Search for alpha condensed states by measuring alpha inelastic scattering

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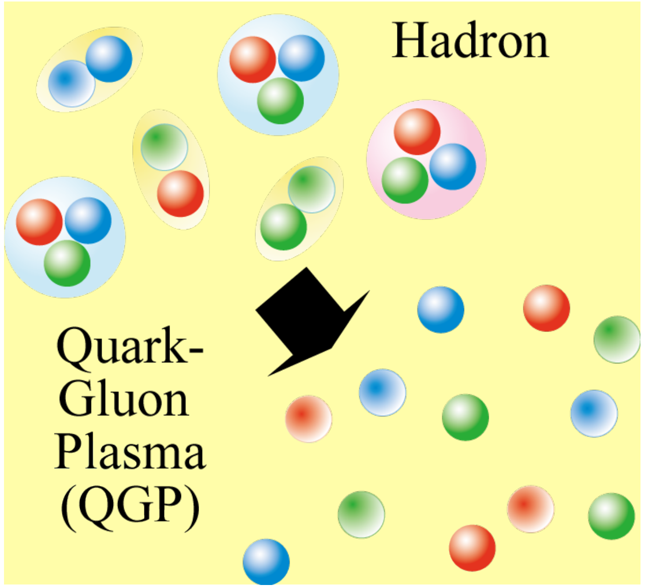
Cluster Structures

Cluster structures can be seen on all physical scale.

Galaxy

Hadron



A galaxy contains 10^7—10^{12} stars.

50—100 galaxies constitute a cluster of galaxies.

Quarks are confined in hadron at normal T.

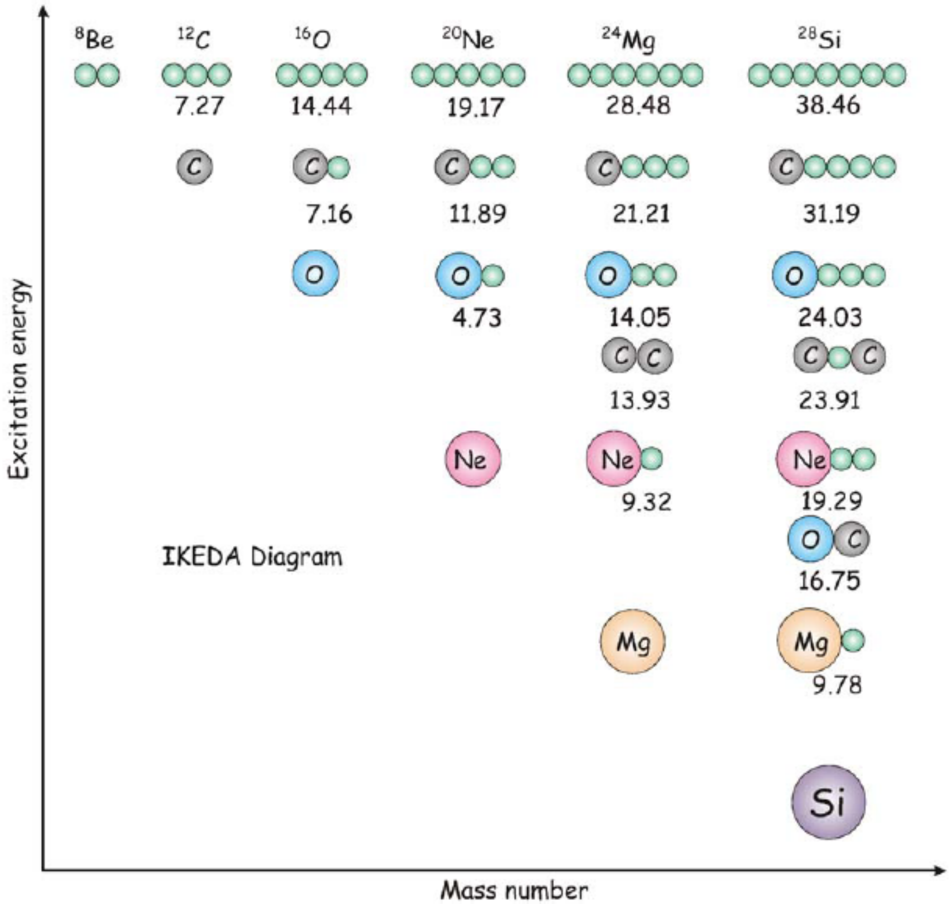
Quarks are deconfined and form QGP at high T.

Cluster correlation is very important to study the dynamics on each physical scale.

Cluster States in N = 4n Nuclei

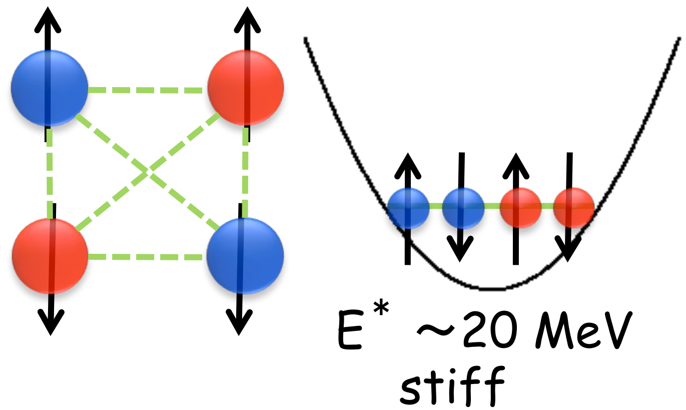
α clustering is an important concept in nuclear physics for light nuclei.

α cluster structure is expected to emerge near the α-decay thresholds in N = 4n nuclei



The most tightly bound light cluster

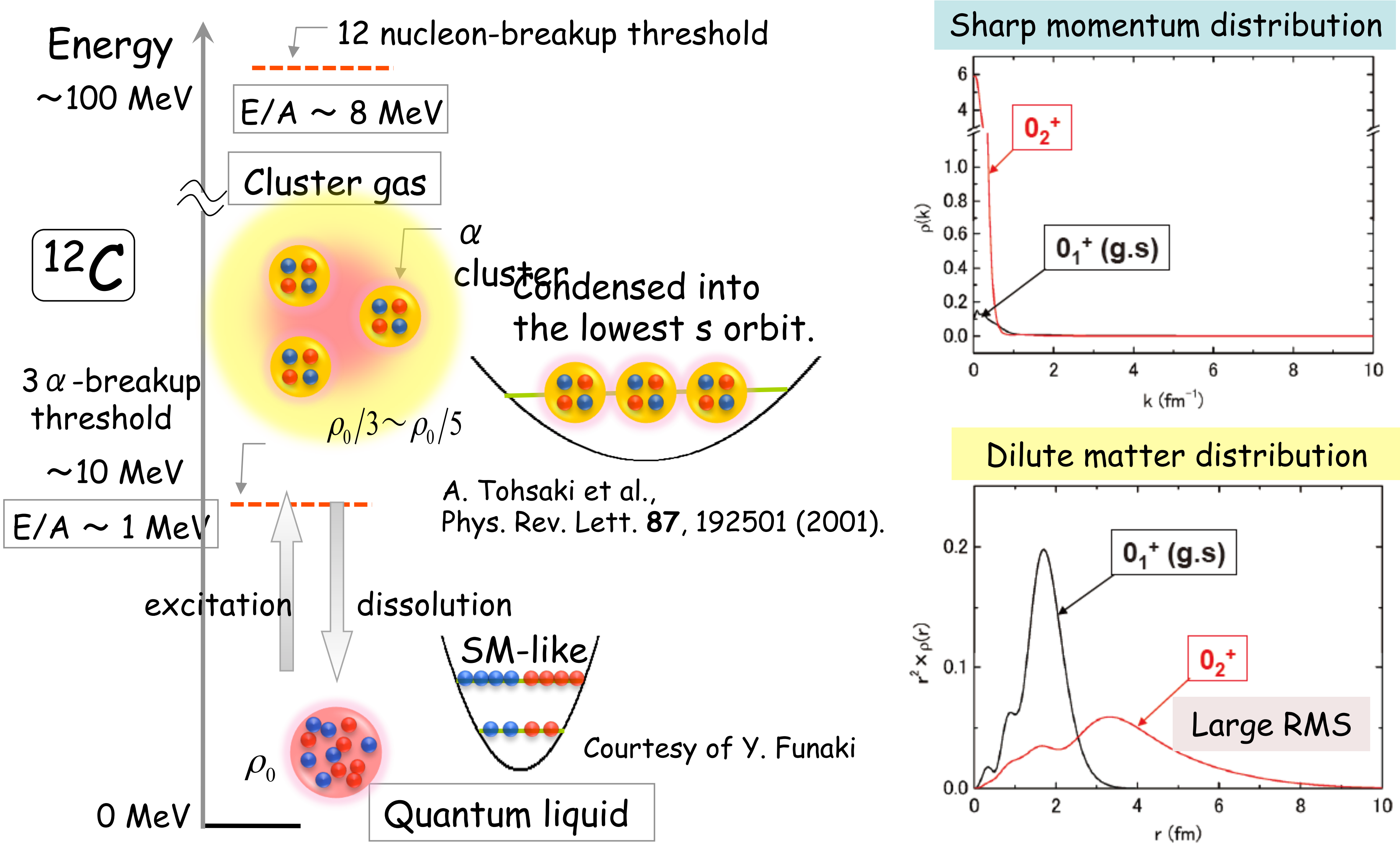
α particle (quartet)



The most elemental subunit in nuclear cluster structures.

The 0^+_2 state at E_x = 7.65 MeV in ^{12}C is a famous 3α cluster state.

Alpha Condensed States in ^{12}C



Maybe, a new conformation of dilute nuclear matter.

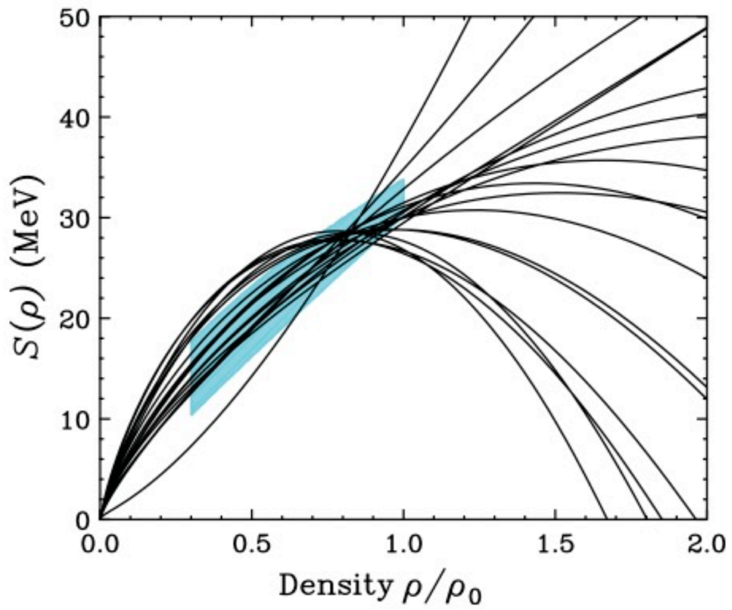
ACS and Symmetry Energy

If α condensed states universally exist in various nuclei ….

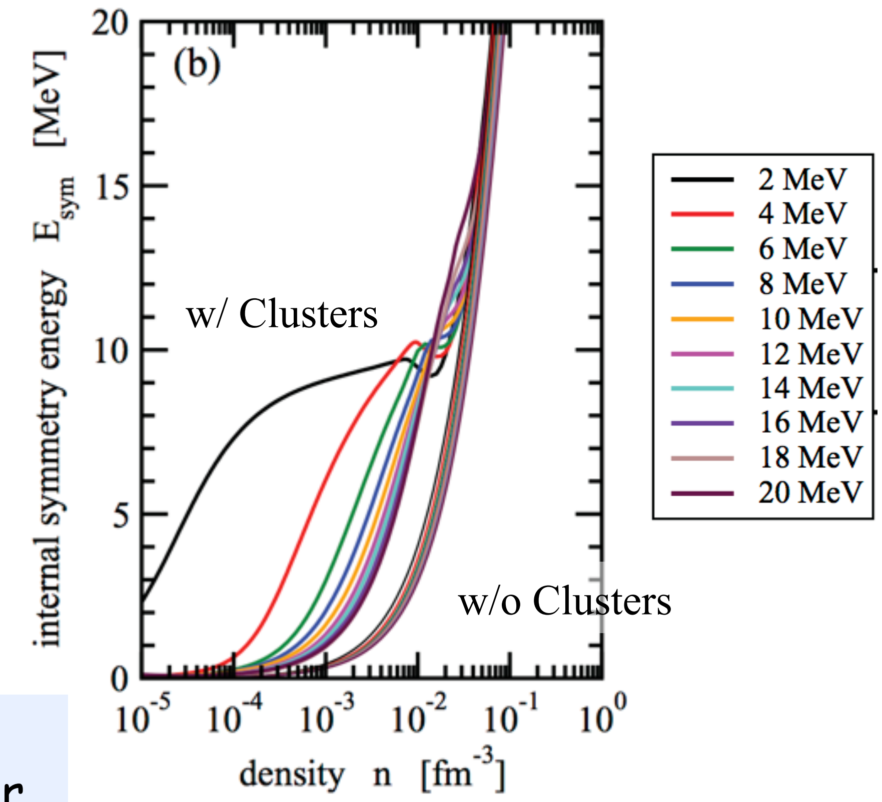
→ Establish α condensed phase as a conformation of the dilute nuclear matter

→ Might appear on the surface of neutron stars

→ Energy and width of ACS give an insight to the dilute nuclear matter.



ACS affects
macroscopic natures of nuclear matter.



S. Typel *et al.*, Phys. Rev. C 81, 015803 (2010).

α Condensed States in Heavier N = 4n Nuclei

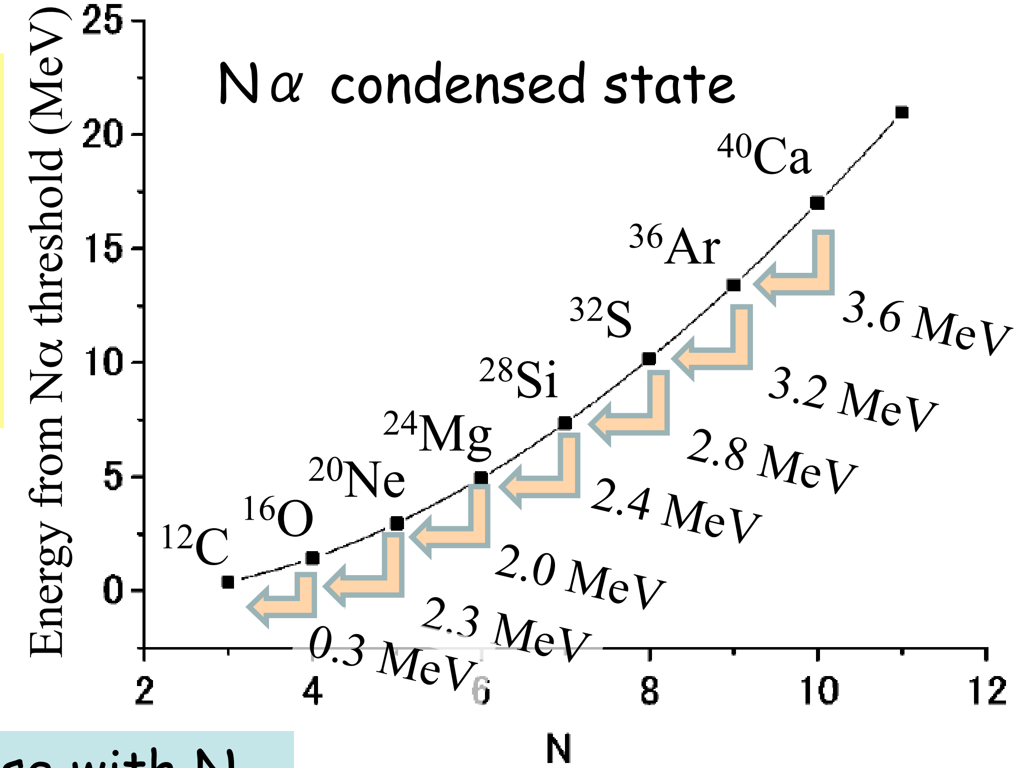
a condensed states in ^{8}Be and ^{12}C seem to be established.

a condensed states in heavier nuclei (A<40) are theoretically predicted.

Short range α - α attraction
Long range Coulomb repulsion

⇓

Energy of dilute Nα state increase with N.
Nα are confined in Coulomb barrier.



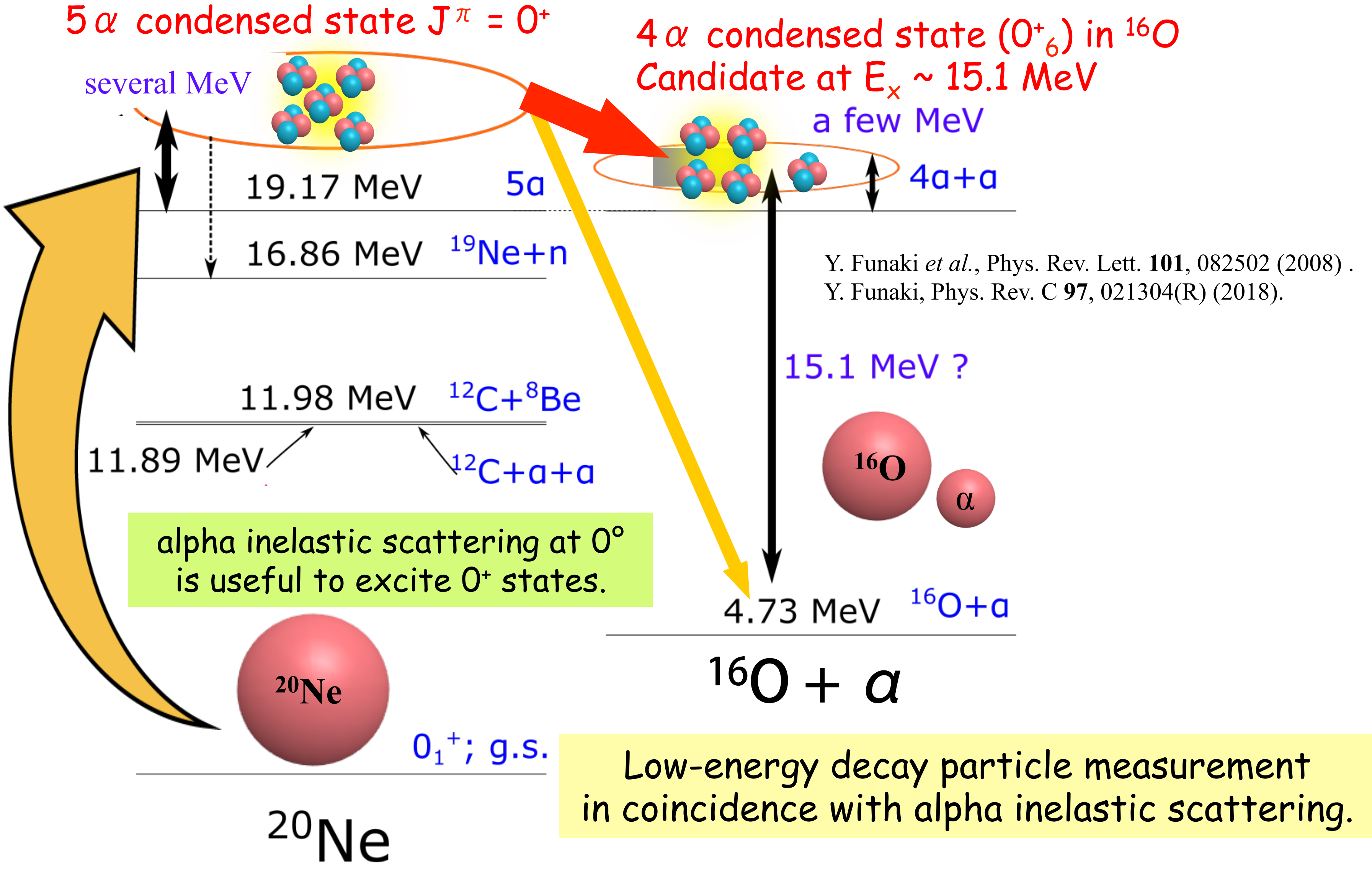
T. Yamada and P. Schuck, Phys. Rev. C **69**, 024309 (2004).

If such Nα condensed states are formed, they should sequentially decay into lighter α condensed states by emitting α particles.

α decay measurement might be a probe to search for the α condensed state.

Decay of Alpha Condensed state in ^{20}Ne

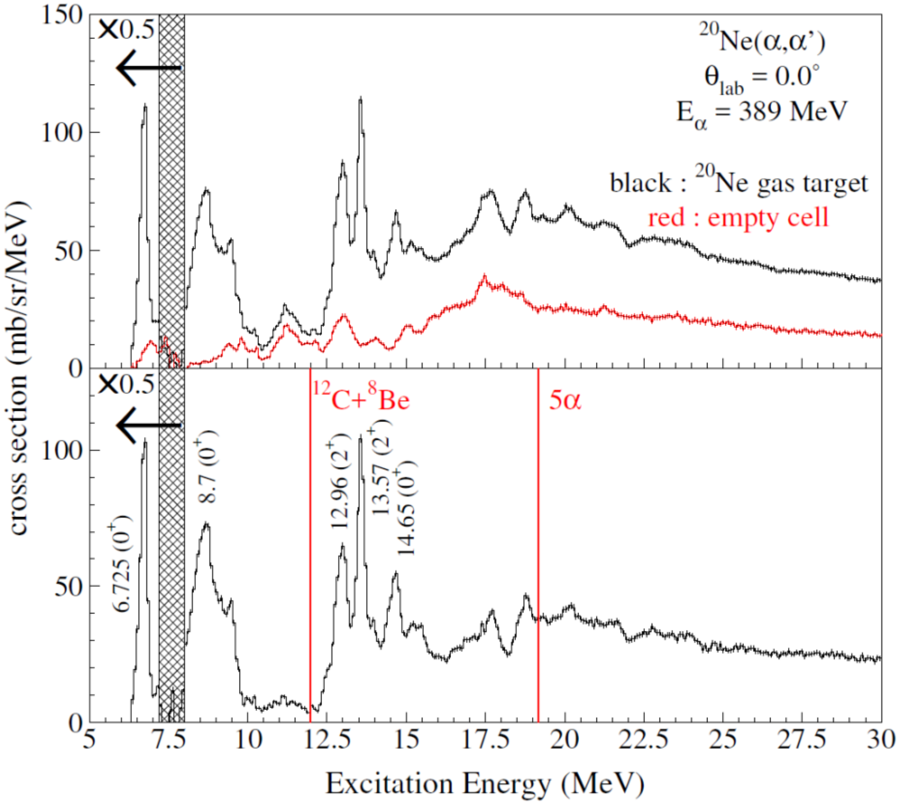
ACS decays via ACM in lighter nuclei by emitting low-energy α particles

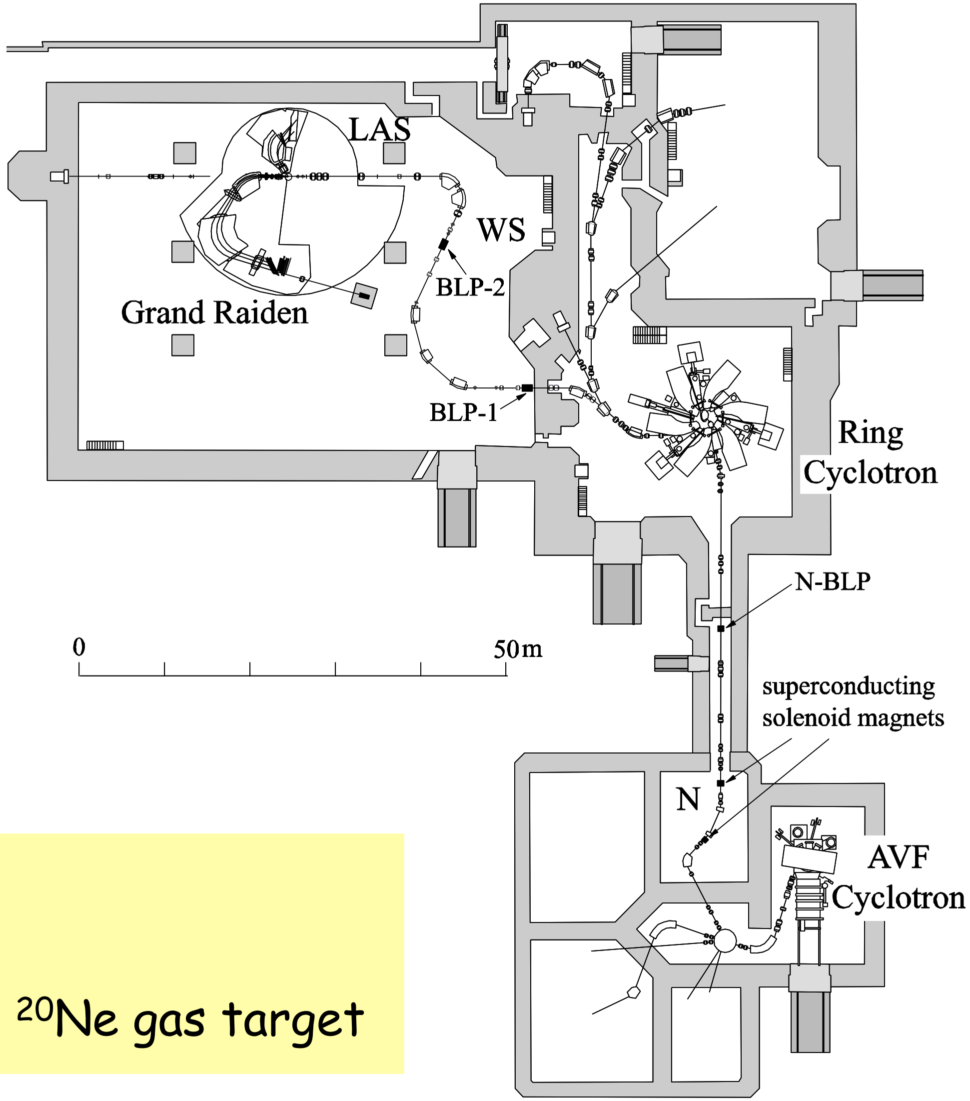


Experiment

Experiment was performed at RCNP, Osaka

Background-free measurement at extremely forward angles





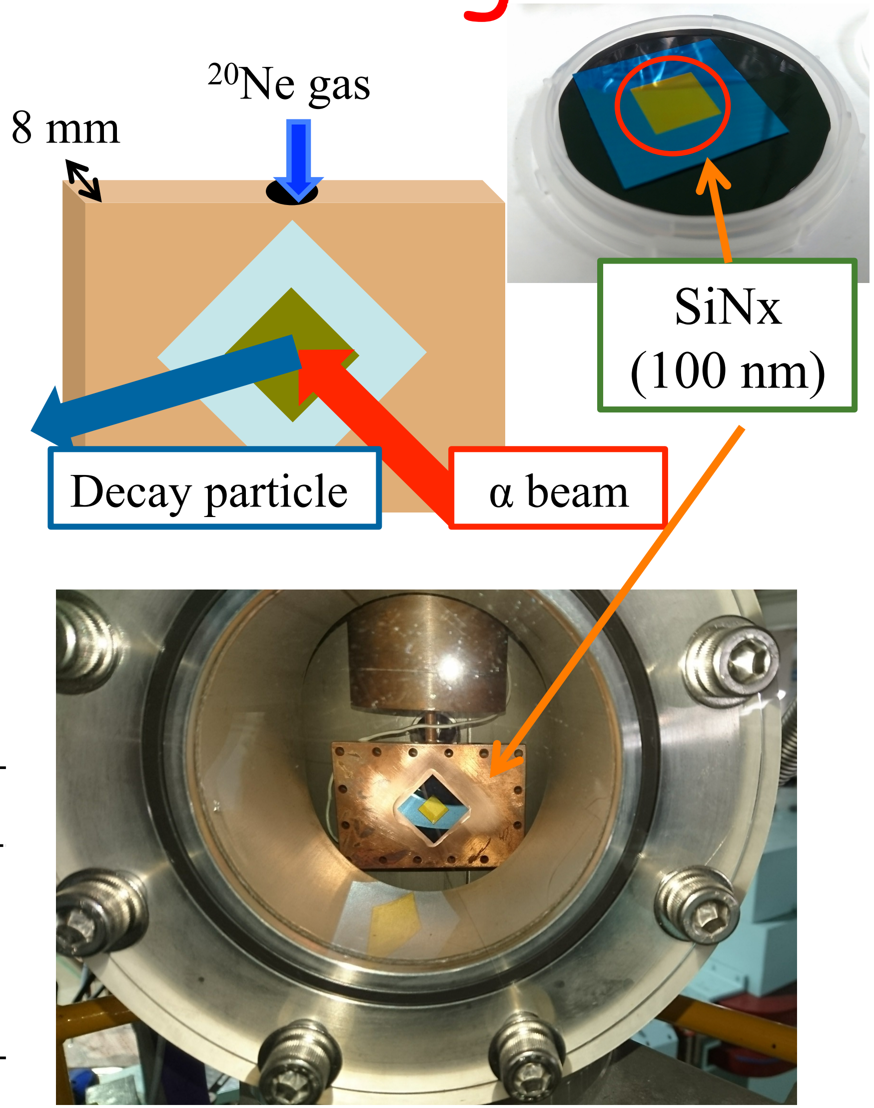
RCNP-E402

S. Adachi, Y. Fujikawa, TK et al

(a, a'+a) @ 400 MeV θ_{lab}= 0° with ^{20}Ne gas target

Ultra Thin ^{20}Ne Gas Target

Isotopically enriched ^{20}Ne gas target
→ Gas searing film causes problems to detect low-energy particles
→ Commonly used Alamid film (a few um) is too thick.



SiNx film (0.1 um) was used to make ^{20}Ne gas target at 14 kPa (89.6 ug/cm^2).

	SiNx	Aramid
Thickness	100 nm	1.5 μm
Threshold energy for α	0.09 MeV	0.51 MeV

Decay Particle Detectors

Si detector array

→ 3 layers × 6 segments

1st layer (thin): 65 um 8 strip

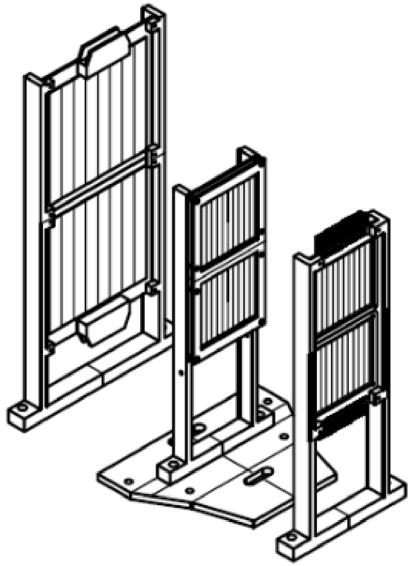
2nd & 3rd layers (thick):

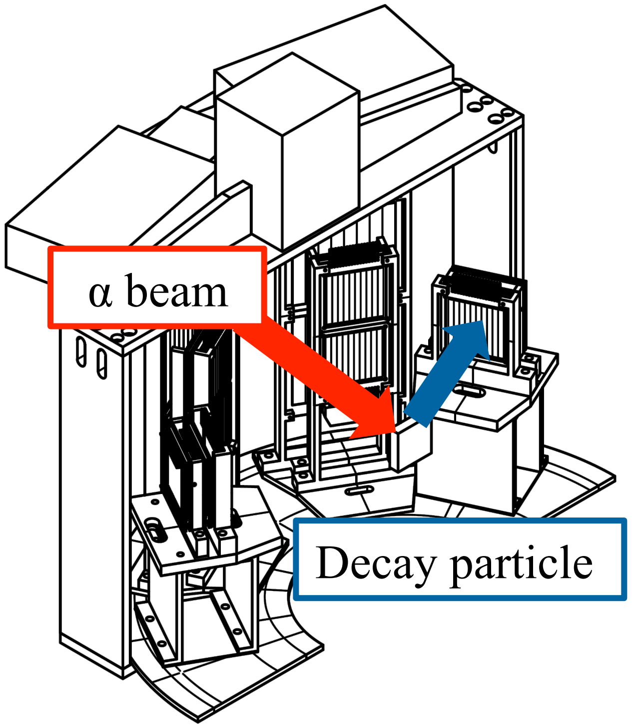
500 um or 600 um

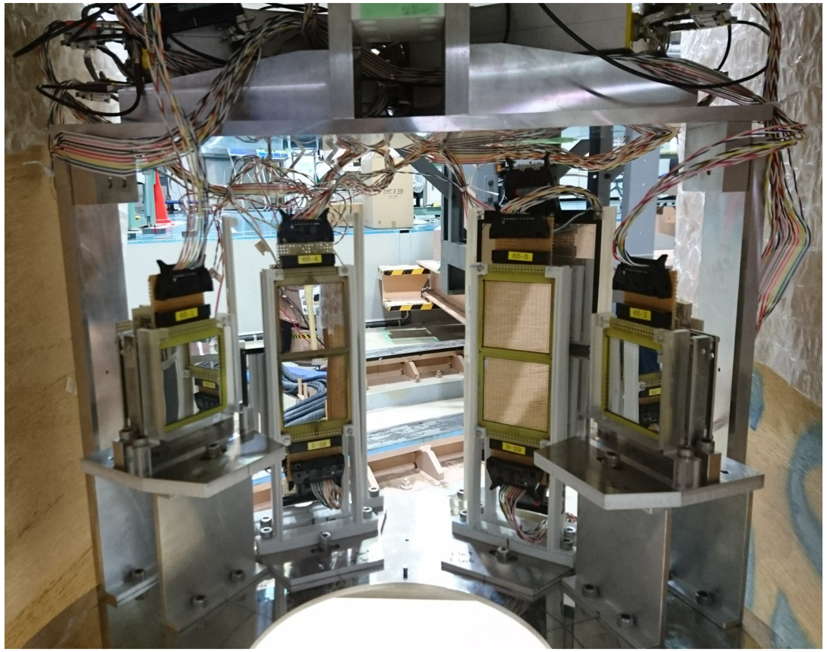
→ PID by TOF

Limitation in distance from target

Solid Angle 4%

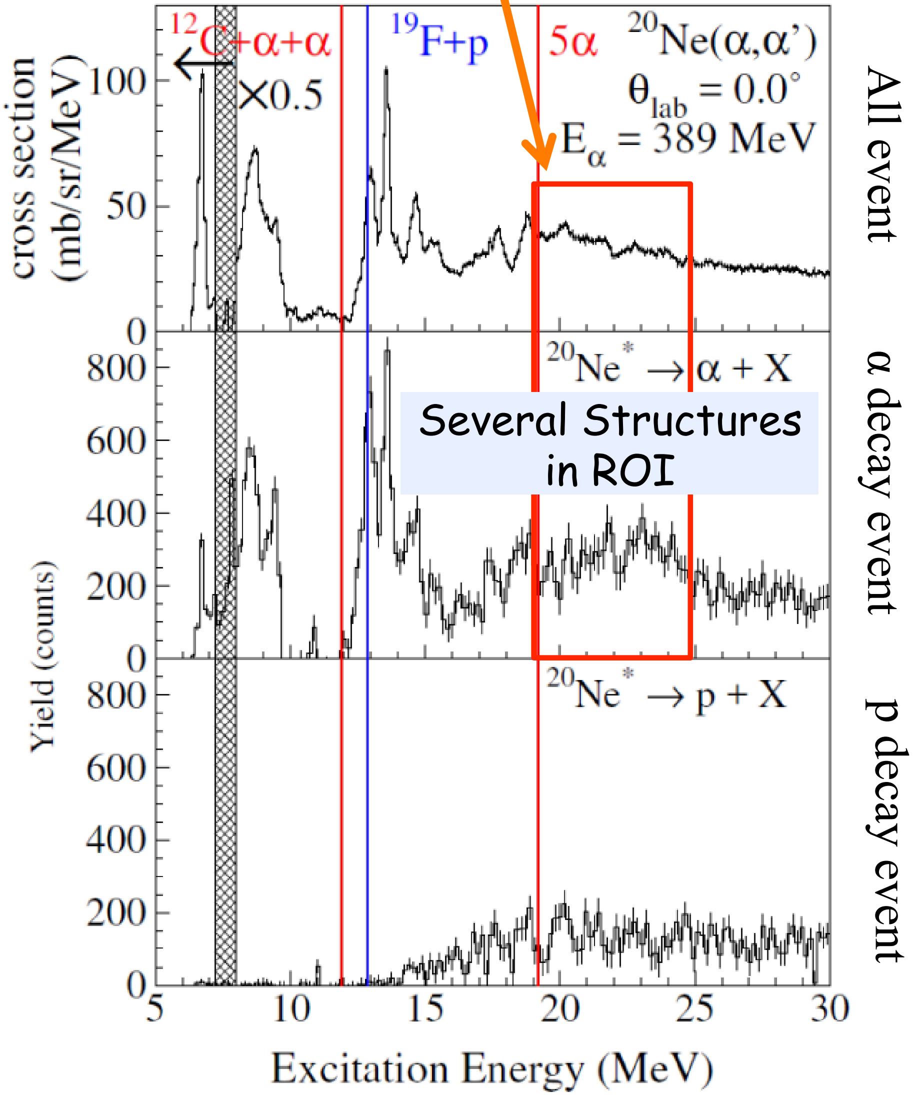


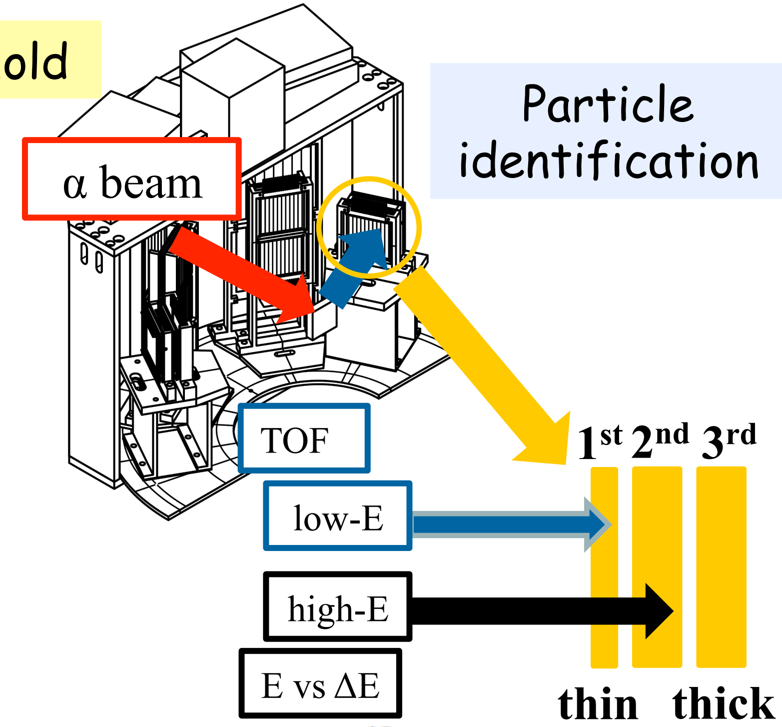


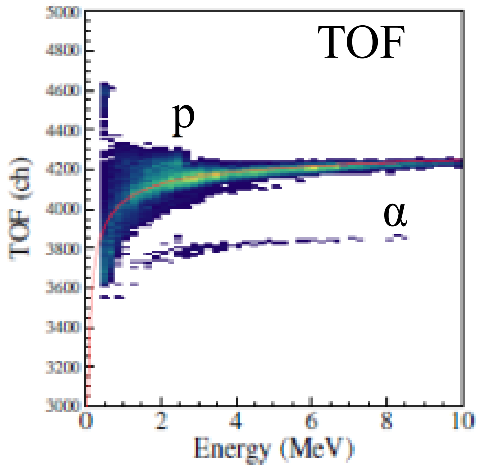


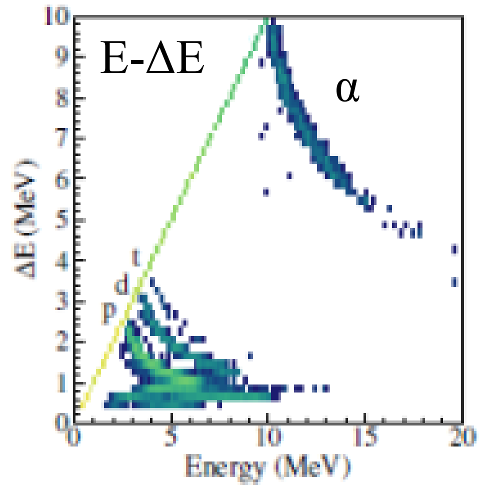
Decay Particle Measurement

Region of Interest: 1—5 MeV above 5α threshold

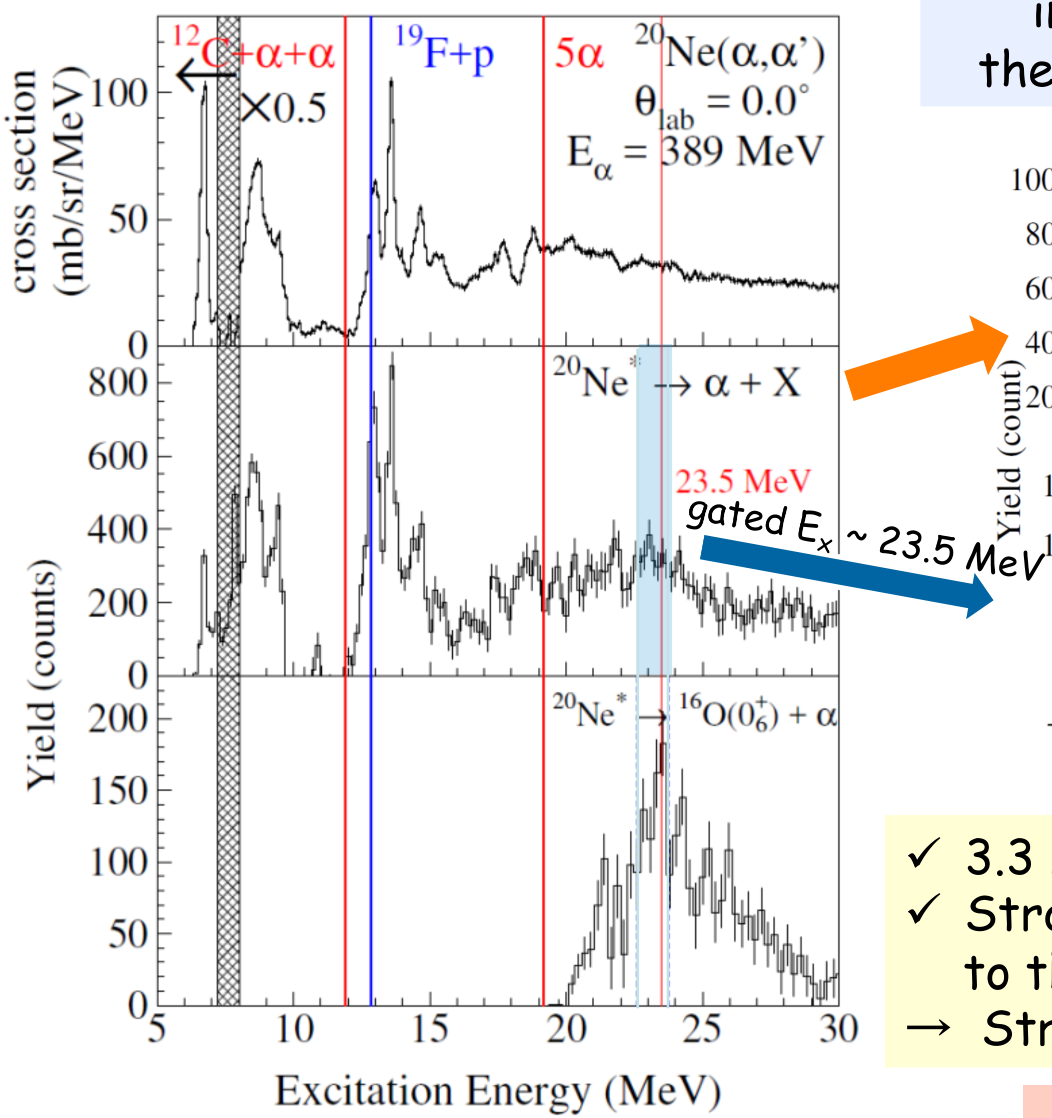






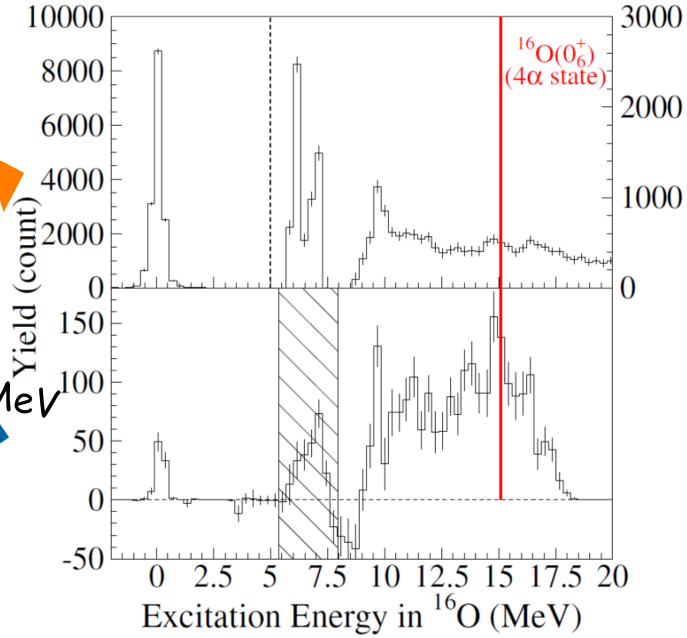


Decay to the 4α condensed state



23.5-MeV state enhances in the decay spectrum to the 4α candidate (0^+_6 in ^{16}O).

Final state in ^{16}O

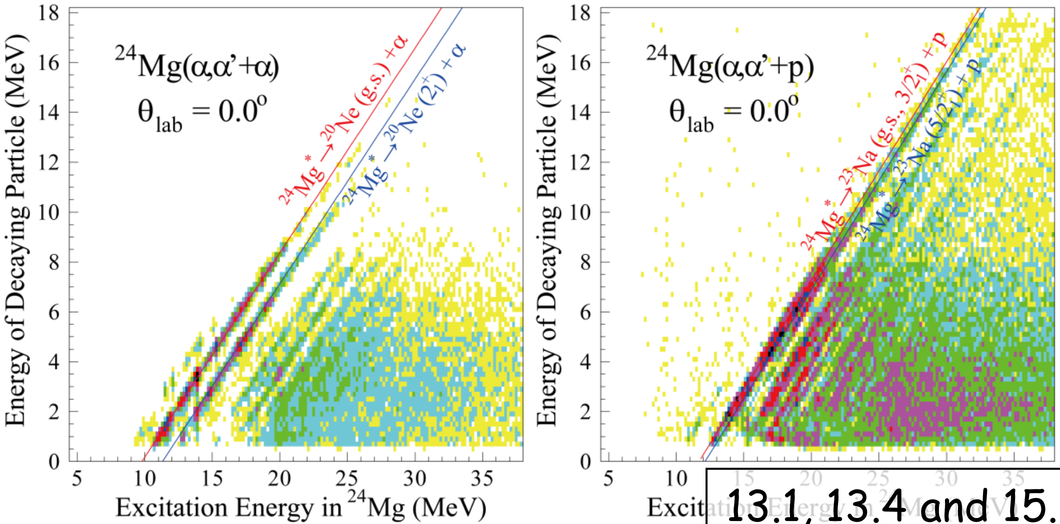


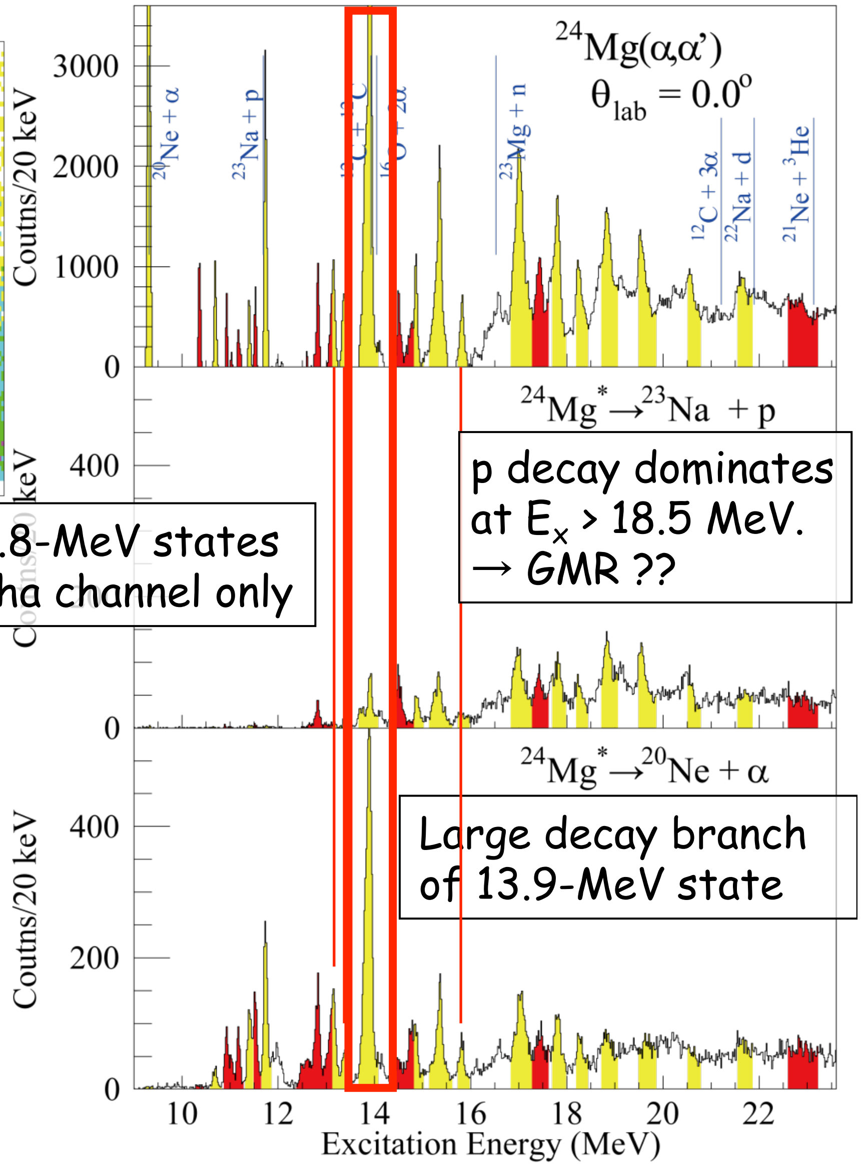
✓ 3.3 MeV above the 5α threshold
✓ Strong coupling to the 4α candidate in ^{16}O
→ Strong candidate of the 5α state

Next step: 6α in ^{24}Mg

Previous Measurement in ^{24}Mg

Decay particles from excited states in ^{24}Mg were measured.





13.1, 13.4 and 15.8-MeV states decay to the alpha channel only

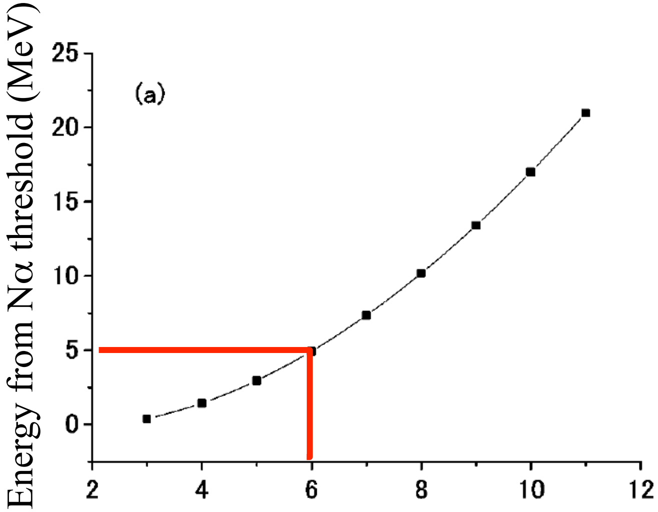
p decay dominates at E_x > 18.5 MeV.
→ GMR ??

Large decay branch of 13.9-MeV state

- Proton and alpha decay channels are separated.
- 13.1, 13.4 and 15.8-MeV states decay to ^{20}Ne only.
- 0^+ state at 13.9 MeV near the ^{12}C + ^{12}C and ^{16}O + 2a thresholds has a large decay branch to ^{20}Ne.

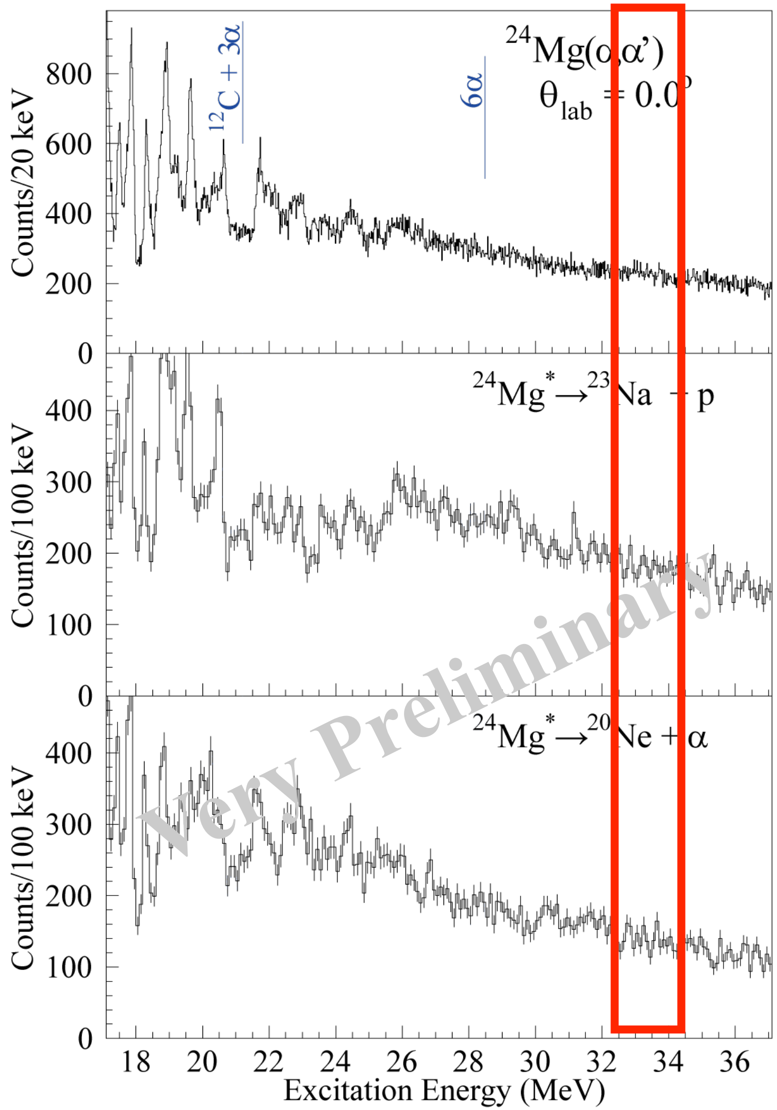
Highly Excited Region

6α condensed state was searched for in the highly excited region.



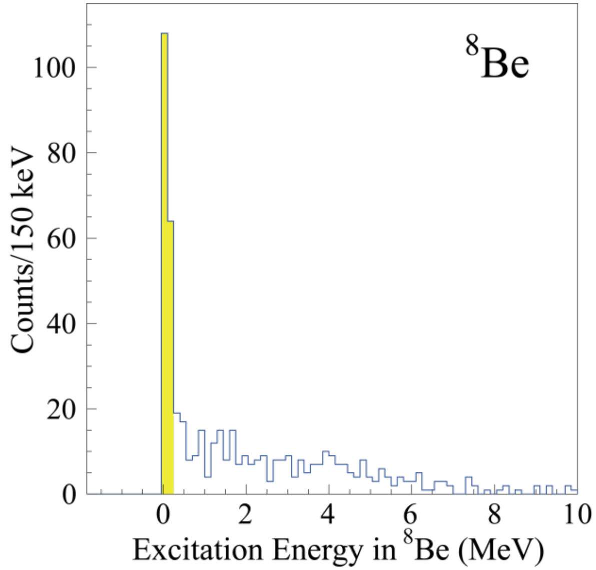
T. Yamada and P. Schuck,
Phys. Rev. C **69**, 024309 (2004).

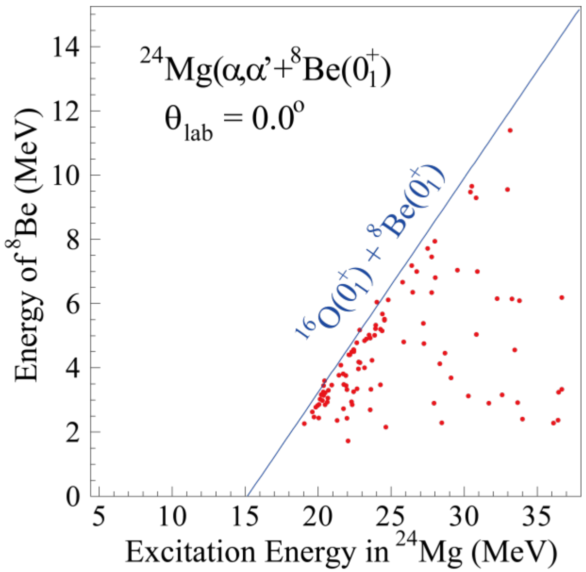
- 6α condensed state is expected at 5 MeV above the 6α threshold.
  - $E_x \sim 28.5 + 5 = 33.5$ MeV
- No significant structure suggesting the 6α condensed state.
  - Several small structures indistinguishable from the statistical fluctuation.
    → Need more statistics.

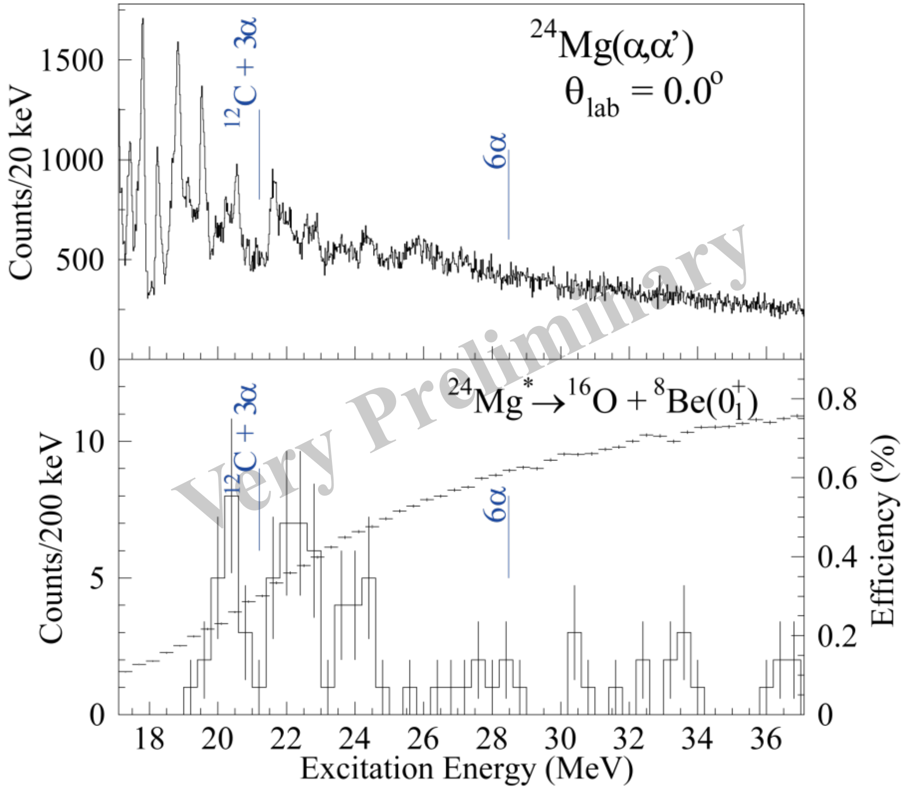


^{8}Be Emission Events

^{8}Be(0^{+}_{1}) emission events were indentified from 2α emission events by E_x in ^{8}Be.







- Several states at 20.5, 22.0, and 24.3 MeV were observed near the ^{12}C+3α threshold.
- Possible structures were seen above the 6a threshold although statistically poor .

  → Need more statistics. Larger solid angle.

How to Increase Detector Solid Angle

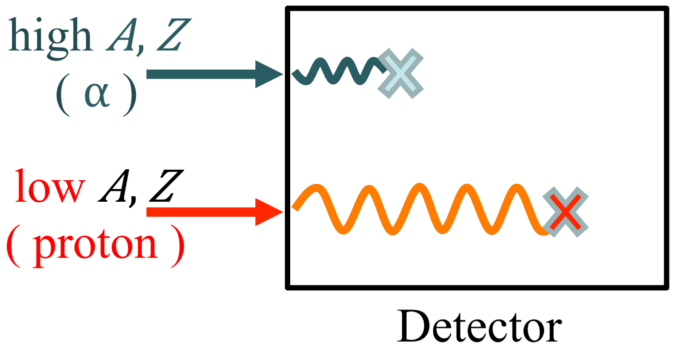
PID by TOF limits distance from target.
Long distance → Small solid angle
Need a new PID method

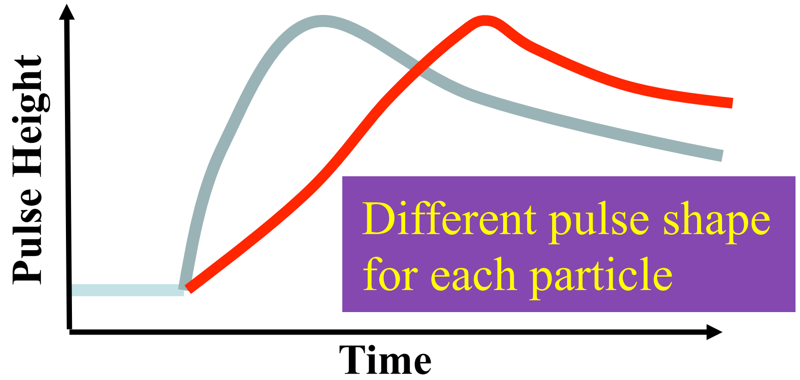
→ **Pulse Shape Analysis**

PSA

Stopping Power : $-\frac{dE}{dx} \propto \frac{AZ^2}{E}$

→ Charged particles with same E stop at different position depending on A and Z.





PSA solves the limitation from the flight distance.
→ Drastically increase detector solid angle.

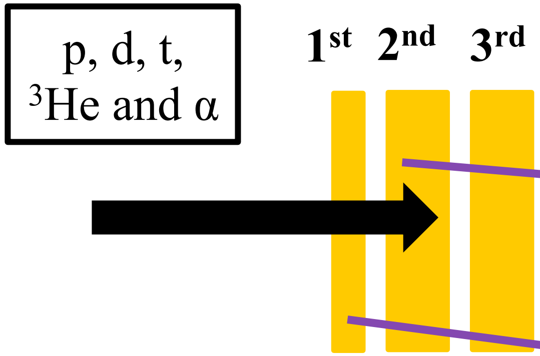
PSA was successfully done for Heavy ion at E > 100 MeV,
but no result for low-energy α particle at E < 3 MeV.

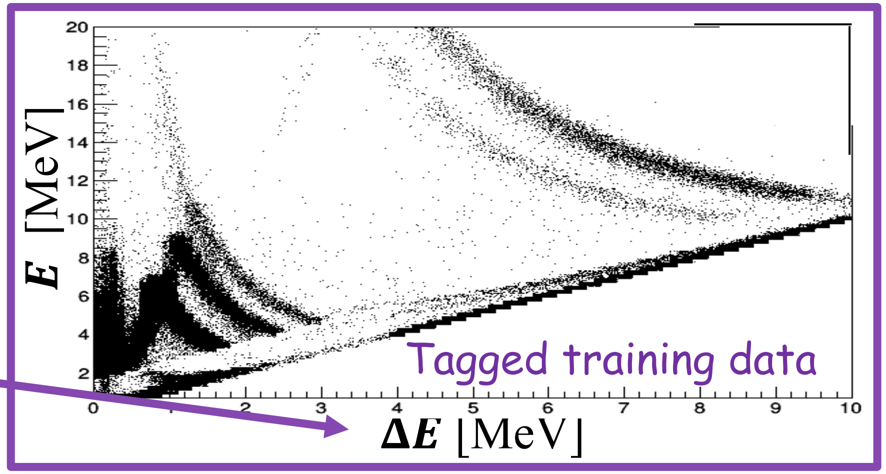
PSA using Neural Network

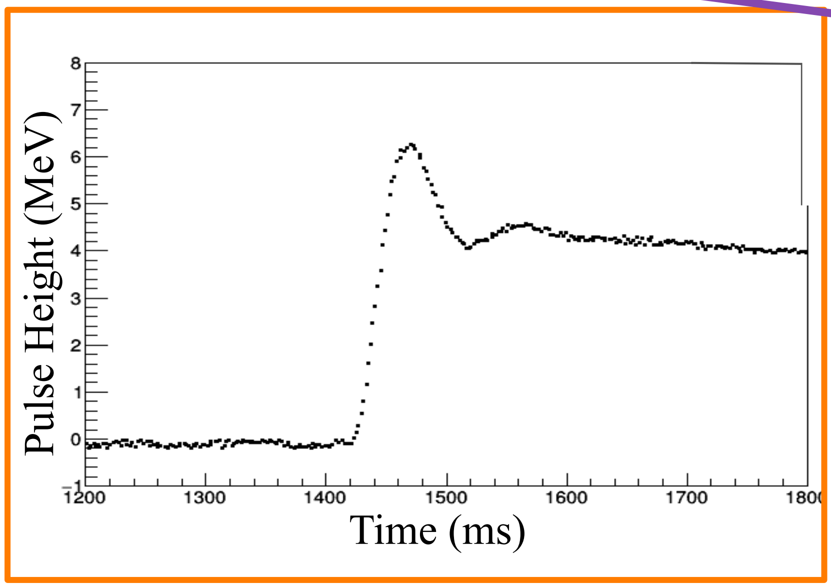
PSA for low-energy light particles is not easy.

→

We tried PSA using the neural network.



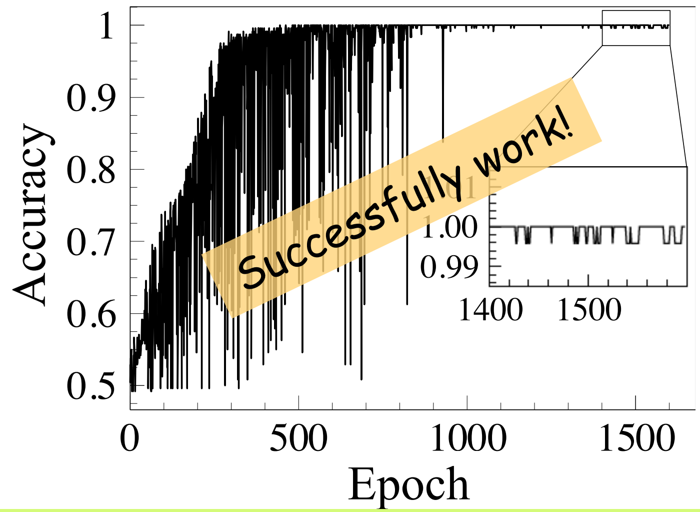




Pulse shape was acquired by 500 MHz Sampling FADC

Machine Learning

→



Decay particle detector with large angular coverage will be developed to search for alpha condensed states.

Summary

Alpha condensed state is a new conformation of dilute nuclear matter.

Inelastic a scattering and decay particle measurements are useful probes to examine α cluster structure in nuclei.

- Low-energy α particle detection over large solid angle is important.

A new particle detector will be developed.

- PSA using a neural network technique