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RIKEN NiSHiNA CENTER

A Candidate of Tetra-neutron State Populated by ^{4}He(^{8}He,^{8}Be) Reaction

SHARAQ06 collaboration
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(PhD. thesis : Center for Nuclear Study, the University of Tokyo)

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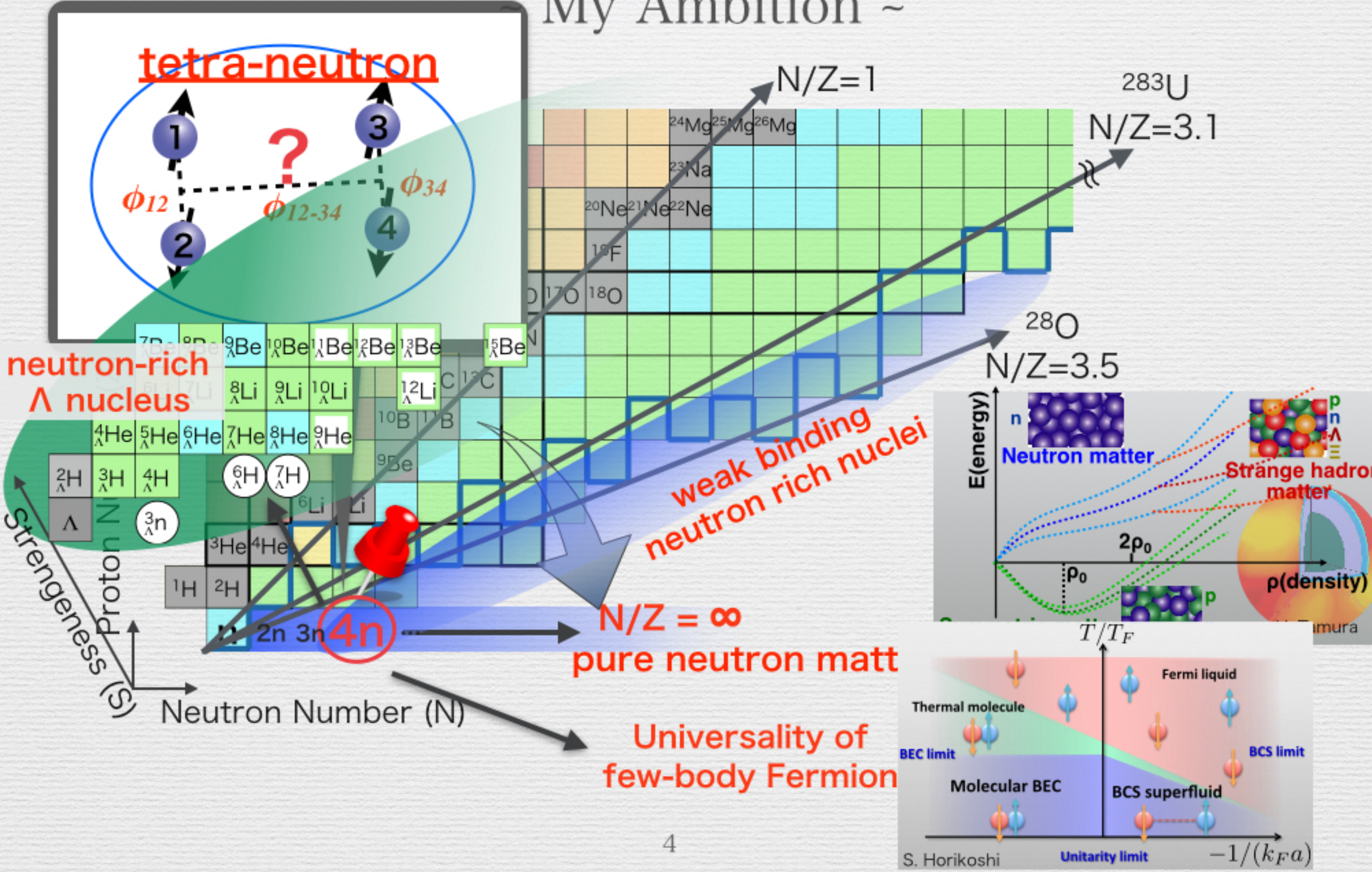
Tetra-Neutron System

~ My Ambition ~



Historical Review

~ search for a bound state of 4n~

1960s

fission of Uranium

- No evidence for particle stable state of tetra-neutron

J. P. Shiffer Phys. Lett. 5, 4, 292 (1963)

1980s

^{4}He(π^-, π^+) reaction

- Only upper limit of cross section was decided.

J. E. Unger, et al., Phys. Lett. B 144, 333 (1984)

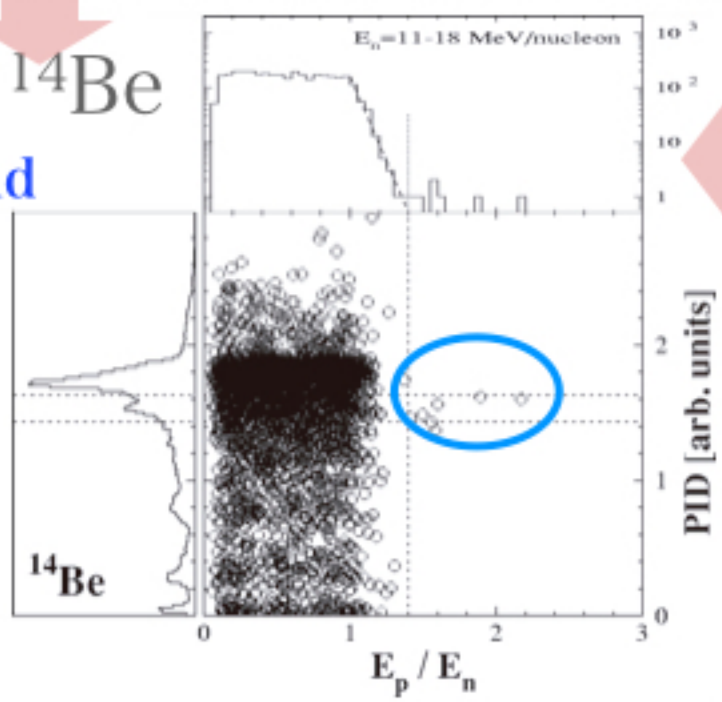
Bound state: No clear evidence.

2000s

Breakup of ^{14}Be

- Candidates of **bound tetra-neutron** were observed.

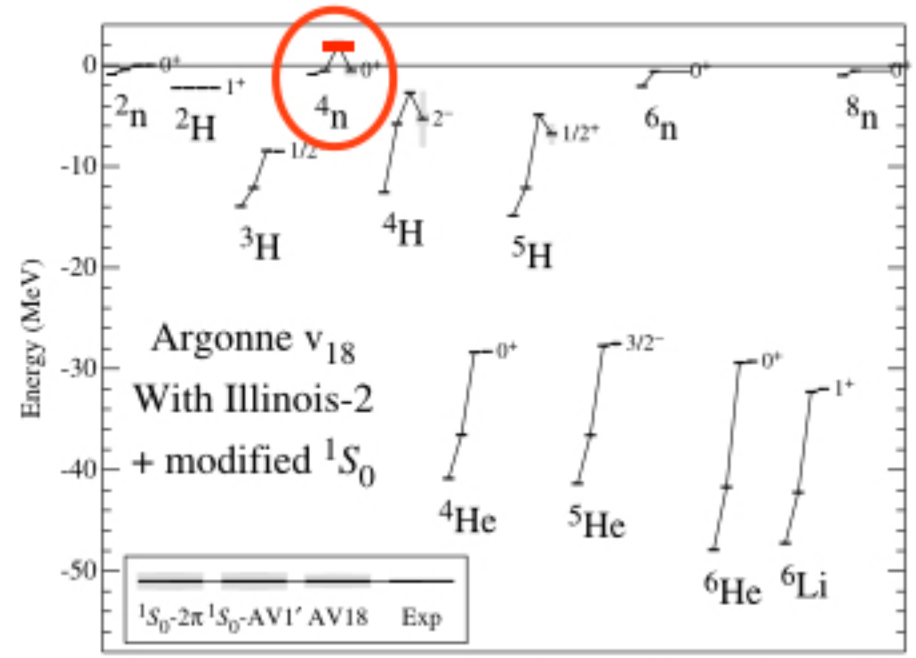
F. M. Marques, et al, Phys. Rev. C 65, 044006 (2002)



2000s

Theoretical work

- ab-initio calculation
  NN, NNN interaction

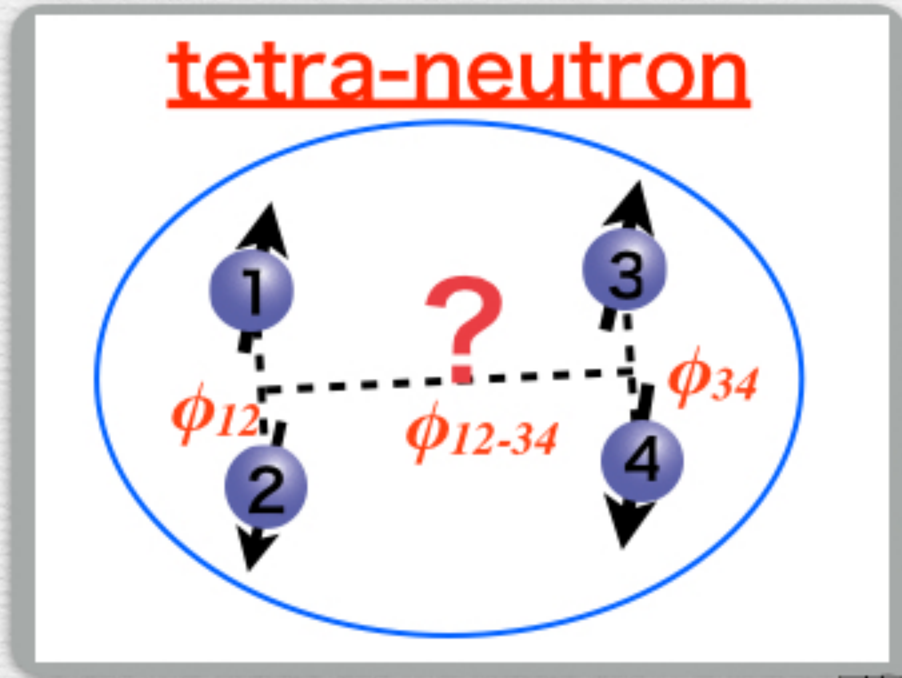


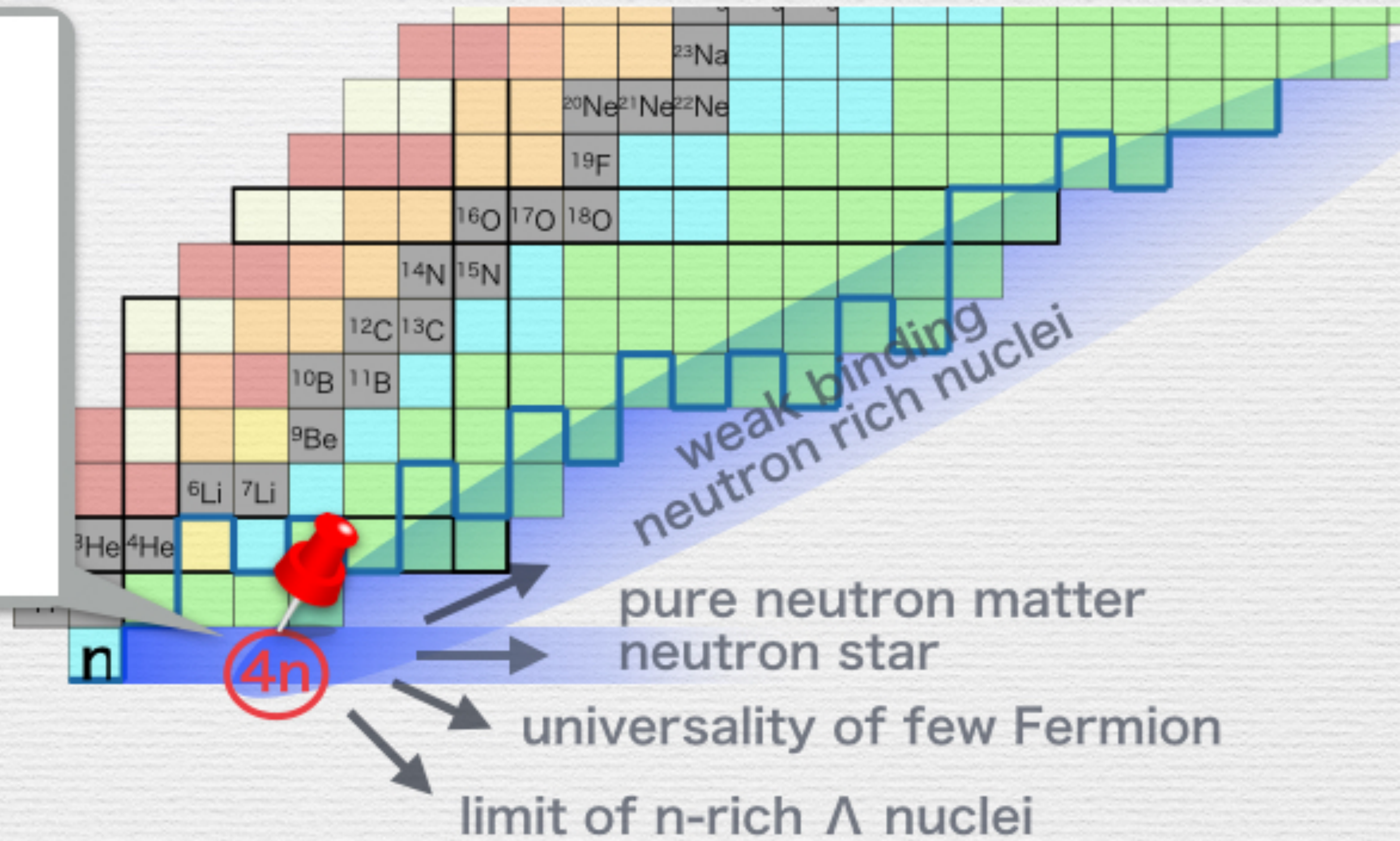
S. C. Piper, Phys. Rev. Lett. 90, 252501 (2003)

- **Bound ^{4}n cannot exist**
- **Possible resonance stete ~2 MeV**

Resonance state : Possibility of the state is still an open and fascinating question.

Purpose of this Work





Clarify whether the four-neutron (tetraneutron) system can exist as a resonance state

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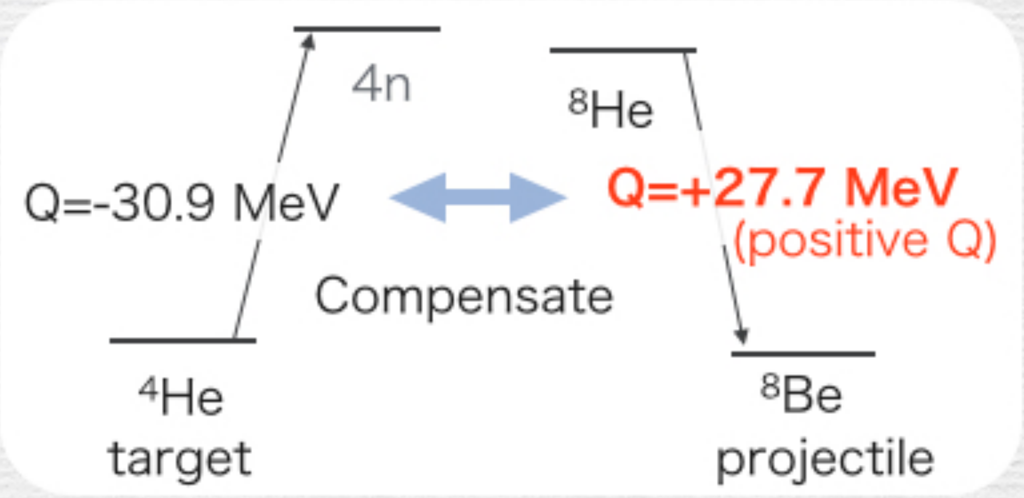
- Introduction
- **Experiment**
- Analysis
- Result and Discussion
- Summary

Outline of the Experiment

- **Exothermic reaction ^{4}He(^{8}He,^{8}Be)4n** at 200 AMeV.
  - Exothermic reaction

    → **small momentum transfer**

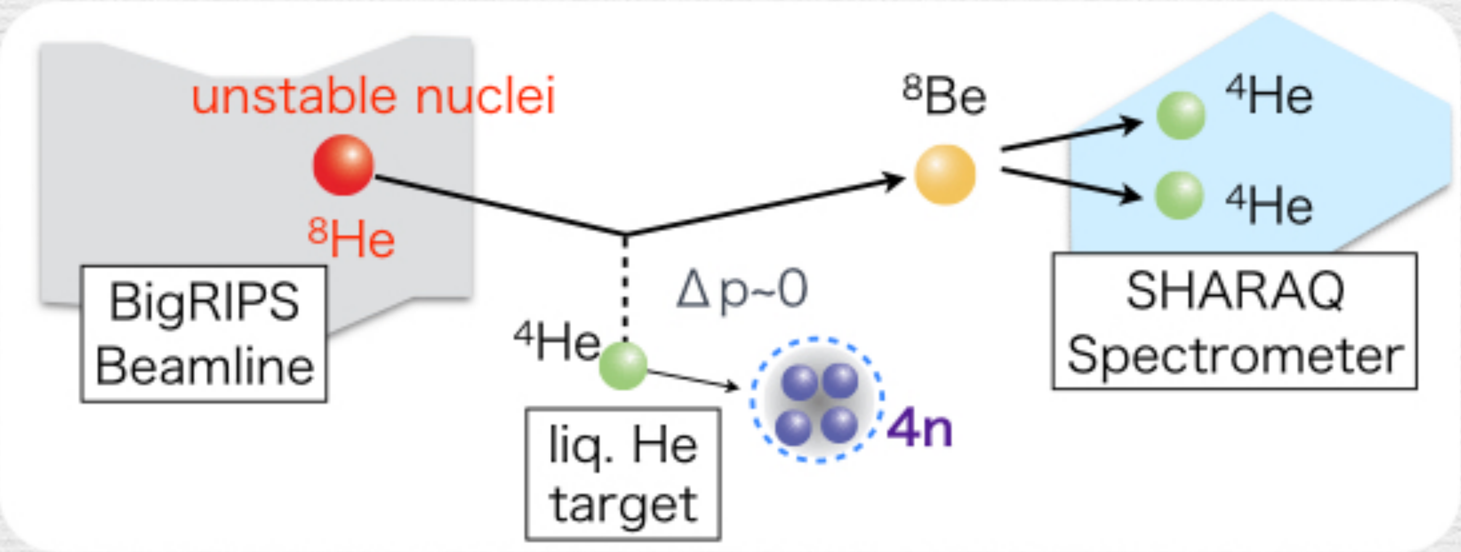
    (q < 20 MeV/c)

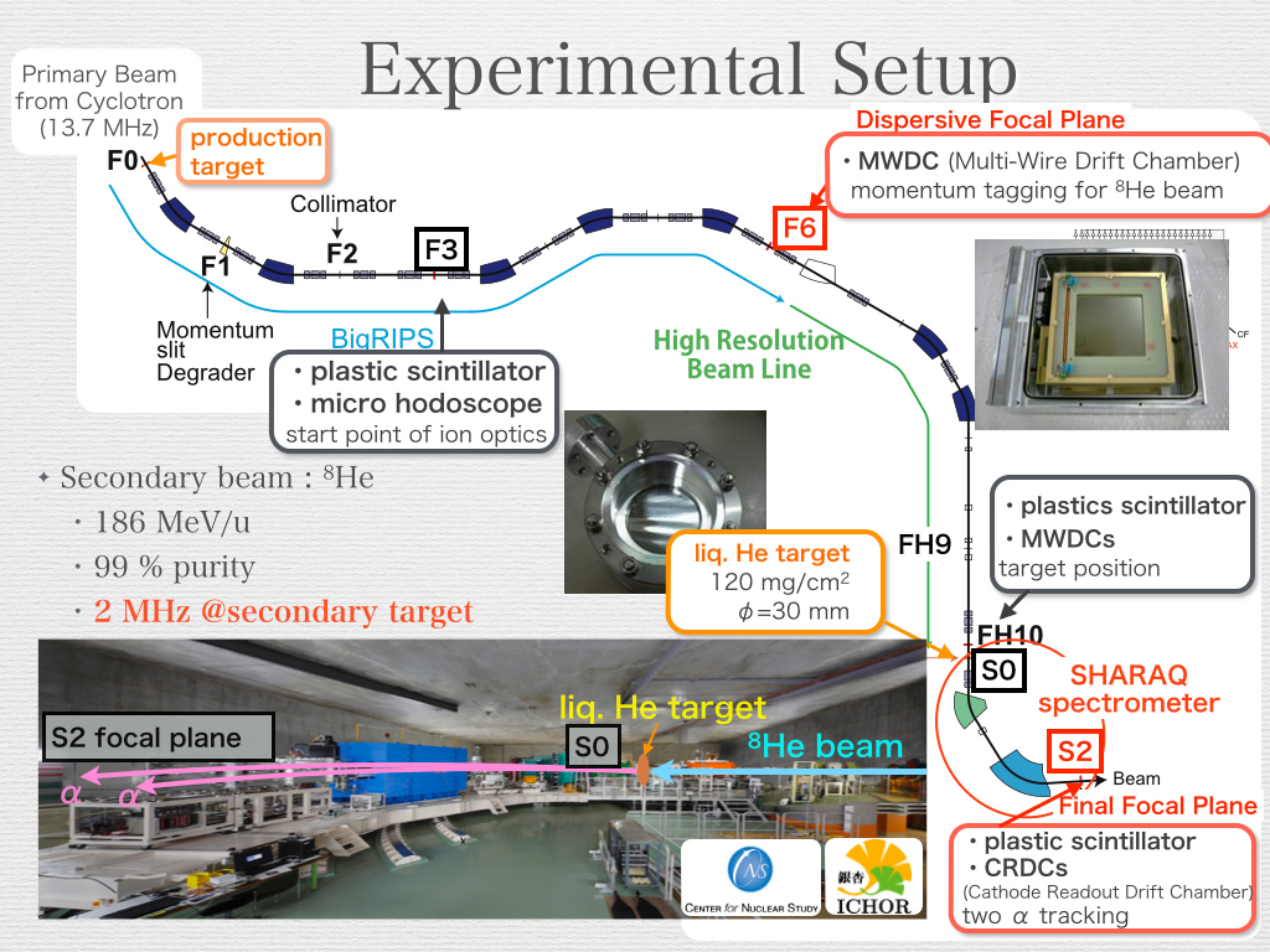


- **Missing-mass spectroscopy**
  - high resolution: ~ 1 MeV

    - BigRIPS beamline : ^{8}He beam (Δp/p ~1/7000)
    - SHARAQ spectrometer : ^{8}Be(→2α) (Δp/p ~1/10000)

      ・2α coincidence → good signal-to-noise ratio



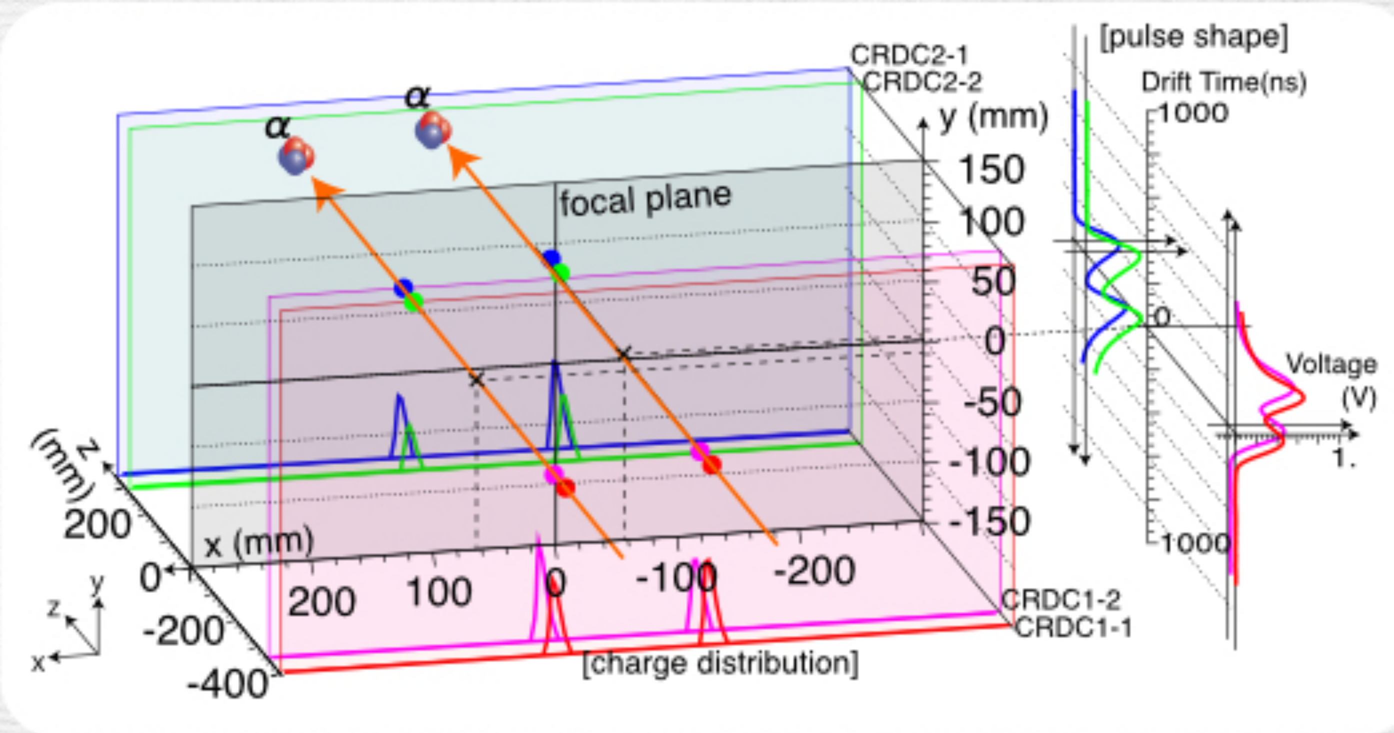


Experimental Setup
Primary Beam from Cyclotron (13.7 MHz)
production target
F0
F1
F2
F3
F6
Collimator
Momentum slit
Degrader
BigRIPS
• plastic scintillator
• micro hodoscope
start point of ion optics
High Resolution Beam Line
Dispersive Focal Plane
• MWDC (Multi-Wire Drift Chamber)
momentum tagging for 8He beam
FH9
FH10
• plastics scintillator
• MWDCs
target position
liq. He target
120 mg/cm2
ϕ=30 mm
S0
SHARAQ spectrometer
S2
Beam
Final Focal Plane
• plastic scintillator
• CRDCs
(Cathode Readout Drift Chamber)
two α tracking
✦ Secondary beam : 8He
・186 MeV/u
・99 % purity
・2 MHz @secondary target
S2 focal plane
S0
liq. He target
8He beam
α
α
Center for Nuclear Study
ICHOR

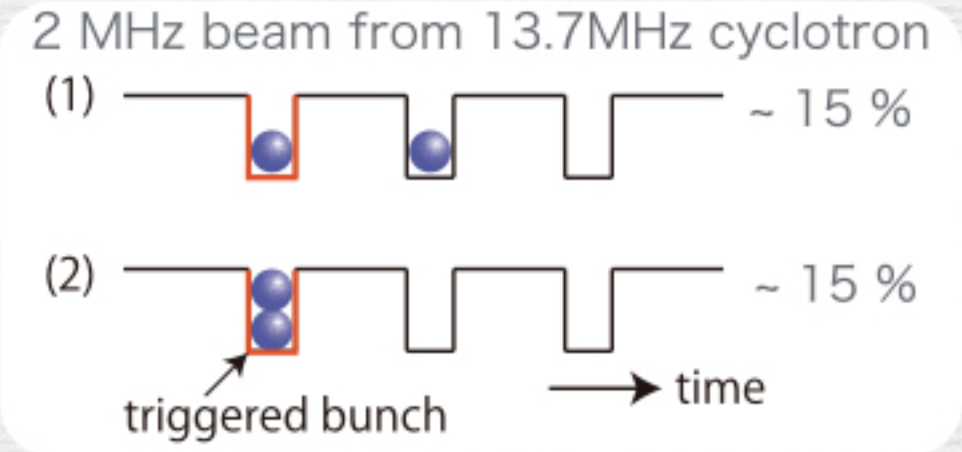
Contents

Analysis

- Selection of 4n Events
  - Extracting 2α events @SHARAQ
  - Multi-particle in high-intensity beam



- Background Estimation
  - Shape in spectrum: random 2α
  - Number of events:
    - failure of the multi-particle rejection at MWDC
    - multi-particle in one cell of MWDC



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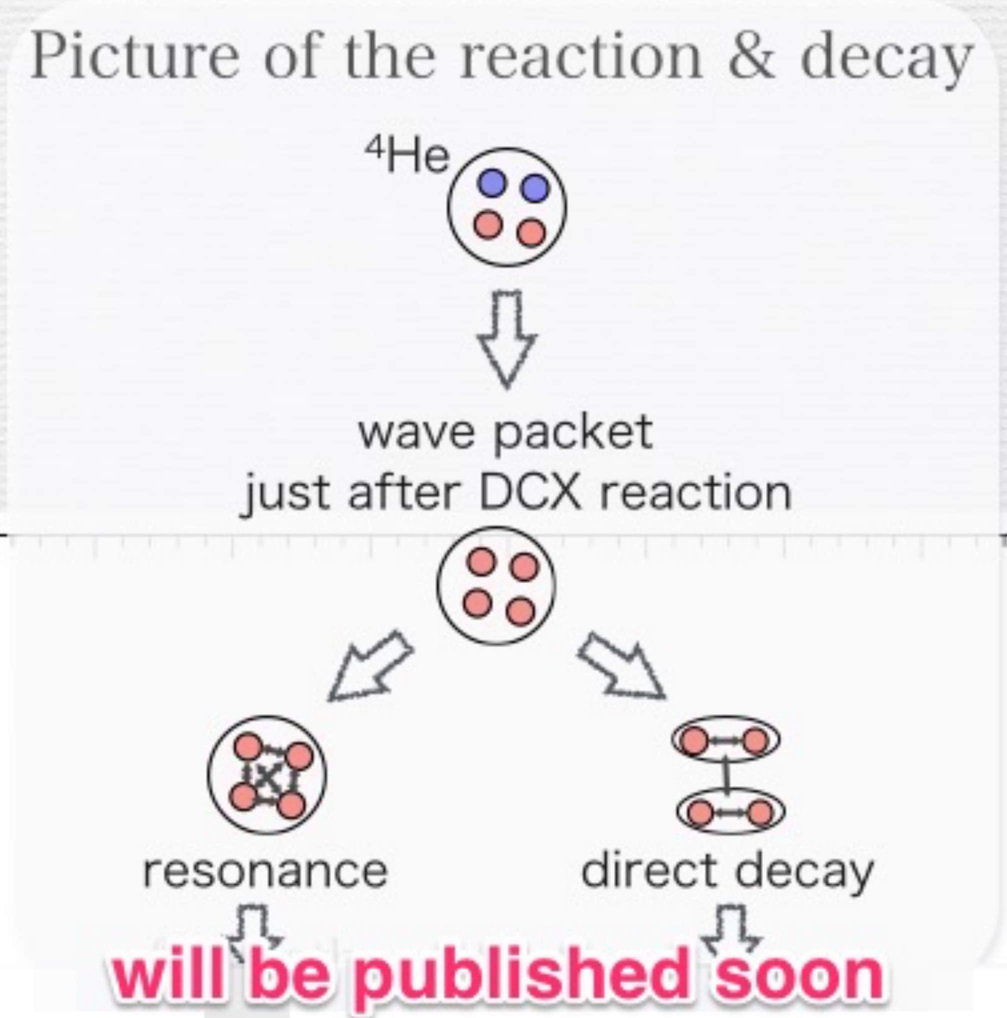
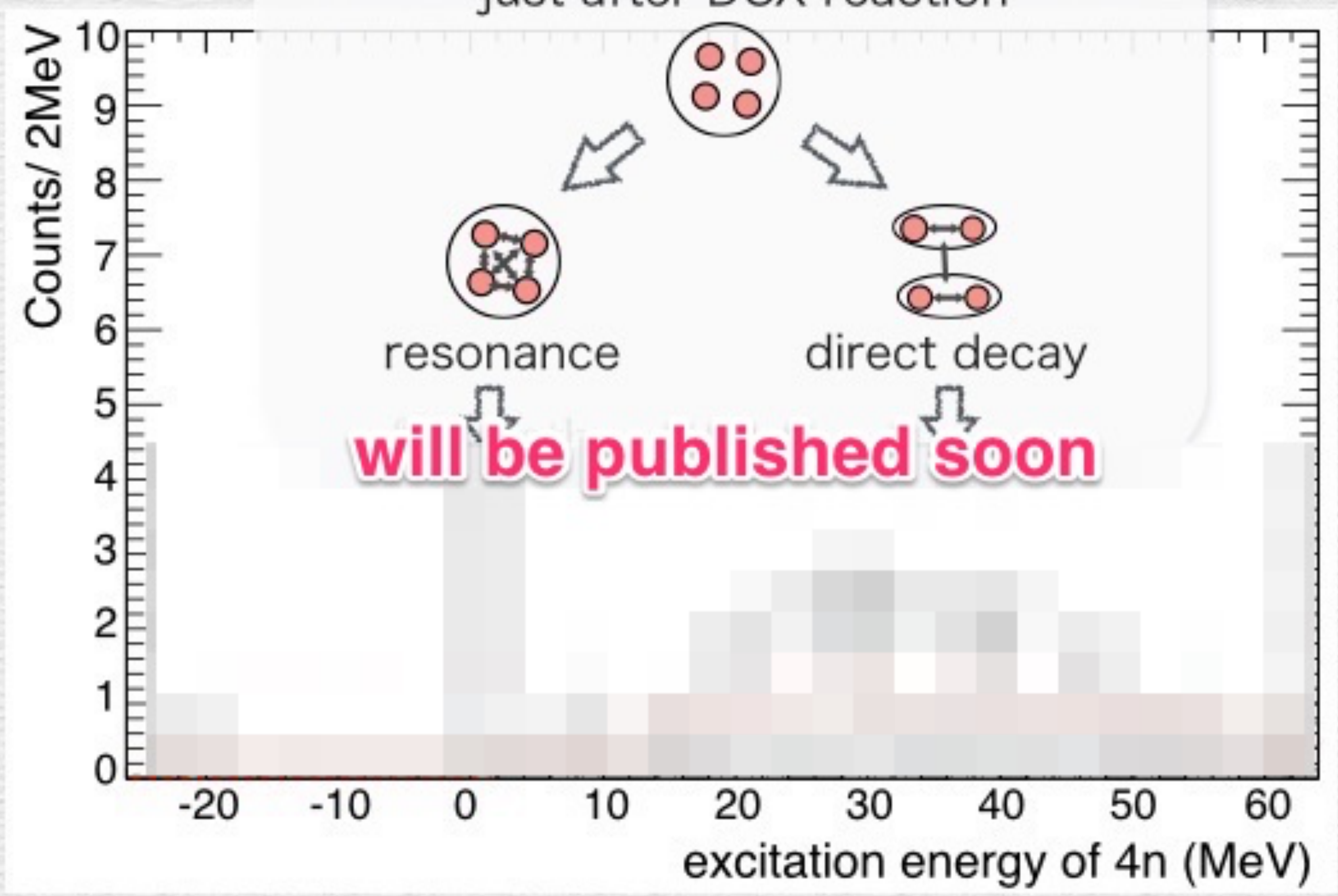
Result

- Missing-mass Spectrum of 4n
  - 27 events in the spectrum
  - energy resolution: 1.2 MeV (σ)
  - uncertainty of calibration: $\pm$ 1.3 MeV
    - $^{1}H(^{8}He, ^{8}Li(1^{+}))n$ reaction
    - $B\rho$ scaling: $^{8}Li \rightarrow ^{8}Be$
  - background: 2.3±1.0 events

    → **almost background free**





Result & Discussion (Cont'd)

Continuum (direct decay)

- decay to two di-neutron pair

^{4}He $\Phi[(0s)^4]$

⇩ DCX reaction (double dipole)

$\Phi[(0s)^2(0p)^2]$ (J=0)

⇩ decay

FSI : di-neutron($^1S_0$)
two di-neutron paris

Bin-by-Bin Goodness-of-Fit

- likelihood ratio test

$$\chi^2_\lambda = -2\ln\left[L(\boldsymbol{y};\boldsymbol{n})/L(\boldsymbol{n};\boldsymbol{n})\right]$$

- Significance:

$$s_i = \sqrt{2[y_i - n_i + n_i \ln{(n_i/y_i)}]}$$

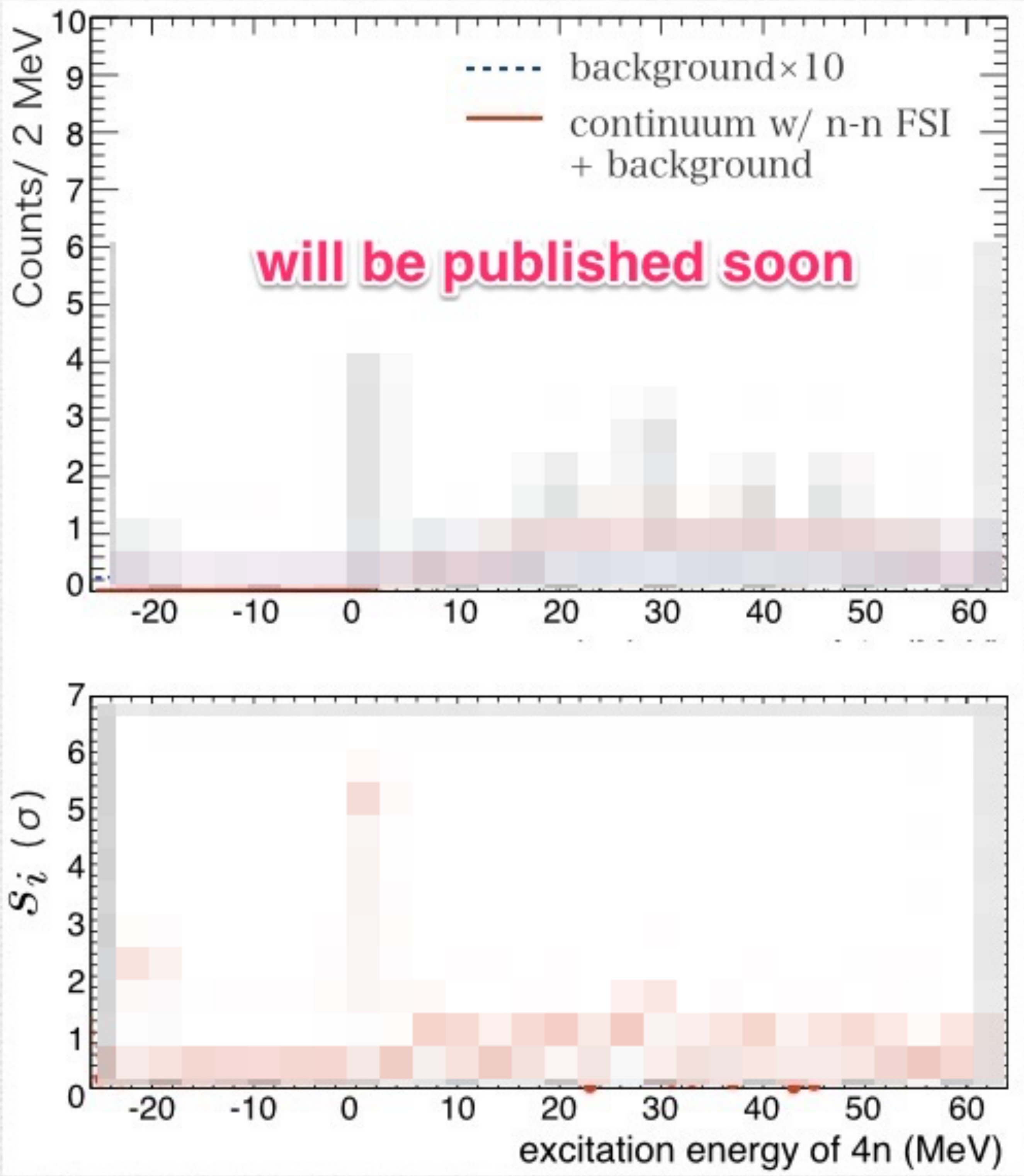
n_i : num. of events in the i-th bin

y_i : trial function in the i-th bin

- Look Elsewhere Effect

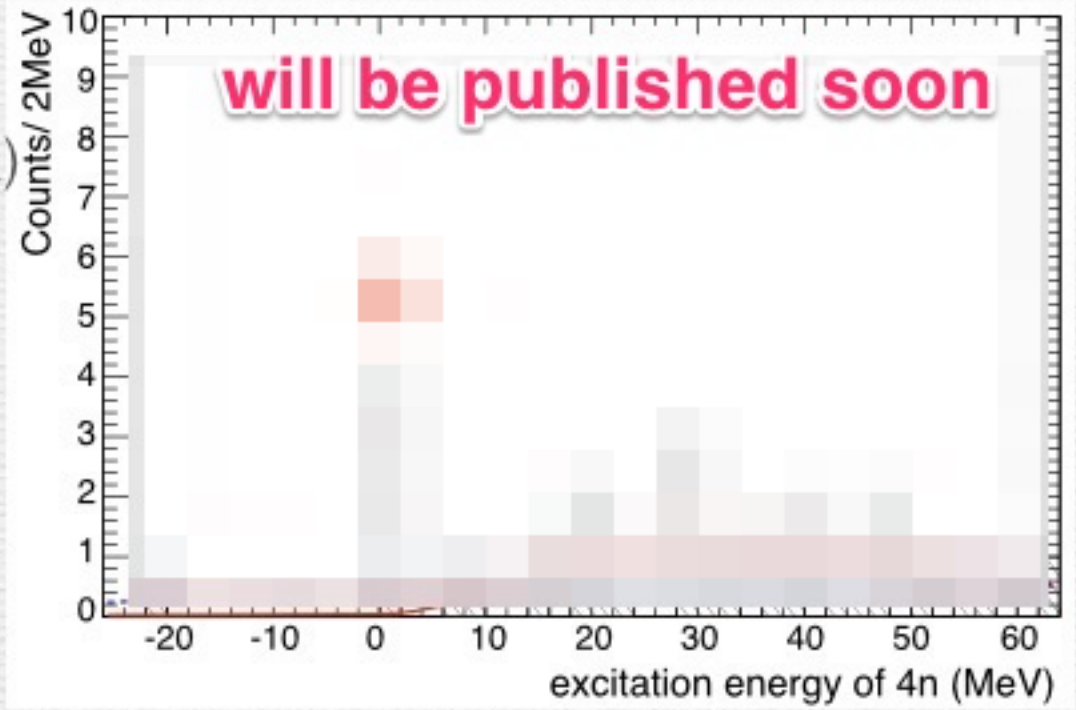
4.9 σ significance (E_{4n}~2 MeV)

➡ **possible resonance state**



Conclusion

- Candidate of the resonant state near the threshold
  - clear strength with **4.9 σ significance level**
  - **E_{4n} = 0.83 ± 0.65 (stat.) ± 1.25 (syst.) MeV**
  - upper limit of **Γ = 2.6 MeV** (FWHM)
    (mainly due to experimental energy resolution)
  - cross section : **3.8 $^{+2.9}_{-1.8}$ nb**
    (int. up of θ_{CM} < 5.4 degree)
    → compatible with a simple estimation of two-step process of GT and dipole



- Possible reason of forming the resonant state
  - **Strong many-body force** : isospin T=3/2 3N, 4N force

Y. A. Lashko, et al., Phys. of Atomic Nucl., 71, 2 (2008)

→ **The result leaves room for further investigation.**

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Summary

- We performed missing-mass spectroscopy of the tetra-neutron system via the double-charge exchange reaction ^{4}He(^{8}He,^{8}Be)4n with the SHARAQ spectrometer at RIBF. Exothermic reaction enabled us to produce the tetraneutron system with small momentum transfer.
- In the careful analysis to identify for multi-particle, the missing-mass spectrum of tetraneutron system containing 27 events was obtained with almost background free.
- The spectrum had a clear strength with 4.9 σ significance level near the four-neutron threshold by a comparison with the theoretical curve assuming the direct decay to the two correlated dineutron pairs.
- The mean of the peak was 0.83±0.65(stat.)±1.25(sys.) MeV and upper limit of width was 2.6 MeV (FWHM). The result suggests a possible resonant state of the tetra-neutron system.

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