Alpha Inelastic Scattering and Cluster Structures in Neutron-Rich Nuclei

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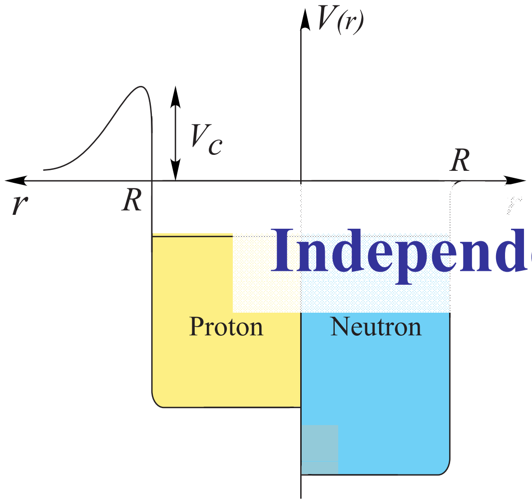
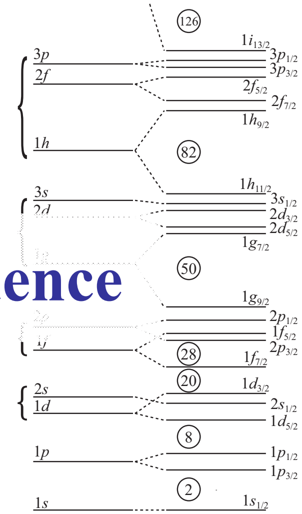
Introduction

Two different pictures of Nuclear Structure

Shell Model



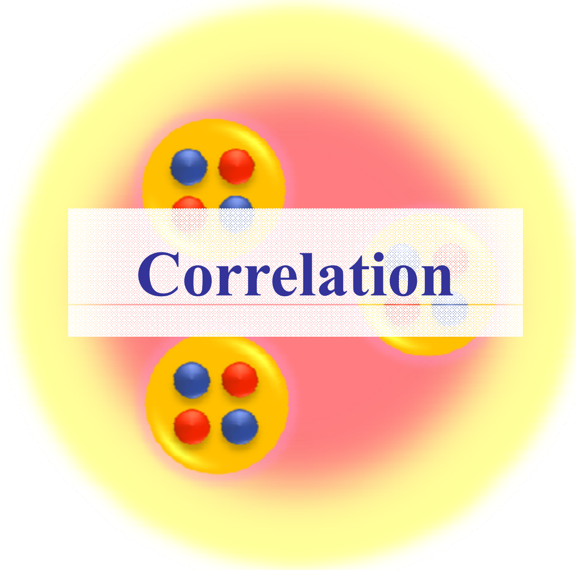


Independence

SU(3) Limit

Multi-$\hbar\omega$ Configuration

Cluster Model



Correlation

Single-particle orbit in the mean-field potential.

Magic numbers (2, 8, 20, ...).

Describes well single-particle excited states.

Strong correlation between nucleons.

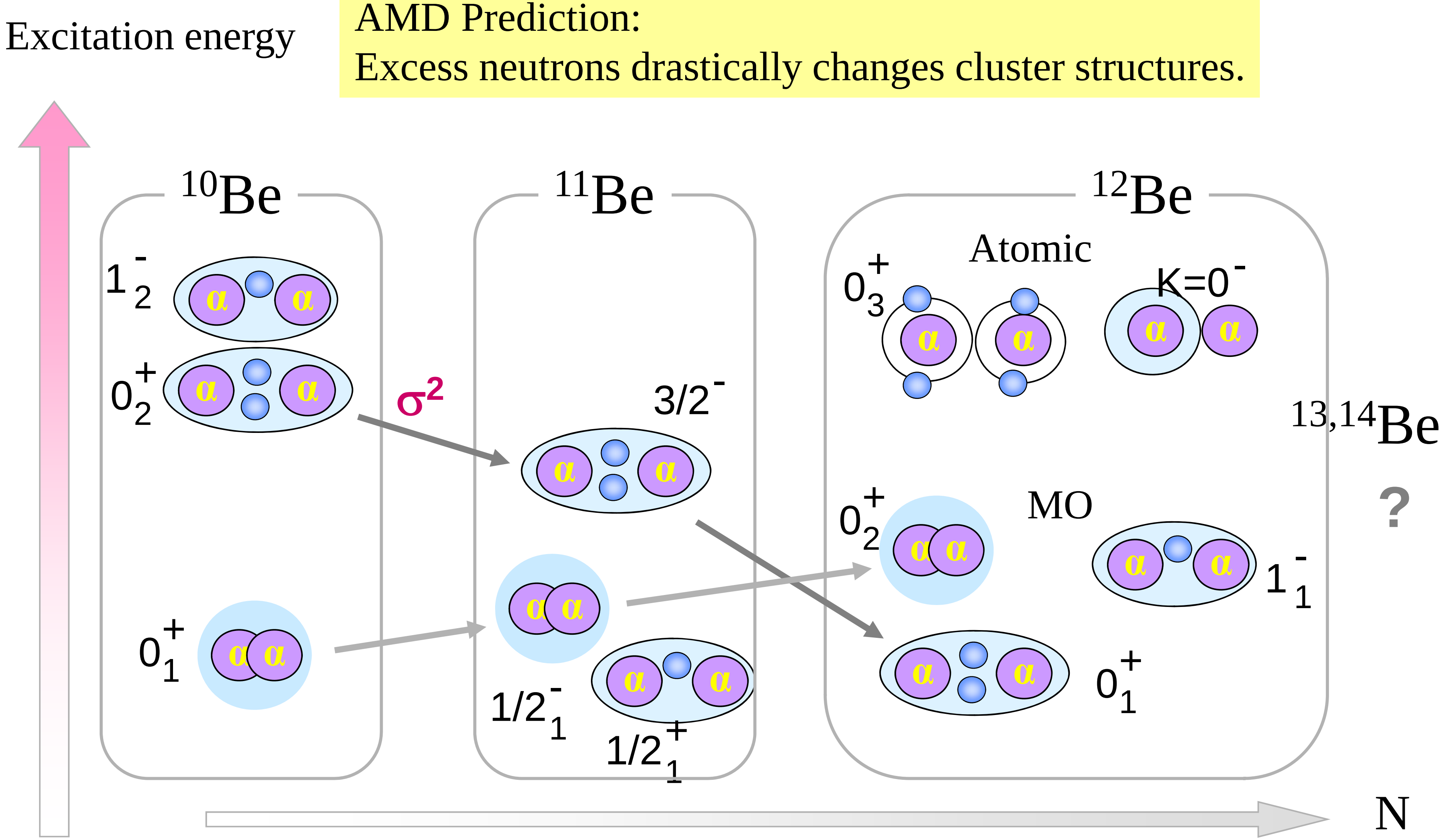
Cluster consists of several nucleons.

Clusters are weakly bound.

It is important to study appearance and disappearance of the cluster correlation for understanding the complex quantum many-body system "Atomic Nucleus".

α Cluster Structures in Be Isotopes

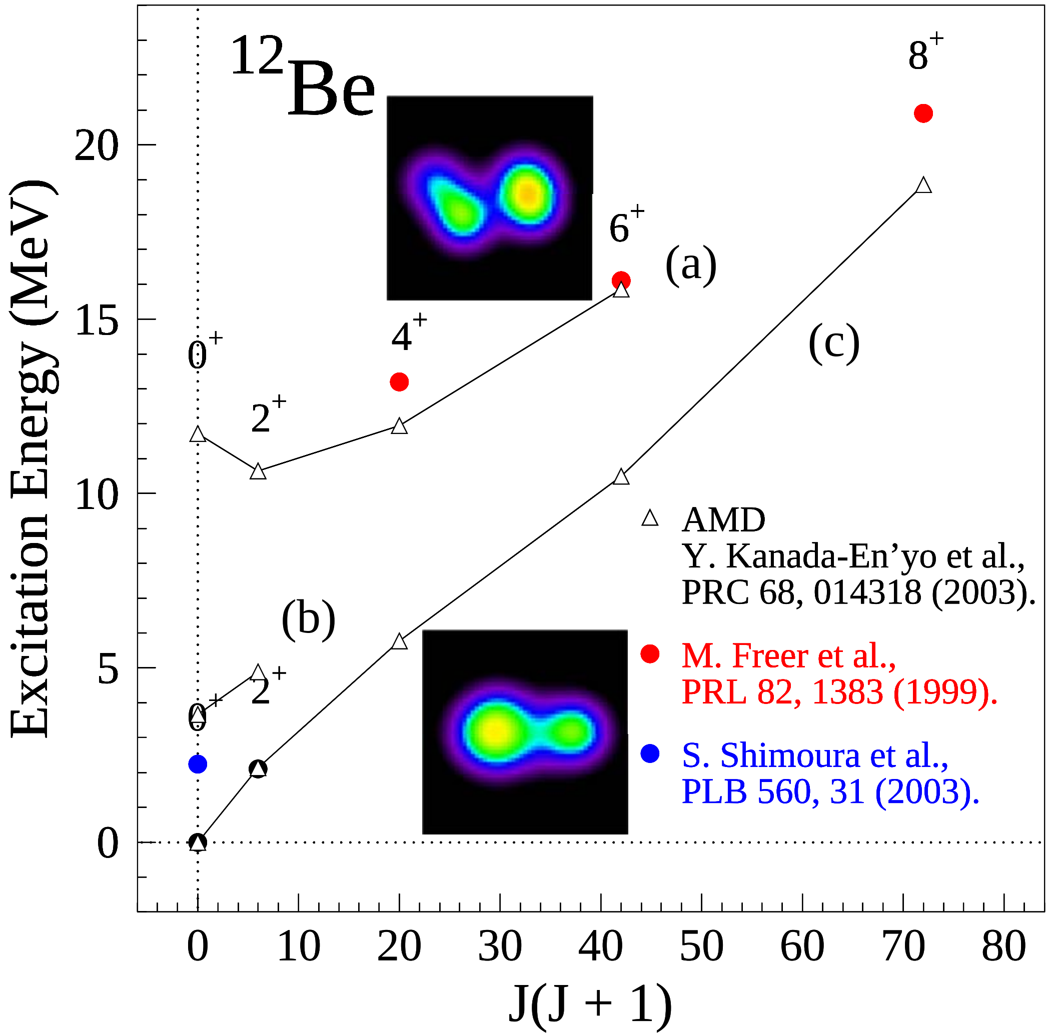
AMD Prediction:
Excess neutrons drastically changes cluster structures.

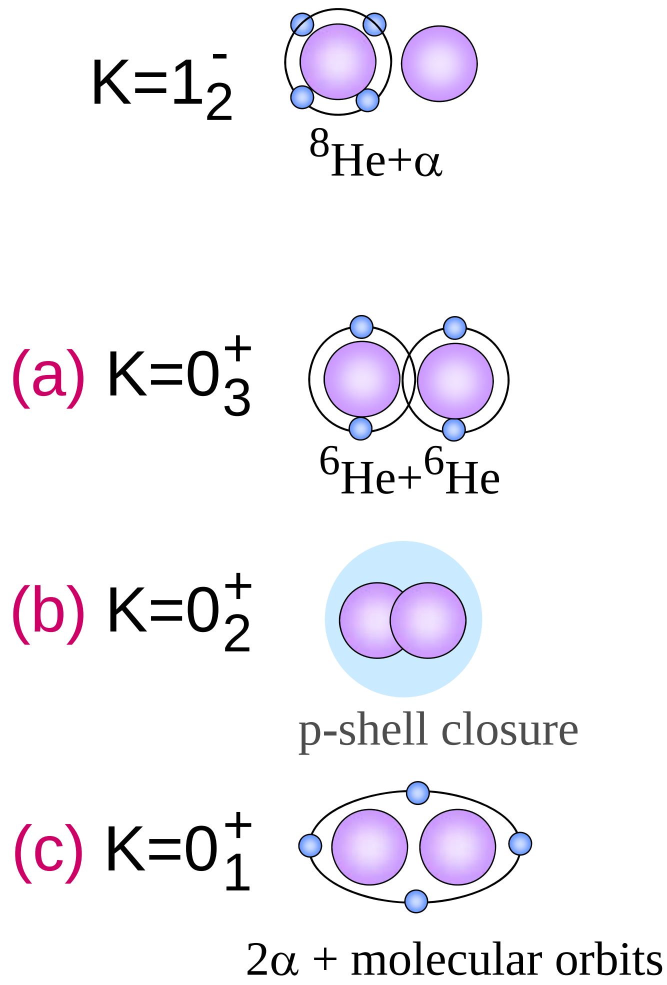


Slide by Y. K-En'yo

α Cluster Structures in ^{12}Be

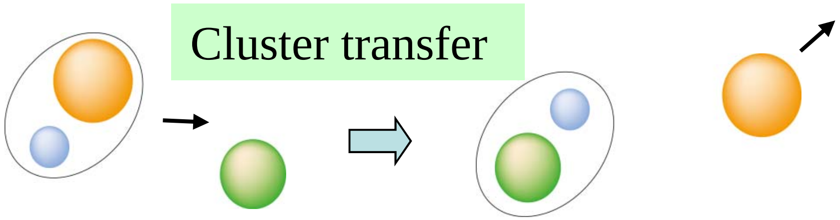
Candidates for the Atomic and Molecular states were observed.

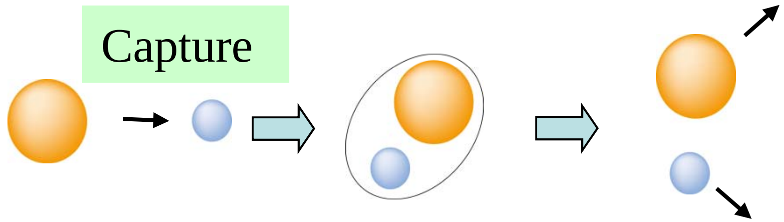




How should we excite Cluster States?

Various reactions were devoted to excite cluster states.





- ✓ Cluster-transfer reaction
  - ☹ Complex reaction mechanism due to the low incident energy.
  - ☹ Small reaction cross section.
  - ☹ Limited energy resolution.
- ✓ Low-energy resonant capture reaction
  - ☹ Sensitive above the cluster-emission threshold only.
  - ☹ Coulomb barrier disturbs the reaction near the threshold.

Inelastic scattering can be a complementary probe.

☺ Simple reaction mechanism at intermediate energies.

☺ High resolution measurement is possible.

☺ Sensitive to the entire E_x region.

☺ Selectivity for the isoscalar natural-parity excitation..

E0 Strengths and α Cluster Structure

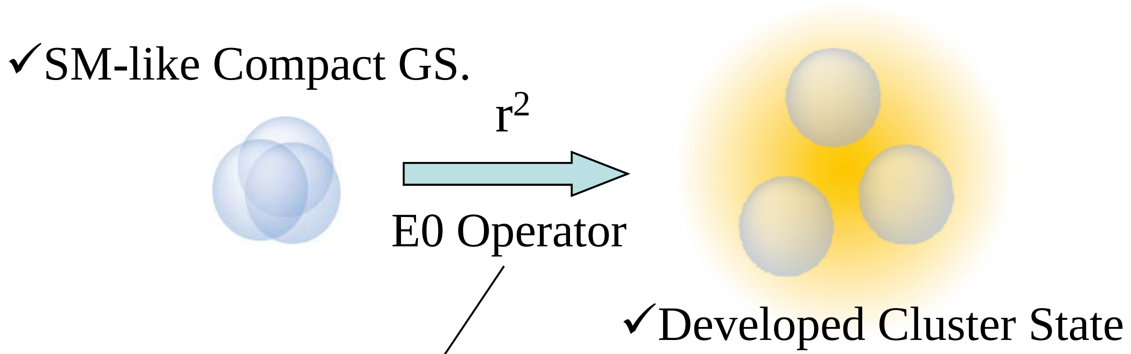
Large E0 strength could be a signature of spatially developed α cluster states.

T. Kawabata *et al*., Phys. Lett. B **646**, 6 (2007).

0^+_2 state in ^{12}C: B(E0; IS) = 121±9 fm^4

Single Particle Unit: B(E0; IS)$_{s.p.}$ ~ 40 fm^4

- ✓ SM-like compact GS w.f. is equivalent to the CM w.f. at SU(3) limit.
- ✓ GS contains CM-like component due to possible alpha correlation.



Monopole operators excite inter-cluster relative motion.

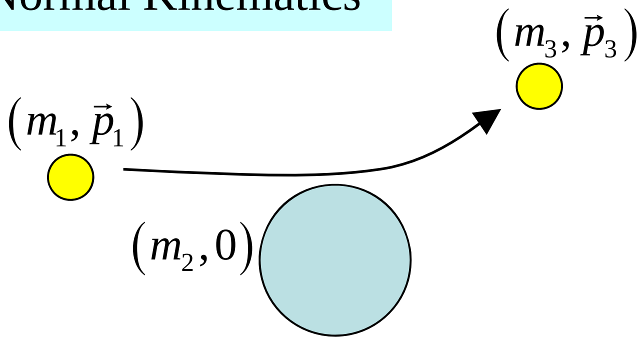
T. Yamada *et al*.,
Prog. Theor. Phys. 120, 1139 (2008).

E0 strength is a key observable to examine α cluster structure.

Inelastic Scattering with RIB

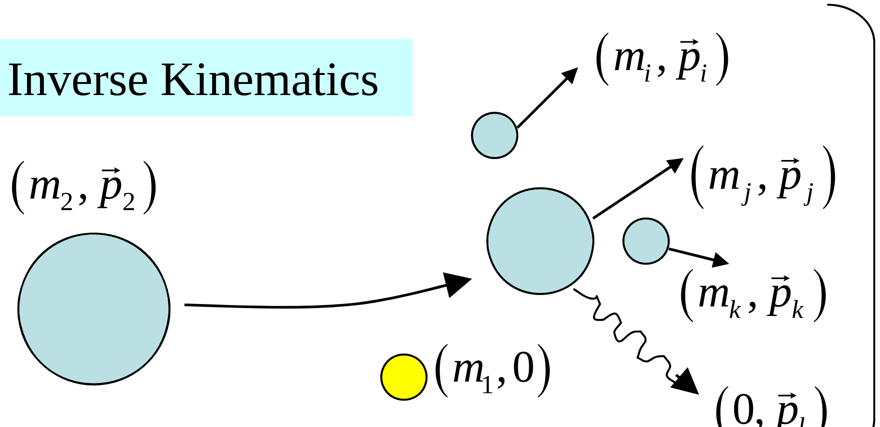
Inverse kinematics must be employed in RI-beam experiments.

Normal Kinematics



Missing mass spectroscopy

Inverse Kinematics



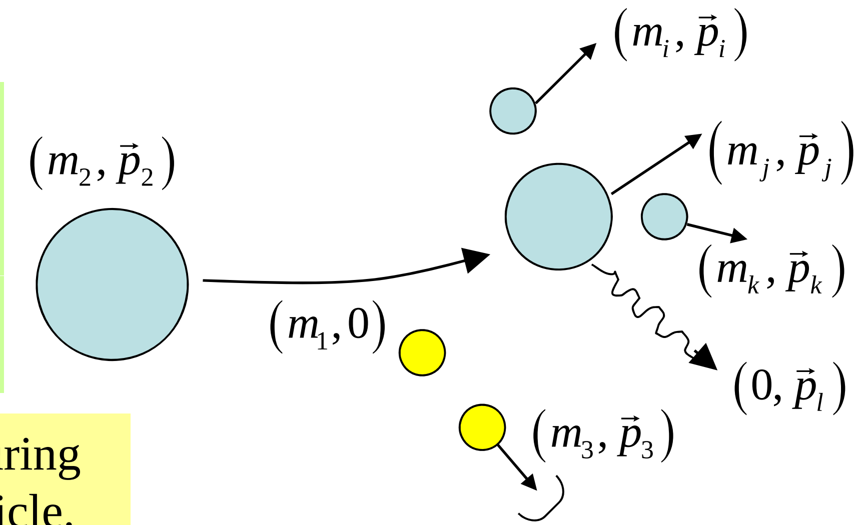
Invariant mass spectroscopy

Brute force solution:

Invariant mass spectroscopy by measuring all the decaying particles.

→ SAMURAI spectrometer

☹ Limited to low multiplicity decay channels.



Missing mass spectroscopy is possible by measuring the low-energy (100 keV to 20 MeV) recoil particle.

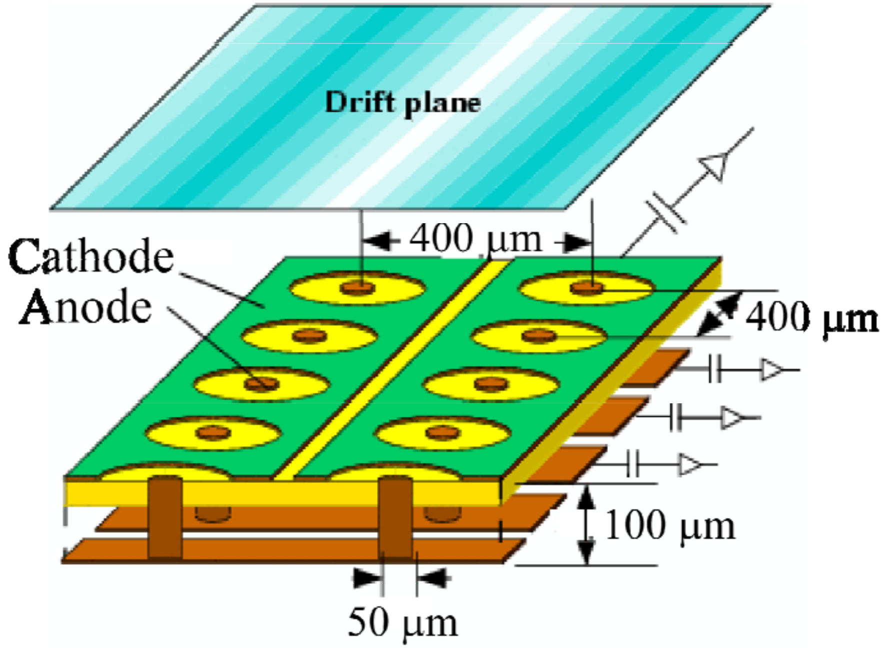
→ Active target

Missing mass spectroscopy with RIB

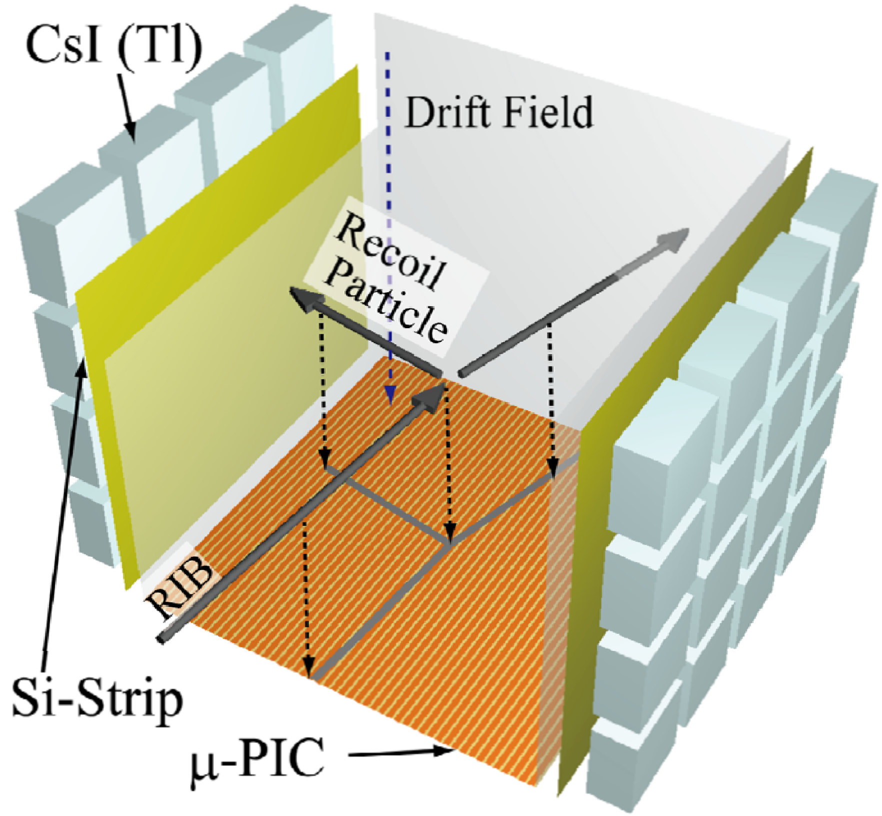
Active Target with μ-PIC

New active target is needed for precise measurement of recoiled α particles.

Active target enables missing-mass spectroscopy.



Micro-Pixel Chamber (μ-PIC)
- High gas gain (> 10^4)
- Good position resolution (~100 μm)
- High allowable rate (10^7 cps/mm^2)



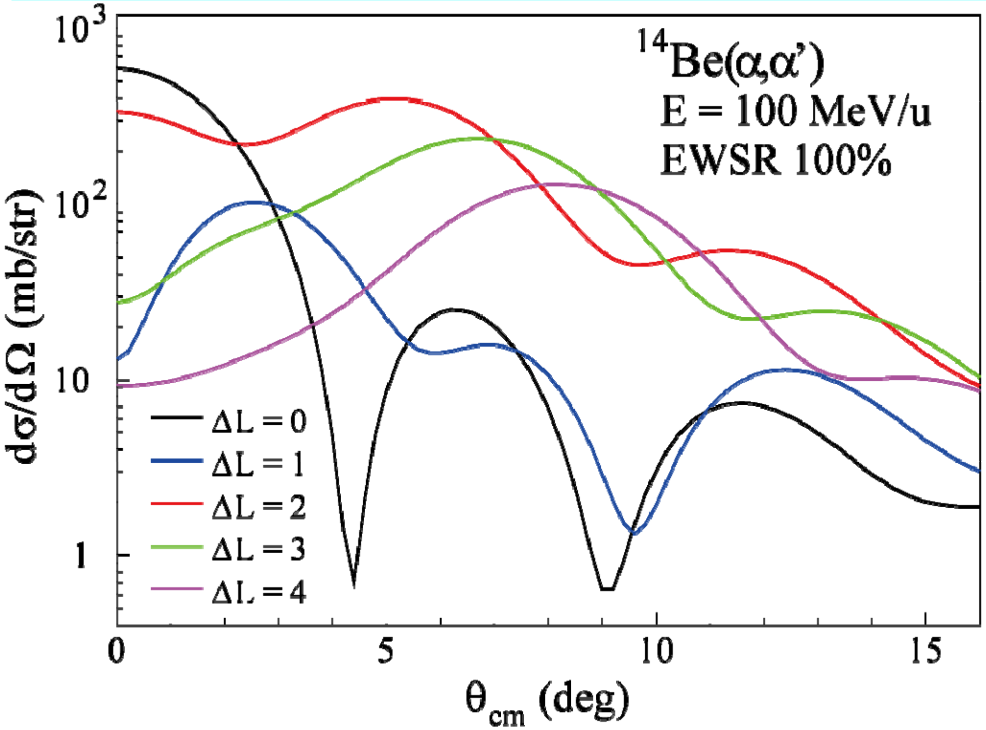
Development of a new TPC with μ-PIC has just launched at RCNP.

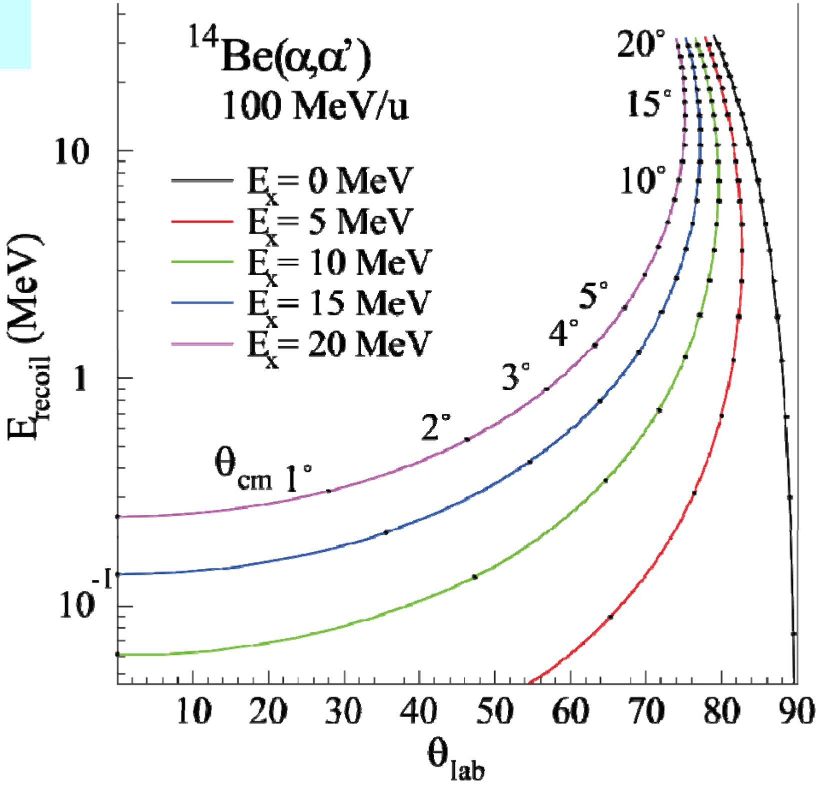
Effective volume: 10 × 10 × 10 cm^3

To be studied:
- Behavior with He gas at low pressure.
- Rate dependence.
- Resolution (Position, Energy)

Kinematical Conditions

Beam energy of 100 MeV/u is selected.
- Simple reaction mechanism.
- Dominance of V_0 term in effective NN int.
- Rich experiences at RCNP.

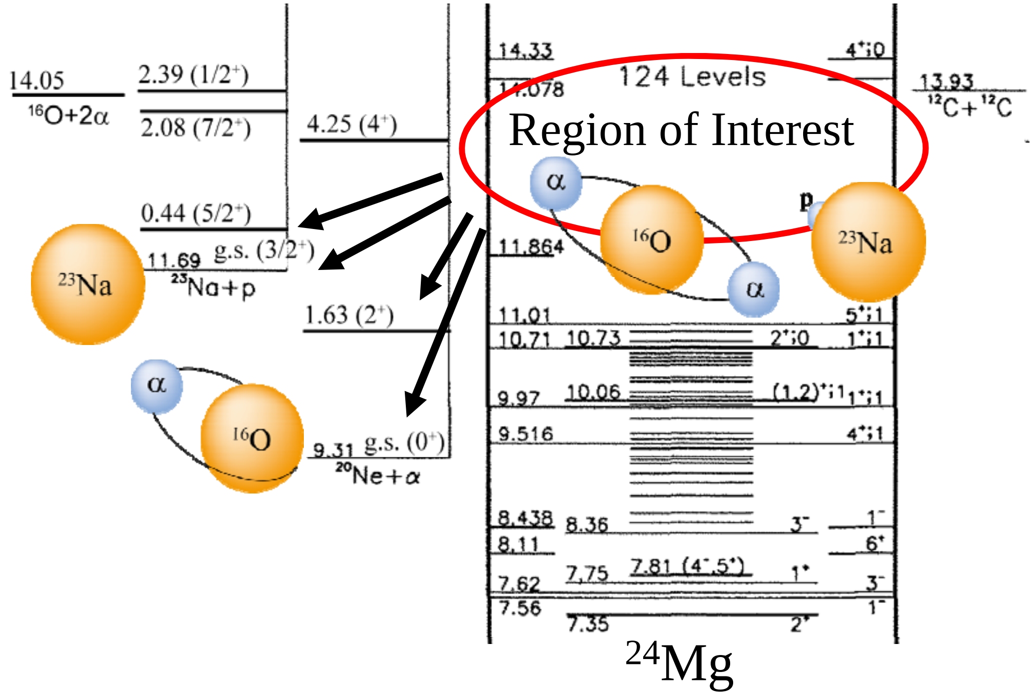


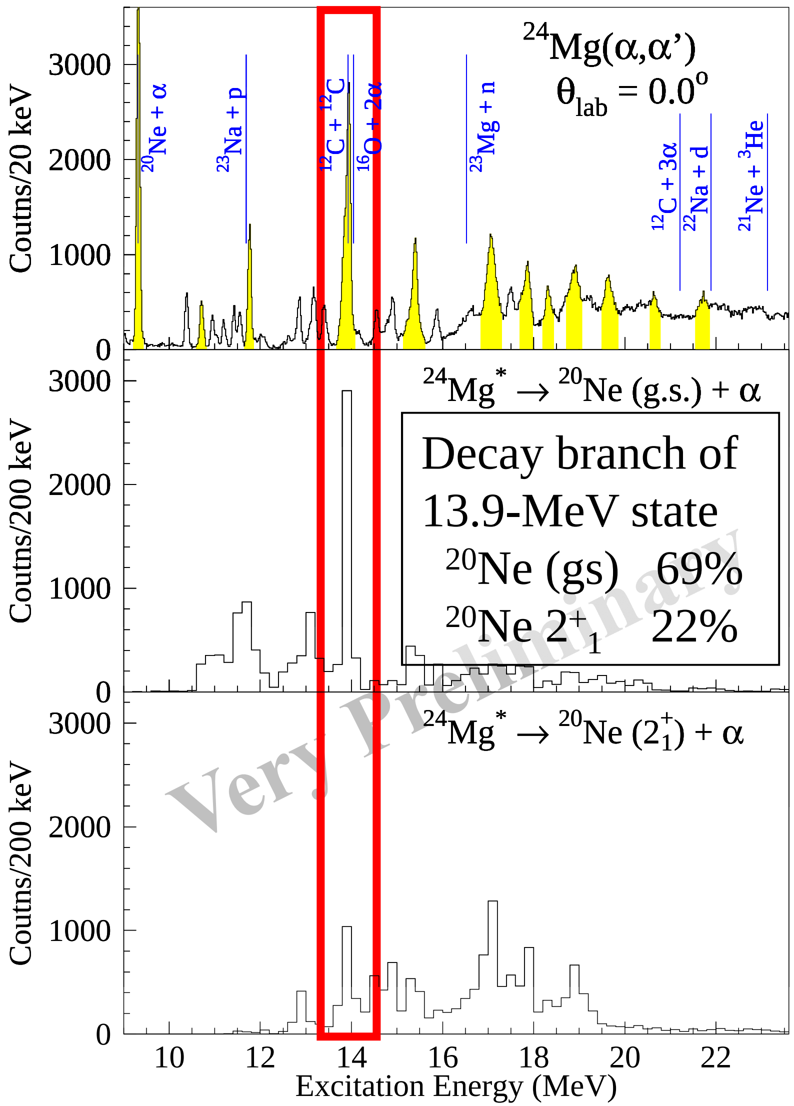


- Monopole transition is strong at $\theta_{cm} < 2^\circ$.
- Recoil α particles are emitted in wide angular range of θ_{lab}~30—80°.
- Energies of recoil α particles are 100 keV—20 MeV.

Decay Particles from α Condensed States

Decay-particle measurement provides structural information.





Complementary information for the E0 strength is expected.

– α cluster state should prefer to decay into the alpha-decay channel.

Decay particles can be analyzed by SAMURAI spectrometer.

α Inelastic Scattering at RIBF

α inelastic scattering from unstable nuclei should be measured at RIBF.

Proposed Experiment:

Combined measurement of invariant and missing mass spectroscopy under the inverse kinematics condition.

Yield Estimation:

Primary Beam: ^{18}O 150 MeV/u 100 pnA

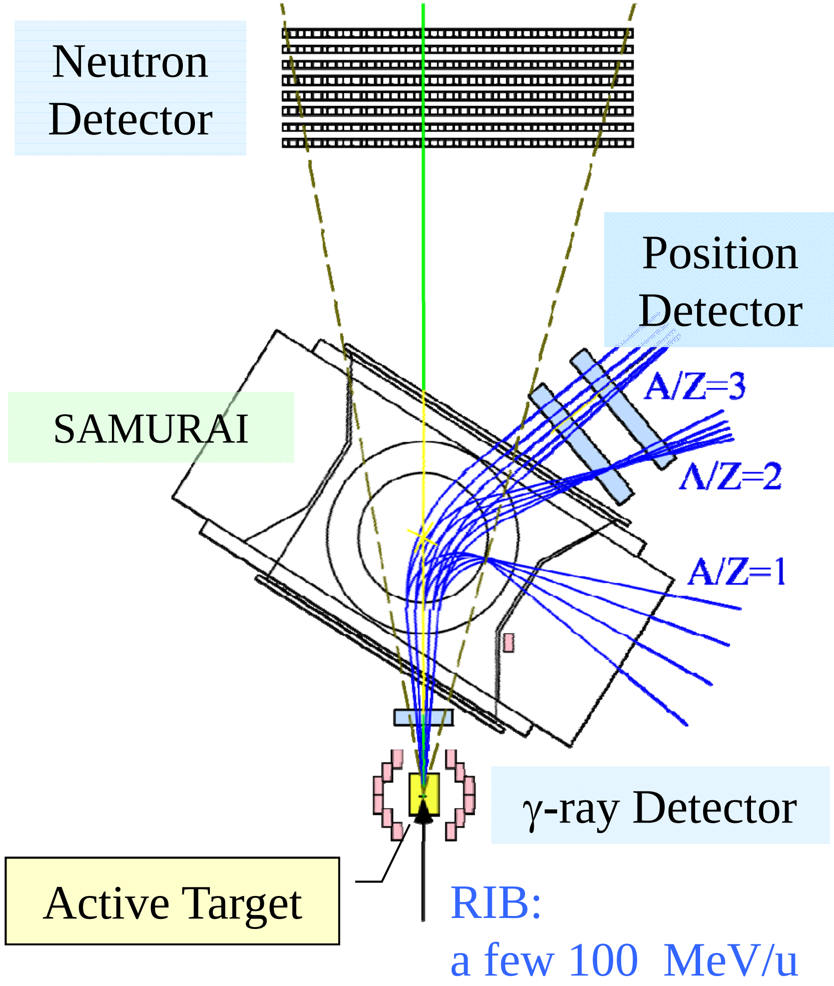
Secondary Beam: ^{10,12}Be > 10^{6} cps,
^{14}Be ~ 4×10^{4} cps

Target: ^{nat}He 10 cm@0.2 atm (330 μg/cm^2)
$N_T \sim 5 \times 10^{19}$ /cm^2

Expected cross section:
~ 50 mb/Sr for 10% of EWSR

Expected Yield:
100 cph for ^{10,12}Be, 4 cph for ^{14}Be @ 10 mSr

Possible Setup



Summary

- Alpha inelastic scattering measurement is proposed to examine the alpha cluster structure in neutron-rich nuclei.
- Combined measurement of Invariant and Missing mass spectroscopy.
  - Invariant mass spectroscopy with SAMURAI.
    - For very forward angles and low multiplicity decay channels.
  - Missing mass spectroscopy with active target.
    - For the other angles.
    - Decaying particle measurements with SAMURAI.
- Development of the new active target with μ-PIC has launched at RCNP.