Search for α-condensed state in $^{20}\mathrm{Ne}$

Yuki FUJIKAWA

Kyoto University

ECT* Trento Workshop

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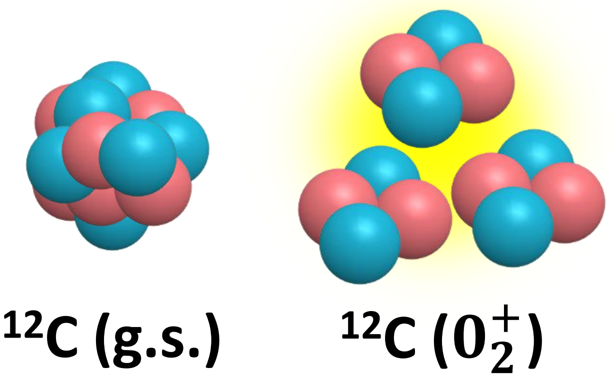
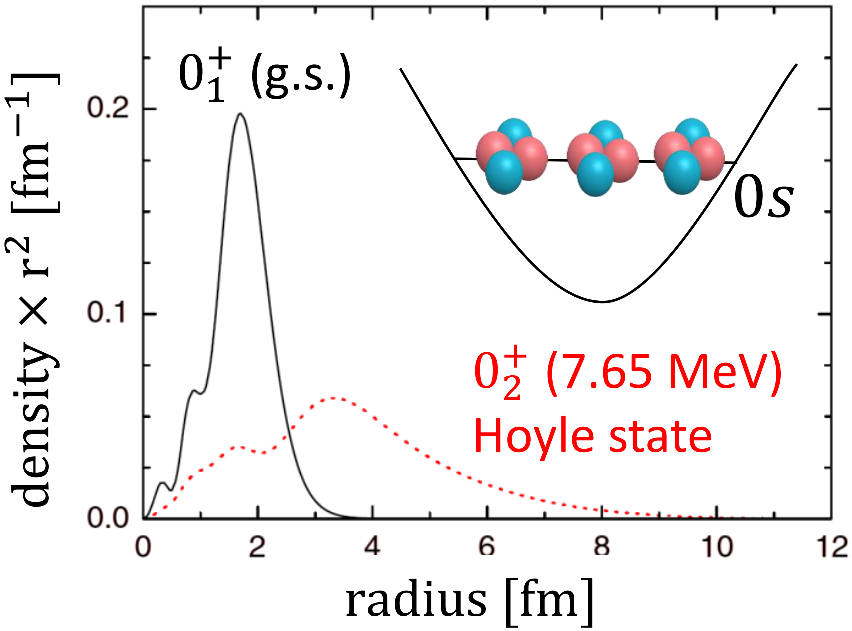
Motivation



"Hoyle state" in $^{12}\mathrm{C} = {}^{12}\mathrm{C}(0_2^+), E_x = 7.65\ \mathrm{MeV}$

- Important in the stellar nucleosynthesis
  - 3α reaction : ^{12}C synthesis
- Well known "spatially developed cluster state"



T. Yamada *et al.*, Eur. Phys. J. A **26**, 185 (2005).

Known to be an α-condensed state

- All α clusters are condensed into the lowest s-orbit
- Low density and large radius
- Main component of the low-density nuclear matter

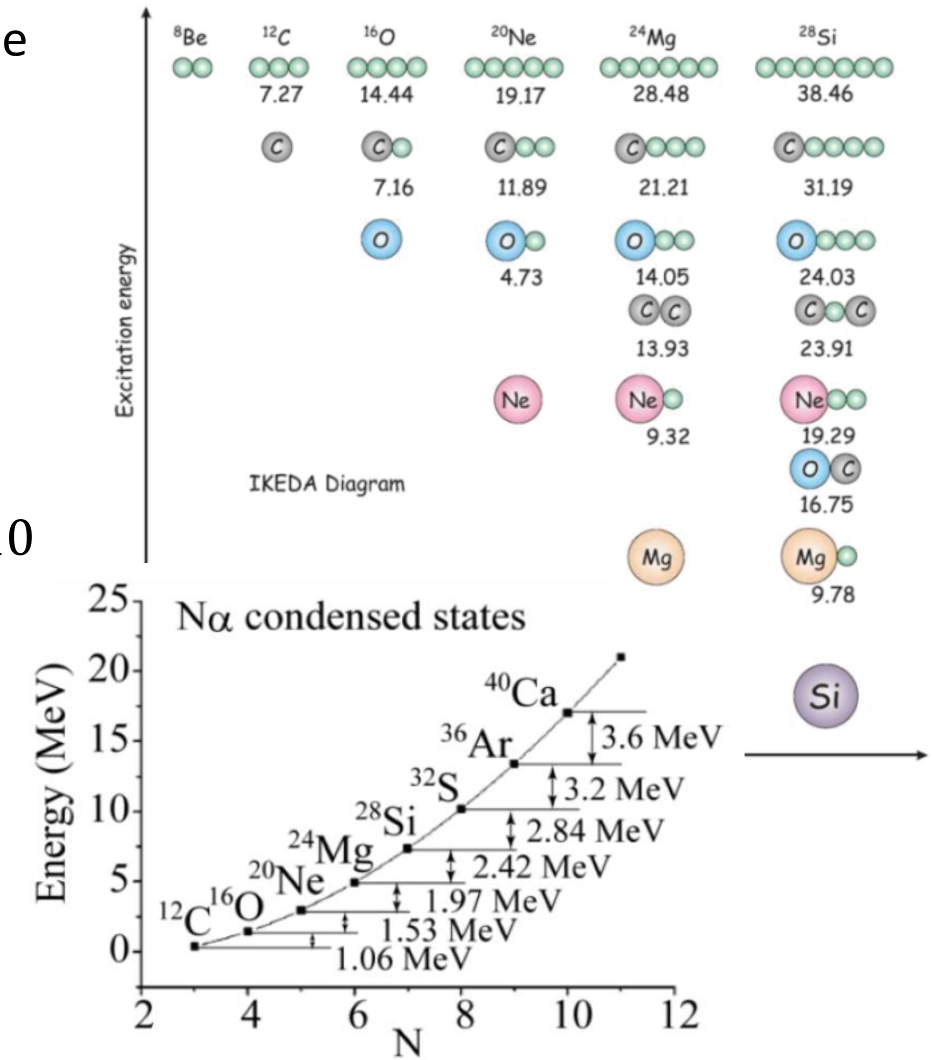
Provide an important insight into the low-density nuclear matter

α-condensed state in heavier nuclei

- Cluster structures should appear near the decay threshold to relevant clusters
  → Threshold rule
    - Ikeda diagram
    - Hoyle state : just above 0.38 MeV

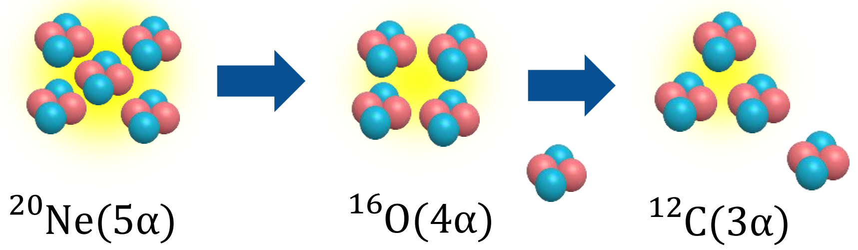
- α-condensed state
  - Predicted to exist in heavier self-conjugate $A = 4N$ nuclei up to $N = 10$
  - Candidate has been found only in $^{8}\mathrm{Be}$, $^{12}\mathrm{C}$, and $^{16}\mathrm{O}$

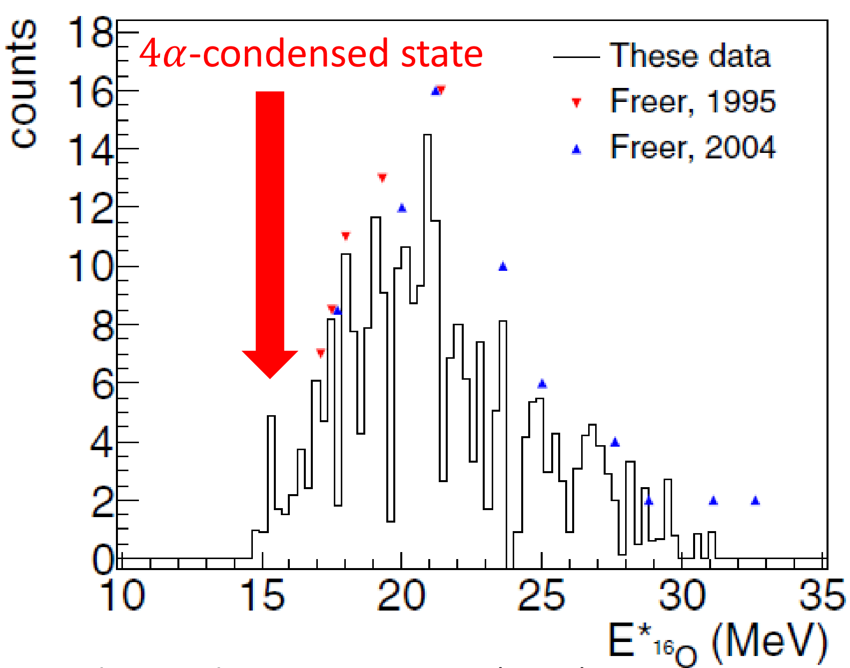
Next is $^{20}\mathrm{Ne}$



T. Yamada, Phys. Rev. C 69, 024309 (2004).

Experimental method





M. Barbui *et al.*, PRC **98**, 044601 (2018).

- Prorerty of α-condensed states
  - $J^{\pi} = 0^{+}, T = 0$
  - Expected to decay to the α-condensed state in lighter nuclei

    ⇒emit multiple low-energy α particles

- To excite α-condensed state

  ⇒α inelastic scattering at 0 degrees
  - C.S. for the E0 transition becomes maximum

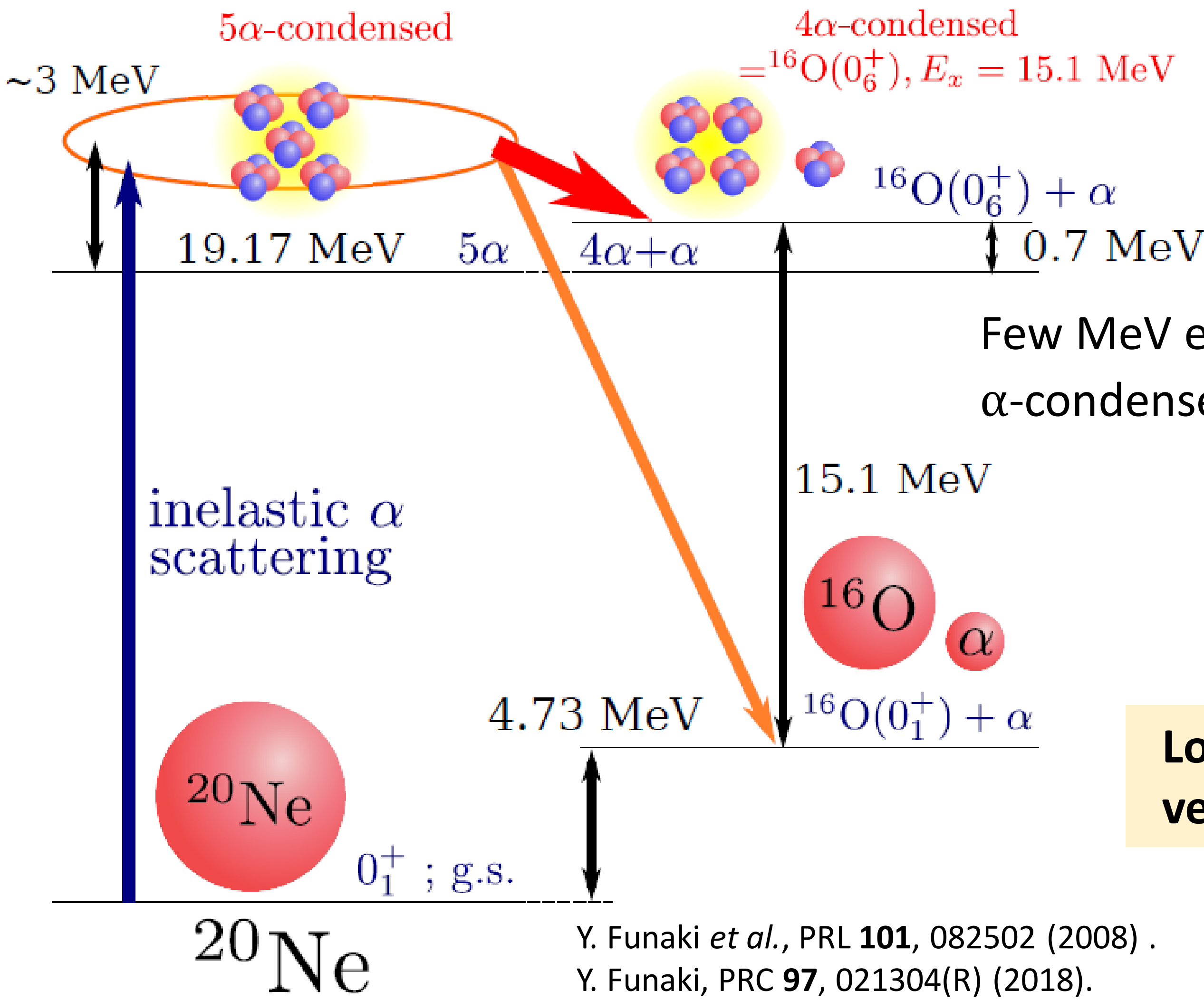
- To identify α-condensed state

  ⇒Decay-particle measurement
  - Identify α particles
  - Identify the final state of the daughter nuclei

ex) The 4α-condensed state in $^{16}\mathrm{O}$
- 4α-decay events (8 events)

→A candidate for 4α-condensed state

Diagram about the 5α-condensed state



Few MeV energy difference between α-condensed states in ^{20}Ne and ^{16}O

Low-energy α decay is very important

Y. Funaki *et al.*, PRL **101**, 082502 (2008) .
Y. Funaki, PRC **97**, 021304(R) (2018).
T. Yamada *et al.*, PRC **85**, 034315 (2012).

Experiment

- $^{20}\mathrm{Ne}(\alpha,\alpha') \;@\; E_\alpha = 389\ \mathrm{MeV}$

"Singles" inelastic scattering measurement
$\theta_{lab} = 0.0° \sim 15.0°$ → DWBA calc. & Multipole decomposition analysis

➡ J^π determination & E0 transition strength distribution

"Coincidence" inelastic scattering measurement
$\theta_{lab} = 0.0°$ → E0 is strongest
Excitation spectrum + **Decay particles from the excited states**

➡ Decay channel, alpha decay width → condensed

"Singles" measurement
→ J^π info. etc.

⟷ Both are important.

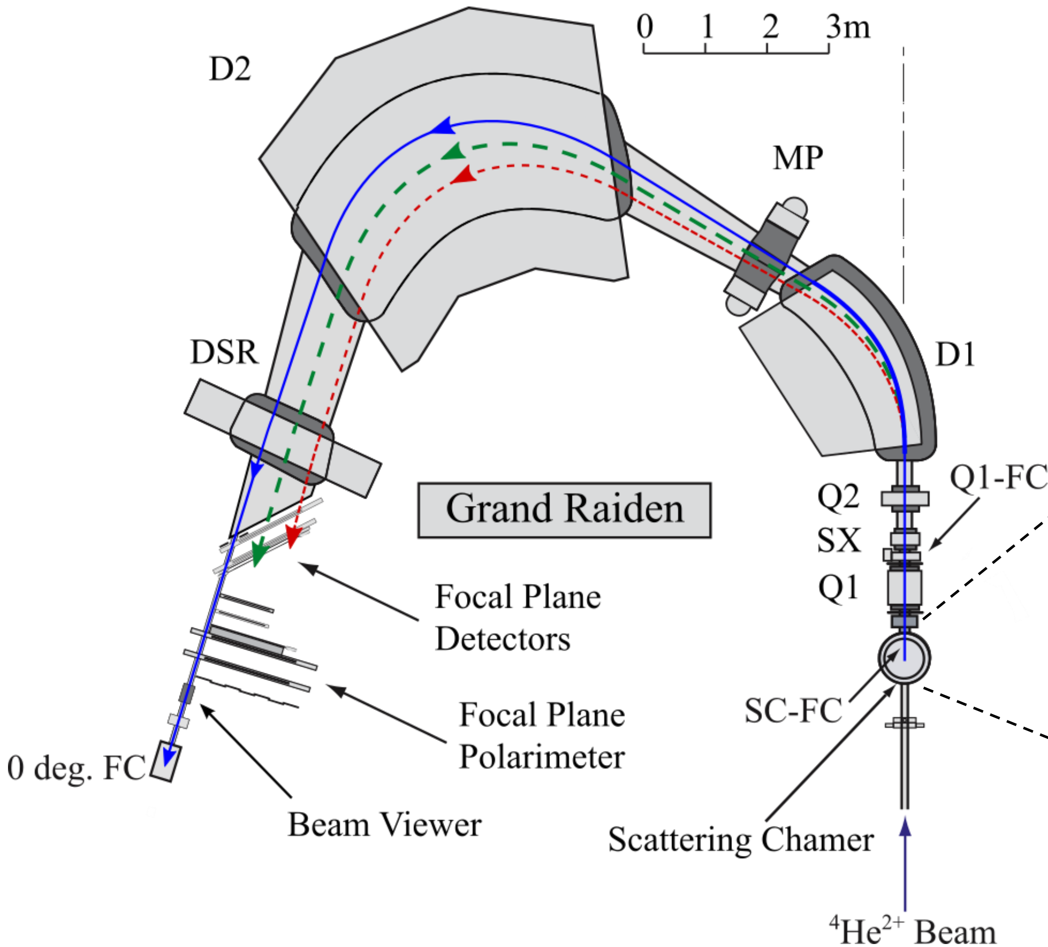
"Coincidence" measurement
→ Characteristic of the state

Unfortunately, we were able to perform "Coincidence" measurement only due to the earthquake during the experiment…

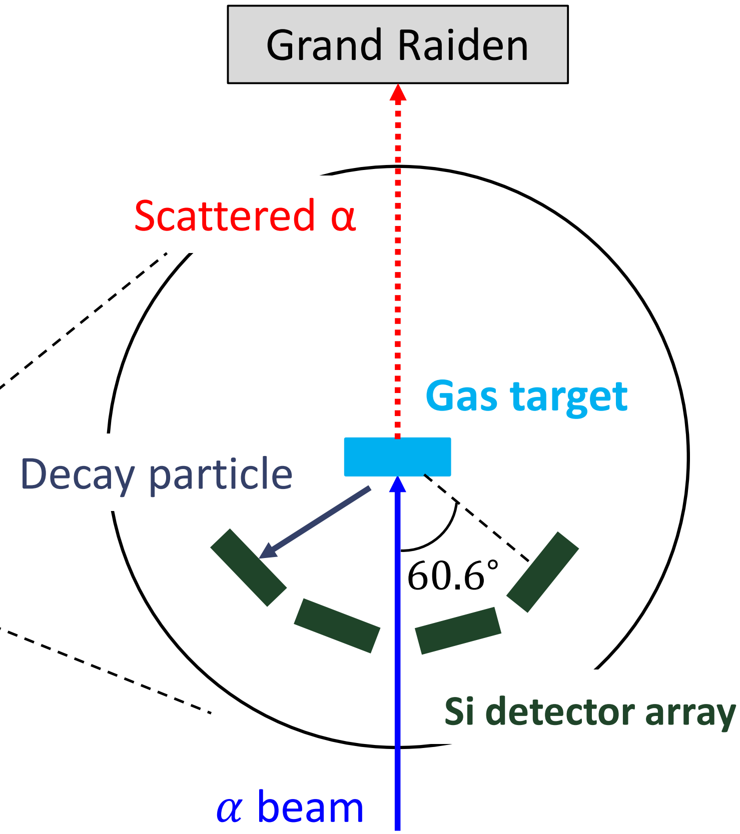
Setup & Instruments

$^{20}\mathrm{Ne}(\alpha,\alpha')$ @ $\mathrm{E}_{\alpha} = 389$ MeV

"Coincidence" inelastic scattering measurement @ $\theta_{lab} = 0.0^{\circ}$

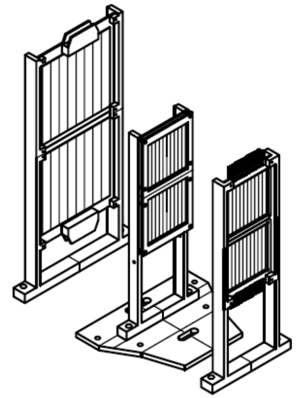


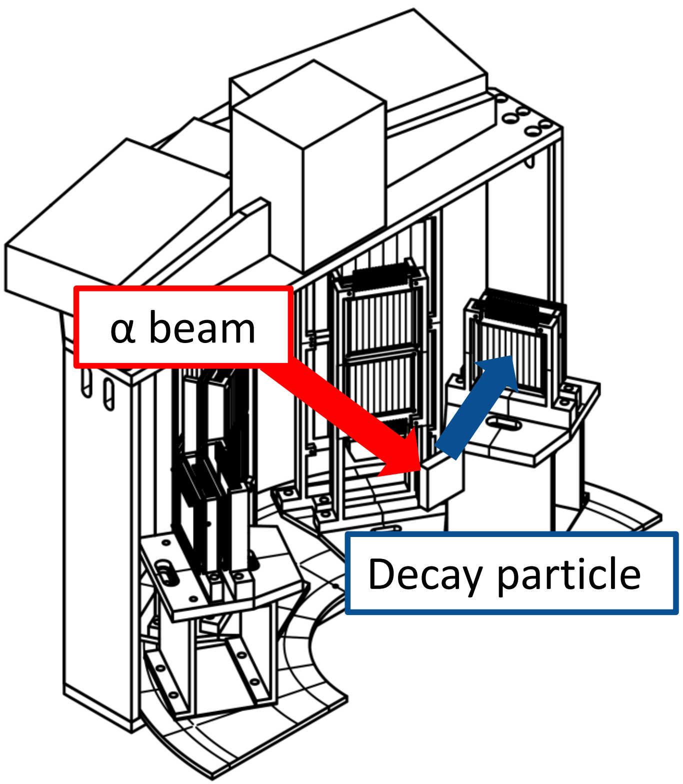
Scattering Chember (Top view)



Silicon detector array

- 6 segments : 3-layer configuration
  - 1st layer (thin) : 65 μm-t, 8ch-strip
  - 2nd & 3rd layer (thick) : 500 μm-t or 600 μm-t





Gas target with very thin windows

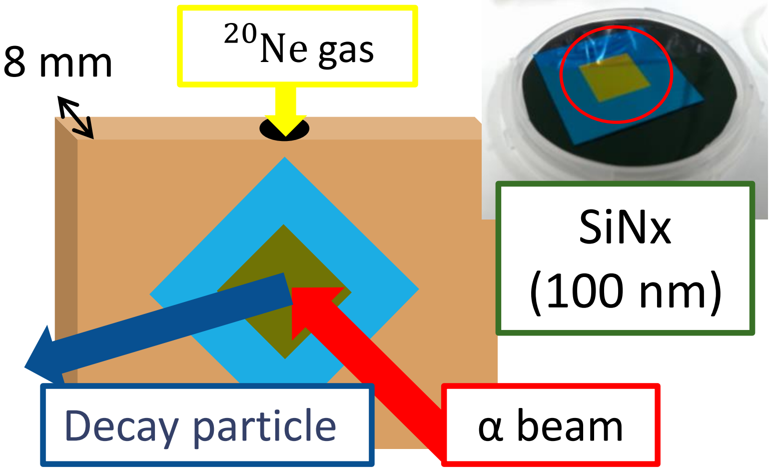
- ^{20}Ne : gas at room temperature

Low-energy α decays are very important
⇒Low energy loss at window is required

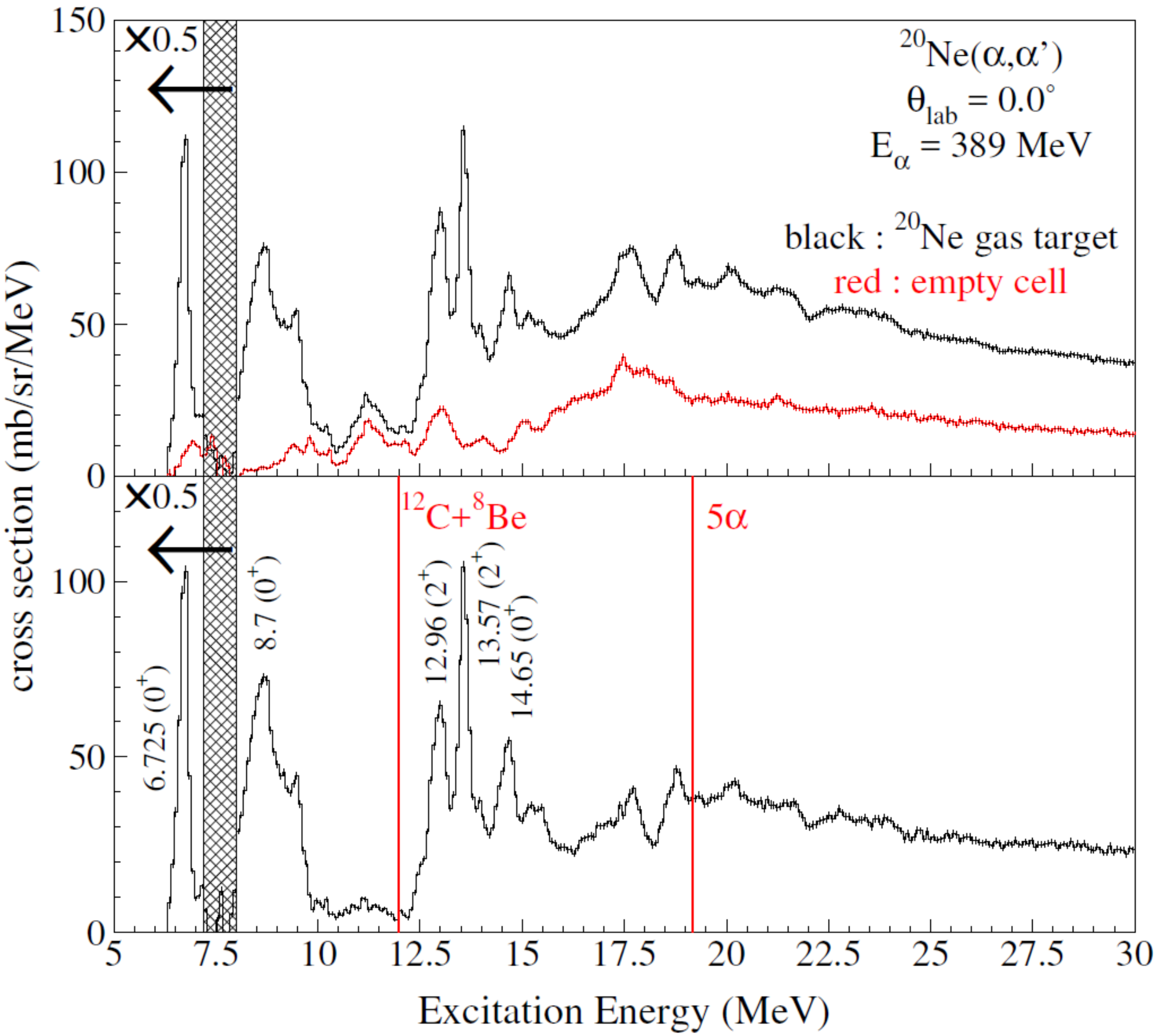
  - Very thin gas sealing windows
    ⇒Silicon Nitride membrane (SiNx)
    - 100 nm-t : 32 $\mu g/cm^2$
    - Less stretch, good gas sealing

	SiNx	Aramid
Thickness	100 nm	1.5 μm
Detection threshold energy of α particles	**0.49 MeV**	0.91 MeV

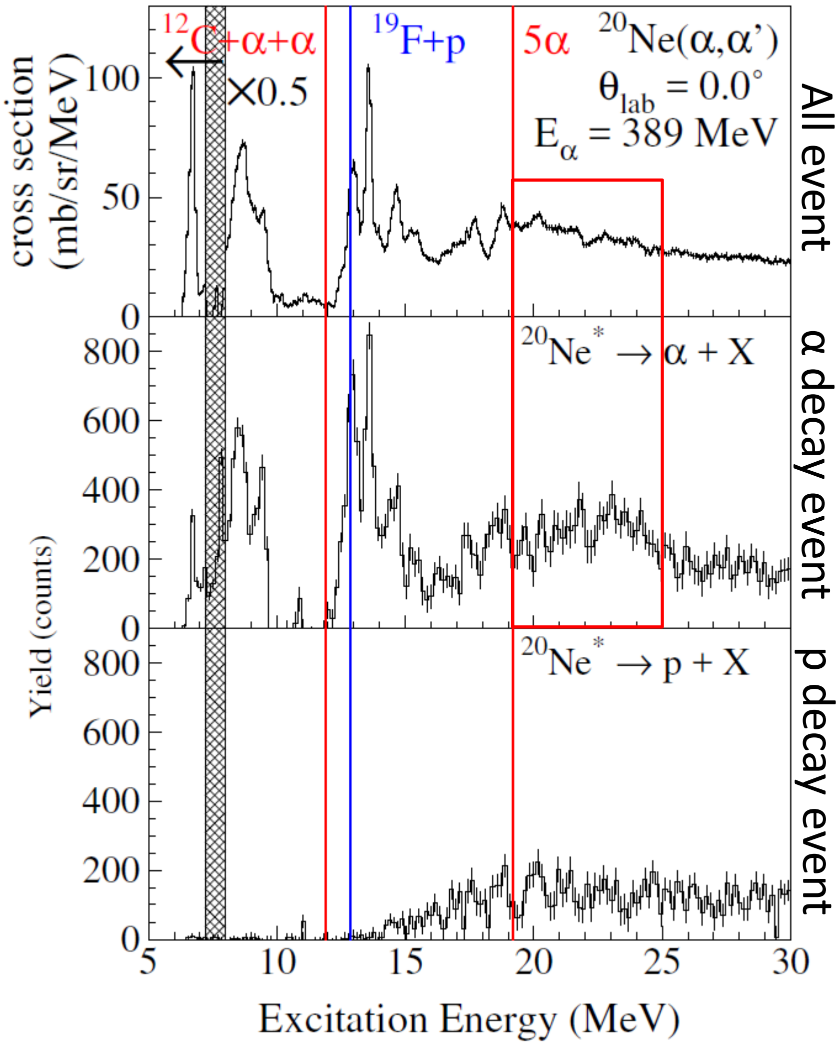
^{20}Ne target : 14 kPa, 89.6 $\mu g/cm^2$

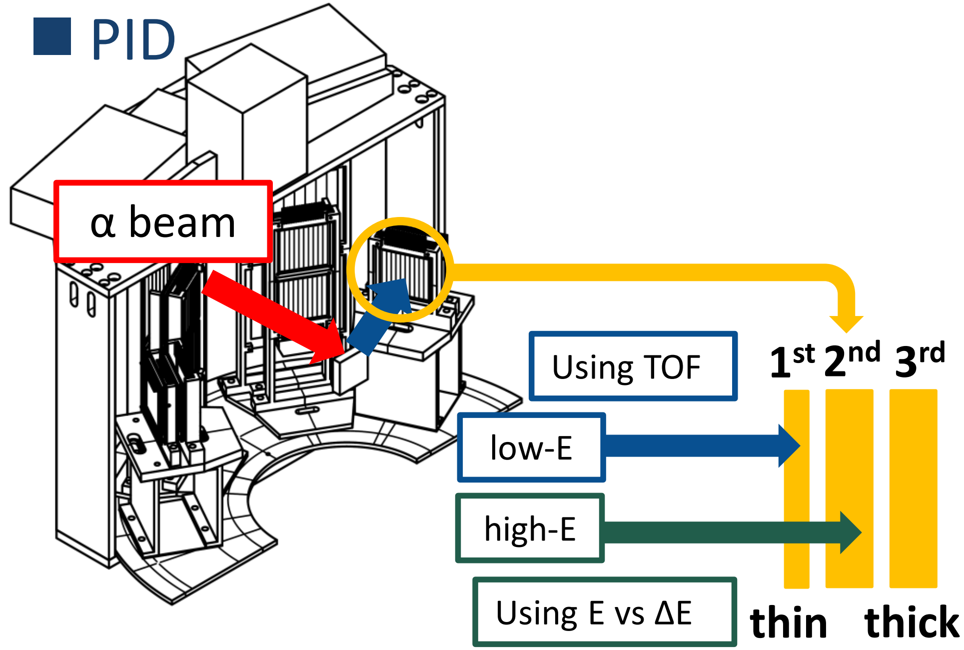


Excitation energy spectrum



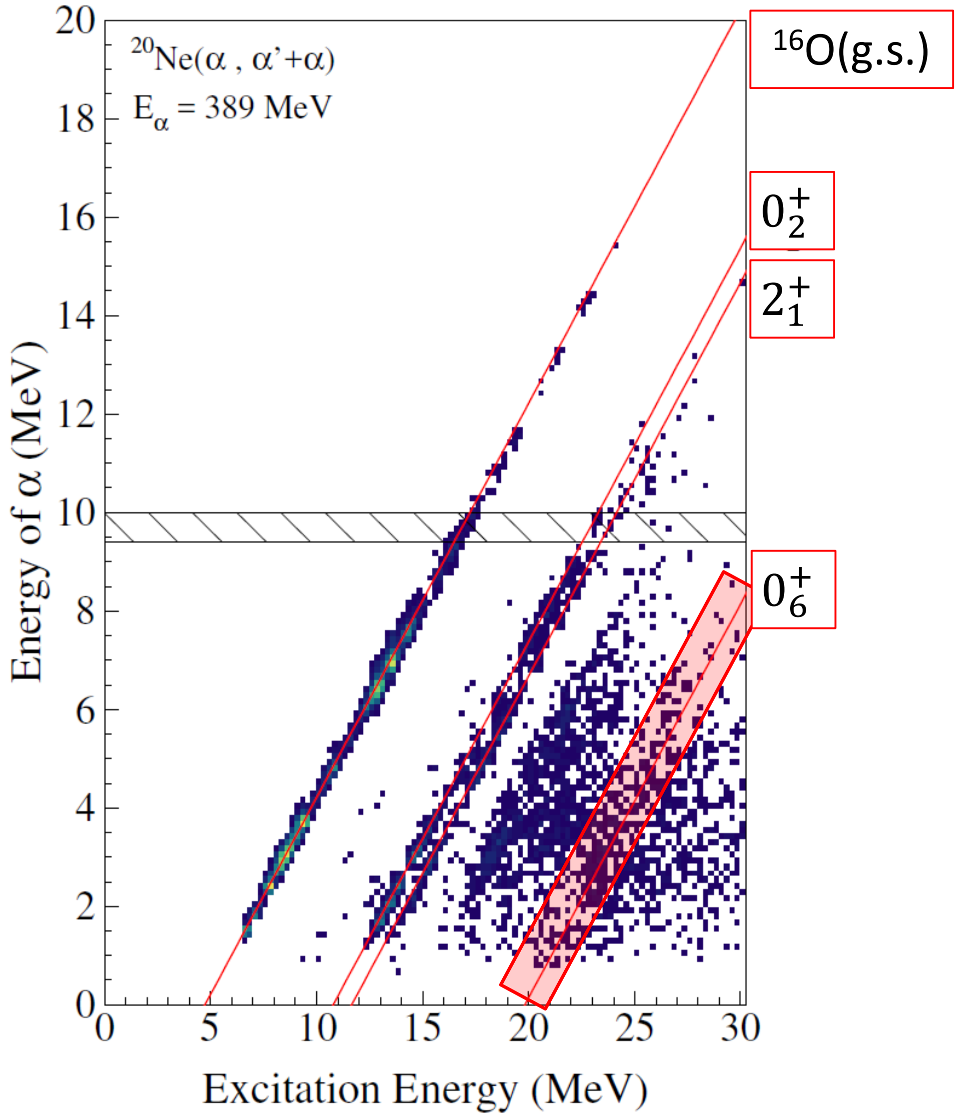
E_x spectrum with decay channel gate





- α decay event
  - ⇒Narrow structures around $E_x = 21 \sim 25$ MeV
  - ⇒α-cluster structure
- To clarify the nature of these structures
  - ⇒The information of the final state of the daughter nuclei

Correlation between E_x and K_α



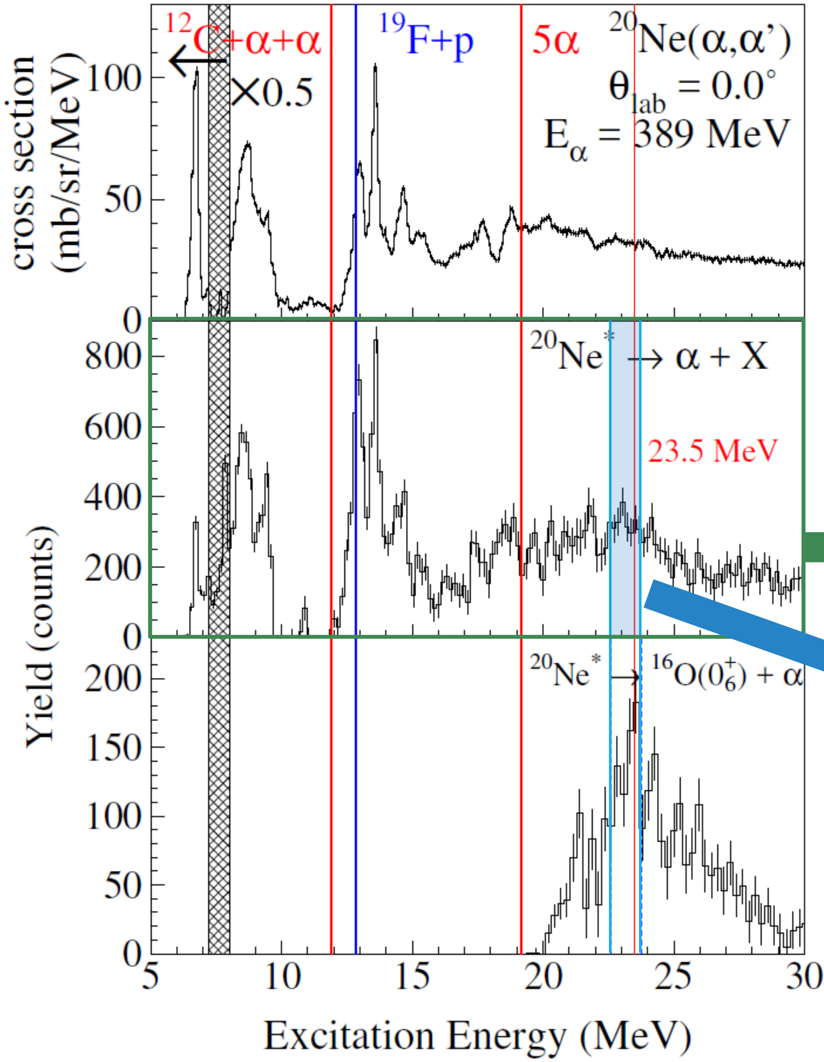
- Assuming the two-body decay
  $$^{20}\mathrm{Ne} \to {}^{16}\mathrm{O} + \alpha$$
- $K_\alpha = \frac{16}{20}\left[E_x(\mathrm{Ne}) - \Delta_{th} - E_x(\mathrm{O})\right]$

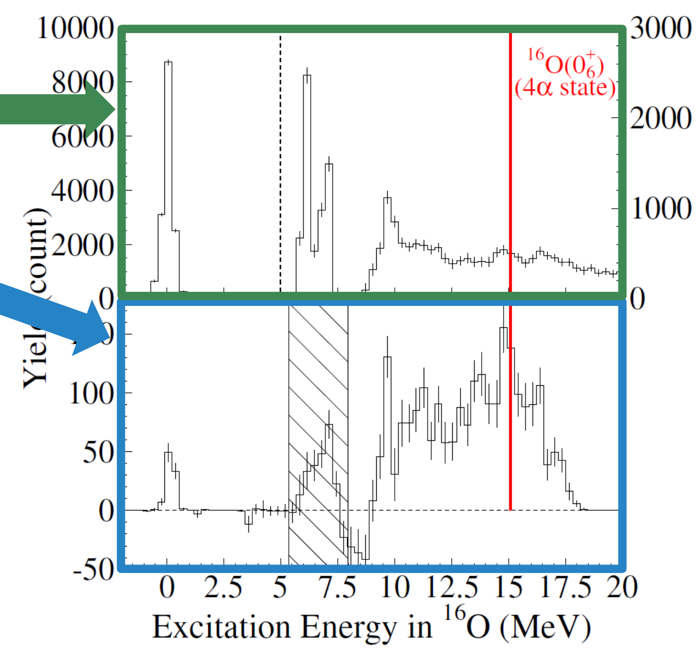
  Δ_{th} : α decay threshold in ^{20}Ne (4.73 MeV)
- Decay events to the g.s., 0_2^+ state and 2_1^+ state in ^{16}O
  ⇒Well isolated
- Select the decay events to the 0_6^+ state in ^{16}O
  ✓The 5α-condensed state should be enhanced

Decay event to $^{16}\mathrm{O}(0_6^+)$

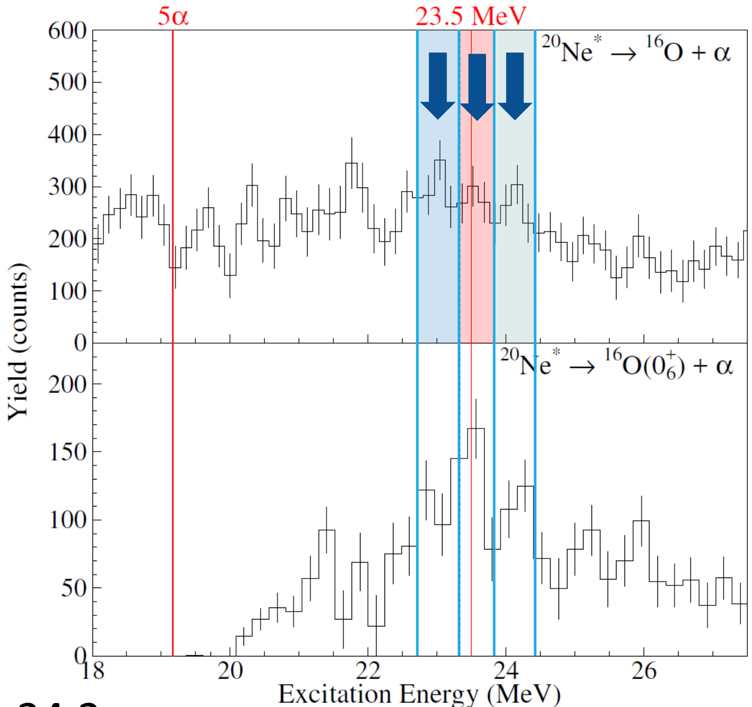
- A prominent peak at $E_x = 23.5$ MeV
  - ⇒Strong coupling with the 0_6^+ state in ^{16}O
- Excitation energy of the daughter ^{16}O
  - ⇒The $E_x = 23.5$ MeV state mainly decay to the 0_6^+ state in ^{16}O

⇒A candidate for the 5α-condensed state

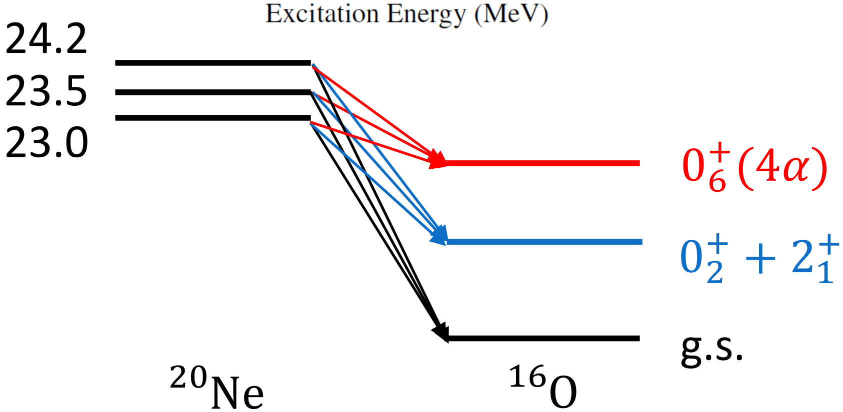


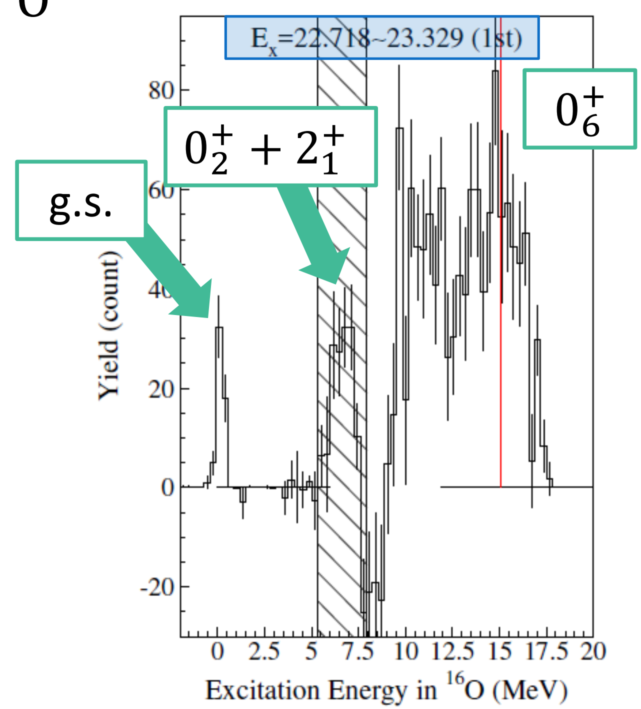


Branching ratio of the 23.5 MeV state

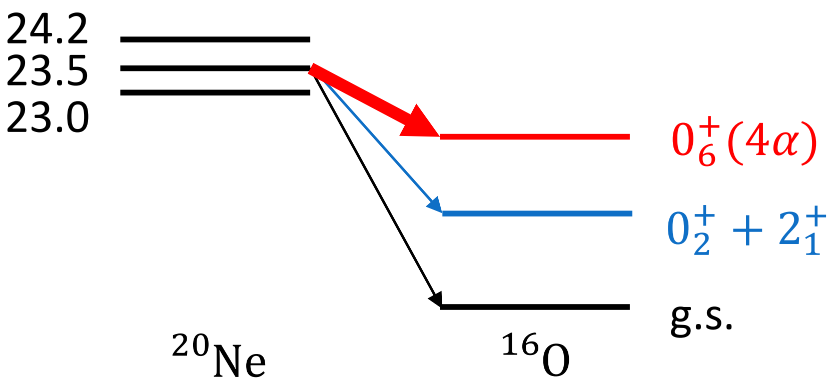


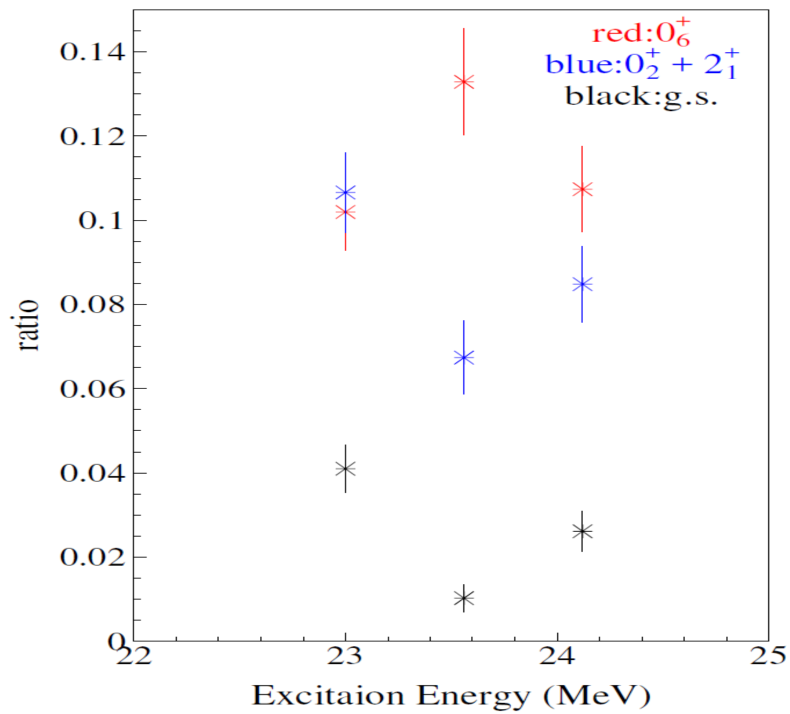
- Other structures around $E_x = 23.5$ MeV ($E_x = 23.0, 24.2$ MeV)
  - These structures are separated state or not?
    ⇒Compare these branching ratio
  - Decay branch of each structure in ^{20}Ne to each state in ^{16}O





Branching ratio to each state in ^{16}O





- ratio $= \dfrac{\text{decay events to each state}}{\text{all the } \alpha\text{−decay events}}$ in each structure
- $E_x = 23.5$ MeV
  - Large ratio to the 0_6^+ state
  - Small ratio to the g.s., $0_2^+ + 2_1^+$

⇒3 structures may be separated state.

※J^π was not decided

✓$J^\pi = 0^+$ at α-condensed state

Future works

- Comparison with the statistical model calculation
- Decide J^π
- Measurement to obtain more statistics

Summary

- In order to search for the α-condensed state in $^{20}\mathrm{Ne}$
  - We measured $^{20}\mathrm{Ne}(\alpha,\alpha')$ at $\theta_{lab} = 0.0°$
  - Coincidence measurement : scattered α and decay particles

- E_x spectrum of $^{20}\mathrm{Ne}$
  - Several peaks were observed above the 5α decay threshold
  - New state at $E_x = 23.5\ \mathrm{MeV}$ is observed

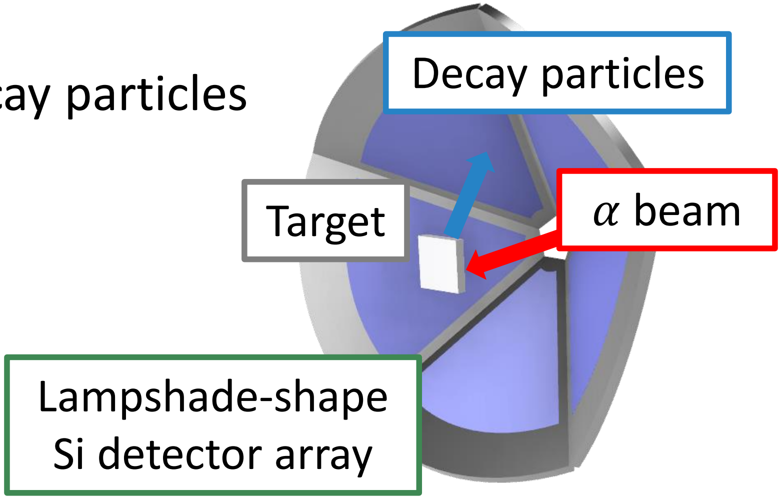
- New state at $E_x = 23.5\ \mathrm{MeV}$
  - Observed in α decay events only
  - Mainly decays to the 0_6^+ state in $^{16}\mathrm{O}$
    ↳ the 4α-condensed state
  - J^π was not decided
  - A candidate for the 5α-condensed state

- Ongoing work
  - Comparison with the statistical model calculation

Future perspective

In order to search for α-condensed states

- (α, α') reaction : angular distribution and decay particles
  - ✓Introduce the machine learning for PID
    - More statistics
  - ^{20}Ne : re-measurement to decide J^{π}
  - ^{24}Mg : next $A = 4N$ nucleus



- Resonance scattering : more effective for multi decay particles
  - AT-TPC (the Active Target Time Projection Chamber)
    - ✓Cover almost 4π of the solid angle
    - ✓Thick-target method
  - Si detector
    - ✓Several beam energy