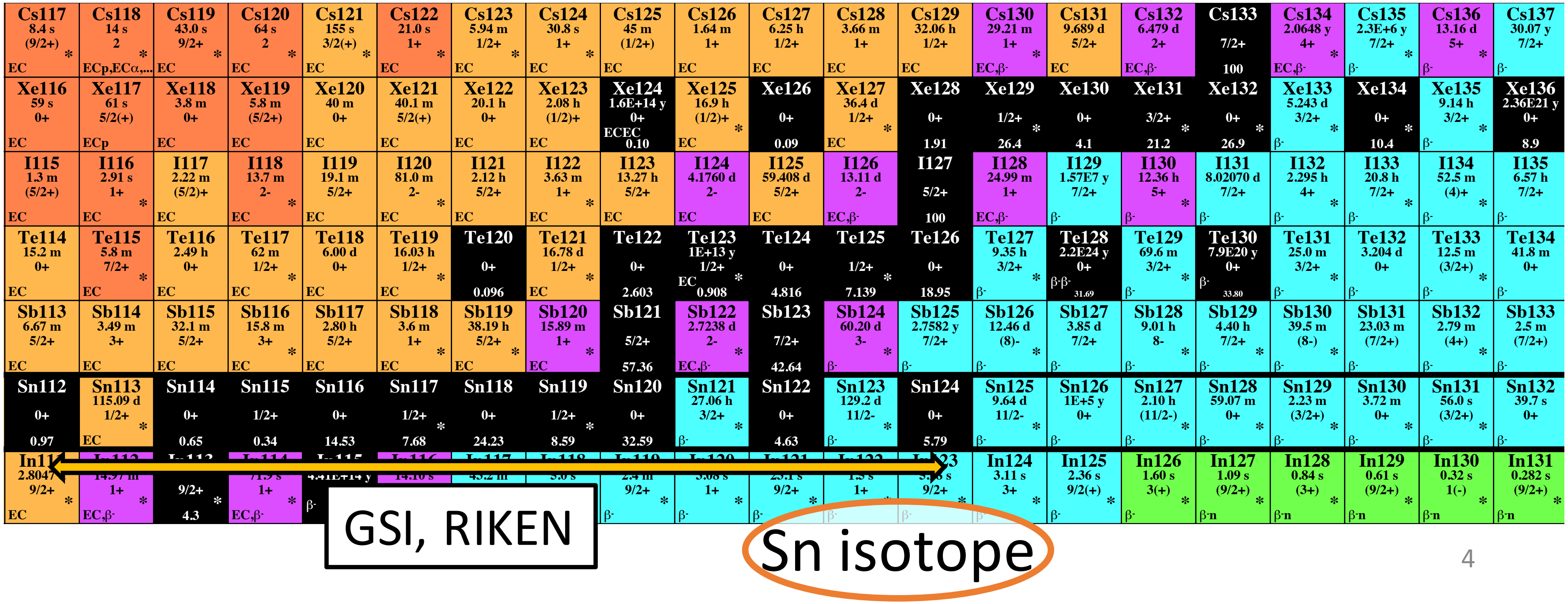
Gell-Mann-Oakes-Renner relation
Tomozawa-Weinberg relation

→ $$\frac{\langle\bar{q}q\rangle_\rho}{\langle\bar{q}q\rangle_0} \approx \frac{b_1^{\text{free}}}{b_1(\rho)}$$

$$U_s(r) = -\frac{2\pi}{\mu}\left[\varepsilon_1\{b_0\rho(r) + b_1[\rho_n(r) - \rho_p(r)]\} + \varepsilon_2 B_0\rho^2(r)\right]$$

Density dependence

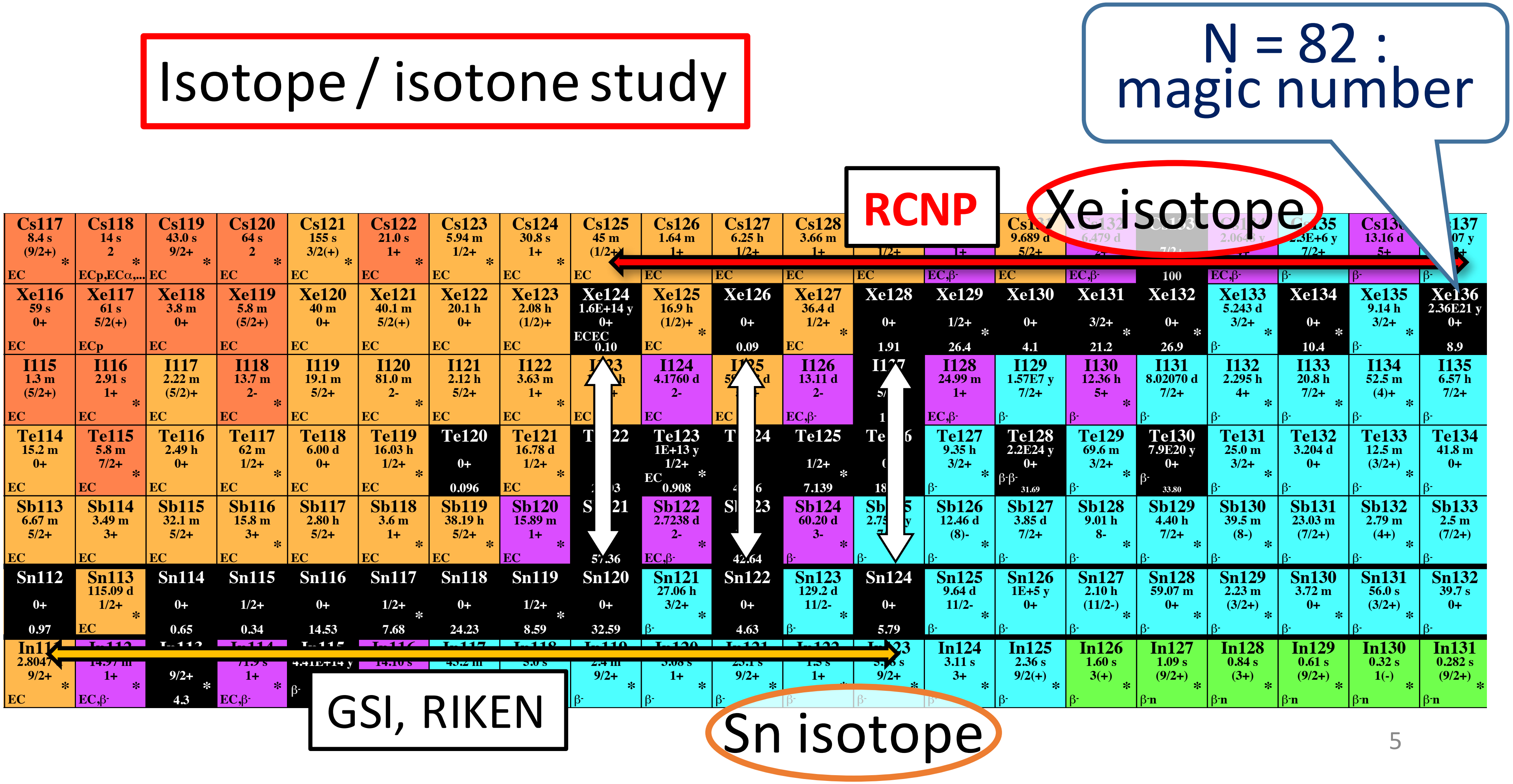
→ Need to study isotope / isotone dependence



- Xe : gas target
  - hard to use at GSI or RIKEN

→ RCNP (Research Center for Nuclear Physics)

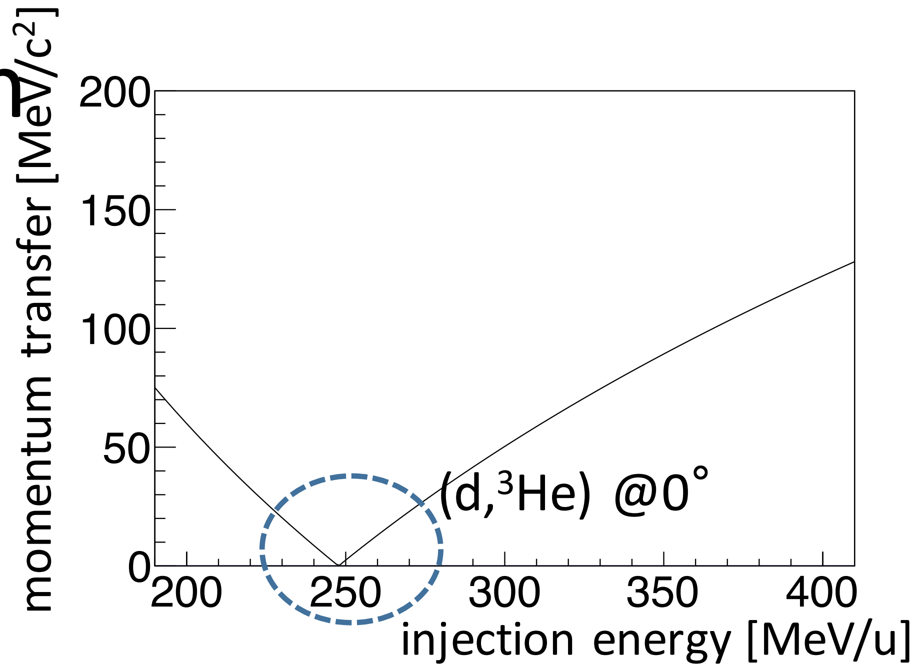
Isotope / isotone study



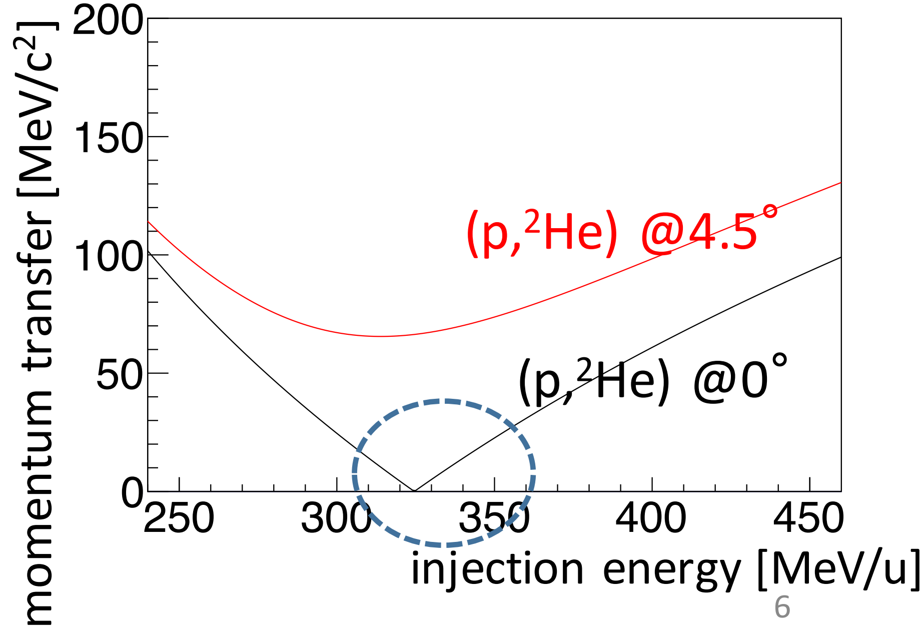
Choice of the reaction

- recoilless condition
  Beam energy
  - (d,^{3}He) ~250 MeV/u
  - (p,^{2}He) ~330 MeV

  Available at RCNP



pionic atoms with (p,^{2}He)
@RCNP

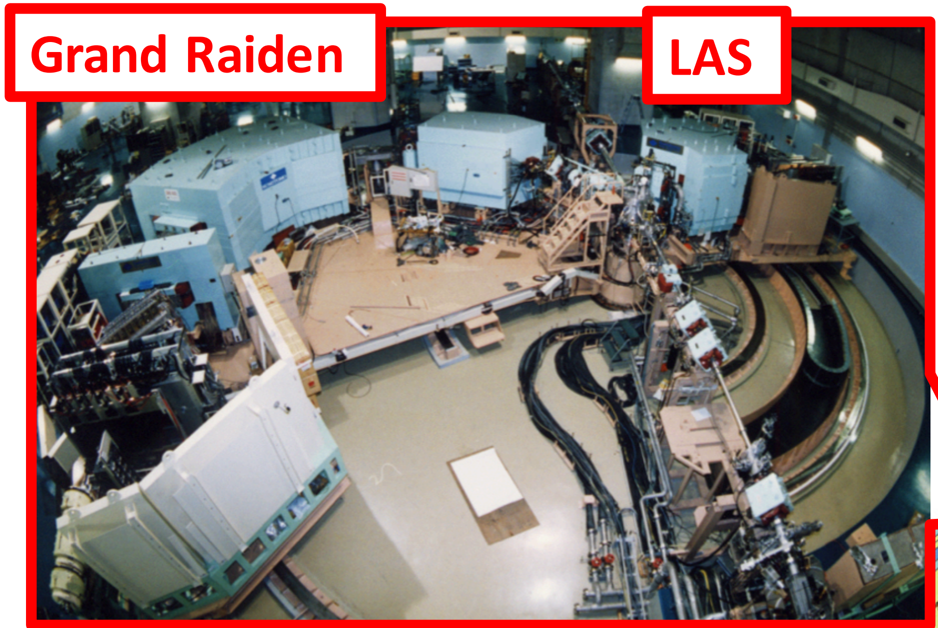


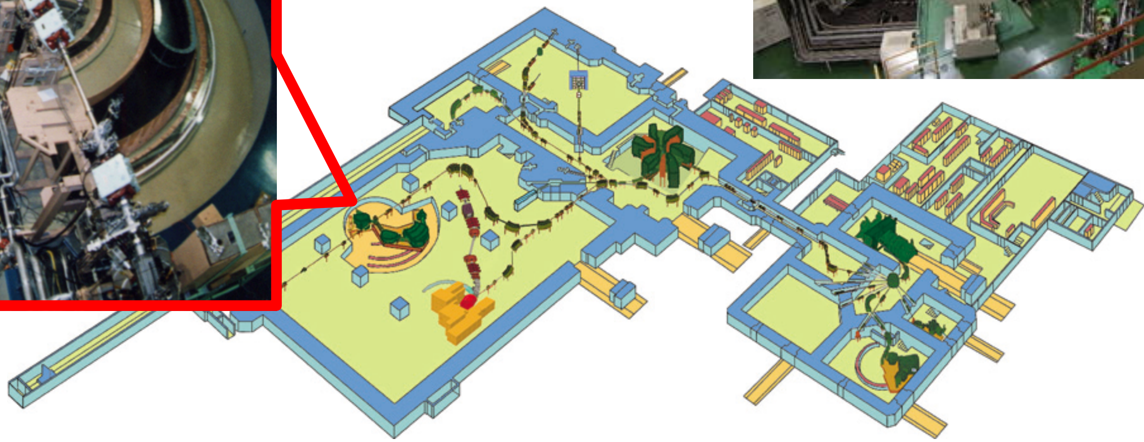
RCNP (Research Center for Nuclear Physics)

- AVF cyclotron + ring cyclotron
- The two-arm spectrometer :

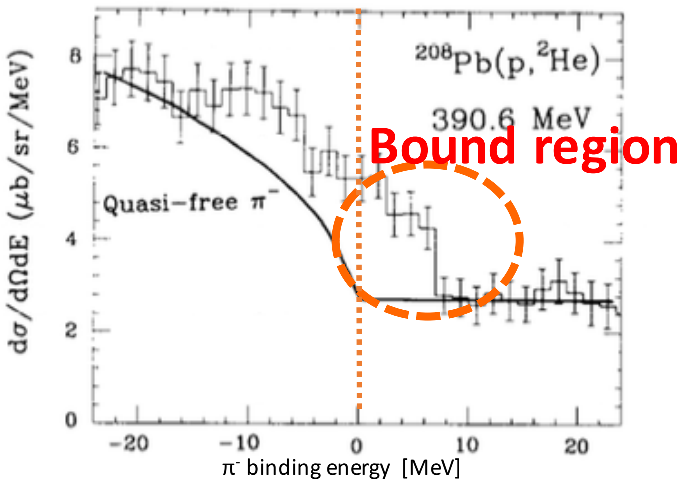
  Grand Raiden / LAS (Large Acceptance Spectrometer)

Proton energy :
up to 400 MeV





Pionic atom at RCNP : (p,^{2}He)



N. Matsuoka et al.,
Phys. Lett. B 359 (1995) 39.

- 1990s
  - Bound states was formed
  - Energy level couldn't be determined

    - resolution : 700 keV (FWHM)

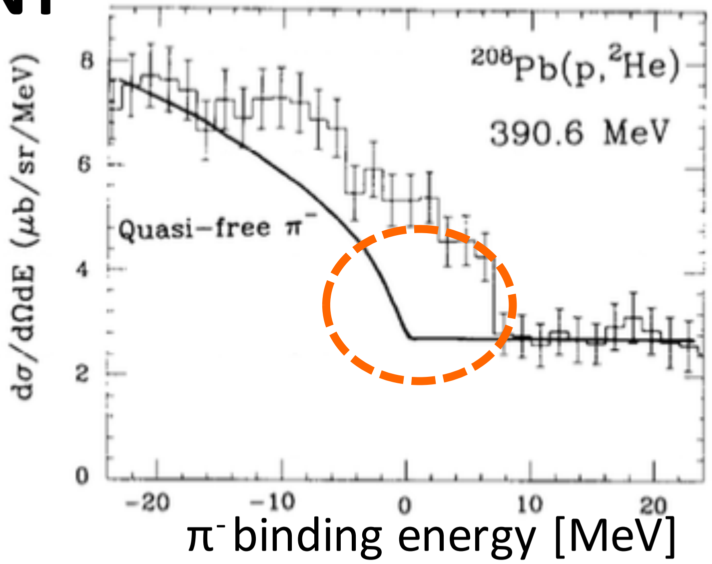
Improvement of the resolution

determination of the binding energy and the width

(p,^{2}He) reaction at RCNP

Previous experiment

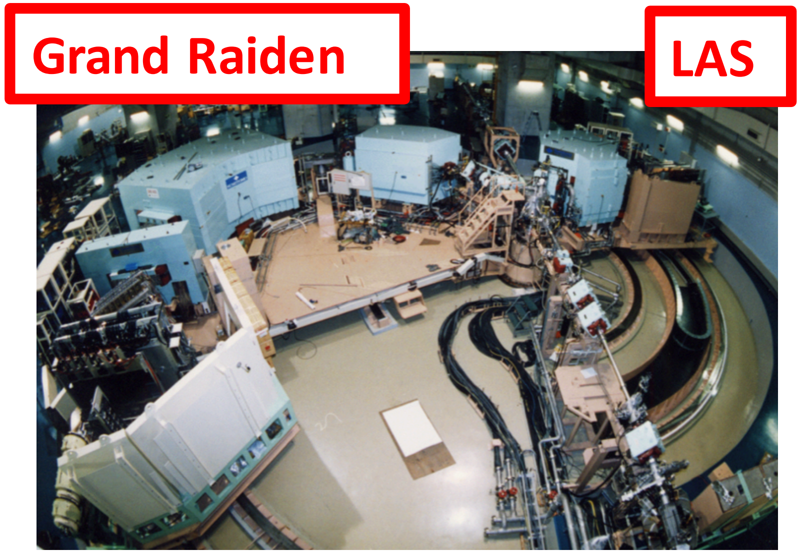
- LAS :
  - resolution 700 keV (FWHM)
  - acceptance : 2.4 msr
- Beam intensity : 0.5~1 nA



N. Matsuoka et al., Phys. Lett. B 359 (1995) 39.

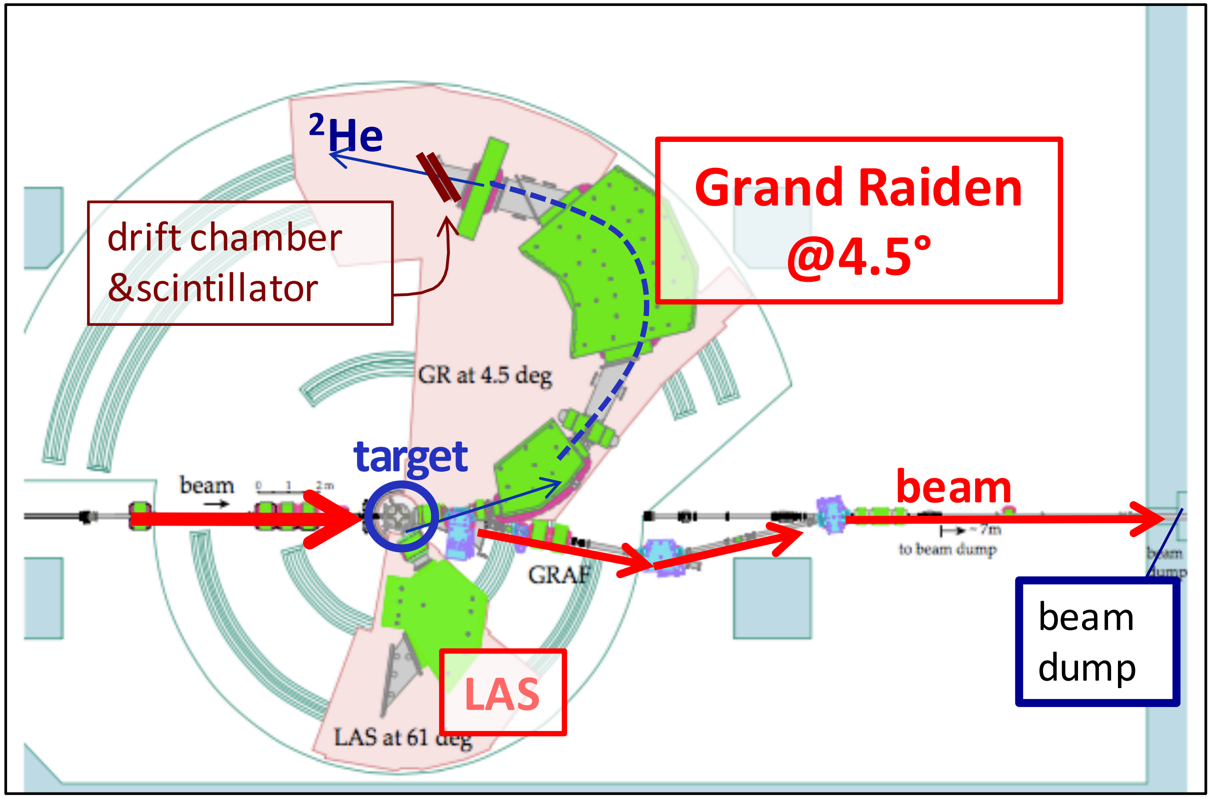
New experiment

- Grand Raiden
  - resolution ~250 keV (FWHM)
  - acceptance : 0.04 msr
- Beam intensity : ~30 nA



Experimental setup

- Grand Raiden ➡ Resolution : 200~250 keV (FWHM)
  - uncertainty of reaction vertex
  - beam resolution



- Intense beam :
  30 nA

Schedule / Future plan

Phase 0 (2015 – 2016)

- Test experiment – feasibility study

Phase 1

- Pilot experiment
  - target : ^{124}Sn
- Proposal was submitted

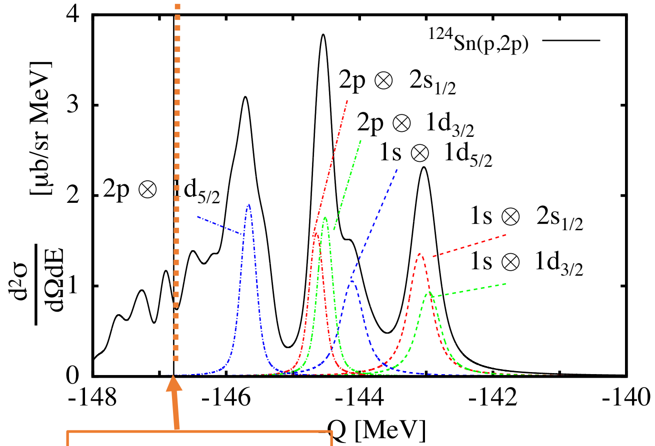
Phase 2

- Target : Xe

Phase 1 experiment – expected spectrum

- Grand Raiden @4.5°
- ^{124}Sn target (30 mg/cm^2)
- 350 MeV proton beam
- Beam intensity : 30 nA, 10days

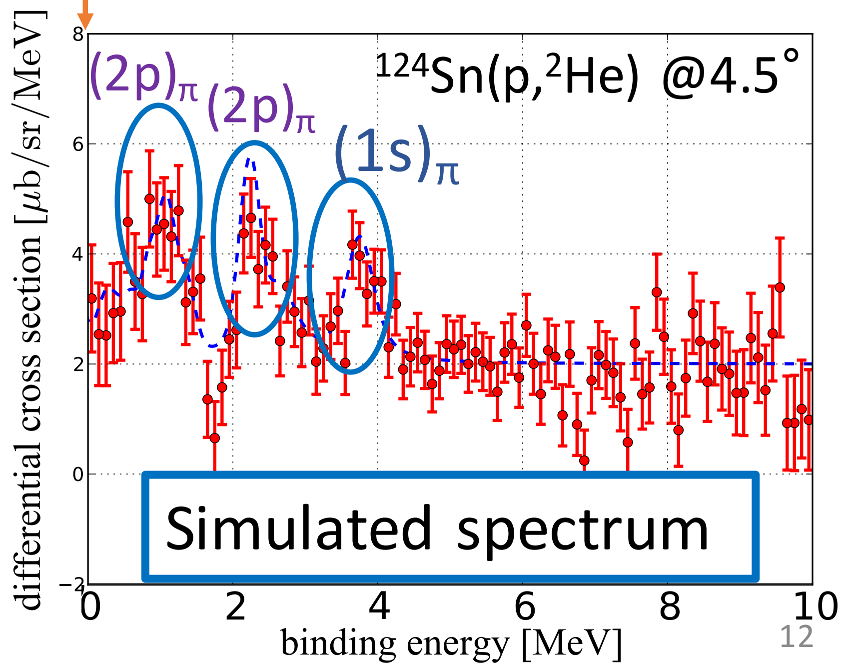
Observe 3 peaks



Theoretical calculation

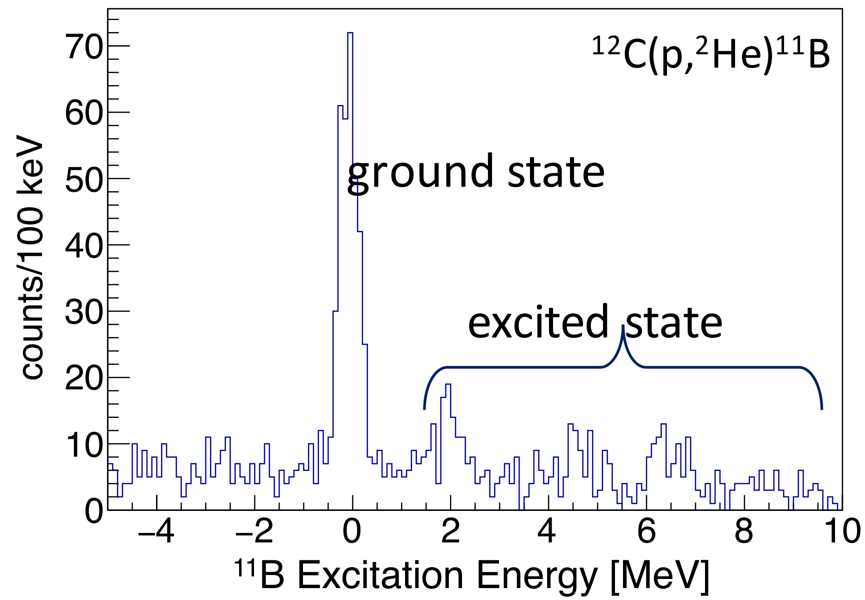
J. Yamagata-Sekihara, N. Ikeno, and S. Hirenzaki, private communication.

πB=0 [MeV]



Feasibility study

- Detection of ^{2}He at Grand Raiden
  - Observed $^{12}C(p,^{2}He)^{11}B$



- Test for intense beam
- Background measurement
- How to check the beam stability
- Optics study

Summary

- (d,^{3}He) – GSI, RIKEN
- (p,^{2}He) – RCNP
  - Possible to use Gas target
  - high precision measurement
    - Grand Raiden – high resolution
- Test experiment at RCNP
- Proposal was submitted
- Target : ^{124}Sn ----→ Xe isotopes (future plan)